

# Anisotropic flow decorrelation in heavy-ion collisions at RHIC-BES energies with 3D event-by-event viscous hydrodynamics

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References: Phys. Rev. C 103, 034902 (2021) and Phys. Rev. C 104, 014904 (2021)

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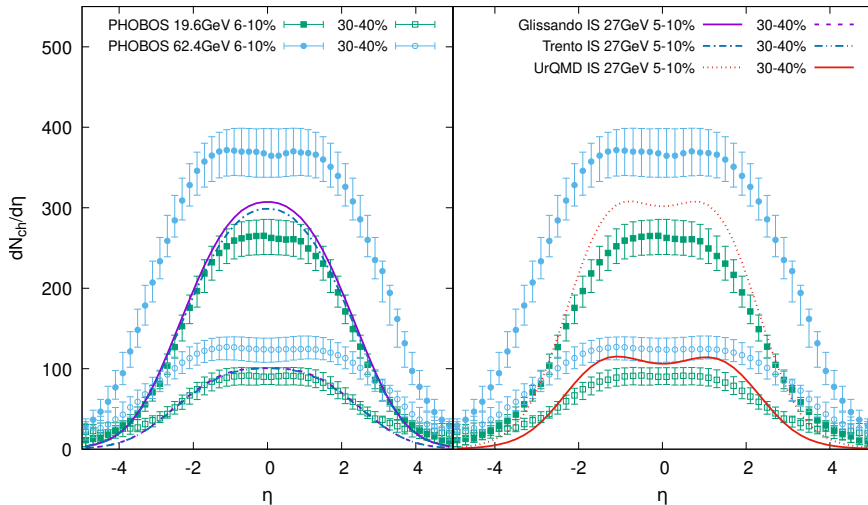


- Longitudinal structure of anisotropic flows brings additional constraints on the initial state and/or transport coefficients of the QGP
- At RHIC-BES energies, flow decorrelation is just starting to be researched
- So far, there are only preliminary results from STAR at  $\sqrt{s_{NN}} = 27$  and 200 GeV [Nucl. Phys. A 982, 403 (2019), Nucl. Phys. A 1005, 121783 (2021)]

- We use hybrid model which have four steps
  - 3D initial state - 3 possibilities:
    - UrQMD [Prog. Part. Nucl. Phys. 41, 255 (1998)]
    - GLISSANDO2 [Comput. Phys. Commun. 185, 1759 (2014)] extended to 3D
    - T<sub>R</sub>ENTo [Phys. Rev. C 92, 011901 (2015)] extended to 3D, with parameter  $p = 0 \Rightarrow T_R = \sqrt{T_A T_B}$
  - vHLLE - (3+1)-dimensional viscous hydrodynamic model for hot and dense stage [Comput. Phys. Commun. 185, 3016 (2014)]
  - Cooper-Frye prescription for particlization
  - Hadronic rescatterings and resonance decays using the UrQMD cascade
  - There is a finite baryon and electric charge density at all stages

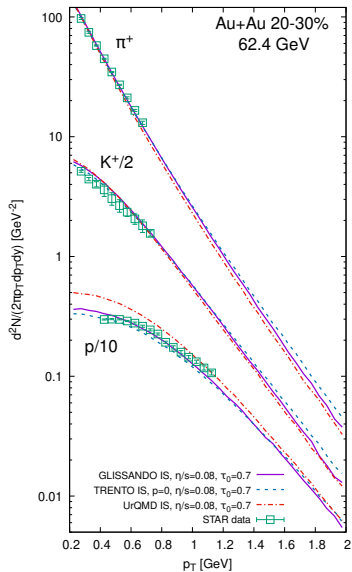
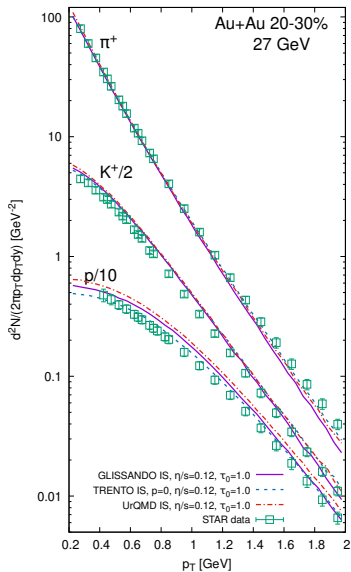
- GLISSANDO2 and T<sub>R</sub>ENTo are extended to longitudinal direction following work of Bozek [Phys. Rev. C 85, 044910 (2012)]
  - Parameters of longitudinal expansion were tuned against  $dN/d\eta$ ,  $p_T$  spectra and  $dN/dy$  of net protons
  - Total energy and total baryon charge are fixed to those of the participants
  - For baryon number we use superposition of two Gaussian distributions
- We simulated Au+Au collisions at energies  $\sqrt{s_{NN}} = 27, 62.4$  and 200 GeV
- For each run we simulated 3000 hydrodynamic simulations and from each we generated 500 events at the particlization step

