First Measurement of Jets and Missing Transverse Energy with the ATLAS Calorimeter at $\sqrt{s} = 900\ \mathrm{GeV}$ and $\sqrt{s} = 7\ \mathrm{TeV}$

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on behalf of the ATLAS Collaboration
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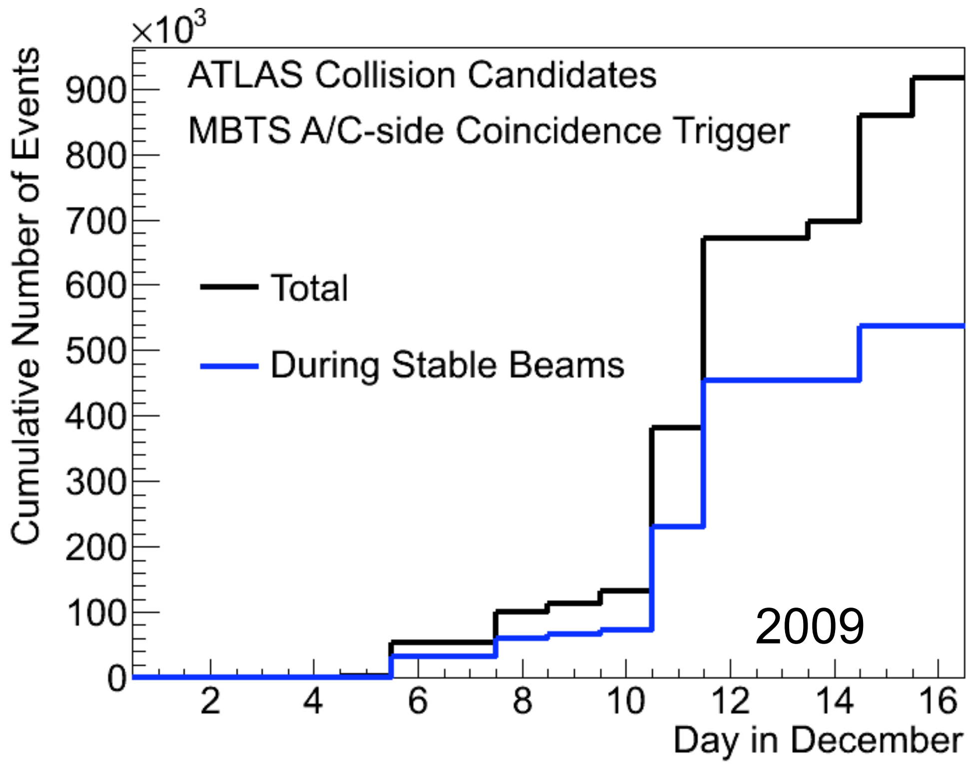
What I will try to convey

- You have heard (quite a bit) about:
  - How we collect data with the missing transverse energy, τ (*next!*) and e/γ trigger systems at both Level-1 and the HLT. (H. Beauchemin, V. Dao, T. Childers, A. Sfyrla)
  - How ATLAS has used the test beams to develop extensive understanding of the hadronic showers and calibrations. (M. Simonyan and G. Pospelov)
  - How the hadronic, EM and forward calorimeters perform in the first data. (D. Gillberg, H. Zhang, C. Gabaldon, V. Rossetti, G. Usai)
  - How these calorimeters respond to single pions and the use of topological cluster calibration in the very first collision data. (M. Simonyan and P. Giovannini)
  - How the ECAL is used to reconstruct e/γ in the very first collision data (D. Banfi)

I will try to convey to you how all of this hard work has translated into the first measurements of jets, jet properties, calibrations and missing transverse energy at several center-of-mass energies.

The 2009 and 2010 Data Sample

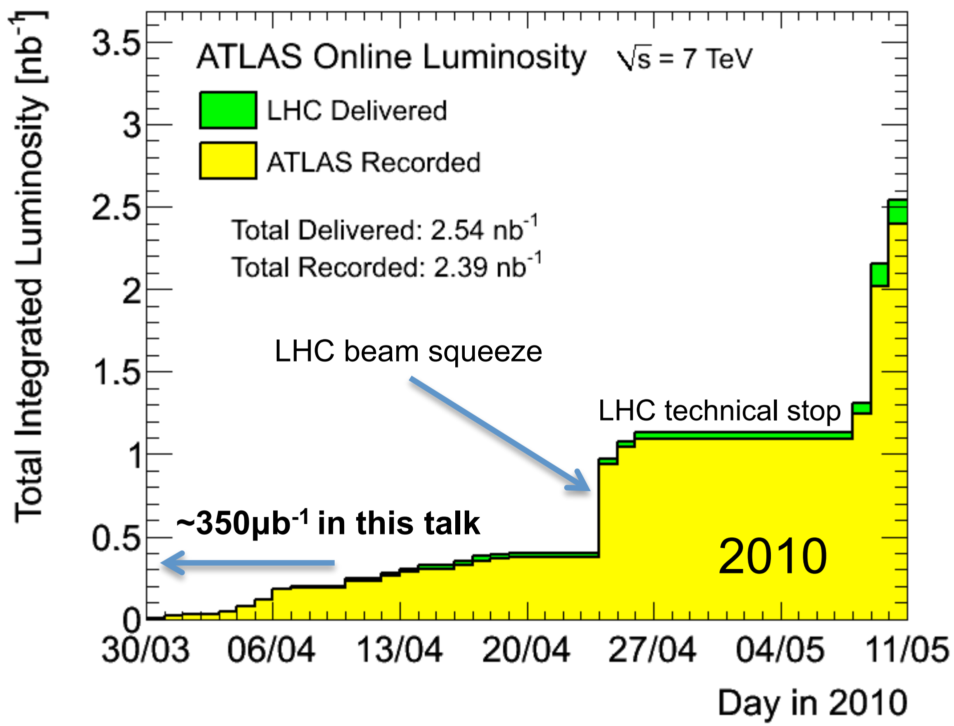
Almost 1 million events collected in 2009 at $\sqrt{s} = 900\ \mathrm{GeV}$



- Peak luminosity: **~7 x 10^{26}cm^{-2}s^{-1}**
- Integrated luminosity: **12 μb^{-1}**

(stable beams, 30% syst)

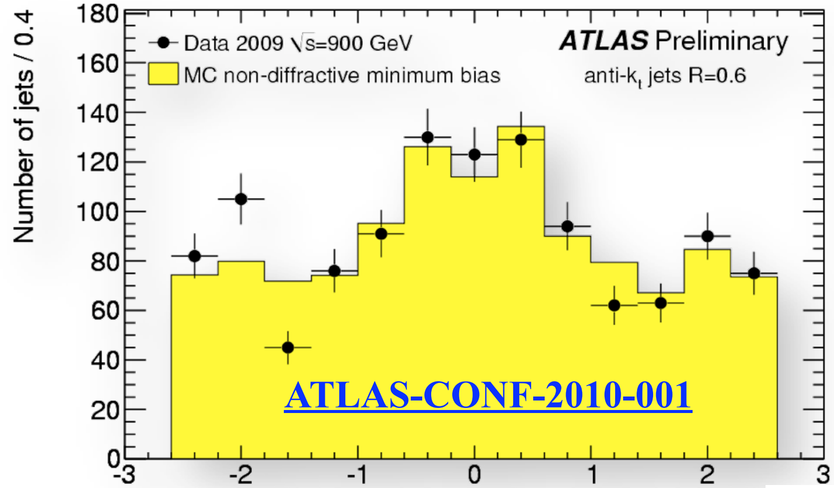
More than 2.5 nb^{-1} accumulated to date in 2010 at $\sqrt{s} = 7\ \mathrm{TeV}$



- Peak luminosity: **~2 x 10^{28}cm^{-2}s^{-1}**
- Integrated luminosity: **2.5 nb^{-1}**

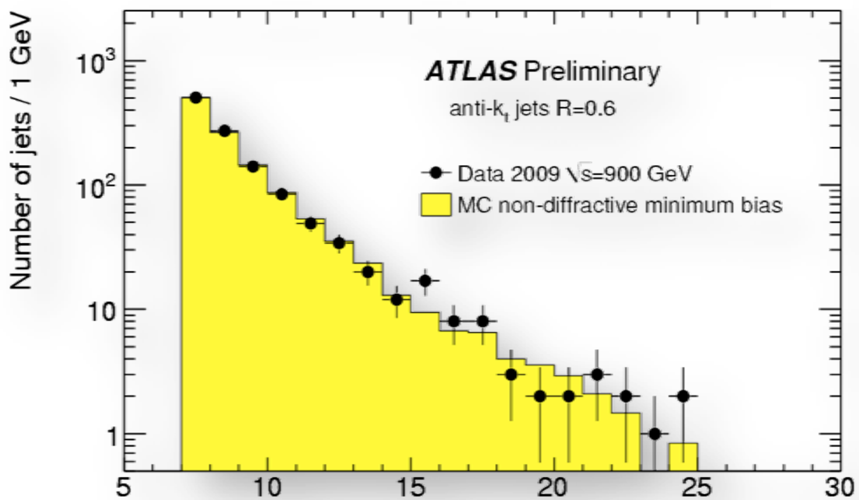
FIRST OBSERVATION OF JETS AND MEASUREMENTS OF MISSING ET

Observation of jets at $\sqrt{s} = 0.9,\ 7\ \text{TeV}$



$\sqrt{s} = 900\ \text{GeV}$

η

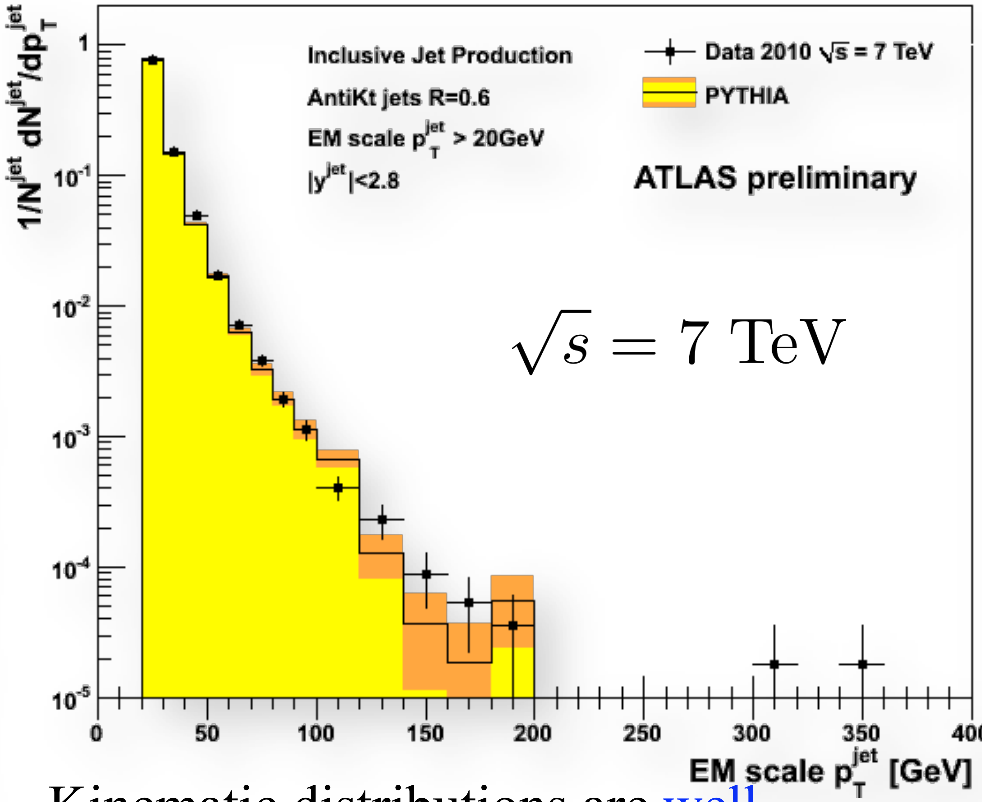


p_T **(EM-scale) [GeV]**

- Infrared and collinear safe jet algorithm:

