Relative elliptic flow fluctuations at NICA energies

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Outline

- Elliptic flow (v_2) at NICA energies
- Description of Q-Cumulant method for flow measurements
- Study of relative elliptic flow fluctuations
- Performance of v₂ of identified charged hadrons in MPD (NICA)
- Summary and outlook

Phase Diagram of the Strongly-Interacting Matter



- Top RHIC/LHC:
 - validation of the cross over transition leading to the sQGP
 - + access to high T and small $\mu_{\scriptscriptstyle B}$

RHIC-BES/SPS/NICA/FAIR

- access to different systems
- broad domain of the (μ_{B} ,T)-plane

Anisotropic Collective Flow at top RHIC / LHC



- Initial eccentricity (and its attendant fluctuations) ε_n drives momentum anisotropy v_n with specific viscous modulation
- v_1 directed flow, v_2 elliptic flow, v_3 triangular flow
- v_n (p_T, centrality):
 - sensitive to the early stages of collision
 - important constraint for transport properties: EoS, η /s, ζ /s, etc.



Elliptic flow at NICA energies



Taranenko et. al., Phys. Part. Nuclei **51**, 309–313 (2020)



• Strong energy dependence of v2 at $\sqrt{s_{_{NN}}}$ = 3-11 GeV

→ $v_2 \approx 0$ at $\sqrt{s_{_{NN}}} = 3.3$ GeV and negative below

- Lack of differential measurements of v_2 at NICA energies (p_{τ} , centrality, PID,...)
- v₂ is sensitive to the properties of strongly interacting matter:
 - At $\sqrt{s_{_{NN}}}$ = 4.5 GeV pure string/hadronic cascade models (UrQMD, SMASH,...) give similar v₂ signal compared to STAR data
 - At $\sqrt{s_{_{NN}}} \ge 7.7$ GeV pure string/hadronic cascade models underestimate v₂ need hybrid models with QGP phase (vHLLE+UrQMD, AMPT with string melting,...)

Q-Cumulant method for elliptic flow measurements

$$v_{n} = \langle \cos n(\varphi - \Psi_{n}) \rangle \qquad Q_{n} \equiv \sum_{i=1}^{M} e^{in\phi_{i}} \qquad (1)$$

$$\langle 2 \rangle_{2} = \frac{|Q_{2}|^{2} - M}{M(M-1)} \approx v_{2}^{2} + \delta \qquad \langle 4 \rangle_{2} = \frac{|Q_{2}|^{4} + |Q_{4}|^{2} - 2|Q_{4}Q_{2}^{*}Q_{2}^{*}| - 4M(M-2)|Q_{2}|^{2} + 2M(M-3)}{M(M-1)(M-2)(M-3)} \approx v_{2}^{4} + 4v_{2}^{2}\delta + 2\delta^{2} \qquad (2)$$

$$\mathbf{v}_{2}\{2\} = \sqrt{\langle \langle 2 \rangle \rangle} \qquad \mathbf{v}_{2}\{4\} = \sqrt{2\langle \langle 2 \rangle \rangle^{2} - \langle \langle 4 \rangle \rangle} \qquad (3)$$

- δ nonflow contribution:
- resonance decays
 ^{K⁰}
 ^{π[−]}
 ^{π[−]}
 jets
- Higher order correlators: <6> and <8> were calculated using recursive algorithm in Phys. Rev. C 89, 064904

• Elliptic flow fluctuations:

 $\sigma_{\mathbf{v}_2}^2 = \langle \mathbf{v}_2^2 \rangle - \langle \mathbf{v}_2 \rangle^2$ (4)

• The difference between $v_2\{k\}$: Fluctuations enhance $v_2\{2\}$ and suppress $v_2\{k=4,6,8\}$ compared to $\langle v_2 \rangle$: $v_2\{2\}\approx \langle v_2 \rangle + \frac{1}{2} \frac{\sigma_{v_2}^2}{\langle v_2 \rangle}$ (5) $v_2\{4\}\approx v_2\{6\}\approx v_2\{8\}\approx \langle v_2 \rangle - \frac{1}{2} \frac{\sigma_{v_2}^2}{\langle v_2 \rangle}$ (6)

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Small value for the v_2 {4}/ v_2 {2} ratio corresponds to large fluctuation

- Relative v₂ fluctuations (v₂{4}/v₂{2}) observed by STAR experiment can be reproduced both in the string/cascade models (UrQMD, SMASH) and hybrid model (AMPT with string melting, vHLLE+UrQMD)
- Dominant source of v₂ fluctuations: participant eccentricity fluctuations in the initial geometry







Elliptic flow fluctuations show weak dependence on particle species

MPD Experiment at NICA



Multi-Purpose Detector (MPD) Stage 1

0.2< p_r<3 GeV/c

Performance study of v2 of pions and protons in MPD



Reconstructed and generated v_2 of pions and protons have a good agreement for all methods

Summary and outlook

• v₂ at NICA energies shows strong energy dependence:

- at $\sqrt{s_{NN}}$ = 4.5 GeV, v₂ from UrQMD, SMASH are in a good agreement with the experimental data
- → at $\sqrt{s_{NN}} \ge 7.7$ GeV, UrQMD & SMASH underestimate v_2 need hybrid models with QGP phase
- lack of existing differential measurements of v₂ (p_T, centrality, PID, ...)
- Relative elliptic flow fluctuations:
 - dominant source: eccentricity fluctuations of participants in the initial geometry
 - weak dependence on particle species
- Feasibility study for elliptic flow in MPD:
 - v₂ of identified charged hadrons: results from reconstructed and generated data are in a good agreement for all methods
- Outlook:
 - Increase of statistics of different models for more detailed v₂ fluctuation study

Thanks for your attention!

Backup



Au+Au, Ch. hadrons, 10-40%



Elliptic flow fluctuations show no p_{τ} dependence at low p_{τ} range except for SMASH model

Setup, event and track selection



Performance study of v2 of inclusive charged hadrons in MPD



Reconstructed (reco) and generated (true) v_2 values are in a good agreement for all methods

Non-uniform acceptance



How robust the future measurements against non-uniform acceptance?

Acceptance correction



The applied acceptance corrections eliminated the influence of non-uniform acceptance

Au+Au vs. Bi+Bi collisions for reconstructed data in MPD



Expected small difference between colliding systems

Eccentricity: Bi+Bi vs Au+Au



UrQMD model predicts small difference between ϵ_n of Au+Au and Bi+Bi 22