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Beam-energy dependence of transverse momentum and flow correlations in STAR

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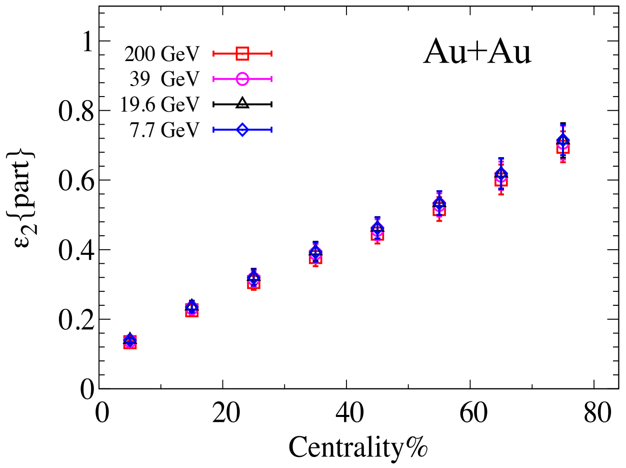
Workshop on Particle Correlation and Femtoscopy

Motivation:

- The beam-energy dependence of flow and p_T correlations will reflect the respective roles of ϵ_n, its fluctuations and $\frac{\eta}{s}$ as a function of T and μ_B

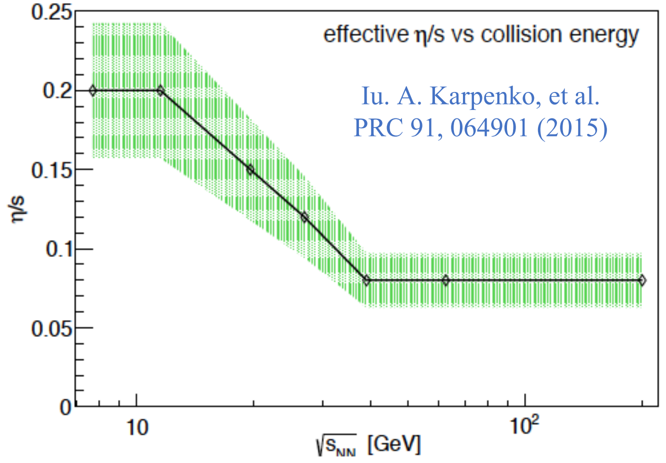
Beam energy dependence for a given collision system:



- Initial-state ε_2 is approximately energy independent
- Viscous attenuation ($\propto \frac{\eta}{s}(T)$) is beam energy dependent

Piotr Bozek
PRC 93, 044908 (2016)

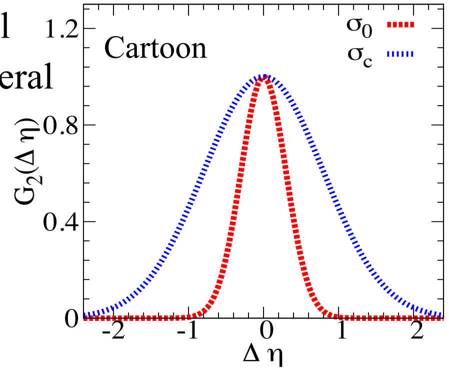
Niseem Magdy, Roy Lacey
PLB 821 136625 (2021)



- The Pearson correlation, $v_n - [p_T]$ correlation, coefficient (PCC) is expected to be more susceptible to the initial conditions of heavy-ion collisions.

S. Gavin and M. Abdel-Aziz
Phys.Rev.Lett. 97 (2006) 162302

σ_c → Central
σ_0 → Peripheral



The Gavin ansatz:

- The $p_T - p_T$ correlation function is sensitive to the dissipative viscous effects that are ensured during the transverse and longitudinal expansion of the medium created in the collisions.
- Because such dissipative effects are more prominent for long-lived systems, they lead to longitudinal broadening of p_T 2-P correlation function as collisions become more central.
- A proposed estimate of this broadening, $\Delta\sigma^2$, can be linked to η/s as:

$$\Delta\sigma^2 = \sigma_c^2 - \sigma_0^2 = \frac{4}{T_c}\frac{\eta}{s}\left(\frac{1}{\tau_0} - \frac{1}{\tau_{c,f}}\right)$$

Analysis procedure:

The $p_T - p_T$ correlator:

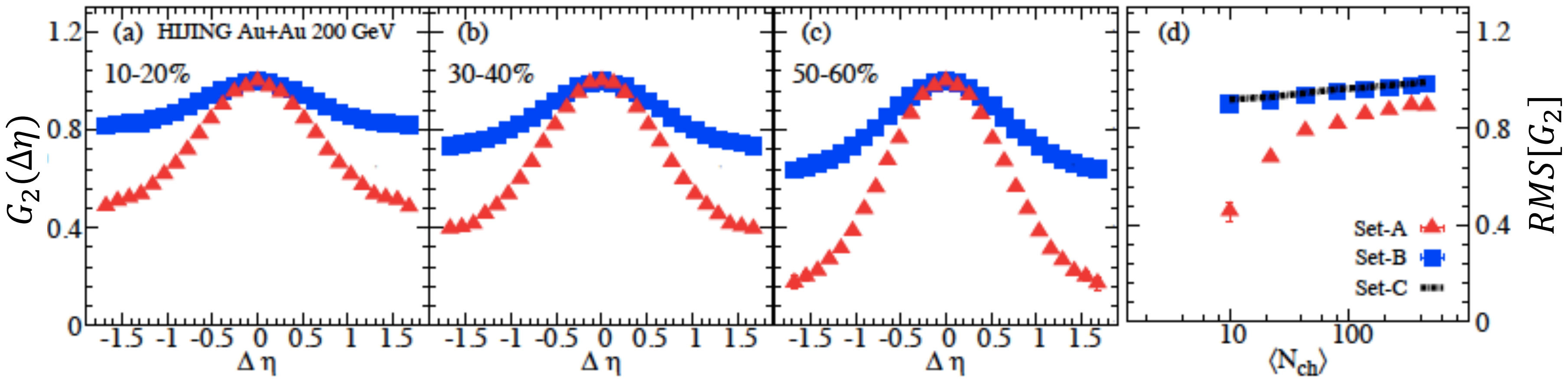
STAR Collaboration
PLB 704 (2011) 467–473

N. Magdy and R. Lacey
PRC 104, 014907 (2021)

Niseem Magdy, et al.
Eur.Phys.J.C 81 (2021) 8, 779

$$G_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} p_{T,i} p_{T,j} \right\rangle}{\langle n_1\rangle\langle n_2\rangle} - \langle p_{T,1}\rangle_{\eta_1,\varphi_1}\langle p_{T,2}\rangle_{\eta_2,\varphi_2}$$

$$\Rightarrow \frac{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} p_{T,i}\, p_{T,j} \right\rangle}{\langle n_1\rangle\langle n_2\rangle} = \frac{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} p_{T,i}\, p_{T,j} \right\rangle}{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} n_i\, n_j \right\rangle} r_{1,2} \Rightarrow r_{1,2} = \frac{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} n_i\, n_j \right\rangle}{\langle n_1\rangle\langle n_2\rangle}$$