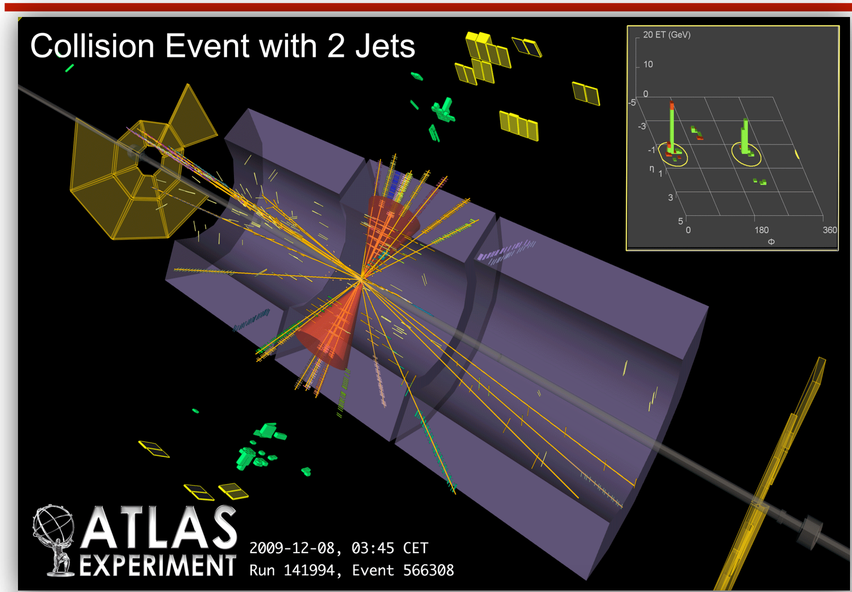
  anti-k_t (R=0.6)

- All jets and MET **uncalibrated** ("EM-scale")
  - validate calibrations first

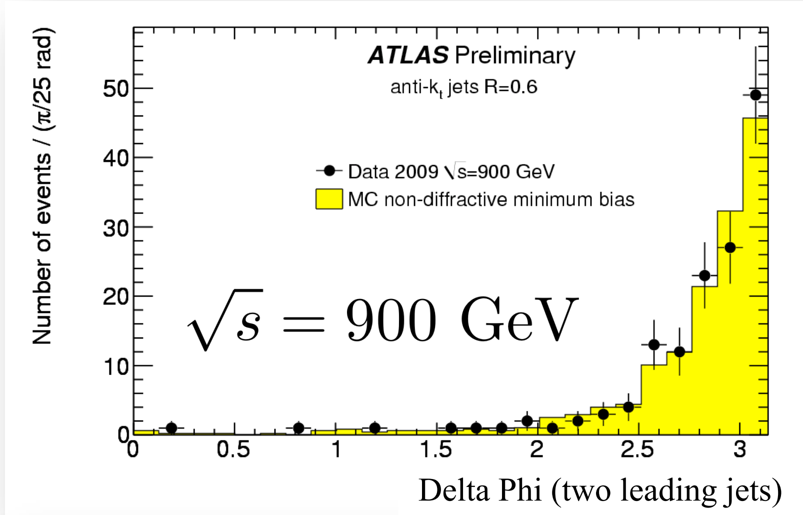


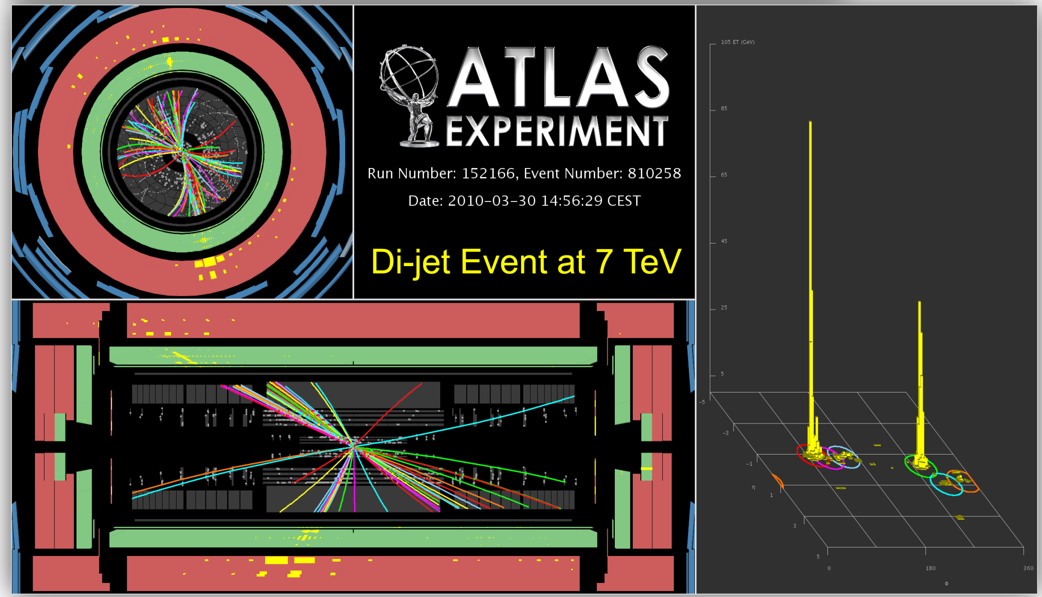
- Kinematic distributions are well described by the MC

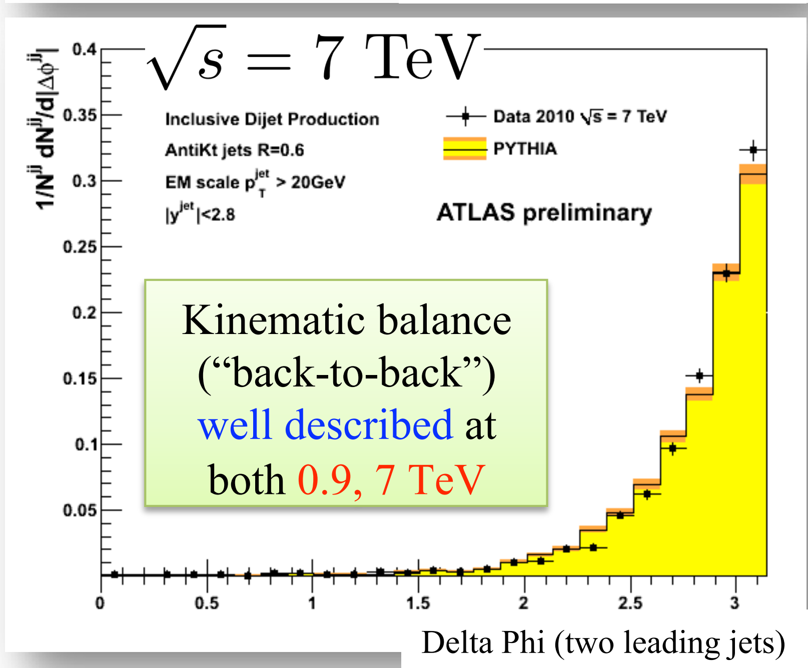
Di-jet production at $\sqrt{s} = 0.9,\ 7$ TeV



QCD di-jet production observed within days of the first collisions



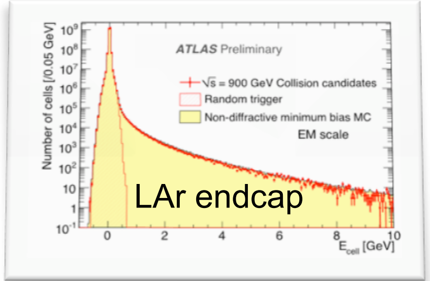


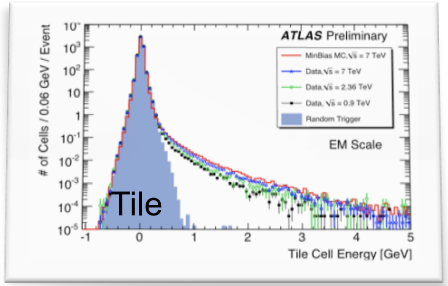


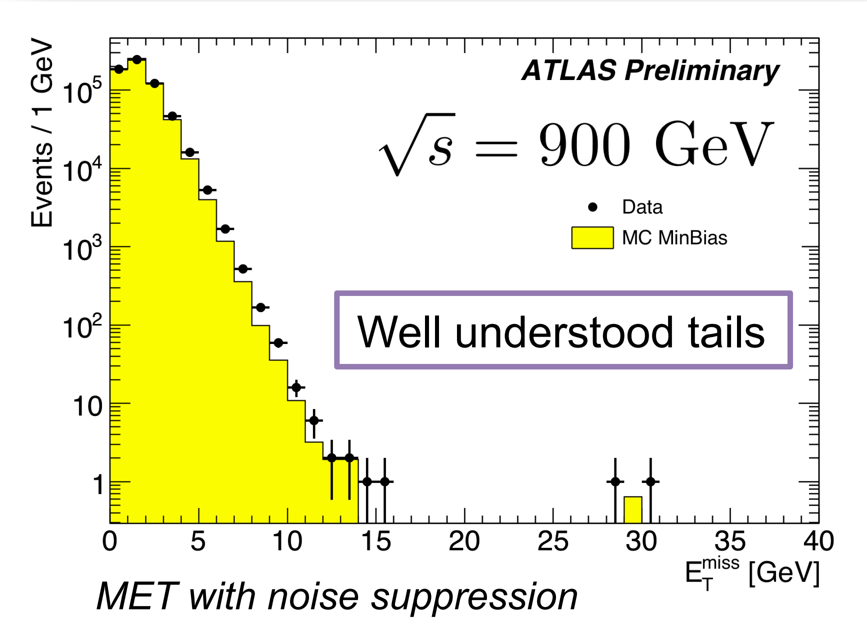
Kinematic balance ("back-to-back") well described at both 0.9, 7 TeV

