Generically Orthogonal Decompositions and Measurement Combinations

A Theme and Variations in the search for Standard Model VHbb

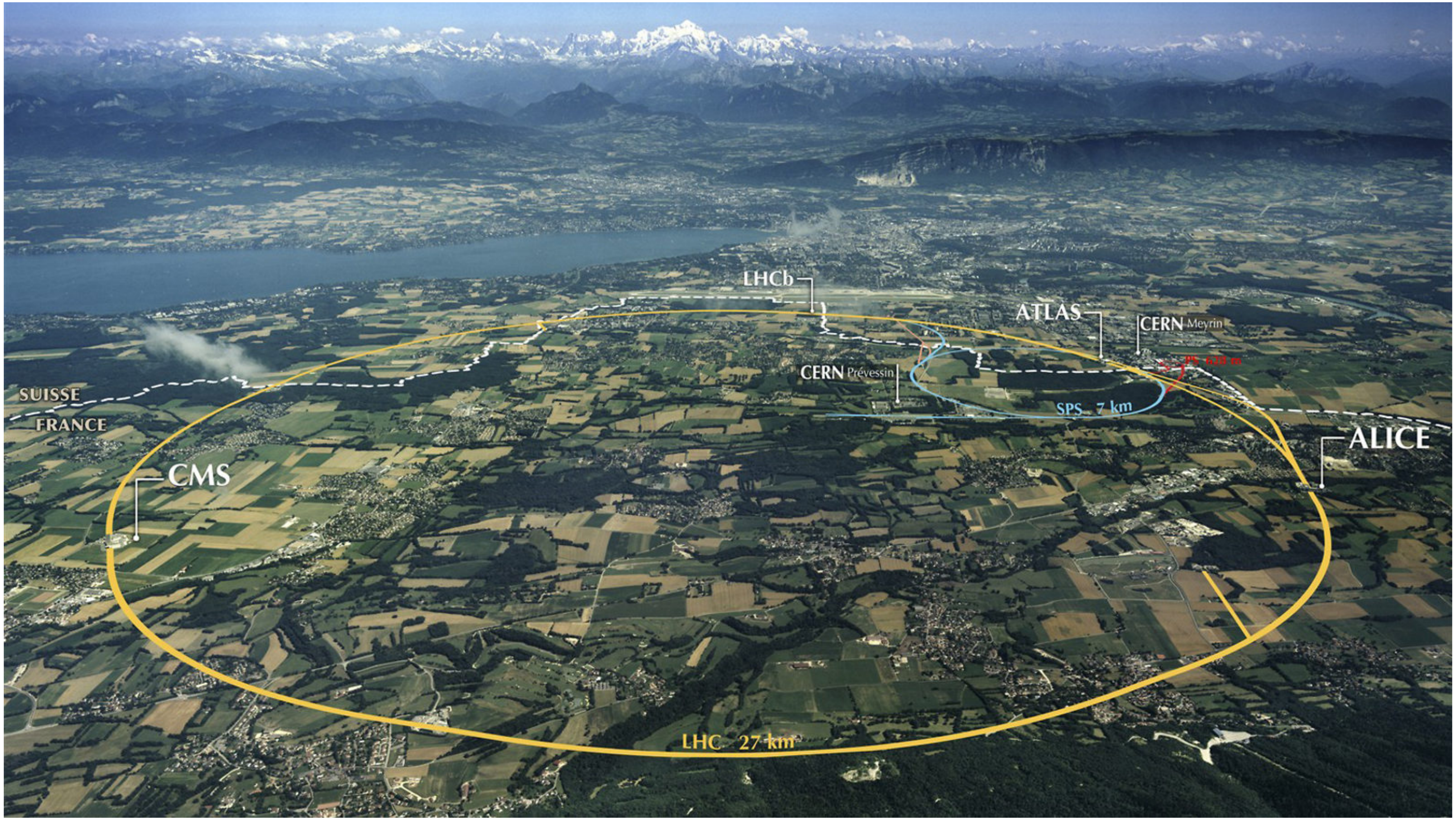
Stephen K. Chan

25 April 2018

Overview

- SM VHbb at ATLAS
- Statistical analysis of LHC data
- Generically orthogonal MVA inputs in SM ZH—>llbb
    - Canonical
    - Lorentz Invariants
    - RestFrames
- Measurement combinations: ATLAS SM VHbb Run 1 + Run 2

Making High Energy Collisions: The LHC



Measuring Collisions: ATLAS

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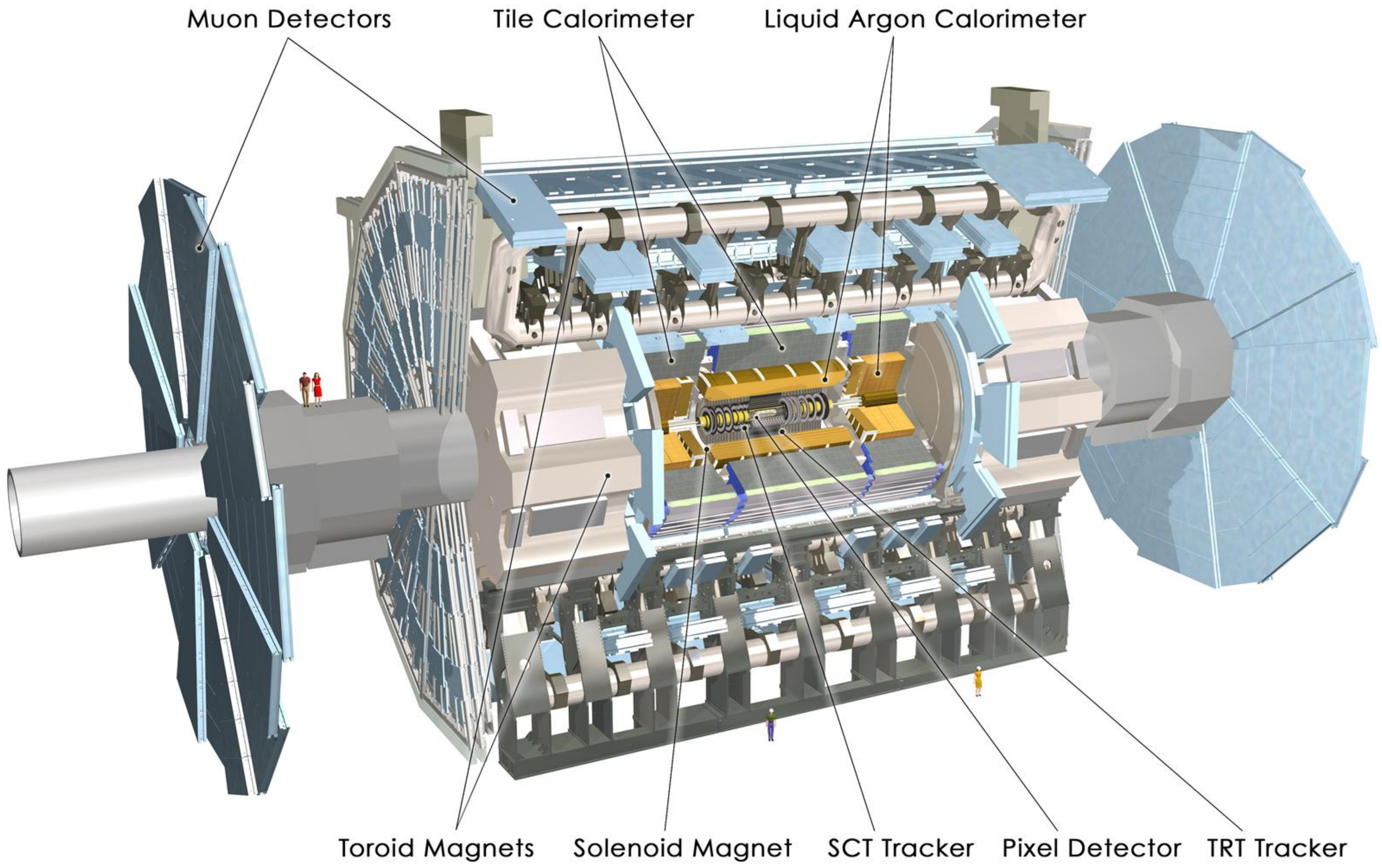
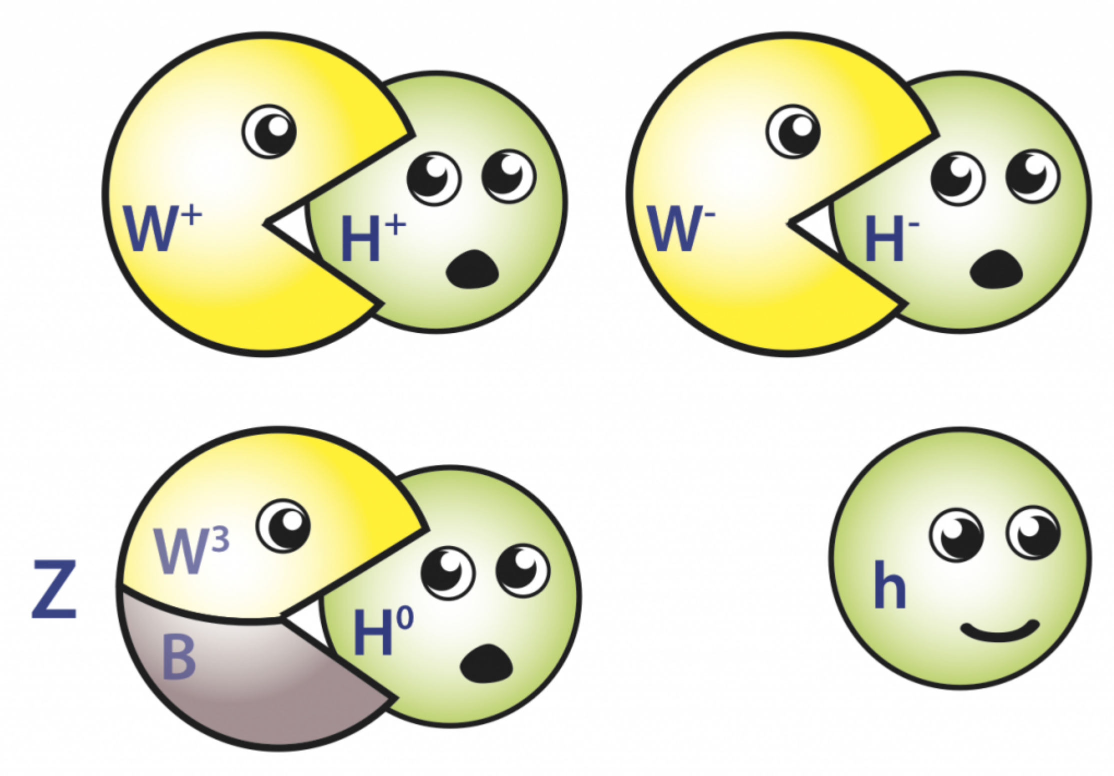
2018.04.25



The Higgs

- SM EWSB—>scalar Higgs
  - Where fundamental particles get mass*
- The Higgs decays a variety of ways; mass dependent
  - γγ/ZZ* discovery channels—>mass of 125 GeV
- Dominant Higgs decay is to b-quarks at 58% of the time



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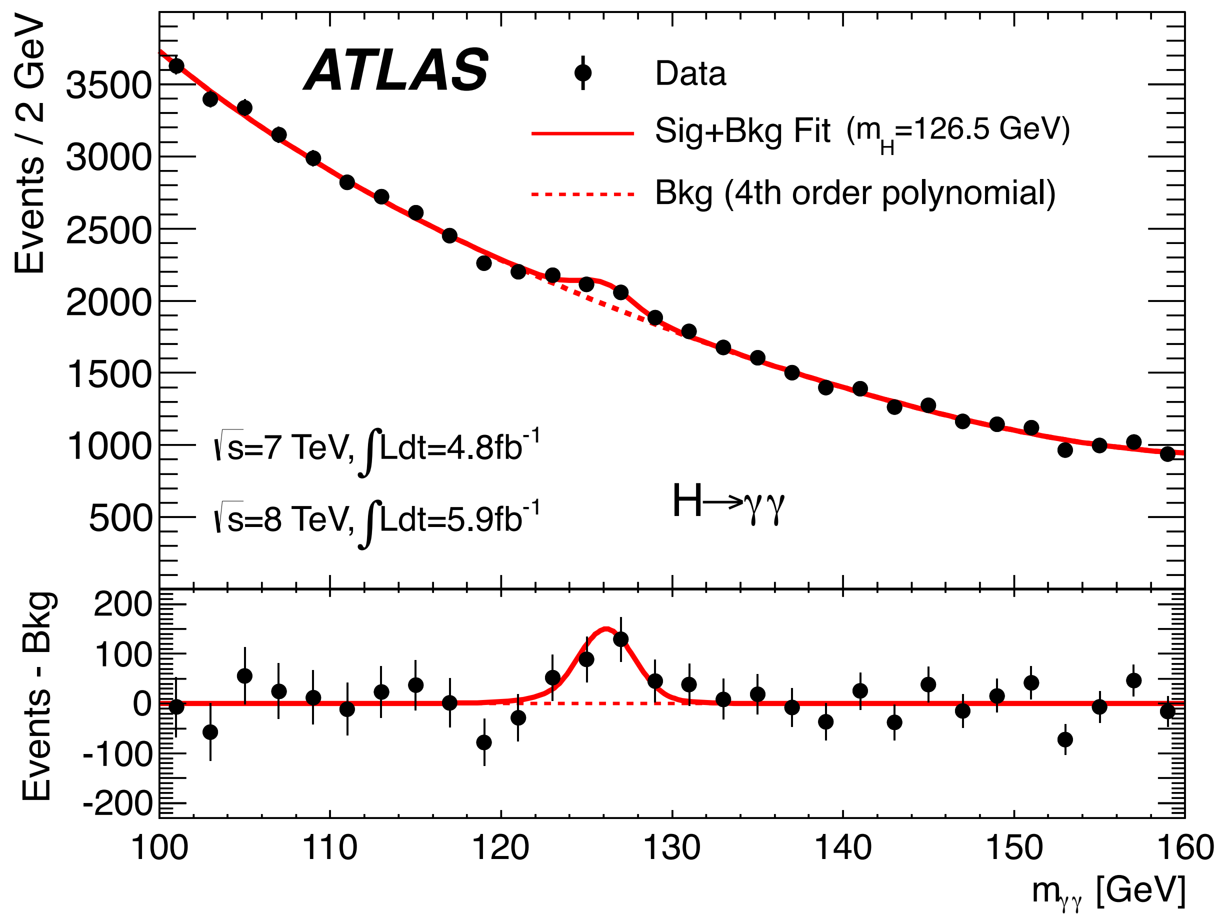

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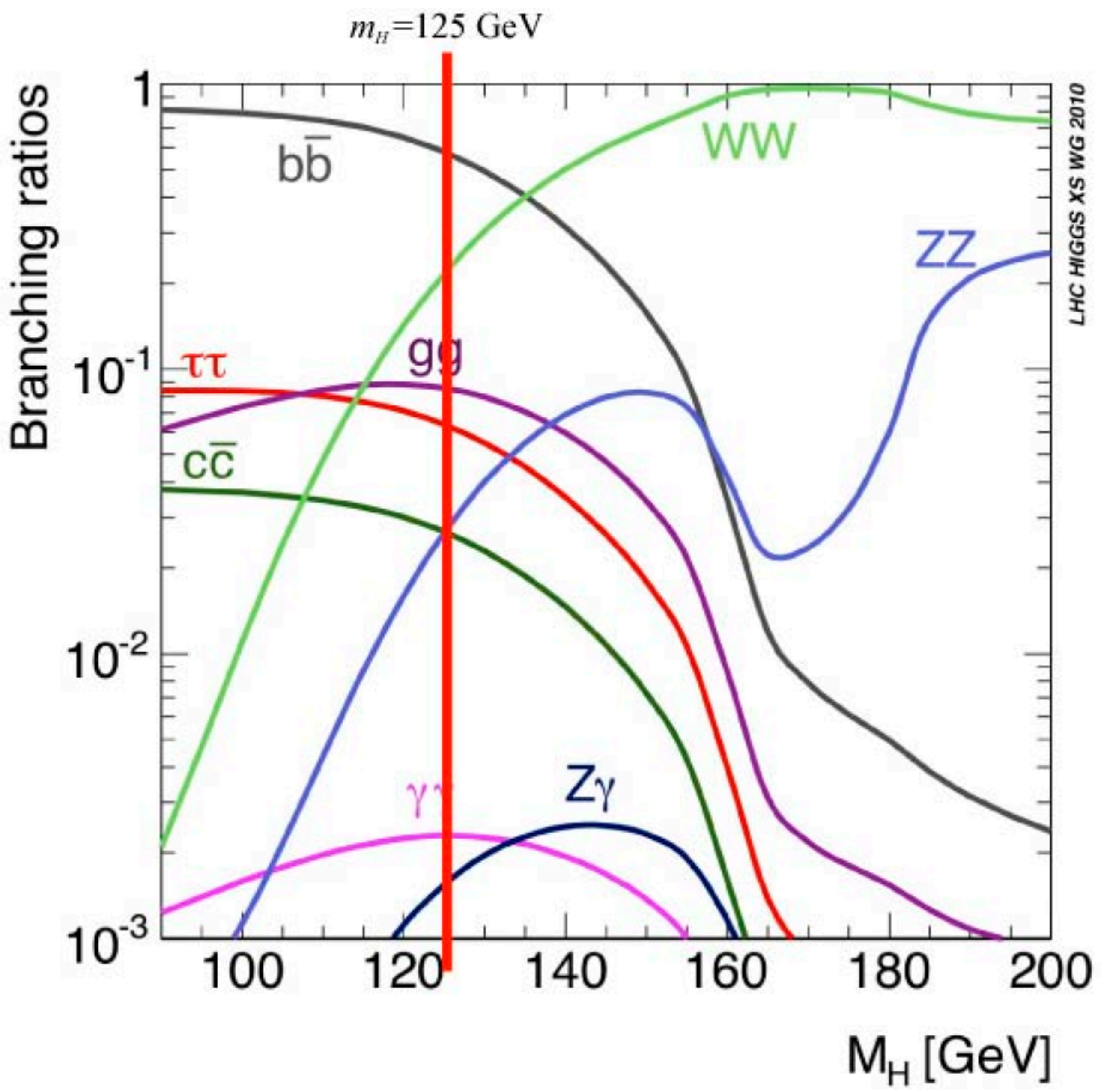

Standard Model VHbb at the LHC

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Finding Standard Model VHbb
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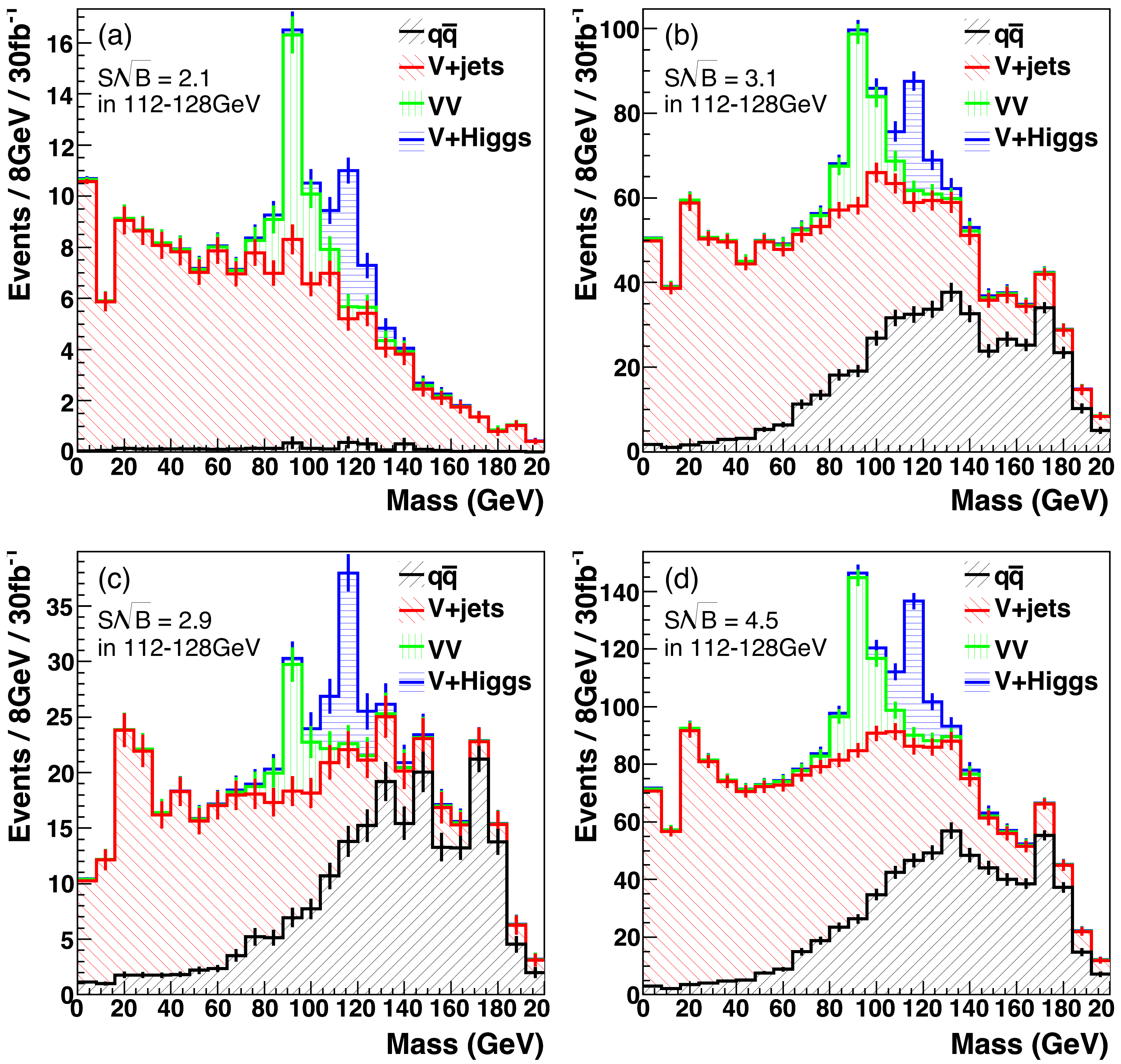
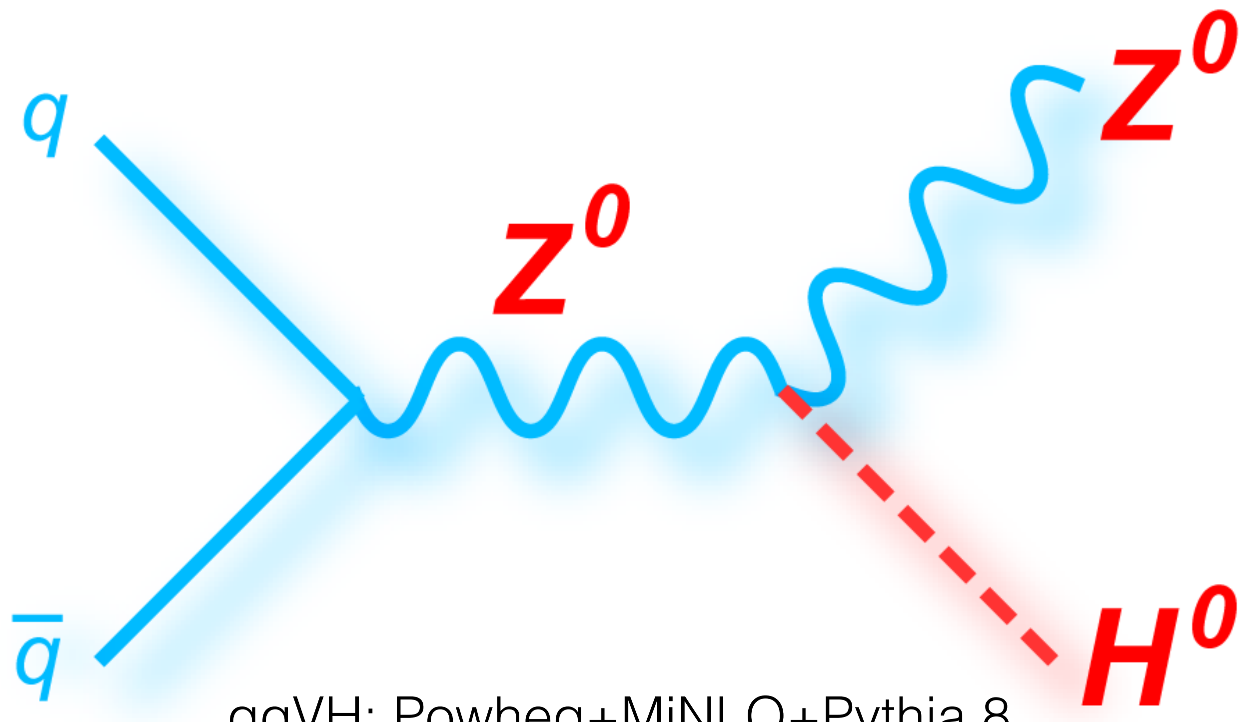
2018.04.25

It is widely considered that, for Higgs boson searches at the Large Hadron Collider, WH and ZH production where the Higgs boson decays to $b\bar{b}$ are poor search channels due to large backgrounds.

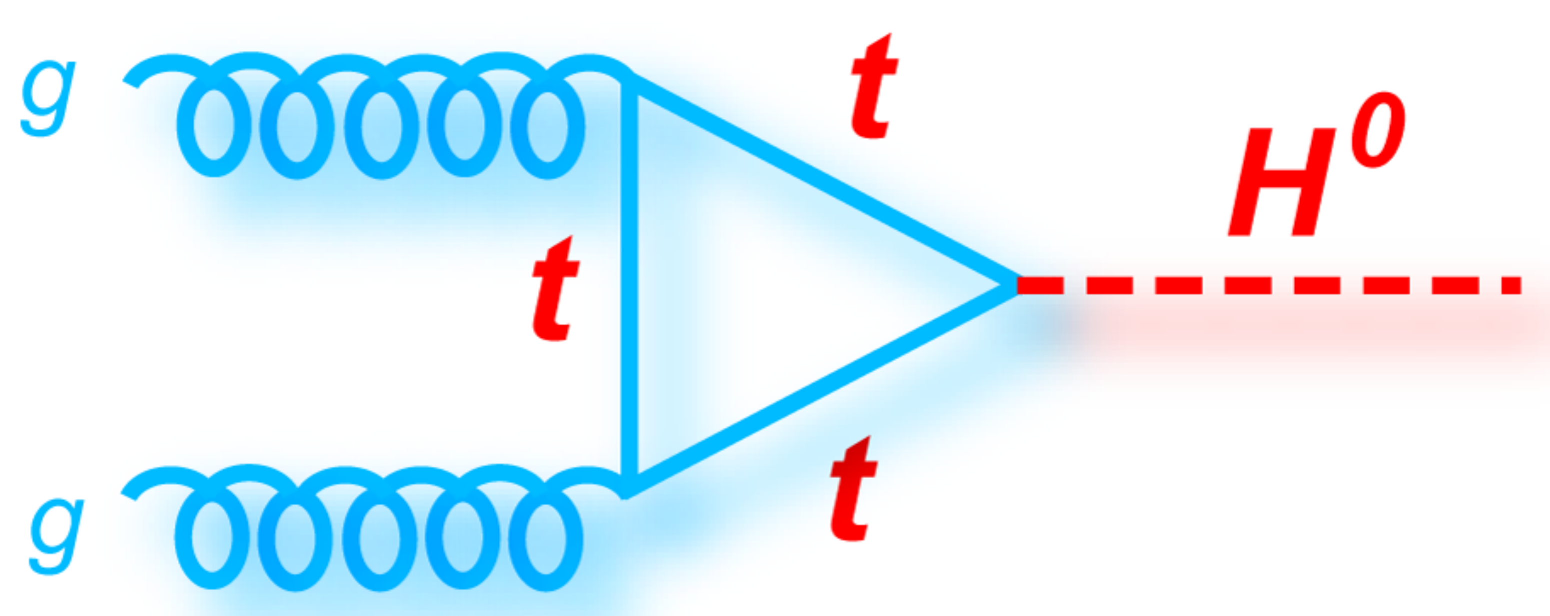
- <=2008: “can’t be done”
- …but what if we add a boost requirement?
    1. Started with W scattering
    2. W/H/Z ID in strongly interacting SUSY schemes
    3. Finally, SM VHbb (Butterworth, et al 2008 at right), combine with triggerable leptonic V decay



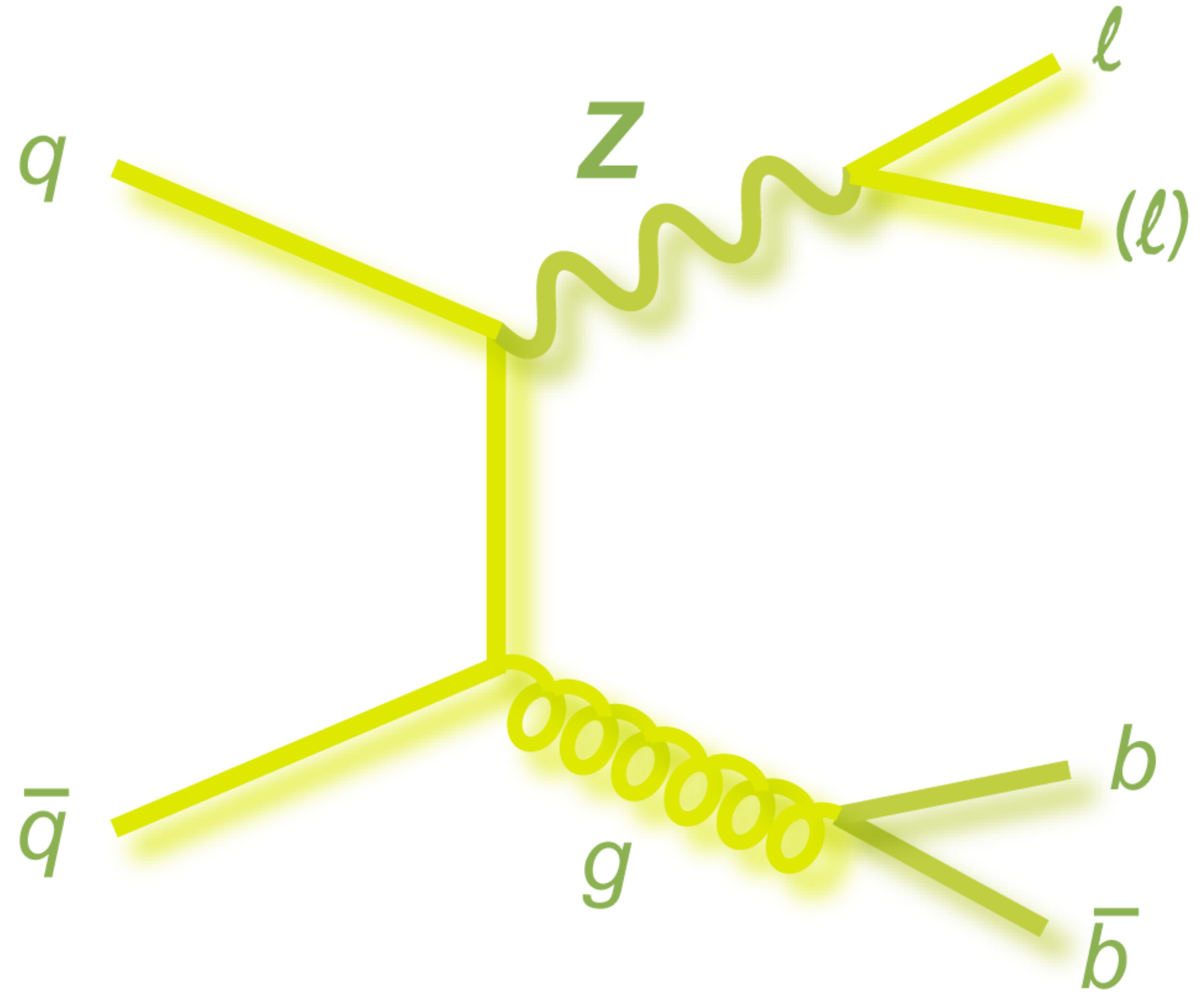
Signal/Background MC



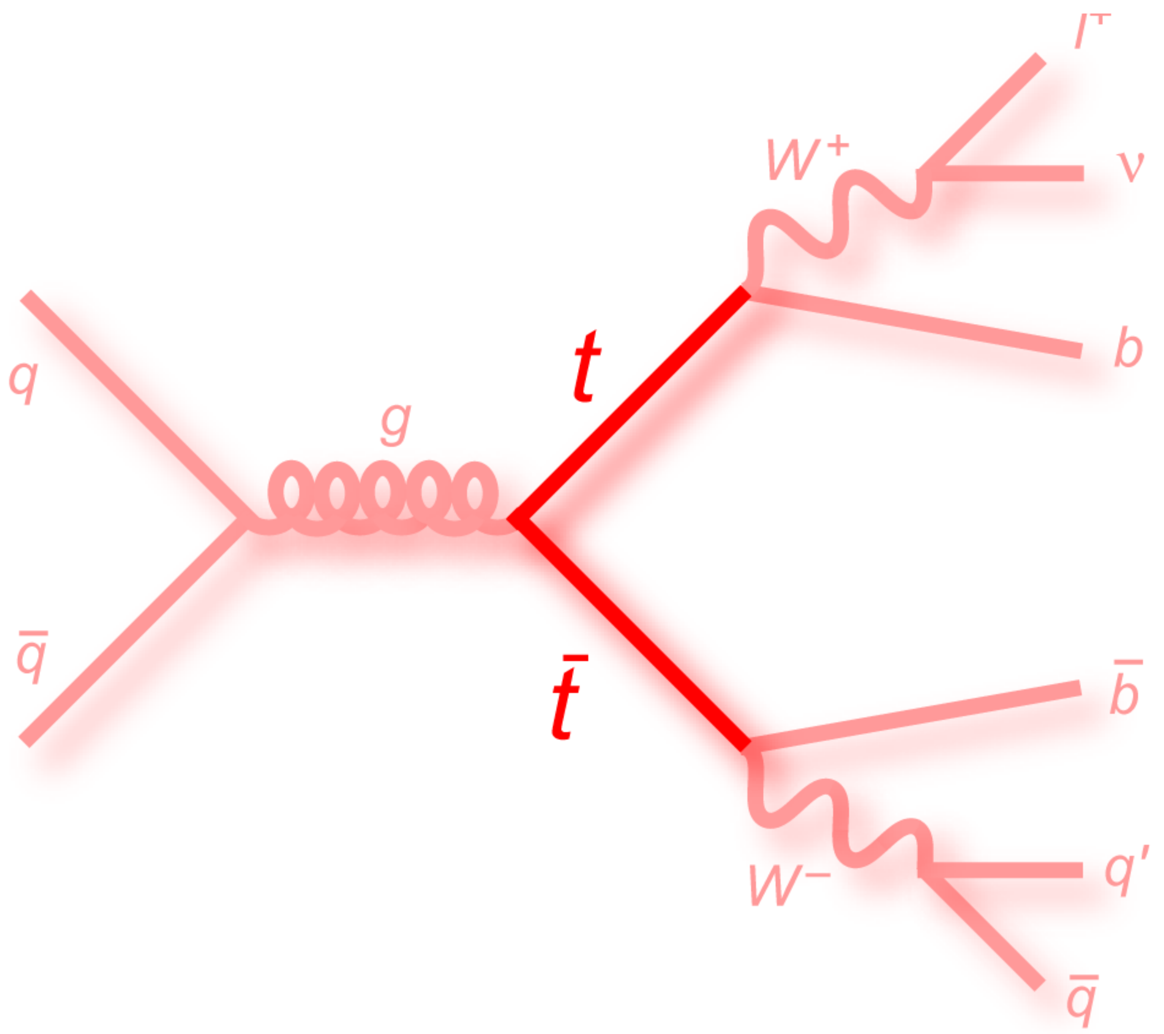
qqVH: Powheg+MiNLO+Pythia 8



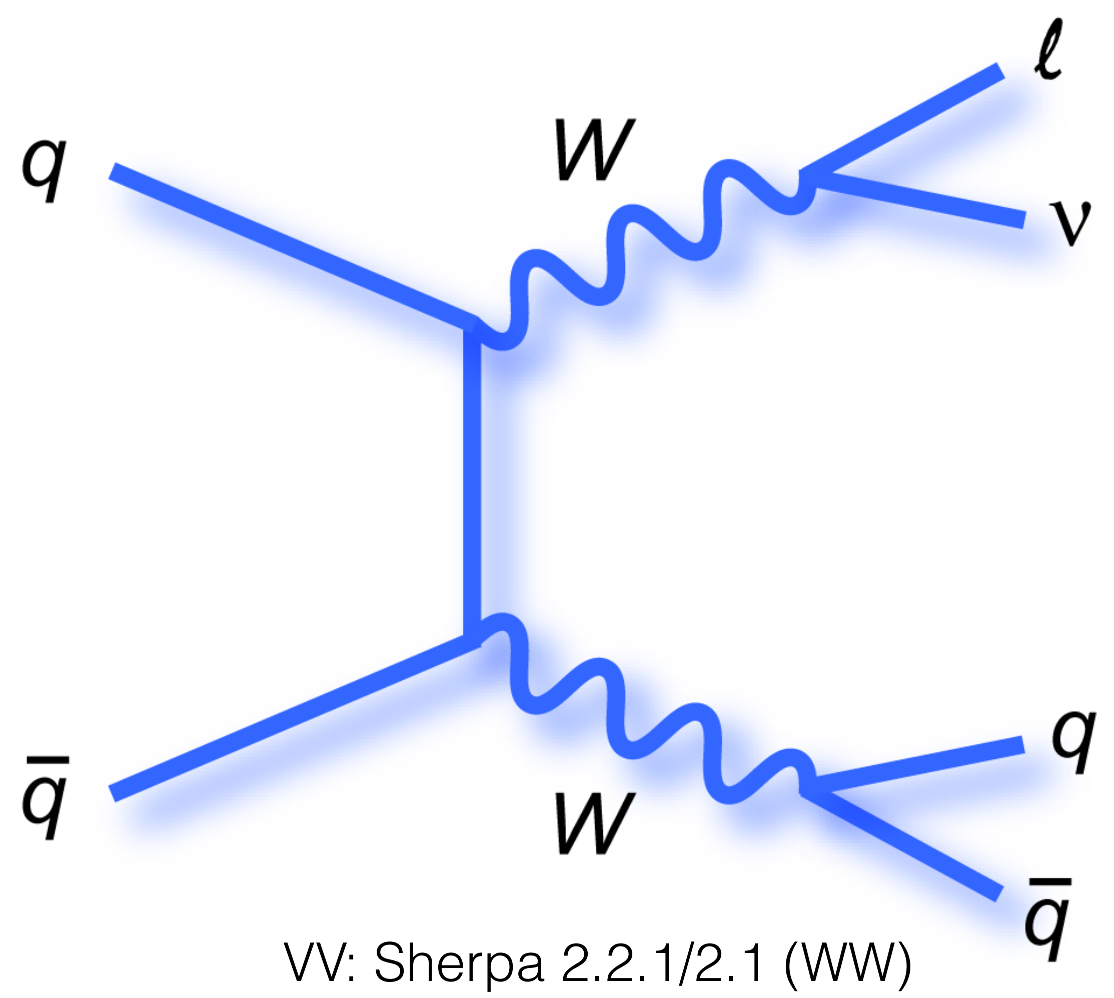
ggZH: Powheg+Pythia 8



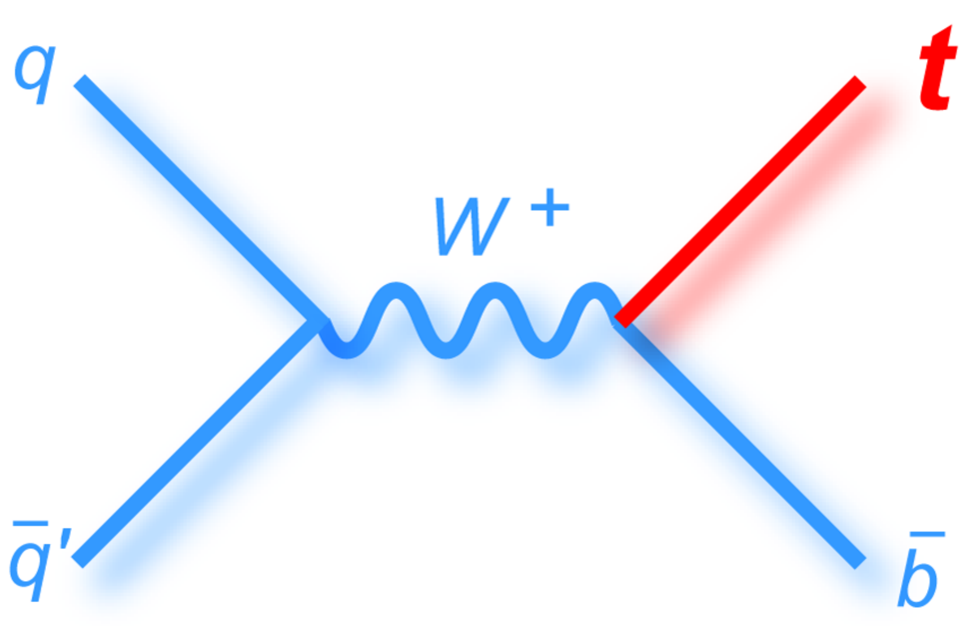
V+jets: Sherpa 2.2.1



ttbar: Powheg+Pythia 8



VV: Sherpa 2.2.1/2.1 (WW)

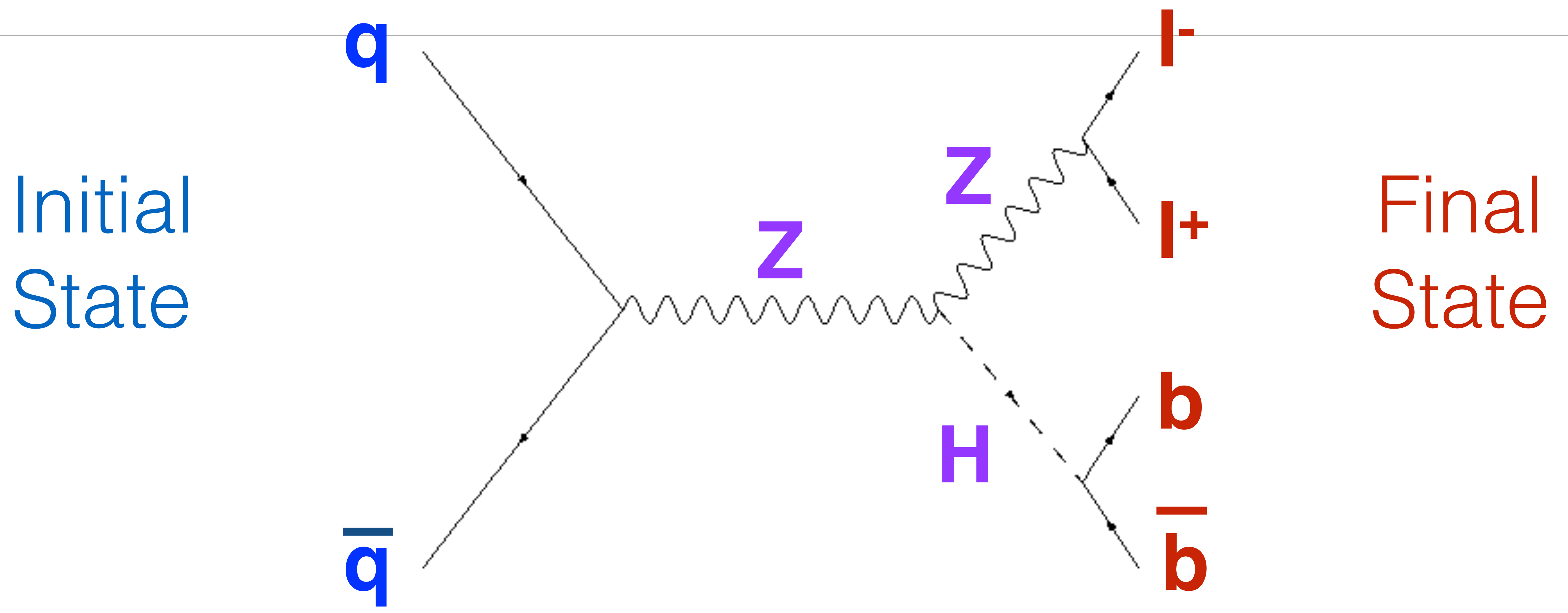


single top: Powheg+Pythia 6

EVENT SELECTION

Collisions—>final state detector "hits"—>collections of labeled 4-vectors

(Automatically done with ATLAS hardware/software)



Category	Requirement
Trigger	un-prescaled, single lepton
Jets	$\geq$ 2 central jets; 2 b-tagged signal jets, harder jet with $p_T > 45$ GeV
Leptons	2 VH-loose leptons ($\geq$ 1 ZH-signal lepton); same (opp) flavor for SR (CR)
$m_{\ell\ell}$	$m_{\ell\ell} \in (81, 101)$ GeV
p_T^V regions (GeV)	$[75, 150)$, $[150, \infty)$

Analyzing Collisions I: Cut and Count

- Can (almost) completely determine number of collisions for background hypothesis using Standard Model + simulation
- Assuming normal statistics, significance is $S/\sqrt{B}$, where S is data events less background prediction
  - Extract p-value from standard tables, etc., etc.
- How to combine multiple measurements/regions?
  - If independent, combine in quadrature
    - Needs to be *physically motivated* (split by pTV, nJet, number of b-tags…)
- What about systematics? Harder to do so…

ANALYZING COLLISIONS II: LIKELIHOOD FITS

- Can also use likelihood (each bin is a Poissonian counting experiment):
    - Parametrize in terms of a signal strength μ (0 is null; 1 is SM expectation) and systematics/NP's θ; S, B are total; s_i, b_i are individual bins; *control regions to improve background estimates*

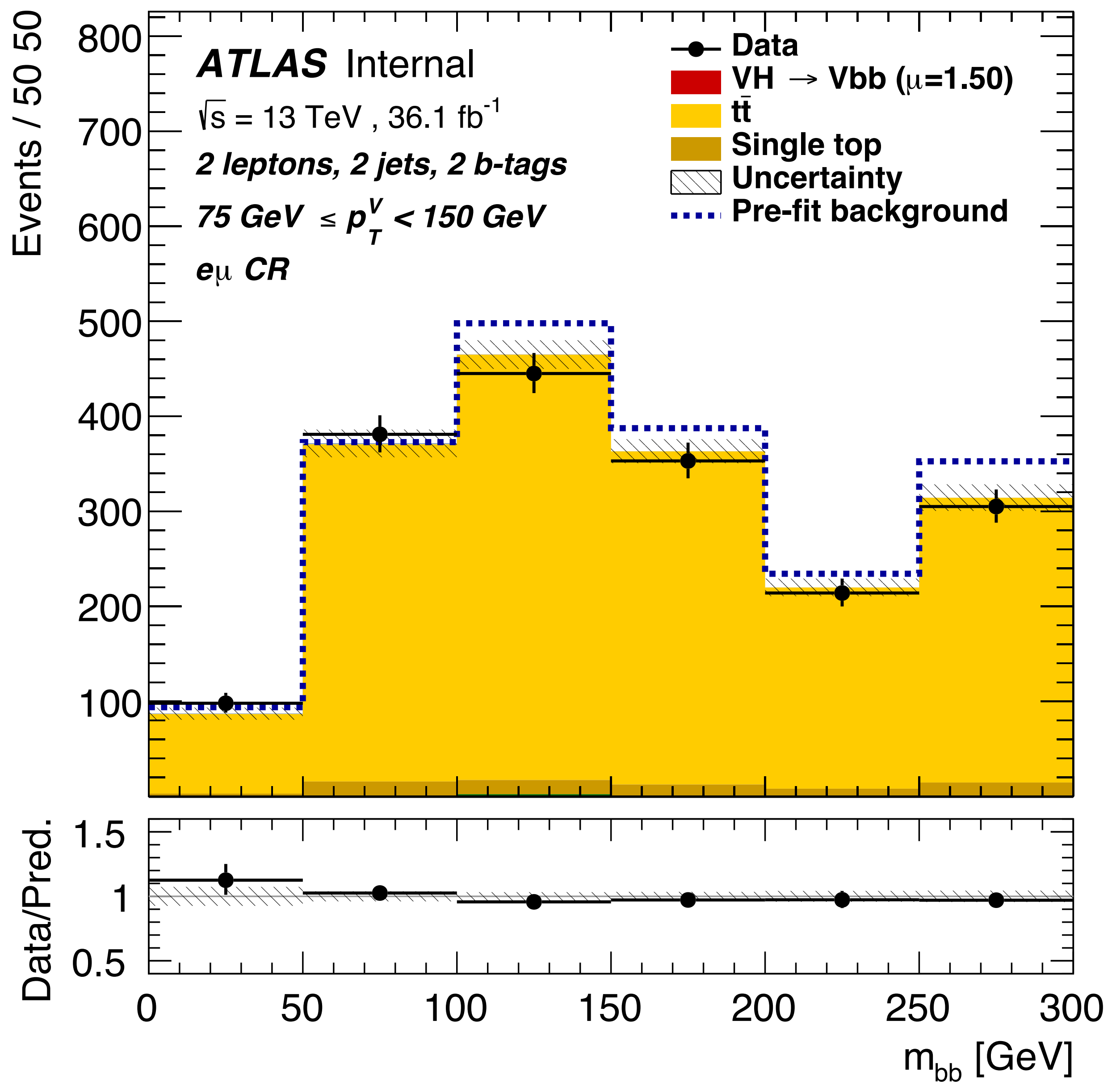
$$\mathcal{L}(\mu,\theta) = \mathrm{Pois}\left(n \mid \mu S + B\right)\left[\prod_{i\in\mathrm{bins}} \frac{\mu s_i + b_i}{\mu S + B}\right] \prod_{j\in\mathrm{NP's}} \mathcal{N}_{\theta_j}\left(\theta_j, \sigma_j^2 \mid 0, 1\right)$$

    - Can do a profile likelihood over μ, test statistic (p-value: use q_0):

$$q_\mu = -2\left(\log\mathcal{L}\left(\mu, \hat{\hat{\theta}}_\mu\right) - \log\mathcal{L}\left(\hat{\mu}, \hat{\theta}\right)\right)$$

Analyzing Collisions III: Input Distributions

- Introduce multiple bins per region: binned distributions
- Can be physics quantities
  - Reconstructed Higgs mass
- And/Or MVA classifiers
  - Use **event level variables**: mJJ, pTV, dRBB…



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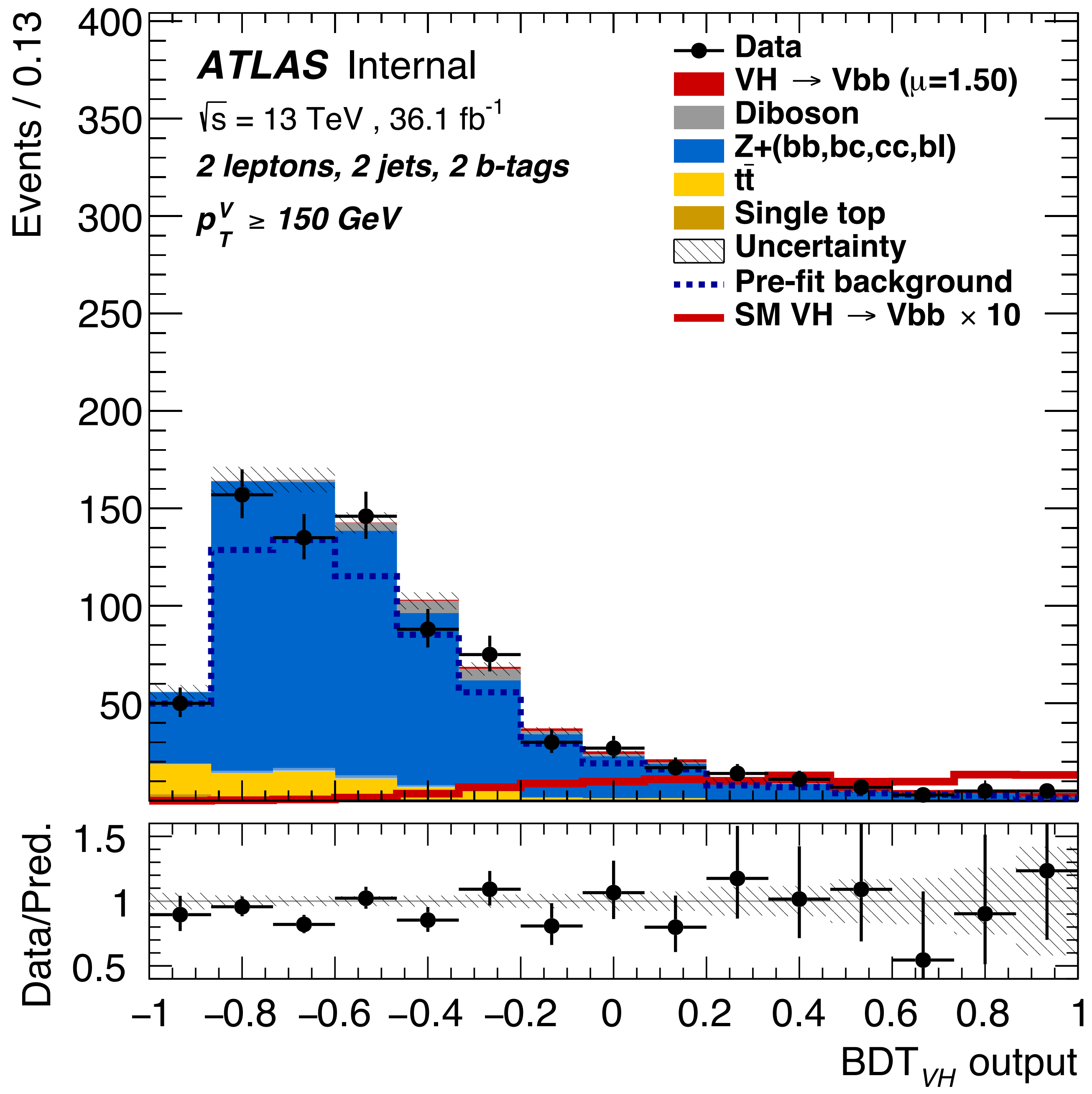

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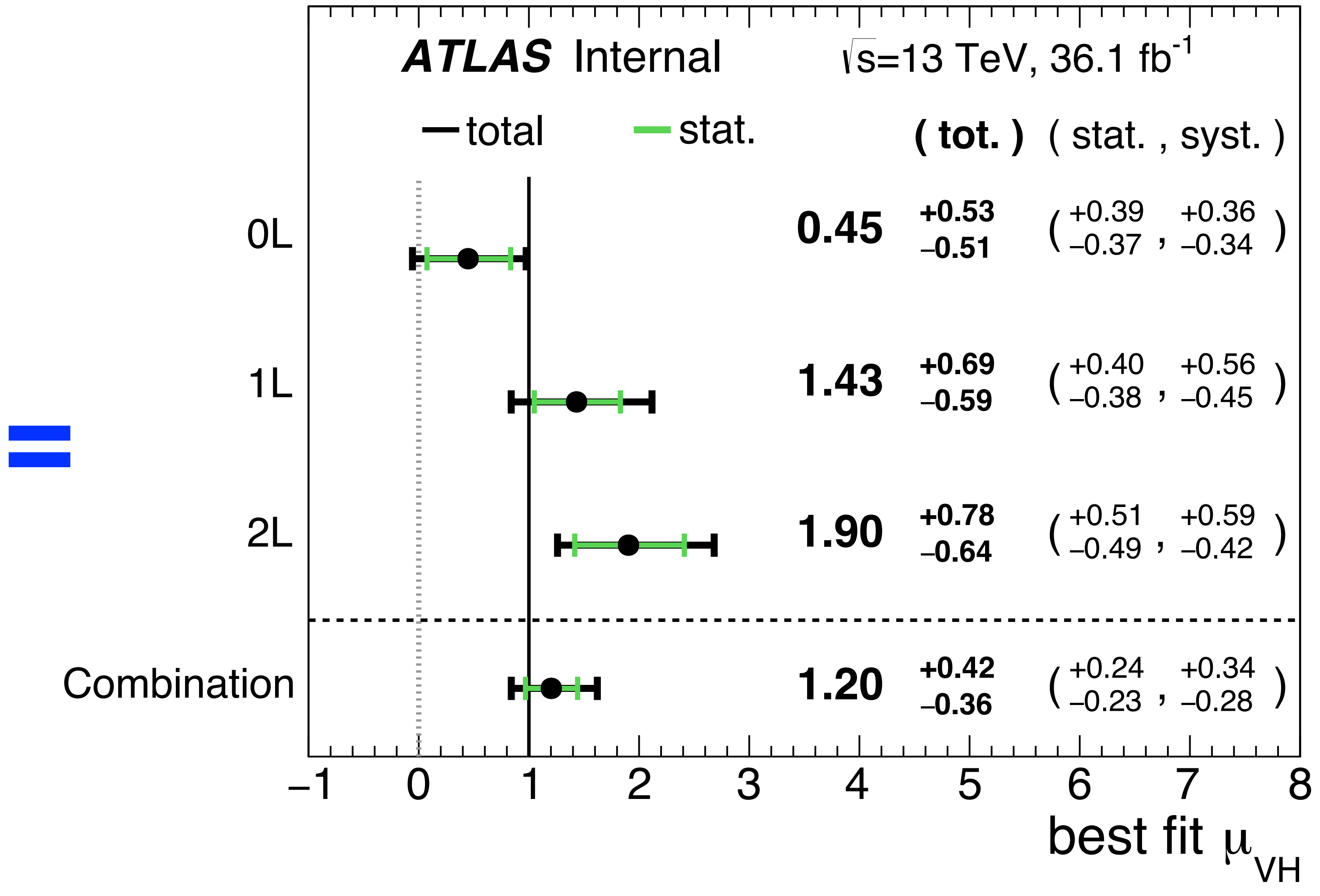
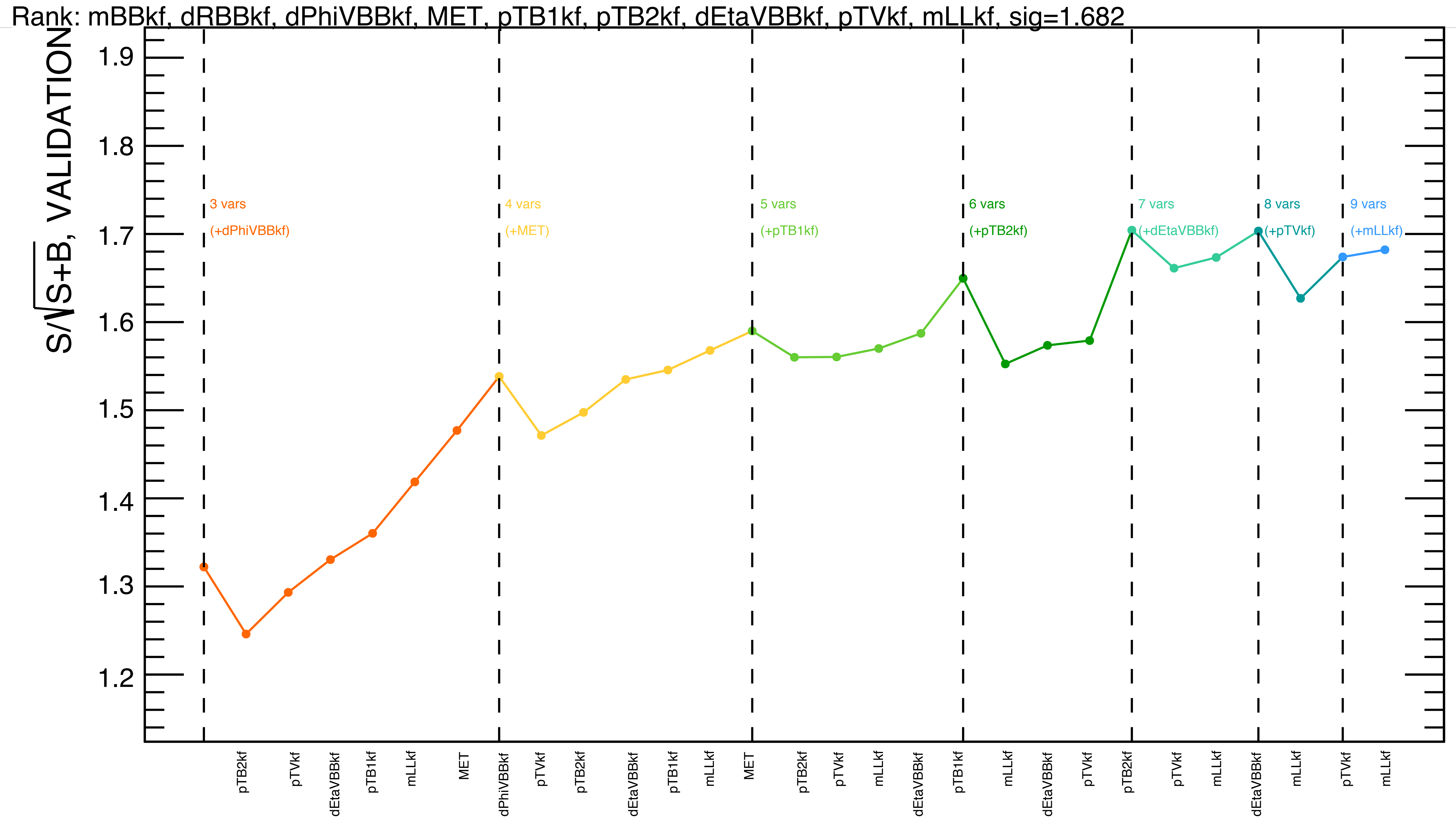


