R-dependence of inclusive jet suppression and groomed jet splittings in heavy-ion collisions with ALICE

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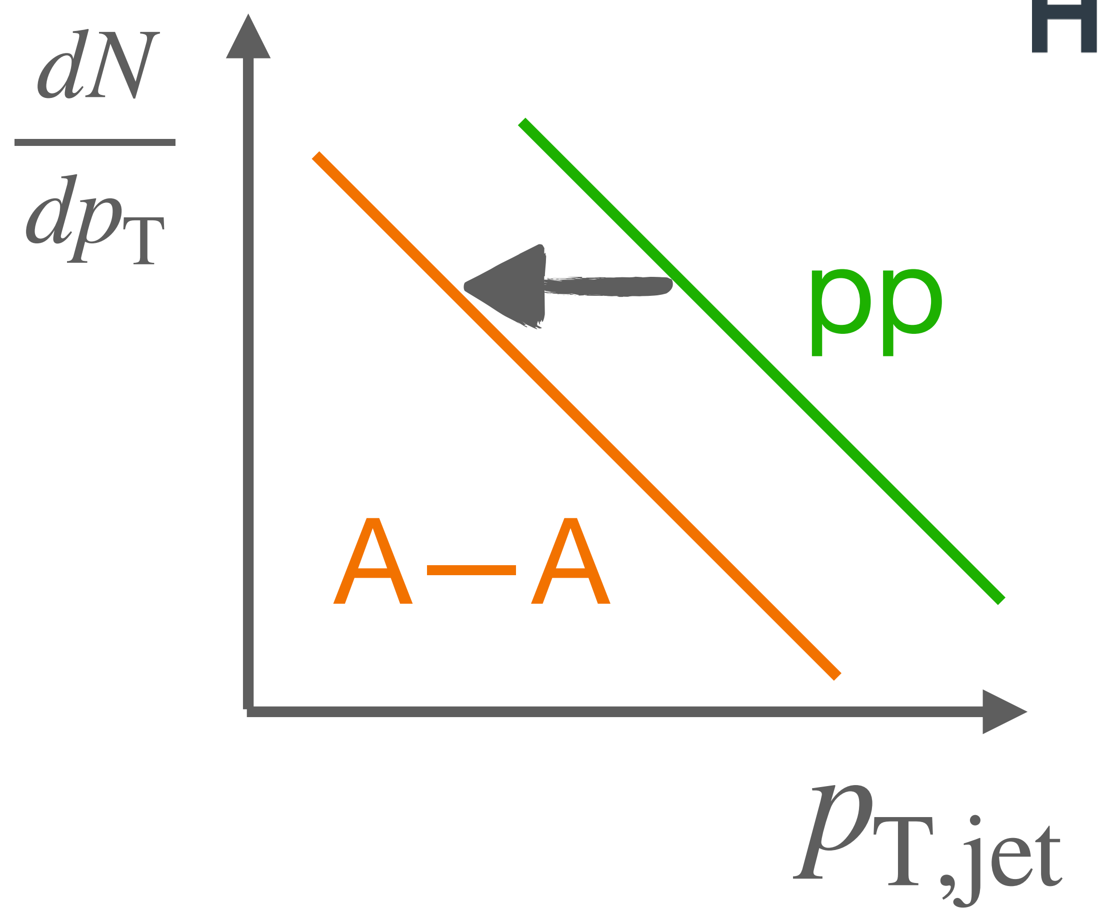
Quark Matter 2022

April 7th, 2022

Kraków, Poland

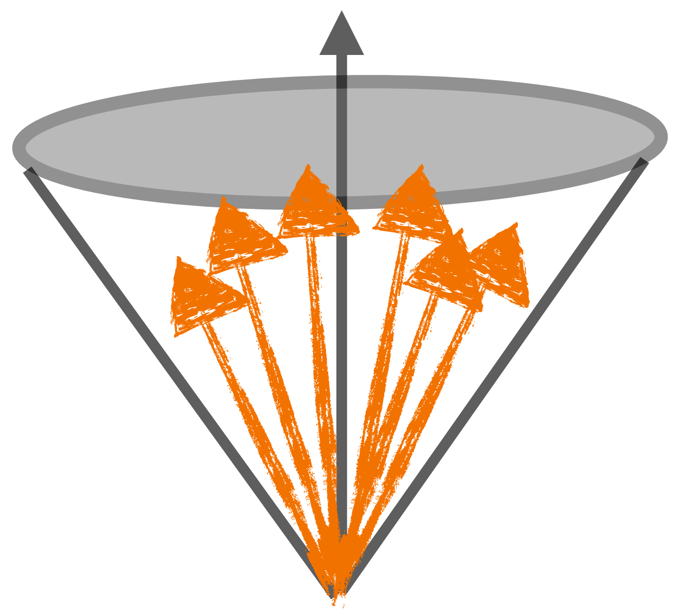
Expectations of jet quenching (1/2)

1. Parton energy loss leading to a suppression of jet yields in heavy-ions (A—A) in comparison to vacuum (pp).



2. Internal structure modification due to…

Vacuum jet



Jet in Medium

Momentum broadening

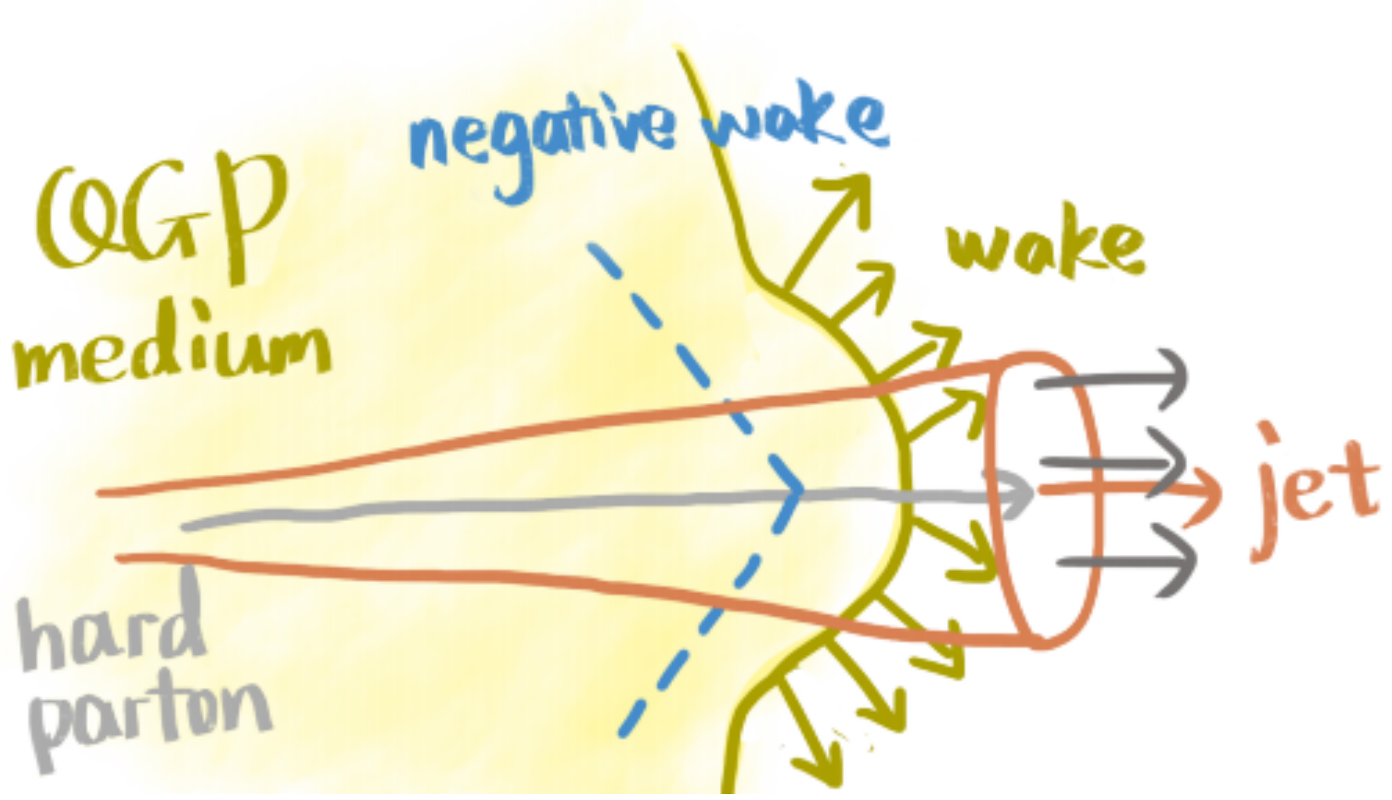


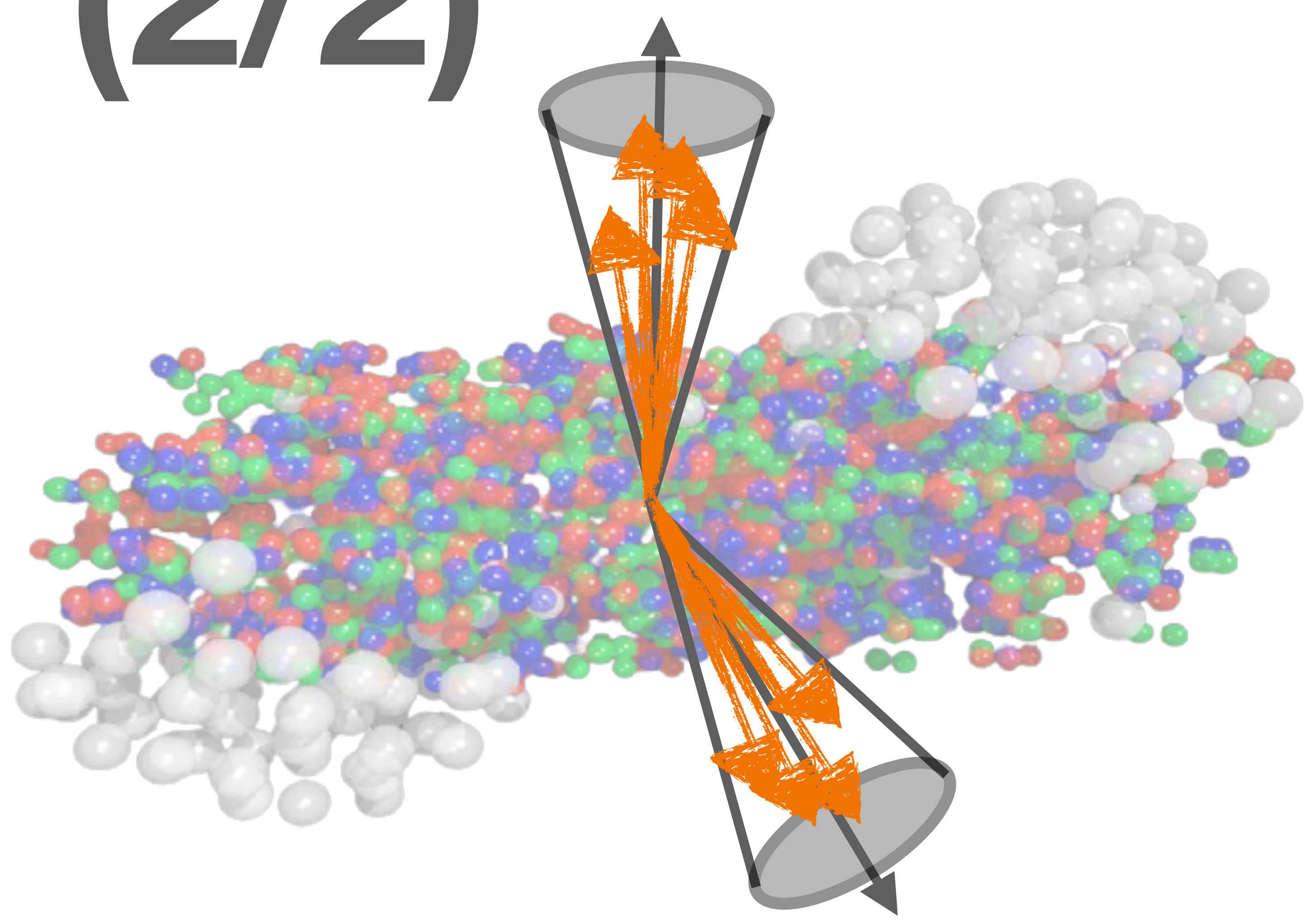
Image Credit:Jing Wang

Medium-induced wake

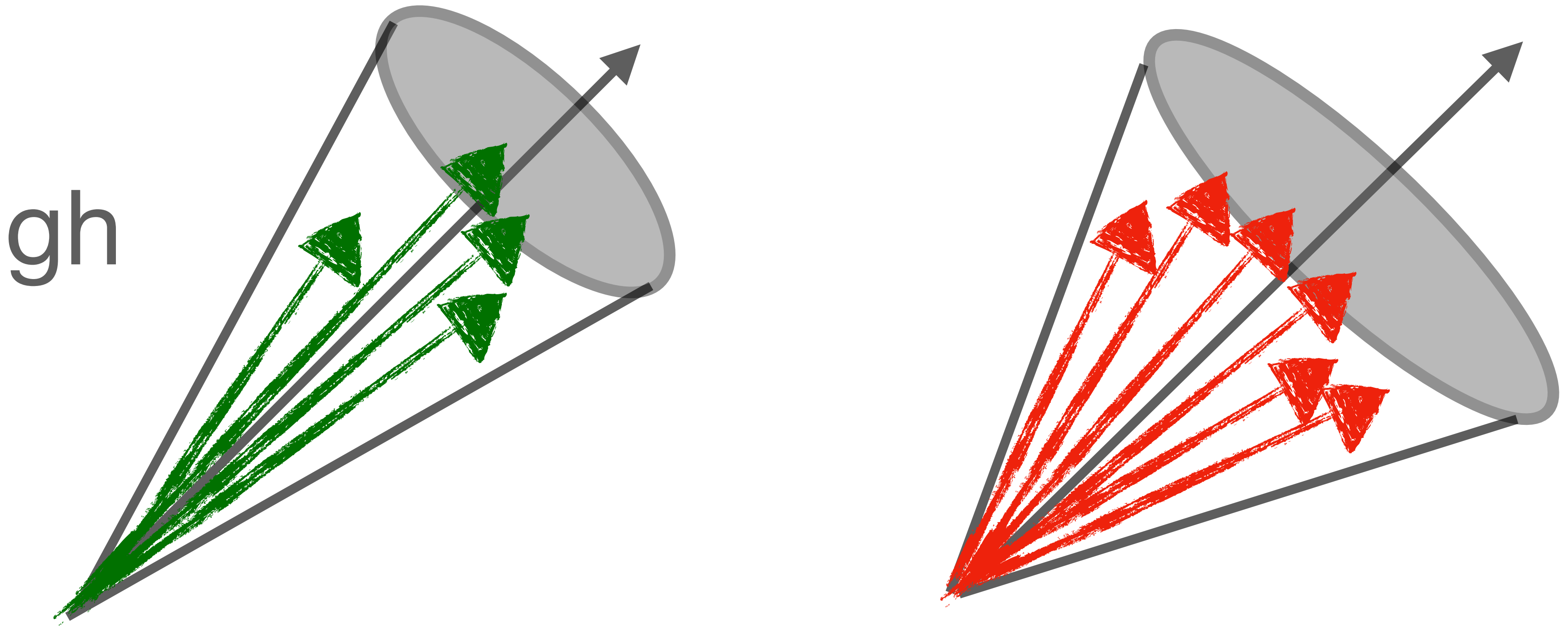
Expectations of jet quenching (2/2)

ALICE

3 Deflection of the jet centroid due to multiple soft scatterings or scatterings with QGP quasi-particles.



→ Different jets with different partonic structures, flavors, transverse momenta, path lengths through the medium, etc. lose energy differently.



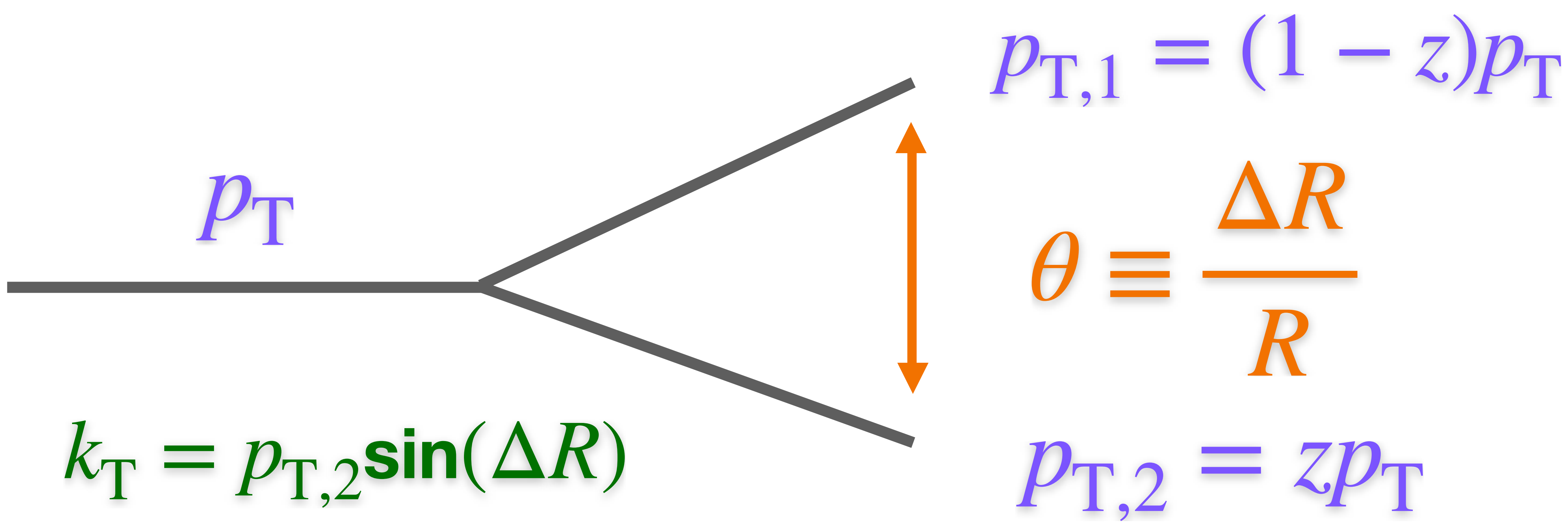
→ The same jets can lose energy differently due to fluctuations in jet-medium interactions.

Isolating the same jet population can be challenging, but useful for disentangling energy loss mechanisms.

Jet splittings

→ Use declustering history to experimentally probe partonic splittings within jets.

