ATLAS measurements of *b*-jet suppression and heavy-flavor azimuthal correlations in 5.02 TeV Pb+Pb collisions

Sebastian Tapia Araya
Universidad Tecnica Federico Santa Maria
for the ATLAS collaboration

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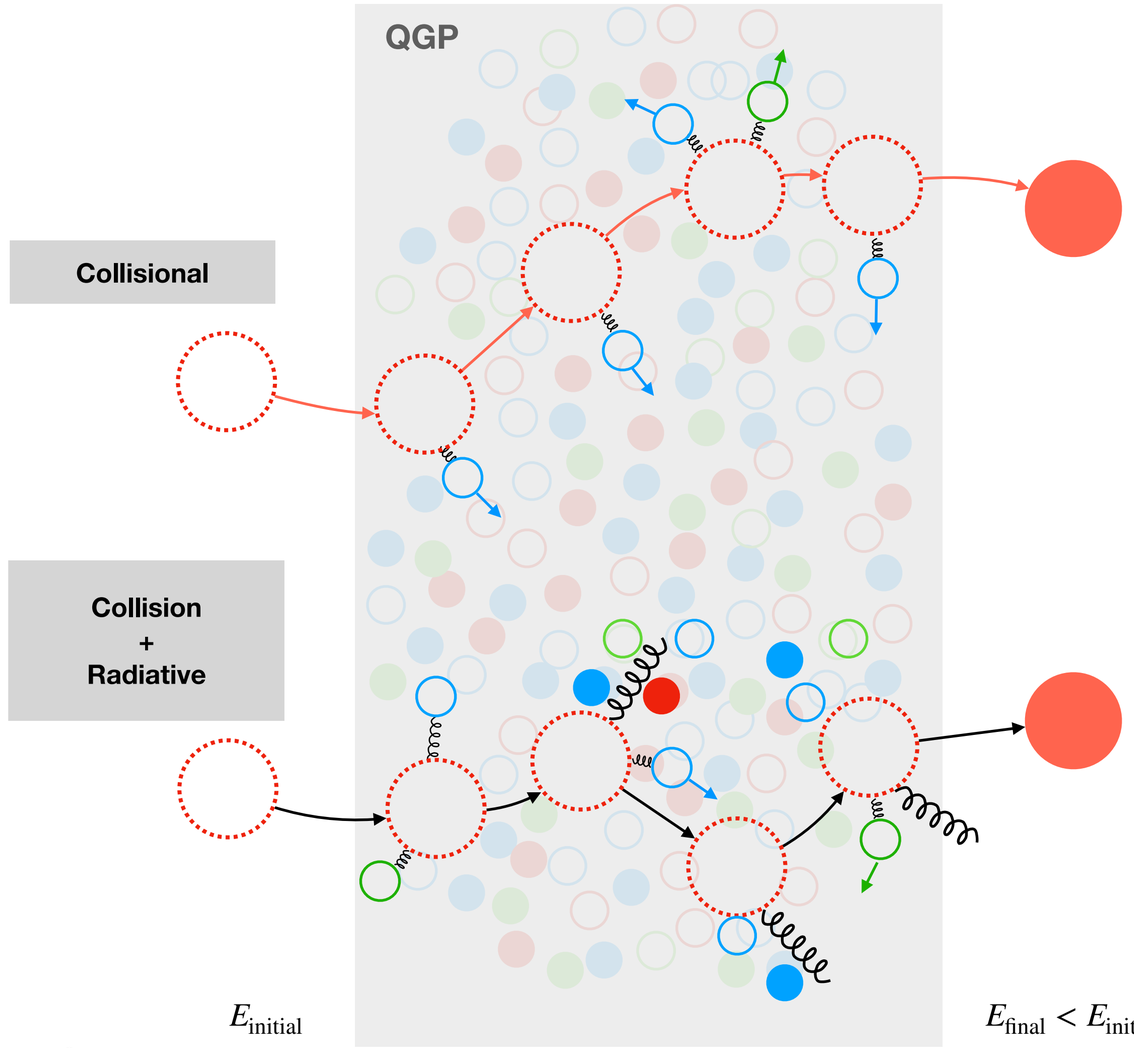
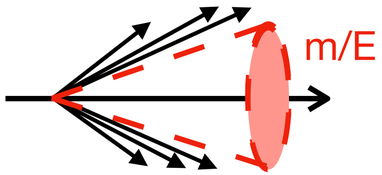
Heavy flavors in heavy ion collisions

- Open heavy flavors (HF) quarks — c, b — are produced early in the collision; masses above QGP temperature
- HF in heavy ion collisions are sensitive probes to energy loss mechanisms and QGP transport properties
- HF pair angular correlations have additional sensitivity to QGP-induced angular deflection

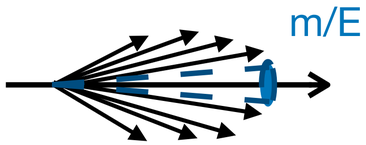


- Mass dependence expected due to “dead-cone effect”

Large parton mass



Small parton mass

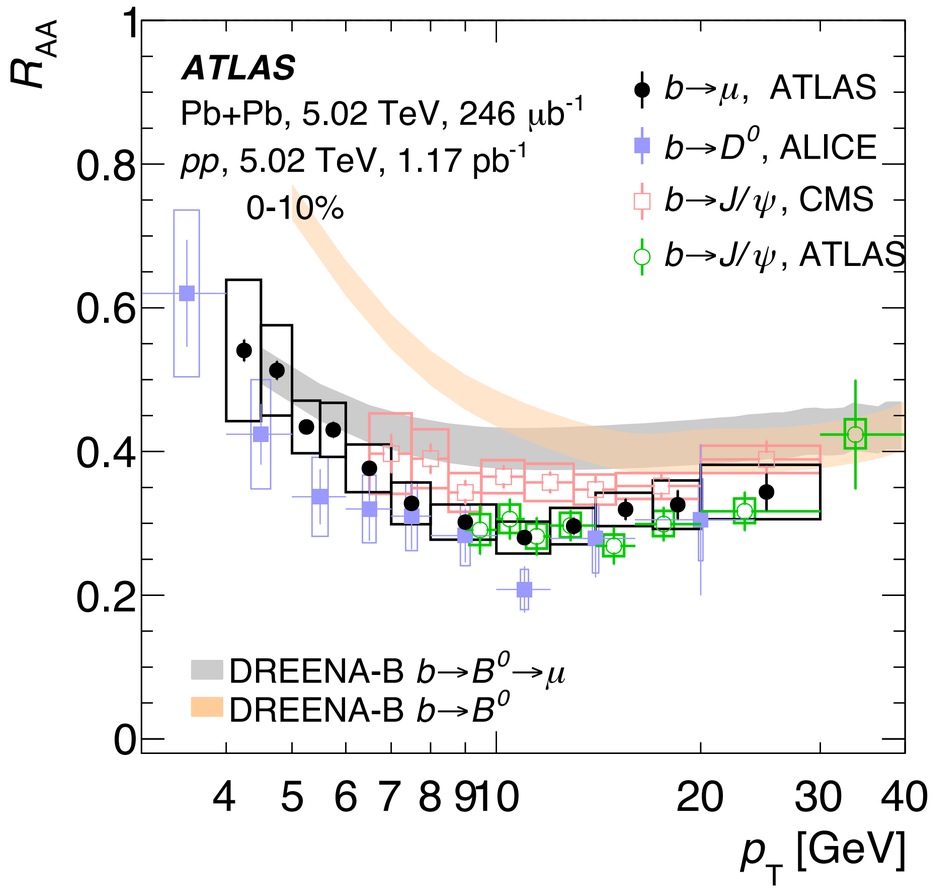


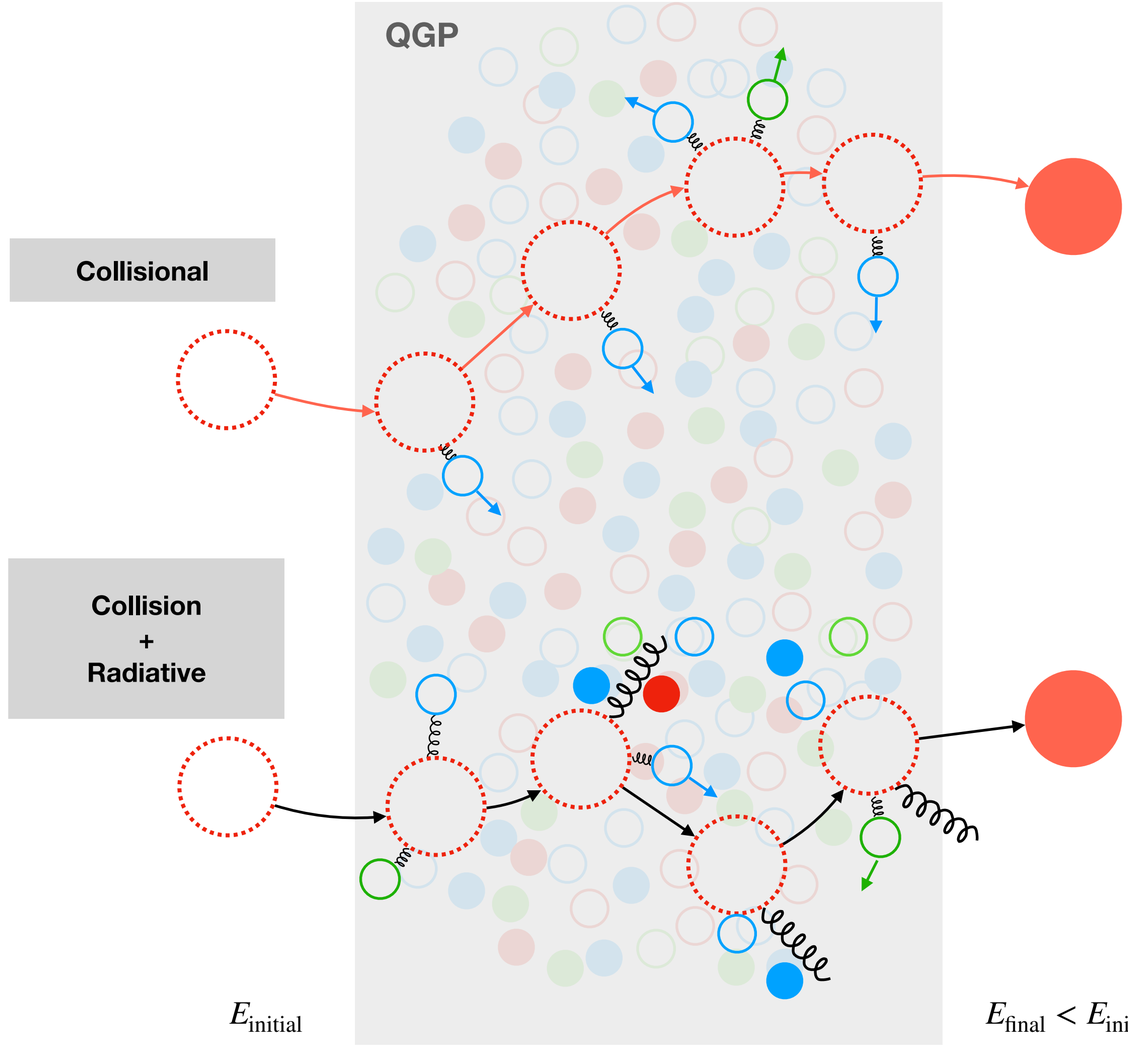
Radiation is suppressed in θ < m/E

$$\mathrm{d}P_{\mathrm{Rad;Q}}(\theta) \propto \left(1 + \left(\frac{M_{\mathrm{Q}}}{E_{\mathrm{Q}}}\right)^2 \frac{1}{\theta^2}\right)^{-2}$$

Heavy flavors in heavy ion collisions

ATLAS muon: arXiv:2109.00411
ATLAS J/ψ: EPJC 78 (2018) 762
ATLAS b-jet: HION-2018-24
ALICE D^0: arXiv:2202.00815
CMS J/ψ: EPJC 78 (2018) 509





- Good agreement from several measurements of different collaborations, using muons, D's, J/Ψ as a proxy for HF
- Sensitive to only part of the HF momentum —> need of fragmentation function and decay kinematics to get HF scale (model dependent)

***b*-jets** from semi-leptonic decays

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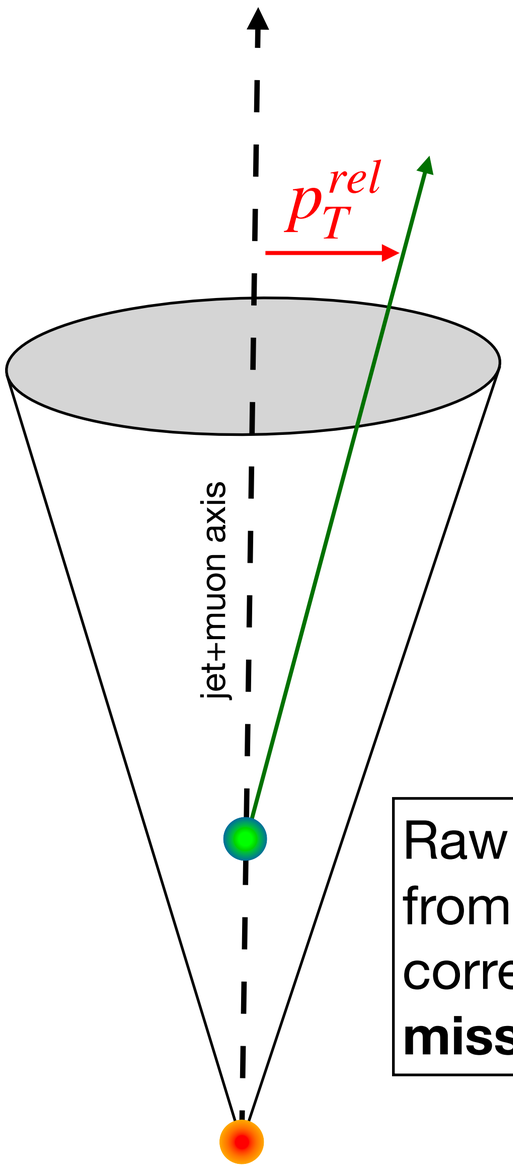


