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STAR

Beam-energy dependence of the longitudinal broadening of two-particle transverse momentum correlations from STAR

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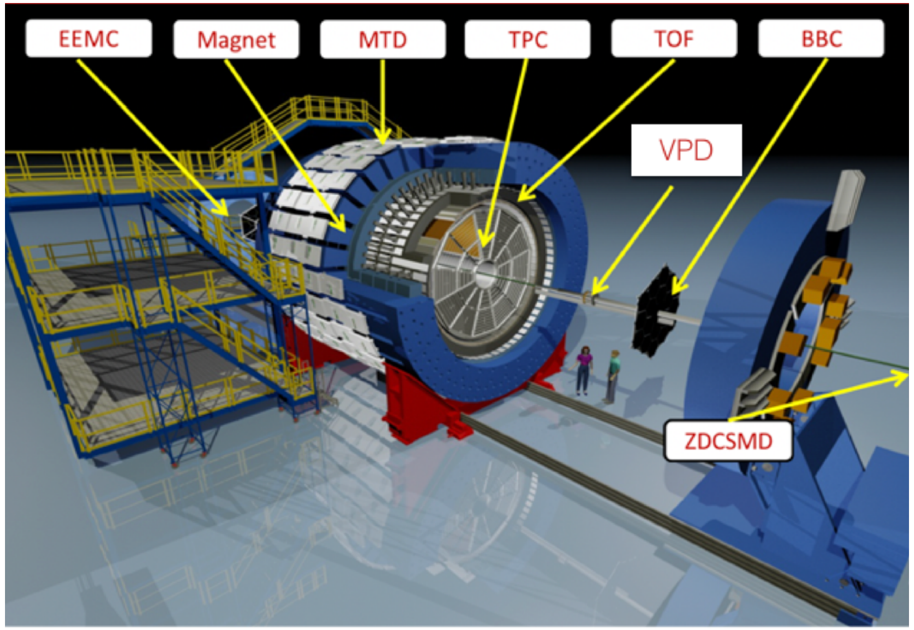
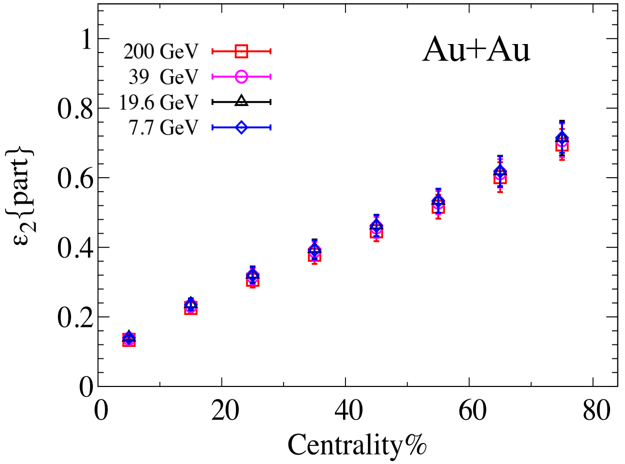


- Time Projection Chamber
  Tracking of charged particles with:
  - ✓ Full azimuthal coverage
  - ✓ $|\eta| < 1$ coverage
- In this analysis we used tracks with:
  $0.2 < p_T < 2$ GeV/c

Motivation:

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

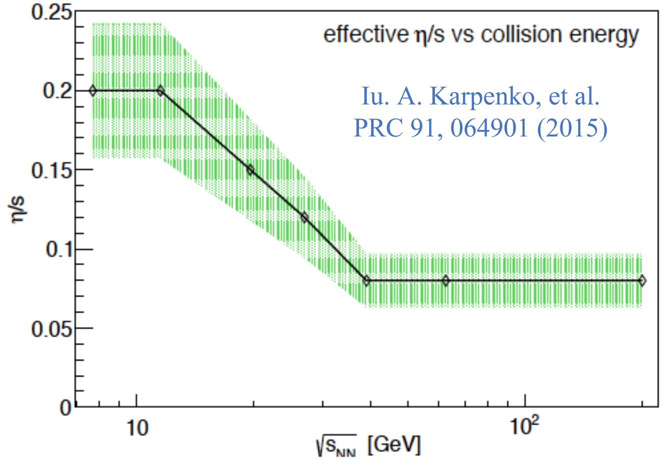
Beam energy dependence for a given collision system:



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

Piotr Bozek
PRC 93, 044908 (2016)

Niseem Magdy, Roy Lacey
PLB 821 136625 (2021)

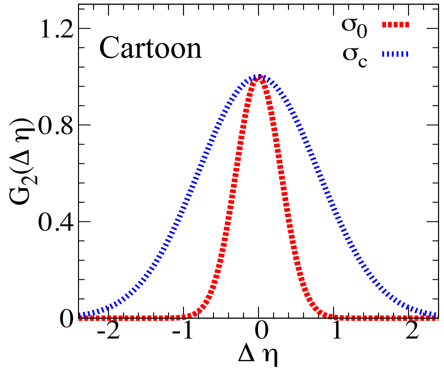


- The Pearson correlation, $v_n - [p_T]$ correlation, coefficient (PCC) is expected to be more susceptible to the initial conditions of heavy-ion collisions.

