

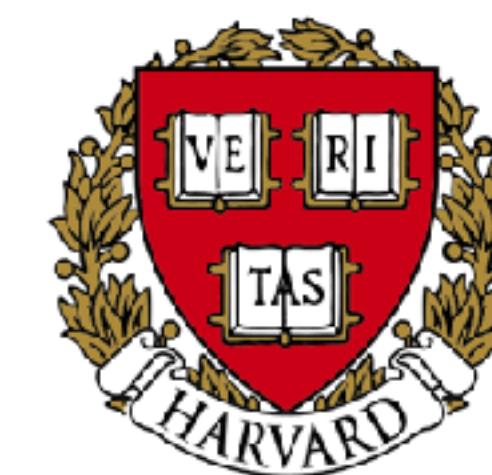
GENERICALLY ORTHOGONAL DECOMPOSITIONS AND MEASUREMENT COMBINATIONS

A Theme and Variations in the search for Standard Model

VHbb

Stephen K. Chan

23 April 2018

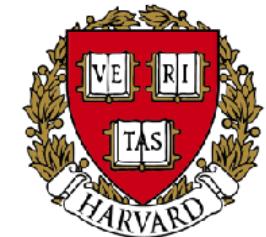


OVERVIEW

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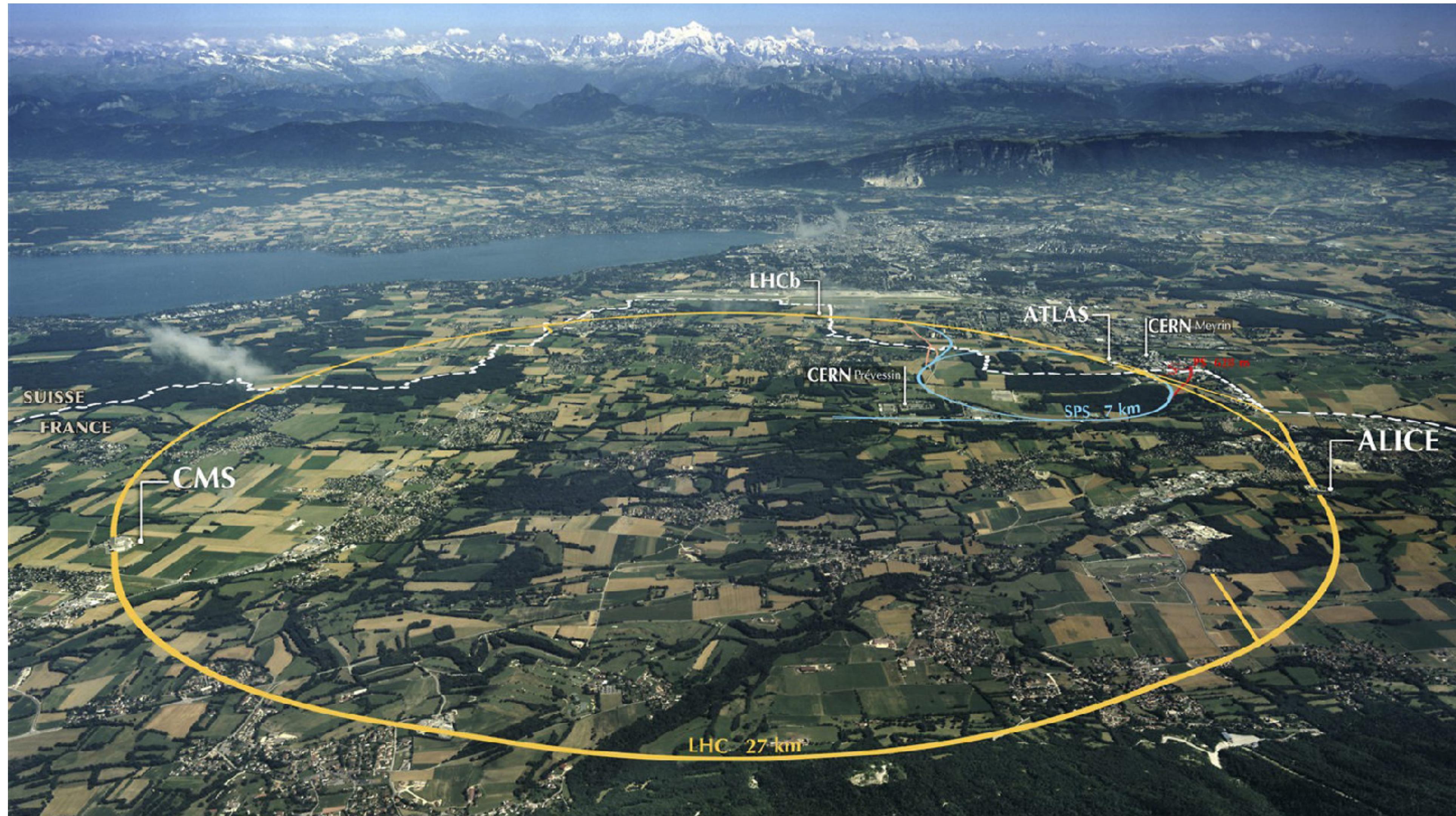
- SM VHbb at ATLAS
- Statistical analysis of LHC data
- Generically orthogonal MVA inputs in SM $ZH \rightarrow llbb$
 - Canonical
 - Lorentz Invariants
 - RestFrames
- Measurement combinations: ATLAS SM VHbb Run 1 + Run 2

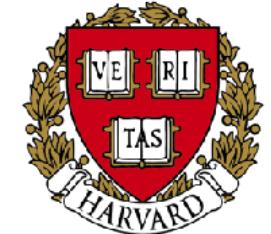


MAKING HIGH ENERGY COLLISIONS: THE LHC

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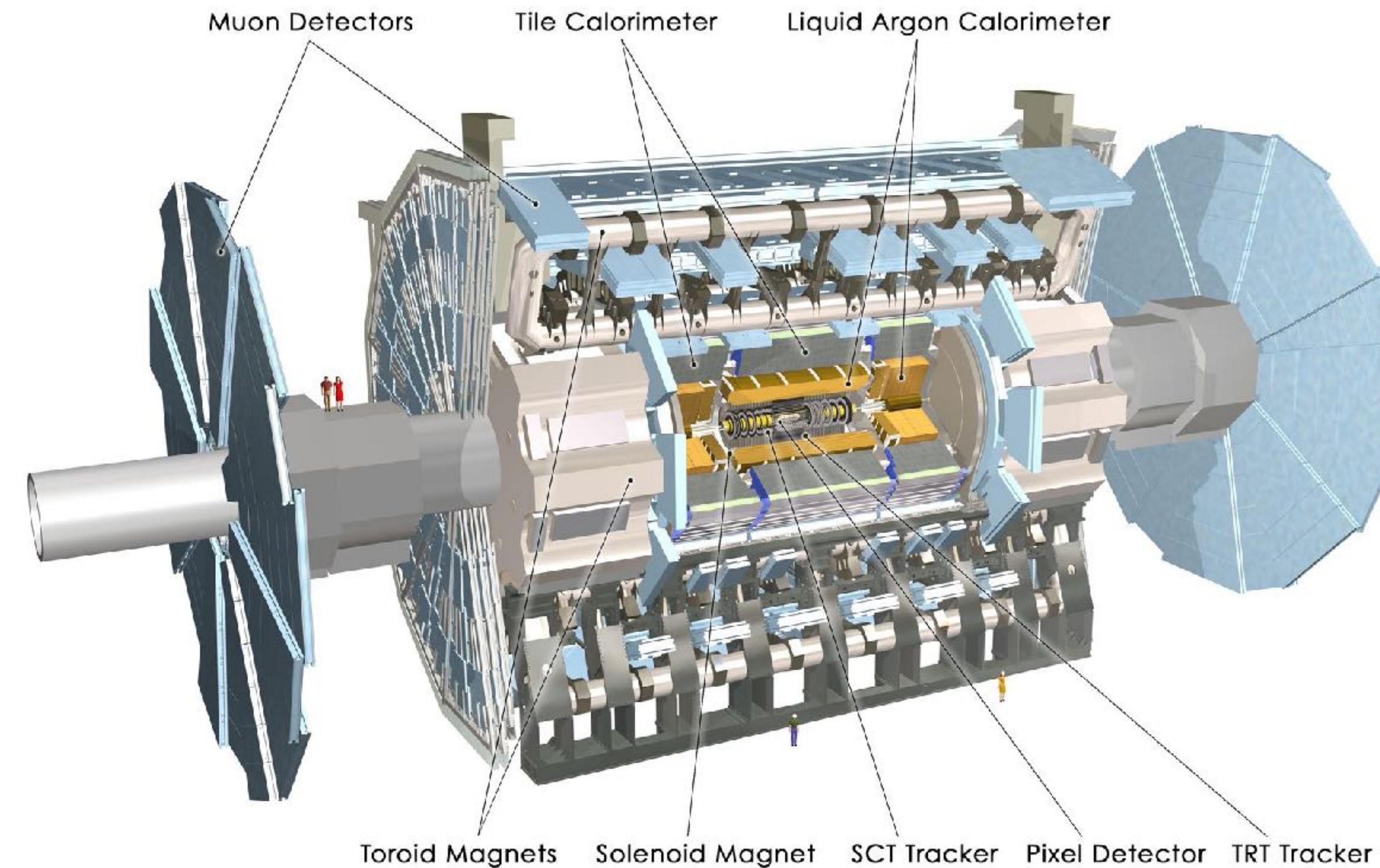




MEASURING COLLISIONS: ATLAS

4

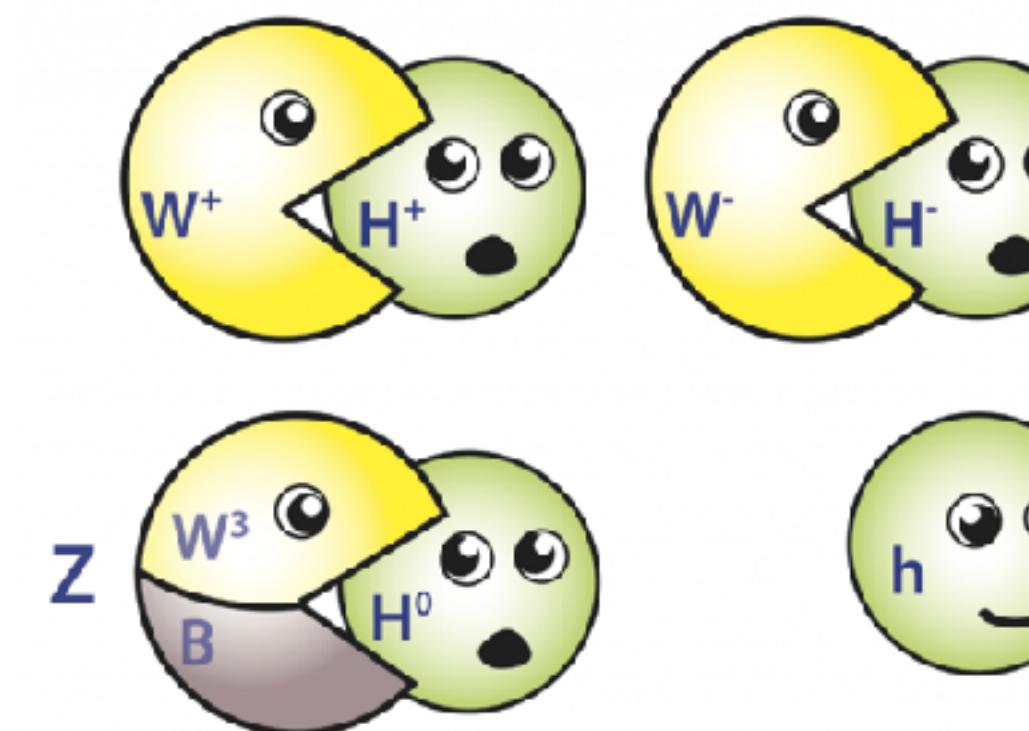
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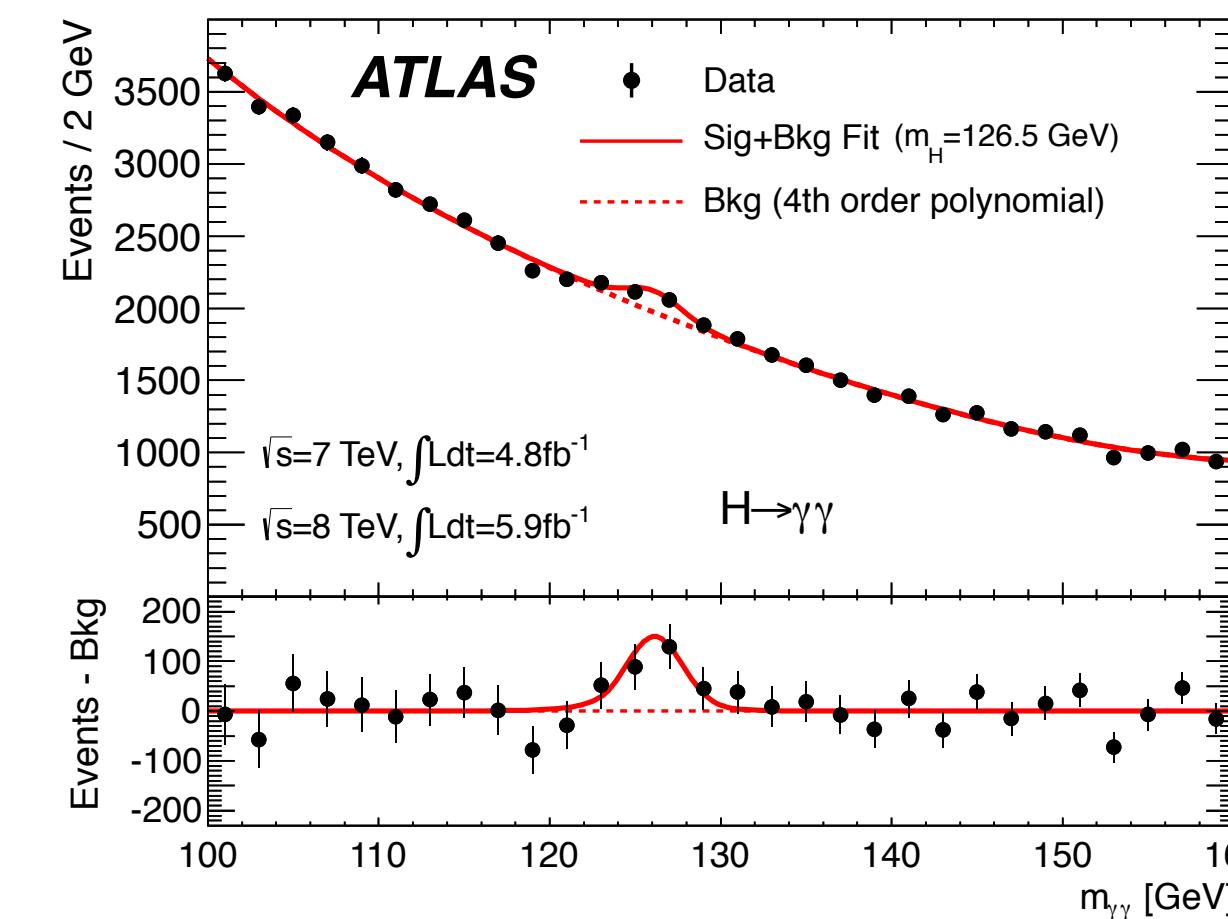
THE HIGGS

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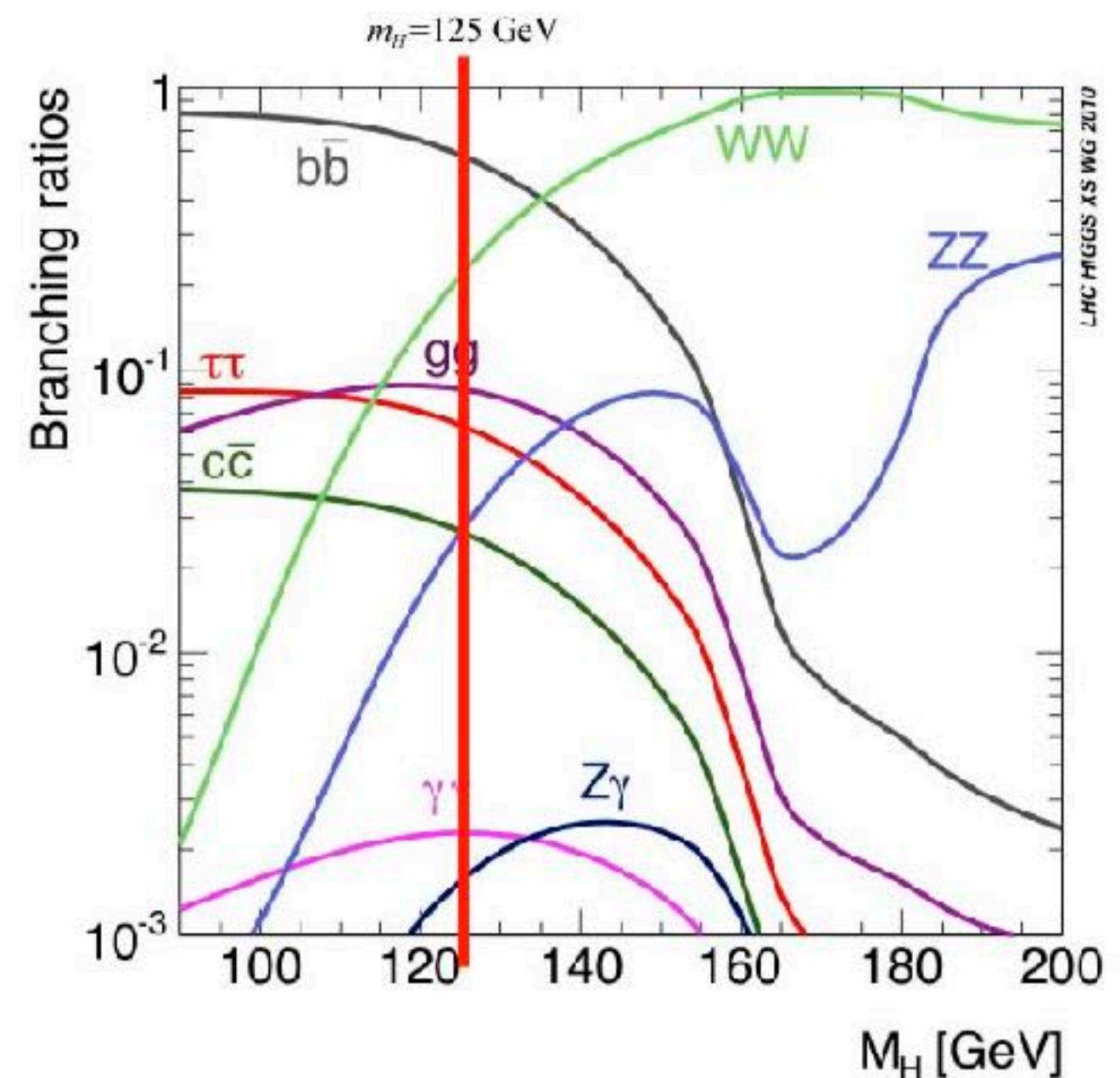
- SM EWSB—>scalar Higgs
 - Where fundamental particles get mass*
- The Higgs decays a variety of ways; mass dependent
 - $\gamma\gamma/ZZ^*$ discovery channels—>mass of 125 GeV
- Dominant Higgs decay is to b-quarks at 58% of the time



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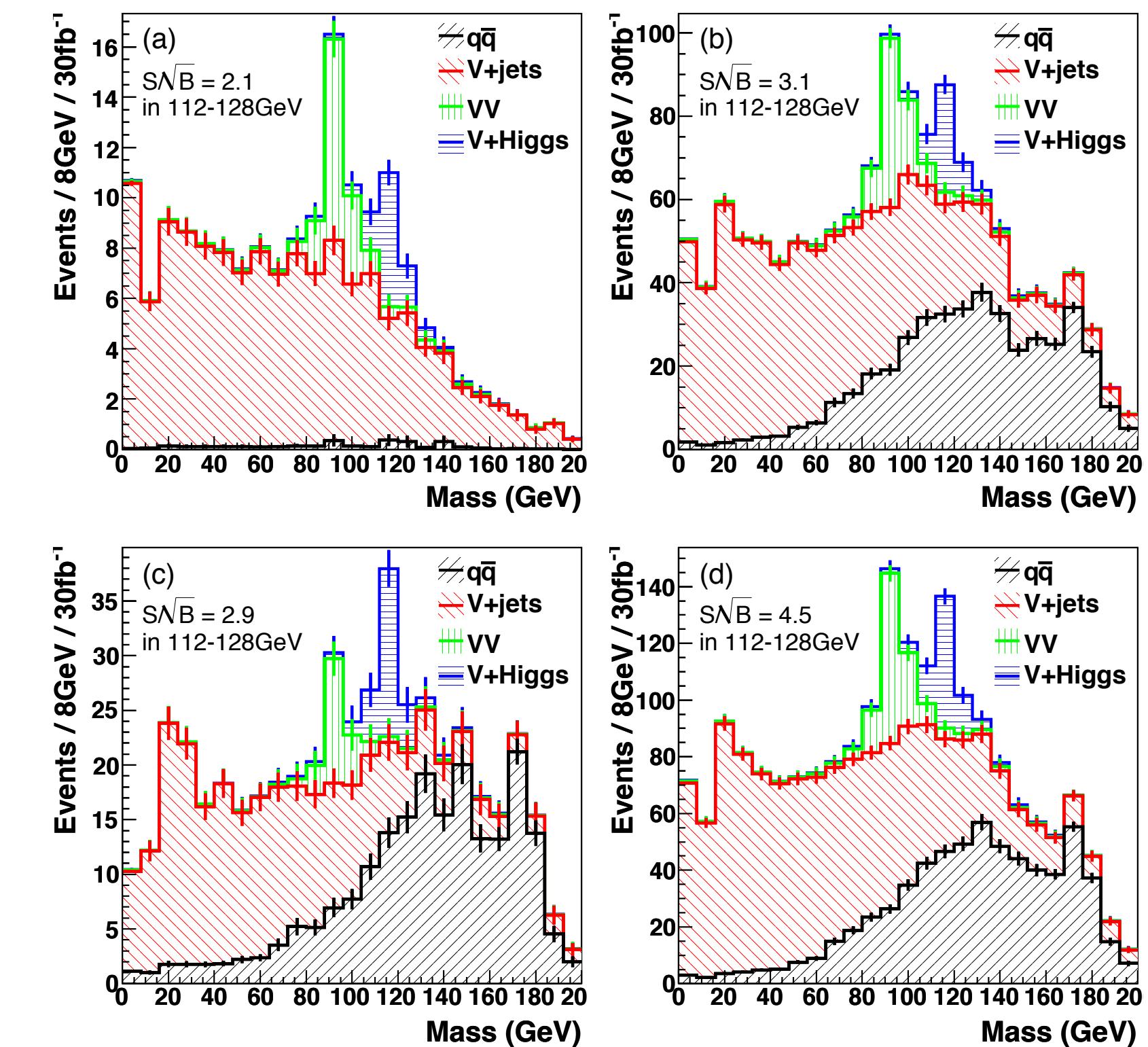


II

 M_H [GeV]

STANDARD MODEL VHBB AT THE LHC

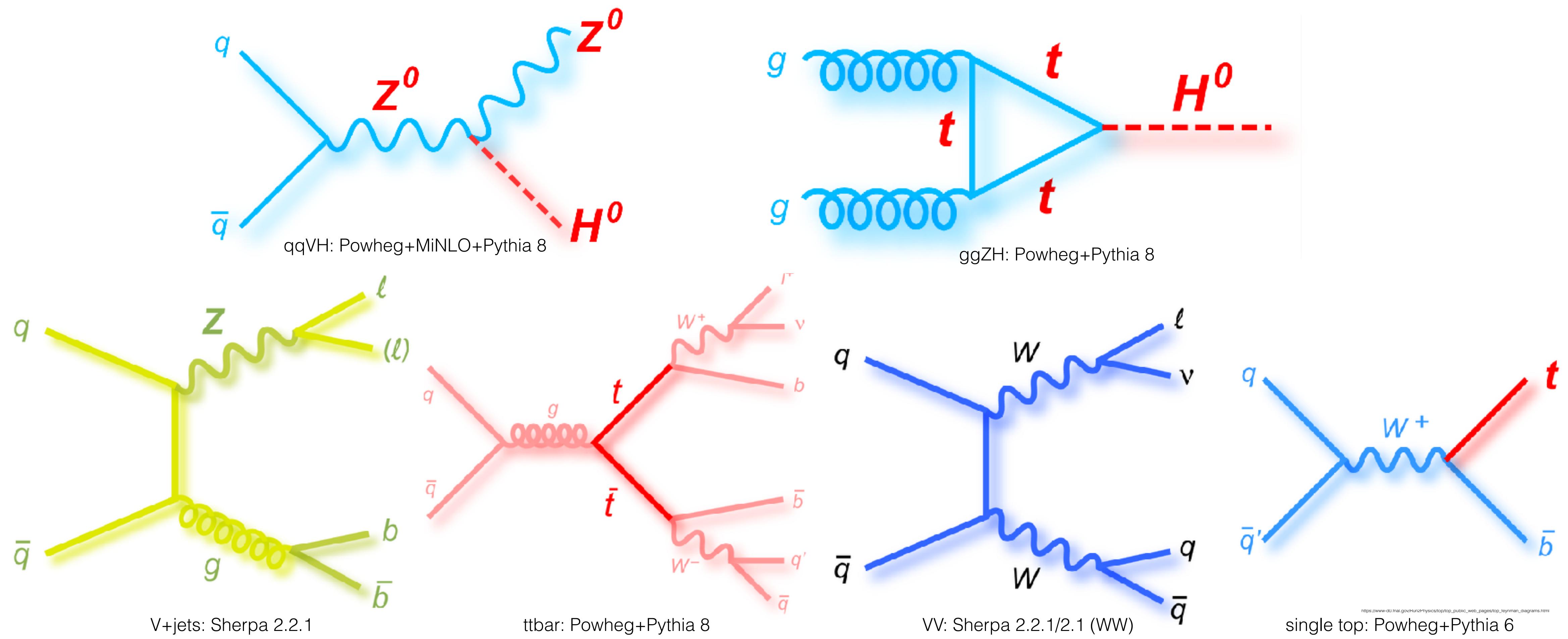
- Not so long ago, QCD background thought too overwhelming for Hbb
- Require hadronically decaying objects be boosted
- Started with W scattering
 - W/H/Z ID in strongly interacting SUSY schemes
 - Finally, SM VHbb (Butterworth, et al 2008 at right), combine with triggerable leptonic V decay



SIGNAL/BACKGROUND MC

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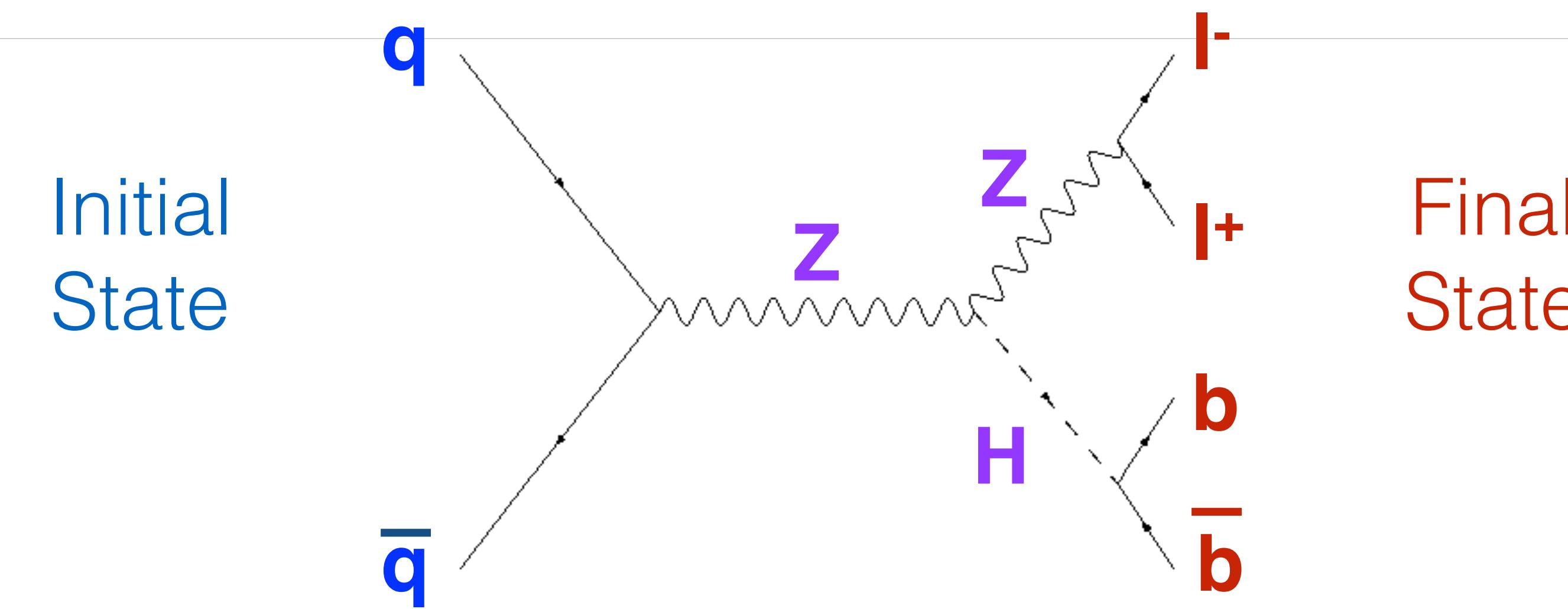


EVENT SELECTION

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Collisions → final state detector “hits” → collections of labeled 4-vectors

(Automatically done with ATLAS hardware/software)



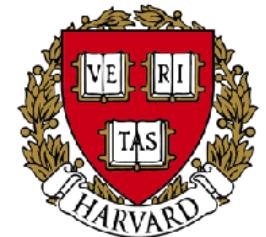
Category	Requirement
Trigger	un-prescaled, single lepton
Jets	≥ 2 central jets; 2 b -tagged signal jets, harder jet with $p_T > 45$ GeV
Leptons	2 VH-loose leptons (≥ 1 ZH-signal lepton); same (opp) flavor for SR (CR)
$m_{\ell\ell}$	$m_{\ell\ell} \in (81, 101)$ GeV
p_T^V regions (GeV)	$[75, 150], [150,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

ANALYZING COLLISIONS I: CUT AND COUNT

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- 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
- How to combine multiple measurements?
 - If independent, combine in quadrature
- For one analysis, use orthogonal regions (exclusive categories) for increased sensitivity
 - 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

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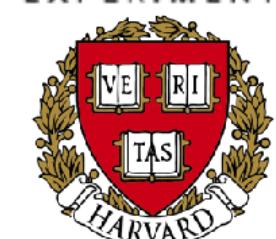
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- Can also use likelihood (each bin is a Poissonian counting experiment):
 - Parametrize in terms of a signal strength μ (0 is null; 1 is SM expectation) and systematics/NP's θ ; S , B are total; s_i , b_i are individual bins; *control regions to improve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

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

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

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

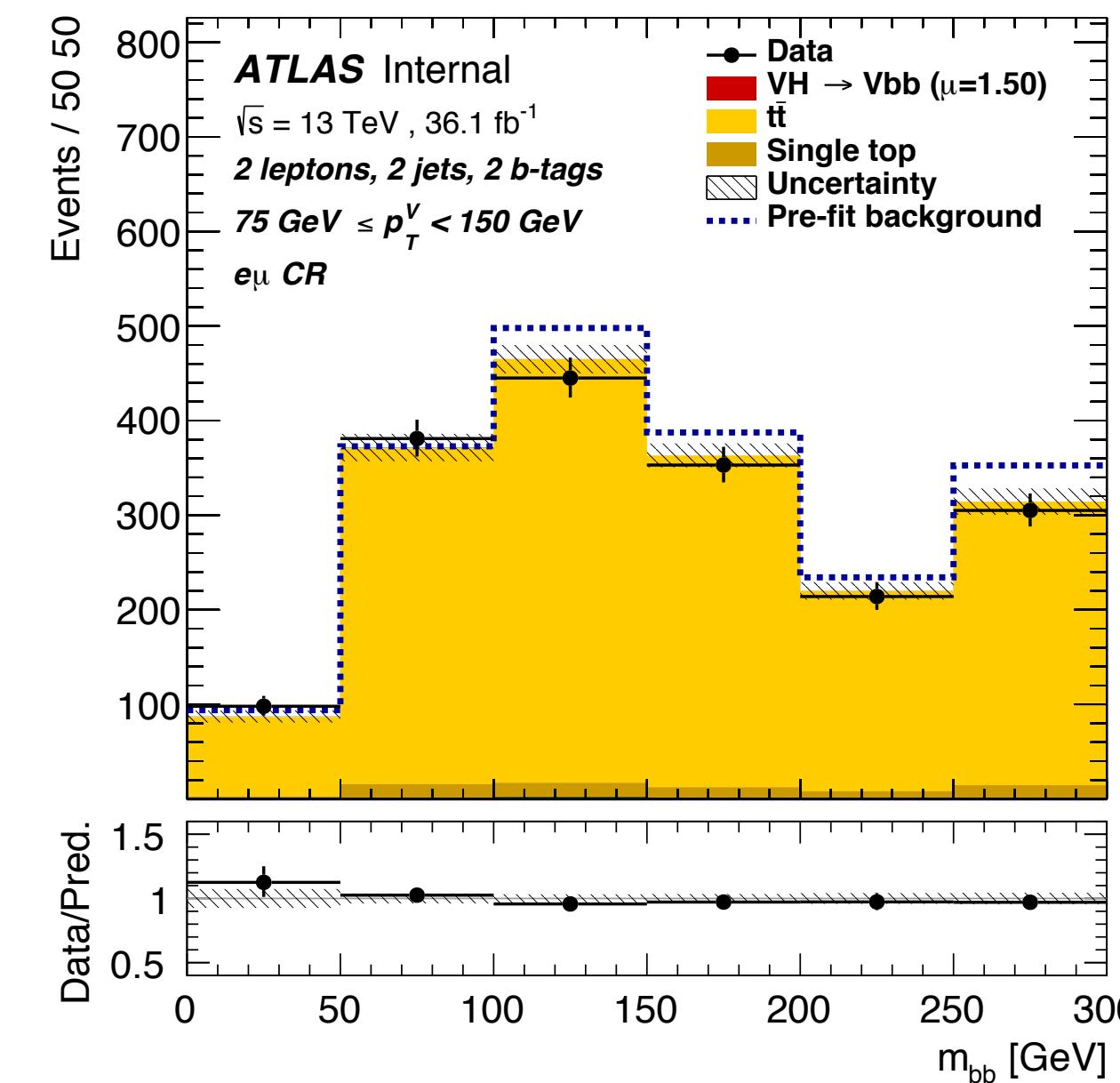
ATLAS
EXPERIMENT

ANALYZING COLLISIONS III: INPUT DISTRIBUTIONS

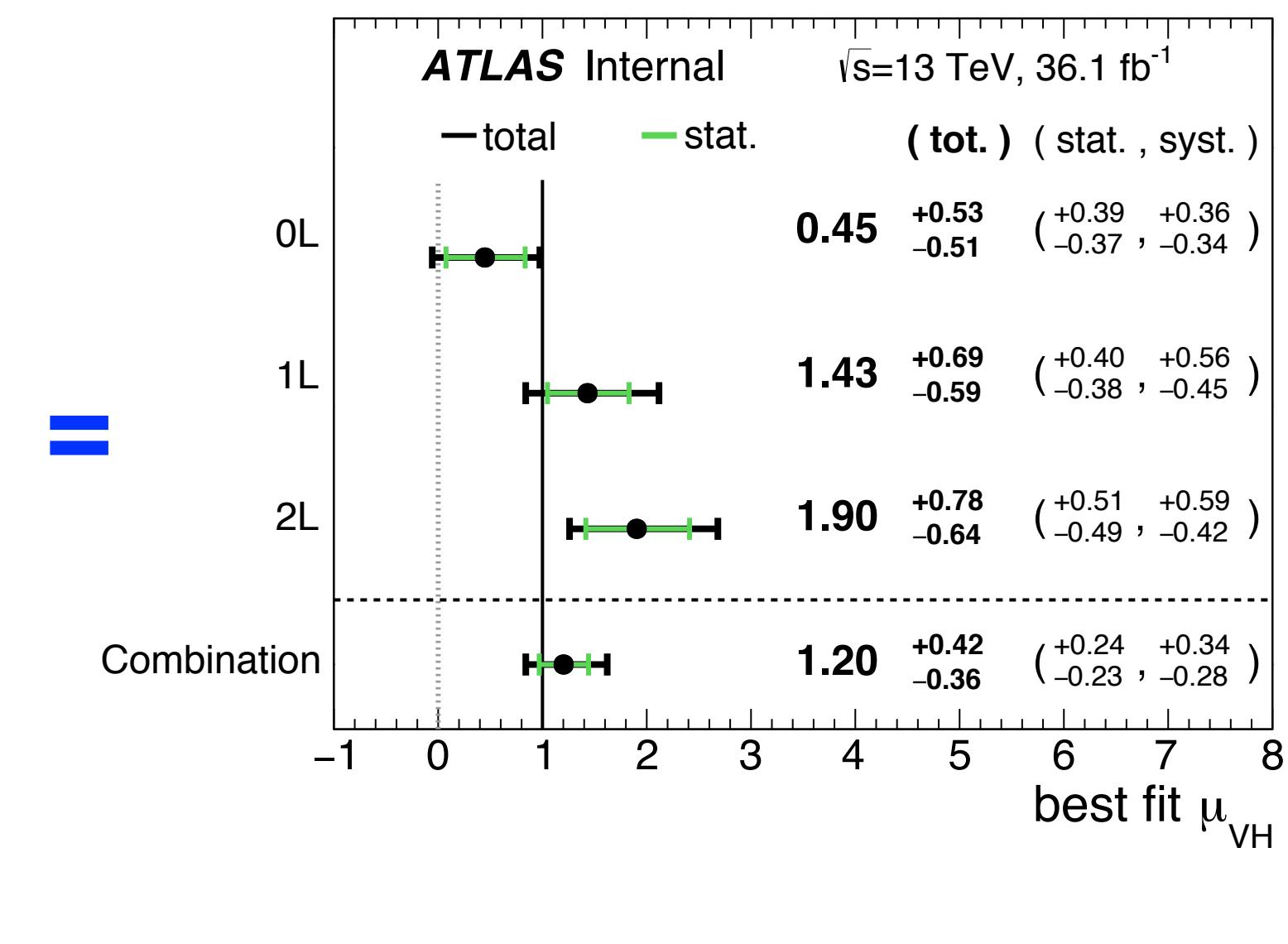
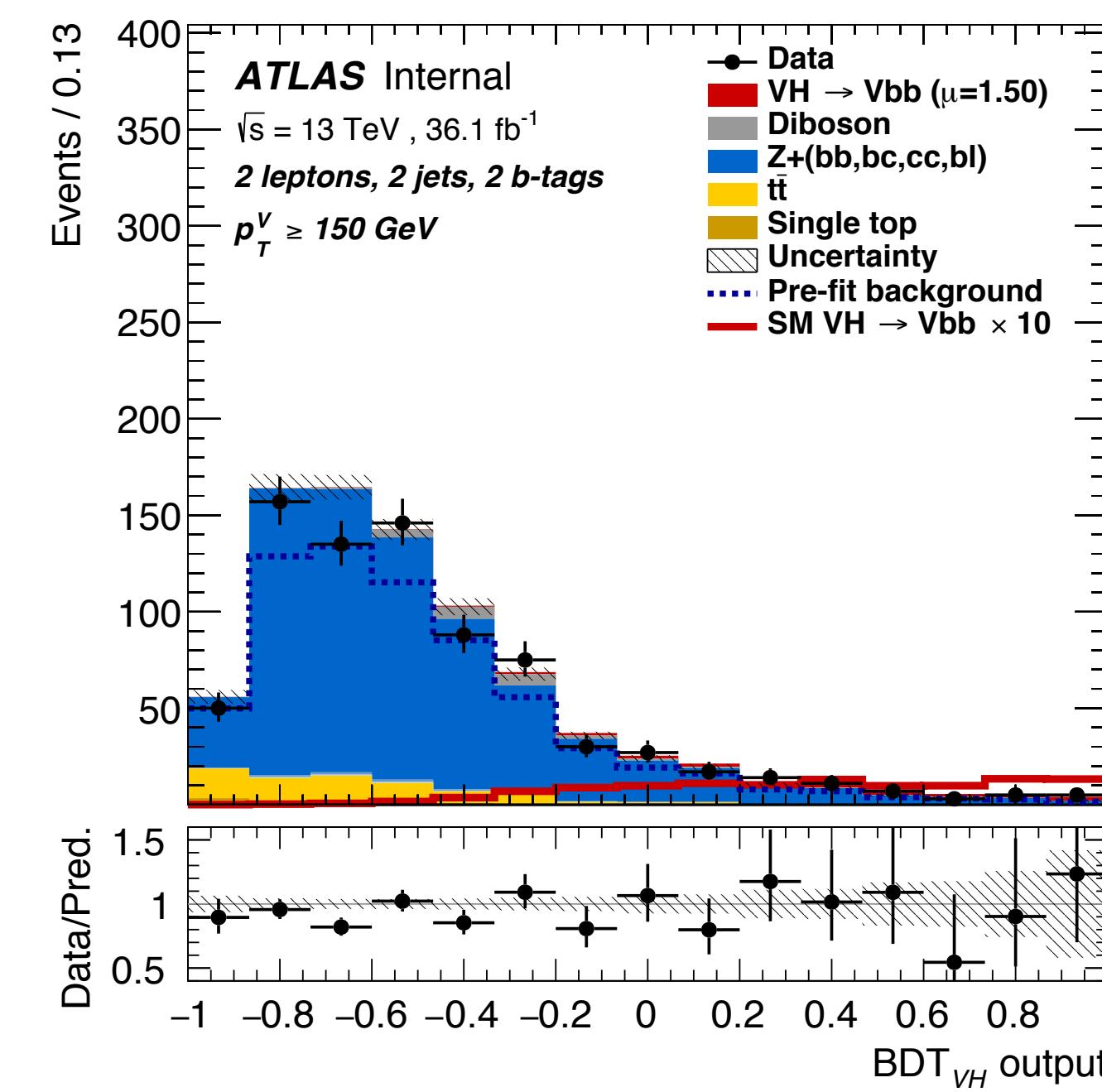
11

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- 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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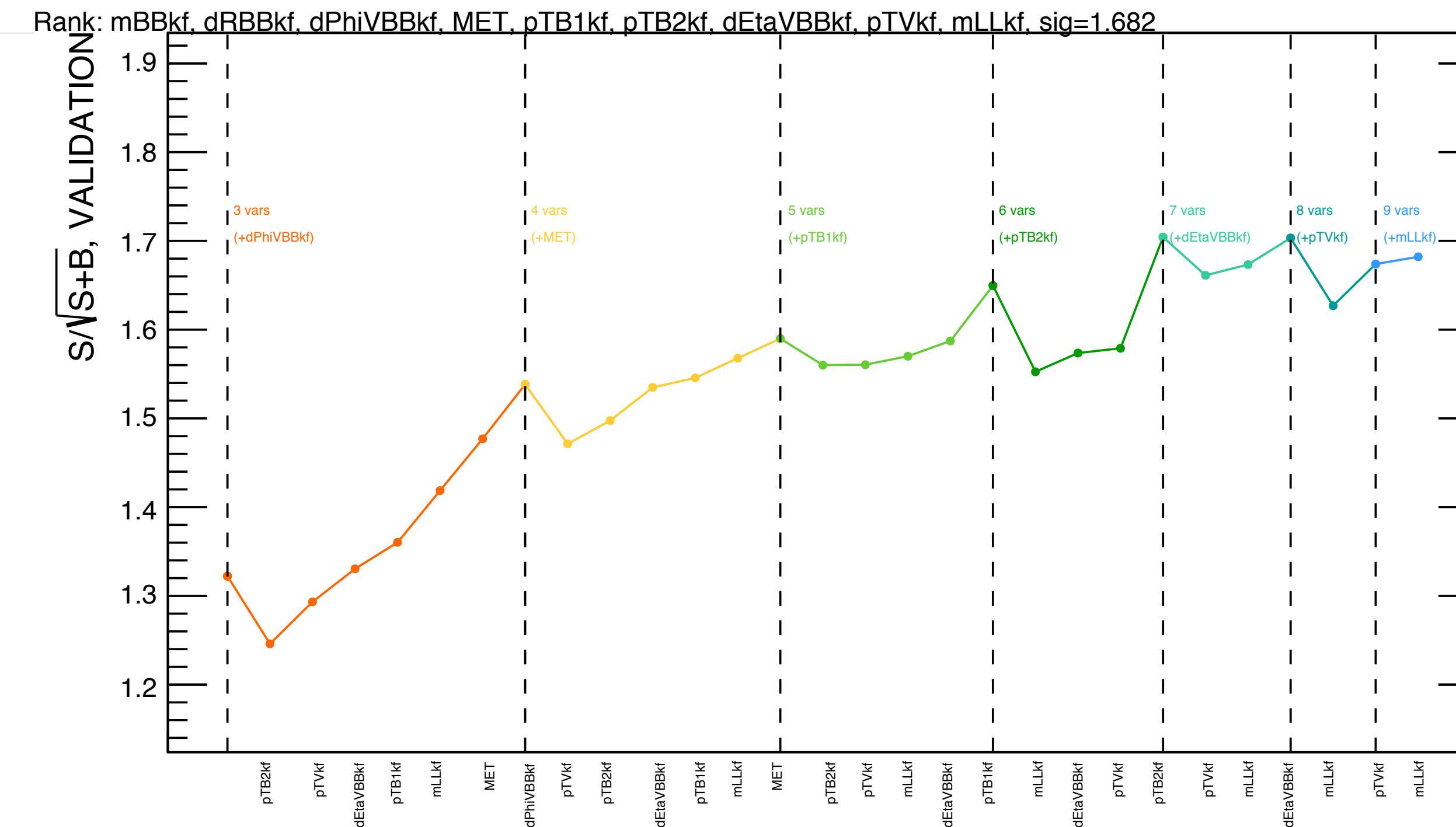


