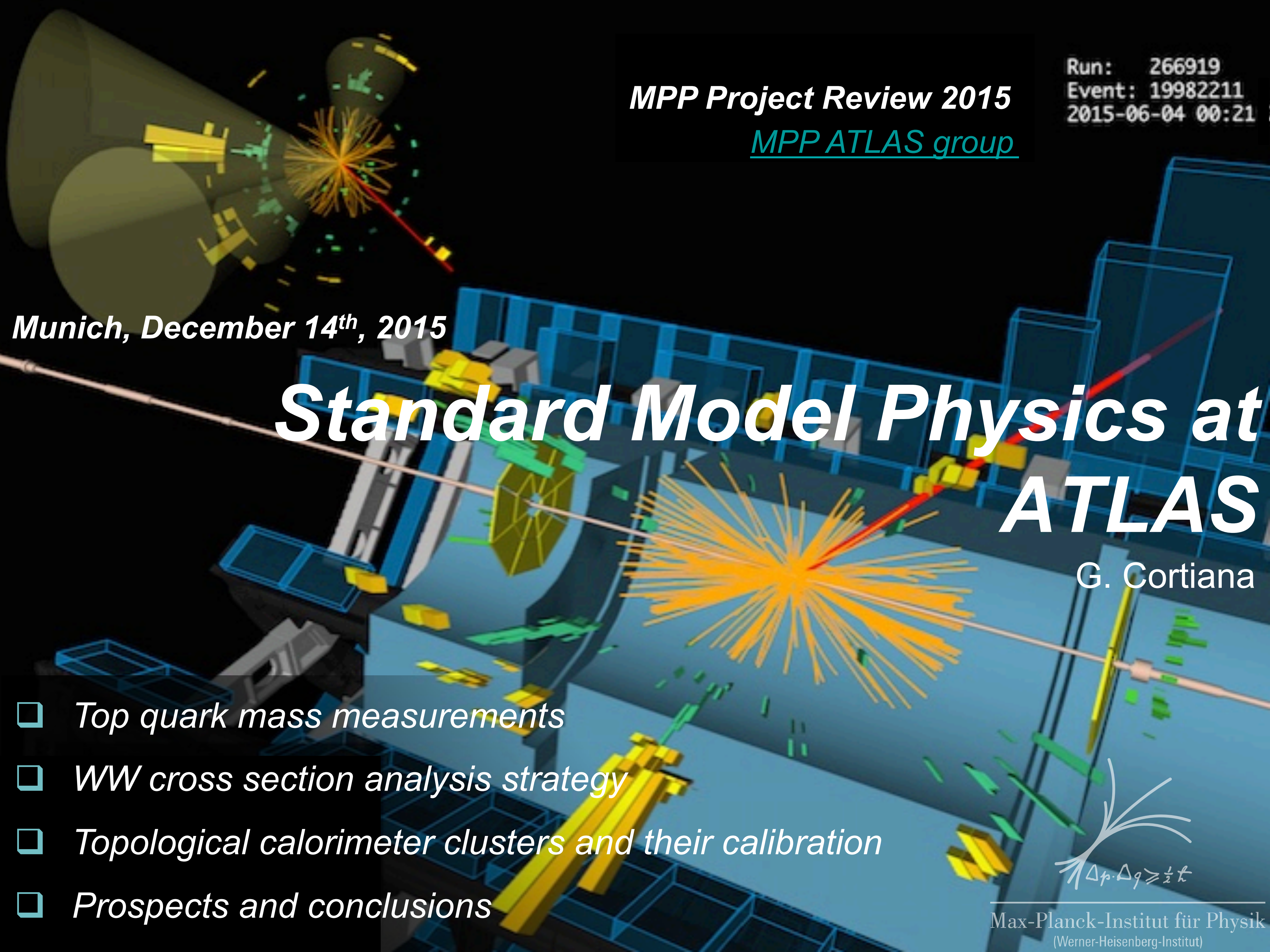

MPP Project Review 2015

MPP ATLAS group

Munich, December 14th, 2015

Standard Model Physics at ATLAS

G. Cortiana

- *Top quark mass measurements*
- *WW cross section analysis strategy*
- *Topological calorimeter clusters and their calibration*
- *Prospects and conclusions*

Max-Planck-Institut für Physik
(Werner-Heisenberg-Institut)

MPP ATLAS group

Director:	S. Bethke
Senior scientists (10):	T. Barillari, A. Kiryunin, S. Kluth, O. Kortner, S. Kortner, H. Kroha, S. Menke, R. Nisius, D. Salihagic, S. Stonjek
Emeriti (4):	H. Oberlack, R. Richter, P. Schacht, H. von der Schmitt
Post docs (14):	G. Compostella, G. Cortiana, C. Delle Fratte, M. Flowerdew, C. Giuliani, T. Ince, A. La Rosa, A. Macchiolo, F. Müller, M. Nagel, P. Schwegler, , F. Sforza, E. Takasugi, A. Wildauer
PhD (12):	K. Ecker, M. Goblirsch-Kolb, N. Köhler, D. Krauss, A. Maier, S. Nowak, R. Röhrig, N. Savic, K. Schmidt-Sommerfeld,, F. Spettel, S. Terzo, G. Wichmann
Master (6):	E. Fons, P. Gadow, J. Junggeburth, S. Maschekl,, V. Walbrecht, I. Weimer
Bachelor (8):	S. Annies, J. Corella Puertas, D. Joseph, D. Kresse, D. Nebe, M. Rendel, L. Schlechter, C. Schmid

ATLAS wide responsibilities:

S. Kluth:	ATLAS software quality coordinator
O. Kortner:	Deputy muon project leader
A. Macchiolo:	ATLAS pixel sensor upgrade co-coordinator
S. Menke:	ATLAS liquid argon electronics upgrade co-coordinator

in 2015: 24 ATLAS publications
(14 in peer-reviewed journals)

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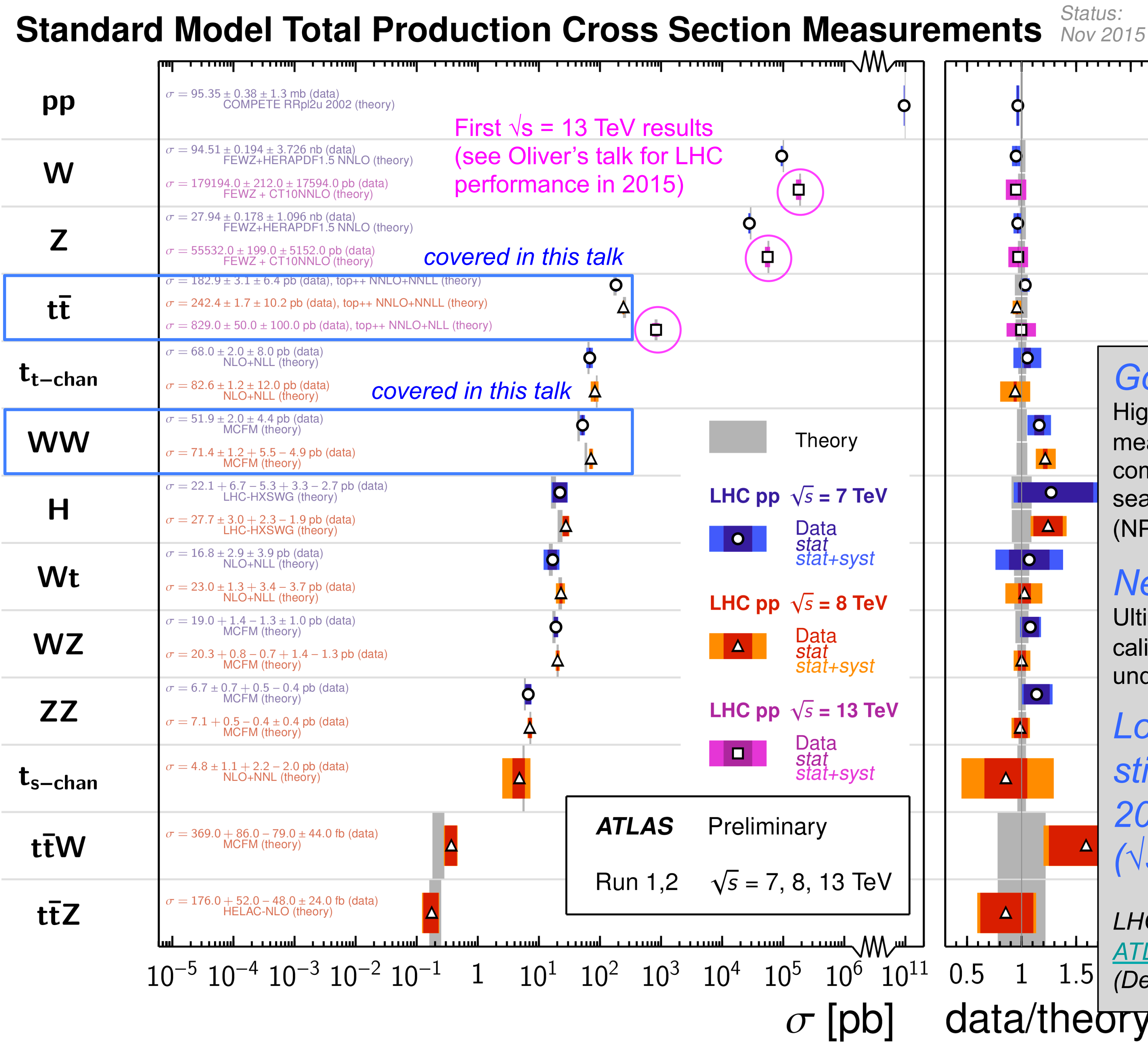


Goals:

High precision measurements complementing direct searches for new physics (NP)

Needs:

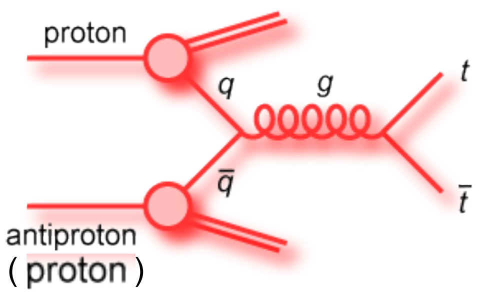
Ultimate detector calibration / data understanding

Long term projects still using 2011 / 2012 datasets (√s=7 and 8 TeV)

