Fluctuations and correlations of the anisotropic flow

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Motivation

- azimuthal anisotropies of hadron transverse momentum distribution $\Leftarrow$ anisotropies in the initial conditions
- measurable access to the initial state—profile of the energy-momentum deposition
- initial states change from event to event $\Rightarrow$ e-by-e fluctuations of anisotropic flow
- Here: initial transverse energy-momentum profile depends on (space-time) rapidity
  $\Rightarrow$ (pseudo-)rapidity dependence of anisotropic flow
- breaking of Bjorken symmetry (even at high collision energies)
  $\Rightarrow$ information about energy deposition into the initial state
  $\Rightarrow$ discriminatory power over initial state models
- Test of initial conditions also at lower collision energies
- This report: Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 27$ GeV

The hybrid model setup

- Initial conditions
  - Glauber Monte Carlo: GLISSANDO 2
    [M. Rybczyński, G. Stefanek, W. Broniowski, P. Bożek, Comp.Phys.Commun. 185 (2014) 1579]
  - uRQMD
    [S.A.Bass, et al., Prog. Part. Nucl. Phys. 41 (1998) 225. M. Bleicher, et al., J. Phys. G: Nucl. Part. Phys. 25 (1999) 1859]
- hydrodynamic evolution: 3D viscous model vHLLE
  [Iu. Karpenko, P. Huovinen, M. Bleicher, Comput.Phys.Commun. 185 (2014) 3016]
- hadronic phase simulated by transport model: uRQMD

GLISSANDO – extension to 3rd dimension

- original GLISSANDO: entropy density in transverse plane according to the mixed model

$$s(x, y, \quad) = \kappa \sum_i \qquad \left[(1-\alpha) + N_i^{\mathrm{coll}} \alpha \right] \exp\left(- \frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma^2} \right)$$

GLISSANDO – extension to 3rd dimension

- original GLISSANDO: entropy density in transverse plane according to the mixed model
- space-time rapidity profile $f_\pm(\eta_s)$ added
  P. Bożek, W. Broniowski, Phys. Rev. C 85 (2012) 044910

$$s(x, y, \eta_s) = \kappa \sum_i f_\pm(\eta_s) \left[(1-\alpha) + N_i^{\mathrm{coll}}\alpha\right] \exp\left(-\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma^2}\right)$$

$$\begin{aligned} f_\pm(\eta_s) &= \frac{\eta_{\mathrm{M}} \pm \eta_s}{2\eta_{\mathrm{M}}} H(\eta_s) \quad \text{for} \quad |\eta_s| < \eta_{\mathrm{M}} \\ H(\eta_s) &= \exp\left(-\frac{(|\eta_s| - \eta_0)^2 \Theta(|\eta_s| - \eta_0)}{2\sigma_\eta^2}\right) \end{aligned}$$

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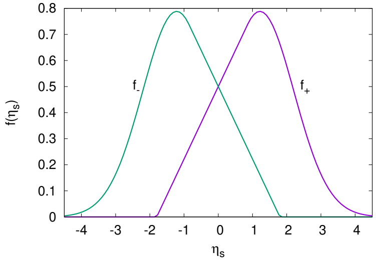
$$f_\pm(\eta_s) = \frac{\eta_{\mathrm{M}} \pm \eta_s}{2\eta_{\mathrm{M}}} H(\eta_s) \quad \text{for} \quad |\eta_s| < \eta_{\mathrm{M}}$$

$$H(\eta_s) = \exp\left(-\frac{(|\eta_s| - \eta_0)^2 \Theta(|\eta_s| - \eta_0)}{2\sigma_\eta^2}\right)$$



