Measurement of the Calorimeter Response to Single Hadrons with ATLAS at 13 TeV

Joakim Olsson

Supervisor: David W. Miller

The University of Chicago

US -LUA @ Fermilab

November 3, 2017

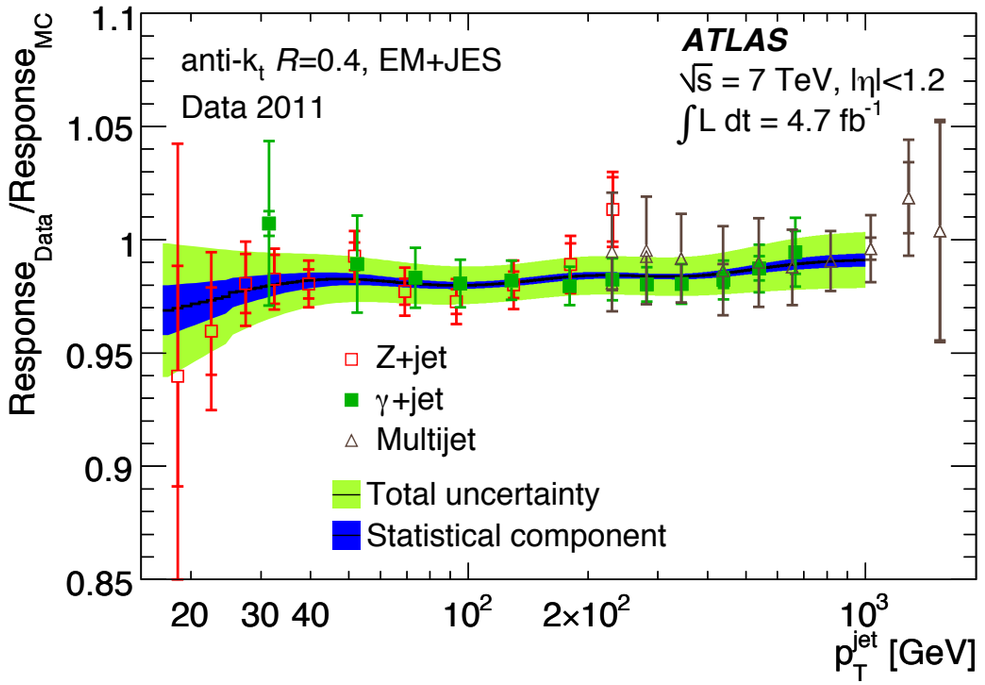
ATLAS EXPERIMENT

THE UNIVERSITY OF CHICAGO

Calorimeter Response to Isolated Charged Hadrons

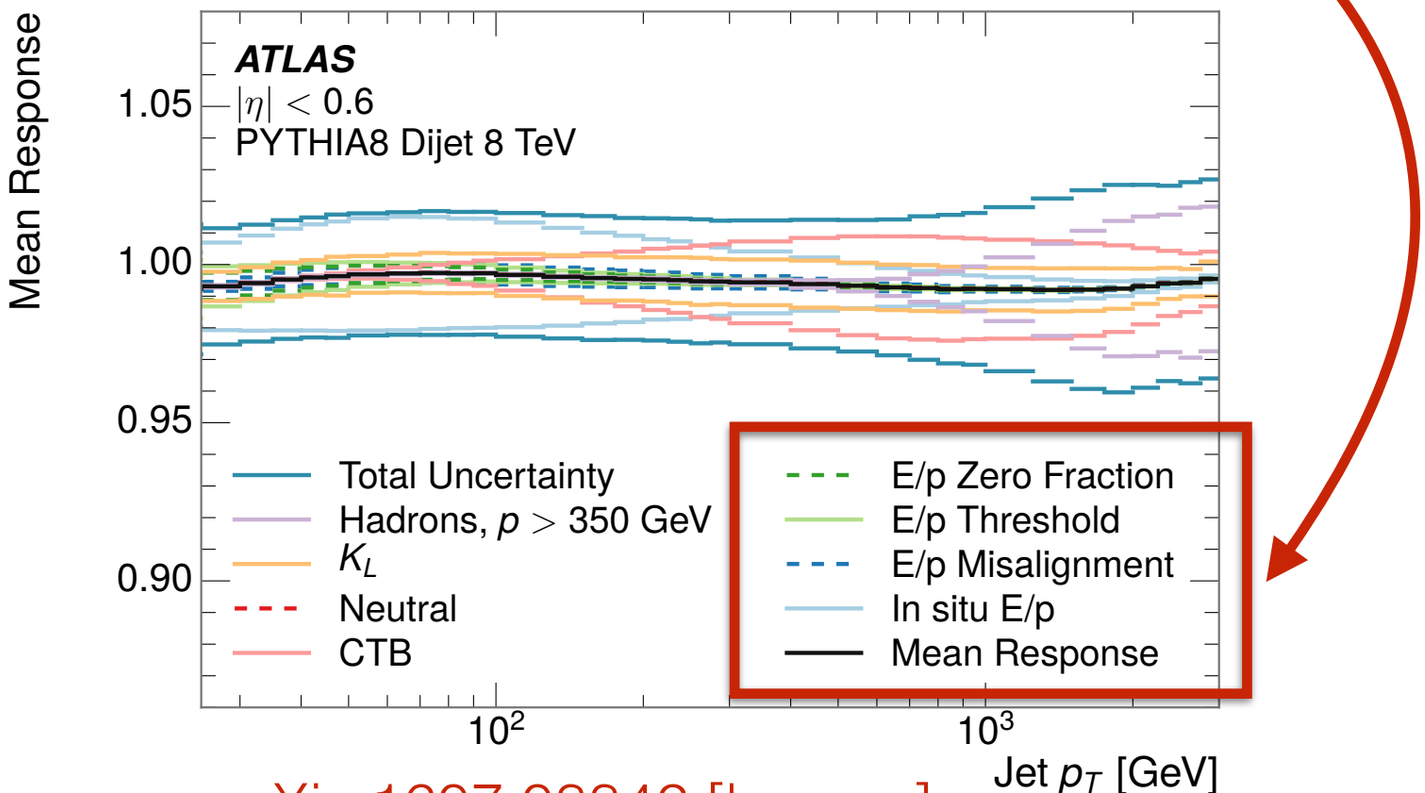
- Important for validation of hadronic shower modeling (e.g. GEANT4 comparisons) and detector geometry
- Important input to jet energy scale uncertainty (JES)

JES from multijet balance



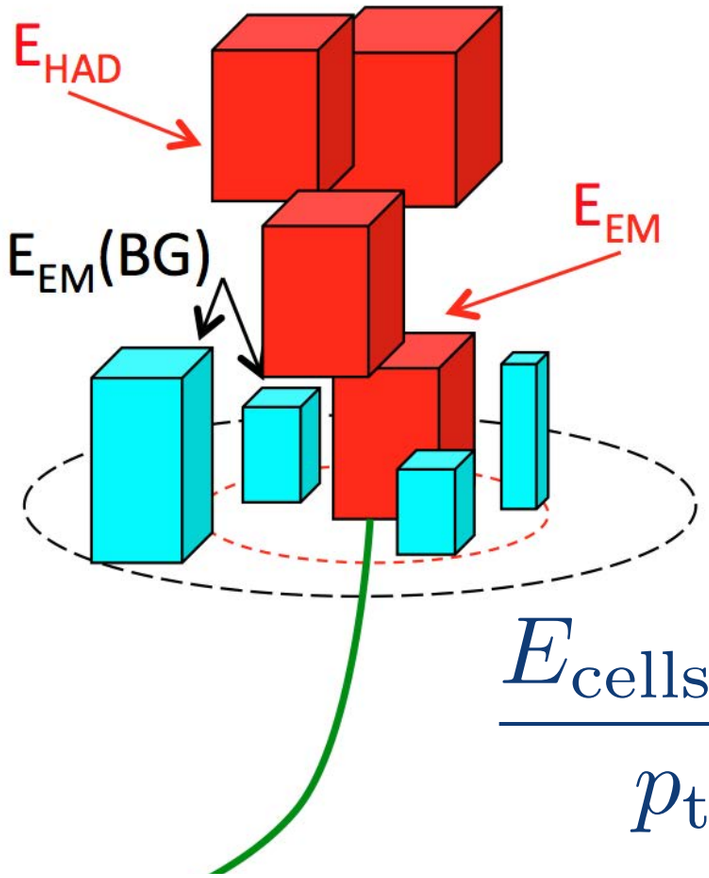
arXiv:1406.0076 [hep-ex]

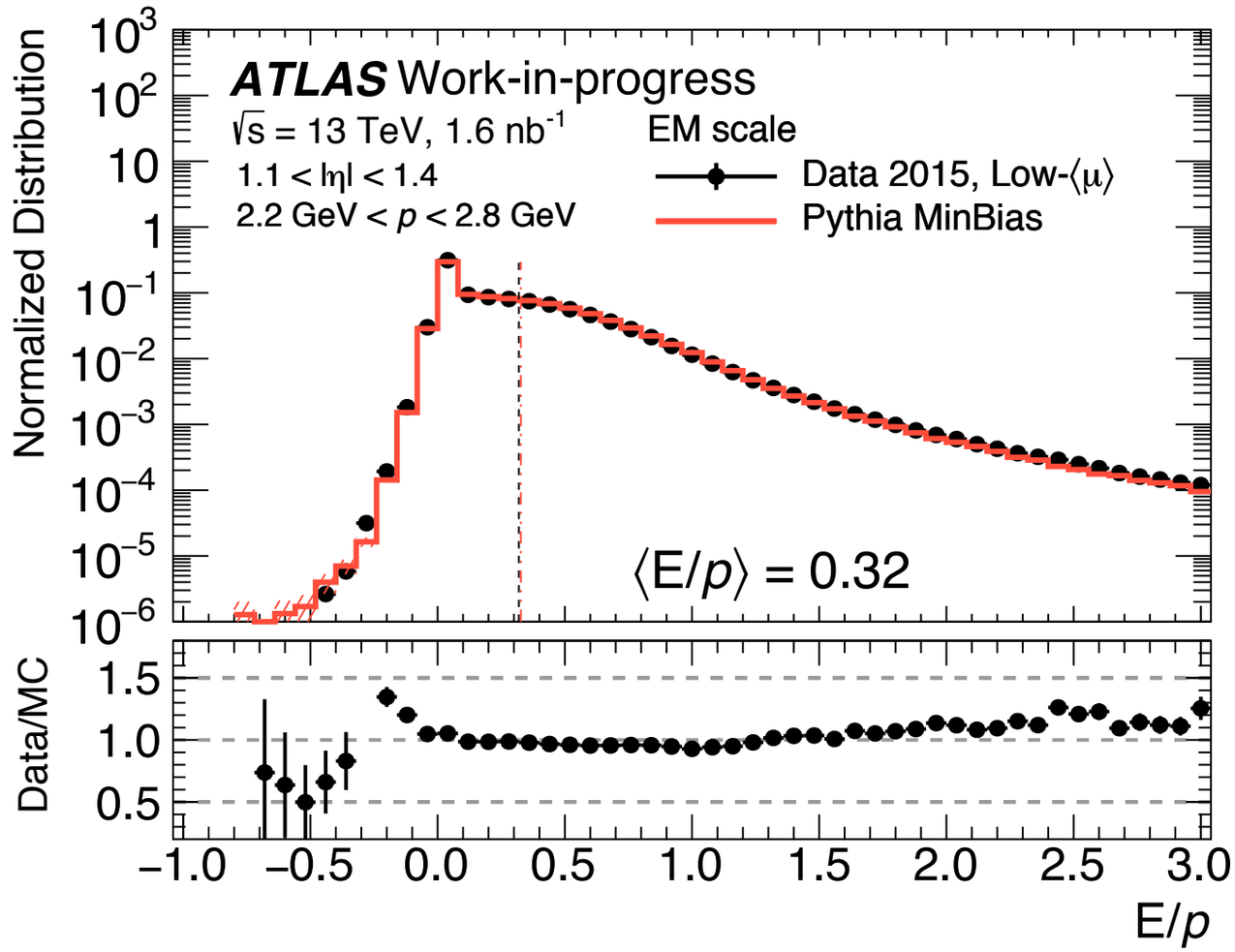
Bottom-up JES



arXiv:1607.08842 [hep-ex]