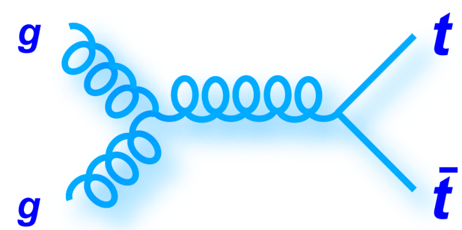
LHC Run-2 highlights at ATLAS and CMS EOYE (Dec 15th, 15:00)

Introduction: top quark

top-quark pair production:

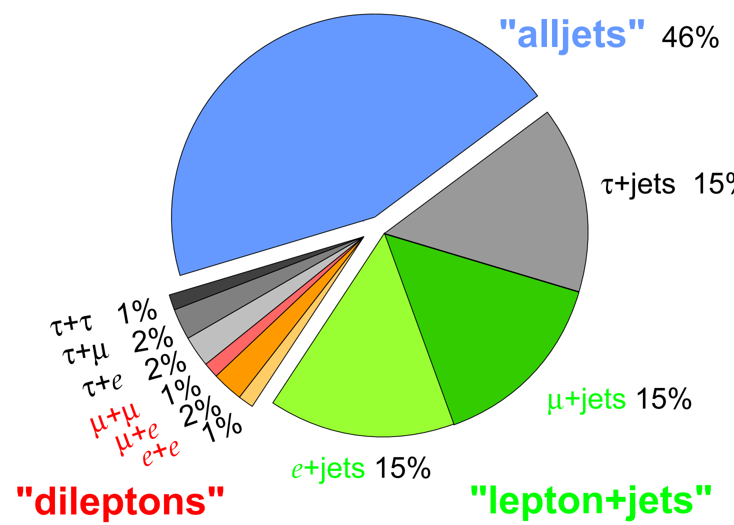


dominant at the Tevatron
$\sqrt{s}$ = 1.8 – 1.96 TeV

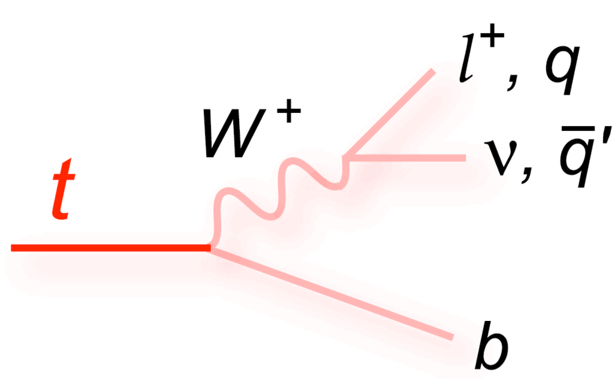


dominant at the LHC
$\sqrt{s} \geq 7$ TeV

Top Pair Branching Fractions



top-quark decays



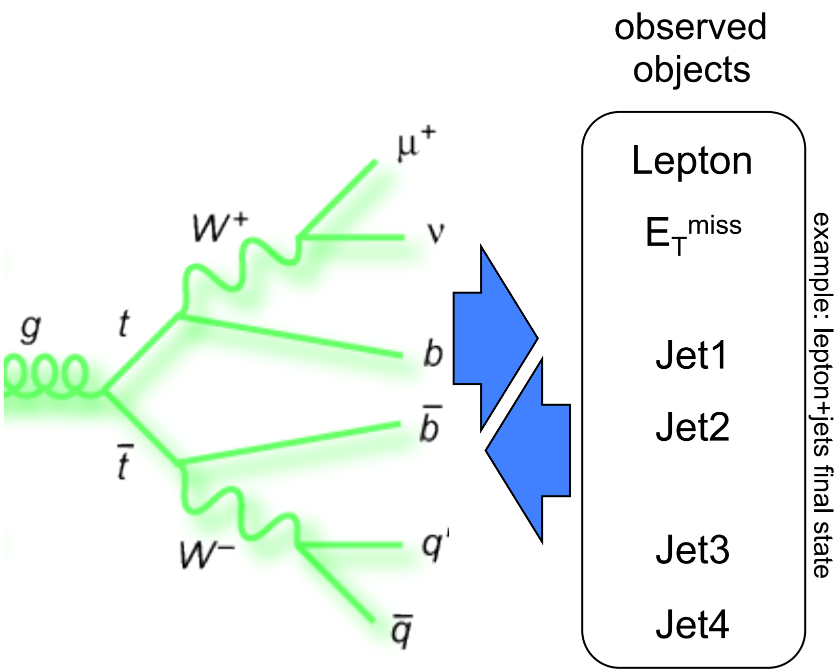
Experimental signatures are classified according to the W boson decay modes

MPP analysis activities cover all final states and deliver precision measurements of the top quark mass

Stringent tests of the SM and its extensions
Important implication for the EW vacuum stability

Analysis techniques: the template method

- Estimator sensitive to m_{top}
  - can be obtained from a kinematic best fit to the decay hypothesis, considering all jet permutations and taking into account physics object resolutions



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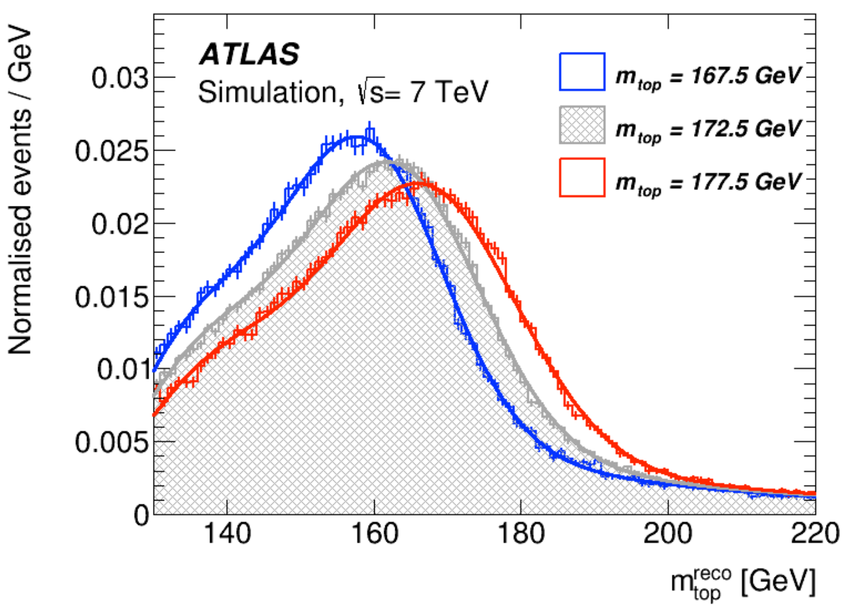
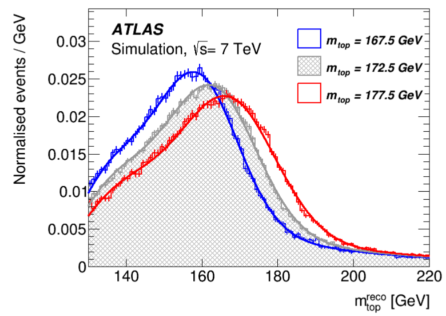


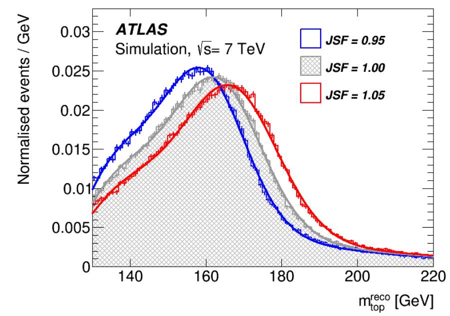
- Template method:
  - the data distribution of a given m_{top} estimator (i.e. m_{top}^{reco}) is fitted to the sum of signal and background PDFs (probability distribution functions)

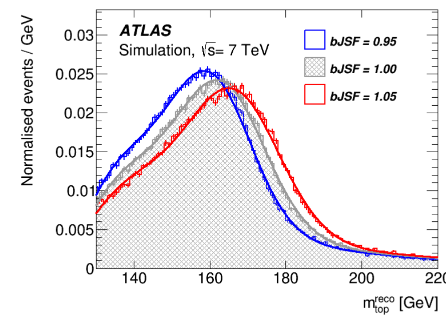
The problem…

Observables' main dependences m_{top} JES bJES

Reco m_{top}







Good sensitivity to the underlying top quark mass. The quantity to be measured

Large dependence on the jet energy scale
Large systematics

Large dependence on the b-jet energy scale
Large systematics

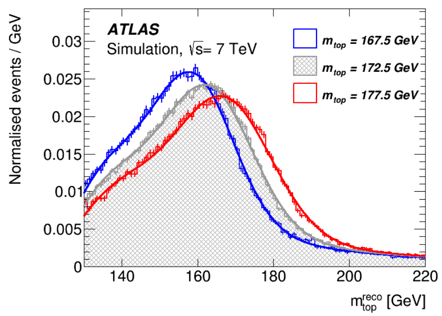
The uncertainties on the jet energy scale (JES) are O(few %) and vary with jet properties, flavor and event topology

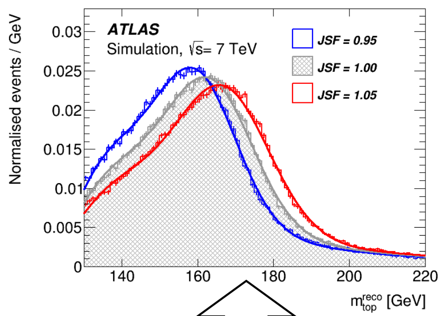
The problem… and its solution

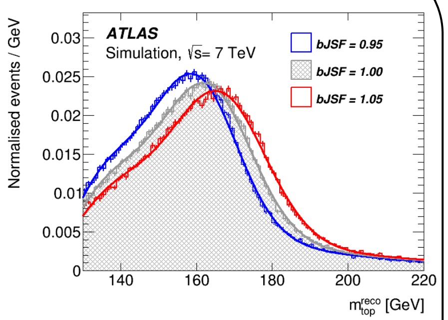
Observables' main dependences m_{top} JES bJES

2-dim fits for m_{top}, JSF

Reco m_{top}

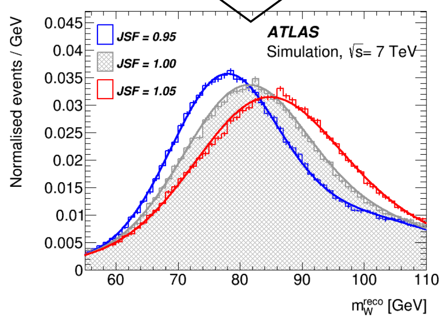






Reco m_W

in the l+jets channel, the light-quark jets from W-decay can be used to determine a global jet energy scale factor (JSF) constraining the light jets JES variations



