LHCP2021

The Ninth Annual Conference on Large Hadron Collider Physics

Online

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Collectivity of soft probes in heavy-ion collisions

Highlights from ALICE, ATLAS, and CMS

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KØBENHAVNS UNIVERSITET

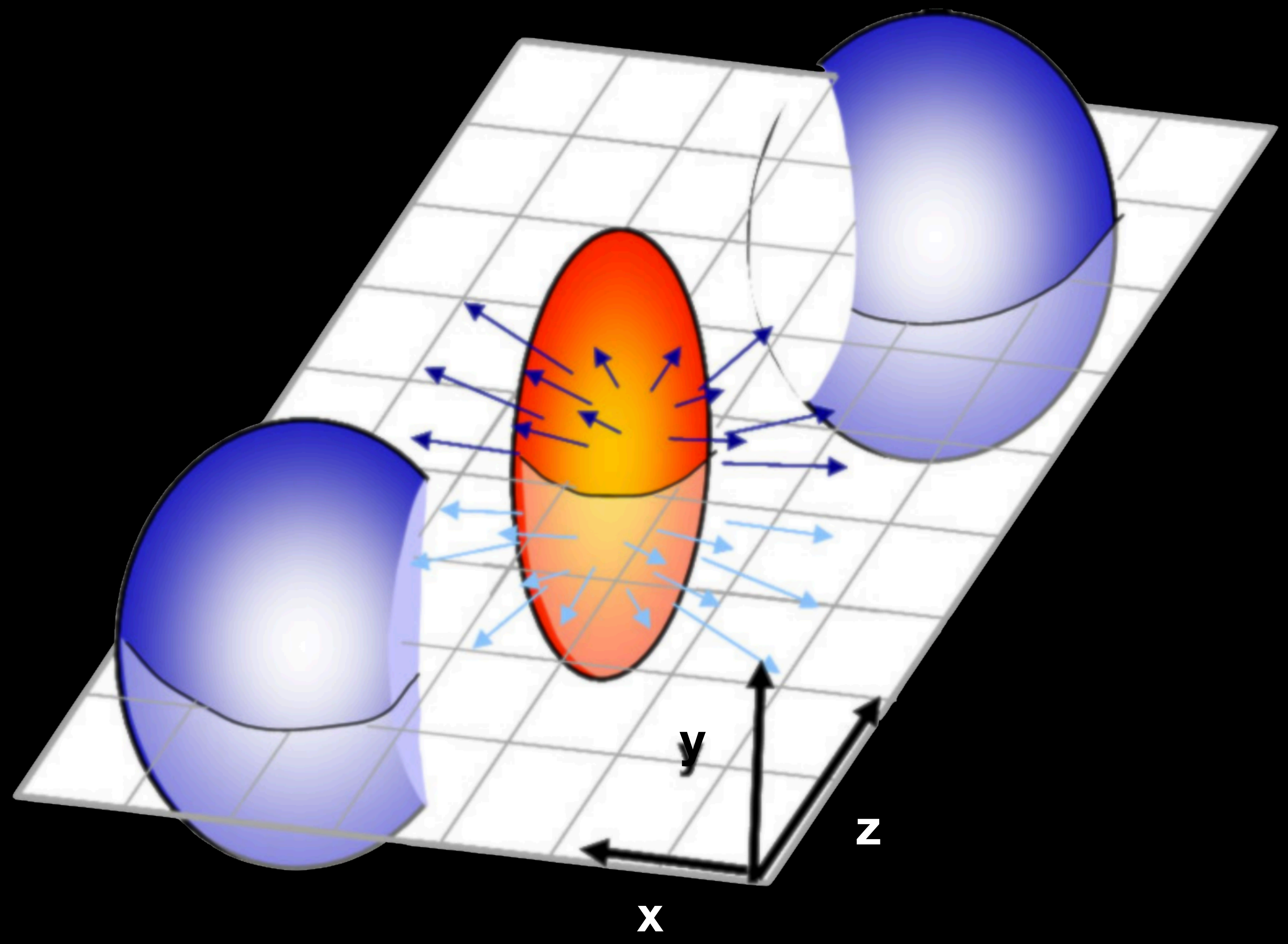
THE VELUX FOUNDATIONS
VILLUM FONDEN VELUX FONDEN

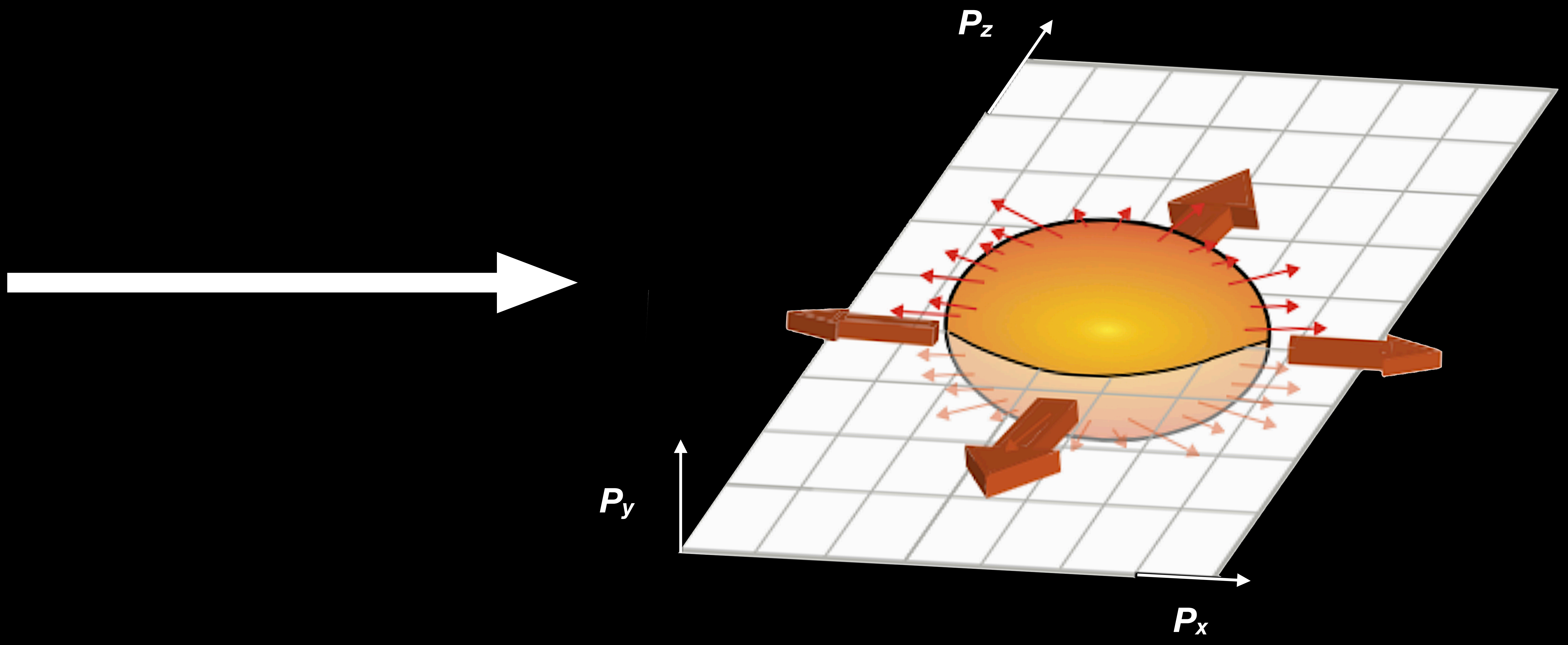
From collision to particle production

Overlap between colliding nuclei:
⇒ Initial state, geometry & its fluctuations

Hydrodynamical expansion of QGP:
⇒ Radial and anisotropic flow, sensitive to initial state and properties of QGP

Freeze-out and hadronization:
⇒ Bulk particle production in a thermalised medium, sensitive to fireball volume and temperature





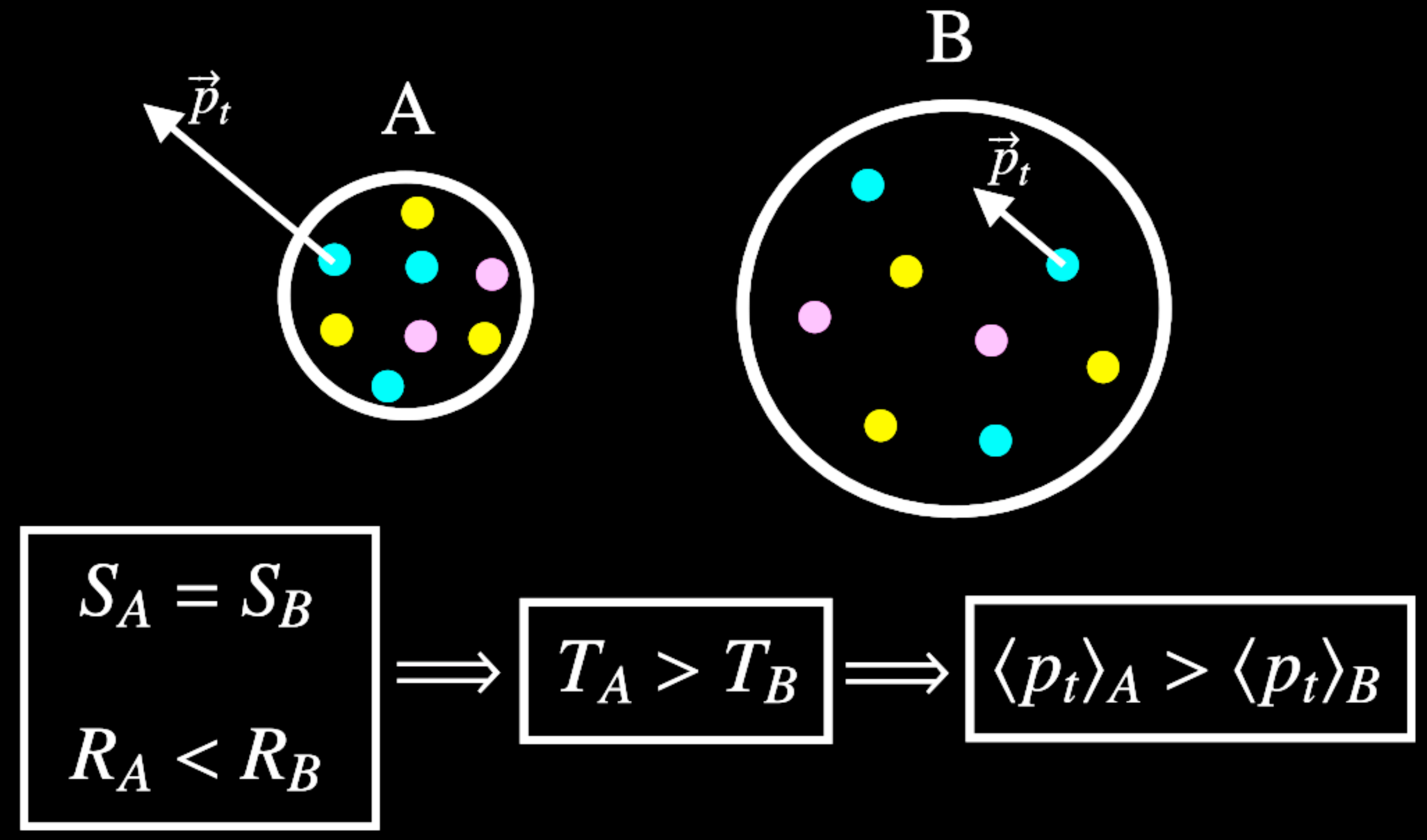
Radial vs. elliptic flow in heavy-ion collisions

p_T-differential p/π ratio:

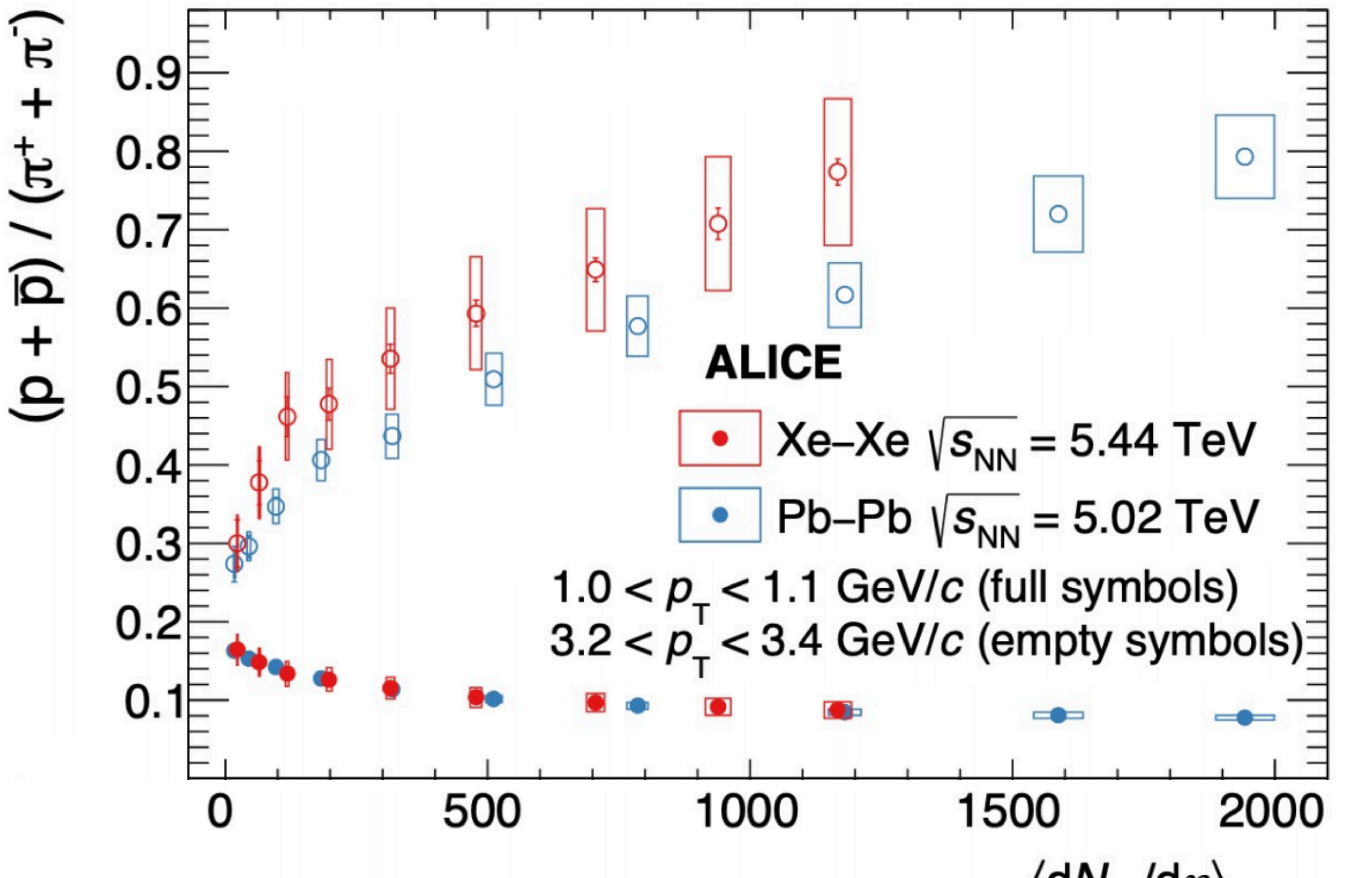
- Multiplicity-dependent "boost" of the ratio towards higher p_T

  ⇒ Dominantly driven by $\langle \mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta \rangle$, slightly larger in Xe—Xe than in Pb—Pb (but comparable)

  ⇒ Smaller volume → larger average p_T



Sketch from G. Giacalone, Phys. Rev. C 102, 024901 (2020)



ALICE, arxiv:2101.03100 [nucl-ex]

