ILLINOIS

SINGLE JET AND DIJET MEASUREMENTS OF JET QUENCHING WITH THE ATLAS DETECTOR

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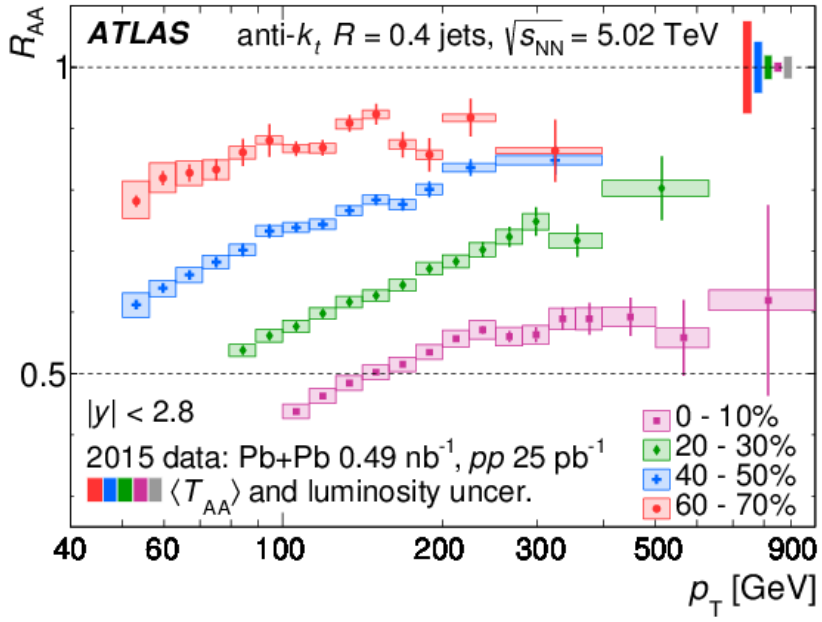
For the ATLAS Collaboration
June 1, 2020

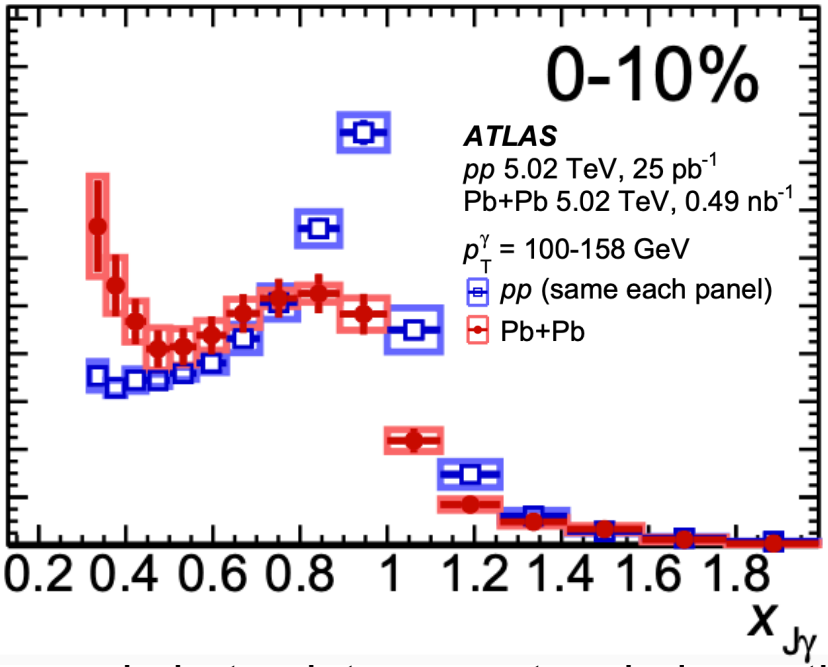
Hard Probes 2020

Jet energy loss

arXiv:1805.05635

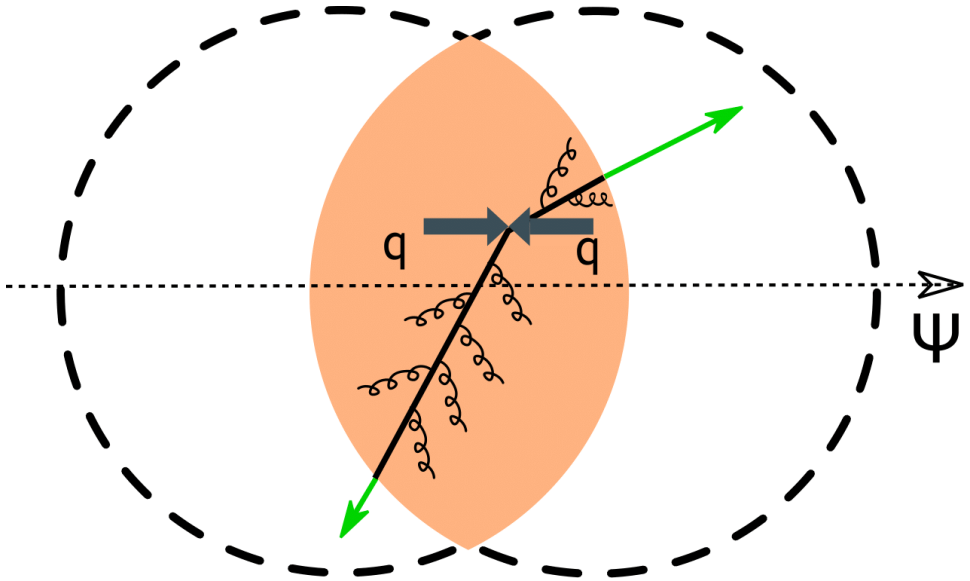


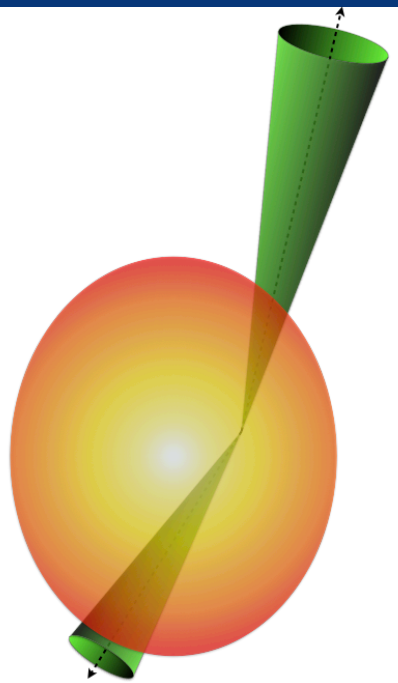
arXiv:1809.07280



- Shown through observables such as R_{AA} and photon jet momentum balance that jets lose energy when traversing QGP- up to 1 TeV in central collisions
- What is the mechanism of this energy loss?
- What is the path-length dependence to energy loss?
- What is the role of fluctuations?

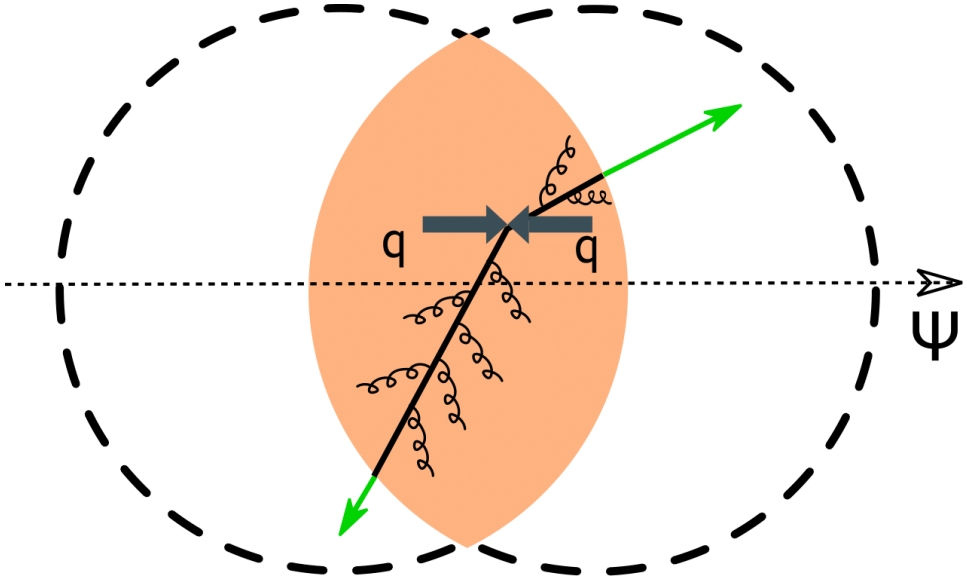
Measurements of jet energy loss





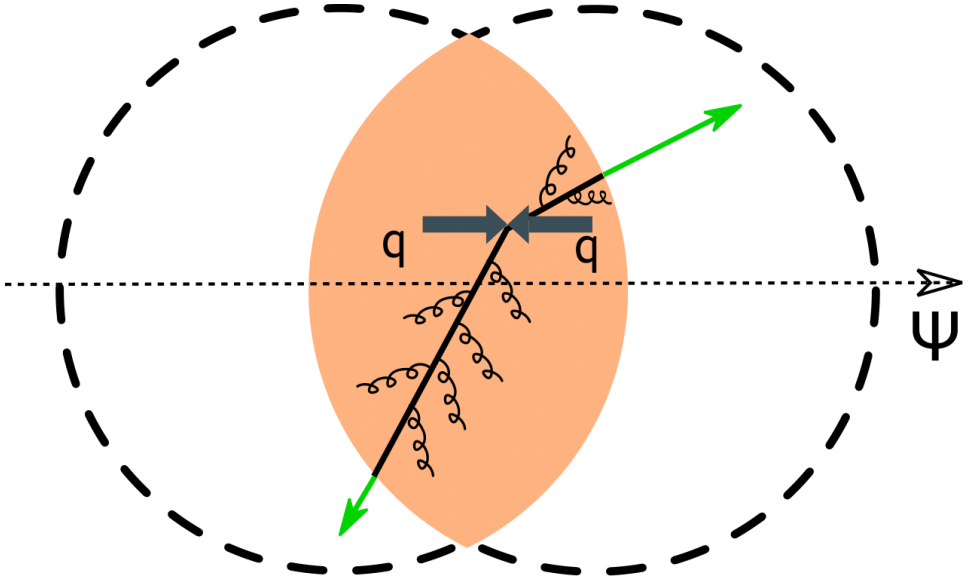
- Dijet momentum balance:
  - Imbalance in jet momentum of back-to-back jets in Pb+Pb collisions compared to *pp* is a signature of energy loss
  - Unequal energy loss could be explained by jets traversing different path lengths of QGP

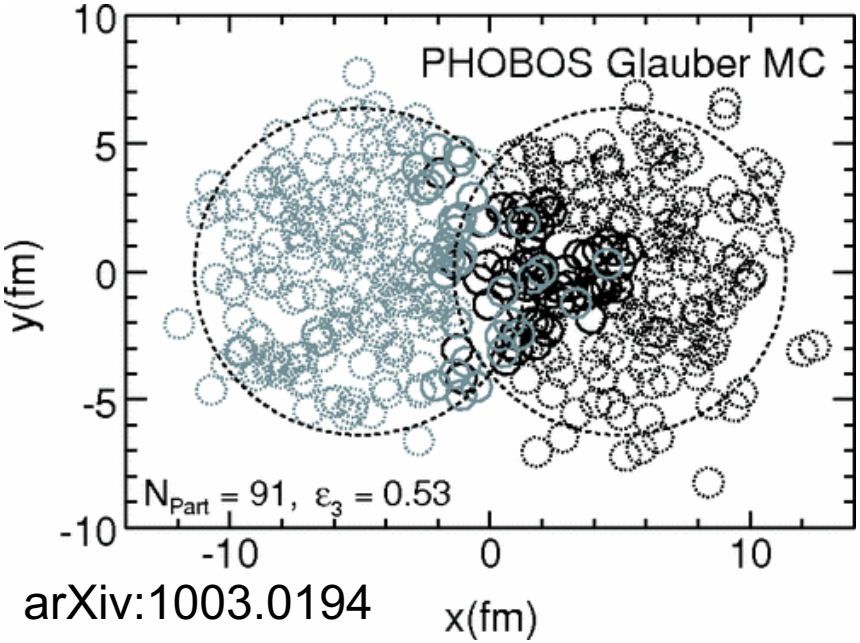
Measurements of jet energy loss



- Jet v_n
  - Path-length dependent energy loss can cause higher jet yield in-plane vs. out-of-plane, causing a positive v_2

Measurements of jet energy loss

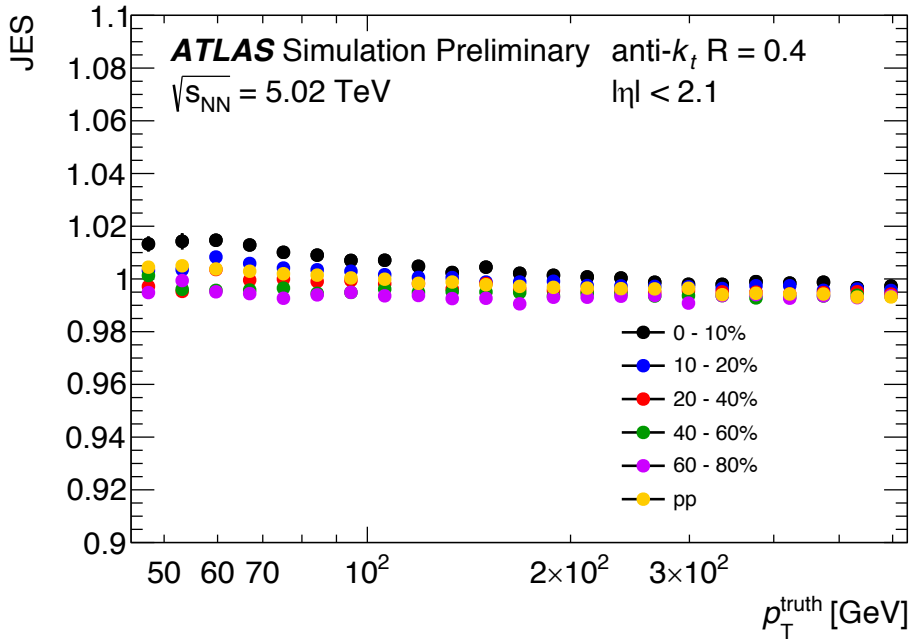




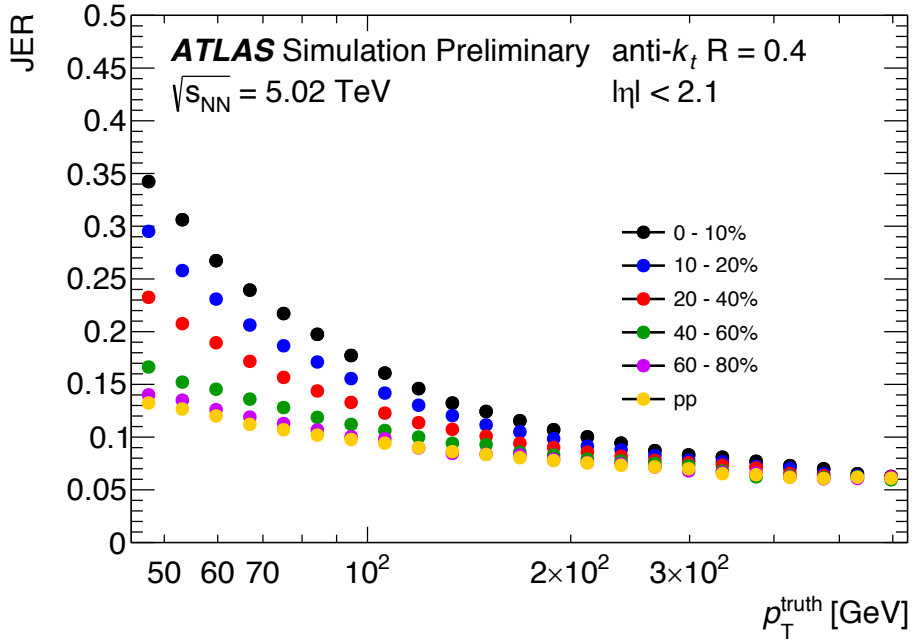
- Jet v_n
  - Path-length dependent energy loss can cause higher jet yield in-plane vs. out-of-plane, causing a positive v_2
  - Jet $v_{n>2}$ can give insight into the role of fluctuations in the initial state

