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The ATLAS Forward Calorimeter

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on behalf of the
ATLAS Liquid Argon Collaboration

Plan of Talk

The ATLAS FCal from Construction to Physics

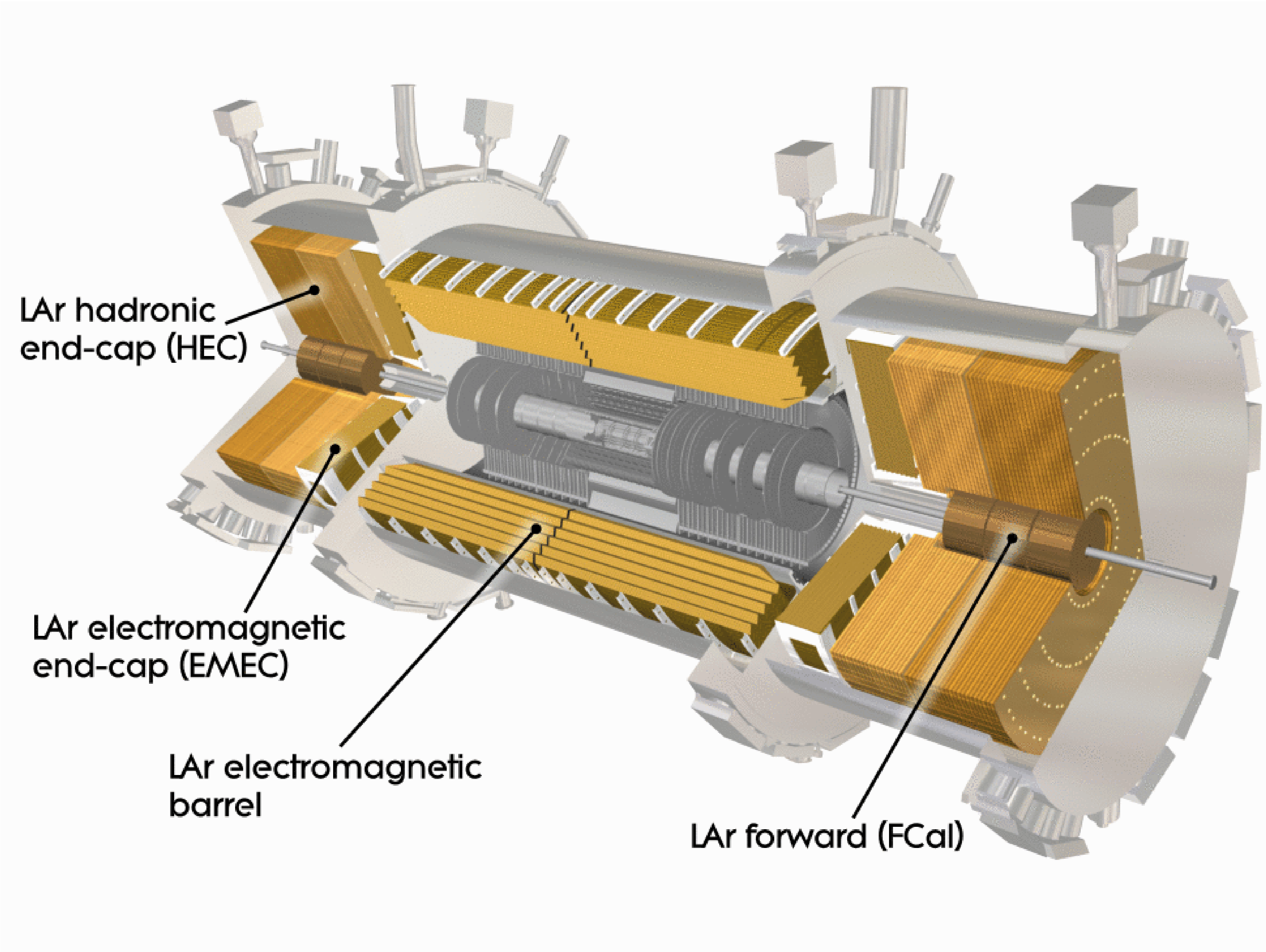
- Motivation
- Construction
- Test Beam
- Collisions 2009 - 2011
- Some Physics

Motivation

- 4π Calorimeter coverage is important for
  - Missing Transverse Energy
    - Neutral, non-interacting particles – SUSY
    - eg $W \rightarrow l\nu$
    - τ decays – important for new physics
  - Forward jet –tagging
    - VBF production of Higgs – no colour flow between protons

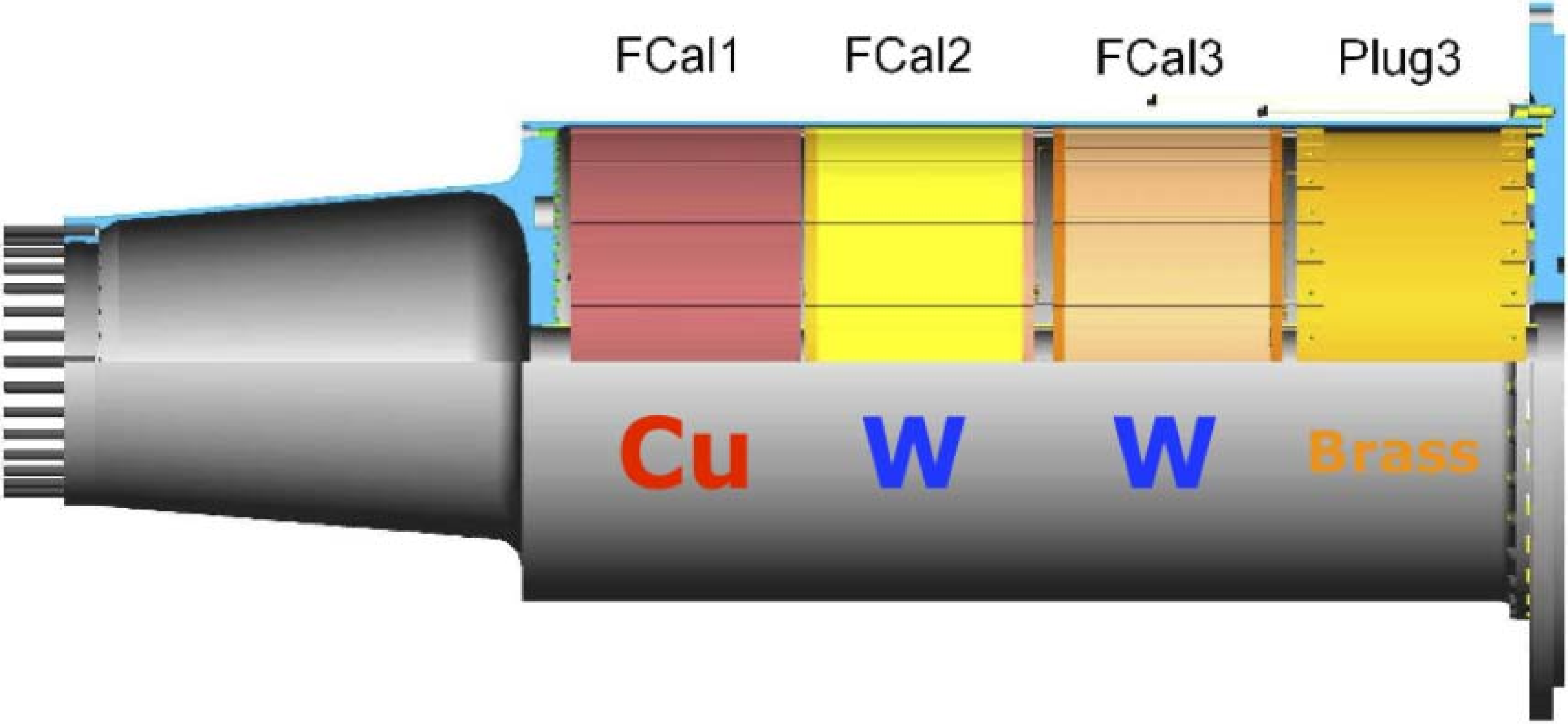
- Only modest stochastic energy resolution required due to high energy jets in forward direction.
- Challenge is survivability close to proton beam.

Layout of ATLAS Liquid Argon Calorimeters



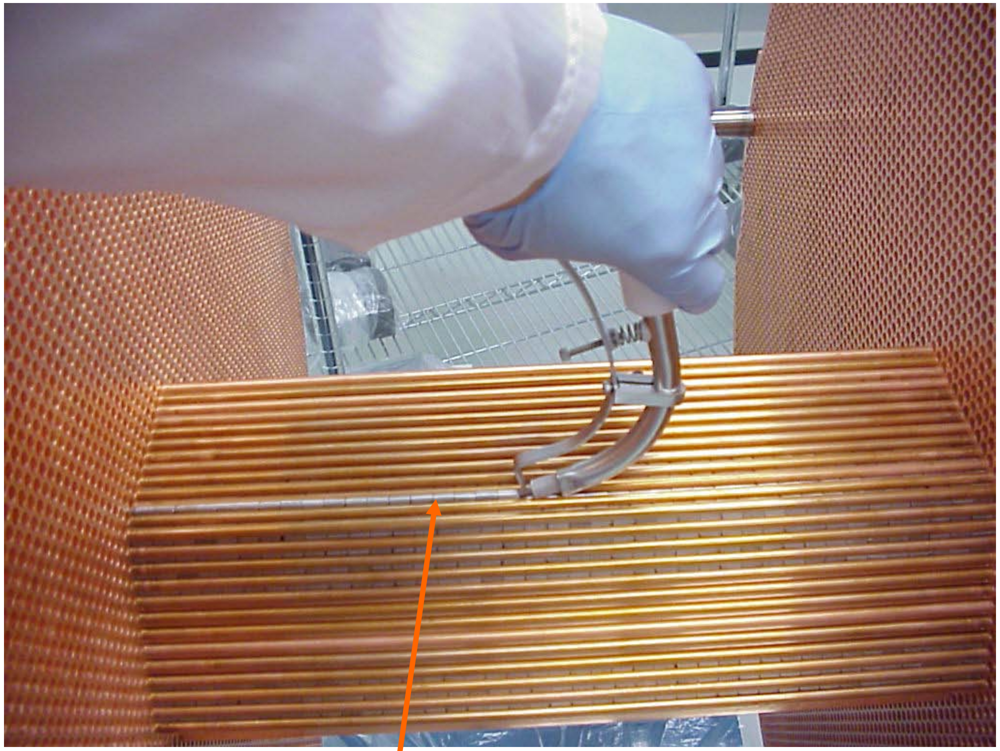
Liquid Argon Forward Calorimeter

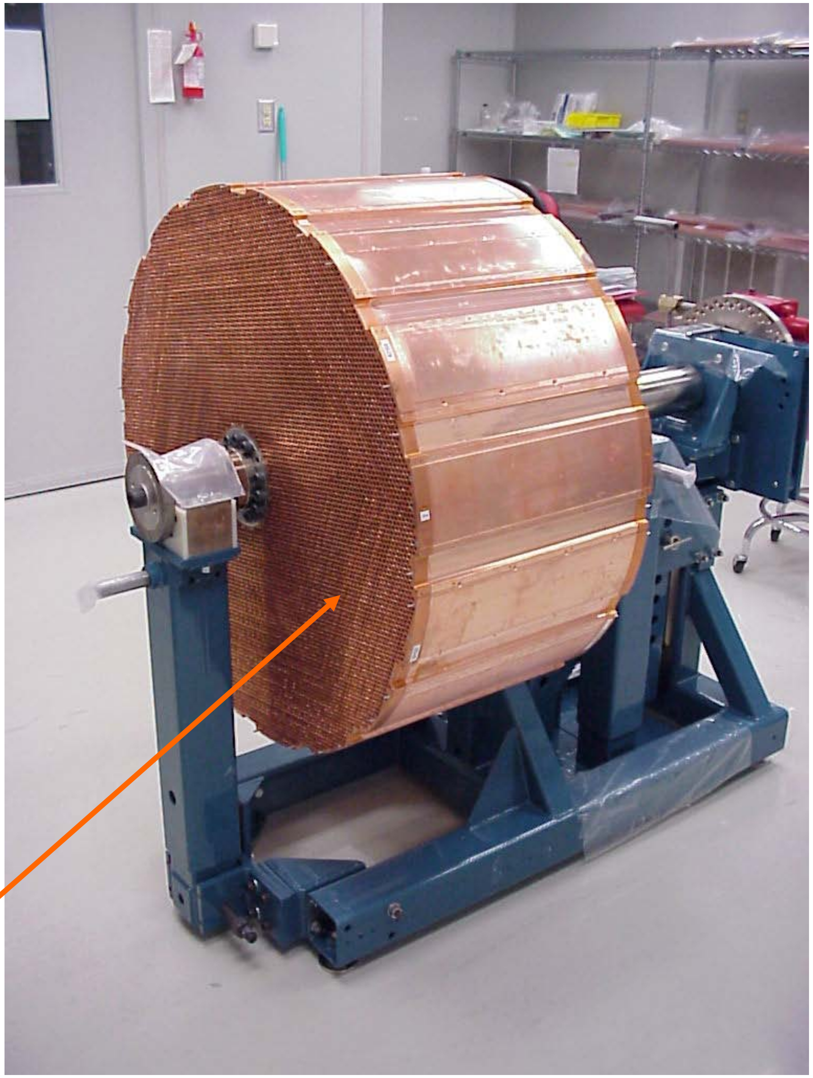
Layer	Absorber	LAr gap	$N_{electrodes}$	$N_{channels}$
FCal1	Cu	269 μm	24,520	2,016
FCal2	W	376 μm	20,400	1,000
FCal3	W	508 μm	16,448	508



It's nice to recall what the FCal looks like, as some of us may never see it again.