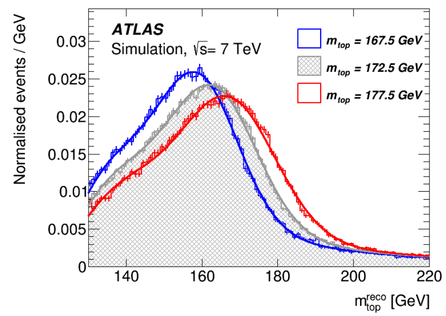
Pioneered by the CDF collaboration in [Phys.Rev.D73:032003,2006]

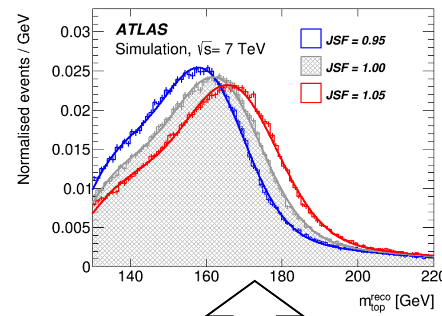
The problem… and its solution

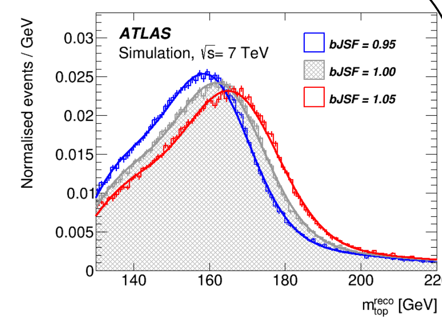
3-dim fits for m_{top}, JSF, bJSF

Observables' main dependences: m_{top} | JES | bJES

Reco m_{top}

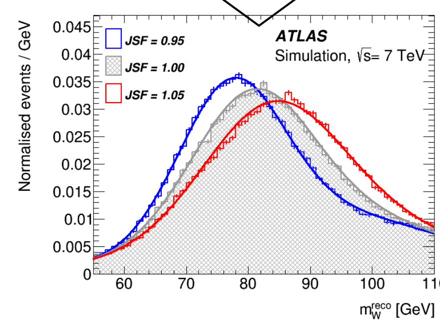






Reco m_W

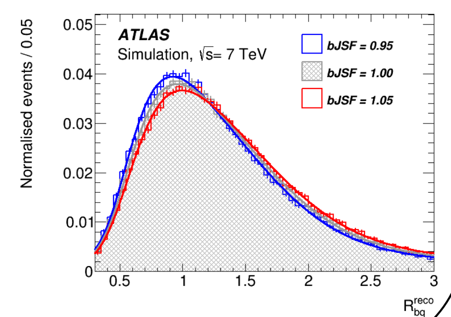
in the l+jets channel, the light-quark jets from W-decay can be used to determine a global jet energy scale factor (JSF) constraining the light jets JES variations



Reco R_{bq}

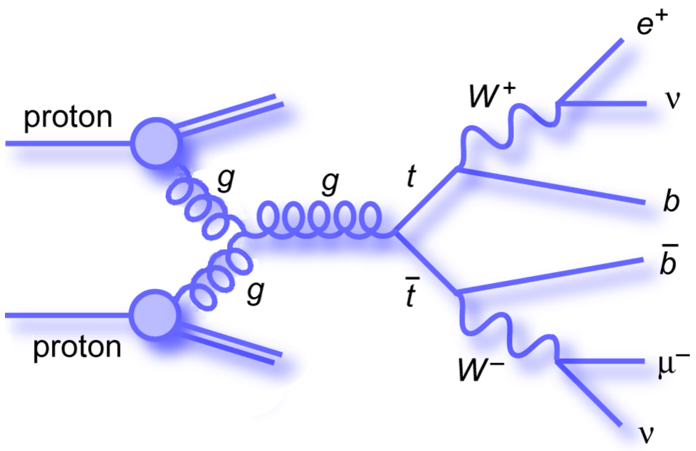
similarly a variable sensitive to the relative b-to-light jet energy scale (bJSF) can be used to constrain the b-jet JES variations (bJES)

$$R_{bq}^{reco} = \frac{\sum p_T^{\mathrm{b-tagged\ jets}}}{\sum p_T^{\mathrm{untagged\ jets}}}$$



The m_{top}^{reco}, m_W^{reco} and R_{bq}^{reco} templates are used in a 3d fit to the data to determine m_{top}, JSF and bJSF

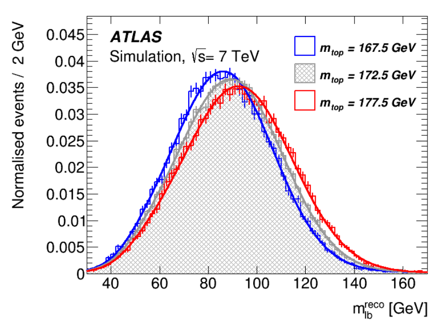
Dilepton final states



- Excellent S/B ratio
- Under-constrained event kinematics (two escaping ν)
- Use the template method with the m_{lb}^{reco} observable as an estimator for m_{top}: exploiting a partial reconstruction of the event

m_{top}

Reco m_{lb}



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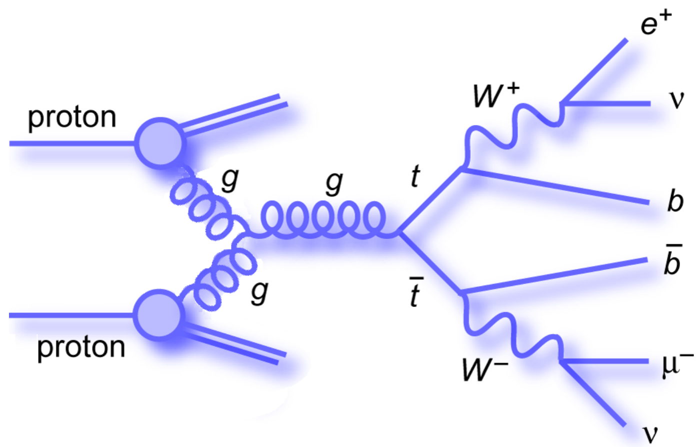
Dilepton final states

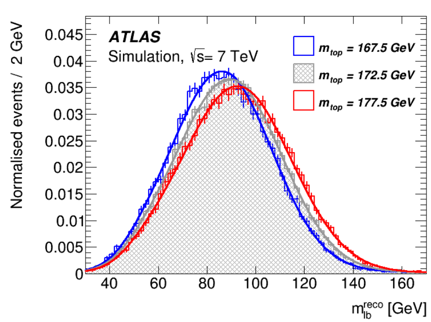


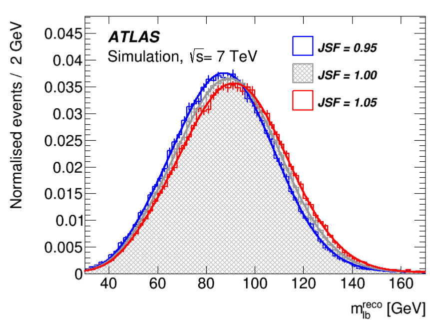
- Excellent S/B ratio
- Under-constrained event kinematics (two escaping ν)
- Use the template method with the m_{lb}^{reco} observable as an estimator for m_{top}: exploiting a partial reconstruction of the event

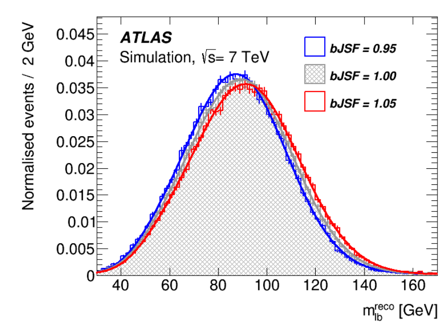
same problem as for the l+jets final state:

m_{top} JES bJES

Reco m_{lb}







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No direct in-situ (b)JSF determination possible. No JSF/bJSF transfer from l+jets analysis, to minimize correlations and maximize gain in the combination

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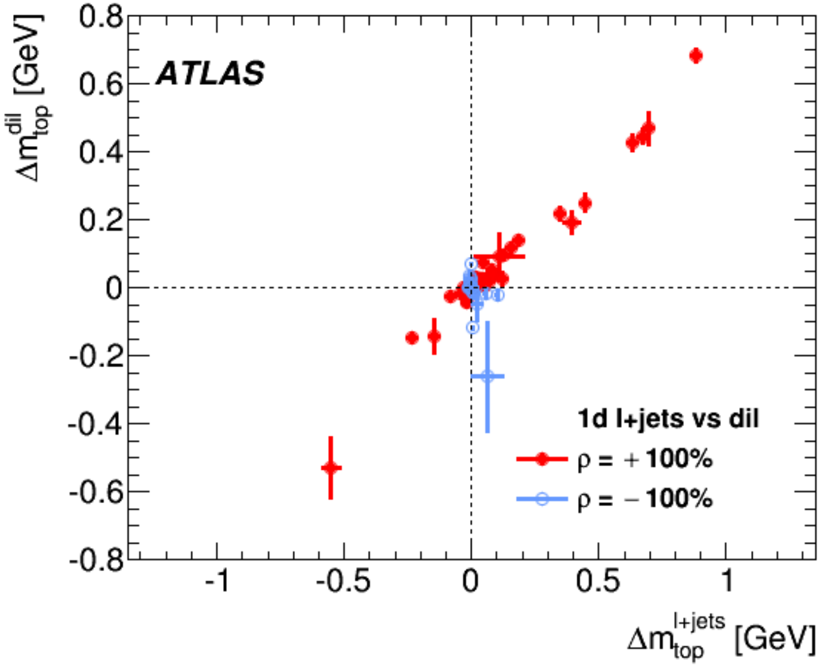

- The use of different techniques (*e.g.* 1-dim or 3-dim templates) introduces anti-correlation effects on the observables used to measure m_{top}
- Size (and sign) of the m_{top} syst. unc. in the lepton+jets and dilepton channels:
  - l+jets (1-dim), fit for m_{top} only
  - l+jets (3-dim), fit for m_{top}, JSF, bJSF
    - overall syst. reduction (l+jets)
    - de-correlation of the observables