Calorimeter Response to Isolated Charged Hadrons

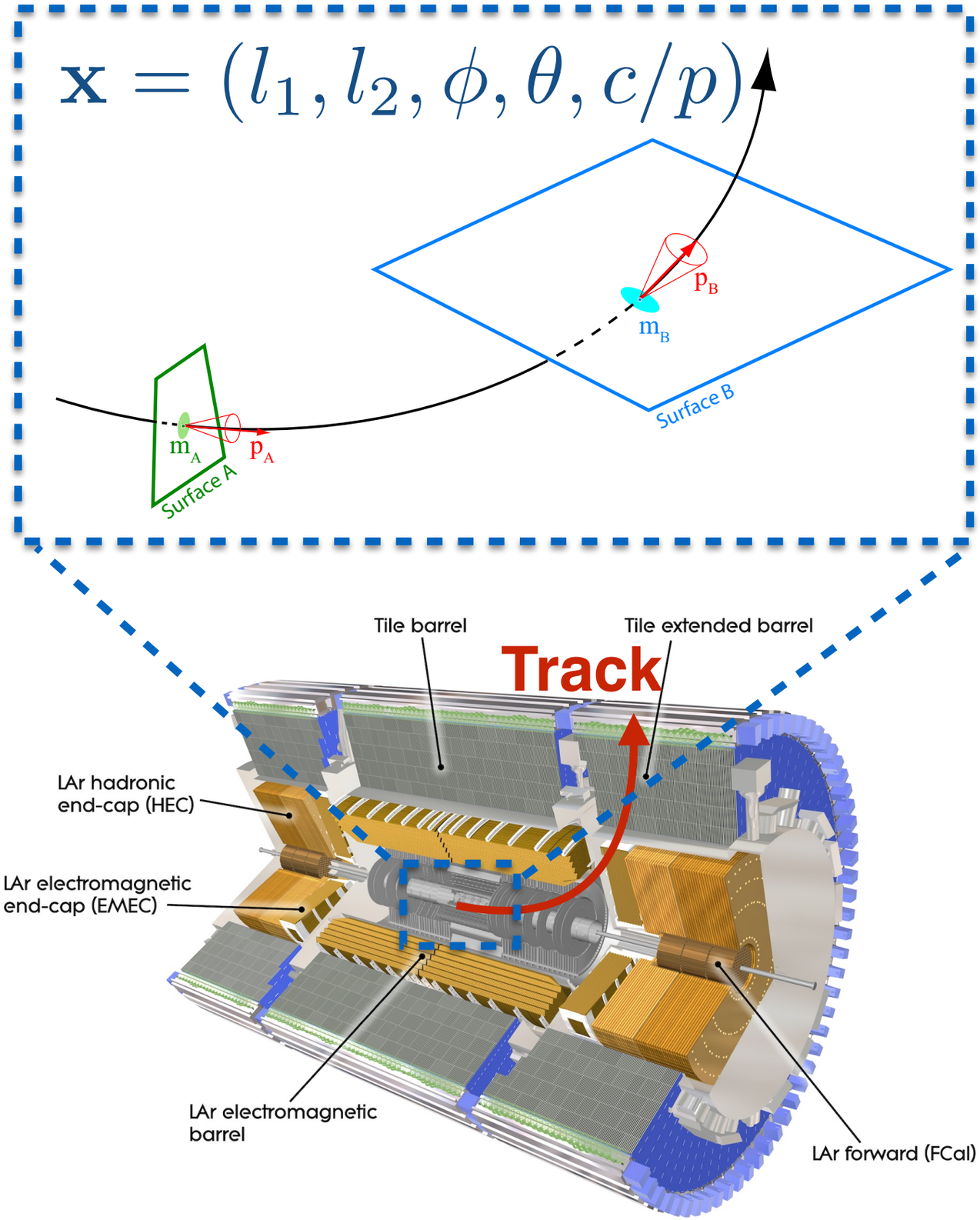




- Momentum from tracks, i.e. isolated charged hadrons (pions, Kaons, protons) from the inner detector
- Extrapolate tracks to the calorimeter and sum energy in a cone of $\Delta R<0.2$ to form E/p
- Track-isolation: no other tracks within $\Delta R<0.4$
- Subtract neutral backgrounds (mainly due to Kaons or neutral pions)

Track Extrapolation and Track-Cluster Matching

1. Track parameters and their associated errors are propagated to the ATLAS calorimeter
2. Track η,φ coordinates are stored for each calorimeter layer
3. Most energetic sampling layer of a cluster is identified: If the track η,φ are within ΔR =0.2 of the energy-weighted center of the cluster, the track and cluster are matched



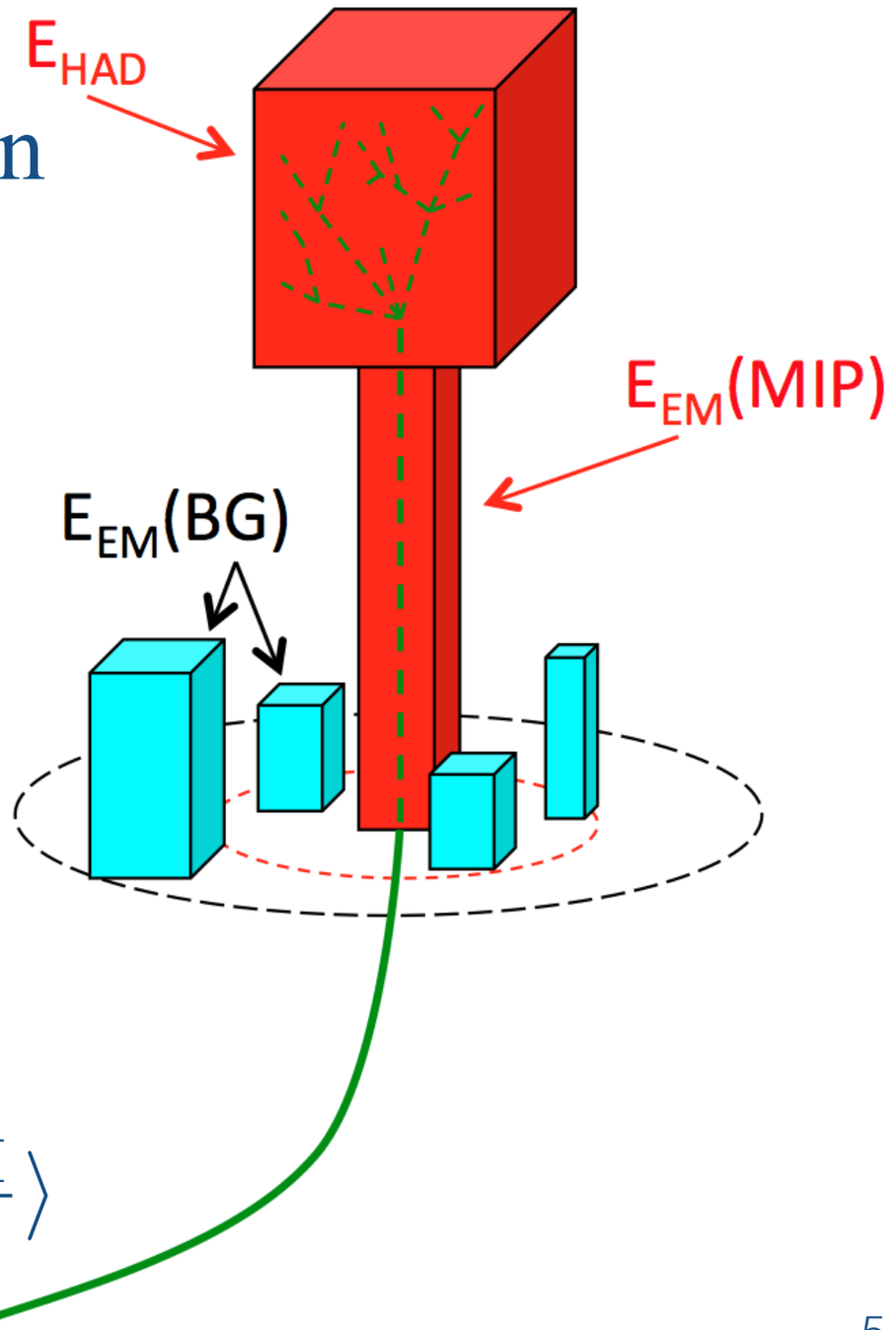
Neutral Background Subtraction

Assumption: Energy in the EM calorimeter from neutral hadrons is independent of the energy deposited by the selected track

