Fluctuations of anisotropic flow in transport

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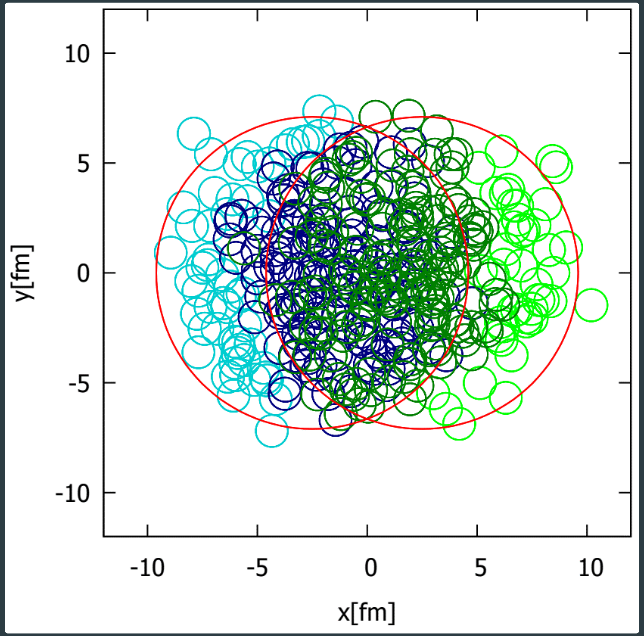
CRC-TR 211
Strong-interaction matter under extreme conditions

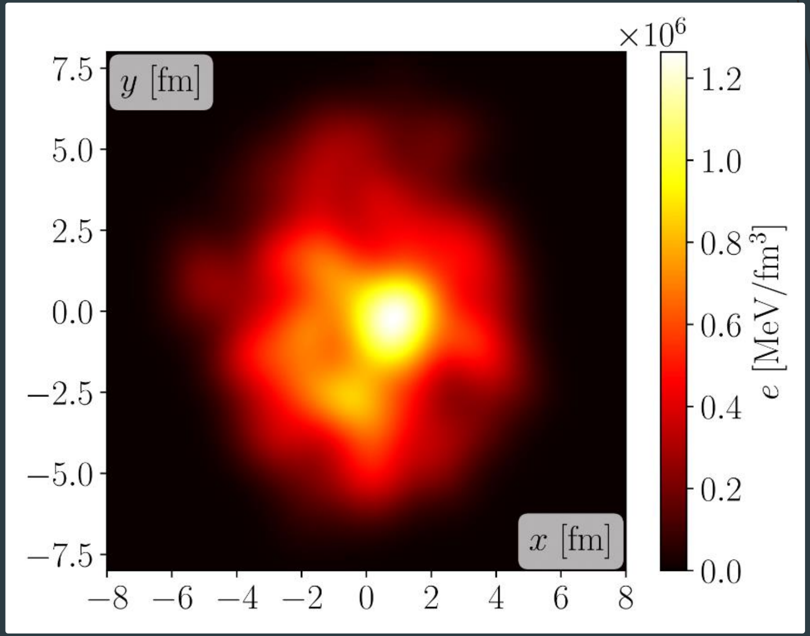
Motivation

- Investigate how the number of scatterings influences the anisotropic flow for a given eccentricity

