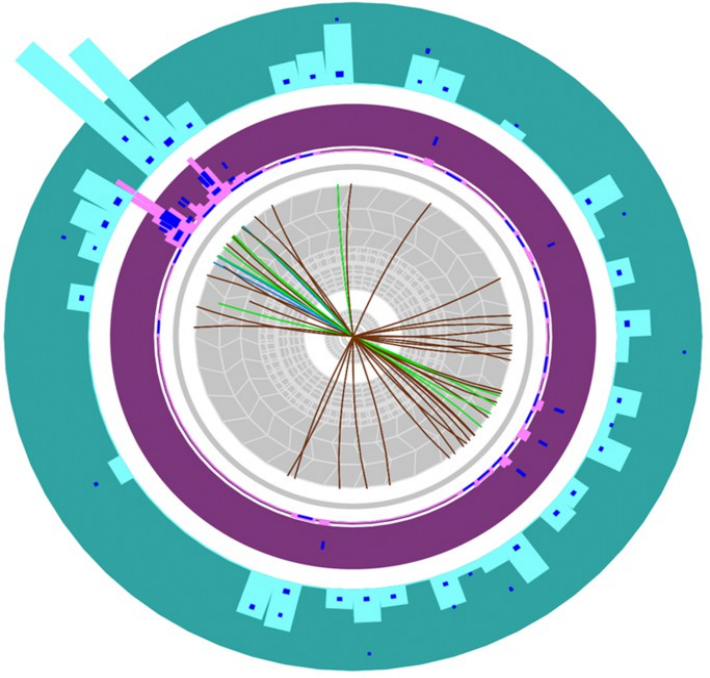
Measurements of jet fragmentation and the angular distributions of charged particles within and around jets in *pp* and Pb+Pb with ATLAS

Martin Rybar
for the ATLAS collaboration

May 16, 2018

Parton shower in QGP

- How is the parton shower modified in the deconfined medium?
  - Is the fragmentation process modified?
  - What is the role of parton flavour?
  - What is the role of jet momentum?
  - Can we see medium response to the fast partons?
  - Previous jet measurements suggest transfer energy out-of the jet cone.
  - Are these modifications described by theoretical models?



Track-to-jet correlations

- ATLAS studies of 3 colliding systems at different $\sqrt{s_{NN}}$:

  pp@5TeV & 2.76TeV *p*+Pb@5TeV Pb+Pb@5TeV & 2.76TeV

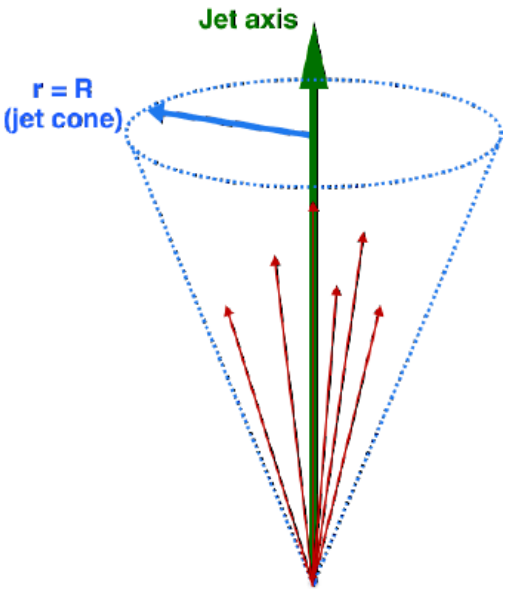
- Measurement of fragmentation functions (FF):

$$D(p_{\mathrm{T}}) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}n_{\mathrm{ch}}}{\mathrm{d}p_{\mathrm{T}}} \qquad D(z) \equiv \frac{1}{N_{\mathrm{jet}}} \frac{\mathrm{d}n_{\mathrm{ch}}}{\mathrm{d}z}$$

, where $z \equiv p_{\mathrm{T}} \cos r / p_{\mathrm{T}}^{\mathrm{jet}}$

Spectra of charged particles in jets

Fragmentation function



Track-to-jet correlations

- ATLAS measurements at 2 different energies and 3 colliding systems:

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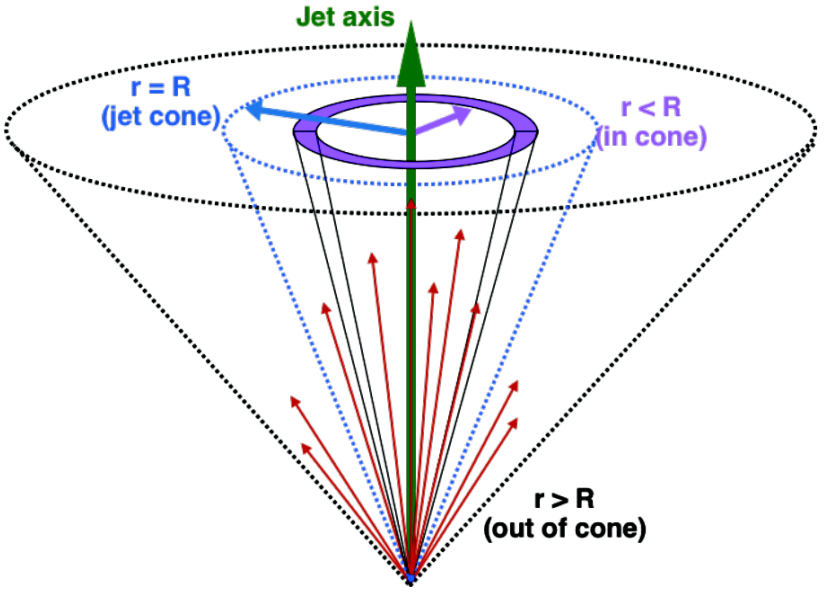
$$D(p_{\mathrm{T}}, r) = \frac{1}{N_{\mathrm{jet}}} \frac{1}{2\pi r} \frac{\mathrm{d}^2 n_{\mathrm{ch}}(r)}{\mathrm{d}r \mathrm{d}p_{\mathrm{T}}}$$

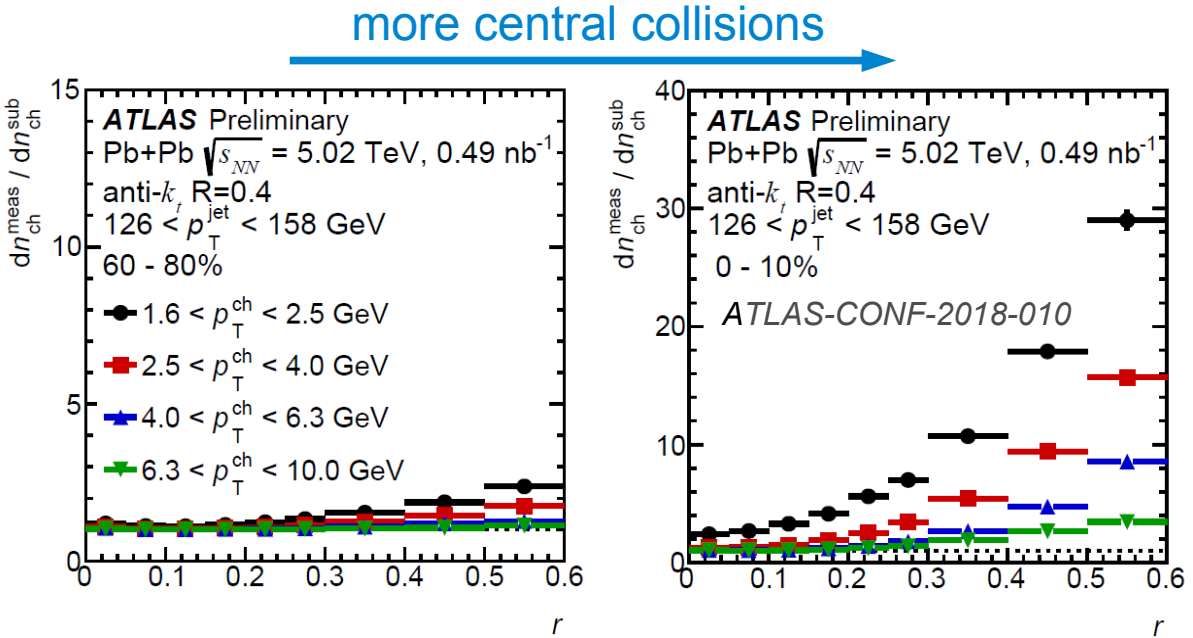
where $r < 0.6$



Aspects of measurement @ low-p_T

- Significant contribution of background from underlying event (UE).

$$\frac{\text{Signal + Background}}{\text{Signal}} :$$

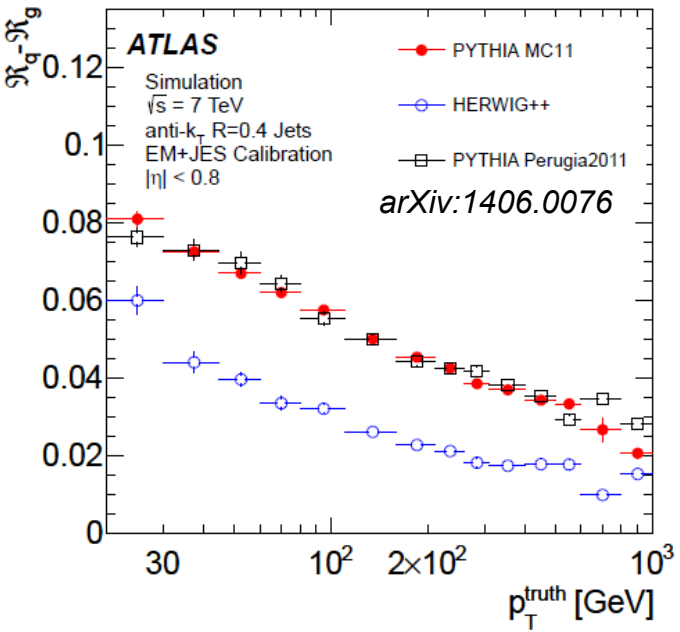


- Signal-to-background ratio decreasing with increasing centrality, increasing r, and decreasing p_T.
- Various properties of UE are taking into account in subtraction method: η-dependence, flow variation, correlation of UE and jet energy resolution.

Aspects of measurement @ high-p_T

- Jet response depends on parton flavour.
- Steeper FF when approaching the z~1.
- Worsening of track momentum resolution at high p_T.
- Difference in the jet energy resolution in *pp* and Pb+Pb at lower p_T.

Difference in response for quark and gluon jets:



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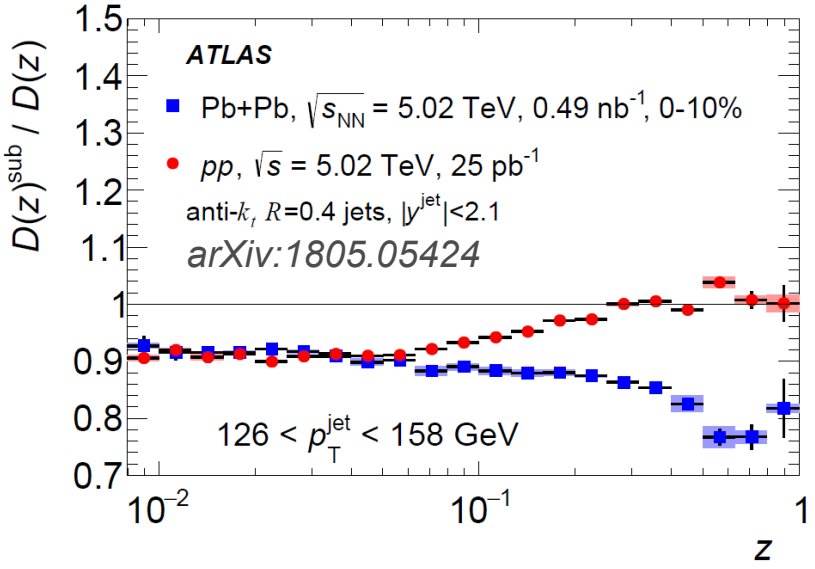
} Need for 2D unfolding

Impact of the unfolding ➡



- The $D(p_T, r)$ are further corrected for position resolution by bin-by-bin correction.

