Measurement of jet mass using ATLAS

Probing quark-gluon matter with jets

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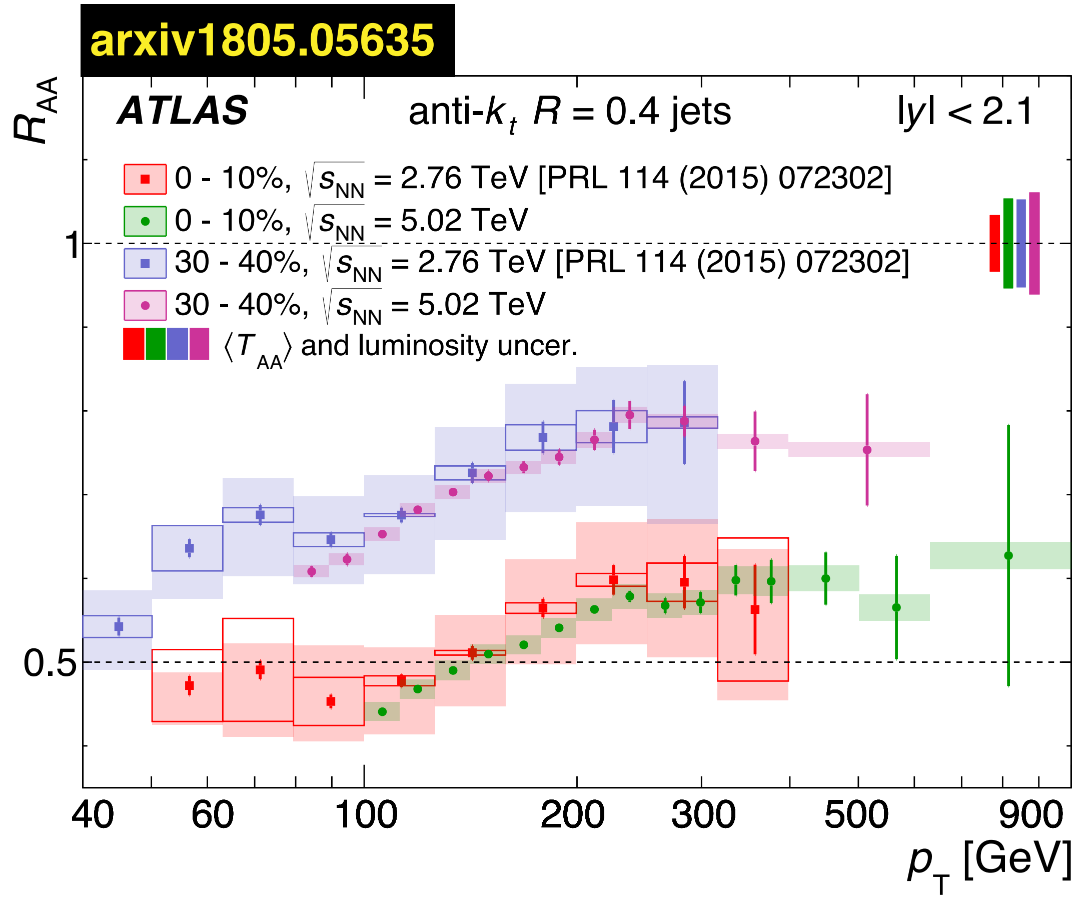
Yongsun Kim

University of Illinois at Urbana Champaign

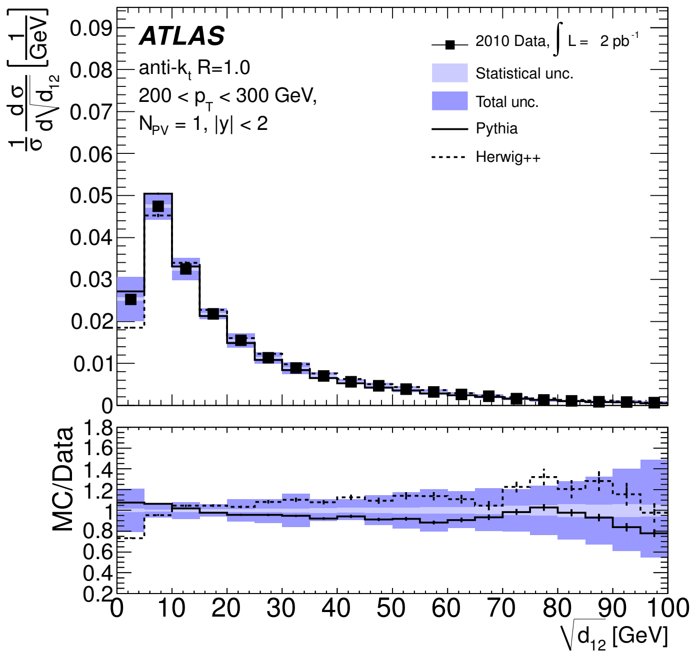
ATLAS collaboration

Motivation: Jet quenching in Heavy ion collisions

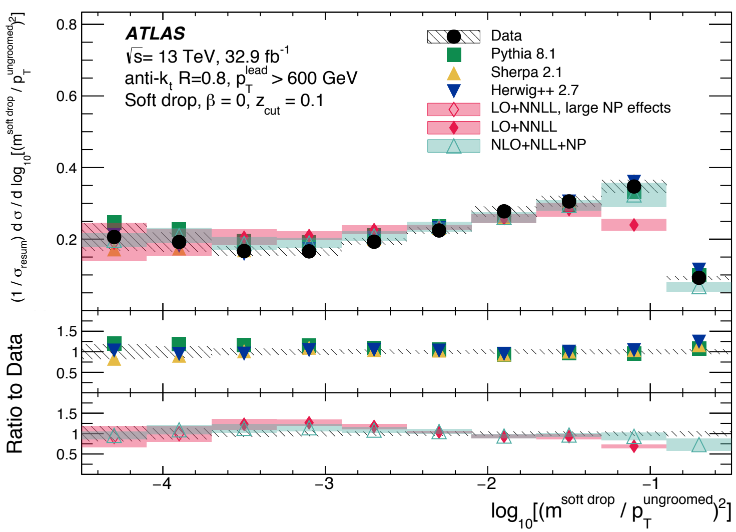


- **Jet R_{AA} Results in Run I (2011) vs Run II (2015)**
  - Huge improvement in analysis techniques and understanding in detector
  - Now, systematic uncertainties are only 3% level 100 < p_T < 500 GeV/c
  - **Ready for the precision measurement for jet substructure**

meanwhile in pp community: Re-clustering jet into subjet



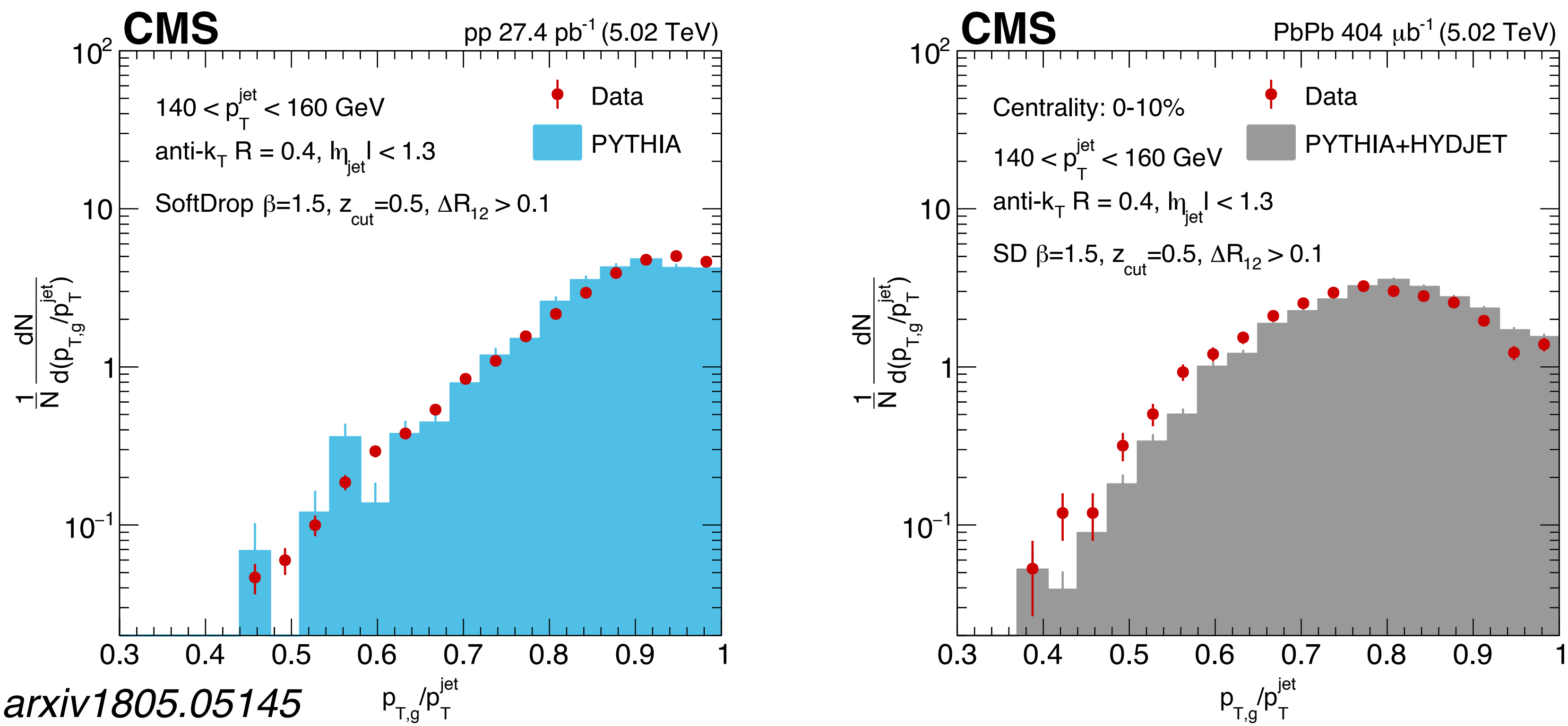
- **Splitting and filtering**
  - Butterworth et al (2008)
  - Search for boosted objects



