THE UNIVERSITY OF ILLINOIS AT CHICAGO

STAR

Beam-energy dependence of flow correlations in heavy-ion collisions

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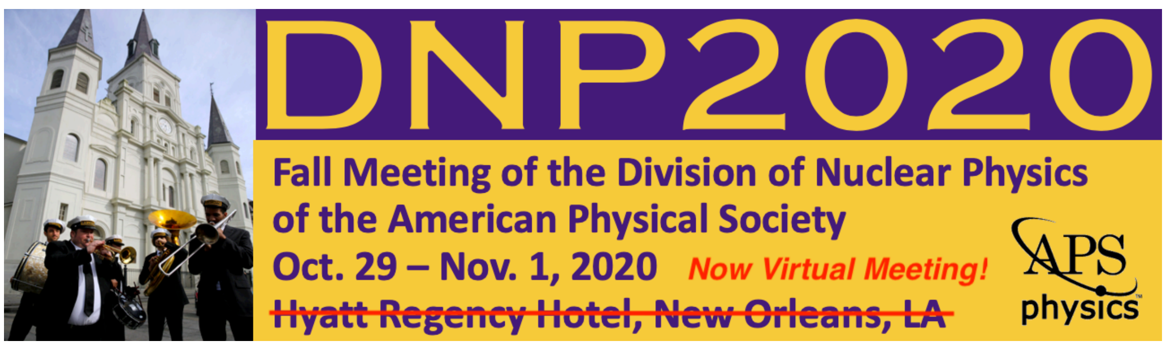

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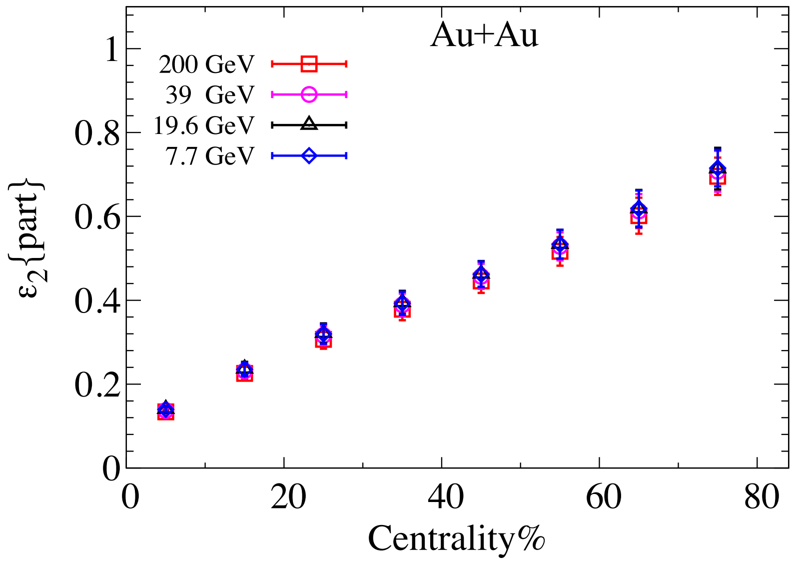
Outline

- Introduction
  - ✓ Motivation
  - ✓ The STAR experiment
  - ✓ Analysis methods
- Results
  - ✓ Beam-energy dependance of flow correlations
  - ✓ Beam-energy dependance of transverse momentum-flow correlations
- Conclusion