ALICE



z **:** shared momentum fraction between subjets **(asymmetry)**

$$z = \frac{p_{\mathrm{T},2}}{p_{\mathrm{T},1} + p_{\mathrm{T},2}} = \frac{p_{\mathrm{T},2}}{p_{\mathrm{T}}}$$

θ **:** opening angle between subjets **(width)**

k_{T} **:** relative transverse momentum of subjets **(hardness)**

Grooming methods

→ In vacuum: mitigate impact of hadronization, MPIs, pileup

→ In medium: reduce sensitivity to soft background, removes some soft signal from momentum broadening and medium response. (Focus on hard structure modification)

Soft Drop Grooming:

- Select hard splittings

$$z > z_{\mathrm{cut}}(\frac{\Delta R}{R})^{\beta}$$

- Results in this talk use $\beta = 0$
- In heavy-ion collisions, increasing z_{cut} can be used to mitigate background

Mulligan et al. Phys. Rev. C 102 (2020) 4, 044913

Larkoski et al. JHEP 05 (2014) 146

Dynamical Grooming:

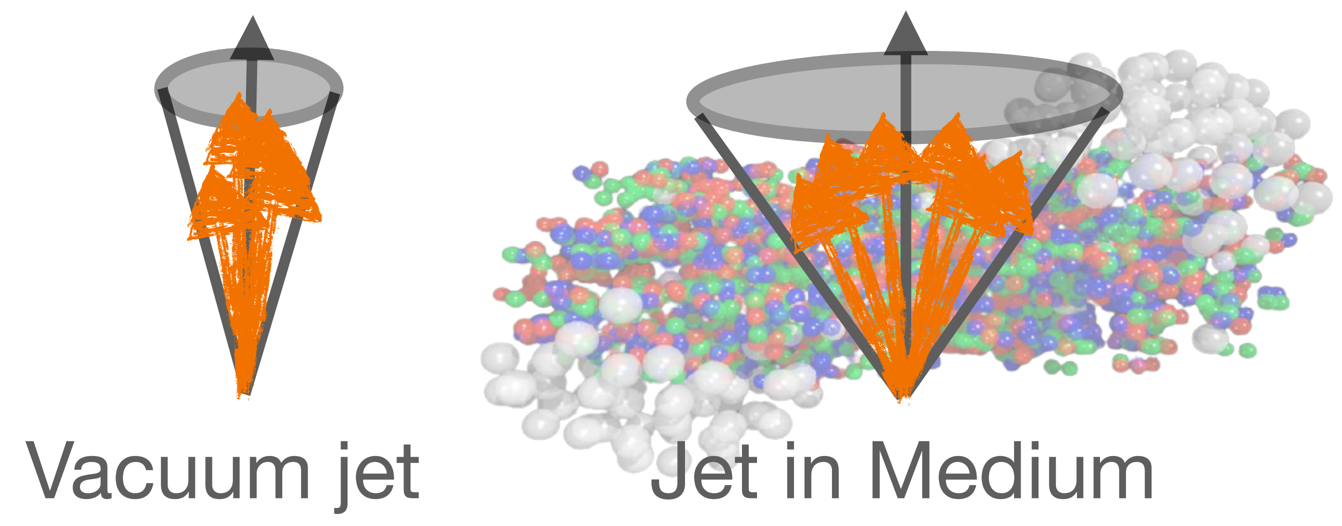
- Find hardest branch amongst set of iterative splittings
- Grooming cutoff in *z* is generated on a jet-by-jet basis
- Different values of a specify different hardness measures

$$\kappa^{(a)} = \frac{1}{p_{\mathrm{T}}}\mathrm{max}_{i\in \mathrm{C/A}} \; z_{\mathrm{i}}(1 - z_{\mathrm{i}}) \; p_{\mathrm{T,i}} \; (\frac{\Delta R_{\mathrm{i}}}{R})^{a}$$

Mehtar-Tani et al., Phys. Rev. D. 101.034004

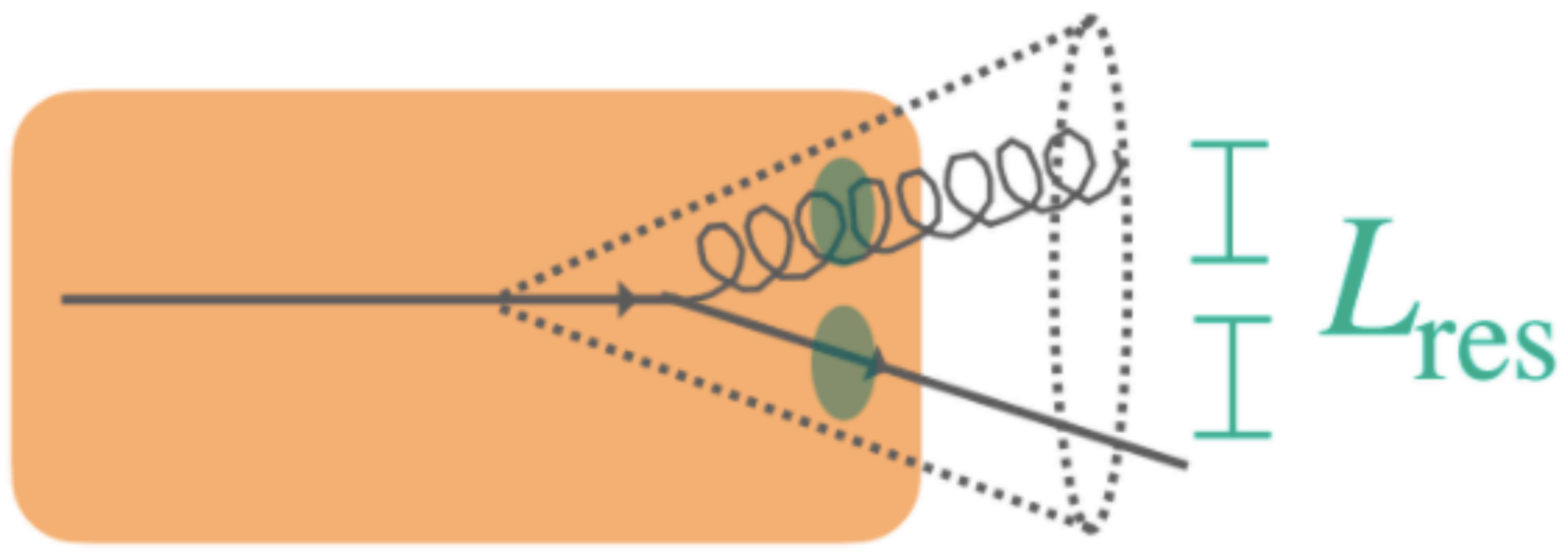
Physics of jet splittings

- In vacuum, jet splittings can be used to probe pQCD, BSM searches etc.
- In medium, jet splittings can be used to probe the modification of jet substructure
  - resolution length of the medium and its space-time structure, QGP effect on the splitting function, identify in-medium scatterings, etc.



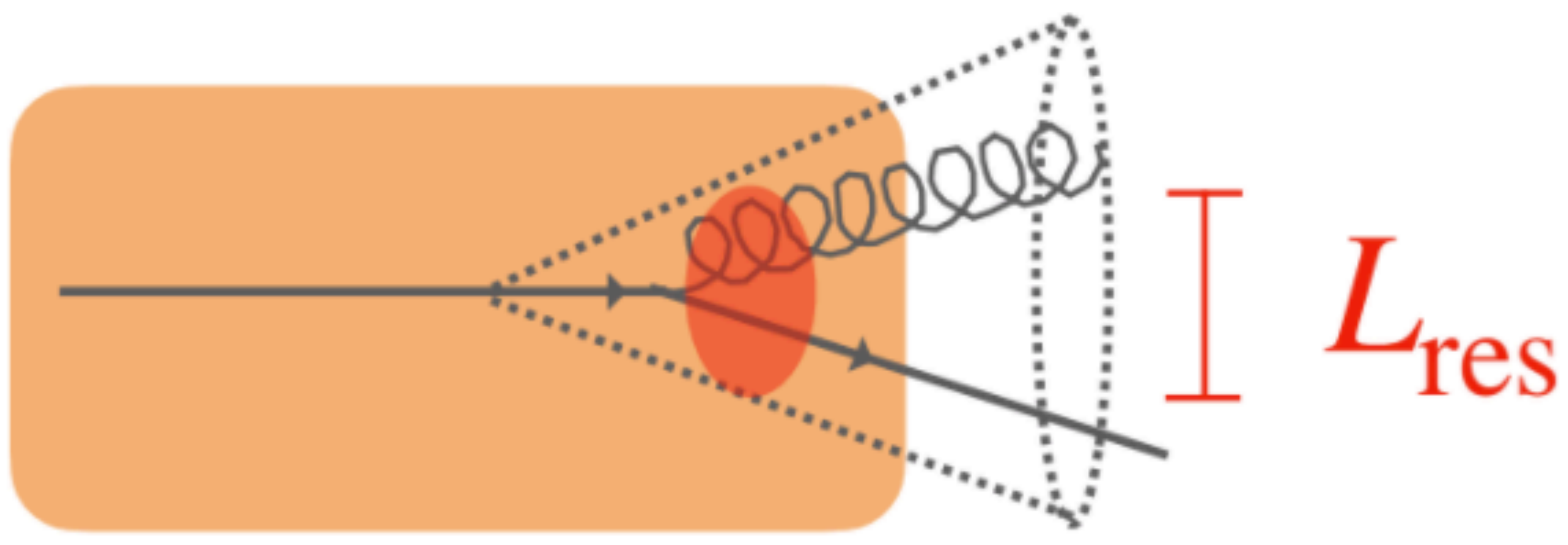
Decoherence: medium resolves split, more energy loss (more effective energy loss sources)

(Fully Decoherent ~ $L_{\text{res}} = 0$)



Coherence: medium does not resolve split, less energy loss

(Fully Coherent ~ $L_{\text{res}} = \infty$)



Groomed momentum splitting fraction

- Increased z_{cut} to reduce the background.
- No observed modification of the groomed momentum splitting fraction (z_g).
- Consistent with quenching models.

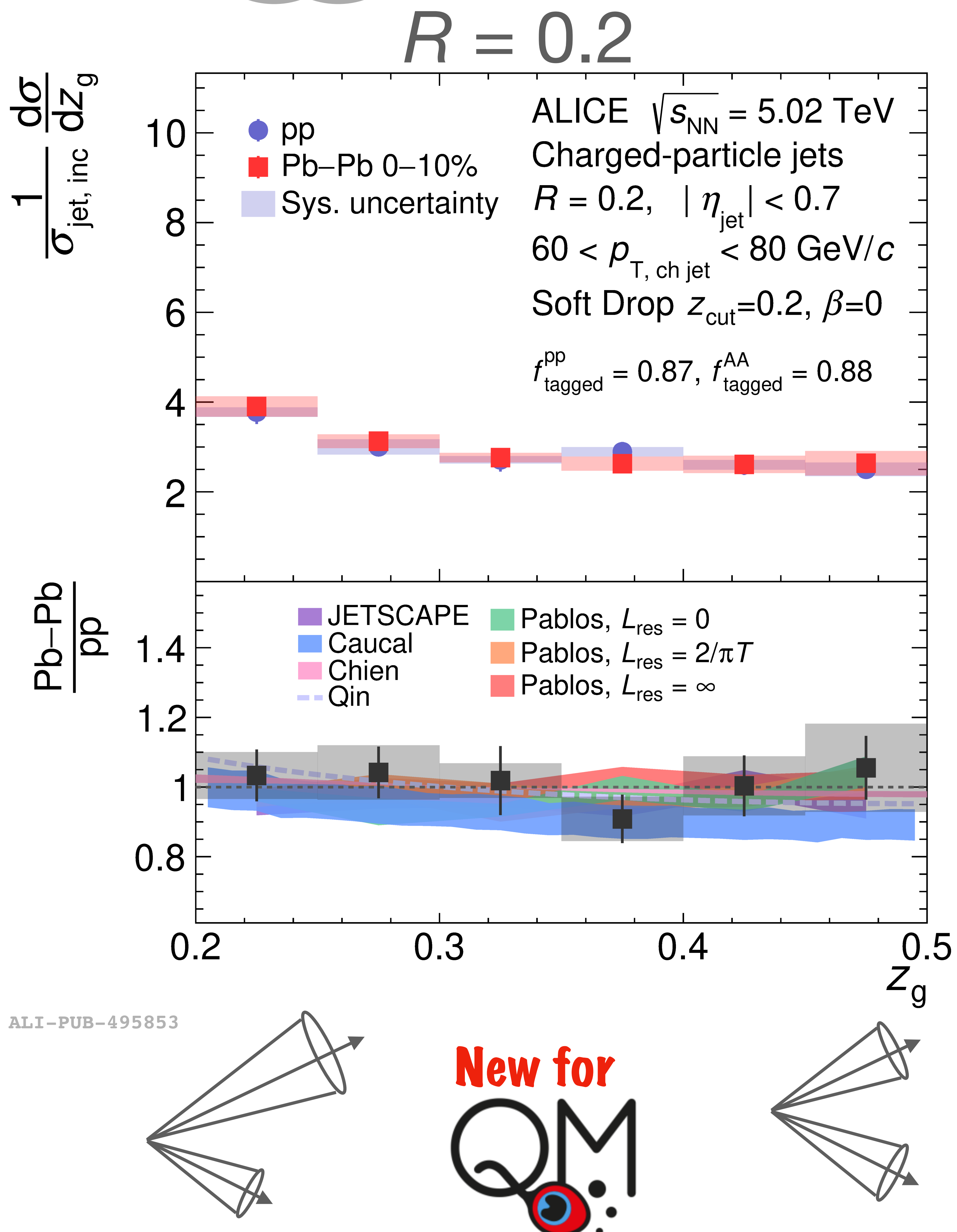
Pablos et al. JHEP (2020) 044

Caucal et al. JHEP (2019) 273

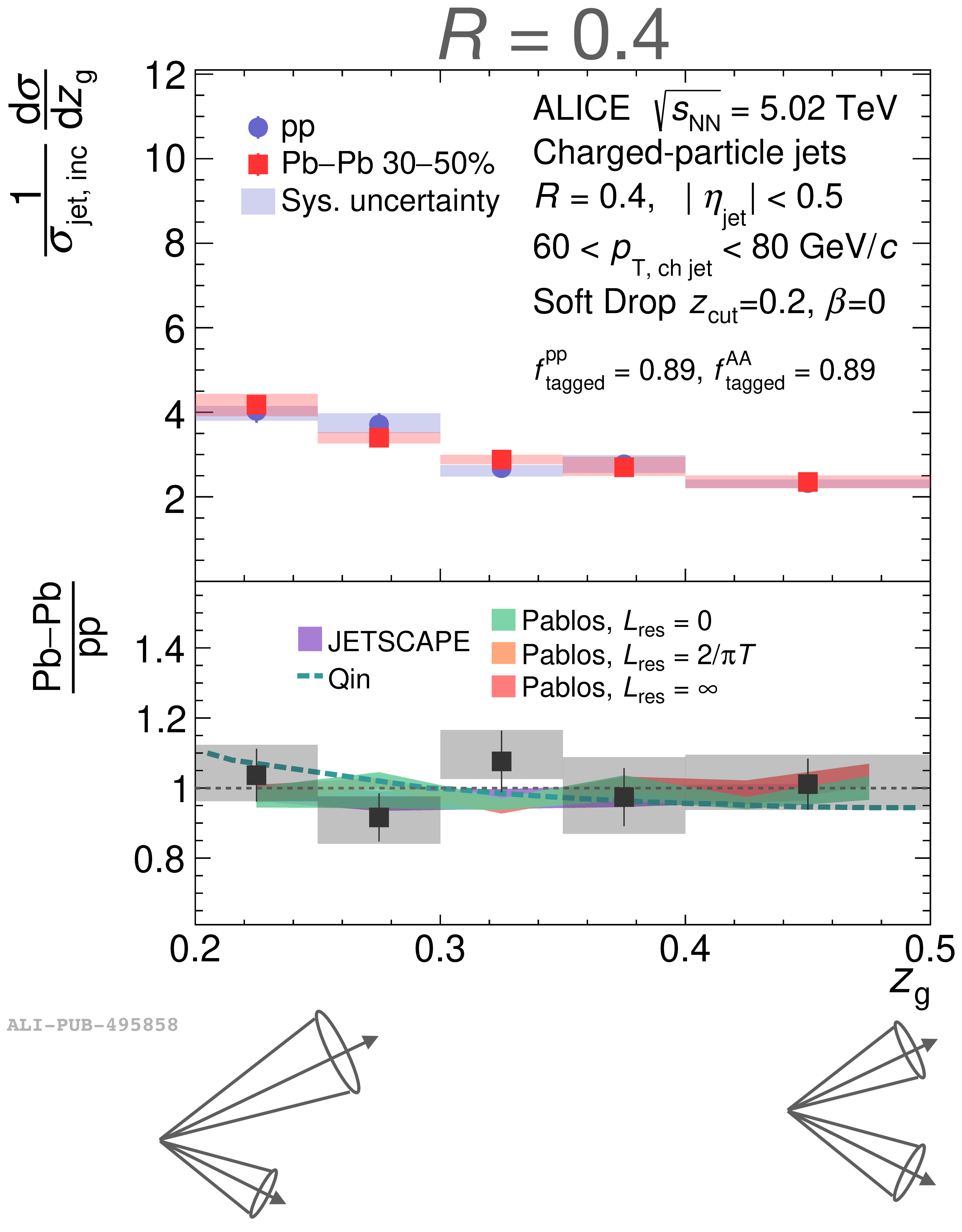
Phys.Lett.B 808 (2020) 135634

JETSCAPE arXiv:1903.07706

Central (0-10%)



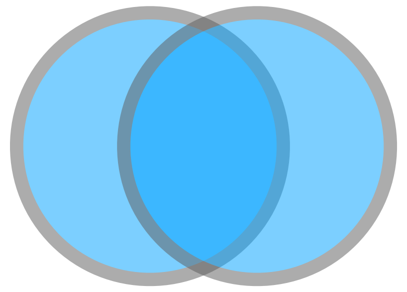
SemiCentral (30-50%)



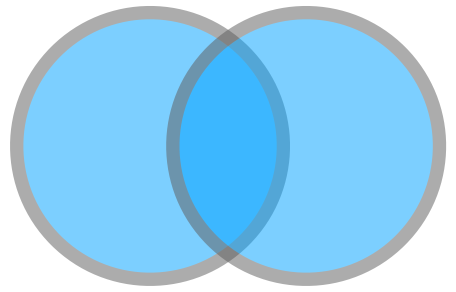
New for QM

Phys. Rev. Lett. 128. 102001 (2022)

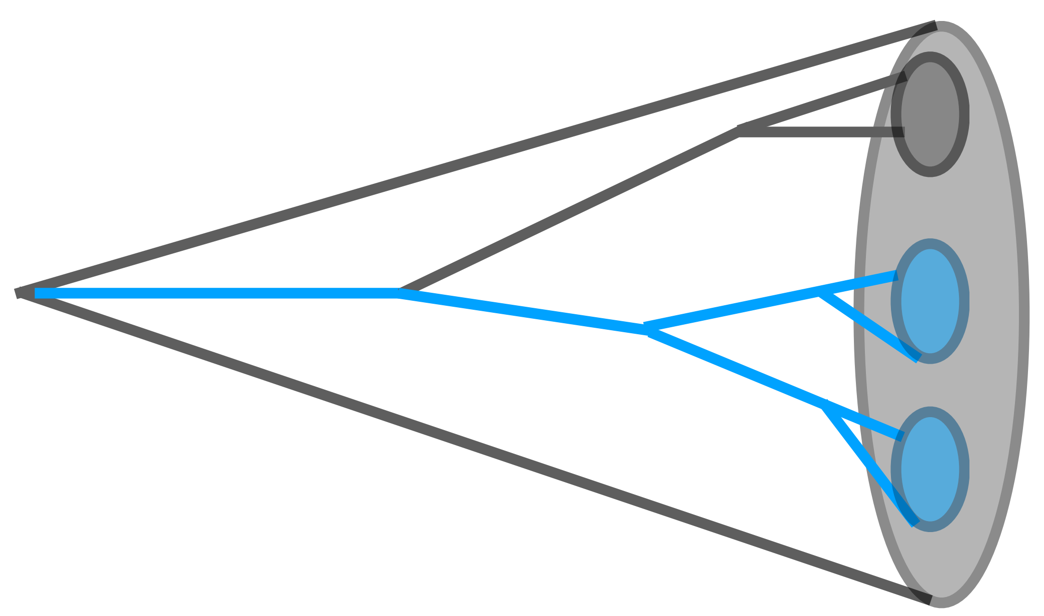
Groomed jet radius



Central (0-10%)



SemiCentral (30-50%)