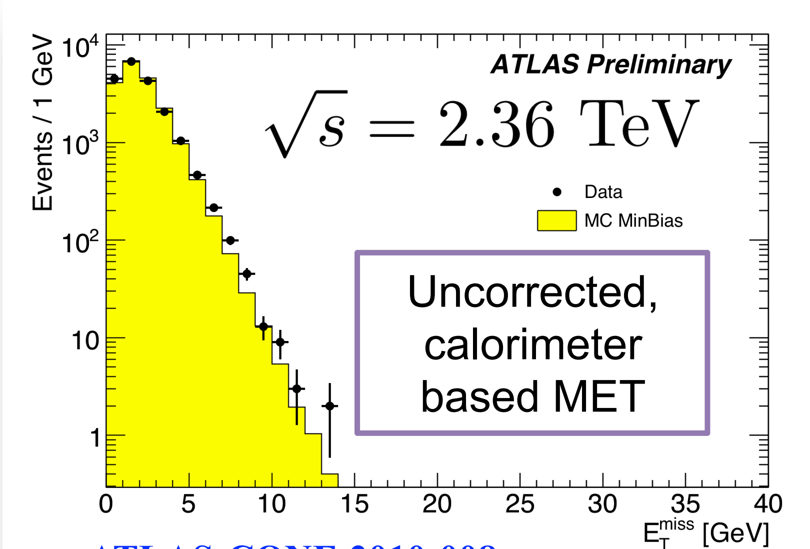
Missing transverse energy at $\sqrt{s} = 0.9,\ 2.36, 7$ TeV

Well understood cell-level energy response directly impacts MET measurements









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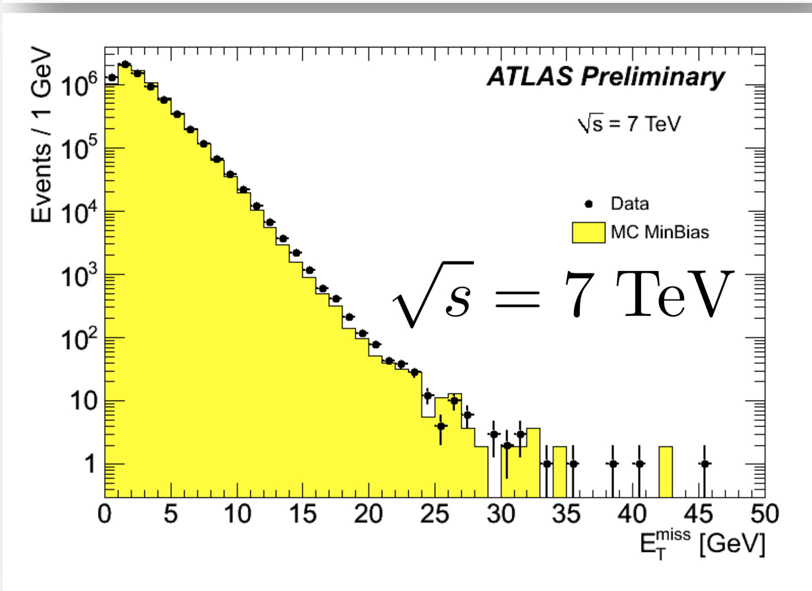
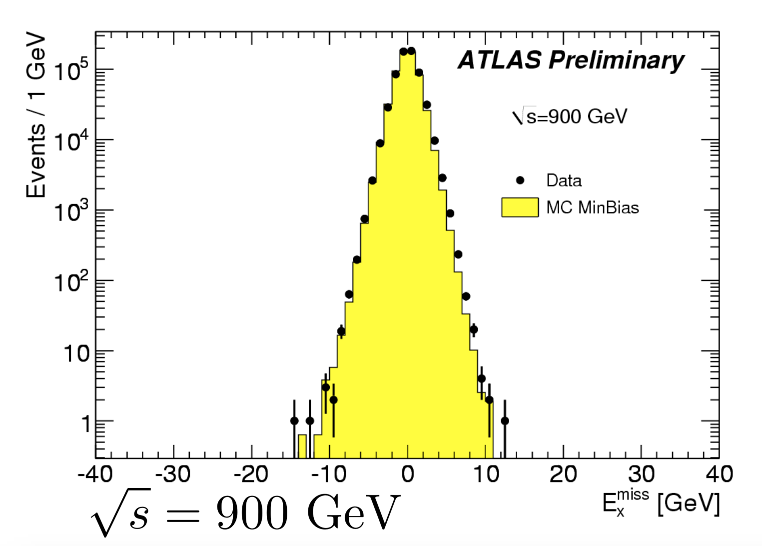
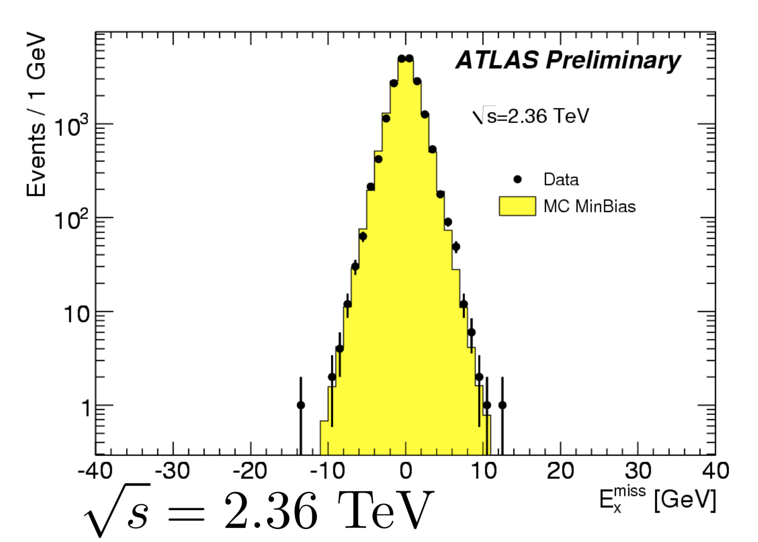
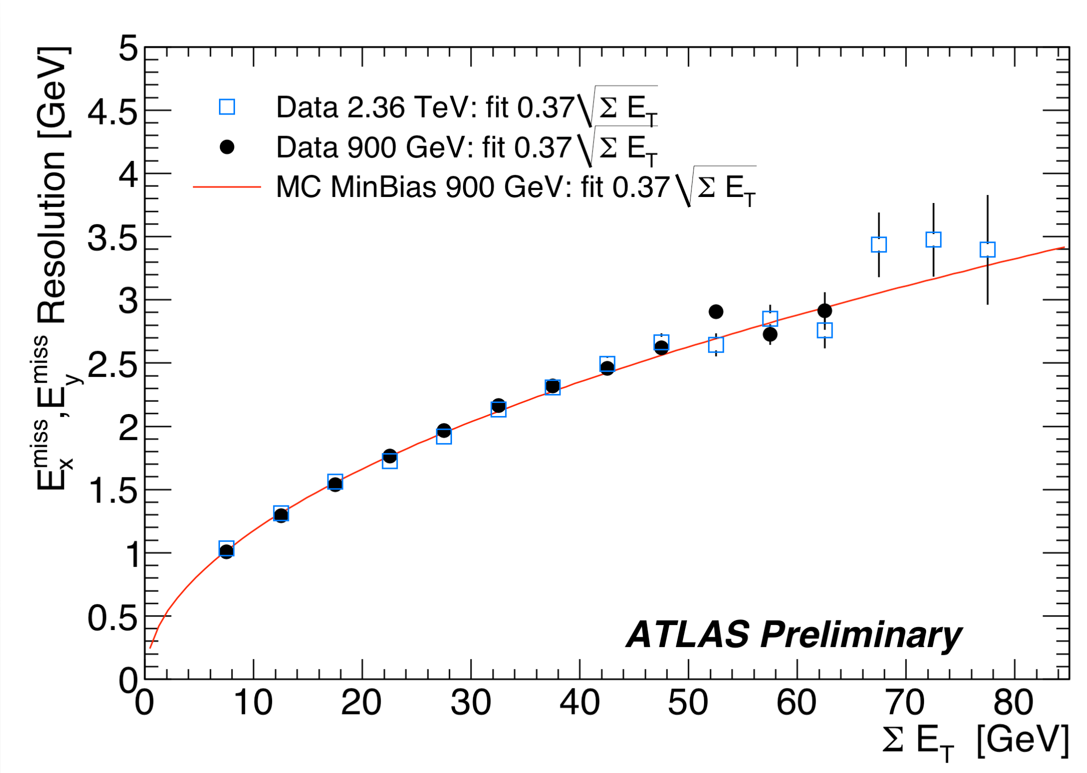


Missing transverse energy resolution







- A very good agreement between data and Monte Carlo at **900 GeV and 2.36 TeV**
- Tails are **well-under control**
- MET measurements **stable to within 3%** over the full 900 GeV running period

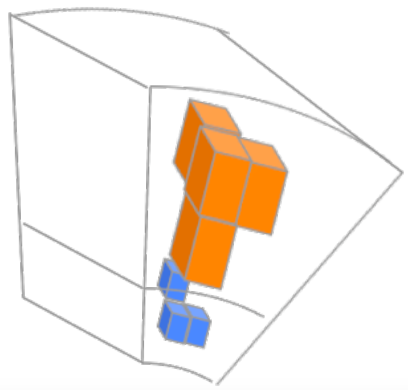
JET RECONSTRUCTION AND CALIBRATION SCHEMES

Inputs to jet reconstruction

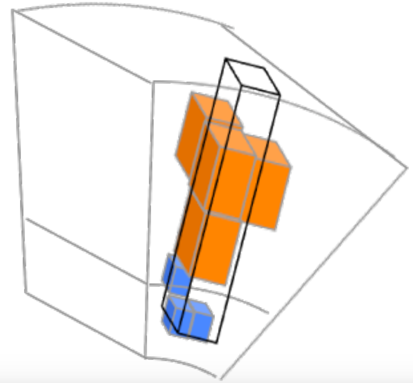
The performance and physics potential of **jet-based analyses** depends crucially on the **calorimeter performance** and the understanding of the **inputs** to jet reconstruction