Tungsten Module

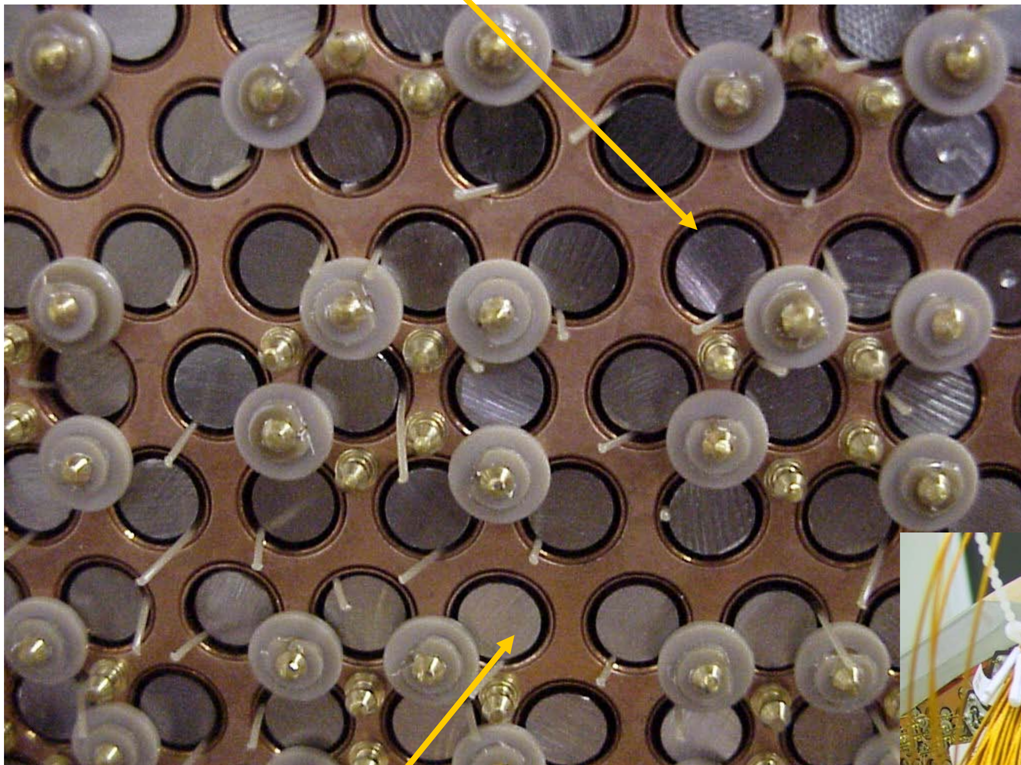




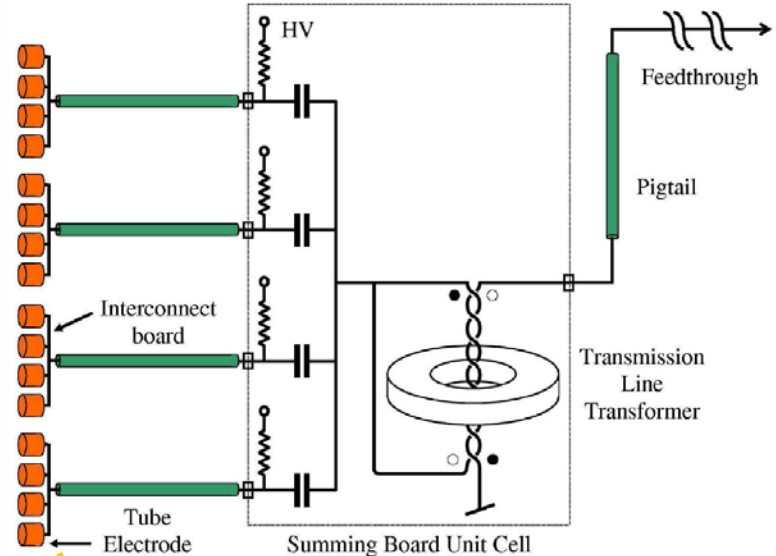
Tungsten slug structure

Cu Endplates + outer shell

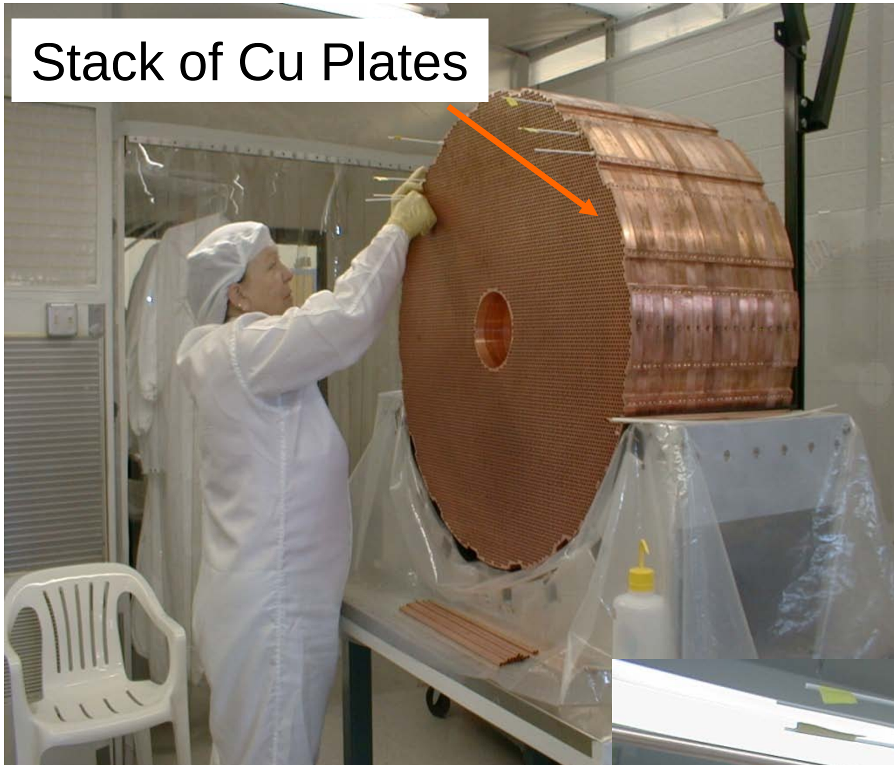
Liquid Argon Gap

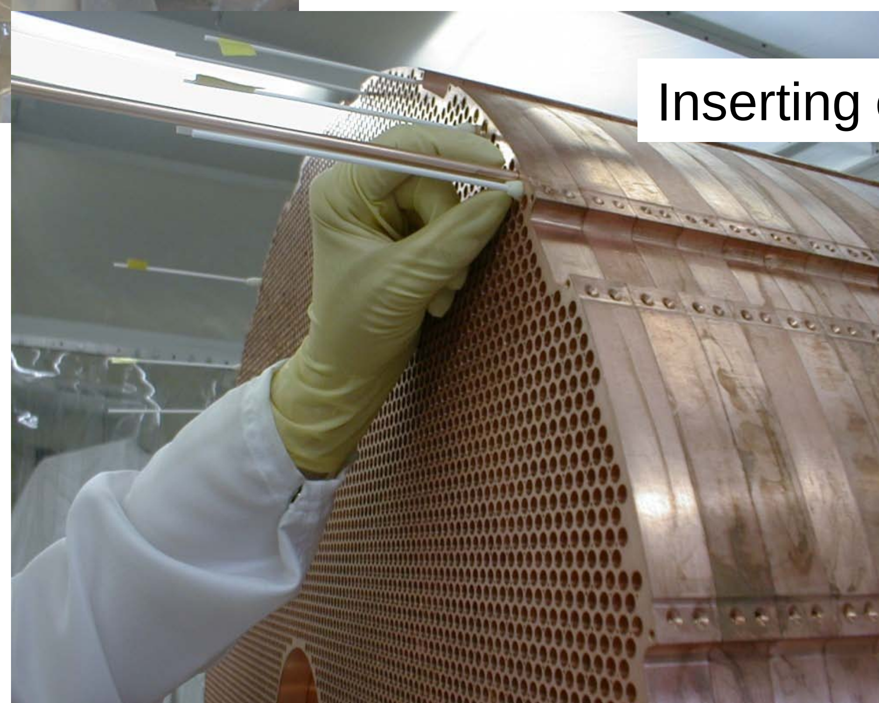


Tungsten Rod



FCal1 Copper Module





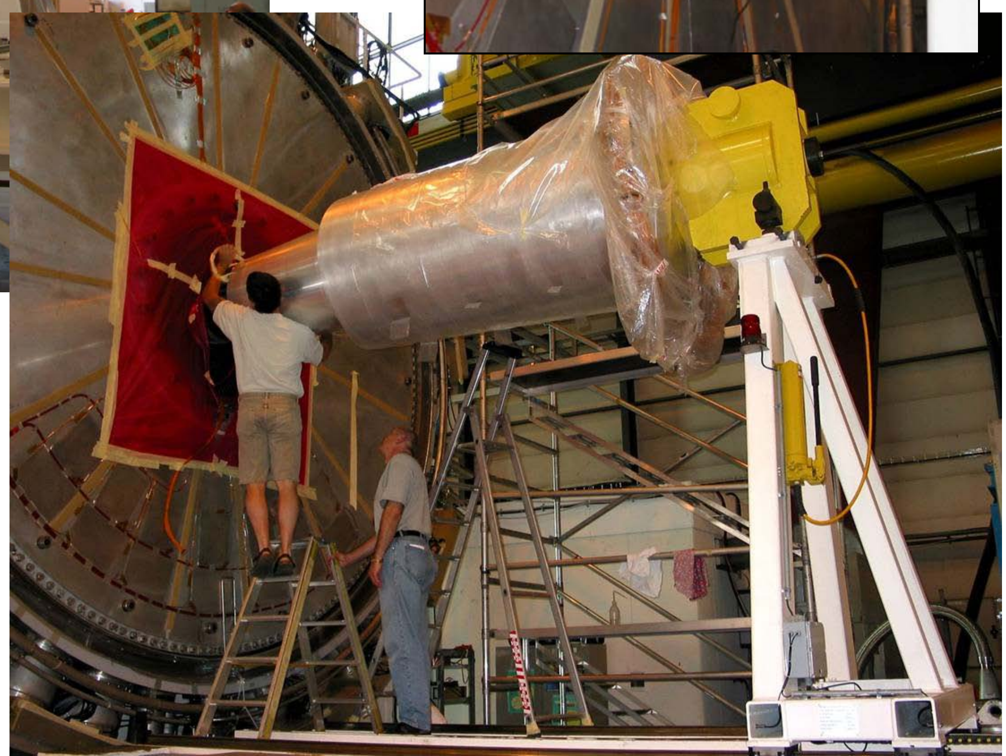
Assembly at CERN

FCal1

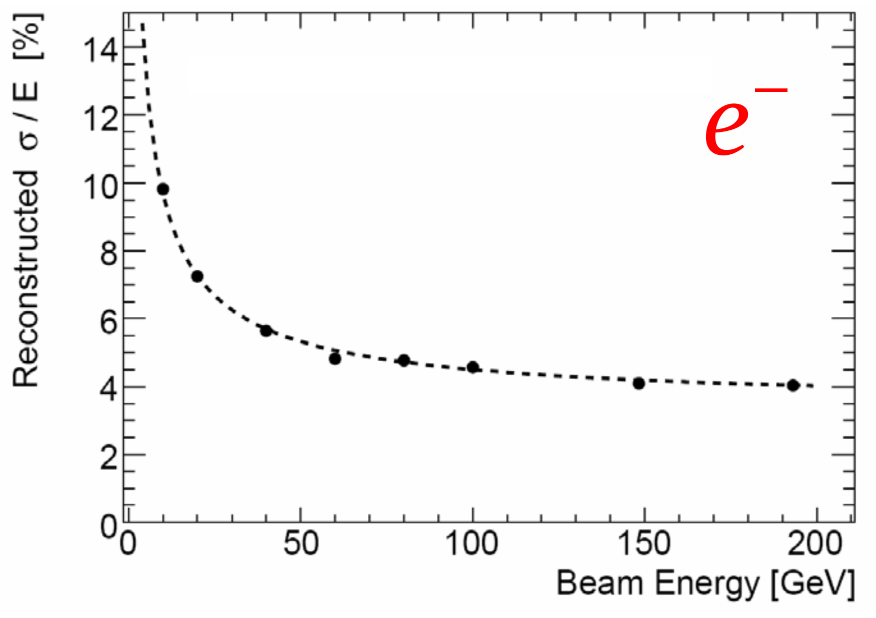
Support Tube

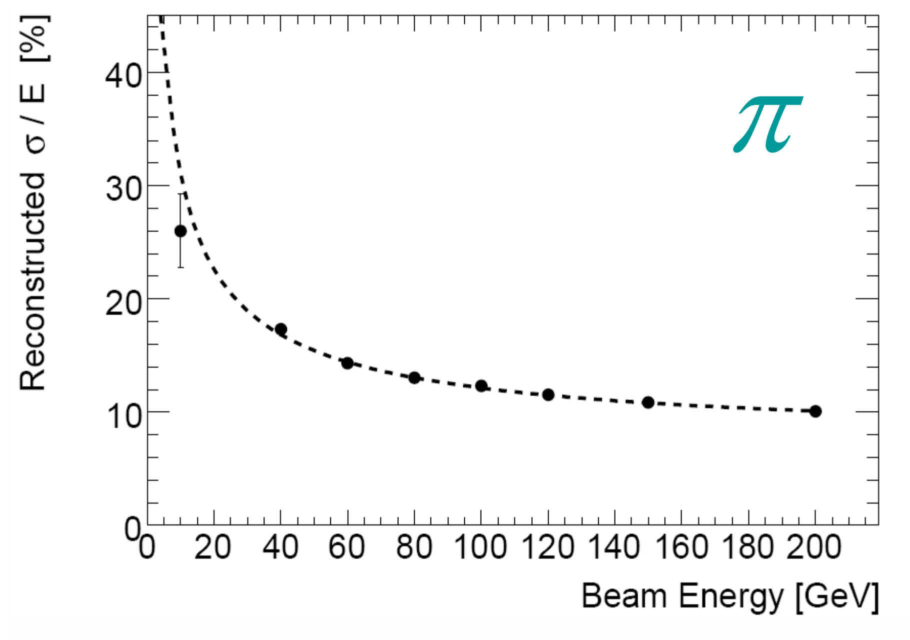
Signal Cables run to rear


HWX 159



Test Beam Single Particle Energy Resolution





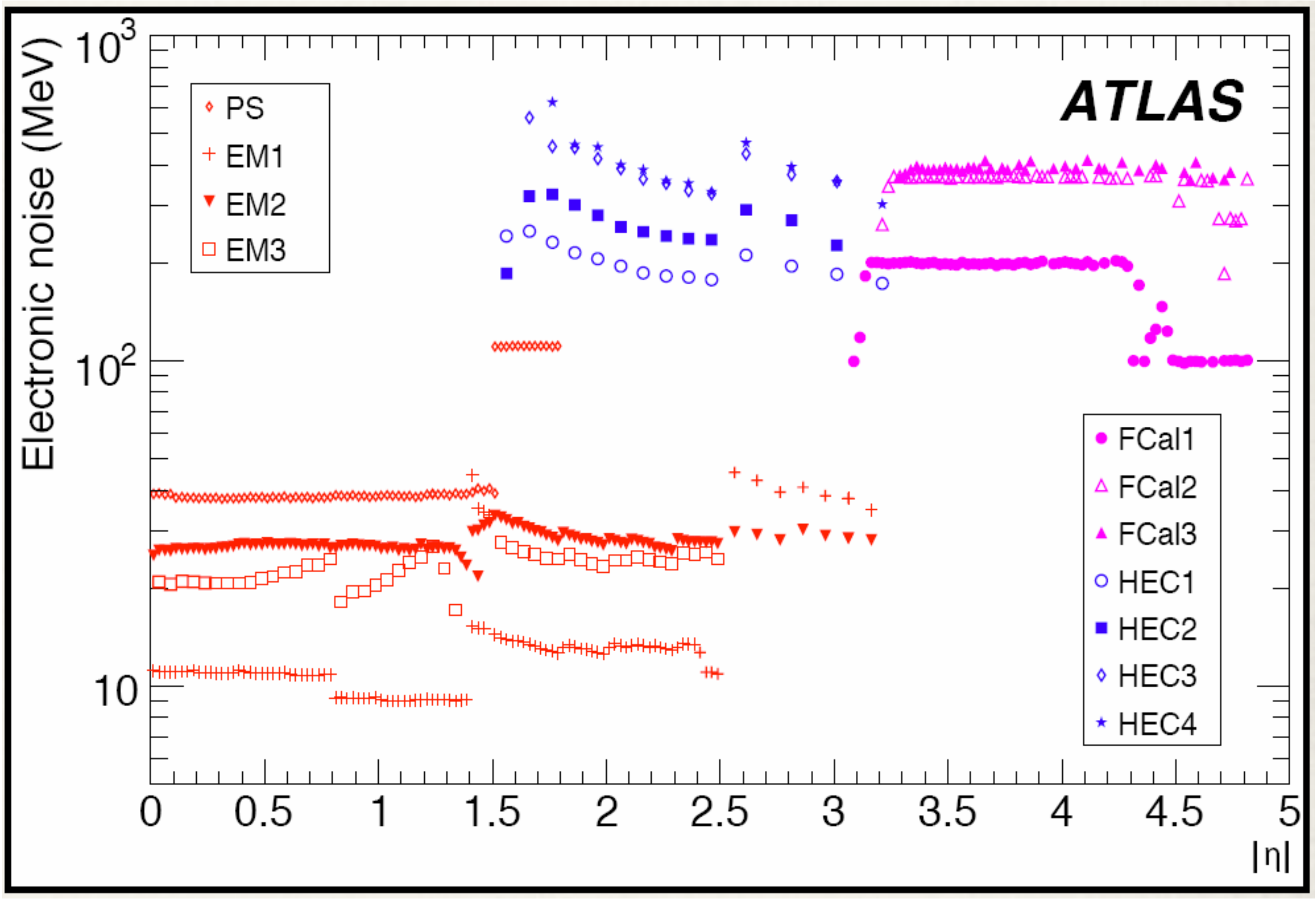
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

Noise subtracted energy resolution

