Explore the Nuclei Deformation with an Expanding QGP Fireball

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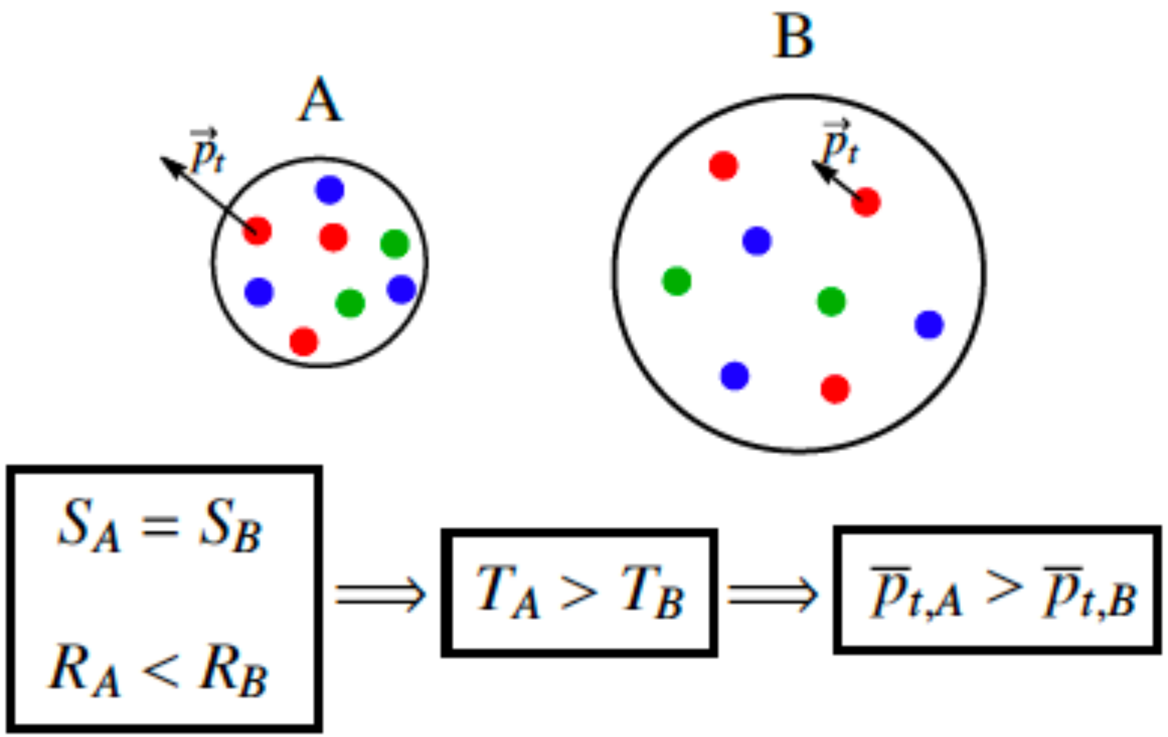
Outline

- 1. Motivations
- 2. Data set and analysis detail
- 3. <p_T> vs Multiplicity(Nch) in ultra-central AA collisions
- 4. v_n vs. <p_T> in ultra-central AA collisions
- 5. Comparison with model calculations
- 6. Summary