Fragmentation functions @ ATLAS

FF @ 2.76 TeV:

Pb+Pb & central-to-peripheral ratio *arXiv:1406.2979*

Pb+Pb & *pp* reference *arXiv:1702.00674*

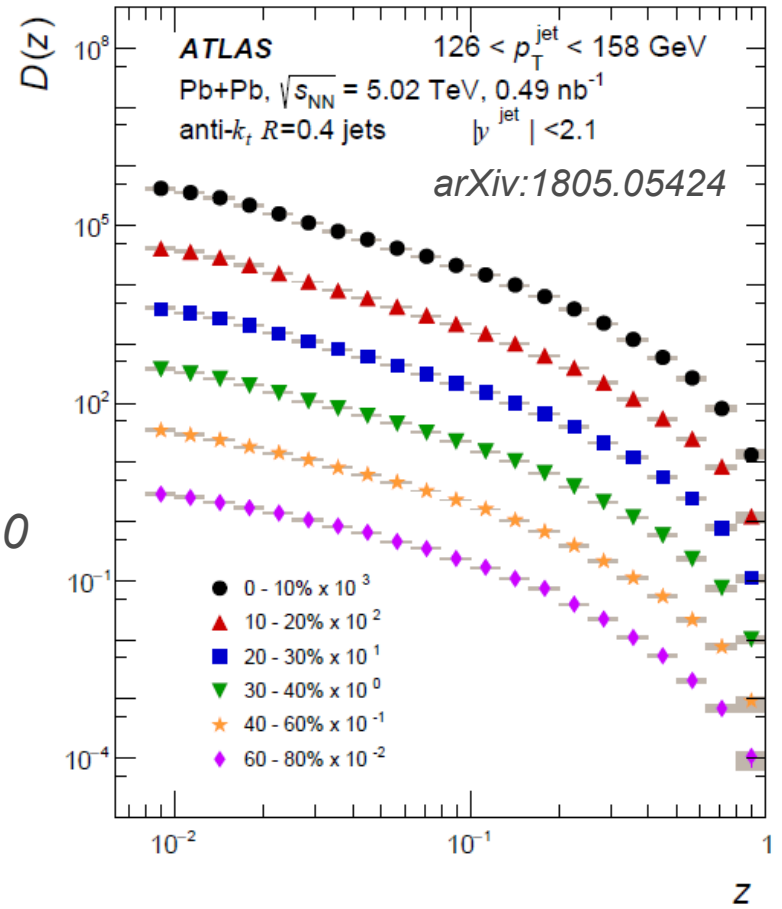
FF @ 5.02 TeV:

p+Pb & *pp* reference *arXiv:1706.02859*

Pb+Pb & *pp* reference *arXiv:1805.05424*

r-dep. in Pb+Pb & *pp* reference *ATLAS-CONF-2018-010*

γ*-tag. Pb*+Pb & *pp* reference *ATLAS-CONF-2017-074*



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p+Pb & *pp* reference *arXiv:1706.02859* **This talk**

Pb+Pb & *pp* reference *arXiv:1805.05424*

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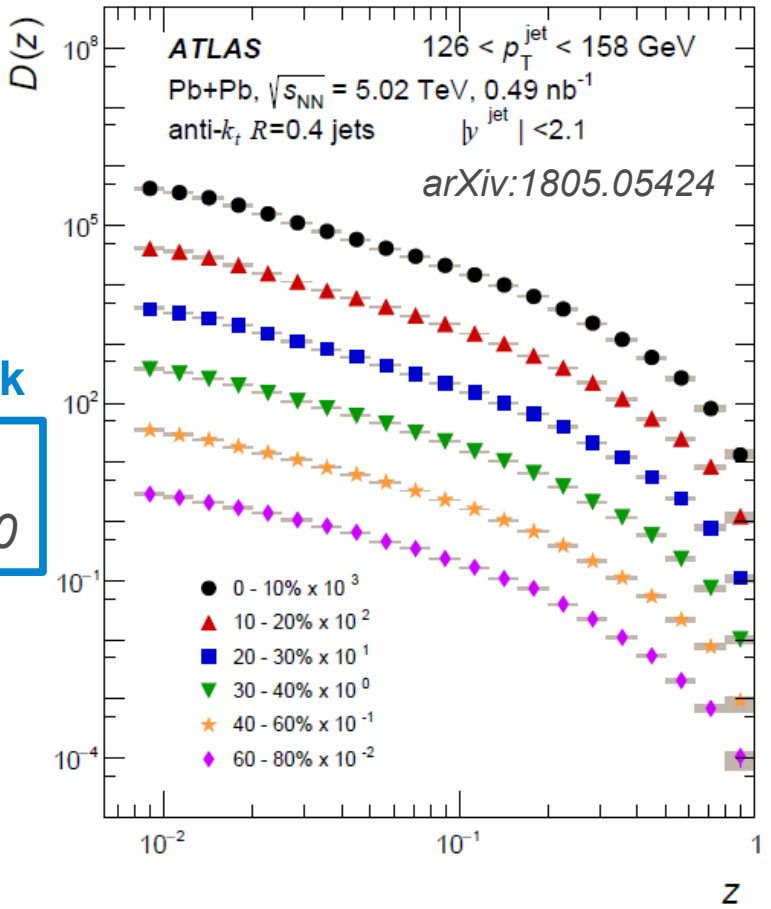
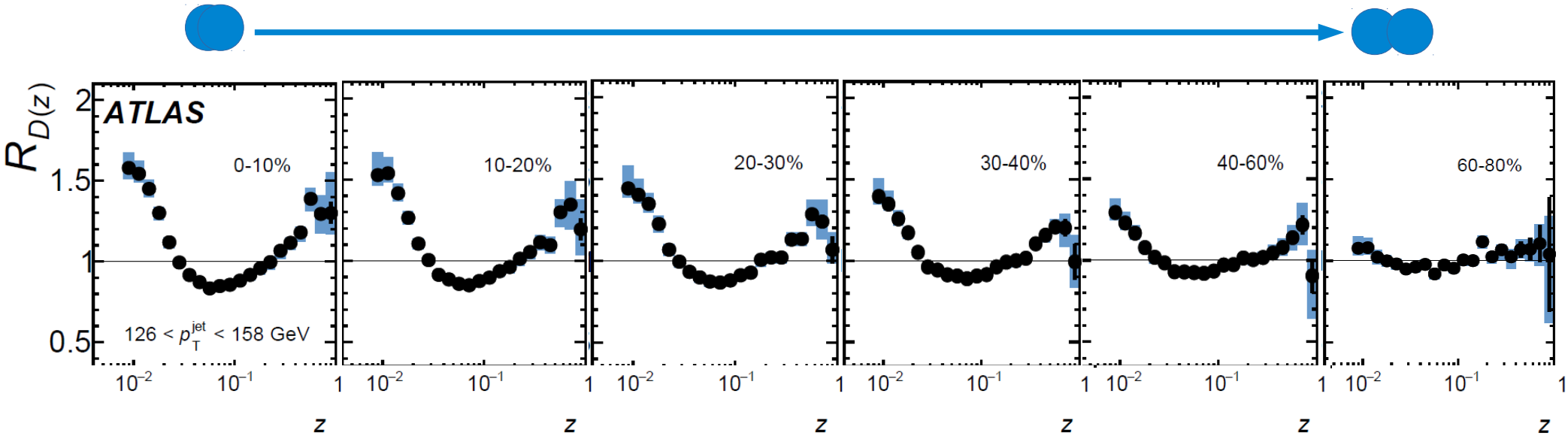
See talk by Dennis Perepelitsa on Photon-tagged measurement today@9:20



Modification of jet fragmentation in Pb+Pb

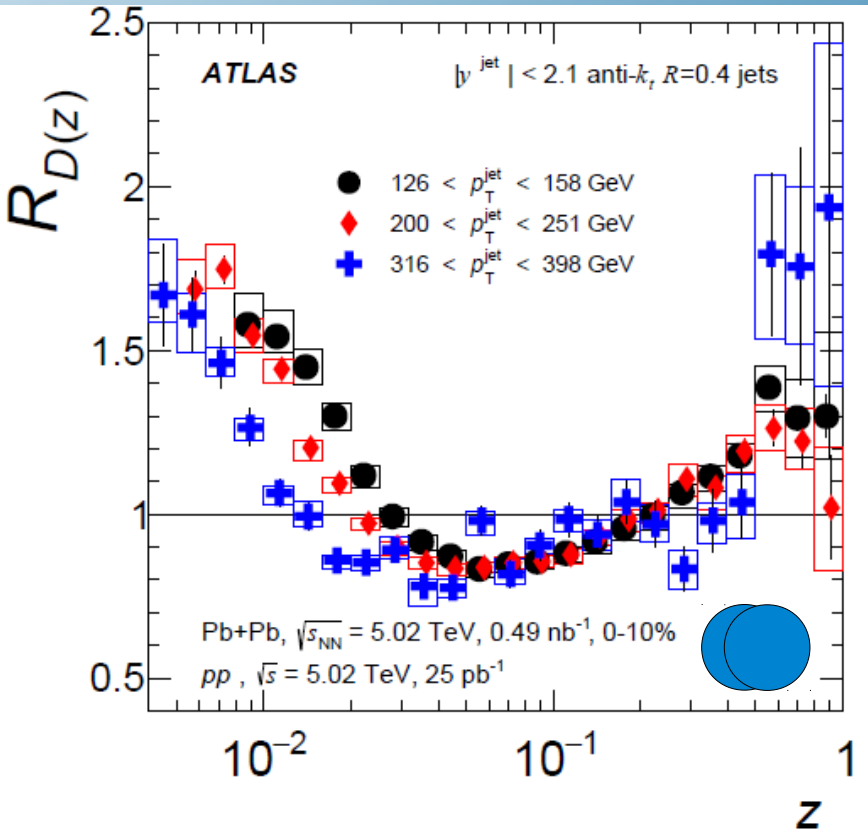


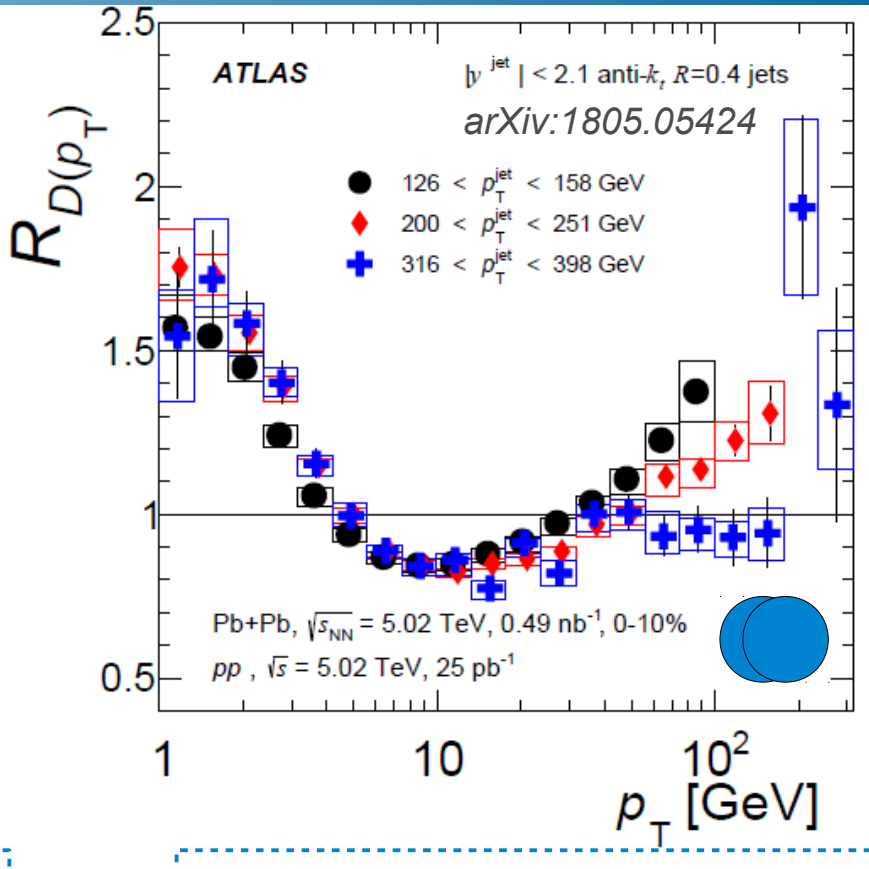
Increasing modification to FF with increasing centrality.

