Jet suppression measurement with the ATLAS detector

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On behalf of the ATLAS Collaboration

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Hot quarks 2016

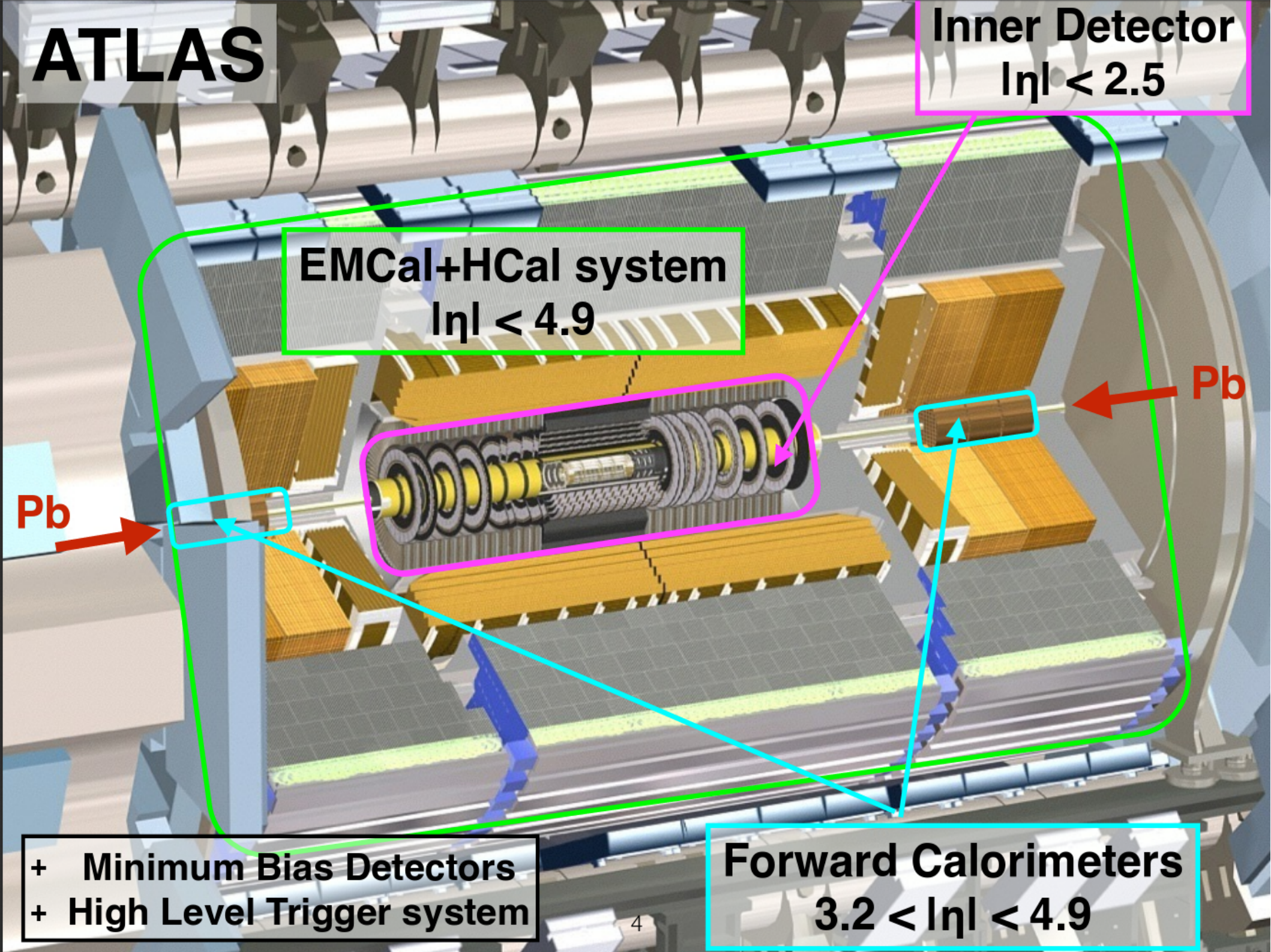
Introduction

- Broad program of jet suppression and modification measurements in Pb+Pb collisions by ATLAS
- Study of jets in Pb+Pb collisions should tell us about e.g.:
  - Properties of de-confined matter created in heavy ion collisions
  - Radiation of energetic color charges in the de-confined medium
- LHC heavy ion runs at ATLAS:
  - Run 1: Pb+Pb: $\sqrt{s_{NN}}$ = 2.76 TeV, L_{int} = 0.15 nb^{-1}

    pp: $\sqrt{s}$ = 2.76 TeV, L_{int} = 4.2 nb^{-1}

    p+Pb: $\sqrt{s_{NN}}$ = 5.02 TeV, L_{int} = 29 nb^{-1}
  - Run 2: Pb+Pb: $\sqrt{s_{NN}}$ = 5.02 TeV, L_{int} = 0.5 nb^{-1}

    pp: $\sqrt{s}$ = 5.02 TeV, L_{int} = 28 nb^{-1}


ATLAS
Inner Detector
|η| < 2.5
EMCal+HCal system
|η| < 4.9
Pb
Pb
+ Minimum Bias Detectors
+ High Level Trigger system
Forward Calorimeters
3.2 < |η| < 4.9

Jets

- Jets probe the medium created in Pb+Pb collisions
- ATLAS has published results from run 1 on jet fragmentation, jet R_{AA} , azimuthal dependence of jet production, dijet asymmetry and production of nearby jets
- New data from Run 2 will allow significant improvements relative to the older measurements, mainly:
  - Extended p_T reach for jet R_{AA} (measurement up to 800 GeV in Run 2)
  - Differential measurement of jet fragmentation functions
  - Reduced statistical uncertainties in the measurement of nearby jets

Inclusive jet suppression

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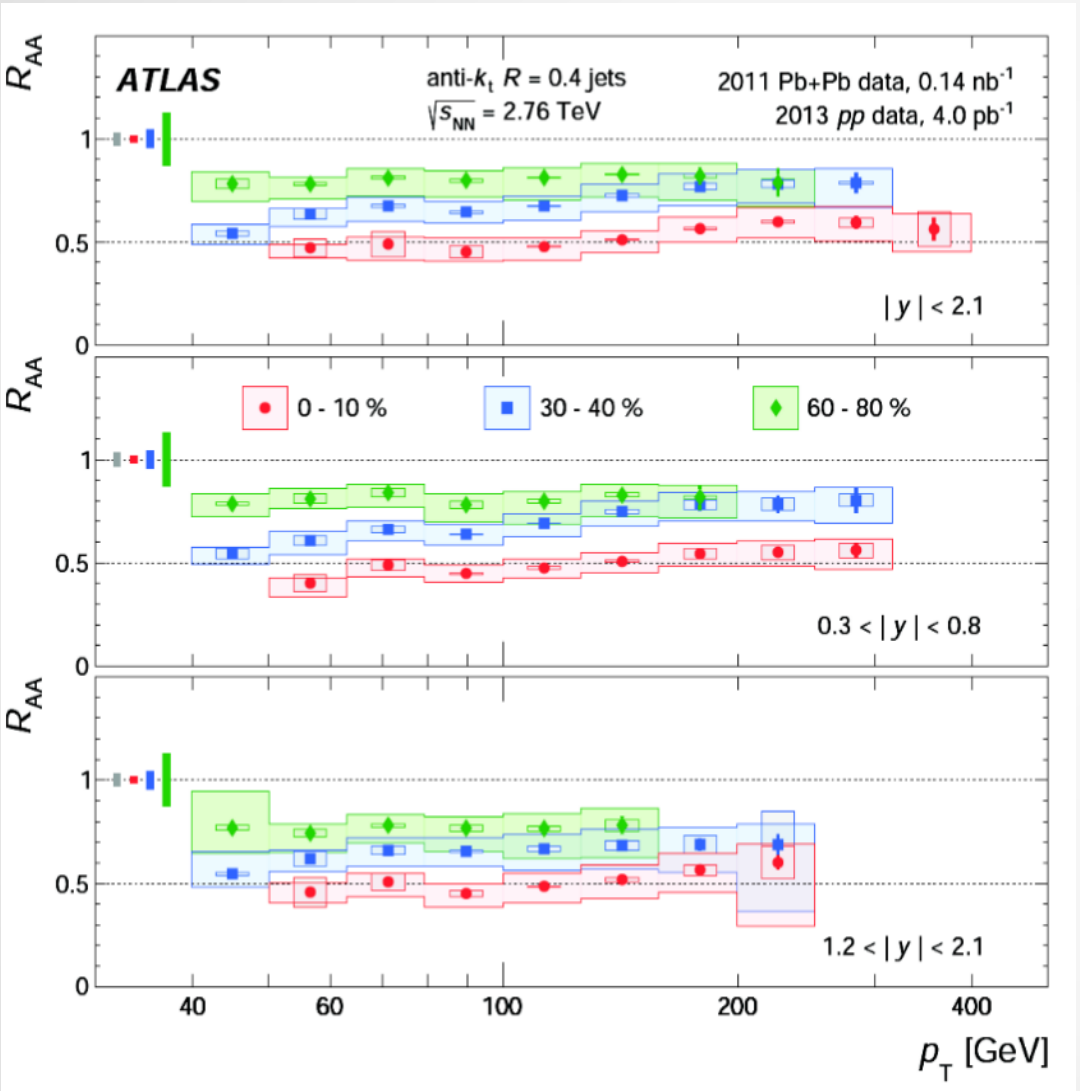


