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# Constraining nuclear quadrupole deformation in relativistic heavy-ion collisions from a multiphase transport model

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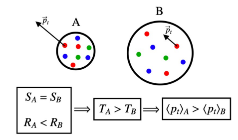
## Motivations

※ Shape-flow transmutation in deformed nuclear collisions

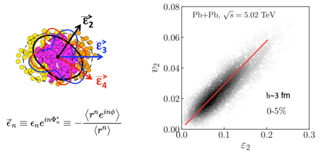
※ System size affect the $p_T$ of particles




G. Giacalone, PRC102, 024901(2020)

$\langle p_T \rangle \sim 1/R$

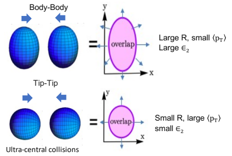
※ Shape affect the $v_n$ of particles




F.G. Gardim et al., arXiv:2002.07008v1

$v_n \propto \epsilon_n$

※ How the prolate nuclei affect the $v_n$ and $\langle p_T \rangle$




$\langle p_T \rangle \sim 1/\epsilon_2$

Study the deformation $\beta_2$ effect on $\rho(v_n)$ and $\rho(v_n, [p_T])$ in heavy ion collisions.

※ Can we constrain quadrupole deformation $\beta_2$ in heavy-ion collisions?

For a deformed nucleus, the leading form of nuclear density becomes: $\rho(r,\theta) = \frac{\rho_0}{1+e^{(r-R_0(1+\beta_2 Y_{20}(\theta))/a}}$

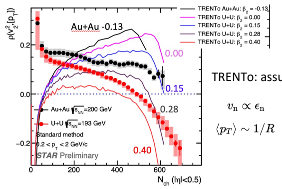
Deformation is dominated by quadrupole component $\beta_2$

Giuliano Giacalone (PRC102, 024901(2020), PRL124, 202301(2020) )

Bjoern Schenke et al., PRC102, 044905(2020))

TRENTo initial conditions | IP-Glasma+MUSIC+UrQMD | AMPT transport model

Private calculation provided by Giuliano Giacalone

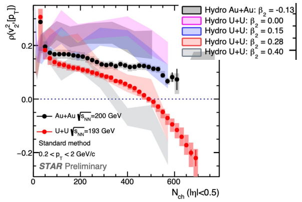



TRENTo: assuming

$v_n \propto \epsilon_n$

$\langle p_T \rangle \sim 1/R$

Private calculation provided by Bjoern Schenke




What can we learn?

TRENTo and IP-Glasma+MUSIC+UrQMD all show hierarchical $\beta_2$ dependence in $\rho(v_2^2, [p_T])$

## Observables

※ Flow coefficient:

$$v_n\{2\} = \sqrt{\langle v_n^2 \rangle} = \sqrt{c_n\{2\}} = \sqrt{\langle\langle e^{in(\phi_1-\phi_2)}\rangle\rangle}$$

※ Pearson coefficient:

P. Bozek et al., PRC96, 014904(2017); ATLAS EPJC79, 985(2019); G. Giacalone, PRL124, 202301(2020); B.Shenke et al., PRC102,034905(2020)

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

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

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

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

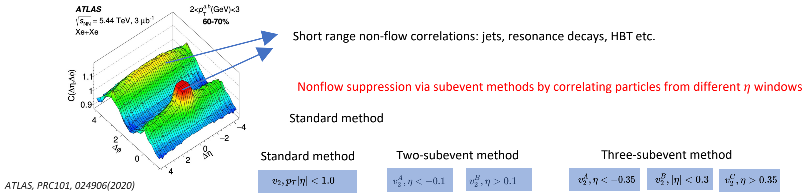
subevent method crucial for non-flow and detector systematics

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

dynamical quantities with self-correlation removed

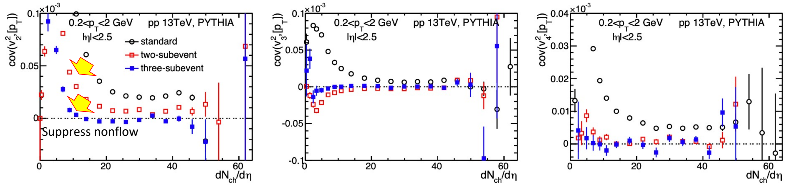
## Nonflow effect on correlation coefficient

※ How about the nonflow contamination in long-range correlation?




ATLAS, PRC101, 024906(2020)

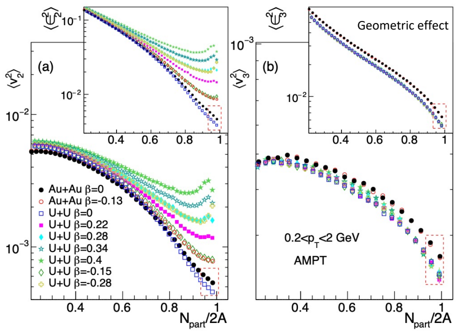
※ Nonflow effect in pp 13TeV in PYTHIA




※ Subevent method plays a role in suppressing nonflow in correlation coefficient $\mathrm{cov}(v_n^2, [p_T])$.

