Jet suppression and jet substructure in Pb+Pb and Xe+Xe collisions with the ATLAS detector

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for the ATLAS Collaboration

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Introduction

- Study of jets in heavy-ion collisions should tell us about e.g.:
  - Properties of de-confined matter created in heavy-ion collisions.
  - Radiation of energetic color charges in this de-confined medium.
- Three measurements to be presented:
  - Inclusive jet R_{AA} in 5.02 TeV Pb+Pb collisions.
  - Jet mass in 5.02 TeV Pb+Pb collisions.
  - Dijet asymmetry in 5.44 TeV Xe+Xe collisions.

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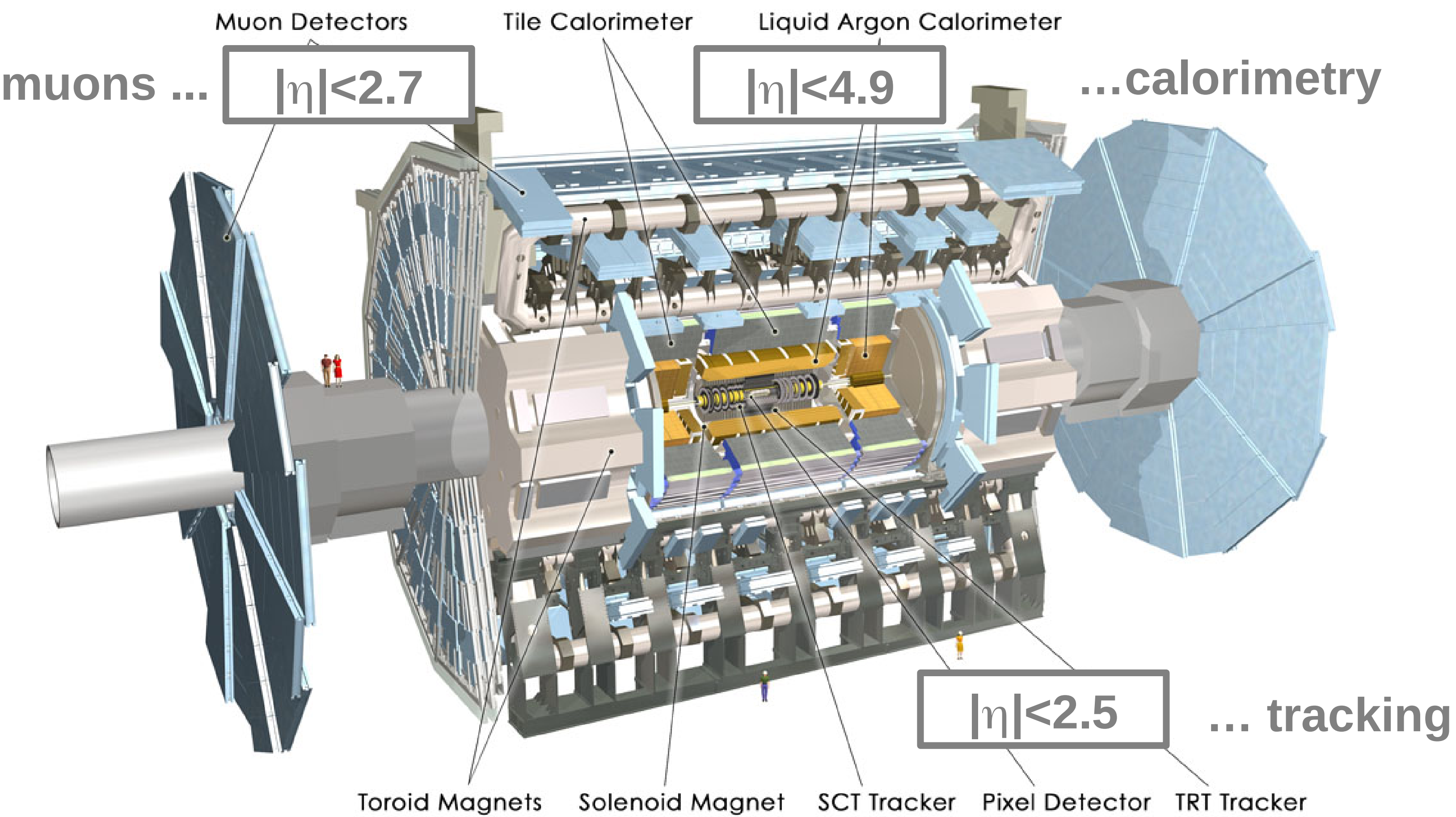
  - Inclusive jet R_{AA} in 5.02 TeV Pb+Pb collisions. **FINAL**
  - Jet mass in 5.02 TeV Pb+Pb collisions. **NEW**
  - Dijet asymmetry in 5.44 TeV Xe+Xe collisions. **NEW**

ATLAS experiment



Inclusive jet suppression

arXiv:1805.05635

$$R_{AA} = \frac{\left. \frac{1}{N_{\mathrm{evnt}}} \frac{\mathrm{d}^2 N_{\mathrm{jet}}^{PbPb}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y} \right|_{\mathrm{cent}}}{\langle T_{\mathrm{AA}} \rangle_{\mathrm{cent}} \times \frac{\mathrm{d}^2 \sigma_{\mathrm{jet}}^{pp}}{\mathrm{d}p_{\mathrm{T}}\mathrm{d}y}}$$

Jet yield in heavy-ion collisions

Nuclear thickness fuction

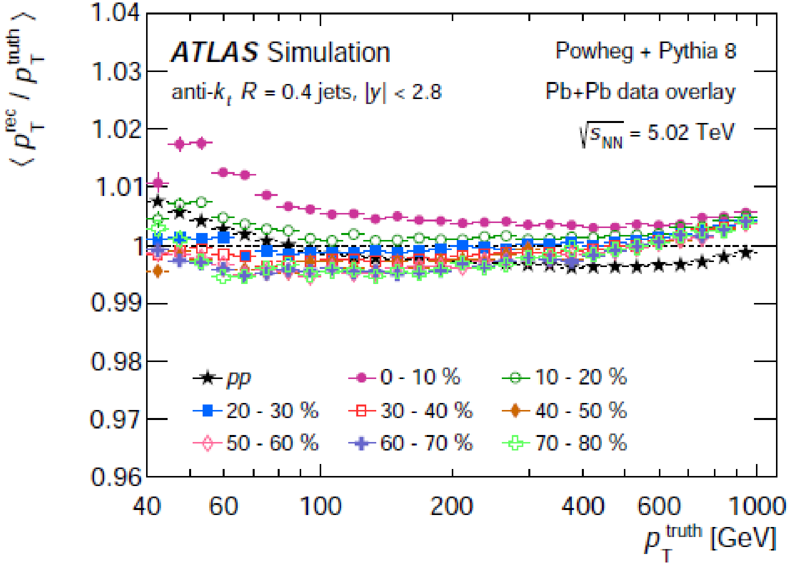
Jet cross-section in *pp* collisions

Number of expected jets per event of a given centrality

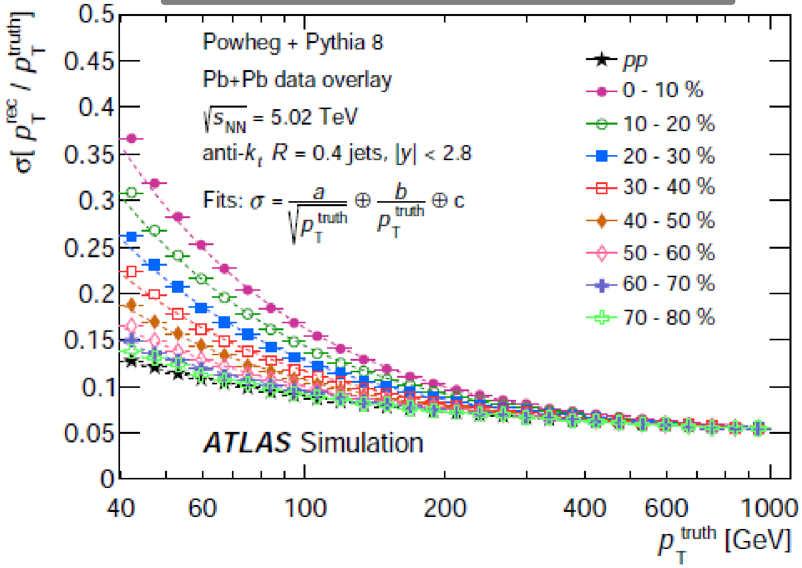
- Jet R_{AA} measured at 5.02 TeV with R=0.4 anti-k_t jets
- p_T = 50 – 1000 GeV (depending on centrality), in bins of rapidity

Jet reconstruction performance

Jet energy scale

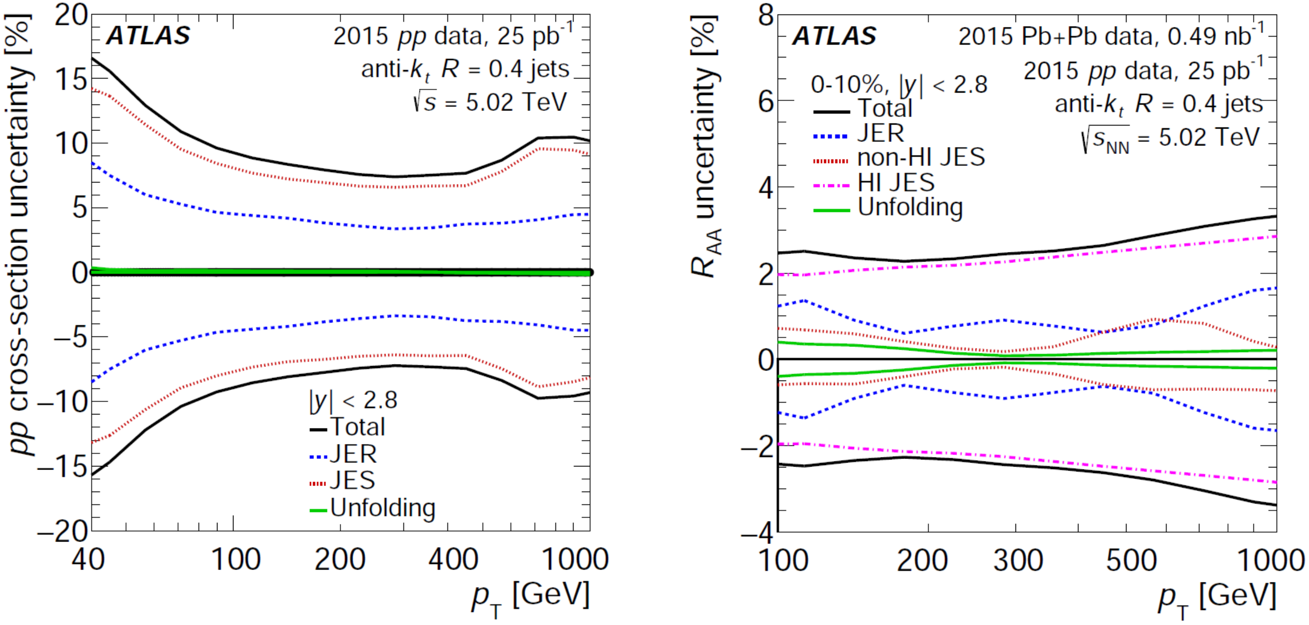


Jet energy resolution



- Realistic jet MC: NLO POWHEG+PYTHIA8 + minimum bias Pb+Pb data overlay with full simulation by Geant4 .
- Good understanding of jet energy scale, expected behavior of jet energy resolution.

