Azimuthal anisotropy in 5.02 TeV Pb+Pb and 5.44 TeV Xe+Xe collisions with the ATLAS experiment

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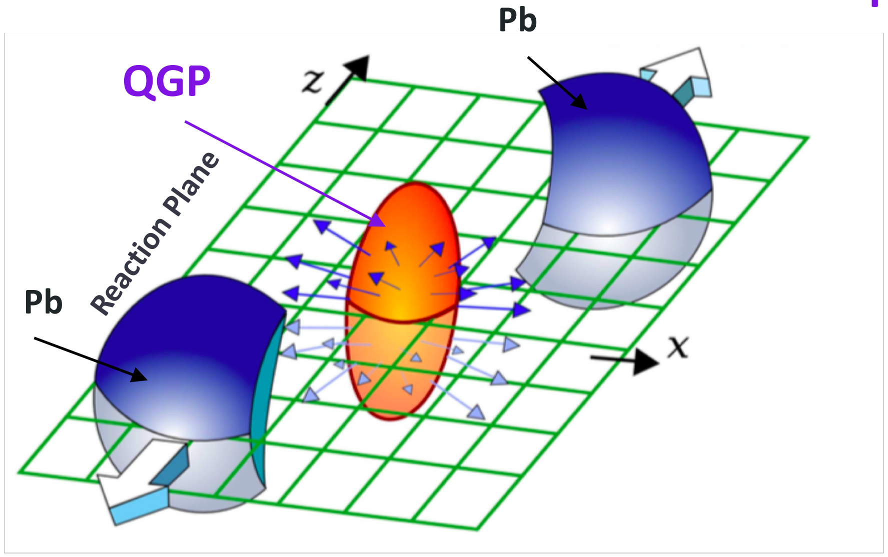
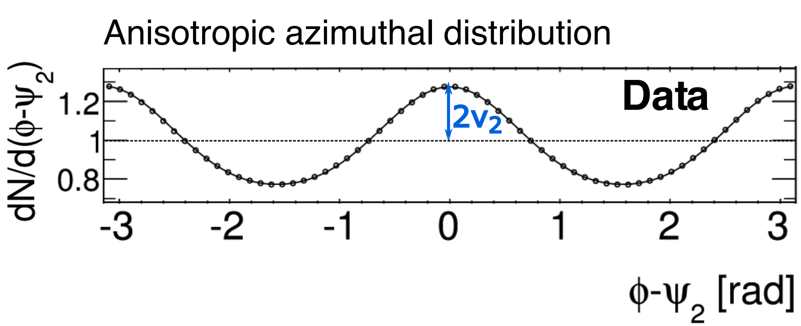
AGH UST

ATLAS EXPERIMENT

Motivation

- Azimuthal anisotropy results from different pressure gradients in different spatial directions

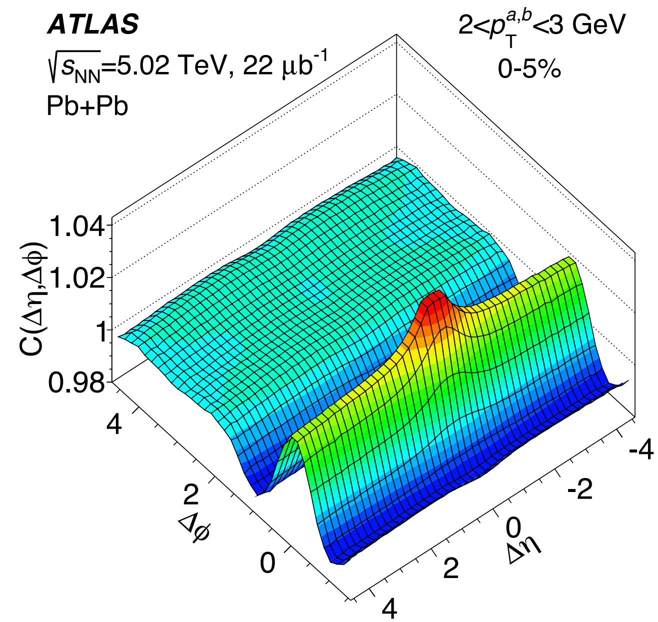




Particle azimuthal distribution

Singles: $$\frac{dN}{d\phi} \propto 1 + \sum_n 2v_n \cos[n(\phi - \Phi_n)]$$

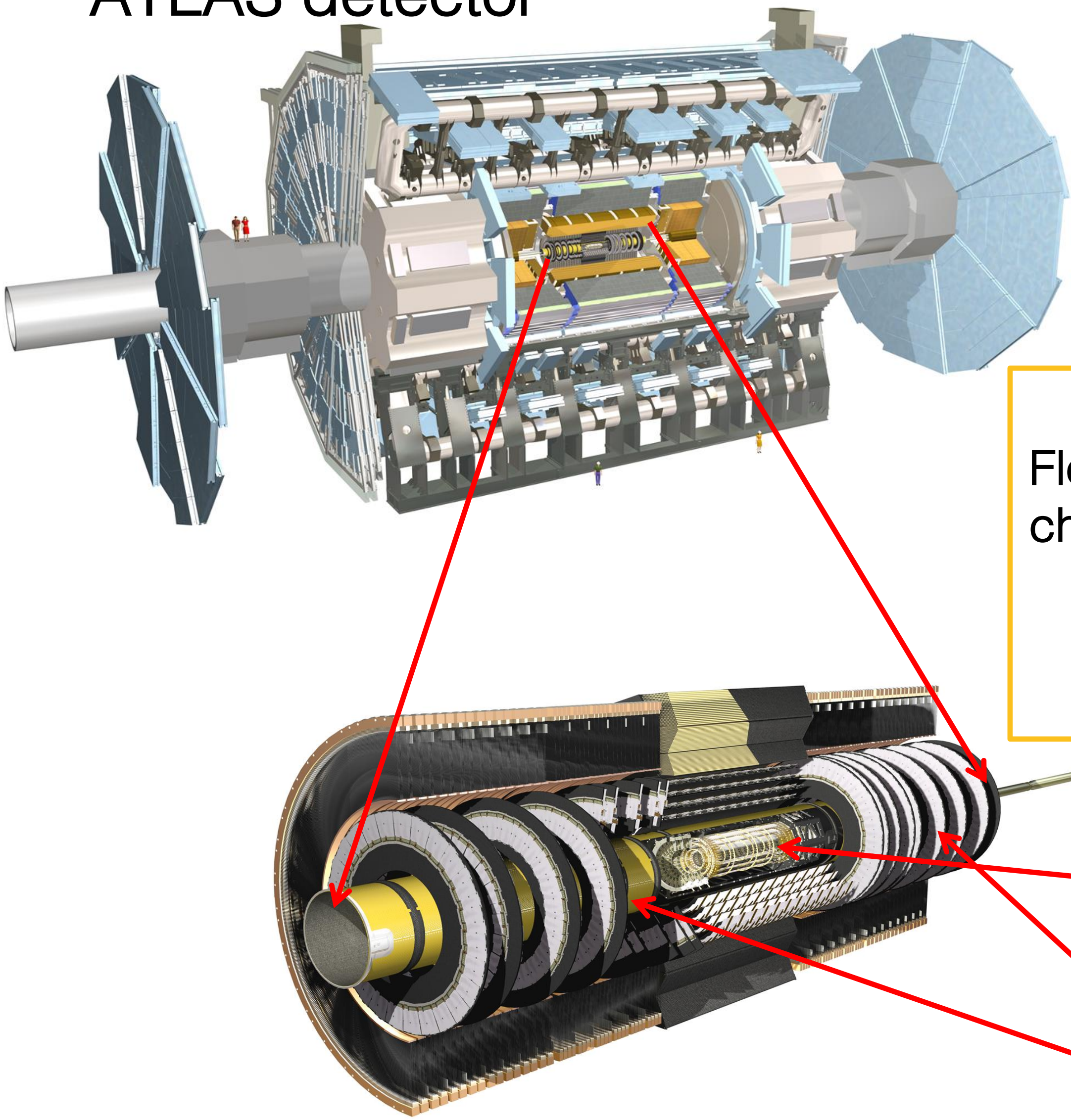
Pairs: $$\frac{dN}{d\Delta\phi} \propto 1 + \sum_n 2v_n^a v_n^b \cos[n(\Delta\phi)]$$



