TFPT theoryv3 analysis report

Generated: 2026-01-28 10:41:29

Output directory: tfpt-suite/theoryv3/out

Executive Summary

Purpose: This report tests the TFPT theoryv3 hypothesis that complexity collapses into discrete building blocks: pi seeds the invariants, a discrete defect partition (g=5) fixes delta2 and alpha_inv(0), exponential suppression exp(-alpha_inv/2) sets the dark energy scale, and Mobius/Z3 structures fix flavor and mass hierarchies.

What we test: Each module targets one piece of that thesis and turns it into an explicit, deterministic check with declared tolerances (no continuous fitting).

What we are searching for: A small set of discrete identities that reproduces multiple observables across sectors and cross-links them consistently (especially the g=5 signature).

How we proceed: Modules consume existing out_physics results when available; otherwise they compute from the TFPT invariants. Each test is a finite enumeration or closed-form calculation. Plot generation is validated by file existence and image load checks (when available).

Result: 14 modules, 50 total checks, PASS=41, WARN=9, FAIL=0. Plot verification: expected=16, present=16, missing=0, invalid=0, extra=0, load_check=on.

Test Map (idea -> test -> signal)

Module	Idea segment	What is checked	Signal we seek
alpha_backreaction_sensitivity_audit	k=2 backreaction exponent is a structural choice, not a fit	sweep k and compute ppm vs CODATA	k=2 near minimum |ppm|
axion_dm_audit	axion DM target frequency and relic fraction	nu from m_a conversion, Omega_a h^2 vs ref	frequency matches conversion; relic fraction near ref
baryon_consistency_audit	beta_rad anchors Omega_b and eta_b	Omega_b identity, eta_b proxy, derived H0	Omega_b within 2 sigma; eta_b within 0.5 dex; H0 within 2 sigma
constant_factory_audit	constant factory: hierarchical TFPT constants from simple rules	compute constants, sensitivities, and compare to reference ledger	derivations + sensitivities documented; references and crosslinks visible
dark_energy_exponential_audit	exp(-alpha_inv/2) suppression sets dark energy scale	phi_star_base and discrete normalization candidates vs rho_L target	best candidate within 0.5 dex, n=1/2 preferred
dark_energy_norm_half_origin_audit	n=1/2 fixed by double cover (k=2)	n_from_cover=1/k and best candidate label	n_from_cover=1/2 and best label n=1/2
defect_partition_g5_audit	discrete defect partition (g=5) fixes delta2 and alpha_inv(0)	g=5 multiplicity, alpha_inv(0) within 2 sigma, and negative control vs g=4,6	g equals 5; z <= 2; g=5 minimizes |z|
flavor_pattern_audit	Mobius/Z3 flavor anchors from varphi0 and delta_star	lambda (Cabibbo), sin2(theta13), cusp set {1,1/3,2/3}	lambda and sin2(theta13) within 2 sigma; cusp set matches
g5_crosslink_audit	g=5 crosslinks across sectors	delta2 factor g/4, unification patch g/2, gamma0=g/(g+1)	g=5; delta_b3 includes g/2; gamma0 matches g/(g+1)
g5_origin_audit	single origin for g from SU(5) holonomy degeneracy	count eigenvalue degeneracies in SU(5) hypercharge spectrum	degeneracies {3,2} and g=5
pmns_tm1_audit	TM1 sum rule for theta12	sin2(theta12) from sin2(theta13)	sin2(theta12) within conservative band
seed_invariants_audit	pi seeds the invariants	c3, varphi0_tree, delta_top, varphi0, beta_rad identities (and optional match to core_invariants)	identities hold and match within numerical tolerance
yukawa_exponent_index_audit	mass ratios follow rational exponent indices q_ij	q_ij rationalization and ratio reconstruction error	max relative error <= 2%
yukawa_index_mapping_audit	q_ij map to charge-squared index sums	bounded integer sum of charge-squared indices	mapping errors <= 2%

Module	Checks	Status
alpha_backreaction_sensitivity_audit	2/2	OK
axion_dm_audit	2/2	OK
baryon_consistency_audit	3/4	WARN:1
constant_factory_audit	3/3	OK
dark_energy_exponential_audit	2/2	OK
dark_energy_norm_half_origin_audit	2/2	OK
defect_partition_g5_audit	4/4	OK
flavor_pattern_audit	3/3	OK
g5_crosslink_audit	3/3	OK
g5_origin_audit	2/2	OK
pmns_tm1_audit	2/2	OK
seed_invariants_audit	7/7	OK
yukawa_exponent_index_audit	3/7	WARN:4
yukawa_index_mapping_audit	3/7	WARN:4

Validated Results Tables

Alpha backreaction sensitivity audit (k sweep)

Module ID: alpha_backreaction_sensitivity_audit

Idea segment: k=2 backreaction exponent is a structural choice, not a fit

Test focus: sweep k and compute ppm vs CODATA

Signal: k=2 near minimum |ppm|

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Is k=2 a natural choice from alpha backreaction sensitivity?
Objective: Quantify how alpha_inv_0 depends on k and show the k=2 near-crossing.

B) Inputs

TFPT invariants (c3, varphi0_tree, delta_top, b1)
CODATA alpha_inv_0 reference

C) Expected result (signal)

k=2 is near the minimum |ppm| in the grid

D) Method (how the test proceeds)

varphi(alpha)=varphi_tree + delta_top * exp(-k alpha)
alpha from CFE fixed point (self-consistent)
ppm = 1e6*(pred-ref)/ref
Determinism: Deterministic (fixed-point iteration).

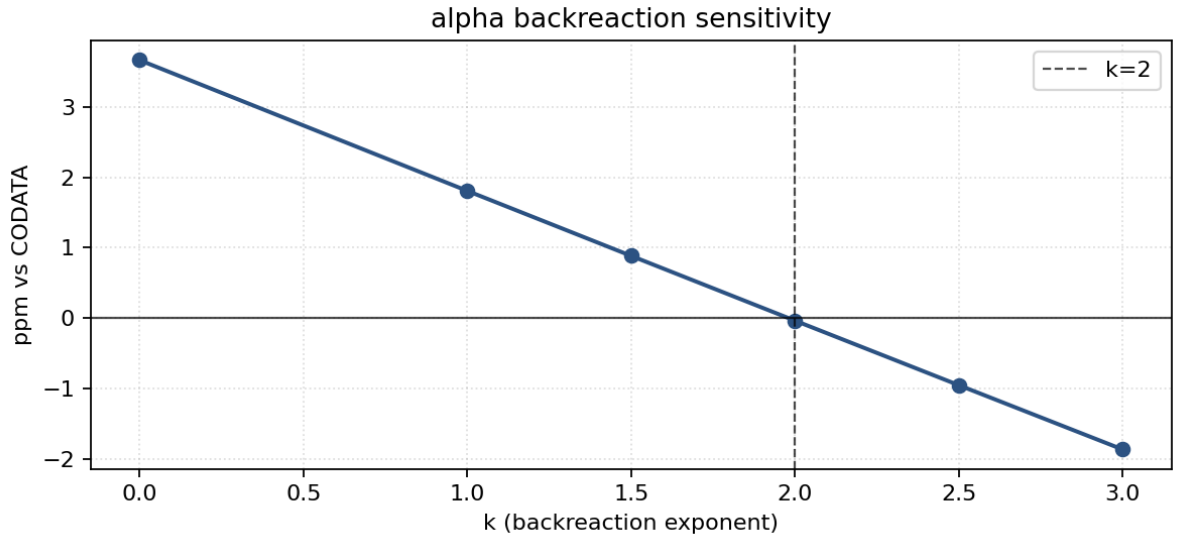
E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: k2_is_near_zero_crossing - min_k=2.0, abs_ppm={0.0: 3.665371791638453, 1.0: 1.8074246412353618, 1.5: 0.883514212976573, 2.0: 0.03703710120260405, 2.5: 0.9542414840493093, 3.0: 1.8681110743677323}
INFO: monotonicity_check - monotonic=True, diffs=[-1.857947150403091, -0.9239104282587889, -0.920551314179177, -0.9172043828467052, -0.913869590318423]

Plot check: missing=[], invalid=[], extra=[]

Plots

alpha_backreaction_ppm.png



Axion DM audit (frequency, relic fraction)

Module ID: axion_dm_audit

Idea segment: axion DM target frequency and relic fraction

Test focus: nu from m_a conversion, Omega_a h^2 vs ref

Signal: frequency matches conversion; relic fraction near ref

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Do the axion numbers map cleanly to a frequency and relic fraction?
Objective: Expose the axion target frequency and relic fraction in a single audit.

B) Inputs

axion_dm_pipeline outputs (preferred)
axion_tfpt_v106.json (fallback)

C) Expected result (signal)

frequency matches the m_a conversion
relic fraction is near Omega_DM reference

D) Method (how the test proceeds)

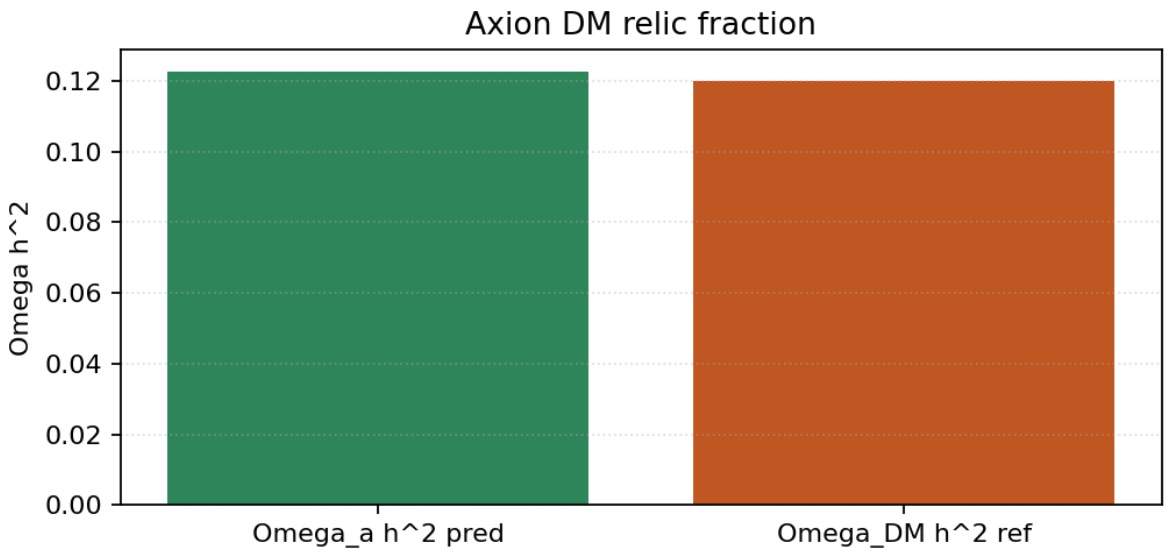
nu_GHz = 0.24179893 * m_a_micro_eV
Determinism: Deterministic given inputs.

E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: frequency_matches - nu_calc=15.76402318010866, nu_reported=15.76402318010866
PASS: omega_a_near_ref - Omega_a_h2=0.12275084115028702
Plot check: missing=[], invalid=[], extra=[]

Plots

axion_summary.png



Baryon consistency audit (Omega_b, eta_b, derived H0)

Module ID: baryon_consistency_audit

Idea segment: beta_rad anchors Omega_b and eta_b

Test focus: Omega_b identity, eta_b proxy, derived H0

Signal: Omega_b within 2 sigma; eta_b within 0.5 dex; H0 within 2 sigma

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Do baryon observables self-consistently close using beta_rad?
Objective: Expose the Omega_b identity and baryogenesis proxy in one audit.
Objective: Quantify the implied H0 from internal TFPT quantities.

B) Inputs

TFPT invariants (beta_rad)
Planck omega_b_h2 and H0 references
Alternative H0 reference (SH0ES)
seesaw thresholds and neutrino masses (eta_b proxy)
reference[H0_planck2018]: Planck 2018 value=67.36 sigma=0.54
reference[H0_sh0es_2022]: SH0ES 2022 value=73.04 sigma=1.04
reference[omega_b_h2_planck2018]: Planck 2018 value=0.02237 sigma=0.00015

C) Expected result (signal)

Omega_b within 2 sigma of reference
eta_b within 0.5 dex of Planck anchor
H0 within 2 sigma of Planck anchor (derived check)

D) Method (how the test proceeds)

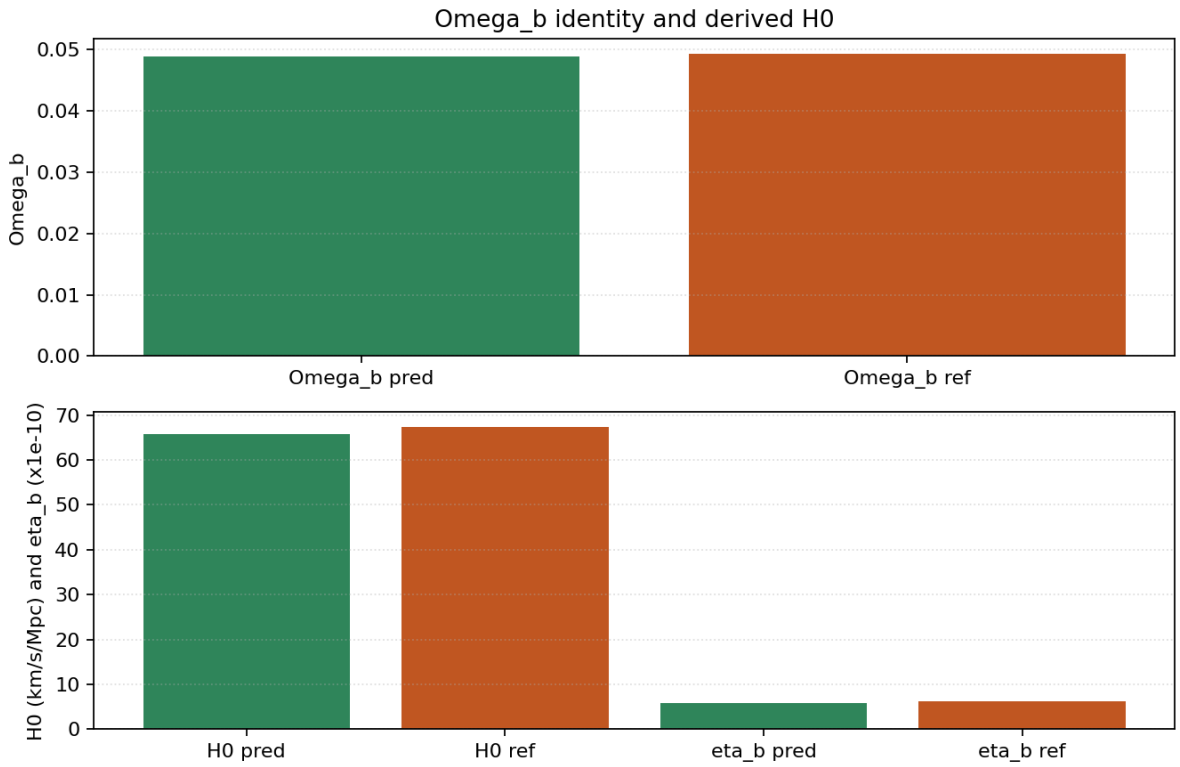
Omega_b = (4*pi - 1) * beta_rad
eta10 = 273.9 * omega_b_h2
eta_b = 0.96e-2 * eps1 * kappa_eff
eta10_pred = 1e10 * eta_b_pred
omega_b_h2_pred = eta10_pred / 273.9
H0 = 100 * sqrt((eta10_pred/273.9) / Omega_b_pred)
Determinism: Deterministic given inputs.

E) Results and JSON outputs

Summary: PASS=3, WARN=1, FAIL=0
PASS: omega_b_within_2sigma - z=-0.42136420161877963
PASS: eta_b_within_0p5_dex - log10 mismatch=-0.024251277714995013
WARN: H0_within_2sigma - z_planck=-2.9880212073872032
INFO: H0_tension_indicator - z_alt=-7.013011011527977 (alt=73.04 ? 1.04; planck=67.36 ? 0.54)
Plot check: missing=[], invalid=[], extra=[]

Plots

baryon_consistency.png



Constant factory audit (hierarchical TFPT constants)

Module ID: constant_factory_audit

Idea segment: constant factory: hierarchical TFPT constants from simple rules

Test focus: compute constants, sensitivities, and compare to reference ledger

Signal: derivations + sensitivities documented; references and crosslinks visible

Plot check: expected=2, present=2, missing=none, invalid=none, extra=none

A) What this test is intended to find

Can TFPT generate a hierarchical constant list from a small discrete grammar without fitting?
Objective: Compute a structured set of constants using the simplest TFPT rules.
Objective: Document derivations and reference comparisons in one report.

B) Inputs

TFPT constants (pi, c3, varphi0, delta_top, beta_rad)
defect partition delta2 (g=5)
theoryv3 outputs (baryon, axion, dark energy, flavor)
reference ledger (references.json)
source list: theoryv3/constantfactory.md
reference[A_s_planck2018]: Planck 2018 value=2.0989031673e-09 sigma=2.938464434e-11
reference[H0_planck2018]: Planck 2018 value=67.36 sigma=0.54
reference[Lambda_planck_derived]: Planck 2018 (k_calibration) value=7.151545310258967e-121 sigma=None

reference[Mpl_reduced]: CODATA value=2.435e+18 sigma=0.0
reference[alpha_bar5_inv_MZ_pdg2024]: PDG 2024 value=127.93 sigma=0.008
reference[alpha_inv_codata_2022]: CODATA 2022 value=137.035999177 sigma=2.1e-08
reference[alpha_s_mz_pdg]: PDG (MZ, MSbar) value=0.1179 sigma=0.0011
reference[beta_deg_minami_komatsu_2020]: Minami & Komatsu 2020 value=0.35 sigma=0.14
reference[cabibbo_lambda_pdg2024]: PDG 2024 value=0.22501 sigma=0.00068
reference[eta_b_planck_derived]: Planck 2018 value=6.127143e-10 sigma=None
reference[m_b_pdg]: PDG (scheme dependent) value=4.18 sigma=None
reference[m_c_pdg]: PDG (scheme dependent) value=1.27 sigma=None
reference[m_e_pdg]: PDG pole mass value=0.0005109989461 sigma=0.0
reference[m_mu_pdg]: PDG pole mass value=0.1056583745 sigma=0.0
reference[m_p_pdg]: PDG pole mass value=0.938272 sigma=None
reference[m_t_pdg]: PDG pole mass value=172.76 sigma=0.3
reference[m_tau_pdg]: PDG pole mass value=1.77686 sigma=0.0
reference[mass_ratio_me_over_mp]: PDG pole masses value=0.0005446170685046554 sigma=None
reference[mass_ratio_mu_over_e_pdg]: PDG pole masses value=206.76828260879265 sigma=0.0
reference[mass_ratio_tau_over_mu_pdg]: PDG pole masses value=16.81702949159037 sigma=0.0
reference[n_s_planck2018]: Planck 2018 value=0.9649 sigma=0.0042
reference[omega_b_planck_derived]: Planck 2018 + Planck 2018 value=0.049301692328524445 sigma=None
reference[omega_dm_planck_derived]: Planck 2018 + Planck 2018 value=0.26447041034523616 sigma=None
reference[pmns_delta_cp_deg_nufit53_no]: NuFIT 5.3 (2024, NO) value=232.0 sigma=39.0
reference[pmns_sin2_theta12_nufit53_no]: NuFIT 5.3 (2024, NO) value=0.307 sigma=0.012
reference[pmns_sin2_theta13_nufit53_no]: NuFIT 5.3 (2024, NO) value=0.02224 sigma=0.00057
reference[pmns_sin2_theta23_nufit53_no]: NuFIT 5.3 (2024, NO) value=0.454 sigma=0.019
reference[rho_L_planck_derived]: Planck 2018 (k_calibration) value=2.514176465474032e-47 sigma=None
reference[sin2_thetaW_mz_pdg]: PDG (MZ, MSbar) value=0.23122 sigma=4e-05
reference[v_ew_246]: SM Higgs vev value=246.0 sigma=0.2

C) Expected result (signal)

reports computed entries with reference comparisons where available
flags missing references as INFO (not a failure)
records grammar violations for non-primitive literals

D) Method (how the test proceeds)

c3 = 1/(8*pi)
varphi0 = 1/(6*pi) + 3/(256*pi^4)
beta_rad = varphi0/(4*pi)
delta2 = (g/4) * delta_top^2 (g=5)
alpha_inv0 from CFE + backreaction
alpha_inv0_simple = 4*pi*exp(1/varphi0)
v/Mpl candidate = (4*pi) * g * c3^2 * exp(-alpha_inv/4)
y_tau = pi*varphi0^2, y_mu = pi*varphi0^3, y_e = 2*pi*varphi0^5
m_l = v * y_l / sqrt(2)
sin2_theta13 = varphi0 * exp(-5/6)
sin2_theta12 = (1/3) * (1 - 2*sin2_theta13)
Determinism: Deterministic (closed forms + deterministic module outputs).

E) Results and JSON outputs

Summary: PASS=3, WARN=0, FAIL=0
PASS: constant_factory_ran - entries=87
INFO: constant_factory_statuses - candidate=14 derived=34 derived_external=19 input=9 pending=8 placeholder=3
INFO: constant_factory_symbol_registry - symbols=82
Plot check: missing=[], invalid=[], extra=[]

Constant tables (grouped)

Group 0: Discrete anchors

Constant	Formula / Calculation	Value	Reference	Deviation	Status
pi (pi)	pi circle constant	3.1415927 dimensionless	analytic: geometry constant	n/a	input/anchor

Constant	Formula / Calculation	Value	Reference	Deviation	Status
g (g)	g SU(5) holonomy multiplicity (two-defect) source: defect_partition_g5_audit /results/delta2/g_value	5 dimensionless	internal_derivation: defect_partition_g5_audit	n/a	derived/discrete_scan
k (k)	k backreaction cover degree (min |ppm|) source: alpha_backreaction_sensitivity_audit /results/abs_ppm	2 dimensionless	internal_derivation: alpha_backreaction_sensitivity_audit	n/a	derived/discrete_scan
gamma0 (gamma0)	g/(g+1) crosslink signature	0.83333333 dimensionless	internal_derivation: g5_crosslink_audit	n/a	derived/axiom
delta2 (delta2)	(g/4)*delta_top^2	1.809146e-08 dimensionless	internal_derivation: defect_partition_g5_audit	n/a	derived/discrete_scan

Group 1: Kernel invariants

Constant	Formula / Calculation	Value	Reference	Deviation	Status
c3 (c3)	1/(8*pi)	0.039788736 dimensionless	n/a	n/a	derived/axiom
varphi0_tree (varphi0_tree)	1/(6*pi)	0.053051648 dimensionless	n/a	n/a	derived/axiom
delta_top (delta_top)	3/(256*pi^4)	0.00012030448 dimensionless	n/a	n/a	derived/axiom
varphi0 (varphi0)	varphi0_tree+delta_top	0.053171952 dimensionless	n/a	n/a	derived/axiom
delta_star (delta_star)	3/5+varphi0/6	0.60886199 dimensionless	n/a	n/a	derived/axiom
beta_rad (beta_rad)	varphi0/(4*pi)	0.0042312895 radian	n/a	n/a	derived/axiom

Group 2: Gauge sectors (couplings)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
alpha_inv(0) (alpha_inv0)	alpha_inv0 Solve CFE(alpha,varphi)=0 with varphi=varphi_tree+delta_top*exp(-2*alpha)+delta2*exp(-4*alpha), then alpha_inv0=1/alpha (k=2).	137.036 dimensionless	137.036 ? 2.1e-08 dimensionless (CODATA 2022)	z=1.86	derived/axiom
alpha(0) (alpha0)	1/alpha_inv0	0.0072973526 dimensionless	n/a	n/a	derived/axiom
alpha_inv(0) (simple) (alpha_inv0_simple)	4*pi*exp(1/varphi0)	1.8490392e+09 dimensionless	n/a	n/a	candidate/candidate
alpha_bar5_inv(MZ) (alpha_bar5_inv_MZ)	alpha_bar5_inv_MZ alpha(0) -> MZ running (alpha_precision_audit) source: alpha_precision_audit /results/secondary_alpha_bar5_MZ/alpha_bar5_inv_MZ_pred	127.94052 dimensionless	127.93 ? 0.008 dimensionless (PDG 2024)	z=1.31	derived_external/derived_external
alpha_s(MZ) (alpha_s_MZ)	alpha_s_MZ SM input (MSbar) source: sm_inputs_mz.json	0.1179 dimensionless	0.1179 ? 0.0011 dimensionless (PDG (MZ, MSbar))	n/a	input/anchor
sin^2(thetaW) (MZ) (sin2_thetaW_MZ)	sin2_thetaW_MZ SM input (MSbar) source: sm_inputs_mz.json	0.23122 dimensionless	0.23122 ? 4e-05 dimensionless (PDG (MZ, MSbar))	n/a	input/anchor
sin^2(thetaW)(0) (sin2_thetaW_0)	sin2_thetaW_0 G(c3,varphi0) (pending)	n/a dimensionless	n/a	n/a	pending/pending
alpha3(mu_star) (alpha3_at_mu_star)	alpha3_at_mu_star alpha3(mu)=varphi0 crossing source: two_loop_rg_fingerprints /results/alpha3/crossing_varphi0/alpha3	0.053171952 dimensionless	pipeline_output: two_loop_rg_fingerprints	n/a	derived_external/derived_external
mu_star (alpha3=varphi0) (mu_star_varphi0)	mu_star_varphi0 alpha3(mu)=varphi0 crossing source: two_loop_rg_fingerprints /results/alpha3/crossing_varphi0/mu_GeV	792005.56 GeV	pipeline_output: two_loop_rg_fingerprints	n/a	derived_external/derived_external
g_a_gamma_gamma (g_a_gamma_gamma)	-4*c3	-0.15915494 dimensionless	n/a	n/a	derived/axiom

Group 3: Architecture (block scales)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
Mpl_reduced (Mpl_reduced)	Mpl_reduced input (reduced Planck mass)	2.435e+18 GeV	2.435e+18 GeV (CODATA)	n/a	input/anchor
Mpl (unreduced) (Mpl_unreduced)	sqrt(8*pi)*Mpl_reduced	1.220728e+19 GeV	n/a	n/a	derived/axiom
M/Mpl (Starobinsky) (M_over_Mpl)	sqrt(8*pi)*c3^4	1.2564942e-05 dimensionless	n/a	n/a	derived/axiom
M_GUT (M_GUT)	M_GUT mu where alpha1=alpha2=alpha3 source: unification_gate /results/best_unification_point/mu_GeV	2.8057333e+15 GeV	pipeline_output: unification_gate	n/a	derived_external/derived_external

Constant	Formula / Calculation	Value	Reference	Deviation	Status
M_R (M_R)	M_R seesaw anchor source: seesaw_block /results/paper_v1_06_anchor/MR_GeV	1.311e+15 GeV	pipeline_output: seesaw_block	n/a	derived_external/derived_external
f_a (f_a)	f_a axion_dm_pipeline source: axion_dm_pipeline /results/axion_claim/f_a_GeV	8.8639887e+10 GeV	pipeline_output: axion_dm_pipeline	n/a	derived_external/derived_external
v (EW scale) (v_ew)	4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced candidate EW-scale closure	320.40888 GeV	246 ? 0.2 GeV (SM Higgs vev)	rel=30.2%	candidate/candidate
Lambda_QCD (Lambda_QCD)	Mpl_reduced*exp(-1/(2*varphi0)) placeholder scaling (RG-based derivation pending)	2.0073857e+14 GeV	literature: PDG Lambda_QCD ~0.2 GeV (numeric bound pending)	n/a	pending/pending
m_p (m_p)	m_p PDG placeholder source: mass_spectrum_minimal	0.938272 GeV	0.938272 GeV (PDG pole mass)	n/a	placeholder/anchor
m_pi (m_pi)	m_pi pending TFPT derivation	n/a GeV	n/a	n/a	pending/pending
G_F * Mpl^2 (G_F_Mpl2)	Mpl_reduced^2/(sqrt(2)*v_ew^2) dimensionless Fermi coupling proxy	4.0838882e+31 dimensionless	n/a	n/a	candidate/candidate

Group 4: Matter (fermion masses & ratios)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
y_tau (y_tau)	pi*varphi0^2	0.0088820882 dimensionless	n/a	n/a	derived/axiom
y_mu (y_mu)	pi*varphi0^3	0.00047227797 dimensionless	n/a	n/a	derived/axiom
y_e (y_e)	2*pi*varphi0^5	2.6705019e-06 dimensionless	n/a	n/a	derived/axiom
m_e (m_e)	v_ew*(2*pi*varphi0^5)/sqrt(2) candidate Yukawa ladder	0.00060503771 GeV	0.000510999 GeV (PDG pole mass)	rel=18.4%	candidate/candidate
m_mu (m_mu)	v_ew*(pi*varphi0^3)/sqrt(2) candidate Yukawa ladder	0.10700085 GeV	0.105658 GeV (PDG pole mass)	rel=1.27%	candidate/candidate
m_tau (m_tau)	v_ew*(pi*varphi0^2)/sqrt(2) candidate Yukawa ladder	2.0123552 GeV	1.77686 GeV (PDG pole mass)	rel=13.3%	candidate/candidate
m_e/m_p (m_e_over_m_p)	alpha0^2*exp(-1/varphi0)	3.6190484e-13 dimensionless	0.000544617 dimensionless (PDG pole masses)	rel=-100%	candidate/candidate
m_mu/m_e (m_mu_over_m_e)	((1+delta_star)/(1-delta_star))^2*((1/3+delta_star)/(1/3-delta_star))^2	197.84536 dimensionless	206.768 dimensionless (PDG pole masses)	rel=-4.32%	derived/axiom
m_tau/m_mu (m_tau_over_m_mu)	((1+delta_star)/(1-delta_star))^2	16.919111 dimensionless	16.817 dimensionless (PDG pole masses)	rel=0.607%	derived/axiom
m_t (top) (m_t)	m_t input (scheme dependent)	172.76 GeV	172.76 ? 0.3 GeV (PDG pole mass)	n/a	input/anchor
m_b (bottom) (m_b)	m_b input (scheme dependent)	4.18 GeV	4.18 GeV (PDG (scheme dependent))	n/a	input/anchor
m_c (charm) (m_c)	m_c input (scheme dependent)	1.27 GeV	1.27 GeV (PDG (scheme dependent))	n/a	input/anchor
m_s (strange) (m_s)	m_s pending (scheme/scale)	n/a GeV	n/a	n/a	pending/pending
m_u (up) (m_u)	m_u pending (scheme/scale)	n/a GeV	n/a	n/a	pending/pending
m_d (down) (m_d)	m_d pending (scheme/scale)	n/a GeV	n/a	n/a	pending/pending
m_nu1 (m_nu1)	m_nu1 placeholder (order-of-mag)	0.05 eV	n/a	n/a	placeholder/anchor
m_nu3 (m_nu3)	v_ew^2/M_R source: seesaw_block /results/derived/mnu3_from_v_sm_eV	0.046160183 eV	pipeline_output: seesaw_block	n/a	derived_external/derived_external
sum m_nu (sum_mnu)	sum_mnu pending (needs consistent neutrino spectrum)	n/a eV	n/a	n/a	pending/pending
Delta m_np (delta_m_np)	delta_m_np pending (EM + isospin)	n/a GeV	n/a	n/a	pending/pending
lambda_C^p/lambda_C^e (lambda_C_ratio)	m_e/m_p	0.00054461707 dimensionless	n/a	n/a	derived_external/derived_external

Group 5: Flavor code (mixing angles)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
Cabibbo lambda (lambda)	sqrt(varphi0)*(1-varphi0/2)	0.22445997 dimensionless	0.22501 ? 0.00068 dimensionless (PDG 2024)	z=-0.809	derived/axiom

Constant	Formula / Calculation	Value	Reference	Deviation	Status
CKM A (CKM_A)	Vcb/lambda^2 Wolfenstein from CKM pipeline source: ckm_full_pipeline /results/alpha_s_sensitivity/matrix_abs_mu_uv/central	0.93486352 dimensionless	pipeline_output: ckm_full_pipeline	n/a	derived_external/derived_external
CKM rho (CKM_rho)	rho_CKM Wolfenstein from |Vub|,|Vtd| source: ckm_full_pipeline /results/alpha_s_sensitivity/matrix_abs_mu_uv/central	0.13172216 dimensionless	pipeline_output: ckm_full_pipeline	n/a	derived_external/derived_external
CKM eta (CKM_eta)	eta_CKM Wolfenstein from |Vub|,|Vtd| source: ckm_full_pipeline /results/alpha_s_sensitivity/matrix_abs_mu_uv/central	0.36822657 dimensionless	pipeline_output: ckm_full_pipeline	n/a	derived_external/derived_external
sin^2(theta13) (sin2_theta13)	varphi0*exp(-5/6)	0.023108435 dimensionless	0.02224 ? 0.00057 dimensionless (NuFIT 5.3 (2024, NO))	z=1.52	derived/axiom
sin^2(theta12) (sin2_theta12)	(1/3)*(1-2*sin2_theta13)	0.31792771 dimensionless	0.307 ? 0.012 dimensionless (NuFIT 5.3 (2024, NO))	z=0.911	derived/axiom
sin^2(theta23) (sin2_theta23)	sin2_theta23 input (NuFIT)	0.454 dimensionless	0.454 ? 0.019 dimensionless (NuFIT 5.3 (2024, NO))	n/a	input/anchor
delta_CP (deg) (delta_cp)	180*(1-delta_star) placeholder until Z3-breaking is wired	70.404841 degrees	232 ? 39 degrees (NuFIT 5.3 (2024, NO))	n/a	placeholder/pending

Group 6: Cosmos (space-time & energy)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
phi_star_base (phi_star_base)	exp(-alpha_inv0/2)	1.7498904e-30 dimensionless	n/a	n/a	derived/axiom
rho_L (rho_L)	(1/2*phi_star_base*Mpl_reduced)^4	2.0602471e-47 GeV^4	2.51418e-47 GeV^4 (Planck 2018 (k_calibration))	rel=-18.1%	derived/scan
Lambda Mpl^-2 (Lambda_Mpl2)	rho_L/Mpl_reduced^4	5.8603486e-121 dimensionless	7.15155e-121 dimensionless (Planck 2018 (k_calibration))	rel=-18.1%	derived/scan
Omega_b (Omega_b)	(4*pi-1)*beta_rad	0.048940663 dimensionless	0.0493017 dimensionless (Planck 2018 + Planck 2018)	rel=-0.732%	derived/axiom
eta_b (eta_b)	eta_b_pred baryon_consistency_audit proxy source: baryon_consistency_audit /results/eta_b_pred	5.7943769e-10 dimensionless	6.12714e-10 dimensionless (Planck 2018)	rel=-5.43%	derived_external/derived_external
H0 (H0)	H0_pred baryon_consistency_audit derived source: baryon_consistency_audit /results/H0_pred	65.746469 km/s/Mpc	67.36 ? 0.54 km s^-1 Mpc^-1 (Planck 2018)	z=-2.99	derived_external/derived_external
Omega_dm (Omega_dm)	Omega_dm (Omega_a h^2)/h^2 source: axion_dm_audit /results/relic/Omega_a_h2	0.27053304 dimensionless	0.26447 dimensionless (Planck 2018 + Planck 2018)	rel=2.29%	derived_external/derived_external
beta (deg) (beta_deg)	180/pi*beta_rad	0.24243503 degrees	0.35 ? 0.14 degrees (Minami & Komatsu 2020)	z=-0.768	derived/axiom
beta (deg, PR) (beta_deg_PR)	beta_deg frequency independent	0.24243503 degrees	n/a	n/a	derived/axiom
axion frequency (GHz) (nu_ghz)	nu_ghz axion_dm_audit pipeline source: axion_dm_audit /results/axion_claim/nu_GHz	15.764023 GHz	pipeline_output: axion_dm_audit	n/a	derived_external/derived_external
g_phys (axion) (g_phys_axion)	g_phys g_coeff/f_a source: axion_dm_pipeline /results/axion_claim/g_phys_GeV_inv_candidate	-1.7955229e-12 GeV^-1	pipeline_output: axion_dm_pipeline	n/a	derived_external/derived_external

Group 7: Inflation & origin

Constant	Formula / Calculation	Value	Reference	Deviation	Status
N_star (N_star)	N_star Starobinsky e-folds (policy)	56 dimensionless	internal_policy: theoryv3 config starobinsky_N	n/a	input/anchor
A_s (A_s)	N_star^2/(24*pi^2)*M_over_Mpl^2 Starobinsky amplitude	2.0901914e-09 dimensionless	2.0989e-09 ? 2.938e-11 dimensionless (Planck 2018)	z=-0.296	derived/axiom
n_s (n_s)	1-2/N_star Starobinsky tilt	0.96428571 dimensionless	0.9649 ? 0.0042 dimensionless (Planck 2018)	z=-0.146	derived/axiom
r (r)	12/N_star^2 Starobinsky tensor ratio	0.0038265306 dimensionless	upper_limit: Planck/BICEP (numeric bound pending)	n/a	derived/axiom
V_star (V_star)	(3/2)*pi^2*A_s*r*Mpl_reduced^4	4.1627287e+63 GeV^4	n/a	n/a	derived/axiom

Constant	Formula / Calculation	Value	Reference	Deviation	Status
bounce scale (bounce_scale)	k_bounce_t bounce_perturbations k_bounce_t (raw) source: bounce_perturbations /results/diagnostics/k_bounce_t_est_raw	7.8080396 dimensionless	pipeline_output: bounce_perturbations	n/a	derived_external/derived_external
x_max (Planck spectrum) (x_max)	x_max Planck spectrum extremum	2.8214394 dimensionless	analytic: Planck spectrum extremum	n/a	derived/axiom

Group 8: Exotic (bounds & tests)

Constant	Formula / Calculation	Value	Reference	Deviation	Status
max torsion coupling (torsion_max)	torsion_max max inferred |S_mu| bound source: torsion_bounds_mapping /results/inferred_bounds	2.9e-27 GeV	pipeline_output: torsion_bounds_mapping	n/a	derived_external/derived_external
vacuum stability scale (lambda_cross)	lambda_cross lambda crossing scale source: stability_unitarity_audit /results/lambda_crossing/mu_cross_GeV	4.5297286e+10 GeV	pipeline_output: stability_unitarity_audit	n/a	derived_external/derived_external

Group 9: QED derived constants

Constant	Formula / Calculation	Value	Reference	Deviation	Status
a_e (a_e)	alpha0/(2*pi)	0.0011614097 dimensionless	literature: CODATA 2022 QED lowest order	n/a	candidate/candidate
R_infty (energy) (Rydberg_E)	1/2*alpha0^2*m_e	1.6109539e-08 GeV	literature: CODATA 2022	n/a	candidate/candidate
Bohr radius (a0) (a0)	1/(alpha0*m_e)	226491.67 GeV^-1	literature: CODATA 2022	n/a	candidate/candidate
Thomson cross section (sigma_T)	8*pi/3*alpha0^2/m_e^2	1218.6651 GeV^-2	literature: classical electrodynamics	n/a	candidate/candidate
fine-structure 2p (H) (fs_2p)	alpha0^4*m_e	1.7157095e-12 GeV	n/a	n/a	candidate/candidate
Lamb shift (proxy) (lamb_shift)	alpha0^5*m_e*log(1/alpha0)	6.1602126e-14 GeV	n/a	n/a	candidate/candidate
proton g-factor (g_p)	2*(1+c3/pi)	2.0253303 dimensionless	literature: classical electrodynamics	n/a	candidate/candidate

Crosslink signatures

Signature	Details
g_signature	g_over_2=2.5, g_over_4=1.25, g_over_g_plus_1=0.8333333333333334, g_value=5
k_signature	best_label=n=1/2, k=2.0, n_from_cover=0.5

Anchor vs TFPT view

Quantity	Anchor	TFPT
H0	67.36	65.7465
Omega_b	0.0493017	0.0489407
eta_b	6.12714e-10	5.79438e-10
Omega_dm	0.26447	0.283975

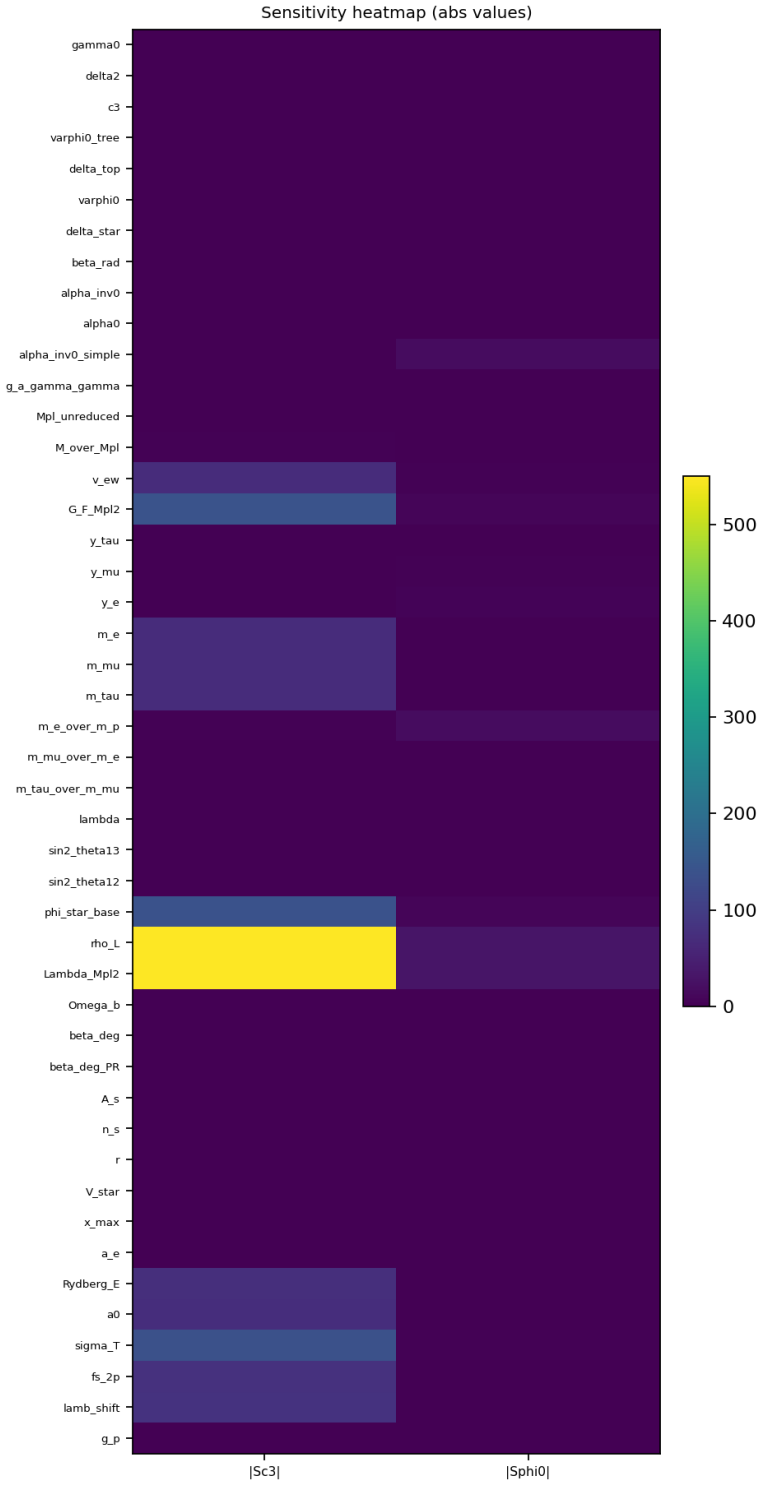
Anchor uses Planck H0/h; TFPT uses predicted H0 where available.