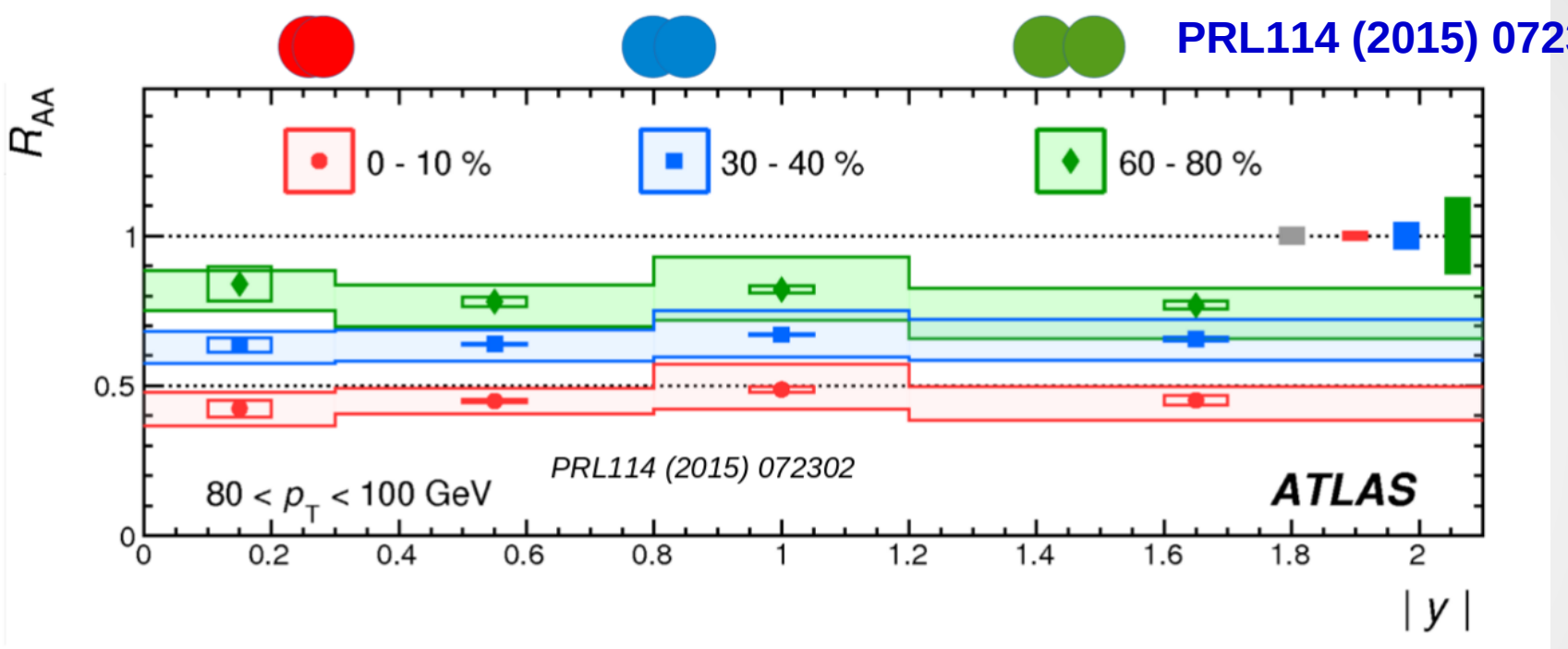
A modest grow of jet R_{AA} with increasing jet p_T

Still a significant suppression even for 60-80% centrality bin

Practically no rapidity dependence

$$R_{\mathrm{AA}} = \frac{\frac{1}{N_{\mathrm{evnt}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}^{PbPb}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}\Big|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}} \times \frac{\mathrm{d}^2 \sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

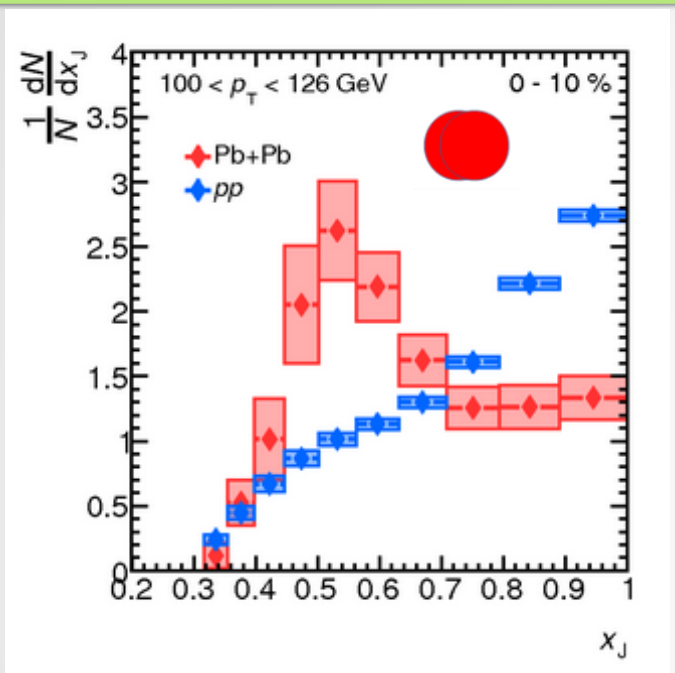
More on the rapidity dependece

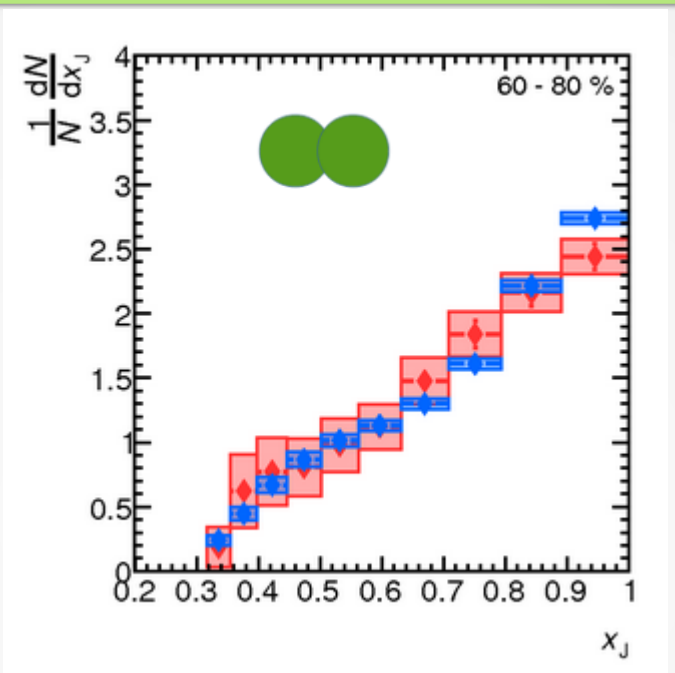


- Increasing rapidity → steeper spectrum → decrease of R_{AA}
- Increasing rapidity → higher quark fraction → increase of R_{AA}
- R_{AA} is completely flat with rapidity → Cancellation ???
- This measurement at 5 TeV could help determine whether the different shape of spectra may reduce the cancelation

Dijet asymmetry measurement

ATLAS-CONF-2015-01





$$x_J = \frac{p_{T,1}}{p_{T,2}}$$

See more in the presentation of L.B.Havener just after the lunch

- Back to back jets see different path lengths, destroying the expected p_T-balance
- Insightful probe of differential energy loss within an event
- Dijets were corrected for jet energy resolution by 2D Bayesian unfolding
- Enhancement of asymmetric dijets in Pb+Pb, relative to *pp* as the centrality increases

