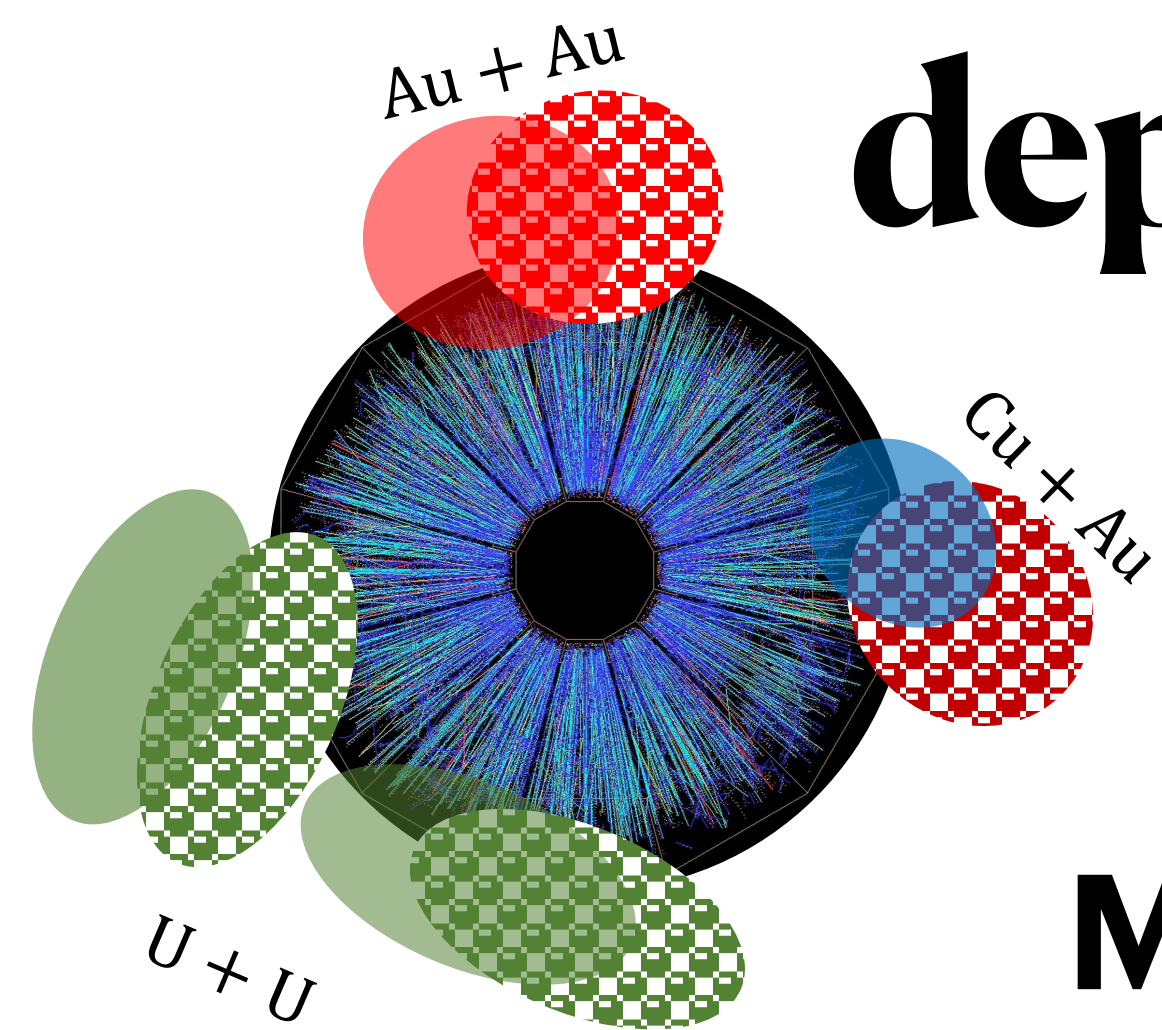


Beam-energy and collision-system size dependence of the anisotropic flow measurements



Maria Stefaniak for STAR Collaboration

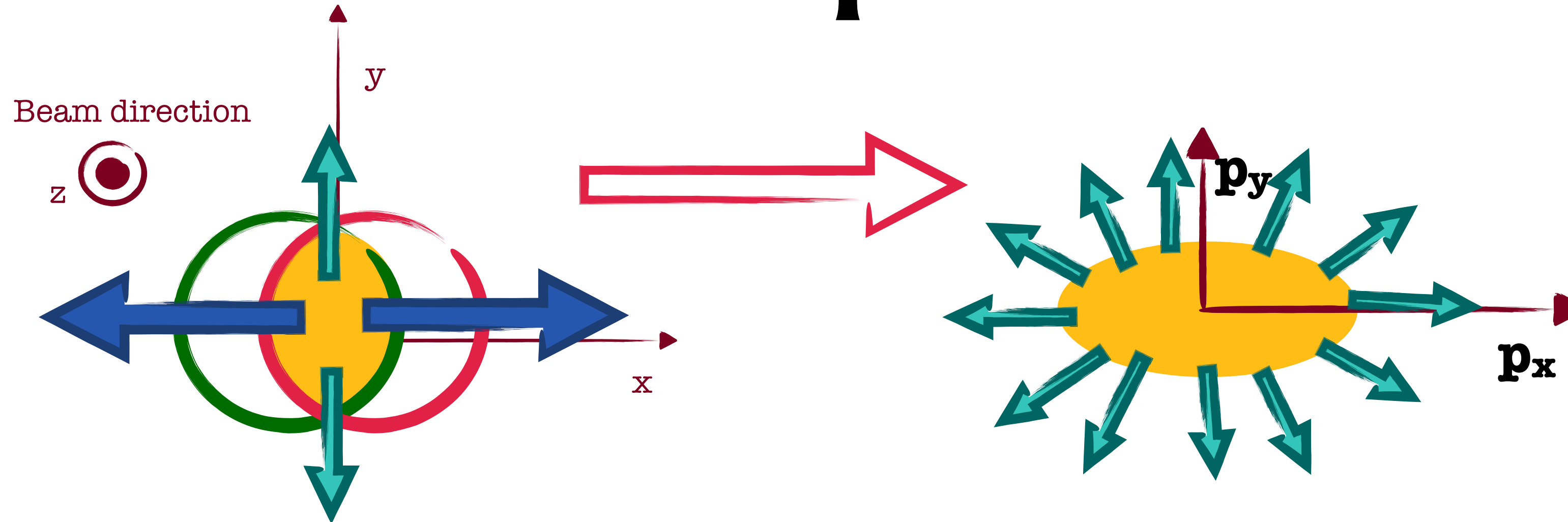


Faculty of Physics

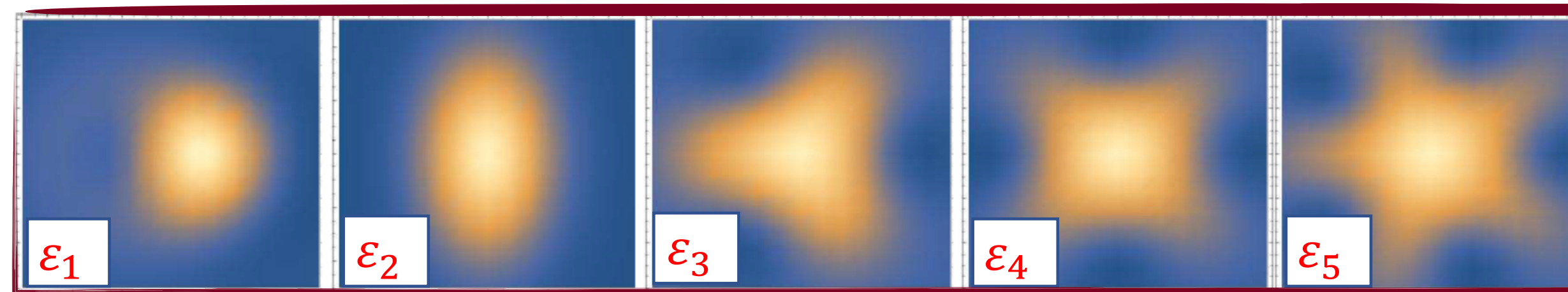
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Anisotropic flow



Anisotropy in initial geometry → **Final-state momentum anisotropy**

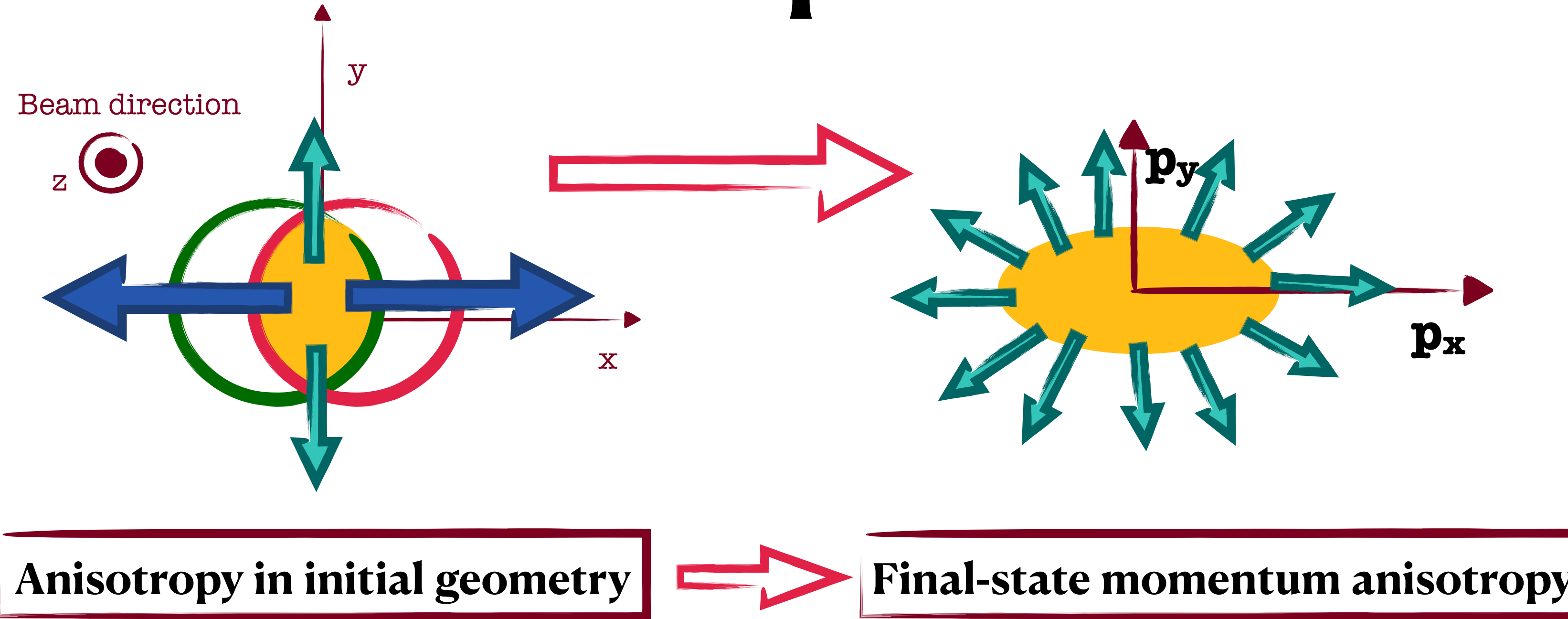


Anisotropic flow measurements are sensitive to:

- Initial-state spatial anisotropy
- Flow fluctuations and correlations
- Transport properties (i.e., $\frac{\eta}{s}$, $\frac{\zeta}{s}$, $\frac{\hat{q}}{T^3}$, ...)

What are the respective roles of ϵ_n and its fluctuations, flow correlations and transport properties on the v_n ?