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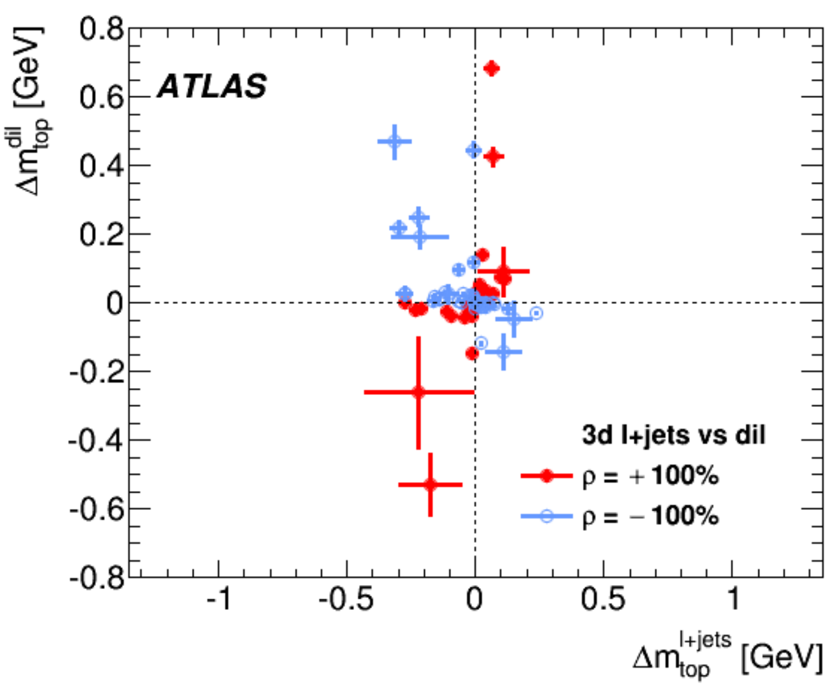
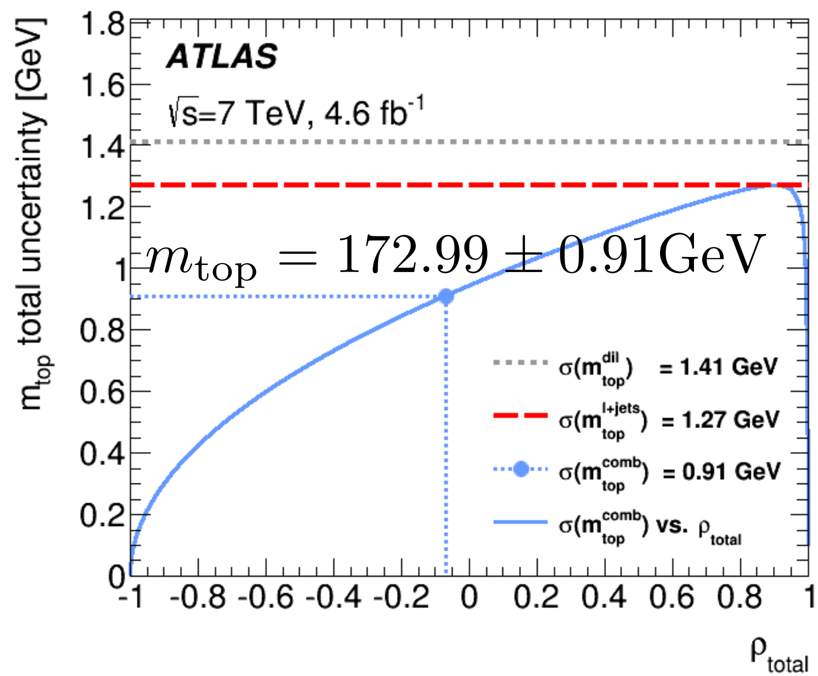
very significant gain (28%) in the combination



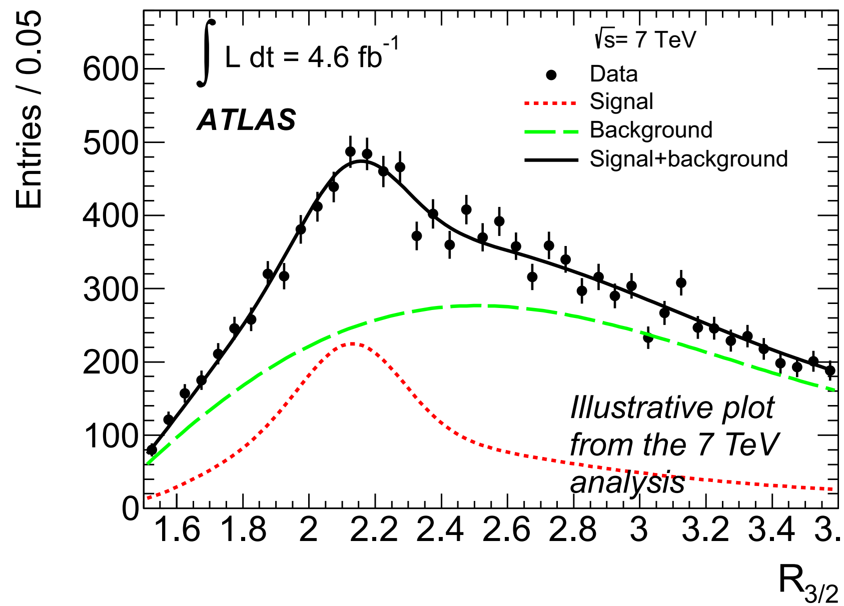


All-jets final states

- Poorer S/B ratio
- Particular attention required to model the background via data-driven techniques
- The $R_{3/2}$ observable, defined as m_{jjb}/m_{jj}, is used as for the 7 TeV analysis (carried out at LMU) which yielded:

$$m_{\rm top} = 175.1 \pm 1.8\ (1.4_{\rm stat} \oplus 1.2_{\rm syst})\ {\rm GeV}$$

  - it achieves a partial cancellation of the systematic effects common to m_{top}^{reco} and m_W^{reco}



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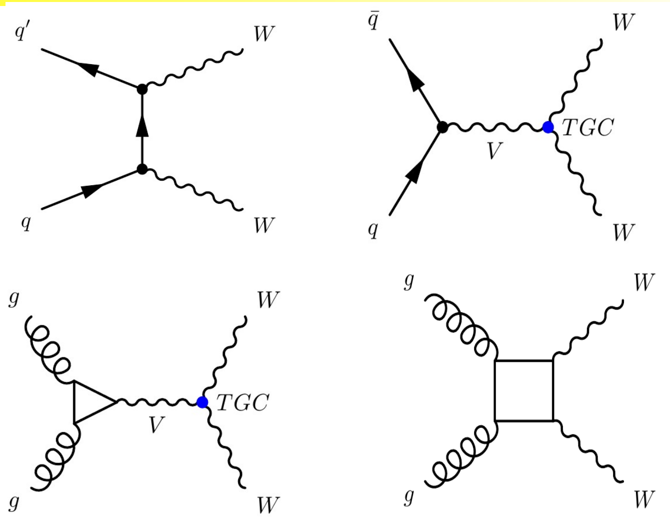
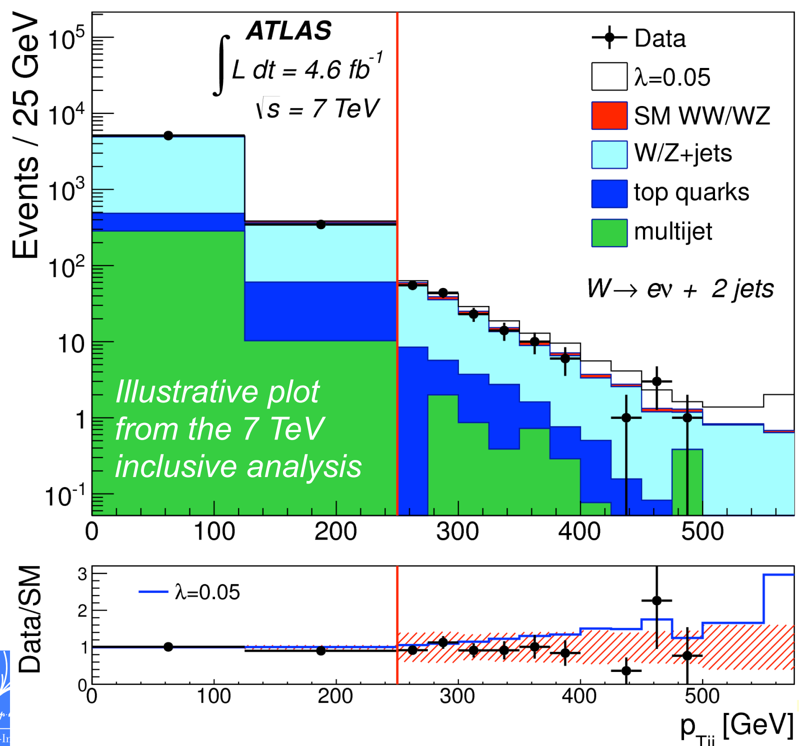
Outlook:

- MPP is leading the efforts towards m_{top} analysis updates using the 8 TeV dataset (x4 more data allows trade-offs between statistical and systematic uncertainties)
- All analyses are well advanced
  - All-jets: PhD thesis T. McCarthy (Sept. 2015, Carleton University + MPP)
  - Dilepton: PhD thesis A. Maier (end 2015)
  - Lepton+jets: phase-space optimization ongoing
- Publications planned for 2016 (including their combination)

(boosted) WW x-section measurement



JHEP 01 (2015) 049

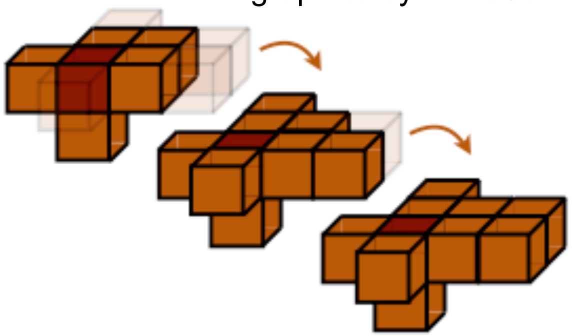


- In addition to being the main background for H→WW analyses, the WW production is sensitive to anomalous triple gauge boson couplings (aTGCs), and to possible new particles decaying into vector bosons (see Claudia's Higgs+NP talk)
- Increasingly important at higher √s and in boosted topologies
- Analysis strategy: *PhD thesis: F. Spettel* *Master thesis: E. Fons*
  - One leptonically decaying W
  - One hadronically decaying W (boosted)
- Use fat-jets techniques based on jet sub-structure identification, as well as multivariate techniques to improve signal/background ratio

