$v_n - [p_T]$ correlation in Pb+Pb and Xe+Xe collisions with ATLAS: assessing the initial condition of the QGP

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for the ATLAS collaboration

Strangeness in Quark Matter 2022,

13th - 17th June, Busan, Republic of Korea

CERN-EP-2022-052

arXiv:2205.00039

ATLAS EXPERIMENT

SQM2022

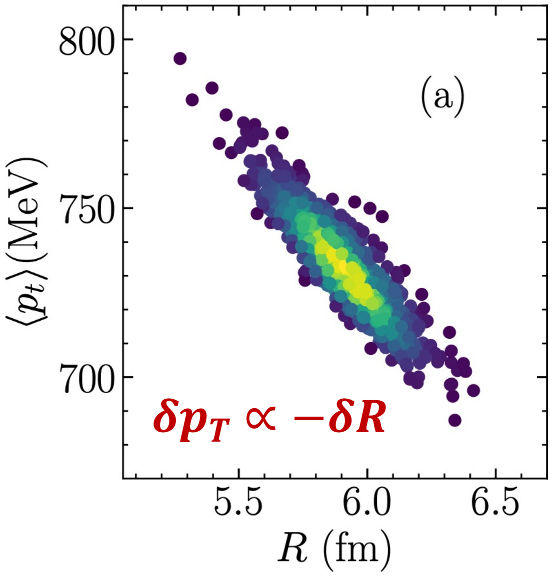
The 20th International Conference on Strangeness in Quark Matter

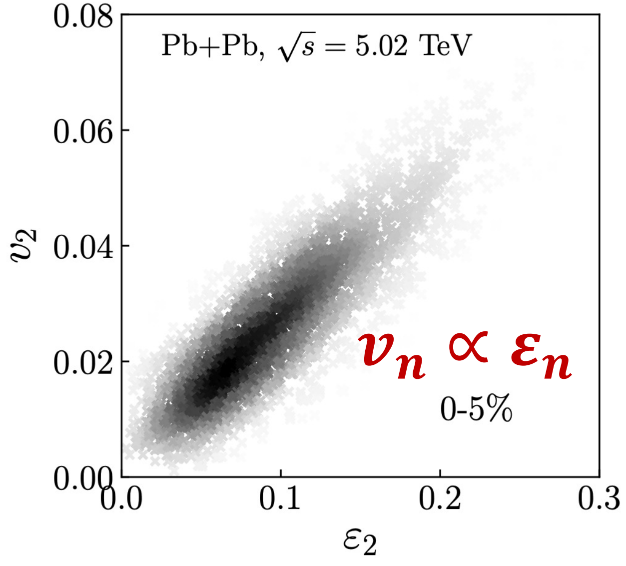
13-17 June 2022 Busan, Republic of Korea

Stony Brook University

$v_n - [p_T]$ Correlation (ρ_n)

- Shape (ε_n) and Size ($d_\perp$) of collision region is determined by: 1) Fluctuations



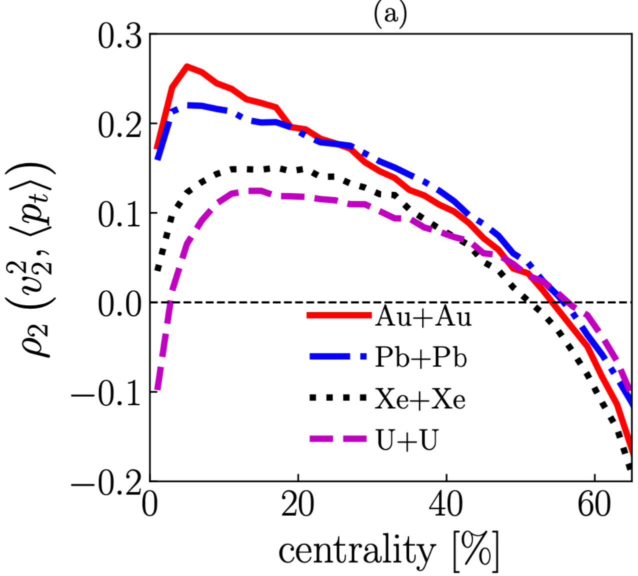


Giacalone et. al, PRC 103, 024909 (2021)