Enhancements of yields of hard and soft fragments.

arXiv:1805.05424

Jet p_T dependence to the FF modification

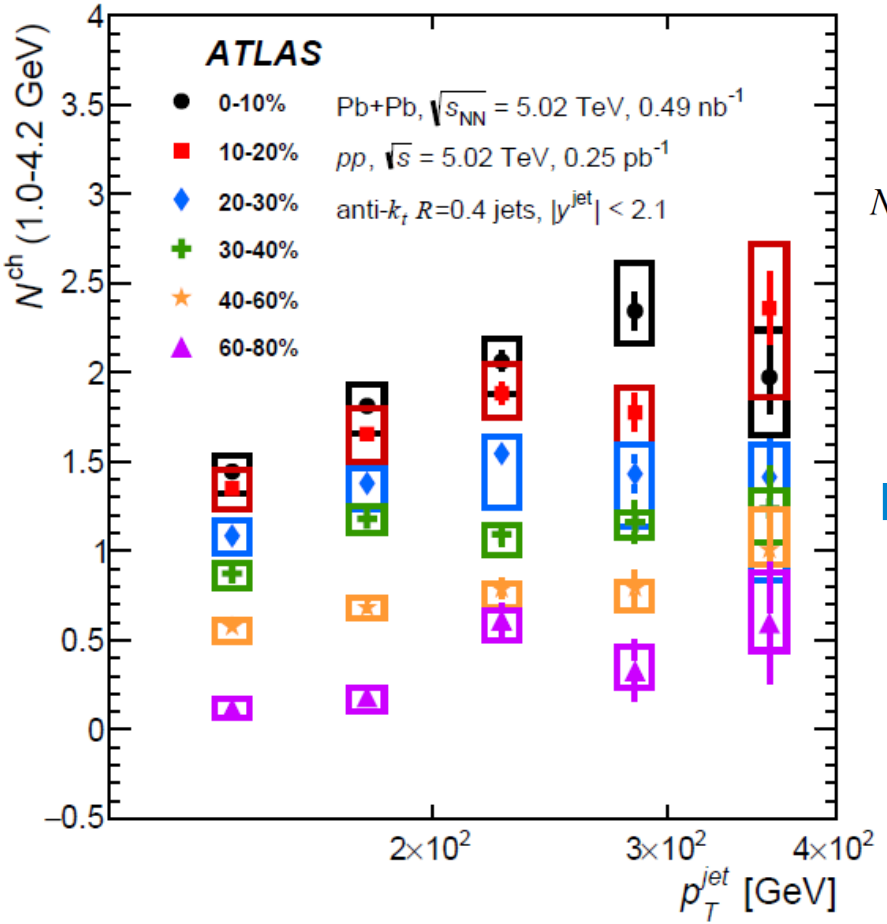




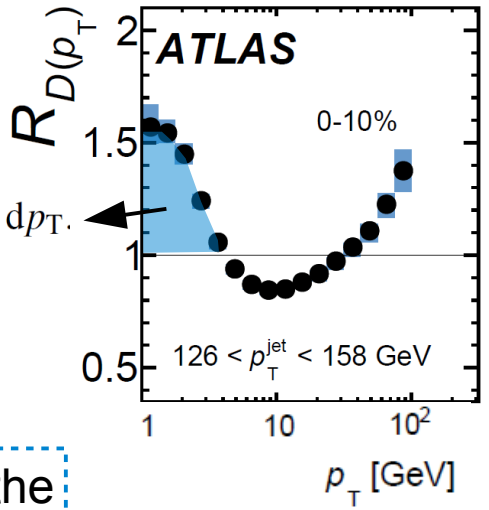
No dependence on jet p_T observed at high z for jets up to 400 GeV.

Enhancement of soft fragments increases for high p_T jets.

Integrals of $D(p_T)$ distributions



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



Jet p_T dependence to the enhancement.

arXiv:1805.05424

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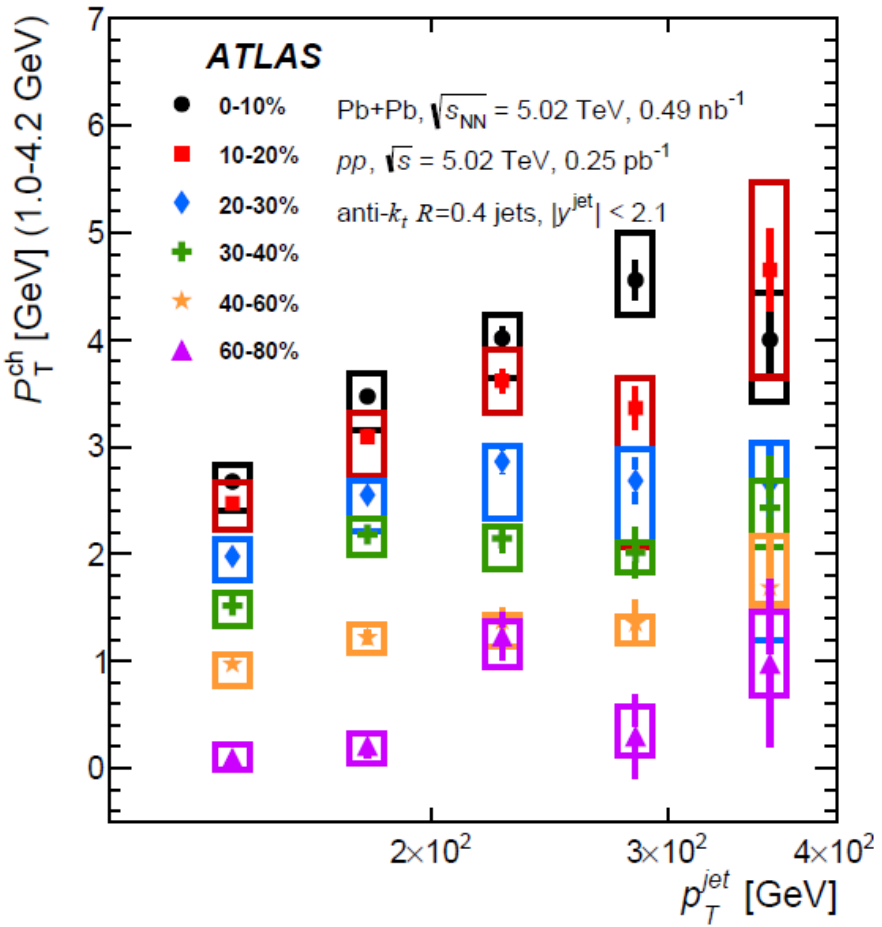

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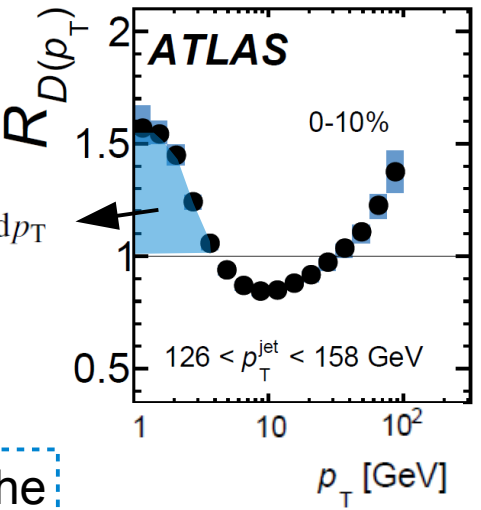


Jet p_T dependence to the enhancement.

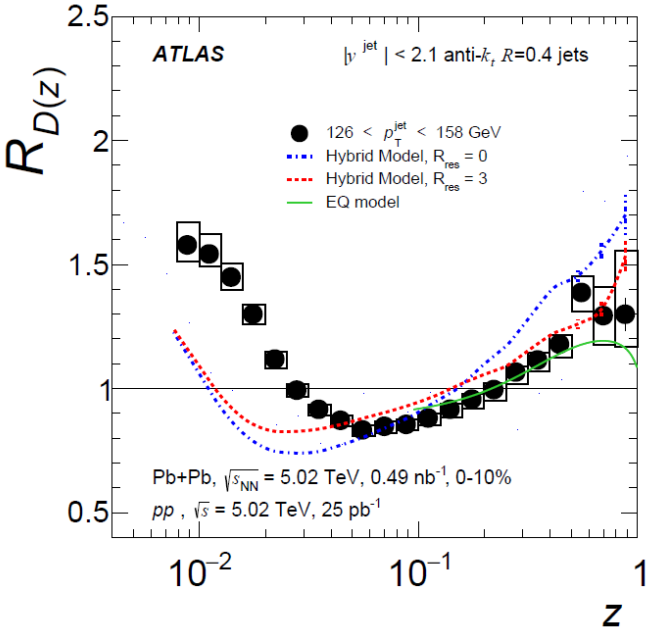
Response of the medium to the high-p_T parton?

arXiv:1805.05424

Can theory describe the measurement?

- Comparison to three theoretical models:

arXiv:1805.05424



Hybrid model (*arXiv:1405.3864, 1707.05245*) with $R_{res} = 3$ consistent at high z and p_T. Disagreement at low z due to simplistic medium response modeling.

EQ model (*arXiv:1504.05169*) is able to describe the high-z excess.

Can theory describe the measurement?

- Comparison to three theoretical models:

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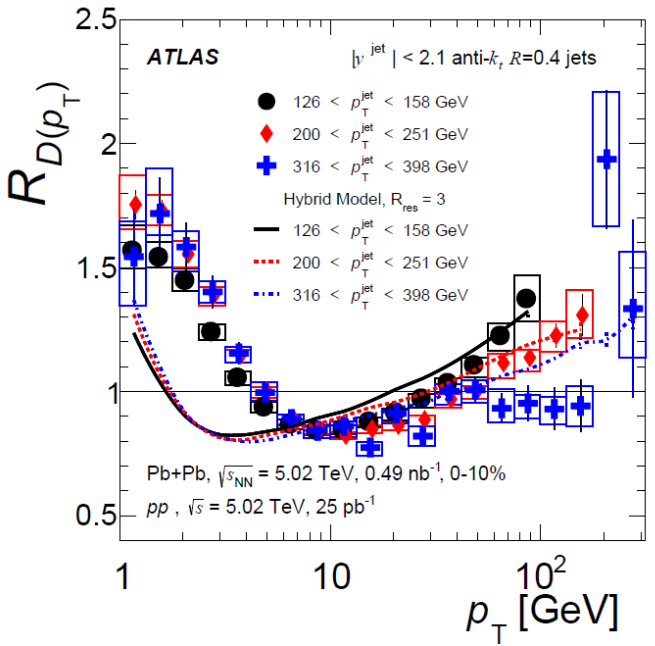
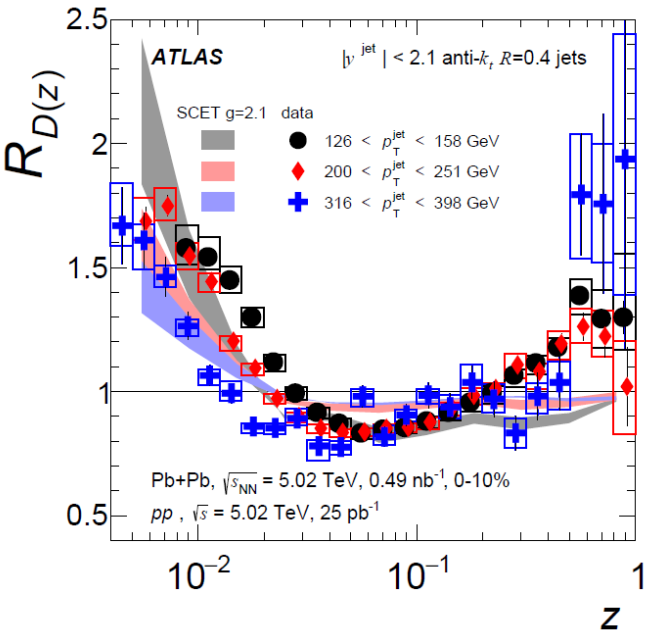


Hybrid model with R_{res} = 3 describes the jet p_T dependence to the $D(p_T)$ at high p_T.