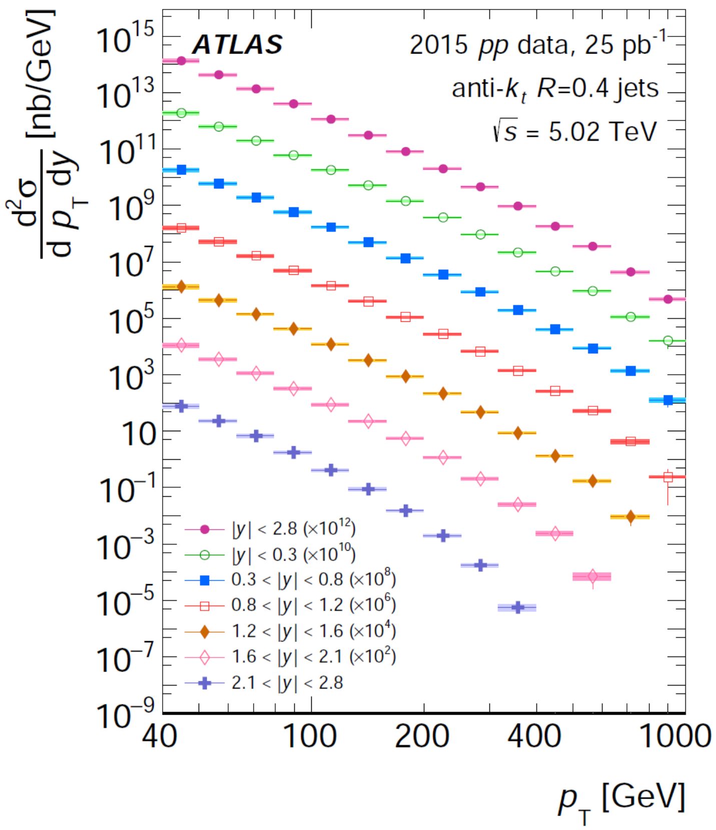
Systematic uncertainties



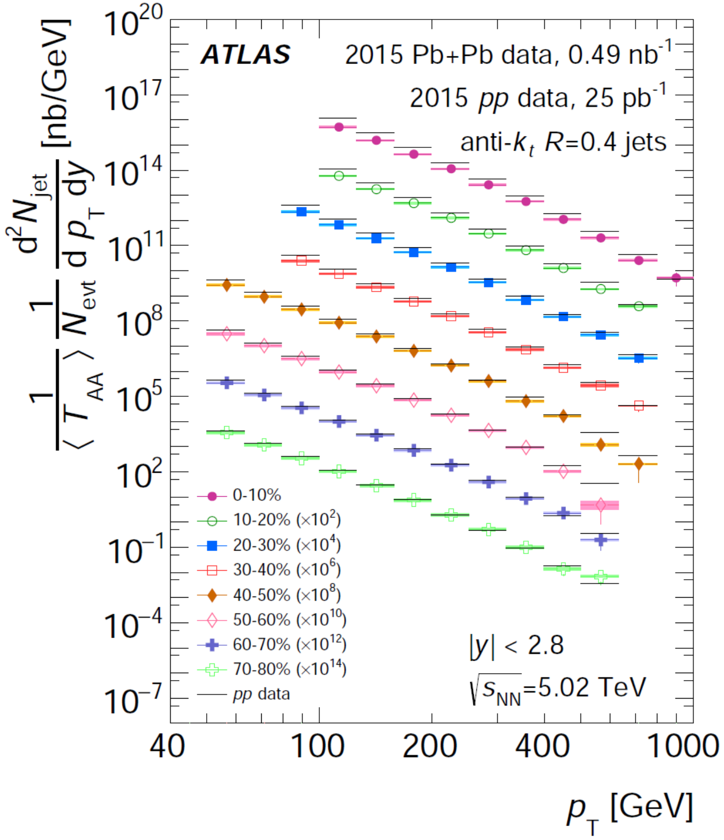
- Jet energy scale (JES) uncertainties: 11 sources for *pp* baseline + 3 heavy-ion specific.
- JES further involves *in situ* studies using γ-jet and Z-jets in *pp*, *in situ* comparison using track jets and various MC checks.

