In Situ Combination of Jet Uncertainties and the Production of Jet Calibrations for the ATLAS Detector

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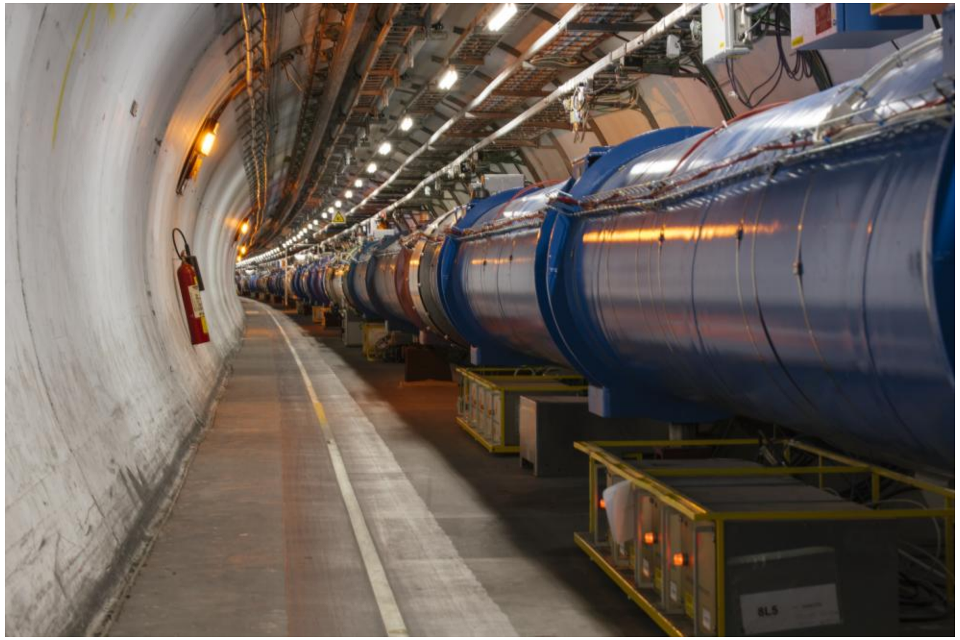
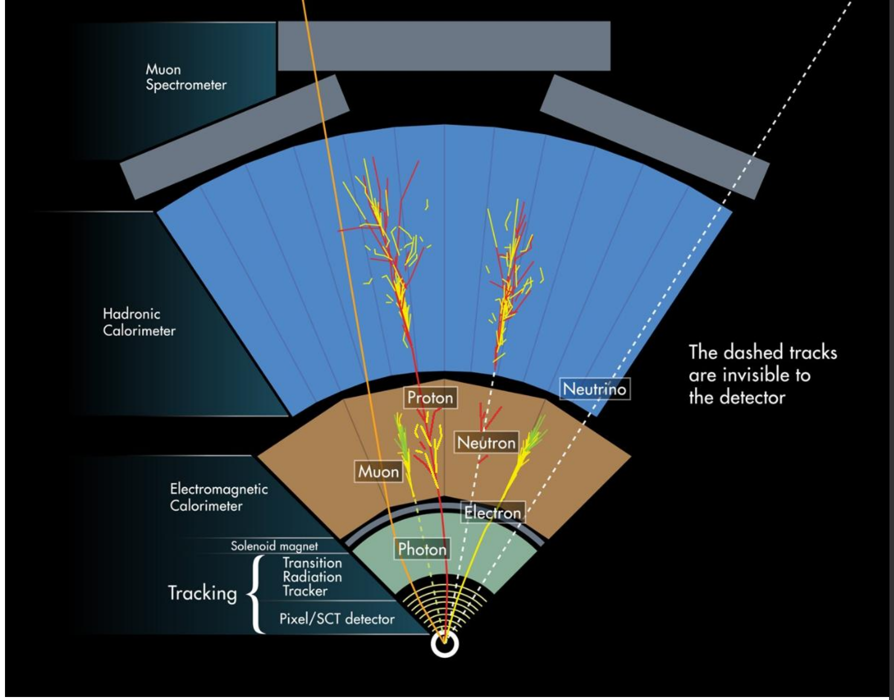
The Large Hadron Collider

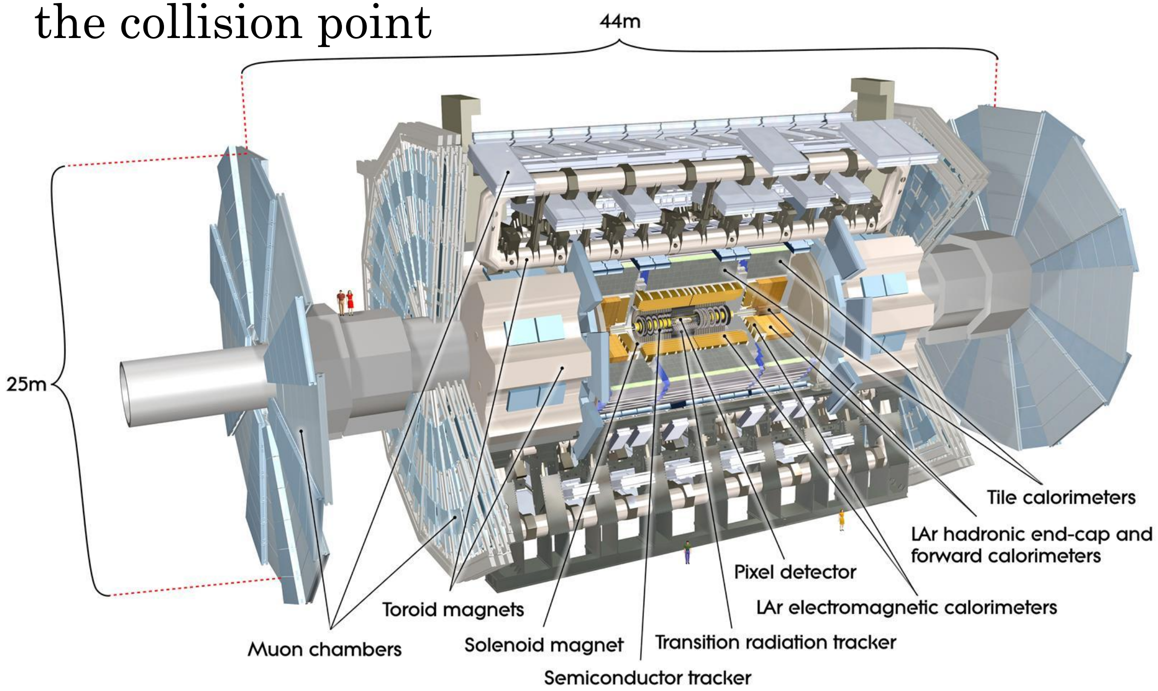
- Located at CERN and in both Switzerland and France
- 27 km loop, ~100 meters below the ground
- Accelerates and collides bunches of protons and heavy ions at high center of mass energies ($\sqrt{s}$)
- Home to detectors like ALICE, CMS, LHCb, and **ATLAS**