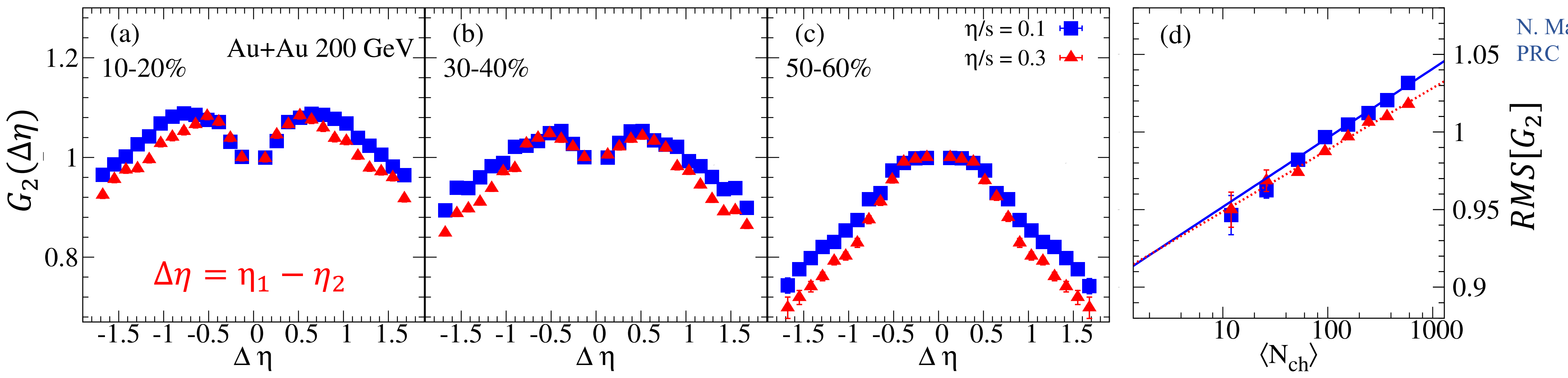
Comparison of the $G_2(\Delta\eta)$ correlators ($|\Delta\varphi| < 1$) obtained from 10-20%, 30-40% and 50-60% central HIJING events for Au+Au collisions at 200 GeV.

(i) Set-A: with centrality defined using all charged particles in an event,
(ii) Set-B: with centrality defined using random sampling of charged particles in an event
(iii) Set-C: with centrality defined using the impact parameter distribution.

Excluding the POI from the collision centrality definition, serves to reduce the possible self-correlations.

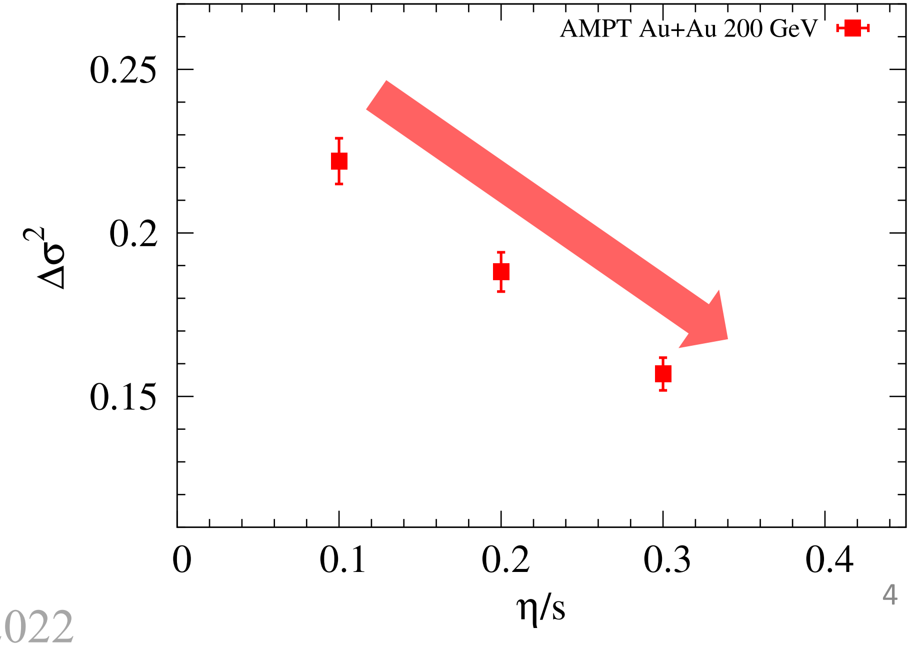
Investigations of the $p_T - p_T$ correlations

- ➢ The longitudinal correlations using AMPT model for Au+Au at 200 GeV



N. Magdy and R. Lacey
PRC 104, 014907 (2021)

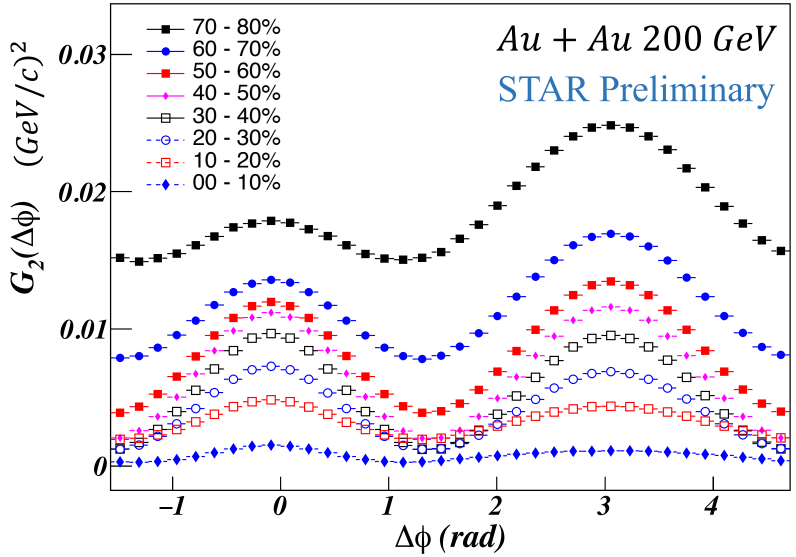
➢ The $\sigma_{\Delta\eta}(G_2)$ is sensitive to the η/s change