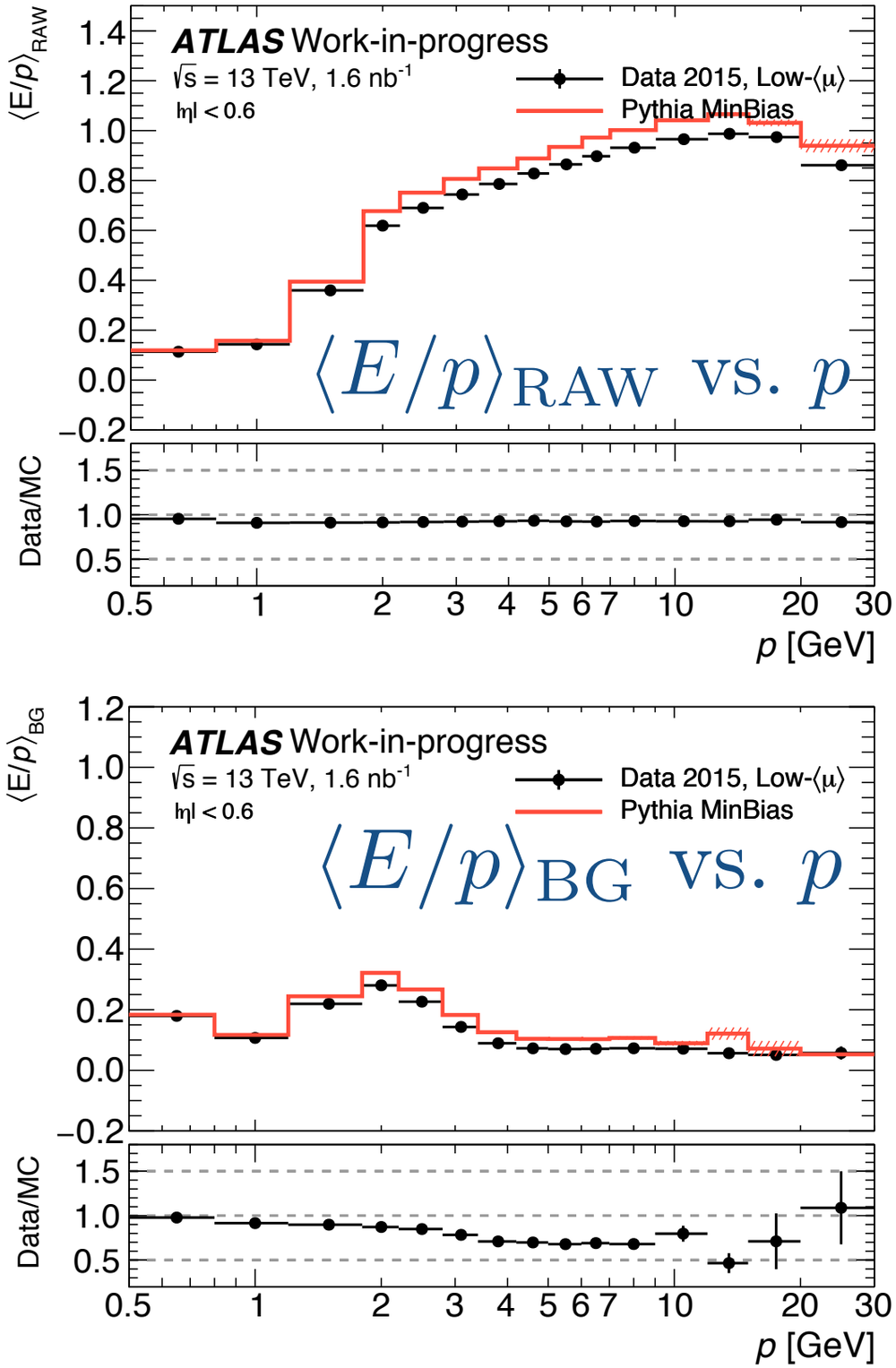
1. Select late-showering hadrons by requiring a small amount of energy in the EM calorimeter, $E_{\mathrm{EM}}^{0.1} < 1.1$ GeV, and $0.4 < E_{\mathrm{HAD}}^{0.1}/p < 0.9$
2. Measure E_{EM} in an annulus with $0.1 \leq \Delta R \leq 0.2$ over many events in a given p and η bin
3. The corrected E/p becomes:

$$\langle E/p \rangle = \langle E/p \rangle_{\mathrm{RAW}} - \frac{4}{3} \times \langle E/p \rangle_{\mathrm{BG}}$$

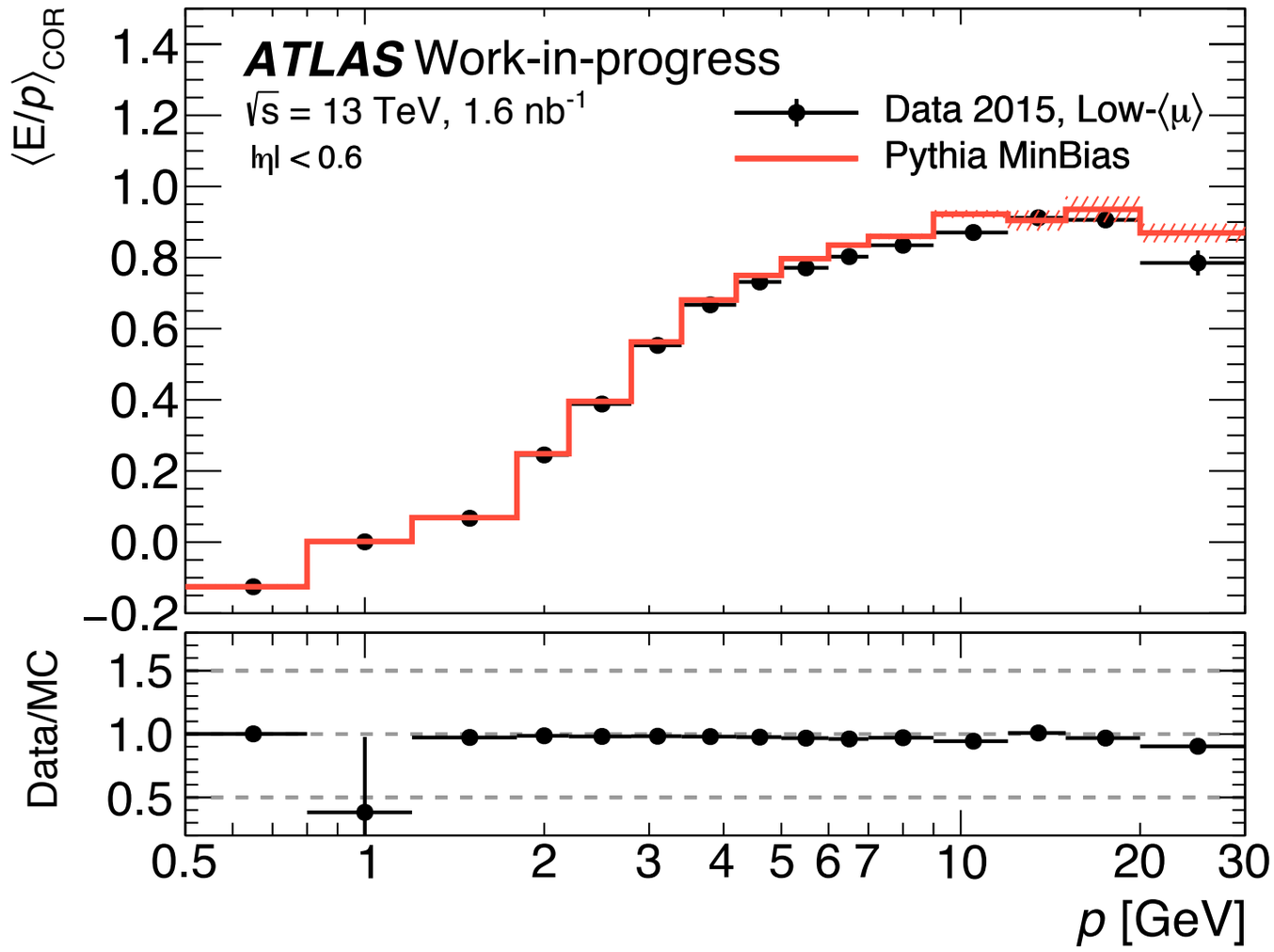
$$\text{where } \langle E/p \rangle_{\mathrm{BG}} = \langle \frac{E_{\mathrm{EM}}^{0.2} - E_{\mathrm{EM}}^{0.1}}{p} \rangle$$



Measured Average E/p Response



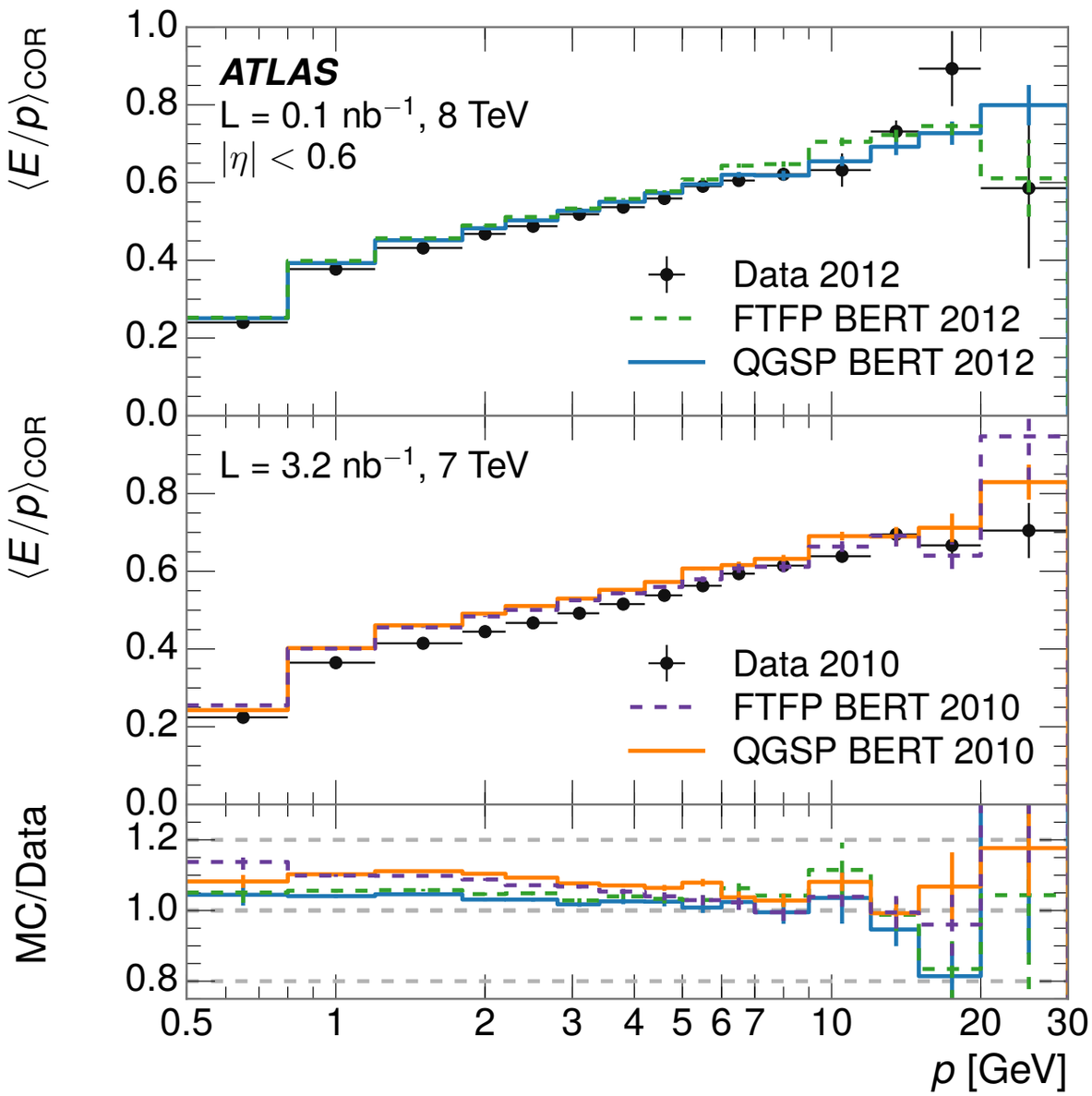
$\langle E/p \rangle_{\mathrm{COR}}$ vs. p



