Fluctuations of anisotropic flow in transport from the finite number of rescatterings

arXiv:2012.02138

Initial Stages 2021

CRC-TR 211 Strong-interaction matter under extreme conditions

IS2021

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1. Introduction

- We investigate anisotropic flow for a 2D system of massless particles, within the approach of C. Gombeaud and J.-Y. Ollitrault [1].
- Using a MC Glauber model as input for the initial condition, we show how the resulting fluctuations in v_2 and v_3 depend on the mean number of rescatterings in the system. Therefore, we use conditional probability distributions $p_{v|\varepsilon}(v_{n,c/s}|\varepsilon_{n,c/s})$ and characterize them by their first moments [2].
- We also investigate the correlations of the initial state symmetry planes and the final state flow angles with dependence on the number of rescatterings.

2. Initial state

- Input: TGlauberMC [3]
  $\to N_{\mathrm{coll}}(x,y), N_{\mathrm{part}}(x,y)$
  - Pb-Pb at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- Energy density: $e(x,y)$
  - $N(x,y) = (1-\xi)N_{\mathrm{part}} + \xi N_{\mathrm{coll}}$ with $\xi \approx 0.15$.
  - Smear the energy density as a Gaussian with width $R_{\mathrm{N}} = \frac{1}{2}\sqrt{\frac{\sigma_{\mathrm{inel}}^{\mathrm{NN}}}{\pi}}$.
- Calculate density profile eccentricities with $\varepsilon_n e^{in\Phi_n} = -\frac{\langle r^n e^{in\theta}\rangle}{\langle r^n\rangle}$.

References

[1] Clément Gombeaud and Jean-Yves Ollitrault. Covariant transport theory approach to elliptic flow in relativistic heavy ion collision. *Phys. Rev. C*, 77:054904, May 2008.

[2] Hendrik Roch and Nicolas Borghini. Fluctuations of anisotropic flow from the finite number of rescatterings in a two-dimensional massless transport model. 12 2020.

[3] C. Loizides, J. Nagle, and P. Steinberg. Improved version of the PHOBOS Glauber Monte Carlo. *SoftwareX*, 1-2:13 – 18, 2015.

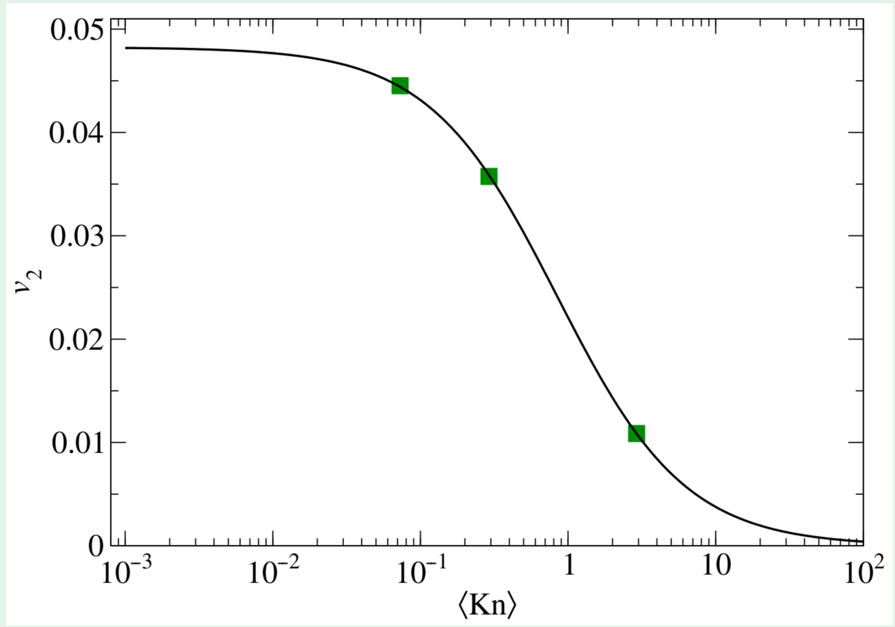
[4] Rajeev S. Bhalerao, Jean-Paul Blaizot, Nicolas Borghini, and Jean-Yves Ollitrault. Elliptic flow and incomplete equilibration at RHIC. *Physics Letters B*, 627(1):49 – 54, 2005.

