Study of Uranium nuclei deformation via flow and mean transverse momentum correlation at STAR

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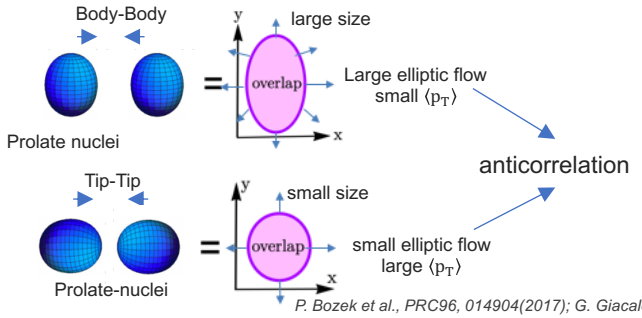
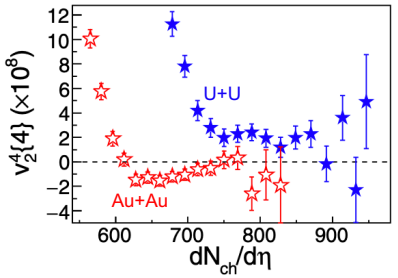
Motivations

- Shape-flow transmutation in deformed nuclear collisions

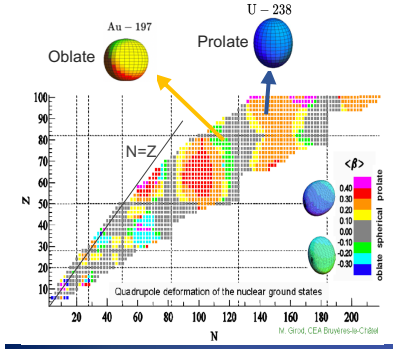


- Different sign of $v_2\{4\}$ in UCC



*P. Bozek et al., PRC96, 014904(2017); G. Giacalone, PRL124, 202301(2020); STAR, PRL**115**, 222301 (2015)*

- Recent paper proposed to use v_n-p_T correlation to study nuclear deformation



G. Giacalone, PRL124, 202301(2020);

For a deformed nucleus, the leading form of nuclear density becomes:

$$\rho(r,\theta) = \frac{\rho_0}{1+e^{(r-R_0(1+\beta_2 Y_{20}(\theta))/a}}$$

deformation is quantified by quadrupole β_2 parameter

⚠ A large uncertainty in the β_2 parameter of highly deformed ^{238}U.

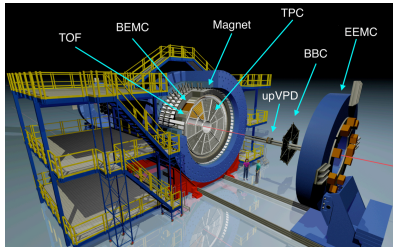
⚠ v_n-p_T correlation is a more direct way to study nuclear deformation comparing with EM transition.

⚠ ^{197}Au with smaller deformation can be a good baseline.

A. gorgen, Tech. Rep. 051, 019(2015); Moller et al., 1508.06294; BNL nuclear data center

Observables

- Performed using STAR TPC



Large, Uniform Acceptance at Mid-rapidity
Datasets: Run11 Au+Au@200GeV; Run12 U+U@193GeV

- Pearson coefficient: v_n-p_T three particle correlator

$$\rho(v_n^2,[p_T]) = \frac{\mathrm{cov}(v_n^2,[p_T])}{\sqrt{\mathrm{Var}\,(v_n^2)_{\mathrm{dyn}}\langle \delta p_T \delta p_T\rangle}}$$

$$\mathrm{cov}(v_n^2,[p_T]) \equiv \left\langle \frac{\sum_{i\neq j\neq k} w_i w_j w_k e^{in(\phi_i-\phi_j)}(p_{T,k}-\langle\langle p_T\rangle\rangle)}{\sum_{i\neq j\neq k} w_i w_j w_k} \right\rangle_{\mathrm{evt}}$$

$$[p_T] \equiv \frac{\sum_i w_i p_{T,i}}{\sum_i w_i}, \langle\langle p_T\rangle\rangle \equiv \langle [p_T]\rangle_{\mathrm{evt}}$$

$$\langle \delta p_T \delta p_T\rangle = \left\langle \frac{\sum_{i\neq j} w_i w_j (p_{T,i}-\langle\langle p_T\rangle\rangle)(p_{T,j}-\langle\langle p_T\rangle\rangle)}{\sum_{i\neq j} w_i w_j} \right\rangle_{\mathrm{evt}}$$

$$\mathrm{Var}\,(v_n^2)_{\mathrm{dyn}} = v_n\{2\}^4 - v_n\{4\}^4$$

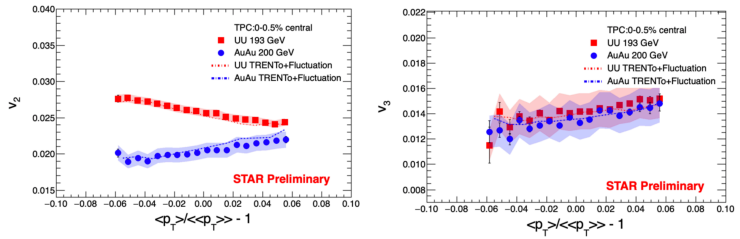
dynamical quantities with self-correlation removed