The Gavin ansatz:

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

- The p_T 2-P correlation function is sensitive to the dissipative viscous effects that are ensured during the transverse and longitudinal expansion of the collisions' medium.
- 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:



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

Motivation:

❖ Transverse momentum-flow correlations:

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

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

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

$|\Delta\eta| > 0.7$

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)

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

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

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

❖ The p_T 2-P correlator:

$$G_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\langle \sum_i^{n1} \sum_{j\neq i}^{n2} p_{T,i} p_{T,j} \rangle}{\langle n_1\rangle \langle n_2\rangle} - \langle p_{T,1}\rangle_{\eta_1,\varphi_1} \langle p_{T,2}\rangle_{\eta_2,\varphi_2}$$

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

- $r_{1,2}$ is a number correlation, it will be unity when the particle pairs are independent
- The $r_{1,2}$ correlations can be impacted by the centrality definition

$$r_{1,2} = \frac{\left\langle \sum_{\mathrm{i}}^{n_1} \sum_{\mathrm{j}\neq \mathrm{i}}^{n_2} n_{\mathrm{i}}\, n_{\mathrm{j}} \right\rangle}{\langle n_1\rangle\langle n_2\rangle}$$

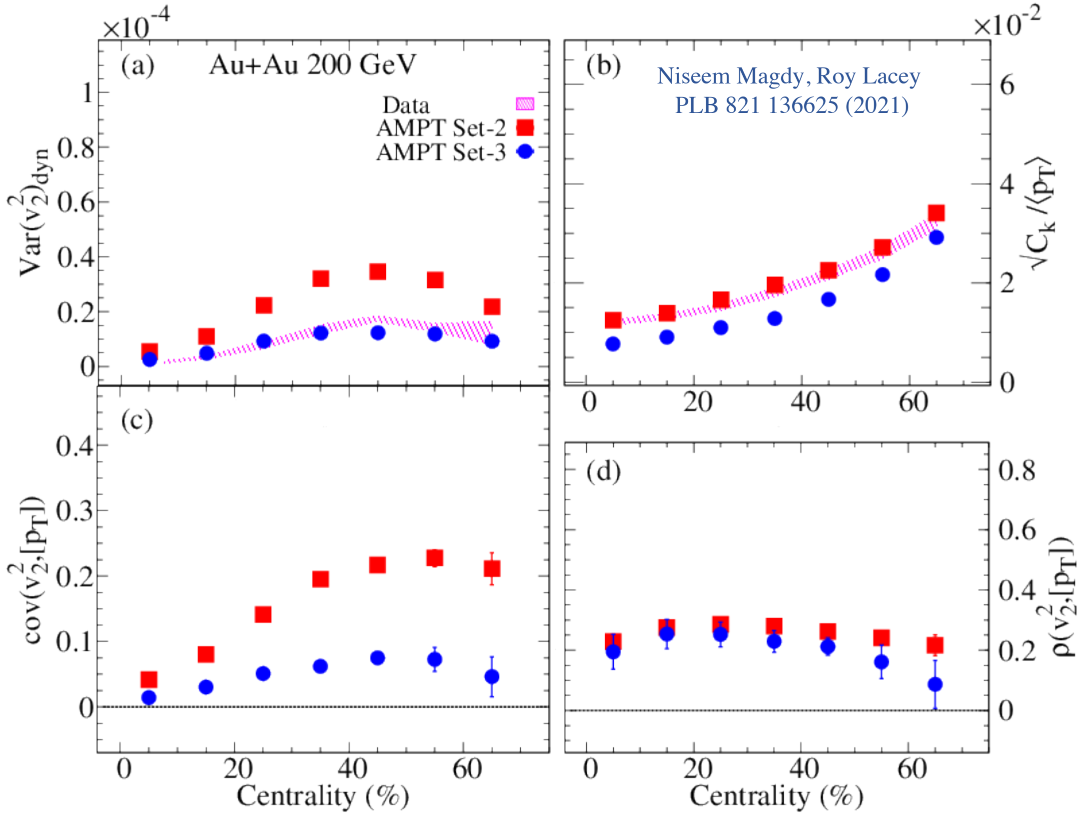
Excluding the POI from the collision centrality definition, helps reduce the possible self-correlations.