Jet cross-section and yields

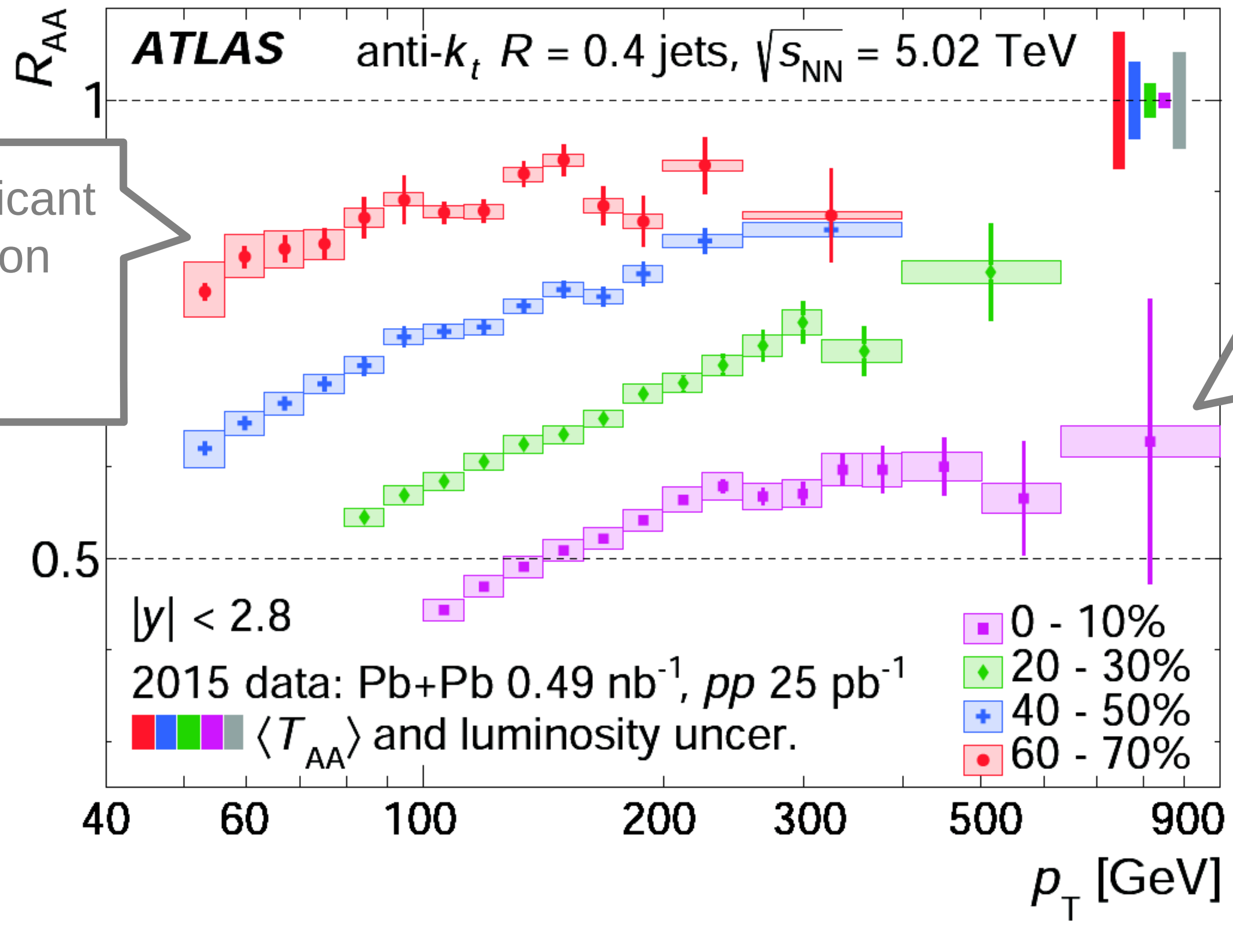
pp



Pb+Pb



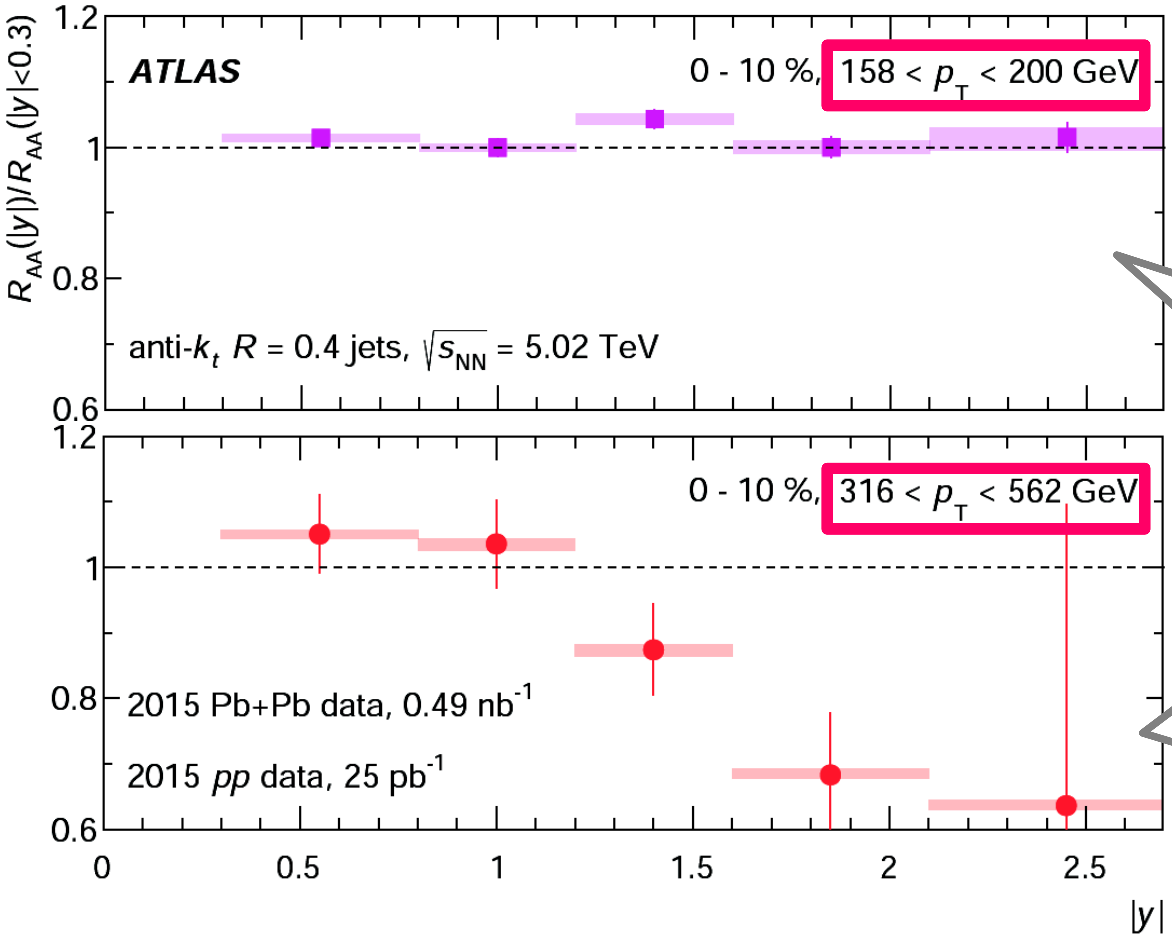
Jet R_{AA} vs. p_T



Still significant suppression even in 60-70%

Only modest grow with p_T, flattening for p_T>200 GeV

Jet R_{AA} vs. rapidity

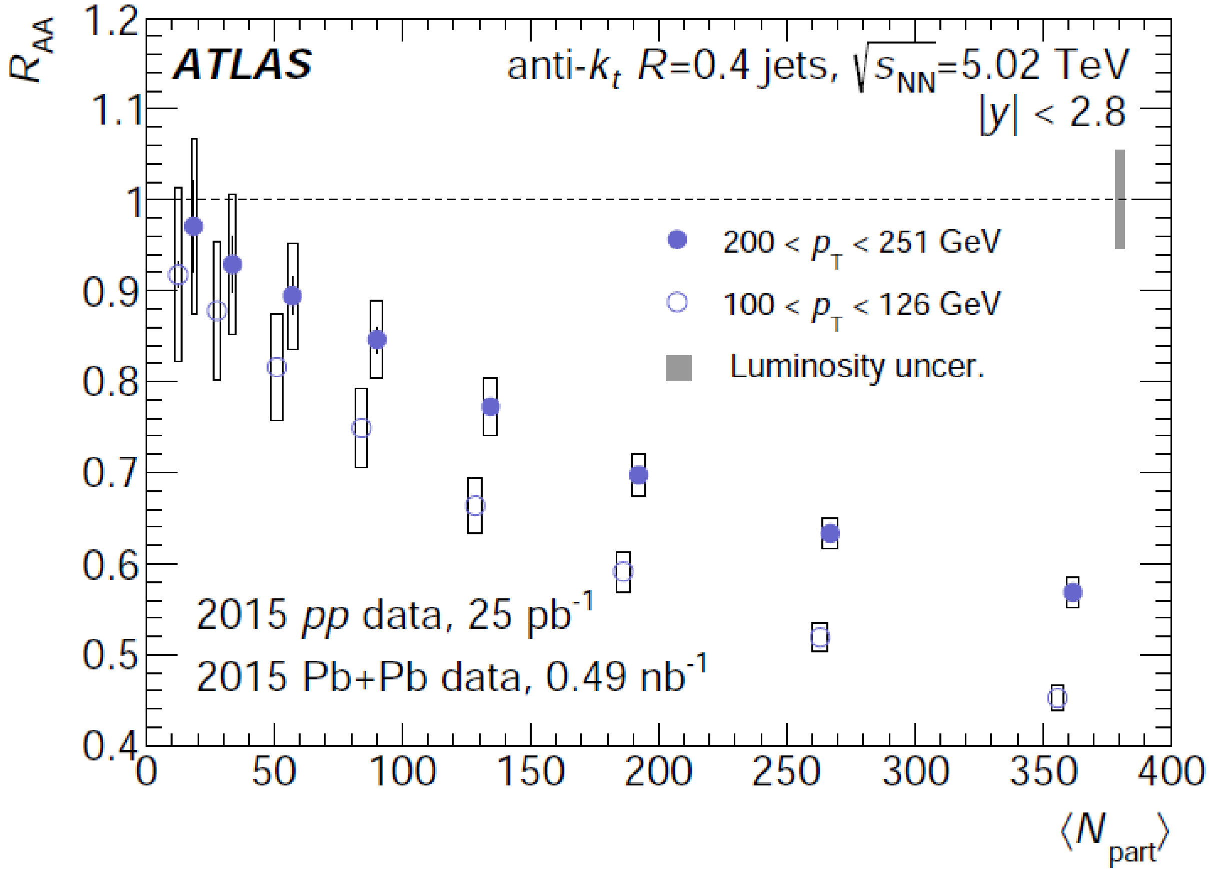


$$\frac{R_{AA}(|y|)}{R_{AA}(|y| < 0.3)}$$

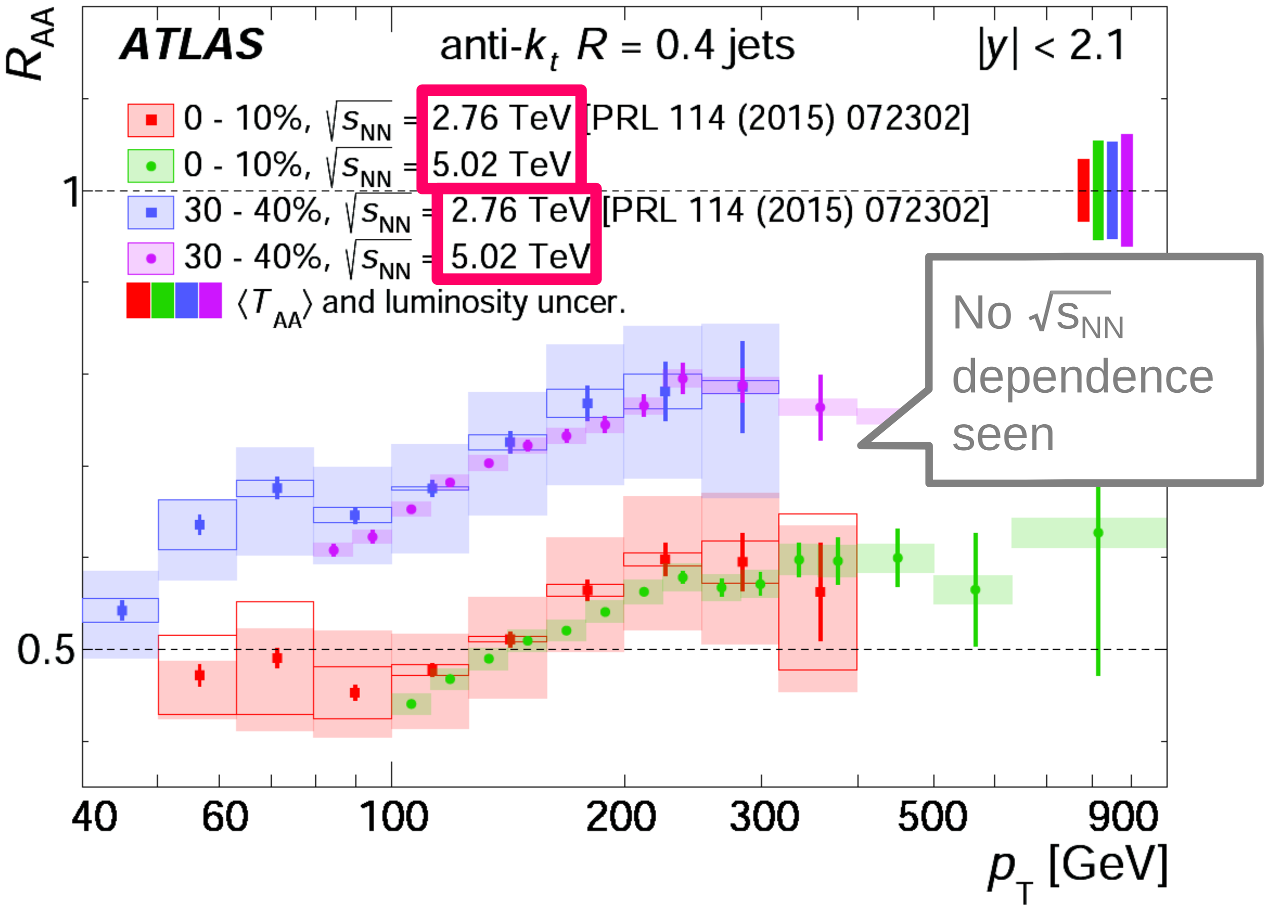
No rapidity dependence at „low" p_T

At high p_T, decreasing R_{AA} in the forward region

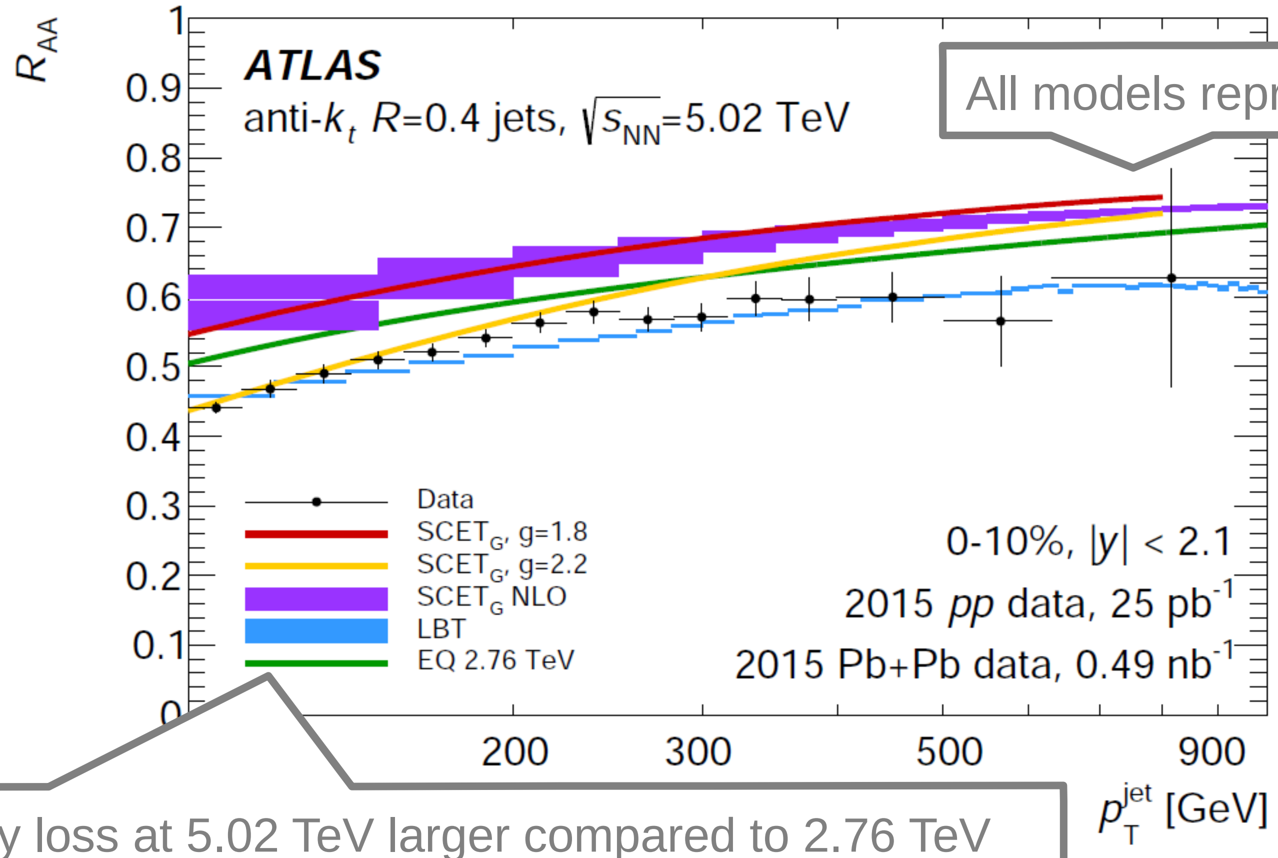
Jet R_{AA} vs. N_{part}



Jet R_{AA} vs. $\sqrt{s_{NN}}$



Jet R_{AA}: theory



All models reproduce trends

Energy loss at 5.02 TeV larger compared to 2.76 TeV

Jet R_{AA} vs. mass at 5.02 TeV

- Information about transverse structure of jet, connection to virtuality of initial parton
- Mass using **calorimeter towers** ($\Delta\eta$ x $\Delta\phi$ = 0.1 x 0.1)

$$m = \sqrt{\Big(\sum_{i \in J} E_i\Big)^2 - \Big(\sum_{i \in J} \vec{p}_i\Big)^2}$$

- Fully **corrected** for the detector effects using 2D Bayesian unfolding, p_T = 126-500 GeV, |y|<2.1
- Observable is $\boldsymbol{m/p_T}$ (dimensionless quantity, weak dependence on p_T, easier unfolding)

ATLAS-CONF-2018-014

Jet R_{AA} vs. mass at 5.02 TeV

$$\frac{d\sigma}{d(m/p_T)}(p_T) = \frac{1}{\mathcal{L}_{Int}} \frac{dN_{jet}^{|y|<2.1}}{d(m/p_T)}(p_T)$$

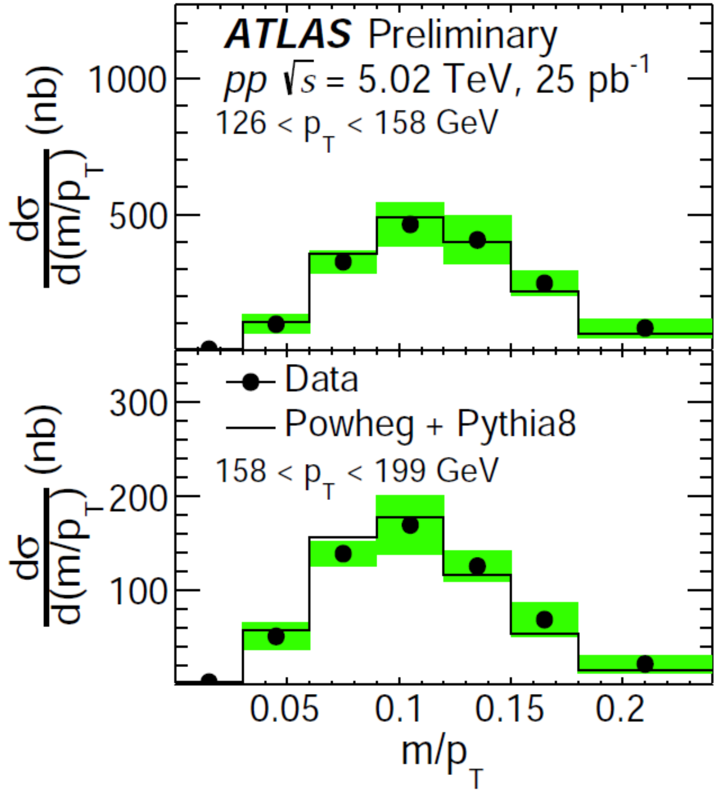
… in *pp*

$$R_{AA}(m/p_T, p_T) = \frac{\left. \frac{1}{N_{evt}} \frac{dN_{jet}^{Pb+Pb}}{d(m/p_T)}(p_T) \right|_{cent}}{\langle T_{AA} \rangle \frac{d\sigma_{jet}^{pp}}{d(m/p_T)}(p_T)}$$