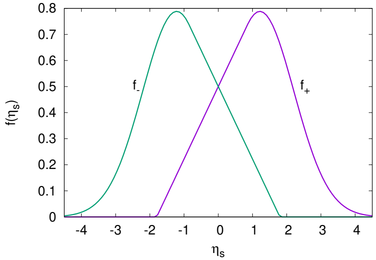
GLISSANDO – extension to 3rd dimension

- original GLISSANDO: entropy density in transverse plane according to the mixed model

$$s(x,y,\eta_s) = \kappa \sum_i f_\pm(\eta_s) \left[(1-\alpha) + N_i^{\text{coll}}\alpha\right] \exp\left(-\frac{(x-x_i)^2+(y-y_i)^2}{2\sigma^2}\right)$$

$$f_\pm(\eta_s) = \frac{\eta_{\rm M} \pm \eta_s}{2\eta_{\rm M}} H(\eta_s) \quad \text{for} \quad |\eta_s| < \eta_{\rm M}$$

$$H(\eta_s) = \exp\left(-\frac{(|\eta_s|-\eta_0)^2 \Theta(|\eta_s|-\eta_0)}{2\sigma_\eta^2}\right)$$



Baryon number deposition:

$$n_B(x,y,\eta_s) = \kappa_B \sum_i \exp\left(-\frac{(\eta_B \pm \eta_s)^2}{2\sigma_B^2}\right) \exp\left(-\frac{(x-x_i)^2+(y-y_i)^2}{2\sigma^2}\right)$$

uRQMD initial conditions

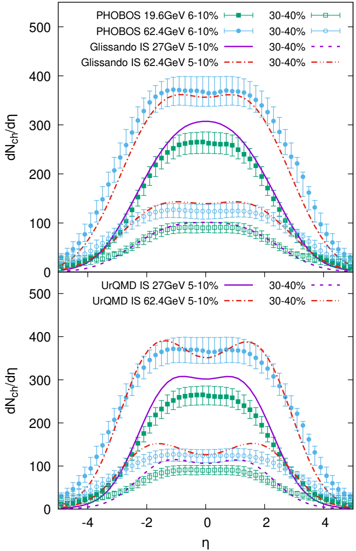
- energy, momentum, baryon number and charge extracted from the participating hadrons
- smeared among the hydrodynamic cells

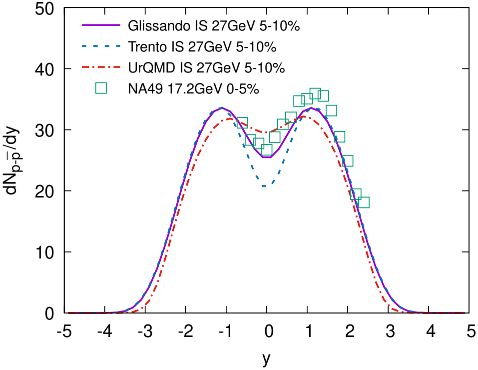
$$w \propto \exp\left(-\frac{(x_h - x_c)^2}{R_T^2} - \frac{(y_h - y_c)^2}{R_T^2} - \gamma^2 \tau_0^2 \frac{(\eta_h - \eta_c)^2}{R_\eta^2}\right)$$

Hydro and transport part

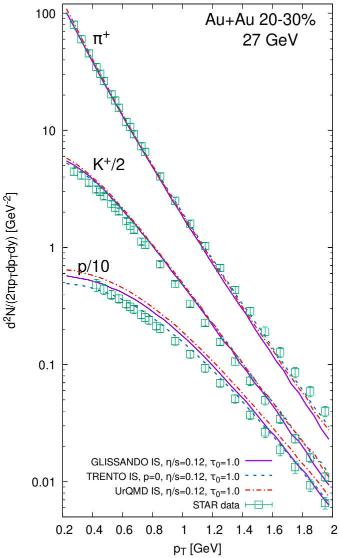
- Hydrodynamics: vHLLE
  - Muller-Israel-Stewart equations
  - chiral EoS (crossover)
- particlisation
  - Cooper-Frye sampling of hadron production
  - viscous corrections included
  - oversampling
- transport model: uRQMD

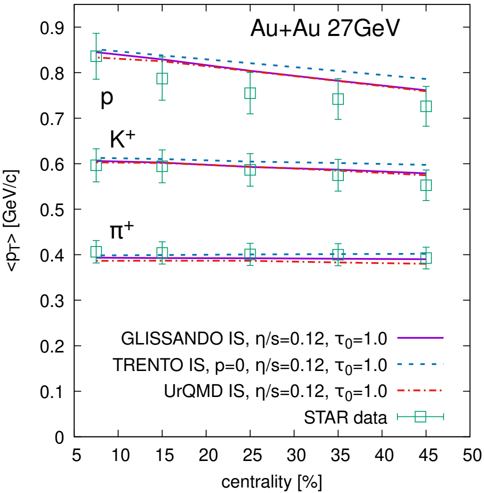
Tuning of the model—fitting basic observables—rapidity spectra