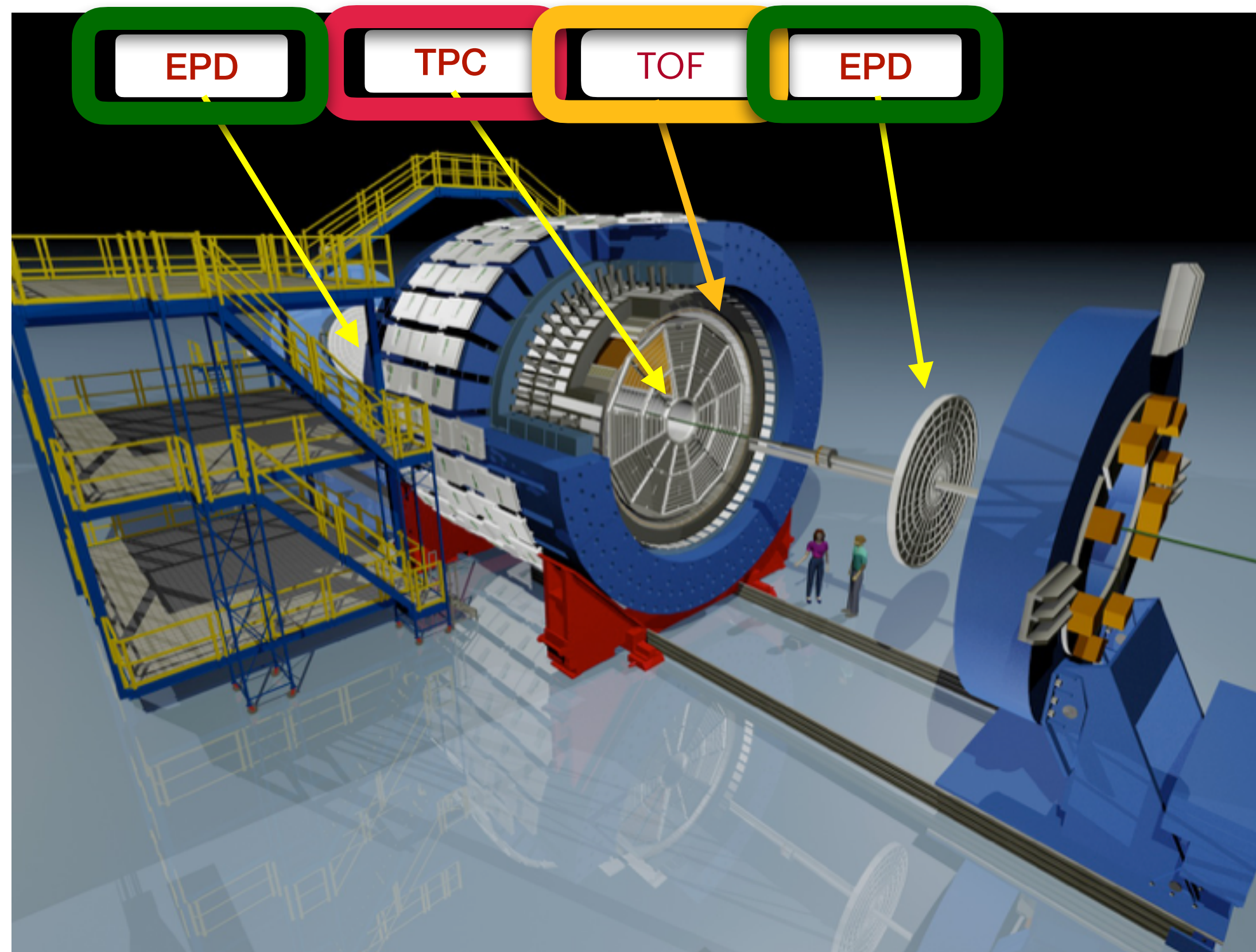
Anisotropic flow



Outline:

- Flow decorrelation
- PID flow harmonics
- High p_T flow harmonics

The Solenoid Tracker At RHIC Experiment



Time Projection Chamber

Tracking charged particles with:

- Full azimuthal coverage
- $|\eta| < 1$ coverage
- Particle Identification

Time-Of-Flight

- Particle identification (high momentum)

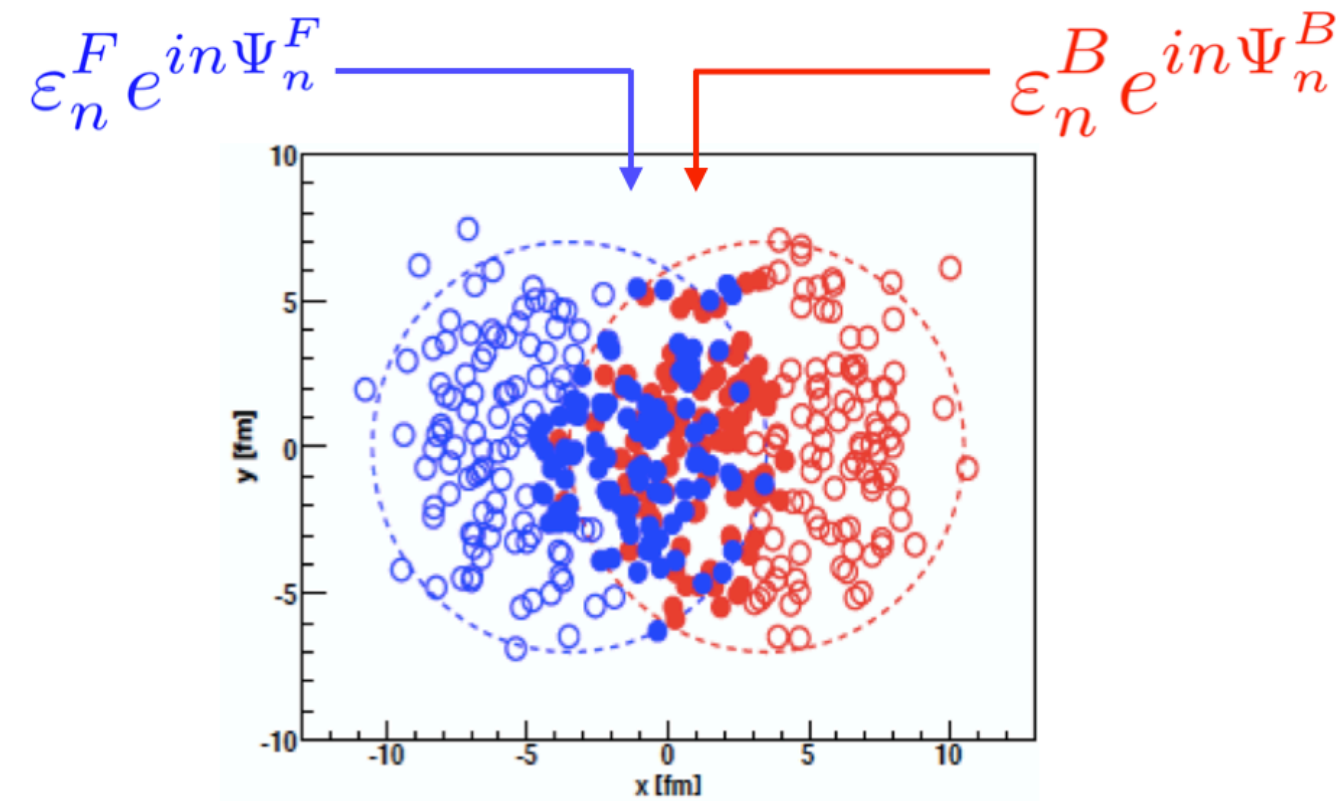
Event Plane Detector

- Acceptance : $2.1 < |\eta| < 5.1$.

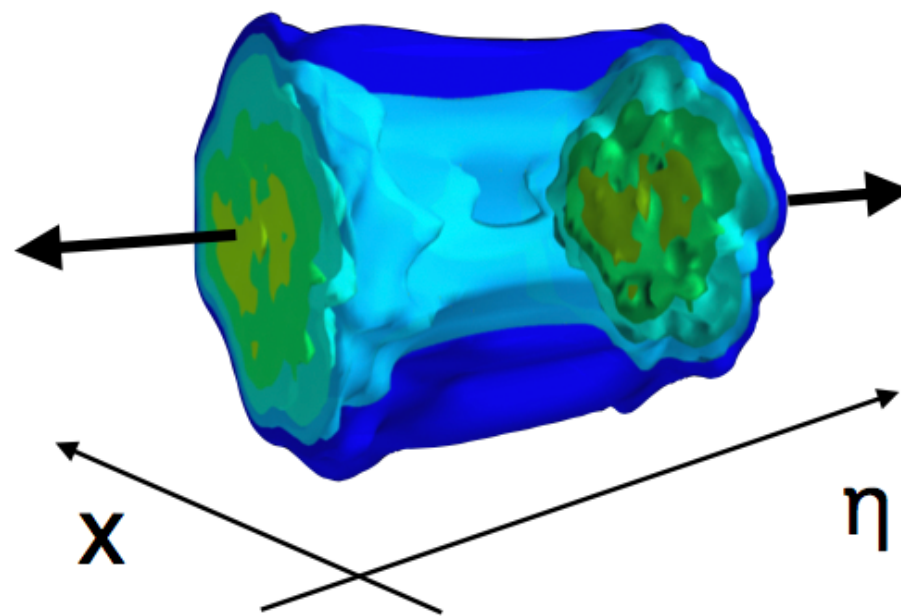
Longitudinal flow correlations

For more information please see **Maowu Nie** poster:
<https://indico.cern.ch/event/854124/contributions/4135474/>

- ◆ Fluctuation of sources in two nuclei



- ◆ Evolution of the QGP in (3+1)D



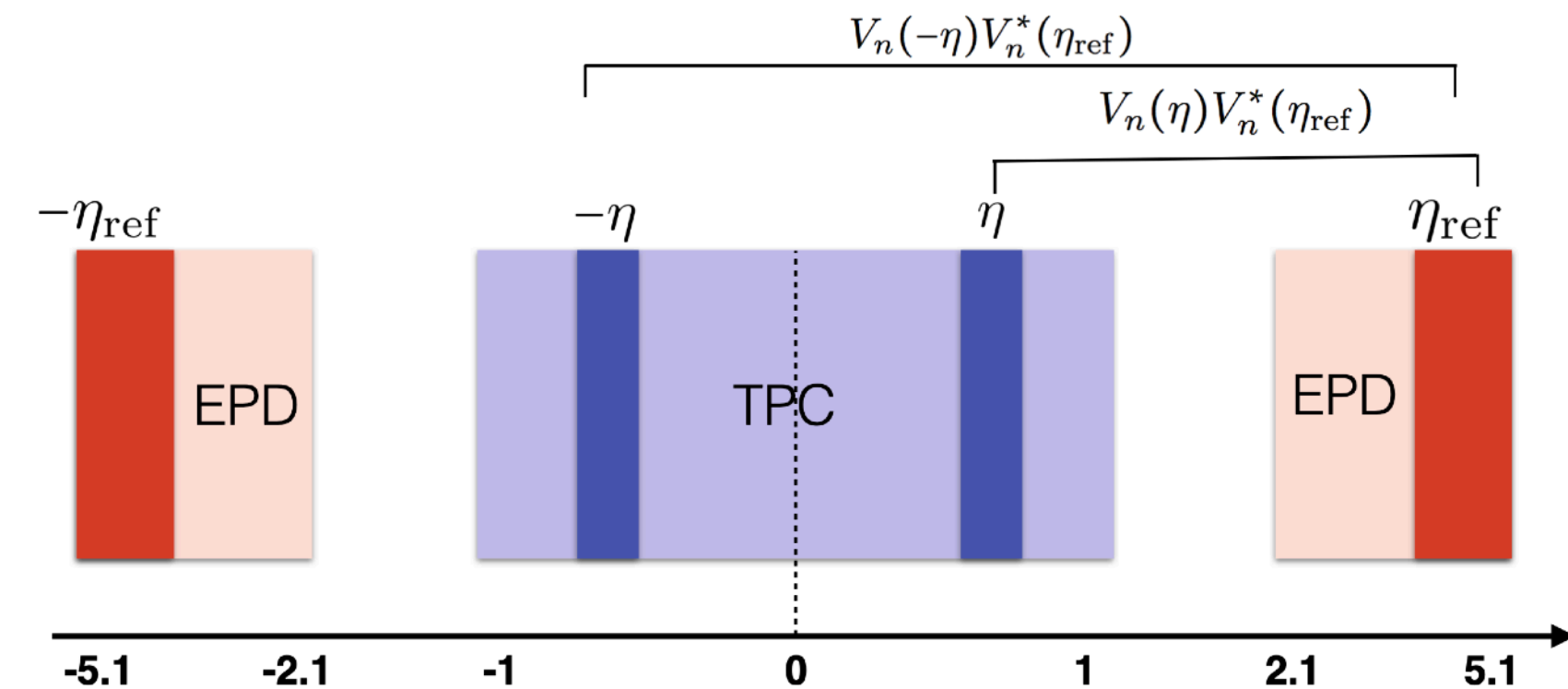
Longitudinal dynamics can provide the full space-time evolution of the fireball.