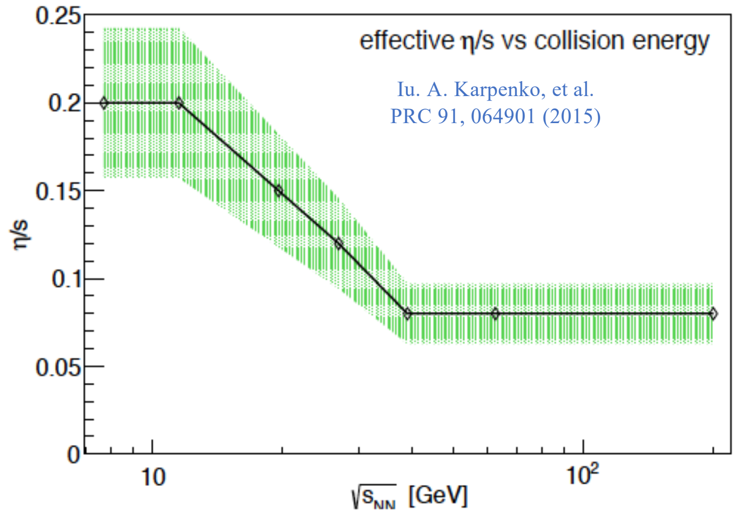
Motivation

- Higher order flow harmonics are sensitive probes for $\frac{\eta}{s}(T)$ due to the enhanced viscous response
- The beam-energy dependence of flow (p_T-flow) correlations will reflect the respective roles of ϵ_n and its fluctuations and $\frac{\eta}{s}$ as a function of T and μ_B

Beam energy dependence for a given collision system:



Initial-state ε_2 is approximately energy independent

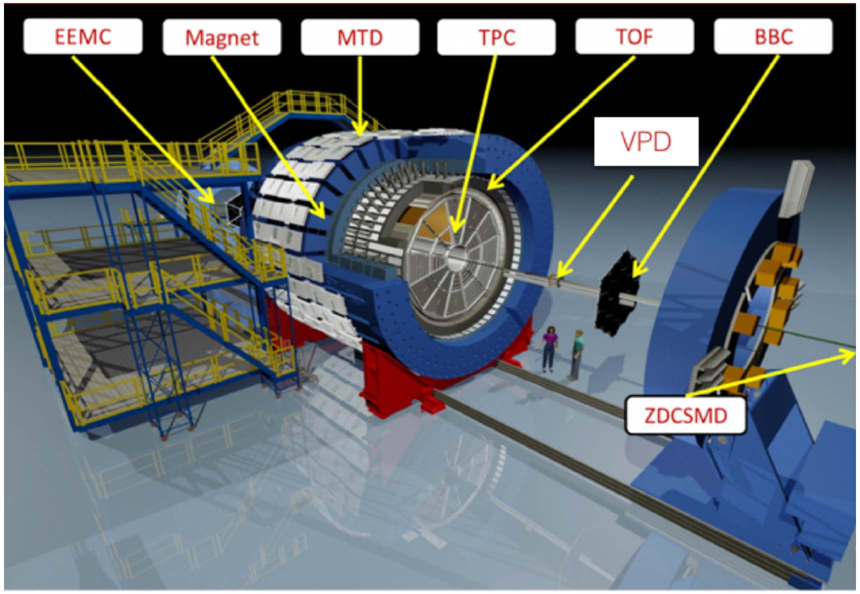


Viscous attenuation ($\propto \frac{\eta}{s}(T)$) is beam energy dependent

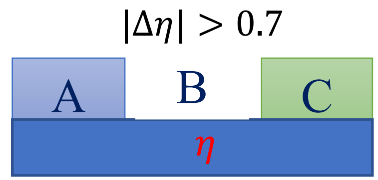
Experimental Setup and Data Analysis

- Data set:
  - ✓ Au +Au BES-I $\sqrt{s_{NN}} = 27 - 200$ GeV
- Time Projection Chamber:
  Tracking of charged particles with:
  - ✓ Full azimuthal coverage
  - ✓ $|\eta| < 1$ coverage

The STAR experiment at RHIC



Analysis Method



J. Jia, M. Zhou, A. Trzupek, PRC 96 034906 (2017)

❖ Flow correlations

$$v_n^{Inclusive} = \left\langle\left\langle \cos(n\varphi_1^A - n\varphi_2^C)\right\rangle\right\rangle^{1/2}$$

$$v_{n+2}^{Non\ Linear} = \left\langle\left\langle \cos((n+2)\varphi_1^A - 2\varphi_2^C - n\varphi_3^C)\right\rangle\right\rangle / \sqrt{\langle v_2^2 v_n^2 \rangle}$$