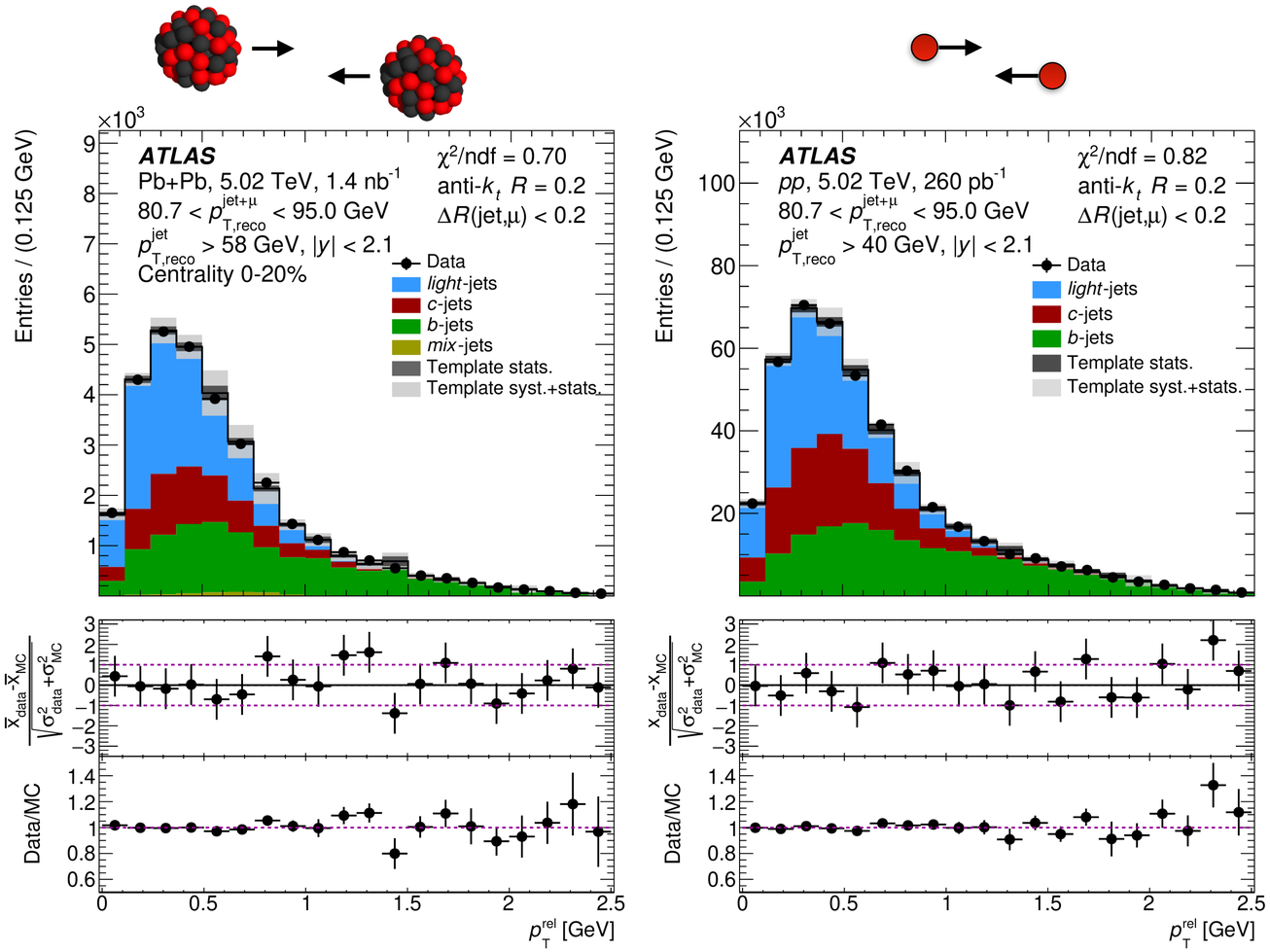
b-fraction estimated using template fit method on muon p_T-rel distribution

$$p_T^{rel} = ||\vec{p}_\mu \times \vec{u}||, \; where \; \vec{u} = \frac{\vec{p}_{jet+\mu}}{||\vec{p}_{jet+\mu}||} \; is \; the \; jet + \mu \; axis$$

Muon selection:

- Muon p_T > 4 GeV
- ΔR(jet,muon) < R

Raw *b*-jet spectra obtained from fit is **unfolded** to correct detector effects and **missing neutrino energy**



***b*-jets vs inclusive jets** in *pp* collisions

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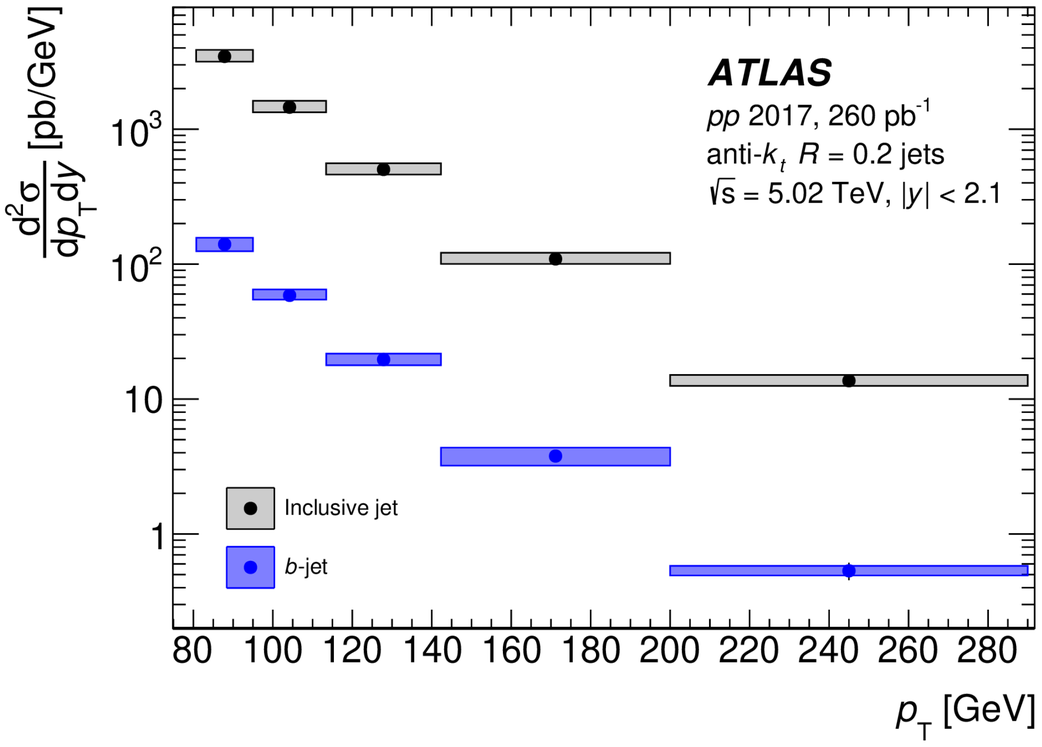

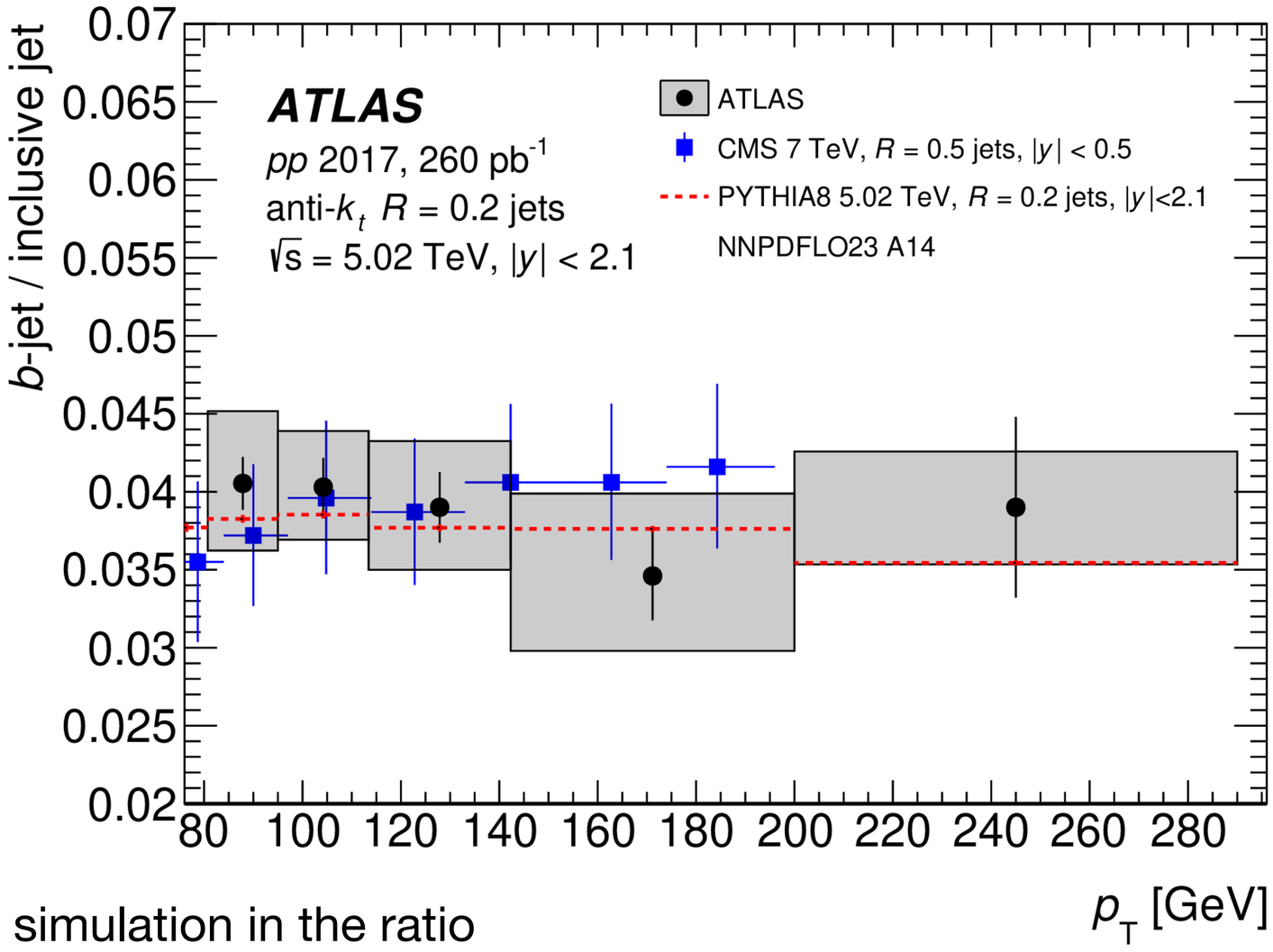

b-jet to inclusive R=0.2 cross-section ratio:

- Good agreement found between data and simulation in the ratio
- Comparison to CMS results consistent within errors
- Ratio consistent with flat within uncertainties, relevant for R_{AA} modification interpretation

***b*-jets vs inclusive jets** in Pb+Pb collisions

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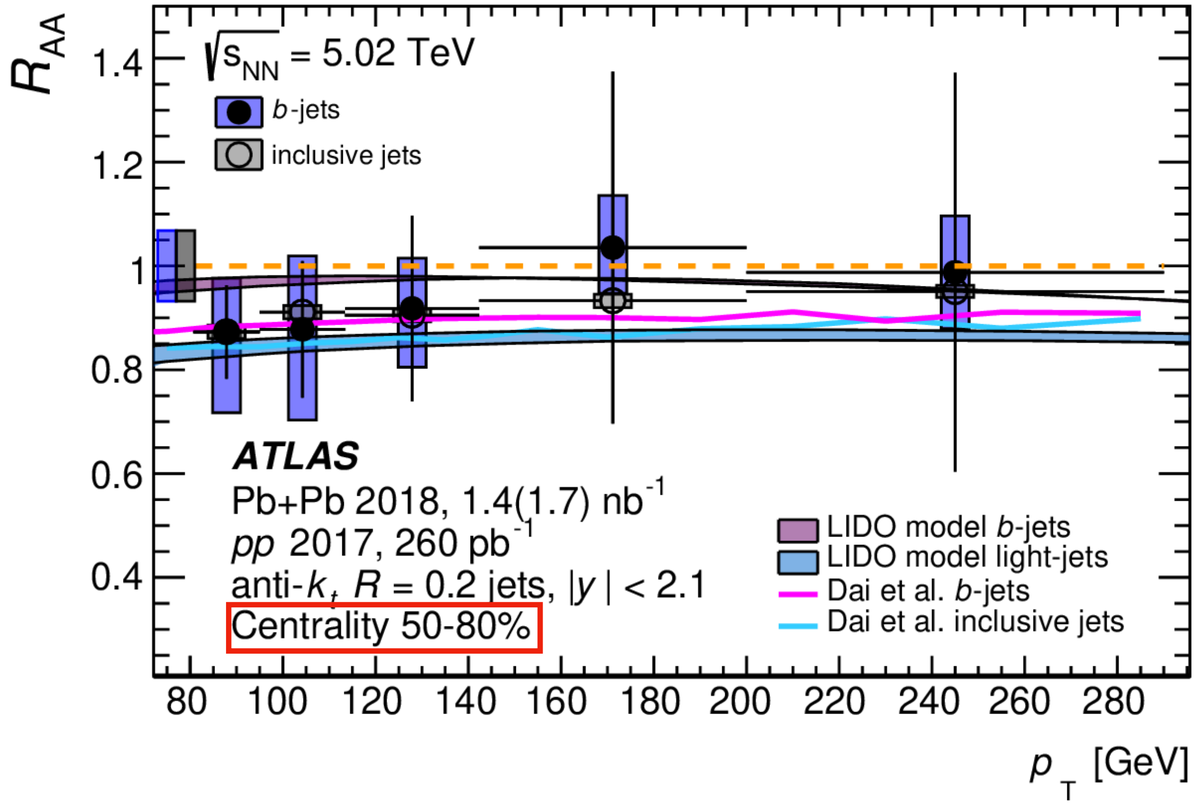