Dijet asymmetry measurement

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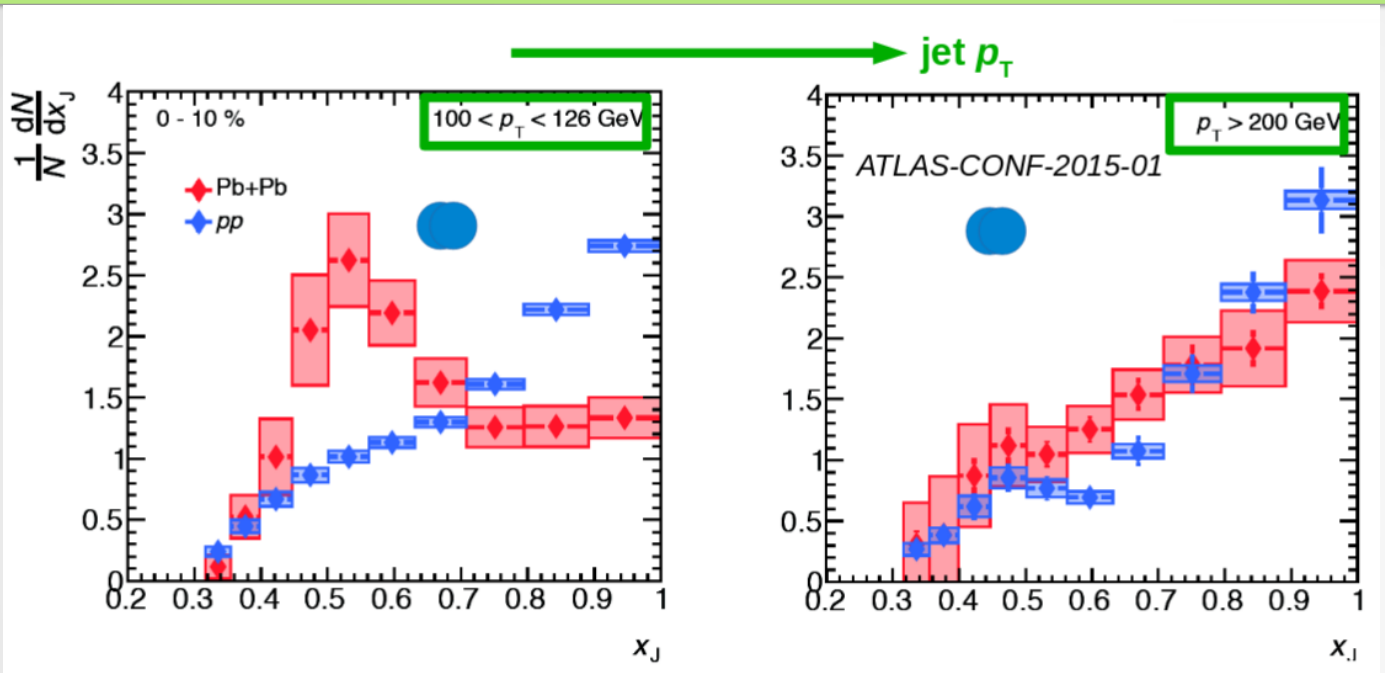

$$x_J = \frac{p_{T,1}}{p_{T,2}}$$

See more in the presentation of L.B.Havener just after the lunch

- Significant shift toward large dijet asymmetry in central Heavy Ion collisions w.r.t. pp reference
- Much less modification at high p_T
- Per jet fluctuations of quenching?
- Change in the flavor compositions?

Jet fragmentation

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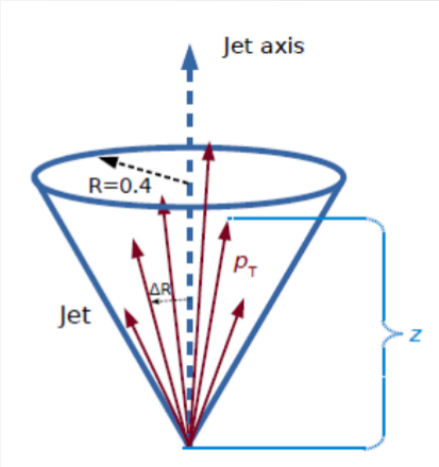

- How much is the jet structure modified?
- Jet fragmentation functions (FF) are defined as:

$$D(p_{\mathrm{T}}) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}p_{\mathrm{T}}^{\mathrm{ch}}} \qquad D(z) = \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}N_{\mathrm{ch}}}{\mathrm{d}z} \qquad z = \frac{p_{\mathrm{T}}}{p_{\mathrm{T}}^{\mathrm{jet}}} \cos\Delta R$$

- N_{ch} is the number of charged particles associated to a jet
- Measurement was done for R = 0.4 jets differentially in η and p_T
- Jet substructure measured using charged tracks starting at p_T = 1 GeV
- FF are background subtracted, corrected for tracking efficiency and fully unfolded with 2D Bayesian unfolding

Jet fragmentation spectra

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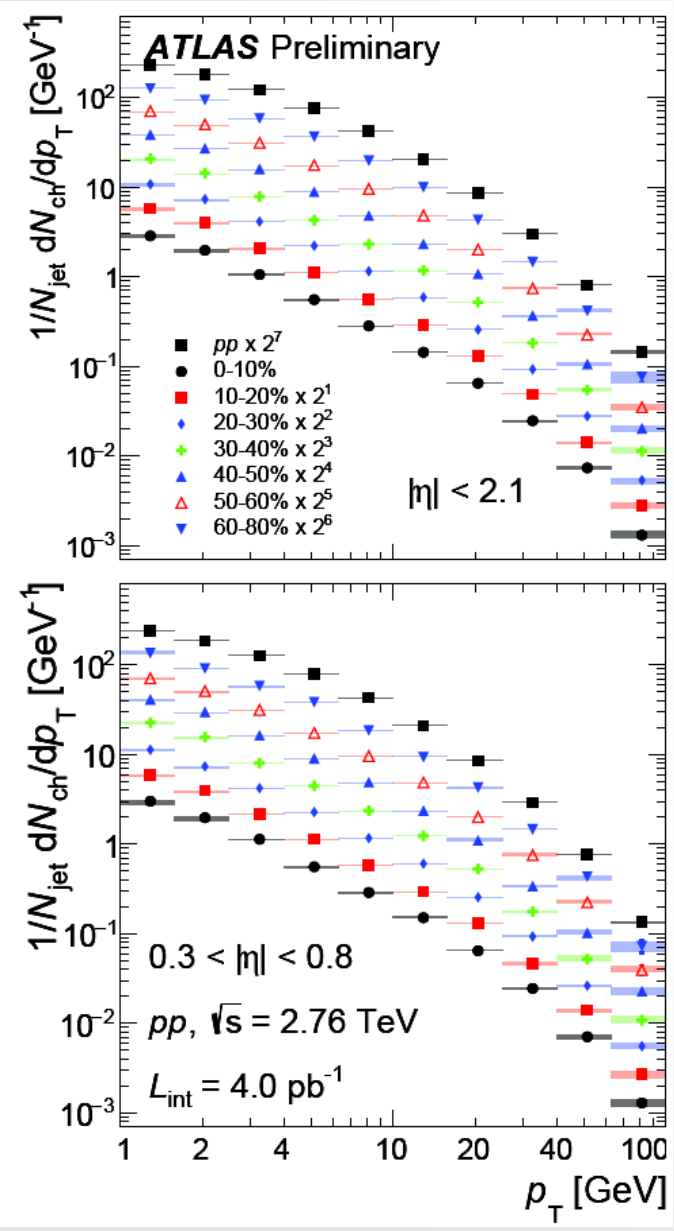
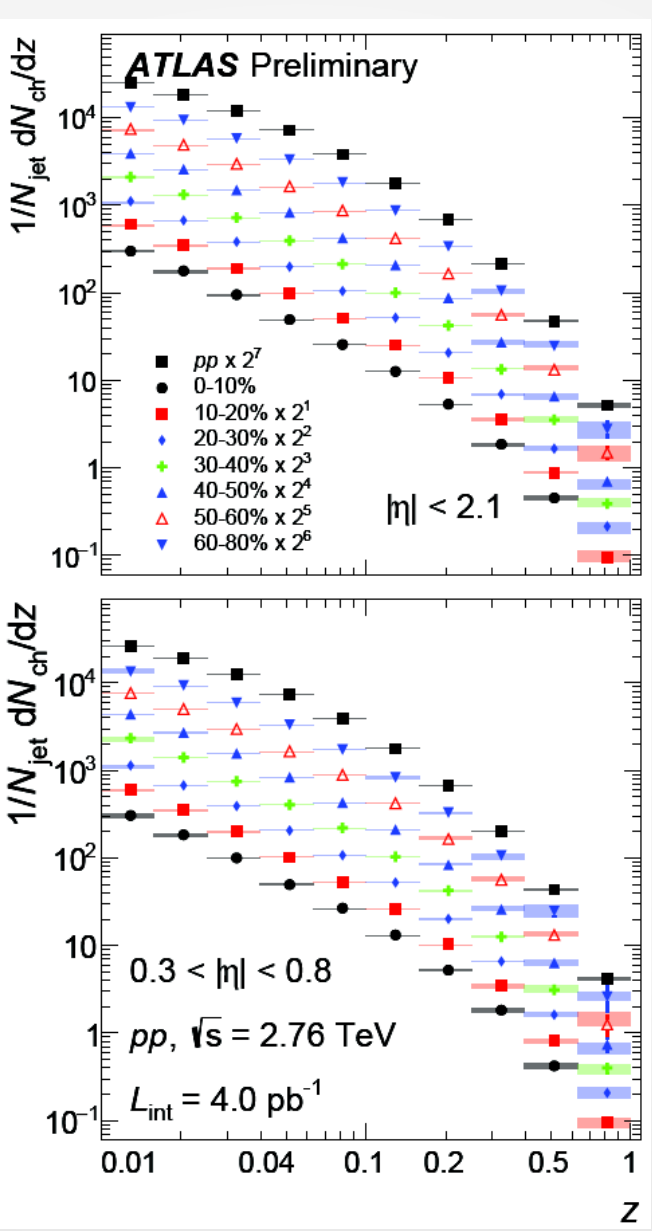
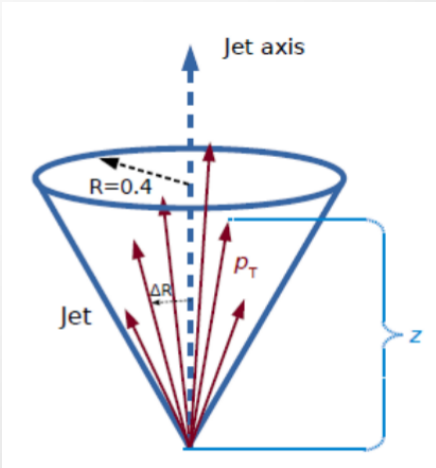