- ◆ Factorization ratio, r_n , is constructed as a measure of the flow decorrelation

CMS Collaboration: Phys. Rev. C 92 (2015) 034911

$$\begin{aligned}
 r_n(\eta) &= \frac{\langle V_n(-\eta) V_n^*(\eta_{\text{ref}}) \rangle}{\langle V_n(\eta) V_n^*(\eta_{\text{ref}}) \rangle} \\
 &= \frac{\langle v_n(-\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(-\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}{\langle v_n(\eta) v_n(\eta_{\text{ref}}) \cos n(\Psi_n(\eta) - \Psi_n(\eta_{\text{ref}})) \rangle}
 \end{aligned}$$

- ◆ r_n measures relative fluctuation between $v_n(-\eta)$ and $v_n(\eta)$

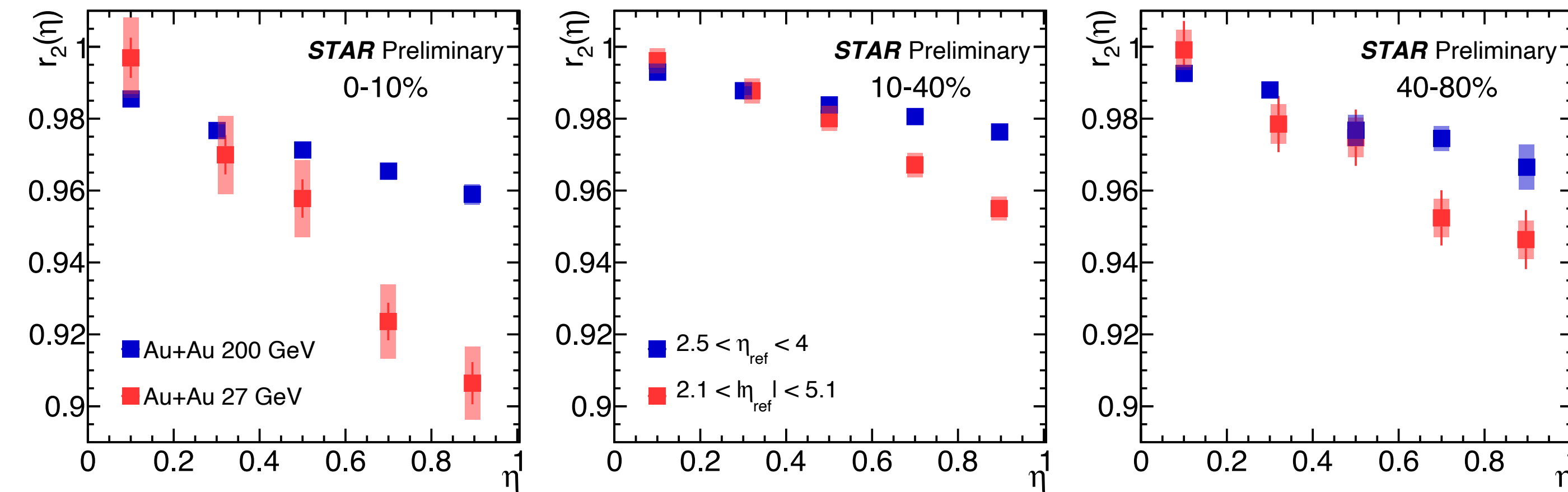


A large η gap is imposed to avoid short-range correlations.

Longitudinal flow correlations

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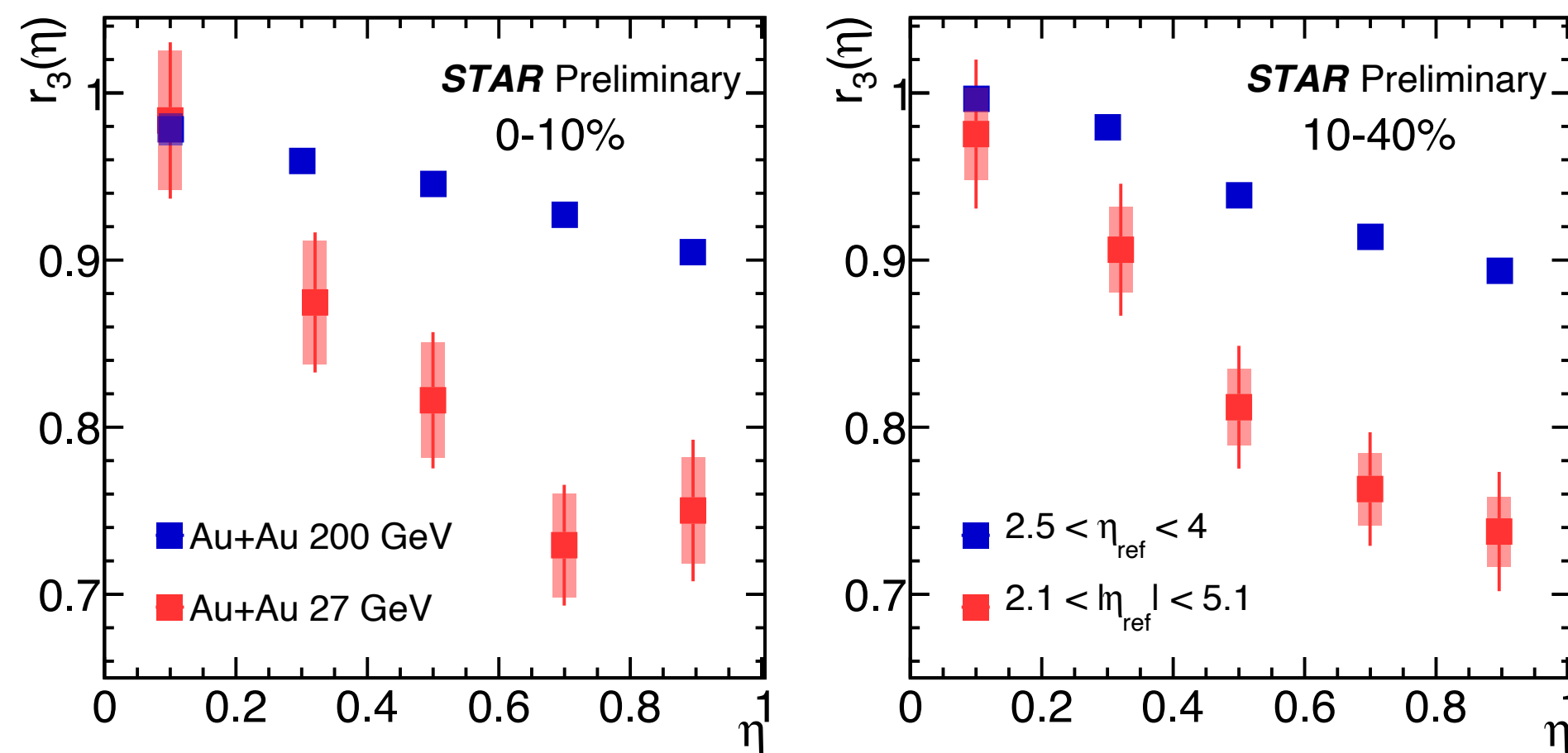
Energy dependence of v_2 decorrelation



r_2 comparison between 27 GeV and 200 GeV

- ◆ Strongest v_2 decorrelation at 27 GeV is observed for all shown centralities.
- ◆ v_2 decorrelation at 27 GeV is ~ 2 times larger than at 200 GeV.

Energy dependence of v_3 decorrelation



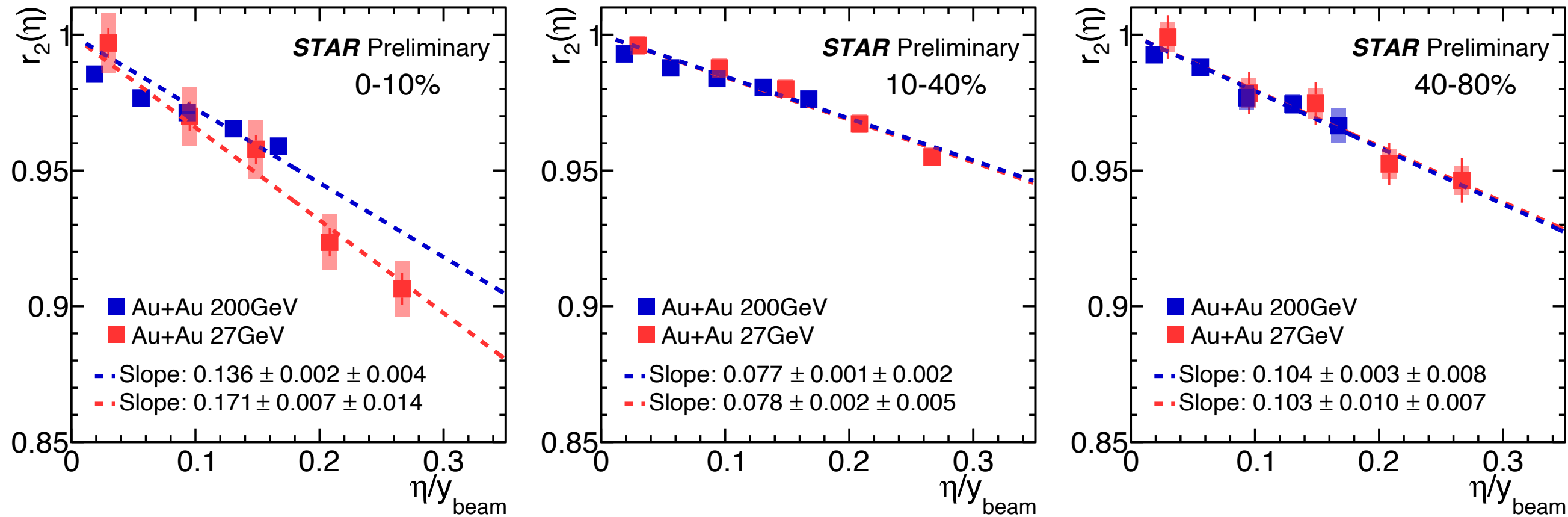
r_3 comparison between 27 GeV and 200 GeV

- ◆ Stronger v_3 decorrelation at 27 GeV is observed for the two centralities.

Longitudinal flow correlations

For more information please see **Maowu Nie** poster:
<https://indico.cern.ch/event/854124/contributions/4135474/>

v_2 decorrelation scaled by beam rapidity

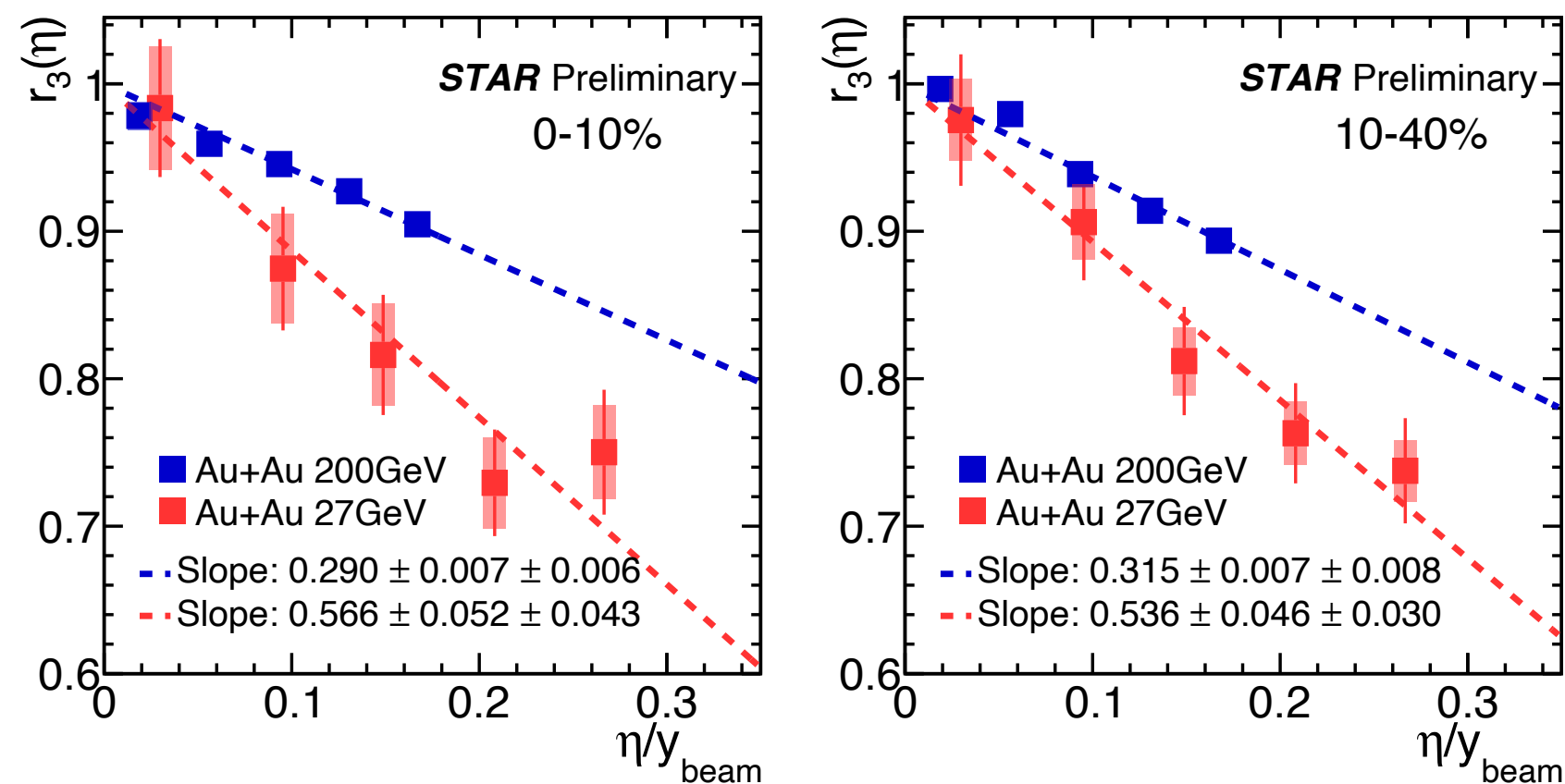


r_2 comparison between 27 GeV and 200 GeV with rapidity normalization

Even after y_{beam} normalization, r_2 shows:

- ◆ 0-10% weak energy dependence;
- ◆ 10-40% & 40-80% no energy dependence.

v_3 decorrelation scaled by beam rapidity



r_3 comparison between 27 GeV and 200 GeV with rapidity normalization

- ◆ Stronger v_3 decorrelation at 27 GeV after y_{beam} normalization...

Identified hadrons flow harmonics:

Integrated flow harmonics

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

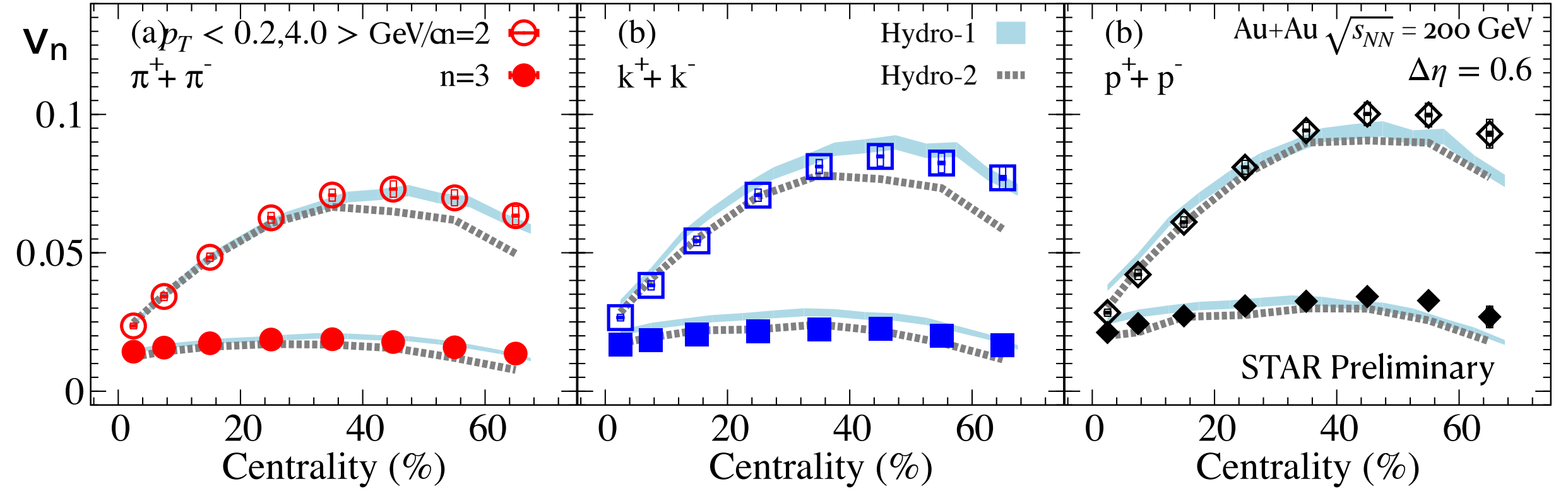
2-particle correlations (2PC)

$$c_n\{2\} = \langle\langle 2 \rangle\rangle_{a|b} = \langle\langle e^{in(\phi_1^a - \phi_2^b)} \rangle\rangle = \frac{\langle\langle Q_{n,a} Q_{n,b}^* \rangle\rangle}{\langle\langle M_a M_b \rangle\rangle}$$

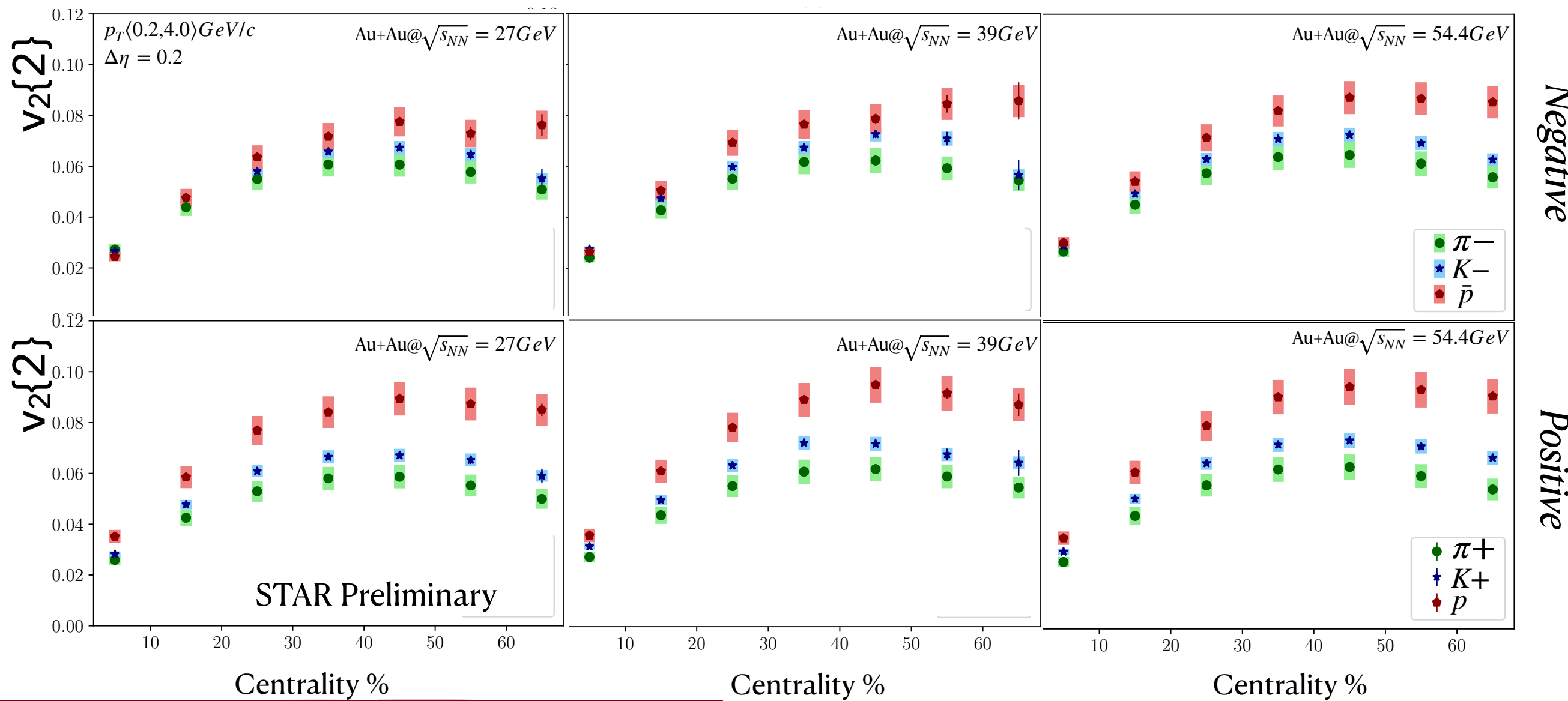
○ The non-flow contribution is reduced with $\Delta\eta$ gap

Integrated & **p_T (PID) - differential flow harmonics**

$$v_n\{2\} = \sqrt{c_n\{2\}} \quad \& \quad v_n(p_T) = v_n^2(p_T, p_T^{ref}) / \sqrt{v_n^2(p_T^{ref}, p_T^{ref})}$$



- Both hydro simulations reproduce qualitatively v_n collisions for Au+Au at $\sqrt{s_{NN}} = 200$ GeV
- Eccentricity does not differ relevantly between collision energies \rightarrow differences ($\sim 5\%$) caused by transitions in transport coefficients