Nuclear modification factor, R_{AA}, measured for *b*-jets and inclusive jets:

- **Similar suppression in peripheral collisions**
- *b*-jet found to be less suppressed than inclusive jets in central collisions
- Both calculations capture the R_{AA} difference
- LIDO calculations reproduce well the measured R_{AA}

***b*-jets vs inclusive jets** in Pb+Pb collisions

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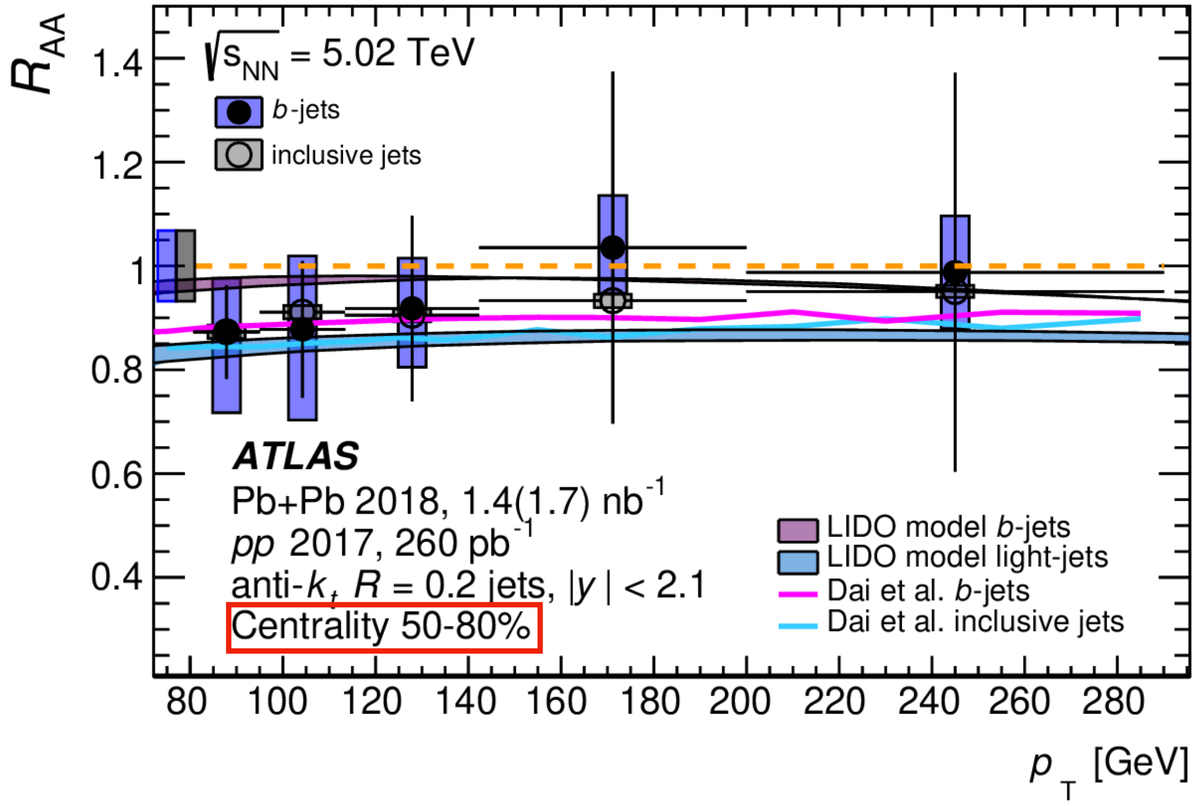

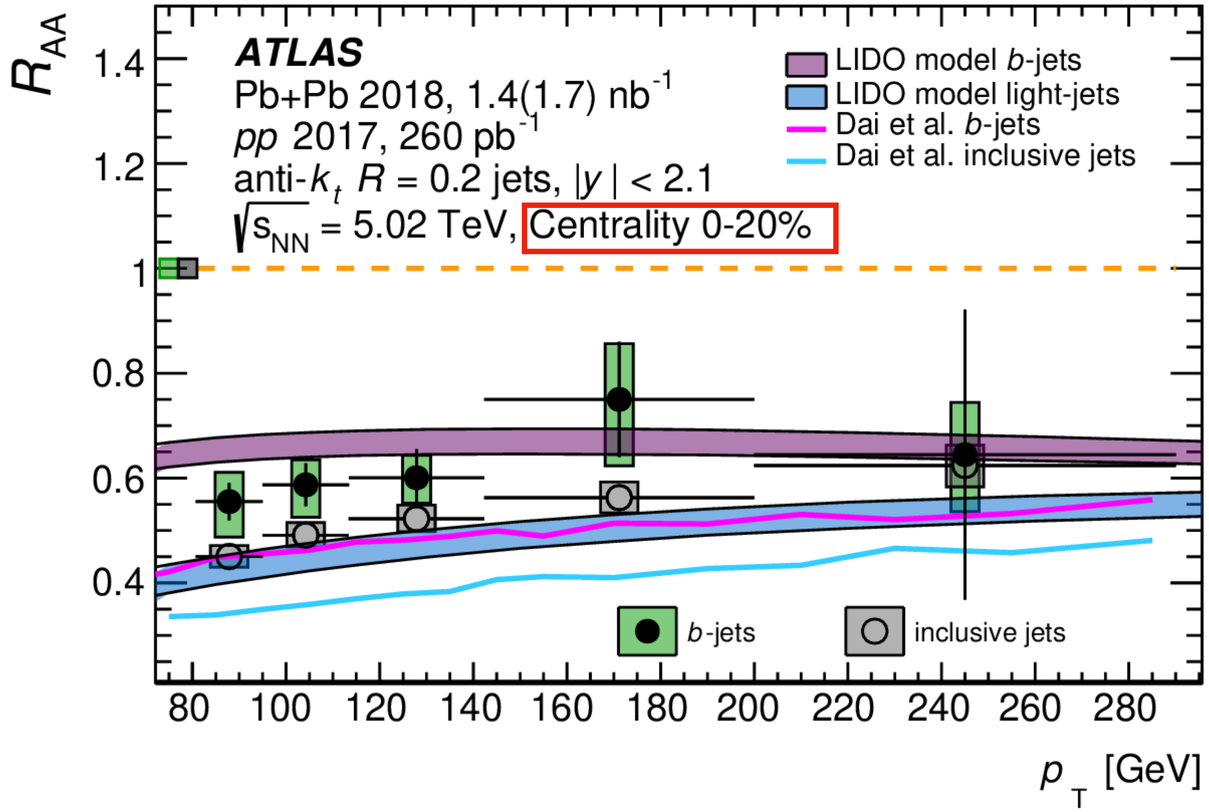

Nuclear modification factor, R_{AA}, measured for *b*-jets and inclusive jets:

- Similar suppression in peripheral collisions
- ***b*-jet found to be less suppressed than inclusive jets in central collisions**
- Both calculations capture the R_{AA} difference
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***b*-jets vs inclusive jets** in Pb+Pb collisions

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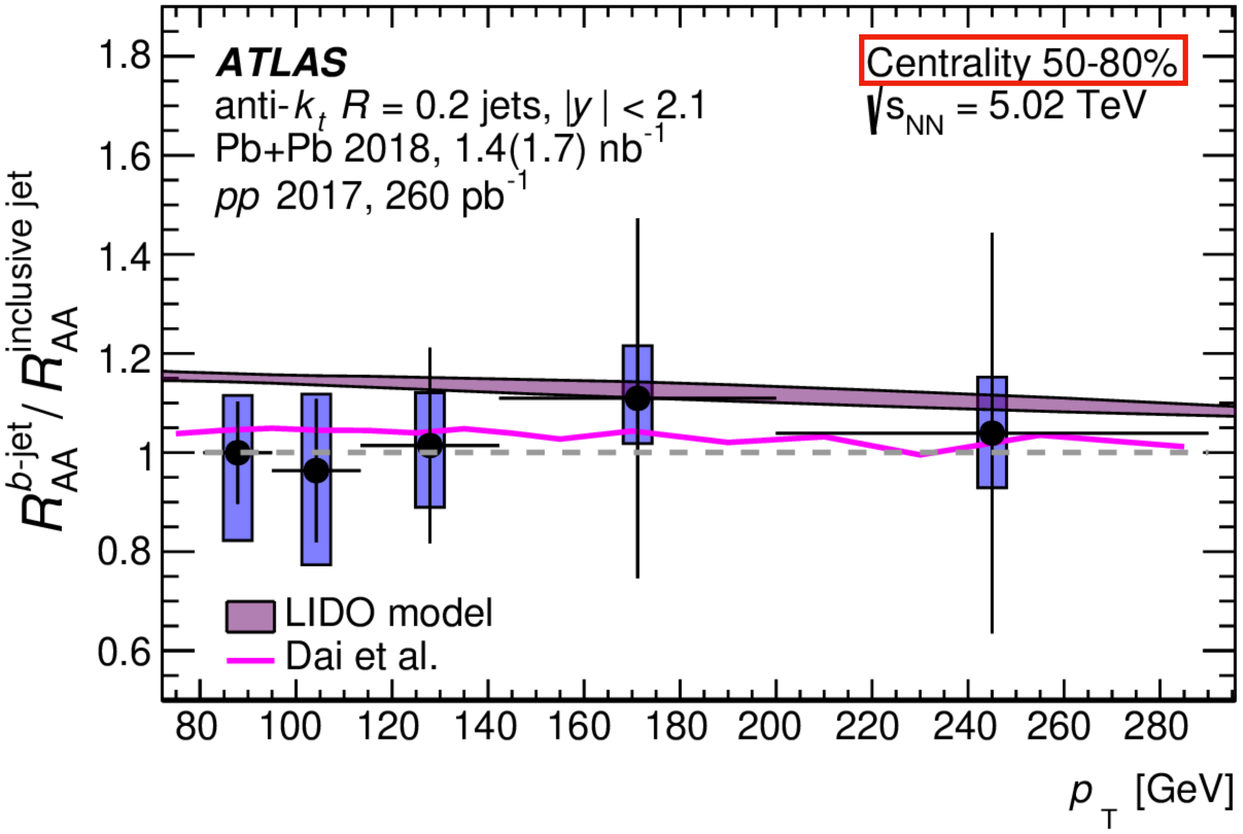

Ratio of nuclear modification factor, R_{AA}, between *b*-jets and inclusive jets:

- Smaller systematic uncertainties than R_{AA}, systematic uncertainties which are shared cancel in ratio
- Ratio **consistent with unity in peripheral** and ~20% above unity in central collisions
- Dai et al, calculations reproduce well R_{AA} ratio

***b*-jets vs inclusive jets** in Pb+Pb collisions

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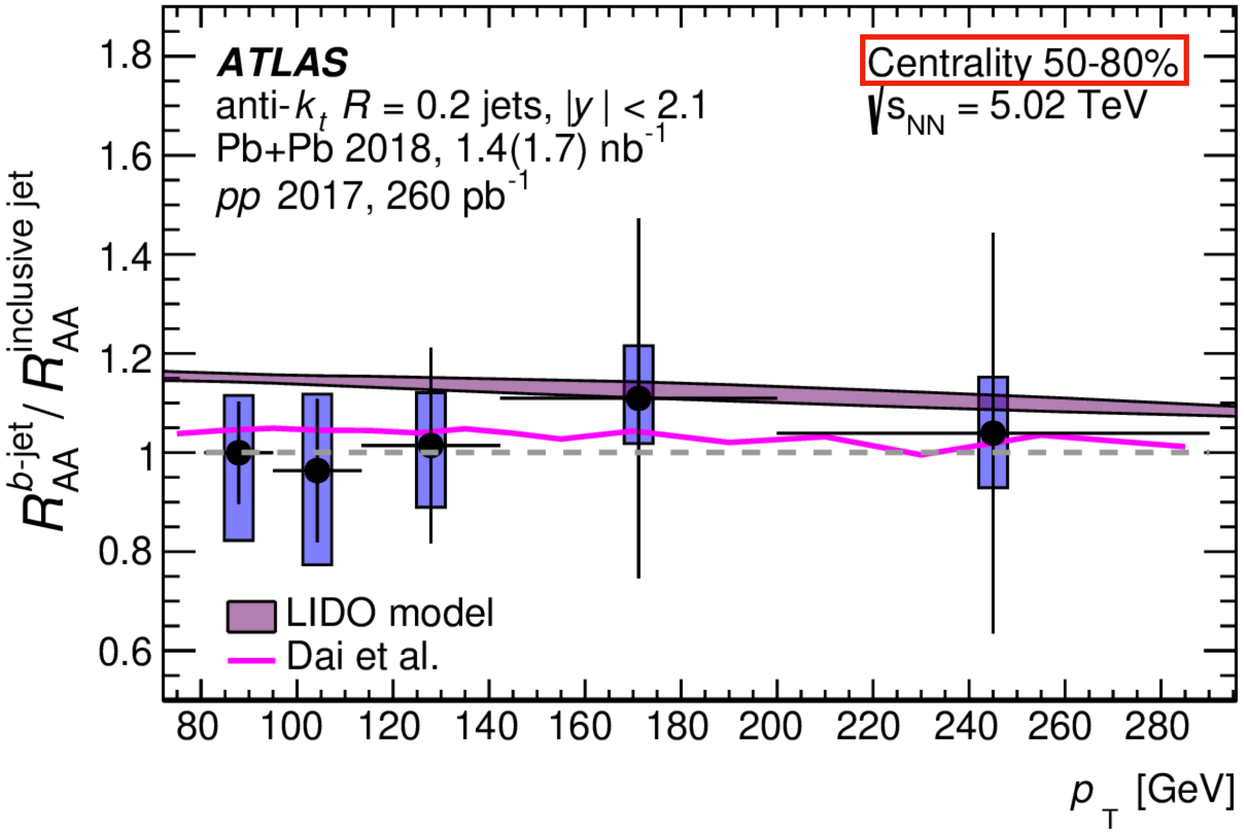
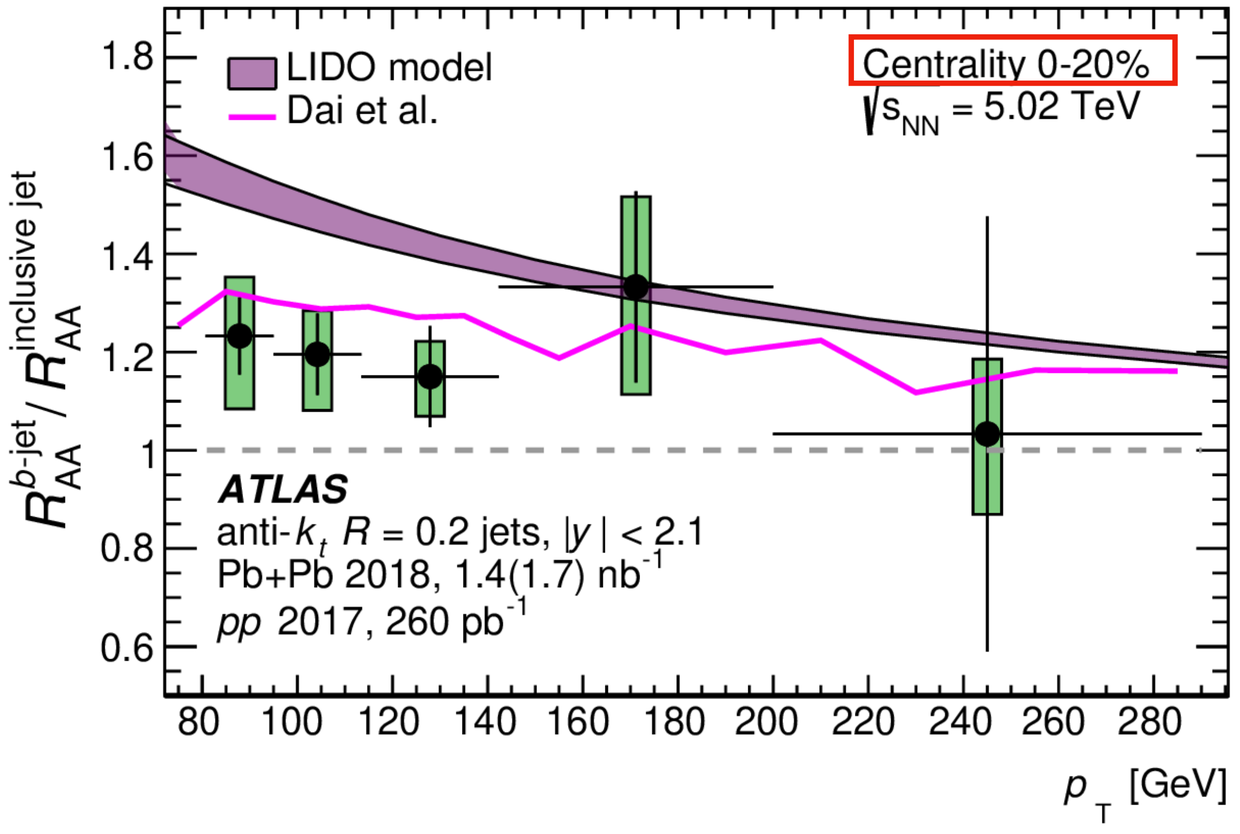