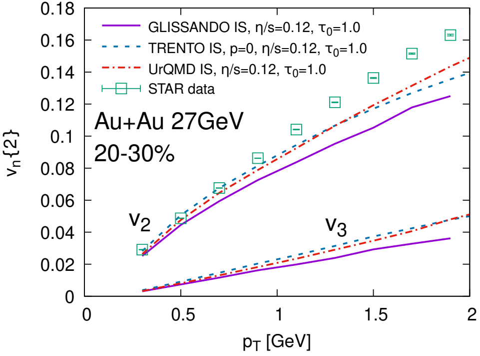


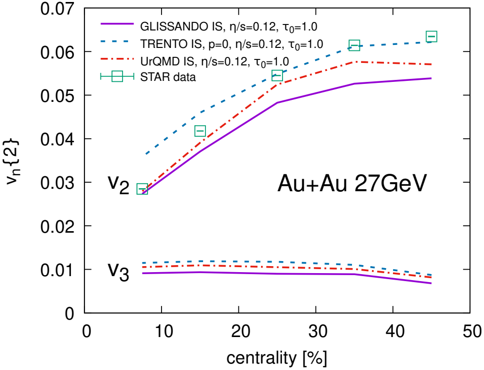
Tuning of the model—fitting basic observables—p_T spectra



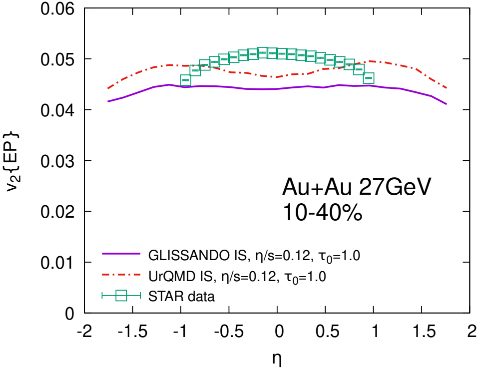


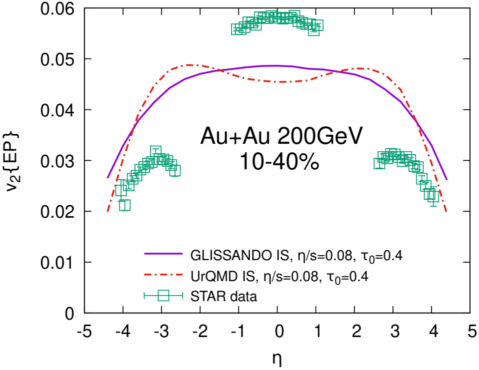
Tuning of the model—fitting basic observables—elliptic flow





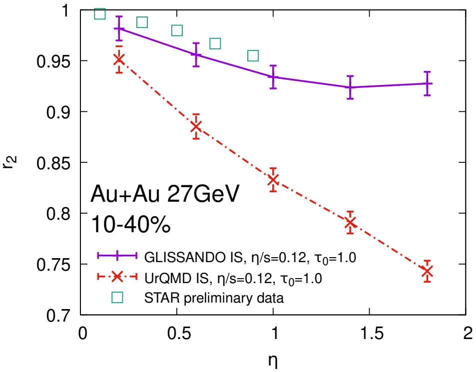
Results: rapidity dependence of the elliptic flow

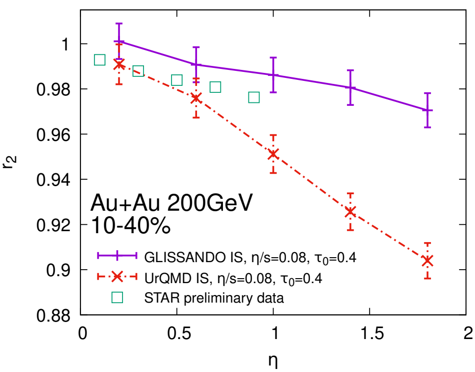




Longitudinal decorrelation of anisotropic flow

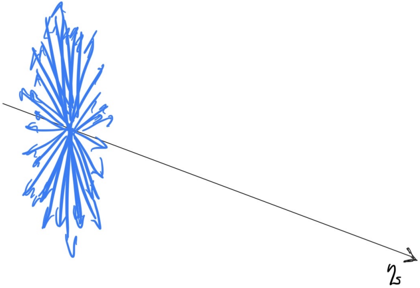
$$r_n(\eta) = \frac{\langle q_n(-\eta) q_n^*(\eta_{\rm ref})\rangle}{\langle q_n(\eta) q_n^*(\eta_{\rm ref})\rangle}.$$





