Response of Single Isolated Hadrons in the ATLAS Calorimeters with 900 GeV Data

Pier-Olivier DeViveiros
University of Toronto

On behalf of
The ATLAS Collaboration

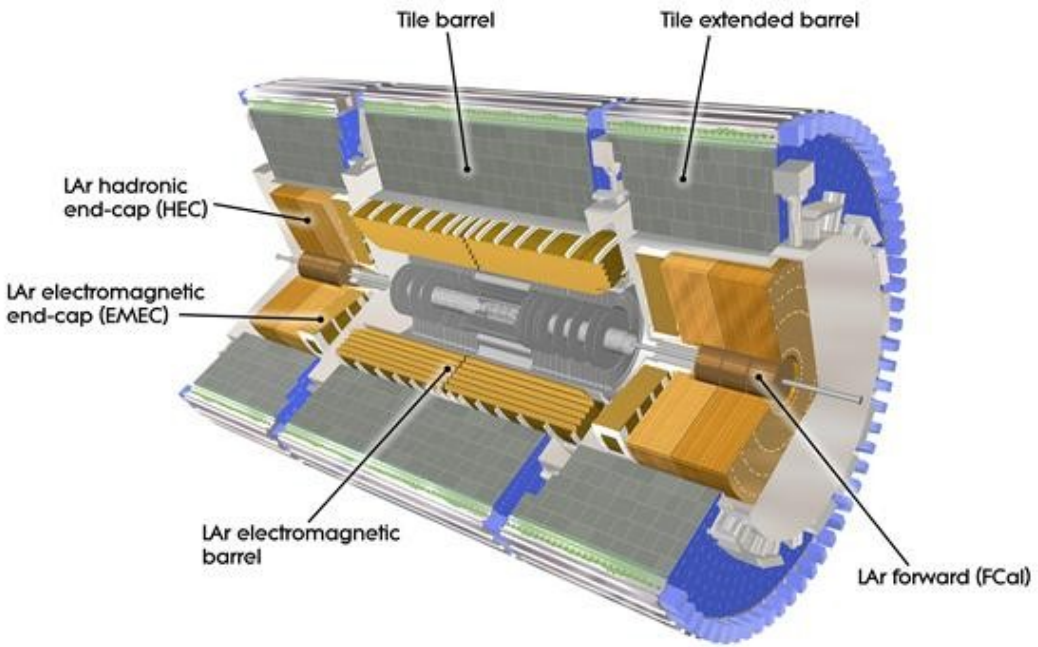
PLHC 2010
Hamburg, Germany

Why measure E/p?

- The uncertainty on the **Jet Energy Scale** is one of the leading sources of uncertainty in many analyses
- ATLAS has excellent tracking resolution/scale
  - We can measure the momentum of charged particles with an accuracy on the absolute scale at the level of < 1% in the range under study
- We can combine **tracking** and **calorimeter** measurements to obtain the calorimeter response of the charged hadrons comprised in jets
  - This allows us to set an uncertainty on our calibration!

The ATLAS Calorimeters

Polar Angle: Θ
Pseudo-Rapidity: $\eta = -\ln \tan(\Theta/2)$
Absolute Coverage $|\eta| < 4.9$



Expected performance in the Barrel & Endcap
For hadrons: $\sigma_E / E = 50\% / \sqrt{E} \oplus 3\%$

