Recent ATLAS measurements in heavy-ion collisions

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Universidad Tecnica Federico Santa Maria
for the ATLAS collaboration

HEP2023

12 January 2023, Valparaiso, Chile

Recent **jet** measurements in heavy-ion collisions with ATLAS

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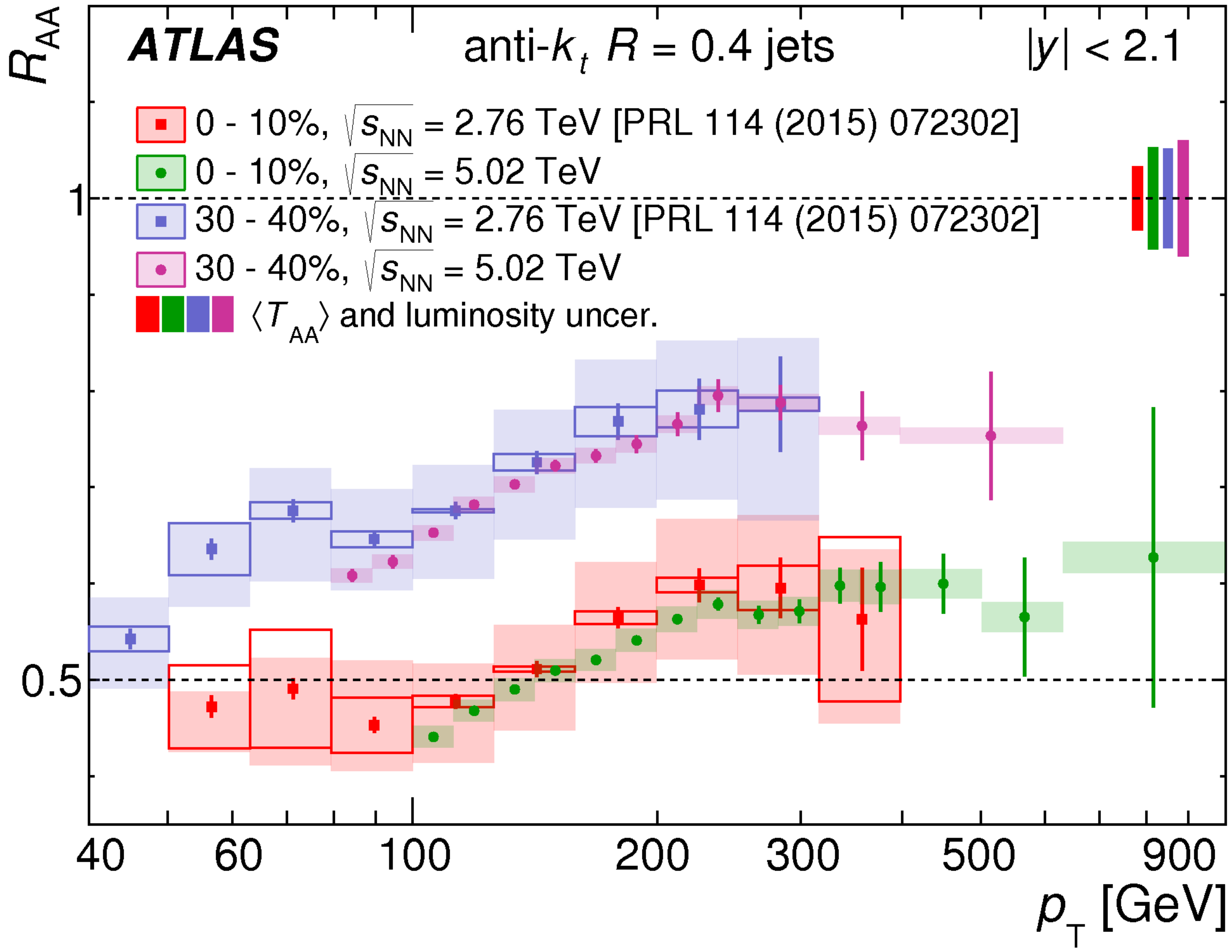
Medium induced Energy loss

Inclusive jets R_{AA}

Phys. Lett. B 790 (2019) 108



From Run1 to Run2;

Better precision but **no significant difference** in Jet energy loss measurements

Jets are known to lose energy when going through the Quark-Gluon-Plasma

What else can we learn about the medium?

Medium induced Energy loss

Inclusive jets R_{AA}

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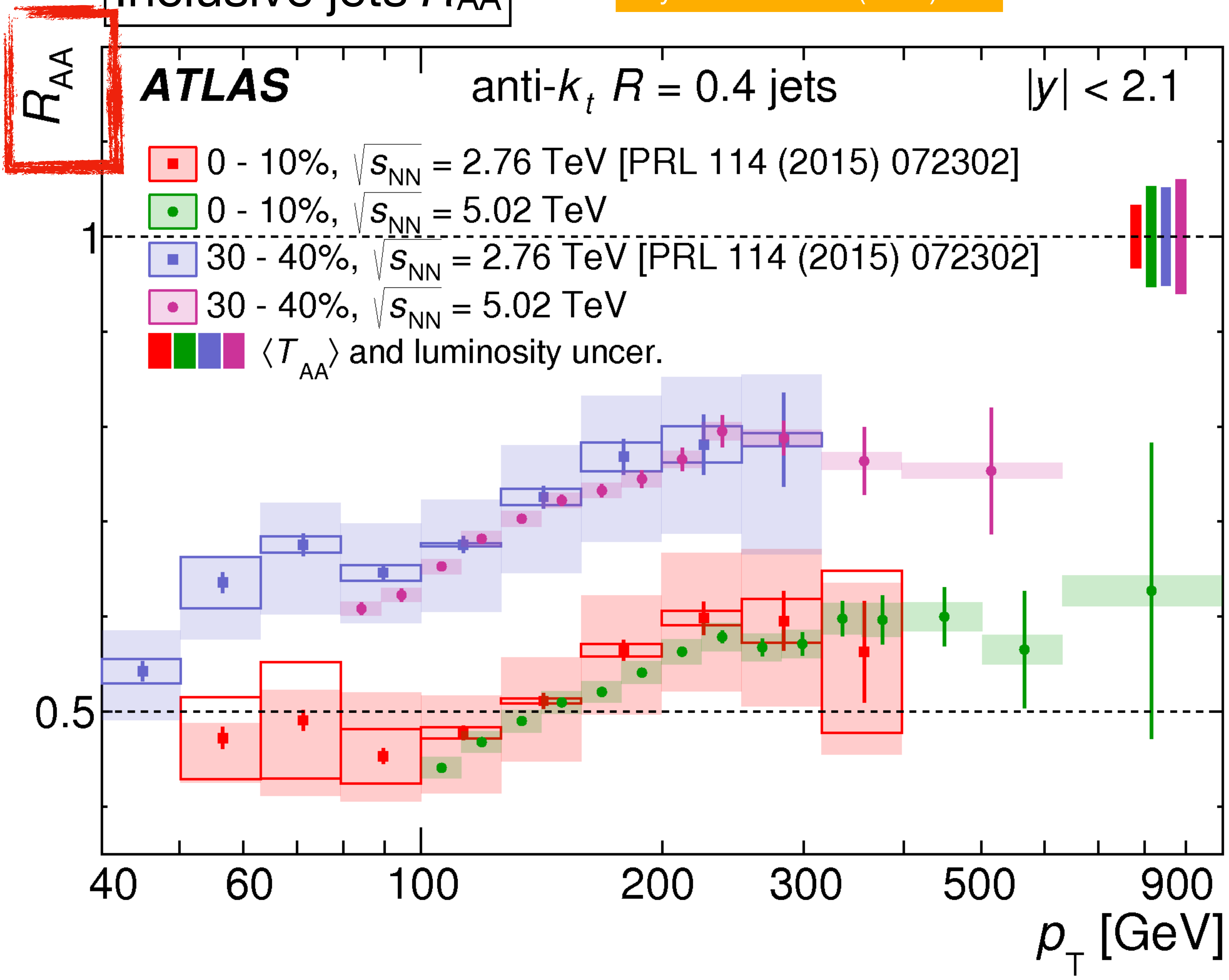
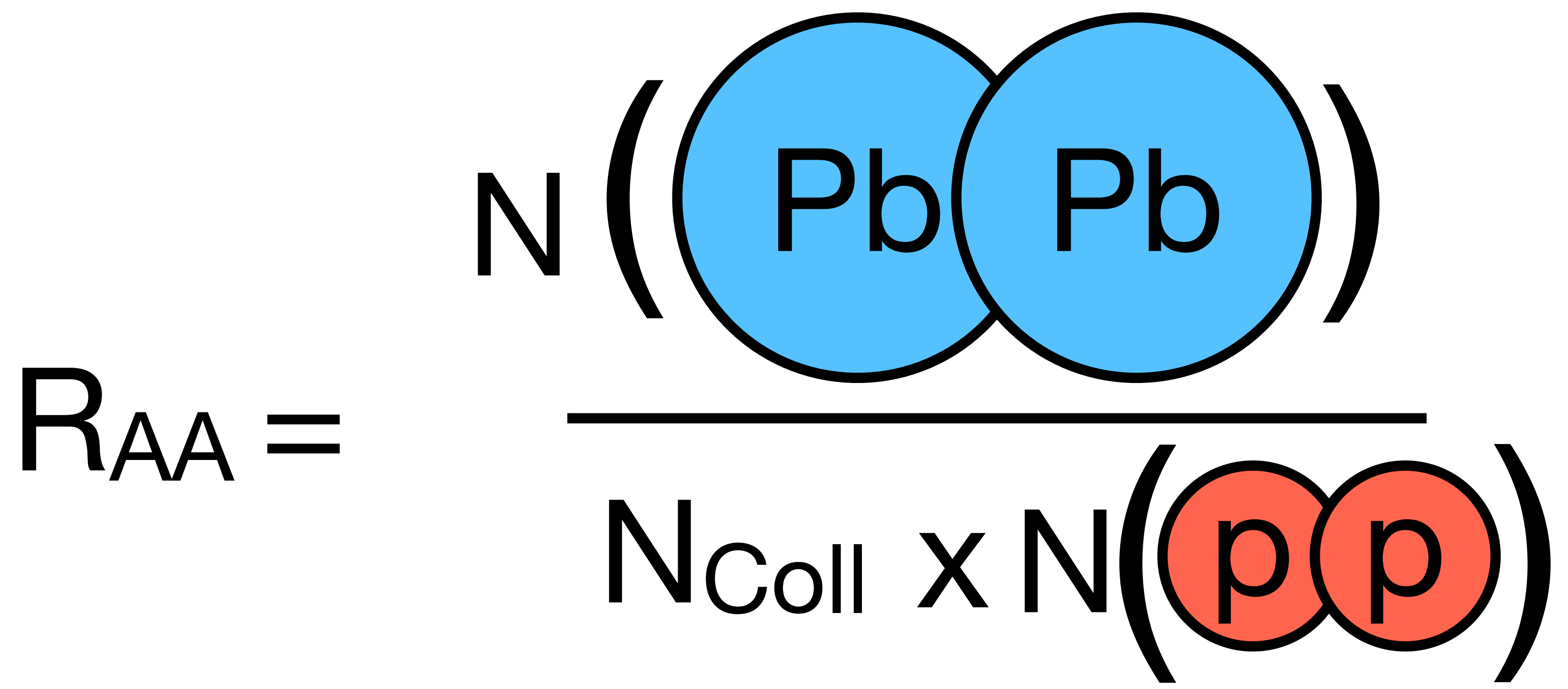


Suppression quantified by the nuclear modification factor:



- $R_{AA} < 1 \rightarrow$ suppression.
- Suppression is stronger for more central collisions.

Medium induced Energy loss

Inclusive jets R_{AA}

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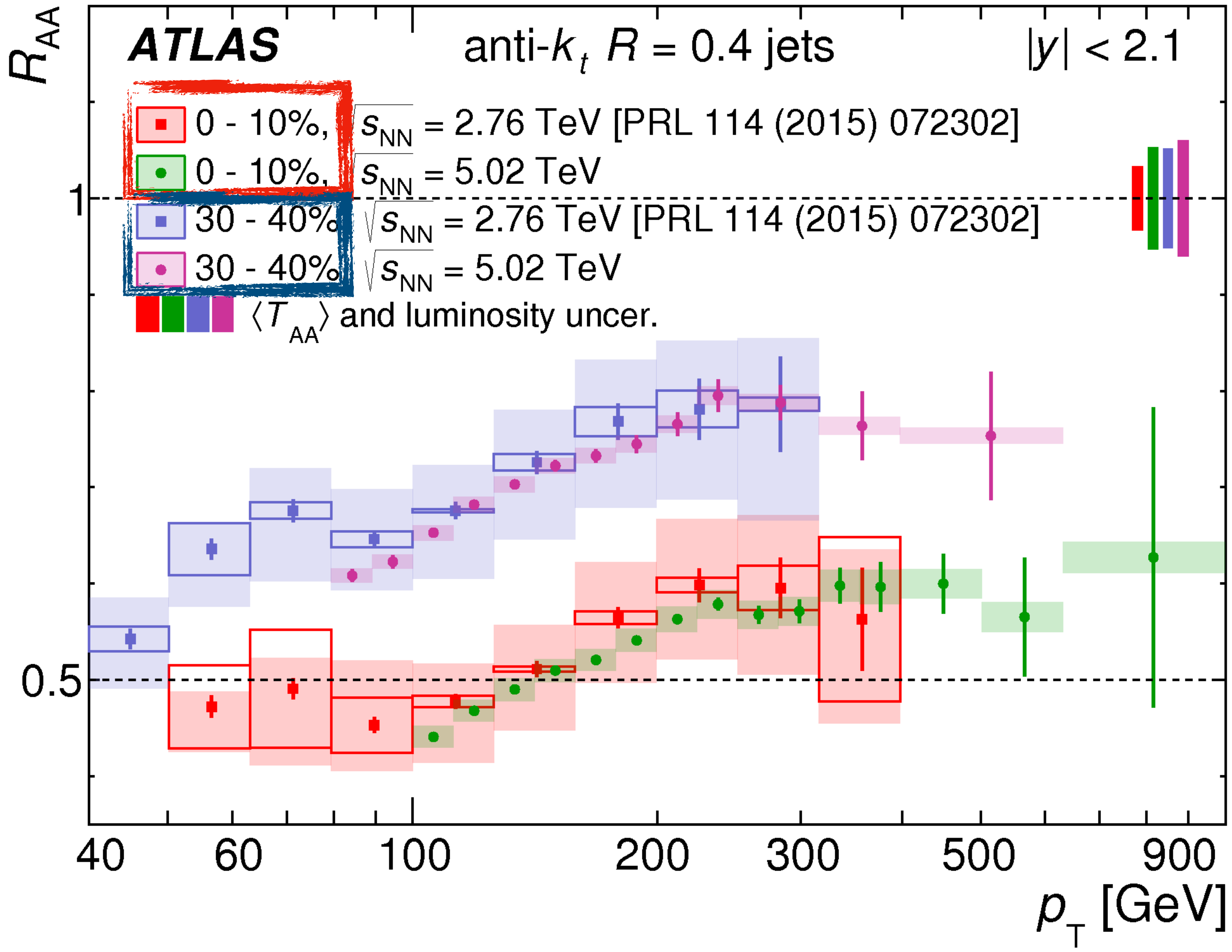
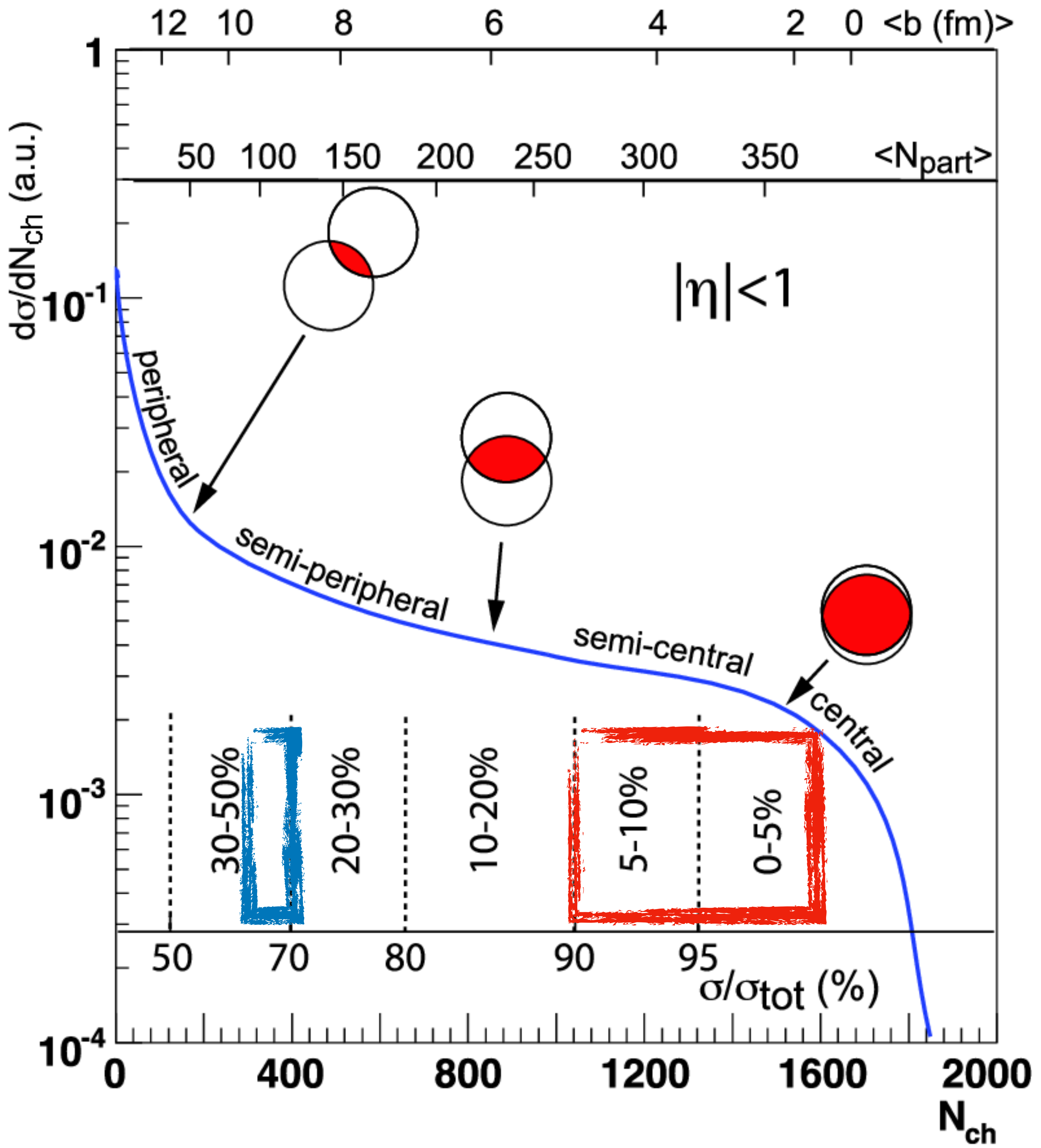