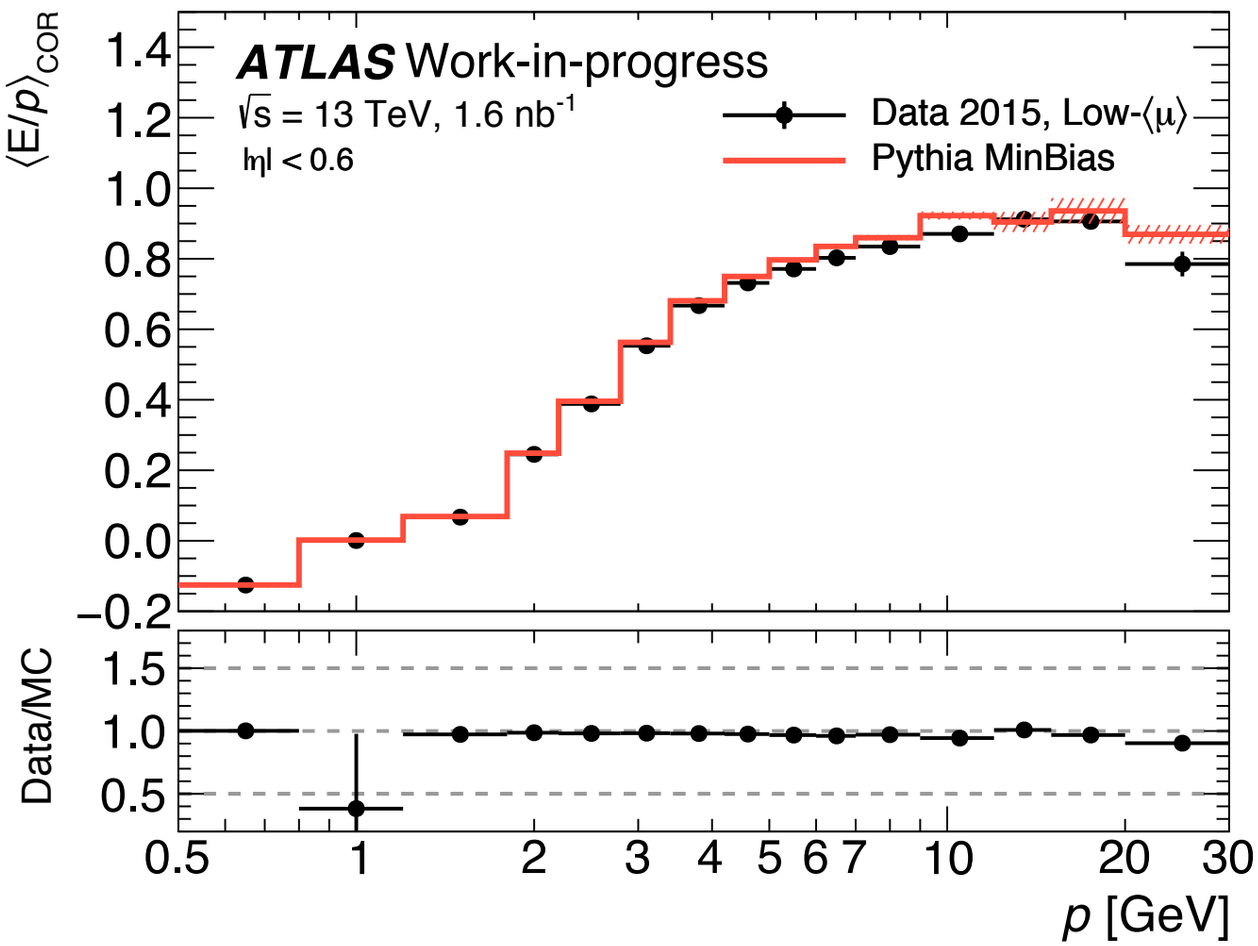
Measured Average E/p Response Compared with Run-I

- Work is ongoing to update the Run-I E/p results

Run 1



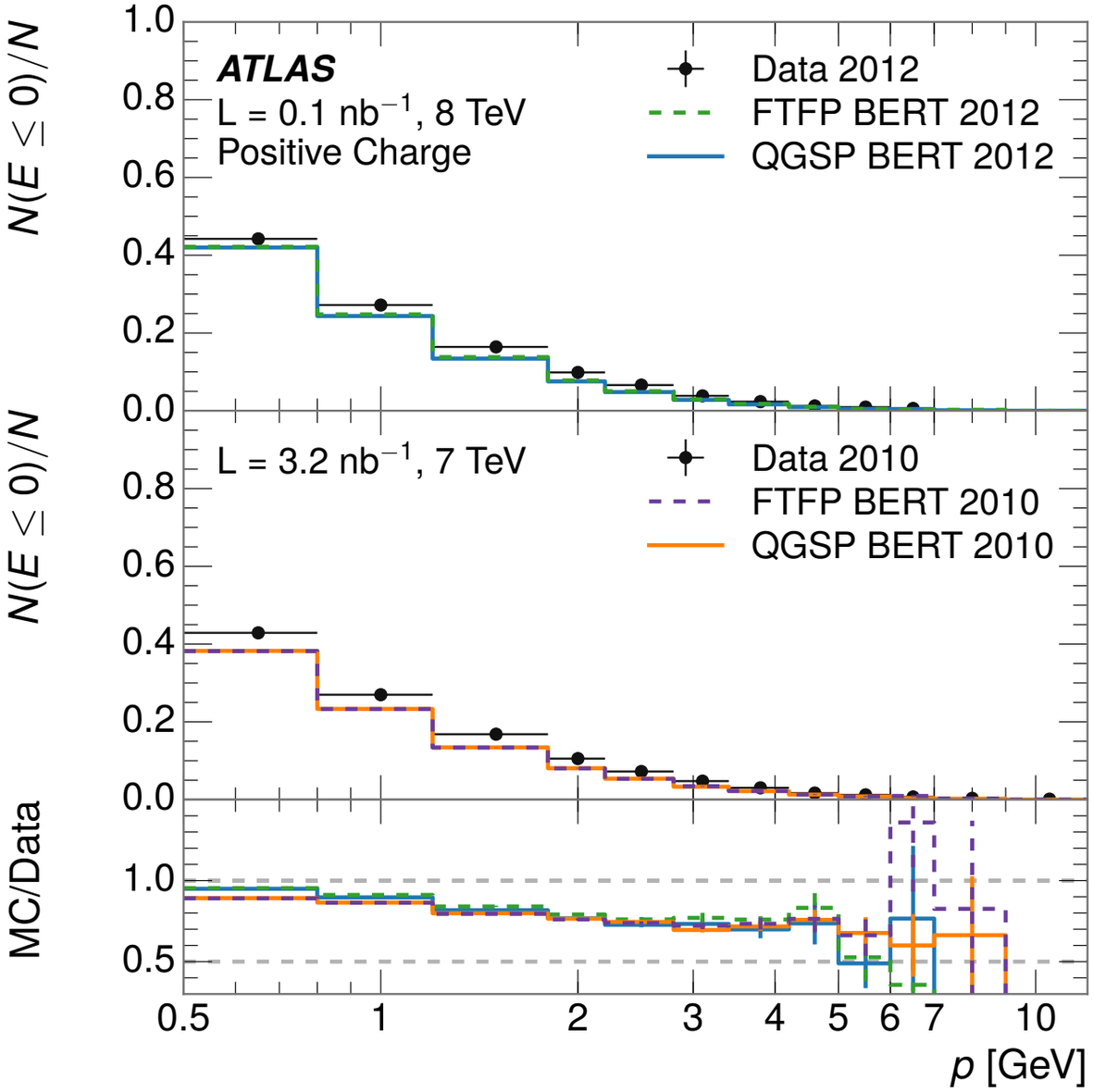
Run 2



arXiv:1607.08842 [hep-ex]

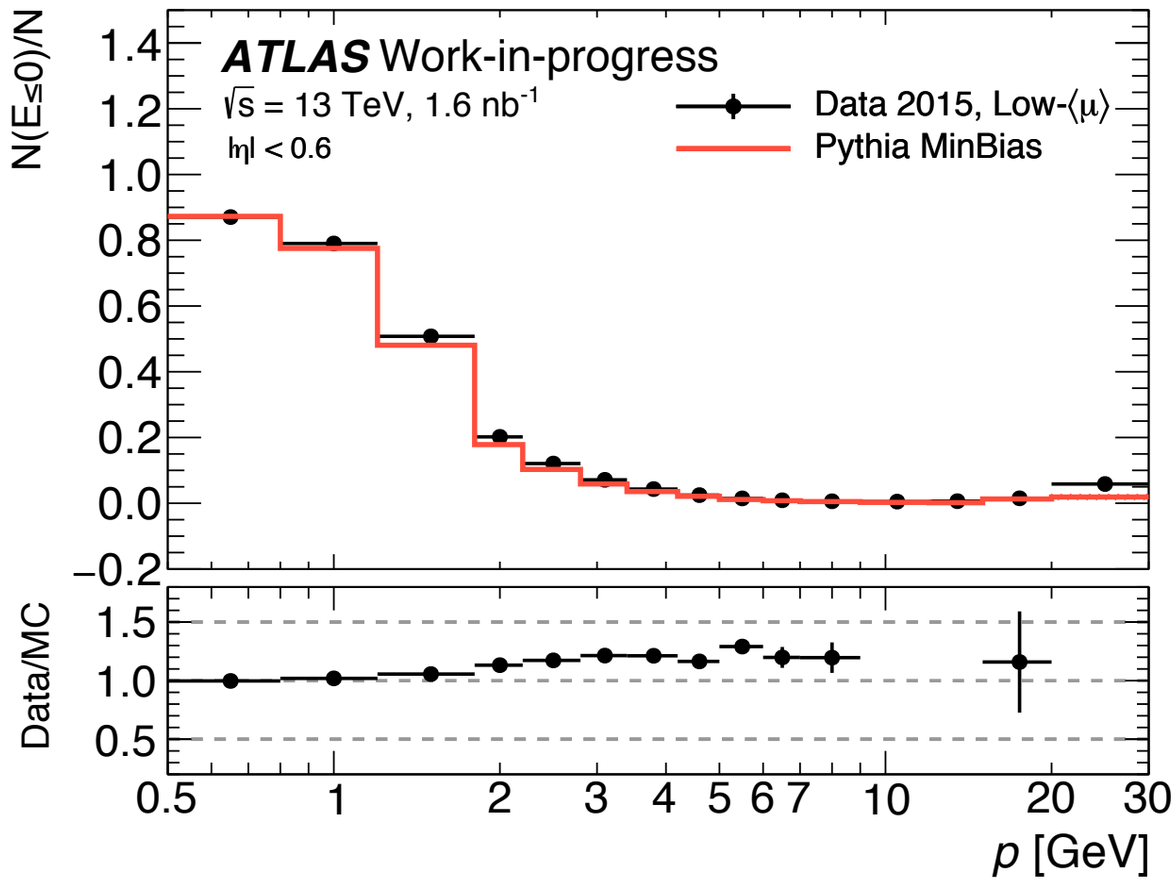
N(E ≤0)/N Compared with Run-I

Run 1



arXiv:1607.08842 [hep-ex]