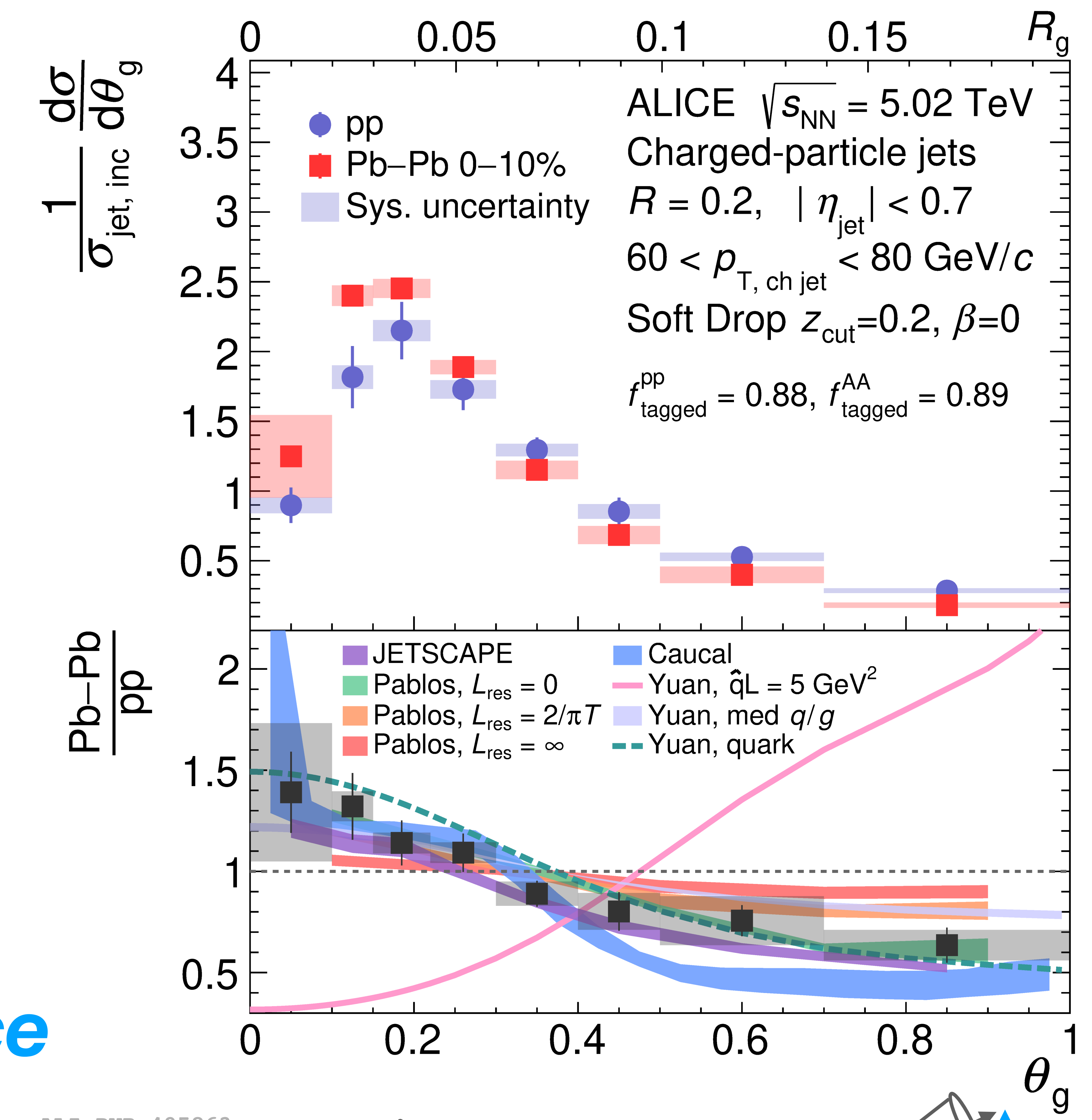


$$\theta_g \equiv \frac{R_g}{R}$$

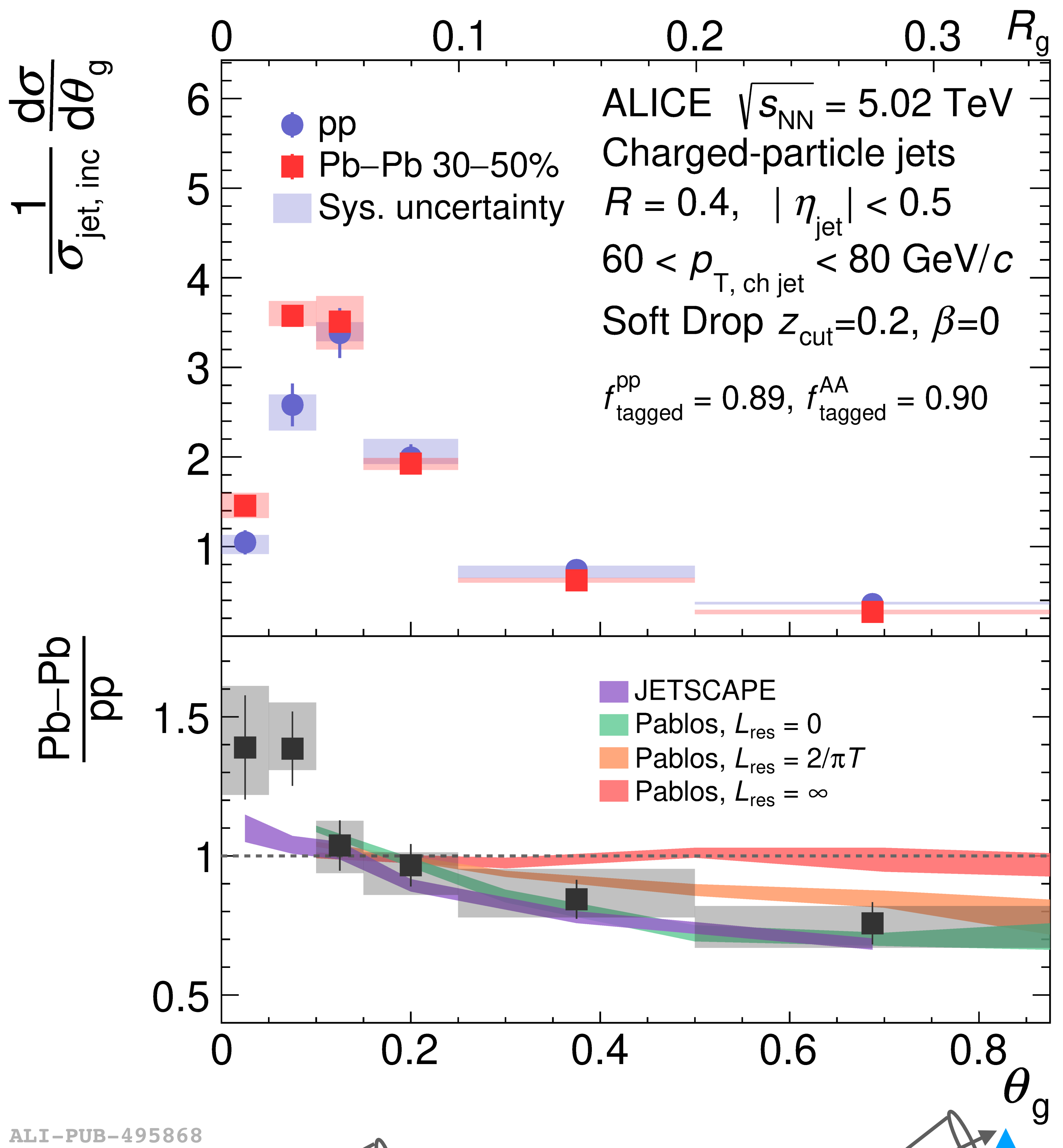
See a suppression of wide angle splittings, favored by models with decoherence.

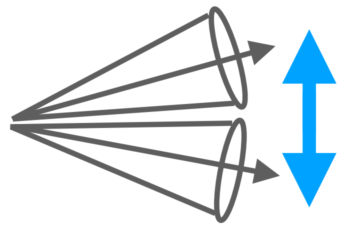
Could this also be coherence with a high quark fraction?

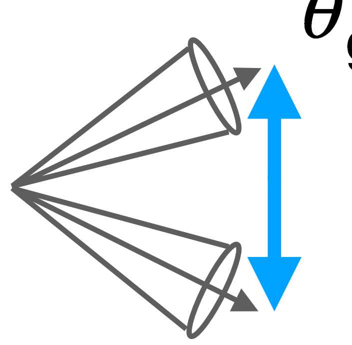
R = 0.2

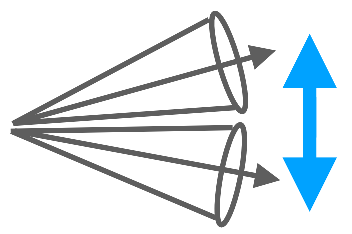


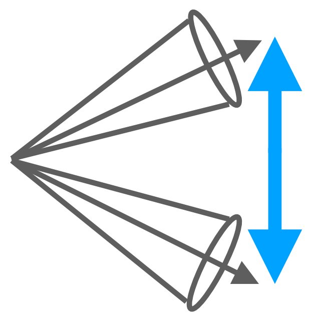
R = 0.4











New for QM

Phys. Rev. Lett. 128. 102001 (2022)

R-dependence of the R_{AA}

- *R*-dependence of the R_{AA} is another way to disentangle energy loss mechanisms.

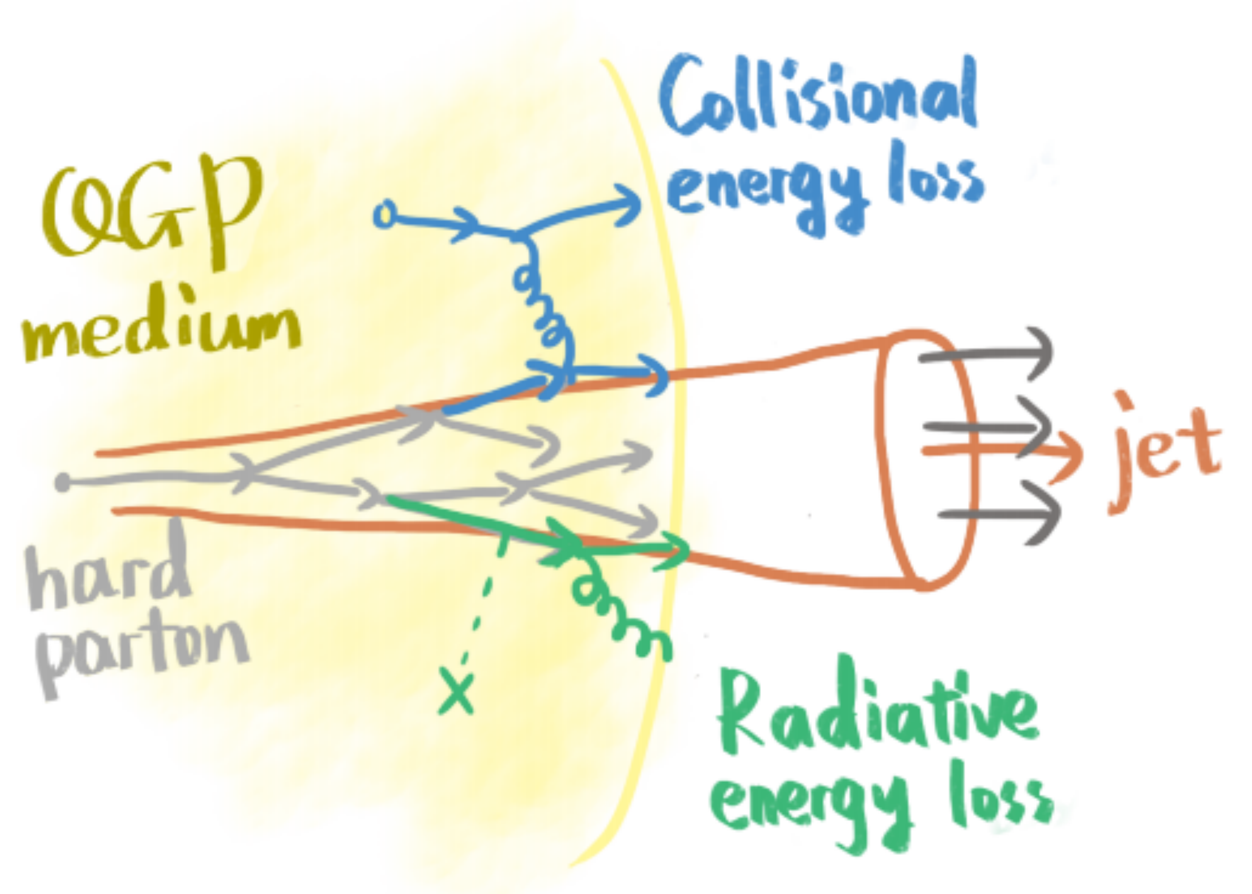
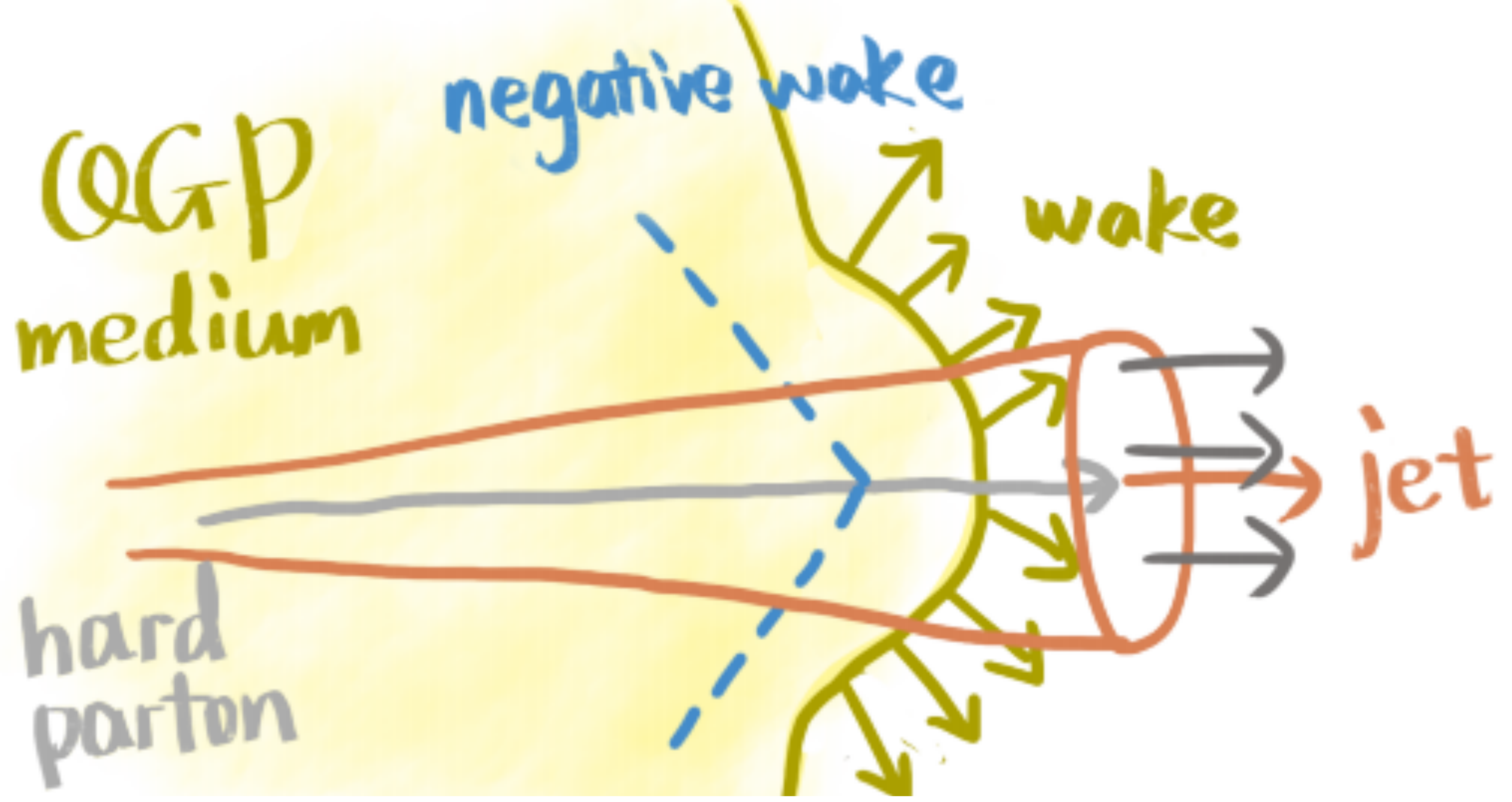


Image Credit:Jing Wang



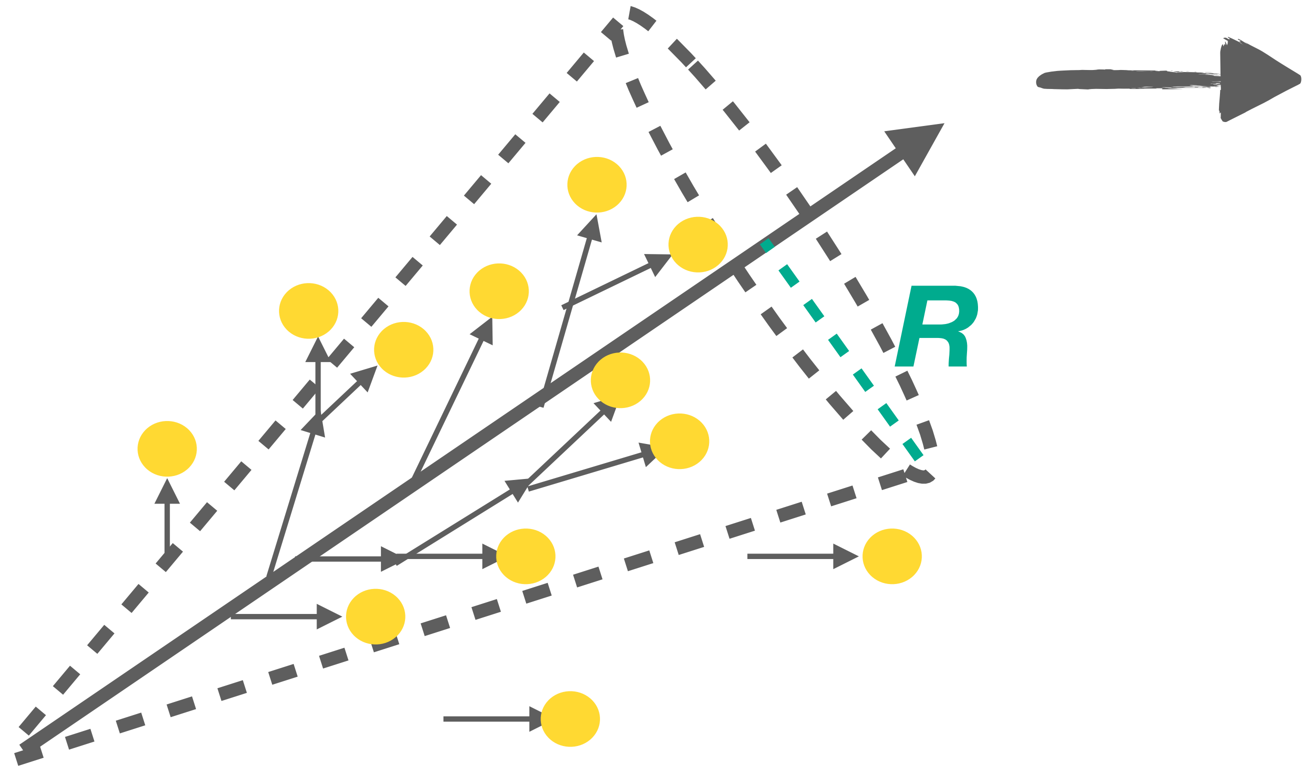
- Recovery of wide angle radiation $R_{\mathrm{AA}} \nearrow$
- Medium response adds energy to the jet cone $R_{\mathrm{AA}} \nearrow$
- Large *R* jets have more effective energy loss sources, therefore could experience more quenching. $R_{\mathrm{AA}} \searrow$
- Increase gluon to quark ratio at fixed p_{T}, gluons lose more energy $R_{\mathrm{AA}} \searrow$

- Inclusive jet measurements at large *R* and low p_{T} difficult due to the large fluctuating underlying event ($\propto R^2$)

ML-based background estimator

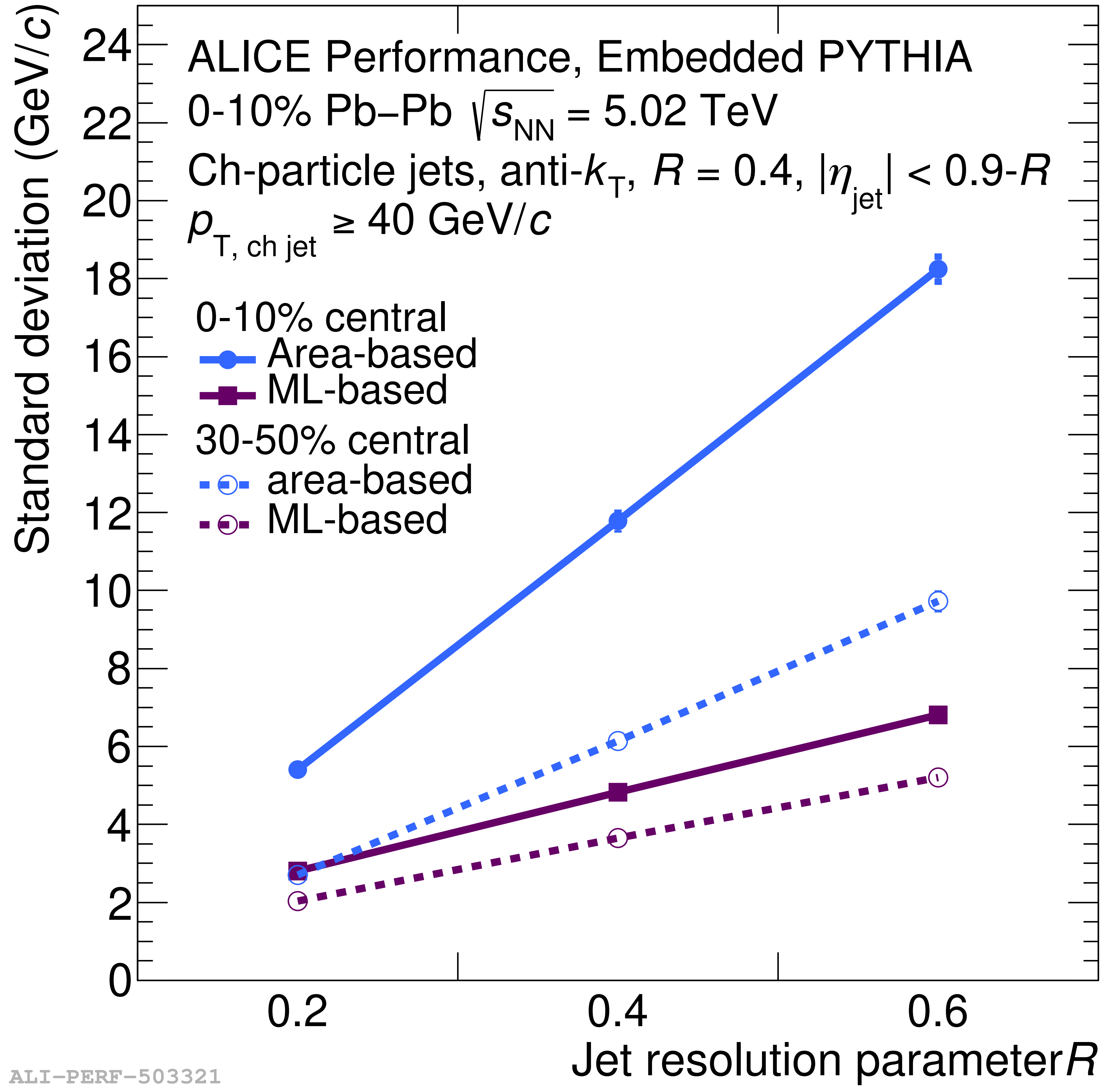
ALICE area-based approach: Correct the jet for the background with a pedestal subtraction. Apply a minimum p_T requirement on the leading track of the jet.