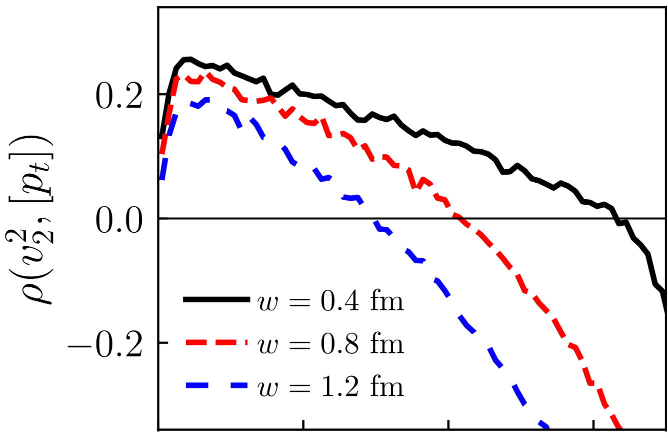
Bozek, Broniowski, PRC **85**, 044910 (2012)

Giacalone, arXiv:2101.00168

Giacalone, PRC **102**, 024901 (2020)



Giacalone, Schenke, Shen, PRL **128**, 042301(2022)



- ***Correlated fluctuations*** **in Shape (ε_n) and Size (R) in initial state: measured using Pearson Correlation:**

$$\rho(\epsilon_n^2, \delta R) = \frac{cov(\epsilon_n^2, \delta R)}{\sqrt{var(\epsilon_n^2) var(\delta R)}}$$

$$\rho(v_n^2, \delta p_T) = \frac{cov(v_n^2, \delta p_T)}{\sqrt{var(v_n^2) var(\delta p_T)}}$$

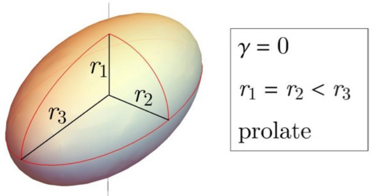
- Early sign change for smaller system in peripheral centrality.
- Large or fat nucleon reduces ρ_2 : stronger sign-change.

Experimental measurement of ρ_2 can help constrain nuclear and nucleon size in initial state.

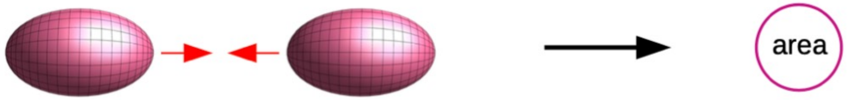
Impact of Nuclear Geometry on Initial State

- Shape (ε_n) and Size ($d_\perp$) of collision region is determined by: 1) Fluctuations
  2) Nuclear Shape

Prolate



tip-tip



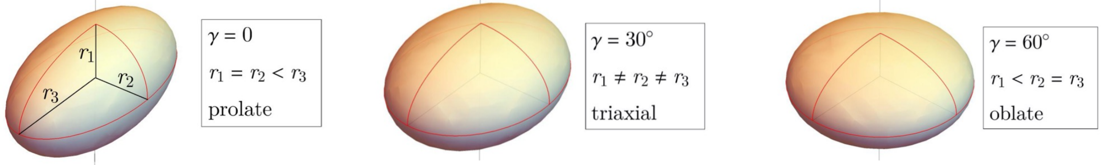
$\boldsymbol{\varepsilon_2} \downarrow, \boldsymbol{R} \downarrow$ $\boldsymbol{v_2} \downarrow, [\boldsymbol{p_T}] \uparrow$

body-body

$\boldsymbol{\varepsilon_2} \uparrow, \boldsymbol{R} \uparrow$ $\boldsymbol{v_2} \uparrow, [\boldsymbol{p_T}] \downarrow$