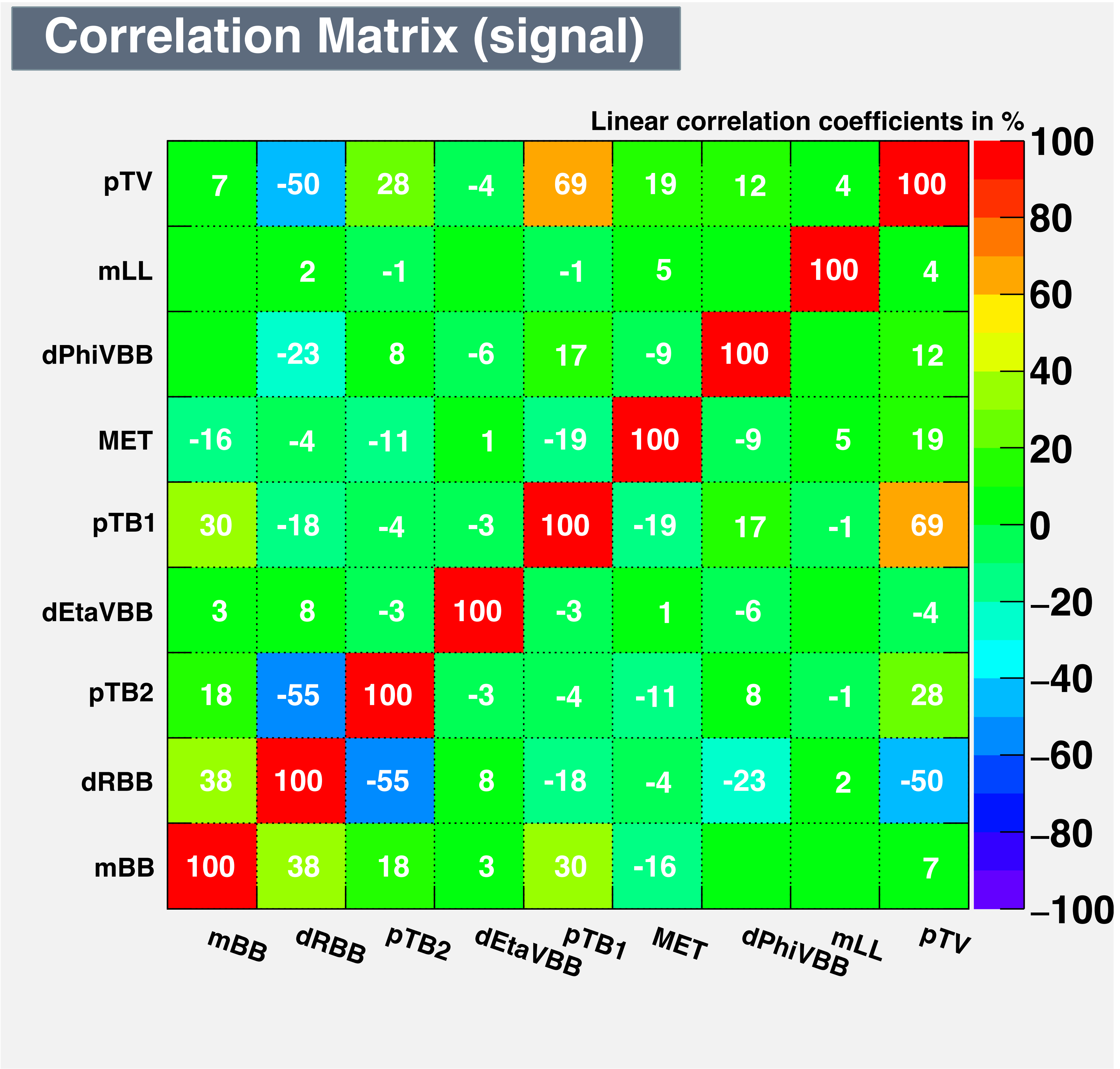
MVA INPUTS: THE USUAL WAY

1. Start with a list of variables known to be discriminating from past experience
2. Use an ML method known to be useful (e.g. BDT with certain settings)
3. Iteratively rank variables until no more gain in sensitivity



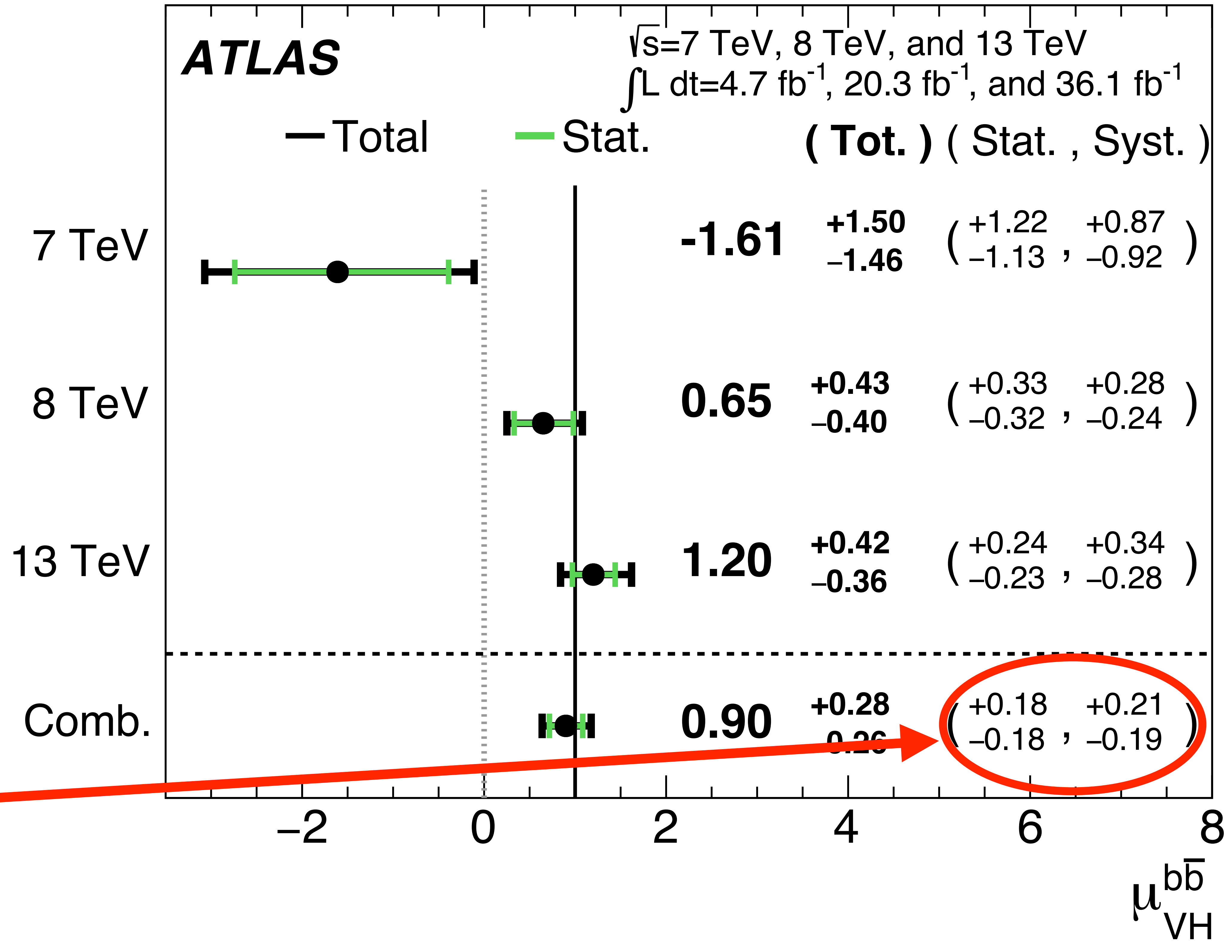
Standard MVA Variables

- Traditionally useful variables
  - Higgs: mBB (~125 GeV), b-jet separation
  - VH: d(Eta|Phi)VBB
  - Z: mLL, pTV
  - MET: ttbar veto
  - Jet pT's: pTB1, pTB2, pTJ3
  - (MV2c scores)
- Non-zero correlations
  - Repeated information



Why Look at Other Variables?

- The promise of new variable sets often falls into two categories:
    1. A clever treatment of invisible final state objects to boost sensitivity
    2. *More orthogonal basis of description* to better constrain systematics
- VHbb is becoming systematics limited



Lorentz Invariants (LI)

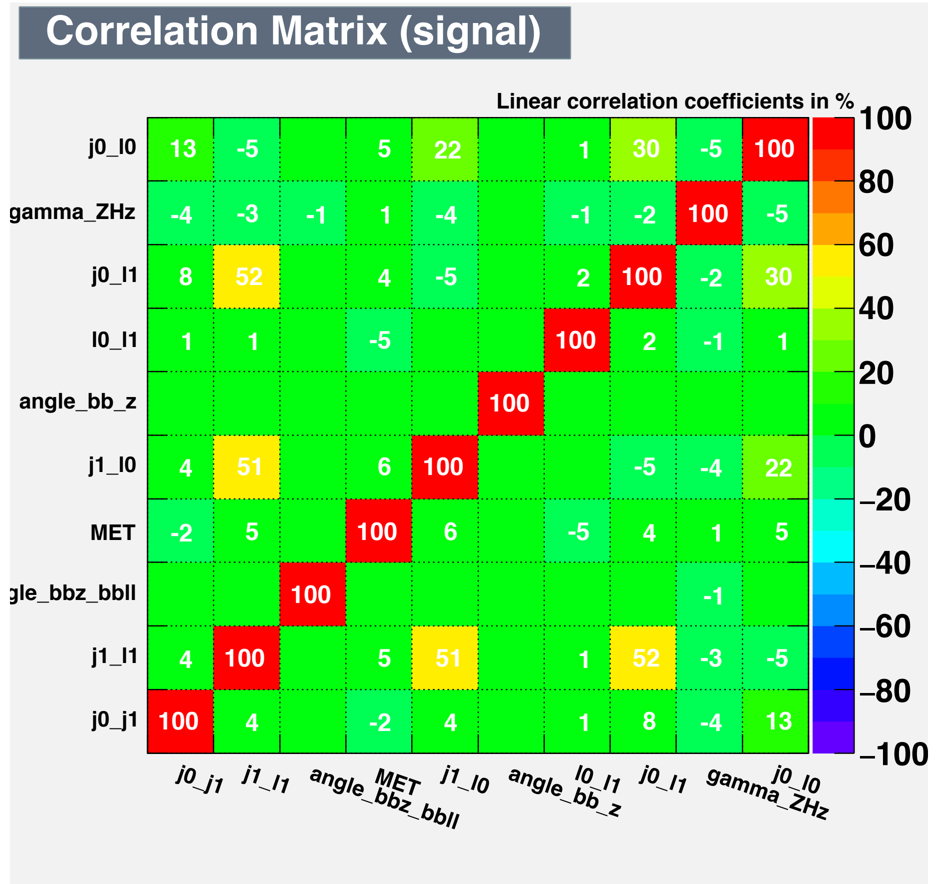
- Lorentz invariant and angles used in BDT training assume a closed, ***llbb*** (labeled *j* because jets not. nec. *b*-tagged) topology
  - 16 quantities define system:
    - -4 invariant masses not so useful
    - Beam axis symmetry (-1)
    - Boost mostly along *z* (-2 angles)
  - 9 remaining = 6 inner products + 3 angles
  - Variables should be very nearly orthogonal
- 3-jet case, we currently ignore the third jet
- Closed topology, no obvious way to handle MET, but…
  - MET has low correlations in practice, just add it in by itself

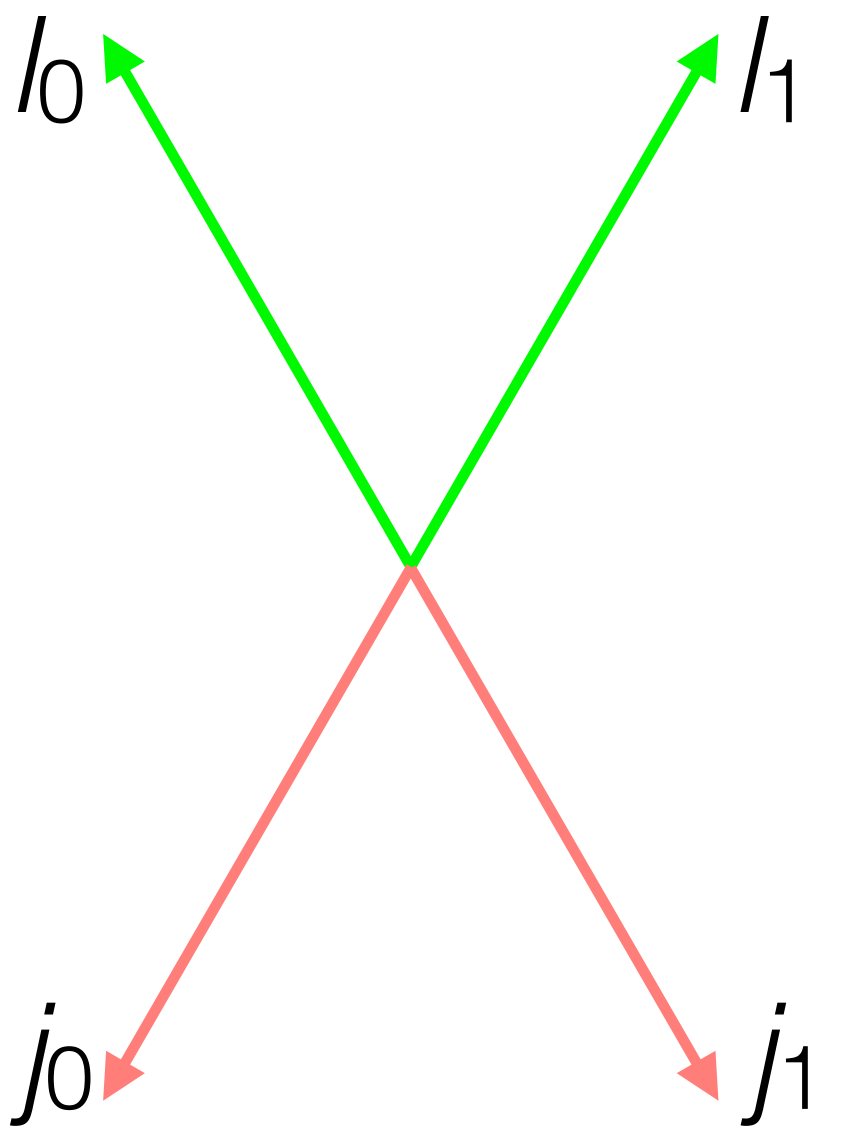
$$\langle j_0 | j_1 \rangle \qquad \langle j_1 | l_0 \rangle$$
$$\langle j_1 | l_1 \rangle \qquad \langle l_0 | l_1 \rangle$$
$$\langle j_0 | l_1 \rangle \qquad \langle j_0 | l_0 \rangle$$

inner products

$$\angle\left(\overrightarrow{bb} \times \hat{z}, \overrightarrow{bb} \times \overrightarrow{ll}\right)$$
$$\angle\left(\overrightarrow{bb}, \hat{z}\right)$$
$$\vec{\gamma}_{ZH} \cdot \hat{z}$$

angles





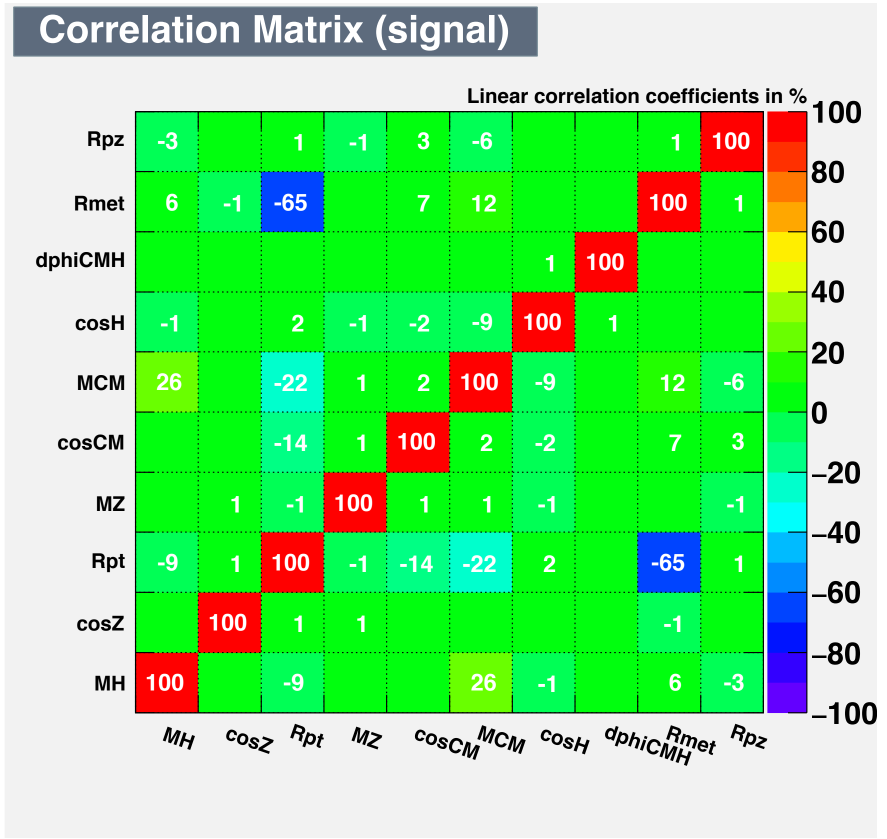
$ZH \to ll b\bar{b}$ topology

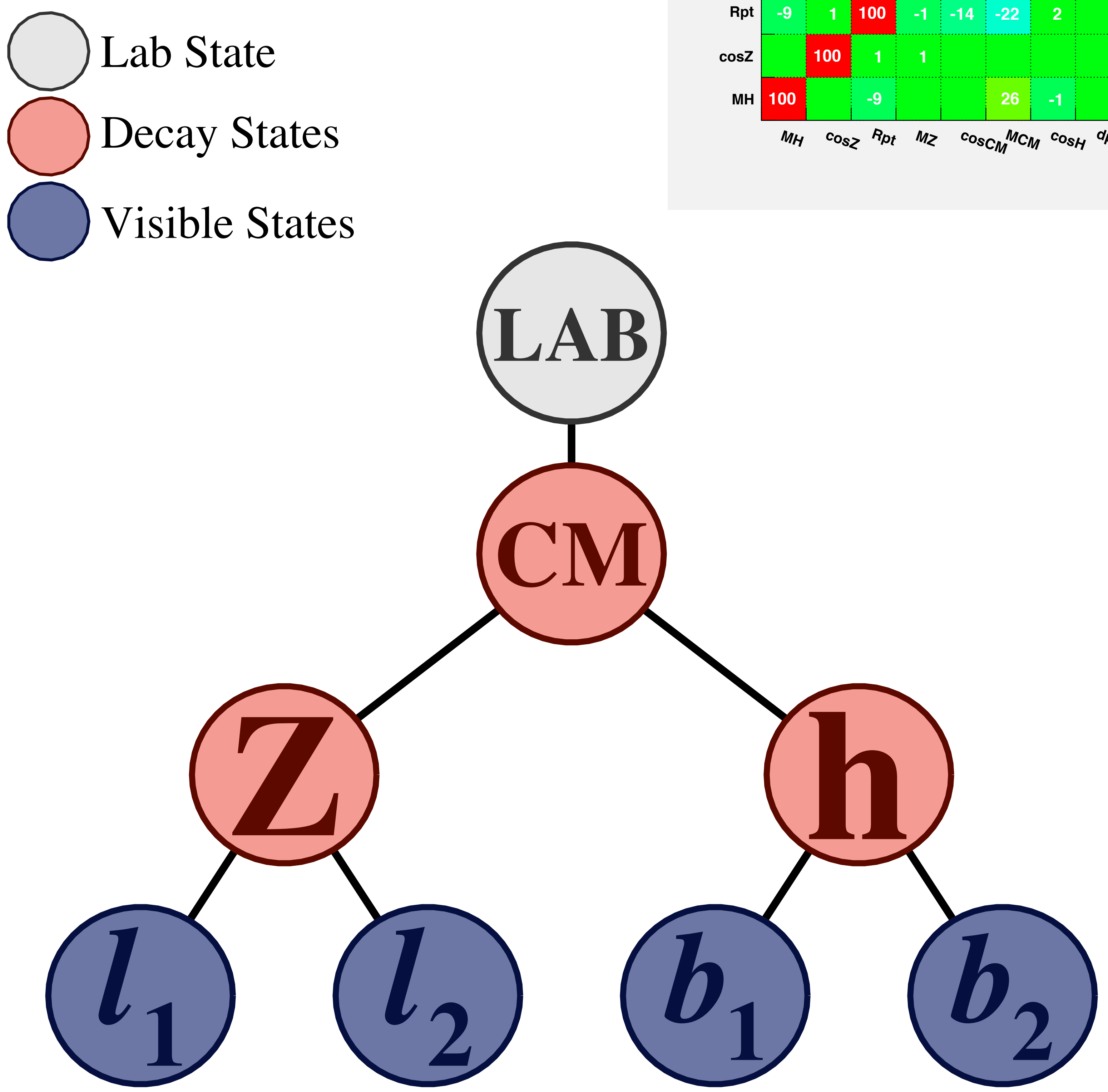
RestFrames Variables

- RestFrames (RF): most natural frame to study objects in a decay tree is their production (rest) frame
  - Each frame has associated with it: Mass scale + boost from parent frame
- Normally, frames/boosts can't be completely determined (use, e.g. jigsaw variables), but in ZHllbb, they can—good test of concept
- Also useful: contextualized event level quantities as ratios

$$R_{p_T} = \frac{p_{T,CM}}{p_{T,CM} + M_{CM}}$$

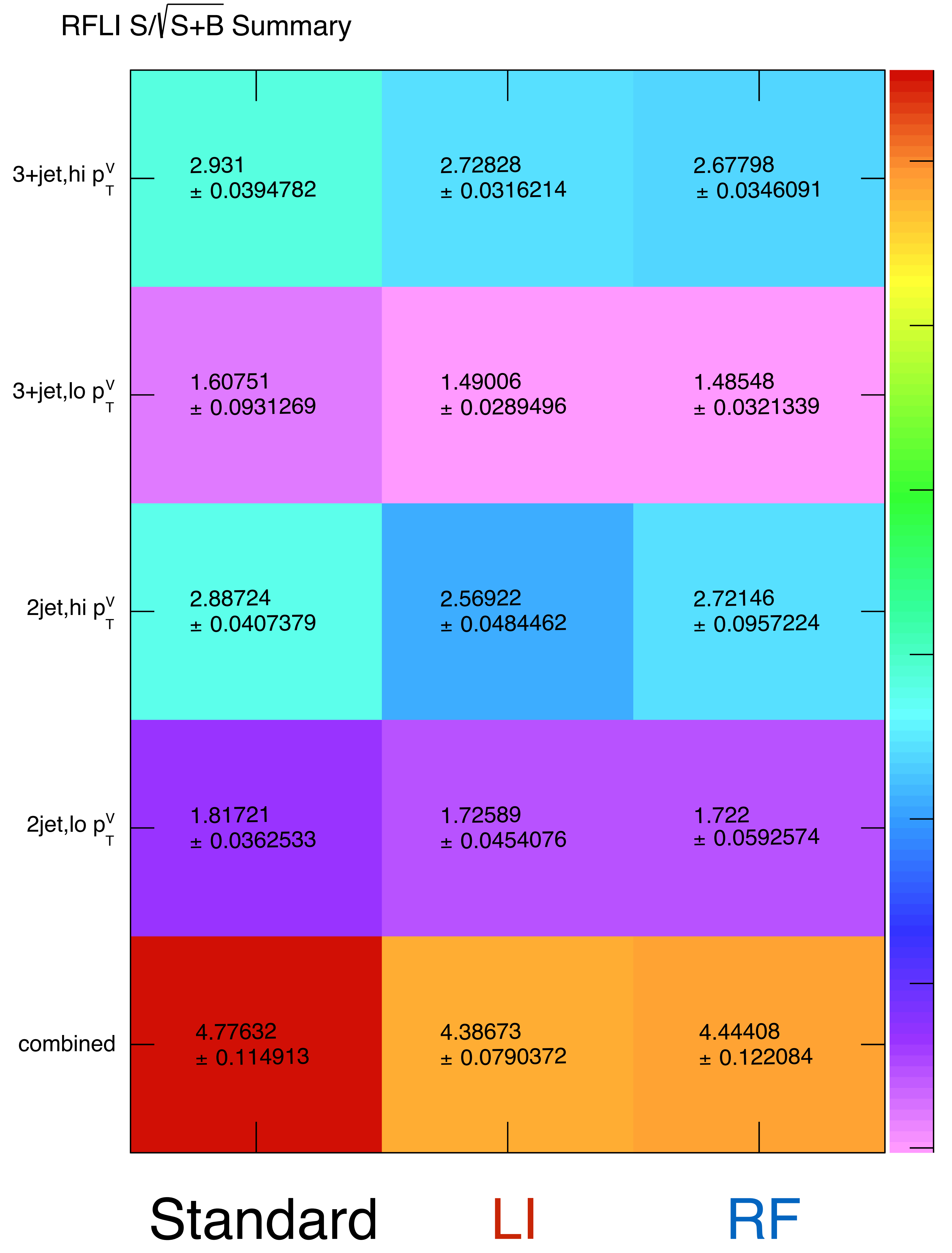
- Variables:
  - Masses: MCM, MH, MZ
  - Angles: cosCM, cosH, cosZ, dphiCMH
    - cosines are between parent and production axis
  - Rpt, Rpz, Rmet





Stats Only Performance

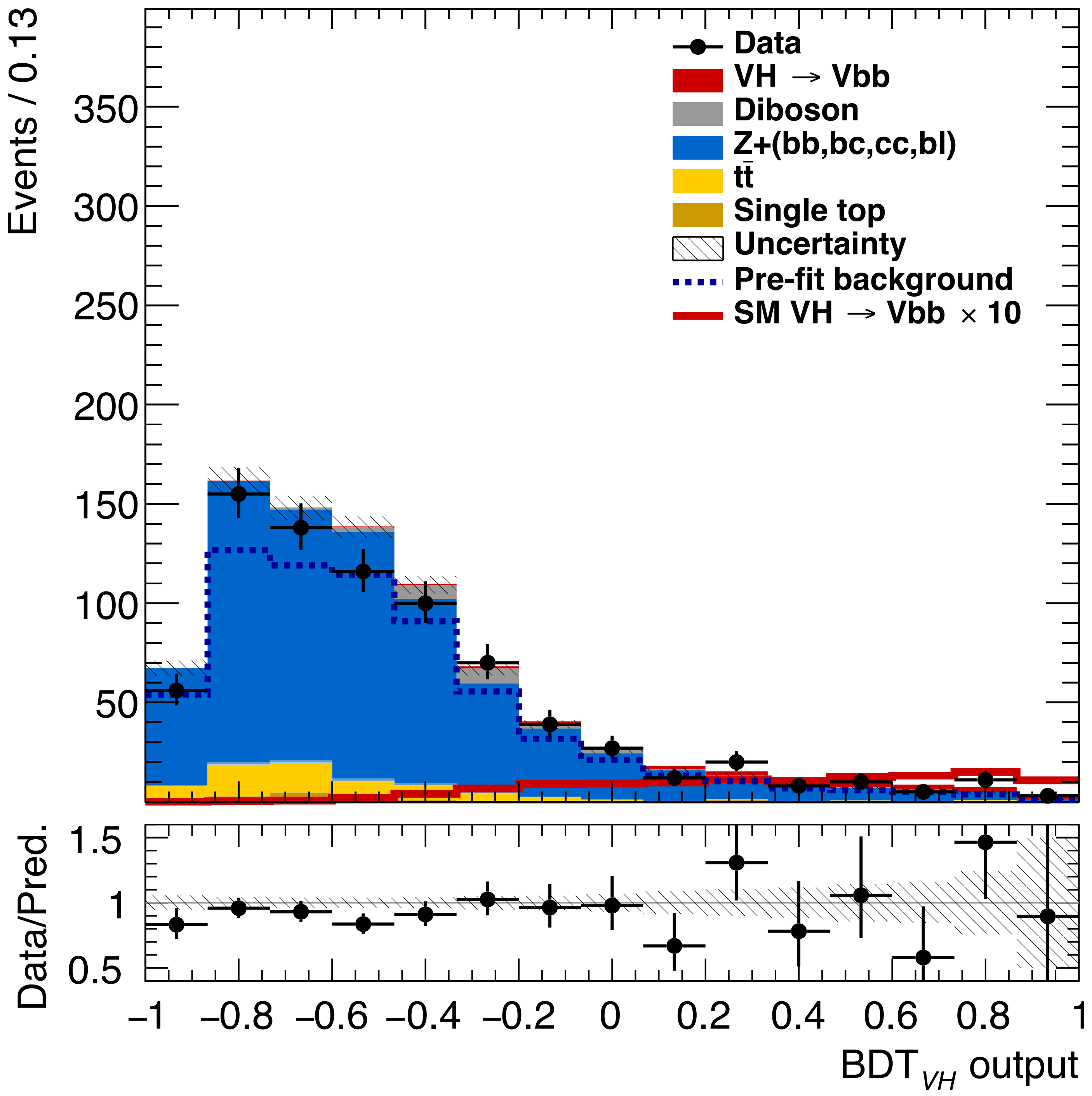
- Standard variables perform best in a stats only context
  - Standard (4.78±0.11)
  - LI (4.39±0.08)
  - RF (4.44±0.12)
  - Not surprising since analysis setup optimized for standard MVA
    - So all three fairly consistent
  - Final state is closed; confirms that *new variables don't contain any new information*



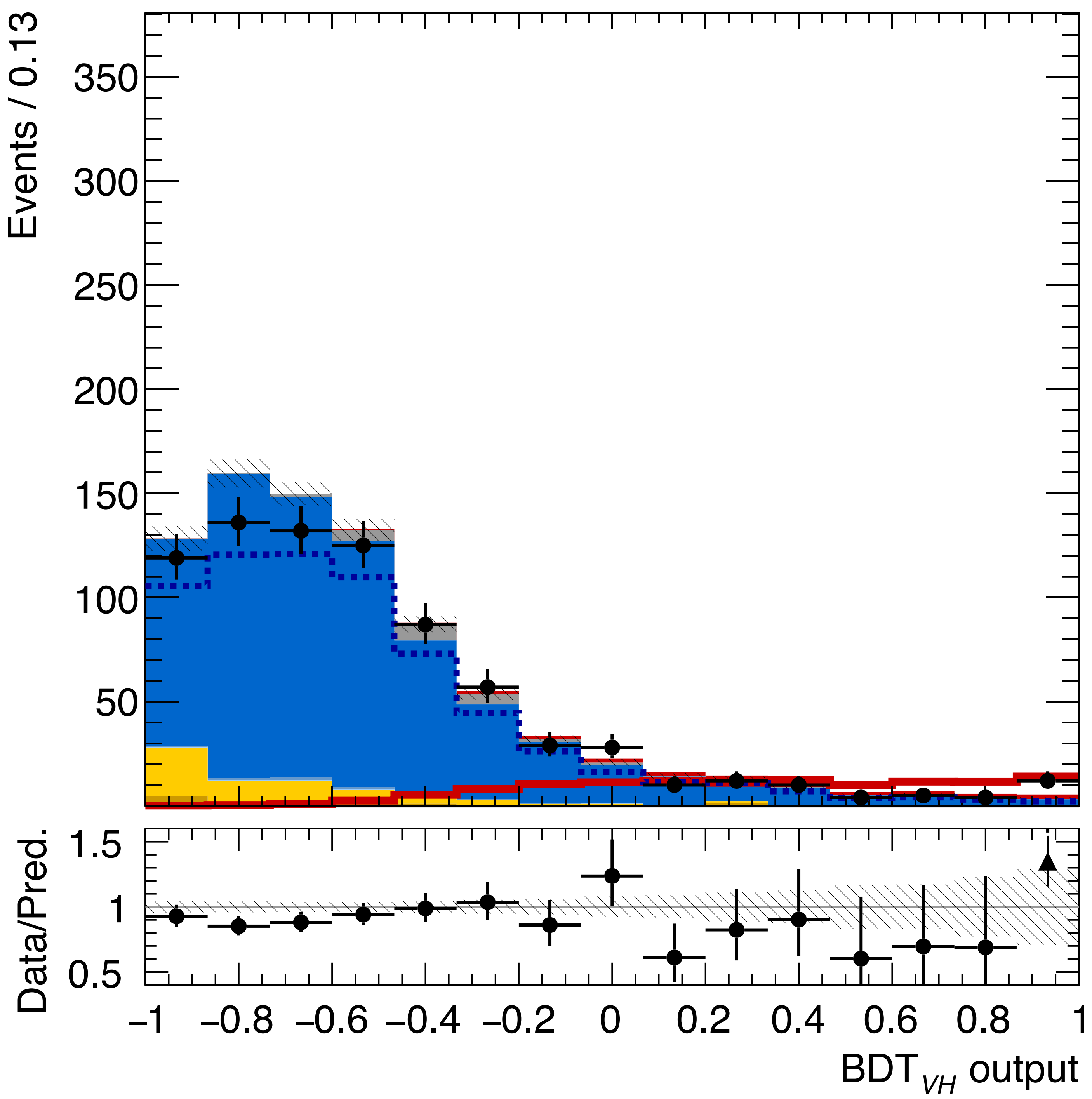
SOME POSTFIT PLOTS

- BDT output distributions
- Comparable agreement with simulation/movement in fits

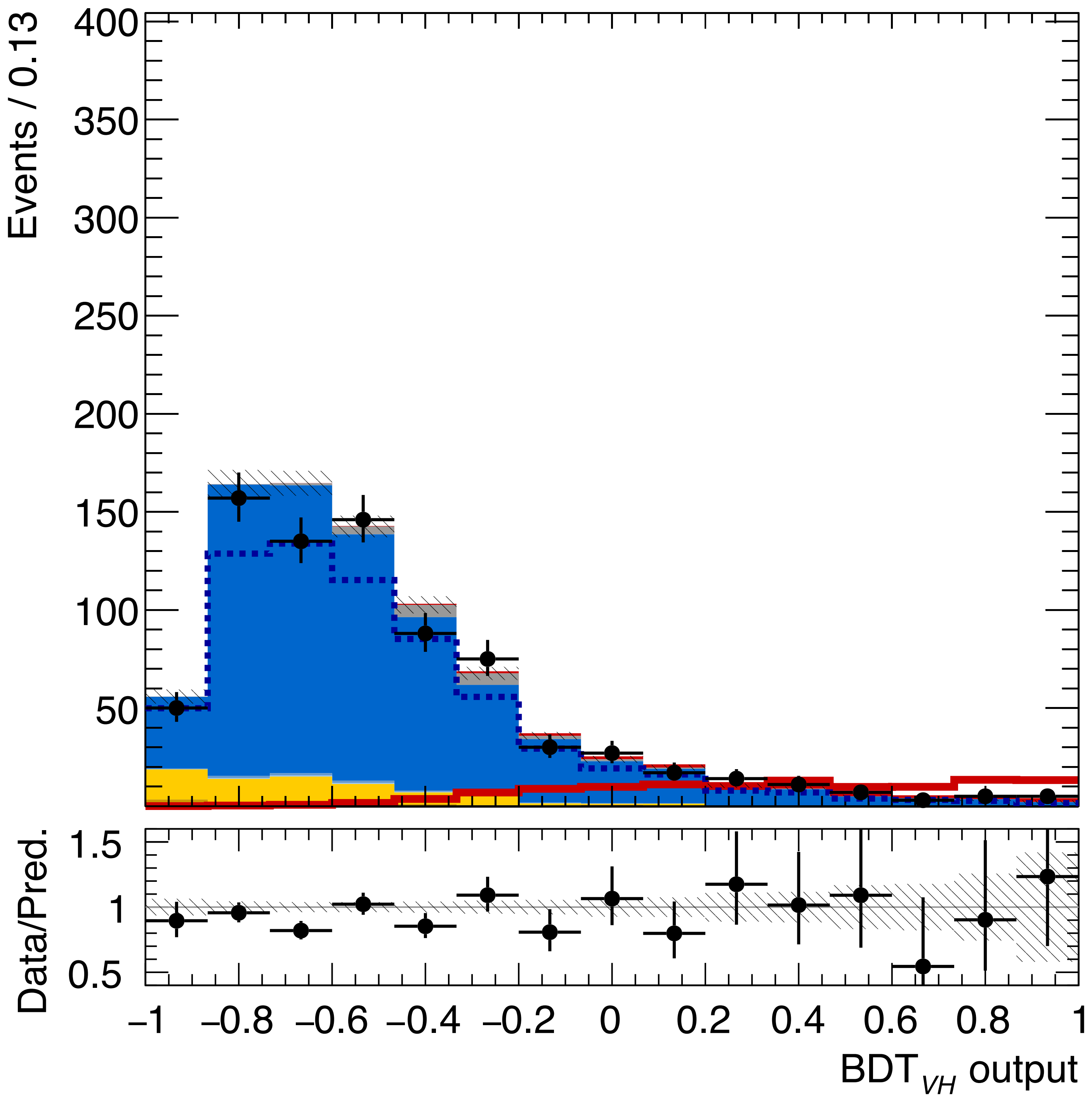
Standard



LI



RF



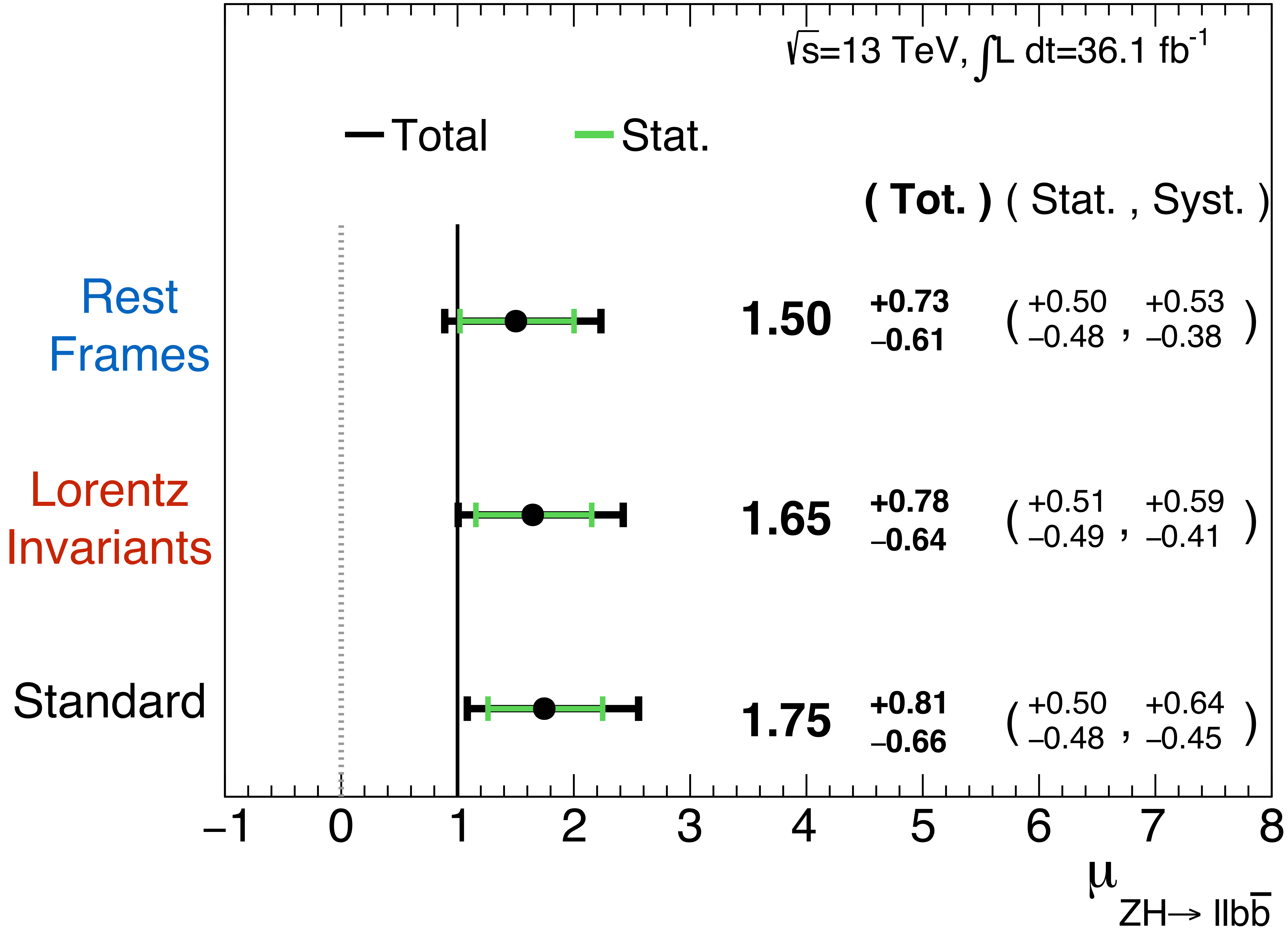
Sensitivities: Data, Best Fit Mu

- See what happens with best fit μ values
  - This value needed to contextualize sensitivities
- Again, all three comparable

	Standard	LI	RF
Expected (data)	1.76	1.73	1.80
Observed (data)	2.87	2.79	2.62
Best fit μ	1.75	1.65	1.50

Signal Strengths and Errors

- Best fit μ values are very much consistent with each other
- LI and RF sets reduce systematics error compared to Standard set
  - LI by 7.5%
  - RF by 16%



Measurement Combinations

- Combining lepton channels is easy (simply add 0+1-lep regions)

$$\mathcal{L}(\mu,\theta) = \mathrm{Pois}\left(n\,|\mu S + B\right)\left[\prod_{i\in\mathrm{bins}} \frac{\mu s_i + b_i}{\mu S + B}\right] \prod_{j\in\mathrm{NP's}} \mathcal{N}_{\theta_j}\left(\theta_j, \sigma_j^2\,|0,1\right)$$

- Different measurements
    - Run 1 (7+8 TeV): 1.37σ, μ_{obs}=0.51±0.39
    - Run 2 (13 TeV): 3.54σ, μ_{obs}=1.20±0.39
    - Correlate parameter of interest (μ), signal NP's (designed for correlation), but what about the rest of the fit model?
        - Correlation scheme must be validated
    - Important (highly ranked) NP categories: JES, b-tagging (modeling)

JES Fits

- JES correlation scheme also has very little impact on breakdowns
  - Effective NP unfolding does not matter
  - Neither does the strong vs. weak correlation scheme
- Use weak scheme, uncorrelated effective (only BJES correlated)

	Comb Unfold	Comb Eff	Strong Unfold	Strong Eff
$\Delta\hat{\mu}$	0.0009		0.0025	
Total	$^{+0.269}_{-0.254}$	$^{+0.27}_{-0.255}$	$^{+0.27}_{-0.255}$	$^{+0.27}_{-0.255}$
DataStat	$^{+0.181}_{-0.177}$	$^{+0.181}_{-0.177}$	$^{+0.181}_{-0.177}$	$^{+0.181}_{-0.178}$
FullSyst	$^{+0.199}_{-0.183}$	$^{+0.2}_{-0.183}$	$^{+0.2}_{-0.183}$	$^{+0.201}_{-0.183}$
Jets	$^{+0.0387}_{-0.032}$	$^{+0.041}_{-0.0337}$	$^{+0.0425}_{-0.0329}$	$^{+0.0432}_{-0.0338}$
BTag	$^{+0.0975}_{-0.0933}$	$^{+0.098}_{-0.0936}$	$^{+0.0979}_{-0.0935}$	$^{+0.098}_{-0.0936}$

Flavor Tagging

	Comb Eff	BTag B0	B0 8TeV Not Flipped
Exp. Sig.	3.998	4.127	3.921
Obs. Sig.	3.571	3.859	3.418
Exp. Limit	$0.51^{+0.2}_{-0.143}$	$0.5^{+0.196}_{-0.14}$	$0.517^{+0.202}_{-0.144}$
Obs. Limit	1.37	1.41	1.35

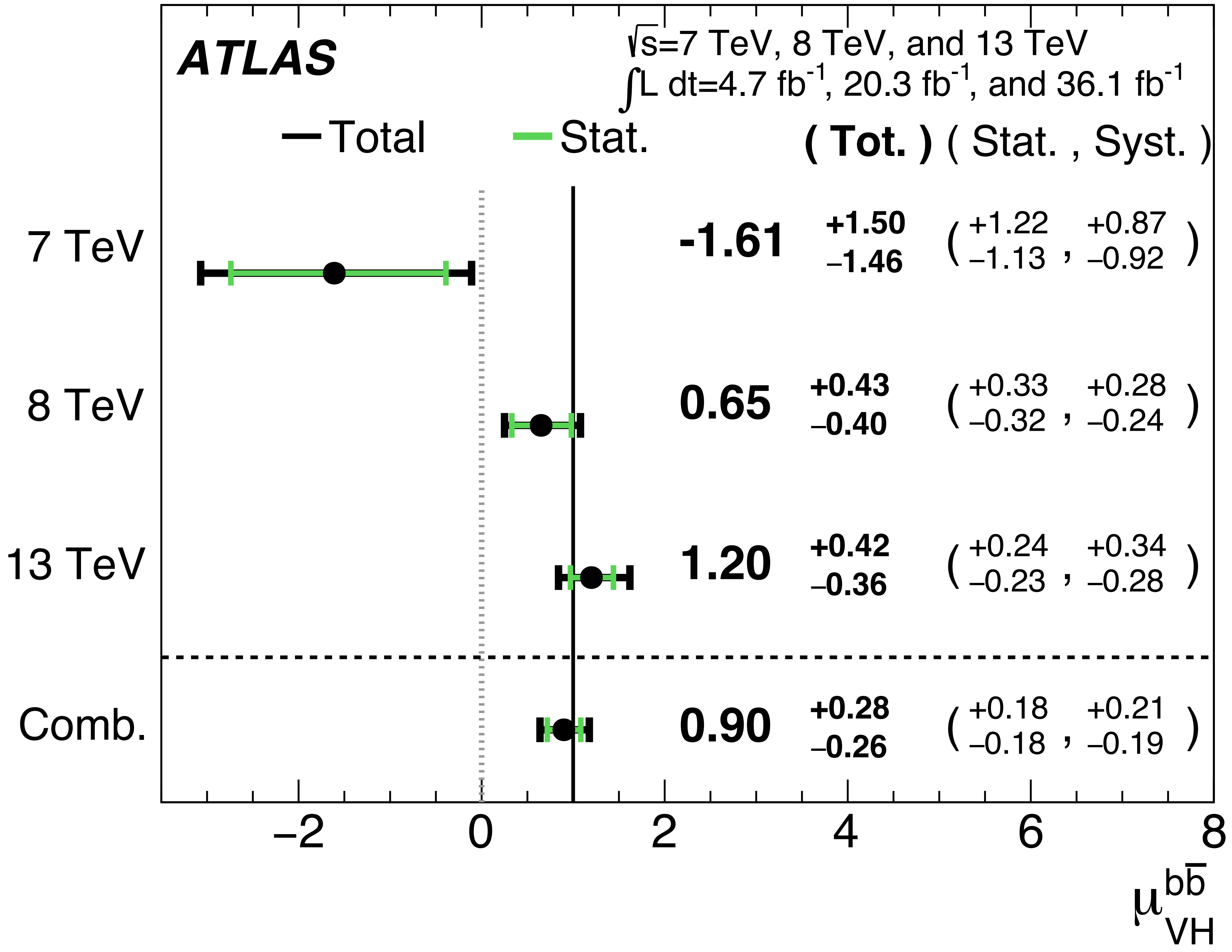
	Comb Eff	BTag B0	B0 8TeV Not Flipped
$\lvert\Delta\hat{\mu}\rvert$	—	0.0446	0.0268
$\hat{\mu}$	0.8985	0.9431	0.8717
Total	+0.278 / -0.261	+0.275 / -0.256	+0.282 / -0.263
DataStat	+0.185 / -0.181	+0.180 / -0.177	+0.189 / -0.186
FullSyst	+0.208 / -0.188	+0.207 / -0.186	+0.209 / -0.186
BTag	+0.077 / -0.076	+0.071 / -0.068	+0.079 / -0.075
BTag b	+0.062 / -0.059	+0.055 / -0.049	+0.064 / -0.060

- Much greater potential impact here
- Physical correspondence less clear
  - Also taken to be "not important" (clear path for future improvement)

CORRELATION SCHEME

7 TeV NP	8 TeV NP	13 TeV NP
ATLAS_BR_bb		SysTheoryBRbb
SysTheoryQCDscale_ggZH		SysTheoryQCDscale_ggZH
SysTheoryQCDscale_qqVH		SysTheoryQCDscale_qqVH
—	SysTheoryPDF_ggZH_8TeV	SysTheoryPDF_ggZH
—	SysTheoryPDF_qqVH_8TeV	SysTheoryPDF_qqVH
—	SysTheoryVHPt_8TeV	SysVHNLOEWK
SysJetFlavB_7TeV	SysJetFlavB_8TeV	SysJET_21NP_JET_BJES_Response

COMBINED FIT RESULTS



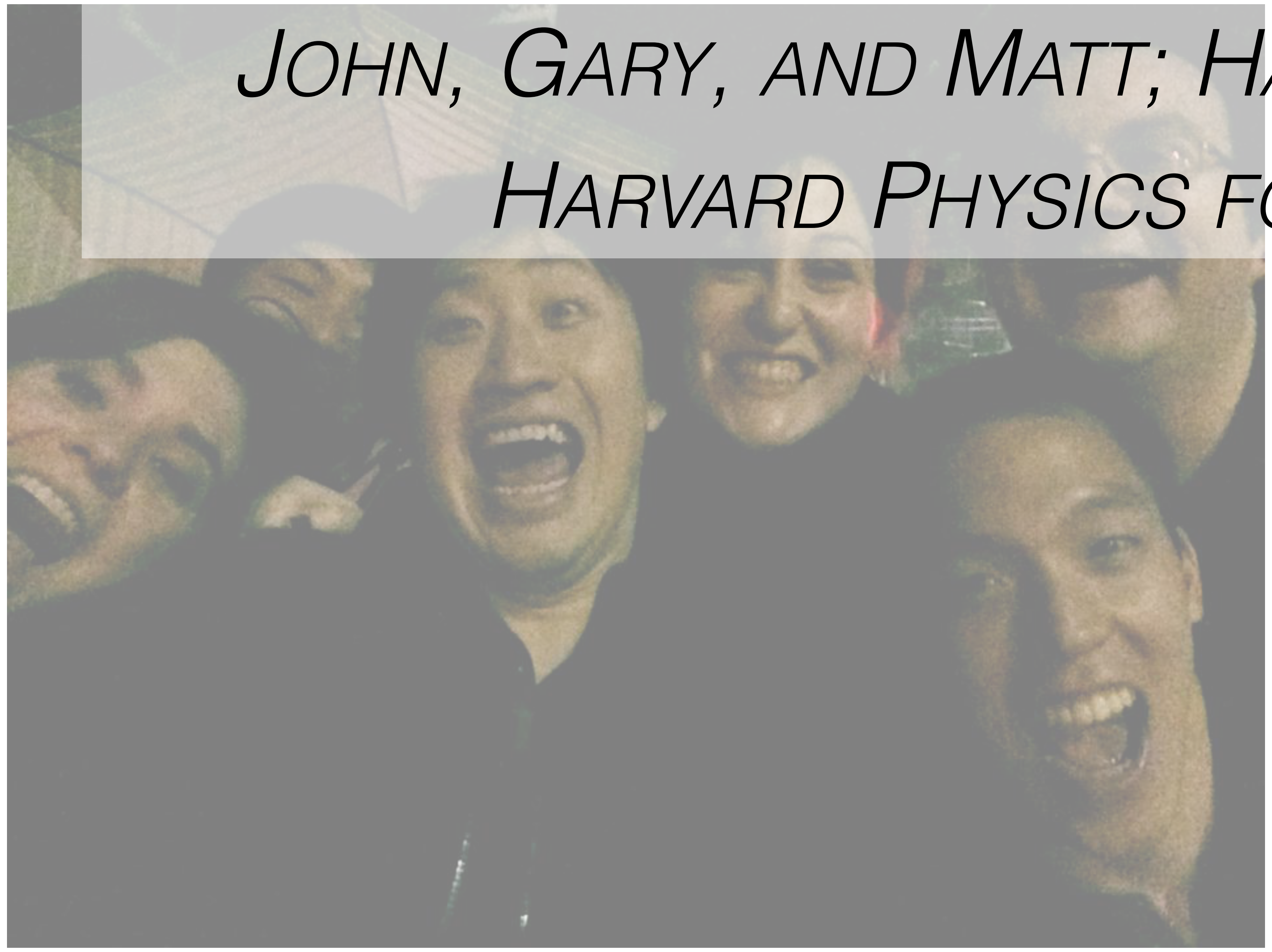
- Significance of 3.57σ (4.00σ, μ=0.95 with minimal flavor tagging correlation)
- First evidence of SM VHbb

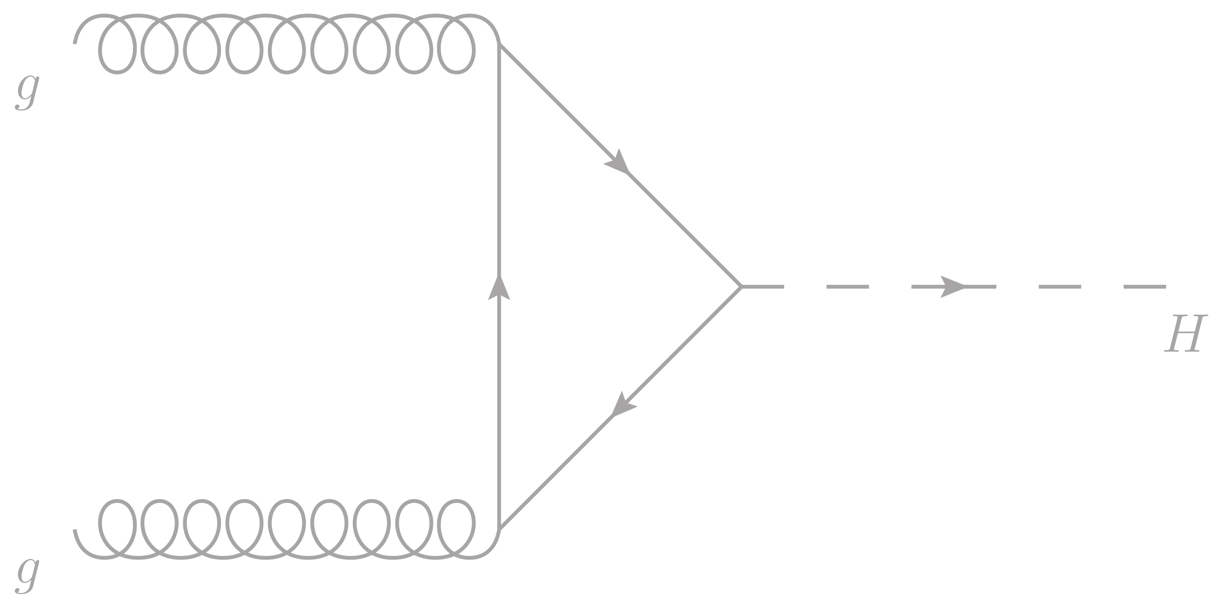
Closing Thoughts

- First evidence of Hbb now in the books
  - 5σ is only a matter of time
- Significance is important for discovery
  - But not for precision tests of the Standard Model
- Precision in observables like μ will likely make or break the SM
  - Combinations and new generically orthogonal decompositions are two pieces of the puzzle

Thank You!