MC Glauber



Energy density



Initial State

Characterize density by eccentricities

$$p^\mu \partial_\mu f = \mathcal{C}[f]$$

Massless test particles

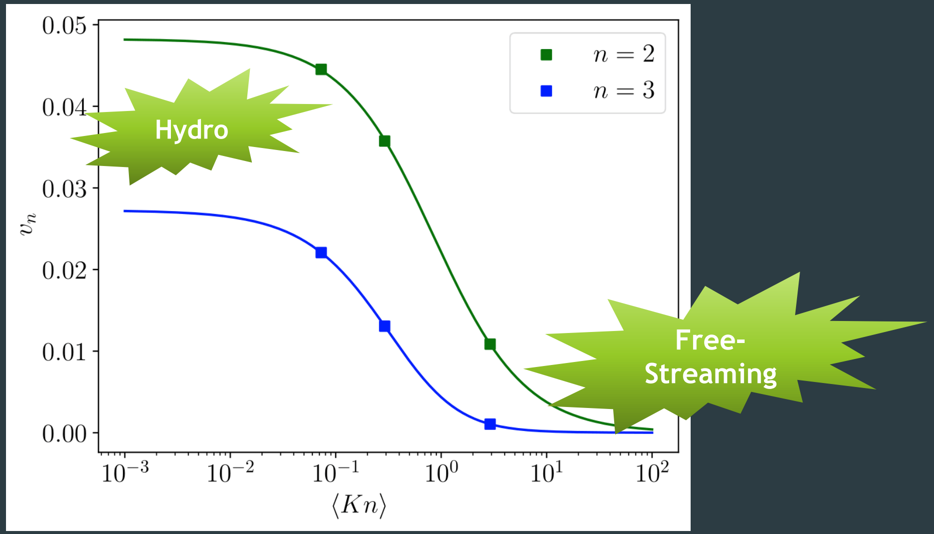
2D covariant transport algorithm by C. Gombeaud & J.-Y. Ollitrault [Phys. Rev. C 77, 054904]