Excellent constrain for the hydrodynamical models

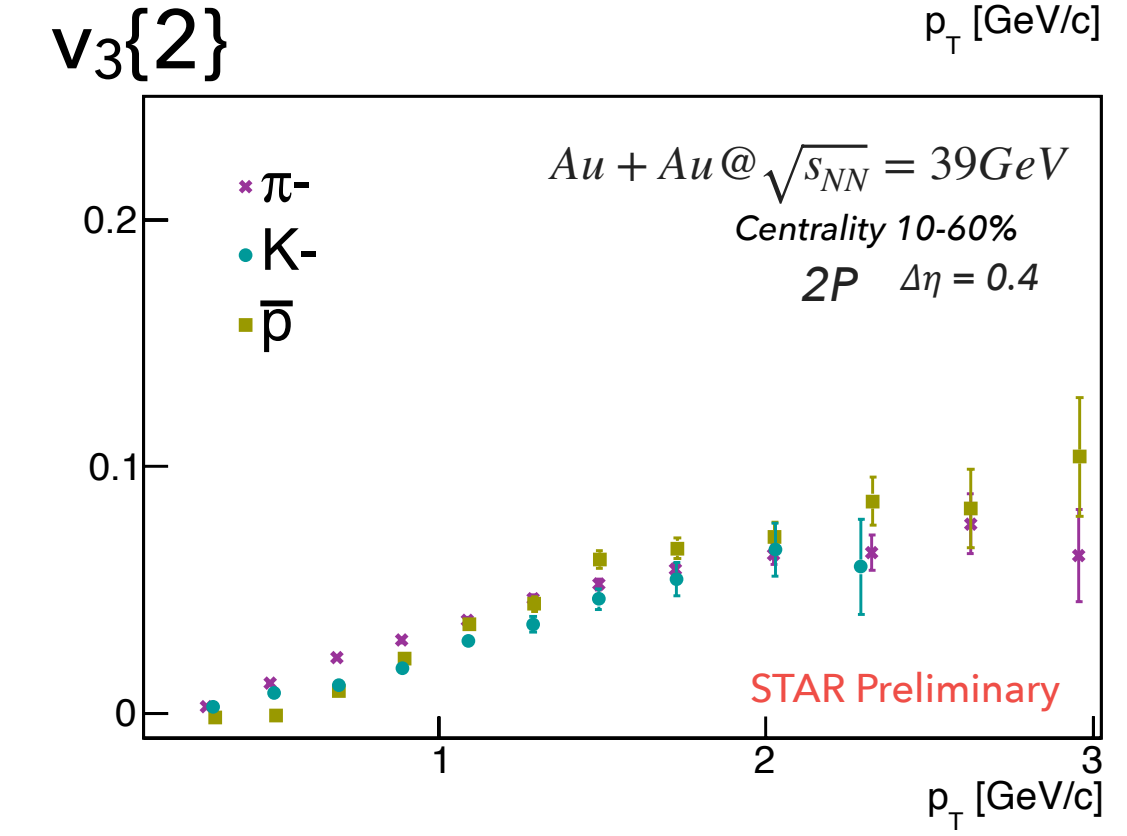
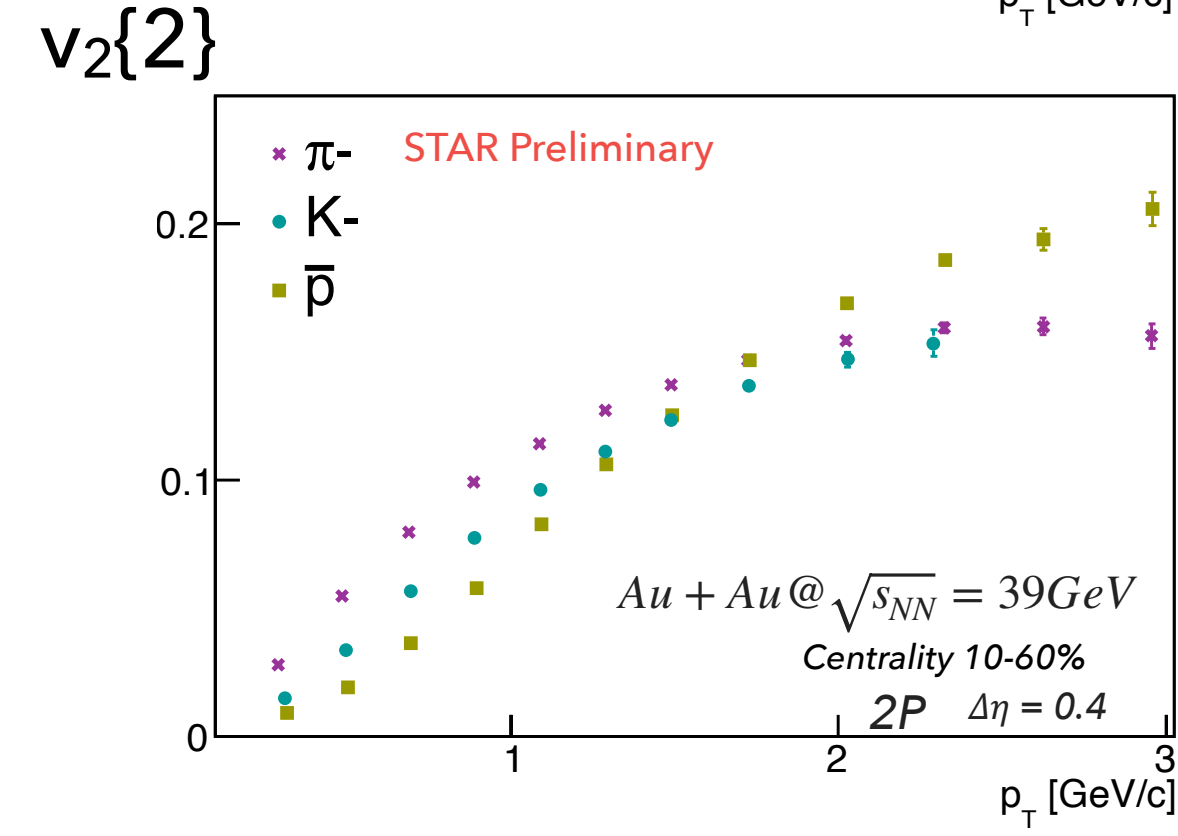
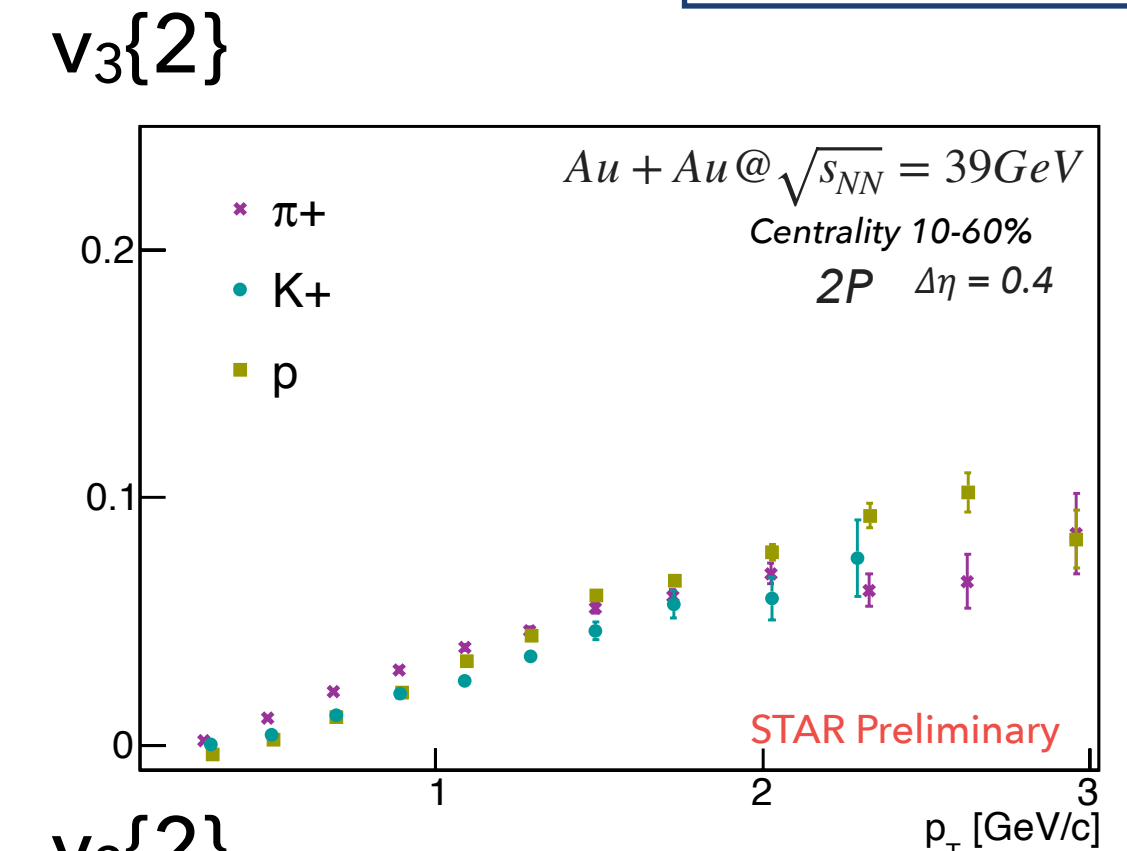