Gap list (pending / placeholder)

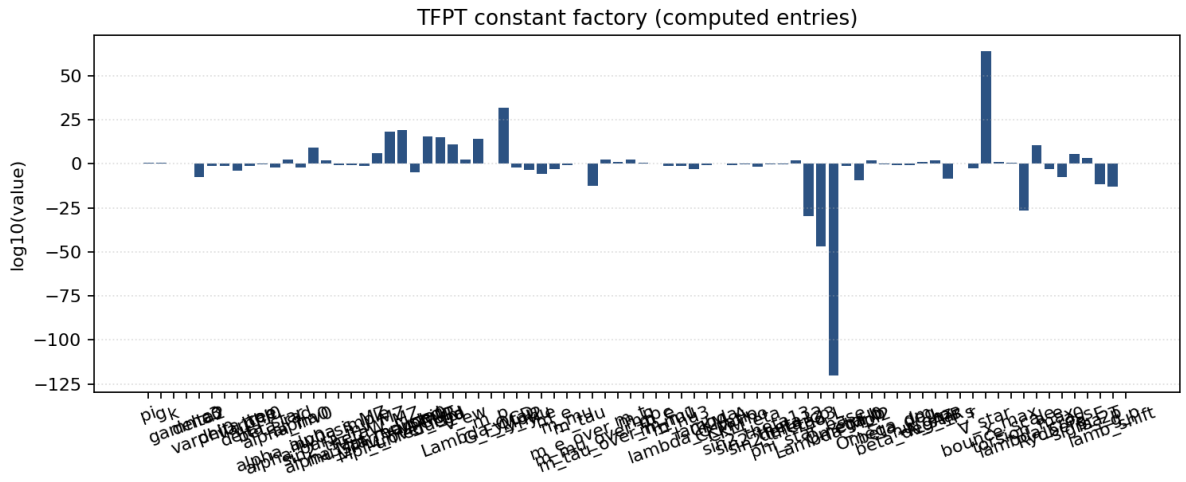
Constant	Reason
sin^2(thetaW)(0) (sin2_thetaW_0)	G(c3,varphi0) (pending)
Lambda_QCD (Lambda_QCD)	placeholder scaling (RG-based derivation pending)
m_p (m_p)	PDG placeholder
m_pi (m_pi)	pending TFPT derivation
m_s (strange) (m_s)	pending (scheme/scale)
m_u (up) (m_u)	pending (scheme/scale)
m_d (down) (m_d)	pending (scheme/scale)
m_nu1 (m_nu1)	placeholder (order-of-mag)
sum m_nu (sum_mnu)	pending (needs consistent neutrino spectrum)
Delta m_np (delta_m_np)	pending (EM + isospin)
delta_CP (deg) (delta_cp)	placeholder until Z3-breaking is wired

Plots

constant_factory_sensitivity.png



constant_factory_summary.png



Dark energy exponential audit (phi_star from exp(-alpha_inv/2))

Module ID: dark_energy_exponential_audit

Idea segment: exp(-alpha_inv/2) suppression sets dark energy scale

Test focus: phi_star_base and discrete normalization candidates vs rho_L target

Signal: best candidate within 0.5 dex, n=1/2 preferred

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Is the dark energy scale explained by exp(-alpha_inv/2) with a discrete normalization?
Objective: Quantify the exponential suppression mechanism with explicit candidates.
Objective: Track mismatch against the cosmology target ledger.

B) Inputs

alpha_inv_0 from g=5 delta2 model
k_calibration cosmology snapshot (Omega_m, Omega_r, H0)

C) Expected result (signal)

best candidate within 0.5 dex of target
n=1/2 branch is preferred under current scan

D) Method (how the test proceeds)

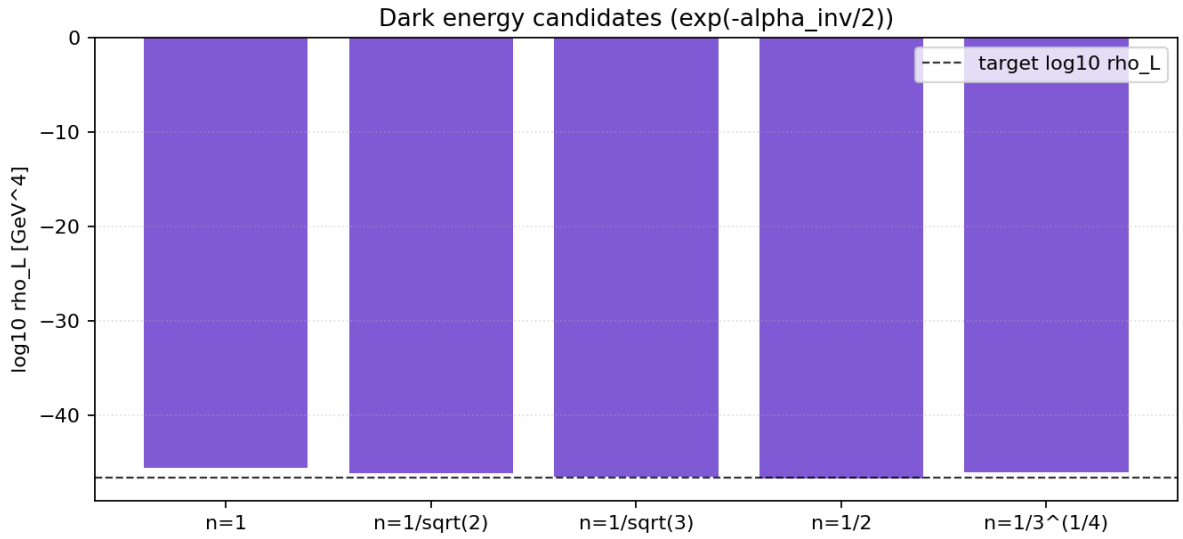
phi_star_base = exp(-alpha_inv_0 / 2)
rho_L = (Mpl_bar * phi_star)^4
Omega_L = 1 - Omega_m - Omega_r
rho_L_target = 3 * Omega_L * H0^2 * Mpl_bar^2
Determinism: Deterministic (finite scan, no continuous tuning).

E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: rho_L_within_tol - best=n=1/2, log10_mismatch=0.0864764405648649261871563479941039082666990305552016205369191751376935656378344 92
PASS: n_half_preferred - best=n=1/2
Plot check: missing=[], invalid=[], extra=[]

Plots

rho_lambda_candidates.png



Dark energy norm origin audit (n=1/2 from double cover)

Module ID: dark_energy_norm_half_origin_audit

Idea segment: n=1/2 fixed by double cover (k=2)

Test focus: n_from_cover=1/k and best candidate label

Signal: n_from_cover=1/2 and best label n=1/2

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Is the dark-energy normalization n=1/2 fixed by the double-cover degree?
Objective: Tie the preferred n=1/2 normalization to the cover degree used in alpha backreaction.

B) Inputs

alpha_precision_audit self_consistent.k (cover degree)
dark_energy_exponential_audit best candidate label

C) Expected result (signal)

n_from_cover equals 1/2
dark_energy_exponential_audit best candidate is n=1/2

D) Method (how the test proceeds)

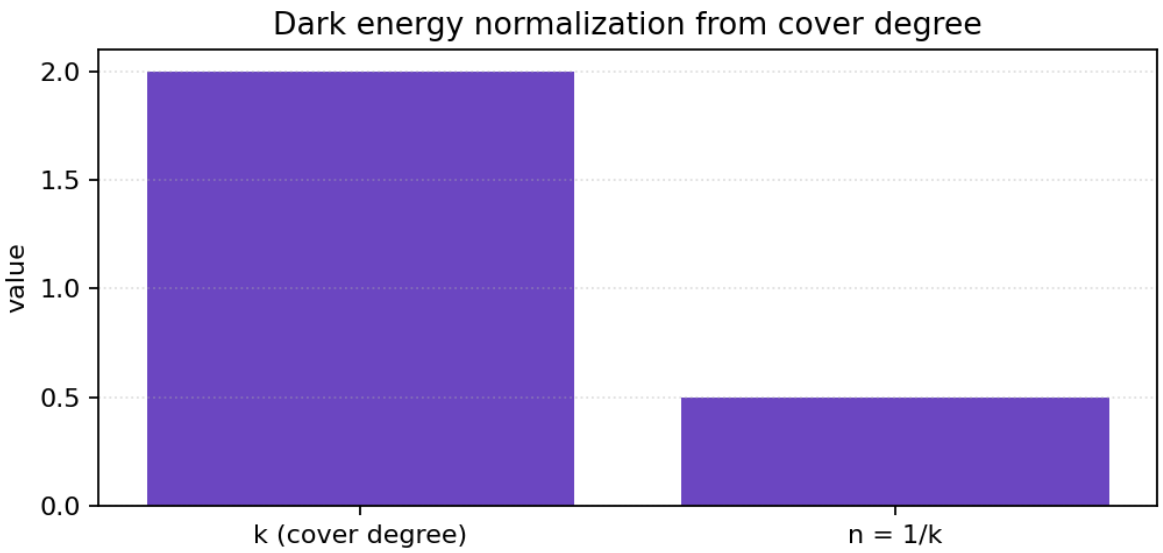
n_from_cover = 1 / k
k=2 corresponds to the double-cover backreaction exponent
Determinism: Deterministic (no fitting).

E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: n_from_cover_equals_half - n_from_cover=0.5
PASS: best_candidate_is_half - best_label=n=1/2
Plot check: missing=[], invalid=[], extra=[]

Plots

dark_energy_norm_origin.png



Defect partition g=5 audit (delta2 -> alpha_inv_0)

Module ID: defect_partition_g5_audit

Idea segment: discrete defect partition (g=5) fixes delta2 and alpha_inv(0)

Test focus: g=5 multiplicity, alpha_inv(0) within 2 sigma, and negative control vs g=4,6

Signal: g equals 5; z <= 2; g=5 minimizes |z|

Plot check: expected=2, present=2, missing=none, invalid=none, extra=none

A) What this test is intended to find

Does the g=5 defect partition close alpha(0) without a fit parameter?
Objective: Lock delta2 to a discrete g=5 multiplicity.
Objective: Show the resulting alpha_inv_0 is within CODATA sigma.

B) Inputs

TFPT constants (delta_top)
defect partition g from discrete enumeration
CODATA alpha_inv_0 reference

C) Expected result (signal)

g is discrete and equals 5 under current enumeration
alpha_inv_0 is within 2 sigma of CODATA
g=5 minimizes |z| among g in {4,5,6}

D) Method (how the test proceeds)

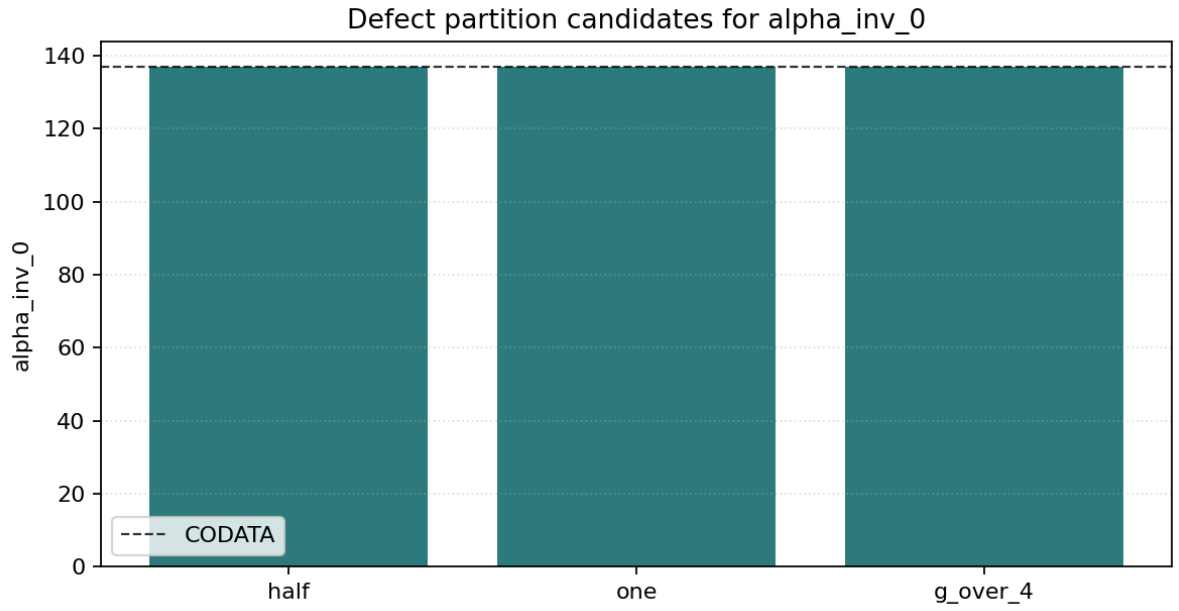
delta2 = (g/4) * delta_top^2
alpha_inv_0 from CFE + backreaction with delta2
z = (pred - mean)/sigma
Determinism: Deterministic (finite enumeration + root finding).

E) Results and JSON outputs

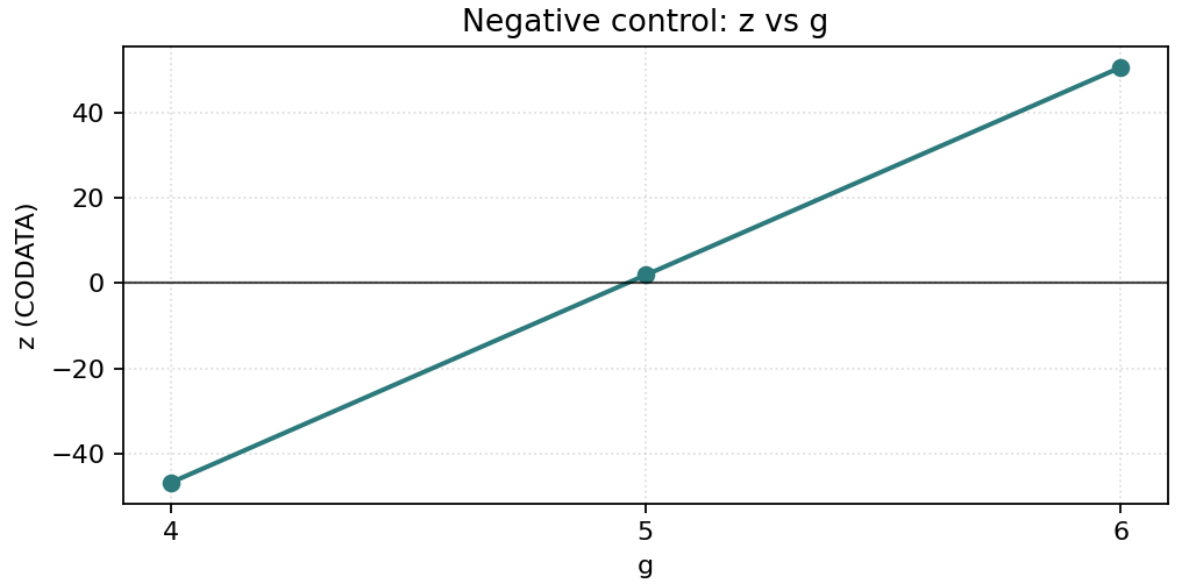
Summary: PASS=4, WARN=0, FAIL=0
PASS: g_equals_5 - g=5
PASS: alpha_within_2sigma - z=1.864687370964843691291141618383604047741993403213211260156274655427579880861449 3
PASS: g5_is_best_by_z - |z5|=1.8646873709648437, others={4: 46.8455434804275, 5: 1.8646873709648437, 6: 50.5749164827739}
PASS: gap_to_next_best - gap=44.98085610946266
Plot check: missing=[], invalid=[], extra=[]

Plots

alpha_defect_series.png



g_negative_control.png



Flavor pattern audit (lambda, delta_star, delta_cp, PMNS theta13)

Module ID: flavor_pattern_audit

Idea segment: Mobius/Z3 flavor anchors from varphi0 and delta_star

Test focus: lambda (Cabibbo), sin2(theta13), cusp set {1,1/3,2/3}

Signal: lambda and sin2(theta13) within 2 sigma; cusp set matches

Plot check: expected=2, present=2, missing=none, invalid=none, extra=none

A) What this test is intended to find

Do the compact flavor formulas reproduce the anchor observables?
Objective: Make the flavor anchor formulas explicit and testable.
Objective: Expose Mobius ratio predictions in one place.

B) Inputs

TFPT constants (varphi0, delta_star)
CKM/PMNS reference tables
Mobius cusp set from SU(5) hypercharge
reference[cabibbo_lambda]: PDG 2024 value=0.22501 sigma=0.00068
reference[pmns_sin2_theta13]: NuFIT 5.3 (2024, NO) value=0.02224 sigma=0.00057

C) Expected result (signal)

lambda within 2 sigma of reference
sin2_theta13 within 2 sigma of NuFIT reference
cusp set equals {1, 1/3, 2/3}

D) Method (how the test proceeds)

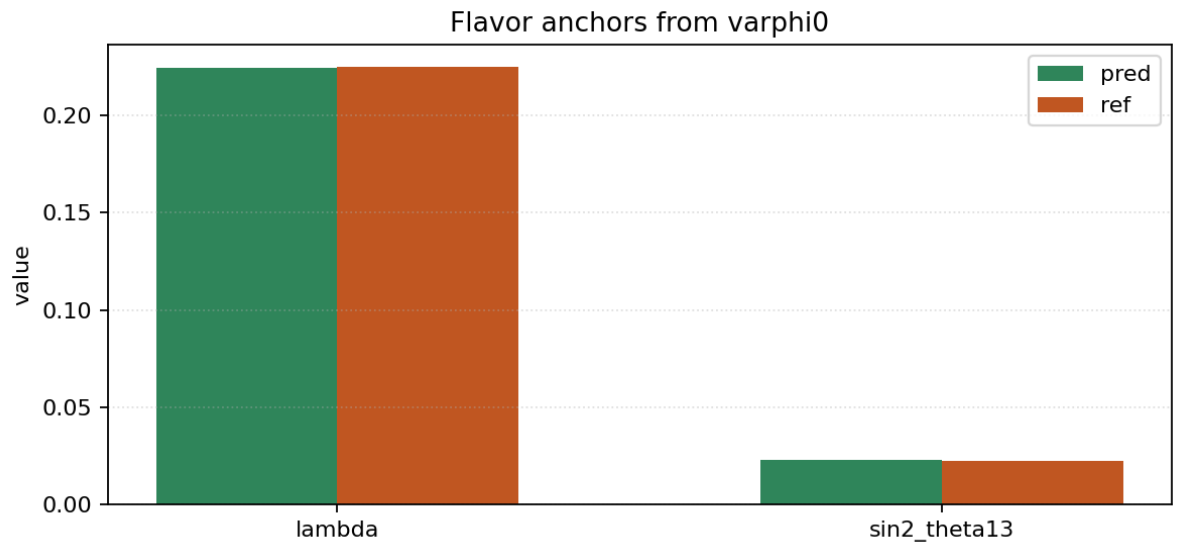
lambda = sqrt(varphi0) * (1 - varphi0/2)
delta_star = 3/5 + varphi0/6
delta_cp = pi * (1 - delta_star)
sin2_theta13 = varphi0 * exp(-5/6)
M_y(delta) = (y + delta)/(y - delta)
Determinism: Deterministic given constants and reference tables.

E) Results and JSON outputs

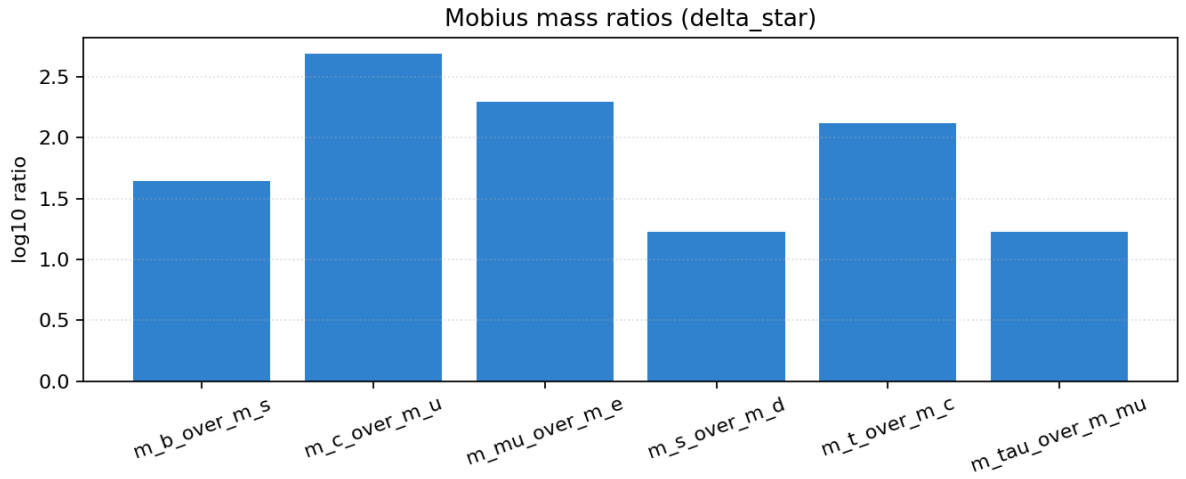
Summary: PASS=3, WARN=0, FAIL=0
PASS: lambda_within_2sigma - z=-0.80886688386215815424120959193831144352504400306915601515778365039223348735049879
PASS: sin2_theta13_within_2sigma - z=1.52357045417737595313098404111890421895490820317578126474593161132333461783883335
PASS: cusp_set_matches - cusp_set=[Fraction(1, 3), Fraction(2, 3), Fraction(1, 1)]
Plot check: missing=[], invalid=[], extra=[]

Plots

flavor_anchors.png



mobius_ratios.png



g=5 crosslink audit (delta2, unification patch, gamma0)

Module ID: g5_crosslink_audit

Idea segment: g=5 crosslinks across sectors

Test focus: delta2 factor g/4, unification patch g/2, gamma0=g/(g+1)

Signal: g=5; delta_b3 includes g/2; gamma0 matches g/(g+1)

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Is g=5 consistently threaded across multiple sectors?
Objective: Summarize the discrete g=5 signature across delta2, unification, and E8 ladder.

B) Inputs

defect partition g
unification_gate_policy delta_b3 candidates
TFPT gamma0

C) Expected result (signal)

g resolves to 5
delta_b3 candidates include g/2
gamma0 equals g/(g+1)

D) Method (how the test proceeds)

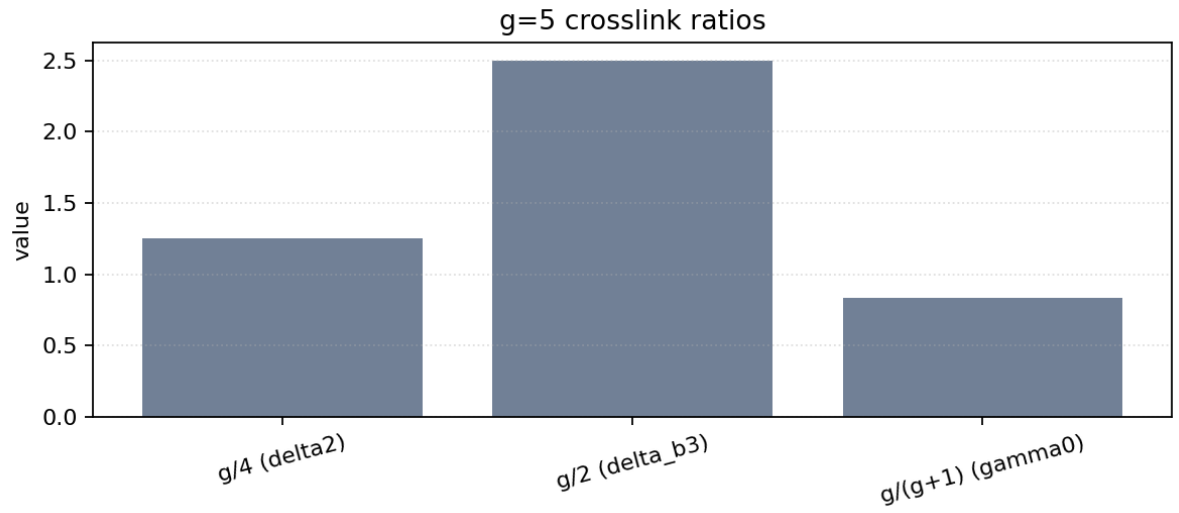
delta2 factor = g/4
unification patch candidate = g/2
gamma0 = g/(g+1)
Determinism: Deterministic (finite comparisons).

E) Results and JSON outputs

Summary: PASS=3, WARN=0, FAIL=0
PASS: g_equals_5 - g=5
PASS: delta_b3_has_g_over_2 - delta_b3 includes 2.5
PASS: gamma0_matches_g_over_g_plus_1 - gamma0=0.8333333333333334
Plot check: missing=[], invalid=[], extra=[]

Plots

g5_links.png



g=5 origin audit (single-source SU(5) holonomy degeneracy)

Module ID: g5_origin_audit

Idea segment: single origin for g from SU(5) holonomy degeneracy

Test focus: count eigenvalue degeneracies in SU(5) hypercharge spectrum

Signal: degeneracies {3,2} and g=5

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Can g be derived from a single discrete origin (SU(5) holonomy degeneracy)?
Objective: Fix g from one source only, not by crosslinking multiple sectors.

B) Inputs

SU(5) hypercharge holonomy spectrum (fundamental)

C) Expected result (signal)

g equals 5 (3 color + 2 weak holonomy channels)

D) Method (how the test proceeds)

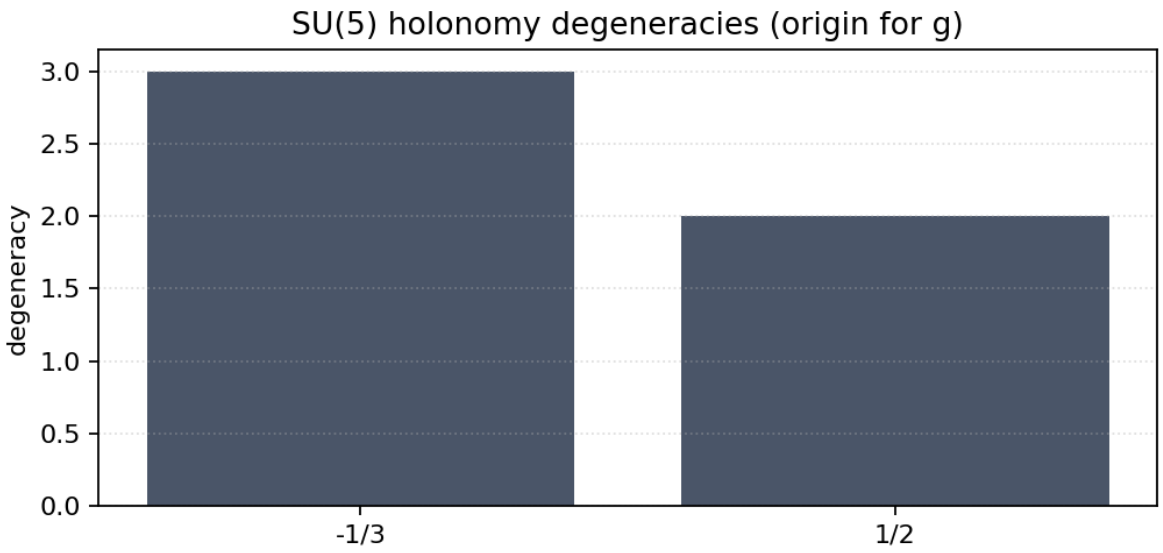
g := sum of degeneracies in SU(5) fundamental holonomy spectrum
degeneracies inferred from repeated eigenvalues
Determinism: Deterministic (no fitting, no scanning).

E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: g_equals_5_from_holonomy - g=5
PASS: degeneracy_pattern - degeneracies=[3, 2]
Plot check: missing=[], invalid=[], extra=[]

Plots

g5_origin.png



PMNS TM1 audit (theta12 from theta13)

Module ID: pmns_tm1_audit

Idea segment: TM1 sum rule for theta12

Test focus: sin2(theta12) from sin2(theta13)

Signal: sin2(theta12) within conservative band

A) What this test is intended to find

Does the TM1 sum rule yield a viable sin2(theta12) given sin2(theta13)?
Objective: Audit the TM1 sum rule with explicit inputs and a conservative band.

B) Inputs

sin2_theta13 from flavor_pattern_audit
NuFIT sin2_theta12 reference (normal ordering)

C) Expected result (signal)

sin2_theta12 within conservative band (3 sigma)

D) Method (how the test proceeds)

sin2_theta12 = (1/3) * (1 - 2 * sin2_theta13)
Determinism: Deterministic (closed form).

E) Results and JSON outputs

Summary: PASS=2, WARN=0, FAIL=0
PASS: sin2_theta12_within_band - z=0.9106424911732719837064077275867902552886501291216558155052677211969832926573258 3
INFO: theta23_placeholder - theta23 and delta_CP are placeholders until Z3-breaking is wired into this audit

Seed invariants audit (pi -> c3, varphi0, beta_rad)

Module ID: seed_invariants_audit

Idea segment: pi seeds the invariants

Test focus: c3, varphi0_tree, delta_top, varphi0, beta_rad identities (and optional match to core_invariants)

Signal: identities hold and match within numerical tolerance

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Does pi alone fix the core invariants used across TFPT?
Objective: Make the pi-seed dependency explicit and auditable.
Objective: Provide a compact reference table for downstream audits.

B) Inputs

pi

C) Expected result (signal)

internal identities are satisfied
optional match to core_invariants output if present

D) Method (how the test proceeds)

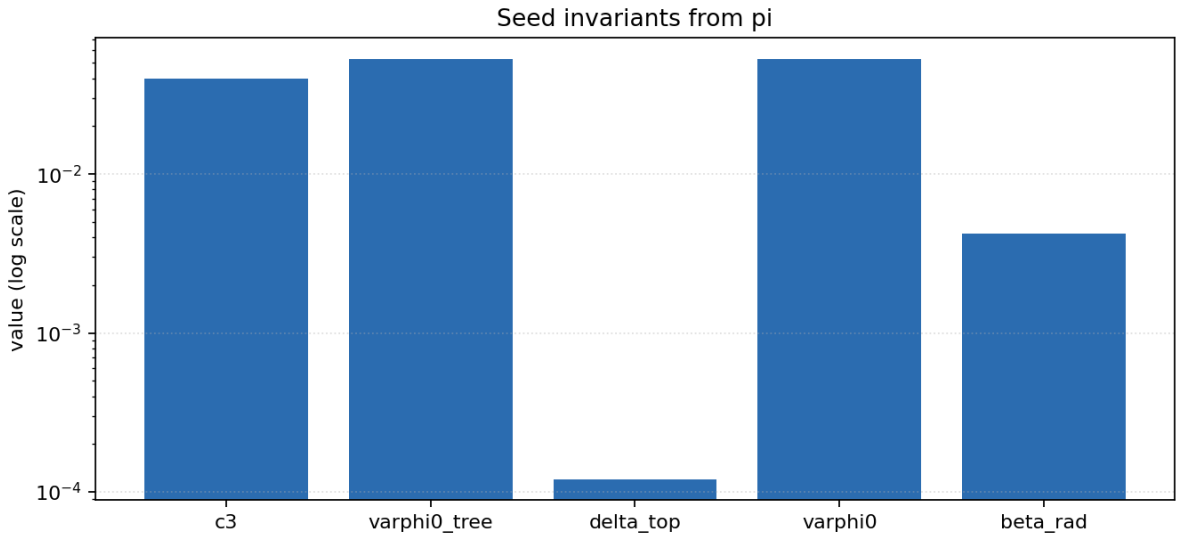
c3 = 1/(8*pi)
varphi0_tree = 1/(6*pi)
delta_top = 3/(256*pi^4)
varphi0 = varphi0_tree + delta_top
beta_rad = varphi0/(4*pi)
Determinism: Deterministic (pure algebra).

E) Results and JSON outputs

Summary: PASS=7, WARN=0, FAIL=0
PASS: match_c3 - c3 matches core_invariants
(diff=-1.97666211435572310456535763461312856394561775919409516563958056720777705455682 99e-82)
PASS: match_varphi0_tree - varphi0_tree matches core_invariants
(diff=-2.63554948580763080608714351281750475192749034559212688751944075627703607274243 99e-82)
PASS: match_delta_top - delta_top matches core_invariants
(diff=-4.50411289078452530337158315178772784753233213358029497378810676121563781962819 32e-84)
PASS: match_varphi0 - varphi0 matches core_invariants
(diff=-1.97666211435572310456535763461312856394561775919409516563958056720777705455682 99e-82)
PASS: match_beta_rad - beta_rad matches core_invariants
(diff=1.64721842862976925380446469551094046995468146599507930469965047267314754546402 49e-83)
PASS: varphi0_identity - varphi0 = varphi0_tree + delta_top
(0.05317195217684552730929247196974966787512775979979113964045097968531945723755463 6)
PASS: beta_rad_identity - beta_rad = varphi0/(4*pi)
(0.00423128951139541510874681820880501639507280772668372576989442290305267327215562 63)
Plot check: missing=[], invalid=[], extra=[]

Plots

seed_invariants.png



Yukawa exponent index audit (q_ij rationalization)

Module ID: yukawa_exponent_index_audit

Idea segment: mass ratios follow rational exponent indices q_ij

Test focus: q_ij rationalization and ratio reconstruction error

Signal: max relative error <= 2%

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Do the Mobius-derived ratios align with rational exponent indices?
Objective: Quantize the exponent indices with a fixed denominator grammar.
Objective: Report which ratios are most stable under the rational map.