Boltzmann Transport Equation

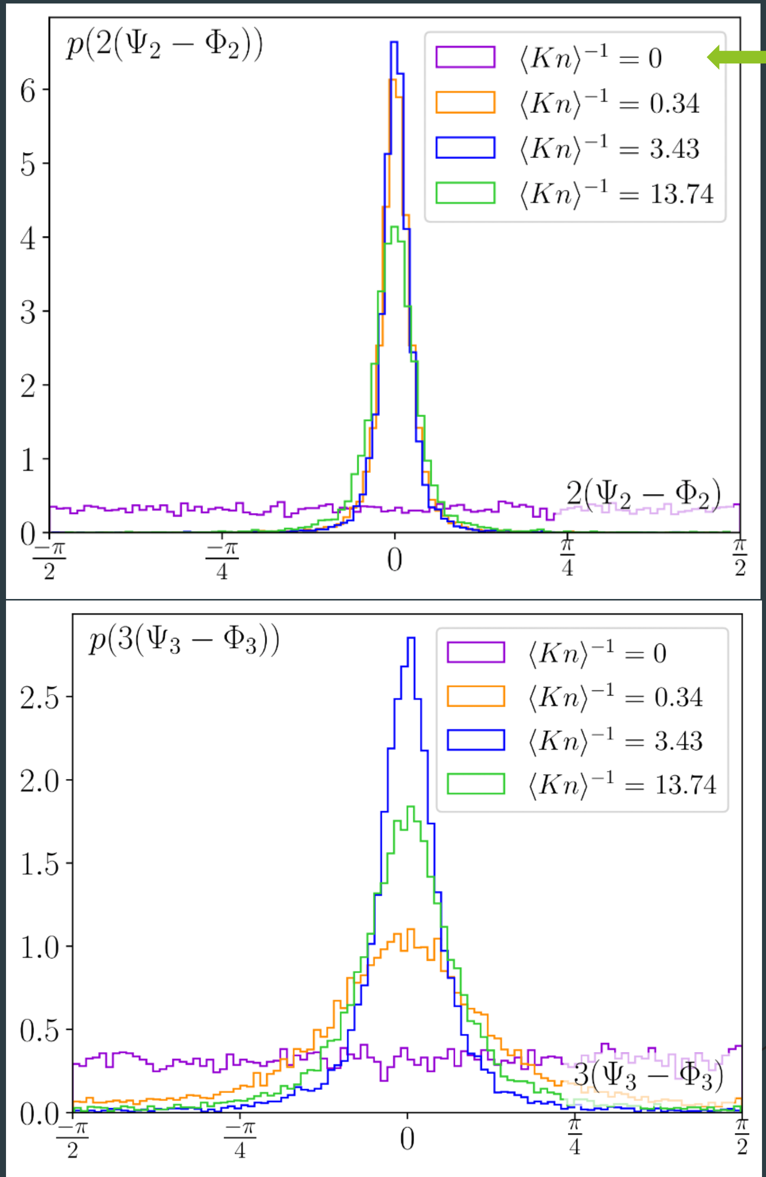
Elastic 2 → 2 scatterings

Event-plane Angle Distributions

$$p(n(\Psi_n - \Phi_n))$$



Faster rise of v_2 with decreasing $\langle Kn \rangle$ than for v_3



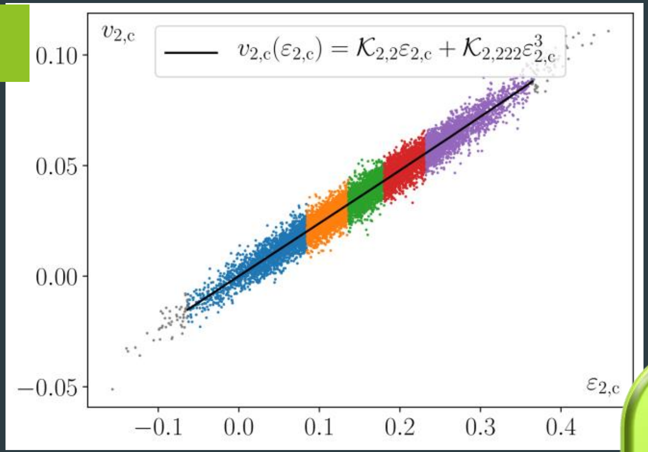
Initial state: uncorrelated

Onset of correlation with inverse $\langle Kn \rangle$ first for n=2, then for n=3

Conditional Probabilities

$$p_{v|\varepsilon}(v_{n,\mathrm{c/s}}|\varepsilon_{n,\mathrm{c/s}})$$

Fit:



$$v_2 = \mathcal{K}_{2,2}\varepsilon_2 + \mathcal{K}_{2,222}\varepsilon_2^3$$

$$v_3 = \mathcal{K}_{3,3}\varepsilon_3$$

Calculate moments centered around fit function in bins

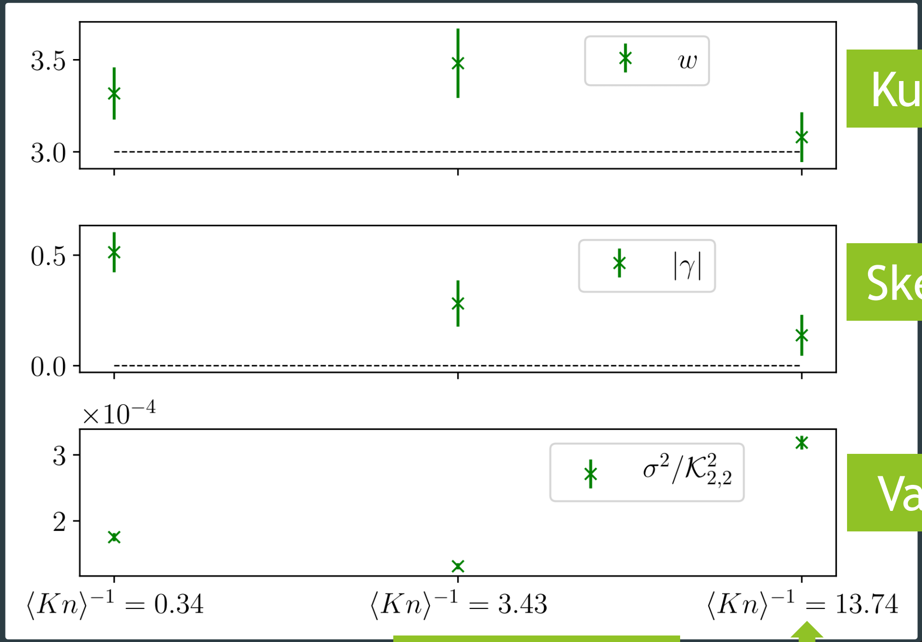
Conditional Probability Distribution

Average moments over eccentricity bins

Conditional Probabilities $p_{v|\varepsilon}(v_{n,\mathrm{c/s}}|\varepsilon_{n,\mathrm{c/s}})$

- Initial state → Gaussian fluctuations (numerical)
- Final state → almost Gaussian fluctuations for many scatterings
- Non-Gaussian fluctuations for low number of scatterings
- Same behavior for all tested impact parameters (b=0,6,9 fm) and for cos/sin parts

Conditional Probability Distribution



Kurtosis

Skewness (modulus)