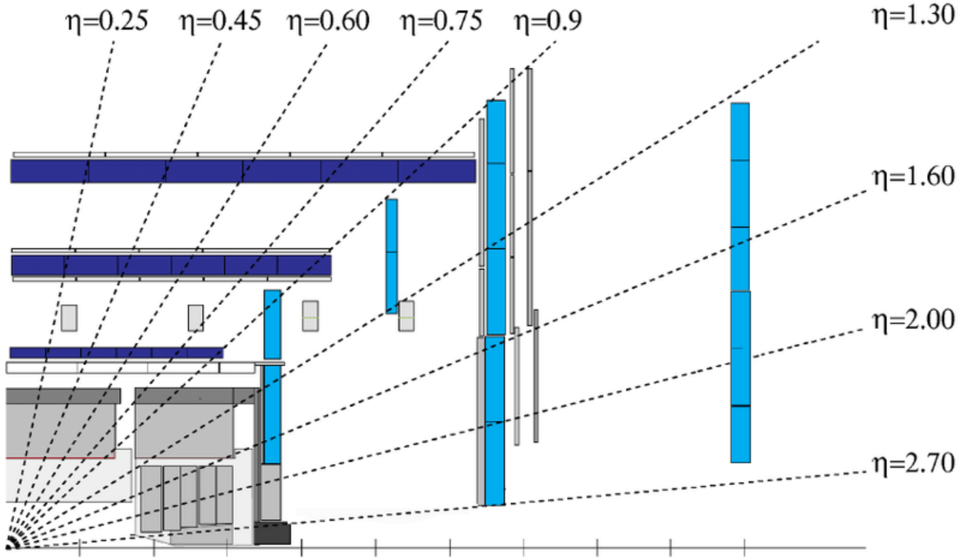
The ATLAS Detector

- ATLAS is a multi-purpose detector
- Layered detector design
  - Inner tracking detectors for charged particles
  - Calorimeters to measure particle energy
  - Muon spectrometer provides secondary measurements of muon momentum
- ‘Onion’-like hermetic design maximises coverage around the collision point



