Fluctuations of anisotropic flow in transport

Quark Matter 2019

Hendrik Roch* and Nicolas Borghini

Faculty of Physics, Bielefeld University, Germany

* hroch@physik.uni-bielefeld.de

UNIVERSITÄT BIELEFELD
Faculty of Physics

CRC-TR 211
Strong-interaction matter under extreme conditions

Introduction

- We investigate anisotropic flow for a 2D system of massless particles, within the approach of C. Gombeaud and J.-Y. Ollitrault [1].
- For controlled initial geometries, we study the change in v_2, v_3, v_4 as the Knudsen number Kn is varied.
- 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.

Dependence of anisotropic flow on Kn for controlled initial conditions

- The spatial part of our initial-state distribution function:

$$f(r,\theta) = \frac{1}{2\pi R^2} e^{-\frac{r^2}{2R^2}} \left[1 - 4\varepsilon_2 e^{-\frac{r^2}{2R^2}} \left(\frac{r}{R}\right)^2 \cos(2\theta) - \sqrt{2\pi}\varepsilon_3 e^{-\frac{r^2}{2R^2}} \left(\frac{r}{R}\right)^3 \cos(3\theta) - \frac{4}{3}\varepsilon_4 e^{-\frac{r^2}{2R^2}} \left(\frac{r}{R}\right)^4 \cos(4\theta)\right]$$

- We performed calculations at different Kn with only one $\varepsilon_n = 0.15$ and the other $\varepsilon_{p\neq n} = 0$. To reduce statistical fluctuations of v_n about 0 in the initial state, we averaged over 500 runs with $2.5 \cdot 10^5$ particles for each (initial) geometry.
- Every anisotropic flow harmonic behaves as $v_n = \frac{v_n^{\rm hydro}}{1+\frac{\rm Kn}{{\rm Kn}_0}}$, as anticipated in [2] and observed in [1] for v_2.
- At fixed Kn, higher harmonics are more suppressed.
- As n grows, v_n sets on at increasingly larger number of rescatterings (smaller Kn).