- Pb+Pb 5.02 TeV → 0.49nb^{-1}
- Xe+Xe 5.44 TeV → 3μb $^{-1}$

ATLAS detector ⟶ v_n measurement

ATLAS detector



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Inner Detector (Pixel+SCT)

Flow measurements is based on charged tracks reconstructed in ID

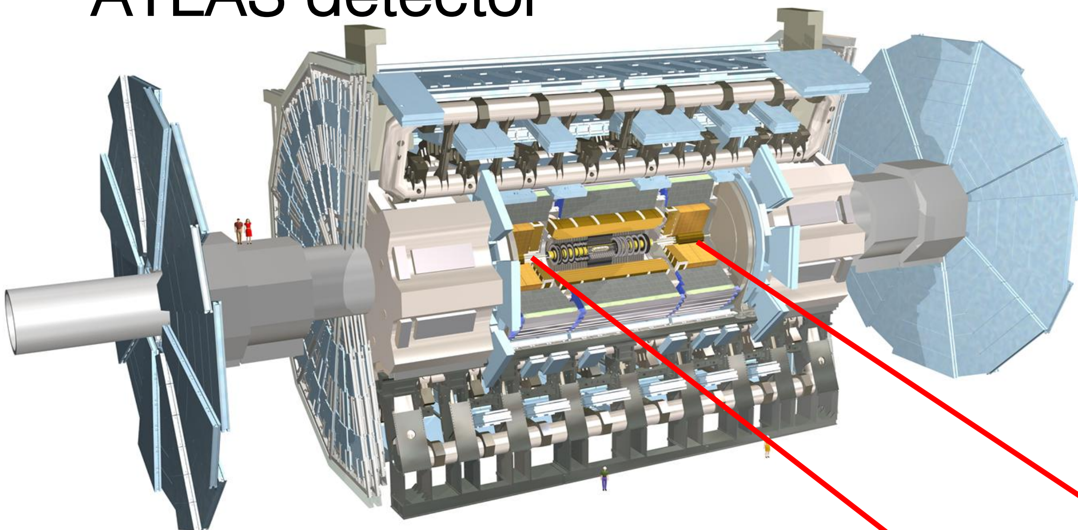
- $|\eta| < 2.5$
- 2π ϕ acceptance
- $p_T > 0.5$ GeV

Pixel detector

SCT detector

ATLAS detector ⟶ v_n measurement

ATLAS detector



- Pb+Pb 5.02 TeV → 0.49nb^{-1}
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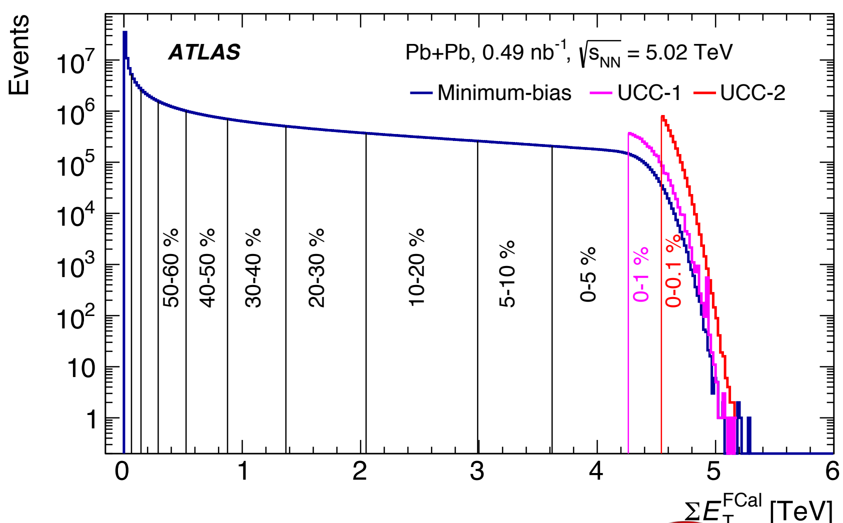
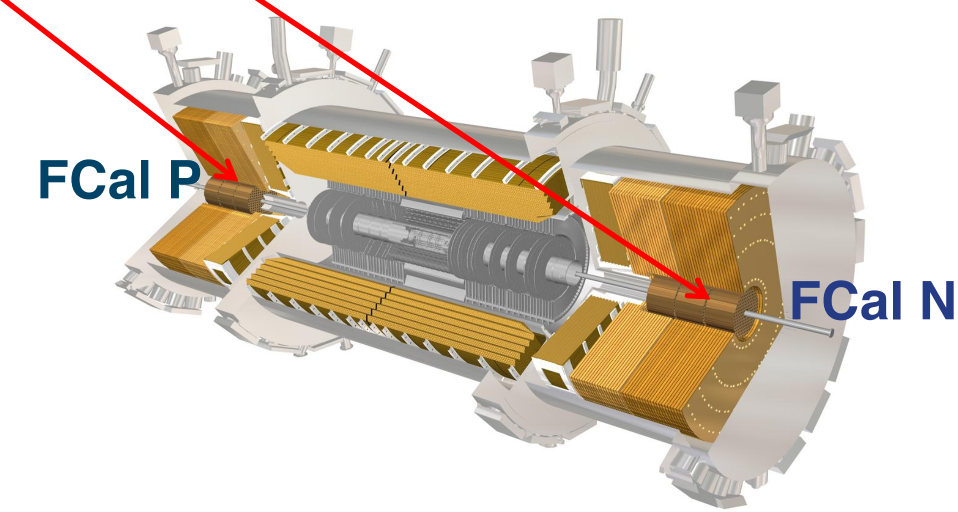
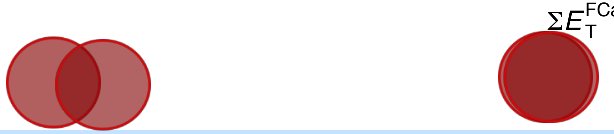
Forward Calorimeter
(3.2 < |η| < 4.9)
- Flow vectors
- Centrality definition





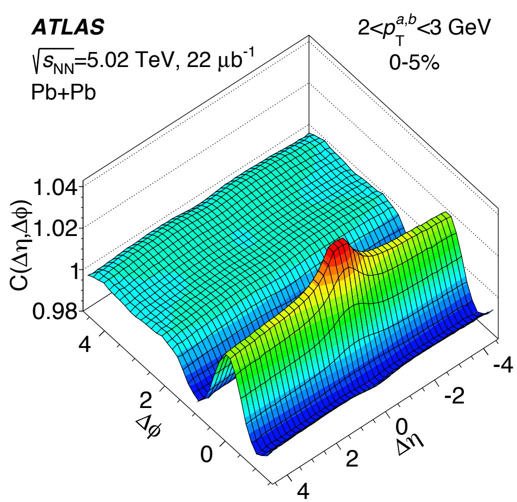


Methodology

✧ Two-particle correlations (2PC) and Scalar-product (SP) methods

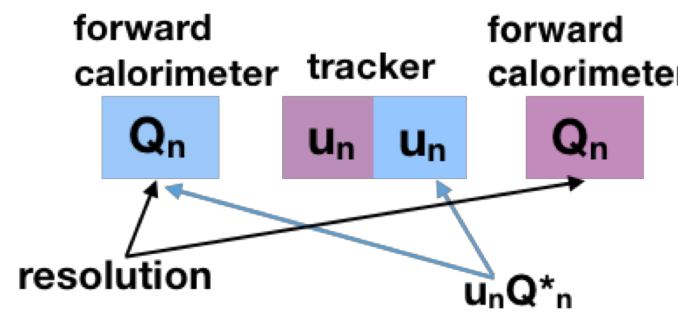
- Correlating tracks with Q-vectors at forward rapidities
- Non-flow suppressed by large Δη-gap (Δη>2)

arXiv:0809.2949 [nucl-ex]



$$u_n, Q_n = \sum_j w_j e^{in\phi_j}$$

$$v^2_2\{2\} = \langle v_2\rangle^2 + \sigma^2_v$$



✧ Multi-particle cumulants:

- Correlating tracks at mid-rapidity with each other
- Analytically suppress non-flow
- Sensitive to flow fluctuations

$$v^2_2\{4\} \approx \langle v_2\rangle^2 - \sigma^2_v$$

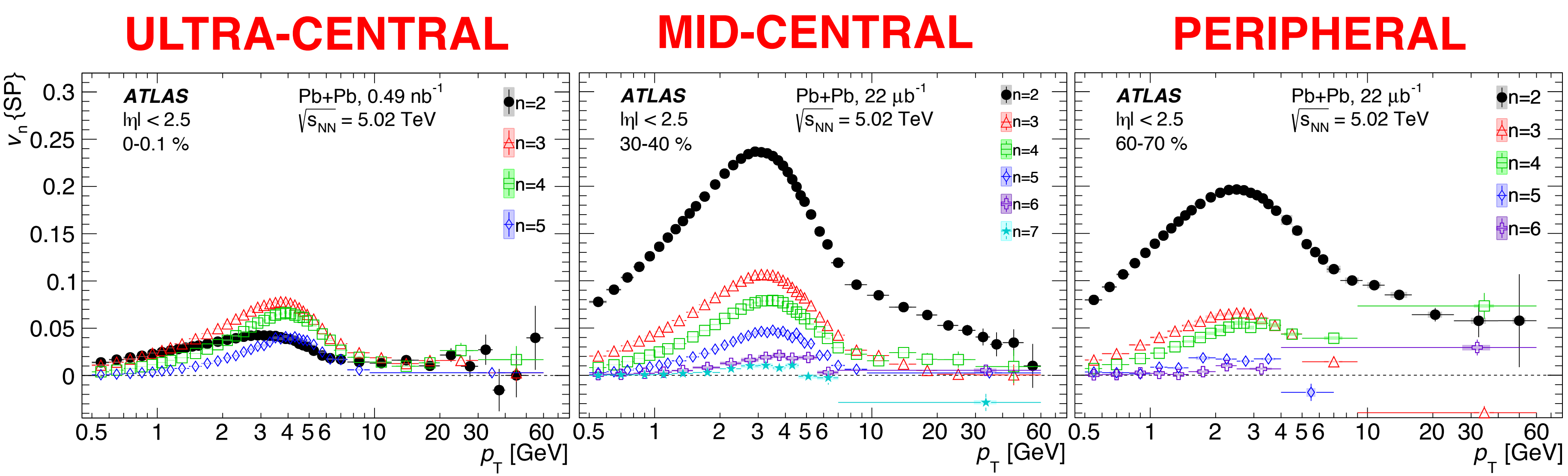
$$v_n\{2\} = \sqrt[2]{\langle v_n^2\rangle},$$

$$v_n\{4\} = \sqrt[4]{2\langle v_n^2\rangle^2 - \langle v_n^4\rangle},$$

$$v_n\{6\} = \sqrt[6]{\langle v_n^6\rangle - 9\langle v_n^2\rangle\langle v_n^4\rangle + 12\langle v_n^2\rangle^3}$$

Phys.Rev. C63 (2001) 054906

v_n harmonics in Pb+Pb collisions ⟶ p_T



- ✧ v_n measured up to p_T = 60 GeV → $v_2(p_T)$ positive at highest p_T → provide information about parton energy loss
- ✧ The ordering: $v_n > v_{n+1}$ in mid-central and peripheral collisions
  - $v_3 > v_4 > v_5 \approx v_2$ for the most central collisions at p_T = 3–5 GeV
- ✧ The v_7 harmonic is found to be non-zero for centralities 0-50%

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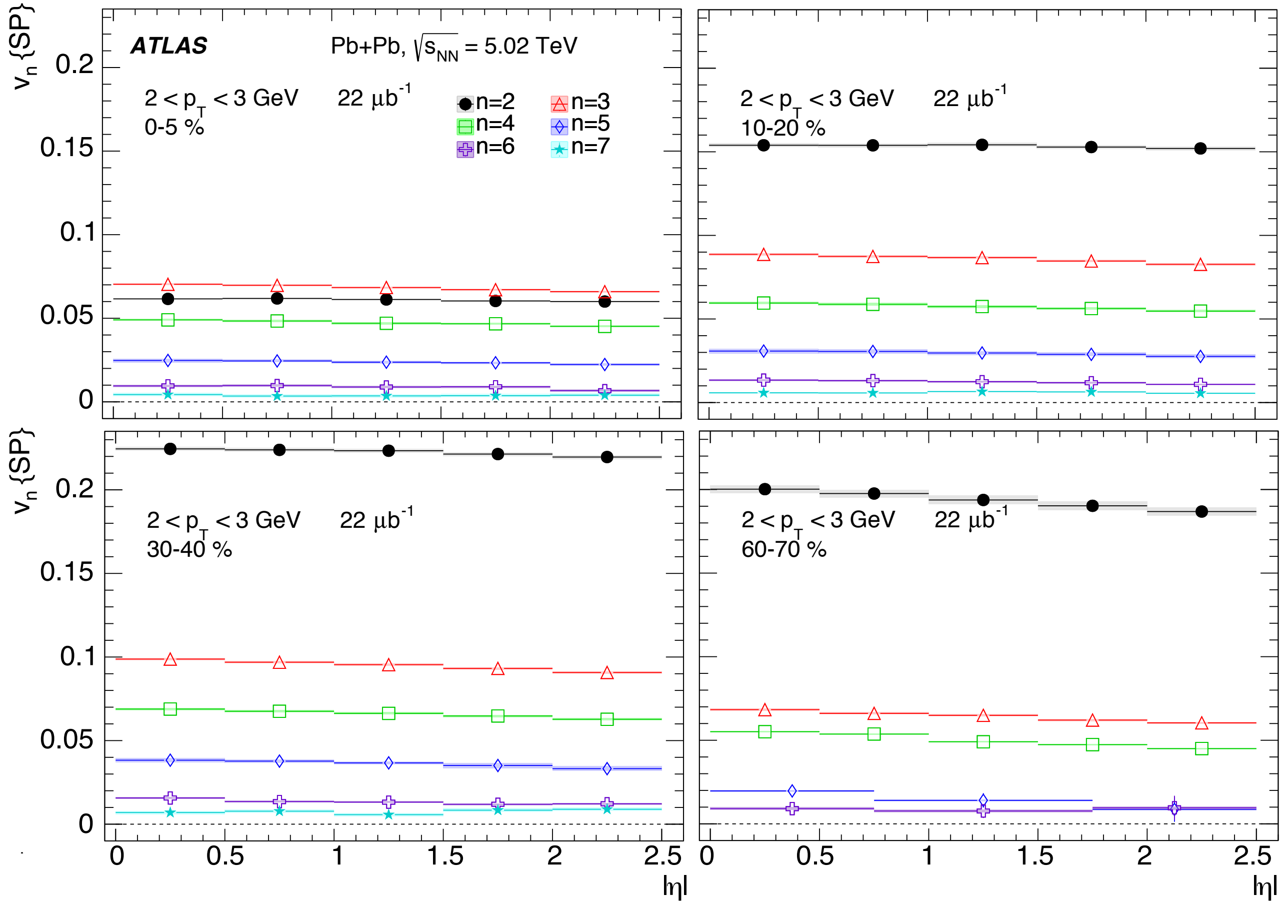
v_n harmonics in Pb+Pb collisions ⟶ η



- ✧ v_n flow harmonics show very weak η-dependence in the range of |η| < 2.5
- ✧ The exceptions are peripheral collisions and v_3, v_4 harmonics for which the differences between v_n(η=0) and v_n(η=2.5) become significant and reach about 10-25%