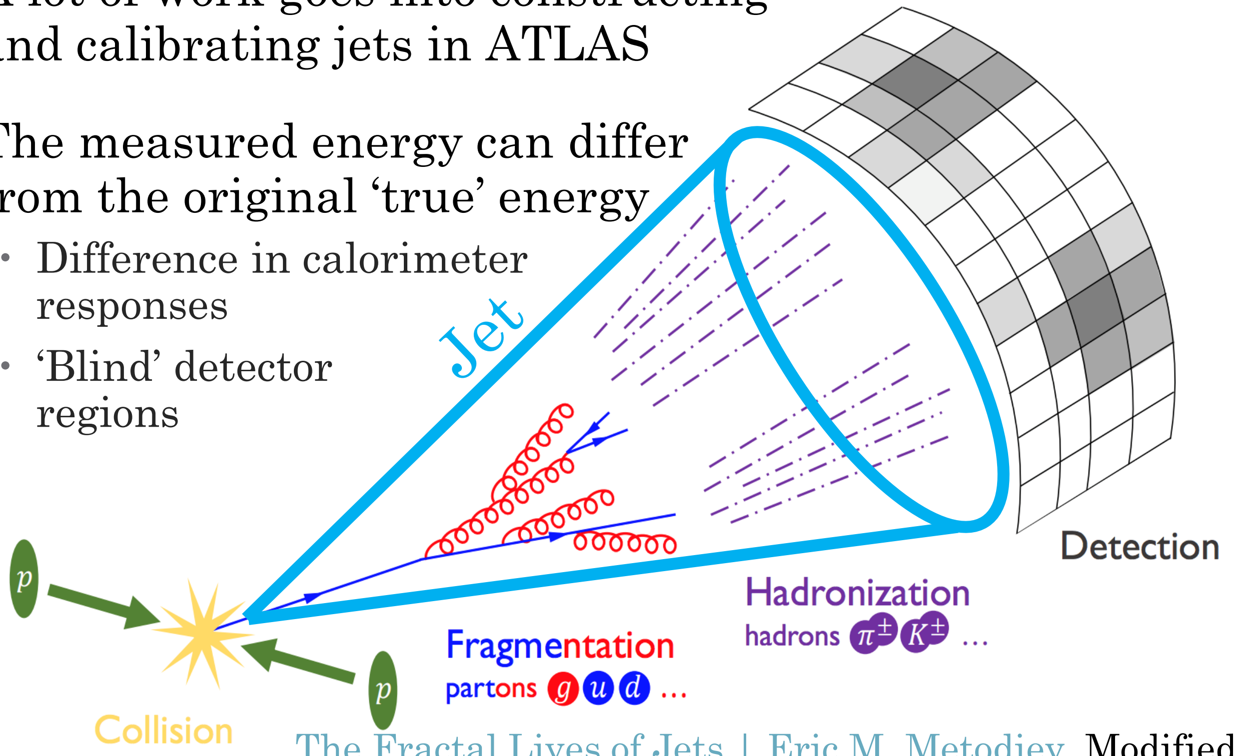


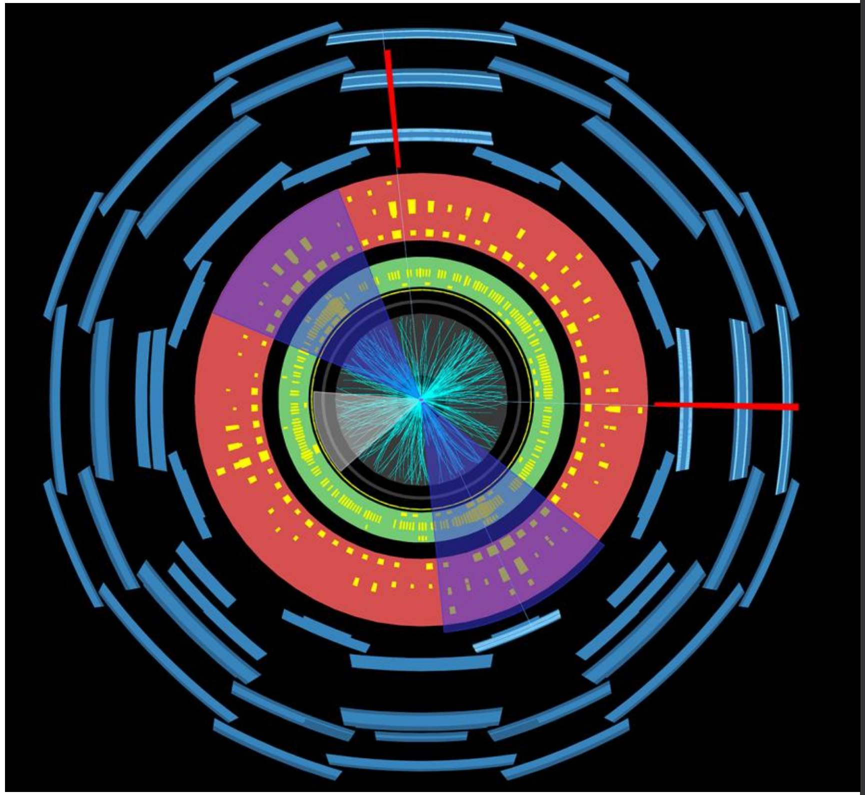
Detector Cross-Sections



Jets and the ATLAS Detector

- High energy collisions produce sprays of particles
- Most ATLAS analyses group these particles and the associated detector responses into useful objects called jets
  - Jets are by far the most common product of collisions
- A lot of work goes into constructing and calibrating jets in ATLAS
- The measured energy can differ from the original 'true' energy
  - Difference in calorimeter responses
  - 'Blind' detector regions

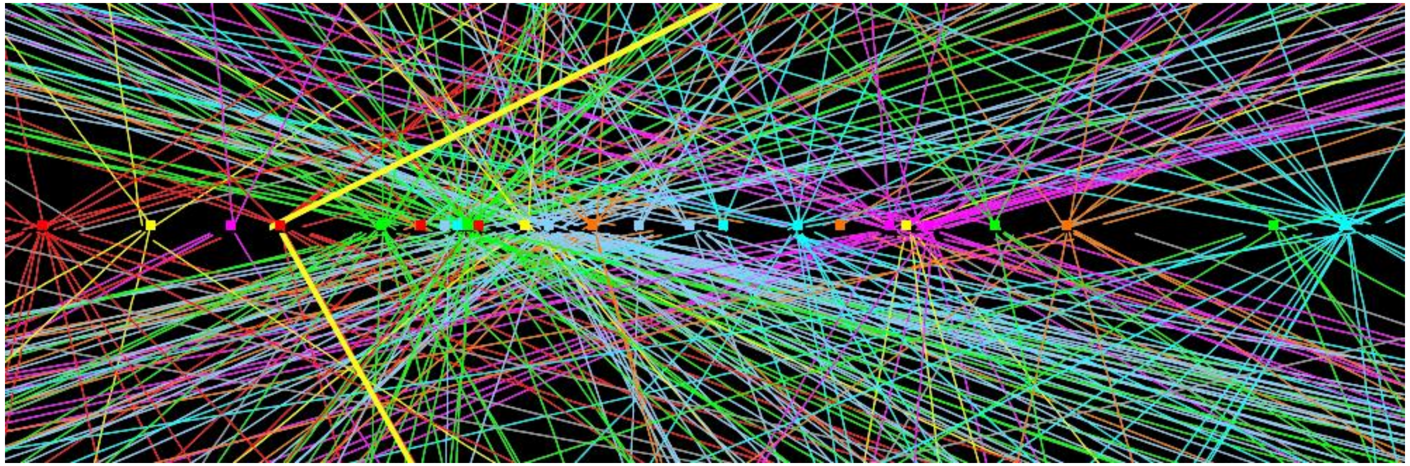




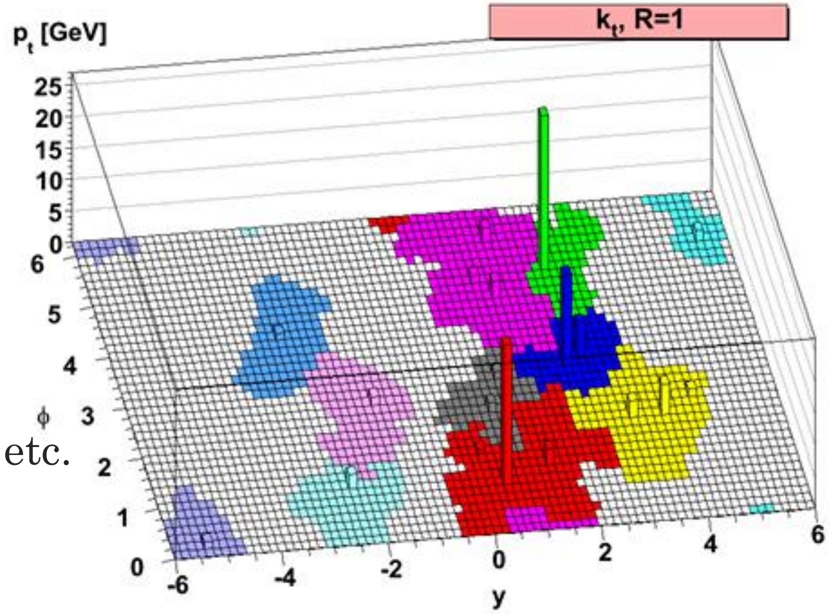
The Fractal Lives of Jets | Eric M. Metodiev, Modified

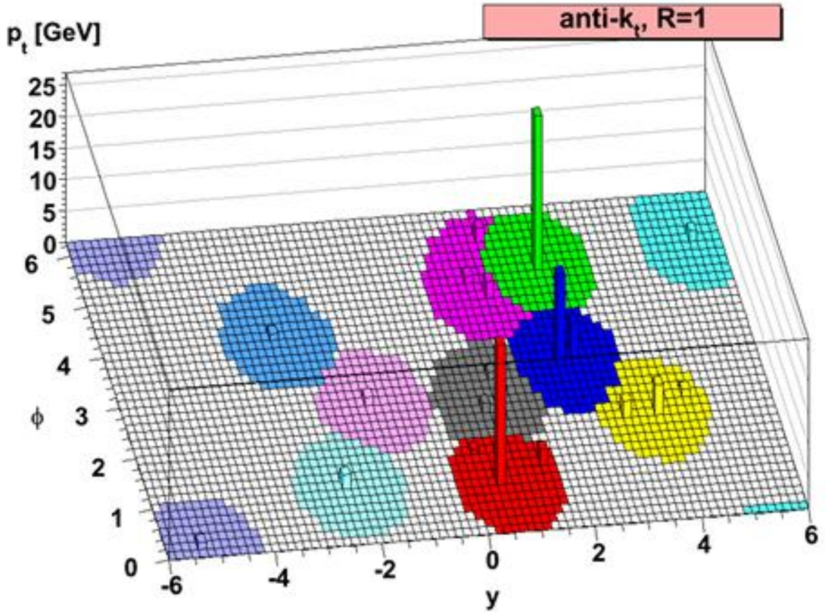
Jet Reconstruction

- The anti-kt algorithm is used to build jets from the detector measurements
- The radius (***R***) characterizes the reconstructed jet size
  - Small-R (***R*** = 0.4) – Good for 'standard' jets
  - Large-R (***R*** = 1.0) – Good for jets from high momentum W, Z, top, etc.
- Corrections are applied to the jets to account for noise from other secondary collisions (pileup)
  - As you can see below, events can be quite noisy!