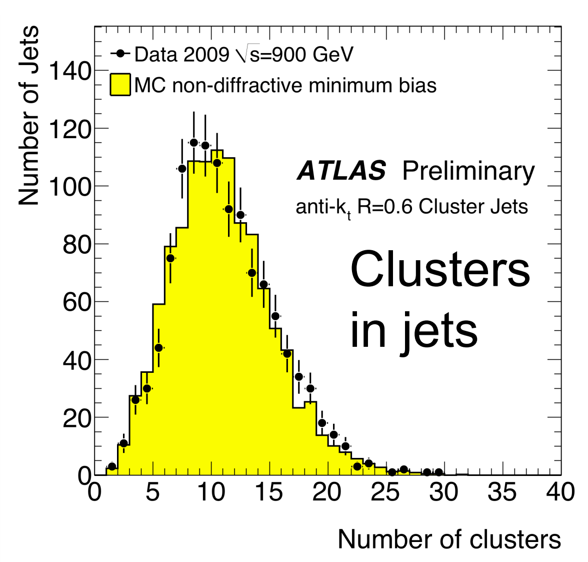
- ***ATLAS uses two primary jet inputs***
  - Topological clusters
    - nearest neighbor energy significance
  - Noise suppressed towers using cells in clusters

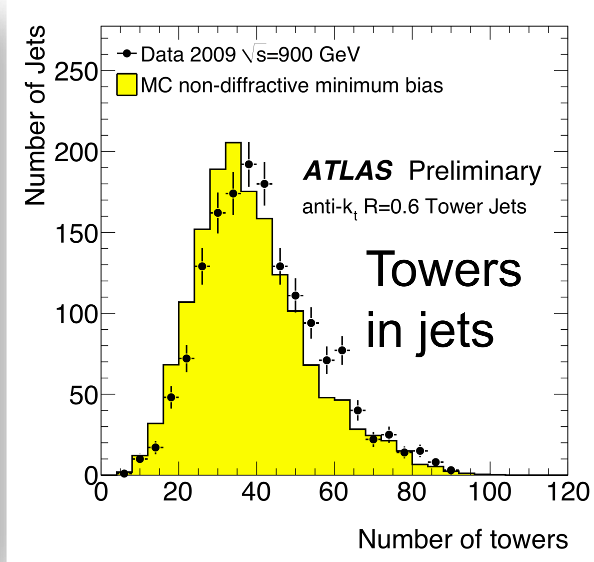
Topological clusters



Projective towers with topo. noise suppression







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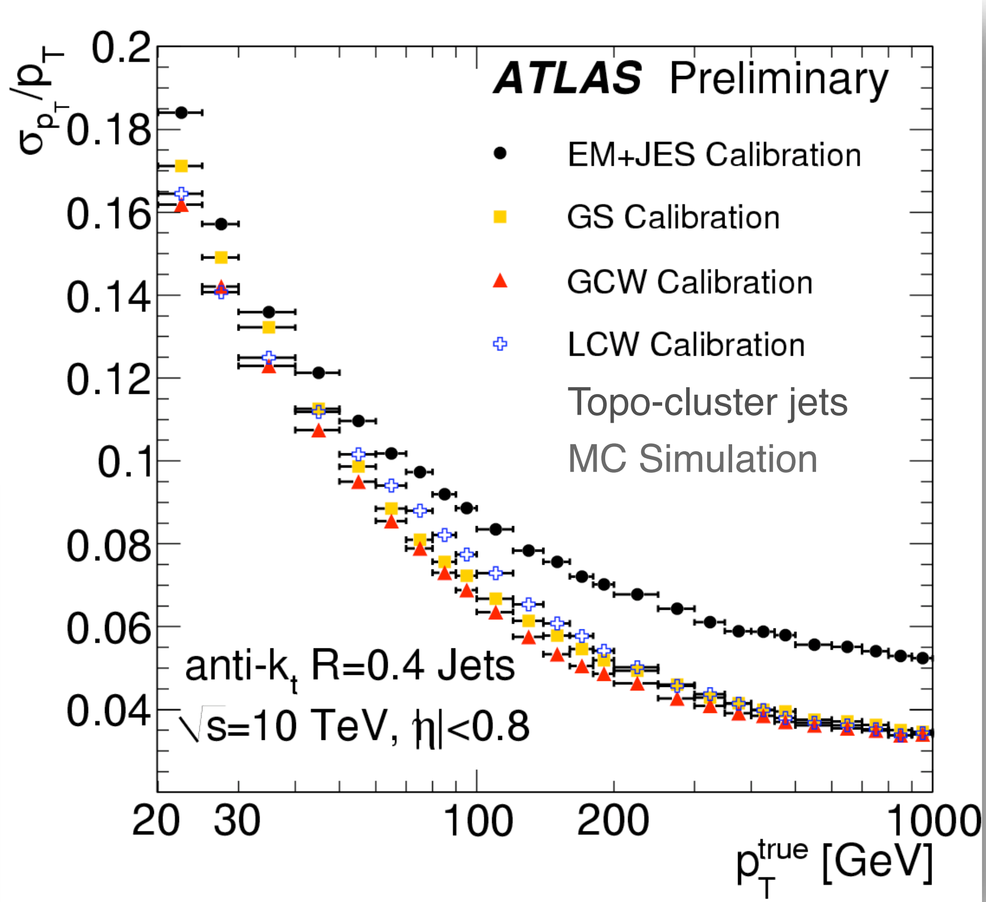
Jet calibration schemes in ATLAS

- ATLAS has developed several calibration schemes with different levels of complexity and sensitivity to systematic effects
- Complementary in how they contribute to the understanding of the jet energy measurement

(Talk by M. Simonyan on in-situ techniques)

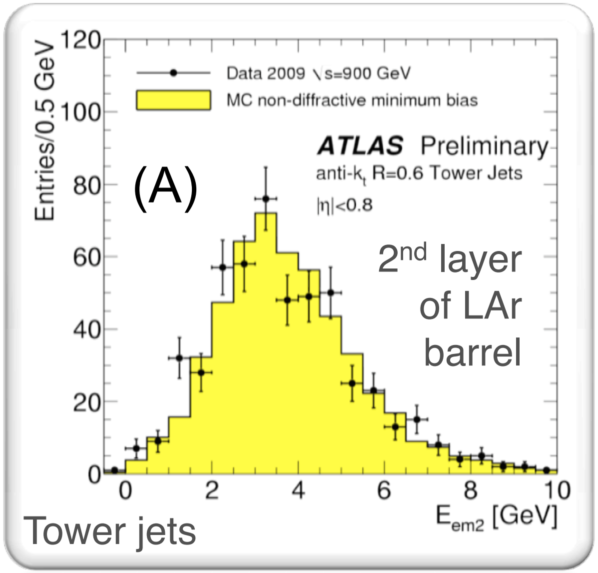
EM+JES	Simple p_T and η-dependent calibration (MC or data)
GS	Global sequential calibration using jet properties (MC or data)
GCW	Cell energy-density-based weighting (MC-based)
LCW	Cluster property-based weighting (MC-based)

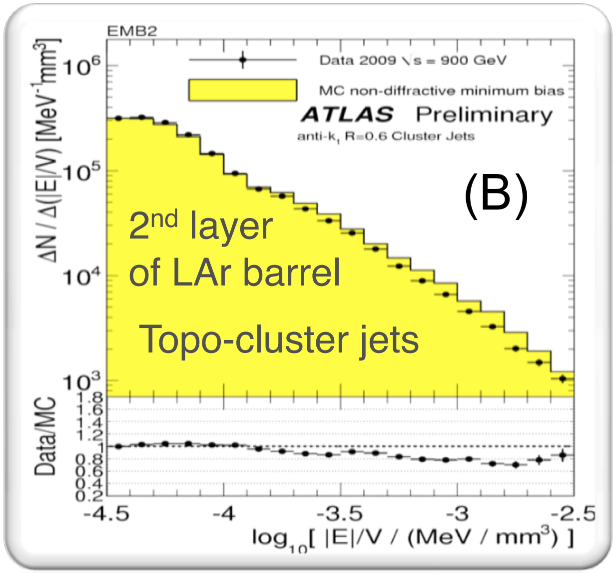


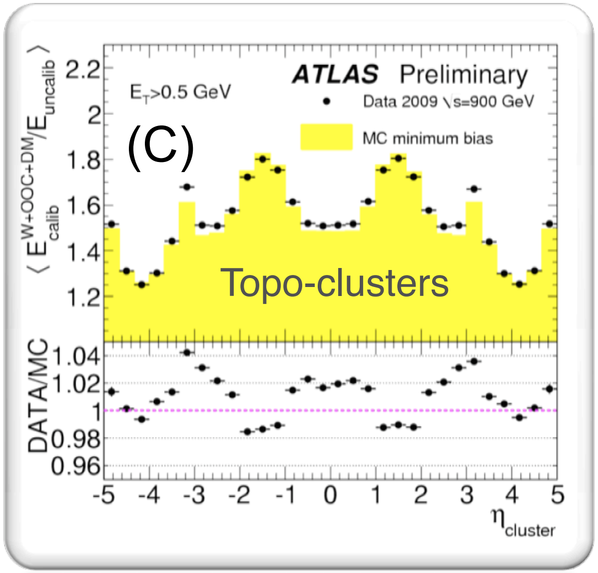
Derived using MC at $\sqrt{s} = 10$ TeV

Inputs to calibration schemes at $\sqrt{s} = 900$ GeV

Energy in 2nd EM layer in data vs MC	**Cell energy density weights in data vs MC**	**Cluster property-based weights in data vs MC**







