Explore the Nuclei Deformation with an Expanding QGP Fireball

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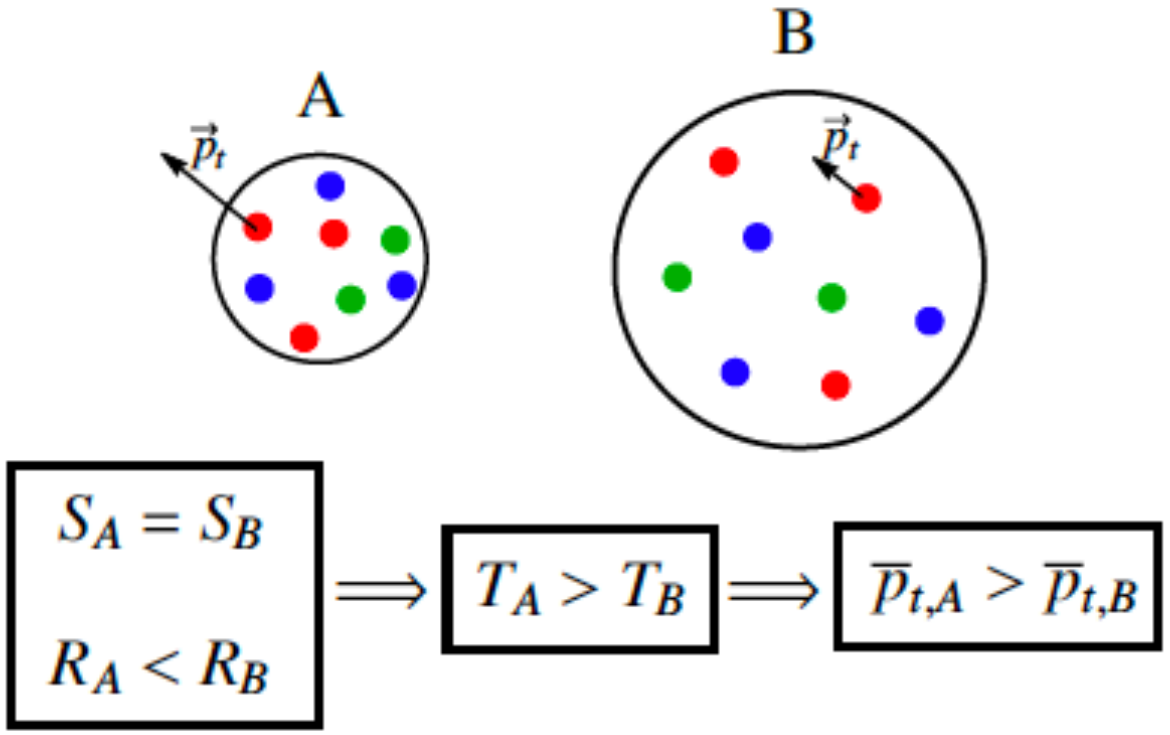
Outline

- 1. Motivations
- 2. Data set and analysis detail
- 3. $\langle p_T \rangle$ vs multiplicity (Nch) in ultra-central A+A collisions
- 4. v_n vs. $\langle p_T \rangle$ in ultra-central A+A collisions
- 5. Comparison with model calculations
- 6. Summary

$\langle p_T \rangle$ vs. Size of Fireball (R)

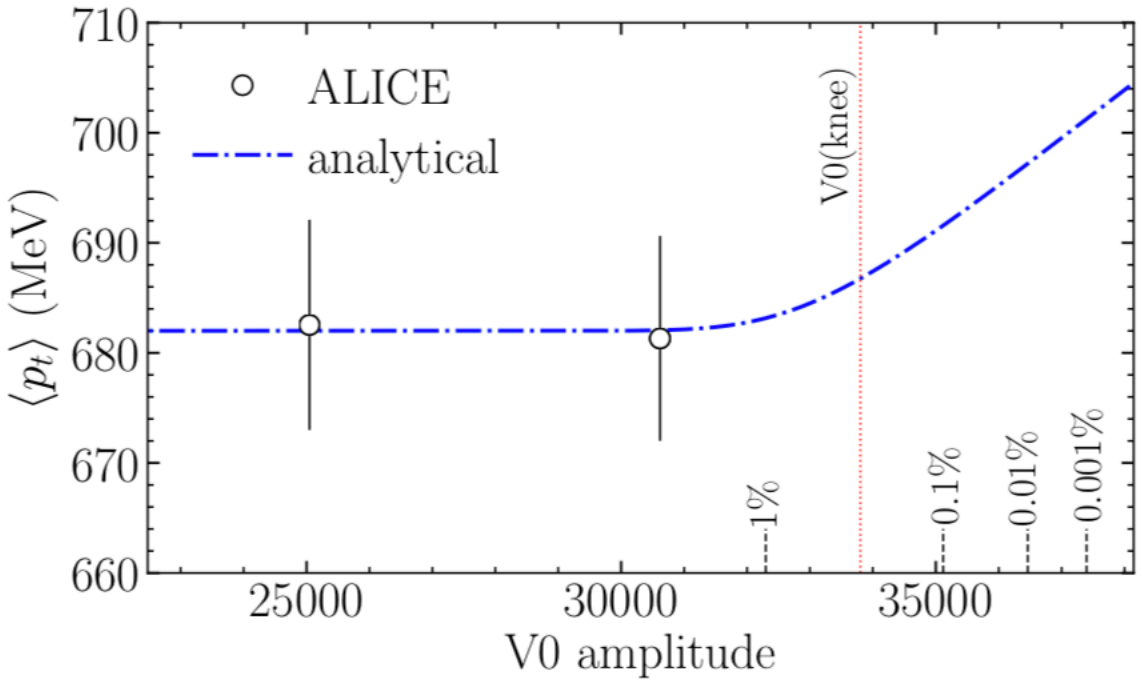


For two systems (A,B) with the fixed final-state multiplicity (same entropy), the temperature is higher in smaller system (A), therefore the smaller system will have a larger <pT>

Hydrodynamic models predicted:
<pT> $\propto$ 1/R

Wojciech Broniowski: PhysRevC.80.051902
Aleksas Mazeliauskas: PhysRevC.93.024913
Piotr Bozek : PhysRevC.96.014904

$\langle p_T \rangle$ in Ultra-Central A+A collisions



F. Gardim, G. Giacalone and J. Ollitrault
arXiv:1909.11609

1. In ultra-central A+A collisions, the multiplicity (entropy) increases while the system size R is saturated

2. A sharp increasing of $\langle p_T \rangle$ is predicted, which will be proportional to the square of speed of sound c_s

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Giuliano Giacalone, BNL seminar

Eccentricity and system size in deformed nuclei

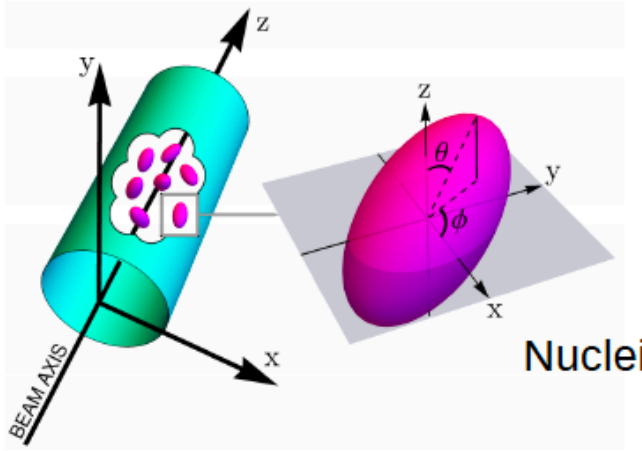
Nuclear matter density:

$$\rho(r) = \frac{\rho_0}{1 + \exp\left[\frac{1}{a}\left(r - R(1 + \beta_2 Y_{20})\right)\right]}$$

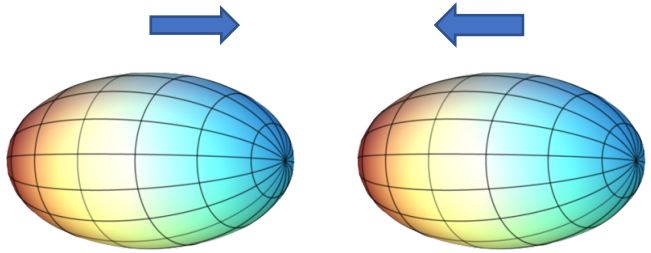
Quadrupole deformation, β_2

Usually from:
BNL nuclear data center
https://www.nndc.bnl.gov/
Or calculations e.g. [Möller, Sierk, Ichikawa, Sagawa, 1508.06294]

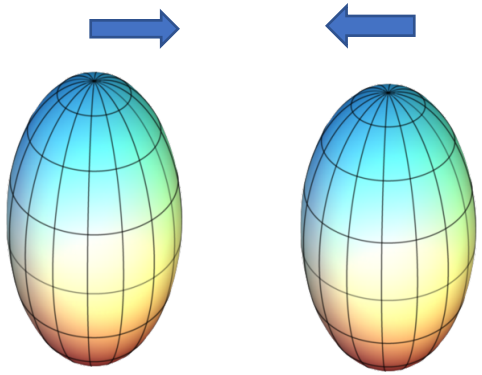
$$Y_{20} = \sqrt{\frac{5}{16\pi}}(3\cos^2\theta - 1)$$



Nuclei are randomly oriented in space.