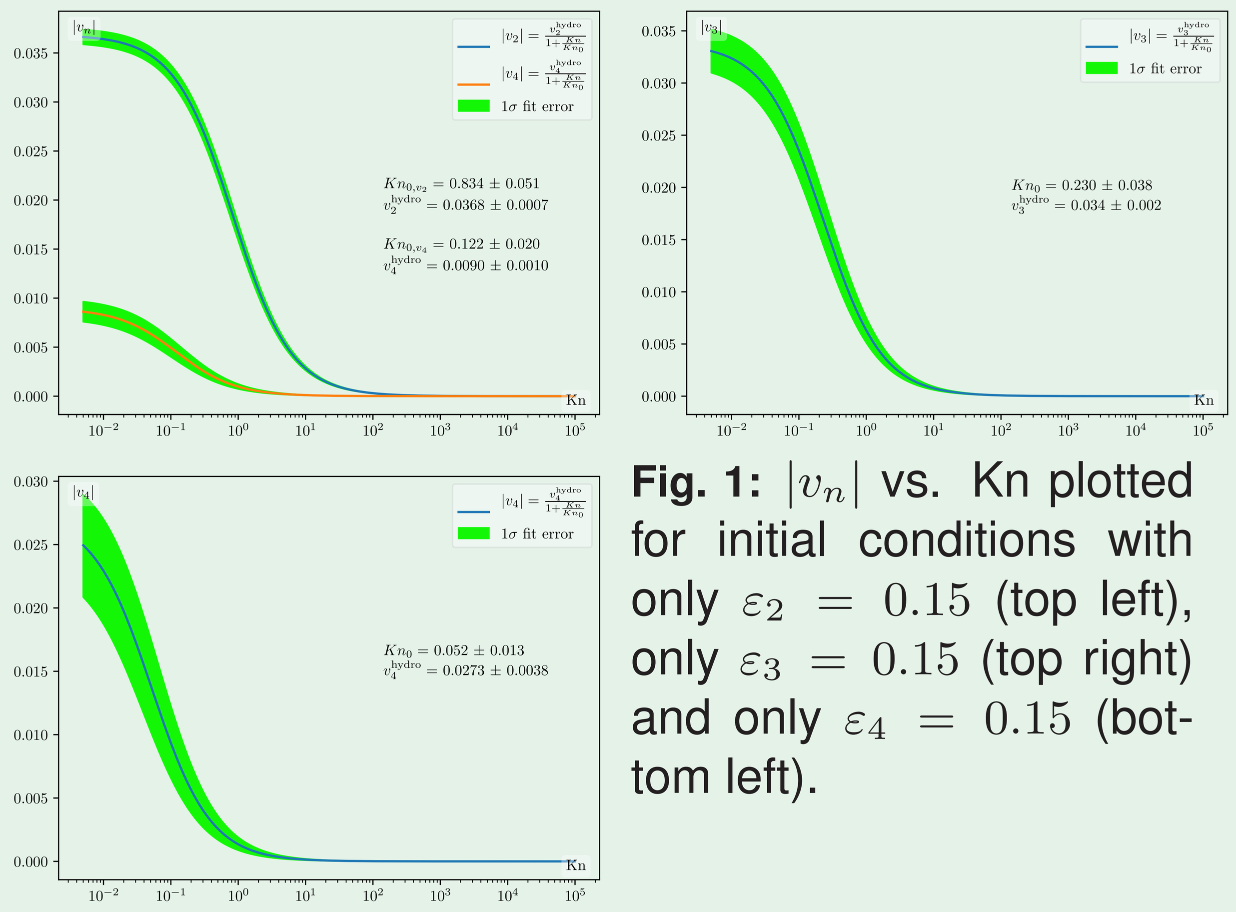

Fig. 1: $|v_n|$ vs. Kn plotted for initial conditions with only $\varepsilon_2 = 0.15$ (top left), only $\varepsilon_3 = 0.15$ (top right) and only $\varepsilon_4 = 0.15$ (bottom left).

Setup for MC initial condition

- Input: TGlauberMC [3] (Pb-Pb $\sqrt{s_{\rm NN}} = 5.02$ TeV) $\rightarrow N_{\rm coll}(x,y), N_{\rm part}(x,y)$
- Energy density: $e(x,y)$
  - $N(x,y) = (1-\xi)N_{\rm part} + \xi N_{\rm coll}$ with $\xi \approx 0.15$.
  - Smear the energy density as a Gaussian with width $R_{\rm N} = \frac{1}{2}\sqrt{\frac{\sigma_{\rm inel}^{\rm NN}}{\pi}}$.
- For the particlization we convert $e(x,y)$ to $n(x,y)$ with the equations for an ideal gas in 2D. We checked the energy conservation in the process.
- Momentum isotropy, i.e. $v_n = 0$.
- We compute 10 runs over one initial condition with $5 \cdot 10^5$ particles each to reduce statistical errors.

Fluctuation characterization

- Fluctuations in the eccentricity probability distribution can be characterized by the elliptic-power law [4]:

$$p(\varepsilon_n) = \frac{2\alpha\varepsilon_n}{\pi}\left(1-\varepsilon_n^2\right)^{\alpha-1}\left(1-\varepsilon_0^2\right)^{\alpha+\frac{1}{2}}\int_0^\pi {\rm d}\varphi\,(1-\varepsilon_0\varepsilon_n\cos\varphi)^{-2\alpha-1}.$$

  - For vanishing mean anisotropy ε_0 in the reaction plane: $p(\varepsilon_n) = 2\alpha\varepsilon_n\left(1-\varepsilon_n^2\right)^{\alpha-1}$.
  - The relation between ε_n and v_n (for $n = 2,3$) is: $v_n \approx \mathcal{K}_{n,n}\varepsilon_n$.