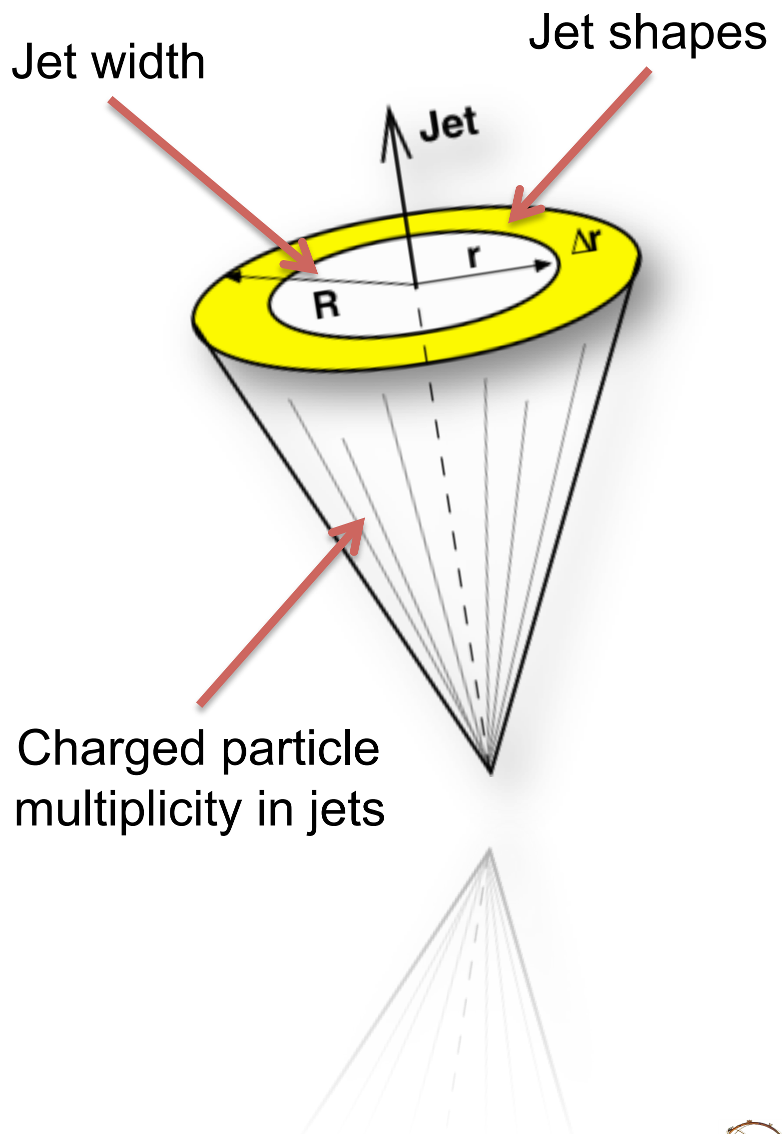
- (A) A good agreement between MC and data for long. layer energies in jets.
- (B) Cell energy densities described well at low energy density with a slightly lower average cell-energy density
- (C) Cluster property-based weighting agrees to within 4% across all η for the combined dead material, hadronic response and out-of-cluster corrections.

(see talk by P. Giovannini)

JET PROPERTIES AND INTERNAL STRUCTURE

Jet properties at $\sqrt{s} = 900\ \mathrm{GeV}$

- **Tracks and energy distributions within jets** will form a basis for understanding the process of jet production and internal jet structure at higher $\sqrt{s}$
- Describing these properties constitutes a crucial step towards the precise determination of the **jet energy scale**



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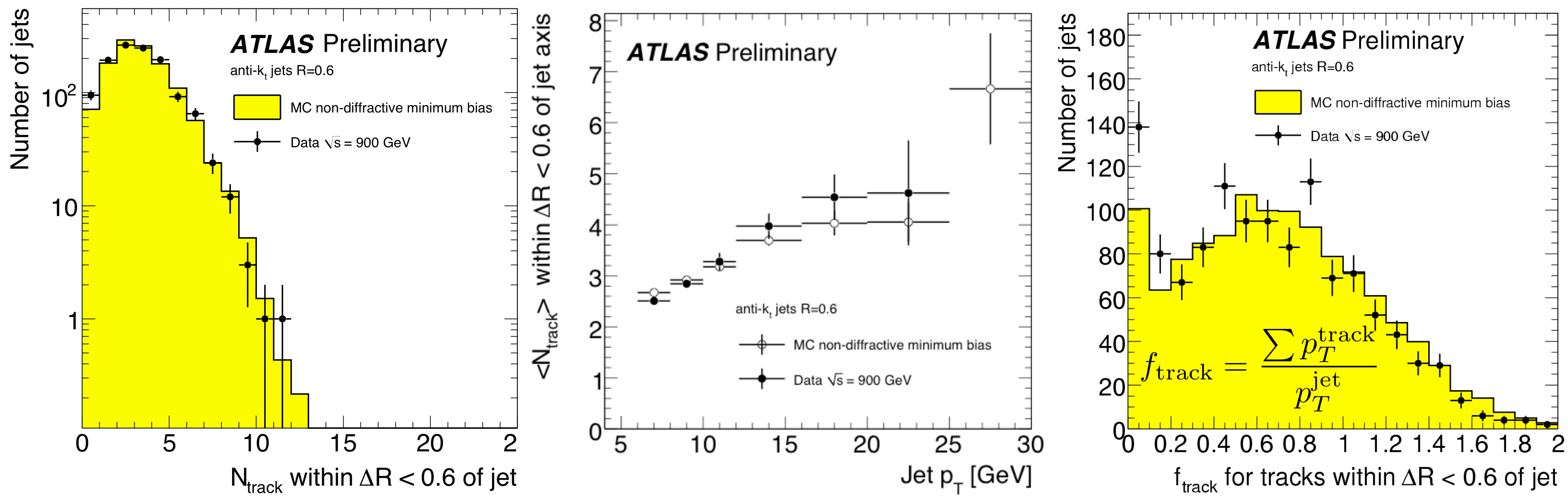
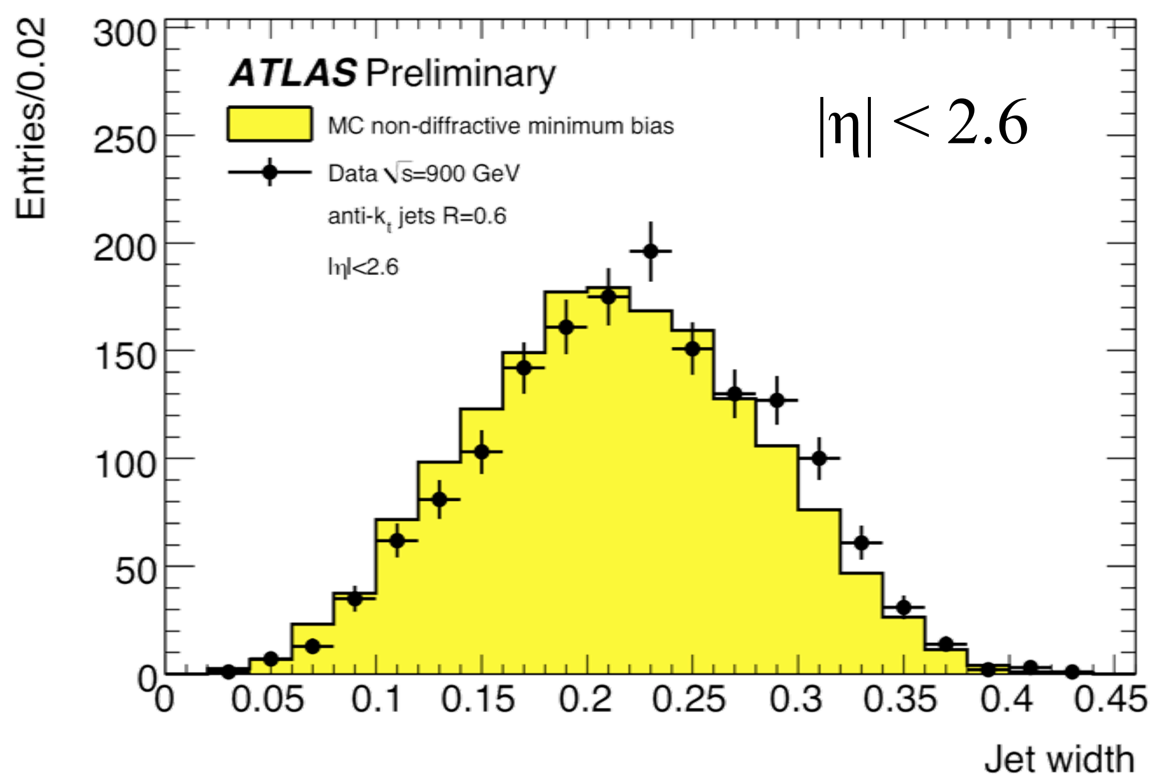
Jet properties using tracking at $\sqrt{s} = 900$ GeV



- Our MC offers a good description of the charged particle properties of jets
  - Track multiplicity in jets very close to expectations
  - Dependence of track multiplicity on jet p_T agrees quite well (sensitive to fragmentation)
- Important for jet energy scale and resolution (as well as systematics)
  - f_{track} has been demonstrated to help improve the jet energy resolution

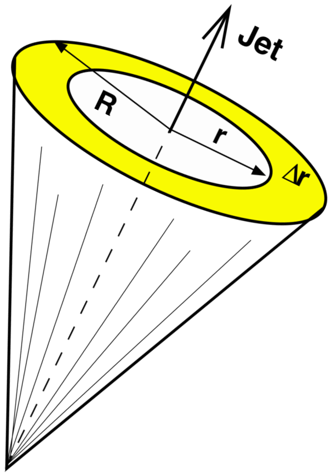
Jet width at $\sqrt{s} = 900$ GeV

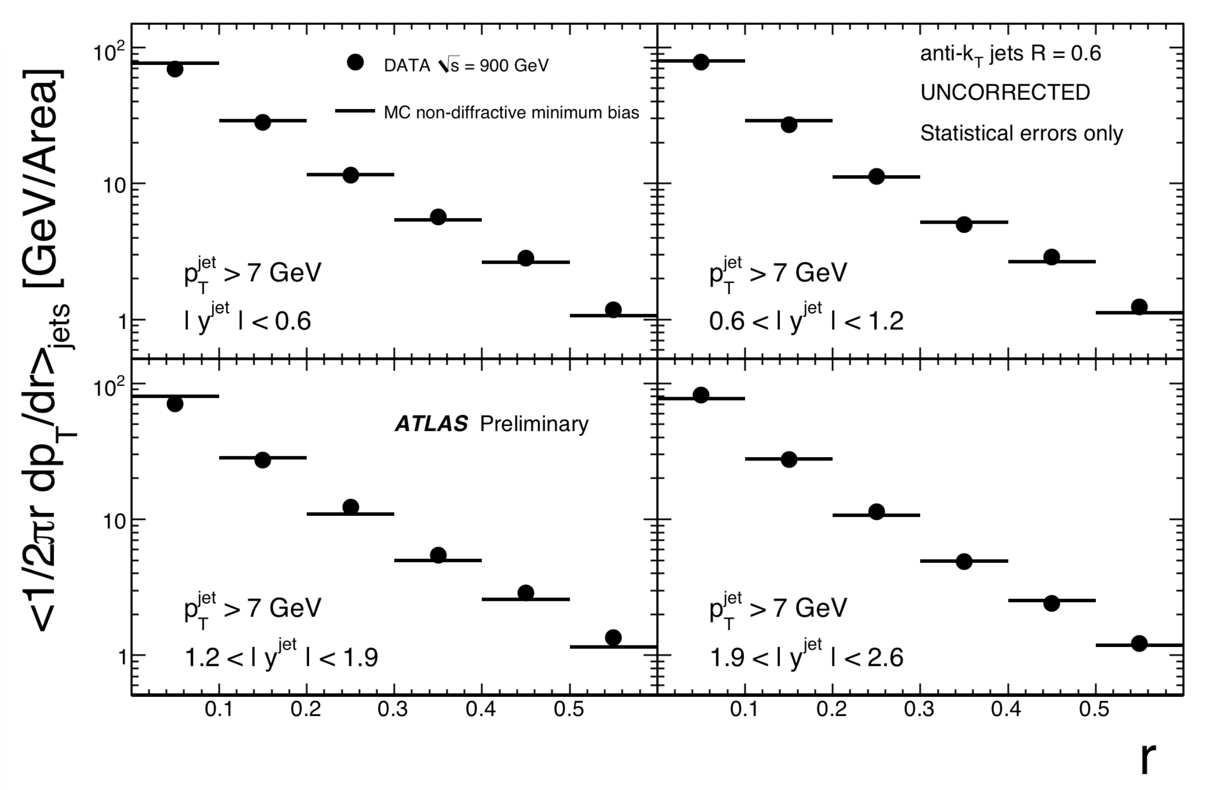
- **Width:** First moment of the radial energy distribution in the jet
  - Reduce sensitivity to quark vs. gluon jets
  - Has been shown to aid in improving the jet energy scale
    - Wider jets typically affected more by non-compensation
- Shape of the width distribution described well by MC
- …but jets in data are "**wider**"



$$\text{width} = \frac{\sum(\Delta r \times E_T^{\text{constituent}})}{\sum E_T^{\text{constituent}}}$$