B) Inputs

mass ratios from mass_spectrum_deriver (preferred)
TFPT invariants (c3, varphi0)

C) Expected result (signal)

relative reconstruction errors are below 2% for the selected ratios

D) Method (how the test proceeds)

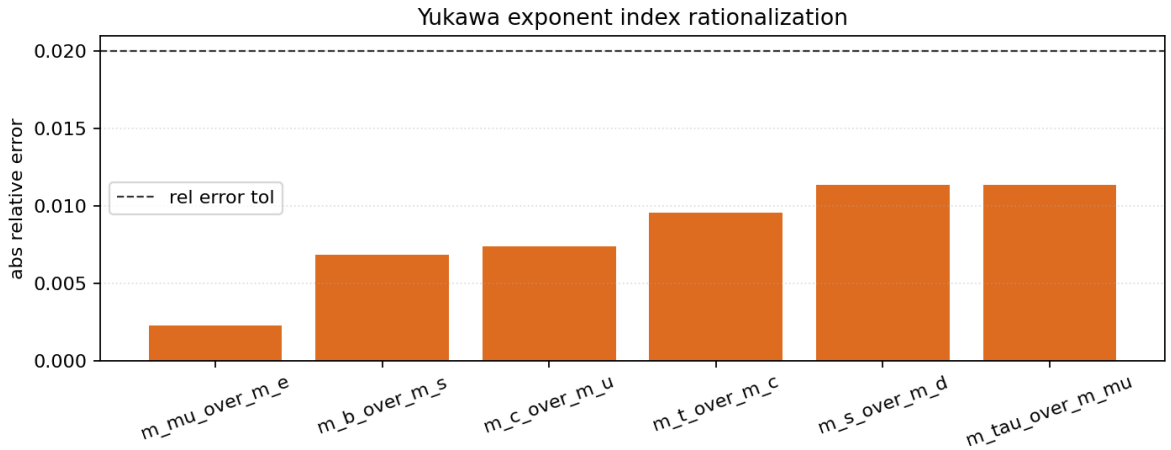
q_ij = (c3/varphi0) * ln(ratio)
ratio_recon = exp(q_rational * varphi0 / c3)
Determinism: Deterministic (finite rational scan).

E) Results and JSON outputs

Summary: PASS=3, WARN=4, FAIL=0
PASS: rationalization_within_tol - max_rel_error=0.01138
PASS: ratio_direct:m_mu_over_m_e - scale-independent reference
WARN: ratio_needs_rg:m_b_over_m_s - scheme=MSbar, scale=n/a
WARN: ratio_needs_rg:m_c_over_m_u - scheme=MSbar, scale=n/a
WARN: ratio_needs_rg:m_t_over_m_c - scheme=MSbar, scale=n/a
WARN: ratio_needs_rg:m_s_over_m_d - scheme=MSbar, scale=n/a
PASS: ratio_direct:m_tau_over_m_mu - scale-independent reference
Plot check: missing=[], invalid=[], extra=[]

Plots

yukawa_q_errors.png



Yukawa index mapping audit (q_ij -> charge-squared sums)

Module ID: yukawa_index_mapping_audit

Idea segment: q_ij map to charge-squared index sums

Test focus: bounded integer sum of charge-squared indices

Signal: mapping errors <= 2%

Plot check: expected=1, present=1, missing=none, invalid=none, extra=none

A) What this test is intended to find

Can q_ij be mapped to discrete charge-squared index sums from the microscopic action?
Objective: Tie exponent indices to explicit charge-squared sums (no continuous tuning).

B) Inputs

mass ratios from mass_spectrum_deriver (preferred)
TFPT invariants (c3, varphi0)
microscopic_action_tfpt_v25.json (charge-squared sums)

C) Expected result (signal)

relative mapping errors are <= 2% for the selected ratios

D) Method (how the test proceeds)

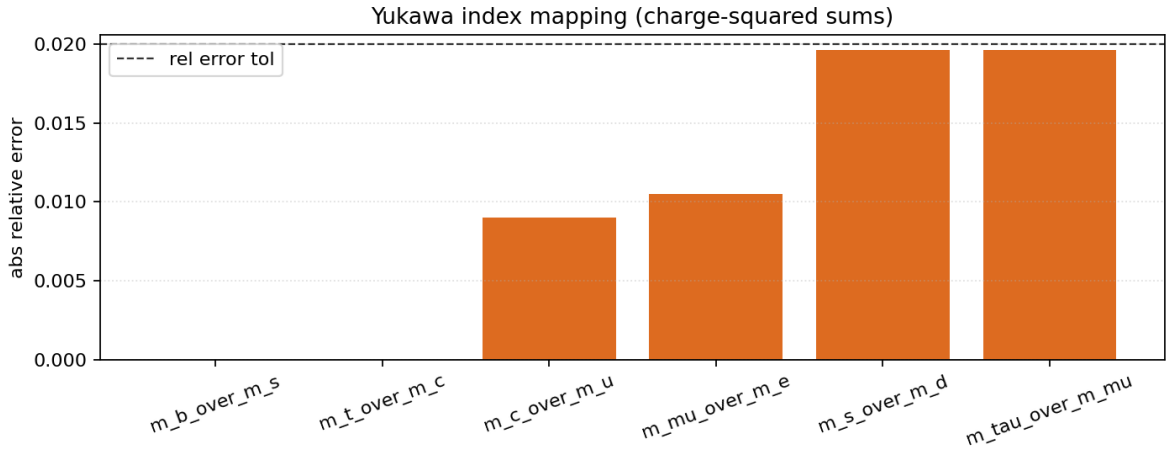
q_ij = (c3/varphi0) * ln(ratio)
I_field = dim(SU3) * dim(SU2) * Y^2
q_target ~ sum_i n_i * I_i (integer coefficients)
Determinism: Deterministic (finite bounded search).

E) Results and JSON outputs

Summary: PASS=3, WARN=4, FAIL=0
PASS: mapping_within_tol - max_rel_error=0.01961
WARN: ratio_needs_rg:m_b_over_m_s - scheme=MSbar, scale=n/a
WARN: ratio_needs_rg:m_t_over_m_c - scheme=MSbar, scale=n/a
WARN: ratio_needs_rg:m_c_over_m_u - scheme=MSbar, scale=n/a
PASS: ratio_direct:m_mu_over_m_e - scale-independent reference
WARN: ratio_needs_rg:m_s_over_m_d - scheme=MSbar, scale=n/a
PASS: ratio_direct:m_tau_over_m_mu - scale-independent reference
Plot check: missing=[], invalid=[], extra=[]

Plots

yukawa_index_mapping.png



Appendix: Raw JSON

alpha_backreaction_sensitivity_audit: report.txt

```
Alpha backreaction sensitivity audit

alpha_ref = 137.035999177 (CODATA 2022)
```

```
k grid results:
- k=0.0: alpha_inv=137.036501464885822366066748176712131267057638985048679067960085645743301584739 74, ppm=3.665371791638
- k=1.0: alpha_inv=137.036246859241648818575018189251999738951329544841687830255308955968585124348 76, ppm=1.807424641235
- k=1.5: alpha_inv=137.036120250252962325454829313990844244615363345759303452038427141424933051658 18, ppm=0.883514212976
- k=2.0: alpha_inv=137.035994101583830081486196229133360094092579041712467224753528413047009013232 15, ppm=-0.037037101200
- k=2.5: alpha_inv=137.035868411564777159589809008377098973730359252264869391526386065589640946264 34, ppm=-0.954241484040
- k=3.0: alpha_inv=137.035743178532350398855639485662579711516080700577620796353154140318279197498 62, ppm=-1.868111074360

Checks:
- k2_is_near_zero_crossing: PASS (min_k=2.0, abs_ppm={0.0: 3.665371791638453, 1.0: 1.8074246412353618, 1.5: 0.883514212976
- monotonicity_check: INFO (monotonic=True, diffs=[-1.857947150403091, -0.9239104282587889, -0.920551314179177, -0.91720
```

alpha_backreaction_sensitivity_audit: results.json (tfpt-suite/theoryv3/out/alpha_backreaction_sensitivity_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "k2_is_near_zero_crossing",
      "detail": "min_k=2.0, abs_ppm={0.0: 3.665371791638453, 1.0: 1.8074246412353618, 1.5: 0.883514212976573, 2.0: 0.037
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "monotonicity_check",
      "detail": "monotonic=True, diffs=[-1.857947150403091, -0.9239104282587889, -0.920551314179177, -0.917204382846705
      "passed": true,
      "severity": "INFO"
    }
  ],
  "module_id": "alpha_backreaction_sensitivity_audit",
  "plot": {
    "alpha_backreaction_ppm.png": "./tfpt-suite/theoryv3/out/alpha_backreaction_sensitivity_audit/alpha_backreaction_ppm
  },
  "results": {
    "abs_ppm": {
      "0.0": 3.665371791638453,
      "1.0": 1.8074246412353618,
      "1.5": 0.883514212976573,
      "2.0": 0.03703710120260405,
      "2.5": 0.9542414840493093,
      "3.0": 1.8681110743677323
    },
    "plot": {
      "alpha_backreaction_ppm.png": "./tfpt-suite/theoryv3/out/alpha_backreaction_sensitivity_audit/alpha_backreaction_p
    },
    "reference": {
      "dataset_id": "alpha_inv_codata_2022",
      "notes": "Inverse fine-structure constant alpha^{-1}(0).",
      "sigma": 2.1e-08,
      "source": "global_reference_minimal.json:observables.alpha_inv_codata_2022",
      "units": "dimensionless",
      "value": 137.035999177,
      "version": "CODATA 2022"
    },
    "series": [
      {
        "alpha_inv": "137.036501464885822366066748176712131267057638985048679067960085645743301584739 74",
        "converged": true,
        "iterations": 1,
        "k": "0.0",
        "ppm_vs_codata": "3.665371791638453043482176704786322467659070897884375704519155171785877040459 4889"
      },
      {
        "alpha_inv": "137.036246859241648818575018189251999738951329544841687830255308955968585124348 76",
        "converged": true,
        "iterations": 5,
        "k": "1.0",
        "ppm_vs_codata": "1.807424641235361910409615752552998596577999114623336398055706706157294199558044"
      },
      {
        "alpha_inv": "137.036120250252962325454829313990844244615363345759303452038427141424933051658 18",
        "converged": true,
        "iterations": 6,
        "k": "1.5",
        "ppm_vs_codata": "0.883514212976572959726156168443847908525005020721059943960519562834286307177644 77"
      },
      {
        "alpha_inv": "137.035994101583830081486196229133360094092579041712467224753528413047009013232 15",
        "converged": true,
```

```
        "iterations": 6,
        "k": "2.0",
        "ppm_vs_codata": "-0.037037101202604046334641968339095182025406625555948066961471526462227692903073795"
      },
      {
        "alpha_inv": "137.035868411564777159589809008377098973730359252264869391526386065589640946264 34",
        "converged": true,
        "iterations": 6,
        "k": "2.5",
        "ppm_vs_codata": "-0.954241484049309316993878913475208087151142698677711802925444585121388753419551 86"
      },
      {
        "alpha_inv": "137.035743178532350398855639485662579711516080700577620796353154140318279197498 62",
        "converged": true,
        "iterations": 6,
        "k": "3.0",
        "ppm_vs_codata": "-1.868111074367732264260179740407020128099747422613734899274376833997012724840828 8"
      }
    ]
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (fixed-point iteration).",
    "formulas": [
      "varphi(alpha)=varphi_tree + delta_top * exp(-k alpha)",
      "alpha from CFE fixed point (self-consistent)",
      "ppm = 1e6*(pred-ref)/ref"
    ],
    "gaps": [],
    "inputs": [
      "TFPT invariants (c3, varphi0_tree, delta_top, b1)",
      "CODATA alpha_inv_0 reference"
    ],
    "maturity": null,
    "module_id": "alpha_backreaction_sensitivity_audit",
    "name": "Alpha backreaction sensitivity audit (k sweep)",
    "objective": [
      "Quantify how alpha_inv_0 depends on k and show the k=2 near-crossing."
    ],
    "outputs": [
      "alpha_inv_0 for k in {0,1,1.5,2,2.5,3}",
      "ppm deviation vs CODATA"
    ],
    "question": "Is k=2 a natural choice from alpha backreaction sensitivity?",
    "references": [
      "alpha_inv_codata_2022"
    ],
    "validation": [
      "k=2 is near the minimum |ppm| in the grid"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


axion_dm_audit: report.txt

```
Axion DM audit

f_a_GeV = 88639886850.34554
m_a_micro_eV = 65.1947598780055
nu_GHz (reported) = 15.76402318010866
nu_GHz (calc) = 15.76402318010866

Omega_a_h2 = 0.12275084115028702 (ref=0.12)
fraction_of_dm = 1.022923676252392
theta_eff = 1.8137993642342178
strings_domain_walls_factor = 2.3333333333333335
scenario_id = post_inflation_theta_rms_with_strings_dw_factor

Checks:
- frequency_matches: PASS (nu_calc=15.76402318010866, nu_reported=15.76402318010866)
- omega_a_near_ref: PASS (Omega_a_h2=0.12275084115028702)
```

axion_dm_audit: results.json (tfpt-suite/theoryv3/out/axion_dm_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "frequency_matches",
```

```
      "detail": "nu_calc=15.76402318010866, nu_reported=15.76402318010866",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "omega_a_near_ref",
      "detail": "Omega_a_h2=0.12275084115028702",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "axion_dm_audit",
  "plot": {
    "axion_summary_png": "./tfpt-suite/theoryv3/out/axion_dm_audit/axion_summary.png"
  },
  "results": {
    "axion_claim": {
      "f_a_GeV": 88639886850.34554,
      "m_a_micro_eV": 65.1947598780055,
      "nu_GHz": 15.76402318010866
    },
    "nu_calc_GHz": 15.76402318010866,
    "plot": {
      "axion_summary_png": "./tfpt-suite/theoryv3/out/axion_dm_audit/axion_summary.png"
    },
    "relic": {
      "Omega_a_h2": 0.12275084115028702,
      "fraction_of_dm": 1.022923676252392
    },
    "scenario": {
      "scenario_id": "post_inflation_theta_rms_with_strings_dw_factor",
      "strings_domain_walls_factor": 2.3333333333333335,
      "theta_eff": 1.8137993642342178
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic given inputs.",
    "formulas": [
      "nu_GHz = 0.24179893 * m_a_micro_eV"
    ],
    "gaps": [],
    "inputs": [
      "axion_dm_pipeline outputs (preferred)",
      "axion_tfpt_v106.json (fallback)"
    ],
    "maturity": null,
    "module_id": "axion_dm_audit",
    "name": "Axion DM audit (frequency, relic fraction)",
    "objective": [
      "Expose the axion target frequency and relic fraction in a single audit."
    ],
    "outputs": [
      "nu_GHz from m_a",
      "Omega_a h^2",
      "theta_eff and strings/domain-walls factor (if available)"
    ],
    "question": "Do the axion numbers map cleanly to a frequency and relic fraction?",
    "references": [],
    "validation": [
      "frequency matches the m_a conversion",
      "relic fraction is near Omega_DM reference"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


baryon_consistency_audit: report.txt

```
Baryon consistency audit

beta_rad = 0.004231289511395415
Omega_b_pred = 0.04894066266545011
Omega_b_ref = 0.049301692328524445 (z=-0.42136420161877963)

eta_b_pred = 5.794376870756092e-10
eta10_pred = 5.794376870756092
omega_b_h2_pred = 0.021155081674903587
```

```
eta_b_ref = 6.127143e-10 (log10 mismatch=-0.024251277714995013)

H0_pred = 65.74646854801091 km/s/Mpc (z_planck=-2.9880212073872032, z_alt=-7.013011011527977)
H0_ref_planck = 67.36 ? 0.54 km/s/Mpc (Planck 2018)
H0_ref_alt = 73.04 ? 1.04 km/s/Mpc (SH0ES 2022)

Checks:
- omega_b_within_2sigma: PASS (z=-0.42136420161877963)
- eta_b_within_0p5_dex: PASS (log10 mismatch=-0.024251277714995013)
- H0_within_2sigma: WARN (z_planck=-2.9880212073872032)
- H0_tension_indicator: INFO (z_alt=-7.013011011527977 (alt=73.04 ? 1.04; planck=67.36 ? 0.54))
```

baryon_consistency_audit: results.json (tfpt-suite/theoryv3/out/baryon_consistency_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "omega_b_within_2sigma",
      "detail": "z=-0.42136420161877963",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "eta_b_within_0p5_dex",
      "detail": "log10 mismatch=-0.024251277714995013",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "H0_within_2sigma",
      "detail": "z_planck=-2.9880212073872032",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "H0_tension_indicator",
      "detail": "z_alt=-7.013011011527977 (alt=73.04 \u00b1 1.04; planck=67.36 \u00b1 0.54)",
      "passed": true,
      "severity": "INFO"
    }
  ],
  "module_id": "baryon_consistency_audit",
  "plot": {
    "baryon_consistency_png": "./tfpt-suite/theoryv3/out/baryon_consistency_audit/baryon_consistency.png"
  },
  "results": {
    "H0_pred": 65.74646854801091,
    "H0_ref_set": {
      "alt": {
        "sigma": 1.04,
        "value": 73.04
      },
      "planck": {
        "sigma": 0.54,
        "value": 67.36
      }
    },
    "H0_z_alt": -7.013011011527977,
    "H0_z_planck": -2.9880212073872032,
    "eta10_pred": 5.794376870756092,
    "eta_b_log10_mismatch": -0.024251277714995013,
    "eta_b_pred": 5.794376870756092e-10,
    "eta_b_ref": 6.127143e-10,
    "h_pred": 0.6574646854801091,
    "omega_b_h2_pred": 0.021155081674903587,
    "omega_b_pred": 0.04894066266545011,
    "omega_b_ref": 0.049301692328524445,
    "omega_b_sigma": 0.0008568114274714094,
    "omega_b_z": -0.42136420161877963,
    "plot": {
      "baryon_consistency_png": "./tfpt-suite/theoryv3/out/baryon_consistency_audit/baryon_consistency.png"
    },
    "references": {
      "H0_planck2018": {
        "dataset_id": "H0_planck2018",
        "notes": "H0 from Planck 2018 base LCDM.",
        "sigma": 0.54,
        "source": "global_reference_minimal.json:observables.H0_planck2018_km_s_Mpc",
        "units": "km s^-1 Mpc^-1",
        "value": 67.36,
        "version": "Planck 2018"
```

```
      },
      "H0_sh0es_2022": {
        "dataset_id": "H0_sh0es_2022",
        "notes": "Local distance-ladder H0 from SH0ES 2022.",
        "sigma": 1.04,
        "source": "Riess et al. 2022 (ApJ 934 L7)",
        "units": "km s^-1 Mpc^-1",
        "value": 73.04,
        "version": "SH0ES 2022"
      },
      "omega_b_h2_planck2018": {
        "dataset_id": "omega_b_h2_planck2018",
        "notes": "Omega_b h^2 (base LCDM).",
        "sigma": 0.00015,
        "source": "global_reference_minimal.json:observables.omega_b_h2_planck2018",
        "units": "dimensionless",
        "value": 0.02237,
        "version": "Planck 2018"
      }
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic given inputs.",
    "formulas": [
      "Omega_b = (4*pi - 1) * beta_rad",
      "eta10 = 273.9 * omega_b_h2",
      "eta_b = 0.96e-2 * eps1 * kappa_eff",
      "eta10_pred = 1e10 * eta_b_pred",
      "omega_b_h2_pred = eta10_pred / 273.9",
      "H0 = 100 * sqrt((eta10_pred/273.9) / Omega_b_pred)"
    ],
    "gaps": [],
    "inputs": [
      "TFPT invariants (beta_rad)",
      "Planck omega_b_h2 and H0 references",
      "Alternative H0 reference (SH0ES)",
      "seesaw thresholds and neutrino masses (eta_b proxy)"
    ],
    "maturity": null,
    "module_id": "baryon_consistency_audit",
    "name": "Baryon consistency audit (Omega_b, eta_b, derived H0)",
    "objective": [
      "Expose the Omega_b identity and baryogenesis proxy in one audit.",
      "Quantify the implied H0 from internal TFPT quantities."
    ],
    "outputs": [
      "Omega_b = (4*pi - 1) * beta_rad",
      "eta_b proxy (leptogenesis-style)",
      "eta10_pred = 1e10 * eta_b_pred",
      "omega_b_h2_pred = eta10_pred / 273.9",
      "derived H0 from Omega_b and eta_b"
    ],
    "question": "Do baryon observables self-consistently close using beta_rad?",
    "references": [
      "H0_planck2018",
      "H0_sh0es_2022",
      "omega_b_h2_planck2018"
    ],
    "validation": [
      "Omega_b within 2 sigma of reference",
      "eta_b within 0.5 dex of Planck anchor",
      "H0 within 2 sigma of Planck anchor (derived check)"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


constant_factory_audit: report.txt

```
Constant factory audit (hierarchical)
Source: theoryv3/constantfactory.md
Status counts: {'input': 9, 'derived': 34, 'candidate': 14, 'derived_external': 19, 'pending': 8, 'placeholder': 3}
Grammar violations: 0

Group 0: Discrete anchors
-------------------------
pi: pi
```

```
  status: input/anchor
  calculation:
    formula_math: pi
    formula_text: circle constant
    value: 3.141592654
g: g
  status: derived/discrete_scan
  calculation:
    formula_math: g
    formula_text: SU(5) holonomy multiplicity (two-defect)
    value: 5
    source: defect_partition_g5_audit
k: k
  status: derived/discrete_scan
  calculation:
    formula_math: k
    formula_text: backreaction cover degree (min |ppm|)
    value: 2
    source: alpha_backreaction_sensitivity_audit
gamma0: gamma0
  status: derived/axiom
  calculation:
    formula_math: g/(g+1)
    formula_text: crosslink signature
    depends_on: g
    value: 0.8333333333
delta2: delta2
  status: derived/discrete_scan
  calculation:
    formula_math: (g/4)*delta_top^2
    depends_on: g, delta_top
    value: 1.809145975e-08

Group 1: Kernel invariants
--------------------------
c3: c3
  status: derived/axiom
  calculation:
    formula_math: 1/(8*pi)
    value: 0.03978873577
varphi0_tree: varphi0_tree
  status: derived/axiom
  calculation:
    formula_math: 1/(6*pi)
    value: 0.0530516477
delta_top: delta_top
  status: derived/axiom
  calculation:
    formula_math: 3/(256*pi^4)
    value: 0.0001203044795
varphi0: varphi0
  status: derived/axiom
  calculation:
    formula_math: varphi0_tree+delta_top
    depends_on: varphi0_tree, delta_top
    value: 0.05317195218
delta_star: delta_star
  status: derived/axiom
  calculation:
    formula_math: 3/5+varphi0/6
    depends_on: varphi0
    value: 0.608861992
beta_rad: beta_rad
  status: derived/axiom
  calculation:
    formula_math: varphi0/(4*pi)
    depends_on: varphi0, pi
    value: 0.004231289511

Group 2: Gauge sectors (couplings)
----------------------------------
alpha_inv0: alpha_inv(0)
  status: derived/axiom
  calculation:
    formula_math: alpha_inv0
    formula_text: Solve CFE(alpha,varphi)=0 with varphi=varphi_tree+delta_top*exp(-2*alpha)+delta2*exp(-4*alpha), then a
    inputs: c3=0.0397887, varphi0=0.053172, delta2=1.80915e-08
    depends_on: c3, varphi0, delta2
    value: 137.0359992
  reference: 137.035999177 ? 2.1e-08 (CODATA 2022)
```

```
  z: 1.864686098651007
alpha0: alpha(0)
  status: derived/axiom
  calculation:
    formula_math: 1/alpha_inv0
    depends_on: alpha_inv0
    value: 0.007297352562
alpha_inv0_simple: alpha_inv(0) (simple)
  status: candidate/candidate
  calculation:
    formula_math: 4*pi*exp(1/varphi0)
    depends_on: pi, varphi0
    value: 1849039231
    note: Simplified closure candidate.
alpha_bar5_inv_MZ: alpha_bar5_inv(MZ)
  status: derived_external/derived_external
  calculation:
    formula_math: alpha_bar5_inv_MZ
    formula_text: alpha(0) -> MZ running (alpha_precision_audit)
    value: 127.9405157
    source: alpha_precision_audit
  reference: 127.93 ? 0.008 (PDG 2024)
  z: 1.3144682362185023
alpha_s_MZ: alpha_s(MZ)
  status: input/anchor
  calculation:
    formula_math: alpha_s_MZ
    formula_text: SM input (MSbar)
    value: 0.1179
    source: sm_inputs_mz.json
  reference: 0.1179 ? 0.0011 (PDG (MZ, MSbar))
sin2_thetaW_MZ: sin^2(thetaW) (MZ)
  status: input/anchor
  calculation:
    formula_math: sin2_thetaW_MZ
    formula_text: SM input (MSbar)
    value: 0.23122
    source: sm_inputs_mz.json
  reference: 0.23122 ? 4e-05 (PDG (MZ, MSbar))
sin2_thetaW_0: sin^2(thetaW)(0)
  status: pending/pending
  calculation:
    formula_math: sin2_thetaW_0
    formula_text: G(c3,varphi0) (pending)
alpha3_at_mu_star: alpha3(mu_star)
  status: derived_external/derived_external
  calculation:
    formula_math: alpha3_at_mu_star
    formula_text: alpha3(mu)=varphi0 crossing
    value: 0.05317195218
    source: two_loop_rg_fingerprints
mu_star_varphi0: mu_star (alpha3=varphi0)
  status: derived_external/derived_external
  calculation:
    formula_math: mu_star_varphi0
    formula_text: alpha3(mu)=varphi0 crossing
    value: 792005.5554
    source: two_loop_rg_fingerprints
g_a_gamma_gamma: g_a_gamma_gamma
  status: derived/axiom
  calculation:
    formula_math: -4*c3
    depends_on: c3
    value: -0.1591549431

Group 3: Architecture (block scales)
------------------------------------
Mpl_reduced: Mpl_reduced
  status: input/anchor
  calculation:
    formula_math: Mpl_reduced
    formula_text: input (reduced Planck mass)
    value: 2.435e+18
  reference: 2.435e+18 ? 0.0 (CODATA)
Mpl_unreduced: Mpl (unreduced)
  status: derived/axiom
  calculation:
    formula_math: sqrt(8*pi)*Mpl_reduced
    depends_on: pi, Mpl_reduced
    value: 1.22072797e+19
```

```
M_over_Mpl: M/Mpl (Starobinsky)
  status: derived/axiom
  calculation:
    formula_math: sqrt(8*pi)*c3^4
    depends_on: c3, pi
    value: 1.256494208e-05
M_GUT: M_GUT
  status: derived_external/derived_external
  calculation:
    formula_math: M_GUT
    formula_text: mu where alpha1=alpha2=alpha3
    value: 2.805733341e+15
    source: unification_gate
M_R: M_R
  status: derived_external/derived_external
  calculation:
    formula_math: M_R
    formula_text: seesaw anchor
    value: 1.311e+15
    source: seesaw_block
f_a: f_a
  status: derived_external/derived_external
  calculation:
    formula_math: f_a
    formula_text: axion_dm_pipeline
    value: 8.863988685e+10
    source: axion_dm_pipeline
v_ew: v (EW scale)
  status: candidate/candidate
  calculation:
    formula_math: 4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced
    formula_text: candidate EW-scale closure
    depends_on: g, c3, alpha_inv0, Mpl_reduced, pi
    value: 320.4088802
    note: Candidate EW-scale formula pending discrete coefficient closure.
  reference: 246.0 ? 0.2 (SM Higgs vev)
  diff: 74.4088801815899
Lambda_QCD: Lambda_QCD
  status: pending/pending
  calculation:
    formula_math: Mpl_reduced*exp(-1/(2*varphi0))
    formula_text: placeholder scaling (RG-based derivation pending)
    depends_on: Mpl_reduced, varphi0
    value: 2.00738574e+14
m_p: m_p
  status: placeholder/anchor
  calculation:
    formula_math: m_p
    formula_text: PDG placeholder
    value: 0.938272
    source: mass_spectrum_minimal
  reference: 0.938272 ? None (PDG pole mass)
m_pi: m_pi
  status: pending/pending
  calculation:
    formula_math: m_pi
    formula_text: pending TFPT derivation
G_F_Mpl2: G_F * Mpl^2
  status: candidate/candidate
  calculation:
    formula_math: Mpl_reduced^2/(sqrt(2)*v_ew^2)
    formula_text: dimensionless Fermi coupling proxy
    depends_on: Mpl_reduced, v_ew
    value: 4.083888206e+31

Group 4: Matter (fermion masses & ratios)
----------------------------------------
y_tau: y_tau
  status: derived/axiom
  calculation:
    formula_math: pi*varphi0^2
    depends_on: pi, varphi0
    value: 0.008882088245
y_mu: y_mu
  status: derived/axiom
  calculation:
    formula_math: pi*varphi0^3
    depends_on: pi, varphi0
    value: 0.0004722779714
y_e: y_e
```

```
  status: derived/axiom
  calculation:
    formula_math: 2*pi*varphi0^5
    depends_on: pi, varphi0
    value: 2.670501927e-06
m_e: m_e
  status: candidate/candidate
  calculation:
    formula_math: v_ew*(2*pi*varphi0^5)/sqrt(2)
    formula_text: candidate Yukawa ladder
    depends_on: v_ew, varphi0, pi
    value: 0.0006050377077
    note: Depends on EW-scale candidate.
  reference: 0.0005109989461 ? 0.0 (PDG pole mass)
  diff: 9.403876163067233e-05
m_mu: m_mu
  status: candidate/candidate
  calculation:
    formula_math: v_ew*(pi*varphi0^3)/sqrt(2)
    formula_text: candidate Yukawa ladder
    depends_on: v_ew, varphi0, pi
    value: 0.1070008519
    note: Depends on EW-scale candidate.
  reference: 0.1056583745 ? 0.0 (PDG pole mass)
  diff: 0.001342477402749398
m_tau: m_tau
  status: candidate/candidate
  calculation:
    formula_math: v_ew*(pi*varphi0^2)/sqrt(2)
    formula_text: candidate Yukawa ladder
    depends_on: v_ew, varphi0, pi
    value: 2.012355152
    note: Depends on EW-scale candidate.
  reference: 1.77686 ? 0.0 (PDG pole mass)
  diff: 0.2354951519581867
m_e_over_m_p: m_e/m_p
  status: candidate/candidate
  calculation:
    formula_math: alpha0^2*exp(-1/varphi0)
    depends_on: alpha0, varphi0
    value: 3.619048444e-13
    note: Candidate ratio from constantfactory.md.
  reference: 0.0005446170685046554 ? None (PDG pole masses)
  diff: -0.0005446170681427505
m_mu_over_m_e: m_mu/m_e
  status: derived/axiom
  calculation:
    formula_math: ((1+delta_star)/(1-delta_star))^2*((1/3+delta_star)/(1/3-delta_star))^2
    depends_on: delta_star
    value: 197.8453644
  reference: 206.76828260879265 ? 0.0 (PDG pole masses)
  diff: -8.922918189809991
m_tau_over_m_mu: m_tau/m_mu
  status: derived/axiom
  calculation:
    formula_math: ((1+delta_star)/(1-delta_star))^2
    depends_on: delta_star
    value: 16.9191112
  reference: 16.81702949159037 ? 0.0 (PDG pole masses)
  diff: 0.10208170530365734
m_t: m_t (top)
  status: input/anchor
  calculation:
    formula_math: m_t
    formula_text: input (scheme dependent)
    value: 172.76
  reference: 172.76 ? 0.3 (PDG pole mass)
m_b: m_b (bottom)
  status: input/anchor
  calculation:
    formula_math: m_b
    formula_text: input (scheme dependent)
    value: 4.18
  reference: 4.18 ? None (PDG (scheme dependent))
m_c: m_c (charm)
  status: input/anchor
  calculation:
    formula_math: m_c
    formula_text: input (scheme dependent)
    value: 1.27
```

```
  reference: 1.27 ? None (PDG (scheme dependent))
m_s: m_s (strange)
  status: pending/pending
  calculation:
    formula_math: m_s
    formula_text: pending (scheme/scale)
m_u: m_u (up)
  status: pending/pending
  calculation:
    formula_math: m_u
    formula_text: pending (scheme/scale)
m_d: m_d (down)
  status: pending/pending
  calculation:
    formula_math: m_d
    formula_text: pending (scheme/scale)
m_nu1: m_nu1
  status: placeholder/anchor
  calculation:
    formula_math: m_nu1
    formula_text: placeholder (order-of-mag)
    value: 0.05
m_nu3: m_nu3
  status: derived_external/derived_external
  calculation:
    formula_math: v_ew^2/M_R
    depends_on: v_ew, M_R
    value: 0.04616018307
    source: seesaw_block
sum_mnu: sum m_nu
  status: pending/pending
  calculation:
    formula_math: sum_mnu
    formula_text: pending (needs consistent neutrino spectrum)
delta_m_np: Delta m_np
  status: pending/pending
  calculation:
    formula_math: delta_m_np
    formula_text: pending (EM + isospin)
lambda_C_ratio: lambda_C^p/lambda_C^e
  status: derived_external/derived_external
  calculation:
    formula_math: m_e/m_p
    depends_on: m_e, m_p
    value: 0.0005446170685
    note: Ratio from PDG masses.

Group 5: Flavor code (mixing angles)
------------------------------------
lambda: Cabibbo lambda
  status: derived/axiom
  calculation:
    formula_math: sqrt(varphi0)*(1-varphi0/2)
    depends_on: varphi0
    value: 0.2244599705
  reference: 0.22501 ? 0.00068 (PDG 2024)
  z: -0.8088668838620974
CKM_A: CKM A
  status: derived_external/derived_external
  calculation:
    formula_math: Vcb/lambda^2
    formula_text: Wolfenstein from CKM pipeline
    value: 0.9348635188
    source: ckm_full_pipeline
CKM_rho: CKM rho
  status: derived_external/derived_external
  calculation:
    formula_math: rho_CKM
    formula_text: Wolfenstein from |Vub|,|Vtd|
    value: 0.1317221622
    source: ckm_full_pipeline
CKM_eta: CKM eta
  status: derived_external/derived_external
  calculation:
    formula_math: eta_CKM
    formula_text: Wolfenstein from |Vub|,|Vtd|
    value: 0.3682265686
    source: ckm_full_pipeline
sin2_theta13: sin^2(theta13)
  status: derived/axiom
```

```
  calculation:
    formula_math: varphi0*exp(-5/6)
    depends_on: varphi0
    value: 0.02310843516
  reference: 0.02224 ? 0.00057 (NuFIT 5.3 (2024, NO))
  z: 1.5235704541773745
sin2_theta12: sin^2(theta12)
  status: derived/axiom
  calculation:
    formula_math: (1/3)*(1-2*sin2_theta13)
    depends_on: sin2_theta13
    value: 0.3179277099
  reference: 0.307 ? 0.012 (NuFIT 5.3 (2024, NO))
  z: 0.9106424911732719
sin2_theta23: sin^2(theta23)
  status: input/anchor
  calculation:
    formula_math: sin2_theta23
    formula_text: input (NuFIT)
    value: 0.454
  reference: 0.454 ? 0.019 (NuFIT 5.3 (2024, NO))
delta_cp: delta_CP (deg)
  status: placeholder/pending
  calculation:
    formula_math: 180*(1-delta_star)
    formula_text: placeholder until Z3-breaking is wired
    value: 70.40484143
    note: Placeholder until Z3-breaking is wired.
  reference: 232.0 ? 39.0 (NuFIT 5.3 (2024, NO))

Group 6: Cosmos (space-time & energy)
-------------------------------------
phi_star_base: phi_star_base
  status: derived/axiom
  calculation:
    formula_math: exp(-alpha_inv0/2)
    depends_on: alpha_inv0
    value: 1.749890443e-30
rho_L: rho_L
  status: derived/scan
  calculation:
    formula_math: (1/2*phi_star_base*Mpl_reduced)^4
    depends_on: phi_star_base, Mpl_reduced
    value: 2.060247122e-47
  reference: 2.514176465474032e-47 ? None (Planck 2018 (k_calibration))
  diff: -4.539293432051601e-48
Lambda_Mpl2: Lambda Mpl^-2
  status: derived/scan
  calculation:
    formula_math: rho_L/Mpl_reduced^4
    depends_on: rho_L, Mpl_reduced
    value: 5.860348646e-121
  reference: 7.151545310258967e-121 ? None (Planck 2018 (k_calibration))
  diff: -1.2911966642626766e-121
Omega_b: Omega_b
  status: derived/axiom
  calculation:
    formula_math: (4*pi-1)*beta_rad
    depends_on: beta_rad, pi
    value: 0.04894066267
  reference: 0.049301692328524445 ? None (Planck 2018 + Planck 2018)
  diff: -0.0003610296630743373
eta_b: eta_b
  status: derived_external/derived_external
  calculation:
    formula_math: eta_b_pred
    formula_text: baryon_consistency_audit proxy
    value: 5.794376871e-10
    source: baryon_consistency_audit
  reference: 6.127143e-10 ? None (Planck 2018)
  diff: -3.327661292439077e-11
H0: H0
  status: derived_external/derived_external
  calculation:
    formula_math: H0_pred
    formula_text: baryon_consistency_audit derived
    value: 65.74646855
    source: baryon_consistency_audit
  reference: 67.36 ? 0.54 (Planck 2018)
  z: -2.9880212073872032
```

```
Omega_dm: Omega_dm
  status: derived_external/derived_external
  calculation:
    formula_math: Omega_dm
    formula_text: (Omega_a h^2)/h^2
    value: 0.2705330444
    source: axion_dm_audit
  reference: 0.26447041034523616 ? None (Planck 2018 + Planck 2018)
  diff: 0.006062634065091388
beta_deg: beta (deg)
  status: derived/axiom
  calculation:
    formula_math: 180/pi*beta_rad
    depends_on: beta_rad, pi
    value: 0.2424350309
  reference: 0.35 ? 0.14 (Minami & Komatsu 2020)
  z: -0.7683212078505032
beta_deg_PR: beta (deg, PR)
  status: derived/axiom
  calculation:
    formula_math: beta_deg
    formula_text: frequency independent
    depends_on: beta_deg
    value: 0.2424350309
nu_ghz: axion frequency (GHz)
  status: derived_external/derived_external
  calculation:
    formula_math: nu_ghz
    formula_text: axion_dm_audit pipeline
    value: 15.76402318
    source: axion_dm_audit
g_phys_axion: g_phys (axion)
  status: derived_external/derived_external
  calculation:
    formula_math: g_phys
    formula_text: g_coeff/f_a
    value: -1.795522859e-12
    source: axion_dm_pipeline

Group 7: Inflation & origin
---------------------------
N_star: N_star
  status: input/anchor
  calculation:
    formula_math: N_star
    formula_text: Starobinsky e-folds (policy)
    value: 56
A_s: A_s
  status: derived/axiom
  calculation:
    formula_math: N_star^2/(24*pi^2)*M_over_Mpl^2
    formula_text: Starobinsky amplitude
    depends_on: N_star, M_over_Mpl, pi
    value: 2.090191364e-09
  reference: 2.0989031673e-09 ? 2.938464434e-11 (Planck 2018)
  z: -0.29647467805761374
n_s: n_s
  status: derived/axiom
  calculation:
    formula_math: 1-2/N_star
    formula_text: Starobinsky tilt
    depends_on: N_star
    value: 0.9642857143
  reference: 0.9649 ? 0.0042 (Planck 2018)
  z: -0.146258503401352
r: r
  status: derived/axiom
  calculation:
    formula_math: 12/N_star^2
    formula_text: Starobinsky tensor ratio
    depends_on: N_star
    value: 0.003826530612
V_star: V_star
  status: derived/axiom
  calculation:
    formula_math: (3/2)*pi^2*A_s*r*Mpl_reduced^4
    depends_on: A_s, r, Mpl_reduced
    value: 4.162728705e+63
bounce_scale: bounce scale
  status: derived_external/derived_external
```

```
  calculation:
    formula_math: k_bounce_t
    formula_text: bounce_perturbations k_bounce_t (raw)
    value: 7.808039644
    source: bounce_perturbations
x_max: x_max (Planck spectrum)
  status: derived/axiom
  calculation:
    formula_math: x_max
    formula_text: Planck spectrum extremum
    value: 2.821439372

Group 8: Exotic (bounds & tests)
--------------------------------
torsion_max: max torsion coupling
  status: derived_external/derived_external
  calculation:
    formula_math: torsion_max
    formula_text: max inferred |S_mu| bound
    value: 2.9e-27
    source: torsion_bounds_mapping
lambda_cross: vacuum stability scale
  status: derived_external/derived_external
  calculation:
    formula_math: lambda_cross
    formula_text: lambda crossing scale
    value: 4.529728562e+10
    source: stability_unitarity_audit

Group 9: QED derived constants
------------------------------
a_e: a_e
  status: candidate/candidate
  calculation:
    formula_math: alpha0/(2*pi)
    depends_on: alpha0, pi
    value: 0.001161409732
Rydberg_E: R_infty (energy)
  status: candidate/candidate
  calculation:
    formula_math: 1/2*alpha0^2*m_e
    depends_on: alpha0, m_e
    value: 1.610953871e-08
a0: Bohr radius (a0)
  status: candidate/candidate
  calculation:
    formula_math: 1/(alpha0*m_e)
    depends_on: alpha0, m_e
    value: 226491.6673
sigma_T: Thomson cross section
  status: candidate/candidate
  calculation:
    formula_math: 8*pi/3*alpha0^2/m_e^2
    depends_on: alpha0, m_e, pi
    value: 1218.665115
fs_2p: fine-structure 2p (H)
  status: candidate/candidate
  calculation:
    formula_math: alpha0^4*m_e
    depends_on: alpha0, m_e
    value: 1.71570951e-12
lamb_shift: Lamb shift (proxy)
  status: candidate/candidate
  calculation:
    formula_math: alpha0^5*m_e*log(1/alpha0)
    depends_on: alpha0, m_e
    value: 6.160212562e-14
g_p: proton g-factor
  status: candidate/candidate
  calculation:
    formula_math: 2*(1+c3/pi)
    depends_on: c3, pi
    value: 2.025330296

Checks:
- constant_factory_ran: PASS (entries=87)
- constant_factory_statuses: INFO (candidate=14 derived=34 derived_external=19 input=9 pending=8 placeholder=3)
- constant_factory_symbol_registry: INFO (symbols=82)
```