3. Transport simulation

- For particlization we convert $e(x,y)$ to $n(x,y)$ using eqns. for an ideal gas in 2D.
- Initial momentum anisotropy only due to finite test particle number, i.e. $\delta v_{n,c/s} = (2N_{\mathrm{p}})^{-1/2}$.
- We compute 10 runs over one initial density with $5\cdot 10^5$ particles each to reduce statistical errors.
- Evolve the system in time with a purely 2D transport algorithm [1] with massless test particles of radius r:
  - $2\to 2$ elastic collision kernel
  - Isotropic scattering angle θ^* (in center-of-momentum frame) is function of impact parameter d: $\theta^* = \pi(1-d/r)$
- Characterize flow regime via Knudsen number Kn and [4]

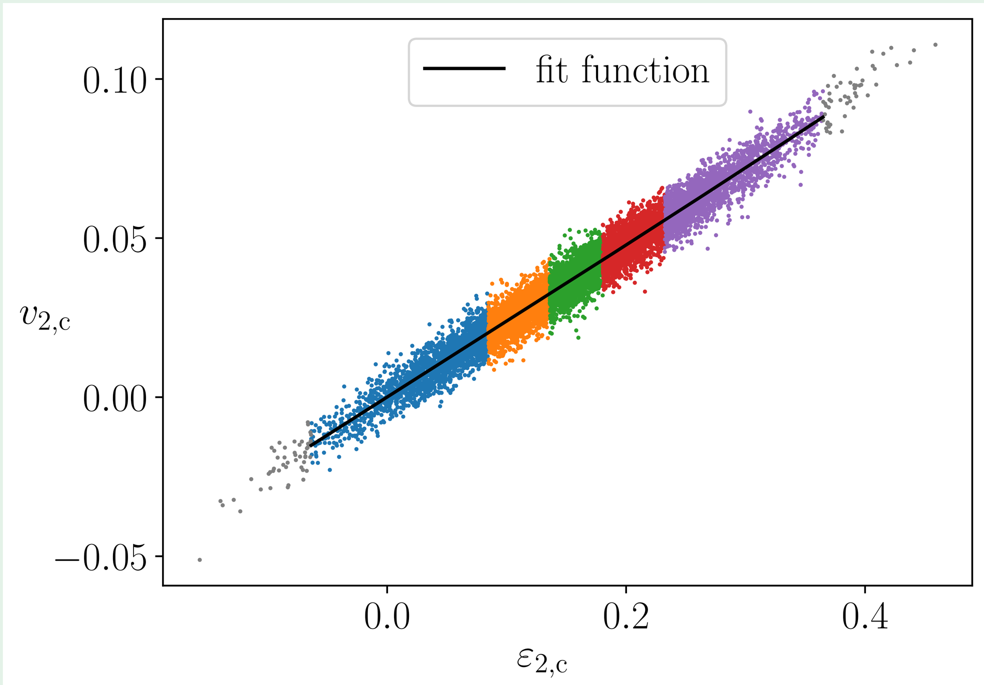
$$v_2 = \frac{v_2^{\mathrm{hydro}}}{1+\frac{Kn}{Kn_0}}$$

for the simulations with three different cross sections.