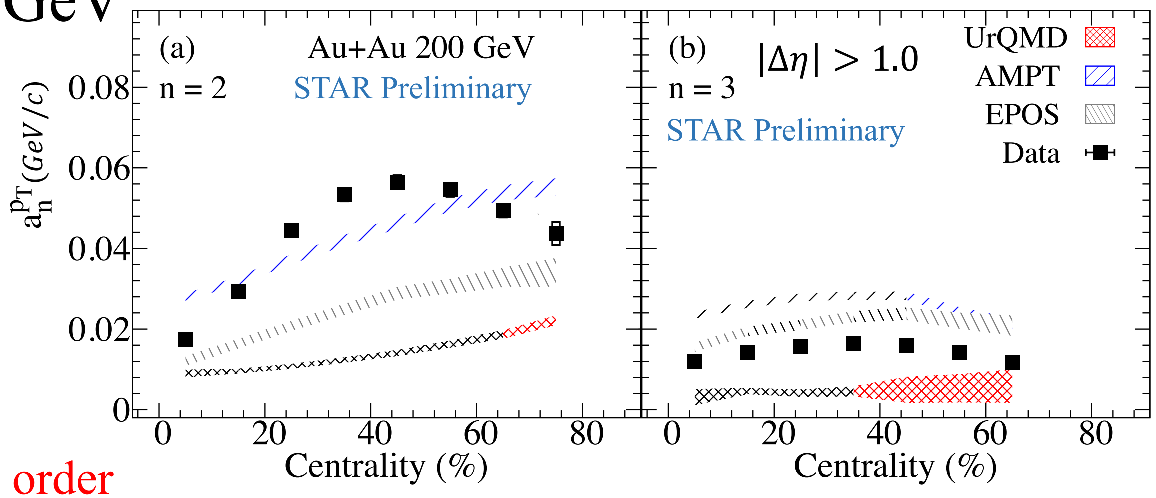
Investigations of the $p_T - p_T$ correlations from STAR

➢ The azimuthal correlations for Au+Au at 200 GeV

$$G_2(\Delta\varphi) = A_0^{p_T} + 2\sum_{n=1}^{6} A_n^{p_T} \cos(n\,\Delta\varphi)$$



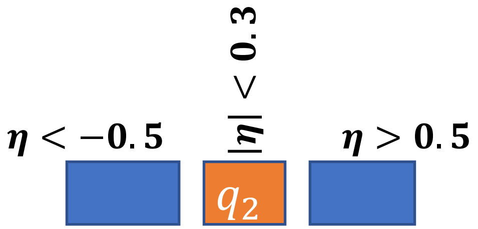
$$a_n^{p_T} = \sqrt{A_n^{p_T}}$$

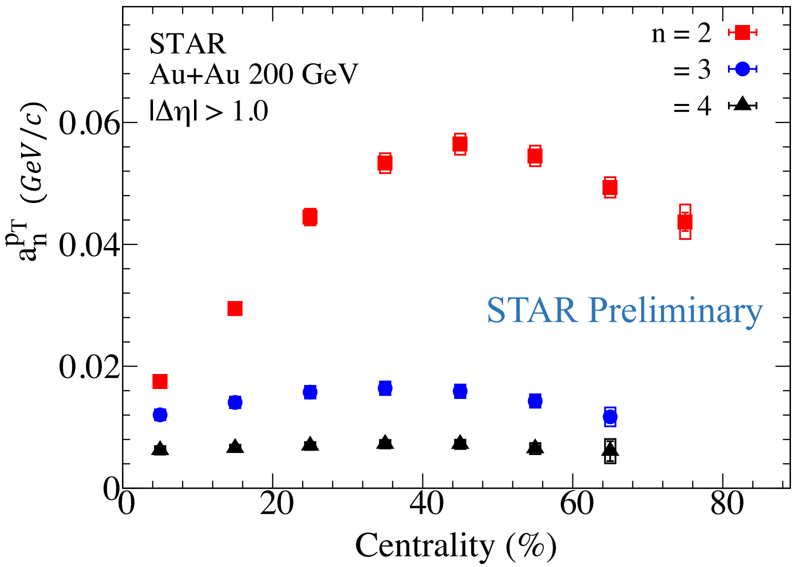


➢ The extracted $a_2^{p_T}$:

- ✓ Decrease with harmonic order
- ✓ Models do not describe the data
- ✓ Event shape dependent