Jet performance R = 0.4

Scale



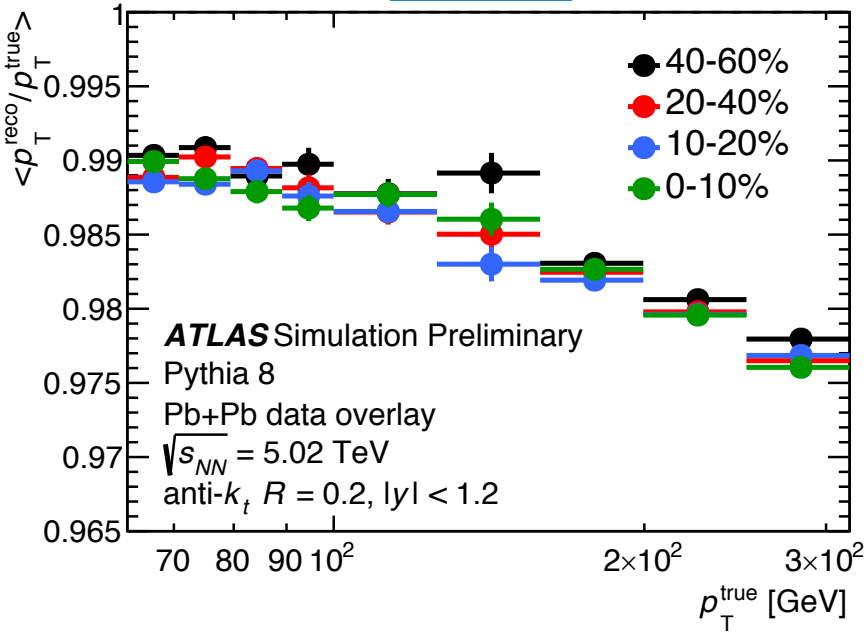
Resolution



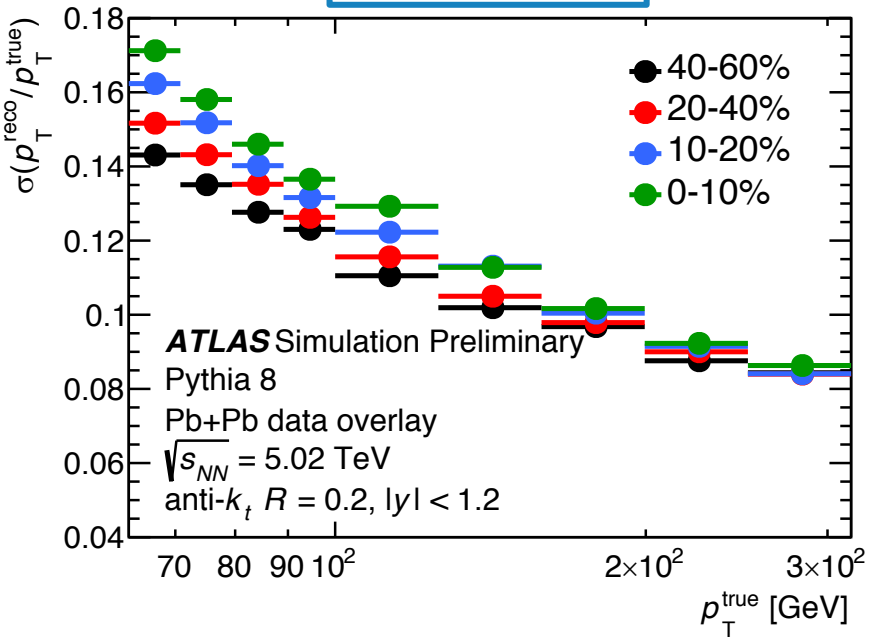
- Dijet momentum balance measured using R = 0.4 jets
- $|\eta| < 2.1$
- Measurement is unfolded to correct for JES/JER effects

Jet performance R = 0.2

Scale



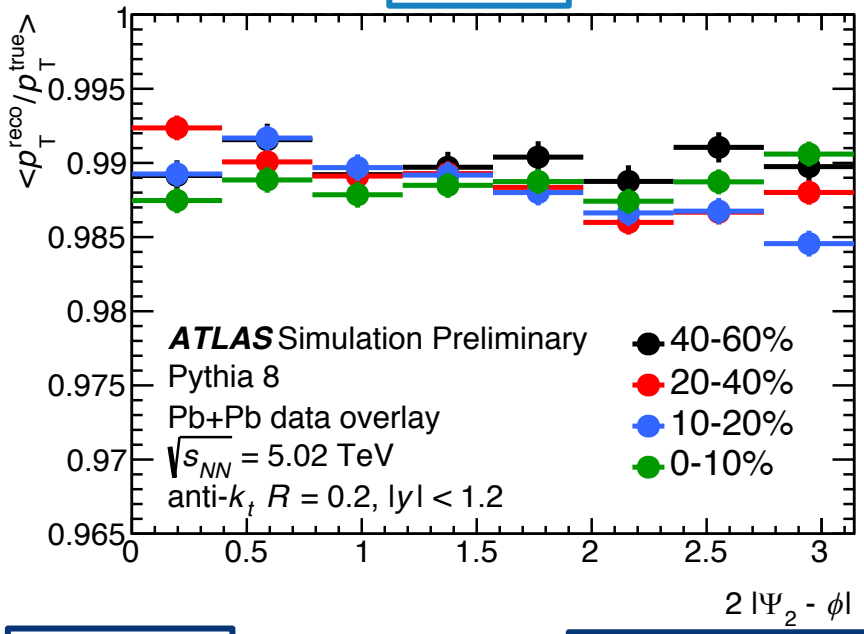
Resolution



- Jet v_n measured using R = 0.2 jets
- Measurement is unfolded to correct for JES/JER effects

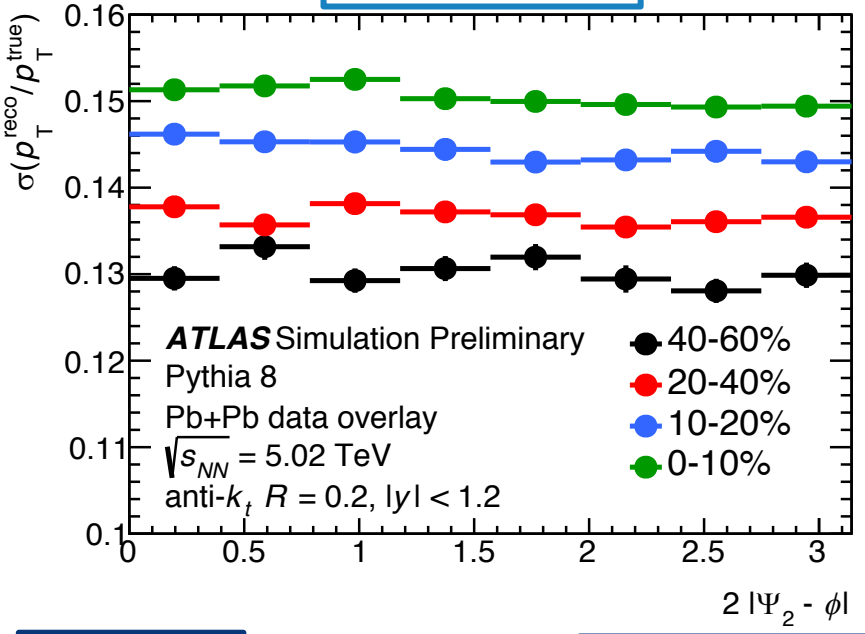
Jet performance R = 0.2

Scale



In-plane → **Out-of-plane**

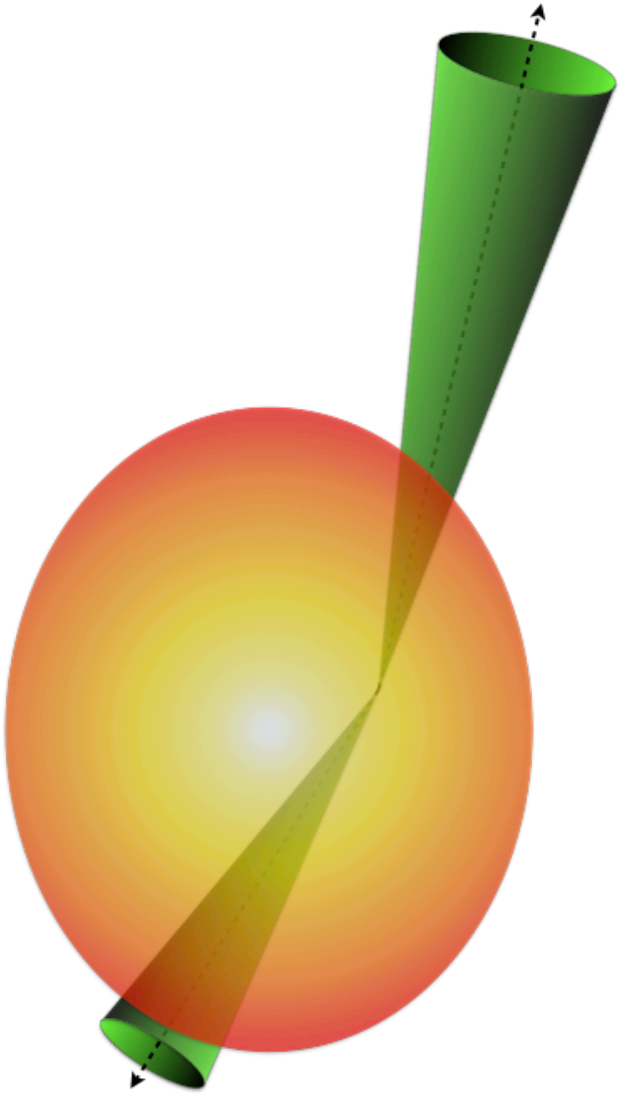
Resolution



In-plane → **Out-of-plane**

- Jet v_n measured using R = 0.2 jets
- Measurement is unfolded to correct for JES/JER effects
- $|y| < 1.2$ chosen to minimize JES and JER dependence on angle with respect to the event plane

Dijet momentum balance

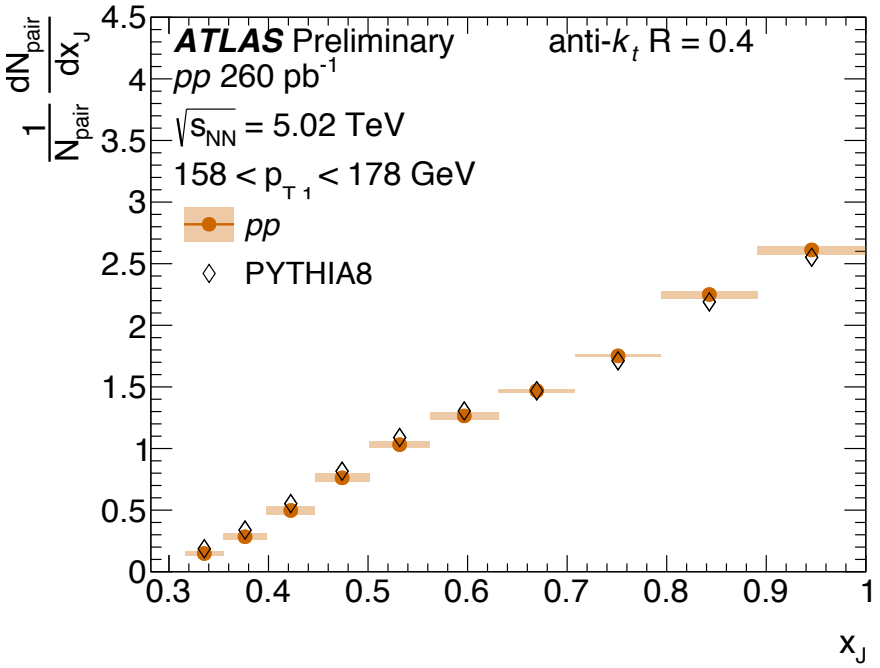


$$x_J = \frac{p_{\mathrm{T},2}}{p_{\mathrm{T},1}}$$

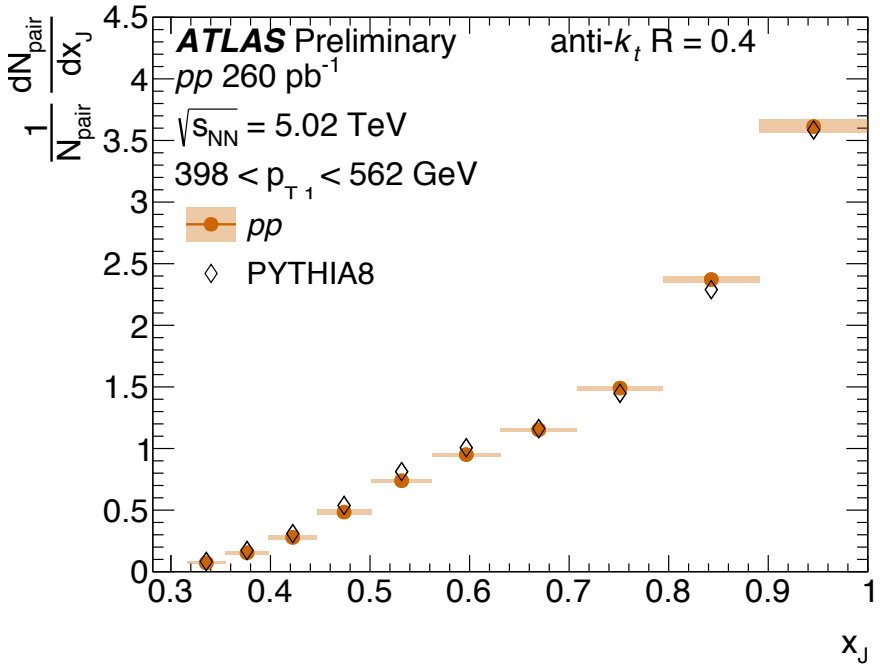
- x_J measured for 5.02 TeV Pb+Pb and *pp* collisions as a function of leading jet p_T ($p_{T,1}$) and centrality
- Dijet pairs selected back-to-back with $|\Delta\varphi| > 7\pi/8$
- Result is unfolded to account for migration in $p_{T,1}$ and $p_{T,2}$

Dijet momentum balance- Pythia comparison

158 – 178 GeV

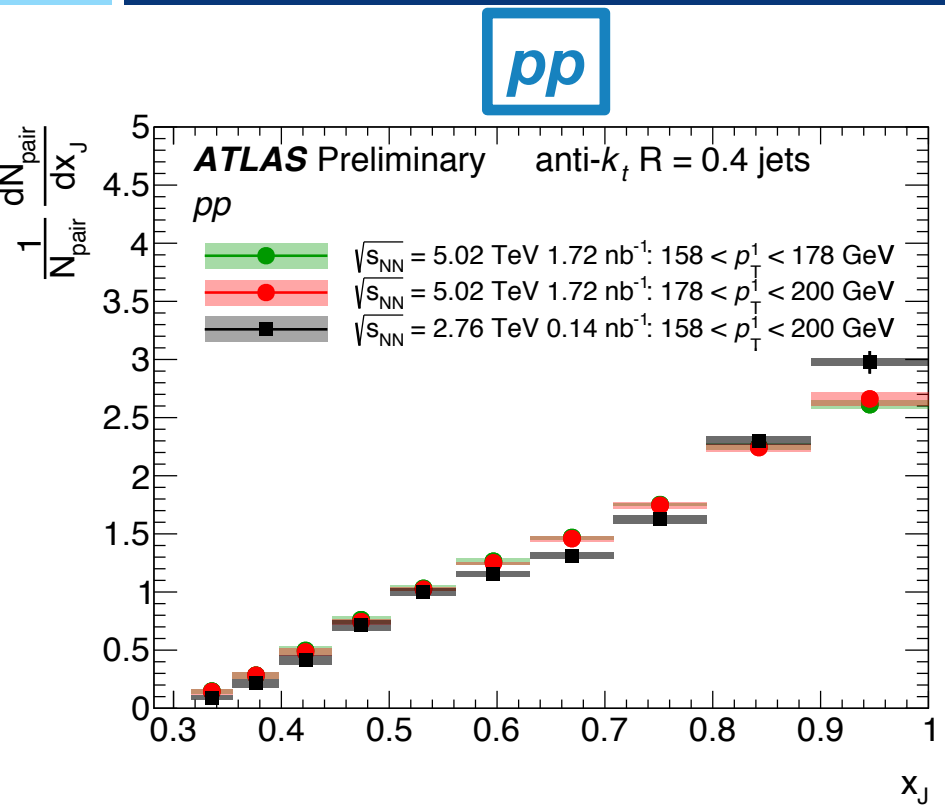


398 – 562 GeV



- Compare *pp* measurement to Pythia8 using A14 ATLAS tune and NNPDF23LO PDFs
- x_J in *pp* collisions is very well described by Pythia8, both at low and high p_T

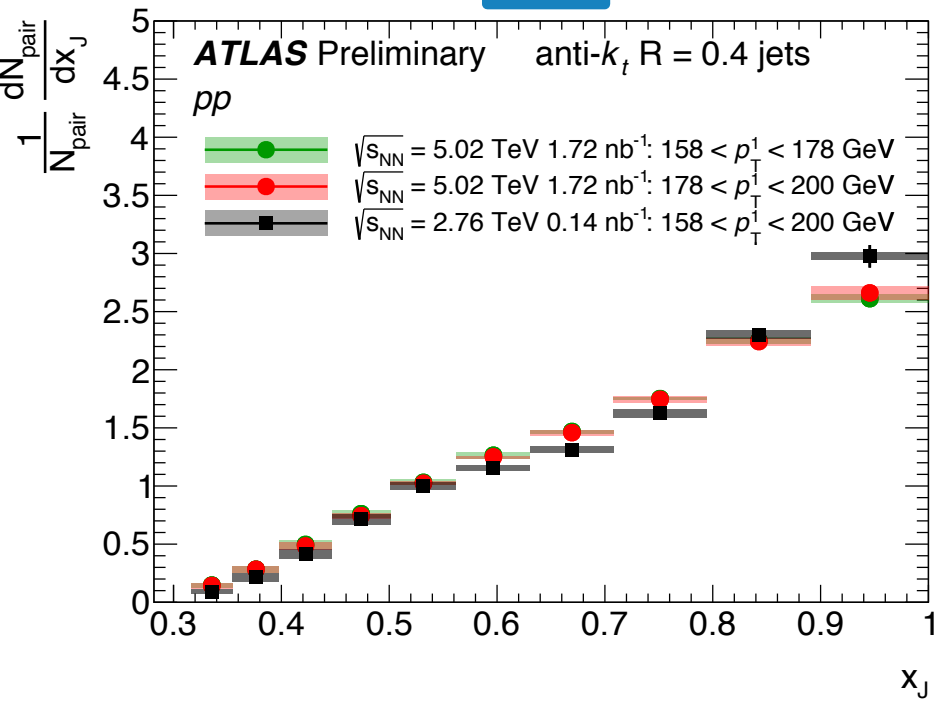
Dijet momentum balance- comparison to 2.76 TeV