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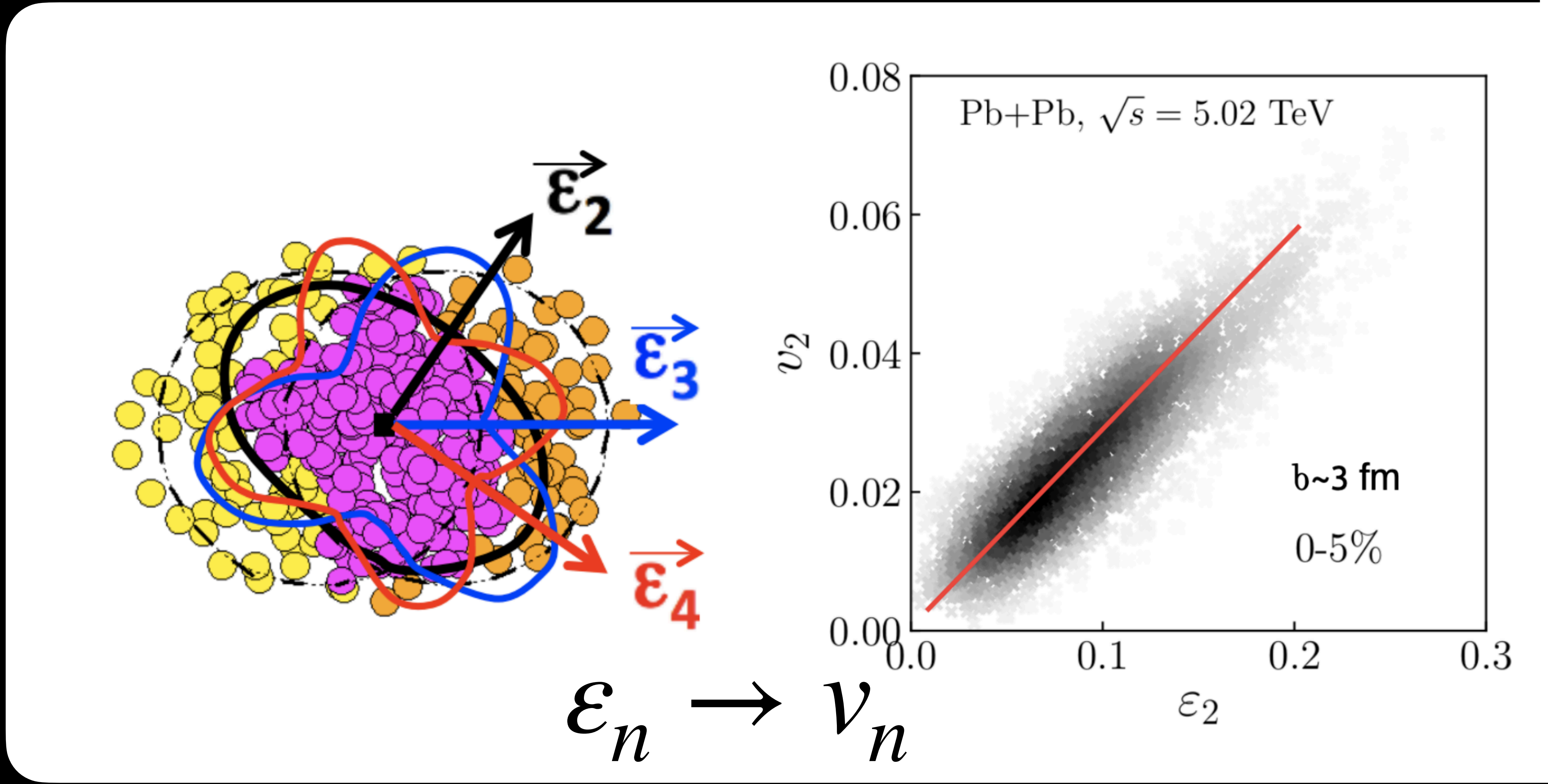
v_2 in Pb—Pb and Xe—Xe:

- Significantly larger in Pb—Pb even at comparable $\langle \mathrm{d}N_{ch}/\mathrm{d}\eta \rangle$ ⇒ Sensitive to initial geometry



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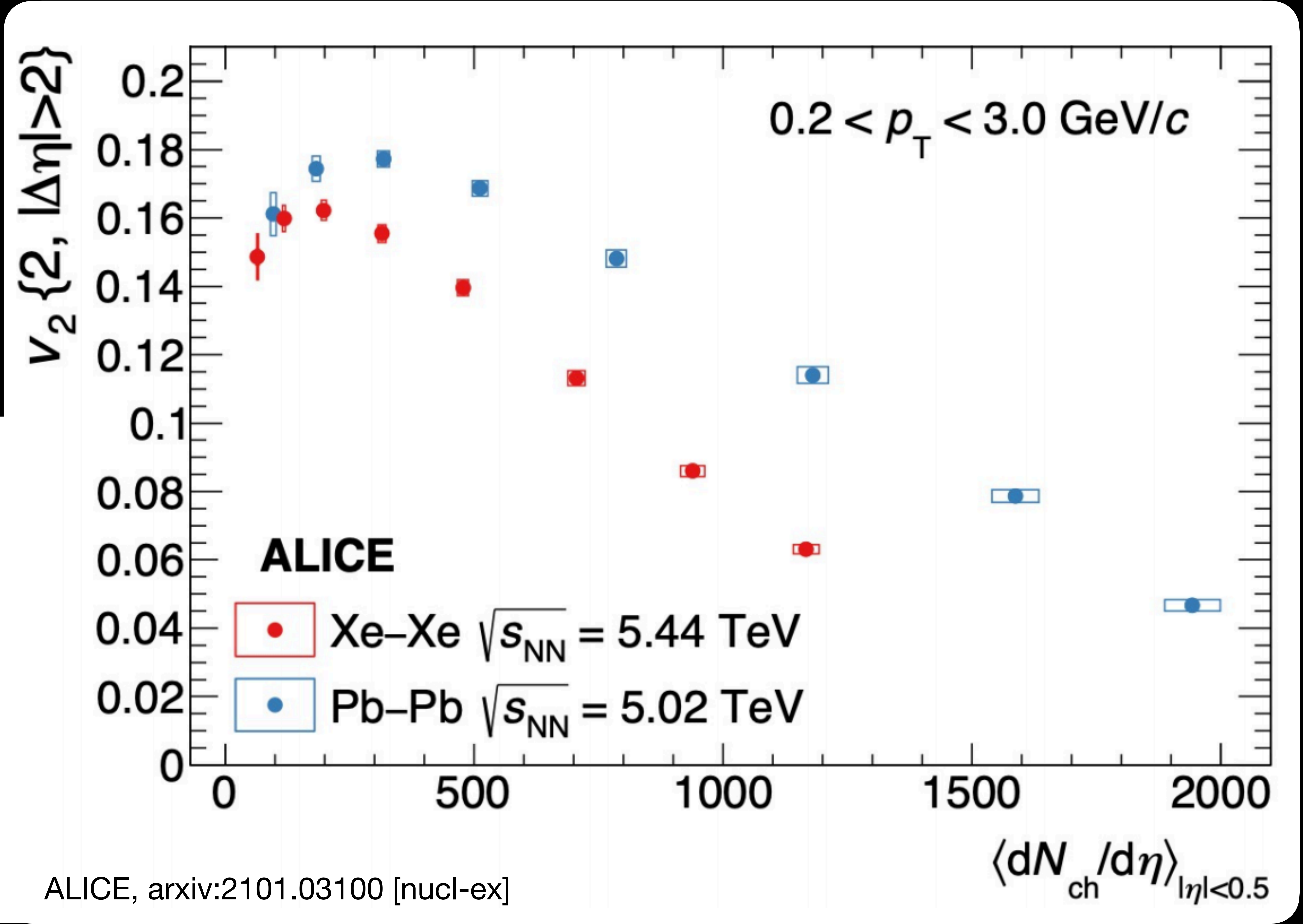

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Correlation between v_n and $[p_\mathrm{T}]$

- Shape of the fireball: anisotropic flow, $\varepsilon_n \rightarrow v_n$
- Size of the fireball: radial flow, $[p_\mathrm{T}]$, $1/R \rightarrow [p_\mathrm{T}]$
- Initial state: geometry and fluctuations of shape and size
- Final state: correlation between v_n and $[p_\mathrm{T}]$

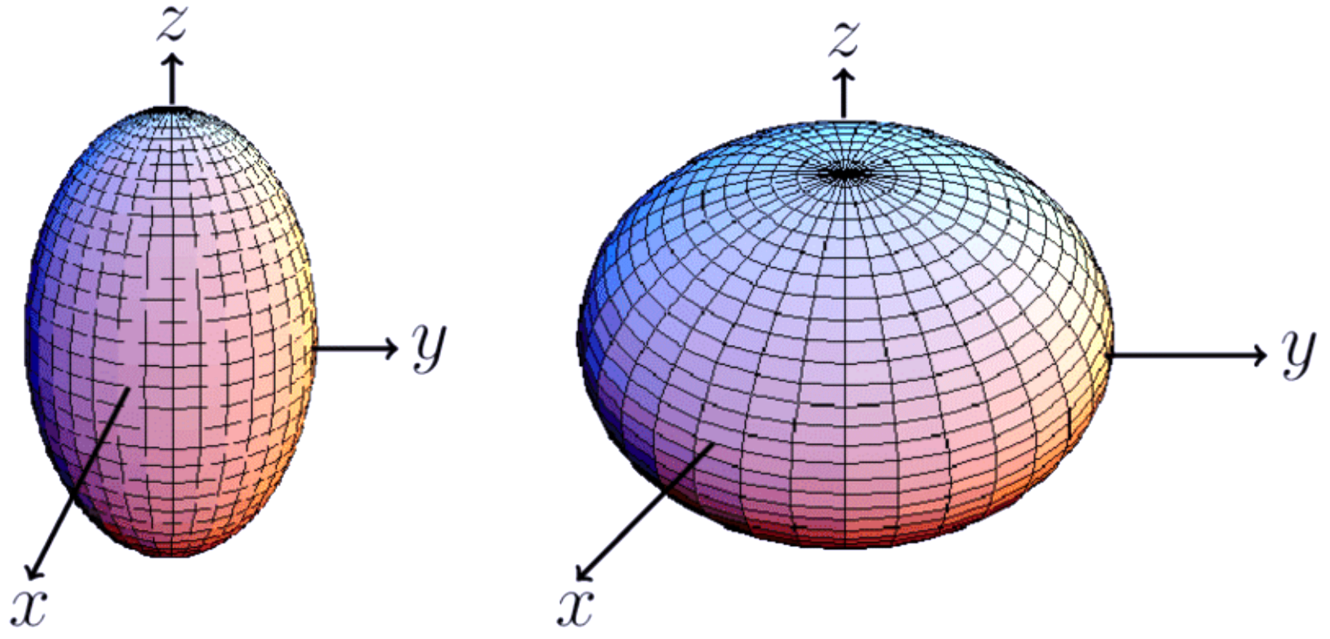
- Study with Pearson correlation coefficient:

$$\rho_n\left(v_n^2, [p_T]\right) = \frac{\mathrm{cov}\left(v_n^2, [p_T]\right)}{\sqrt{\mathrm{var}\left(v_n^2\right)}\sqrt{\mathrm{var}\left([p_T]\right)}}$$

For deformed nuclei

- Significantly smaller ρ_2 in central Xe—Xe, compared to Pb—Pb
  $\Rightarrow$ Deformation β reduces ρ_2

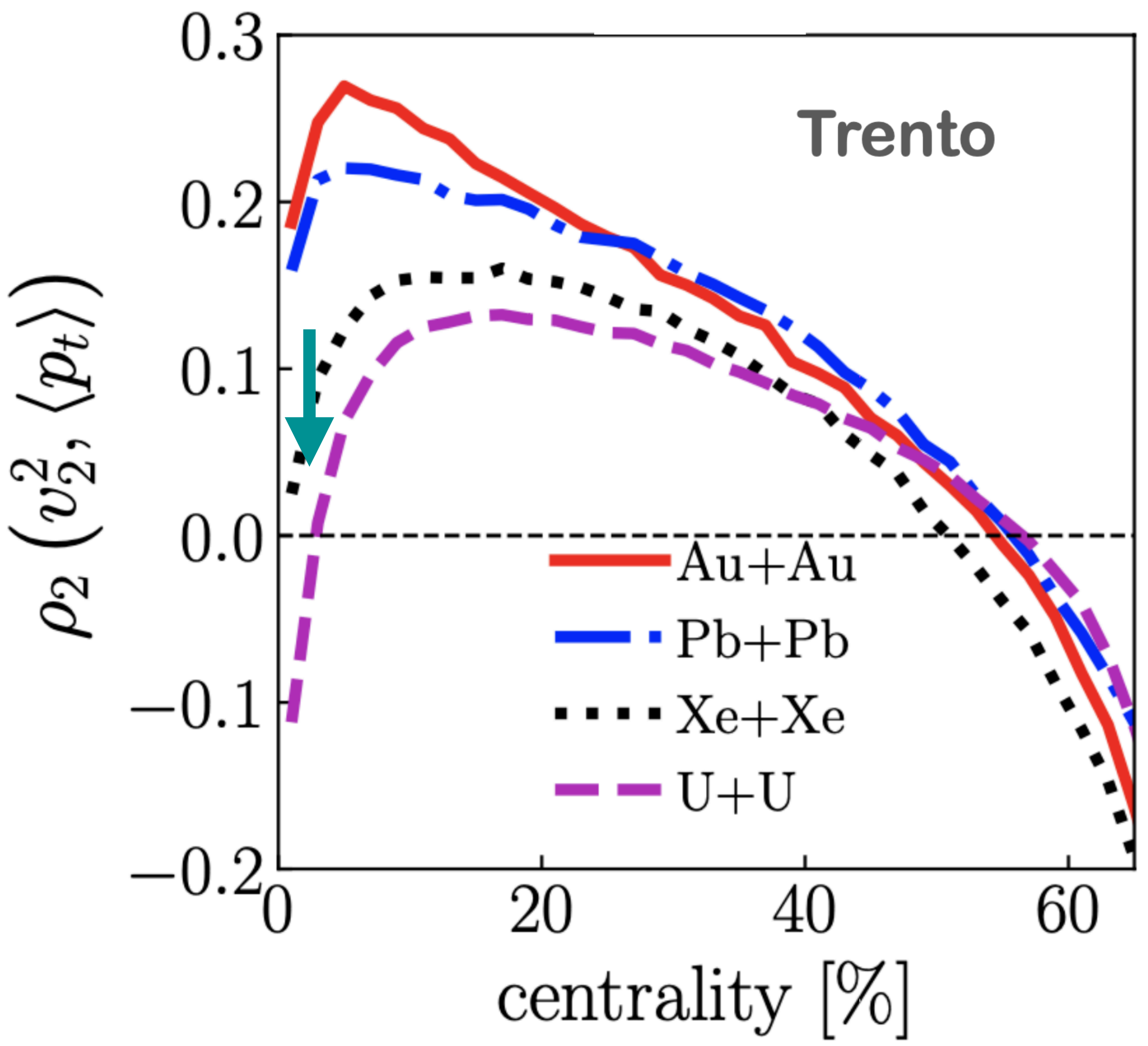
$$D_{WS}(r) = \frac{D_0}{1 + e^{\left(r - R_0\left(1+\beta Y_{20}\right)\right)/a}}$$



$\beta > 0$ $\beta > 0$

Pb—Pb: $\beta \approx 0$
Xe—Xe: $\beta \approx 0.16$

G. Giacalone, Phys. Rev. C 102, 024901 (2020)



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For deformed nuclei

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Probing the initial state

- Low multiplicity: geometry → initial momentum correlations
  $\Rightarrow$ Change of slope sign → presence of CGC?