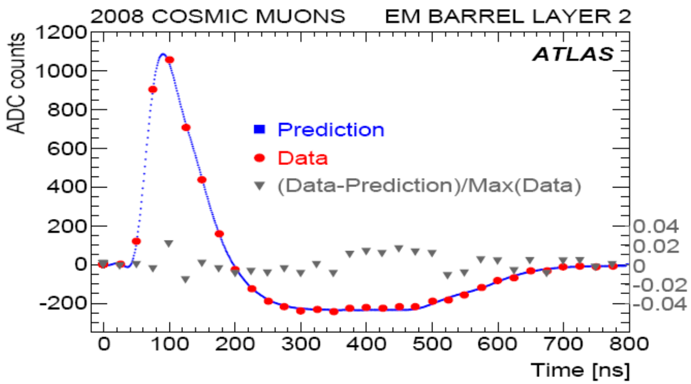
$$a = (28.5 \pm 1.0)\% \cdot \sqrt{GeV}$$
$$b = (3.5 \pm 0.1)\%$$

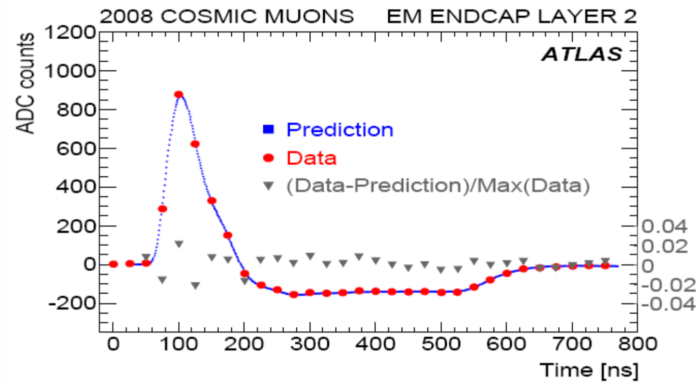
$$a = (94.2 \pm 1.6)\% \cdot \sqrt{GeV}$$
$$b = (7.5 \pm 0.4)\%$$

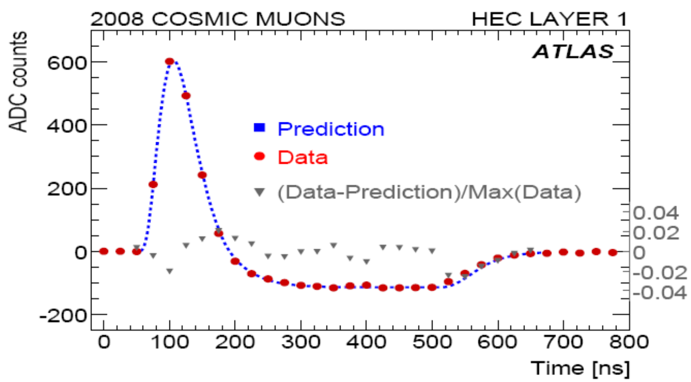
Noise Level in LAr Calorimeters

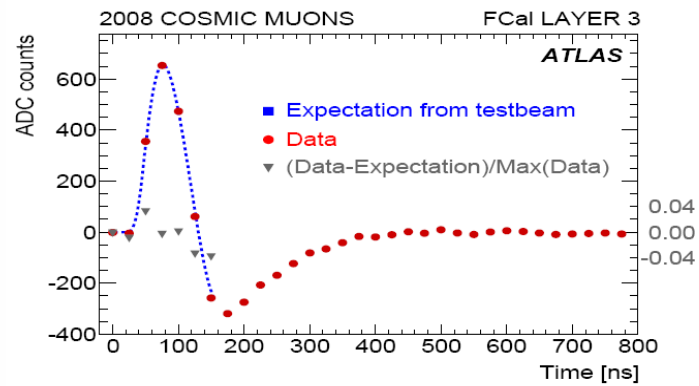


Since the FCal is in the very forward region, these noise levels are OK

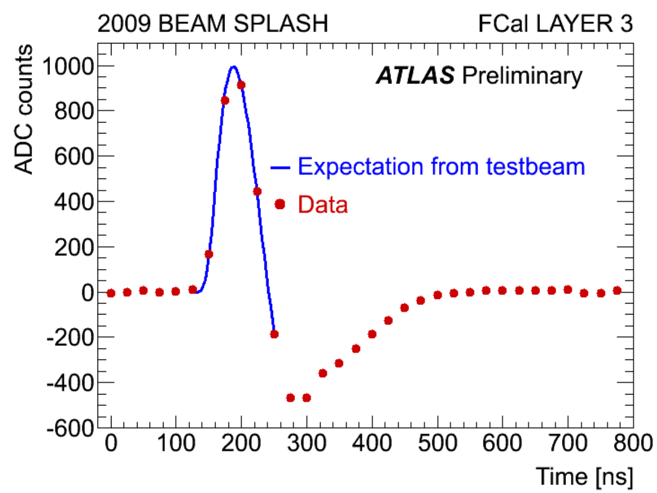




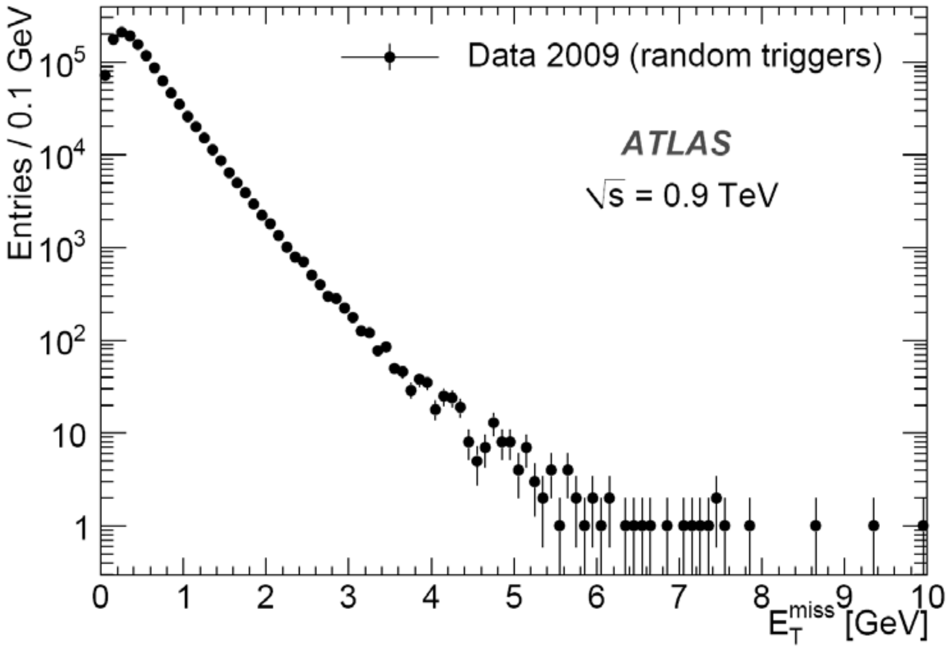




Signal Shape before startup



Early Look at E_T^{miss}



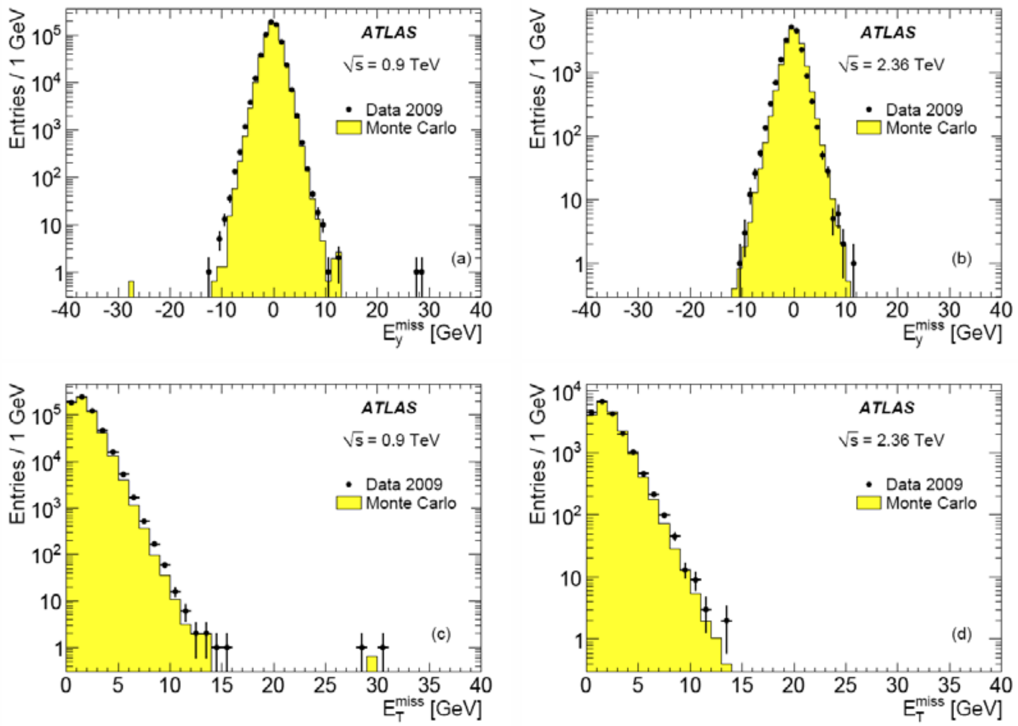
$$E_x^{miss,calo} = -\sum_{i=1}^{N_{cell}} E_i \sin\theta_i \cos\phi_i$$