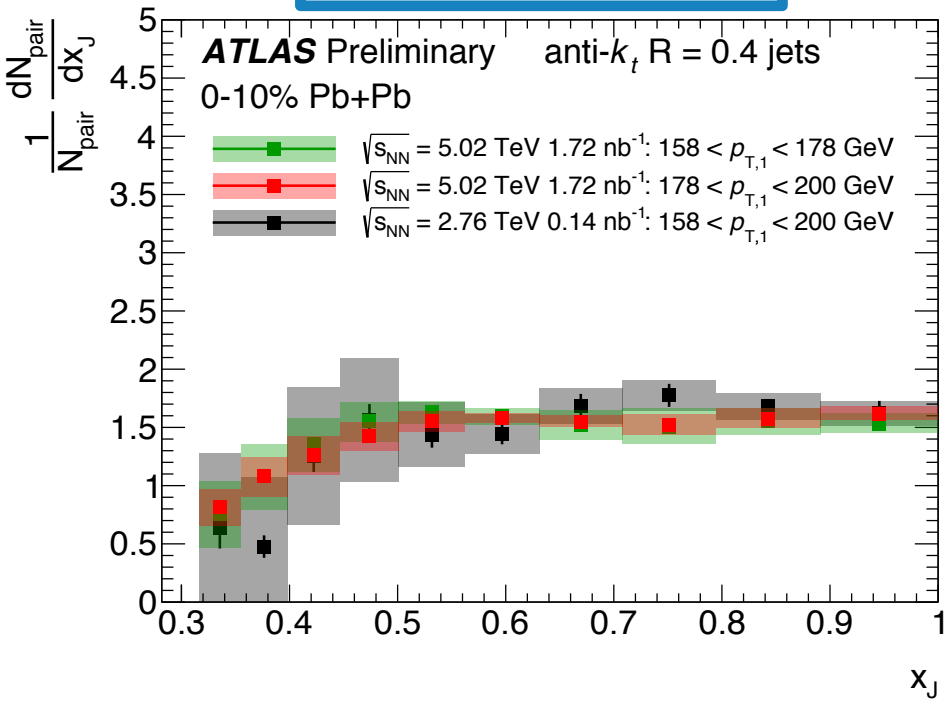
- Comparing to arXiv:1706.09363
- Depletion in high x_J dijet pairs in 5.02 TeV *pp* collisions compared to 2.76 TeV

Dijet momentum balance- comparison to 2.76 TeV

pp



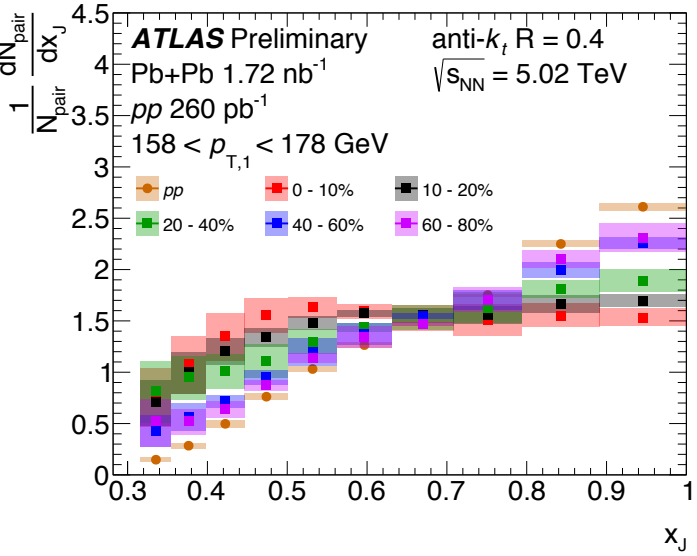
Central Pb+Pb



- Comparing to arXiv:1706.09363
- Depletion in high x_J dijet pairs in 5.02 TeV *pp* collisions compared to 2.76 TeV
- Results in Pb+Pb consistent within uncertainties between 5.02 TeV and 2.76 TeV

Dijet momentum balance- centrality dependence

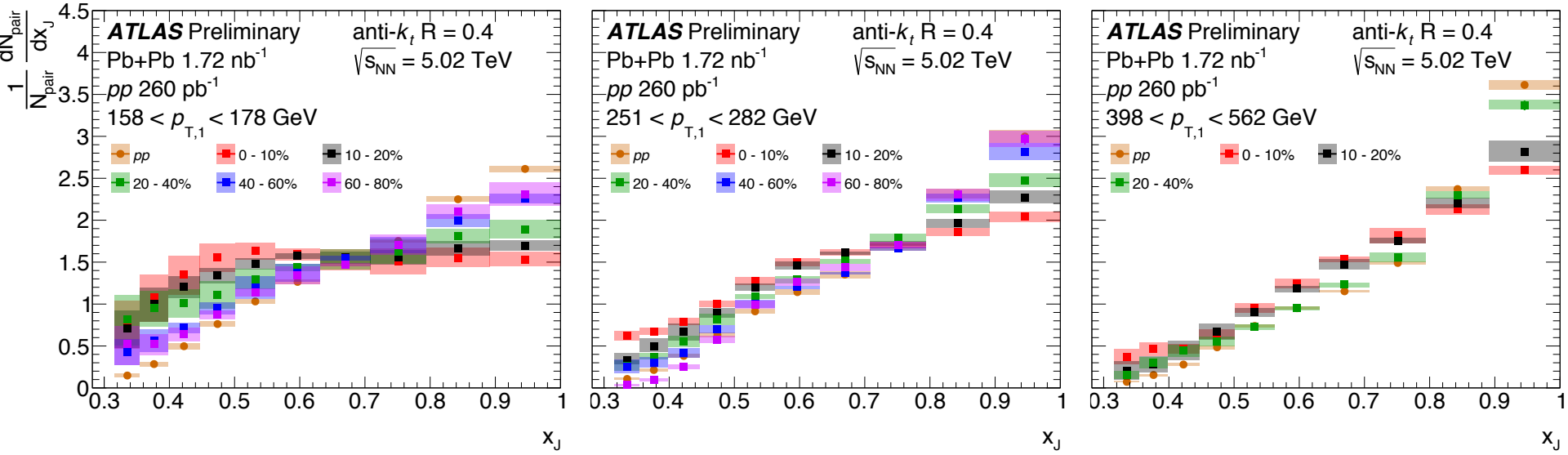
Leading jet p_T



- With increasing centrality observe a gradual flattening of the x_J distributions above $x_J > 0.5$
- Jets in peripheral Pb+Pb collisions have similar x_J distribution to *pp*

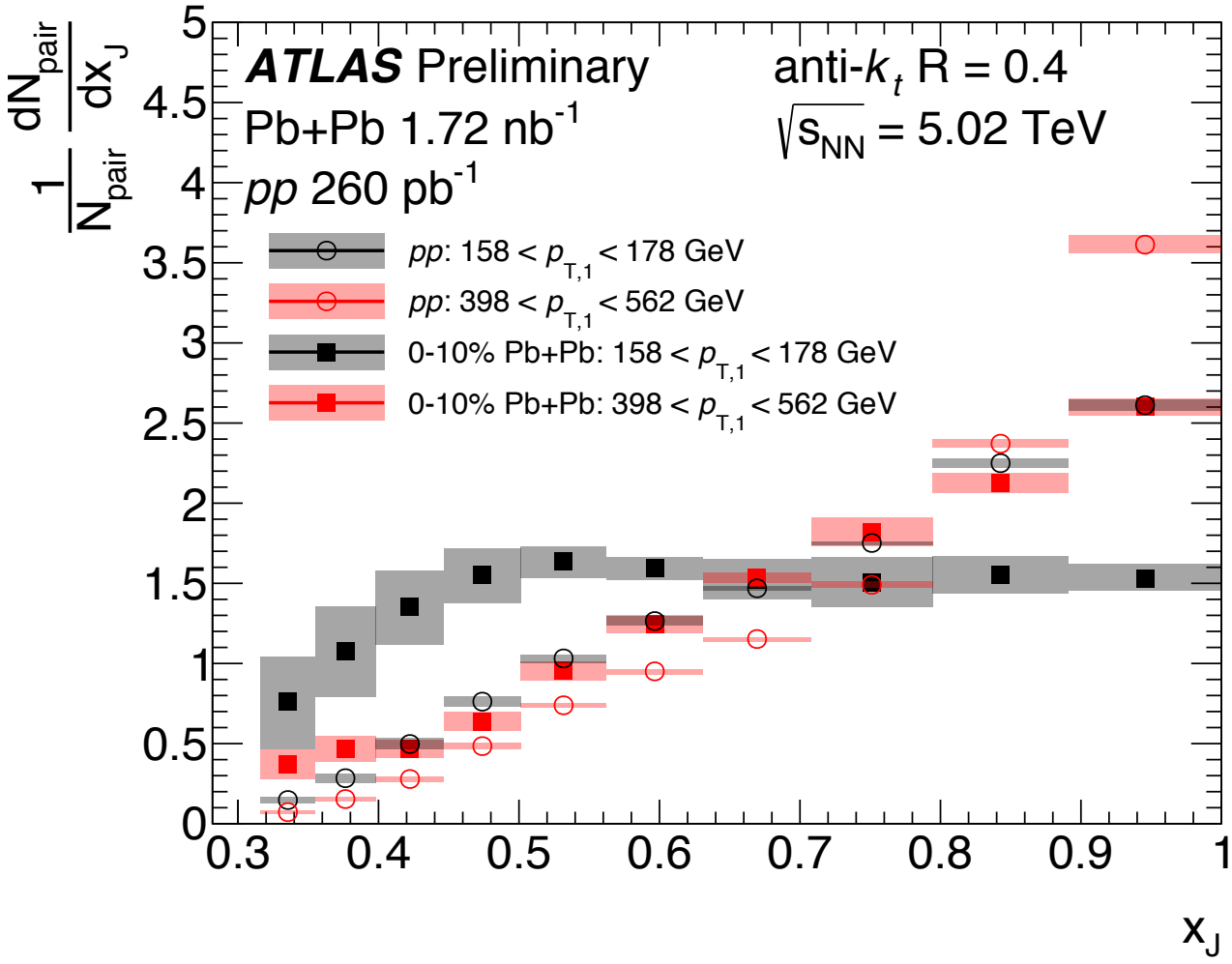
Dijet momentum balance- p_T dependence

Leading jet p_T



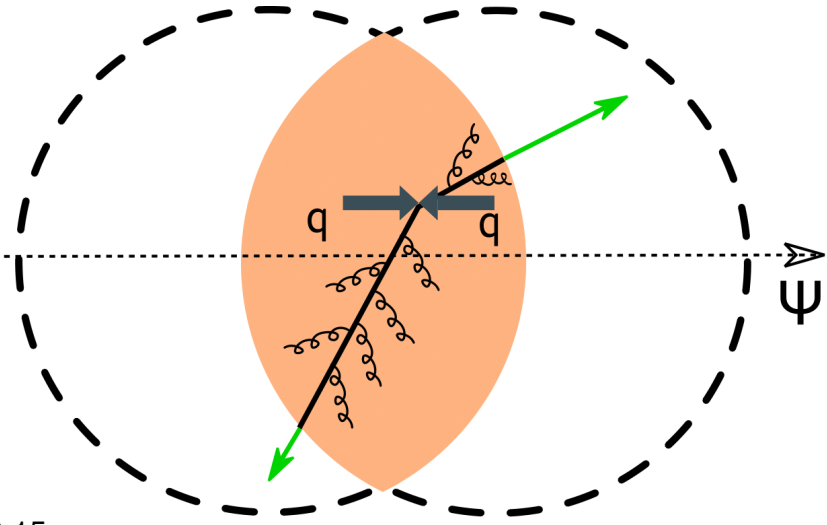
- Run 2 data allows us to measure x_J at high p_T
  - Still see modification between central Pb+Pb and *pp* for jets above 400 GeV
  - Modification of x_J becomes smaller at high p_T
  - Both Pb+Pb and *pp* distributions are steeper at high p_T

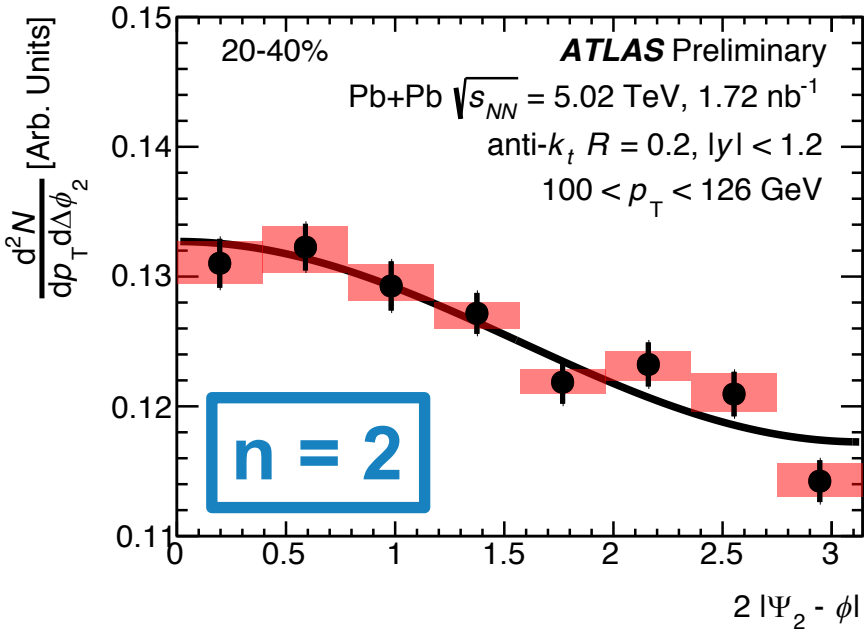
Dijet momentum balance

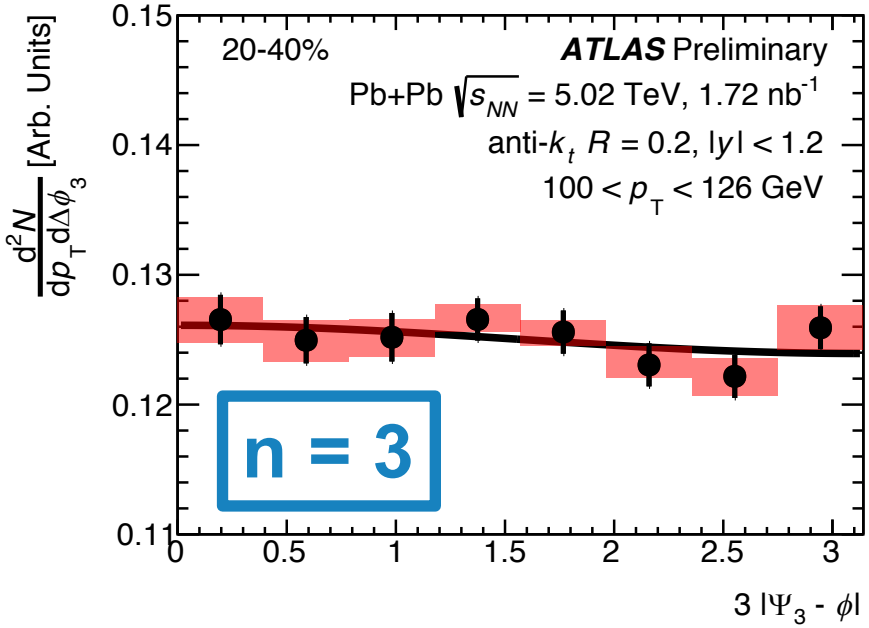


Still see modification at $p_T > 400$ GeV

Jet v_n



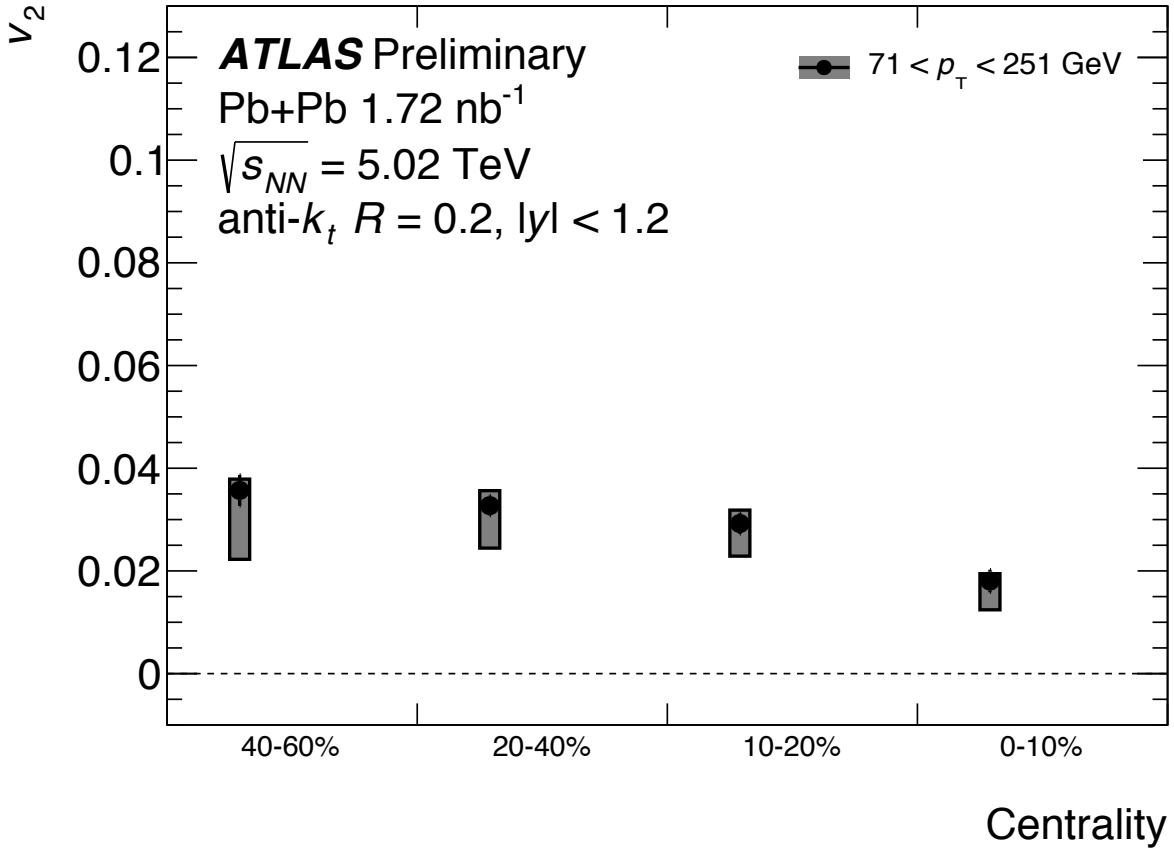




- Measure jet yield as a function of $n\Delta\varphi_n = n|\Psi_n - \varphi|$ in bins of p_T and centrality
- n = 2,3,4
- Yields unfolded in p_T and $\Delta\varphi_n$
- Fit to extract v_n