Niseem Magdy, Roy Lacey PRC 104 1, 014907 (2021)

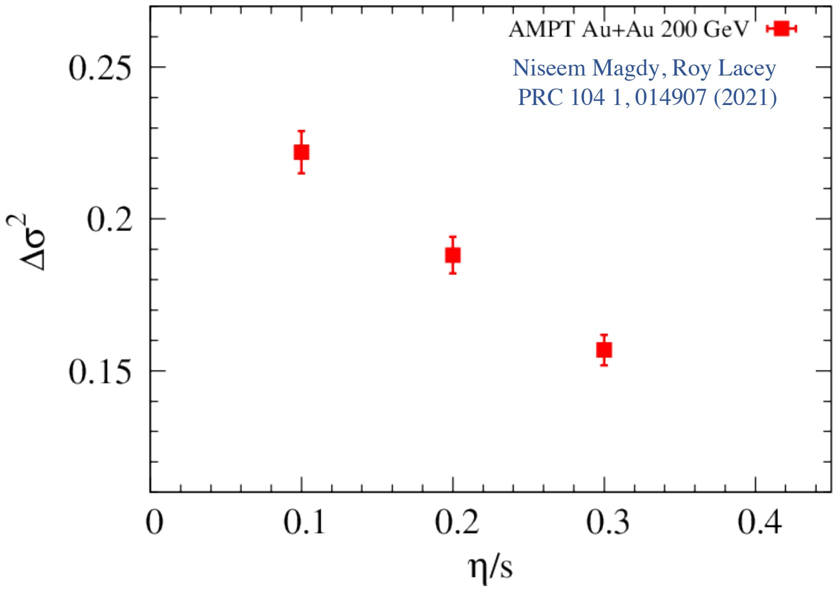
STAR Collaboration PLB 704 (2011) 467–473

Motivation:

AMPT-set	η/s	String Melting Mechanism
Set-1	0.1	OFF
Set-2	0.1	ON
Set-3	0.3	ON



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

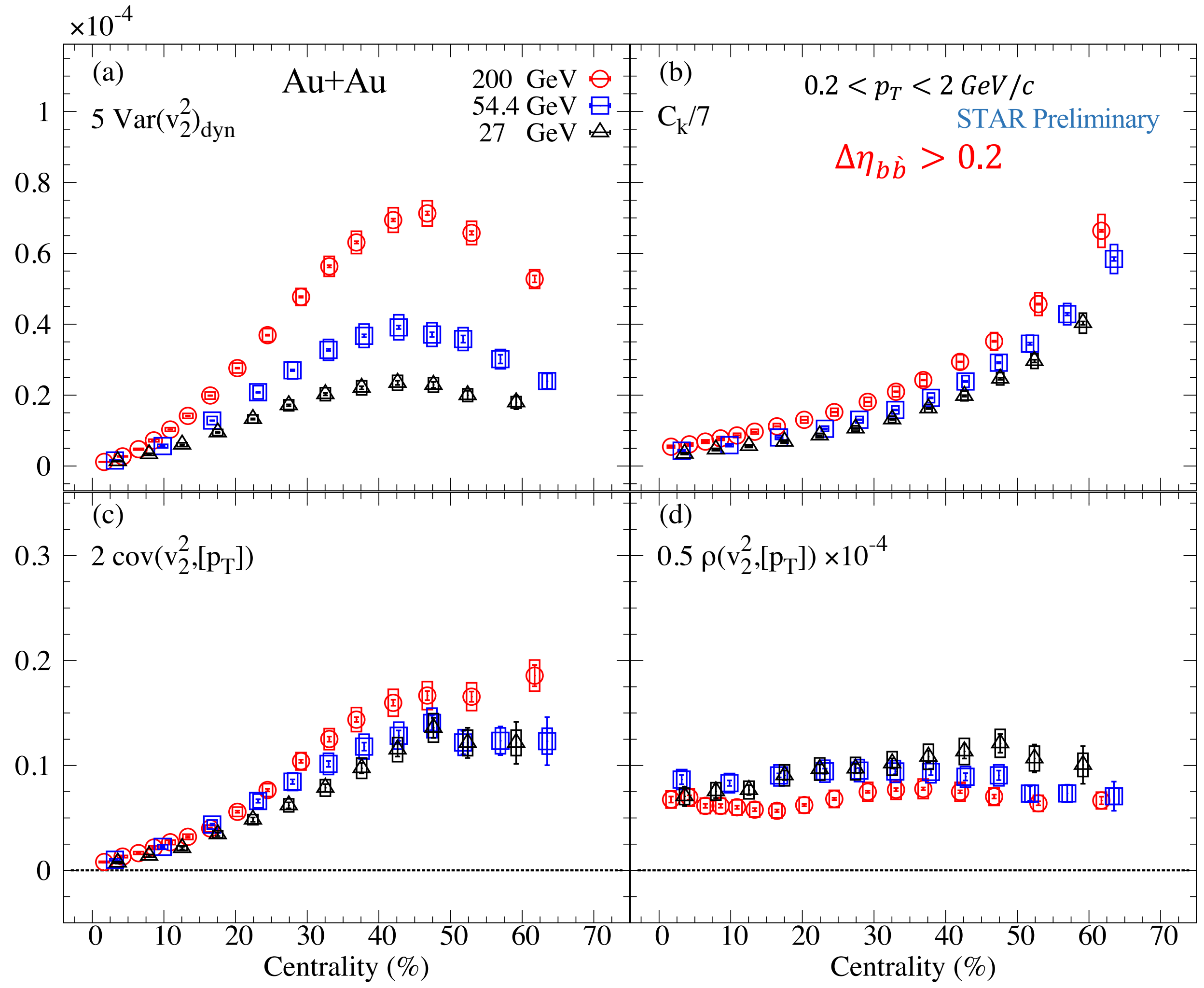


- $\rho(v_2^2, [p_T])$ values show little, if any, change with η/s, suggesting that $\rho(v_2^2 - [p_T])$ is dominated by initial state effects
- $\Delta\sigma^2$ values show a strong η/s synsitivety

❖Transverse momentum-flow correlations:

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

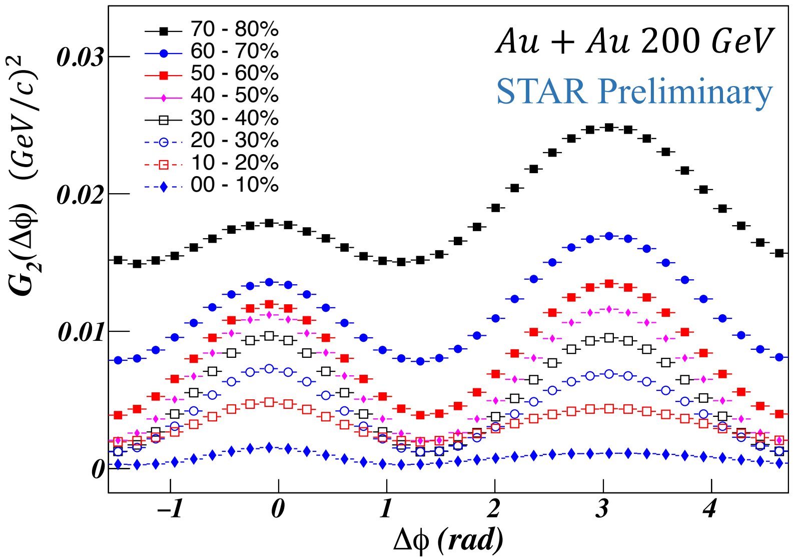


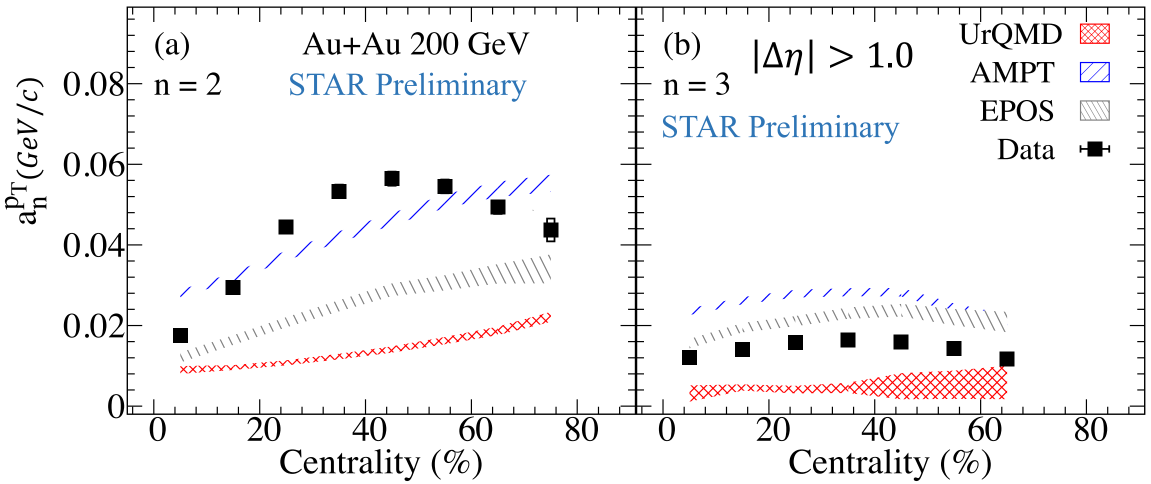
➢ The Pearson correlation, $\rho(v_2^2, [p_T])$, increases with decreasing the beam-energy