MVA INPUTS: THE USUAL WAY

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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

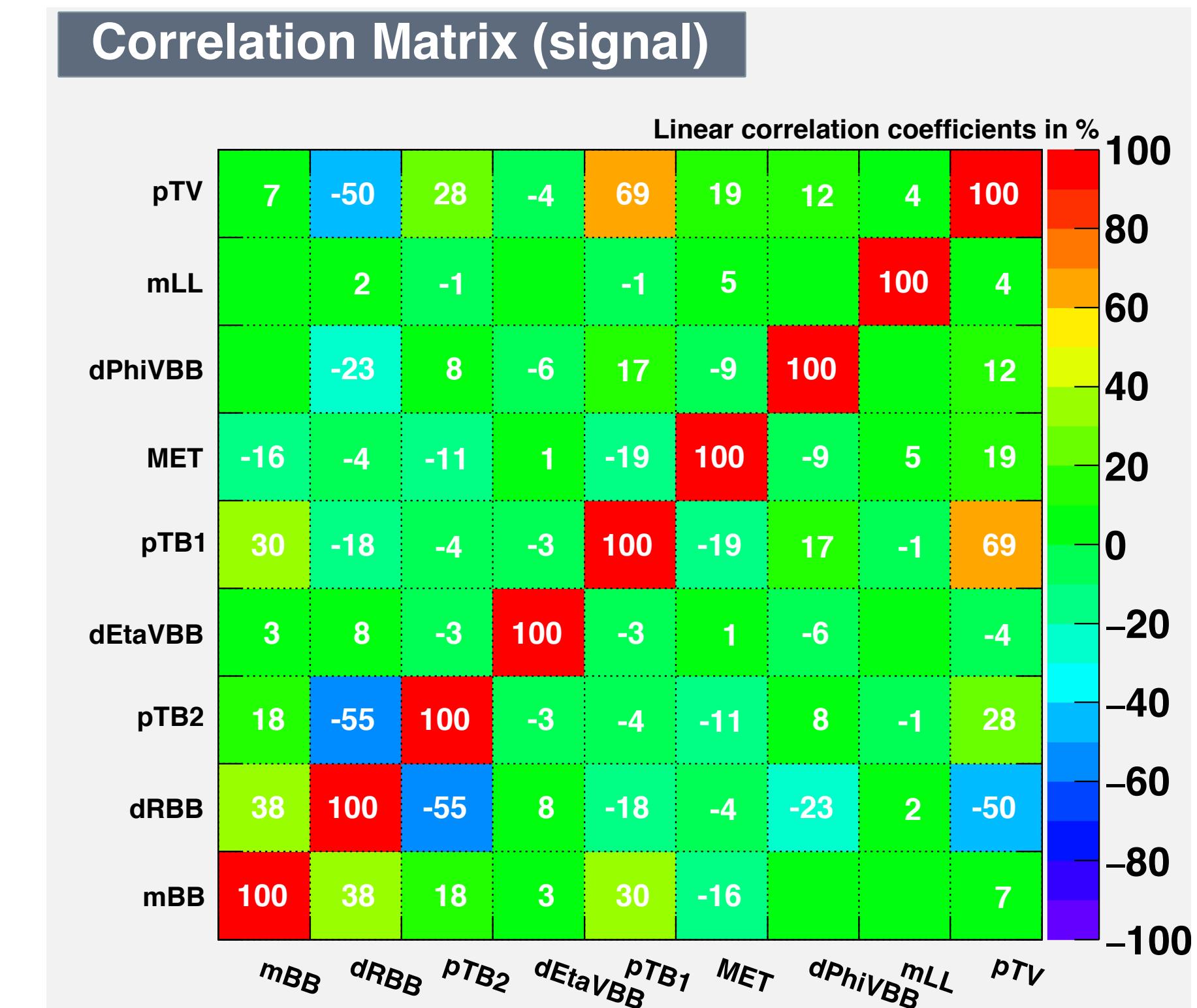


STANDARD MVA VARIABLES

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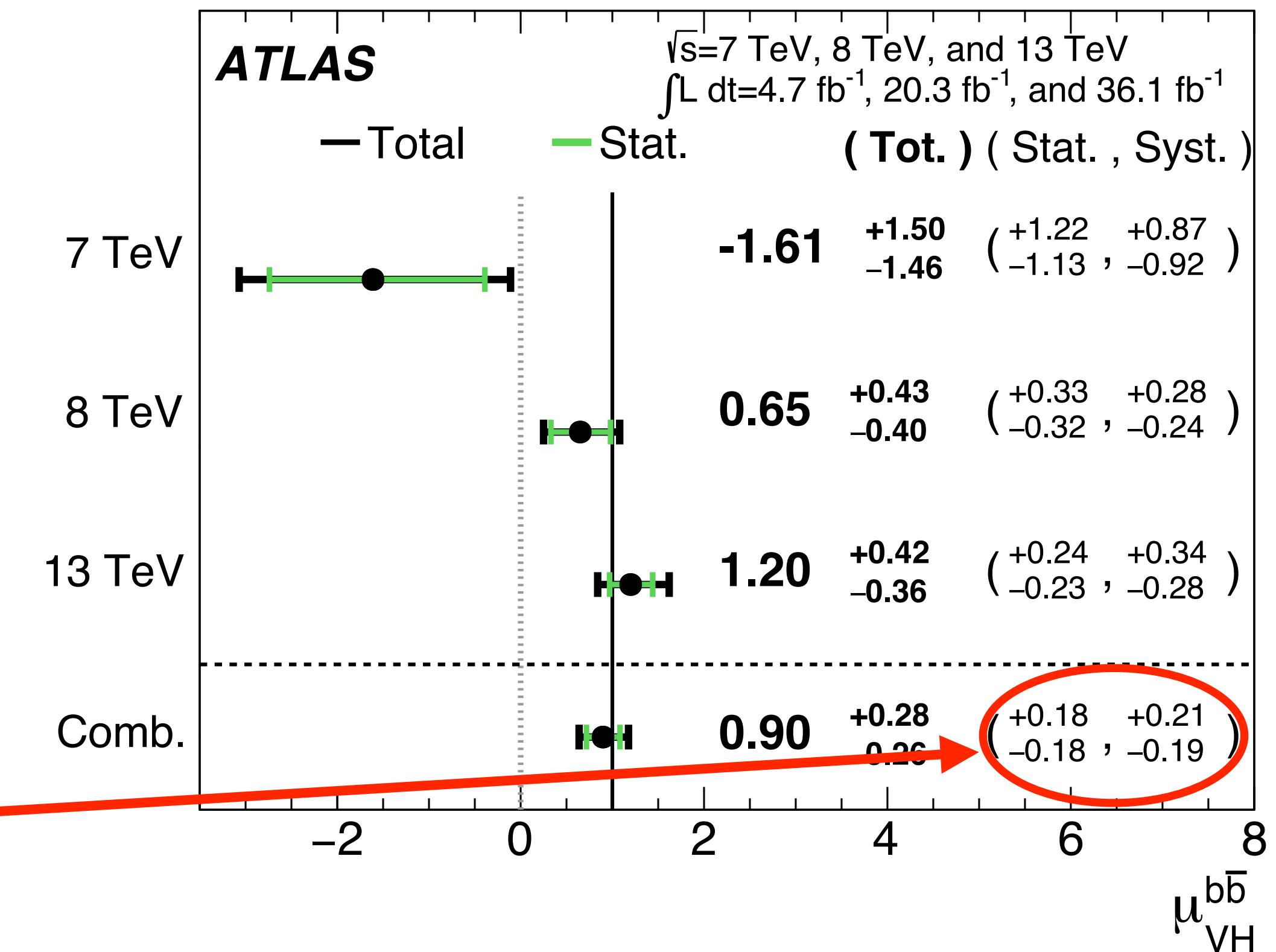
Finding Standard del VHbb S. Chan

- Traditionally useful variables
 - Higgs: mBB (~ 125 GeV), b jet separation
 - VH: $d(\text{Eta}|\text{Phi})_{\text{VBB}}$
 - 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:
 - A clever treatment of invisible final state objects to boost sensitivity
 - More orthogonal basis of description* to better constrain systematics
- VHbb is becoming systematics limited



LORENTZ INVARIANTS (LI)

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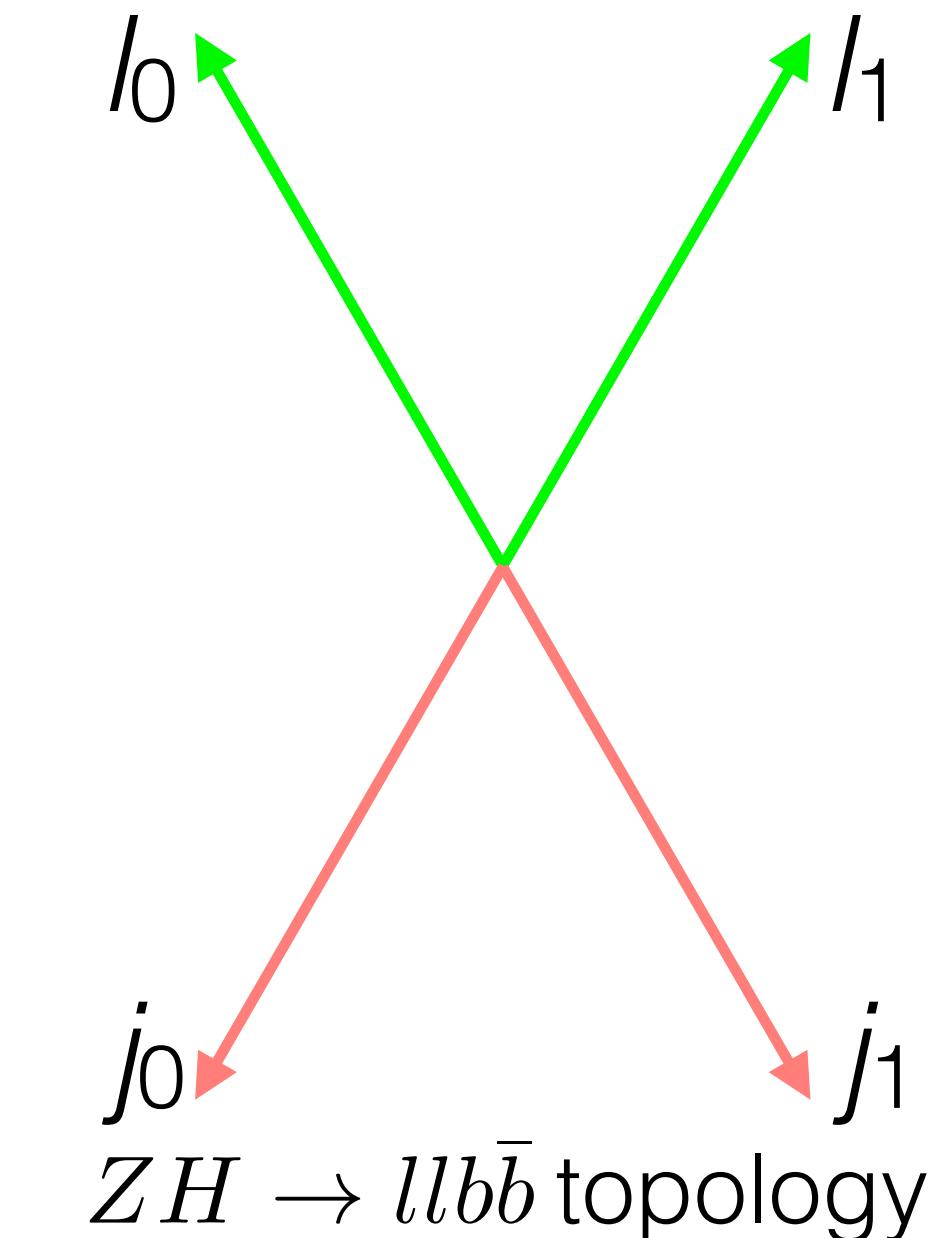
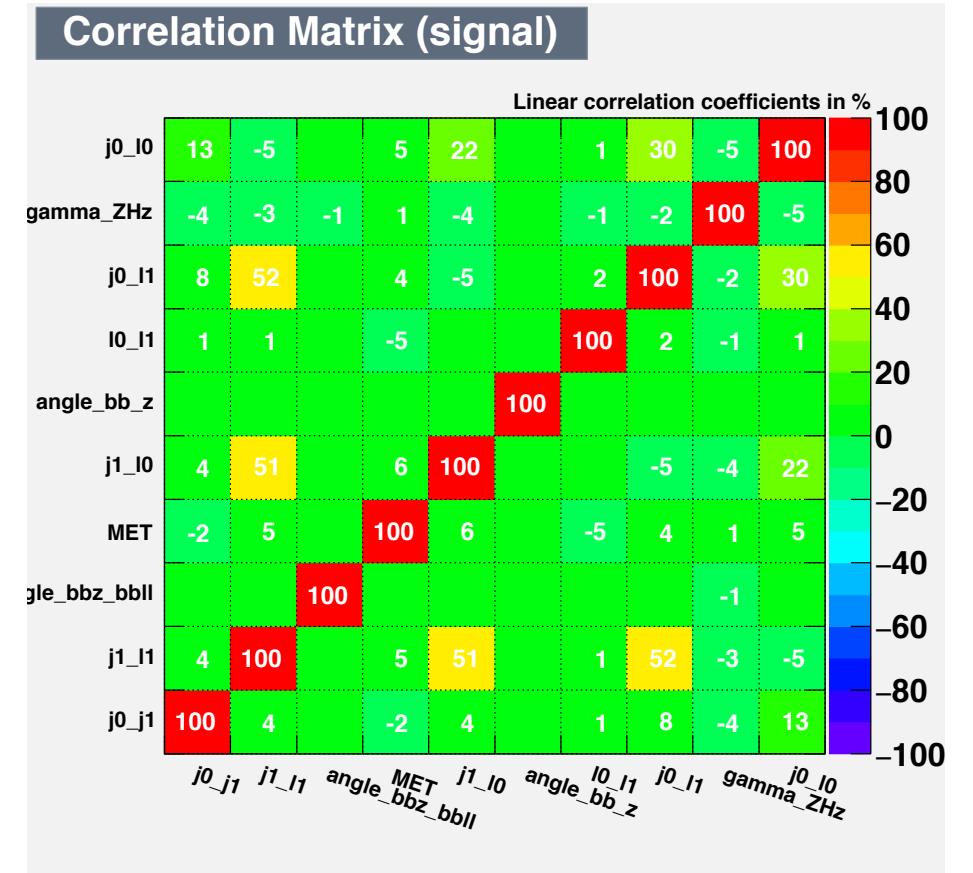
- Lorentz invariant and angles used in BDT training assume a closed, $llbb$ (labeled j because jets not. nec. b -tagged) topology
 - 16 quantities define system:
 - 4 invariant masses not so useful
 - Beam axis symmetry (-1)
 - Boost mostly along z (-2 angles)
 - Boost magnitude contains no ZH info (-1)
 - 8 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

$$\begin{array}{cc} \langle j_0 | j_1 \rangle & \langle j_1 | l_0 \rangle \\ \langle j_1 | l_1 \rangle & \langle l_0 | l_1 \rangle \\ \langle j_0 | l_1 \rangle & \langle j_0 | l_0 \rangle \end{array}$$

inner products

$$\begin{array}{c} \angle(\vec{bb} \times \hat{z}, \vec{bb} \times \vec{ll}) \\ \angle(\vec{bb}, \hat{z}) \\ \vec{\gamma}_{ZH} \cdot \hat{z} \end{array}$$

angles



RESTFRAMES VARIABLES

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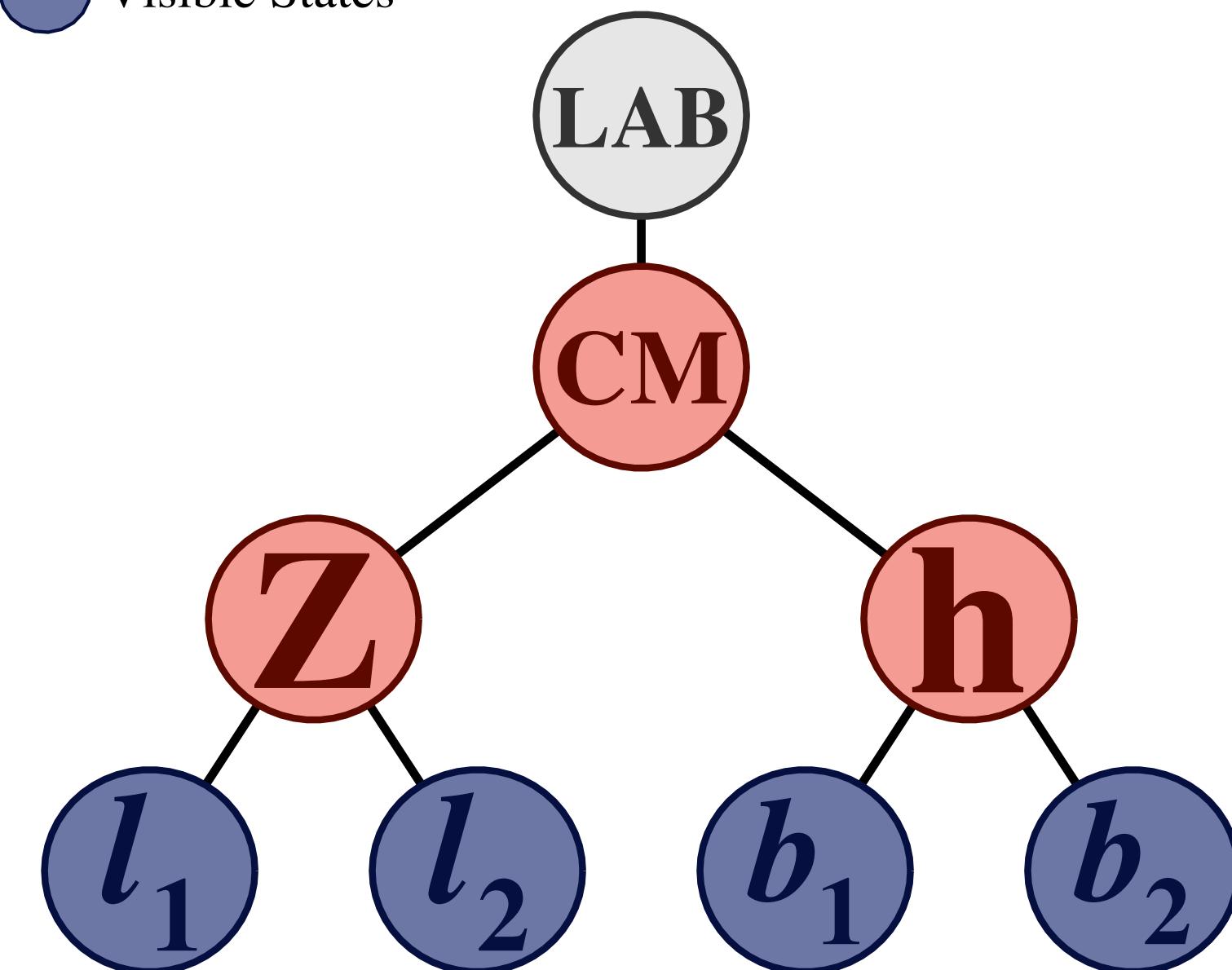
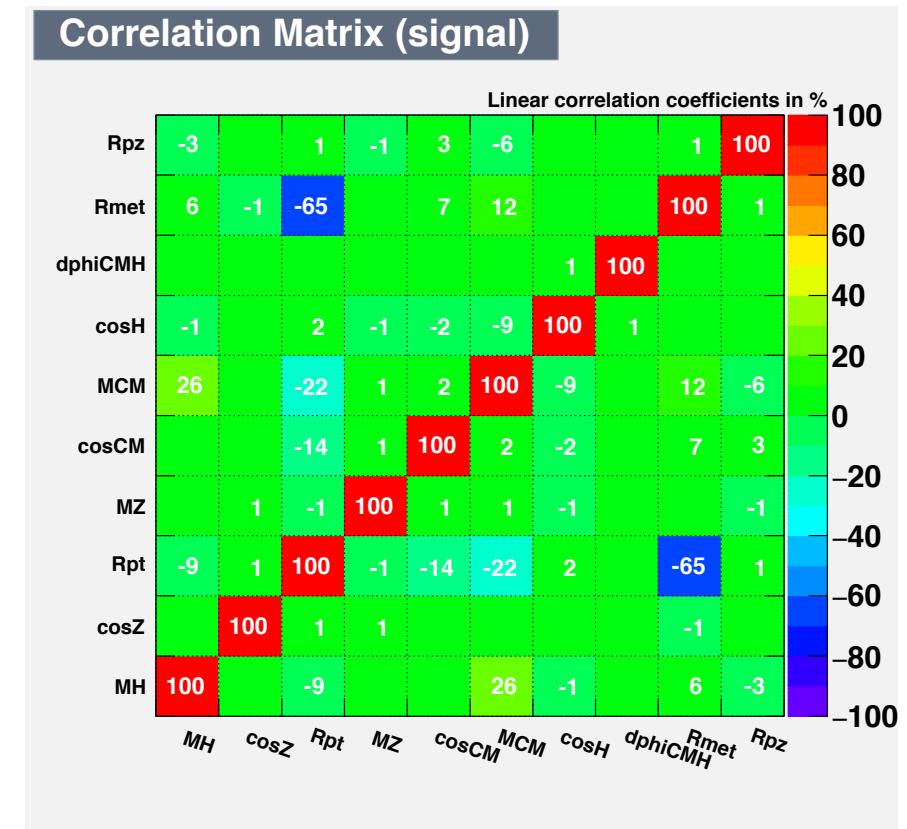
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- RestFrames (RF): most natural frame to study objects in a decay tree is their production (rest) frame
 - Each frame has associated with it: Mass scale + boost from parent frame
- Normally, frames/boosts can't be completely determined (use, e.g. jigsaw 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

 Lab State
 Decay States
 Visible States

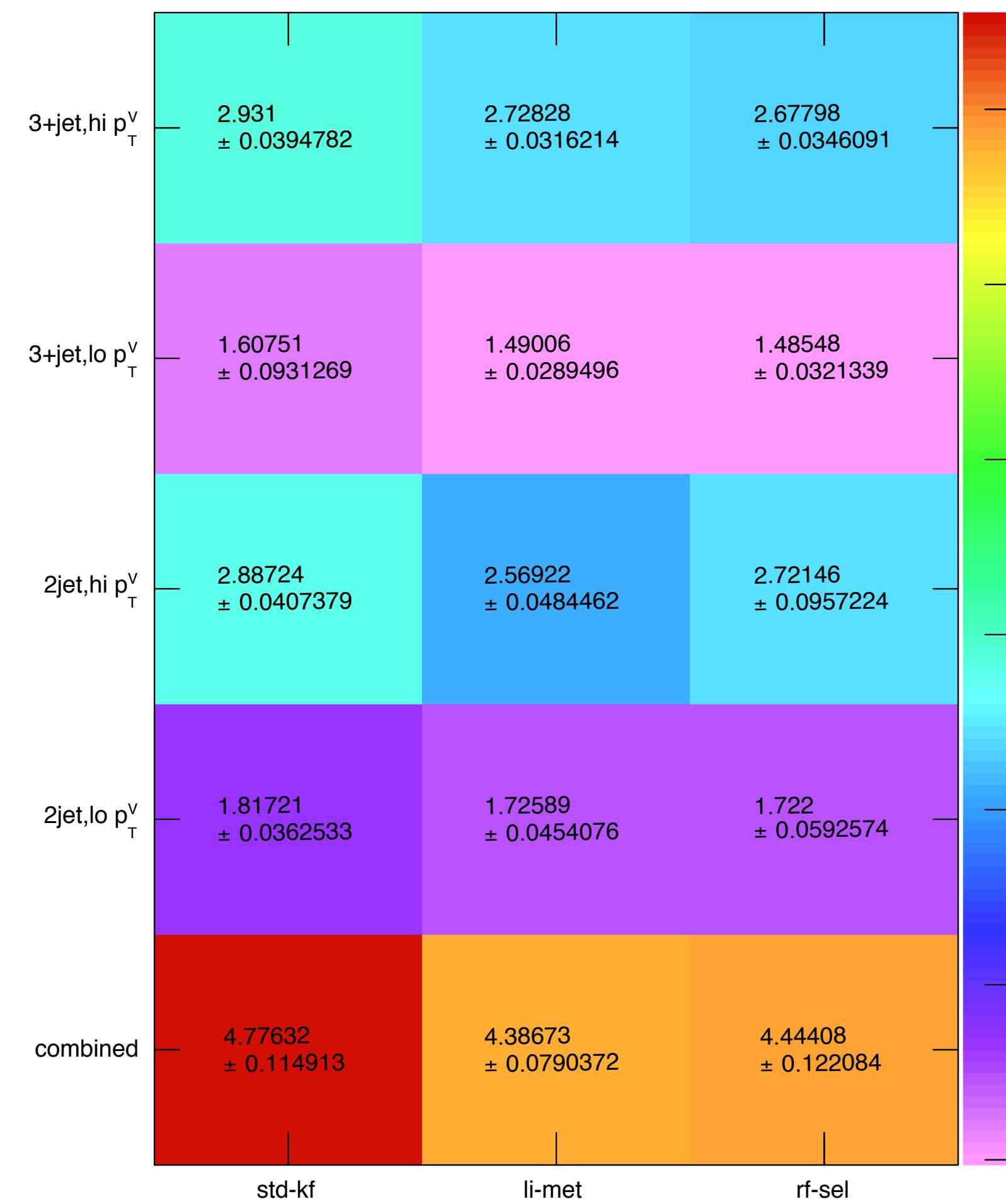


STATS ONLY PERFORMANCE

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- Standard variables perform best in a stats only context
 - Particularly in the 3pjett bins
- Not surprising
 - Third jet ignored in both the LI and RF cases
 - Easy enough to add for RF variables (add to H in decay tree for 3pjett events), not so easy for LI case
 - Final state is closed; confirms that *new variables don't contain any new information*

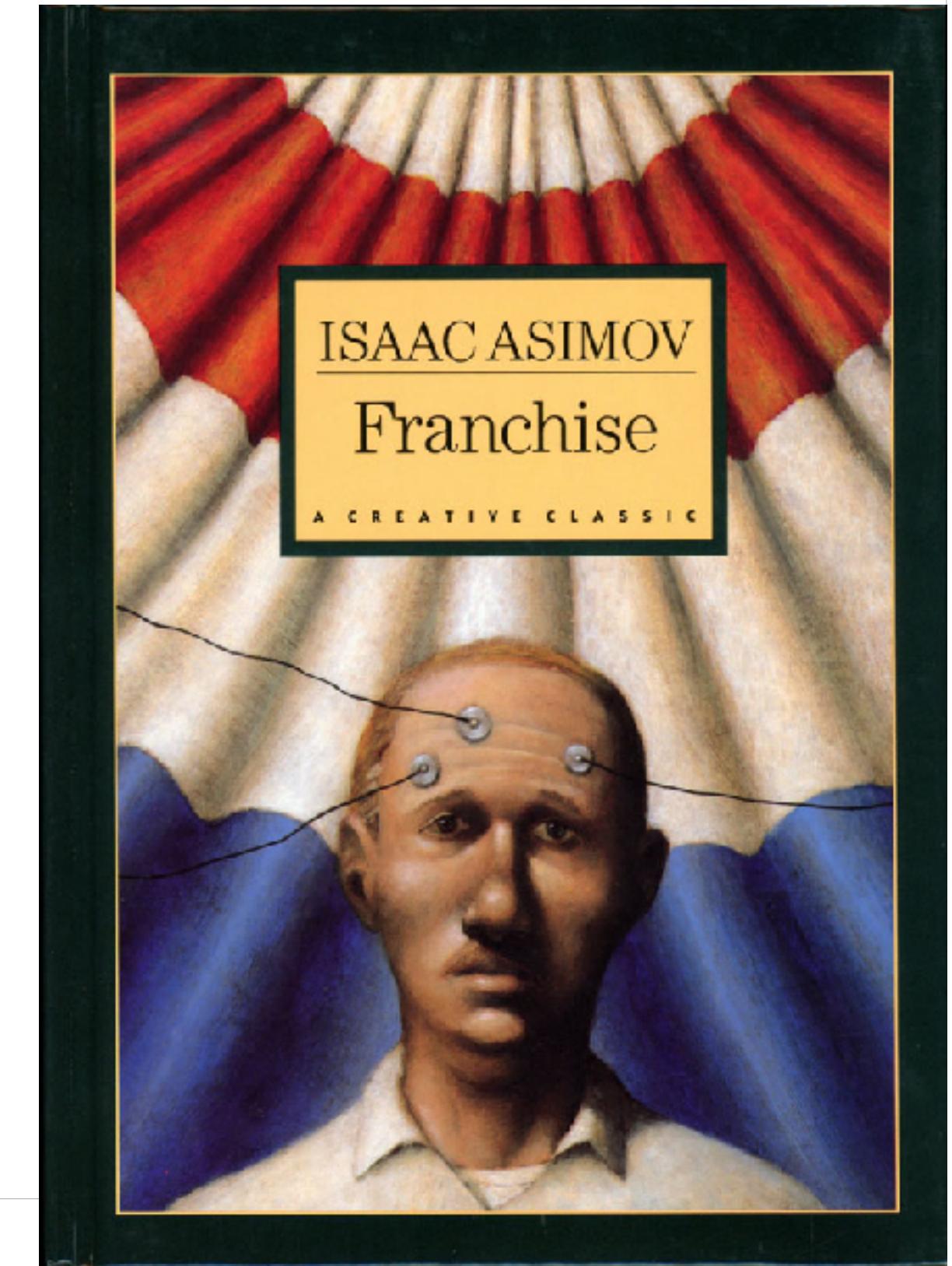
RFLI S/ $\sqrt{S+B}$ Summary

TECHNICAL ASIDE: ASIMOV DATASETS

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- 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>

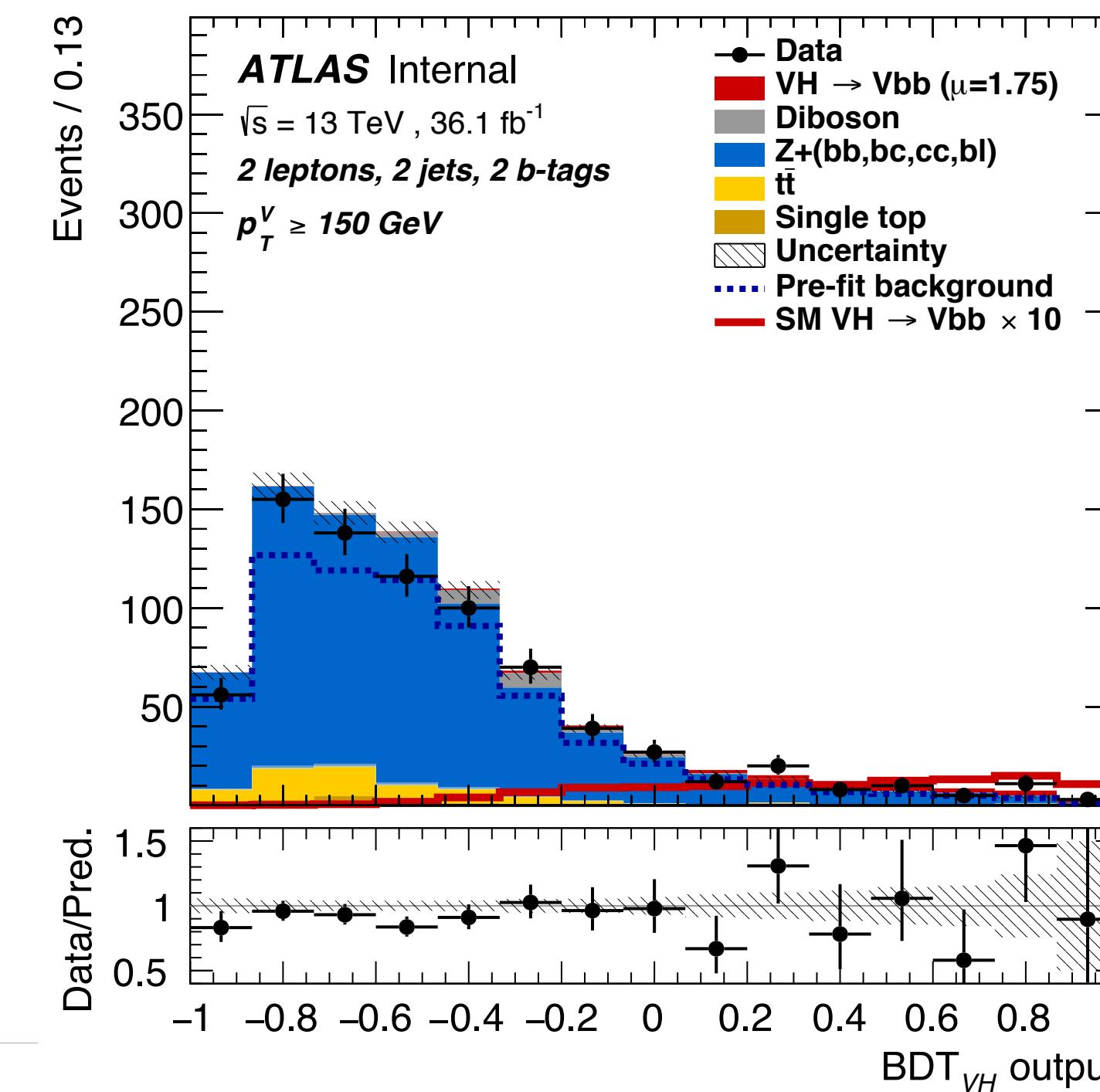
SOME POSTFIT PLOTS

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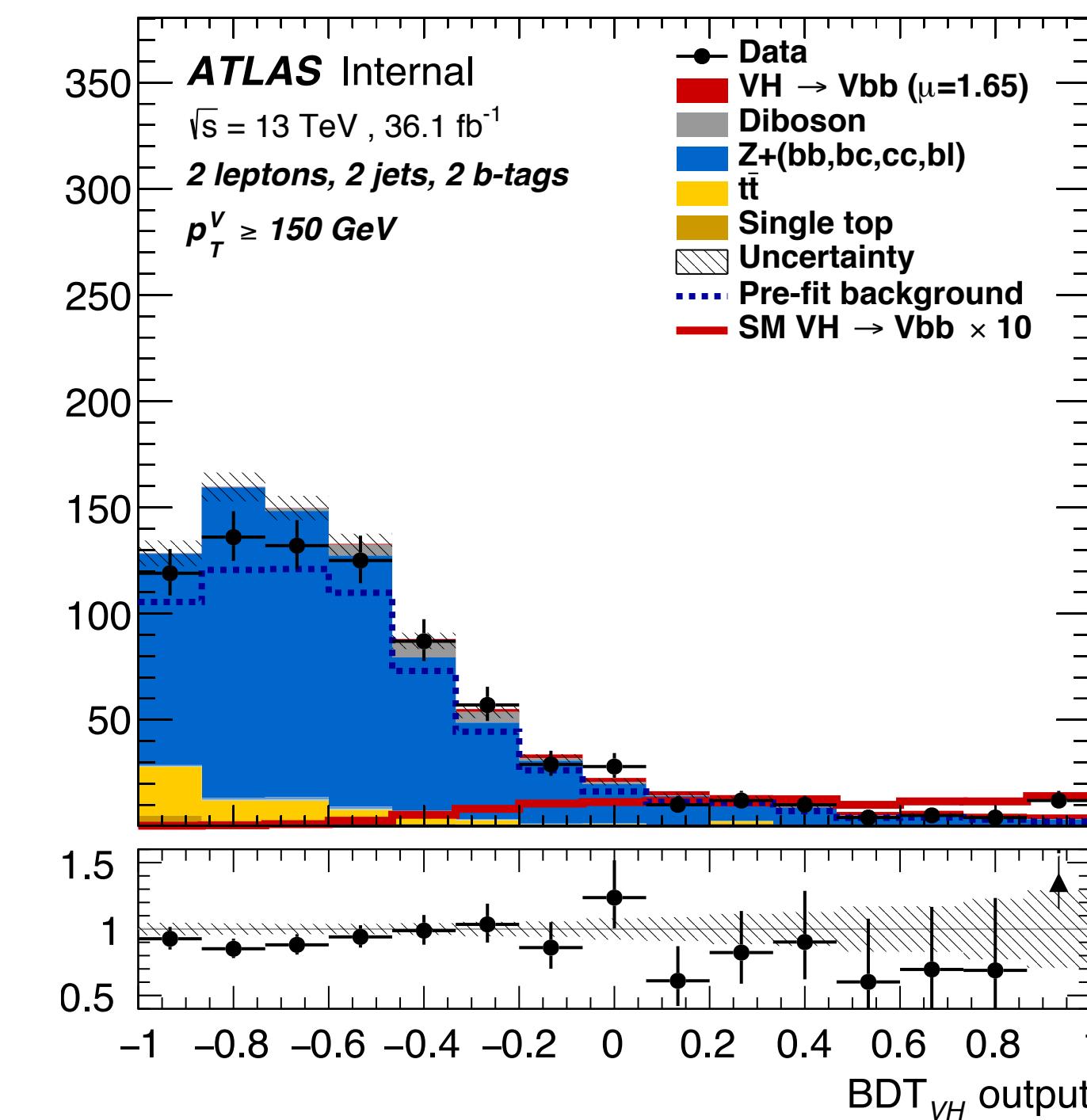
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- 2jet, hi pTV, See companion slides for all of them

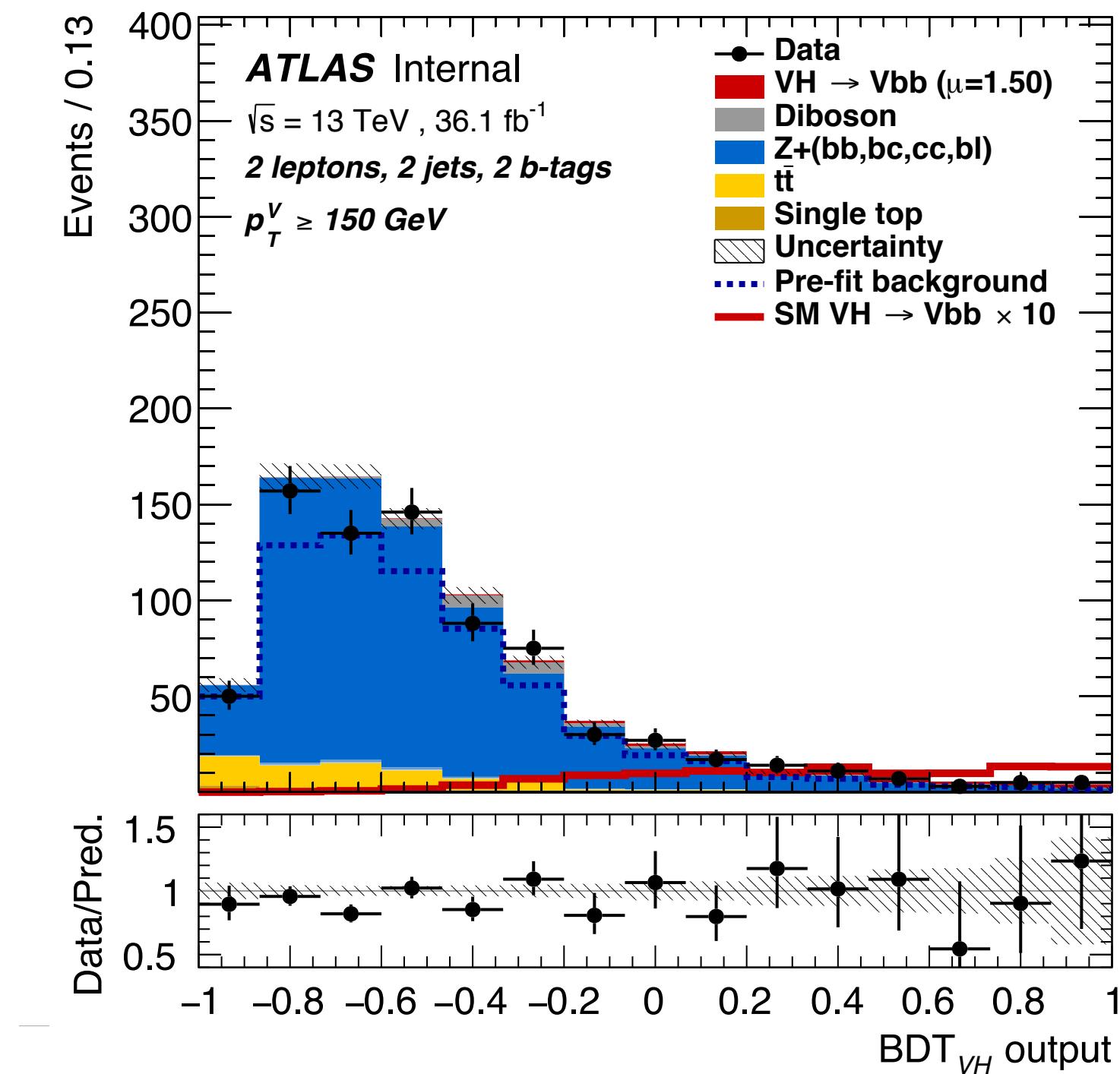
Standard



LI



RF

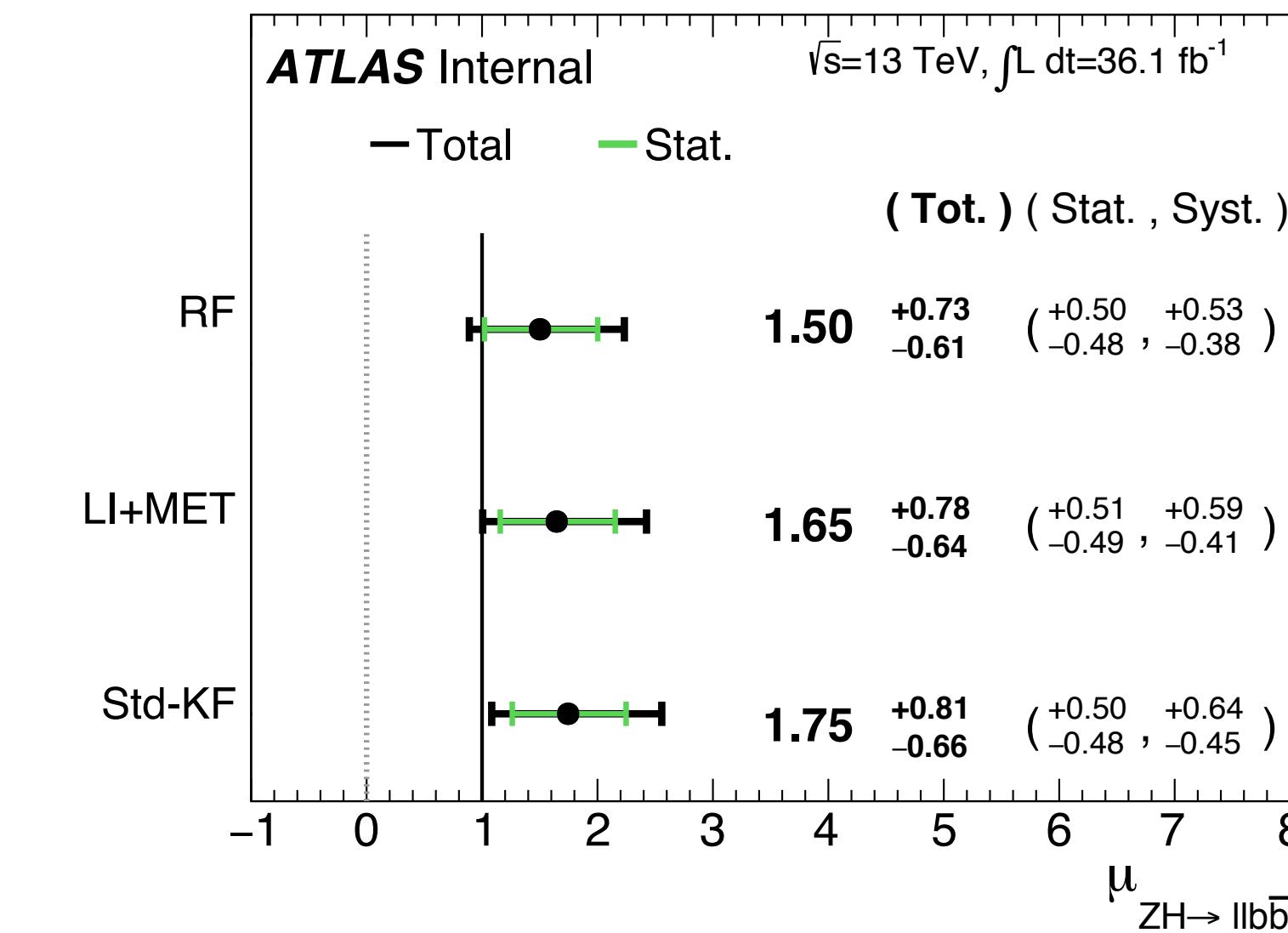
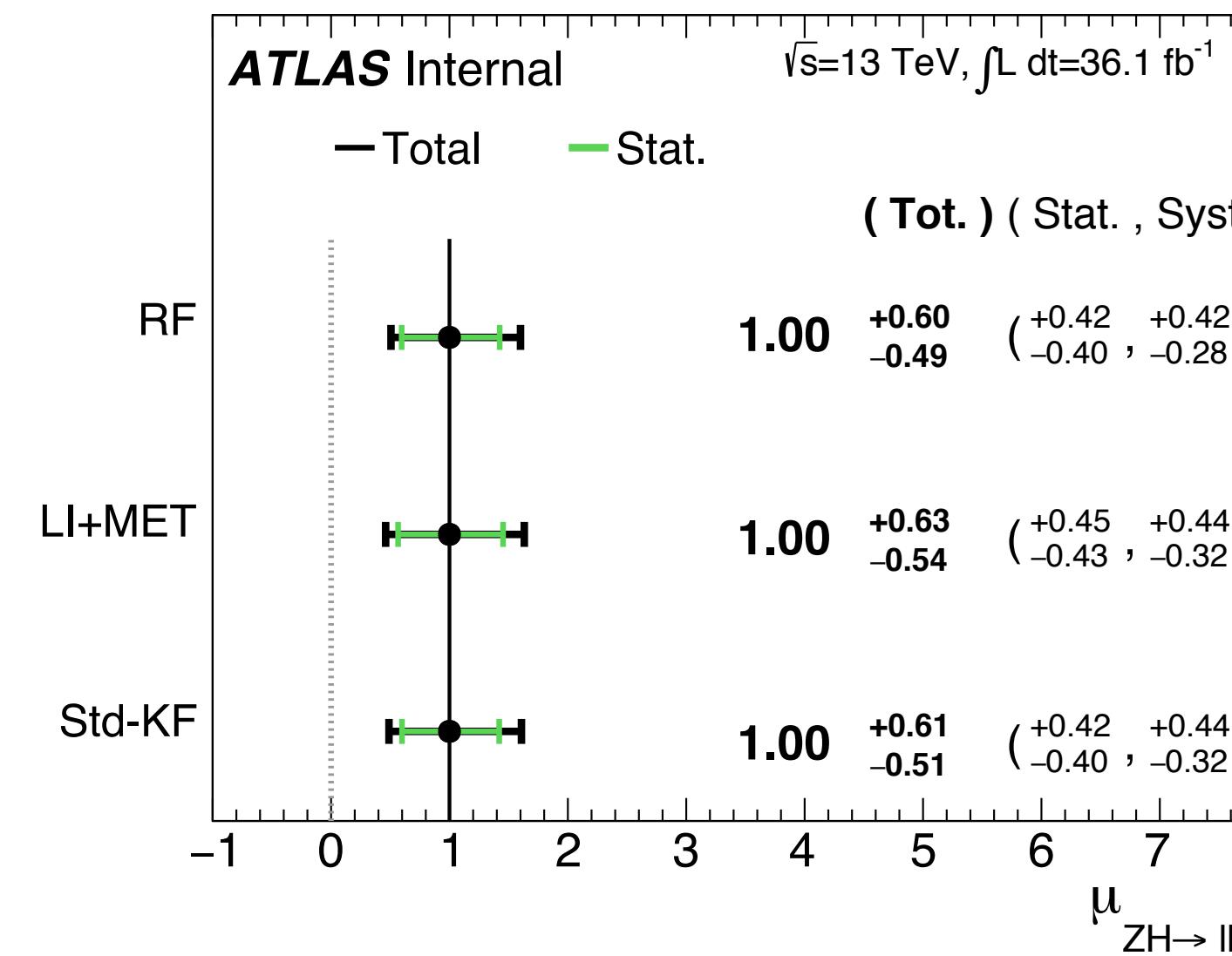