constant_factory_audit: results.json (tfpt-suite/theoryv3/out/constant_factory_audit/results.json)

```
{
  "checks": [
    {
      "check_id": "constant_factory_ran",
      "detail": "entries=87",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "constant_factory_statuses",
      "detail": "candidate=14 derived=34 derived_external=19 input=9 pending=8 placeholder=3",
      "passed": true,
      "severity": "INFO"
    },
    {
      "check_id": "constant_factory_symbol_registry",
      "detail": "symbols=82",
      "passed": true,
      "severity": "INFO"
    }
  ],
  "module_id": "constant_factory_audit",
  "plot": {
    "constant_factory_sensitivity.png": "./tfpt-suite/theoryv3/out/constant_factory_audit/constant_factory_sensitivity.p
    "constant_factory_summary.png": "./tfpt-suite/theoryv3/out/constant_factory_audit/constant_factory_summary.png"
  },
  "results": {
    "crosslinks": [
      {
        "g_over_2": 2.5,
        "g_over_4": 1.25,
        "g_over_g_plus_1": 0.8333333333333334,
        "g_value": 5,
        "kind": "g_signature"
      },
      {
        "best_label": "n=1/2",
        "k": 2.0,
        "kind": "k_signature",
        "n_from_cover": 0.5
      }
    ],
    "groups": [
      {
        "group": "Group 0: Discrete anchors",
        "items": [
          {
            "approximation": null,
            "calculation": "formula_math: pi\nformula_text: circle constant\nvalue: 3.141592654",
            "comparison": null,
            "delta_ppm": null,
            "depends_on": [],
            "deviation": null,
            "fixed_point": true,
            "formula_math": "pi",
            "formula_text": "circle constant",
            "grammar": {
              "allowed": true,
              "fractions": [],
              "issues": []
            },
            "group": "Group 0: Discrete anchors",
            "hierarchy_level": 0,
            "inputs": {},
            "key": "pi",
            "label": "pi",
            "latex_ref": null,
            "lineage": "anchor",
            "note": null,
            "reference": null,
            "reference_info": {
              "origin": "geometry constant",
              "type": "analytic"
            },
            "reference_role": "anchor",
            "sensitivity": {
              "Sc3": null,
              "Sphi0": null,
              "log_abs": false,
              "mode": "external"
```

```
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "status_label": "input/anchor",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 3.141592653589793
},
{
  "approximation": null,
  "calculation": "formula_math: g\nformula_text: SU(5) holonomy multiplicity (two-defect)\nvalue: 5\nsource: d
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "g",
  "formula_text": "SU(5) holonomy multiplicity (two-defect)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 0: Discrete anchors",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "g",
  "label": "g",
  "latex_ref": null,
  "lineage": "discrete_scan",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "defect_partition_g5_audit",
    "type": "internal_derivation"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "defect_partition_g5_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/delta2/g_value",
  "source_module_id": "defect_partition_g5_audit",
  "status": "derived",
  "status_label": "derived/discrete_scan",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 5.0
},
{
  "approximation": null,
  "calculation": "formula_math: k\nformula_text: backreaction cover degree (min |ppm|)\nvalue: 2\nsource: alph
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "k",
  "formula_text": "backreaction cover degree (min |ppm|)",
  "grammar": {
    "allowed": true,
```

```
      "fractions": [],
      "issues": []
    },
    "group": "Group 0: Discrete anchors",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "k",
    "label": "k",
    "latex_ref": null,
    "lineage": "discrete_scan",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "alpha_backreaction_sensitivity_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "alpha_backreaction_sensitivity_audit",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/abs_ppm",
    "source_module_id": "alpha_backreaction_sensitivity_audit",
    "status": "derived",
    "status_label": "derived/discrete_scan",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 2.0
  },
  {
    "approximation": null,
    "calculation": "formula_math: g/(g+1)\nformula_text: crosslink signature\ndepends_on: g\nvalue: 0.8333333333
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "g"
    ],
    "deviation": null,
    "fixed_point": true,
    "formula_math": "g/(g+1)",
    "formula_text": "crosslink signature",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 0: Discrete anchors",
    "hierarchy_level": 1,
    "inputs": {},
    "key": "gamma0",
    "label": "gamma0",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "g5_crosslink_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
```

```
          "sigma_rel": 0.0
        },
        "source": null,
        "source_artifact": null,
        "source_json_pointer": null,
        "source_module_id": null,
        "status": "derived",
        "status_label": "derived/axiom",
        "unit_system": "natural_units",
        "units": "dimensionless",
        "value": 0.8333333333333334
      },
      {
        "approximation": null,
        "calculation": "formula_math: (g/4)*delta_top^2\ndepends_on: g, delta_top\nvalue: 1.809145975e-08",
        "comparison": null,
        "delta_ppm": null,
        "depends_on": [
          "g",
          "delta_top"
        ],
        "deviation": null,
        "fixed_point": null,
        "formula_math": "(g/4)*delta_top^2",
        "formula_text": null,
        "grammar": {
          "allowed": true,
          "fractions": [],
          "issues": []
        },
        "group": "Group 0: Discrete anchors",
        "hierarchy_level": 1,
        "inputs": {},
        "key": "delta2",
        "label": "delta2",
        "latex_ref": null,
        "lineage": "discrete_scan",
        "note": null,
        "reference": null,
        "reference_info": {
          "origin": "defect_partition_g5_audit",
          "type": "internal_derivation"
        },
        "reference_role": "internal",
        "sensitivity": {
          "Sc3": 0.0,
          "Sphi0": 0.0,
          "log_abs": false,
          "mode": "numeric"
        },
        "sigma": {
          "sigma_abs": 0.0,
          "sigma_c3_rel": 0.0,
          "sigma_phi0_rel": 0.0,
          "sigma_rel": 0.0
        },
        "source": null,
        "source_artifact": null,
        "source_json_pointer": null,
        "source_module_id": null,
        "status": "derived",
        "status_label": "derived/discrete_scan",
        "unit_system": "natural_units",
        "units": "dimensionless",
        "value": 1.8091459748867854e-08
      }
    ]
  },
  {
    "group": "Group 1: Kernel invariants",
    "items": [
      {
        "approximation": null,
        "calculation": "formula_math: 1/(8*pi)\nvalue: 0.03978873577",
        "comparison": null,
        "delta_ppm": null,
        "depends_on": [],
        "deviation": null,
        "fixed_point": true,
        "formula_math": "1/(8*pi)",
```

```
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 1: Kernel invariants",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "c3",
  "label": "c3",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.9999999999177334,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.039788735772973836
},
{
  "approximation": null,
  "calculation": "formula_math: 1/(6*pi)\nvalue: 0.0530516477",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "1/(6*pi)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 1: Kernel invariants",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "varphi0_tree",
  "label": "varphi0_tree",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.002267686178726,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
```

```
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.05305164769729844
},
{
  "approximation": null,
  "calculation": "formula_math: 3/(256*pi^4)\nvalue: 0.0001203044795",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "3/(256*pi^4)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 1: Kernel invariants",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "delta_top",
  "label": "delta_top",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.00012030447954708205
},
{
  "approximation": null,
  "calculation": "formula_math: varphi0_tree+delta_top\ndepends_on: varphi0_tree, delta_top\nvalue: 0.05317195
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "varphi0_tree",
    "delta_top"
  ],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "varphi0_tree+delta_top",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 1: Kernel invariants",
  "hierarchy_level": 1,
  "inputs": {},
  "key": "varphi0",
  "label": "varphi0",
  "latex_ref": null,
  "lineage": "axiom",
```

```
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.000000000139778,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.053171952176845526
},
{
  "approximation": null,
  "calculation": "formula_math: 3/5+varphi0/6\ndepends_on: varphi0\nvalue: 0.608861992",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "varphi0"
  ],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "3/5+varphi0/6",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [
      "3/5"
    ],
    "issues": []
  },
  "group": "Group 1: Kernel invariants",
  "hierarchy_level": 2,
  "inputs": {},
  "key": "delta_star",
  "label": "delta_star",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.014555009419936482,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.6088619920294742
},
{
  "approximation": null,
```

```
      "calculation": "formula_math: varphi0/(4*pi)\ndepends_on: varphi0, pi\nvalue: 0.004231289511",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [
        "varphi0",
        "pi"
      ],
      "deviation": null,
      "fixed_point": true,
      "formula_math": "varphi0/(4*pi)",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 1: Kernel invariants",
      "hierarchy_level": 2,
      "inputs": {},
      "key": "beta_rad",
      "label": "beta_rad",
      "latex_ref": null,
      "lineage": "axiom",
      "note": null,
      "reference": null,
      "reference_info": null,
      "reference_role": "prediction",
      "sensitivity": {
        "Sc3": 0.0,
        "Sphi0": 0.9999999996956888,
        "log_abs": false,
        "mode": "numeric"
      },
      "sigma": {
        "sigma_abs": 0.0,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": 0.0
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "derived",
      "status_label": "derived/axiom",
      "unit_system": "natural_units",
      "units": "radian",
      "value": 0.004231289511395415
    }
  ]
},
{
  "group": "Group 2: Gauge sectors (couplings)",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: alpha_inv0\nformula_text: Solve CFE(alpha,varphi)=0 with varphi=varphi_tree+de
      "comparison": {
        "ref_sigma": 2.1e-08,
        "ref_value": 137.035999177,
        "z": 1.864686098651007
      },
      "delta_ppm": 0.0002857527095569458,
      "depends_on": [
        "c3",
        "varphi0",
        "delta2"
      ],
      "deviation": {
        "abs": 1.864686098651007,
        "metric": "z",
        "value": 1.864686098651007
      },
      "fixed_point": true,
      "formula_math": "alpha_inv0",
      "formula_text": "Solve CFE(alpha,varphi)=0 with varphi=varphi_tree+delta_top*exp(-2*alpha)+delta2*exp(-4*alp
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
```

```
  },
  "group": "Group 2: Gauge sectors (couplings)",
  "hierarchy_level": 2,
  "inputs": {
    "c3": 0.039788735772973836,
    "delta2": 1.8091459748867854e-08,
    "varphi0": 0.053171952176845526
  },
  "key": "alpha_inv0",
  "label": "alpha_inv(0)",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": {
    "dataset_id": "alpha_inv_codata_2022",
    "notes": "Inverse fine-structure constant alpha^{-1}(0).",
    "sigma": 2.1e-08,
    "source": "global_reference_minimal.json:observables.alpha_inv_codata_2022",
    "units": "dimensionless",
    "value": 137.035999177,
    "version": "CODATA 2022"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": -2.005829094375855,
    "Sphi0": 0.11294333379652244,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 137.03599921615842
},
{
  "approximation": null,
  "calculation": "formula_math: 1/alpha_inv0\ndepends_on: alpha_inv0\nvalue: 0.007297352562",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha_inv0"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "1/alpha_inv0",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 2: Gauge sectors (couplings)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "alpha0",
  "label": "alpha(0)",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 2.005829094375855,
    "Sphi0": -0.11294333379652244,
    "log_abs": false,
    "mode": "numeric"
  },
```

```
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/axiom",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.007297352562246186
  },
  {
    "approximation": null,
    "calculation": "formula_math: 4*pi*exp(1/varphi0)\ndepends_on: pi, varphi0\nvalue: 1849039231\nnote: Simplif
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "pi",
      "varphi0"
    ],
    "deviation": null,
    "fixed_point": true,
    "formula_math": "4*pi*exp(1/varphi0)",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 2,
    "inputs": {},
    "key": "alpha_inv0_simple",
    "label": "alpha_inv(0) (simple)",
    "latex_ref": null,
    "lineage": "candidate",
    "note": "Simplified closure candidate.",
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": -18.806907759127967,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "status_label": "candidate/candidate",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 1849039231.4764473
  },
  {
    "approximation": null,
    "calculation": "formula_math: alpha_bar5_inv_MZ\nformula_text: alpha(0) -> MZ running (alpha_precision_audit
    "comparison": {
      "ref_sigma": 0.008,
      "ref_value": 127.93,
      "z": 1.3144682362185023
    },
    "delta_ppm": 82.1992174607052,
    "depends_on": [],
    "deviation": {
      "abs": 1.3144682362185023,
      "metric": "z",
```

```
      "value": 1.3144682362185023
    },
    "fixed_point": null,
    "formula_math": "alpha_bar5_inv_MZ",
    "formula_text": "alpha(0) -> MZ running (alpha_precision_audit)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "alpha_bar5_inv_MZ",
    "label": "alpha_bar5_inv(MZ)",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": {
      "dataset_id": "alpha_bar5_inv_MZ_pdg2024",
      "notes": "MSbar alpha_hat^(5)(MZ) inverse.",
      "sigma": 0.008,
      "source": "global_reference_minimal.json:observables.alpha_bar5_inv_MZ",
      "units": "dimensionless",
      "value": 127.93,
      "version": "PDG 2024"
    },
    "reference_info": {
      "origin": "alpha_precision_audit",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "alpha_precision_audit",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/secondary_alpha_bar5_MZ/alpha_bar5_inv_MZ_pred",
    "source_module_id": "alpha_precision_audit",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 127.94051574588975
  },
  {
    "approximation": null,
    "calculation": "formula_math: alpha_s_MZ\nformula_text: SM input (MSbar)\nvalue: 0.1179\nsource: sm_inputs_m
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "alpha_s_MZ",
    "formula_text": "SM input (MSbar)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "alpha_s_MZ",
    "label": "alpha_s(MZ)",
    "latex_ref": null,
    "lineage": "anchor",
    "note": null,
    "reference": {
      "dataset_id": "alpha_s_mz_pdg",
      "notes": "Strong coupling at MZ (MSbar).",
```

```
      "sigma": 0.0011,
      "source": "sm_inputs_mz.json:alpha_s",
      "units": "dimensionless",
      "value": 0.1179,
      "version": "PDG (MZ, MSbar)"
    },
    "reference_info": null,
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "sm_inputs_mz.json",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "sm_inputs_mz.json",
    "status": "input",
    "status_label": "input/anchor",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.1179
  },
  {
    "approximation": null,
    "calculation": "formula_math: sin2_thetaW_MZ\nformula_text: SM input (MSbar)\nvalue: 0.23122\nsource: sm_inp
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "sin2_thetaW_MZ",
    "formula_text": "SM input (MSbar)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "sin2_thetaW_MZ",
    "label": "sin^2(thetaW) (MZ)",
    "latex_ref": null,
    "lineage": "anchor",
    "note": null,
    "reference": {
      "dataset_id": "sin2_thetaW_mz_pdg",
      "notes": "Weak mixing angle sin^2(thetaW) at MZ (MSbar).",
      "sigma": 4e-05,
      "source": "sm_inputs_mz.json:sin2_thetaW",
      "units": "dimensionless",
      "value": 0.23122,
      "version": "PDG (MZ, MSbar)"
    },
    "reference_info": null,
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "sm_inputs_mz.json",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "sm_inputs_mz.json",
```

```
    "status": "input",
    "status_label": "input/anchor",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.23122
  },
  {
    "approximation": null,
    "calculation": "formula_math: sin2_thetaW_0\nformula_text: G(c3,varphi0) (pending)",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "sin2_thetaW_0",
    "formula_text": "G(c3,varphi0) (pending)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "sin2_thetaW_0",
    "label": "sin^2(thetaW)(0)",
    "latex_ref": null,
    "lineage": "pending",
    "note": null,
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
    "status_label": "pending/pending",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": null
  },
  {
    "approximation": null,
    "calculation": "formula_math: alpha3_at_mu_star\nformula_text: alpha3(mu)=varphi0 crossing\nvalue: 0.0531719
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "alpha3_at_mu_star",
    "formula_text": "alpha3(mu)=varphi0 crossing",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "alpha3_at_mu_star",
    "label": "alpha3(mu_star)",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "two_loop_rg_fingerprints",
```

```
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "two_loop_rg_fingerprints",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/alpha3/crossing_varphi0/alpha3",
    "source_module_id": "two_loop_rg_fingerprints",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.053171952176845526
  },
  {
    "approximation": null,
    "calculation": "formula_math: mu_star_varphi0\nformula_text: alpha3(mu)=varphi0 crossing\nvalue: 792005.5554
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "mu_star_varphi0",
    "formula_text": "alpha3(mu)=varphi0 crossing",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 2: Gauge sectors (couplings)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "mu_star_varphi0",
    "label": "mu_star (alpha3=varphi0)",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "two_loop_rg_fingerprints",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "two_loop_rg_fingerprints",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/alpha3/crossing_varphi0/mu_GeV",
    "source_module_id": "two_loop_rg_fingerprints",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 792005.555441517
  },
  {
    "approximation": null,
    "calculation": "formula_math: -4*c3\ndepends_on: c3\nvalue: -0.1591549431",
    "comparison": null,
```

```
      "delta_ppm": null,
      "depends_on": [
        "c3"
      ],
      "deviation": null,
      "fixed_point": true,
      "formula_math": "-4*c3",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 2: Gauge sectors (couplings)",
      "hierarchy_level": 1,
      "inputs": {},
      "key": "g_a_gamma_gamma",
      "label": "g_a_gamma_gamma",
      "latex_ref": null,
      "lineage": "axiom",
      "note": null,
      "reference": null,
      "reference_info": null,
      "reference_role": "prediction",
      "sensitivity": {
        "Sc3": 0.9999999999177334,
        "Sphi0": 0.0,
        "log_abs": true,
        "mode": "numeric"
      },
      "sigma": {
        "sigma_abs": 0.0,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": 0.0
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "derived",
      "status_label": "derived/axiom",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": -0.15915494309189535
    }
  ]
},
{
  "group": "Group 3: Architecture (block scales)",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: Mpl_reduced\nformula_text: input (reduced Planck mass)\nvalue: 2.435e+18",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "Mpl_reduced",
      "formula_text": "input (reduced Planck mass)",
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 3: Architecture (block scales)",
      "hierarchy_level": 0,
      "inputs": {},
      "key": "Mpl_reduced",
      "label": "Mpl_reduced",
      "latex_ref": null,
      "lineage": "anchor",
      "note": null,
      "reference": {
        "dataset_id": "Mpl_reduced",
        "notes": "Reduced Planck mass.",
        "sigma": 0.0,
        "source": "tfpt_suite.cosmo_scale_map.MPL_REDUCED_GEV",
        "units": "GeV",
```

```
    "value": 2.435e+18,
    "version": "CODATA"
  },
  "reference_info": null,
  "reference_role": "anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "status_label": "input/anchor",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 2.435e+18
},
{
  "approximation": null,
  "calculation": "formula_math: sqrt(8*pi)*Mpl_reduced\ndepends_on: pi, Mpl_reduced\nvalue: 1.22072797e+19",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "pi",
    "Mpl_reduced"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "sqrt(8*pi)*Mpl_reduced",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 1,
  "inputs": {},
  "key": "Mpl_unreduced",
  "label": "Mpl (unreduced)",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 1.2207279697452972e+19
},
{
  "approximation": null,
```

```
  "calculation": "formula_math: sqrt(8*pi)*c3^4\ndepends_on: c3, pi\nvalue: 1.256494208e-05",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "c3",
    "pi"
  ],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "sqrt(8*pi)*c3^4",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 1,
  "inputs": {},
  "key": "M_over_Mpl",
  "label": "M/Mpl (Starobinsky)",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 3.9999999996709334,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 1.2564942083228452e-05
},
{
  "approximation": null,
  "calculation": "formula_math: M_GUT\nformula_text: mu where alpha1=alpha2=alpha3\nvalue: 2.805733341e+15\nsc
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "M_GUT",
  "formula_text": "mu where alpha1=alpha2=alpha3",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "M_GUT",
  "label": "M_GUT",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "unification_gate",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
```

```
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "unification_gate",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/best_unification_point/mu_GeV",
    "source_module_id": "unification_gate",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 2805733340894862.0
  },
  {
    "approximation": null,
    "calculation": "formula_math: M_R\nformula_text: seesaw anchor\nvalue: 1.311e+15\nsource: seesaw_block",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "M_R",
    "formula_text": "seesaw anchor",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 3: Architecture (block scales)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "M_R",
    "label": "M_R",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "seesaw_block",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "seesaw_block",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/paper_v1_06_anchor/MR_GeV",
    "source_module_id": "seesaw_block",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 1311000000000000.0
  },
  {
    "approximation": null,
    "calculation": "formula_math: f_a\nformula_text: axion_dm_pipeline\nvalue: 8.863988685e+10\nsource: axion_dm
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "f_a",
```

```
  "formula_text": "axion_dm_pipeline",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "f_a",
  "label": "f_a",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "axion_dm_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "axion_dm_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/axion_claim/f_a_GeV",
  "source_module_id": "axion_dm_pipeline",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 88639886850.34554
},
{
  "approximation": null,
  "calculation": "formula_math: 4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced\nformula_text: candidate EW-scale c
  "comparison": {
    "diff": 74.4088801815899,
    "ref_sigma": null,
    "ref_value": 246.0
  },
  "delta_ppm": 302475.1226893898,
  "depends_on": [
    "g",
    "c3",
    "alpha_inv0",
    "Mpl_reduced",
    "pi"
  ],
  "deviation": {
    "metric": "rel",
    "value": 0.3024751226893898
  },
  "fixed_point": null,
  "formula_math": "4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced",
  "formula_text": "candidate EW-scale closure",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "v_ew",
  "label": "v (EW scale)",
  "latex_ref": null,
  "lineage": "candidate",
  "note": "Candidate EW-scale formula pending discrete coefficient closure.",
  "reference": {
    "dataset_id": "v_ew_246",
```

```
      "notes": "Electroweak vev v (approx).",
      "sigma": 0.2,
      "source": "Standard Model reference",
      "units": "GeV",
      "value": 246.0,
      "version": "SM Higgs vev"
    },
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 70.71769854993804,
      "Sphi0": -3.869325652772204,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "status_label": "candidate/candidate",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 320.4088801815899
  },
  {
    "approximation": null,
    "calculation": "formula_math: Mpl_reduced*exp(-1/(2*varphi0))\nformula_text: placeholder scaling (RG-based d
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "Mpl_reduced",
      "varphi0"
    ],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "Mpl_reduced*exp(-1/(2*varphi0))",
    "formula_text": "placeholder scaling (RG-based derivation pending)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 3: Architecture (block scales)",
    "hierarchy_level": 2,
    "inputs": {},
    "key": "Lambda_QCD",
    "label": "Lambda_QCD",
    "latex_ref": null,
    "lineage": "pending",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "PDG Lambda_QCD ~0.2 GeV (numeric bound pending)",
      "type": "literature"
    },
    "reference_role": "pending_reference",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
```

```
    "status_label": "pending/pending",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 200738573987935.12
  },
  {
    "approximation": null,
    "calculation": "formula_math: m_p\nformula_text: PDG placeholder\nvalue: 0.938272\nsource: mass_spectrum_min
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "m_p",
    "formula_text": "PDG placeholder",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 3: Architecture (block scales)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "m_p",
    "label": "m_p",
    "latex_ref": null,
    "lineage": "anchor",
    "note": null,
    "reference": {
      "dataset_id": "m_p_pdg",
      "notes": "Proton mass (PDG); placeholder in mass_spectrum_minimal.",
      "sigma": null,
      "source": "mass_spectrum_minimal:ledger.placeholders.proton_mass_GeV",
      "units": "GeV",
      "value": 0.938272,
      "version": "PDG pole mass"
    },
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "mass_spectrum_minimal",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "mass_spectrum_minimal",
    "status": "placeholder",
    "status_label": "placeholder/anchor",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": 0.938272
  },
  {
    "approximation": null,
    "calculation": "formula_math: m_pi\nformula_text: pending TFPT derivation",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "m_pi",
    "formula_text": "pending TFPT derivation",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 3: Architecture (block scales)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "m_pi",
```

```
  "label": "m_pi",
  "latex_ref": null,
  "lineage": "pending",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "status_label": "pending/pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": null
},
{
  "approximation": "scaling_proxy",
  "calculation": "formula_math: Mpl_reduced^2/(sqrt(2)*v_ew^2)\nformula_text: dimensionless Fermi coupling pro
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "Mpl_reduced",
    "v_ew"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "Mpl_reduced^2/(sqrt(2)*v_ew^2)",
  "formula_text": "dimensionless Fermi coupling proxy",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 3: Architecture (block scales)",
  "hierarchy_level": 4,
  "inputs": {},
  "key": "G_F_Mpl2",
  "label": "G_F * Mpl^2",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "order_of_magnitude_only",
  "sensitivity": {
    "Sc3": -141.43539710431696,
    "Sphi0": 7.738651305544408,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 4.083888206079671e+31
}
```

```
  ]
},
{
  "group": "Group 4: Matter (fermion masses & ratios)",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: pi*varphi0^2\ndepends_on: pi, varphi0\nvalue: 0.008882088245",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [
        "pi",
        "varphi0"
      ],
      "deviation": null,
      "fixed_point": true,
      "formula_math": "pi*varphi0^2",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 4: Matter (fermion masses & ratios)",
      "hierarchy_level": 2,
      "inputs": {},
      "key": "y_tau",
      "label": "y_tau",
      "latex_ref": null,
      "lineage": "axiom",
      "note": null,
      "reference": null,
      "reference_info": null,
      "reference_role": "prediction",
      "sensitivity": {
        "Sc3": 0.0,
        "Sphi0": 2.000000000279556,
        "log_abs": false,
        "mode": "numeric"
      },
      "sigma": {
        "sigma_abs": 0.0,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": 0.0
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "derived",
      "status_label": "derived/axiom",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": 0.008882088244863067
    },
    {
      "approximation": null,
      "calculation": "formula_math: pi*varphi0^3\ndepends_on: pi, varphi0\nvalue: 0.0004722779714",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [
        "pi",
        "varphi0"
      ],
      "deviation": null,
      "fixed_point": true,
      "formula_math": "pi*varphi0^3",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 4: Matter (fermion masses & ratios)",
      "hierarchy_level": 2,
      "inputs": {},
      "key": "y_mu",
      "label": "y_mu",
      "latex_ref": null,
```

```
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 2.9999999999752447,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.00047227797138638073
},
{
  "approximation": null,
  "calculation": "formula_math: 2*pi*varphi0^5\ndepends_on: pi, varphi0\nvalue: 2.670501927e-06",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "pi",
    "varphi0"
  ],
  "deviation": null,
  "fixed_point": true,
  "formula_math": "2*pi*varphi0^5",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 2,
  "inputs": {},
  "key": "y_e",
  "label": "y_e",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 5.00000000069889,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 2.6705019272091007e-06
},
{
  "approximation": null,
```

```
  "calculation": "formula_math: v_ew*(2*pi*varphi0^5)/sqrt(2)\nformula_text: candidate Yukawa ladder\ndepends_
  "comparison": {
    "diff": 9.403876163067233e-05,
    "ref_sigma": null,
    "ref_value": 0.0005109989461
  },
  "delta_ppm": 184029.26727811567,
  "depends_on": [
    "v_ew",
    "varphi0",
    "pi"
  ],
  "deviation": {
    "metric": "rel",
    "value": 0.18402926727811567
  },
  "fixed_point": null,
  "formula_math": "v_ew*(2*pi*varphi0^5)/sqrt(2)",
  "formula_text": "candidate Yukawa ladder",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 4,
  "inputs": {},
  "key": "m_e",
  "label": "m_e",
  "latex_ref": null,
  "lineage": "candidate",
  "note": "Depends on EW-scale candidate.",
  "reference": {
    "dataset_id": "m_e_pdg",
    "notes": "Electron pole mass.",
    "sigma": 0.0,
    "source": "lepton_masses_pdg.json:masses.electron",
    "units": "GeV",
    "value": 0.0005109989461,
    "version": "PDG pole mass"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 70.71769854993804,
    "Sphi0": 1.1306743474825964,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 0.0006050377077306724
},
{
  "approximation": null,
  "calculation": "formula_math: v_ew*(pi*varphi0^3)/sqrt(2)\nformula_text: candidate Yukawa ladder\ndepends_on
  "comparison": {
    "diff": 0.001342477402749398,
    "ref_sigma": null,
    "ref_value": 0.1056583745
  },
  "delta_ppm": 12705.830551551764,
  "depends_on": [
    "v_ew",
    "varphi0",
    "pi"
  ],
  "deviation": {
```

```
    "metric": "rel",
    "value": 0.012705830551551766
  },
  "fixed_point": null,
  "formula_math": "v_ew*(pi*varphi0^3)/sqrt(2)",
  "formula_text": "candidate Yukawa ladder",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 4,
  "inputs": {},
  "key": "m_mu",
  "label": "m_mu",
  "latex_ref": null,
  "lineage": "candidate",
  "note": "Depends on EW-scale candidate.",
  "reference": {
    "dataset_id": "m_mu_pdg",
    "notes": "Muon pole mass.",
    "sigma": 0.0,
    "source": "lepton_masses_pdg.json:masses.muon",
    "units": "GeV",
    "value": 0.1056583745,
    "version": "PDG pole mass"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 70.71769854993804,
    "Sphi0": -0.8693256525749149,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 0.1070008519027494
},
{
  "approximation": null,
  "calculation": "formula_math: v_ew*(pi*varphi0^2)/sqrt(2)\nformula_text: candidate Yukawa ladder\ndepends_on
  "comparison": {
    "diff": 0.2354951519581867,
    "ref_sigma": null,
    "ref_value": 1.77686
  },
  "delta_ppm": 132534.4438831347,
  "depends_on": [
    "v_ew",
    "varphi0",
    "pi"
  ],
  "deviation": {
    "metric": "rel",
    "value": 0.13253444388313468
  },
  "fixed_point": null,
  "formula_math": "v_ew*(pi*varphi0^2)/sqrt(2)",
  "formula_text": "candidate Yukawa ladder",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 4,
```

```
  "inputs": {},
  "key": "m_tau",
  "label": "m_tau",
  "latex_ref": null,
  "lineage": "candidate",
  "note": "Depends on EW-scale candidate.",
  "reference": {
    "dataset_id": "m_tau_pdg",
    "notes": "Tau pole mass.",
    "sigma": 0.0,
    "source": "lepton_masses_pdg.json:masses.tau",
    "units": "GeV",
    "value": 1.77686,
    "version": "PDG pole mass"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 70.71769854993804,
    "Sphi0": -1.8693256527146929,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 2.012355151958187
},
{
  "approximation": null,
  "calculation": "formula_math: alpha0^2*exp(-1/varphi0)\ndepends_on: alpha0, varphi0\nvalue: 3.619048444e-13\
  "comparison": {
    "diff": -0.0005446170681427505,
    "ref_sigma": null,
    "ref_value": 0.0005446170685046554
  },
  "delta_ppm": -999999.9993354876,
  "depends_on": [
    "alpha0",
    "varphi0"
  ],
  "deviation": {
    "metric": "rel",
    "value": -0.9999999993354876
  },
  "fixed_point": null,
  "formula_math": "alpha0^2*exp(-1/varphi0)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 4,
  "inputs": {},
  "key": "m_e_over_m_p",
  "label": "m_e/m_p",
  "latex_ref": null,
  "lineage": "candidate",
  "note": "Candidate ratio from constantfactory.md.",
  "reference": {
    "dataset_id": "mass_ratio_me_over_mp",
    "notes": "Derived from m_e and m_p.",
    "sigma": null,
    "units": "dimensionless",
    "value": 0.0005446170685046554,
    "version": "PDG pole masses"
  },
```

```
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 4.011658189639888,
    "Sphi0": 18.58102109153492,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 3.6190484438523293e-13
},
{
  "approximation": null,
  "calculation": "formula_math: ((1+delta_star)/(1-delta_star))^2*((1/3+delta_star)/(1/3-delta_star))^2\ndeper
  "comparison": {
    "diff": -8.922918189809991,
    "ref_sigma": null,
    "ref_value": 206.76828260879265
  },
  "delta_ppm": -43154.19210930057,
  "depends_on": [
    "delta_star"
  ],
  "deviation": {
    "metric": "rel",
    "value": -0.043154192109300576
  },
  "fixed_point": null,
  "formula_math": "((1+delta_star)/(1-delta_star))^2*((1/3+delta_star)/(1/3-delta_star))^2",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [
      "1/3",
      "1/3"
    ],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "m_mu_over_m_e",
  "label": "m_mu/m_e",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": {
    "dataset_id": "mass_ratio_mu_over_e_pdg",
    "notes": "Direct lepton pole-mass ratio (scale independent for this audit).",
    "scale": "pole",
    "scheme": "pole",
    "sigma": 0.0,
    "source": "lepton_masses_pdg.json (mu/e)",
    "units": "dimensionless",
    "value": 206.76828260879265,
    "version": "PDG pole masses"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.010814541706594127,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
```

```
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 197.84536441898265
},
{
  "approximation": null,
  "calculation": "formula_math: ((1+delta_star)/(1-delta_star))^2\ndepends_on: delta_star\nvalue: 16.9191112",
  "comparison": {
    "diff": 0.10208170530365734,
    "ref_sigma": null,
    "ref_value": 16.81702949159037
  },
  "delta_ppm": 6070.138924041547,
  "depends_on": [
    "delta_star"
  ],
  "deviation": {
    "metric": "rel",
    "value": 0.006070138924041547
  },
  "fixed_point": null,
  "formula_math": "((1+delta_star)/(1-delta_star))^2",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "m_tau_over_m_mu",
  "label": "m_tau/m_mu",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": {
    "dataset_id": "mass_ratio_tau_over_mu_pdg",
    "notes": "Direct lepton pole-mass ratio (scale independent for this audit).",
    "scale": "pole",
    "scheme": "pole",
    "sigma": 0.0,
    "source": "lepton_masses_pdg.json (tau/mu)",
    "units": "dimensionless",
    "value": 16.81702949159037,
    "version": "PDG pole masses"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.05633036126440061,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 16.91911119689403
```

```
},
{
  "approximation": null,
  "calculation": "formula_math: m_t\nformula_text: input (scheme dependent)\nvalue: 172.76",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_t",
  "formula_text": "input (scheme dependent)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_t",
  "label": "m_t (top)",
  "latex_ref": null,
  "lineage": "anchor",
  "note": null,
  "reference": {
    "dataset_id": "m_t_pdg",
    "notes": "Top pole mass (scheme dependent).",
    "sigma": 0.3,
    "source": "sm_inputs_mz.json:mt_GeV",
    "units": "GeV",
    "value": 172.76,
    "version": "PDG pole mass"
  },
  "reference_info": null,
  "reference_role": "needs_rg",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "status_label": "input/anchor",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 172.76
},
{
  "approximation": null,
  "calculation": "formula_math: m_b\nformula_text: input (scheme dependent)\nvalue: 4.18",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_b",
  "formula_text": "input (scheme dependent)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_b",
  "label": "m_b (bottom)",
  "latex_ref": null,
  "lineage": "anchor",
  "note": null,
```

```
  "reference": {
    "dataset_id": "m_b_pdg",
    "notes": "Bottom mass (scheme dependent; SM input proxy).",
    "sigma": null,
    "source": "sm_inputs_mz.json:mb_GeV",
    "units": "GeV",
    "value": 4.18,
    "version": "PDG (scheme dependent)"
  },
  "reference_info": null,
  "reference_role": "needs_rg",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "status_label": "input/anchor",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 4.18
},
{
  "approximation": null,
  "calculation": "formula_math: m_c\nformula_text: input (scheme dependent)\nvalue: 1.27",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_c",
  "formula_text": "input (scheme dependent)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_c",
  "label": "m_c (charm)",
  "latex_ref": null,
  "lineage": "anchor",
  "note": null,
  "reference": {
    "dataset_id": "m_c_pdg",
    "notes": "Charm mass (scheme dependent; SM input proxy).",
    "sigma": null,
    "source": "sm_inputs_mz.json:mc_GeV",
    "units": "GeV",
    "value": 1.27,
    "version": "PDG (scheme dependent)"
  },
  "reference_info": null,
  "reference_role": "needs_rg",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
```

```
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "status_label": "input/anchor",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 1.27
},
{
  "approximation": null,
  "calculation": "formula_math: m_s\nformula_text: pending (scheme/scale)",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_s",
  "formula_text": "pending (scheme/scale)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_s",
  "label": "m_s (strange)",
  "latex_ref": null,
  "lineage": "pending",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "status_label": "pending/pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": null
},
{
  "approximation": null,
  "calculation": "formula_math: m_u\nformula_text: pending (scheme/scale)",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_u",
  "formula_text": "pending (scheme/scale)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_u",
  "label": "m_u (up)",
  "latex_ref": null,
  "lineage": "pending",
  "note": null,
```

```
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "status_label": "pending/pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": null
},
{
  "approximation": null,
  "calculation": "formula_math: m_d\nformula_text: pending (scheme/scale)",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "m_d",
  "formula_text": "pending (scheme/scale)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 4: Matter (fermion masses & ratios)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "m_d",
  "label": "m_d (down)",
  "latex_ref": null,
  "lineage": "pending",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "status_label": "pending/pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": null
},
{
  "approximation": null,
  "calculation": "formula_math: m_nu1\nformula_text: placeholder (order-of-mag)\nvalue: 0.05",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
```

```
    "fixed_point": null,
    "formula_math": "m_nu1",
    "formula_text": "placeholder (order-of-mag)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 4: Matter (fermion masses & ratios)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "m_nu1",
    "label": "m_nu1",
    "latex_ref": null,
    "lineage": "anchor",
    "note": null,
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "placeholder",
    "status_label": "placeholder/anchor",
    "unit_system": "natural_units",
    "units": "eV",
    "value": 0.05
  },
  {
    "approximation": null,
    "calculation": "formula_math: v_ew^2/M_R\ndepends_on: v_ew, M_R\nvalue: 0.04616018307\nsource: seesaw_block"
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "v_ew",
      "M_R"
    ],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "v_ew^2/M_R",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 4: Matter (fermion masses & ratios)",
    "hierarchy_level": 4,
    "inputs": {},
    "key": "m_nu3",
    "label": "m_nu3",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "seesaw_block",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
```

```
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "seesaw_block",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/derived/mnu3_from_v_sm_eV",
    "source_module_id": "seesaw_block",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "eV",
    "value": 0.046160183066361556
  },
  {
    "approximation": null,
    "calculation": "formula_math: sum_mnu\nformula_text: pending (needs consistent neutrino spectrum)",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "sum_mnu",
    "formula_text": "pending (needs consistent neutrino spectrum)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 4: Matter (fermion masses & ratios)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "sum_mnu",
    "label": "sum m_nu",
    "latex_ref": null,
    "lineage": "pending",
    "note": null,
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
    "status_label": "pending/pending",
    "unit_system": "natural_units",
    "units": "eV",
    "value": null
  },
  {
    "approximation": null,
    "calculation": "formula_math: delta_m_np\nformula_text: pending (EM + isospin)",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "delta_m_np",
    "formula_text": "pending (EM + isospin)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 4: Matter (fermion masses & ratios)",
    "hierarchy_level": 0,
```

```
    "inputs": {},
    "key": "delta_m_np",
    "label": "Delta m_np",
    "latex_ref": null,
    "lineage": "pending",
    "note": null,
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
    "status_label": "pending/pending",
    "unit_system": "natural_units",
    "units": "GeV",
    "value": null
  },
  {
    "approximation": null,
    "calculation": "formula_math: m_e/m_p\ndepends_on: m_e, m_p\nvalue: 0.0005446170685\nnote: Ratio from PDG ma
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "m_e",
      "m_p"
    ],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "m_e/m_p",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 4: Matter (fermion masses & ratios)",
    "hierarchy_level": 5,
    "inputs": {},
    "key": "lambda_C_ratio",
    "label": "lambda_C^p/lambda_C^e",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": "Ratio from PDG masses.",
    "reference": null,
    "reference_info": null,
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
```

```
      "value": 0.0005446170685046554
    }
  ]
},
{
  "group": "Group 5: Flavor code (mixing angles)",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: sqrt(varphi0)*(1-varphi0/2)\ndepends_on: varphi0\nvalue: 0.2244599705",
      "comparison": {
        "ref_sigma": 0.00068,
        "ref_value": 0.22501,
        "z": -0.8088668838620974
      },
      "delta_ppm": -2444.466828257528,
      "depends_on": [
        "varphi0"
      ],
      "deviation": {
        "abs": 0.8088668838620974,
        "metric": "z",
        "value": -0.8088668838620974
      },
      "fixed_point": null,
      "formula_math": "sqrt(varphi0)*(1-varphi0/2)",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 5: Flavor code (mixing angles)",
      "hierarchy_level": 2,
      "inputs": {},
      "key": "lambda",
      "label": "Cabibbo lambda",
      "latex_ref": null,
      "lineage": "axiom",
      "note": null,
      "reference": {
        "dataset_id": "cabibbo_lambda_pdg2024",
        "notes": "Cabibbo lambda ~ |Vus|.",
        "sigma": 0.00068,
        "source": "global_reference.json:observables.cabibbo_lambda",
        "units": "dimensionless",
        "value": 0.22501,
        "version": "PDG 2024"
      },
      "reference_info": null,
      "reference_role": "compare",
      "sensitivity": {
        "Sc3": 0.0,
        "Sphi0": 0.47268790515087034,
        "log_abs": false,
        "mode": "numeric"
      },
      "sigma": {
        "sigma_abs": 0.0,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": 0.0
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "derived",
      "status_label": "derived/axiom",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": 0.22445997051897376
    },
    {
      "approximation": null,
      "calculation": "formula_math: Vcb/lambda^2\nformula_text: Wolfenstein from CKM pipeline\nvalue: 0.9348635188
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
```

```
  "fixed_point": null,
  "formula_math": "Vcb/lambda^2",
  "formula_text": "Wolfenstein from CKM pipeline",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 5: Flavor code (mixing angles)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "CKM_A",
  "label": "CKM A",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "ckm_full_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "ckm_full_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
  "source_module_id": "ckm_full_pipeline",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.9348635188312315
},
{
  "approximation": null,
  "calculation": "formula_math: rho_CKM\nformula_text: Wolfenstein from |Vub|,|Vtd|\nvalue: 0.1317221622\nsour
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "rho_CKM",
  "formula_text": "Wolfenstein from |Vub|,|Vtd|",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 5: Flavor code (mixing angles)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "CKM_rho",
  "label": "CKM rho",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "ckm_full_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
```

```
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "ckm_full_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
  "source_module_id": "ckm_full_pipeline",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.13172216223602146
},
{
  "approximation": null,
  "calculation": "formula_math: eta_CKM\nformula_text: Wolfenstein from |Vub|,|Vtd|\nvalue: 0.3682265686\nsour
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "eta_CKM",
  "formula_text": "Wolfenstein from |Vub|,|Vtd|",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 5: Flavor code (mixing angles)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "CKM_eta",
  "label": "CKM eta",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "ckm_full_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "ckm_full_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
  "source_module_id": "ckm_full_pipeline",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.368226568606463
},
{
  "approximation": null,
  "calculation": "formula_math: varphi0*exp(-5/6)\ndepends_on: varphi0\nvalue: 0.02310843516",
  "comparison": {
    "ref_sigma": 0.00057,
    "ref_value": 0.02224,