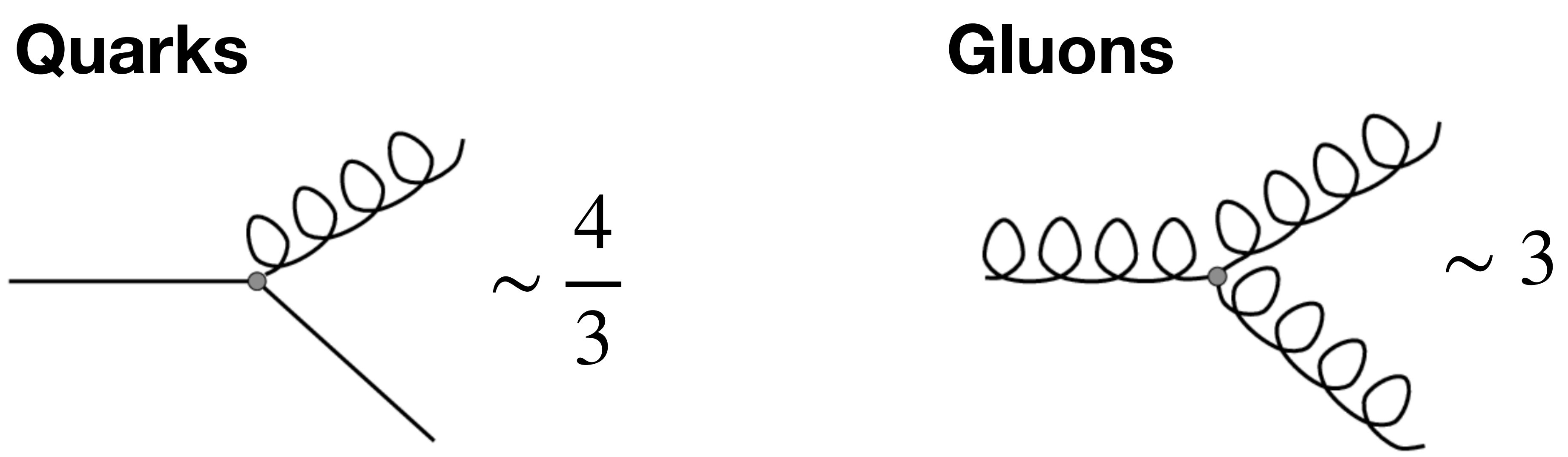
Centrality: event activity



Central collisions
—> larger volumen QGP
—> more suppression

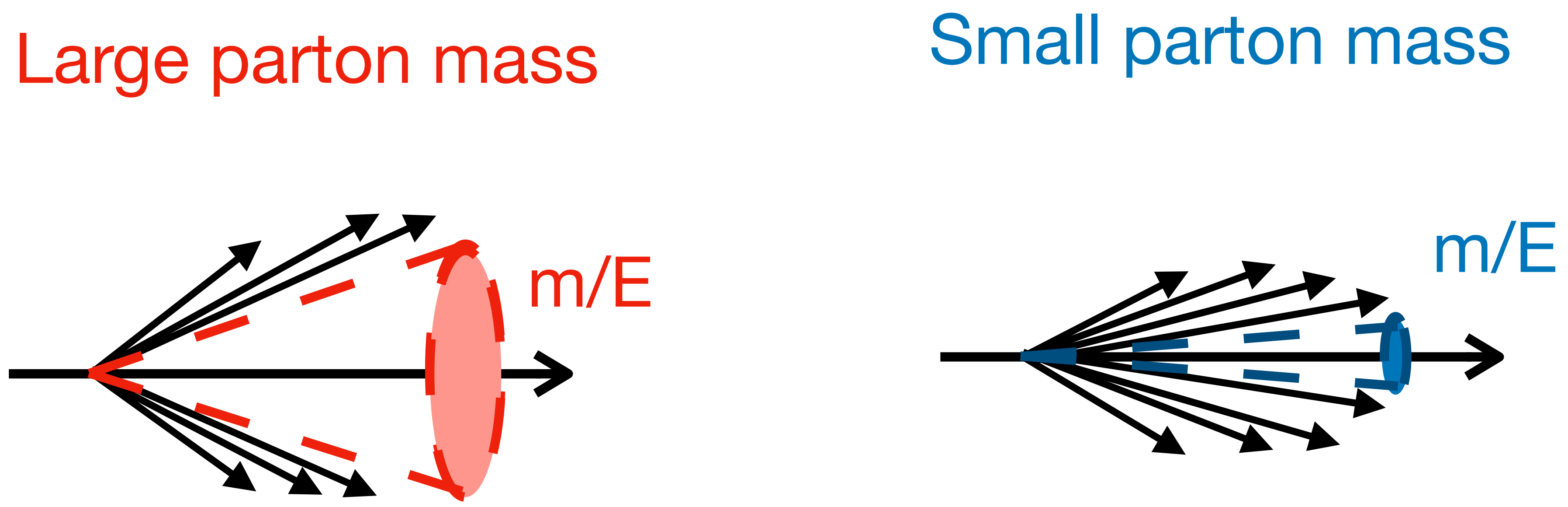
In this talk

- Color-charge dependence



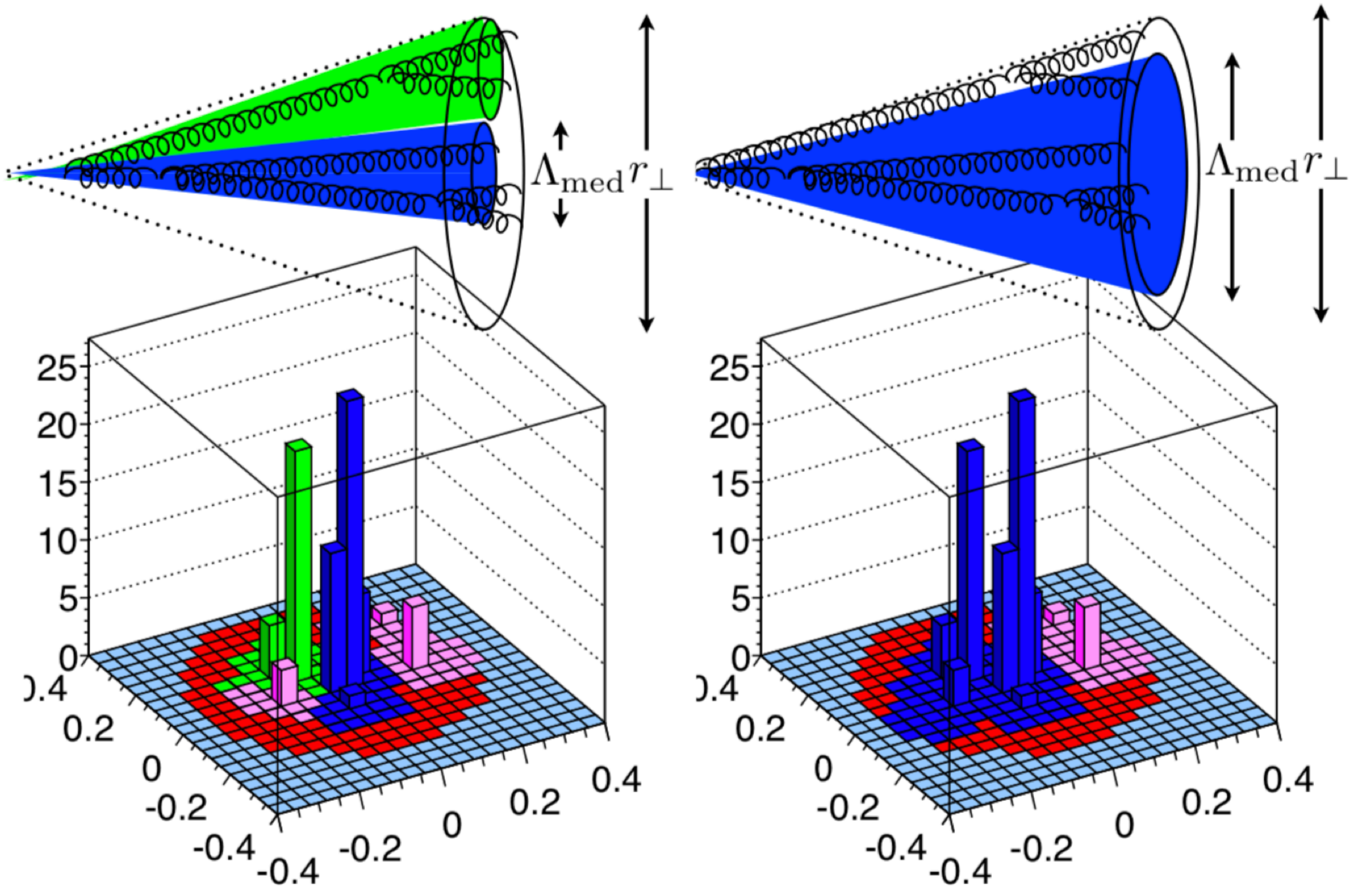
QCD suggest, gluons are more likely to radiate than quarks

- Mass dependence expected due to "dead-cone effect"



Radiation is suppressed in θ < m/E

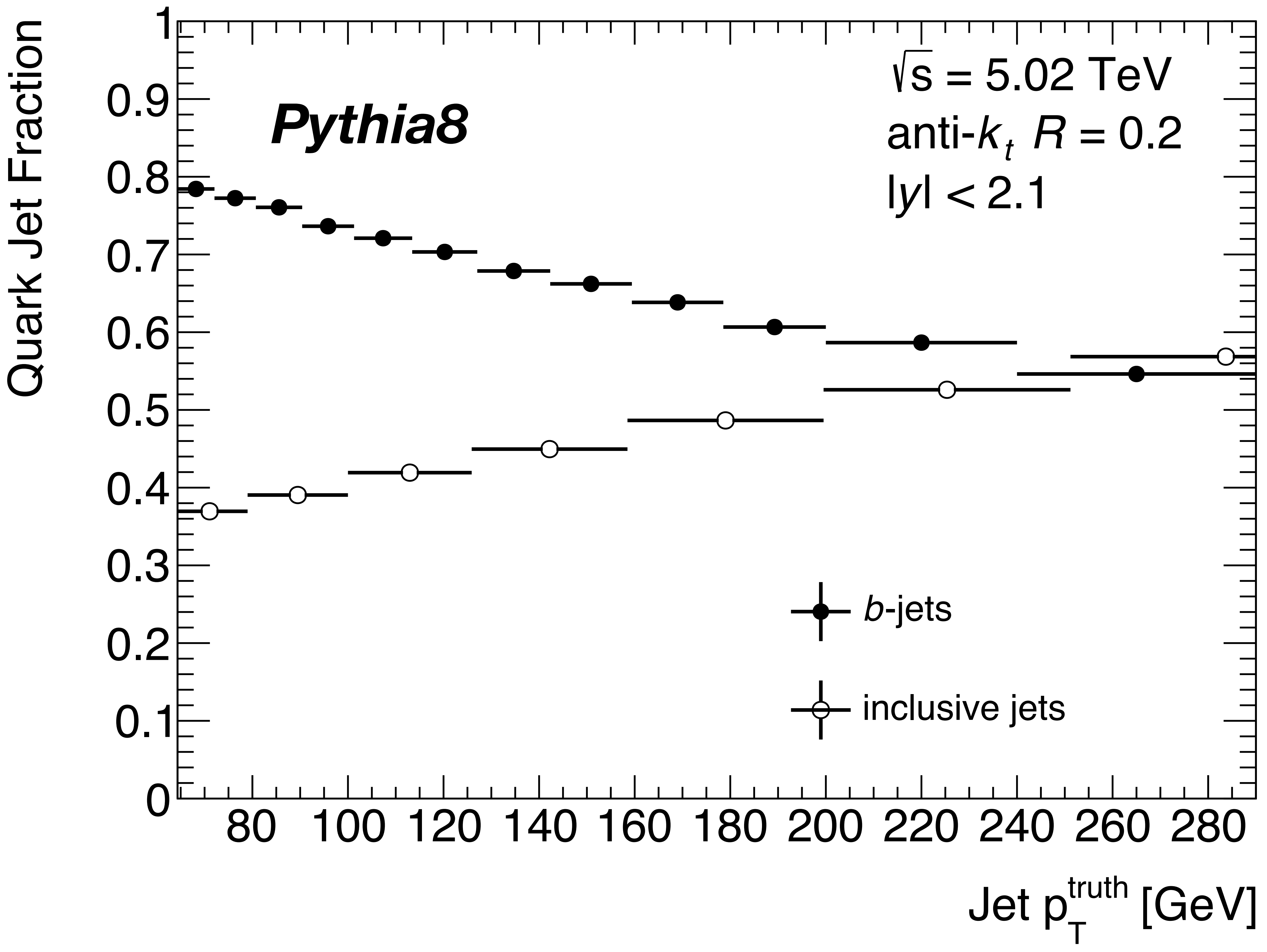
- Color-coherence of in-medium energy loss



What is the resolution scale of the medium?

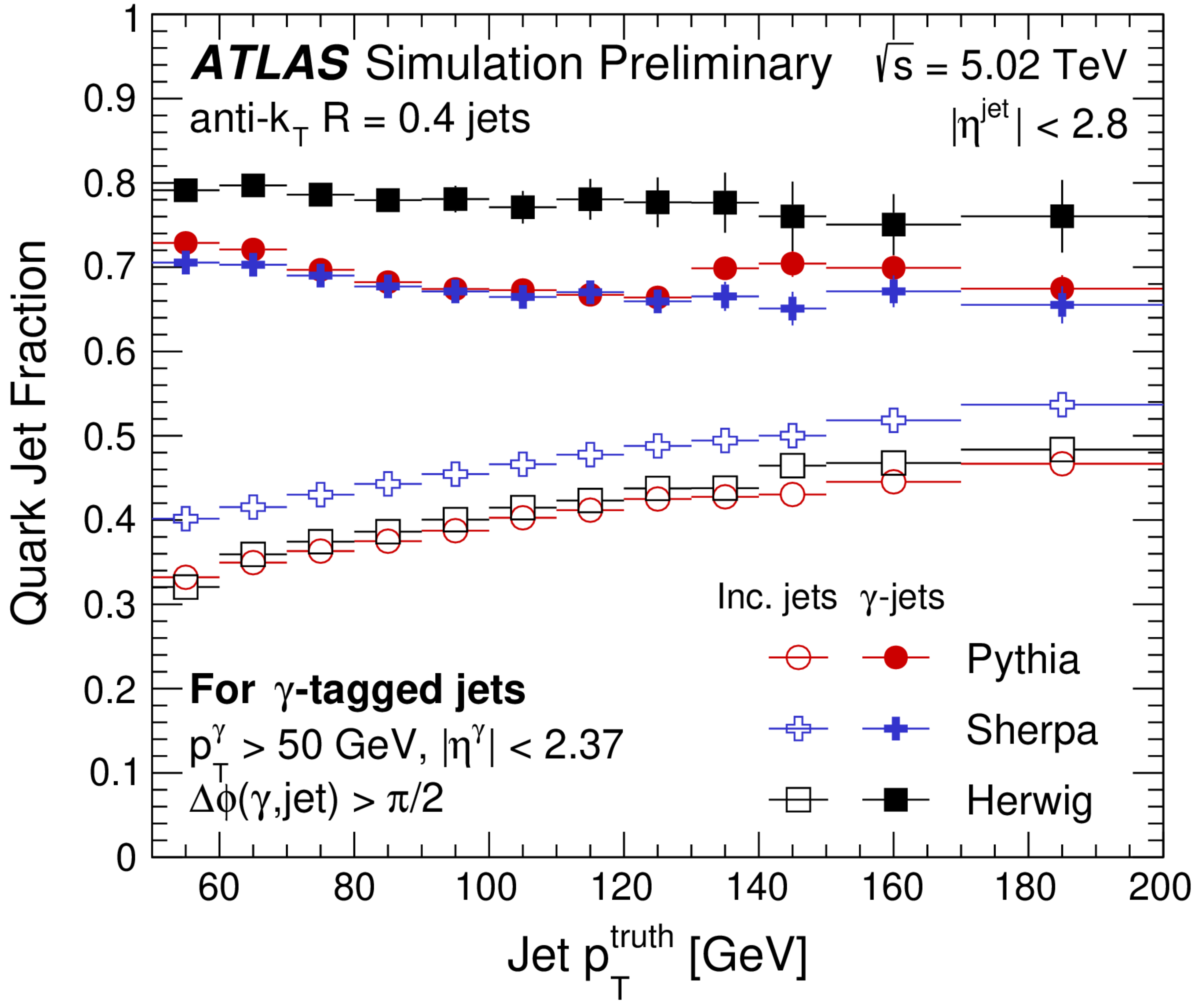
Color charge and mass dependence

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



Sensitive to color-charge and parton mass

γ-tagged jets vs inclusive jets



Sensitive to color-charge

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

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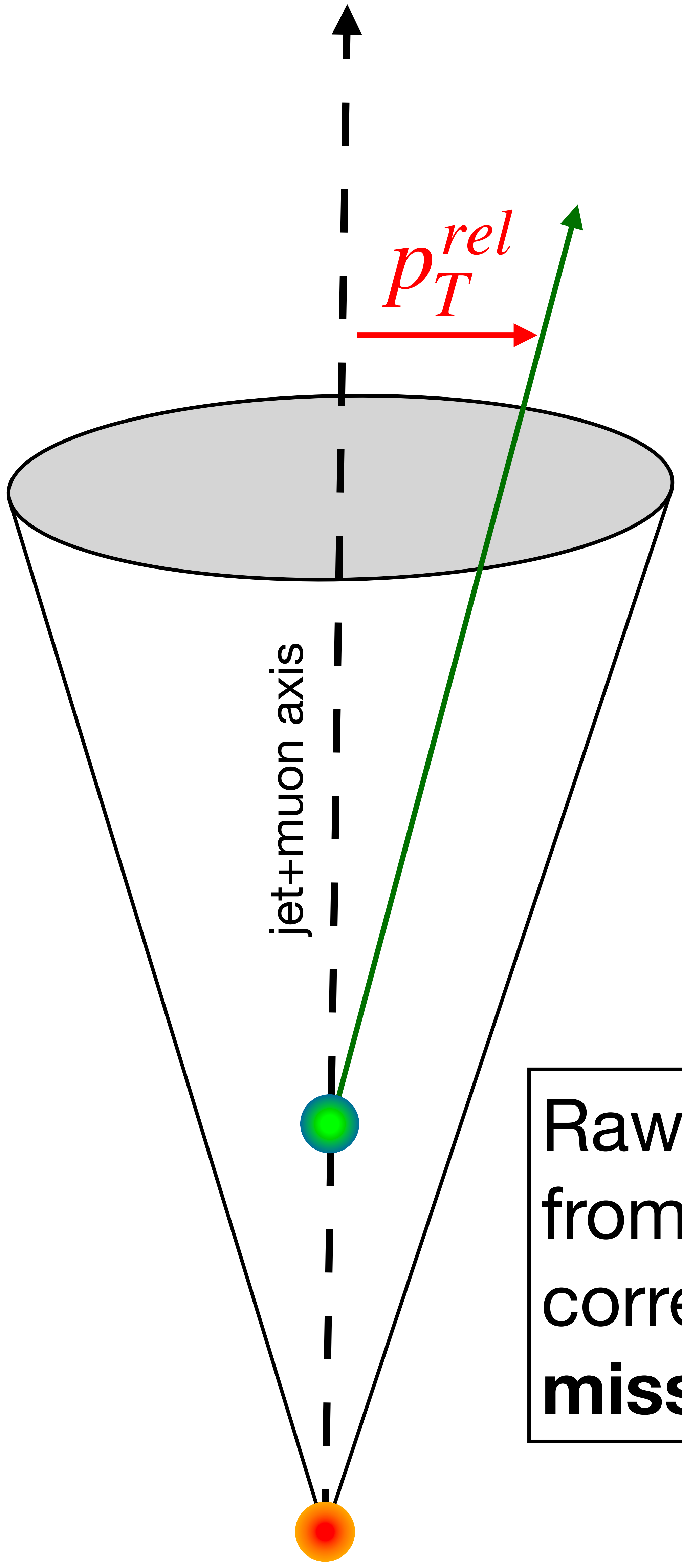


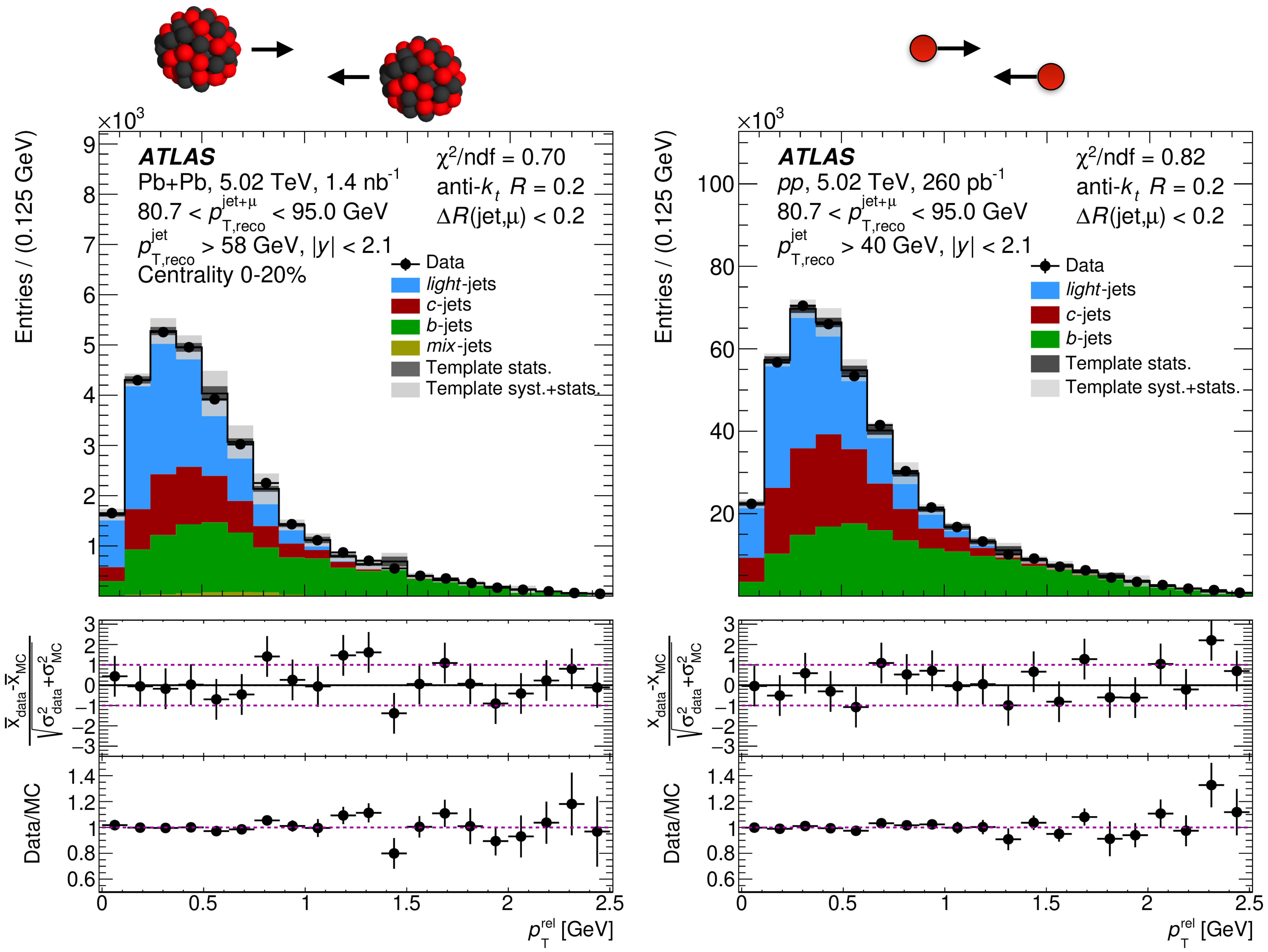
b-fraction estimated using template fit method on muon p_T-rel distribution

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

Muon selection:

- Muon p_T > 4 GeV
- Δ*R*(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 Pb+Pb collisions