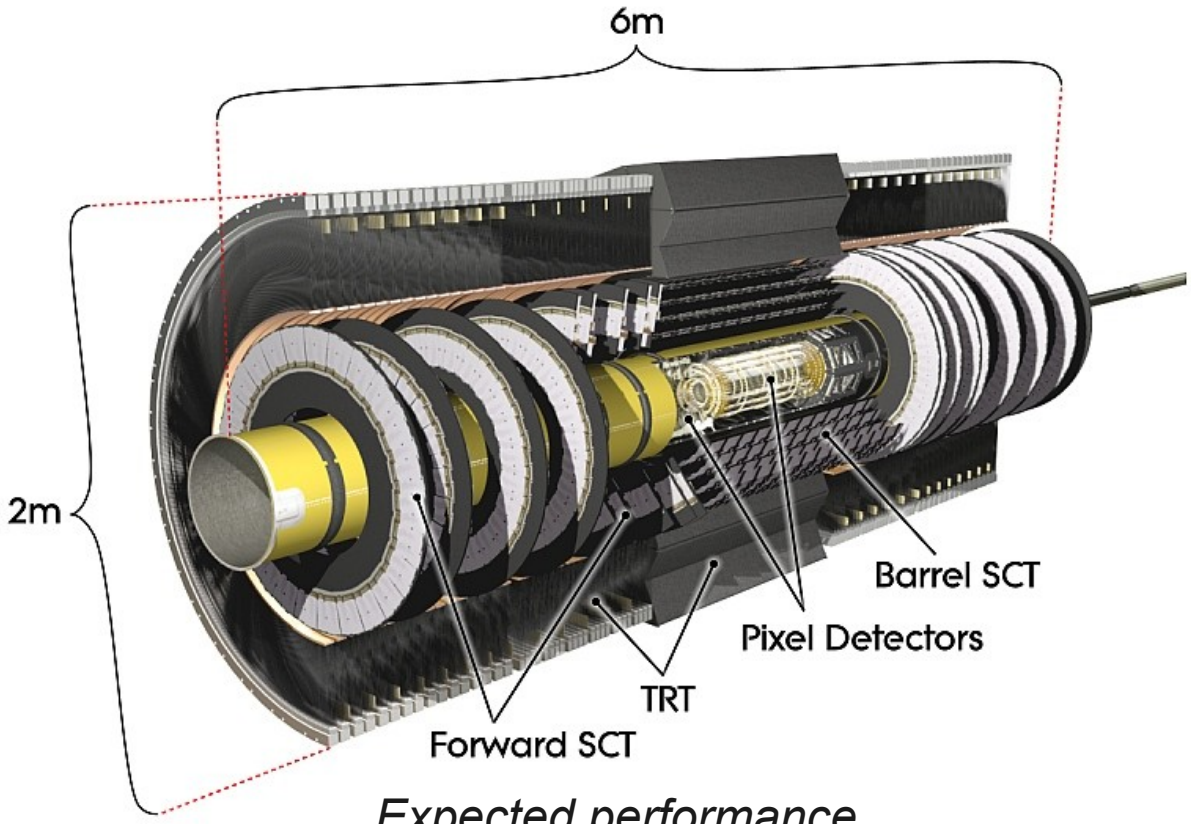
All calorimeters use sampling technology with different materials

Component	Longitudinal Layers	# Channels (Sample) (Granularity)	X_0 Lengths
EM Barrel	3 (+1)	109k (0.025x0.025)	~ 2
EM Endcap	3	64k (0.025x0.025)	~ 2
Tile Barrel	3	10k (0.1x0.1)	~ 9
Hadronic Endcap	4	5k (0.1x0.1)	~ 10

Reminder: ATLAS Calorimeters are non-compensating!

Tracking in ATLAS

Coverage up to |η| < 2.5



Expected performance

$\sigma_{pT} / p_T = 0.05\% \, p_T \oplus 1\%$

Central Layers
Endcap Layers

Pixel:
3 Pixel Layers
2 x 3 Pixel Disks

SCT:
(Silicon Microstrips)
4 Silicon Strip Layers
2 x 9 Disks (SCT)

TRT:
(Transition Radiation Tracker)
73 Straw Planes
160 Straw Planes

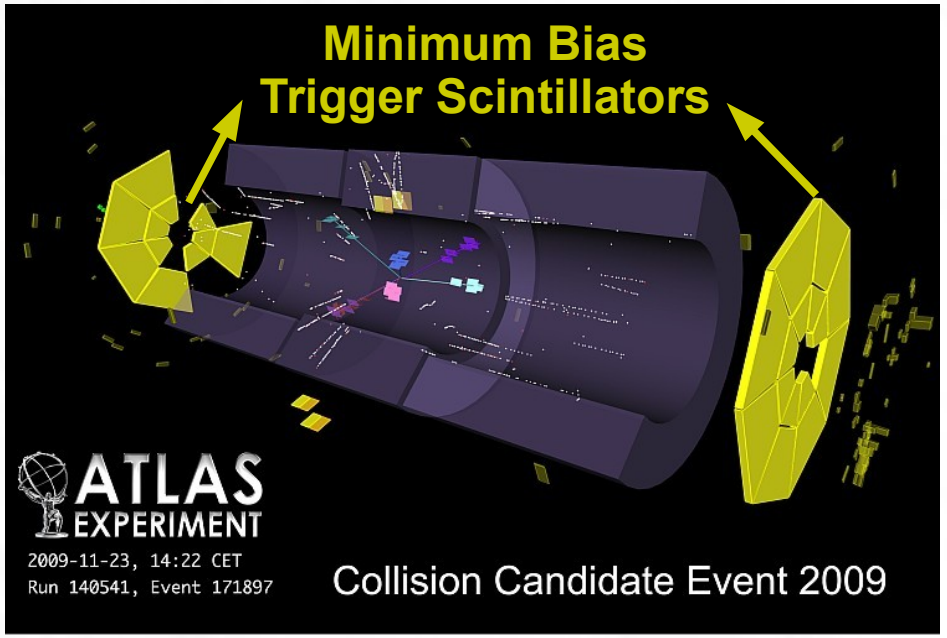
*Solenoidal Magnetic Field of **2 T***

Event Sample

- Events collected during the December 2009 LHC commissioning run at **900 GeV**
  - Approximately 360,000 events used after selection

• Events required to have at least 1 hit from either side of the Minimum Bias Trigger Scintillators

• A vertex with at least 2 associated tracks is required



How do we measure E?