Investigations of the $p_T - p_T$ correlations from STAR

➢ The azimuthal correlations for Au+Au at 200 GeV

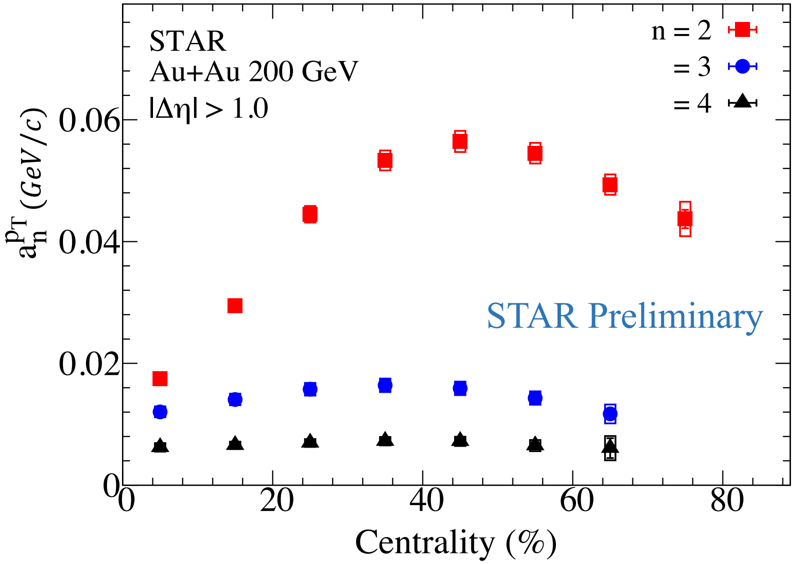
$$G_2(\Delta\varphi) = A_0^{p_T} + 2\sum_{n=1}^{6} A_n^{p_T} \cos(n\,\Delta\varphi) \qquad a_n^{p_T} = \sqrt{A_n^{p_T}}$$





➢ The extracted $a_n^{p_T}$:

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

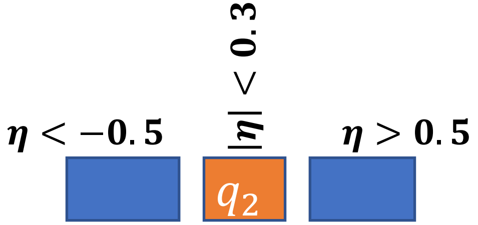


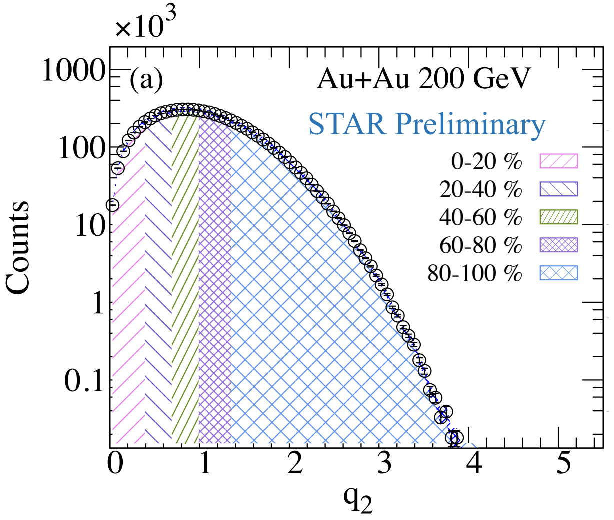
$$Q_{2,x} = \sum_{i=1}^{M} \cos(2\,\varphi_i)$$

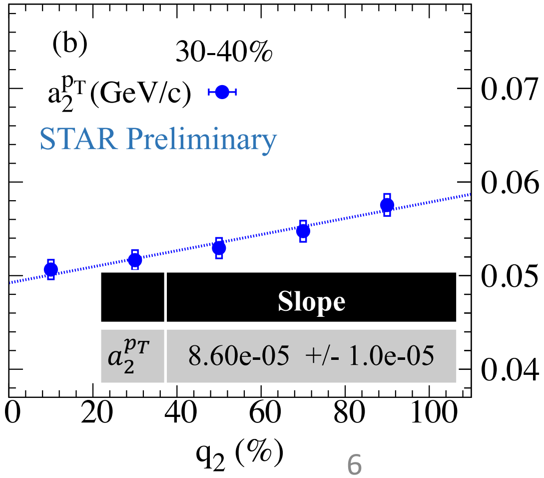
$$Q_{2,y} = \sum_{i=1}^{M} \sin(2\,\varphi_i)$$