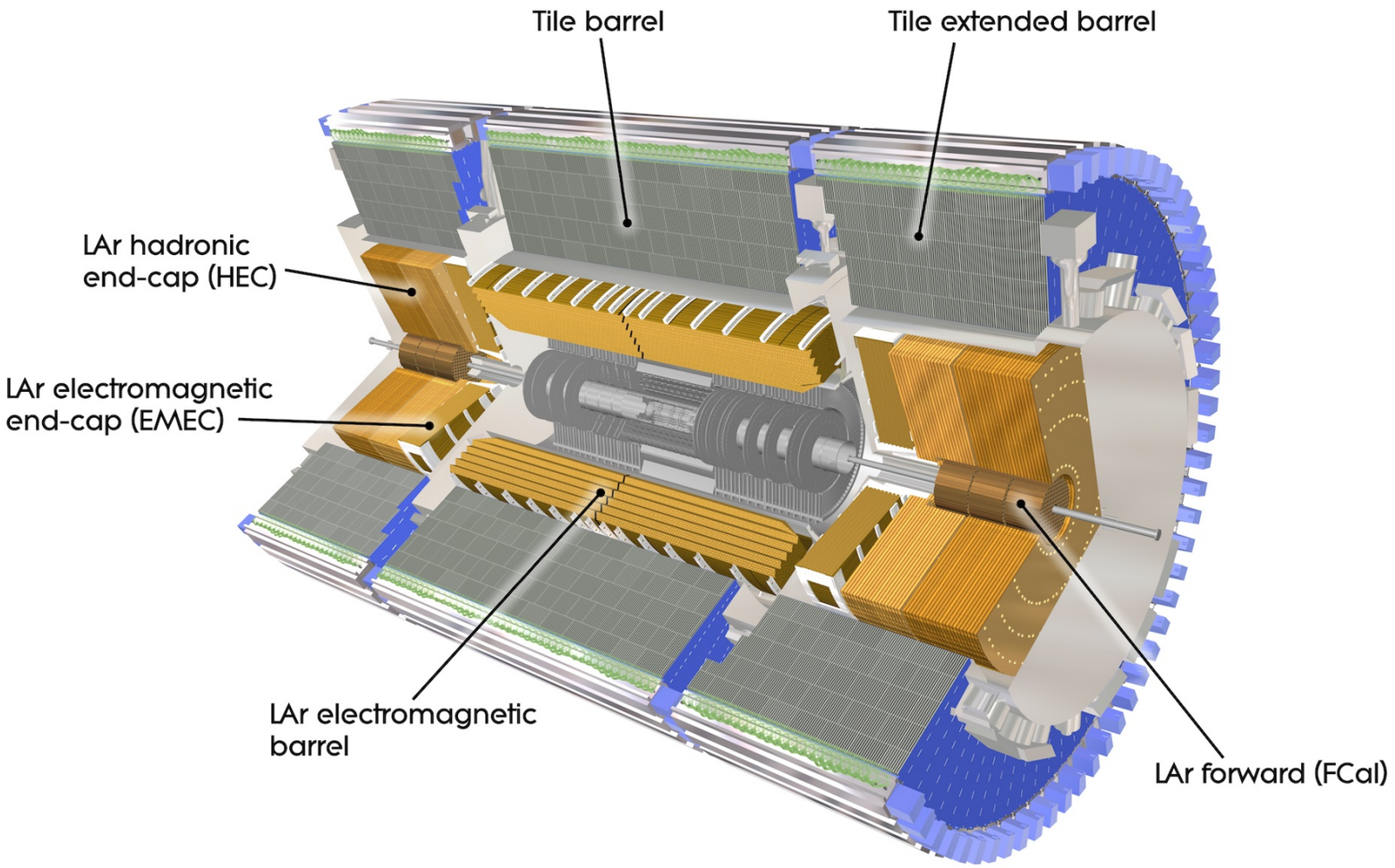
Run 2

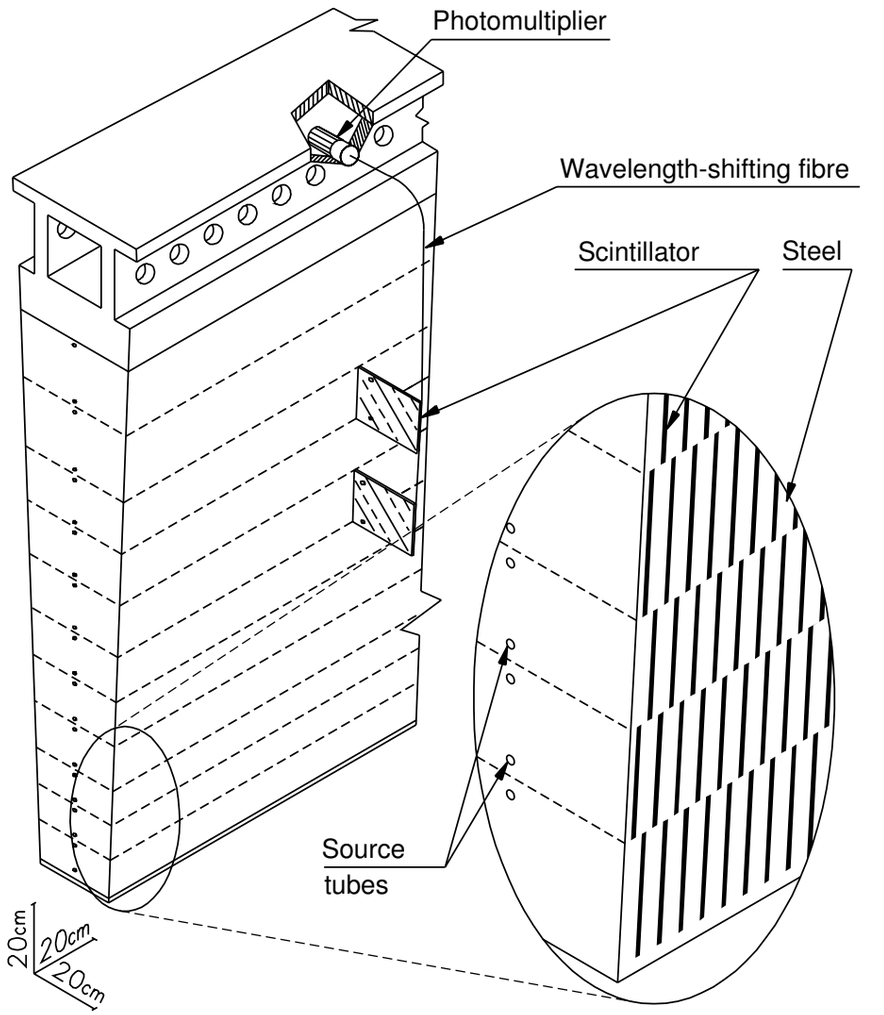


- Significant decrease in $\langle E/p \rangle_{\mathrm{COR}}$ for tracks with p < 3 GeV
- Consistent with increased fraction of tracks with E ≤0 for p < 3 GeV

The ATLAS Hadronic Tile Calorimeter (TileCal)

- Hadronic non-compensating sampling calorimeter
  - Composed of steel absorbers and ~500,000 scintillating tiles
  - Read out via fibers coupled to ~10,000 photo-multiplier tubes (PMTs)
  - 2 PMTs per cell ~ 5000 cells
- TileCal (together with the LAr EM calorimeter) is crucial for measuring energy and direction of hadrons