The mechanism of decorrelation

varying amplitude of the flow anisotropy



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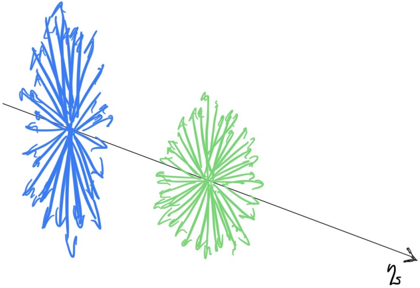

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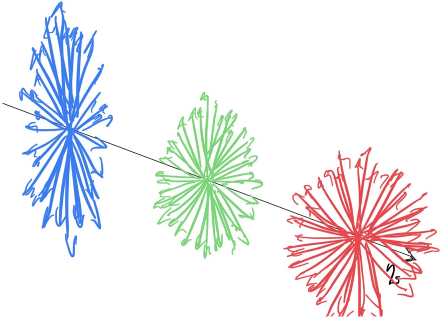

$$r_n^v(\eta) = \frac{\langle v_n(-\eta) v_n(\eta_{\rm ref}) \rangle}{\langle v_n(\eta) v_n(\eta_{\rm ref}) \rangle}$$

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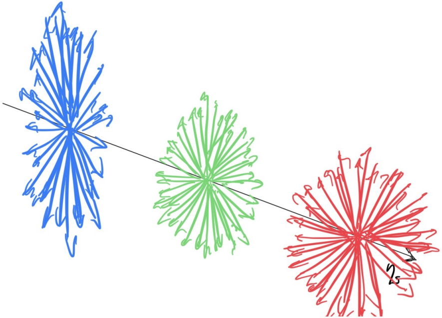

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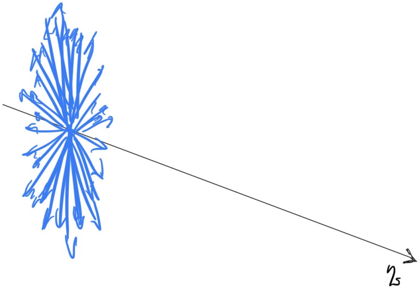

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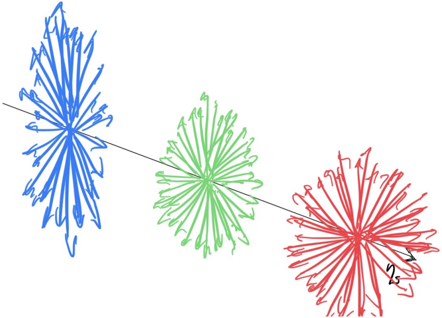
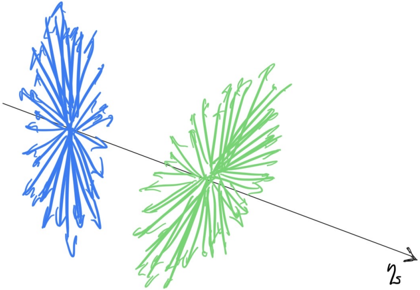


varying angle of the flow anisotropy



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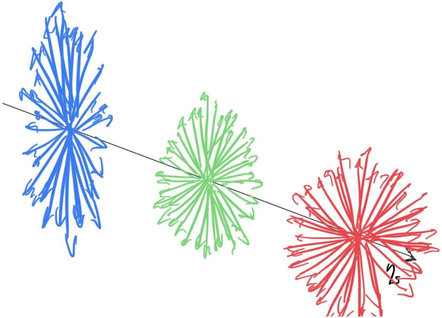

