13th ICATPP Conference

Como – October 3-7 2011

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

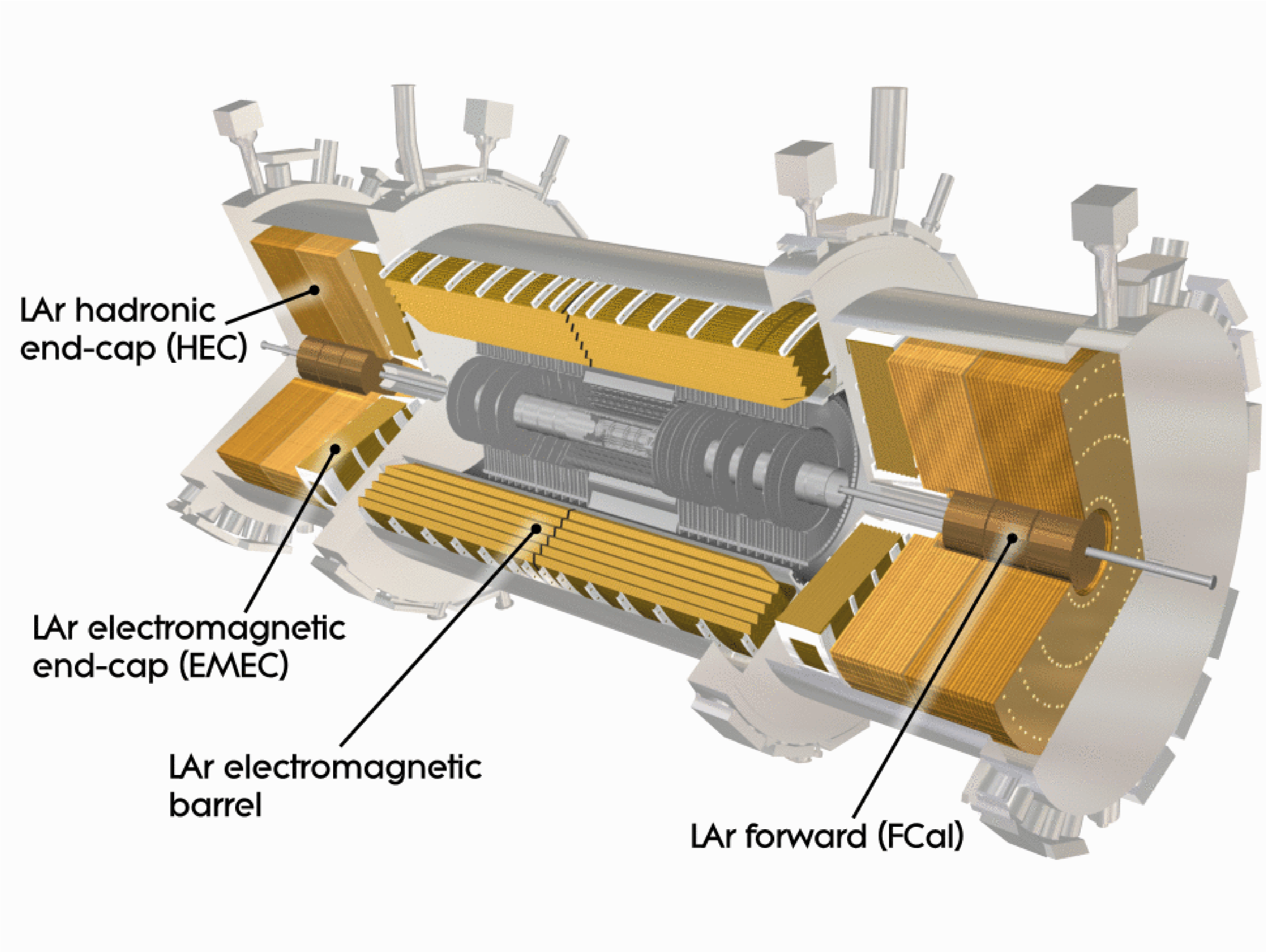
- Motivation
- Construction
- Test Beam
- Collisions 2009 - 2011
- Some Physics

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

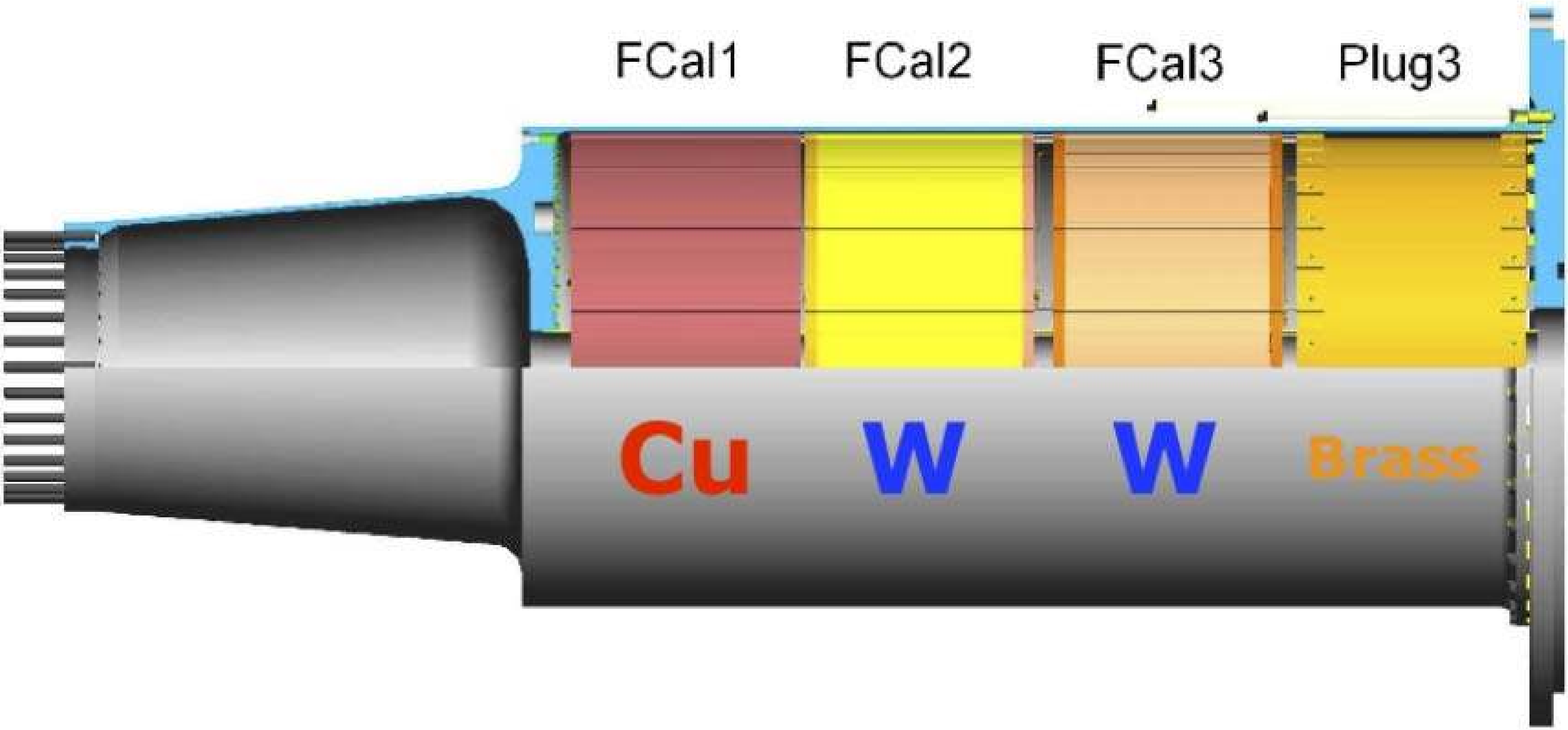
- Only modest stochastic energy resolution required due to high energy jets in forward direction.
- Challenge is survivability close to proton beam.

Layout of ATLAS Liquid Argon Calorimeters



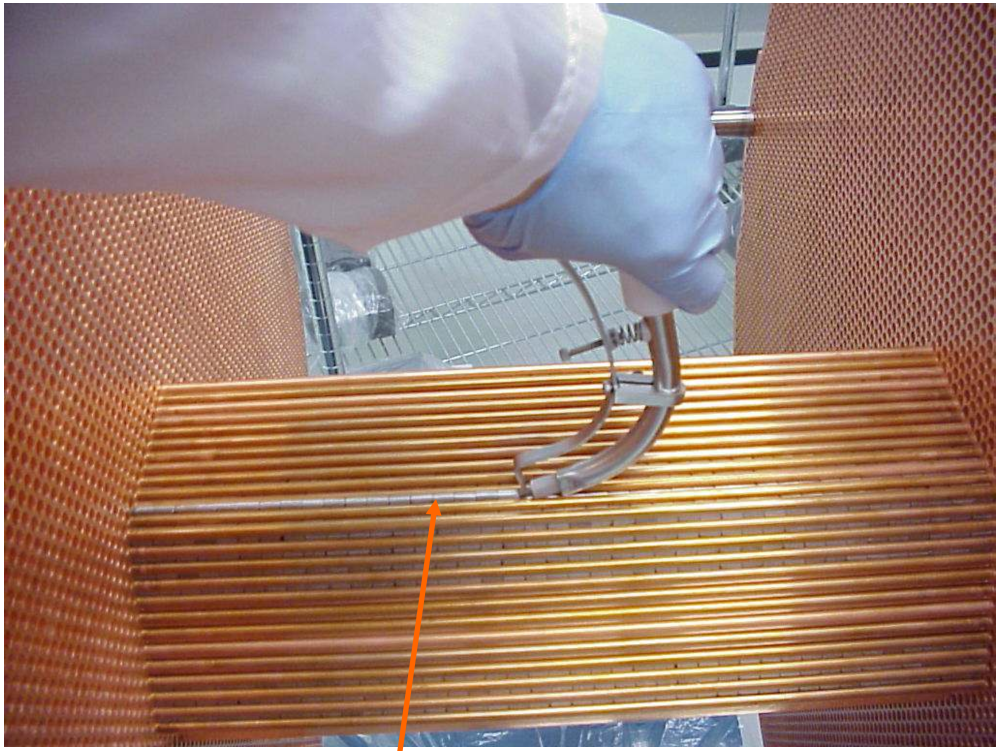
Liquid Argon Forward Calorimeter

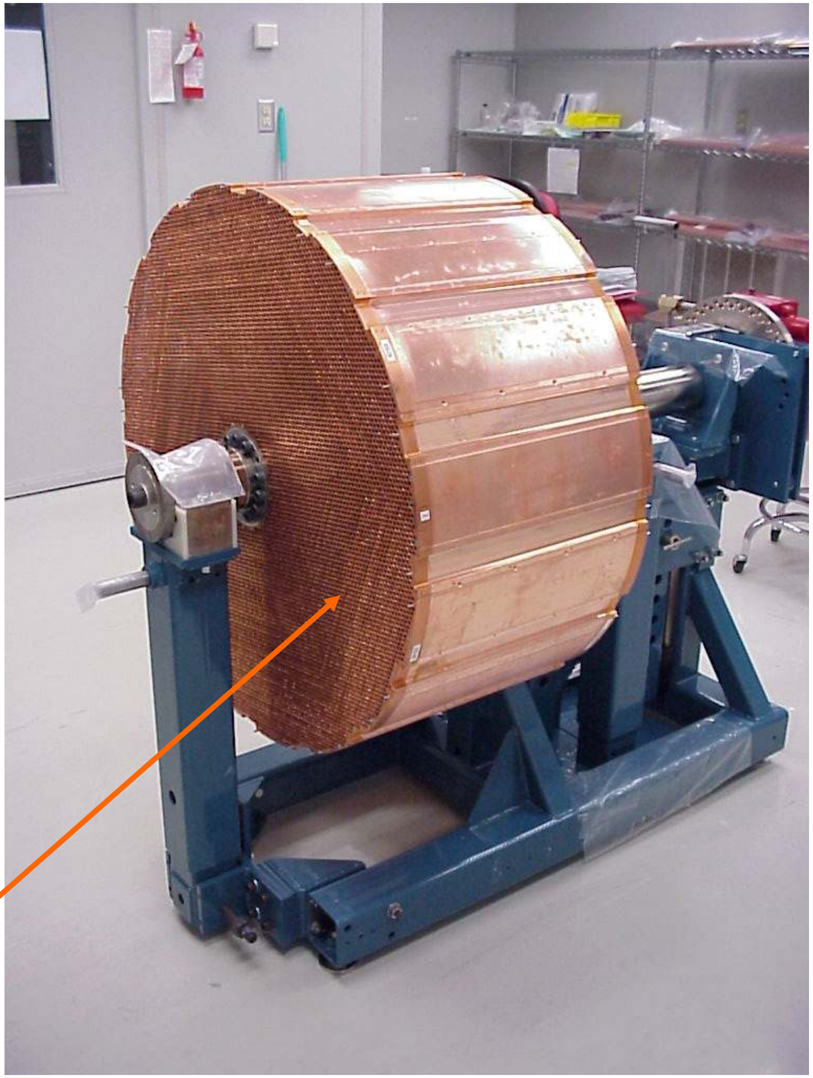
Layer	Absorber	LAr gap	$N_{electrodes}$	$N_{channels}$
FCal1	Cu	269 μm	24,520	2,016
FCal2	W	376 μm	20,400	1,000
FCal3	W	508 μm	16,448	508