ML approach: Use ML to construct the mapping between measured and corrected jet without a leading track bias.



Fragmentation dependence introduced by learning on constituent information included as a systematic.

$$\delta p_T = p_{T,rec} - p_{T,true}$$

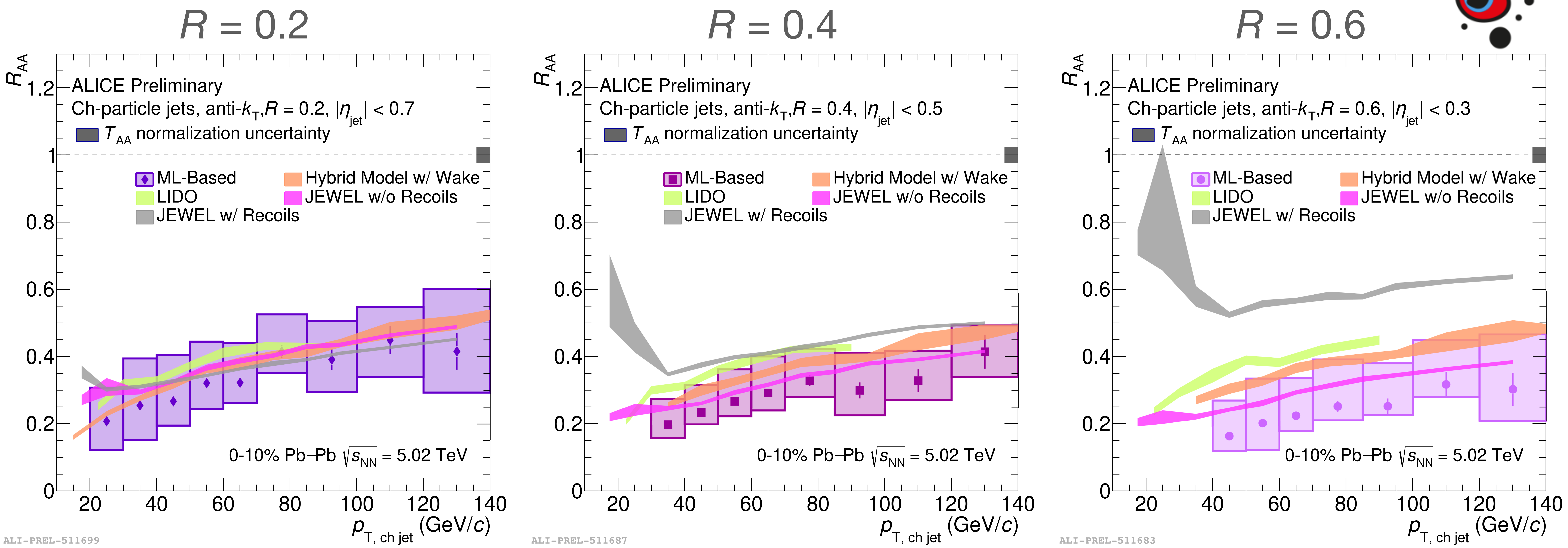


R.Haake, C. Loizides Phys. Rev. C 99, 064904 (2019)

Nuclear modification factors (0-10%)

New for QM

LIDO: JHEP 05 (2021) 041 JEWEL: JHEP 1707 (2017) 141 Hybrid Model: Phys. Rev. Lett. 124, 052301 (2020)



- Measuring down to lower p_T and larger R than ever before in heavy-ions at the LHC!
- Models generally agree with data, but can they describe the R-dependence?

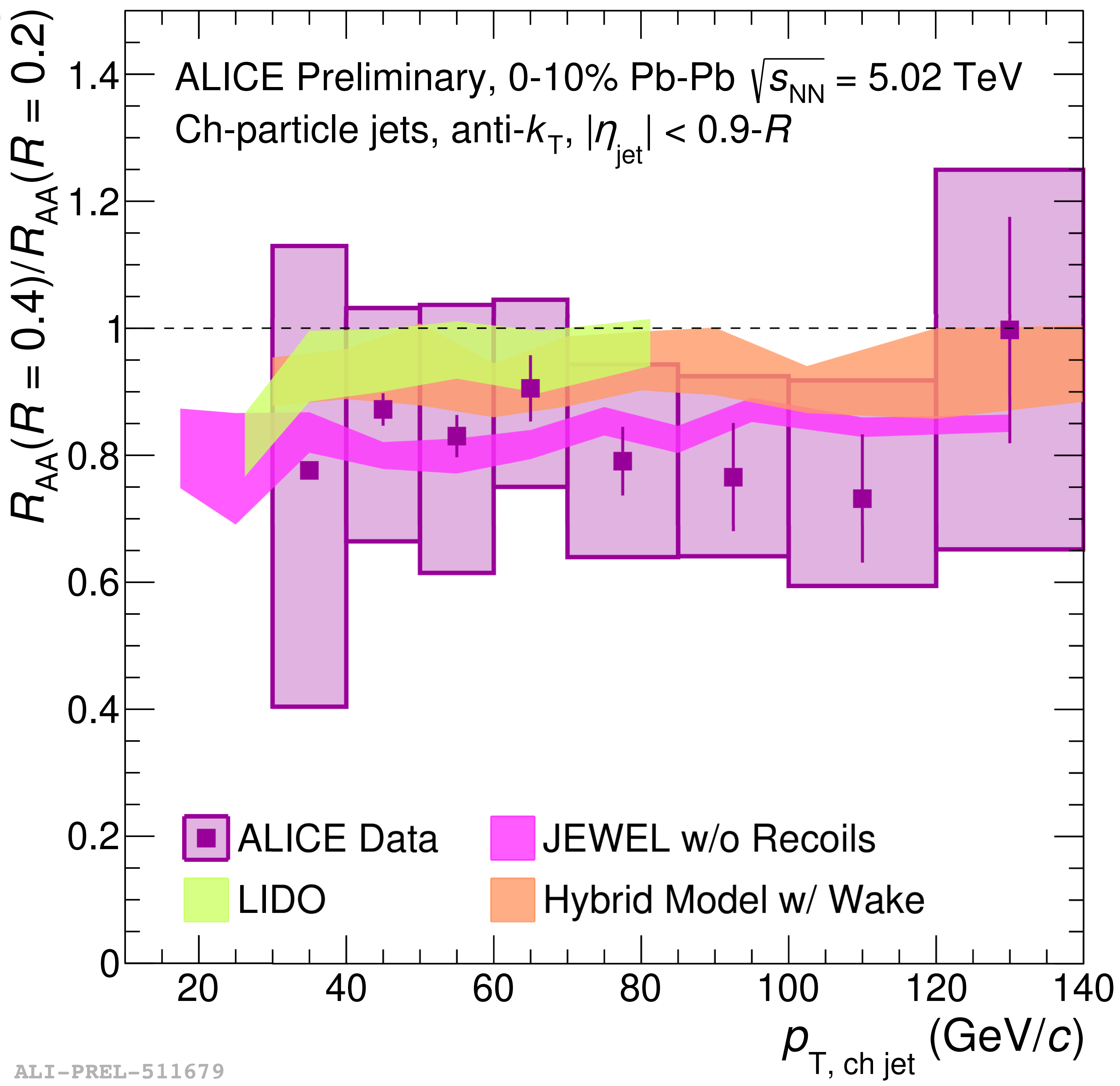
R-dependence via R_{AA} ratios

Central (0-10%)

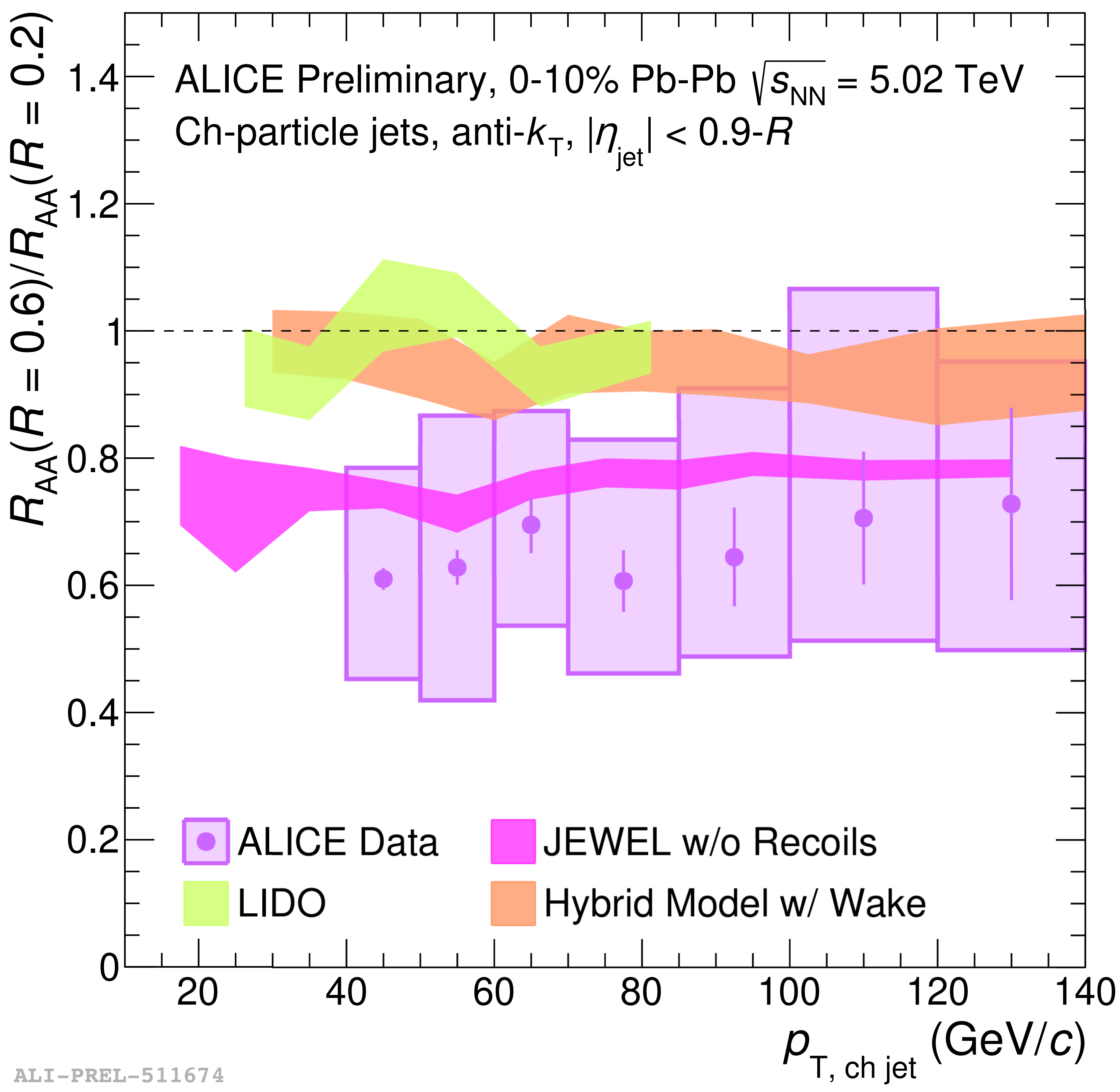
New for QM

- *R*-dependence of the R_{AA} is a useful and discriminative measurement when compared to models.
- No evidence of *R*-dependence between *R* = 0.2 and *R* = 0.4.

R = 0.4 / *R* = 0.2



R = 0.6 / *R* = 0.2

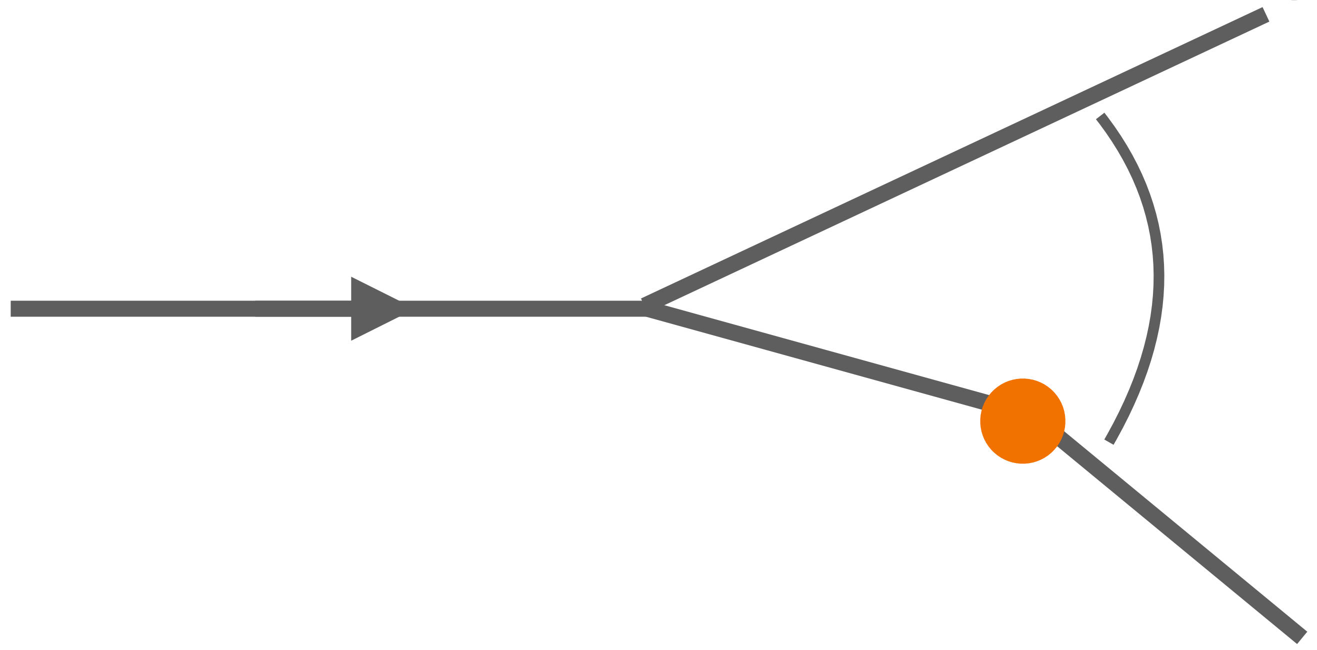


R = 0.6 jets appear more suppressed than R = 0.2 jets, suggesting an R-dependence.

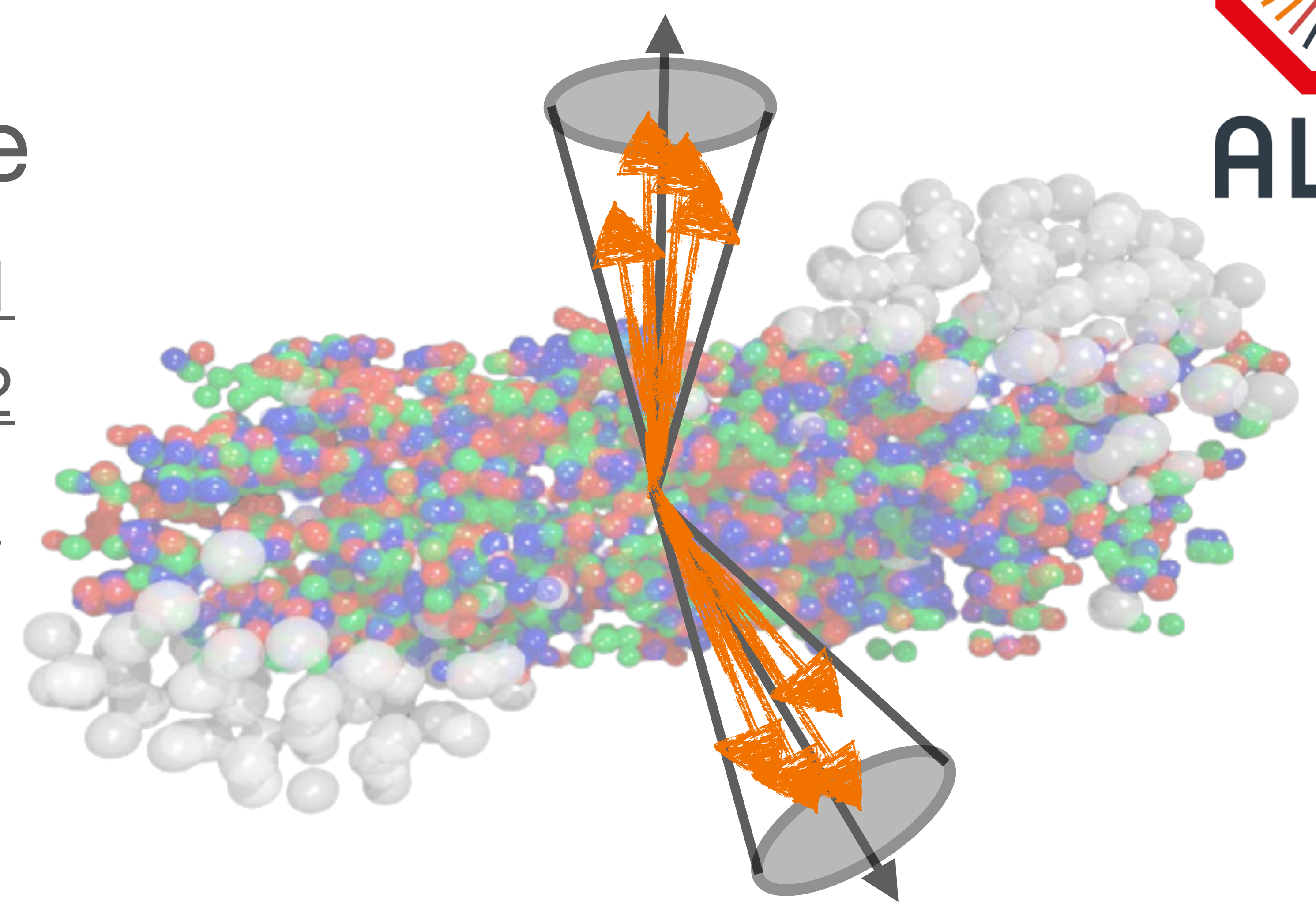
Hardest $k_{\mathrm{T,g}}$ splittings

- Use jet substructure techniques to search for point-like (Moliere) scattering

D'Eramo et al. JHEP 05 (2013) 031
D'Eramo et al. JHEP 01 (2019) 172
Barata et al. JHEP 09 (2021) 153

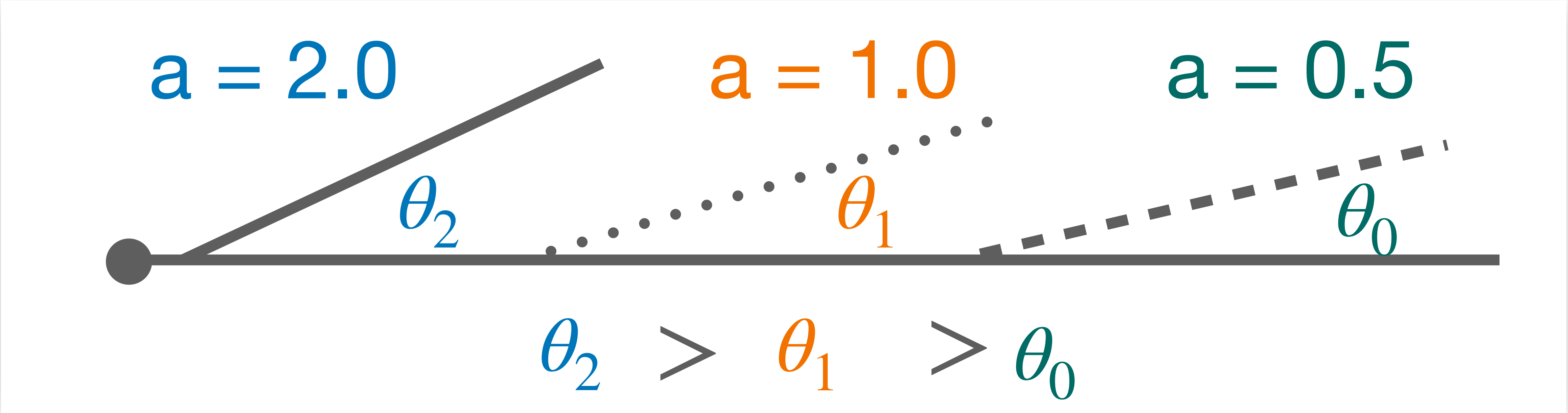


$k_{\mathrm{T}} = p_{\mathrm{T},2}\sin(\Delta R)$



- Experimentally appears as an excess of (large) k_{T} splittings in Pb—Pb collisions relative to pp collisions
- Also sensitive to substructure modification as probed by z_{g} and R_{g}.
- Use various grooming methods to identify the hardest k_{T} splitting within a jet