$$D(p_T) \equiv \frac{1}{N_{jet}} \frac{dN_{ch}(p_T)}{dp_T}$$

$$D(z) \equiv \frac{1}{N_{jet}} \frac{dN_{ch}}{dz}$$

$$z \equiv \frac{p_T}{p_T^{jet}} \cos \Delta R$$



Jet fragmentation ratios

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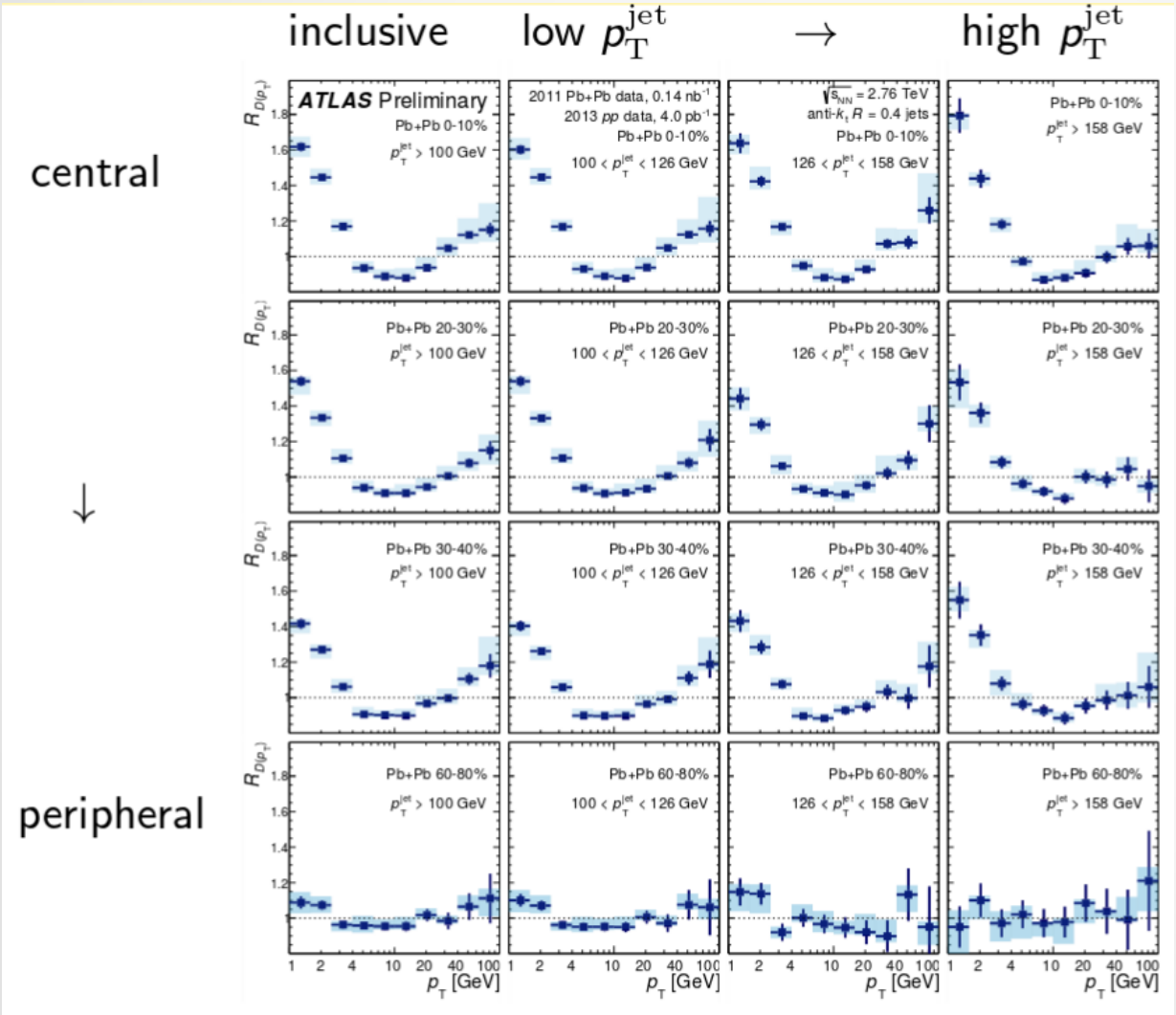
Ratios of $D(p_T)$ fragmentation functions



Centrality dependence

- Enhancement at low and high p_T
- Suppression at intermediate p_T

Jet p_T dependence

- No significant dependence on jet p_T

Rapidity dependence

- Hint of rapidity dependence
- Consistent with prediction in arXiv: 1504.05169

Jet fragmentation – flow of particles

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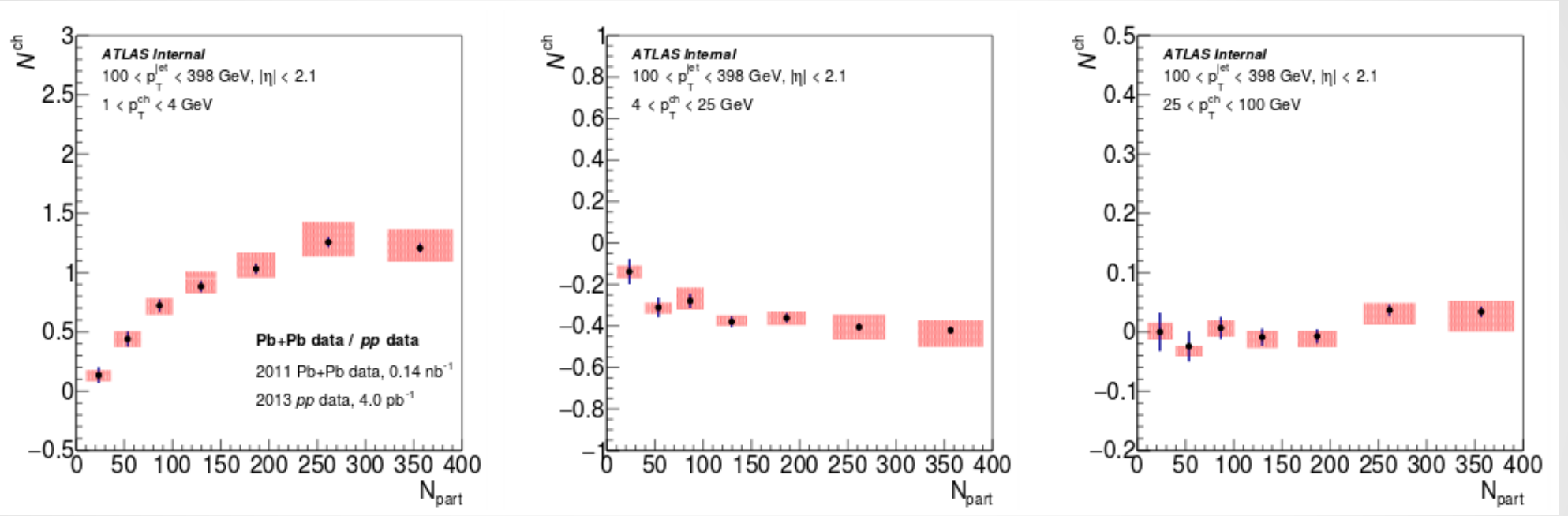

- To quantify the flow of particles as a function of N_{part}:

$$N^{ch} \equiv \int_{p_{T,min}}^{p_{T,max}} \left(D(p_T)|_{cent} - D(p_T)|_{pp} \right) dp_T$$

- Tells us how many extra/missing particles are present in a given p_T range
- Observed a clear increase of yields of particles with low tranverse momenta as the collision's centrality increases
- Particles with p_T > 4 GeV do not exhibit noticeable variations with centrality

Jet fragmentation – flow of energy

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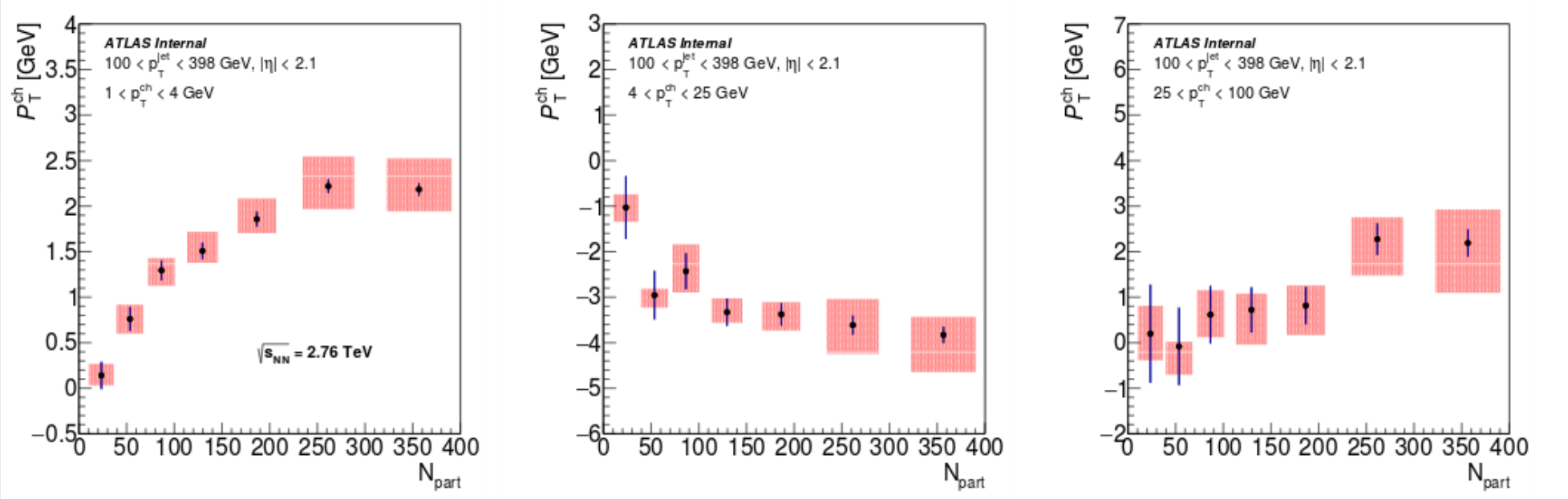