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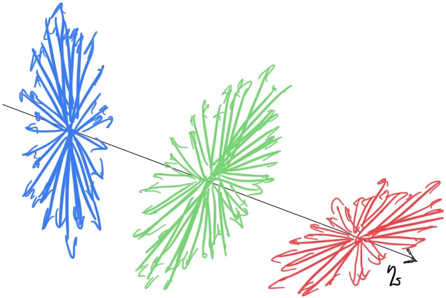
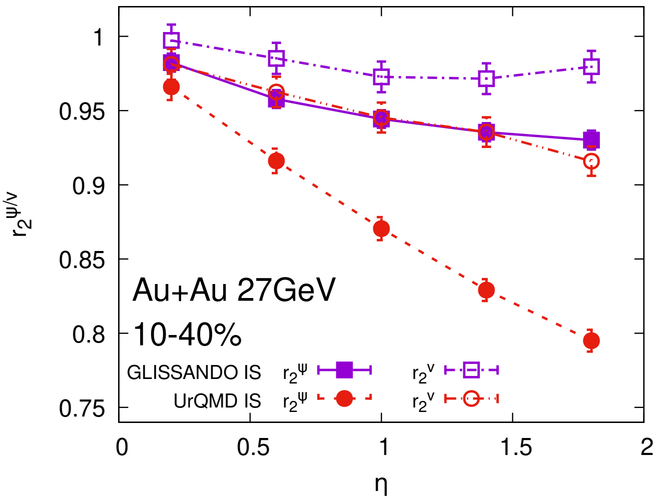


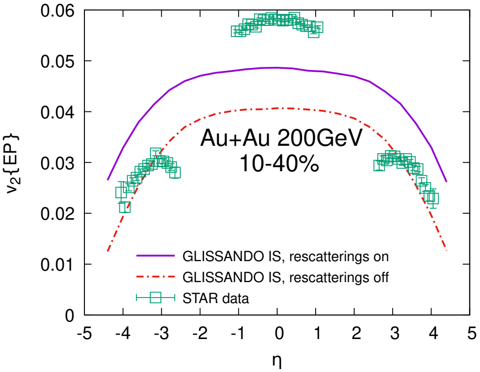
$$r_n^v(\eta) = \frac{\langle v_n(-\eta) v_n(\eta_{\rm ref})\rangle}{\langle v_n(\eta) v_n(\eta_{\rm ref})\rangle}$$

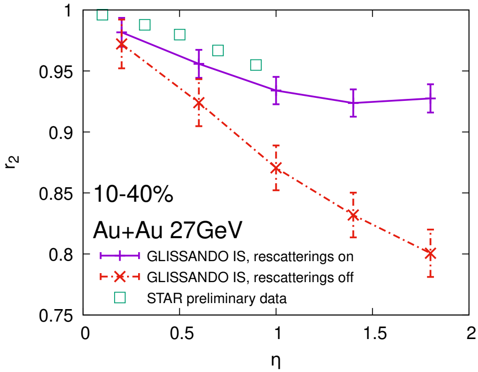
$$r_n^\Psi(\eta) = \frac{\langle \cos[n\,(\Psi_n(-\eta) - \Psi_n(\eta_{\rm ref}))]\rangle}{\langle \cos[n\,(\Psi_n(\eta) - \Psi_n(\eta_{\rm ref}))]\rangle}$$