Assume the orthogonality between linear and non-linear contributions

$$v_{n+2}^{Linear} = \sqrt{\left(v_{n+2}^{Inclusive}\right)^2 - \left(v_{n+2}^{Non\ Linear}\right)^2}$$

➢ EP angular correlations

Weak viscous effect expected

$$\rho_{n+2,2n} = \frac{v_{n+2}^{Non\ Linear}}{v_{n+2}^{Inclusive}} \sim \langle \cos((n+2)\Psi_{n+2} - 2\Psi_2 - n\Psi_n)\rangle$$

➢ Eccentricity coupling

$$\chi_{n+2,2n} = \frac{v_{n+2}^{Non\ Linear}}{\sqrt{\langle v_2^2 v_n^2\rangle}}$$

❖ Transverse momentum-flow correlations

$$cov(v_n^2 - [p_T]) = Re\left(\left\langle \frac{\sum_{a,c} w_a\, w_c\, e^{in(\phi_a - \phi_c)} ([p_T] - \langle [p_T]\rangle)_b}{\sum_{a,c} w_a\, w_c} \right\rangle\right)$$

$$\rho(v_n^2 - [p_T]) = \frac{cov(v_n^2 - [p_T])}{\sqrt{Var(v_n^2)_{dyn}\, C_{\{k\}}}}$$

$$C_k = \left\langle \frac{\sum_b \sum_{b'} w_b w_{b'} \, (p_{T,b} - \langle [p_T]\rangle)\,(p_{T,b'} - \langle [p_T]\rangle)}{\left((\sum_b w_b)^2 - \sum_b (w_b)^2\right)} \right\rangle$$

$\Delta\eta_{b\grave{b}} > 0.2$

$$Var(v_n^2)_{dyn} = v_n^4\{2\} - v_n^4\{4\}$$

The Pearson correlation coefficient (PCC) measure the strength of the v_n, $[p_T]$ correlation

ATLAS Collaboration, Eur. Phys. J. C 79, 985 (2019).

Piotr Bozek arXiv:1601.04513

Experimental Measurements

The beam-energy dependence of :

- ✓ The linear and non-linear flow harmonics decomposition
- ✓ The mode-coupling coefficients $\chi_{\mathrm{k,nm}}$ and the EP angular correlations $\rho_{\mathrm{k},nm}$
- ✓ The transverse momentum-flow correlations

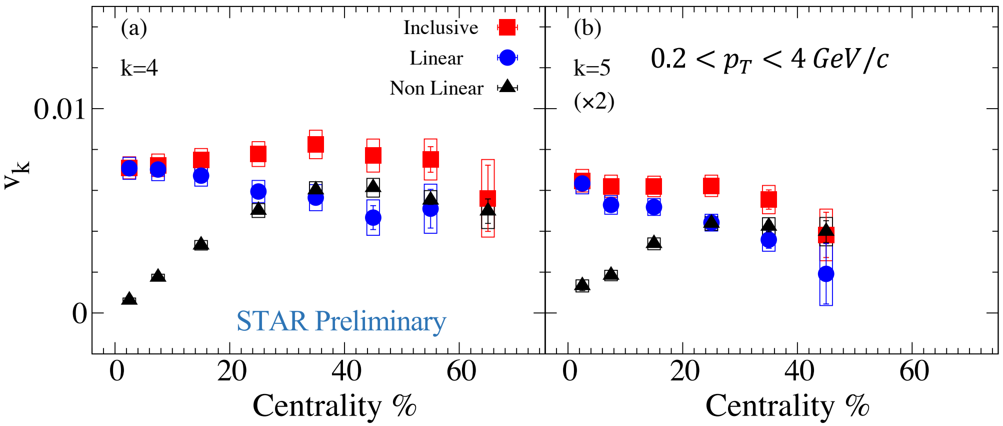
Models Comparisons

	Hydro-1	**Hydro-2**
η/s	0.05	0.12
Initial conditions	TRENTO Initial conditions	IP-Glasma Initial conditions
Contributions	Hydro + Direct decays	Hydro + Hadronic cascade