- Study with Pearson correlation coefficient:

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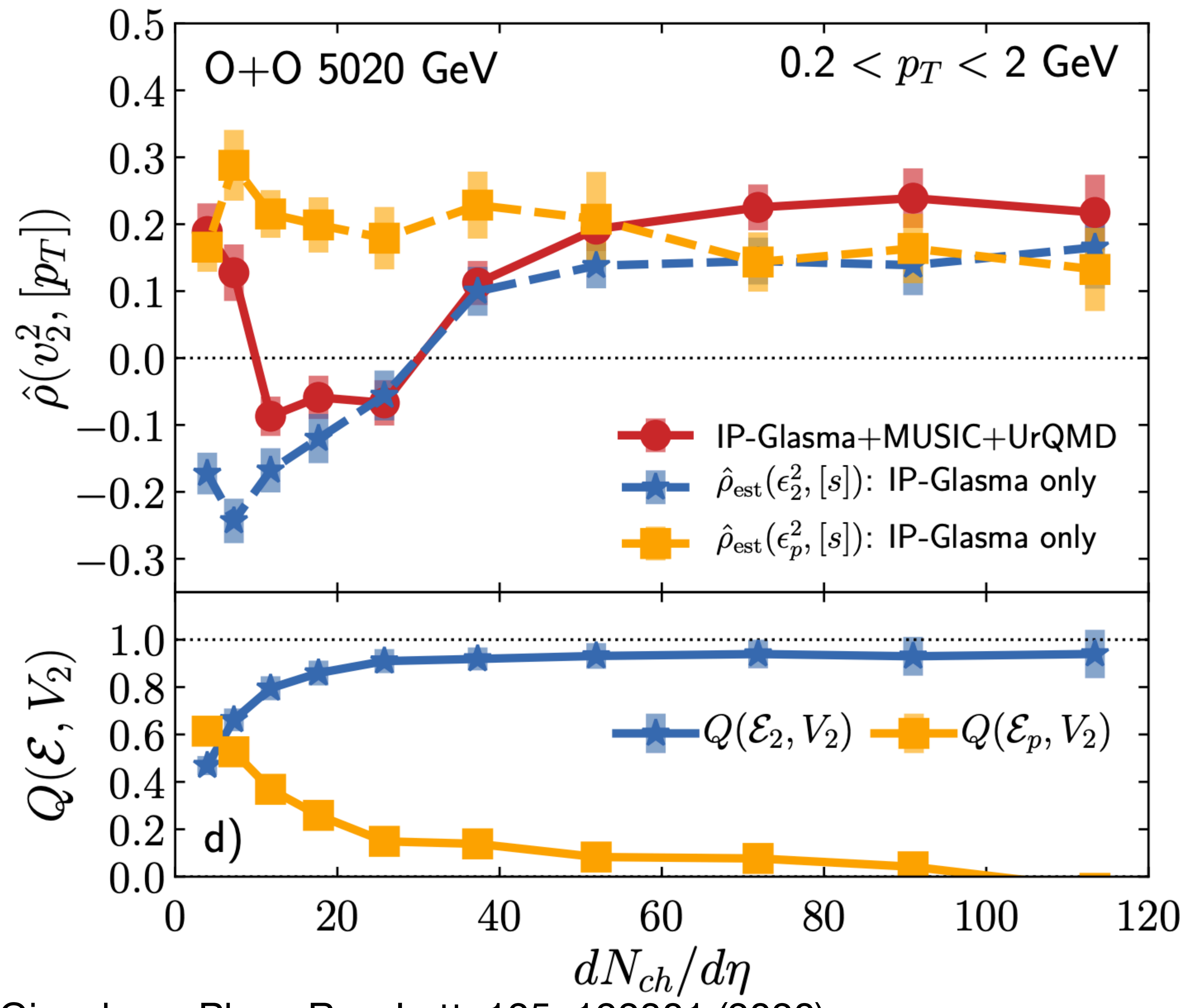
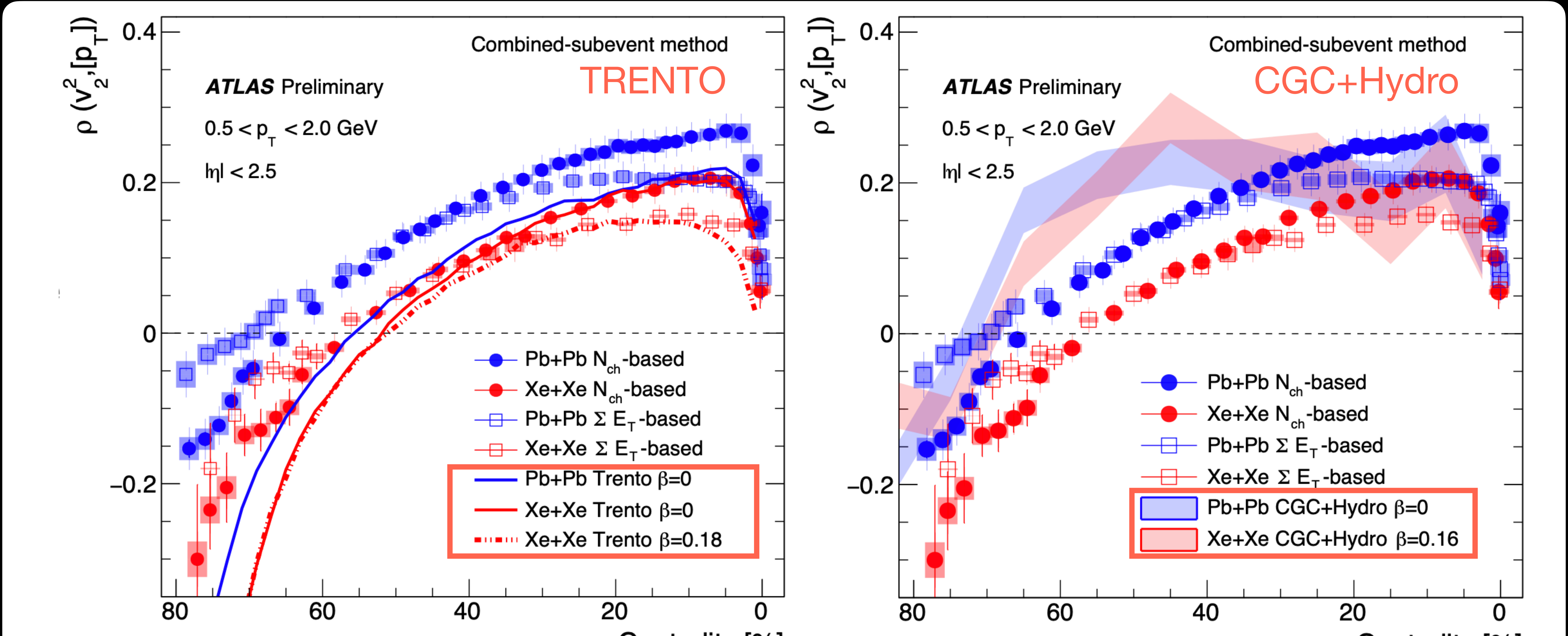


G. Giacalone, Phys. Rev. Lett. 125, 192301 (2020)

Deformation of Xe nuclei

- ATLAS: significant difference between Pb—Pb and Xe—Xe
- TRENTo: the difference between Pb—Pb and Xe—Xe in central collisions captured by the model with β = 0.18; underestimates the data in more peripheral collisions
- CGC+Hydro: no significant difference between Pb—Pb & Xe—Xe



ATLAS, ATLAS-CONF-2021-001

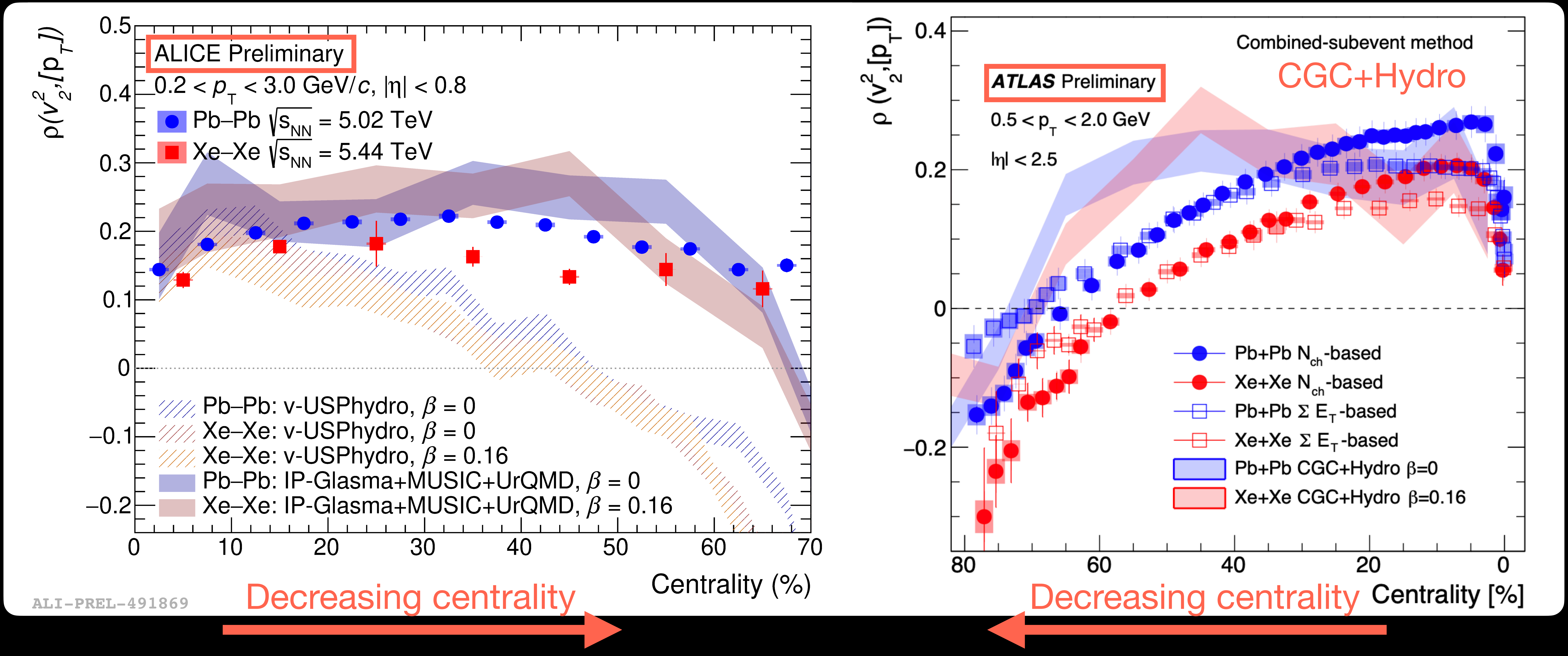
Deformation of Xe nuclei

ALICE vs. ATLAS:

- Evolution with centrality less pronounced in ALICE
- But different centrality estimator + different kinematic cuts
- ρ_2 sensitive to collision system, centrality & kinematics

Comparison to models:

- Central collisions agree with data, tension in peripheral
- No quantitative description



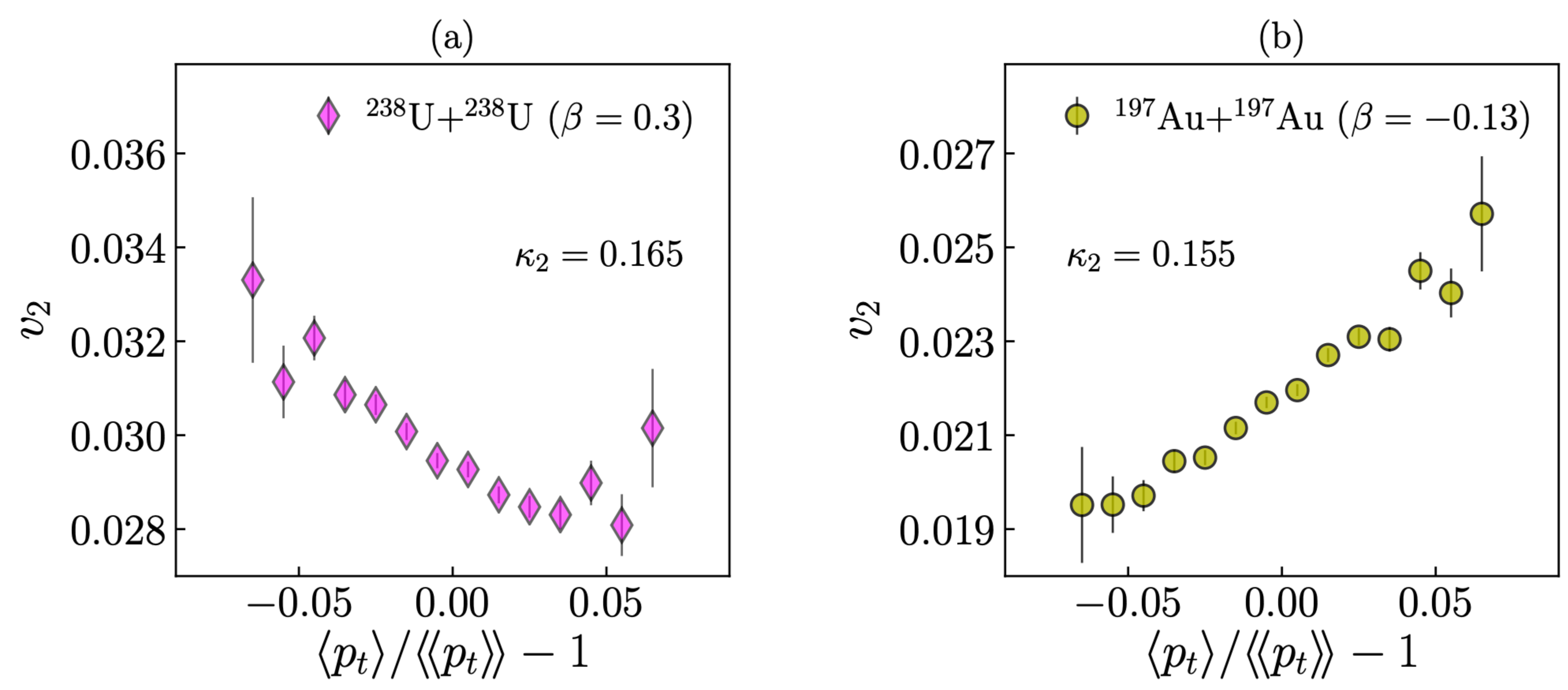
Deformation of Xe nuclei

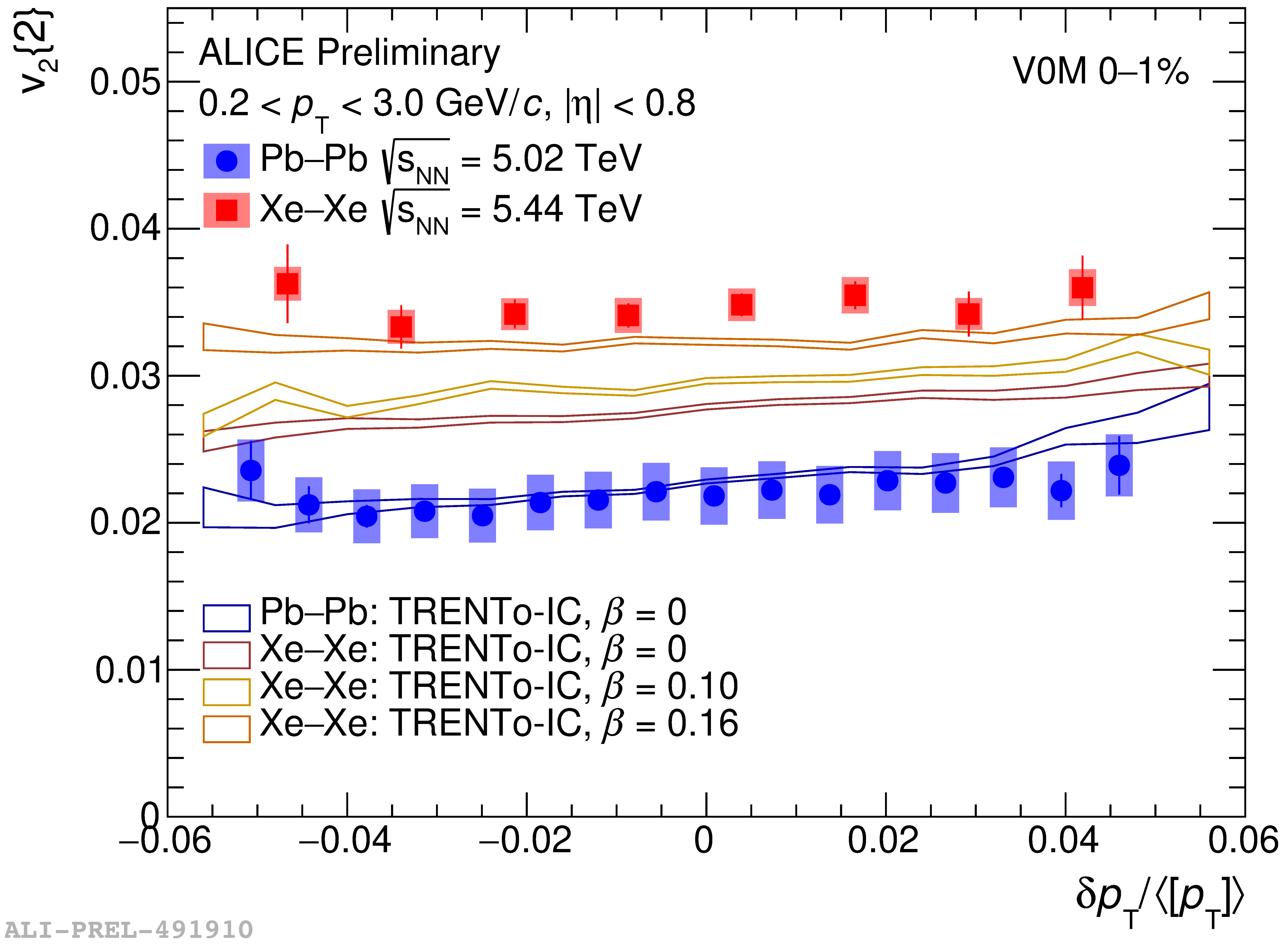
Modeling:

- Measure v_2 as a function of $\left([p_T] - \langle [p_T] \rangle\right)/\langle [p_T] \rangle$ in most central collisions
- Pb—Pb (no deformation): flat
- Xe—Xe: v_2 larger in events with smaller $[p_T]$

ALICE:

- Pb—Pb and Xe—Xe significantly different
- Xe—Xe best described with $\beta = 0.16$





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$\rho(v_2^2, [p_T])$ at low multiplicity

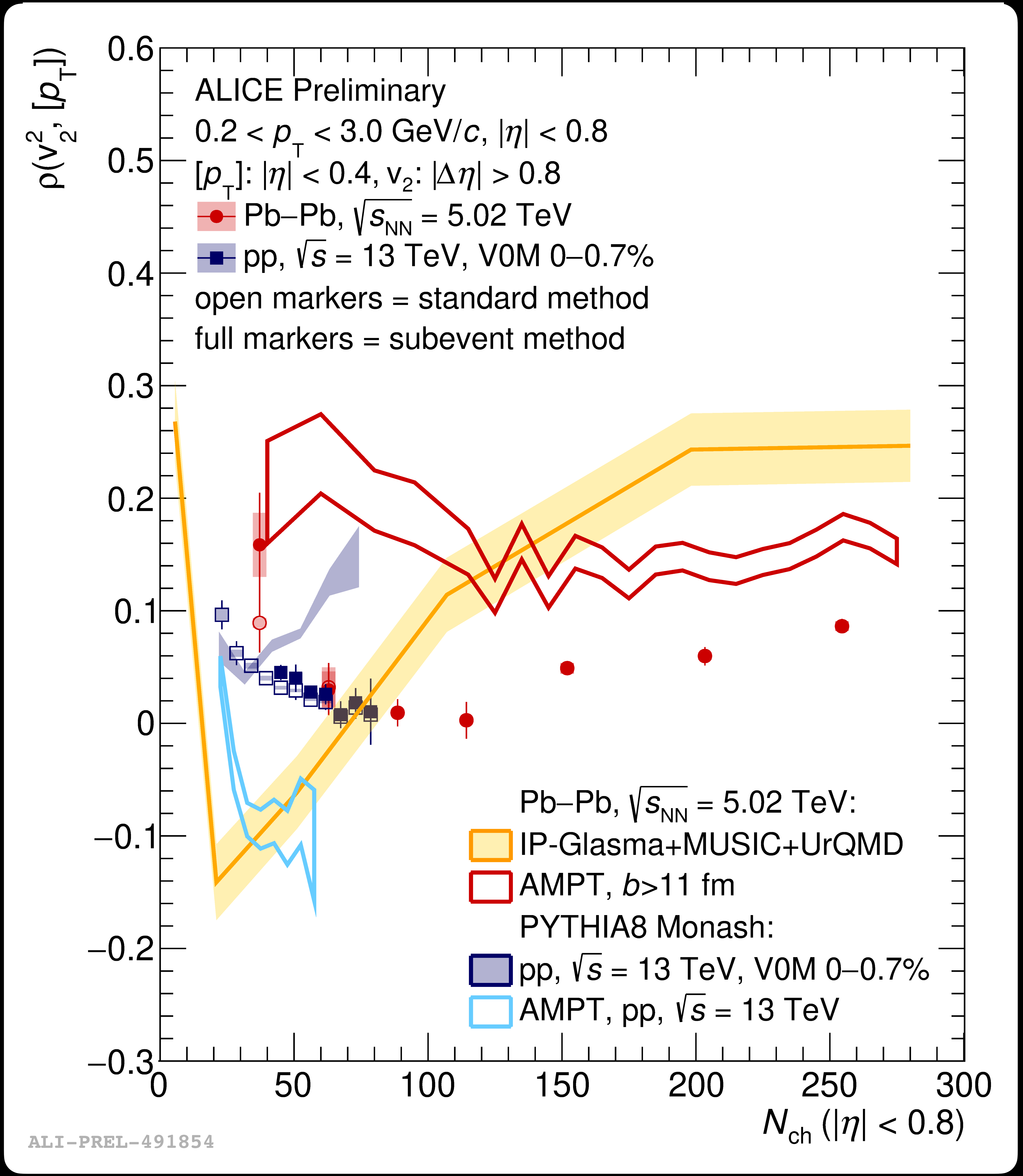
$\rho(v_2^2, [p_T])$ in Pb—Pb in ALICE:

- Slope changes around N_{ch} of 100
  ⇒ IP-Glasma slope changes around 20 ch. tracks
- Both AMPT and IP-Glasma+hydro predict slope change
  ⇒ Not unique for CGC?
- No quantitative description

PCC in pp:

- Decreasing trend with N_{ch}, HM-triggered data consistent with Pb—Pb
- Underestimated by AMPT, overestimated by PYTHIA

PCC in Pb—Pb by ATLAS also available at:
ATLAS-CONF-2021-001



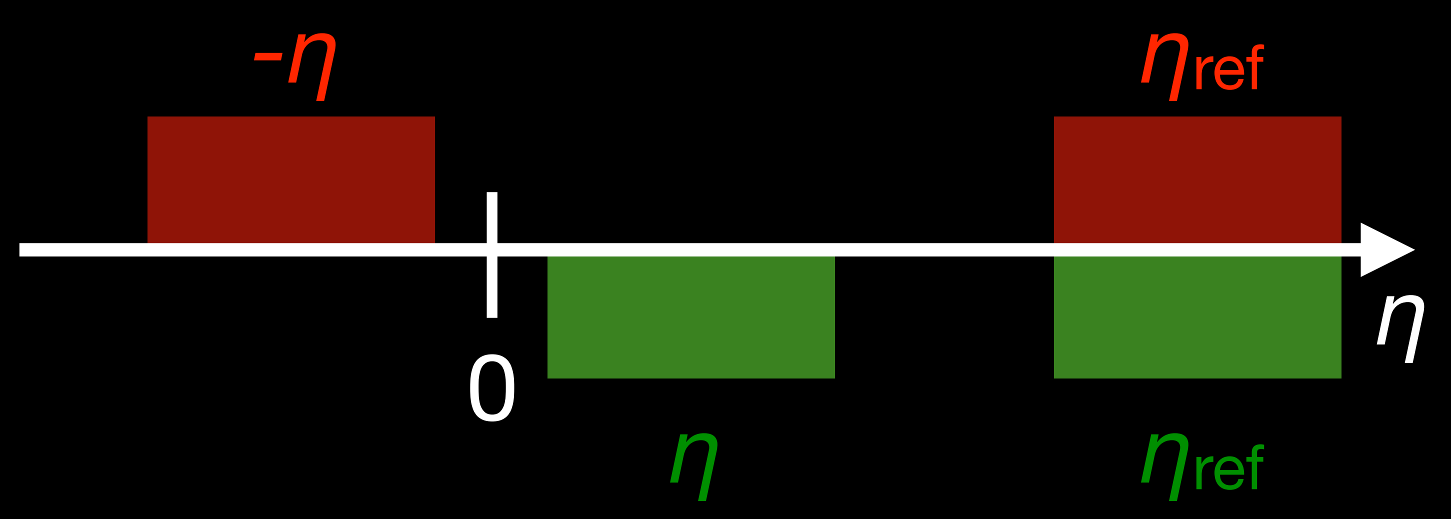
AMPT for Pb—Pb:
S.H.Lim, J.L. Nagle, arXiv:2103.01348

Longitudinal decorrelation of azimuthal flow

Longitudinal decorrelation in Xe—Xe:

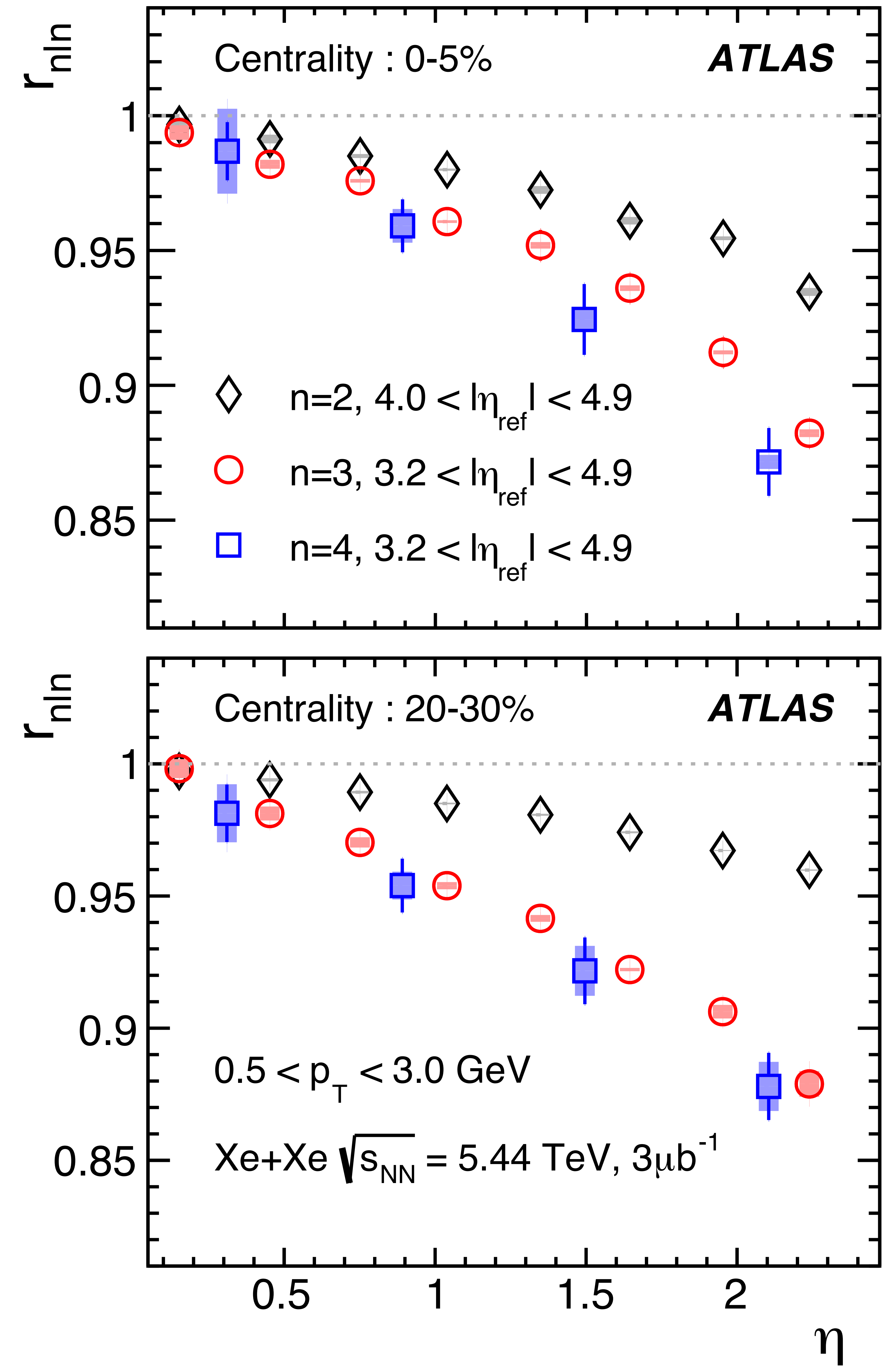
- Measure decorrelation as:

$$r_{n|n}(\eta) = \frac{\left\langle q_n(-\eta) q_n^*(\eta_{\rm ref}) \right\rangle}{\left\langle q_n(\eta) q_n^*(\eta_{\rm ref}) \right\rangle}$$



⇒ probes decorrelation between -η and η

- Approx. linear decrease with increasing separation
- Decorrelation for 3rd and 4th harmonic significantly stronger than that for 2nd harmonic



ATLAS, Phys. Rev. Lett. 126, 122301 (2021)

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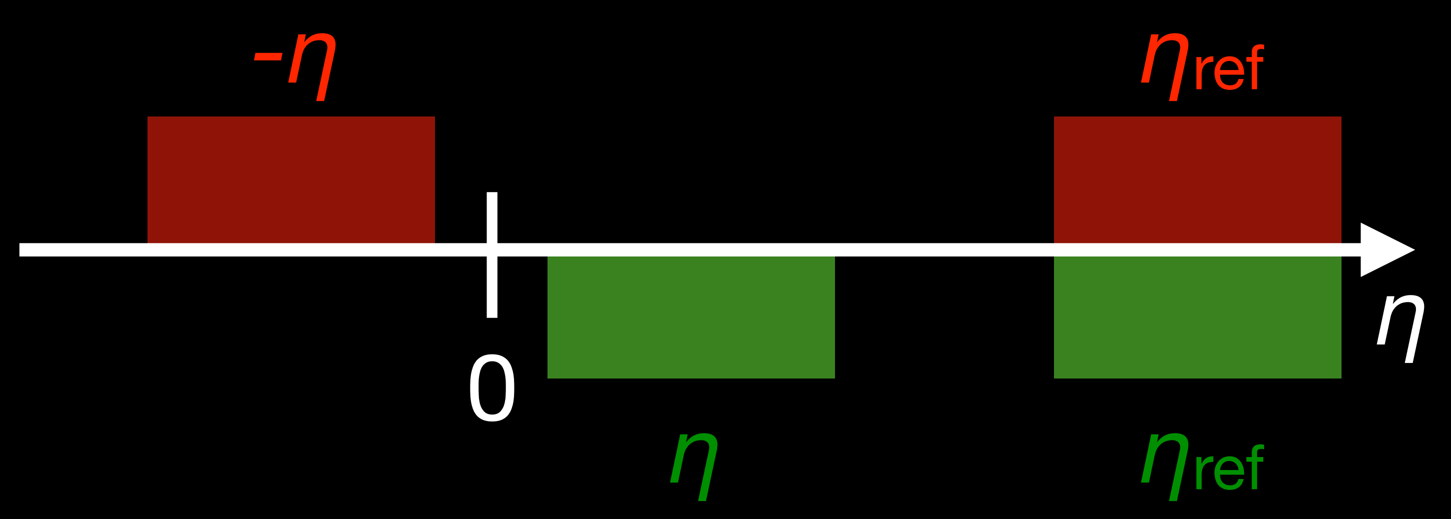