Tip-Tip: Smaller R and ε_2



Body-Body: Larger R and ε_2

1. ε_2 and system size depend on the deformation factor

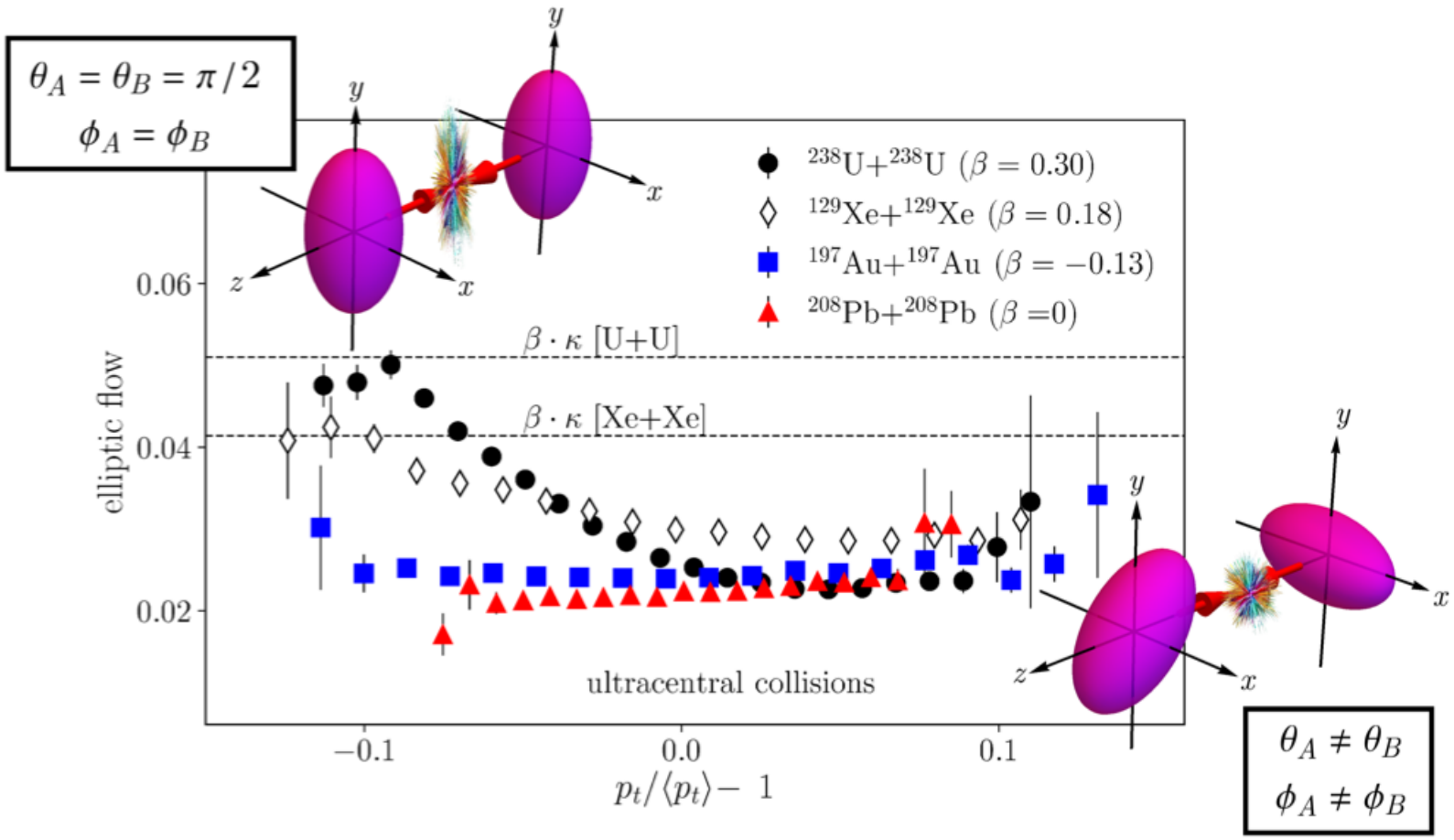
2. ε_2 is bigger in larger system: Tip-Tip vs. Body-Body

3. $\langle p_T \rangle \propto 1/R$ and $v_2 \propto \varepsilon_2$: **Anticorrelation between v_2 and $\langle p_T \rangle$ due to deformation**

Measuring the v_2 vs. $\langle p_T \rangle$ can be used to reveal the deformation factor!

v_2 vs. $\langle p_T \rangle$

Giuliano Giacalone, 1910.04673



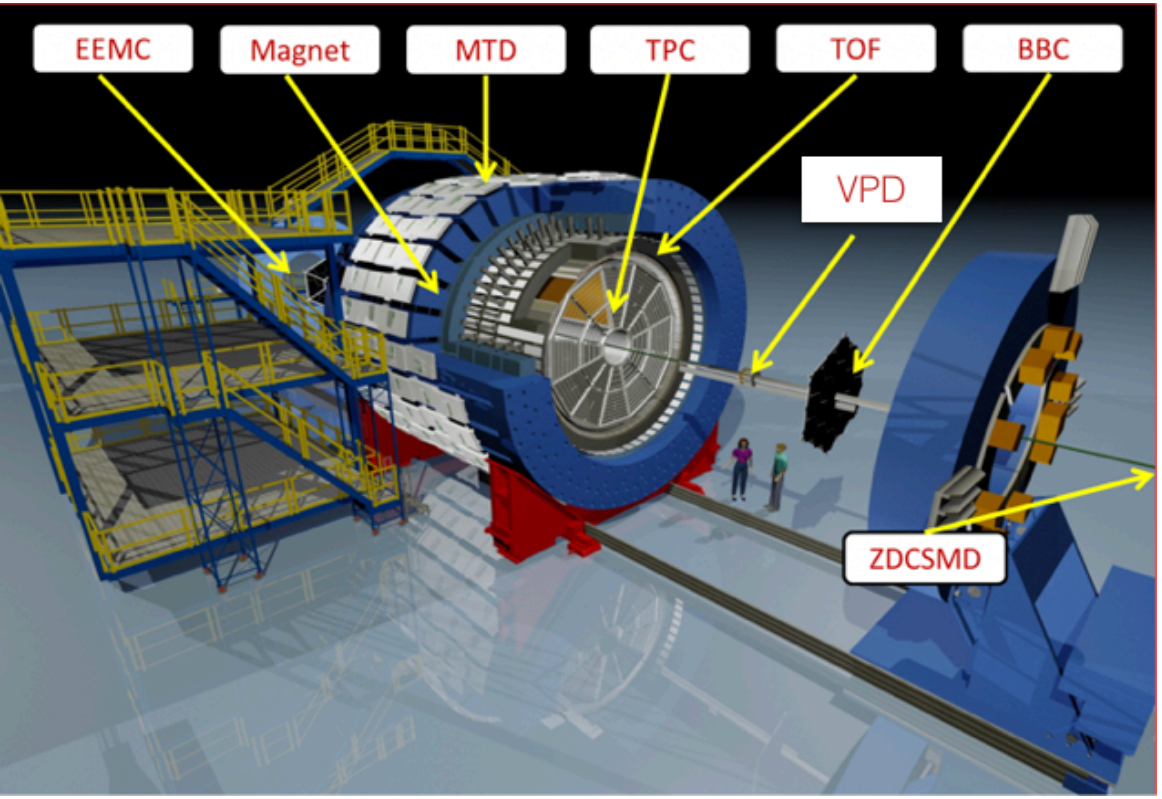
$$\frac{\bar{p}_t}{\langle \bar{p}_t \rangle} - 1 = -3c_s^2 \left(\frac{R}{\langle R \rangle} - 1 \right)$$

c_s^2=0.19: Speed of Sound

1. $\langle p_T \rangle$ is converted from R by TRENTo initial model, no final-state effects and statistical fluctuations

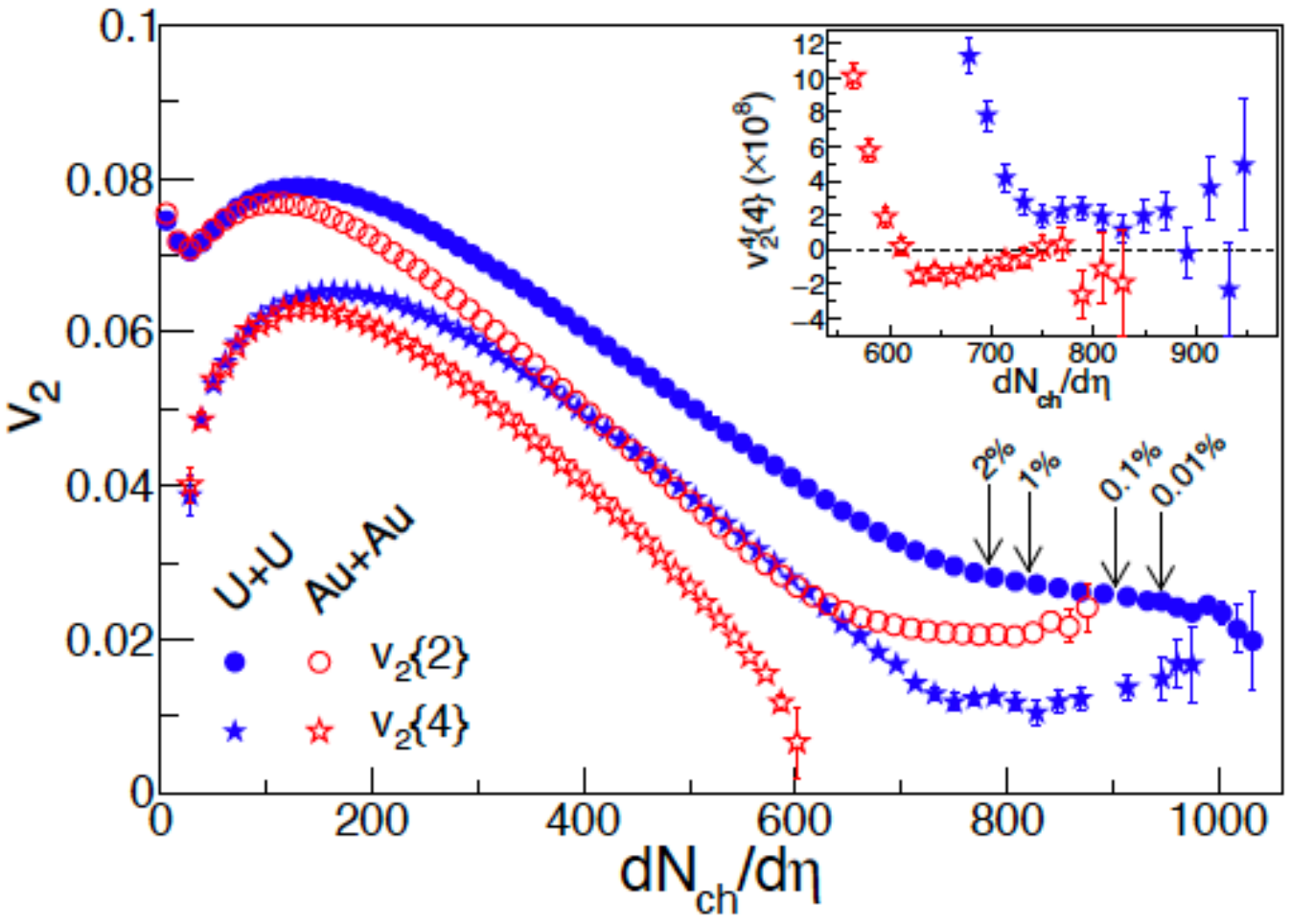
2. Uranium nuclei are largely deformed comparing with Au nuclei. An anticorrelation between elliptic flow and $\langle p_T \rangle$ is expected in ultra-central U+U collisions