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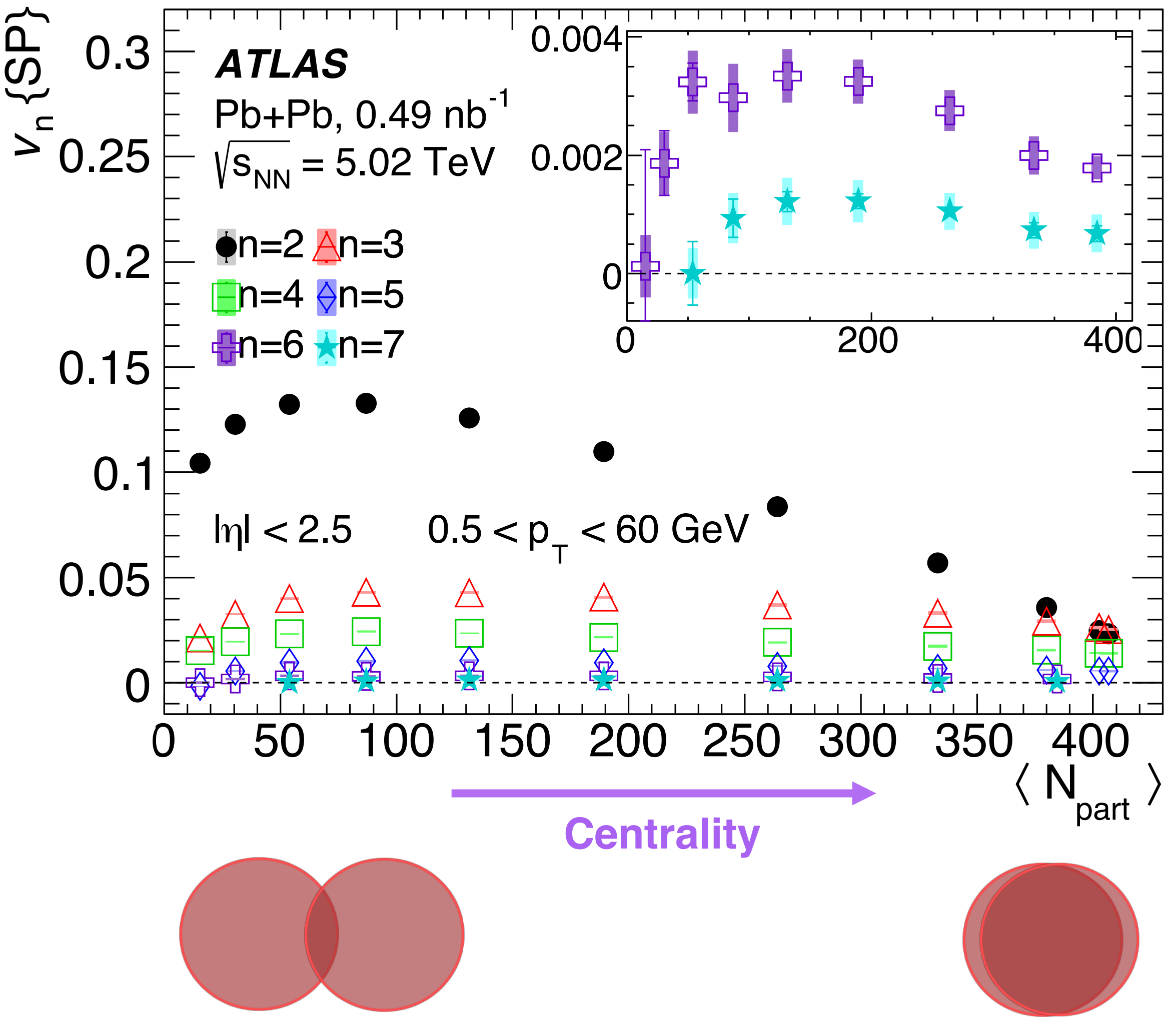
v_n harmonics in Pb+Pb collisions ⟶ centrality

- ✧ Elliptic flow is strongly dependent on event centrality and is largest in mid-central events N_{part} = 70-110
- ✧ Higher order v_n show weak centrality dependence



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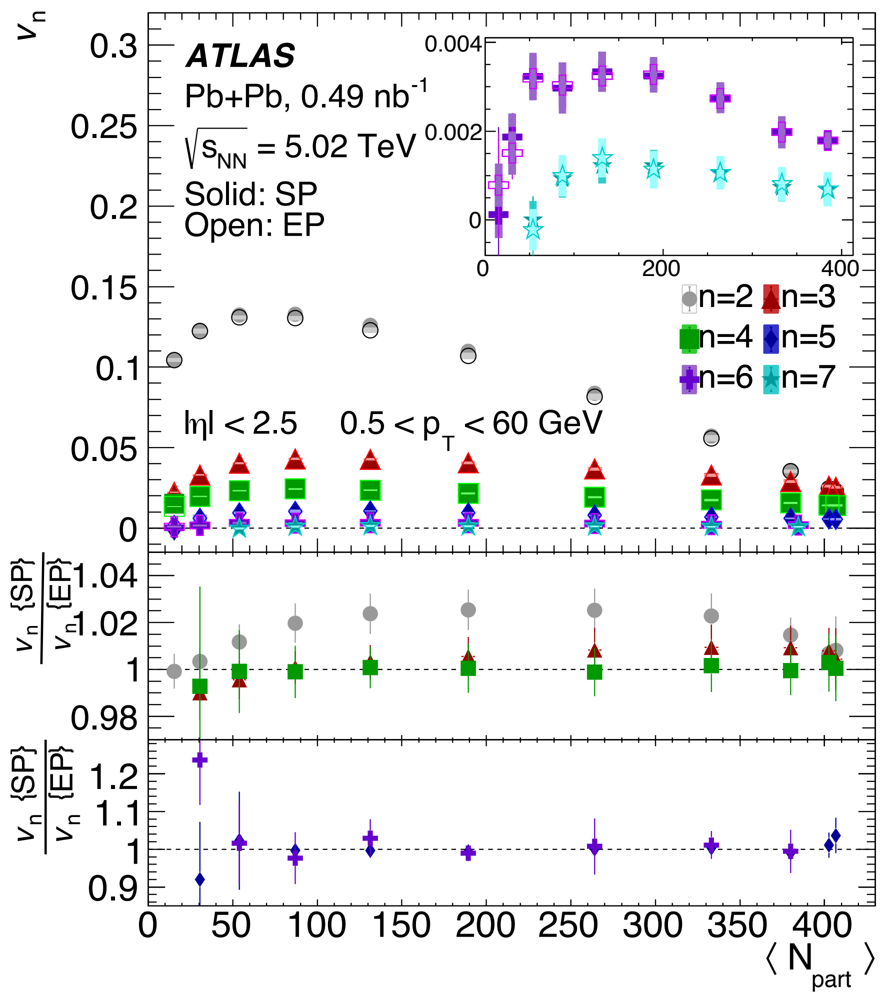
Methods comparison in Pb+Pb collisions

SCALAR-PRODUCT vs. EVENT-PLANE

- The SP method → always $\sqrt{\langle \mathbf{v_n^2} \rangle}$
- The EP method → values between $\langle \mathbf{v_n} \rangle$ and $\sqrt{\langle \mathbf{v_n^2} \rangle}$
- A small difference seen for v_2
  - Largest for 20-50% centralities reaching ~3%
- For n > 2 the EP and SP results are consistent



Phys.Rev. C87 (2013) 044907

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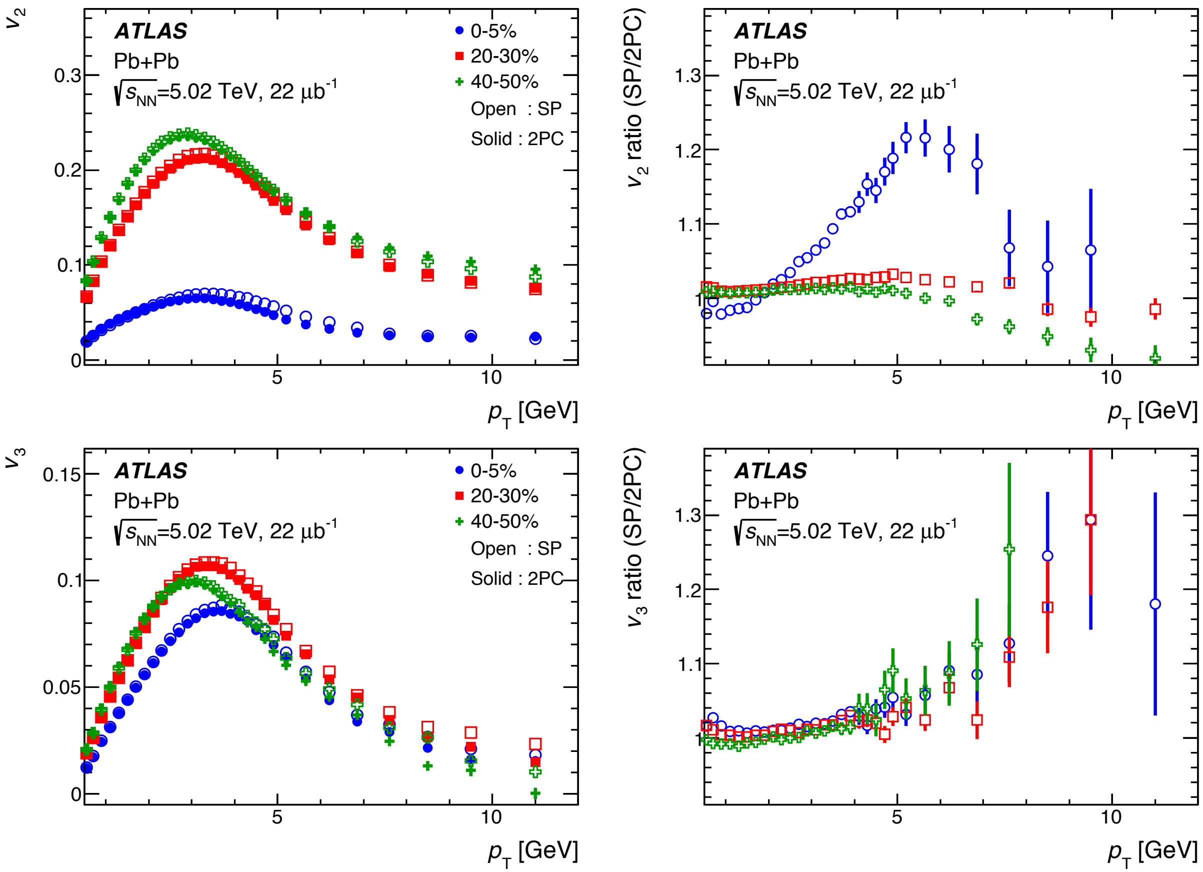
Methods comparison in Pb+Pb collisions