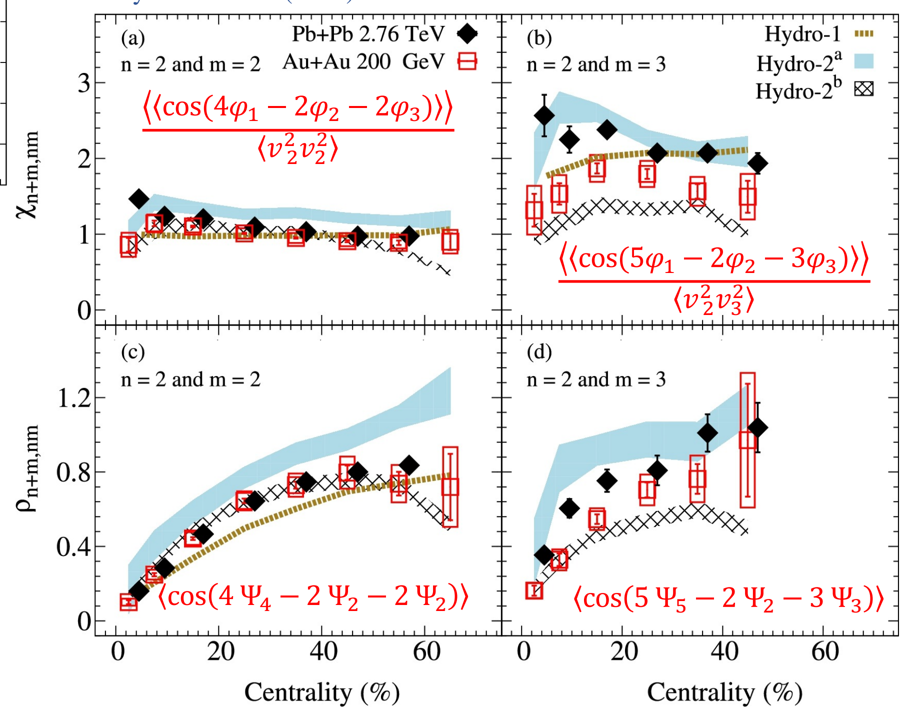
- (1) P. Alba, et al. PRC 98 , 034909 (2018)
- (2) B.Schenke, C.Shen, and P.Tribedy PRC 99, 044908 (2019)

Results

Linear and non-linear flow $v_{4,5}$ decomposition, the χ_{knm} and the $\rho_{k,nm}$ for Au+Au at 200 GeV