Jet shapes using calorimetry

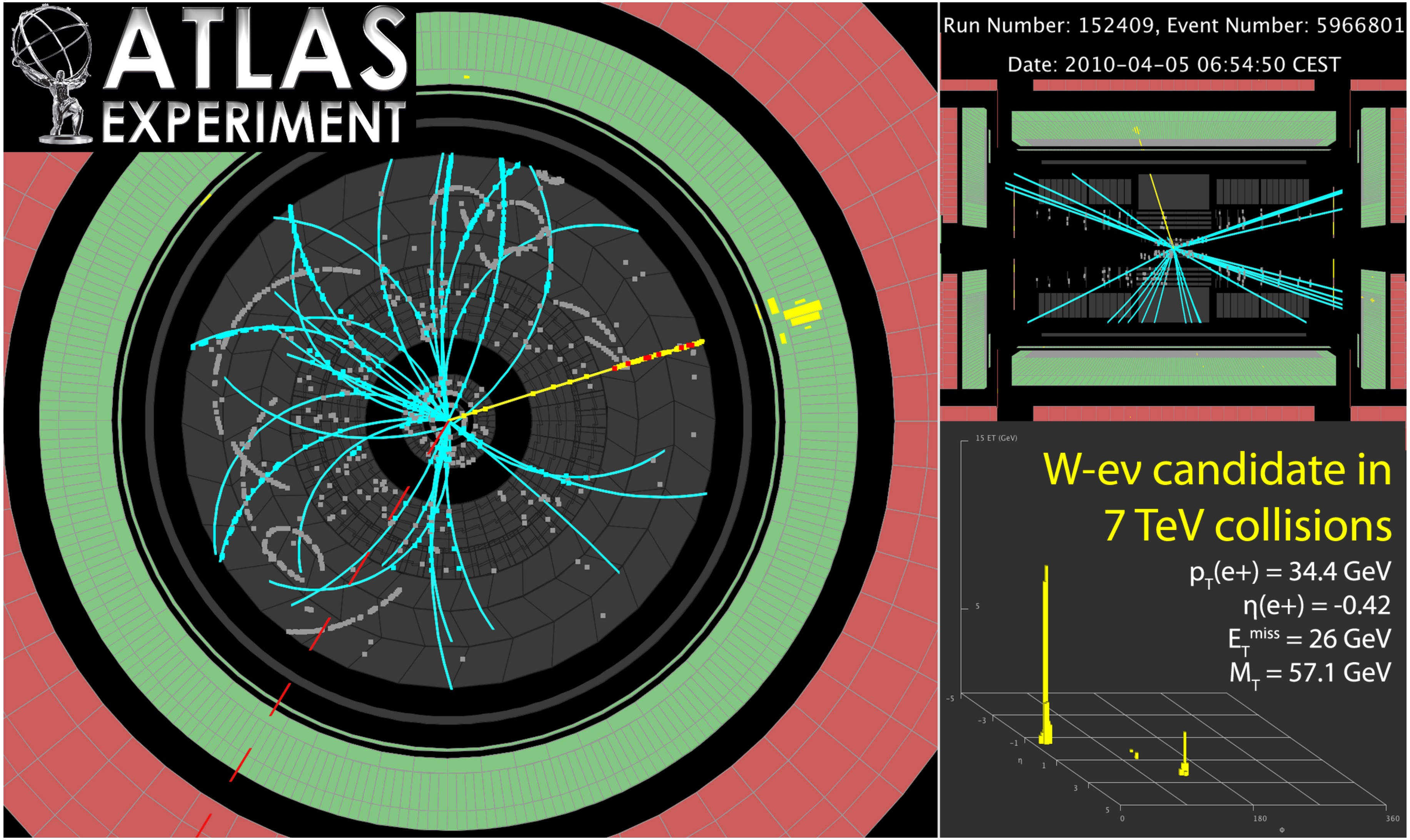




- The more detailed "**jet profile**" has been measured at multiple colliders
- It is sensitive to a proper understanding of the jet fragmentation process, the detector response to low energy particles, underlying event and more.
- We find that our MC provides a good description of the jet profile, although here we ***also see wider jets in the data*** (*less energy in core, more in periphery*).

USING MISSING ET AT $\sqrt{s} = 7\ \mathrm{TeV}$

Observation of W→eν at $\sqrt{s} = 7$ TeV



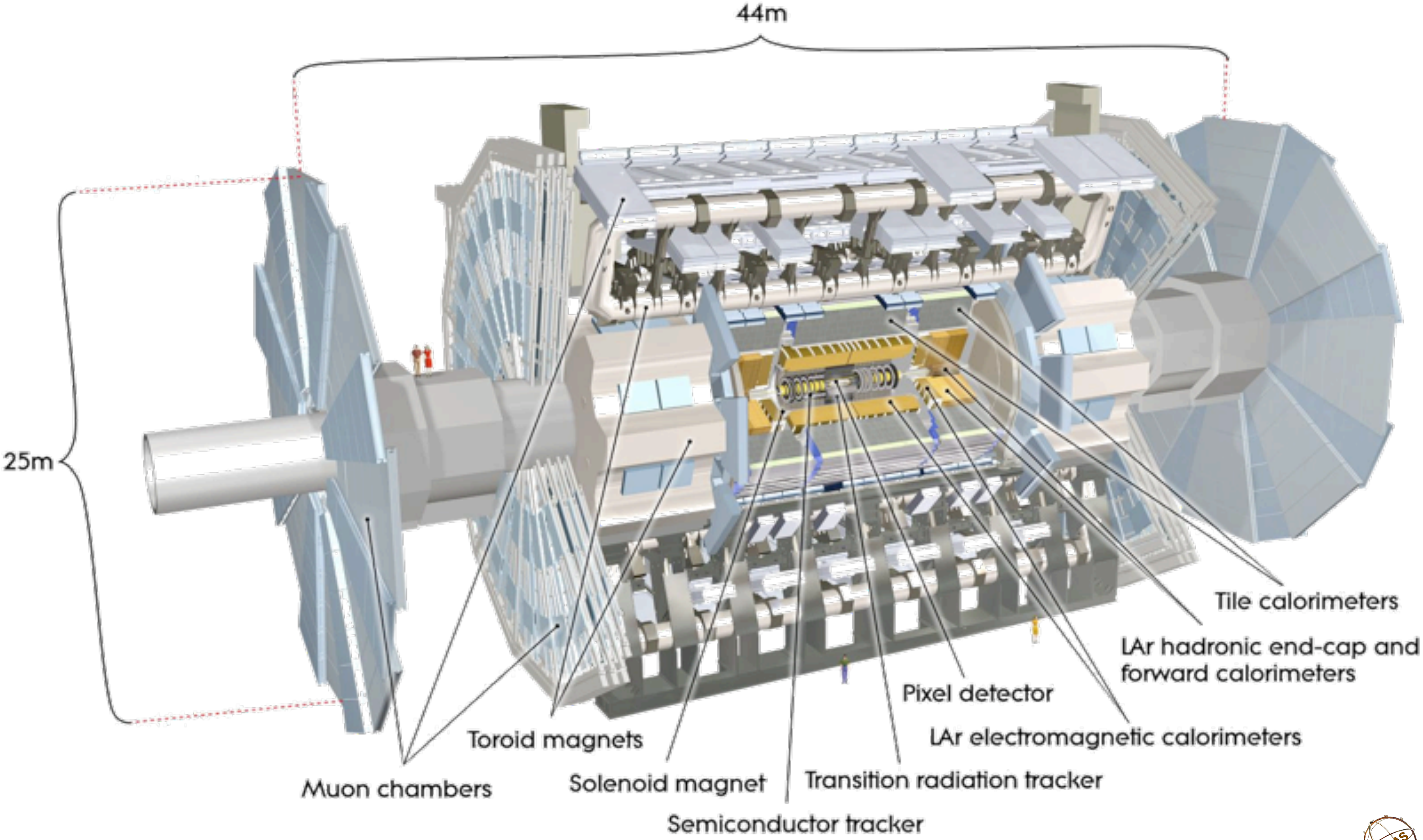
Candidate for W→e ν decay, collected on 5 April 2010.