SCALAR-PRODUCT vs. TWO-PARTICLE CORRELATION



- $v_2 \longrightarrow$ the largest differences seen in 0-5%
  - It decreases with centrality
  - v_2\{2PC\} and v_2\{SP\} matches within ~2-5% for mid-central collisions
- $v_3 \longrightarrow$ match within ~5% for p_T < 4 GeV
- Differences due to the factorization brakedown

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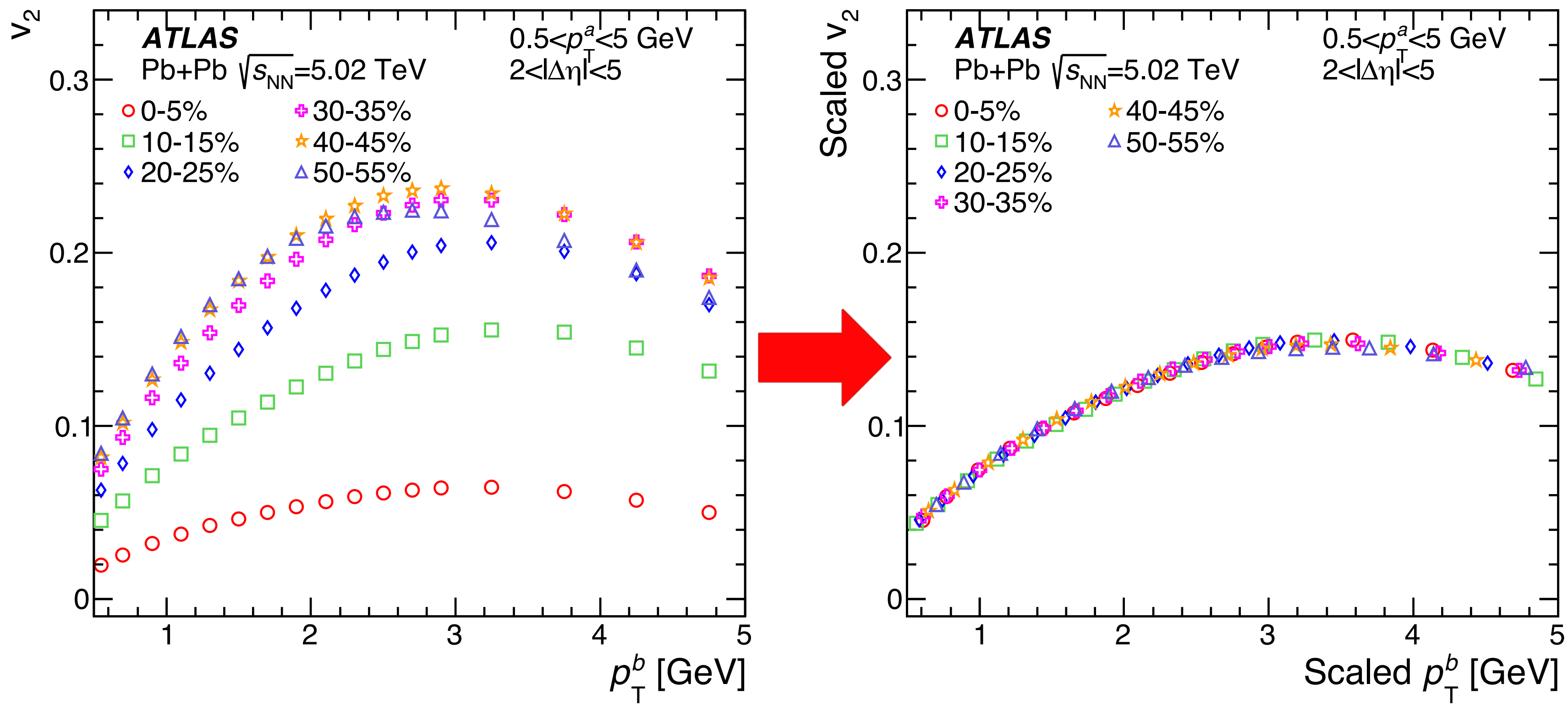
Universal scaling of v_n harmonics



- Simultanous scaling along the p_T and v_n axes was performed
  - Universal shapes for the v_n (n=2,3) across the different centrality classes
  - Similarity in properties of the QGP evolving from different initial conditions

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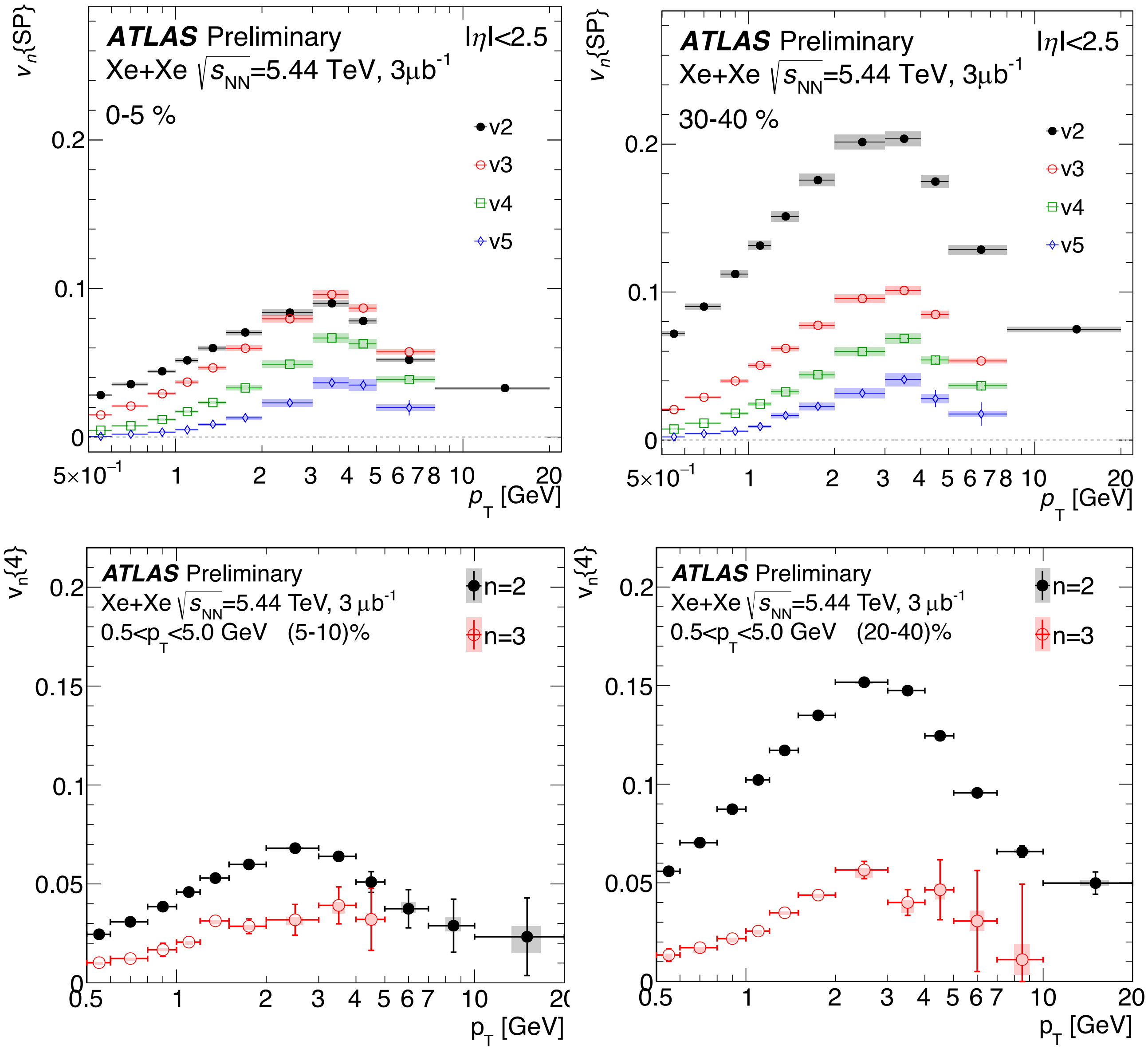
Azimuthal anisotropy in Xe+Xe collisions