- **SoftDrop**
  - Larkoski et al (2014)
  - Well selling algorithm in QCD society
  - Appreciated by analytical calculation

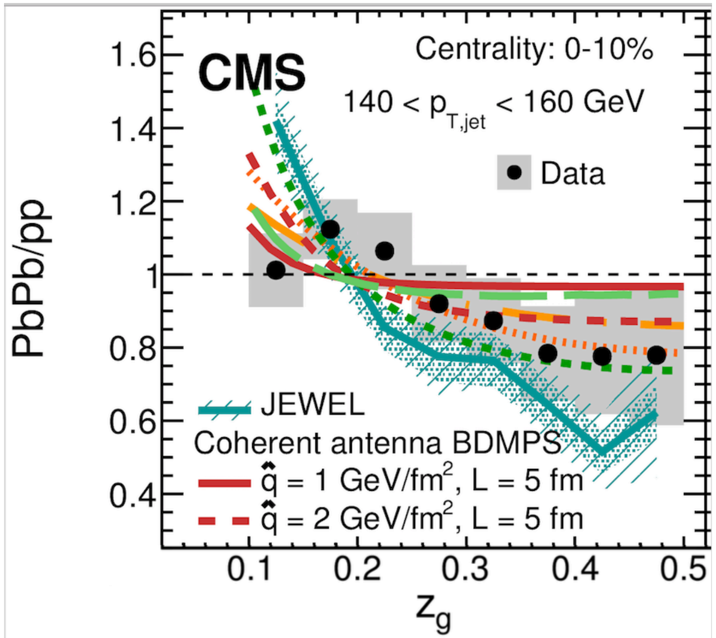
Application of SoftDrop to HI data

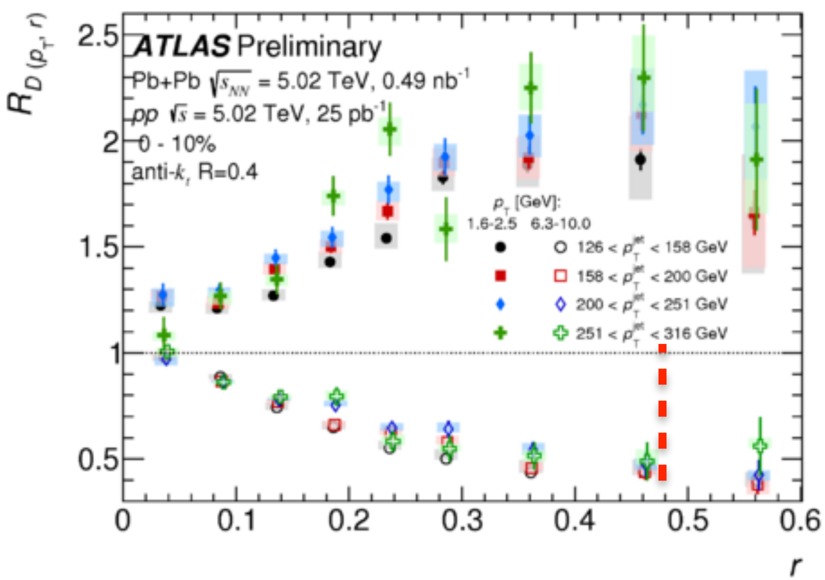
- Challenge: Large UE background (and its fluctuation)
  - Should subtract up to 150 GeV for each jet in central collisions
  - Particle-level subtraction is needed instead of cone-integrated one
  - Constituent subtraction method solved the problem



arxiv1805.05145

Decoherence of sub-jets in HI data



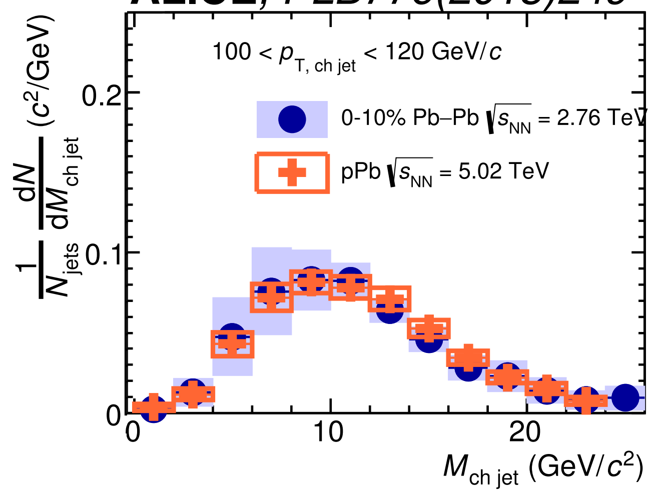


- Study of coherence of sub-jets in heavy ion collisions
- **Jet mass**, as a proxy of the transverse width, is sensitive to the decoherence by jet quenching
- Modification of jet mass can also be inferred from the jet shape result

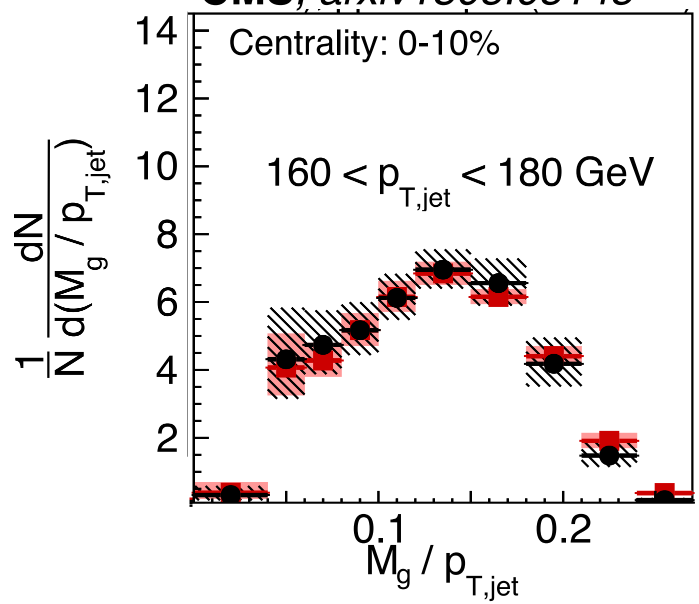
Jet mass

- Jet mass was measured by ALICE (ungroomed) and CMS (groomed) in per-jet normalization —> Focus on the modification on jet mass shape
- However, jet mass and energy loss mutually affect
- **R_{AA} vs m/p_T** provides useful input to "*modification of jet mass by quenching*"
- **R_{AA} vs p_T in p_T bins** provides input to "*mass dependence of jet energy loss by medium*"
- We measured **jet R_{AA} as a function of p_T and m/p_T**