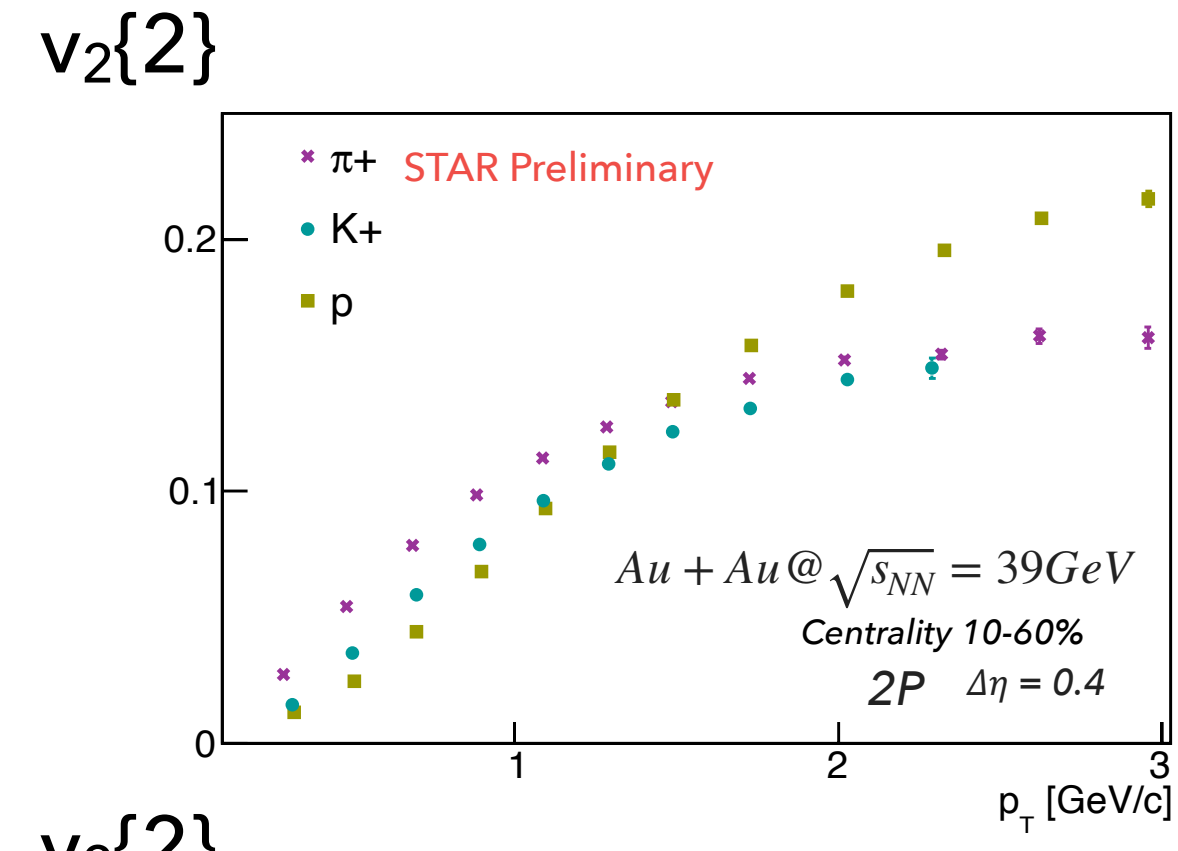
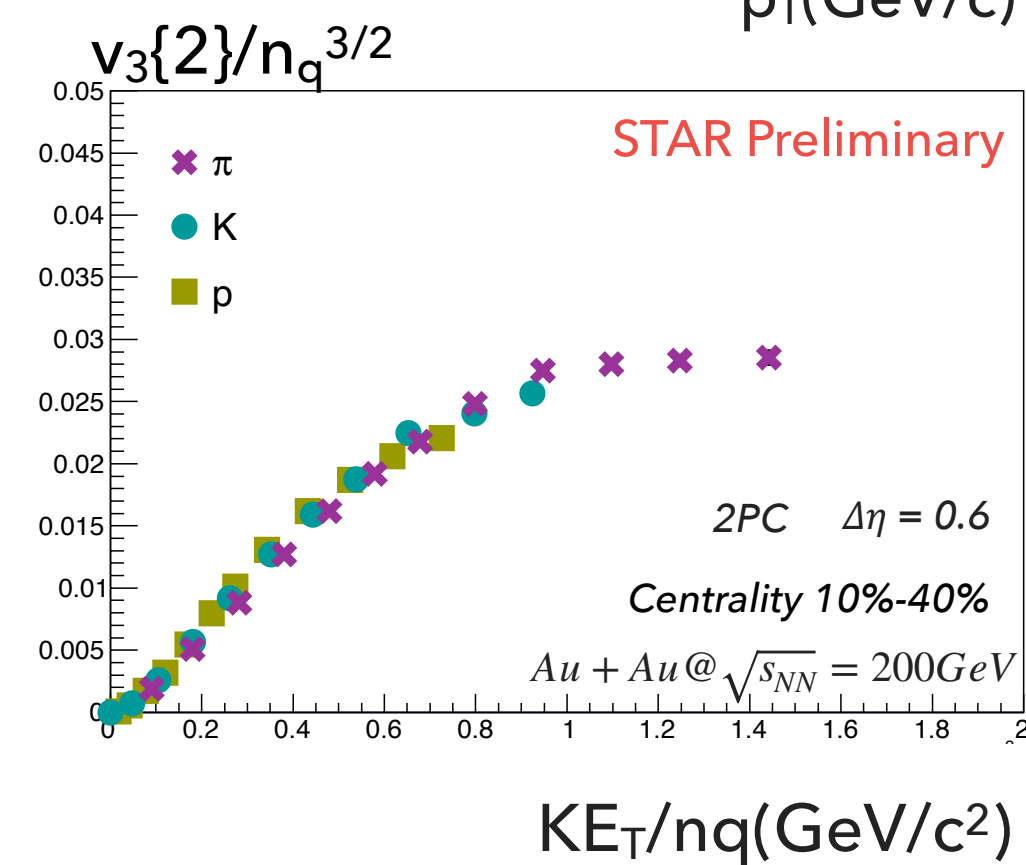
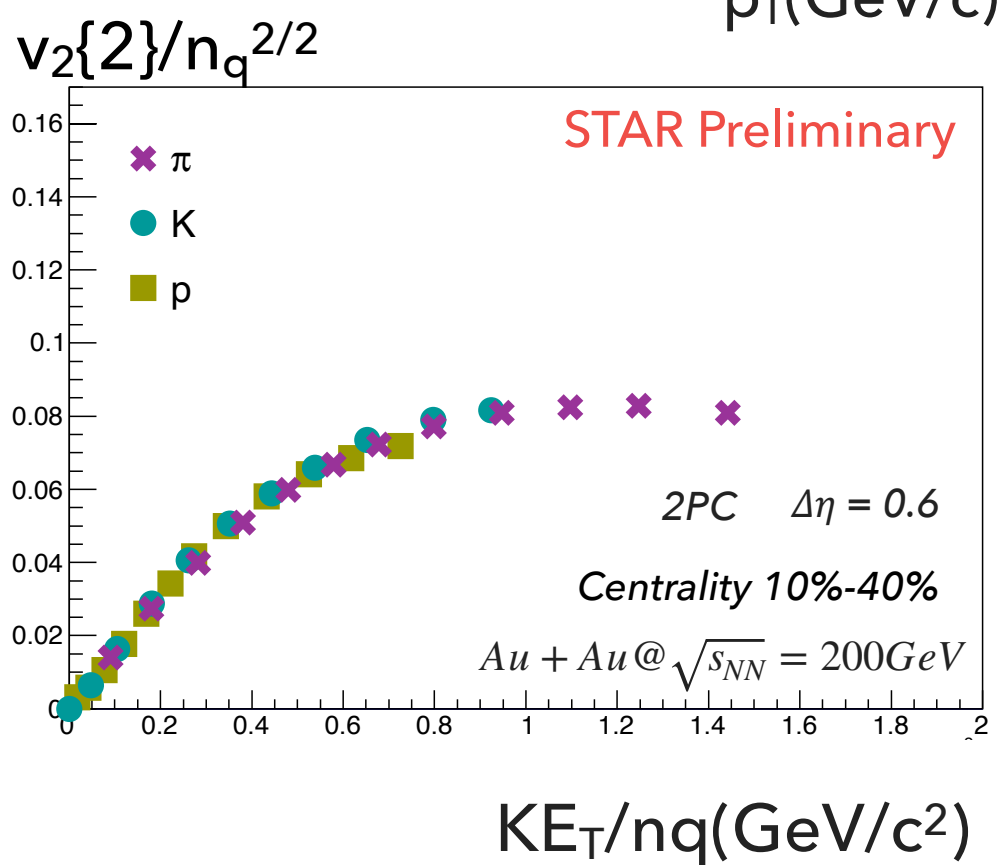
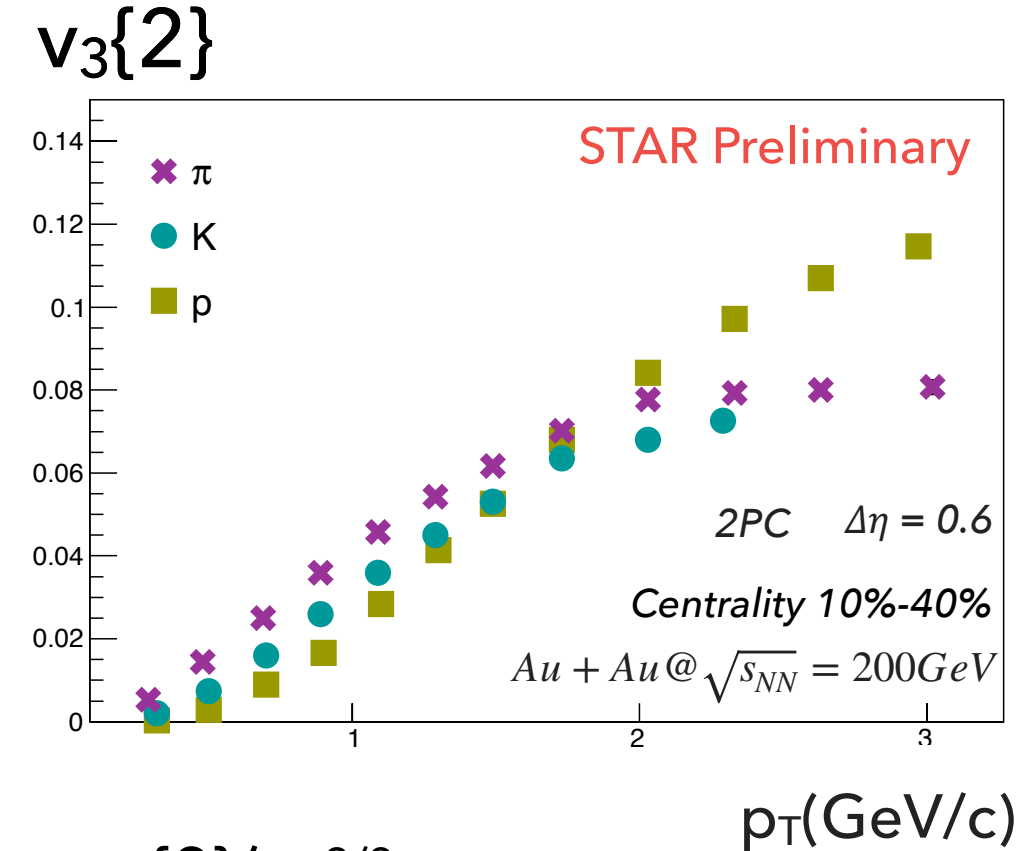
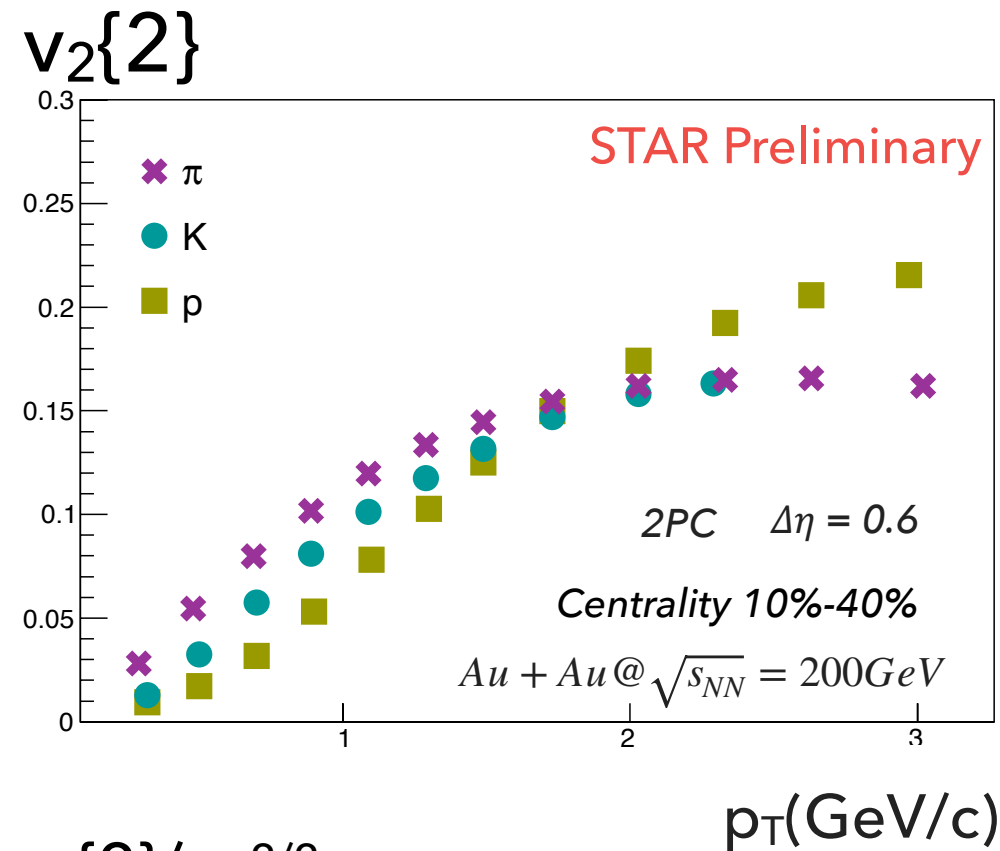