John, Gary, and Matt; Harvard ATLAS members past and present; Harvard Physics folks; Family and Friends (Hi, Mom!)





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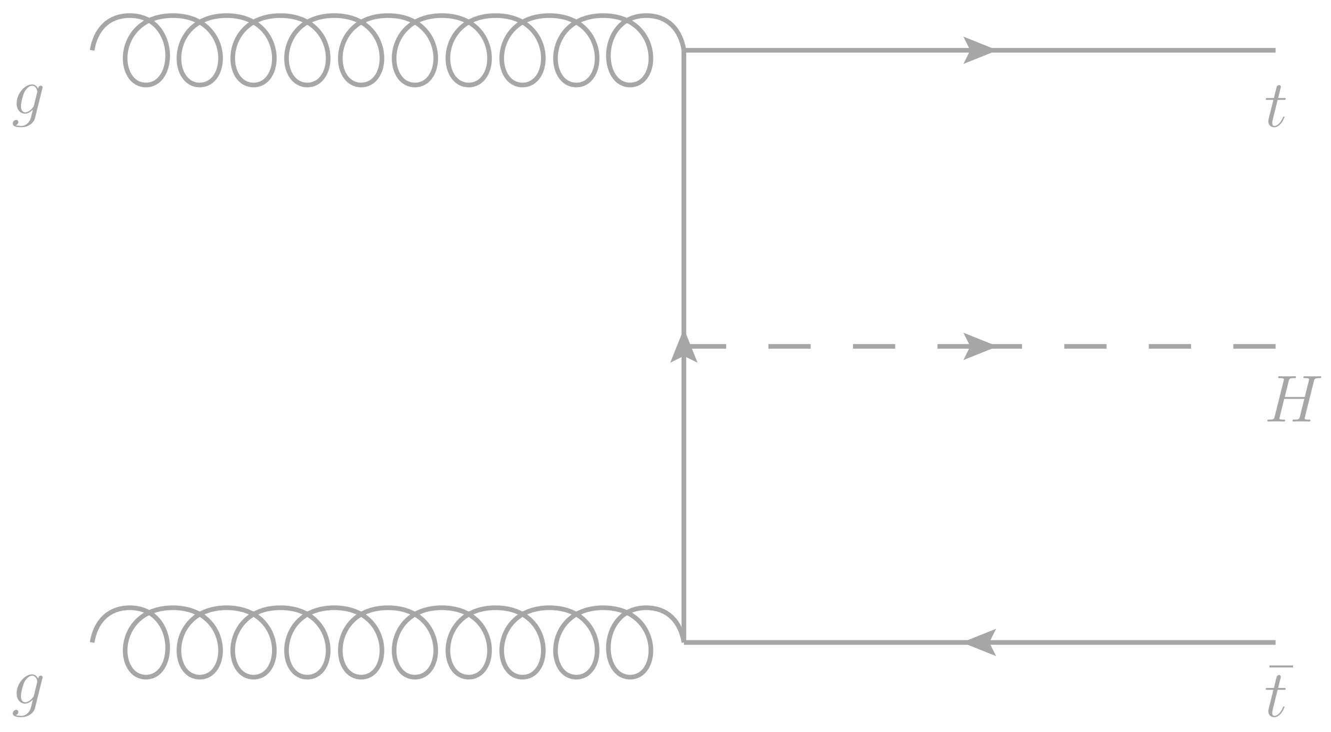
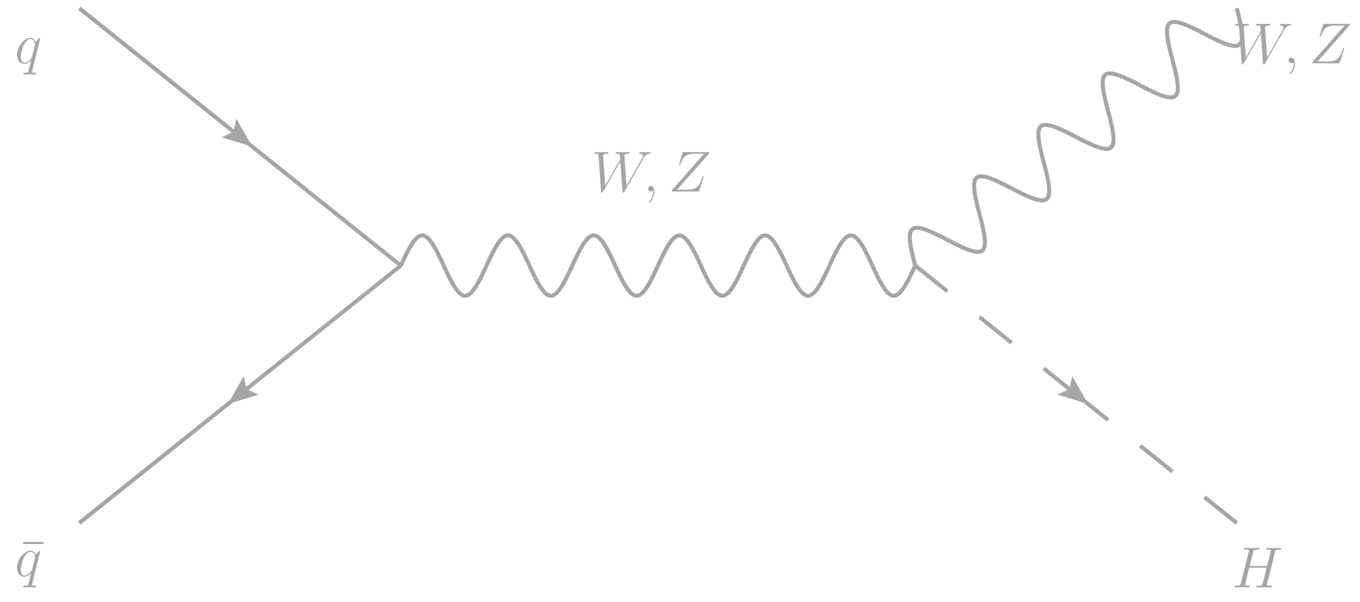
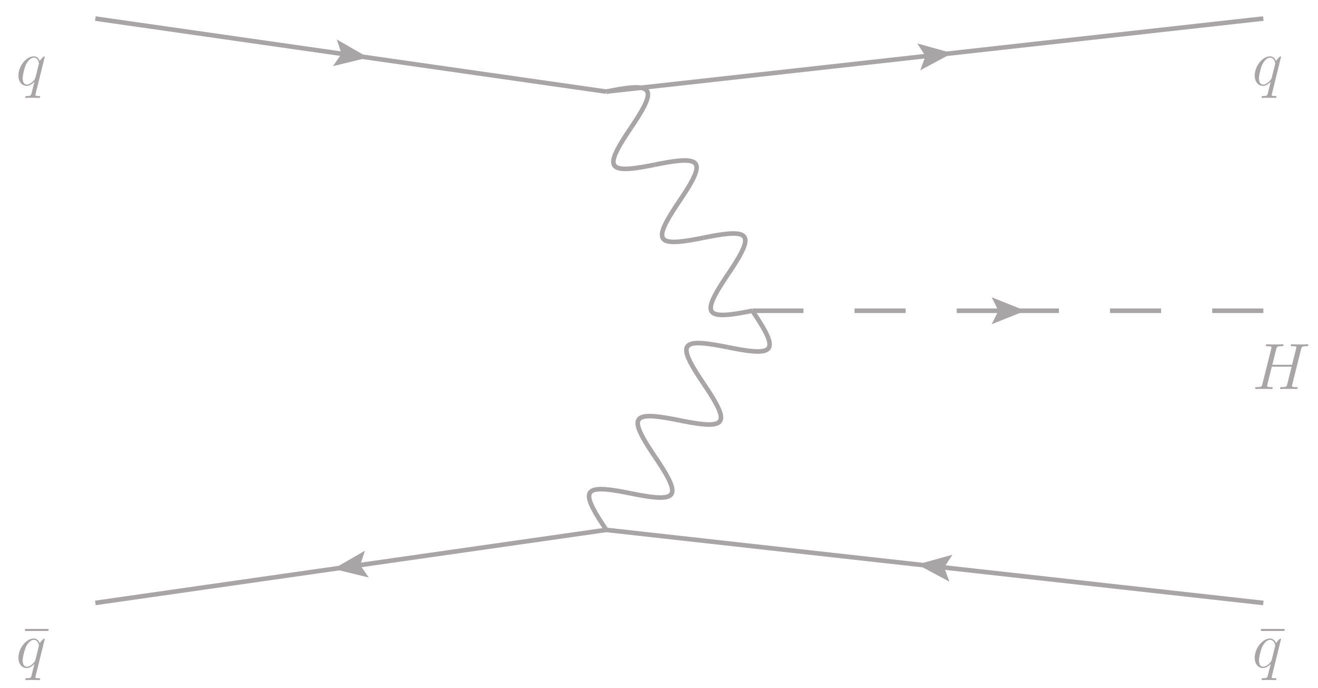


$t\bar{t}H$

BACKUP

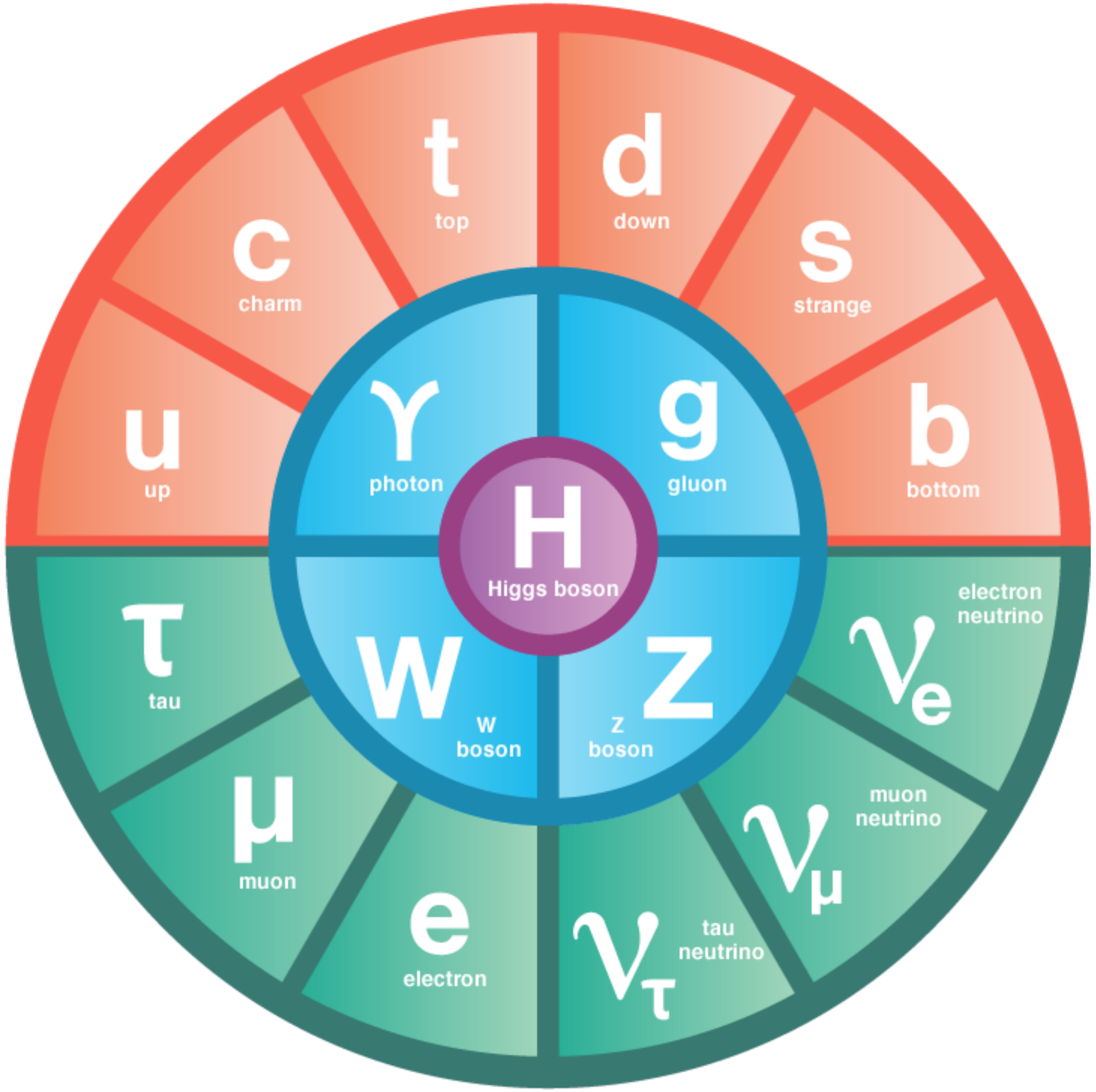


VH



VBF

The Standard Model of Physics



Higgs Mechanism

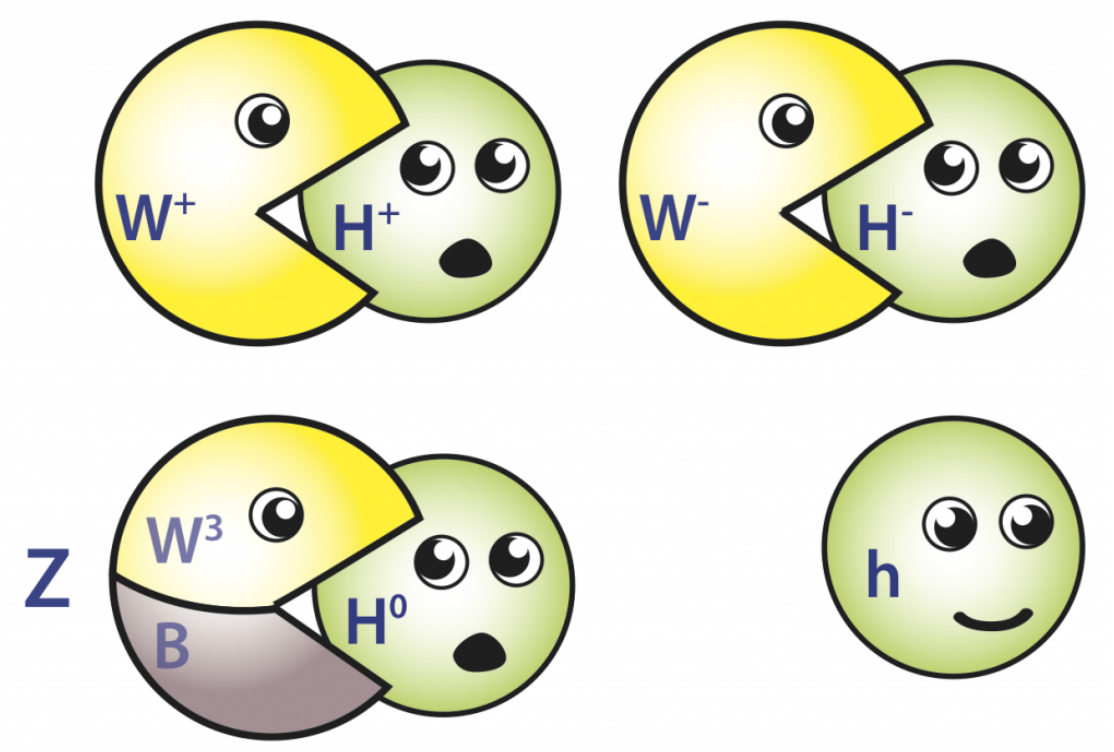
- Higgs potential spontaneously breaks the $SU(2) \times U(1)_Y$ —> $U(1)_{EM}$

$$V(\Phi) = m^2 \Phi^\dagger \Phi + \lambda \left(\Phi^\dagger \Phi\right)^2$$

- After symmetry breaking, with $v = \sqrt{(2m^2/\lambda)} \sim 246$ GeV

$$\Phi = \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \rightarrow \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v + h \end{pmatrix}$$

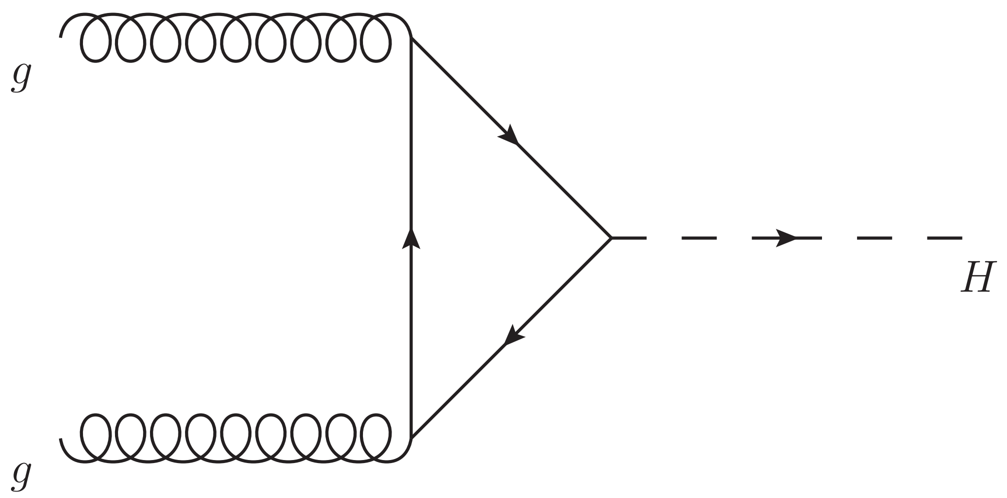
- The W and Z bosons acquire mass by "eating" Goldstone bosons, leaving neutral Higgs and massless photon



- Fermion masses via Yukawa couplings:

$$Y^d_{ij} \bar{Q}^i H d^j_R + h.c.,\ Y^u_{ij} \bar{Q}^i \tilde{H} u^j_R + h.c.$$

Higgs Production and Decay



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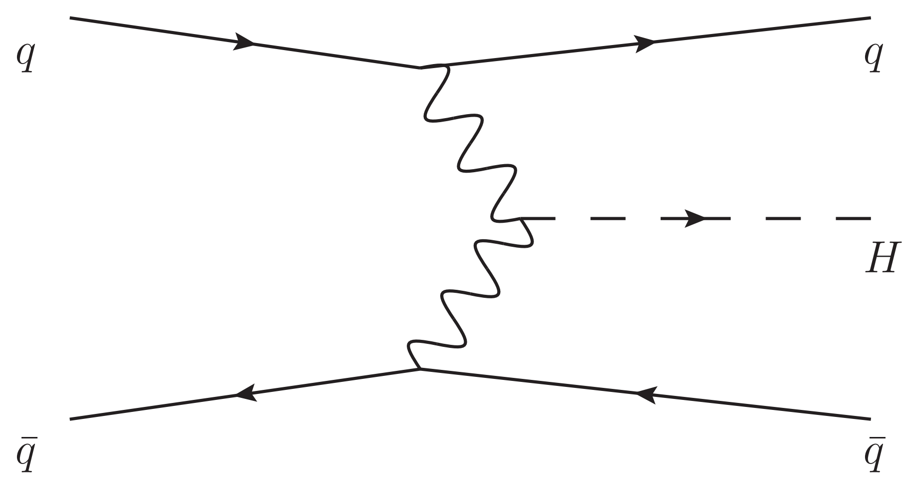
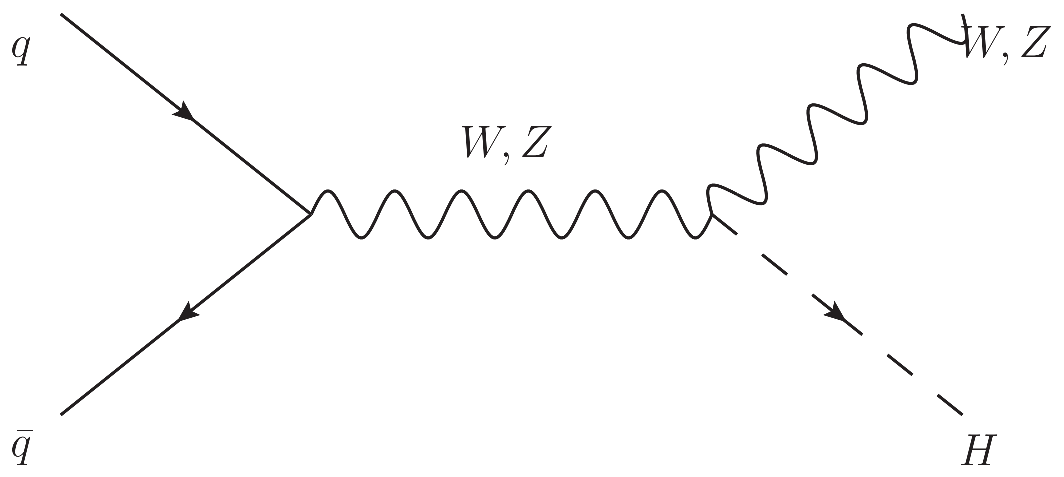
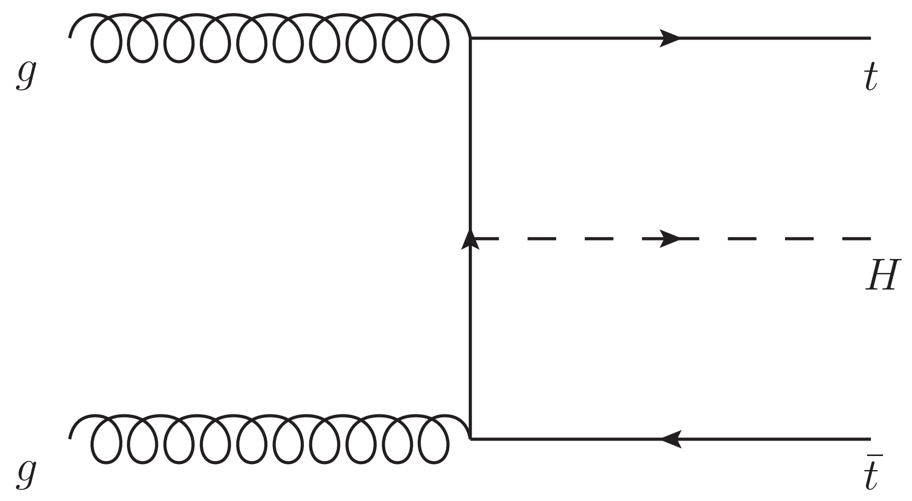


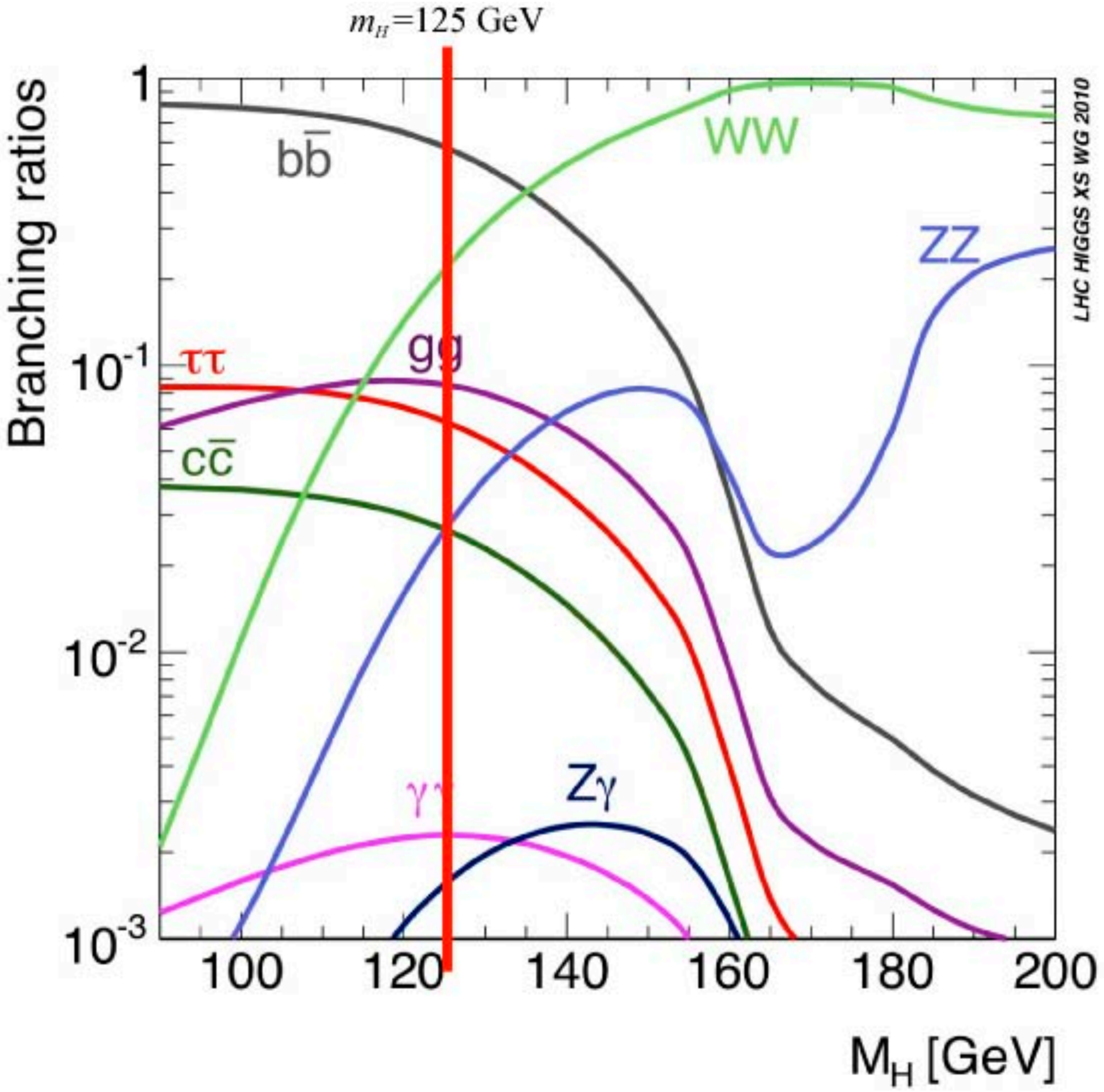
VBF



VH

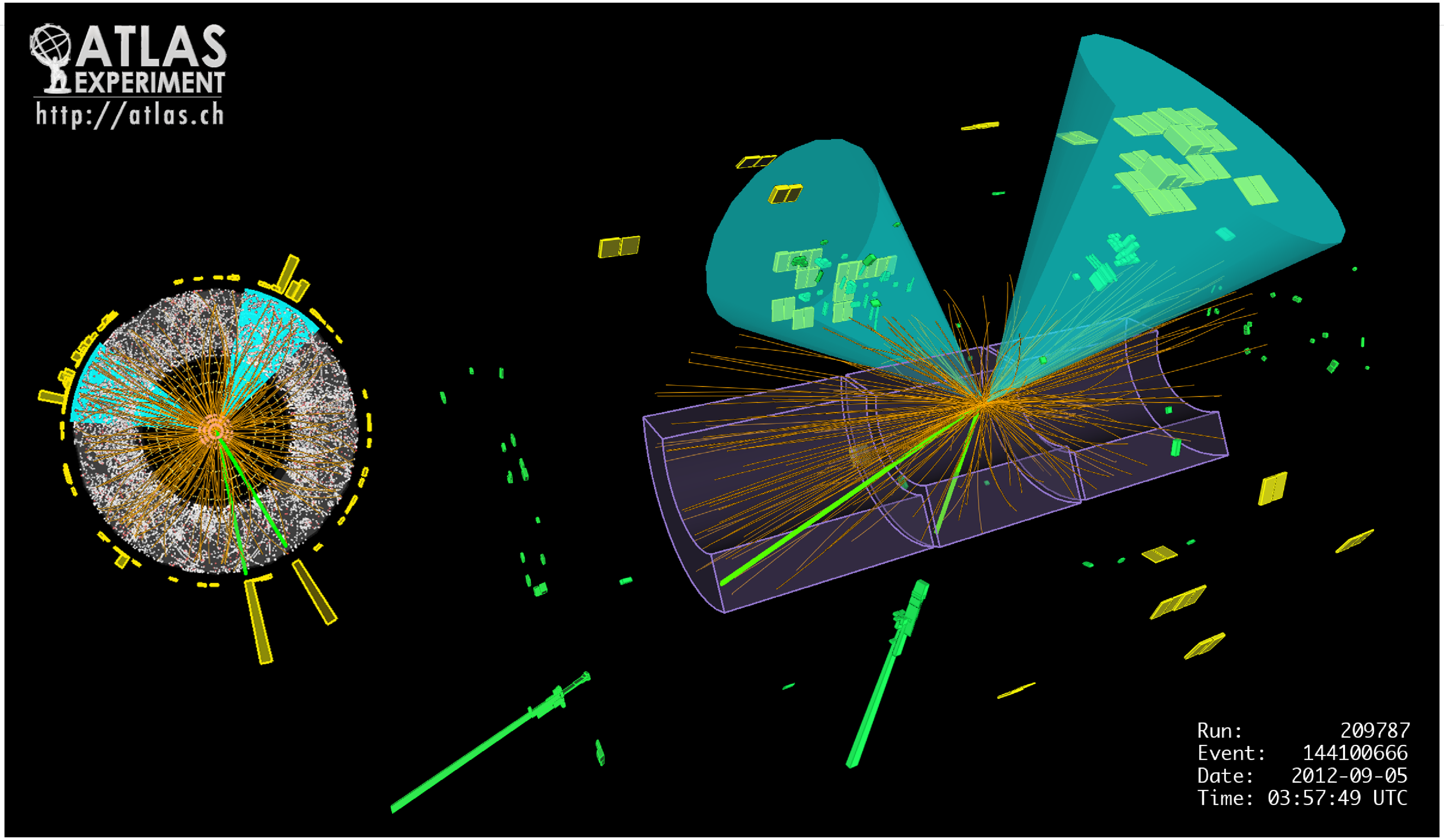


$t\bar{t}H$



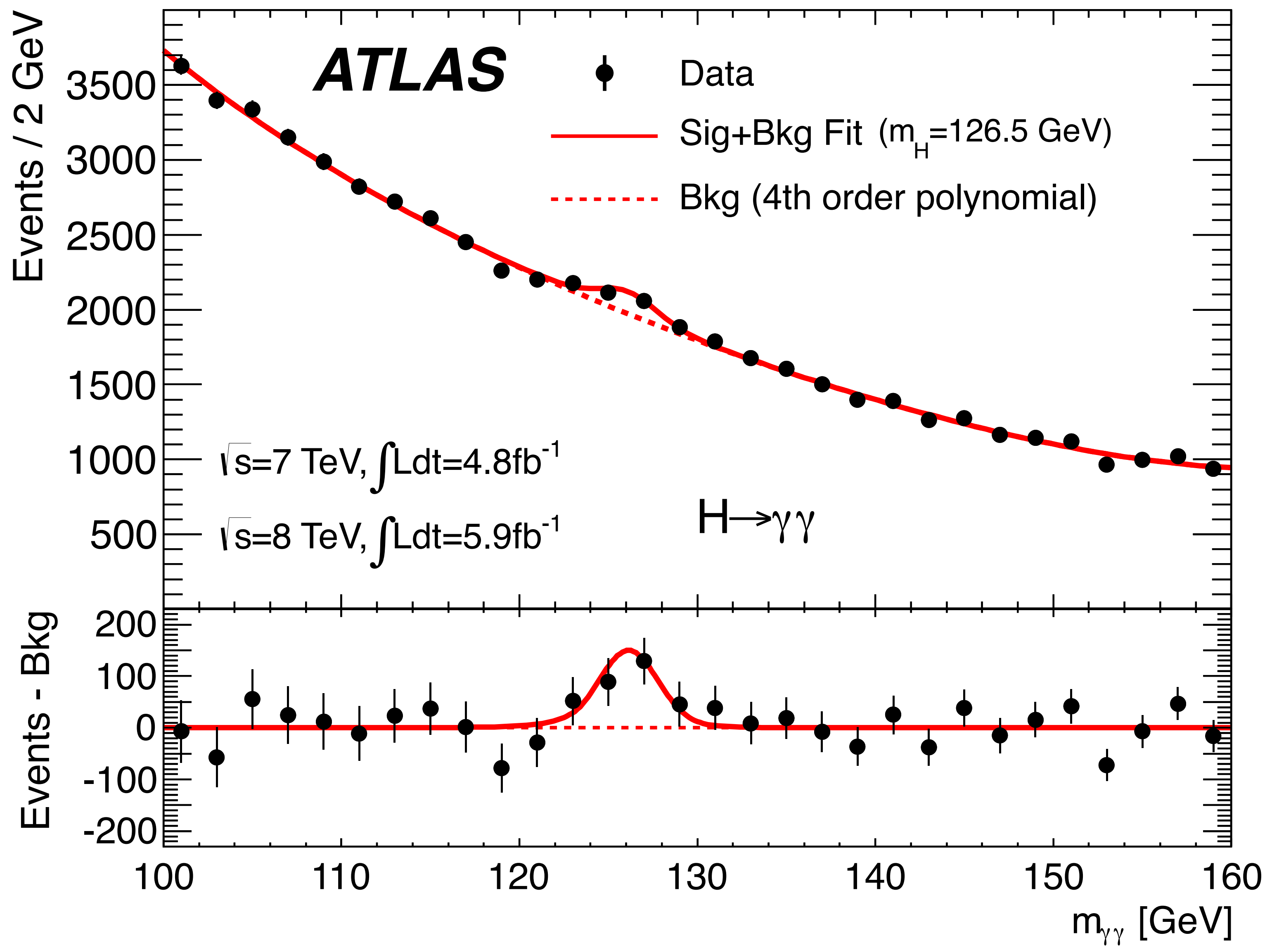
COLLISION EVENTS IN ATLAS

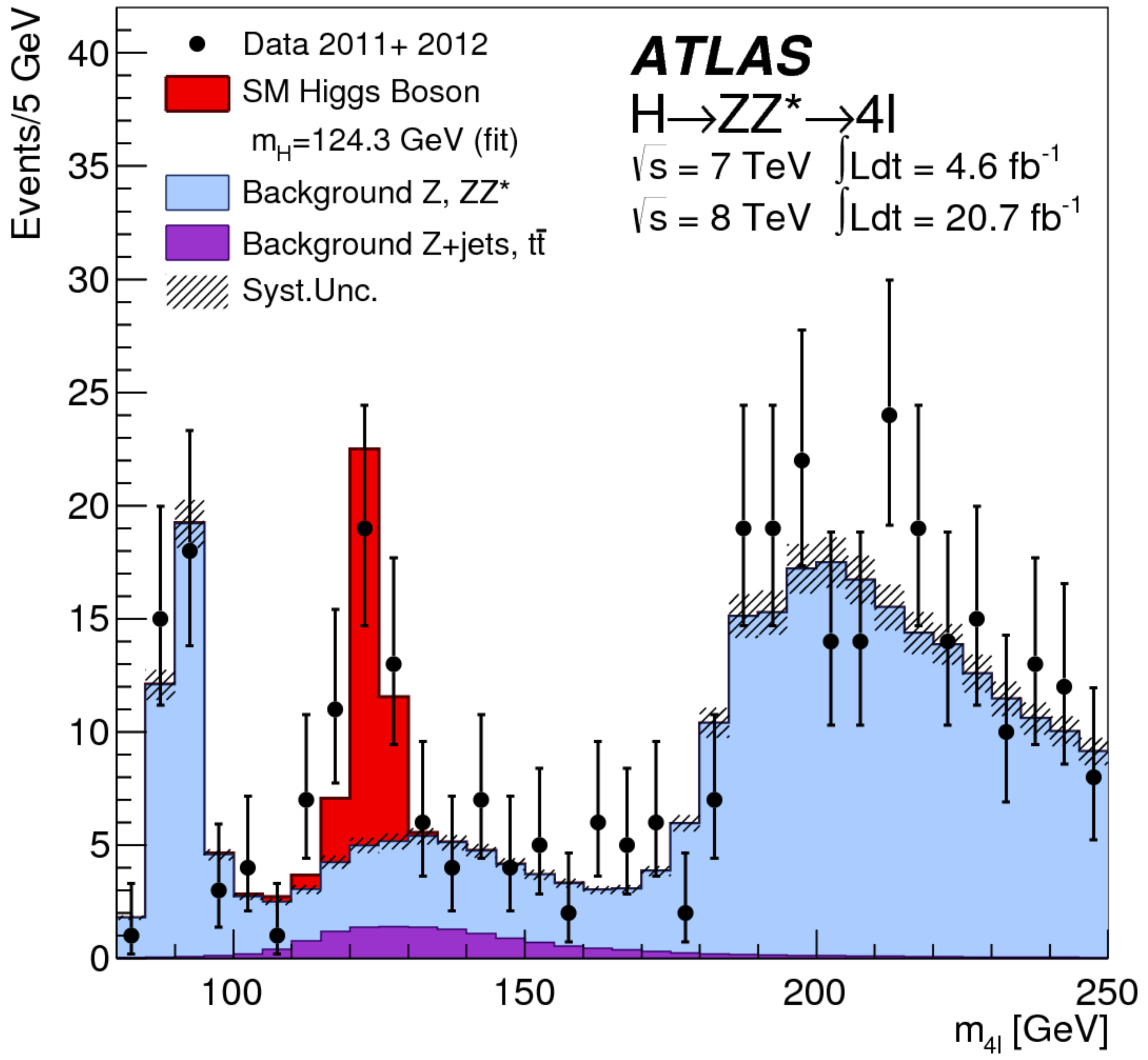
- ATLAS is like a digital camera with lots of pixels



HIGGS DISCOVERY

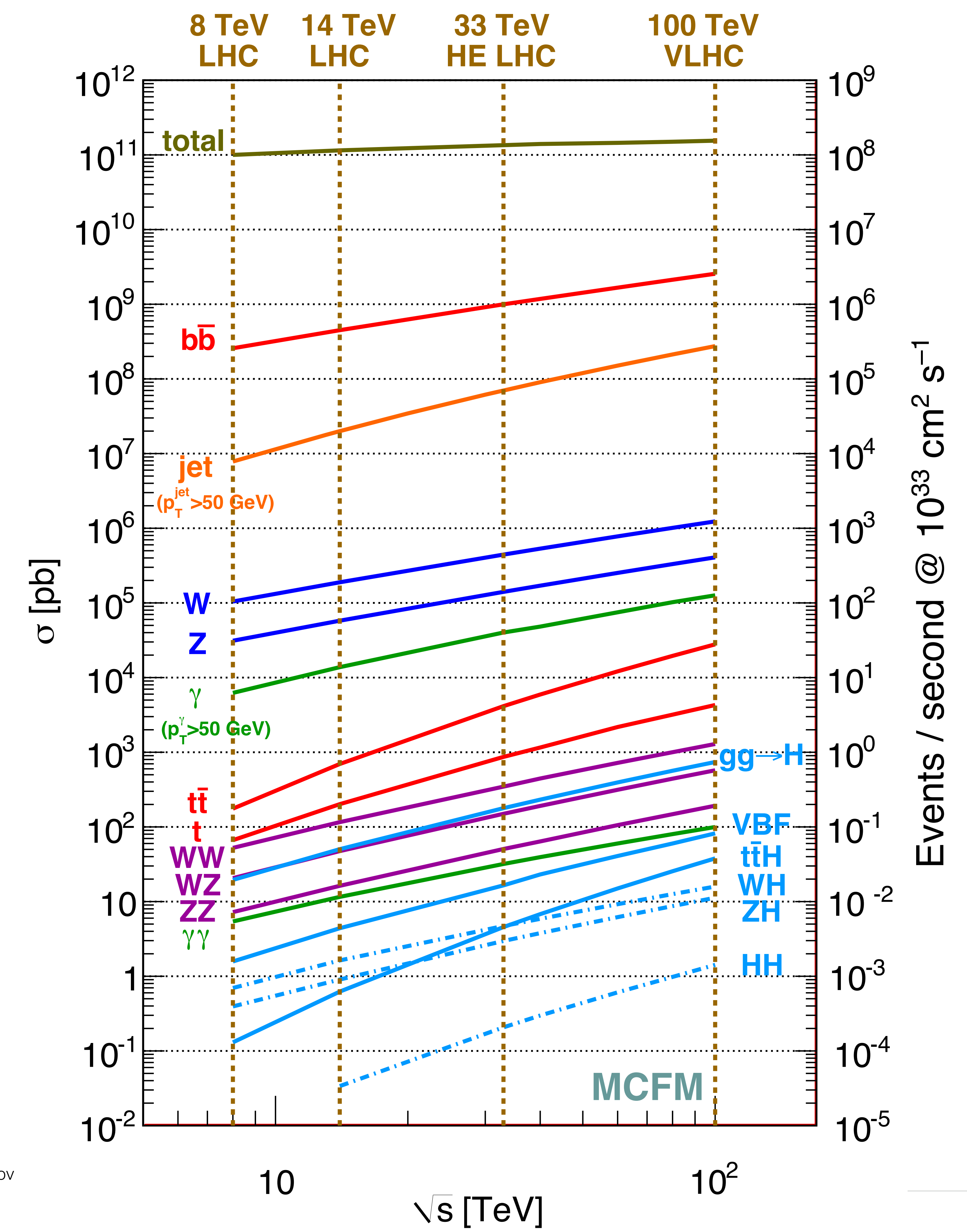
- Clean discovery channels: H—>γγ and H—>ZZ*—>4l placed the Higgs mass at 125 GeV
- So the Higgs should decay to b's 58% of the time



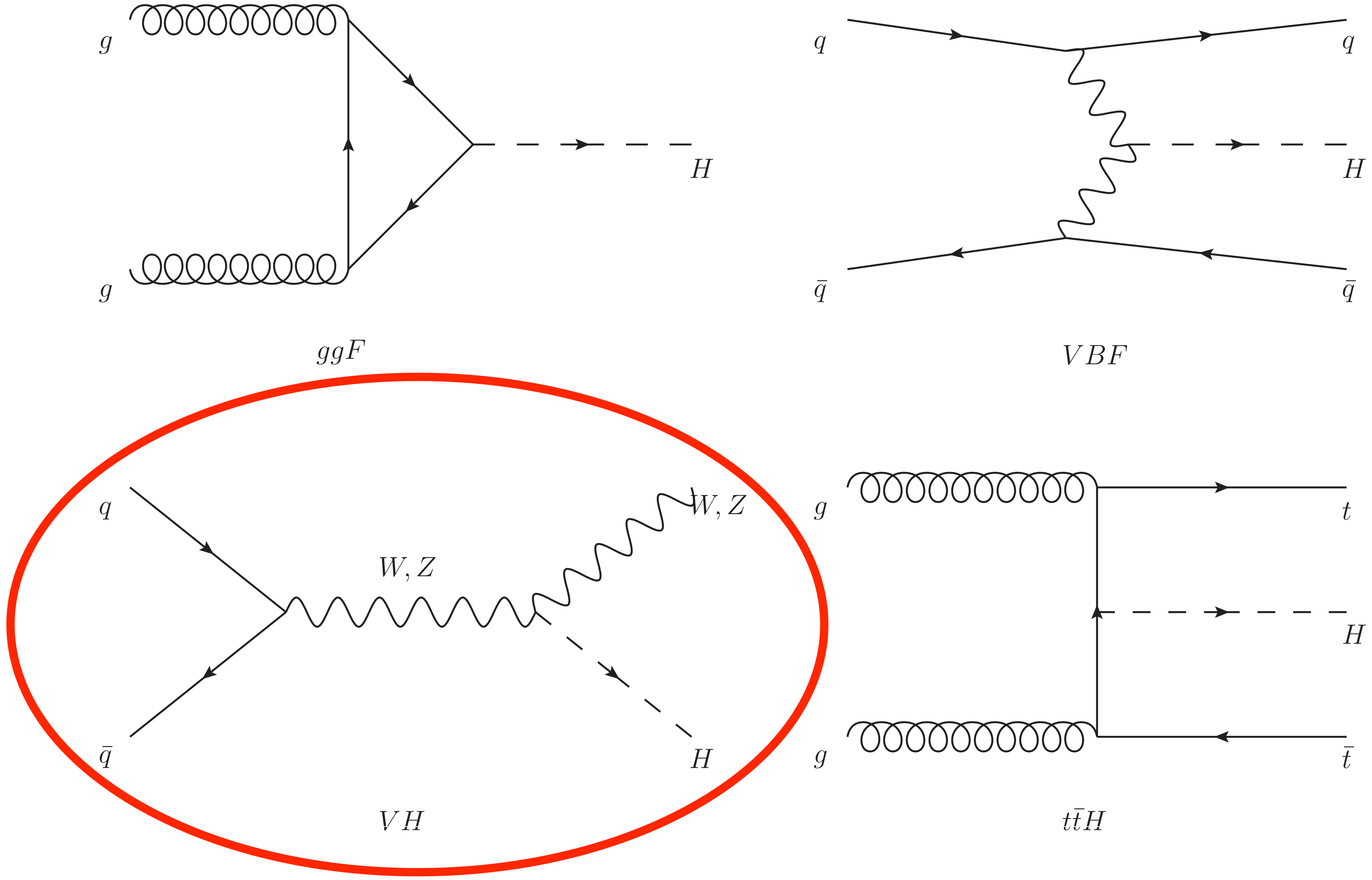


CHOOSING A SIGNAL TOPOLOGY

- Four main production modes; *VH* suppresses multijet background



https://mcfm.fnal.gov



MODELING SYSTEMATICS

Process	Systematics
Signal	$H \rightarrow bb$ decay, QCD scale, PDF+α_S scale, UE+PS (acc, p_T^V, m_{bb}, 3/2 jet ratio)
Z+jets	Acc, flavor composition, p_T^V+m_{bb} shape
$t\bar{t}$	Acc, p_T^V+m_{bb} shape
Diboson	Overall acc, UE+PS (acc, p_T^V, m_{bb}, 3/2 jet ratio), QCD scale (acc (2, 3 jet, jet veto), p_T^V, m_{bb})
Single top	Acc, p_T^V+m_{bb} shape

Modeling Example: Signal

DS ID	Process	Generator	Events
	qq-initiated (nominal)		
345053	$qq \to W^+H \to l^+\nu b\bar{b}$	Powheg +MiNLO+Pythia 8	3999950
345054	$qq \to W^-H \to l^-\nu b\bar{b}$	Powheg +MiNLO+Pythia 8	3999950
345055	$qq \to ZH \to llb\bar{b}$	Powheg +MiNLO+Pythia 8	3000000
345056	$qq \to ZH \to \nu\nu b\bar{b}$	Powheg +MiNLO+Pythia 8	2000000
	qq-initiated (alternative)		
343608	$qq \to WH \to l\nu b\bar{b}$	MadGraph 5_aMC@NLO+Pythia 8	1000000
343619	$qq \to ZH \to llb\bar{b}$	MadGraph 5_aMC@NLO+Pythia 8	1000000
343629	$qq \to ZH \to \nu\nu b\bar{b}$	MadGraph 5_aMC@NLO+Pythia 8	1000000
	gg-initiated (nominal)		
345057	$gg \to ZH \to llb\bar{b}$	Powheg +Pythia 8	
345058	$gg \to ZH \to \nu\nu b\bar{b}(*)$	Powheg +Pythia 8	

NP name	0L		1L		2L	
	2j	3j	2j	3j	2j	≥3j
ATLAS_UEPS_VH_hbb	10.0%	10.0%	12.1%	12.1%	13.9%	13.9%
ATLAS_UEPS_VH_hbb_32JR	–	13.0%	–	12.9%	–	13.4%
ATLAS_UEPS_VH_hbb_VPT	shape only				shape+norm	
ATLAS_UEPS_VH_hbb_MBB	shape only					
QCDscale_VH_ANA_hbb_J2	6.9%	–	8.8%	–	3.3%	–
QCDscale_VH_ANA_hbb_J3	-7%	+5%	-8.6%	+6.8%	-3.2%	+3.9%
QCDscale_VH_ANA_hbb_JVeto	–	-2.5%	–	3.8%	–	–
QCDscale_VH_ANA_hbb_VPT	shape only				shape+norm	
QCDscale_VH_ANA_hbb_MBB	shape only					
pdf_HIGGS_VH_ANA_hbb	1.1%	1.1%	1.3%	1.3%	0.5%	0.5%
pdf_VH_ANA_hbb_VPT	shape only				shape+norm	
pdf_VH_ANA_hbb_MBB	shape only					

Sys Name	source	Norm. effect	applied to
ATLAS_BR_bb	$H \to bb$ dec. unc, (HO effects, m_b, α_S)	1.7%	all VH
ATLAS_QCDscale_VH	QCD scale uncertainty	0.7%	$qq \to VH$
ATLAS_QCDscale_ggZH	QCD scale uncertainty	27%	$gg \to ZH$
ATLAS_pdf_Higgs_VH	PDF+α_S uncertainty	1.9% 1.6%	$qq \to WH$ $qq \to ZH$
ATLAS_pdf_Higgs_ggZH	PDF+α_S uncertainty	5.0%	$gg \to ZH$

OBJECT DEFINITIONS: LEPTONS

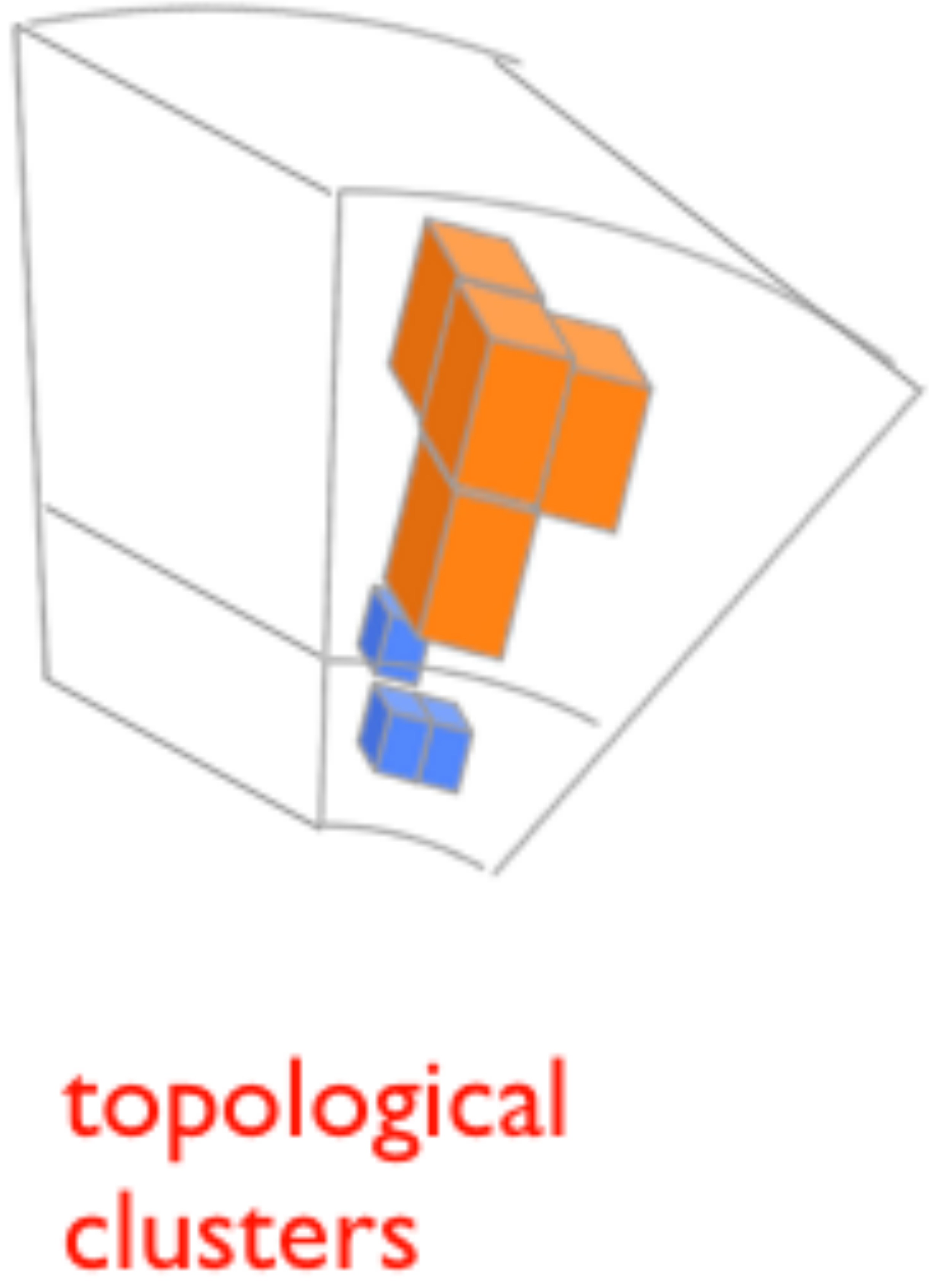
- Electrons: “Sliding window” clusters, ID tracks
  - Match electron clusters to ID tracks
  - Likelihood discriminant for quality
- Muons: tracks in MS, ID tracks, clusters
  - Combined: match ID and MD tracks
  - Standalone: MS only
  - Segment/calorimeter tagged (no MS for |η|<0.1)
- Triggers: unprescaled single lepton (1/2-lep)

e Selection	p_T	η	ID	d_0^{sig}	$\|\Delta z_0^{BL} \sin\theta\|$	Isolation
$VH-loose$	>7 GeV	$\|\eta\| < 2.47$	LH Loose + B-layer cut	< 5	< 0.5 mm	LooseTrackOnly
$ZH-signal$	>27 GeV	$\|\eta\| < 2.47$	LH Loose + B-layer cut	< 5	< 0.5 mm	LooseTrackOnly
$WH-signal$	>27 GeV	$\|\eta\| < 2.47$	LH Tight	< 5	< 0.5 mm	FixedCutHighPtCaloOnly

μ Selection	p_T	η	ID	d_0^{sig}	$\|\Delta z_0^{BL} \sin\theta\|$	Isolation
$VH-loose$	>7 GeV	$\|\eta\| < 2.7$	Loose quality	< 3	< 0.5 mm	LooseTrackOnly
$ZH-signal$	>27 GeV	$\|\eta\| < 2.5$	Loose quality	< 3	< 0.5 mm	LooseTrackOnly
$WH-signal$	>25 GeV	$\|\eta\| < 2.5$	Medium quality	< 3	< 0.5 mm	FixedCutHighPtTrackOnly

OBJECT DEFINITIONS: JETETMISS

- Jets: anti-kt with R=0.4
  - EM scale calibrated
  - Inputs: CaloTopoClusters
  - b-tagging: MV2c10, 70% efficiency
- MET: negative sectoral sum of physics objects and “track soft term” (ID tracks not associated with objects)
  - MET trigger used in 0/1-lep channels



EXPERIMENTAL SYSTEMATICS

Process	Systematics
Jets	21 NP scheme for JES, JER as single NP
E_T^{miss}	trigger efficiency, track-based soft terms, scale uncertainty due to jet tracks
Flavor Tagging	Eigen parameter scheme (CDI File: `2016-20_7-13TeV-MC15-CDI-2017-06-07_v2`)
Electrons	trigger eff, reco/ID eff, isolation eff, energy scale/resolution
Muons	trigger eff, reco/ID eff, isolation eff, track to vertex association, momentum resolution/scale
Event	total luminosity, pileup reweighting

- Flavor Tagging: “medium” Eigen scheme for flavor

SMOOTHING

- Smoothing
    - Merge bins iteratively where differences are smallest until no local extrema remain (one is fine)
    - Merge bins (high to low) until stat uncertainty is <5% total bin content

Pruning Conditions

- Norm/acceptance
  - (Total variation <0.5%) || (Up and down have same sign)
- Shape
  - (No single bin deviates >0.5% after normalization effects removed) || (only up or down is non-zero)
- Shape+norm
  - (Sample is <2% total B) &&
    - ((S is <2% of B in all bins) && (shape/norm err <0.5% B)) ||
    - ((One bin with S >2% of B) && (shape/norm err <2% of S in these bins))

Transformation D

- Addresses the issue of making predictors more stable
  - While maintaining meaningful sensitivity

$$Z(I[k,l]) = Z(z_s, n_s(I[k,l]), N_s, z_b, n_b(I[k,l]), N_b) \tag{6.1}$$

where

- $I[k,l]$ is an interval of the histograms, containing the bins between bin k and bin l;
- N_s is the total number of signal events in the histogram;
- N_b is the total number of background events in the histogram;
- $n_s(I[k,l])$ is the total number of signal events in the interval $I[k,l]$;
- $n_b(I[k,l])$ is the total number of background events in the interval $I[k,l]$;
- z_s and z_b are parameters used to tune the algorithm.