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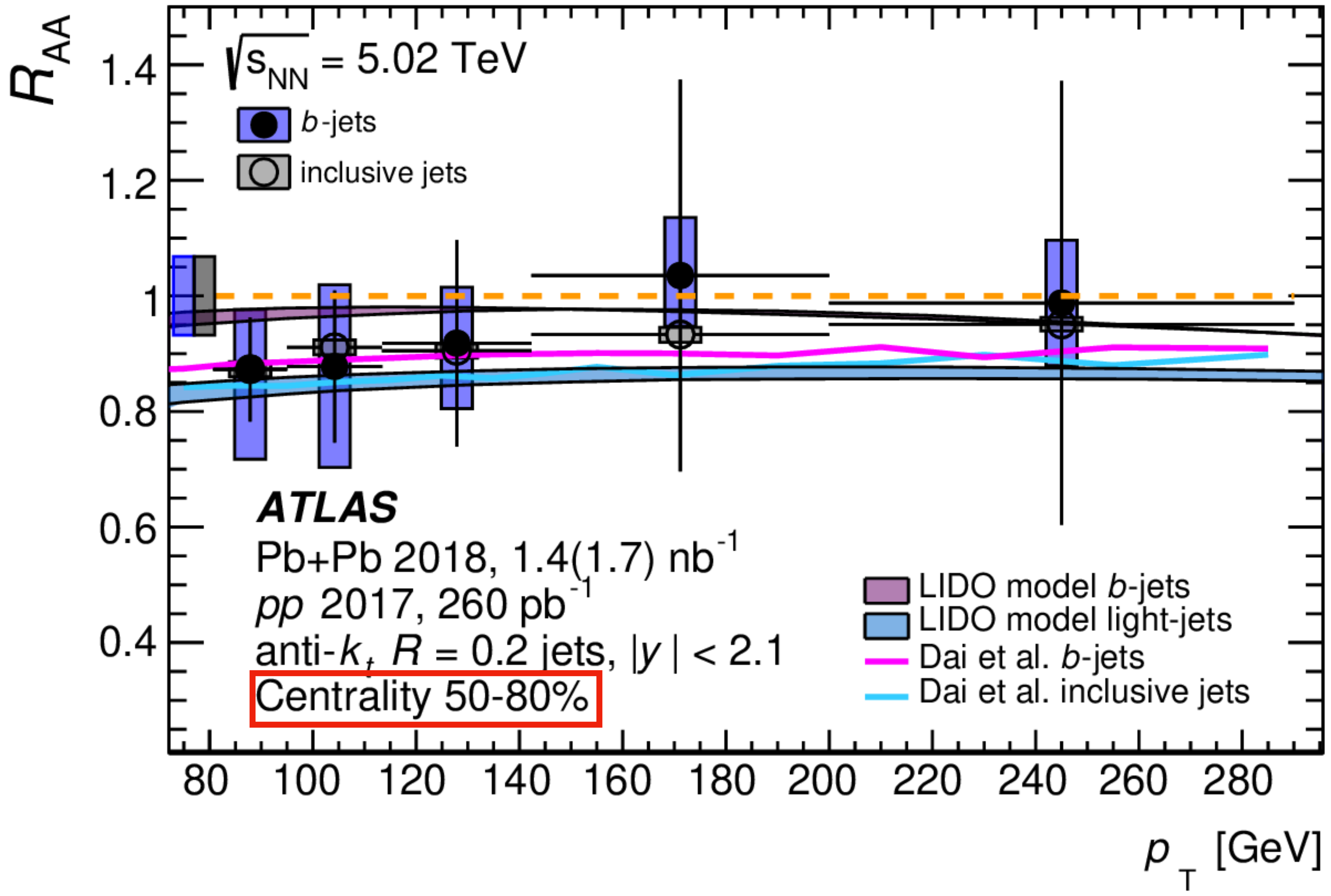

Nuclear modification factor, R_{AA}, measured for *b*-jets and inclusive jets:

- **Similar suppression in peripheral collisions**
- *b*-jets 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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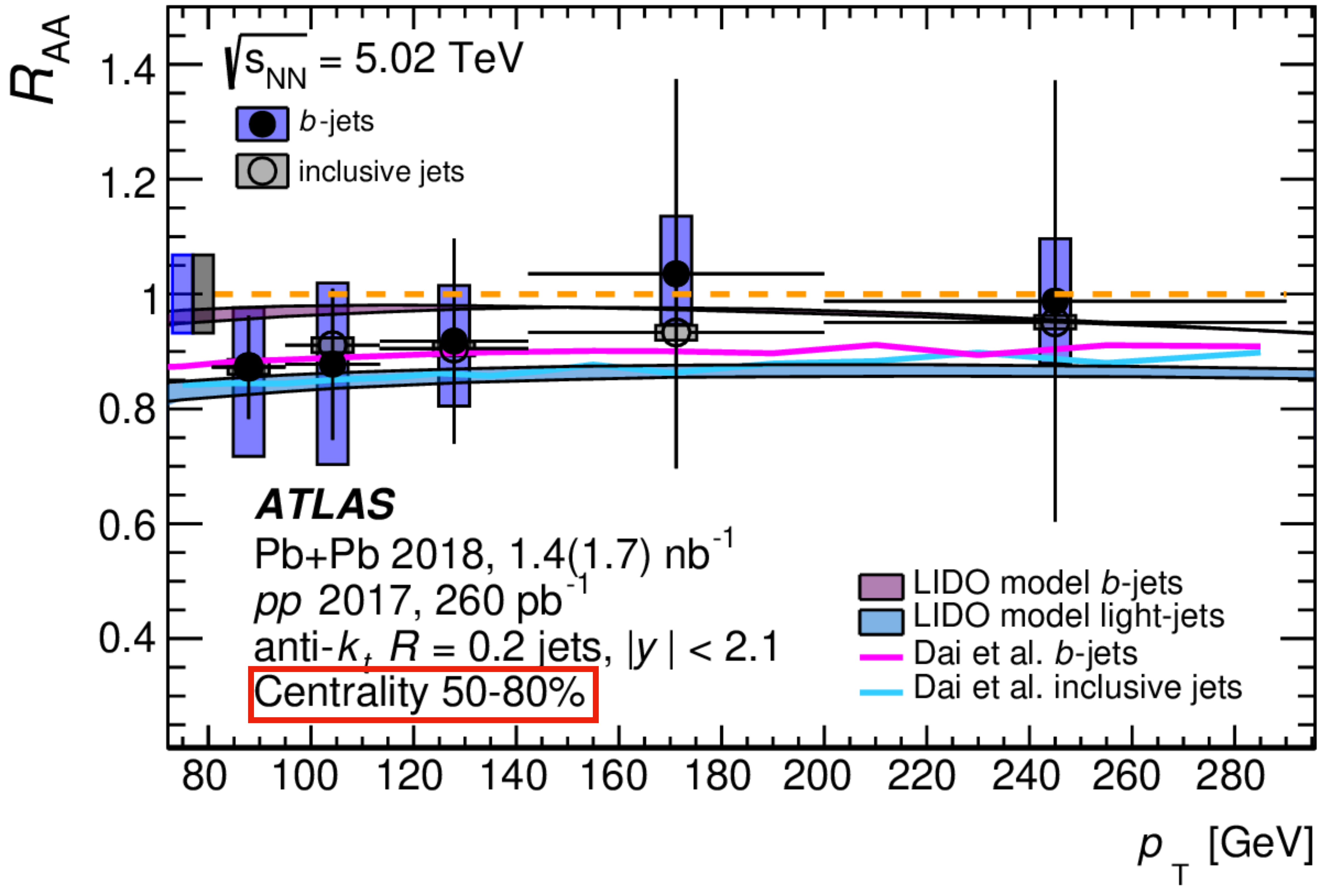

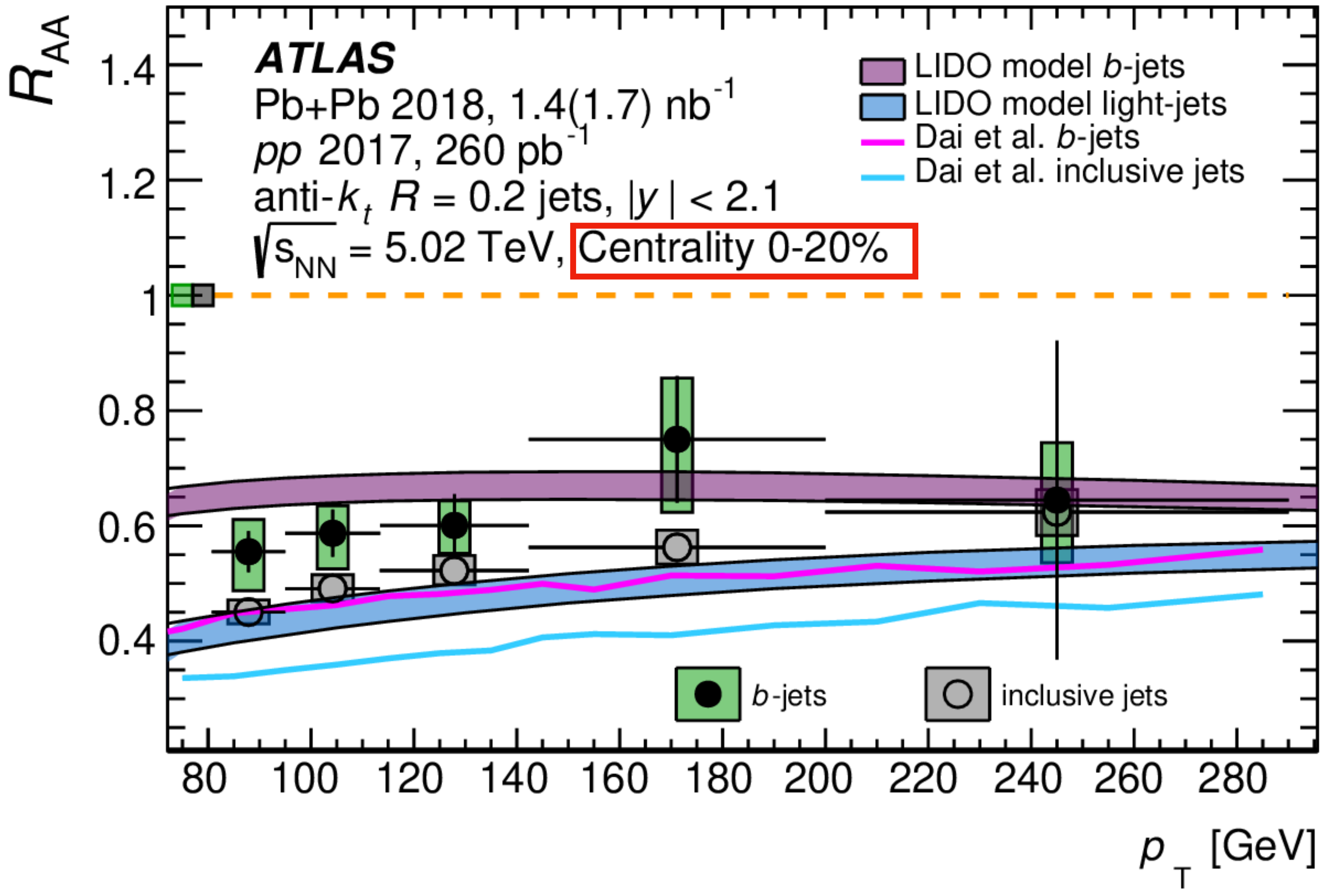

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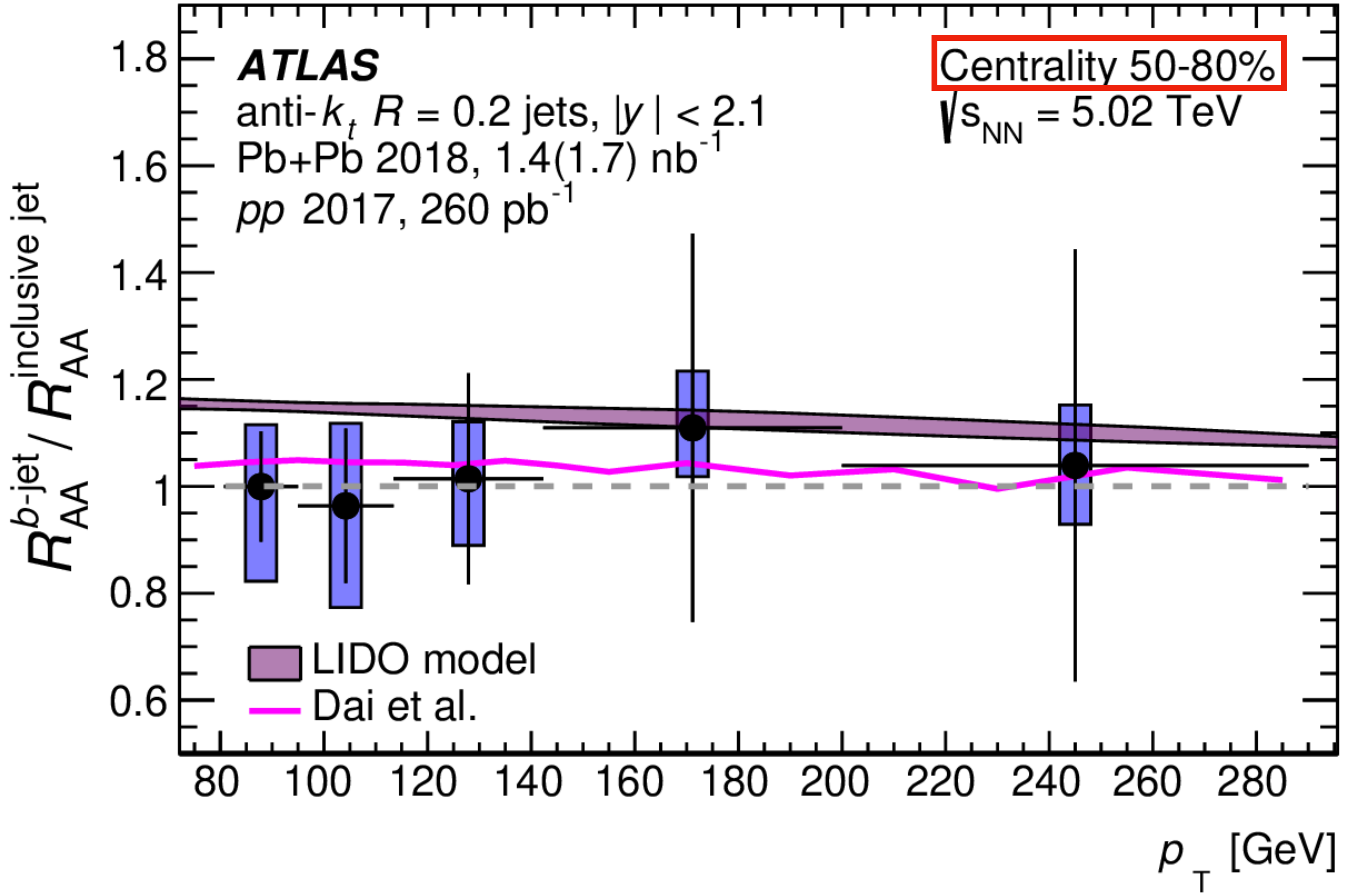

Ratio of nuclear modification factor, R_{AA}, between *b*-jets and inclusive jets:

- Smaller systematic uncertainties than R_{AA}, systematic uncertainties which are shared cancels 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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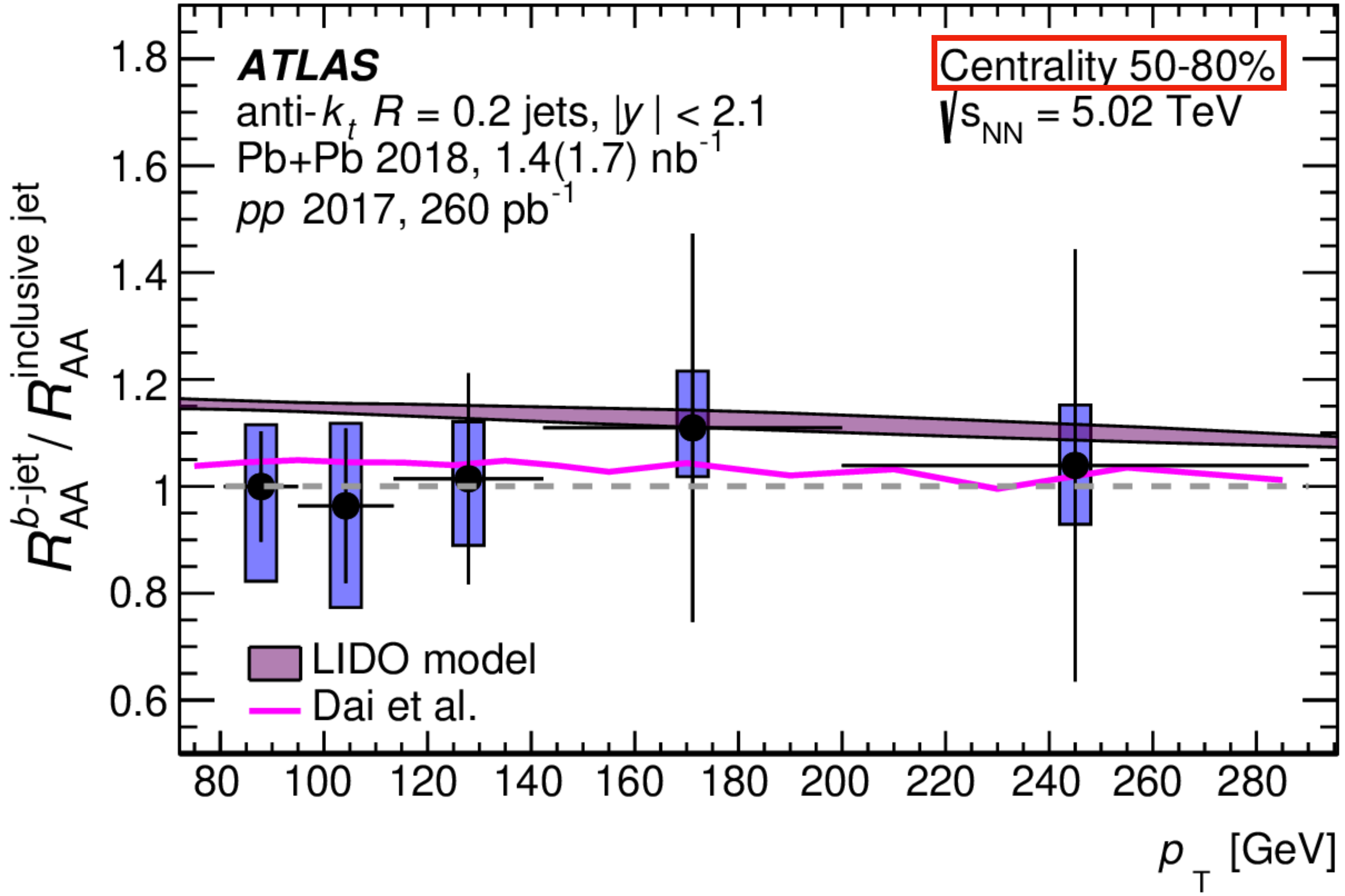

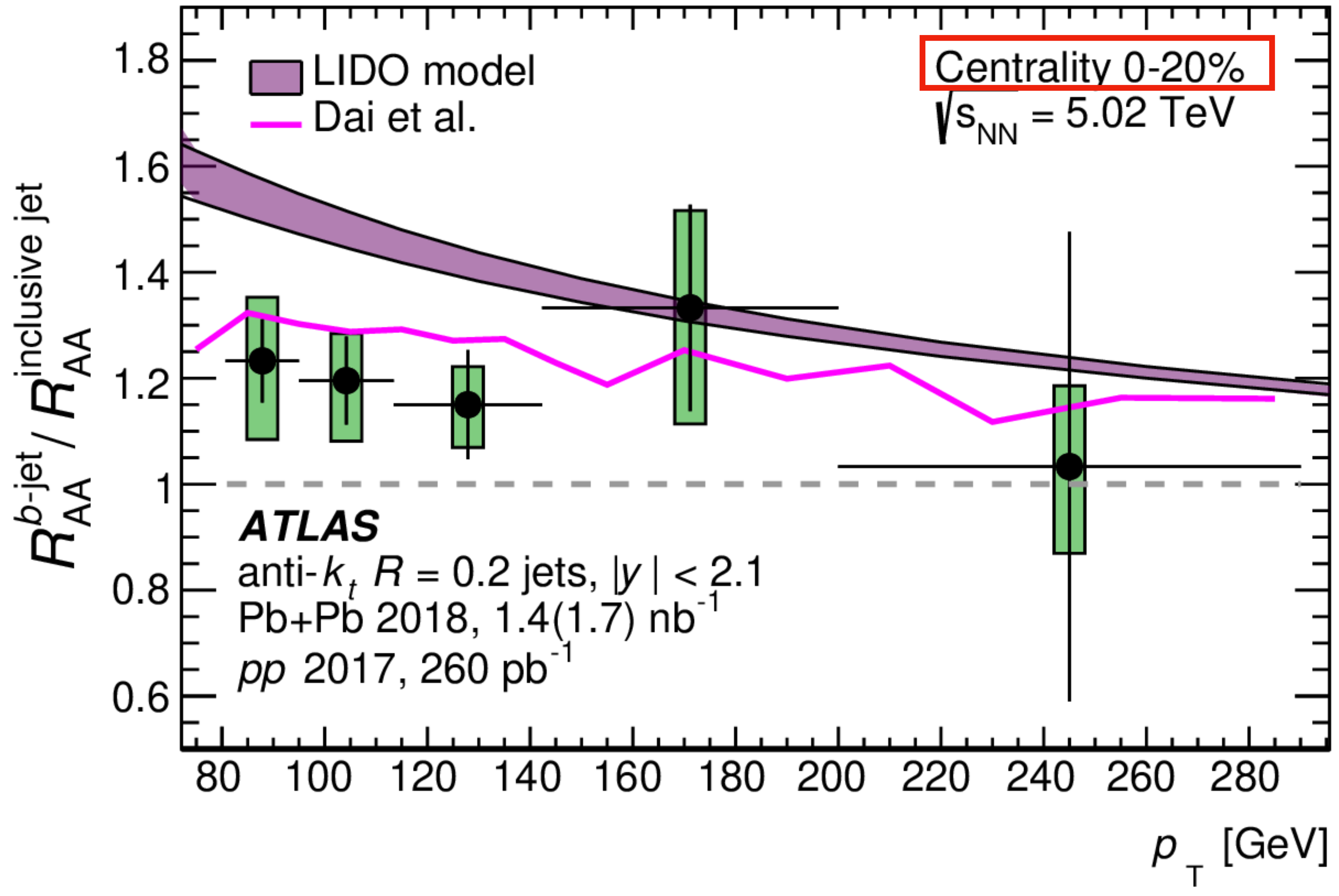

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Isolating color-charge effects