Identified hadrons flow harmonics:

p_T (PID) - differential flow harmonics

$\sqrt{s_{NN}} = 200 \text{ GeV}$

$\sqrt{s_{NN}} = 39 \text{ GeV}$

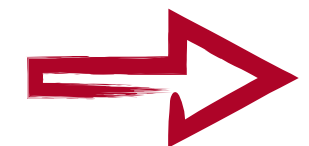


Positive

Negative

○ Visible mass ordering for both harmonics and energies

Odd ϵ_n coefficients vanish because of symmetry
 $\phi \rightarrow (-\phi)$ or $\phi \rightarrow (\phi + \pi)$

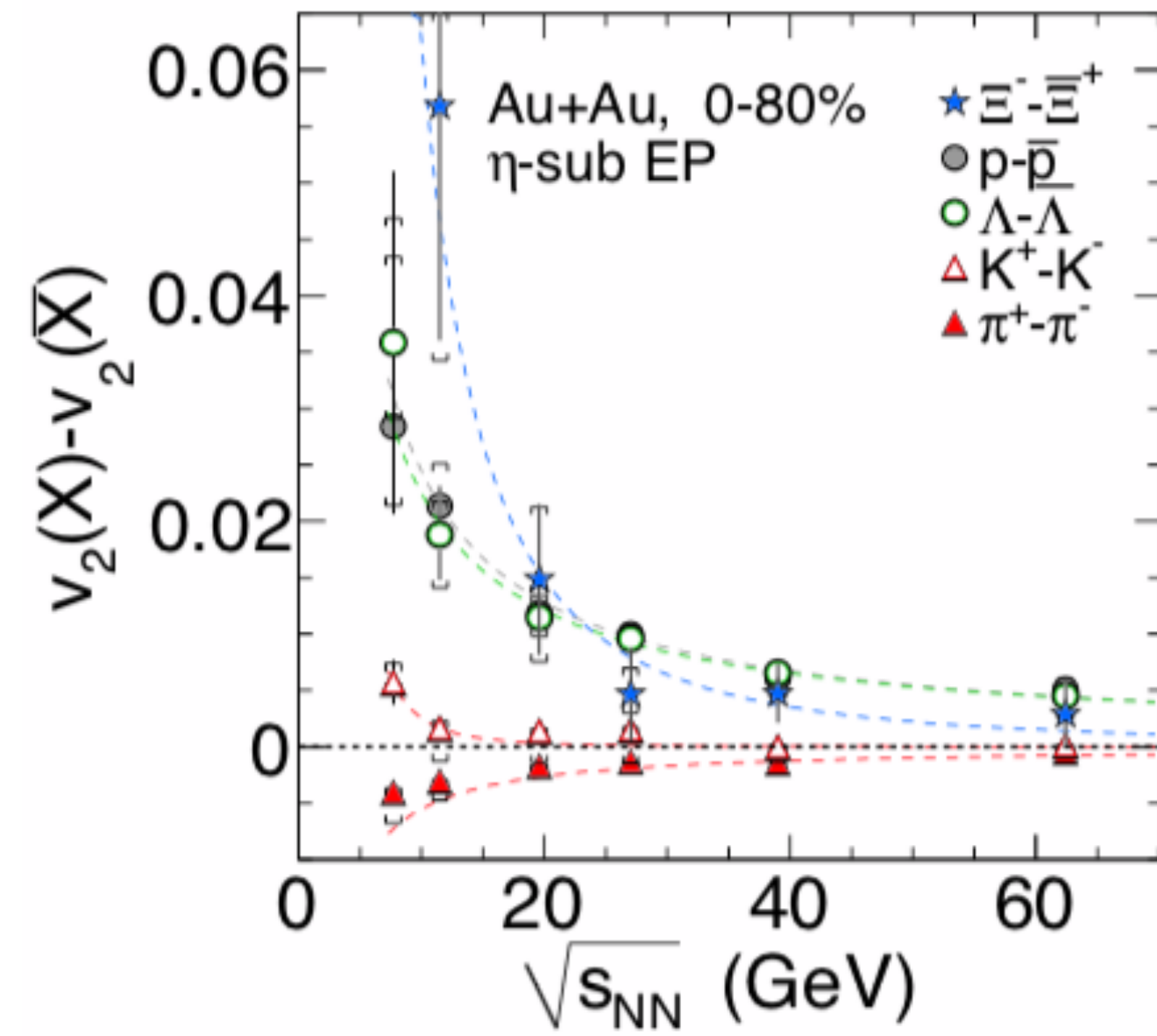


Triangular flow - more sensitive to fluctuations than elliptic flow

Significant reference for the theoretical studies of initial fluctuation and QGP



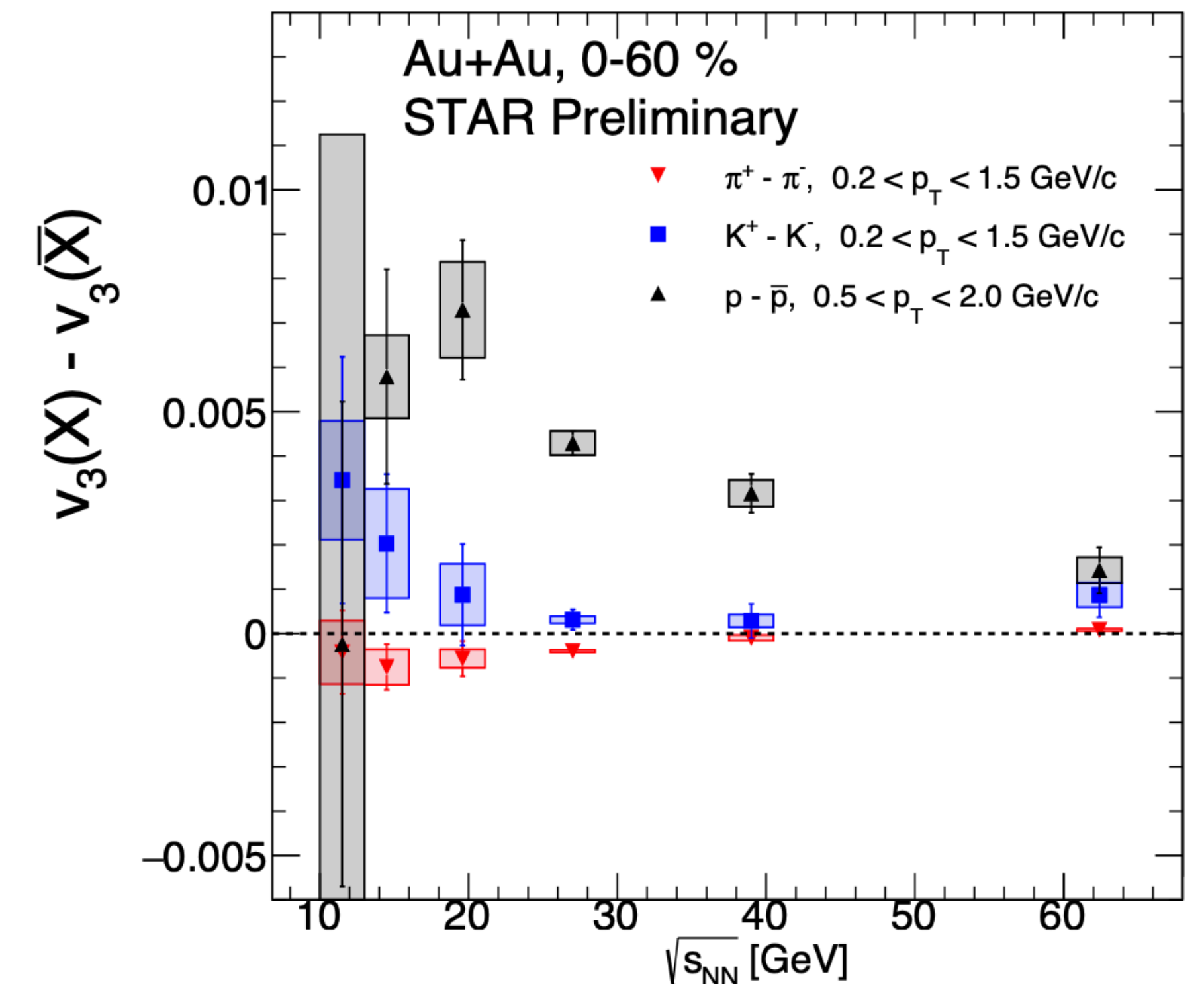
(Anti)particle v_n difference in $\sqrt{s_{NN}}$



- Difference of protons - antiprotons elliptic flow increases with decreasing collision energy

STAR Collaboration: *Phys. Rev. C* 88 (2013) 14902

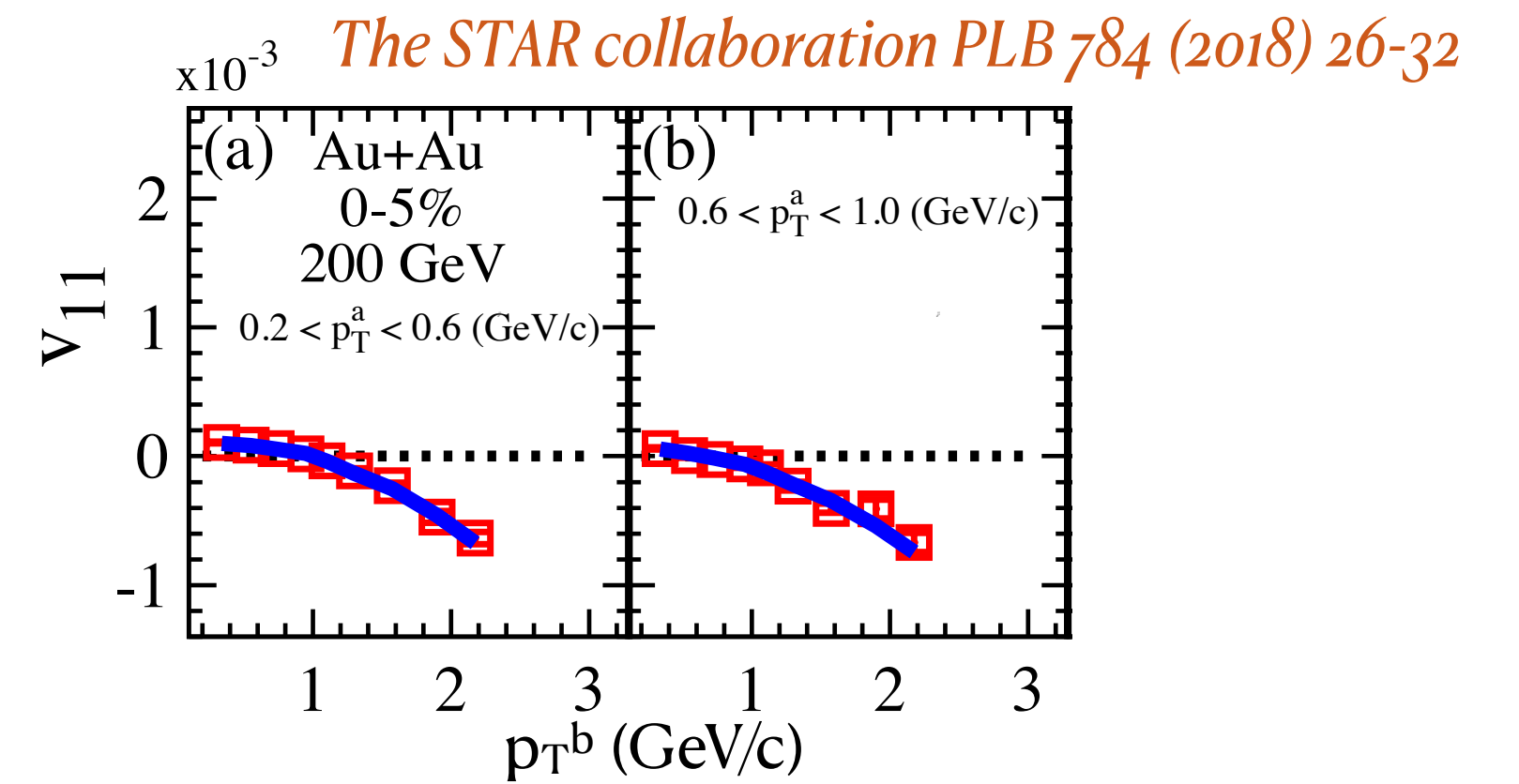
- Similar trends for differences in triangular flow



High p_T flow harmonics

For more information please see **Niseem Magdy** poster:
<https://indico.cern.ch/event/854124/contributions/4135478/>

$$v_n^{ab} = v_n^a v_n^b + \delta_{short} + \delta_{long}$$



○ The two-particle flow harmonics contains short- and long-range non-flow correlations:

- ◆ Short-range non-flow effect gets reduced using $|\Delta\eta| > 0.7$ cut
- ◆ Long-range non-flow effect gets reduced using:
 - ◆ **Peripheral Subtraction**
 - ◆ **Global Momentum Conservation**

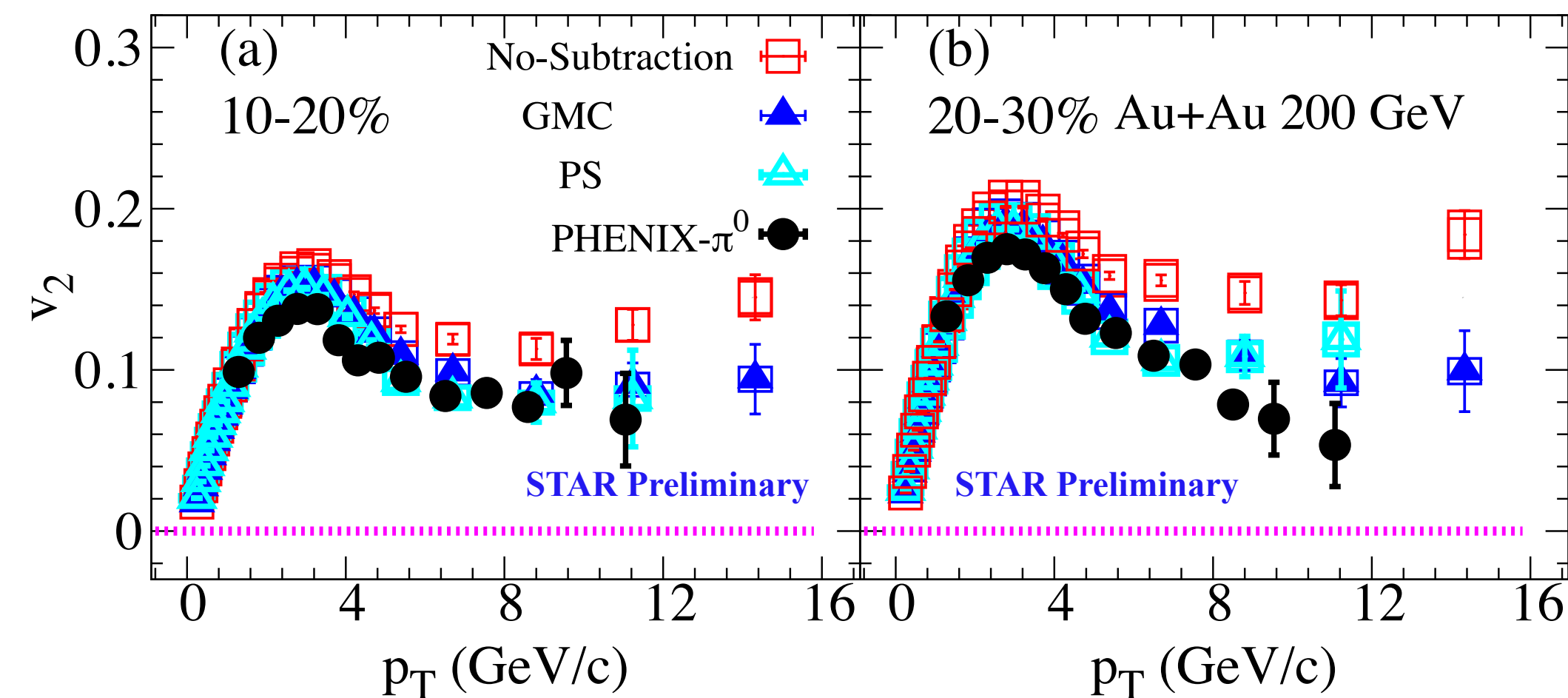
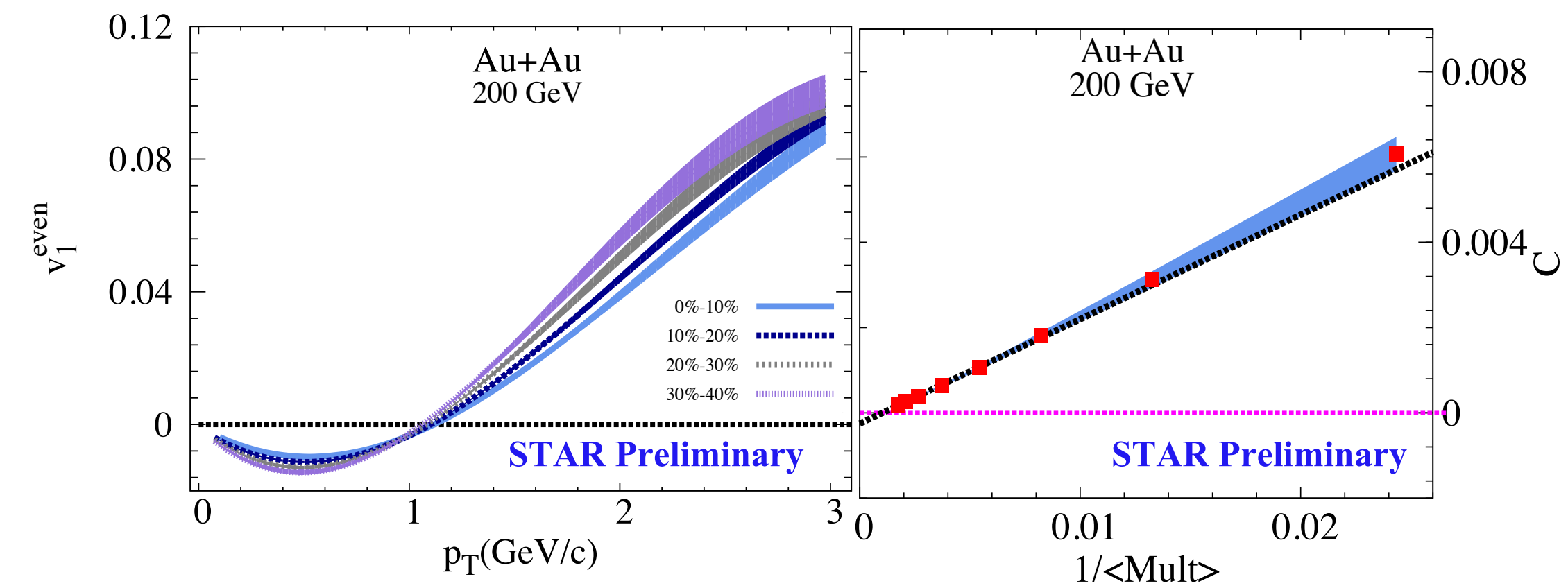
○ Peripheral Subtraction