Transformation D uses:

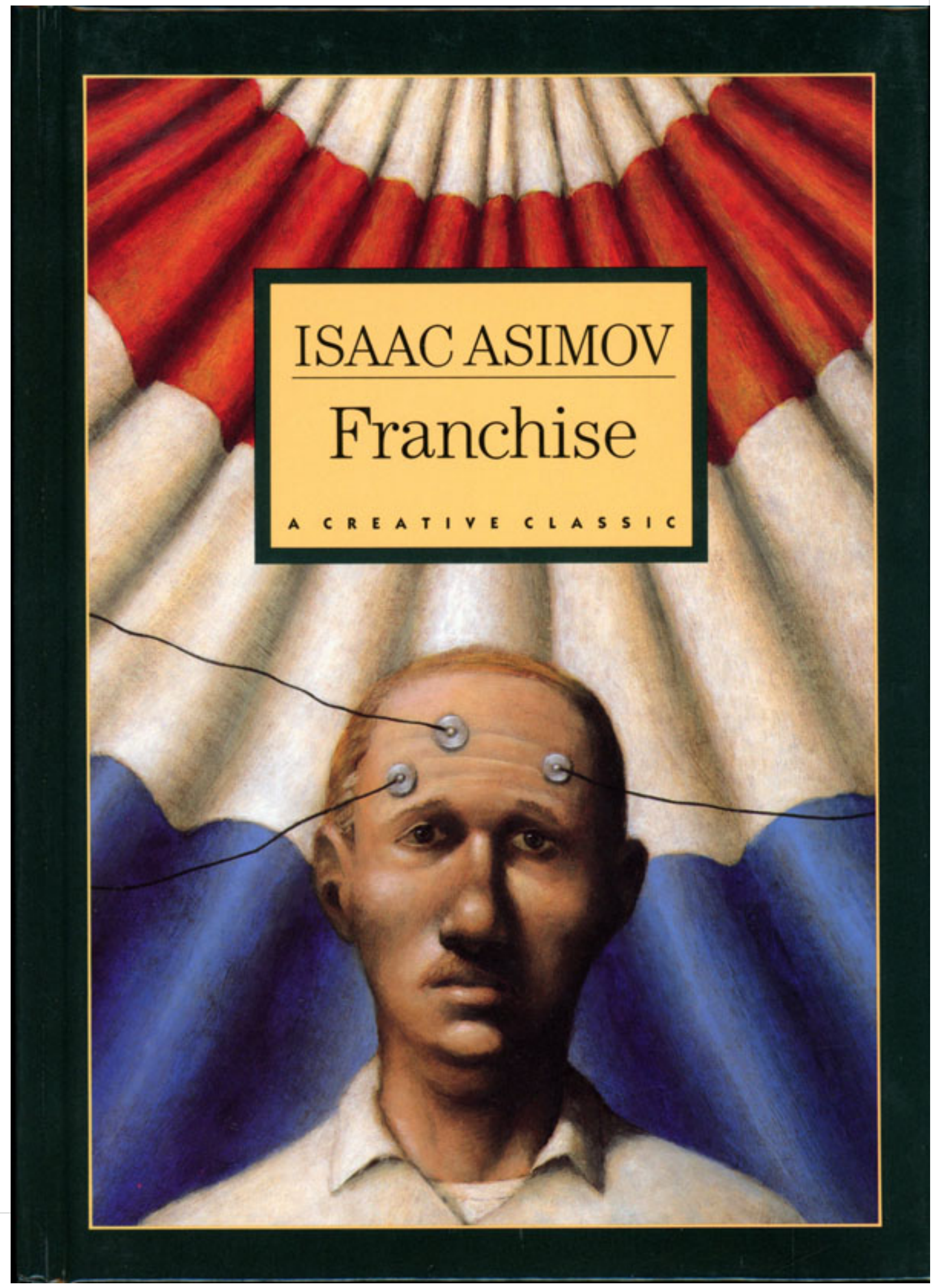
$$Z = z_s \frac{n_s}{N_s} + z_b \frac{n_b}{N_b} \tag{6.2}$$

Rebinning occurs as follow:

1. Begin with the highest valued bin in the original pair of distributions. Call this the "last" bin and use it as l, and have k be this bin as well.
2. Calculate $Z(I[k,l])$
3. If $Z \leq 1$, set $k \to k-1$ and return to step 2. If not, rebin bins k–l into a single bin and name $k-1$ the new "last" bin l.
4. Continue until all bins have been iterated through; if $Z \leq 1$ for any remaining n of the lowest-valued bins (as is often the case), simply rebin these as a single bin.

Technical Aside: Asimov Datasets

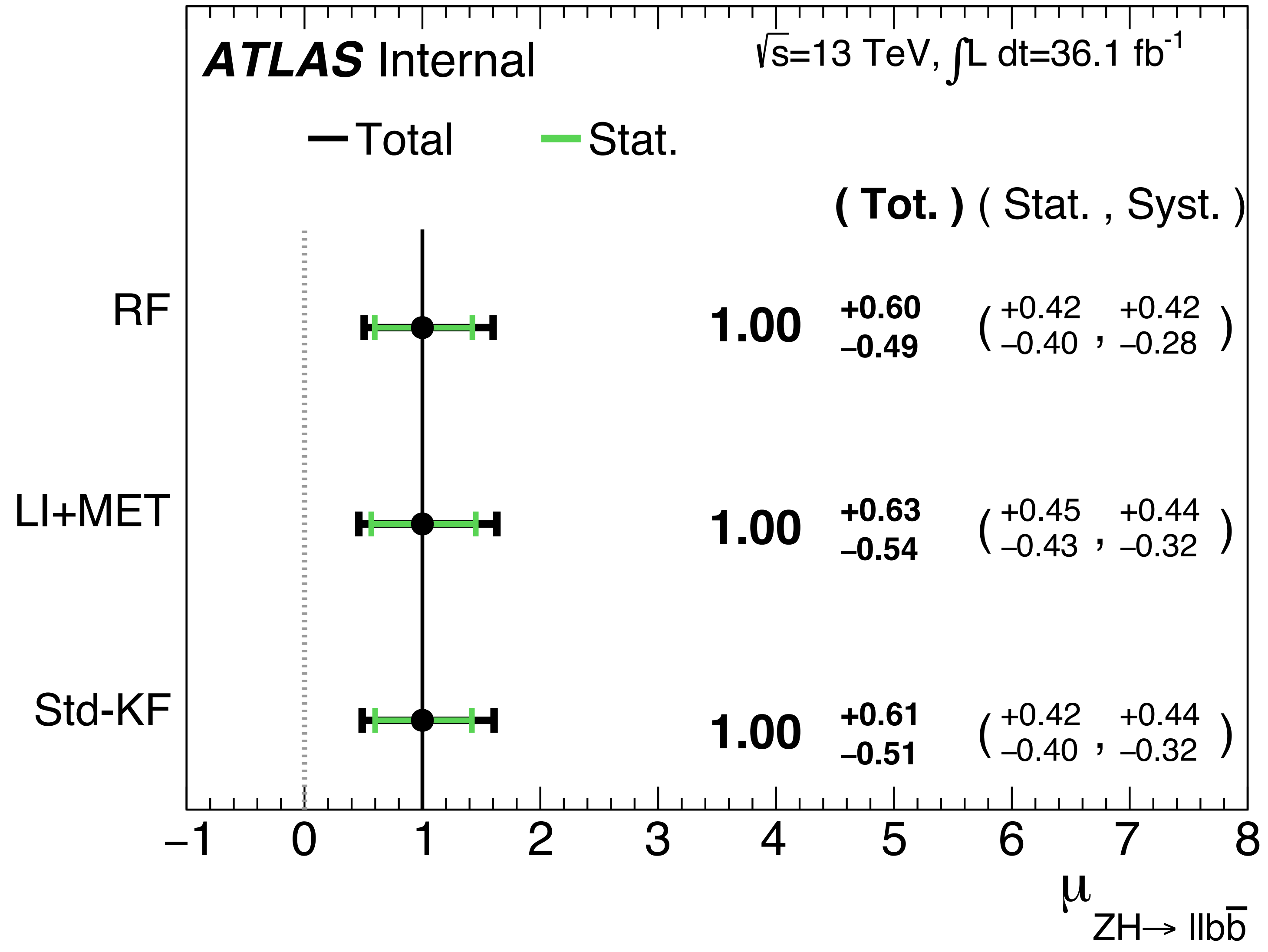
- Since we work with blinded data (or might not even have/want data during development), how to evaluate expected performance?
- Enter the "Asimov" dataset
  1. Set μ to 1*, all floating normalizations to 1
  2. NP's to 0 (expectation values)
  3. Generate dataset
  4. Run fit
- Standard Model + Perfect NP modeling

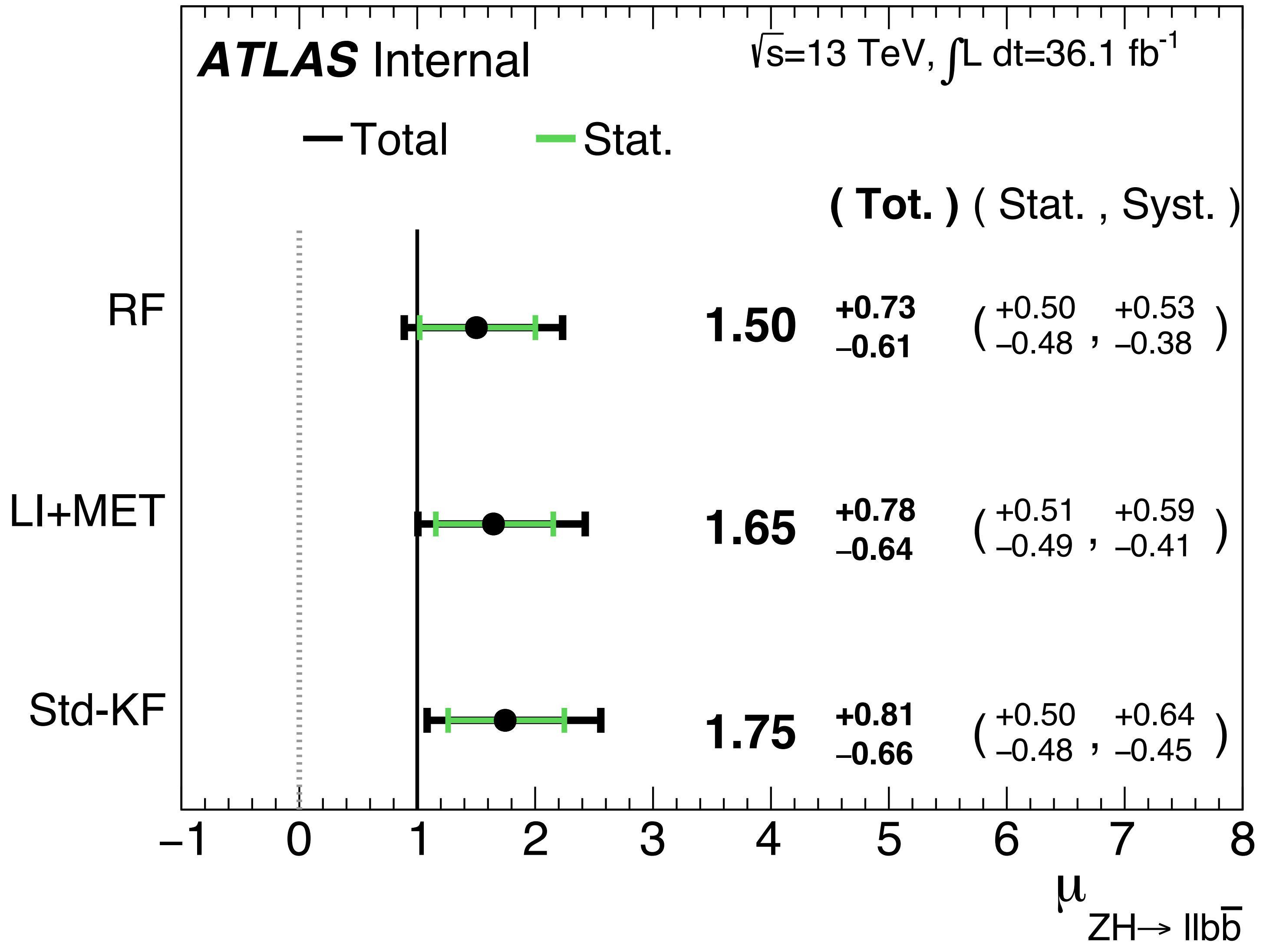


IC: https://vignette.wikia.nocookie.net/asimov/images/8/8c/Franchise.jpg/revision/latest?cb=20160827221657

Signal Strengths and Errors

- Asimov at left, observed at right
- Results are very much consistent with each other
- LI and RF sets reduce systematics error
  - RF by **16%** (6.5% on Asimov), LI by **7.5%**
  - And this is true across individual categories as well (next slide)





FIT RESULTS SUMMARY

	Standard	LI	RF
$\hat{\mu}$	$1.75^{+0.24}_{-0.23}(\text{stat.})^{+0.34}_{-0.28}(\text{syst.})$	$1.65^{+0.24}_{-0.23}(\text{stat.})^{+0.34}_{-0.28}(\text{syst.})$	$1.50^{+0.24}_{-0.23}(\text{stat.})^{+0.34}_{-0.28}(\text{syst.})$
Asi. Δerr (μ)	—	$<$ 1%, +4.6%	-6.5%, -2.2%
Obs. Δerr ($\hat{\mu}$)	—	-7.5%, -3.7%	-16%, -8.8%
Stat only sig.	4.78	4.39 (-7.9%)	4.44 (-6.9%)
Exp. (Asi.) sig.	2.06	1.92 (-6.7%)	2.13 (+3.5%)
Exp. (data) sig.	1.76	1.73 (-1.7%)	1.80 (+3.4%)
Obs. (data) sig.	2.87	2.79 (-2.8%)	2.62 (-8.6%)

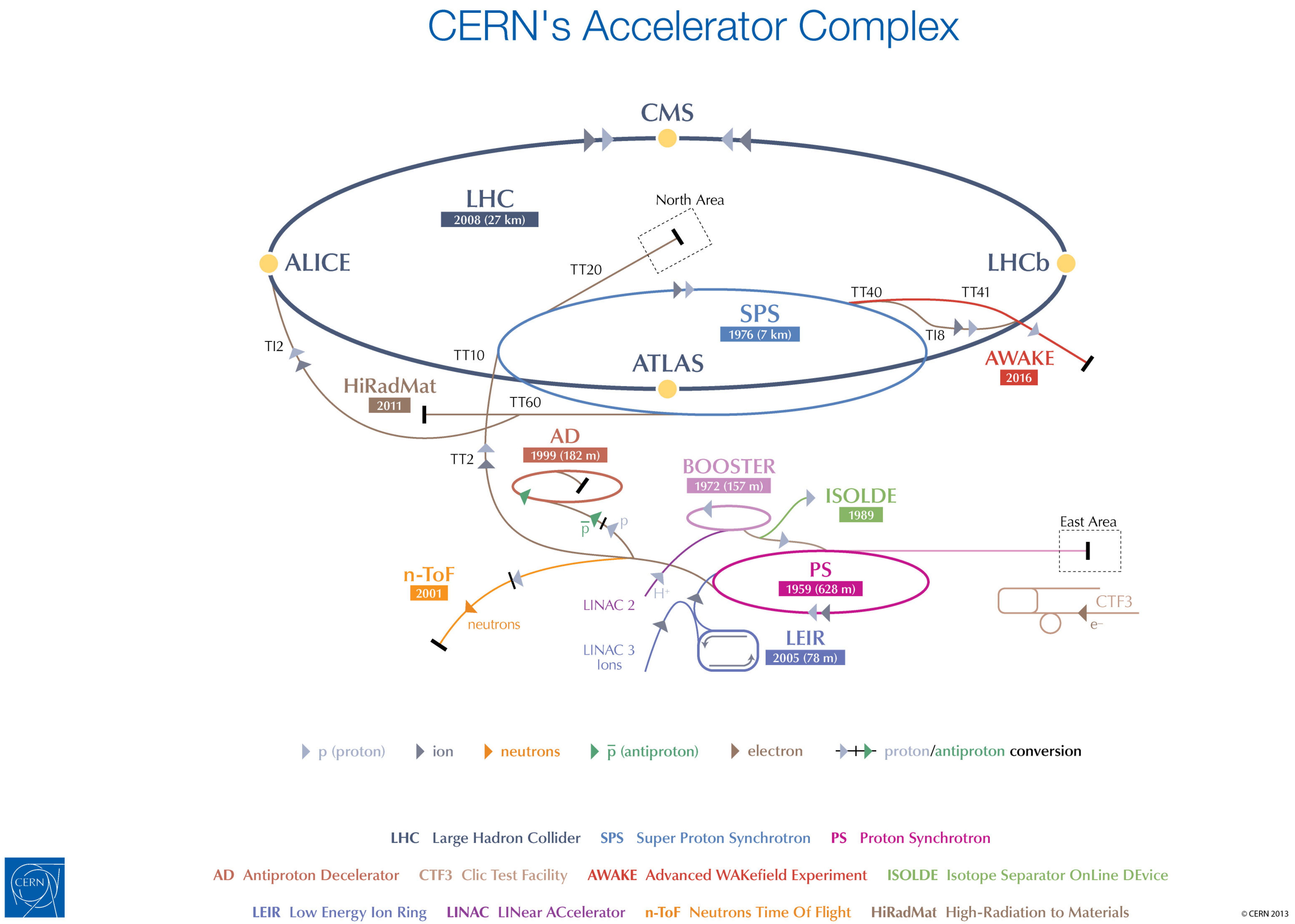
- Both the LI and RF variable sets offer a potential avenue forward to reducing overall impact of systematics
  - Both sets reduce error on signal strength from systematics
  - LI and RF variables provide competitive performance in sensitivities, with RF doing slightly better in expected sensitivities

HIGGS CROSS SECTIONS

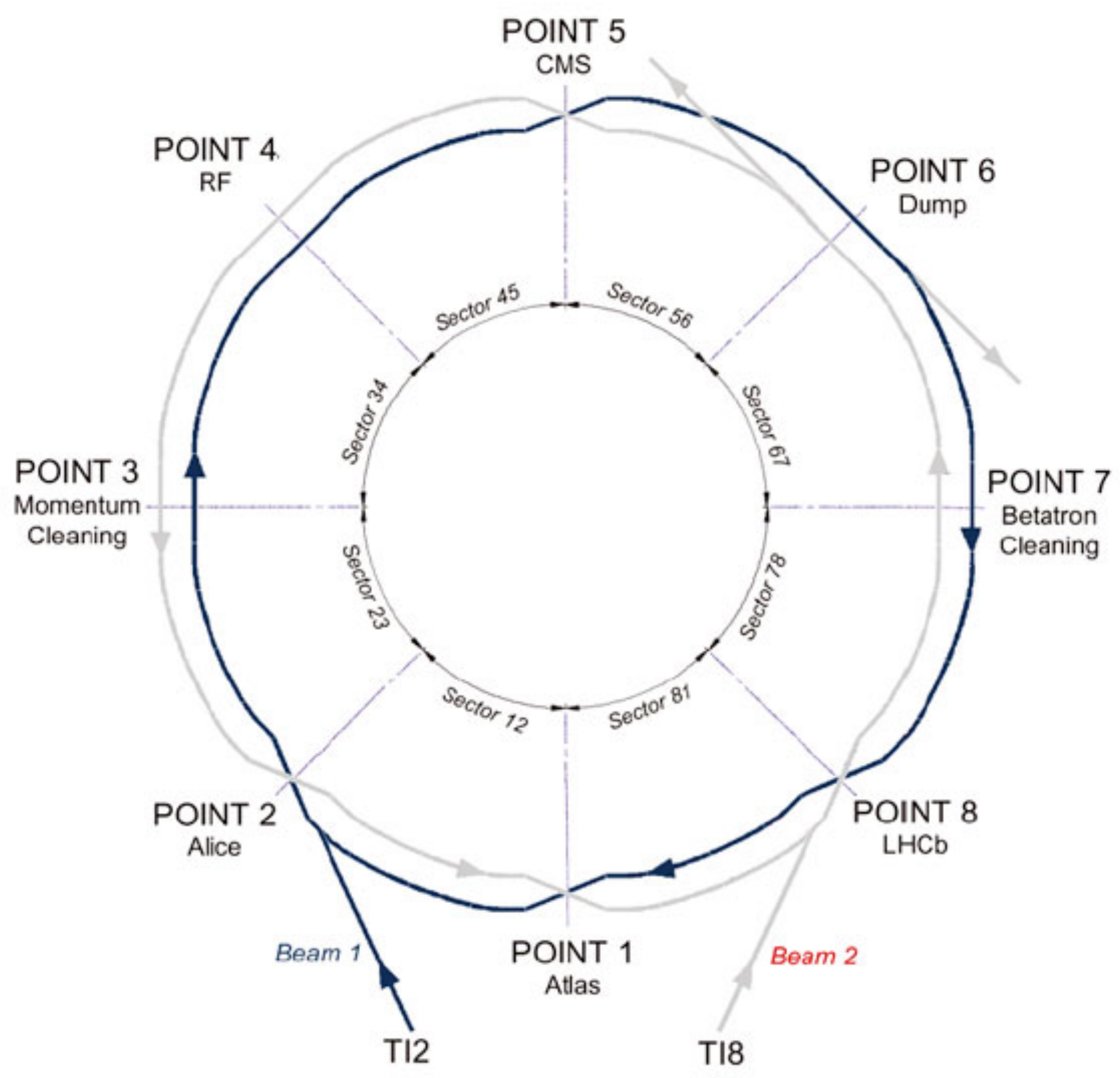
- Cross sections are in pb; for reference, we generally tell the public that 1 fb^{-1} corresponds to ~10^{14} pp collisions at the LHC

$\sqrt{s}$ (TeV)	ZH	WH	ggF	total σ	$N_{V\to\ell\|\nu H}$
7	$0.34^{+4\%}_{-4\%}$	$0.58^{+3\%}_{-3\%}$	$15.3^{+10\%}_{-10\%}$	17.5	$4.7\ fb^{-1} \to 589$
8	$0.42^{+5\%}_{-5\%}$	$0.70^{+3\%}_{-3\%}$	$19.5^{+10\%}_{-11\%}$	22.3	$20.3\ fb^{-1} \to 3\,100$
13	$0.88^{+5\%}_{-5\%}$	$1.37^{+2\%}_{-2\%}$	$44.1^{+11\%}_{-11\%}$	50.6	$36.1\ fb^{-1} \to 11\,100$
14	$0.99^{+5\%}_{-5\%}$	$1.51^{+2\%}_{-2\%}$	$49.7^{+11\%}_{-11\%}$	57.1	$1000\ fb^{-1} \to 343\,000$

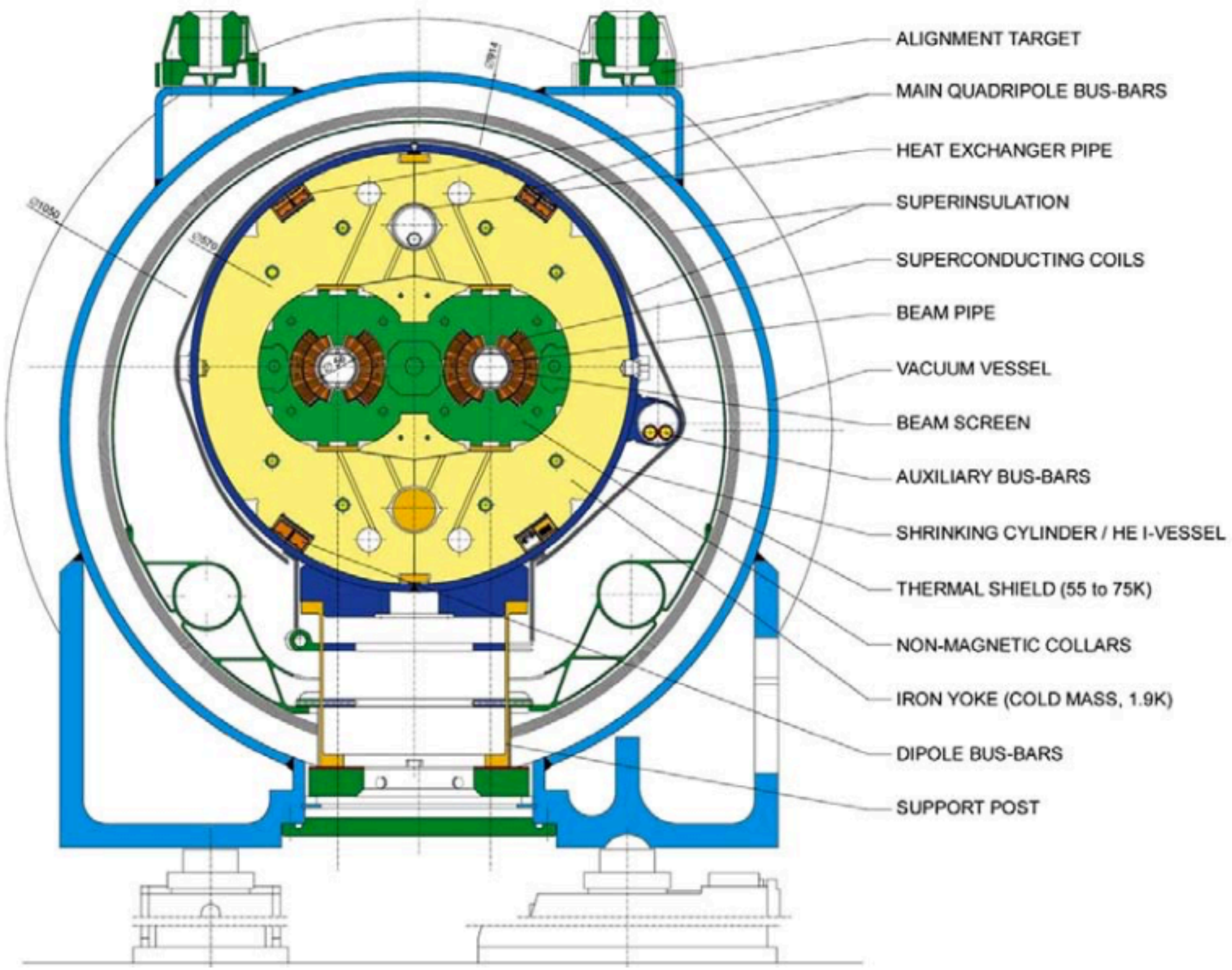
THE CERN ACCELERATOR COMPLEX



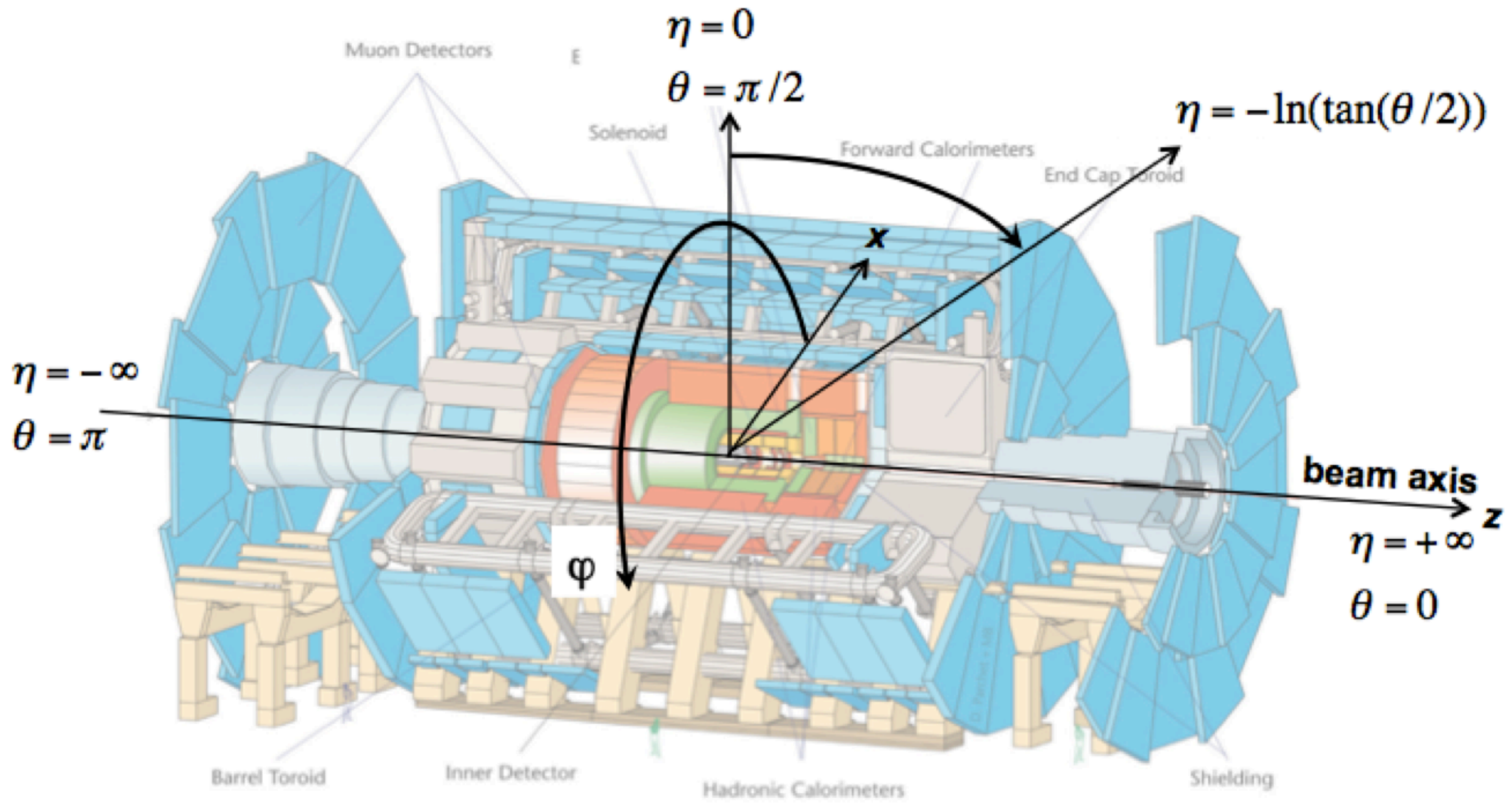
LHC Layout


POINT 5
CMS
POINT 4
RF
POINT 6
Dump
Sector 45
Sector 56
Sector 34
Sector 67
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
Sector 23
Sector 78
Sector 12
Sector 81
POINT 2
Alice
POINT 8
LHCb
Beam 1
POINT 1
Atlas
Beam 2
TI2
TI8

An LHC Magnet



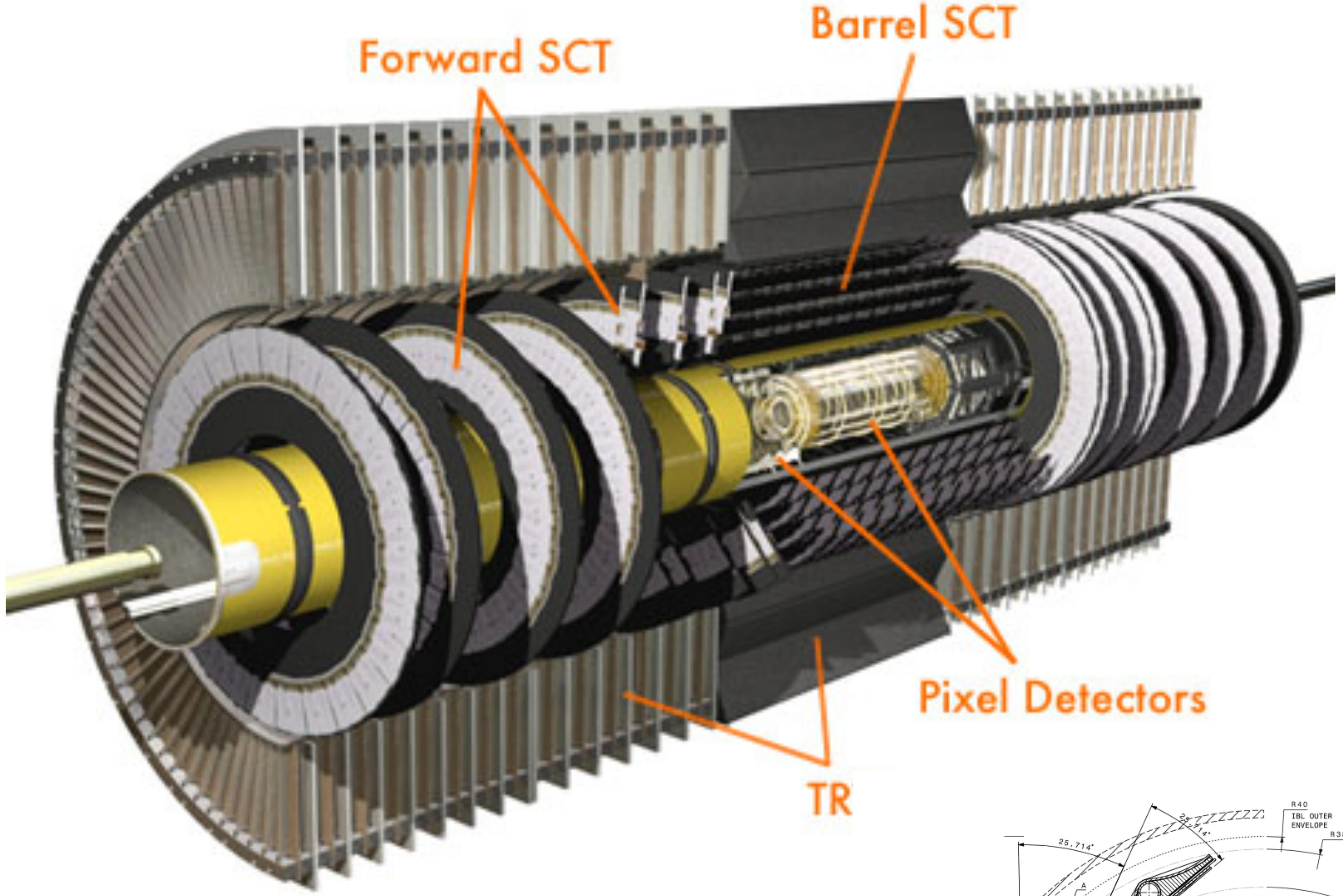
ATLAS Coordinates

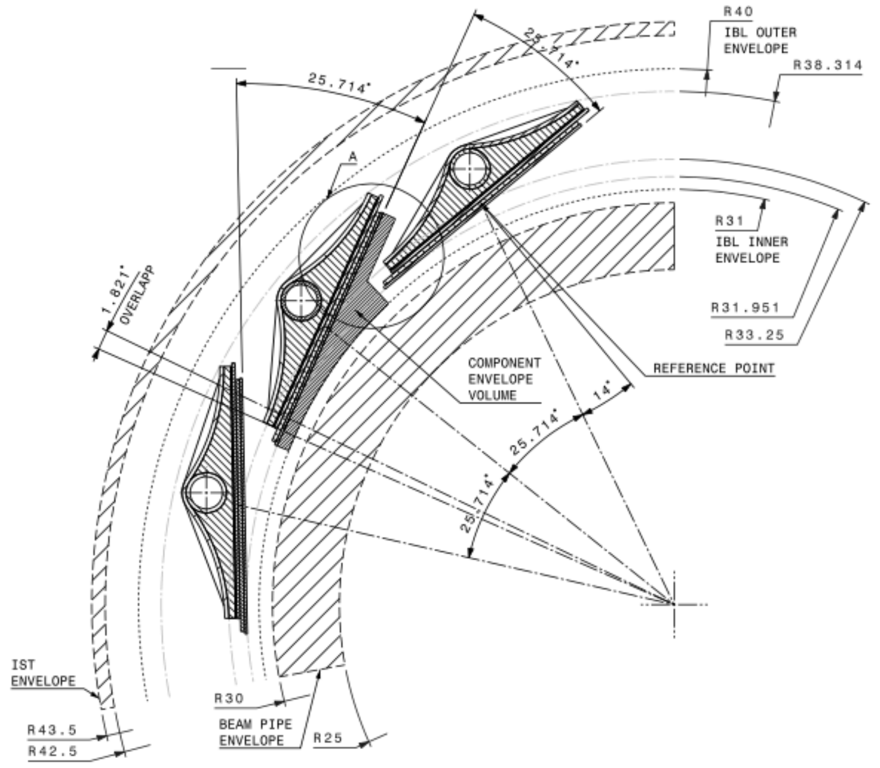


$\vec{p}_T = (p_x, p_y)$ $\quad p_T = p\sin\theta, \quad E_T = E\sin\theta$

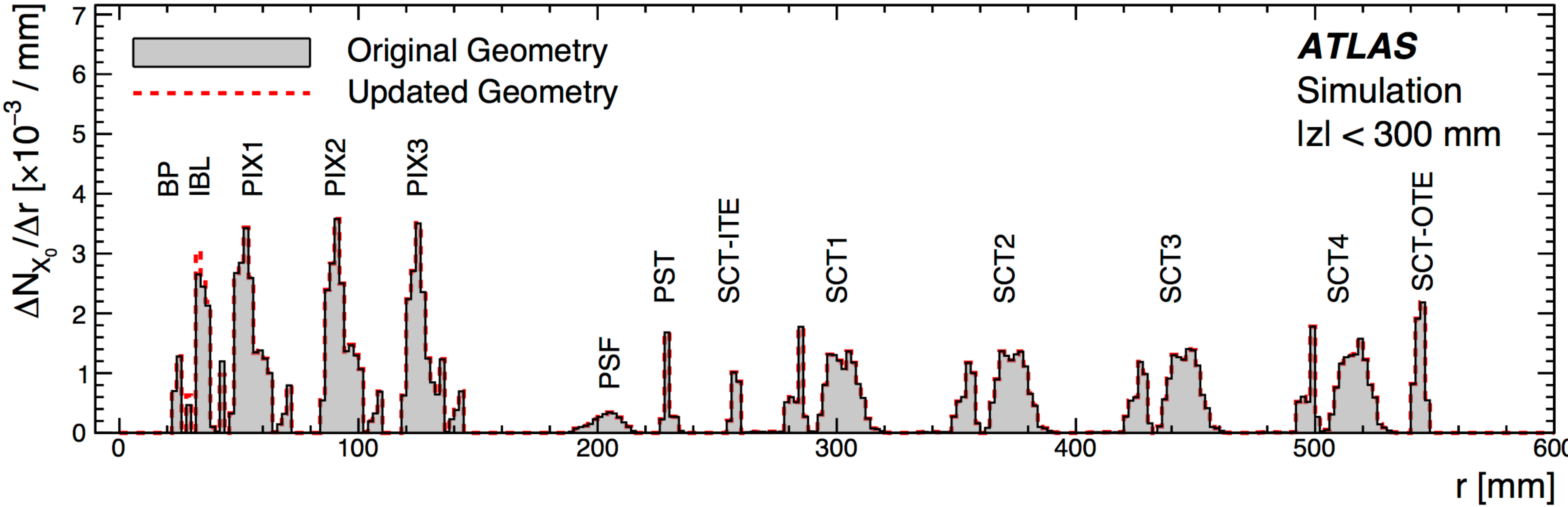
THE ATLAS ID

- Pixel
  - 4 layers, 80 M channels, 50 × 400(600) × 250 μm, 10(115) μm r−ϕ (z) resolution
  - Insertable B-Layer
- SemiConductor Tracker
  - Silicon strips, 80 × 6000 × 285 μm
  - 4 barrel, 9 end cap
- Transition Radiation Tracker
  - 4 mm straws with 70-27-3 Xe-CO_2-O_2 gas
  - Transition radiation ~ γ (1/m; electrons have 260 more than pions)





ID Material Budget



CALORIMETRY

- Calorimeter response is measured as

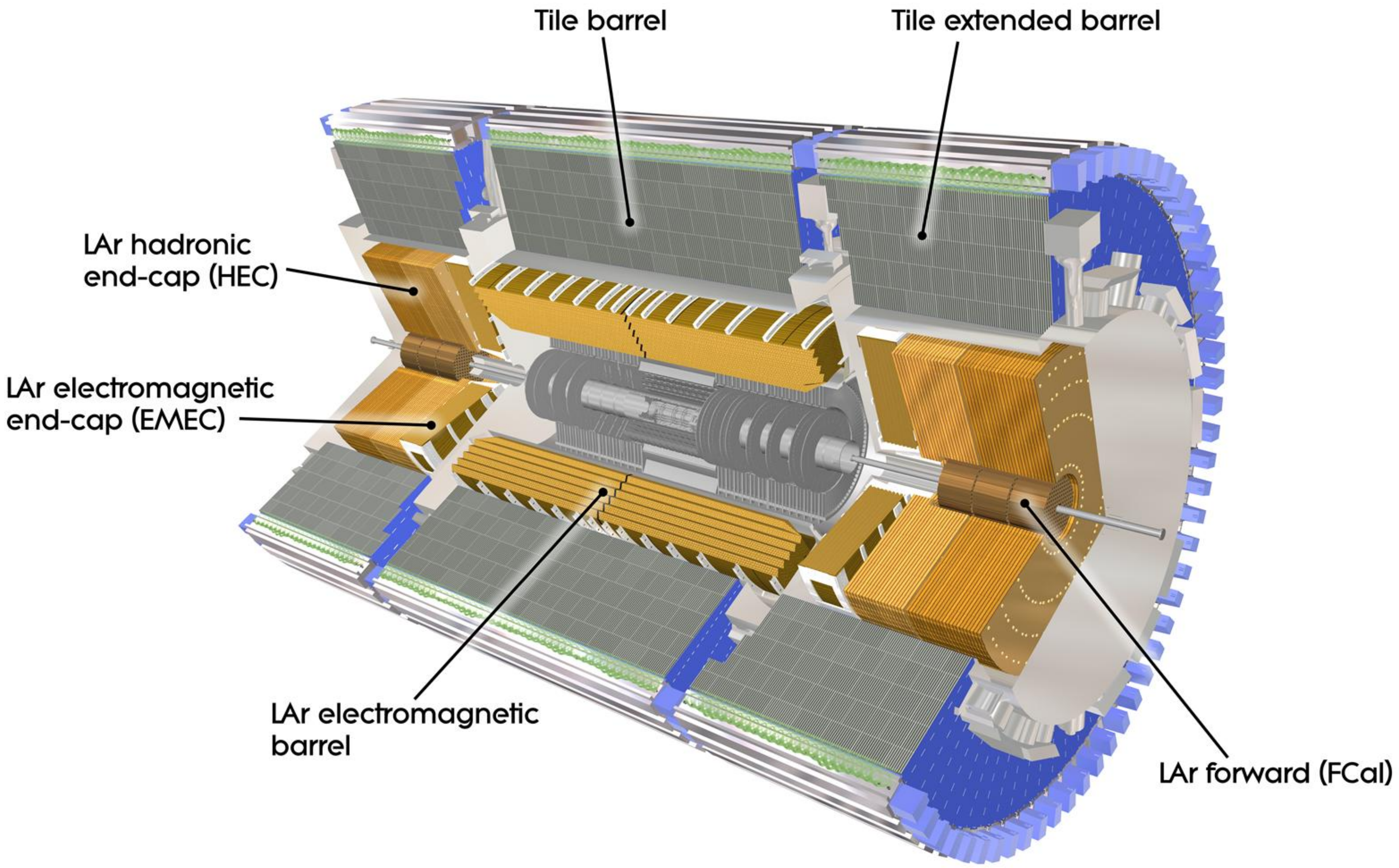
$$\frac{\sigma_E}{E} = \frac{S}{\sqrt{E}} \oplus \frac{N}{E} \oplus C$$

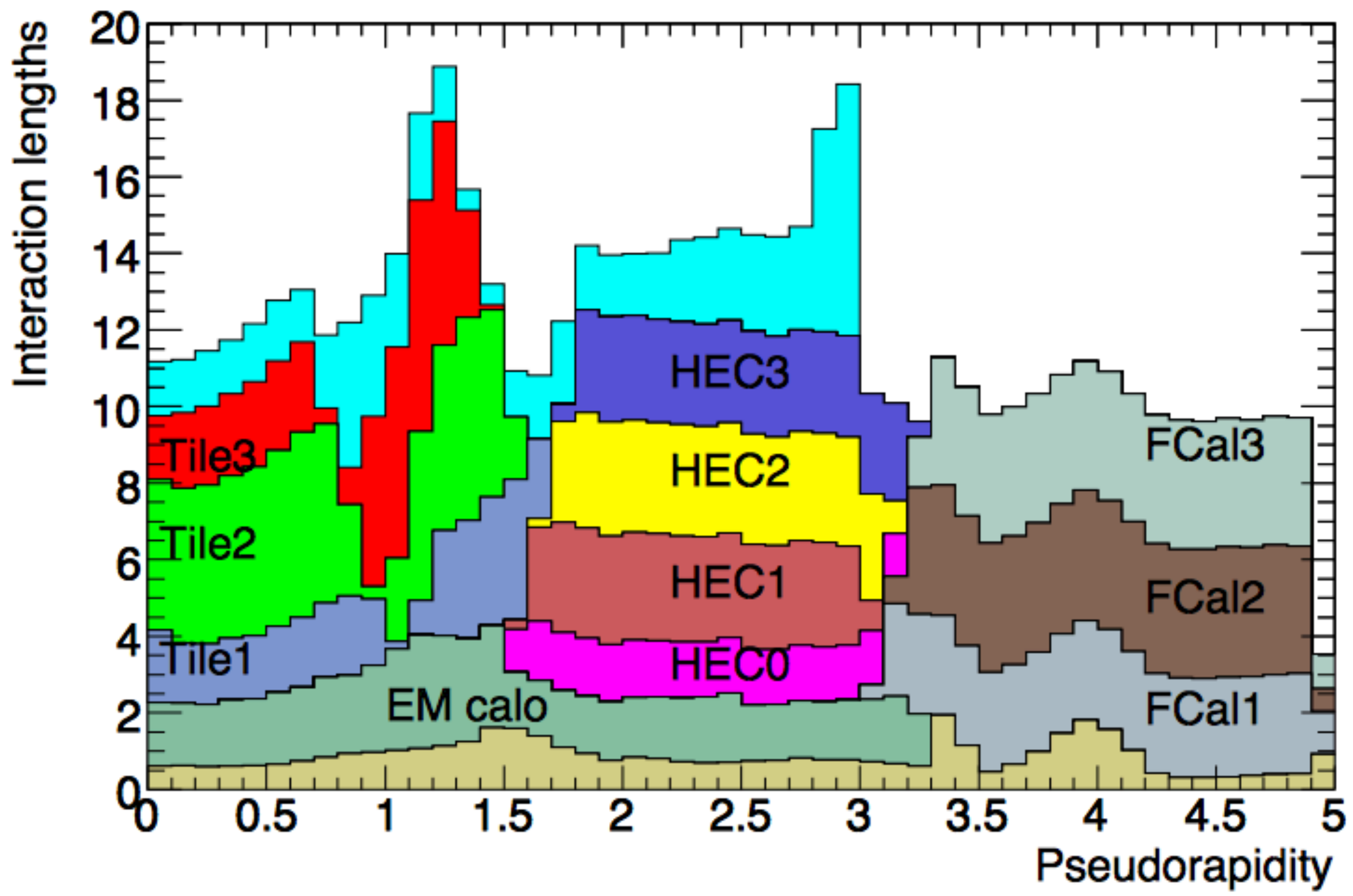
- S is stochastic/photoelectron stats (counting)

$$S \sim \mathrm{few}\% \sqrt{d_{active}\,[\mathrm{mm}]\,/\,f_{samp}}$$

- N is noise (constant per channel) typically 0.1-0.5 GeV regardless to detector type
- C is calibration

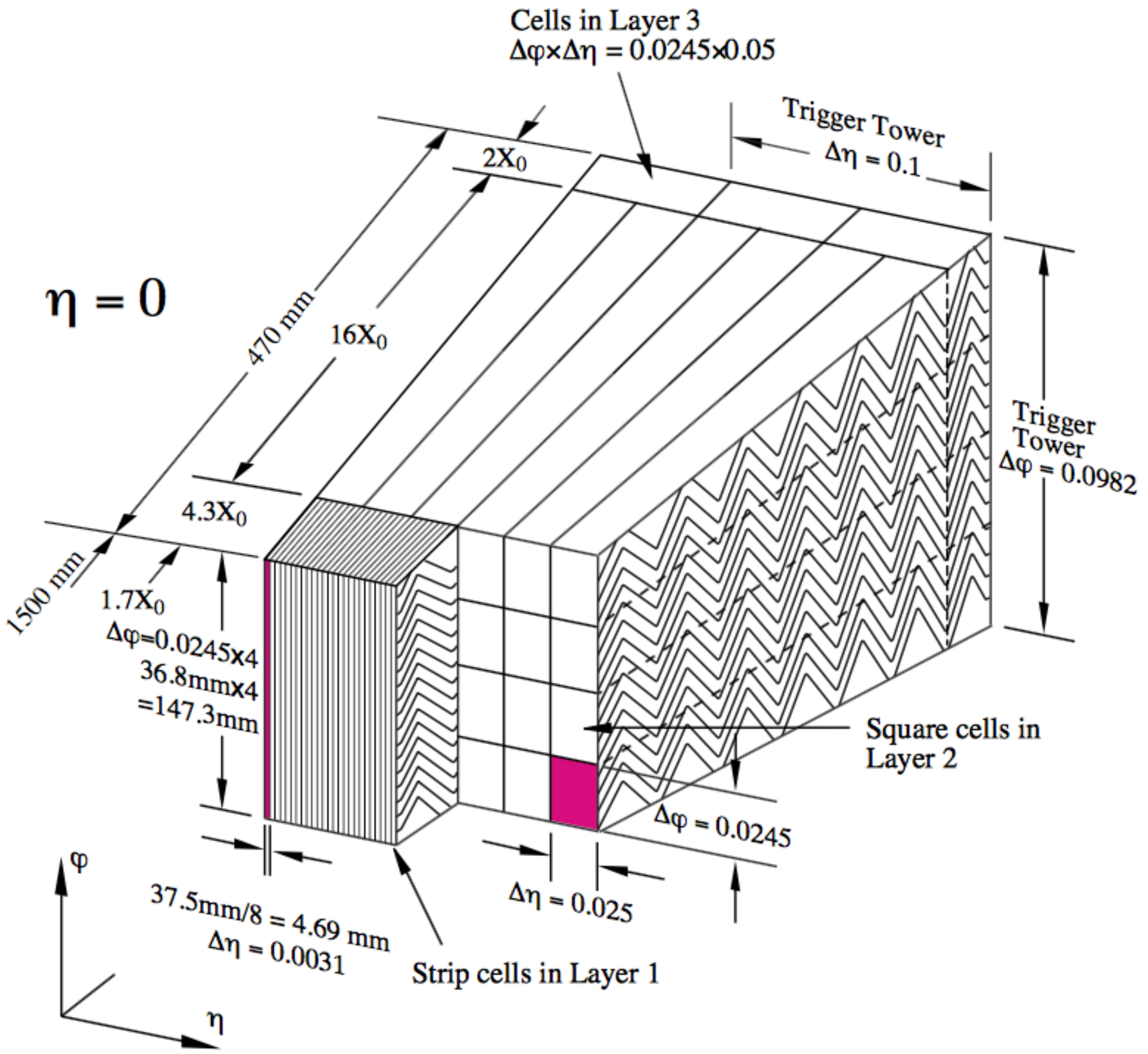
ATLAS Calorimeters





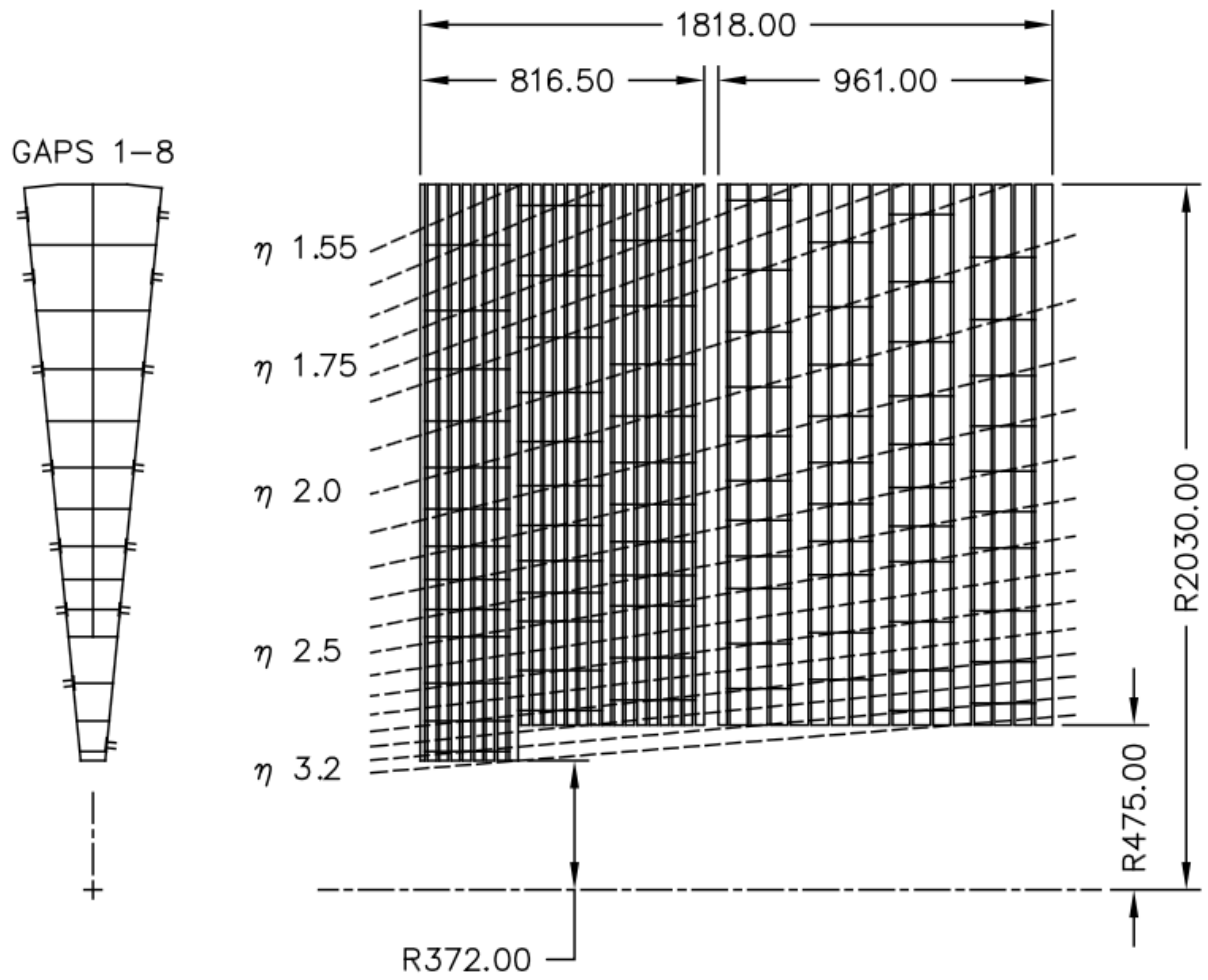
ECAL

- LAr, lead "accordion"
- S~0.1 GeV$^{-1/2}$, C=0.002; 450 ns drift time; middle barrel layer of ηxϕ resolution 0.025x0.025 sets granularity of calorimeter reconstruction
- 3 barrel (to |η| 1.475) layers
  - Presampler
- 3 (2)EC (1.375<|η|<2.5 (3.2)) inner (outer) wheels



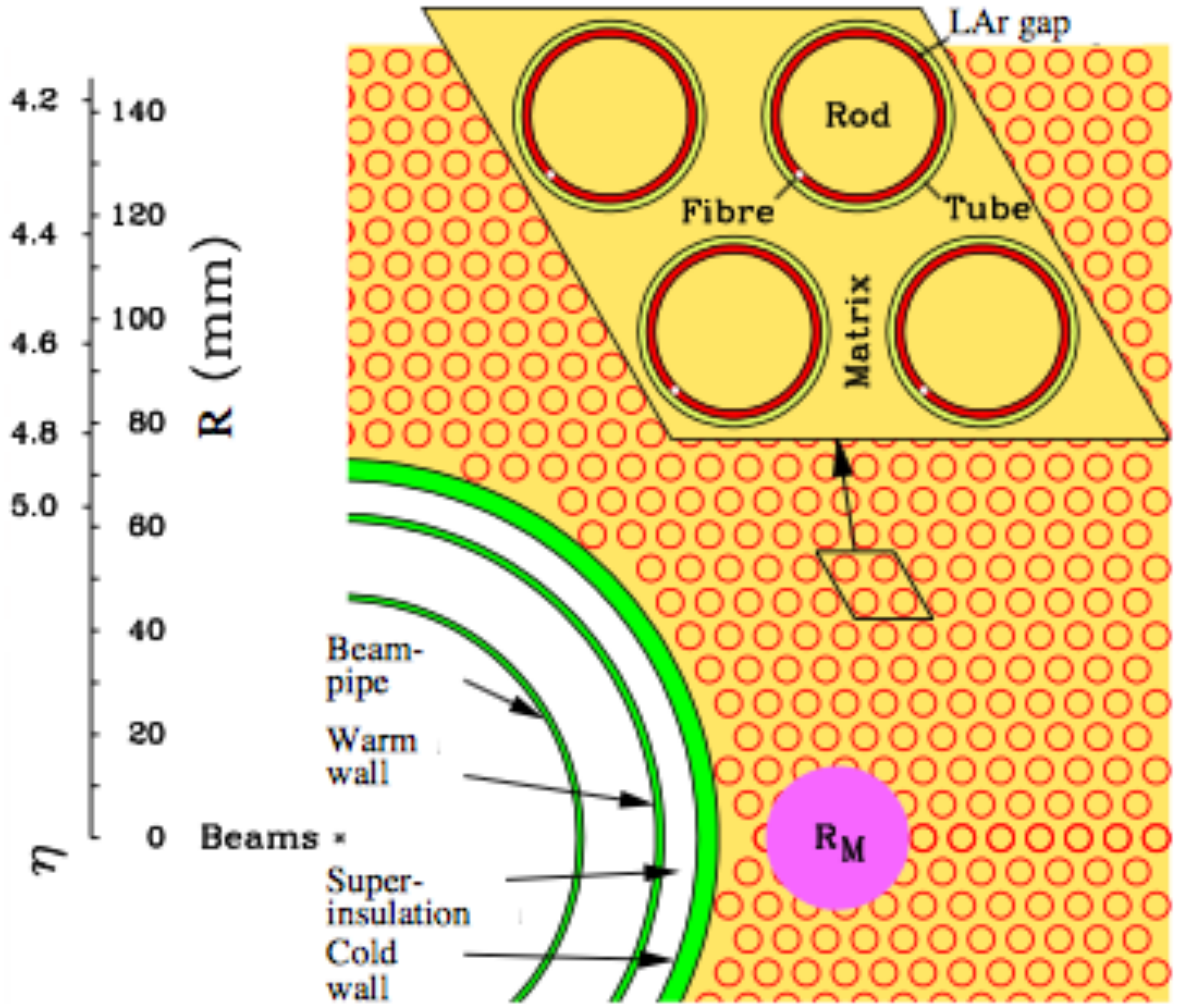
HEC

- Hadronic end cap
- Two wheels beyond ECAL EC
- 1.5<|η|<3.2
- 0.1x0.1 (to 2.5), 0.2x0.2 granularity
- LAr-Cu