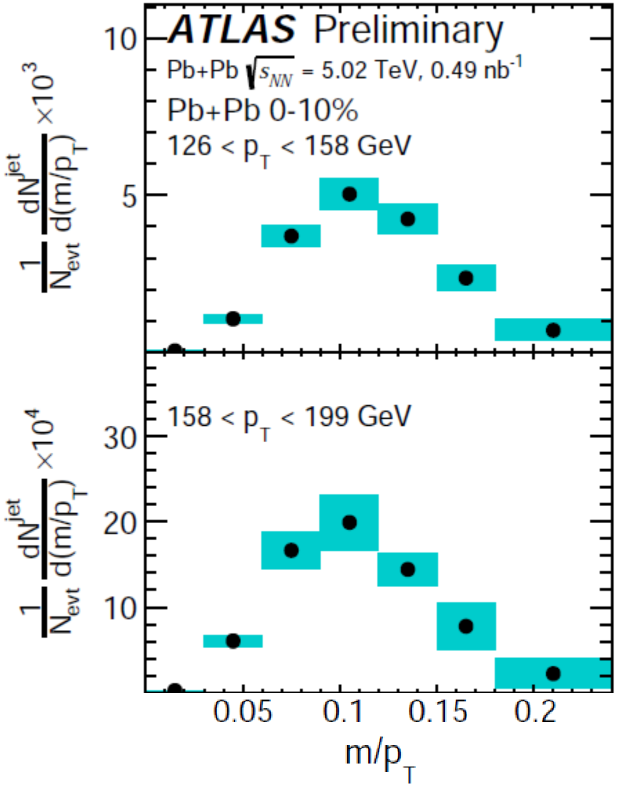
… in Pb+Pb

Jet mass distributions

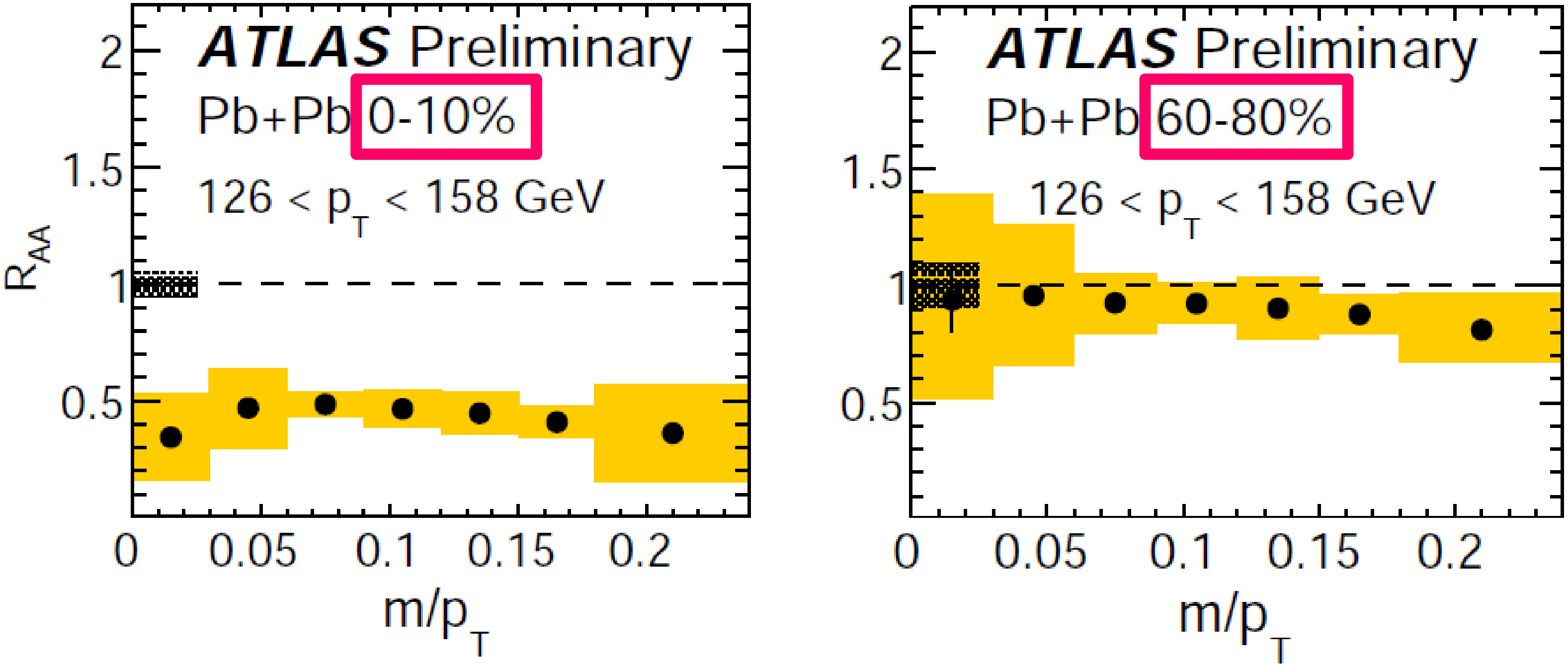
pp



Pb+Pb



$R_{AA}(m/p_T)$



- No significant variations of jet R_{AA} **with varying m/p_T**

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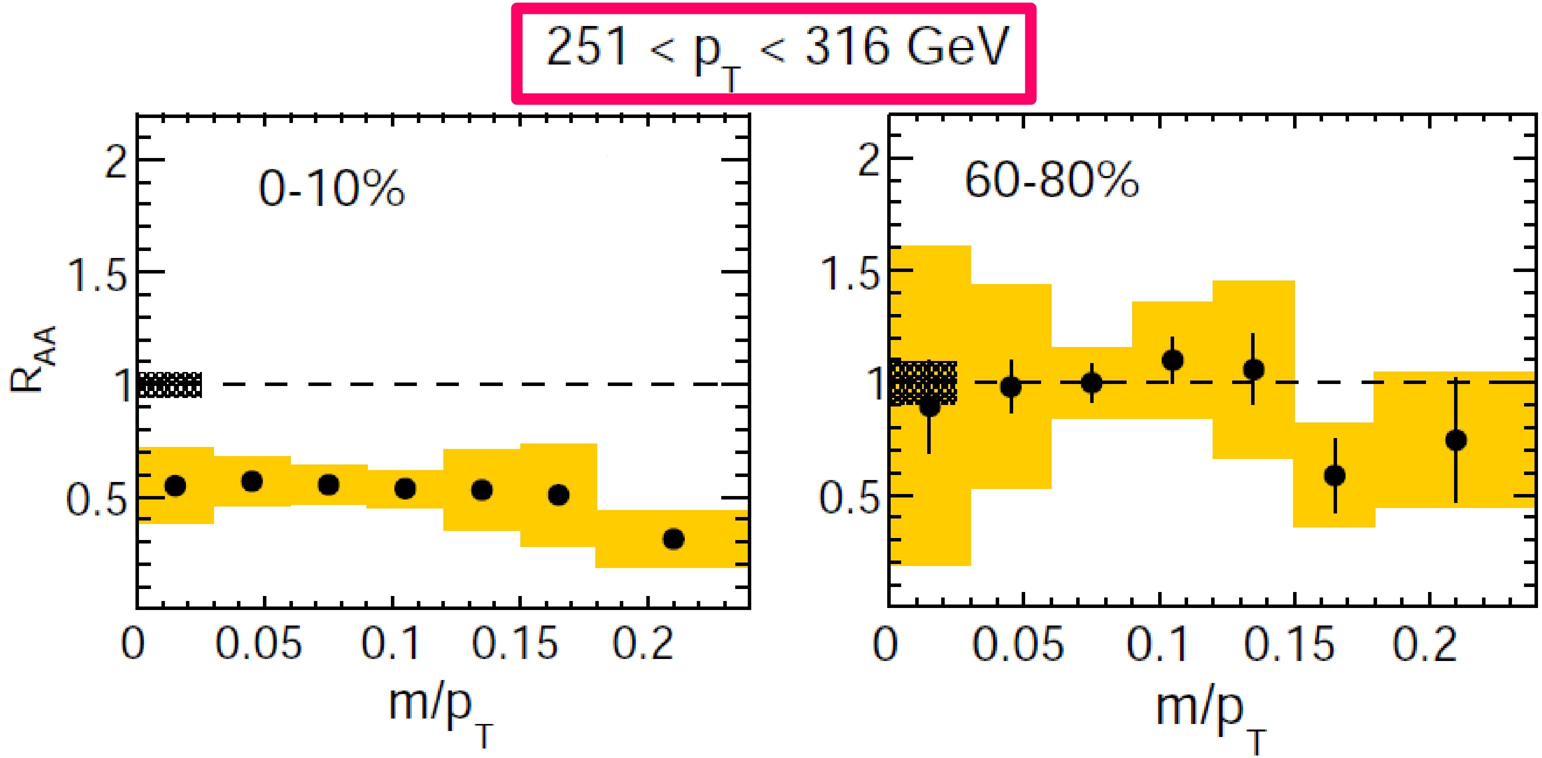
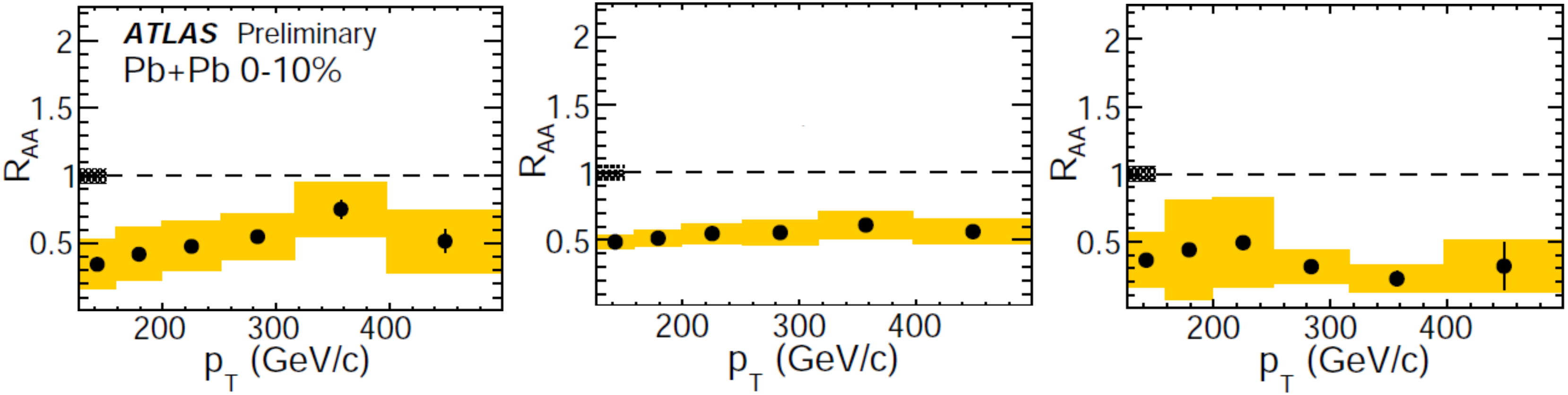


- No significant variations of jet R_{AA} **with varying m/p_T**
- No significant change **with increasing jet p_T**

$R_{AA}(p_T)$ in m/p_T

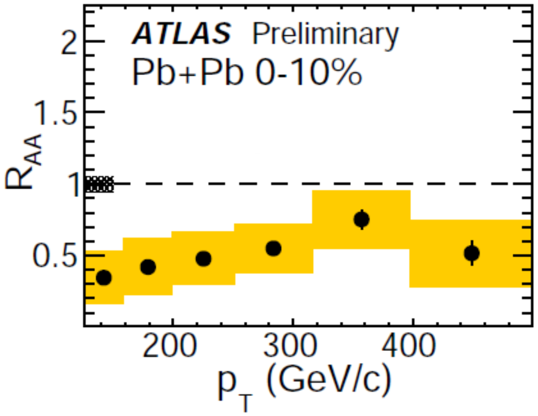
$m/p_T < 0.03$ | $0.06 < m/p_T < 0.09$ | $0.18 < m/p_T < 0.24$