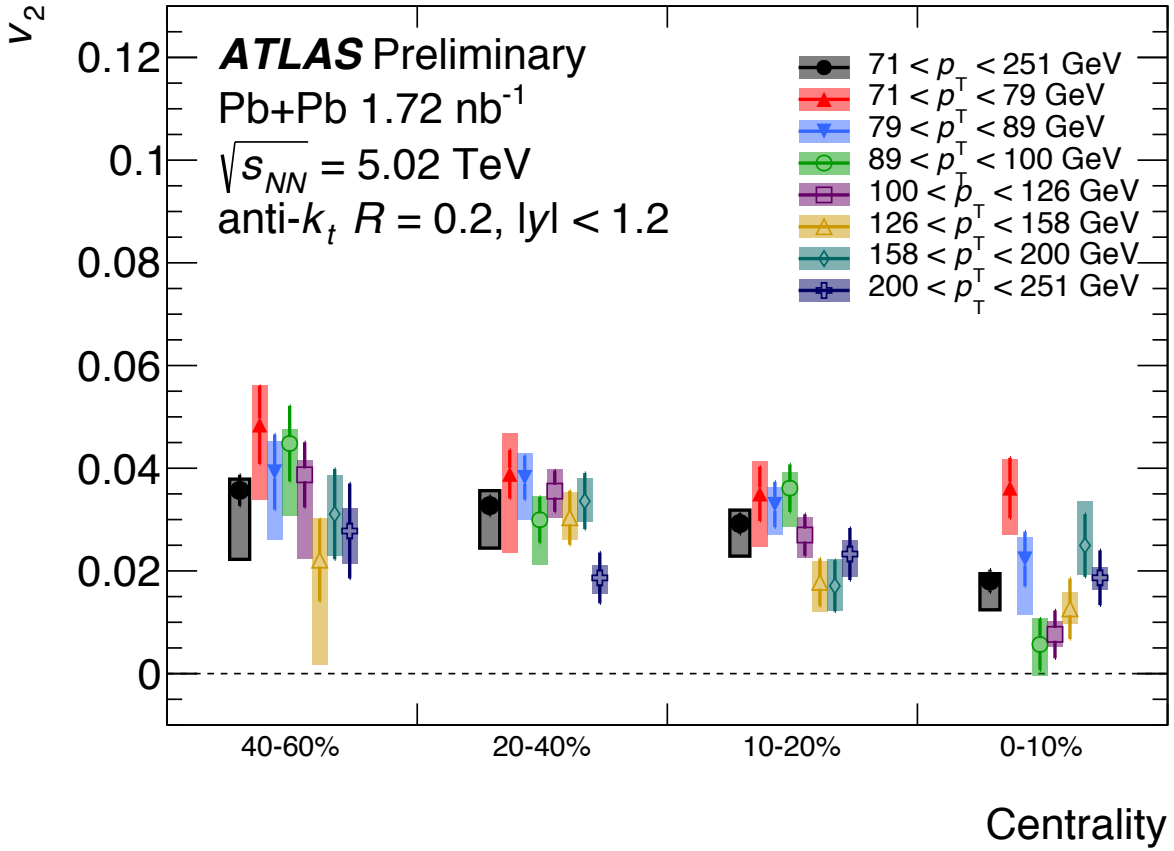
ATLAS-CONF-2020-019

Jet v_2



- Positive v_2 on the order of 1-4% for inclusive p_T

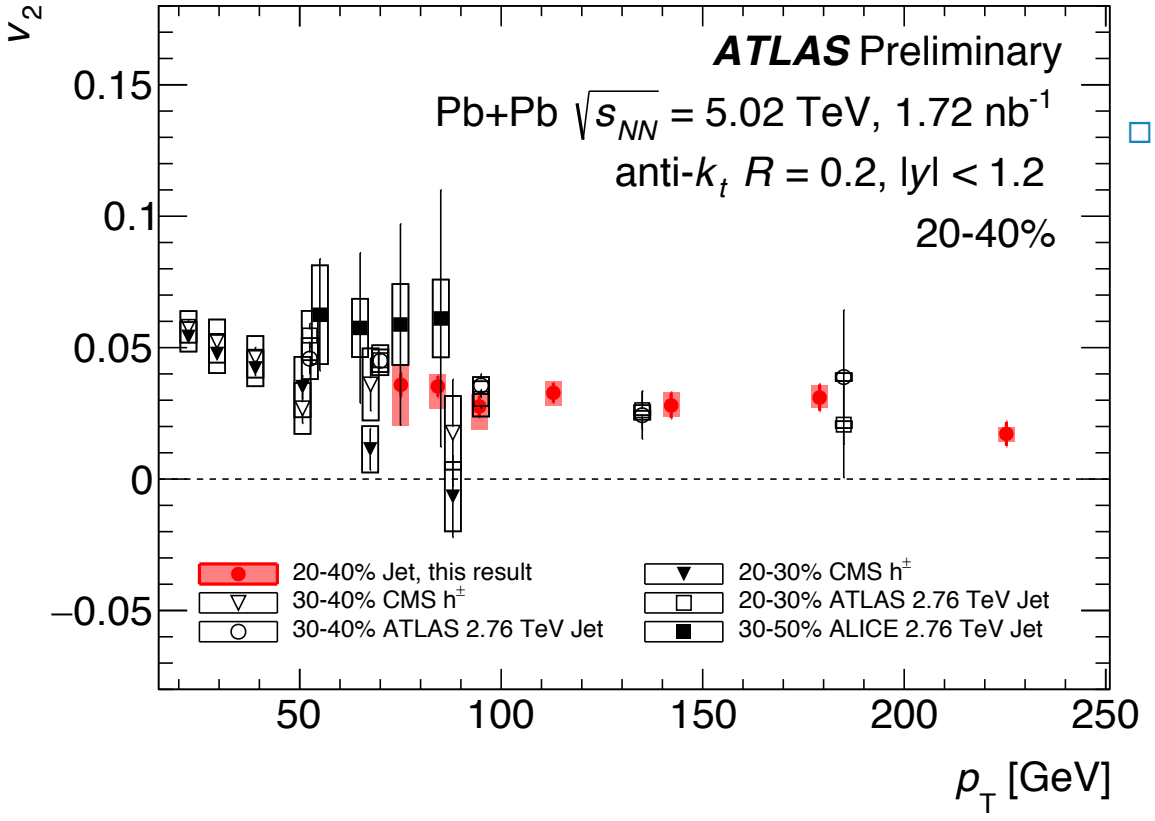
Jet v_2



- Positive v_2 on the order of 1-4% for inclusive p_T
- No significant p_T dependence for jets with p_T 71-251 GeV

Jet v_2 comparison to other results

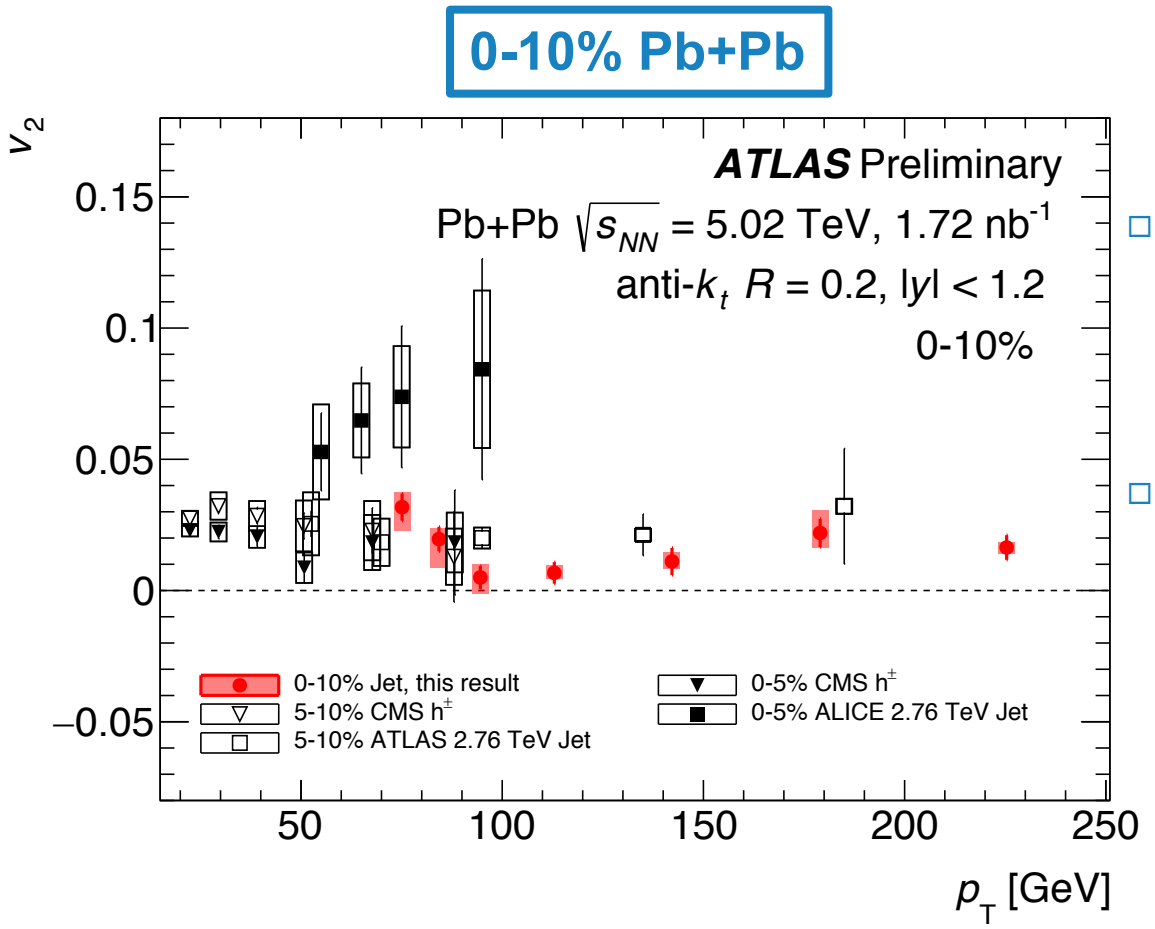
20-40% Pb+Pb



- In 20-40% collisions jet v_2 consistent with:
  - CMS high p_T charged particle v_2
  - ATLAS jet v_2 at 2.76 TeV
  - ALICE jet v_2 at 2.76 TeV

CMS charged particle: arXiv:1702.00630
ATLAS 2.76 TeV: arXiv:1306.6469
ALICE 2.76 TeV: arXiv:1509.07334

Jet v_2 comparison to other results

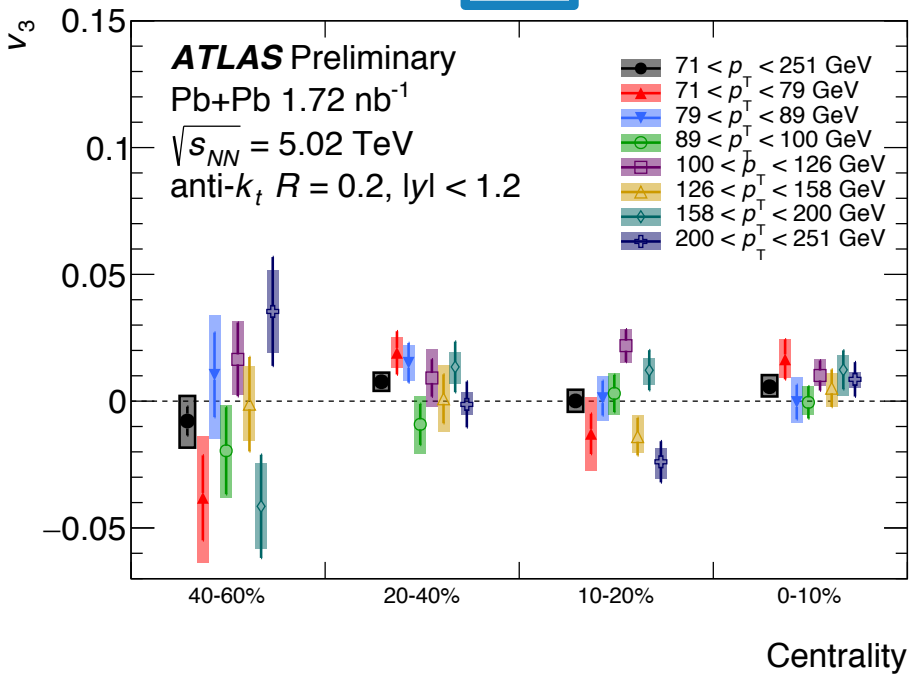


- In 0-10% central collisions jet v_2 consistent with:
  - CMS high p_T charged particle v_2
  - ATLAS jet v_2 at 2.76 TeV
- ALICE jet v_2 at 2.76 TeV higher than other measurements

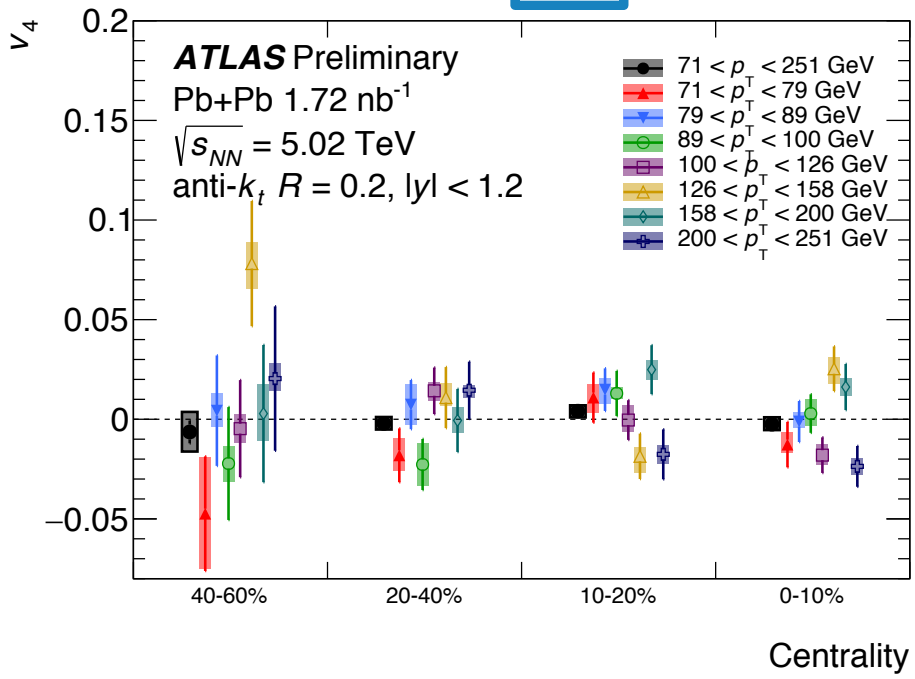
CMS charged particle: arXiv:1702.00630
ATLAS 2.76 TeV: arXiv:1306.6469
ALICE 2.76 TeV: arXiv:1509.07334