- To quantify the flow of momentum as a function of N_{part}:

$$P_{\text{T}}^{\text{ch}} \equiv \int_{p_{\text{T,min}}}^{p_{\text{T,max}}} \left(D(p_{\text{T}})|_{\text{cent}} - D(p_{\text{T}})|_{\text{pp}} \right) p_{\text{T}} \, \mathrm{d}p_{\text{T}}$$

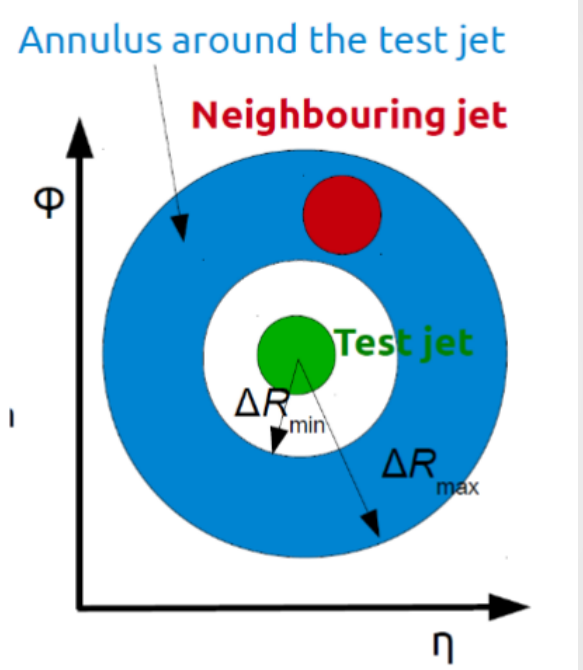
- Tells us how much p_{T} is carried by extra/missing particles in a given p_{T} range

Nearby jets

PLB 751 (2015) 376

- The rate of the neighbouring jets that accompany a test jet was measured:

$$R_{\Delta R} = \frac{1}{\mathrm{d}N_{\mathrm{jet}}^{\mathrm{test}}/\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}} \sum_{i=1}^{N_{\mathrm{jet}}^{\mathrm{test}}} \frac{\mathrm{d}N_{\mathrm{jet},i}^{\mathrm{nbr}}}{\mathrm{d}E_{\mathrm{T}}^{\mathrm{test}}}(E_{\mathrm{T}}^{\mathrm{test}}, E_{\mathrm{T,min}}^{\mathrm{nbr}}, \Delta R)$$



- Neighboring jet production quantified using this quantity previously measured at Tevatron

- To quantify the centrality dependence the central to peripheral ratios $\rho(R_{\Delta R})$ are evaluated

Nearby jets

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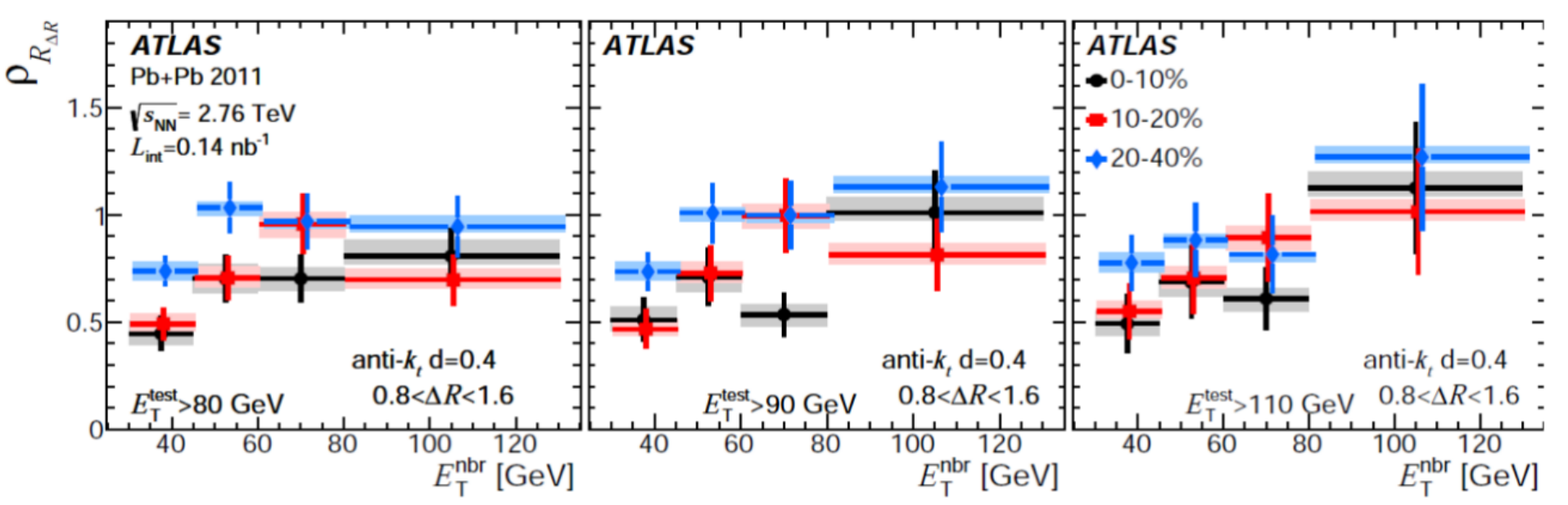
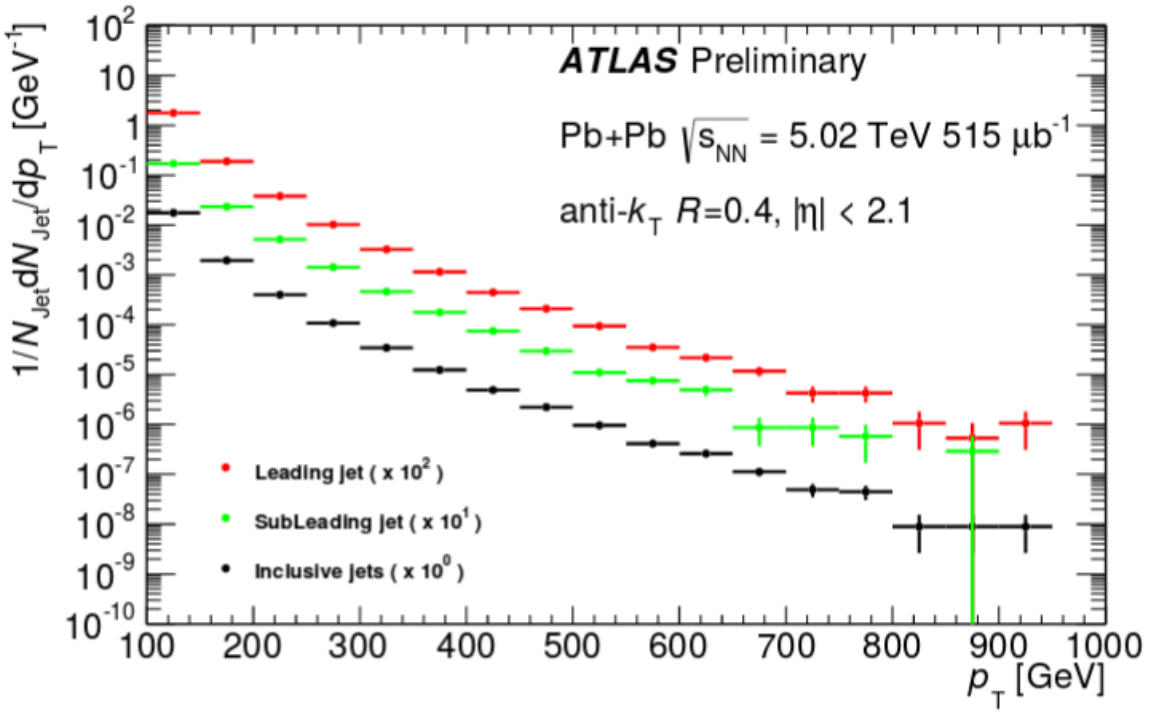