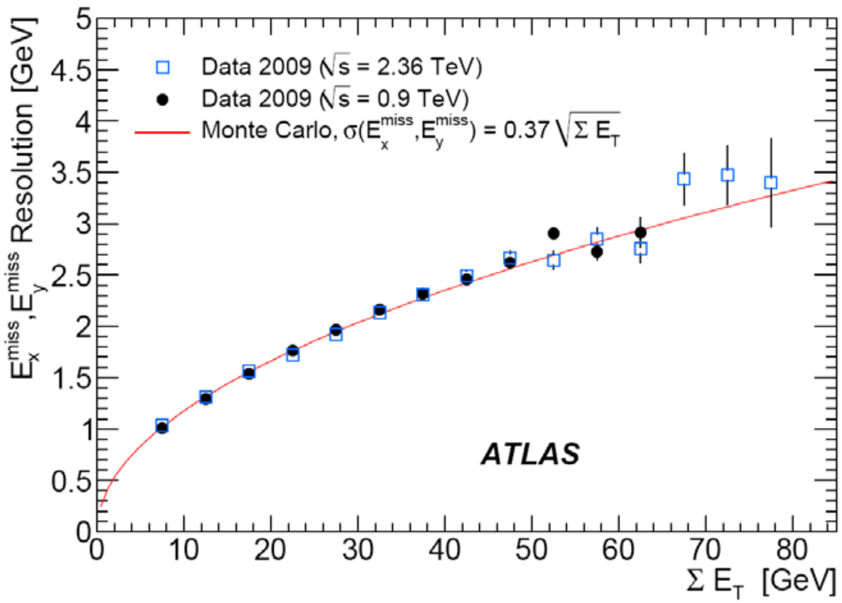
$$E_y^{miss,calo} = -\sum_{i=1}^{N_{cell}} E_i \sin\theta_i \sin\phi_i$$

$$E_T^{miss} = \sqrt{\left(E_x^{miss}\right)^2 + \left(E_y^{miss}\right)^2}$$

- Calorimeter noise – produce tail in spectrum
- Study using random triggers where little real energy deposition
- Suppress noise from 187,000 cells by topological clustering

Minimum Bias Trigger Study of E_T^{miss}

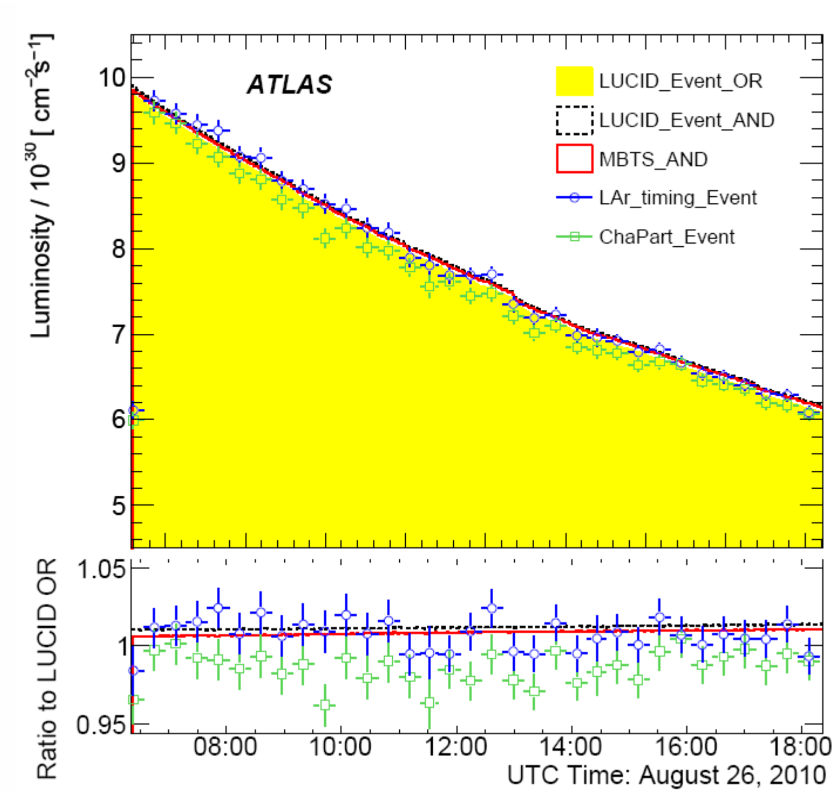


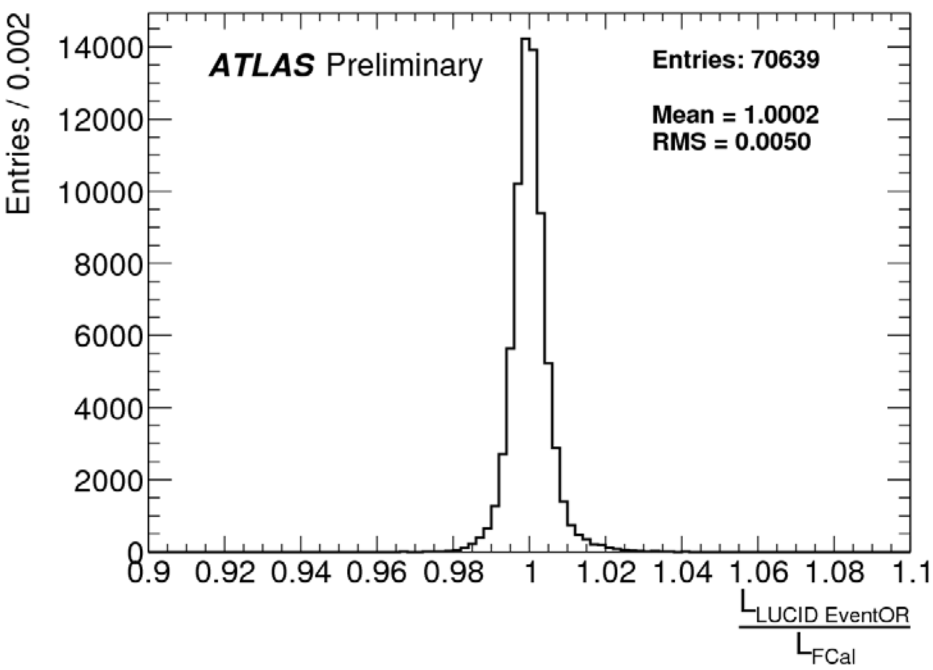


- Soft proton collisions – no real E_T^{miss}
- Width of $E_{x(y)}^{miss}$ gives resolution

- From stochastic energy resolution expect E_T^{miss} resolution to be proportional to $\sqrt{\sum E_T} = \sqrt{\sum_{i=1}^{N_{cell}} E_i \sin\theta_i}$
- Find $\sigma\left(E_{x(y)}^{miss}\right) GeV = 0.37 \cdot \sqrt{\sum E_T}$

FCal as a Luminosity Measuring Device





- Time of energy deposits in EMEC inner wheel& FCal1.
- EFCal > 1200 MeV
- Two cells A and C ends within +-5ns

- Relative Luminosity
- 128 HV lines calibrated to LUCID
- Measured every 2 minutes for each line
- 0.5% spread

In-situ Pseudorapidity Intercalibration of Jet Energy Scale

- The full pseudo rapidity range in ATLAS spans several technologies, so one must intercalibrate the energy scale over this range.
- This is done using di-jets and quantifying the p_T balance between a reference (central) jet and a probe (forward) jet.
- The p_T balance is characterized by the asymmetry

$$A = \frac{p_T^{probe} - p_T^{ref}}{p_T^{avg}} \quad \text{with} \quad p_T^{avg} = p_T^{probe} + p_T^{ref} / 2$$

- The reference region is the central barrel $0.1 < |\eta| < 0.6$
- Relative response is $\frac{p_T^{probe}}{p_T^{ref}} = \frac{2 + A}{2 - A} = \frac{1}{c}$

- If both jets calibrated, this ratio is unity
- If not, *c* can be used to correct the probe jet energy scale to the scale of the reference jet.

In-situ Pseudorapidity Intercalibration of Jet Energy Scale

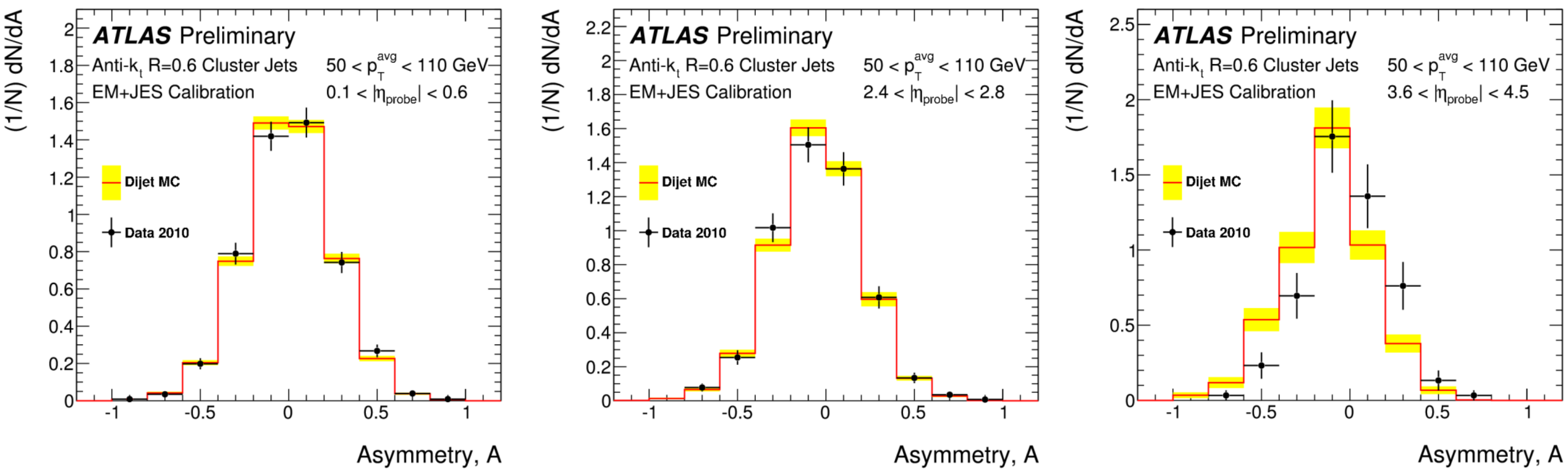
- The analysis is done in bins of η and p_T^{avg}.
- This gives an asymmetry A_{ik} for each probe jet η -bin *i* and each p_T^{avg}-bin *k*
- Intercalibration factors are calculated for each bin according to

$$\frac{p_T^{probe}}{p_T^{ref}} = \frac{2+A}{2-A} = \frac{1}{c}$$

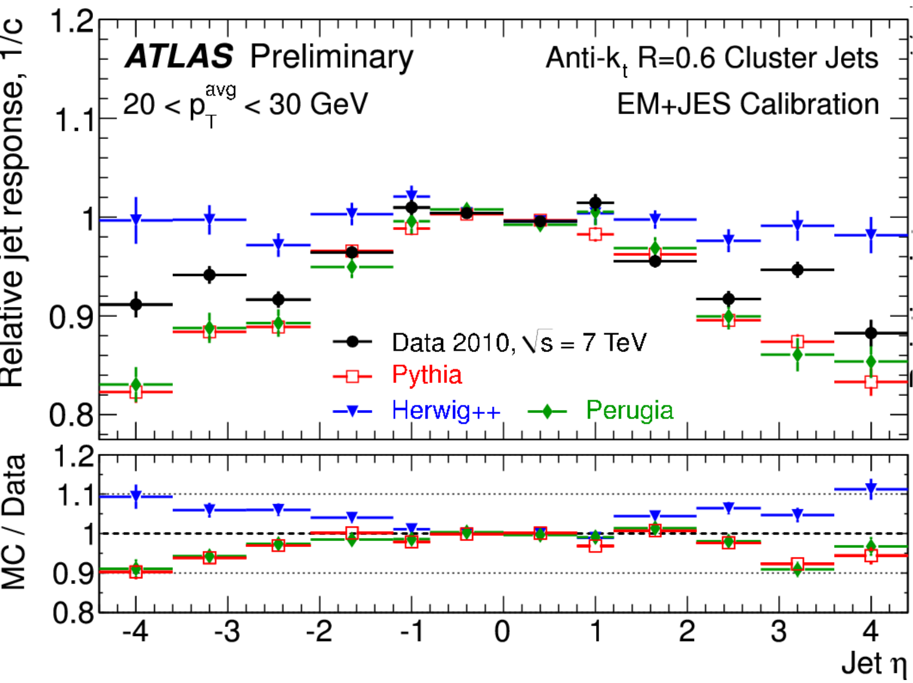
$$c_{ik} = \frac{2-\langle A_{ik} \rangle}{2+\langle A_{ik} \rangle}$$