ATLAS Event Display



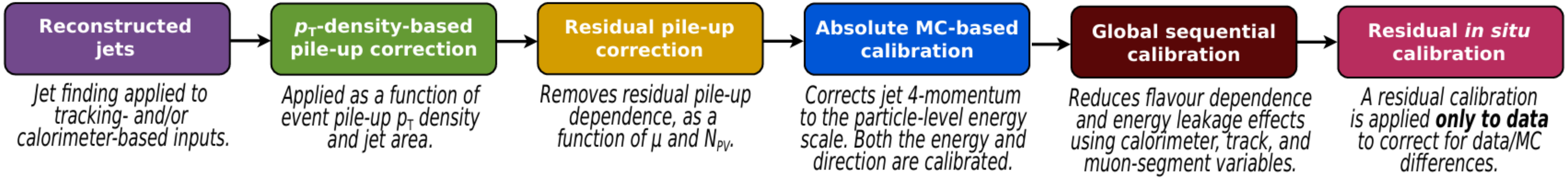


arXiv:0802.1189 [hep-ph]

Jet Calibrations

- Biases in the detector response are accounted for by calibrations to the jet energy and direction
  - Important near boundaries between detector components
  - Also account for jet properties such as flavour, topology, and the simulator used

- The final step is to correct data to match simulations using in situ measurements of the Jet Energy Scale (JES)
  - This corrects the jet energy to the particle level scale
  - In Situ: calibrations are derived from jet measurements within the detector
    - Uses same datasets as analyses



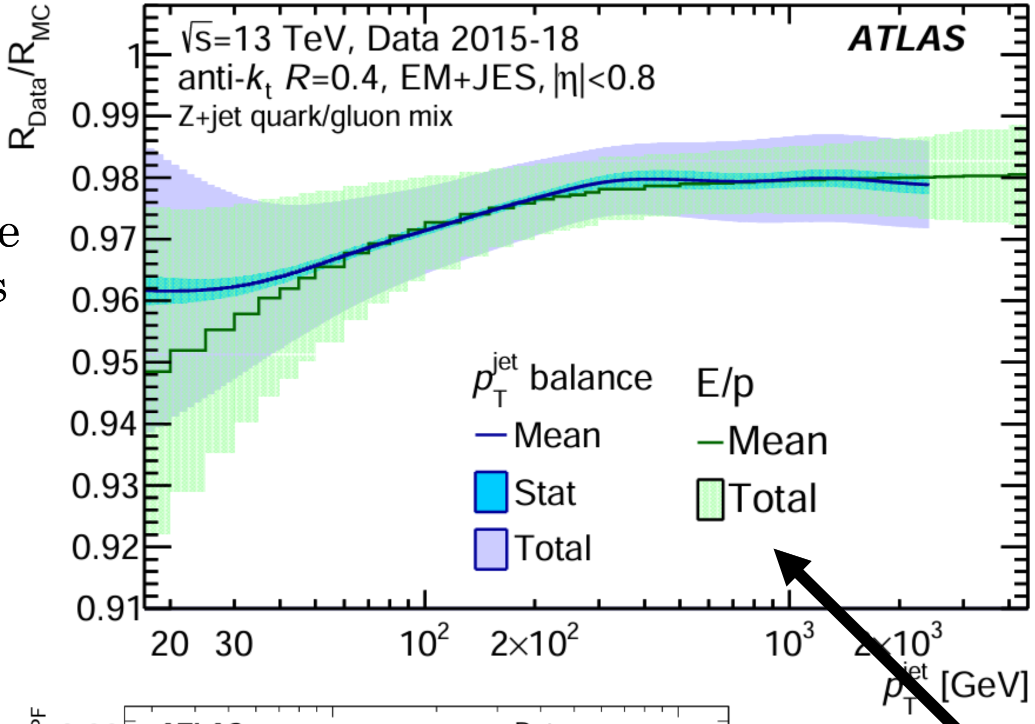
arXiv:2007.02645 [hep-ex]

JES Measurements

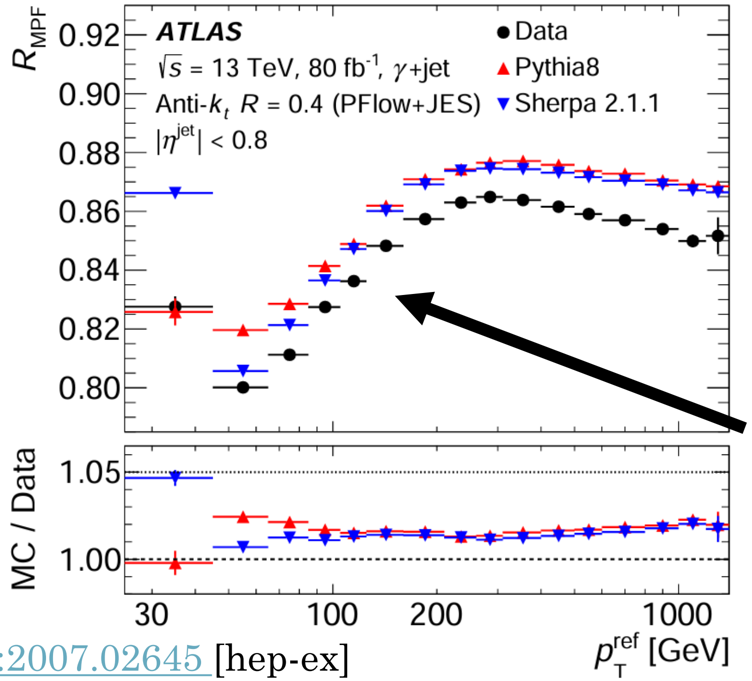
- Multiple statistically independent measurements are used to evaluate the JES across a range of pT values
  - Momentum balance between reference and probe jets
  - Measurements from complimentary detectors