Can theory describe the measurement?

- Comparison to three theoretical models:

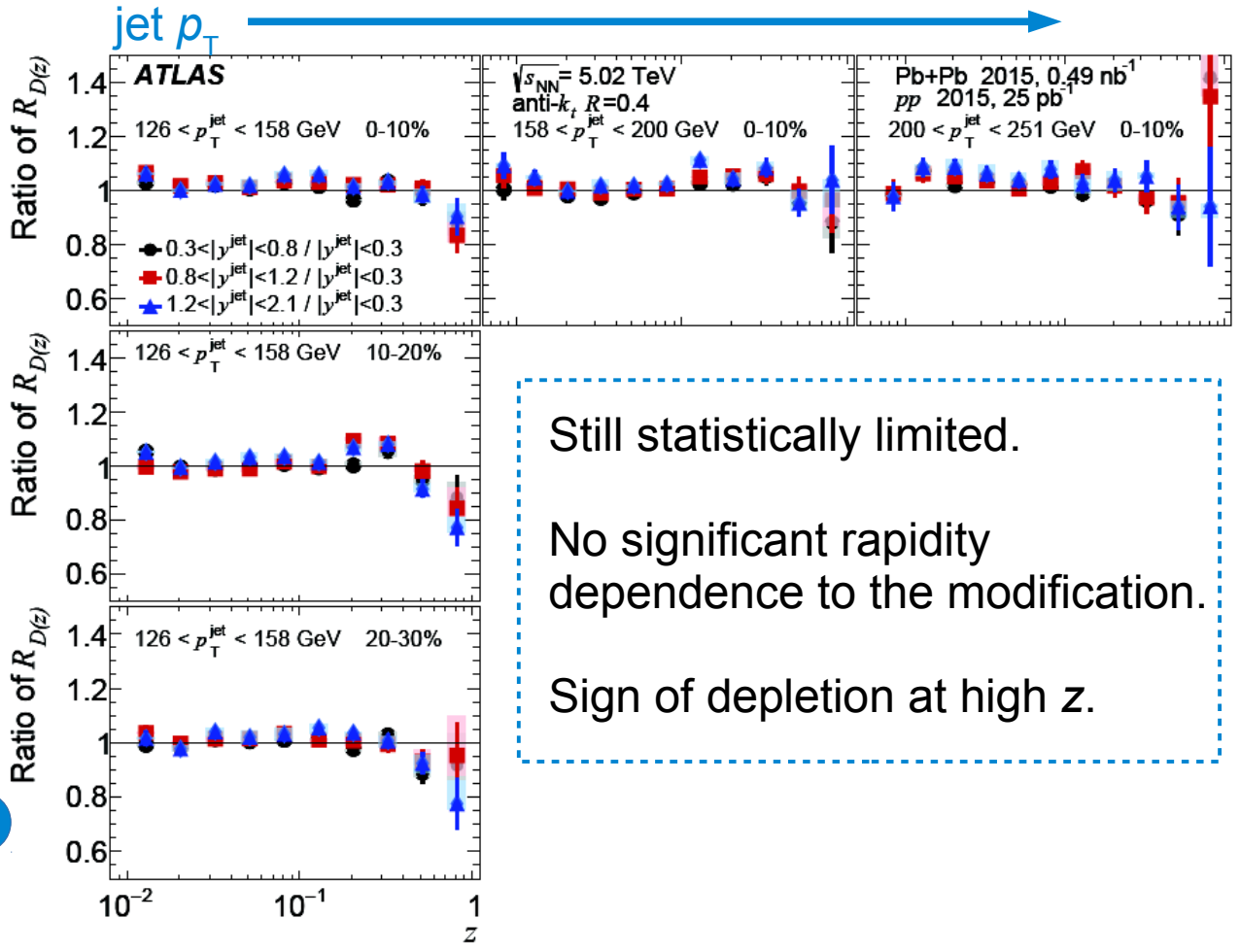
arXiv:1805.05424



SCET (*arXiv:1509.02936, 1701.05839*) model is able to qualitatively described the low-*z* excess.

Some disagreement at high-*z*.

Rapidity dependence



- Measured as ratio of $R_{D(z)}$ in different jet y bins to the $R_{D(z)}$ in $|y|<0.3$.

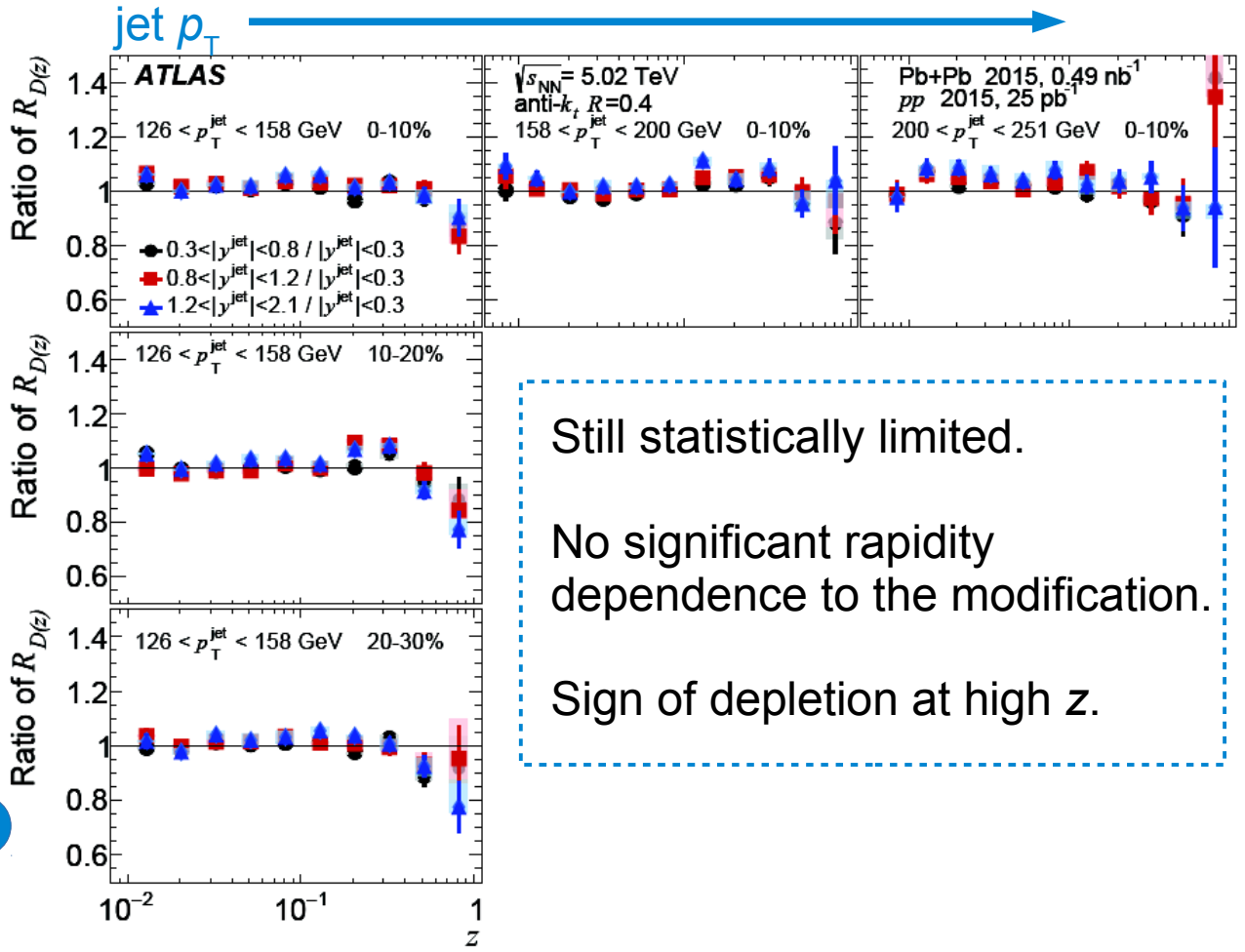
Still statistically limited.

No significant rapidity dependence to the modification.

Sign of depletion at high z.

arXiv:1805.05424

Rapidity dependence



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- Measured as ratio of $R_{D(z)}$ in different jet y bins to the $R_{D(z)}$ in $|y|<0.3$.

Can this be described by theoretical calculation?

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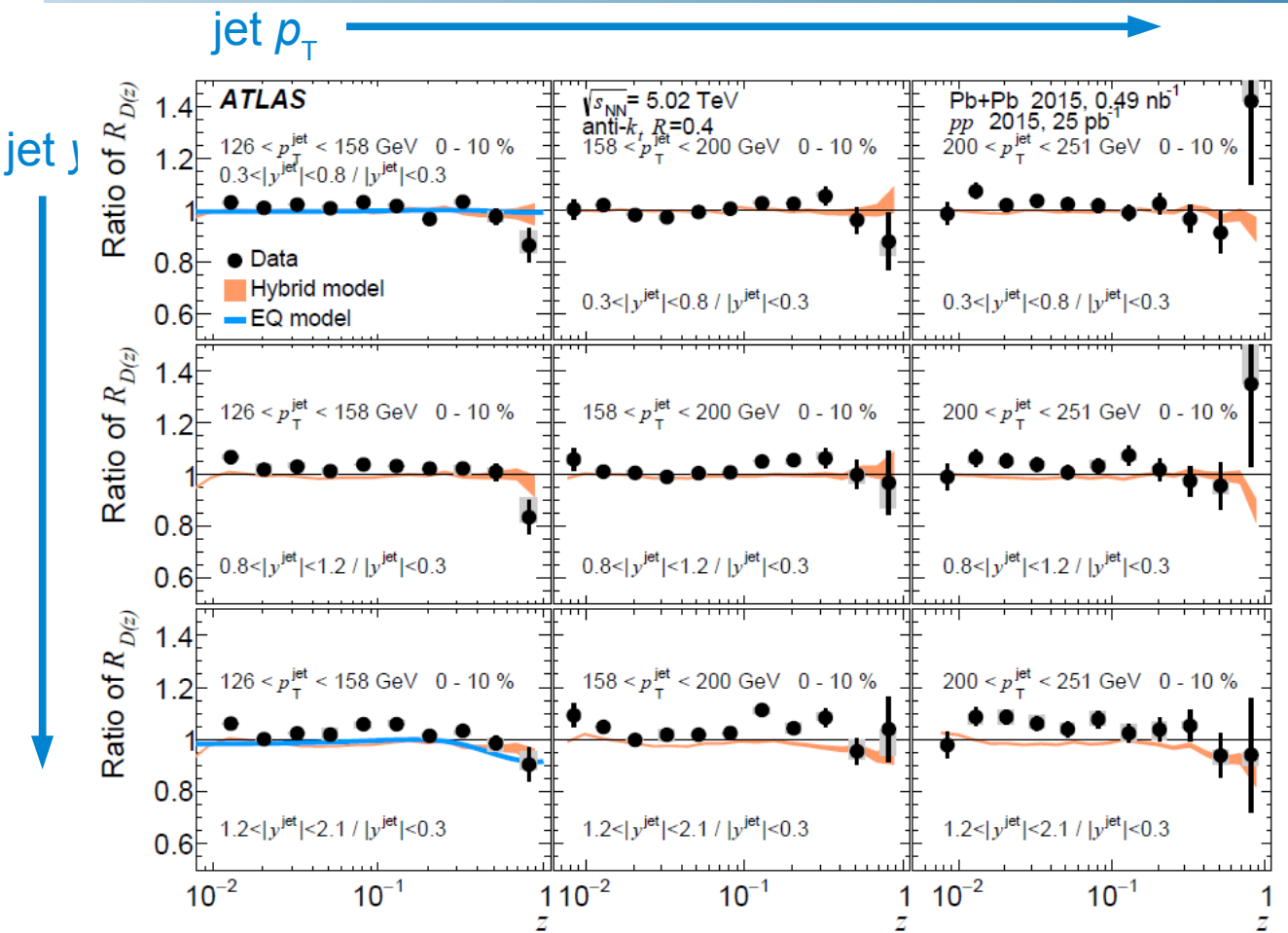
Rapidity dependence



- Comparison to EQ and Hybrid model.