The mechanism of anisotoropy decorrelation



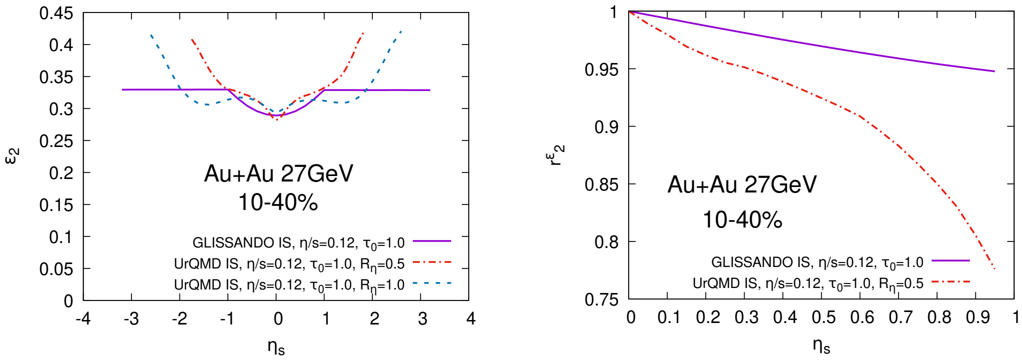
The effect of rescattering





Decorrelation in the initial conditions

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



Decorrelation in the initial conditions

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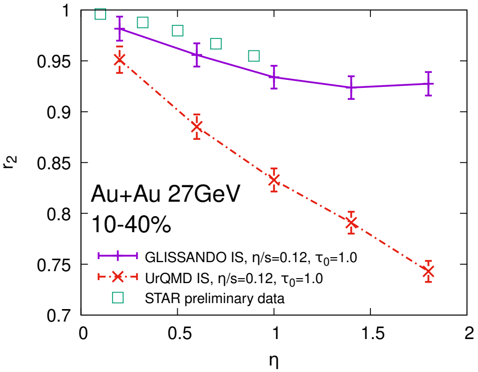
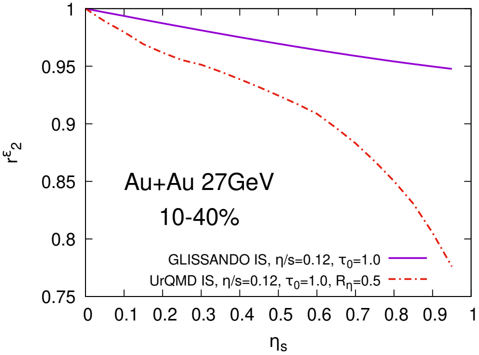
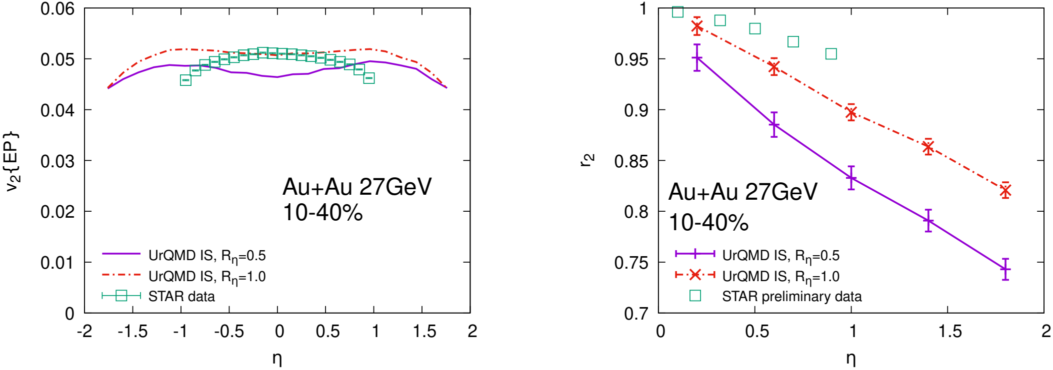




The effect of smearing in uRQMD initial conditions



Conclusions

- longitudinal flow anisotropy decorrelation seems to prefer Glauber MC over uRQMD initial conditions for Au+Au collisions at 27 GeV
  - mainly caused by flow angle decorrelations (like at 200 GeV)
  - corresponds to decorrelation of the initial conditions
  - too small rapidity smearing in uRQMD initial conditions
- Outlook: look at decorrelation in transverse momentum
  [ALICE collab: arXiv:2206.04574]

References:

J. Cimerman, *et al.*, Phys.Rev.C 104 (2021) 014904

J. Cimerman, *et al.*, Phys.Rev.C 103 (2021) 034902

BACKUP

Values of parameters

$\sqrt{s_{NN}}$ [GeV]	27	72	200
τ_0 [fm/c]	1.0	0.7	0.4
η/s	0.12	0.08	0.08
η_0	$0.89 - 0.2\chi$	1.8	1.5
σ_η	$1.09 - 0.2\chi$	0.7	1.4
η_M	1.0	1.8	3.36
η_B	$1.33 - 0.32\chi$	2.2	
σ_B	$0.79 - 0.21\chi$	1.0	