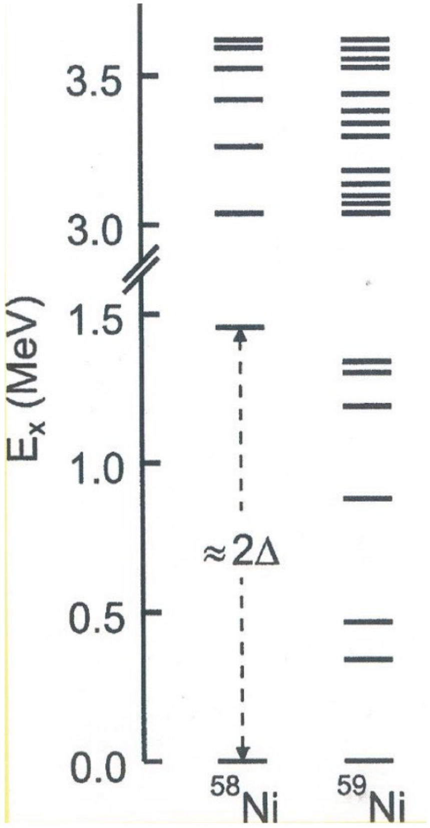
- Nuclear geometry parametrized by Woods-Saxon distribution, $\rho(r) = \dfrac{\rho_0}{[1 + exp(r - R(\theta,\phi))/a]}$

$$R(\theta,\phi) = R_0(1 + \beta(cos\gamma Y_{20}(\theta,\phi) + sin\gamma Y_{22}(\theta,\phi)))$$



Prolate Triaxial Oblate

➢ **Nuclear geometric deformation can impact shape and size of overlap area in initial state.**



- β is generally estimated from spectroscopic measurements:

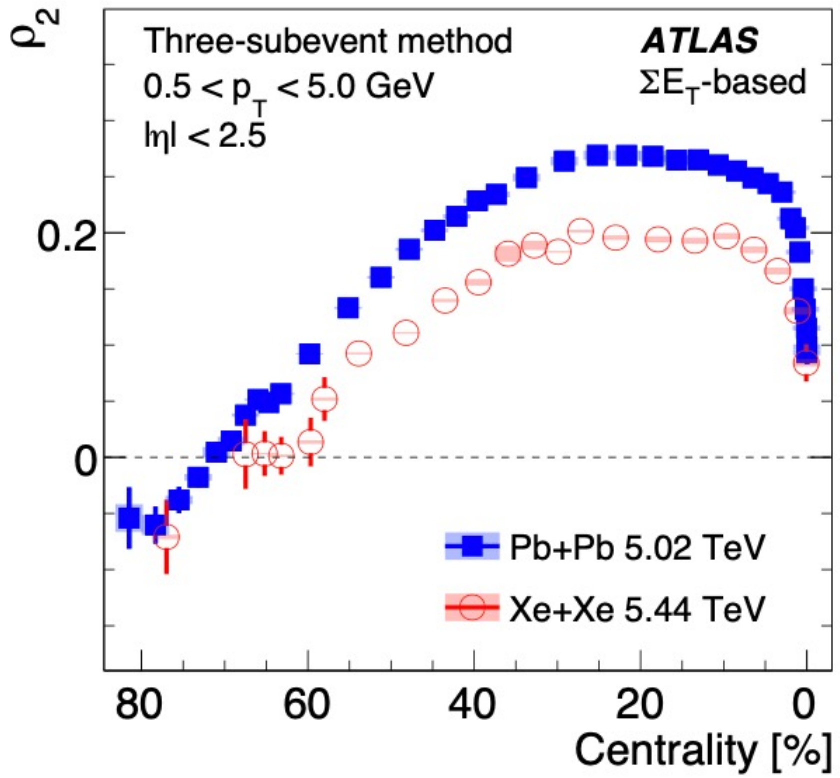
$$\beta = \frac{4\pi}{3ZeR_0^2}\sqrt{B(E2)\uparrow}$$

➢ Works well for even-even nuclei, existence of unpaired nucleon (odd-mass) complicates this estimation.

https://ns.ph.liv.ac.uk/~ajb/summerschool/files/Bristol-intro-part1.pdf

➢ **Therefore, heavy-ion collisions provides unique way to constrain deformation parameters for odd-mass nuclei.**