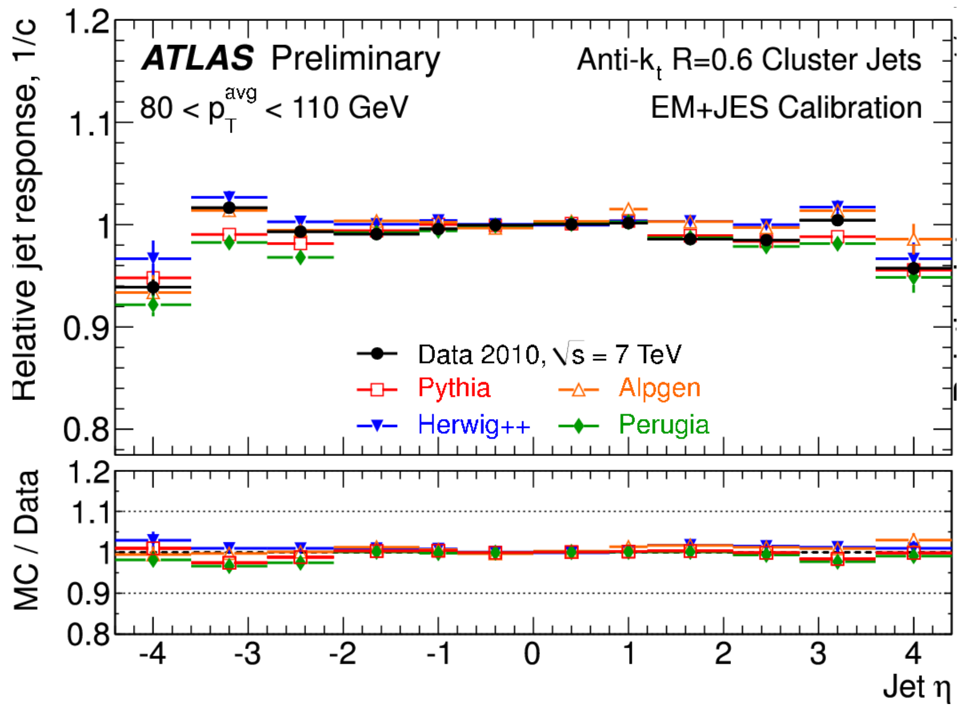
$\langle A_{ik} \rangle$ Is the mean value of the asymmetry in each bin.

In-situ Pseudorapidity Intercalibration of Jet Energy Scale

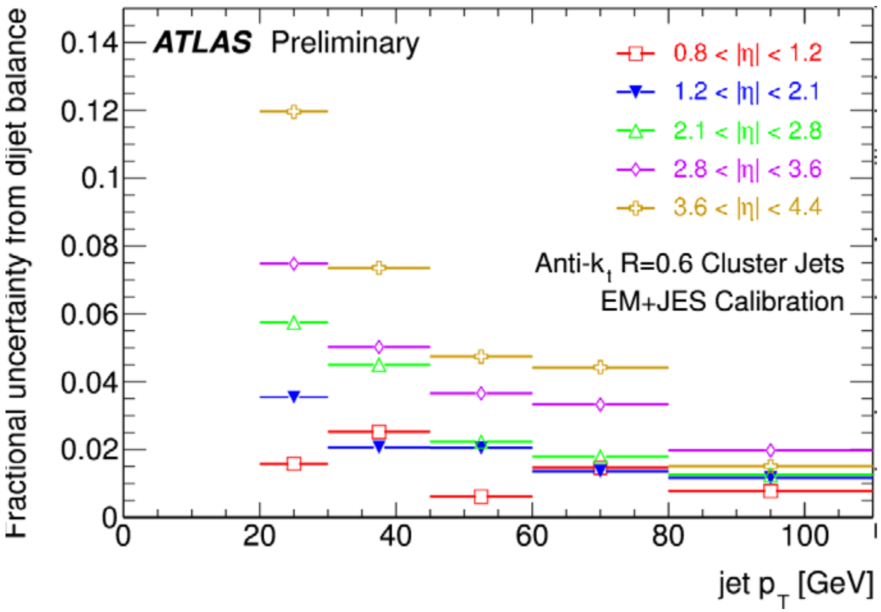


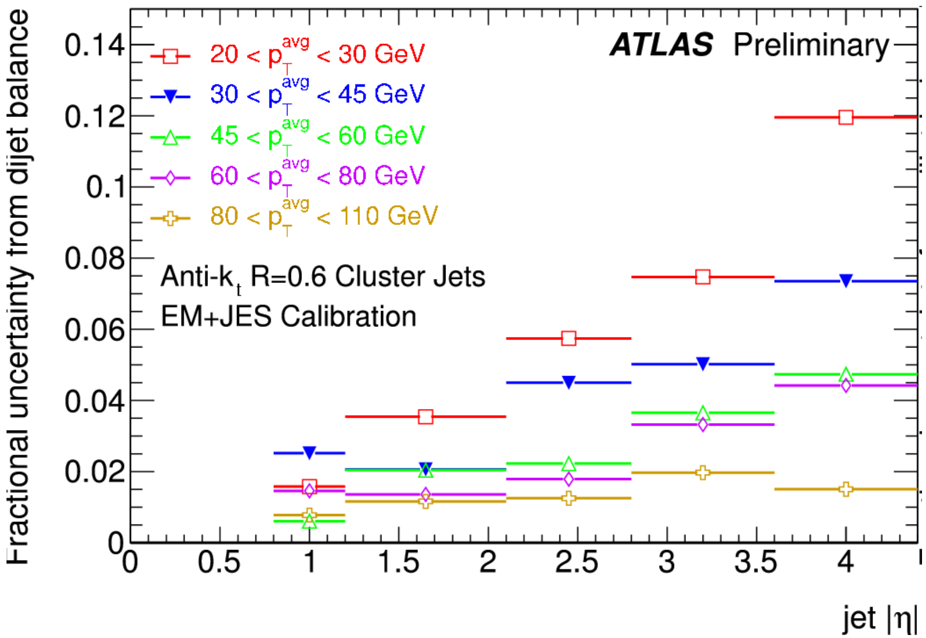
In-situ Pseudorapidity Intercalibration of Jet Energy Scale



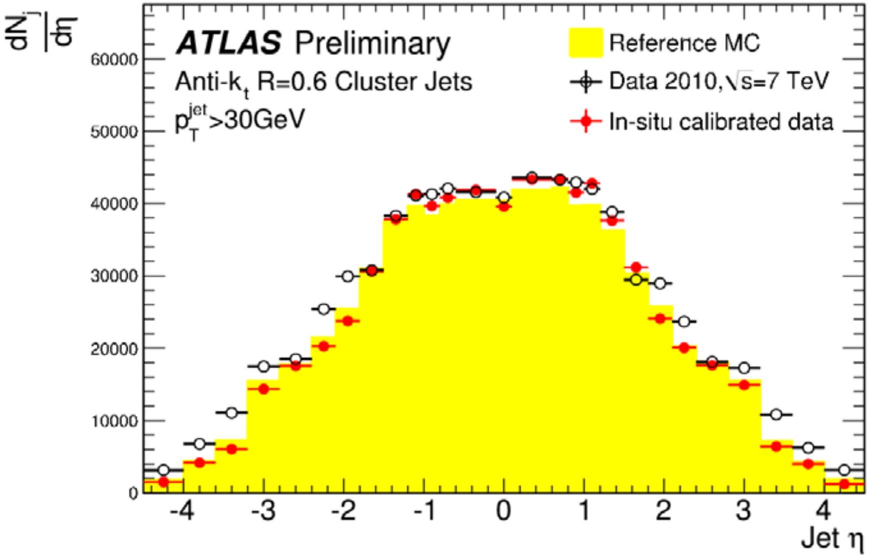


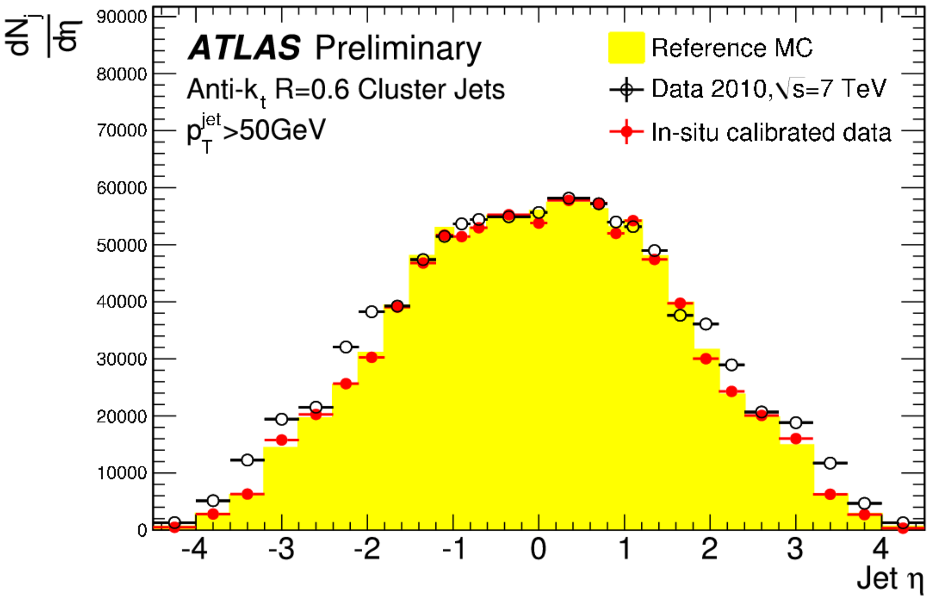
In-situ Pseudorapidity Intercalibration of Jet Energy Scale





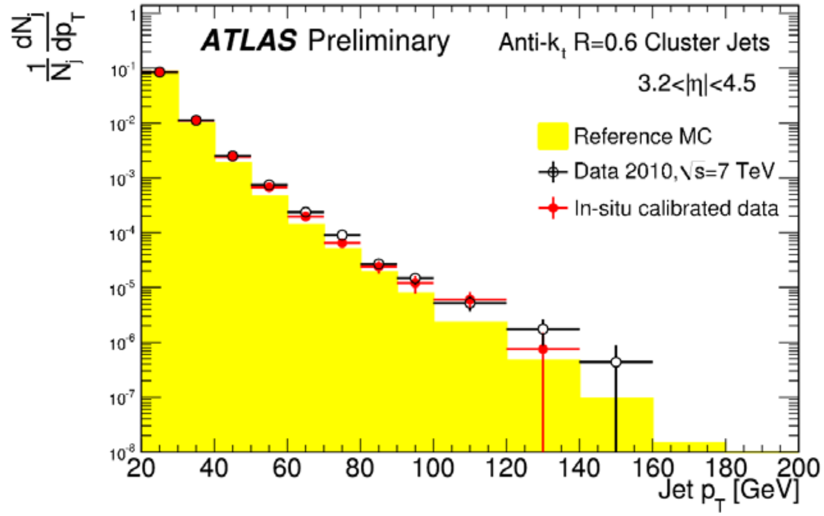
Comparison of Corrected and Uncorrected data

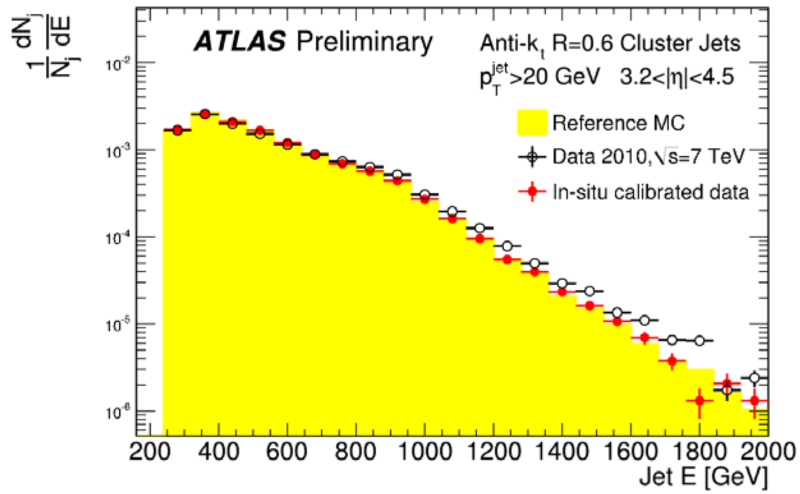


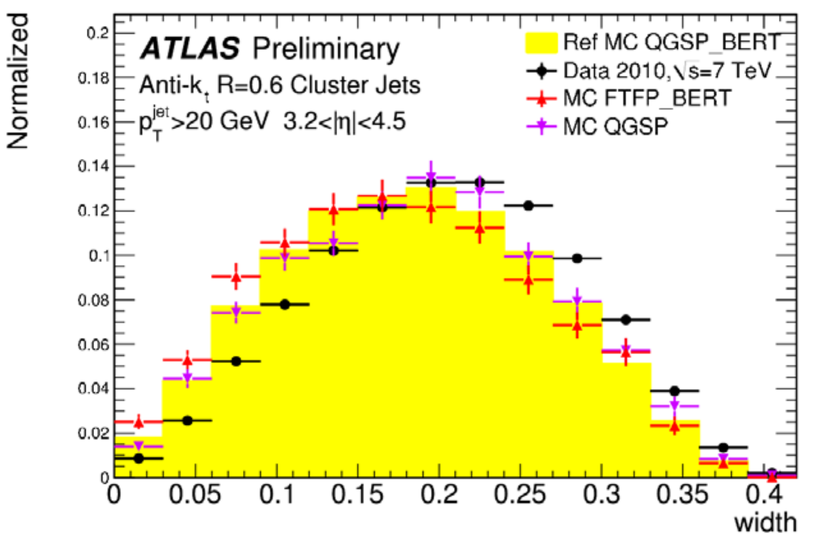


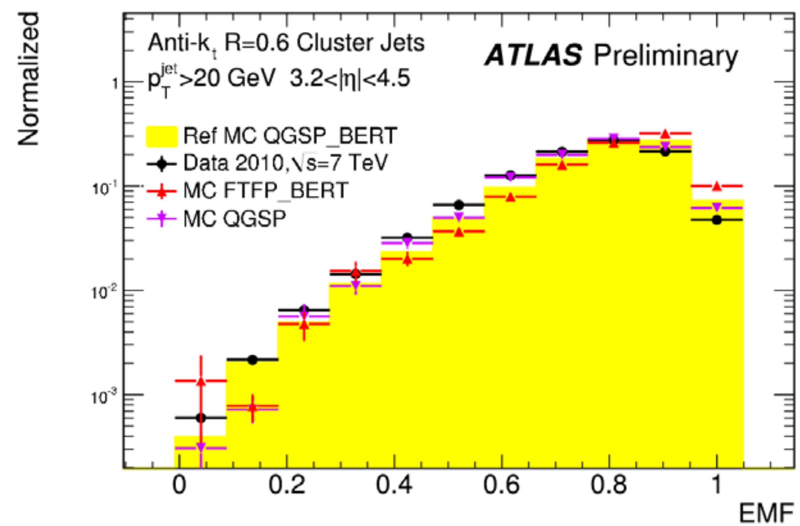
- Before correction forward region has an excess cf. Monte Carlo
- After correction agreement is within 10%