The STAR Detector



- $\langle p_T \rangle$, v_n and Nch are measured within $0.2 < p_T < 2.0$ GeV/c and $|\eta| < 1.0$
- Centrality is defined by Nch or ZDC energy
- The track efficiency iscorrected from embedding data

V_2 vs. Nch



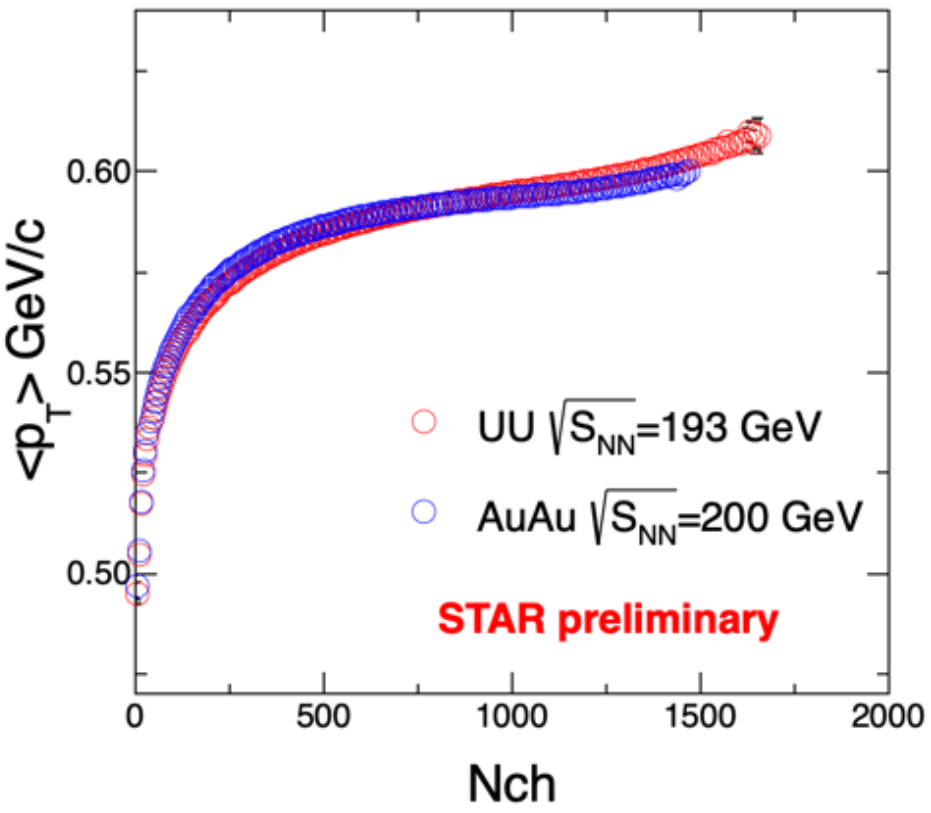
In ultra-central A+A collisions, the $v_2\{2\}$ shows different slopes between Au+Au and U+U

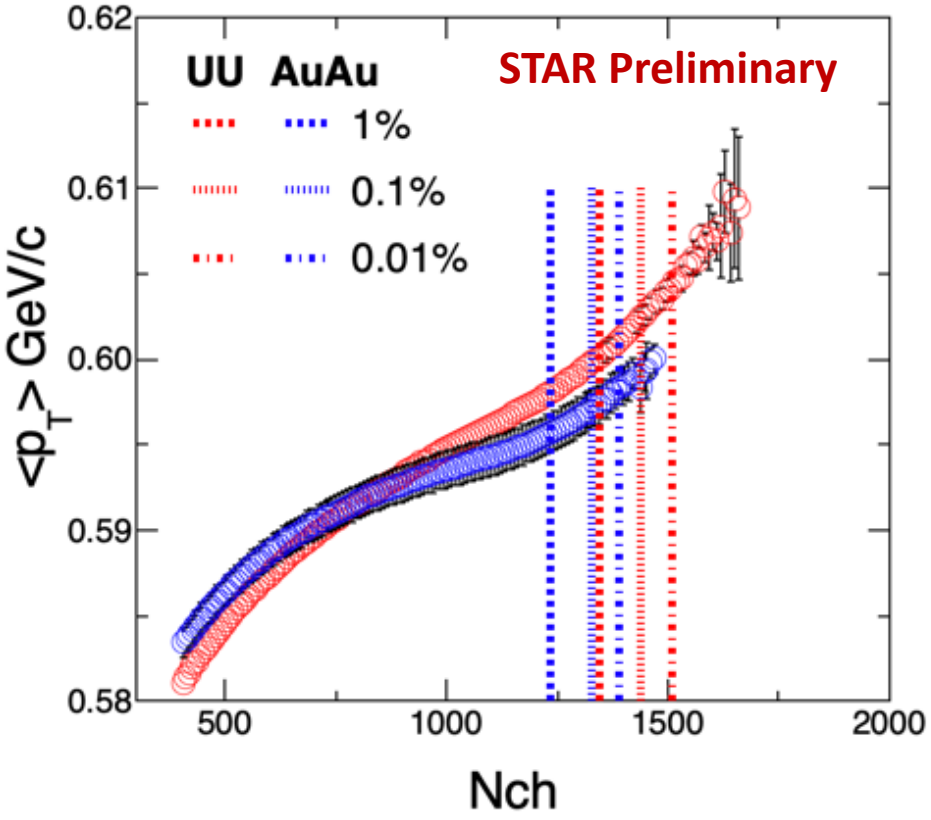
$v_2\{4\}$ from Au+Au changes the sign while not for $v_2\{4\}$ from U+U

The difference between Au+Au and UU indicates that deformation affects the flow behavior in ultra-central A+A collisions