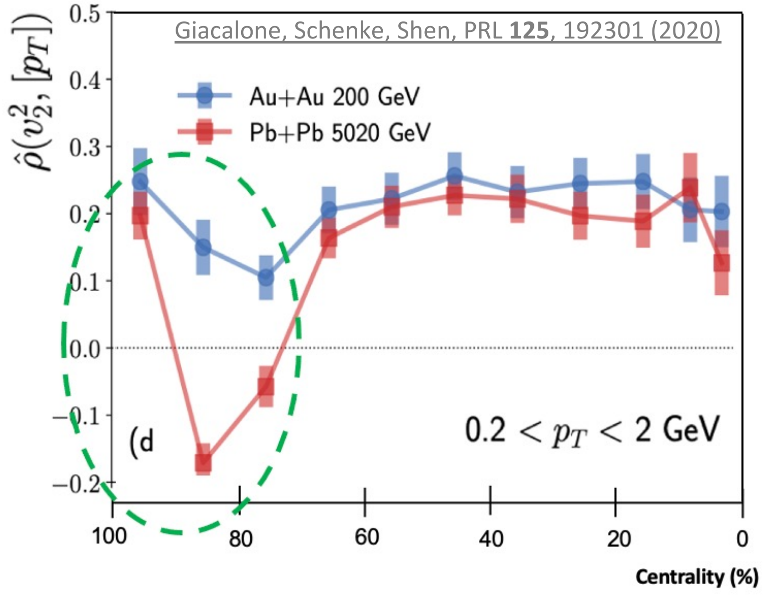
System size comparison

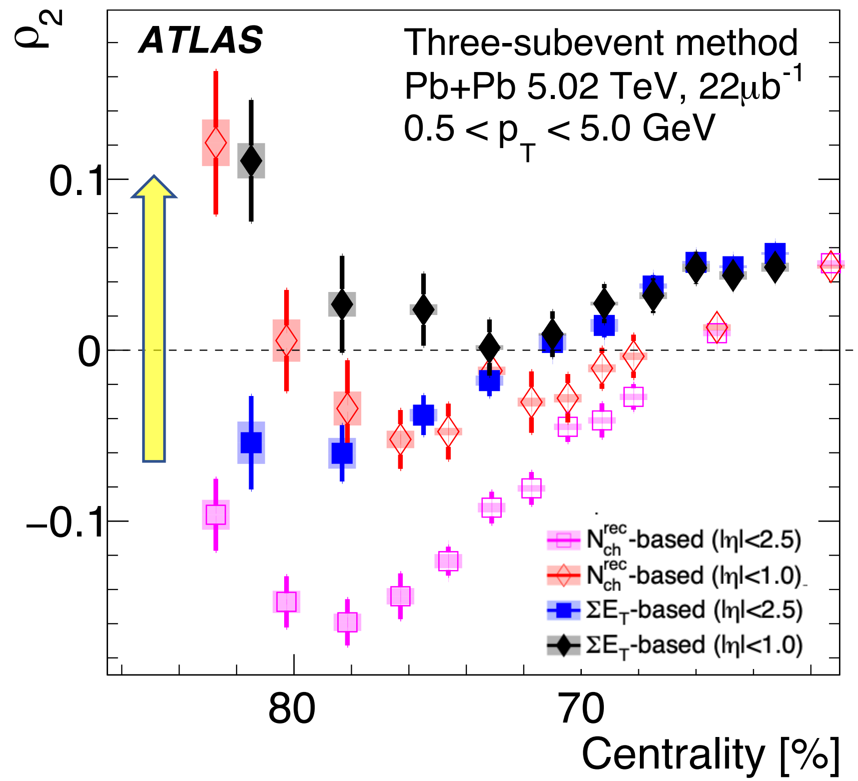


- ρ_2 follows system size ordering, $\rho_2(Xe+Xe) < \rho_2(Pb+Pb)$.
- Ordering consistent with prediction from Trento and Hydro models