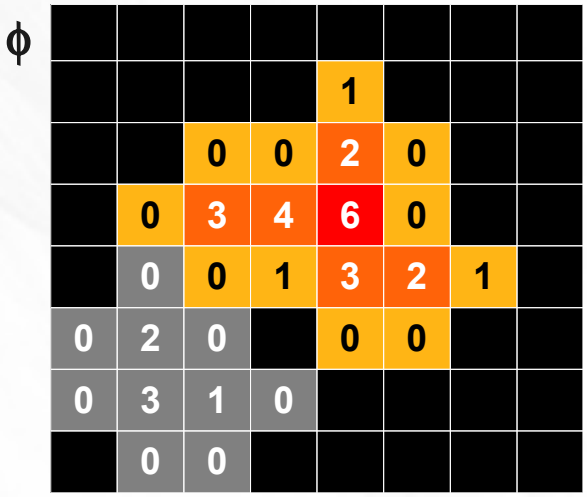
- Topological Clustering
  - We group calorimeter energy deposits into 3D clusters, following a noise suppression scheme
  - This allows us to make full use of the granularity of the ATLAS detector

Noise Suppression Procedure:

Look for a cluster **seed**
with a signal significance $|E| > 4\ \sigma_{Noise}$

Include all **neighboring** cells
with a signal significance $|E| > 2\ \sigma_{Noise}$

Include all **nearest neighbors**
with a signal significance $|E| > 0\ \sigma_{Noise}$



Not a cluster!

Track Selection

- We require *good isolated* tracks of p_T > 500 MeV

- **Good:** More than 1 hit in the Pixel detector and more than 6 hits in the Silicon strips, matched to the primary vertex

- **Isolated:** To reduce backgrounds, we require no nearby track-like objects within a ΔR of 0.4

- ΔR is defined as:

$$(\Delta R)^2 = (\eta_1-\eta_2)^2 + (\phi_1-\phi_2)^2$$

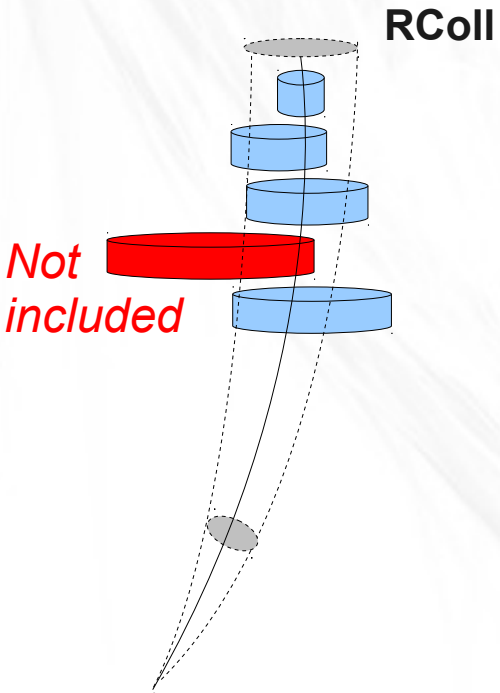
What range of track momenta is useful for studying the Jet Energy Scale?

- From Monte Carlo studies of Jet fragmentation, fraction of energy comprised in particles for a *100 GeV* jet:
  ~1% for 0 < p < 0.35 GeV
  ~5% for 0.35 < p < 1 GeV
  ~10% for 1 < p < 3 GeV
  ~10% for 3 < p < 5 GeV
  ~20% for 5 < p < 10 GeV

- We only have enough statistics to reach up to **p** of *10 GeV* (accounts for ~ 45% of a jet's energy!)
- We need another form of input (testbeam!)