• Soft Drop with a z_{cut} of 0.2



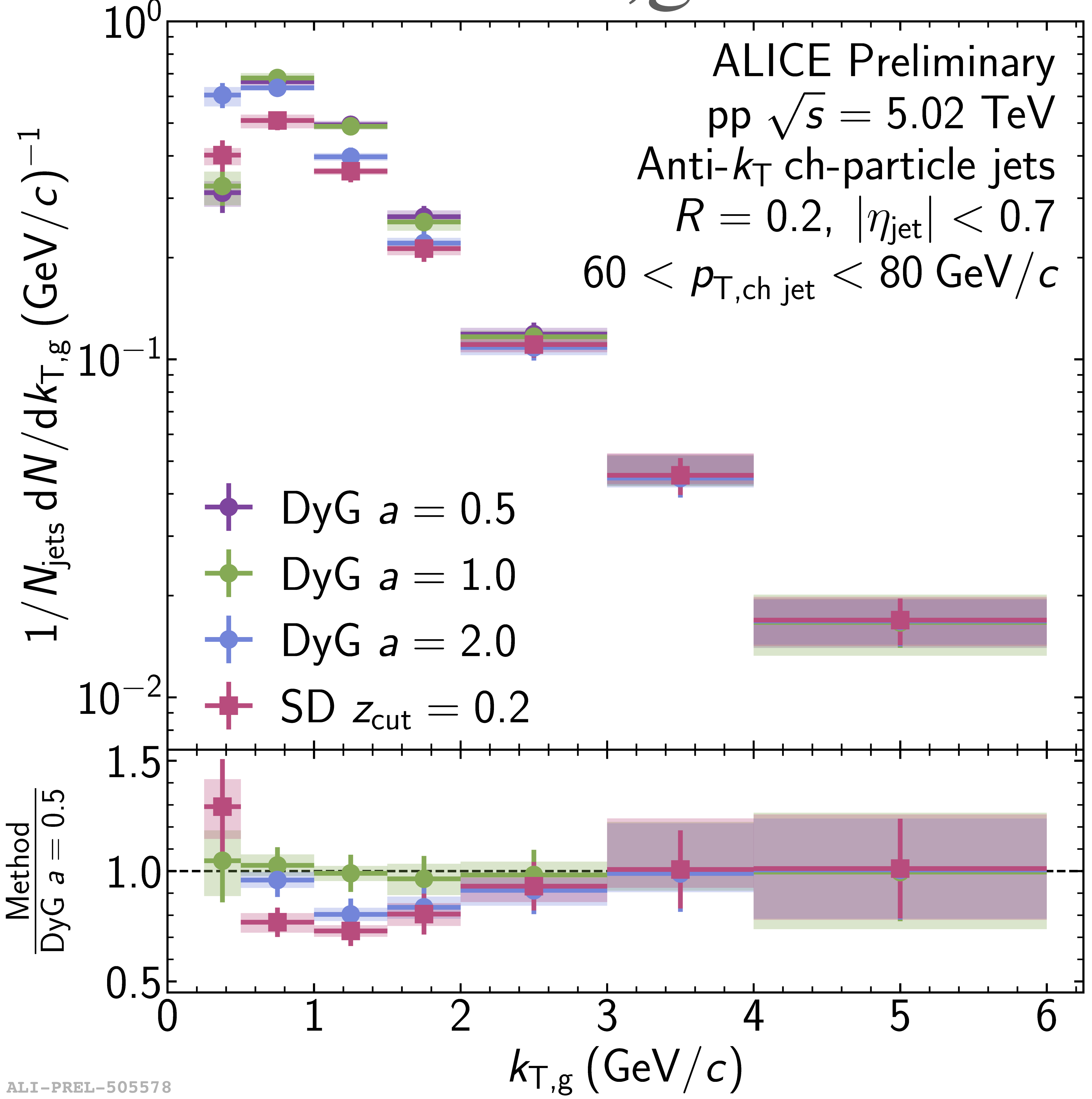
• Dynamical Grooming a = 0.5

• Dynamical Grooming a = 1.0
largest k_{T}

• Dynamical Grooming a = 2.0
shortest splitting time

Hardest $k_{T,g}$ splittings in pp

New for QM

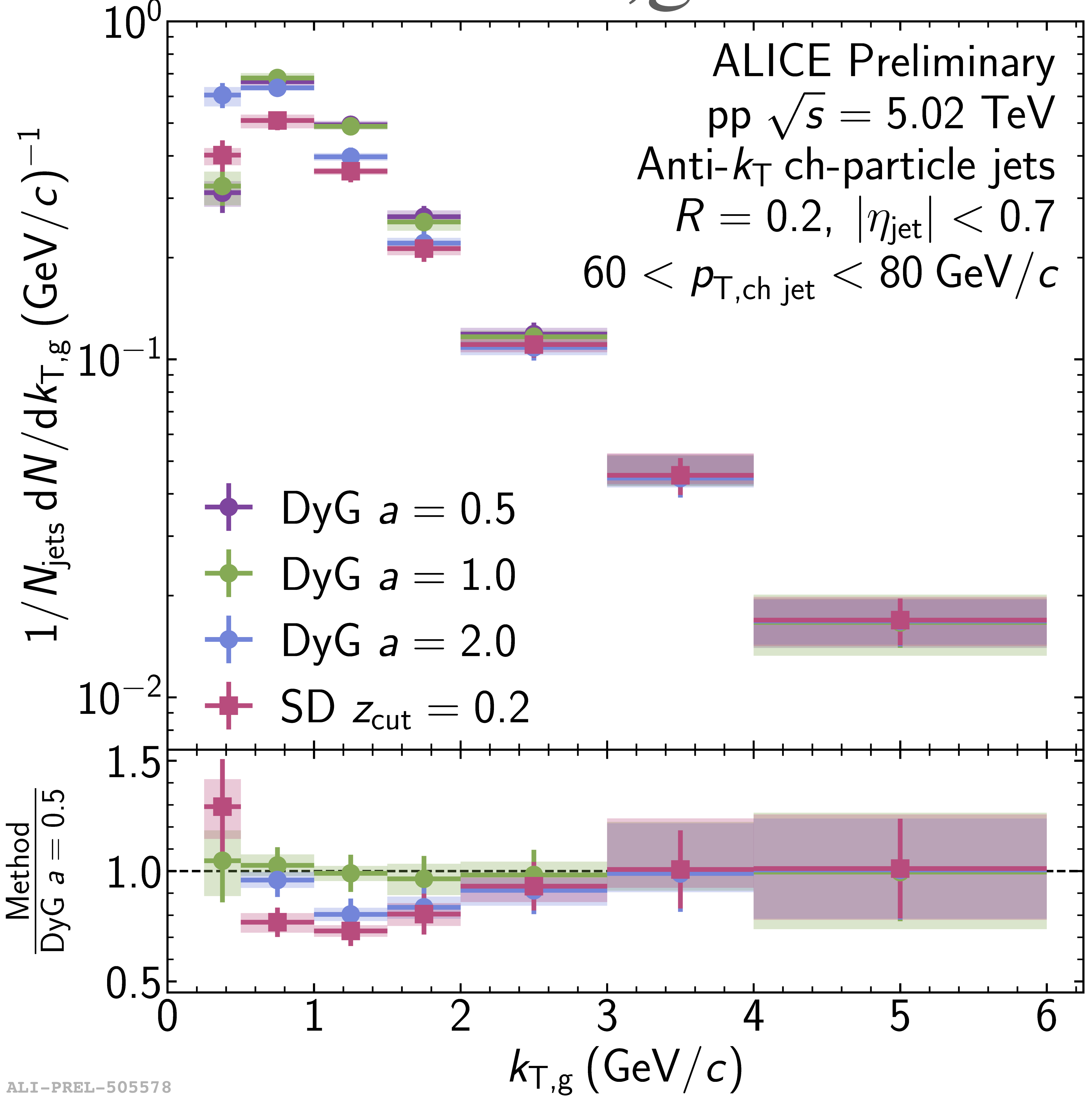


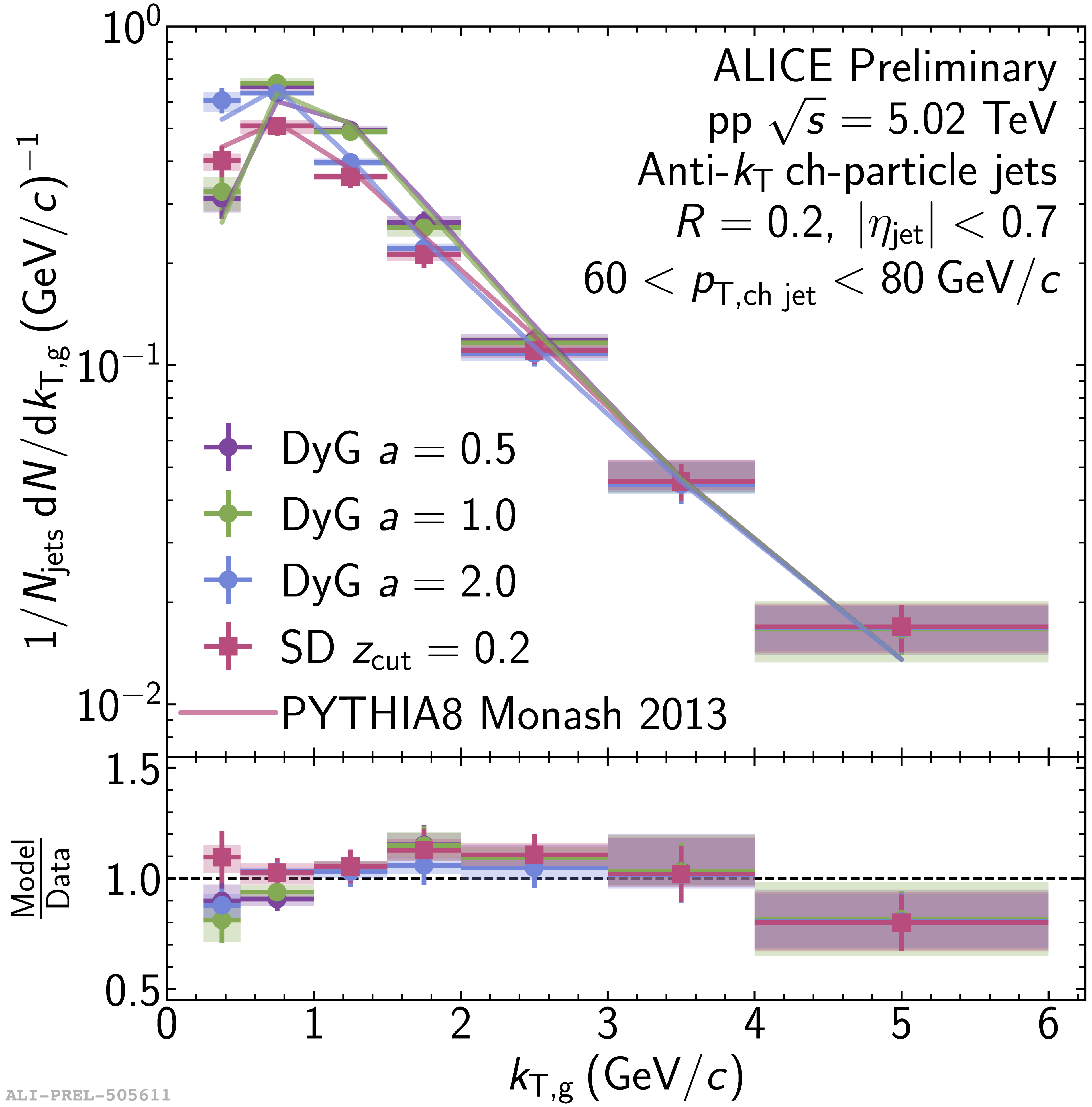
- Grooming methods converge at high $k_{T,g}$
- Some difference in grooming methods at low $k_{T,g}$

Hardest $k_{T,g}$ splittings in pp

New for QM

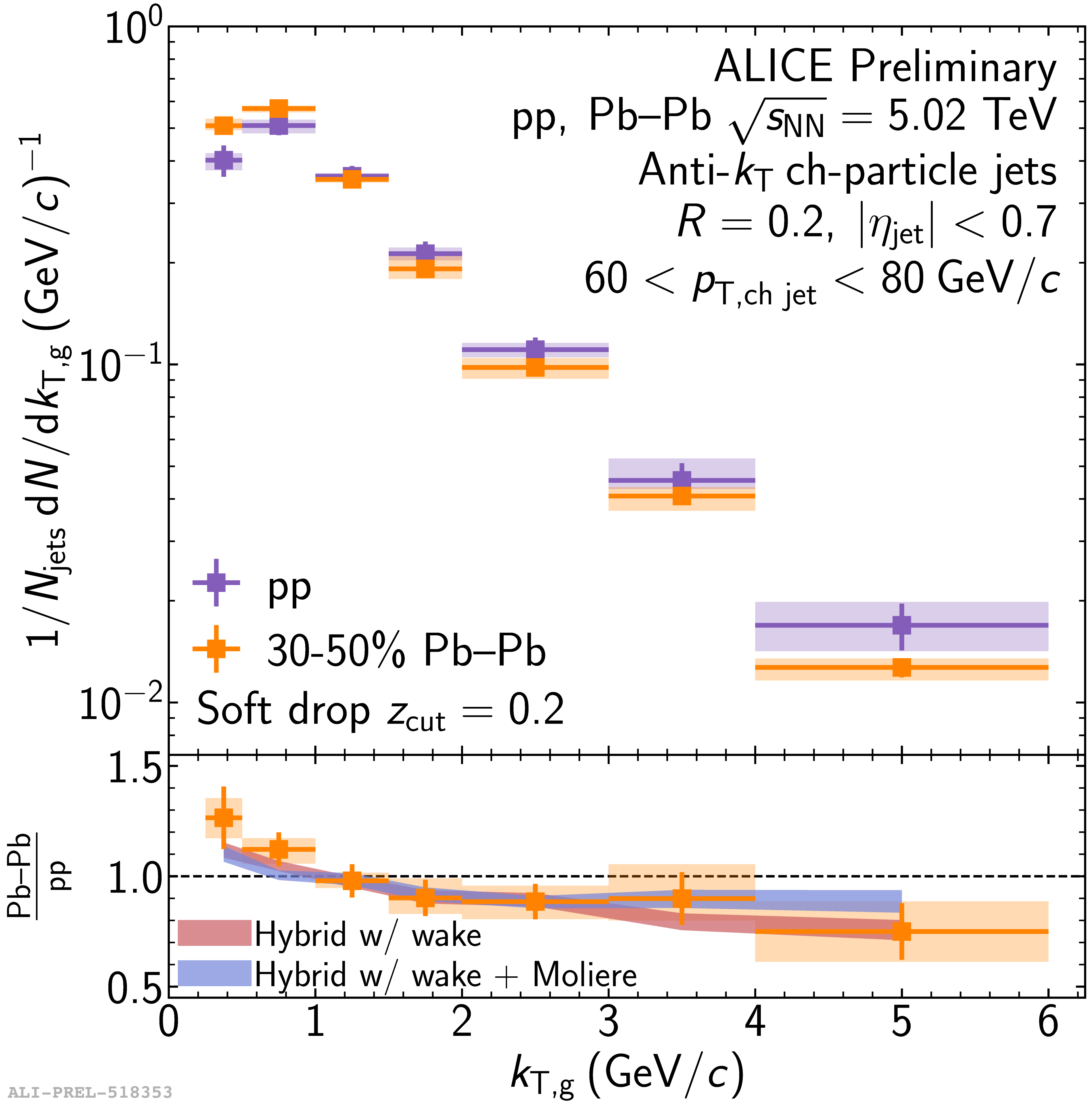
ALICE





- All grooming methods in pp generally agree with PYTHIA 8 within uncertainties
- Grooming methods converge at high $k_{T,g}$
- Some difference in grooming methods at low $k_{T,g}$

Hardest $k_{T,g}$ splittings in 30-50% Pb—Pb



New for QM

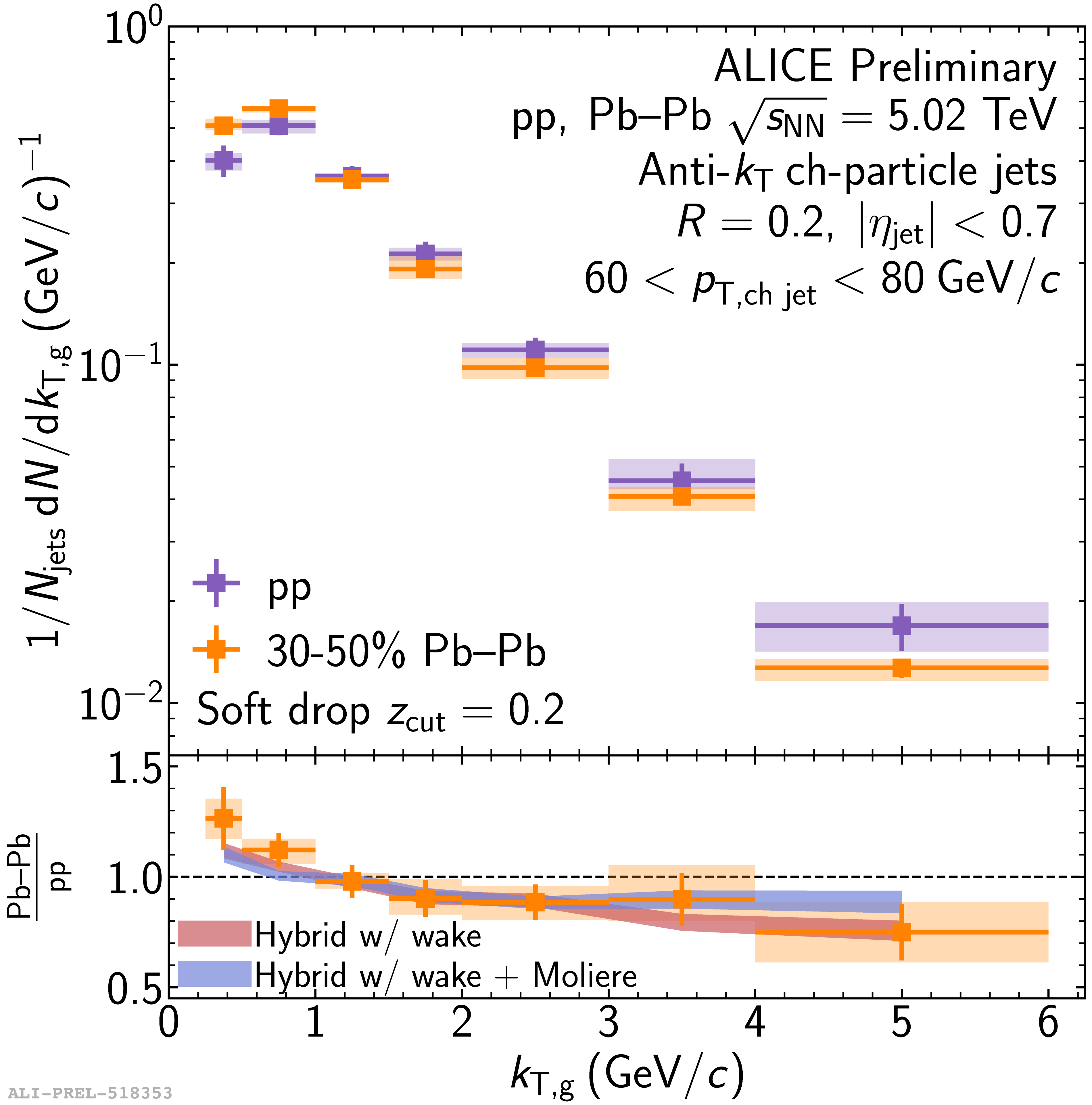
→ Consistent with no modification at high $k_{T,g}$.