We have studied how mass can modify quenching

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

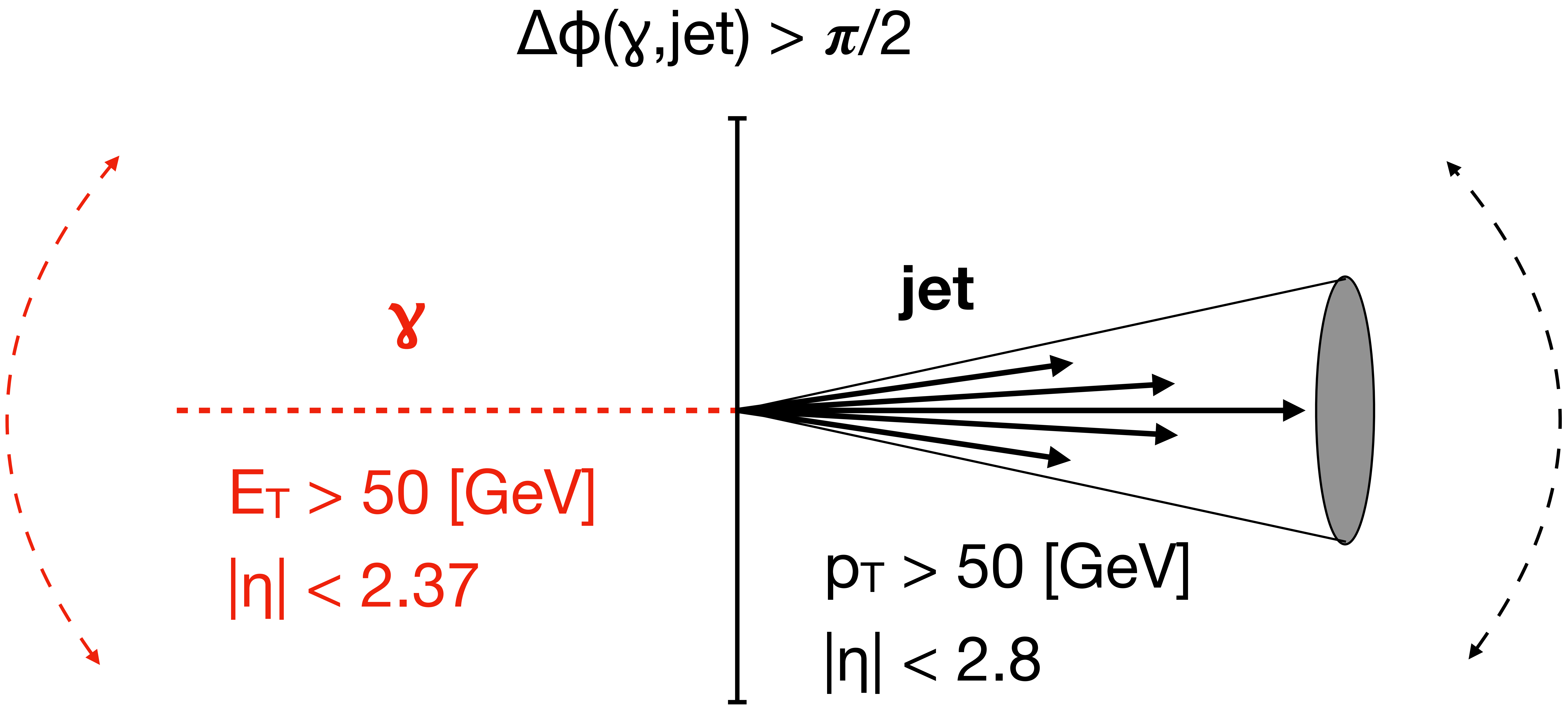
Sensitive to color-charge and parton mass

Now, can we ask the same question about color-charge?

γ-tagged jets vs inclusive jets

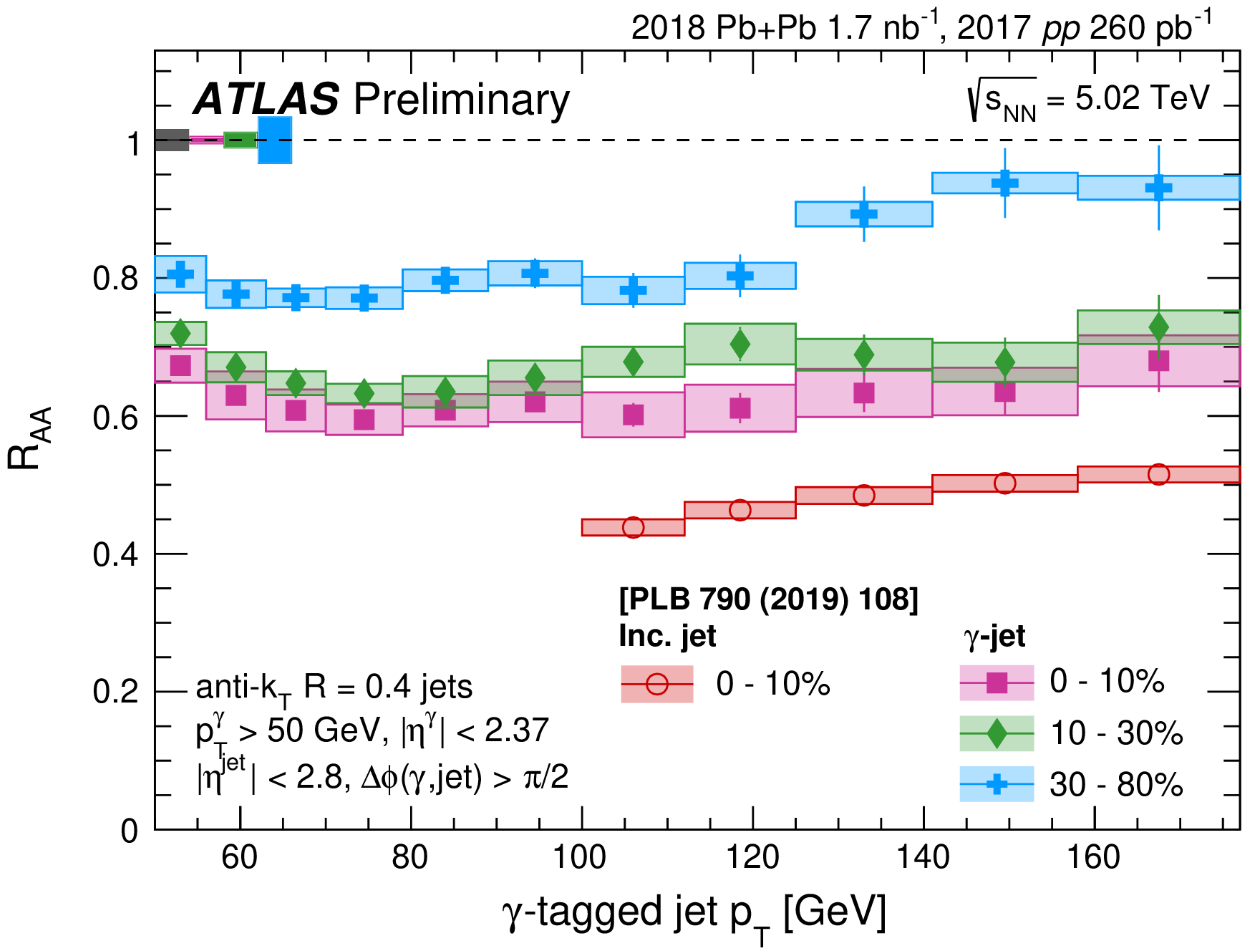
Sensitive to color-charge

γ-tagged jets analysis



- Combinatorial background removed
- Correction for background photons using photon purity
- 2D unfolding in γ and jet momentum
  - Corrects for resolutions, efficiency

γ-tagged jets vs inclusive jets in Pb+Pb collisions



Nuclear modification factor, R_{AA}, measured for γ-tagged jets and inclusive jets from *PLB 790 (2019) 108*:

- γ-tagged jets R_{AA} measured for three centrality classes
- γ-tagged jets (quark-jet dominant) **found to be less suppressed** than inclusive (gluon-jet dominant) jets in central collisions

ɣ-tagged jets vs inclusive jets in Pb+Pb collisions

Central collisions nuclear modification factor, R_{AA}, of **inclusive jets**, ɣ-tagged jets, and ratio:

- **Inclusive jets R_{AA}**, is well modeled by theoretical calculations

ɣ-tagged jets vs inclusive jets in Pb+Pb collisions

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- Inclusive jets R_{AA}, is well modeled by theoretical calculations
- **ɣ-tagged jets R_{AA}**, in general, under-estimated by theoretical calculations
- $SCET_G$ reproduces both, this results could help constrain the parameter space

γ-tagged jets vs inclusive jets in Pb+Pb collisions

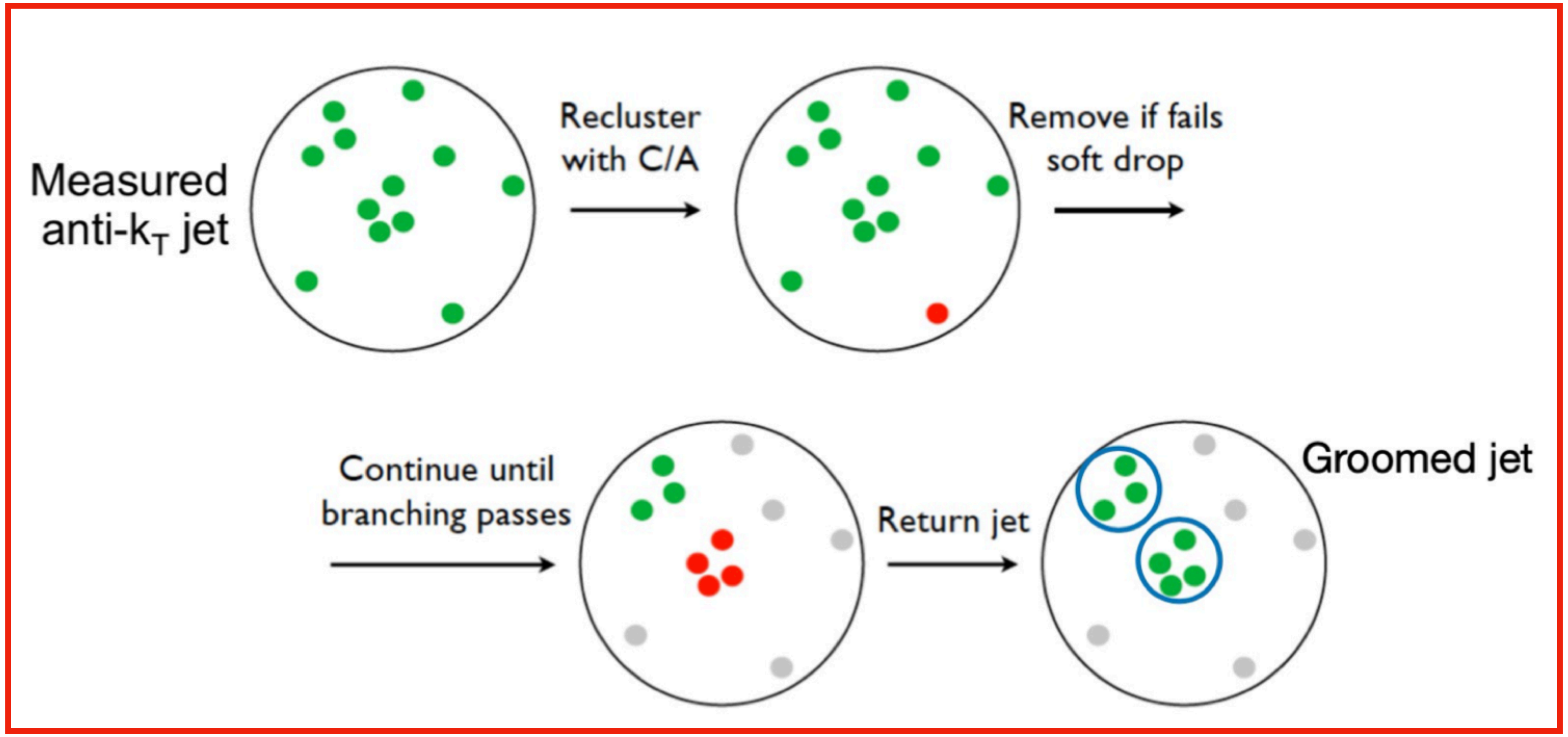
Central collisions nuclear modification factor, R_{AA}, of inclusive jets, γ-tagged jets, and **ratio**:

- Inclusive jets R_{AA}, is well modeled by theoretical calculations
- γ-tagged jets R_{AA}, in general, under-estimated by theoretical calculations
- SCET$_G$ reproduces both, this results could help constrain the parameter space
- **R_{AA} ratio ~30% above unity in central collisions**

What is the resolution scale of the medium? Looking inside the jet

Sub-Structure procedure:

- Jets are reclustered with C/A algorithm and iteratively declustered till the subjets satisfy the Soft Drop (SD) condition
- r_g and jet p_T are unfolded using 2D Bayesian unfolding to the truth level



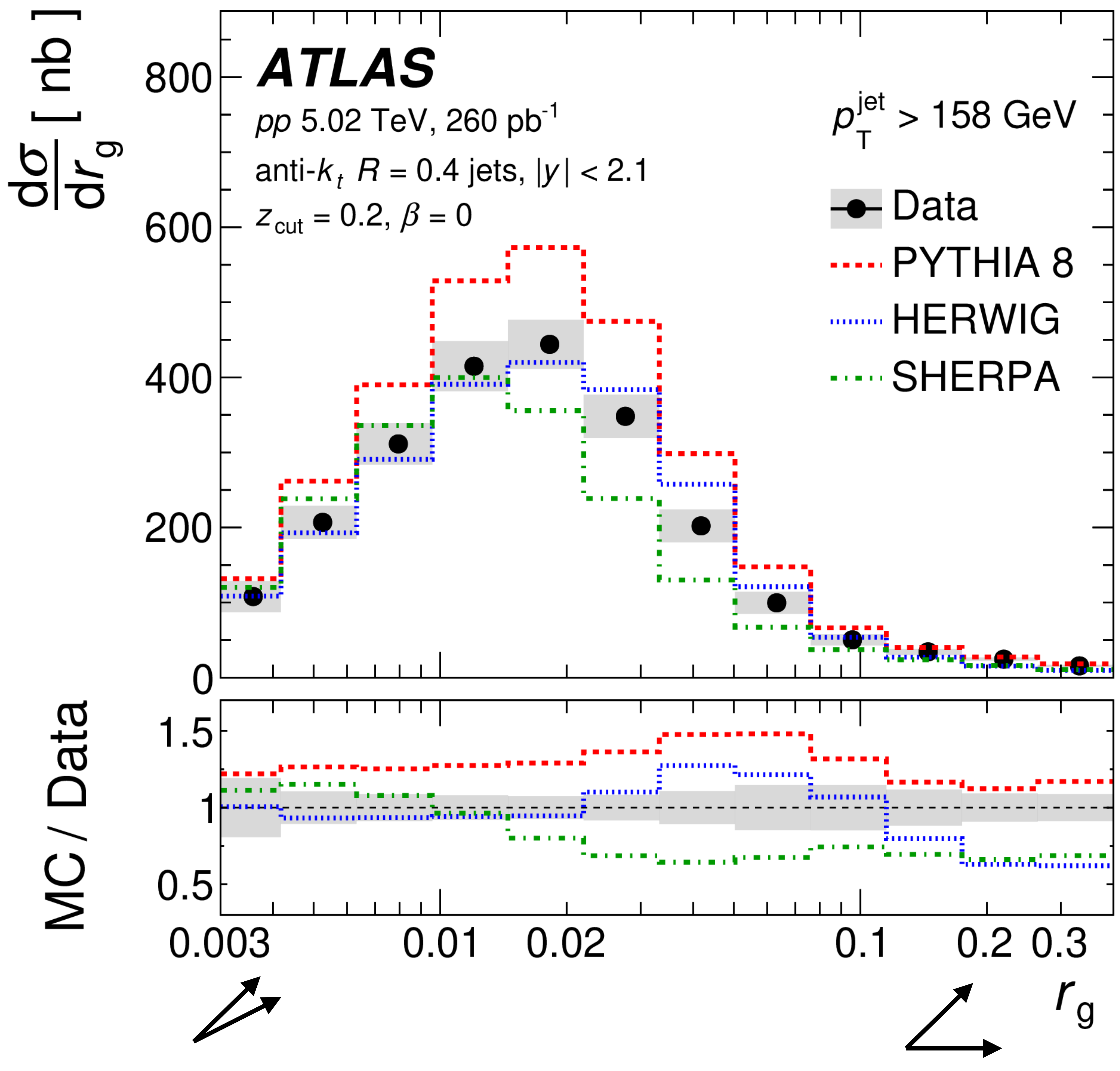
SD condition:

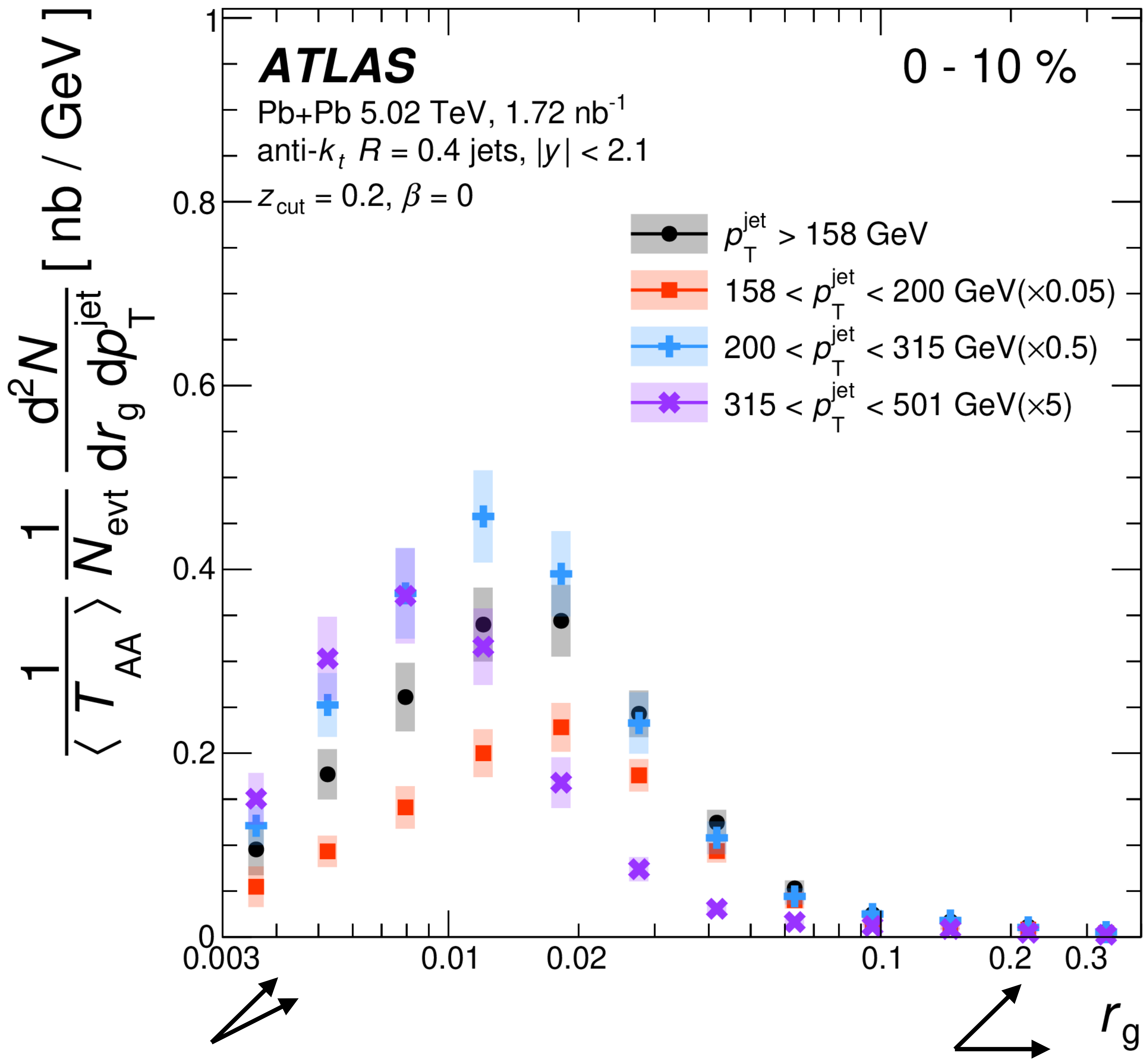
$$z_g = \frac{min(p_{T,i}, p_{T,j})}{p_{T,i} + p_{T,j}} > 0.2$$