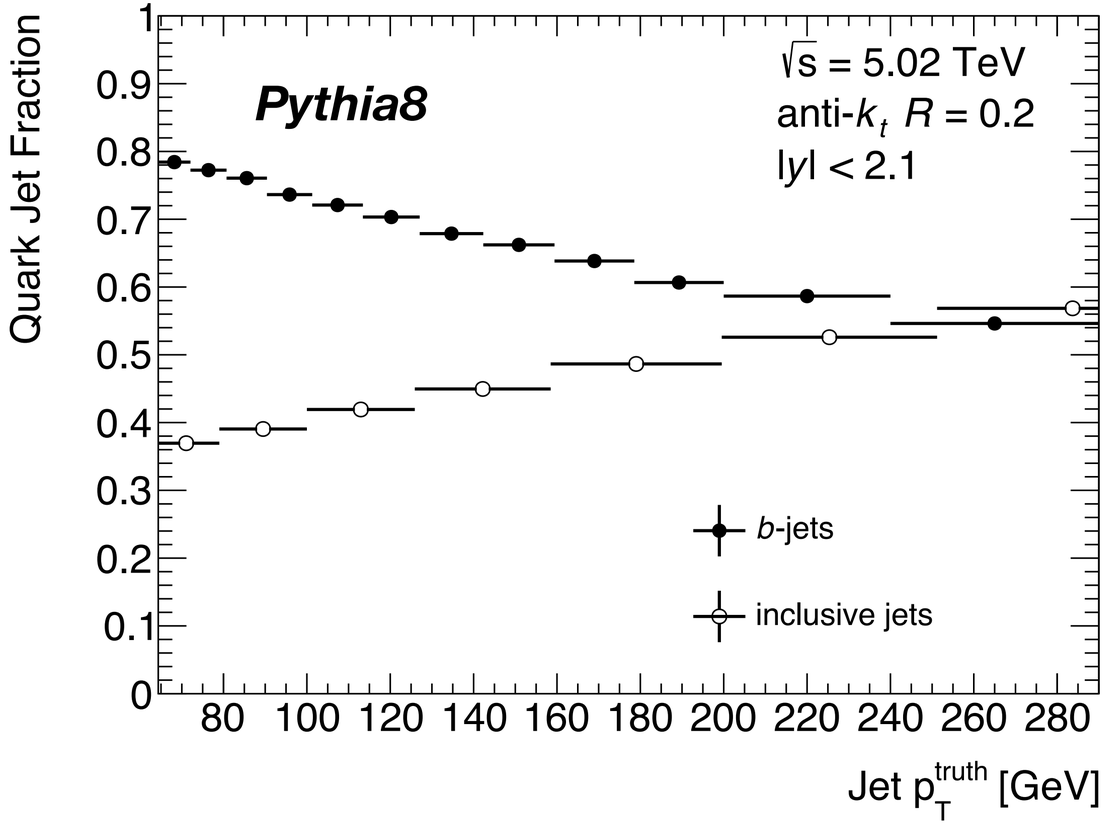


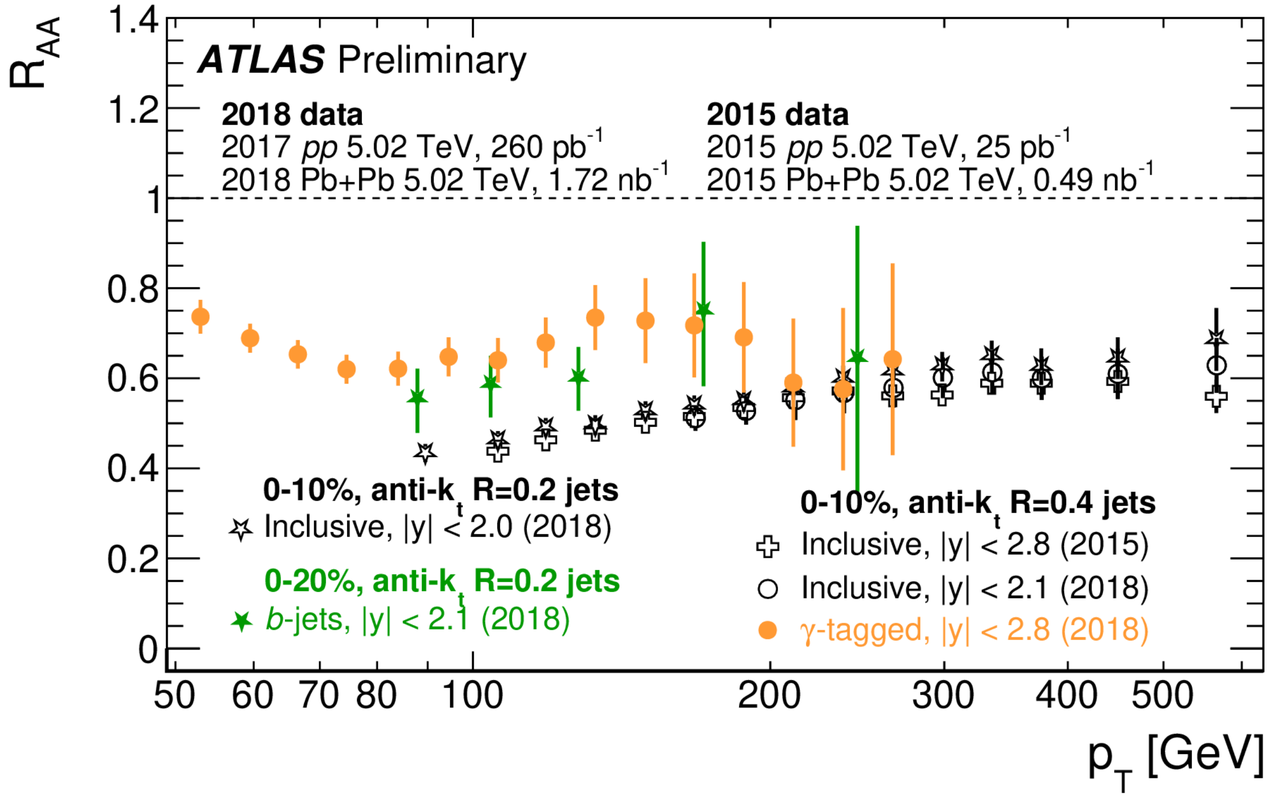
Ratio of nuclear modification factor, R_{AA}, between *b*-jets and inclusive jets:

- Smaller systematic uncertainties than R_{AA}, systematic uncertainties which are shared cancel in ratio
- Ratio consistent with unity in peripheral and **~20% above unity in central collisions**
- Dai et al, calculations are able to reproduce R_{AA} ratio better than LIDO

But interpretation is not so direct

***b*-jets** vs inclusive jets





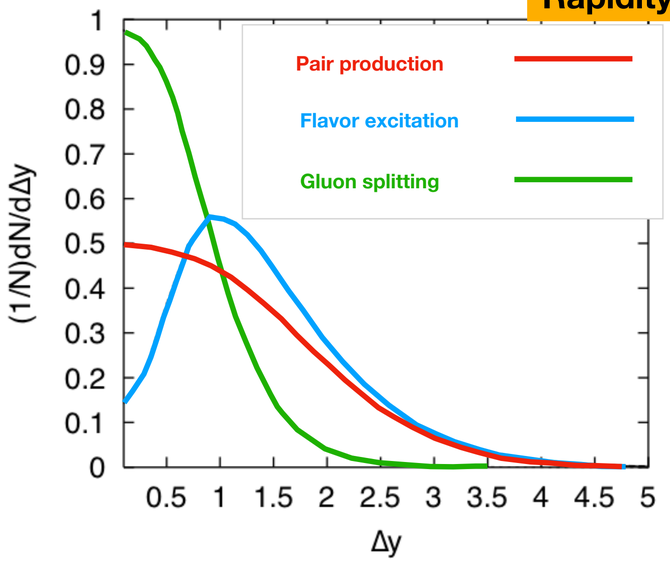
- Large contribution from gluon-splitting
  - b-jets are sensitive to quark mass but also flavor
  - different fragmentation than direct b production

- **γ-tagged jets** (dominated by quarks) can help in isolating the mass effect
  - Caveat: different *R* and centrality, spectra

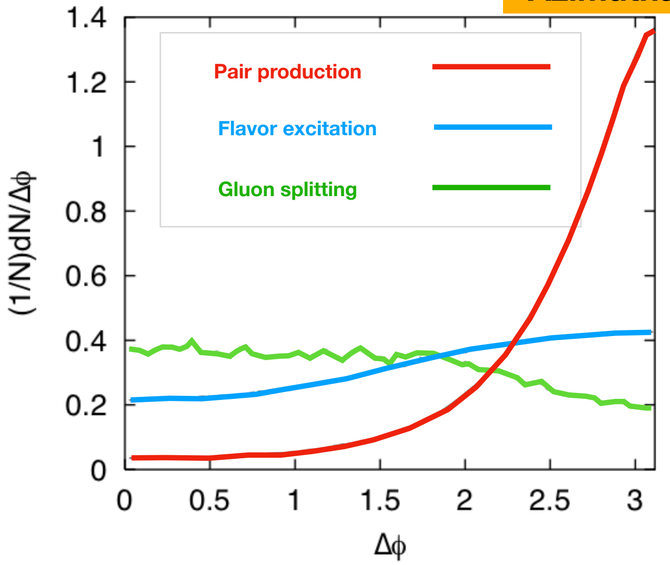
HF muon pair selection

E. Norrbin & T. Sjöstrand: EPJC 17 (2000) 137

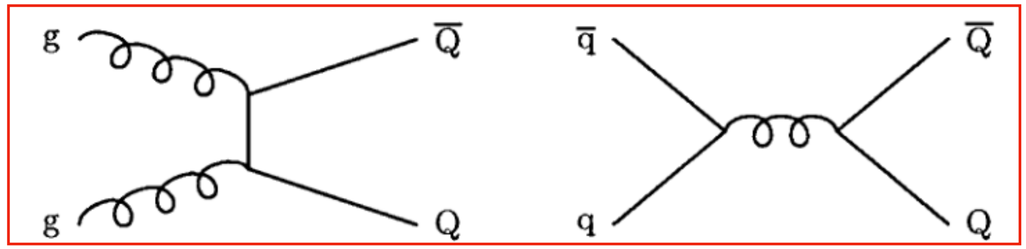
Rapidity Correlation



Azimuthal Correlation



$b - \bar{b}$ correlation at 2 TeV from **pQCD**



back-to-back muon pairs from LO pair production processes sensitive to induced angular broadening:

Rapidity gap between two muons: $|\Delta\eta| > 0.8$

- Suppress HF-bkg contribution from jets
- Suppress gluon splitting contribution

Azimuthal correlation at $\Delta\phi \sim \pi$:

- Enhanced Back-to-back pair production contribution
  - Smaller contribution of flavor excitation
  - Small non-HF bkg contamination