- Jet $R_{AA}(p_T)$ in bins of m/p_T
- All m/p_T bins consistent with inclusive jet $R_{AA}(p_T)$

$R_{AA}(p_T)$ in m/p_T

$m/p_T < 0.03$



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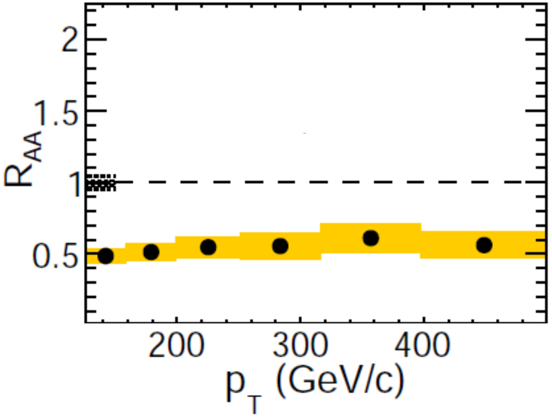

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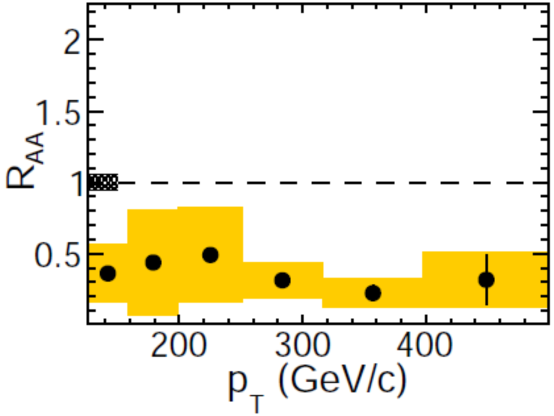

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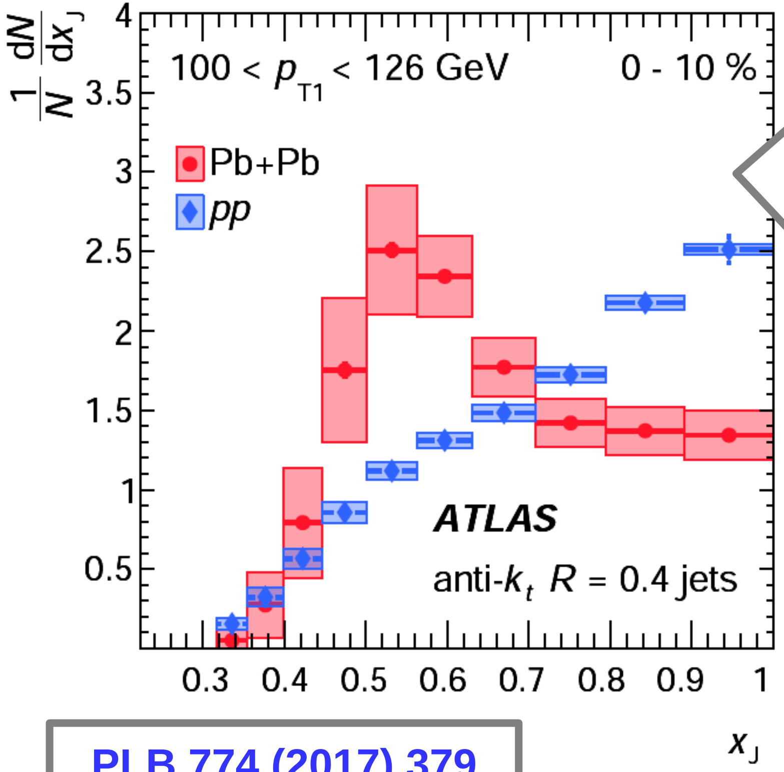
Poster JET-16
by Yongsun Kim

Reminder: Dijet asymmetry

$$x_J = \frac{p_{T,1}}{p_{T,2}}$$



PLB 774 (2017) 379

- **Measured for:**
  - $p_{T,subleadning}$ >25 GeV,
  - $p_{T,leading}$ >100 GeV (various bins),
  - $|\Delta\varphi| > 7\pi/8$
  - $|\eta| < 2.1$
  - R=0.4, R=0.3 jets

- Corrected to **particle-level** by 2D bayesian unfolding (in p_{T1} and p_{T2} simultaneously).
- Energy **loss very different** for the second jet.

x_J in Xe+Xe

- Xe+Xe: smaller system, larger eccentricity
  … impact on jet suppression?

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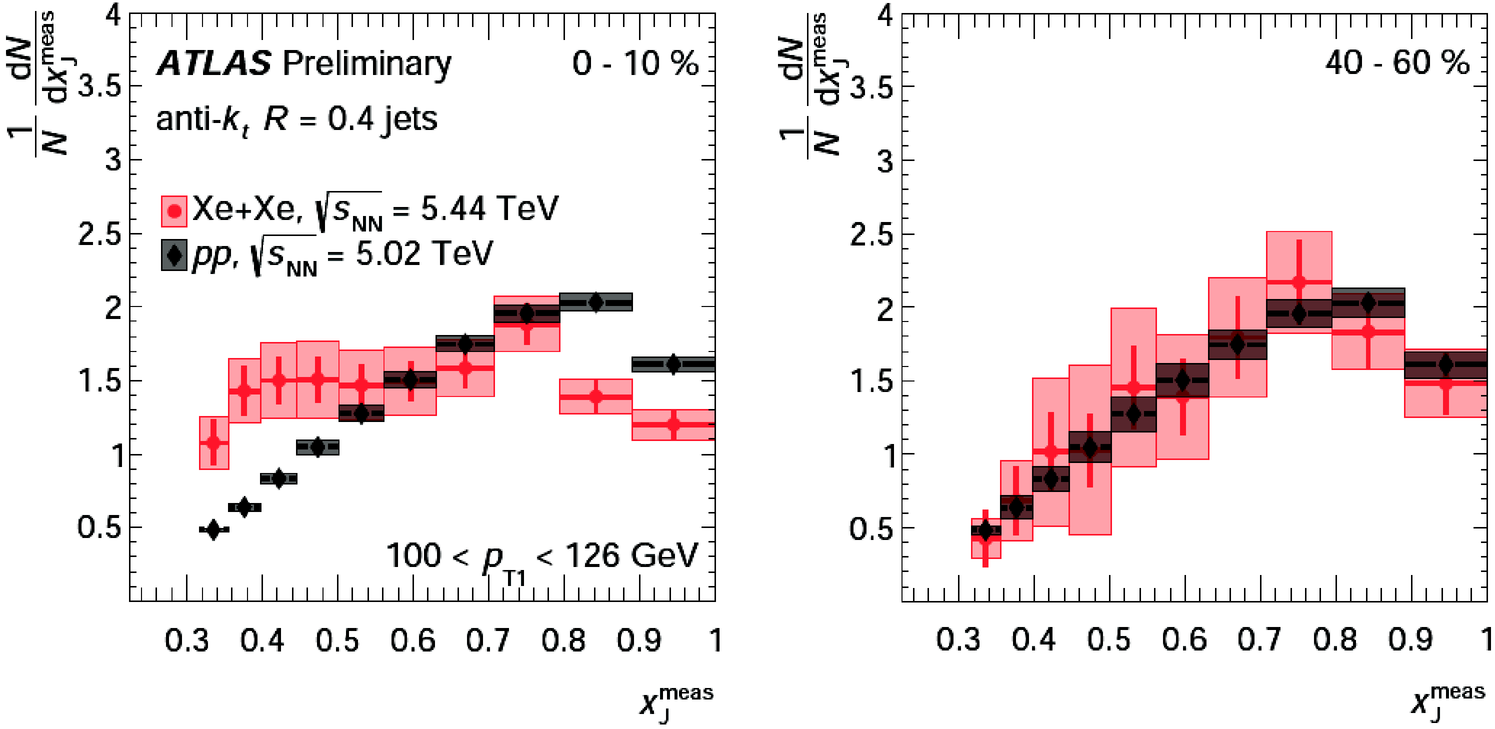
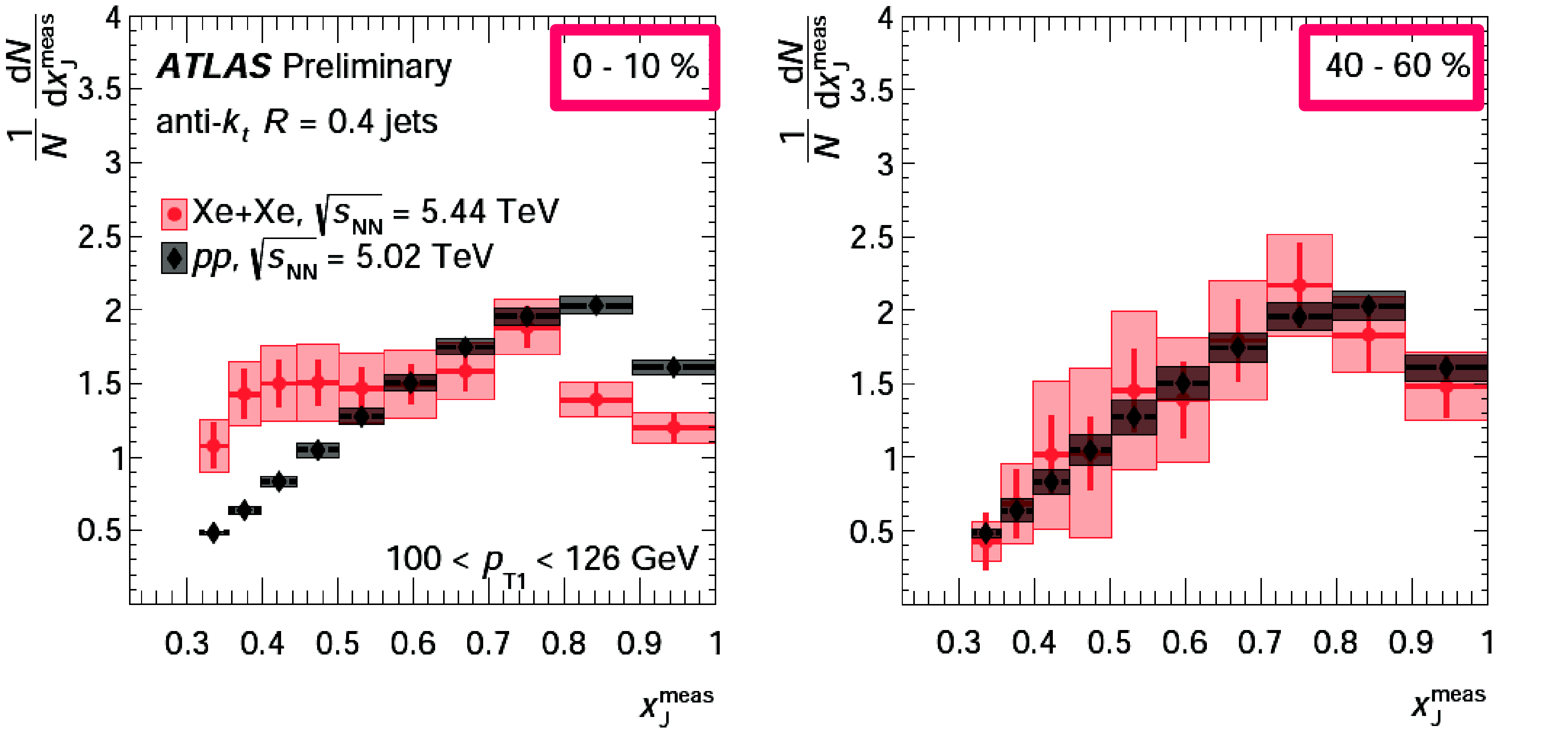
ATLAS-CONF-2018-007