Calorimeter topo-clusters and their calibration

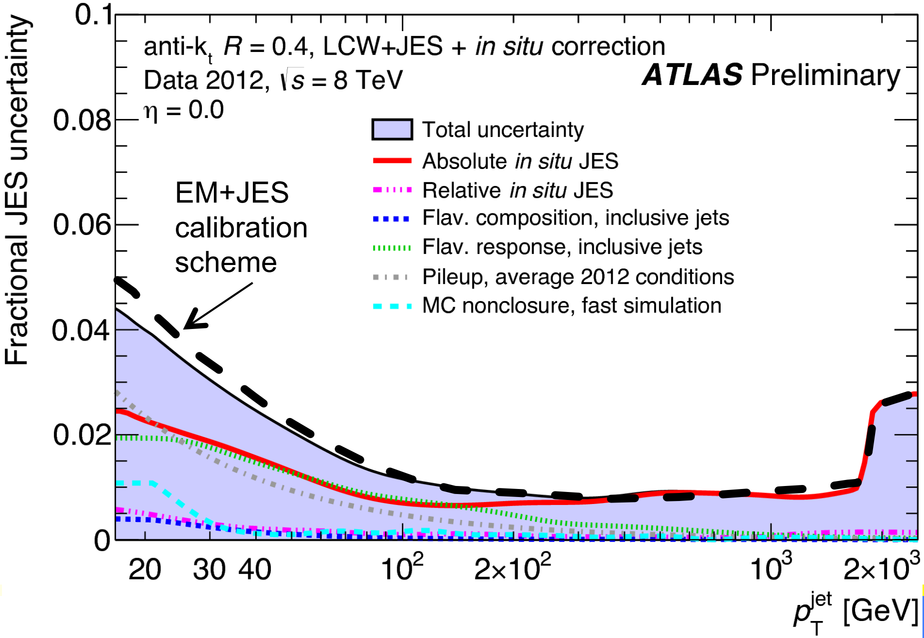
- For all analyses described before, jet calibration (and its uncertainty) constitutes a critical input
- MPP developed and fully commissioned novel ideas for the clustering and calibration of calorimeter signals into topological clusters (topo-clusters) that are used in subsequent physics object reconstruction
  - follow electromagnetic / hadronic shower development
  - suppress noise and pile-up energy contributions (see also arXiv:1510.03823)
  - their features are used to classify and calibrate clusters

graphics by T. McCarthy



Topo-clusters grow around seeds according to noise dependent energy thresholds

- Default for $\sqrt{s} \geq 8$ TeV analyses
  - particularly important for E_T^{miss} and jet (sub-structures) calibration
  - provides a reduced JES uncertainty (important for precision analyses)
- ATLAS paper to appear soon



ATLAS-CONF-2015-037

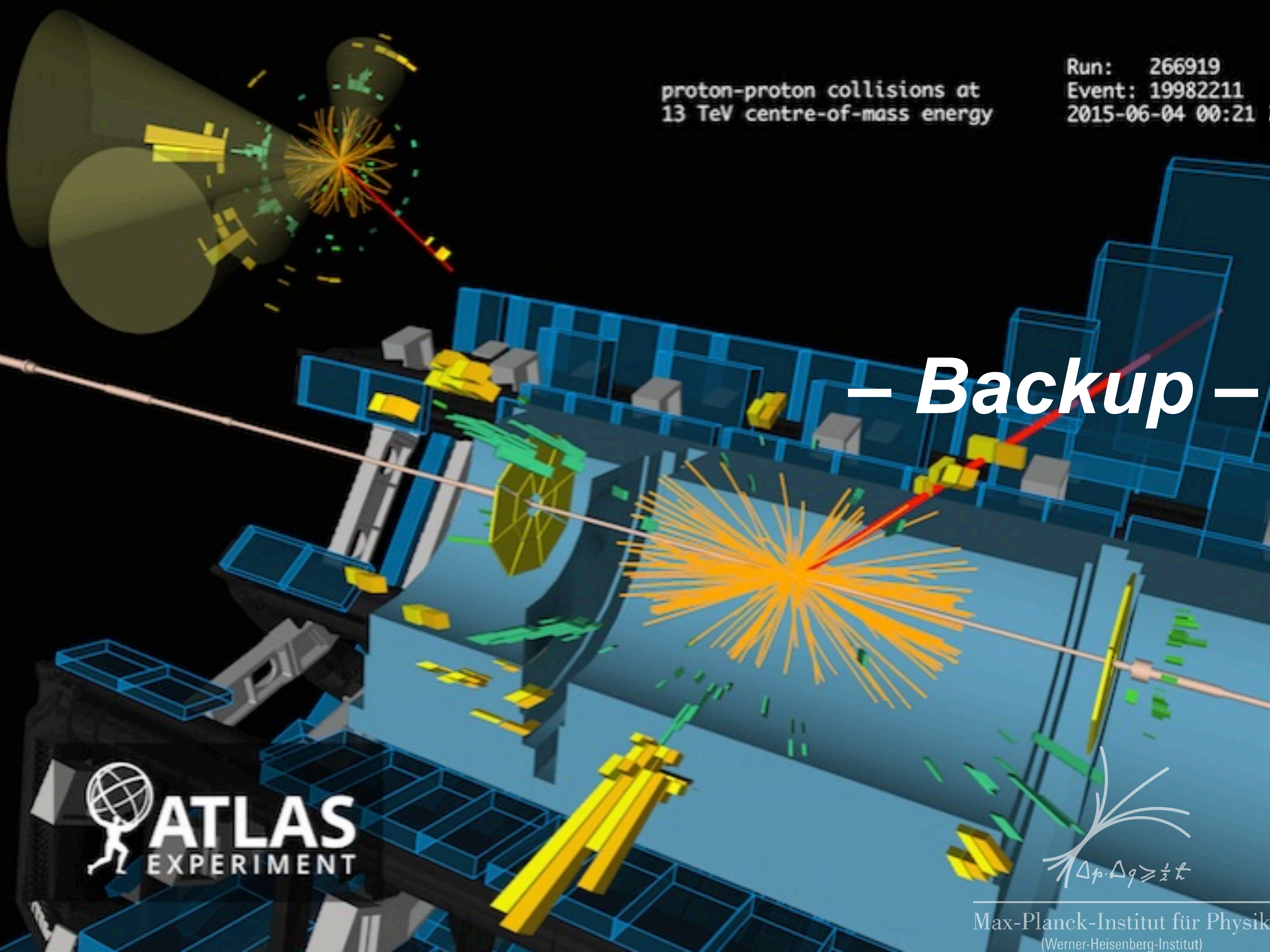
Conclusions

- The MPP group is very active on high impact Standard Model measurements performed using ATLAS data
  - it provides the most precise ATLAS m_{top} results and has a long history driving multi-experiment combination efforts (LHC and Tevatron+LHC). This will resume as soon as 8 TeV results are published
  - it is pursuing a WW -> $l\nu jj$ production cross section measurement in the boosted regime, very sensitive to anomalous triple gauge boson coupling
  - it delivers standards for the calorimeter energy measurements and calibrations vital for physics object reconstruction and precision measurements (successful hand-shake between physics analyses and detector performance studies)
  - Papers / theses based on 8 TeV datasets are in the pipeline

… know-how and expertise ready to be applied to the 13 TeV dataset

Stay tuned!
Thanks for your attention!

– Backup –



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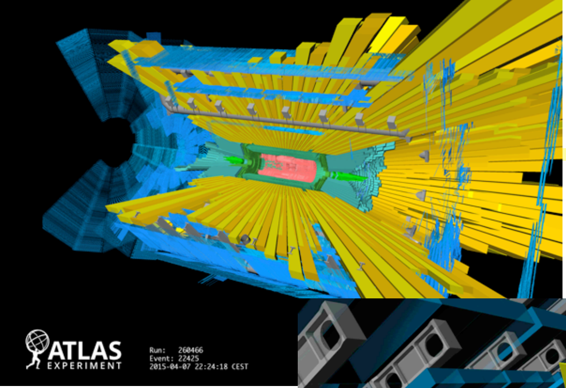
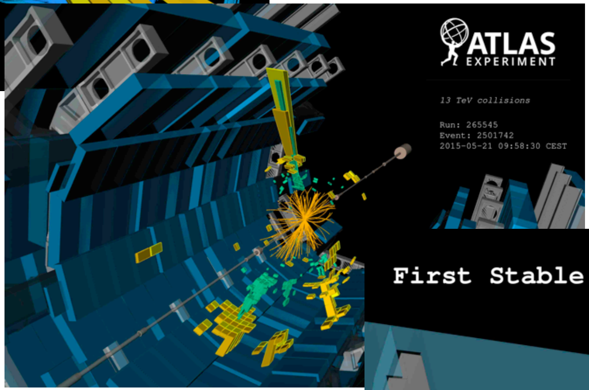
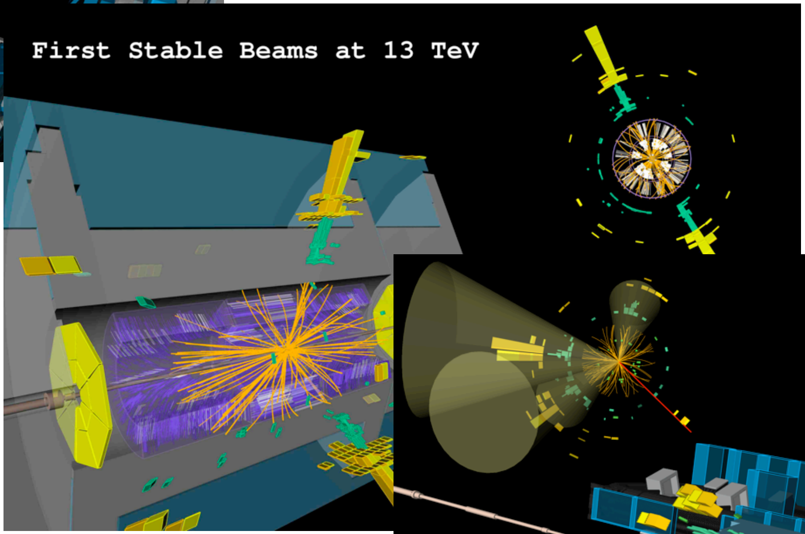
2015 : LHC @ 13 TeV