- The combination in this presentation uses the following measurements:
  - Photon + Jet
  - Z → ee + Jet
  - Z → μμ + Jet
  - Single Particle Response (E/p)

- Data/Simulation ratio of jet response $R = \left\langle p_t^{jet} / p_t^{ref} \right\rangle$ used to evaluate the JES for each method



E/p

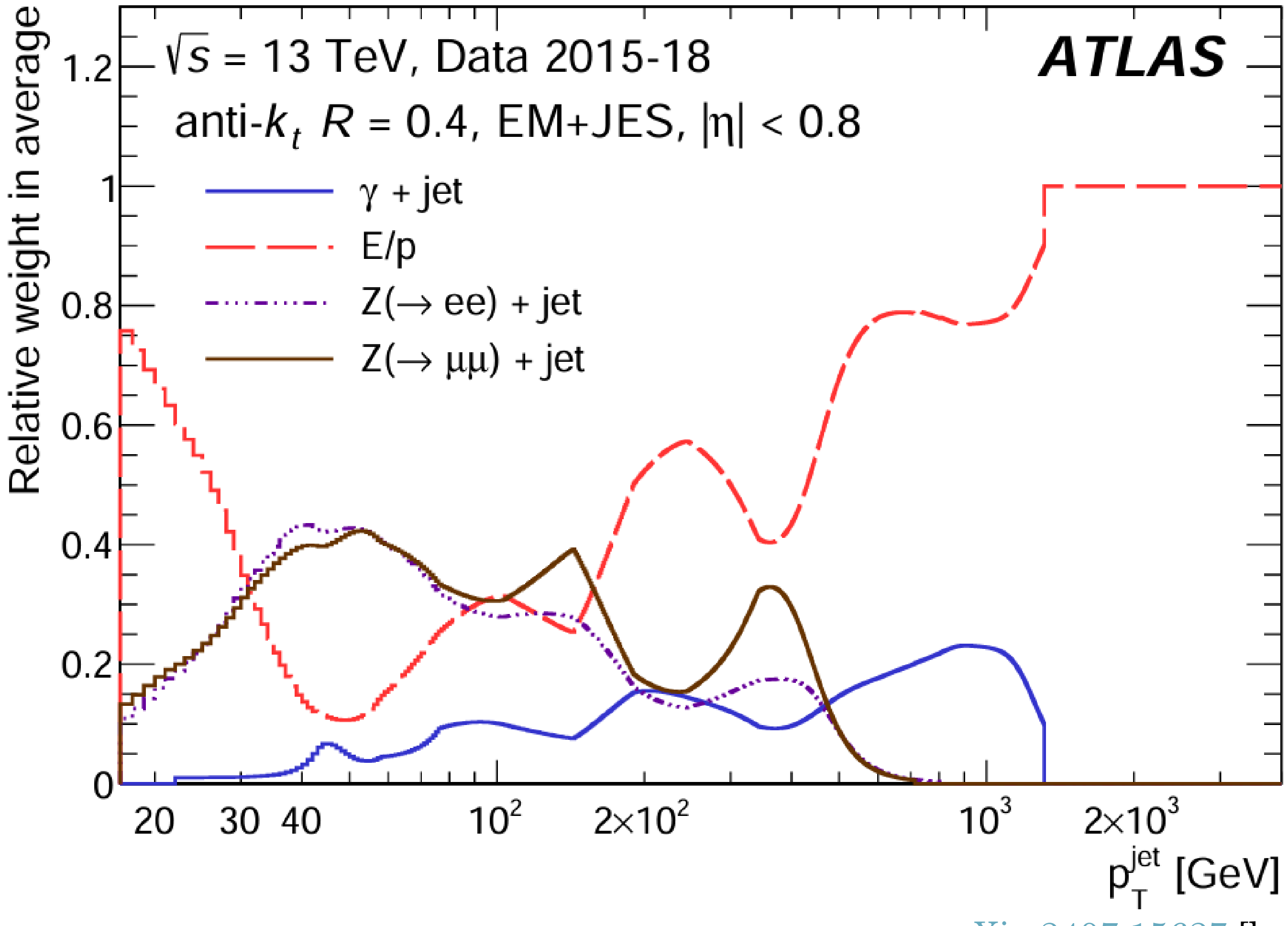


Photon + Jet

arXiv:2407.15627 [hep-ex] , arXiv:2007.02645 [hep-ex]

JES Statistical Combination

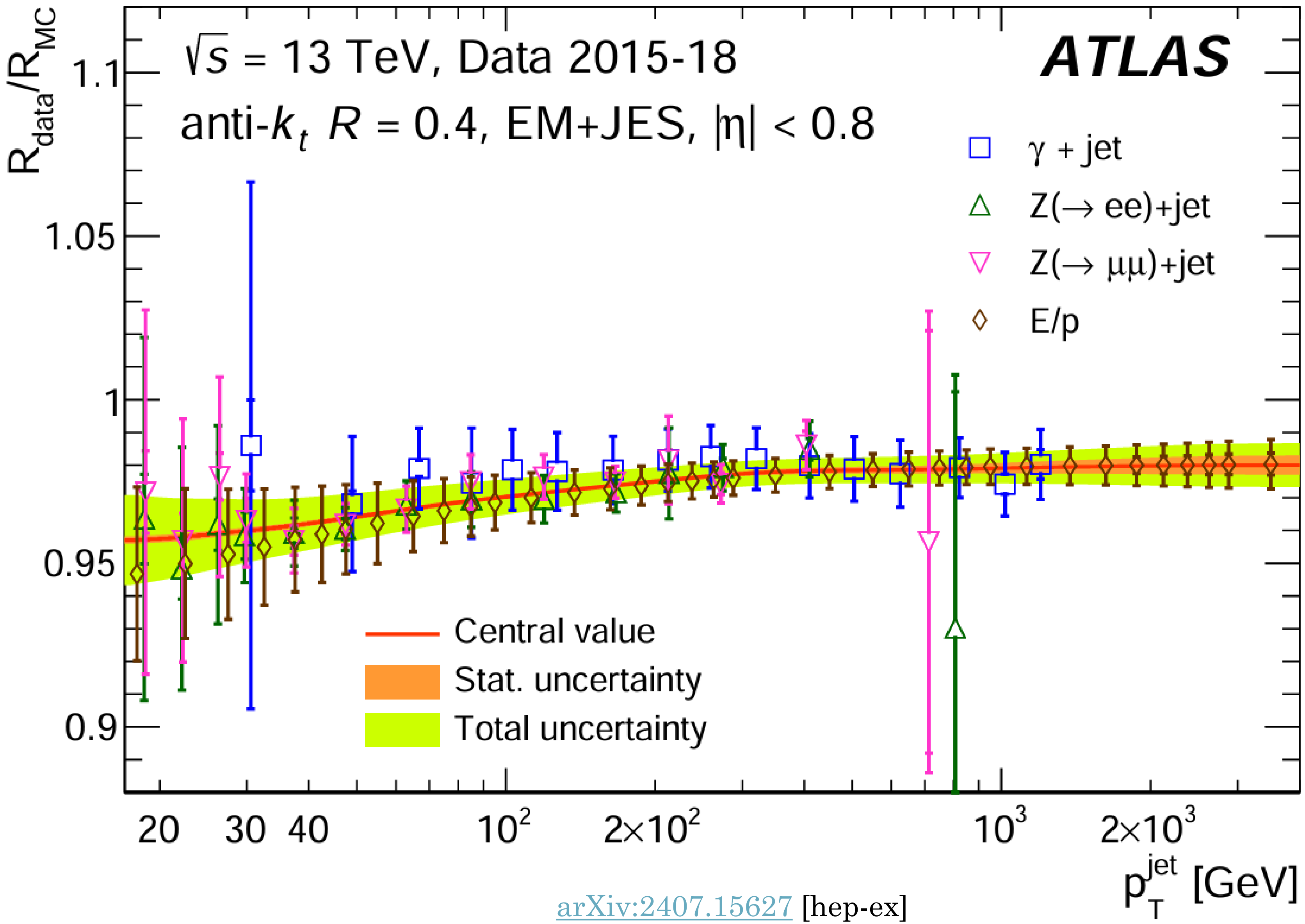
- The JES calibration is a weighted average combining all the measurements