    "z": 1.5235704541773745
  },
  "delta_ppm": 39048.34347486976,
  "depends_on": [
    "varphi0"
  ],
  "deviation": {
    "abs": 1.5235704541773745,
```

```
      "metric": "z",
      "value": 1.5235704541773745
    },
    "fixed_point": null,
    "formula_math": "varphi0*exp(-5/6)",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [
        "5/6"
      ],
      "issues": []
    },
    "group": "Group 5: Flavor code (mixing angles)",
    "hierarchy_level": 2,
    "inputs": {},
    "key": "sin2_theta13",
    "label": "sin^2(theta13)",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": {
      "dataset_id": "pmns_sin2_theta13_nufit53_no",
      "notes": "Normal ordering, PDG convention.",
      "sigma": 0.00057,
      "source": "pmns_reference.json:normal_ordering.sin2_theta13",
      "units": "dimensionless",
      "value": 0.02224,
      "version": "NuFIT 5.3 (2024, NO)"
    },
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.000000000139778,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/axiom",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.023108435158881103
  },
  {
    "approximation": null,
    "calculation": "formula_math: (1/3)*(1-2*sin2_theta13)\ndepends_on: sin2_theta13\nvalue: 0.3179277099",
    "comparison": {
      "ref_sigma": 0.012,
      "ref_value": 0.307,
      "z": 0.9106424911732719
    },
    "delta_ppm": 35595.14623478587,
    "depends_on": [
      "sin2_theta13"
    ],
    "deviation": {
      "abs": 0.9106424911732719,
      "metric": "z",
      "value": 0.9106424911732719
    },
    "fixed_point": null,
    "formula_math": "(1/3)*(1-2*sin2_theta13)",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [
        "1/3"
      ],
      "issues": []
```

```
  },
  "group": "Group 5: Flavor code (mixing angles)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "sin2_theta12",
  "label": "sin^2(theta12)",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": {
    "dataset_id": "pmns_sin2_theta12_nufit53_no",
    "notes": "Normal ordering, PDG convention.",
    "sigma": 0.012,
    "source": "pmns_reference.json:normal_ordering.sin2_theta12",
    "units": "dimensionless",
    "value": 0.307,
    "version": "NuFIT 5.3 (2024, NO)"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": -0.048456372248040225,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.31792770989407926
},
{
  "approximation": null,
  "calculation": "formula_math: sin2_theta23\nformula_text: input (NuFIT)\nvalue: 0.454",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "sin2_theta23",
  "formula_text": "input (NuFIT)",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 5: Flavor code (mixing angles)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "sin2_theta23",
  "label": "sin^2(theta23)",
  "latex_ref": null,
  "lineage": "anchor",
  "note": null,
  "reference": {
    "dataset_id": "pmns_sin2_theta23_nufit53_no",
    "notes": "Normal ordering, PDG convention.",
    "sigma": 0.019,
    "source": "pmns_reference.json:normal_ordering.sin2_theta23",
    "units": "dimensionless",
    "value": 0.454,
    "version": "NuFIT 5.3 (2024, NO)"
  },
  "reference_info": null,
  "reference_role": "anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
```

```
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "input",
      "status_label": "input/anchor",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": 0.454
    },
    {
      "approximation": null,
      "calculation": "formula_math: 180*(1-delta_star)\nformula_text: placeholder until Z3-breaking is wired\nvalu
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "180*(1-delta_star)",
      "formula_text": "placeholder until Z3-breaking is wired",
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 5: Flavor code (mixing angles)",
      "hierarchy_level": 0,
      "inputs": {},
      "key": "delta_cp",
      "label": "delta_CP (deg)",
      "latex_ref": null,
      "lineage": "pending",
      "note": "Placeholder until Z3-breaking is wired.",
      "reference": {
        "dataset_id": "pmns_delta_cp_deg_nufit53_no",
        "notes": "Normal ordering, PDG convention.",
        "sigma": 39.0,
        "source": "pmns_reference.json:normal_ordering.delta_cp_deg",
        "units": "degrees",
        "value": 232.0,
        "version": "NuFIT 5.3 (2024, NO)"
      },
      "reference_info": null,
      "reference_role": "compare",
      "sensitivity": {
        "Sc3": null,
        "Sphi0": null,
        "log_abs": false,
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "placeholder",
      "status_label": "placeholder/pending",
      "unit_system": "natural_units",
      "units": "degrees",
      "value": 70.40484143469465
    }
  ]
},
{
  "group": "Group 6: Cosmos (space-time & energy)",
  "items": [
    {
```

```
  "approximation": null,
  "calculation": "formula_math: exp(-alpha_inv0/2)\ndepends_on: alpha_inv0\nvalue: 1.749890443e-30",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha_inv0"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "exp(-alpha_inv0/2)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "phi_star_base",
  "label": "phi_star_base",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 137.43539710020514,
    "Sphi0": -7.738651305544408,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 1.7498904425913166e-30
},
{
  "approximation": null,
  "calculation": "formula_math: (1/2*phi_star_base*Mpl_reduced)^4\ndepends_on: phi_star_base, Mpl_reduced\nval
  "comparison": {
    "diff": -4.539293432051601e-48,
    "ref_sigma": null,
    "ref_value": 2.514176465474032e-47
  },
  "delta_ppm": -180547.92471361975,
  "depends_on": [
    "phi_star_base",
    "Mpl_reduced"
  ],
  "deviation": {
    "metric": "rel",
    "value": -0.18054792471361975
  },
  "fixed_point": null,
  "formula_math": "(1/2*phi_star_base*Mpl_reduced)^4",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [
      "1/2"
    ],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 4,
  "inputs": {},
  "key": "rho_L",
```

```
  "label": "rho_L",
  "latex_ref": null,
  "lineage": "scan",
  "note": null,
  "reference": {
    "dataset_id": "rho_L_planck_derived",
    "notes": "Derived target rho_L from k_calibration cosmology snapshot.",
    "sigma": null,
    "units": "GeV^4",
    "value": 2.514176465474032e-47,
    "version": "Planck 2018 (k_calibration)"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 549.7415884008205,
    "Sphi0": -30.954605222177634,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/scan",
  "unit_system": "natural_units",
  "units": "GeV^4",
  "value": 2.060247122268872e-47
},
{
  "approximation": null,
  "calculation": "formula_math: rho_L/Mpl_reduced^4\ndepends_on: rho_L, Mpl_reduced\nvalue: 5.860348646e-121",
  "comparison": {
    "diff": -1.2911966642626766e-121,
    "ref_sigma": null,
    "ref_value": 7.151545310258967e-121
  },
  "delta_ppm": -180547.92471361978,
  "depends_on": [
    "rho_L",
    "Mpl_reduced"
  ],
  "deviation": {
    "metric": "rel",
    "value": -0.1805479247136198
  },
  "fixed_point": null,
  "formula_math": "rho_L/Mpl_reduced^4",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "Lambda_Mpl2",
  "label": "Lambda Mpl^-2",
  "latex_ref": null,
  "lineage": "scan",
  "note": null,
  "reference": {
    "dataset_id": "Lambda_planck_derived",
    "notes": "Derived Lambda/Mpl^2 from rho_L_target.",
    "sigma": null,
    "units": "dimensionless",
    "value": 7.151545310258967e-121,
    "version": "Planck 2018 (k_calibration)"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
```

```
      "Sc3": 549.7415884008205,
      "Sphi0": -30.954605222177634,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/scan",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 5.86034864599629e-121
  },
  {
    "approximation": null,
    "calculation": "formula_math: (4*pi-1)*beta_rad\ndepends_on: beta_rad, pi\nvalue: 0.04894066267",
    "comparison": {
      "diff": -0.0003610296630743373,
      "ref_sigma": null,
      "ref_value": 0.049301692328524445
    },
    "delta_ppm": -7322.8655249519015,
    "depends_on": [
      "beta_rad",
      "pi"
    ],
    "deviation": {
      "metric": "rel",
      "value": -0.007322865524951902
    },
    "fixed_point": null,
    "formula_math": "(4*pi-1)*beta_rad",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 6: Cosmos (space-time & energy)",
    "hierarchy_level": 3,
    "inputs": {},
    "key": "Omega_b",
    "label": "Omega_b",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": {
      "dataset_id": "omega_b_planck_derived",
      "notes": "Derived Omega_b from Omega_b h^2 and H0 (Planck).",
      "sigma": null,
      "units": "dimensionless",
      "value": 0.049301692328524445,
      "version": "Planck 2018 + Planck 2018"
    },
    "reference_info": null,
    "reference_role": "derived_from_anchor",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.000000000139778,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
```

```
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.04894066266545011
},
{
  "approximation": null,
  "calculation": "formula_math: eta_b_pred\nformula_text: baryon_consistency_audit proxy\nvalue: 5.794376871e-
  "comparison": {
    "diff": -3.327661292439077e-11,
    "ref_sigma": null,
    "ref_value": 6.127143e-10
  },
  "delta_ppm": -54310.162051694846,
  "depends_on": [],
  "deviation": {
    "metric": "rel",
    "value": -0.054310162051694845
  },
  "fixed_point": null,
  "formula_math": "eta_b_pred",
  "formula_text": "baryon_consistency_audit proxy",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "eta_b",
  "label": "eta_b",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": {
    "dataset_id": "eta_b_planck_derived",
    "notes": "Derived eta_b from Omega_b h^2 (Planck) using eta10=273.9*Omega_b h^2.",
    "sigma": null,
    "units": "dimensionless",
    "value": 6.127143e-10,
    "version": "Planck 2018"
  },
  "reference_info": {
    "origin": "baryon_consistency_audit",
    "type": "pipeline_output"
  },
  "reference_role": "derived_from_anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "baryon_consistency_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/eta_b_pred",
  "source_module_id": "baryon_consistency_audit",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 5.794376870756092e-10
},
{
  "approximation": null,
  "calculation": "formula_math: H0_pred\nformula_text: baryon_consistency_audit derived\nvalue: 65.74646855\ns
  "comparison": {
    "ref_sigma": 0.54,
    "ref_value": 67.36,
    "z": -2.9880212073872032
  },
  "delta_ppm": -23953.851721928295,
```

```
  "depends_on": [],
  "deviation": {
    "abs": 2.9880212073872032,
    "metric": "z",
    "value": -2.9880212073872032
  },
  "fixed_point": null,
  "formula_math": "H0_pred",
  "formula_text": "baryon_consistency_audit derived",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "H0",
  "label": "H0",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": {
    "dataset_id": "H0_planck2018",
    "notes": "H0 from Planck 2018 base LCDM.",
    "sigma": 0.54,
    "source": "global_reference_minimal.json:observables.H0_planck2018_km_s_Mpc",
    "units": "km s^-1 Mpc^-1",
    "value": 67.36,
    "version": "Planck 2018"
  },
  "reference_info": {
    "origin": "baryon_consistency_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "baryon_consistency_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/H0_pred",
  "source_module_id": "baryon_consistency_audit",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "cosmology_units",
  "units": "km/s/Mpc",
  "value": 65.74646854801091
},
{
  "approximation": null,
  "calculation": "formula_math: Omega_dm\nformula_text: (Omega_a h^2)/h^2\nvalue: 0.2705330444\nsource: axion_
  "comparison": {
    "diff": 0.006062634065091388,
    "ref_sigma": null,
    "ref_value": 0.26447041034523616
  },
  "delta_ppm": 22923.676252391735,
  "depends_on": [],
  "deviation": {
    "metric": "rel",
    "value": 0.022923676252391736
  },
  "fixed_point": null,
  "formula_math": "Omega_dm",
  "formula_text": "(Omega_a h^2)/h^2",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
```

```
    "group": "Group 6: Cosmos (space-time & energy)",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "Omega_dm",
    "label": "Omega_dm",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": {
      "dataset_id": "omega_dm_planck_derived",
      "notes": "Derived Omega_dm from Omega_dm h^2 and H0 (Planck).",
      "sigma": null,
      "units": "dimensionless",
      "value": 0.26447041034523616,
      "version": "Planck 2018 + Planck 2018"
    },
    "reference_info": {
      "origin": "axion_dm_audit",
      "type": "pipeline_output"
    },
    "reference_role": "derived_from_anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "axion_dm_audit",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/relic/Omega_a_h2",
    "source_module_id": "axion_dm_audit",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.27053304441032755
  },
  {
    "approximation": null,
    "calculation": "formula_math: 180/pi*beta_rad\ndepends_on: beta_rad, pi\nvalue: 0.2424350309",
    "comparison": {
      "ref_sigma": 0.14,
      "ref_value": 0.35,
      "z": -0.7683212078505032
    },
    "delta_ppm": -307328.4831402013,
    "depends_on": [
      "beta_rad",
      "pi"
    ],
    "deviation": {
      "abs": 0.7683212078505032,
      "metric": "z",
      "value": -0.7683212078505032
    },
    "fixed_point": null,
    "formula_math": "180/pi*beta_rad",
    "formula_text": null,
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 6: Cosmos (space-time & energy)",
    "hierarchy_level": 3,
    "inputs": {},
    "key": "beta_deg",
    "label": "beta (deg)",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": {
      "dataset_id": "beta_deg_minami_komatsu_2020",
      "notes": "CMB cosmic birefringence global rotation angle beta.",
```

```
      "sigma": 0.14,
      "source": "global_reference.json:observables.beta_deg",
      "units": "degrees",
      "value": 0.35,
      "version": "Minami & Komatsu 2020"
    },
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.0000000000287557,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/axiom",
    "unit_system": "cosmology_units",
    "units": "degrees",
    "value": 0.24243503090092952
  },
  {
    "approximation": null,
    "calculation": "formula_math: beta_deg\nformula_text: frequency independent\ndepends_on: beta_deg\nvalue: 0.
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "beta_deg"
    ],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "beta_deg",
    "formula_text": "frequency independent",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 6: Cosmos (space-time & energy)",
    "hierarchy_level": 4,
    "inputs": {},
    "key": "beta_deg_PR",
    "label": "beta (deg, PR)",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.0000000000287557,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/axiom",
    "unit_system": "cosmology_units",
    "units": "degrees",
    "value": 0.24243503090092952
  },
```

```
{
  "approximation": null,
  "calculation": "formula_math: nu_ghz\nformula_text: axion_dm_audit pipeline\nvalue: 15.76402318\nsource: axi
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "nu_ghz",
  "formula_text": "axion_dm_audit pipeline",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "nu_ghz",
  "label": "axion frequency (GHz)",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "axion_dm_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "log_abs": false,
    "mode": "external"
  },
  "sigma": {
    "sigma_abs": null,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": null
  },
  "source": "axion_dm_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/axion_claim/nu_GHz",
  "source_module_id": "axion_dm_audit",
  "status": "derived_external",
  "status_label": "derived_external/derived_external",
  "unit_system": "cosmology_units",
  "units": "GHz",
  "value": 15.76402318010866
},
{
  "approximation": null,
  "calculation": "formula_math: g_phys\nformula_text: g_coeff/f_a\nvalue: -1.795522859e-12\nsource: axion_dm_p
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "g_phys",
  "formula_text": "g_coeff/f_a",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 6: Cosmos (space-time & energy)",
  "hierarchy_level": 0,
  "inputs": {},
  "key": "g_phys_axion",
  "label": "g_phys (axion)",
  "latex_ref": null,
  "lineage": "derived_external",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "axion_dm_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
```

```
      "sensitivity": {
        "Sc3": null,
        "Sphi0": null,
        "log_abs": false,
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": "axion_dm_pipeline",
      "source_artifact": "results.json",
      "source_json_pointer": "/results/axion_claim/g_phys_GeV_inv_candidate",
      "source_module_id": "axion_dm_pipeline",
      "status": "derived_external",
      "status_label": "derived_external/derived_external",
      "unit_system": "natural_units",
      "units": "GeV^-1",
      "value": -1.7955228593714628e-12
    }
  ]
},
{
  "group": "Group 7: Inflation & origin",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: N_star\nformula_text: Starobinsky e-folds (policy)\nvalue: 56",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "N_star",
      "formula_text": "Starobinsky e-folds (policy)",
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 7: Inflation & origin",
      "hierarchy_level": 0,
      "inputs": {},
      "key": "N_star",
      "label": "N_star",
      "latex_ref": null,
      "lineage": "anchor",
      "note": null,
      "reference": null,
      "reference_info": {
        "origin": "theoryv3 config starobinsky_N",
        "type": "internal_policy"
      },
      "reference_role": "anchor",
      "sensitivity": {
        "Sc3": null,
        "Sphi0": null,
        "log_abs": false,
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "input",
      "status_label": "input/anchor",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": 56.0
    },
    {
      "approximation": null,
```

```
  "calculation": "formula_math: N_star^2/(24*pi^2)*M_over_Mpl^2\nformula_text: Starobinsky amplitude\ndepends_
  "comparison": {
    "ref_sigma": 2.938464434e-11,
    "ref_value": 2.0989031673e-09,
    "z": -0.29647467805761374
  },
  "delta_ppm": -4150.645492495838,
  "depends_on": [
    "N_star",
    "M_over_Mpl",
    "pi"
  ],
  "deviation": {
    "abs": 0.29647467805761374,
    "metric": "z",
    "value": -0.29647467805761374
  },
  "fixed_point": null,
  "formula_math": "N_star^2/(24*pi^2)*M_over_Mpl^2",
  "formula_text": "Starobinsky amplitude",
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 7: Inflation & origin",
  "hierarchy_level": 2,
  "inputs": {},
  "key": "A_s",
  "label": "A_s",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": {
    "dataset_id": "A_s_planck2018",
    "notes": "Scalar amplitude A_s at k0=0.05 Mpc^-1.",
    "sigma": 2.938464434e-11,
    "source": "global_reference.json:observables.A_s",
    "units": "dimensionless",
    "value": 2.0989031673e-09,
    "version": "Planck 2018"
  },
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 2.090191364329461e-09
},
{
  "approximation": null,
  "calculation": "formula_math: 1-2/N_star\nformula_text: Starobinsky tilt\ndepends_on: N_star\nvalue: 0.96428
  "comparison": {
    "ref_sigma": 0.0042,
    "ref_value": 0.9649,
    "z": -0.146258503401352
  },
  "delta_ppm": -636.631479205802,
  "depends_on": [
    "N_star"
  ],
  "deviation": {
    "abs": 0.146258503401352,
```

```
      "metric": "z",
      "value": -0.146258503401352
    },
    "fixed_point": null,
    "formula_math": "1-2/N_star",
    "formula_text": "Starobinsky tilt",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 7: Inflation & origin",
    "hierarchy_level": 1,
    "inputs": {},
    "key": "n_s",
    "label": "n_s",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": {
      "dataset_id": "n_s_planck2018",
      "notes": "Scalar spectral index at k0=0.05 Mpc^-1.",
      "sigma": 0.0042,
      "source": "global_reference_minimal.json:observables.n_s_planck2018",
      "units": "dimensionless",
      "value": 0.9649,
      "version": "Planck 2018"
    },
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "log_abs": false,
      "mode": "numeric"
    },
    "sigma": {
      "sigma_abs": 0.0,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": 0.0
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "status_label": "derived/axiom",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 0.9642857142857143
  },
  {
    "approximation": null,
    "calculation": "formula_math: 12/N_star^2\nformula_text: Starobinsky tensor ratio\ndepends_on: N_star\nvalue
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [
      "N_star"
    ],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "12/N_star^2",
    "formula_text": "Starobinsky tensor ratio",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 7: Inflation & origin",
    "hierarchy_level": 1,
    "inputs": {},
    "key": "r",
    "label": "r",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "Planck/BICEP (numeric bound pending)",
```

```
    "type": "upper_limit"
  },
  "reference_role": "bound",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.003826530612244898
},
{
  "approximation": null,
  "calculation": "formula_math: (3/2)*pi^2*A_s*r*Mpl_reduced^4\ndepends_on: A_s, r, Mpl_reduced\nvalue: 4.1627
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "A_s",
    "r",
    "Mpl_reduced"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "(3/2)*pi^2*A_s*r*Mpl_reduced^4",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [
      "3/2"
    ],
    "issues": []
  },
  "group": "Group 7: Inflation & origin",
  "hierarchy_level": 3,
  "inputs": {},
  "key": "V_star",
  "label": "V_star",
  "latex_ref": null,
  "lineage": "axiom",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "status_label": "derived/axiom",
  "unit_system": "natural_units",
  "units": "GeV^4",
  "value": 4.162728704945294e+63
},
{
```

```
    "approximation": null,
    "calculation": "formula_math: k_bounce_t\nformula_text: bounce_perturbations k_bounce_t (raw)\nvalue: 7.8080
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "k_bounce_t",
    "formula_text": "bounce_perturbations k_bounce_t (raw)",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 7: Inflation & origin",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "bounce_scale",
    "label": "bounce scale",
    "latex_ref": null,
    "lineage": "derived_external",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "bounce_perturbations",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "log_abs": false,
      "mode": "external"
    },
    "sigma": {
      "sigma_abs": null,
      "sigma_c3_rel": 0.0,
      "sigma_phi0_rel": 0.0,
      "sigma_rel": null
    },
    "source": "bounce_perturbations",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/diagnostics/k_bounce_t_est_raw",
    "source_module_id": "bounce_perturbations",
    "status": "derived_external",
    "status_label": "derived_external/derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value": 7.808039644294931
  },
  {
    "approximation": null,
    "calculation": "formula_math: x_max\nformula_text: Planck spectrum extremum\nvalue: 2.821439372",
    "comparison": null,
    "delta_ppm": null,
    "depends_on": [],
    "deviation": null,
    "fixed_point": null,
    "formula_math": "x_max",
    "formula_text": "Planck spectrum extremum",
    "grammar": {
      "allowed": true,
      "fractions": [],
      "issues": []
    },
    "group": "Group 7: Inflation & origin",
    "hierarchy_level": 0,
    "inputs": {},
    "key": "x_max",
    "label": "x_max (Planck spectrum)",
    "latex_ref": null,
    "lineage": "axiom",
    "note": null,
    "reference": null,
    "reference_info": {
      "origin": "Planck spectrum extremum",
      "type": "analytic"
    },
    "reference_role": "internal",
    "sensitivity": {
```

```
        "Sc3": 0.0,
        "Sphi0": 0.0,
        "log_abs": false,
        "mode": "numeric"
      },
      "sigma": {
        "sigma_abs": 0.0,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": 0.0
      },
      "source": null,
      "source_artifact": null,
      "source_json_pointer": null,
      "source_module_id": null,
      "status": "derived",
      "status_label": "derived/axiom",
      "unit_system": "natural_units",
      "units": "dimensionless",
      "value": 2.8214393721220787
    }
  ]
},
{
  "group": "Group 8: Exotic (bounds & tests)",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: torsion_max\nformula_text: max inferred |S_mu| bound\nvalue: 2.9e-27\nsource:
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "torsion_max",
      "formula_text": "max inferred |S_mu| bound",
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 8: Exotic (bounds & tests)",
      "hierarchy_level": 0,
      "inputs": {},
      "key": "torsion_max",
      "label": "max torsion coupling",
      "latex_ref": null,
      "lineage": "derived_external",
      "note": null,
      "reference": null,
      "reference_info": {
        "origin": "torsion_bounds_mapping",
        "type": "pipeline_output"
      },
      "reference_role": "pipeline",
      "sensitivity": {
        "Sc3": null,
        "Sphi0": null,
        "log_abs": false,
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": "torsion_bounds_mapping",
      "source_artifact": "results.json",
      "source_json_pointer": "/results/inferred_bounds",
      "source_module_id": "torsion_bounds_mapping",
      "status": "derived_external",
      "status_label": "derived_external/derived_external",
      "unit_system": "natural_units",
      "units": "GeV",
      "value": 2.9e-27
    },
    {
      "approximation": null,
      "calculation": "formula_math: lambda_cross\nformula_text: lambda crossing scale\nvalue: 4.529728562e+10\nsou
```

```
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "lambda_cross",
      "formula_text": "lambda crossing scale",
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 8: Exotic (bounds & tests)",
      "hierarchy_level": 0,
      "inputs": {},
      "key": "lambda_cross",
      "label": "vacuum stability scale",
      "latex_ref": null,
      "lineage": "derived_external",
      "note": null,
      "reference": null,
      "reference_info": {
        "origin": "stability_unitarity_audit",
        "type": "pipeline_output"
      },
      "reference_role": "pipeline",
      "sensitivity": {
        "Sc3": null,
        "Sphi0": null,
        "log_abs": false,
        "mode": "external"
      },
      "sigma": {
        "sigma_abs": null,
        "sigma_c3_rel": 0.0,
        "sigma_phi0_rel": 0.0,
        "sigma_rel": null
      },
      "source": "stability_unitarity_audit",
      "source_artifact": "results.json",
      "source_json_pointer": "/results/lambda_crossing/mu_cross_GeV",
      "source_module_id": "stability_unitarity_audit",
      "status": "derived_external",
      "status_label": "derived_external/derived_external",
      "unit_system": "natural_units",
      "units": "GeV",
      "value": 45297285617.694756
    }
  ]
},
{
  "group": "Group 9: QED derived constants",
  "items": [
    {
      "approximation": null,
      "calculation": "formula_math: alpha0/(2*pi)\ndepends_on: alpha0, pi\nvalue: 0.001161409732",
      "comparison": null,
      "delta_ppm": null,
      "depends_on": [
        "alpha0",
        "pi"
      ],
      "deviation": null,
      "fixed_point": null,
      "formula_math": "alpha0/(2*pi)",
      "formula_text": null,
      "grammar": {
        "allowed": true,
        "fractions": [],
        "issues": []
      },
      "group": "Group 9: QED derived constants",
      "hierarchy_level": 4,
      "inputs": {},
      "key": "a_e",
      "label": "a_e",
      "latex_ref": null,
      "lineage": "candidate",
      "note": null,
      "reference": null,
```

```
  "reference_info": {
    "origin": "CODATA 2022 QED lowest order",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": 2.005829094375855,
    "Sphi0": -0.11294333379652244,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value": 0.0011614097317657883
},
{
  "approximation": null,
  "calculation": "formula_math: 1/2*alpha0^2*m_e\ndepends_on: alpha0, m_e\nvalue: 1.610953871e-08",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha0",
    "m_e"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "1/2*alpha0^2*m_e",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [
      "1/2"
    ],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "Rydberg_E",
  "label": "R_infty (energy)",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "CODATA 2022",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": 74.72935673824566,
    "Sphi0": 0.9047876794454623,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
```

```
  "units": "GeV",
  "value": 1.6109538705225757e-08
},
{
  "approximation": null,
  "calculation": "formula_math: 1/(alpha0*m_e)\ndepends_on: alpha0, m_e\nvalue: 226491.6673",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha0",
    "m_e"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "1/(alpha0*m_e)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "a0",
  "label": "Bohr radius (a0)",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "CODATA 2022",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": -72.72352764431389,
    "Sphi0": -1.0177310132419848,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV^-1",
  "value": 226491.66732126864
},
{
  "approximation": null,
  "calculation": "formula_math: 8*pi/3*alpha0^2/m_e^2\ndepends_on: alpha0, m_e, pi\nvalue: 1218.665115",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha0",
    "m_e",
    "pi"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "8*pi/3*alpha0^2/m_e^2",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "sigma_T",
```

```
  "label": "Thomson cross section",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": {
    "origin": "classical electrodynamics",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": -137.42373891112436,
    "Sphi0": -2.4872353621141485,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV^-2",
  "value": 1218.6651146076479
},
{
  "approximation": "scaling_proxy",
  "calculation": "formula_math: alpha0^4*m_e\ndepends_on: alpha0, m_e\nvalue: 1.71570951e-12",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha0",
    "m_e"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "alpha0^4*m_e",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "fs_2p",
  "label": "fine-structure 2p (H)",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "order_of_magnitude_only",
  "sensitivity": {
    "Sc3": 78.74101492610919,
    "Sphi0": 0.6789010118524175,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
```

```
  "units": "GeV",
  "value": 1.7157095101959414e-12
},
{
  "approximation": "scaling_proxy",
  "calculation": "formula_math: alpha0^5*m_e*log(1/alpha0)\ndepends_on: alpha0, m_e\nvalue: 6.160212562e-14",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "alpha0",
    "m_e"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "alpha0^5*m_e*log(1/alpha0)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 5,
  "inputs": {},
  "key": "lamb_shift",
  "label": "Lamb shift (proxy)",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
  "reference": null,
  "reference_info": null,
  "reference_role": "order_of_magnitude_only",
  "sensitivity": {
    "Sc3": 80.33917537098034,
    "Sphi0": 0.5889125045399624,
    "log_abs": false,
    "mode": "numeric"
  },
  "sigma": {
    "sigma_abs": 0.0,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "sigma_rel": 0.0
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "status_label": "candidate/candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value": 6.160212562428027e-14
},
{
  "approximation": null,
  "calculation": "formula_math: 2*(1+c3/pi)\ndepends_on: c3, pi\nvalue: 2.025330296",
  "comparison": null,
  "delta_ppm": null,
  "depends_on": [
    "c3",
    "pi"
  ],
  "deviation": null,
  "fixed_point": null,
  "formula_math": "2*(1+c3/pi)",
  "formula_text": null,
  "grammar": {
    "allowed": true,
    "fractions": [],
    "issues": []
  },
  "group": "Group 9: QED derived constants",
  "hierarchy_level": 1,
  "inputs": {},
  "key": "g_p",
  "label": "proton g-factor",
  "latex_ref": null,
  "lineage": "candidate",
  "note": null,
```

```
        "reference": null,
        "reference_info": {
          "origin": "classical electrodynamics",
          "type": "literature"
        },
        "reference_role": "internal",
        "sensitivity": {
          "Sc3": 0.01250674813713104,
          "Sphi0": 0.0,
          "log_abs": false,
          "mode": "numeric"
        },
        "sigma": {
          "sigma_abs": 0.0,
          "sigma_c3_rel": 0.0,
          "sigma_phi0_rel": 0.0,
          "sigma_rel": 0.0
        },
        "source": null,
        "source_artifact": null,
        "source_json_pointer": null,
        "source_module_id": null,
        "status": "candidate",
        "status_label": "candidate/candidate",
        "unit_system": "natural_units",
        "units": "dimensionless",
        "value": 2.0253302959105843
      }
    ]
  }
],
"hierarchy": {
  "levels": {
    "A_s": 2,
    "CKM_A": 0,
    "CKM_eta": 0,
    "CKM_rho": 0,
    "G_F_Mpl2": 4,
    "H0": 0,
    "Lambda_Mpl2": 5,
    "Lambda_QCD": 2,
    "M_GUT": 0,
    "M_R": 0,
    "M_over_Mpl": 1,
    "Mpl_reduced": 0,
    "Mpl_unreduced": 1,
    "N_star": 0,
    "Omega_b": 3,
    "Omega_dm": 0,
    "Rydberg_E": 5,
    "V_star": 3,
    "a0": 5,
    "a_e": 4,
    "alpha0": 3,
    "alpha3_at_mu_star": 0,
    "alpha_bar5_inv_MZ": 0,
    "alpha_inv0": 2,
    "alpha_inv0_simple": 2,
    "alpha_s_MZ": 0,
    "beta_deg": 3,
    "beta_deg_PR": 4,
    "beta_rad": 2,
    "bounce_scale": 0,
    "c3": 0,
    "delta2": 1,
    "delta_cp": 0,
    "delta_m_np": 0,
    "delta_star": 2,
    "delta_top": 0,
    "eta_b": 0,
    "f_a": 0,
    "fs_2p": 5,
    "g": 0,
    "g_a_gamma_gamma": 1,
    "g_p": 1,
    "g_phys_axion": 0,
    "gamma0": 1,
    "k": 0,
    "lamb_shift": 5,
    "lambda": 2,
```

```
    "lambda_C_ratio": 5,
    "lambda_cross": 0,
    "m_b": 0,
    "m_c": 0,
    "m_d": 0,
    "m_e": 4,
    "m_e_over_m_p": 4,
    "m_mu": 4,
    "m_mu_over_m_e": 3,
    "m_nu1": 0,
    "m_nu3": 4,
    "m_p": 0,
    "m_pi": 0,
    "m_s": 0,
    "m_t": 0,
    "m_tau": 4,
    "m_tau_over_m_mu": 3,
    "m_u": 0,
    "mu_star_varphi0": 0,
    "n_s": 1,
    "nu_ghz": 0,
    "phi_star_base": 3,
    "pi": 0,
    "r": 1,
    "rho_L": 4,
    "sigma_T": 5,
    "sin2_theta12": 3,
    "sin2_theta13": 2,
    "sin2_theta23": 0,
    "sin2_thetaW_0": 0,
    "sin2_thetaW_MZ": 0,
    "sum_mnu": 0,
    "torsion_max": 0,
    "v_ew": 3,
    "varphi0": 1,
    "varphi0_tree": 0,
    "x_max": 0,
    "y_e": 2,
    "y_mu": 2,
    "y_tau": 2
  },
  "max_level": 5
},
"ledger": [
  {
    "approximation": null,
    "definition": "pi",
    "delta_ppm": null,
    "fixed_point": true,
    "formula_text": "circle constant",
    "label": "pi",
    "latex_snippet": "\\paragraph{pi (pi)}\nDefinition: ${pi}$.\\\\\\nMeaning: circle constant.\\\\\\nValue: ${3.14159
    "lineage": "anchor",
    "name": "pi",
    "primitives": [
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "geometry constant",
      "type": "analytic"
    },
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "input",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 3.141592653589793,
    "value_ref": null
  },
  {
    "approximation": null,
```

```
    "definition": "g",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "SU(5) holonomy multiplicity (two-defect)",
    "label": "g",
    "latex_snippet": "\\paragraph{g (g)}\nDefinition: ${g}$.\\\\\\nMeaning: SU(5) holonomy multiplicity (two-defect).
    "lineage": "discrete_scan",
    "name": "g",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "defect_partition_g5_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "defect_partition_g5_audit",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/delta2/g_value",
    "source_module_id": "defect_partition_g5_audit",
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 5.0,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "k",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "backreaction cover degree (min |ppm|)",
    "label": "k",
    "latex_snippet": "\\paragraph{k (k)}\nDefinition: ${k}$.\\\\\\nMeaning: backreaction cover degree (min |ppm|).\\\
    "lineage": "discrete_scan",
    "name": "k",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "alpha_backreaction_sensitivity_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "alpha_backreaction_sensitivity_audit",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/abs_ppm",
    "source_module_id": "alpha_backreaction_sensitivity_audit",
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 2.0,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "g/(g+1)",
    "delta_ppm": null,
    "fixed_point": true,
    "formula_text": "crosslink signature",
    "label": "gamma0",
    "latex_snippet": "\\paragraph{gamma0 (gamma0)}\nDefinition: ${g/(g+1)}$.\\\\\\nMeaning: crosslink signature.\\\\\
    "lineage": "axiom",
    "name": "gamma0",
```

```
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "g5_crosslink_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.8333333333333334,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "(g/4)*delta_top^2",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "delta2",
    "latex_snippet": "\\paragraph{delta2 (delta2)}\nDefinition: ${(g/4)*delta_top^2}$.\\\\\\nValue: ${1.8091459748867
    "lineage": "discrete_scan",
    "name": "delta2",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "defect_partition_g5_audit",
      "type": "internal_derivation"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 1.8091459748867854e-08,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "1/(8*pi)",
    "delta_ppm": null,
    "fixed_point": true,
    "formula_text": null,
    "label": "c3",
    "latex_snippet": "\\paragraph{c3 (c3)}\nDefinition: ${1/(8*pi)}$.\\\\\\nValue: ${0.039788735772973836}\\,\\mathrm
    "lineage": "axiom",
    "name": "c3",
    "primitives": [
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.9999999999177334,
```

```
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.039788735772973836,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "1/(6*pi)",
    "delta_ppm": null,
    "fixed_point": true,
    "formula_text": null,
    "label": "varphi0_tree",
    "latex_snippet": "\\paragraph{varphi0_tree (varphi0_tree)}\nDefinition: ${1/(6*pi)}$.\\\\\\nValue: ${0.053051647
    "lineage": "axiom",
    "name": "varphi0_tree",
    "primitives": [
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.002267686178726,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.05305164769729844,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "3/(256*pi^4)",
    "delta_ppm": null,
    "fixed_point": true,
    "formula_text": null,
    "label": "delta_top",
    "latex_snippet": "\\paragraph{delta_top (delta_top)}\nDefinition: ${3/(256*pi^4)}$.\\\\\\nValue: ${0.000120304479
    "lineage": "axiom",
    "name": "delta_top",
    "primitives": [
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.00012030447954708205,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "varphi0_tree+delta_top",
    "delta_ppm": null,
    "fixed_point": true,
```

```
  "formula_text": null,
  "label": "varphi0",
  "latex_snippet": "\\paragraph{varphi0 (varphi0)}\nDefinition: ${varphi0_tree+delta_top}$.\\\\\\nValue: ${0.053171
  "lineage": "axiom",
  "name": "varphi0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.000000000139778,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.053171952176845526,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "3/5+varphi0/6",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "delta_star",
  "latex_snippet": "\\paragraph{delta_star (delta_star)}\nDefinition: ${3/5+varphi0/6}$.\\\\\\nValue: ${0.608861992
  "lineage": "axiom",
  "name": "delta_star",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.014555009419936482,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.6088619920294742,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "varphi0/(4*pi)",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "beta_rad",
  "latex_snippet": "\\paragraph{beta_rad (beta_rad)}\nDefinition: ${varphi0/(4*pi)}$.\\\\\\nValue: ${0.004231289511
  "lineage": "axiom",
  "name": "beta_rad",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
```

```
    "Sc3": 0.0,
    "Sphi0": 0.9999999996956888,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "radian",
  "value_pred": 0.004231289511395415,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "alpha_inv0",
  "delta_ppm": 0.0002857527095569458,
  "fixed_point": true,
  "formula_text": "Solve CFE(alpha,varphi)=0 with varphi=varphi_tree+delta_top*exp(-2*alpha)+delta2*exp(-4*alpha),
  "label": "alpha_inv(0)",
  "latex_snippet": "\\paragraph{alpha_inv0 (alpha_inv(0))}\nDefinition: ${alpha_inv0}$.\\\\\\nMeaning: Solve CFE(al
  "lineage": "axiom",
  "name": "alpha_inv0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": -2.005829094375855,
    "Sphi0": 0.11294333379652244,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 137.03599921615842,
  "value_ref": 137.035999177
},
{
  "approximation": null,
  "definition": "1/alpha_inv0",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "alpha(0)",
  "latex_snippet": "\\paragraph{alpha0 (alpha(0))}\nDefinition: ${1/alpha_inv0}$.\\\\\\nValue: ${0.0072973525622461
  "lineage": "axiom",
  "name": "alpha0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 2.005829094375855,
    "Sphi0": -0.11294333379652244,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.007297352562246186,
  "value_ref": null
},
```

```
{
  "approximation": null,
  "definition": "4*pi*exp(1/varphi0)",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "alpha_inv(0) (simple)",
  "latex_snippet": "\\paragraph{alpha_inv0_simple (alpha_inv(0) (simple))}\nDefinition: ${4*pi*exp(1/varphi0)}$.\\
  "lineage": "candidate",
  "name": "alpha_inv0_simple",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": -18.806907759127967,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 1849039231.4764473,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "alpha_bar5_inv_MZ",
  "delta_ppm": 82.1992174607052,
  "fixed_point": false,
  "formula_text": "alpha(0) -> MZ running (alpha_precision_audit)",
  "label": "alpha_bar5_inv(MZ)",
  "latex_snippet": "\\paragraph{alpha_bar5_inv_MZ (alpha_bar5_inv(MZ))}\nDefinition: ${alpha_bar5_inv_MZ}$.\\\\\\nM
  "lineage": "derived_external",
  "name": "alpha_bar5_inv_MZ",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "alpha_precision_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "alpha_precision_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/secondary_alpha_bar5_MZ/alpha_bar5_inv_MZ_pred",
  "source_module_id": "alpha_precision_audit",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 127.94051574588975,
  "value_ref": 127.93
},
{
  "approximation": null,
  "definition": "alpha_s_MZ",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "SM input (MSbar)",
  "label": "alpha_s(MZ)",
  "latex_snippet": "\\paragraph{alpha_s_MZ (alpha_s(MZ))}\nDefinition: ${alpha_s_MZ}$.\\\\\\nMeaning: SM input (MSb
  "lineage": "anchor",
  "name": "alpha_s_MZ",
  "primitives": [
```

```
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "sm_inputs_mz.json",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "sm_inputs_mz.json",
    "status": "input",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.1179,
    "value_ref": 0.1179
  },
  {
    "approximation": null,
    "definition": "sin2_thetaW_MZ",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "SM input (MSbar)",
    "label": "sin^2(thetaW) (MZ)",
    "latex_snippet": "\\paragraph{sin2_thetaW_MZ (sin^2(thetaW) (MZ))}\nDefinition: ${sin2_thetaW_MZ}$.\\\\\\nMeaning
    "lineage": "anchor",
    "name": "sin2_thetaW_MZ",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "sm_inputs_mz.json",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "sm_inputs_mz.json",
    "status": "input",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.23122,
    "value_ref": 0.23122
  },
  {
    "approximation": null,
    "definition": "sin2_thetaW_0",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "G(c3,varphi0) (pending)",
    "label": "sin^2(thetaW)(0)",
    "latex_snippet": "\\paragraph{sin2_thetaW_0 (sin^2(thetaW)(0))}\nDefinition: ${sin2_thetaW_0}$.\\\\\\nMeaning: G(
    "lineage": "pending",
    "name": "sin2_thetaW_0",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
```

```
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": null,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "alpha3_at_mu_star",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "alpha3(mu)=varphi0 crossing",
  "label": "alpha3(mu_star)",
  "latex_snippet": "\\paragraph{alpha3_at_mu_star (alpha3(mu_star))}\nDefinition: ${alpha3_at_mu_star}$.\\\\\\nMean
  "lineage": "derived_external",
  "name": "alpha3_at_mu_star",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "two_loop_rg_fingerprints",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "two_loop_rg_fingerprints",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/alpha3/crossing_varphi0/alpha3",
  "source_module_id": "two_loop_rg_fingerprints",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.053171952176845526,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "mu_star_varphi0",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "alpha3(mu)=varphi0 crossing",
  "label": "mu_star (alpha3=varphi0)",
  "latex_snippet": "\\paragraph{mu_star_varphi0 (mu_star (alpha3=varphi0))}\nDefinition: ${mu_star_varphi0}$.\\\\\\
  "lineage": "derived_external",
  "name": "mu_star_varphi0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "two_loop_rg_fingerprints",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "two_loop_rg_fingerprints",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/alpha3/crossing_varphi0/mu_GeV",
  "source_module_id": "two_loop_rg_fingerprints",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 792005.555441517,
  "value_ref": null
},
```

```
{
  "approximation": null,
  "definition": "-4*c3",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "g_a_gamma_gamma",
  "latex_snippet": "\\paragraph{g_a_gamma_gamma (g_a_gamma_gamma)}\nDefinition: ${-4*c3}$.\\\\\\nValue: ${-0.159154
  "lineage": "axiom",
  "name": "g_a_gamma_gamma",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.9999999999177334,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": -0.15915494309189535,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "Mpl_reduced",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "input (reduced Planck mass)",
  "label": "Mpl_reduced",
  "latex_snippet": "\\paragraph{Mpl_reduced (Mpl_reduced)}\nDefinition: ${Mpl_reduced}$.\\\\\\nMeaning: input (redu
  "lineage": "anchor",
  "name": "Mpl_reduced",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 2.435e+18,
  "value_ref": 2.435e+18
},
{
  "approximation": null,
  "definition": "sqrt(8*pi)*Mpl_reduced",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "Mpl (unreduced)",
  "latex_snippet": "\\paragraph{Mpl_unreduced (Mpl (unreduced))}\nDefinition: ${sqrt(8*pi)*Mpl_reduced}$.\\\\\\nVal
  "lineage": "axiom",
  "name": "Mpl_unreduced",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
```

```
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 1.2207279697452972e+19,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "sqrt(8*pi)*c3^4",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "M/Mpl (Starobinsky)",
  "latex_snippet": "\\paragraph{M_over_Mpl (M/Mpl (Starobinsky))}\nDefinition: ${sqrt(8*pi)*c3^4}$.\\\\\\nValue: ${
  "lineage": "axiom",
  "name": "M_over_Mpl",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 3.9999999996709334,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 1.2564942083228452e-05,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "M_GUT",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "mu where alpha1=alpha2=alpha3",
  "label": "M_GUT",
  "latex_snippet": "\\paragraph{M_GUT (M_GUT)}\nDefinition: ${M_GUT}$.\\\\\\nMeaning: mu where alpha1=alpha2=alpha3
  "lineage": "derived_external",
  "name": "M_GUT",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "unification_gate",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "unification_gate",
  "source_artifact": "results.json",
```

```
  "source_json_pointer": "/results/best_unification_point/mu_GeV",
  "source_module_id": "unification_gate",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 2805733340894862.0,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "M_R",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "seesaw anchor",
  "label": "M_R",
  "latex_snippet": "\\paragraph{M_R (M_R)}\nDefinition: ${M_R}$.\\\\\\nMeaning: seesaw anchor.\\\\\\nValue: ${131100
  "lineage": "derived_external",
  "name": "M_R",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "seesaw_block",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "seesaw_block",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/paper_v1_06_anchor/MR_GeV",
  "source_module_id": "seesaw_block",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 1311000000000000.0,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "f_a",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "axion_dm_pipeline",
  "label": "f_a",
  "latex_snippet": "\\paragraph{f_a (f_a)}\nDefinition: ${f_a}$.\\\\\\nMeaning: axion_dm_pipeline.\\\\\\nValue: ${88
  "lineage": "derived_external",
  "name": "f_a",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "axion_dm_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "axion_dm_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/axion_claim/f_a_GeV",
  "source_module_id": "axion_dm_pipeline",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 88639886850.34554,
  "value_ref": null
},
```

```
{
  "approximation": null,
  "definition": "4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced",
  "delta_ppm": 302475.1226893898,
  "fixed_point": false,
  "formula_text": "candidate EW-scale closure",
  "label": "v (EW scale)",
  "latex_snippet": "\\paragraph{v_ew (v (EW scale))}\nDefinition: ${4*pi*g*c3^2*exp(-alpha_inv0/4)*Mpl_reduced}$.\
  "lineage": "candidate",
  "name": "v_ew",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 70.71769854993804,
    "Sphi0": -3.869325652772204,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 320.4088801815899,
  "value_ref": 246.0
},
{
  "approximation": null,