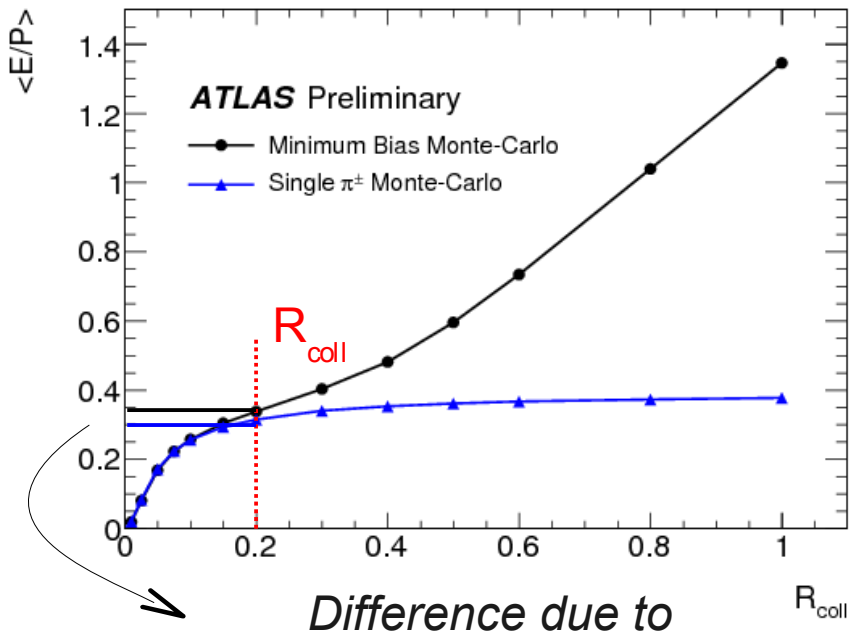
Energy to Track Association

- To reduce backgrounds, only include calorimeter energy from layers where the cluster centroid is within R_{coll} of the extrapolated track



Choose:
$R_{coll} < 0.2$

Corresponds to a shower containment of 90% and a small background contamination

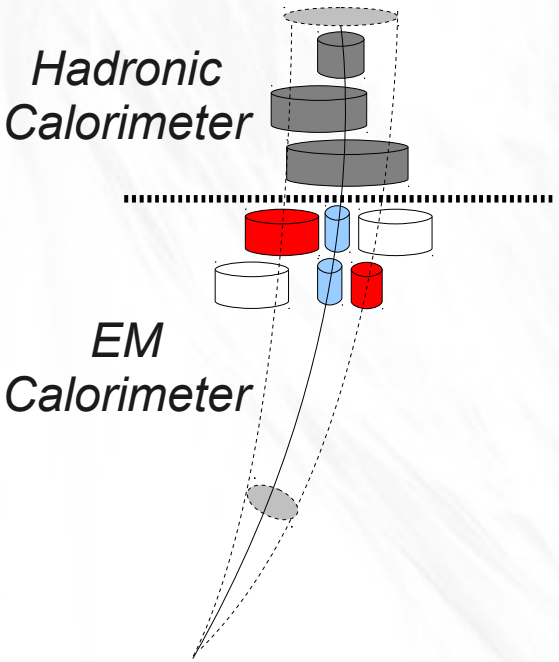


Difference due to background contamination

Background Contamination

- Background contamination (extra Energy associated to a track) comes from:
  - Neutral particles: No tracks!
  - Charged particles: Unlikely since we cut on anything with a track-like signature!
- We can estimate the contamination from Monte Carlo, or using a Data-Driven method
  - Both methods show good agreement and are used as a cross-check