arXiv:2407.15627 [hep-ex]

- The weights are determined by a χ^2 minimization
  - Accounts for correlations in uncertainties within measurements
  - Measurements with smaller uncertainties have larger weights
- Additional uncertainty scaling is applied where measurements have less agreement
- Combining measurements reduces the overall uncertainty
- First time combining single particle response (E/P) with jet momentum balance!

Combined JES Calibration



arXiv:2407.15627 [hep-ex]

In Situ Uncertainties

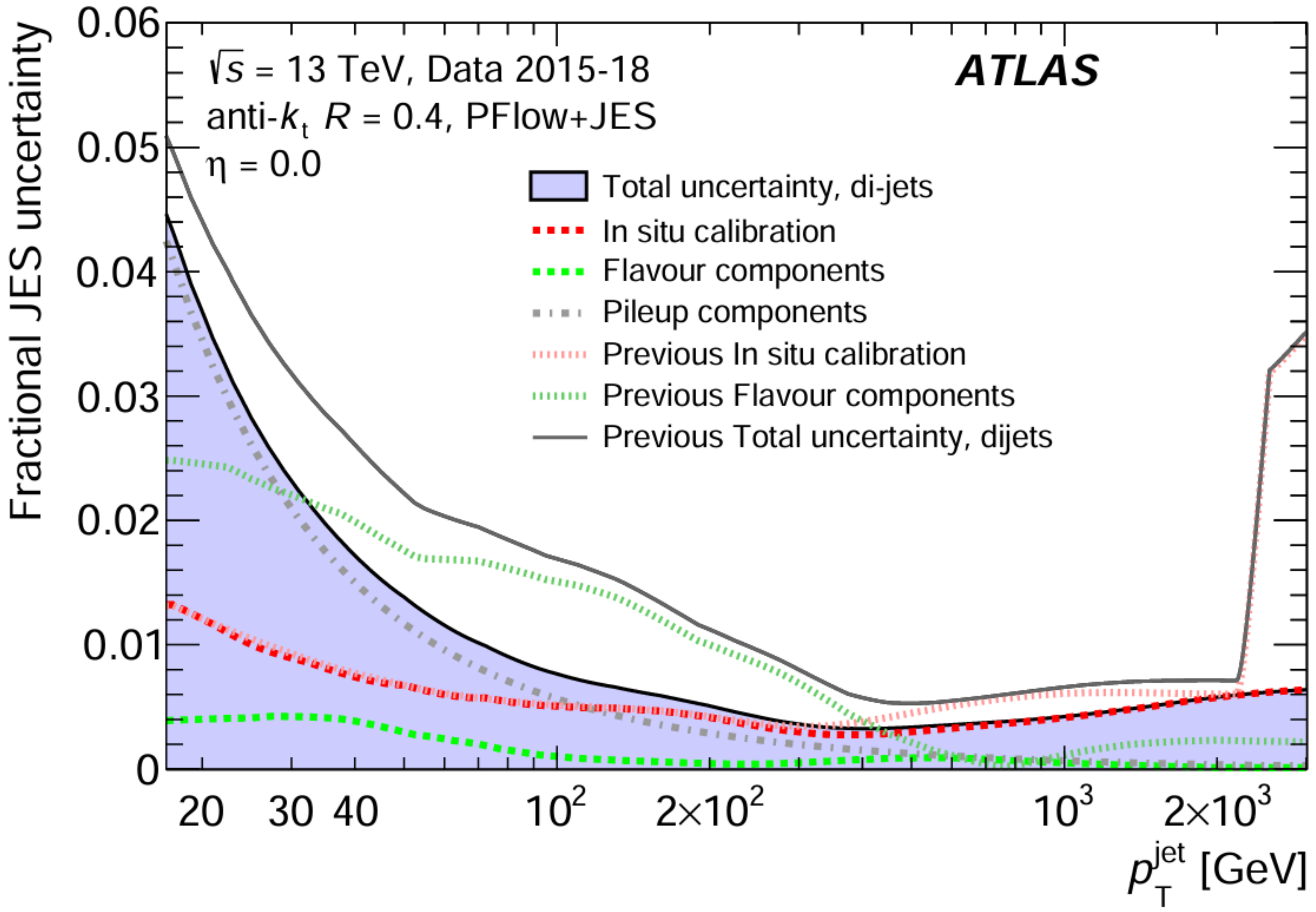
- The full JES calibration uncertainties come from statistical and systematic sources
  - These include jet particle flavour, biases from using select event topologies for the calibration, etc.

- Uncertainties are collected and defined in configurations which ATLAS analyses can use to easily apply uncertainties correctly
  - Contain information on correlations, parametrization, etc.

- Like for the JES, there are sets of uncertainties for the Jet Energy Resolution (JER), Jet Mass Scale (JMS) calibration, and Jet Mass Resolution (JMS)

Final JES Uncertainties

- Shifts from the individual uncertainties are applied to jets
  - Modify their energy and mass
- Analyses are designed to account for the impact of these uncertainties on their results
- Much smaller (world-leading) total uncertainty compared to the previous JES!