Jet v_3 and v_4

v_3



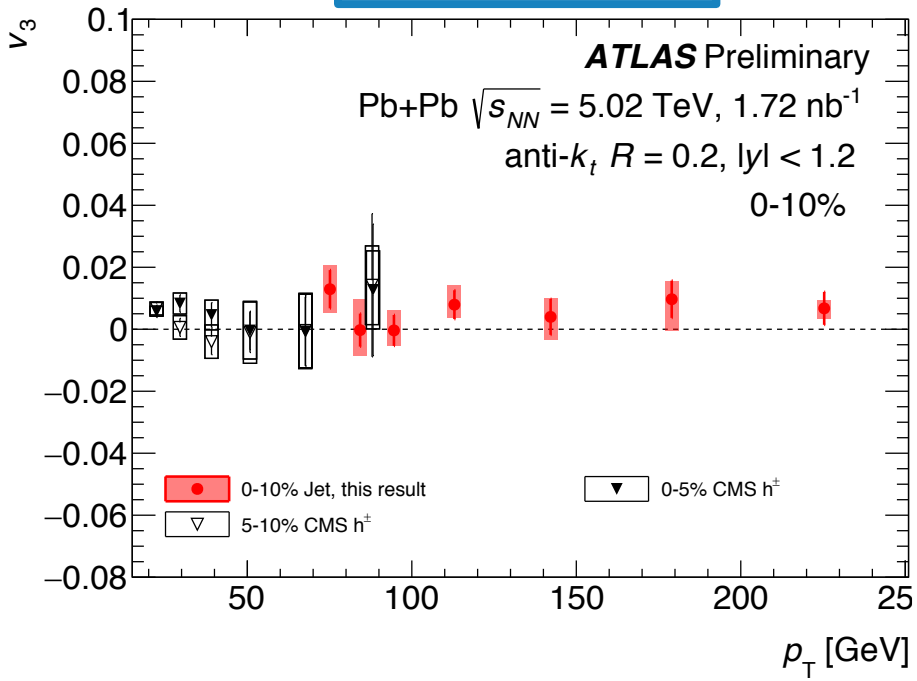
v_4



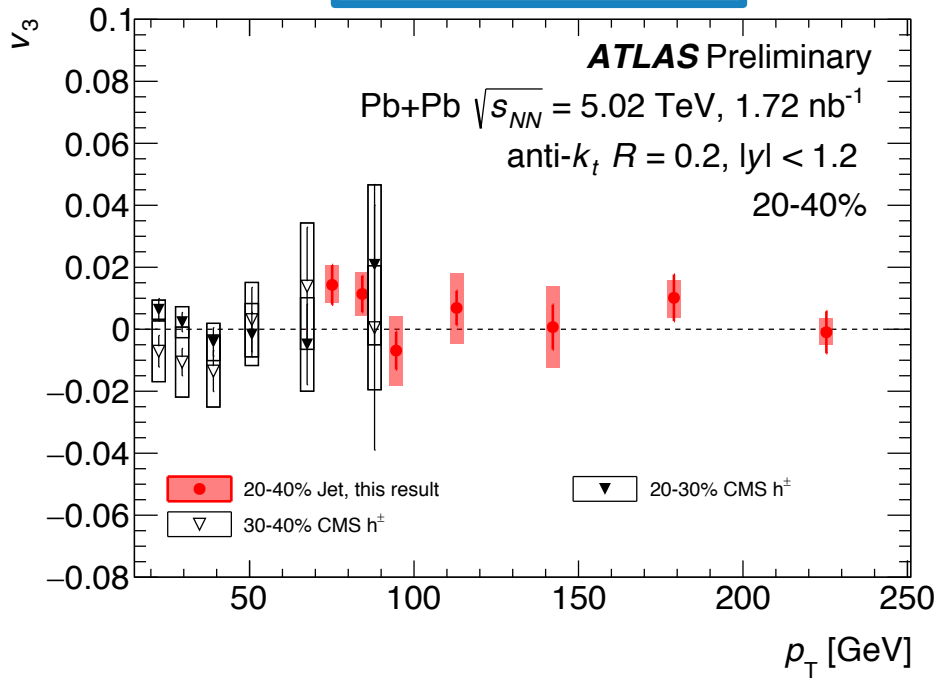
- No evidence for non-zero v_3 and v_4

Jet v_3 comparison to other results

0-10% Pb+Pb



20-40% Pb+Pb

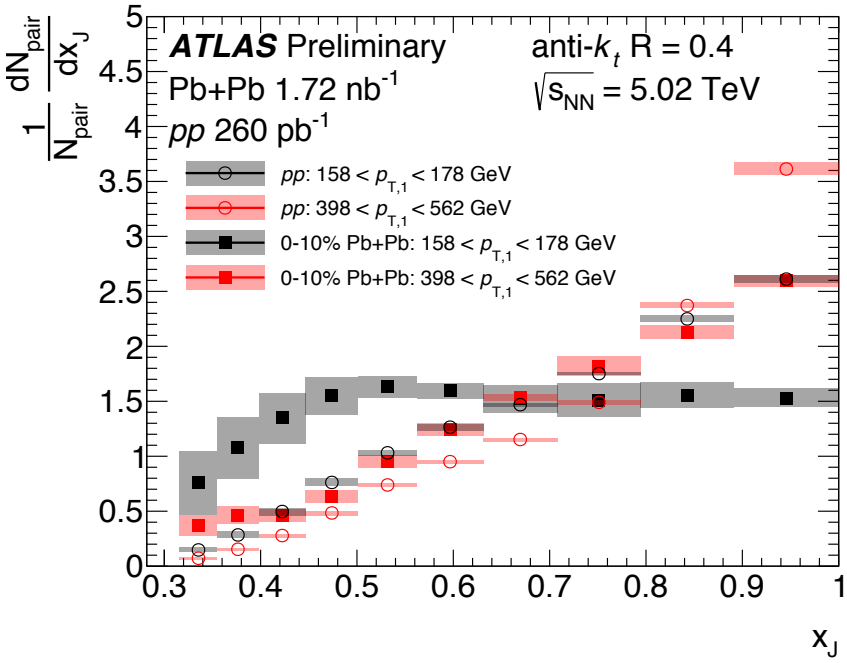


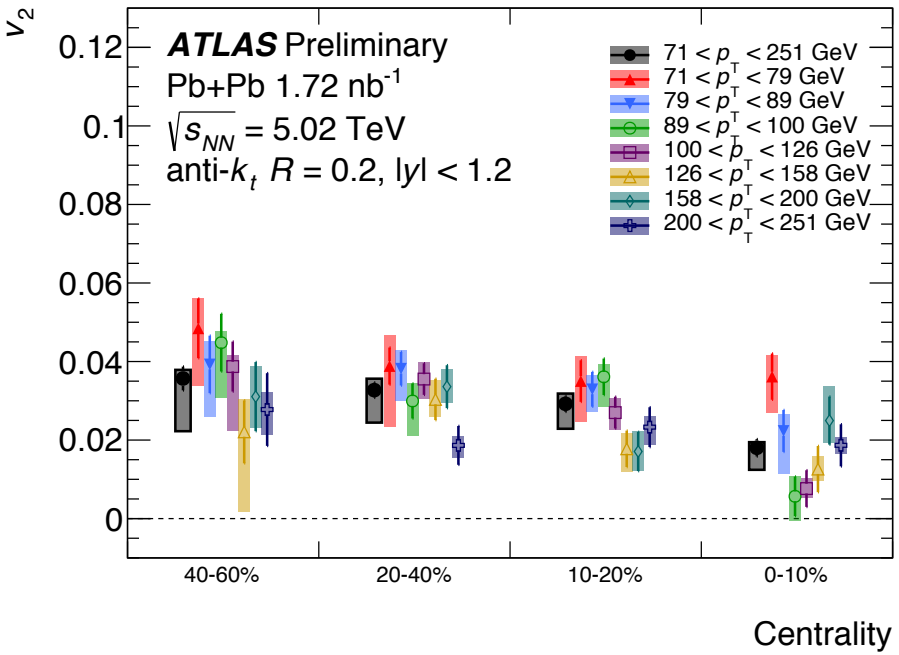
- Jet v_3 values are consistent with high p_T charged particle v_3 measured by CMS in central and mid-central collisions at 5.02 TeV

CMS charged particle: arXiv:1702.00630

Summary

See poster by Tim Rinn on dijets





- See evidence of path-length dependent energy loss:
  - Increased asymmetry in dijet pairs in Pb+Pb collisions vs. *pp* collisions, even at high p_T
  - Increased yields of jets in-plane vs. out-of-plane leading to positive v_2
- First measurement of jet v_3 and v_4 shows values consistent with zero
- ATLAS heavy-ions public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

Backup

x_J selections

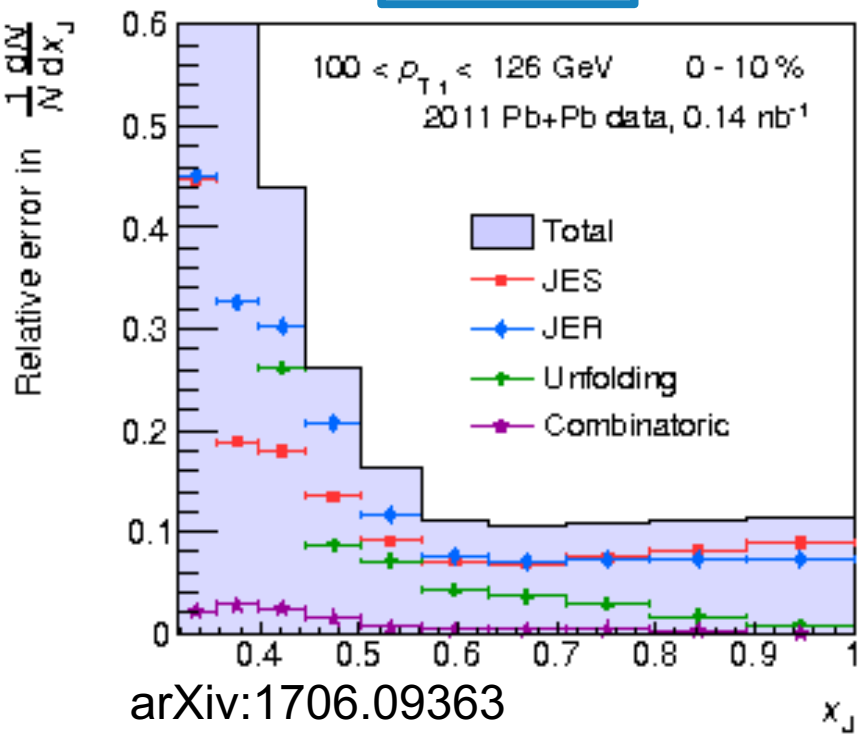
- 1.72 nb^{-1} Pb+Pb data at 5.02 TeV
- 260 pb^{-1} *pp* data at 5.02 TeV
- 0-10%, 10-20%, 20-40%, 40-60%, 60-80% centrality bins
- R = 0.4 jets
- $|\eta| < 2.1$
- $|\Delta\varphi| > 7\pi/8$
- $158 < p_{T,1} < 562$ GeV
- $0.32 < x_J < 1$
- 2D Bayesian unfolding in $p_{T,1}$, $p_{T,2}$

v_n selections

- 1.72 nb^{-1} 2018 Pb+Pb data at 5.02 TeV
- 0-10%, 10-20%, 20-40%, 40-60% centrality bins
- R = 0.2 jets
- Inclusive jets
- $|y| < 1.2$
- $71 < p_T < 251$ GeV
- 2D Bayesian unfolding in p_T, $\Delta\varphi_n$

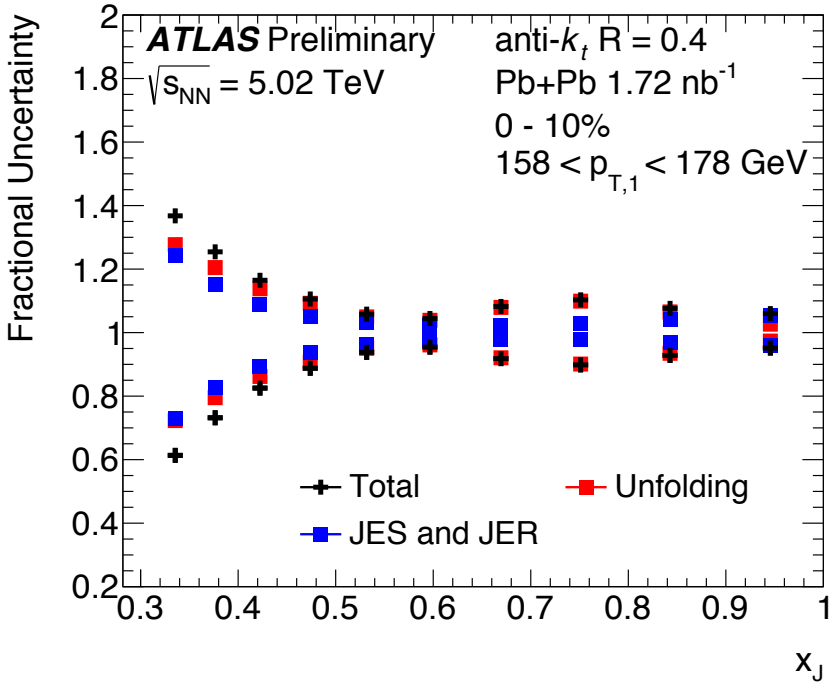
x_J systematic comparison at 2.76 TeV

2.76 TeV



arXiv:1706.09363

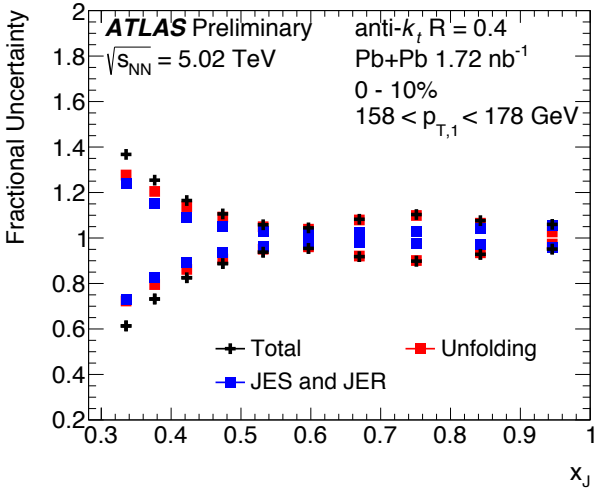
5.02 TeV

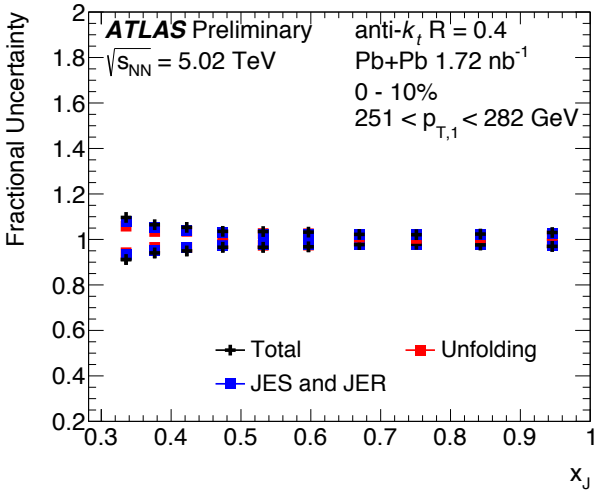


- Improved uncertainties come largely from better understanding of JES and JER in run 2 data