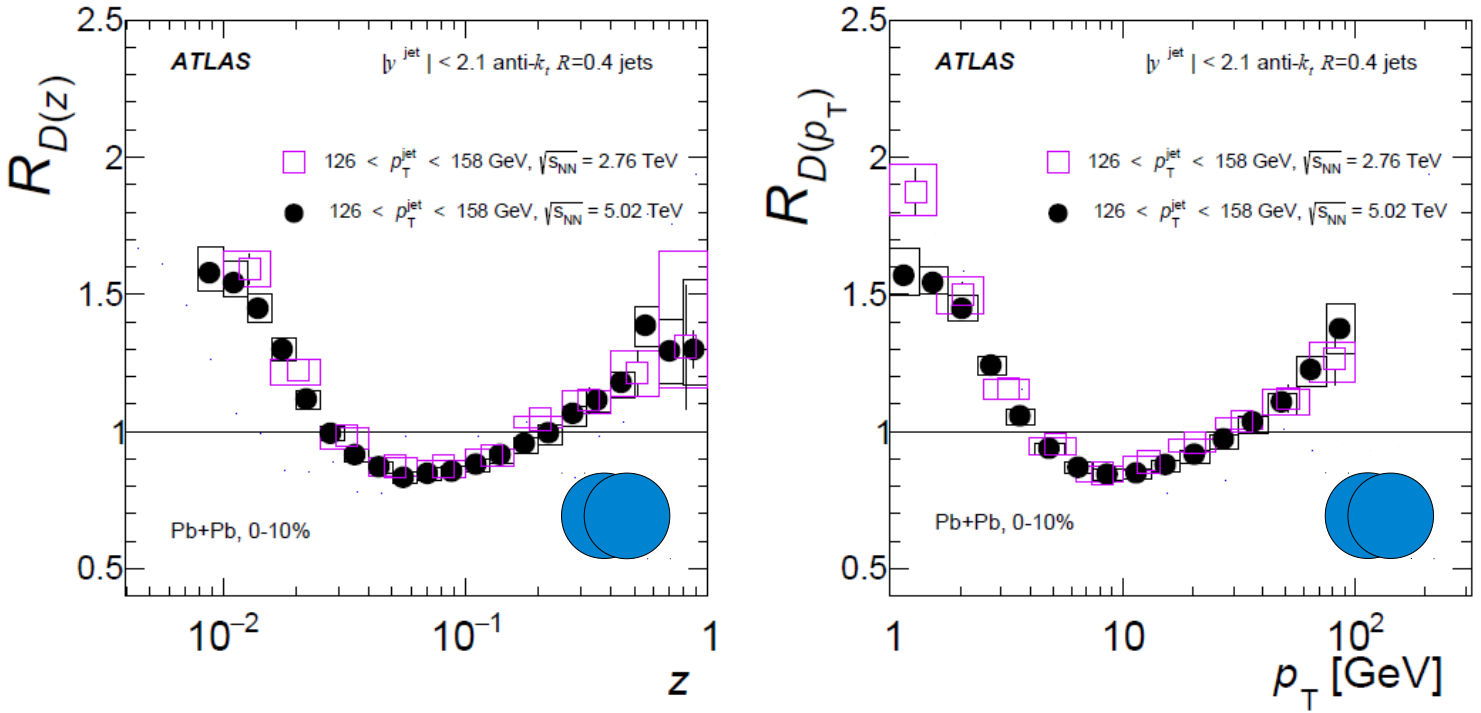
Both models are able to describe the rapidity dependence in data.

See talk by Martin Spousta on rapidity dependence of jet R_{AA}.

arXiv:1805.05424

Is there dependence on collision energy?

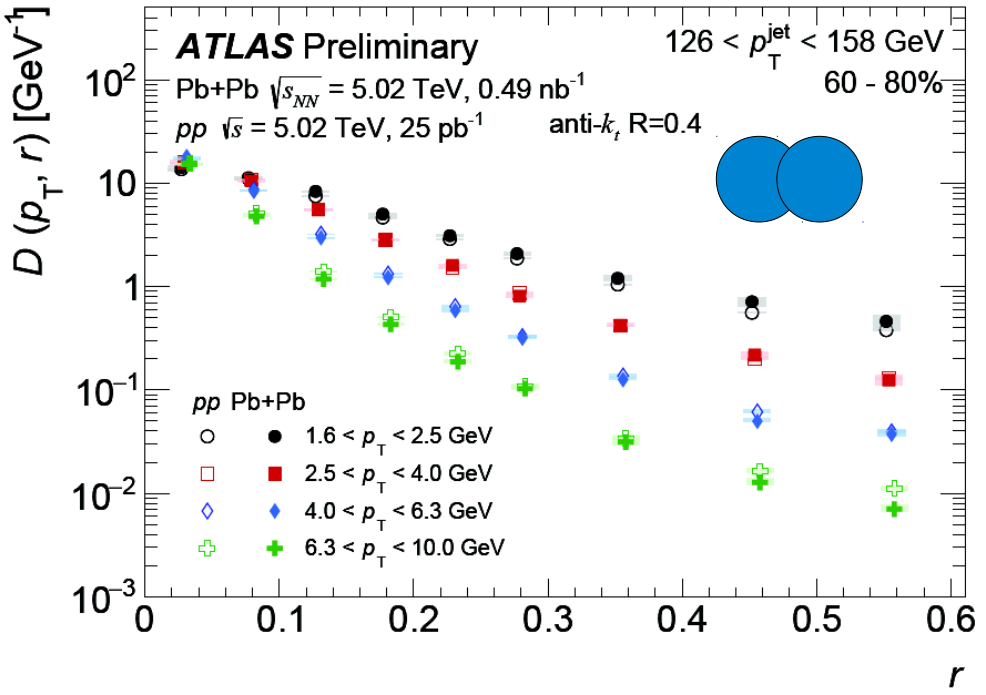
- Comparison to the result at 2.76 TeV.

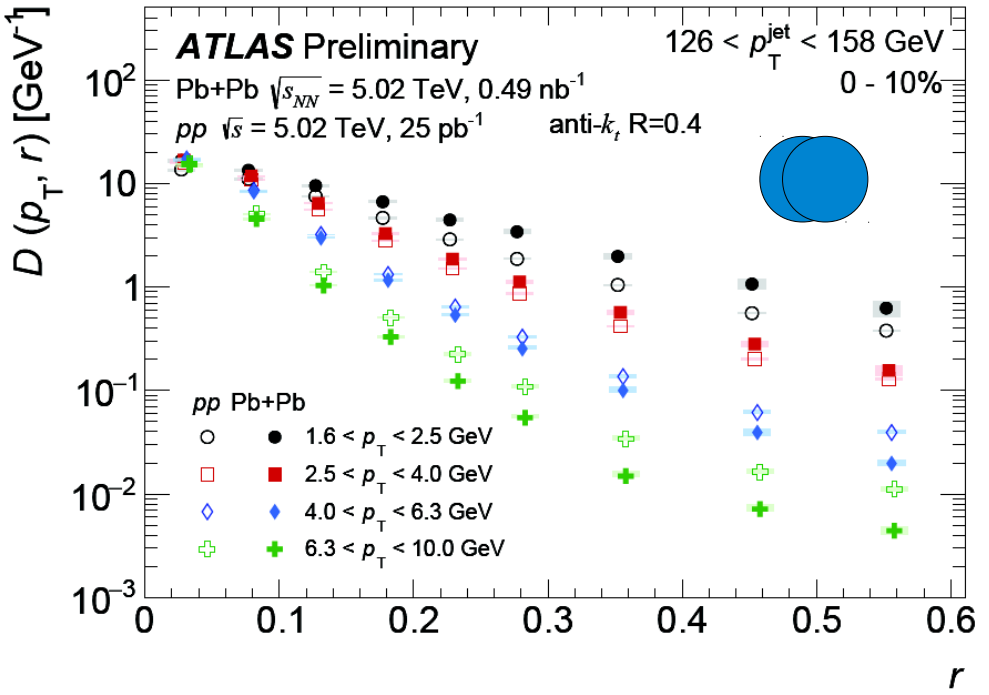


No dependence on the collision energy.
Similar to other jet observables.

arXiv:1805.05424

Radial Profile





Change of shapes in central Pb+Pb collisions compared to *pp* reference.