  "definition": "Mpl_reduced*exp(-1/(2*varphi0))",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "placeholder scaling (RG-based derivation pending)",
  "label": "Lambda_QCD",
  "latex_snippet": "\\paragraph{Lambda_QCD (Lambda_QCD)}\nDefinition: ${Mpl_reduced*exp(-1/(2*varphi0))}$.\\\\\\nMe
  "lineage": "pending",
  "name": "Lambda_QCD",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "PDG Lambda_QCD ~0.2 GeV (numeric bound pending)",
    "type": "literature"
  },
  "reference_role": "pending_reference",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 200738573987935.12,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "m_p",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "PDG placeholder",
  "label": "m_p",
  "latex_snippet": "\\paragraph{m_p (m_p)}\nDefinition: ${m_p}$.\\\\\\nMeaning: PDG placeholder.\\\\\\nValue: ${0.93
  "lineage": "anchor",
  "name": "m_p",
  "primitives": [
```

```
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "mass_spectrum_minimal",
    "source_artifact": "results.json",
    "source_json_pointer": null,
    "source_module_id": "mass_spectrum_minimal",
    "status": "placeholder",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 0.938272,
    "value_ref": 0.938272
  },
  {
    "approximation": null,
    "definition": "m_pi",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "pending TFPT derivation",
    "label": "m_pi",
    "latex_snippet": "\\paragraph{m_pi (m_pi)}\nDefinition: ${m_pi}$.\\\\\\nMeaning: pending TFPT derivation.\\\\\\nVa
    "lineage": "pending",
    "name": "m_pi",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": null,
    "value_ref": null
  },
  {
    "approximation": "scaling_proxy",
    "definition": "Mpl_reduced^2/(sqrt(2)*v_ew^2)",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "dimensionless Fermi coupling proxy",
    "label": "G_F * Mpl^2",
    "latex_snippet": "\\paragraph{G_F_Mpl2 (G_F * Mpl^2)}\nDefinition: ${Mpl_reduced^2/(sqrt(2)*v_ew^2)}$.\\\\\\nMean
    "lineage": "candidate",
    "name": "G_F_Mpl2",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "order_of_magnitude_only",
    "sensitivity": {
      "Sc3": -141.43539710431696,
      "Sphi0": 7.738651305544408,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
```

```
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 4.083888206079671e+31,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "pi*varphi0^2",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "y_tau",
  "latex_snippet": "\\paragraph{y_tau (y_tau)}\nDefinition: ${pi*varphi0^2}$.\\\\\\nValue: ${0.008882088244863067}\
  "lineage": "axiom",
  "name": "y_tau",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 2.000000000279556,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.008882088244863067,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "pi*varphi0^3",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
  "label": "y_mu",
  "latex_snippet": "\\paragraph{y_mu (y_mu)}\nDefinition: ${pi*varphi0^3}$.\\\\\\nValue: ${0.0004722779713863807 3}\
  "lineage": "axiom",
  "name": "y_mu",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 2.9999999999752447,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.00047227797138638073,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "2*pi*varphi0^5",
  "delta_ppm": null,
  "fixed_point": true,
  "formula_text": null,
```

```
    "label": "y_e",
    "latex_snippet": "\\paragraph{y_e (y_e)}\nDefinition: ${2*pi*varphi0^5}$.\\\\\\nValue: ${2.6705019272091007e-06}\
    "lineage": "axiom",
    "name": "y_e",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 5.00000000069889,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 2.6705019272091007e-06,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "v_ew*(2*pi*varphi0^5)/sqrt(2)",
    "delta_ppm": 184029.26727811567,
    "fixed_point": false,
    "formula_text": "candidate Yukawa ladder",
    "label": "m_e",
    "latex_snippet": "\\paragraph{m_e (m_e)}\nDefinition: ${v_ew*(2*pi*varphi0^5)/sqrt(2)}$.\\\\\\nMeaning: candidate
    "lineage": "candidate",
    "name": "m_e",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 70.71769854993804,
      "Sphi0": 1.1306743474825964,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 0.0006050377077306724,
    "value_ref": 0.0005109989461
  },
  {
    "approximation": null,
    "definition": "v_ew*(pi*varphi0^3)/sqrt(2)",
    "delta_ppm": 12705.830551551764,
    "fixed_point": false,
    "formula_text": "candidate Yukawa ladder",
    "label": "m_mu",
    "latex_snippet": "\\paragraph{m_mu (m_mu)}\nDefinition: ${v_ew*(pi*varphi0^3)/sqrt(2)}$.\\\\\\nMeaning: candidate
    "lineage": "candidate",
    "name": "m_mu",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 70.71769854993804,
```

```
    "Sphi0": -0.8693256525749149,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 0.1070008519027494,
  "value_ref": 0.1056583745
},
{
  "approximation": null,
  "definition": "v_ew*(pi*varphi0^2)/sqrt(2)",
  "delta_ppm": 132534.4438831347,
  "fixed_point": false,
  "formula_text": "candidate Yukawa ladder",
  "label": "m_tau",
  "latex_snippet": "\\paragraph{m_tau (m_tau)}\nDefinition: ${v_ew*(pi*varphi0^2)/sqrt(2)}$.\\\\\nMeaning: candida
  "lineage": "candidate",
  "name": "m_tau",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 70.71769854993804,
    "Sphi0": -1.8693256527146929,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 2.012355151958187,
  "value_ref": 1.77686
},
{
  "approximation": null,
  "definition": "alpha0^2*exp(-1/varphi0)",
  "delta_ppm": -999999.9993354876,
  "fixed_point": false,
  "formula_text": null,
  "label": "m_e/m_p",
  "latex_snippet": "\\paragraph{m_e_over_m_p (m_e/m_p)}\nDefinition: ${alpha0^2*exp(-1/varphi0)}$.\\\\\nValue: ${3
  "lineage": "candidate",
  "name": "m_e_over_m_p",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 4.011658189639888,
    "Sphi0": 18.58102109153492,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 3.6190484438523293e-13,
  "value_ref": 0.0005446170685046554
},
{
```

```
  "approximation": null,
  "definition": "((1+delta_star)/(1-delta_star))^2*((1/3+delta_star)/(1/3-delta_star))^2",
  "delta_ppm": -43154.19210930057,
  "fixed_point": false,
  "formula_text": null,
  "label": "m_mu/m_e",
  "latex_snippet": "\\paragraph{m_mu_over_m_e (m_mu/m_e)}\nDefinition: ${((1+delta_star)/(1-delta_star))^2*((1/3+d
  "lineage": "axiom",
  "name": "m_mu_over_m_e",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.010814541706594127,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 197.84536441898265,
  "value_ref": 206.76828260879265
},
{
  "approximation": null,
  "definition": "((1+delta_star)/(1-delta_star))^2",
  "delta_ppm": 6070.138924041547,
  "fixed_point": false,
  "formula_text": null,
  "label": "m_tau/m_mu",
  "latex_snippet": "\\paragraph{m_tau_over_m_mu (m_tau/m_mu)}\nDefinition: ${((1+delta_star)/(1-delta_star))^2}$.\
  "lineage": "axiom",
  "name": "m_tau_over_m_mu",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.05633036126440061,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 16.91911119689403,
  "value_ref": 16.81702949159037
},
{
  "approximation": null,
  "definition": "m_t",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "input (scheme dependent)",
  "label": "m_t (top)",
  "latex_snippet": "\\paragraph{m_t (m_t (top))}\nDefinition: ${m_t}$.\\\\\\nMeaning: input (scheme dependent).\\\\
  "lineage": "anchor",
  "name": "m_t",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
```

```
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "needs_rg",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "input",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 172.76,
    "value_ref": 172.76
  },
  {
    "approximation": null,
    "definition": "m_b",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "input (scheme dependent)",
    "label": "m_b (bottom)",
    "latex_snippet": "\\paragraph{m_b (m_b (bottom))}\nDefinition: ${m_b}$.\\\\\\nMeaning: input (scheme dependent).\
    "lineage": "anchor",
    "name": "m_b",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "needs_rg",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "input",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 4.18,
    "value_ref": 4.18
  },
  {
    "approximation": null,
    "definition": "m_c",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "input (scheme dependent)",
    "label": "m_c (charm)",
    "latex_snippet": "\\paragraph{m_c (m_c (charm))}\nDefinition: ${m_c}$.\\\\\\nMeaning: input (scheme dependent).\\\
    "lineage": "anchor",
    "name": "m_c",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "needs_rg",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "input",
    "unit_system": "natural_units",
```

```
  "units": "GeV",
  "value_pred": 1.27,
  "value_ref": 1.27
},
{
  "approximation": null,
  "definition": "m_s",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "pending (scheme/scale)",
  "label": "m_s (strange)",
  "latex_snippet": "\\paragraph{m_s (m_s (strange))}\nDefinition: ${m_s}$.\\\\\\nMeaning: pending (scheme/scale).\\
  "lineage": "pending",
  "name": "m_s",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": null,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "m_u",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "pending (scheme/scale)",
  "label": "m_u (up)",
  "latex_snippet": "\\paragraph{m_u (m_u (up))}\nDefinition: ${m_u}$.\\\\\\nMeaning: pending (scheme/scale).\\\\\\nV
  "lineage": "pending",
  "name": "m_u",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": null,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "m_d",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "pending (scheme/scale)",
  "label": "m_d (down)",
  "latex_snippet": "\\paragraph{m_d (m_d (down))}\nDefinition: ${m_d}$.\\\\\\nMeaning: pending (scheme/scale).\\\\\
  "lineage": "pending",
  "name": "m_d",
```

```
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "pending",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": null,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "m_nu1",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "placeholder (order-of-mag)",
    "label": "m_nu1",
    "latex_snippet": "\\paragraph{m_nu1 (m_nu1)}\nDefinition: ${m_nu1}$.\\\\\\nMeaning: placeholder (order-of-mag).\\
    "lineage": "anchor",
    "name": "m_nu1",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "placeholder",
    "unit_system": "natural_units",
    "units": "eV",
    "value_pred": 0.05,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "v_ew^2/M_R",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "m_nu3",
    "latex_snippet": "\\paragraph{m_nu3 (m_nu3)}\nDefinition: ${v_ew^2/M_R}$.\\\\\\nValue: ${0.046160183066361556}\\,
    "lineage": "derived_external",
    "name": "m_nu3",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "seesaw_block",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
```

```
    "mode": "external"
  },
  "source": "seesaw_block",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/derived/mnu3_from_v_sm_eV",
  "source_module_id": "seesaw_block",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "eV",
  "value_pred": 0.046160183066361556,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "sum_mnu",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "pending (needs consistent neutrino spectrum)",
  "label": "sum m_nu",
  "latex_snippet": "\\paragraph{sum_mnu (sum m_nu)}\nDefinition: ${sum_mnu}$.\\\\\\nMeaning: pending (needs consist
  "lineage": "pending",
  "name": "sum_mnu",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "eV",
  "value_pred": null,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "delta_m_np",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "pending (EM + isospin)",
  "label": "Delta m_np",
  "latex_snippet": "\\paragraph{delta_m_np (Delta m_np)}\nDefinition: ${delta_m_np}$.\\\\\\nMeaning: pending (EM +
  "lineage": "pending",
  "name": "delta_m_np",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "pending",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": null,
  "value_ref": null
},
{
  "approximation": null,
```

```
    "definition": "m_e/m_p",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "lambda_C^p/lambda_C^e",
    "latex_snippet": "\\paragraph{lambda_C_ratio (lambda_C^p/lambda_C^e)}\nDefinition: ${m_e/m_p}$.\\\\\\nValue: ${0.
    "lineage": "derived_external",
    "name": "lambda_C_ratio",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.0005446170685046554,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "sqrt(varphi0)*(1-varphi0/2)",
    "delta_ppm": -2444.466828257528,
    "fixed_point": false,
    "formula_text": null,
    "label": "Cabibbo lambda",
    "latex_snippet": "\\paragraph{lambda (Cabibbo lambda)}\nDefinition: ${sqrt(varphi0)*(1-varphi0/2)}$.\\\\\\nValue:
    "lineage": "axiom",
    "name": "lambda",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.47268790515087034,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.22445997051897376,
    "value_ref": 0.22501
  },
  {
    "approximation": null,
    "definition": "Vcb/lambda^2",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "Wolfenstein from CKM pipeline",
    "label": "CKM A",
    "latex_snippet": "\\paragraph{CKM_A (CKM A)}\nDefinition: ${Vcb/lambda^2}$.\\\\\\nMeaning: Wolfenstein from CKM p
    "lineage": "derived_external",
    "name": "CKM_A",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
```

```
    "reference_info": {
      "origin": "ckm_full_pipeline",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "ckm_full_pipeline",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
    "source_module_id": "ckm_full_pipeline",
    "status": "derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.9348635188312315,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "rho_CKM",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "Wolfenstein from |Vub|,|Vtd|",
    "label": "CKM rho",
    "latex_snippet": "\\paragraph{CKM_rho (CKM rho)}\nDefinition: ${rho_CKM}$.\\\\\\nMeaning: Wolfenstein from |Vub|,
    "lineage": "derived_external",
    "name": "CKM_rho",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "ckm_full_pipeline",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "ckm_full_pipeline",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
    "source_module_id": "ckm_full_pipeline",
    "status": "derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.13172216223602146,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "eta_CKM",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "Wolfenstein from |Vub|,|Vtd|",
    "label": "CKM eta",
    "latex_snippet": "\\paragraph{CKM_eta (CKM eta)}\nDefinition: ${eta_CKM}$.\\\\\\nMeaning: Wolfenstein from |Vub|,
    "lineage": "derived_external",
    "name": "CKM_eta",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "ckm_full_pipeline",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
```

```
      "mode": "external"
    },
    "source": "ckm_full_pipeline",
    "source_artifact": "results.json",
    "source_json_pointer": "/results/alpha_s_sensitivity/matrix_abs_mu_uv/central",
    "source_module_id": "ckm_full_pipeline",
    "status": "derived_external",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.368226568606463,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "varphi0*exp(-5/6)",
    "delta_ppm": 39048.34347486976,
    "fixed_point": false,
    "formula_text": null,
    "label": "sin^2(theta13)",
    "latex_snippet": "\\paragraph{sin2_theta13 (sin^2(theta13))}\nDefinition: ${varphi0*exp(-5/6)}$.\\\\\\nValue: ${0
    "lineage": "axiom",
    "name": "sin2_theta13",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 1.000000000139778,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.023108435158881103,
    "value_ref": 0.02224
  },
  {
    "approximation": null,
    "definition": "(1/3)*(1-2*sin2_theta13)",
    "delta_ppm": 35595.14623478587,
    "fixed_point": false,
    "formula_text": null,
    "label": "sin^2(theta12)",
    "latex_snippet": "\\paragraph{sin2_theta12 (sin^2(theta12))}\nDefinition: ${(1/3)*(1-2*sin2_theta13)}$.\\\\\\nVal
    "lineage": "axiom",
    "name": "sin2_theta12",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": -0.048456372248040225,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.31792770989407926,
    "value_ref": 0.307
  },
  {
    "approximation": null,
```

```
    "definition": "sin2_theta23",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "input (NuFIT)",
    "label": "sin^2(theta23)",
    "latex_snippet": "\\paragraph{sin2_theta23 (sin^2(theta23))}\nDefinition: ${sin2_theta23}$.\\\\\\nMeaning: input
    "lineage": "anchor",
    "name": "sin2_theta23",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "anchor",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "input",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.454,
    "value_ref": 0.454
  },
  {
    "approximation": null,
    "definition": "180*(1-delta_star)",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "placeholder until Z3-breaking is wired",
    "label": "delta_CP (deg)",
    "latex_snippet": "\\paragraph{delta_cp (delta_CP (deg))}\nDefinition: ${180*(1-delta_star)}$.\\\\\\nMeaning: plac
    "lineage": "pending",
    "name": "delta_cp",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "compare",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "placeholder",
    "unit_system": "natural_units",
    "units": "degrees",
    "value_pred": 70.40484143469465,
    "value_ref": 232.0
  },
  {
    "approximation": null,
    "definition": "exp(-alpha_inv0/2)",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "phi_star_base",
    "latex_snippet": "\\paragraph{phi_star_base (phi_star_base)}\nDefinition: ${exp(-alpha_inv0/2)}$.\\\\\\nValue: ${
    "lineage": "axiom",
    "name": "phi_star_base",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
```

```
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 137.43539710020514,
    "Sphi0": -7.738651305544408,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 1.7498904425913166e-30,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "(1/2*phi_star_base*Mpl_reduced)^4",
  "delta_ppm": -180547.92471361975,
  "fixed_point": false,
  "formula_text": null,
  "label": "rho_L",
  "latex_snippet": "\\paragraph{rho_L (rho_L)}\nDefinition: ${(1/2*phi_star_base*Mpl_reduced)^4}$.\\\\\nValue: ${2
  "lineage": "scan",
  "name": "rho_L",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 549.7415884008205,
    "Sphi0": -30.954605222177634,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "GeV^4",
  "value_pred": 2.060247122268872e-47,
  "value_ref": 2.514176465474032e-47
},
{
  "approximation": null,
  "definition": "rho_L/Mpl_reduced^4",
  "delta_ppm": -180547.92471361978,
  "fixed_point": false,
  "formula_text": null,
  "label": "Lambda Mpl^-2",
  "latex_snippet": "\\paragraph{Lambda_Mpl2 (Lambda Mpl^-2)}\nDefinition: ${rho_L/Mpl_reduced^4}$.\\\\\nValue: ${5
  "lineage": "scan",
  "name": "Lambda_Mpl2",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 549.7415884008205,
    "Sphi0": -30.954605222177634,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
```

```
  "value_pred": 5.86034864599629e-121,
  "value_ref": 7.151545310258967e-121
},
{
  "approximation": null,
  "definition": "(4*pi-1)*beta_rad",
  "delta_ppm": -7322.8655249519015,
  "fixed_point": false,
  "formula_text": null,
  "label": "Omega_b",
  "latex_snippet": "\\paragraph{Omega_b (Omega_b)}\nDefinition: ${(4*pi-1)*beta_rad}$.\\\\\\nValue: ${0.0489406626
  "lineage": "axiom",
  "name": "Omega_b",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "derived_from_anchor",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.000000000139778,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.04894066266545011,
  "value_ref": 0.049301692328524445
},
{
  "approximation": null,
  "definition": "eta_b_pred",
  "delta_ppm": -54310.162051694846,
  "fixed_point": false,
  "formula_text": "baryon_consistency_audit proxy",
  "label": "eta_b",
  "latex_snippet": "\\paragraph{eta_b (eta_b)}\nDefinition: ${eta_b_pred}$.\\\\\\nMeaning: baryon_consistency_audit
  "lineage": "derived_external",
  "name": "eta_b",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "baryon_consistency_audit",
    "type": "pipeline_output"
  },
  "reference_role": "derived_from_anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "baryon_consistency_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/eta_b_pred",
  "source_module_id": "baryon_consistency_audit",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 5.794376870756092e-10,
  "value_ref": 6.127143e-10
},
{
  "approximation": null,
  "definition": "H0_pred",
  "delta_ppm": -23953.851721928295,
  "fixed_point": false,
  "formula_text": "baryon_consistency_audit derived",
  "label": "H0",
  "latex_snippet": "\\paragraph{H0 (H0)}\nDefinition: ${H0_pred}$.\\\\\\nMeaning: baryon_consistency_audit derived.
```

```
  "lineage": "derived_external",
  "name": "H0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "baryon_consistency_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "baryon_consistency_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/H0_pred",
  "source_module_id": "baryon_consistency_audit",
  "status": "derived_external",
  "unit_system": "cosmology_units",
  "units": "km/s/Mpc",
  "value_pred": 65.74646854801091,
  "value_ref": 67.36
},
{
  "approximation": null,
  "definition": "Omega_dm",
  "delta_ppm": 22923.676252391735,
  "fixed_point": false,
  "formula_text": "(Omega_a h^2)/h^2",
  "label": "Omega_dm",
  "latex_snippet": "\\paragraph{Omega_dm (Omega_dm)}\nDefinition: ${Omega_dm}$.\\\\\\nMeaning: (Omega_a h^2)/h^2.\\
  "lineage": "derived_external",
  "name": "Omega_dm",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "axion_dm_audit",
    "type": "pipeline_output"
  },
  "reference_role": "derived_from_anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "axion_dm_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/relic/Omega_a_h2",
  "source_module_id": "axion_dm_audit",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.27053304441032755,
  "value_ref": 0.26447041034523616
},
{
  "approximation": null,
  "definition": "180/pi*beta_rad",
  "delta_ppm": -307328.4831402013,
  "fixed_point": false,
  "formula_text": null,
  "label": "beta (deg)",
  "latex_snippet": "\\paragraph{beta_deg (beta (deg))}\nDefinition: ${180/pi*beta_rad}$.\\\\\\nValue: ${0.24243030
  "lineage": "axiom",
  "name": "beta_deg",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
```

```
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.0000000000287557,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "cosmology_units",
  "units": "degrees",
  "value_pred": 0.24243503090092952,
  "value_ref": 0.35
},
{
  "approximation": null,
  "definition": "beta_deg",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "frequency independent",
  "label": "beta (deg, PR)",
  "latex_snippet": "\\paragraph{beta_deg_PR (beta (deg, PR))}\nDefinition: ${beta_deg}$.\\\\\nMeaning: frequency i
  "lineage": "axiom",
  "name": "beta_deg_PR",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "prediction",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 1.0000000000287557,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "cosmology_units",
  "units": "degrees",
  "value_pred": 0.24243503090092952,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "nu_ghz",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "axion_dm_audit pipeline",
  "label": "axion frequency (GHz)",
  "latex_snippet": "\\paragraph{nu_ghz (axion frequency (GHz))}\nDefinition: ${nu_ghz}$.\\\\\nMeaning: axion_dm_au
  "lineage": "derived_external",
  "name": "nu_ghz",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "axion_dm_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "axion_dm_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/axion_claim/nu_GHz",
  "source_module_id": "axion_dm_audit",
```

```
  "status": "derived_external",
  "unit_system": "cosmology_units",
  "units": "GHz",
  "value_pred": 15.76402318010866,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "g_phys",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "g_coeff/f_a",
  "label": "g_phys (axion)",
  "latex_snippet": "\\paragraph{g_phys_axion (g_phys (axion))}\nDefinition: ${g_phys}$.\\\\\\nMeaning: g_coeff/f_a.
  "lineage": "derived_external",
  "name": "g_phys_axion",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "axion_dm_pipeline",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "axion_dm_pipeline",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/axion_claim/g_phys_GeV_inv_candidate",
  "source_module_id": "axion_dm_pipeline",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV^-1",
  "value_pred": -1.7955228593714628e-12,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "N_star",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "Starobinsky e-folds (policy)",
  "label": "N_star",
  "latex_snippet": "\\paragraph{N_star (N_star)}\nDefinition: ${N_star}$.\\\\\\nMeaning: Starobinsky e-folds (polic
  "lineage": "anchor",
  "name": "N_star",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "theoryv3 config starobinsky_N",
    "type": "internal_policy"
  },
  "reference_role": "anchor",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "input",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 56.0,
  "value_ref": null
},
{
  "approximation": null,
```

```
  "definition": "N_star^2/(24*pi^2)*M_over_Mpl^2",
  "delta_ppm": -4150.645492495838,
  "fixed_point": false,
  "formula_text": "Starobinsky amplitude",
  "label": "A_s",
  "latex_snippet": "\\paragraph{A_s (A_s)}\nDefinition: ${N_star^2/(24*pi^2)*M_over_Mpl^2}$.\\\\\\nMeaning: Starobi
  "lineage": "axiom",
  "name": "A_s",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 2.090191364329461e-09,
  "value_ref": 2.0989031673e-09
},
{
  "approximation": null,
  "definition": "1-2/N_star",
  "delta_ppm": -636.631479205802,
  "fixed_point": false,
  "formula_text": "Starobinsky tilt",
  "label": "n_s",
  "latex_snippet": "\\paragraph{n_s (n_s)}\nDefinition: ${1-2/N_star}$.\\\\\\nMeaning: Starobinsky tilt.\\\\\\nValue
  "lineage": "axiom",
  "name": "n_s",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": null,
  "reference_role": "compare",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.9642857142857143,
  "value_ref": 0.9649
},
{
  "approximation": null,
  "definition": "12/N_star^2",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "Starobinsky tensor ratio",
  "label": "r",
  "latex_snippet": "\\paragraph{r (r)}\nDefinition: ${12/N_star^2}$.\\\\\\nMeaning: Starobinsky tensor ratio.\\\\\n
  "lineage": "axiom",
  "name": "r",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
```

```
    "reference_info": {
      "origin": "Planck/BICEP (numeric bound pending)",
      "type": "upper_limit"
    },
    "reference_role": "bound",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 0.003826530612244898,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "(3/2)*pi^2*A_s*r*Mpl_reduced^4",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "V_star",
    "latex_snippet": "\\paragraph{V_star (V_star)}\nDefinition: ${(3/2)*pi^2*A_s*r*Mpl_reduced^4}$.\\\\\\nValue: ${4.
    "lineage": "axiom",
    "name": "V_star",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "prediction",
    "sensitivity": {
      "Sc3": 0.0,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "derived",
    "unit_system": "natural_units",
    "units": "GeV^4",
    "value_pred": 4.162728704945294e+63,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "k_bounce_t",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": "bounce_perturbations k_bounce_t (raw)",
    "label": "bounce scale",
    "latex_snippet": "\\paragraph{bounce_scale (bounce scale)}\nDefinition: ${k_bounce_t}$.\\\\\\nMeaning: bounce_per
    "lineage": "derived_external",
    "name": "bounce_scale",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "bounce_perturbations",
      "type": "pipeline_output"
    },
    "reference_role": "pipeline",
    "sensitivity": {
      "Sc3": null,
      "Sphi0": null,
      "mode": "external"
    },
    "source": "bounce_perturbations",
```

```
  "source_artifact": "results.json",
  "source_json_pointer": "/results/diagnostics/k_bounce_t_est_raw",
  "source_module_id": "bounce_perturbations",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 7.808039644294931,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "x_max",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "Planck spectrum extremum",
  "label": "x_max (Planck spectrum)",
  "latex_snippet": "\\paragraph{x_max (x_max (Planck spectrum))}\nDefinition: ${x_max}$.\\\\\\nMeaning: Planck spec
  "lineage": "axiom",
  "name": "x_max",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "Planck spectrum extremum",
    "type": "analytic"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": 0.0,
    "Sphi0": 0.0,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "derived",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 2.8214393721220787,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "torsion_max",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "max inferred |S_mu| bound",
  "label": "max torsion coupling",
  "latex_snippet": "\\paragraph{torsion_max (max torsion coupling)}\nDefinition: ${torsion_max}$.\\\\\\nMeaning: ma
  "lineage": "derived_external",
  "name": "torsion_max",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "torsion_bounds_mapping",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "torsion_bounds_mapping",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/inferred_bounds",
  "source_module_id": "torsion_bounds_mapping",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 2.9e-27,
  "value_ref": null
```

```
},
{
  "approximation": null,
  "definition": "lambda_cross",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": "lambda crossing scale",
  "label": "vacuum stability scale",
  "latex_snippet": "\\paragraph{lambda_cross (vacuum stability scale)}\nDefinition: ${lambda_cross}$.\\\\\\nMeaning
  "lineage": "derived_external",
  "name": "lambda_cross",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "stability_unitarity_audit",
    "type": "pipeline_output"
  },
  "reference_role": "pipeline",
  "sensitivity": {
    "Sc3": null,
    "Sphi0": null,
    "mode": "external"
  },
  "source": "stability_unitarity_audit",
  "source_artifact": "results.json",
  "source_json_pointer": "/results/lambda_crossing/mu_cross_GeV",
  "source_module_id": "stability_unitarity_audit",
  "status": "derived_external",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 45297285617.694756,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "alpha0/(2*pi)",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "a_e",
  "latex_snippet": "\\paragraph{a_e (a_e)}\nDefinition: ${alpha0/(2*pi)}$.\\\\\\nValue: ${0.0011614097317657883}\\,
  "lineage": "candidate",
  "name": "a_e",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "CODATA 2022 QED lowest order",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": 2.005829094375855,
    "Sphi0": -0.11294333379652244,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "dimensionless",
  "value_pred": 0.0011614097317657883,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "1/2*alpha0^2*m_e",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "R_infty (energy)",
```

```
  "latex_snippet": "\\paragraph{Rydberg_E (R_infty (energy))}\nDefinition: ${1/2*alpha0^2*m_e}$.\\\\\nValue: ${1.6
  "lineage": "candidate",
  "name": "Rydberg_E",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "CODATA 2022",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": 74.72935673824566,
    "Sphi0": 0.9047876794454623,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "GeV",
  "value_pred": 1.6109538705225757e-08,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "1/(alpha0*m_e)",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "Bohr radius (a0)",
  "latex_snippet": "\\paragraph{a0 (Bohr radius (a0))}\nDefinition: ${1/(alpha0*m_e)}$.\\\\\nValue: ${226491.66732
  "lineage": "candidate",
  "name": "a0",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
  "proof_ref": null,
  "reference_info": {
    "origin": "CODATA 2022",
    "type": "literature"
  },
  "reference_role": "internal",
  "sensitivity": {
    "Sc3": -72.72352764431389,
    "Sphi0": -1.0177310132419848,
    "mode": "numeric"
  },
  "source": null,
  "source_artifact": null,
  "source_json_pointer": null,
  "source_module_id": null,
  "status": "candidate",
  "unit_system": "natural_units",
  "units": "GeV^-1",
  "value_pred": 226491.66732126864,
  "value_ref": null
},
{
  "approximation": null,
  "definition": "8*pi/3*alpha0^2/m_e^2",
  "delta_ppm": null,
  "fixed_point": false,
  "formula_text": null,
  "label": "Thomson cross section",
  "latex_snippet": "\\paragraph{sigma_T (Thomson cross section)}\nDefinition: ${8*pi/3*alpha0^2/m_e^2}$.\\\\\nValu
  "lineage": "candidate",
  "name": "sigma_T",
  "primitives": [
    "c3",
    "varphi0",
    "pi"
  ],
```

```
    "proof_ref": null,
    "reference_info": {
      "origin": "classical electrodynamics",
      "type": "literature"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": -137.42373891112436,
      "Sphi0": -2.4872353621141485,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "unit_system": "natural_units",
    "units": "GeV^-2",
    "value_pred": 1218.6651146076479,
    "value_ref": null
  },
  {
    "approximation": "scaling_proxy",
    "definition": "alpha0^4*m_e",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "fine-structure 2p (H)",
    "latex_snippet": "\\paragraph{fs_2p (fine-structure 2p (H))}\nDefinition: ${alpha0^4*m_e}$.\\\\\nValue: ${1.7157
    "lineage": "candidate",
    "name": "fs_2p",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "order_of_magnitude_only",
    "sensitivity": {
      "Sc3": 78.74101492610919,
      "Sphi0": 0.6789010118524175,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 1.7157095101959414e-12,
    "value_ref": null
  },
  {
    "approximation": "scaling_proxy",
    "definition": "alpha0^5*m_e*log(1/alpha0)",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "Lamb shift (proxy)",
    "latex_snippet": "\\paragraph{lamb_shift (Lamb shift (proxy))}\nDefinition: ${alpha0^5*m_e*log(1/alpha0)}$.\\\\\\
    "lineage": "candidate",
    "name": "lamb_shift",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": null,
    "reference_role": "order_of_magnitude_only",
    "sensitivity": {
      "Sc3": 80.33917537098034,
      "Sphi0": 0.5889125045399624,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
```

```
    "source_module_id": null,
    "status": "candidate",
    "unit_system": "natural_units",
    "units": "GeV",
    "value_pred": 6.160212562428027e-14,
    "value_ref": null
  },
  {
    "approximation": null,
    "definition": "2*(1+c3/pi)",
    "delta_ppm": null,
    "fixed_point": false,
    "formula_text": null,
    "label": "proton g-factor",
    "latex_snippet": "\\paragraph{g_p (proton g-factor)}\nDefinition: ${2*(1+c3/pi)}$.\\\\\\nValue: ${2.025330295910
    "lineage": "candidate",
    "name": "g_p",
    "primitives": [
      "c3",
      "varphi0",
      "pi"
    ],
    "proof_ref": null,
    "reference_info": {
      "origin": "classical electrodynamics",
      "type": "literature"
    },
    "reference_role": "internal",
    "sensitivity": {
      "Sc3": 0.01250674813713104,
      "Sphi0": 0.0,
      "mode": "numeric"
    },
    "source": null,
    "source_artifact": null,
    "source_json_pointer": null,
    "source_module_id": null,
    "status": "candidate",
    "unit_system": "natural_units",
    "units": "dimensionless",
    "value_pred": 2.0253302959105843,
    "value_ref": null
  }
],
"negative_controls": [
  {
    "kind": "g",
    "payload": {
      "g_candidates": [
        4,
        5,
        6
      ],
      "gap_to_next_best": 44.98085610946266,
      "z_by_g": [
        {
          "g": 4,
          "z": -46.8455434804275
        },
        {
          "g": 5,
          "z": 1.8646873709648437
        },
        {
          "g": 6,
          "z": 50.5749164827739
        }
      ]
    }
  },
  {
    "kind": "k",
    "payload": {
      "0.0": 3.665371791638453,
      "1.0": 1.8074246412353618,
      "1.5": 0.883514212976573,
      "2.0": 0.03703710120260405,
      "2.5": 0.9542414840493093,
      "3.0": 1.8681110743677323
    }
```

```
    },
    {
      "kind": "n",
      "payload": [
        {
          "label": "n=1",
          "log10_mismatch_rho_L": "1.1176435420910598546677992309038681988060604952932325447047906693707391914598635",
          "norm_factor": "1.0",
          "phi_star": "1.74989044259130020458945827116174131782900278797088052495057947234301645906508 14e-30",
          "rho_L_GeV4": "3.29639539563007284590571289656311482903203300029955078876539686186244286937672 63e-46"
        },
        {
          "label": "n=1/sqrt(2)",
          "log10_mismatch_rho_L": "0.515583550763097310237484262507636043687654435178966004083648624925336476689797 32",
          "norm_factor": "0.70710678118654746171500846685376018285751342773437 5",
          "phi_star": "1.23735939828983720661665306102920142993179471712929957101076446924320193581800 05e-30",
          "rho_L_GeV4": "8.24098848907517919247154917520686027366066377528588598017569838942493891377278 64e-47"
        },
        {
          "label": "n=1/sqrt(3)",
          "log10_mismatch_rho_L": "0.163401032651735213482681689919030072798676569168198704295569355295921195141422 06",
          "norm_factor": "0.57735026918962584208117050366126932203769683837890625",
          "phi_star": "1.01029971808244067890564621916673190899302235416645036691376932705741281815785 39e-30",
          "rho_L_GeV4": "3.66266155070008290833676355946249688790582128542333288197367265647970639300731 49e-47"
        },
        {
          "label": "n=1/2",
          "log10_mismatch_rho_L": "0.086476440564864926187156347994103908266699030555201620536919175137693565637834492",
          "norm_factor": "0.5",
          "phi_star": "8.74945221295650102294729135580870658914501393985440262475289736171508229532 5407e-31",
          "rho_L_GeV4": "2.06024712226879552869107056035194676814502062518721924297837303866402679336045 4e-47"
        },
        {
          "label": "n=1/3^(1/4)",
          "log10_mismatch_rho_L": "0.640522287371397401986955270739083184094361412893491708549122800737062962685825 48",
          "norm_factor": "0.75983568565159254060148441567434929311275482177734375",
          "phi_star": "1.32962920426152932525719248181421890278877041166845809281546875434983466085731 9e-30",
          "rho_L_GeV4": "1.09879846521002424304127215378472567687649525536912633455518396055866798291306 96e-46"
        }
      ]
    }
  ],
  "plot": {
    "constant_factory_sensitivity.png": "./tfpt-suite/theoryv3/out/constant_factory_audit/constant_factory_sensitivity
    "constant_factory_summary.png": "./tfpt-suite/theoryv3/out/constant_factory_audit/constant_factory_summary.png"
  },
  "policy": {
    "sensitivity_eps": 1e-06,
    "sigma_c3_rel": 0.0,
    "sigma_phi0_rel": 0.0,
    "symbol_registry": {
      "count": 82,
      "path": "./tfpt-suite/theoryv3/theoryv3_suite/symbols.yaml"
    }
  },
  "references": {
    "A_s_planck2018": {
      "dataset_id": "A_s_planck2018",
      "notes": "Scalar amplitude A_s at k0=0.05 Mpc^-1.",
      "sigma": 2.938464434e-11,
      "source": "global_reference.json:observables.A_s",
      "units": "dimensionless",
      "value": 2.0989031673e-09,
      "version": "Planck 2018"
    },
    "H0_planck2018": {
      "dataset_id": "H0_planck2018",
      "notes": "H0 from Planck 2018 base LCDM.",
      "sigma": 0.54,
      "source": "global_reference_minimal.json:observables.H0_planck2018_km_s_Mpc",
      "units": "km s^-1 Mpc^-1",
      "value": 67.36,
      "version": "Planck 2018"
    },
    "Lambda_planck_derived": {
      "dataset_id": "Lambda_planck_derived",
      "notes": "Derived Lambda/Mpl^2 from rho_L_target.",
      "sigma": null,
      "units": "dimensionless",
      "value": 7.151545310258967e-121,
```

```
  "version": "Planck 2018 (k_calibration)"
},
"Mpl_reduced": {
  "dataset_id": "Mpl_reduced",
  "notes": "Reduced Planck mass.",
  "sigma": 0.0,
  "source": "tfpt_suite.cosmo_scale_map.MPL_REDUCED_GEV",
  "units": "GeV",
  "value": 2.435e+18,
  "version": "CODATA"
},
"alpha_bar5_inv_MZ_pdg2024": {
  "dataset_id": "alpha_bar5_inv_MZ_pdg2024",
  "notes": "MSbar alpha_hat^(5)(MZ) inverse.",
  "sigma": 0.008,
  "source": "global_reference_minimal.json:observables.alpha_bar5_inv_MZ",
  "units": "dimensionless",
  "value": 127.93,
  "version": "PDG 2024"
},
"alpha_inv_codata_2022": {
  "dataset_id": "alpha_inv_codata_2022",
  "notes": "Inverse fine-structure constant alpha^{-1}(0).",
  "sigma": 2.1e-08,
  "source": "global_reference_minimal.json:observables.alpha_inv_codata_2022",
  "units": "dimensionless",
  "value": 137.035999177,
  "version": "CODATA 2022"
},
"alpha_s_mz_pdg": {
  "dataset_id": "alpha_s_mz_pdg",
  "notes": "Strong coupling at MZ (MSbar).",
  "sigma": 0.0011,
  "source": "sm_inputs_mz.json:alpha_s",
  "units": "dimensionless",
  "value": 0.1179,
  "version": "PDG (MZ, MSbar)"
},
"beta_deg_minami_komatsu_2020": {
  "dataset_id": "beta_deg_minami_komatsu_2020",
  "notes": "CMB cosmic birefringence global rotation angle beta.",
  "sigma": 0.14,
  "source": "global_reference.json:observables.beta_deg",
  "units": "degrees",
  "value": 0.35,
  "version": "Minami & Komatsu 2020"
},
"cabibbo_lambda_pdg2024": {
  "dataset_id": "cabibbo_lambda_pdg2024",
  "notes": "Cabibbo lambda ~ |Vus|.",
  "sigma": 0.00068,
  "source": "global_reference.json:observables.cabibbo_lambda",
  "units": "dimensionless",
  "value": 0.22501,
  "version": "PDG 2024"
},
"eta_b_planck_derived": {
  "dataset_id": "eta_b_planck_derived",
  "notes": "Derived eta_b from Omega_b h^2 (Planck) using eta10=273.9*Omega_b h^2.",
  "sigma": null,
  "units": "dimensionless",
  "value": 6.127143e-10,
  "version": "Planck 2018"
},
"m_b_pdg": {
  "dataset_id": "m_b_pdg",
  "notes": "Bottom mass (scheme dependent; SM input proxy).",
  "sigma": null,
  "source": "sm_inputs_mz.json:mb_GeV",
  "units": "GeV",
  "value": 4.18,
  "version": "PDG (scheme dependent)"
},
"m_c_pdg": {
  "dataset_id": "m_c_pdg",
  "notes": "Charm mass (scheme dependent; SM input proxy).",
  "sigma": null,
  "source": "sm_inputs_mz.json:mc_GeV",
  "units": "GeV",
  "value": 1.27,
```

```
  "version": "PDG (scheme dependent)"
},
"m_e_pdg": {
  "dataset_id": "m_e_pdg",
  "notes": "Electron pole mass.",
  "sigma": 0.0,
  "source": "lepton_masses_pdg.json:masses.electron",
  "units": "GeV",
  "value": 0.0005109989461,
  "version": "PDG pole mass"
},
"m_mu_pdg": {
  "dataset_id": "m_mu_pdg",
  "notes": "Muon pole mass.",
  "sigma": 0.0,
  "source": "lepton_masses_pdg.json:masses.muon",
  "units": "GeV",
  "value": 0.1056583745,
  "version": "PDG pole mass"
},
"m_p_pdg": {
  "dataset_id": "m_p_pdg",
  "notes": "Proton mass (PDG); placeholder in mass_spectrum_minimal.",
  "sigma": null,
  "source": "mass_spectrum_minimal:ledger.placeholders.proton_mass_GeV",
  "units": "GeV",
  "value": 0.938272,
  "version": "PDG pole mass"
},
"m_t_pdg": {
  "dataset_id": "m_t_pdg",
  "notes": "Top pole mass (scheme dependent).",
  "sigma": 0.3,
  "source": "sm_inputs_mz.json:mt_GeV",
  "units": "GeV",
  "value": 172.76,
  "version": "PDG pole mass"
},
"m_tau_pdg": {
  "dataset_id": "m_tau_pdg",
  "notes": "Tau pole mass.",
  "sigma": 0.0,
  "source": "lepton_masses_pdg.json:masses.tau",
  "units": "GeV",
  "value": 1.77686,
  "version": "PDG pole mass"
},
"mass_ratio_me_over_mp": {
  "dataset_id": "mass_ratio_me_over_mp",
  "notes": "Derived from m_e and m_p.",
  "sigma": null,
  "units": "dimensionless",
  "value": 0.0005446170685046554,
  "version": "PDG pole masses"
},
"mass_ratio_mu_over_e_pdg": {
  "dataset_id": "mass_ratio_mu_over_e_pdg",
  "notes": "Direct lepton pole-mass ratio (scale independent for this audit).",
  "scale": "pole",
  "scheme": "pole",
  "sigma": 0.0,
  "source": "lepton_masses_pdg.json (mu/e)",
  "units": "dimensionless",
  "value": 206.76828260879265,
  "version": "PDG pole masses"
},
"mass_ratio_tau_over_mu_pdg": {
  "dataset_id": "mass_ratio_tau_over_mu_pdg",
  "notes": "Direct lepton pole-mass ratio (scale independent for this audit).",
  "scale": "pole",
  "scheme": "pole",
  "sigma": 0.0,
  "source": "lepton_masses_pdg.json (tau/mu)",
  "units": "dimensionless",
  "value": 16.81702949159037,
  "version": "PDG pole masses"
},
"n_s_planck2018": {
  "dataset_id": "n_s_planck2018",
  "notes": "Scalar spectral index at k0=0.05 Mpc^-1.",
```

```
  "sigma": 0.0042,
  "source": "global_reference_minimal.json:observables.n_s_planck2018",
  "units": "dimensionless",
  "value": 0.9649,
  "version": "Planck 2018"
},
"omega_b_planck_derived": {
  "dataset_id": "omega_b_planck_derived",
  "notes": "Derived Omega_b from Omega_b h^2 and H0 (Planck).",
  "sigma": null,
  "units": "dimensionless",
  "value": 0.049301692328524445,
  "version": "Planck 2018 + Planck 2018"
},
"omega_dm_planck_derived": {
  "dataset_id": "omega_dm_planck_derived",
  "notes": "Derived Omega_dm from Omega_dm h^2 and H0 (Planck).",
  "sigma": null,
  "units": "dimensionless",
  "value": 0.26447041034523616,
  "version": "Planck 2018 + Planck 2018"
},
"pmns_delta_cp_deg_nufit53_no": {
  "dataset_id": "pmns_delta_cp_deg_nufit53_no",
  "notes": "Normal ordering, PDG convention.",
  "sigma": 39.0,
  "source": "pmns_reference.json:normal_ordering.delta_cp_deg",
  "units": "degrees",
  "value": 232.0,
  "version": "NuFIT 5.3 (2024, NO)"
},
"pmns_sin2_theta12_nufit53_no": {
  "dataset_id": "pmns_sin2_theta12_nufit53_no",
  "notes": "Normal ordering, PDG convention.",
  "sigma": 0.012,
  "source": "pmns_reference.json:normal_ordering.sin2_theta12",
  "units": "dimensionless",
  "value": 0.307,
  "version": "NuFIT 5.3 (2024, NO)"
},
"pmns_sin2_theta13_nufit53_no": {
  "dataset_id": "pmns_sin2_theta13_nufit53_no",
  "notes": "Normal ordering, PDG convention.",
  "sigma": 0.00057,
  "source": "pmns_reference.json:normal_ordering.sin2_theta13",
  "units": "dimensionless",
  "value": 0.02224,
  "version": "NuFIT 5.3 (2024, NO)"
},
"pmns_sin2_theta23_nufit53_no": {
  "dataset_id": "pmns_sin2_theta23_nufit53_no",
  "notes": "Normal ordering, PDG convention.",
  "sigma": 0.019,
  "source": "pmns_reference.json:normal_ordering.sin2_theta23",
  "units": "dimensionless",
  "value": 0.454,
  "version": "NuFIT 5.3 (2024, NO)"
},
"rho_L_planck_derived": {
  "dataset_id": "rho_L_planck_derived",
  "notes": "Derived target rho_L from k_calibration cosmology snapshot.",
  "sigma": null,
  "units": "GeV^4",
  "value": 2.514176465474032e-47,
  "version": "Planck 2018 (k_calibration)"
},
"sin2_thetaW_mz_pdg": {
  "dataset_id": "sin2_thetaW_mz_pdg",
  "notes": "Weak mixing angle sin^2(thetaW) at MZ (MSbar).",
  "sigma": 4e-05,
  "source": "sm_inputs_mz.json:sin2_thetaW",
  "units": "dimensionless",
  "value": 0.23122,
  "version": "PDG (MZ, MSbar)"
},
"v_ew_246": {
  "dataset_id": "v_ew_246",
  "notes": "Electroweak vev v (approx).",
  "sigma": 0.2,
  "source": "Standard Model reference",
```

```
      "units": "GeV",
      "value": 246.0,
      "version": "SM Higgs vev"
    }
  },
  "source_document": "tfpt-suite/theoryv3/constantfactory.md",
  "status_counts": {
    "candidate": 14,
    "derived": 34,
    "derived_external": 19,
    "input": 9,
    "pending": 8,
    "placeholder": 3
  },
  "views": {
    "anchor": {
      "H0": 67.36,
      "Omega_b": 0.049301692328524445,
      "Omega_dm": 0.26447041034523616,
      "eta_b": 6.127143e-10
    },
    "note": "Anchor uses Planck H0/h; TFPT uses predicted H0 where available.",
    "tfpt": {
      "H0": 65.74646854801091,
      "Omega_b": 0.04894066266545011,
      "Omega_dm": 0.2839746780917984,
      "eta_b": 5.794376870756092e-10
    }
  }
},
"schema_version": 1,
"spec": {
  "assumptions": [],
  "determinism": "Deterministic (closed forms + deterministic module outputs).",
  "formulas": [
    "c3 = 1/(8*pi)",
    "varphi0 = 1/(6*pi) + 3/(256*pi^4)",
    "beta_rad = varphi0/(4*pi)",
    "delta2 = (g/4) * delta_top^2 (g=5)",
    "alpha_inv0 from CFE + backreaction",
    "alpha_inv0_simple = 4*pi*exp(1/varphi0)",
    "v/Mpl candidate = (4*pi) * g * c3^2 * exp(-alpha_inv/4)",
    "y_tau = pi*varphi0^2, y_mu = pi*varphi0^3, y_e = 2*pi*varphi0^5",
    "m_l = v * y_l / sqrt(2)",
    "sin2_theta13 = varphi0 * exp(-5/6)",
    "sin2_theta12 = (1/3) * (1 - 2*sin2_theta13)"
  ],
  "gaps": [],
  "inputs": [
    "TFPT constants (pi, c3, varphi0, delta_top, beta_rad)",
    "defect partition delta2 (g=5)",
    "theoryv3 outputs (baryon, axion, dark energy, flavor)",
    "reference ledger (references.json)",
    "source list: theoryv3/constantfactory.md"
  ],
  "maturity": null,
  "module_id": "constant_factory_audit",
  "name": "Constant factory audit (hierarchical TFPT constants)",
  "objective": [
    "Compute a structured set of constants using the simplest TFPT rules.",
    "Document derivations and reference comparisons in one report."
  ],
  "outputs": [
    "hierarchical list of constants with formulas",
    "grouped table data with calculation traces",
    "computed values and references (z-score where applicable)",
    "summary plot of log10 magnitudes",
    "sensitivity ledger (Sc3, Sphi0) with propagated sigmas",
    "sensitivity heatmap plot",
    "crosslink summary blocks (g, k)"
  ],
  "question": "Can TFPT generate a hierarchical constant list from a small discrete grammar without fitting?",
  "references": [
    "A_s_planck2018",
    "H0_planck2018",
    "Lambda_planck_derived",
    "Mpl_reduced",
    "alpha_bar5_inv_MZ_pdg2024",
    "alpha_inv_codata_2022",
    "alpha_s_mz_pdg",
```

```
      "beta_deg_minami_komatsu_2020",
      "cabibbo_lambda_pdg2024",
      "eta_b_planck_derived",
      "m_b_pdg",
      "m_c_pdg",
      "m_e_pdg",
      "m_mu_pdg",
      "m_p_pdg",
      "m_t_pdg",
      "m_tau_pdg",
      "mass_ratio_me_over_mp",
      "mass_ratio_mu_over_e_pdg",
      "mass_ratio_tau_over_mu_pdg",
      "n_s_planck2018",
      "omega_b_planck_derived",
      "omega_dm_planck_derived",
      "pmns_delta_cp_deg_nufit53_no",
      "pmns_sin2_theta12_nufit53_no",
      "pmns_sin2_theta13_nufit53_no",
      "pmns_sin2_theta23_nufit53_no",
      "rho_L_planck_derived",
      "sin2_thetaW_mz_pdg",
      "v_ew_246"
    ],
    "validation": [
      "reports computed entries with reference comparisons where available",
      "flags missing references as INFO (not a failure)",
      "records grammar violations for non-primitive literals"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


dark_energy_exponential_audit: report.txt