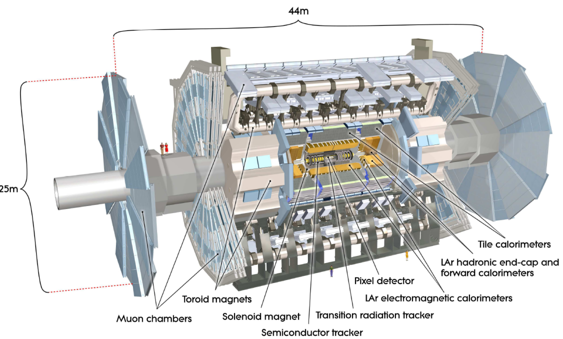
ALICE, *PLB776(2018)249*

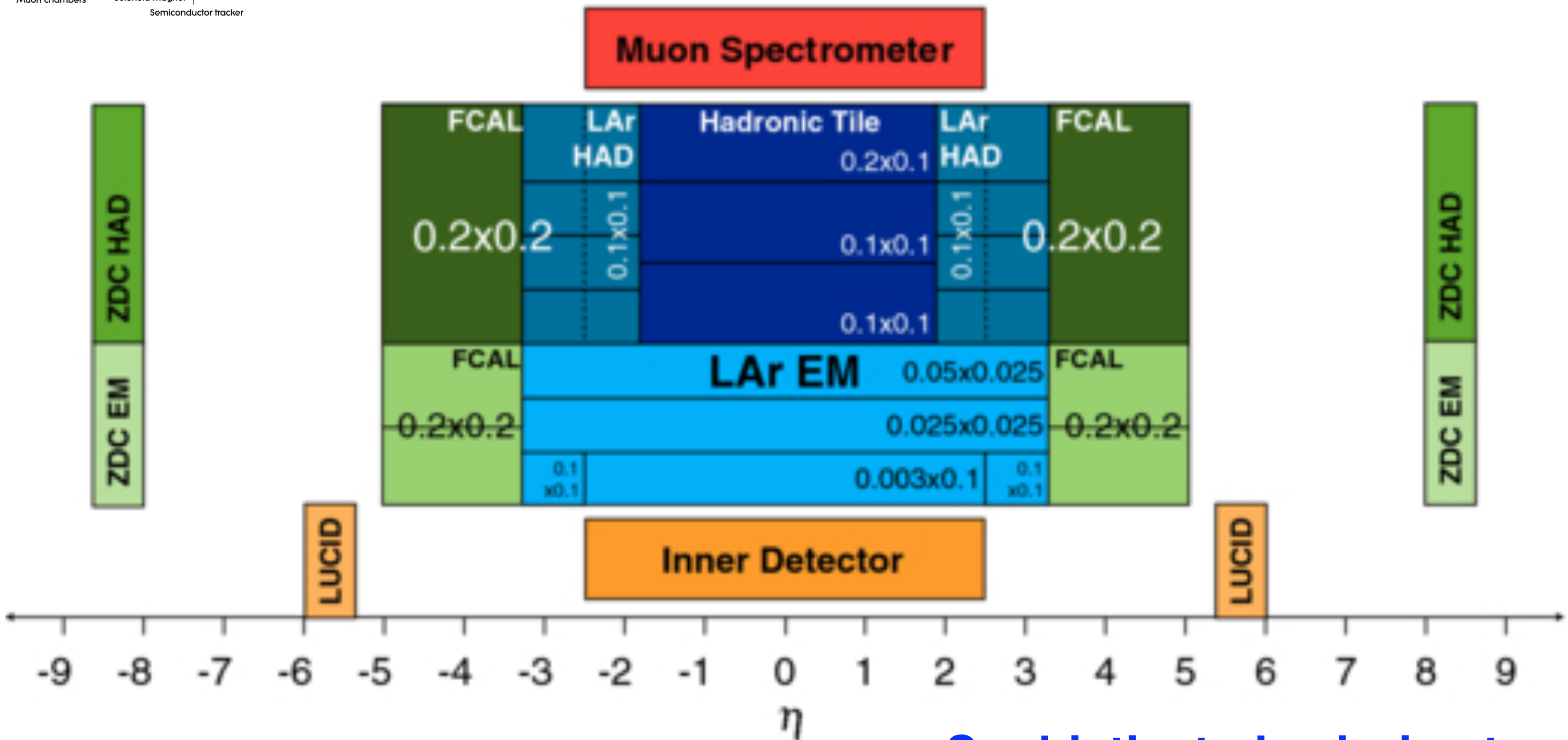


CMS, *arxiv1805.05145*



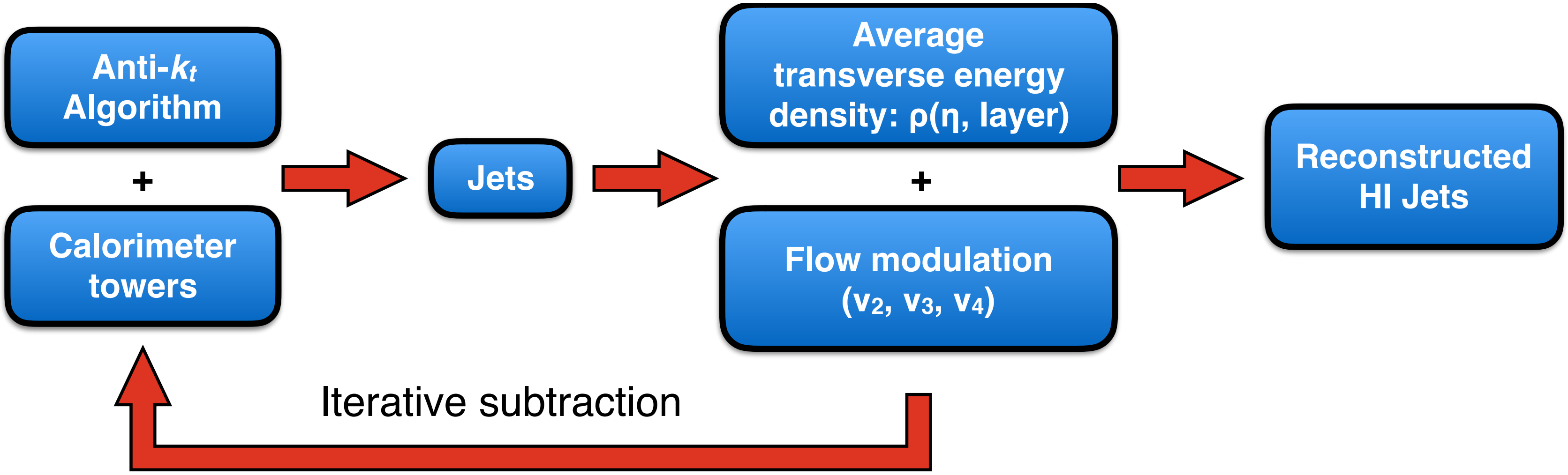
ATLAS detector





Sophisticated calorimeter

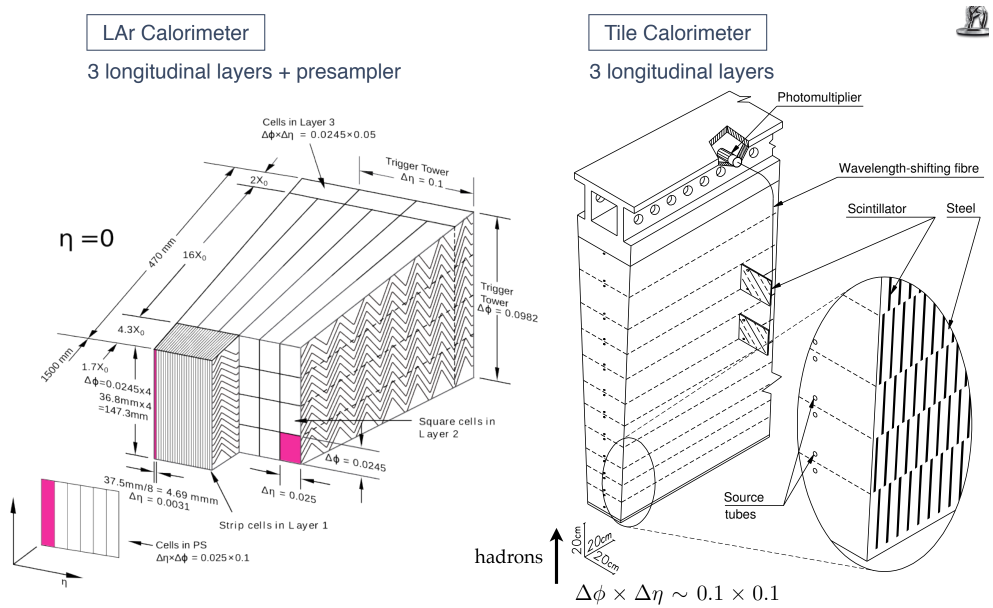
Reconstruction of jet in ATLAS at 5.02 TeV



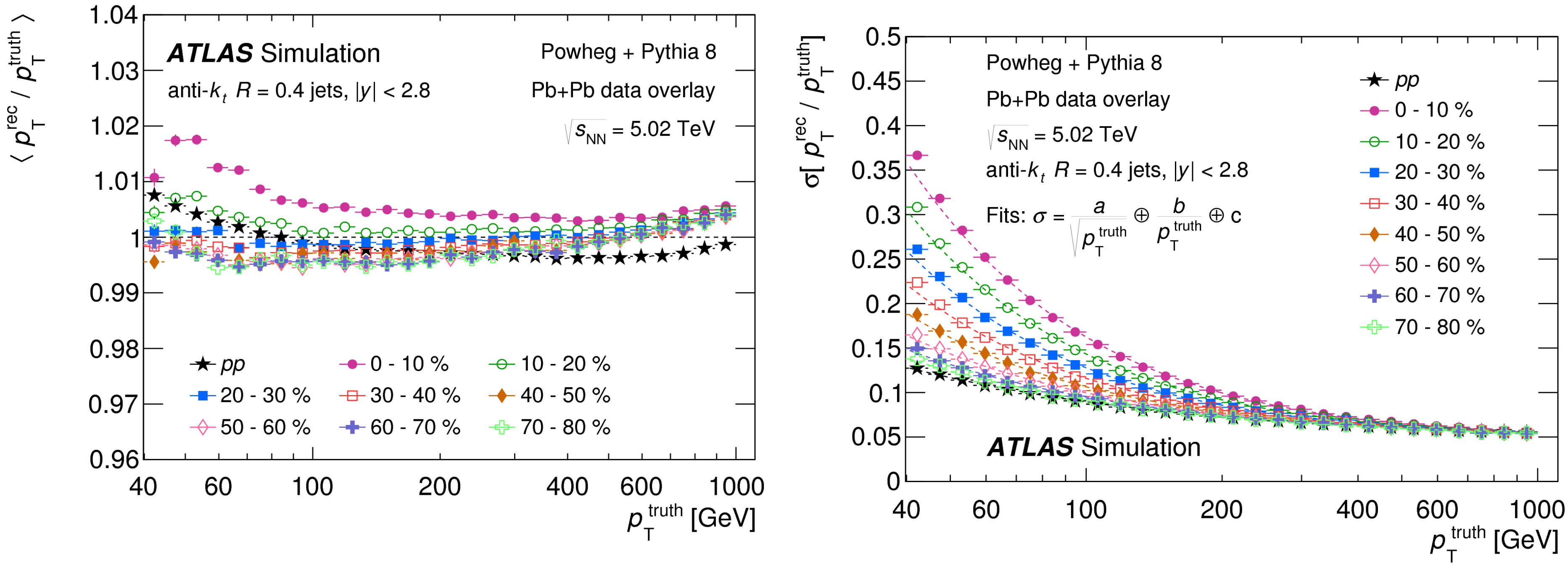
anti-kT jet with R=0.4

jet constituents are the Calorimeter towers after UE subtraction

$(\Delta\eta \times \Delta\phi) = (0.1 \times 0.1)$

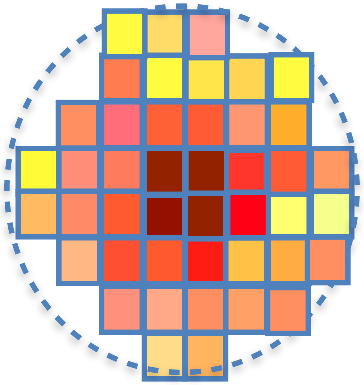


Jet reconstruction in ATLAS HI



- Jet energy scale is off less than 1% for all centrality intervals above 100 GeV
- Energy resolution is degraded as function of centrality due to the event-by-event fluctuation of the underlying event