STAR Collaboration,
Phys.Lett.B 809 (2020) 135728

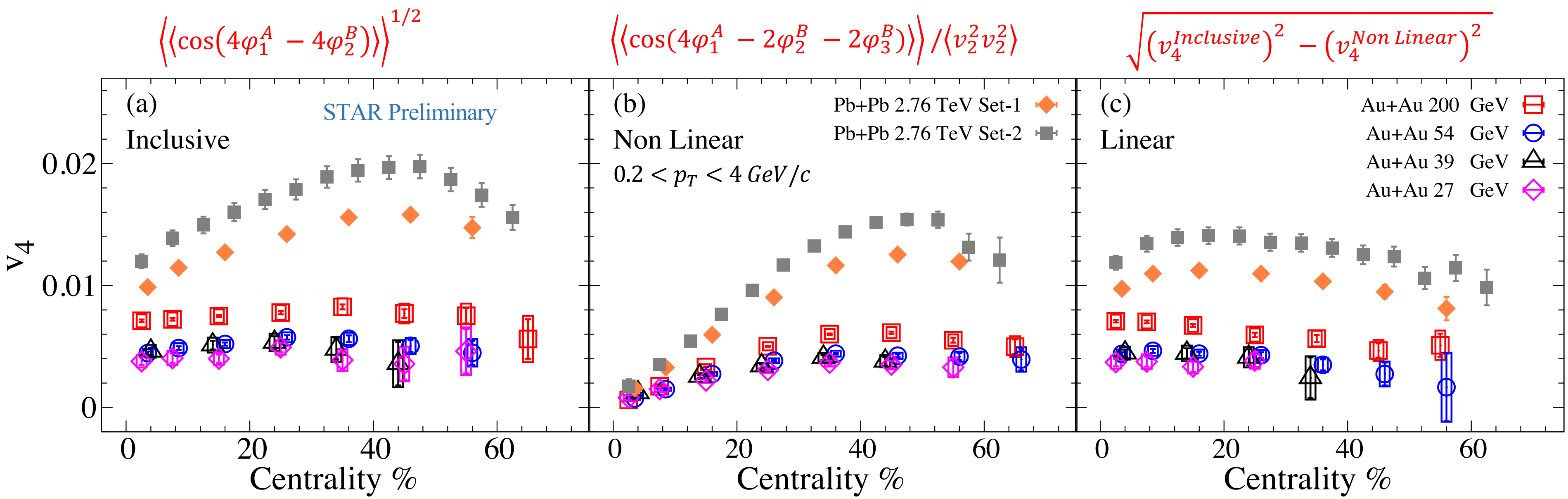


- The linear v_k (k=4,5) terms dominate in central collisions, while the non-linear terms take over or are comparable in peripheral collisions
- $\chi_{k,nm}$ shows a weak centrality dependence
- $\rho_{k,nm}$ shows a strong centrality dependence

The influence from final-state is less than the one from initial-state?

Results

The beam-energy dependance of the linear and non-linear flow v_4 decomposition



- The inclusive, linear and non-linear v_4 show strong beam-energy dependence
- The linear terms dominates the central collisions

Possible temperature dependence of viscous effects

Set-1
The ALICE collaboration
PLB 773 68-80, (2017)

Set-2
The ATLAS collaboration
PRC 92, 034903 (2015)

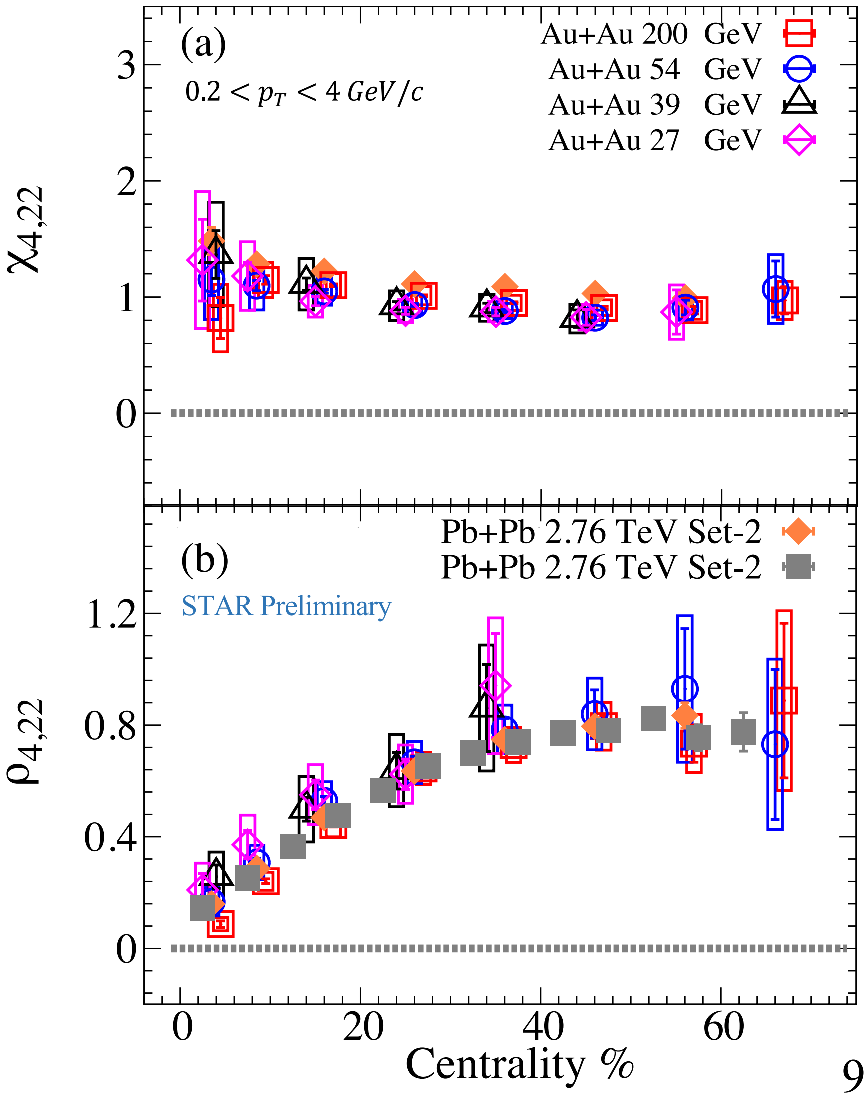
STAR Collaboration,
Phys.Lett.B 809 (2020) 135728