Jets in the Forward Calorimeter









Probe jets allow investigation of FCal

Physics Object Based study of E_T^{miss}

- Large sample of data collected in 2010 allowed a study of E_T^{miss} where physics objects are used, and the correct energy calibration applied to each.
- Muon energy deposition corrected for.

$$E_{x(y)}^{miss} = E_{x(y)}^{miss,calo} + E_{x(y)}^{miss,\mu}$$

$$E_T^{miss} = \sqrt{\left(E_x^{miss}\right)^2 + \left(E_y^{miss}\right)^2}$$

$$\phi^{miss} = \arctan\left(E_x^{miss}, E_y^{miss}\right)$$

$$E_{x(y)}^{miss,calo} = E_{x(y)}^{miss,e} + E_{x(y)}^{miss,\gamma} + E_{x(y)}^{miss,\tau} + E_{x(y)}^{miss,jets} + E_{x(y)}^{miss,softjets} + \left(E_{x(y)}^{miss,calo,\mu}\right) + E_{x(y)}^{miss,CellOut}$$

- Where each term

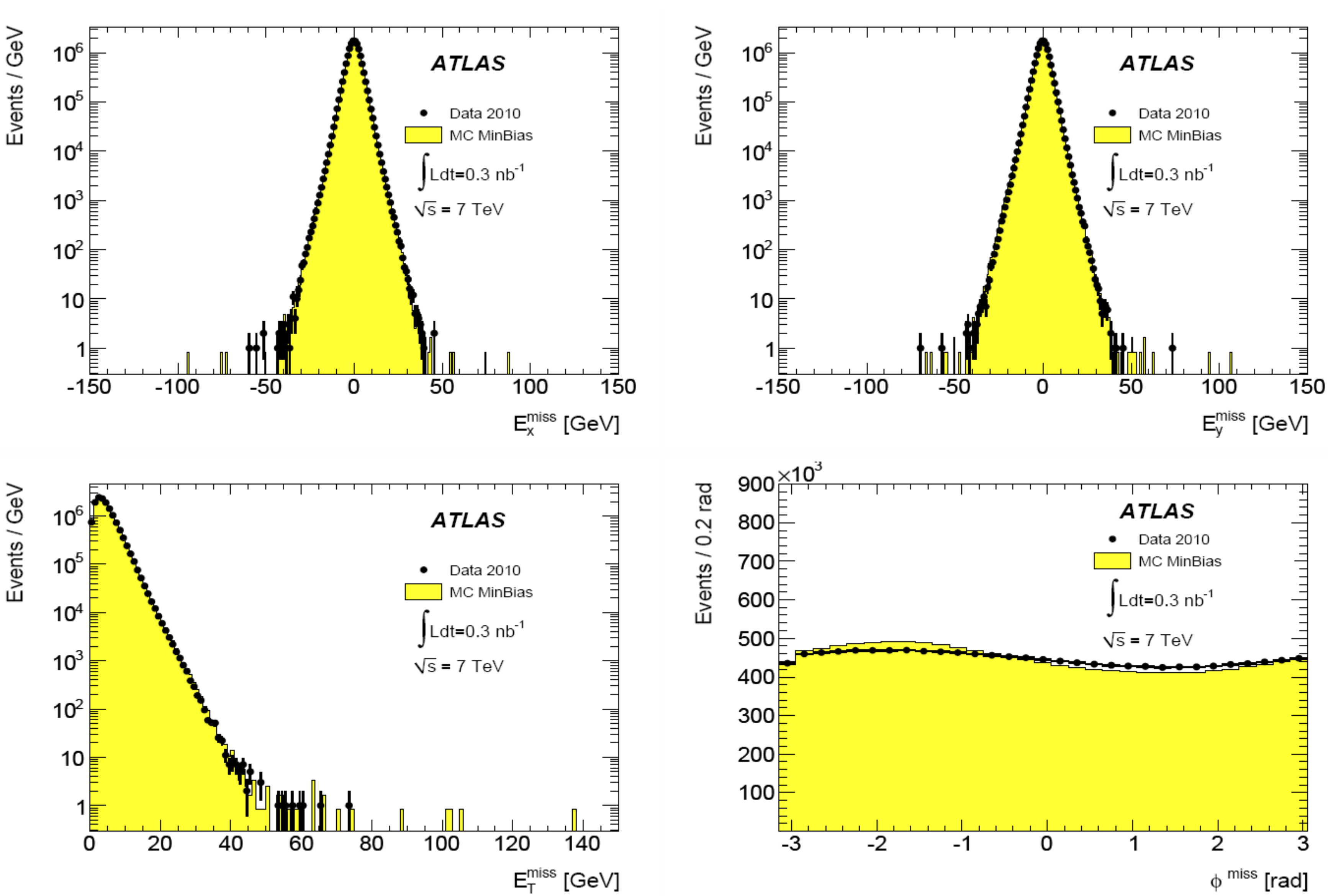
$$E_x^{miss,term} = -\sum_{i=1}^{N_{cell}^{term}} E_i \sin\theta_i \cos\phi_i$$

$$E_y^{miss,term} = -\sum_{i=1}^{N_{cell}^{term}} E_i \sin\theta_i \sin\phi_i$$

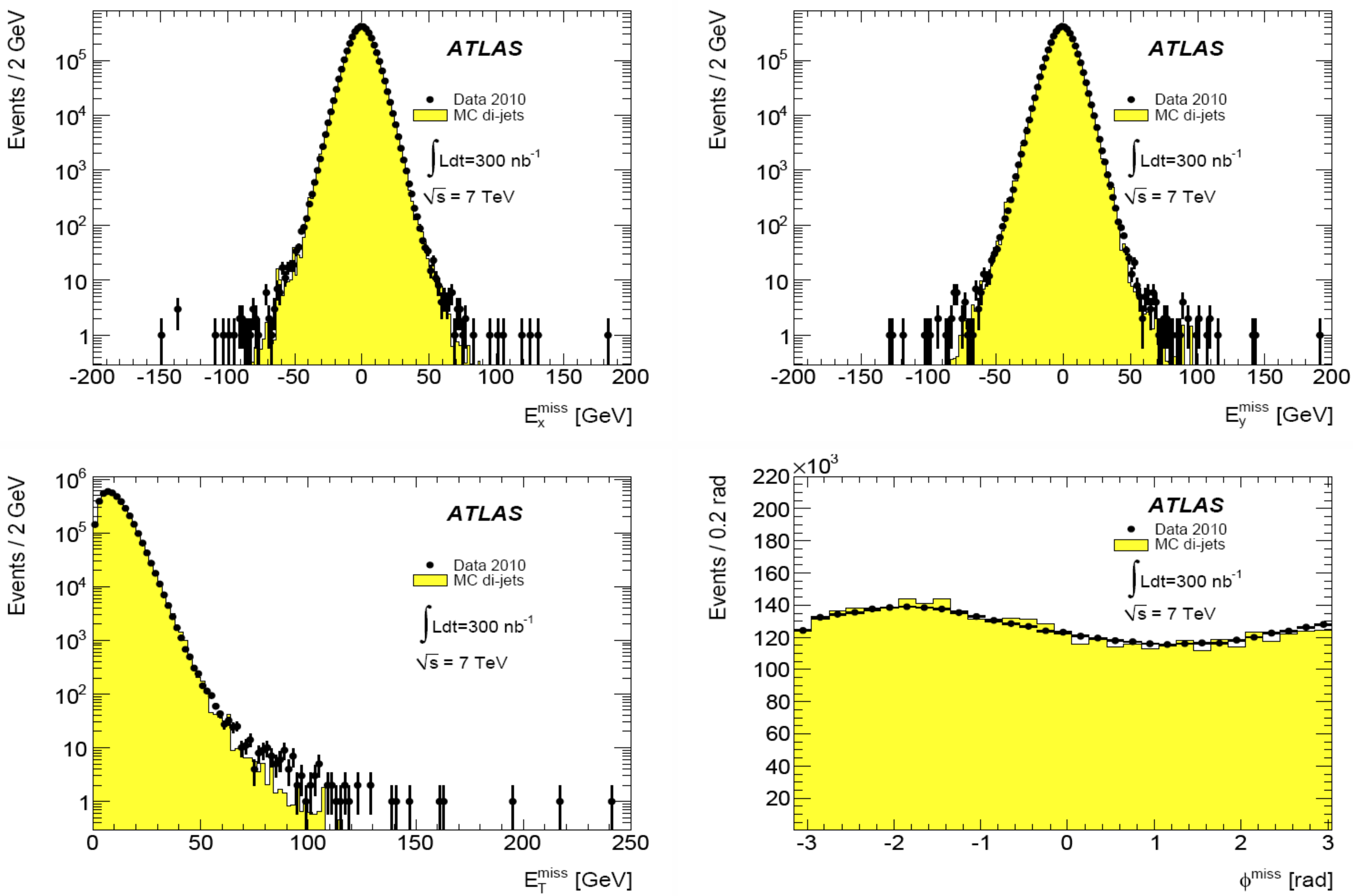
and

$$E_{x(y)}^{miss,\mu} = -\sum_{muons} p_{x(y)}^{\mu}$$

Minimum Bias

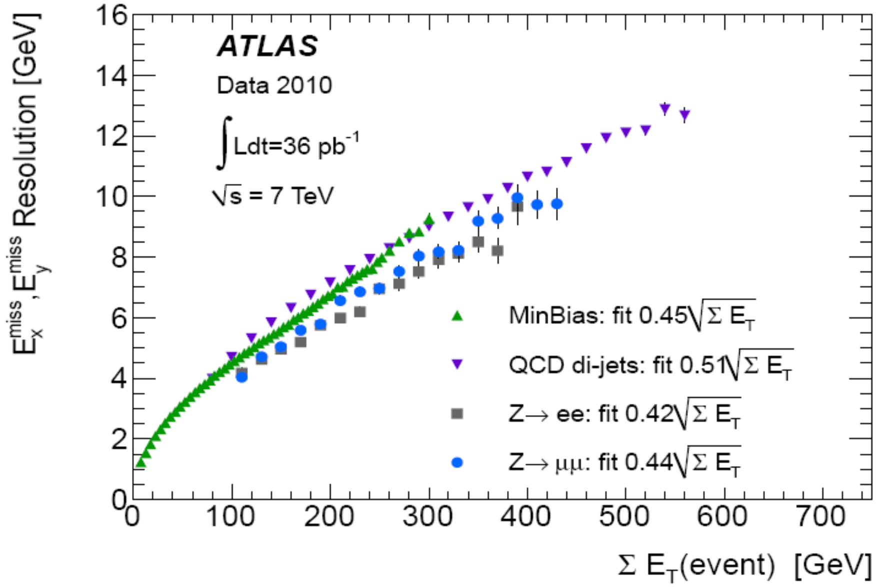


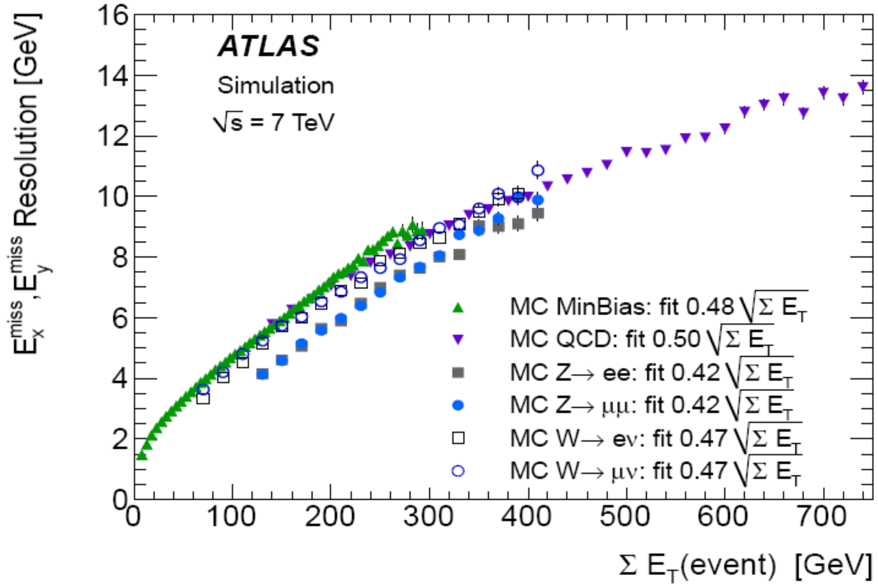
Di-Jets



ATLAS
Data 2010
MC di-jets
∫Ldt=300 nb⁻¹
√s = 7 TeV
Events / 2 GeV
E_x^miss [GeV]
E_y^miss [GeV]
E_T^miss [GeV]
Events / 0.2 rad
φ^miss [rad]
×10³