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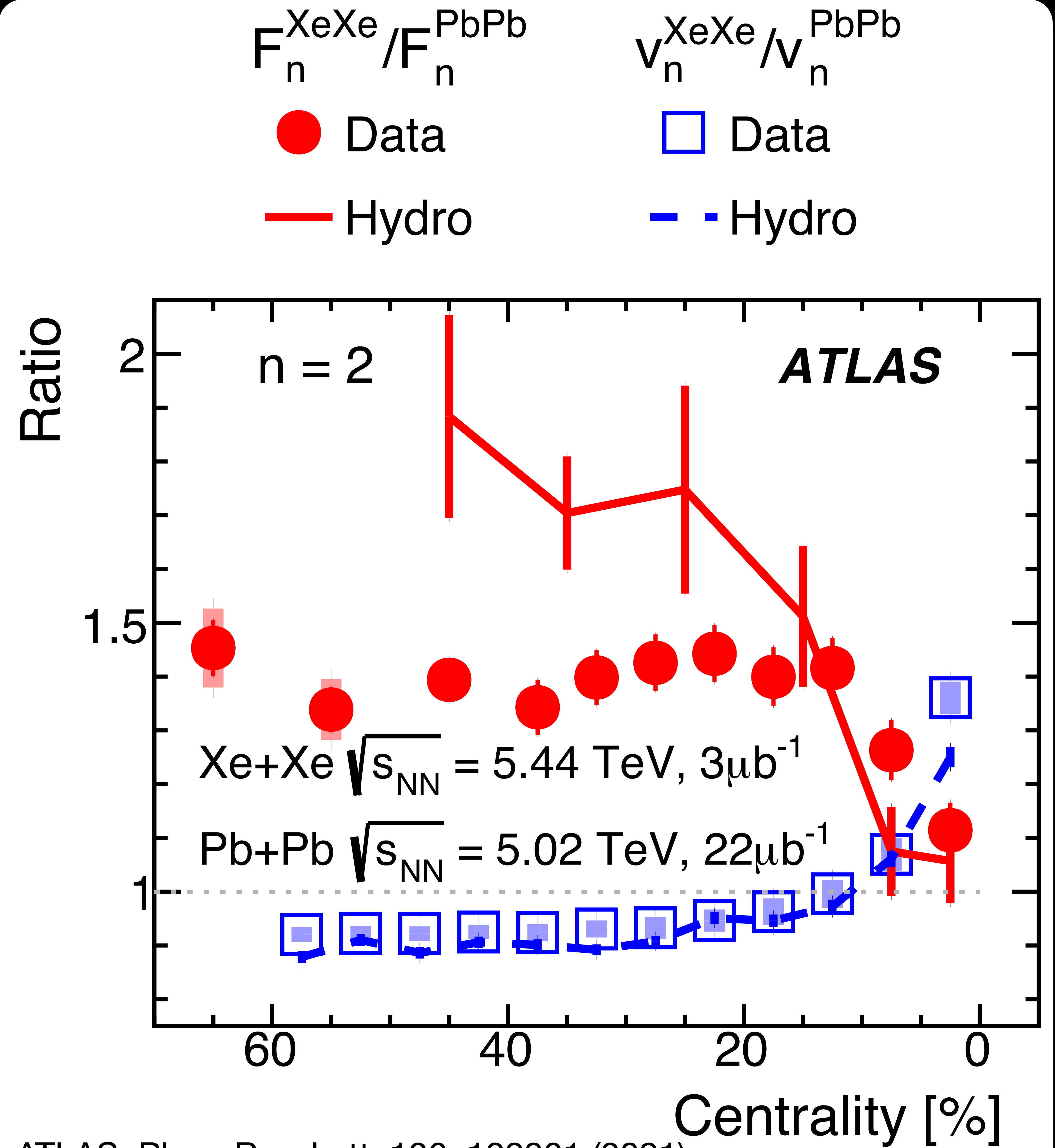


ATLAS, Phys. Rev. Lett. 126, 122301 (2021)

Parametrize $1 - r_{n|n}(\eta)$ with linear function, study the slope (ratio)

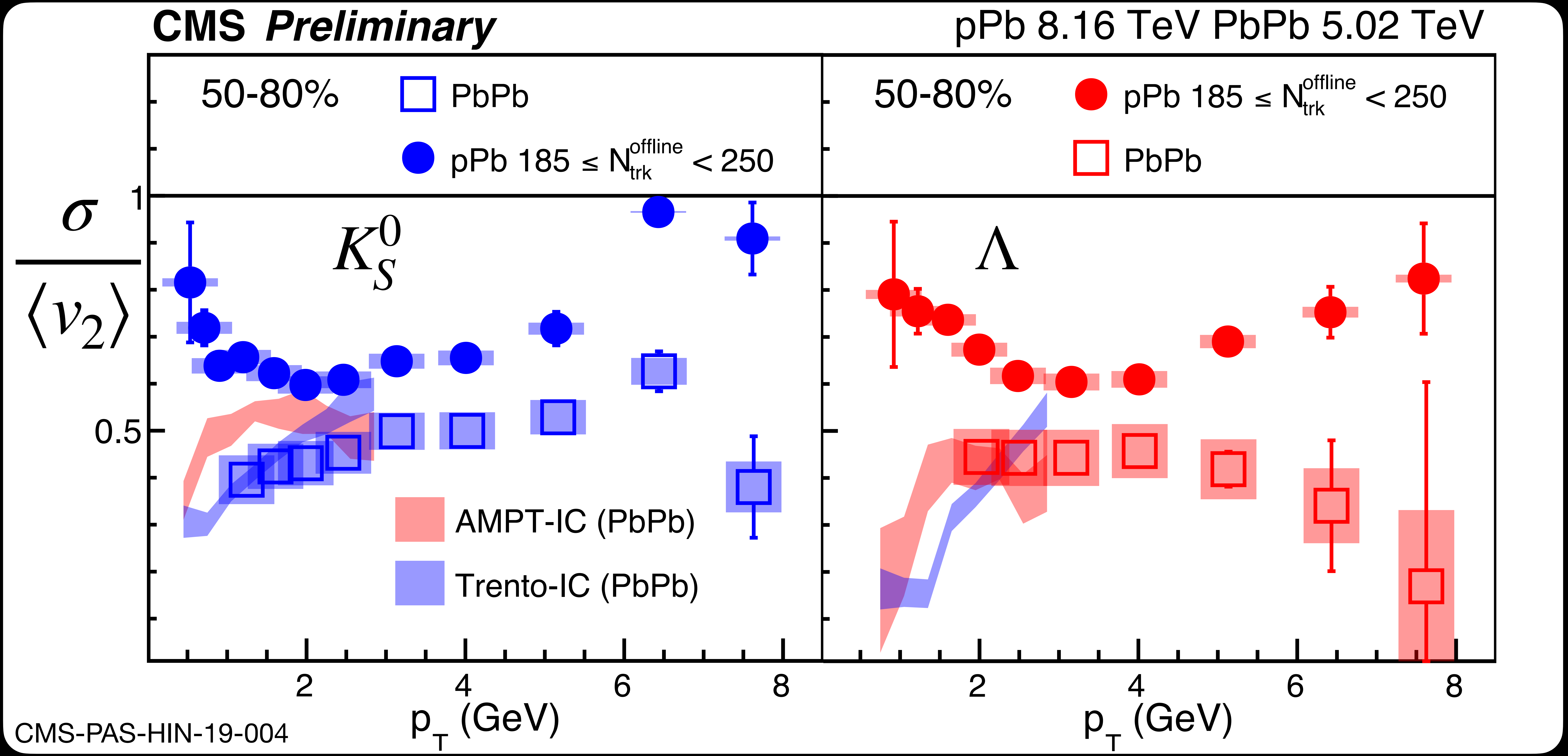
- Slope for 2nd harmonic larger in Xe—Xe ⇒ stronger decorrelation
- Hydro models: describe v_2 ratios, but not longitudinal decorrelation

Flow of strange particles in Pb—Pb and p—Pb collisions

First measurement of K_S^0 and Λ flow in p—Pb collisions:

⇒ Large non-flow in p—Pb, suppressed by higher order correlations

⇒ Flow fluctuations larger in p—Pb with respect to Pb—Pb, no obvious species dependence

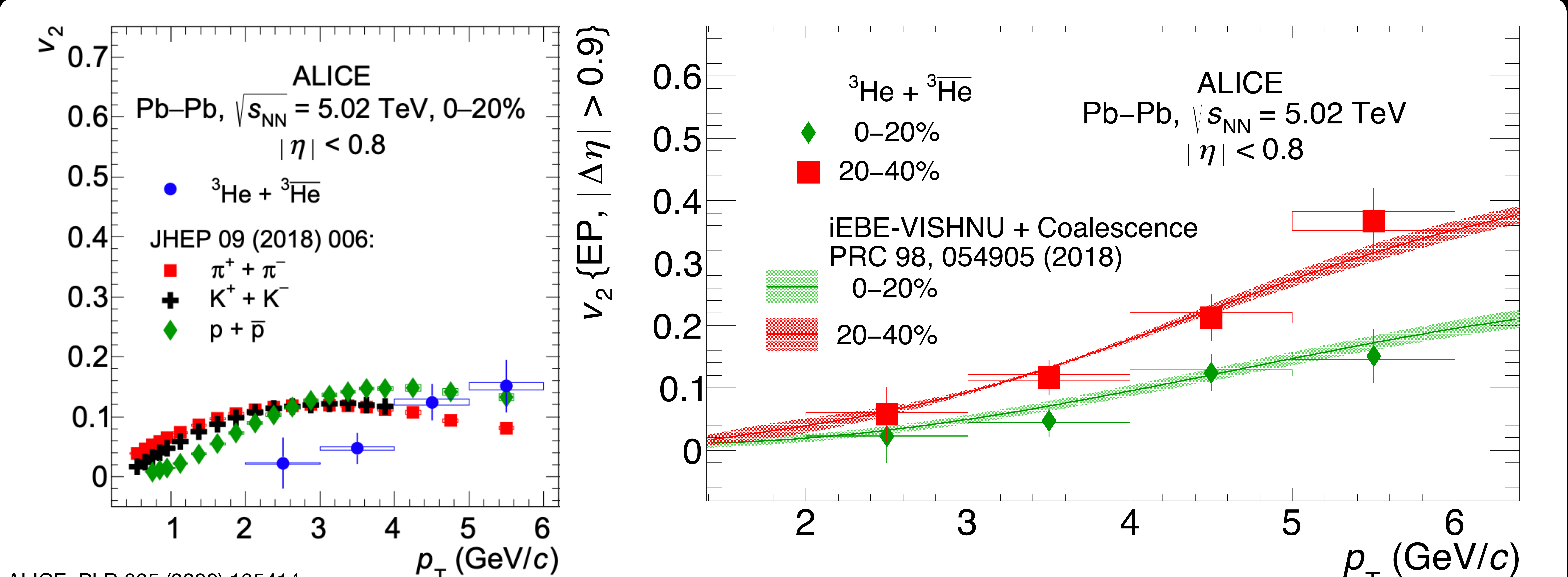


Flow of nuclei in Pb—Pb collisions

First measurement of ^{3}He flow in Pb—Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV:

⇒ Rising trend up to 6 GeV/*c*, smaller than that in π/K/p

⇒ Hydro + coalescence provide good description of the data



ALICE, PLB 805 (2020) 135414

Summary

Correlations between $[p_T]$ and v_2:

- Models with deformed Xe nuclei provide a better description of the data
- Slope change of $\rho(v_2^2, [p_T])$ at low N_{ch} not unique to CGC-based models

Longitudinal decorrelation of azimuthal flow:

- Stronger for n > 2 harmonics, centrality dependence
- Ratio between Xe—Xe and Pb—Pb not described by current hydro models

Flow measurements:

- First measurements of strange particle v_2 in p—Pb collisions at 8.16 TeV
  ⇒ Fluctuations larger in p—Pb compared to Pb—Pb, no obvious species dependence
- First measurements of ^{3}He v_2:
  ⇒ Well-described by hydrodynamics + coalescence

Deformation of Xe nuclei

Modeling:

- Measure v_2 as a function of $\left([p_\mathrm{T}] - \langle[p_\mathrm{T}]\rangle\right)/\langle[p_\mathrm{T}]\rangle$ in most central collisions
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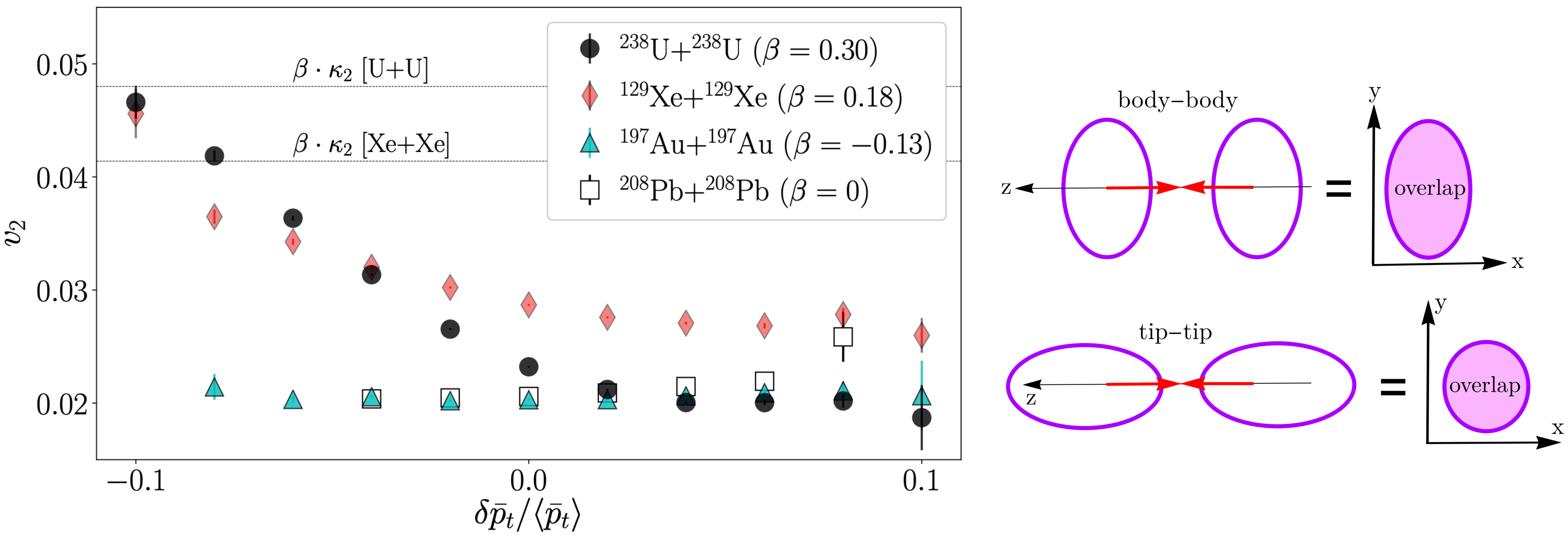
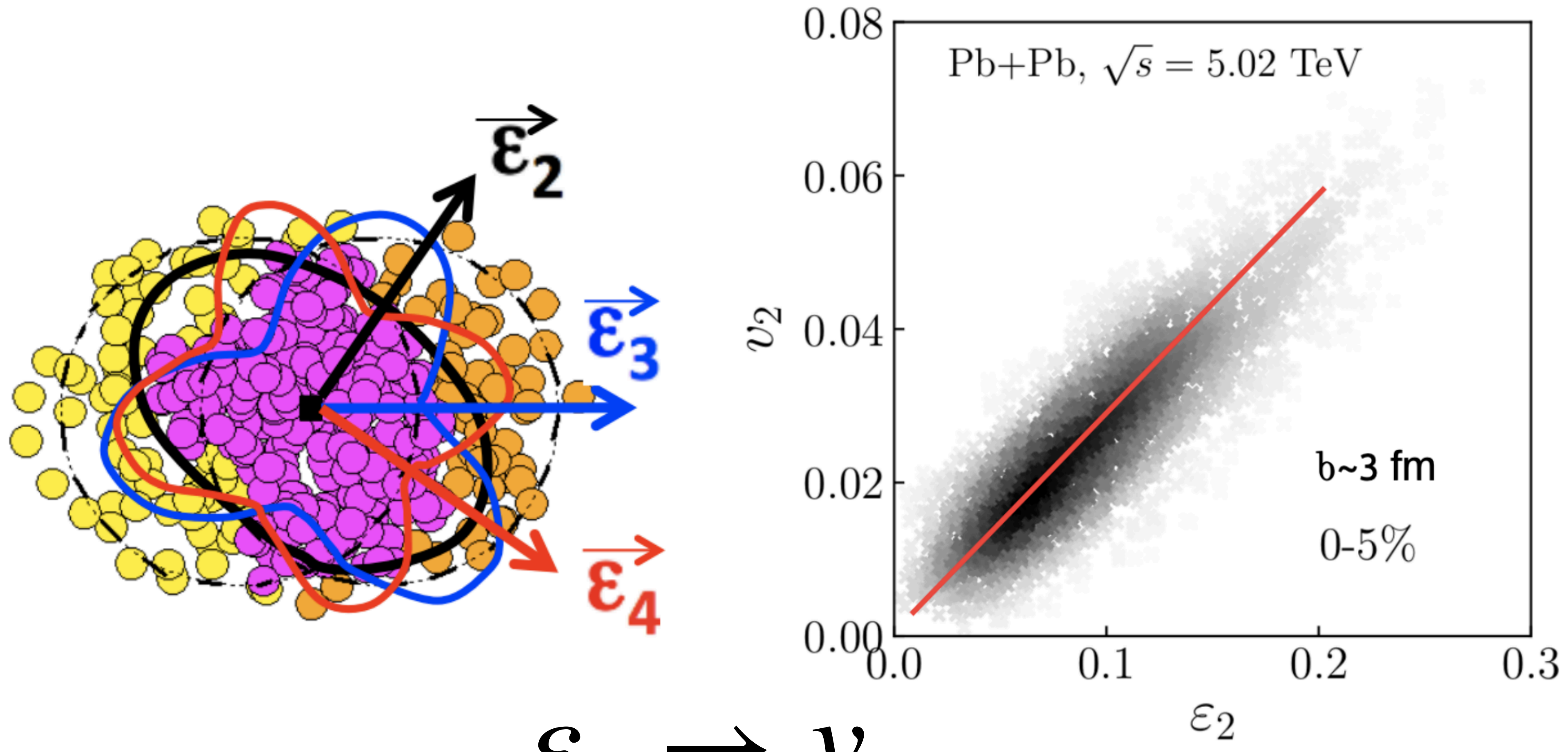