Results

The beam-energy dependance of the mode-coupling coefficients $\chi_{4,22}$ and the EP angular correlations $\rho_{4,22}$

- The non-linear mode-coupling coefficients $\chi_{4,22}$ show similar values and trends for different beam energies, and a weak centrality dependence.
- The EP angular correlations $\rho_{4,22}$ show similar values and trends for different beam energies, and a strong centrality dependence.

Dominated by the initial-state effects



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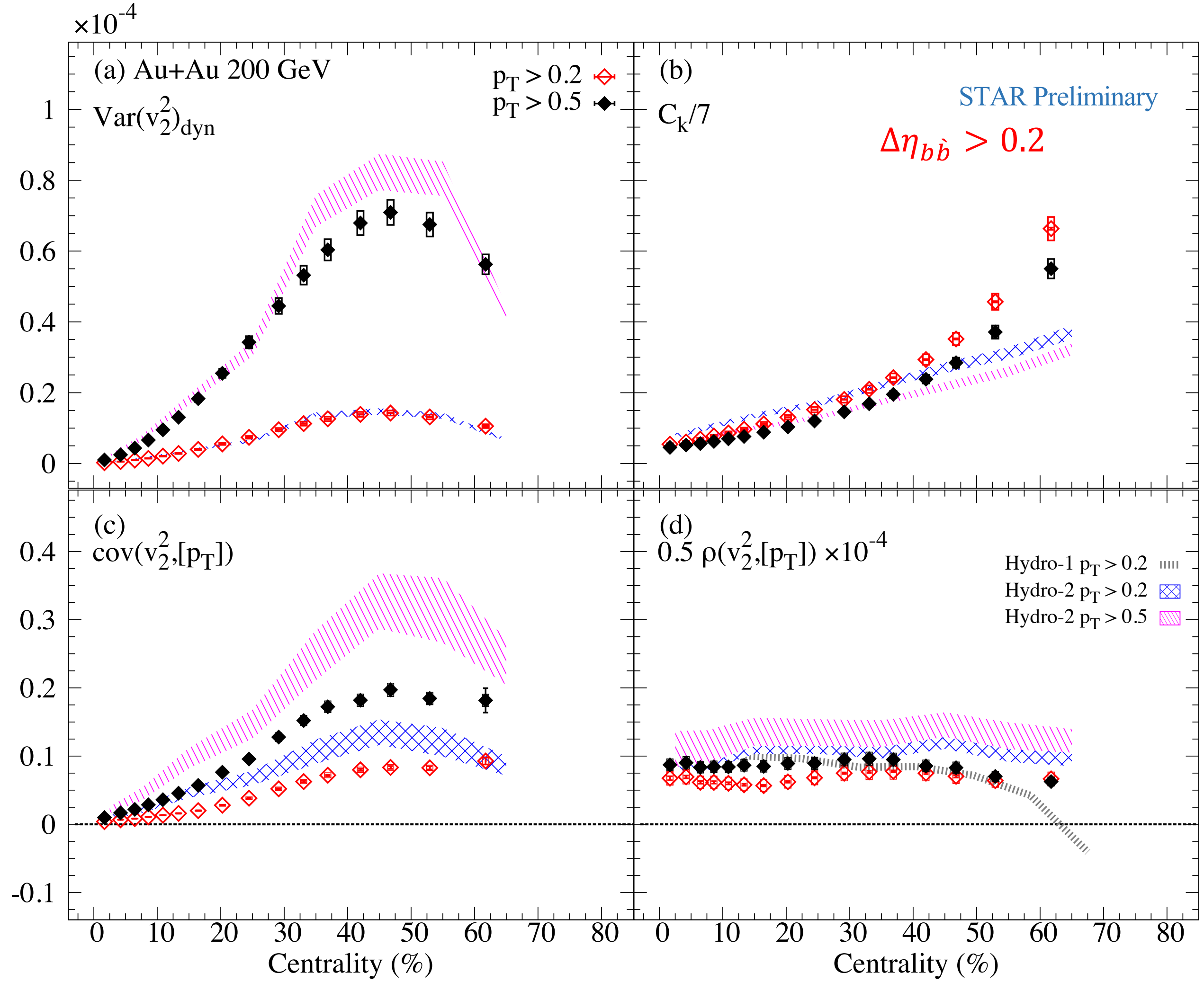
Results