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Summary

- Jets are by far the most common object in ATLAS collisions
  - Precise measurements of jet characteristics are very important for most analyses

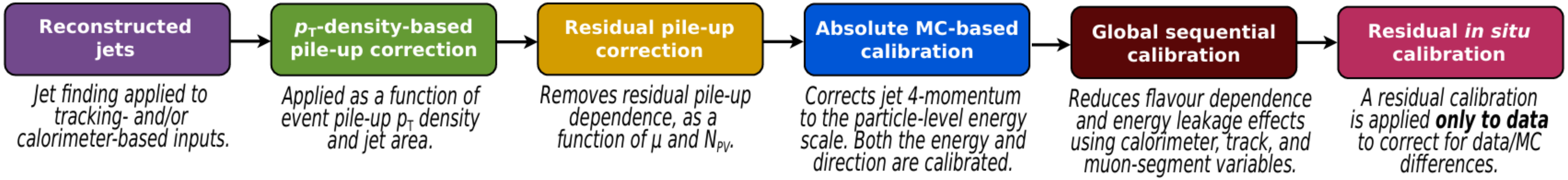
- The JES calibration is crucial to accurately analyse jets in the ATLAS datasets
  - The calibration uncertainties account for the majority of the jet uncertainty and so achieving a precise measurement is a challenging but important effort
  - Currently we can achieve sub 1% uncertainties for most jets!

- Thanks for your attention!
- Many thank for the help from the ATLAS JetEtMiss and In Situ group as well as the Carleton ATLAS group

Backup Slides

Jet Construction in ATLAS

- Many steps go into producing jet objects used by analyses:
  - A jet finding algorithm is used to produce initial objects
  - Numerous corrections and calibrations are used to refine the initial jet object
  - Finally the in situ calibration corrects for differences between data and Monte Carlo simulations
- The Jet Energy Scale (JES) in situ calibration corrects the reconstructed jet energy to match simulation
  - Derived from the differences between data and simulation using well understood reference objects
  - A similar calibration also exist for the Jet Mass Scale (JMS)

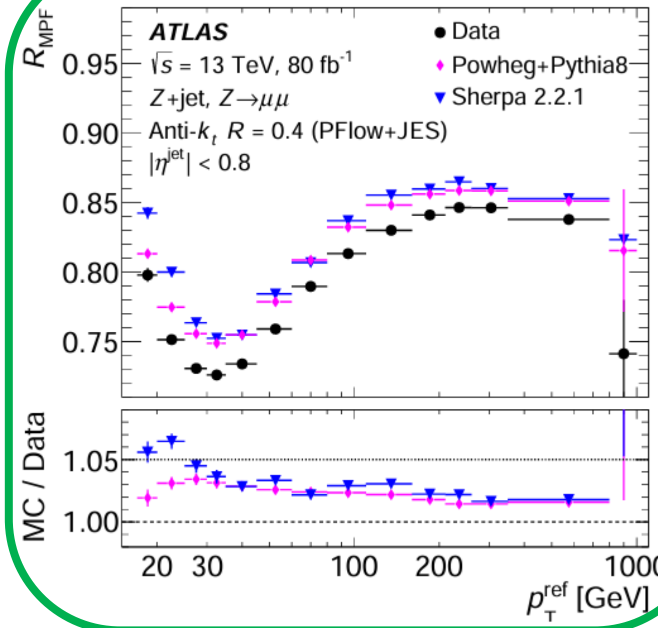


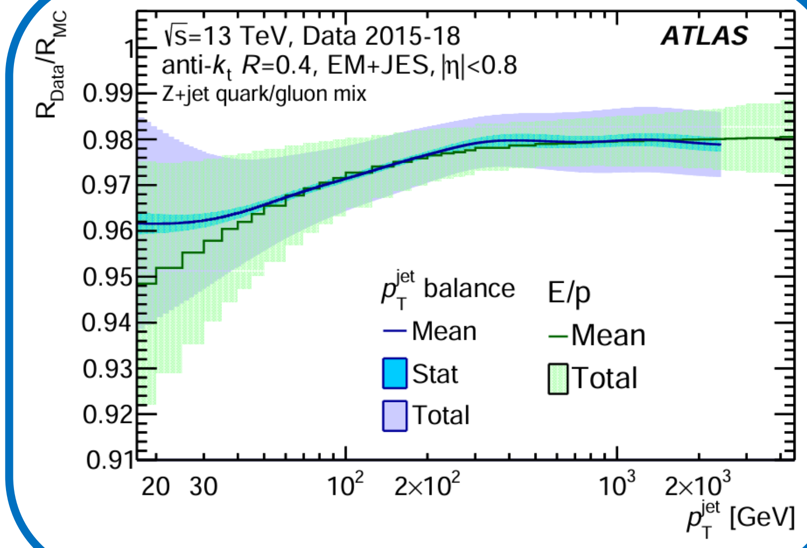
arXiv:2007.02645 [hep-ex]