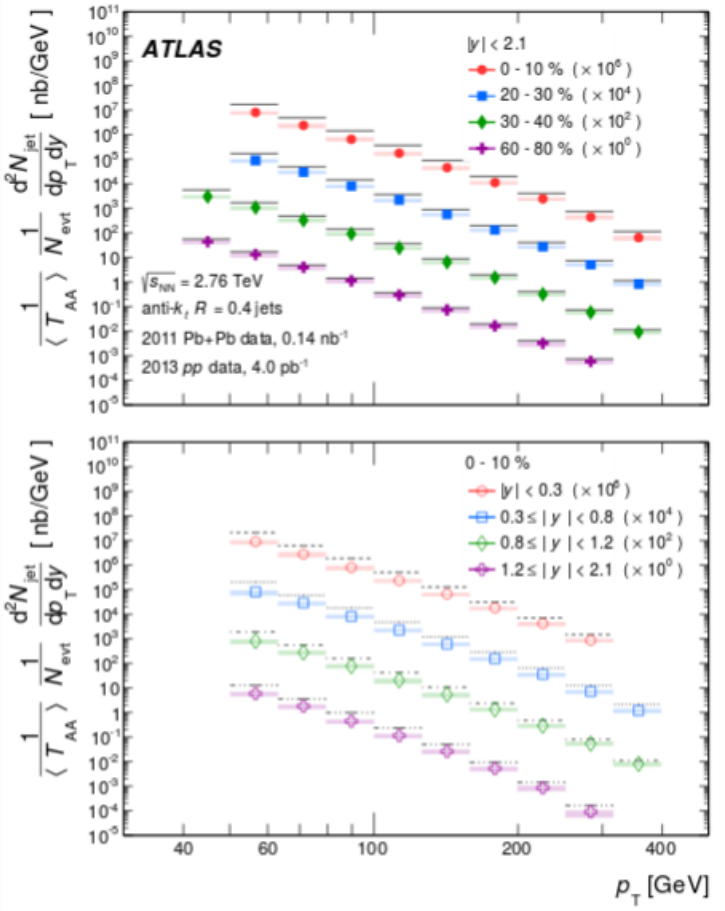
- Central to peripheral ratio of $R_{\Delta R}$ as a function of neighboring jet E_T
- Decrease of suppression (by a factor ≈ 2 in central collisions) with increasing jet E_T
- With increased statictics in Run 2 we expect a significant reduction in statistical uncertainties

Outlook - Jets

Run 1

Run 2





May double the p_T reach

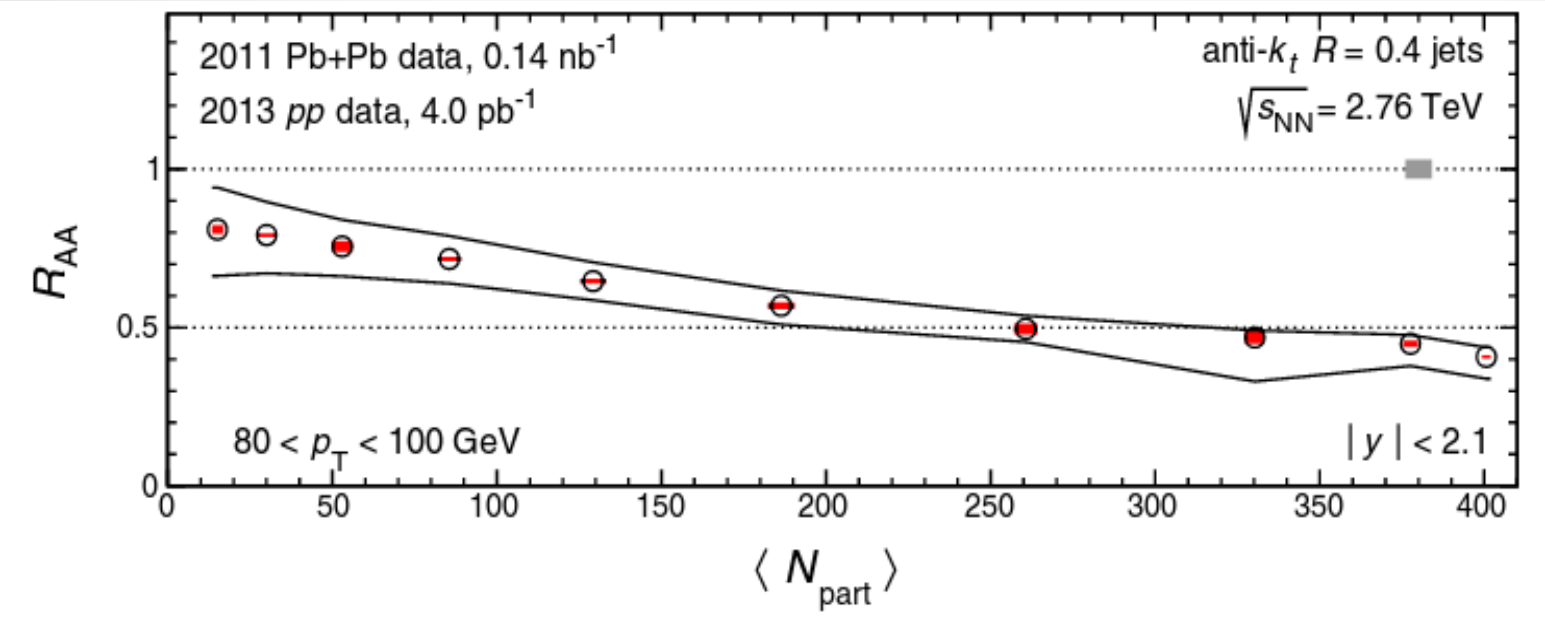
Summary

- Broad program of jet-based imaging of the hot nuclear medium in ATLAS
- Inclusive jets in Pb+Pb are suppressed relatively to *pp* up to a factor of 2, no dependence on rapidity
- First fully corrected dijet measurement
  - Enhancement in Pb+Pb, relatively to *pp* as the centrality increases
  - Clear dependence on the p_T of the leading jet in contrast to inclusive jets

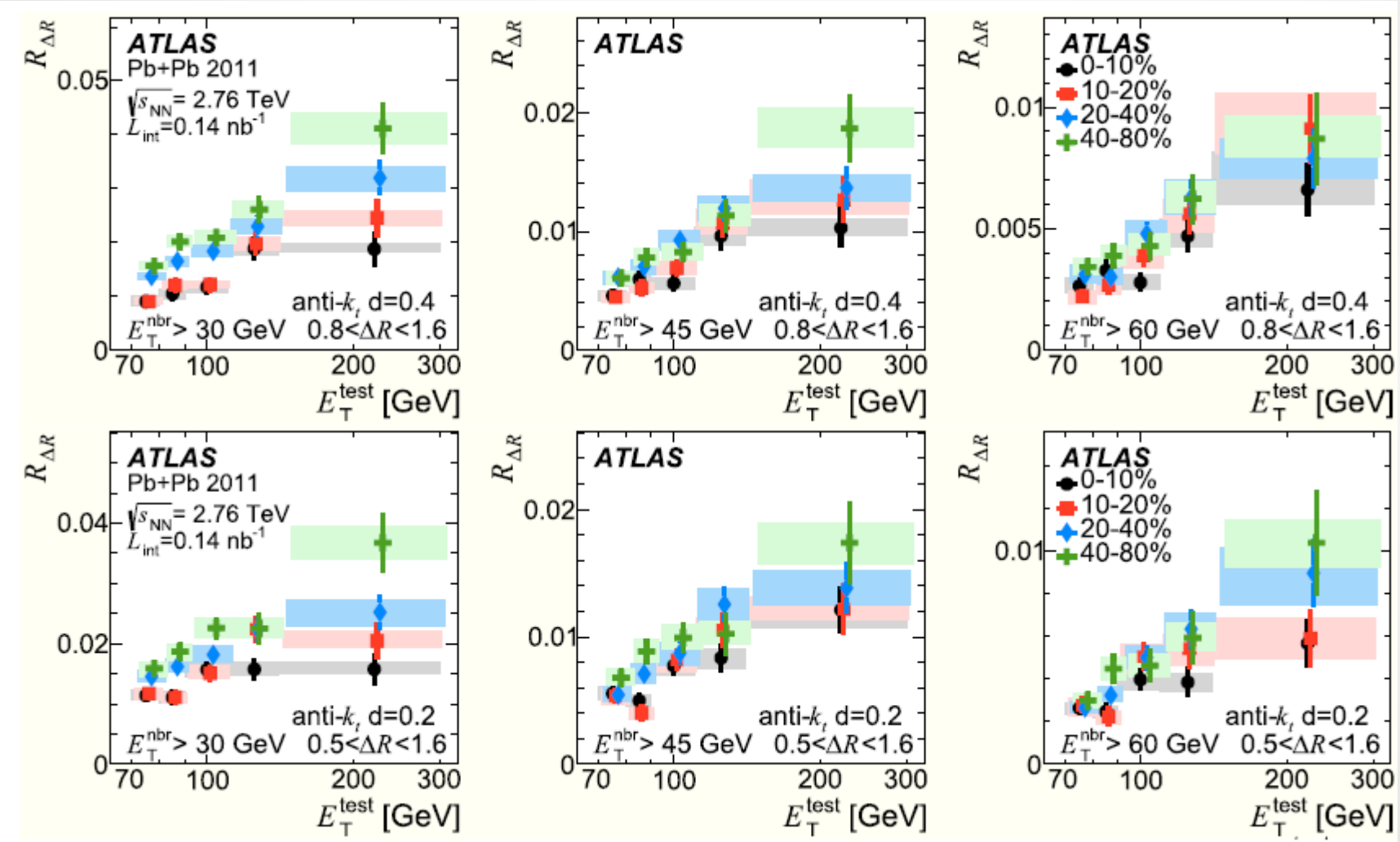
Summary

- Jet internal structure measured differentially in jet p_T and rapidity, observed modest but significant modification of jet fragmentation functions
- Production of nearby jets quantified
- ATLAS is expected to perform exciting high-statistics jet measurement in Run 2!
- https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