```
Dark energy exponential audit

alpha_inv_0 (g/4 delta2) = 137.035999216158434790261717517113973986055685002581861467477436463281767763979 18
phi_star_base = exp(-alpha_inv_0/2) = 1.74989044259130020458945827116174131782900278797088052495057947234301645906508 14e

Target ledger (from k_calibration.json):
- H0 = 67.36 km/s/Mpc
- Omega_L = 0.684608
- rho_L_target = 2.514176465474032e-47 GeV^4

Candidates:
- n=1: log10 mismatch=1.1176435420910598546677992309038681988060604952932325447047906693707391914598635 (phi_star=1.7498
- n=1/sqrt(2): log10 mismatch=0.5155835507630973102374842625076360436876544351789660040836486249253364766897973 2 (phi_st
- n=1/sqrt(3): log10 mismatch=0.1634010326517352134826816899190300727986765691681987042955693552959211951414220 6 (phi_st
- n=1/2: log10 mismatch=0.0864764405648649261871563479941039082666990305552016205369191751376935656378344 92 (phi_star=8.
- n=1/3^(1/4): log10 mismatch=0.6405222873713974019869552707390831840943614128934917085491228007370629626858254 8 (phi_st

Best: {'label': 'n=1/2', 'norm_factor': '0.5', 'phi_star': '8.7494522129565010229472913558087065891450139398544026247528

Checks:
- rho_L_within_tol: PASS (best=n=1/2, log10_mismatch=0.0864764405648649261871563479941039082666990305552016205369191751 3
- n_half_preferred: PASS (best=n=1/2)
```

dark_energy_exponential_audit: results.json (tfpt-suite/theoryv3/out/dark_energy_exponential_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "rho_L_within_tol",
      "detail": "best=n=1/2, log10_mismatch=0.0864764405648649261871563479941039082666990305552016205369191751376935656 3
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "n_half_preferred",
      "detail": "best=n=1/2",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "dark_energy_exponential_audit",
  "plot": {
    "rho_lambda_candidates_png": "./tfpt-suite/theoryv3/out/dark_energy_exponential_audit/rho_lambda_candidates.png"
  },
  "results": {
```

```
    "alpha_inv_0": "137.035999216158434790261717517113973986055685002581861467477436463281767763979 18",
    "best": {
      "label": "n=1/2",
      "label_str": "n=1/2",
      "log10_mismatch_rho_L": "0.086476440564864926187156347994103908266699030555201620536919175137693565637834492",
      "norm_factor": "0.5",
      "phi_star": "8.749452212956501022947291355808706589145013939854402624752897361715082295325407e-31",
      "rho_L_GeV4": "2.060247122268795528691070560351946768145020625187219242978373038664026793360454e-47"
    },
    "best_label_str": "n=1/2",
    "candidates": [
      {
        "label": "n=1",
        "log10_mismatch_rho_L": "1.1176435420910598546677992309038681988060604952932325447047906693707391914598635",
        "norm_factor": "1.0",
        "phi_star": "1.749890442591300204589458271161741317829002787970880524950579472343016459065 0814e-30",
        "rho_L_GeV4": "3.296395395630072845905712896563114829032033000299550788765396861862442869376 7263e-46"
      },
      {
        "label": "n=1/sqrt(2)",
        "log10_mismatch_rho_L": "0.515583550763097310237484262507636043687654435178966004083648624925336476689797 32",
        "norm_factor": "0.707106781186547461715008466853760182857513427734375",
        "phi_star": "1.237359398289837206616653061029201429931794717129299571010764469243201935818000 5e-30",
        "rho_L_GeV4": "8.240988489075179192471549175206860273660663775285885980175698389424938913772 7864e-47"
      },
      {
        "label": "n=1/sqrt(3)",
        "log10_mismatch_rho_L": "0.163401032651735213482681689919030072798676569168198704295569355295921195141422 06",
        "norm_factor": "0.577350269189625842081170503661269322037692683837890625",
        "phi_star": "1.010299718082440678905646219166731908993022354166450366913769327057412818157853 9e-30",
        "rho_L_GeV4": "3.662661550700082908336763559462496887905821285423332881973672656479706393007314 9e-47"
      },
      {
        "label": "n=1/2",
        "log10_mismatch_rho_L": "0.086476440564864926187156347994103908266699030555201620536919175137693565637834492",
        "norm_factor": "0.5",
        "phi_star": "8.749452212956501022947291355808706589145013939854402624752897361715082295325407e-31",
        "rho_L_GeV4": "2.060247122268795528691070560351946768145020625187219242978373038664026793360454e-47"
      },
      {
        "label": "n=1/3^(1/4)",
        "log10_mismatch_rho_L": "0.640522287371397401986955270739083184094361412893491708549122800737062962685 82548",
        "norm_factor": "0.759835685651592540601484415674349293112754821777343 75",
        "phi_star": "1.329629204261529325257192481814218902788770411668458092815468754349834660857319e-30",
        "rho_L_GeV4": "1.098798465210024243041272153784725676876495255369126334555183960558667982913069 6e-46"
      }
    ],
    "phi_star_base": "1.749890442591300204589458271161741317829002787970880524950579472343016459065 0814e-30",
    "plot": {
      "rho_lambda_candidates_png": "./tfpt-suite/theoryv3/out/dark_energy_exponential_audit/rho_lambda_candidates.png"
    },
    "targets": {
      "H0_km_s_Mpc": 67.36,
      "Omega_L": 0.684608,
      "rho_L_target": 2.514176465474032e-47
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (finite scan, no continuous tuning).",
    "formulas": [
      "phi_star_base = exp(-alpha_inv_0 / 2)",
      "rho_L = (Mpl_bar * phi_star)^4",
      "Omega_L = 1 - Omega_m - Omega_r",
      "rho_L_target = 3 * Omega_L * H0^2 * Mpl_bar^2"
    ],
    "gaps": [],
    "inputs": [
      "alpha_inv_0 from g=5 delta2 model",
      "k_calibration cosmology snapshot (Omega_m, Omega_r, H0)"
    ],
    "maturity": null,
    "module_id": "dark_energy_exponential_audit",
    "name": "Dark energy exponential audit (phi_star from exp(-alpha_inv/2))",
    "objective": [
      "Quantify the exponential suppression mechanism with explicit candidates.",
      "Track mismatch against the cosmology target ledger."
    ],
    "outputs": [
```

```
      "phi_star_base = exp(-alpha_inv_0/2)",
      "rho_L for discrete normalization candidates",
      "best candidate and log10 mismatch vs target"
    ],
    "question": "Is the dark energy scale explained by exp(-alpha_inv/2) with a discrete normalization?",
    "references": [],
    "validation": [
      "best candidate within 0.5 dex of target",
      "n=1/2 branch is preferred under current scan"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


dark_energy_norm_half_origin_audit: report.txt

```
Dark energy norm origin audit

k (cover degree) = 2.0
n_from_cover = 0.5
best candidate label = n=1/2

Checks:
- n_from_cover_equals_half: PASS (n_from_cover=0.5)
- best_candidate_is_half: PASS (best_label=n=1/2)
```

dark_energy_norm_half_origin_audit: results.json (tfpt-suite/theoryv3/out/dark_energy_norm_half_origin_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "n_from_cover_equals_half",
      "detail": "n_from_cover=0.5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "best_candidate_is_half",
      "detail": "best_label=n=1/2",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "dark_energy_norm_half_origin_audit",
  "plot": {
    "dark_energy_norm_origin.png": "./tfpt-suite/theoryv3/out/dark_energy_norm_half_origin_audit/dark_energy_norm_origin
  },
  "results": {
    "best_candidate_label": "n=1/2",
    "k": 2.0,
    "n_from_cover": 0.5,
    "plot": {
      "dark_energy_norm_origin.png": "./tfpt-suite/theoryv3/out/dark_energy_norm_half_origin_audit/dark_energy_norm_orig
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (no fitting).",
    "formulas": [
      "n_from_cover = 1 / k",
      "k=2 corresponds to the double-cover backreaction exponent"
    ],
    "gaps": [],
    "inputs": [
      "alpha_precision_audit self_consistent.k (cover degree)",
      "dark_energy_exponential_audit best candidate label"
    ],
    "maturity": null,
    "module_id": "dark_energy_norm_half_origin_audit",
    "name": "Dark energy norm origin audit (n=1/2 from double cover)",
    "objective": [
      "Tie the preferred n=1/2 normalization to the cover degree used in alpha backreaction."
    ],
    "outputs": [
      "n_from_cover = 1/k",
      "consistency with best candidate n=1/2"
    ],
```

```
    "question": "Is the dark-energy normalization n=1/2 fixed by the double-cover degree?",
    "references": [],
    "validation": [
      "n_from_cover equals 1/2",
      "dark_energy_exponential_audit best candidate is n=1/2"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


defect_partition_g5_audit: report.txt


```
Defect partition g=5 audit

delta_top = 0.000120304479547082052997884178911547196974544552972323391228531665687191359479124 07
delta2 (g/4) = 0.000000018091459748867855014525576506215873427709357460729151458474190949106463016708746 (model_id=two_c
alpha_inv_0 (g/4) = 137.035999216158434790261717517113973986055685002581861467477436463281767763979 18
alpha_inv_0 ref (CODATA) = 137.035999177 ? 0.000000021 (CODATA 2022)
z = 1.864687370964843691291141618383604047741993403213211260156274655427579880861449 3

Candidate series:
- half: alpha_inv_0=137.03599614741378
- one: alpha_inv_0=137.03599819324359
- g_over_4: alpha_inv_0=137.03599921615844

Negative control (z by g):
- g=4: z=-46.8455434804275
- g=5: z=1.8646873709648437
- g=6: z=50.5749164827739