Variance (scaled)

Hydro limit

Further information

- arXiv:2012.02138 [nucl-th]

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Backup

Initial state

- Pb – Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV
- Mixed scaling: $N(x,y) = (1-\xi)N_{\mathrm{part}} + \xi N_{\mathrm{coll}}$ with $\xi = 0.15$
- Smear energy density with a Gaussian:

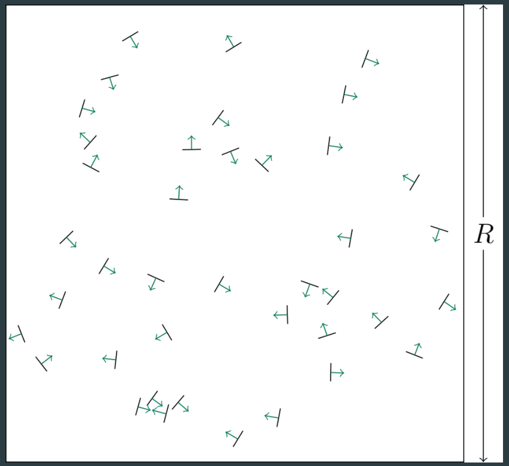
$$R_N = \frac{1}{2}\sqrt{\frac{\sigma_{\mathrm{inel}}^{\mathrm{NN}}}{\pi}}$$

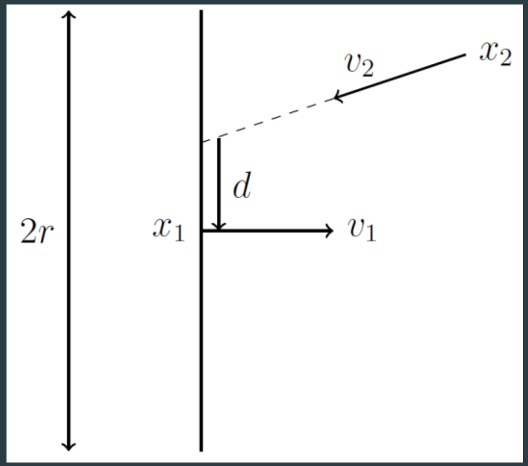
- Standard eccentricities:

$$\varepsilon_n e^{in\Phi_n} = -\frac{\langle r^n e^{in\theta}\rangle}{\langle r^n\rangle}$$

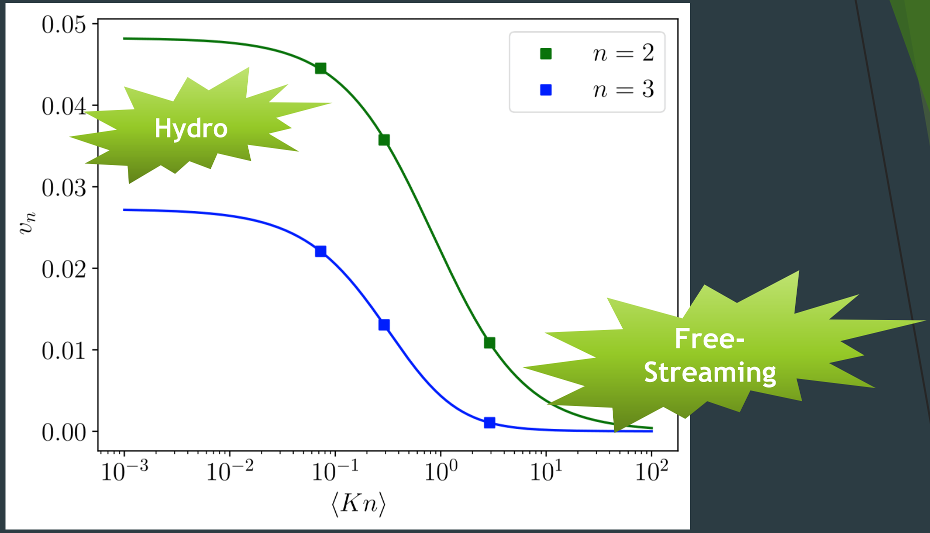
Transport algorithm

- For particlization we use 2D ideal gas equations to convert $e(x,y)$ to $n(x,y)$
- Initial state momentum anisotropy due to finite test particle number: $\mathcal{O}((2N_{\mathrm{p}})^{-1/2})$
- Reduce stat. errors with multiple runs over one initial density
- Isotropic scattering angle in center-of-momentum frame is function of impact parameter