Reconstruction of jet mass in ATLAS at 5.02 TeV



- Illustration of tower constituents in a R =0.4 jet
- A jet includes up to 50 constituent towers

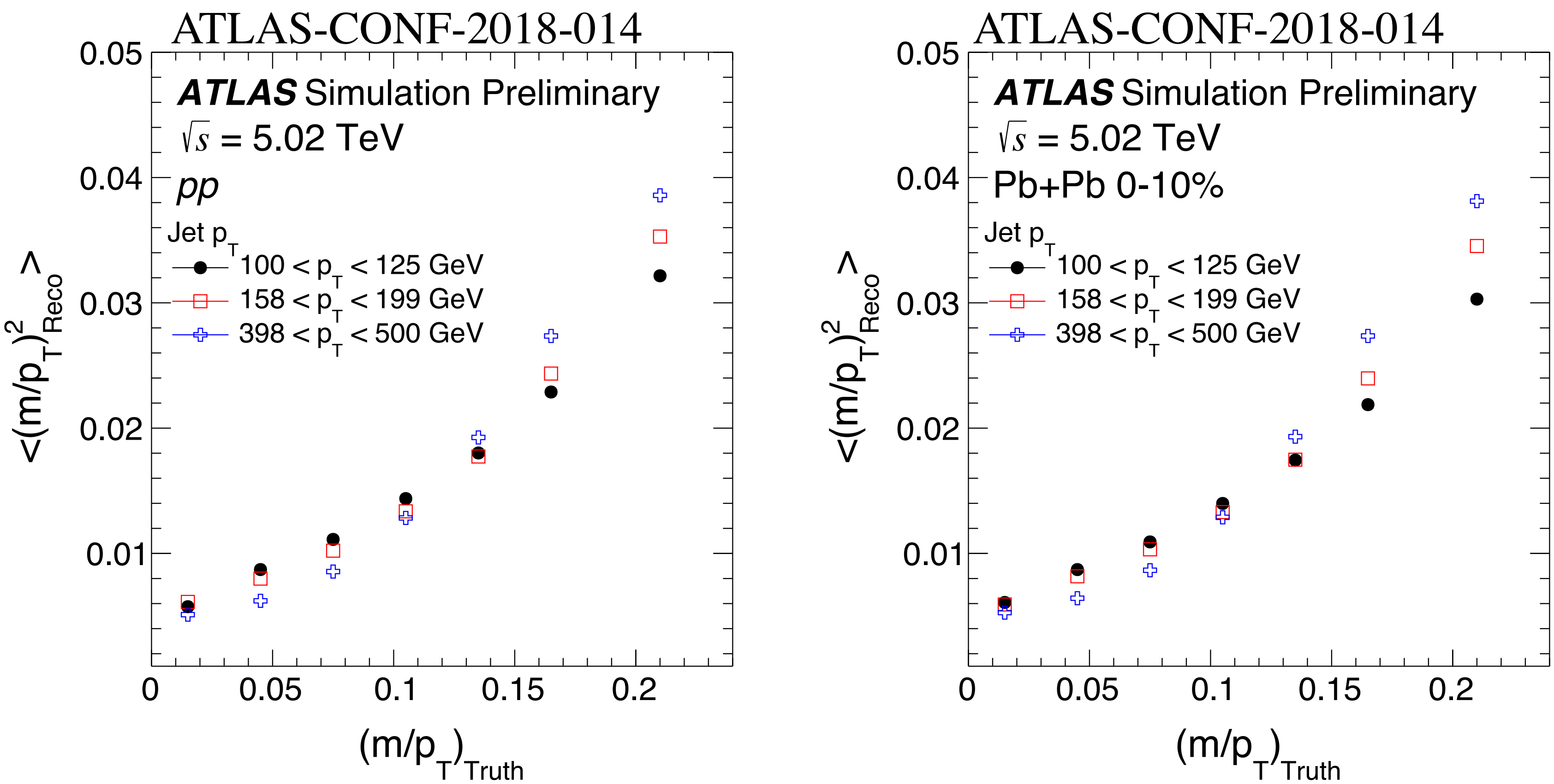
- For each tower, we subtract the UE event estimated from rho and modulated by v_2 and v_3
- After subtraction, each tower contributes as a massless four-momentum for jet mass calculation

$$m = \sqrt{(\sum_i E_i^{subt'd})^2 - |\sum_i \vec{p}_i^{subt'd}|^2}$$

$$= \sqrt{(E_{jet,raw} - E_{background})^2 - |\vec{p}_{jet,raw} - \vec{p}_{background}|^2}$$

- Constituent background subtraction is not necessary for jet mass measurement

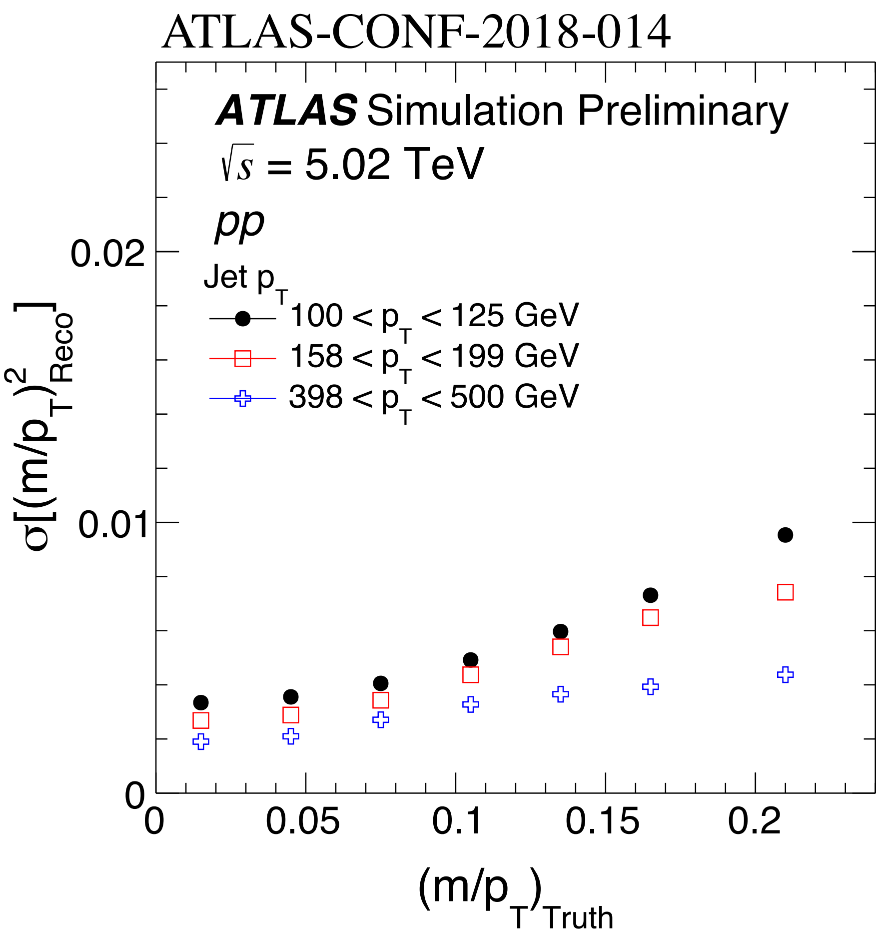
Jet substructure in ATLAS HI program

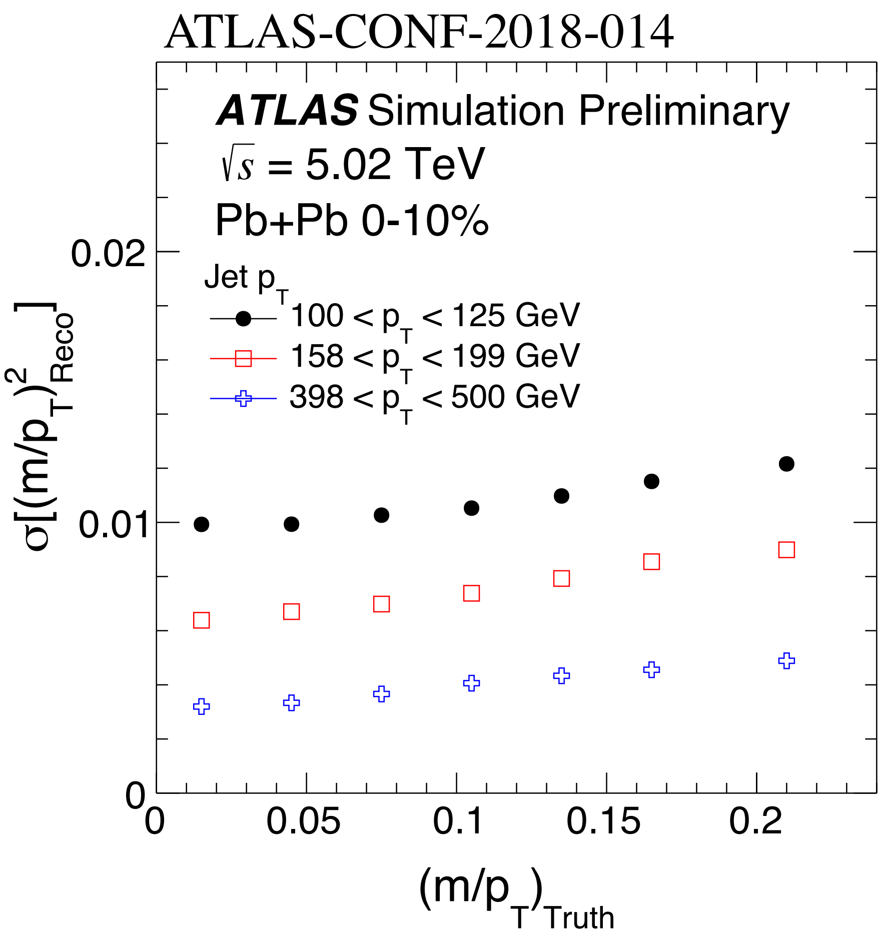


- Jet mass scale has very small dependence on the centrality
    - The same HI reconstruction algorithm was used for pp as well