Back-to-back yield extraction

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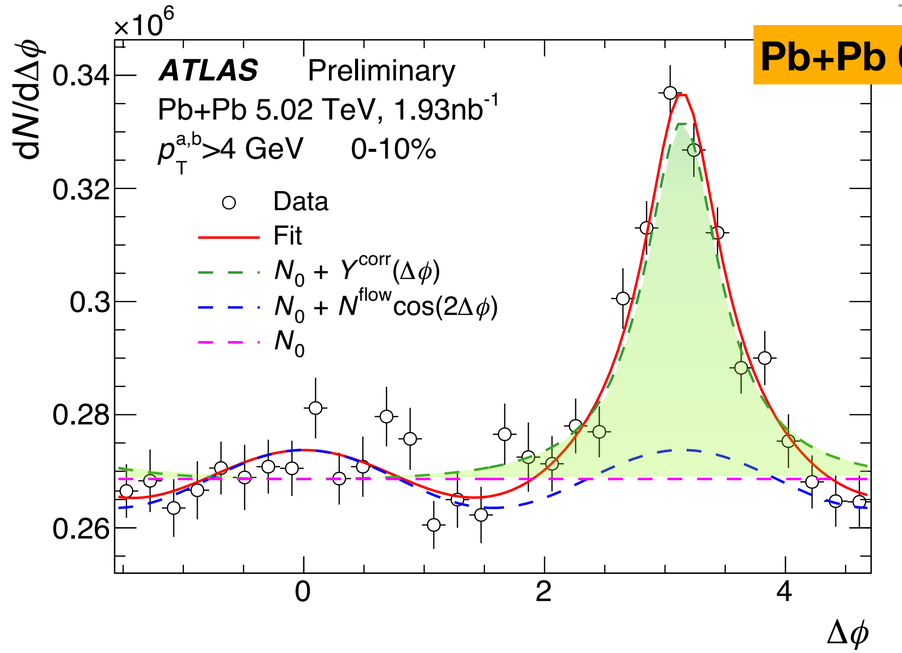

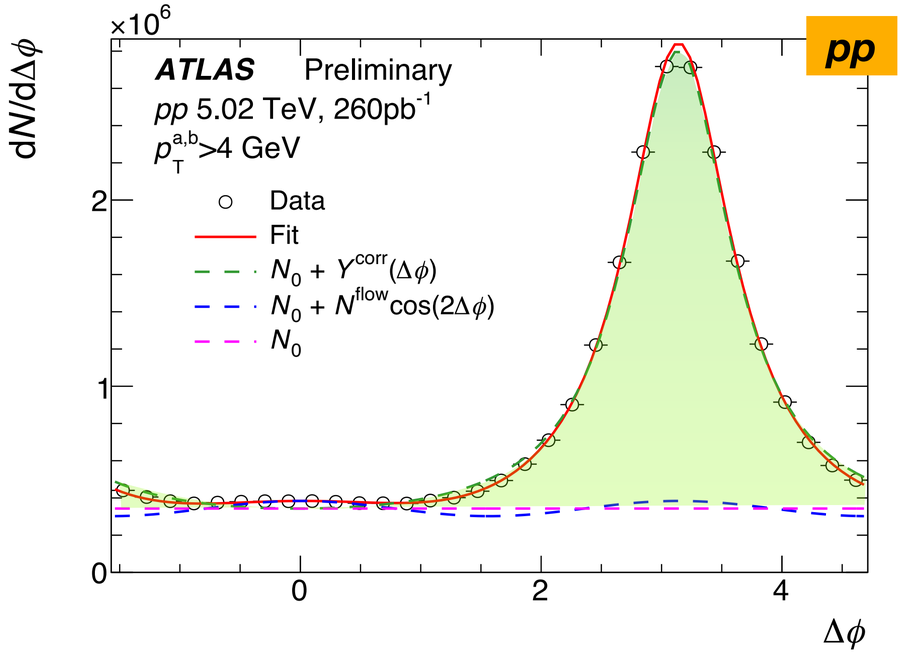

$$dN/d\Delta\phi = N_0 + N^{\text{flow}}\cos(2\Delta\phi) + Y^{\text{corr}}(\Delta\phi)$$

Yields with no azimuthal correlation

Collective flow modulation

Back-to-back correlation yields

Lorentzian

$$Y^{\text{corr}}(\Delta\phi) = \frac{N^{\text{corr}}}{(\Delta\phi - \pi)^2 + \tau^2} - N^{\text{pedestal}}$$

- Correlated yields (N^{corr}) and its width (τ) are extracted
- Separately for same-sign ($b\bar{b}$) and opposite-sign ($c\bar{c} + b\bar{b}$) HF pairs

HF pair azimuthal correlation — yields

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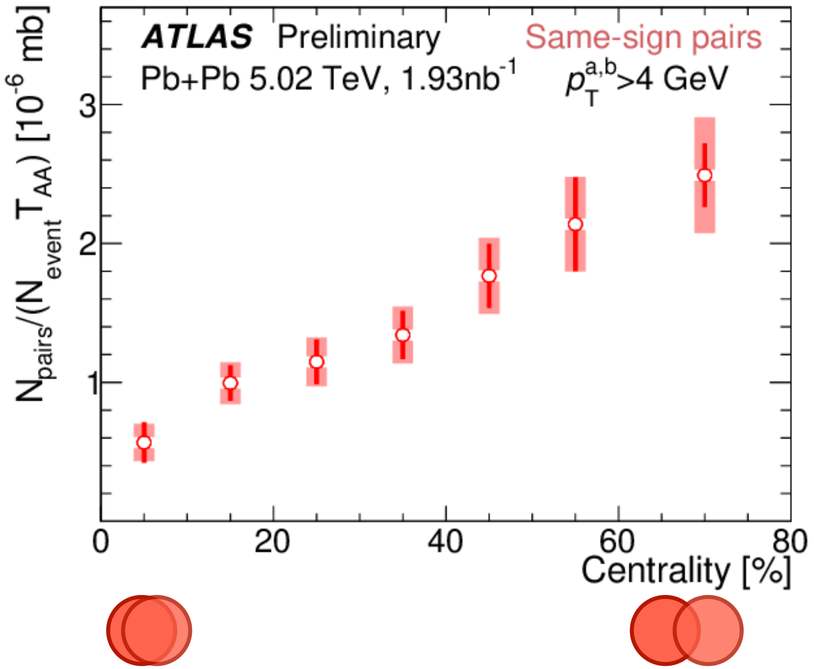
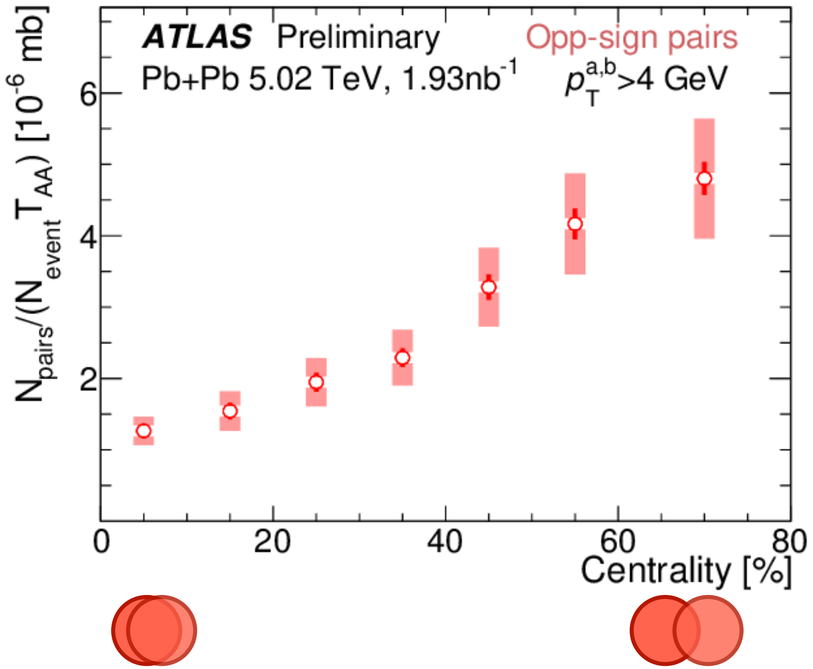
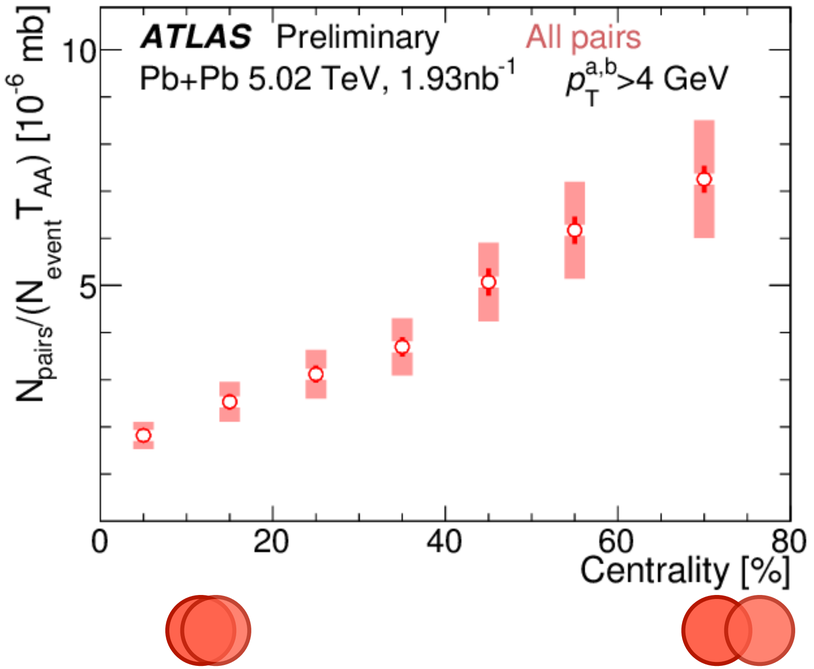
Same-sign ($b\bar{b}$)



Opposite-sign ($c\bar{c} + b\bar{b}$)



All pairs



- Larger suppression on back-to-back HF pair production in central wrt. peripheral
- Same-sign and Opposite-sign pairs have a similar trend

HF pair azimuthal correlation — width

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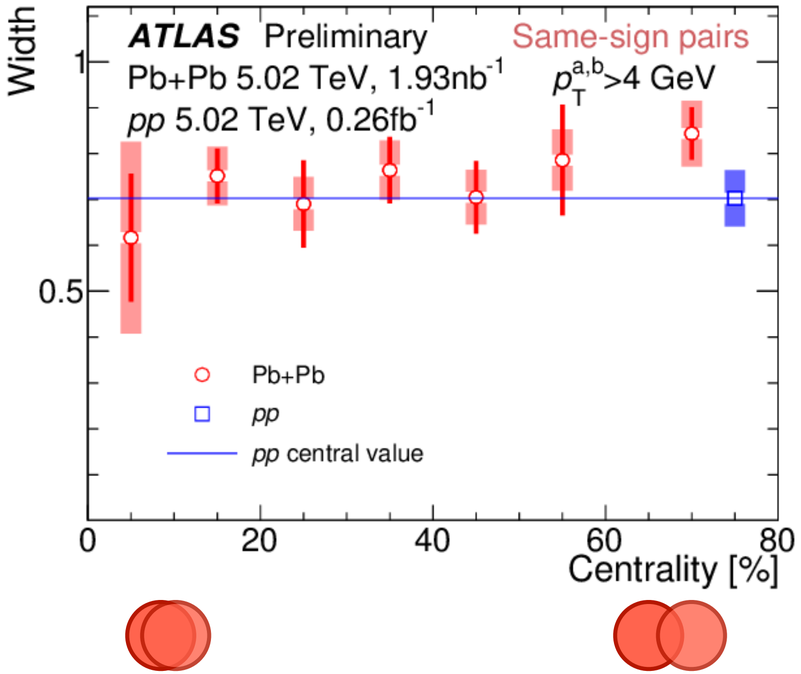
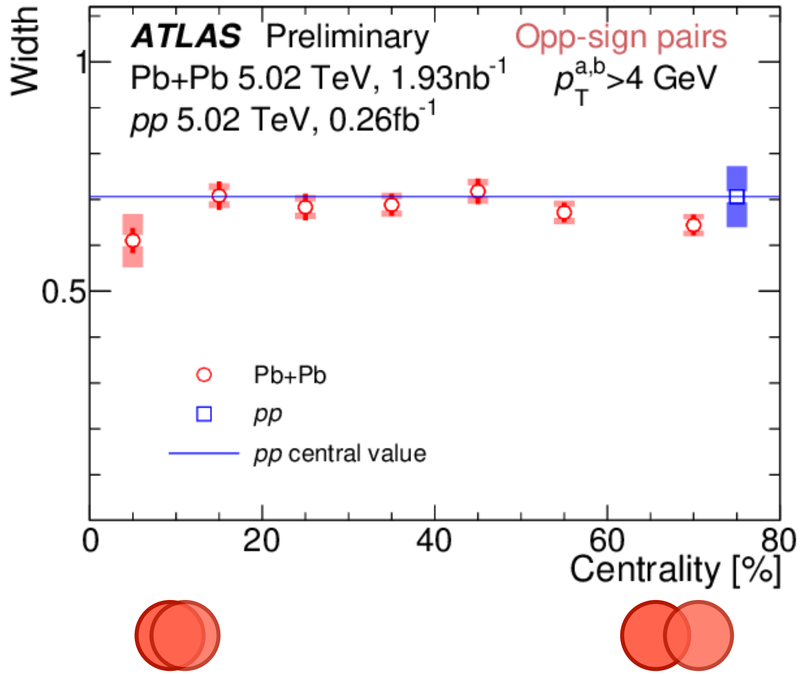
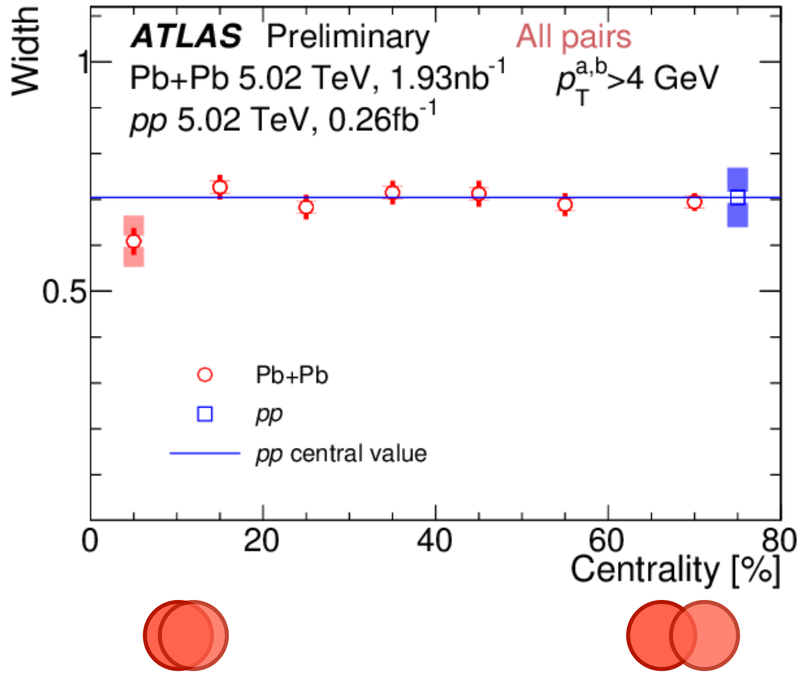
Same-sign ($b\bar{b}$)