The transverse momentum-flow correlations for Au+Au at 200 GeV

- $Var(v_2^2)_{dyn}$ increases with p_T
- C_k decreases with p_T increas
- $cov(v_2^2, [p_T])$ increases with p_T



- The Pearson correlation, $\rho(v_2^2, [p_T])$, increases with p_T

- Hydro models can qualitatively describe the data

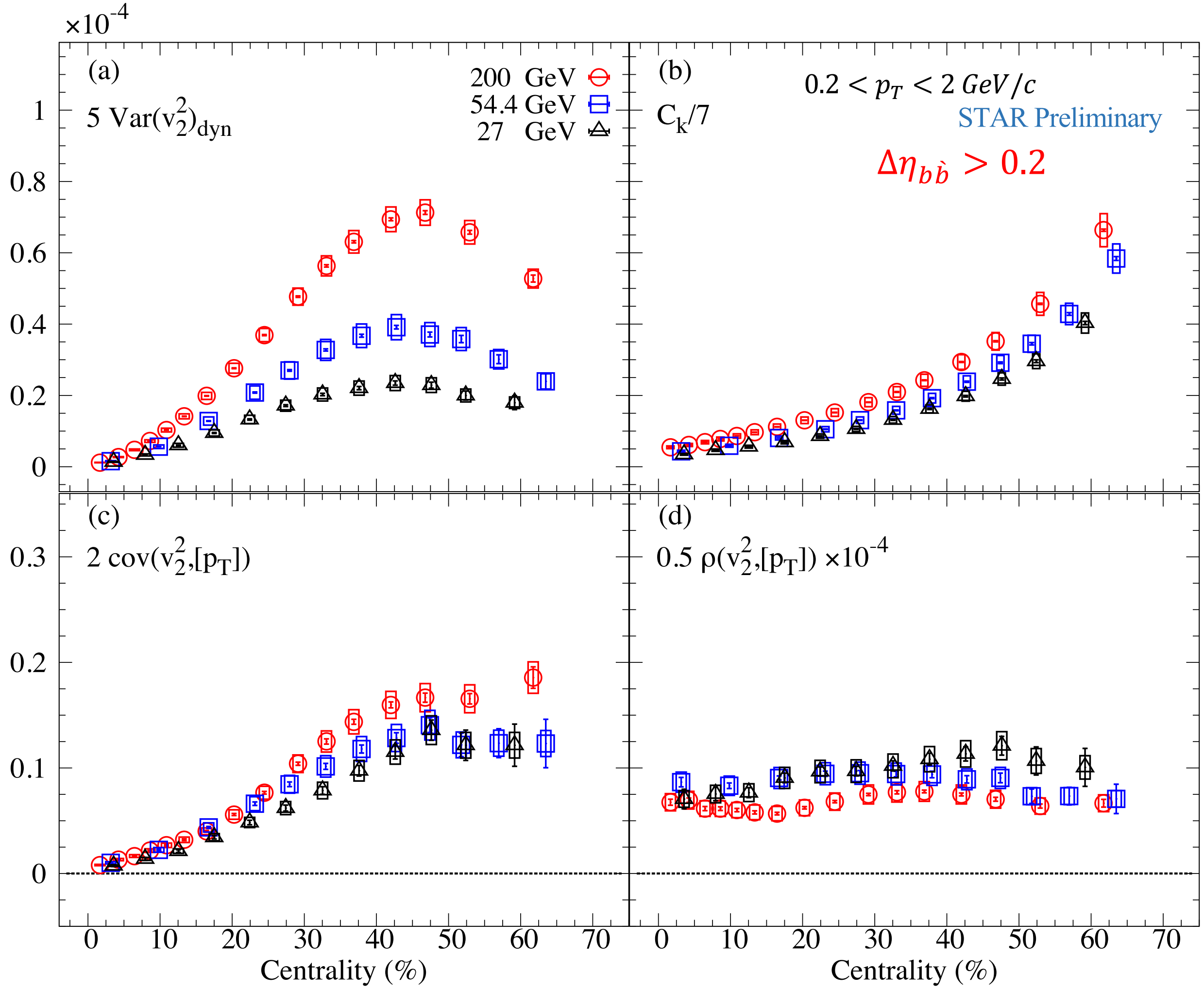
Niseem Magdy

More about Au+Au and U+U collisions please see Chunjian Zhang talk
10:30 AM–12:30 PM, Friday, October 30, 2020

Results

The beam-energy dependance of the transverse momentum-flow correlations

- $Var(v_2^2)_{dyn}$ decreases with beam-energy
- C_k decreases with beam-energy
- $cov(v_2^2, [p_T])$ decreases with beam-energy



- The Pearson correlation, $\rho(v_2^2, [p_T])$, increases with decreasing the beam-energy

Conclusion

The two- and multi-particle correlations are used to study the flow correlations and the transverse momentum-flow correlations dependence on beam-energies.

- Flow correlations:
  - ✓ The linear component of v_n (n>3) dominates in central collisions
  - ✓ The inclusive, linear and non-linear v_4 show strong beam energy dependence
  - ✓ The mode-coupling coefficients and the EP angular correlations show similar values and trends for different beam energy