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

Tungsten Module

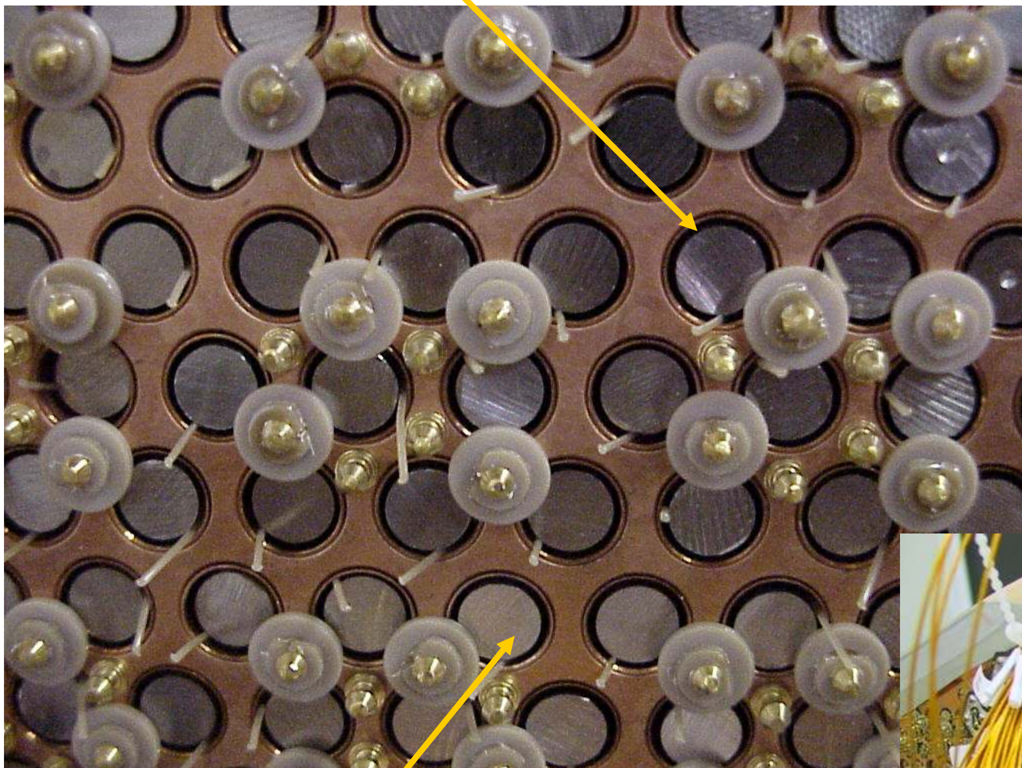


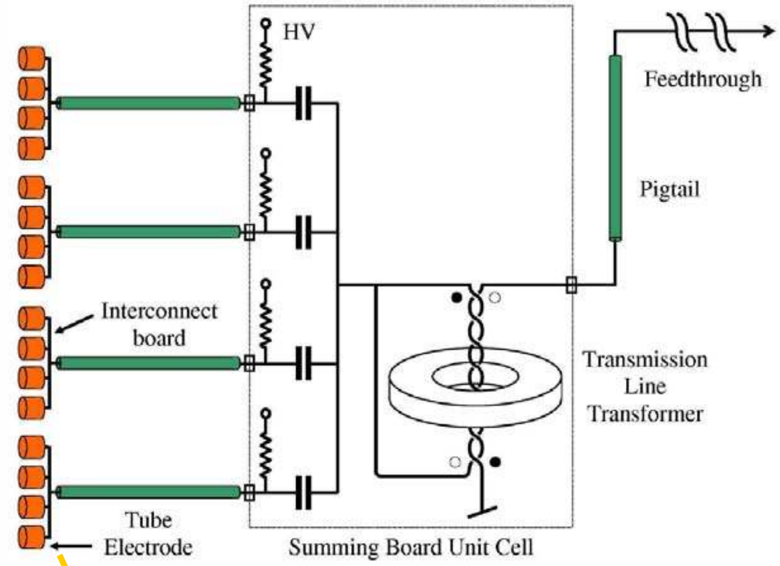


Tungsten slug structure

Cu Endplates + outer shell

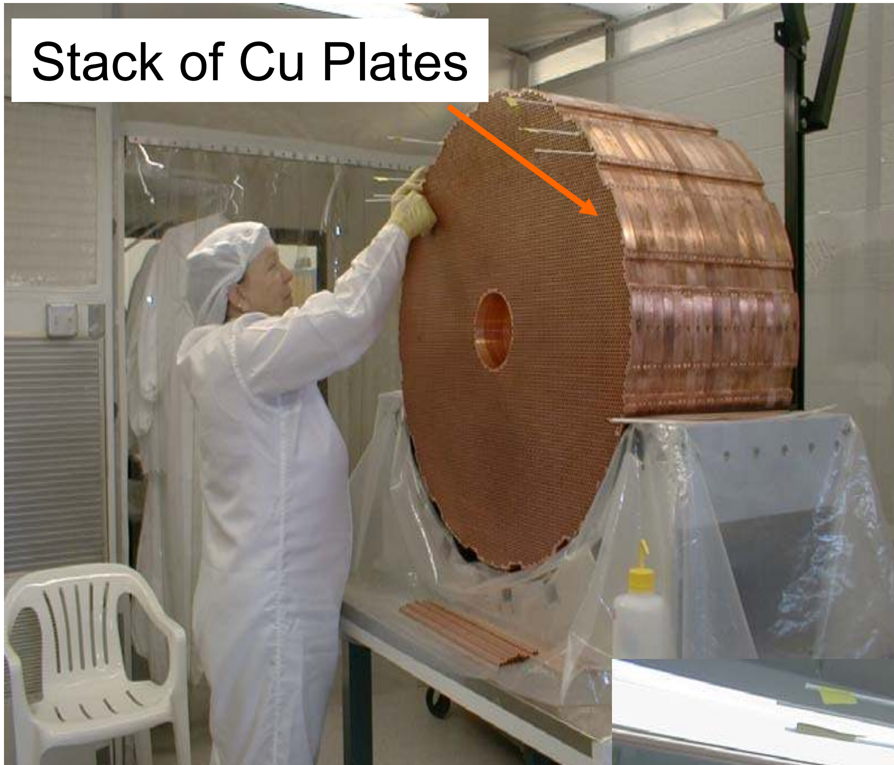
Liquid Argon Gap

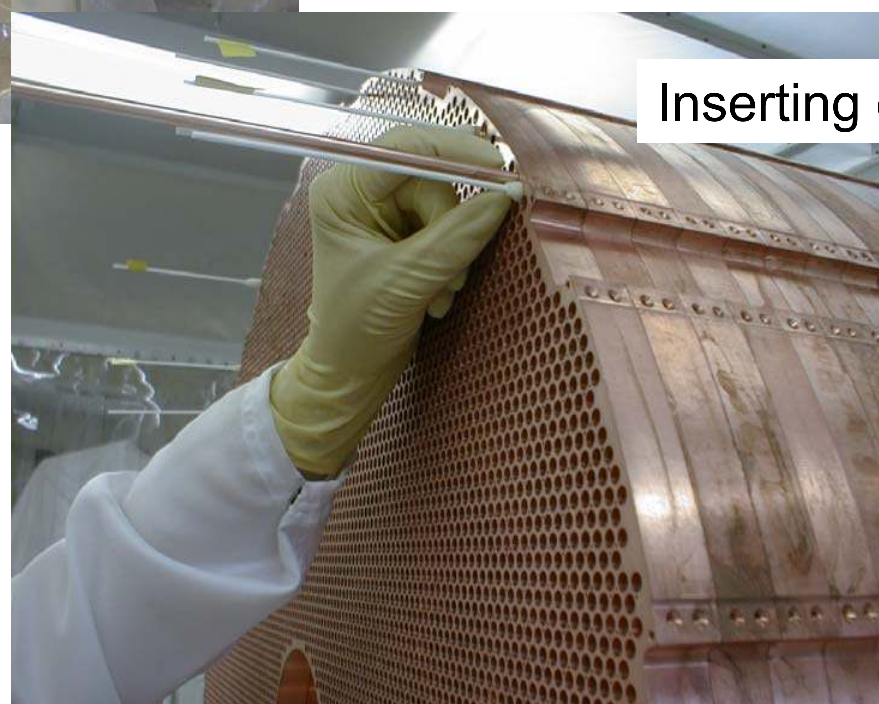




Tungsten Rod

FCal1 Copper Module





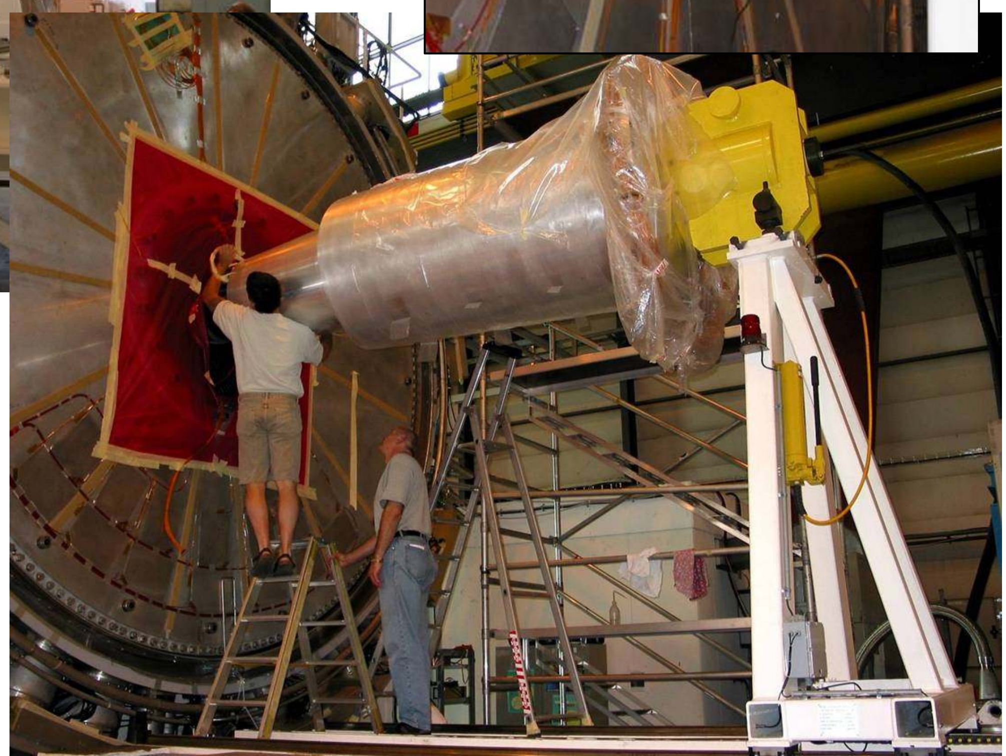
Assembly at CERN

FCal1