➢ q_2 is separated from particle of interest

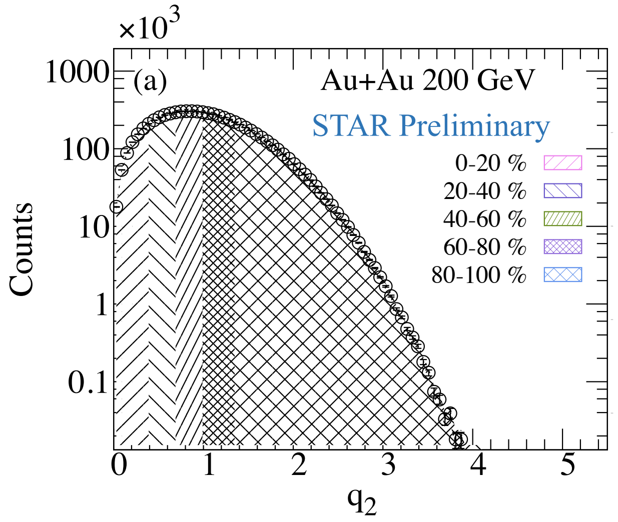


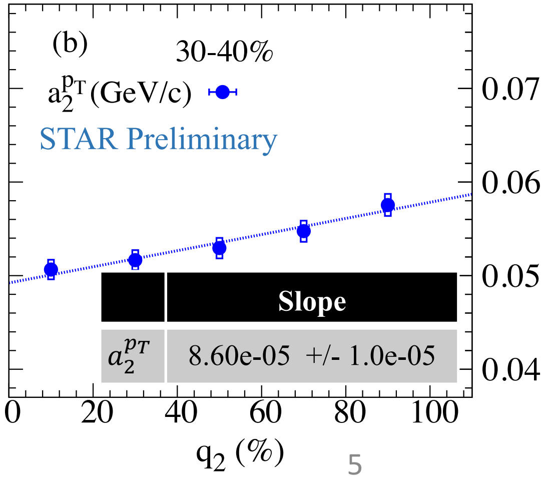


$$Q_{2,x} = \sum_{i=1}^{M} \cos(2\,\varphi_i)$$

$$Q_{2,y} = \sum_{i=1}^{M} \sin(2\,\varphi_i)$$

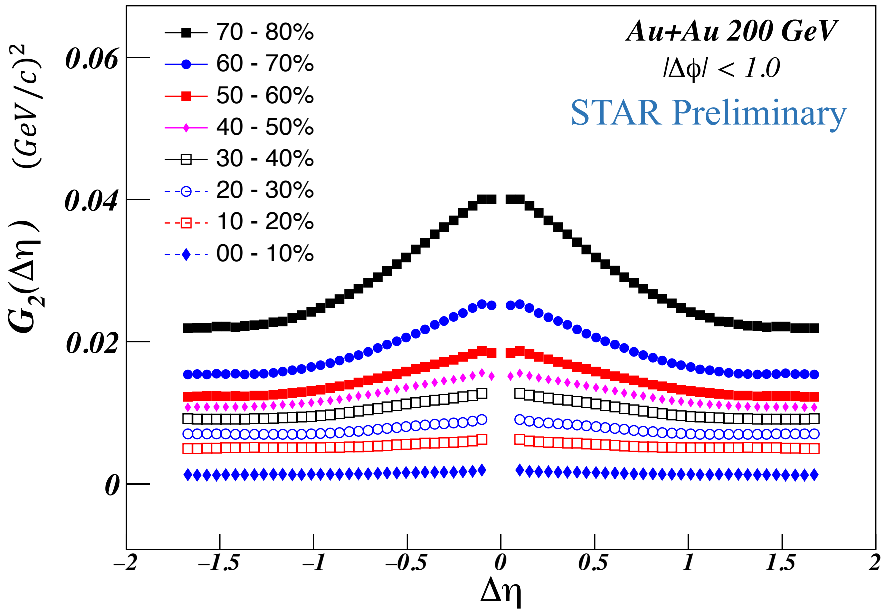
$$|Q_2| = \sqrt{Q_{2,x}^2 + Q_{2,y}^2} \qquad q_2 = \frac{|Q_2|}{\sqrt{M}}$$





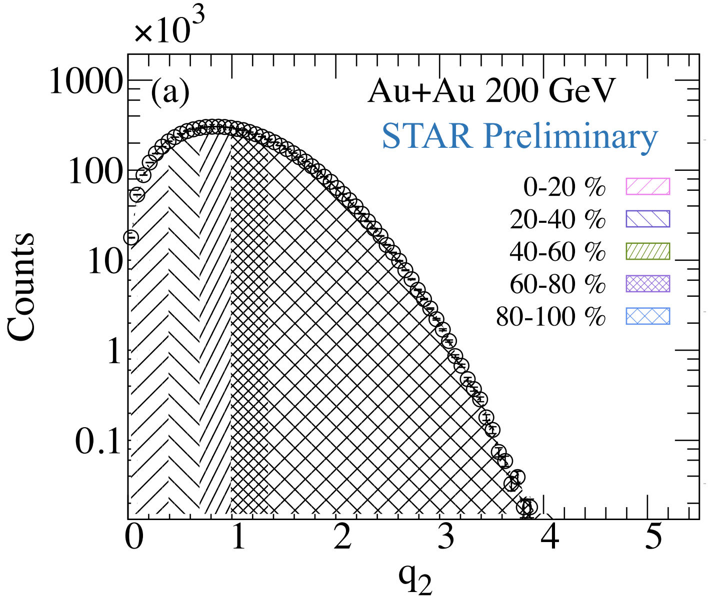
Investigations of the $p_T - p_T$ correlations from STAR

➢ The longitudinal correlations for Au+Au at 200 GeV

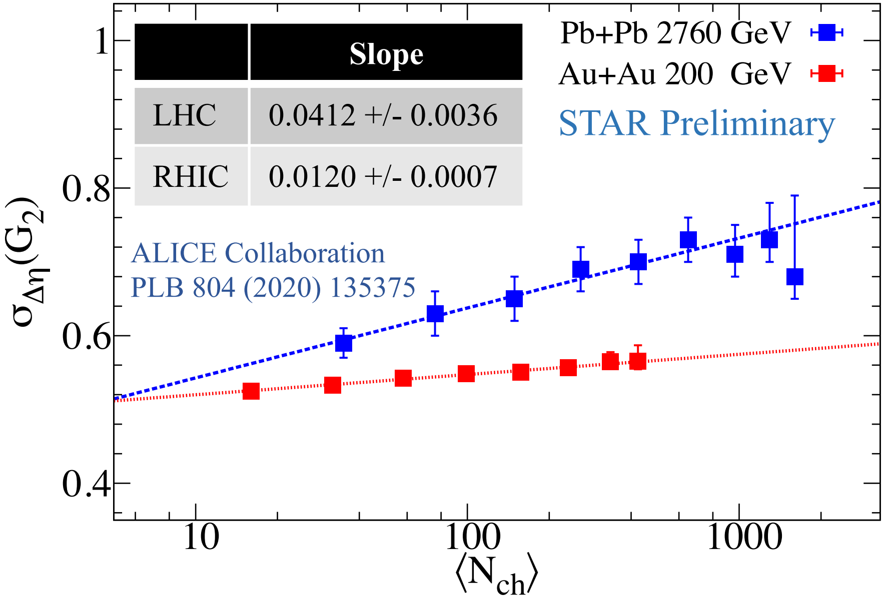


$$\sigma_{\Delta\eta}(G_2) = RMS[G_2(\Delta\eta)]$$

- ➢ The slope of $\sigma_{\Delta\eta}(G_2)$ vs. $\langle N_{ch} \rangle$ is softer for RHIC
  - ✓ Smaller η/s for RHIC

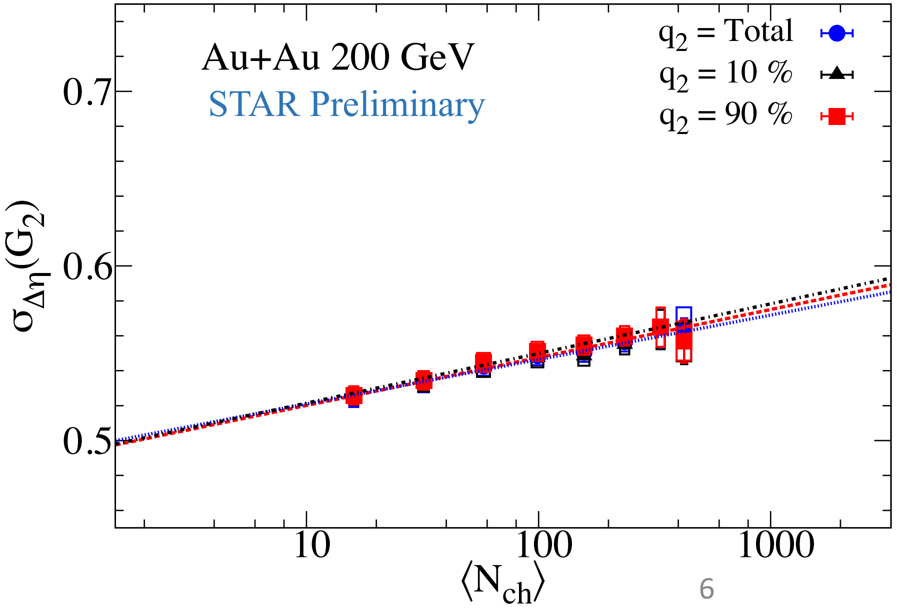


P. Alba et al.
PRC 98, 034909 (2018)



- ➢ The $\sigma_{\Delta\eta}(G_2)$ is event shape independent

	Slope
Total	0.0120 +/- 0.0007
10 %	0.0119 +/- 0.0009
90 %	0.0110 +/- 0.0012



Analysis procedure:

❖Transverse momentum-flow correlations:

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

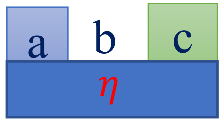
$$C_k = \left\langle \frac{\sum_b \sum_{b'} w_b w_{b'} \; (p_{T,b} - \langle [p_T] \rangle)\,(p_{T,b'} - \langle [p_T] \rangle)}{\left((\sum_b w_b)^2 - \sum_b (w_b)^2 \right)} \right\rangle \quad \Delta\eta_{b\grave{b}} > 0.2$$

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

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

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

$|\Delta\eta| > 0.7$



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

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

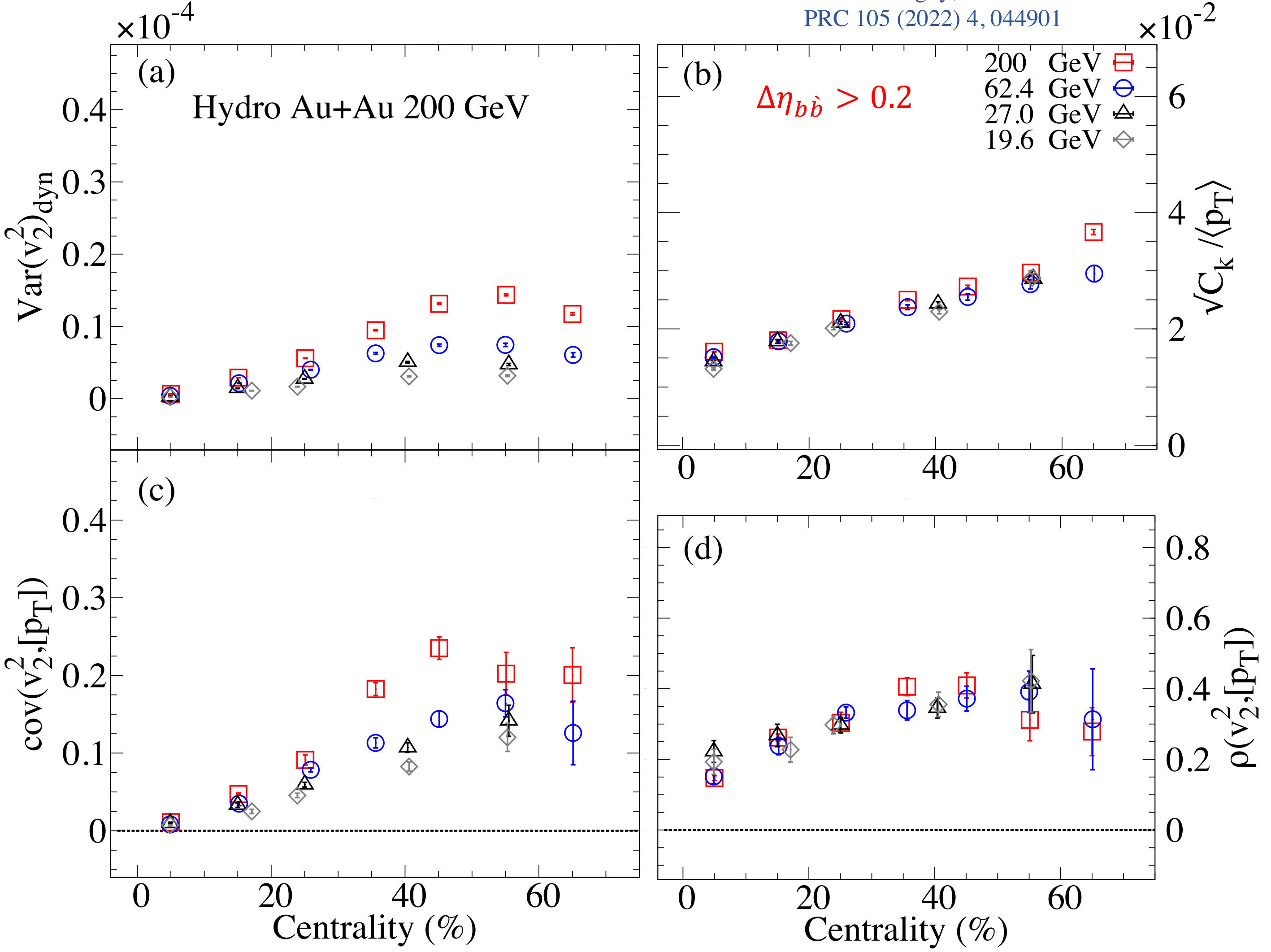
Piotr Bozek PRC 93, 044908 (2016)

Niseem Magdy, Roy Lacey PLB 821 136625 (2021)

Niseem Magdy, et al. PRC 105 (2022) 4, 044901

❖Transverse momentum-flow correlations:

The beam-energy dependance of the transverse momentum-flow correlations using hydro model



- ➢ $Var(v_2^2)_{dyn}$ decreases with beam-energy
- ➢ $\sqrt{C_k}/\langle p_T\rangle$ shows no change with beam energy
- ➢ $cov(v_2^2,[p_T])$ decreases with beam-energy

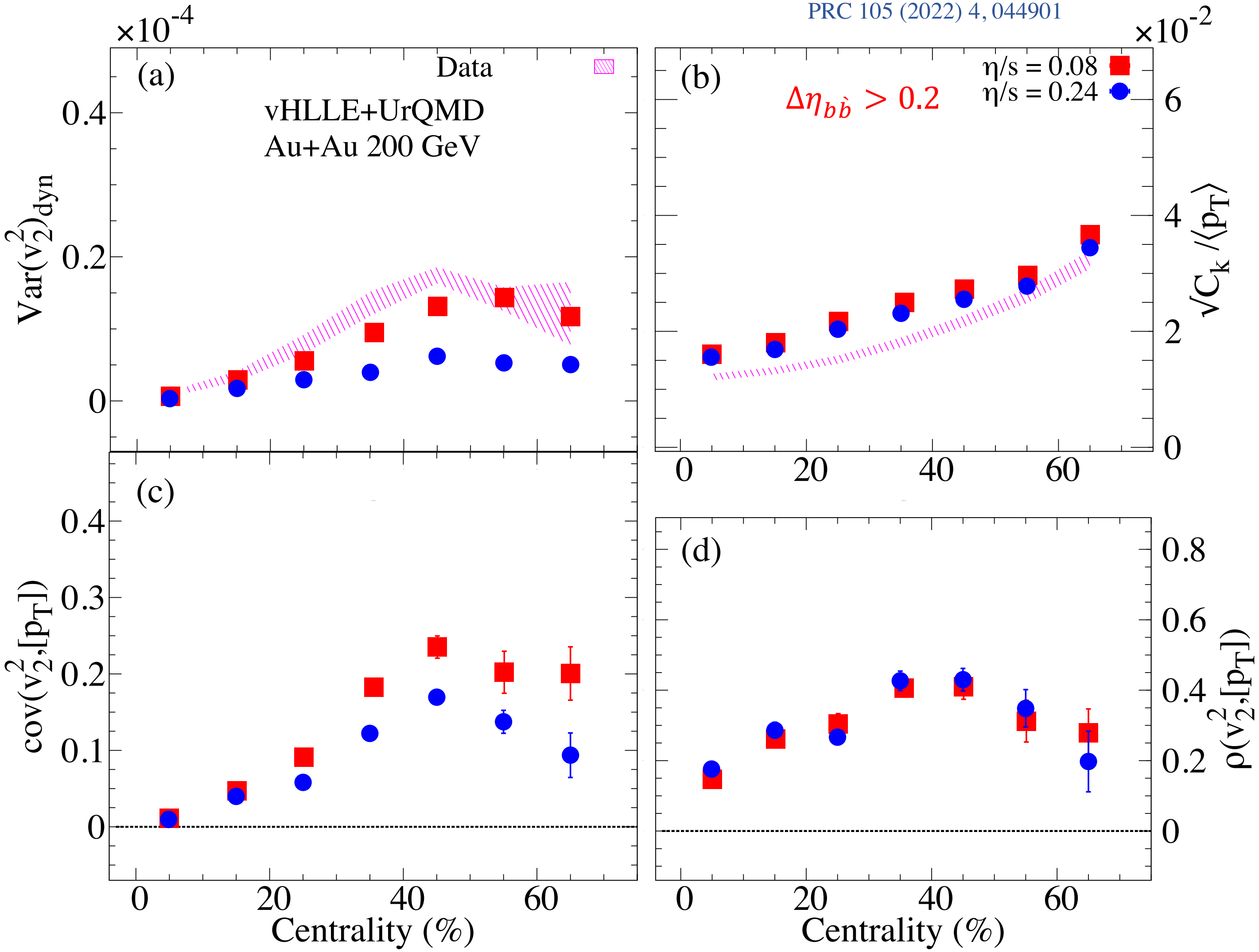
➢ **The Pearson correlation, $\rho(v_2^2,[p_T])$ shows no change with beam energy**