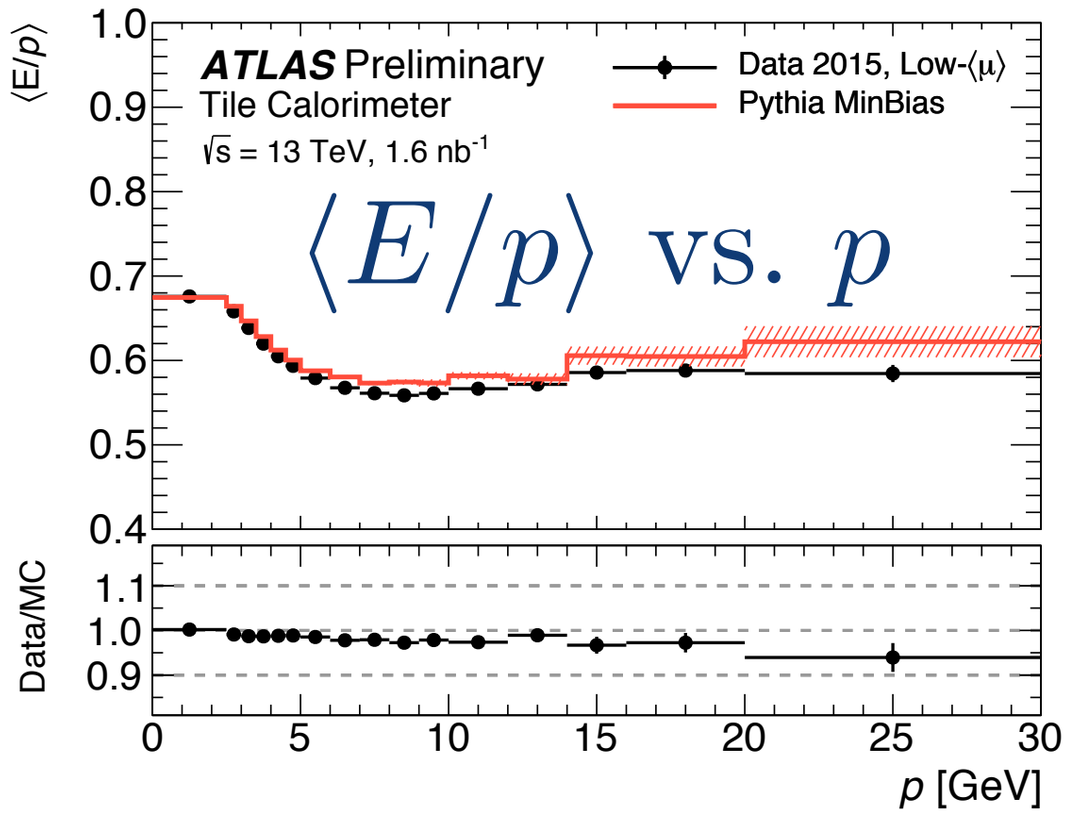


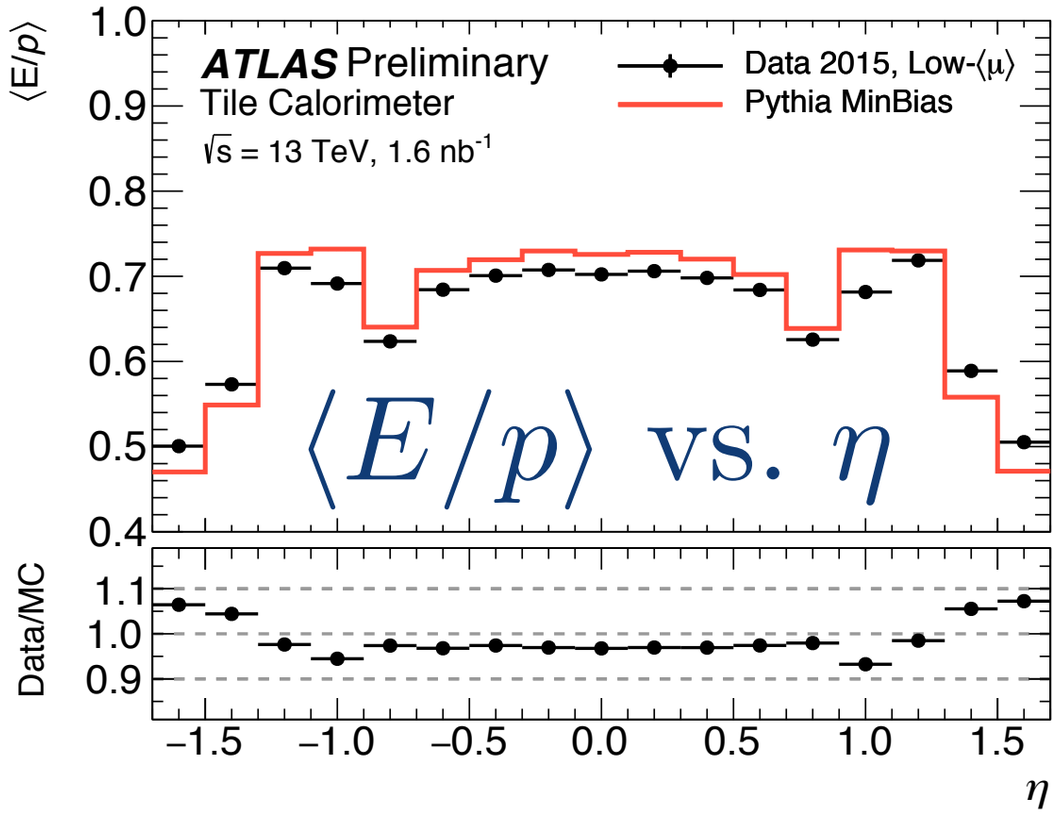


TileCal Studies: Measured Average E/p Response

Source: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileSingleParticleResponse

Low (~1) number of pp collisions per bunch crossing





- Selections to reject background
  - **Charged hadrons:** No other tracks allowed within a cone of $\Delta R < 0.4$ of selected track
  - **Neutral hadrons:** Energy in EM calo compatible with minimum ionizing particle
  - **Muons:** Require a 70% of the energy to be deposited in TileCal
- Good agreement between Data and MC

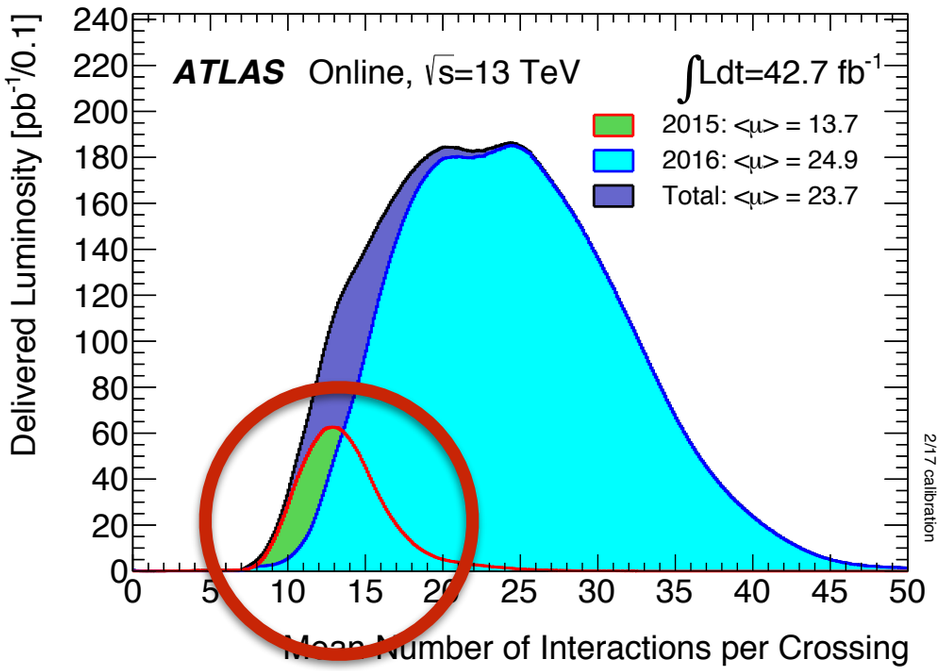
TileCal Studies: Measured Average E/p Response

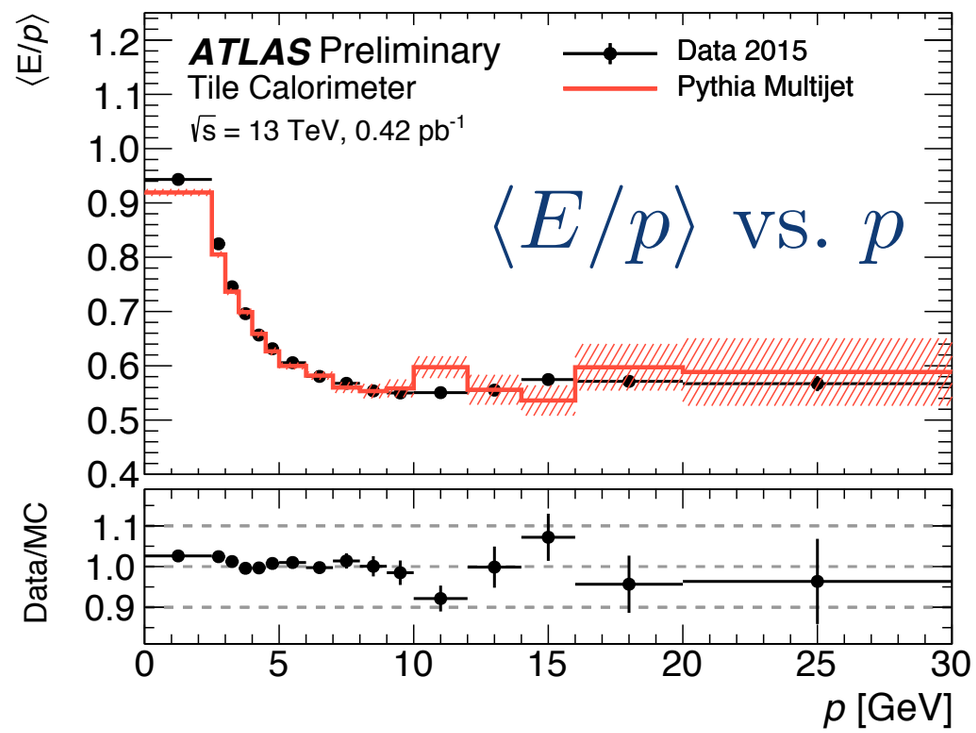
Source: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/ApprovedPlotsTileSingleParticleResponse

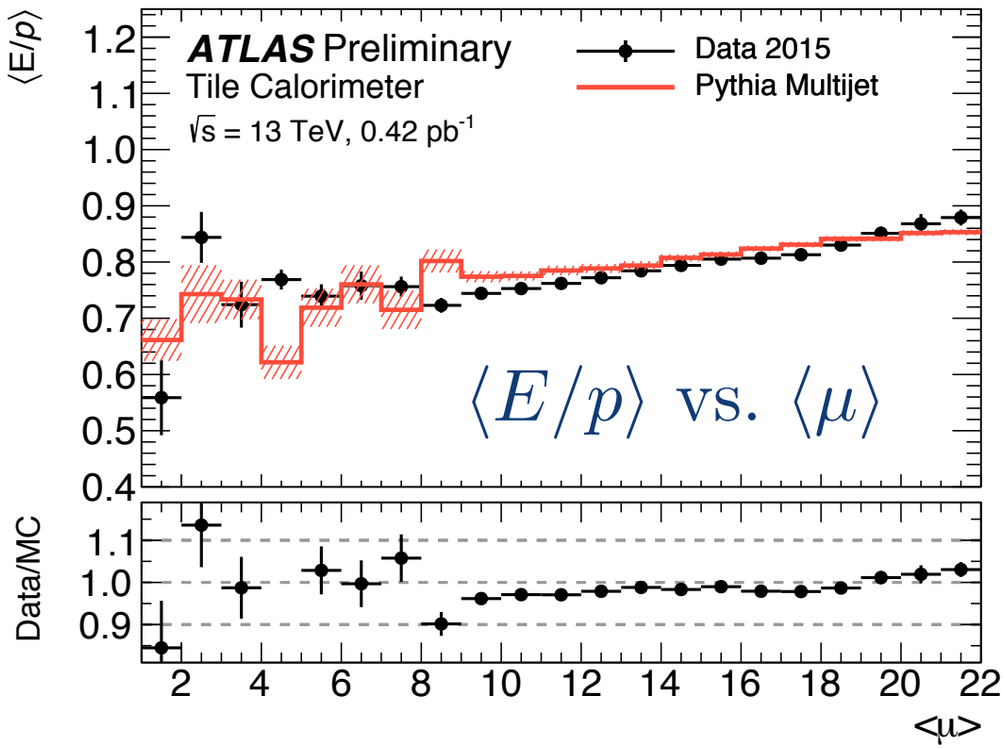
Multiple pp collisions per bunch crossing (pile-up)