Measured Resolution in $E_{x(y)}^{miss}$

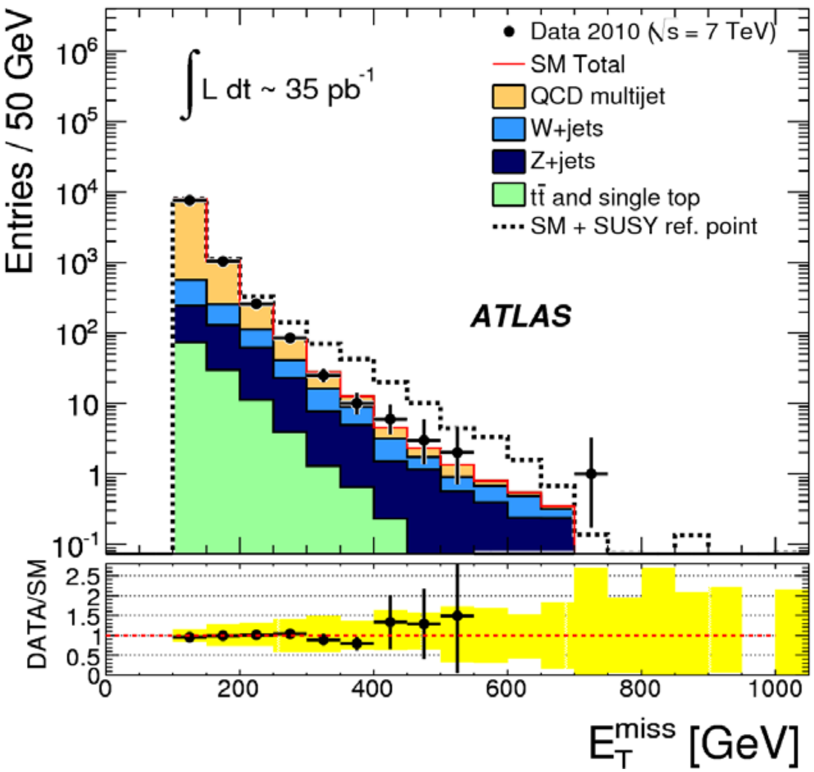


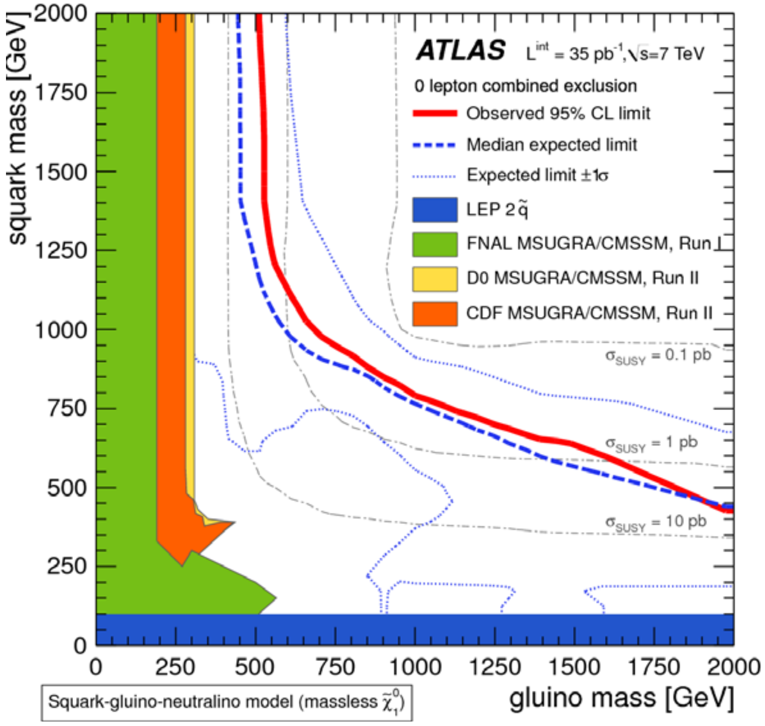


$$\sum E_T = \sum_{i=1}^{N_{cell}} E_i \sin\theta_i$$

These plots also include result of studies using *Z* decays

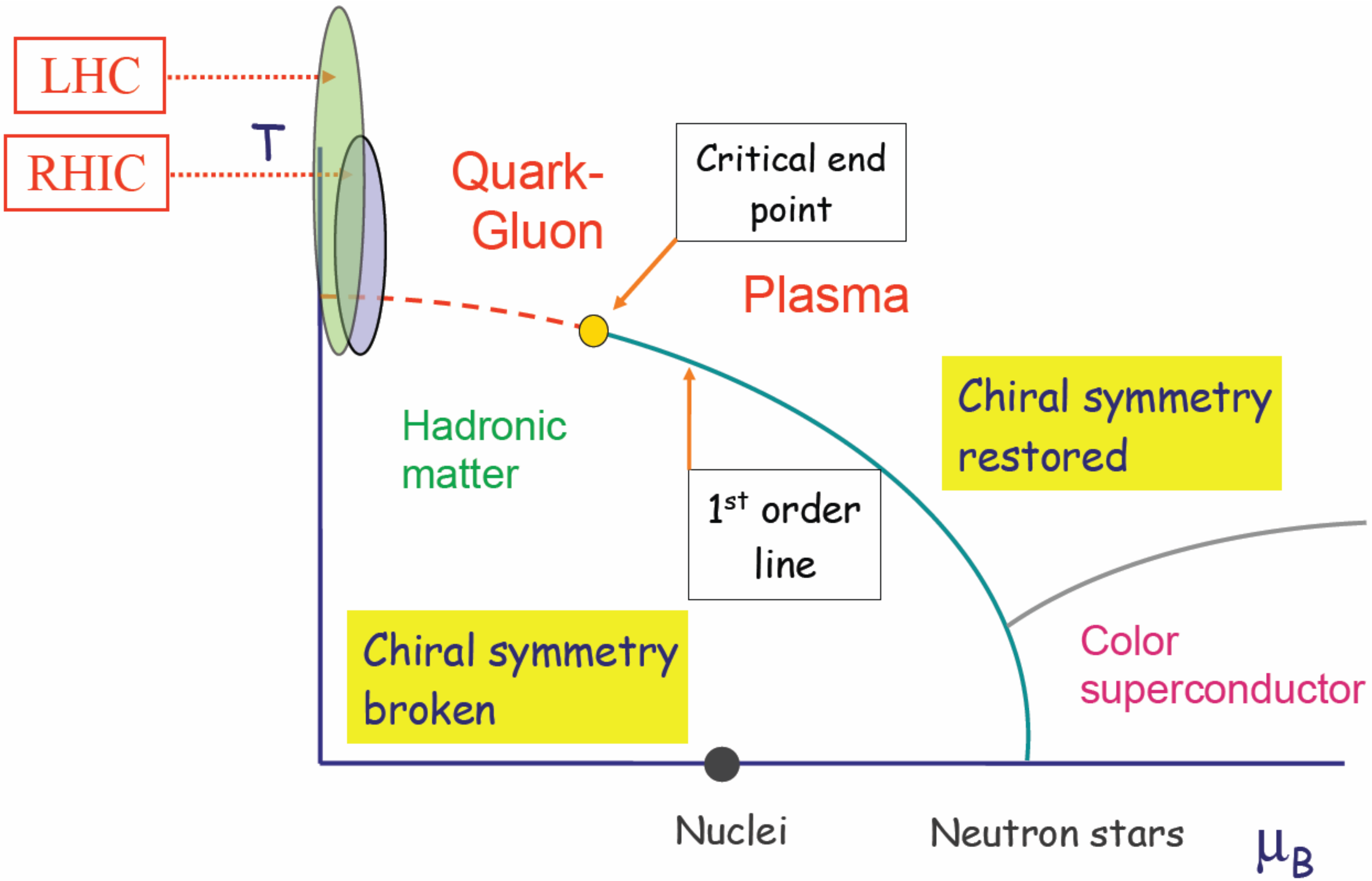
E_T^{miss} in search for squarks and sleptons