❖Transverse momentum-flow correlations:

The beam-energy dependance of the transverse momentum-flow correlations using hydro model

- ➢ $Var(v_2^2)_{dyn}$ decreases with increasing η/s
- ➢ $\sqrt{C_k}/\langle p_T\rangle$ shows no change with η/s
- ➢ $cov(v_2^2, [p_T])$ decreases with increasing η/s
- ➢ The Pearson correlation, $\rho(v_2^2, [p_T])$ shows little change with η/s

Niseem Magdy, et al.
PRC 105 (2022) 4, 044901



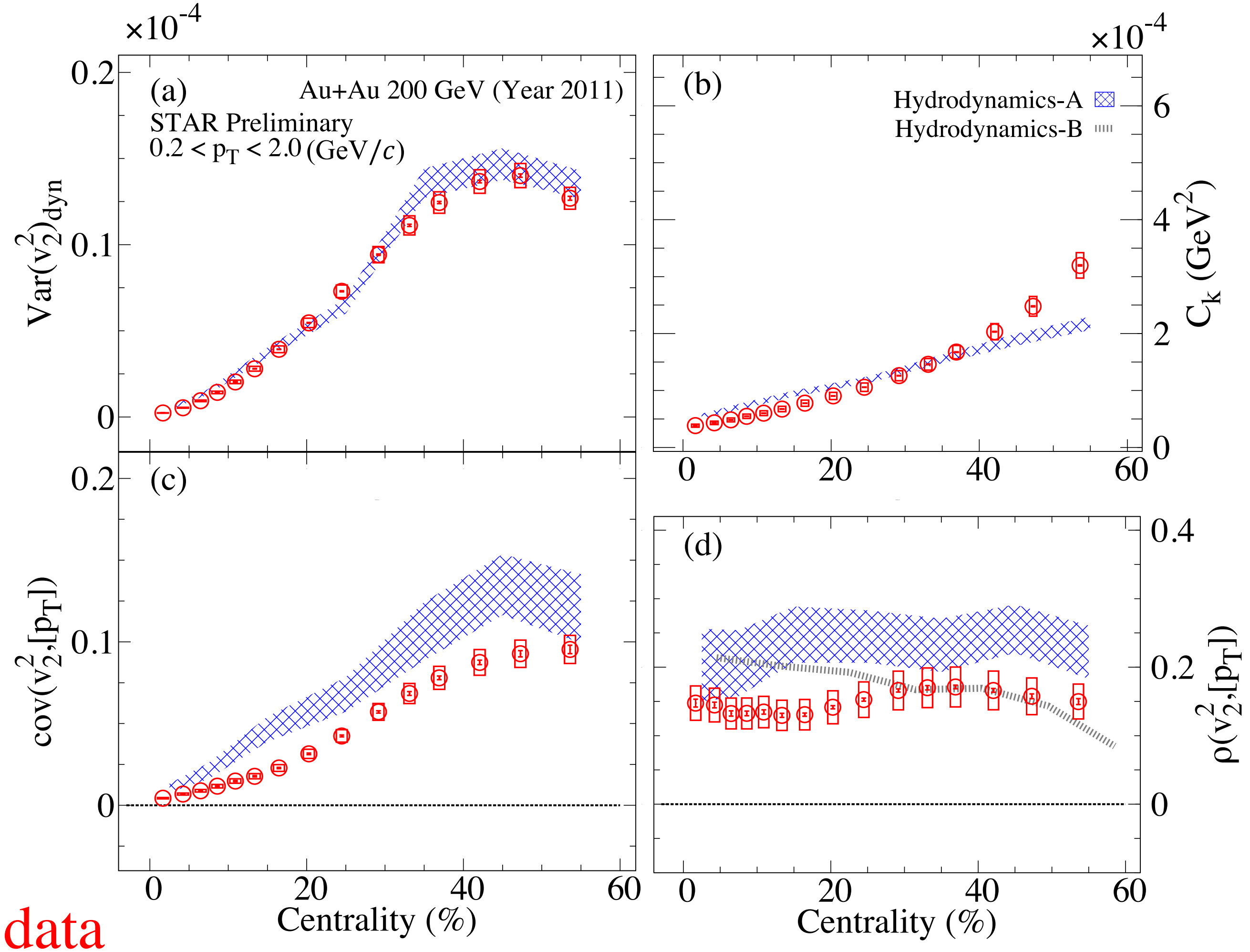
Transverse momentum-flow correlations measurements:

❖ Hydro comparisons

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

	Hydro-A	Hydro-B
η/s	0.12	0.05
Initial conditions	IP-Glasma	TRENTO
Contributions	Hydro + Hadronic cascade	Hydro + Direct decay

- $Var(v_2^2)_{dyn}$ shows a good agreement with Hydro-A
- C_k shows a good agreement with Hydro-A from central to mid central
- Hydro-A overestimate $cov(v_2^2, [p_T])$



- Hydro models can qualitatively describe the data
  - ✓ Both Hydro-A and -B overestimates $\rho(v_2^2, [p_T])$

Transverse momentum-flow correlations measurements:

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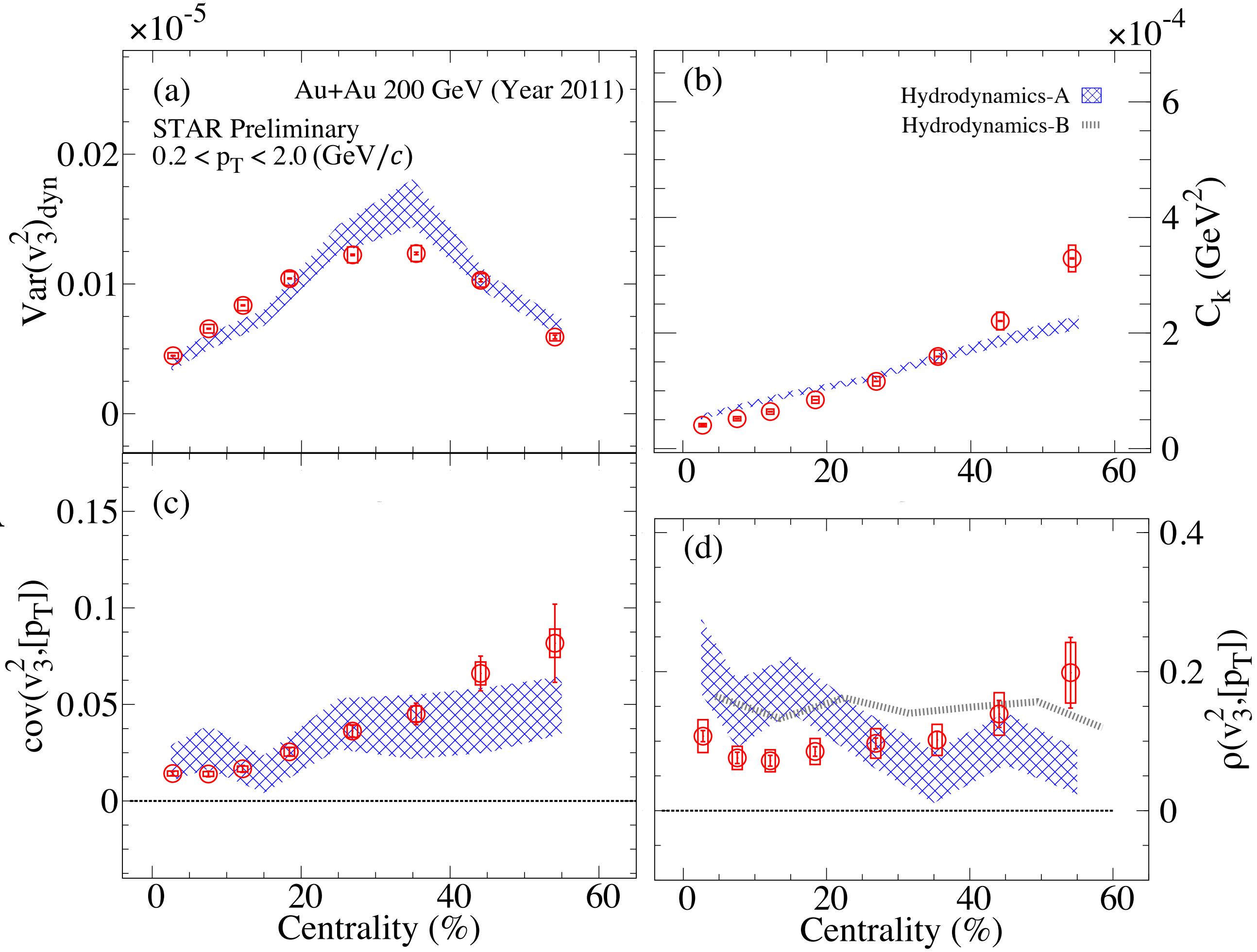
Contributions	Hydro + Hadronic cascade	Hydro + Direct decay

- $Var(v_3^2)_{dyn}$ shows a good agreement with Hydro-A
- C_k shows a good agreement with Hydro-A from central to mid central
- Hydro-A within the uncertainty shows a good agreement with $cov(v_3^2, [p_T])$



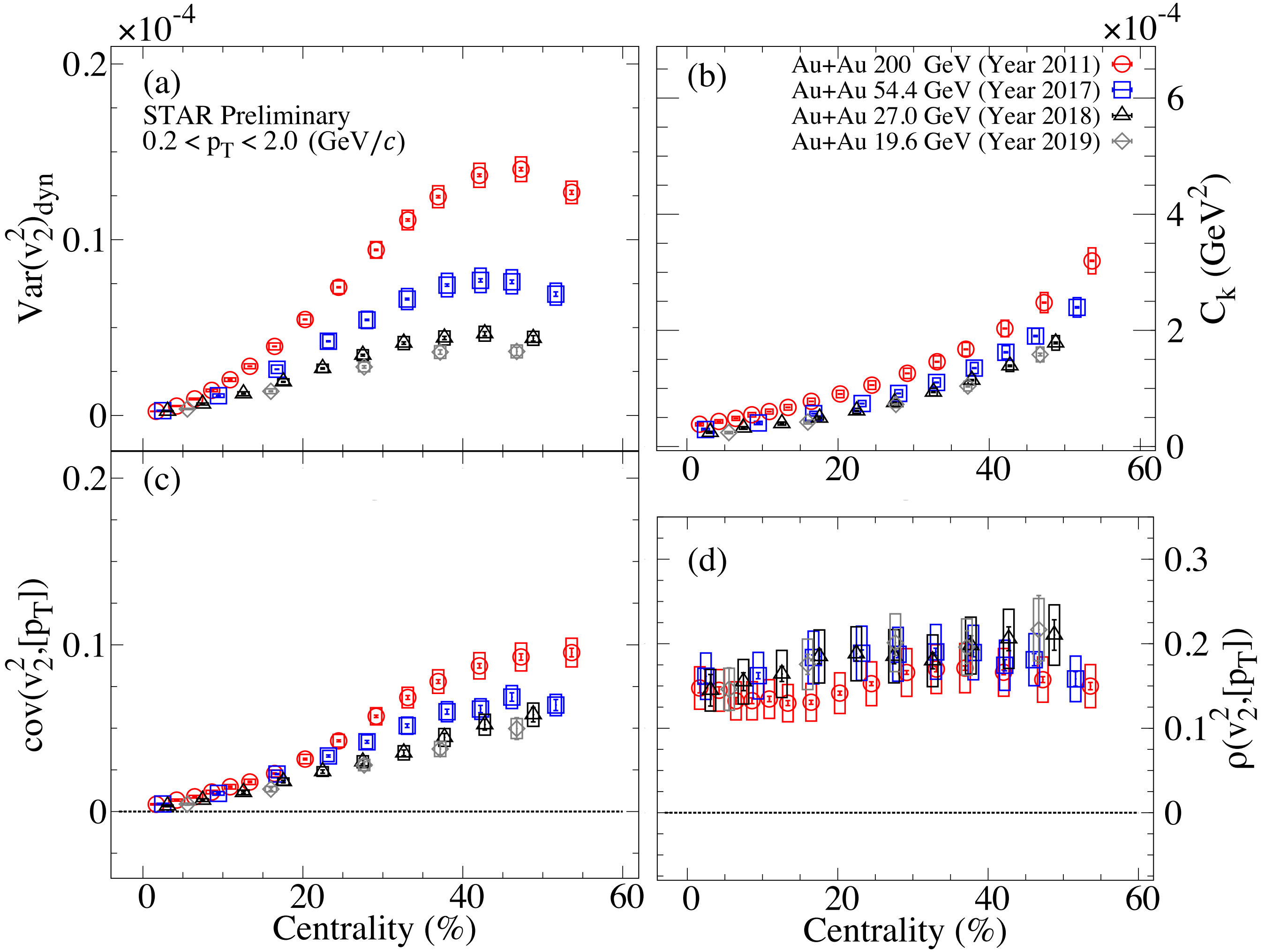
- Hydro models can qualitatively describe the data
  - ✓ Both Hydro-A and -B overestimates $\rho(v_3^2, [p_T])$ in more central collisions