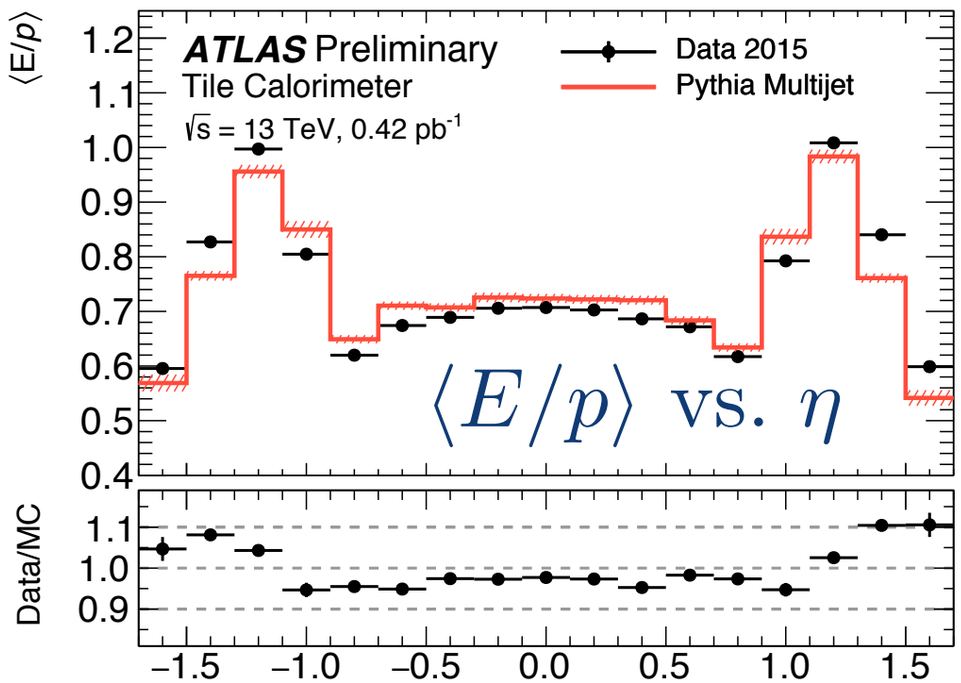
2015:

$\langle\mu\rangle = 13.7$









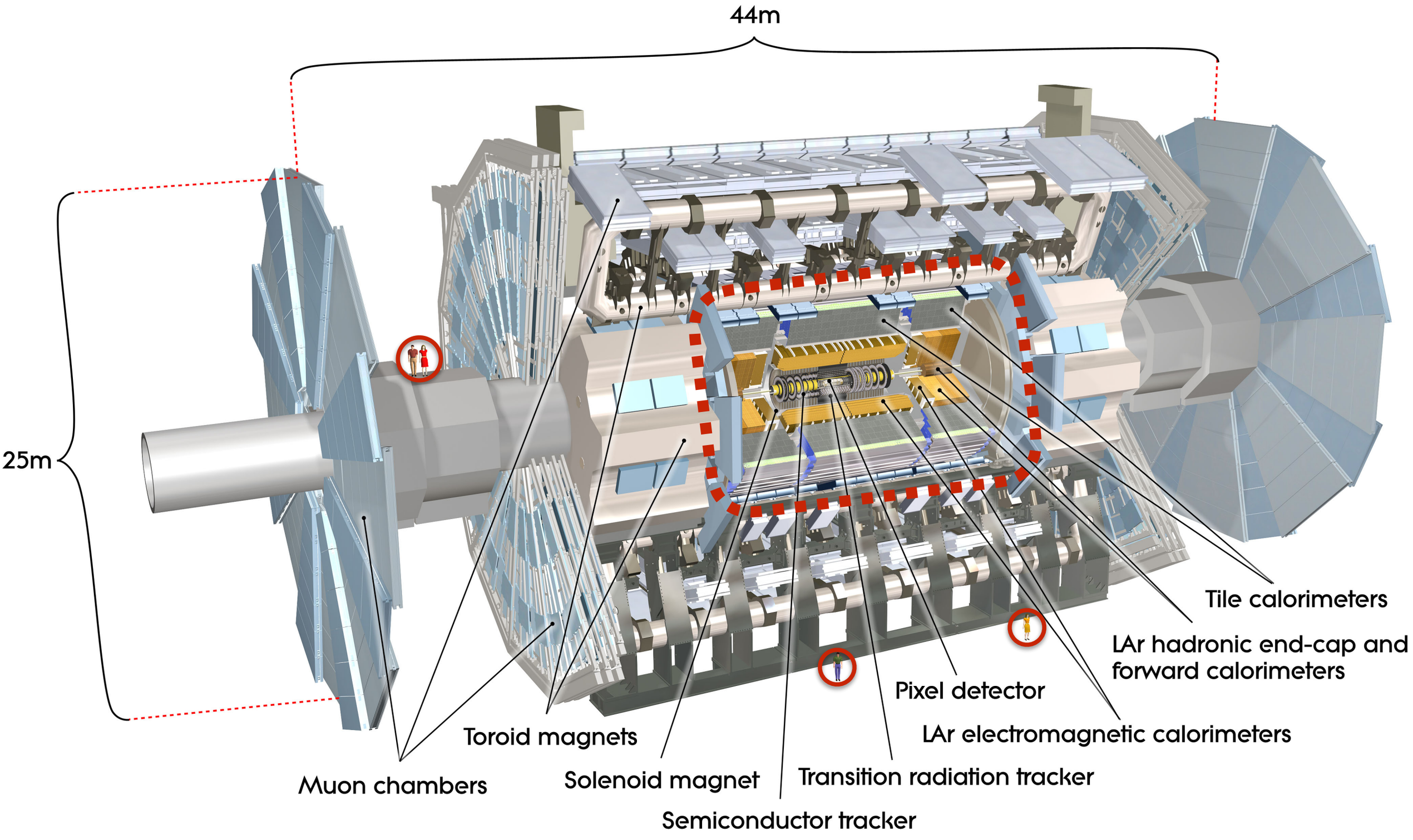
Summary

- Measurements of the calorimeter response to single isolated charged hadrons (E/p) is useful for validation of hadronic shower modeling and detector geometry and provides an important input to the jet energy scale uncertainty
- ATLAS 13 TeV E/p measurements where presented
- Measurements of the average E/p as a function of momentum and pseudo-rapidity in the ATLAS hadronic (Tile) calorimeter show good agreement between simulation and data

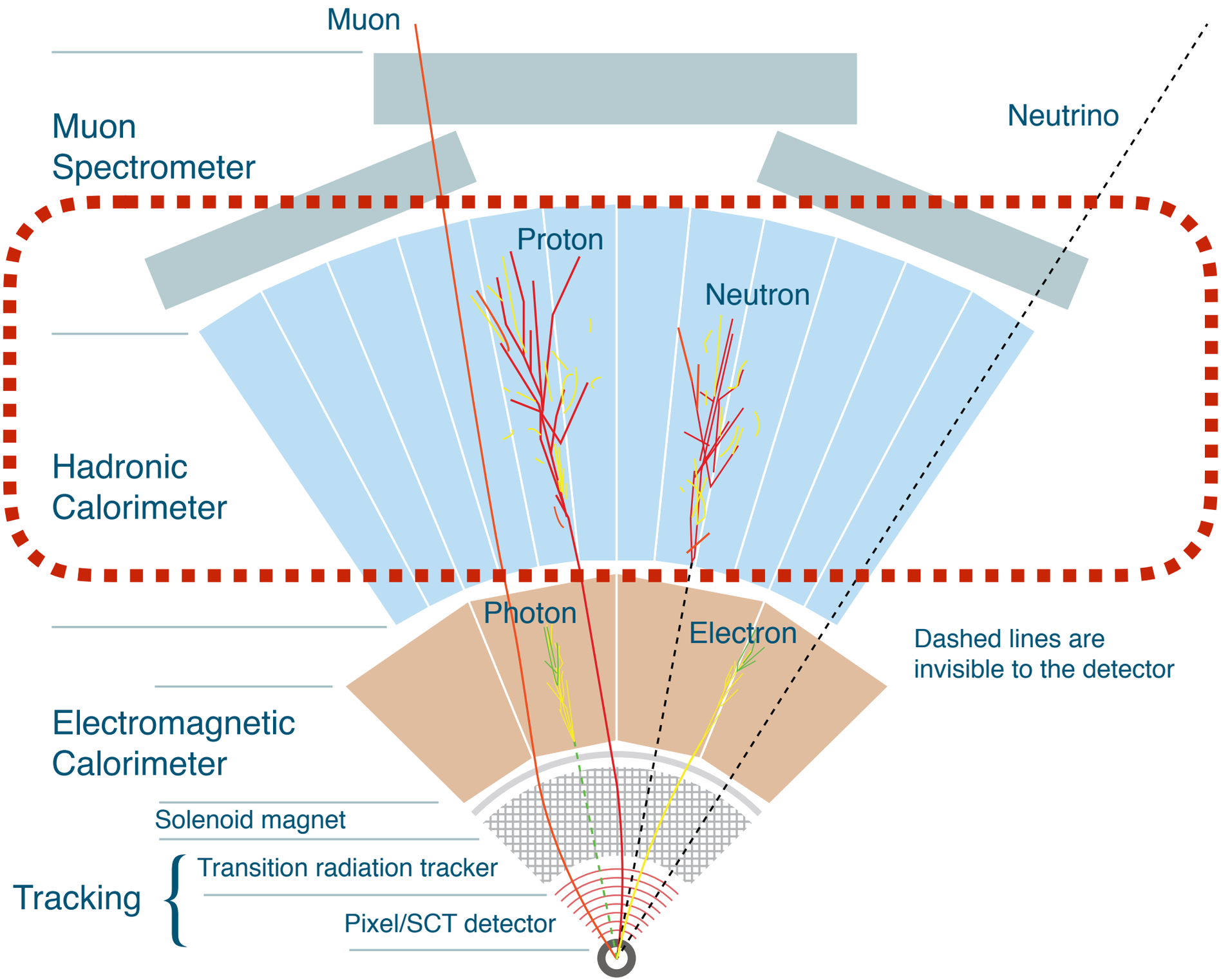
Thanks for your attention!