FCAL

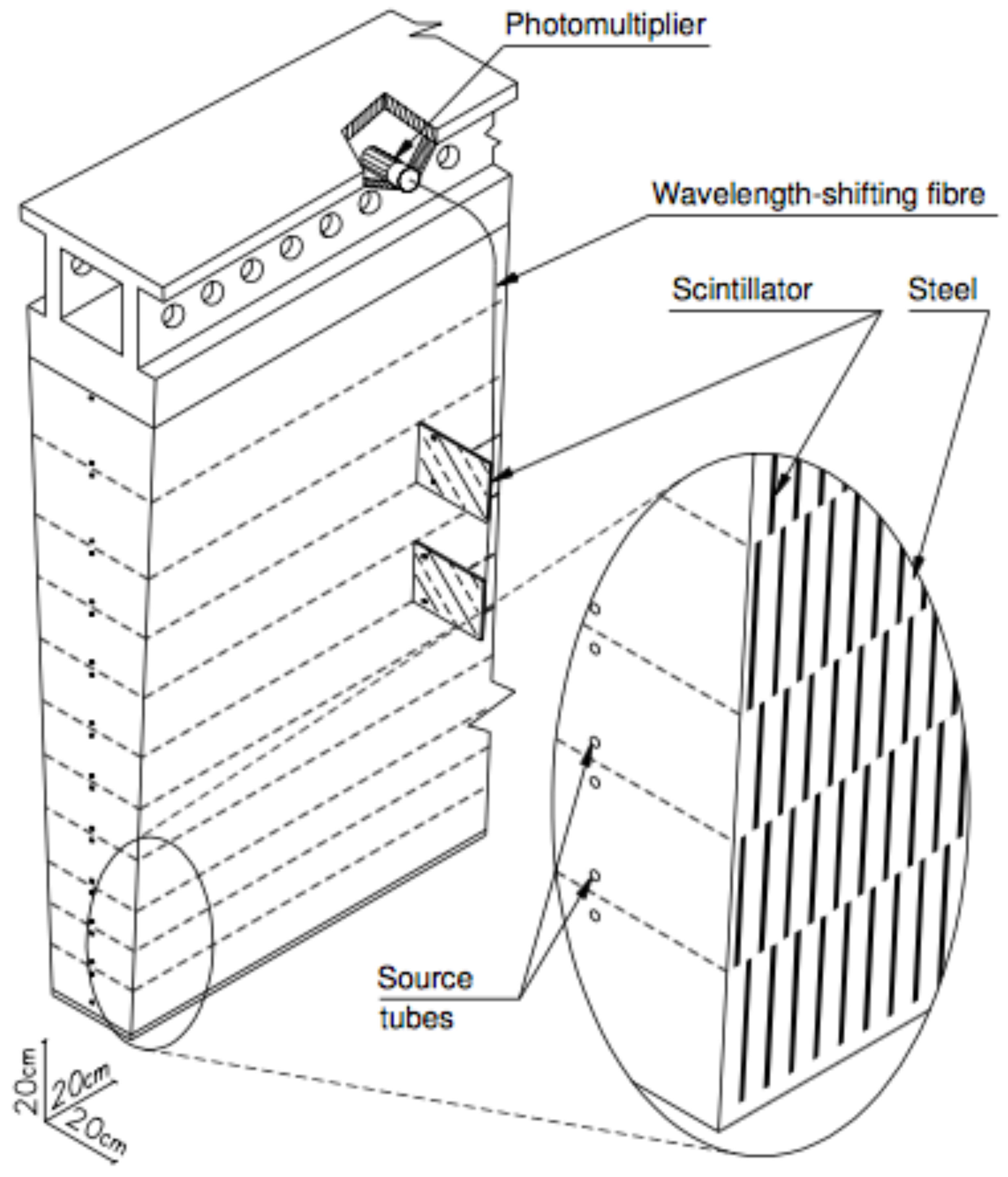
- 3.1<|η|<4.9
- LAr in gaps in Cu-W matrix
- 1 EM, 2 had modules (more W in hadronic)
- S~1 GeV$^{-1/2}$



TILECAL

Finding Standard Model VHbb
S. Chan
2018.04.25

- Barrel only; 64 polystyrene-steel modules in ϕ
- S~0.5 $GeV^{-1/2}$, C=0.05 (0.03 after calibration)
- 0.1(0.2)x0.1 ηxϕ resolution in first two (last) layer



Muon Spectroscopy

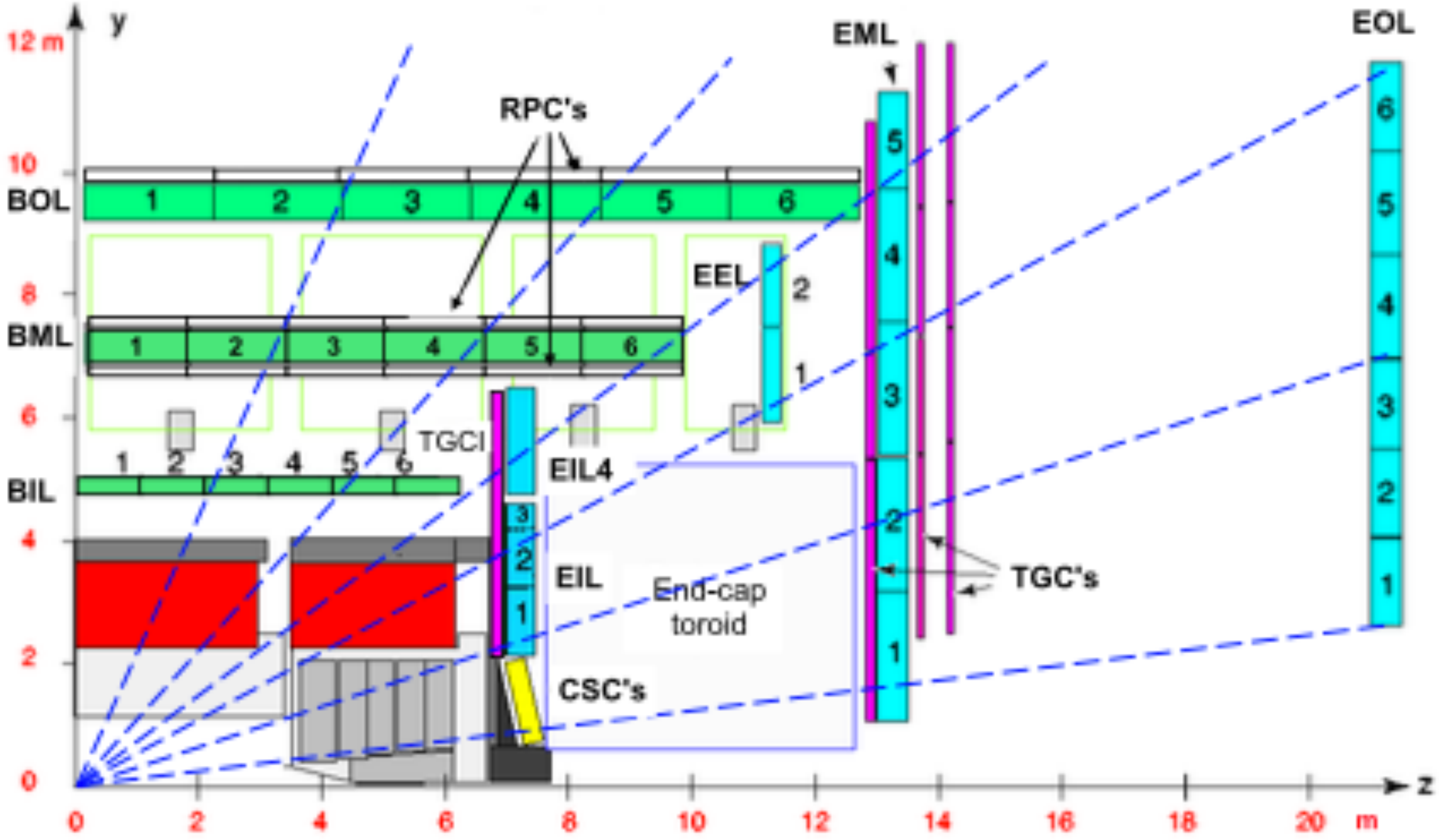
- Muons leave the detector, so we bend them with magnets to make a momentum measurement

$$\frac{\sigma_{p_T}}{p_T} = c_0 \oplus c_1 \cdot p_T$$

- 0 term is constant from multiple scattering ~0.5-2%
- 1 term from larger curvature of higher momentum muons (harder to measure) ~0.0001-0.001 /GeV; very important at high values
- ATLAS: 5-3000 GeV muons, 10% at 1 TeV, 3% at 100 GeV

The ATLAS MS

		Chamber resolution (RMS) in			Measurements/track		Number of	
Type	**Function**	z/R	ϕ	time	barrel	end-cap	chambers	channels
MDT	tracking	35 μm (z)	—	—	20	20	1088 (1150)	339k (354k)
CSC	tracking	40 μm (R)	5 mm	7 ns	—	4	32	30.7k
RPC	trigger	10 mm (z)	10 mm	1.5 ns	6	—	544 (606)	359k (373k)
TGC	trigger	2–6 mm (R)	3–7 mm	4 ns	—	9	3588	318k

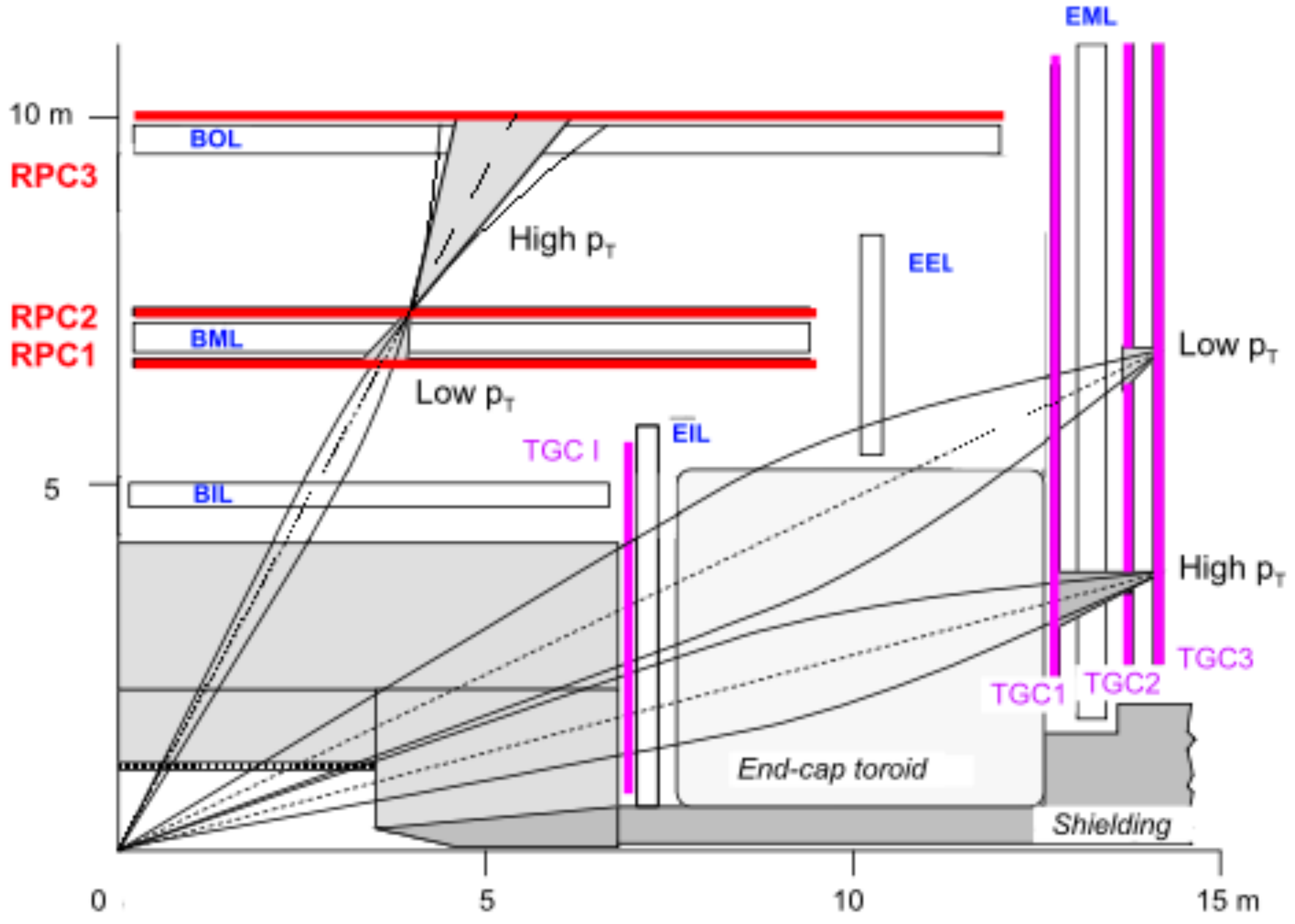


ATLAS MS Precision

- MDT: monitored drift tube
  - 3 cm tube; Ar/CO2; 3 kV
  - 35 μm resolution in longitudinal plane
  - 700 ns dead time
- CSC: cathode strip chamber
  - Forward region (EC $2.0<|\eta|<2.7$) is too high rate for MDT's (40 ns dead time)
  - Multiwire proportional chamber: 5.31 (5.56) mm strip pitch
  - 60 (5000) μm resolution in (non-)bending direction

ATLAS MS TRIGGER

- $|\eta|<2.4$
- RPC: resistive plate chambers
  - Parallel plate detectors, strip pitch 23-35 mm (orthogonal top/bottom)
  - 5 ns dead time, 9.8 kV, barrel
- TGC: thin gap chambers
  - MWPC, end cap
  - 25 ns dead time



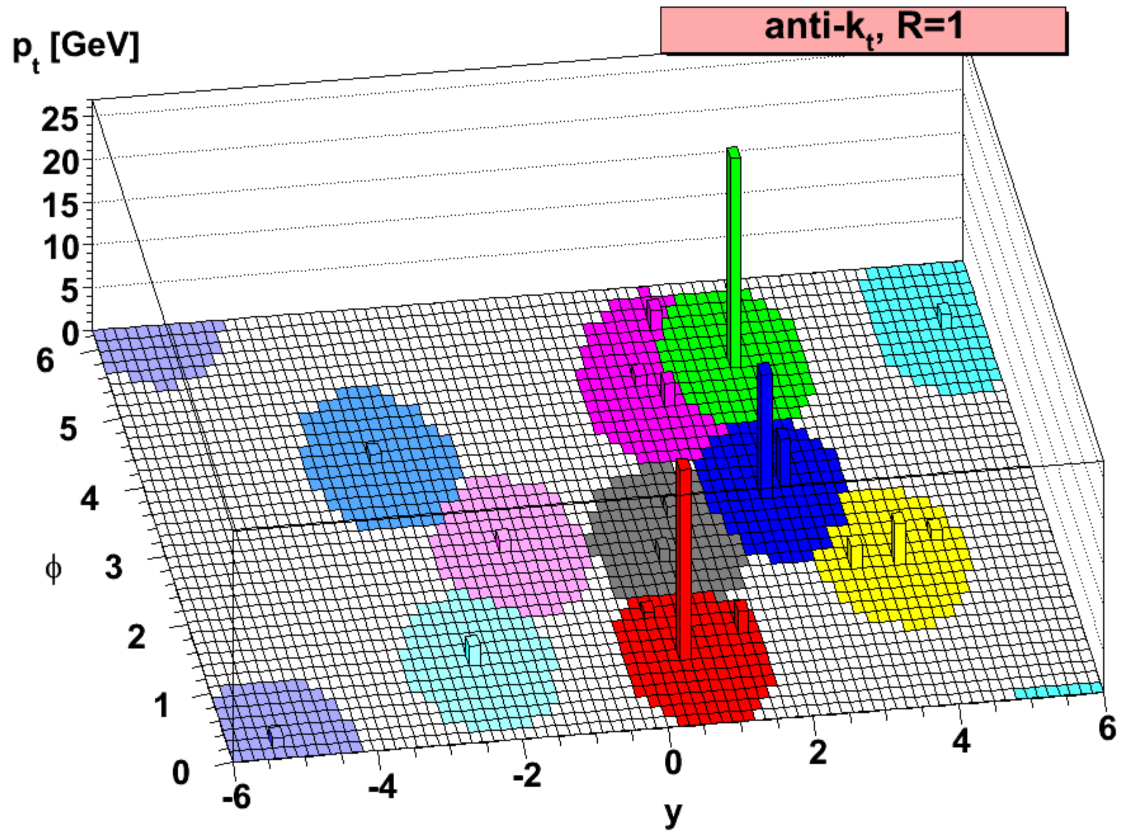
Jet Algorithms

- There are two main types of jet algorithms: *cone* and *cluster* based algorithms
  - Cone algorithms draw circles in the $\eta - \phi$ plane.
  - Clustering algorithms pair hits (towers, tracks...) based on a distance parameter

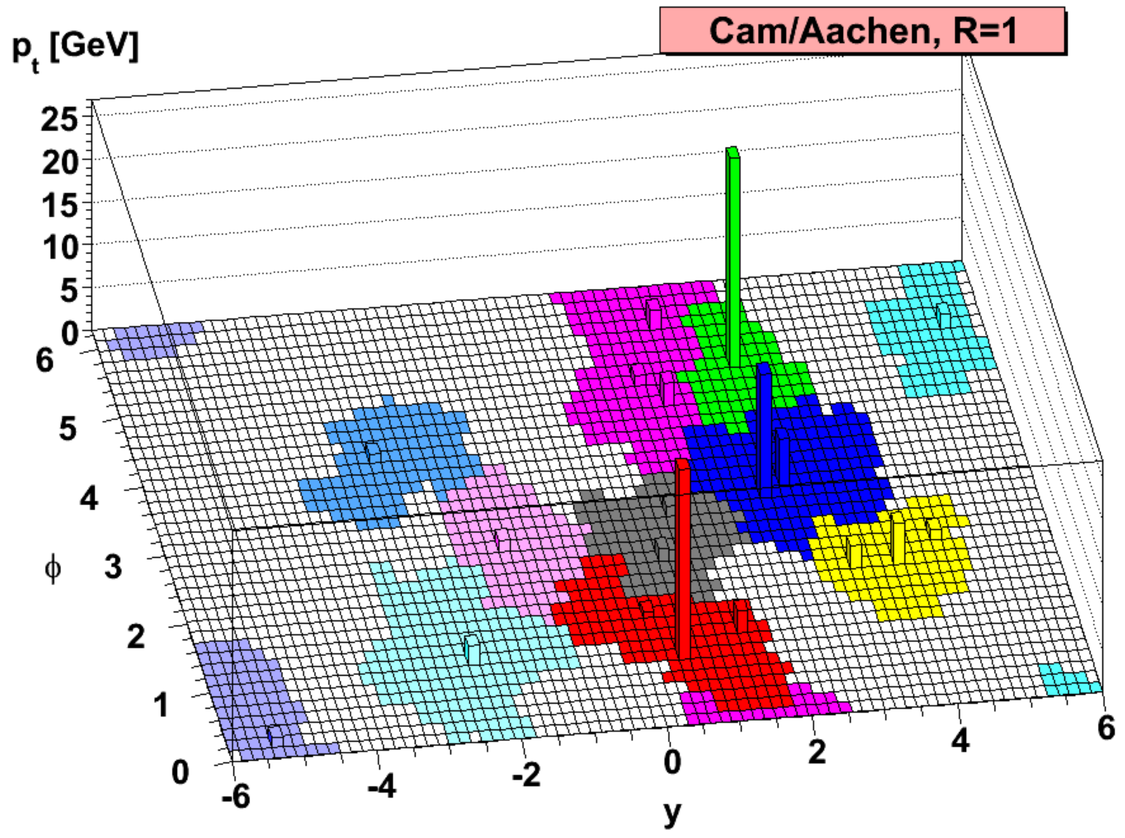
$$d_{ij} = \min\left(p_{Ti}^{2p}, p_{Tj}^{2p}\right)\frac{\Delta R_{ij}^2}{R^2},\ d_{iB} = p_{Ti}^{2p}$$
$$\Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i + \phi_j)^2$$

  - $p = 1 \rightarrow k_t$, $p = 0 \rightarrow$C/A, $p = -1 \rightarrow$anti-k_t
- Choosing an algorithm: algorithm type, R size parameter? (ATLAS uses anti-k_t jets with $R = 0.4$ as a default)
  - Different algorithms give different results: different interpretations of what happened in an event

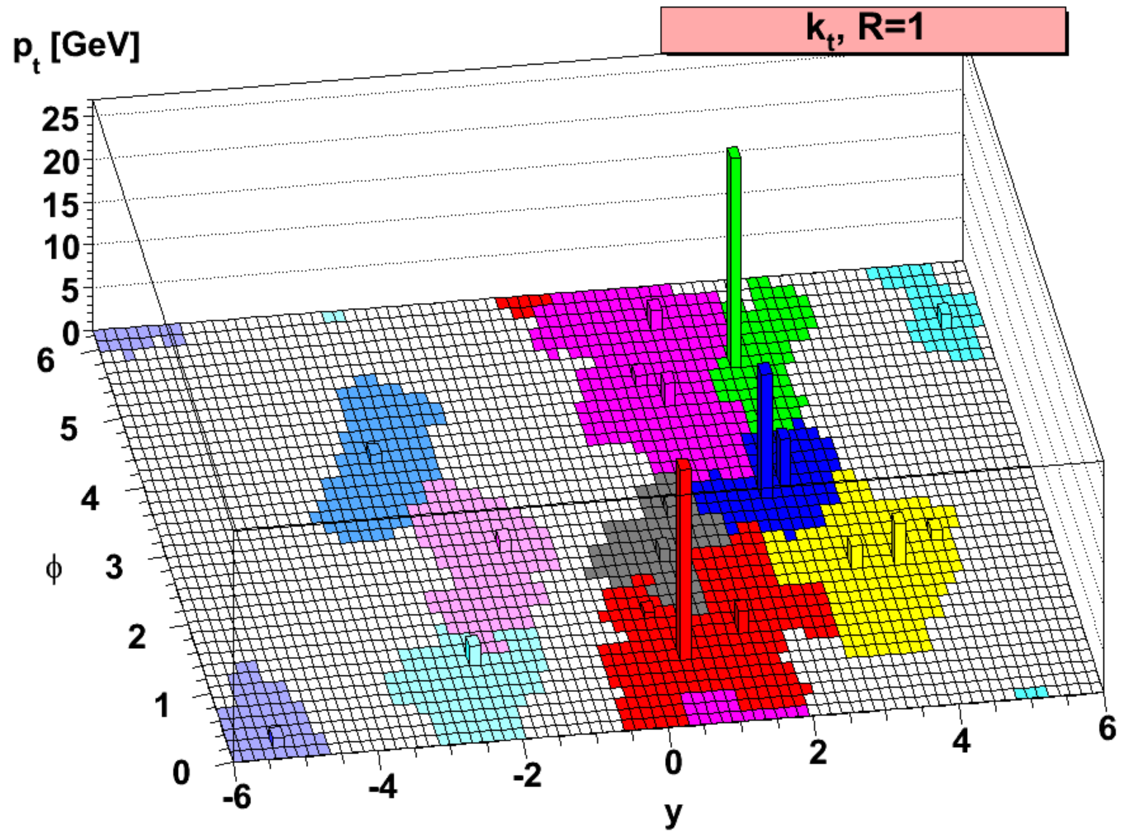
Different Jet Algorithms



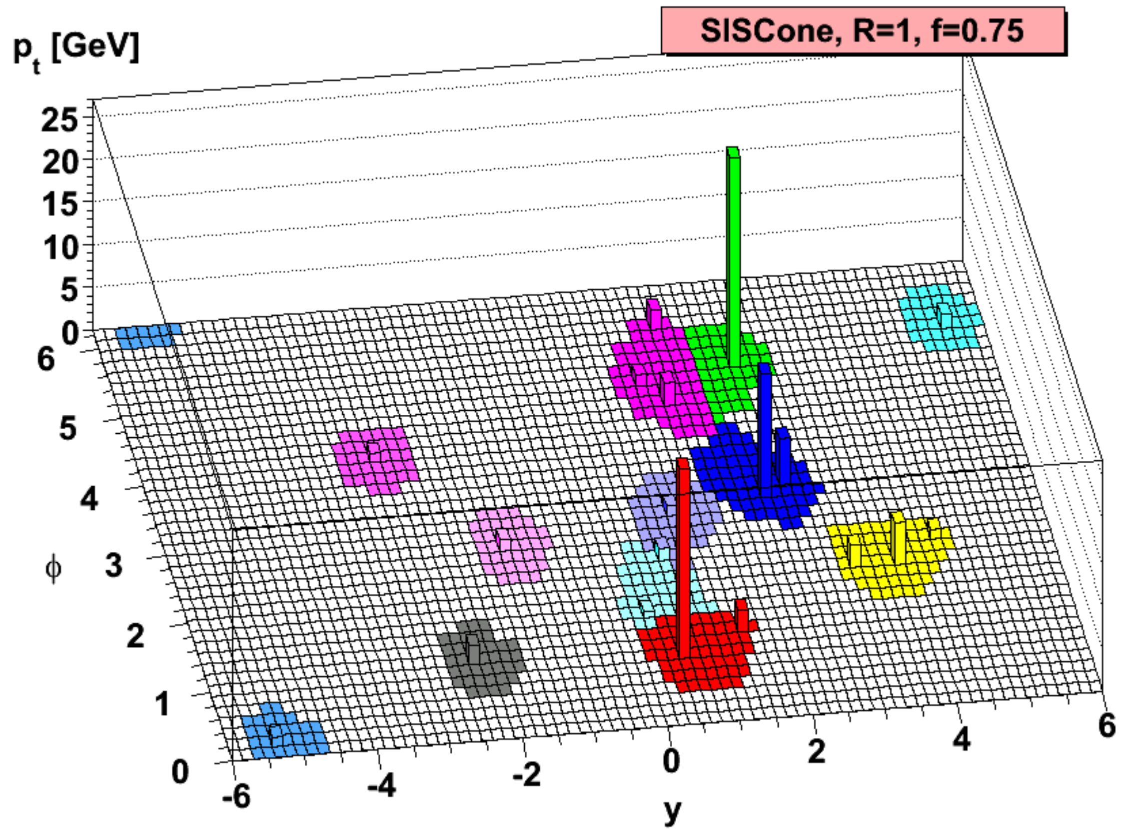
: anti-k_t



: C/A



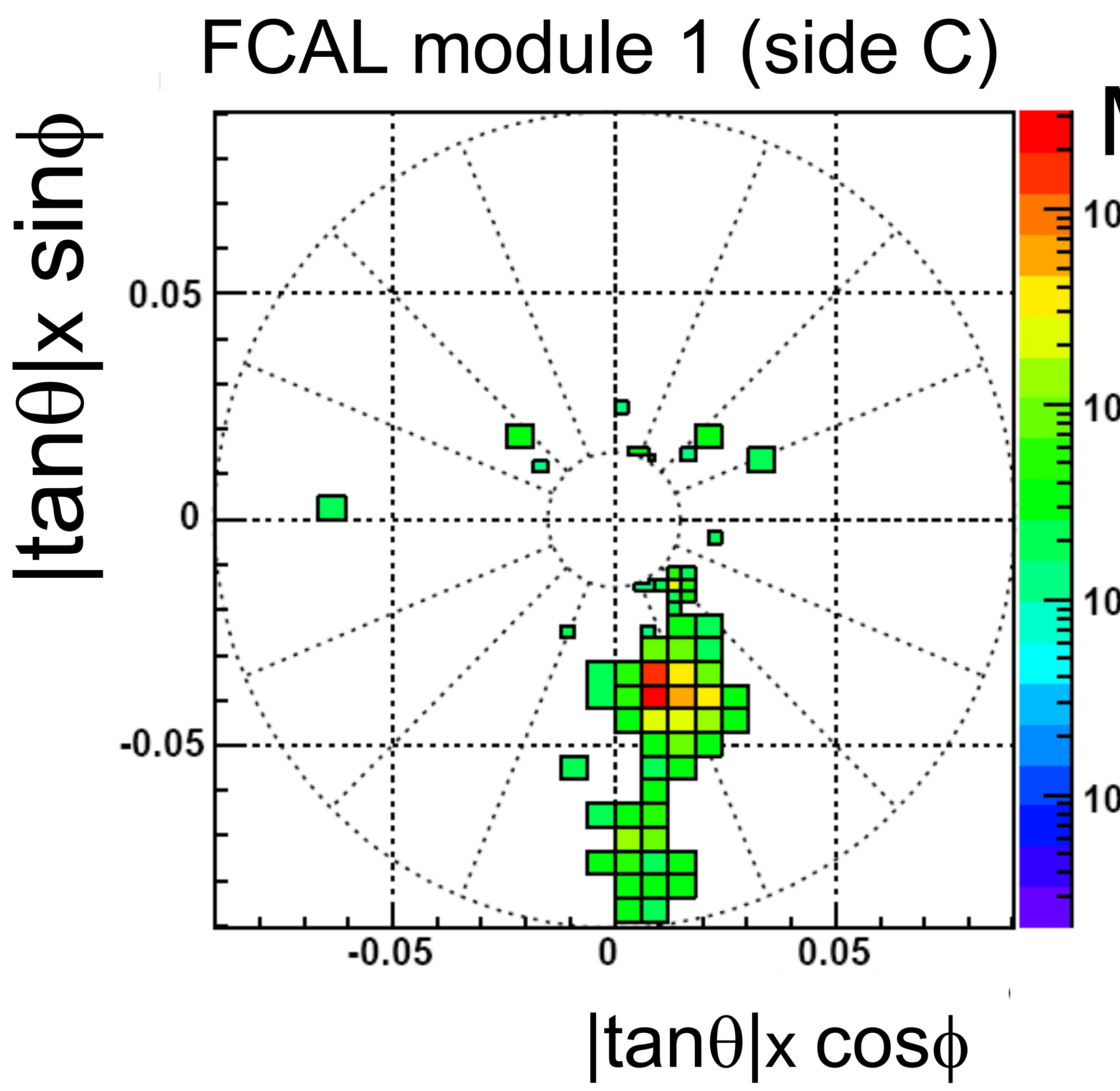
: k_t



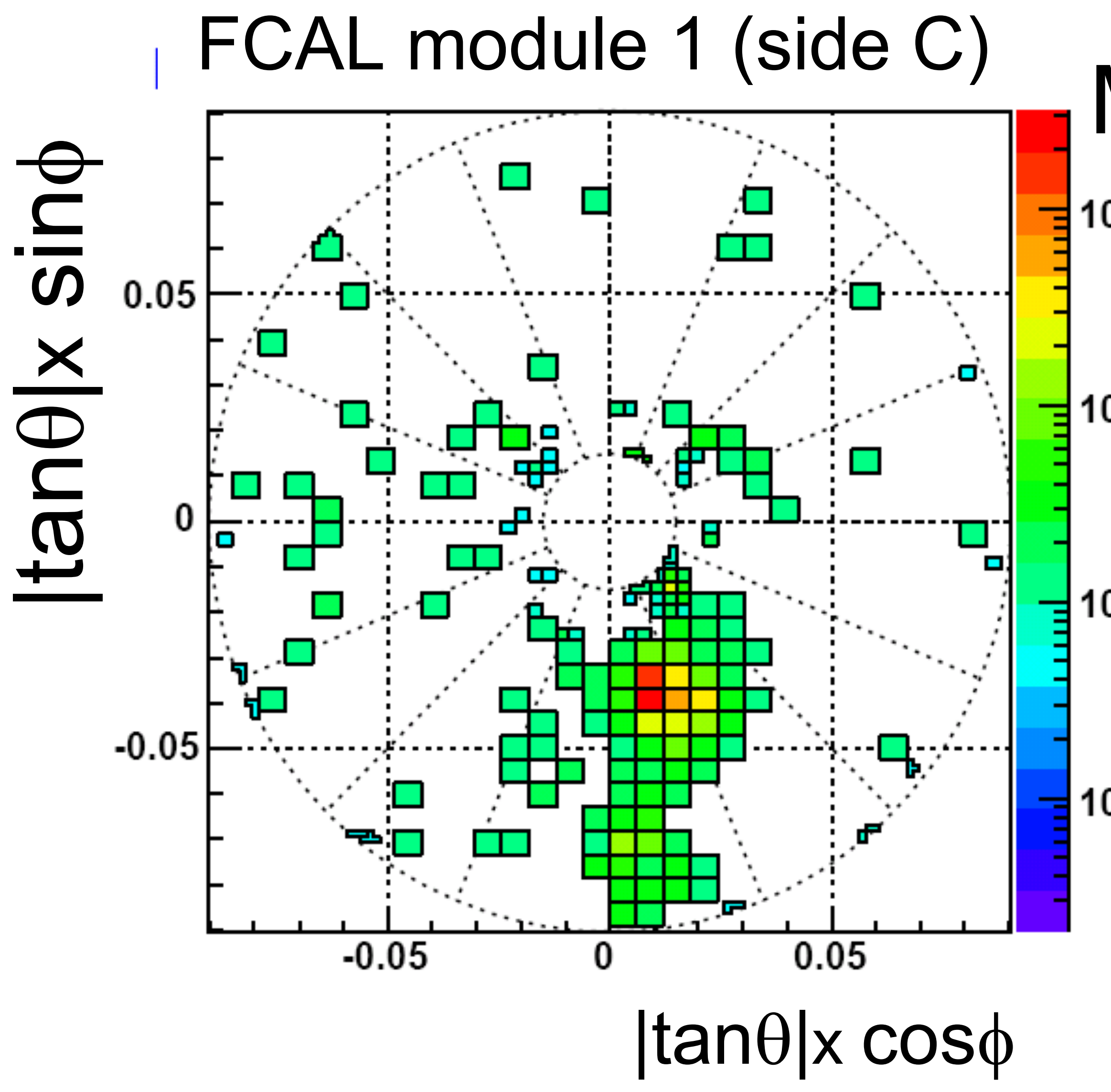
: SISCone

Local Hadronic Calibration: Clusters

Sven Menke

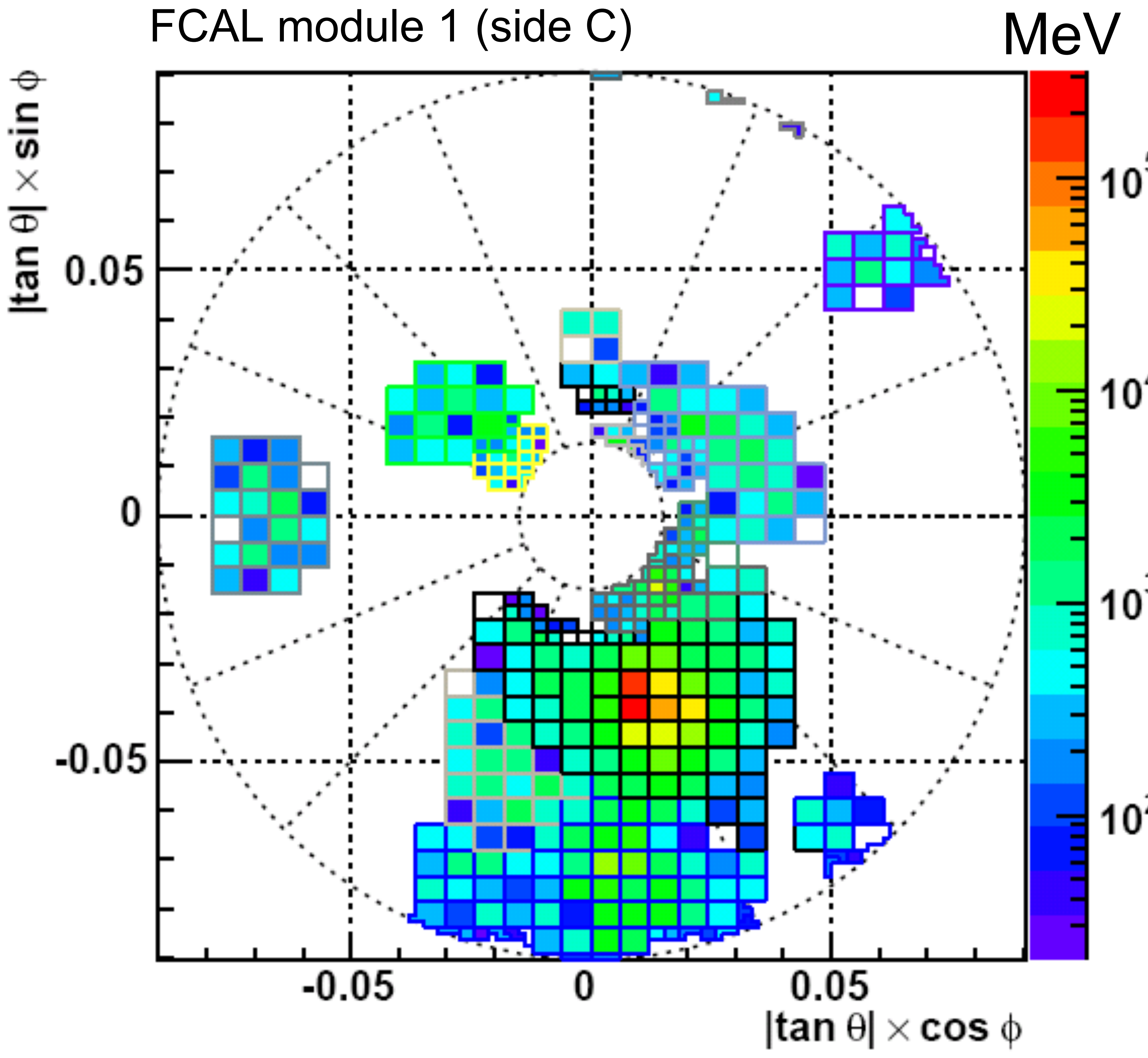


cells with $|E_{cell}|>4\sigma_{noise}$



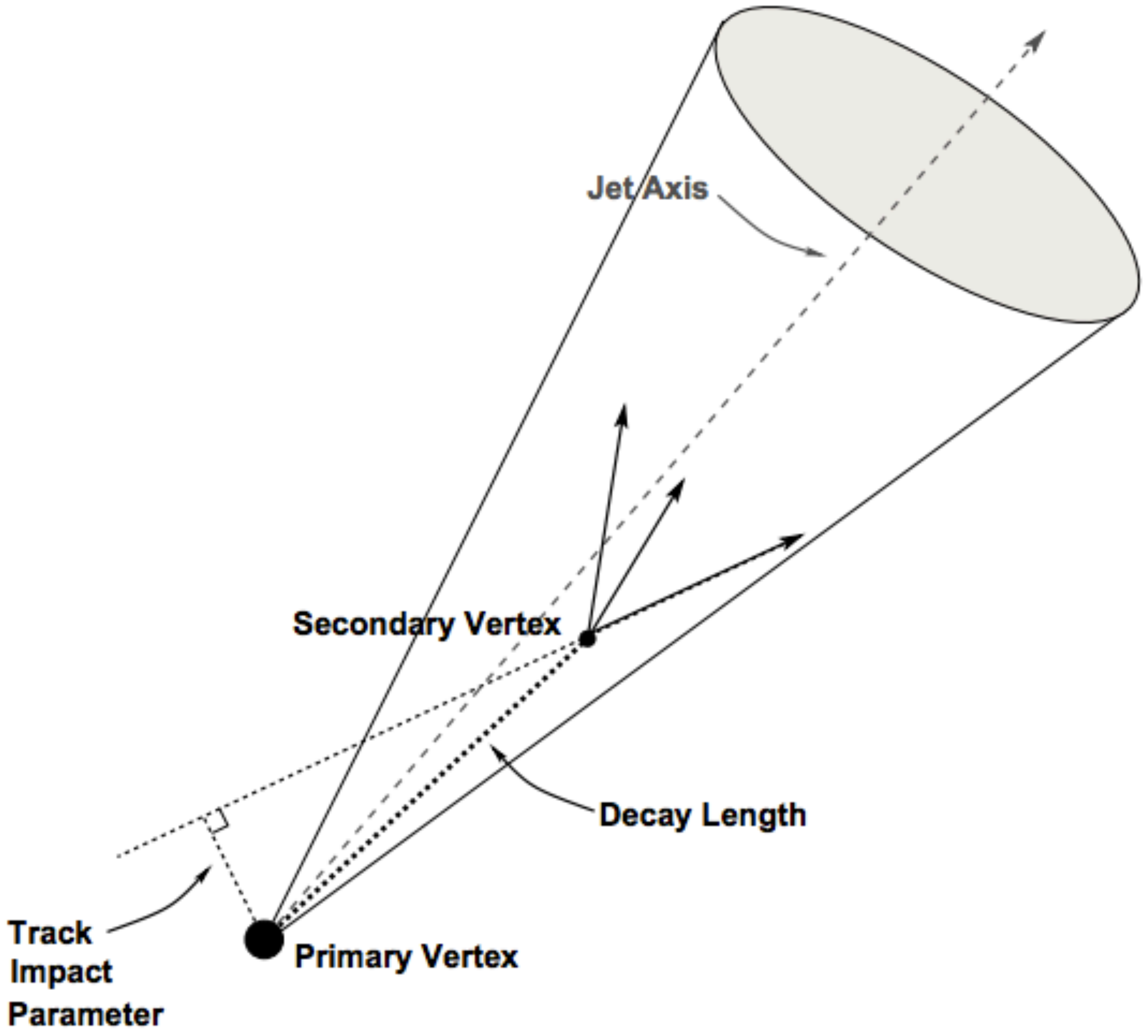
cells with $|E_{cell}|>2\sigma_{noise}$

- Topological clustering
  - 4,2,0 clusters in FCal
    - jets with p_T > 50 GeV



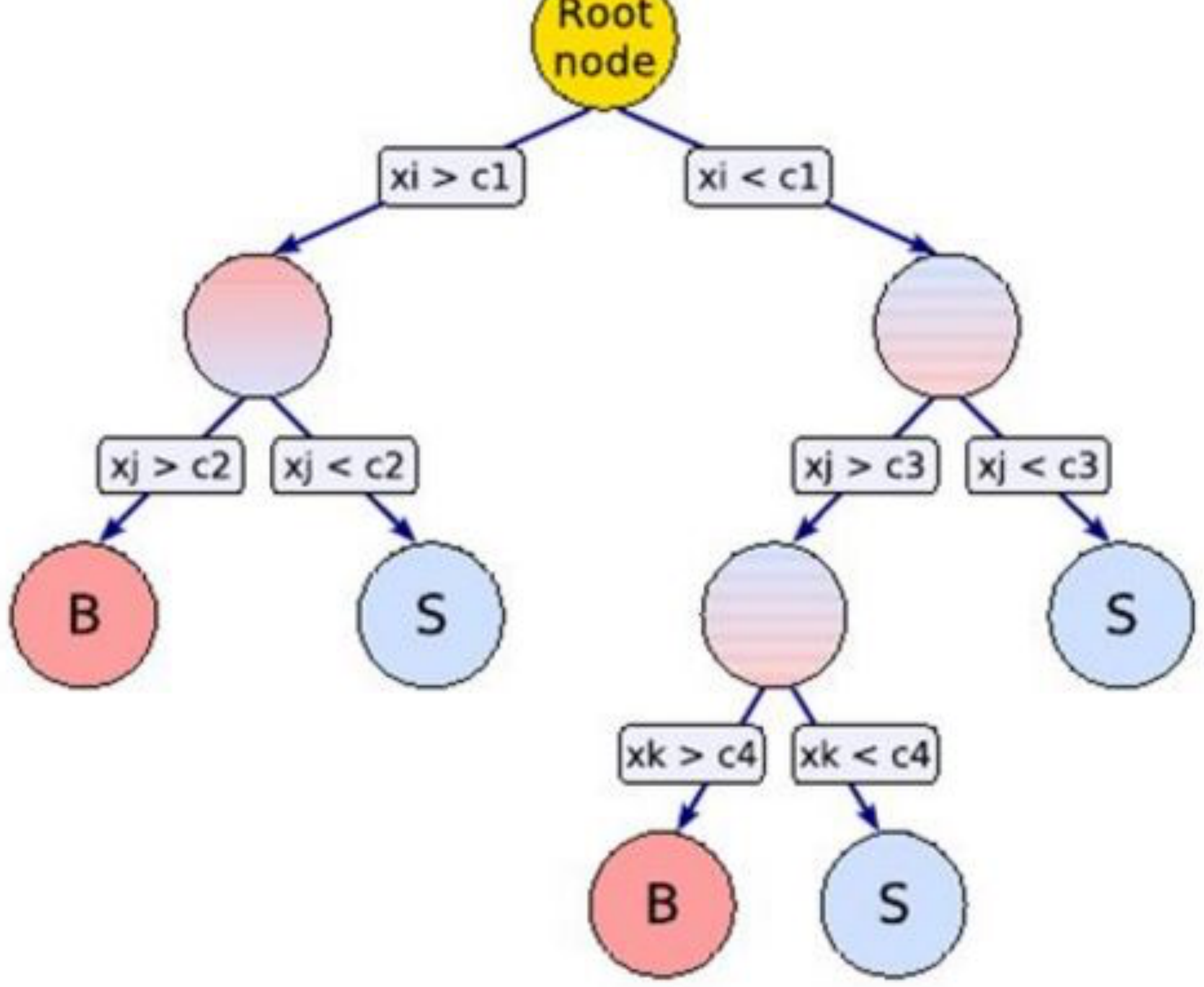
FLAVOR TAGGING

- Jets originating from gluons and u/d/s quarks hadronize promptly
  - D and B mesons have ~ps lifetimes and form displaced, **secondary vertices**
- Secondary vertices identified in different ways
  - Impact parameters (I[23]PD)
  - Inclusive SV reco (track pairs, SV[01])
  - Multiple vx reco (JetFitter; PV —> b —> c chain with Kalman filter)
- All 3 are used as inputs to MV2c10
  - Trained on MC: signal b's, background 90/10 charm/light



WHAT'S A BDT?

- An ensemble of decision trees; AdaBoost:
  - At each step, which variable/cut value gives most discriminating power?
  - After a tree is formed, calculate α=(1-error)/error; reweight misclassified events by α^β
  - Output is $$\frac{1}{N_{trees}}\sum_{i=1}^{N_{trees}} \ln\left(\alpha_i\right) h_i\left(x\right)$$
- Many other ML algorithms



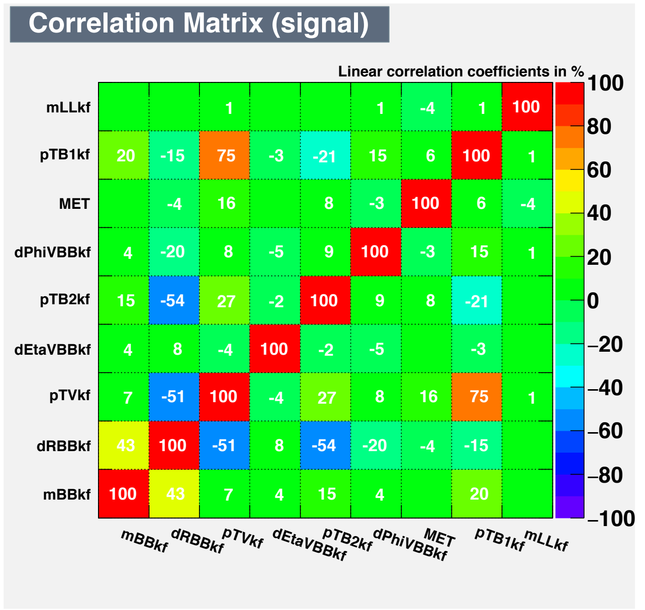
http://www.science20.com/tommaso_dorigo/decision_trees_explained_to_kids-224948

MVA Training and Optimization Settings

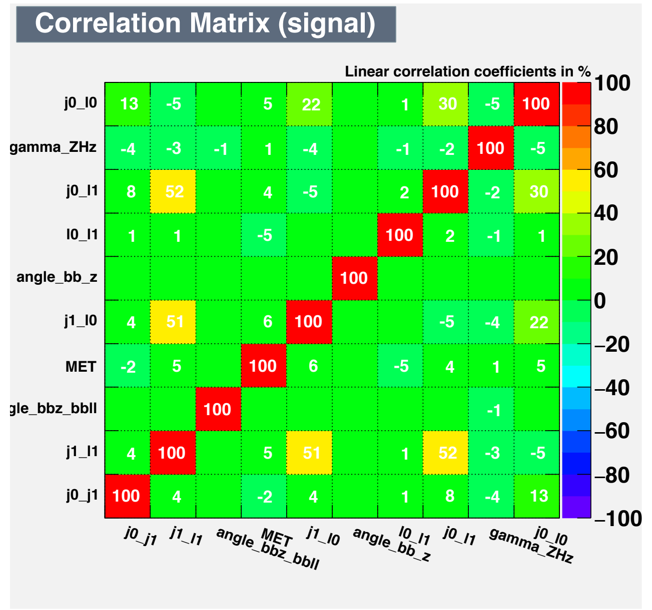
- BDT settings the same as in support note
  - BoostType=AdaBoost:AdaBoostBeta=0.15:SeparationType=GiniIndex:PruneMethod=NoPruning:NTrees=200:MaxDepth=4:nCuts=100:nEventsMin=5%
- Holdout method for ranking+stat only performance evaluation—EventNumber%3
  - Training
  - Validation: use significance on validation set for ranking
  - Testing: use final third with final BDT settings in each region for stat only significance
  - Still use the usual k-folds to make xml’s for fit inputs making
- Stat only significance: cumulative S/sqrt(S+B) with transformation D (z_s=z_b=10); normalize to 36.1 fb^{-1}
- Use the usual iterative ranking to determine BDT variable order
  - Start with mBB+dRBB for standard, j0_j1 for LI, MH for RF

VARIABLE CORRELATIONS

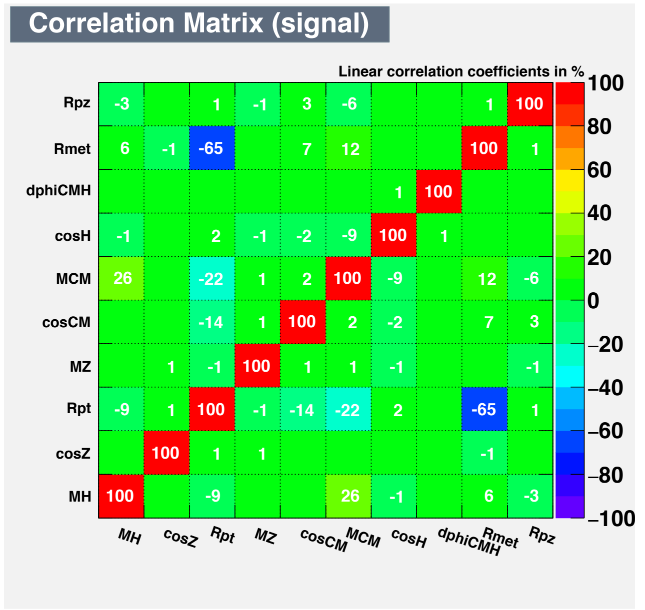
- LI and RF variables have markedly lower correlations (especially for signal events)
    - Higher correlations in background not unexpected (variables uncorrelated in your signal decay tree might be correlated for background processes by construction)
    - LI: Inner products between leading/subleading jets/leptons have higher correlations
    - RF: Rmet and Rpt (they both have CM pT in definition; expect MET to be antiparallel to CM pT)



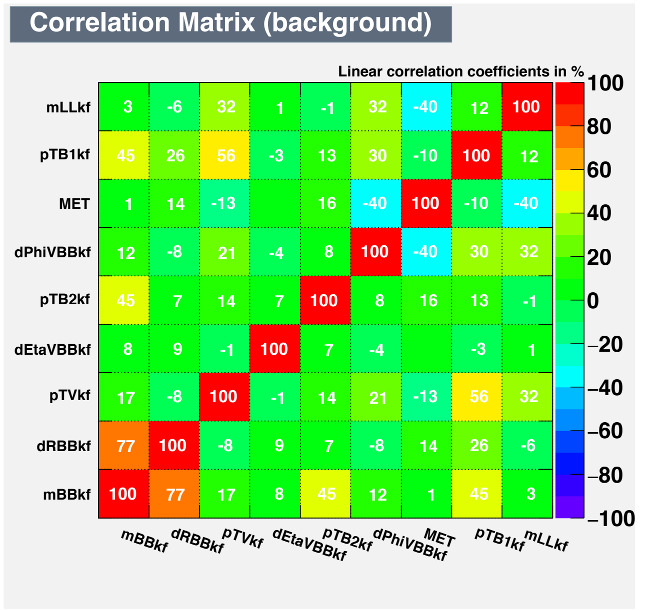
(a) Standard (S)



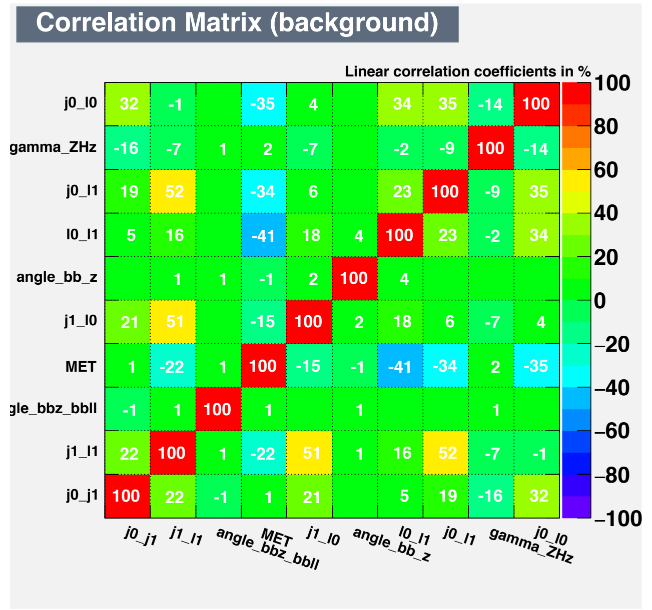
(b) LI (S)



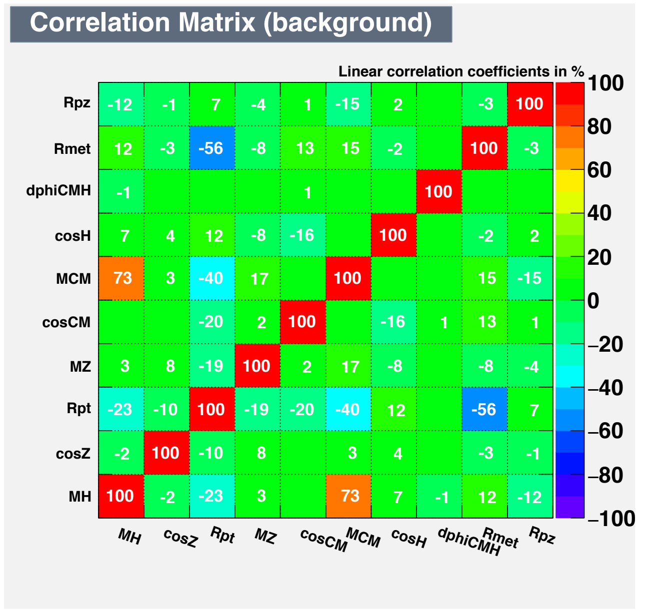
(c) RF (S)



(d) Standard (B)



(e) LI (B)

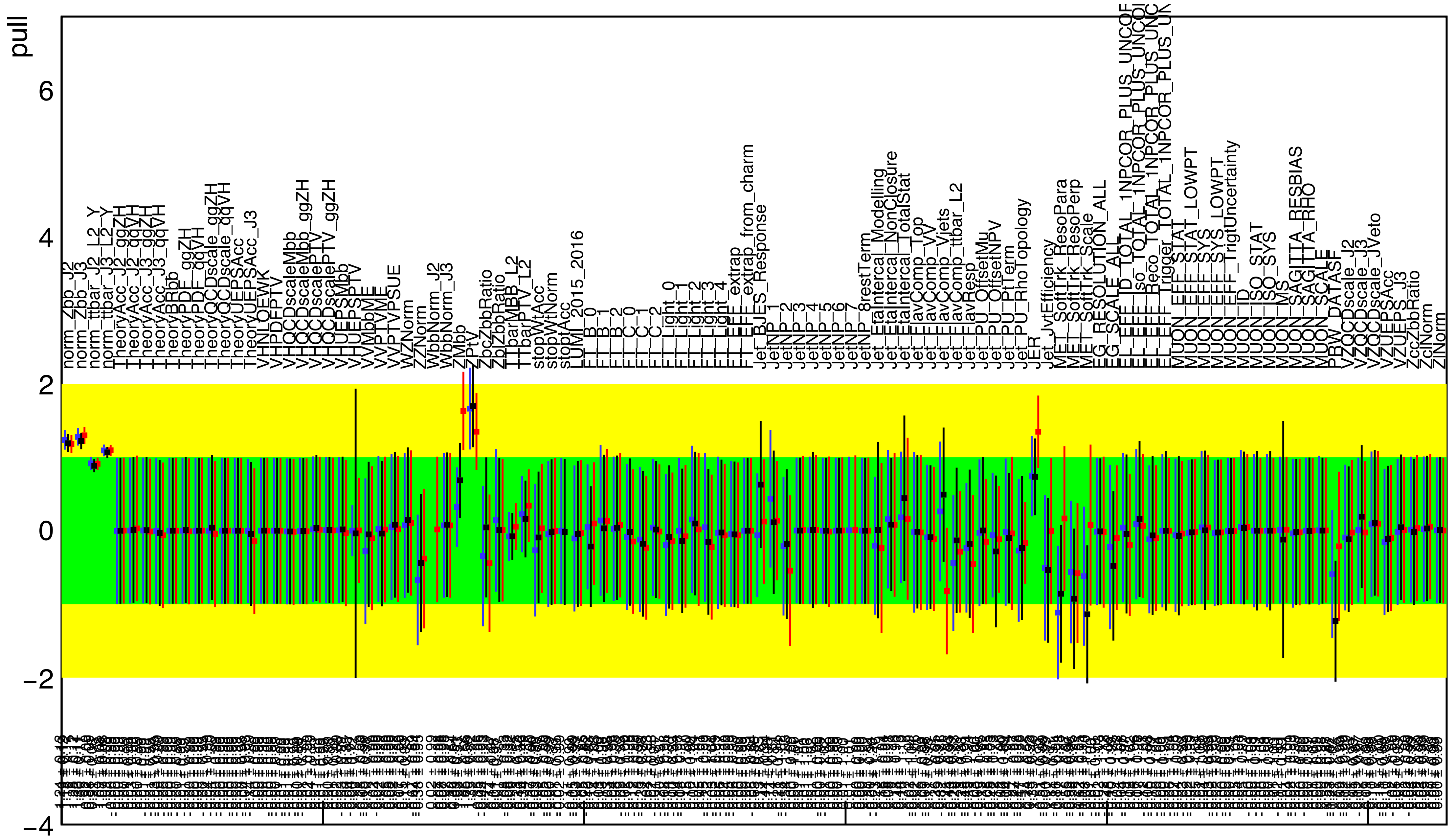


(f) RF (B)

How Does a More Orthogonal Basis Help?