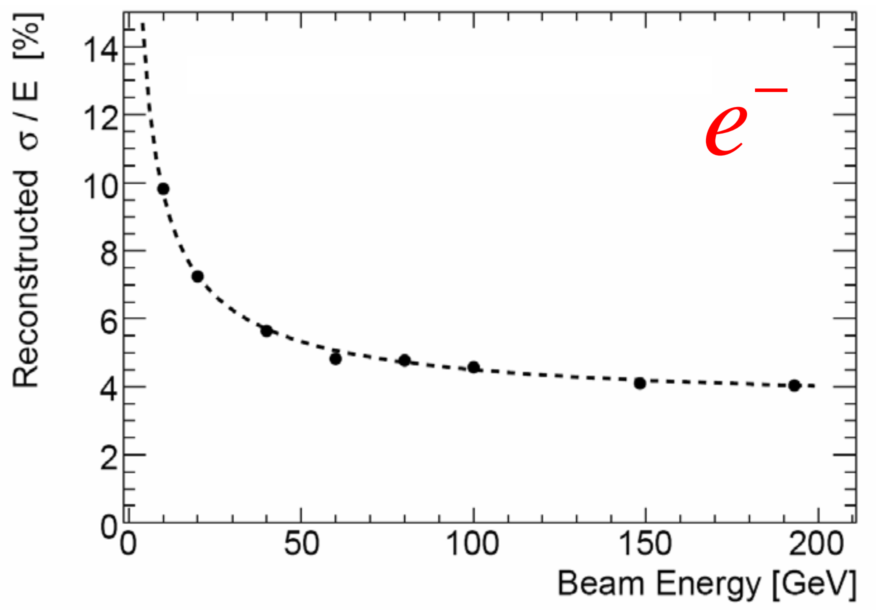
Support Tube

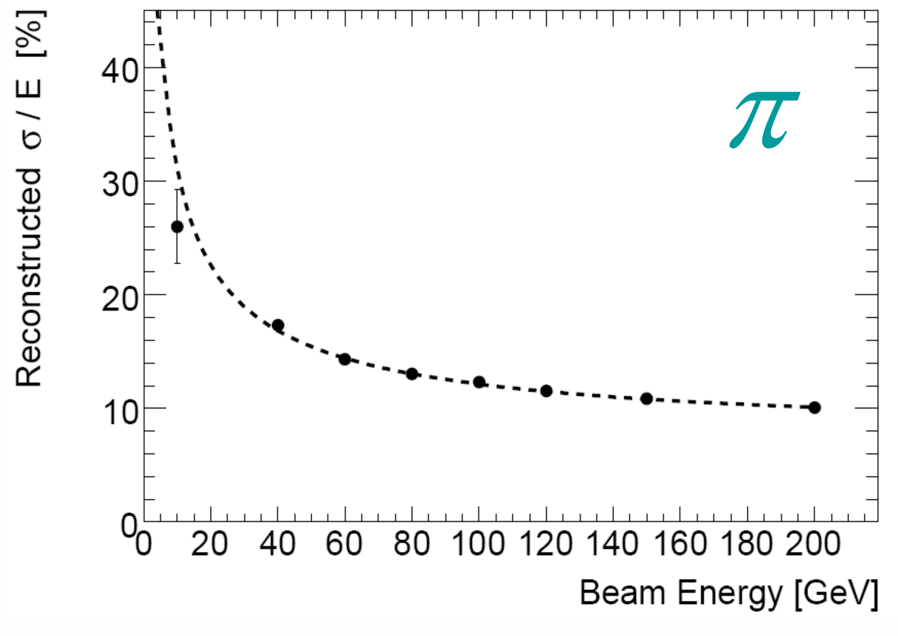
Signal Cables run to rear


HWX 159



Test Beam Single Particle Energy Resolution





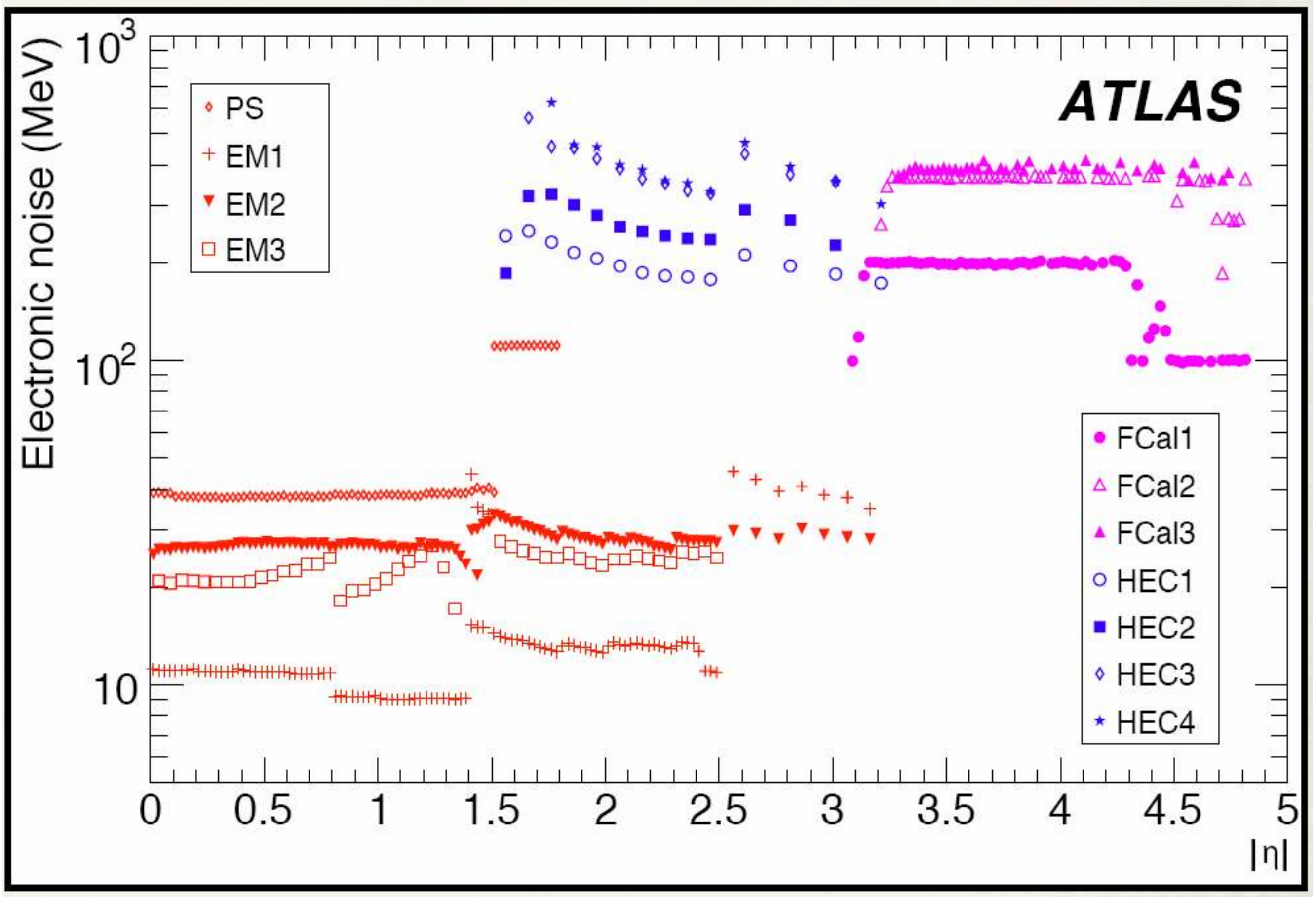
$$\frac{\sigma_E}{E} = \frac{a}{\sqrt{E}} \oplus b$$

Noise subtracted energy resolution

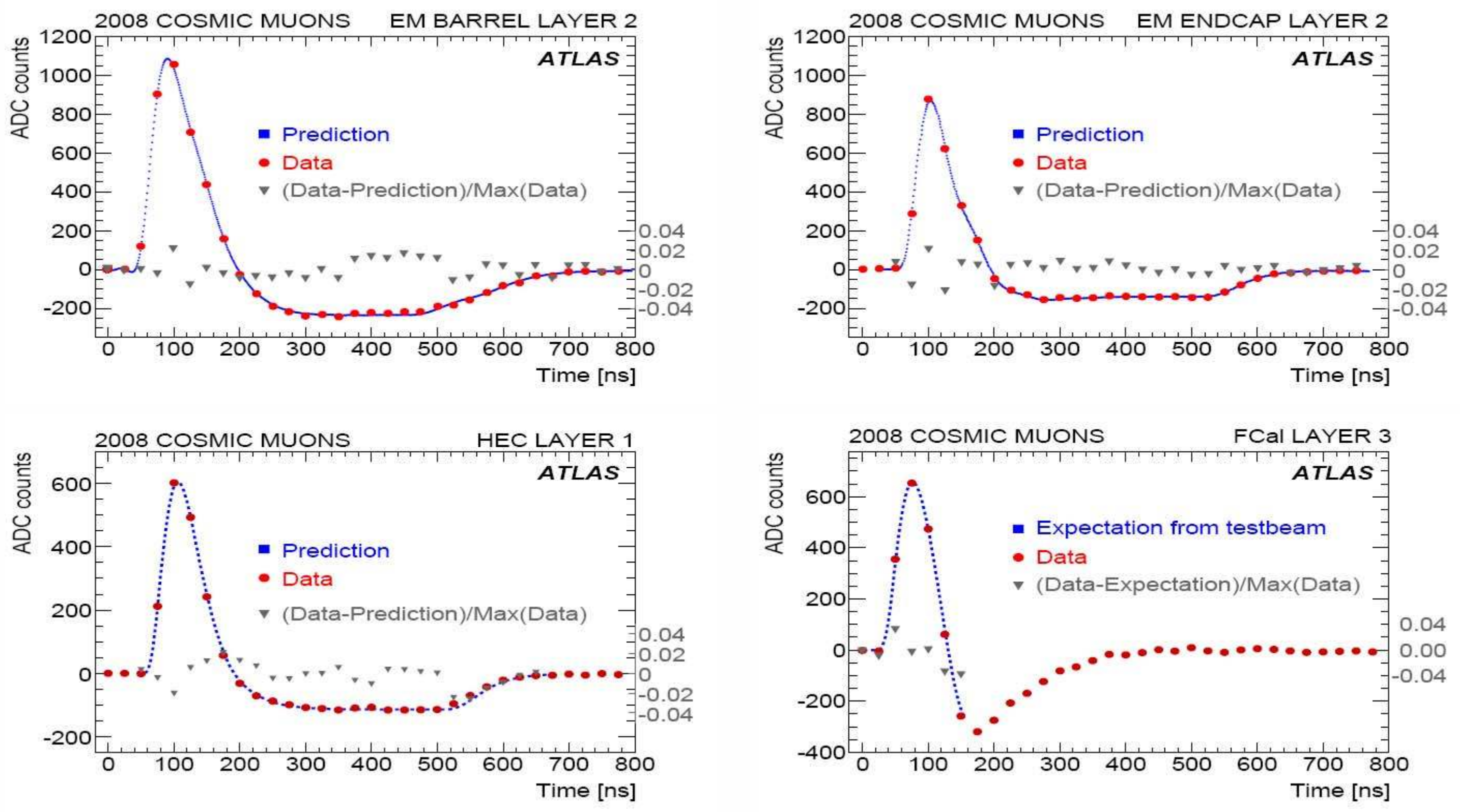
$$a = (28.5 \pm 1.0)\% \cdot \sqrt{GeV}$$
$$b = (3.5 \pm 0.1)\%$$