Additional material

The ATLAS Experiment

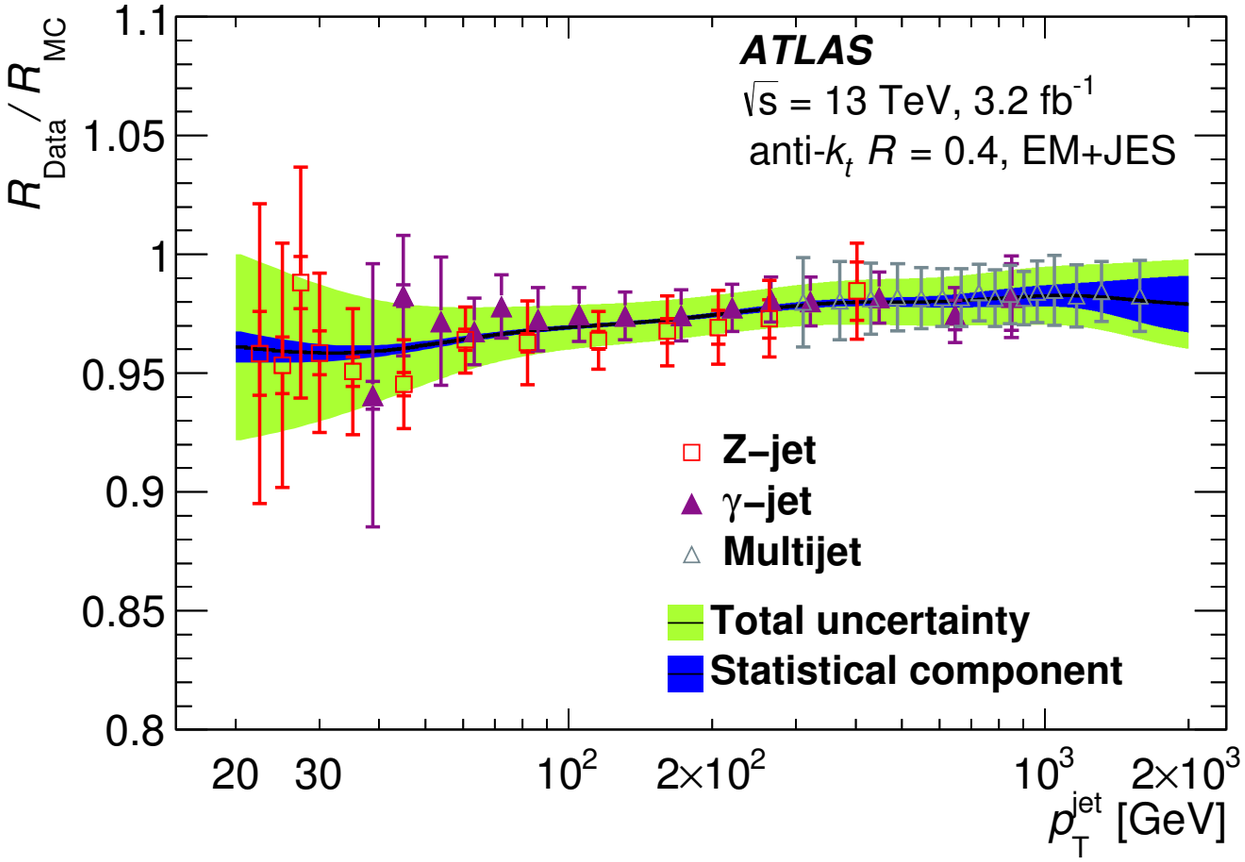


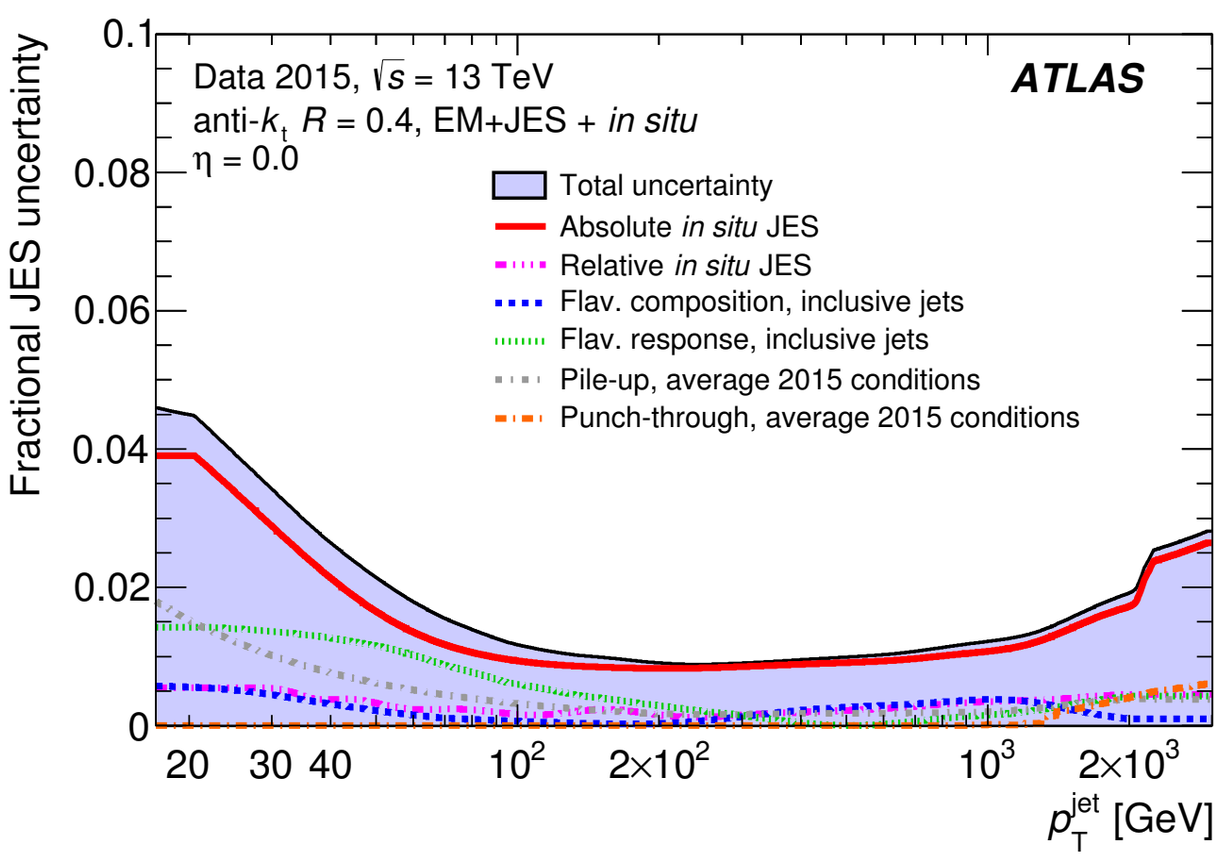
The ATLAS Experiment



ATLAS Jet Energy Scale Uncertainty @ 13 TeV

arXiv:1703.09665 [hep-ex]





E/p Measurements in ATLAS

- Calorimeter response in Run-I determined using
  - Combined test beam measurements, Monte Carlo, and in-situ E/p measurements for $\pi^{\pm}$
  - In-situ measurements of Z to ee decays using 2010 data for π^{0}
- Run-II E/p measurements performed using 1.6 nb^{-1} of 2015 low-μ minimum bias data
  - My studies mostly focused on the Tile Calorimeter (which was ATLAS authorship qualification task)
  - I'm also part of an effort of deriving more general ATLAS E/p results, hopefully public results should be ready within a few months.
  - The plan is to also include 2016 (and at some point 2017) data.

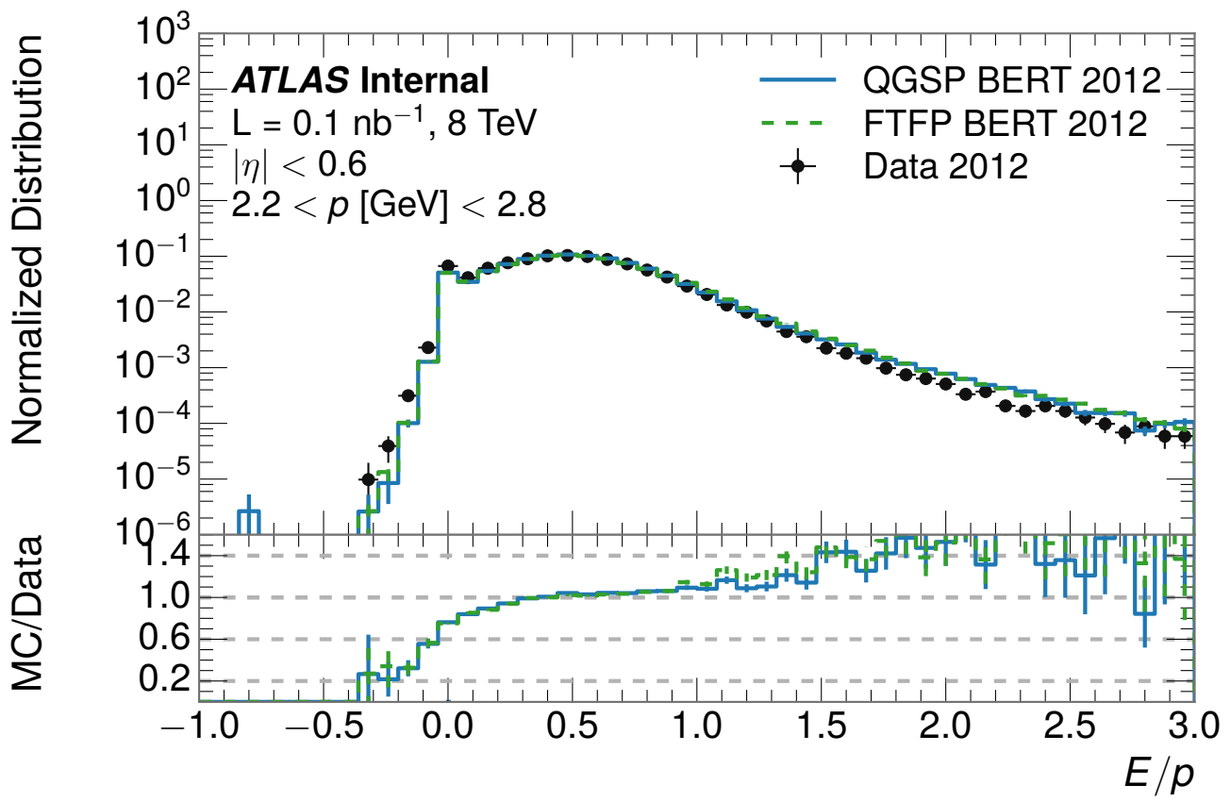
TileCal Studies: Event and Track Selections

- Standard ATLAS event and track selections
  - Using Minimum bias trigger
- Track isolation
  - No other tracks are allowed within a cone of $\Delta R < 0.4$ of the selected track
- Track-cluster/cell matching
  - Energy deposits associated with a cluster are matched to a track if $\Delta R < 0.2$ between the cluster/cell and the track (extrapolated to the most energetic sampling layer of a cluster)
- Reject background from neutral hadrons and muons and ensure that a significant fraction of the total energy is deposited in TileCal
  - **Track $p > 2$ GeV and $|\eta| < 1.7$ GeV**
    - Increase fraction of particles depositing significant energy fraction in TileCal)
  - **$E_{EM} < 1$ GeV**
    - Energy deposited in EM calo compatible with minimum ionizing particle
  - **$E_{Tile} / E_{Tot.} > 0.7$**
    - Reject background contamination from muons

Measured E/p Response Compared with Run-I

- Work is ongoing to update the Run-I E/p results

Run 1



Run 2