$$m^2 = (E_{jet,raw} - E_{background})^2 - |\vec{p}_{jet,raw} - \vec{p}_{background}|^2$$

jet mass resolution

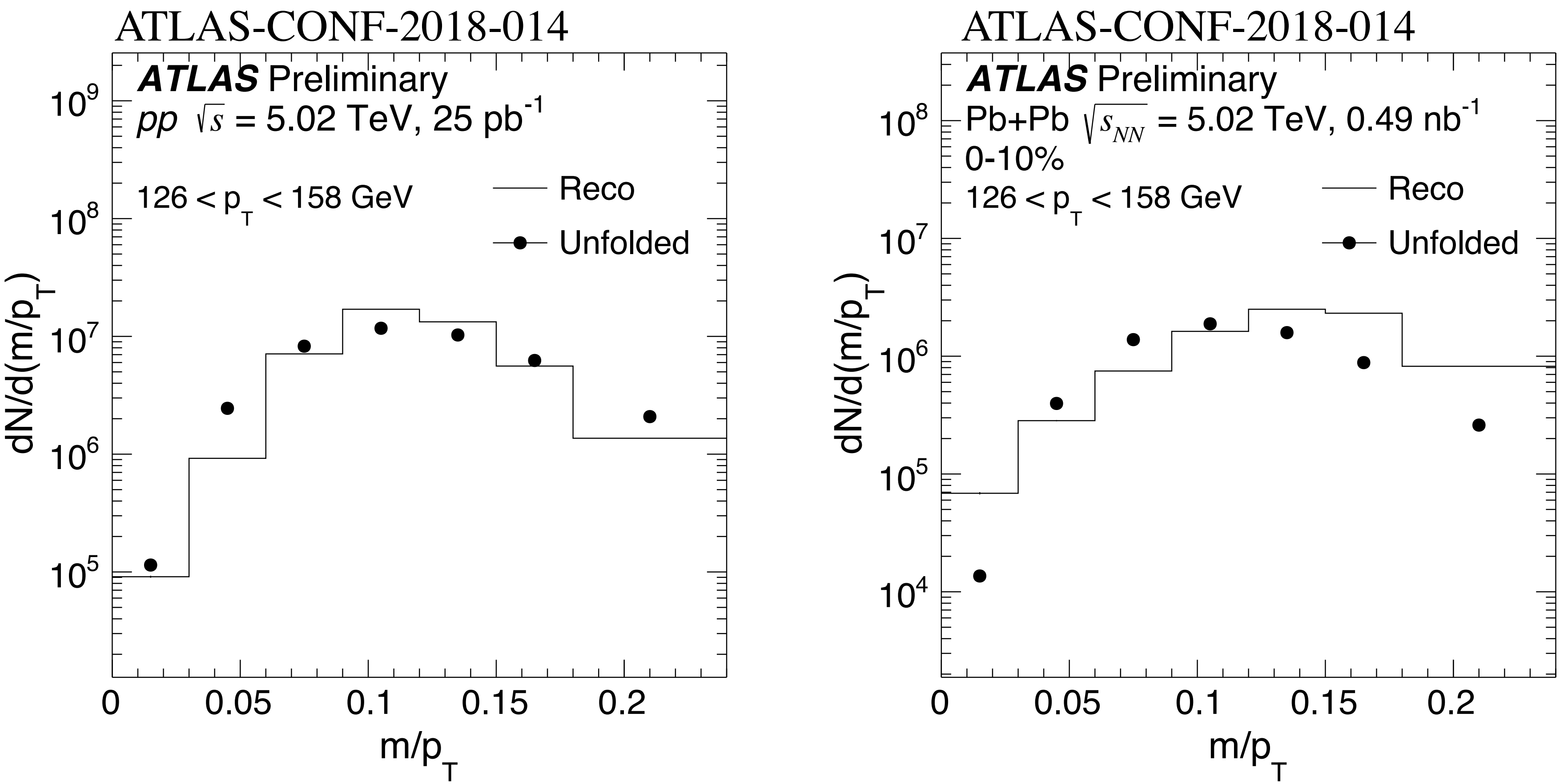




- Jet mass resolution degrades for higher centrality due to the background fluctuation

$$m^2 = (E_{jet,raw} - E_{background})^2 - |\vec{p}_{jet,raw} - \vec{p}_{background}|^2$$