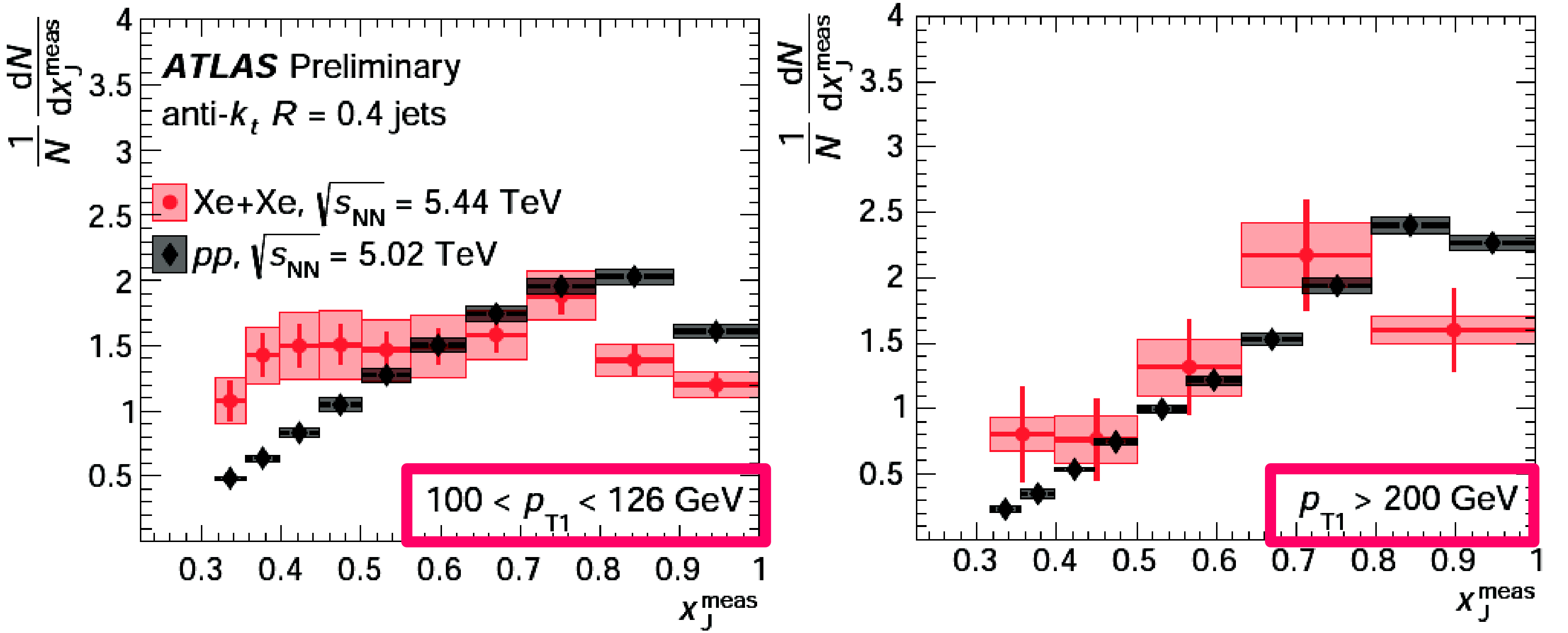
x_J in Xe+Xe

- Not unfolded for the detector response … but still **similar to Pb+Pb**
- x_J decreases with decreasing **centrality**



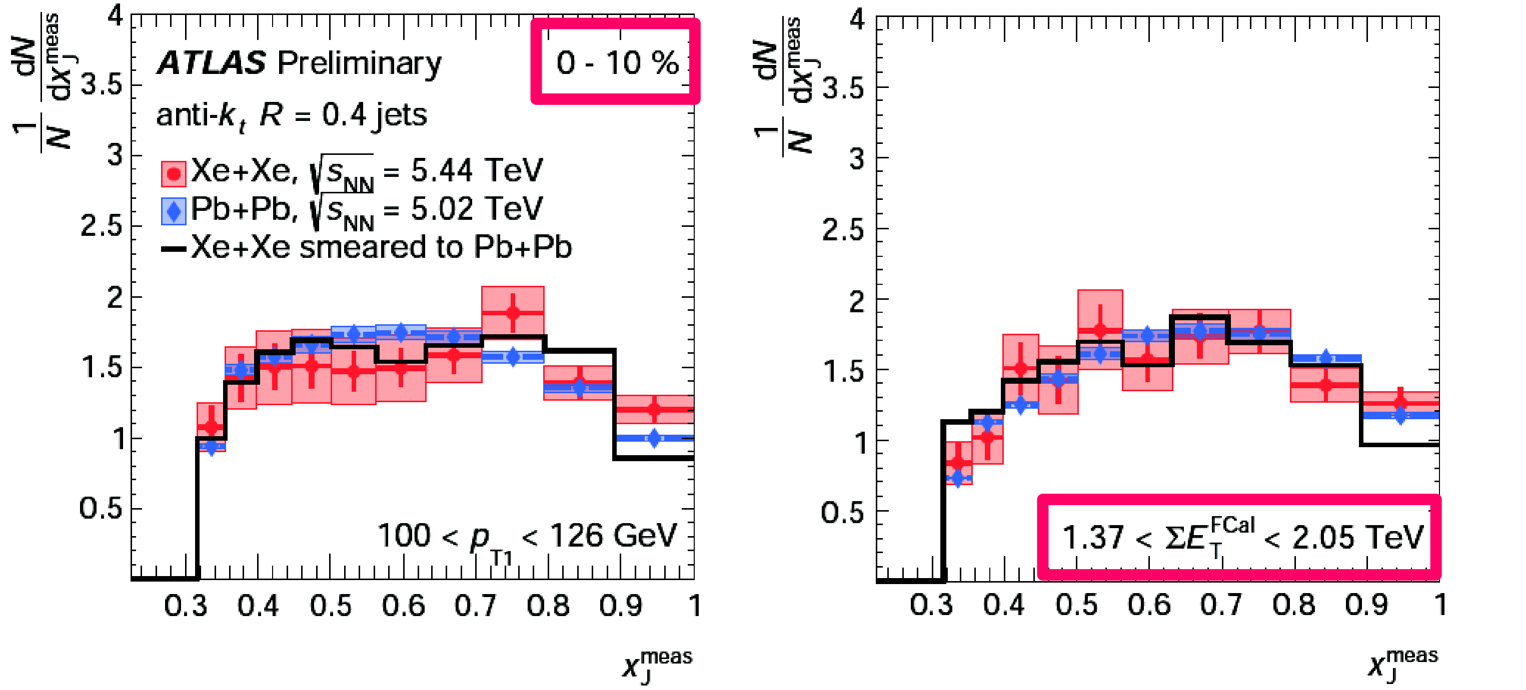
x_J in Xe+Xe

- Not unfolded for the detector response … but still **similar to Pb+Pb**
- **Larger dijet asymmetry** decreases with increasing jet p_T



Xe+Xe versus Pb+Pb

- Consistent in same **centrality percentiles** (left)
- Consistent in same **FCal E_T bins** (right)



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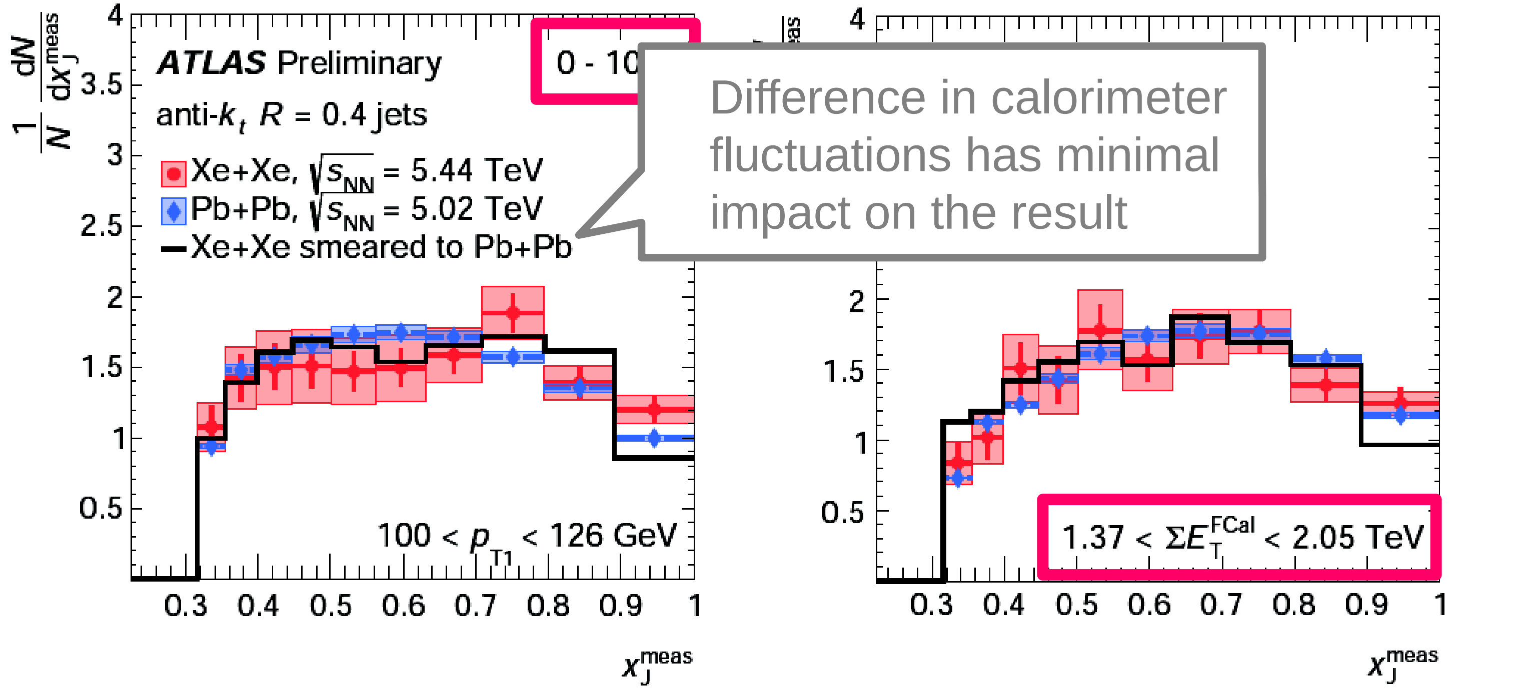

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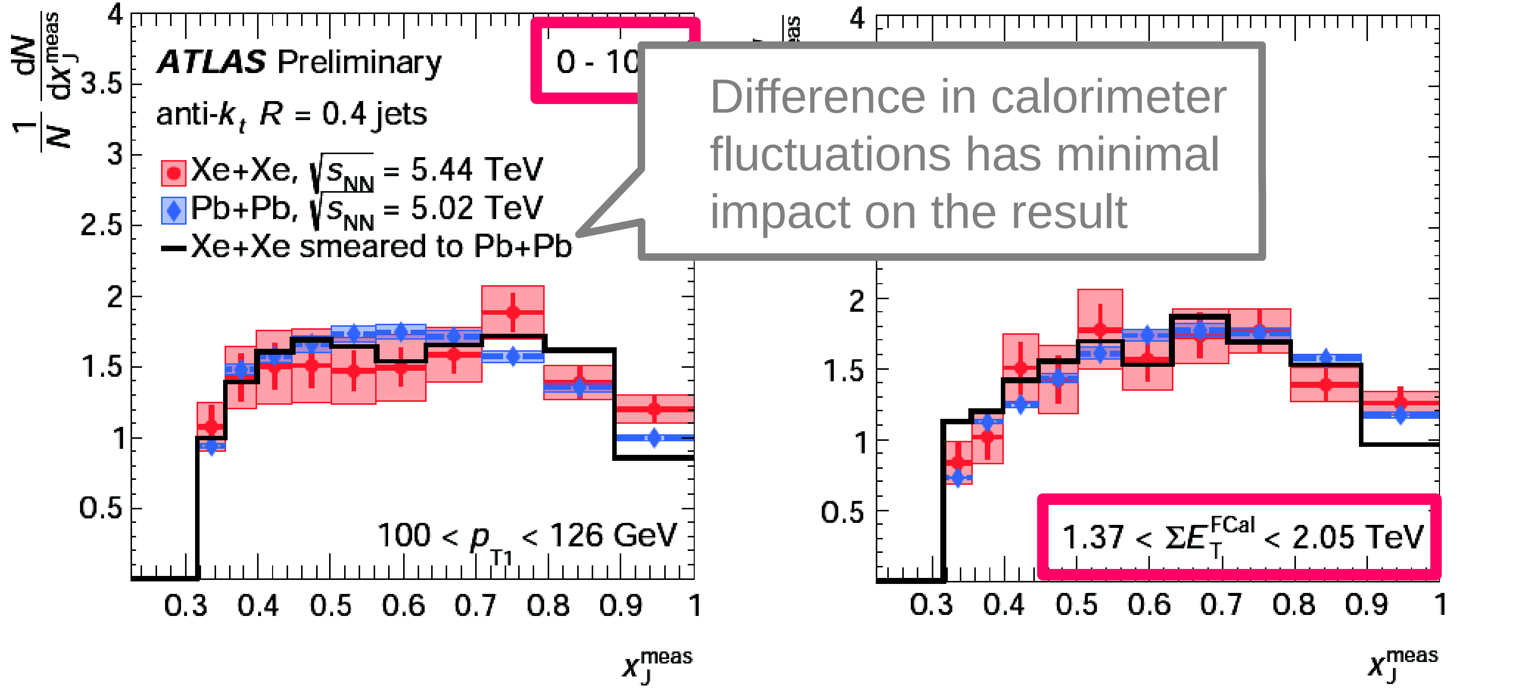
Xe+Xe quenching, more by Petr Balek Tue 9:40