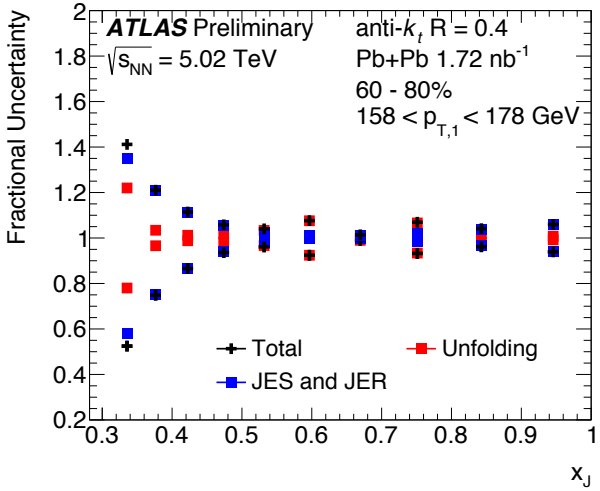
x_J systematics

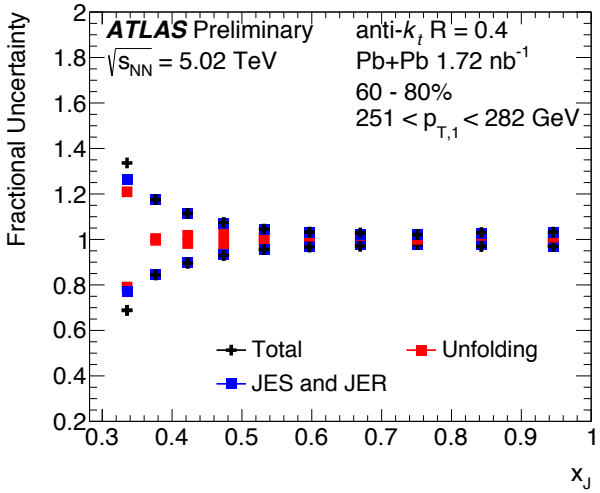
0-10%



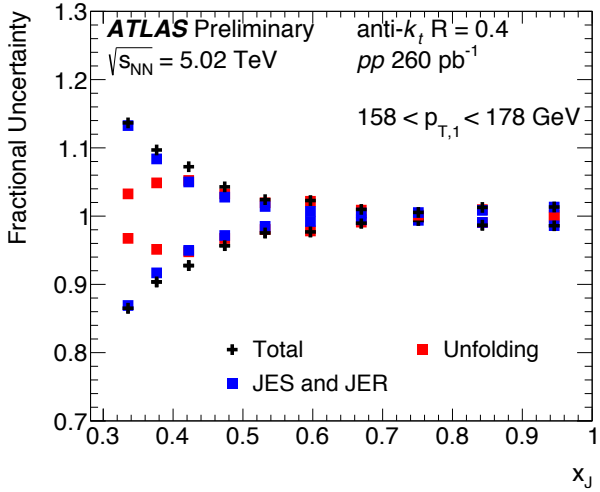


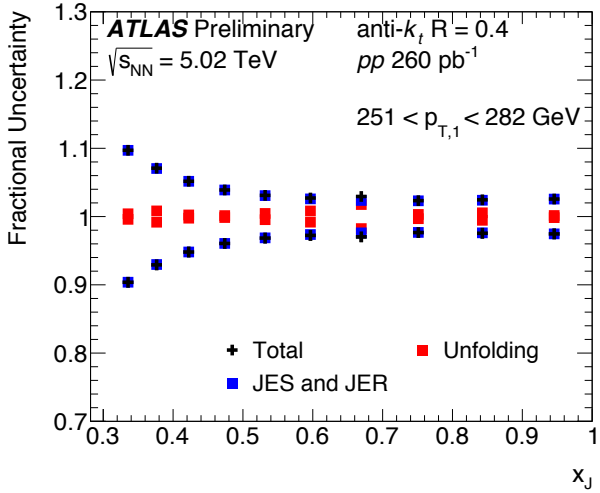
60-80%



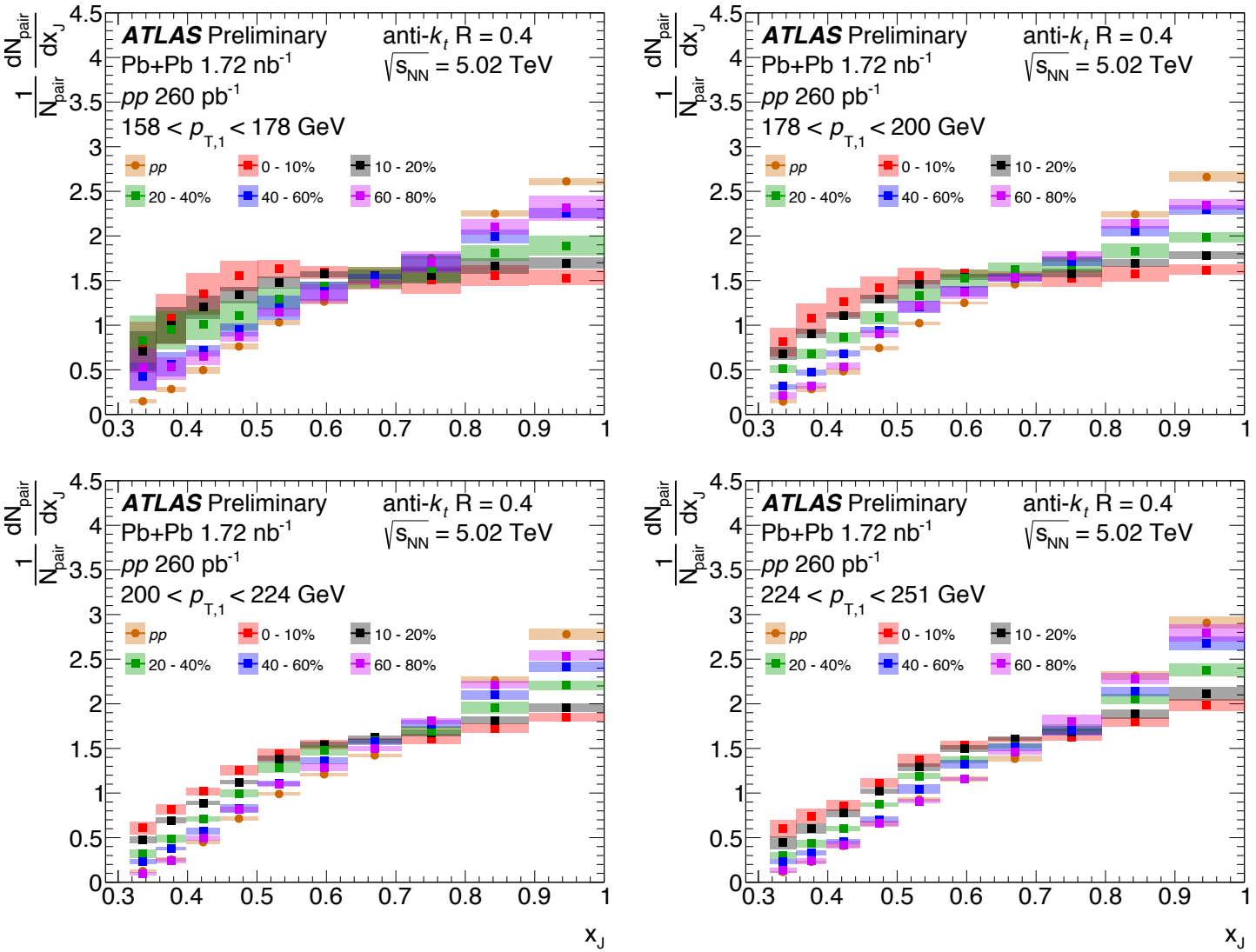


pp

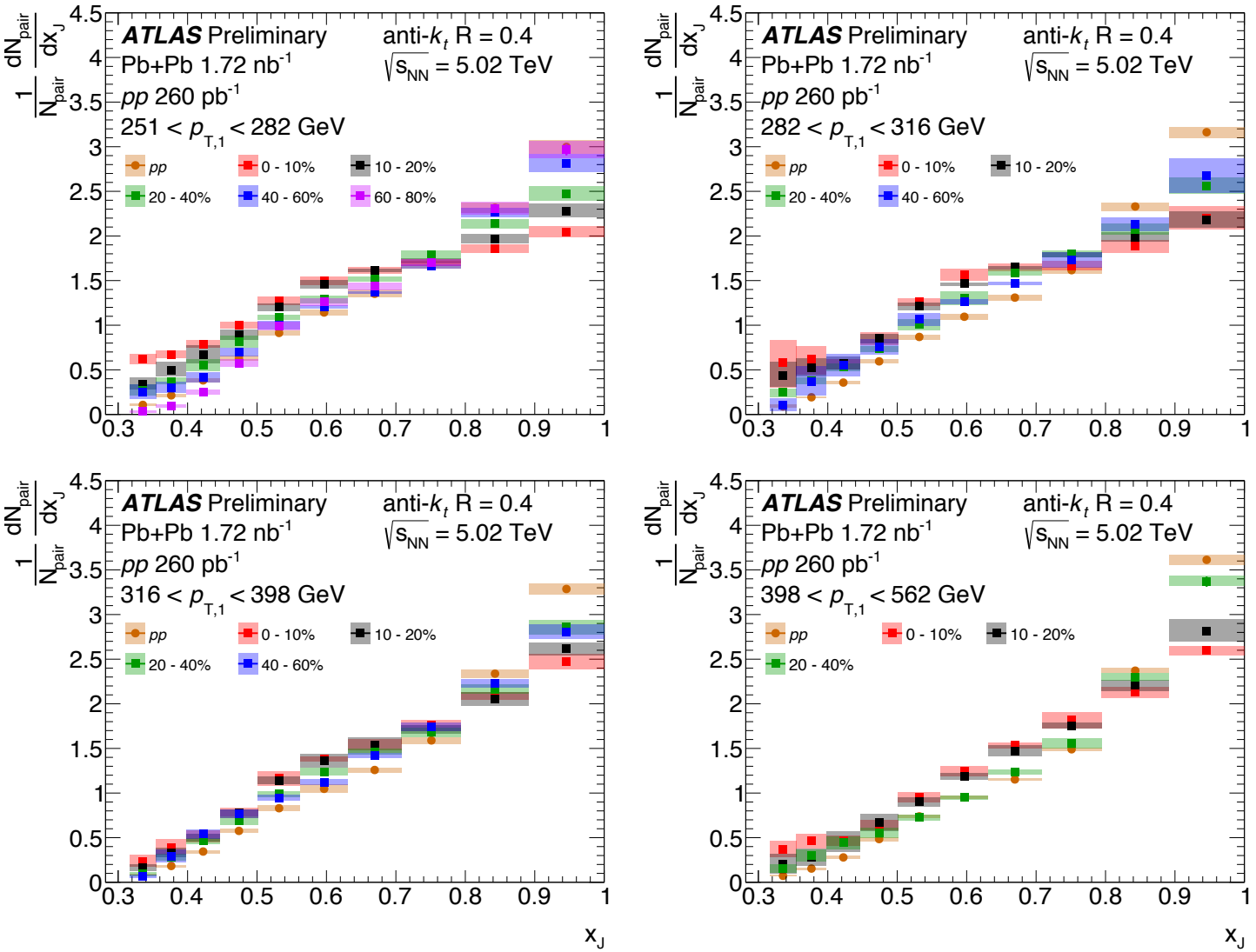




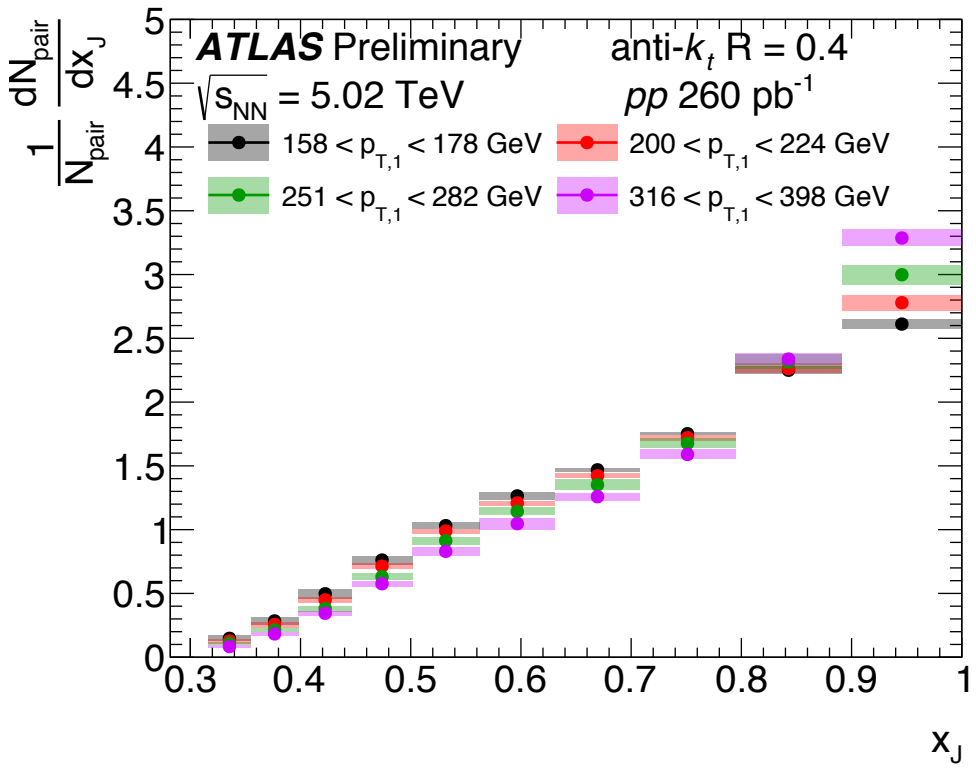
x_J p_T dependence



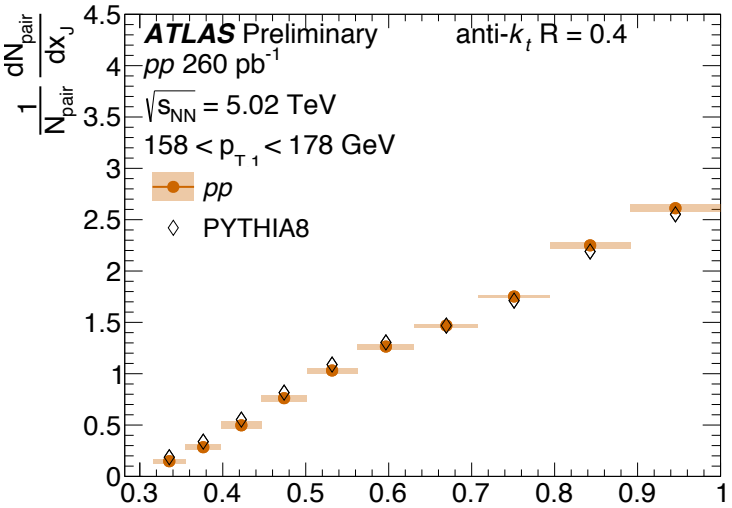
x_J p_T dependence

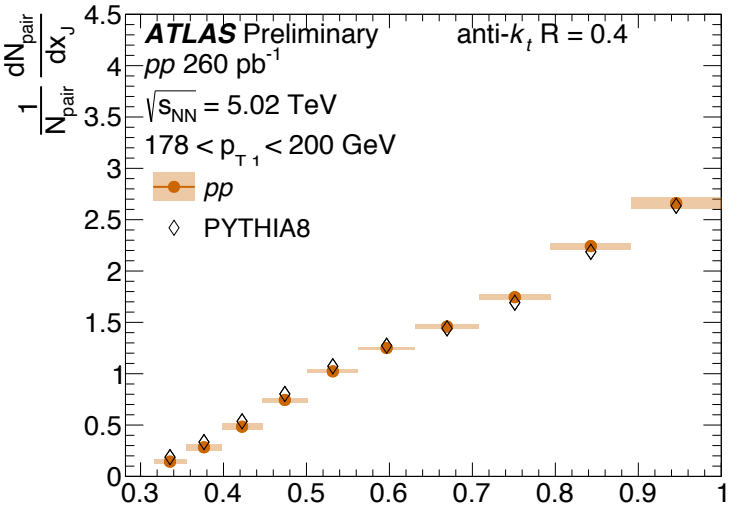


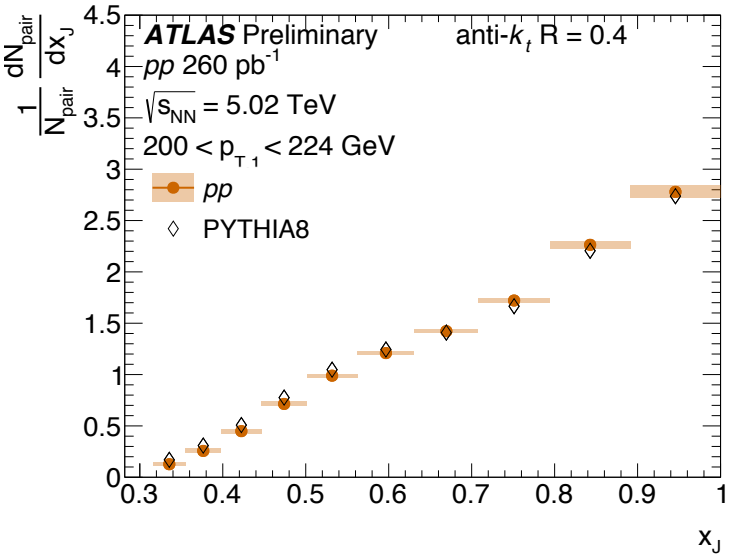
x_J in *pp*

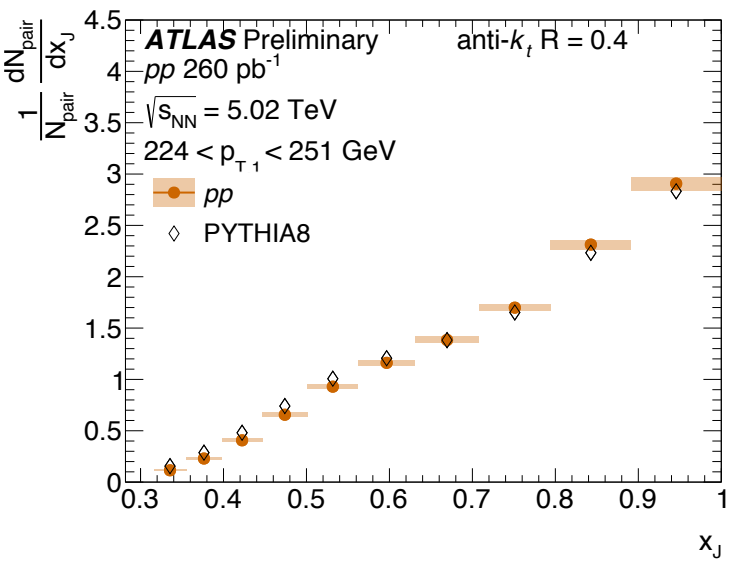

ATLAS Preliminary
anti-k_t R = 0.4
$\sqrt{s_{NN}}$ = 5.02 TeV
pp 260 pb^{-1}
158 < $p_{T,1}$ < 178 GeV
200 < $p_{T,1}$ < 224 GeV
251 < $p_{T,1}$ < 282 GeV
316 < $p_{T,1}$ < 398 GeV
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$
x_J
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

x_J in Pythia

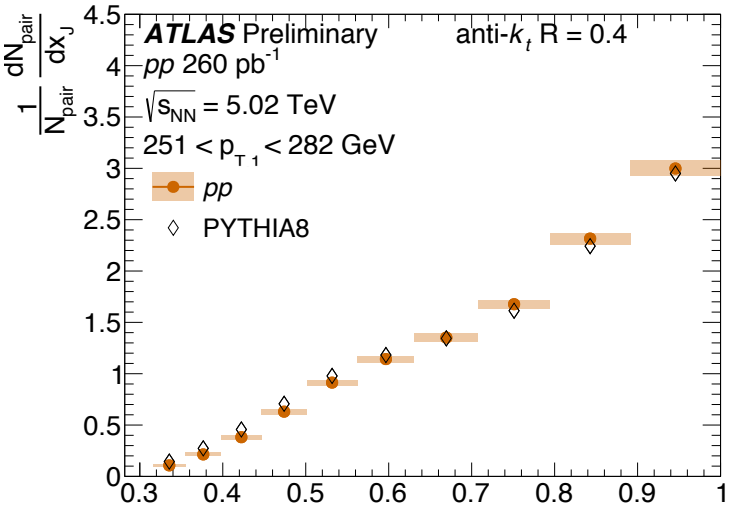

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
158 < $p_{T\,1}$ < 178 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$

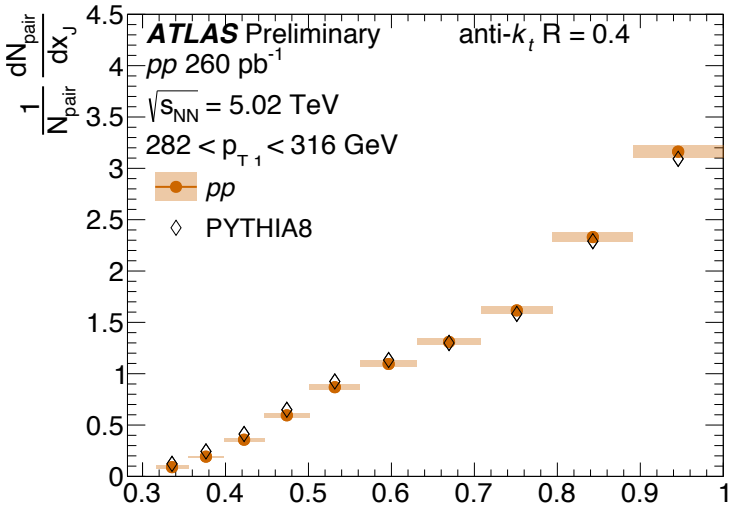

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
178 < $p_{T\,1}$ < 200 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$