Knudsen number



- Defines the regime of the simulation:

$$Kn \equiv \frac{\lambda_{\mathrm{mfp}}}{R} = \frac{1}{n\sigma R}$$

- Relation for anisotropic flow and Knudsen number:

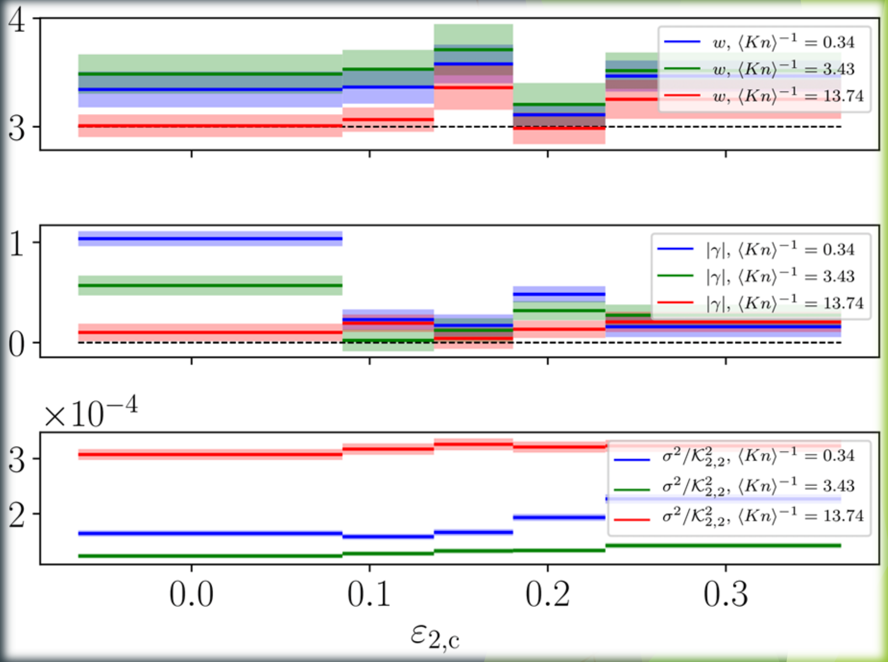
$$v_2 = \frac{v_2^{\mathrm{hydro}}}{1 + \frac{Kn}{Kn_0}} \qquad v_3 = \frac{v_2^{\mathrm{hydro}}(1 + B_3 \cdot Kn)}{1 + (A_3 + B_3) \cdot Kn + C_3 \cdot Kn^2}$$

[Phys. Lett. B 627 (2005) 49]

[Phys. Rev. C 82 (2010) 034913]

Centered moments

- Mean: $$\mu = \frac{1}{N}\sum_{i=1}^{N}\big(v_{n,i}(\varepsilon_{n,i}) - \underbrace{\bar{v}_{n,i}(\varepsilon_{n,i})}_{\hat{=}\ \text{fit value}}\big)$$
- Variance (scaled): $$\frac{\sigma^2}{\mathcal{K}_{n,n}^2} = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{v_{n,i}(\varepsilon_{n,i}) - \bar{v}_{n,i}(\varepsilon_{n,i})}{\mathcal{K}_{n,n}}\right)^2$$
- Skewness: $$\gamma = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{v_{n,i}(\varepsilon_{n,i}) - \bar{v}_{n,i}(\varepsilon_{n,i})}{\sigma}\right)^3$$
- Kurtosis: $$w = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{v_{n,i}(\varepsilon_{n,i}) - \bar{v}_{n,i}(\varepsilon_{n,i})}{\sigma}\right)^4$$



i runs over events in one eccentricity bin

Outlook

- Analysis of v_4 fluctuations → more challenging due to $v_4 = \mathcal{K}_{4,4}\varepsilon_4 + \mathcal{K}_{4,22}\varepsilon_2^2$
- p_{T} - dependence of fluctuations
- Allowing for fluctuations in the impact parameters → Centrality bins