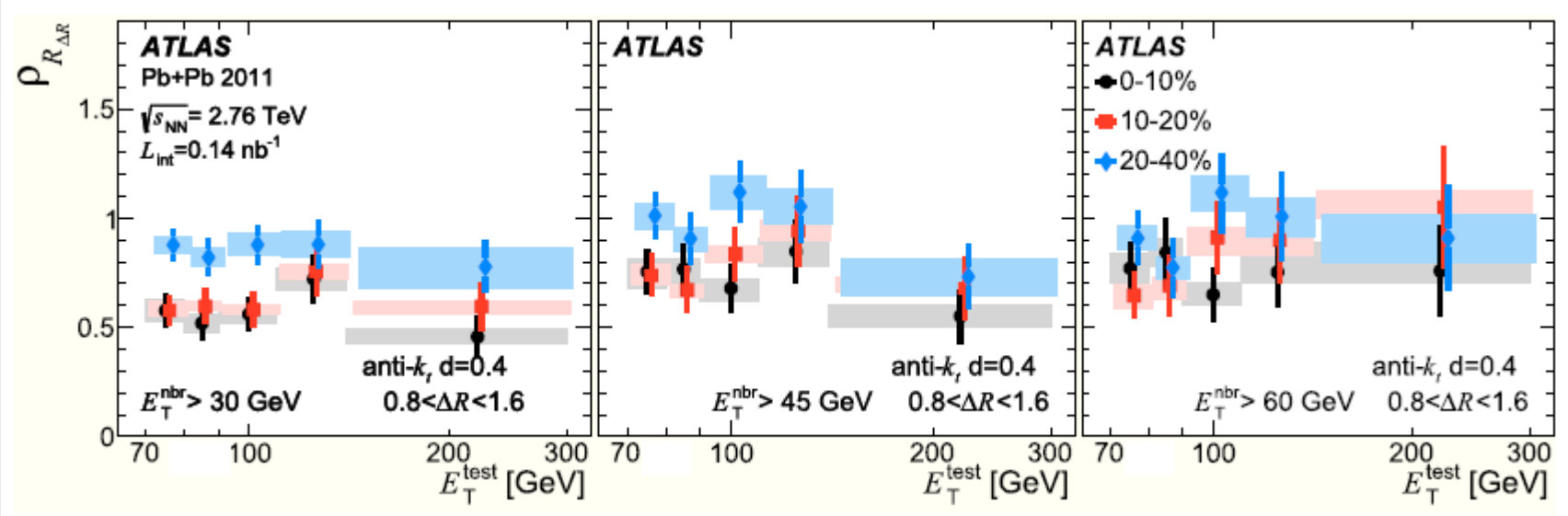
BackUp – Inclusive jets



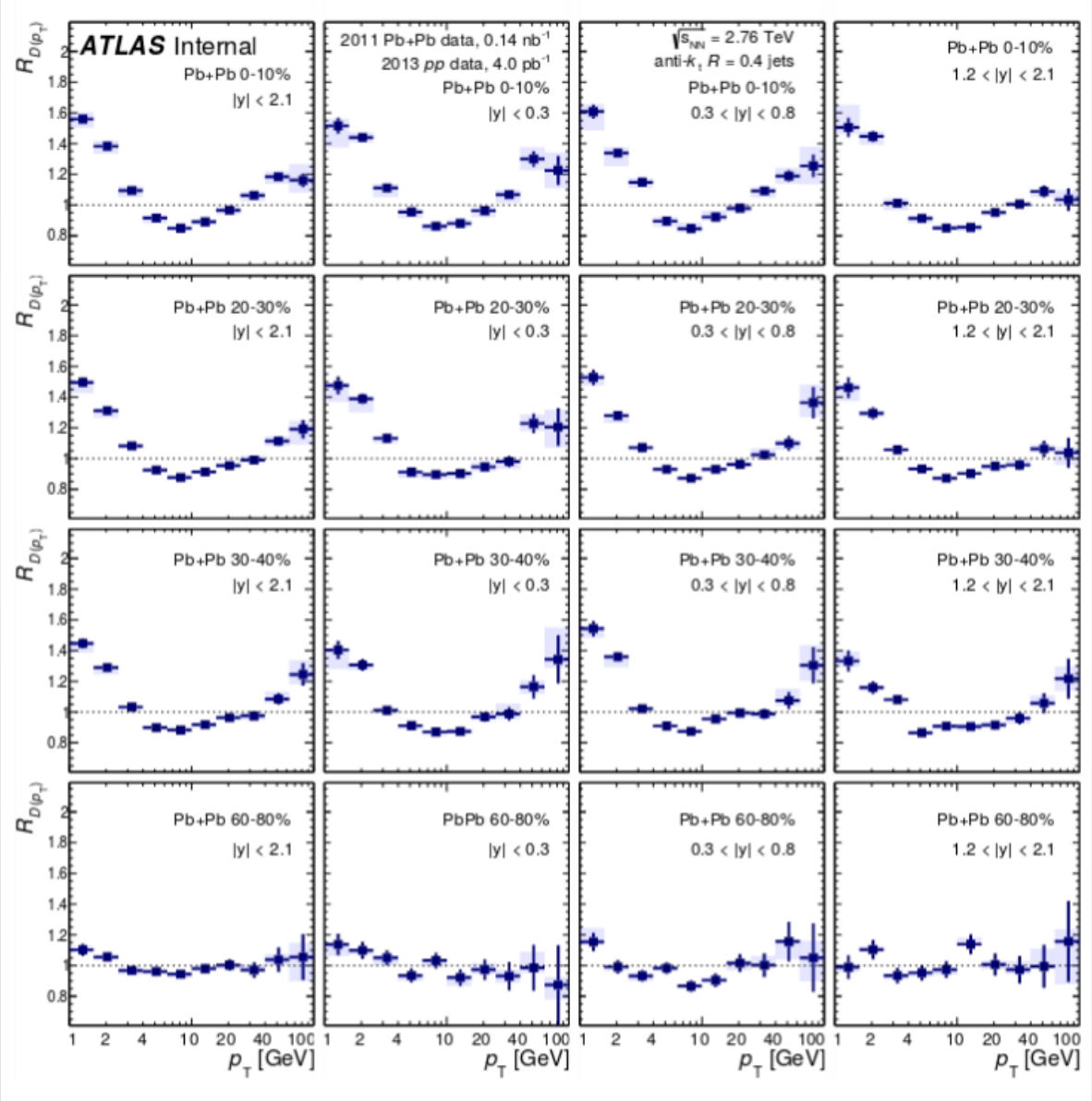
BackUp – nearby jets



BackUp – nearby jets

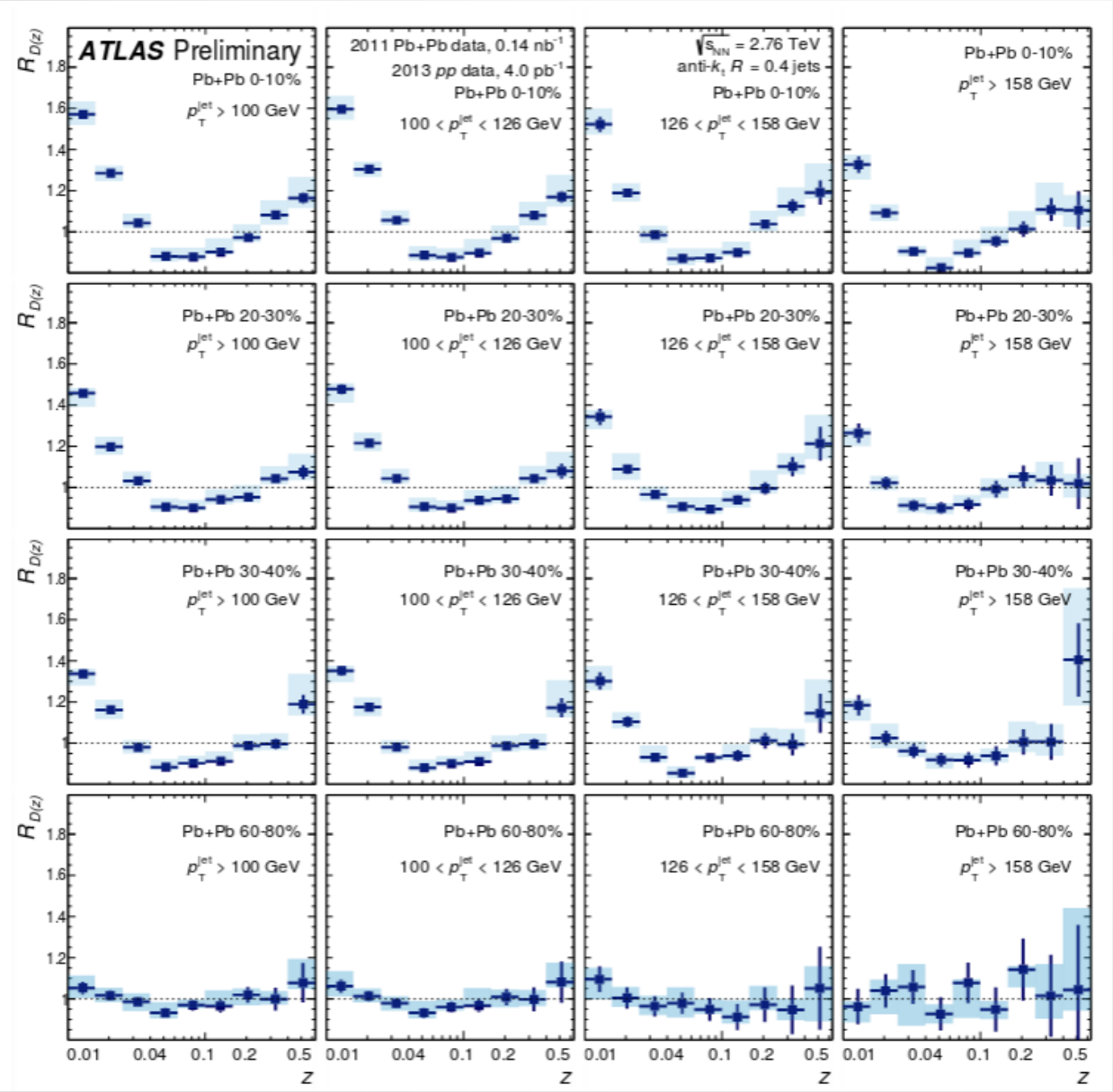


BackUp – Jet fragmentation



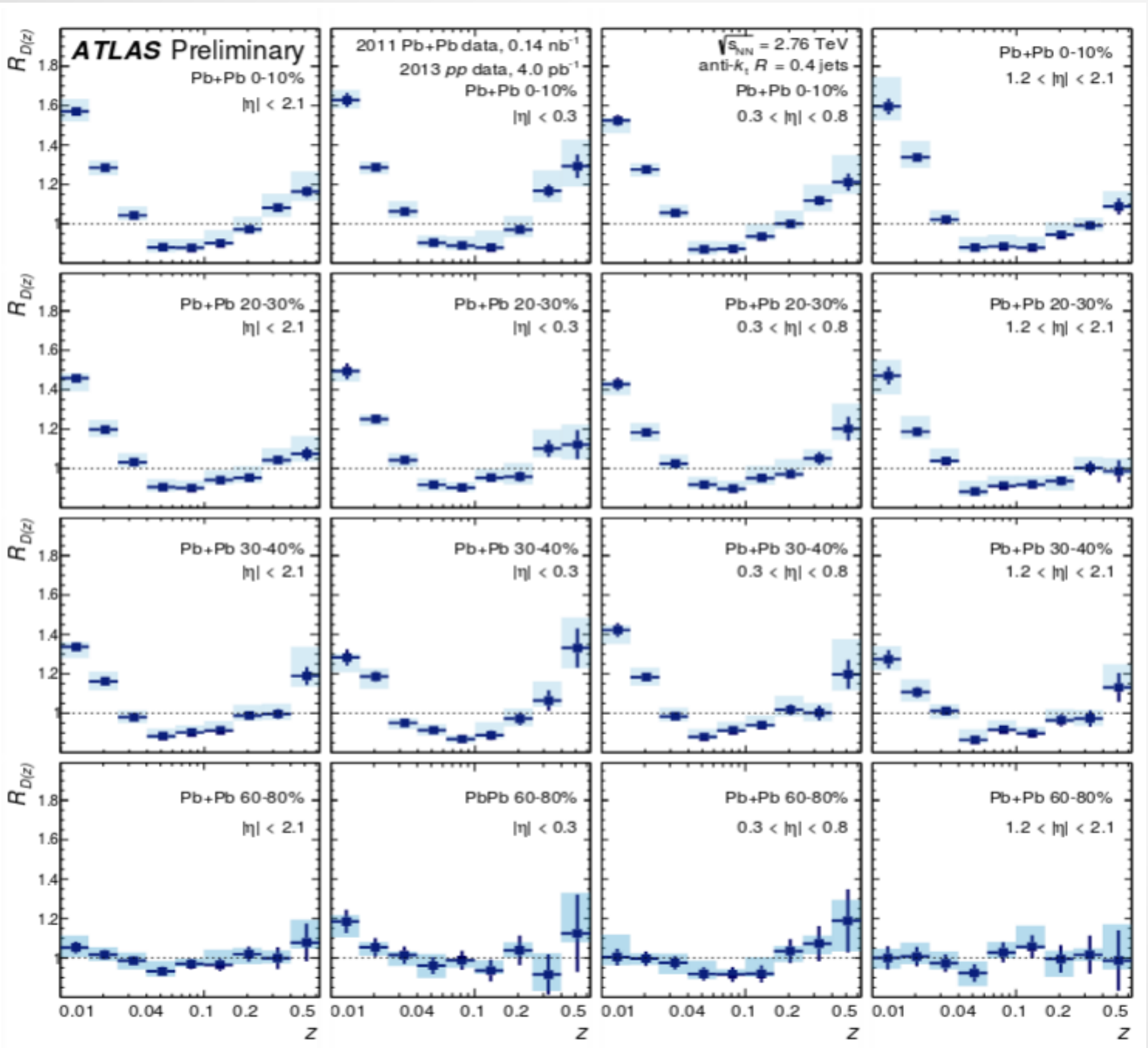