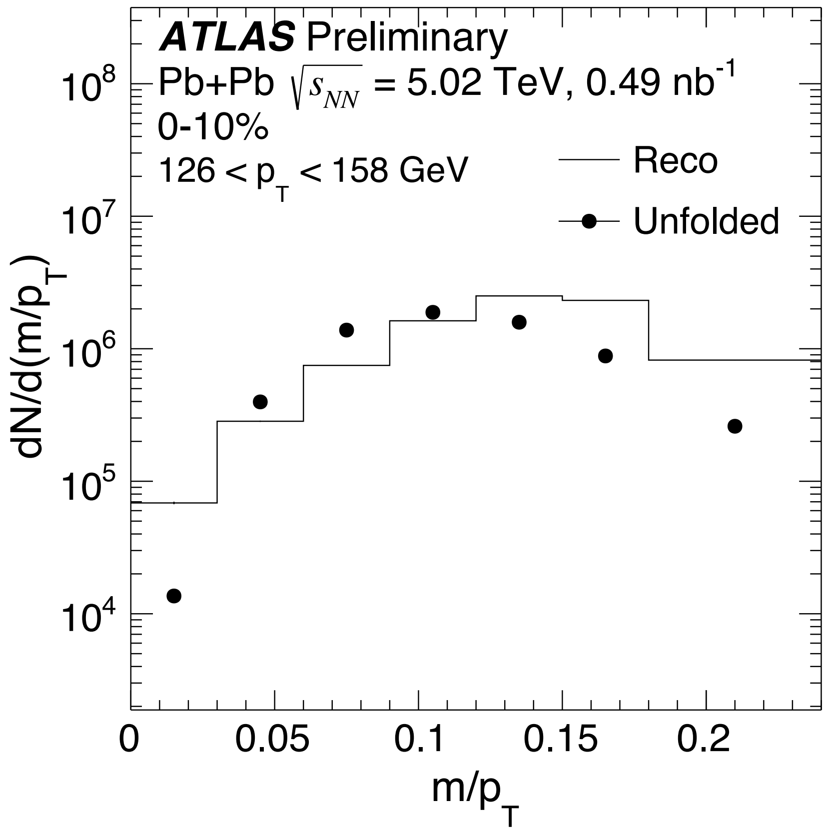
Unfolding



- More bin migration for higher central collisions in PbPb

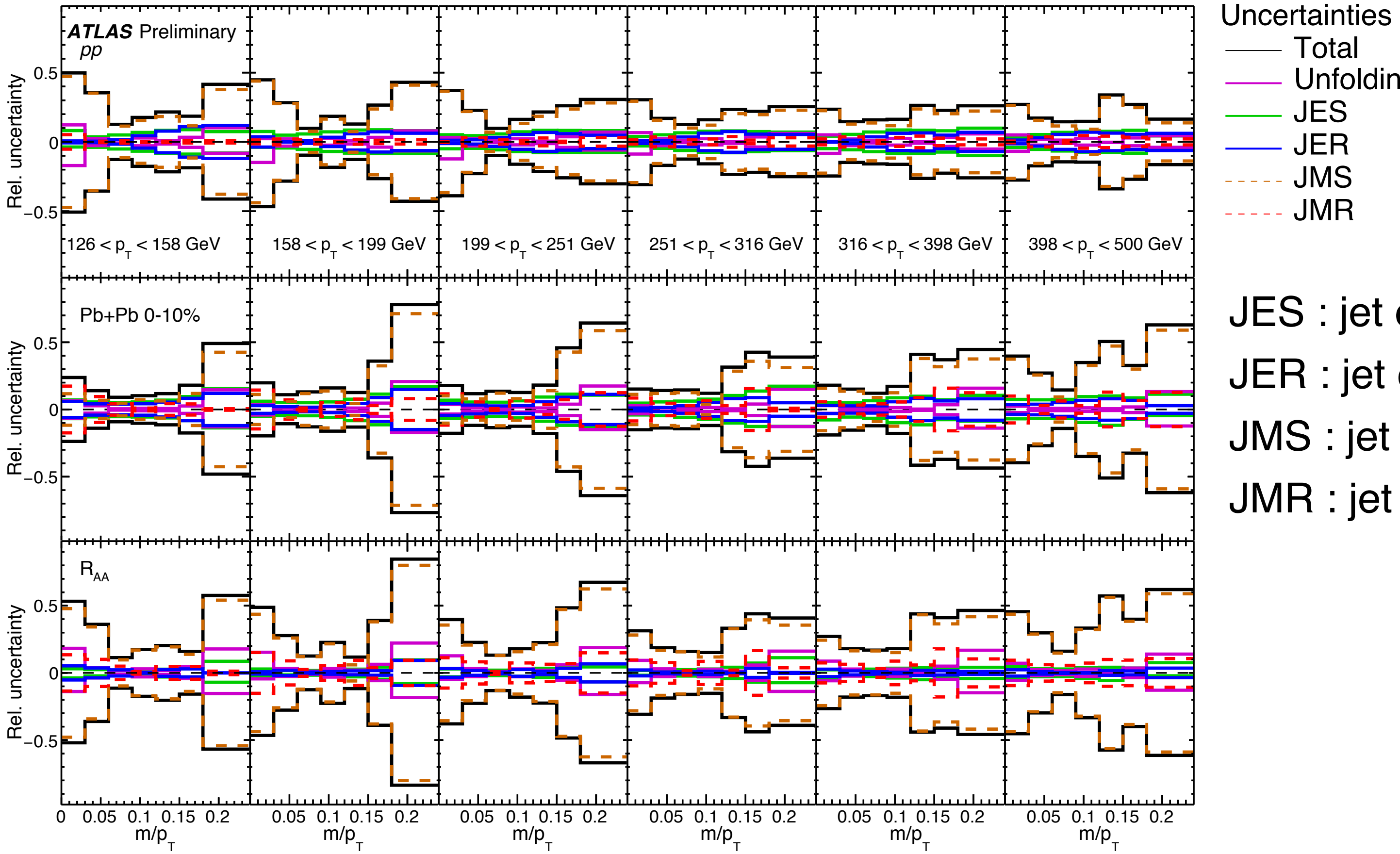
Unfolding

- In reconstruction level,
  - m/p_T is smeared by the jet mass resolution
  - A shift toward higher mass observed, due to the granularity of the calorimeter tower (0.1 x 0.1)



- More bin migration for higher central collisions in PbPb

systematic uncertainty



JES : jet energy scale

JER : jet energy resolution

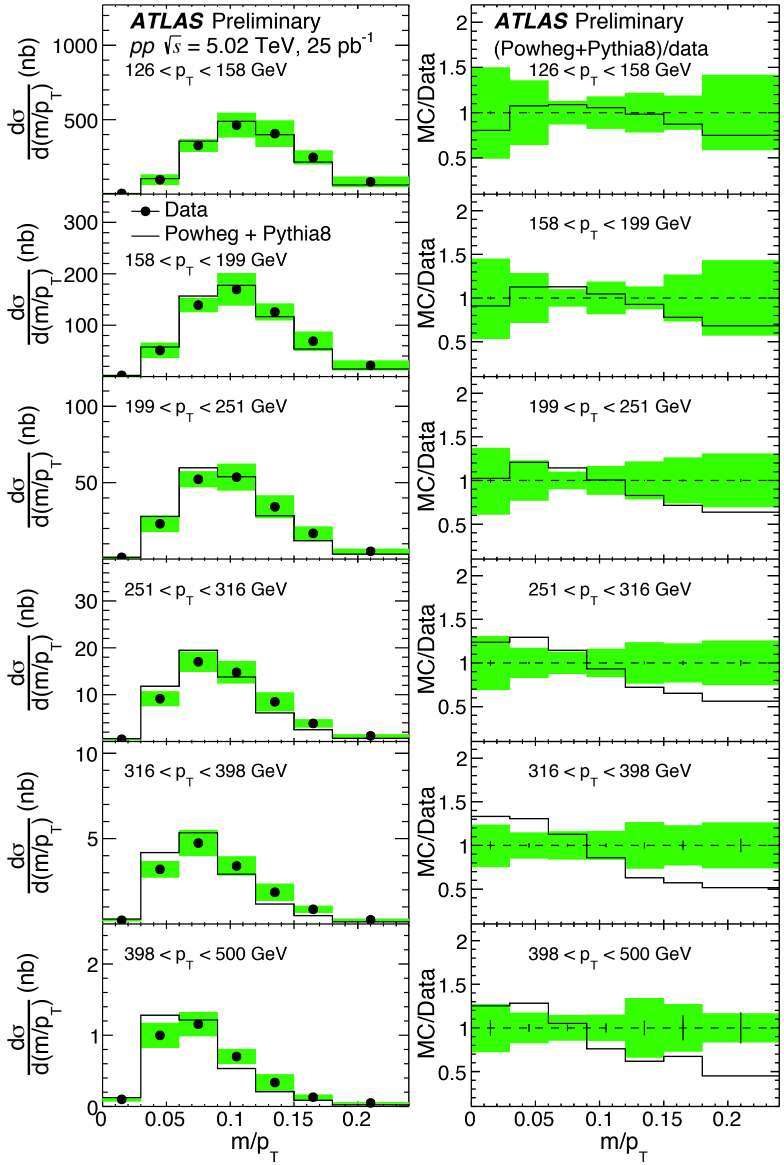
JMS : jet mass scale

JMR : jet mass resolution

- The jet mass scale is the dominant source of the uncertainties
- Cross-check was done with track-jet mass.

Result in pp

ATLAS-CONF-2018-014

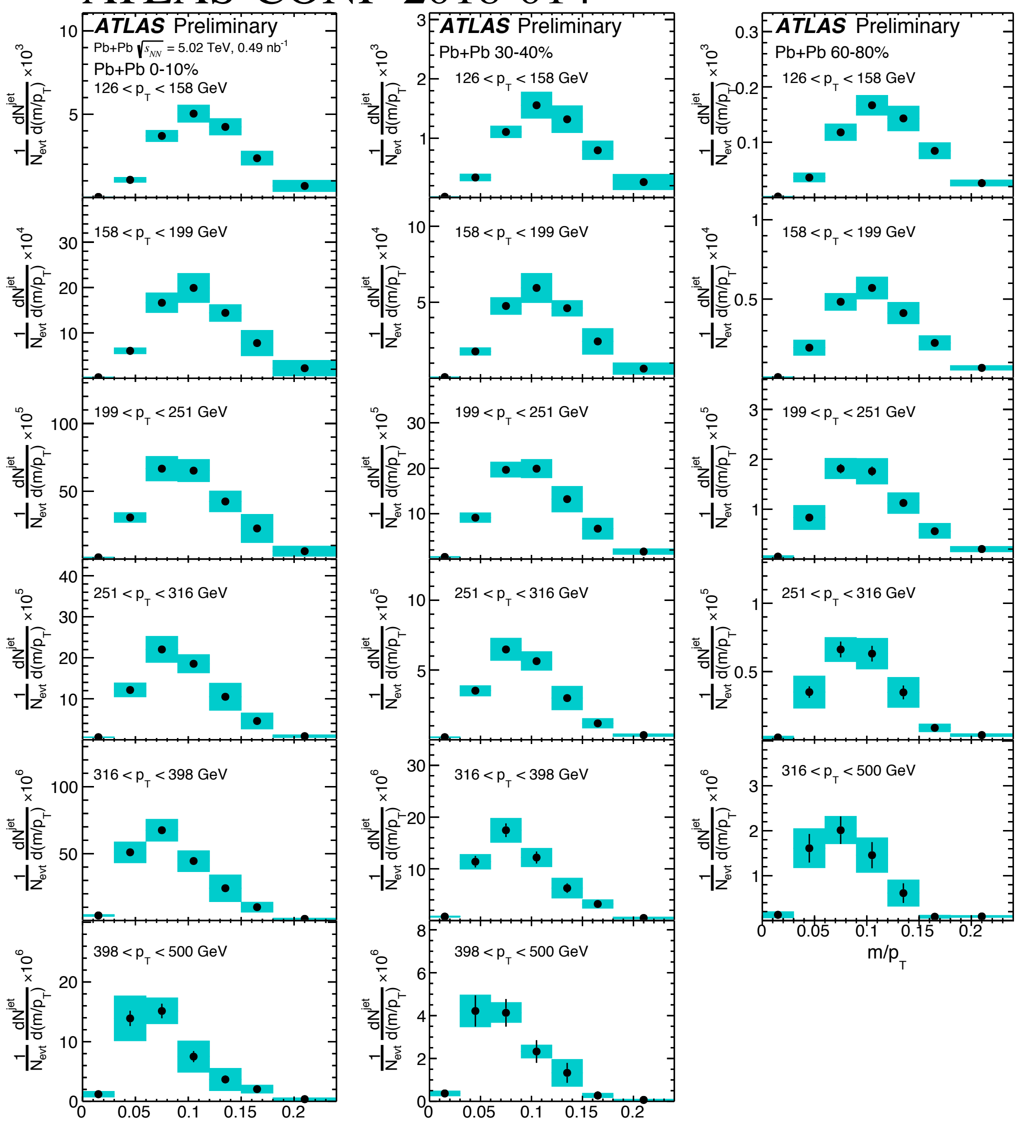


Cross section of jets in 2-d differential bins of p_T and m/p_T for a wide kinematic range.