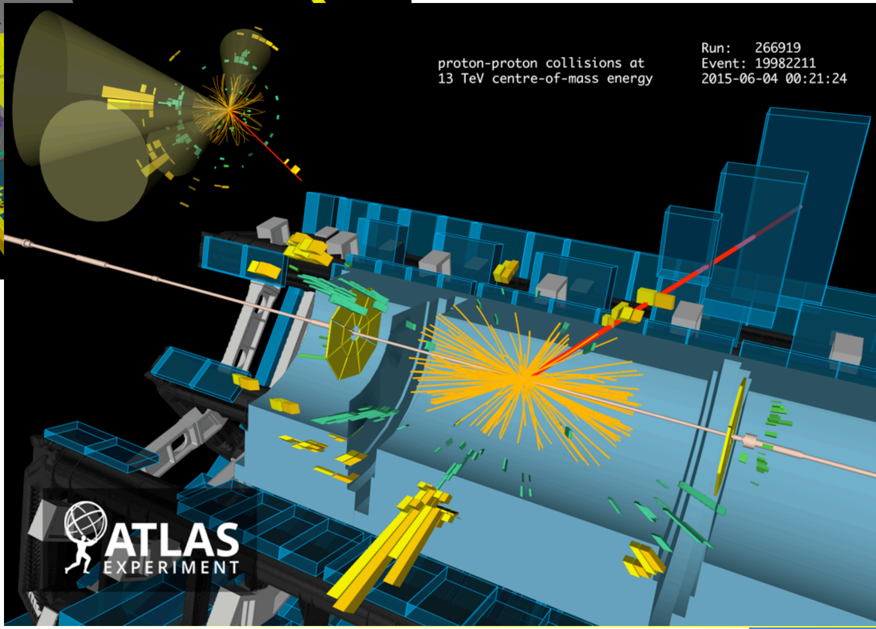
April 7th, 2015: Splash events



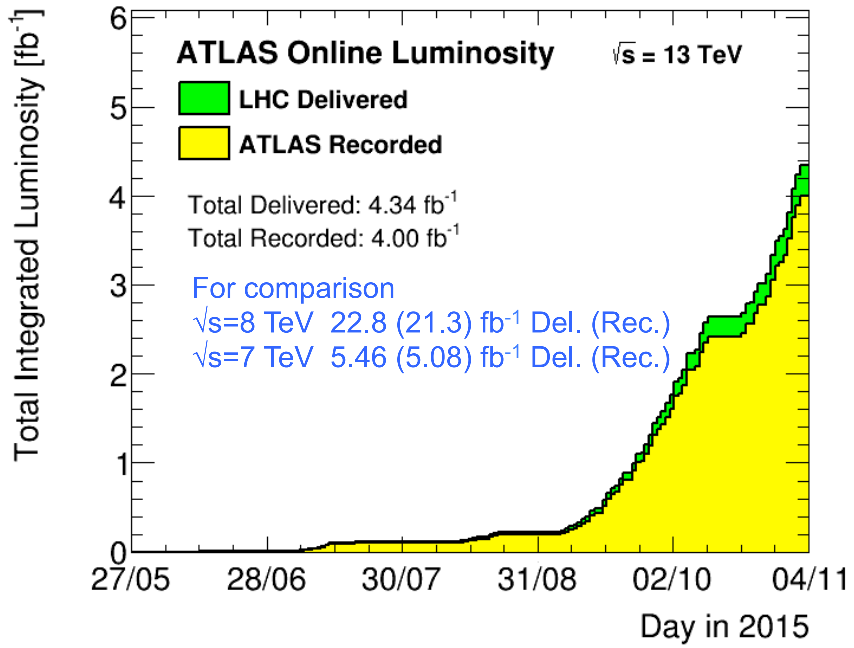
May 5th, 2015: first 900 GeV collisions (injection energy)
May 21st, 2015: first 13 TeV collisions

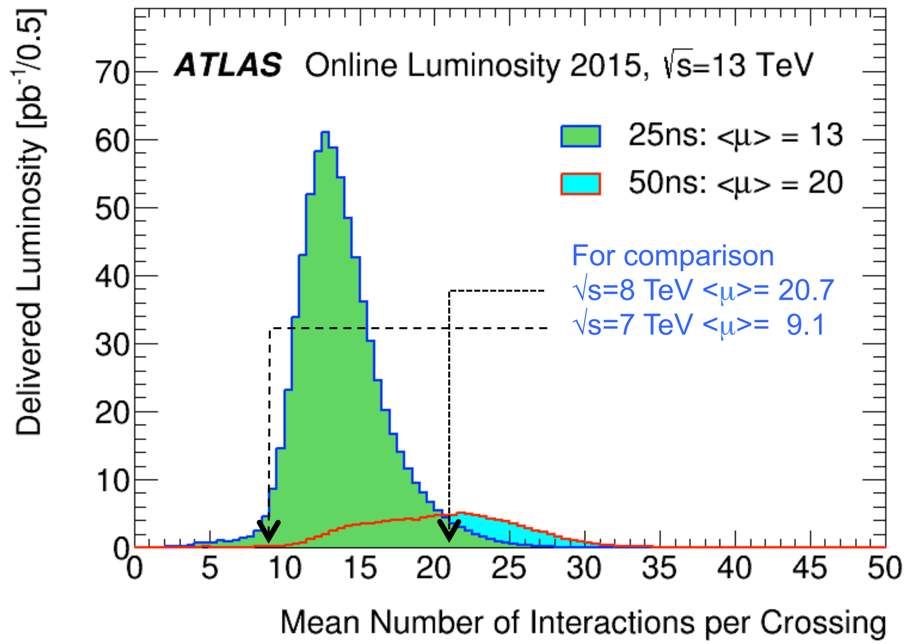


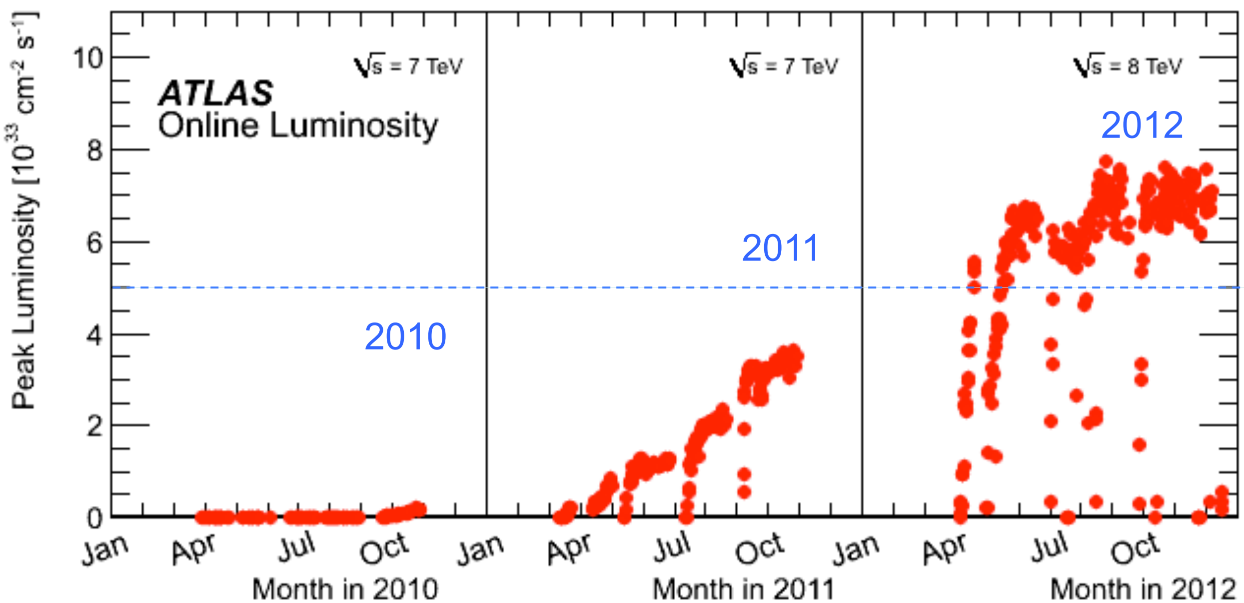
First Stable beams at 13 TeV
June 3rd, 2015

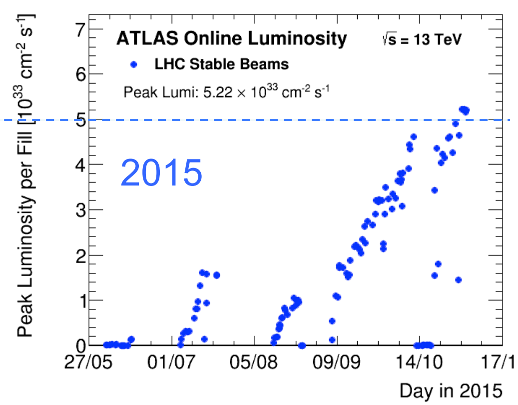


First top quark pair candidate event at 13 TeV
June 4th, 2015





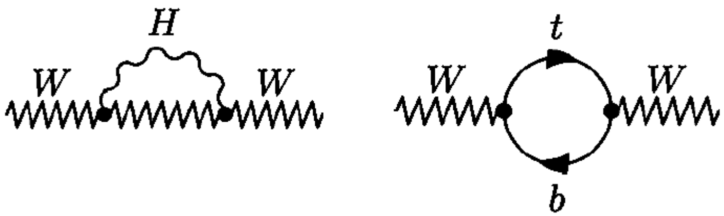




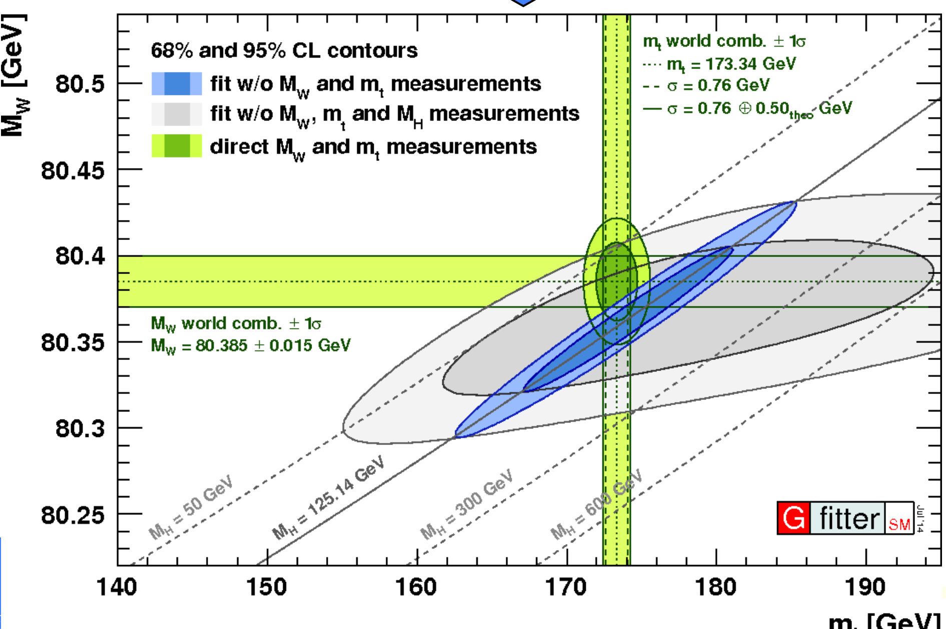
Similar performance/conditions as for 2011 data, but with almost doubled √s!