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

➢ q_2 is separated from particle of interest

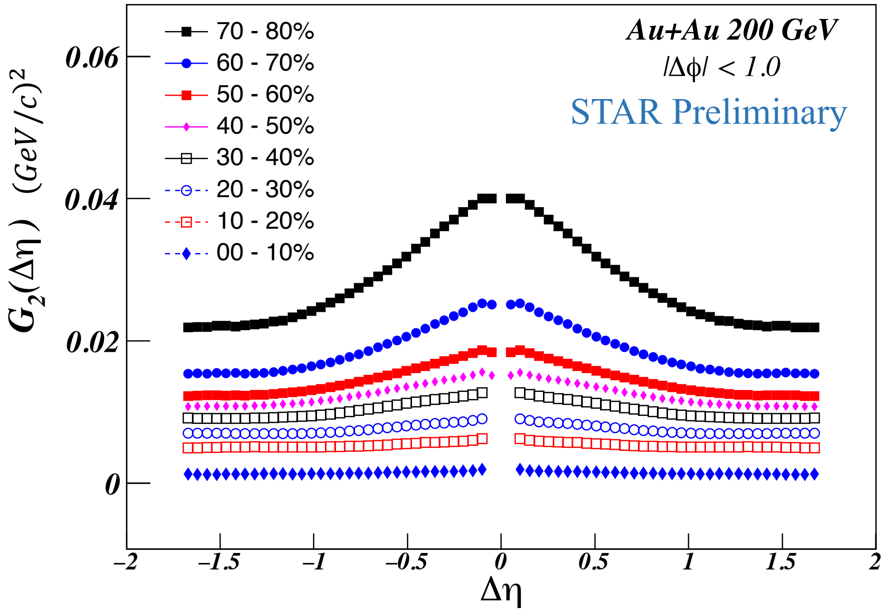






Investigations of the $p_T - p_T$ correlations from STAR

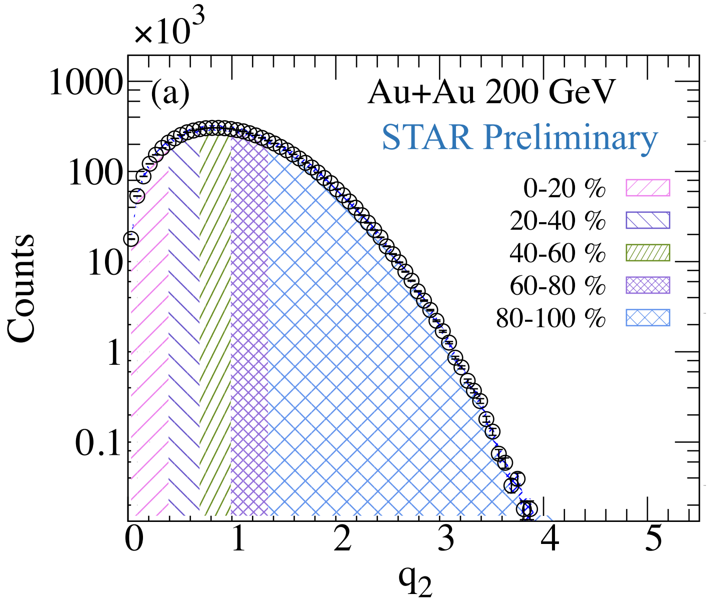
- ➢ The longitudinal correlations for Au+Au at 200 GeV