Observable:

$$r_g = \Delta R_{i,j}$$ Between the subjets satisfying the SD conditions

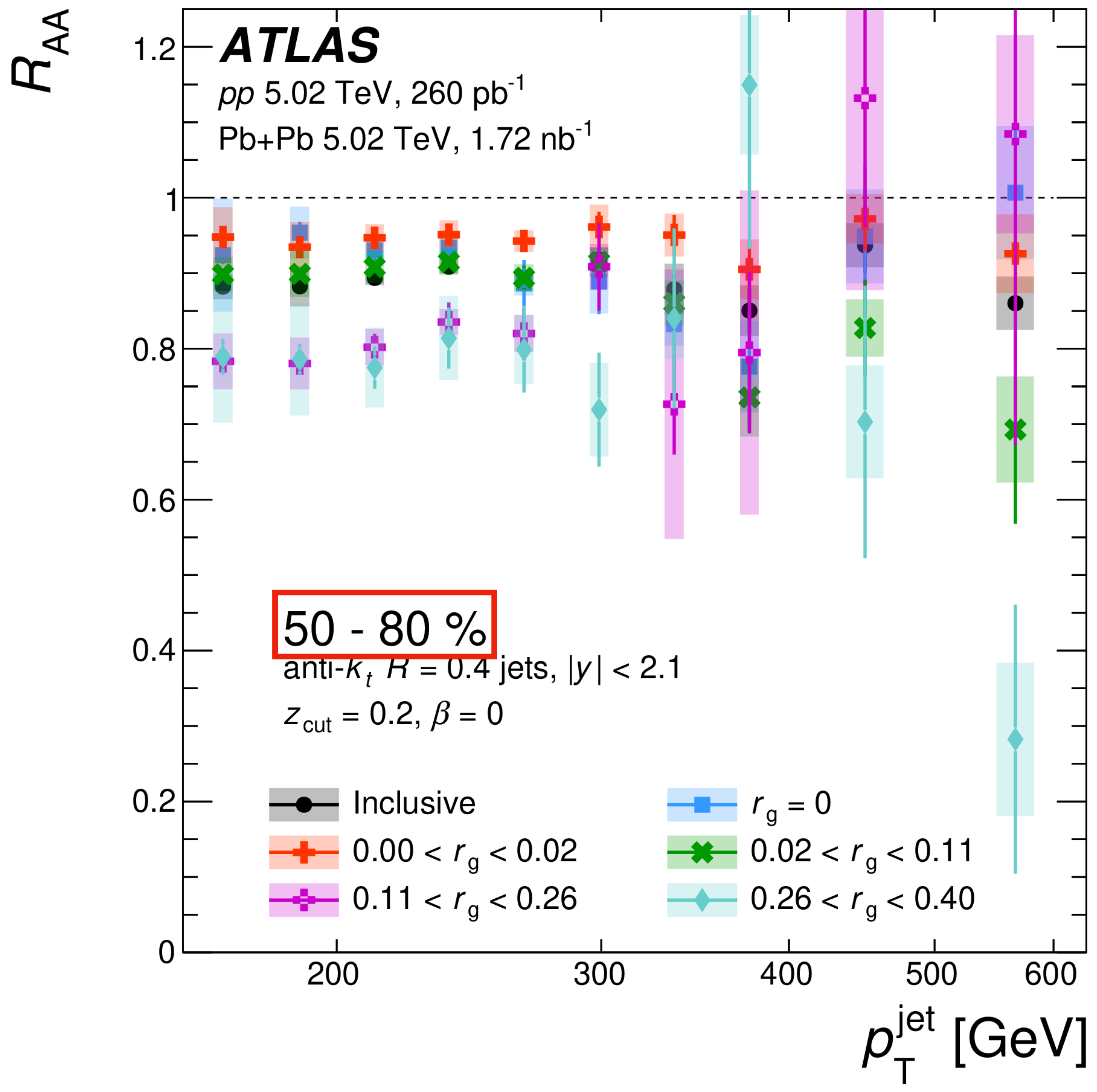
r_g distribution

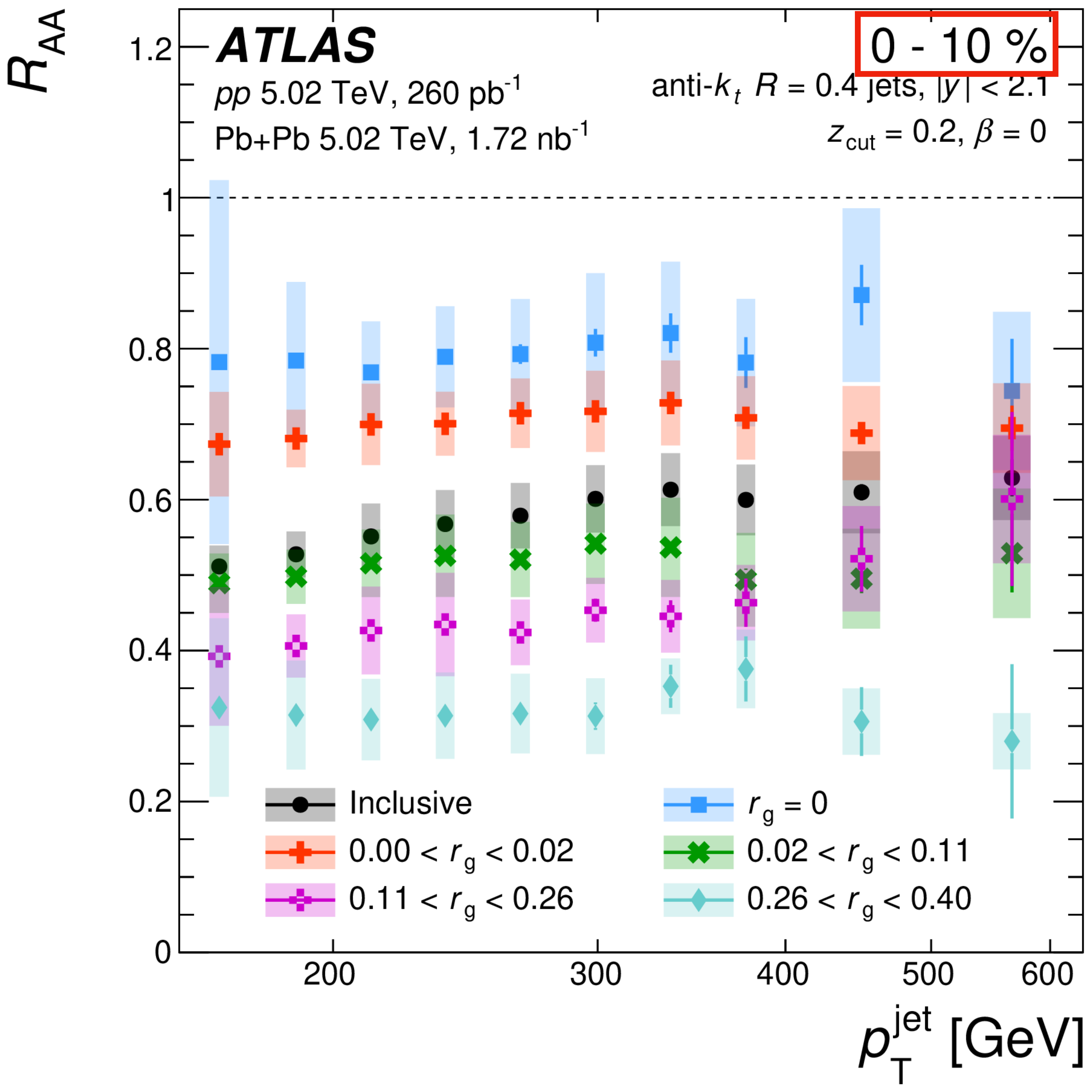


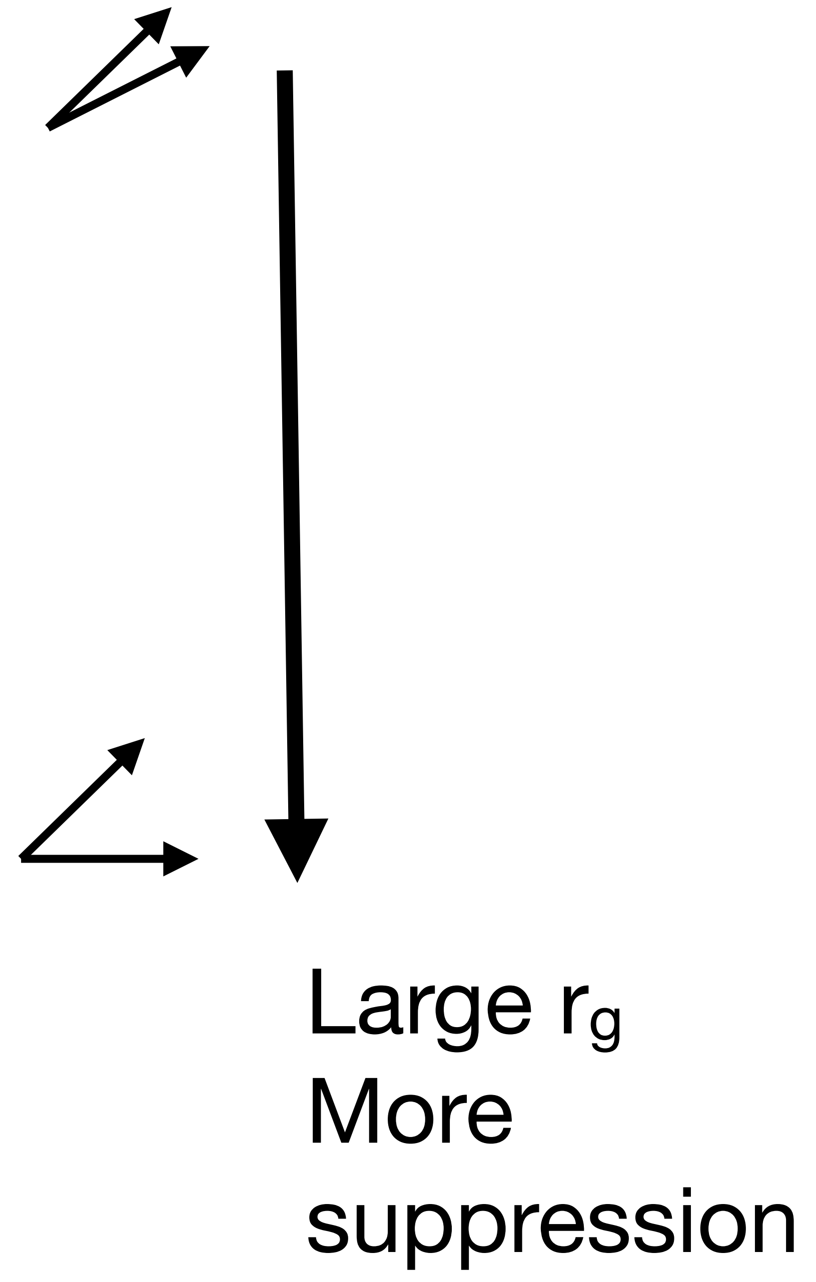


- In general shape well modeled by generators
- r_g distribution shape has jet p_T dependence but little centrality dependence

Suppression dependence to r_g

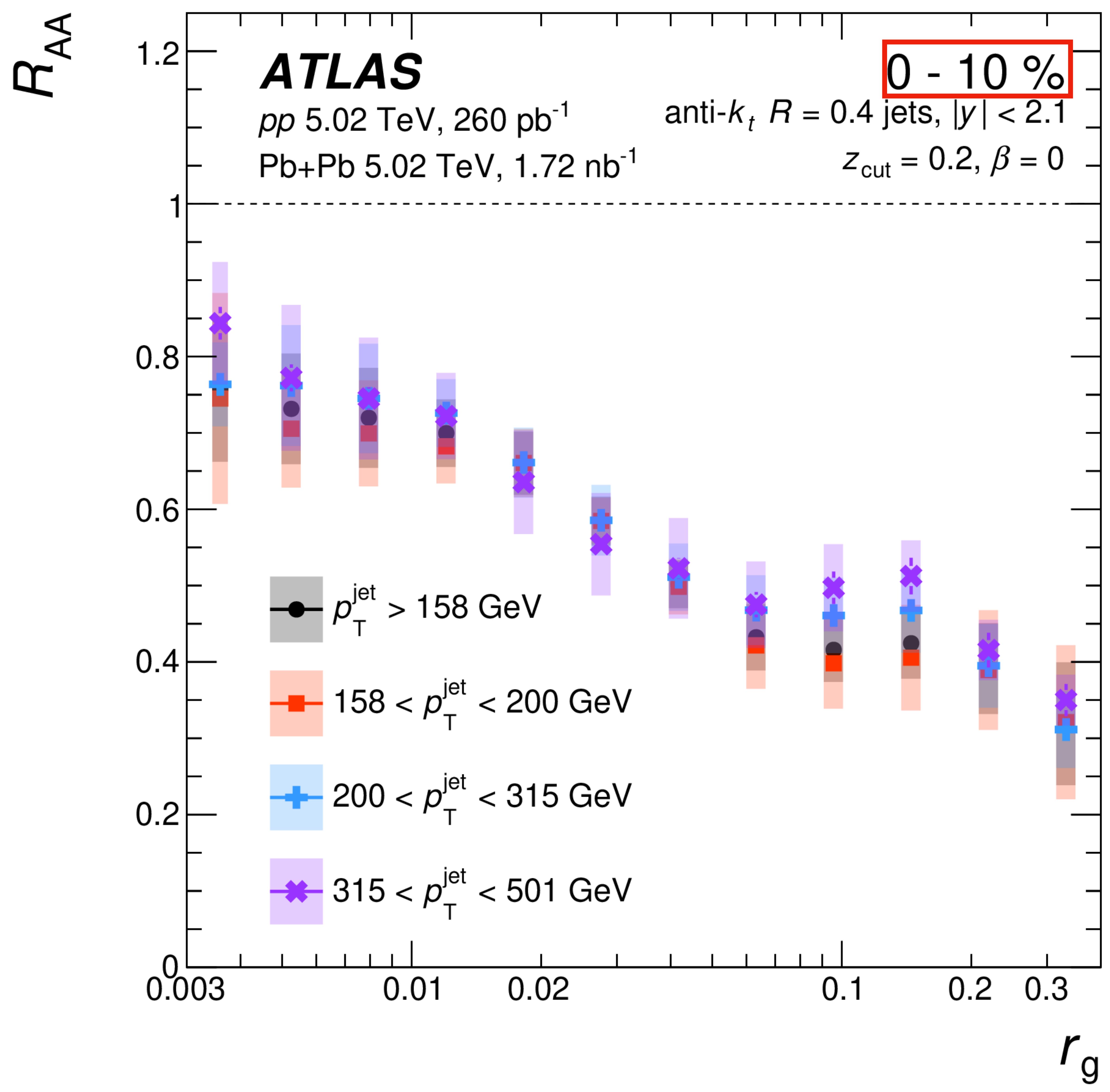






- Flatter R_{AA} as a function of p_T when bin in r_g
- More suppression was observed for larger r_g jets

Suppression dependence to r_g



- Clear r_g dependence to R_{AA}
- r_g, not jet p_T, determines the R_{AA}

Suppression dependence to r_g

- R_{AA} vs. r_g trend reproduced for most energy loss models
  - even those not including coherence
  - due to quenching-induced change in quark-gluon fractions?

Summary

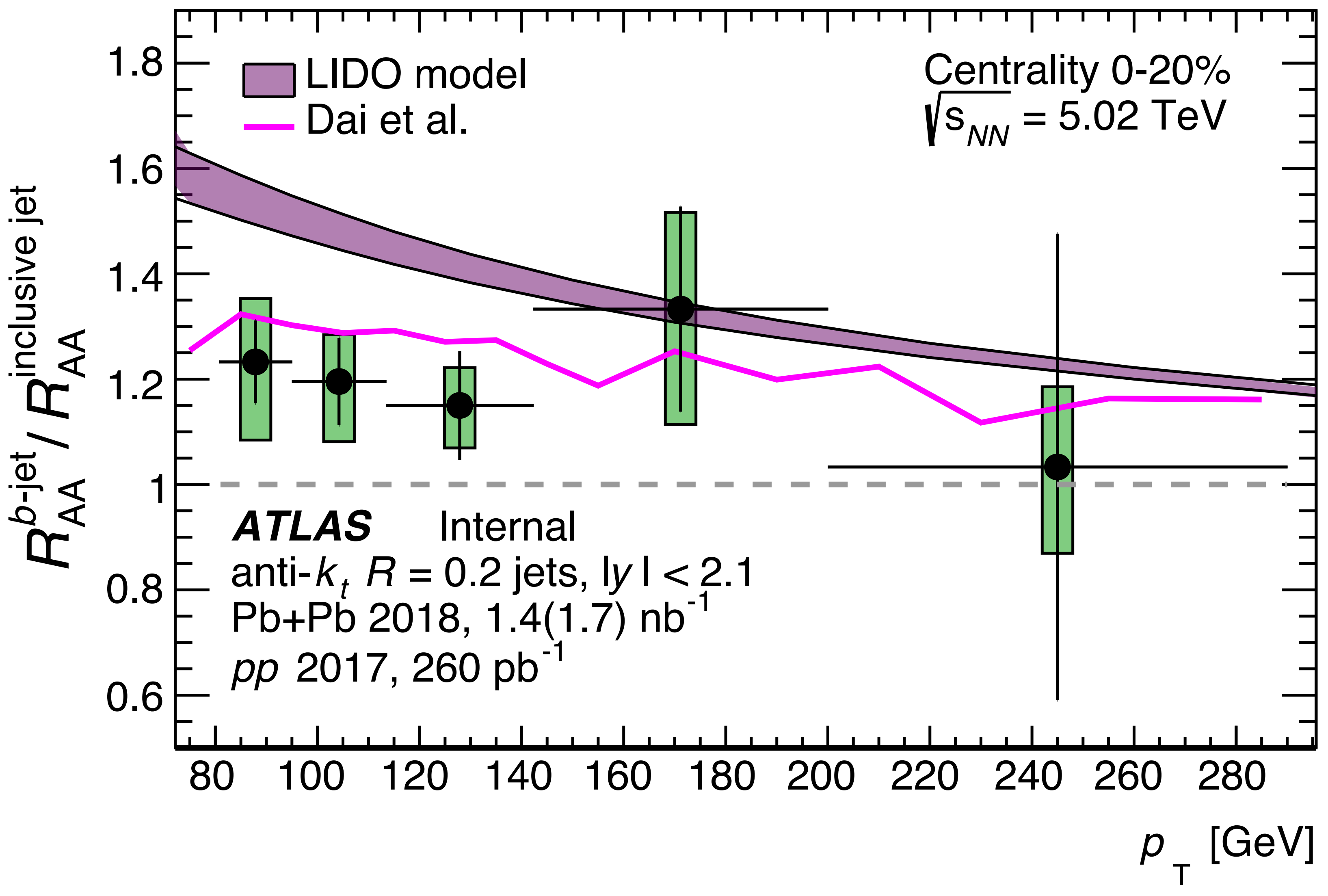
ATLAS new jet results show;

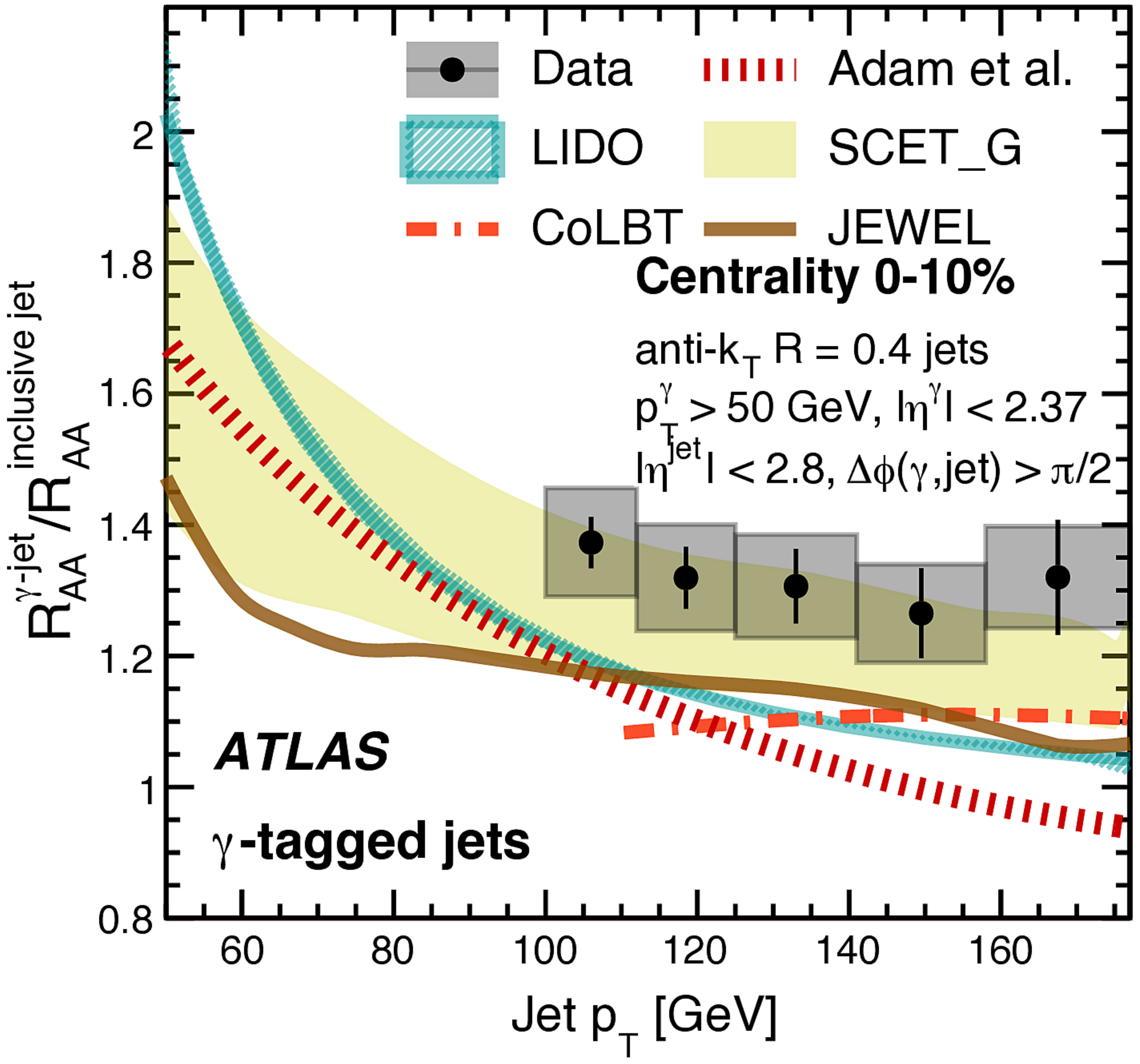
Less suppression for **b-jets** than inclusive, mass-dependent Eloss