Checks:
- g_equals_5: PASS (g=5)
- alpha_within_2sigma: PASS (z=1.864687370964843691291141618383604047741993403213211260156274655427579880861449 3)
- g5_is_best_by_z: PASS (|z5|=1.8646873709648437, others={4: 46.8455434804275, 5: 1.8646873709648437, 6: 50.574916482773
- gap_to_next_best: PASS (gap=44.98085610946266)
```


defect_partition_g5_audit: results.json (tfpt-suite/theoryv3/out/defect_partition_g5_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "g_equals_5",
      "detail": "g=5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "alpha_within_2sigma",
      "detail": "z=1.864687370964843691291141618383604047741993403213211260156274655427579880861449 3",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "g5_is_best_by_z",
      "detail": "|z5|=1.8646873709648437, others={4: 46.8455434804275, 5: 1.8646873709648437, 6: 50.5749164827739}",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "gap_to_next_best",
      "detail": "gap=44.98085610946266",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "defect_partition_g5_audit",
  "plot": {
    "alpha_defect_series_png": "./tfpt-suite/theoryv3/out/defect_partition_g5_audit/alpha_defect_series.png",
    "g_negative_control.png": "./tfpt-suite/theoryv3/out/defect_partition_g5_audit/g_negative_control.png"
  },
  "results": {
    "alpha_inv_0": {
      "pred": "137.035999216158434790261717517113973986055685002581861467477436463281767763979 18",
      "ref": "137.035999177",
      "sigma": "0.000000021",
      "z": "1.864687370964843691291141618383604047741993403213211260156274655427579880861449 3"
    },
    "delta2": {
      "delta2": "0.000000018091459748867855014525576506215873427709357460729151458474190949106463016708746",
      "delta2_over_delta_top2": "1.25",
```

```
      "g_value": 5,
      "model_id": "two_defect_partition_g5_over_4"
    },
    "negative_control": {
      "g_candidates": [
        4,
        5,
        6
      ],
      "gap_to_next_best": 44.98085610946266,
      "z_by_g": [
        {
          "g": 4,
          "z": -46.8455434804275
        },
        {
          "g": 5,
          "z": 1.8646873709648437
        },
        {
          "g": 6,
          "z": 50.5749164827739
        }
      ]
    },
    "plot": {
      "alpha_defect_series_png": "./tfpt-suite/theoryv3/out/defect_partition_g5_audit/alpha_defect_series.png",
      "g_negative_control.png": "./tfpt-suite/theoryv3/out/defect_partition_g5_audit/g_negative_control.png"
    },
    "reference": {
      "dataset_id": "alpha_inv_codata_2022",
      "notes": "Inverse fine-structure constant alpha^{-1}(0).",
      "sigma": 2.1e-08,
      "source": "global_reference_minimal.json:observables.alpha_inv_codata_2022",
      "units": "dimensionless",
      "value": 137.035999177,
      "version": "CODATA 2022"
    },
    "series": [
      {
        "alpha_inv_0": 137.03599614741378,
        "label": "half"
      },
      {
        "alpha_inv_0": 137.03599819324359,
        "label": "one"
      },
      {
        "alpha_inv_0": 137.03599921615844,
        "label": "g_over_4"
      }
    ]
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (finite enumeration + root finding).",
    "formulas": [
      "delta2 = (g/4) * delta_top^2",
      "alpha_inv_0 from CFE + backreaction with delta2",
      "z = (pred - mean)/sigma"
    ],
    "gaps": [],
    "inputs": [
      "TFPT constants (delta_top)",
      "defect partition g from discrete enumeration",
      "CODATA alpha_inv_0 reference"
    ],
    "maturity": null,
    "module_id": "defect_partition_g5_audit",
    "name": "Defect partition g=5 audit (delta2 -> alpha_inv_0)",
    "objective": [
      "Lock delta2 to a discrete g=5 multiplicity.",
      "Show the resulting alpha_inv_0 is within CODATA sigma."
    ],
    "outputs": [
      "delta2 = (g/4) delta_top^2",
      "alpha_inv_0 from delta2",
      "z score vs CODATA",
      "negative control: z(g) for g=4,5,6"
```

```
    ],
    "question": "Does the g=5 defect partition close alpha(0) without a fit parameter?",
    "references": [
      "alpha_inv_codata_2022"
    ],
    "validation": [
      "g is discrete and equals 5 under current enumeration",
      "alpha_inv_0 is within 2 sigma of CODATA",
      "g=5 minimizes |z| among g in {4,5,6}"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


flavor_pattern_audit: report.txt

```
Flavor pattern audit

lambda_pred = 0.22445997051897373245511597747748194821840297007791297390969270711773328122860166 (ref=0.22501, z=-0.8088
delta_star = 0.60886199202947425455154874532829161131252129329996518994007516328088657620625911
delta_cp_rad = 1.22879629237994967485496625121236602494680665514385150749357782921914647211601 34 (deg=70.40484143469463)
sin2_theta13 = 0.023108435158881104293284660903437775404804297675810195320905181018454300732168135 (ref=0.02224, z=1.523
theta13_deg = 8.743693008411187

cusp_set = [Fraction(1, 3), Fraction(2, 3), Fraction(1, 1)]

Mobius ratios:
- m_b_over_m_s: 43.79405189623337
- m_c_over_m_u: 486.9165313620135
- m_mu_over_m_e: 197.84536441898265
- m_s_over_m_d: 16.91911119689403
- m_t_over_m_c: 133.01222546408377
- m_tau_over_m_mu: 16.91911119689403

Checks:
- lambda_within_2sigma: PASS (z=-0.8088668838621581542412095919383114435250440030691560151577836503922334873504987 9)
- sin2_theta13_within_2sigma: PASS (z=1.523570454177375953130984041118904218954908203175781264745931611323334617838833 5)
- cusp_set_matches: PASS (cusp_set=[Fraction(1, 3), Fraction(2, 3), Fraction(1, 1)])
```

flavor_pattern_audit: results.json (tfpt-suite/theoryv3/out/flavor_pattern_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "lambda_within_2sigma",
      "detail": "z=-0.8088668838621581542412095919383114435250440030691560151577836503922334873504987 9",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "sin2_theta13_within_2sigma",
      "detail": "z=1.523570454177375953130984041118904218954908203175781264745931611323334617838833 5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "cusp_set_matches",
      "detail": "cusp_set=[Fraction(1, 3), Fraction(2, 3), Fraction(1, 1)]",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "flavor_pattern_audit",
  "plot": {
    "flavor_anchors_png": "./tfpt-suite/theoryv3/out/flavor_pattern_audit/flavor_anchors.png",
    "mobius_ratios_png": "./tfpt-suite/theoryv3/out/flavor_pattern_audit/mobius_ratios.png"
  },
  "results": {
    "cusp_set": [
      "1/3",
      "2/3",
      "1"
    ],
    "delta_cp_deg": 70.40484143469463,
    "delta_cp_rad": "1.22879629237994967485496625121236602494680665514385150749357782921914647211601 34",
    "delta_star": "0.60886199202947425455154874532829161131252129329996518994007516328088657620625911",
    "lambda_pred": "0.22445997051897373245511597747748194821840297007791297390969270711773328122860166",
    "lambda_ref": "0.22501",
    "lambda_z": "-0.8088668838621581542412095919383114435250440030691560151577836503922334873504987 9",
    "mobius_ratios": {
```

```
      "m_b_over_m_s": 43.79405189623337,
      "m_c_over_m_u": 486.9165313620135,
      "m_mu_over_m_e": 197.84536441898265,
      "m_s_over_m_d": 16.91911119689403,
      "m_t_over_m_c": 133.01222546408377,
      "m_tau_over_m_mu": 16.91911119689403
    },
    "plot": {
      "flavor_anchors_png": "./tfpt-suite/theoryv3/out/flavor_pattern_audit/flavor_anchors.png",
      "mobius_ratios_png": "./tfpt-suite/theoryv3/out/flavor_pattern_audit/mobius_ratios.png"
    },
    "references": {
      "cabibbo_lambda": {
        "dataset_id": "cabibbo_lambda_pdg2024",
        "notes": "Cabibbo lambda ~ |Vus|.",
        "sigma": 0.00068,
        "source": "global_reference.json:observables.cabibbo_lambda",
        "units": "dimensionless",
        "value": 0.22501,
        "version": "PDG 2024"
      },
      "pmns_sin2_theta13": {
        "dataset_id": "pmns_sin2_theta13_nufit53_no",
        "notes": "Normal ordering, PDG convention.",
        "sigma": 0.00057,
        "source": "pmns_reference.json:normal_ordering.sin2_theta13",
        "units": "dimensionless",
        "value": 0.02224,
        "version": "NuFIT 5.3 (2024, NO)"
      }
    },
    "sin2_theta13": "0.023108435158881104293284660903437775404804297675810195320905181018454300732168135",
    "sin2_theta13_ref": "0.02224",
    "sin2_theta13_z": "1.523570454177375953130984041118904218954908203175781264745931611323334617838833 5",
    "theta13_deg": 8.743693008411187
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic given constants and reference tables.",
    "formulas": [
      "lambda = sqrt(varphi0) * (1 - varphi0/2)",
      "delta_star = 3/5 + varphi0/6",
      "delta_cp = pi * (1 - delta_star)",
      "sin2_theta13 = varphi0 * exp(-5/6)",
      "M_y(delta) = (y + delta)/(y - delta)"
    ],
    "gaps": [],
    "inputs": [
      "TFPT constants (varphi0, delta_star)",
      "CKM/PMNS reference tables",
      "Mobius cusp set from SU(5) hypercharge"
    ],
    "maturity": null,
    "module_id": "flavor_pattern_audit",
    "name": "Flavor pattern audit (lambda, delta_star, delta_cp, PMNS theta13)",
    "objective": [
      "Make the flavor anchor formulas explicit and testable.",
      "Expose Mobius ratio predictions in one place."
    ],
    "outputs": [
      "lambda (Cabibbo) from varphi0",
      "delta_star and delta_cp",
      "PMNS sin^2 theta13 from varphi0",
      "Mobius mass ratios for quark/lepton hierarchy"
    ],
    "question": "Do the compact flavor formulas reproduce the anchor observables?",
    "references": [
      "cabibbo_lambda",
      "pmns_sin2_theta13"
    ],
    "validation": [
      "lambda within 2 sigma of reference",
      "sin2_theta13 within 2 sigma of NuFIT reference",
      "cusp set equals {1, 1/3, 2/3}"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```

g5_crosslink_audit: report.txt

```
g=5 crosslink audit

g = 5
g/4 = 1.25
g/2 = 2.5
g/(g+1) = 0.8333333333333334
gamma0 (TFPT) = 0.8333333333333334

delta_b3 candidates include g/2: True

Checks:
- g_equals_5: PASS (g=5)
- delta_b3_has_g_over_2: PASS (delta_b3 includes 2.5)
- gamma0_matches_g_over_g_plus_1: PASS (gamma0=0.8333333333333334)
```

g5_crosslink_audit: results.json (tfpt-suite/theoryv3/out/g5_crosslink_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "g_equals_5",
      "detail": "g=5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "delta_b3_has_g_over_2",
      "detail": "delta_b3 includes 2.5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "gamma0_matches_g_over_g_plus_1",
      "detail": "gamma0=0.8333333333333334",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "g5_crosslink_audit",
  "plot": {
    "g5_links_png": "./tfpt-suite/theoryv3/out/g5_crosslink_audit/g5_links.png"
  },
  "results": {
    "delta_b3_candidates": [
      0.0,
      1.0,
      2.0,
      2.25,
      2.5,
      2.75,
      3.0,
      4.0
    ],
    "g_over_2": 2.5,
    "g_over_4": 1.25,
    "g_over_g_plus_1": 0.8333333333333334,
    "g_value": 5,
    "gamma0_ref": 0.8333333333333334,
    "plot": {
      "g5_links_png": "./tfpt-suite/theoryv3/out/g5_crosslink_audit/g5_links.png"
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (finite comparisons).",
    "formulas": [
      "delta2 factor = g/4",
      "unification patch candidate = g/2",
      "gamma0 = g/(g+1)"
    ],
    "gaps": [],
    "inputs": [
      "defect partition g",
      "unification_gate_policy delta_b3 candidates",
      "TFPT gamma0"
    ],
    "maturity": null,
    "module_id": "g5_crosslink_audit",
```

```
    "name": "g=5 crosslink audit (delta2, unification patch, gamma0)",
    "objective": [
      "Summarize the discrete g=5 signature across delta2, unification, and E8 ladder."
    ],
    "outputs": [
      "g/4, g/2, g/(g+1) ratios",
      "consistency checks for g=5 usage"
    ],
    "question": "Is g=5 consistently threaded across multiple sectors?",
    "references": [],
    "validation": [
      "g resolves to 5",
      "delta_b3 candidates include g/2",
      "gamma0 equals g/(g+1)"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


g5_origin_audit: report.txt

```
g=5 origin audit (SU(5) holonomy degeneracy)

eigenvalues_fund = [Fraction(-1, 3), Fraction(-1, 3), Fraction(-1, 3), Fraction(1, 2), Fraction(1, 2)]
degeneracies = {'-1/3': 3, '1/2': 2}
g = 5

Checks:
- g_equals_5_from_holonomy: PASS (g=5)
- degeneracy_pattern: PASS (degeneracies=[3, 2])
```

g5_origin_audit: results.json (tfpt-suite/theoryv3/out/g5_origin_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "g_equals_5_from_holonomy",
      "detail": "g=5",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "degeneracy_pattern",
      "detail": "degeneracies=[3, 2]",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "g5_origin_audit",
  "plot": {
    "g5_origin.png": "./tfpt-suite/theoryv3/out/g5_origin_audit/g5_origin.png"
  },
  "results": {
    "degeneracies": {
      "-1/3": 3,
      "1/2": 2
    },
    "eigenvalues_fund": [
      "-1/3",
      "-1/3",
      "-1/3",
      "1/2",
      "1/2"
    ],
    "g": 5,
    "plot": {
      "g5_origin.png": "./tfpt-suite/theoryv3/out/g5_origin_audit/g5_origin.png"
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (no fitting, no scanning).",
    "formulas": [
      "g := sum of degeneracies in SU(5) fundamental holonomy spectrum",
      "degeneracies inferred from repeated eigenvalues"
    ],
    "gaps": [],
    "inputs": [
      "SU(5) hypercharge holonomy spectrum (fundamental)"
```

```
    ],
    "maturity": null,
    "module_id": "g5_origin_audit",
    "name": "g=5 origin audit (single-source SU(5) holonomy degeneracy)",
    "objective": [
      "Fix g from one source only, not by crosslinking multiple sectors."
    ],
    "outputs": [
      "degeneracy counts",
      "g from degeneracy sum"
    ],
    "question": "Can g be derived from a single discrete origin (SU(5) holonomy degeneracy)?",
    "references": [],
    "validation": [
      "g equals 5 (3 color + 2 weak holonomy channels)"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


pmns_tm1_audit: report.txt

```
PMNS TM1 audit

sin2_theta13 (input) = 0.023108435158881104293284660903437775404804297675810195320905181018454300732168135
sin2_theta12 (TM1) = 0.317927709894079263804476892731041483063463801549459869786063212654363799511887 91
sin2_theta12 ref = 0.307 ? 0.012 (NuFIT 5.3 (2024, NO))
z = 0.910642491173271983706407727586790255288650129121655815505267721196983292657325 83

Checks:
- sin2_theta12_within_band: PASS (z=0.910642491173271983706407727586790255288650129121655815505267721196983292657325 83)
- theta23_placeholder: INFO (theta23 and delta_CP are placeholders until Z3-breaking is wired into this audit)
```

pmns_tm1_audit: results.json (tfpt-suite/theoryv3/out/pmns_tm1_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "sin2_theta12_within_band",
      "detail": "z=0.910642491173271983706407727586790255288650129121655815505267721196983292657325 83",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "theta23_placeholder",
      "detail": "theta23 and delta_CP are placeholders until Z3-breaking is wired into this audit",
      "passed": true,
      "severity": "INFO"
    }
  ],
  "module_id": "pmns_tm1_audit",
  "plot": null,
  "results": {
    "reference": {
      "dataset_id": "pmns_sin2_theta12_nufit53_no",
      "notes": "Normal ordering, PDG convention.",
      "sigma": 0.012,
      "source": "pmns_reference.json:normal_ordering.sin2_theta12",
      "units": "dimensionless",
      "value": 0.307,
      "version": "NuFIT 5.3 (2024, NO)"
    },
    "sin2_theta12": "0.317927709894079263804476892731041483063463801549459869786063212654363799511887 91",
    "sin2_theta13": "0.023108435158881104293284660903437775404804297675810195320905181018454300732168135",
    "z": "0.910642491173271983706407727586790255288650129121655815505267721196983292657325 83"
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (closed form).",
    "formulas": [
      "sin2_theta12 = (1/3) * (1 - 2 * sin2_theta13)"
    ],
    "gaps": [],
    "inputs": [
      "sin2_theta13 from flavor_pattern_audit",
      "NuFIT sin2_theta12 reference (normal ordering)"
    ],
    "maturity": null,
    "module_id": "pmns_tm1_audit",
```

```
    "name": "PMNS TM1 audit (theta12 from theta13)",
    "objective": [
      "Audit the TM1 sum rule with explicit inputs and a conservative band."
    ],
    "outputs": [
      "sin2_theta12 from TM1 sum rule",
      "z score vs NuFIT reference"
    ],
    "question": "Does the TM1 sum rule yield a viable sin2(theta12) given sin2(theta13)?",
    "references": [
      "pmns_sin2_theta12_nufit53_no"
    ],
    "validation": [
      "sin2_theta12 within conservative band (3 sigma)"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


seed_invariants_audit: report.txt


```
Seed invariants audit (pi -> c3, varphi0, beta_rad)

pi = 3.14159265358979323846264338327950288419716939937510582097494459230781640628620 9
c3 = 0.03978873577297383394222094084312859050861491143511411218691683601472419940855 6634
varphi0_tree = 0.05305164769729844525629458779083812067815321524681881624922244801963226587807551 2
delta_top = 0.00012030447954708205299788417891154719697454455297232339122853166568719135947912407
varphi0 = 0.05317195217684552730929247196974966787512775979979113964045097968531945723755 4636
beta_rad = 0.00423128951139541510874681820880501639507280772668372576989442290305267327215562 63

Comparison to core_invariants (if present):
- c3: ref=0.03978873577297383394222094084312859050861491143511411218691683601472419940855 6634, diff=-1.976662114355723
- varphi0_tree: ref=0.05305164769729844525629458779083812067815321524681881624922244801963226587807551 2, diff=-2.635549
- delta_top: ref=0.00012030447954708205299788417891154719697454455297232339122853166568719135947912407, diff=-4.5041128
- varphi0: ref=0.05317195217684552730929247196974966787512775979979113964045097968531945723755 4636, diff=-1.97666211435
- beta_rad: ref=0.00423128951139541510874681820880501639507280772668372576989442290305267327215562 63, diff=1.64721842862

Checks:
- match_c3: PASS (c3 matches core_invariants (diff=-1.976662114355723104565357634613128563945617759194095165639580567207
- match_varphi0_tree: PASS (varphi0_tree matches core_invariants (diff=-2.635549485807630806087143512817504751927490345
- match_delta_top: PASS (delta_top matches core_invariants (diff=-4.504112890784525303371583151787727847532332133580294
- match_varphi0: PASS (varphi0 matches core_invariants (diff=-1.976662114355723104565357634613128563945617759194095165
- match_beta_rad: PASS (beta_rad matches core_invariants (diff=1.647218428629769253804464695510940469954681465995079304
- varphi0_identity: PASS (varphi0 = varphi0_tree + delta_top (0.053171952176845527309292471969749667875127759799791139641
- beta_rad_identity: PASS (beta_rad = varphi0/(4*pi) (0.004231289511395415108746818208805016395072807726683725769894422
```


seed_invariants_audit: results.json (tfpt-suite/theoryv3/out/seed_invariants_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "match_c3",
      "detail": "c3 matches core_invariants (diff=-1.976662114355723104565357634613128563945617759194095165639580567207
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "match_varphi0_tree",
      "detail": "varphi0_tree matches core_invariants (diff=-2.635549485807630806087143512817504751927490345592126887519
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "match_delta_top",
      "detail": "delta_top matches core_invariants (diff=-4.504112890784525303371583151787727847532332133580294973788106
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "match_varphi0",
      "detail": "varphi0 matches core_invariants (diff=-1.976662114355723104565357634613128563945617759194095165639580567
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "match_beta_rad",
      "detail": "beta_rad matches core_invariants (diff=1.647218428629769253804464695510940469954681465995079304699650479
      "passed": true,
      "severity": "PASS"
    },
```

```
    {
      "check_id": "varphi0_identity",
      "detail": "varphi0 = varphi0_tree + delta_top (0.053171952176845527309292471969749667875127759799791139640450979685319457237554636",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "beta_rad_identity",
      "detail": "beta_rad = varphi0/(4*pi) (0.004231289511395415108746818208805016395072807726683725769894422903052673271",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "seed_invariants_audit",
  "plot": {
    "seed_invariants_png": "./tfpt-suite/theoryv3/out/seed_invariants_audit/seed_invariants.png"
  },
  "results": {
    "comparison": {
      "beta_rad": {
        "diff": "1.647218428629769253804464695510940469954681465995079304699650472673147545464024 9e-83",
        "ref": "0.004231289511395415108746818208805016395072807726683725769894422903052673272155 6263"
      },
      "c3": {
        "diff": "-1.976662114355723104565357634613128563945617759194095165639580567207777054556 8299e-82",
        "ref": "0.039788735772973833942220940843128590508614911435114112186916836014724199408556 634"
      },
      "delta_top": {
        "diff": "-4.504112890784525303371583151787727847532332133580294973788106761215637819628 1932e-84",
        "ref": "0.000120304479547082052997884178911547196974544552972323391228531665687191359479 12407"
      },
      "varphi0": {
        "diff": "-1.976662114355723104565357634613128563945617759194095165639580567207777054556 8299e-82",
        "ref": "0.053171952176845527309292471969749667875127759799791139640450979685319457237554 636"
      },
      "varphi0_tree": {
        "diff": "-2.635549485807630806087143512817504751927490345592126887519440756277036072742 4399e-82",
        "ref": "0.053051647697298445256294587790838120678153215246818816249222448019632265878075 512"
      }
    },
    "plot": {
      "seed_invariants_png": "./tfpt-suite/theoryv3/out/seed_invariants_audit/seed_invariants.png"
    },
    "values": {
      "beta_rad": "0.004231289511395415108746818208805016395072807726683725769894422903052673272155 6263",
      "c3": "0.039788735772973833942220940843128590508614911435114112186916836014724199408556 634",
      "delta_top": "0.000120304479547082052997884178911547196974544552972323391228531665687191359479 12407",
      "pi": "3.141592653589793238462643383279502884197169399375105820974944592307816406286209",
      "varphi0": "0.053171952176845527309292471969749667875127759799791139640450979685319457237554 636",
      "varphi0_tree": "0.053051647697298445256294587790838120678153215246818816249222448019632265878075 512"
    }
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (pure algebra).",
    "formulas": [
      "c3 = 1/(8*pi)",
      "varphi0_tree = 1/(6*pi)",
      "delta_top = 3/(256*pi^4)",
      "varphi0 = varphi0_tree + delta_top",
      "beta_rad = varphi0/(4*pi)"
    ],
    "gaps": [],
    "inputs": [
      "pi"
    ],
    "maturity": null,
    "module_id": "seed_invariants_audit",
    "name": "Seed invariants audit (pi -> c3, varphi0, beta_rad)",
    "objective": [
      "Make the pi-seed dependency explicit and auditable.",
      "Provide a compact reference table for downstream audits."
    ],
    "outputs": [
      "c3",
      "varphi0_tree",
      "delta_top",
      "varphi0",
      "beta_rad"
```

```
    ],
    "question": "Does pi alone fix the core invariants used across TFPT?",
    "references": [],
    "validation": [
      "internal identities are satisfied",
      "optional match to core_invariants output if present"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


yukawa_exponent_index_audit: report.txt

```
Yukawa exponent index audit

c3/varphi0 = 0.748303083562547798554257091172139001058675376235833630613441267742142724664421 52
denominators = (2, 3, 4, 5, 6, 8, 10, 12, 16, 24), max_numerator = 200

Ratios:
- m_mu_over_m_e: q=3.956642, q_rational=95/24, rel_error=0.002263
- m_b_over_m_s: q=2.828210, q_rational=17/6, rel_error=0.00687
- m_c_over_m_u: q=4.630569, q_rational=37/8, rel_error=-0.007414
- m_t_over_m_c: q=3.659532, q_rational=11/3, rel_error=0.00958
- m_s_over_m_d: q=2.116533, q_rational=17/8, rel_error=0.01138
- m_tau_over_m_mu: q=2.116533, q_rational=17/8, rel_error=0.01138

Checks:
- rationalization_within_tol: PASS (max_rel_error=0.01138)
- ratio_direct:m_mu_over_m_e: PASS (scale-independent reference)
- ratio_needs_rg:m_b_over_m_s: WARN (scheme=MSbar, scale=n/a)
- ratio_needs_rg:m_c_over_m_u: WARN (scheme=MSbar, scale=n/a)
- ratio_needs_rg:m_t_over_m_c: WARN (scheme=MSbar, scale=n/a)
- ratio_needs_rg:m_s_over_m_d: WARN (scheme=MSbar, scale=n/a)
- ratio_direct:m_tau_over_m_mu: PASS (scale-independent reference)
```

yukawa_exponent_index_audit: results.json (tfpt-suite/theoryv3/out/yukawa_exponent_index_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "rationalization_within_tol",
      "detail": "max_rel_error=0.01138",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "ratio_direct:m_mu_over_m_e",
      "detail": "scale-independent reference",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "ratio_needs_rg:m_b_over_m_s",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_needs_rg:m_c_over_m_u",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_needs_rg:m_t_over_m_c",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_needs_rg:m_s_over_m_d",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_direct:m_tau_over_m_mu",
      "detail": "scale-independent reference",
      "passed": true,
      "severity": "PASS"
```

```
  }
],
"module_id": "yukawa_exponent_index_audit",
"plot": {
  "yukawa_q_errors_png": "./tfpt-suite/theoryv3/out/yukawa_exponent_index_audit/yukawa_q_errors.png"
},
"results": {
  "plot": {
    "yukawa_q_errors_png": "./tfpt-suite/theoryv3/out/yukawa_exponent_index_audit/yukawa_q_errors.png"
  },
  "ratio_policies": {
    "m_b_over_m_s": {
      "dataset_id": "mass_ratio_mb_over_ms",
      "scale": "n/a",
      "scheme": "MSbar",
      "status": "needs_rg"
    },
    "m_c_over_m_u": {
      "dataset_id": "mass_ratio_mc_over_mu_quark",
      "scale": "n/a",
      "scheme": "MSbar",
      "status": "needs_rg"
    },
    "m_mu_over_m_e": {
      "dataset_id": "mass_ratio_mu_over_e_pdg",
      "scale": "pole",
      "scheme": "pole",
      "status": "direct"
    },
    "m_s_over_m_d": {
      "dataset_id": "mass_ratio_ms_over_md",
      "scale": "n/a",
      "scheme": "MSbar",
      "status": "needs_rg"
    },
    "m_t_over_m_c": {
      "dataset_id": "mass_ratio_mt_over_mc",
      "scale": "n/a",
      "scheme": "MSbar",
      "status": "needs_rg"
    },
    "m_tau_over_m_mu": {
      "dataset_id": "mass_ratio_tau_over_mu_pdg",
      "scale": "pole",
      "scheme": "pole",
      "status": "direct"
    }
  },
  "ratios": {
    "m_b_over_m_s": 43.79405189623337,
    "m_c_over_m_u": 486.9165313620135,
    "m_mu_over_m_e": 197.84536441898265,
    "m_s_over_m_d": 16.91911119689403,
    "m_t_over_m_c": 133.01222546408377,
    "m_tau_over_m_mu": 16.91911119689403
  },
  "rows": [
    {
      "log10_ratio": 2.296325879060772,
      "q_float": 3.9566418818751004,
      "q_rational": "95/24",
      "ratio": "m_mu_over_m_e",
      "ratio_recon": 198.29307649780313,
      "rel_error": 0.0022629394433136027,
      "value": 197.84536441898265
    },
    {
      "log10_ratio": 1.6414151286761858,
      "q_float": 2.8282100127356213,
      "q_rational": "17/6",
      "ratio": "m_b_over_m_s",
      "ratio_recon": 44.09492037647158,
      "rel_error": 0.006870076350804272,
      "value": 43.79405189623337
    },
    {
      "log10_ratio": 2.6874545195806525,
      "q_float": 4.630568859920046,
      "q_rational": "37/8",
      "ratio": "m_c_over_m_u",
```

```
        "ratio_recon": 483.30635619740156,
        "rel_error": -0.00741436146050214,
        "value": 486.9165313620135
      },
      {
        "log10_ratio": 2.1238915598210766,
        "q_float": 3.6595321137896337,
        "q_rational": "11/3",
        "ratio": "m_t_over_m_c",
        "ratio_recon": 134.28646999970803,
        "rel_error": 0.009579905389736703,
        "value": 133.01222546408377
      },
      {
        "log10_ratio": 1.2283775447300098,
        "q_float": 2.1165332344821928,
        "q_rational": "17/8",
        "ratio": "m_s_over_m_d",
        "ratio_recon": 17.111631615607397,
        "rel_error": 0.011378873066849407,
        "value": 16.91911119689403
      },
      {
        "log10_ratio": 1.2283775447300098,
        "q_float": 2.1165332344821928,
        "q_rational": "17/8",
        "ratio": "m_tau_over_m_mu",
        "ratio_recon": 17.111631615607397,
        "rel_error": 0.011378873066849407,
        "value": 16.91911119689403
      }
    ]
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (finite rational scan).",
    "formulas": [
      "q_ij = (c3/varphi0) * ln(ratio)",
      "ratio_recon = exp(q_rational * varphi0 / c3)"
    ],
    "gaps": [],
    "inputs": [
      "mass ratios from mass_spectrum_deriver (preferred)",
      "TFPT invariants (c3, varphi0)"
    ],
    "maturity": null,
    "module_id": "yukawa_exponent_index_audit",
    "name": "Yukawa exponent index audit (q_ij rationalization)",
    "objective": [
      "Quantize the exponent indices with a fixed denominator grammar.",
      "Report which ratios are most stable under the rational map."
    ],
    "outputs": [
      "q_ij = (c3/varphi0) * ln(m_i/m_j)",
      "best rational approximation for q_ij",
      "reconstruction error for each ratio"
    ],
    "question": "Do the Mobius-derived ratios align with rational exponent indices?",
    "references": [],
    "validation": [
      "relative reconstruction errors are below 2% for the selected ratios"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```


yukawa_index_mapping_audit: report.txt

```
Yukawa index mapping audit

c3/varphi0 = 0.748303083562547798554257091172139001058675376235833630613441267742142724664421 52
basis (I = dim(SU3)*dim(SU2)*Y^2): ['Q=0.16666666666666665333333333333333336', 'L=0.5', 'u_c=1.33333333333333306666666666

Mappings:
- m_b_over_m_s: q_target=2.8333333333333335, combo={'Q': 2, 'L': 5}, rel_error=0
- m_t_over_m_c: q_target=3.6666666666666665, combo={'d_c': 2, 'e_c': 3}, rel_error=0
- m_c_over_m_u: q_target=4.625, combo={'Q': 2, 'u_c': 1, 'd_c': 9}, rel_error=0.009009
- m_mu_over_m_e: q_target=3.9583333333333335, combo={'d_c': 9, 'e_c': 1}, rel_error=0.01053
```

```
- m_s_over_m_d: q_target=2.125, combo={'L': 1, 'd_c': 5}, rel_error=0.01961
- m_tau_over_m_mu: q_target=2.125, combo={'L': 1, 'd_c': 5}, rel_error=0.01961

Checks:
- mapping_within_tol: PASS (max_rel_error=0.01961)
- ratio_needs_rg:m_b_over_m_s: WARN (scheme=MSbar, scale=n/a)
- ratio_needs_rg:m_t_over_m_c: WARN (scheme=MSbar, scale=n/a)
- ratio_needs_rg:m_c_over_m_u: WARN (scheme=MSbar, scale=n/a)
- ratio_direct:m_mu_over_m_e: PASS (scale-independent reference)
- ratio_needs_rg:m_s_over_m_d: WARN (scheme=MSbar, scale=n/a)
- ratio_direct:m_tau_over_m_mu: PASS (scale-independent reference)
```

yukawa_index_mapping_audit: results.json (tfpt-suite/theoryv3/out/yukawa_index_mapping_audit/results.json)


```
{
  "checks": [
    {
      "check_id": "mapping_within_tol",
      "detail": "max_rel_error=0.01961",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "ratio_needs_rg:m_b_over_m_s",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_needs_rg:m_t_over_m_c",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_needs_rg:m_c_over_m_u",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_direct:m_mu_over_m_e",
      "detail": "scale-independent reference",
      "passed": true,
      "severity": "PASS"
    },
    {
      "check_id": "ratio_needs_rg:m_s_over_m_d",
      "detail": "scheme=MSbar, scale=n/a",
      "passed": true,
      "severity": "WARN"
    },
    {
      "check_id": "ratio_direct:m_tau_over_m_mu",
      "detail": "scale-independent reference",
      "passed": true,
      "severity": "PASS"
    }
  ],
  "module_id": "yukawa_index_mapping_audit",
  "plot": {
    "yukawa_index_mapping.png": "./tfpt-suite/theoryv3/out/yukawa_index_mapping_audit/yukawa_index_mapping.png"
  },
  "results": {
    "basis": {
      "L": "0.5",
      "Q": "0.16666666666666665333333333333333336",
      "d_c": "0.33333333333333326666666666666667",
      "e_c": "1.0",
      "u_c": "1.33333333333333306666666666666668"
    },
    "plot": {
      "yukawa_index_mapping.png": "./tfpt-suite/theoryv3/out/yukawa_index_mapping_audit/yukawa_index_mapping.png"
    },
    "ratio_policies": {
      "m_b_over_m_s": {
        "dataset_id": "mass_ratio_mb_over_ms",
        "scale": "n/a",
        "scheme": "MSbar",
        "status": "needs_rg"
      },
```

```
  "m_c_over_m_u": {
    "dataset_id": "mass_ratio_mc_over_mu_quark",
    "scale": "n/a",
    "scheme": "MSbar",
    "status": "needs_rg"
  },
  "m_mu_over_m_e": {
    "dataset_id": "mass_ratio_mu_over_e_pdg",
    "scale": "pole",
    "scheme": "pole",
    "status": "direct"
  },
  "m_s_over_m_d": {
    "dataset_id": "mass_ratio_ms_over_md",
    "scale": "n/a",
    "scheme": "MSbar",
    "status": "needs_rg"
  },
  "m_t_over_m_c": {
    "dataset_id": "mass_ratio_mt_over_mc",
    "scale": "n/a",
    "scheme": "MSbar",
    "status": "needs_rg"
  },
  "m_tau_over_m_mu": {
    "dataset_id": "mass_ratio_tau_over_mu_pdg",
    "scale": "pole",
    "scheme": "pole",
    "status": "direct"
  }
},
"ratios": {
  "m_b_over_m_s": 43.79405189623337,
  "m_c_over_m_u": 486.9165313620135,
  "m_mu_over_m_e": 197.84536441898265,
  "m_s_over_m_d": 16.91911119689403,
  "m_t_over_m_c": 133.01222546408377,
  "m_tau_over_m_mu": 16.91911119689403
},
"rows": [
  {
    "abs_error": 0.0,
    "combo": {
      "L": 5,
      "Q": 2
    },
    "combo_value": 2.8333333333333335,
    "q_float": 2.8282100127356213,
    "q_target": "2.8333333333333335",
    "ratio": "m_b_over_m_s",
    "rel_error": 0.0,
    "value": 43.79405189623337
  },
  {
    "abs_error": 0.0,
    "combo": {
      "d_c": 2,
      "e_c": 3
    },
    "combo_value": 3.6666666666666665,
    "q_float": 3.6595321137896337,
    "q_target": "3.6666666666666665",
    "ratio": "m_t_over_m_c",
    "rel_error": 0.0,
    "value": 133.01222546408377
  },
  {
    "abs_error": 0.041666666666665186,
    "combo": {
      "Q": 2,
      "d_c": 9,
      "u_c": 1
    },
    "combo_value": 4.666666666666665,
    "q_float": 4.630568859920046,
    "q_target": "4.625",
    "ratio": "m_c_over_m_u",
    "rel_error": 0.00900900900900869,
    "value": 486.9165313620135
  },
```

```
      {
        "abs_error": 0.04166666666666563,
        "combo": {
          "d_c": 9,
          "e_c": 1
        },
        "combo_value": 3.999999999999999,
        "q_float": 3.9566418818751004,
        "q_target": "3.9583333333333335",
        "ratio": "m_mu_over_m_e",
        "rel_error": 0.010526315789473422,
        "value": 197.84536441898265
      },
      {
        "abs_error": 0.041666666666666075,
        "combo": {
          "L": 1,
          "d_c": 5
        },
        "combo_value": 2.166666666666666,
        "q_float": 2.1165332344821928,
        "q_target": "2.125",
        "ratio": "m_s_over_m_d",
        "rel_error": 0.019607843137254624,
        "value": 16.91911119689403
      },
      {
        "abs_error": 0.041666666666666075,
        "combo": {
          "L": 1,
          "d_c": 5
        },
        "combo_value": 2.166666666666666,
        "q_float": 2.1165332344821928,
        "q_target": "2.125",
        "ratio": "m_tau_over_m_mu",
        "rel_error": 0.019607843137254624,
        "value": 16.91911119689403
      }
    ]
  },
  "schema_version": 1,
  "spec": {
    "assumptions": [],
    "determinism": "Deterministic (finite bounded search).",
    "formulas": [
      "q_ij = (c3/varphi0) * ln(ratio)",
      "I_field = dim(SU3) * dim(SU2) * Y^2",
      "q_target ~ sum_i n_i * I_i (integer coefficients)"
    ],
    "gaps": [],
    "inputs": [
      "mass ratios from mass_spectrum_deriver (preferred)",
      "TFPT invariants (c3, varphi0)",
      "microscopic_action_tfpt_v25.json (charge-squared sums)"
    ],
    "maturity": null,
    "module_id": "yukawa_index_mapping_audit",
    "name": "Yukawa index mapping audit (q_ij -> charge-squared sums)",
    "objective": [
      "Tie exponent indices to explicit charge-squared sums (no continuous tuning)."
    ],
    "outputs": [
      "q_ij rational targets",
      "best charge-squared sum mapping",
      "relative mapping errors"
    ],
    "question": "Can q_ij be mapped to discrete charge-squared index sums from the microscopic action?",
    "references": [],
    "validation": [
      "relative mapping errors are <= 2% for the selected ratios"
    ],
    "what_was_done": []
  },
  "warnings": []
}
```