CENTRAL **MID-CENTRAL**



- v_n measured up to n=5 in a wide p_T range (20 GeV for v_2)
- v_2 is dominant except the most central collisions
- v_n measured with higher order correlations smaller
  - suppressed non-flow
  - impact of fluctuations

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Initial state fluctuations in Xe+Xe & Pb+Pb collisions

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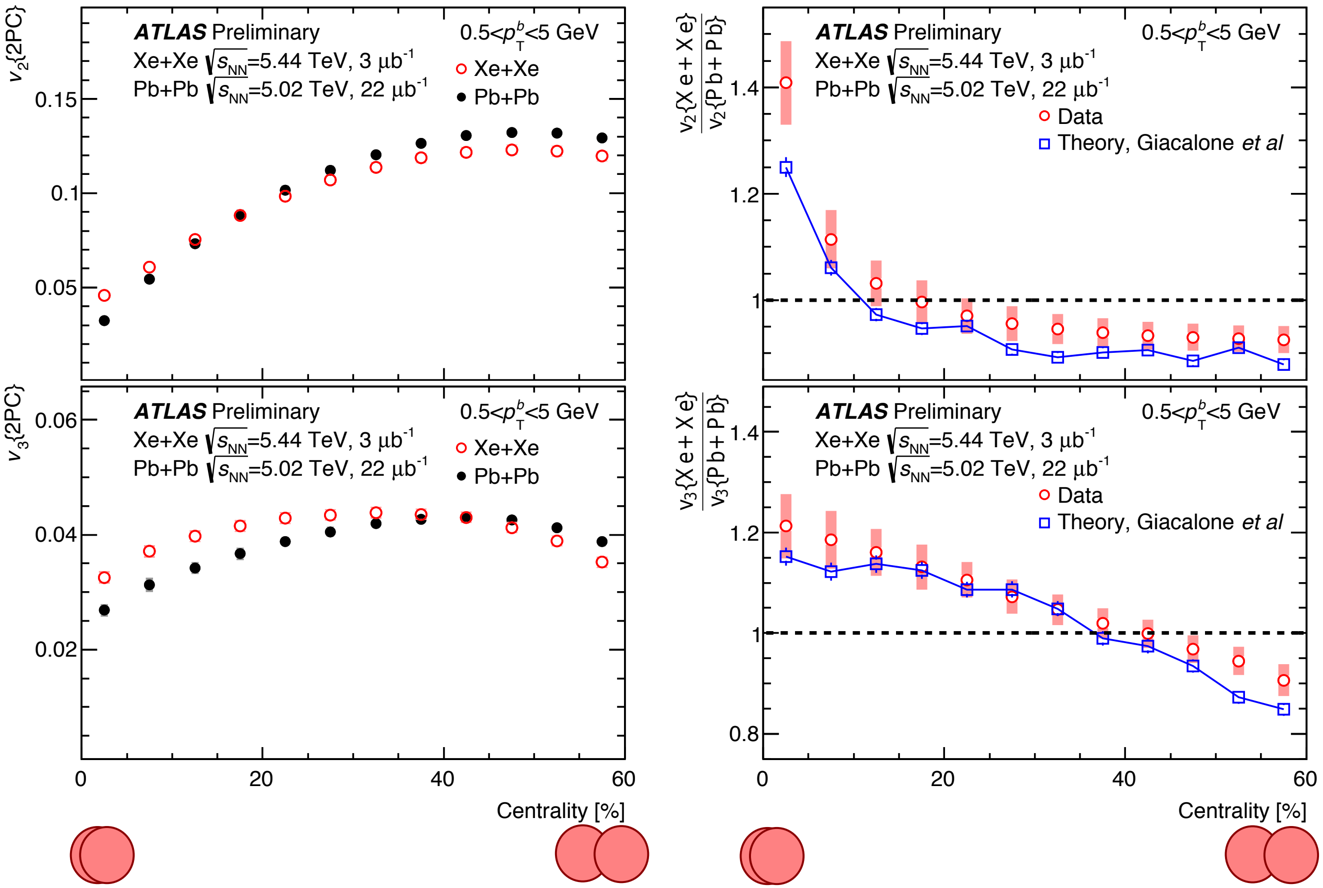
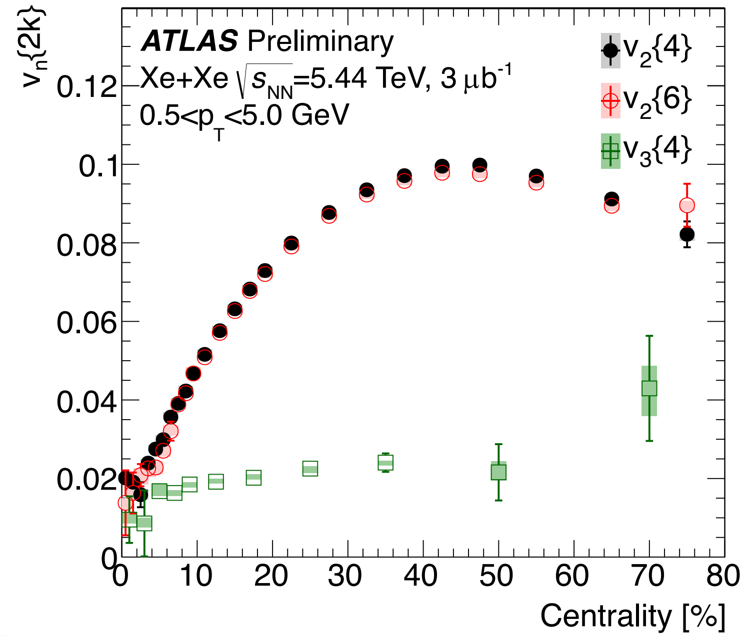


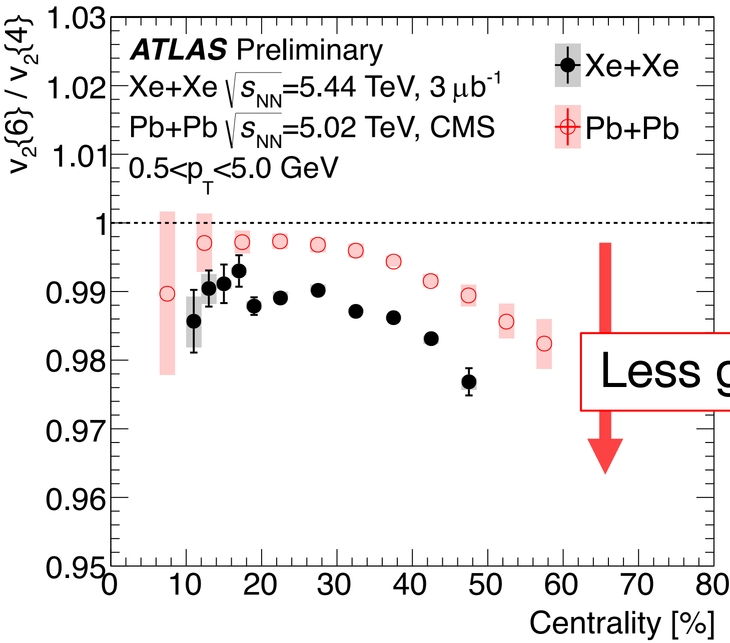
- ✧ Integrated v_n higher in the most central events for Xe+Xe
  - Smaller collision system → larger initial fluctuations
- ✧ Reduced v_n\{Xe+Xe\} value in mid-central and peripheral
  - Viscous effects