⇒ Larger v_2, smaller $[p_\mathrm{T}]$

⇒ Smaller v_2, larger $[p_\mathrm{T}]$

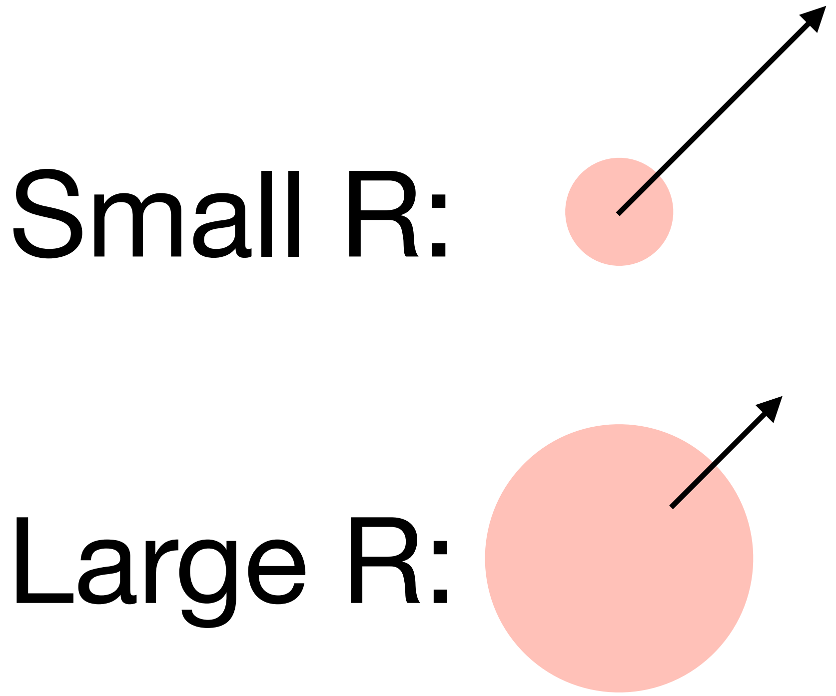
Initial state: shape vs. size

Shape of the fireball: anisotropic flow



$\varepsilon_n \rightarrow v_n$

Size of the fireball: radial flow



$\Rightarrow 1/R \rightarrow [p_T]$

- Initial state: correlations and fluctuations in shape and size
- Final state: correlations between v_n and mean p_T

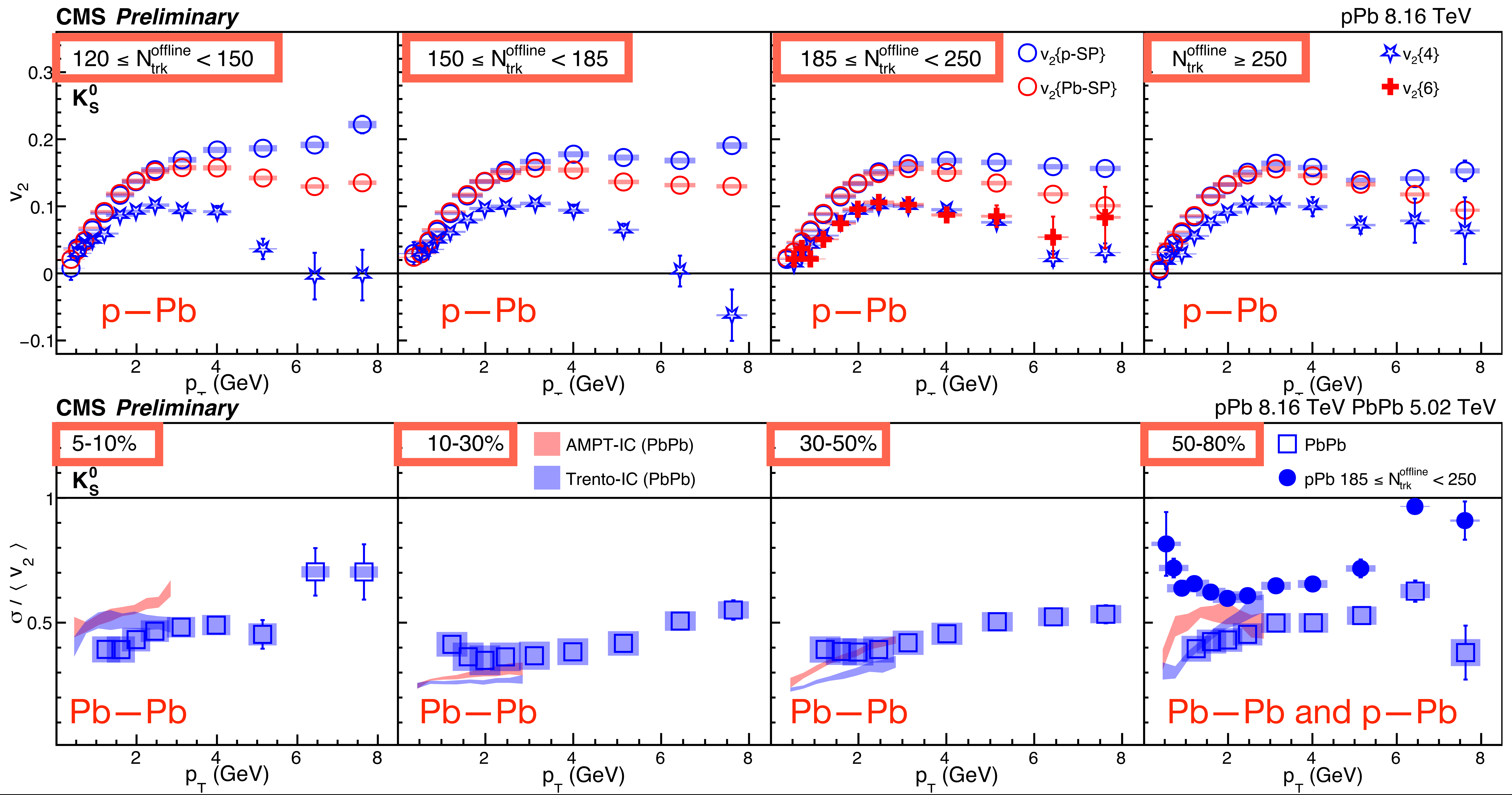
$$\Rightarrow \langle \varepsilon_n^2 \frac{1}{R} \rangle \rightarrow \langle v_n^2 \cdot [p_T] \rangle$$

Flow of K_S^0 in Pb—Pb and p—Pb collisions

First measurement of strange particle flow in p—Pb collisions

v_2

$\frac{\sigma}{\langle v_2 \rangle}$



Pearson Correlation Coefficient at low multiplicity

PCC in Pb—Pb in ALICE:

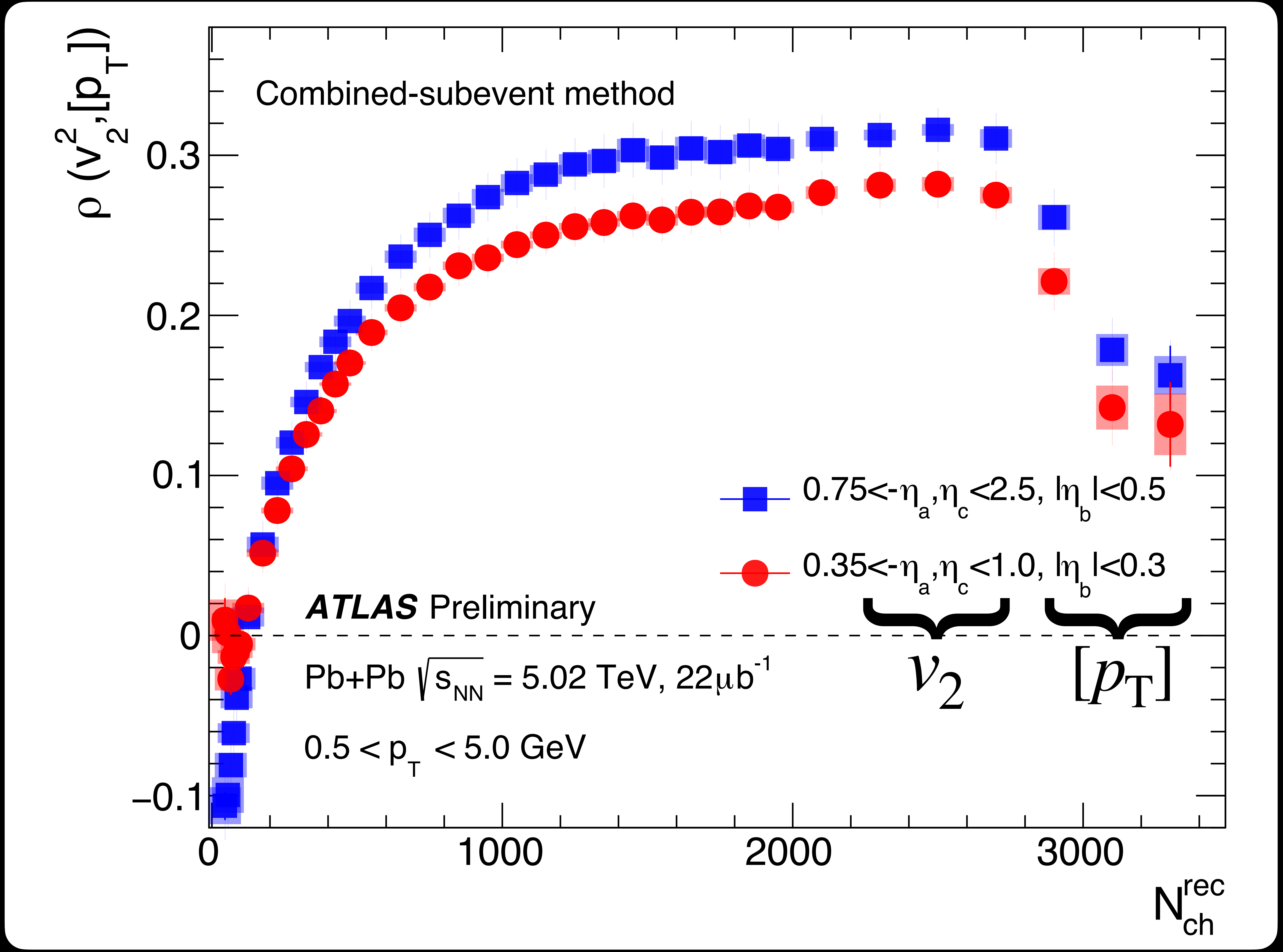
- Slope changes around N_{ch} of 100
  ⇒ IP-Glasma slope changes around 20 ch. tracks
- Both AMPT and IP-Glasma+hydro predict slope change
  ⇒ Not unique for CGC?
- No quantitative description

PCC in pp:

- Decreasing trend with N_{ch}, HM-triggered data consistent with Pb—Pb, MB above
  ⇒ Sensitive to event selection
- Underestimated by AMPT, overestimated by PYTHIA

PCC in Pb—Pb in ATLAS:

- Slope change only present for smaller η-gal
  ⇒ Non-flow or decorrelation?



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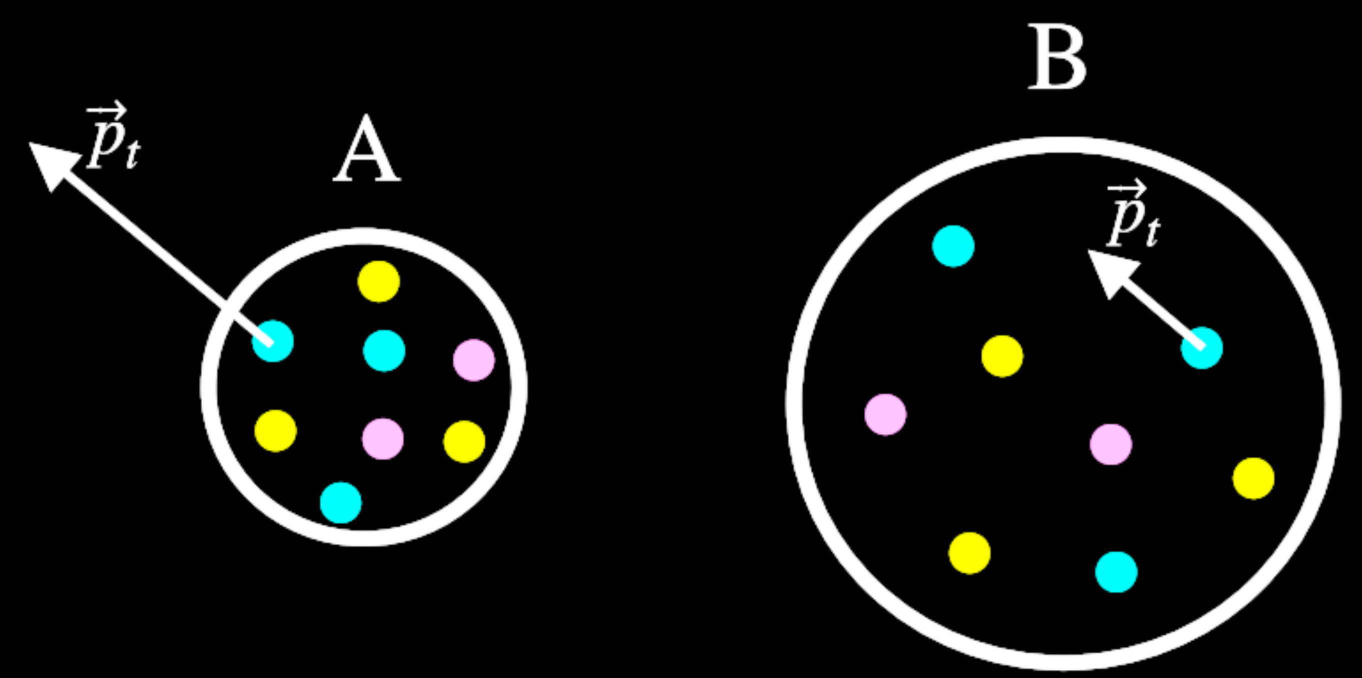
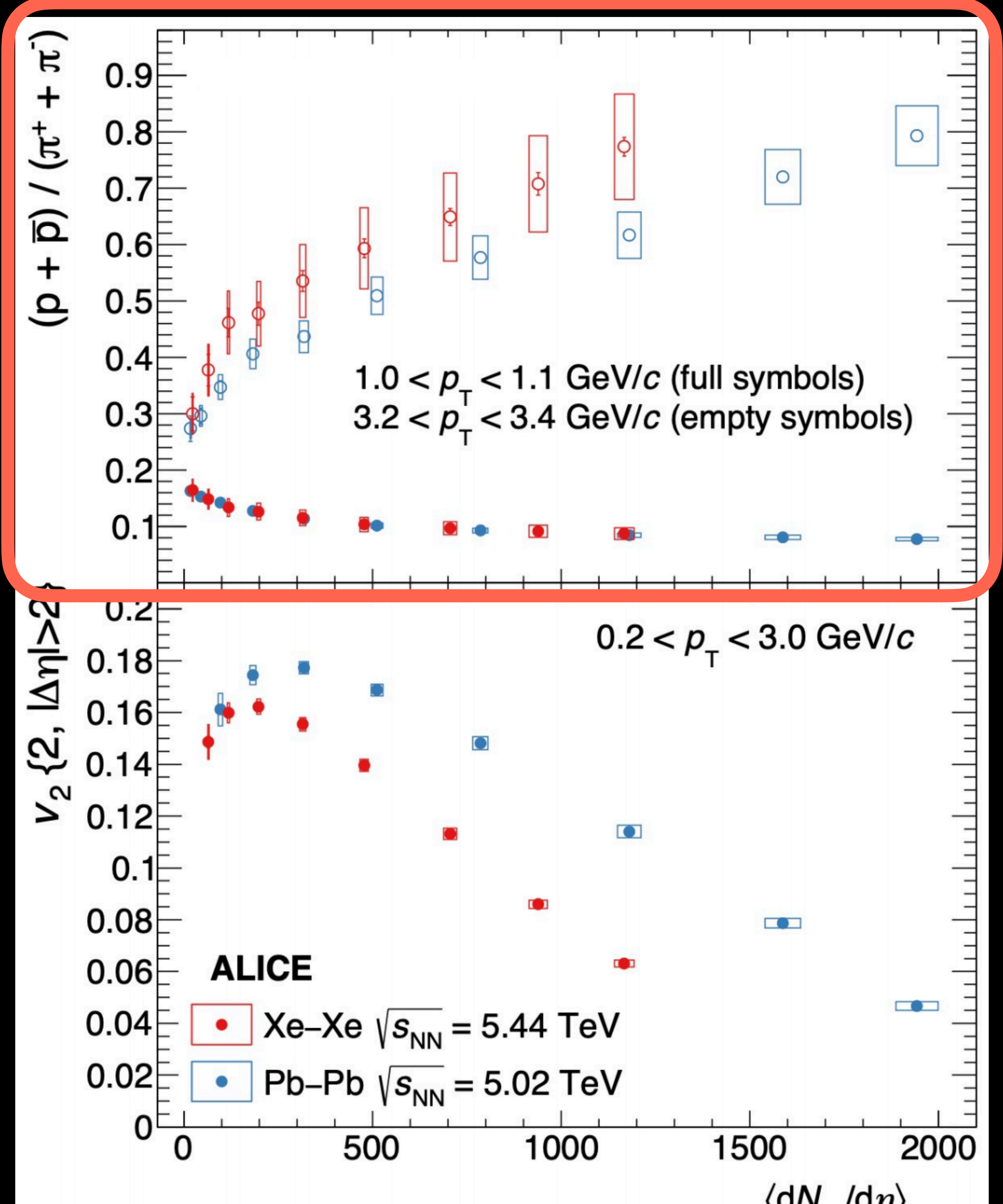


$$S_A = S_B, \quad R_A < R_B \implies T_A > T_B \implies \langle p_t \rangle_A > \langle p_t \rangle_B$$



