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STAR

Probing the nuclear deformation effects in Au+Au and U+U collisions from STAR experiment

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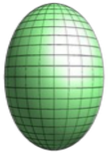
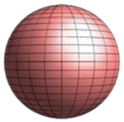
Nuclear shape:

$$R(\theta,\phi) = R_0\left(1+\beta[\cos\gamma Y_{2,0} + \sin\gamma Y_{2,2}]\right)$$

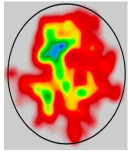


^{238}U $(\beta,\gamma)_{\mathrm{U}} \sim (0.28, 0°)$



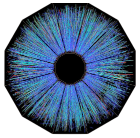
^{197}Au $(\beta,\gamma)_{\mathrm{Au}} \sim (0.14, 60°)$

Initial state:



$$\langle \epsilon_2^2 \rangle, \quad \left\langle \left(\delta \frac{1}{R}\right)^2 \right\rangle, \quad \left\langle \epsilon_2^2 \delta \frac{1}{R} \right\rangle, \quad \left\langle \left(\delta \frac{1}{R}\right)^3 \right\rangle$$

Final state:

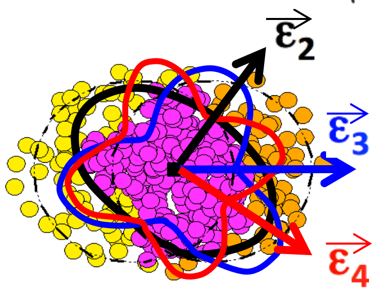


$$\langle v_2^2 \rangle, \quad \langle (\delta p_{\mathrm{T}})^2 \rangle, \quad \langle v_2^2 \delta p_{\mathrm{T}} \rangle, \quad \langle (\delta p_{\mathrm{T}})^3 \rangle$$

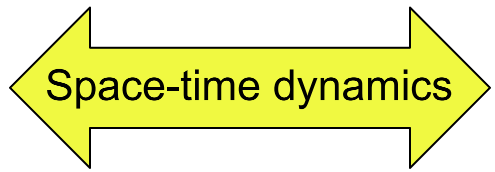
Connecting the final state to the initial state

Initial Shape

$$\vec{\epsilon}_n \equiv \epsilon_n e^{in\Phi_n^*} \equiv -\frac{\langle r^n e^{in\phi}\rangle}{\langle r^n\rangle}$$



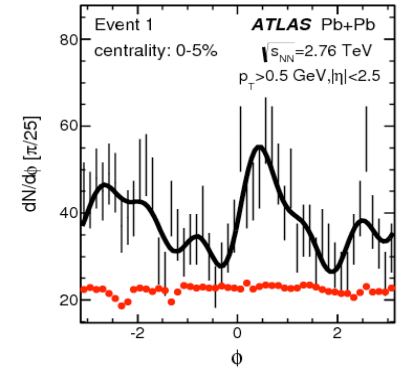
Hydro-response



$$\epsilon_n \rightarrow v_n$$

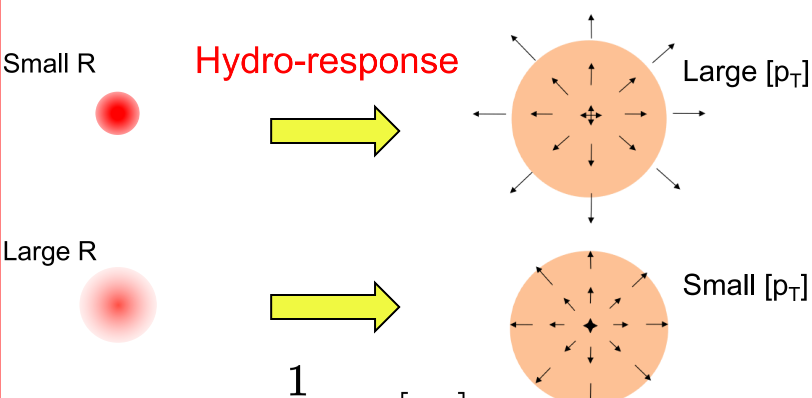
Harmonic flow

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



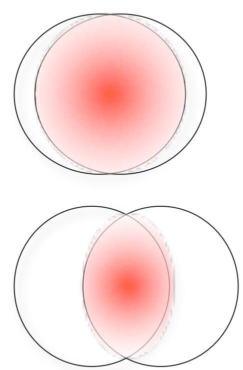
Initial Size

Radial flow $[p_T]$



$$\frac{1}{R} \rightarrow [p_T]$$

Correlated fluctuations in shape & size
→Correlated fluctuations in v_n and $[p_T]$