STAR: PhysRevLett.115.222301

$\langle p_T \rangle$ vs. Nch

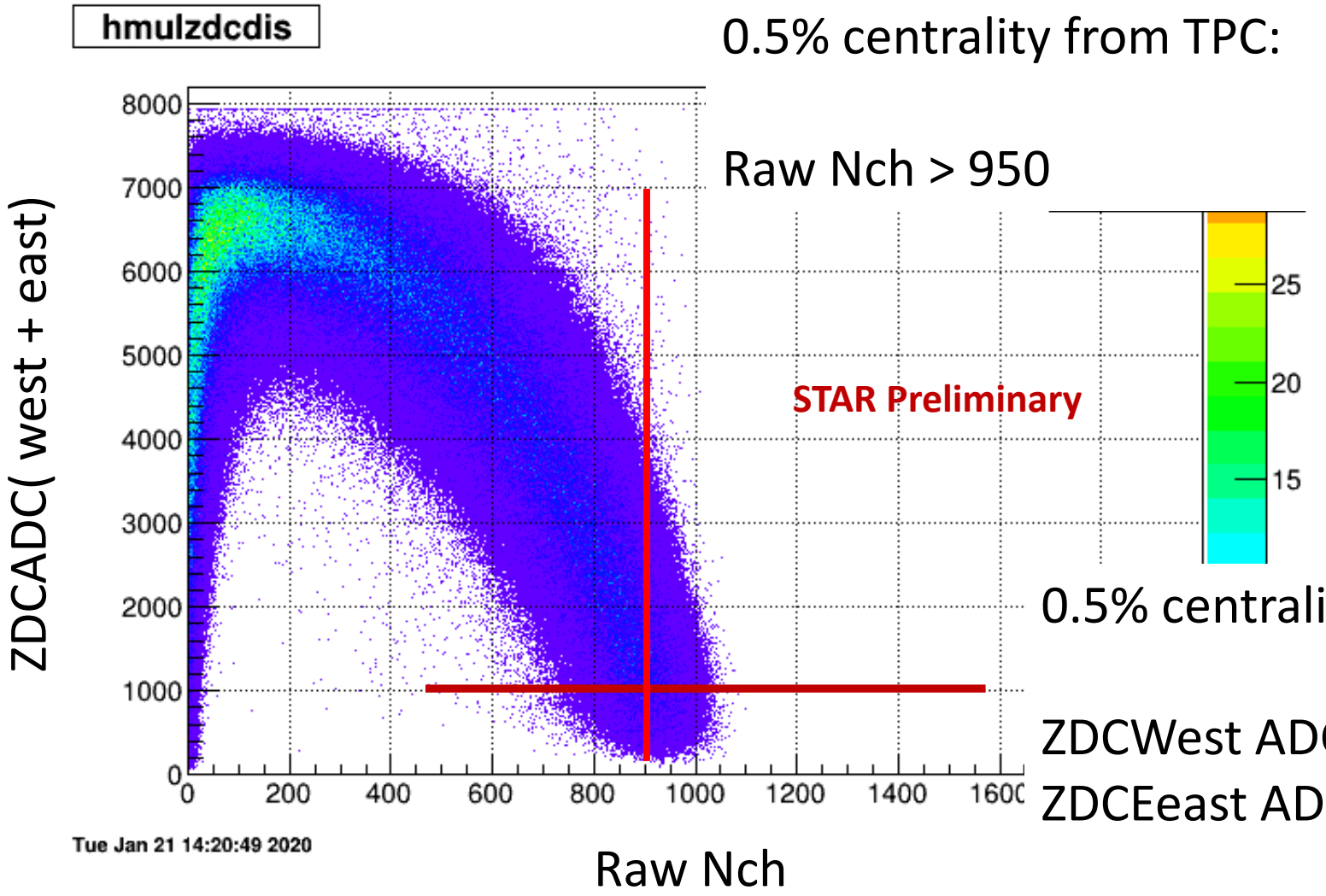




$\langle p_T \rangle$ increasing trend becomes sharper in ultra-central A+A collisions

It indicates a tight correspondence between $\langle p_T \rangle$ and system size, and will be useful to extract the speed of sound (C_s) of fireball

Centrality From TPC vs. ZDC



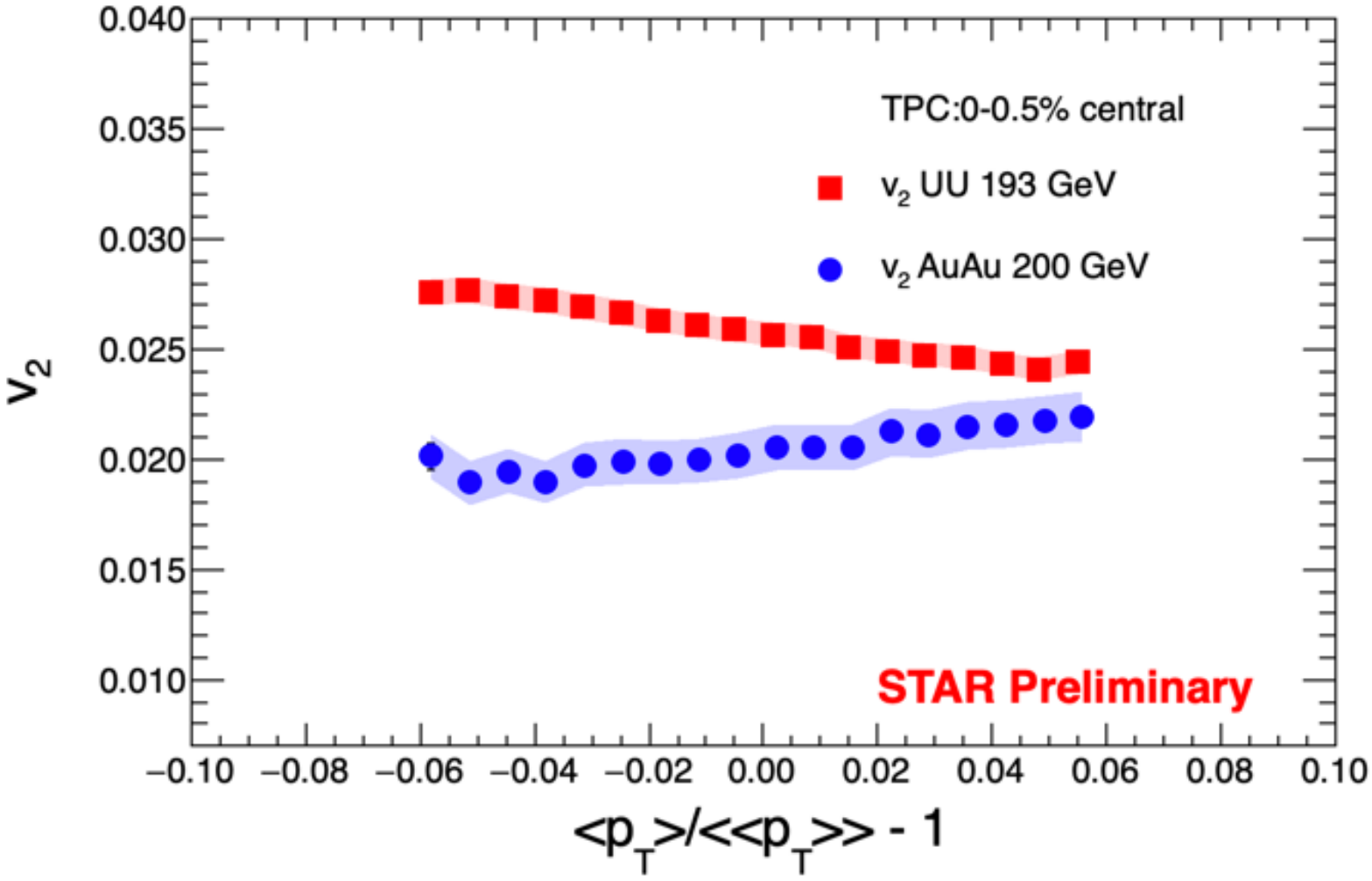
0.5% centrality from TPC:

Raw Nch > 950

0.5% centrality from ZDC:

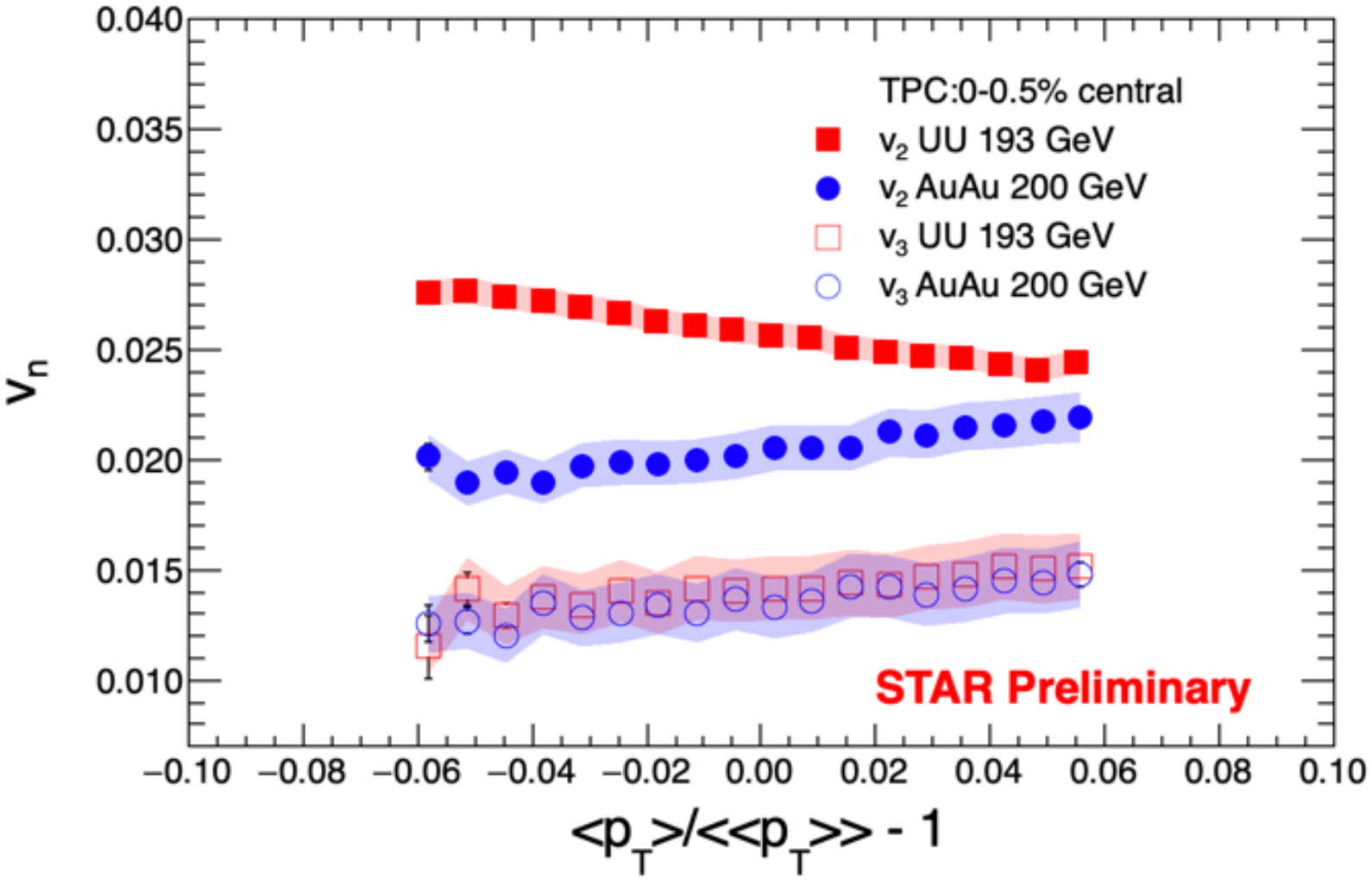
ZDCWest ADC < 497 &&
ZDCEeast ADC < 497

v_2 vs. $\langle p_T \rangle$



An anticorrelation is observed between v_2 and $\langle p_T \rangle$ in top 0.5% UU collisions while not in AuAu