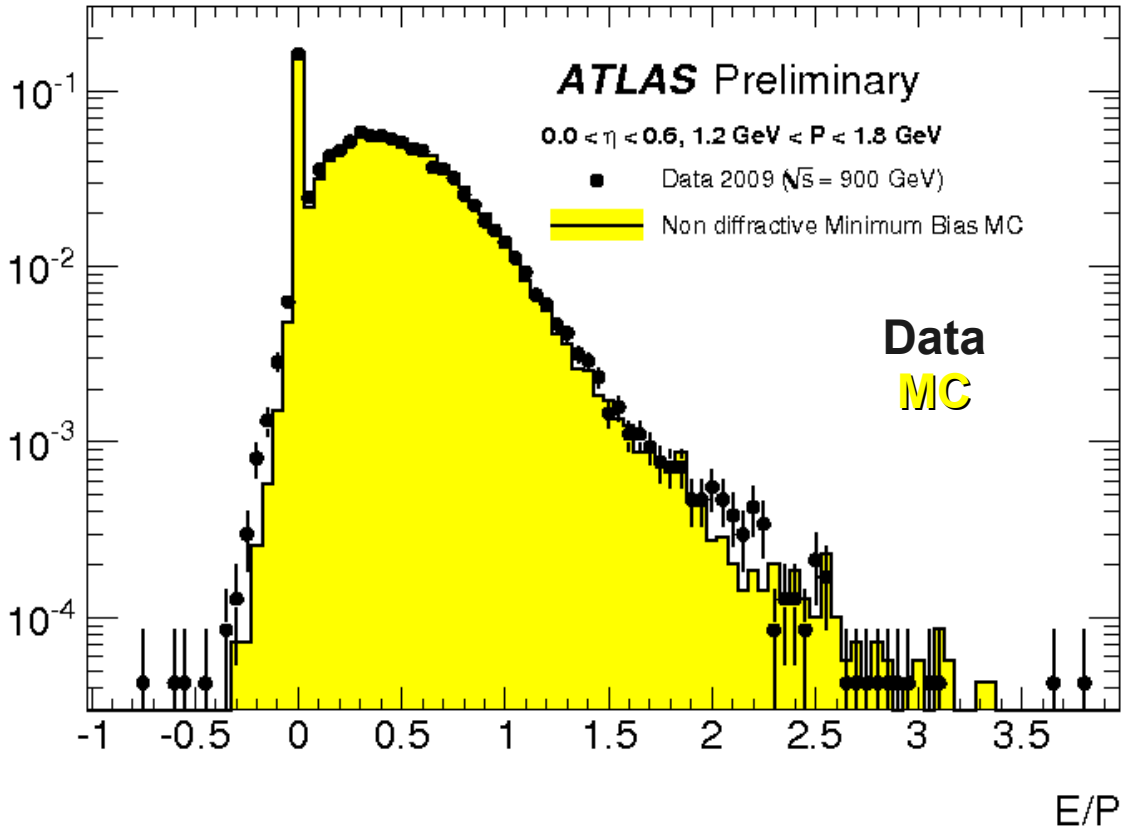
Data-Driven Technique



- Look for **late showering hadrons** (most of the energy deposited in the hadronic calorimeter)
- Require that the deposits in the EM calorimeter be compatible with those of a **minimum ionizing particle**
- Sum up the energy in the EM Calorimeter around the track which **does not come** from the minimum ionizing signature, using the original selection criteria
- This is a slight underestimate, as contributions in the hadronic calorimeter are not used
- However, good agreement is found with Monte Carlo:

$$Contamination_{\langle E/p \rangle} = (2.5 \pm 1.5)\%$$

Measurement of the E/p Distribution

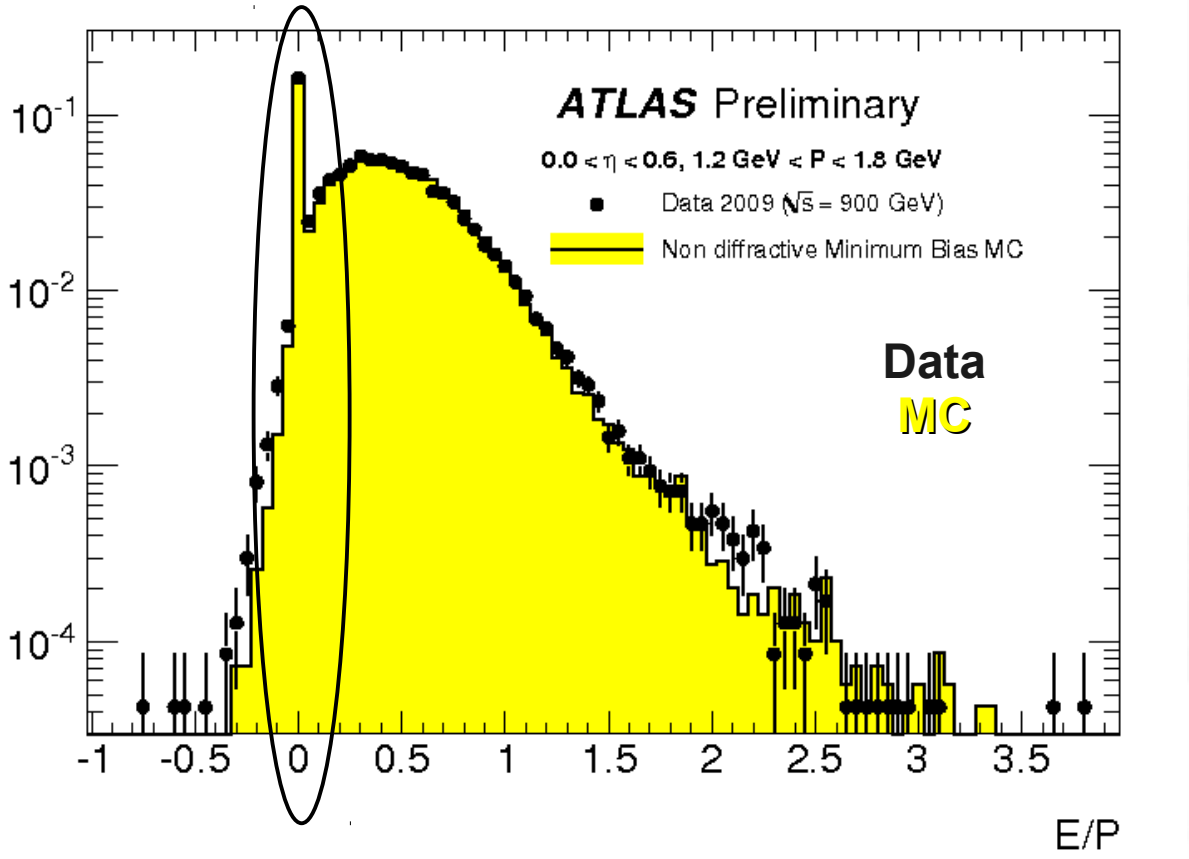


Region under study:
$0.0 < \eta < 0.6$
$1.2\ \text{GeV} < p < 1.6\ \text{GeV}$

Good agreement with Monte Carlo!

ATLAS Monte Carlo for this study:
Pythia Event Generator
Detector response simulation using full detector description in GEANT 4

Measurement of the E/p Distribution



E/p measurement of 0 means **no calorimeter energy** assigned to a good isolated track...

Due to:

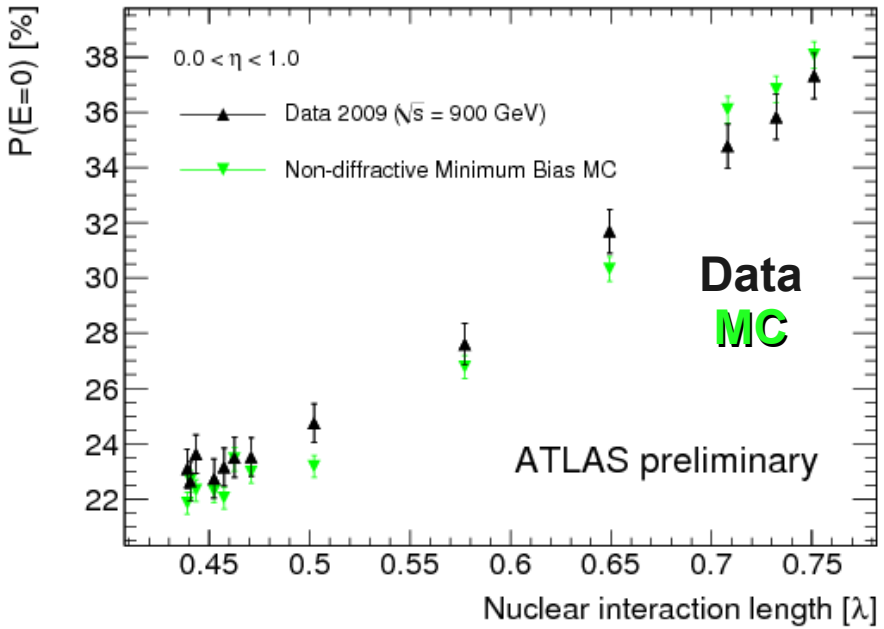
Noise suppression: No cell seed found for clusters

Particle interacted hadronically before the calorimeter ('Dead' Material)

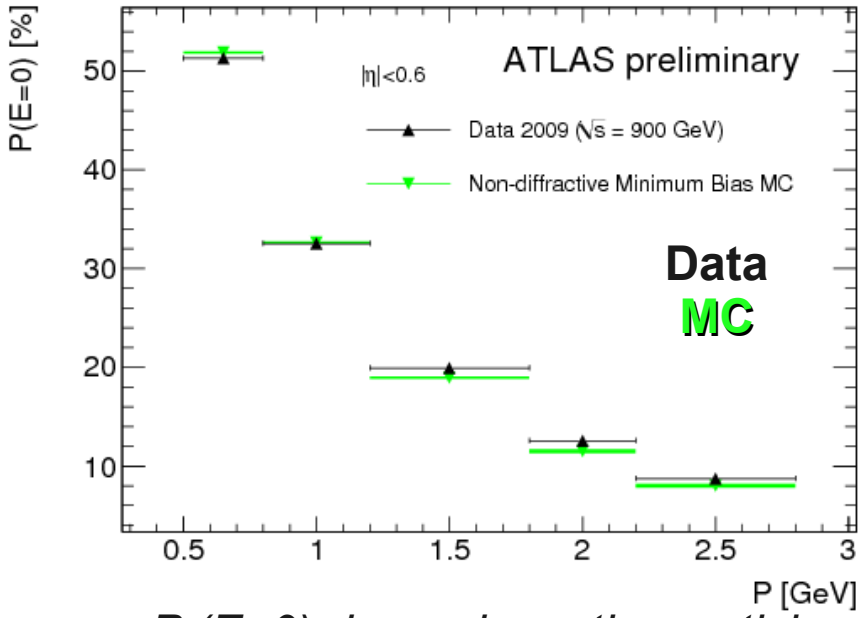
Tracks with no Associated Energy

- Study cases when the calorimeter energy deposition associated to a track is zero
  - Provides an experimental handle on the amount of **dead material** in front of the calorimeter
- Probability of 'Zero energy' measurements is defined as the probability that a measurement is compatible with noise:
  - $\mathbf{P (E = 0) = N (E/p < \sigma) / N_{tot}}$
  - σ is approximated by looking at the width in the negative energy tail