- There are a lot of NP's
- ~105 here (not incl. MC stat errors); ~500 for combined full ATLAS *VH*
- Gaussian penalty terms can really add up

$$\mathcal{L}\left(\mu,\theta\right) = \mathrm{Pois}\left(n \mid \mu S + B\right)\left[\prod_{i\in \mathrm{bins}} \frac{\mu s_i + b_i}{\mu S + B}\right] \prod_{j\in \mathrm{NP's}} \mathcal{N}_{\theta_j}\left(\theta_j, \sigma_j^2 \mid 0,1\right)$$



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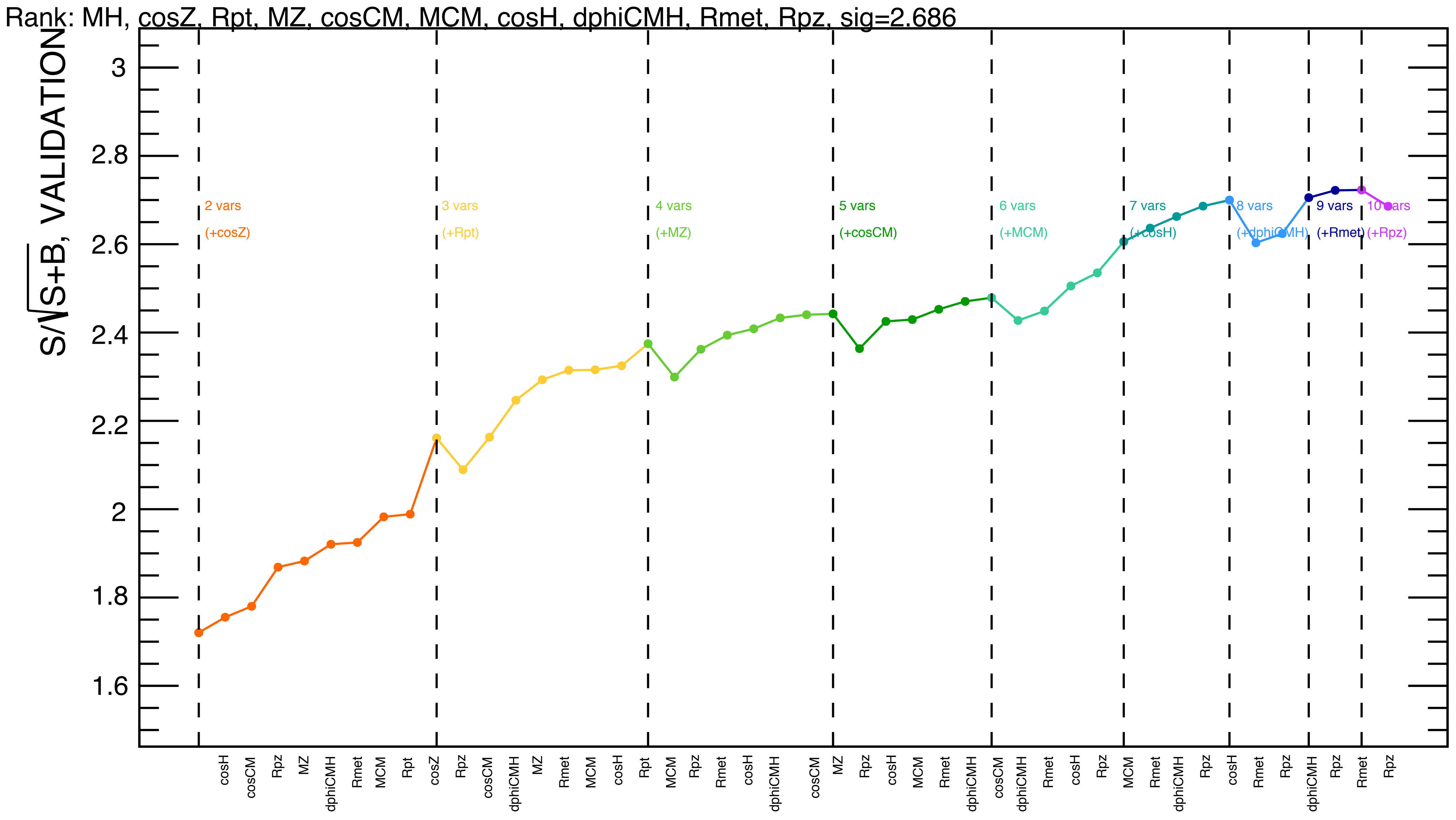
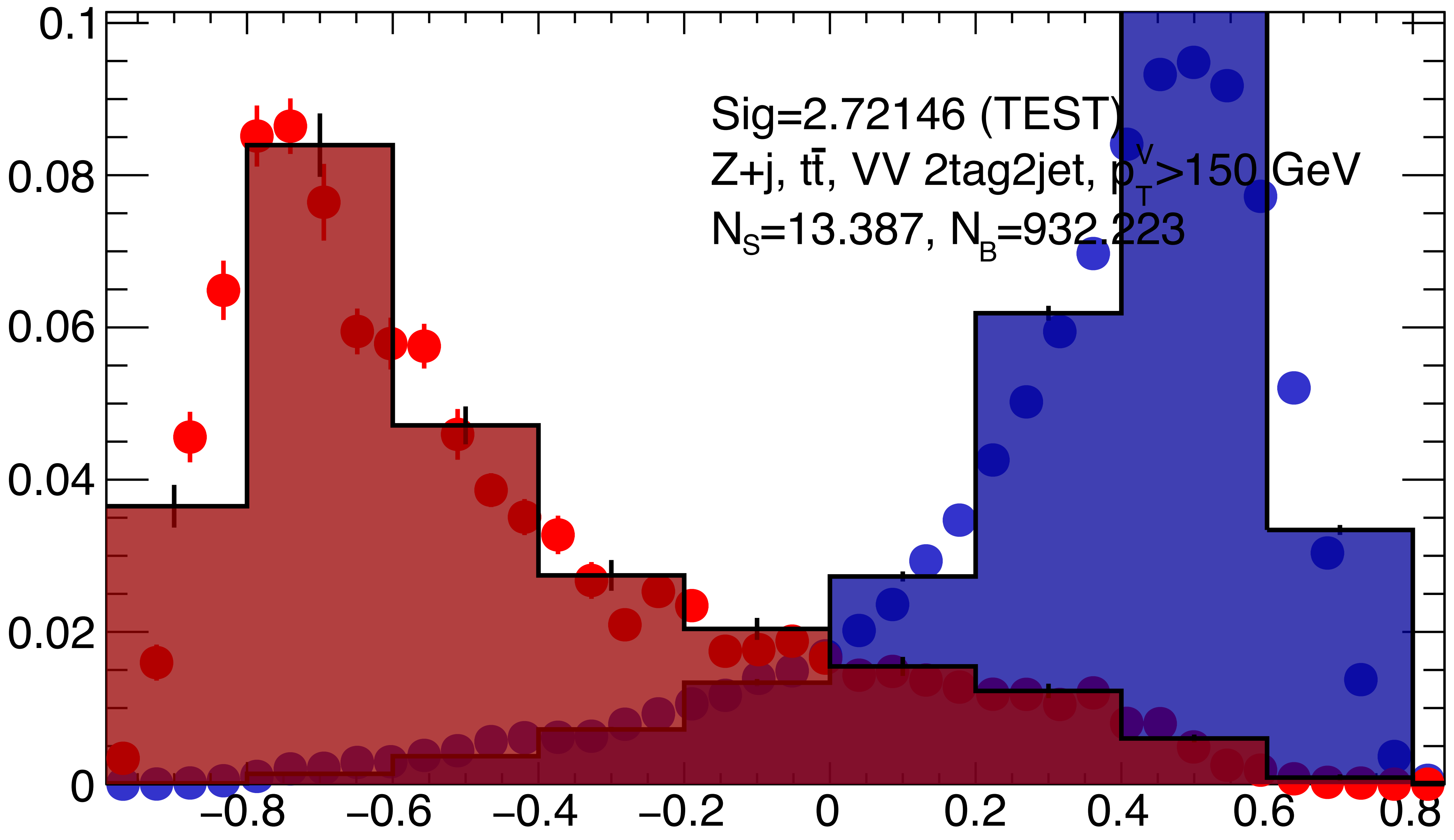
Finding Standard Model VHbb
S. Chan
2018.04.25

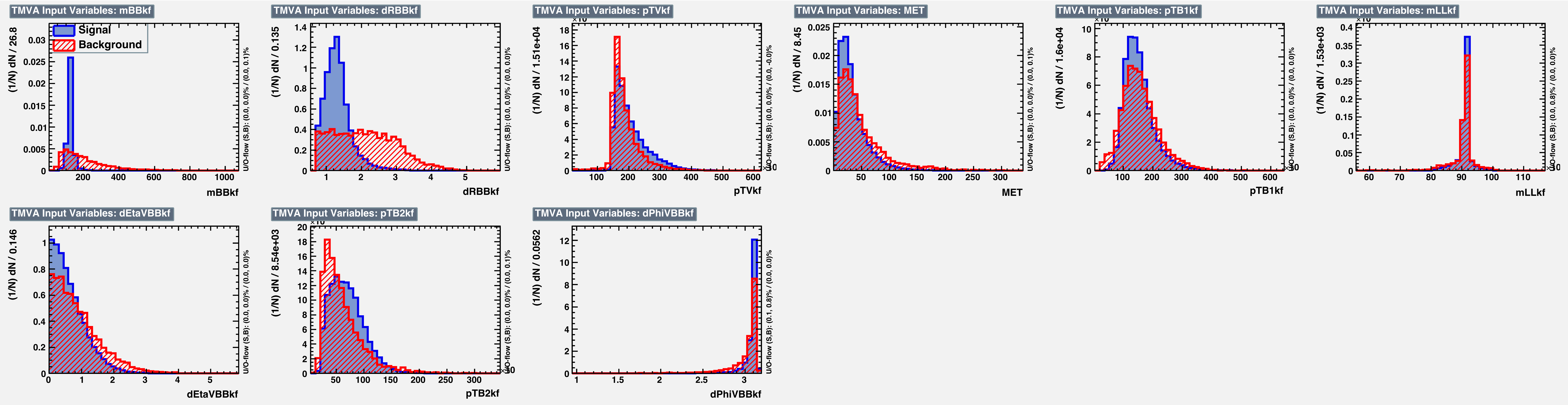
Ranking Example: RF 2Jet Hi pTV

- For full plots, see companion slides



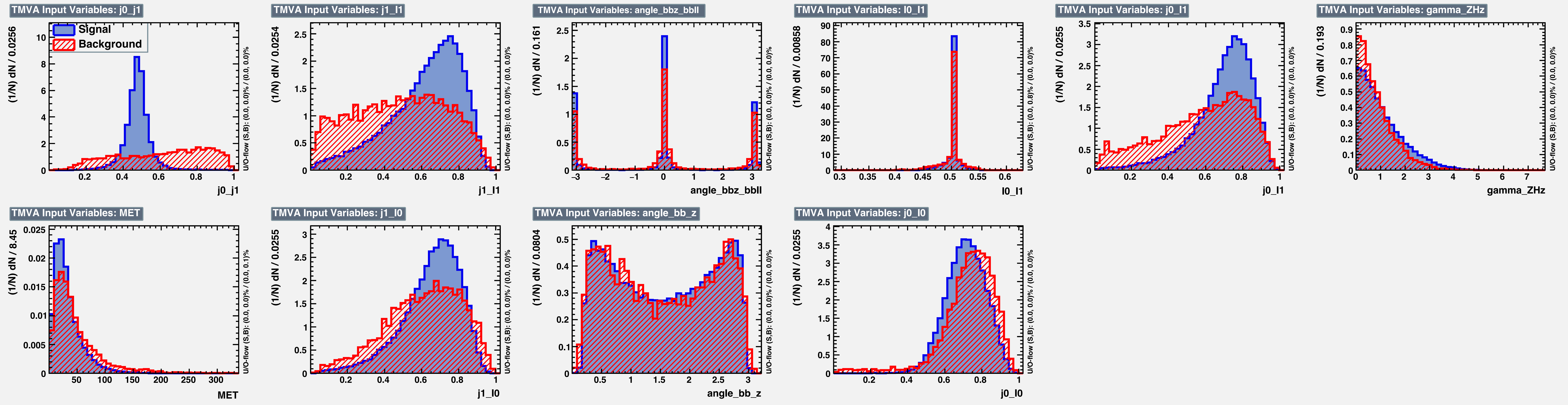


MVA Input Examples: Std

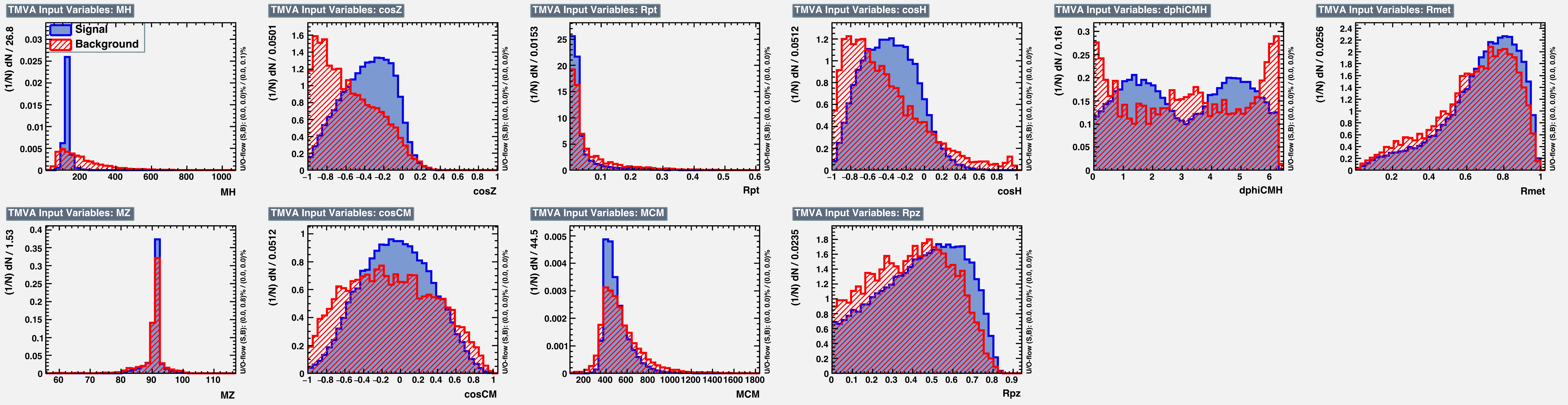


MVA Input Examples: LI

SM VHbb Theme and Variations
S. Chan
2018.02

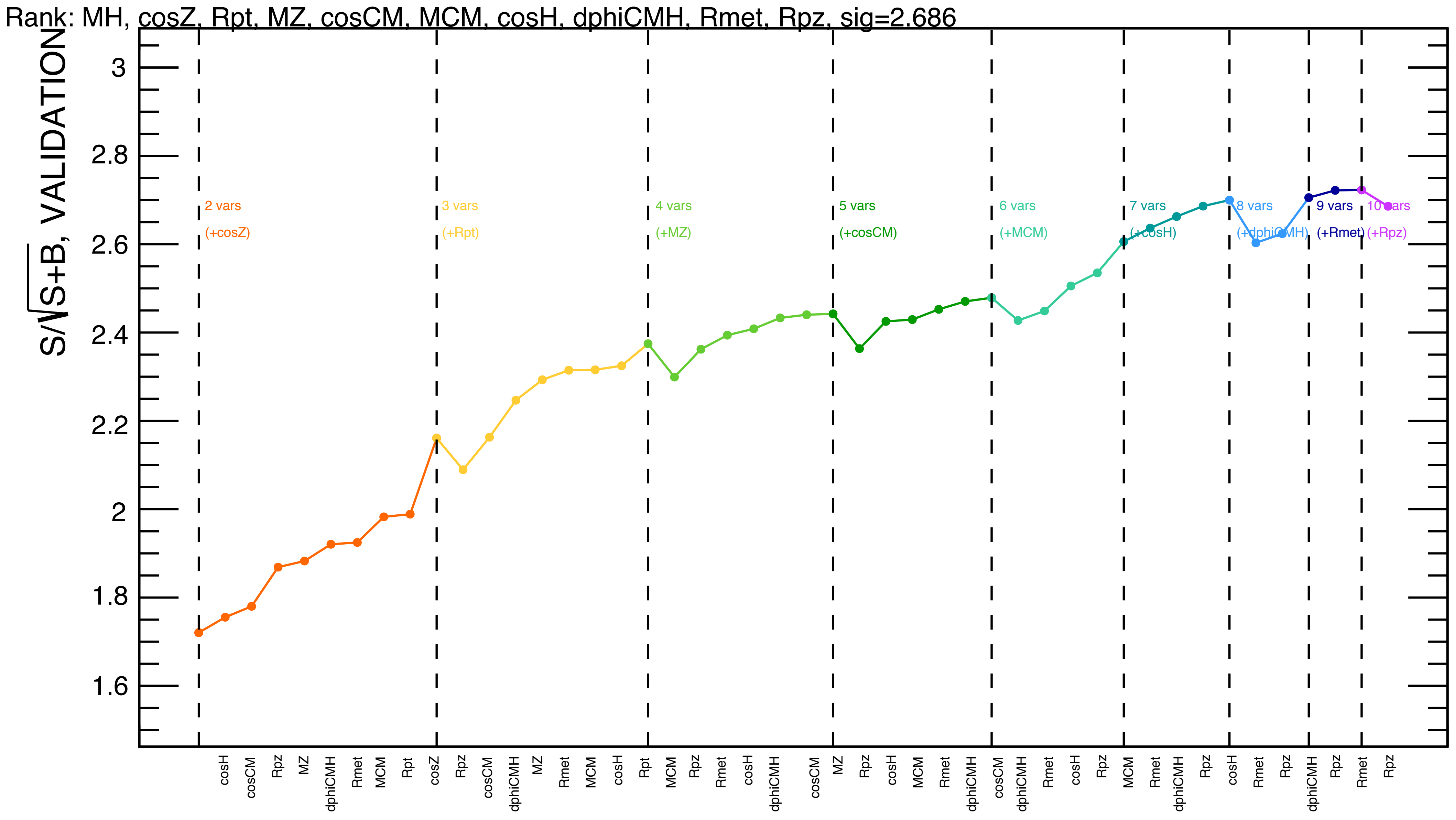


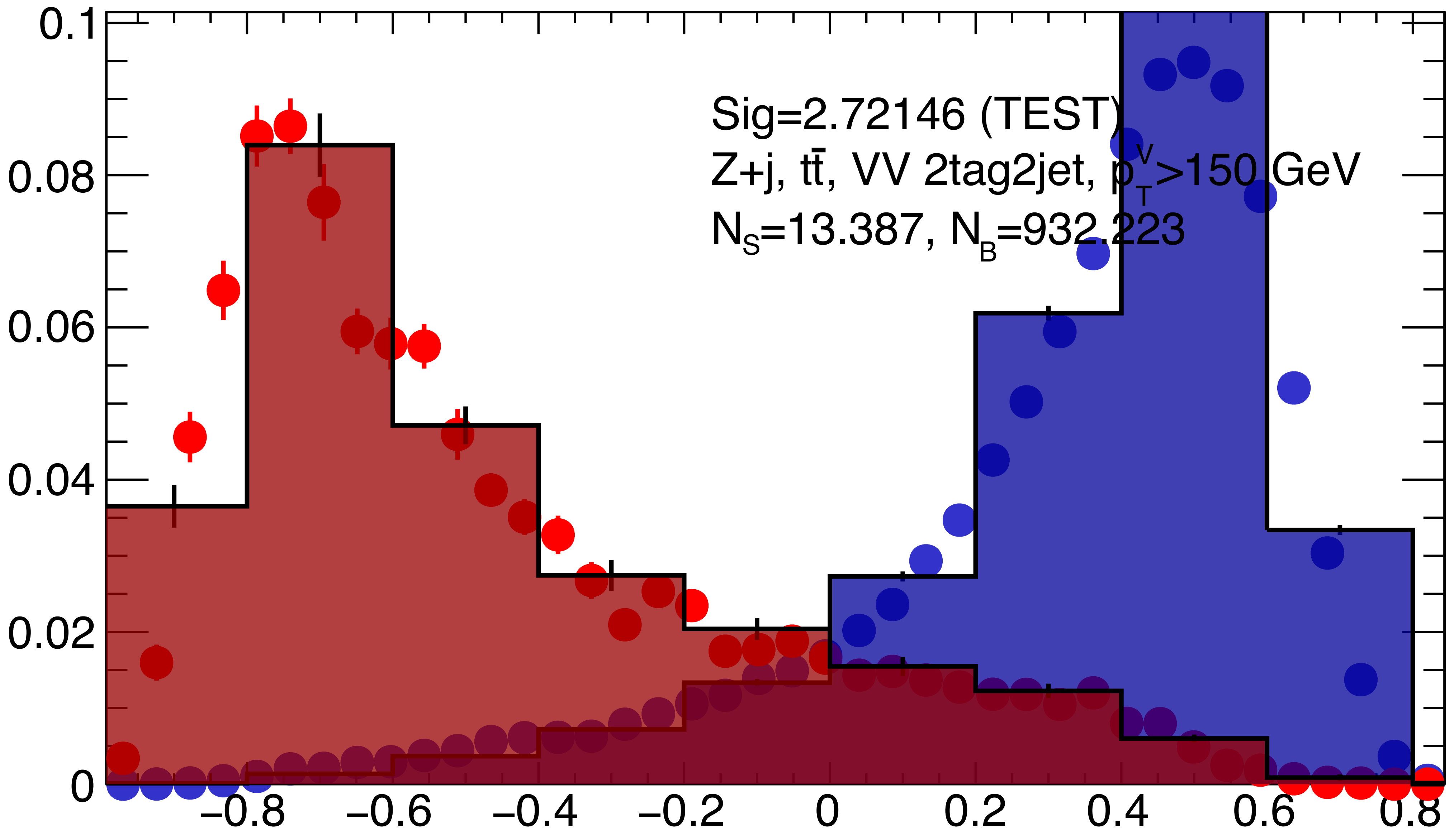
MVA Input Examples: RF



RANKING EXAMPLE: RF 2JET HI PTV

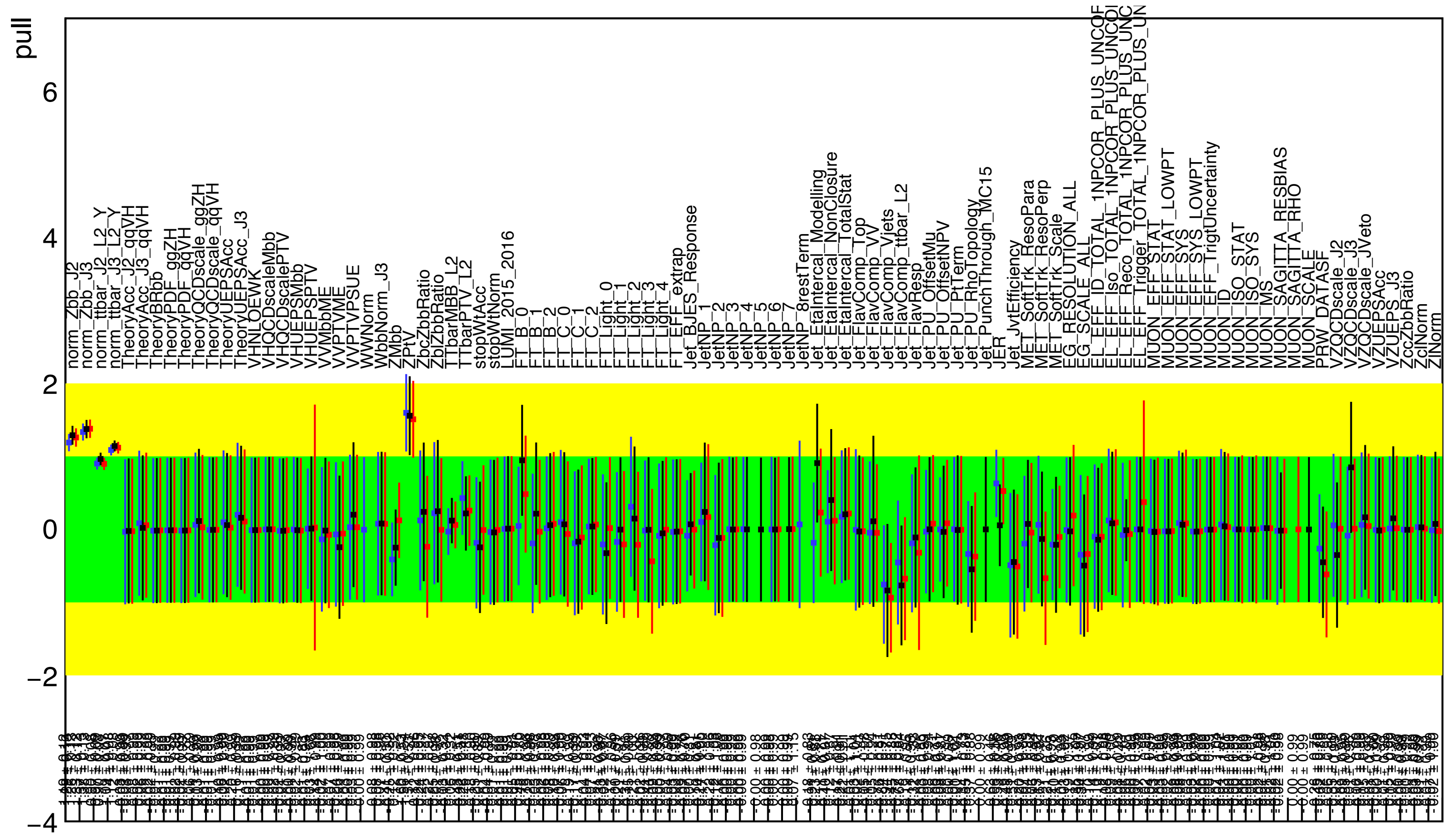
SM VHbb Theme and Variations
S. Chan
2018.02

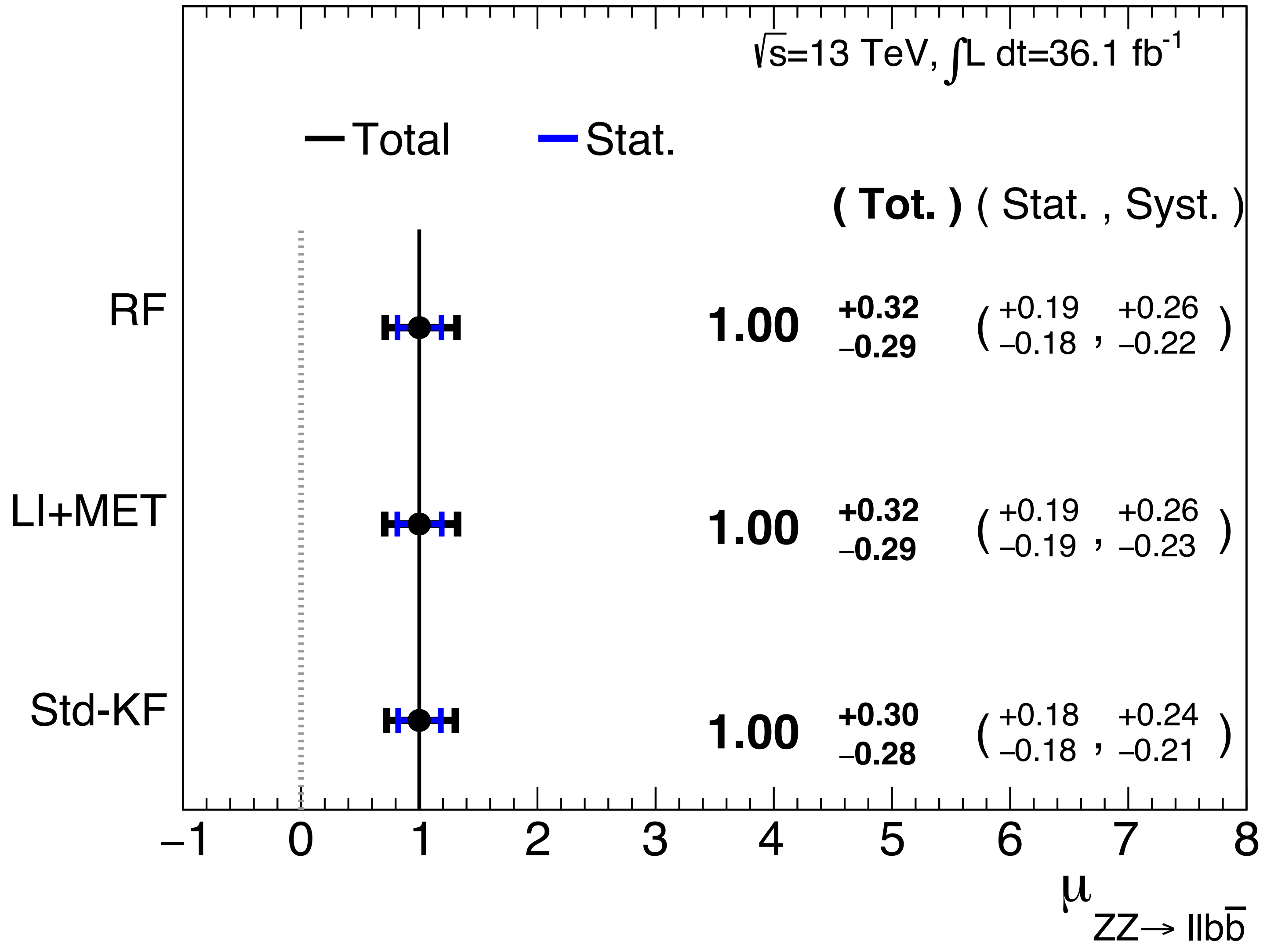


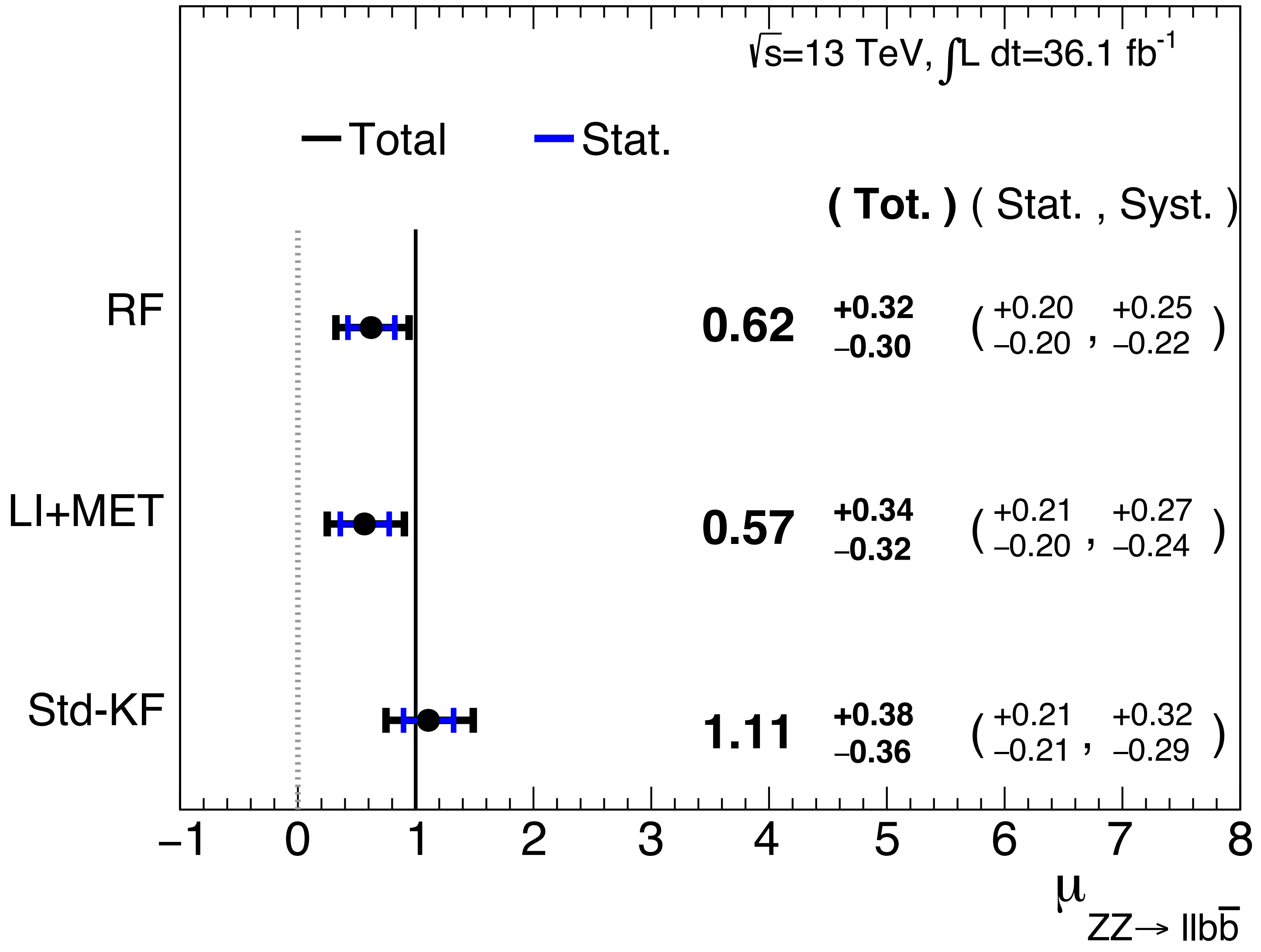


VZ Fits

	Standard	LI	RF
Expected (Asimov)	3.83	3.67	3.72
Expected (data)	3.00	2.95	3.11
Observed (data)	3.17	1.80	2.09



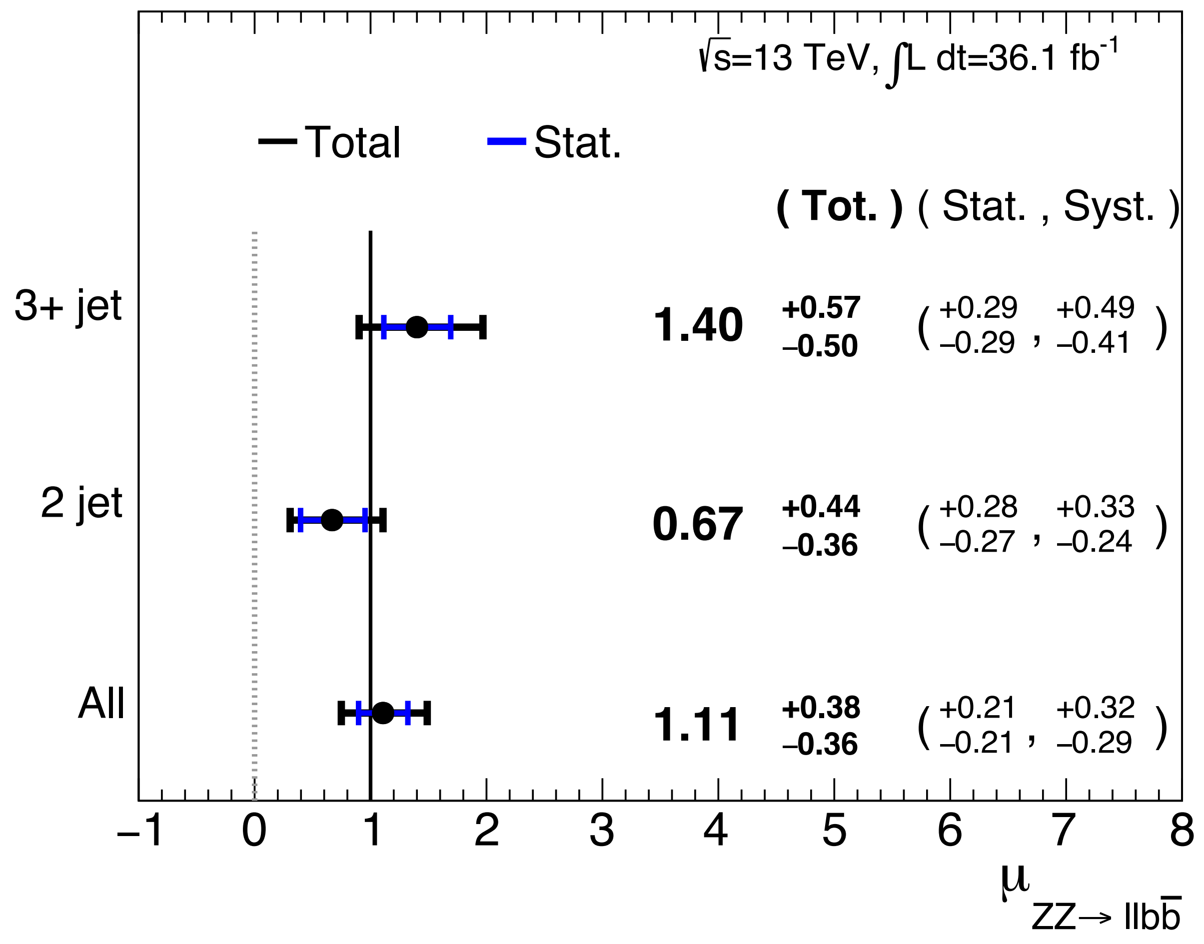




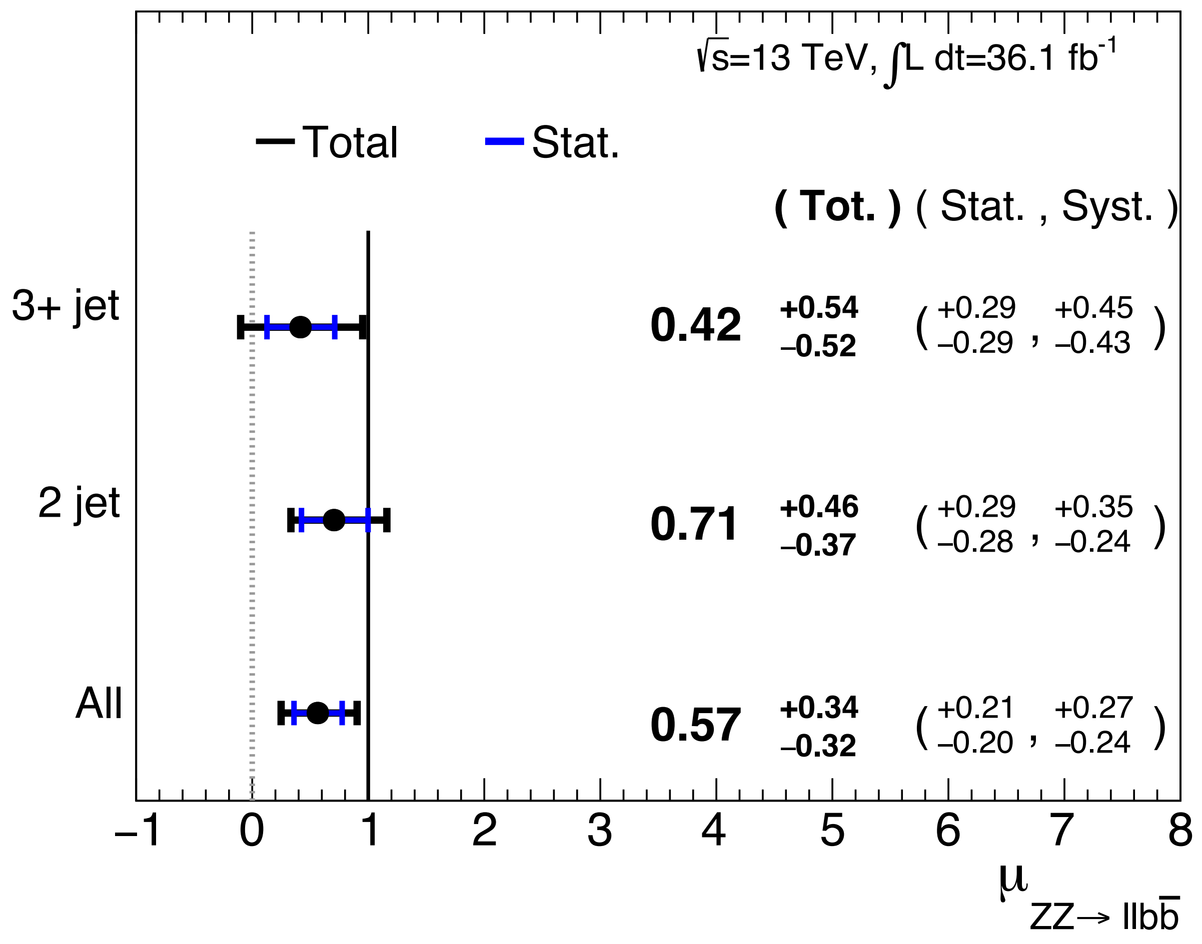
- VZ fits look okay and very consistent
- Significances consistent (when taking μ values into account)
  - Why are they different?

VZ MYSTERIES: NJET

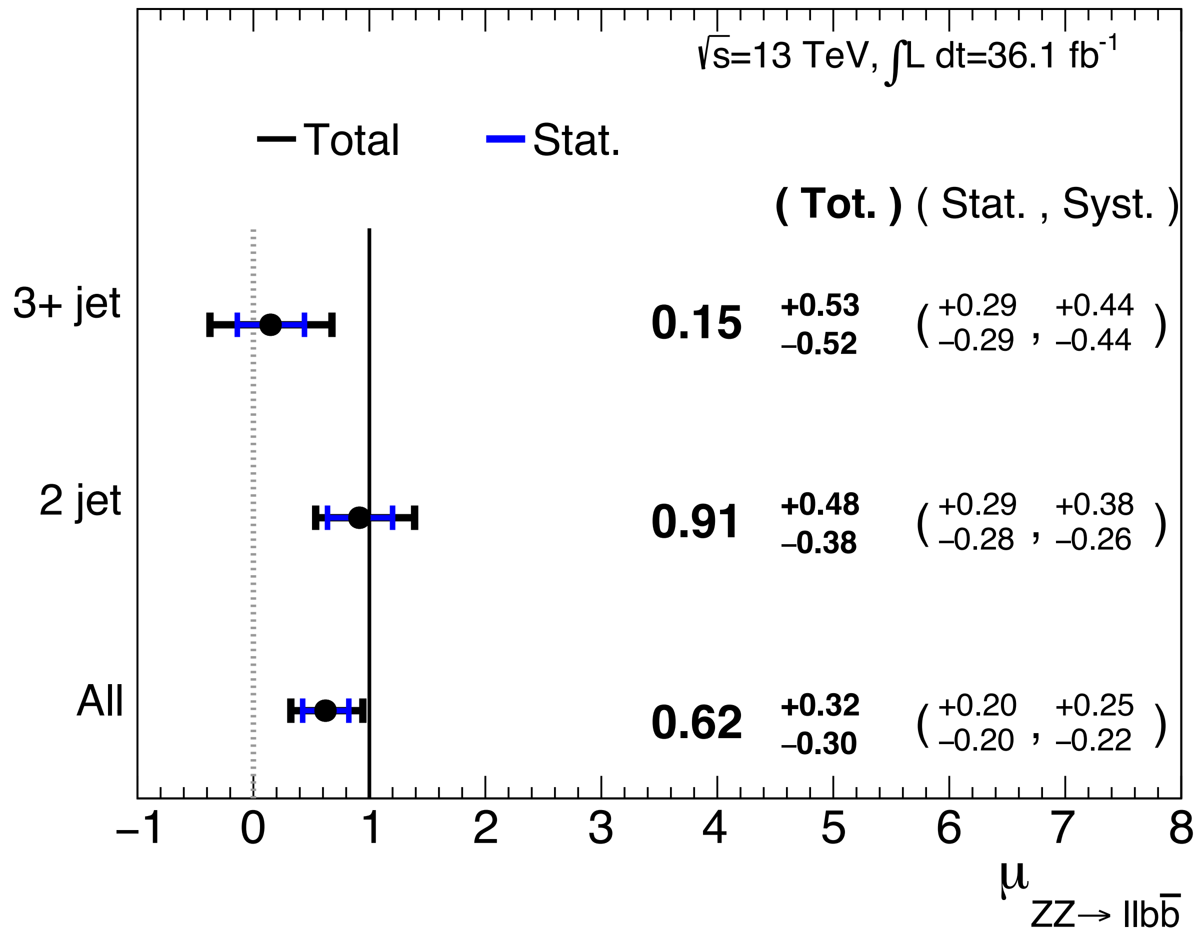
- Why does the VZ fit have lower values for the LI and RF cases?
  1. pTV split at 150 GeV is
  2. New variable cases do not include any information about third jet
    - Clearly important for finding events
    - Avenues forward:
      - LI: ???
      - RF: Include 3rd jet as ratio or in candidate H



(a) Std-KF



(b) LI+MET



(c) RF

Sensitivities

- Both LI and RF variables are competitive with respect to expected sensitivities
  - RF performs slightly better (~3.5%) than standard set
- Observed values should be viewed in context of observed signal strengths…

	Standard	LI	RF
Expected (Asimov)	2.06	1.92	2.13
Expected (data)	1.76	1.73	1.80
Observed (data)	2.87	2.79	2.62

Breakdown Summary

	Std-KF	LI+MET	RF
Total	+0.811 / -0.662	+0.778 / -0.641	+0.731 / -0.612
DataStat	+0.502 / -0.484	+0.507 / -0.489	+0.500 / -0.481
FullSyst	+0.637 / -0.451	+0.591 / -0.415	+0.533 / -0.378
Signal Systematics	+0.434 / -0.183	+0.418 / -0.190	+0.364 / -0.152
MET	+0.209 / -0.130	+0.190 / -0.102	+0.152 / -0.077
Flavor Tagging	+0.162 / -0.166	+0.093 / -0.070	+0.115 / -0.099
Model Zjets	+0.164 / -0.152	+0.141 / -0.143	+0.101 / -0.105

- Breakdowns shown for categories where impact is greater than 0.1 on signal strength for the standard case
- LI and RF help mitigate all systematics categories (full breakdowns in companion slides)

JES Unfolding Setup

- NP map from Dave DeMarco gives scalar coefficient for linear combinations for 75 unfolded NP's for 8 effective NP's (8th is currently all 0's)
  - ProjectionCoefficientFile_Moriond2017_test_withAmplitudes_April29.root
    - Three maps: "original," "complem," and "zero"
    - A fourth map is potentially forthcoming
  - Technical note—linear combinations are (for effective (unfolded) NP's EFFNP (UNFNP), map factors A_ij, and unfolded amplitudes |UNFNP|):
    - EFFNP_i = (sum_j A_ij * |UNFNP_j| * UNFNP_j) / (sum_(j,quadrature) A_ij * |UNFNP_j|)
- Run1 map ProjectionCoefficientFile_Final2012_test_withAmplitudes_April29.root has 6 NP's and 56 unfolded parameters
- For maps and effective NP correlations, see backup

Modeling Systematics

- Physics is different at different center of mass energies
- MC state of the art changes
  - NP's are defined differently, too
- Use χ2 extrapolation to estimate effects
- Not significant (biggest shift shown below)

	$\lvert\Delta\mu\rvert$	σ	$\lvert\Delta\sigma\rvert$	χ^2
ρ=-1	0.0024	0.2448	0.011 (4.3%)	0.95
ρ=-0.6	0.0015	0.2493	0.00654 (2.55%)	0.9804
ρ=-0.3	0.0008	0.2526	0.00325 (1.27%)	1.0045
ρ=0	—	0.2558	—	1.0298
ρ=0.3	0.0008	0.259	0.0032 (1.25%)	1.0564
ρ=0.6	0.0017	0.2622	0.00636 (2.49%)	1.0844
ρ=1	0.0029	0.2664	0.0105 (4.11%)	1.1242

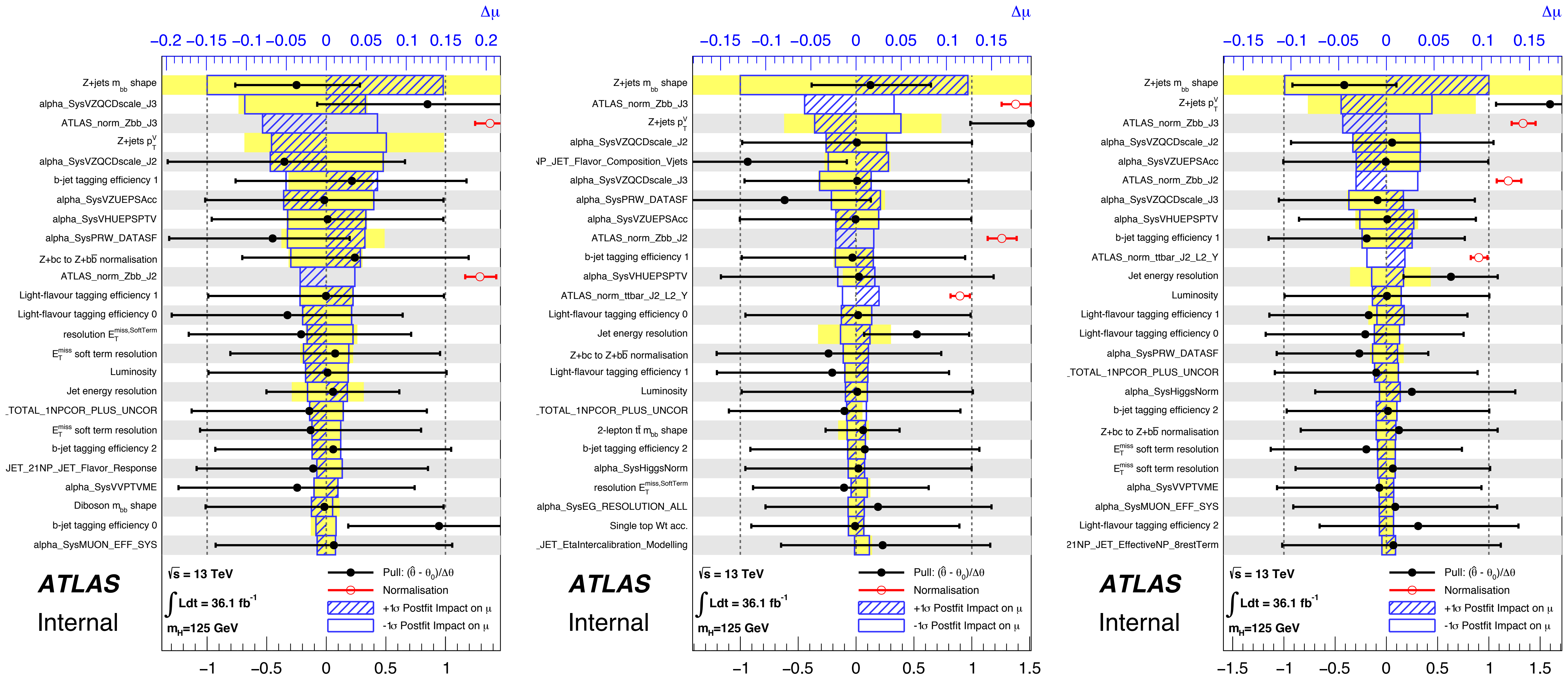
Table 9.11: Run 1 + Run 2 W+jets modeling correlation projections

EXPERIMENTAL SYSTEMATICS

- More backwards compatibility than with modeling; only JES/b-tagging of concern
- Explicitly correlate NP's whose meaning remains the same
  - JES: JetEtMiss CP group provides maps to unfold and correlate NP's
  - FTag: check leading Eigen NP's (meaning roughly same)

NP Ranking

- These are also fairly similar—Z+jets and signal systematics NP's consistently highly ranked



(a) Standard (b) LI (c) RF

Analysis JES Details

- 2011:
  - JetCalibconfigFile: InsituJES_2011_Preliminary.config
  - JetAFIICalibconfigFile: Rel17_JES_AFII.config
- 2012:
  - JES_2012/Moriond2013/InsituJES2012_14NP.config
  - JES_2012/Moriond2013/MultijetJES_2012.config
- 2015+2016:
  - JES_data2016_data2015_Recommendation_Dec2016.config
  - AFII: JES_MC15Prerecommendation_AFII_June2015.config

JES NP Matching Run1,2 Schemes

- Following recommendation from JetEtMiss described in depth here
- Two schemes “strong” and weak”
  - Strong: match all non-stat NP’s with some exceptions:
    - No Run2 counterpart: LAr_ESmaterial, LAr_ESpresampler
    - Run1 Zjet_JVF with Run2 LAr_JVT
    - Run2 EtaIntercalibration_NonClosure has no listed Run1 match (what about alpha_SysJetNonClos?)
    - Pileup_RhoTopology and Flavor_Composition as “use physics judgement”
  - Weak: some NP’s are not matched
    - Effective NP components: Zjet_Veto, Gjet_Veto, MJB_Beta, MJB_Threshold
    - Named: EtaIntercalibration_Modelling, EtaIntercalibration_TotalStat, Pileup_OffsetMu, Pileup_OffsetNPV, Pileup_PtTerm
- We test the weak scheme here

VALIDATING THE UNFOLDING AND MATCHING

- Workspaces:
  - Run1: conditional mu=0.51 Asimov, combined 7+8 TeV workspace
  - Run2: conditional mu=1 Asimov, workspace with following inputs
    - v22(0lep) v15(1lep) and v54(2lep, owing to Flavour tagging bug) in v55)
  - Combined: both of those above
- Correlation schemes: JES “weak” scheme
  - Unfolded: 75 or 56 unfolded NP’s + named NP’s
    - combined: match named and unfolded NP’s
  - Effective: 8 effective NP’s + named NP’s
    - combined: match only non-effective NP’s proposed in the weak matching scheme NP’s
- Fits: unblinded postfit unconditional

JES Sensitivities

- Virtually no difference depending on JES scheme

Table: Expected Sensitivities: jes

	R1 Unfold	R1 Eff	R2 Unfold	R2 Eff	Comb Unfold	Comb Eff
Exp. Sig.	2.604	2.606	2.952	2.952	3.96	3.951
Exp. p0	0.0046	0.0046	0.0016	0.0016	0.0	0.0
Exp. Limit	$0.755^{+0.296}_{-0.211}$	$0.755^{+0.296}_{-0.211}$	$0.707^{+0.277}_{-0.198}$	$0.707^{+0.277}_{-0.198}$	$0.506^{+0.198}_{-0.141}$	$0.505^{+0.198}_{-0.141}$

Table: Observed Sensitivities: jes

	R1 Unfold	R1 Eff	R2 Unfold	R2 Eff	Comb Unfold	Comb Eff
Obs. Sig.	1.369	1.374	3.539	3.539	3.58	3.572
Obs. p0	0.0854	0.0847	0.0002	0.0002	0.0002	0.0002
Obs. Limit	1.21	1.21	1.87	1.87	1.37	1.38

JES NP Ranking

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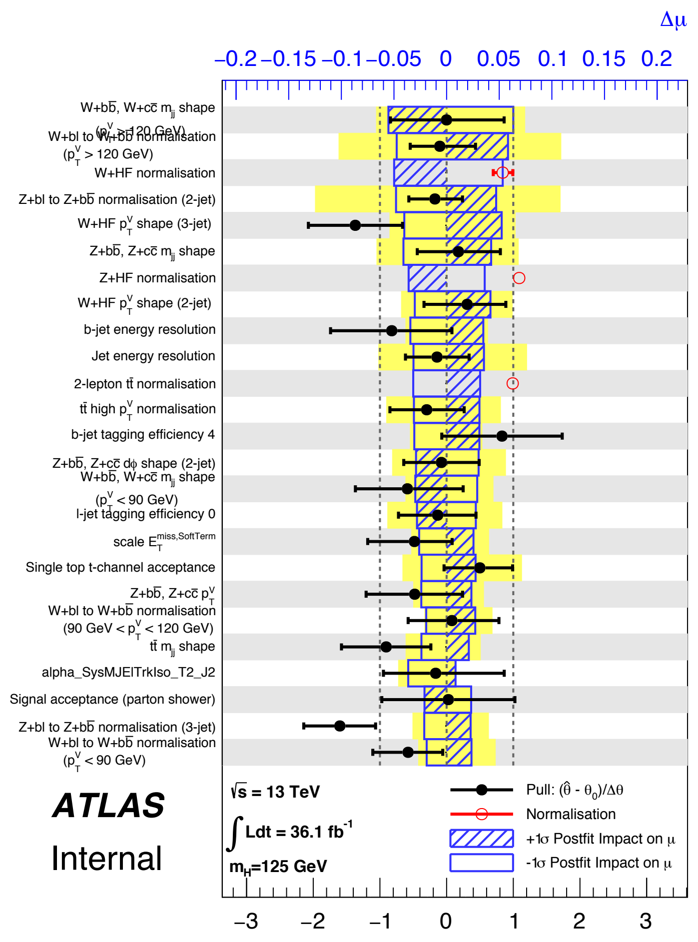
Finding Standard Model VHbb