The top-quark mass

Higgs, top quark, and W boson masses are related

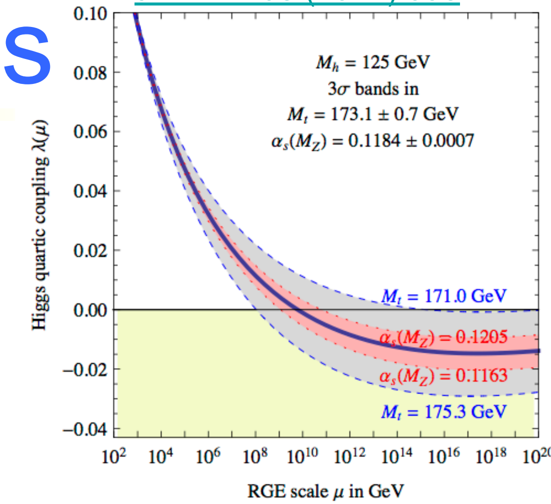


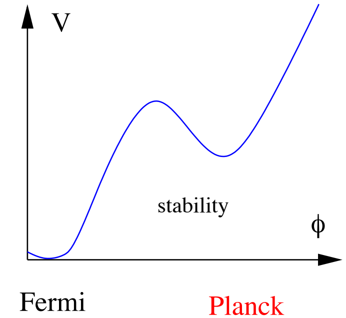
A precise determination of m_{top} combined with EW precision measurements allows for stringent tests of the SM and its extensions

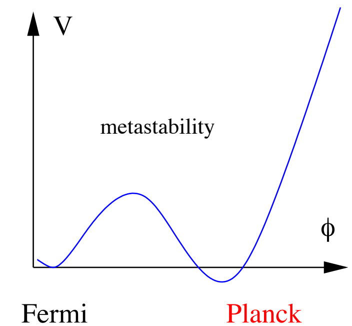


Eur.Phys.J. C74 (2014) 3046

JHEP 1208 (2012) 098







$$V = \frac{1}{2}\mu^2\Phi^2 + \frac{1}{4}\lambda\Phi^4$$

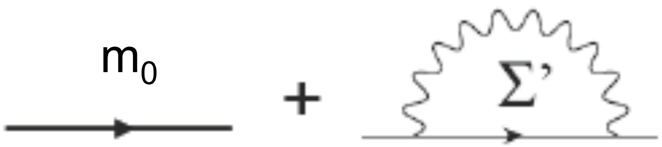
- Also interesting theoretically due to its possible cosmological implications:
  - depending on the values of m_H and m_{top}, the Higgs quartic coupling could be rather small, vanish or even turn negative at a scale smaller than the Planck scale.
  - This affects the shape of the SM Higgs potential: if the Higgs field is trapped in a local minimum during the early universe, it can cause inflation (requires a non-minimal Higgs coupling to gravity)

On the m_{top} definition

Pole mass = pole in the propagator

$$i\frac{p\!\!\!/ + m}{p^2 - m^2 + i\epsilon}$$

but there are self-energy corrections:



and Σ' is divergent.

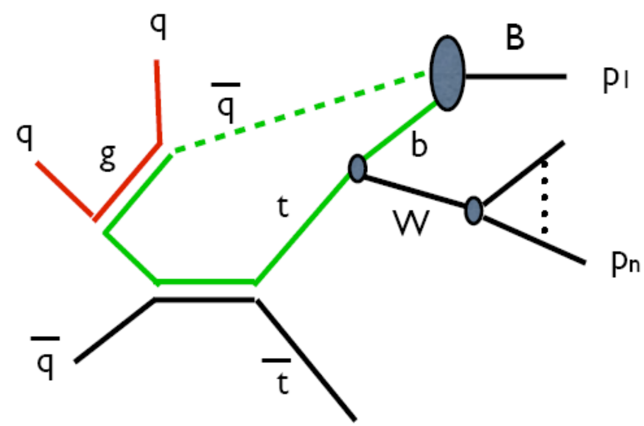
The choice of the renormalization scheme corresponds to a particular definition of the mass parameter

$$m_{\text{top}}^{\text{scheme}} = m_0 + \delta m$$

δm can be used to absorb the divergencies

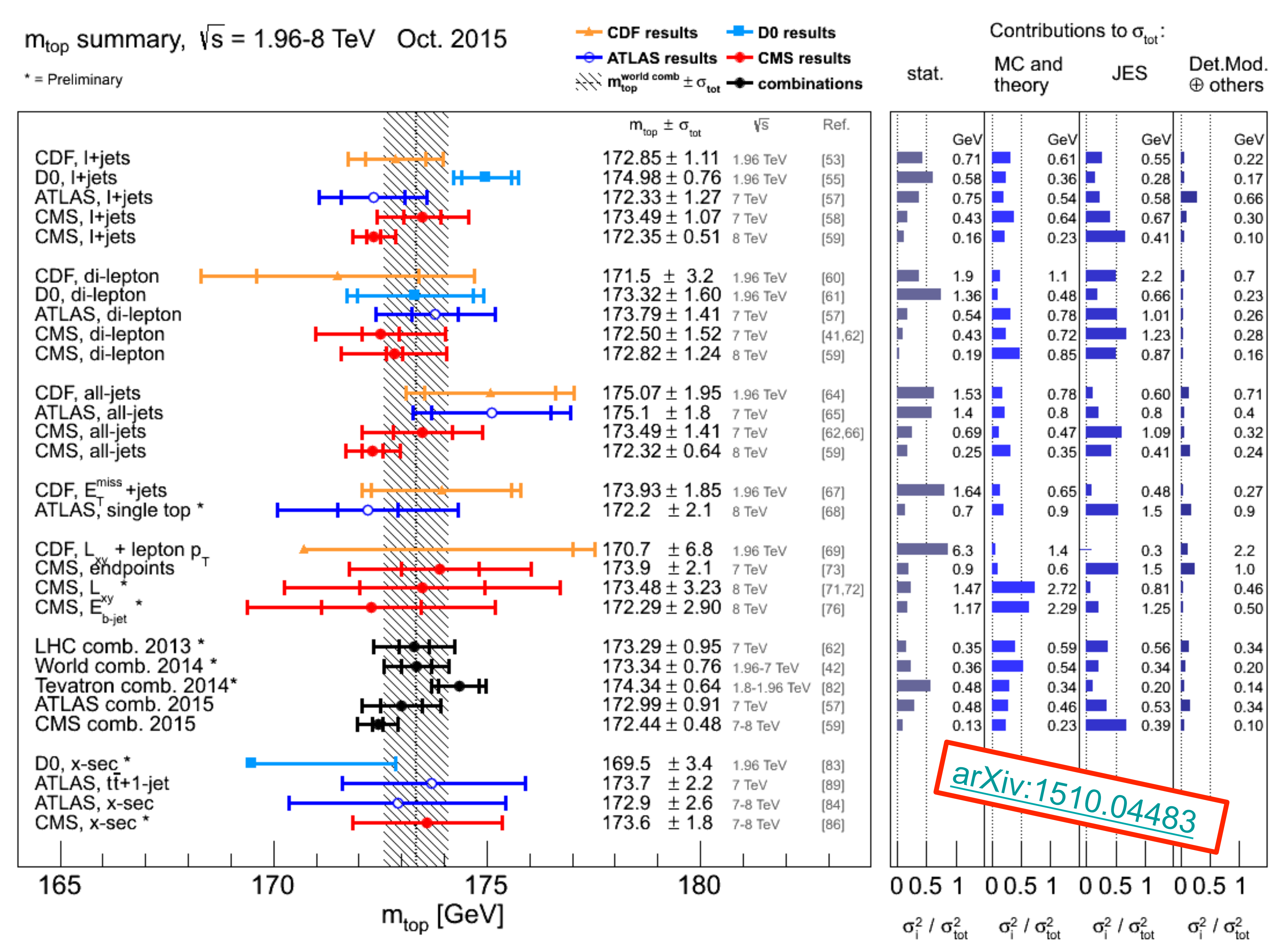
$$m_{\text{top}}^{\text{pole}} : \delta m \equiv \Sigma'$$

- Renormalization schemes are defined by which quantum fluctuations are kept in the dynamical matrix elements and which ones are absorbed into the couplings and masses
  - *Different renormalization schemes yield different mass definitions*



$$m^2_{\text{top, exp}} \equiv \left(m_{\text{top}}^{\text{MC}}\right)^2 = \left(\sum_{i=1,\dots,n} p_i\right)^2$$

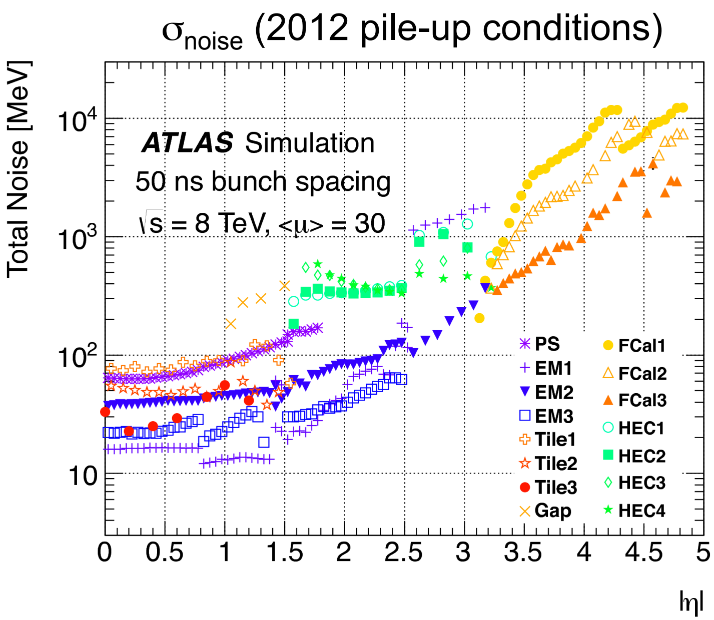
  - *e.g. :* $\Delta(m_{\text{top}}^{\text{pole}} - m_{\text{top}}^{\text{MC}}) \leq \mathcal{O}(1\text{GeV})$