Result was compared with Powheg generator.

unfolded result in PbPb

ATLAS-CONF-2018-014

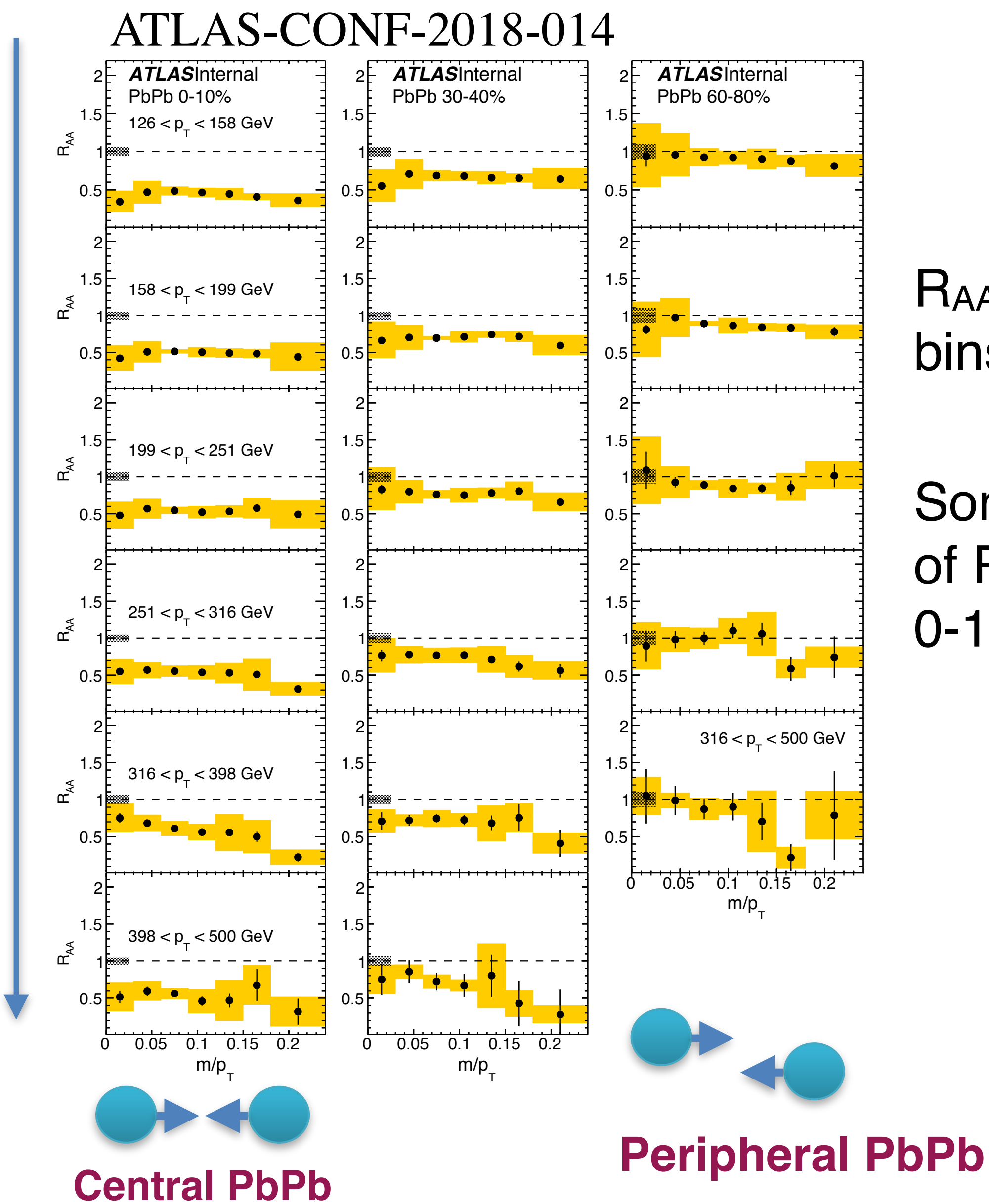


PbPb result in 7 centrality bins

Results in 0-10%, 30-40%, 60-80% are shown in this slide

What have we learn from it? in pp

Lower p_T
126 GeV/c



Higher p_T
500 GeV/c

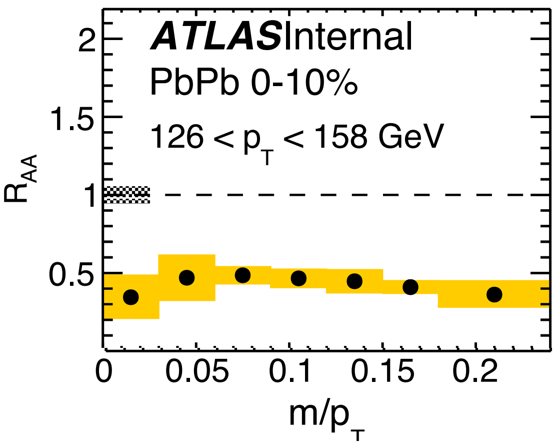
R_{AA} (m/p_T) is flat for most p_T bins for all centrality bins.

Some hint for the decrease of R_{AA} at high p_T bins for 0-10% centrality.

Comparison of ATLAS, ALICE and CMS results

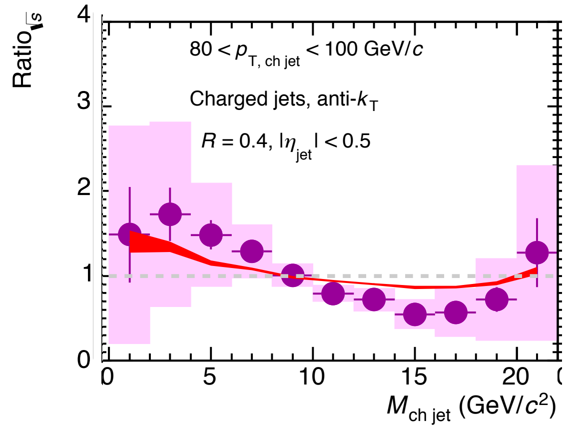
ATLAS

126 - 158 GeV



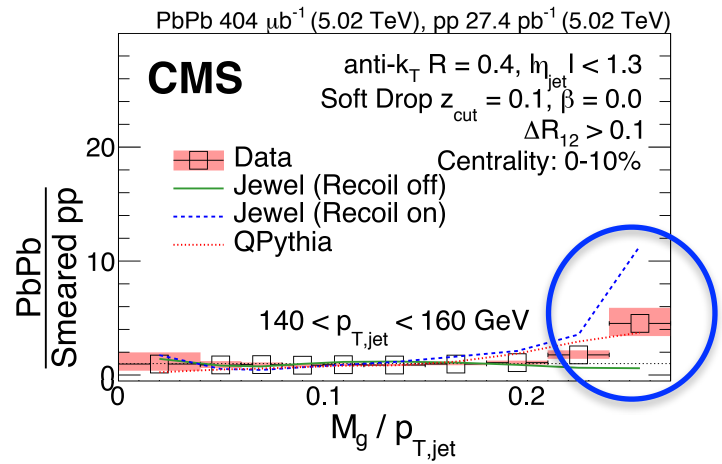
ALICE

80 - 100 GeV



CMS

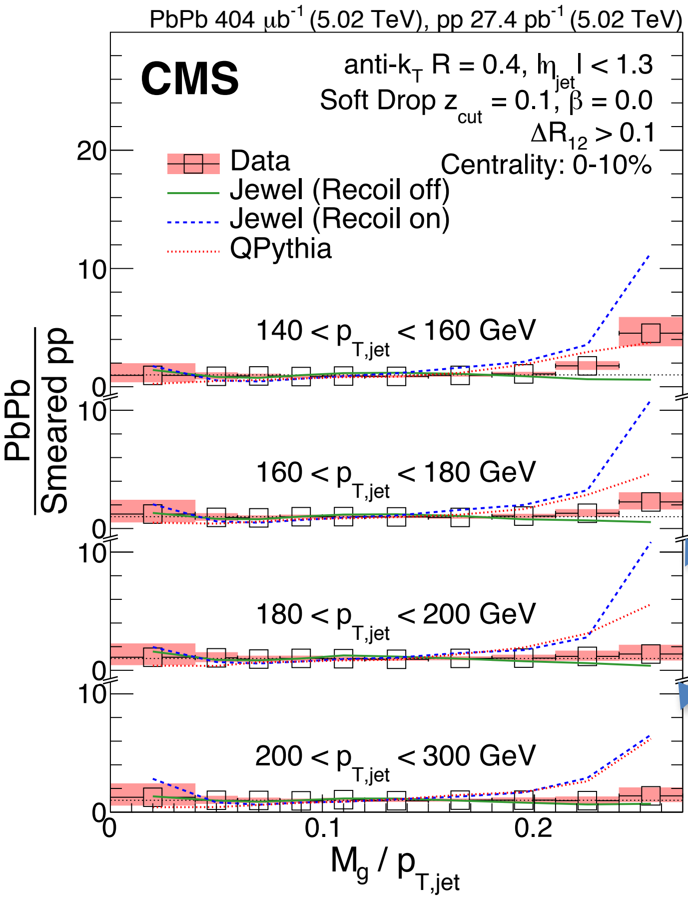
140 - 160 GeV



for $m/p_T < 0.25$ region, the PbPb/pp is consistent with flat ratio, which means no modification overall.