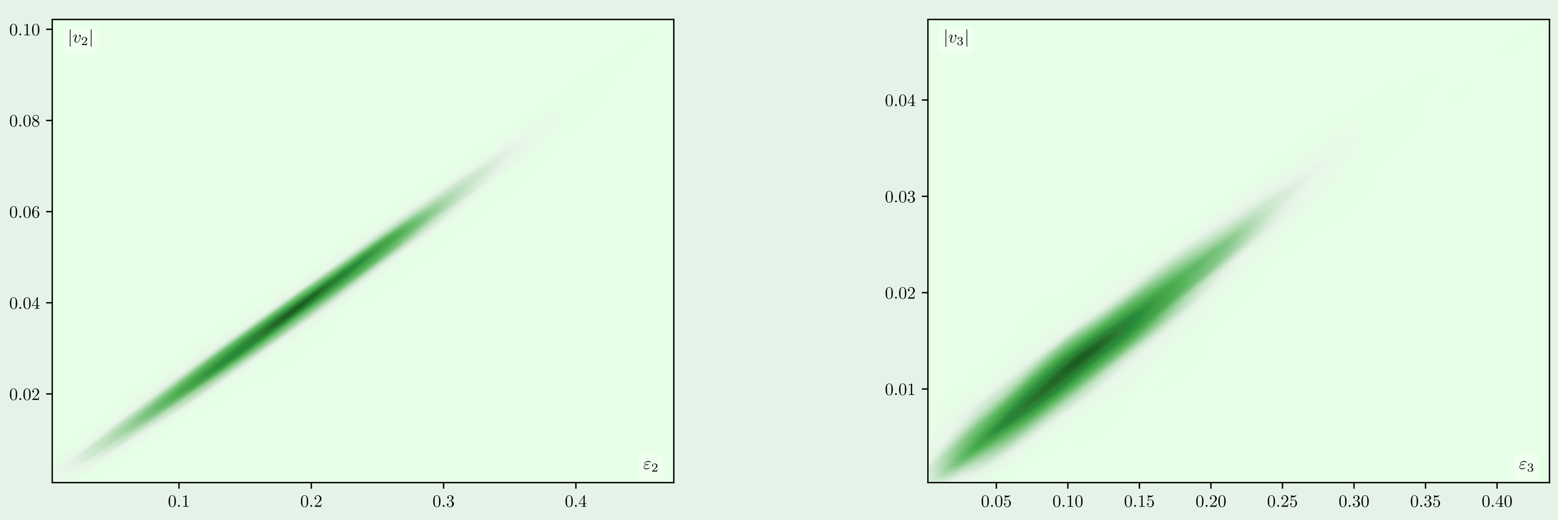

Fig. 2: Distribution of ε_2 and v_2 (left) and the distribution of ε_3 and v_3 (right) for $\langle{\rm Kn}\rangle = 0.29$.

  - The anisotropic flow distribution reads: $p(v_n) = \frac{1}{\mathcal{K}_{n,n}} p\left(\frac{v_n}{\mathcal{K}_{n,n}}\right)$.

Propagation of fluctuations

- The integral form of the power law is better suited for the distributions with non vanishing mean anisotropy.