ALICE, arxiv:2101.03100 [nucl-ex]

Flow of strange particles in Pb—Pb and p—Pb collisions

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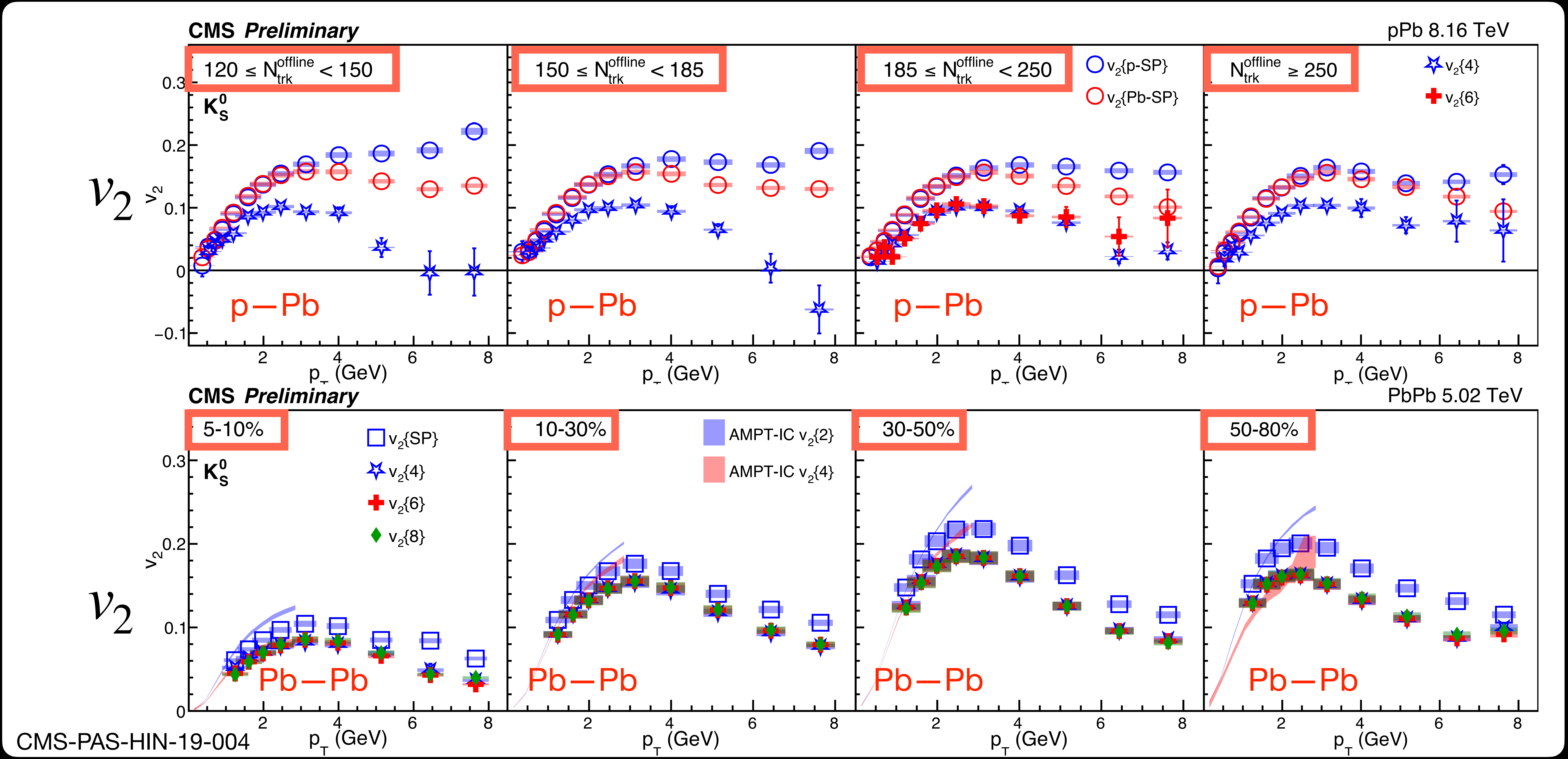

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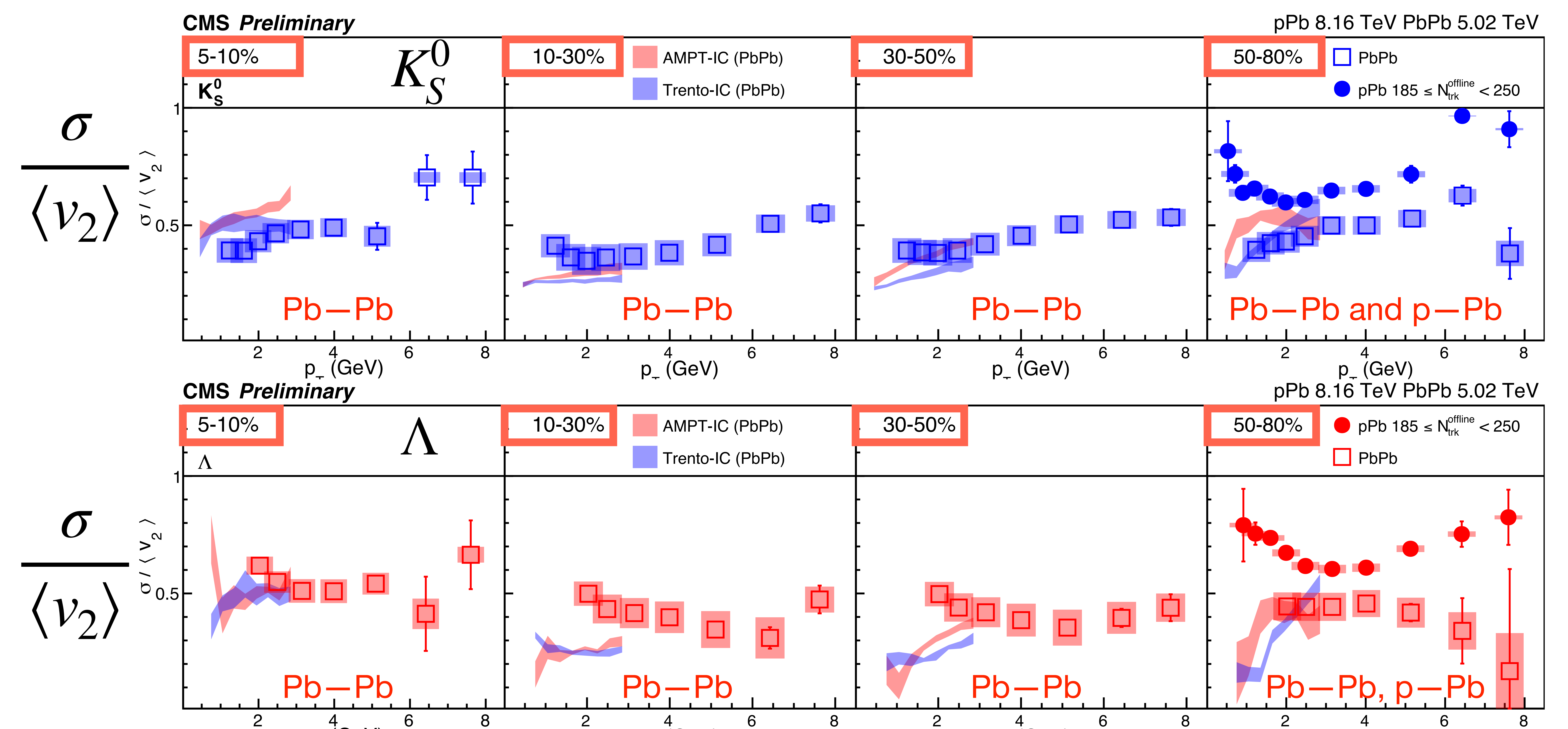

CMS-PAS-HIN-19-004

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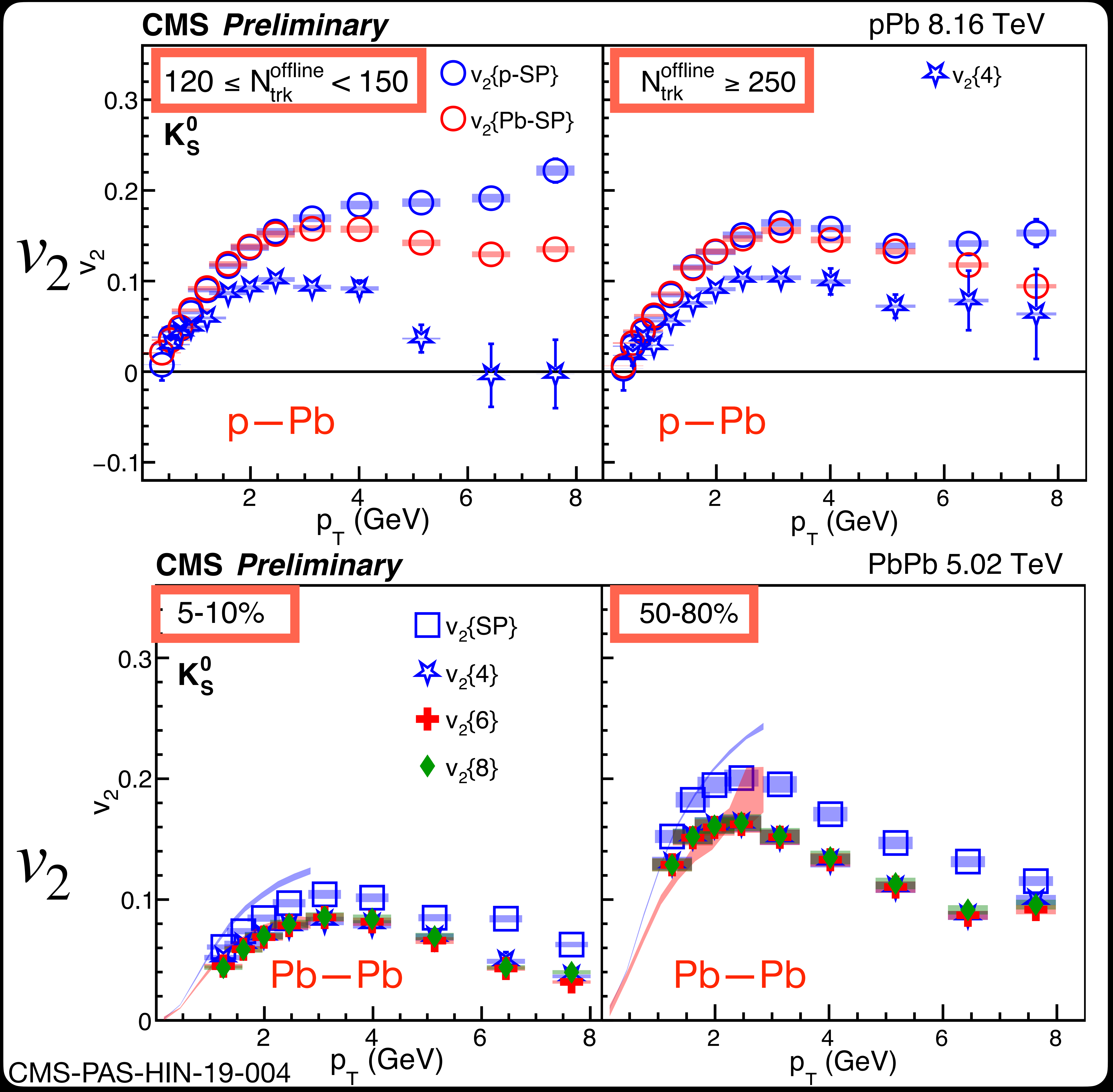

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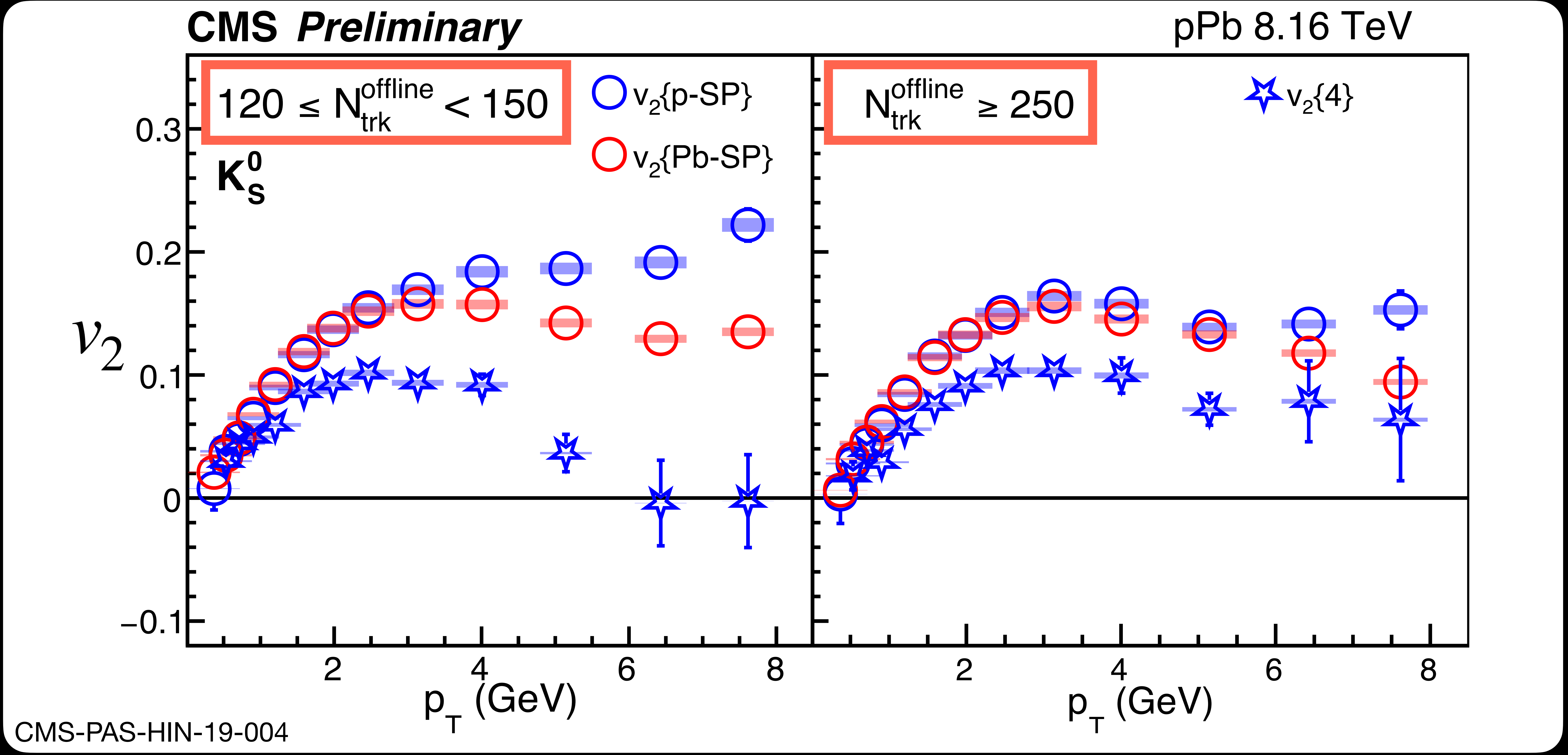