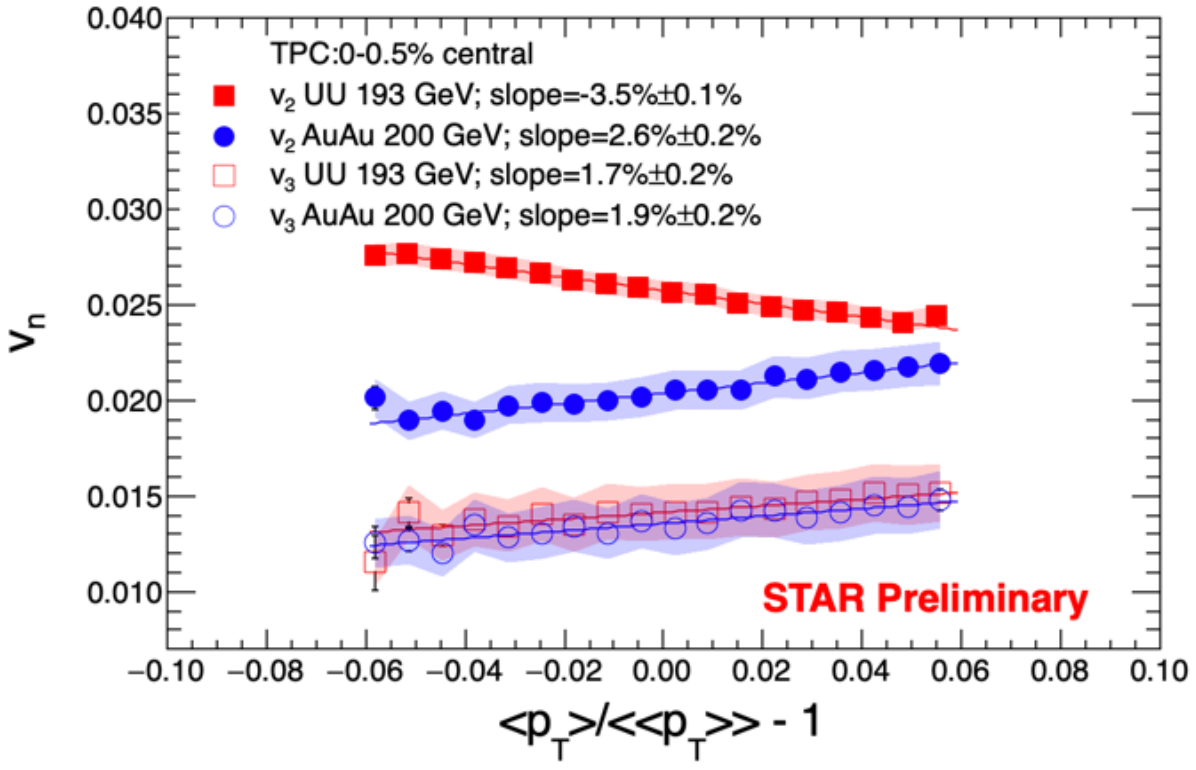
v_3 vs. $\langle p_T \rangle$

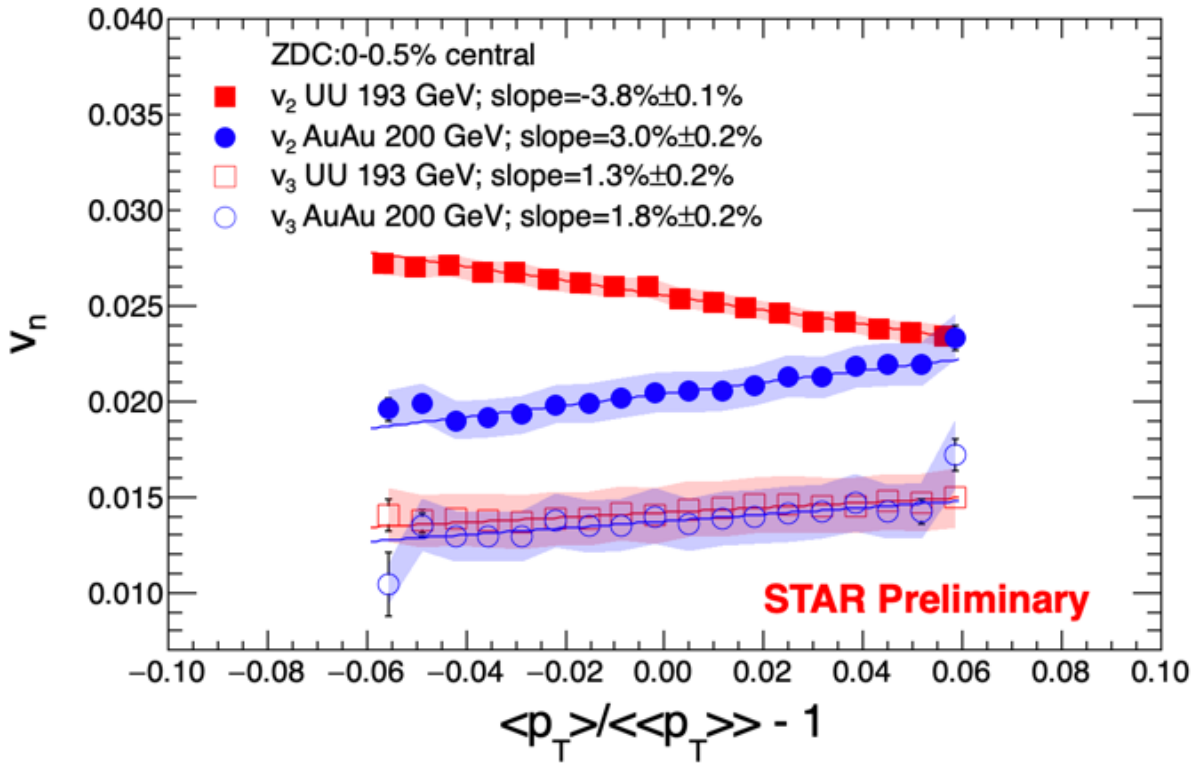


An anticorrelation is observed between v_2 and $\langle p_T \rangle$ in top 0.5% U+U collisions while not in Au+Au

v_3 and $\langle p_T \rangle$ correlations are positive and similar for AuAu and UU collisions

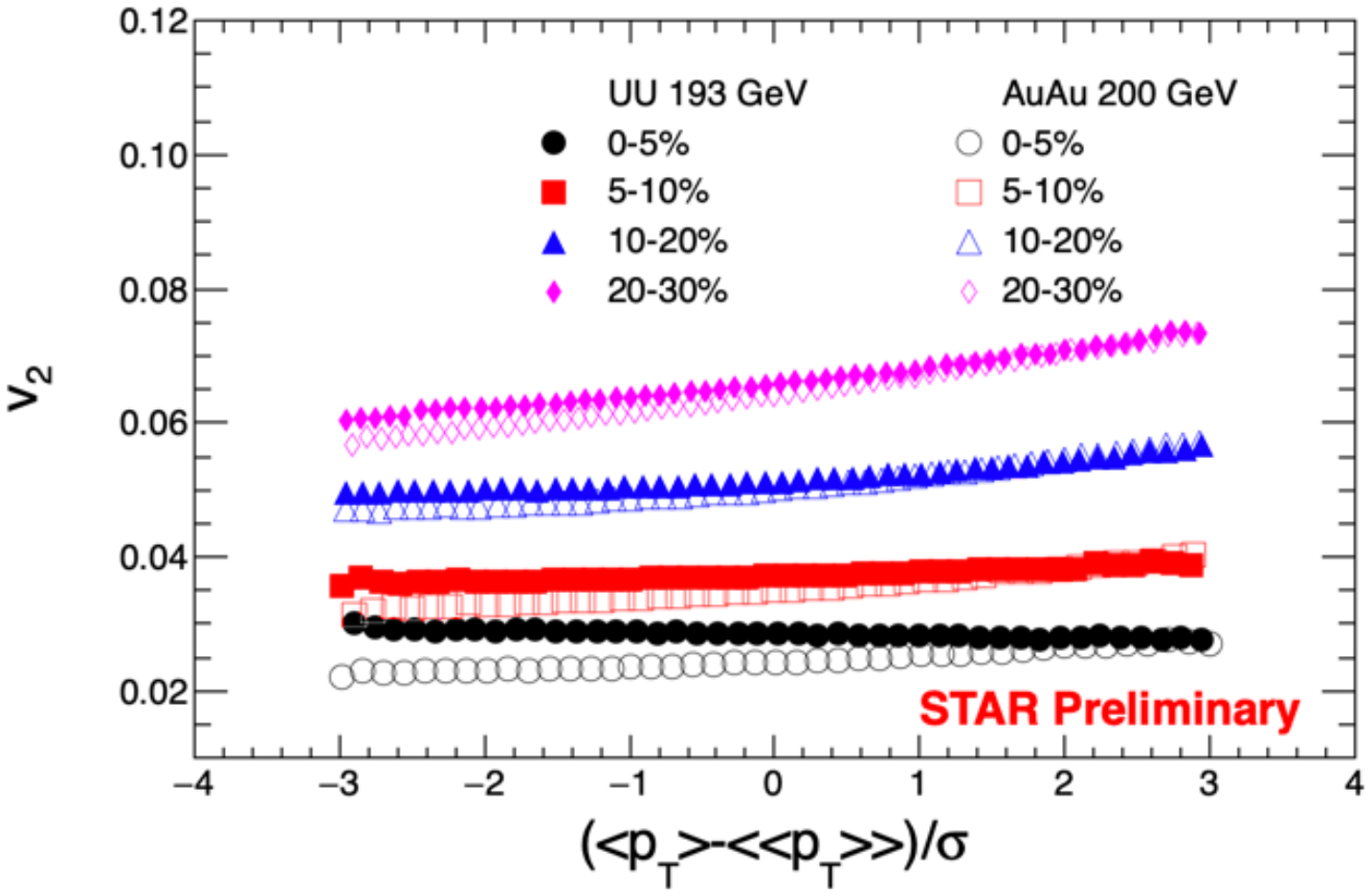
TPC Centrality vs ZDC Centrality





	System	TPC Centrality	ZDC Centrality
v_2 slope	U+U	-3.5%±0.1%	-3.8%±0.1%
v_2 slope	Au+Au	2.6%±0.2%	3.0%±0.2%
v_3 slope	U+U	1.7%±0.2%	1.3%±0.2%
v_3 slope	Au+Au	1.9%±0.2%	1.8%±0.2%