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

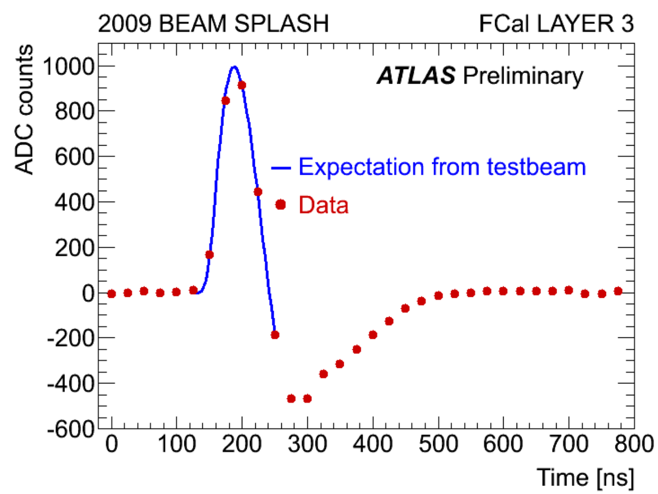
Noise Level in LAr Calorimeters

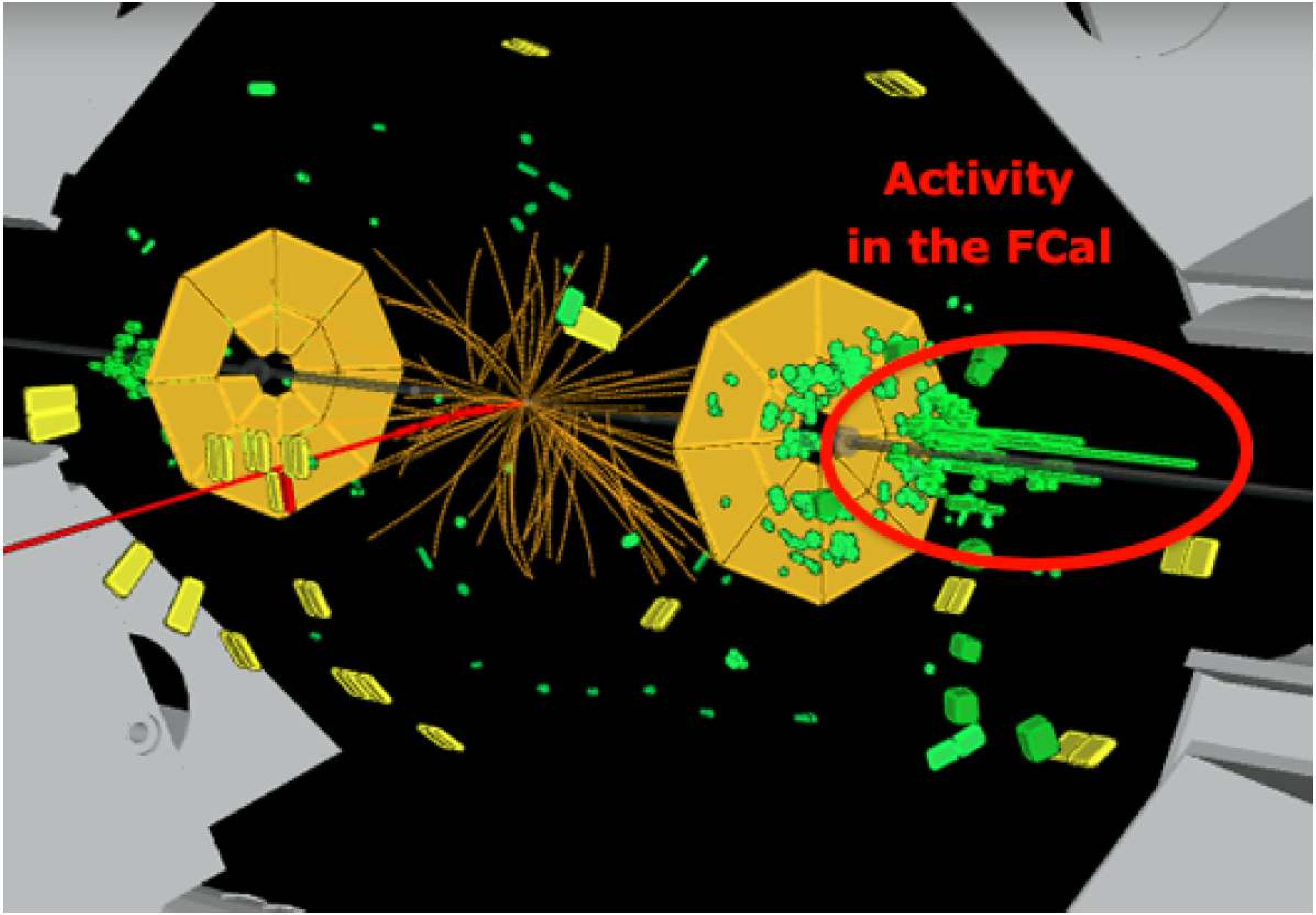


Since the FCal is in the very forward region, these noise levels are OK

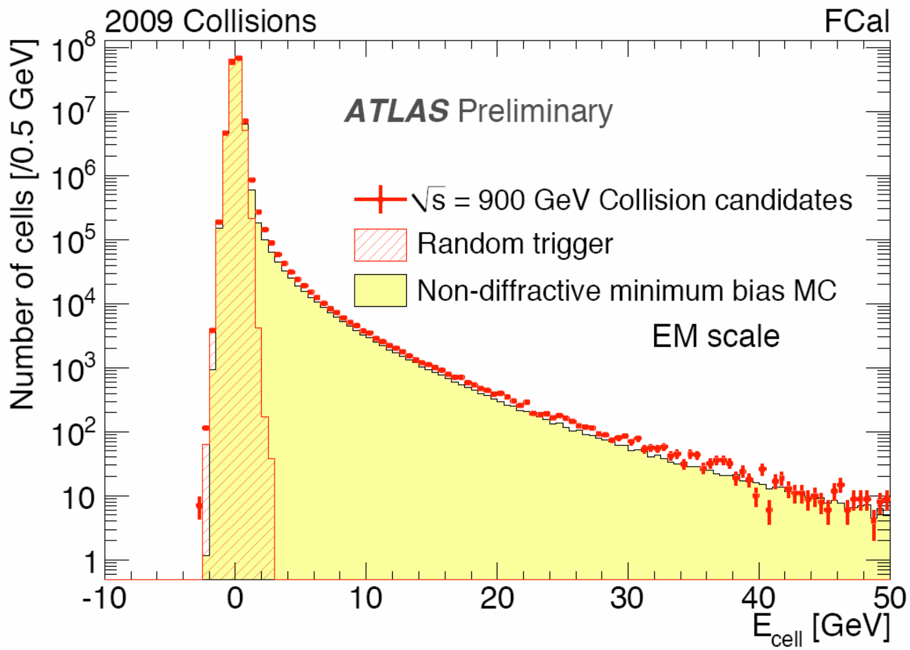


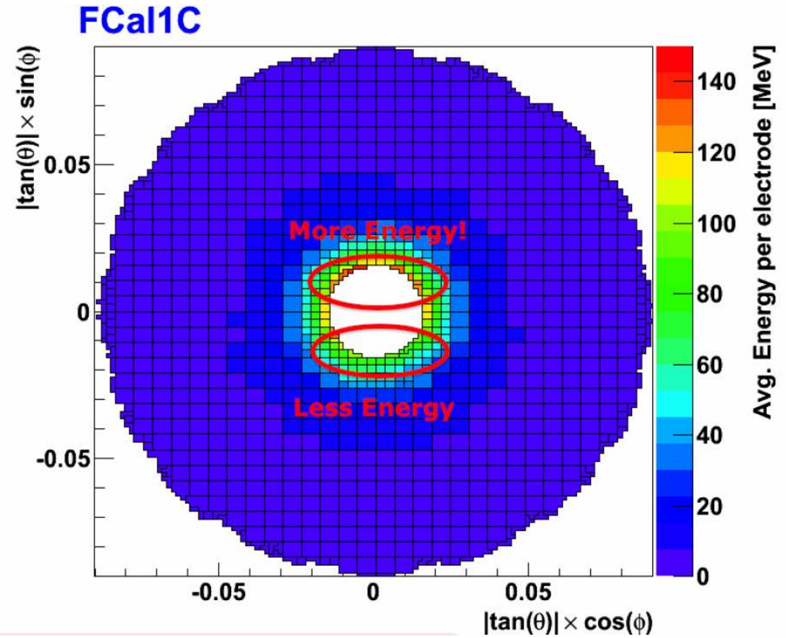
Signal Shape before startup

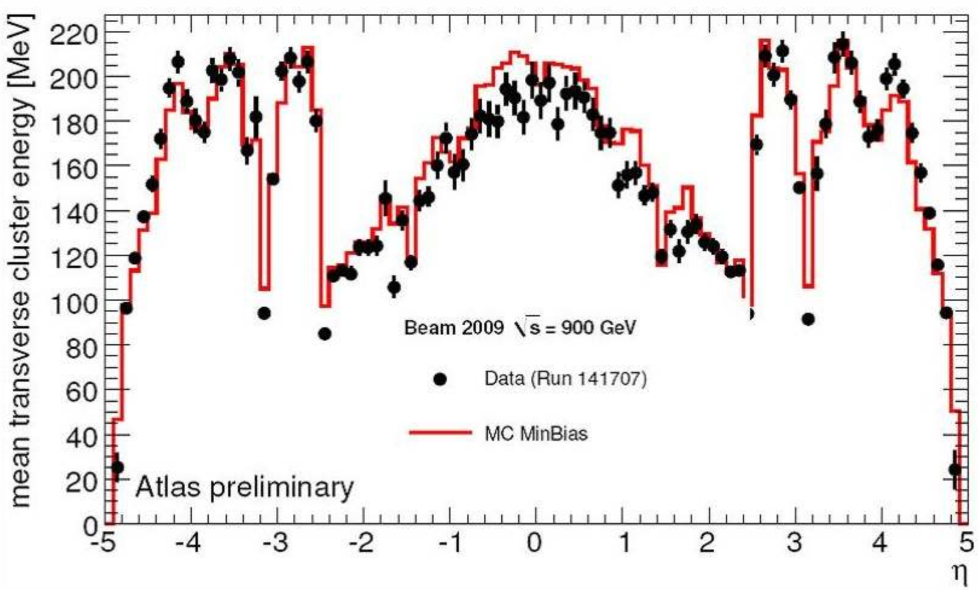



Activity
in the FCal

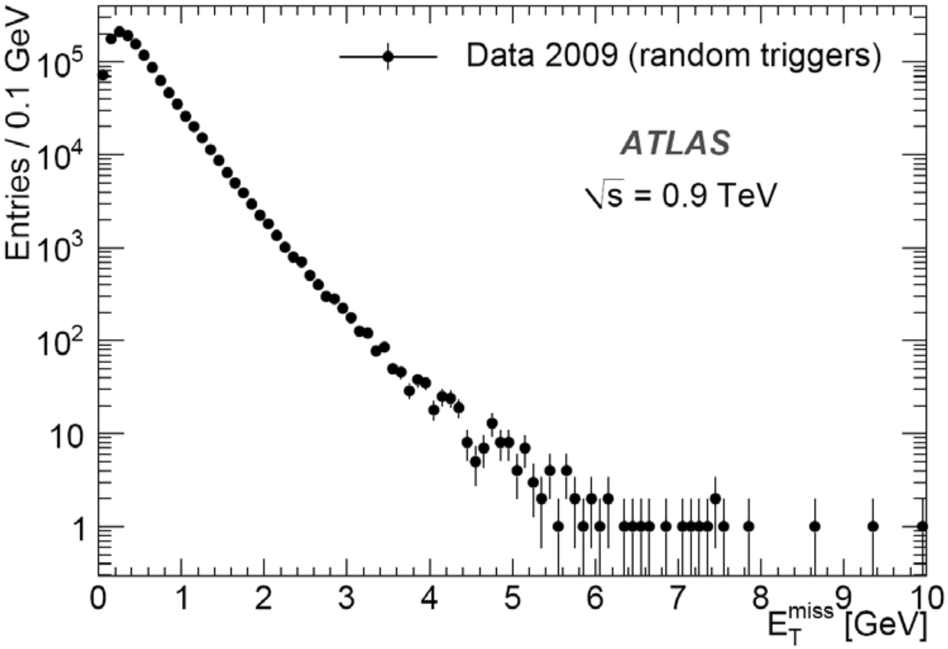
FCal in First Collisions







Early Look at E_T^{miss}



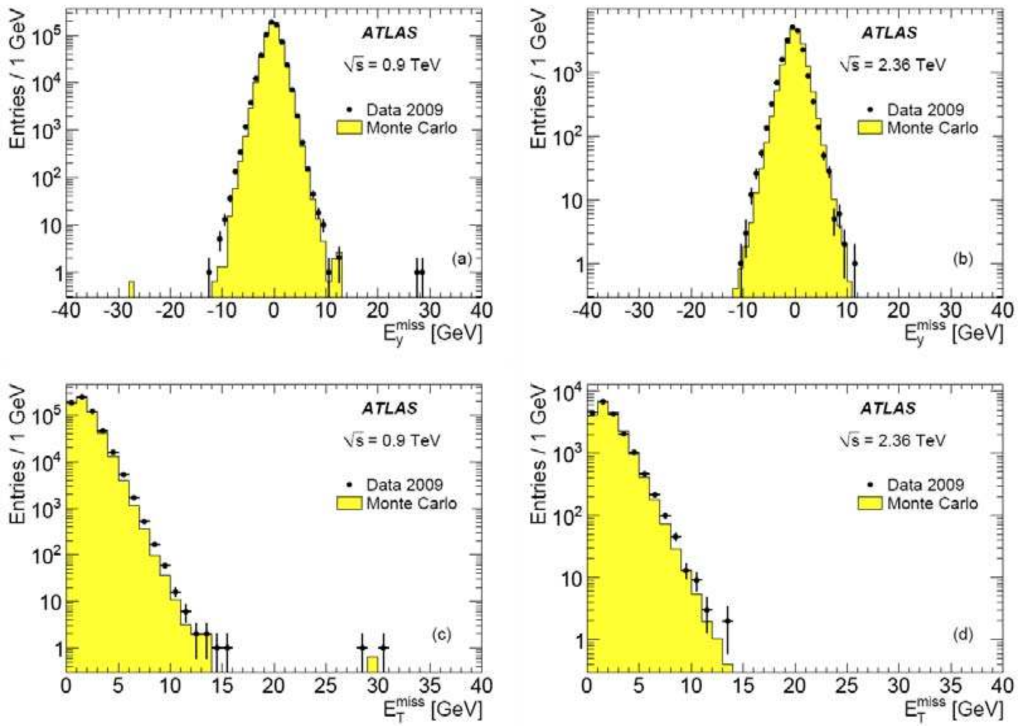
$$E_x^{miss,calo} = -\sum_{i=1}^{N_{cell}} E_i \sin\theta_i \cos\phi_i$$

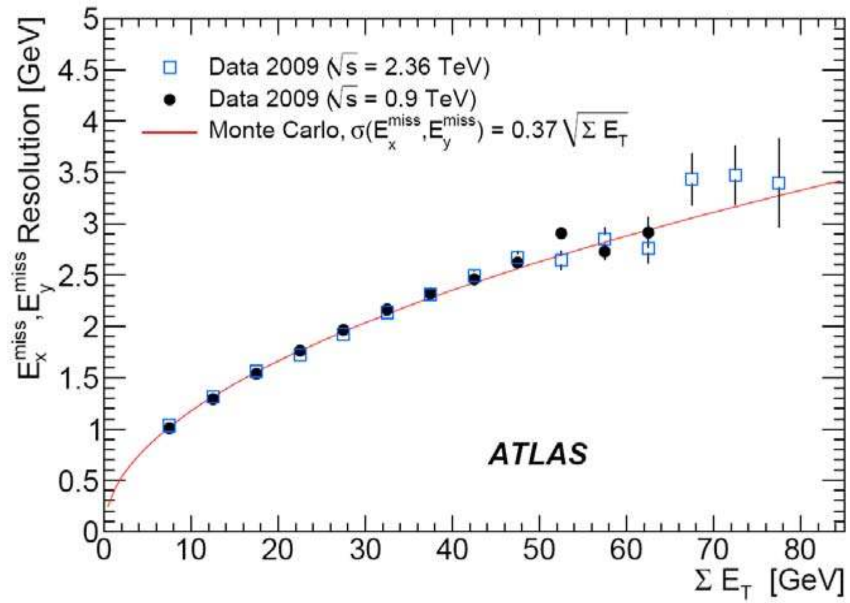
$$E_y^{miss,calo} = -\sum_{i=1}^{N_{cell}} E_i \sin\theta_i \sin\phi_i$$

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

- 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}

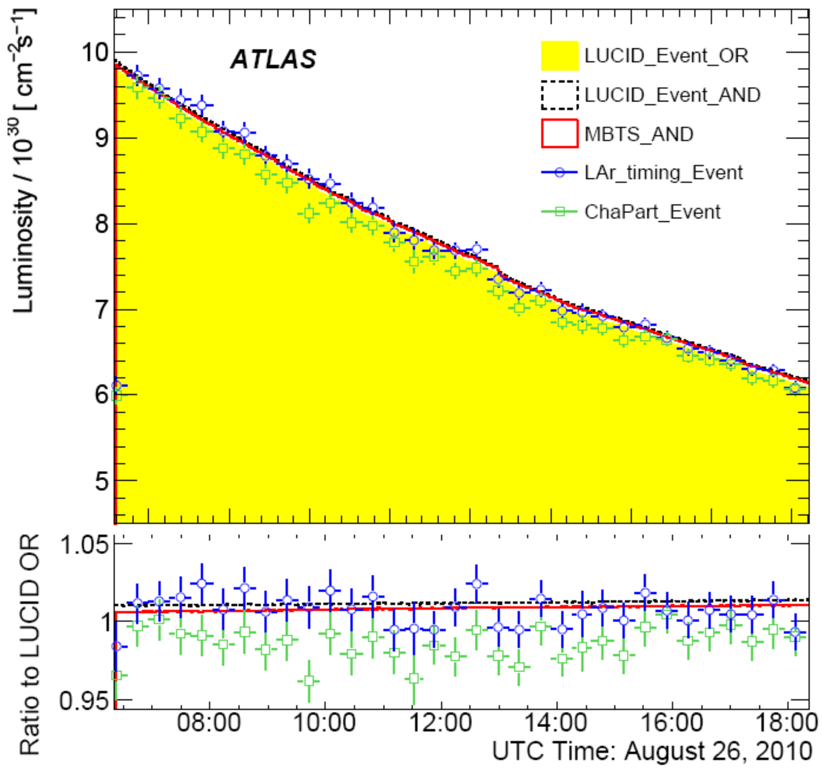


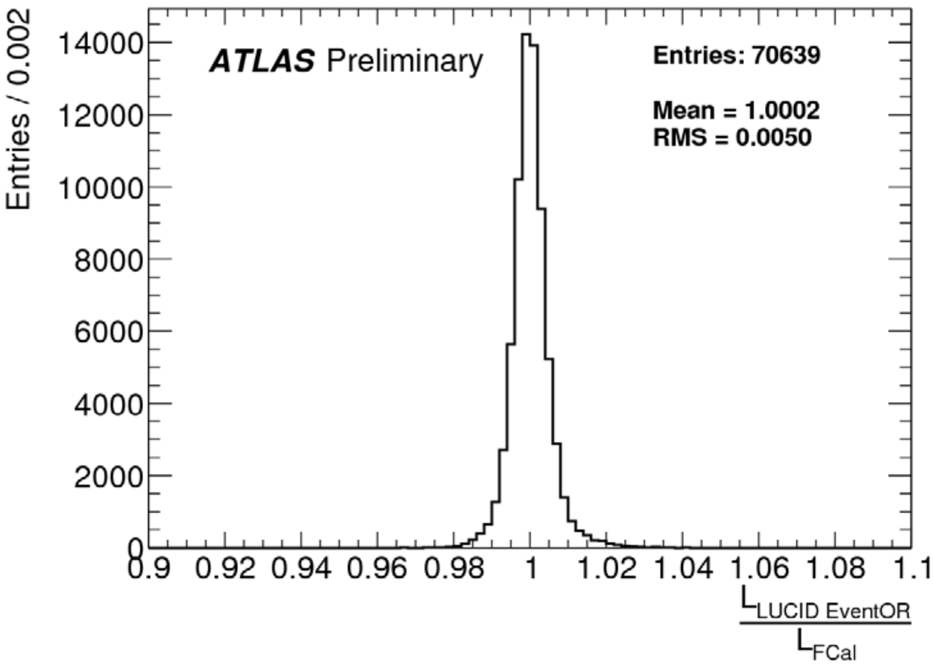


- Soft proton collisions – no real E_T^{miss}
- Width of $E_{x(y)}^{miss}$ gives resolution