Flow of heavy mesons D^0

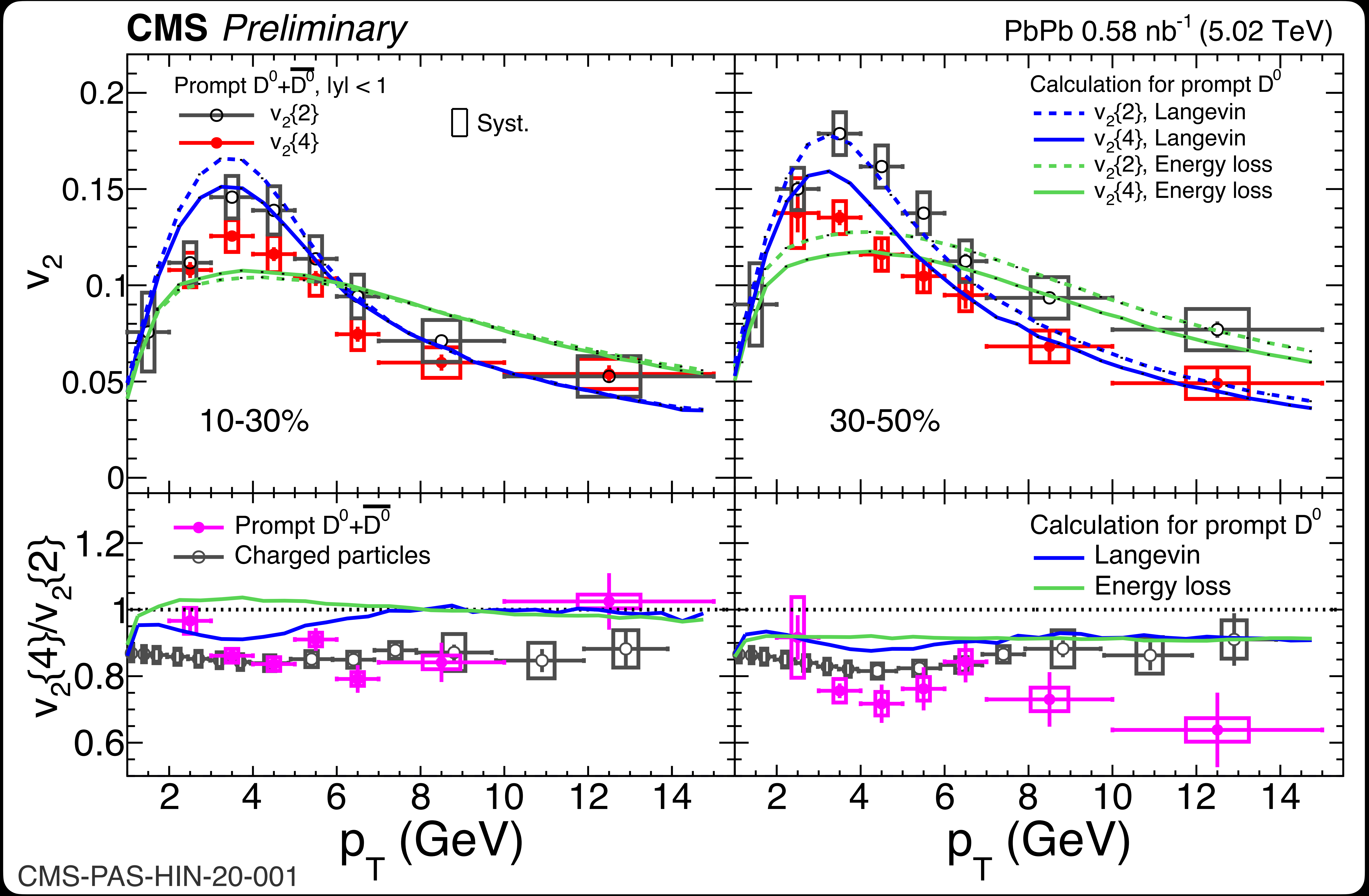
Heavy flavours: produced in hard scatterings, but thermalise inside QGP

⇒ Probes the full evolution of QGP

- $v_2\{2\} > v_2\{4\}$ ⇒ affected by initial geometry and its fluctuations
- Effect similar to that seen for all charged particles

Model comparisons:

- Energy loss (high-p_T) and Langevin (low-p_T) provide only qualitative description



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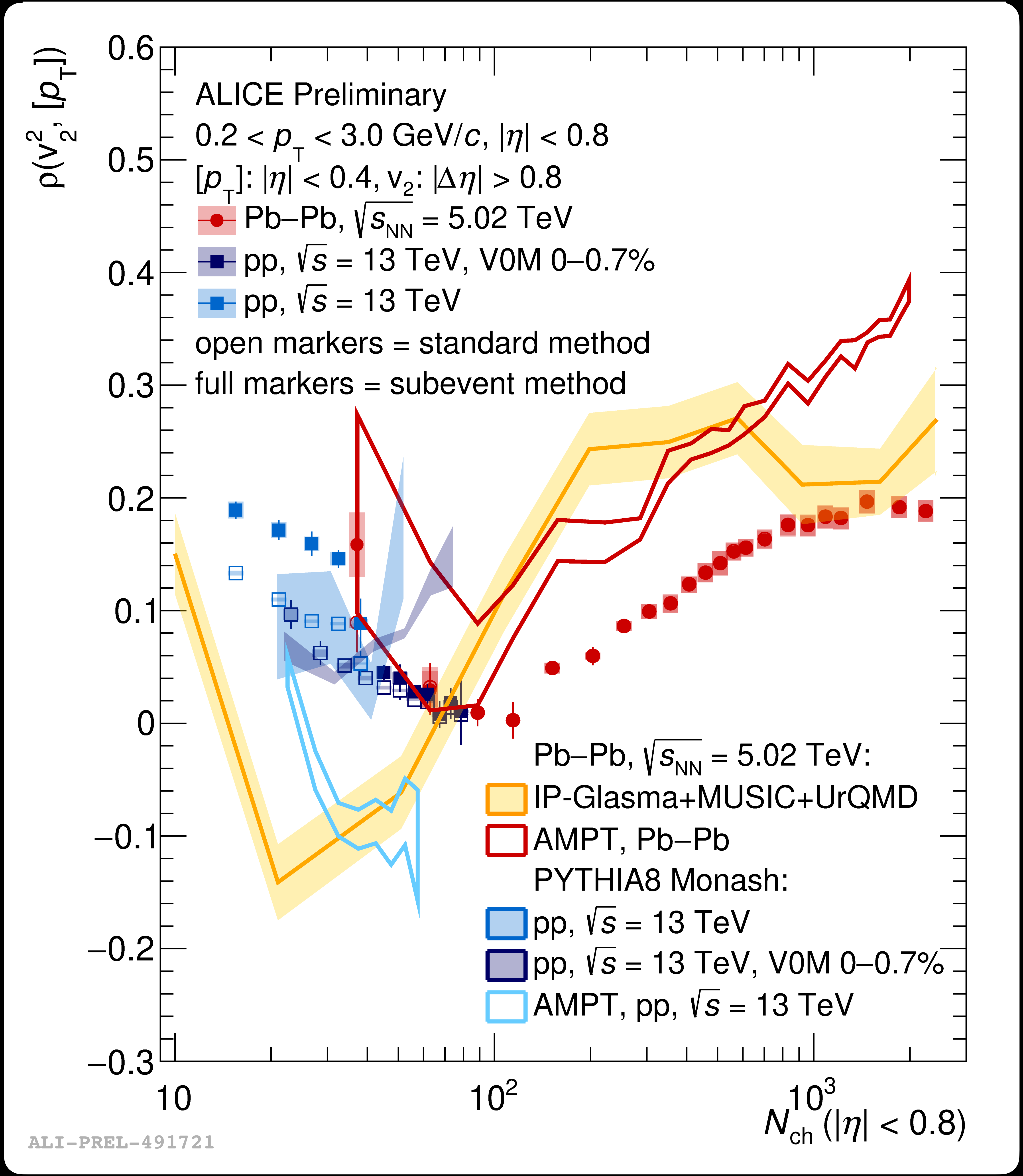
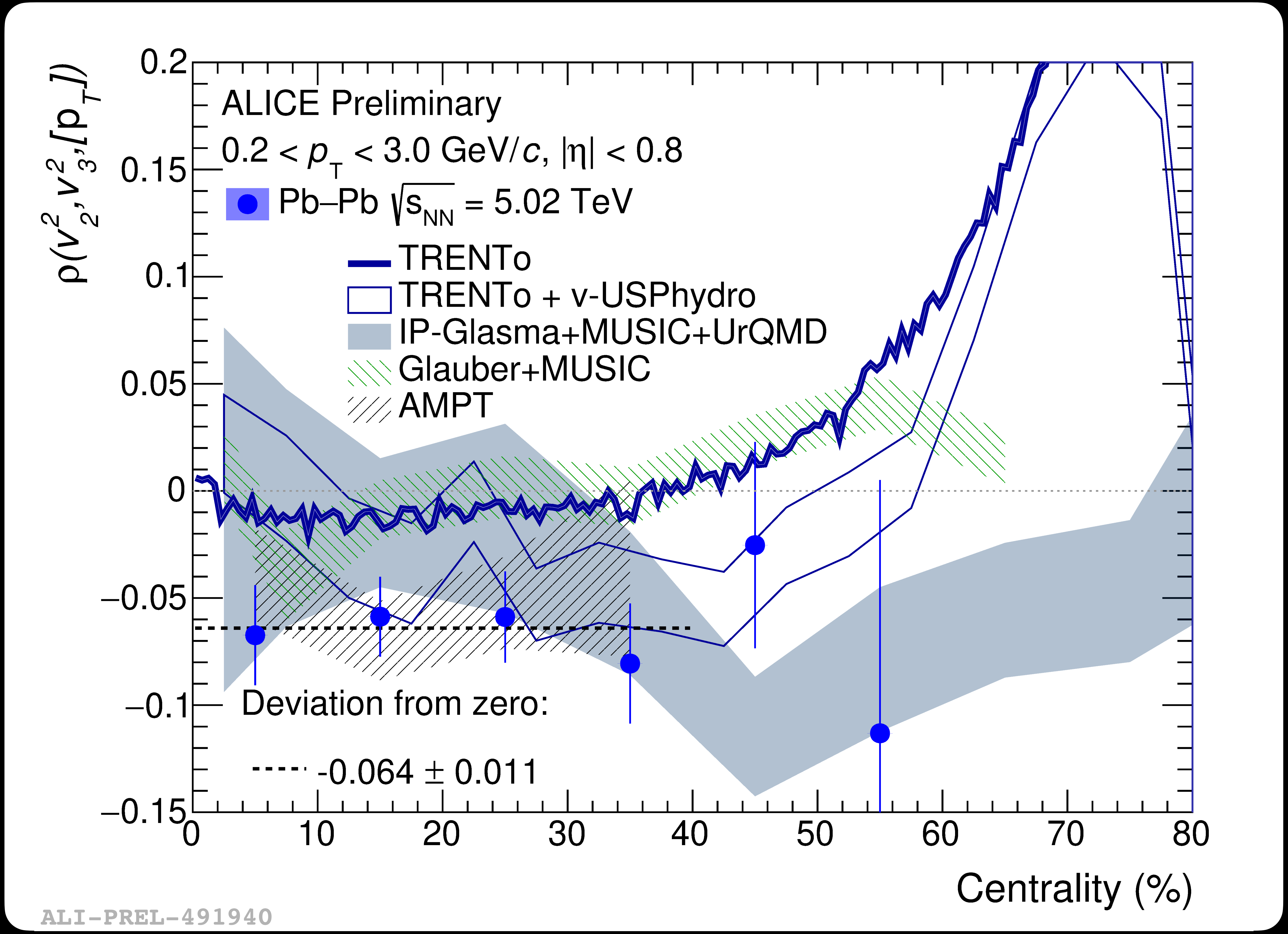


$\rho(v_2^2, v_3^2, [p_T])$

Correlation of multiple harmonics with $[p_T]$:

— More sensitivity to initial state?

— Additional constrains on HI modelling



Glauber+MUSIC: P. Bozek, arXiv:2103.15338

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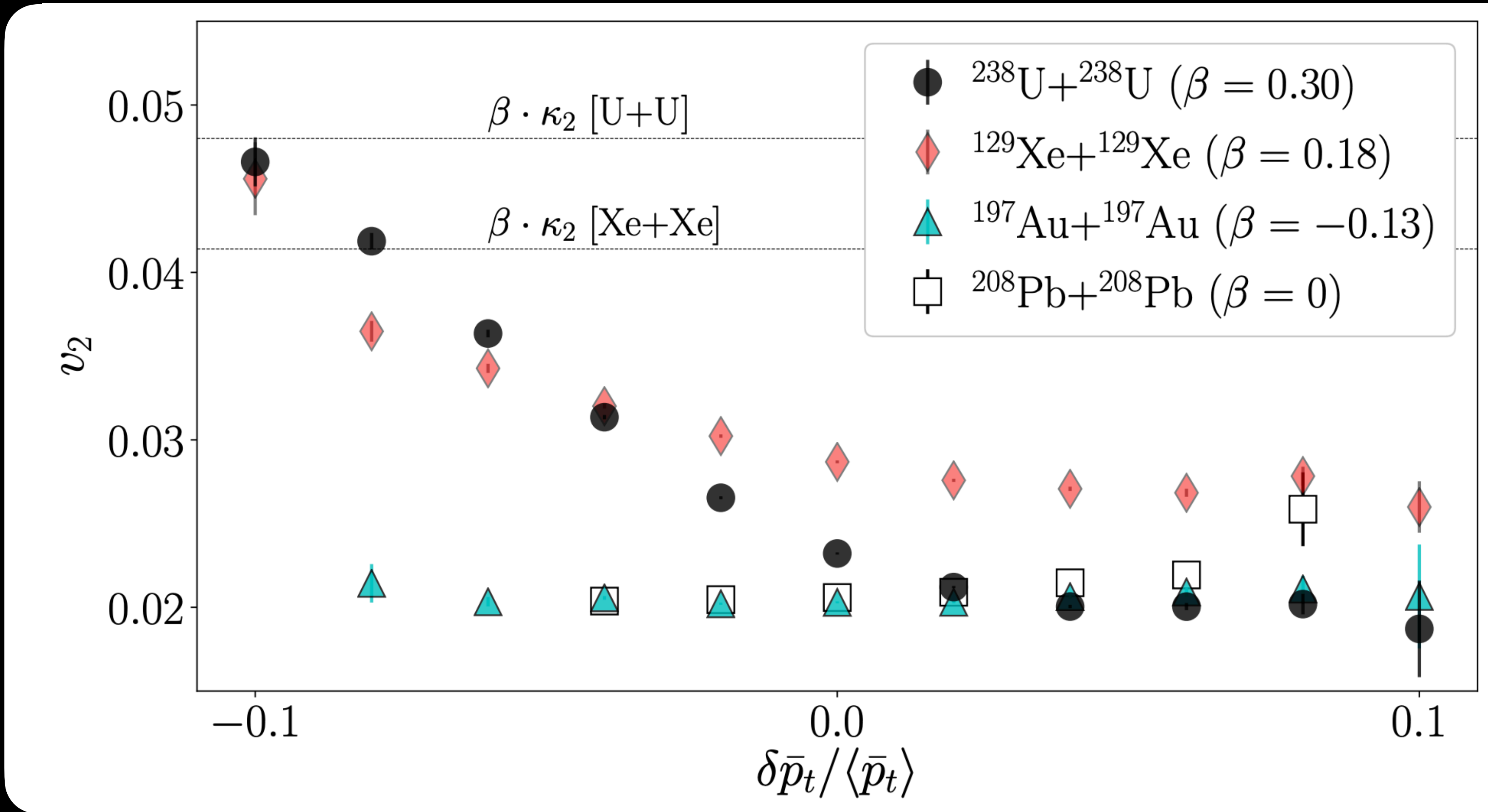

G. Giacalone, Phys. Rev. Lett. 124, 202301 (2020)