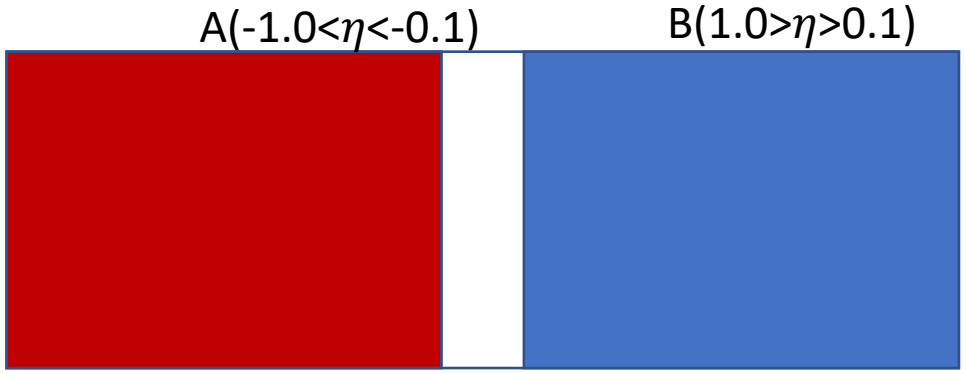
Centrality Dependence



Besides ultra-centrality, the v_2 slopes between Au+Au and U+U are also different in other centralities.

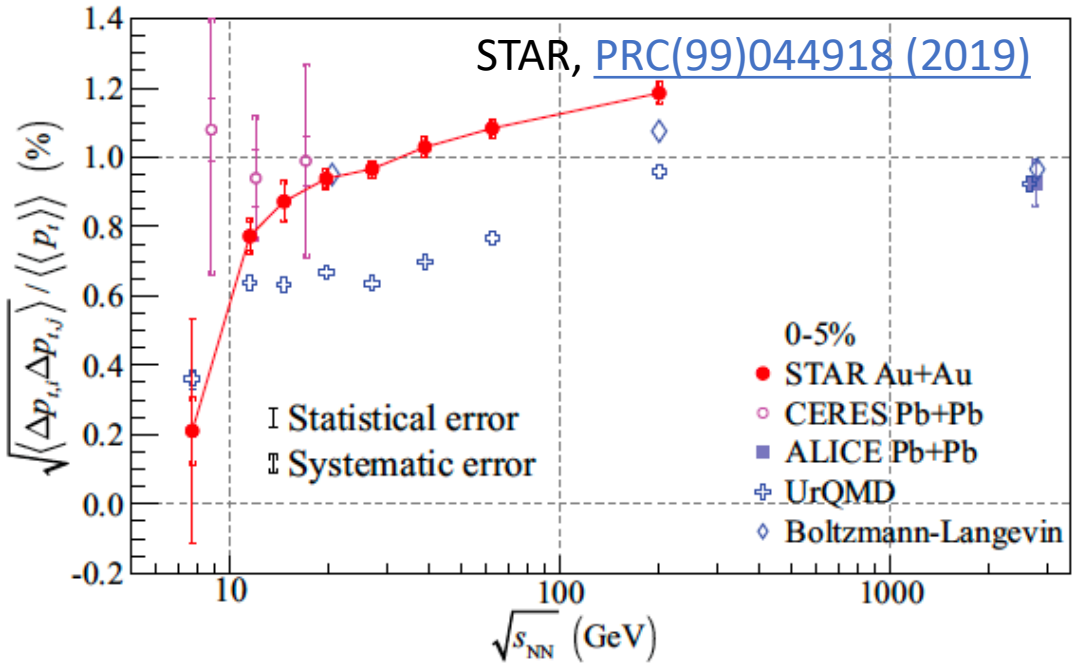
It is due to the deformation effect and consistent with the Glauber model prediction!