# Charged Hadron Pseudorapidity Distributions



●  $\sqrt{s_{NN}} = 27 \text{ GeV}$ , centralities 5-10% and 30-40%

# Transverse Momentum Spectra



- Hadron distribution in azimuthal angle can be written as a Fourier series

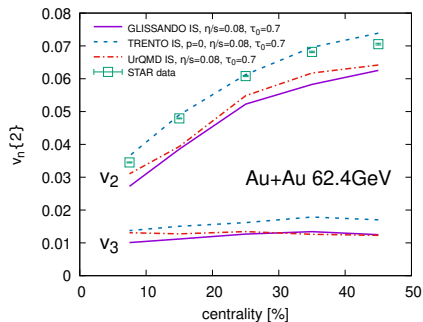
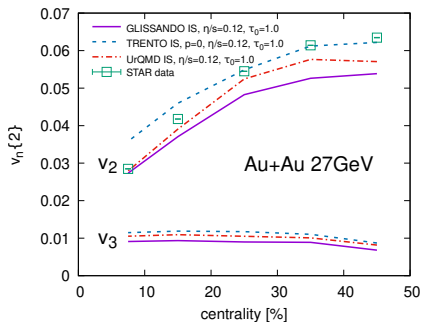
$$\frac{d^3N}{p_T dp_T dy d\phi} = \frac{1}{2\pi} \frac{d^2N}{p_T dp_T dy} \left( 1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_n)) \right)$$

- The flow coefficients can then be computed from

$$v_n = \frac{\int d\phi \cos(n(\phi - \Psi_n)) \frac{d^3N}{p_T dp_T dy d\phi}}{\int d\phi \frac{d^3N}{p_T dp_T dy d\phi}}$$

- To calculate flow coefficients we used event plane method [Phys. Rev. C 58, 1671 (1998)] and 2-particle cumulant method [Phys. Rev. C 83, 044913 (2011)]

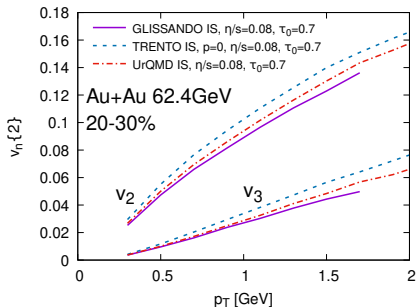
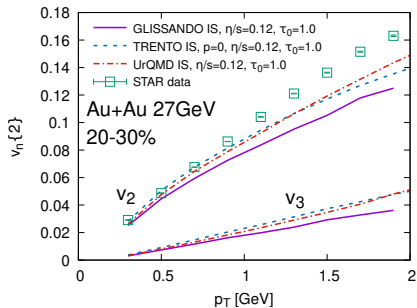
# Elliptic Flow as Function of Centrality



- models with Glissando and UrQMD IC underestimate the  $p_T$ -integrated elliptic flow

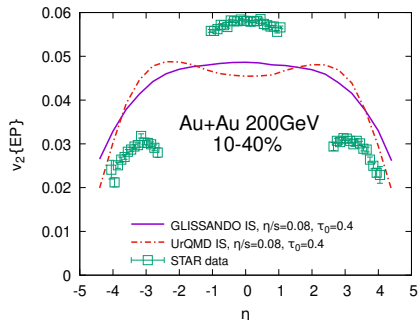
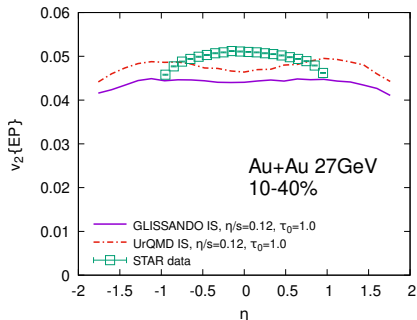


# Elliptic Flow as Function of Transverse Momentum



- All three IS underestimate the elliptic flow at large  $p_T$

# Elliptic Flow as Function of Pseudorapidity

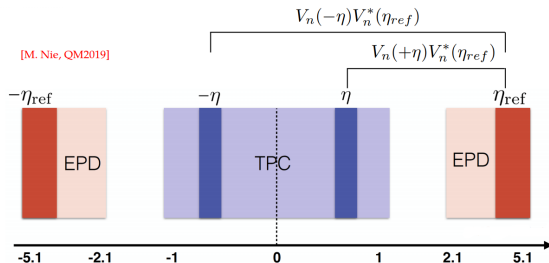


- Ballpark value is reproduced, but not the shape

# Decorrelation

- Longitudinal fluctuations can lead to decorrelations of anisotropic flows along the pseudorapidity direction
- We use flow vector  $\mathbf{V}_n = v_n e^{in\Psi_n}$  to calculate factorisation ratio
- The factorisation ratio is defined