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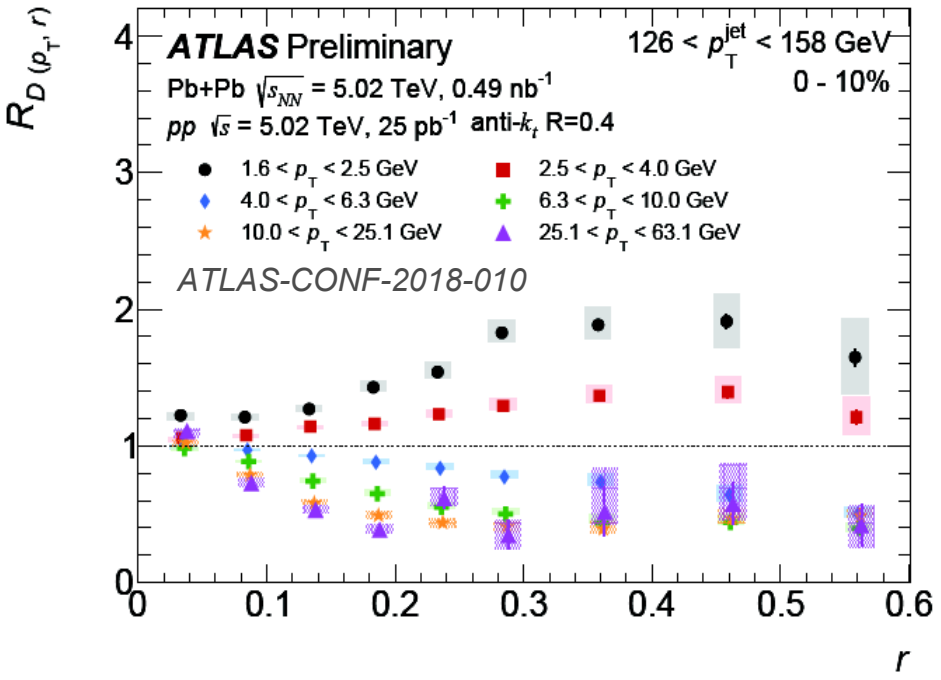
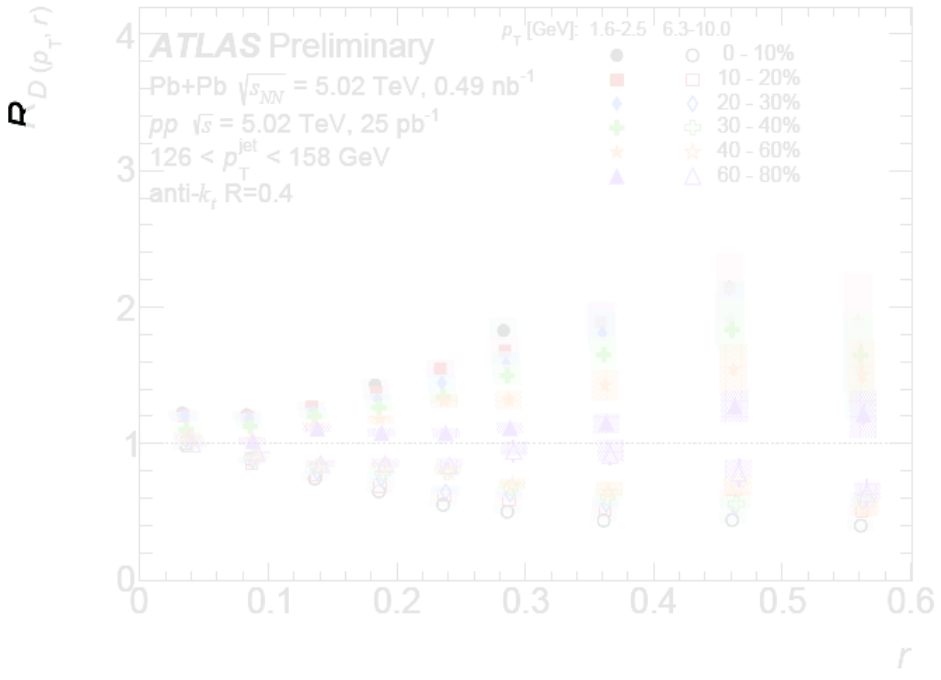
Modification of Radial Profile





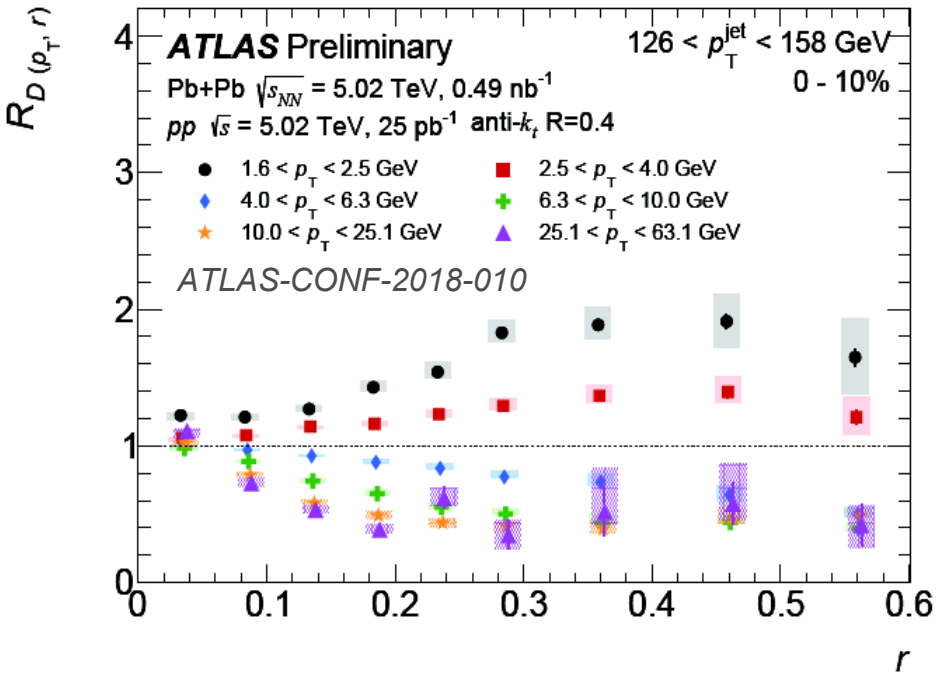
Jets are broader in more central collisions.

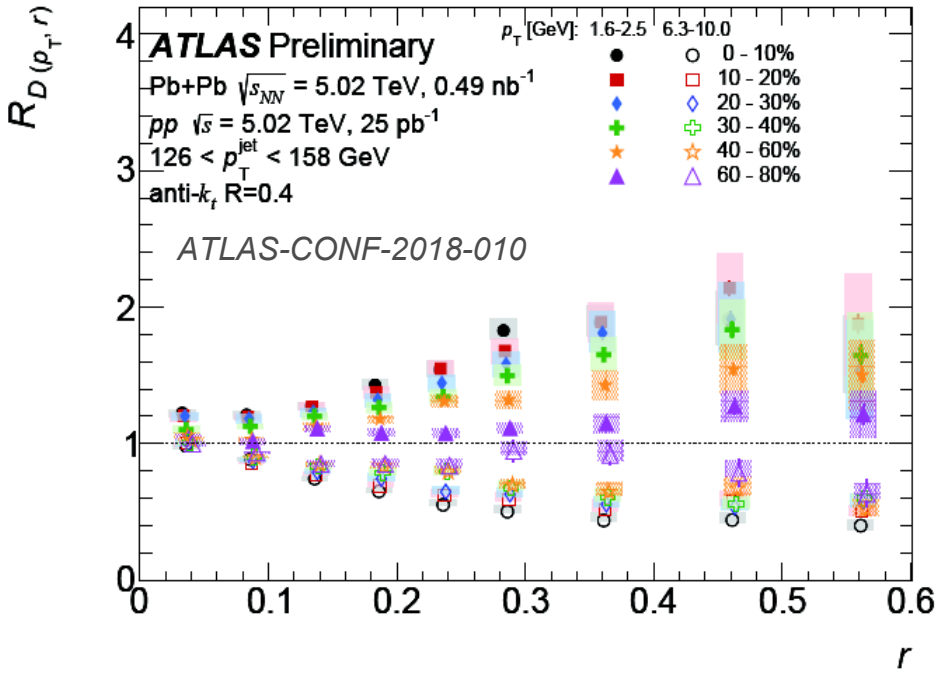
Smallest modification seen in the jet core.

Increase of yields of soft fragments with increasing *r*.

Decrease of yields of intermediate p_T particles with *r*.

Modification of Radial Profile





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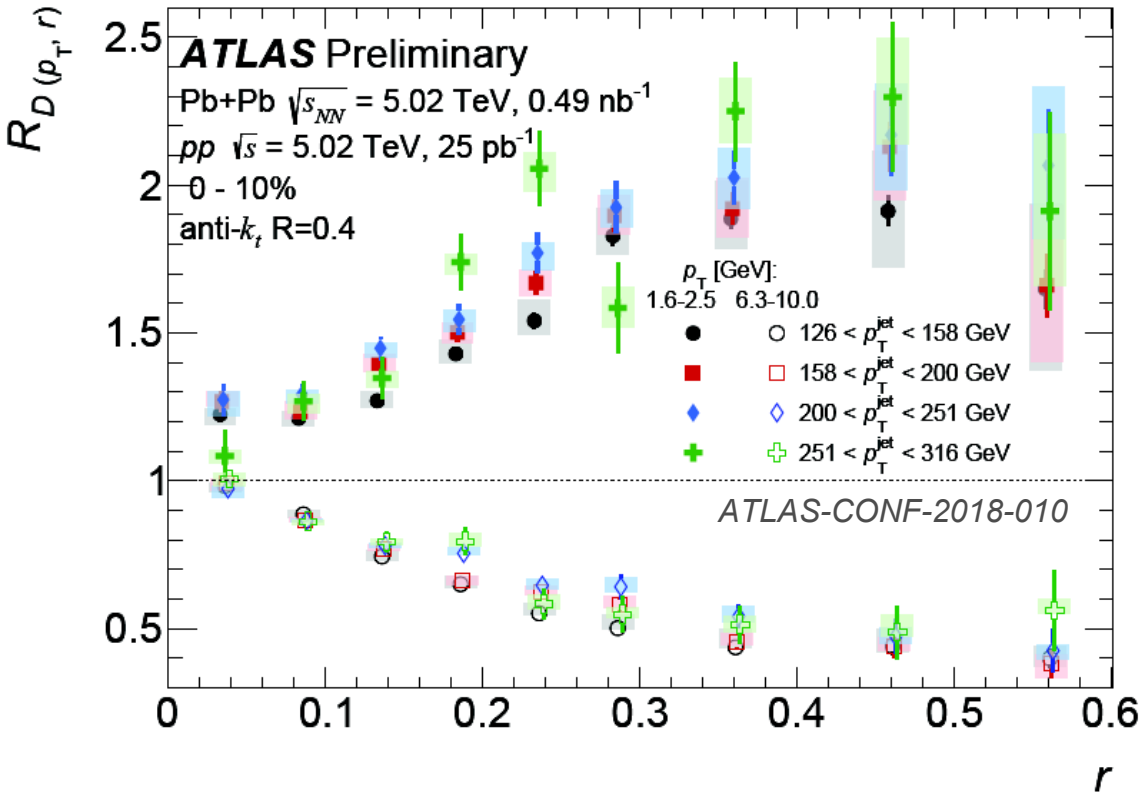
Jet p_T dependence of $R_{D(pT,r)}$



Similar observation as for *r*-inclusive measurement:

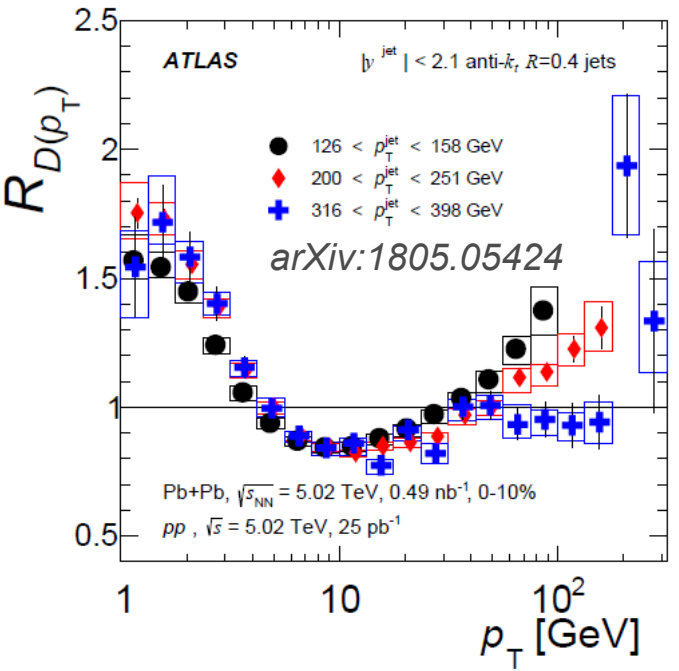
Yield of soft fragments more enhanced for higher p_T jets.

No significant dependence of yields for fragments with intermediate p_T.

See poster by Akshat Puri on more details of the angular dependence of fragmentation.

Conclusions

- Evidence that jet fragmentation in heavy ion collisions is modified.
- Yields of soft and hard fragments are enhanced in Pb+Pb compared to *pp* collisions.
- Using high statistics LHC data and new techniques bring us to era of precise measurements and put strong constrains on models.
  - Theoretical models are able to describe various features in the result.