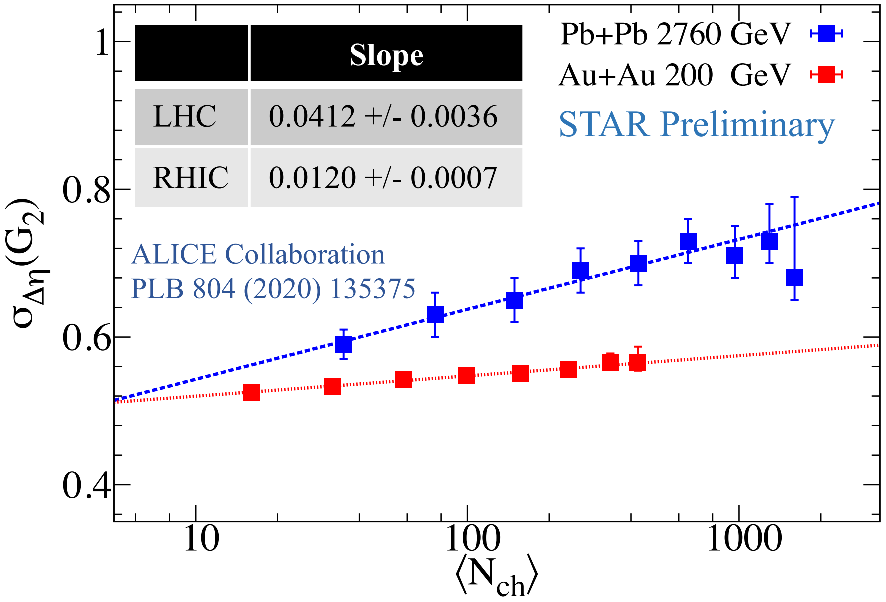


$$\sigma_{\Delta\eta}(G_2) = RMS[G_2(\Delta\eta)]$$

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

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

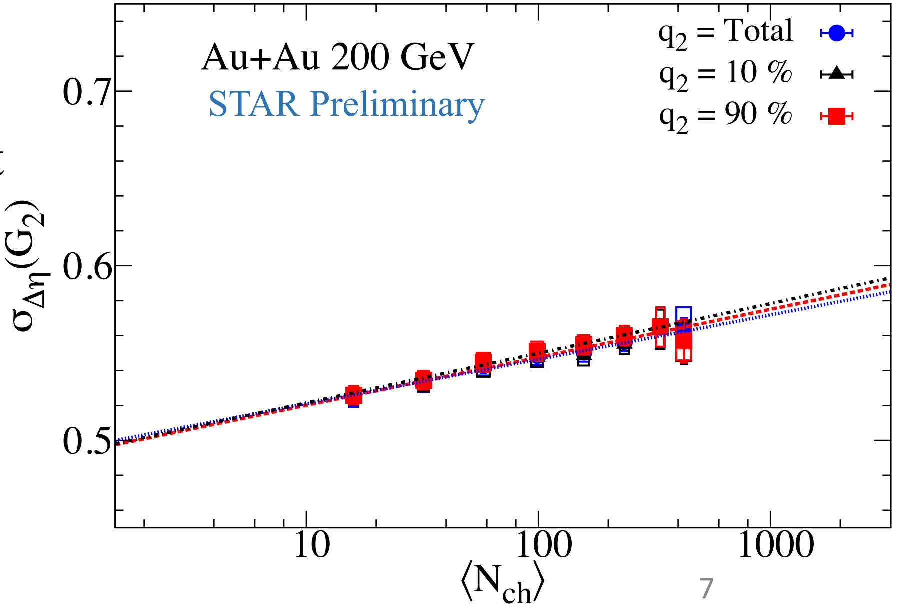




	Slope
LHC	0.0412 +/- 0.0036
RHIC	0.0120 +/- 0.0007

- ➢ 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



Conclusions

STAR

We studied the transverse momentum-flow correlations as well as the transverse momentum 2-P correlations;

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

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

- The extracted $a_n^{p_T}$:
  - ✓ Decrease with harmonic order
  - ✓ Models don't describe the $a_n^{p_T}$ data
  - ✓ Event shape dependent $a_2^{p_T}$
- 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.

Thank You

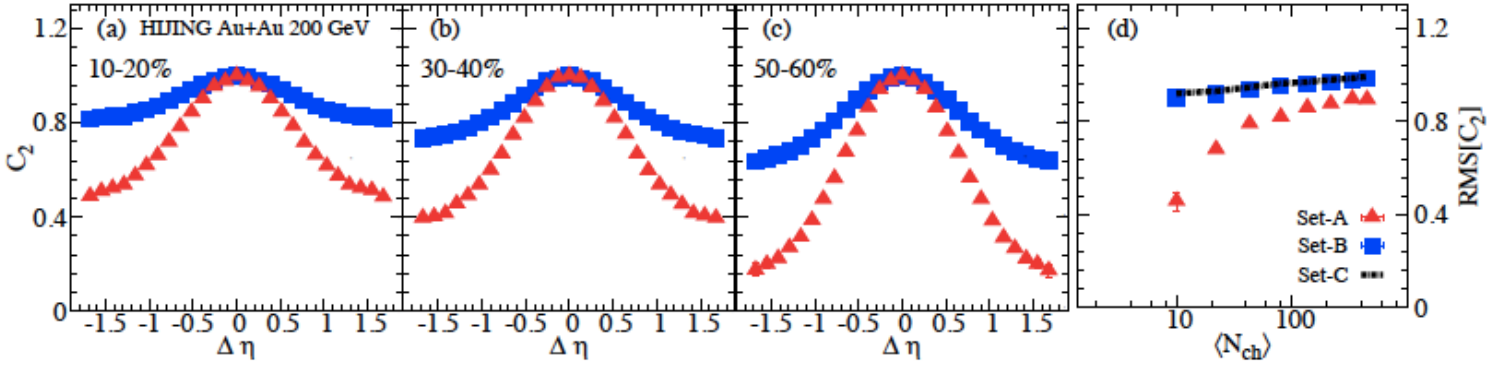
Thank You

N. Magdy and R. Lacey
PRC 104 1, 014907 (2021)

- The p_T 2-P correlator is given as: $G_2(\eta_1,\varphi_1,\eta_2,\varphi_2) = \frac{\left\langle \sum_{i}^{n_1}\sum_{j\neq i}^{n_2} p_{T,i}p_{T,j} \right\rangle}{\langle n_1\rangle\langle n_2\rangle} - \langle p_{T,1}\rangle_{\eta_1,\varphi_1}\langle p_{T,2}\rangle_{\eta_2,\varphi_2}$
- The first term can be given as:

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

- $r_{1,2}$ is a number correlation, it will be 1 when the particle pairs are independent.
- The $r_{1,2}$ correlations can be impacted by the centrality definition.