✧ Ratio v_n\{Xe+Xe\}/v_n\{Pb+Pb\} consistent with theoretical predictions: Giacalone et al. Phys.Rev.C97,034904(2018)

Flow fluctuations in Xe+Xe collisions

- Comparisons of 2PC/SP to cumulant results:
  - $v_2\{2PC/SP\} \gg v_2\{4\}$ (central collisions)
  - $v_3\{2PC/SP\} \gg v_3\{4\}$
- Indicate strong flow fluctuations
- The ordering $v_2\{2PC\} > v_2\{4\} \approx v_2\{6\}$ is observed, which indicates that v_2 fluctuations are close to Gaussian





Less gaussian

$$v_n\{2\} = \sqrt{\bar{v}_n^2 + \delta_n^2},\ v_n\{4\} = v_n\{6\} = \bar{v}_n$$

- If v_2 ~ Gaussian: $v_2\{6\}/v_2\{4\} = 1$
- v_2 in Xe+Xe deviates further from Gauss --> deformed nucleus

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Summary

✧ New results from Pb+Pb and Xe+Xe collisions are obtained (Eur. Phys. J. C (2018) 78: 997, ATLAS-CONF-2018-011)

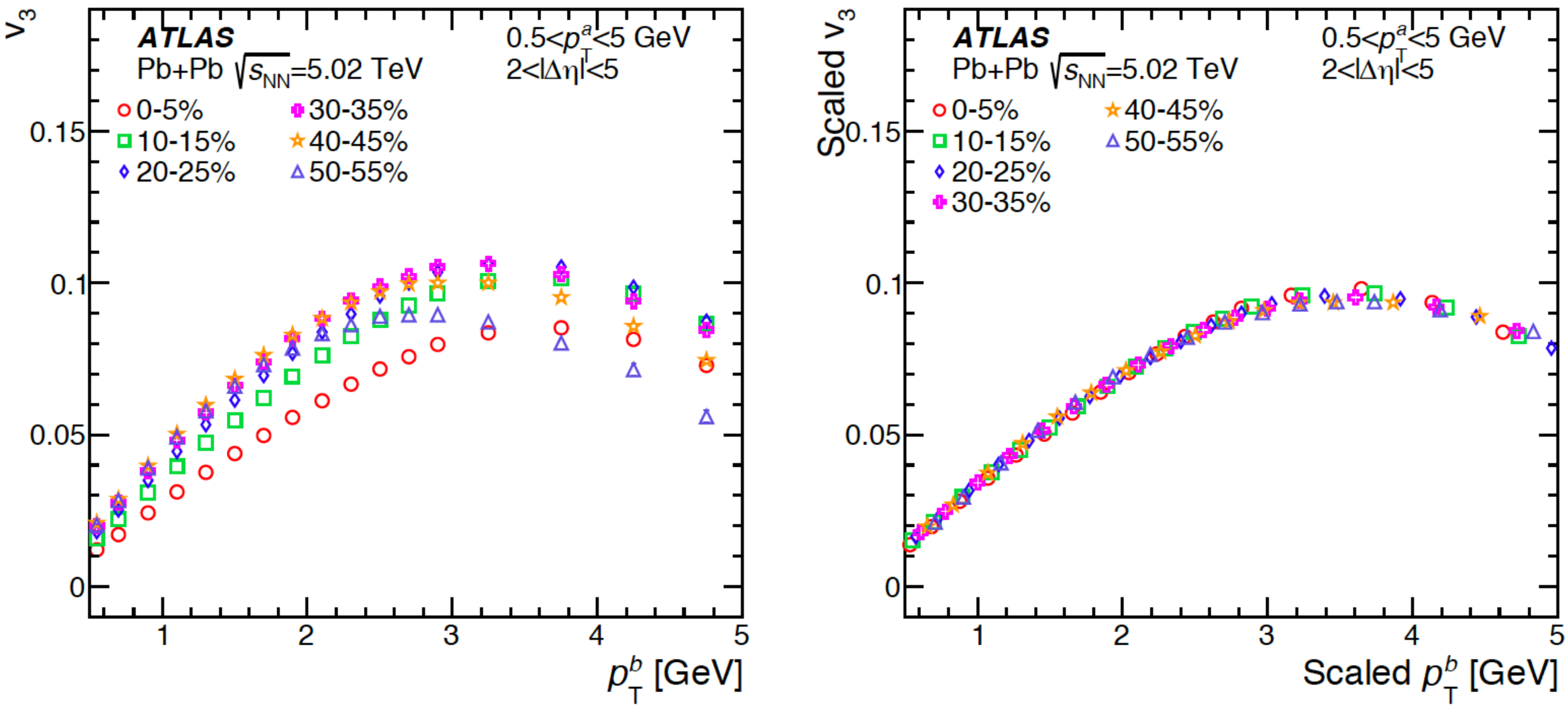
✧ Thanks to the excellent ATLAS detector and rich datasets:

→ Measured flow harmonics up v_7 and to a very high p_T in Pb+Pb

→ Performed a comprehensive study of flow in Xe+Xe collisions at 5.44 TeV and compared to Pb+Pb at 5.02 TeV

Thank you for your attention!

Universal scaling of v_n harmonics – v_3



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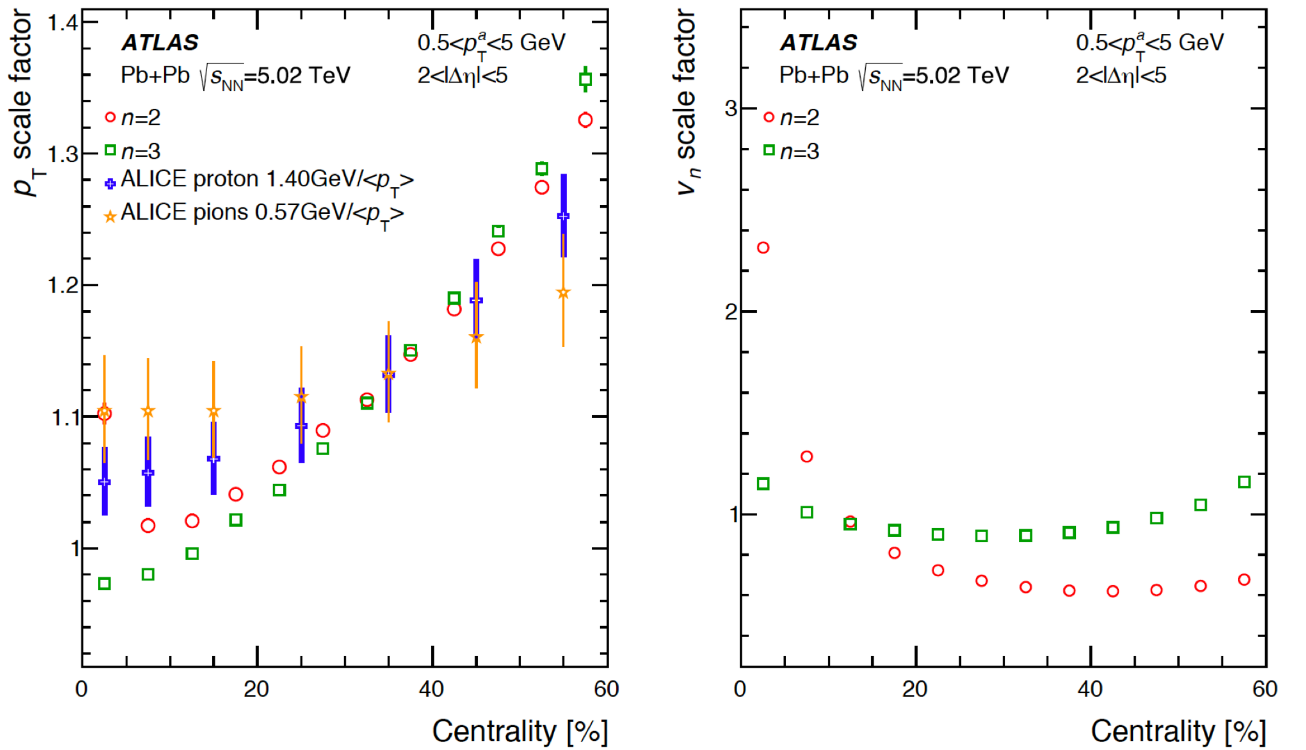
Universal scaling of v_n harmonics – scale factors



- the p_T-scale factors are quite comparable between v_2 and v_3
  - in the 0–10% most central events, larger difference → could be due to larger jet-bias and factorization-breaking effects in the v_2 as compared to v_3

- the y-scale factors are different → to be expected as the y-scale factors corresponds to the changing collision geometry, which becomes more and more elliptic from central to mid-central events resulting in a large increase in v_2, while v_3, which is driven by fluctuations, changes only gradually.