Opposite-sign ($c\bar{c} + b\bar{b}$)



All pairs



- Comparable width between different centralities and between Pb+Pb and *pp*
- Centrality-independent width indicates small angular deflection.
  In weakly interacting picture: important role of radiative energy loss

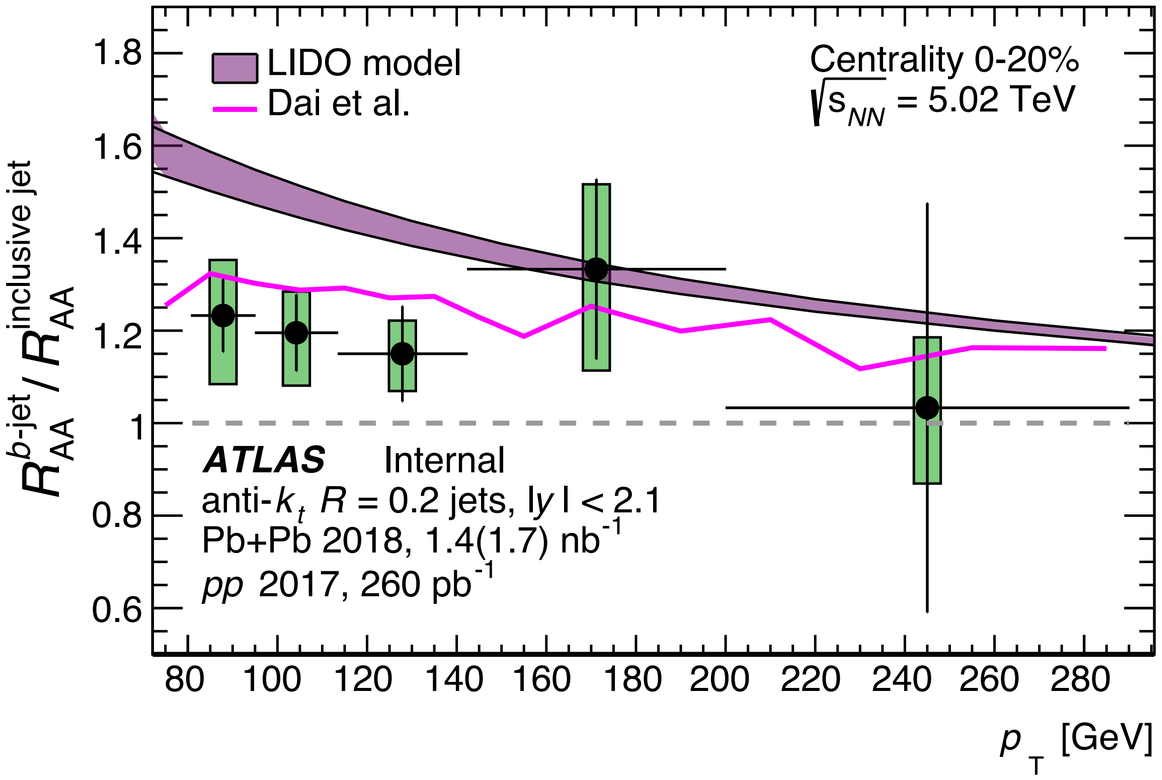
Summary

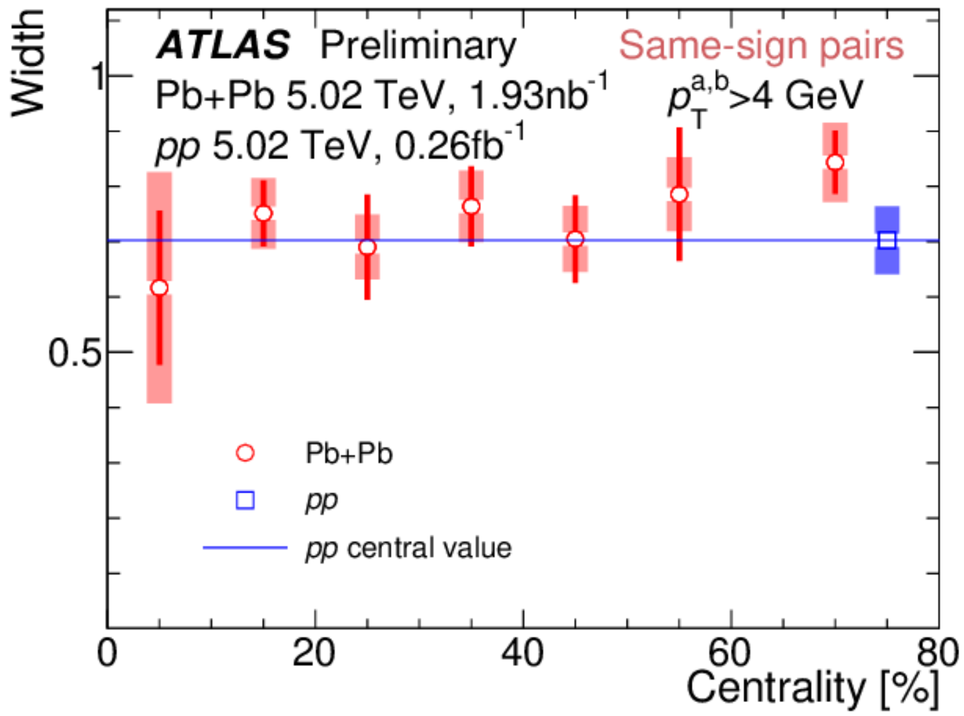
***b*-jet** R_{AA} measured by tagging semi-leptonic decays

- *b*-jet in central collisions were found to be **less suppressed than inclusive jets**

HF pair azimuthal correlation measured with muon pairs

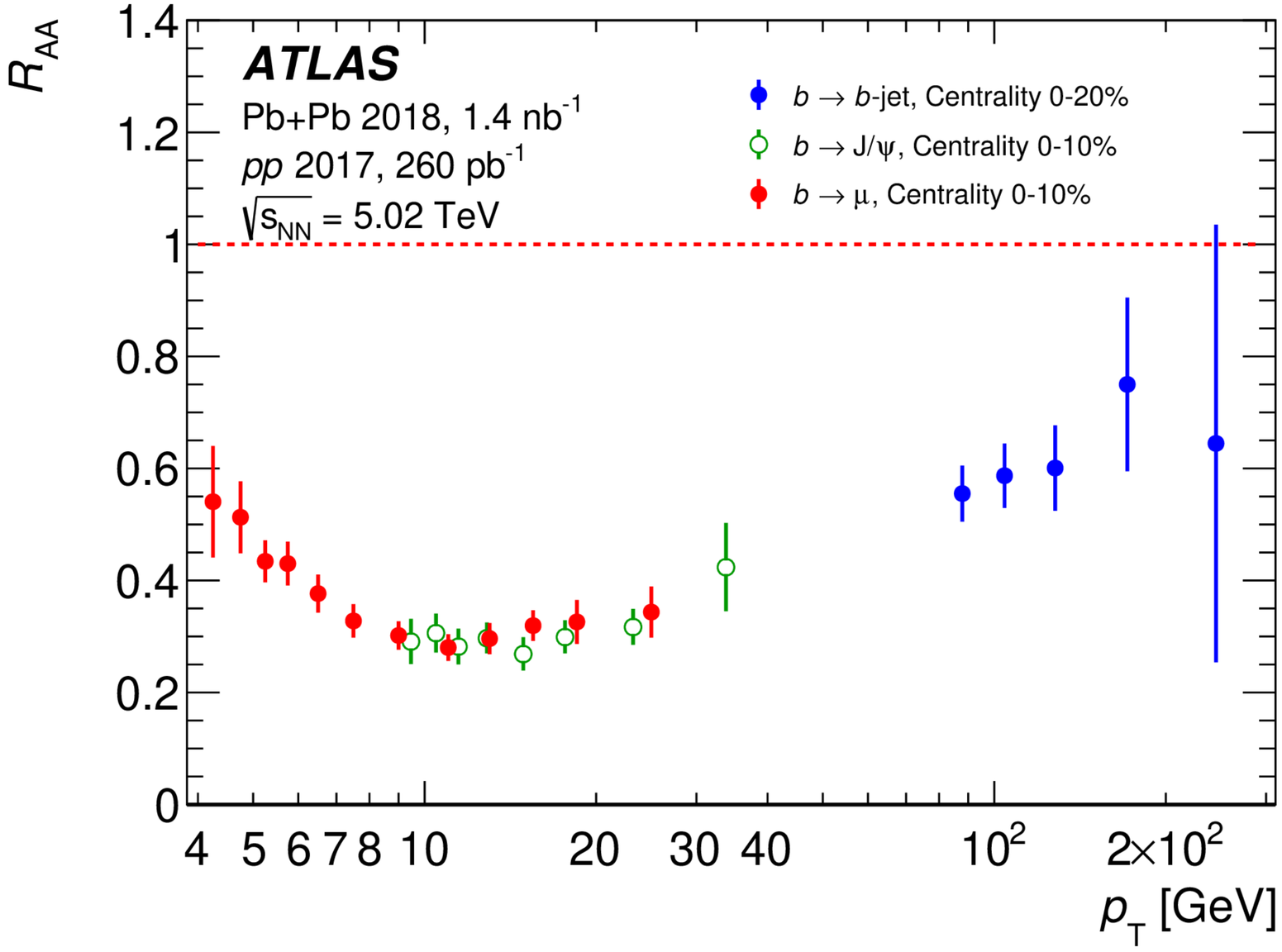
- **No significant broadening observed** in the azimuthal correlation





Thank you!

more results at: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults



New and more precise results coming for **RUN3 data!**

Additional slides

***b*-jets** muon fragmentation

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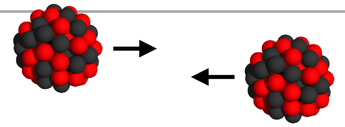
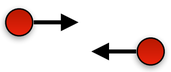




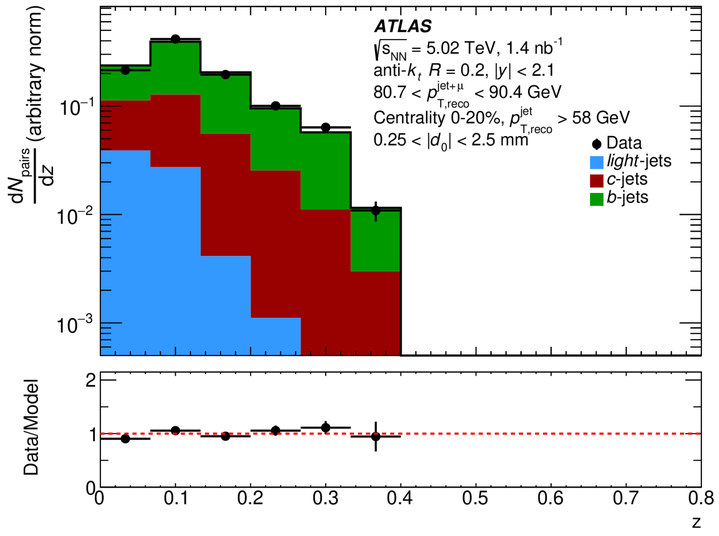
p_T-rel is sensitive to muon momentum modeling

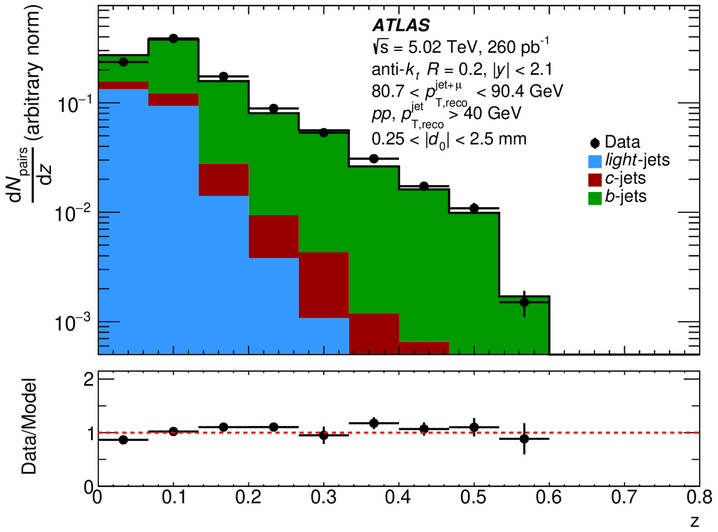
Independent test on muon fragmentation function, “z”, using measured flavor-fractions