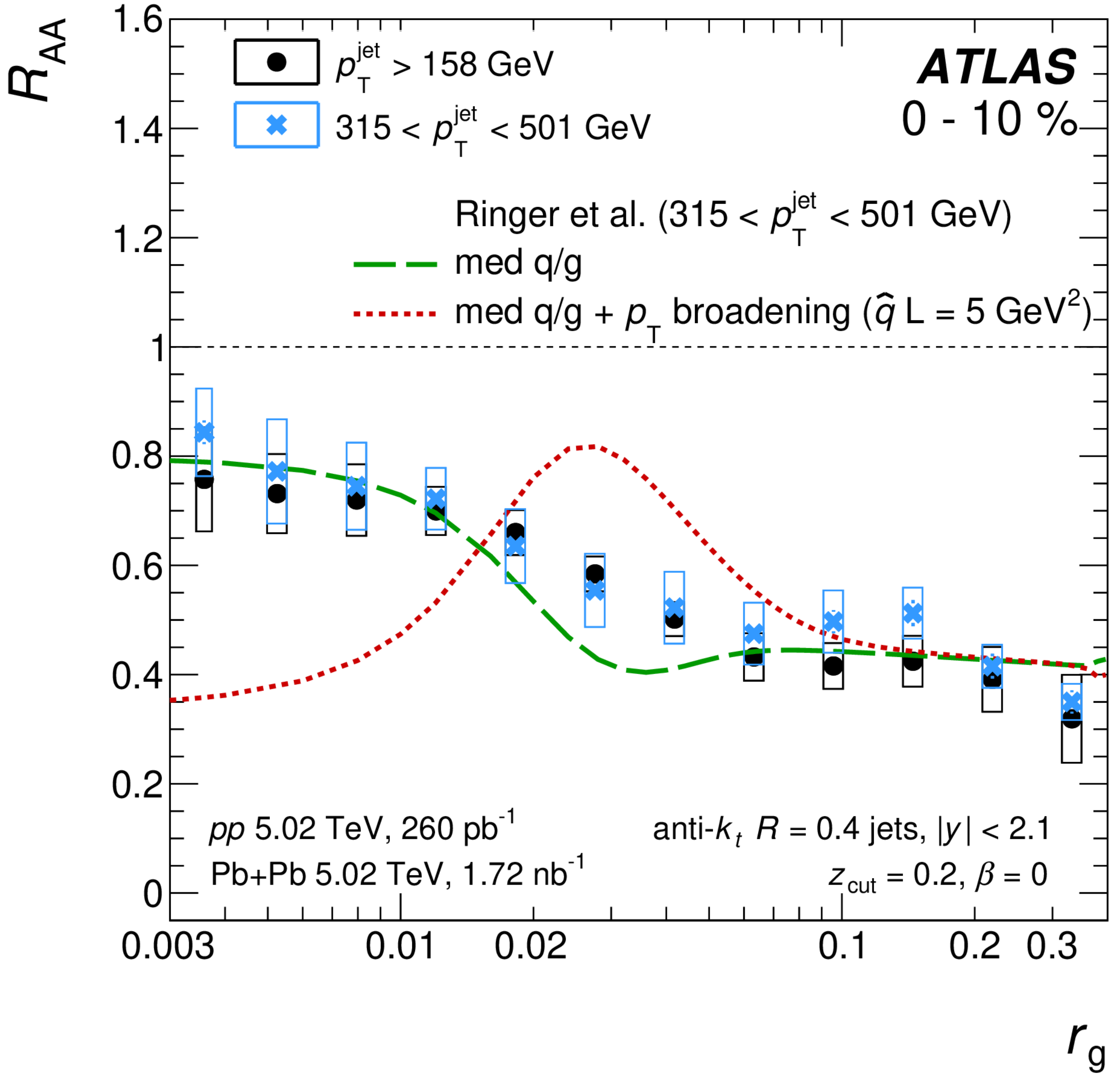
Less suppression for **ɣ-tagged** jets than inclusive, flavor-dependent Eloss

Less suppression for **smaller r_g** jets, angular scale of splitting-dependent Eloss

Can all be explained by differences in flavor fractions? 😱

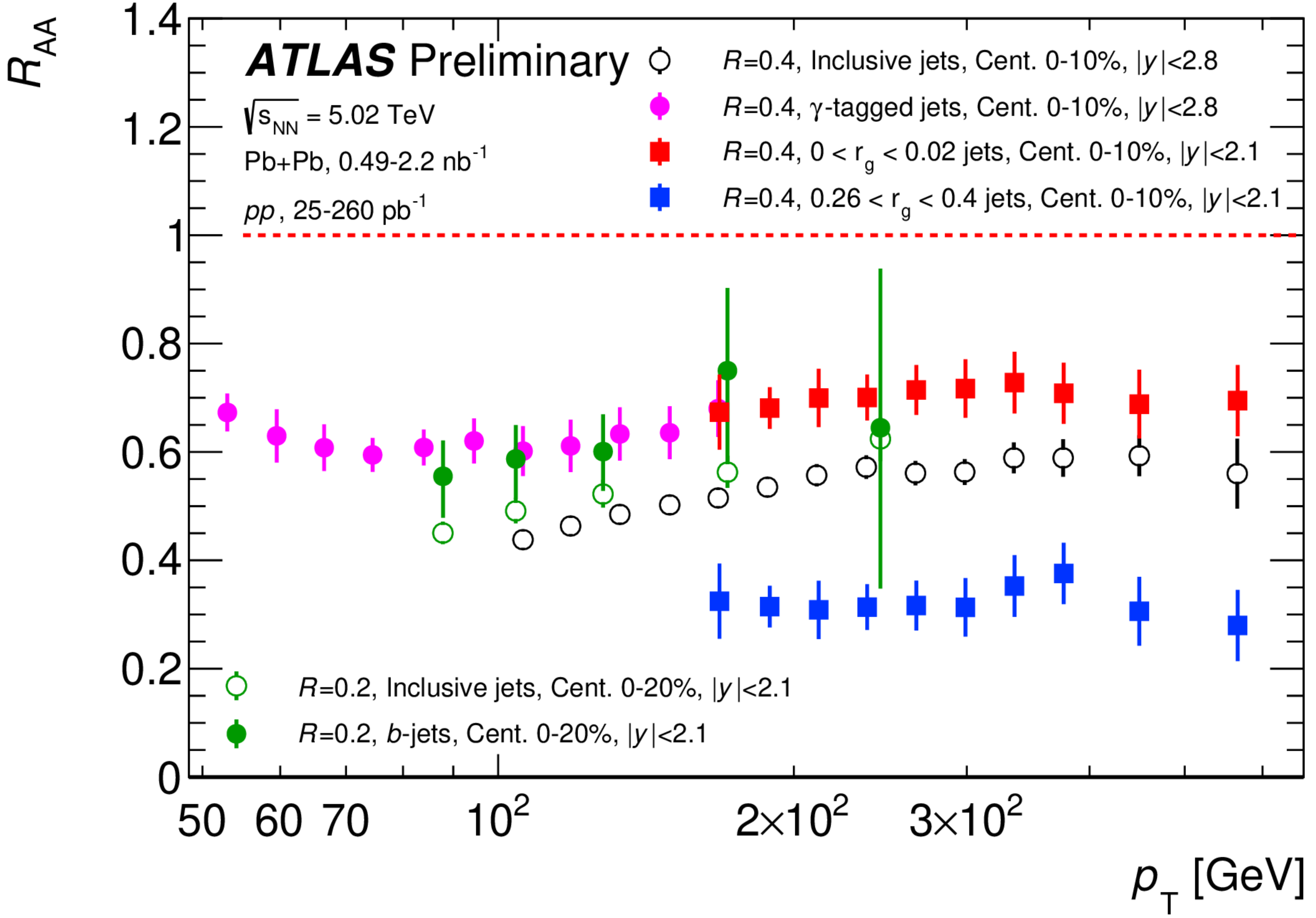






Thank you!

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



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

Additional slides

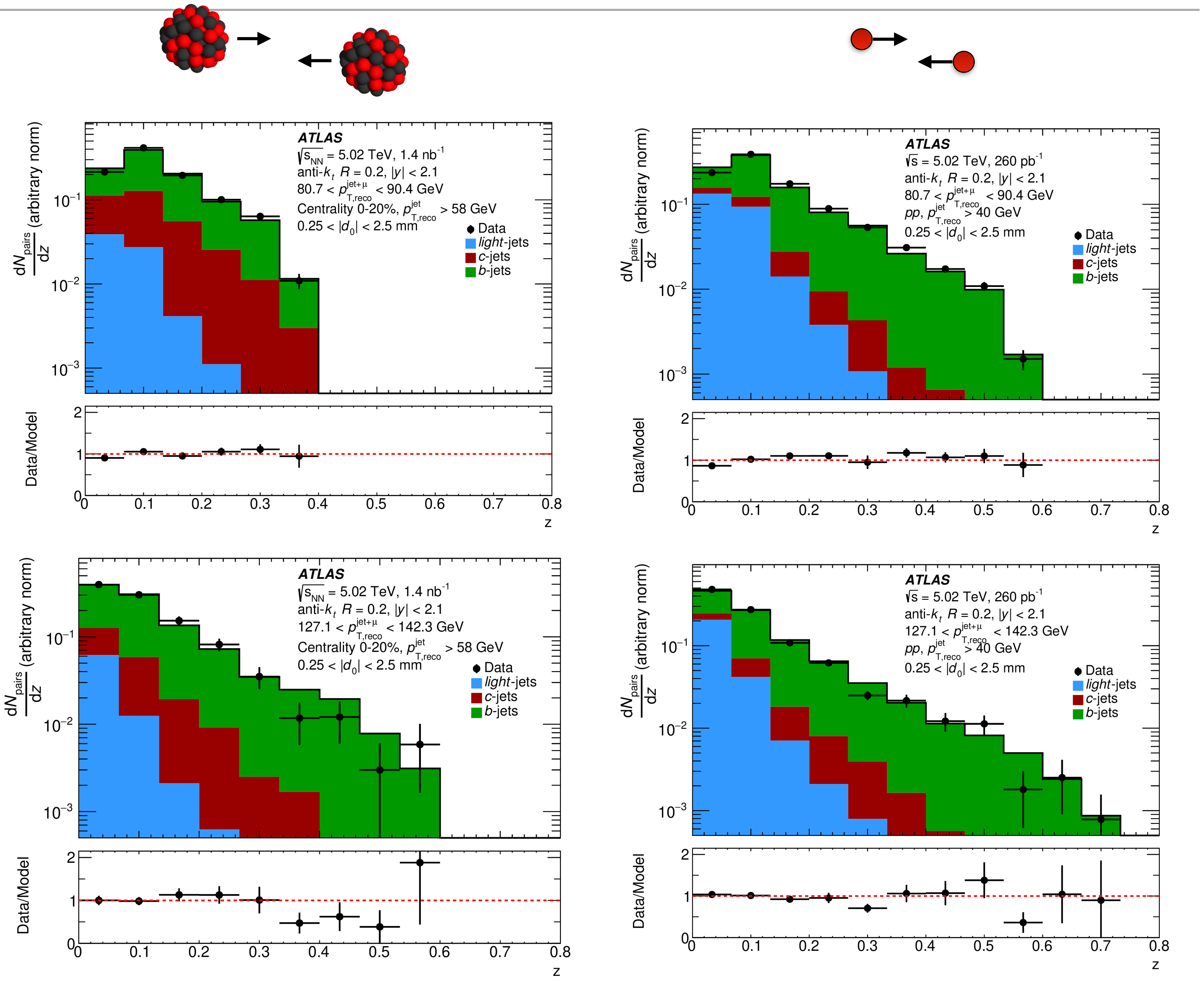
***b*-jets** muon fragmentation

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-24/

p_T-rel is sensitive to muon momentum modeling

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

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

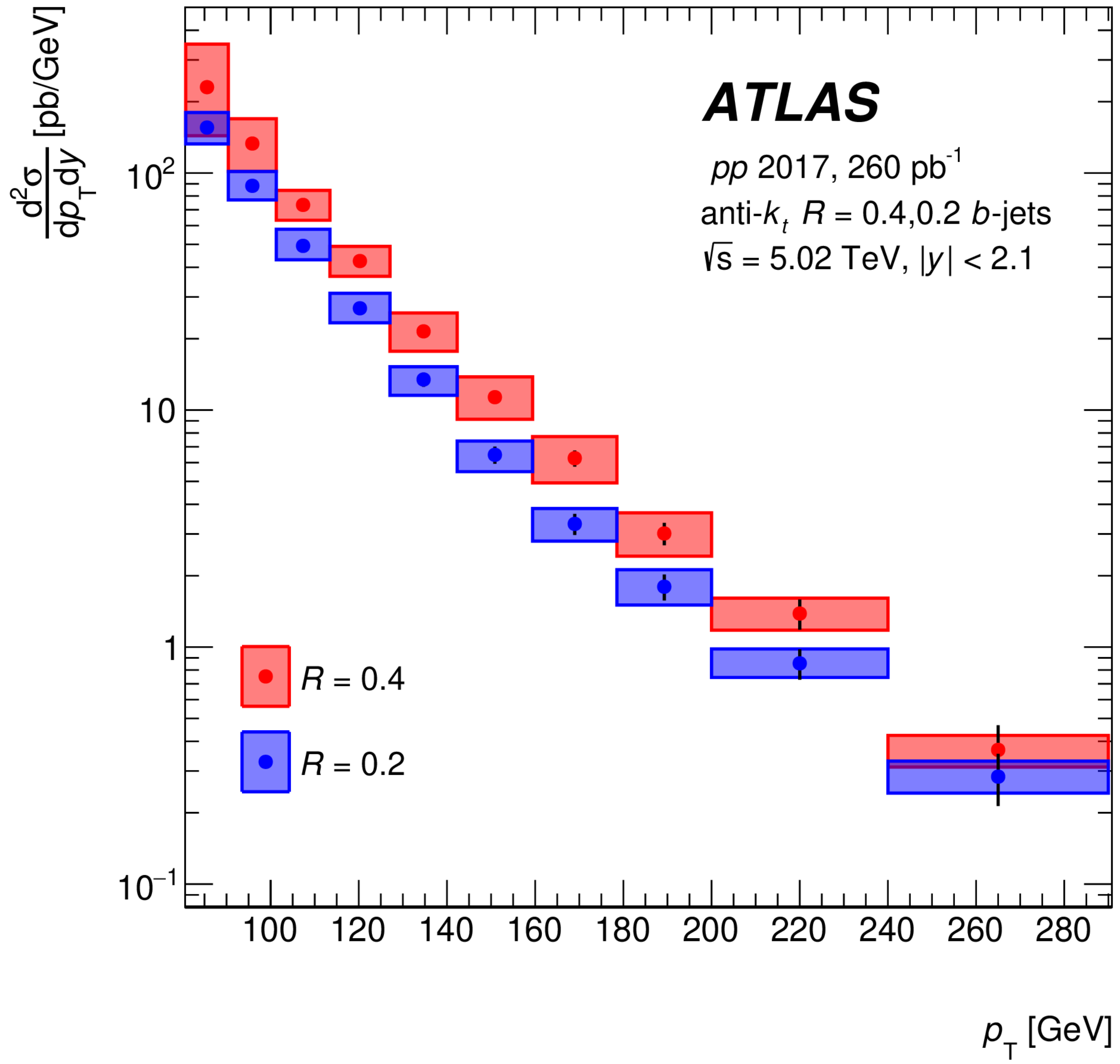


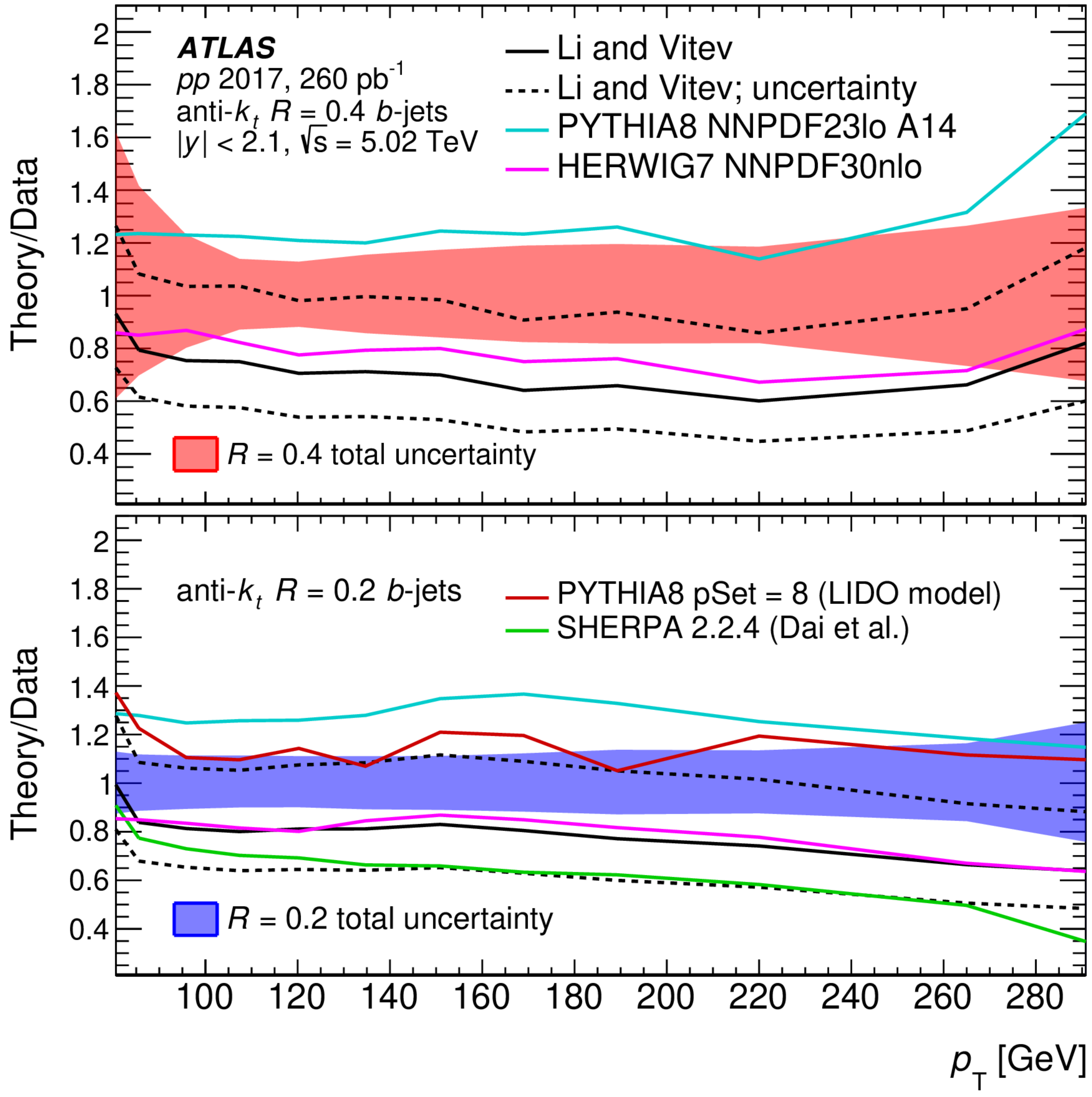
The muon momentum distribution is well reproduced by PYTHIA8