small ε_2, larger R

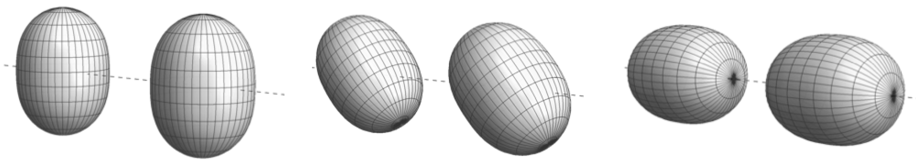
large ε_2, small R

$$\langle \epsilon_n^2 \frac{1}{R} \rangle \rightarrow \langle v_n^2\, p_T \rangle$$

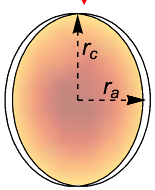
shape & size fluctuations from $\langle v_2^2 \rangle$, $\langle (\delta p_T)^2 \rangle$, $\langle v_2^2 \delta p_T \rangle$, $\langle (\delta p_T)^3 \rangle$

Influence of nuclear deformation

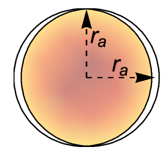
Average over all orientation U+U



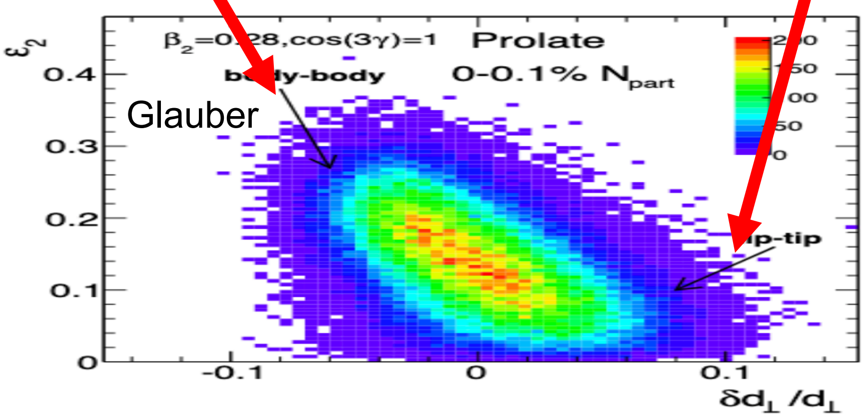
1910.04673, 2004.14463, 2106.08768, 2109.00604



large v_2
large area
small $[p_t]$



small v_2
small area
large $[p_t]$



More body+body than tip-tip events

Two-particle correlations:

$$\langle v_2^2 \rangle \propto \langle \epsilon_2^2 \rangle \sim a_2 + b_2 \beta^2$$

$b_2, b_0 > 0$

$$\frac{\langle (\delta p_{\rm T})^2 \rangle}{\langle p_{\rm T} \rangle^2} \propto \frac{\langle (\delta R)^2 \rangle}{R^2} \sim a_0 + b_0 \beta^2$$

Pearson correlator:

$$\rho_2 = \frac{\langle v_2^2 \delta p_{\rm T} \rangle}{\sqrt{{\rm var}(v_2^2) \langle \delta p_T \delta p_T \rangle}} \sim -\cos(3\gamma)\beta^3$$

$= -\beta^3$

Negative contribution

pT skewness:

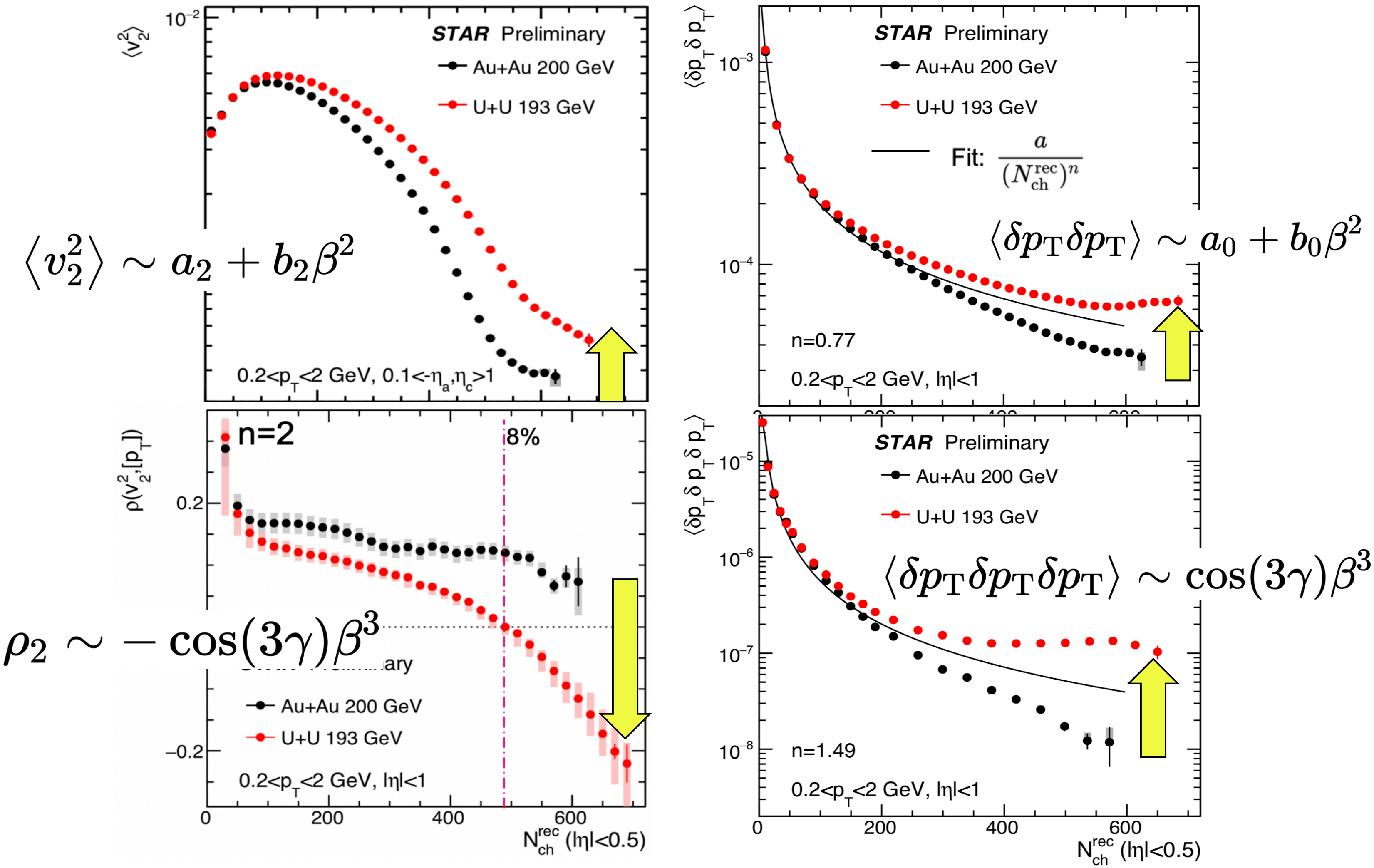
$$\langle (\delta p_{\rm T})^3 \rangle \sim \cos(3\gamma)\beta^3$$