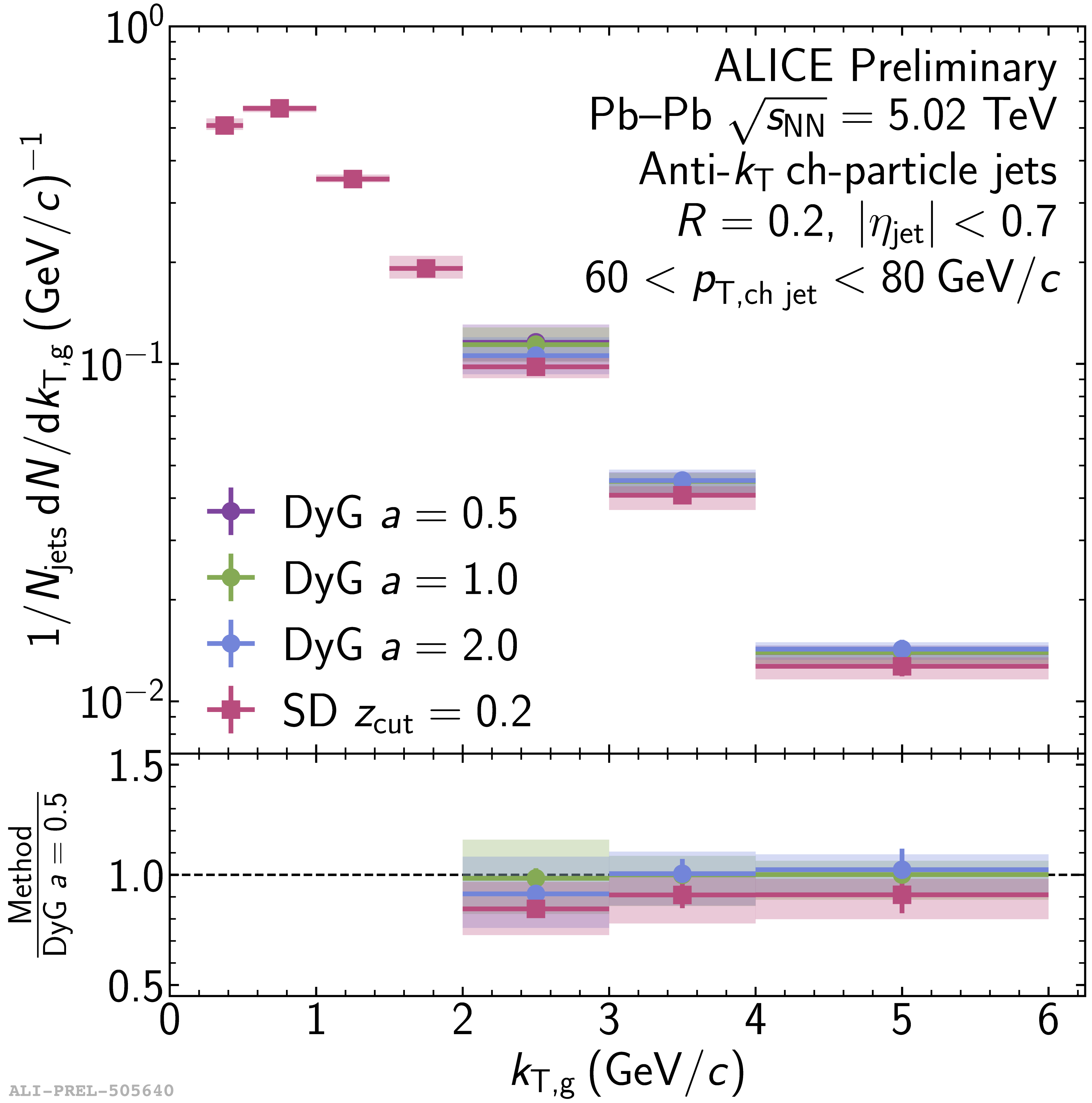
→ Hint of modification at low $k_{T,g}$ for Soft Drop, consistent with models.

See talk by Zach Hulcher JHEP 01 (2019) 172

Hardest $k_{T,g}$ splittings in 30-50% Pb—Pb

New for QM





→ Soft Drop and dynamical grooming consistent in Pb—Pb within uncertainties.

→ Consistent with no modification at high $k_{T,g}$.

→ Hint of modification at low $k_{T,g}$ for Soft Drop, consistent with models.

See talk by Zach Hulcher JHEP 01 (2019) 172

Conclusions

ALICE

- Hint of larger *R* jets being more suppressed via the R_{AA}.

- Suppression of wide-angle splittings via R_g.

- Hint of the modification of the $k_{\mathrm{T,g}}$ distribution for Soft Drop groomed splittings.

- Consistent with narrowing of jet distribution at a fixed p_{T}.

See talks by James Mulligan and Rey Cruz-Torres (next!) for other hints of narrowing.

ALICE Jet Results at QM

	Longitudinal: energy loss, path length dependence	Transverse: wide vs. narrow, quark/ gluon, intrajet broadening	Jet Deflection	Mass/Flavor Dependence	Jet Grooming	Non-Perturbative Effects	Small Systems
Isolated photon-jet correlations: Alwina Liu Tues. 16:30	ALICE		ALICE				
Path length dependence in Pb--Pb and p—Pb collisions: Caitie Beattie Wed. 8:40	ALICE						ALICE
Jet angularity and fragmentation in Pb-Pb: James Mulligan Wed. 10:00	ALICE	ALICE			ALICE	ALICE	
Search for jet quenching in high-multiplicity pp collisions: Filip Krizek Wed. 12:50			ALICE				ALICE
Heavy-flavor jets from small to large systems: Marianna Mazzilli Wed. 14:40	ALICE	ALICE		ALICE		ALICE	ALICE
R-dependence of jet suppression and groomed jet splittings in Pb--Pb: Hannah Bossi Thurs. 18:10	ALICE	ALICE	ALICE		ALICE		
Jet acoplanarity and energy flow within jets in Pb—Pb and pp: Rey Cruz-Torres Thurs. 18:30	ALICE	ALICE	ALICE		ALICE	ALICE	

Thanks!

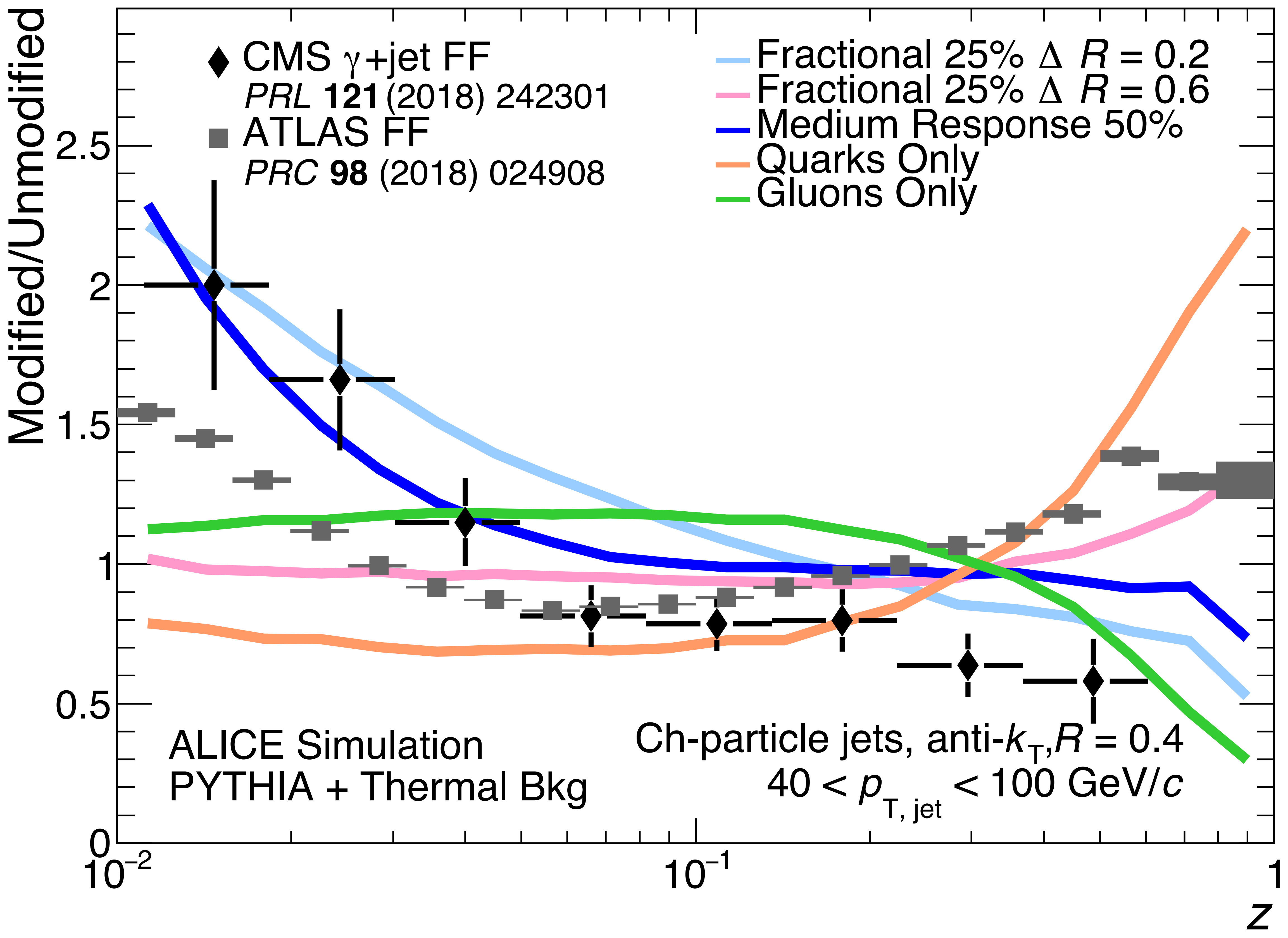
Backup

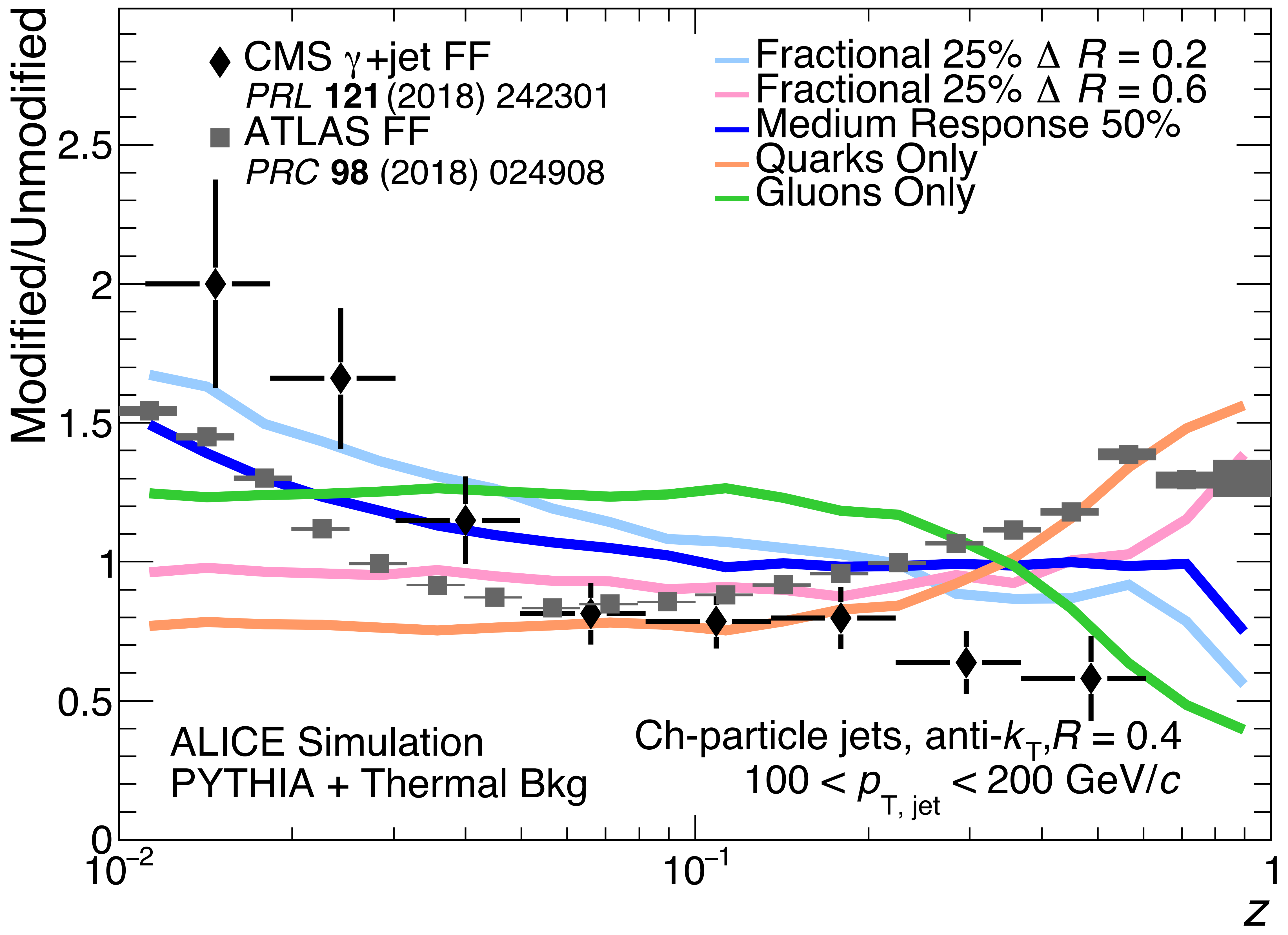
Fragmentation toy modifications

We also study a toy model with three different ways to alter constituents of the jet, changing the fragmentation to generate a different training set.

Also use this varied fragmentation to fill the response - use systematic to check the whole procedure! In the ratio these systematic (along with tracking) are largest.

Fragmentation toy modifications



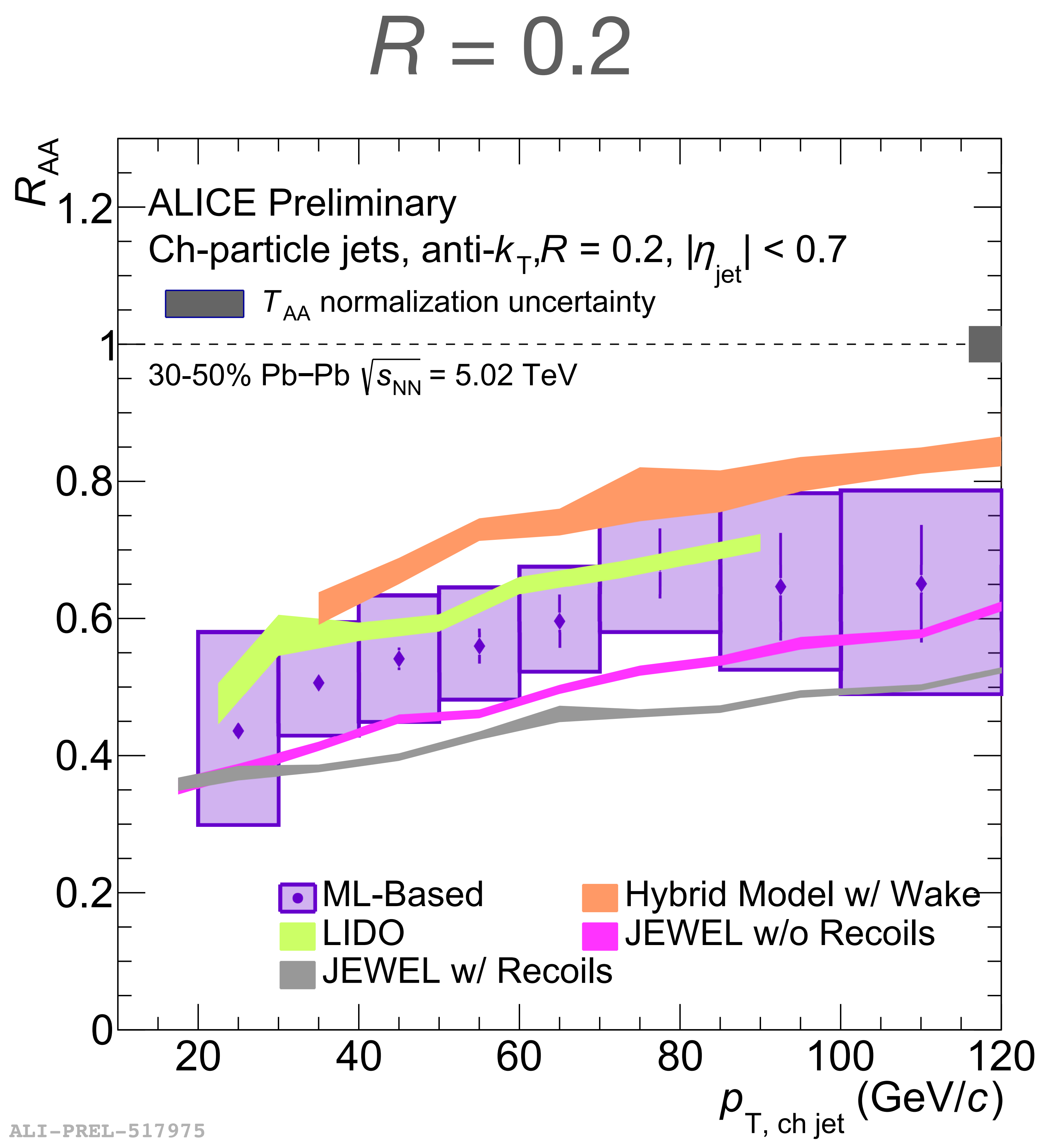


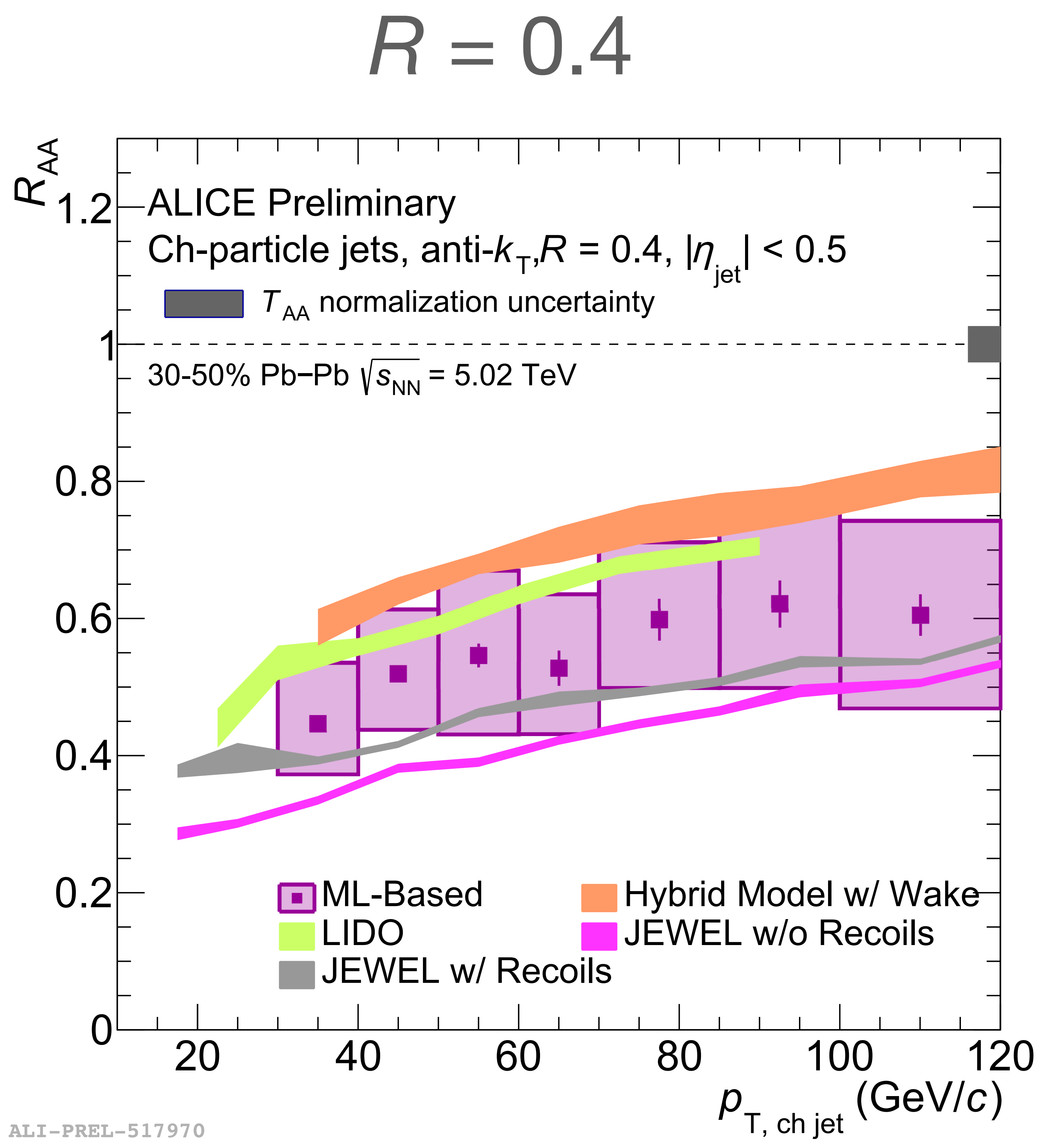
- Our fragmentation variations qualitatively cover the data in different regions of phase space.
- Toy model parameters motivated by experimental data: JHEP 05 (2018) 006