> **ρ_2 dominated by geometric origin**

ρ_2 in peripheral centrality

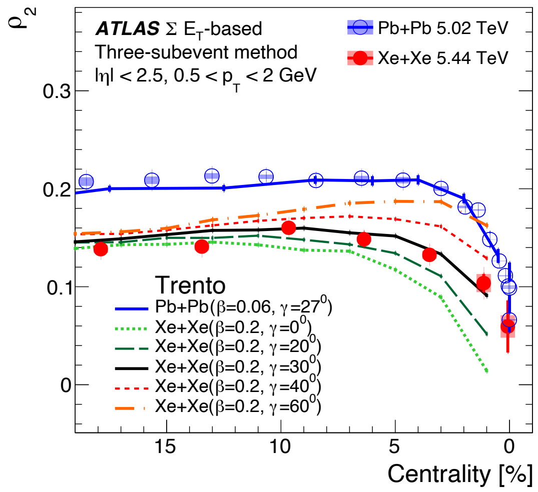


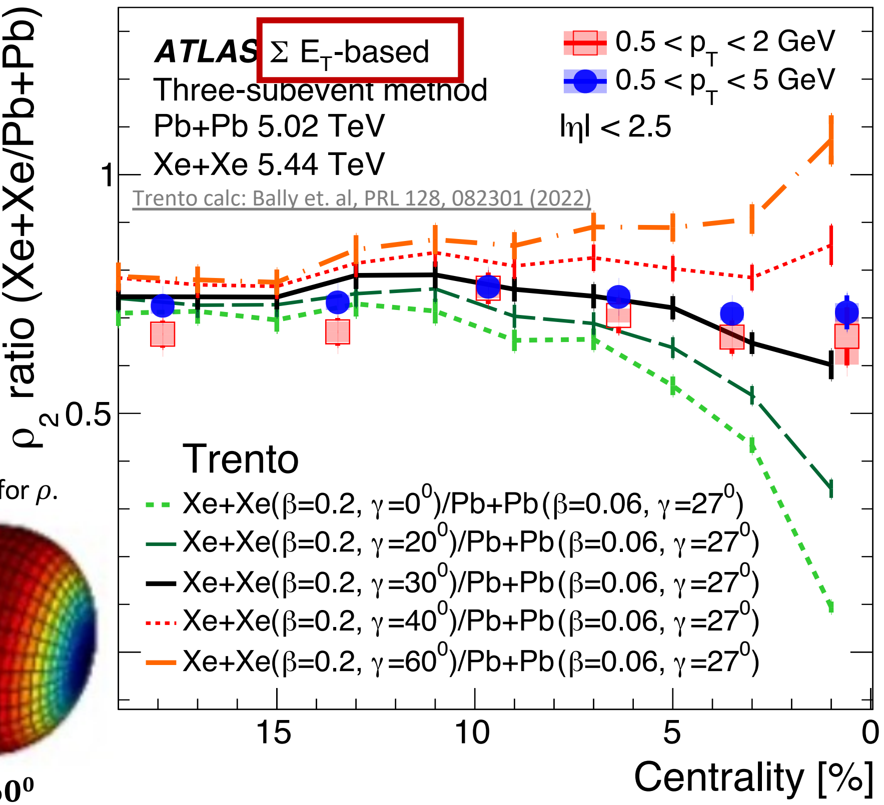


- ρ_2 double sign change in peripheral centralities at 5 TeV: **Strong evidence of initial p_T anisotropy**.
- Interpretation complicated by: Residual Non-Flow, Centrality Fluctuations

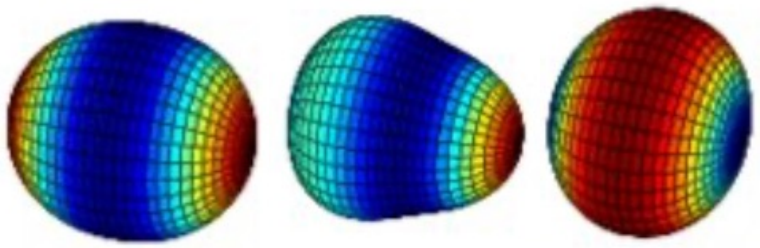
> **Experimental evidence for initial p_T anisotropy unclear (upto 84% centrality)**

Constraining β,γ parameters





Use (β,γ) parameters from HFB and Trento predictors for ρ.