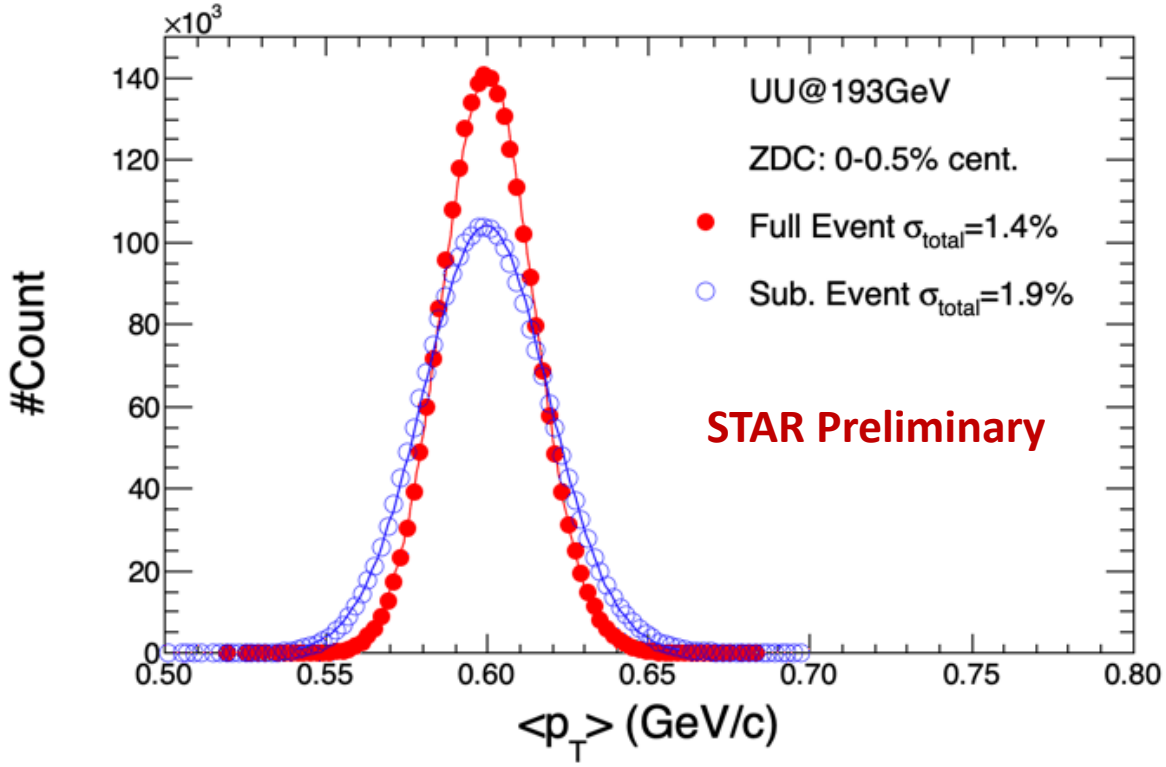
Two-subevent Method



$\langle V_{nn} \rangle = \langle Q_{n,A} \times Q_{n,B}^{*} \rangle$

$\langle\langle p_T \rangle\rangle$: $Full\ Event, Subevent\ (A, B)$



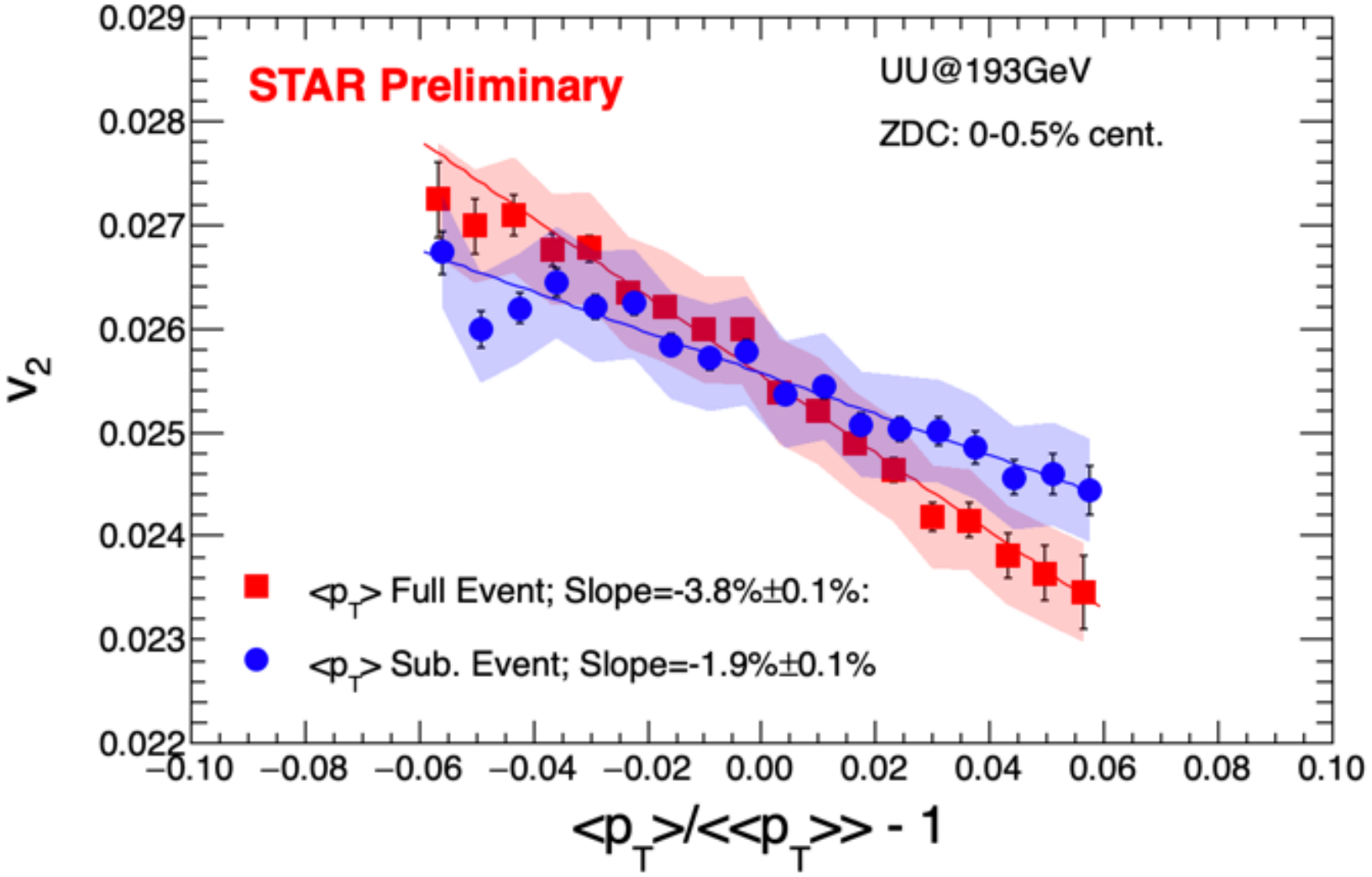


$\sigma^2_{total} = \sigma^2_{statistical} + \sigma^2_{dynamical}$

$\sigma_{dynamical} / \ll p_T \gg = 1.2\%$

$\langle\langle p_T \rangle\rangle = 0.6 GeV/c$

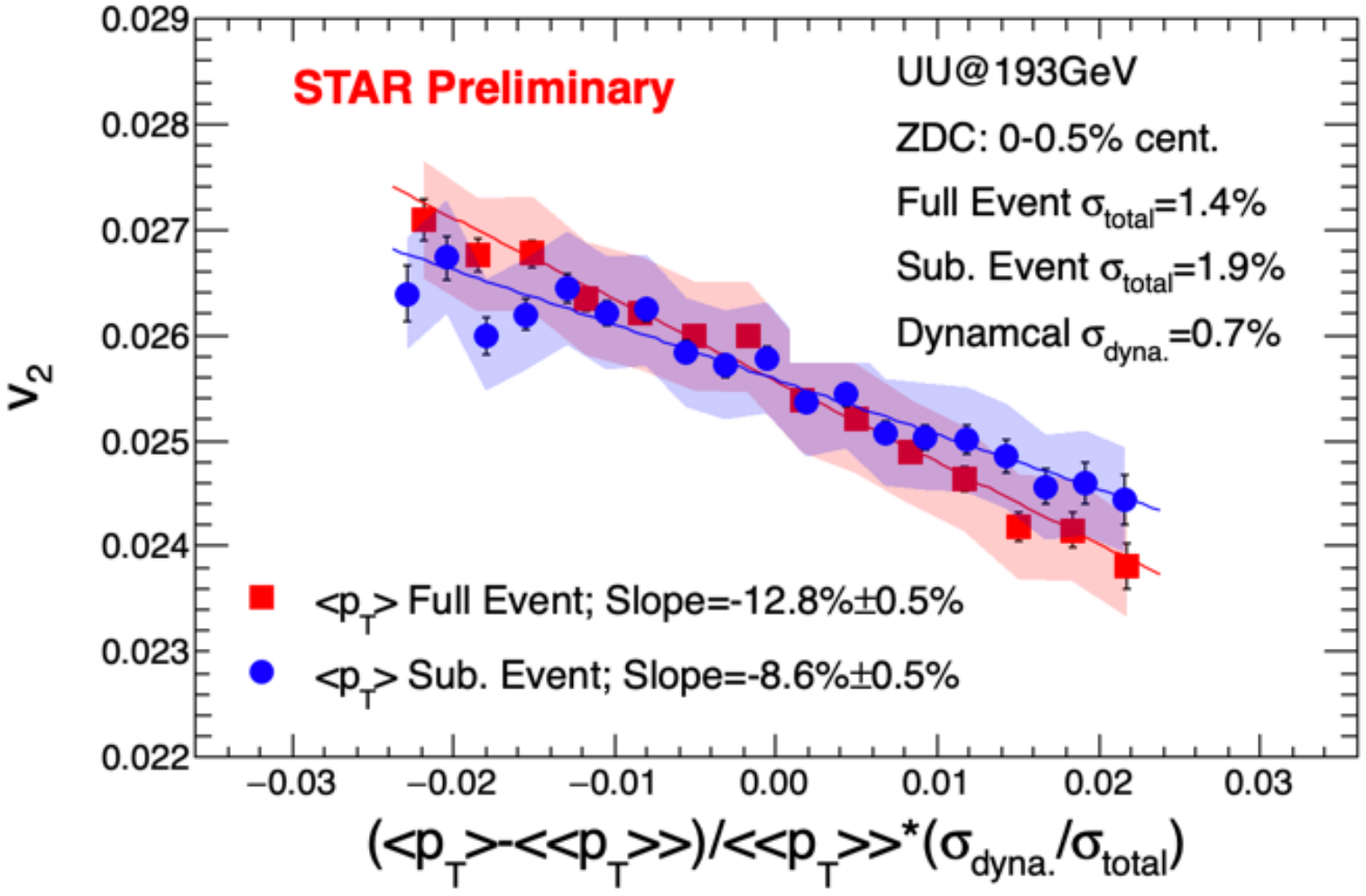
Effect of Statistical Fluctuations



The slope is a factor of two smaller for $\langle p_T \rangle$ from sub-events

The effect of statistical fluctuations is huge!

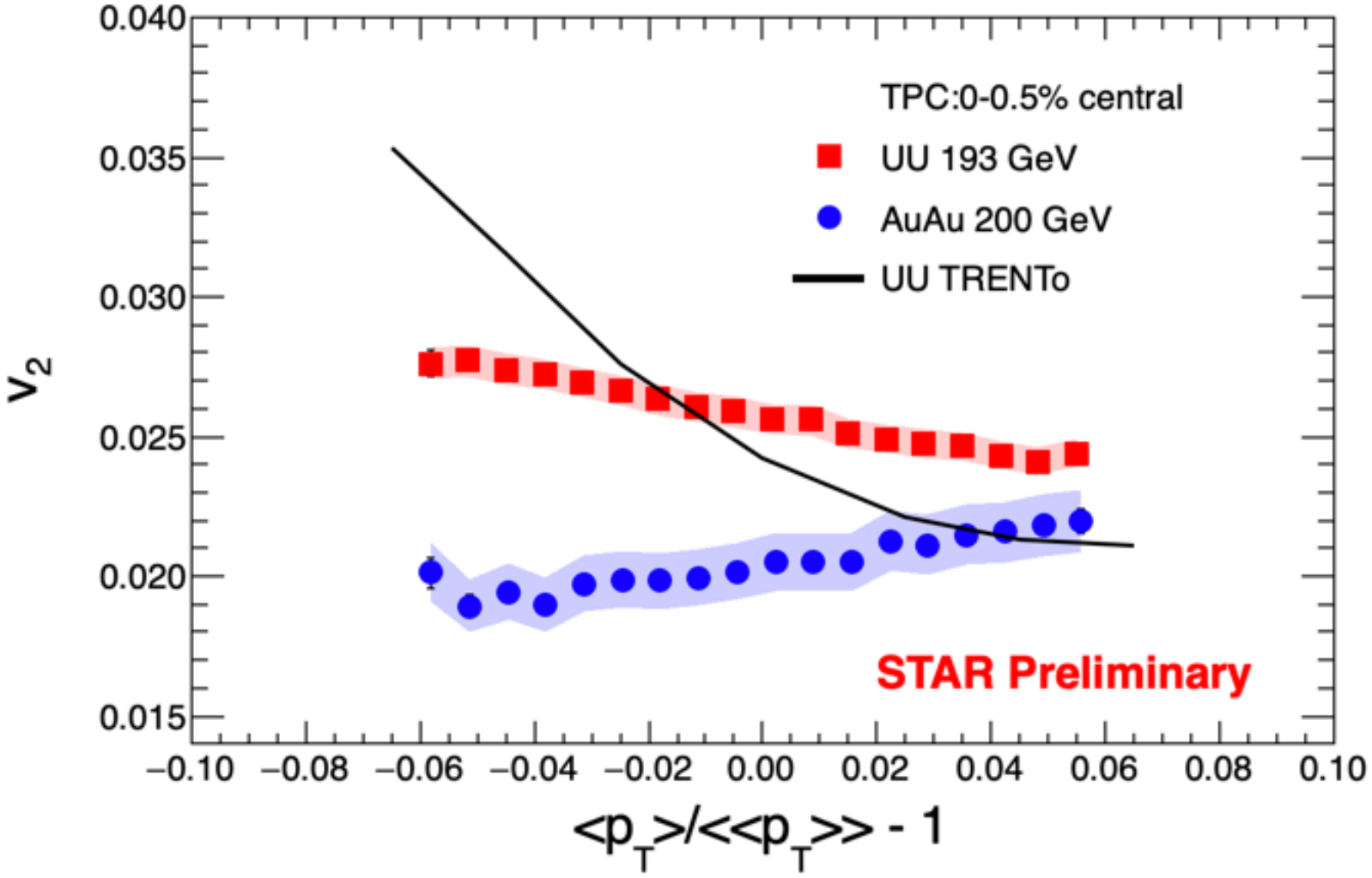
Normalized Slope



After normalized by the sigma of $\langle p_T \rangle$ distribution, the slope difference between full event and half event drop to 50%