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

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

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-24/

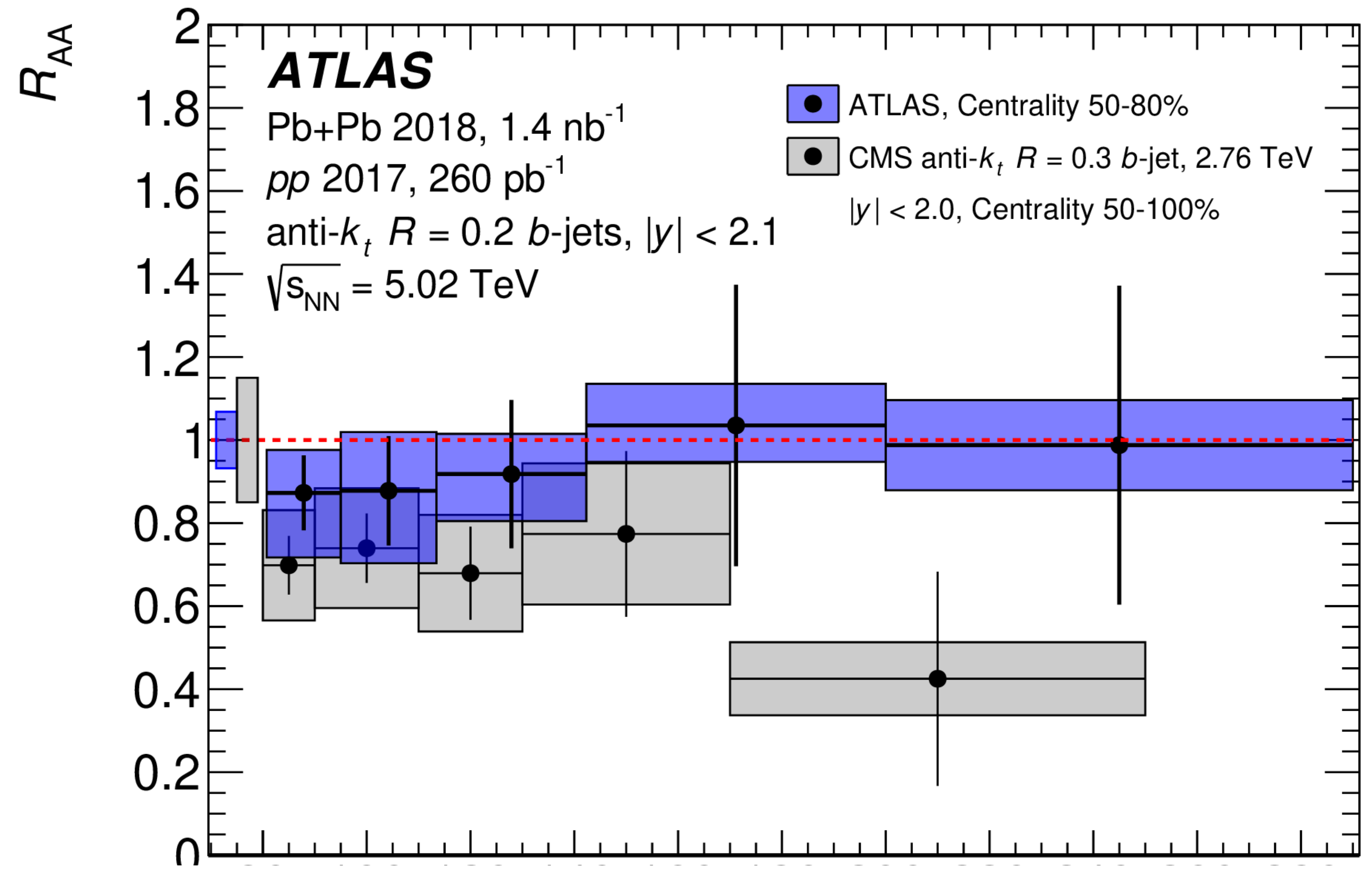


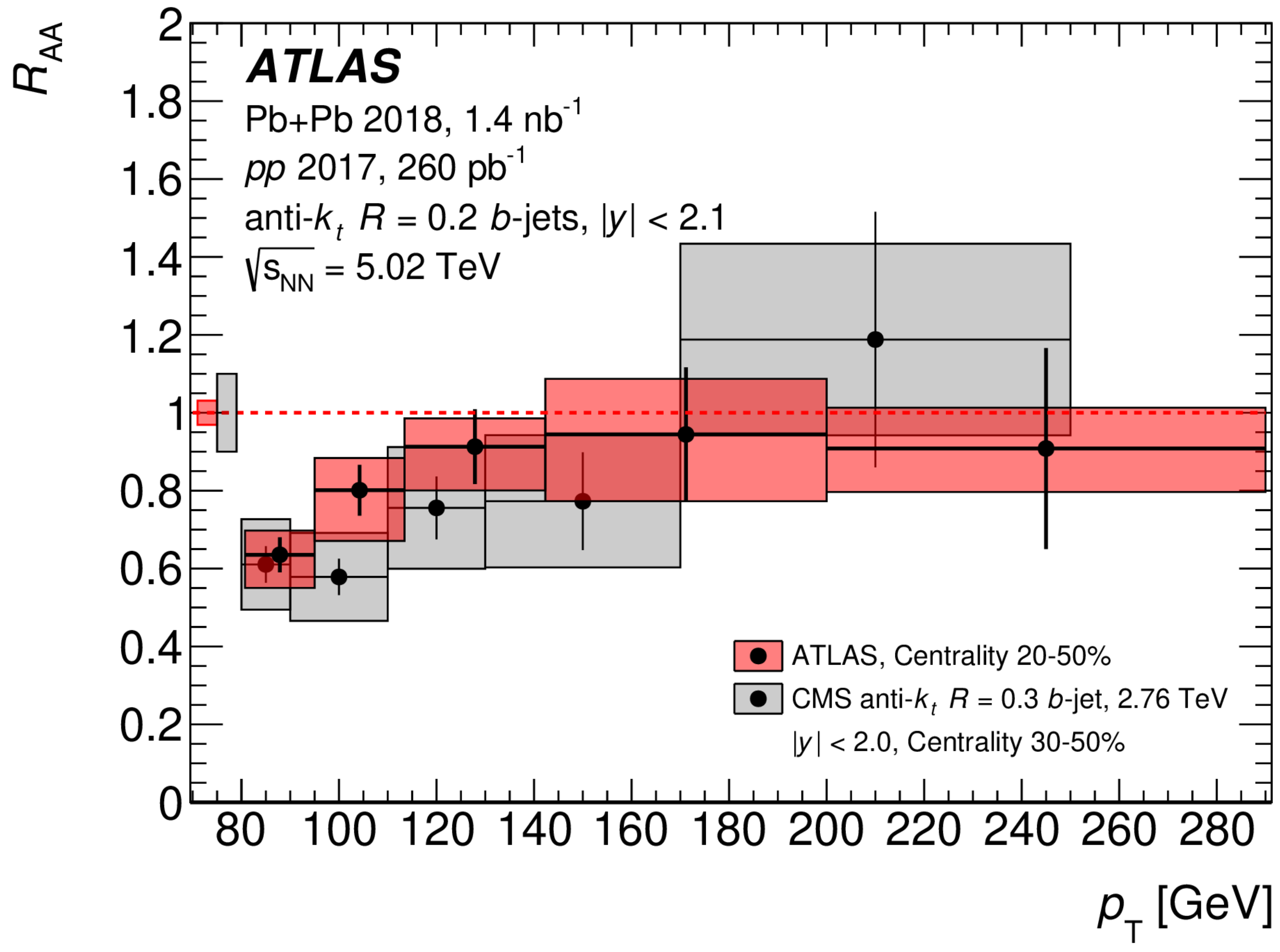


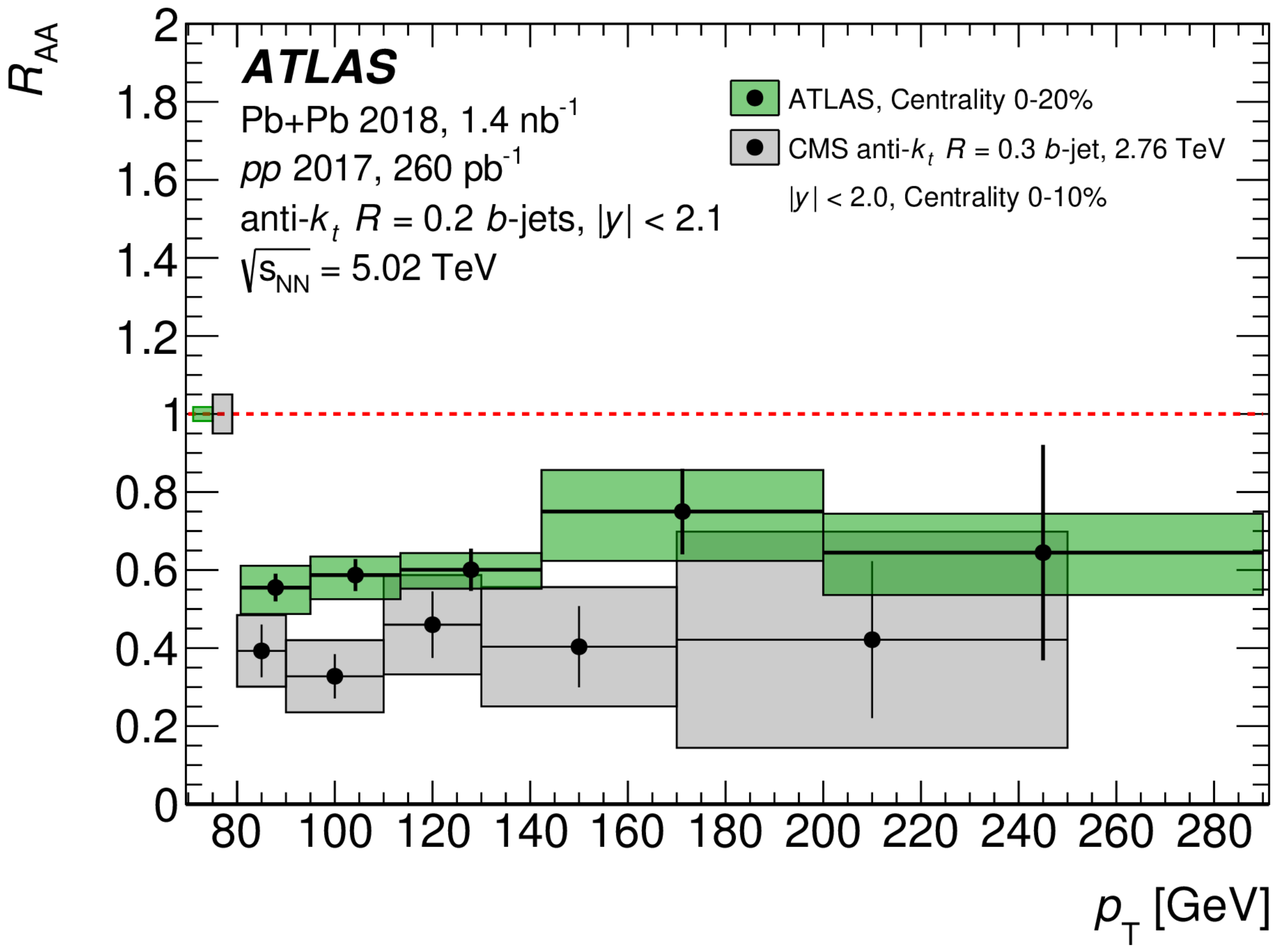
- *b*-jet cross-section measured for Jet *R* = 0.2, and 0.4 in *pp* collisions
- **Fully unfolded** results include neutrino energy, ***b*-jet p_T range: 80-250 GeV**
- Results are compared against generators and theoretical calculations

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

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-24/







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

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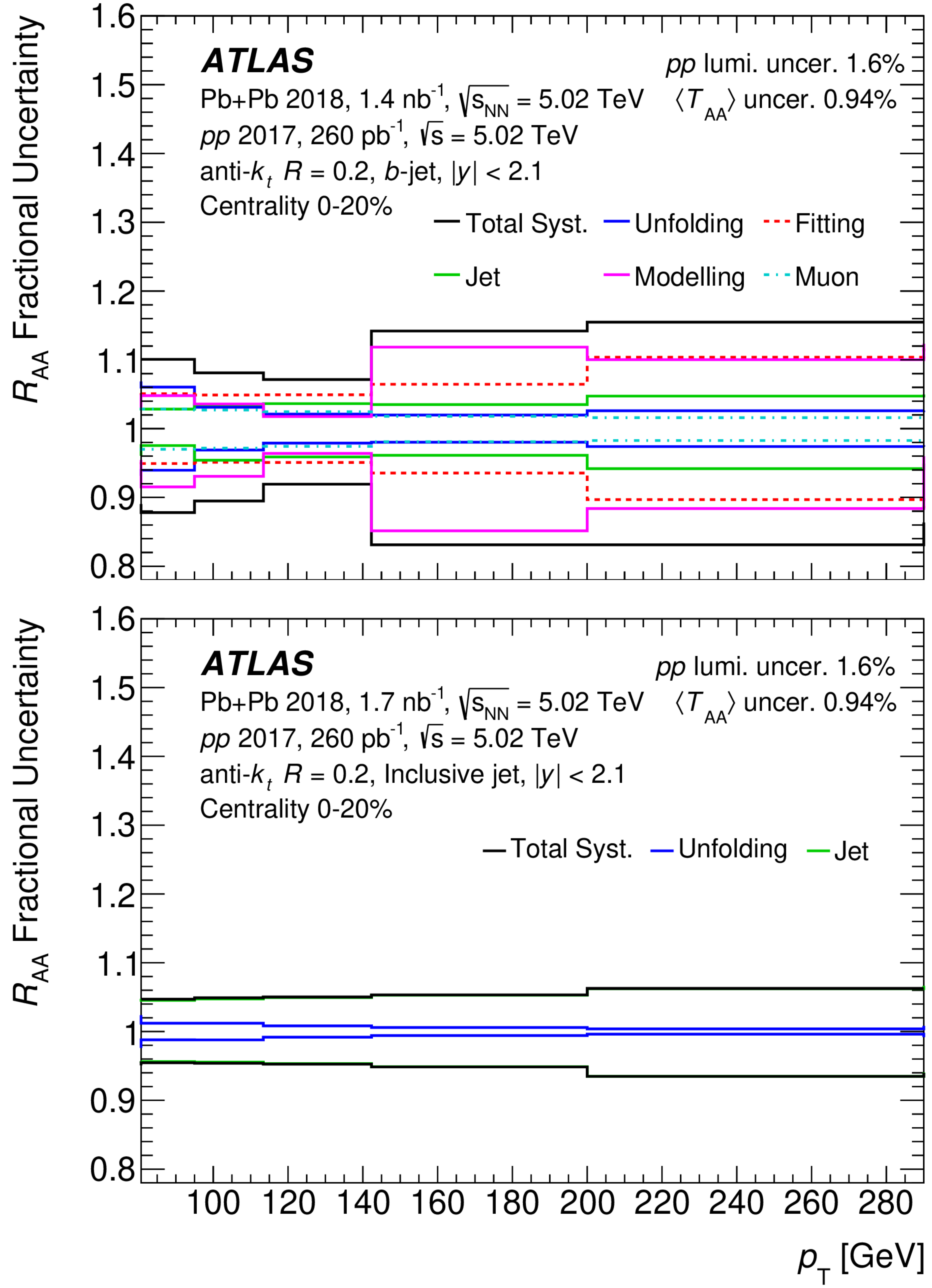
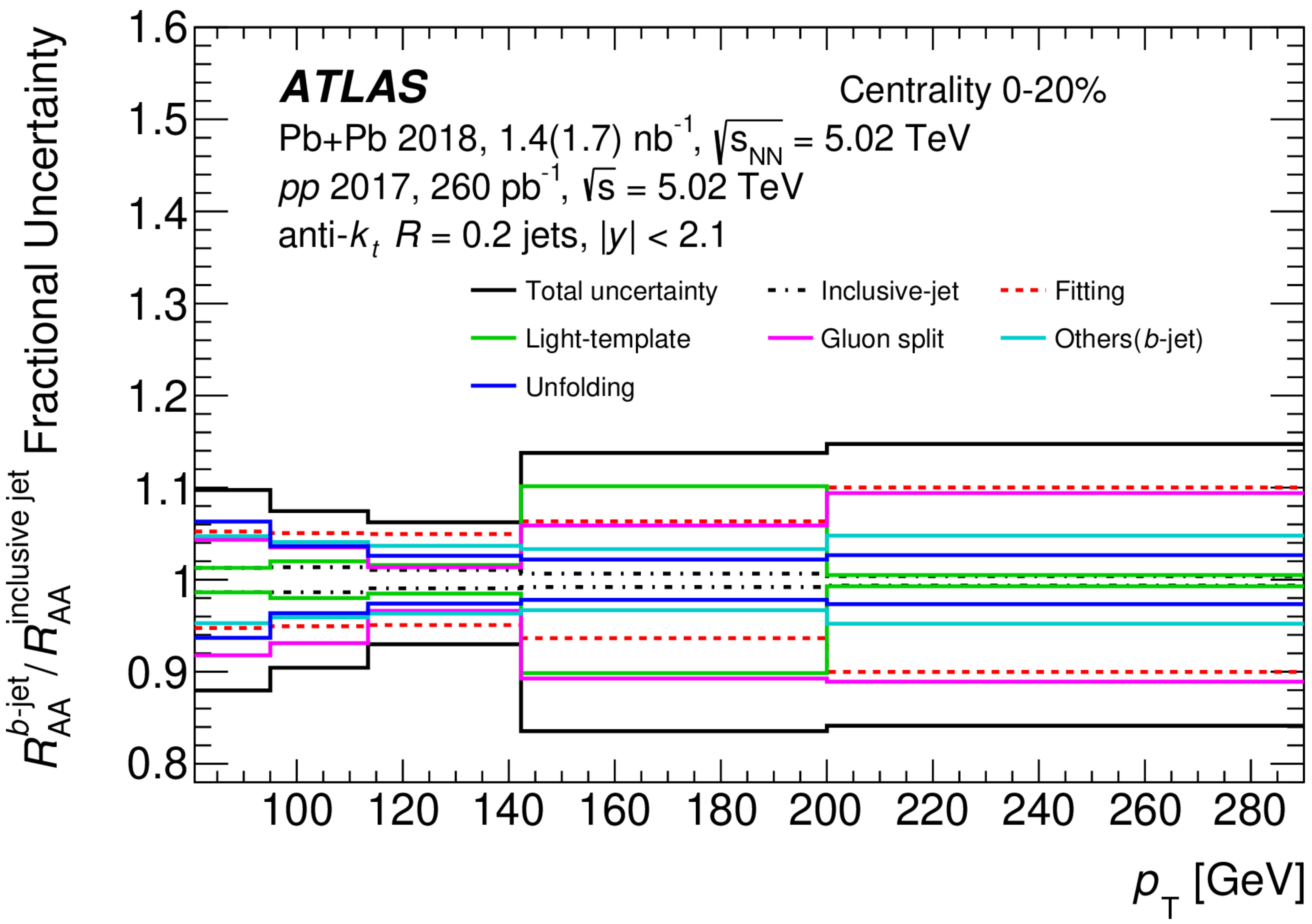
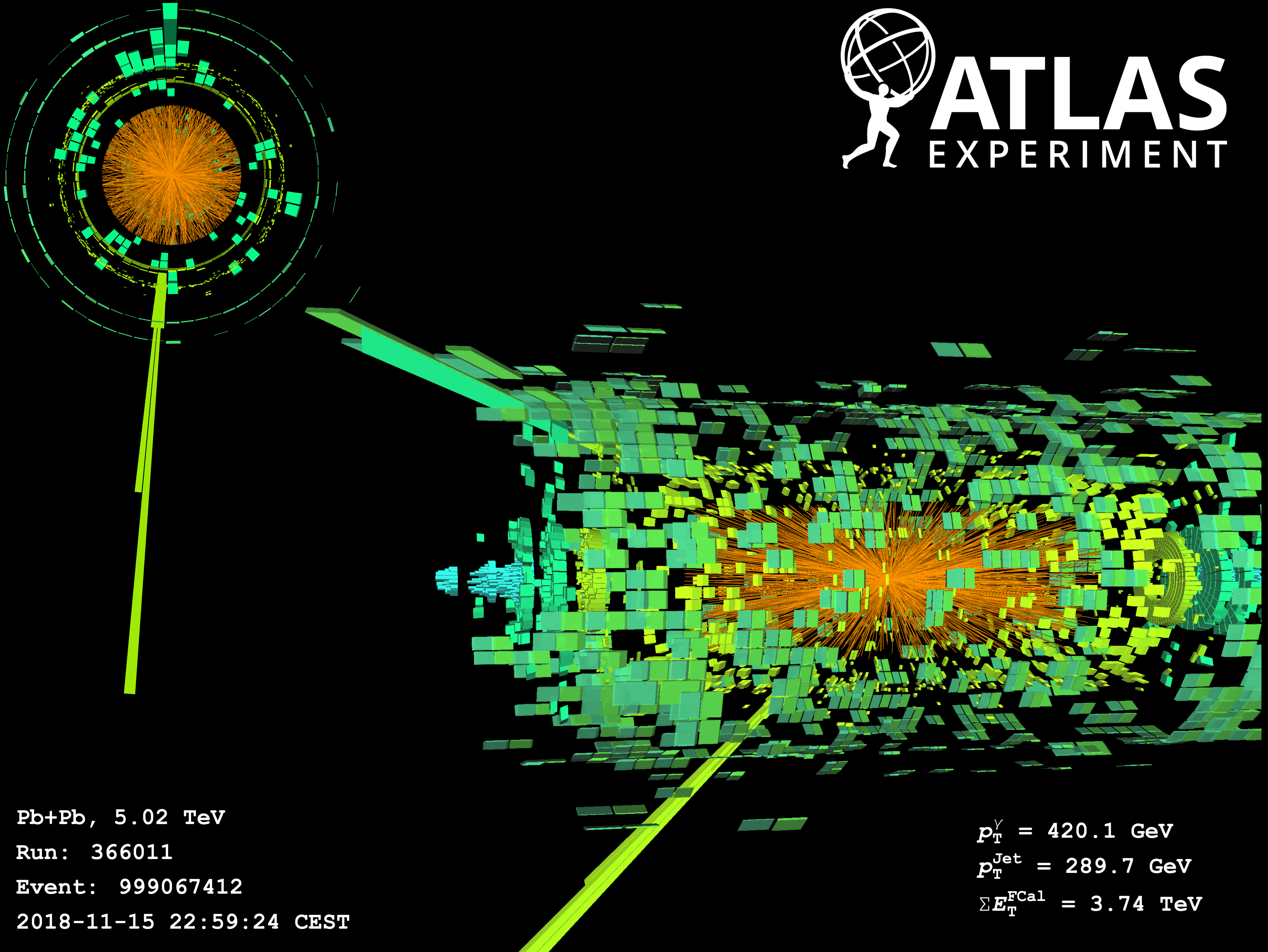