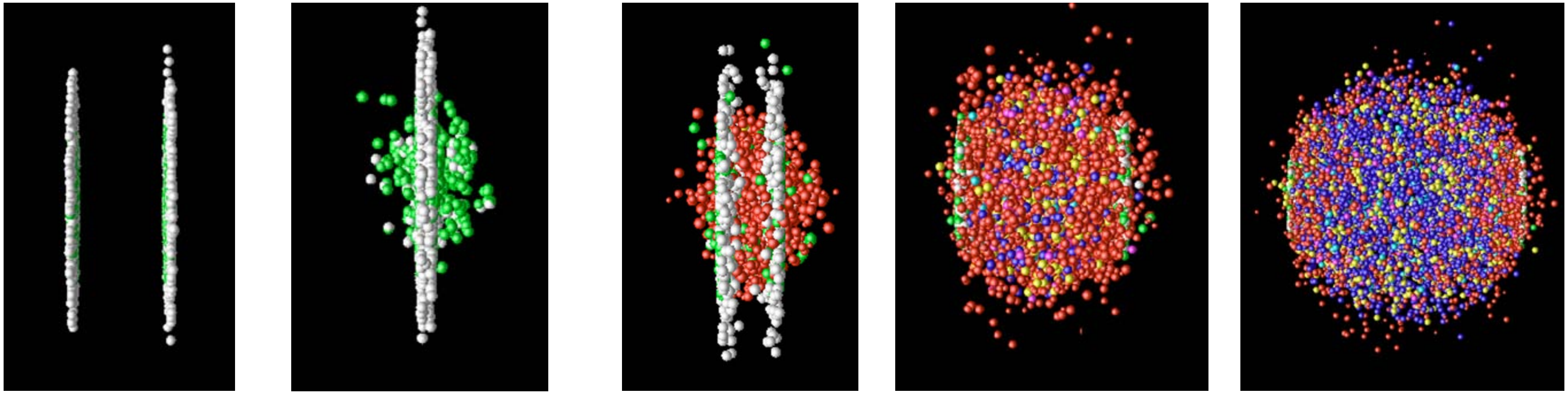


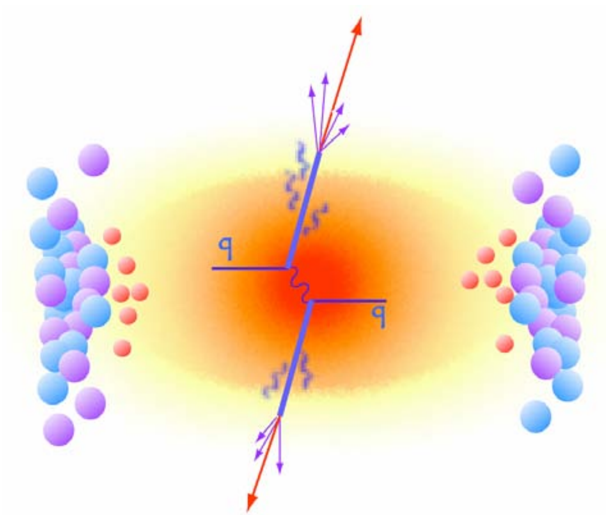
FCal in Heavy Ion Collisions

Exploitation of pseudorapidity coverage out to 4.5

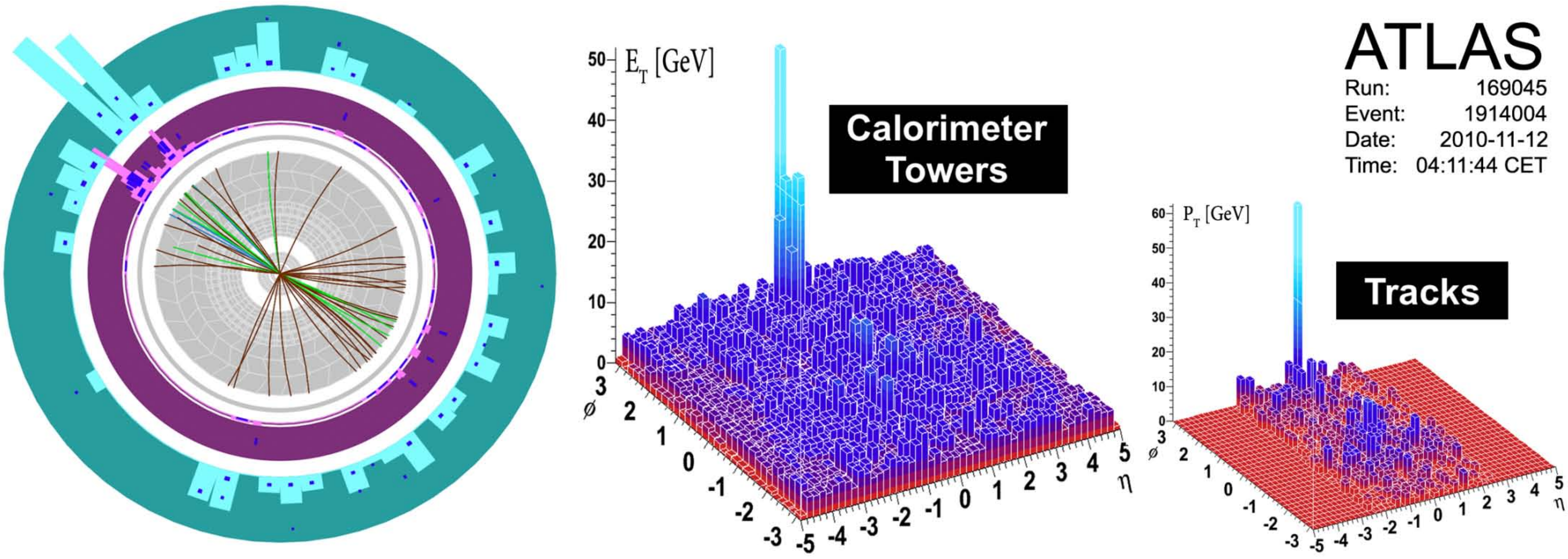


Time Evolution of Pb-Pb Collision at NN CM Energy of 2.76 TeV



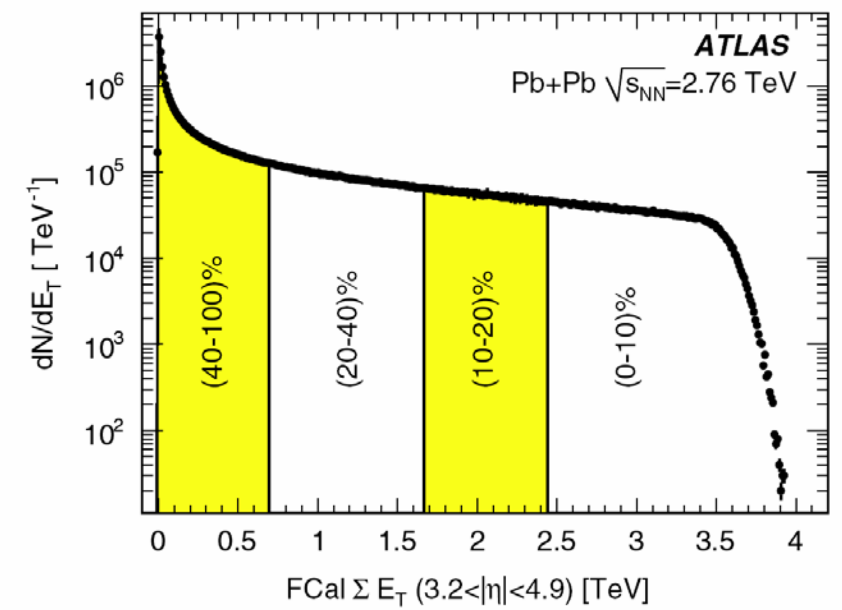


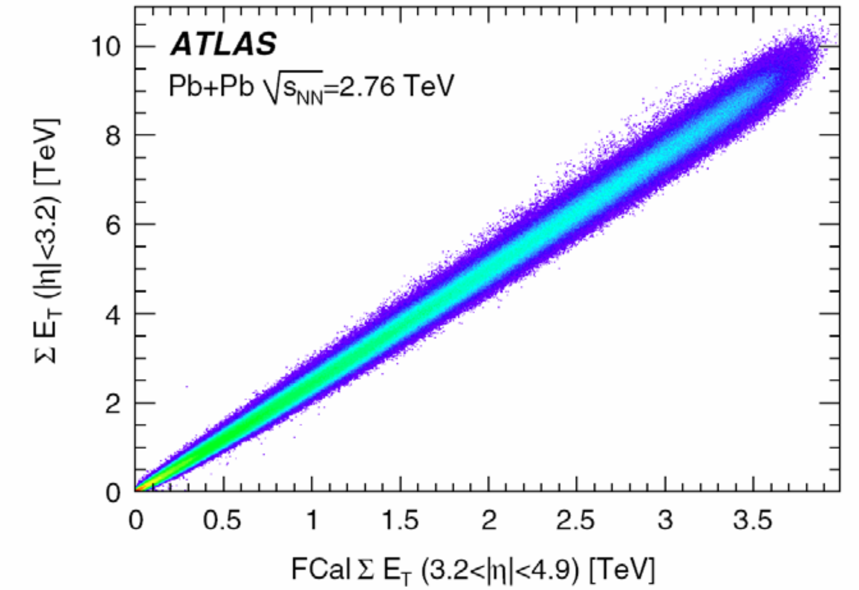
- Peripheral collisions much like *pp* collisions.
- Head-on, central, collisions produce hot, dense plasma.
- Jets from di-jets in this ambient plasma have to propagate through it.
- One jet may lose a lot of energy
- Asymmetric “di-jets” – jet quenching



- Very early in Pb-Pb running, ATLAS saw asymmetric events.
- If these are due to jet quenching, expect asymmetry to be correlated overall activity in the event – centrality.

Characterizing Centrality of Collisions





Bins in fraction of Pb-Pb total cross section

Correlation between activity in central pseudorapidity region, and activity in FCal

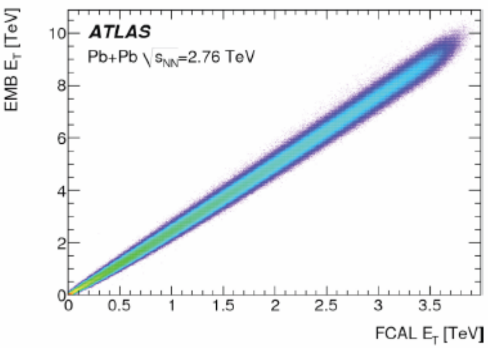
Analysis looks at asymmetry in barrel

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}} \qquad \Delta\phi > \frac{\pi}{2}$$

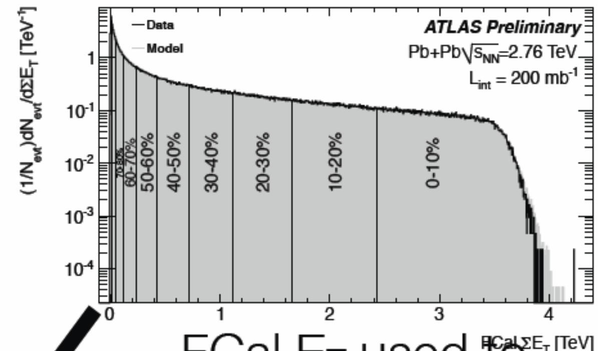
$$E_{T1} > 100\,GeV,\; E_{T2} > 25\,GeV$$ jets

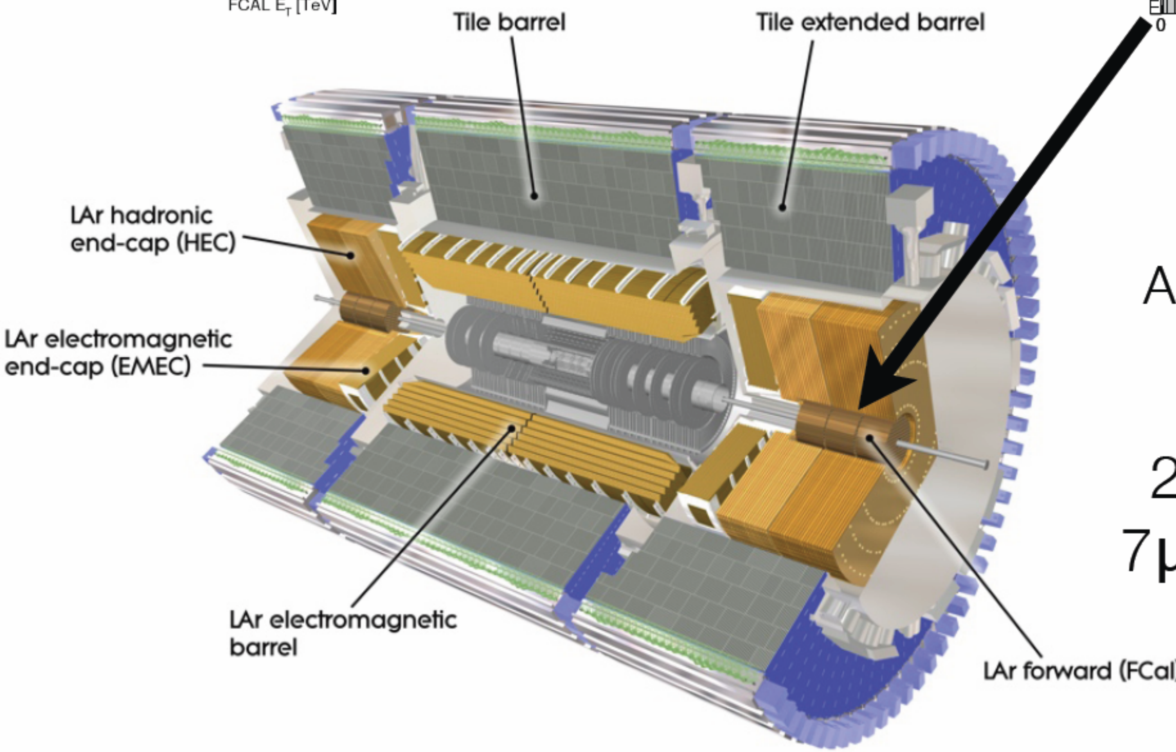
As a function of centrality tagged by

$$FCal \sum E_T$$



E_T in barrel strongly correlated with FCal



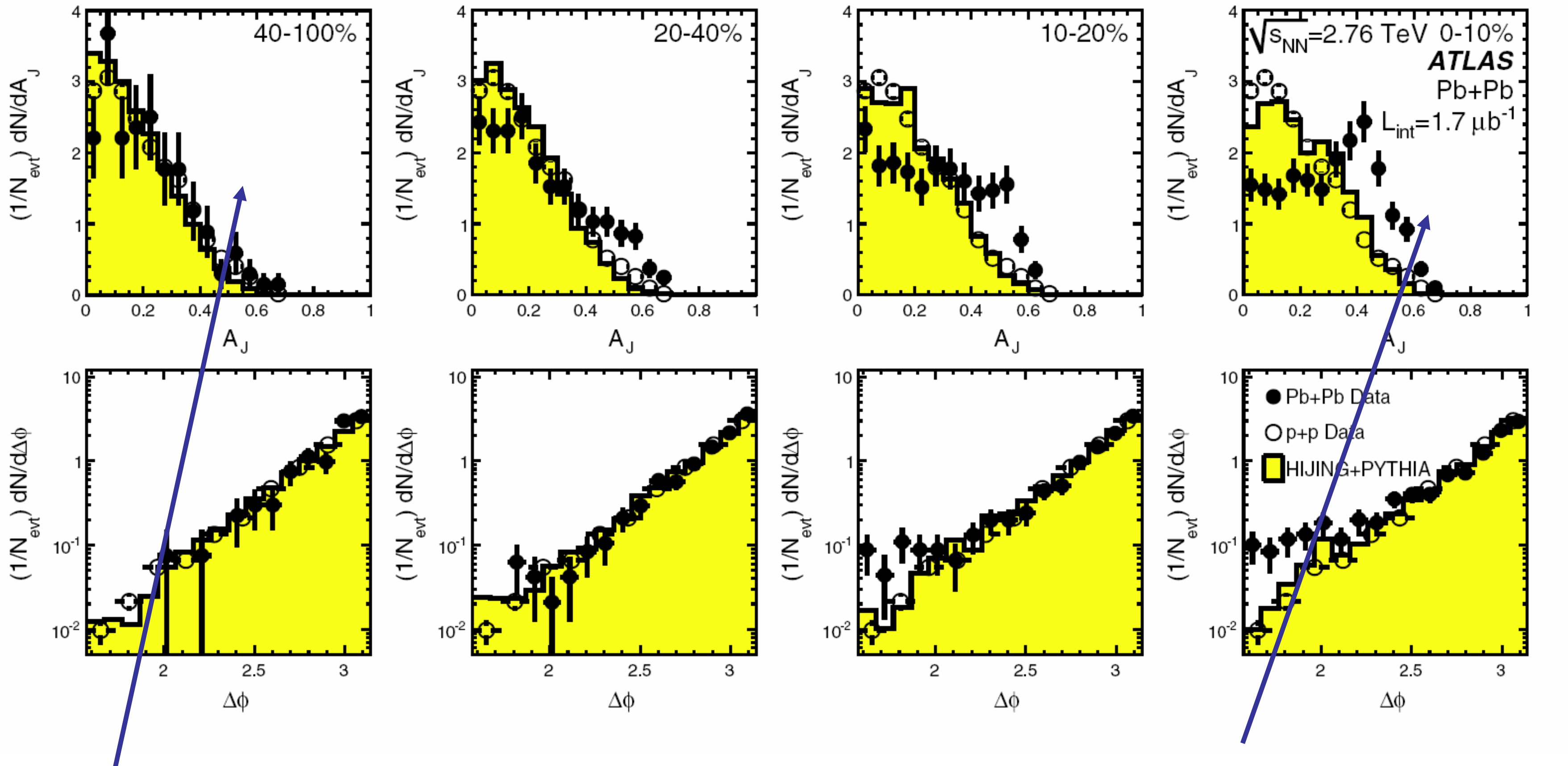


FCal E_T used to determine centrality
$3.2 < |\eta| < 4.9$

Analysis uses jets in barrel: $|\eta| < 2.8$

2010 Pb Ion run:
$7\mu b^{-1}$, 50 M events

Di-Jet Asymmetry as a Funtion of Centrality



- Peripheral
- Looks like pp

$$A_J = \frac{E_{T1} - E_{T2}}{E_{T1} + E_{T2}}$$

- $FCal \sum E_T$ large
- Central Collisions
- Large asymmetry

- ATLAS Hermeticity is central to search for new physics
- FCal covers 30% of ATLAS pseudorapidity coverage
- FCal works well in a challenging environment

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