Summary

- **Inclusive jet suppression** in 5.02 TeV Pb+Pb collisions:
  - Significant suppression seen up to ~1 TeV with weak p_T dependence.
  - Sign of rapidity dependence of R_{AA} observed for high-p_T jets.
  - No differences in R_{AA} between 2.76 TeV and 5.02 TeV.
- **Jet mass** in 5.02 TeV Pb+Pb collisions:
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  - No differences between the two collision systems observed.

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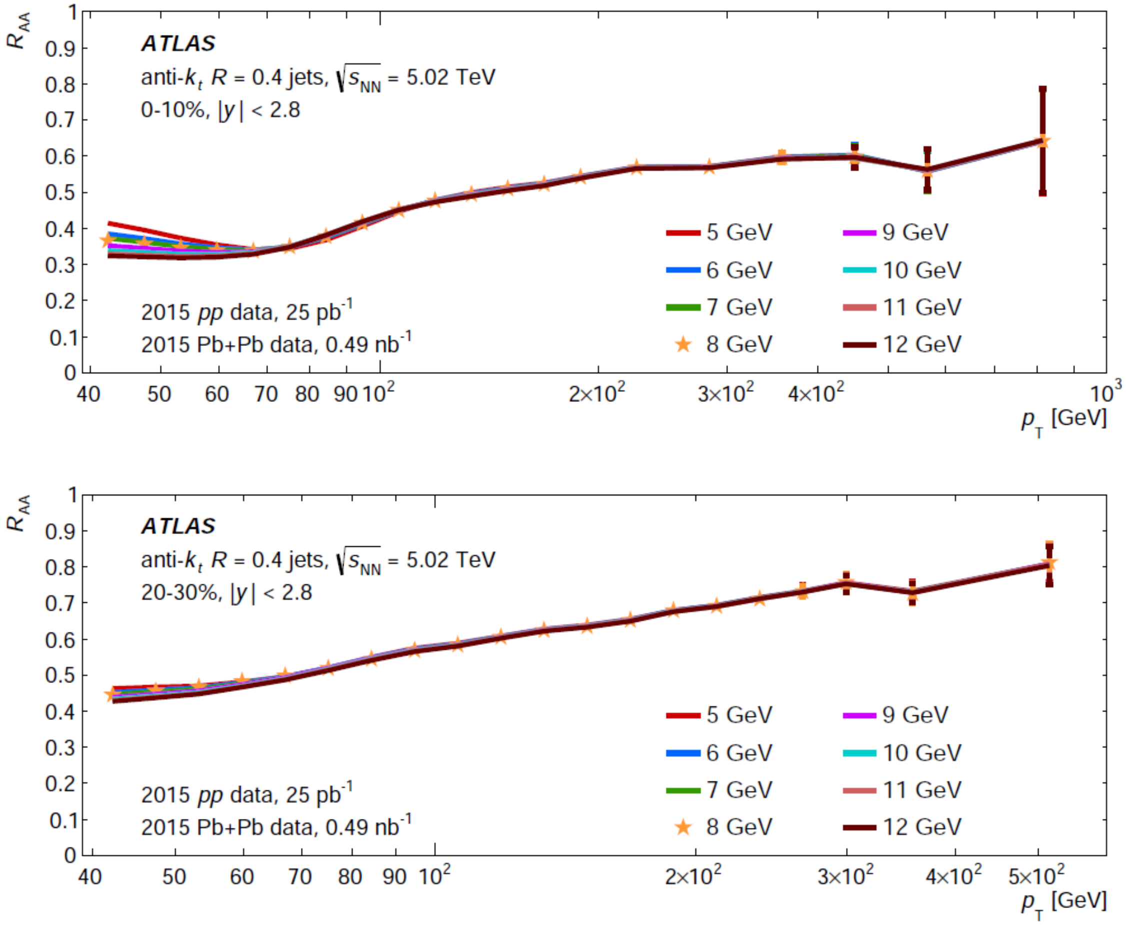
More on
jet structure
Martin Rybář
Wed 12:30

More on
jet structure
Akshat Puri
JET-27

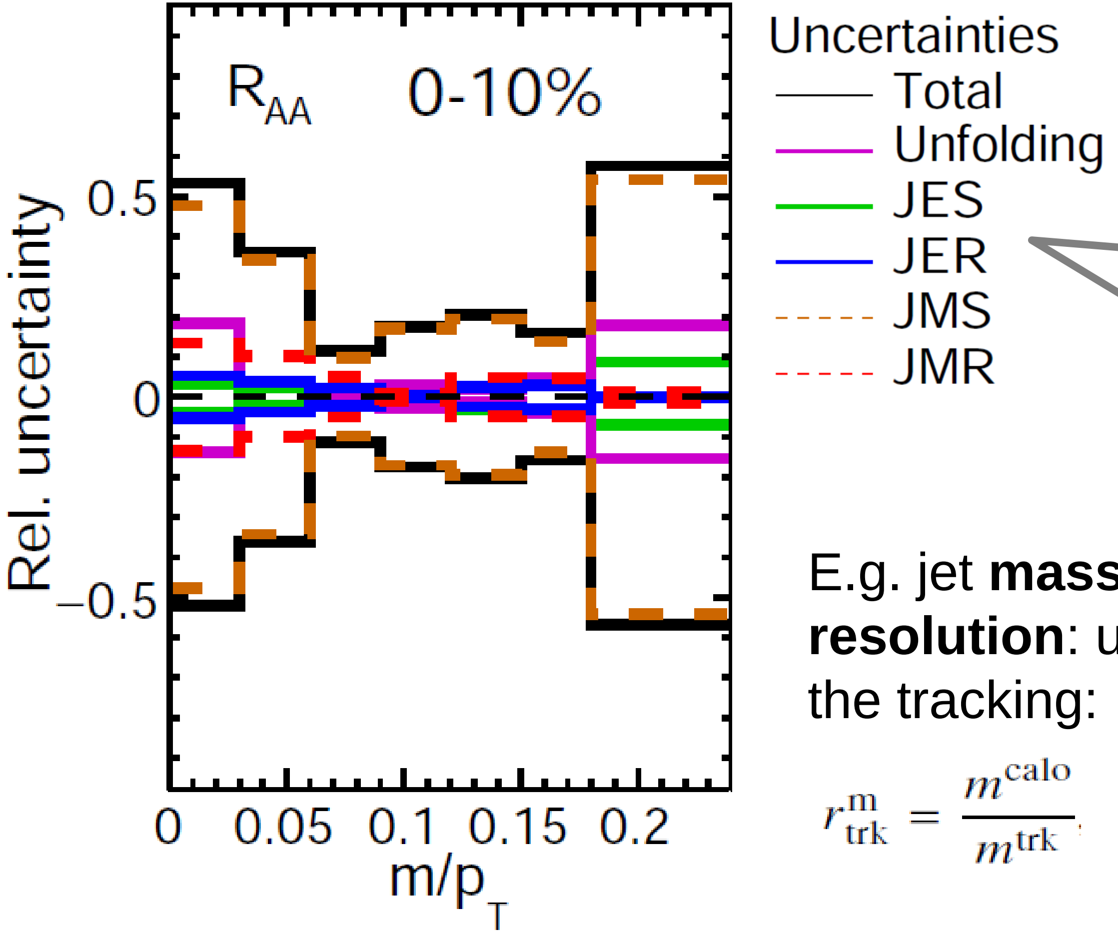
More on
structure and γ-jets
Dennis Perepelitsa
Wed 9:20