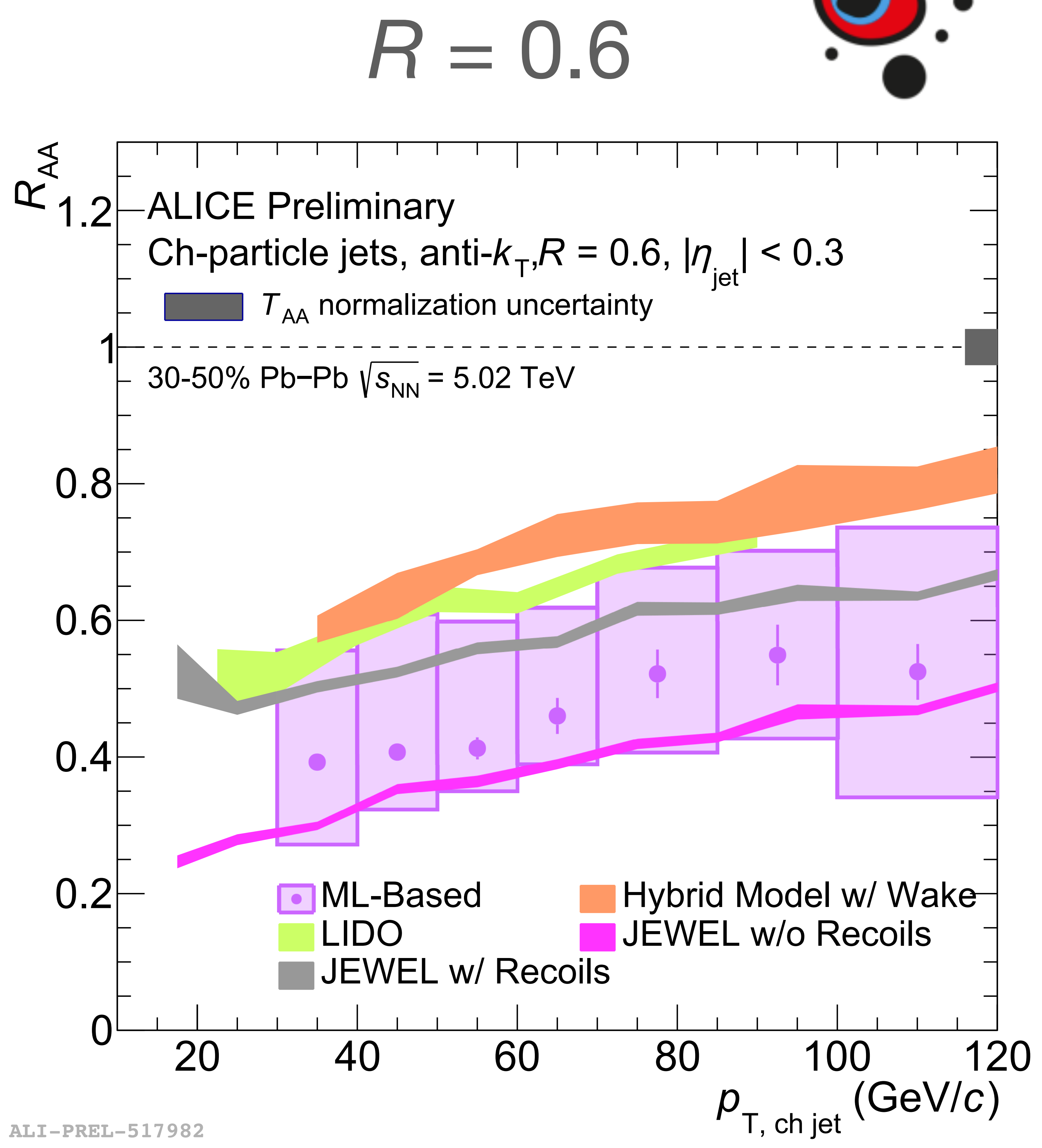
Nuclear modification factors (30-50%)

New for QM

ALICE

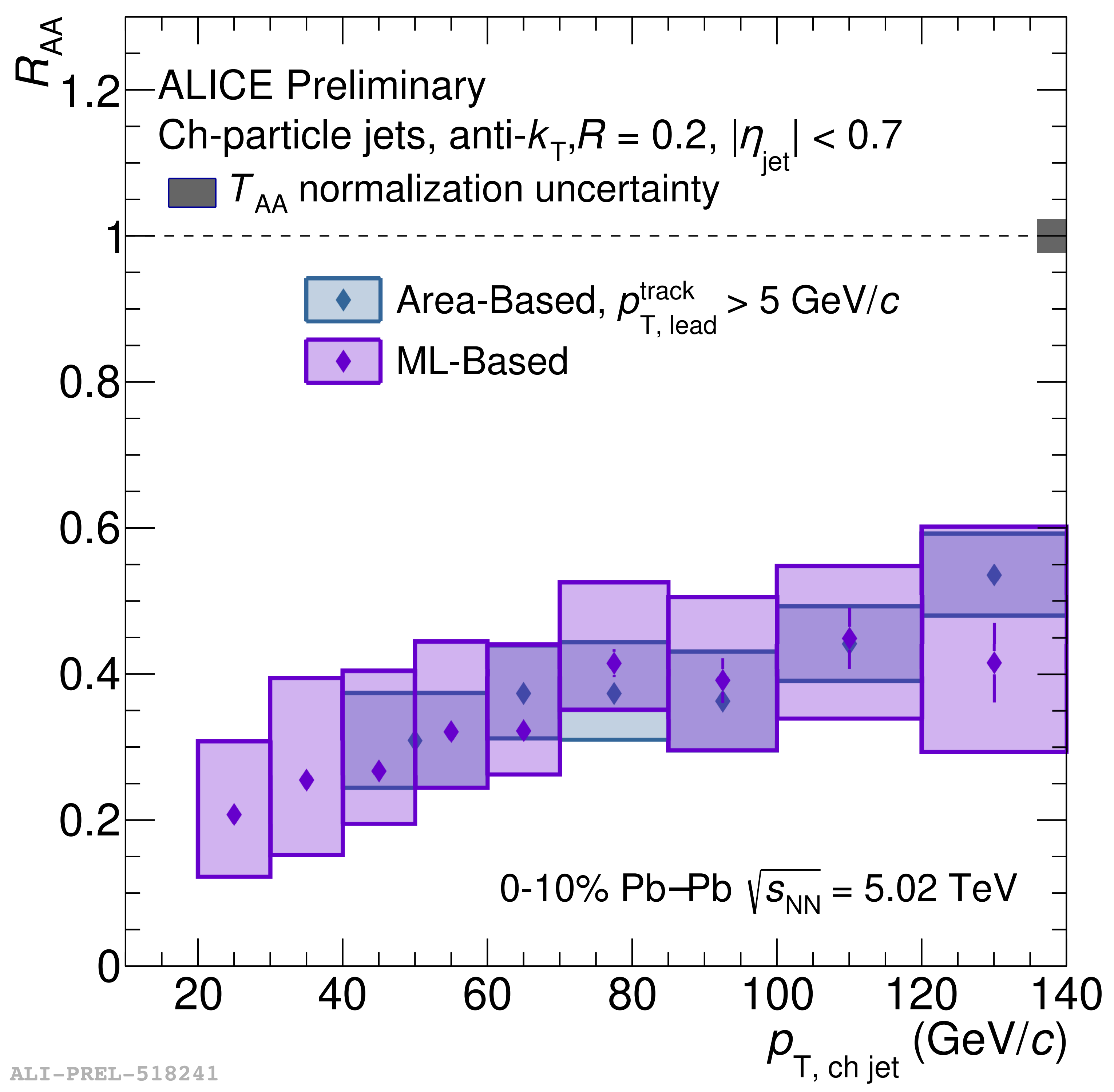




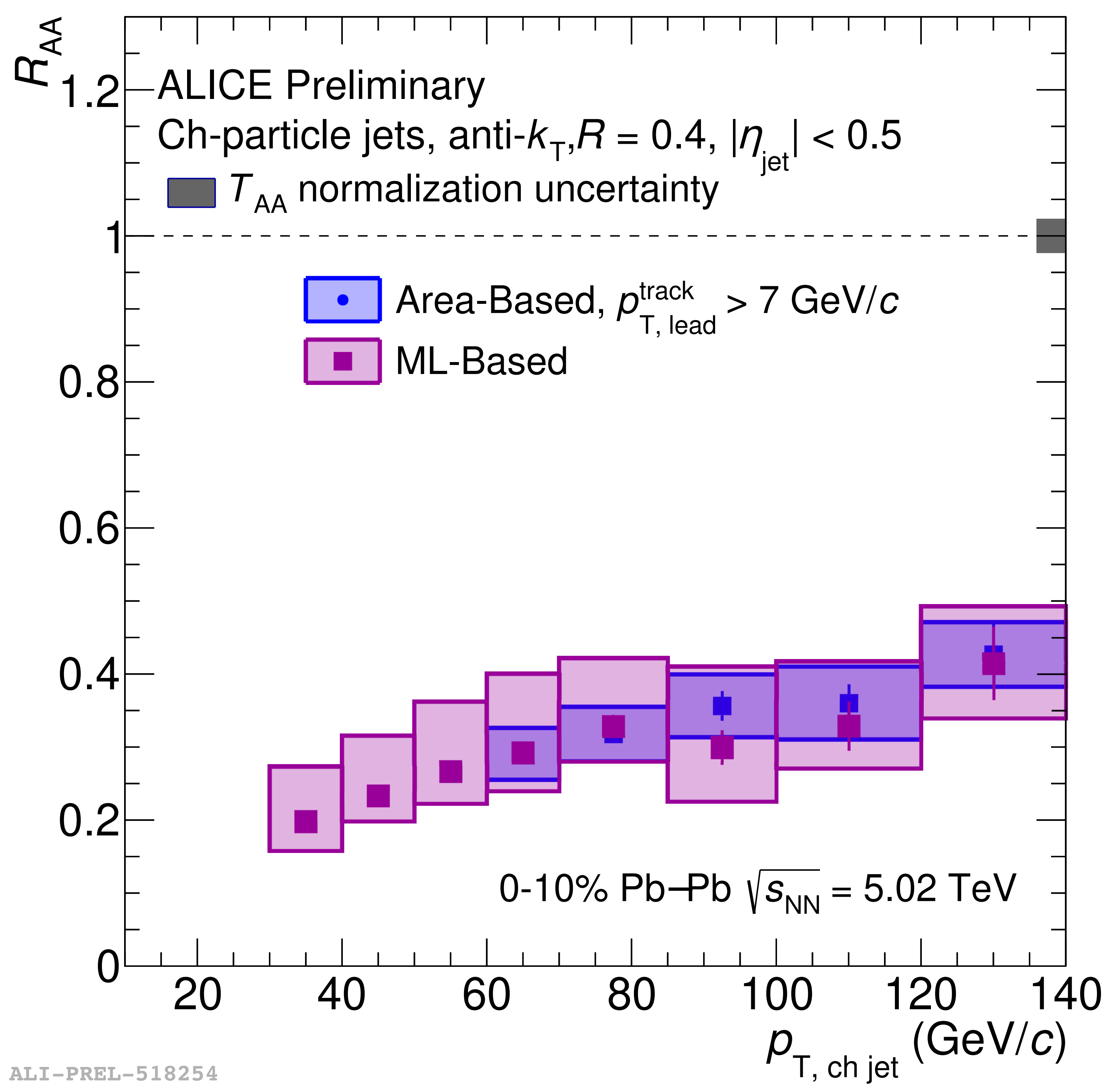


Area-based comparisons (0-10%)

R = 0.2



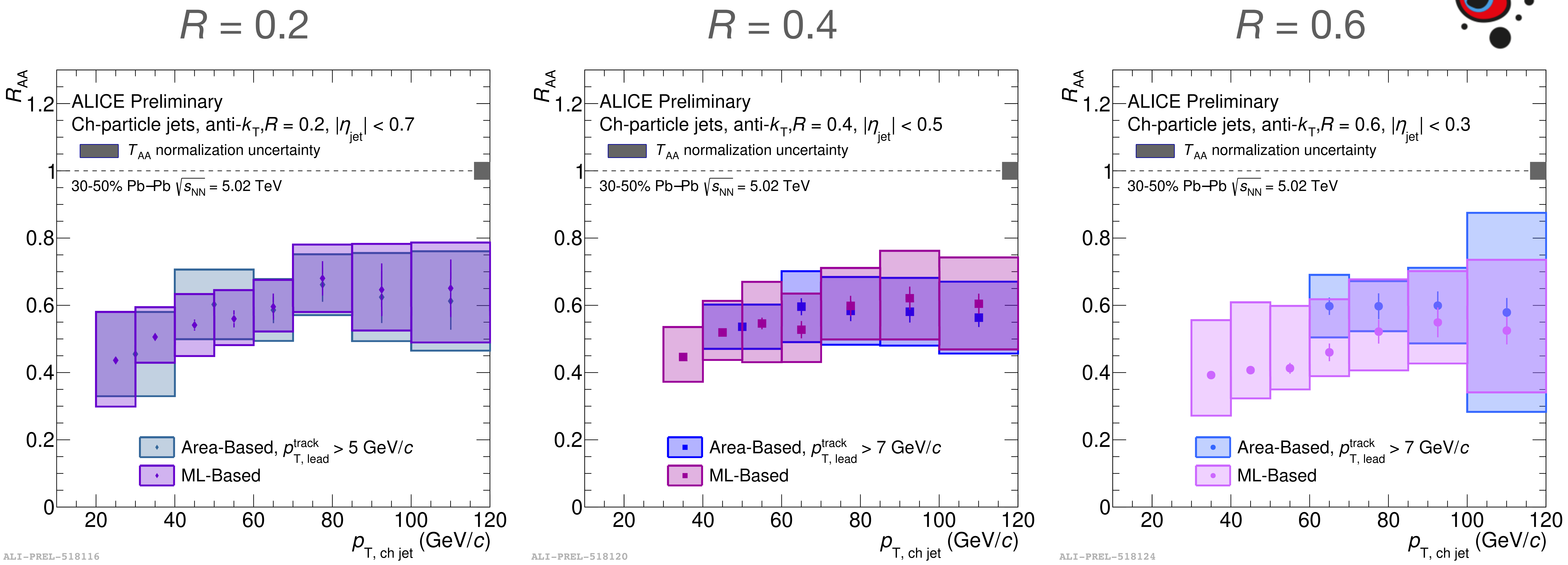
R = 0.4



No area-based comparison for R = 0.6 (not possible in this region of phase space).

Area-based comparisons (30-50%)

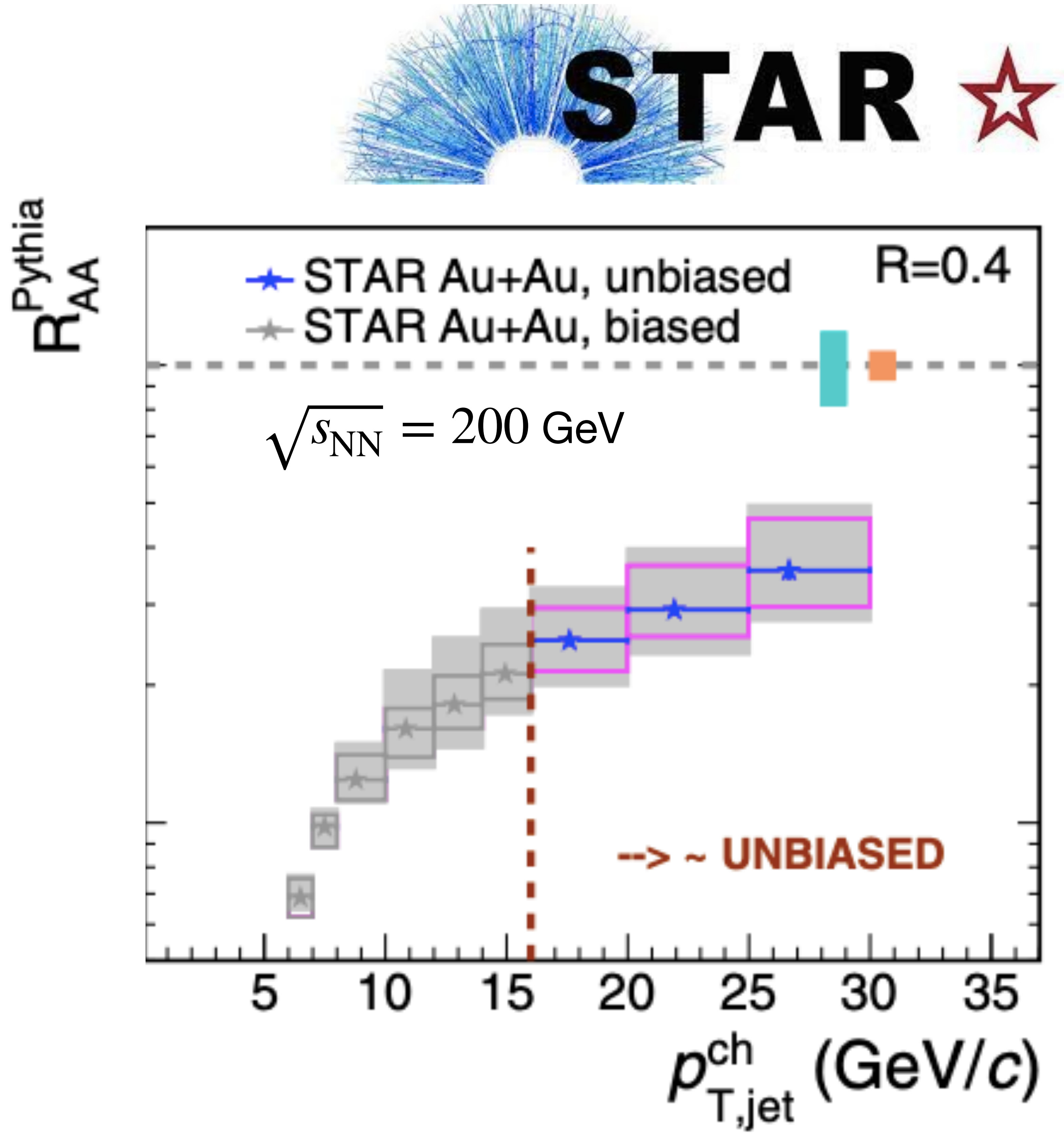
New for QM



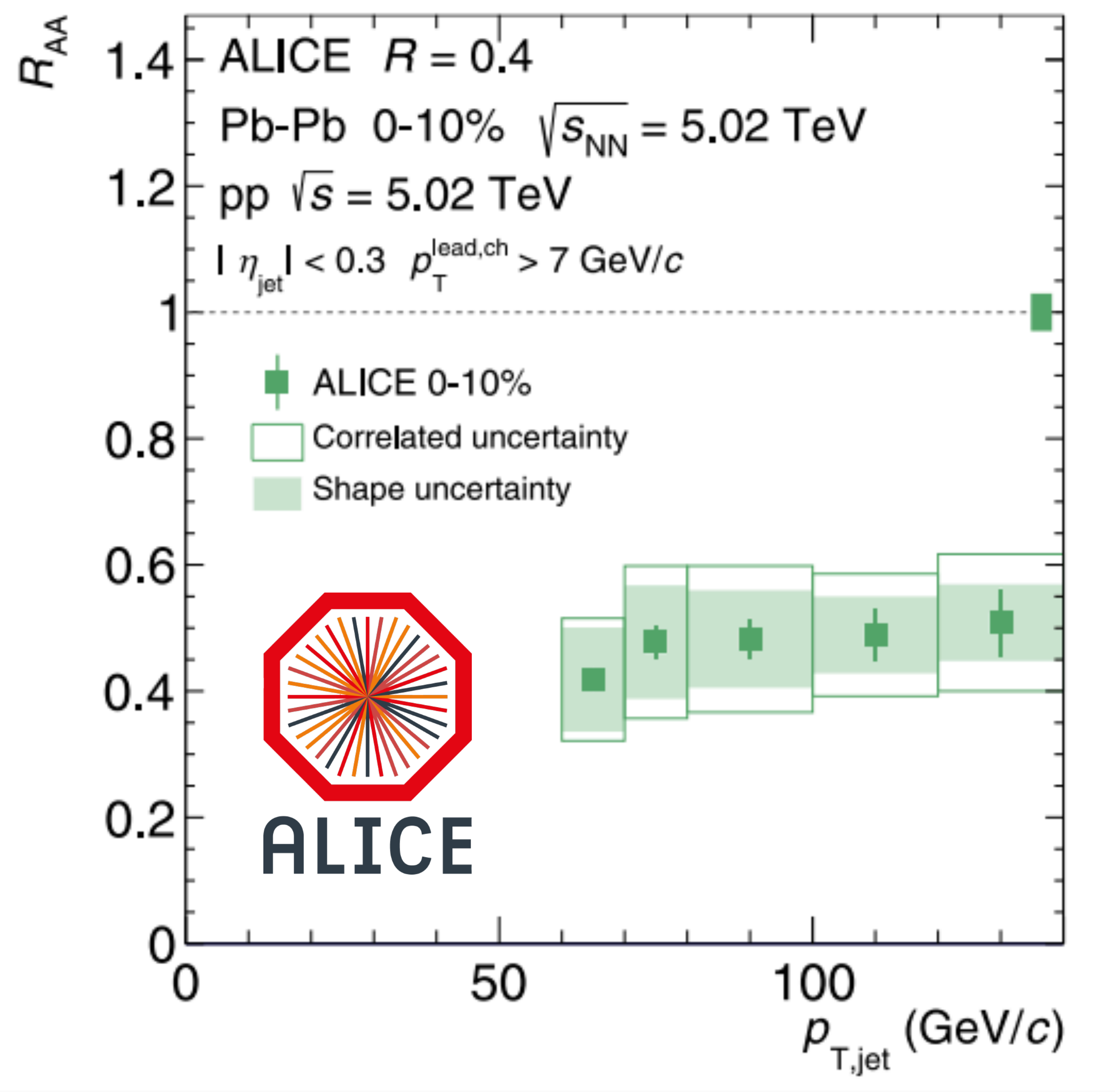
Experimental Measurements of the R_{AA}

Clear evidence of suppression at many different p_T scales!