4. Analysis method

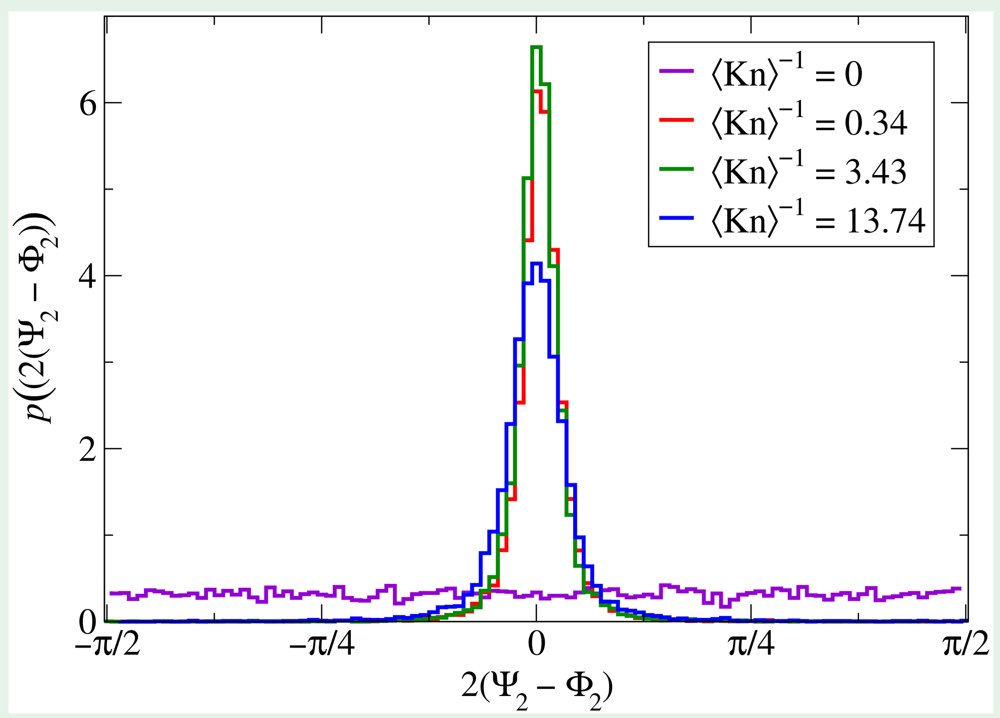
- Relation between initial and final state:
  - $v_2 \simeq \mathcal{K}_{2,2}\varepsilon_2 + \mathcal{K}_{2,222}\varepsilon_2^3$ (cubic term only used for $b = 6, 9$ fm)
  - $v_3 \simeq \mathcal{K}_{3,3}\varepsilon_3$
- We divide the 10^5 events at impact parameters $b = 0, 6, 9$ fm into five eccentricity bins and remove the outliers (gray points):
- We calculate the moments of $p_{v|\varepsilon}(v_{n,c/s}|\varepsilon_{n,c/s})$ centered around the fit for each $\varepsilon_{n,c/s}$ bin.
- Perform weighted average over the $\varepsilon_{n,c/s}$ bins.
- Errors are determined via delete-d Jackknife algorithm.

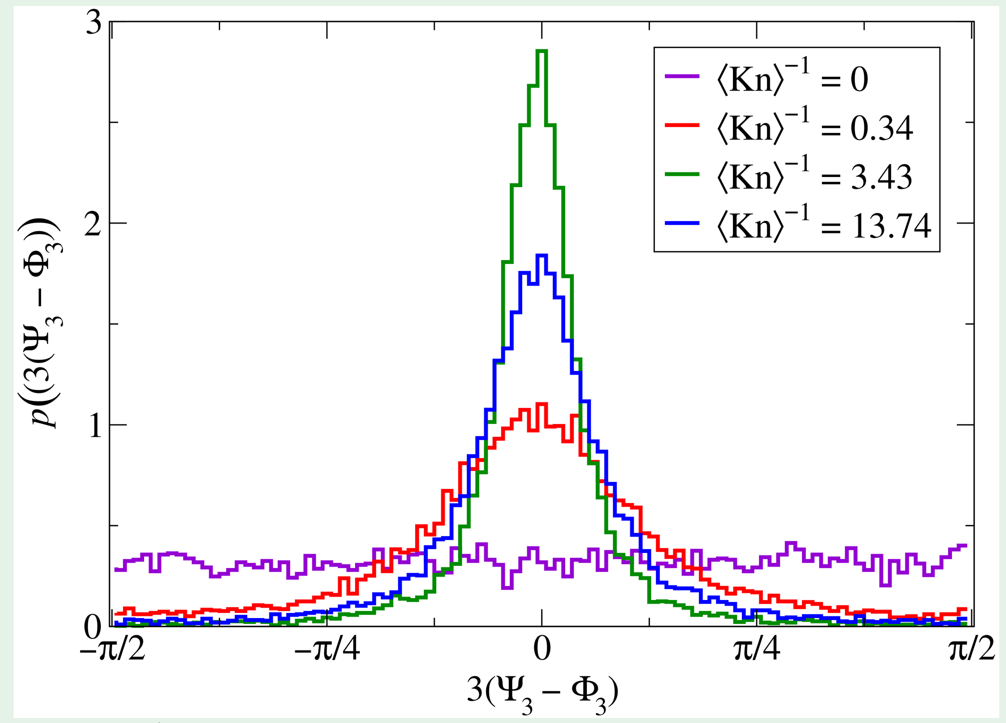


Acknowledgements

We acknowledge support by the Deutsche Forschungsgemeinschaft (DFG) through the grant CRC-TR 211 "Strong-interaction matter under extreme conditions". Computational resources have been provided by the Center for Scientific Computing (CSC) at the Goethe-University of Frankfurt and the Bielefeld GPU cluster.