Summary and Conclusions

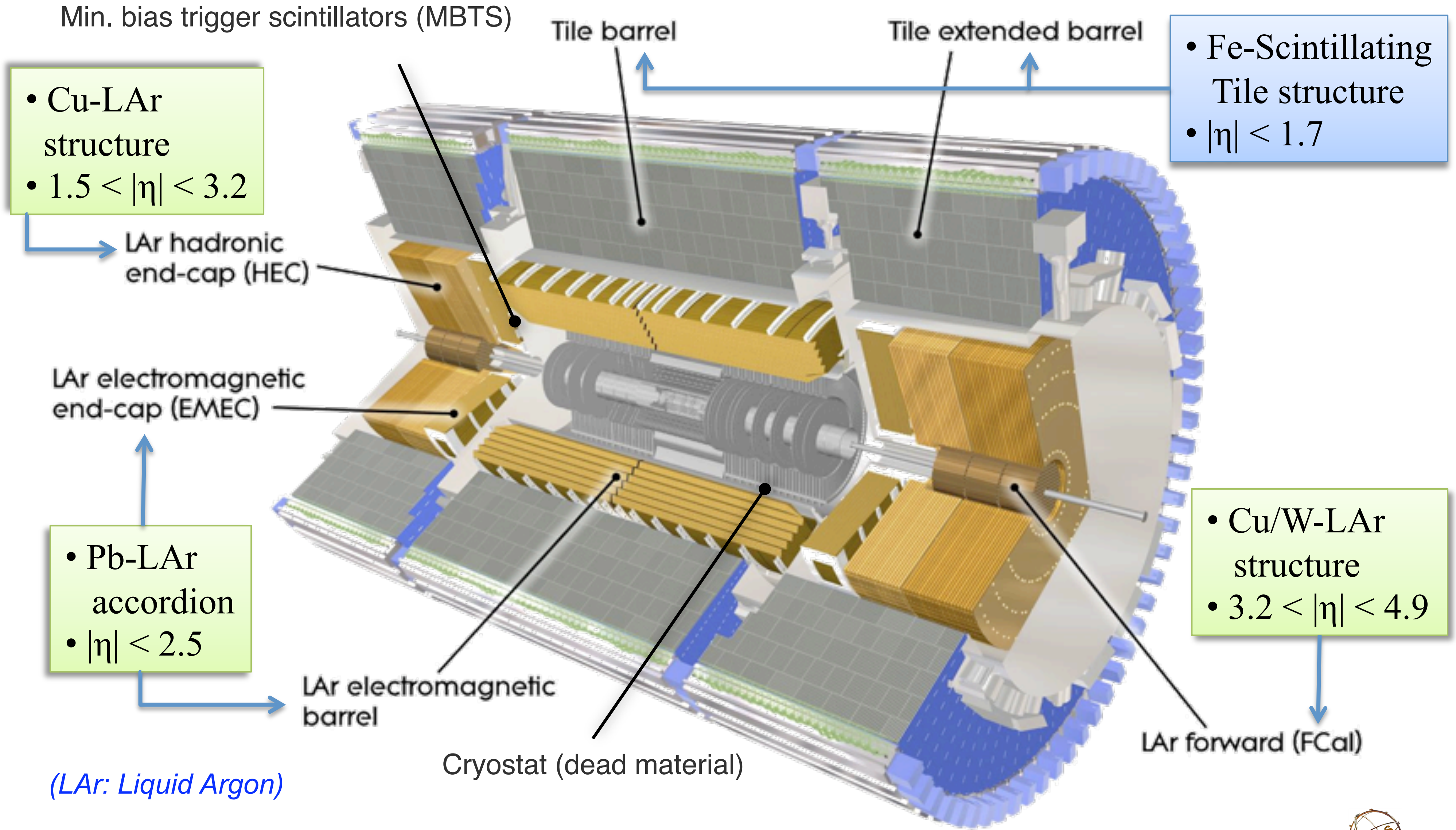
- The ATLAS detector has been operating and collecting data at high efficiency at both 900 GeV and 7 TeV center-of-mass energy since November 2009.
- Calorimeter performance meets expectations and is well modeled by the Monte Carlo simulation.
- Jet production, missing transverse energy measurements and kinematic distributions are in excellent agreement with predictions.
- Jet reconstruction and calibration are studied with multiple schemes and inputs within ATLAS and the performances are very close to that expected from MC.
- Jet properties and shapes studies indicate important differences with respect to MC that are likely related to a combination of detector and physics effects.

ADDITIONAL MATERIAL

The ATLAS Detector



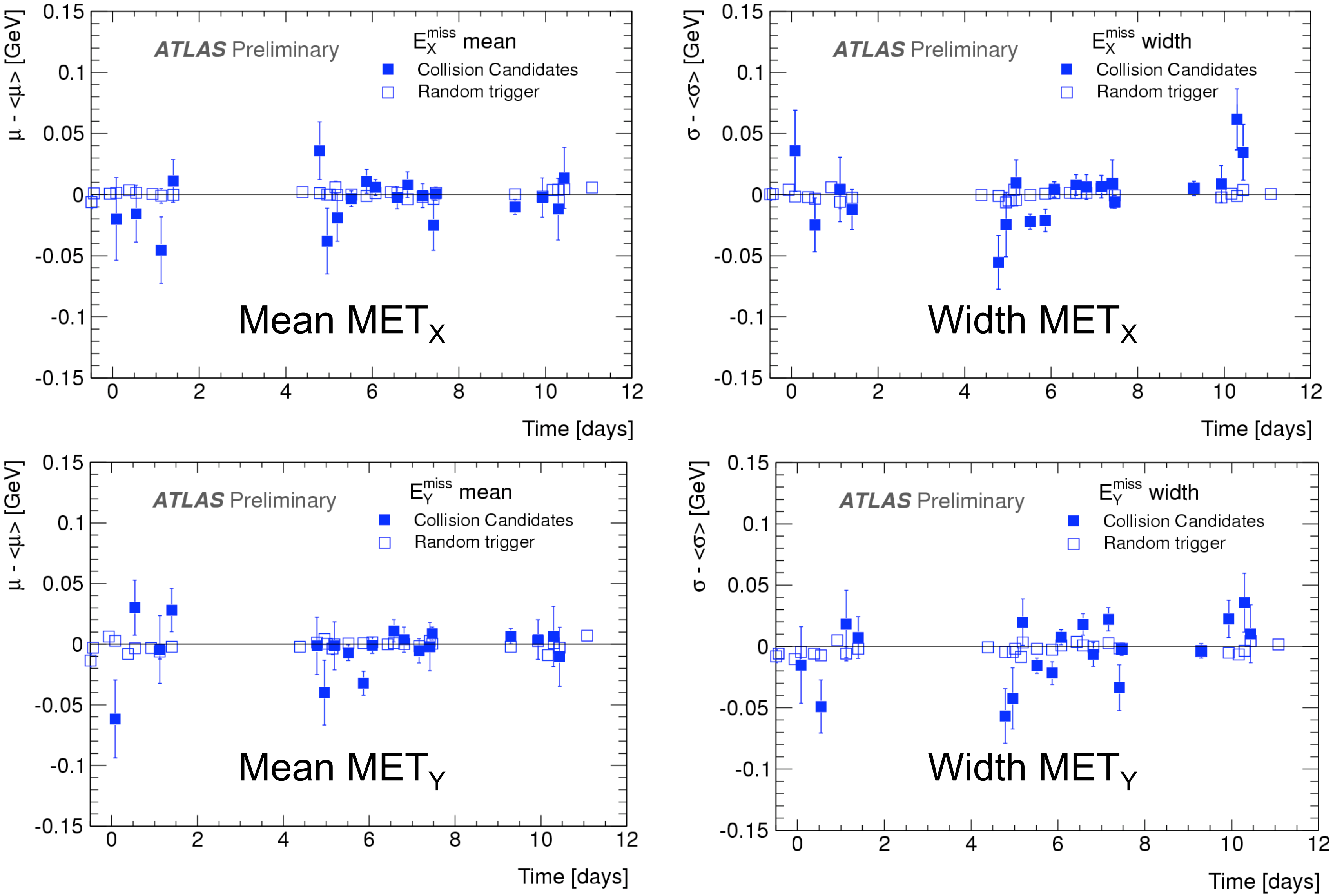
The ATLAS Calorimeters



(LAr: Liquid Argon)

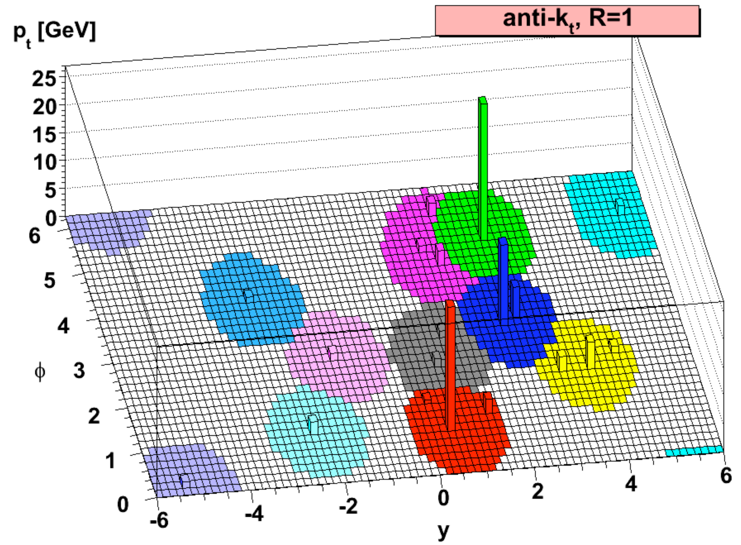
> 98% operational

Stability of MET over time at $\sqrt{s} = 900$ GeV



Anti-k_t jet algorithm in ATLAS

- The anti-k_t jet algorithm
  - Infrared and collinear safe algorithm
  - Use *exactly the same* algorithm for theory calculations and experimental measurements
- Primary algorithm for ATLAS
  - Common choice between ATLAS and CMS
  - Shows best stability and performance even at high luminosities



- Using AntiKt algorithm of the fastjet [1] library
- Use clusters or towers as proto-jets and define a distance measure:

$$d_{ij} = min\left(\frac{1}{p_{Ti}^2}, \frac{1}{p_{Tj}^2}\right)\frac{\Delta_{ij}^2}{R^2} \quad (1)$$

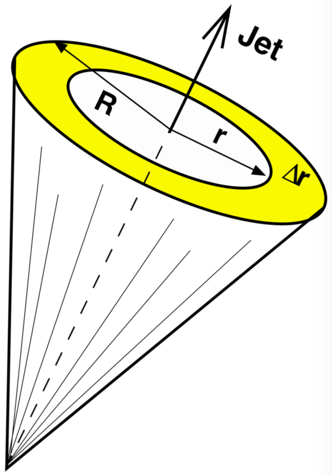
$$d_{ii} = \frac{1}{p_{Ti}^2} \quad (2)$$