- 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

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

- 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

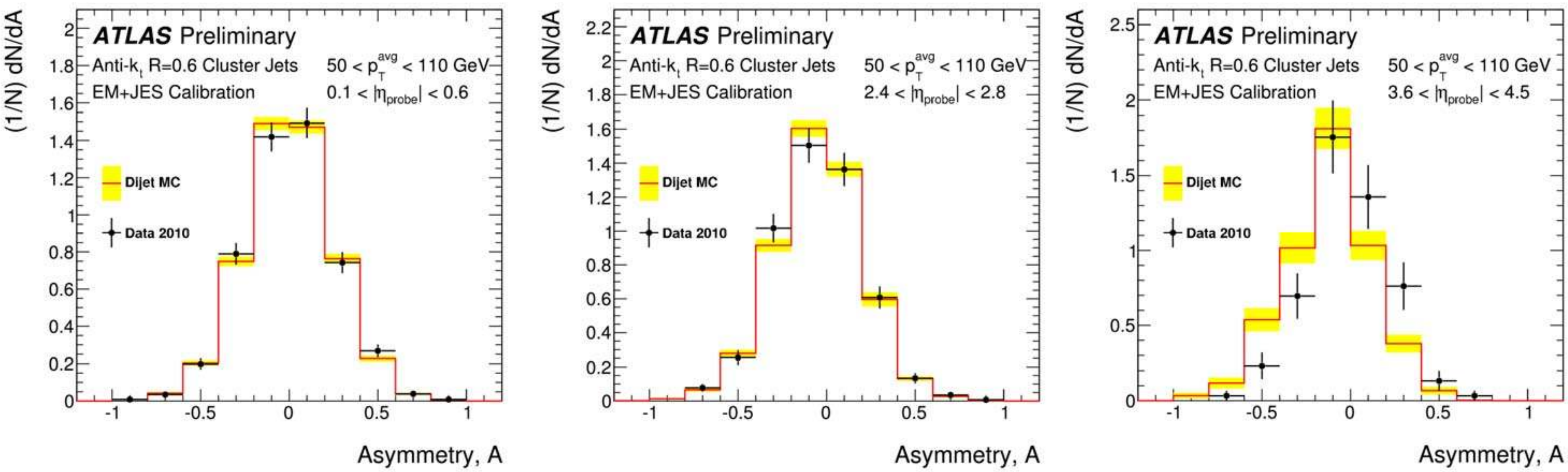
- The analysis is done in bins of η and p_T^{avg}.
- This gives an asymmetry A_{ik} for each probe jet η -bin *i* and each p_T^{avg}-bin *k*
- Intercalibration factors are calculated for each bin according to

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

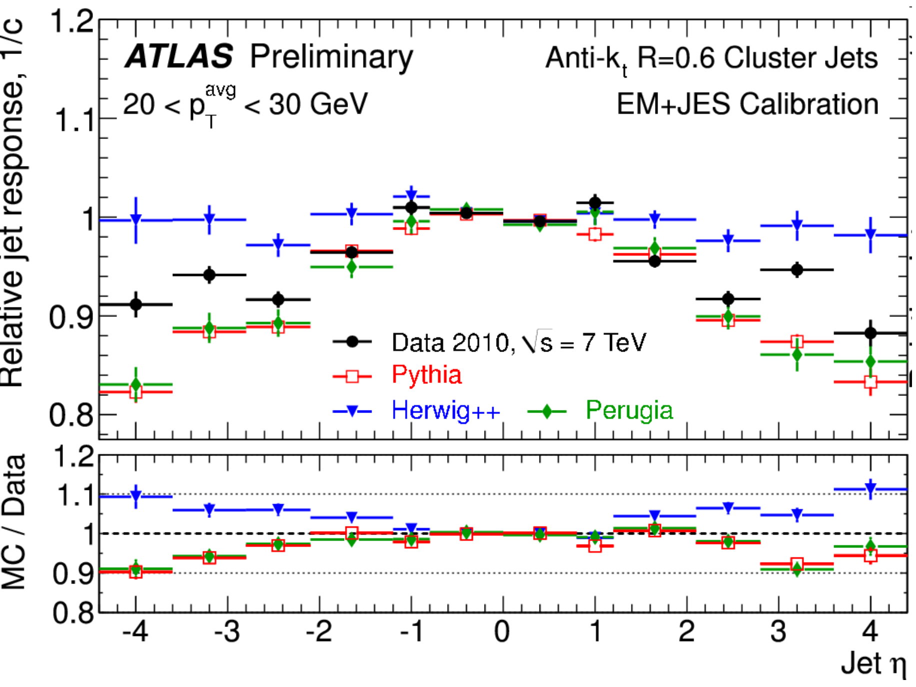
$$c_{ik} = \frac{2-\langle A_{ik} \rangle}{2+\langle A_{ik} \rangle}$$

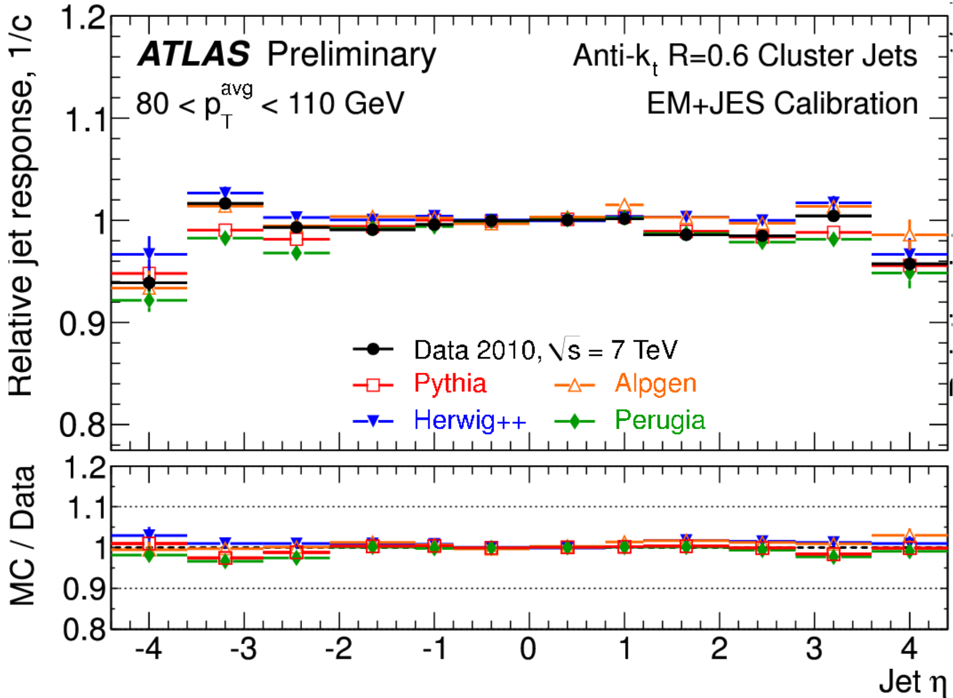
$\langle A_{ik} \rangle$ Is the mean value of the asymmetry in each bin.

In-situ Pseudorapidity Intercalibration of Jet Energy Scale

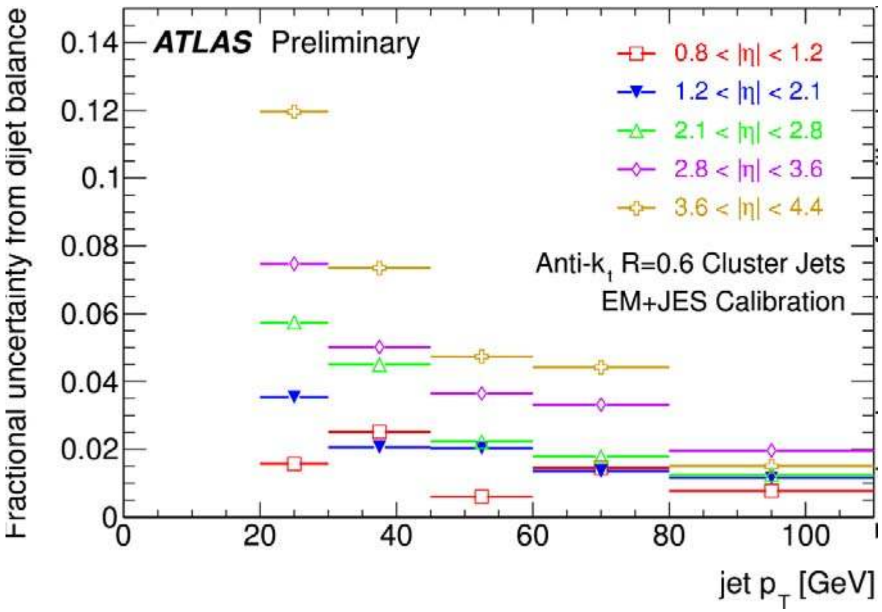


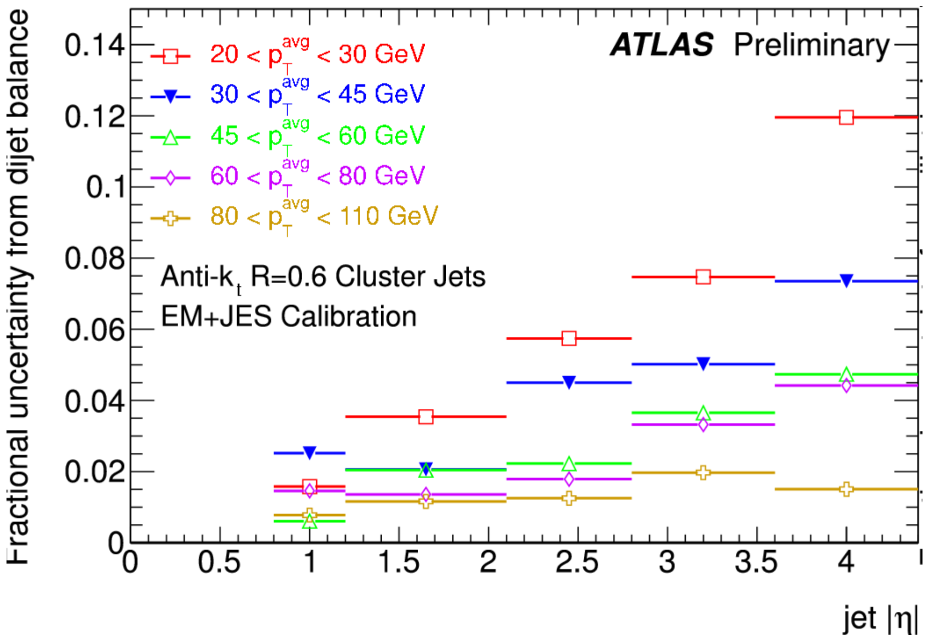
In-situ Pseudorapidity Intercalibration of Jet Energy Scale



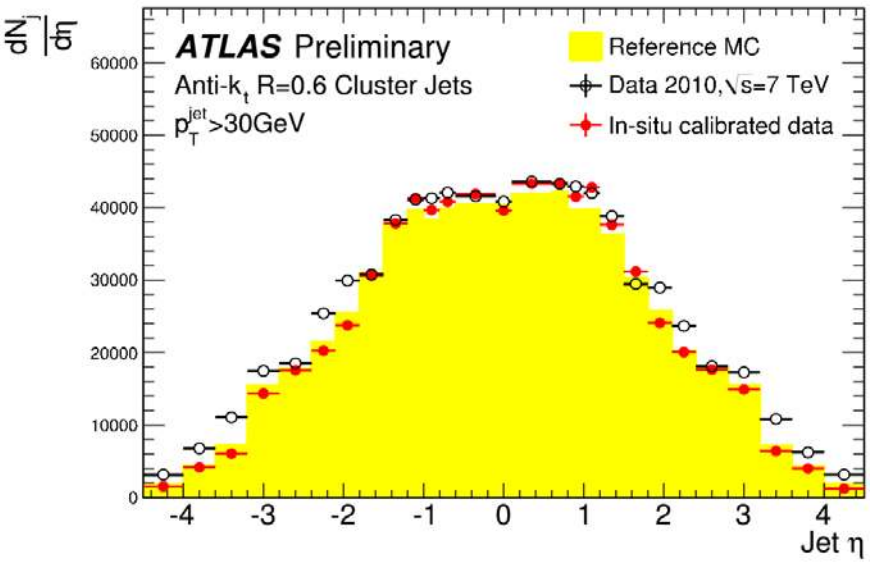


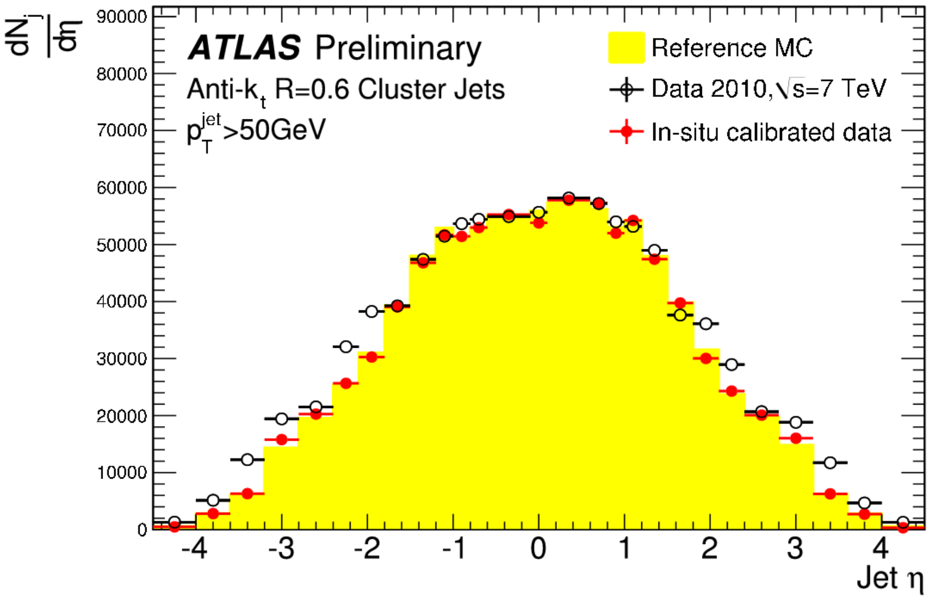
In-situ Pseudorapidity Intercalibration of Jet Energy Scale