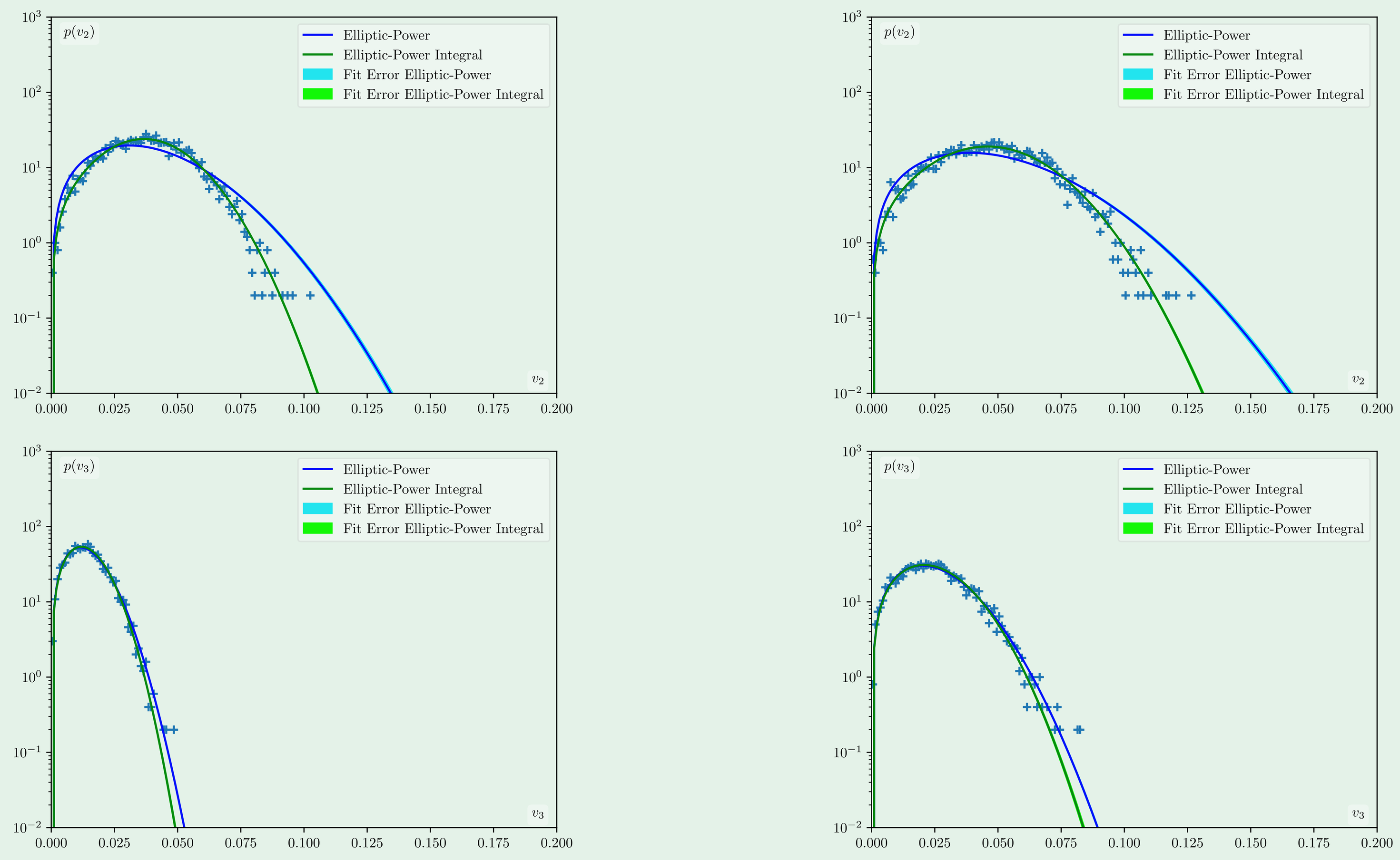

Fig. 3: Fitted distributions of v_2 (top row) and v_3 (bottom row) for $\langle{\rm Kn}\rangle = 0.29$ (left column) and $\langle{\rm Kn}\rangle = 0.07$ (right column).

- We find that for ε_2 and ε_3 the fluctuations in the distributions are washed out during the time evolution, resulting in larger values of α for the v_n distributions.
- The value of α decreases and that of v_0 increases with growing number of rescatterings. The computation with the largest Kn, approaching the free-streaming limit, yields a peaked $p(v_n)$, for which the value of α is limited by numerical fluctuations in the initial momentum distribution.

$b = 6$ fm	ε_0 or v_0	α	$b = 6$ fm	ε_0 or v_0	α
ε_2	0.160 ± 0.002	62 ± 2	ε_3	0.066 ± 0.005	71 ± 4
$v_{2,\langle{\rm Kn}\rangle=2.91}$	-	6400 ± 30	$v_{3,\langle{\rm Kn}\rangle=2.91}$	-	802100 ± 700
$v_{2,\langle{\rm Kn}\rangle=0.29}$	0.0327 ± 0.0002	1560 ± 20	$v_{3,\langle{\rm Kn}\rangle=0.29}$	0.0088 ± 0.0002	5707 ± 100
$v_{2,\langle{\rm Kn}\rangle=0.07}$	0.0408 ± 0.0002	980 ± 20	$v_{3,\langle{\rm Kn}\rangle=0.07}$	0.0153 ± 0.0003	1840 ± 40

Tab. 1: Fit values for the $\varepsilon_{2,3}$ and $v_{2,3}$ distributions for collisions at $b = 6$ fm. Cells with a "-" indicate fits with the distribution function where $v_0 = 0$.

Outlook Further transport calculations with smaller Kn are needed to see if the value of α decreases further and finally approaches the α value of the initial state eccentricity distribution.
The calculation will also be performed for different impact parameters.

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] 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] C. Loizides, J. Nagle, and P. Steinberg. Improved version of the PHOBOS Glauber Monte Carlo. *SoftwareX*, 1-2:13 – 18, 2015.
[4] Li Yan, Jean-Yves Ollitrault, and Arthur M. Poskanzer. Azimuthal anisotropy distributions in high-energy collisions. *Physics Letters B*, 742:290 – 295, 2015.

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.