Enhancement of large m/p_T yield in CMS was not observed in ATLAS and ALICE result. One explanation was the

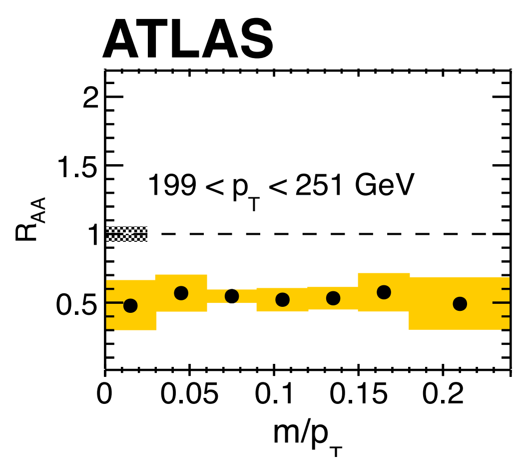
Can we explain this tension using medium recoil?

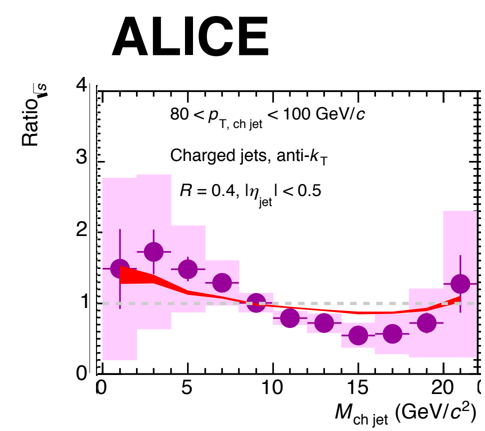


Maybe yes, but it might be a naive solution. For example, JEWEL doesn't explain the full results yet.

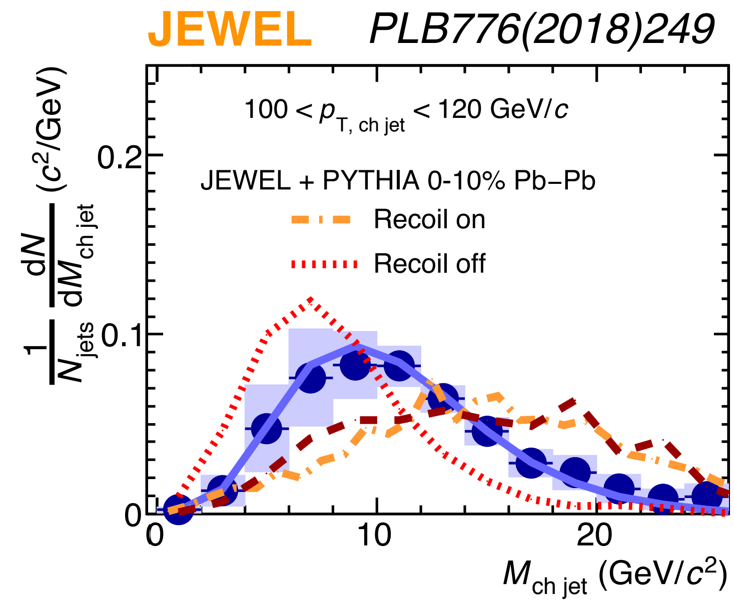
1. we don't see the same rise for higher p_T bins.

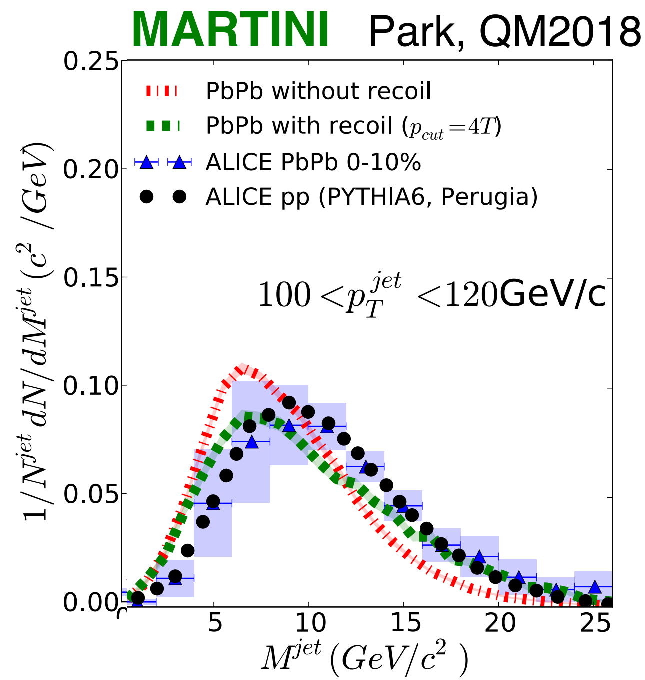
2. it doesn't explain the flat (or decreasing) ratio for ungroomed jet result in ALICE and ATLAS

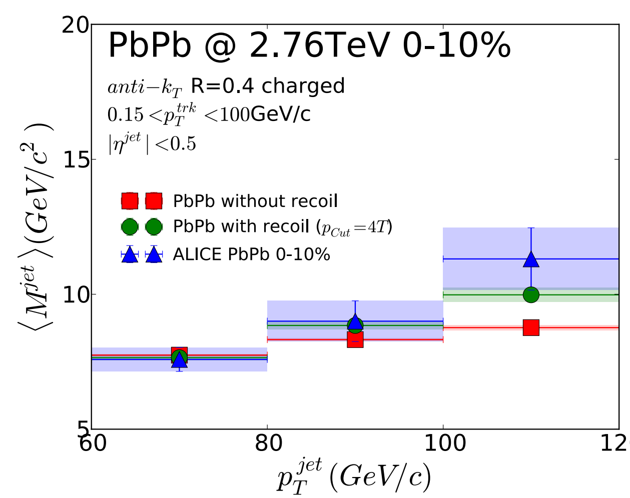




Reproduction of ALICE *ungroomed* result by JEWEL and MARTINI

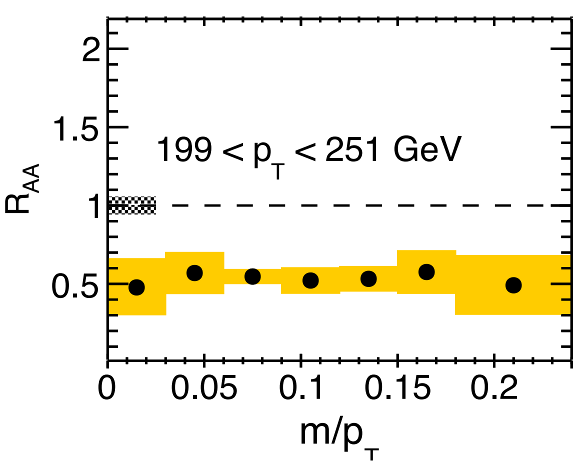


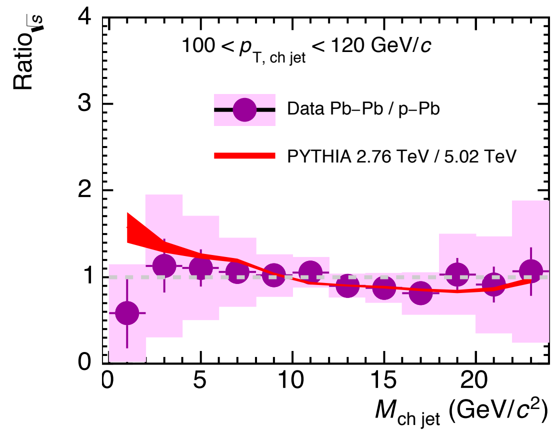


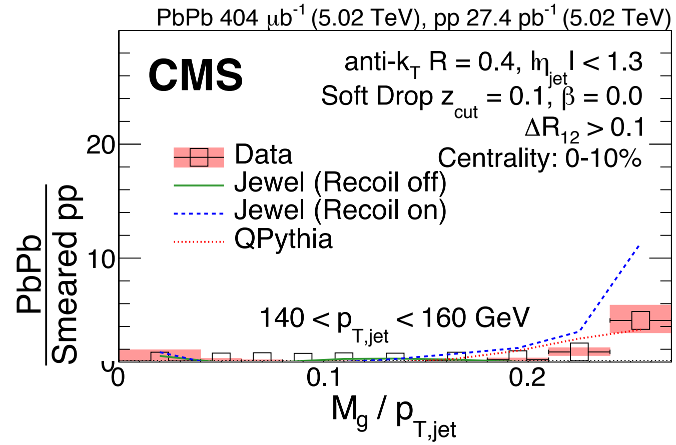


- Both models qualitatively reflect the two competing effects for mass distribution
  - (a) Modification of mass by quenching including p_T shift by energy loss
  - (b) Medium recoil
- MARTINI shows a nice agreement with data for high m/p_T region. Same result for SoftDropped jet?

apple to orange to tomato







ATLAS

- Ungroomed mass
- $|\eta| < 2.1$
- full jet
- Fully unfolded

ALICE

- Ungroomed mass
- $|\eta| < 0.5$
- charged jet
- Fully unfolded

CMS

- SoftDrop mass
- $|\eta| < 1.3$
- full jet
- pp reference smeared

- Maybe the key difference is in the SoftDrop? The rise was observed only when beta = 0 case.

Summary

- Reported the result of ungroomed jet mass in pp and PbPb collisions at 5.02 TeV using ATLAS
- Measured the R_{AA} of jets as a function of the m/p_T and p_T to study the modification of jet mass by medium, and the dependence of energy loss on the jet mass
- No significant dependence of R_{AA} on mass was observed, but found some hint for larger suppression for high m/p_T in $p_T > 316$ GeV/c
- The result of ungroomed mass, being complementary to the SoftDrop mass result from CMS, can provide the input to understand the medium recoil