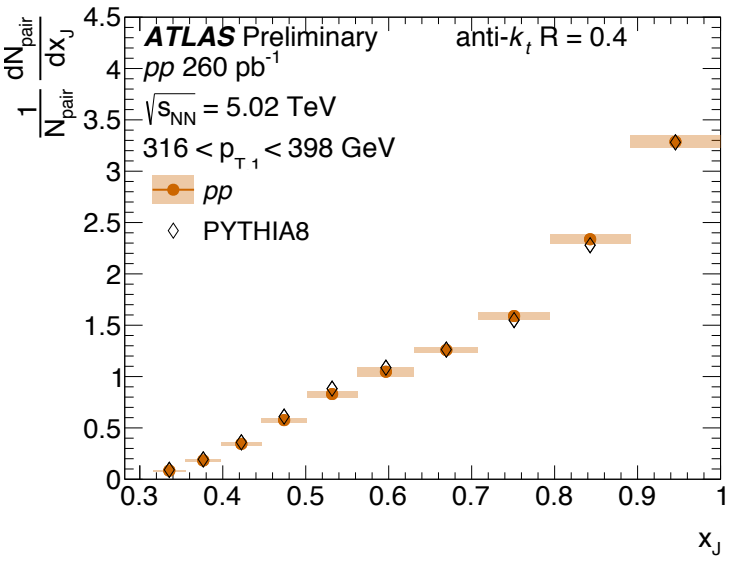

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
200 < $p_{T\,1}$ < 224 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$
x_J

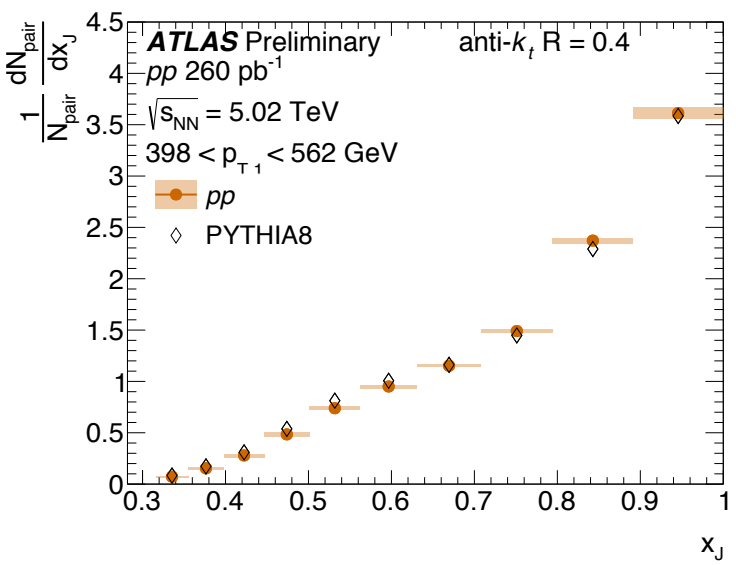

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
224 < $p_{T\,1}$ < 251 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$
x_J

x_J in Pythia


ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
251 < $p_{T\,1}$ < 282 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$

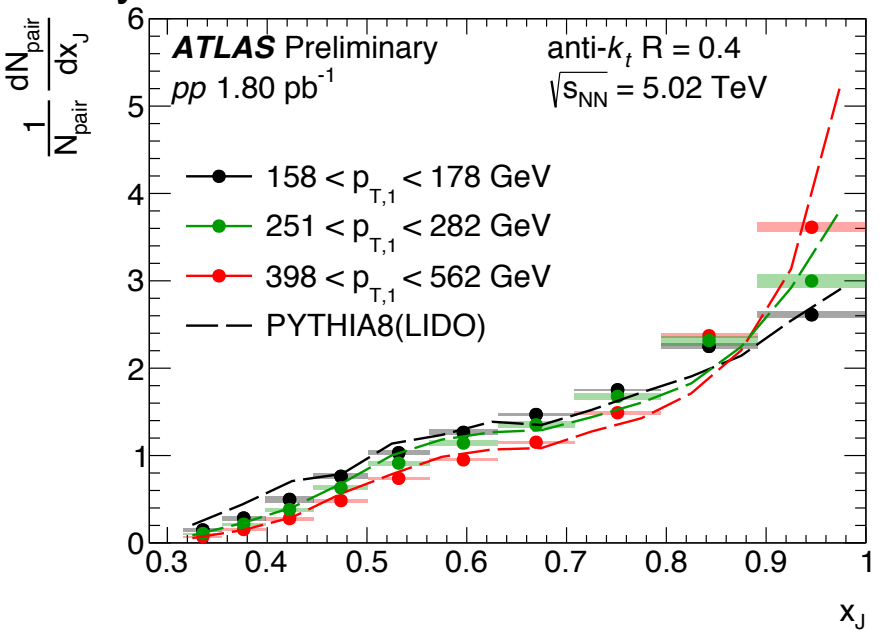

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
282 < $p_{T\,1}$ < 316 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$


ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
316 < $p_{T\,1}$ < 398 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$
x_J

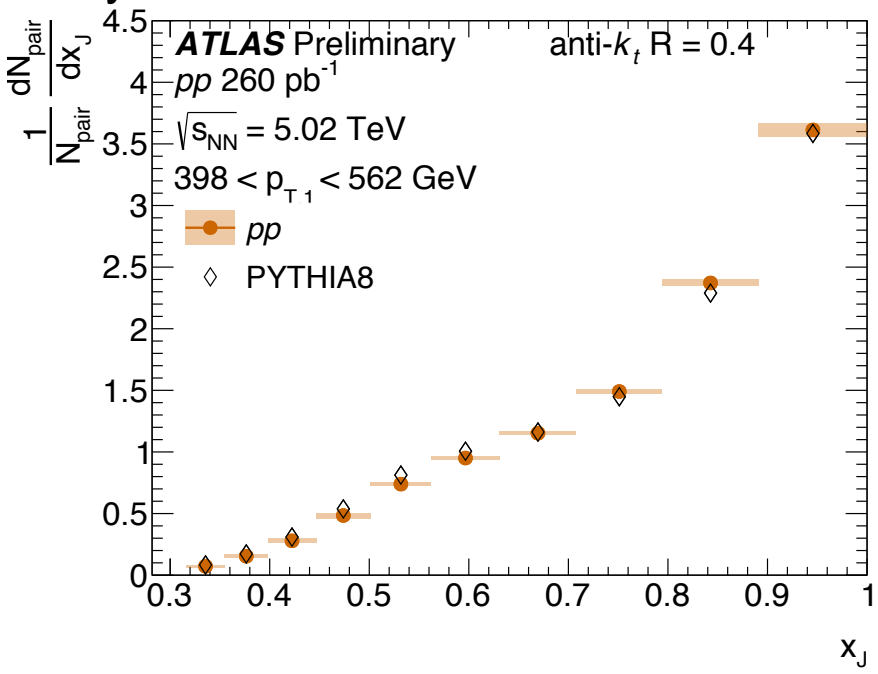

ATLAS Preliminary
anti-k_t R = 0.4
pp 260 pb^{-1}
$\sqrt{s_{NN}}$ = 5.02 TeV
398 < $p_{T\,1}$ < 562 GeV
pp
PYTHIA8
$\frac{1}{N_{pair}}\frac{dN_{pair}}{dx_J}$
x_J

Theory comparison

Pythia8 4C tune with CTEQ6L1 PDFs

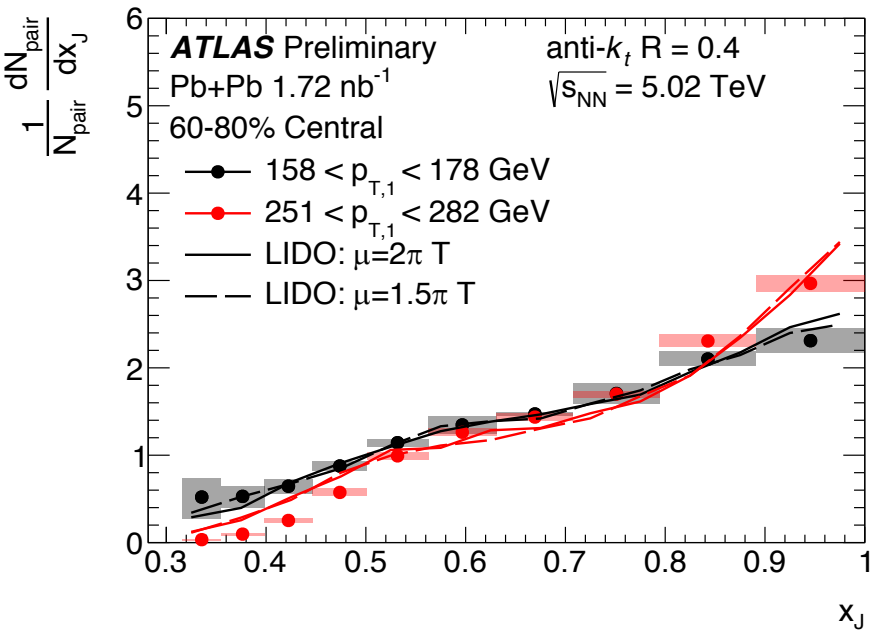


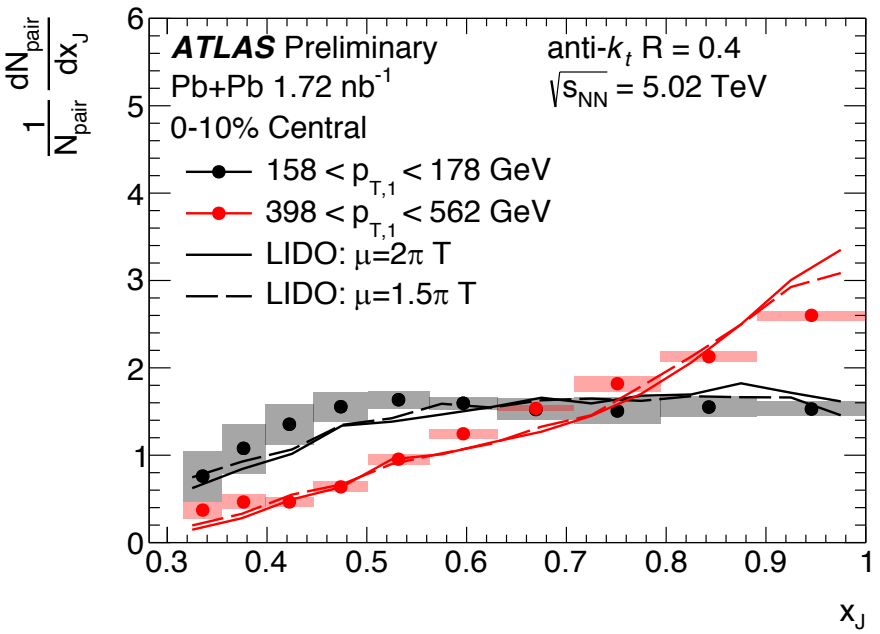
Pythia8A14 tune with NNPDF23LO PDFs



- Pythia8 4C used as baseline for LIDO model
- Pythia8 4C over-predicts the contribution from balanced dijets

Theory comparison

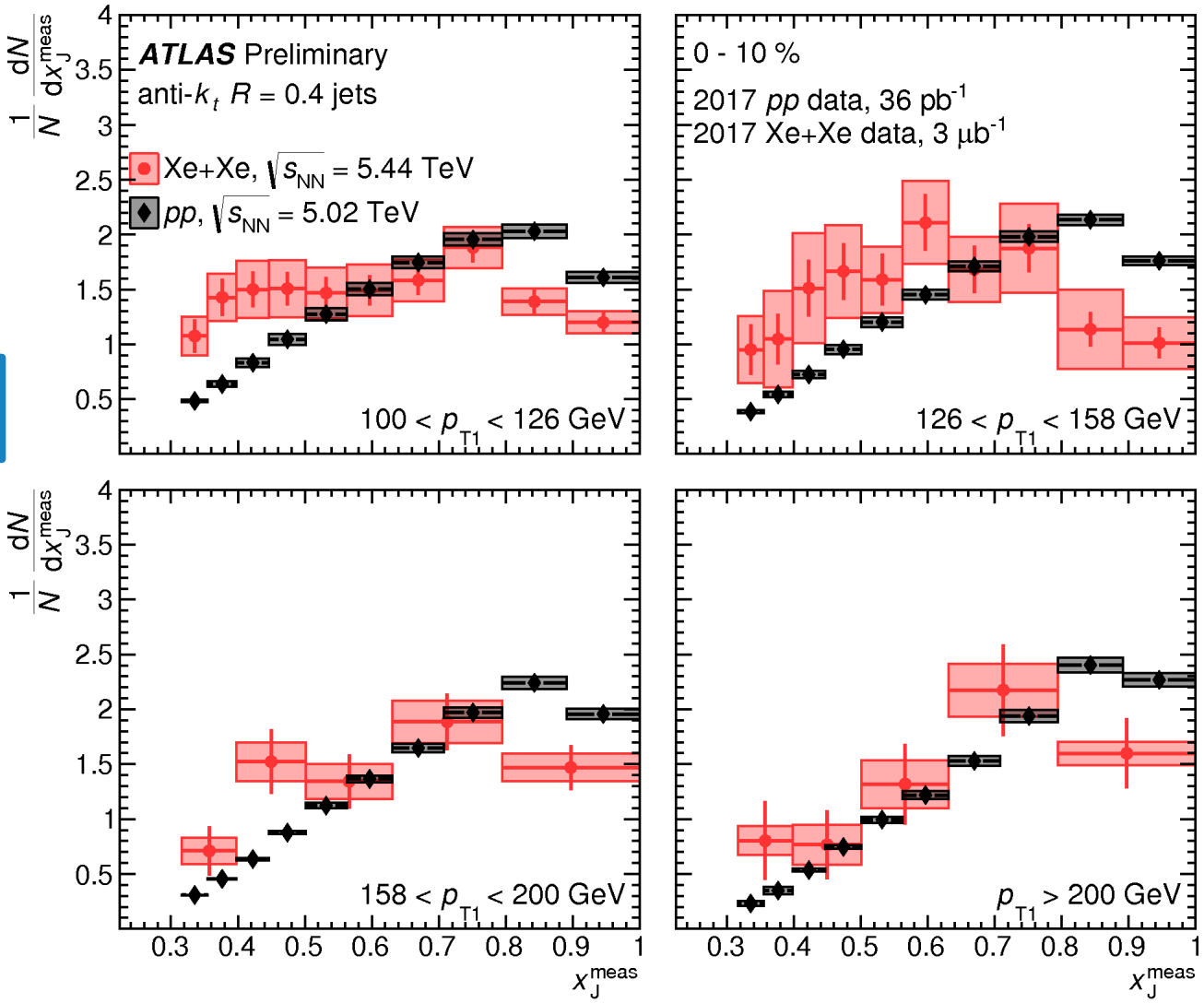




- Comparison to LIDO energy loss model qualitatively consistent with our measurement
- Pythia8 4C baseline
- LIDO transport model- energy loss from
  - Elastic collisions
  - Path-length dependent medium induced radiation
- Initial conditions from TRENTo model