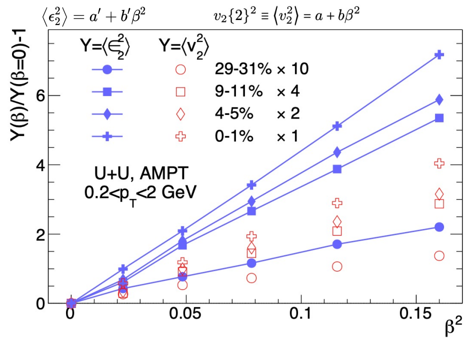
## Quadrupole deformation on $v_n$

※ Clear geometric effect and the linear $\beta_2$ dependence



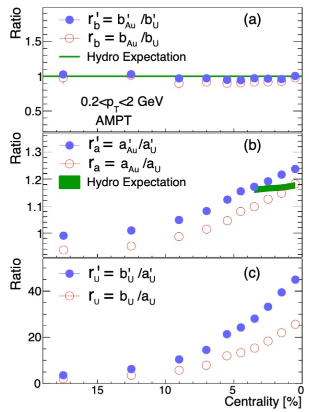

※ $\langle v_2^2 \rangle$ strongly depends $\beta_2$ in central collisions, while $\langle v_3^2 \rangle$ isn't .

$\langle \epsilon_2^2 \rangle = a' + b'\beta^2$ $\quad v_2\{2\}^2 \equiv \langle v_2^2 \rangle = a + b\beta^2$

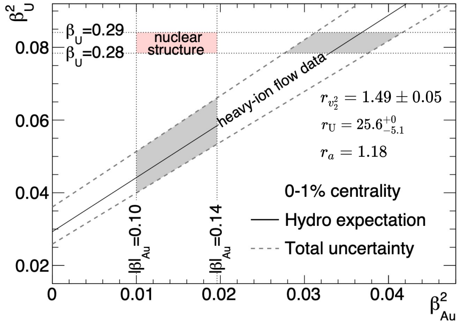



※ $\langle v_2^2 \rangle$ and $\langle \epsilon_2^2 \rangle$ are indeed linear in $\beta_2^2$.

※ Constraint the $\beta_2$




$$\beta_Y^2 = \left(\frac{r_{v_2^2} r_a - 1}{r_Y}\right) + \left(r_{v_2^2} r_b\right)\beta_X^2$$



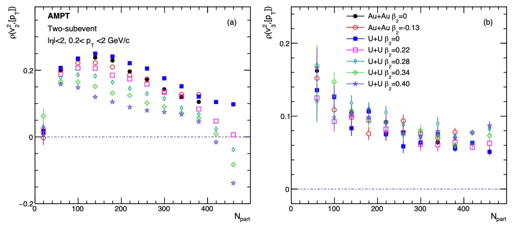

Intrinsic connection between the phenomenology of heavy-ion collisions and the structure of the atomic nuclei.

※ A minor role of the hydrodynamic response.

※ Numerical results are confirmed.

## Quadrupole deformation on $\rho(v_n^2, [p_T])$

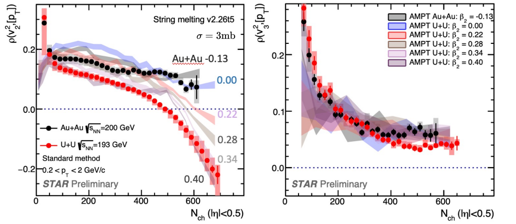
※ Quadrupole deformation $\beta_2$ effect on the Pearson correlation coefficient




※ AMPT shows the hierarchical $\beta_2$ dependence in $\rho(v_2^2, [p_T])$ while not in $\rho(v_3^2, [p_T])$.

※ AMPT could also be used to quantify the $\beta_2$ value of uranium nuclei.

※ AMPT $\rho(v_n^2, [p_T])$ compared with STAR Preliminary results




※ AMPT show comparable trend and a clear $\beta_2$ dependence in Uranium $\rho(v_2^2, [p_T])$.

## Summary

※ The nonflow were suppressed in $\mathrm{cov}(v_2^2, [p_T])$ clearly by subevent methods.

※ Numerically calculate the intrinsic connection between the phenomenology heavy-ion collisions and the structure of atomic nuclei:

- ▹ Clear geometric effect and the linear $\beta_2$ dependence in central collisions.
- ▹ $\langle v_2^2 \rangle$ strongly depends $\beta_2$ in central collisions, while $\langle v_3^2 \rangle$ is independent of $\beta_2$.

※ AMPT shows the anticorrelation between $v_2$ vs $\langle p_T \rangle$ in U+U while not in Au+Au.

- ▹ The sign-change behavior in $\rho(v_2^2, [p_T])$ is robust in U+U collisions.
- ▹ It could be used to quantify quadrupole component $\beta_2$ compared with STAR data.