SIGNAL STRENGTHS AND ERRORS

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- 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

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	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

MEASUREMENT ComBINATIONS

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- Combining lepton channels is easy (simply add 0+1-lep regions)
$$\mathcal{L}(\mu, \theta) = \text{Pois}(n | \mu S + B) \left[\prod_{i \in \text{bins}} \frac{\mu s_i + b_i}{\mu S + B} \right] \prod_{j \in \text{NP's}} \mathcal{N}_{\theta_j}(\theta_j, \sigma_j^2 | 0, 1)$$
- Different measurements
 - Run 1 (7+8 TeV): 1.37σ , $\mu_{\text{obs}} = 0.51 \pm 0.39$
 - Run 2 (13 TeV): 3.54σ , $\mu_{\text{obs}} = 1.20 \pm 0.39$
 - 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

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- 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

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	Comb Eff	BTag Bo	Bo 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 Bo	Bo 8TeV Not Flipped
$ \Delta\hat{\mu} $	—	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

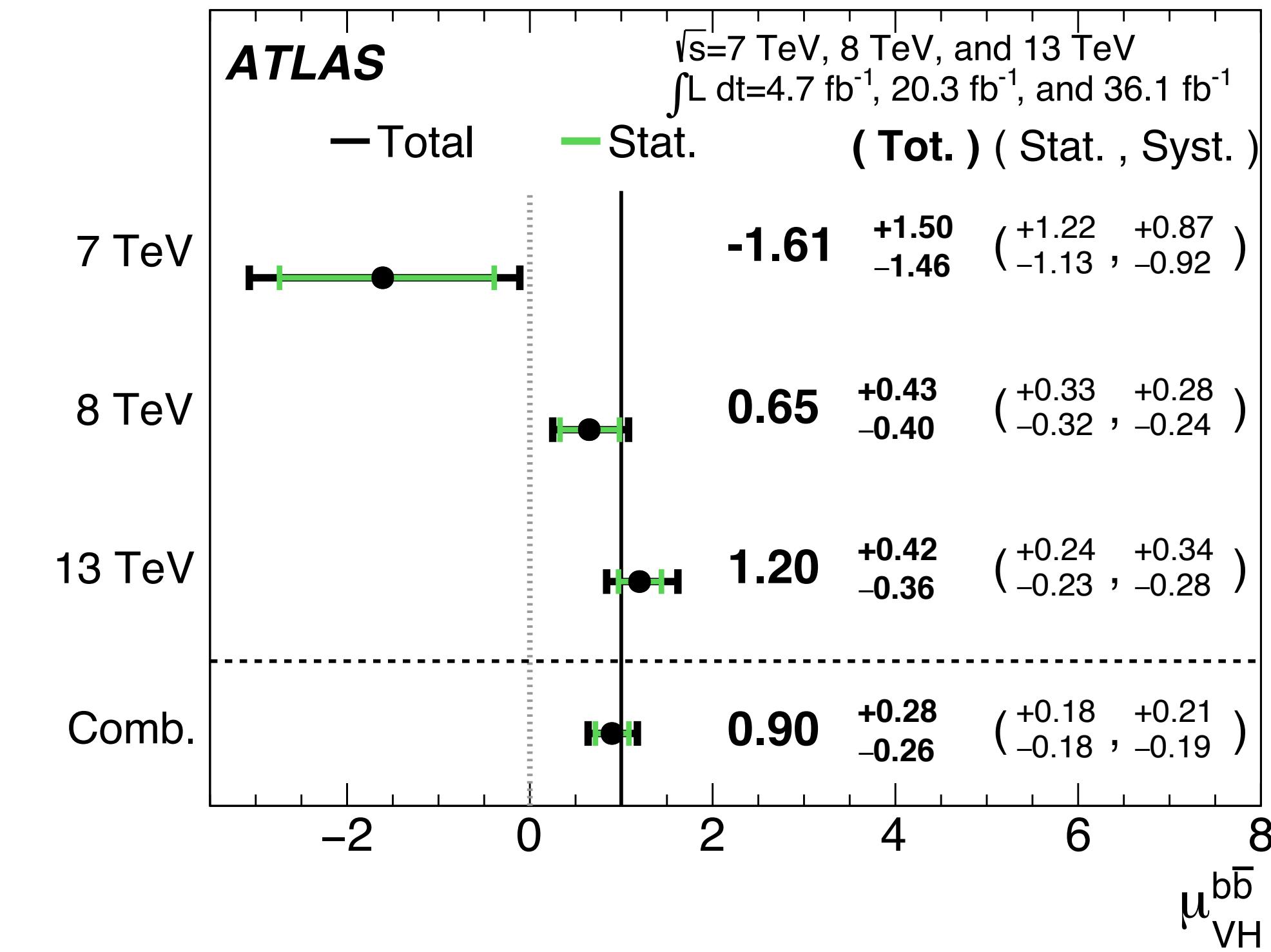
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7 TeV NP	8 TeV NP	13 TeV NP
	ATLAS_BR_bb	SysTheoryBRbb
	SysTheoryQCDscale_ggZH	SysTheoryQCDscale_ggZH
	SysTheoryQCDscale_qqVH	SysTheoryQCDscale_qqVH
—	SysTheoryPDF_ggZH_8TeV	SysTheoryPDF_ggZH
—	SysTheoryPDF_qqVH_8TeV	SysTheoryPDF_qqVH
—	SysTheoryVHPt_8TeV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

COMBINED FIT RESULTS

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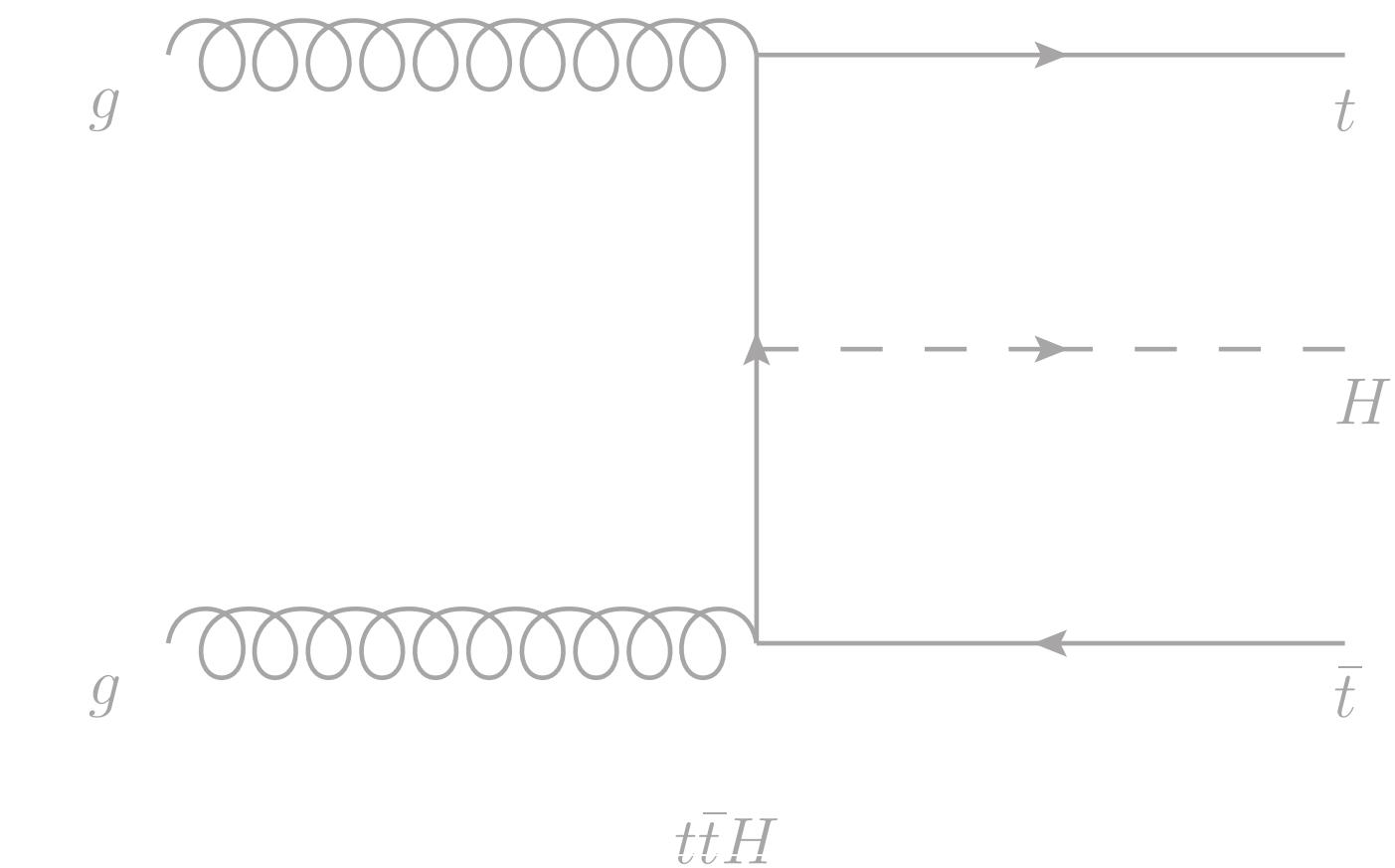
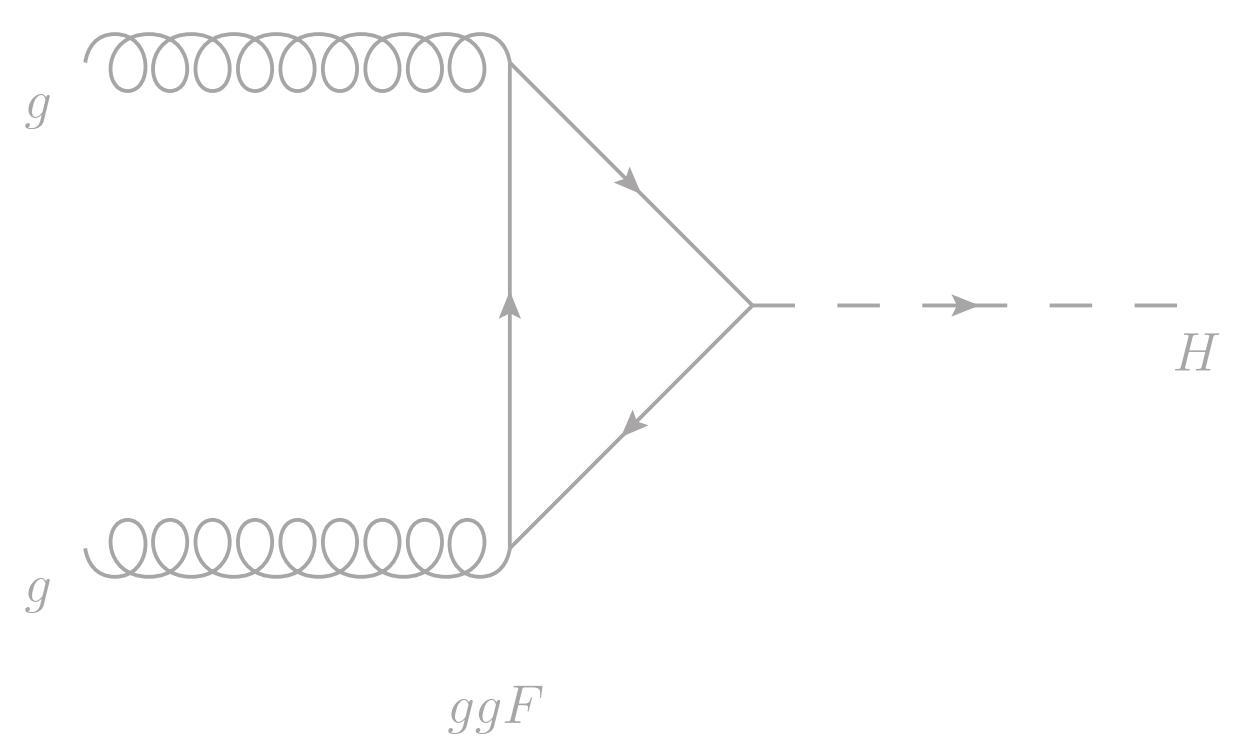
- Significance of 3.57σ (4.00σ , $\mu=0.95$ with minimal flavor tagging correlation);)
- First evidence of SM VHbb

CLOSING THOUGHTS

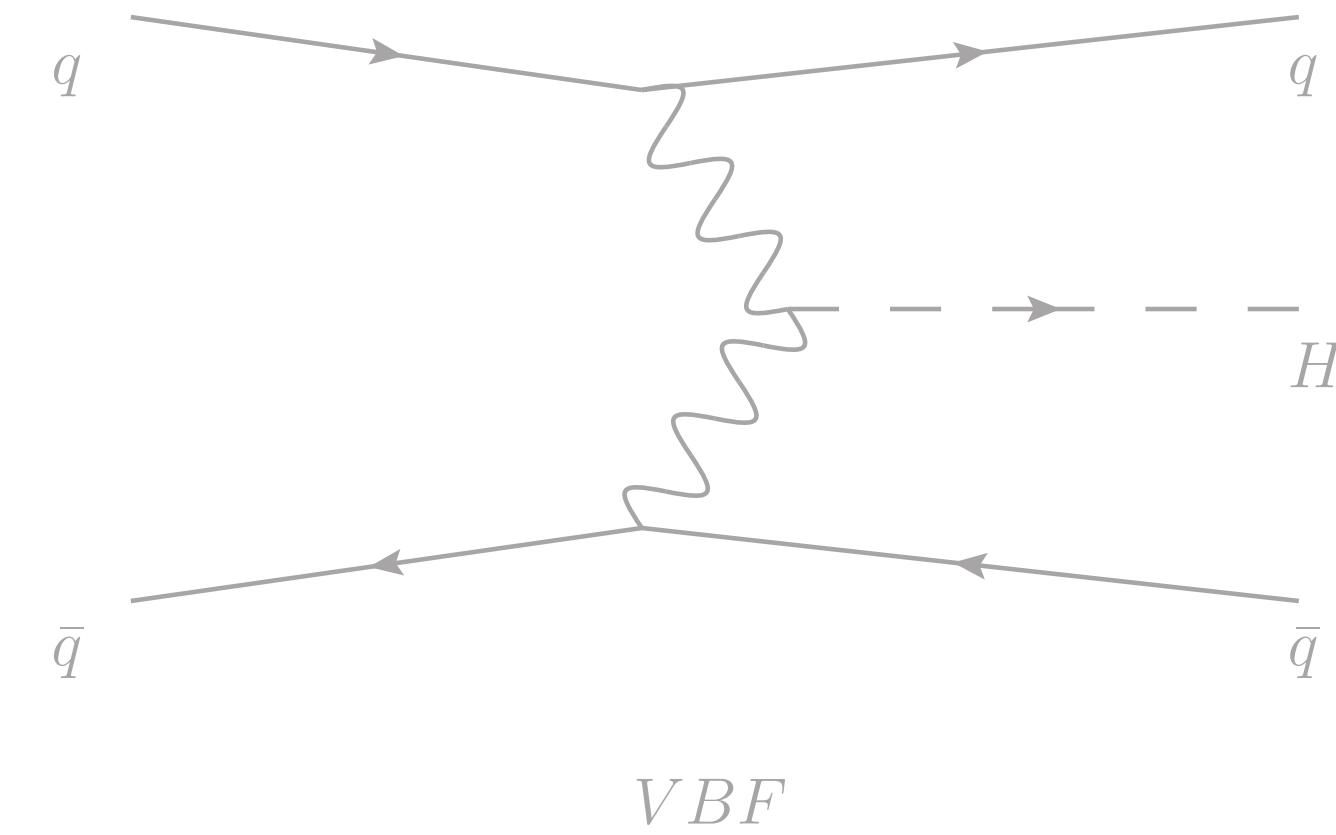
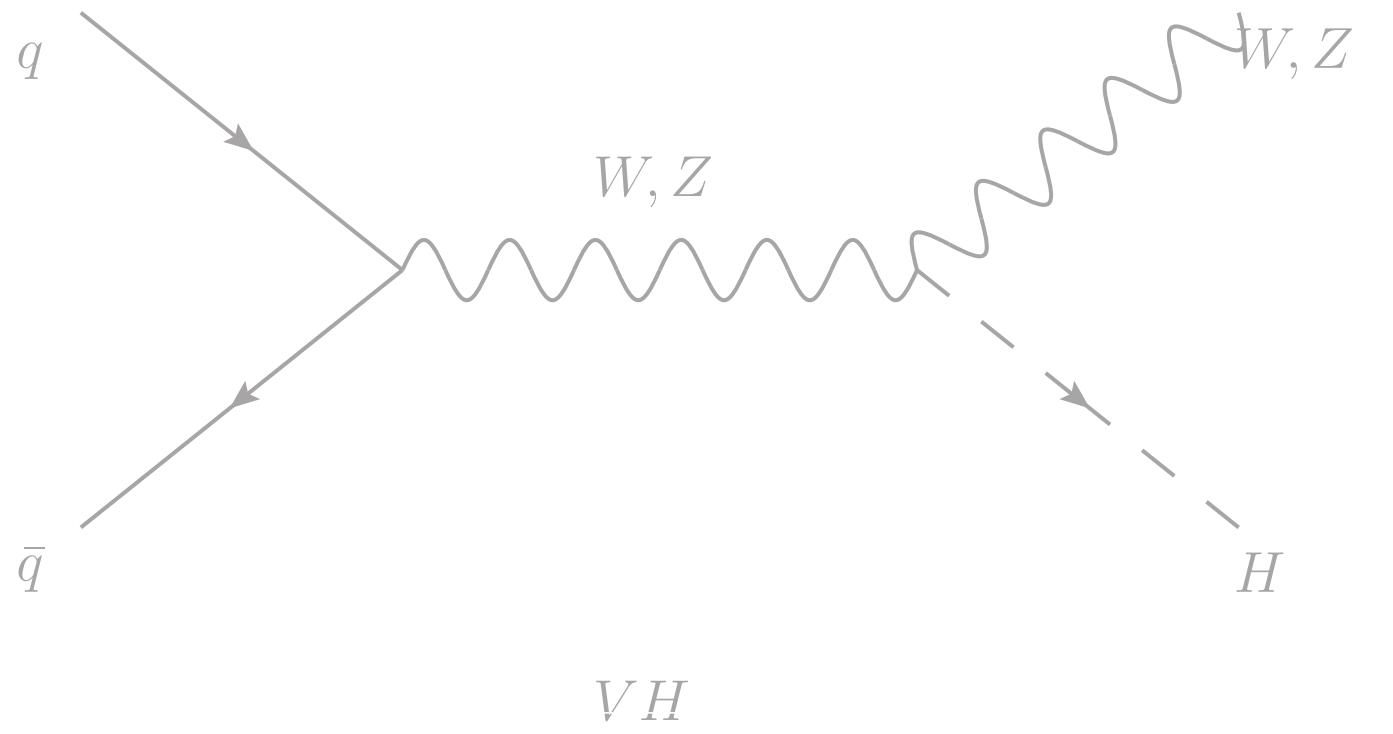
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- First evidence of Hbb now in the books
 - 5σ is only a matter of time
- Significance is important for discovery
 - But not for precision tests of the Standard Model
- Precision in observables like μ will likely make or break the SM
 - Combinations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



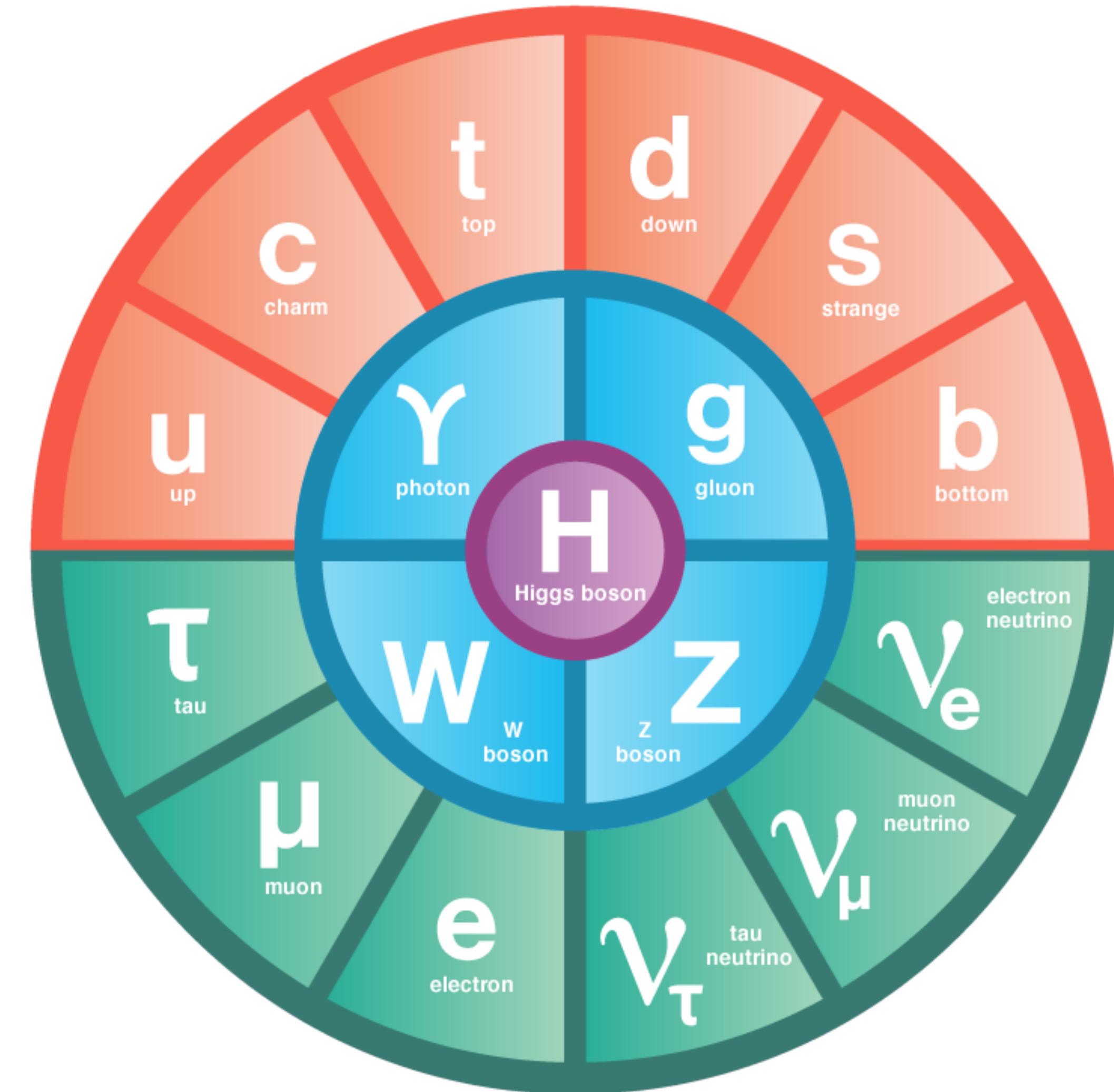
BACKUP



THE STANDARD MODEL OF PHYSICS

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HIGGS MECHANISM

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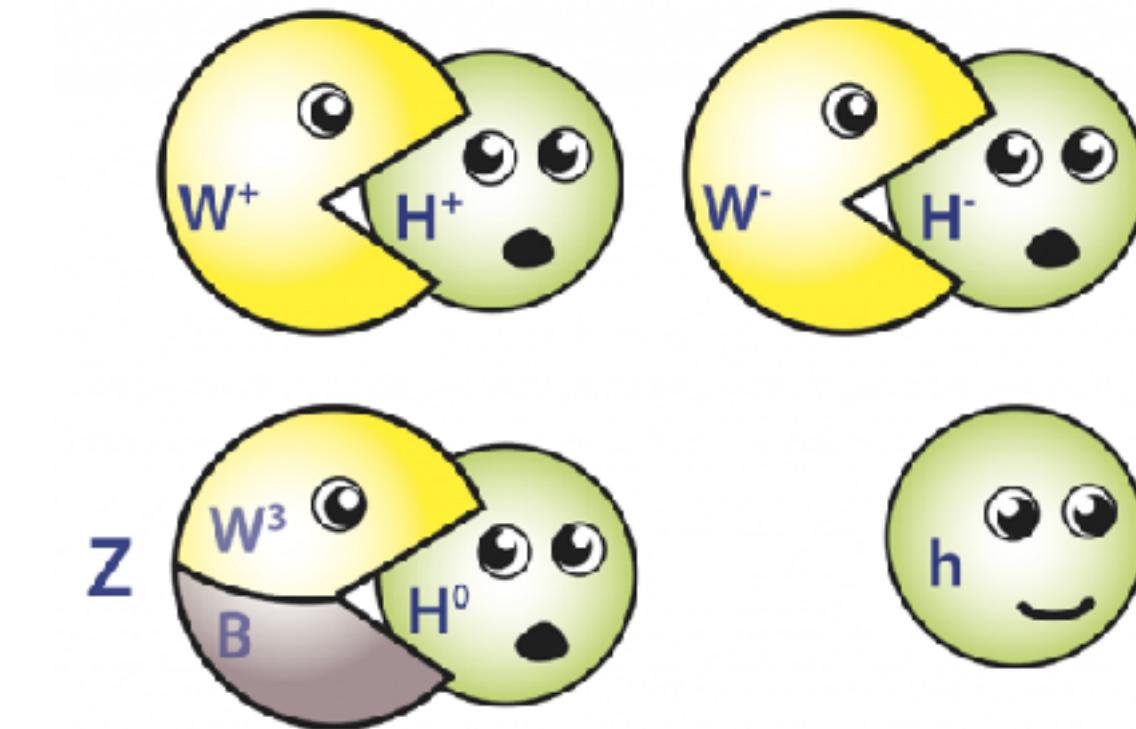
- Higgs potential spontaneously breaks the $SU(2) \times U(1)_Y \rightarrow U(1)_{EM}$

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

- 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



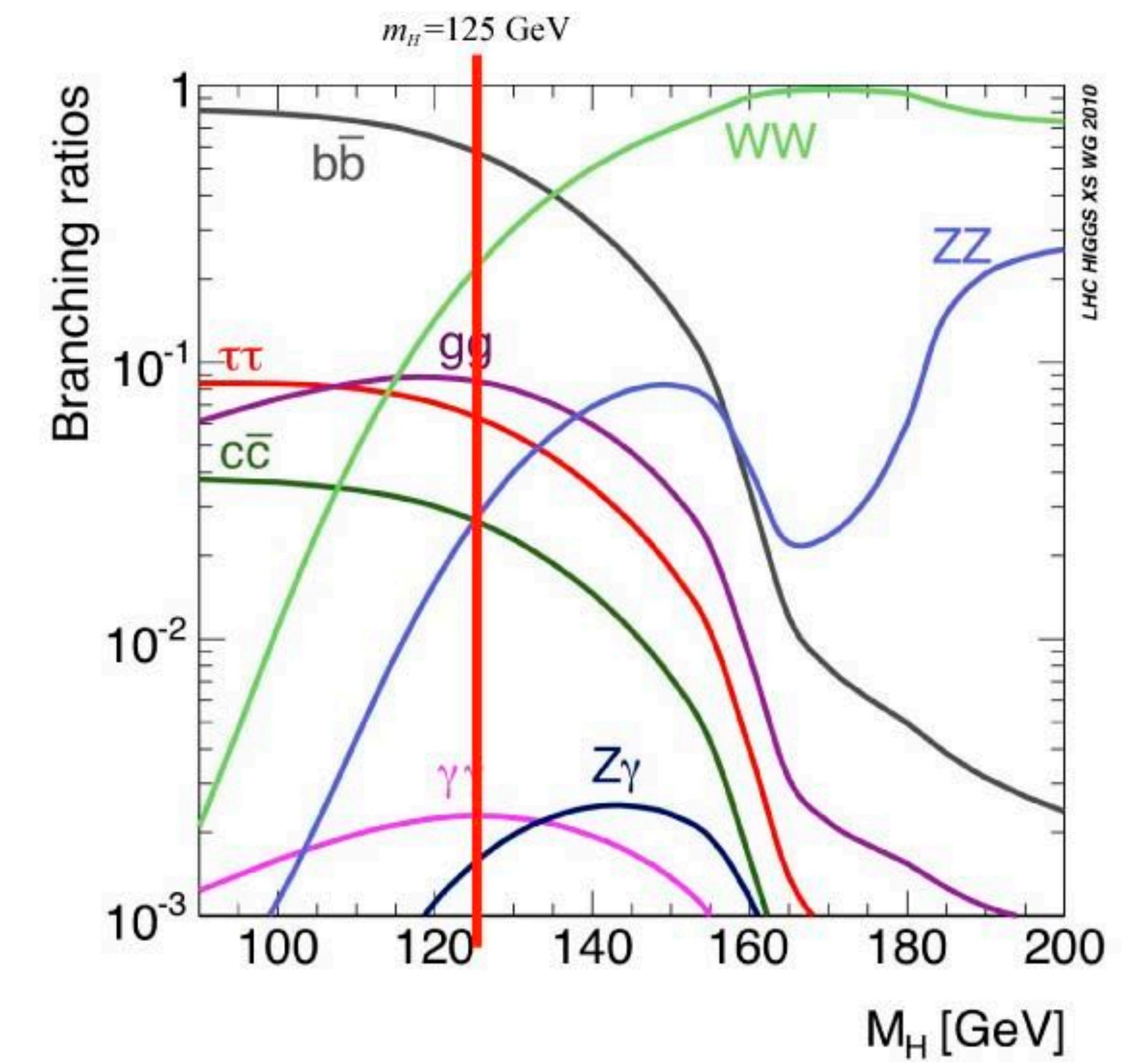
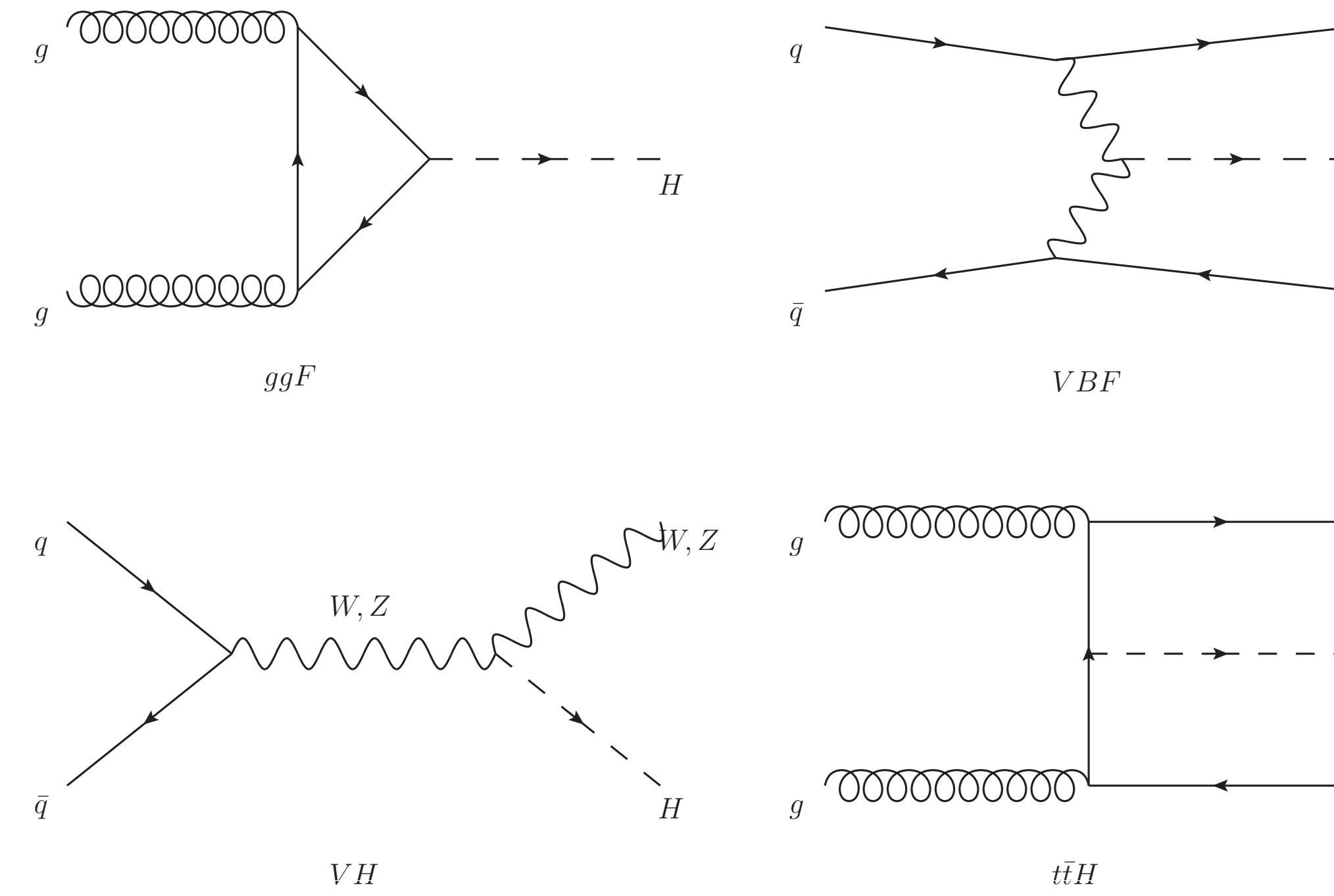
- Fermion masses via Yukawa couplings:

$$Y_{ij}^d \bar{Q}^i H d_R^j + h.c., \quad Y_{ij}^u \bar{Q}^i \tilde{H} u_R^j + h.c.$$

HIGGS PRODUCTION AND DECAY

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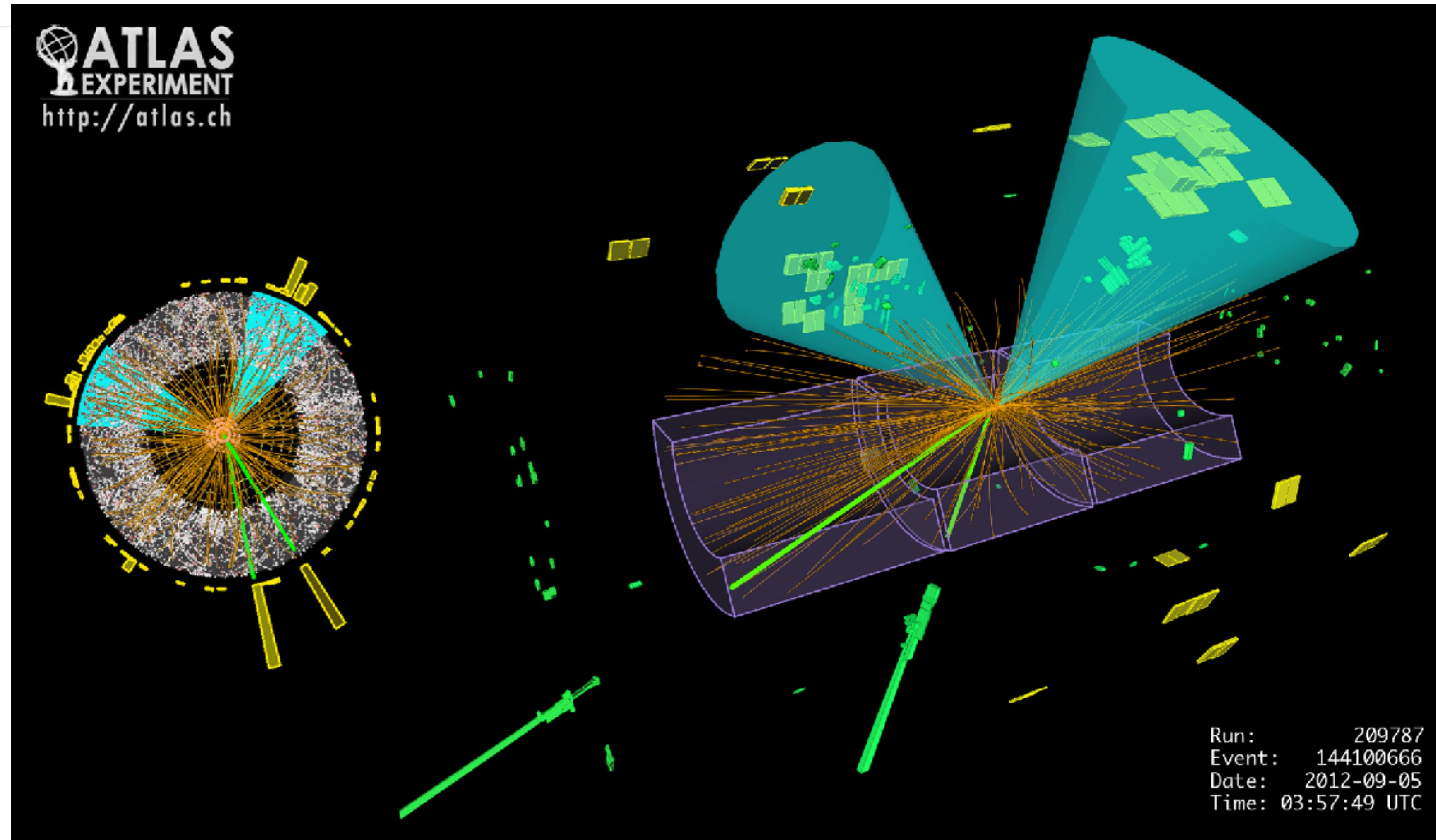


COLLISION EVENTS IN ATLAS

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- ATLAS is like a digital camera with lots of pixels

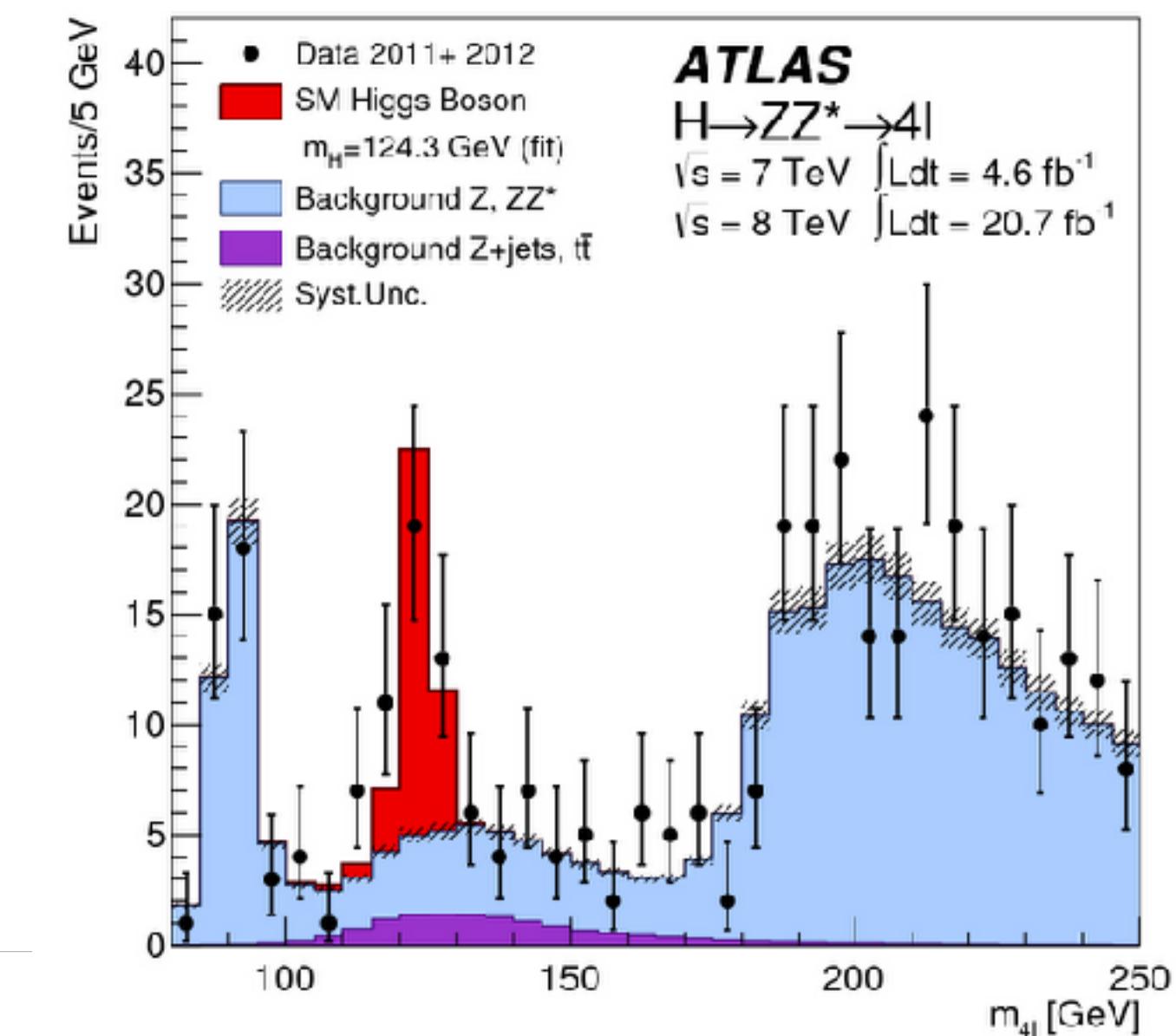
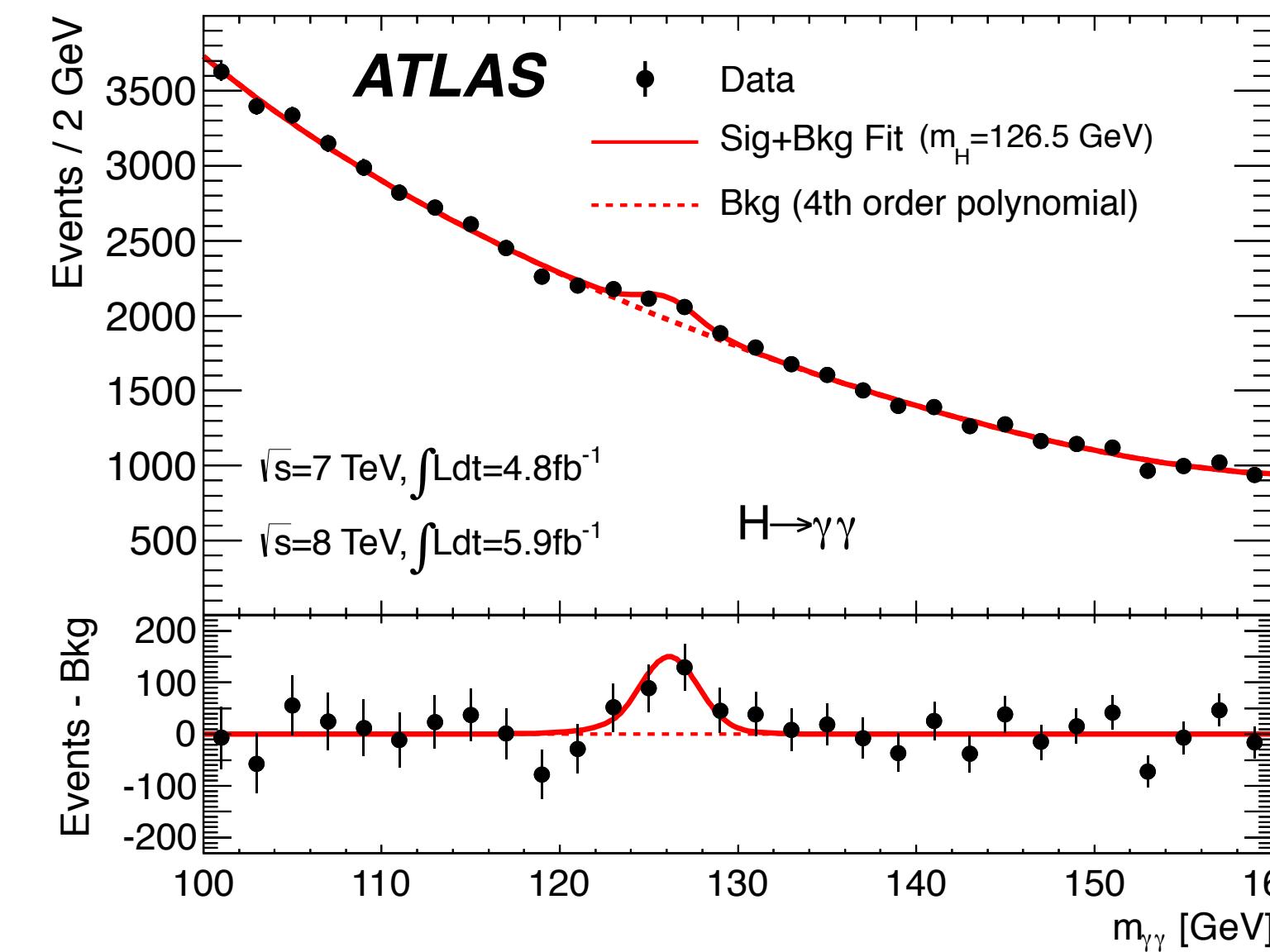