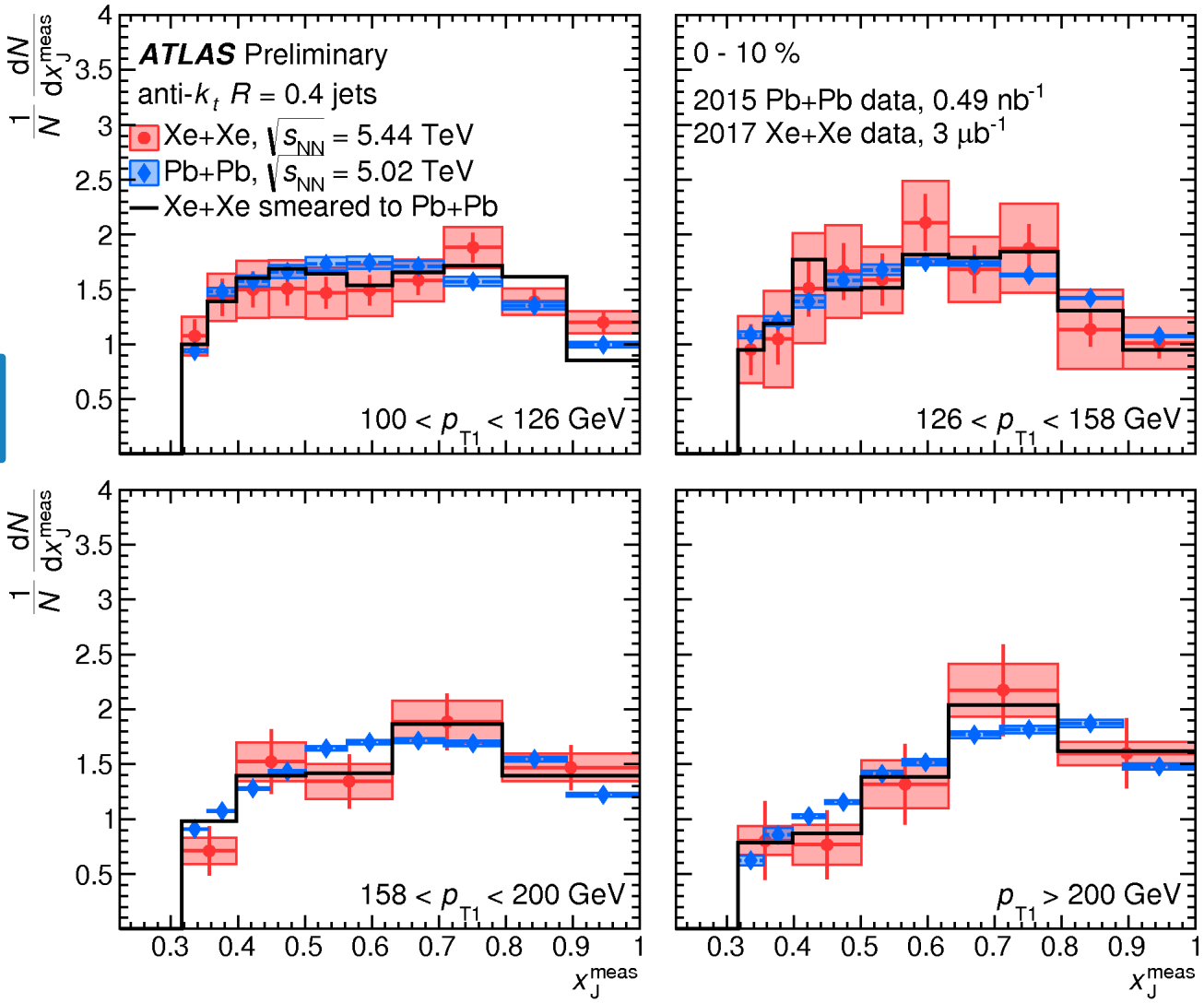
x_J in Xe+Xe

Not unfolded

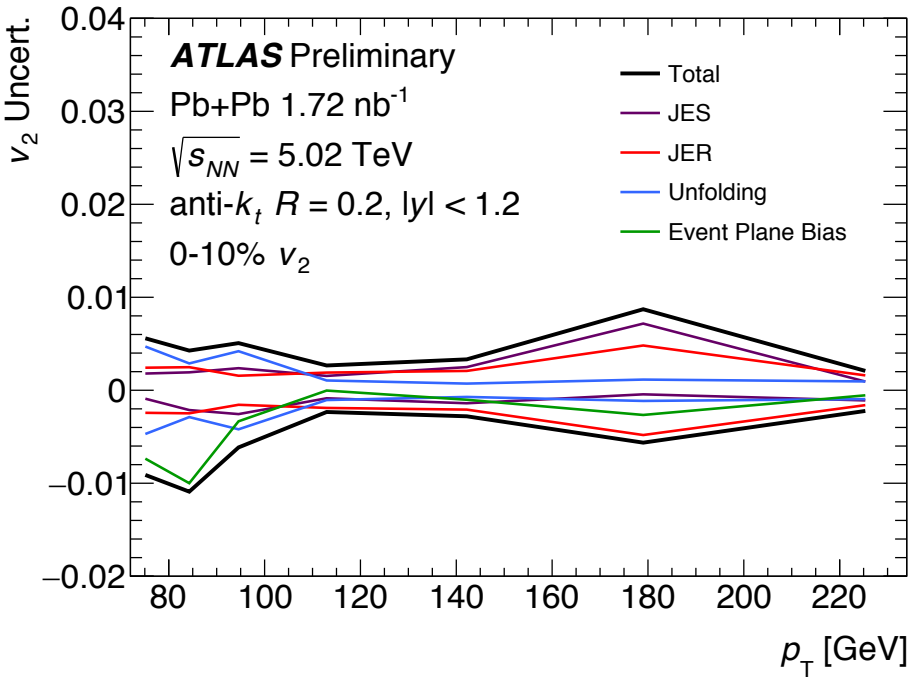


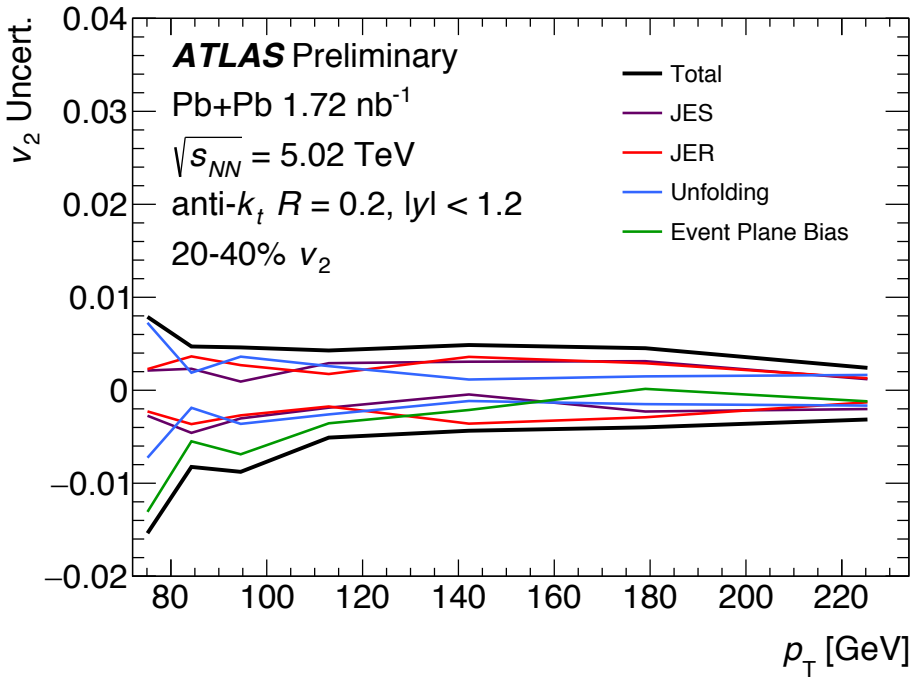
x_J in Xe+Xe

Not unfolded

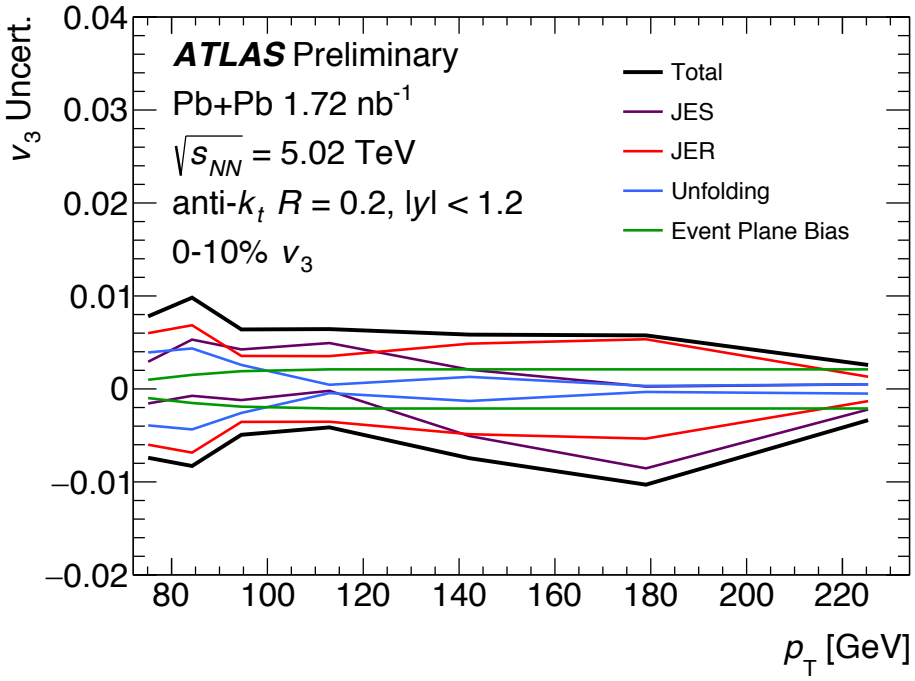


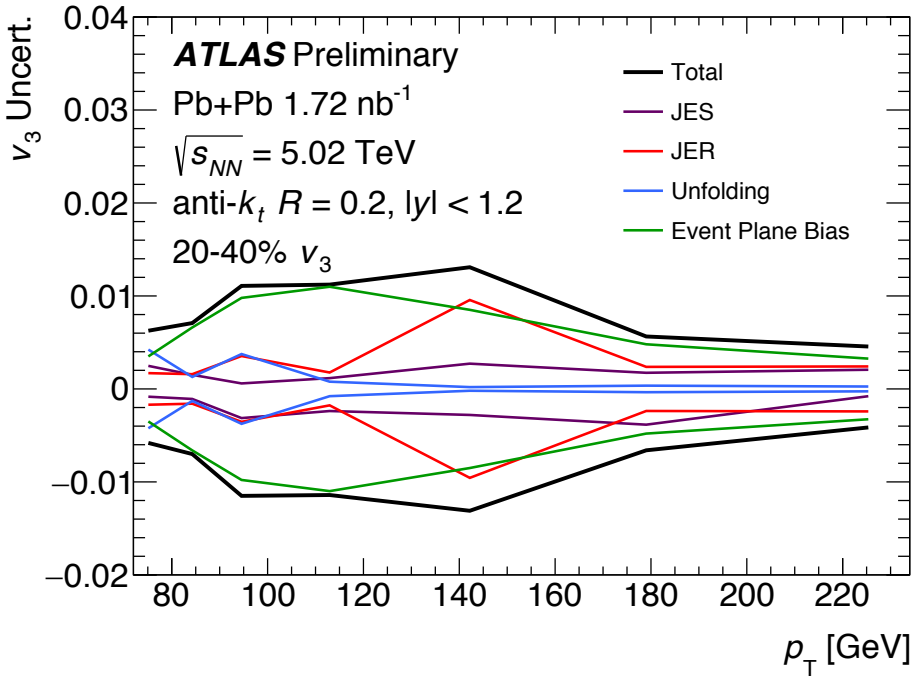
Jet v_2 systematics



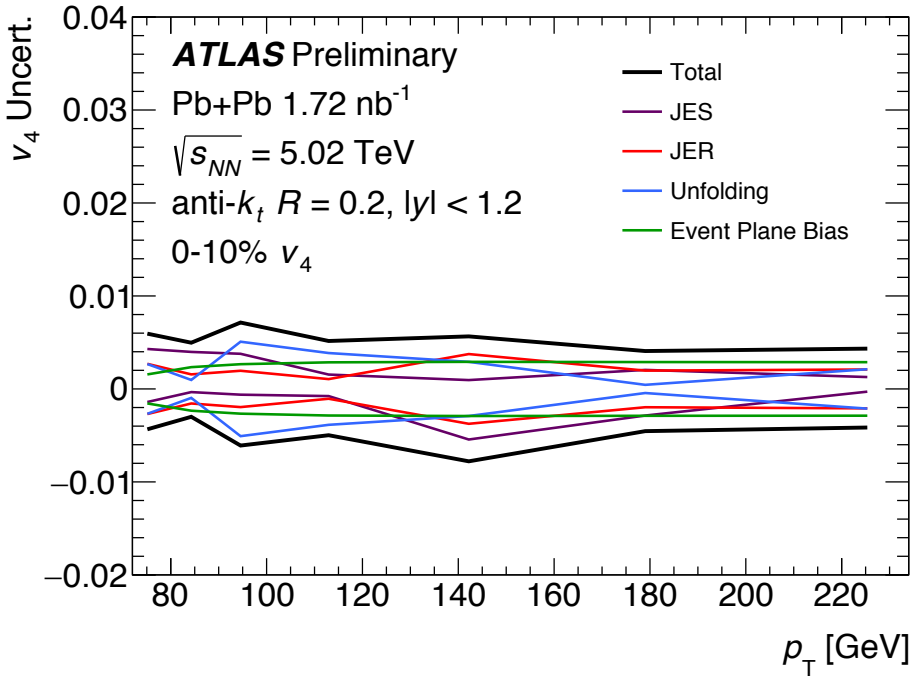


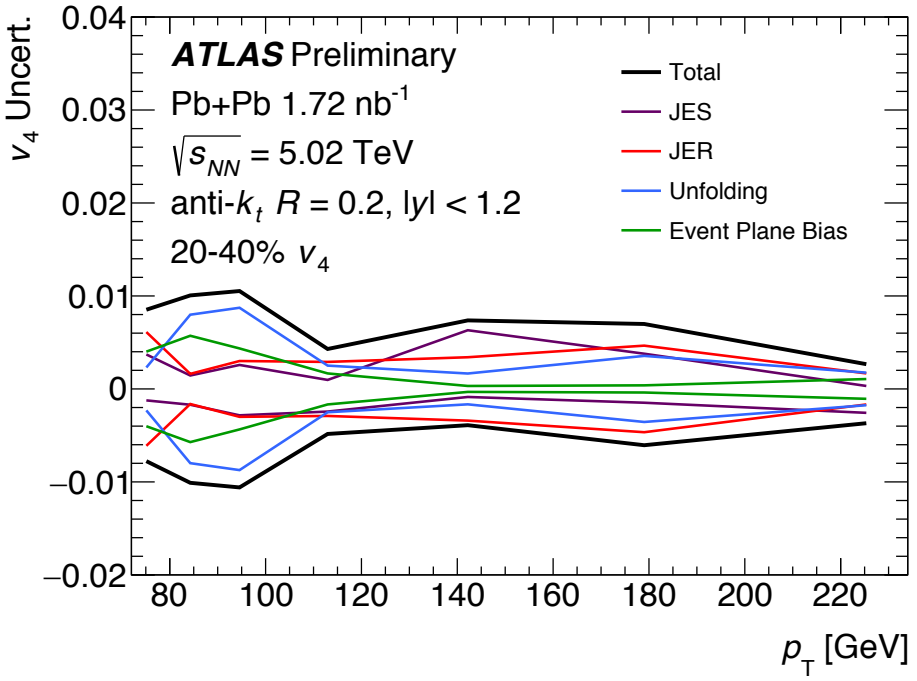
Jet v_3 systematics



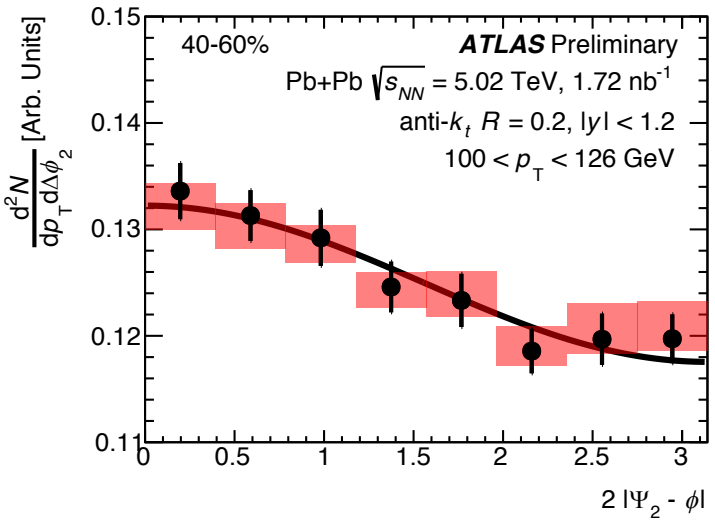


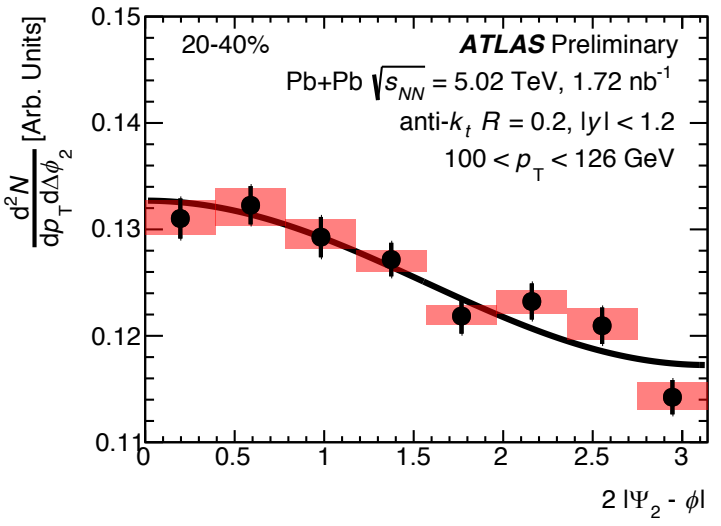
Jet v_4 systematics

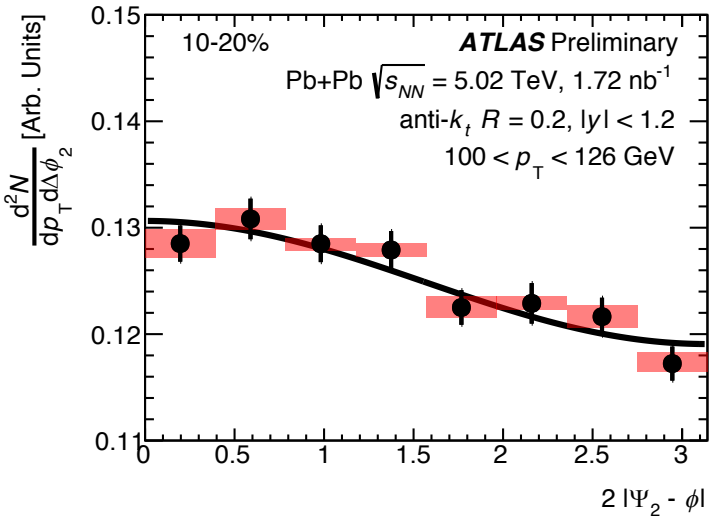


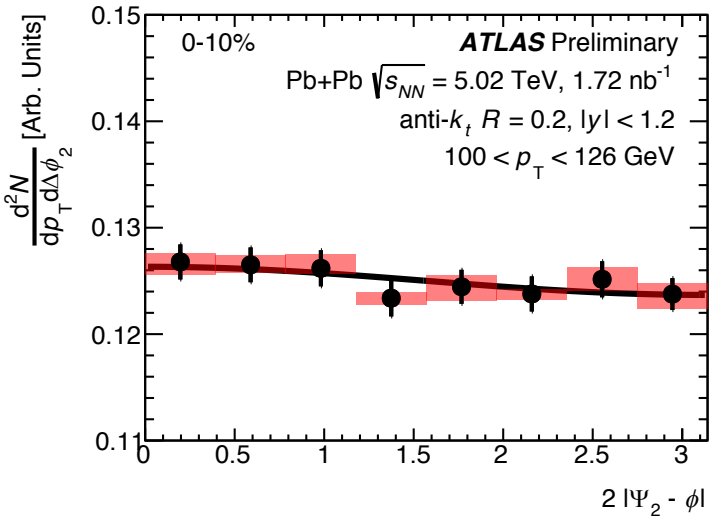


Jet $\Delta\varphi_2$









Jet $\Delta\varphi_3$