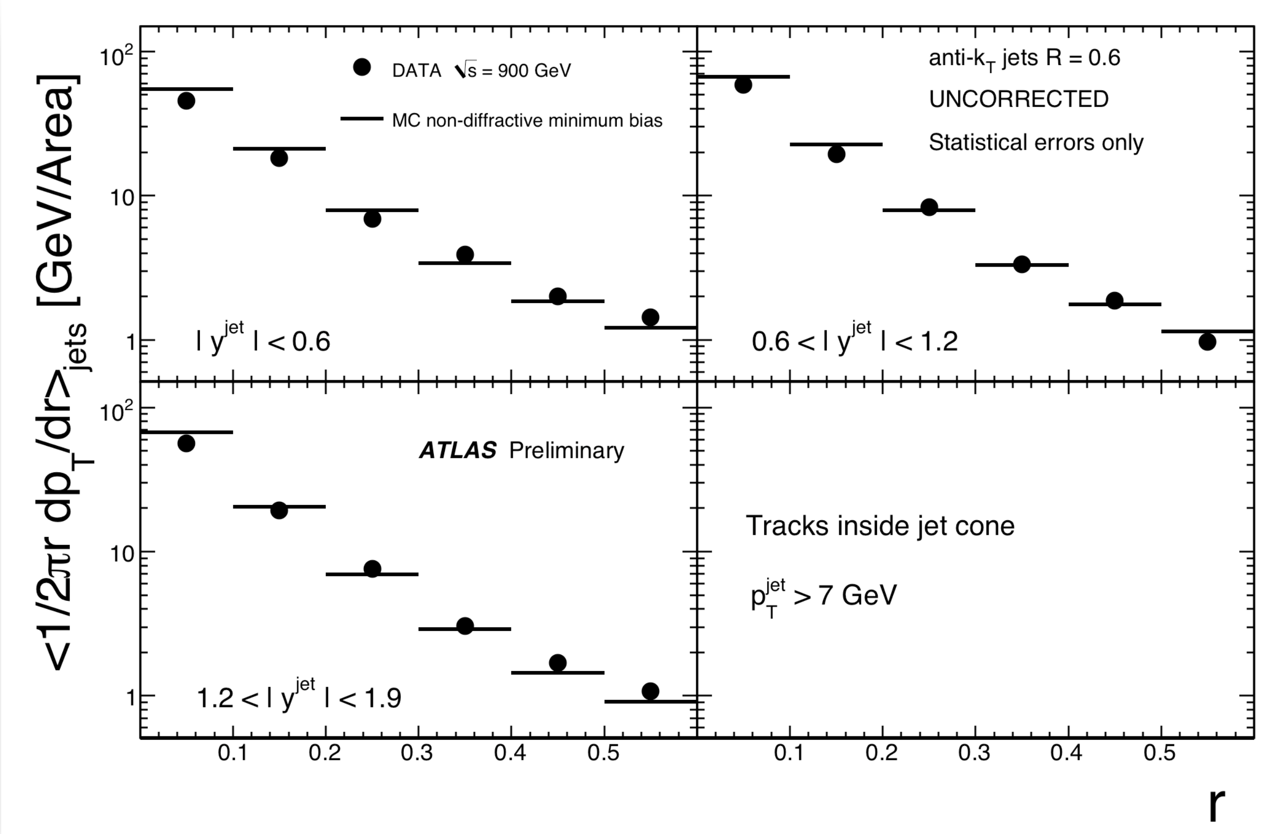
where:

- $\Delta_{ij} = (\phi_i - \phi_j)^2 + (y_i - y_j)^2$
- p_{Ti}, y_i, and ϕ_i are the transverse momentum, rapidity and azimuth of proto-jet i
- $R = 0.6$ (0.4) in ATLAS reconstruction

- Until no proto-jet are left compute all d_{ij} and take smallest d_{ij}:
  - $i \neq j$ Remove proto-jet i and j and add 4-vector sum as new proto-jet
  - $i = j$ Remove proto-jet i and call it a final jet

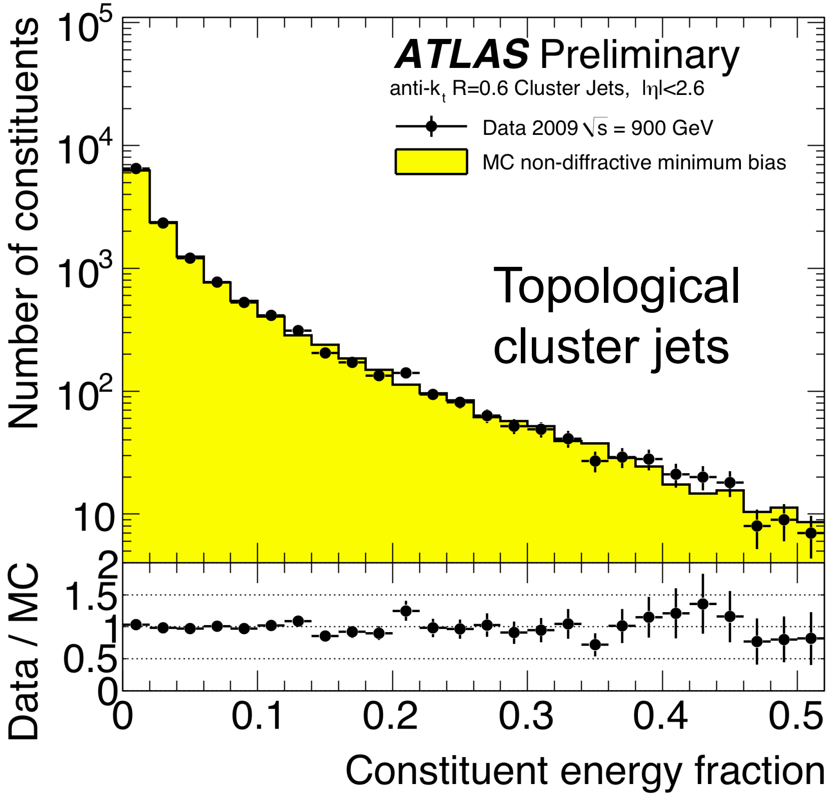
Jet shapes using tracking

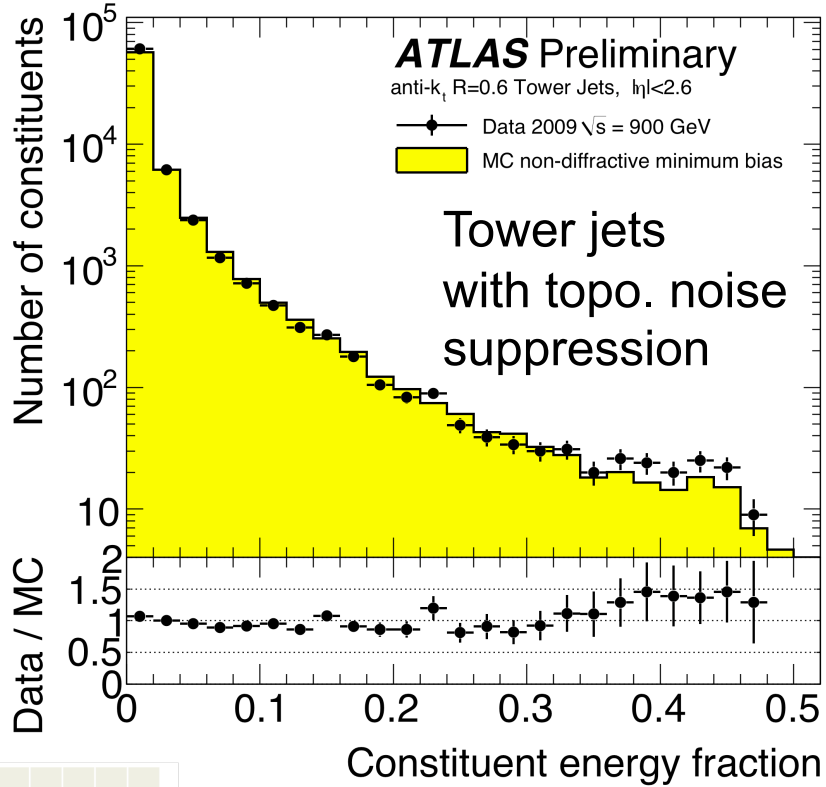




- Can also measure jet profile using **tracks**
- See the same effects: *jets are wider in data than in MC*
- Measurement only possible in fiducial tracking volume ($|\eta|<2.5$, so $|\eta^{jet}|<1.9$ for R=0.6 jets)

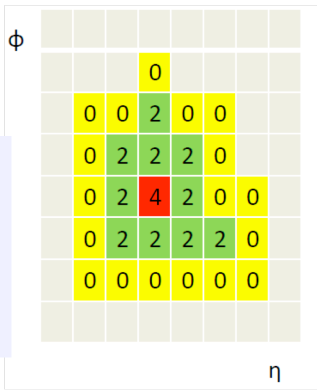
More on inputs to jet reconstruction



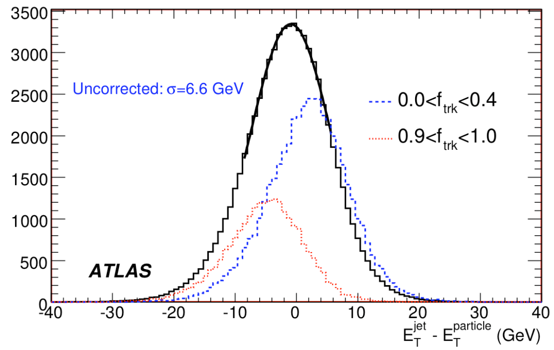


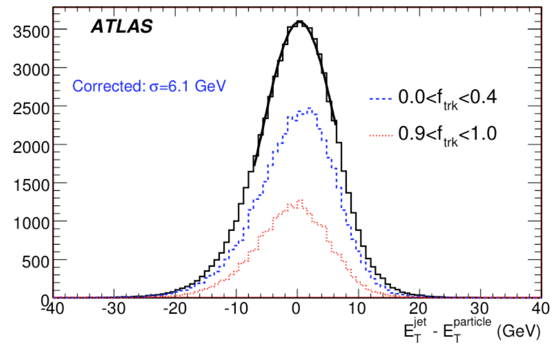
Topological noise suppression

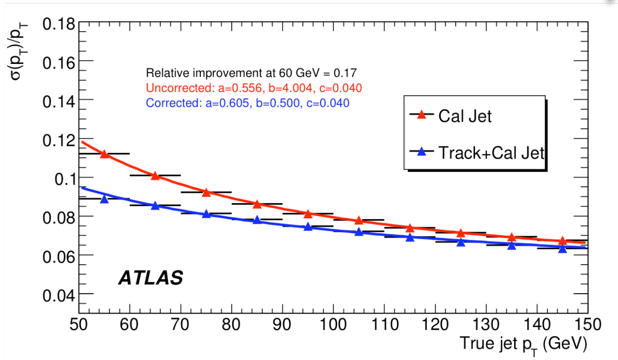
- Seed, Neighbor, and Perimeter cells (S, N, P)
  - Seed cells with $|E_{\text{cell}}| > S \cdot \sigma_{\text{noise}}$ (S = 4)
  - Expand in 3D adding neighbors with $|E_{\text{cell}}| > N \cdot \sigma_{\text{noise}}$ (N = 2)
  - Add perimeter cells with $|E_{\text{cell}}| > P \cdot \sigma_{\text{noise}}$ (P = 0)
  - (S, N, P) = (4, 2, 0) for good results in beam tests



ATLAS Tracking and Jets







- **f_{track}**: Using the ratio of track-to-calo momentum measurements to improve jet resolution at 14 TeV (MC)

Charged particle analyses at both CoM energies indicate very good description of tracking in MC