Backup slides

Impact of UE fluctuations



Jet mass: systematics

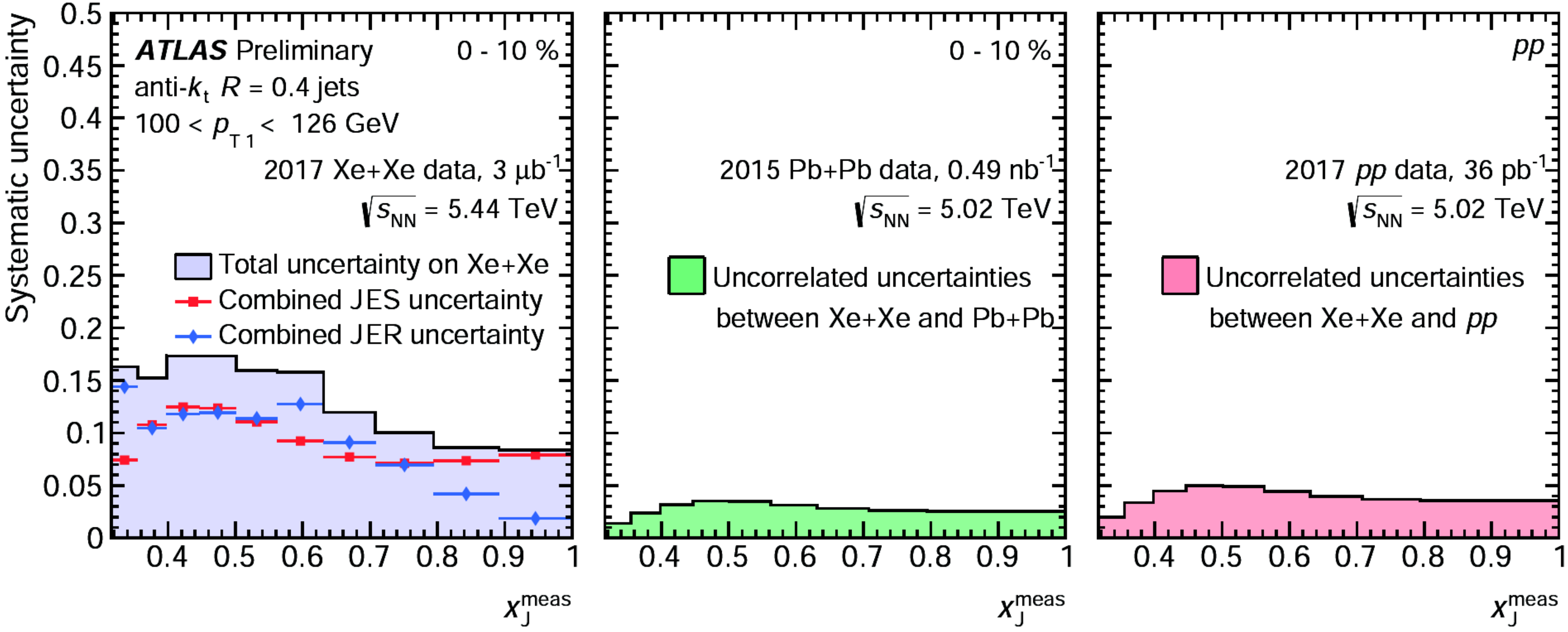


Jet energy scale and resolution … the same as for the inclusive R_{AA}

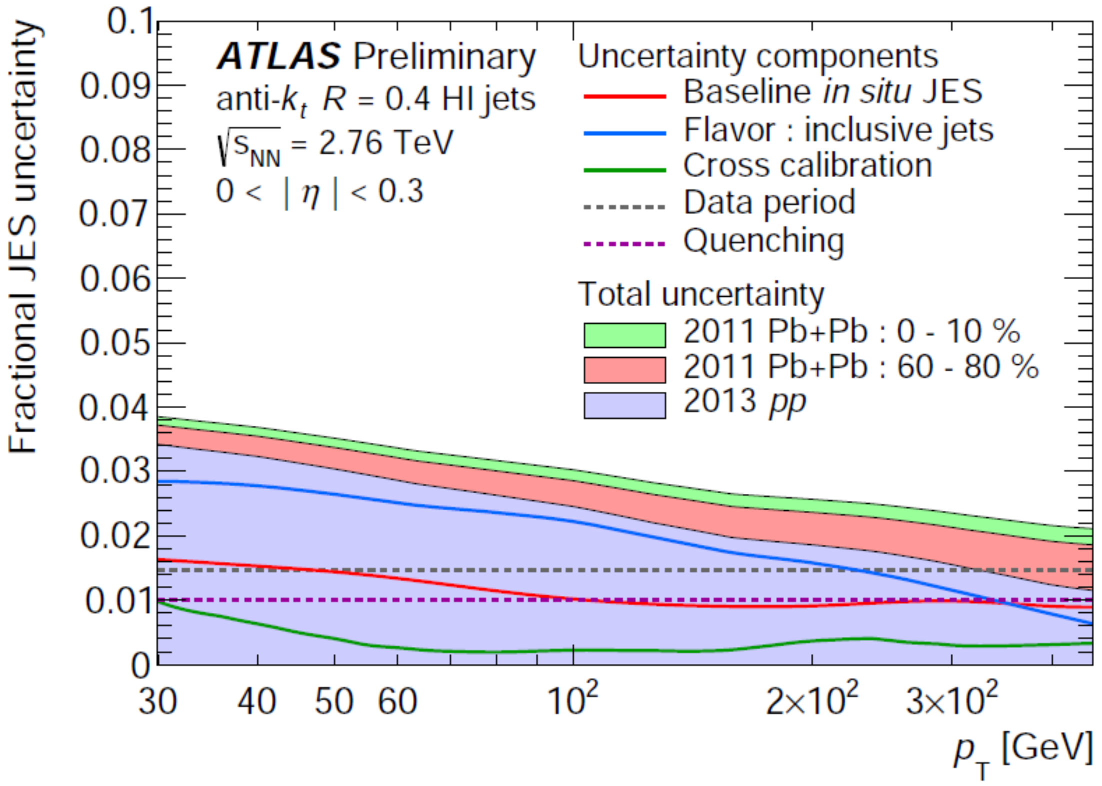
E.g. jet **mass scale**, jet **mass resolution**: using information from the tracking:

$$r^{m}_{trk} = \frac{m^{calo}}{m^{trk}} \longrightarrow R^{m} = \frac{\langle r^{m}_{trk} \rangle|_{data}}{\langle r^{m}_{trk} \rangle|_{MC}}$$

x_J: systematics



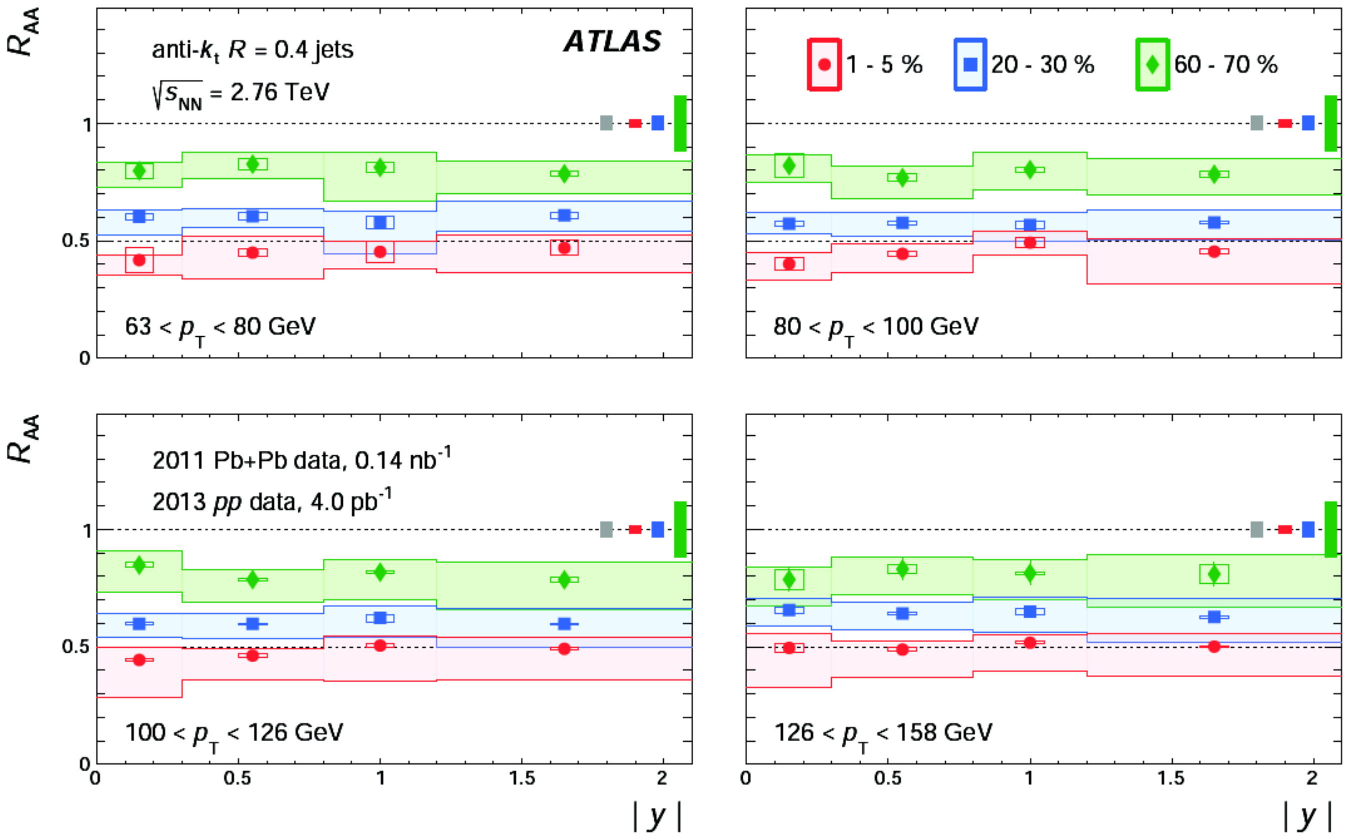
Jet energy scale uncertainties



Inclusive jet measurements

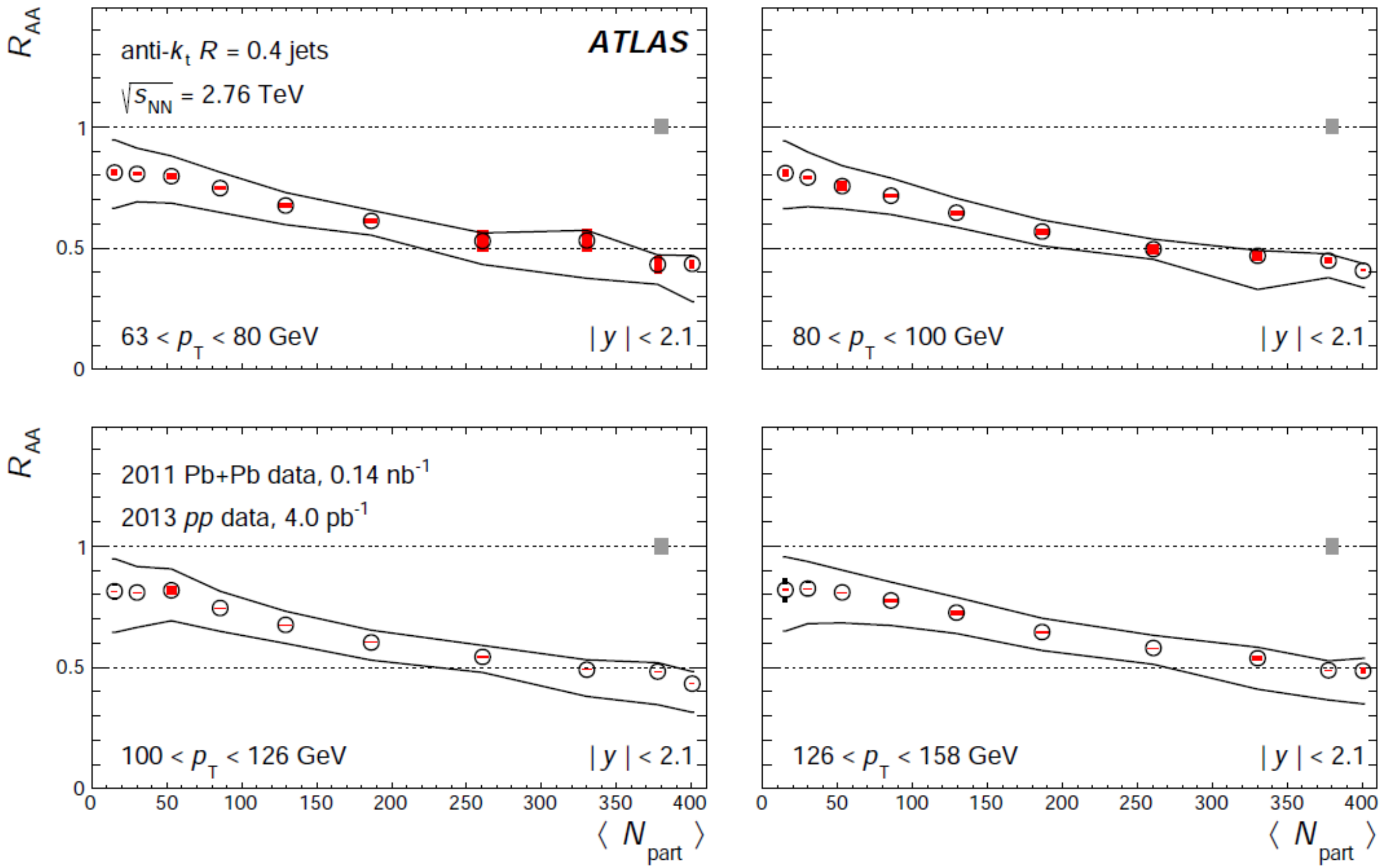
- Measurements of inclusive jet suppression:
  - Phys. Lett. B 719 (2013) 220 … Pb+Pb @ 2.76 TeV
  - Phys. Rev. Lett. 114 (2015) 072302 … pp, Pb+Pb @ 2.76 TeV
  - Phys. Lett. B 748 (2015) 392-413 … p+Pb @ 5.02 TeV
  - arXiv: 1805.05645 … pp, Pb+Pb @ 5.02 TeV
- Measurements of jet substructure via fragmentation functions:
  - Phys. Lett. B739 (2014) 320 … Pb+Pb @ 2.76 TeV
  - Eur. Phys. J. C 77 (2017) 379 … pp, Pb+Pb @ 2.76 TeV
  - arXiv: 1706.02859 … pp, p+Pb @ 5.02 TeV
  - arXiv: 1805.05424 ... pp, Pb+Pb @ 5.02 TeV
  - ATLAS-CONF-2018-009 … Pb+Pb @ 5.02 TeV (γ+jet)
- Jet substructure via jet mass: ATLAS-CONF-2018-014
- Dijet measurement in XeXe: ATLAS-CONF-2018-007

Jet R_{AA}



R_{AA}
anti-k_t R = 0.4 jets
$\sqrt{s_{NN}}$ = 2.76 TeV
ATLAS
1 - 5 %
20 - 30 %
60 - 70 %
63 < p_T < 80 GeV
80 < p_T < 100 GeV
2011 Pb+Pb data, 0.14 nb^{-1}
2013 pp data, 4.0 pb^{-1}
100 < p_T < 126 GeV
126 < p_T < 158 GeV
0
0.5
1
0
0.5
1
1.5
2
| y |

Jet R_{AA}



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| y | < 2.1
R_{AA}
$\langle N_{part} \rangle$