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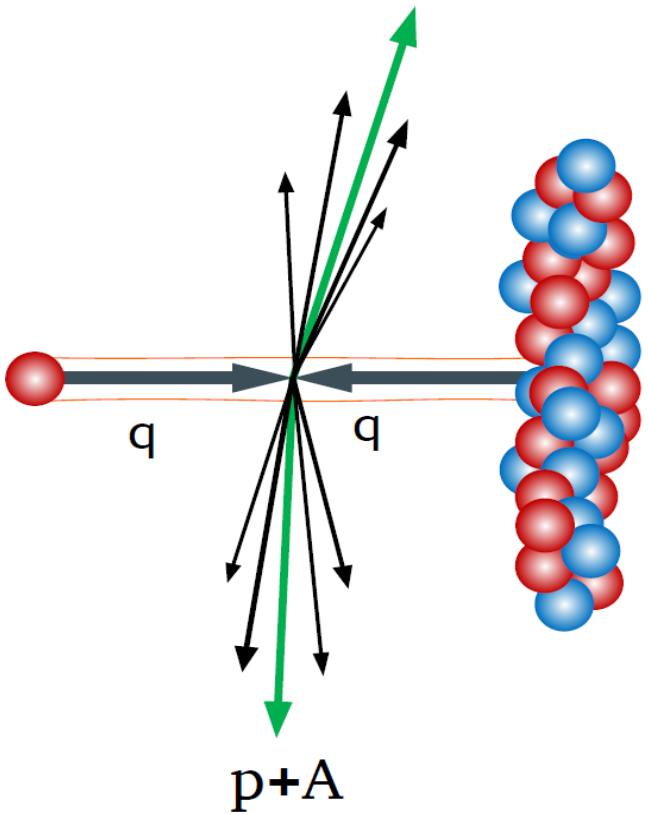
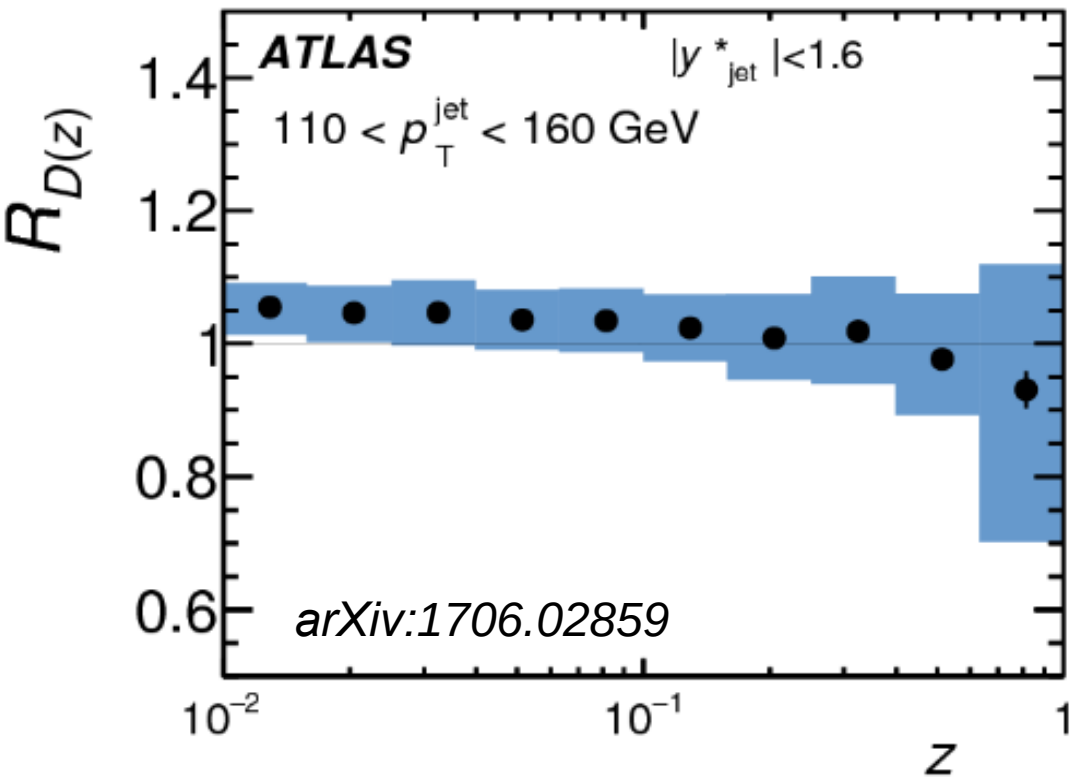
ATLAS HI Public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

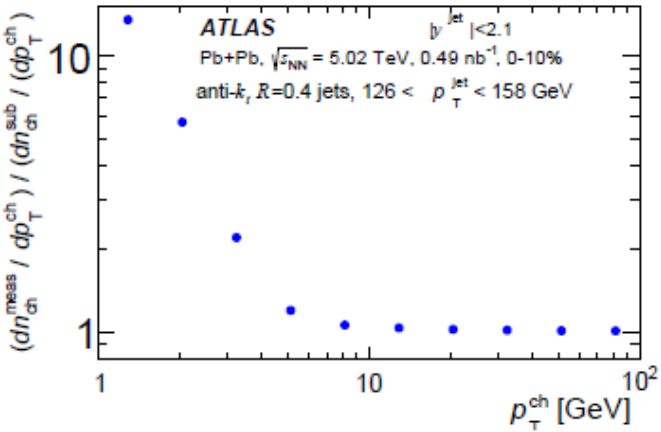
Shower modifications in *p*+Pb collisions?

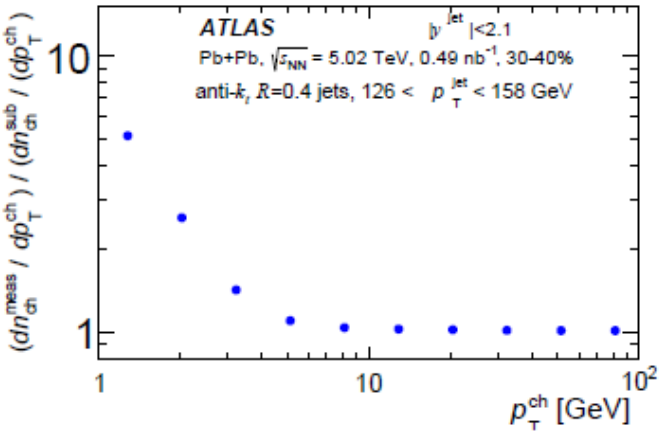


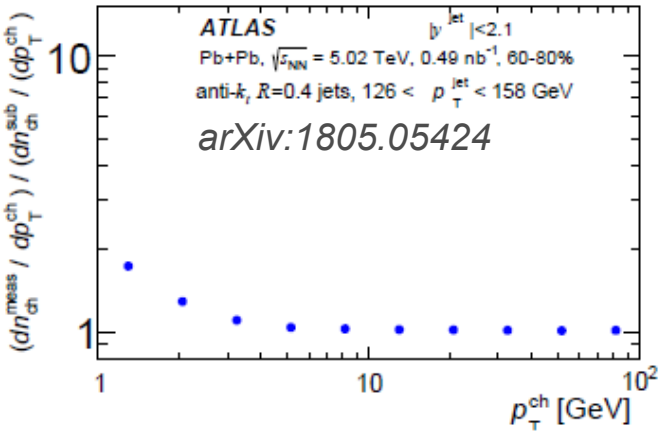


No modification of parton shower is observed in *p*+Pb system.