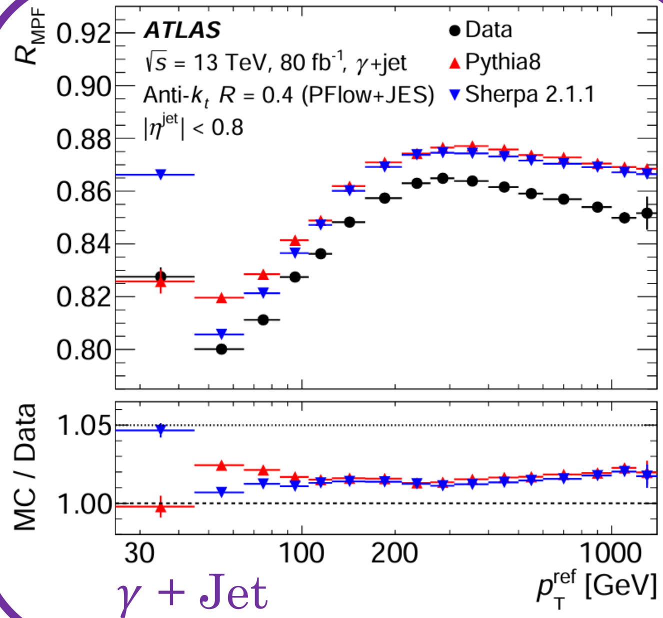
Carleton ATLAS

JES Combinations

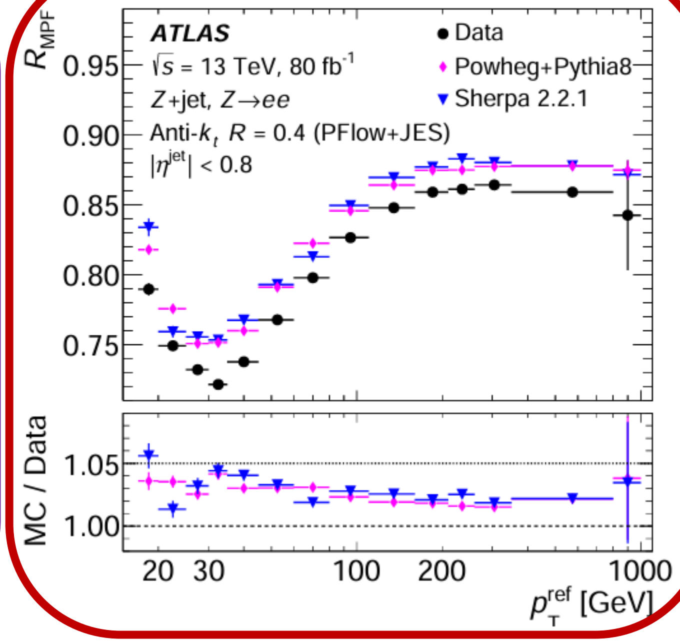
- Multiple measurements are used to evaluate the JES across a range of pT values
  - Single Particle Response (E/p)
  - Photon + Jet
  - Z → ee + Jet
  - Z → μμ + Jet







γ + Jet



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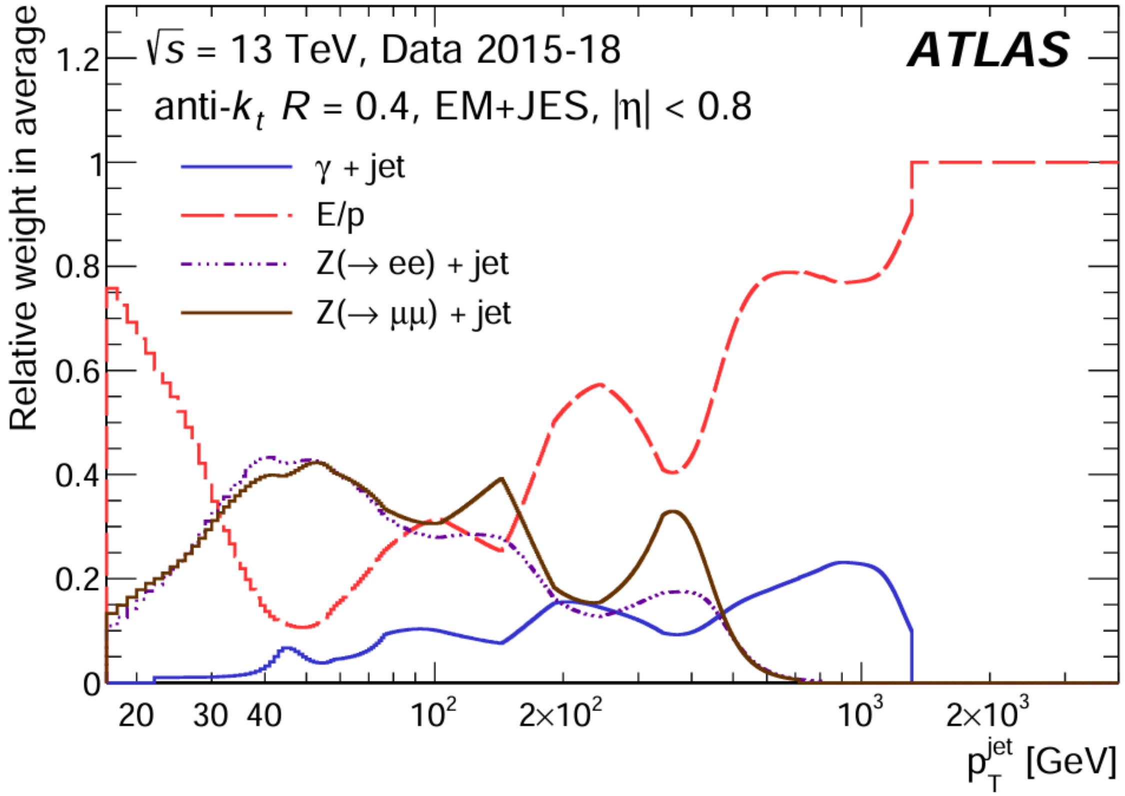
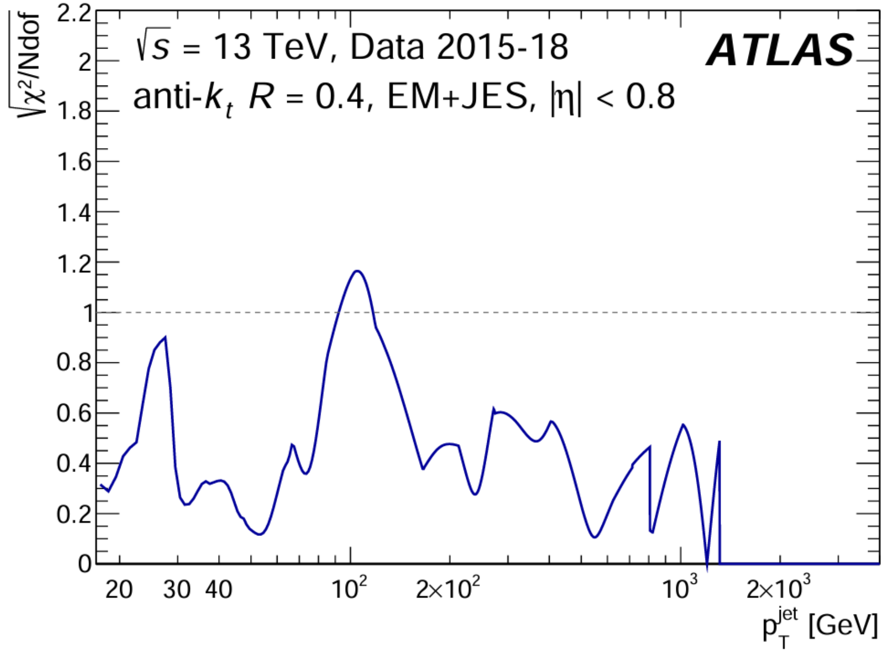
JES Statistical Combination

- A fine binning is used for the combination
- For each bin the JES response is determined from a weighted average from each method's interpolated result





- A χ^2 minimization is used to weigh the inputs for each bin in pT
  - Weights are proportional to the inverse of the square uncertainties
  - Uncertainties are rescaled by the tension $\left(\sqrt{\chi^2/dof}\right)$ if it is larger than 1

arXiv:2407.15627 [hep-ex]