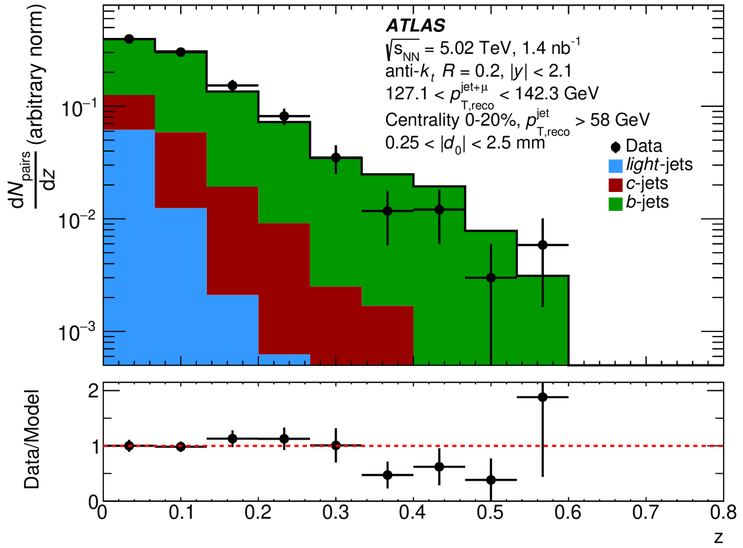
$$z = p_T^{\mu} cos(\theta) / p_T^{jet+\mu}$$

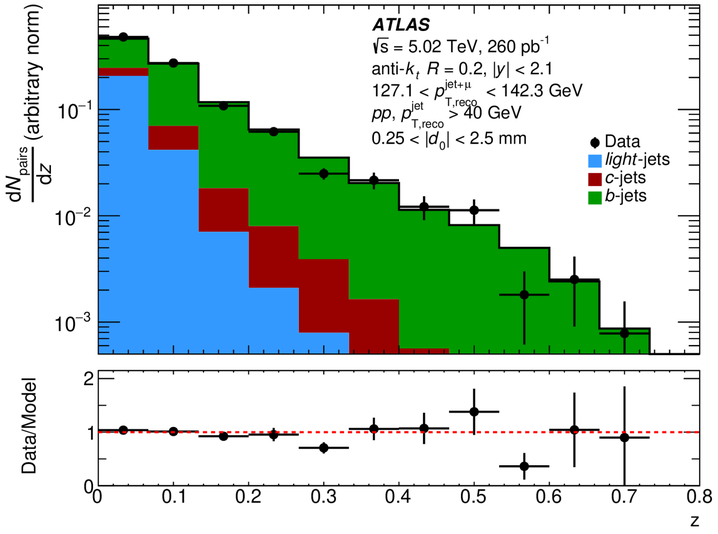
The muon momentum distribution is well reproduced by PYTHIA8

PYTHIA8 setting:
- **A14** (ATLAS-PHYS-PUB-2014-021)
- **NNPDF23LO** (arXiv:1207.1303)









***b*-jets *pp* cross-section**

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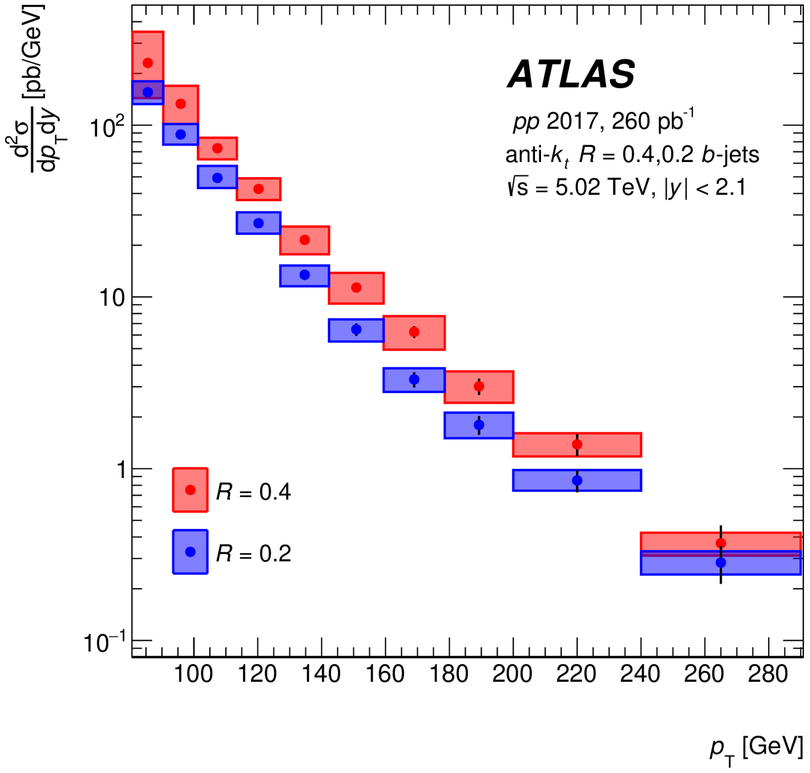
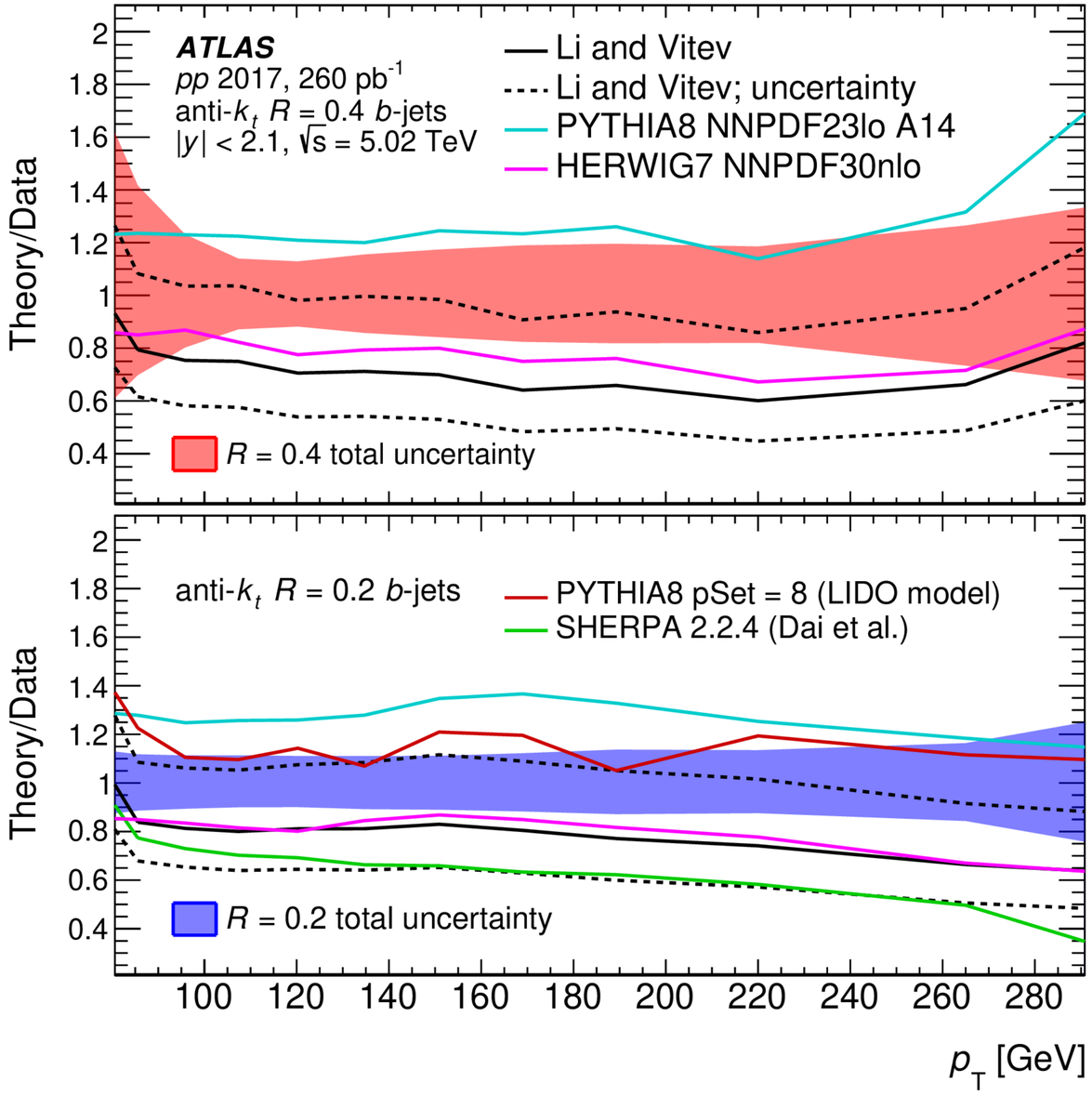


- *b*-jet cross-section measured for Jet $R = 0.2$, and 0.4 in *pp* collisions
- **Fully unfolded** results include neutrino energy, ***b*-jet p_T range: 80-250 GeV**
- Results are compared against generators and theoretical calculations



***b*-jets R_{AA} CMS comparison**

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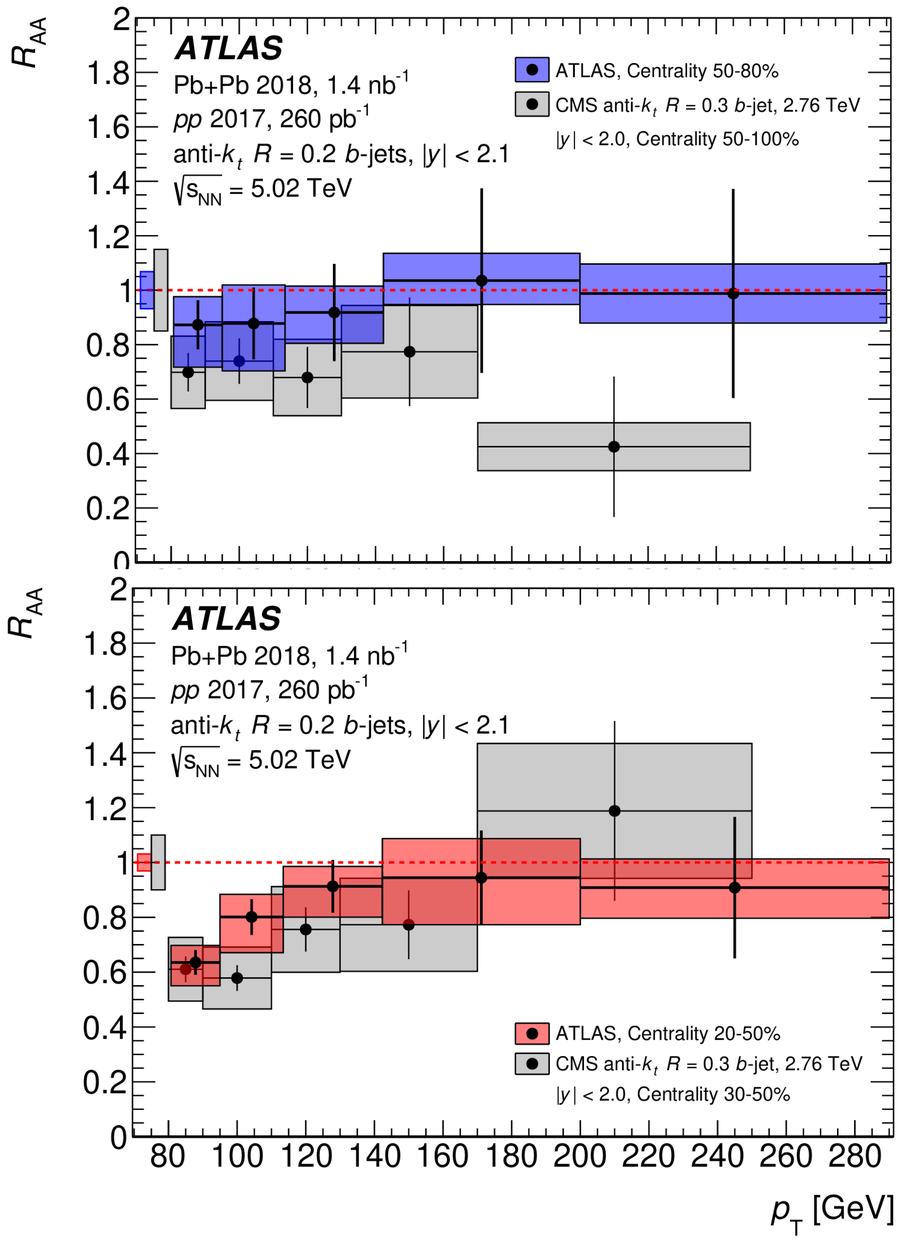