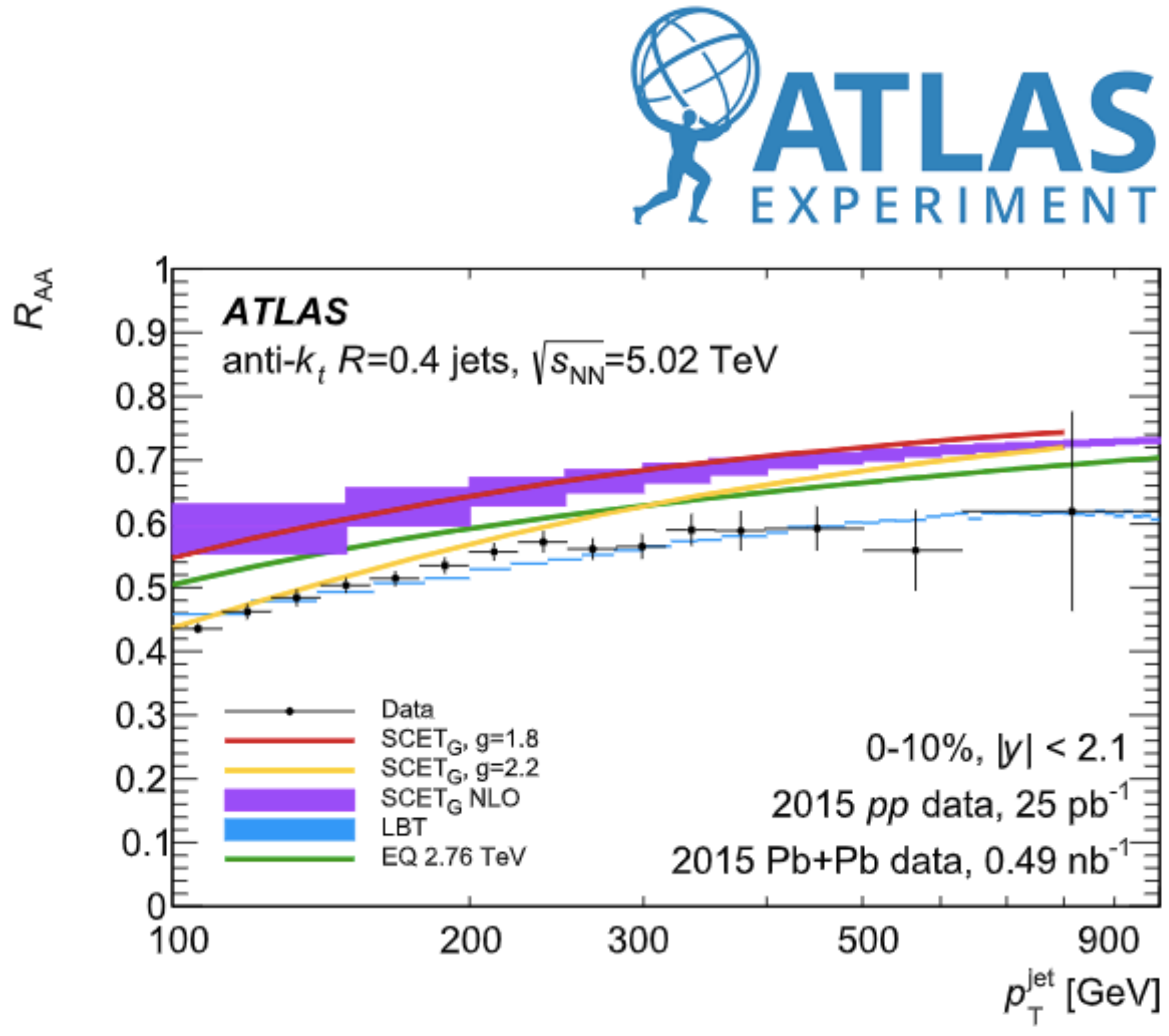
→ Extending ALICE measurements to lower p_T can bridge the gap!



Phys. Rev. C. 102, 054913



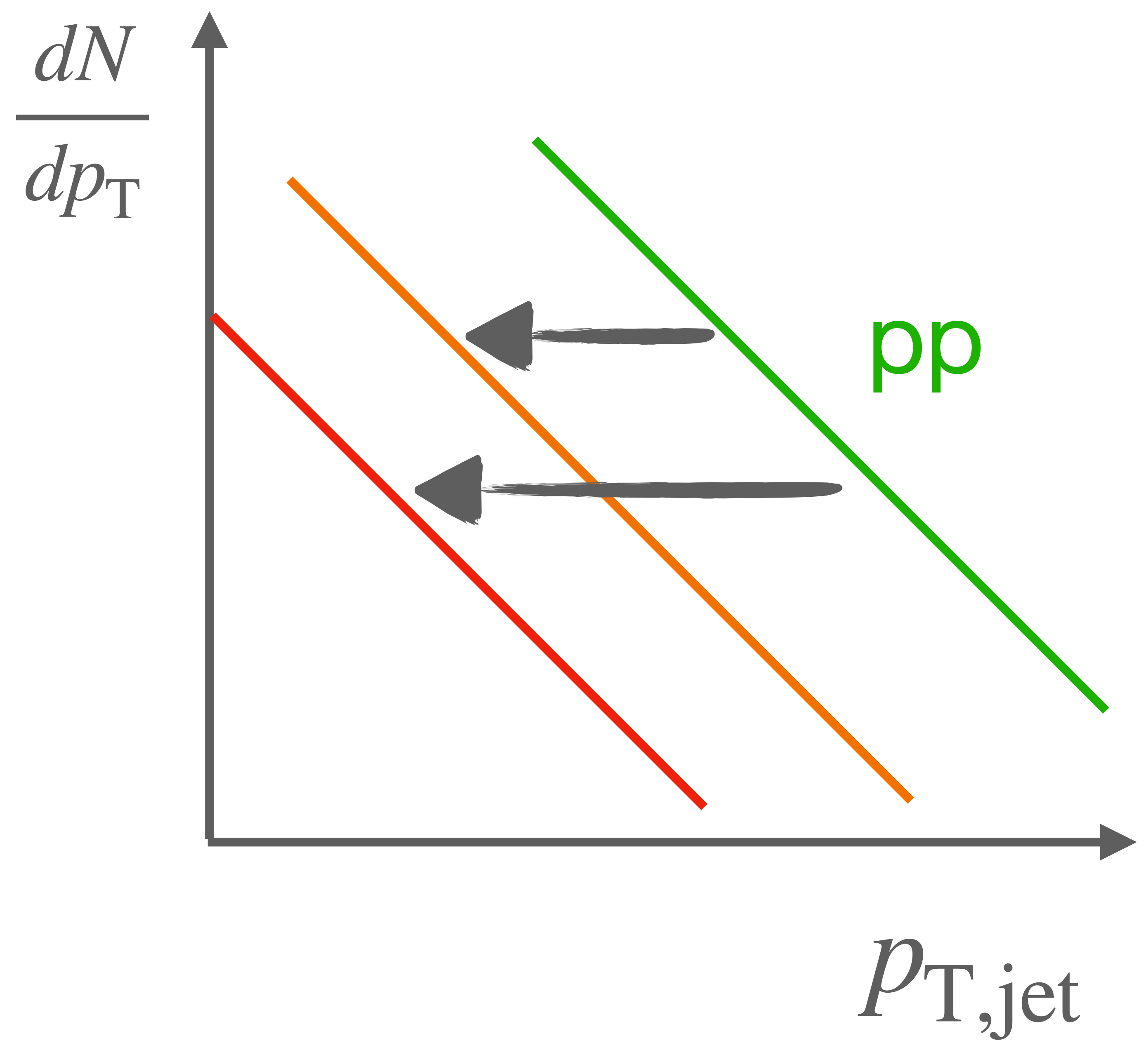
Phys. Rev. C 101, 034911



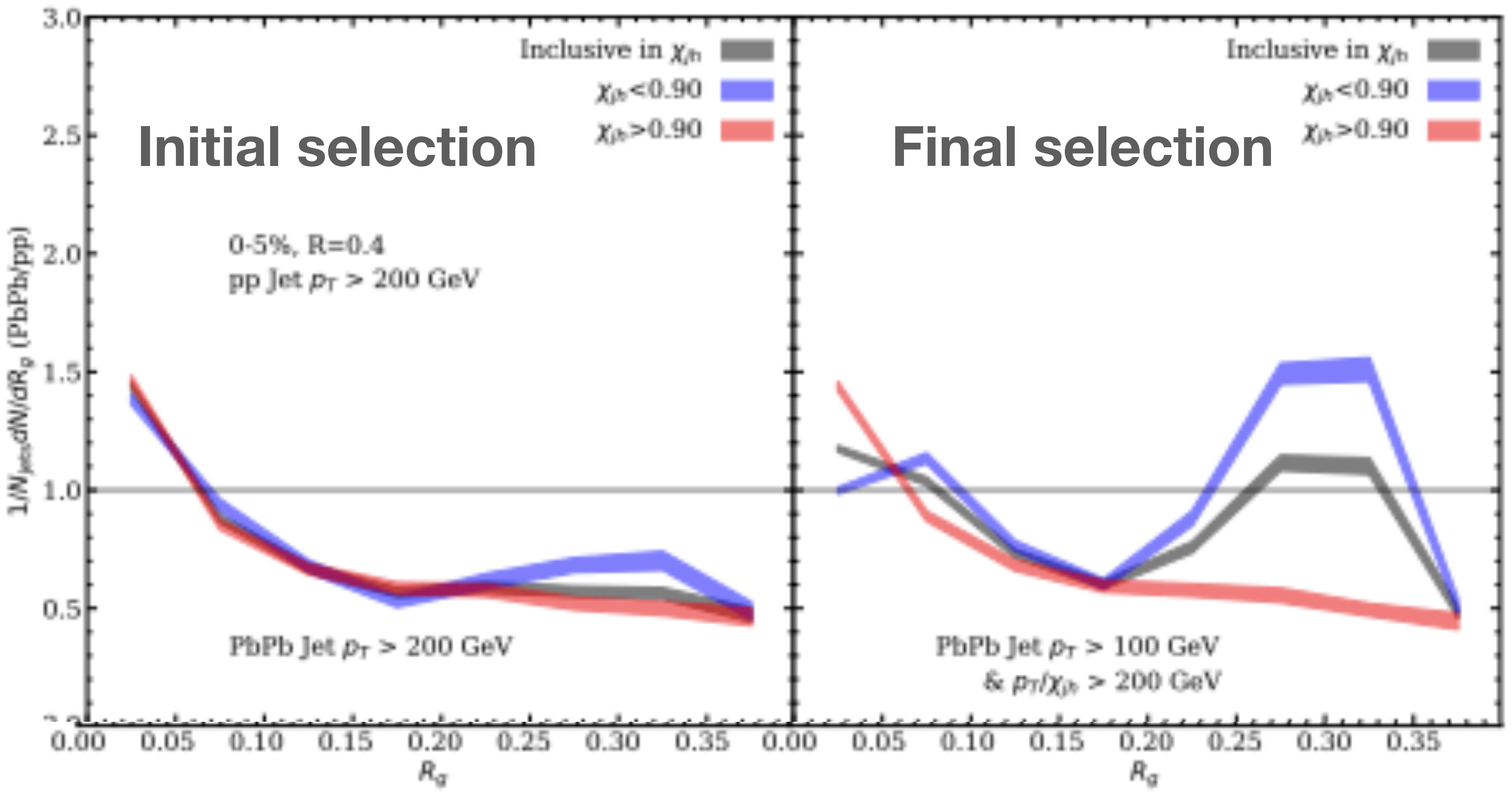
Phys. Lett. B 790 (2019) 108

Selection bias

[Brewer et. al: Phys. Rev. Lett.122.222301](#)



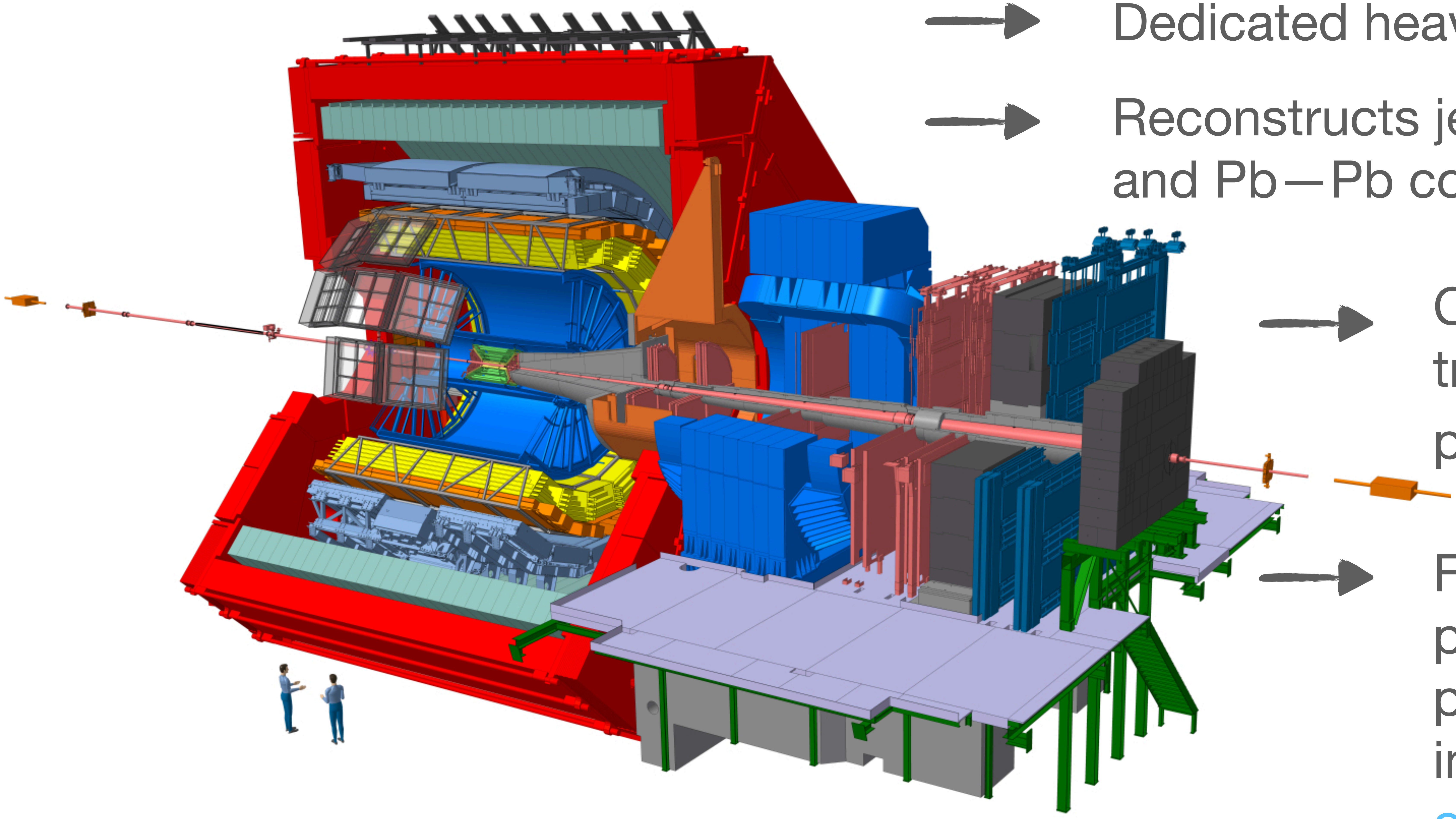
→ If some populations lose more energy than others, we will see a suppression purely from the selection bias by measuring modified jets at a fixed p_T.



→ Changing selection removes narrowing for more quenched jets.

JHEP. 2021, 206 (2021)

The ALICE Detector

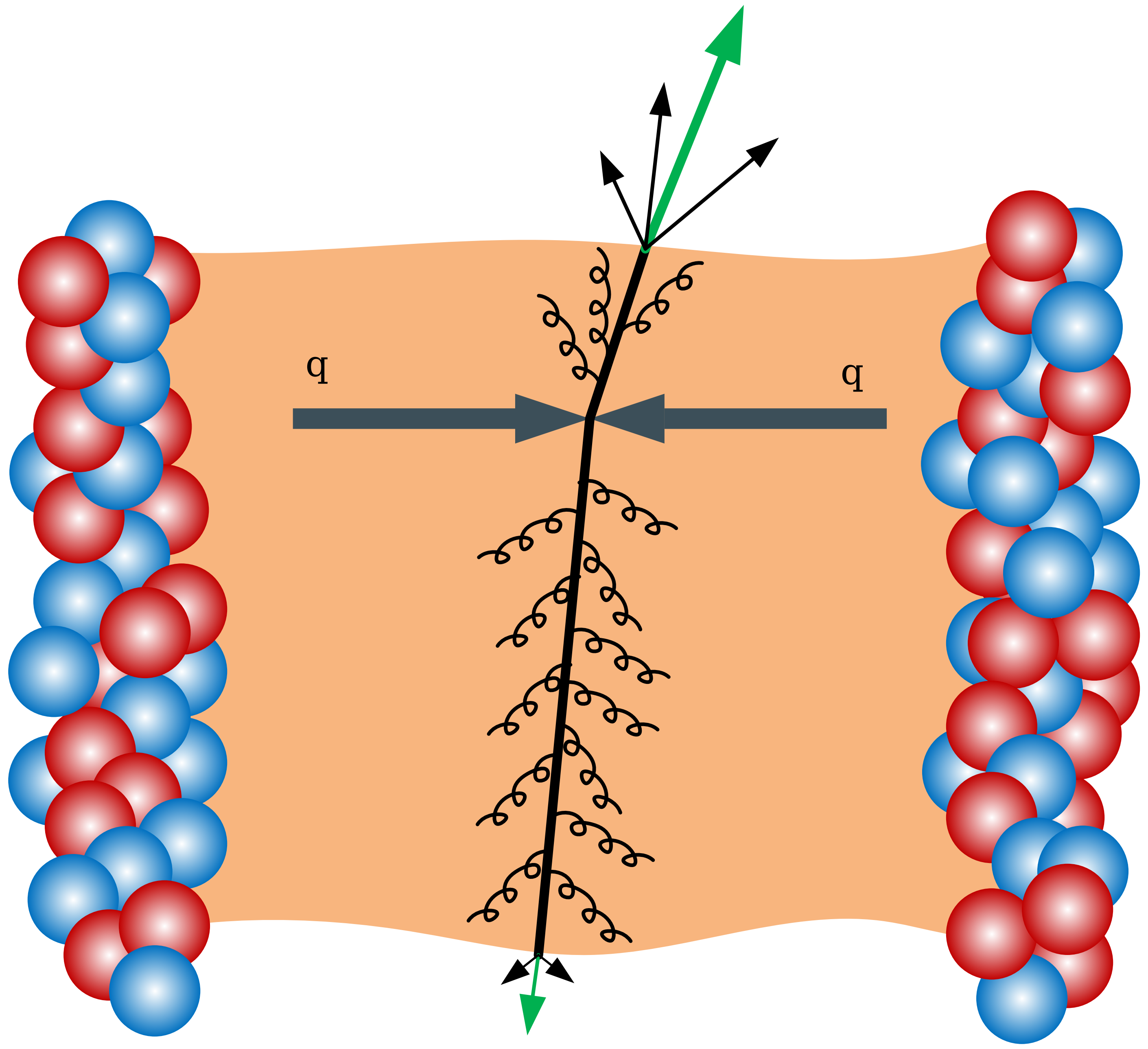


- Dedicated heavy-ion experiment at the LHC.
- Reconstructs jets at mid-rapidity in pp, p-Pb and Pb—Pb collisions.
- Can utilize high precision tracker to measure charged-particle jets up to high p_{T}.
- Full jets combine charged particle information with neutral particle information measured in the electromagnetic calorimeter.

ALICE is great for jet measurements, especially measurements of jet substructure!

ML background estimator

Use machine learning (ML) to correct the jet for the large uncorrelated background in heavy-ion collisions!



Conventional approach: Apply a minimum p_{T} requirement on the leading track of the jet, correct the jet for the background with a pedestal subtraction.

ML approach: Use ML to construct the mapping between measured and corrected jet without a leading track bias.

Jet Properties

(Including constituent properties)

→ **ML** →

Corrected Jet p_{T}

→

Unfold for fluctuations and detector effects

R.Haake, C. Loizides Phys. Rev. C 99, 064904 (2019)