5. Event-plane angle distributions





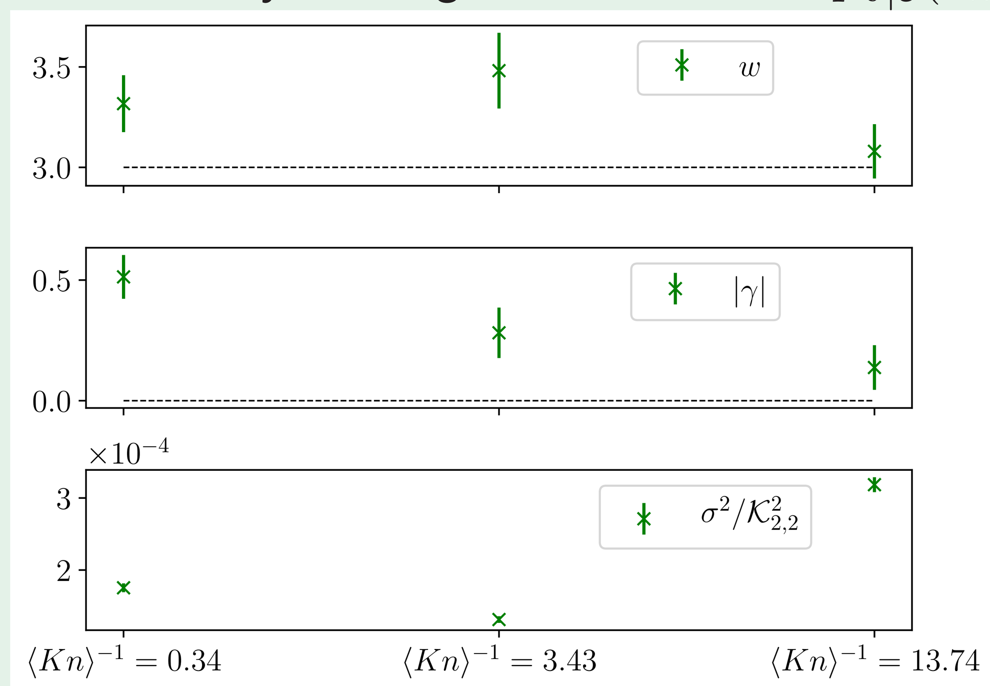
- In the initial state of the simulation, i.e., $\langle Kn\rangle^{-1} = 0$ there is no correlation.
- Onset of correlation between initial and final state angles first for $n = 3$ and then for $n = 2$ with $\langle Kn\rangle^{-1}$.
- Consistent with behaviour of moments for increasing $\langle Kn\rangle^{-1}$.

6. Flow fluctuations

- Moments of $p_{v|\varepsilon}(v_{n,c/s}|\varepsilon_{n,c/s})$ averaged over $\varepsilon_{n,c/s}$ exemplary for $b = 0$ fm in the initial state of the transport simulation:

	$\sigma_v^2/(2N_{\mathrm{p}})^{-1}$	$\lvert\gamma_1\rvert$	γ_2
$v_{2,c}$	1.014 ± 0.020	0.041 ± 0.055	-0.030 ± 0.069
$v_{2,s}$	0.990 ± 0.020	0.079 ± 0.057	0.063 ± 0.078
$v_{3,c}$	0.996 ± 0.020	0.034 ± 0.057	0.013 ± 0.075
$v_{3,s}$	0.996 ± 0.020	0.089 ± 0.055	-0.014 ± 0.073

  - Skewness and (excess) kurtosis are in most cases compatible with zero. Therefore, the initial state of the transport has Gaussian fluctuations (numerics).
- Eccentricity averaged moments of $p_{v|\varepsilon}(v_{n,c}|\varepsilon_{n,c})$ for $b = 6$ fm in the final state:



  - Similar behaviour $\forall\ \langle Kn\rangle^{-1}$, $\forall\ b \in \{0, 6, 9\}$ fm and for $n = 2, 3$
  - Average variance is largest for the largest number of collisions. The increase is stronger than that of the fit function itself.
  - Average absolute value of the skewness $\lvert\gamma_1\rvert$ decreases and approaches zero.
  - Distributions are more peaked than a Gaussian for small $\langle Kn\rangle^{-1}$. For the most "hydrodynamical" simulation the kurtosis almost vanishes.
- For the largest $\langle Kn\rangle^{-1}$ the Gaussian fluctuations of the initial state are recovered, while for smaller $\langle Kn\rangle^{-1}$ the finite number of scatterings yields non-Gaussianities.