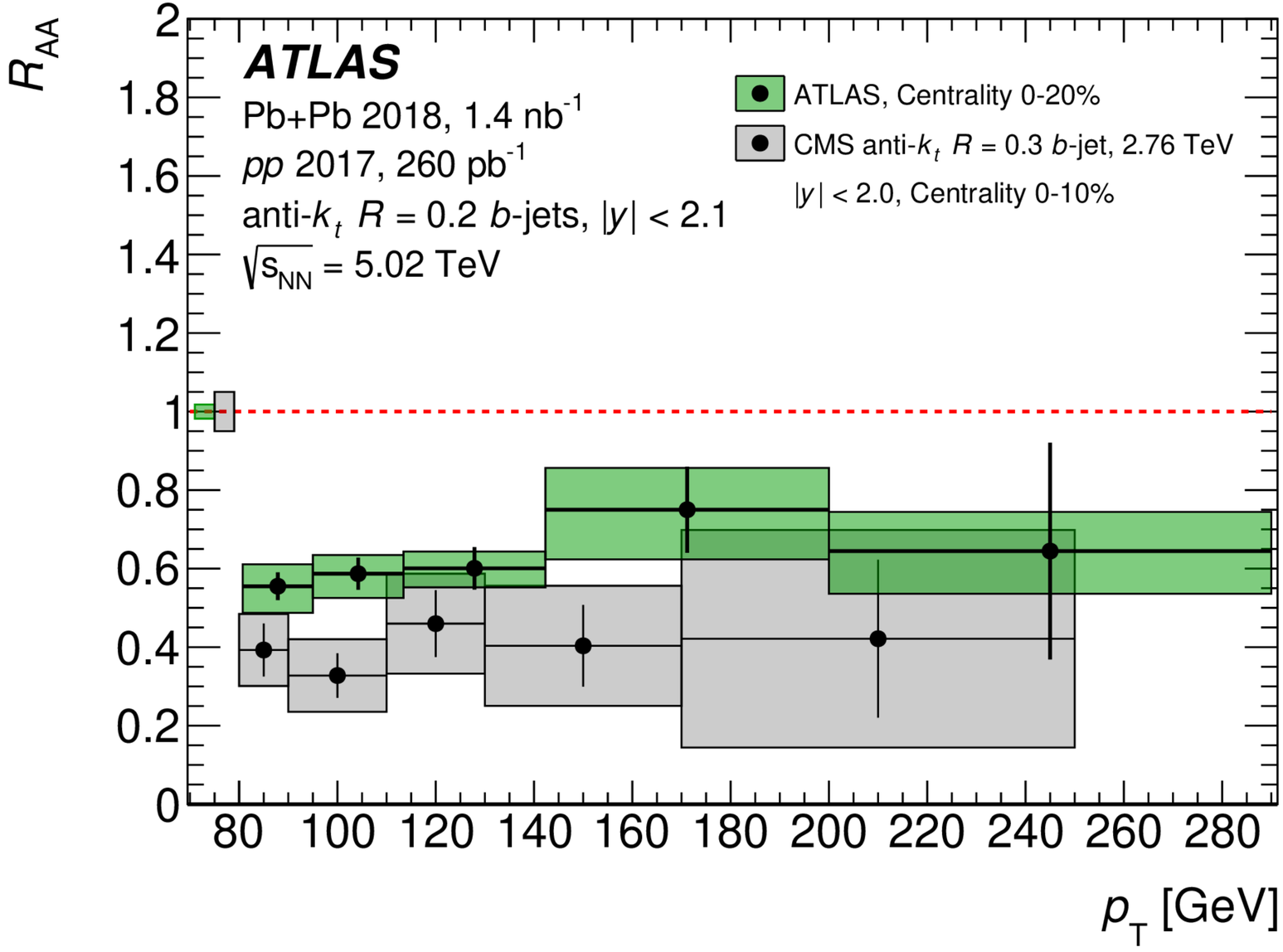

***b*-jets** *systematics*

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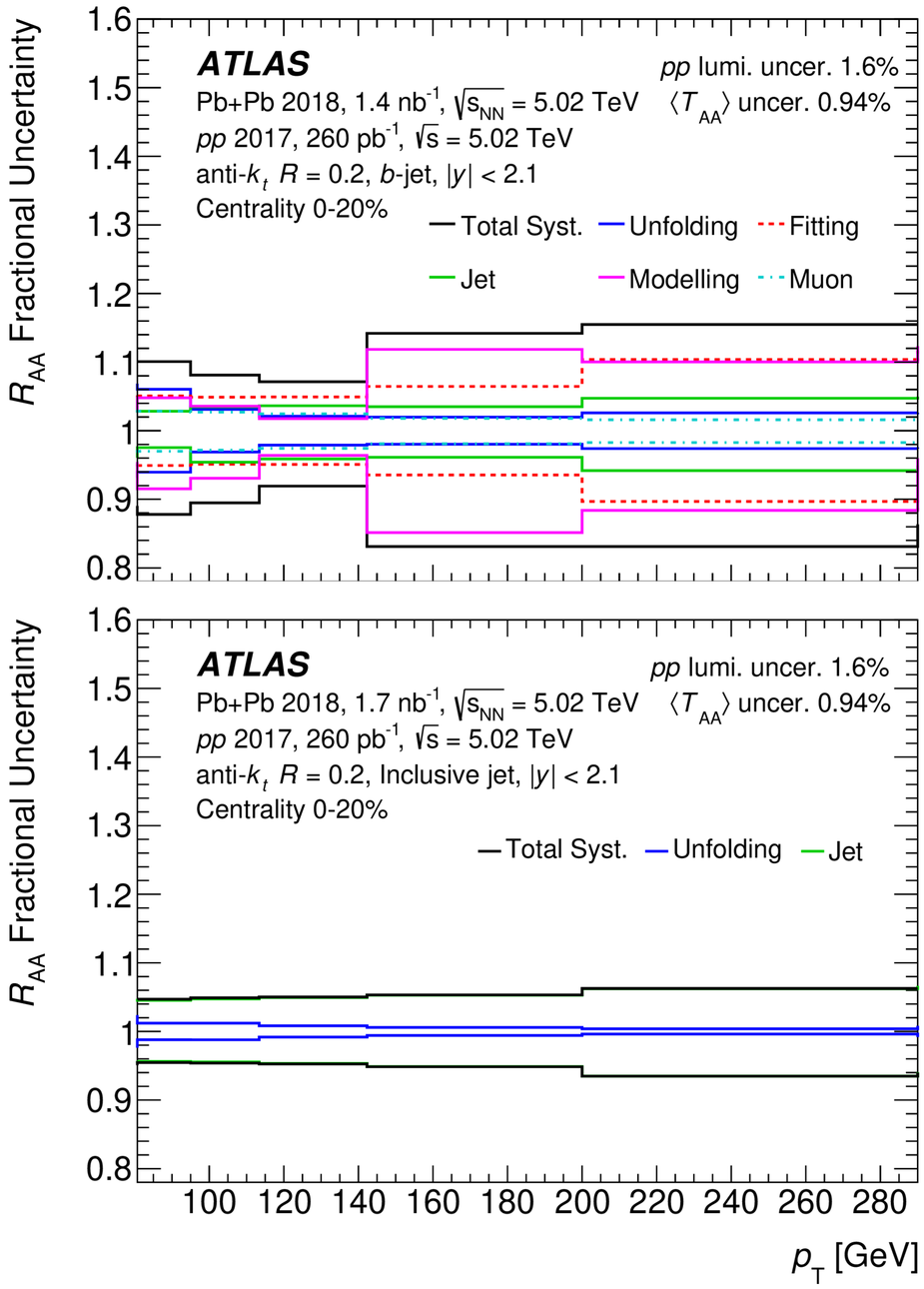
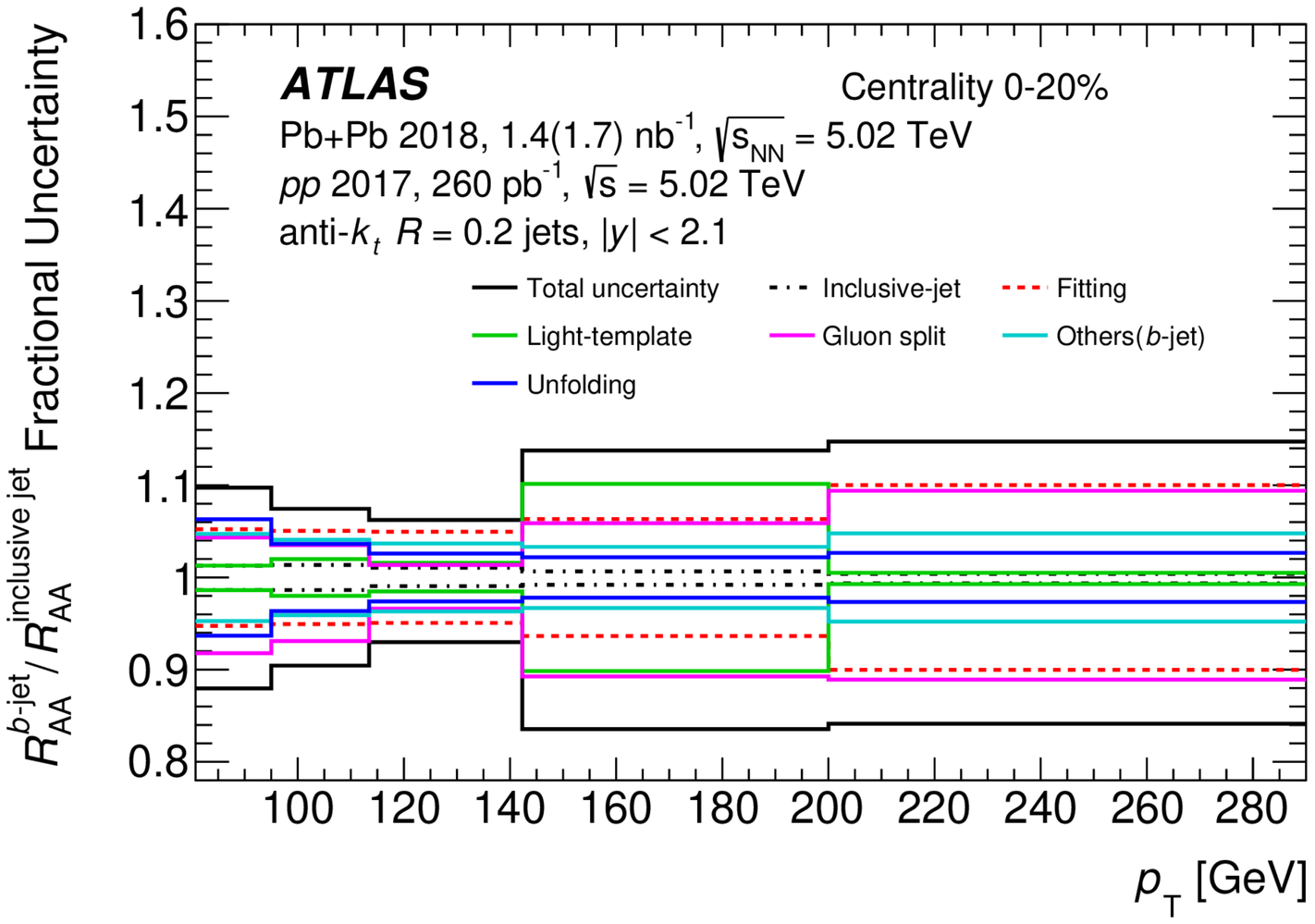
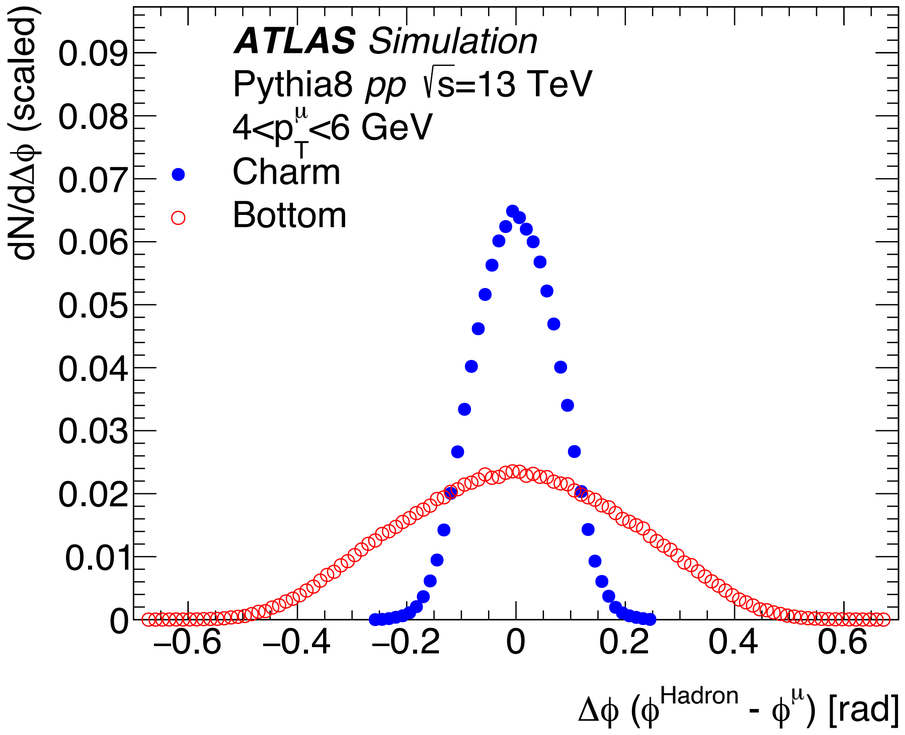
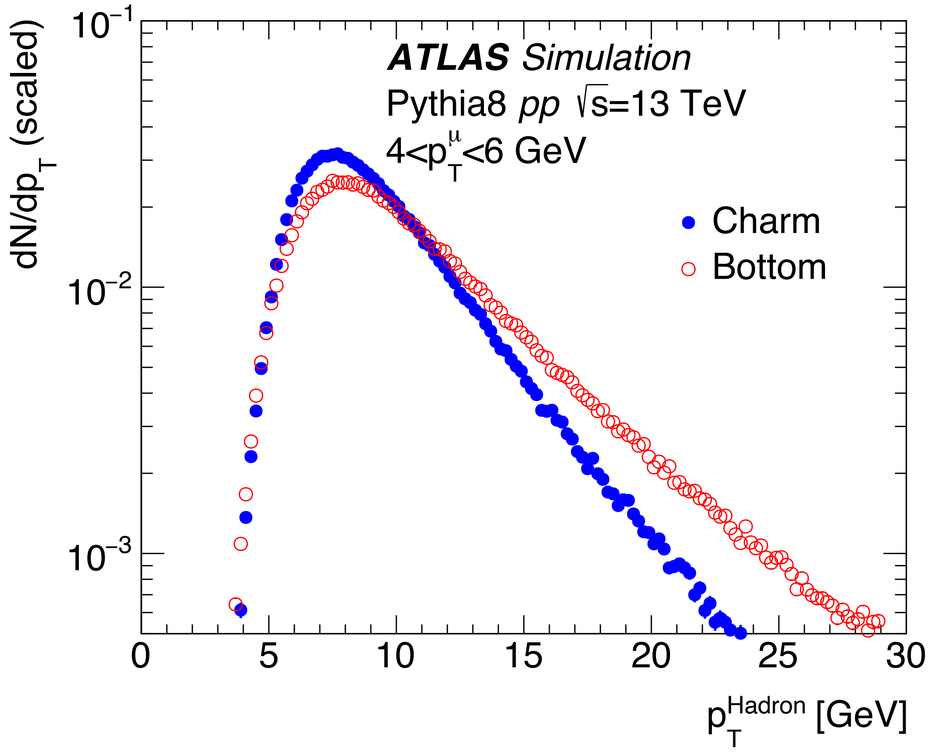




Hadron to muon smearing in Pythia



azimuthal angle smearing



p_T shift and smearing