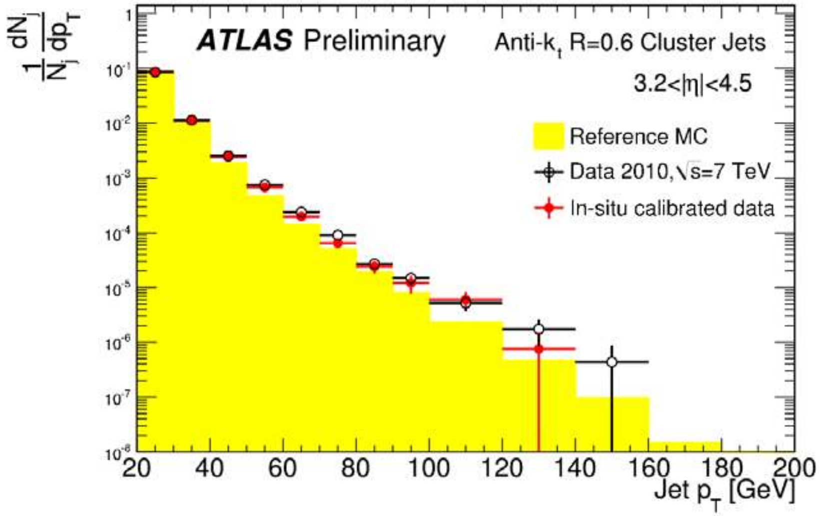
Comparison of Corrected and Uncorrected data

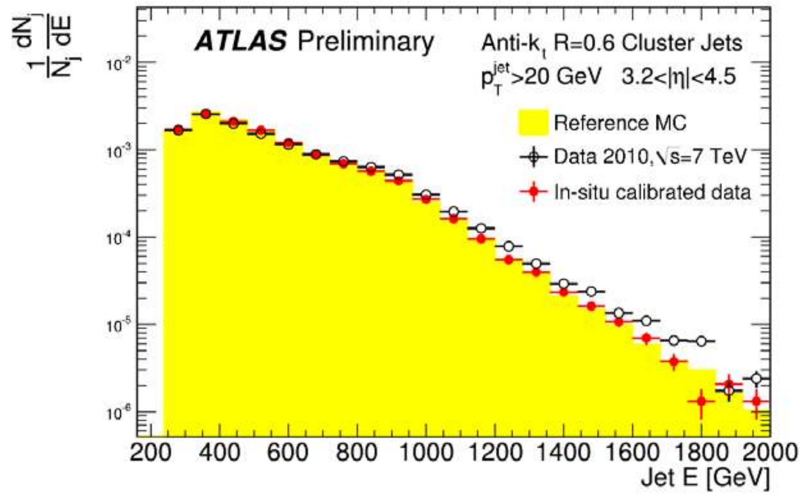


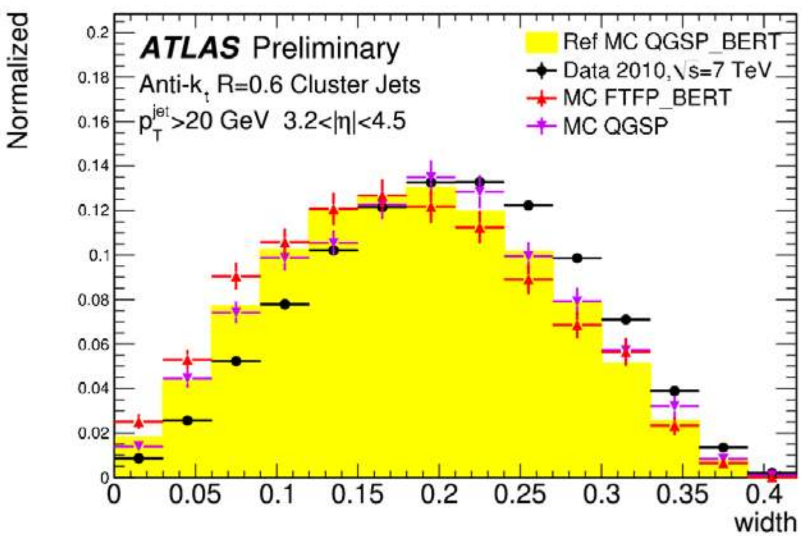


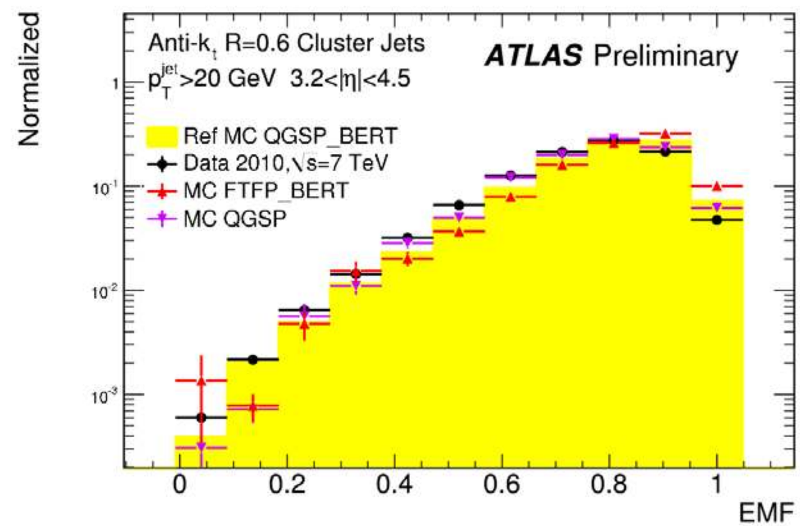
- Before correction forward region has an excess cf. Monte Carlo
- After correction agreement is within 10%

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 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

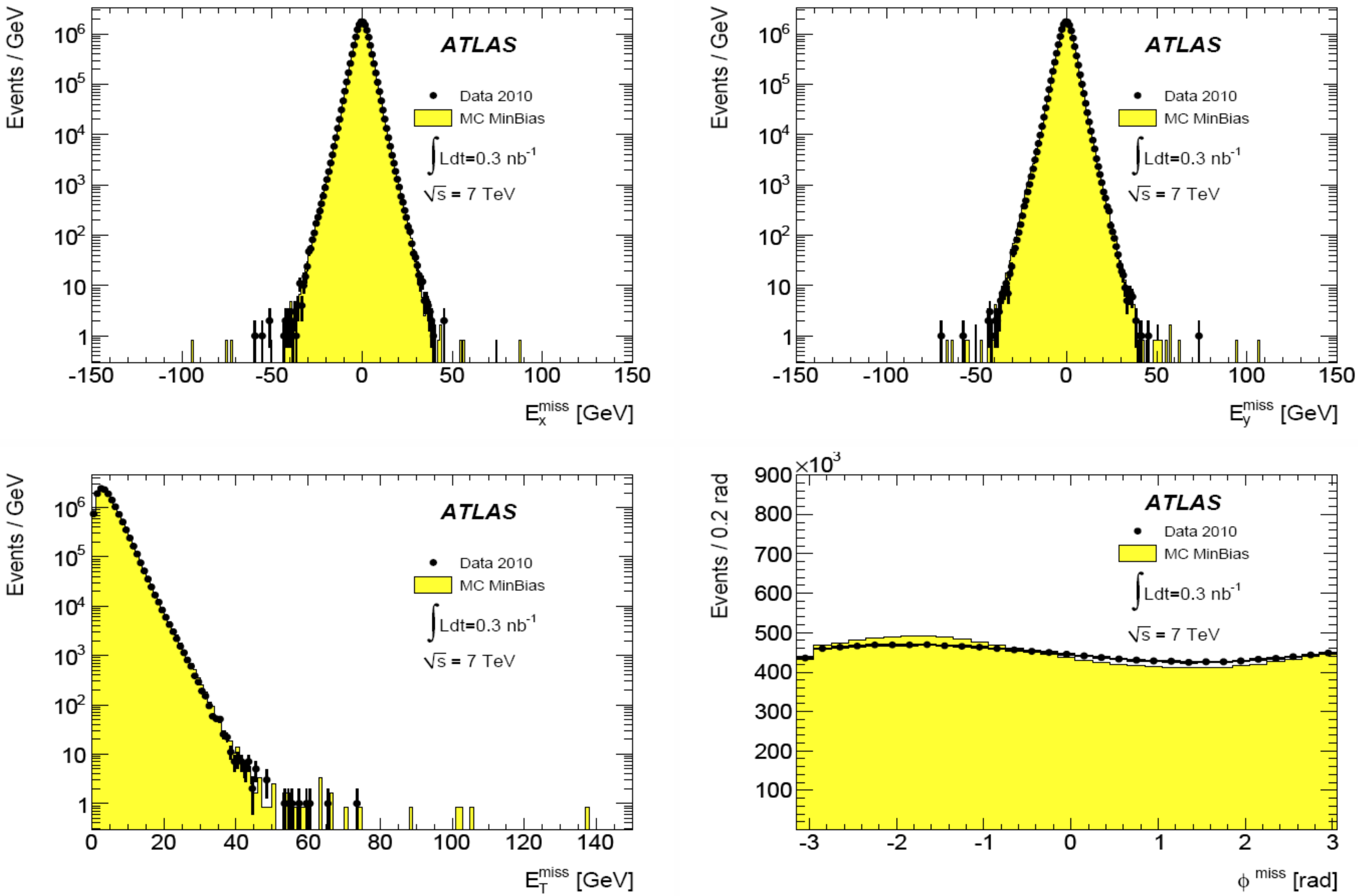
$$E_x^{miss,term} = -\sum_{i=1}^{N_{cell}^{term}} E_i \sin\theta_i \cos\phi_i$$

