Systematic study on nuclei deformation and nonflow effect in v_n - p_T correlations from model simulations

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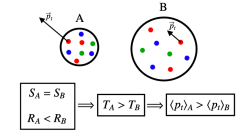
Motivations

Shape-flow transmutation in deformed nuclear collisions

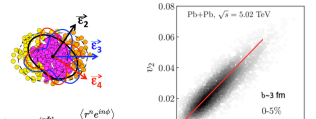
System size affect the p_T of particles



G. Giacalone, PRC102, 024901(2020)

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

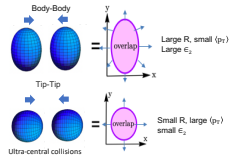
Shape affect the v_n of particles



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

$$v_n \propto \epsilon_n$$

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



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

Can we constrain quadrupole deformation β_2 in heavy-ion collisions?

Deformation is dominated by quadrupole component β_2

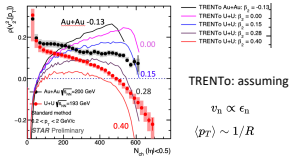
For a deformed nucleus, the leading form of nuclear density becomes: $\rho(r,\theta) = \frac{\rho_0}{1+e^{(r-R_0(1+\beta_2 Y_{20}(\theta))/a}}$

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

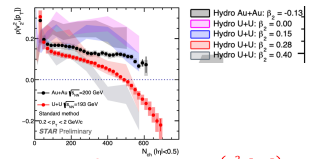


TRENTo: assuming

$v_n \propto \epsilon_n$

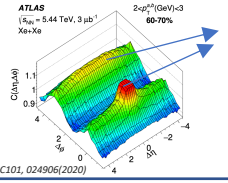
$\langle p_T \rangle \sim 1/R$

Private calculation provided by Bjoern Schenke



TRENTo and IP-Glasma+MUSIC+UrQMD all show hierarchical β_2 dependence in $\rho(v_2^2, [p_T])$

How about the nonflow contamination in long-range correlation?



ATLAS, PRC101, 024906(2020)

Short range non-flow correlations: jets, resonance decays, HBT etc.

Nonflow suppression via subevent methods by correlating particles from different η windows

Standard method	Two-subevent method	Three-subevent method
$v_2, p_T \|\eta\| < 1.0$	$v_2^4, \eta < -0.1$	$v_2^B, \eta > 0.1$	$v_2^A, \eta < -0.35$	$v_2^B, \|\eta\| < 0.3$	$v_2^C, \eta > 0.35$

Observables

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)

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

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

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

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

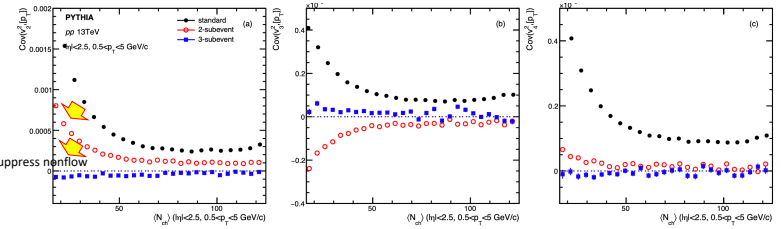
subevent method crucial for non-flow and detector systematics

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

dynamical quantities with self-correlation removed

Nonflow effect on correlation coefficient

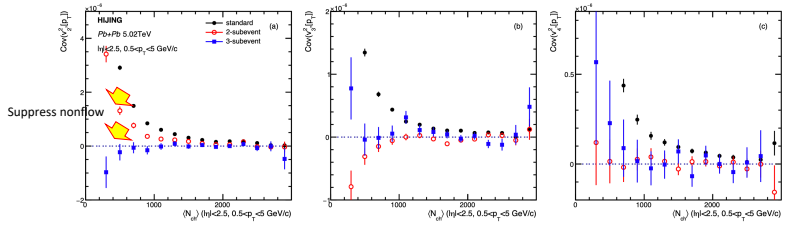
Nonflow effect in *pp* 13TeV in PYTHIA 8



Two-subevent method do suppress nonflow clearly.

Three-subevent method do suppress nonflow more.