$$v_{nn}^{PS}(p_T) = v_{nn}^{cent\%}(p_T) - \chi^{cent\%}(p_T) v_{nn}^{90\%}(p_T)$$

$$\chi^{cent\%}(p_T) = v_{11}^{cent\%}(p_T) / v_{11}^{90\%}(p_T)$$

○ Global Momentum Conservation

$$v_{nn} = v_{nn}^{flow} - K (\bar{v}_{n+1 n+1} + \bar{v}_{n-1 n-1})$$



○ Good agreement observed between;

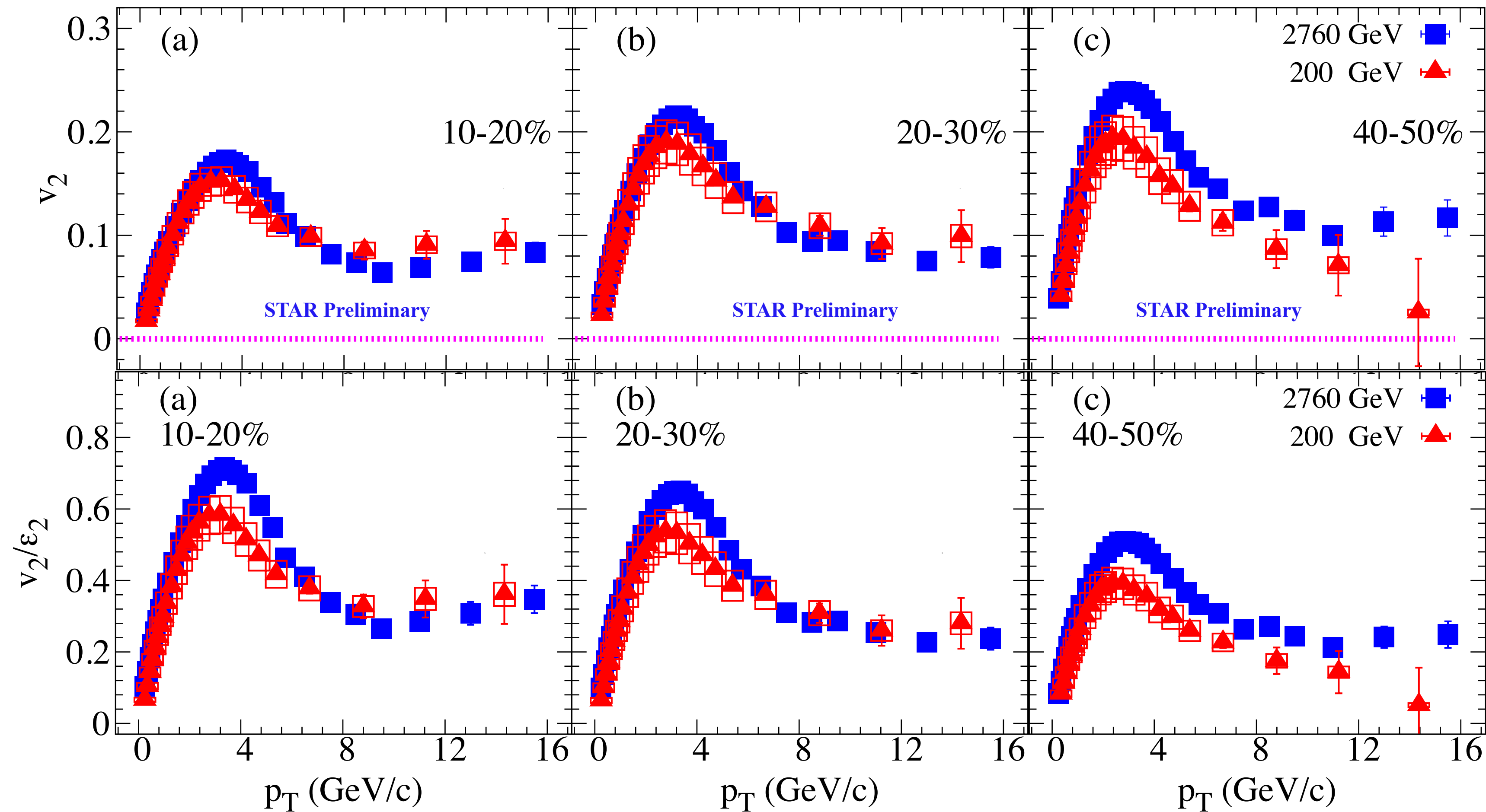
- ◆ **GMC and the peripheral subtraction methods**
- ◆ **STAR after the subtraction and PENIX π^0 measurements**



High p_T flow harmonics

For more information please see **Niseem Magdy** poster:
<https://indico.cern.ch/event/854124/contributions/4135478/>

$v_2(p_T)$ compared to similar LHC



- ◆ $v_2(p_T)$ for high and low p_T show similar trend to the LHC data
- ◆ Measurements of high p_T v_2 will add an additional constrain on energy dependance of \hat{q}/T^3

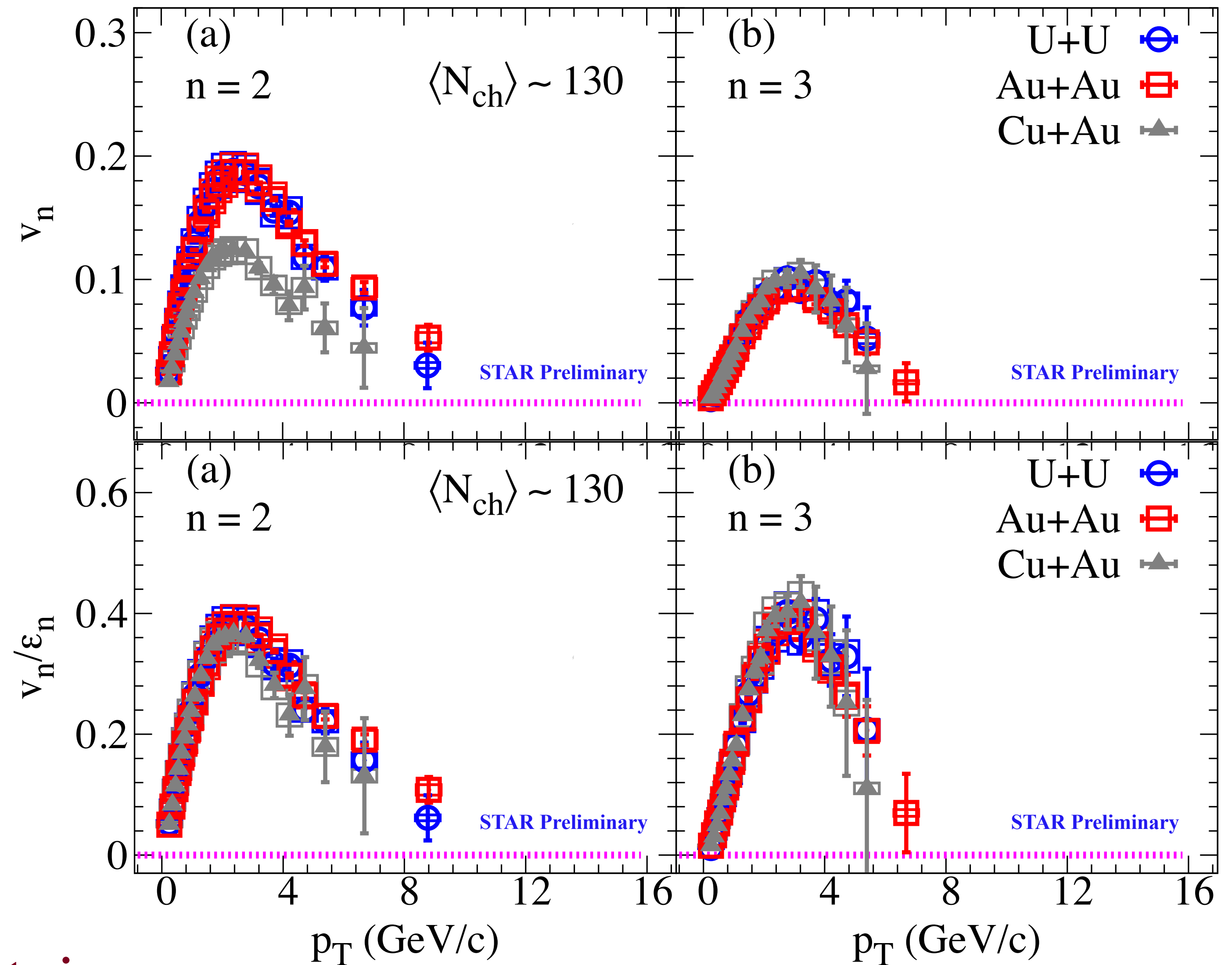
High p_T flow harmonics

For more information please see **Niseem Magdy** poster:
<https://indico.cern.ch/event/854124/contributions/4135478/>

The collision-system size dependence of $v_n(p_T)$

- $v_2(p_T)$ for high and low p_T show a collision-system size dependence
- $v_3(p_T)$ for high and low p_T are collision-system size independent
- $v_n(p_T)/\epsilon_n$ scales into one curve

◆ The $v_n(p_T)$ measurement will add additional constrain on the path length dependence of the energy loss



Summary

- Longitudinal flow decorrelations:
 - ◆ Energy dependence of longitudinal flow decorrelation at RHIC provide new constraints on longitudinal dynamics of heavy-ion collisions
 - ◆ After beam rapidity normalization, r_2 shows no clear energy dependence, while r_3 still has clear energy dependence
- Identified hadrons flow harmonics:
 - ◆ Eccentricity does not differ relevantly between examined collision energies - differences caused by transitions in transport coefficients
 - ◆ Mass ordering present for v_2 and v_3 for $\sqrt{s_{NN}} = 39$ and 200 GeV
 - ◆ Similar trends of differences between triangular flow of particles and antiparticles as in elliptic flow
- High p_T flow harmonics
 - ◆ We observe a good agreement between GMC and the peripheral subtraction methods
 - ◆ v_2 at RHIC shows a similar p_T dependence to LHC data in a wide range of p_T .
 - ◆ Our high p_T measurements will add additional constrain on the path length dependence of the energy loss.

Thank you for your attention