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

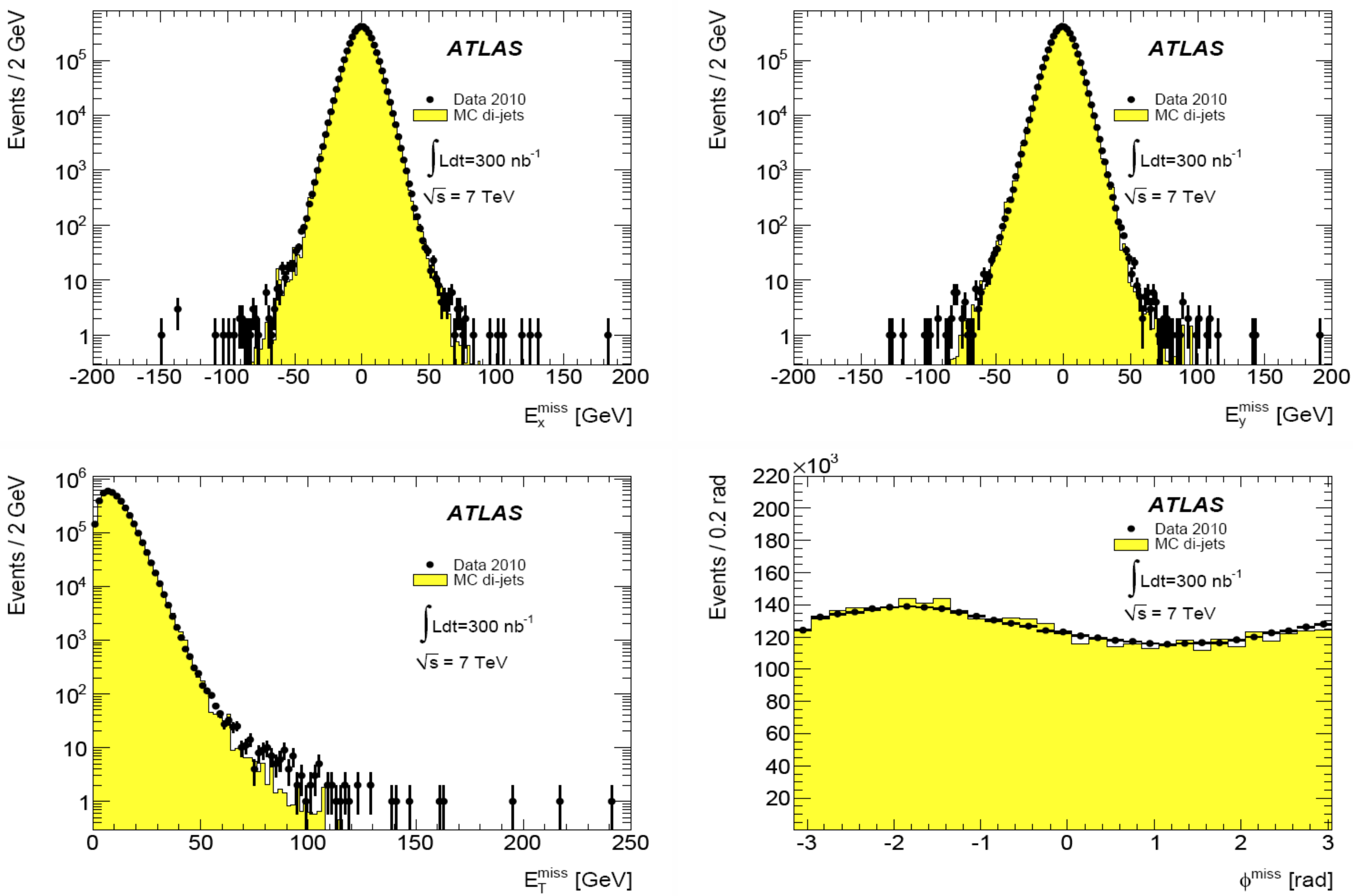
and

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

Minimum Bias

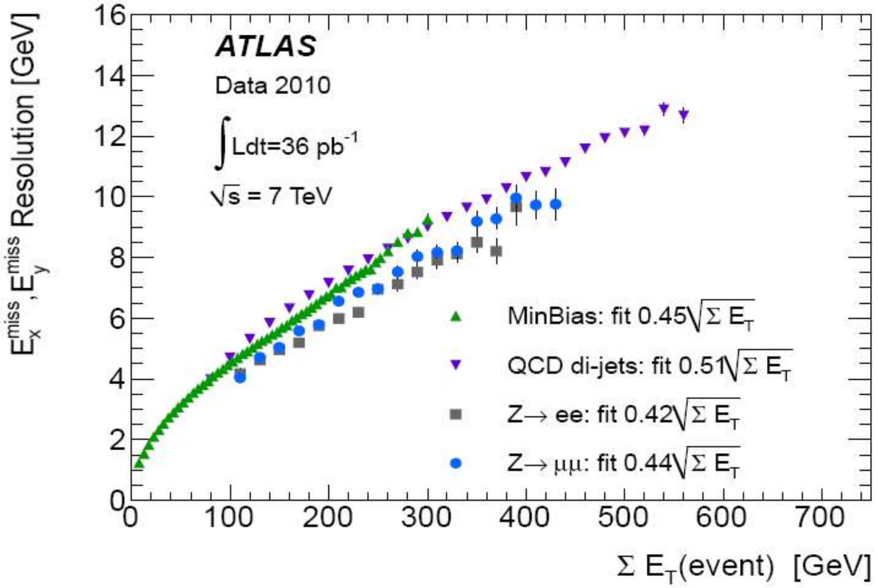


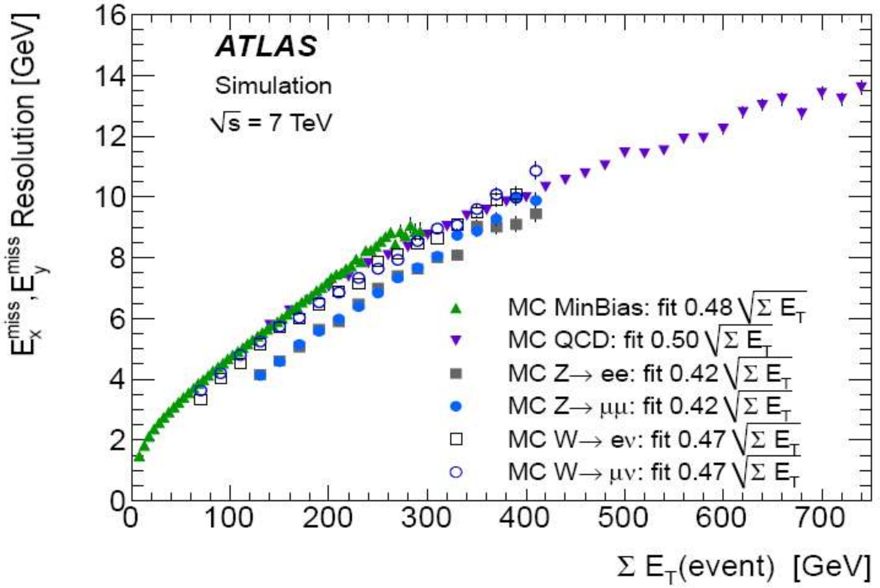
Di-Jets



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
×10^3
φ^miss [rad]

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

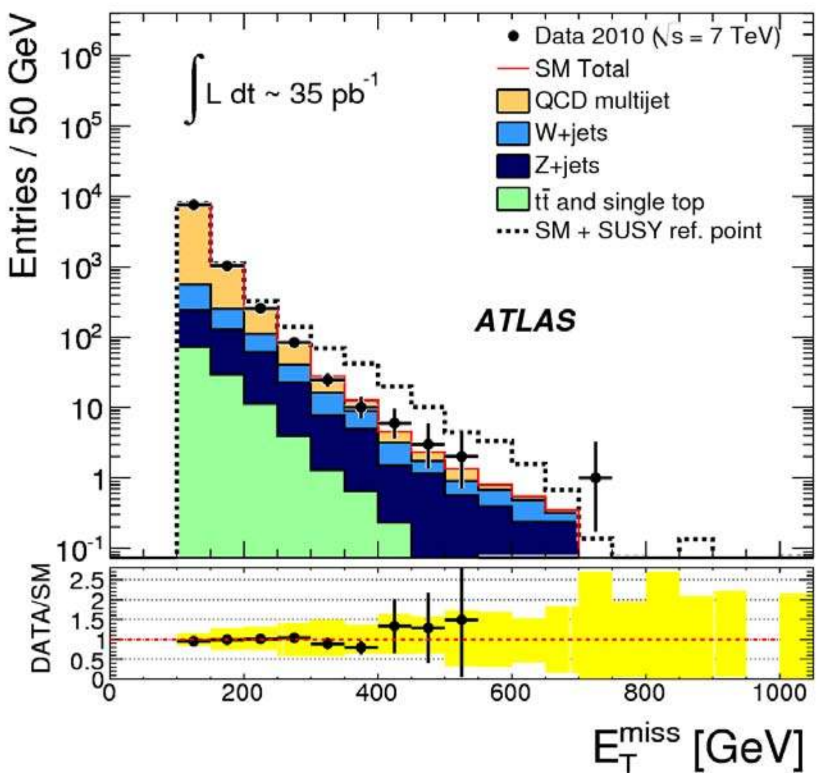


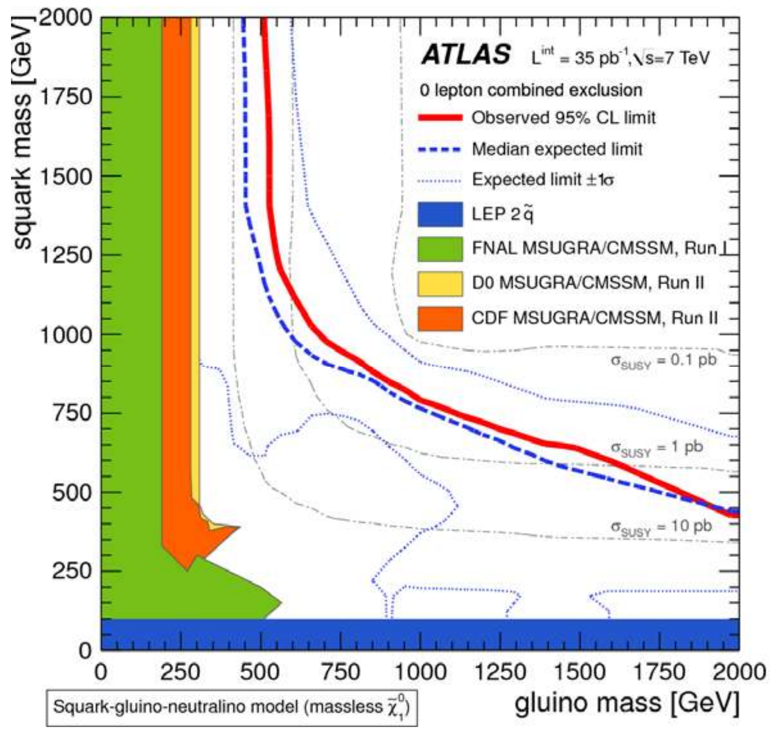


$$\sum E_T = \sum_{i=1}^{N_{cell}} E_i \sin\theta_i$$

These plots also include result of studies using Z decays

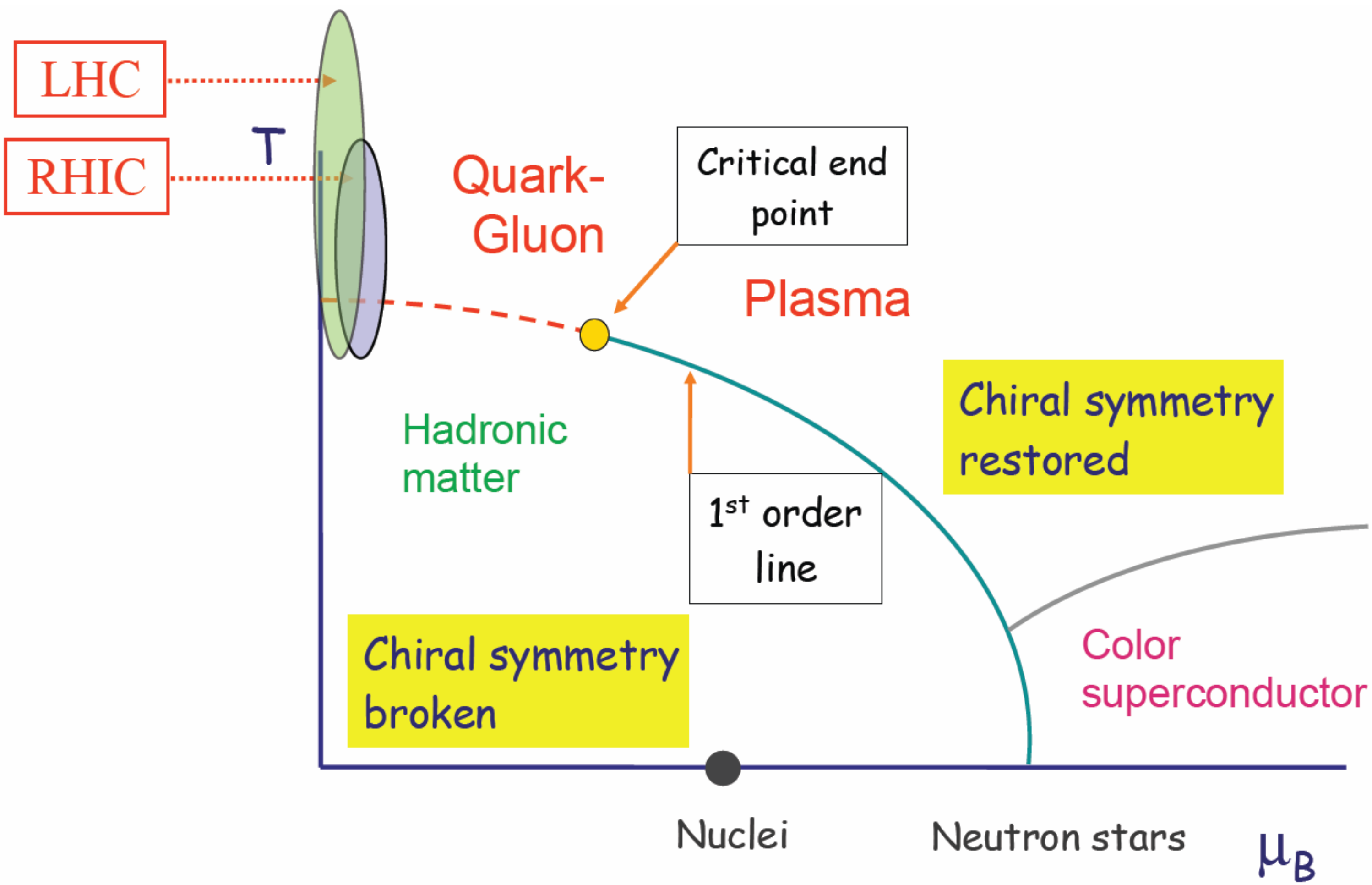
E_T^{miss} in search for squarks and sleptons