Transverse momentum-flow correlations measurements:

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

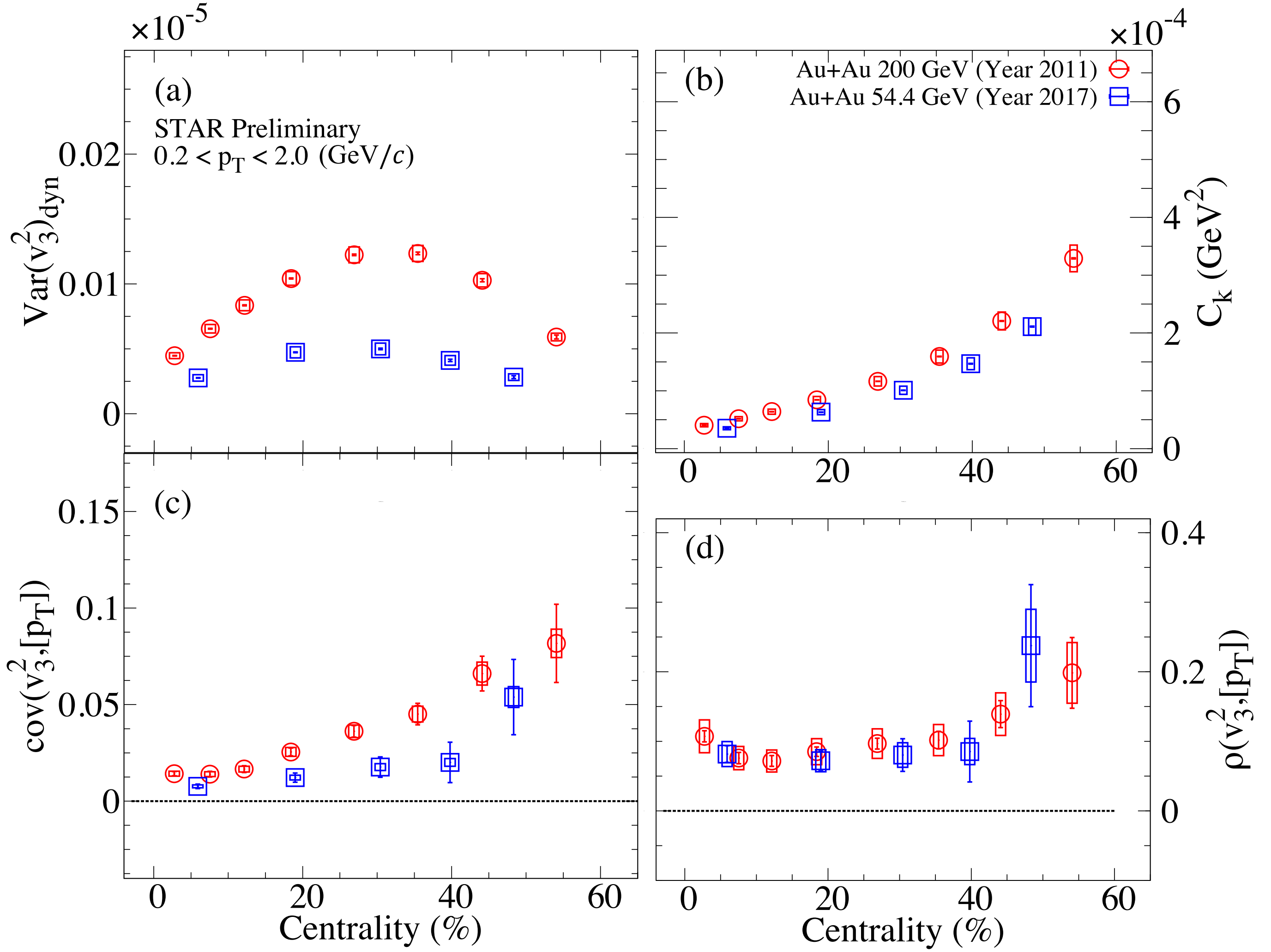
  - $Var(v_2^2)_{dyn}$ decreases with beam-energy
  - C_k decreases with beam-energy
  - $cov(v_2^2, [p_T])$ decreases with beam-energy

  - The Pearson correlation, $\rho\left(v_2^2, [p_T]\right)$, shows no significant energy dependence within the systematic uncertainties



Transverse momentum-flow correlations measurements:

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



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- ➢ C_k decreases with beam-energy
- ➢ $cov(v_3^2, [p_T])$ decreases with beam-energy

➢ The Pearson correlation, $\rho(v_3^2, [p_T])$, show no significant energy dependence within the systematic uncertainties

Conclusions

We studied the transverse momentum and the transverse momentum-flow correlations as a function centrality for different beam energies

- The extracted $a_2^{p_T}$:
  - ✓ Decrease with harmonic order
  - ✓ Models don't describe the $a_2^{p_T}$ data
  - ✓ Event shape dependent
- The slope of $\sigma_{\Delta\eta}(G_2)$ vs multiplicity is:
  - ✓ Softer for RHIC (indicating smaller η/s for RHIC) than LHC
  - ✓ Event shape independent

These comparisons are reflecting the efficacy of the $G_2(\Delta\eta,\Delta\varphi)$ correlator to differentiate among theoretical models as well as to constrain the η/s.

- Transverse momentum-flow correlations:
  - ✓ The $cov(v_n^2,[p_T])$ increases with beam energy
  - ✓ The normalized $\rho(v_n^2,[p_T])$: Show little, if any, change with beam energy

The $\rho\left(v_n^2,[p_T]\right)$ measurements show little, if any, change with beam energy, suggesting that $\rho\left(v_n^2,[p_T]\right)$ is dominated by initial state effects.

Thank You