- Ratios of FF $D(p_T)$ for different centrality and rapidity bins

BackUp – Jet fragmentation



- Ratios of FF $D(z)$ for different centrality and jet p_T bins

BackUp – Jet fragmentation



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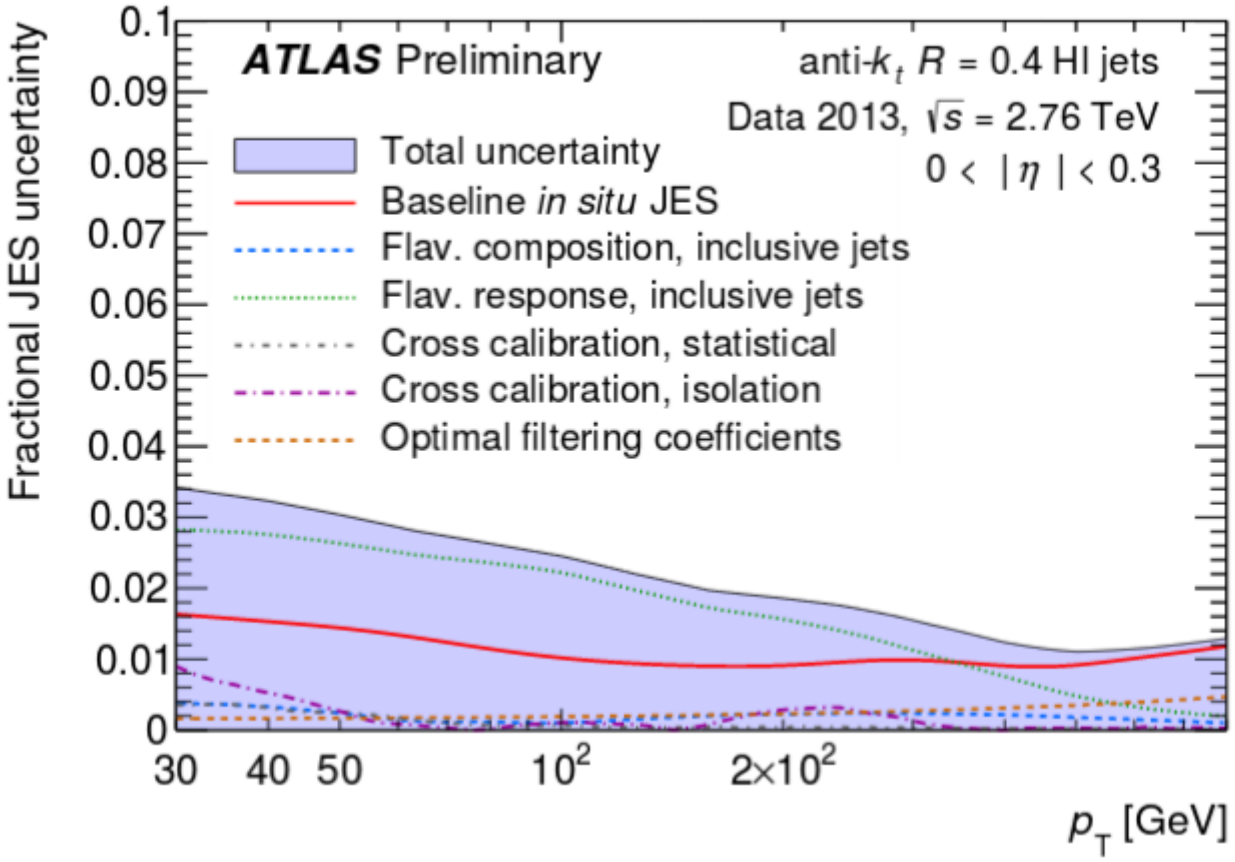
BackUp – JES uncertainty