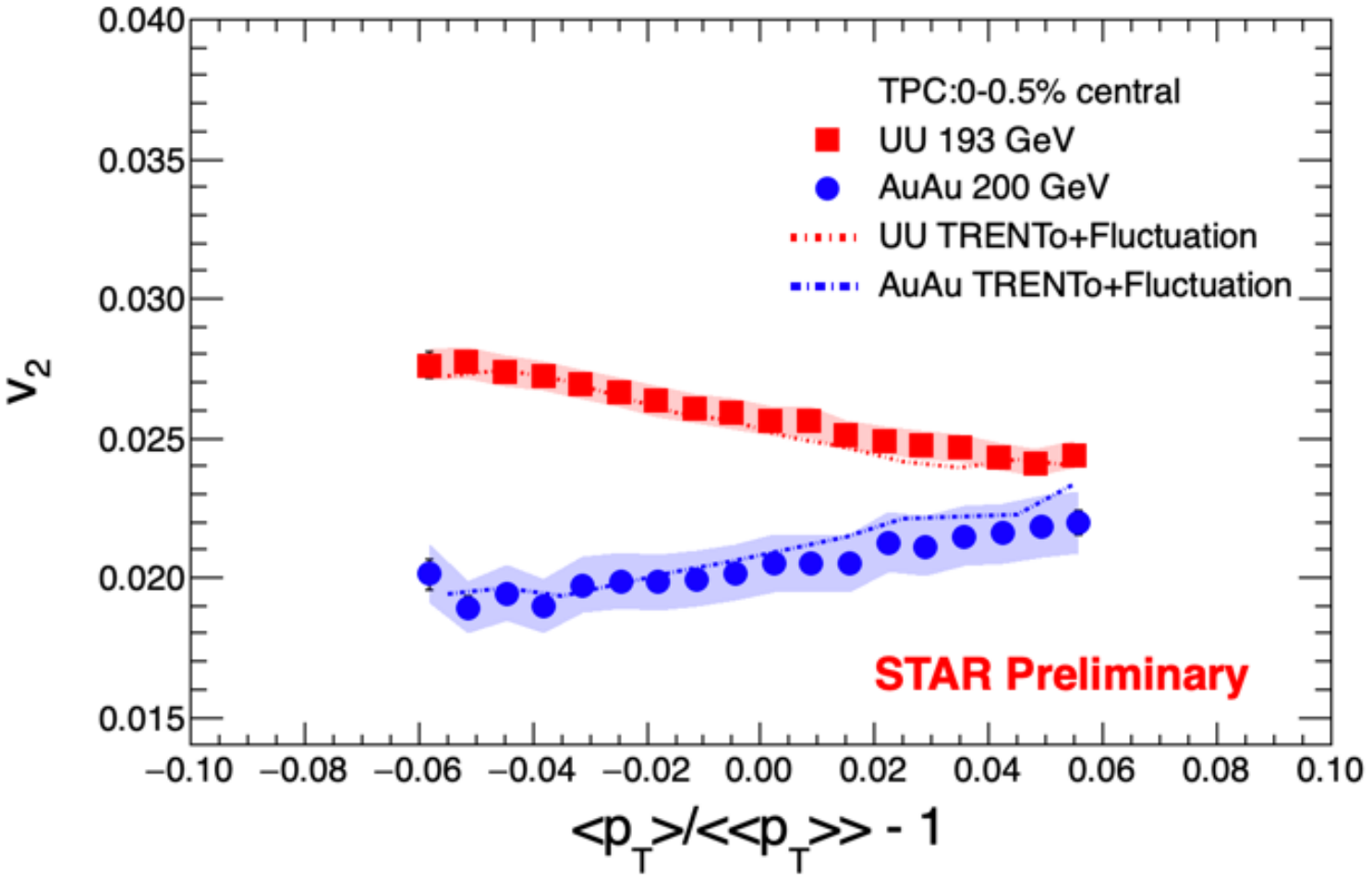
Still working to understand the residual difference

Comparing with TRENTo



Without the statistical fluctuations, TRENTo initial-state model overpredicts the slope with β_2(UU)=0.30 and β_2(AuAu)=-0.13

Comparing with TRENTo+Fluctuation: v_2

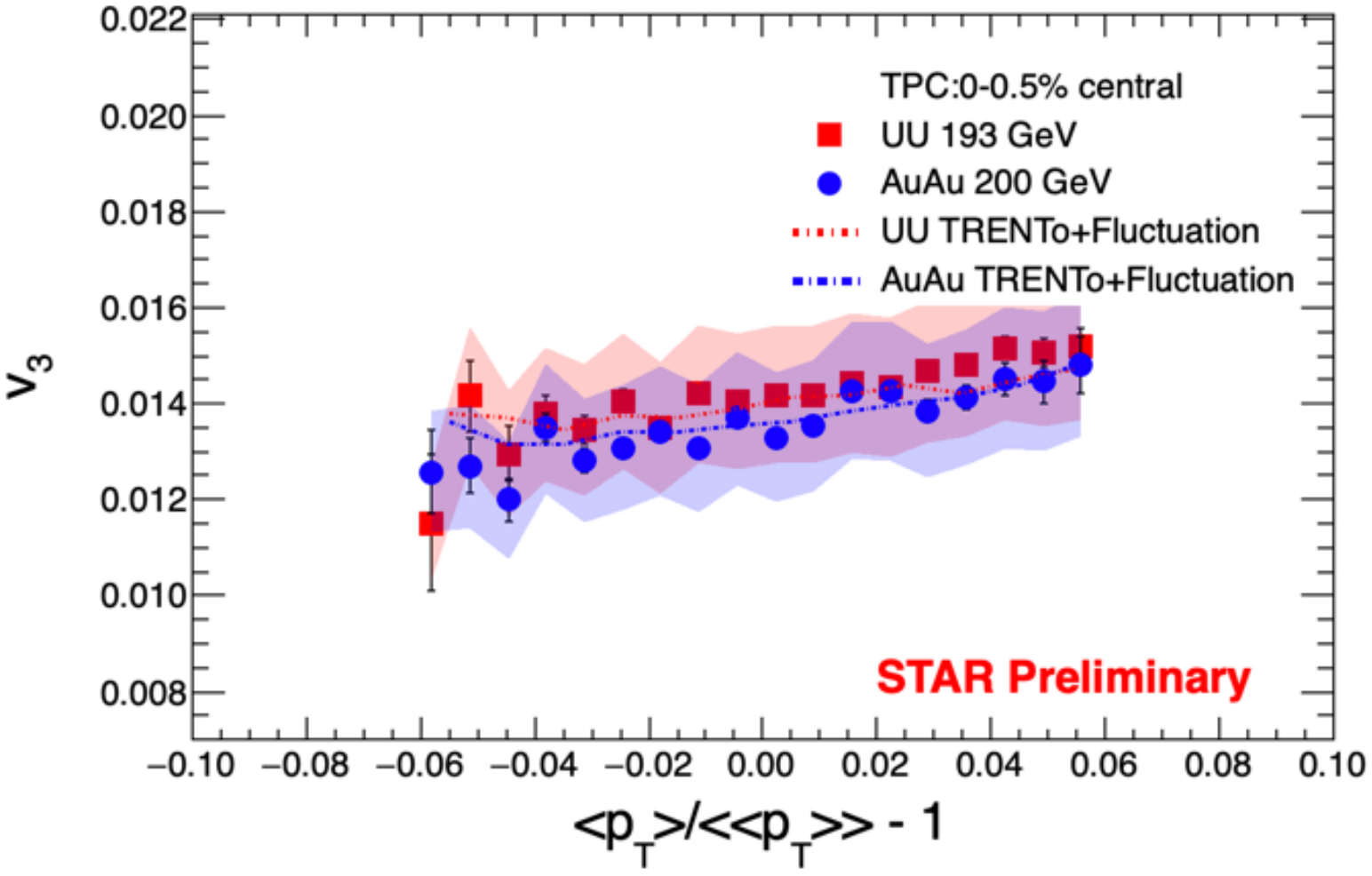


Statistical fluctuations added by hand in model: $^{\delta\langle pt\rangle}/_{\langle\langle pt\rangle\rangle} = 0.018$

After adding the statistical fluctuations, the model can re-produce data

The statistical fluctuations are crucial!

Comparing with TRENTo+Fluctuation ~ v_3



Model can reproduce v_3 slope with same parameters!

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Summary

- We observed that increasing trend of $\langle p_T \rangle$ vs. Nch become shaper in ultra-central A+A collisions, which maybe useful to extract the c_s as predicted by hydrodynamics

- The slope of v_2 vs $\langle p_T \rangle$ are different between Au+Au and U+U due to the deformation

- After adding the statistical fluctuations by hand, the TRENTo initial-state model can reproduce the data with deformation factor $\boldsymbol{\beta}_2$=0.30 for U+U and $\boldsymbol{\beta}_2$=-0.13 for Au+Au