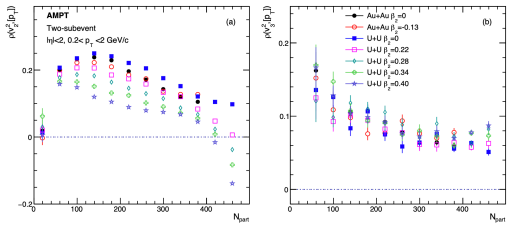
Nonflow effect in Pb+Pb 5.02 TeV in HIJING



Subevent method play a role in suppressing nonflow in correlation coefficient cov(v_n^2, [p_T]).

Systematic study on nuclei deformation

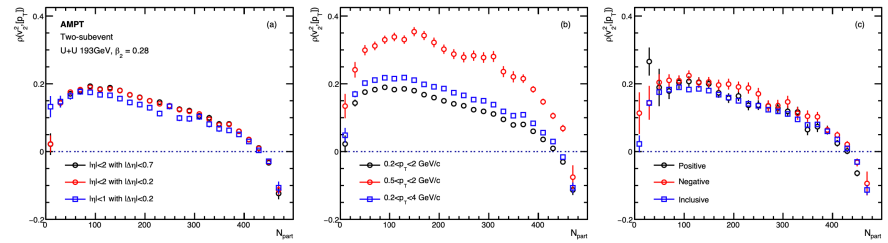
Quadrupole deformation β_2 effect on the Pearson correlation coefficient



AMPT shows the hierarchical β_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 β_2 value of uranium nuclei.

Sign-change behavior is robust against different systematic checks

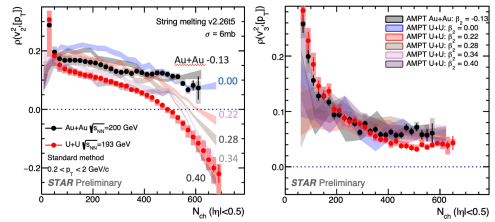


A Clear acceptance effect.

A Clear p_T dependence.

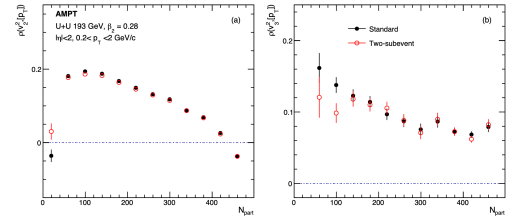
Not big effect in resonance decay.

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



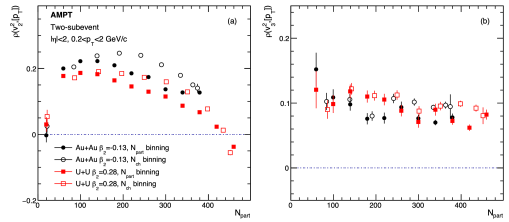
AMPT show comparable trend and a clear β_2 dependence in Uranium $\rho(v_2^2, [p_T])$.

The effect of nonflow in $\rho(v_n^2, [p_T])$



Nonflow can be suppressed by subevent method in peripheral collisions.

The effect of centrality fluctuation in $\rho(v_n^2, [p_T])$



Centrality fluctuation is non-negligible which could bias the $\rho(v_n^2, [p_T])$ in mid-central region.

The sign-change behavior of $\rho(v_2^2, [p_T])$ in ultra-central region is robust and only be dominated by quadruple deformation β_2.

Summary

- The nonflow were suppressed in $\rho(v_2^2, [p_T])$ clearly by subevent methods.
- The AMPT with simple Monte-Carlo do show the anticorrelation between v_2 vs $\langle p_T \rangle$ in U+U while not in Au+Au collisions.
- The sign-change behavior in $\rho(v_2^2, [p_T])$ in central U+U collisions could be used to quantify quadrupole component β_2 compared with STAR data.
- Main features are robust against different systematic checks including η acceptance/Δη gap, different p_T selections and resonance decay.
- Centrality fluctuation is non-negligible and could bias the $\rho(v_2^2, [p_T])$ in mid-central region.
- The sign-change behavior of $\rho(v_2^2, [p_T])$ in UCC is robust and only be dominated by quadruple deformation β_2.

References

- PYTHIA 8: T. Sjostrand et al., Comput. Phys. Commun. 178, 852 (2008)
- HIJING: M. Gyulassy et al., Comput. Phys. Commun. 83, 307 (1994)
- AMPT: Zi-wei Lin et al., Phy. Rew C 72, 064901(2005)
- TRENTo: Giuliano Giacalone , Phy. Rew. Lett. 124, 202301(2020)
- IP-Glasam+MUSIC+UrQMD: Bjoern Schenke et al., Phy. Rew. C 102, 044905(2020)