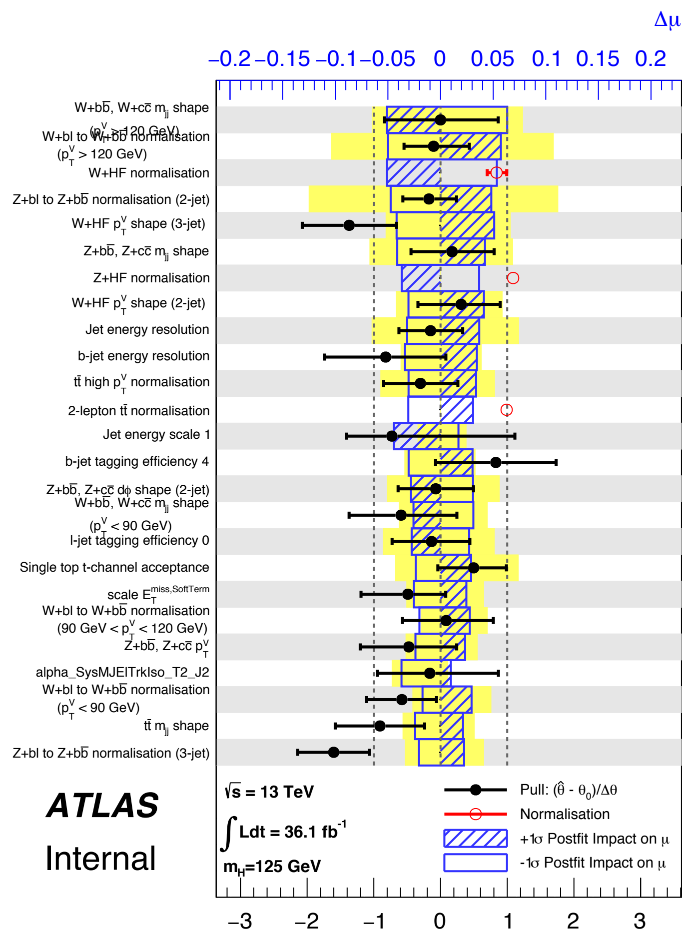
S. Chan

2018.04.25

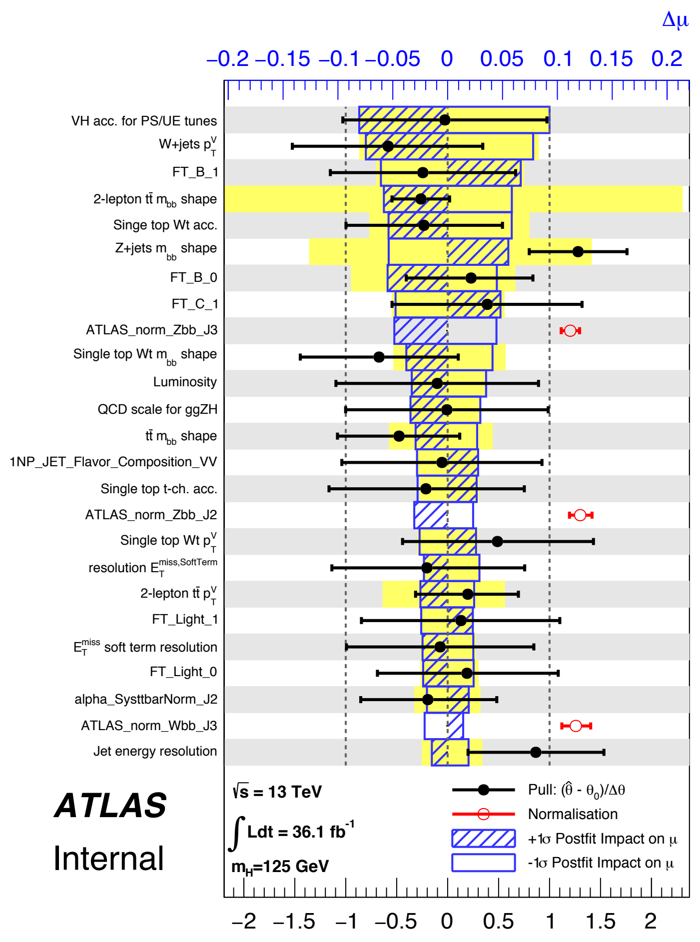
: R1 Unfold



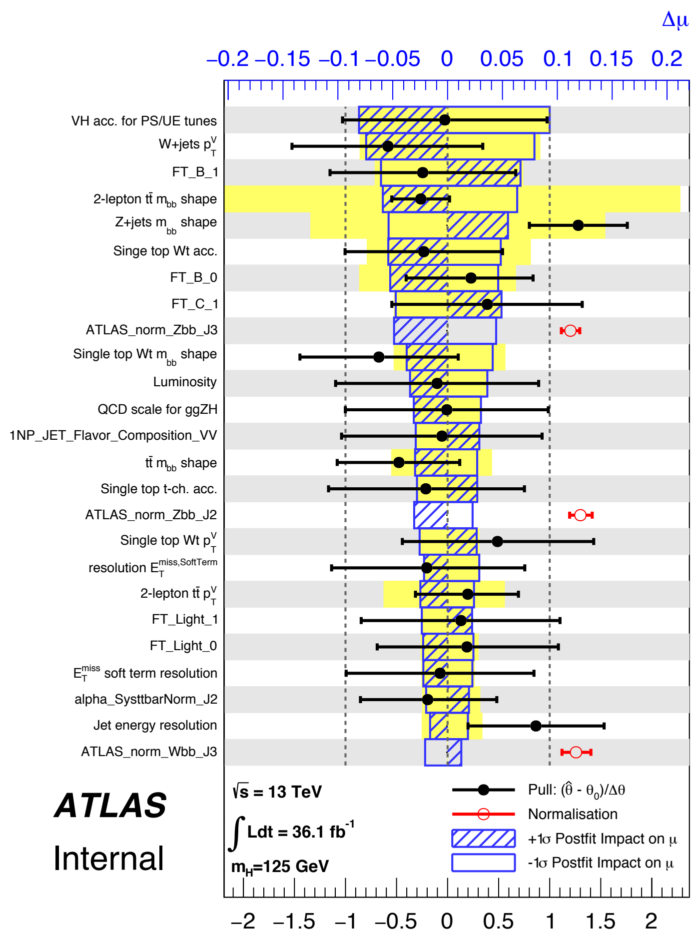
: R1 Eff



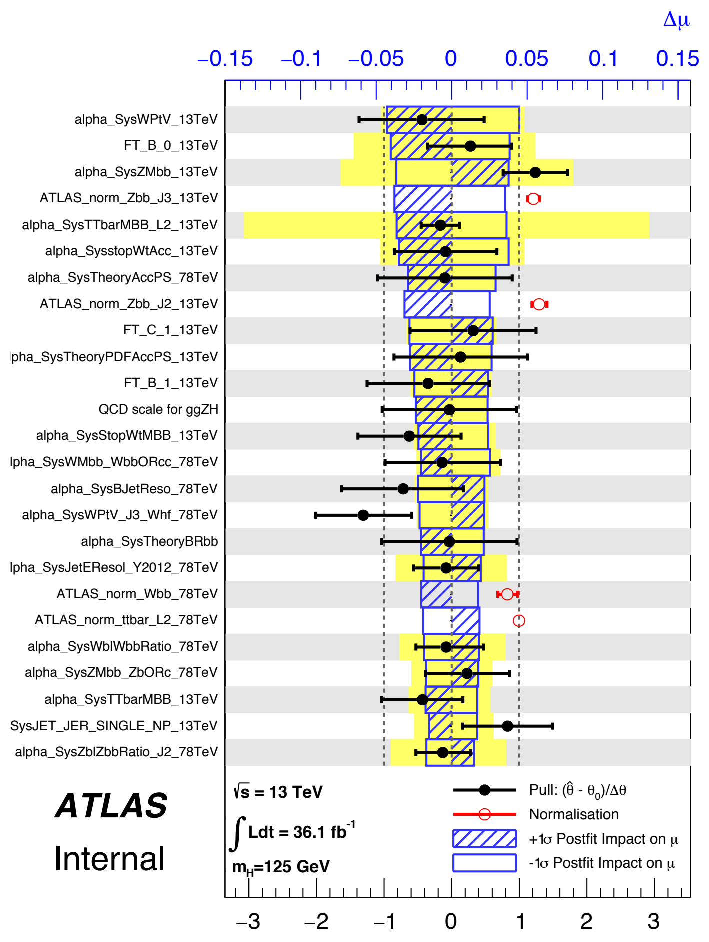
: R2 Unfold



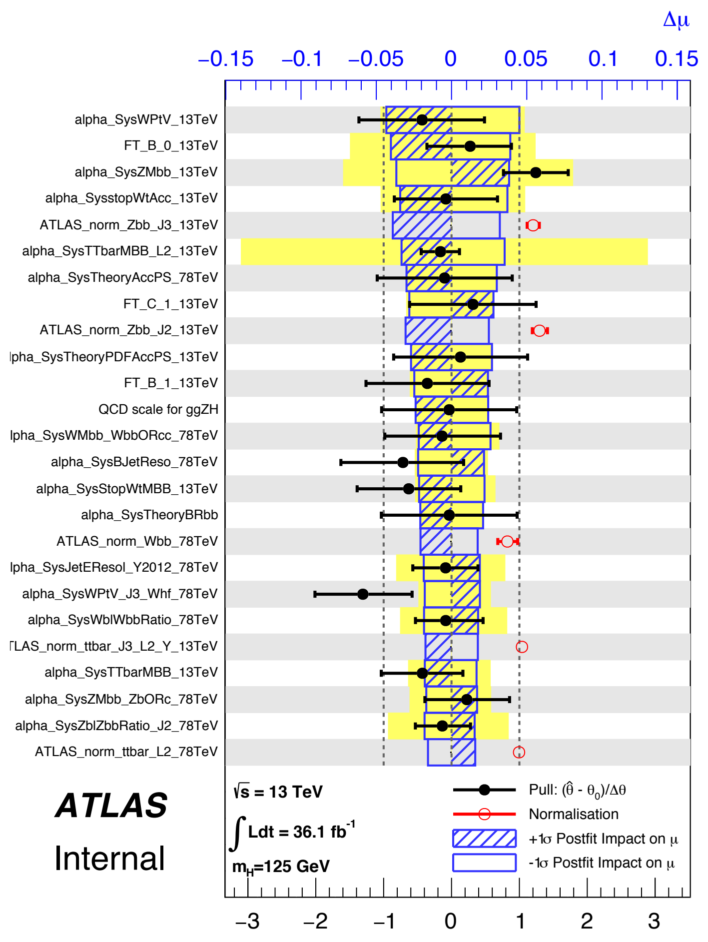
: R2 Eff



: Comb Unfold



: Comb Eff



Modeling Systematics Cross-Checks

- The companion slides contain results using the strategy adopted in the Run1 ATLAS+CMS combination
- Do a simple extrapolation assuming different levels of correlation according to the usual scaling
  - These are done using numbers from the full Run1 and Run2 breakdowns
- cf. agenda

Revised b-tagging Cross Check

- Following feedback from Flavour Tagging Group, only concerned with correlating b systematics (c-tagging changed considerably from Run1 to Run2, and light systematics are low ranked)
- What follows are correlating the leading B eigen systematics only
  - Run1: SysBTagB0Effic_(7TeV|Y2012_8TeV)
  - Run2: SysFT_EFF_Eigen_B_0
  - Checking the effect of these NP's on the ttbar normalization, 8 TeV moves in the opposite direction as 7 TeV and 13 TeV
    - Reparametrize workspace similar to JES to get signs correct
- Compare JES weak scheme (proposed new default) with JES weak + correlating B0, and JES weak + correlating B0 with 8 TeV B0 UNFLIPPED

B-TAGGING SENSITIVITIES

- Significances move around much more than before
  - BTagB0 mu: +5.3%; BTagB0 8 TeV Not Flipped: -3.4%
  - The results that didn't show movement were doExp=1 i.e. mu=1 asimov for *both* Run1+Run2 (hadn't figured out Run1 Asimov at the time)

Table: Expected Sensitivities: btag-b

	Comb Eff	BTag B0	B0 8TeV Not Flipped
Exp. Sig.	3.951	4.071	3.868
Exp. p0	0.0	0.0	0.0001
Exp. Limit	$0.505^{+0.198}_{-0.141}$	$0.493^{+0.193}_{-0.138}$	$0.513^{+0.201}_{-0.143}$

Table: Observed Sensitivities: btag-b

	Comb Eff	BTag B0	B0 8TeV Not Flipped
Obs. Sig.	3.572	3.866	3.4
Obs. p0	0.0002	0.0001	0.0003
Obs. Limit	1.38	1.42	1.36

B-tagging Breakdowns

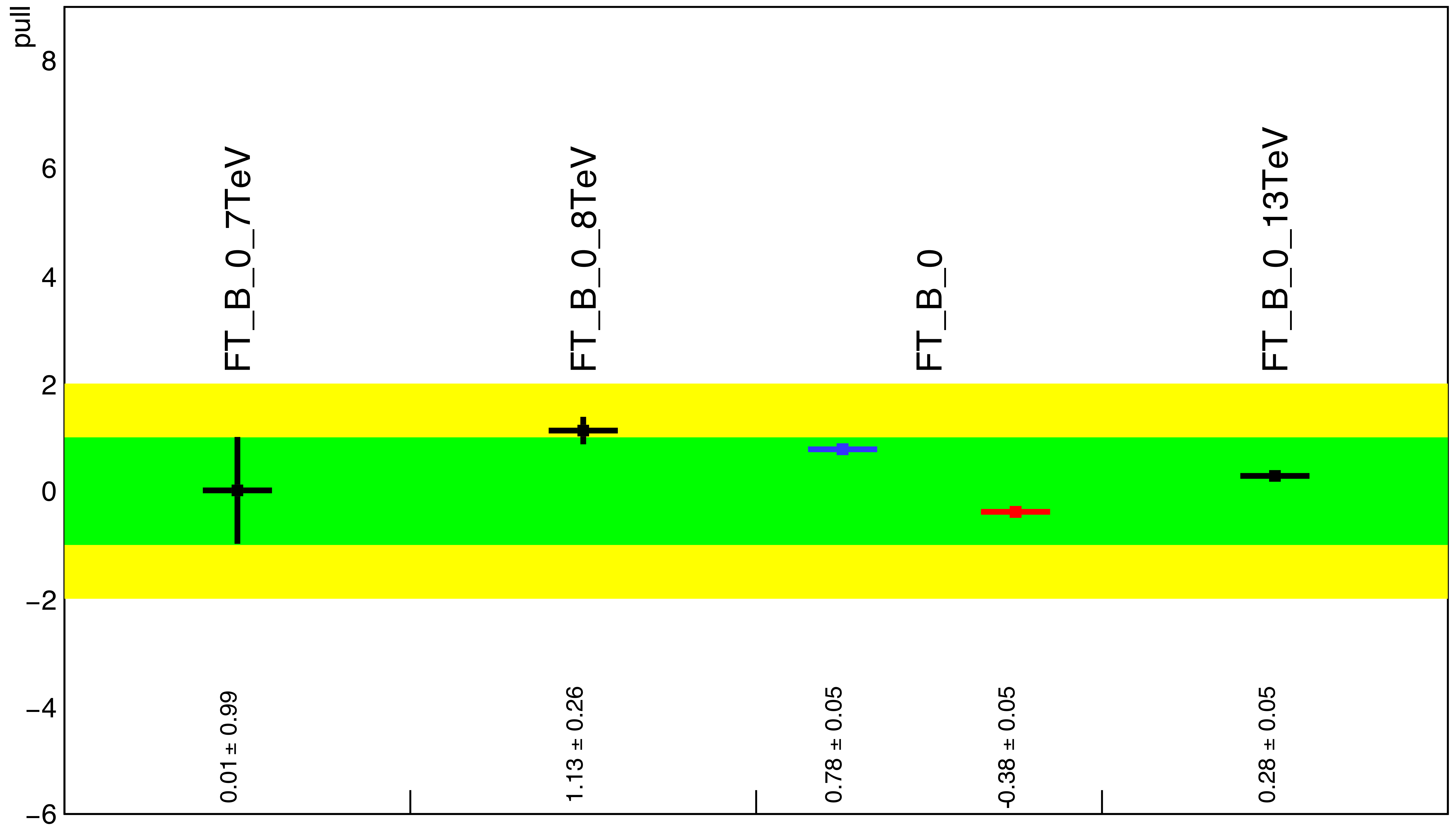
- Overall muhat errors not moving around; mu does

Table: Breakdowns: btag-b

	Comb Eff	BTag B0	B0 8TeV Not Flipped
muhat	0.9115	0.9598	0.8806
Total	+0.277 / -0.265	+0.273 / -0.260	+0.282 / -0.268
DataStat	+0.189 / -0.185	+0.185 / -0.181	+0.193 / -0.189
FullSyst	+0.203 / -0.190	+0.201 / -0.186	+0.206 / -0.189
BTag	+0.080 / -0.080	+0.073 / -0.072	+0.083 / -0.079
BTag b	+0.064 / -0.062	+0.056 / -0.051	+0.066 / -0.063

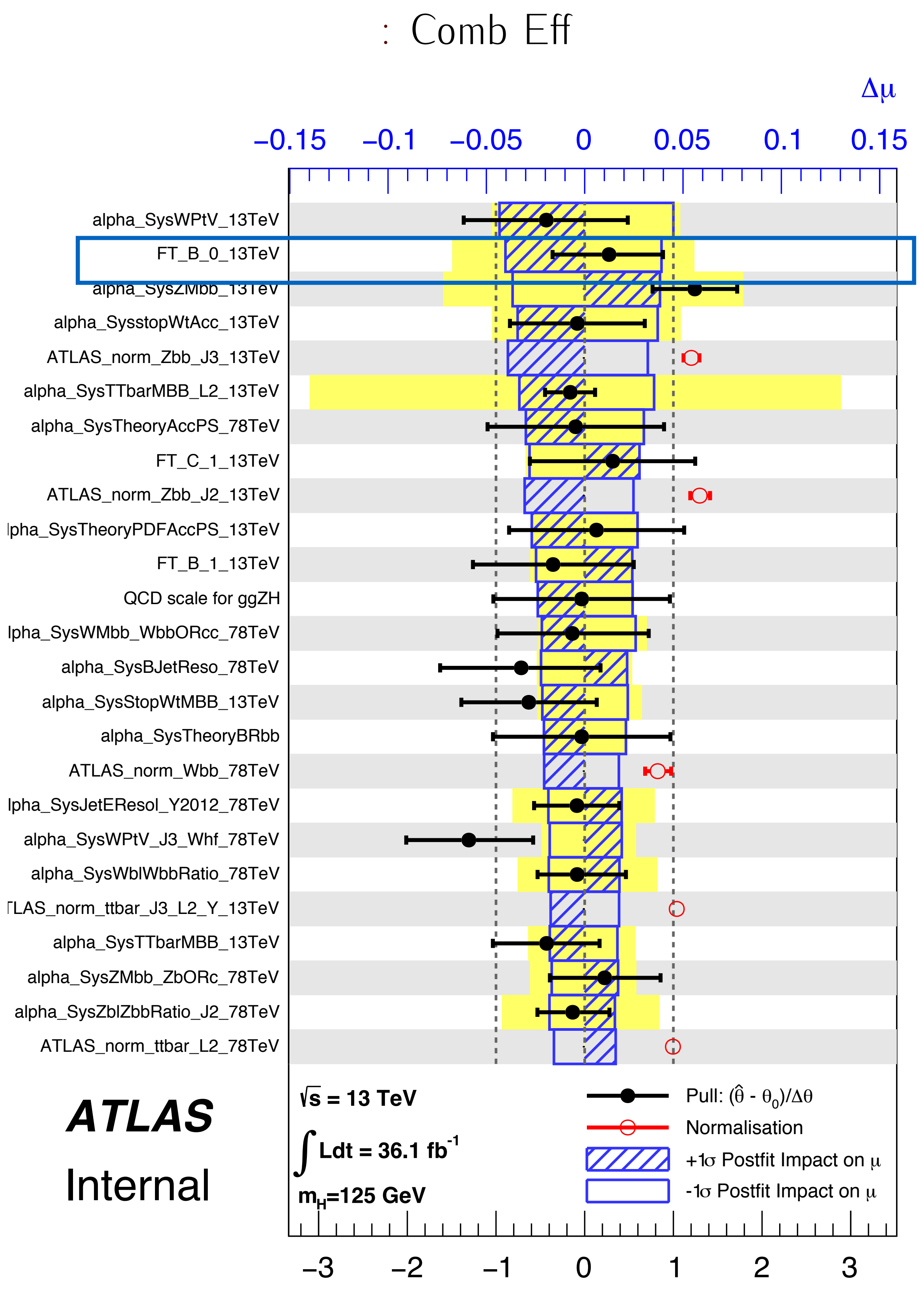
B-TAGGING PULL COMPARISONS: BTAGB0

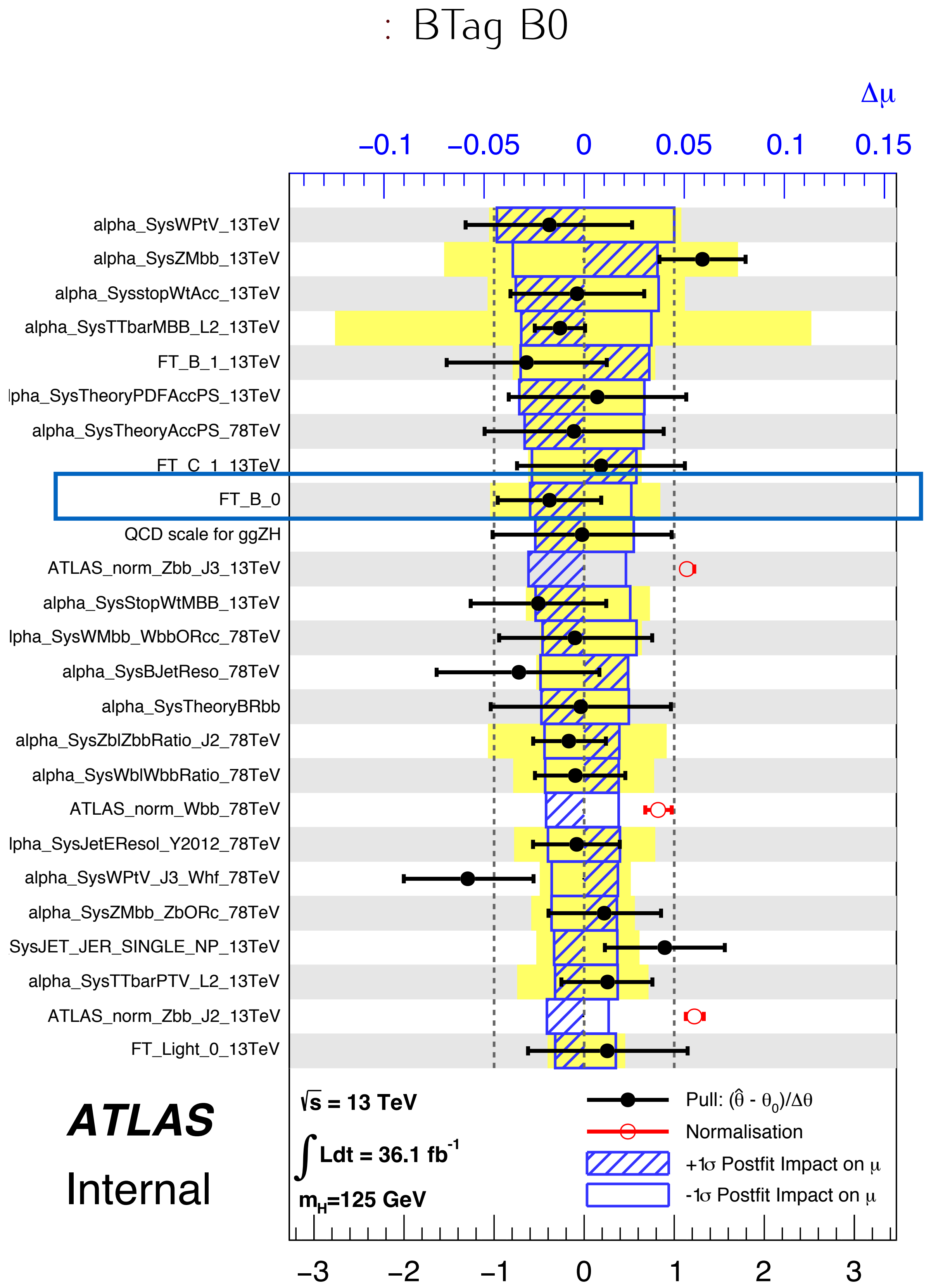
- Default, Default + correlating B0, correlating B0 with 8 TeV B0 UNFLIPPED
    - Keep in mind: central values are correct, but error bars are not (FCC can't invert large matrices)
    - So *clearly 8 TeV drives the combined NP*

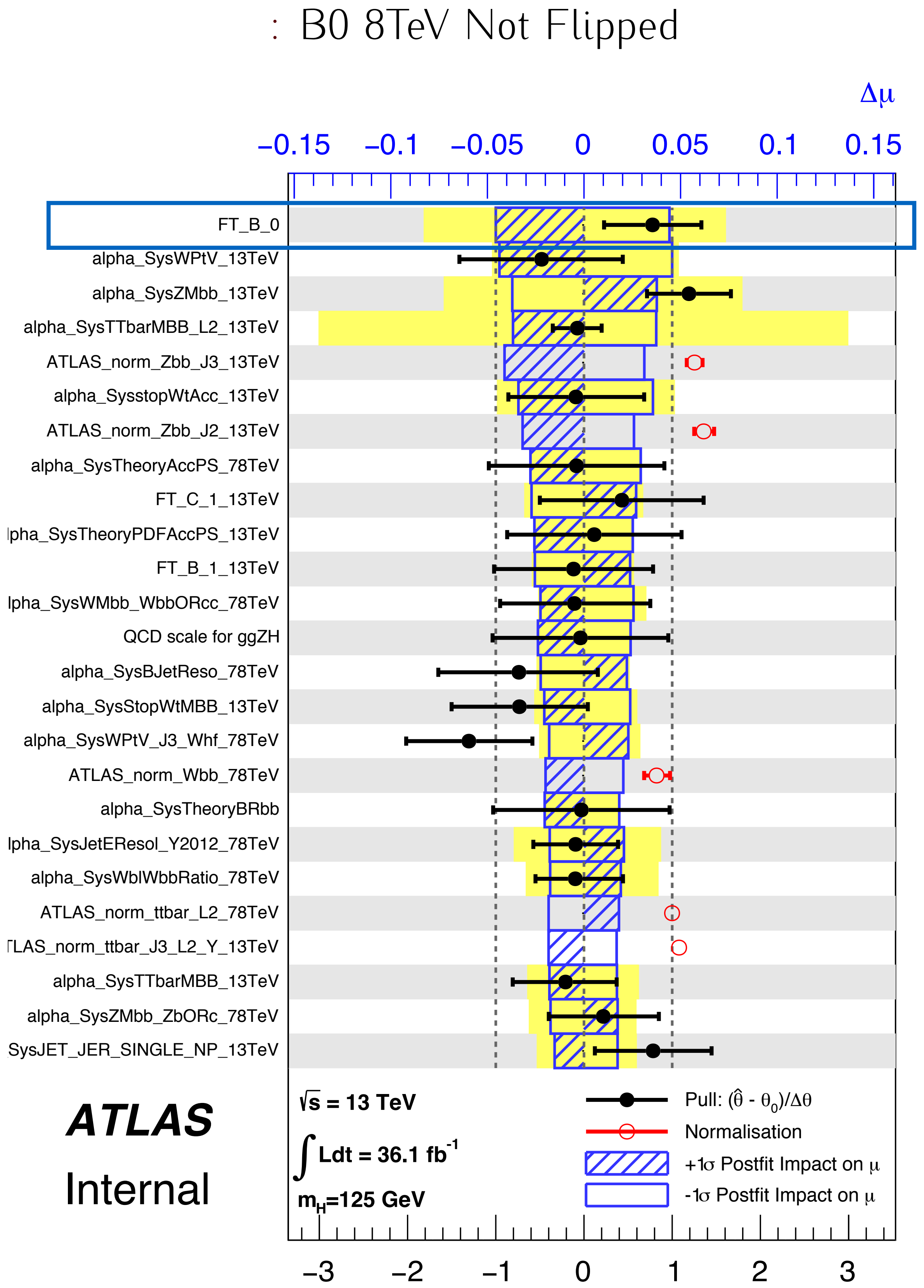


B-TAGGING COMBINED NP RANKING

- Why is the effect so big?
  - 13 TeV B0 is the #2 ranked NP in the nominal correlation scheme
  - Correlating the “right” (“wrong”) way makes for a “better” B0 measurement (8 TeV helps (hurts) you)





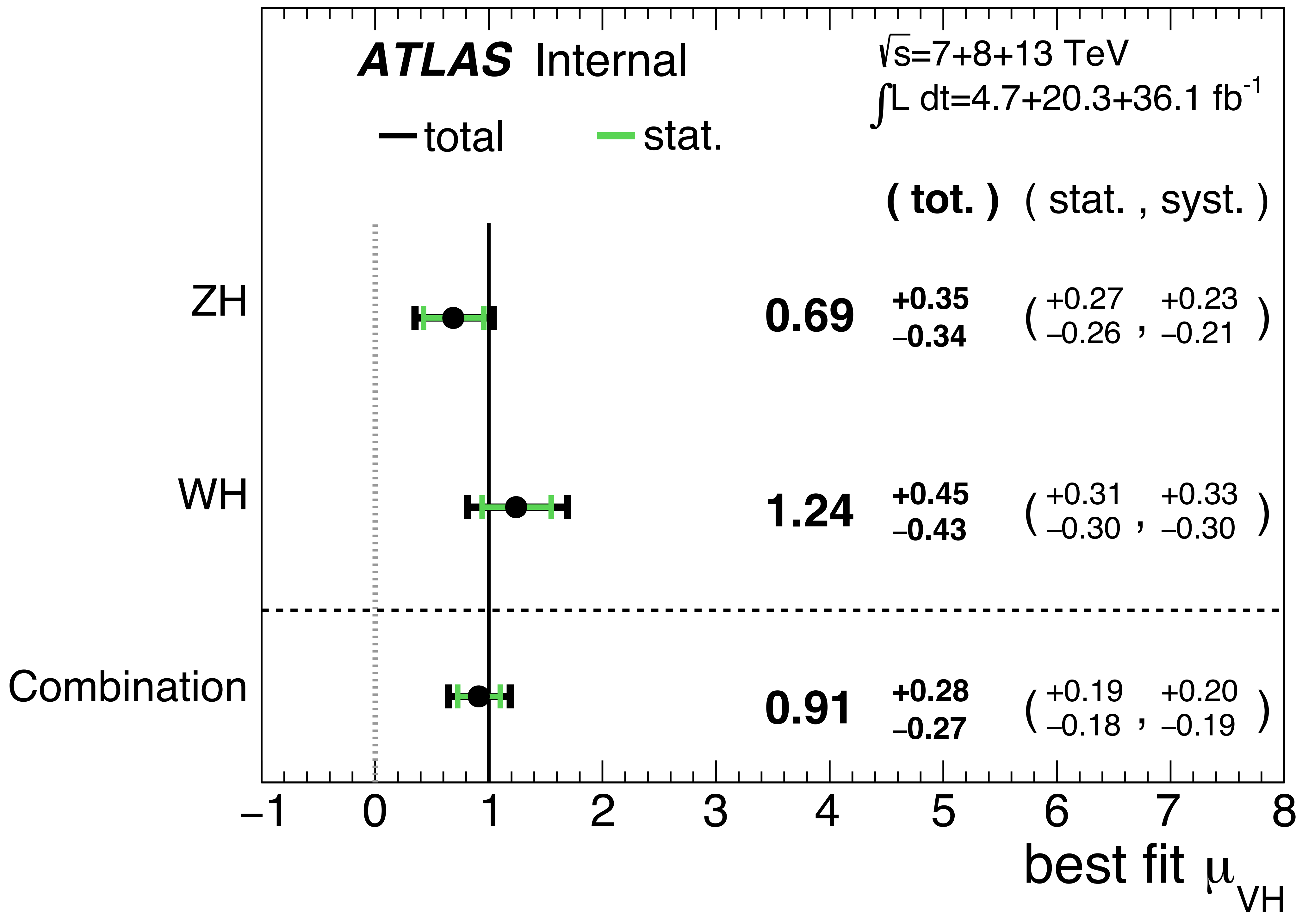


Compatibility Summary

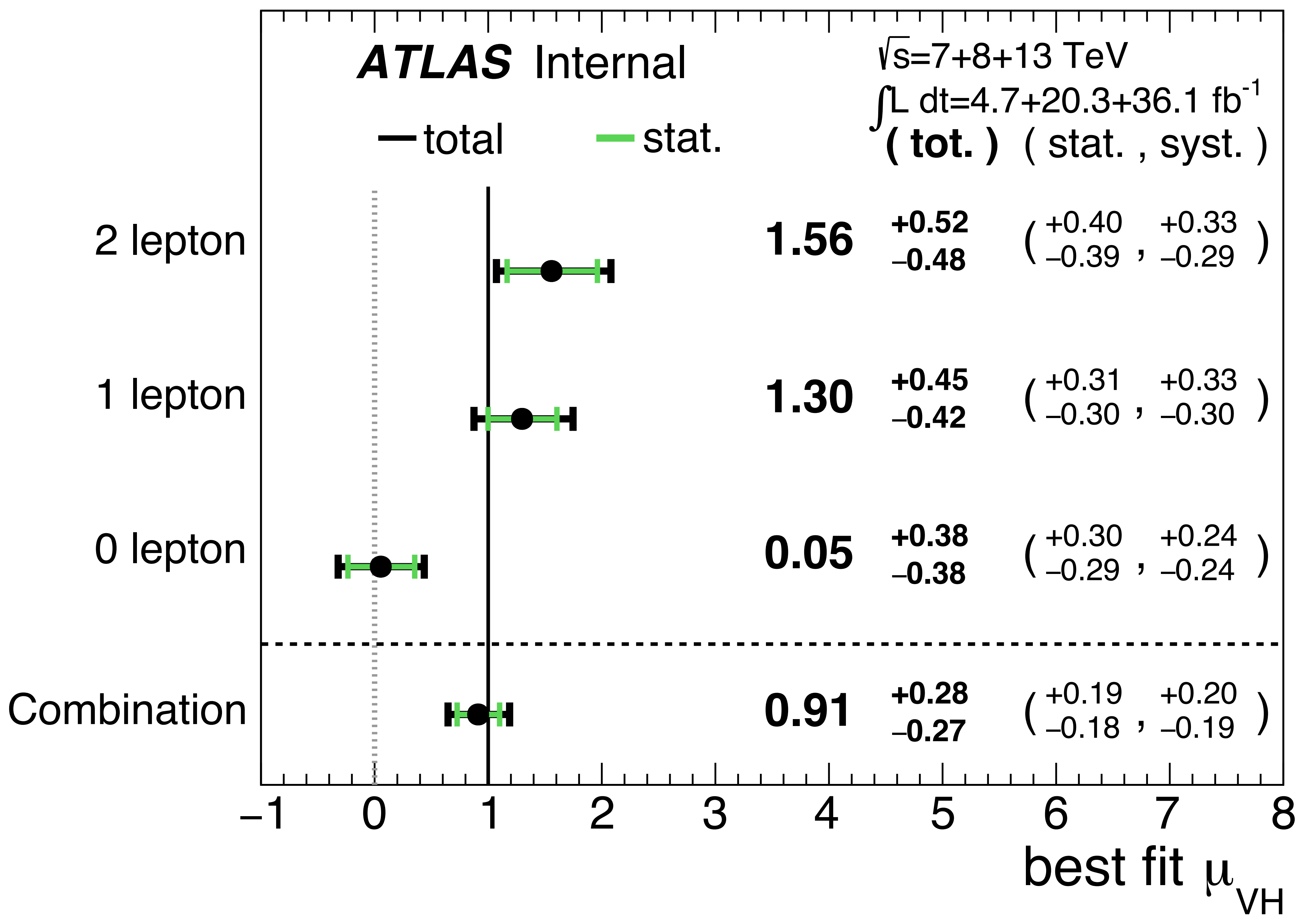
- Nominal fit (Run1+Run2 1 POI): 3636626.6821
- 2 POI (Run1/Run2): 3636625.8346 —> 19%
- 2 POI (WH/ZH): 3636626.1827 —> 32%
- 3 POI (012lep): 3636622.3274 —> 1.2%
- 6 POI (012lep x Run1/Run2): 3636621.4741 —>6.4%
    - 3POI has a 64% compatibility with the 6POI

Combined Nice Plots (012lep, WH/ZH)

: WH/ZH: 31.76%

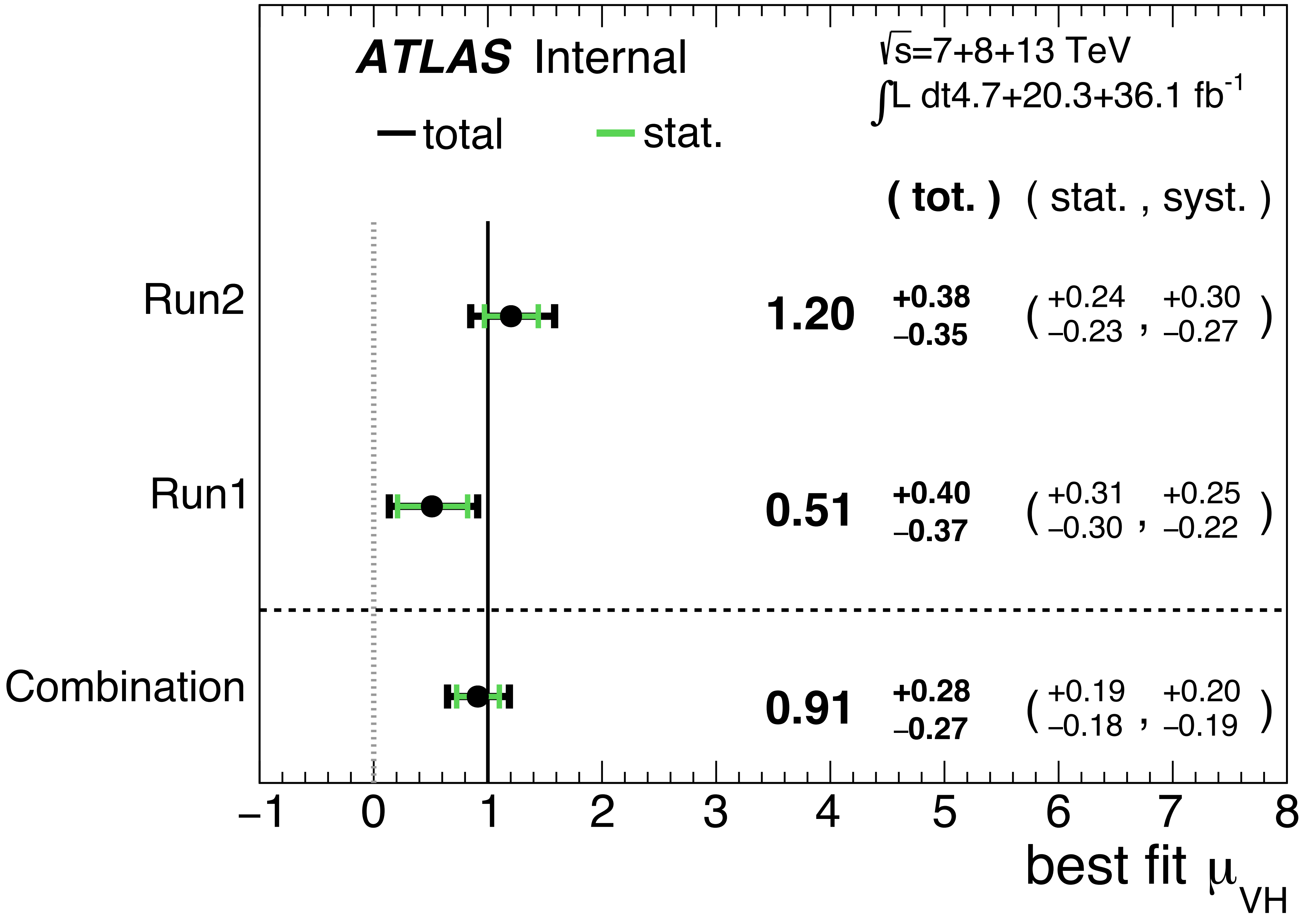


: Leptons: 1.28%

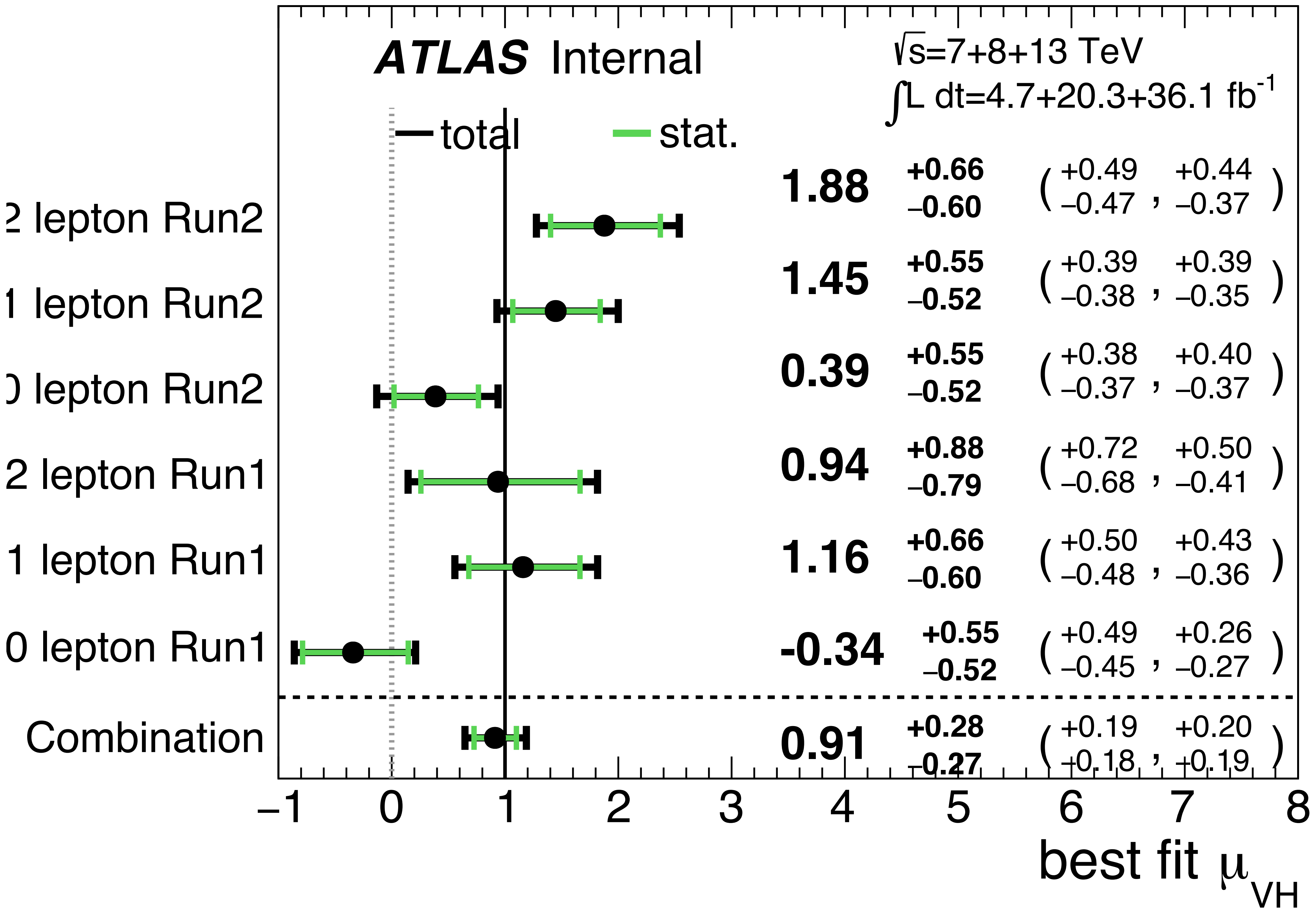


Run1/Run2 Nice Plots (R1/R2, 6POI)

: Run1/Run2: 19.29%



: Run1/Run2 leptons: 6.43%



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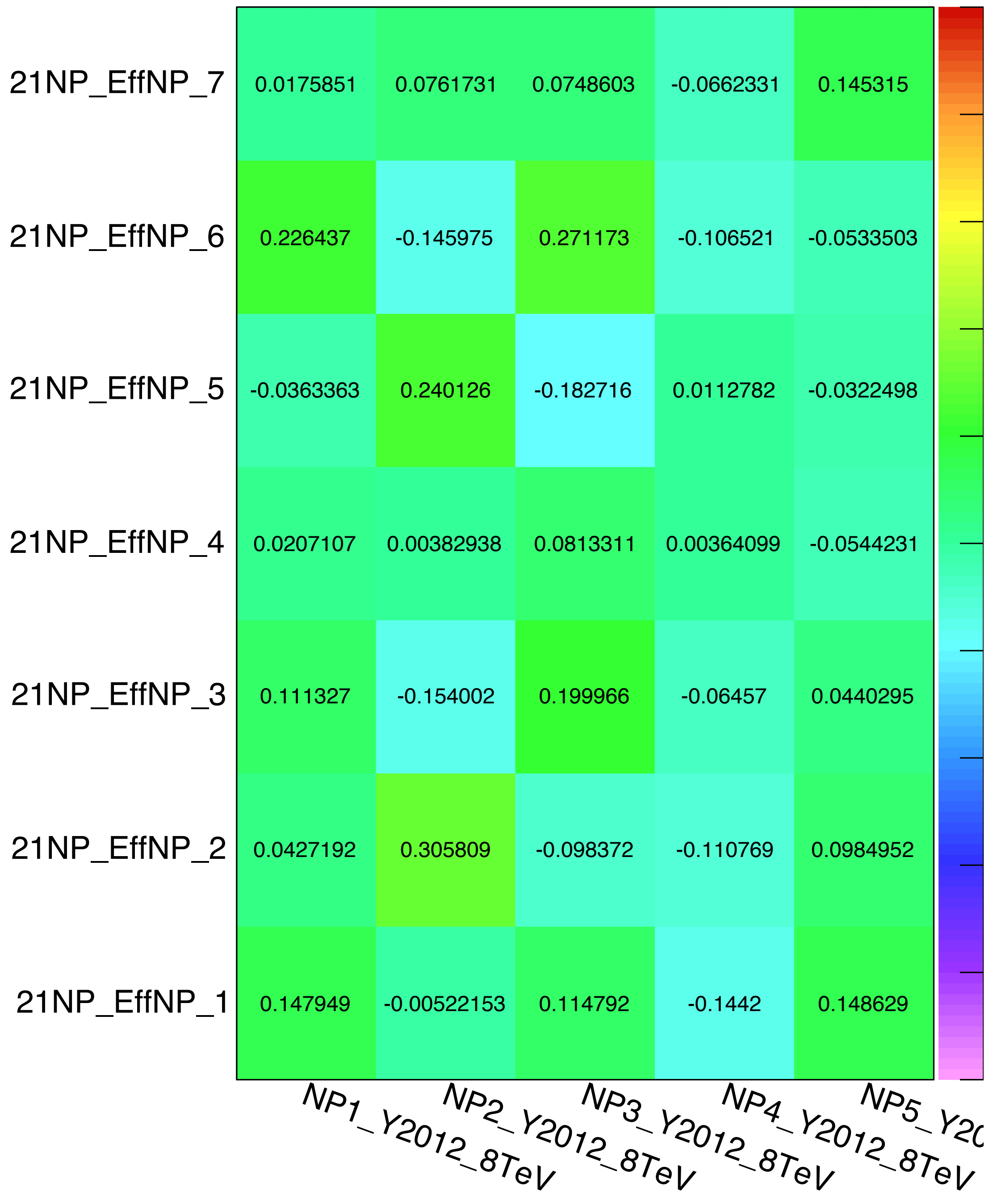
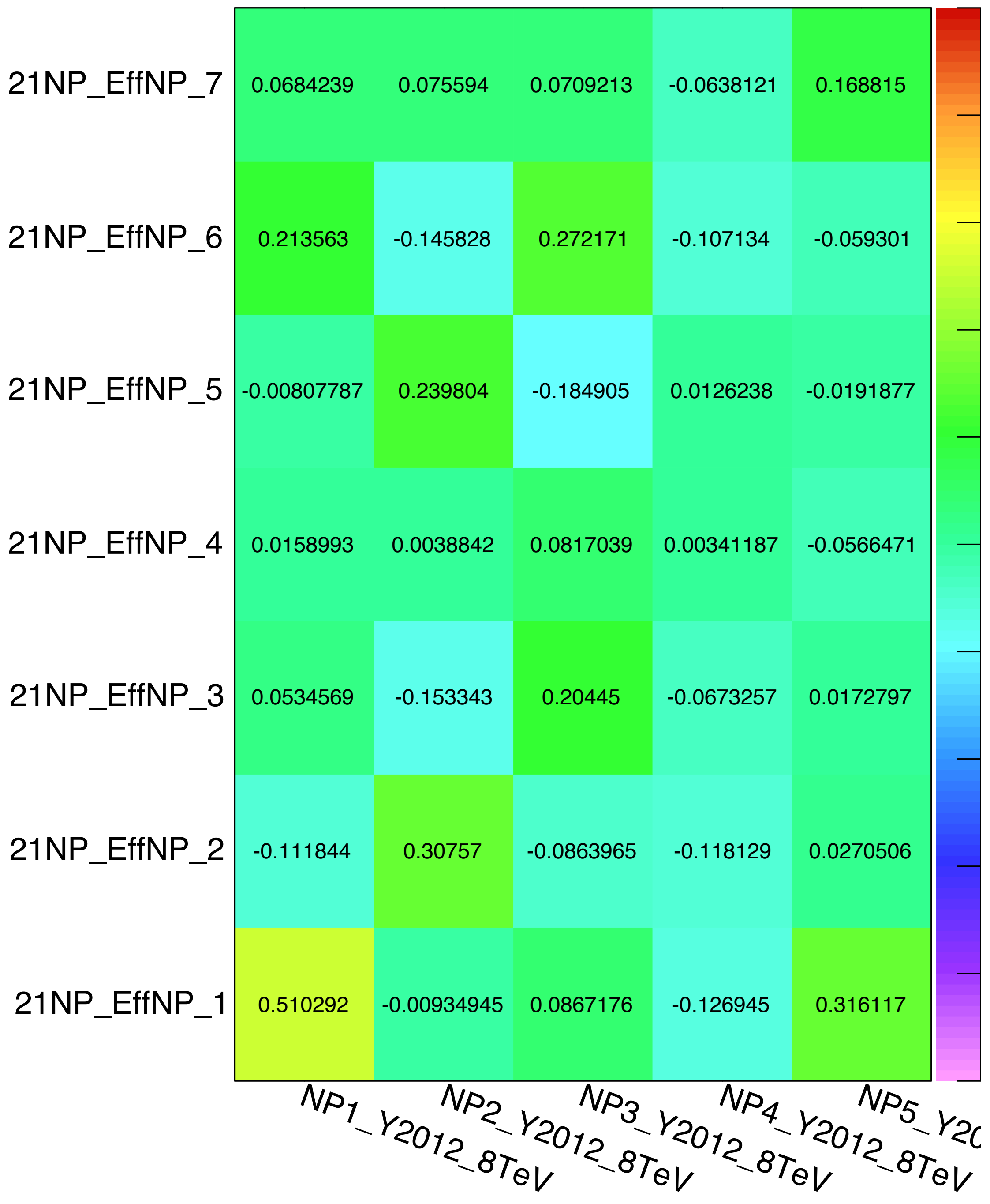
Relating Effective NP's: Leptons

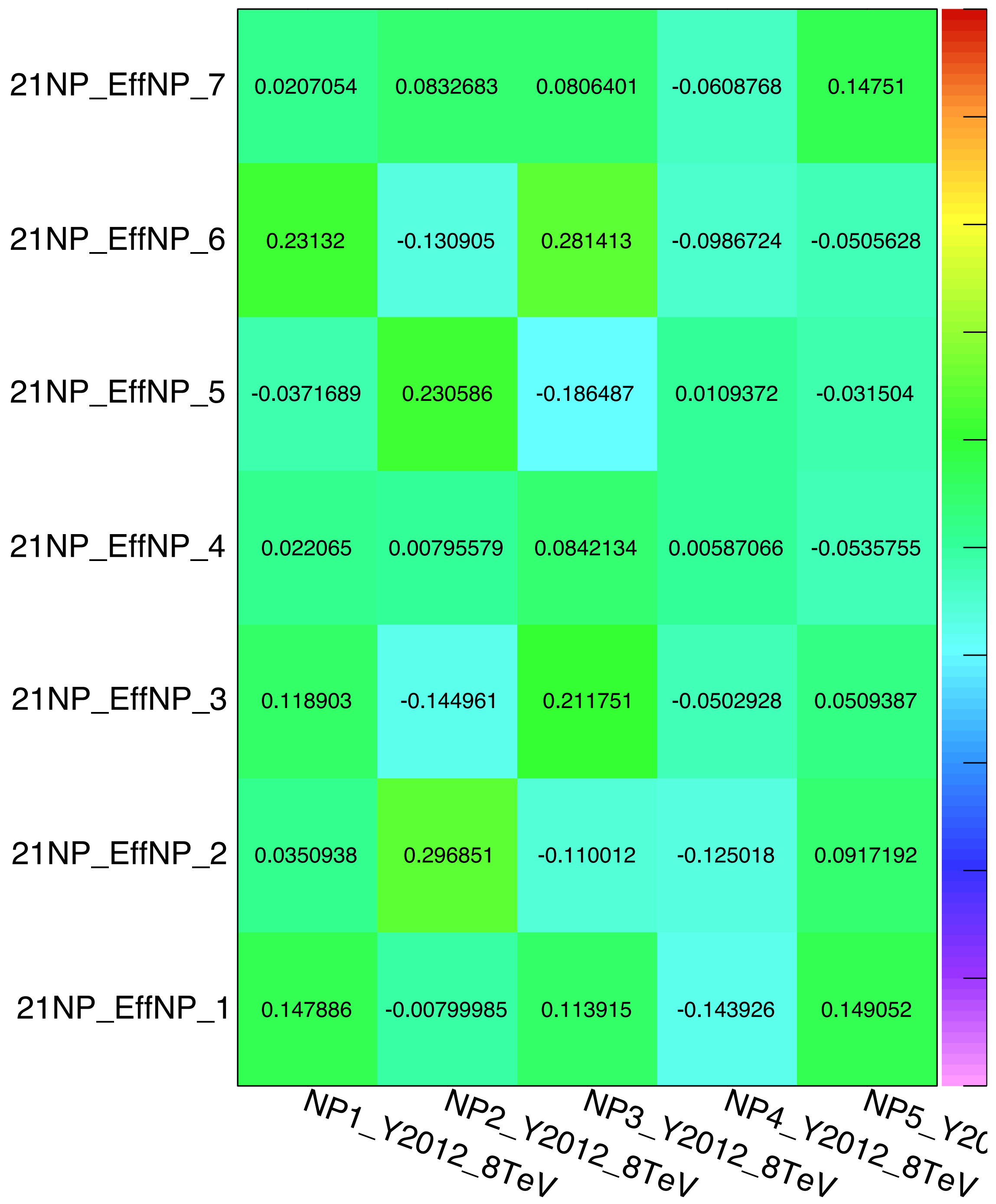
- Using the Run1 and Run2 maps and a correlation matrix that indicates level of correlation between Run1/Run2 effective NP's
  - Correlate electrons and muons? LAr_ESZee is largest source of correlation between Run1 and Run2 effective NP's