Full event	2-subevent		3-subevent		
$v_2, p_T, \lvert\eta\rvert < 1.0$	$v_2^A, \eta < -0.1$	$v_2^B, \eta > 0.1$	$v_2^A, \eta < -0.35$	$v_2^B, \lvert\eta\rvert < 0.3$	$v_2^C, \eta > 0.35$

subevent method crucial for non-flow and detector systematics

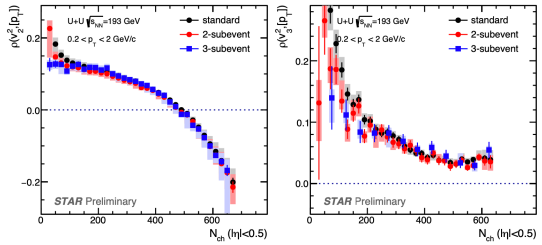
Results

- Deformation observed in direct v_n- $\langle p_T\rangle$ correlation in UCC



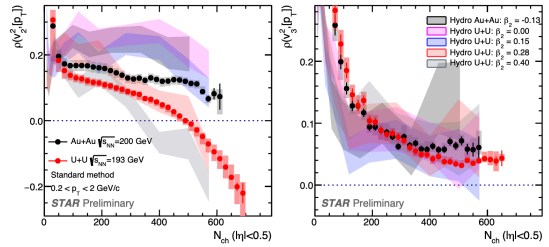
- An anticorrelation is observed between v_2 and $\langle p_T\rangle$ in top 0.5% U+U while not in Au+Au.
- v_3 and $\langle p_T\rangle$ correlations are positive and similar for Au+Au and U+U collisions.
- After adding the statistical fluctuations, TRENTo can reproduce data quantitatively.

- $\rho(v_n^2,[p_T])$ is not affected by non-flow



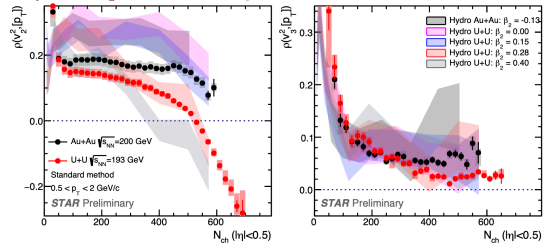
- Standard method is consistent with subevent methods.
- Subevent calculations indicate a decrease of non-flow contributions in peripheral collisions.

- $\rho(v_n^2,[p_T])$ is sensitive to β_2 in 0.2<p_T<2 GeV/c



- $\rho(v_2^2,[p_T])$ has a sign-change behavior in U+U central collisions.
- $\rho(v_3^2,[p_T])$ is positive in both U+U and Au+Au collisions.
- IP-Glasma + Hydro shows the hierarchical β_2 dependence in $\rho(v_2^2,[p_T])$

- $\rho(v_n^2,[p_T])$ in 0.5<p_T<2GeV/c



- Main features are robust against p_T selection.

TRENTo: *G. Giacalone, PRC102, 104901(2020)*
IP-Glasma: *Schenke, Shen, Tribedy, PRC102, 044905(2020)*

Summary

- We presented flow and mean transverse momentum correlation from STAR that demonstrate a clear shape–flow transmutation.
- Negative slope of v_2 vs $\langle p_T\rangle$ in U+U is due to the deformation.
- This is also confirmed by the sign-change of Pearson coefficient $\rho(v_2^2,[p_T])$ in central U+U collisions while not in Au+Au collisions.
- Non-flow contribution is negligible based on the consistency between standard and subevent methods.
- Hydro within IP-Glasma initial configuration shows the hierarchical β_2 dependence in $\rho(v_2^2,[p_T])$, and can reproduce $\rho(v_2^2,[p_T])$ with quadrupole deformation $\boldsymbol{\beta}_2$=0.28 for U+U collisions.
- These measurements provide novel ways to constrain quadrupole deformation $\boldsymbol{\beta}_2$ in heavy-ion collisions.