HIGGS DISCOVERY

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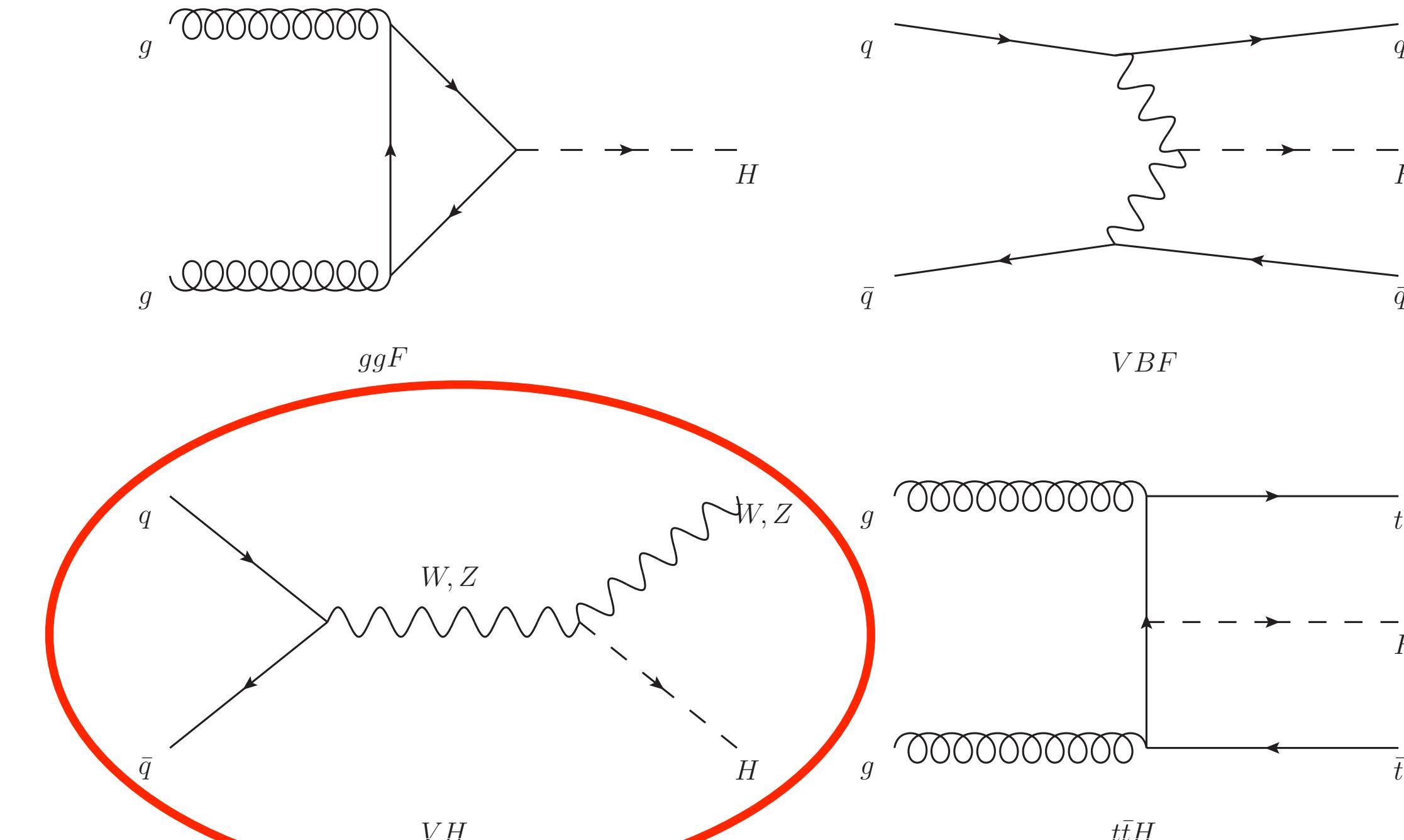
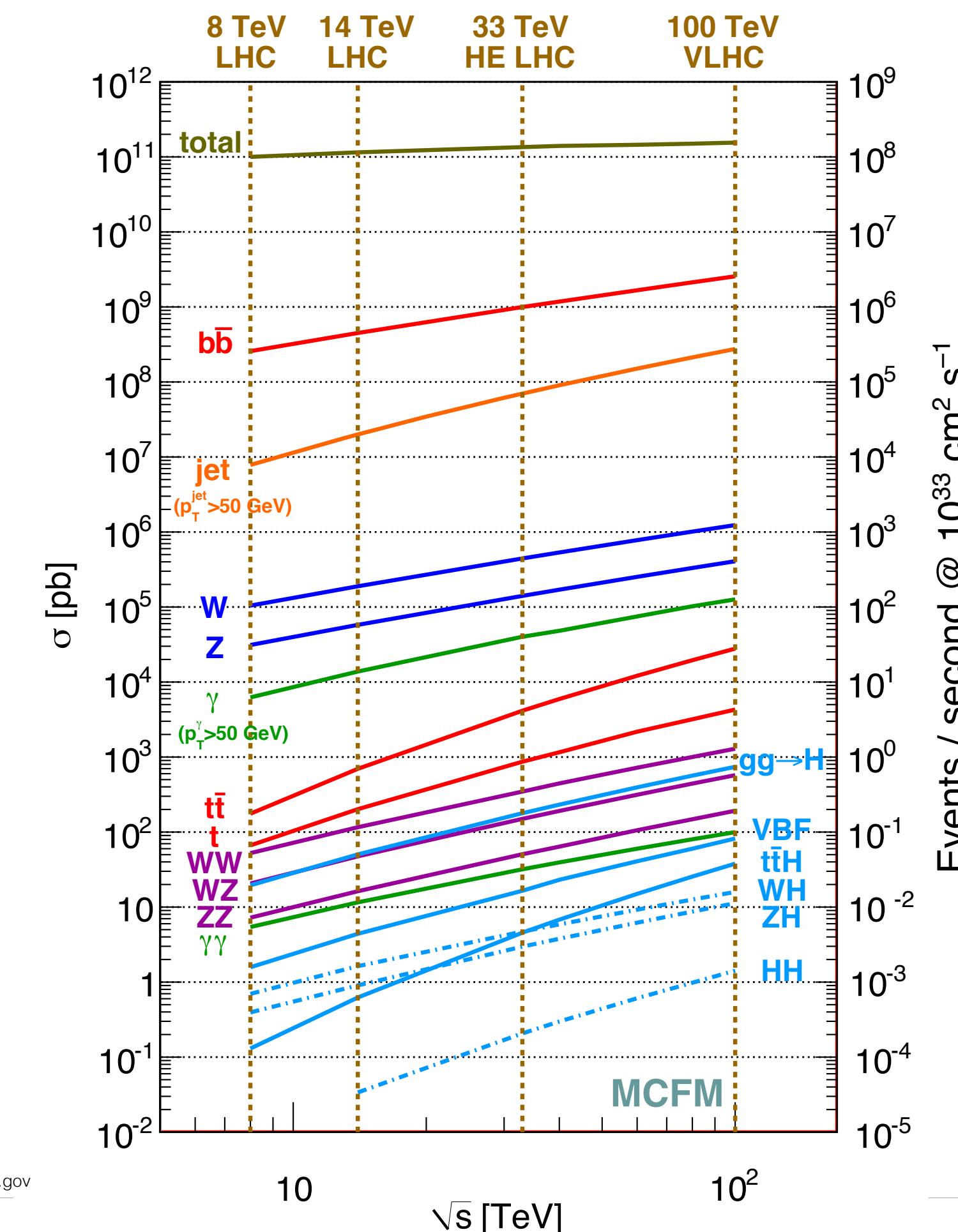
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- Clean discovery channels: $H \rightarrow \gamma\gamma$ and $H \rightarrow ZZ^* \rightarrow 4l$ placed the Higgs mass at 125 GeV
- So the Higgs should decay to b's 58% of the time



CHOOSING A SIGNAL TOPOLOGY

- Four main production modes; VH suppresses multijet background

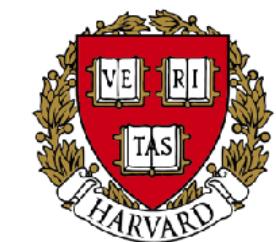


MODELING SYSTEMATICS

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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

ATLAS
EXPERIMENT

OBJECT DEFINITIONS: LEPTONS

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- 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 $|\eta| < 0.1$)
- Triggers: unprescaled single lepton (1/2-lep)

e Selection	p_T	η	ID	$d_0^{\pi^0}$	$ \Delta z_0^{\pi^0} \sin \theta $	Isolation
<i>VH - loose</i>	> 7 GeV	$ \eta < 2.47$	LH Loose + B-layer cut	< 5	< 0.5 mm	LooseTrackOnly
<i>ZH - signal</i>	> 27 GeV	$ \eta < 2.47$	LH Loose + B-layer cut	< 5	< 0.5 mm	LooseTrackOnly
<i>WH - signal</i>	> 27 GeV	$ \eta < 2.47$	LH Tight	< 5	< 0.5 mm	FixedCutHighPtCaloOnly

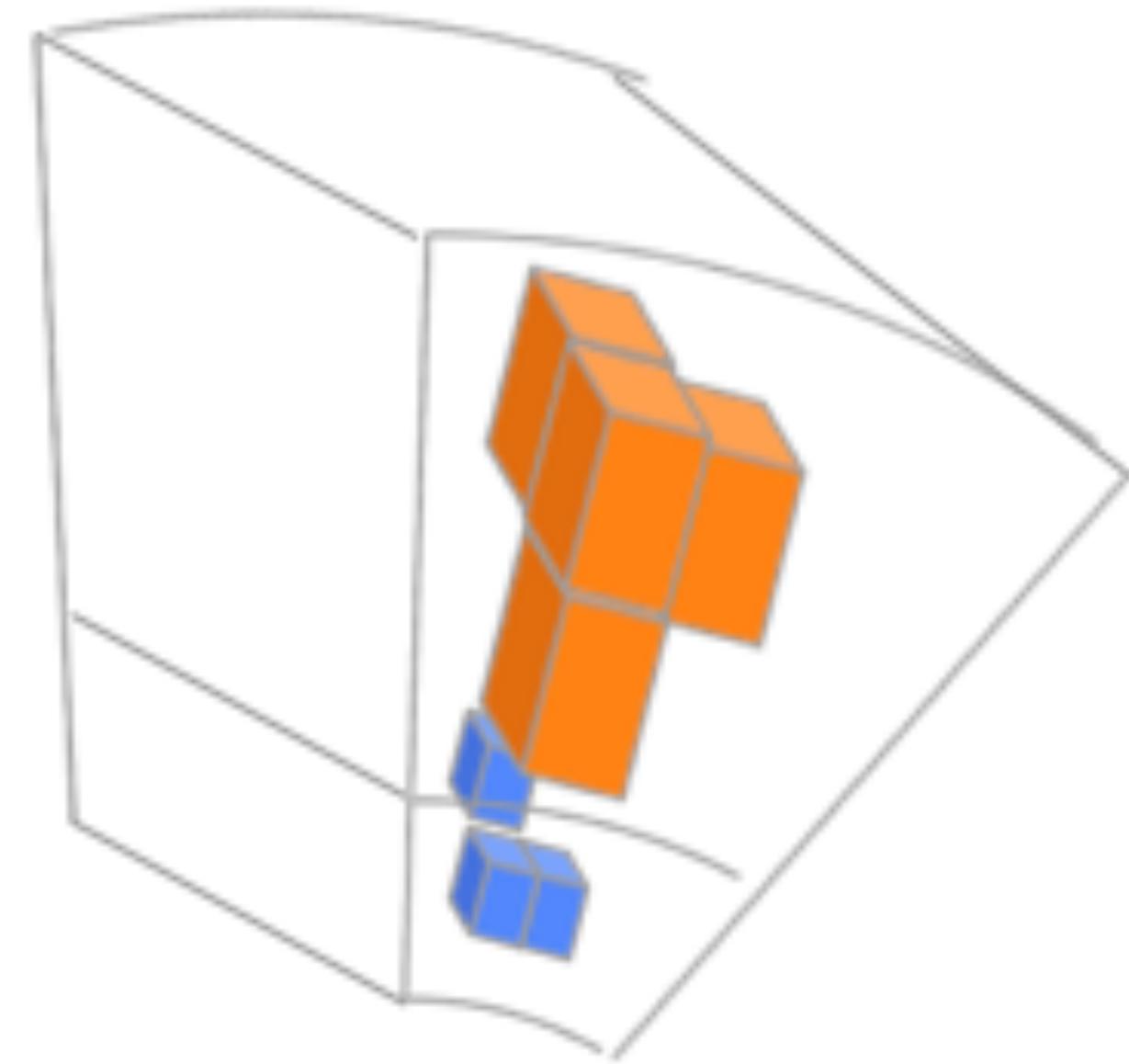
μ Selection	p_T	η	ID	$d_0^{\pi^0}$	$ \Delta z_0^{\pi^0} \sin \theta $	Isolation
<i>VH - loose</i>	> 7 GeV	$ \eta < 2.7$	Loose quality	< 3	< 0.5 mm	LooseTrackOnly
<i>ZH - signal</i>	> 27 GeV	$ \eta < 2.5$	Loose quality	< 3	< 0.5 mm	LooseTrackOnly
<i>WH - signal</i>	> 25 GeV	$ \eta < 2.5$	Medium quality	< 3	< 0.5 mm	FixedCutHighPtTrackOnly

OBJECT DEFINITIONS: JETETMISS

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- 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



topological
clusters

EXPERIMENTAL SYSTEMATICS

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- Jets: 21 JES NP scheme, energy resolution, JVT
 - Flavor Tagging: “medium” Eigen scheme for flavor
- Electron: efficiency, energy scale/resolution, trigger
- Muons: efficiency, isolation, track to vertex association, momentum resolution/scale, trigger
- MET: TST, jets, trigger
- Luminosity/pileup reweighting

HIGGS CROSS SECTIONS

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- Cross sections are in pb; for reference, we generally tell the public that 1 fb⁻¹ corresponds to ~10¹⁴ pp collisions at the LHC

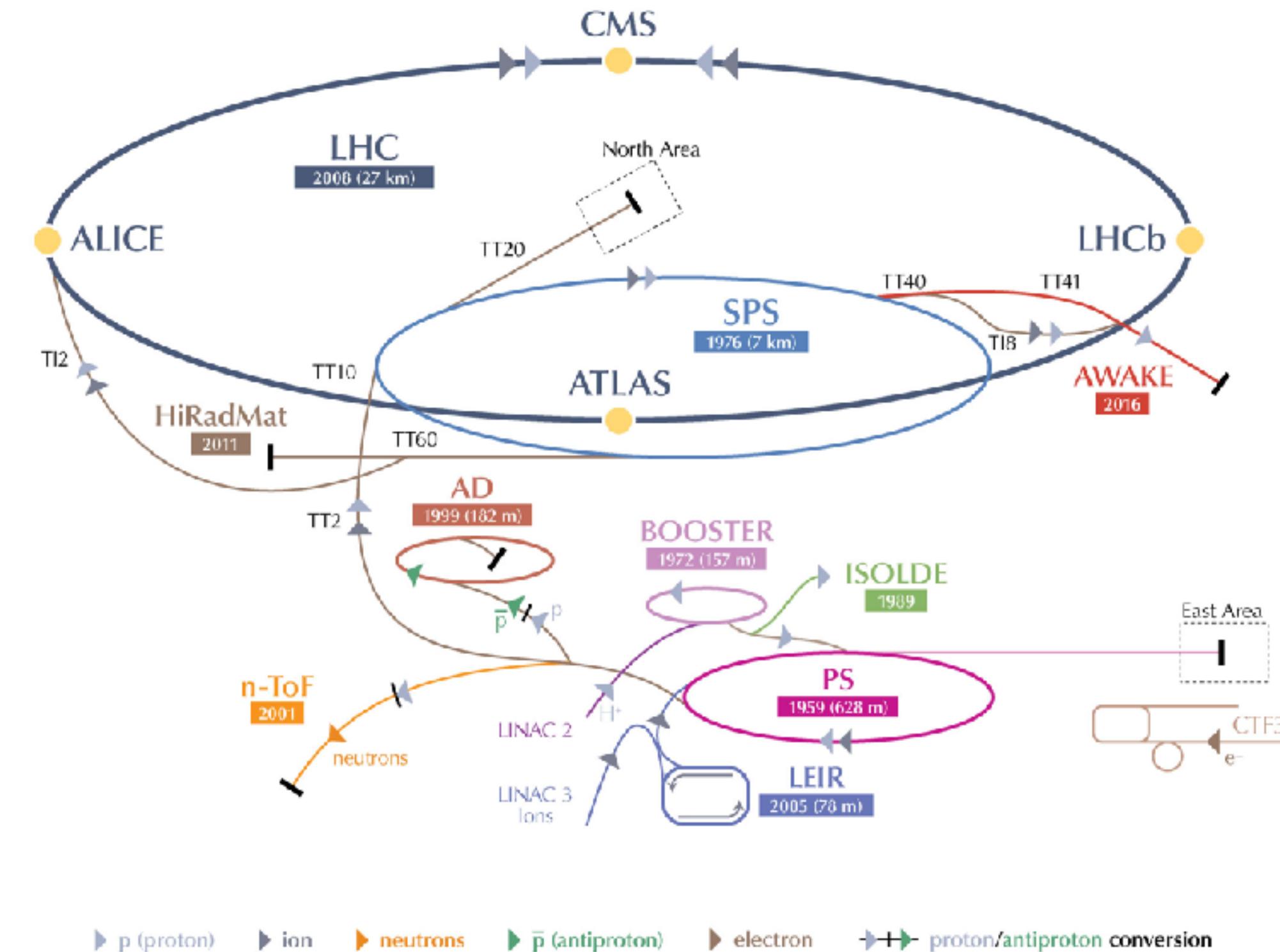
\sqrt{s} (TeV)	ZH	WH	ggF	total σ	$N_{V \rightarrow l^+ l^- H}$
7	$0.34^{+4\%}_{-4\%}$	$0.58^{+3\%}_{-3\%}$	$15.3^{+10\%}_{-10\%}$	17.5	$4.7 \text{ fb}^{-1} \rightarrow 589$
8	$0.42^{+5\%}_{-5\%}$	$0.70^{+3\%}_{-3\%}$	$19.5^{+10\%}_{-11\%}$	22.3	$20.3 \text{ fb}^{-1} \rightarrow 3100$
13	$0.88^{+5\%}_{-5\%}$	$1.37^{+2\%}_{-2\%}$	$44.1^{+11\%}_{-11\%}$	50.6	$36.1 \text{ fb}^{-1} \rightarrow 11100$
14	$0.99^{+5\%}_{-5\%}$	$1.51^{+2\%}_{-2\%}$	$49.7^{+11\%}_{-11\%}$	57.1	$1000 \text{ fb}^{-1} \rightarrow 343000$

THE CERN ACCELERATOR COMPLEX

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CERN's Accelerator Complex



LHC Large Hadron Collider SPS Super Proton Synchrotron PS Proton Synchrotron

AD Antiproton Decelerator CTF3 Clic Test Facility AWAKE Advanced WAKEfield Experiment ISOLDE Isotope Separator Online Device

LEIR Low Energy Ion Ring LINAC LINear ACcelerator n-ToF Neutrons Time Of Flight HiRadMat High-Radiation to Materials

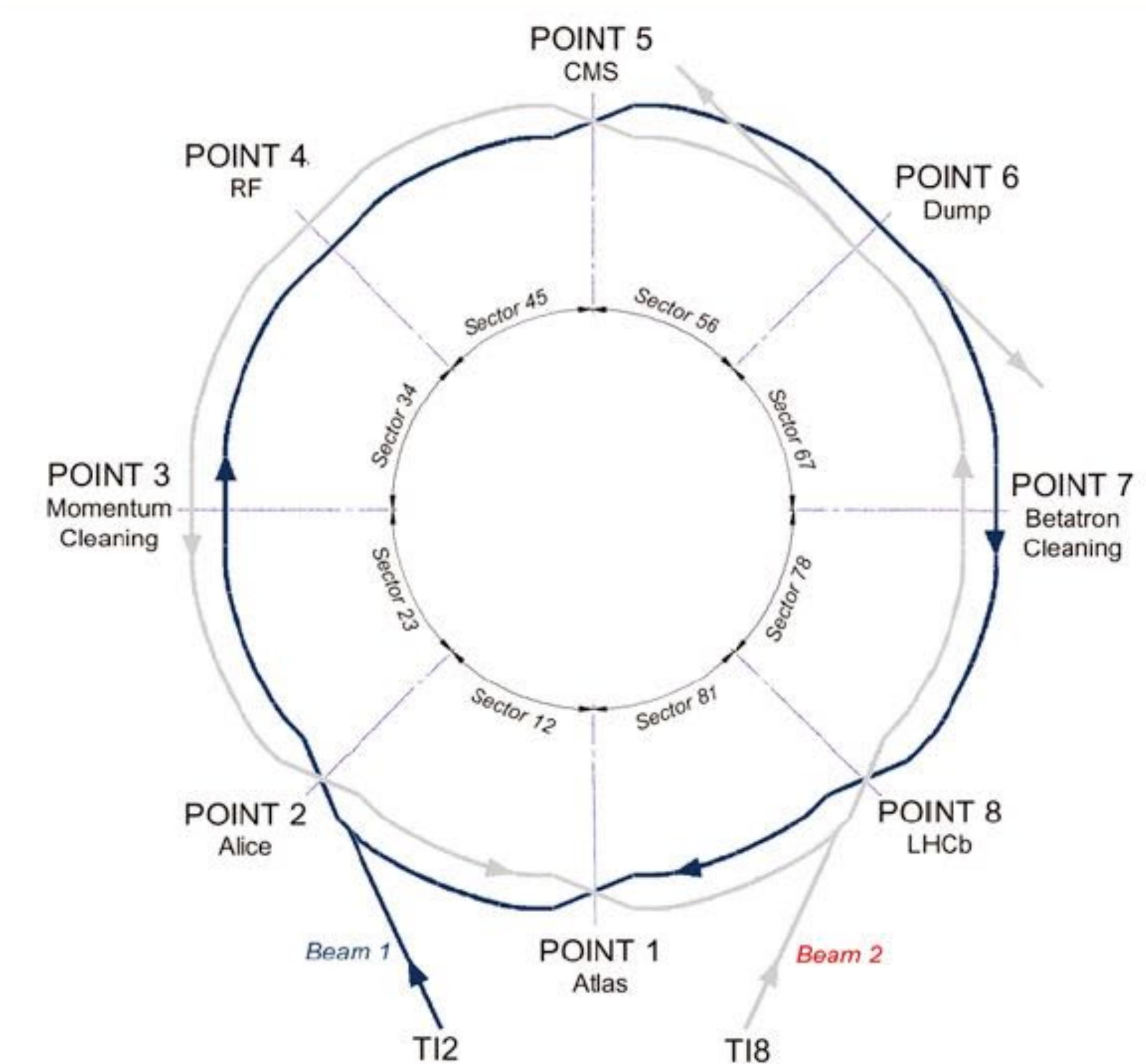
©CERN 2013

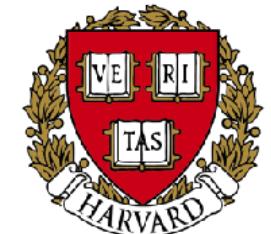


LHC LAYOUT

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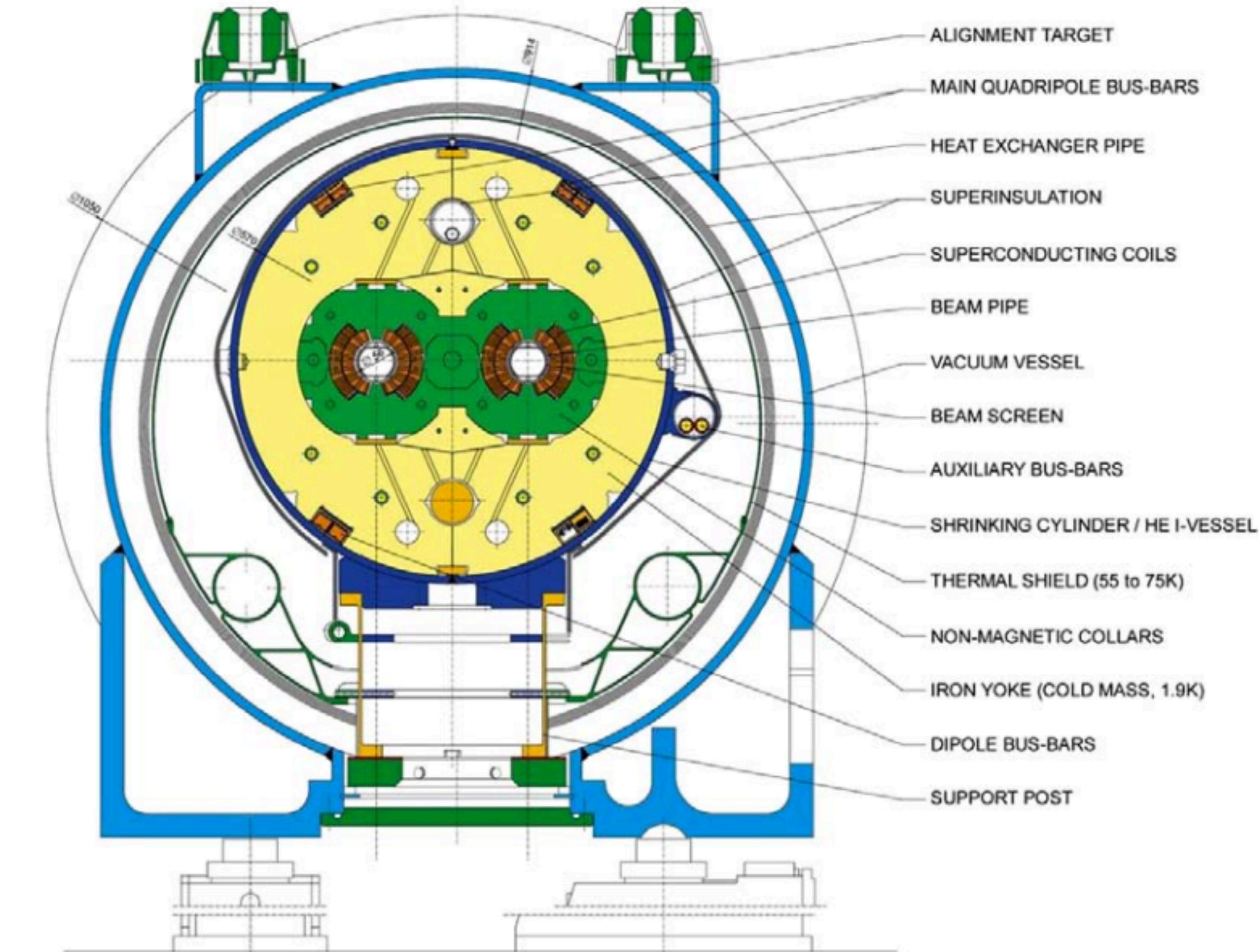




AN LHC MAGNET

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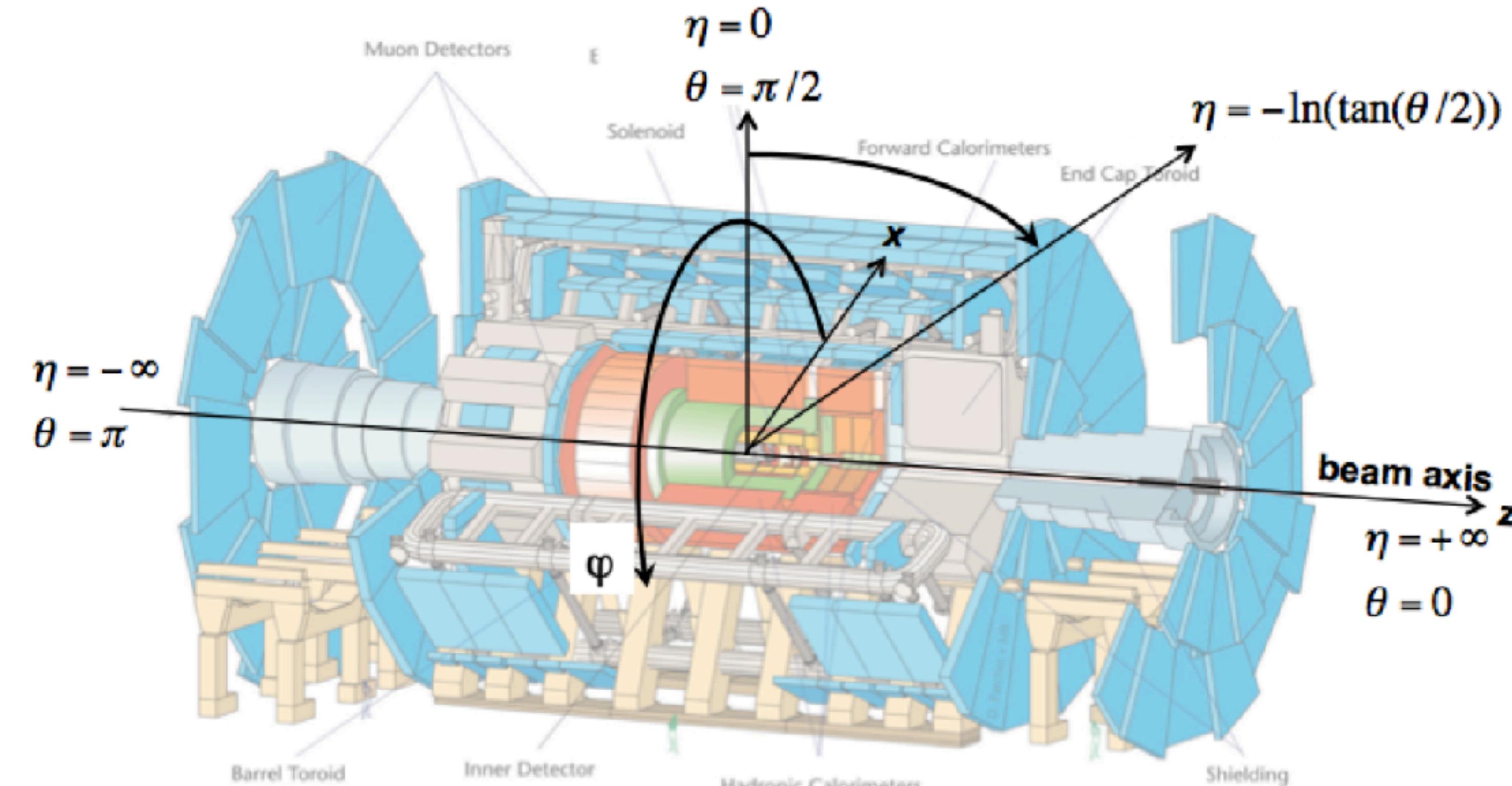
Finding
Standard
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ATLAS COORDINATES

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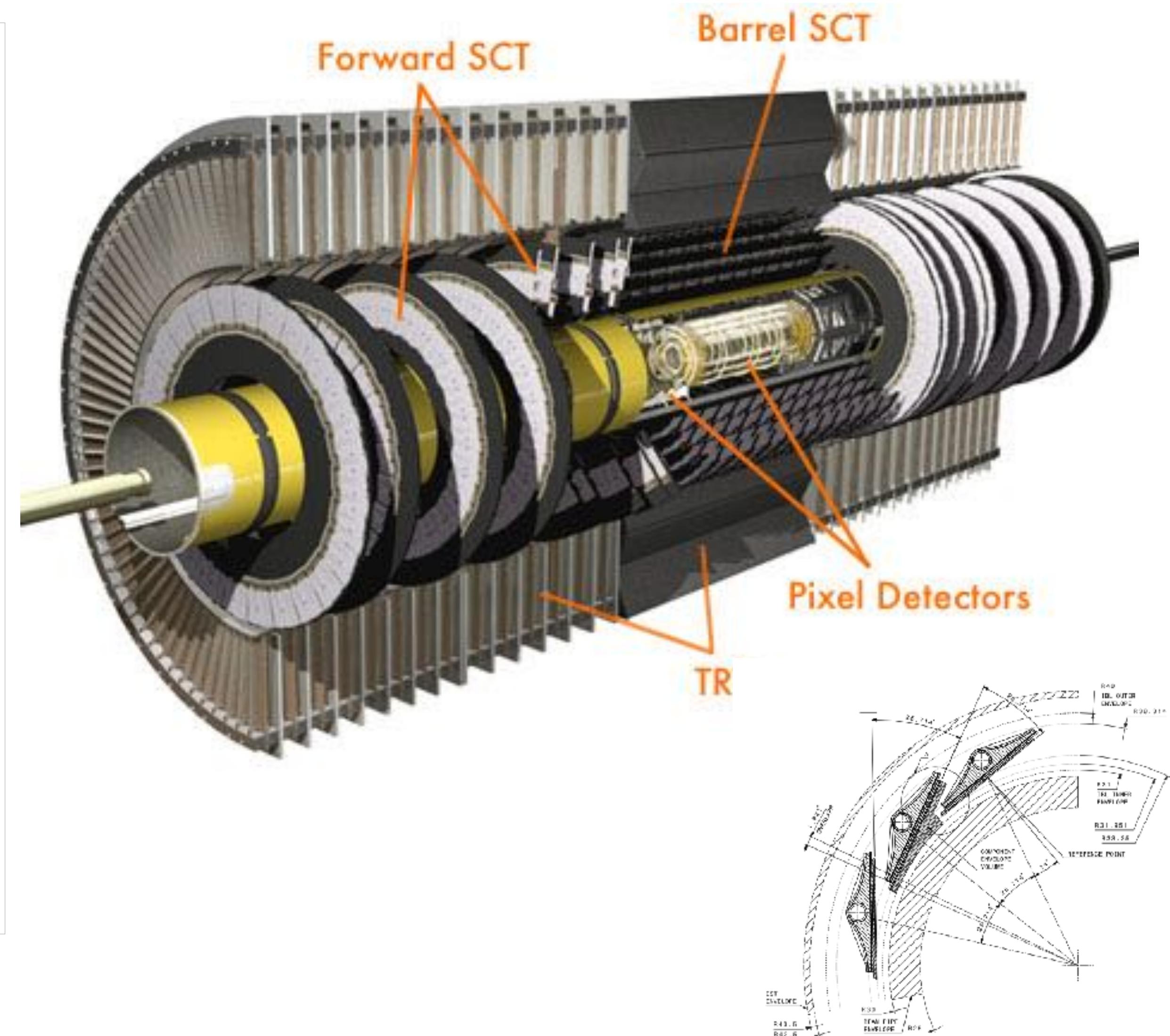
$$\vec{p}_T = (p_x, p_y) \quad p_T = p \sin \theta, \quad E_T = E \sin \theta$$

THE ATLAS ID

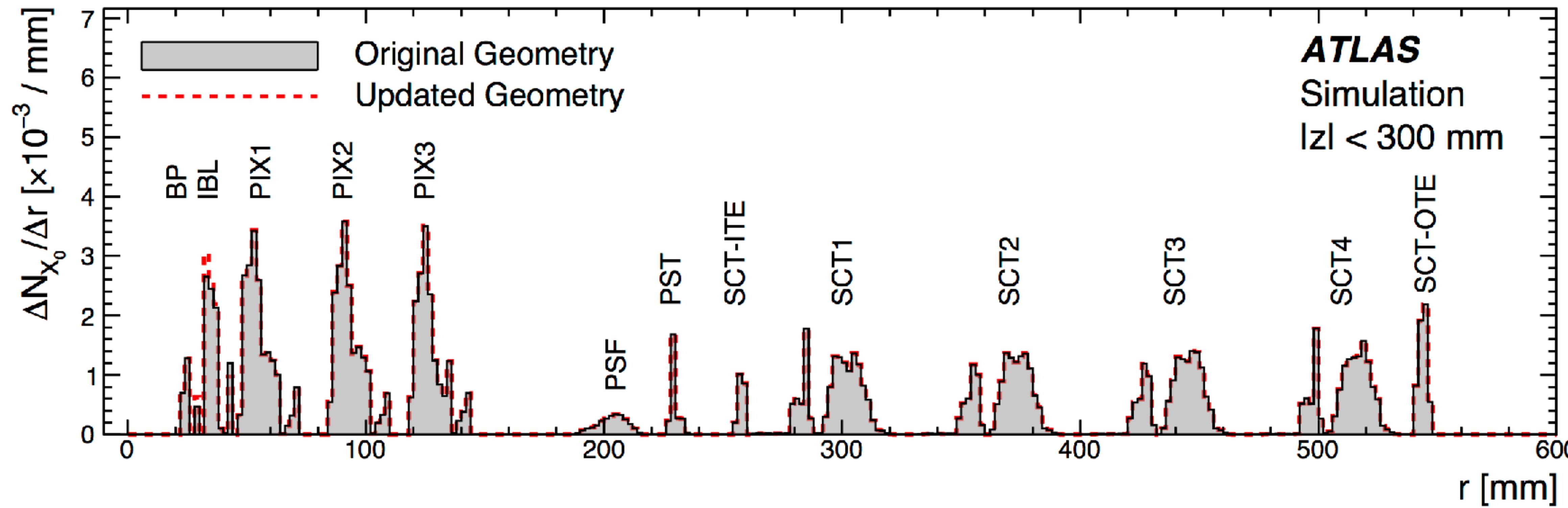
44

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- Pixel
 - 4 layers, 80 M channels, $50 \times 400(600) \times 250 \mu\text{m}$, $10(115) \mu\text{m r-}\phi$ (z) resolution
 - Insertable B-Layer
- SemiConductor Tracker
 - Silicon strips, $80 \times 6000 \times 285 \mu\text{m}$
 - 4 barrel, 9 end cap
- Transition Radiation Tracker
 - 4 mm straws with 70-27-3 Xe-CO₂-O₂ gas
 - Transition radiation $\sim \gamma / m$; electrons have 260 more than pions)



ID MATERIAL BUDGET



CALORIMETRY

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- 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)

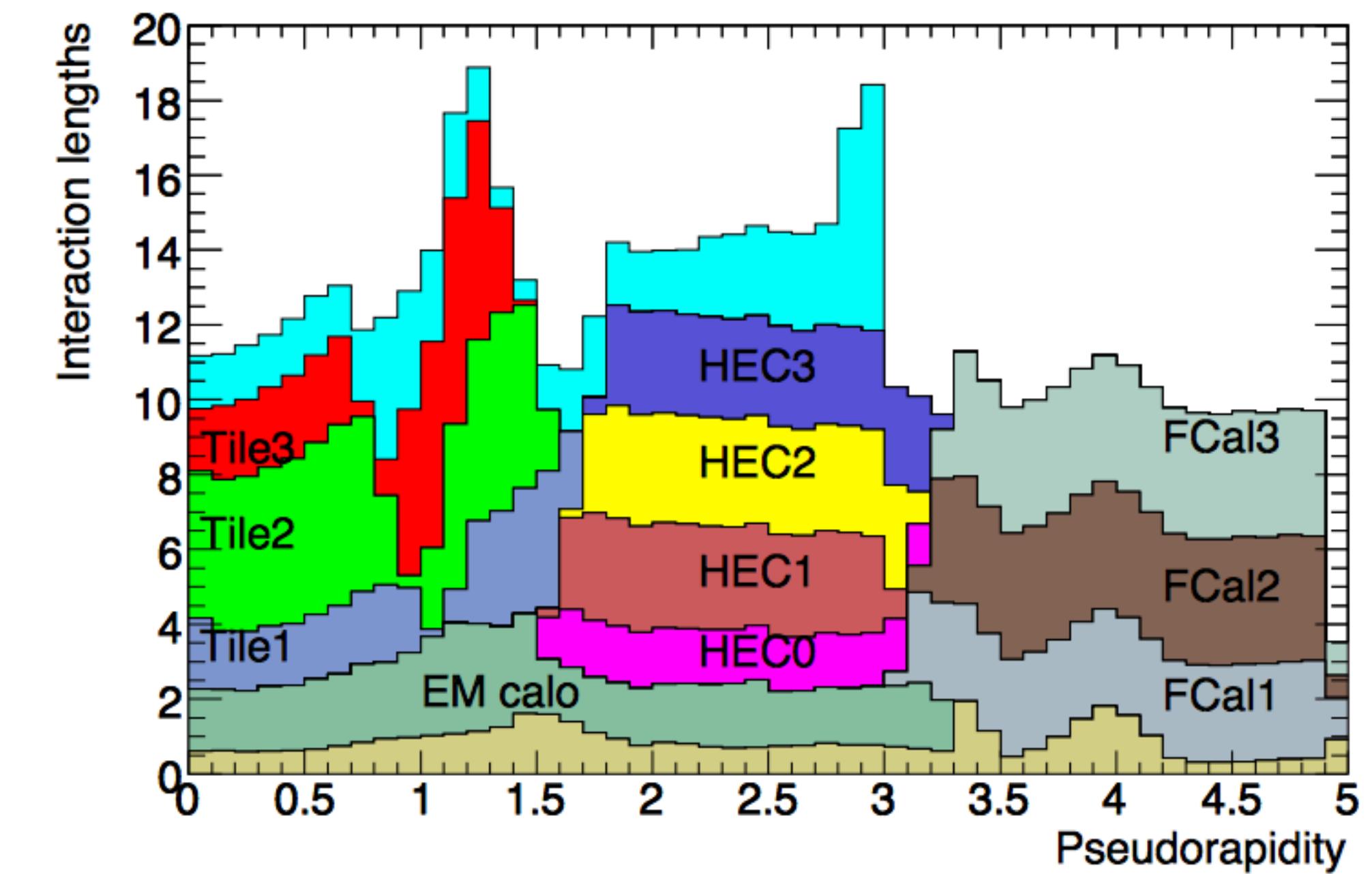
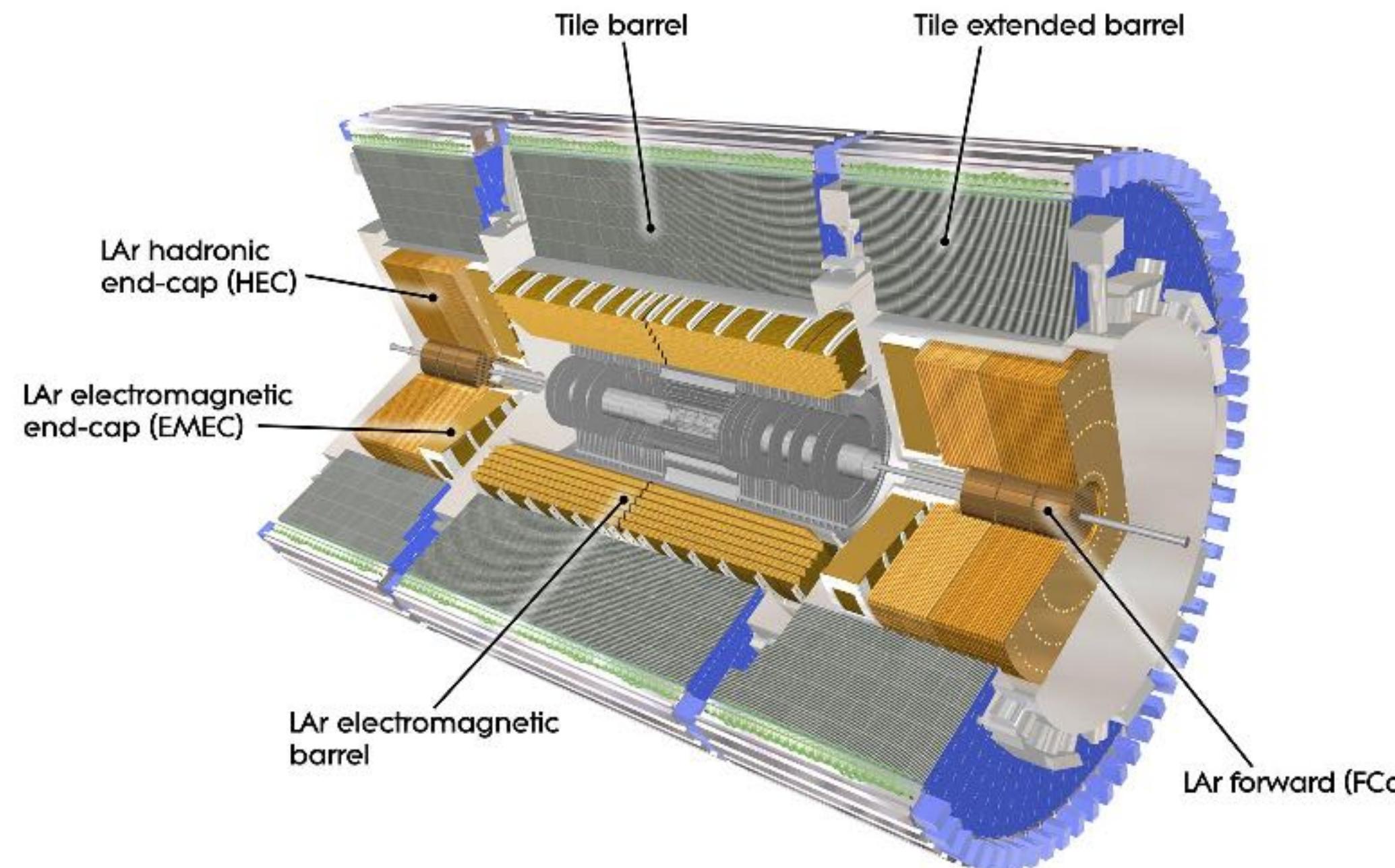
$$S \sim \text{few}\% \sqrt{d_{active} [\text{mm}] / f_{samp}}$$