Probability that no Energy is Associated to an Isolated Track



P (E=0) depends on the amount of material in front of the calorimeter

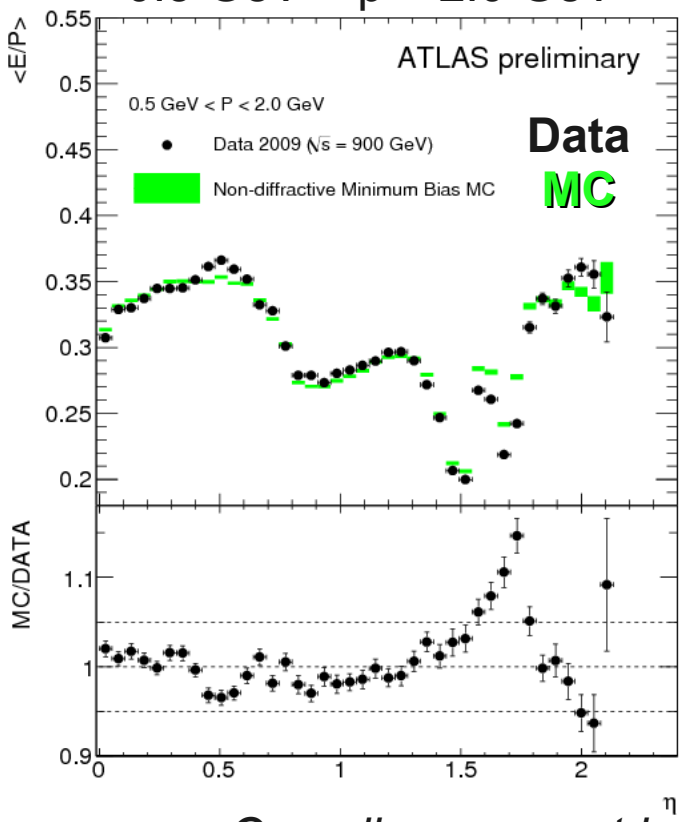


P (E=0) depends on the particle momentum (larger cross-section for hadronic interactions at low momentum)

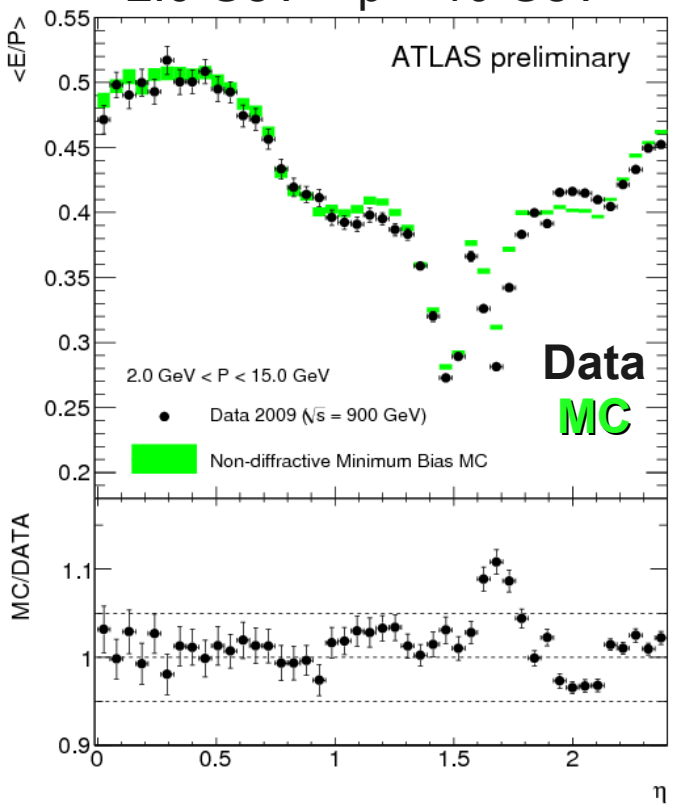
Good agreement with Monte Carlo simulations!