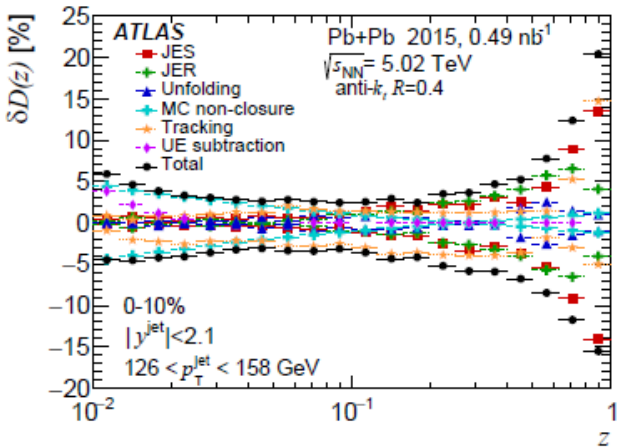
UE in FF measurement

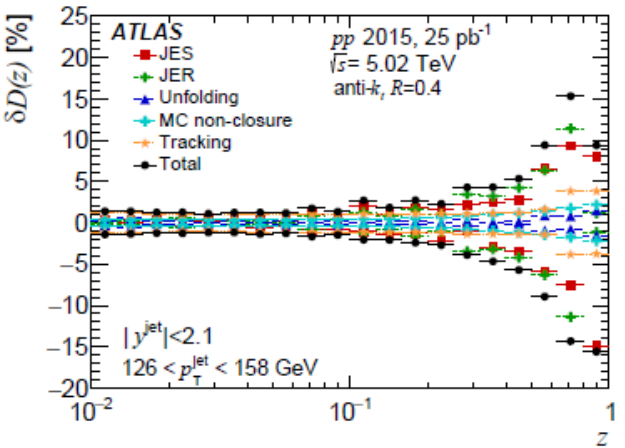


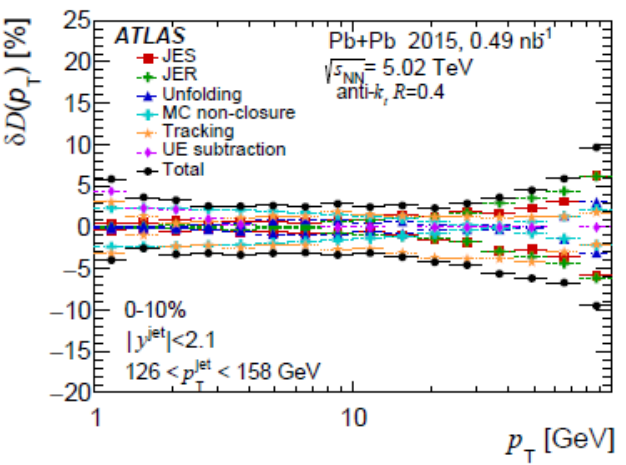


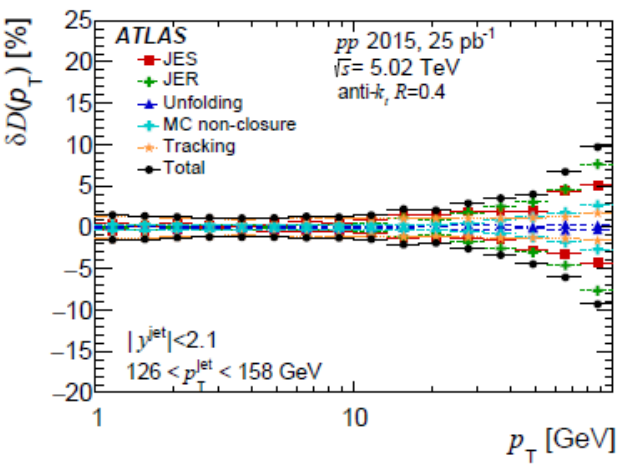


Systematic uncertainties: FF



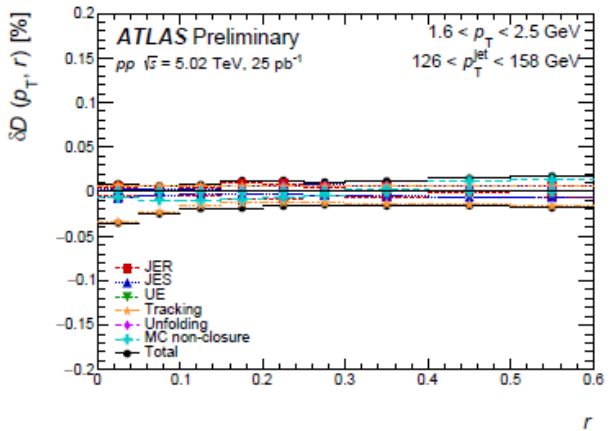


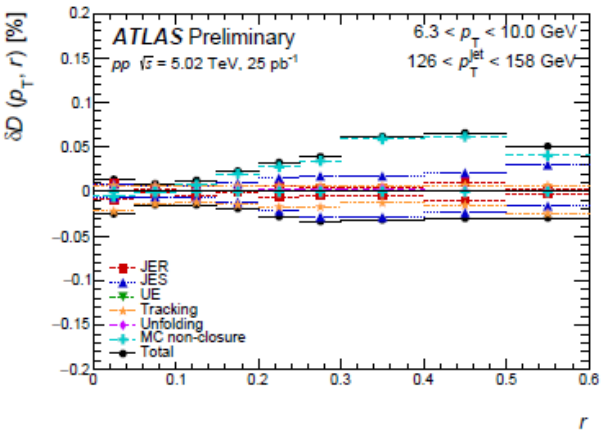


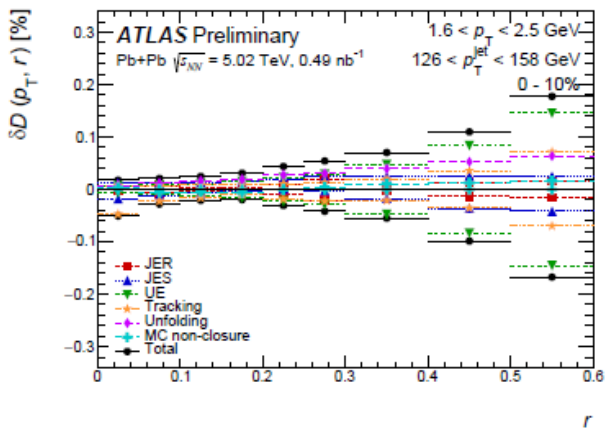


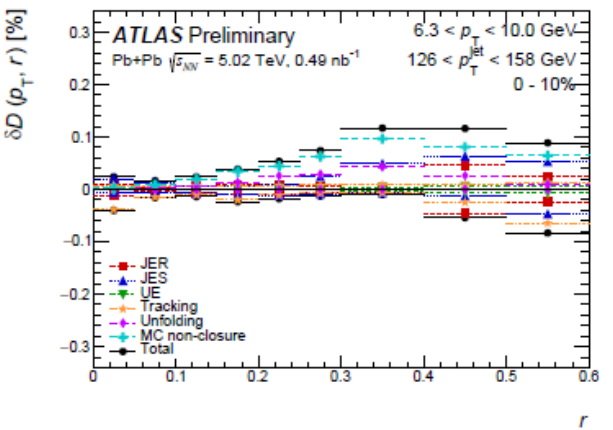
arXiv:1805.05424

Systematic uncertainties: $D(p_T,r)$



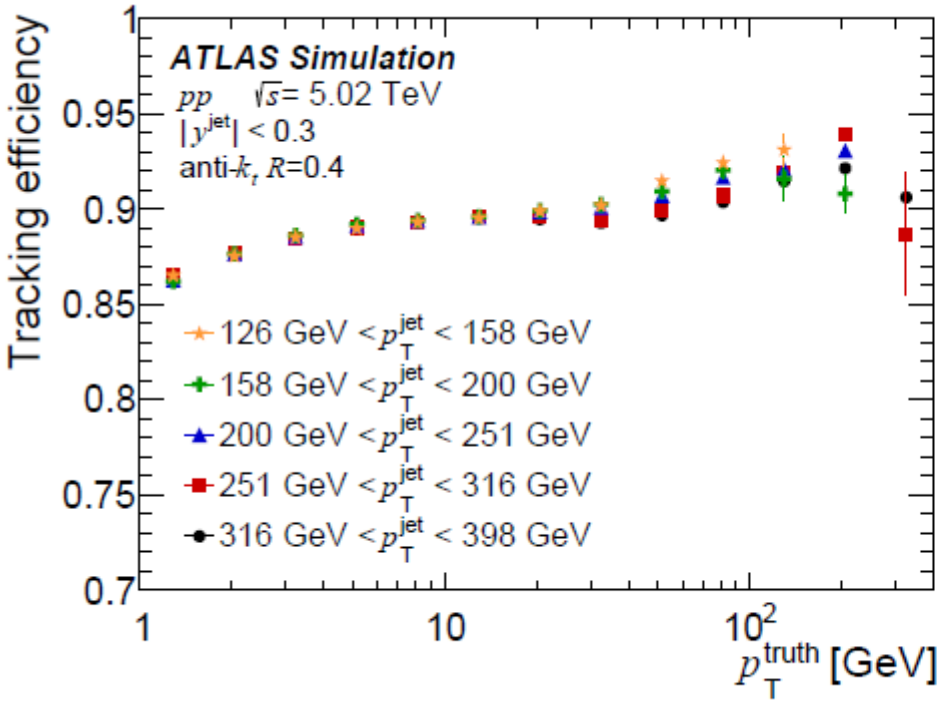


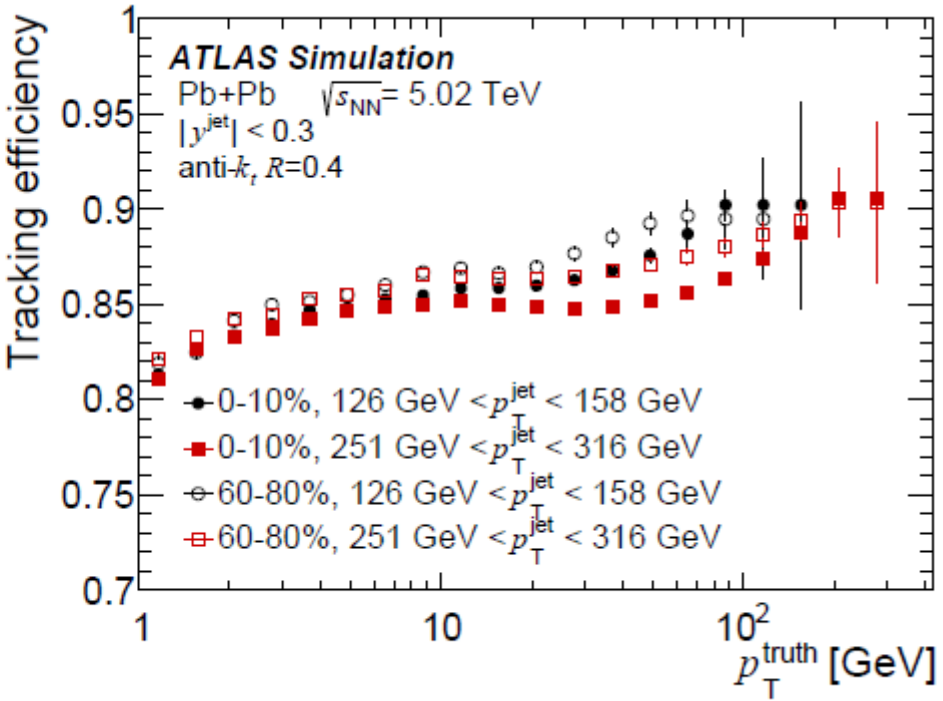




ATLAS-CONF-2018-010

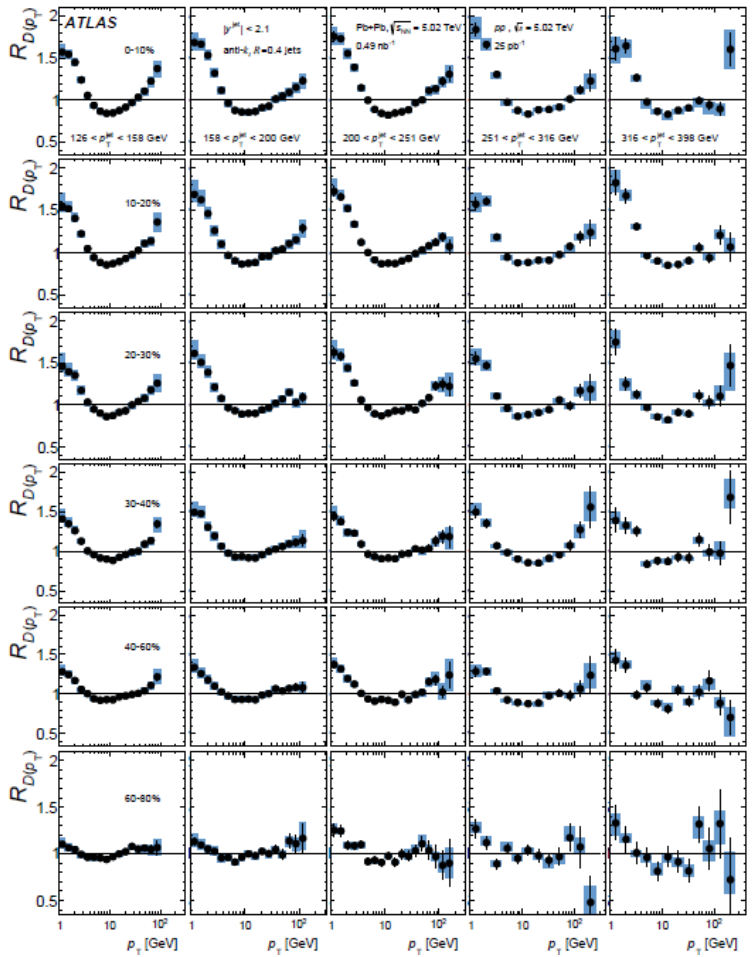
Tracking efficiency

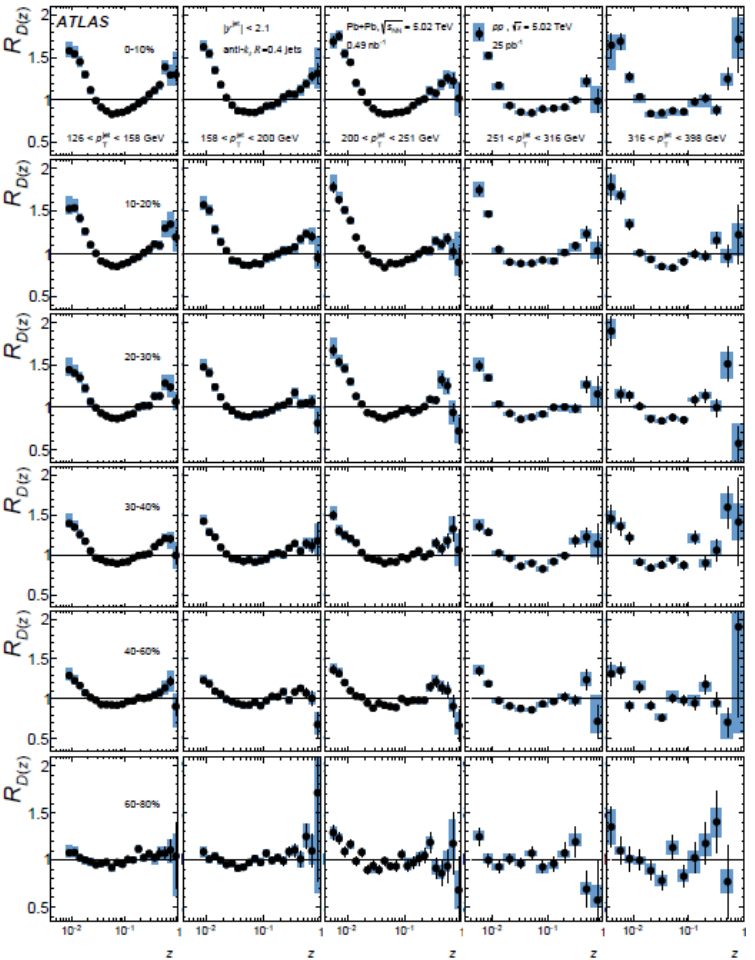




arXiv:1805.05424

$D(p_T)$ and $D(z)$





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