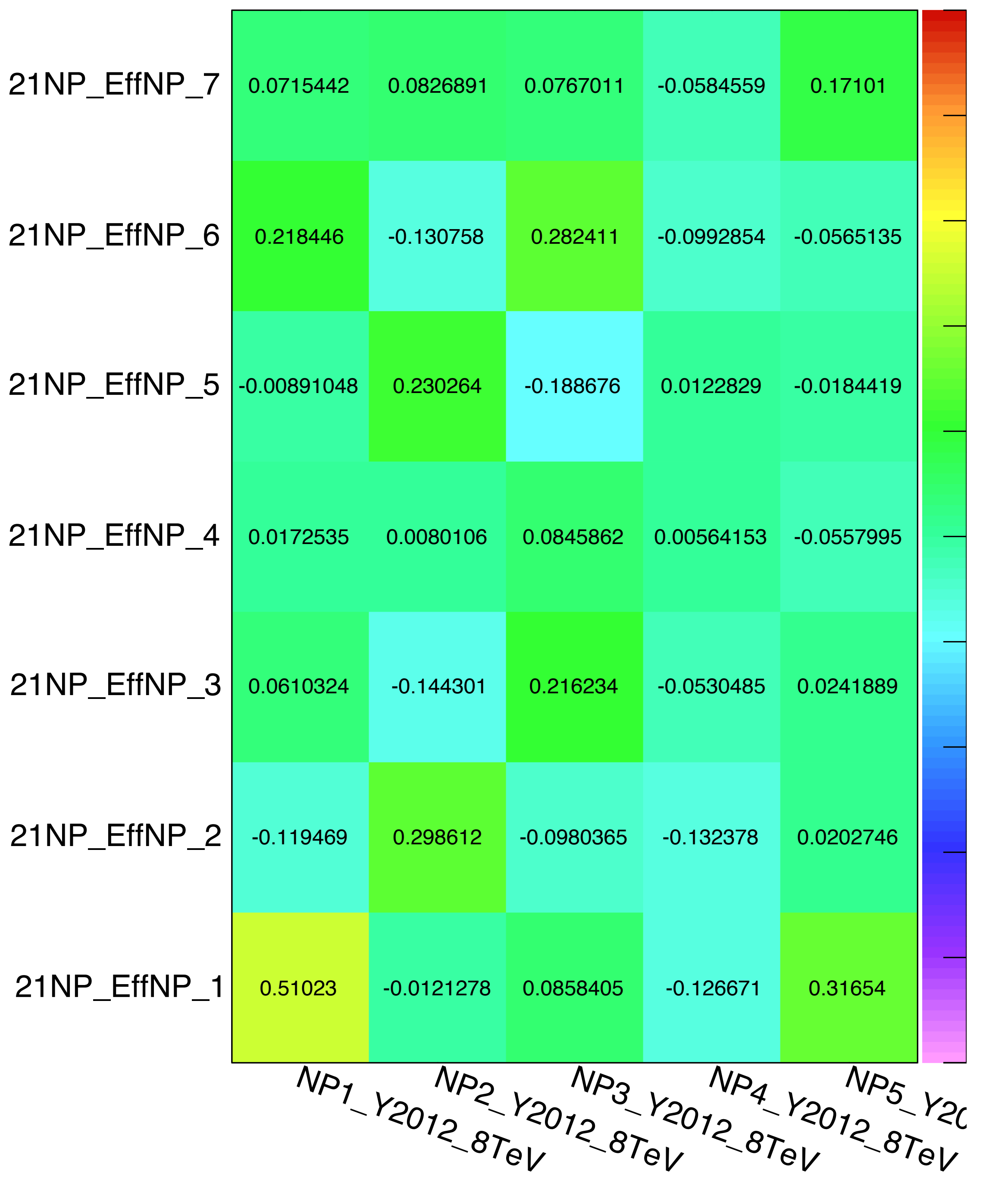
No emu



Corr electrons



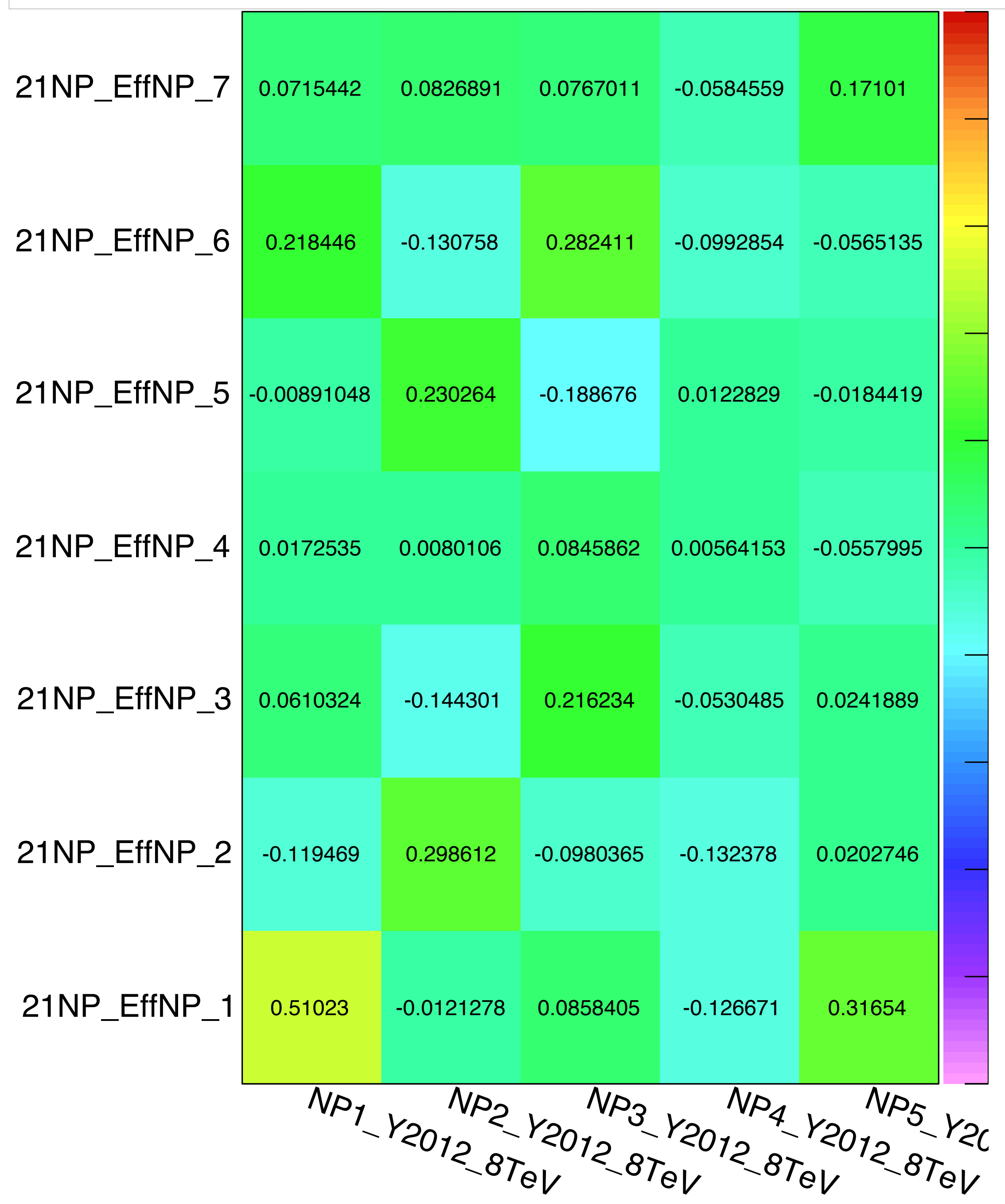
Corr muons



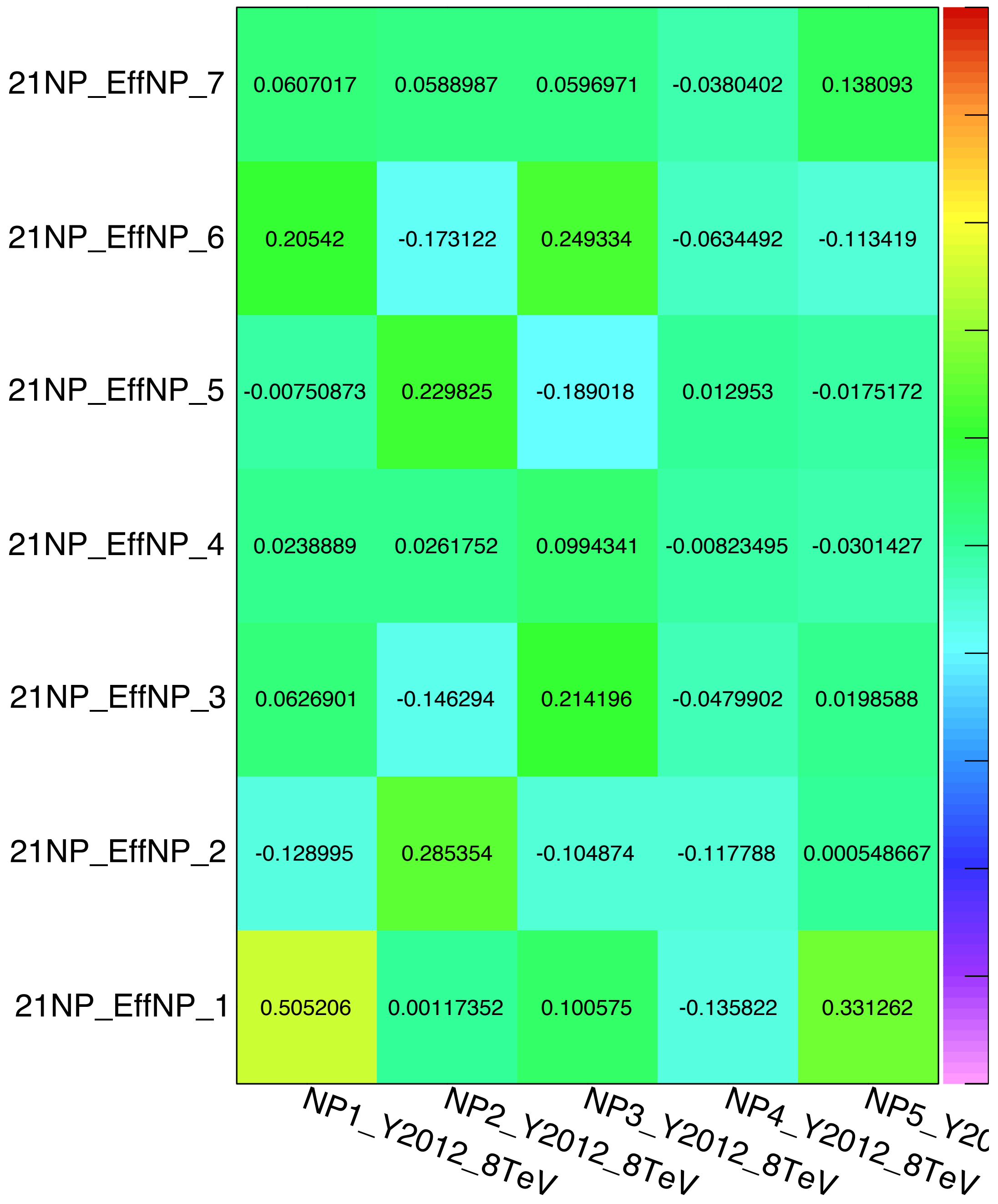
Both

Relating Eff NP's: Weak/Strong; Leptons/Not

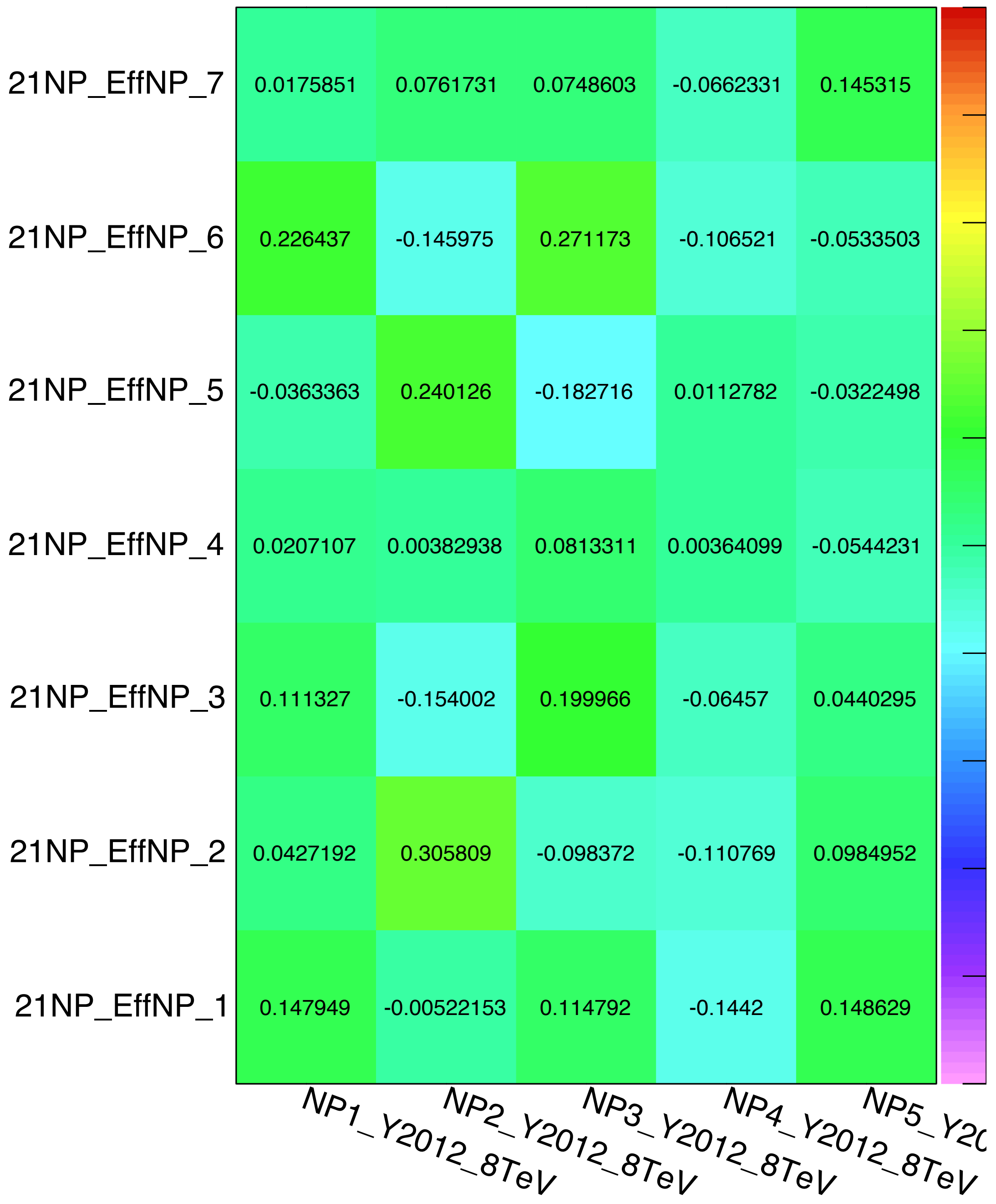
- Using the Run1 and Run2 maps and a correlation matrix that indicates level of correlation between Run1/Run2 effective NP's
  - Strong vs. weak makes little difference for effective NP's; emu correlation (and hence LAr_ESZee) is largest source of correlation between Run1 and Run2 effective NP's regardless of scheme



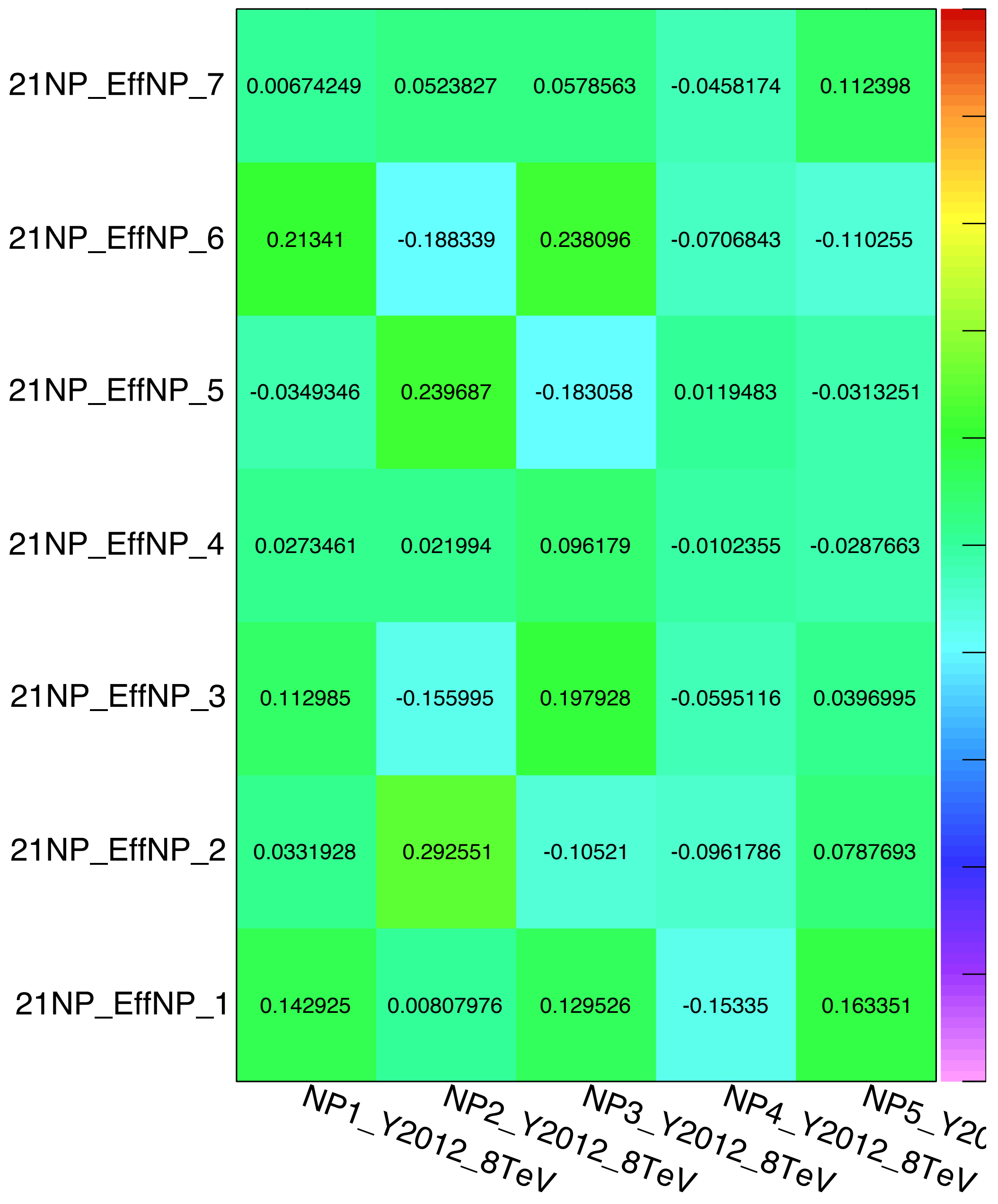
Emu, Strong



Emu, Weak



No emu, strong



No emu, weak

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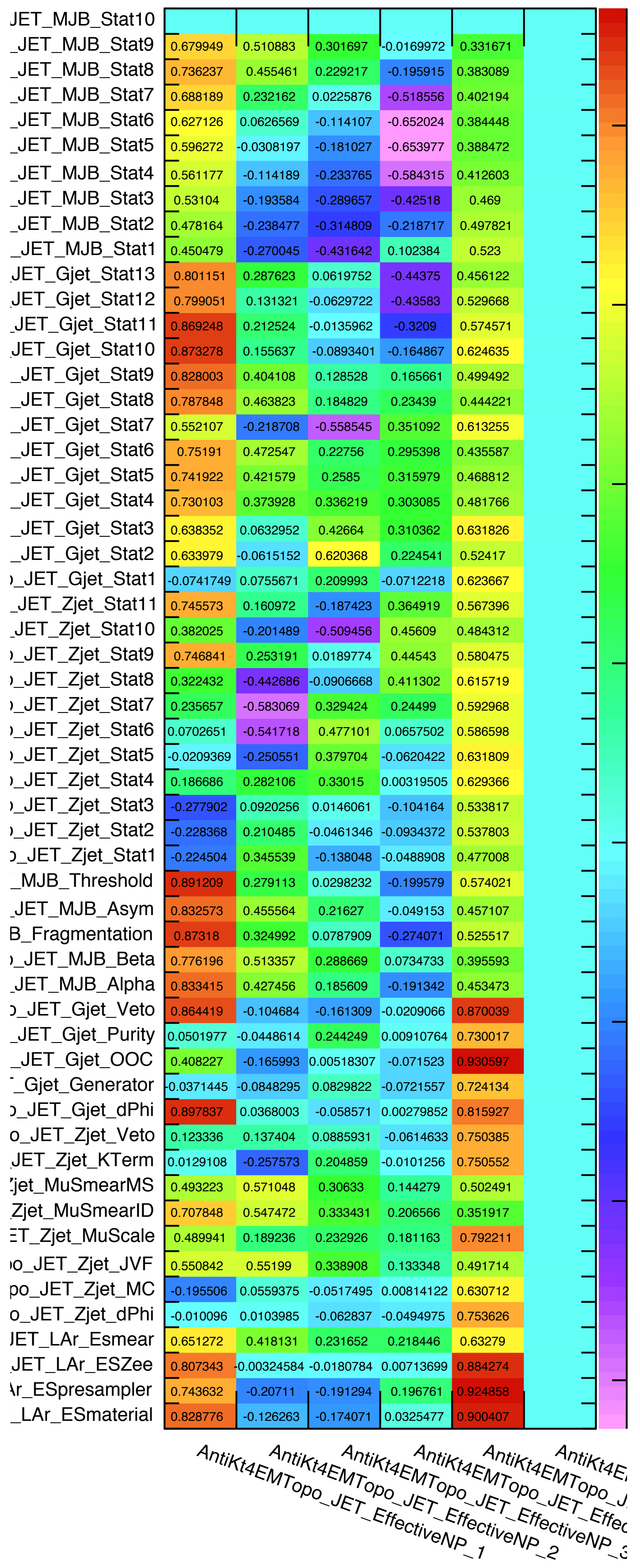
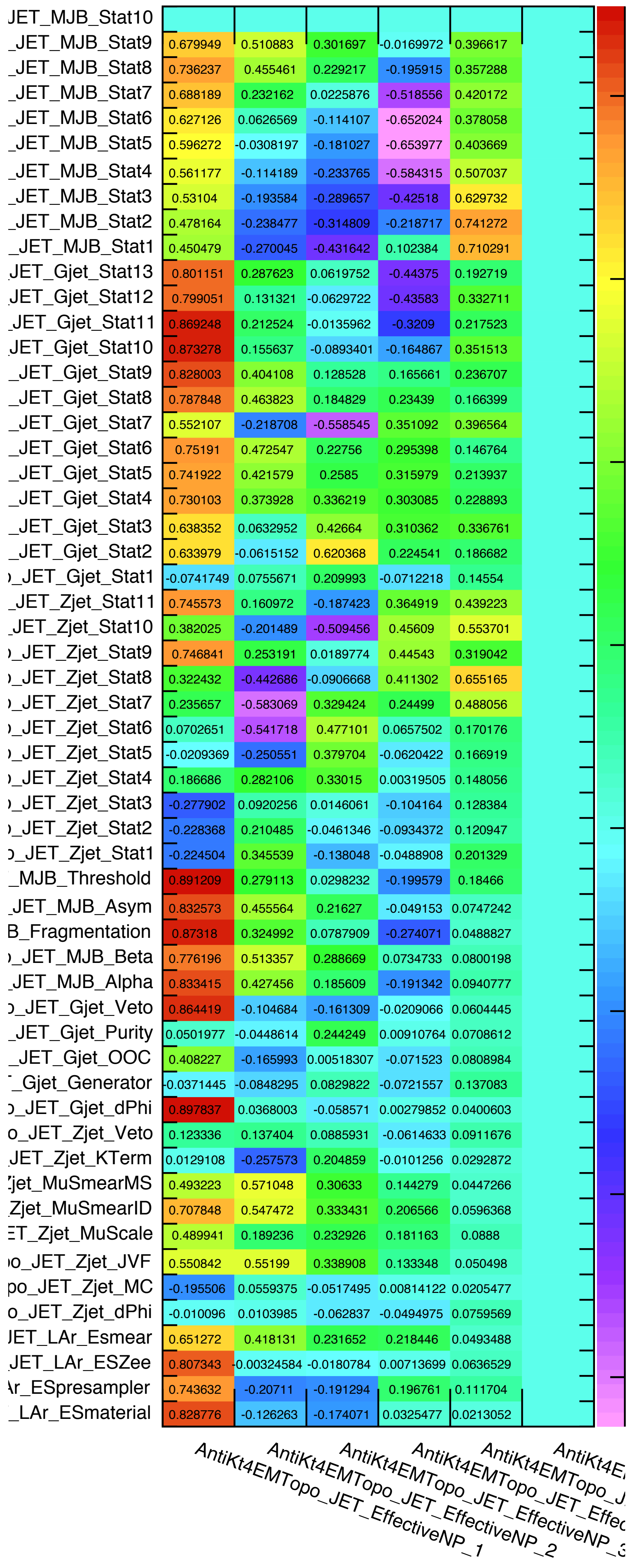
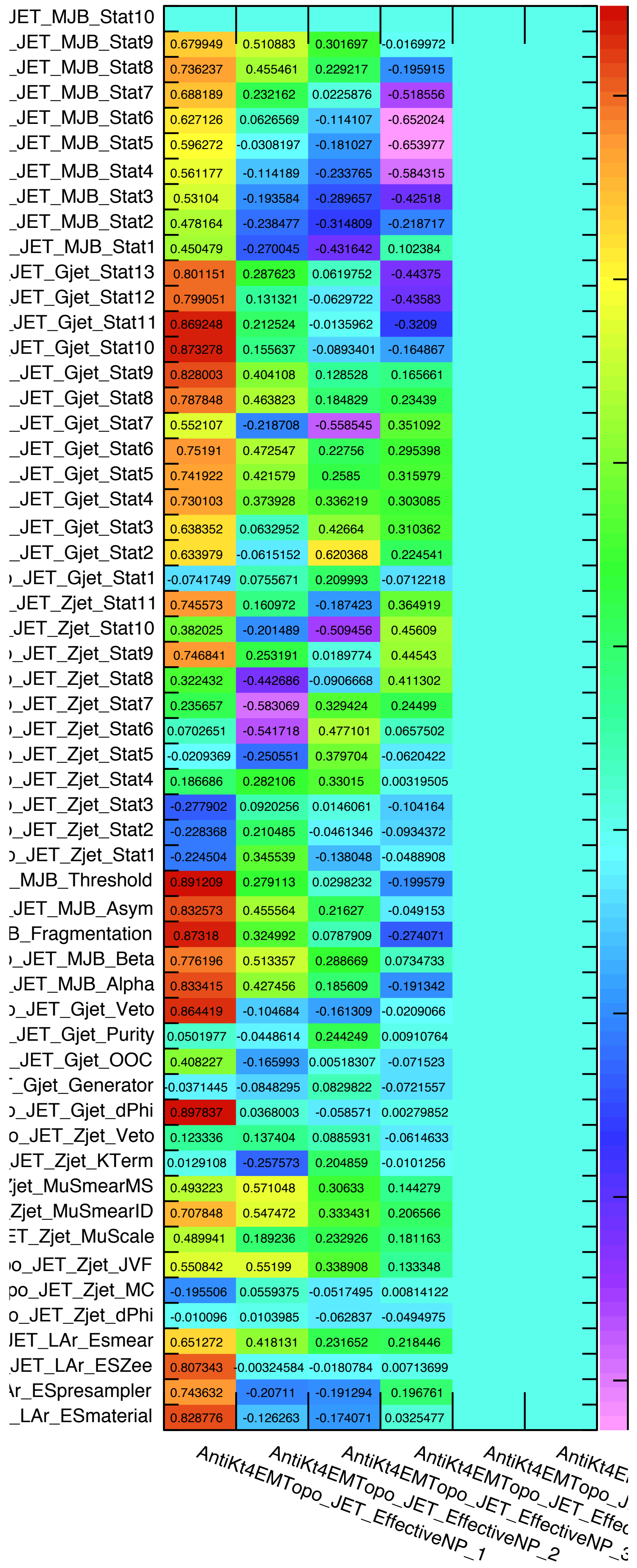
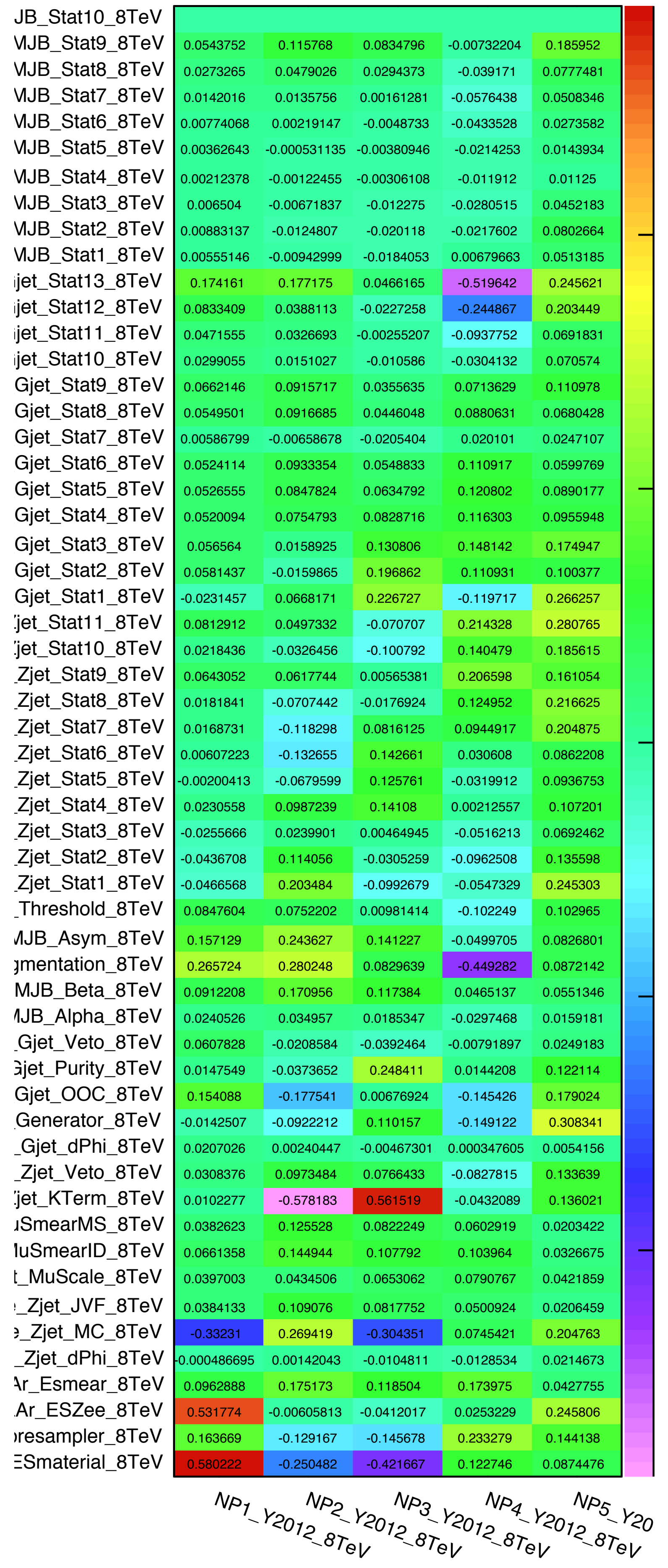
JES Maps Run1









- L to R
- "Original"
- "Complem"
- "Zero"
- "Original" + amplitude weighting + norm.

JES Maps Run2

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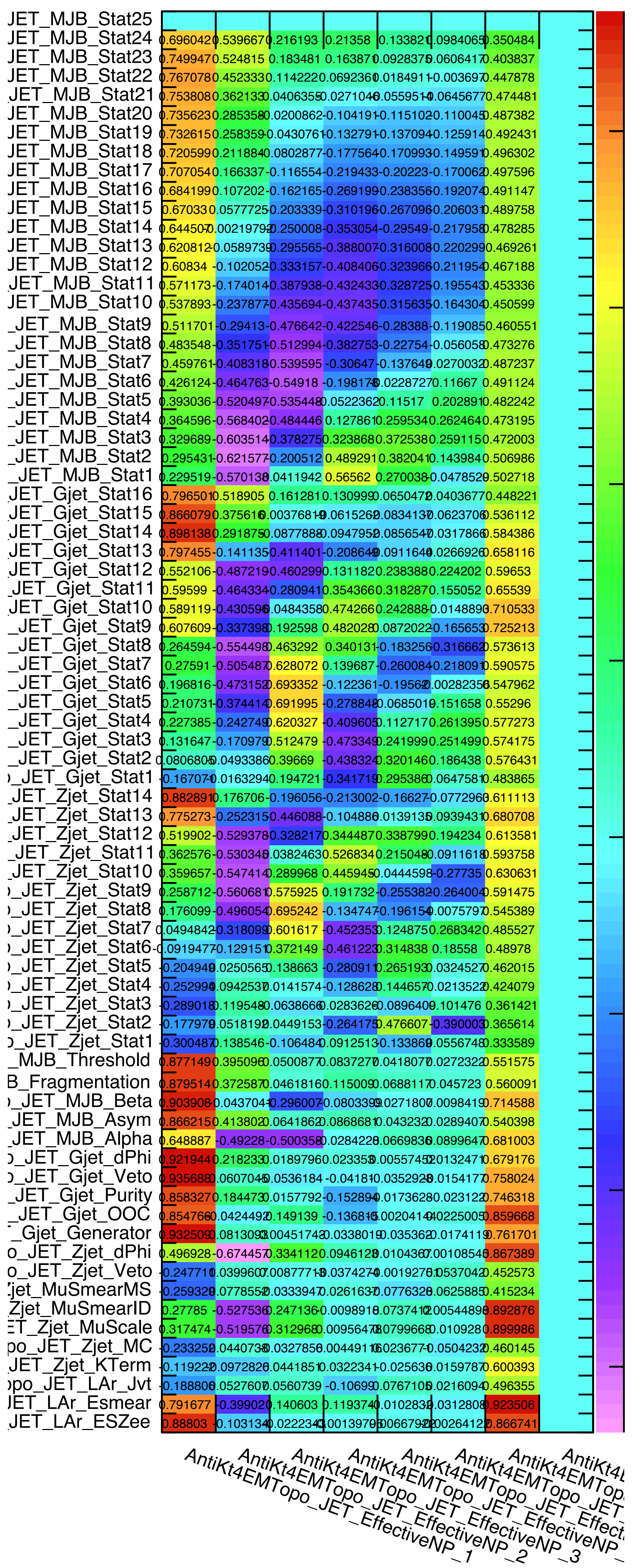
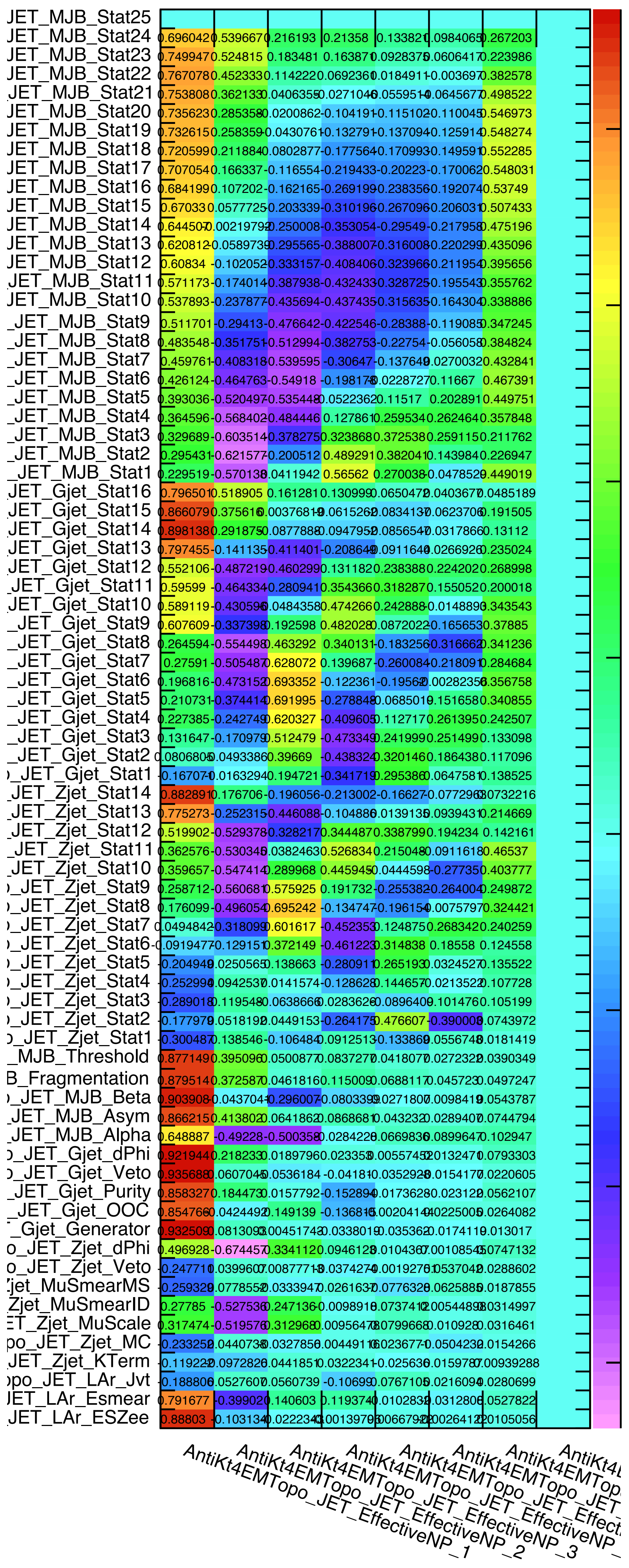
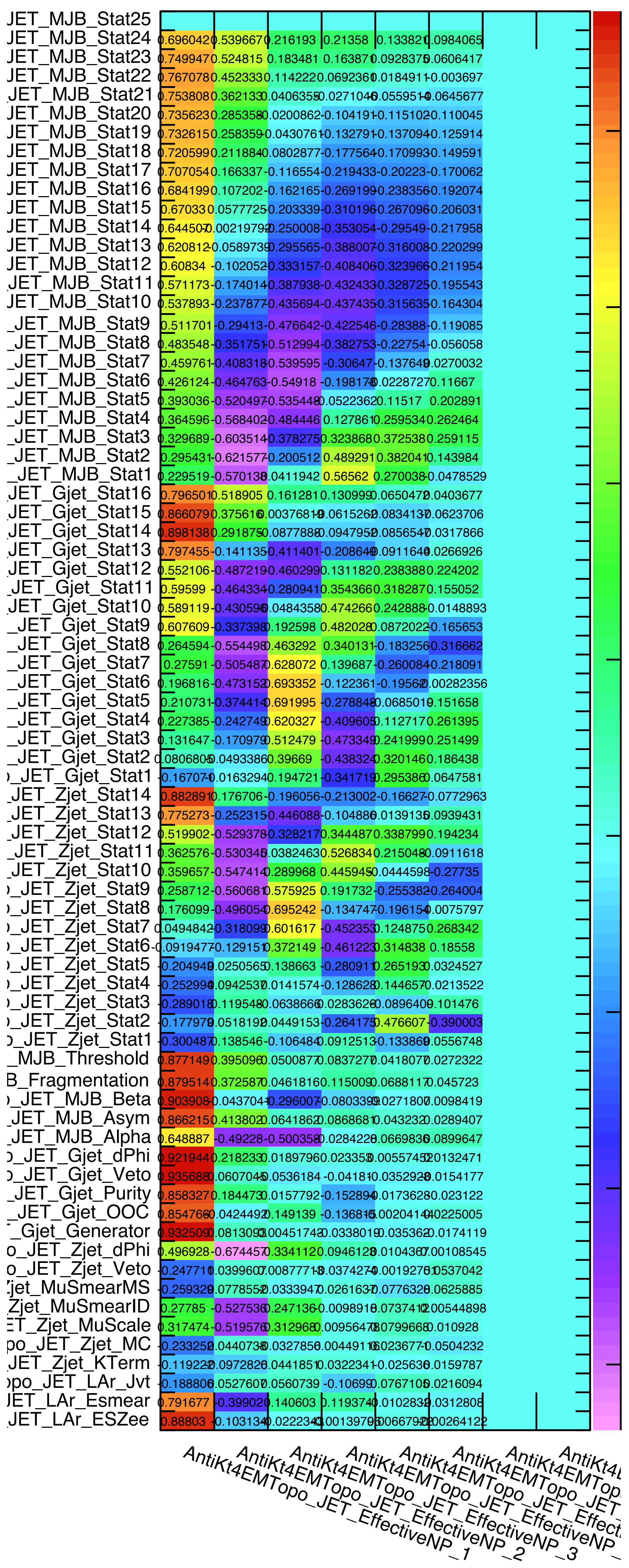
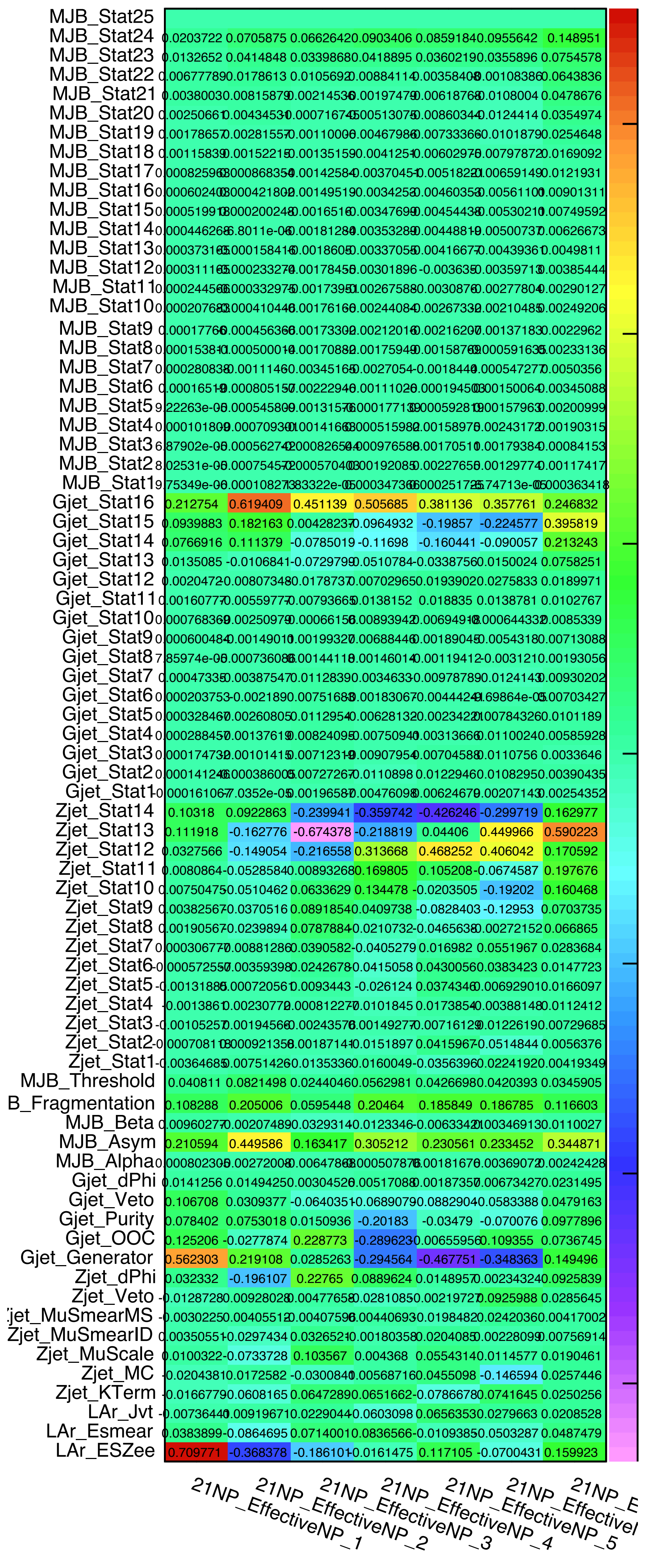








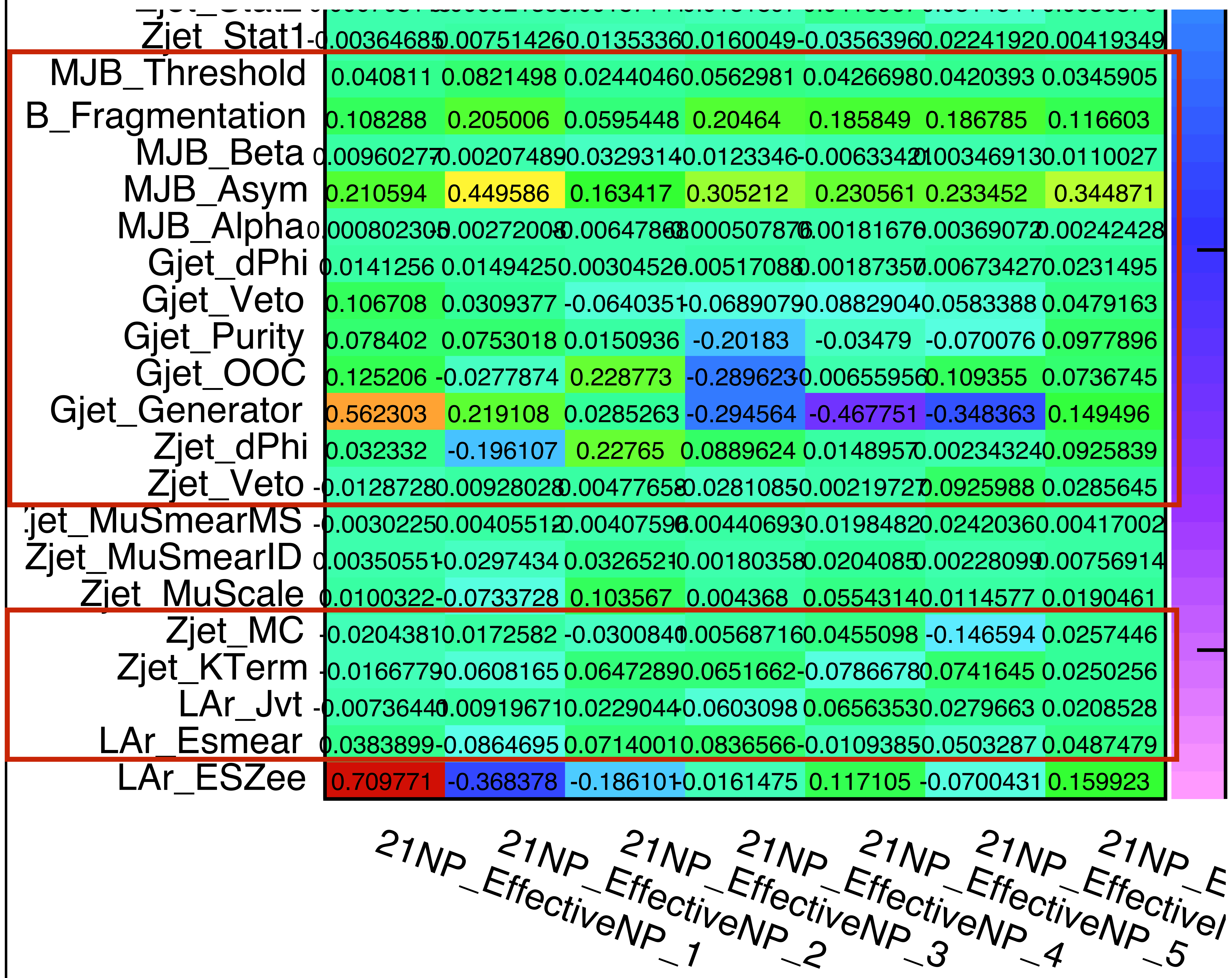
- L to R
- “Original”
- “Complem”
- “Zero”
- “Original” + amplitude weighting + norm.

JES Map: NP's Run1 Detail

	NP1_Y2012_8TeV	NP2_Y2012_8TeV	NP3_Y2012_8TeV	NP4_Y2012_8TeV	NP5_Y20
Zjet_Stat1_8TeV	-0.0466568	0.203484	-0.0992679	-0.0547329	0.245303
_Threshold_8TeV	0.0847604	0.0752202	0.00981414	-0.102249	0.102965
MJB_Asym_8TeV	0.157129	0.243627	0.141227	-0.0499705	0.0826801
gmentation_8TeV	0.265724	0.280248	0.0829639	-0.449282	0.0872142
MJB_Beta_8TeV	0.0912208	0.170956	0.117384	0.0465137	0.0551346
MJB_Alpha_8TeV	0.0240526	0.034957	0.0185347	-0.0297468	0.0159181
_Gjet_Veto_8TeV	0.0607828	-0.0208584	-0.0392464	-0.00791897	0.0249183
Gjet_Purity_8TeV	0.0147549	-0.0373652	0.248411	0.0144208	0.122114
Gjet_OOC_8TeV	0.154088	-0.177541	0.00676924	-0.145426	0.179024
Generator_8TeV	-0.0142507	-0.0922212	0.110157	-0.149122	0.308341
_Gjet_dPhi_8TeV	0.0207026	0.00240447	-0.00467301	0.000347605	0.0054156
_Zjet_Veto_8TeV	0.0308376	0.0973484	0.0766433	-0.0827815	0.133639
jet_KTerm_8TeV	0.0102277	-0.578183	0.561519	-0.0432089	0.136021
SmearMS_8TeV	0.0382623	0.125528	0.0822249	0.0602919	0.0203422
MuSmearID_8TeV	0.0661358	0.144944	0.107792	0.103964	0.0326675
_MuScale_8TeV	0.0397003	0.0434506	0.0653062	0.0790767	0.0421859
Zjet_JVF_8TeV	0.0384133	0.109076	0.0817752	0.0500924	0.0206459
e_Zjet_MC_8TeV	-0.33231	0.269419	-0.304351	0.0745421	0.204763
_Zjet_dPhi_8TeV	-0.000486695	0.00142043	-0.0104811	-0.0128534	0.0214673
Ar_Esmear_8TeV	0.0962888	0.175173	0.118504	0.173975	0.0427755
Ar_ESZee_8TeV	0.531774	-0.00605813	-0.0412017	0.0253229	0.245806
resampler_8TeV	0.163669	-0.129167	-0.145678	0.233279	0.144138
ESmaterial_8TeV	0.580222	-0.250482	-0.421667	0.122746	0.0874476

- Zoomed into map used in following
- NP's we care about highlighted
  - Ignore stat, electron, and muon NP's for combination; ones not in Run2
  - Bottom portion of plot (all above are Stat NP's)

JES Map: NP's Run2 Detail



- Zoomed into map used in following
- NP's we care about highlighted
  - Ignore stat, electron, and muon NP's for combination
  - Bottom portion of plot (all above are Stat NP's)

TECHNICAL DETAILS: PIPELINE

1. Add Asimov data to Run2 workspace (see following slides) for different μ values—WSMaker (~0.5 h)
2. Make combined workspaces (correlation schemes, μ values)—CombinationTool (~0.5 h)
3. Make usual WSMaker results: if Run2 in combined workspace is (conditional) Asimov, run “observed” fit
   1. Limits, significances, and pulls: run as per usual, but specify dataset is “combData” instead of “obsData” (~2-3 h)
   2. Breakdowns: new modes and parallelization implemented (see following slides, ~2.5+6 h)
   3. Ranks: if “quick” turnaround becomes important, can try to implement parallelization similar to (~10-12 h)

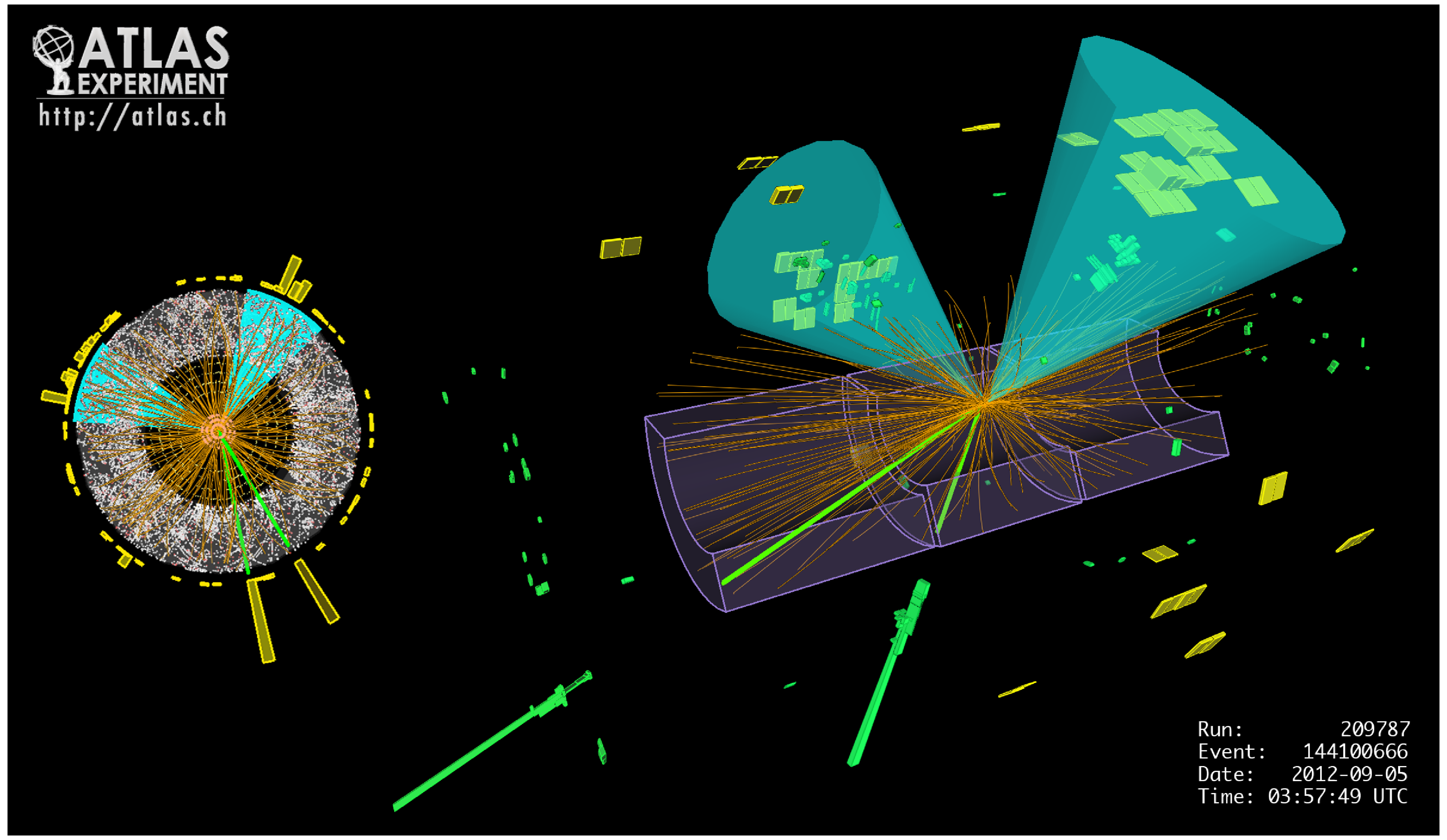
Technical Details: Adding Asimov Data

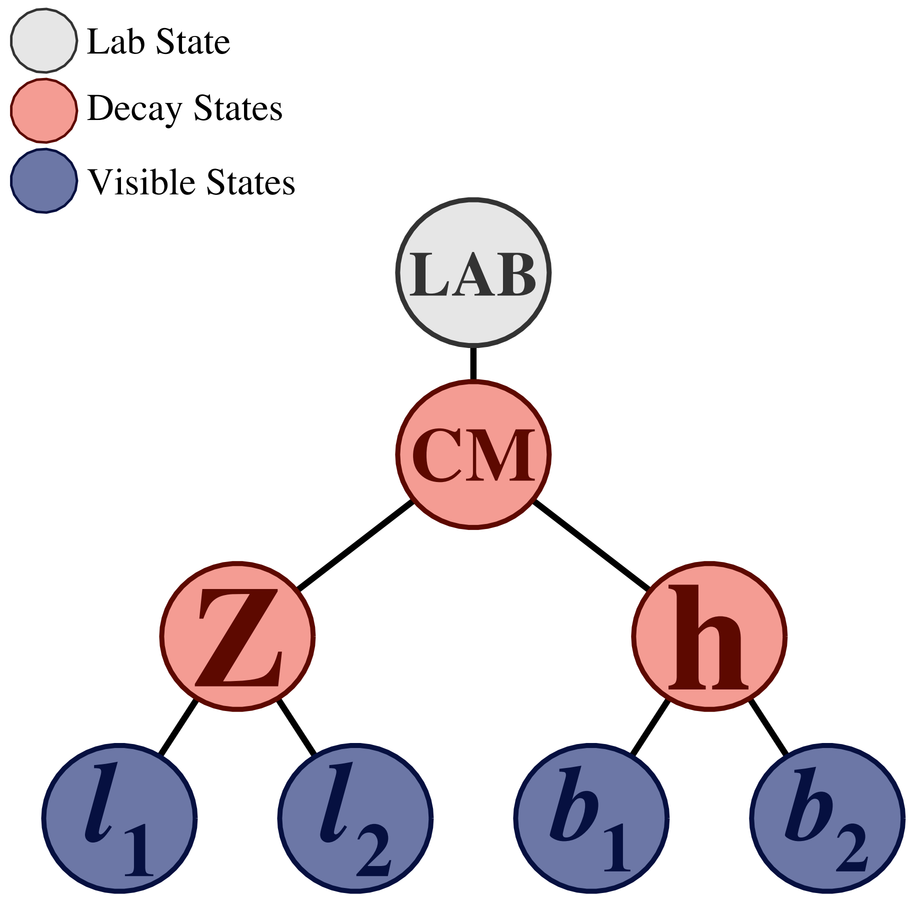
- Load workspace
- Use macros/makeAsimovData.C specifying the μ value you want
- Save the workspace to a new file (the macro imports the new dataset)
    - Available at /afs/cern.ch/work/s/stchan/public/hcomb

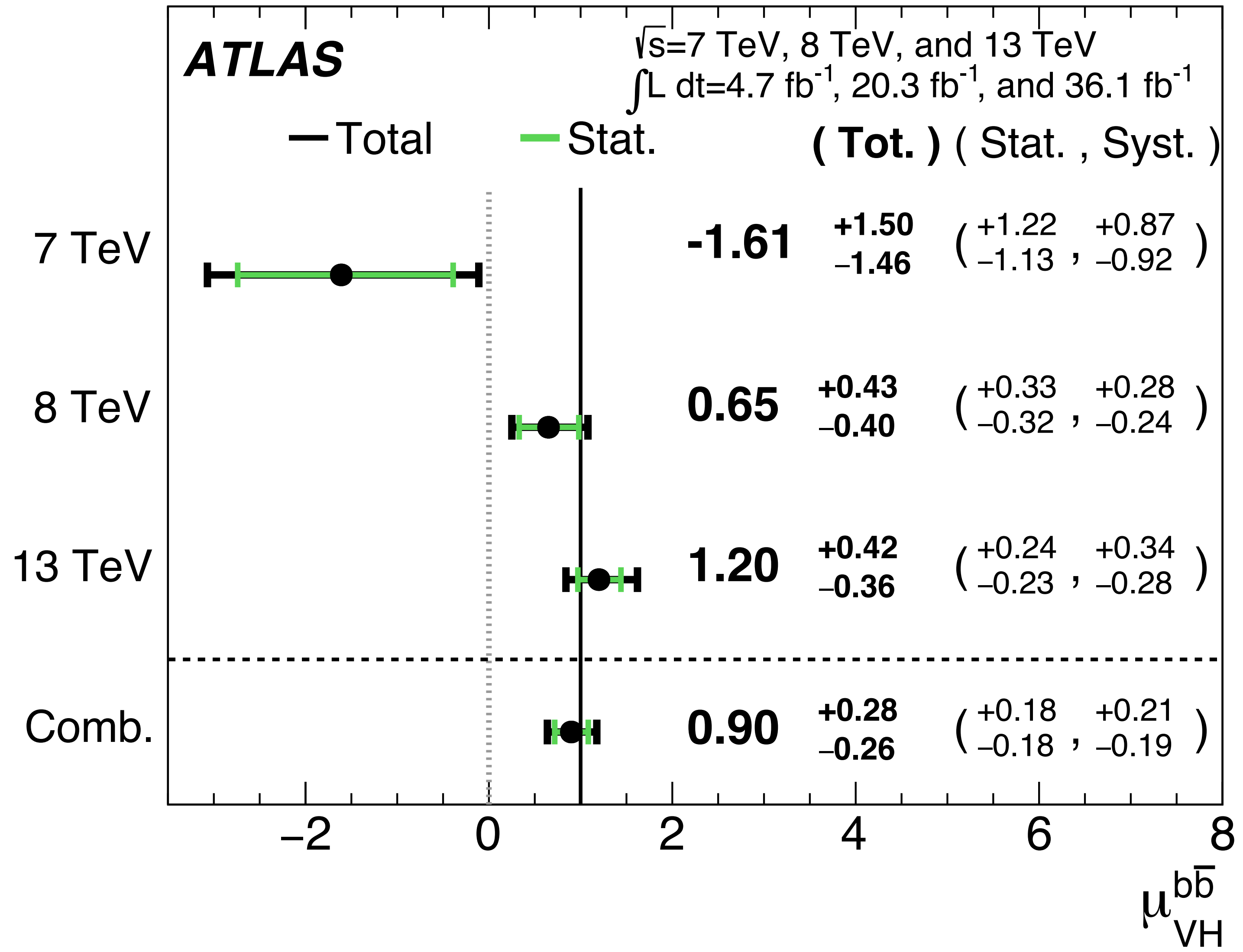
Technical Details: Breakdowns

- Personal/devbranch copy of newGetMuHat.C has new breakdown modes
  - Covers both Run1 and Run2 NP naming conventions
  - /afs/cern.ch/work/s/stchan/public/hcomb
- Breakdowns can now be done in parallel
  - The Run1 workspace is very large—there is a lot of overhead that gets duplicated if parallel jobs are done naively
  - Run the usual breakdown on the combined workspace in new mode "-1" (does the nominal fit and calculates the total error)
    - Results are saved in a root file from which results can be loaded
  - cf. newGetMuHat.C, macros/minimize.C (couple lines changed to enable saving the minimization result)

SM VHbb at Harvard







- Significance of 3.57σ (4.00σ, μ=0.95 with minimal flavor tagging correlation)
  - First evidence of SM VHbb
- Measurement combinations and generically orthogonal decompositions for precision