m_top summary, √s = 1.96-8 TeV Oct. 2015
* = Preliminary
CDF results
D0 results
ATLAS results
CMS results
m_top^world comb ± σ_tot
combinations
Contributions to σ_tot:
stat.
MC and theory
JES
Det.Mod. ⊕ others
m_top ± σ_tot
√s
Ref.
GeV
CDF, l+jets 172.85 ± 1.11 1.96 TeV [53] 0.71 0.61 0.55 0.22
D0, l+jets 174.98 ± 0.76 1.96 TeV [55] 0.58 0.36 0.28 0.17
ATLAS, l+jets 172.33 ± 1.27 7 TeV [57] 0.75 0.54 0.58 0.66
CMS, l+jets 173.49 ± 1.07 7 TeV [58] 0.43 0.64 0.67 0.30
CMS, l+jets 172.35 ± 0.51 8 TeV [59] 0.16 0.23 0.41 0.10
CDF, di-lepton 171.5 ± 3.2 1.96 TeV [60] 1.9 1.1 2.2 0.7
D0, di-lepton 173.32 ± 1.60 1.96 TeV [61] 1.36 0.48 0.66 0.23
ATLAS, di-lepton 173.79 ± 1.41 7 TeV [57] 0.54 0.78 1.01 0.26
CMS, di-lepton 172.50 ± 1.52 7 TeV [41,62] 0.43 0.72 1.23 0.28
CMS, di-lepton 172.82 ± 1.24 8 TeV [59] 0.19 0.85 0.87 0.16
CDF, all-jets 175.07 ± 1.95 1.96 TeV [64] 1.53 0.78 0.60 0.71
ATLAS, all-jets 175.1 ± 1.8 7 TeV [65] 1.4 0.8 0.8 0.4
CMS, all-jets 173.49 ± 1.41 7 TeV [62,66] 0.69 0.47 1.09 0.32
CMS, all-jets 172.32 ± 0.64 8 TeV [59] 0.25 0.35 0.41 0.24
CDF, E_T^miss +jets 173.93 ± 1.85 1.96 TeV [67] 1.64 0.65 0.48 0.27
ATLAS, single top * 172.2 ± 2.1 8 TeV [68] 0.7 0.9 1.5 0.9
CDF, L_xy + lepton p_T 170.7 ± 6.8 1.96 TeV [69] 6.3 1.4 0.3 2.2
CMS, endpoints 173.9 ± 2.1 7 TeV [73] 0.9 0.6 1.5 1.0
CMS, L_xy * 173.48 ± 3.23 8 TeV [71,72] 1.47 2.72 0.81 0.46
CMS, E_b-jet * 172.29 ± 2.90 8 TeV [76] 1.17 2.29 1.25 0.50
LHC comb. 2013 * 173.29 ± 0.95 7 TeV [62] 0.35 0.59 0.56 0.34
World comb. 2014 * 173.34 ± 0.76 1.96-7 TeV [42] 0.36 0.54 0.34 0.20
Tevatron comb. 2014* 174.34 ± 0.64 1.8-1.96 TeV [82] 0.48 0.34 0.20 0.14
ATLAS comb. 2015 172.99 ± 0.91 7 TeV [57] 0.48 0.46 0.53 0.34
CMS comb. 2015 172.44 ± 0.48 7-8 TeV [59] 0.13 0.23 0.39 0.10
D0, x-sec * 169.5 ± 3.4 1.96 TeV [83]
ATLAS, tt̄+1-jet 173.7 ± 2.2 7 TeV [89]
ATLAS, x-sec 172.9 ± 2.6 7-8 TeV [84]
CMS, x-sec * 173.6 ± 1.8 7-8 TeV [86]
165 170 175 180
m_top [GeV]
0 0.5 1
σ_i^2 / σ_tot^2
arXiv:1510.04483

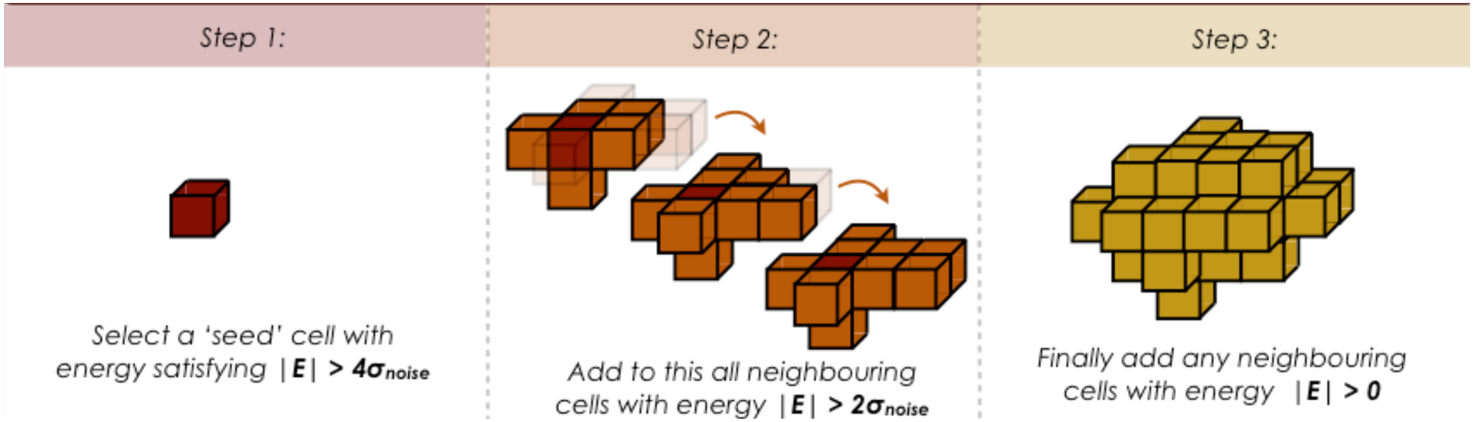
Calorimeter topo-clusters and their calibration

- For all analyses described before, jet calibration (and its uncertainty) constitutes a critical input
- MPP developed and fully commissioned novel ideas for the clustering and calibration of calorimeter signals into topological clusters (topo-clusters) that are used in subsequent physics object reconstruction
  - follow electromagnetic (EM) / hadronic (HAD) shower development
  - suppress noise and pile-up energy contributions (see also arXiv:1510.03823)



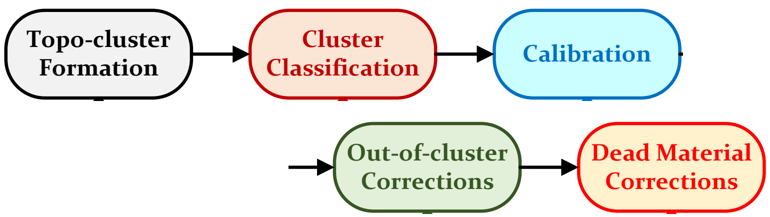
arXiv:1510.03823

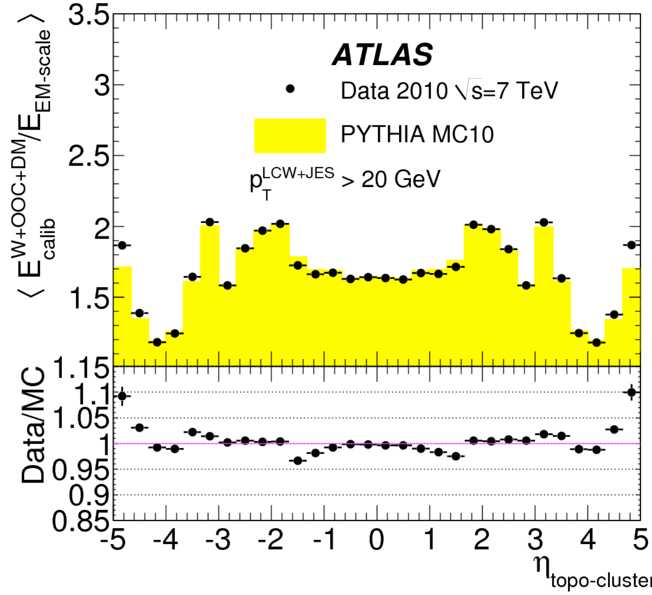
graphics by T. McCarthy



Local Hadron Calibration

- Topo-custer shapes and other features are used to classify EM-like/HAD-like cluster for proper MC based local calibration





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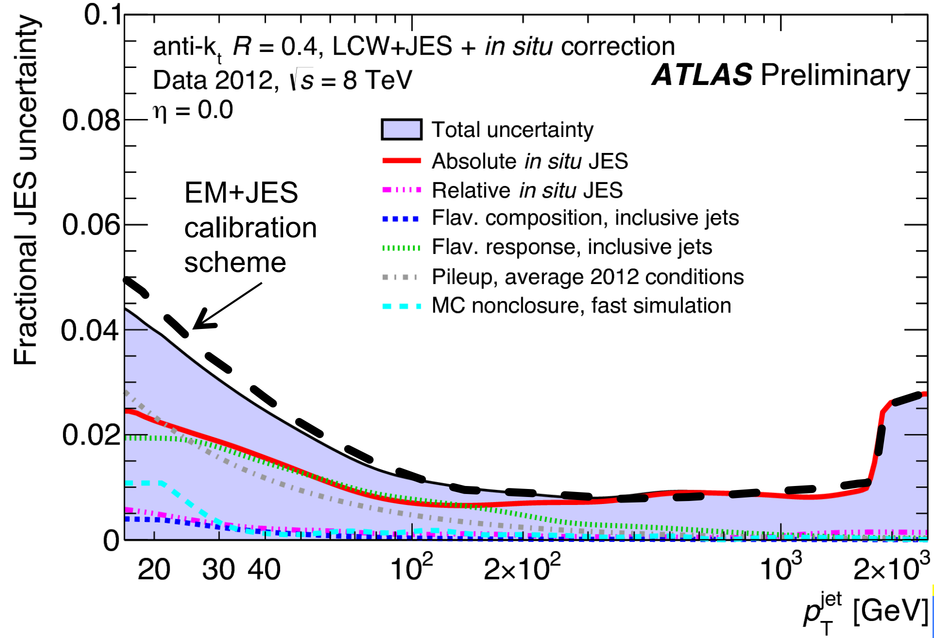
  - in addition out-of-cluster and dead-material corrections are applied

- Default for $\sqrt{s} \geq 8$ TeV analyses
  - particularly important for E_T^{miss} and jet (sub-structures) calibration
  - provides a reduced JES uncertainty (important for precision analyses)



ATLAS-CONF-2015-037

- ATLAS paper to appear soon