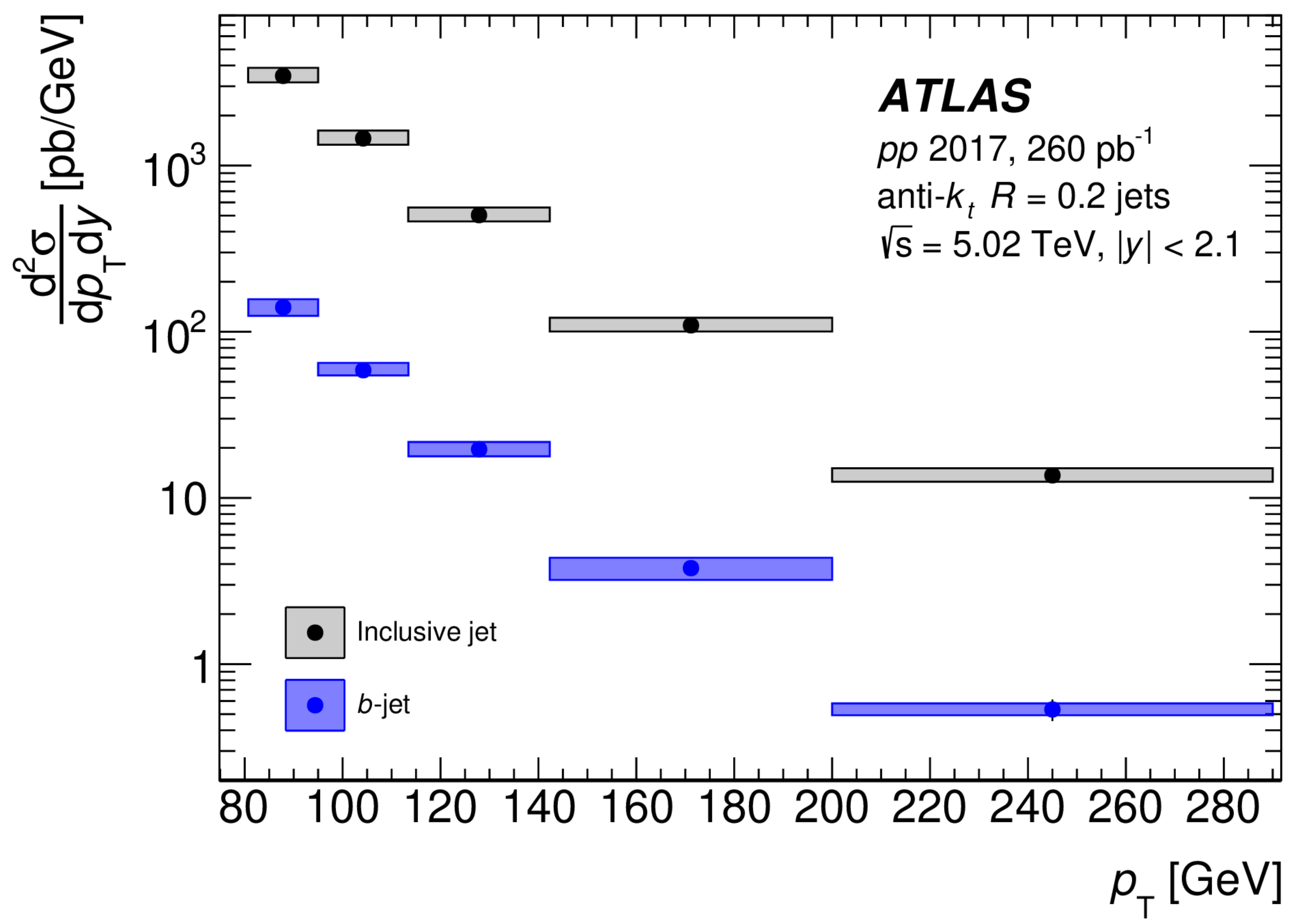


ATLAS EXPERIMENT

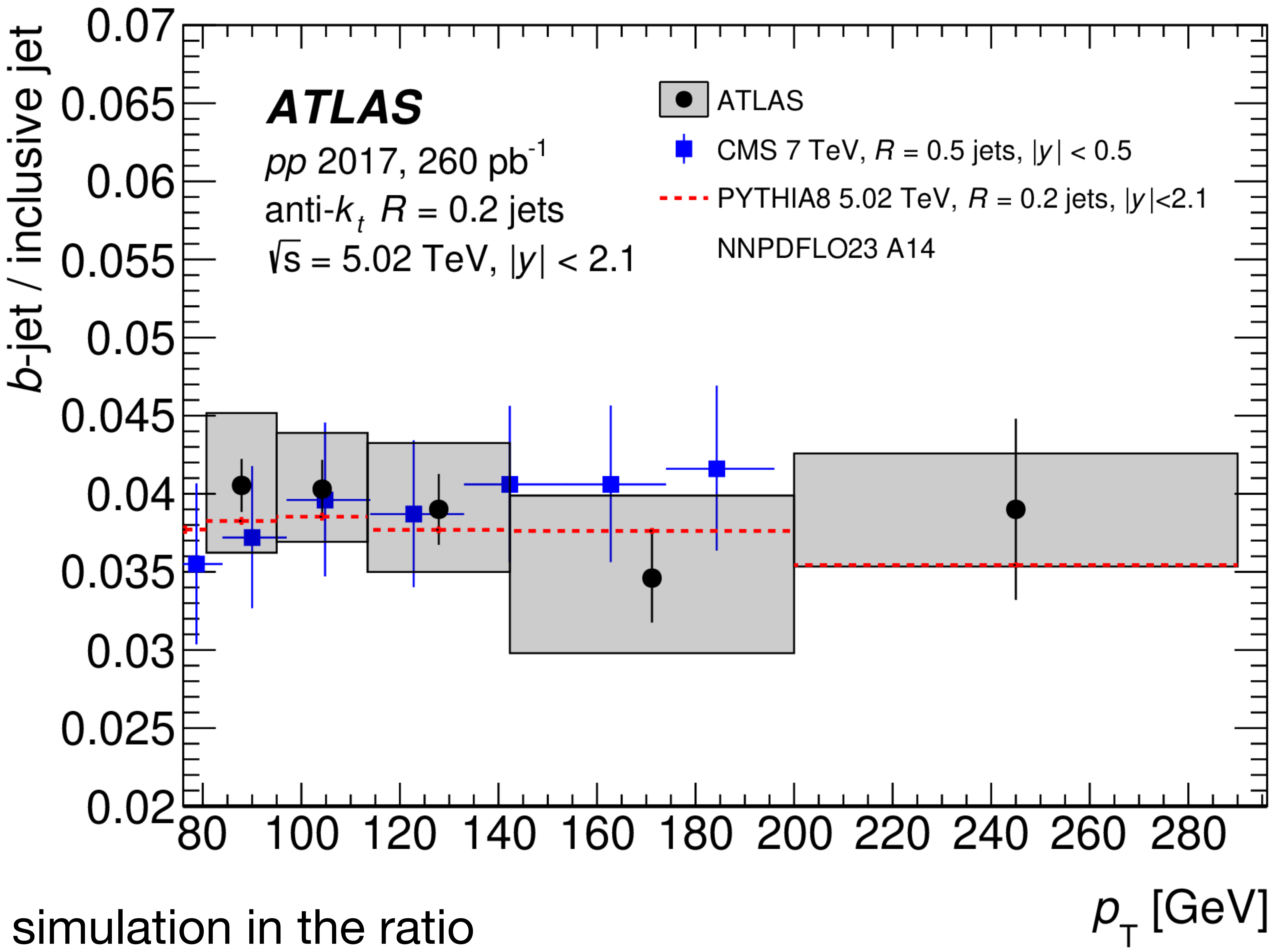


b-jets vs inclusive jets in *pp* collisions

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PAPERS/HION-2018-24/

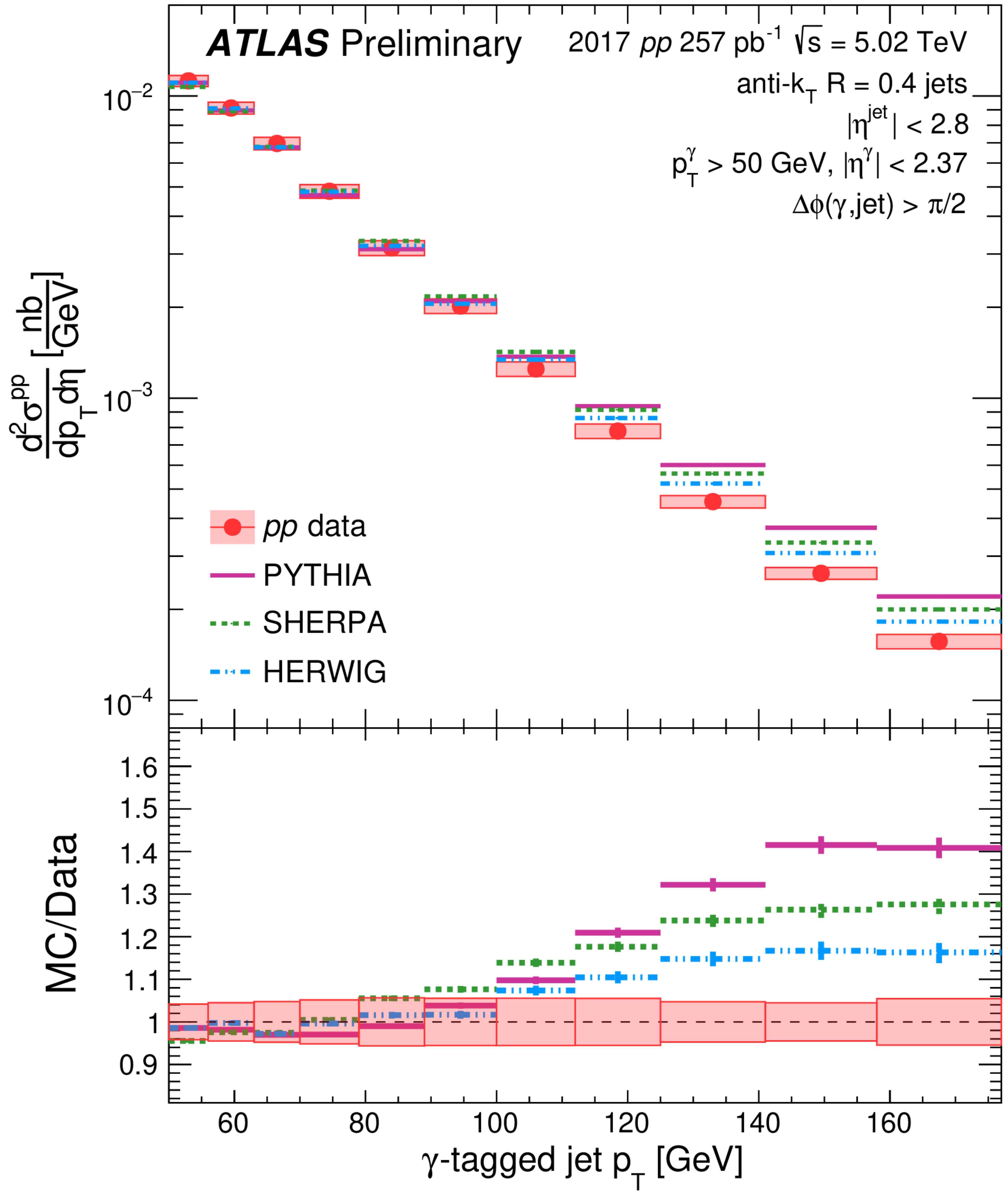


b-jet to inclusive *R*=0.2 cross-section ratio:



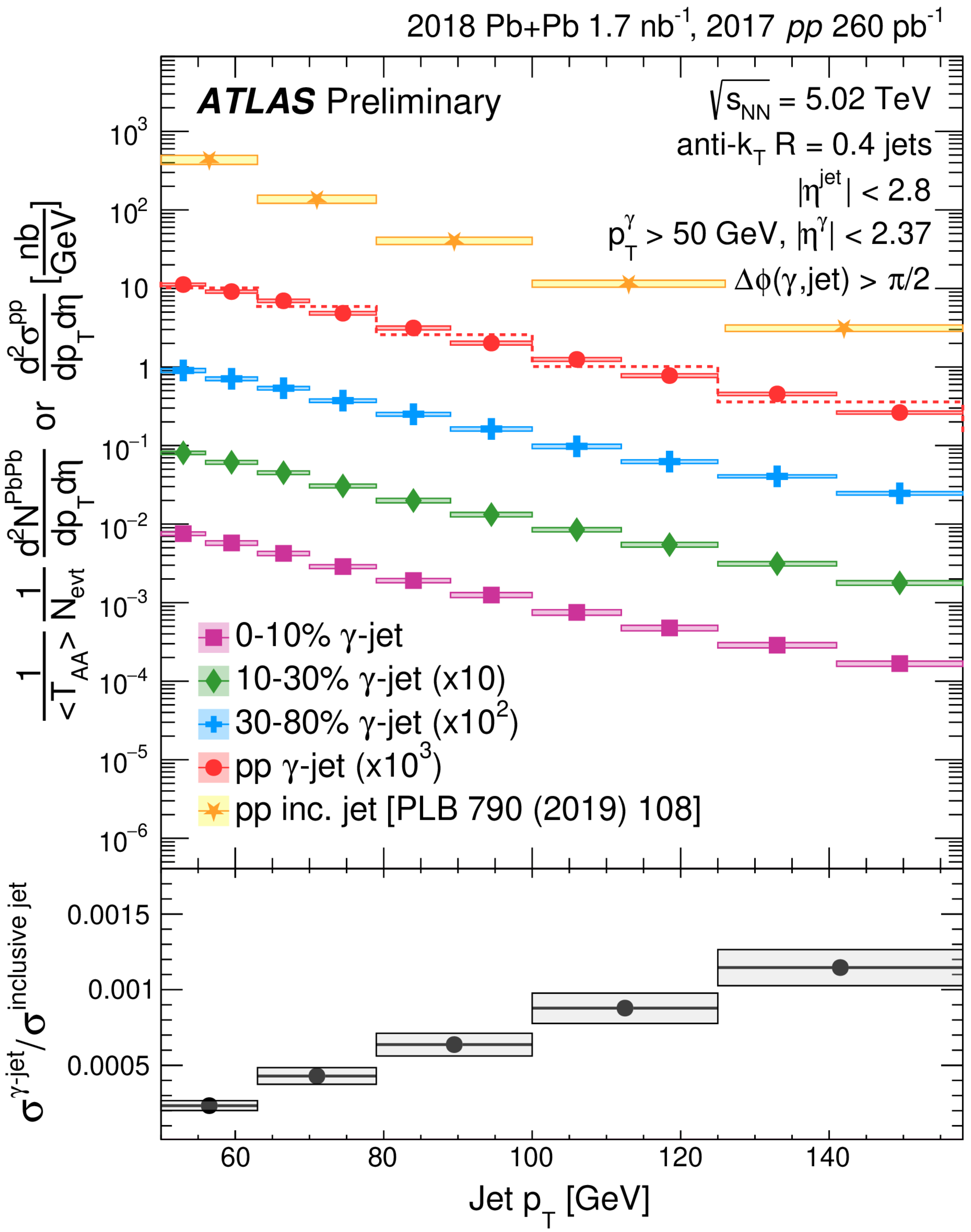
- Good agreement found between data and simulation in the ratio
- Comparison to CMS results consistent within errors
- Ratio consistent with flat withing uncertainties, relevant R_{AA} modification interpretation

γ-tagged jets *pp* cross-section



- γ-tagged jets cross-section measured for Jet $R = 0.4$ in *pp* collisions
- **Fully unfolded** results, γ-*tagged jets* $p_T > 50$ GeV
- Results are compared against generators
  - Good agreement up to 100 GeV
  - Data spectra steeper than MC for $p_T > 100$ GeV
    - Sensitive to multijet topology, fragmentation photon contribution
    - Opportunity to improve modeling

ɣ-tagged jets vs inclusive jets in *pp* and Pb+Pb collisions



ɣ-tagged jets measured for three centralities classes in Pb+Pb data

ɣ-tagged jets to inclusive *R*=0.4 cross-section ratio:

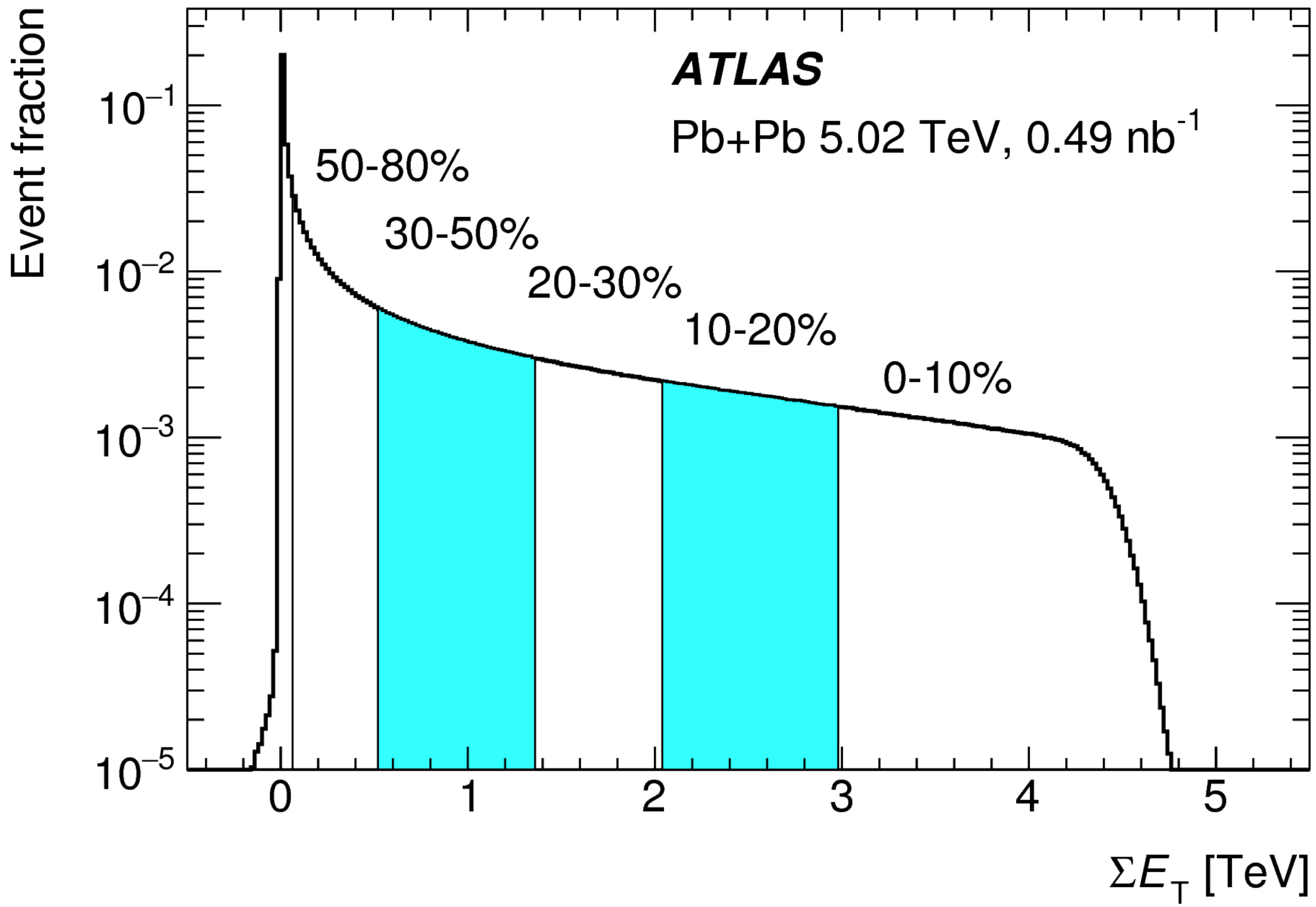
- Relevant for R_{AA} modification interpretation
  - Inclusive jet spectra steeper than ɣ-tagged jets —> less suppression for ɣ-tagged jets
  - Isospin/nPDF effect also plays an important role —> larger suppression for ɣ-tagged jets
  - The two effects are expected to have similar magnitude but opposite sign

Inclusive jets from *PLB 790 (2019) 108*

Theoretical calculation

	Vitev	Wang	LIDO
Vacuum (Baseline)	Calculated: PDF+hard kernel+semi-inclusive jet functions	SHERPA	PYTHIA8
Medium	Calculated: nPDF+**Medium** semi-inclusive jet functions	Modified Langevin transport model	Linear partonic transport model
Hydro	(2+1)D viscous hydrodynamics averaged over multiple events	Smooth iEBE-VISHNU hydro model	(2+1)D viscous hydrodynamics with averaged initial conditions
Hadronization		SHERPA	PYTHIA8
Parameters	g = 1.8-2.2, jet-medium coupling	q_0 = 1.2 GeV^2/fm, local parton density in medium initial value. T_c = 165 MeV, hot medium termination temperature. $2\pi TD_s$ = 4, Spatial diffusion coefficient.	Q_0=1.8 GeV switching scale between vacuum parton shower and transport equation. T_f = 165 MeV, hot medium termination temperature. μ_{min} = 1.5—2.0, jet-medium coupling.

CENTRALITY



Only forward

Centrality is parametrized using the energy deposited in the Forward calorimeter