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

ATLAS CALORIMETERS

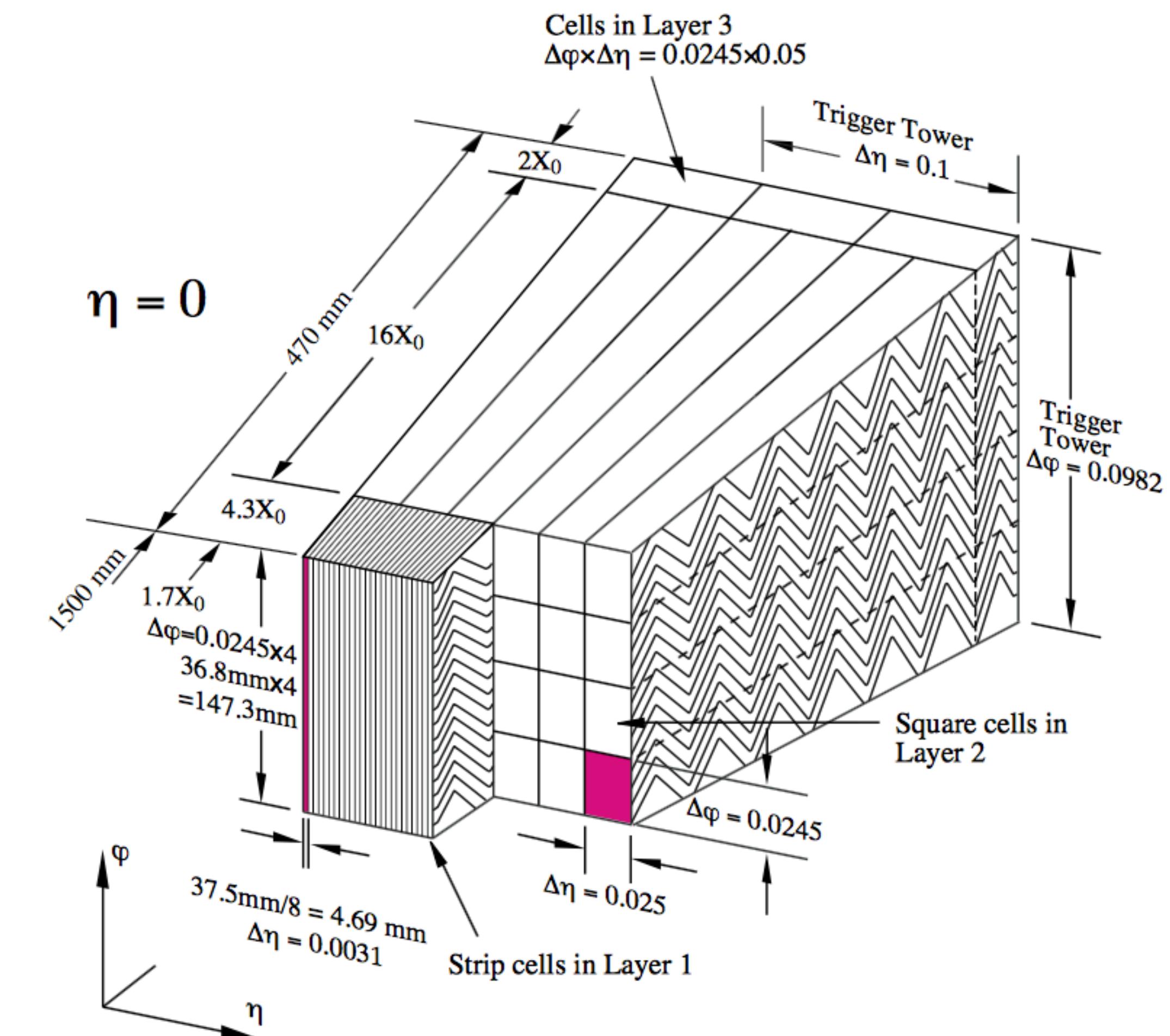
47

Finding Standard del VHbb S. Chan



ECAL

- LAr, lead “accordion”
- $S \sim 0.1 \text{ GeV}^{-1/2}$, $C=0.002$; 450 ns drift time; middle barrel layer of $\eta \times \phi$ resolution 0.025×0.025 sets granularity of calorimeter reconstruction
- 3 barrel (to $|\eta| 1.475$) layers
 - Presampler
- 3 (2)EC ($1.375 < |\eta| < 2.5$ (3.2)) inner (outer) wheels

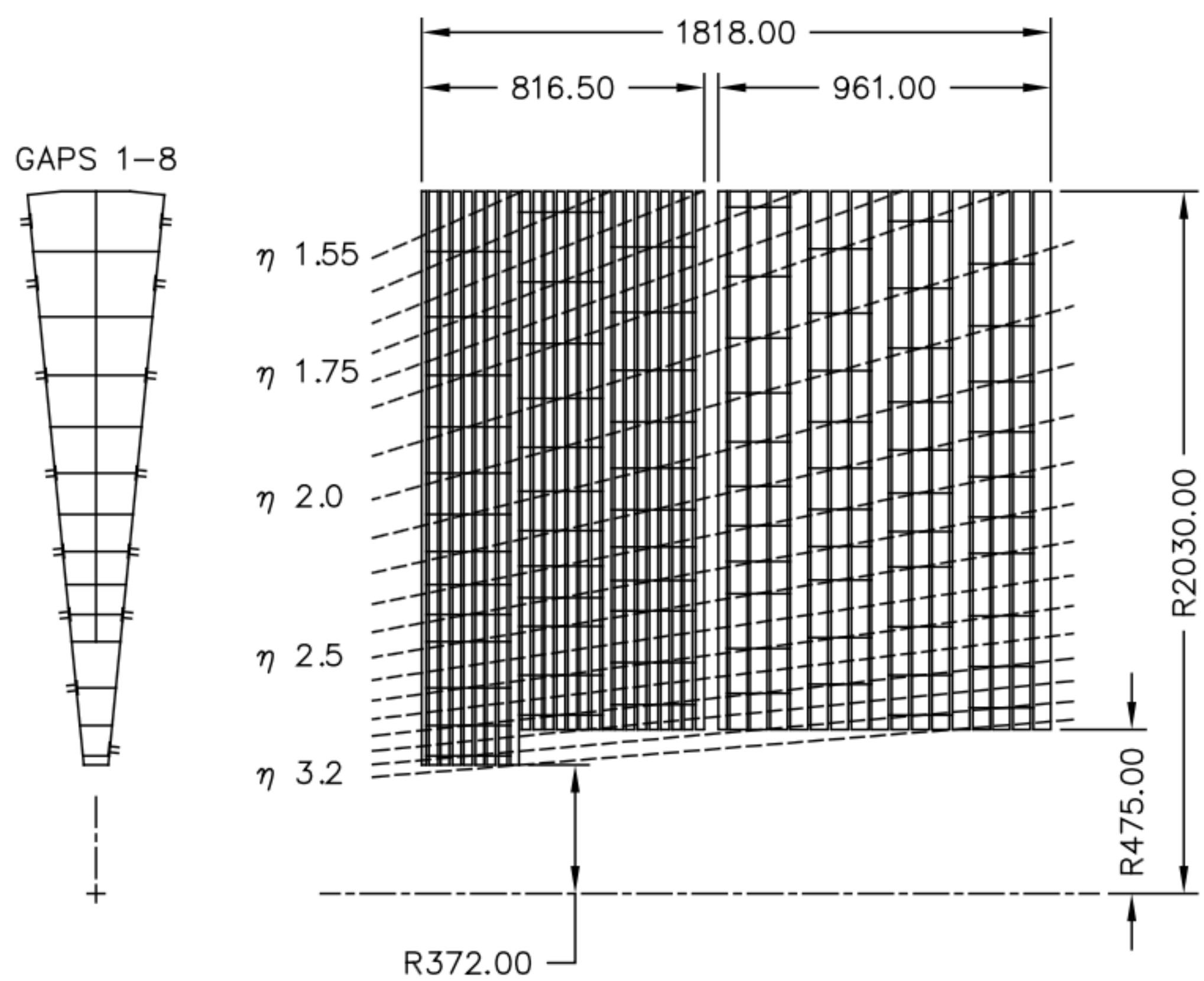


HEC

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- Hadronic end cap
- Two wheels beyond ECAL EC
- $1.5 < |\eta| < 3.2$
- 0.1×0.1 (to 2.5), 0.2×0.2 granularity
- LAr-Cu

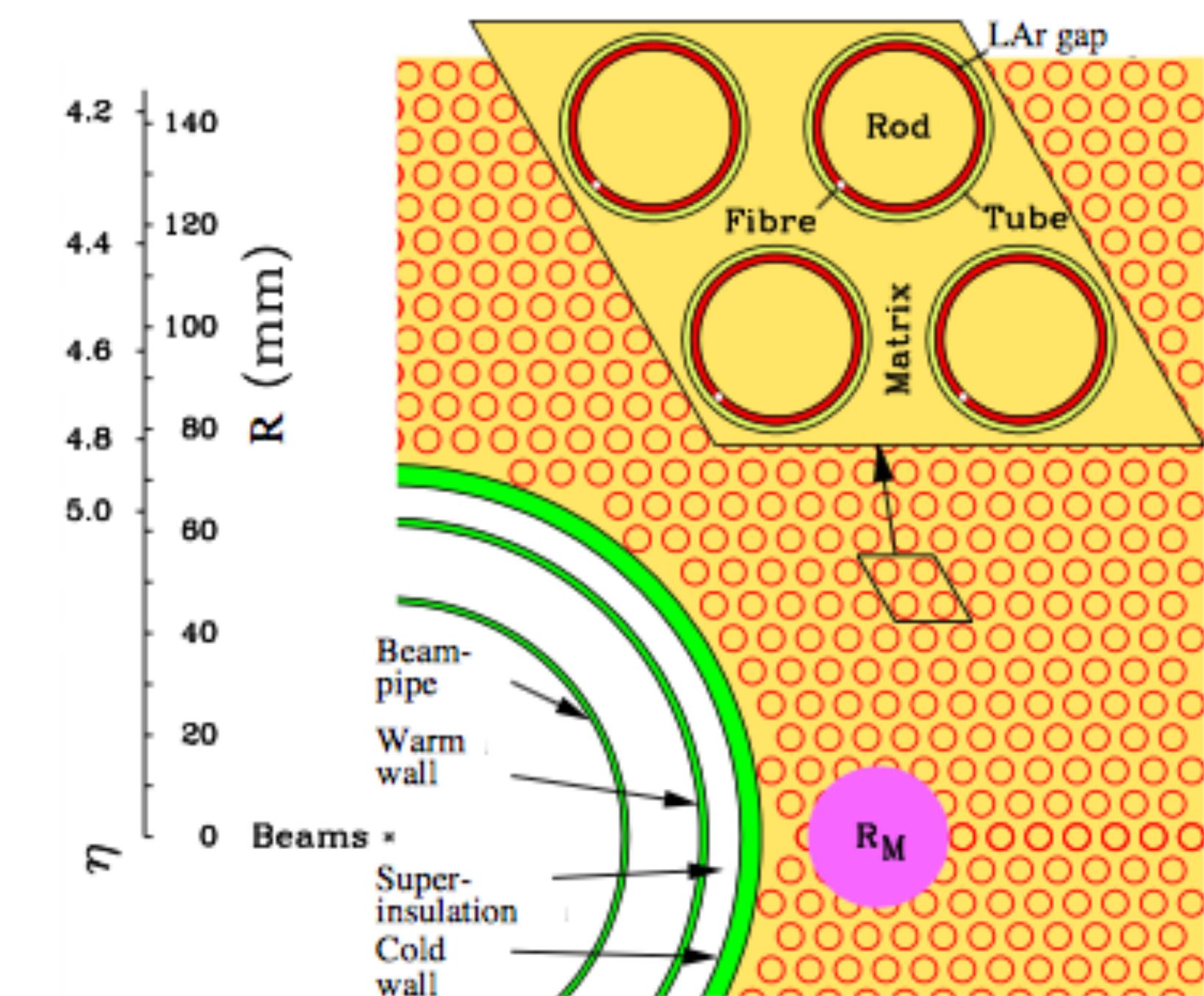


FCAL

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

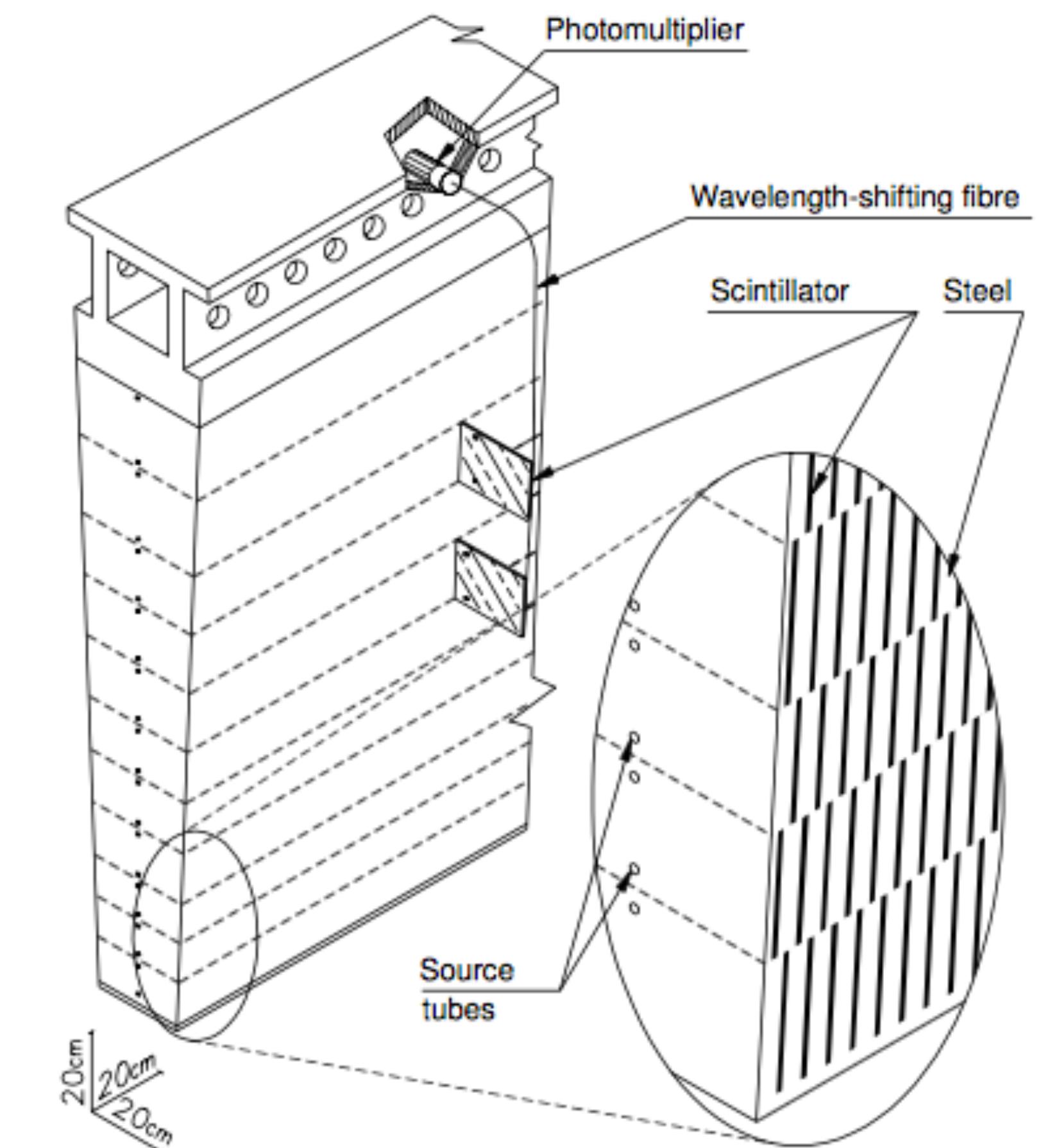


TILECAL

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- Barrel only; 64 polystyrene-steel modules in ϕ
- $S \sim 0.5 \text{ GeV}^{-1/2}$, $C = 0.05$ (0.03 after calibration)
- $0.1(0.2) \times 0.1 \text{ }\eta \times \phi$ resolution in first two (last) layer



MUON SPECTROSCOPY

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

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

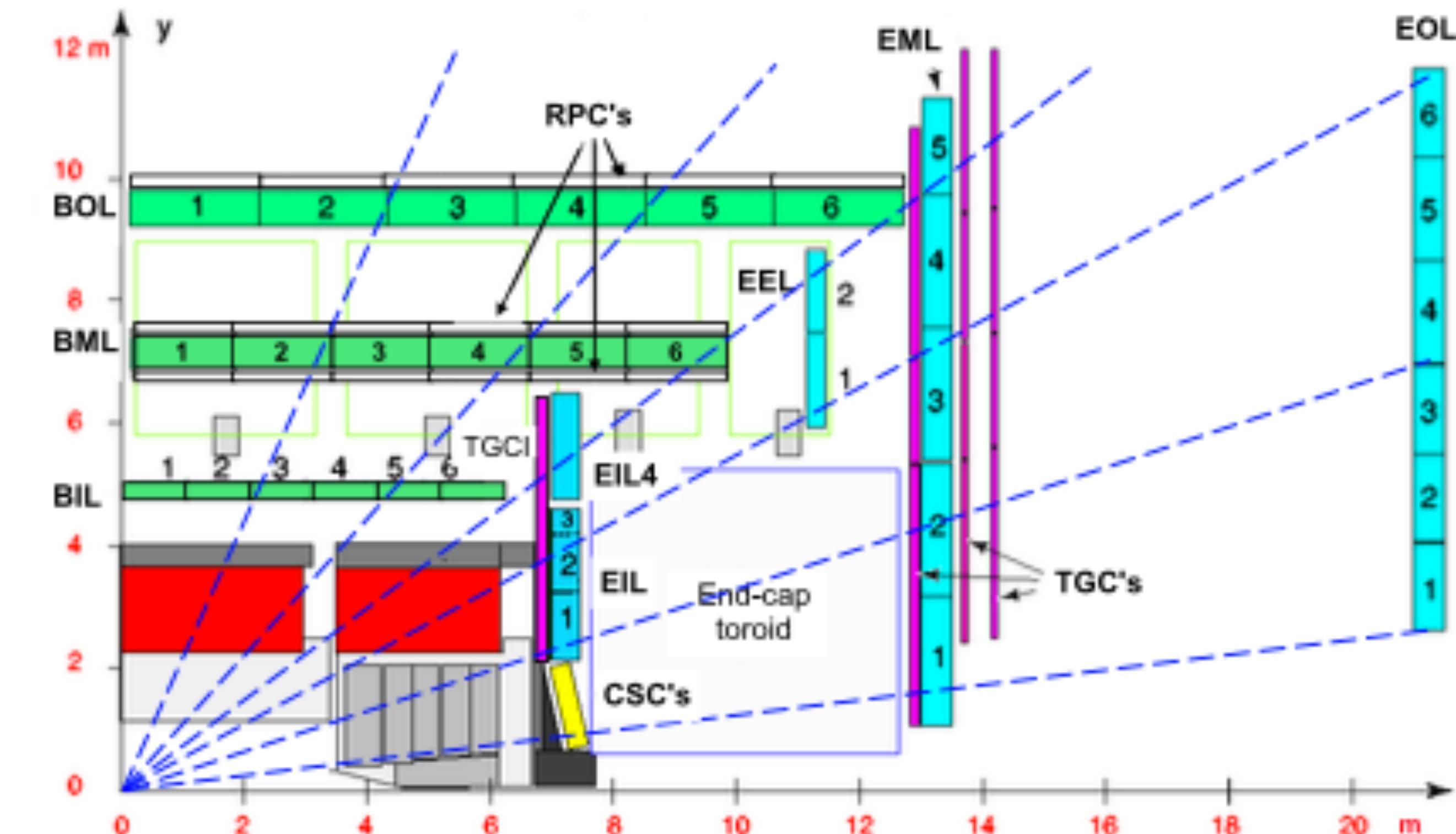
- 0 term is constant from multiple scattering ~0.5-2%
- 1 term from larger curvature of higher momentum muons (harder to measure) ~0.0001-0.001 /GeV; very important at high values
- ATLAS: 5-3000 GeV muons, 10% at 1 TeV, 3% at 100 GeV

THE ATLAS MS

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Type	Function	Chamber resolution (RMS) in			Measurements/track		Number of	
		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

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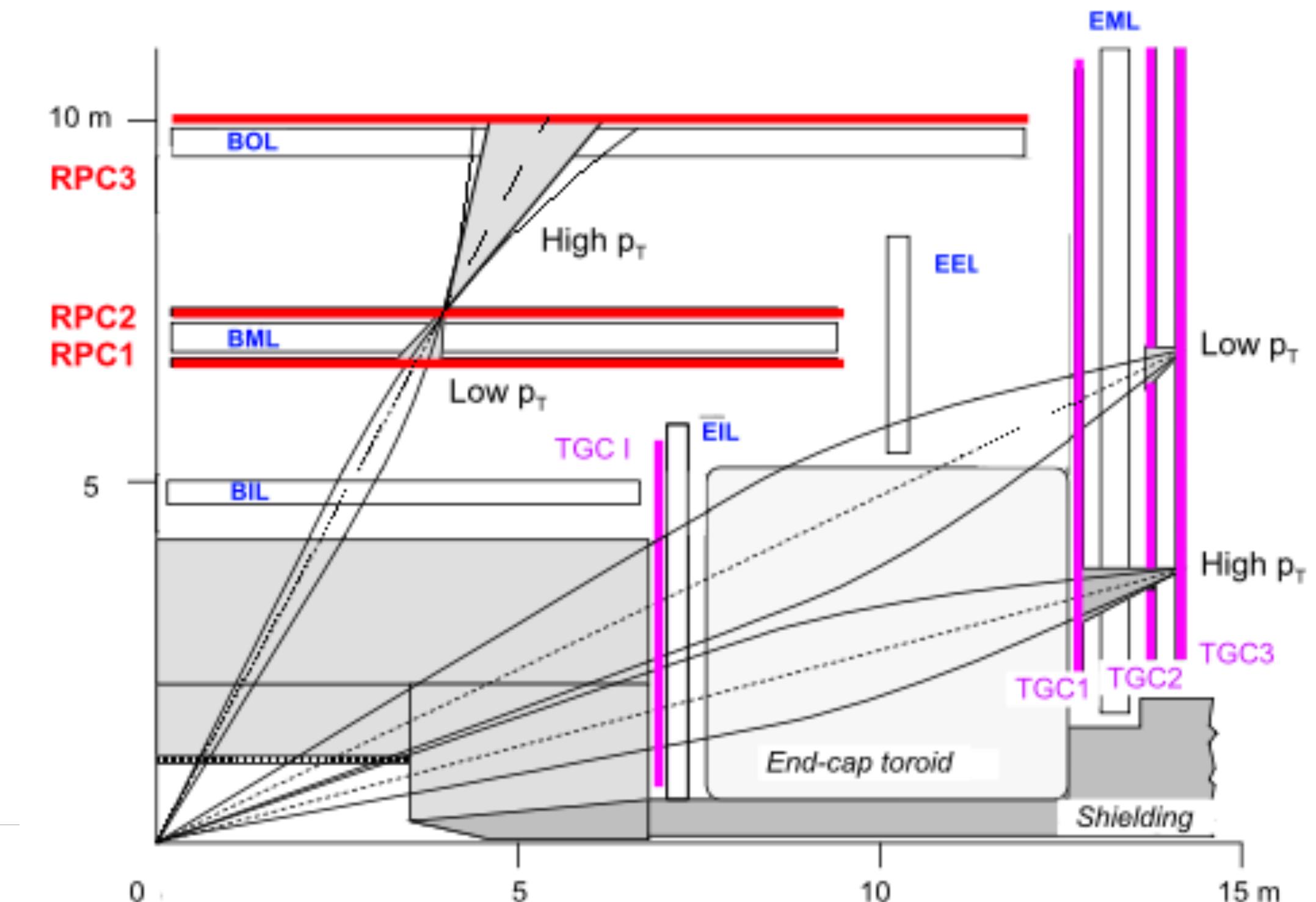
- MDT: monitored drift tube
 - 3 cm tube; Ar/CO₂; 3 kV
 - 35 μm resolution in longitudinal plane
 - 700 ns dead time
- CSC: cathode strip chamber
 - Forward region ($| \eta | < 2.7$) is too high rate for MDT's (40 ns dead time)
 - Multiwire proportional chamber: 5.31 (5.56) mm strip pitch
 - 60 (5000)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

ATLAS MS TRIGGER

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- $|h| < 2.4$
- 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



MODELING EXAMPLE: SIGNAL

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DS ID	Process	Generator	Events
<i>qq</i> -initiated (nominal)			
345053	$qq \rightarrow W^+ H \rightarrow l^+ v b\bar{b}$	POWHEG +MiNLO+PYTHIA 8	3999950
345054	$qq \rightarrow W^- H \rightarrow l^- v b\bar{b}$	POWHEG +MiNLO+PYTHIA 8	3999950
345055	$qq \rightarrow ZH \rightarrow ll b\bar{b}$	POWHEG +MiNLO+PYTHIA 8	3000000
345056	$qq \rightarrow ZH \rightarrow vv b\bar{b}$	POWHEG +MiNLO+PYTHIA 8	2000000
<i>qq</i> -initiated (alternative)			
343608	$qq \rightarrow WH \rightarrow lv b\bar{b}$	MADGRAPH 5_aMC@NLO+PYTHIA 8	1000000
343619	$qq \rightarrow ZH \rightarrow ll b\bar{b}$	MADGRAPH 5_aMC@NLO+PYTHIA 8	1000000
343629	$qq \rightarrow ZH \rightarrow vv b\bar{b}$	MADGRAPH 5_aMC@NLO+PYTHIA 8	1000000
<i>gg</i> -initiated (nominal)			
345057	$gg \rightarrow ZH \rightarrow ll b\bar{b}$	POWHEG +PYTHIA 8	
345058	$gg \rightarrow ZH \rightarrow vv b\bar{b} (*)$	POWHEG +PYTHIA 8	

NP name	oL 2j	oL 3j	1L 2j	1L 3j	2L 2j	2L $\geq 3j$
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				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				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				shape only	

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

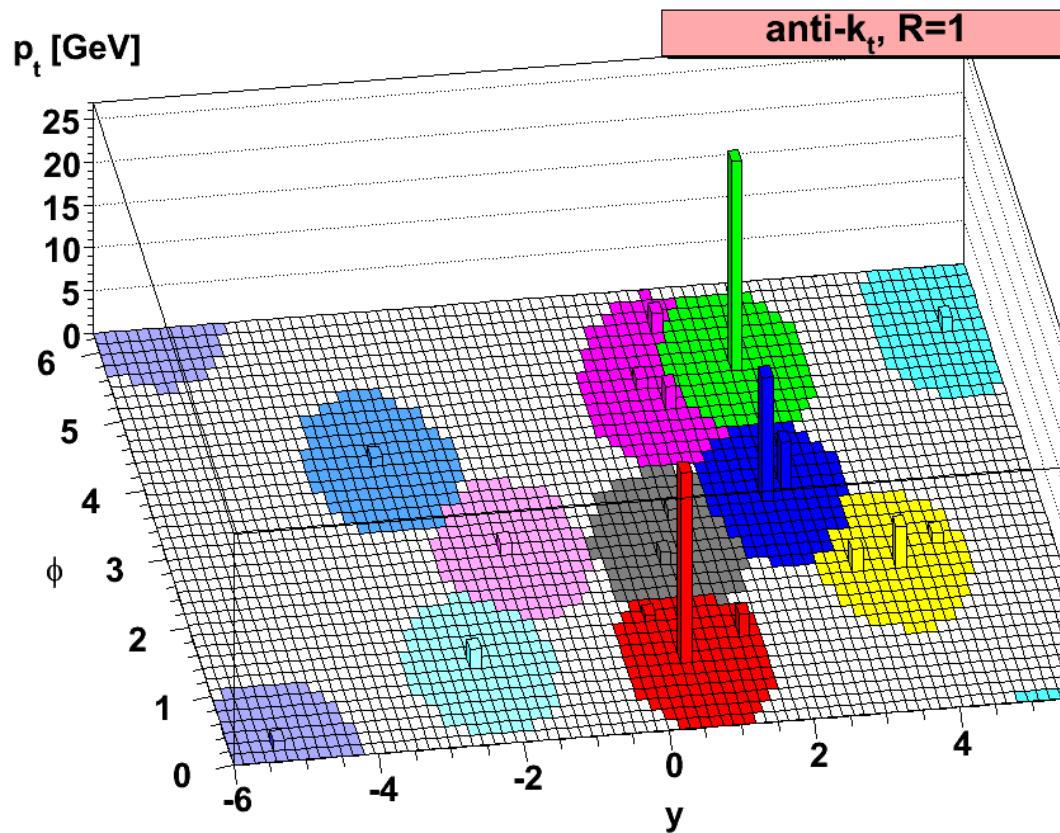
Jet Algorithms

- ▶ 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

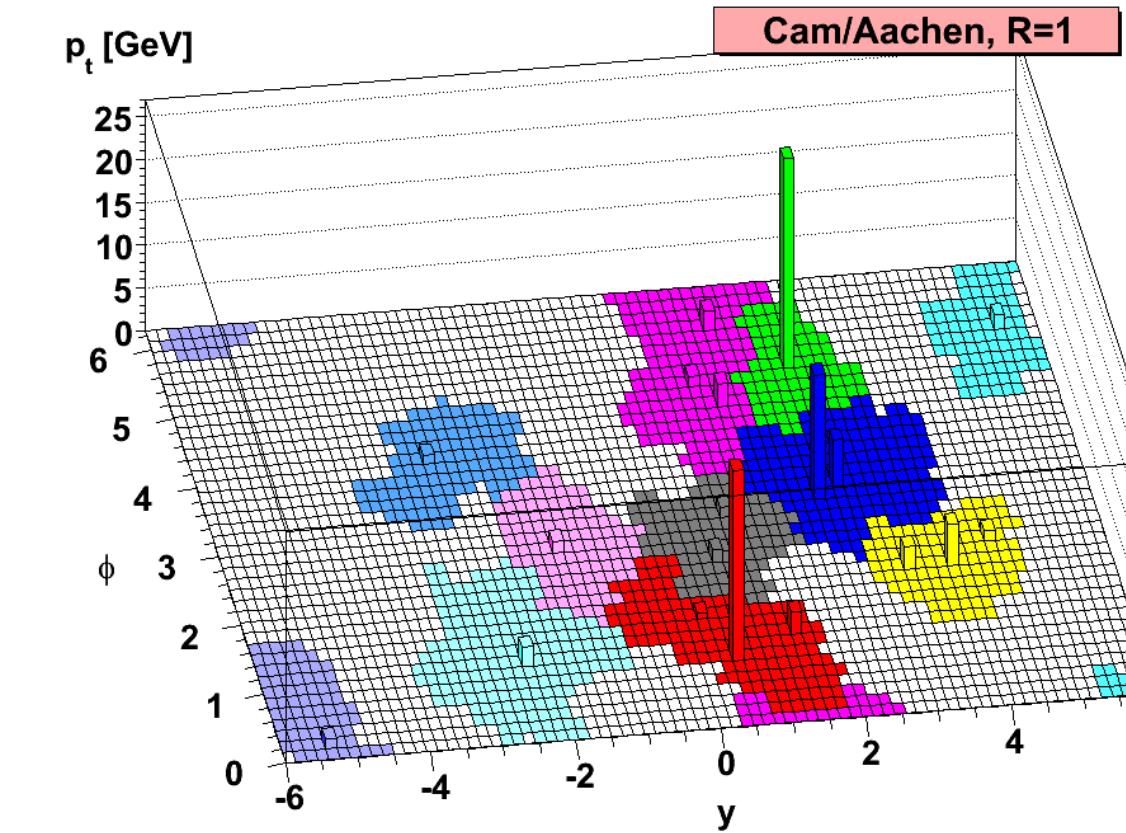
$$d_{ij} = \min \left(p_{Ti}^{2p}, p_{Tj}^{2p} \right) \frac{\Delta R_{ij}^2}{R^2}, \quad d_{iB} = p_{Ti}^{2p}$$
$$\Delta R_{ij}^2 = (\eta_i - \eta_j)^2 + (\phi_i + \phi_j)^2$$

- ▶ $p = 1 \rightarrow k_t$, $p = 0 \rightarrow \text{C/A}$, $p = -1 \rightarrow \text{anti-}k_t$
- ▶ 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**

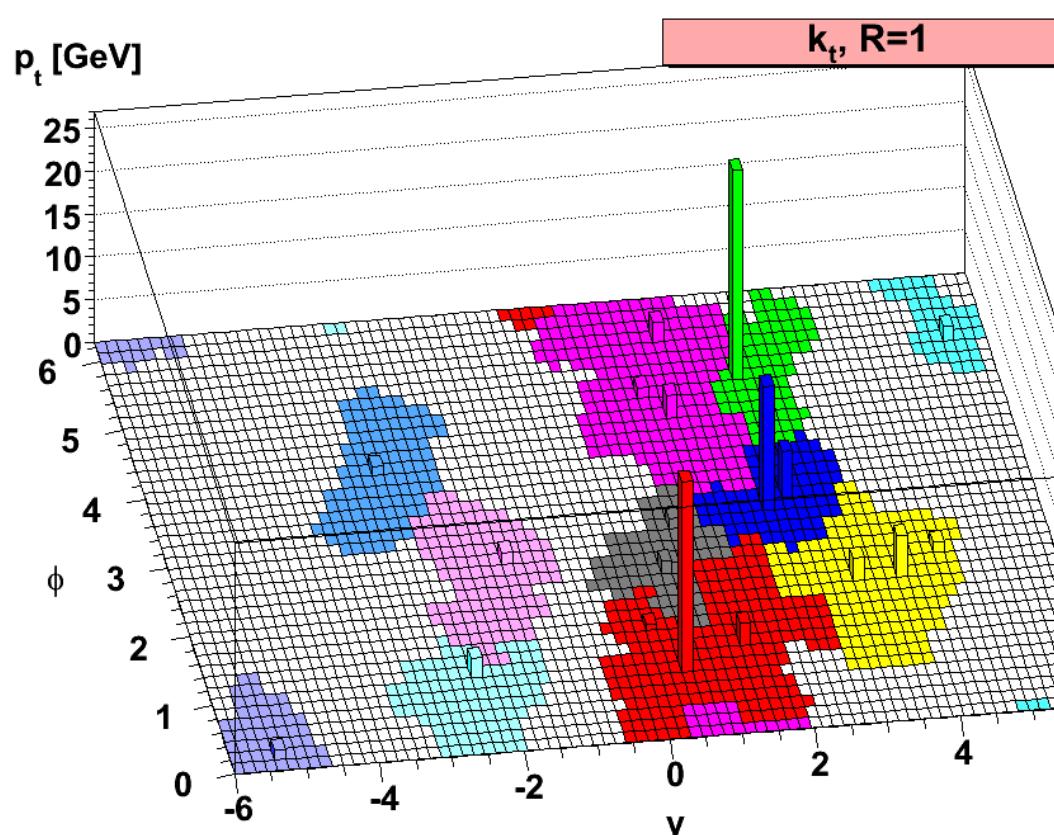
Different Jet Algorithms



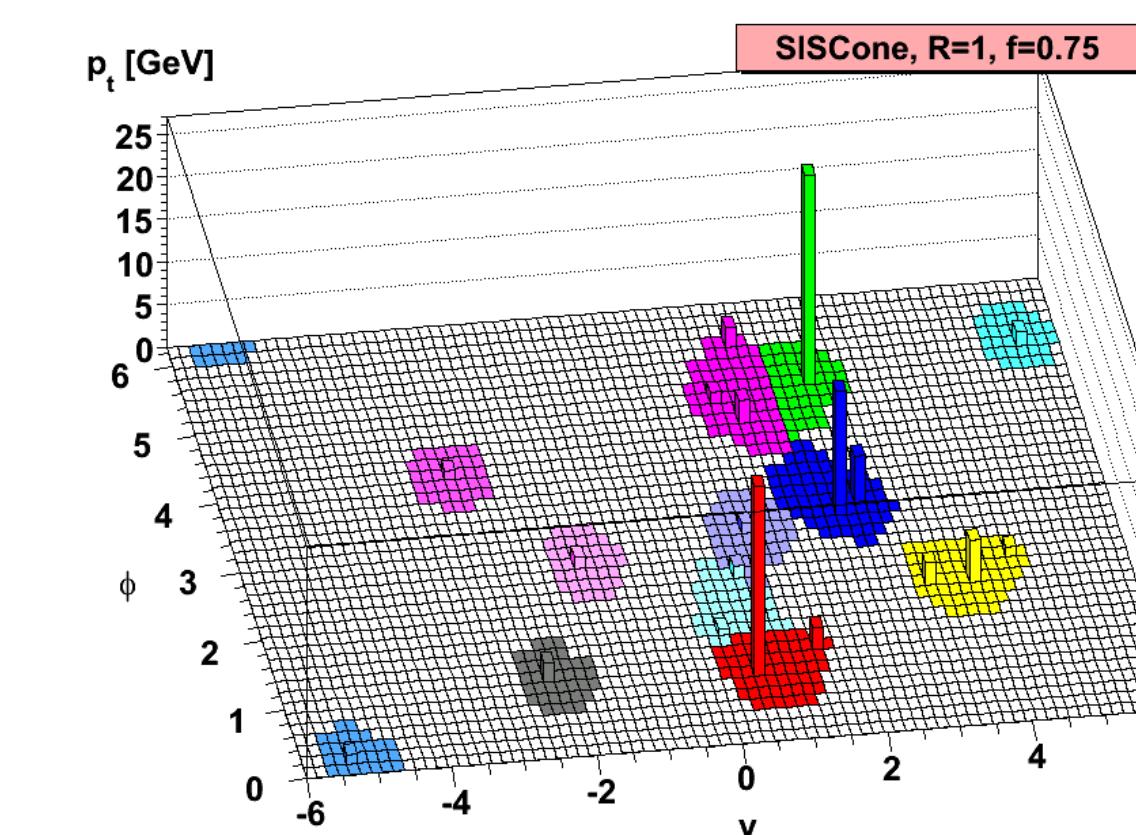
: $\text{anti-}k_t$



: C/A



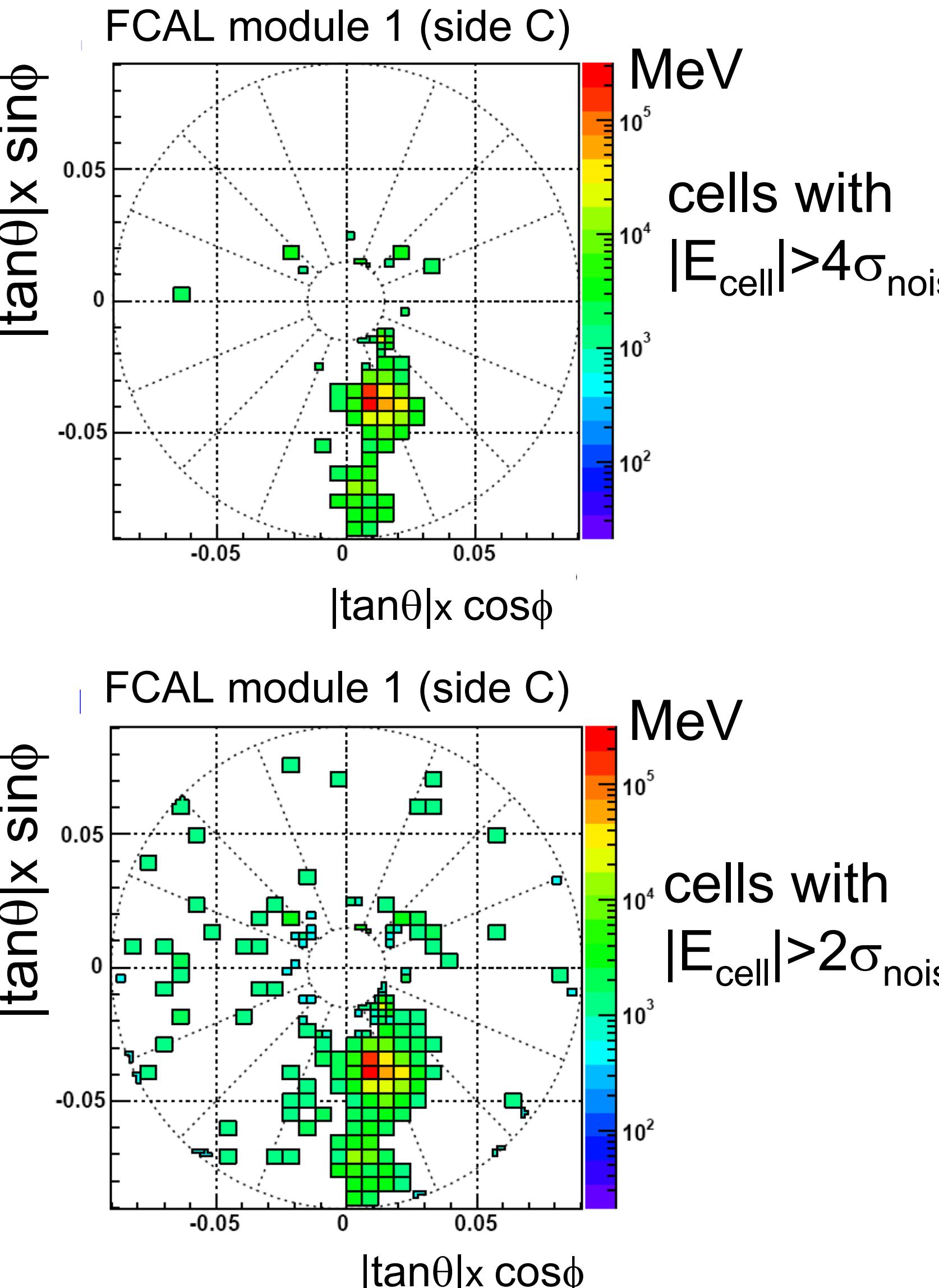
: k_t



: SIScone

Local Hadronic Calibration: Clusters

Sven Menke

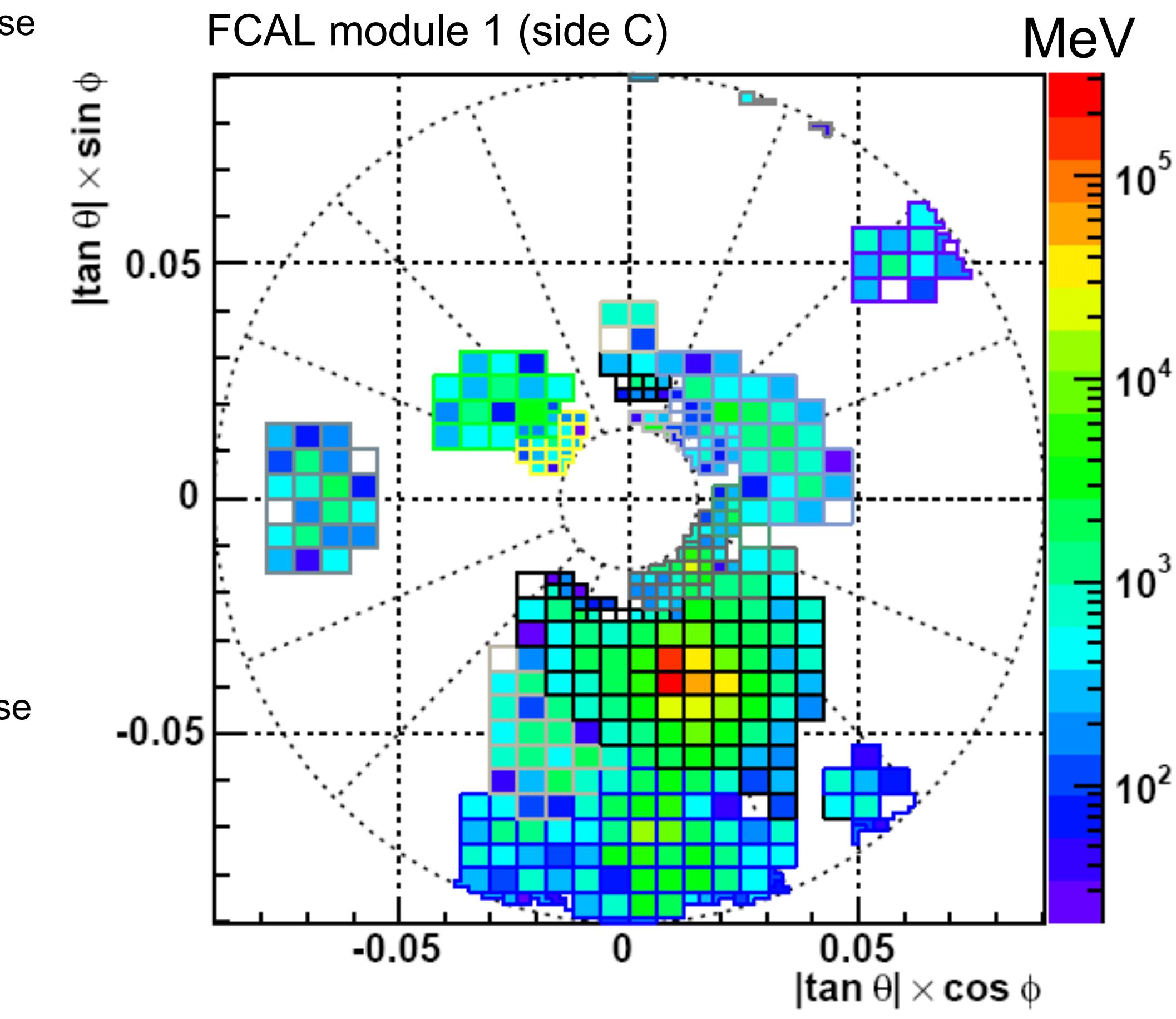


□ Topological clustering

❖ 4,2,0 clusters in FCal

➤ jets with $p_T > 50 \text{ GeV}$

FCAL module 1 (side C)