$$r_n(\eta, \eta_{ref}) = \frac{\langle \mathbf{V}_n(-\eta) \mathbf{V}_n^*(\eta_{ref}) \rangle}{\langle \mathbf{V}_n(+\eta) \mathbf{V}_n^*(\eta_{ref}) \rangle} = \frac{\langle v_n(-\eta) v_n(\eta_{ref}) \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{ref})) \rangle}{\langle v_n(+\eta) v_n(\eta_{ref}) \cos n(\Psi_n(+\eta) - \Psi_n(\eta_{ref})) \rangle}$$



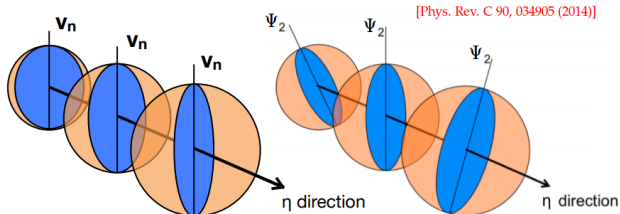
- $r_n(\eta) = 1 \Rightarrow$  no decorrelation
- $r_n(\eta) < 1 \Rightarrow$  decorrelation

# Magnitude and Angle Decorrelation

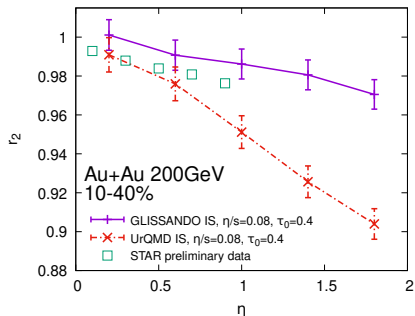
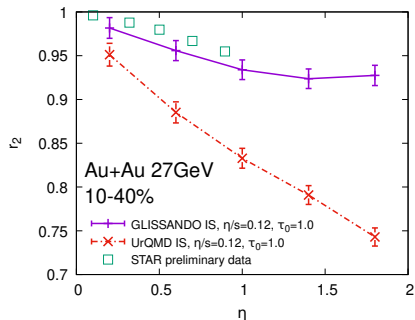
- The factorisation ratio can be split to magnitude and angle decorrelation

$$r_n^v(\eta) = \frac{\langle v_n(-\eta)v_n(\eta_{ref}) \rangle}{\langle v_n(+\eta)v_n(\eta_{ref}) \rangle}$$

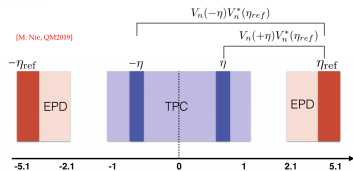
$$r_n^\Psi(\eta) = \frac{\langle \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{ref})) \rangle}{\langle \cos n(\Psi_n(+\eta) - \Psi_n(\eta_{ref})) \rangle}$$



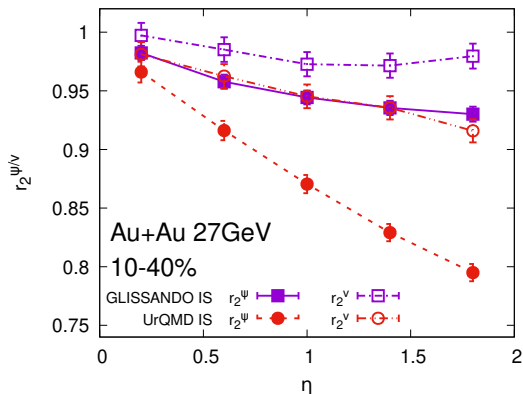
# Results of Flow Decorrelation



- UrQMD IS results in significantly stronger decorrelation



# Angle and Magnitude Decorrelation



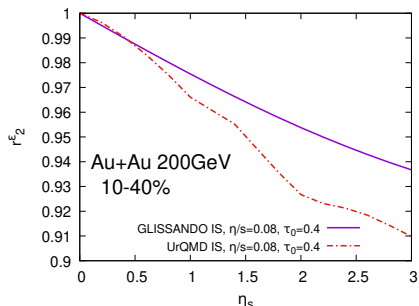
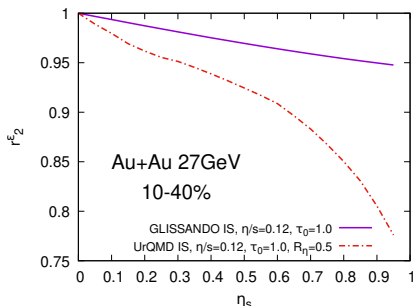
- The flow decorrelation is mainly caused by flow angle decorrelation