- Transverse momentum-flow correlations:
  - ✓ The $cov(v_2^2, [p_T])$ increases with the mean p_T and beam energy
  - ✓ The normalized $\rho(v_2^2, [p_T])$:
    - Increases with increasing the mean p_T
    - Increases with decreasing the beam-energy

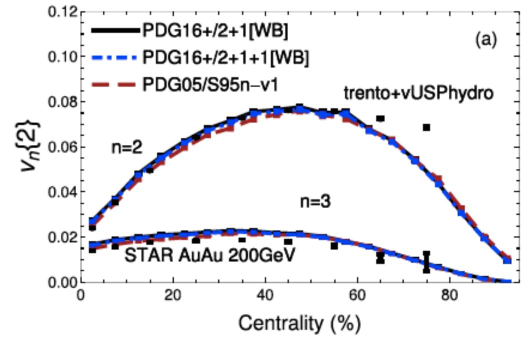
These measurements compared to viscous hydrodynamic model calculation will provide constraints on the initial conditions and $\frac{\eta}{s}(T)$

Thank You

Backup

(1) P. Alba, et al. PRC 98 , 034909 (2018)

- The model use event-by-event fluctuating initial conditions generated by the TRENTO model with free parameters calibrated to fit experimental observables.
- The model use the smoothed particle hydrodynamics (SPH) Lagrangian code, v-USPhydro, to solve the viscous hydrodynamic equations taking into account shear viscous effects.
- The viscosity is determined by fitting $v_2\{2\}$ and $v_3\{2\}$ across centrality for different equation of state individually.



(2) B.Schenke , et al. PRC 99, 044908 (2019)

- The model used the impact parameter-dependent Glasma model to initialize the viscous hydrodynamic simulation MUSIC and employ the UrQMD transport model for the low-temperature region of the collisions.

Width, height, and position of ζ/s are free parameters