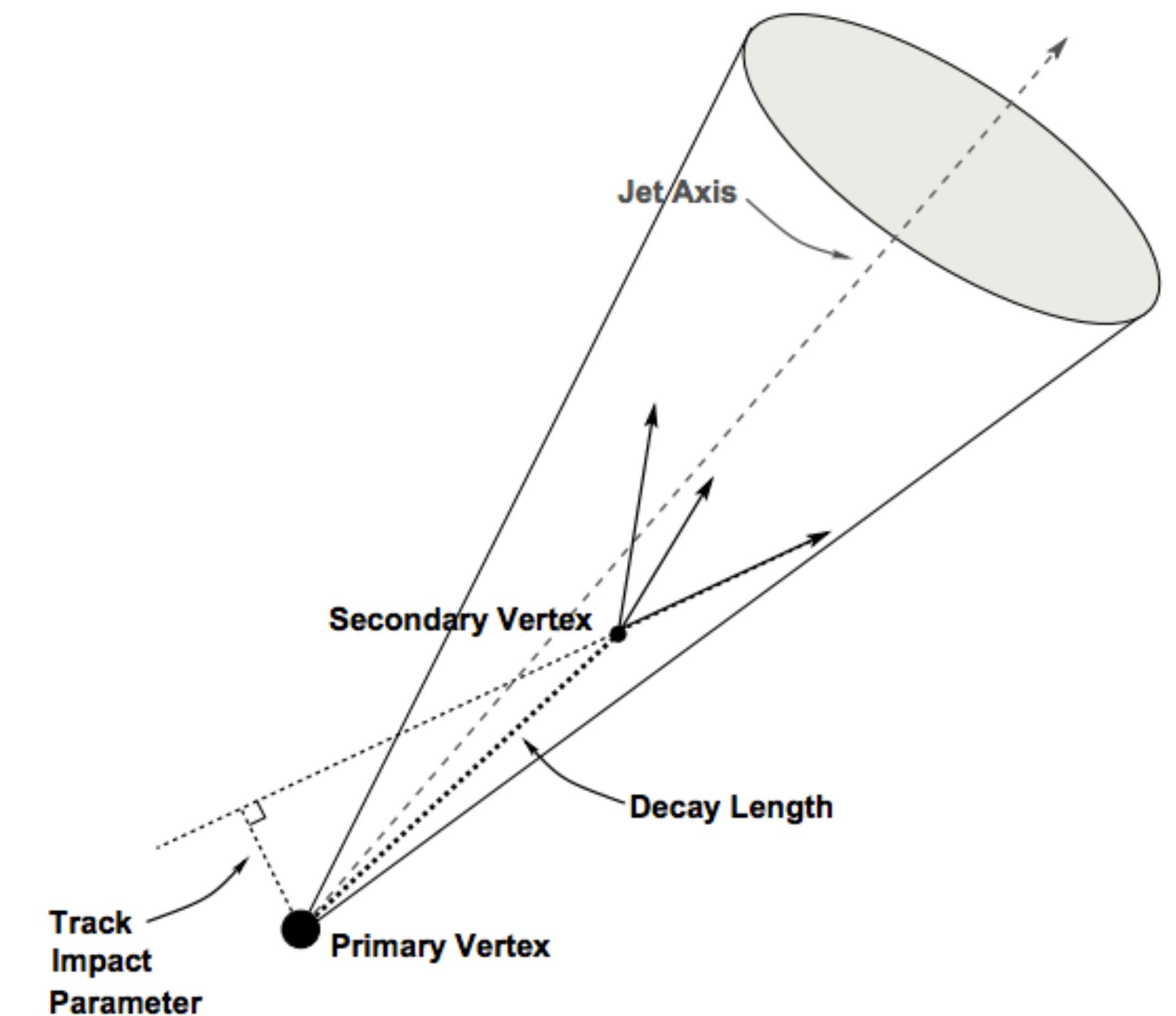


FLAVOR TAGGING

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Finding
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Model VHbb
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2018.04.23

- Jets originating from gluons and u/d/s quarks hadronize promptly
 - D and B mesons have \sim 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 \rightarrow b \rightarrow c chain with Kalman filter)
- All 3 are used as inputs to MV2c10
 - Trained on MC: signal b's, background 90/10 charm/light

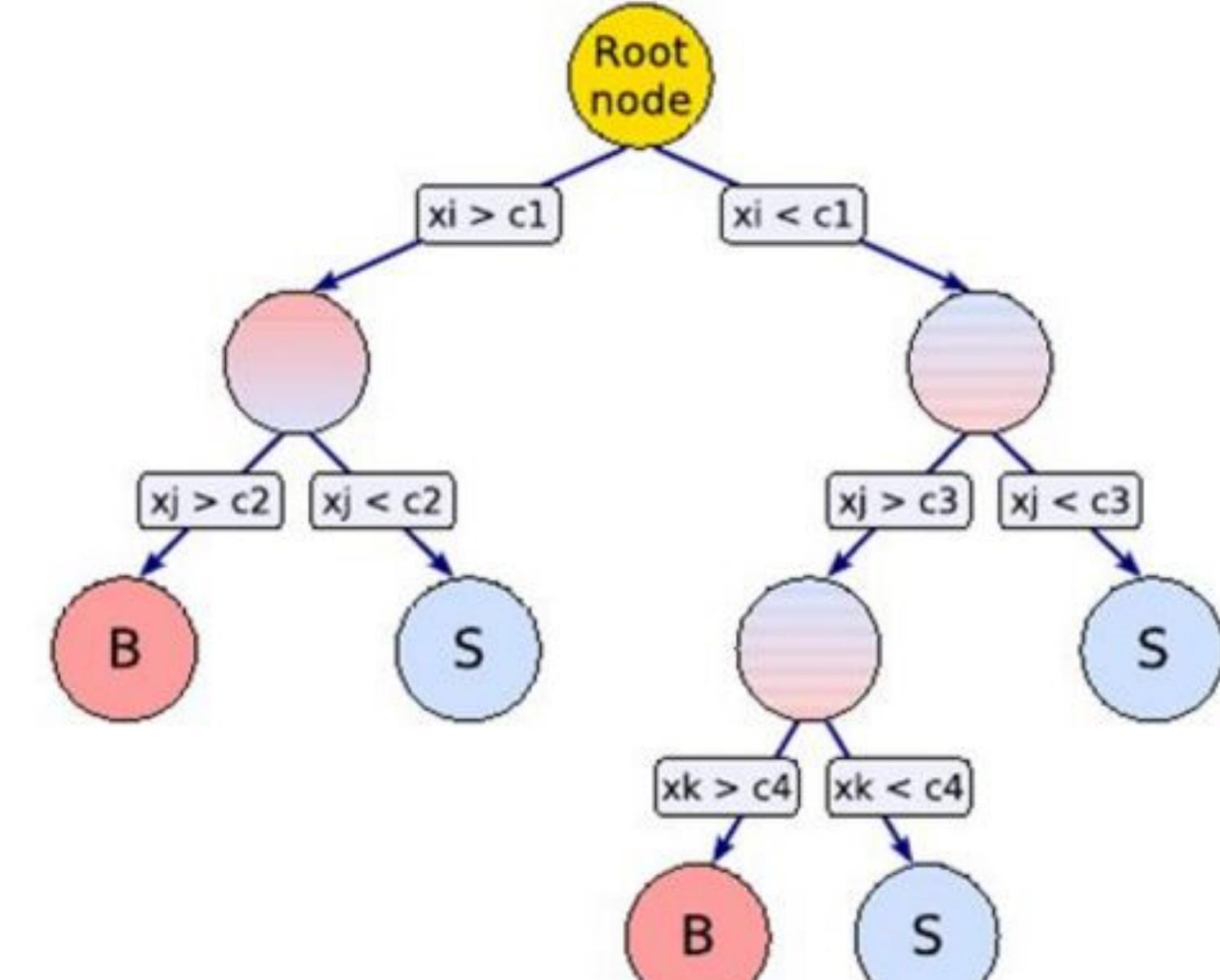


WHAT'S A BDT?

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



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

MVA TRAINING AND OPTIMIZATION SETTINGS

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- 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

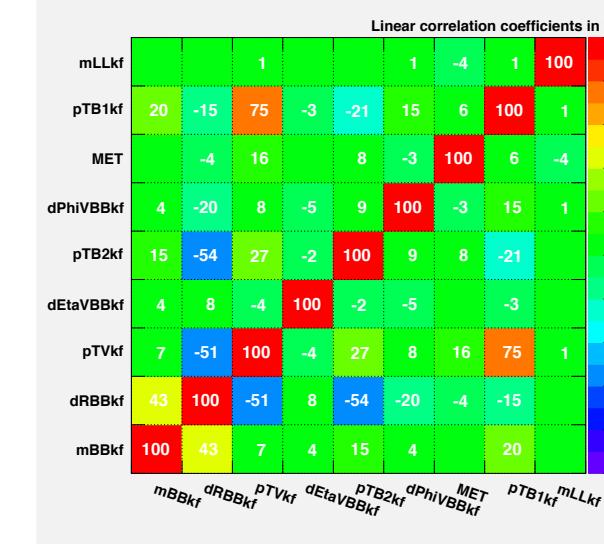
VARIABLE CORRELATIONS

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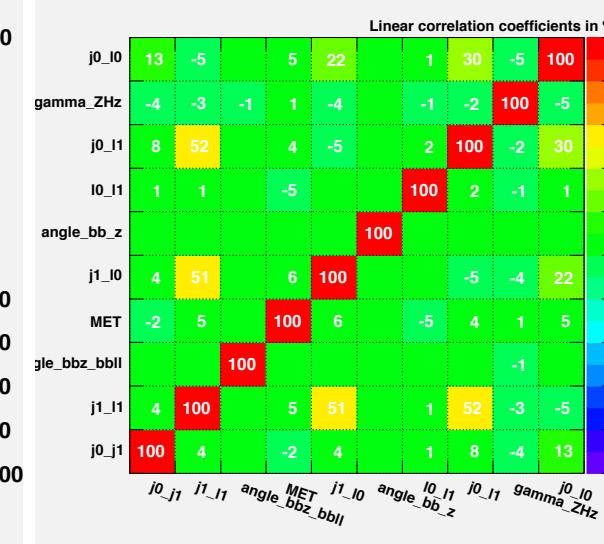
Finding
Standard
Model VHbb
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- LI and RF variables have markedly lower correlations (especially for signal events)
 - Higher correlations in background not unexpected (variables uncorrelated in your signal decay tree might be correlated for background 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)

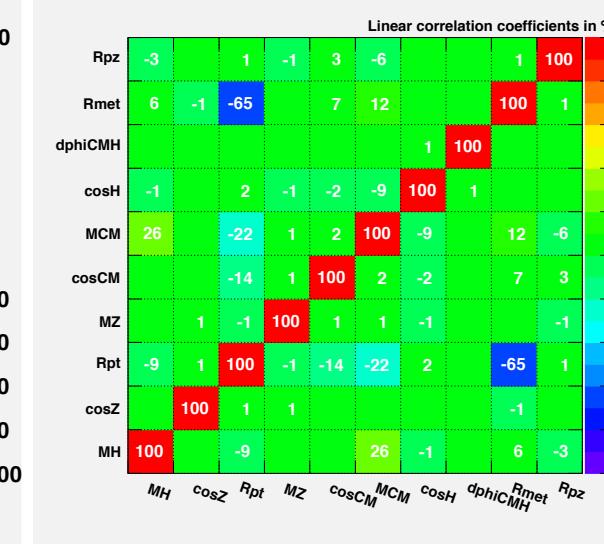
Correlation Matrix (signal)



Correlation Matrix (signal)



Correlation Matrix (signal)

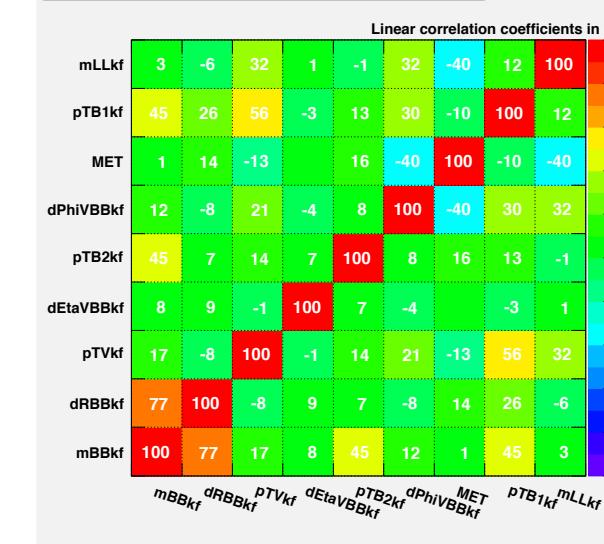


(a) Standard (S)

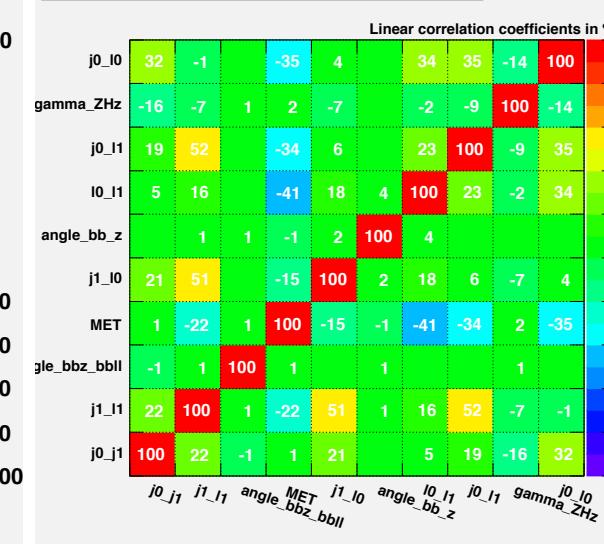
(b) LI (S)

(c) RF (S)

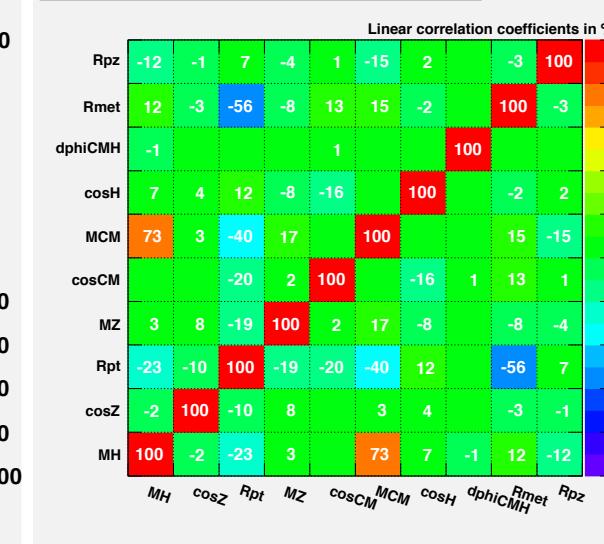
Correlation Matrix (background)



Correlation Matrix (background)



Correlation Matrix (background)



(d) Standard (B)

(e) LI (B)

(f) RF (B)

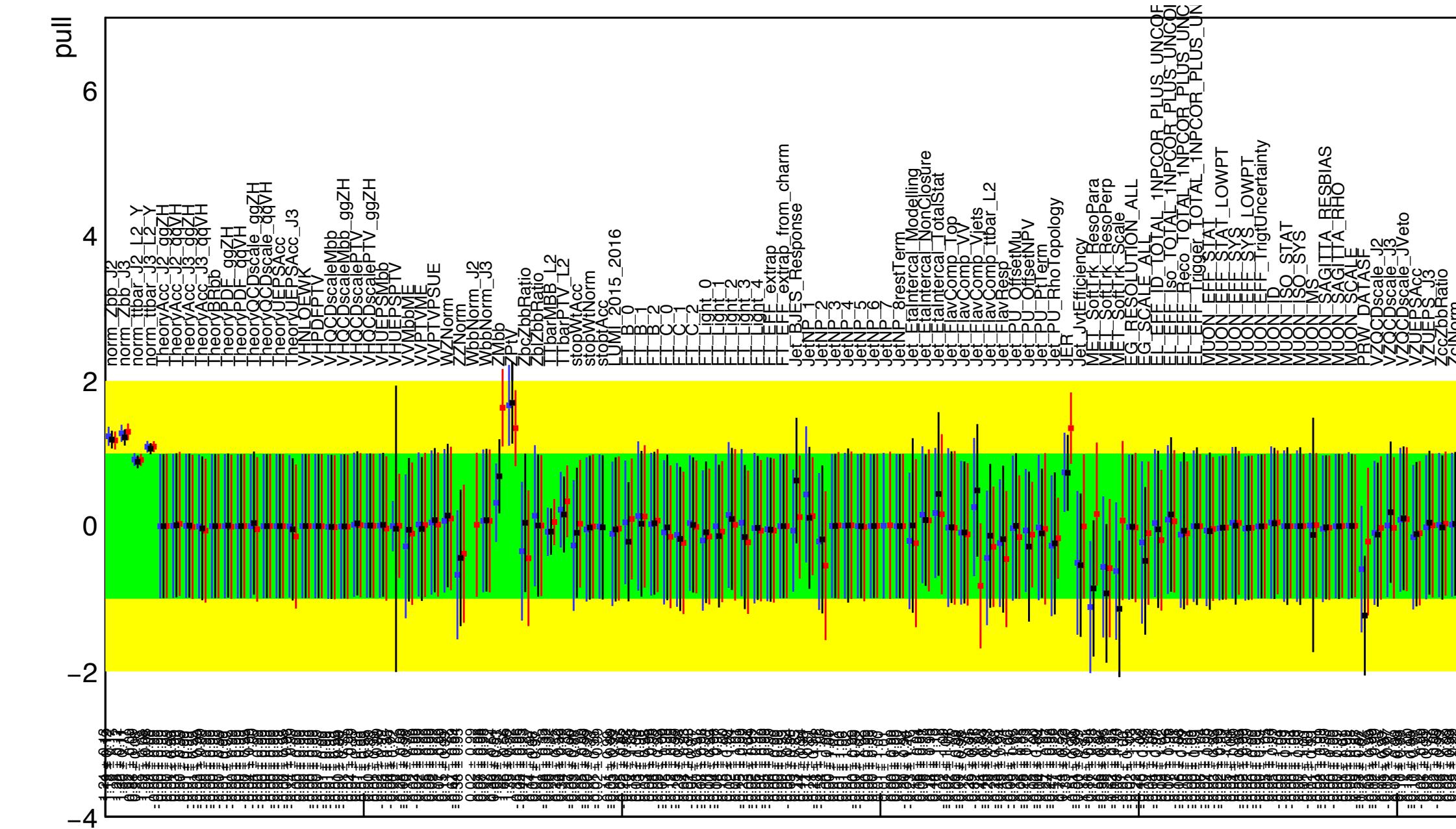
HOW DOES A MORE ORTHOGONAL BASIS HELP?

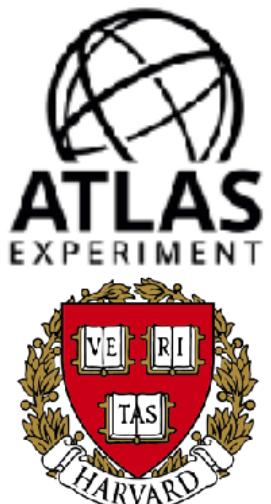
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- There are a lot of NP's
- ~105 here (not incl. MC stat errors); ~500 for combined full ATLAS VH
- Gaussian penalty terms can really add up

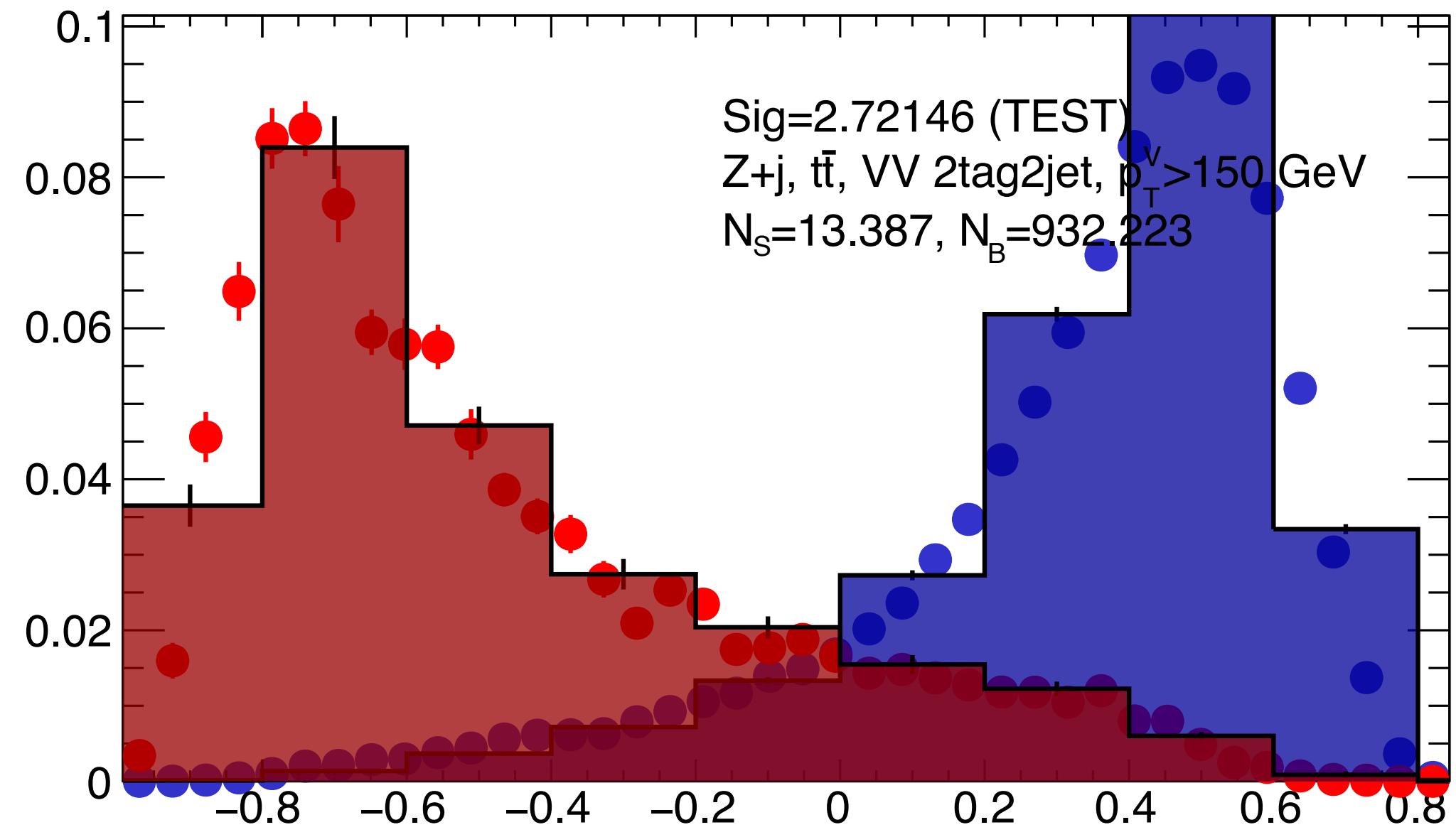
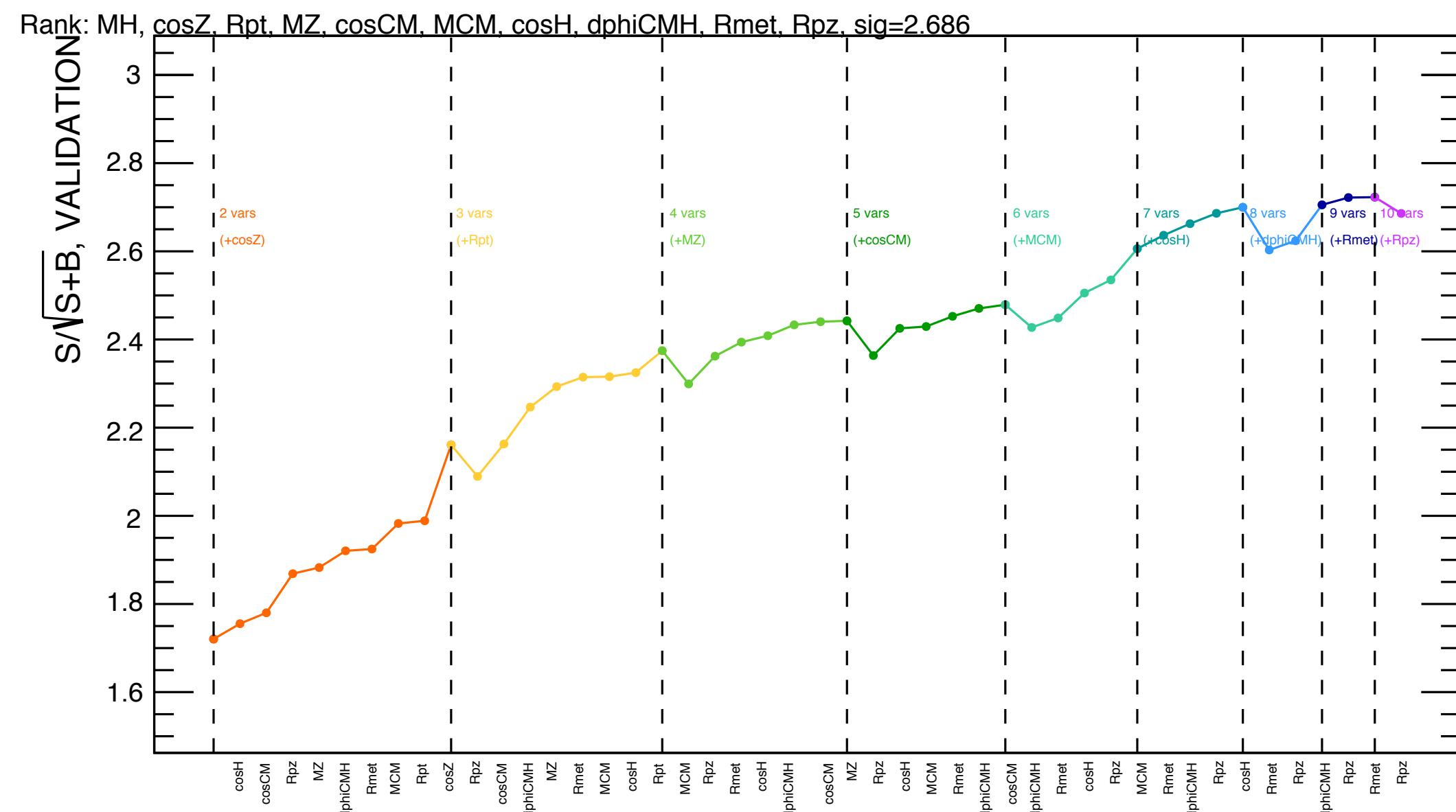
$$\mathcal{L}(\mu, \theta) = \text{Pois}(n | \mu S + B) \left[\prod_{i \in \text{bins}} \frac{\mu s_i + b_i}{\mu S + B} \right] \prod_{j \in \text{NP's}} \mathcal{N}_{\theta_j}(\theta_j, \sigma_j^2 | 0, 1)$$





RANKING EXAMPLE: RF 2JET HI PTV

- For full plots, see companion slides



SENSITIVITIES

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- 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

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	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

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- 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 $\text{EFFNP}_{\text{UNFNP}}$, map factors A_{ij} , and unfolded amplitudes $|\text{UNFNP}_j|$):
 - $\text{EFFNP}_i = (\sum_j A_{ij} * |\text{UNFNP}_j| * \text{UNFNP}_j) / (\sum_{(j,\text{quadrature})} A_{ij} * |\text{UNFNP}_j|)$
- 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

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- Physics is different at different center of mass energies
- MC state of the art changes
 - NP's are defined differently, too
- Use χ^2 extrapolation to estimate effects
- Not significant (biggest shift shown below)

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

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

EXPERIMENTAL SYSTEMATICS

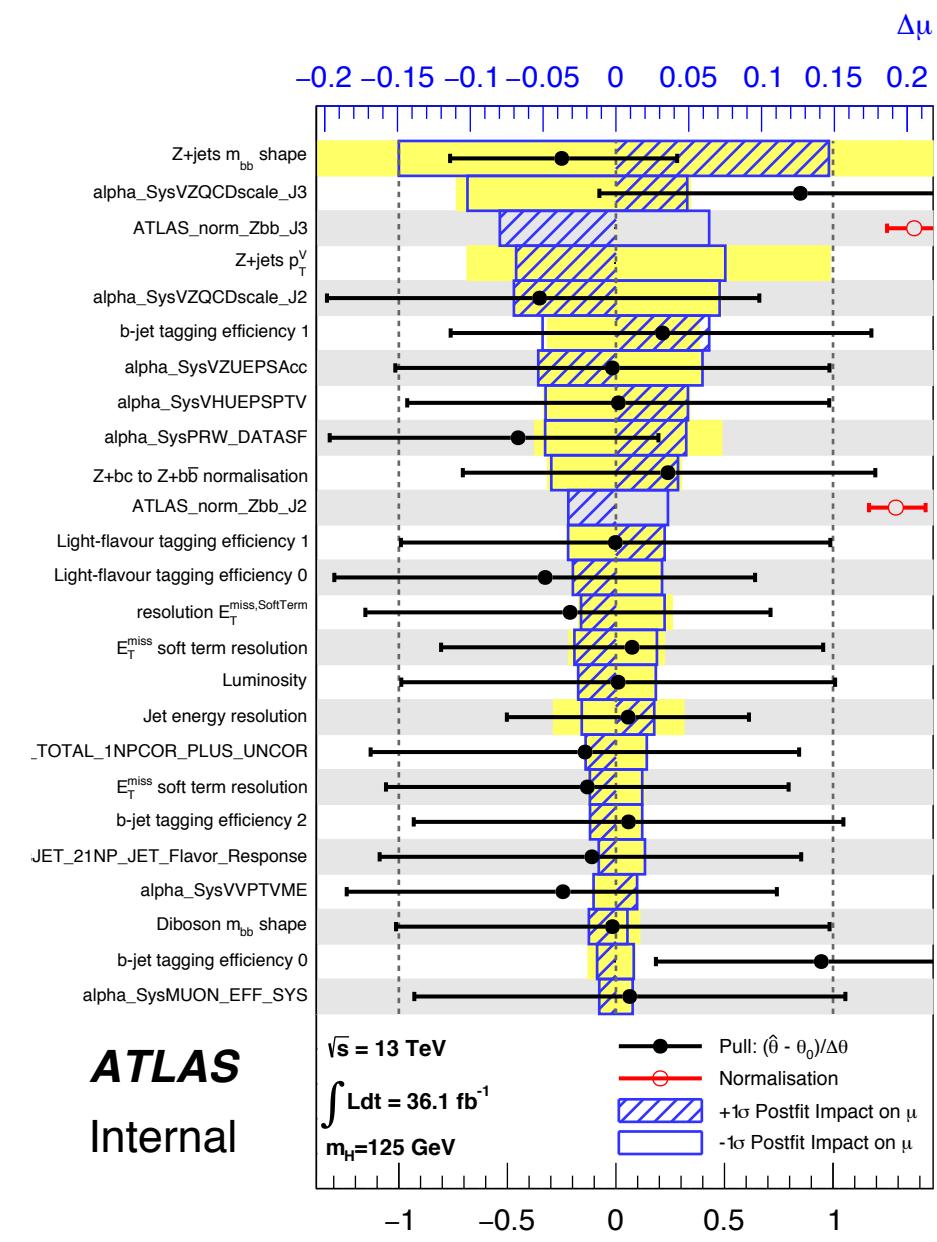
70

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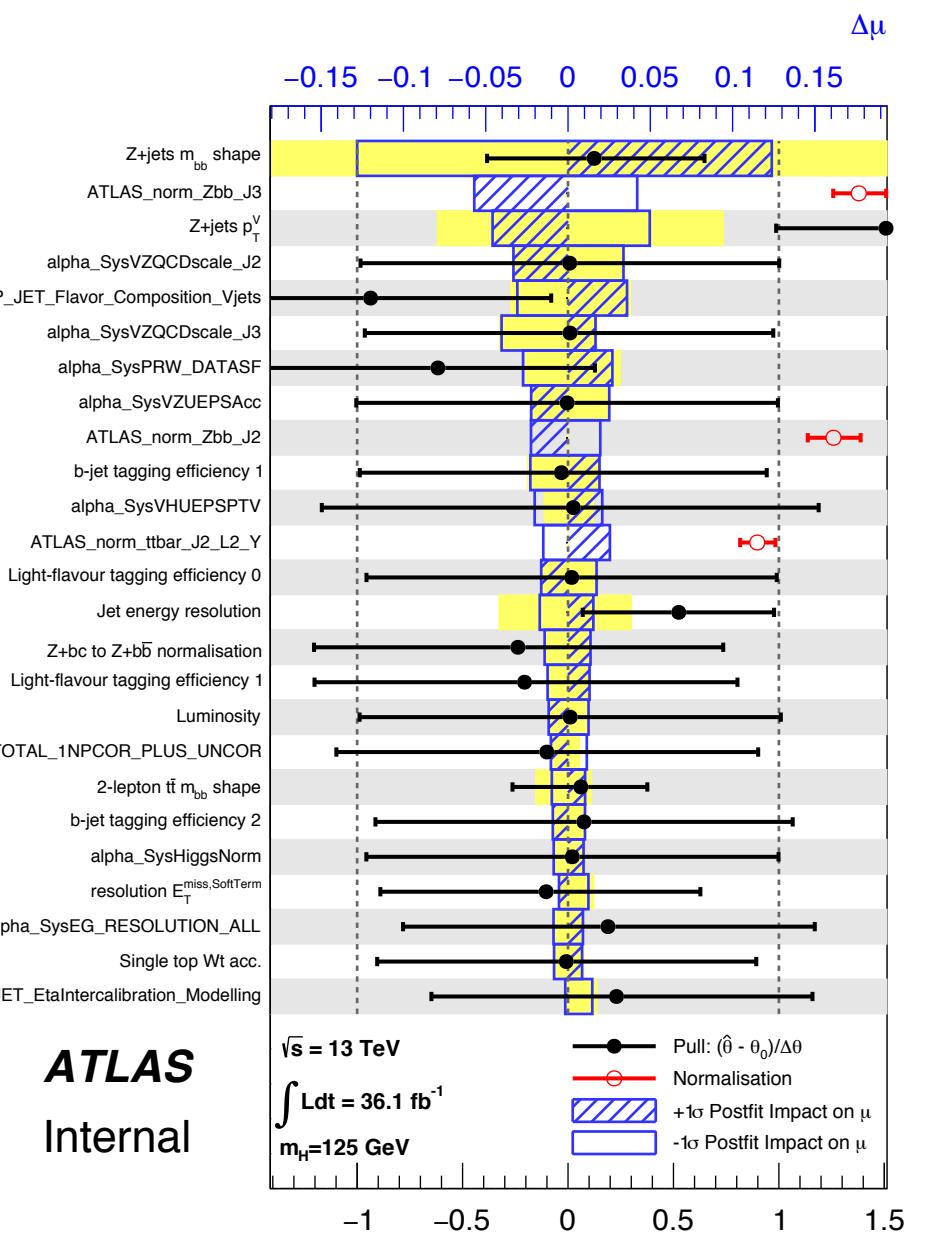
- More backwards compatibility than with modeling; only JES/b-tagging of concern
- Explicitly correlate NP's whose meaning remains the same
 - JES: JetEtMiss CP group provides maps to unfold and correlate NP's
 - FTag: check leading Eigen NP's (meaning roughly same)

NP RANKING

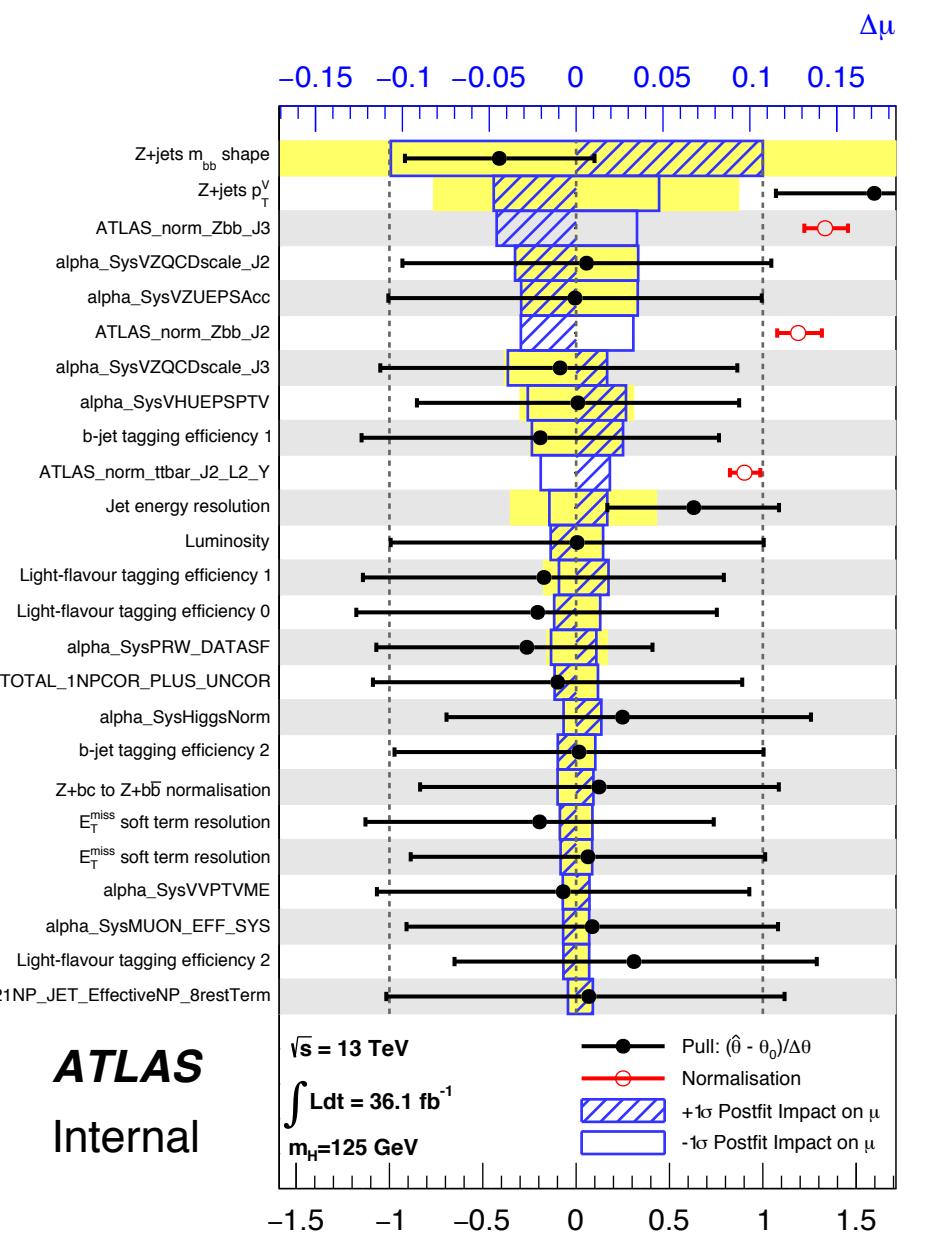
- These are also fairly similar—Z+jets and signal systematics NP's consistently highly ranked



(a) Standard



(b) LI



(c) RF

ANALYSIS JES DETAILS

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- 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

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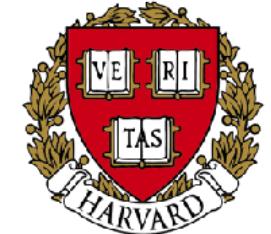
- Following recommendation from JetEtMiss described in depth [here](#)
- Two schemes “strong” and weak
 - Strong: match all non-stat NP’s with some exceptions:
 - No Run2 counterpart: LAr_ESmaterial, LAr_ESpresampler
 - Run1 Zjet_JVF with Run2 LAr_JVT
 - Run2 EtaIntercalibration_NonClosure has no listed 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

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- 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

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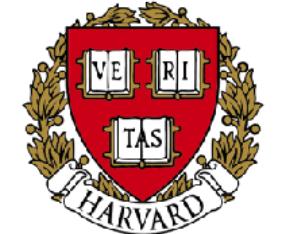
- Virtually no difference depending on JES scheme

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

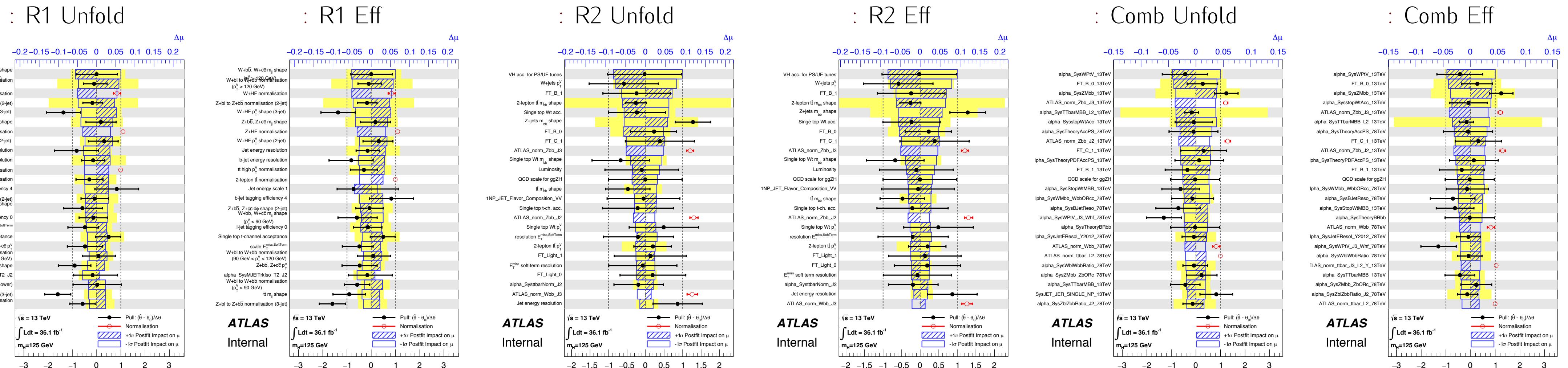
	R1 Unfold	R1 Eff	R2 Unfold	R2 Eff	Comb Unfold	Comb Eff
Obs. Sig.	1.369	1.374	3.539	3.539	3.58	3.572
Obs. p0	0.0854	0.0847	0.0002	0.0002	0.0002	0.0002
Obs. Limit	1.21	1.21	1.87	1.87	1.37	1.38



JES NP RANKING

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MODELING SYSTEMATICS CROSS-CHECKS

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- 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

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- 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

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- 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

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- Overall muhat errors not moving around; mu does