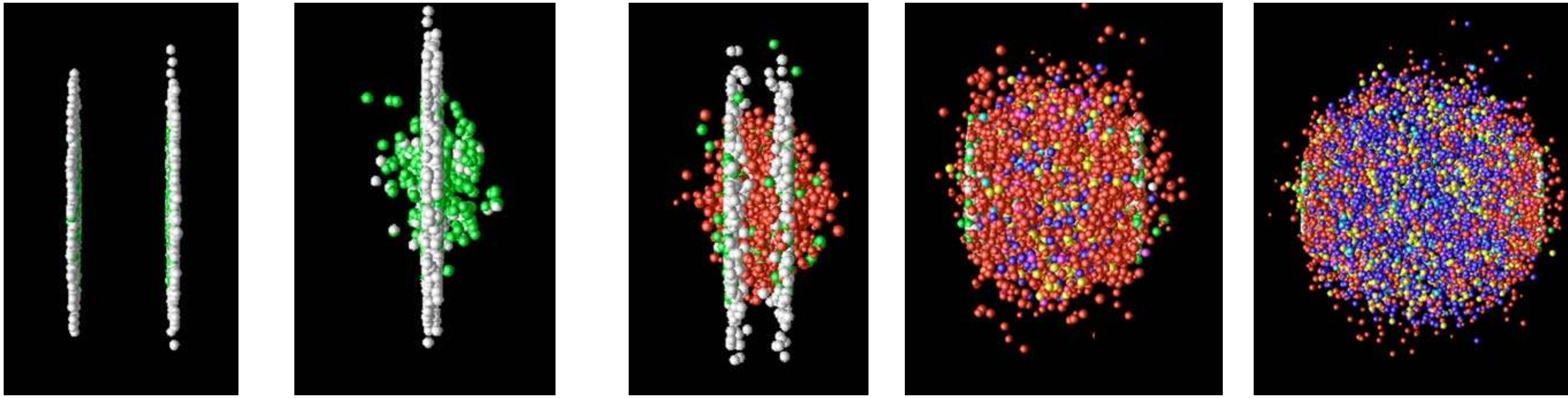


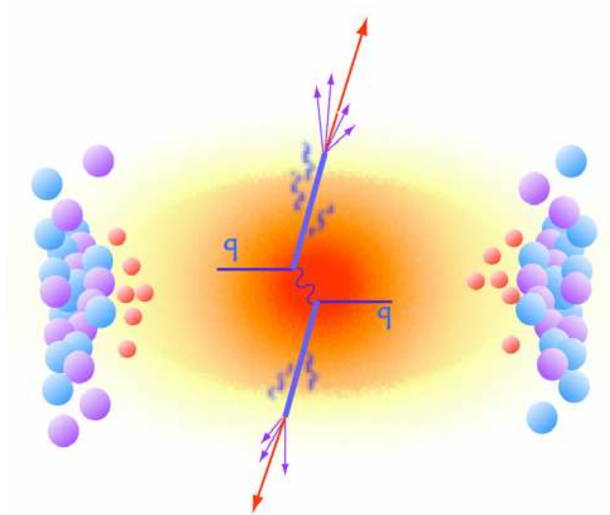
FCal in Heavy Ion Collisions

Exploitation of pseudorapidity coverage out to 4.5

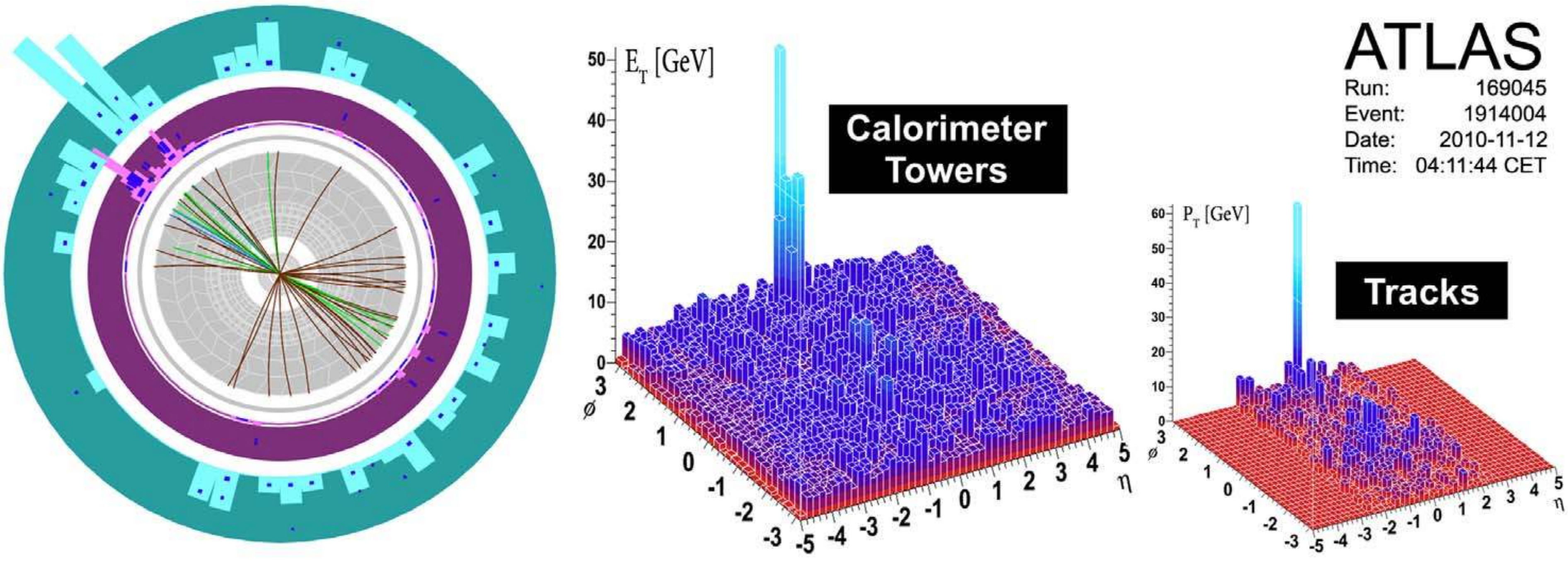


Time Evolution of Pb-Pb Collision at NN CM Energy of 2.76 TeV



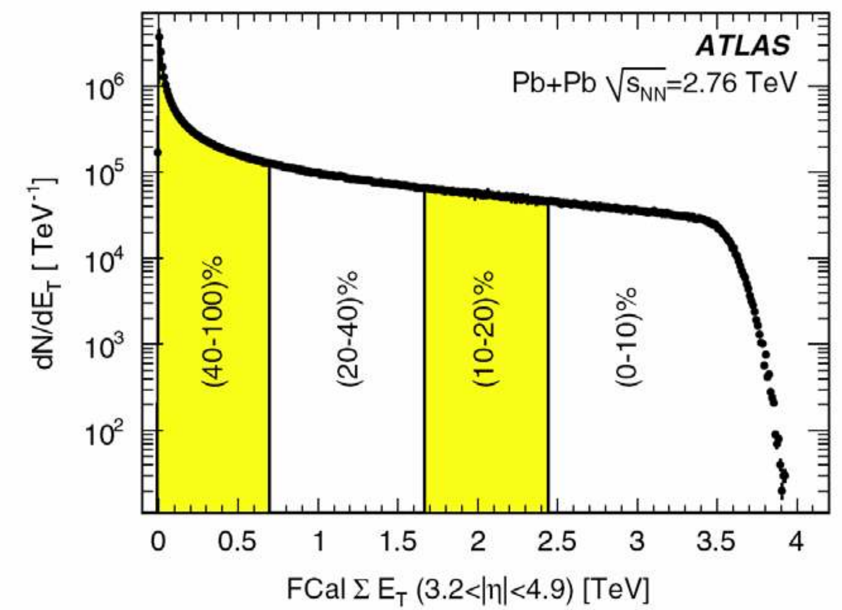


- Peripheral collisions much like *pp* collisions.
- Head-on, central, collisions produce hot, dense plasma.
- Jets from di-jets in this ambient plasma have to propagate through it.
- One jet may lose a lot of energy
- Asymmetric “di-jets” – jet quenching

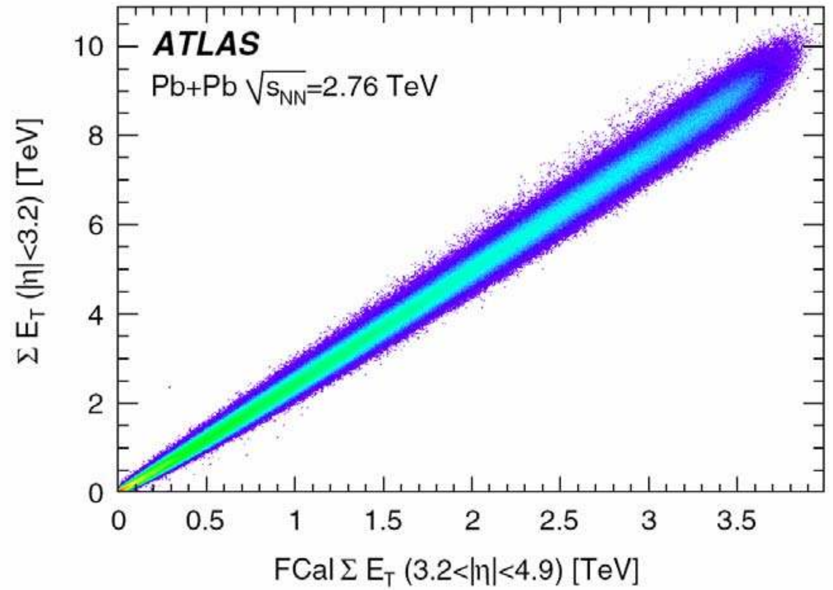


- Very early in Pb-Pb running, ATLAS saw asymmetric events.
- If these are due to jet quenching, expect asymmetry to be correlated overall activity in the event – centrality.
- Asymmetry is.

Characterizing Centrality of Collisions



Bins in fraction of Pb-Pb total cross section



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

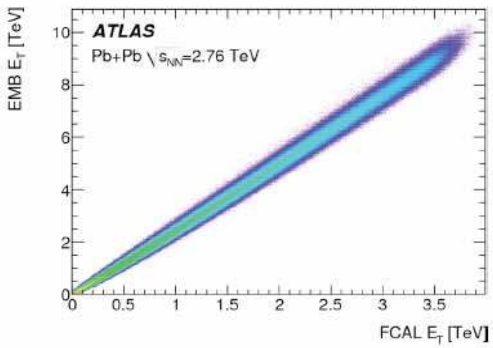
Analysis looks at asymmetry in barrel

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

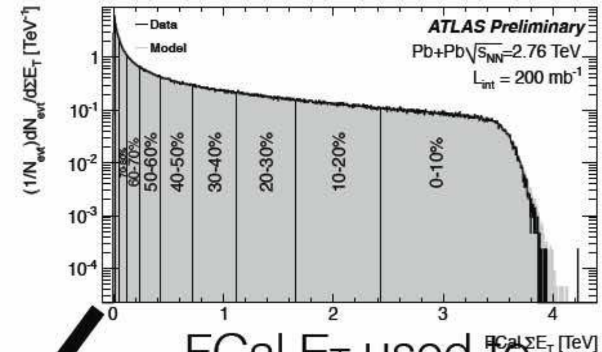
$$E_{T1} > 100\,GeV,\ E_{T2} > 25\,GeV$$ jets

As a function of centrality tagged by

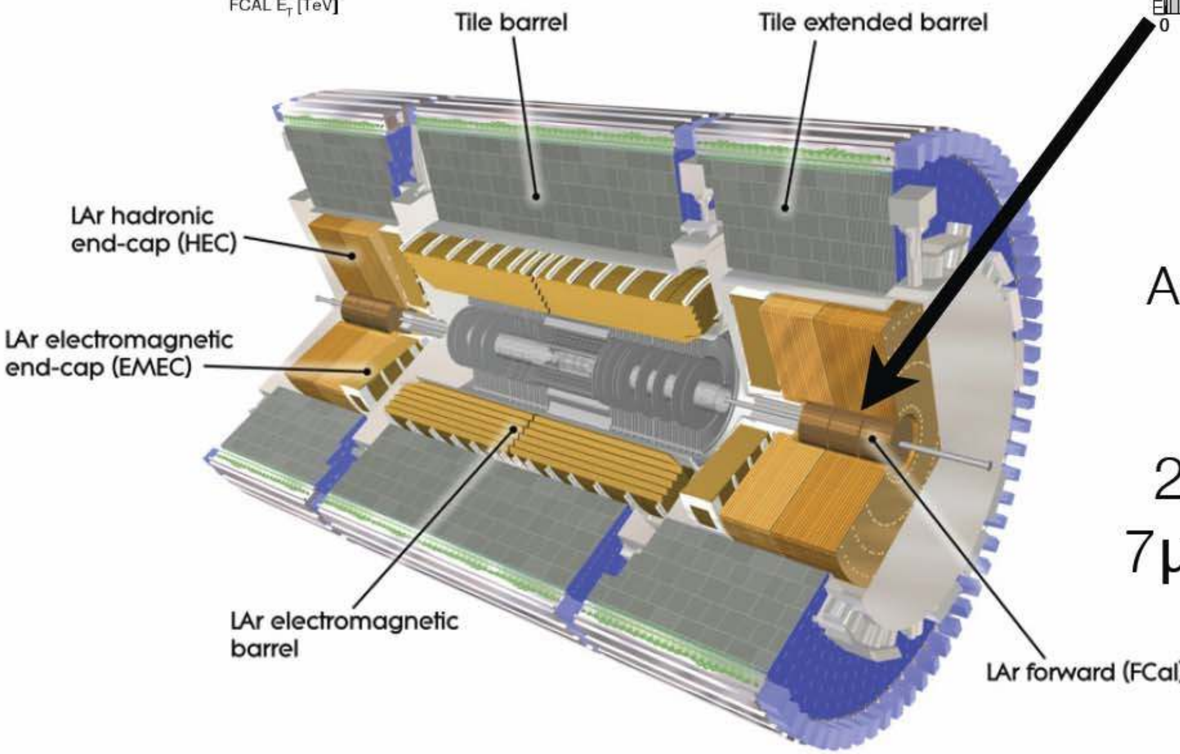
$$FCal \sum E_T$$



E_T in barrel strongly correlated with FCal



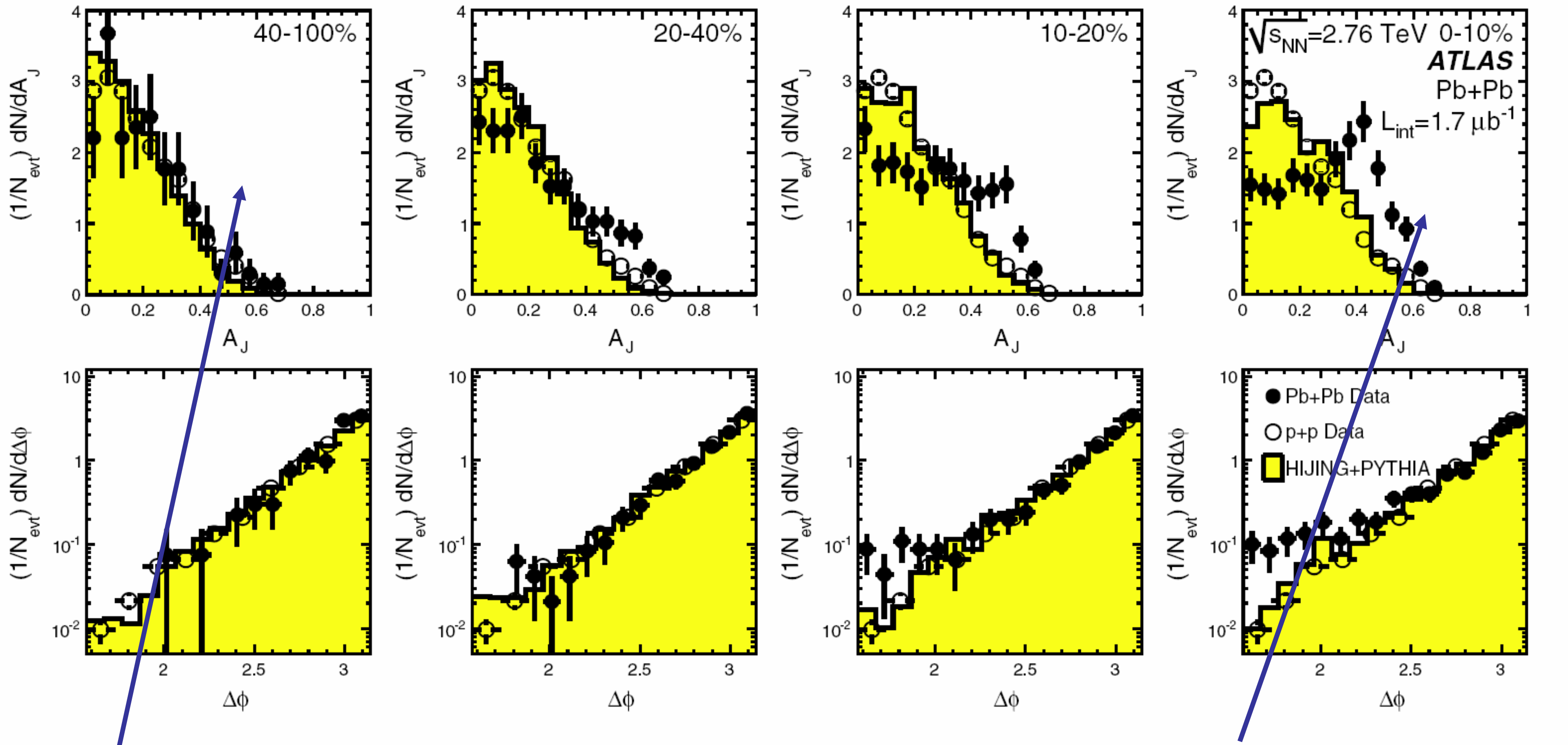
FCal E_T used to determine centrality
$3.2 < |\eta| < 4.9$



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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