Mean E/p: η-dependence

0.5 GeV < p < 2.0 GeV



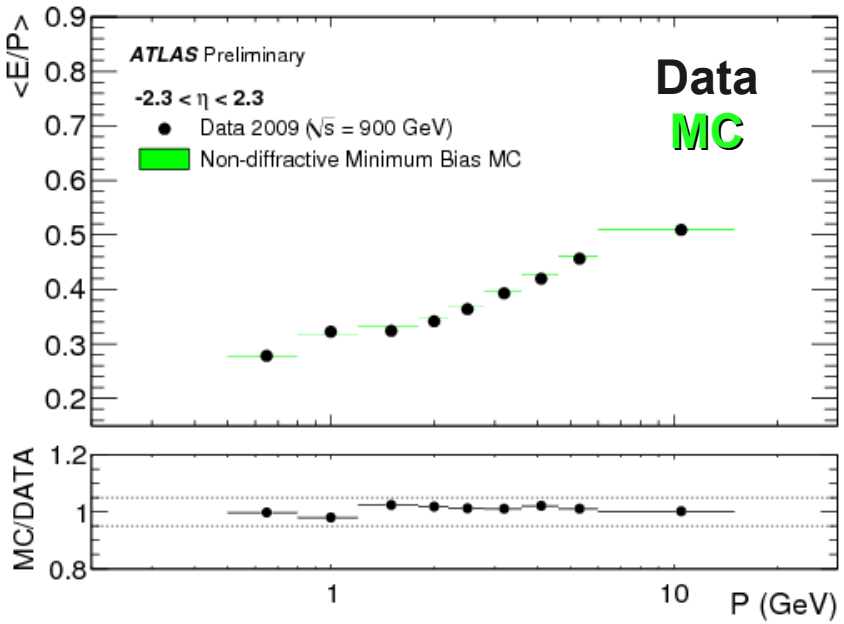
2.0 GeV < p < 10 GeV



Overall agreement between Data and MC within 3%
Around η ~ 1.7, agreement at the 10% level

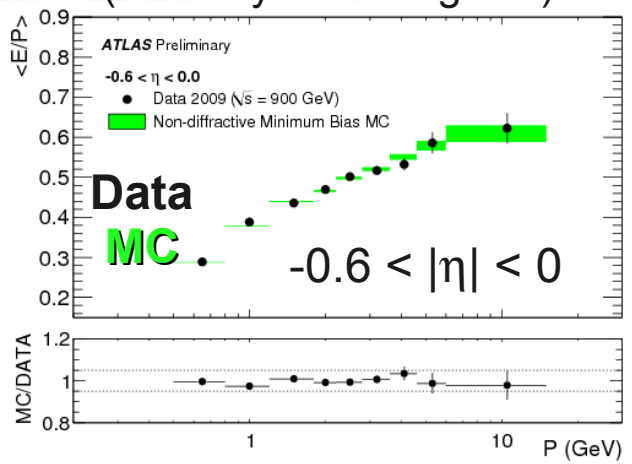
Mean E/p: Momentum dependence

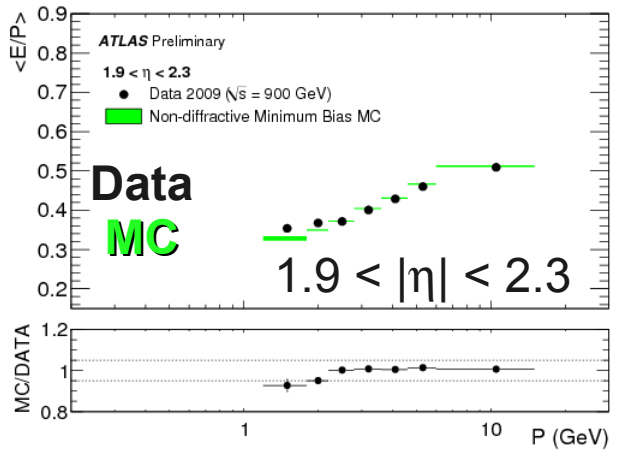
|η| < 2.3
(Full pseudo-rapidity range of the study)



Overall Agreement at the 5% level

(arbitrary set of regions)





Outlook

- E/p has been measured for **$|\eta| < 2.3$** and **$500\ \text{MeV} < p < 10\ \text{GeV}$**
- The calorimeter response to isolated hadrons shows agreement between Data and MC at the 5% level for most of the calorimeter
- This measurement is an important input to the estimation of the jet calibration uncertainty!
- Dead material and cluster threshold effects are well understood and in general well modeled by the simulation!
- *This measurement is being repeated with 7 TeV data and new results will be shown soon!!*

Thanks for your time!

Back-up

Tracking Variables

Good agreement between Data & Monte Carlo for the Track Selection Variables