Table: Breakdowns: btag-b

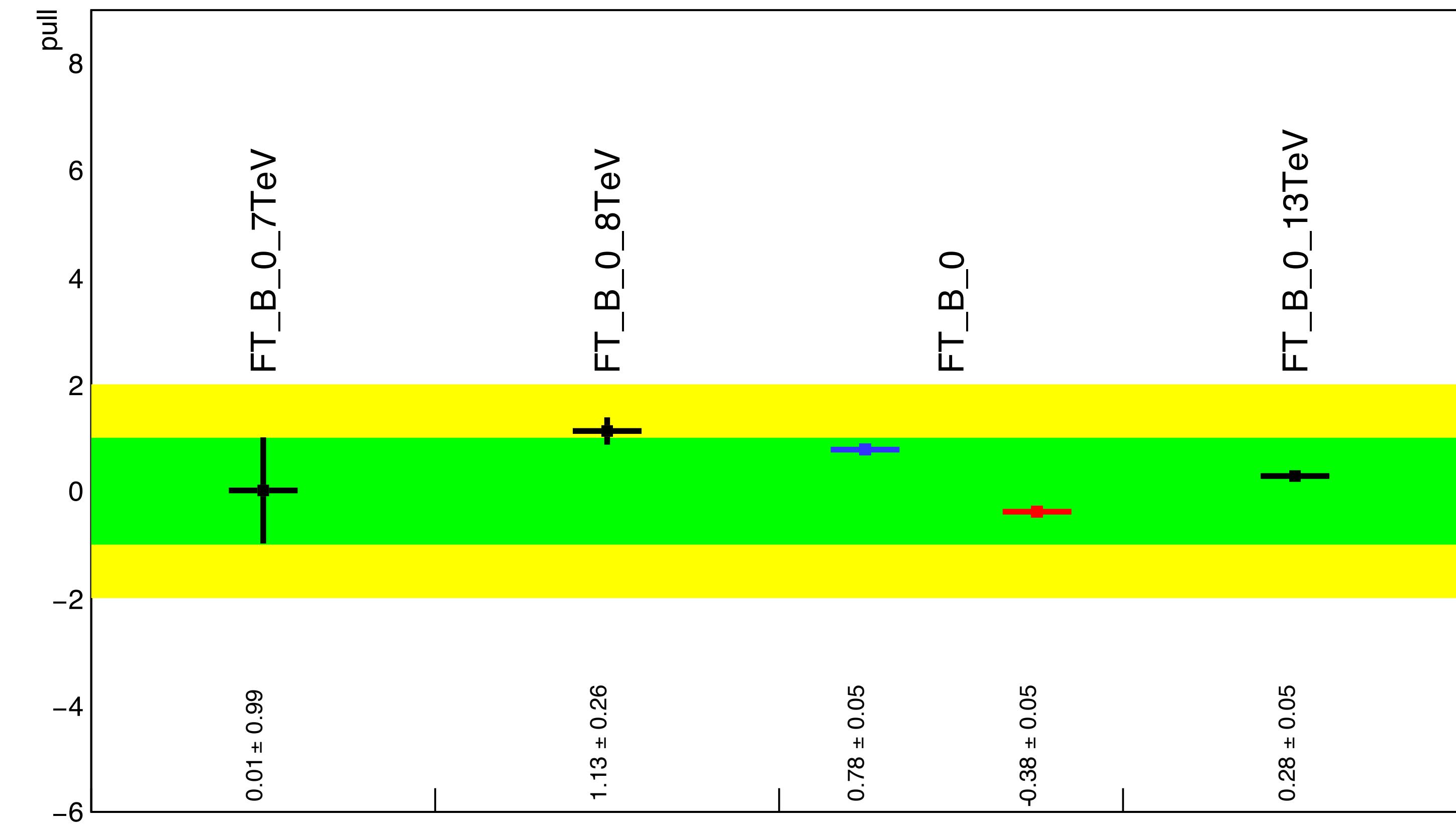
	Comb Eff	BTag B0	B0 8TeV Not Flipped
muhat	0.9115	0.9598	0.8806
Total	+0.277 / -0.265	+0.273 / -0.260	+0.282 / -0.268
DataStat	+0.189 / -0.185	+0.185 / -0.181	+0.193 / -0.189
FullSyst	+0.203 / -0.190	+0.201 / -0.186	+0.206 / -0.189
BTag	+0.080 / -0.080	+0.073 / -0.072	+0.083 / -0.079
BTag b	+0.064 /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

B-TAGGING PULL COMPARISONS: BTAGB0

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- 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*

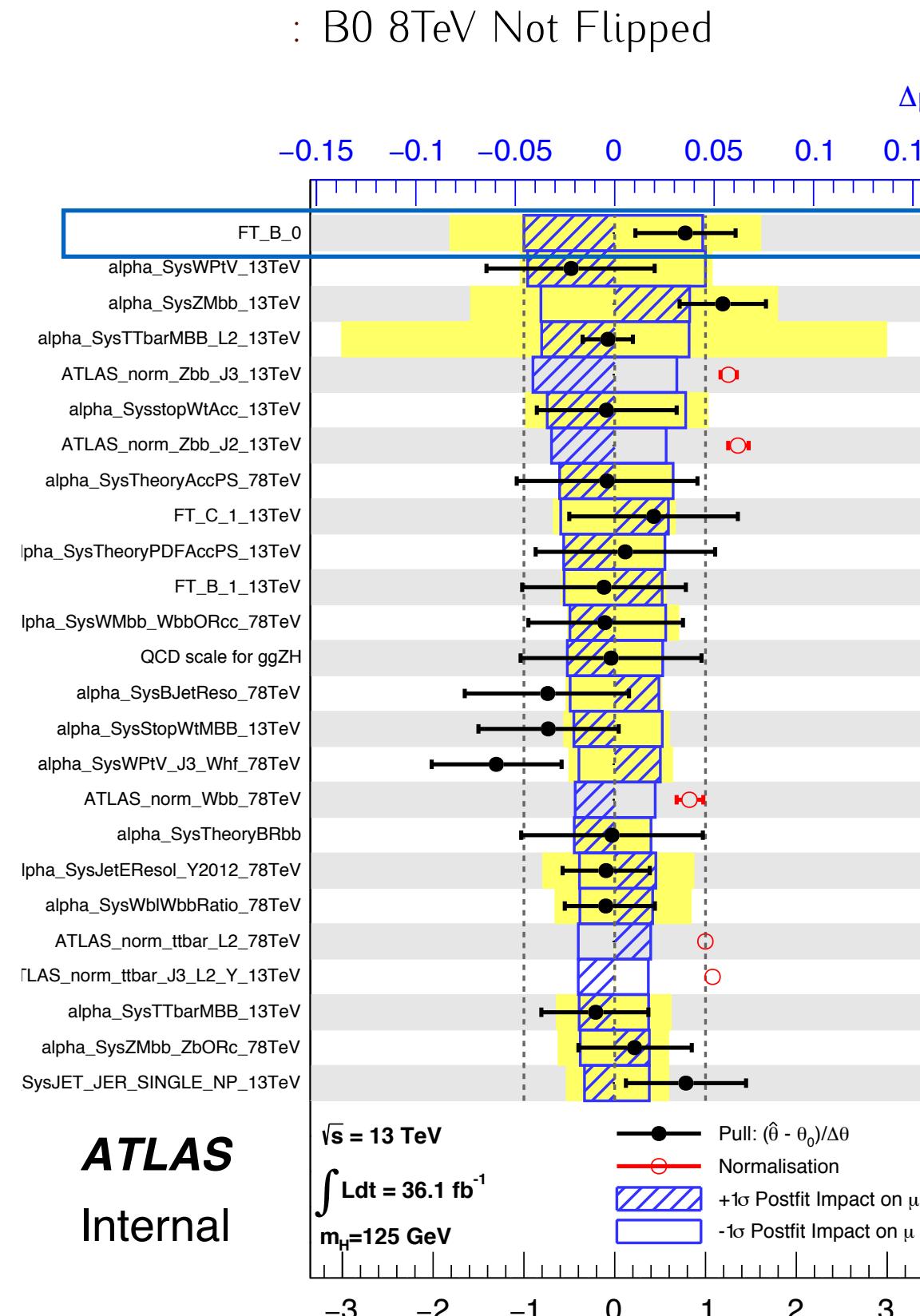
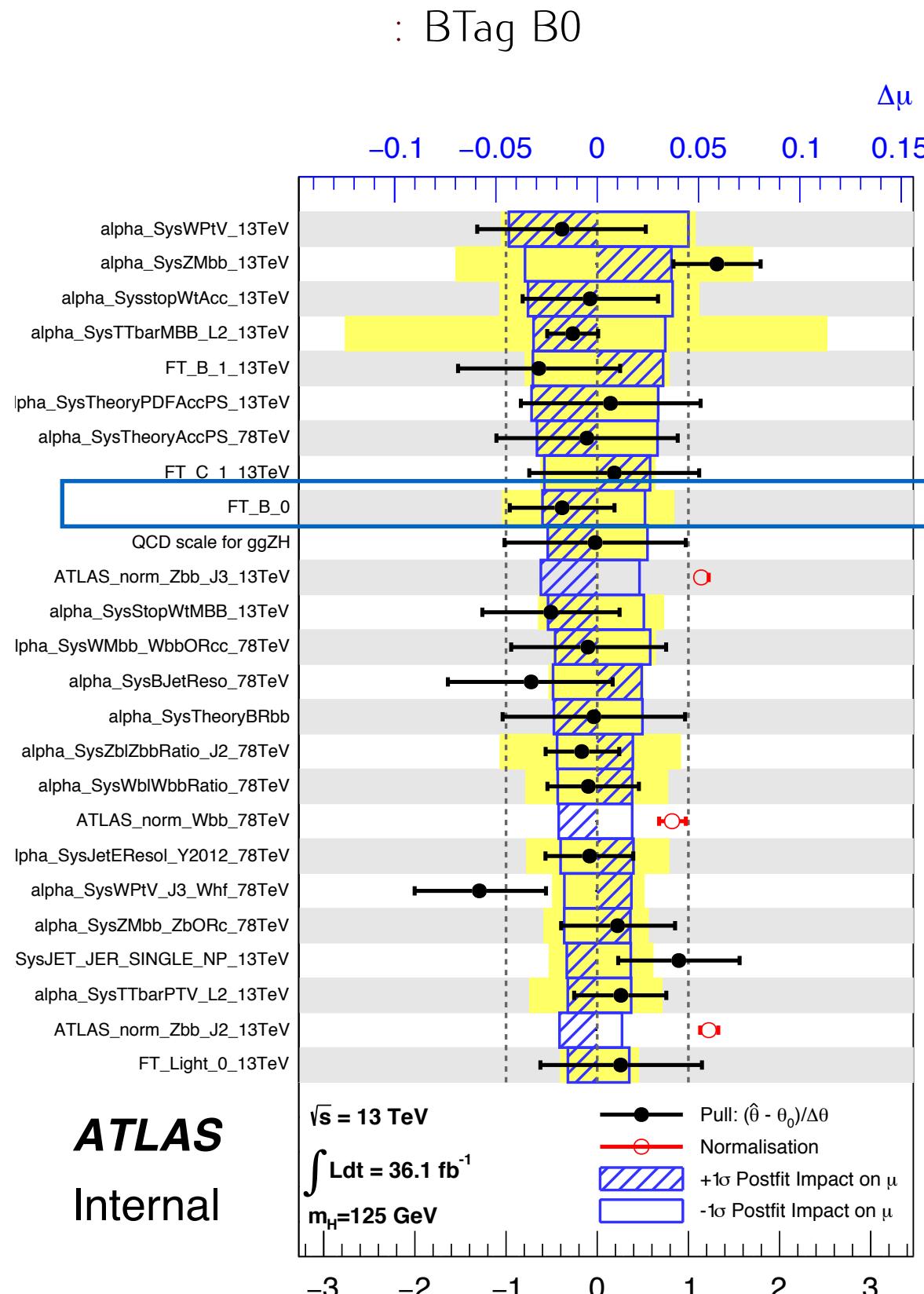
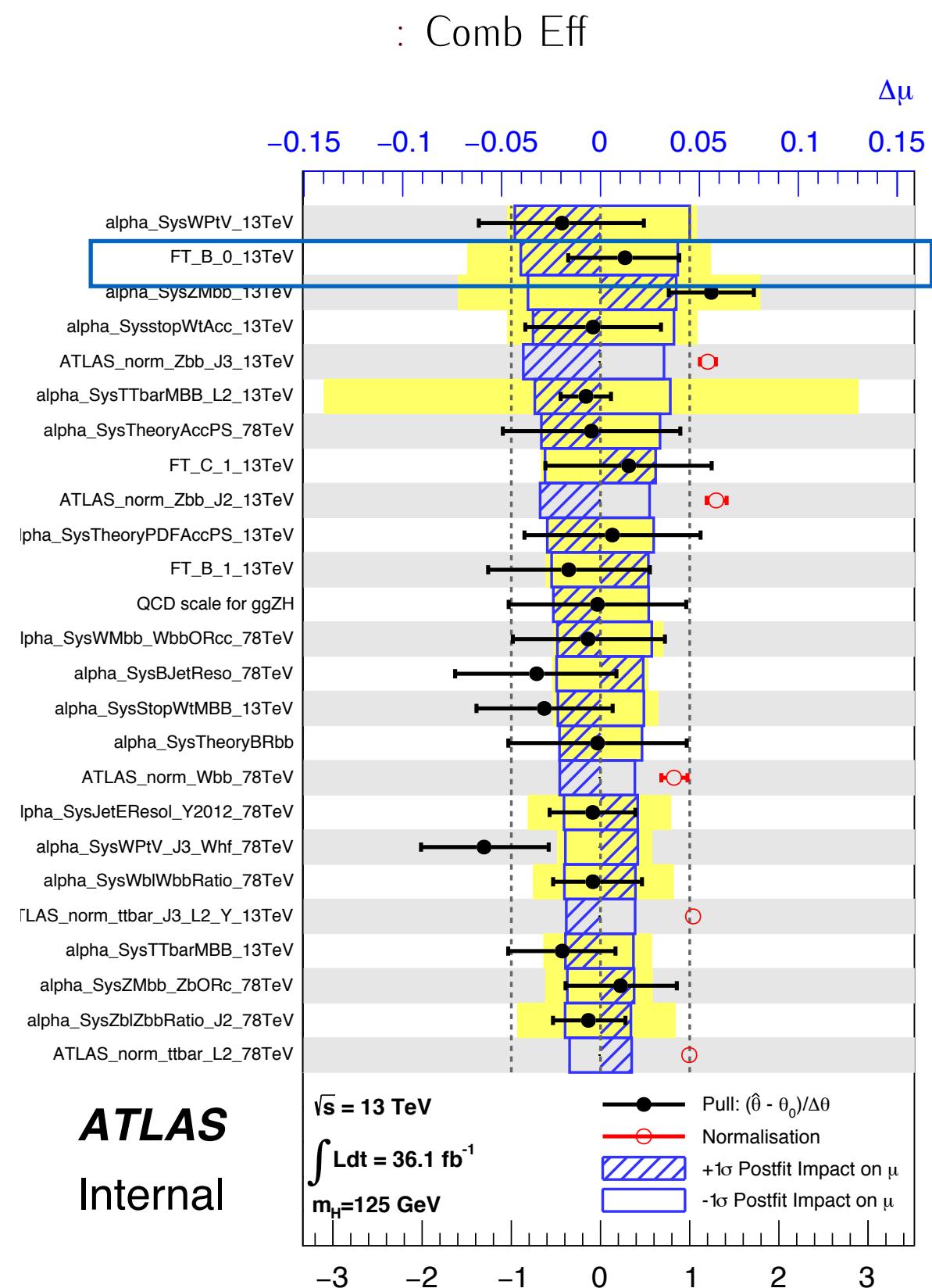


B-TAGGING COMBINED NP RANKING

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- 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

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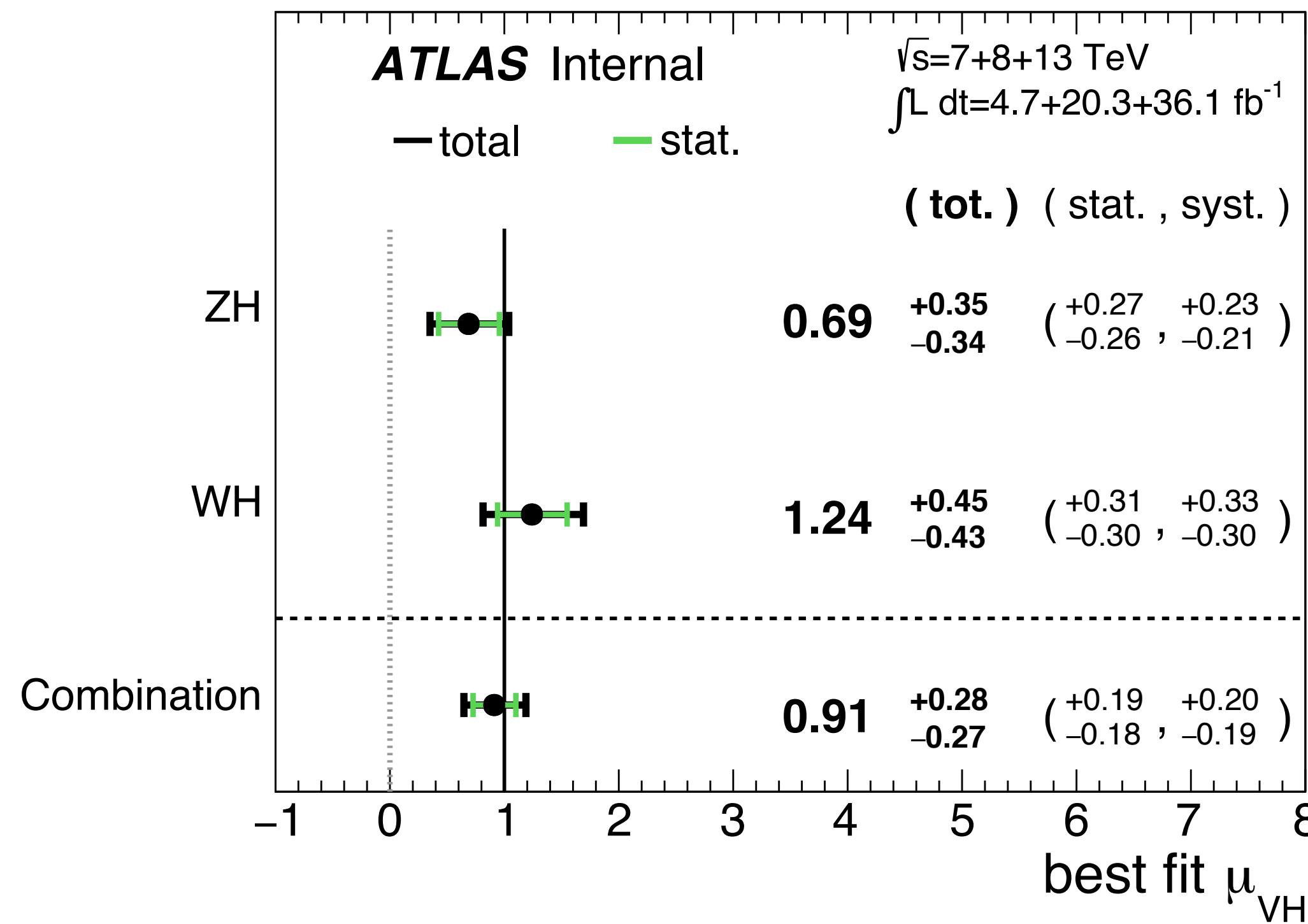
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- Nominal fit (Run1+Run2 1 POI): 3636626.6821
- 2 POI (Run1/Run2): 3636625.8346 → 19%
- 2 POI (WH/ZH): 3636626.1827 → 32%
- 3 POI (012lep): 3636622.3274 → 1.2%
- 6 POI (012lep × Run1/Run2): 3636621.4741 → 6.4%
- 3POI has a 64% compatibility with the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

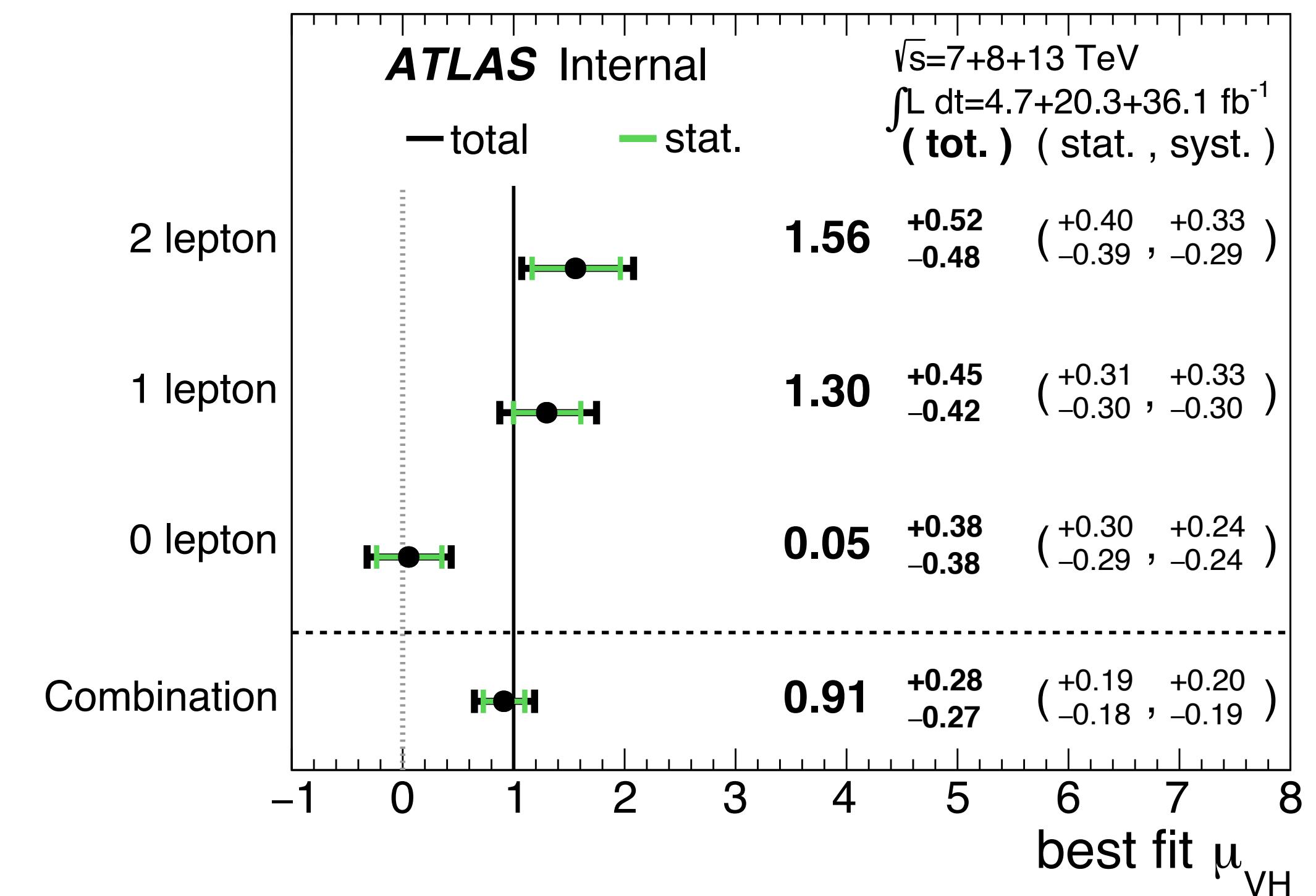
COMBINED NICE PLOTS (012LEP, WH/ZH)

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: WH/ZH: 31.76%



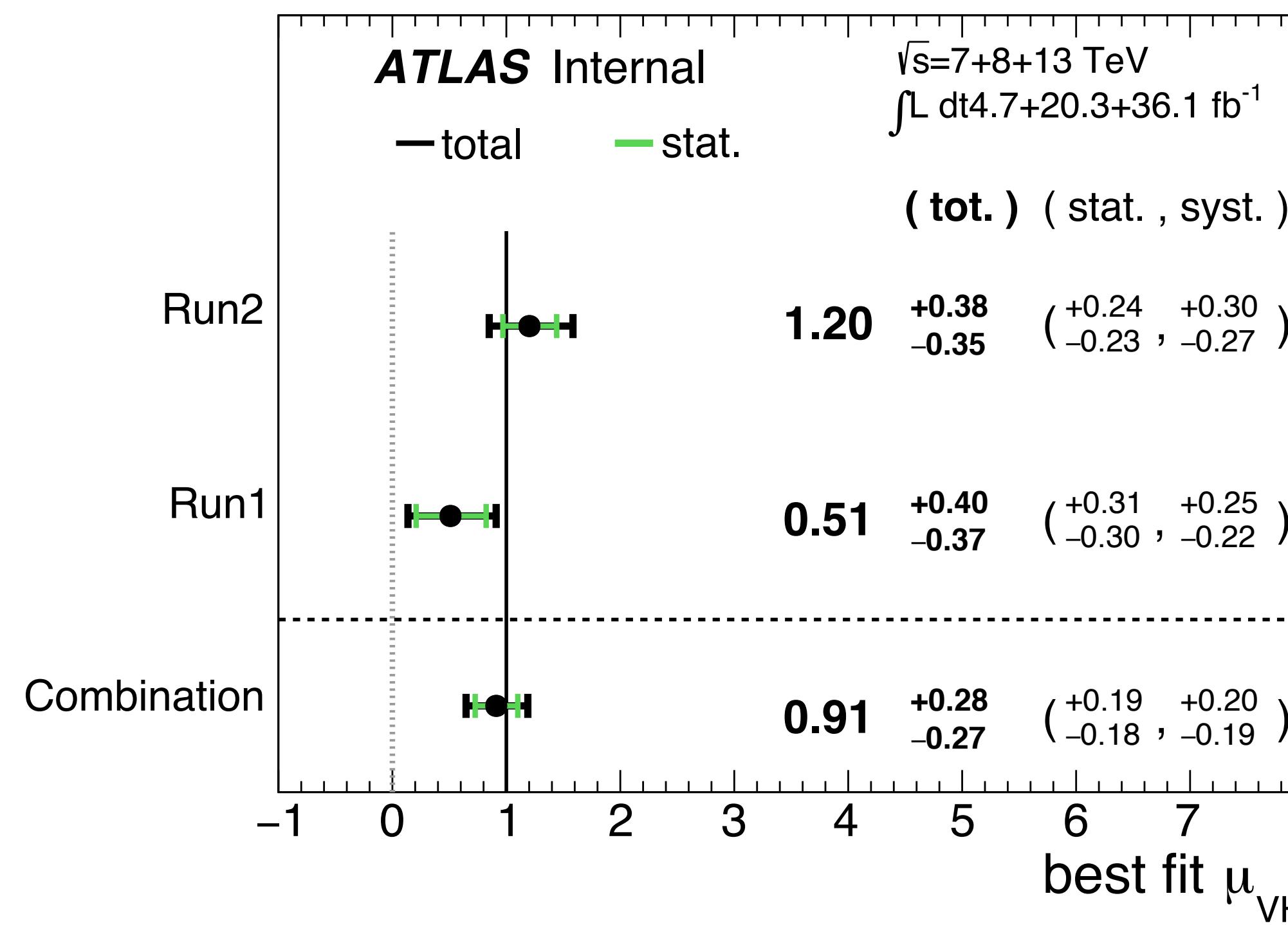
: Leptons: 1.28%



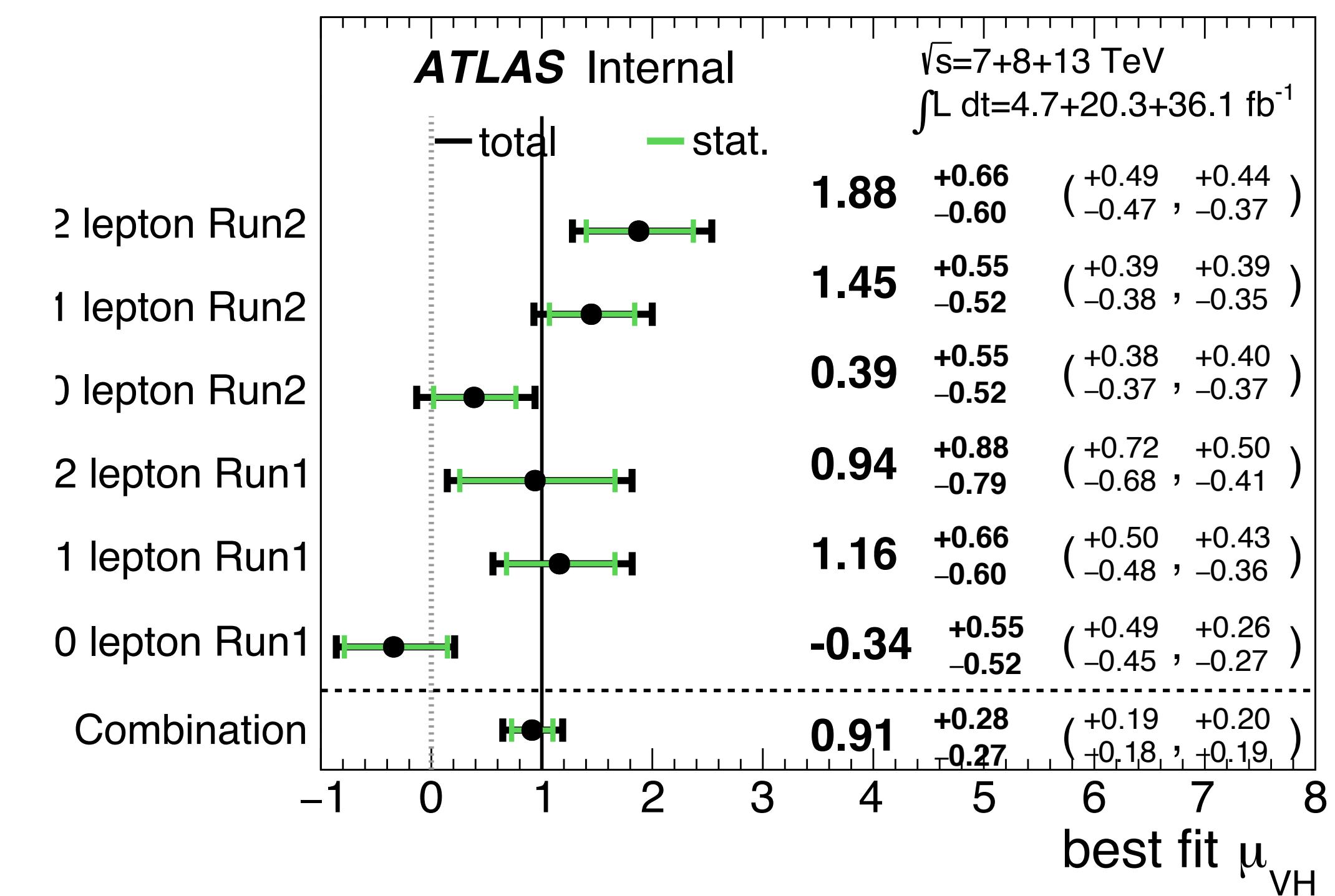
RUN1/RUN2 NICE PLOTS (R1/R2, 6POI)

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: Run1/Run2: 19.29%



: Run1/Run2 leptons: 6.43%

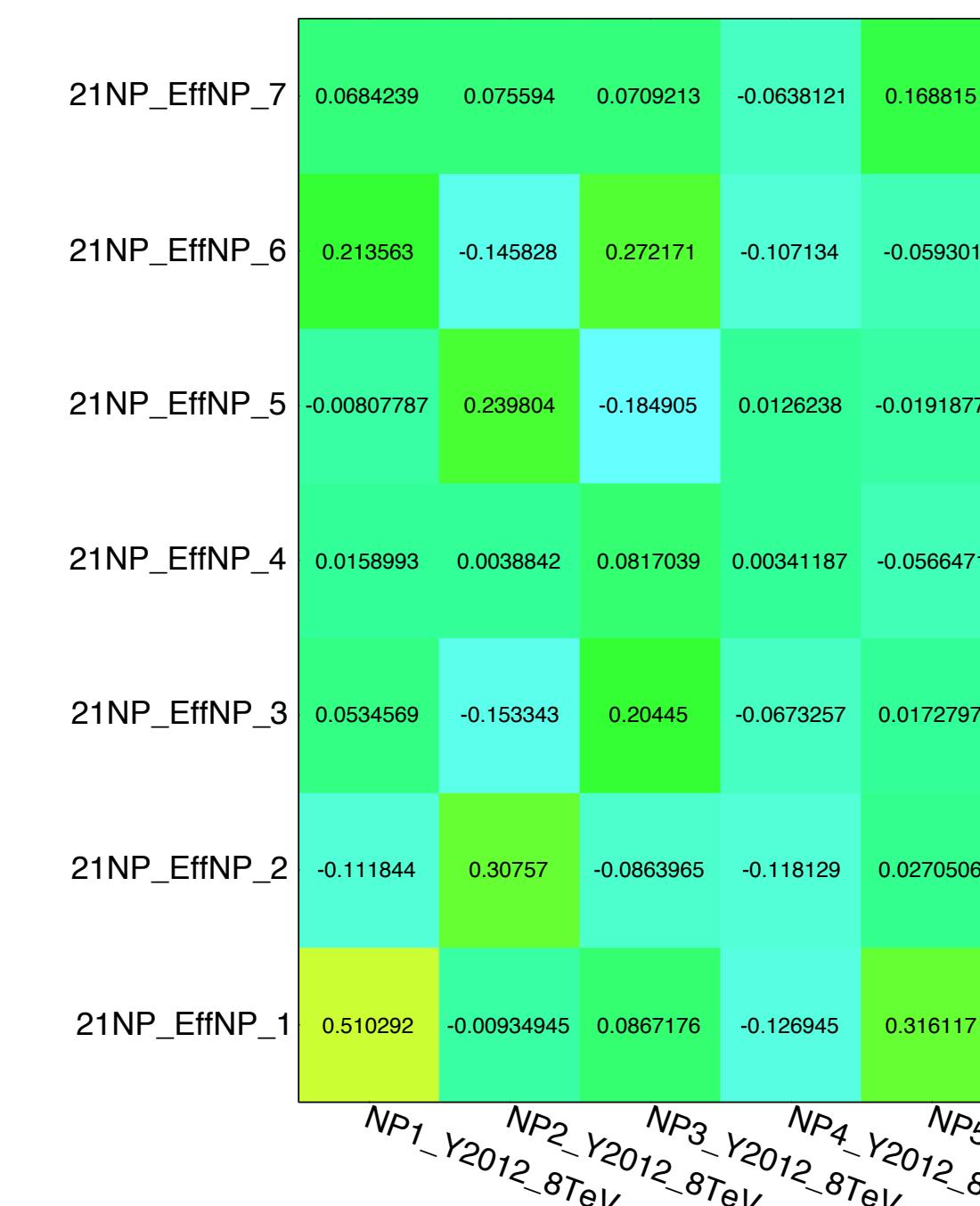
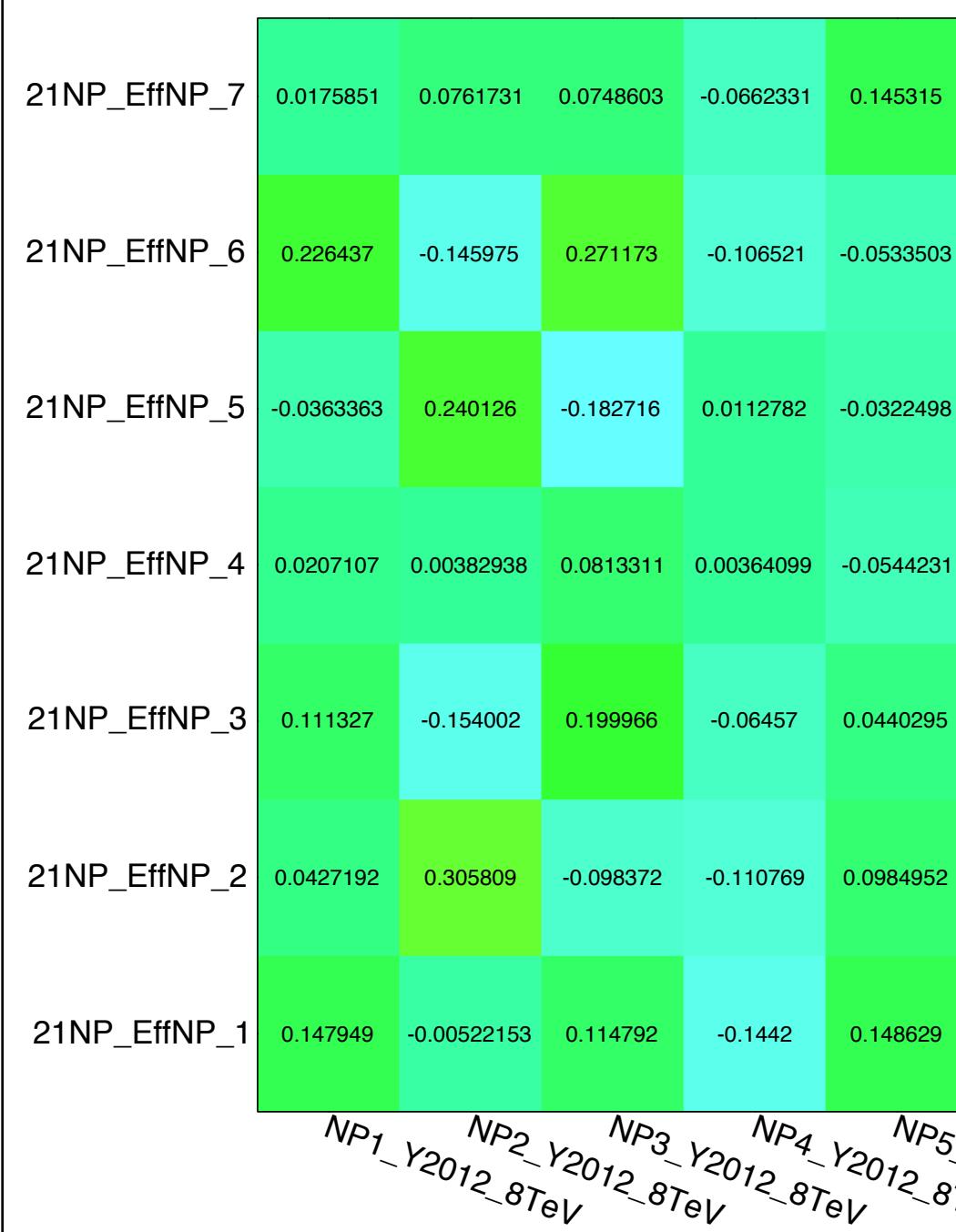


RELATING EFFECTIVE NP'S: LEPTONS

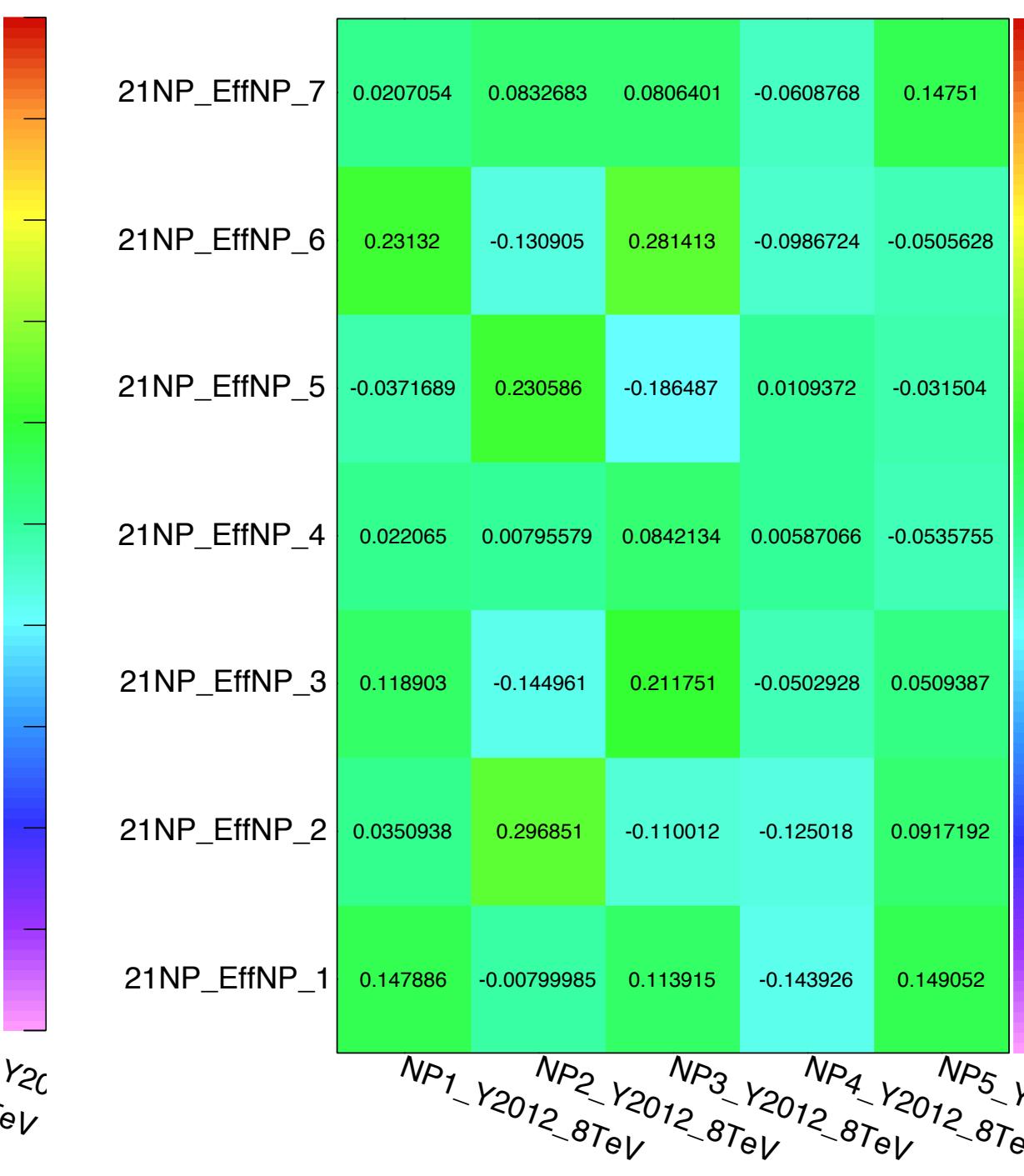
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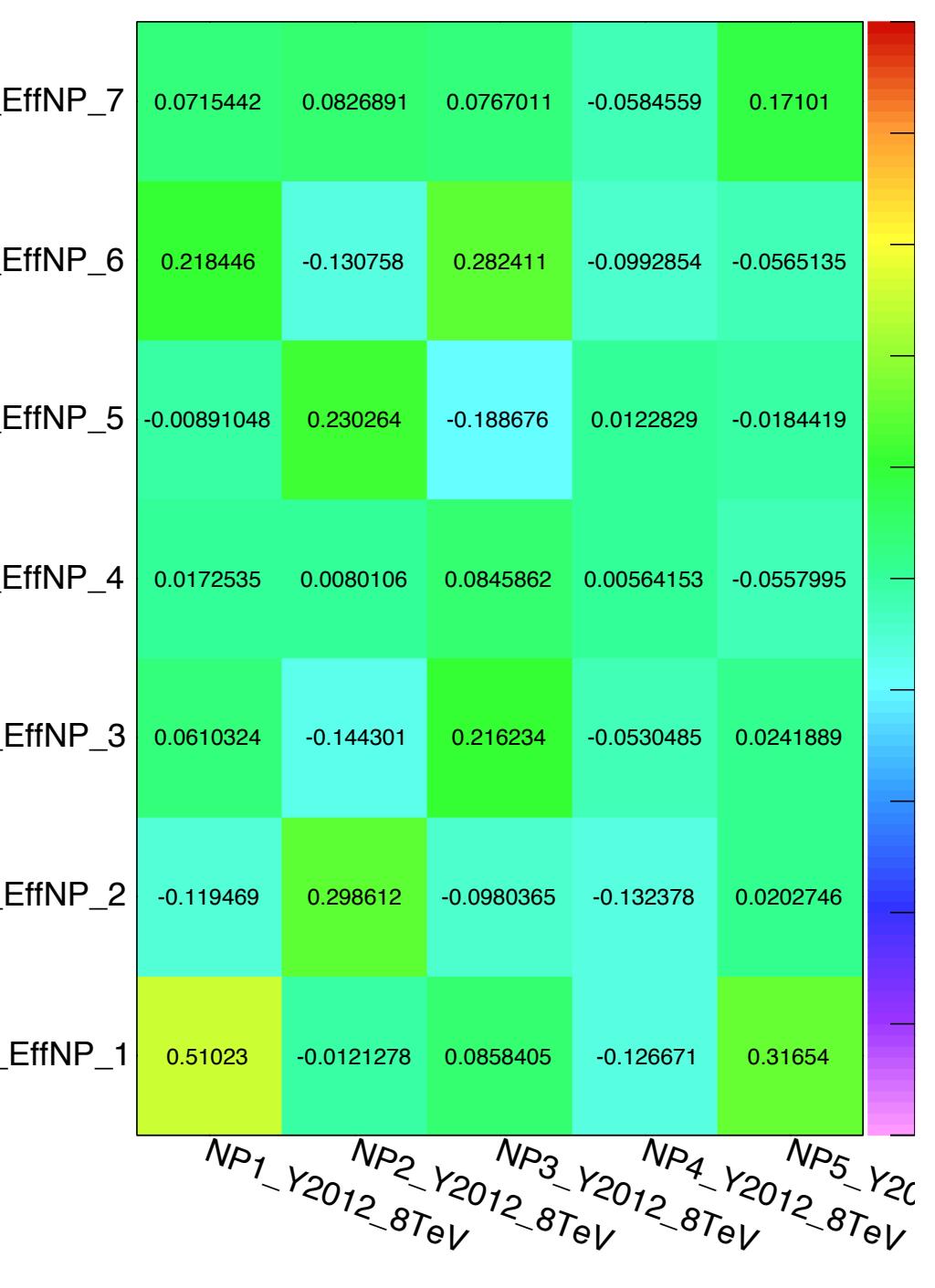
- Using the Run1 and Run2 maps and a correlation matrix that indicates level of correlation between Run1/Run2 effective NP's
 - Correlate electrons and muons? LAr_ESZee is largest source of correlation between Run1 and Run2 effective NP's