$\gamma = 00$ — Prolate

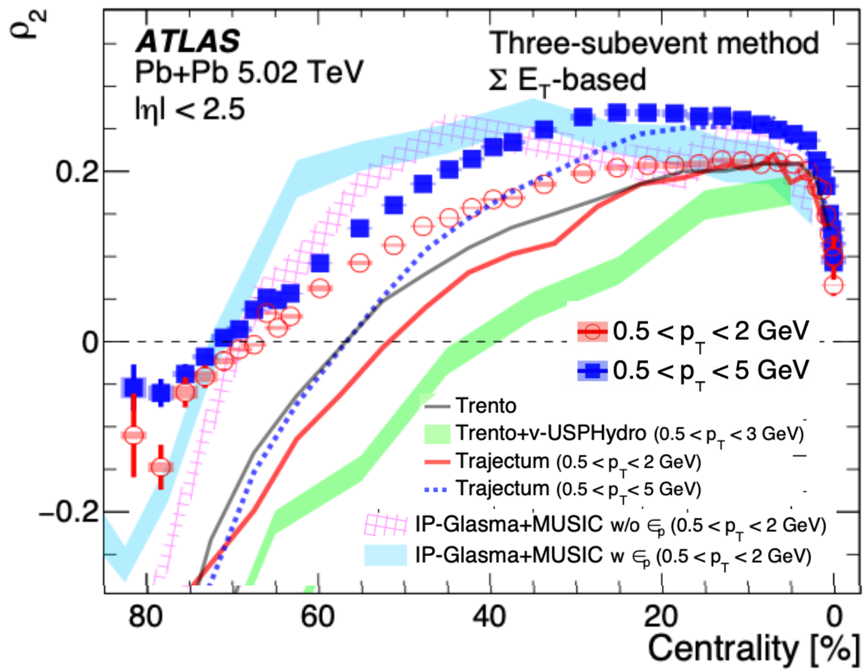
$\gamma = 30^0$ — Triaxial

$\gamma = 60^0$ — Oblate

- $\rho(v_2^2,[p_T])$ shows large sensitivity to γ in central collision.
- Trento has no final state dependencies: take ratios, cancel final state effects
- **This ratio is robust against change in methods and FS effects**

^{208}Pb has a near spherical geometry.
^{129}Xe corresponds to $\beta\sim0.2$ and $\gamma\sim30^0$ *(highly deformed triaxial nucleus).*

Model Comparisons for ρ_2



Models Compared: **Trento (Initial state only) ,**
USPHydro, Trajectum (Trento IS+2D Hydro) ,
CGC based IP-Glasma IS+MUSIC (3D hydro)

- In 0 –10% all models show reasonable agreement with each other and with data.

➢ **Large spread between different models for ρ_2 : *partially due to different effective nucleon sizes***
(Giacalone, Schenke, Shen, PRL. **128**, 042301(2022)).

➢ **Constrain effective nucleon size used in models.**

SUMMARY

- We present experimental results on $v_n - [p_T]$ correlations (ρ_n, n = 2, 3, 4) from ATLAS with the aim to
  (i) constrain the initial state and (ii) nuclear deformation.

- ρ_n mostly reflects initial state correlations between eccentricity and overlap area.

- ρ_2 has a geometric origin, $\rho_2(Xe+Xe) < \rho_2(Pb+Pb)$.

- In the peripheral centralities, evidence of initial p_T anisotropy (using ρ_2) is complicated by residual non-flow and centrality fluctuation. Effects might be more severe in smaller systems.

- In the central collisions, ***FIRST experimental constraint*** on **triaxiality of odd mass nucleus** ^{129}**Xe** (**$\beta \sim 0.2$, $\gamma \sim 30^0$**) from heavy-ion collisions.

THANK YOU!!