$= \beta^3$

Positive contribution

Results

The ordering between U+U and Au+Au follow the expectation



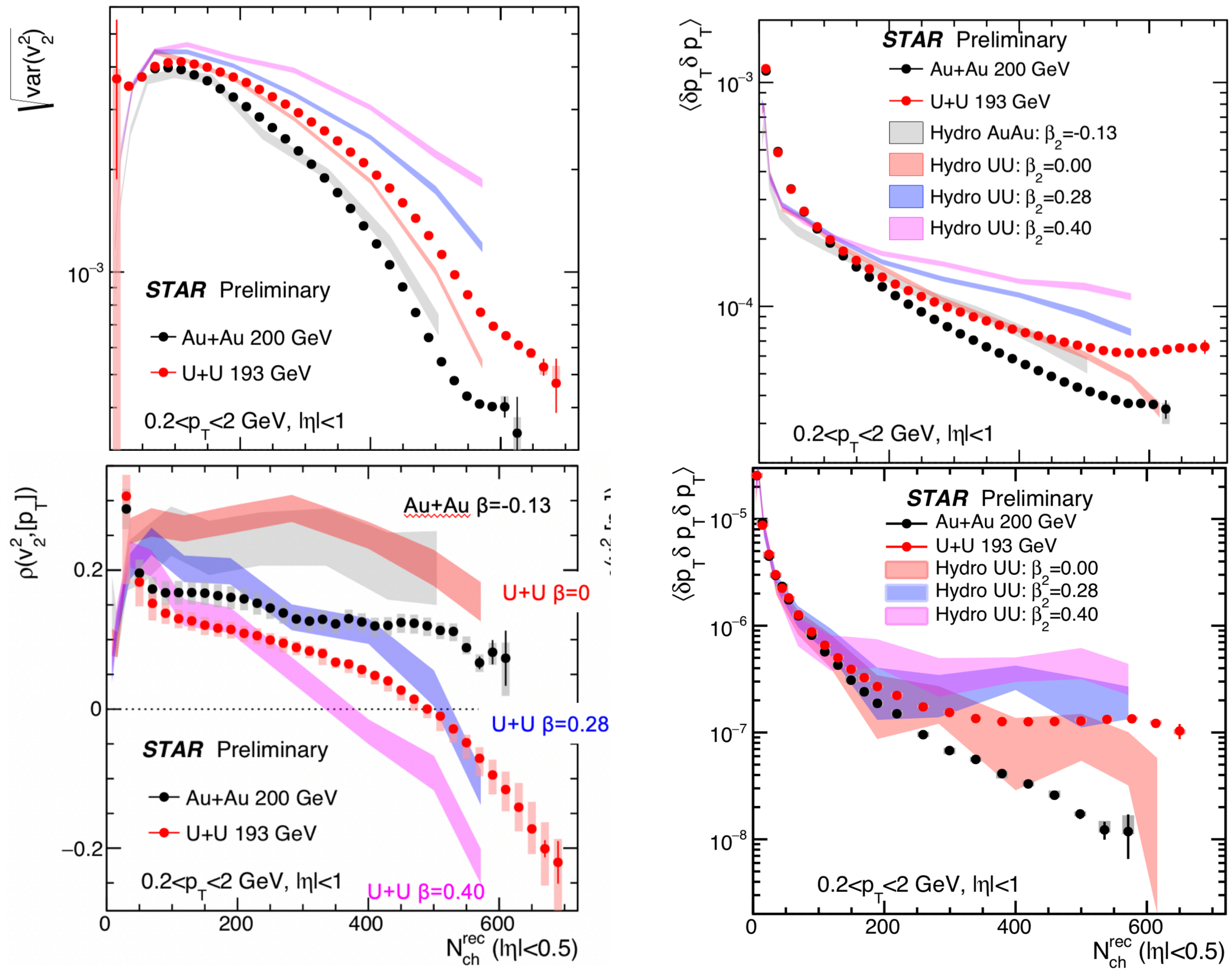
Much dramatic influence for three-particle correlators.

Influence largest in central collisions, but impacts the full centrality range.

Model comparisons

Phys. Rev. C 102, 034905 (2020)

Trends reproduced by the IP-Glasma+Hydro model from B.Schenke



Reasonable description of v_2 and $\boldsymbol{\rho}_2$, over-predicts p_T fluctuations.

Constrains from central data based on IP-Glasma ➔ $\beta \sim 0.28 \pm 0.03$

Further improvement on the initial condition in the model is needed.

Summary

- Azimuthal and radial flow → shape and size fluctuations of initial state
  - Inferred from fluctuations in v_n, $[p_T]$ and v_n-$[p_T]$ correlations

  Linear response approximation: $\epsilon_{\rm n} \rightarrow v_{\rm n}$ $\quad \frac{1}{R} \rightarrow [p_{\rm T}]$ $\quad \langle \epsilon_{\rm n}^2 \frac{1}{R} \rangle \rightarrow \langle v_{\rm n}^2\, p_{\rm T} \rangle$

- These observables are sensitive to the quadrupole deformation parameter

$$\rho = \frac{\rho_0}{1 + e^{(r - R_0(1+\beta[\cos(3\gamma)Y_{20}+\sin(3\gamma)Y_{22}])/a}}$$

- Compared to Au+Au, results from U+U collisions show
  - Enhance v_2, $[p_T]$ and v_2-$[p_T]$ fluct: γ_U=0, large β_U
  - Effects largest in central collisions, but also observed in mid-central collisions.

  → nuclear deformation influences collisions over a wide centrality range.

- Qualitatively described by hydro model.
  - Central data where deformation is most import, implies large β_U.
    - Estimate based on comparison of $\rho(v_2^2, p_T)$ with IP-Glasma prefers: $\beta \sim 0.28 \pm 0.03$
  - Data can improve model tuning and provide new ways to probe nuclear structure.