Corr electrons



Corr muons



Both

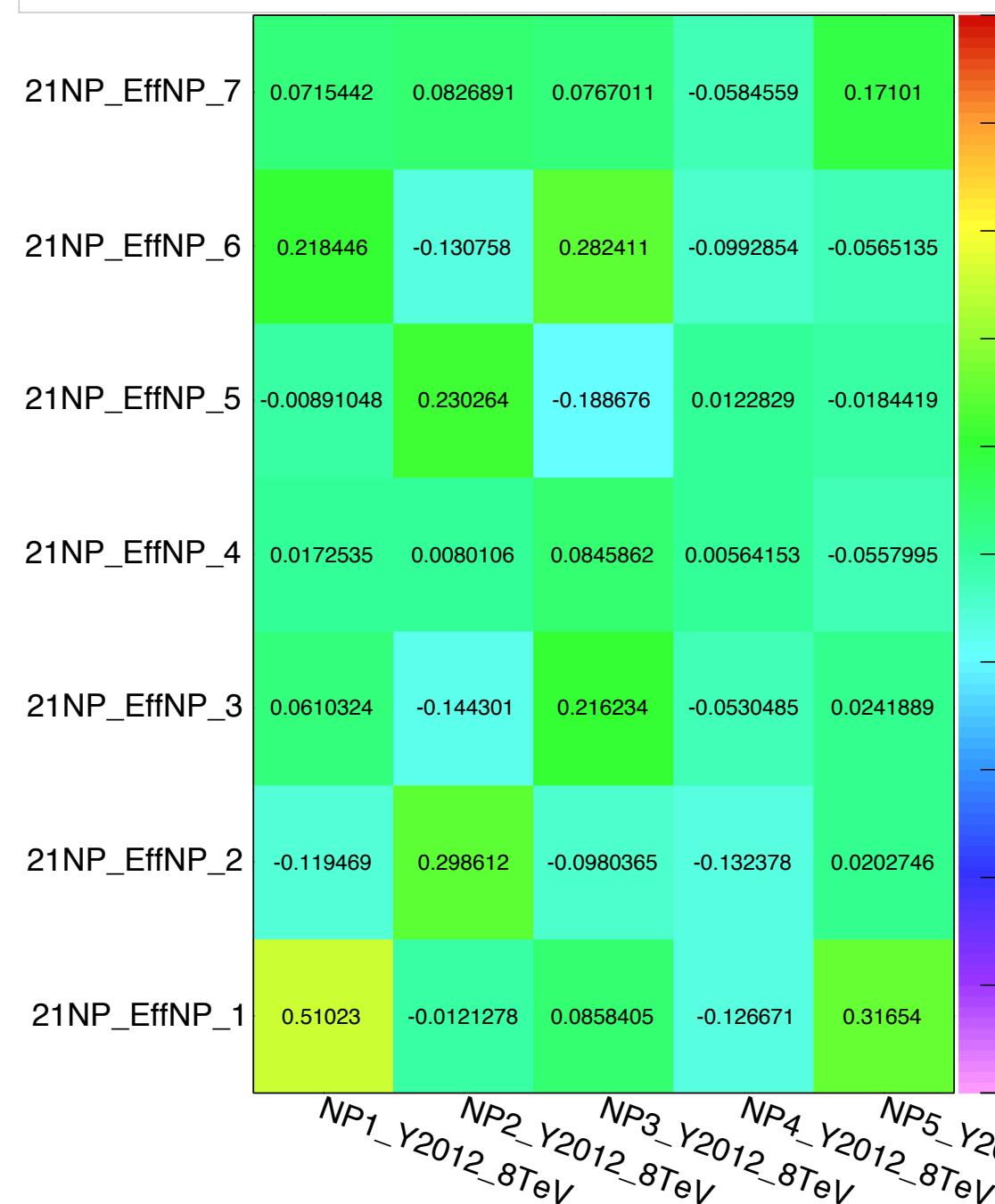
ATLAS
EXPERIMENT

RELATING EFF NP'S: WEAK/STRONG; LEPTONS/NOT

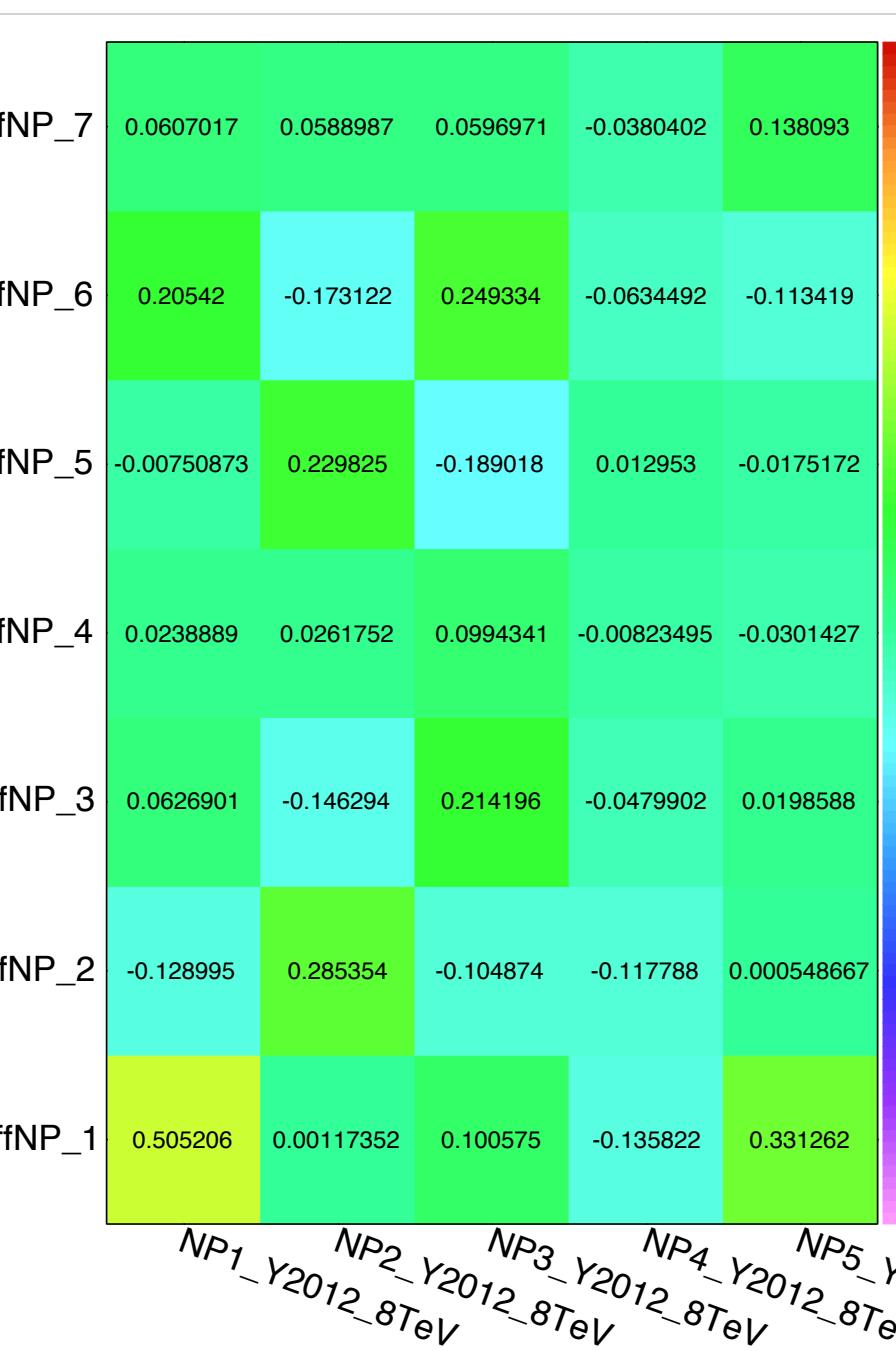
87

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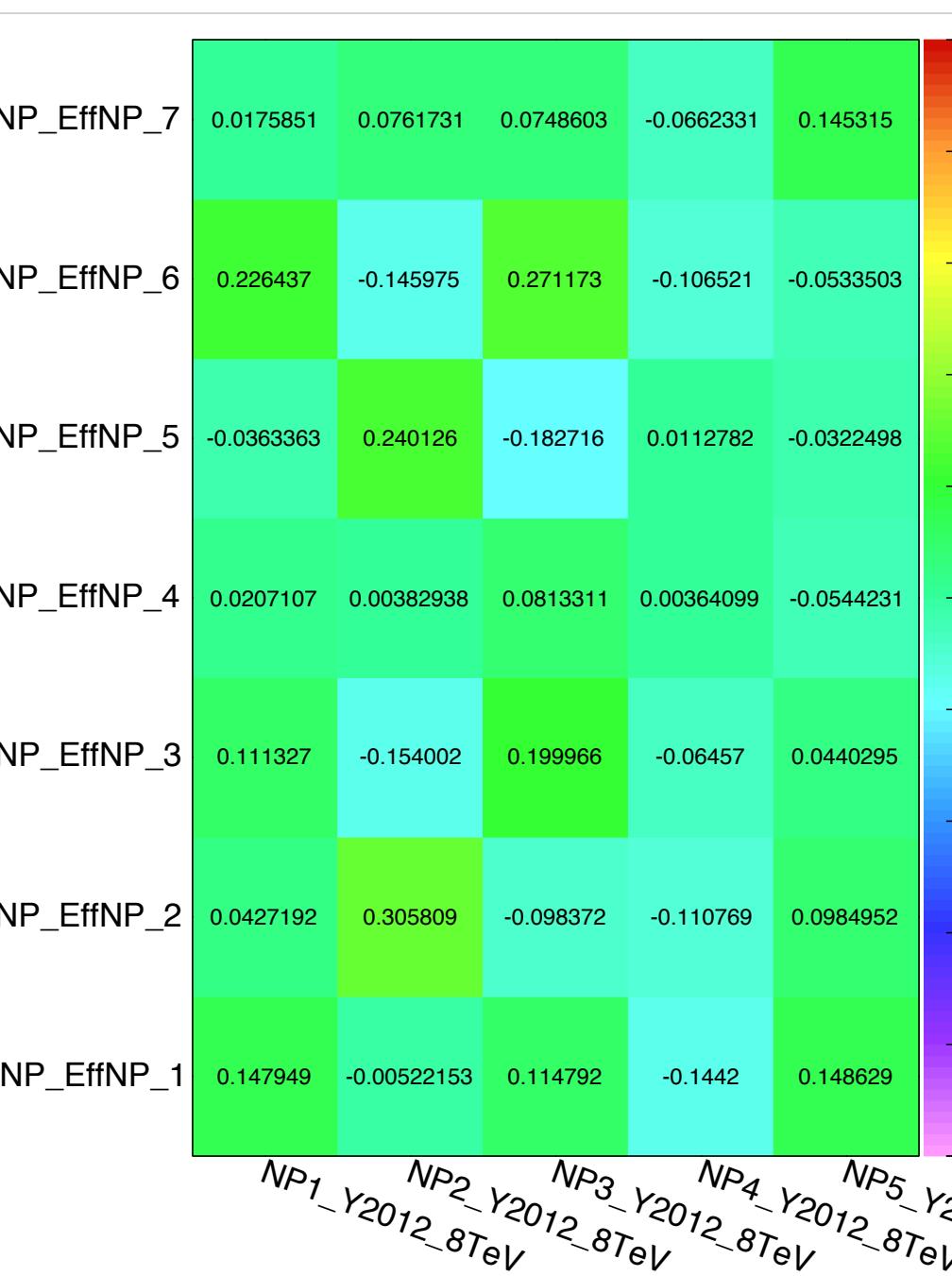
- Using the Run1 and Run2 maps and a correlation matrix that indicates level of correlation between Run1/Run2 effective NP's
 - Strong vs. weak makes little difference for effective NP's; emu correlation (and hence LAr_ESZee) is largest source of correlation between Run1 and Run2 effective NP's regardless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



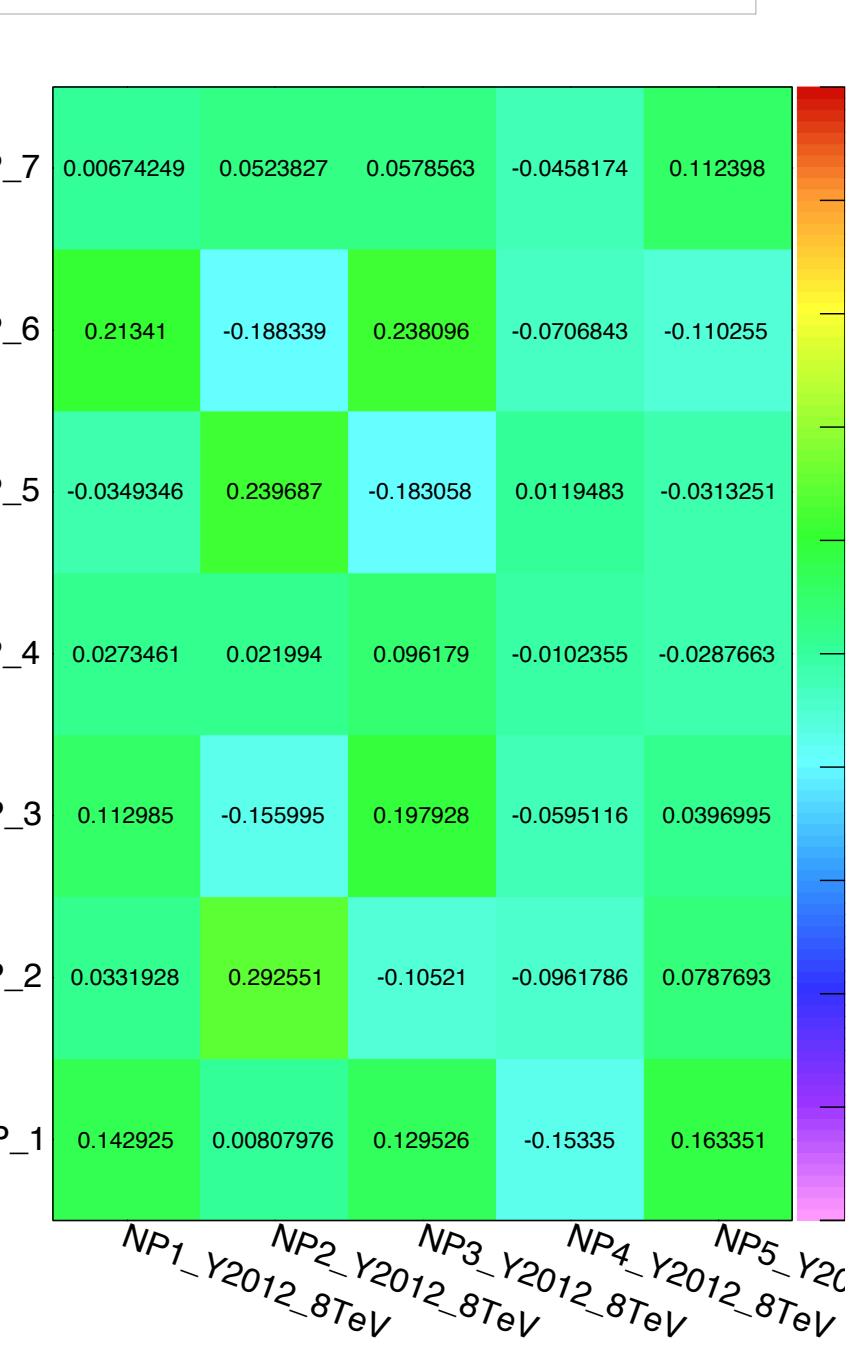
Emu, Strong



Emu, Weak



No emu, strong

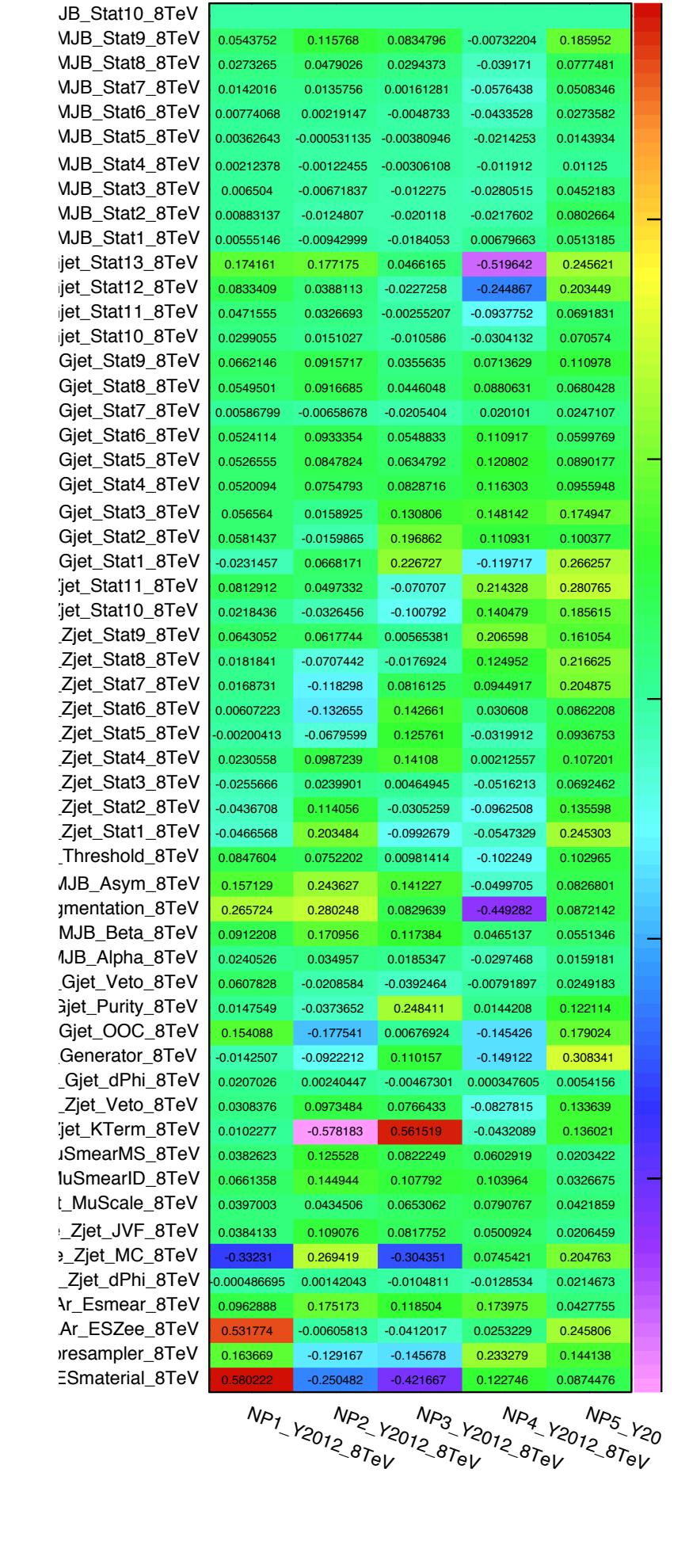
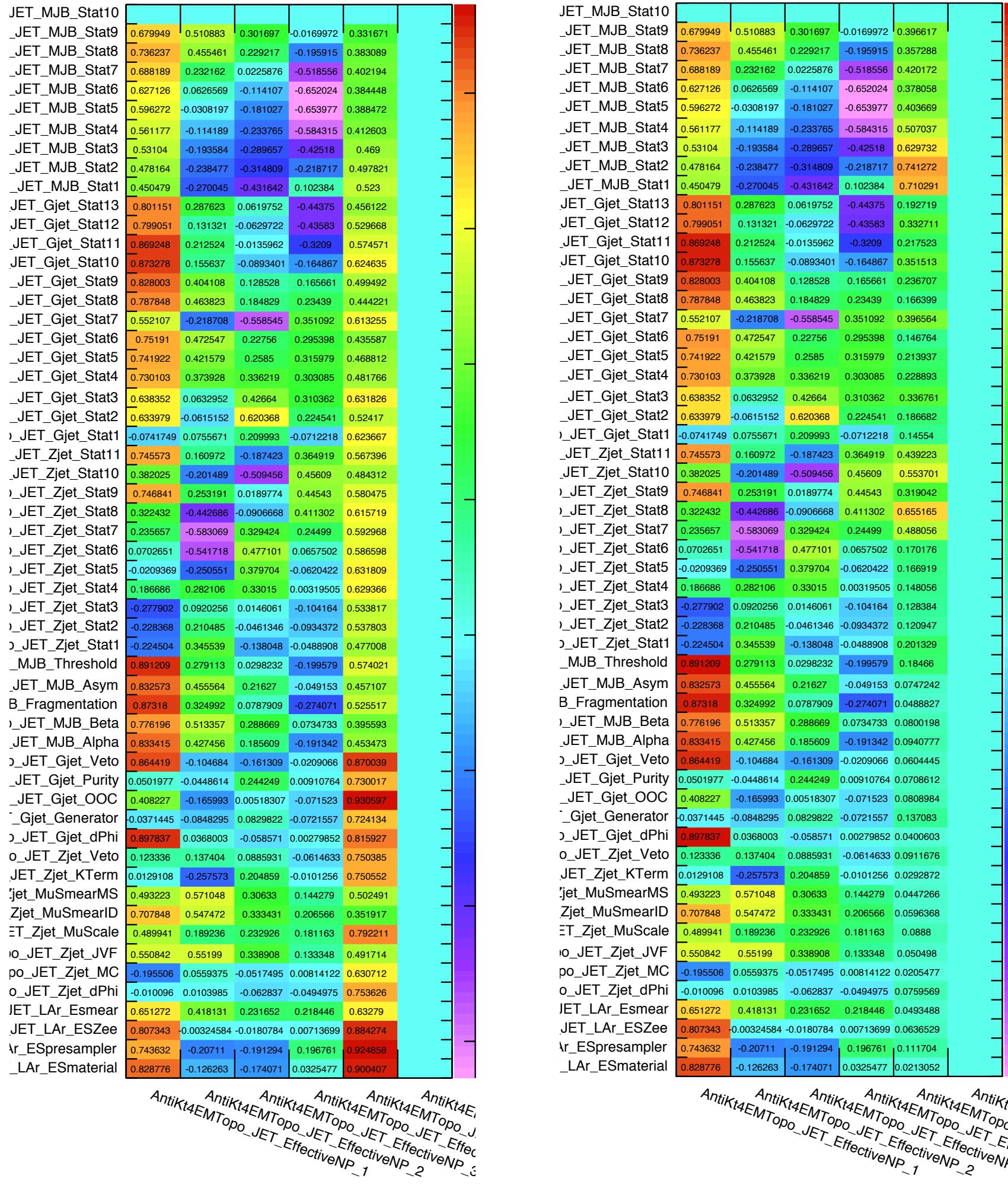


No emu, weak

JES MAPS RUN1

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

$NP_1, Y_{2012}, 8\text{TeV}$
 $NP_2, Y_{2012}, 8\text{TeV}$
 $NP_3, Y_{2012}, 8\text{TeV}$
 $NP_4, Y_{2012}, 8\text{TeV}$
 NP_5, Y_{2012}

AntiKt4EMTopo_JET_EffectiveNP_1
AntiKt4EMTopo_JET_EffectiveNP_2
AntiKt4EMTopo_JET_EffectiveNP_3
AntiKt4EMTopo_JET_EffectiveNP_4
AntiKt4EMTopo_JET_EffectiveNP_5
AntiKt4EMTopo_JET_EffectiveNP_6
AntiKt4EMTopo_JET_EffectiveNP_7
AntiKt4EMTopo_JET_EffectiveNP_8
AntiKt4EMTopo_JET_EffectiveNP_9
AntiKt4EMTopo_JET_EffectiveNP_10
AntiKt4EMTopo_JET_EffectiveNP_11
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AntiKt4EMTopo_JET_EffectiveNP_16
AntiKt4EMTopo_JET_EffectiveNP_17
AntiKt4EMTopo_JET_EffectiveNP_18
AntiKt4EMTopo_JET_EffectiveNP_19
AntiKt4EMTopo_JET_EffectiveNP_20



ATLAS
EXPERIMENT

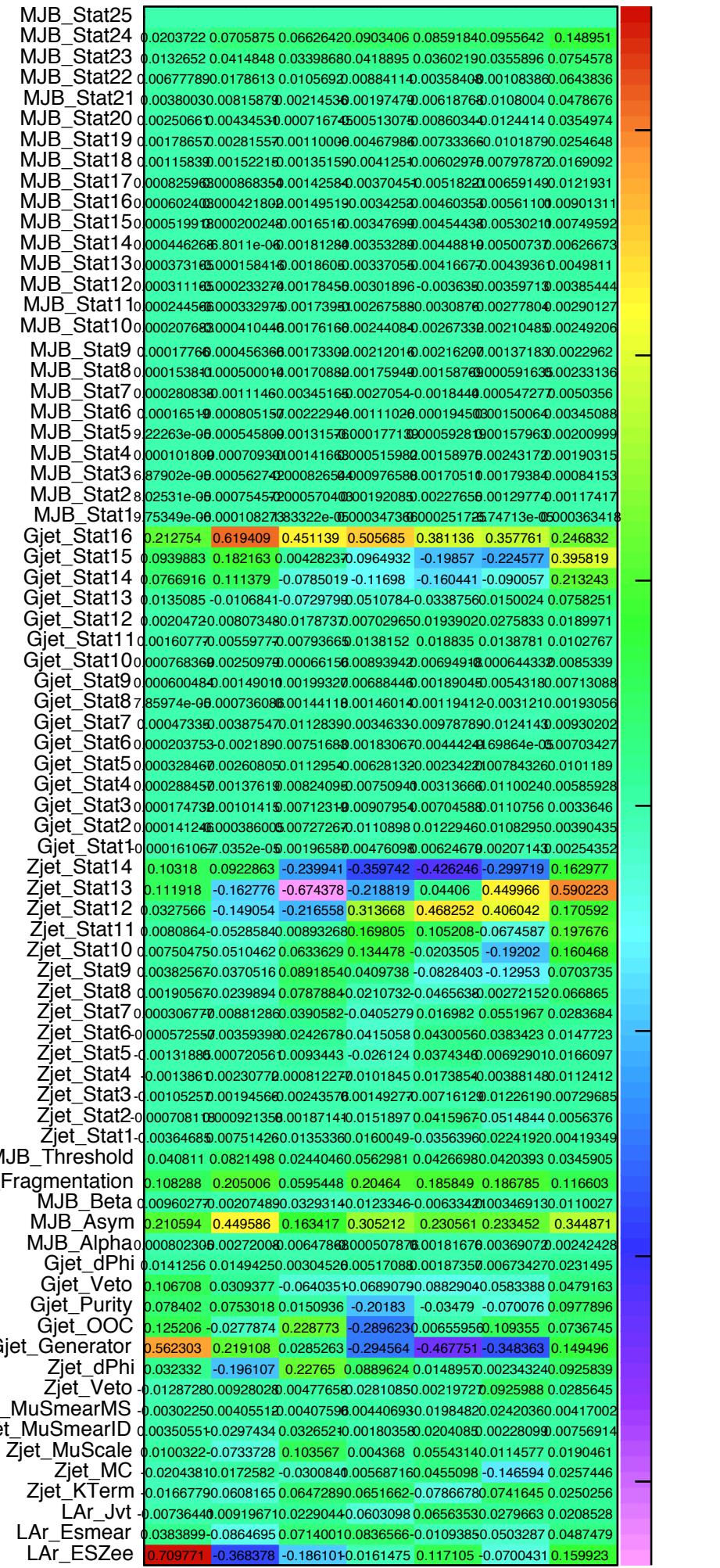
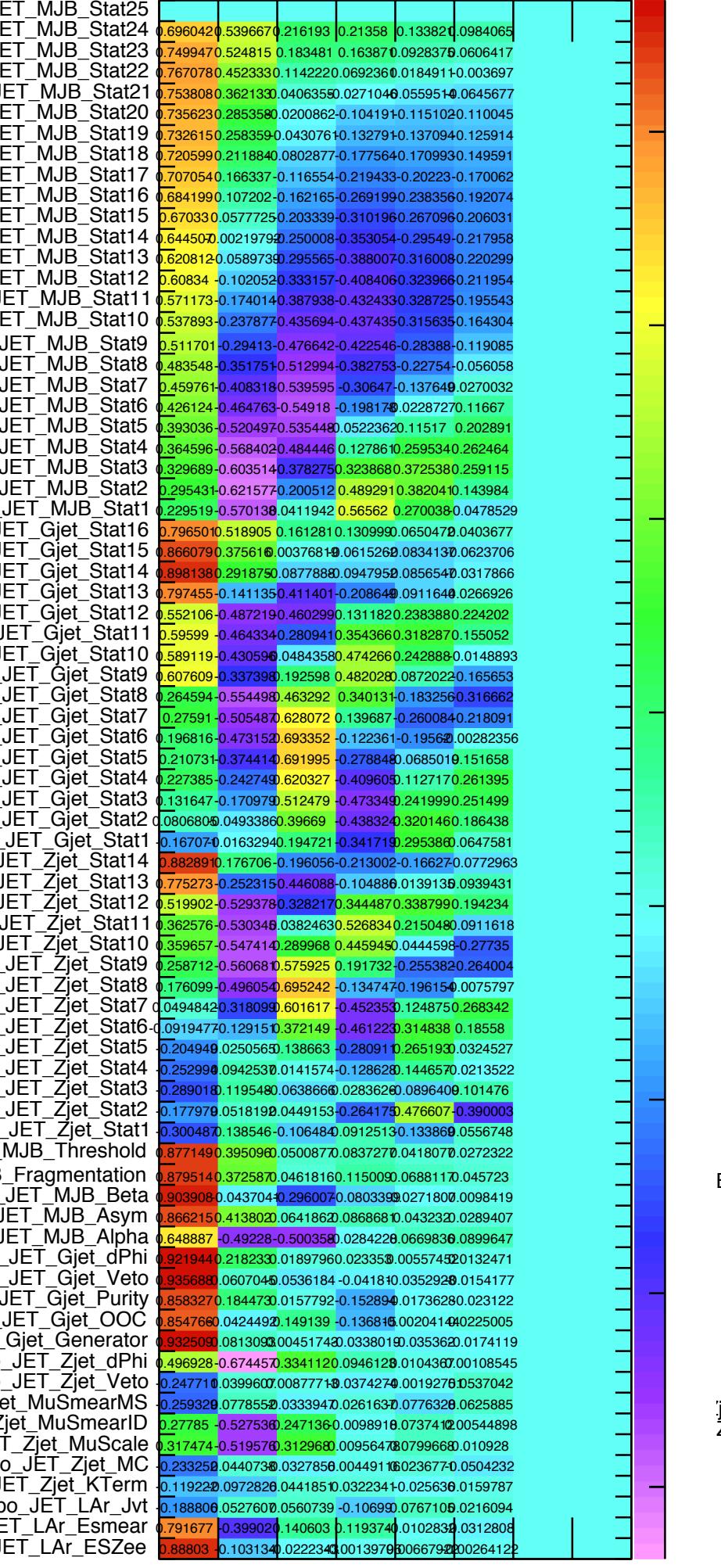
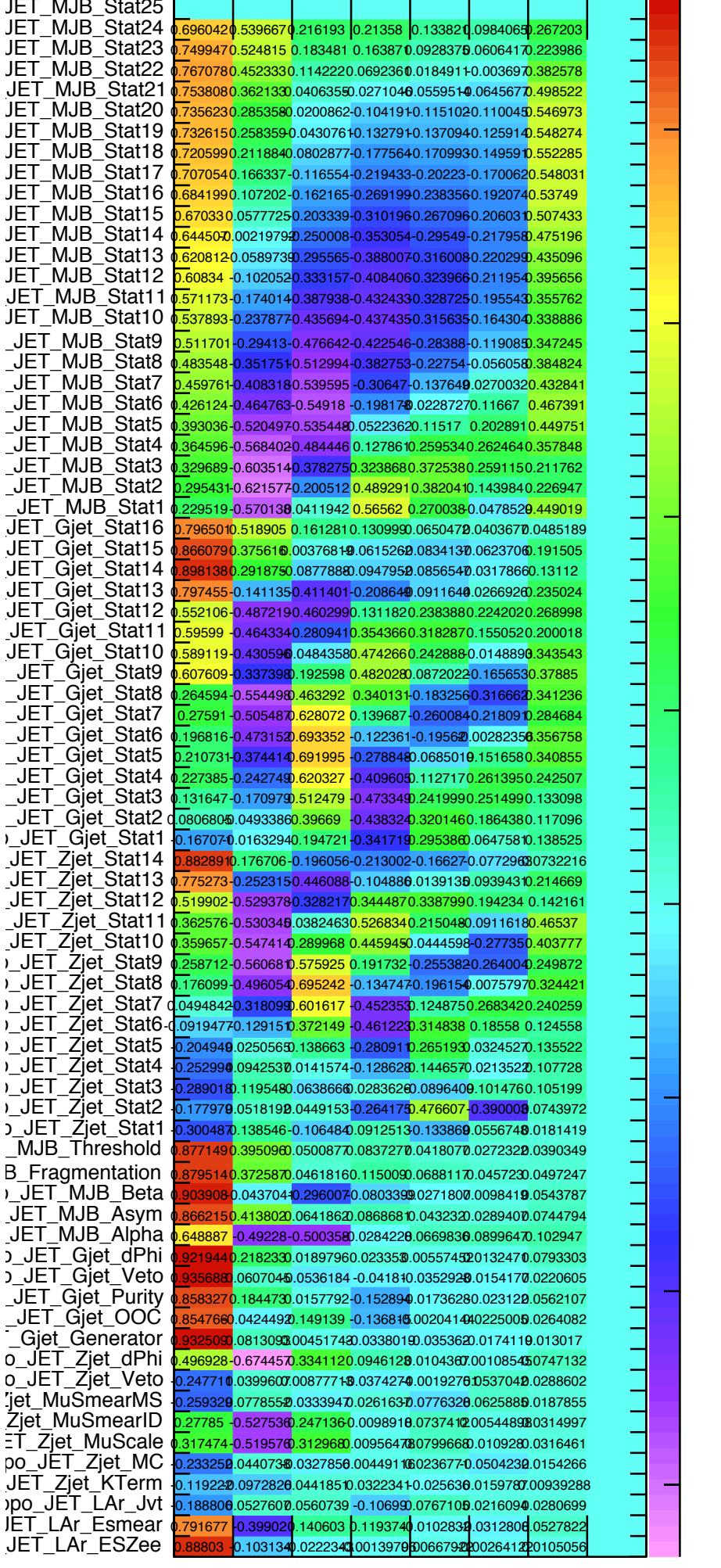
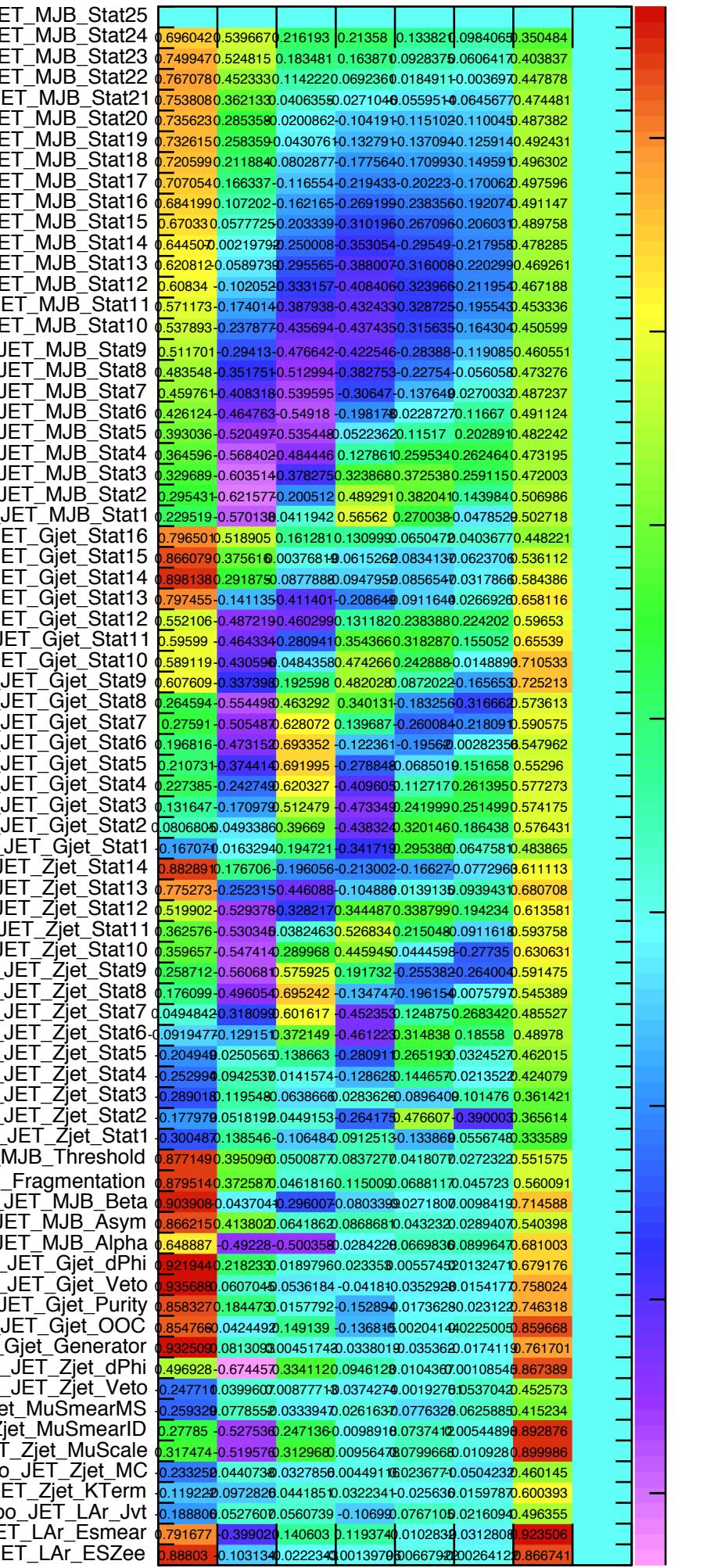


JES MAPS RUN2

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Finding Standard Model VHbb S. Chan

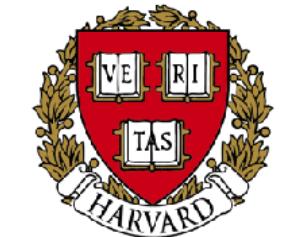
2018.04.23



- L to R
 - “Original”
 - “Comple
m”
 - “Zero”
 - “Original”

+

amplitud
e
weightin
g +
norm.

ATLAS
EXPERIMENT

JES MAP: NP'S RUN1 DETAIL

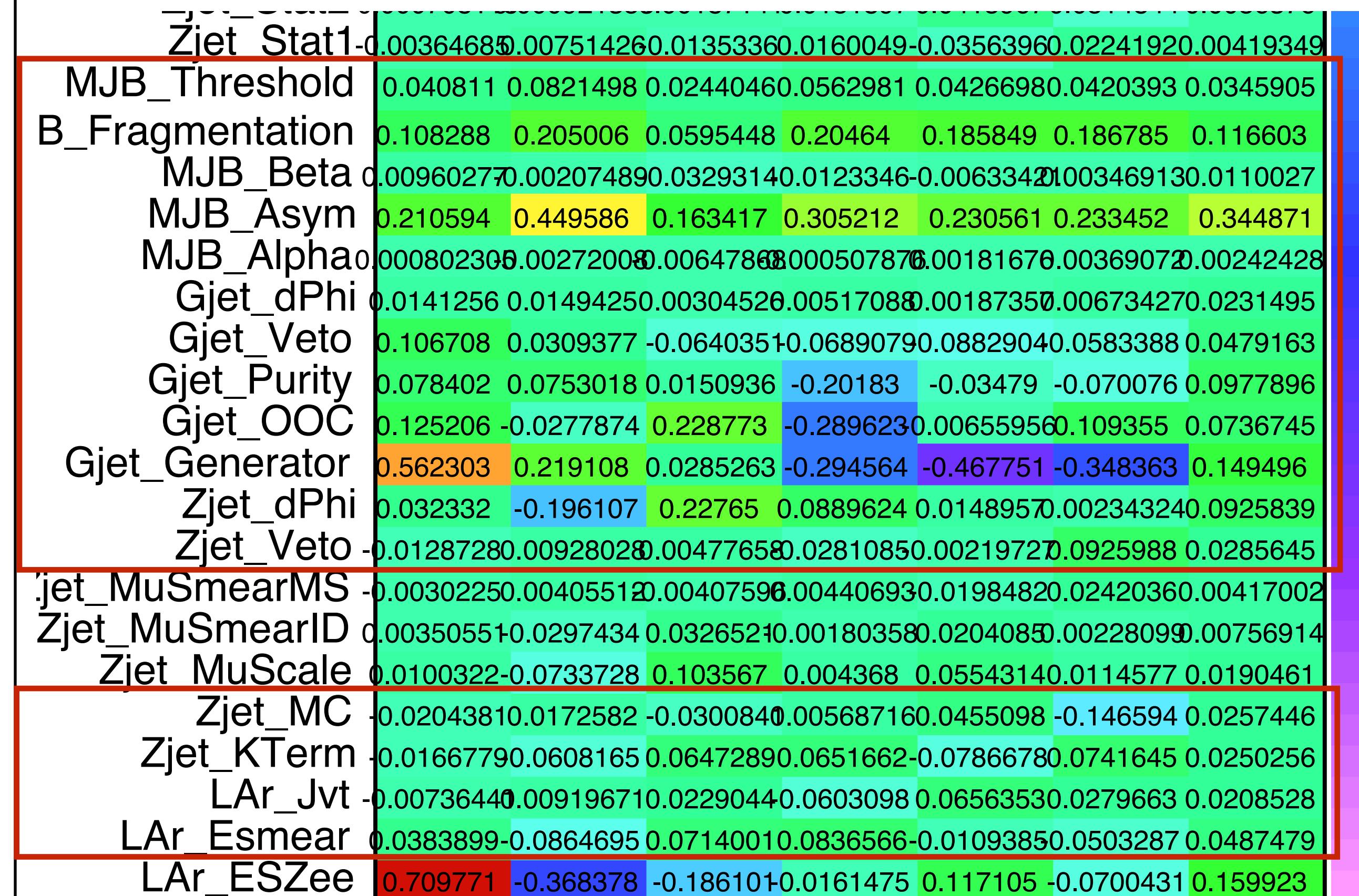
90

Finding
Standard
Model VHbb
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	$Z_{jet_Stat1_8TeV}$	$NP_1_Y_{2012_8TeV}$	$NP_2_Y_{2012_8TeV}$	$NP_3_Y_{2012_8TeV}$	$NP_4_Y_{2012_8TeV}$	$NP_5_Y_{2012_8TeV}$
$Z_{jet_Stat1_8TeV}$	-0.0466568	0.203484	-0.0992679	-0.0547329	0.245303	
$Z_{Threshold_8TeV}$	0.0847604	0.0752202	0.00981414	-0.102249	0.102965	
$M_{JB_Asym_8TeV}$	0.157129	0.243627	0.141227	-0.0499705	0.0826801	
$\gamma_{jet_Augmentation_8TeV}$	0.265724	0.280248	0.0829639	-0.449282	0.0872142	
$M_{JB_Beta_8TeV}$	0.0912208	0.170956	0.117384	0.0465137	0.0551346	
$M_{JB_Alpha_8TeV}$	0.0240526	0.034957	0.0185347	-0.0297468	0.0159181	
$Z_{jet_Veto_8TeV}$	0.0607828	-0.0208584	-0.0392464	-0.00791897	0.0249183	
$Z_{jet_Purity_8TeV}$	0.0147549	-0.0373652	0.248411	0.0144208	0.122114	
$Z_{jet_OOC_8TeV}$	0.154088	-0.177541	0.00676924	-0.145426	0.179024	
$Z_{jet_Generator_8TeV}$	-0.0142507	-0.0922212	0.110157	-0.149122	0.308341	
$Z_{jet_dPhi_8TeV}$	0.0207026	0.00240447	-0.00467301	0.000347605	0.0054156	
$Z_{jet_Veto_8TeV}$	0.0308376	0.0973484	0.0766433	-0.0827815	0.133639	
$Z_{jet_KTerm_8TeV}$	0.0102277	-0.578183	0.561519	-0.0432089	0.136021	
$Z_{SmearMS_8TeV}$	0.0382623	0.125528	0.0822249	0.0602919	0.0203422	
$Z_{SmearID_8TeV}$	0.0661358	0.144944	0.107792	0.103964	0.0326675	
$Z_{MuScale_8TeV}$	0.0397003	0.0434506	0.0653062	0.0790767	0.0421859	
$Z_{jet_JVF_8TeV}$	0.0384133	0.109076	0.0817752	0.0500924	0.0206459	
$Z_{jet_MC_8TeV}$	-0.33231	0.269419	-0.304351	0.0745421	0.204763	
$Z_{jet_dPhi_8TeV}$	-0.000486695	0.00142043	-0.0104811	-0.0128534	0.0214673	
$Z_{Ar_Esmear_8TeV}$	0.0962888	0.175173	0.118504	0.173975	0.0427755	
$Z_{Ar_ESZee_8TeV}$	0.531774	-0.00605813	-0.0412017	0.0253229	0.245806	
$Z_{resampler_8TeV}$	0.163669	-0.129167	-0.145678	0.233279	0.144138	
$Z_{Smaterial_8TeV}$	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

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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

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- 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](https://afs.cern.ch/work/s/stchan/public/hcomb)

TECHNICAL DETAILS: BREAKDOWNS

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- 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)