# Initial State Eccentricity Decorrelation

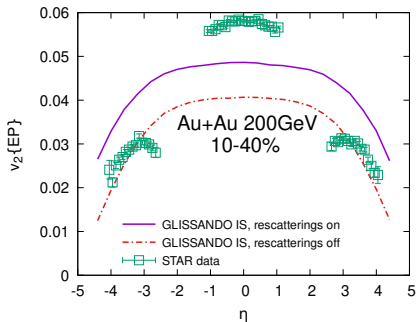
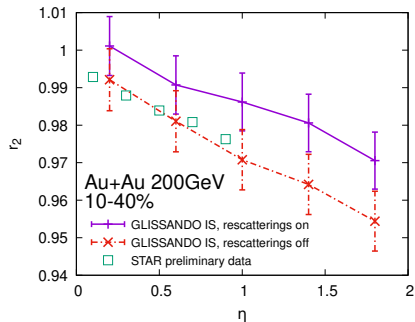
- Analogously, we can define decorrelation of initial state spatial eccentricity

$$r_n^\epsilon(\eta_s) = \frac{\langle \epsilon_n(-\eta_s) \epsilon_n(\eta_{s,\text{ref}}) \cos[n(\Psi_n(-\eta_s) - \Psi_n(\eta_{s,\text{ref}}))] \rangle}{\langle \epsilon_n(\eta_s) \epsilon_n(\eta_{s,\text{ref}}) \cos[n(\Psi_n(\eta_s) - \Psi_n(\eta_{s,\text{ref}}))] \rangle}$$

- where  $\epsilon_n e^{in\Psi_n} = \frac{\int e^{in\phi} r^n \rho(\vec{r}) d\phi r dr}{\int r^n \rho(\vec{r}) d\phi r dr}$



# Impact of Final-State Rescatterings



- Final-state rescatterings can bring the factorisation ratio closer to the experimental data, however it also reduces the already underestimated elliptic flow



# Summary

- We presented the elliptic flow and flow decorrelation in Au-Au collisions at  $\sqrt{s_{\text{NN}}} = 27, 62.4$  and 200 GeV in 3-dimensional viscous hydrodynamic model with UrQMD, 3D GLISSANDO and 3D T<sub>R</sub>ENTo initial states
- Flow decorrelation at  $\sqrt{s_{\text{NN}}} = 27$  GeV is a first calculation of a kind in a hydrodynamic model
- At midrapidity, model with T<sub>R</sub>ENTo IS ( $p = 0$ ) best describes the data
- We observe that the flow decorrelation is mainly caused by flow angle decorrelation, which is in agreement with other studies [Phys. Rev. C 98, 024913 (2018), Phys. Rev. C 97, 034913 (2018)]
- The model with UrQMD IS overestimates the decorrelation, which is rooted in much stronger decorrelation of initial state eccentricity
- References: Phys. Rev. C 103, 034902 (2021) and Phys. Rev. C 104, 014904 (2021)

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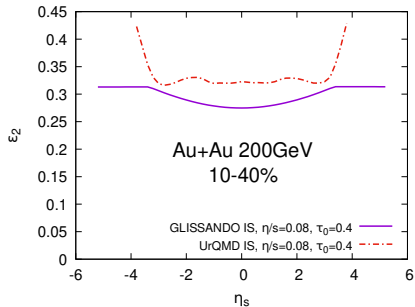
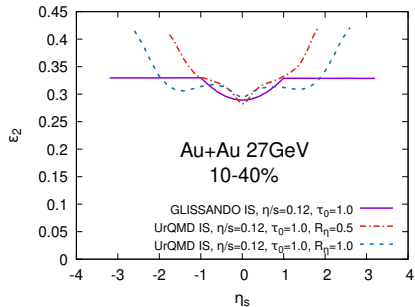


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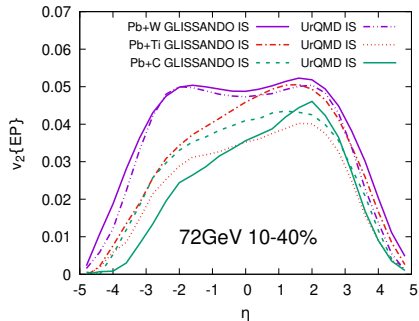
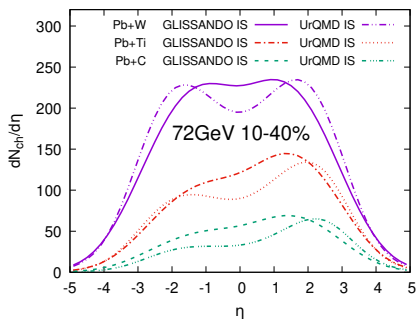


# Backup Slides

# Initial-State Eccentricity



# Predictions for Experiment AFTER@LHC



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