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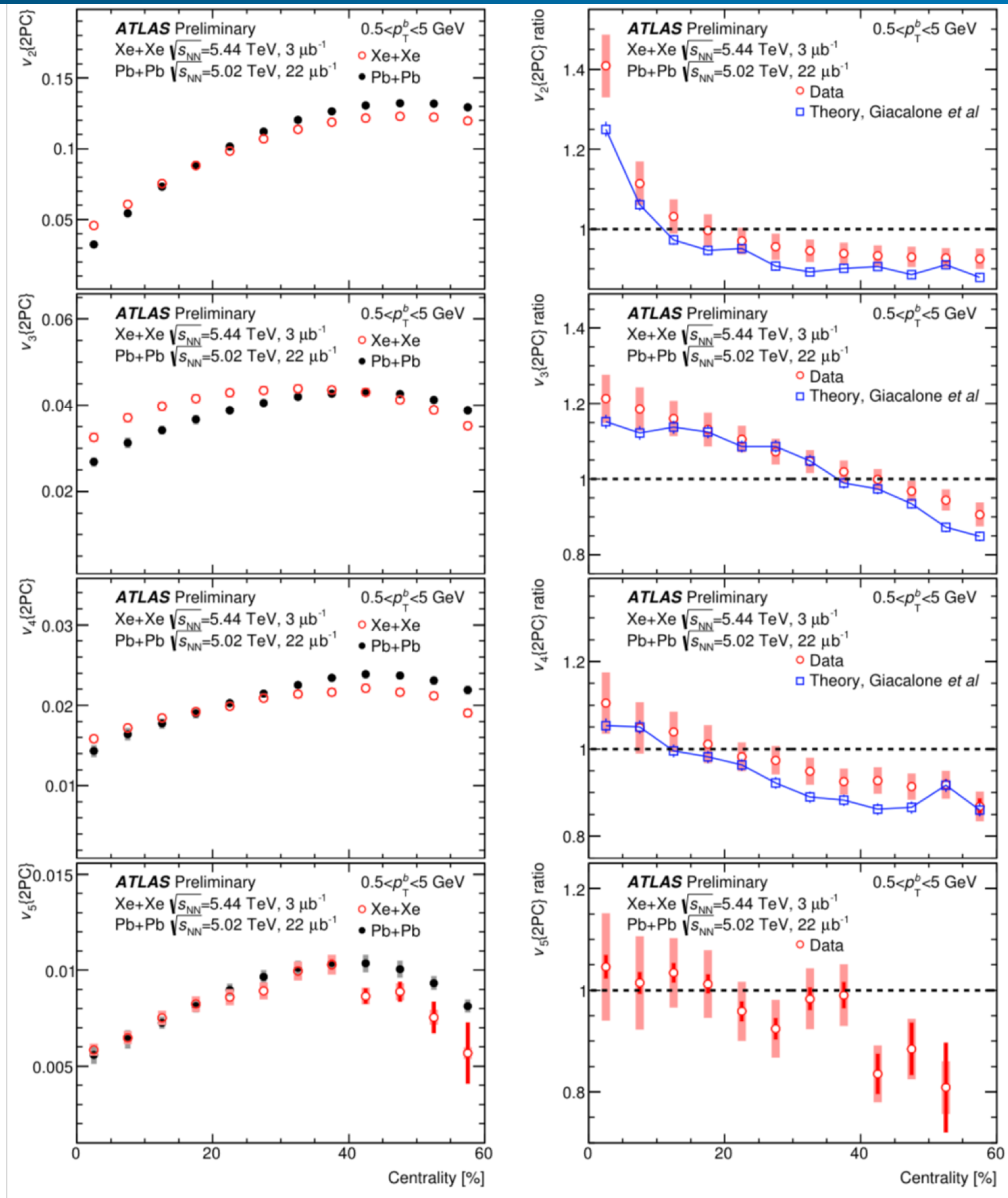
Xe+Xe/Pb+Pb flow harmonics ratios



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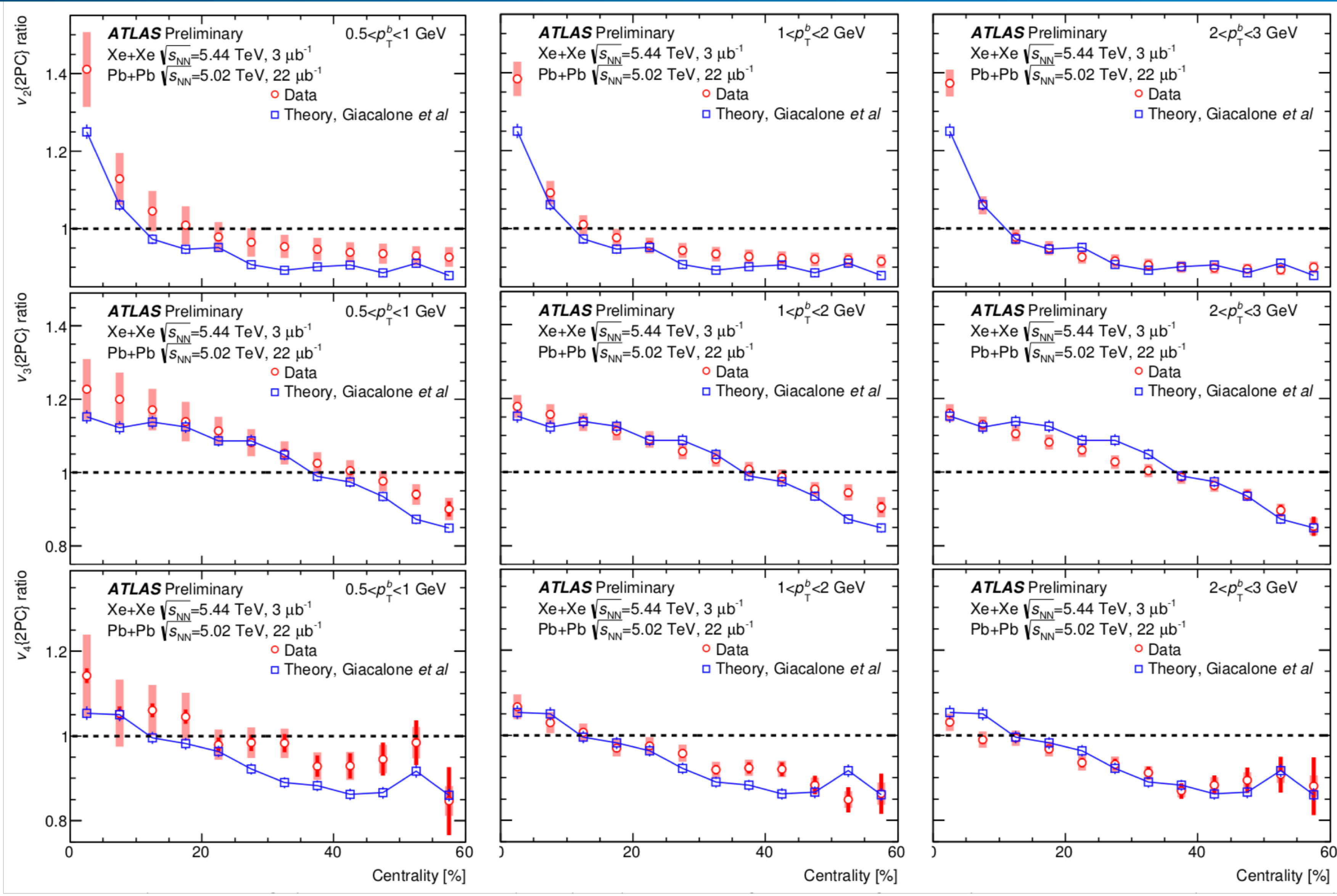

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