Comparison of the $C_2(\Delta\eta)$ correlators ($|\Delta\varphi| < 1$) obtained from 10-20%, 30-40% and 50-60% central HIJING events for Au+Au collisions at 200 GeV.

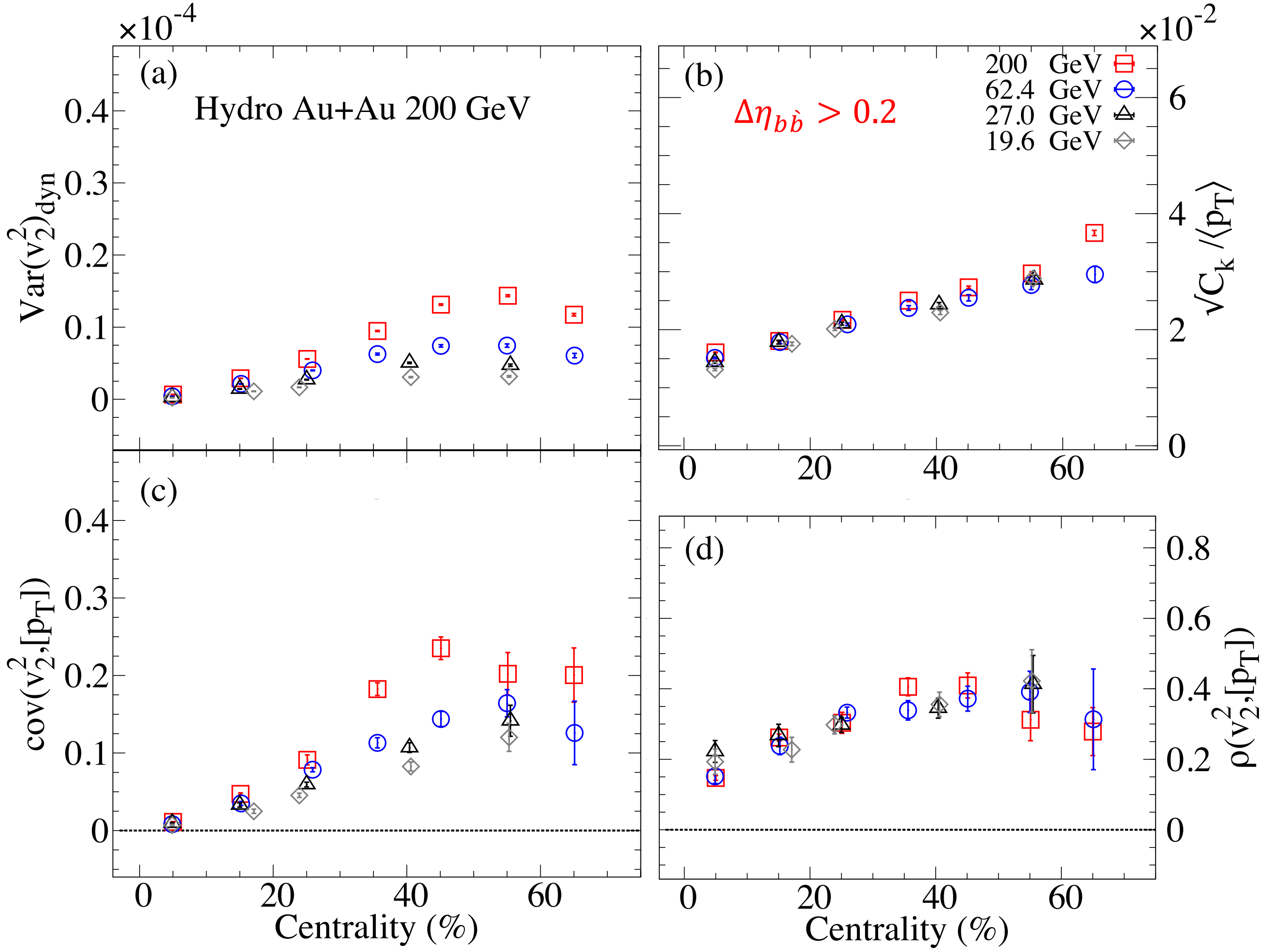
(i) Set-A: with centrality defined using all charged particles in an event,
(ii) Set-B: with centrality defined using random sampling of charged particles in an event
(iii) Set-C: with centrality defined using the impact parameter distribution.

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

❖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
- 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