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

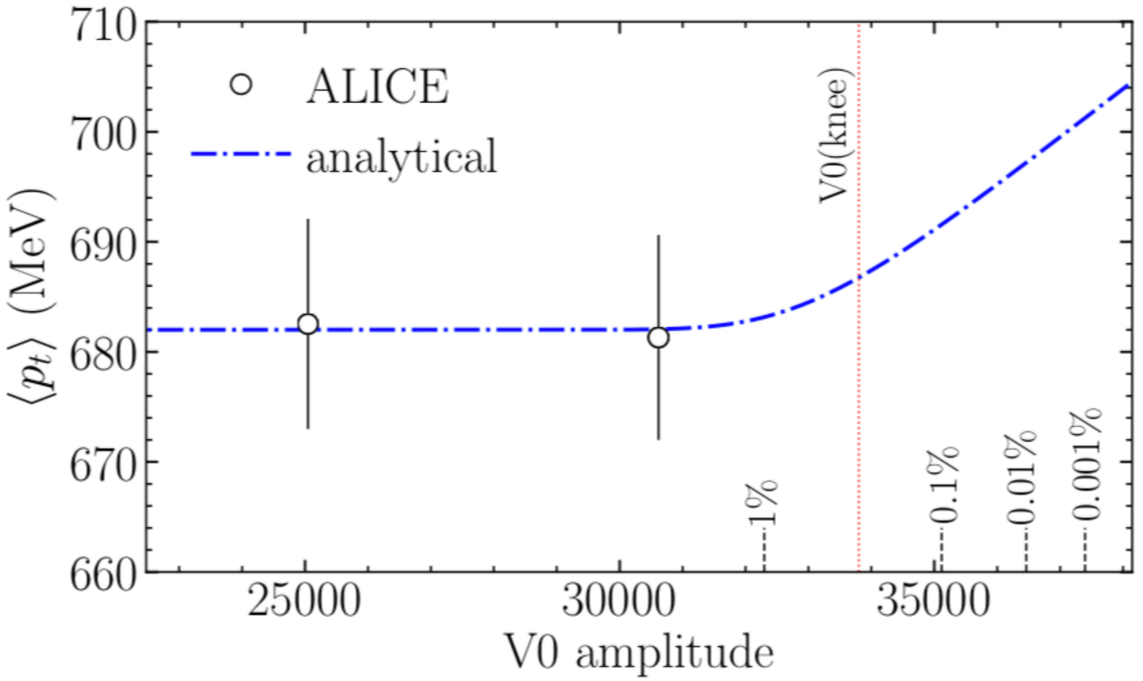


For two systems(A,B) with the fix multiplicity(same entropy), the temperature is higher in smaller system(A), therefore the smaller system will have a larger $\langle p_T \rangle$

Hydrodynamic models predicted:
$\langle p_T \rangle \propto 1/R$

Wojciech Broniowski: **0907.3216**
Aleksas Mazeliauskas: **1509.07492**
Piotr Bozek :**1701.09105**

$\langle p_T \rangle$ in Ultra-Central AA collisions



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

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

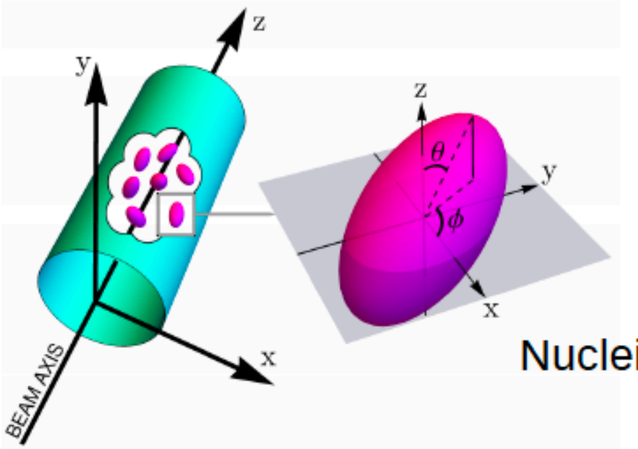
2. A sharp increasing of $\langle p_T \rangle$ is predicted, which will be proportional to the square of speed of sound c_s

Giuliano Giacalone, BNL seminar

Eccentricity and system size in deformed nuclei

Nuclear matter density:

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

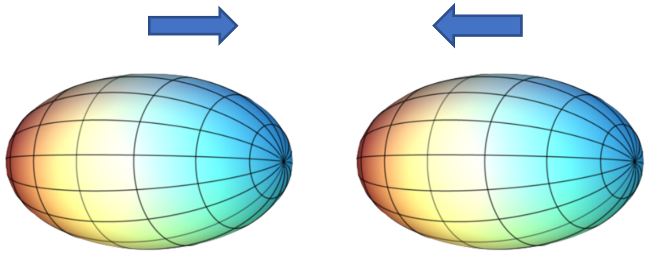


Quadrupole deformation, β_2

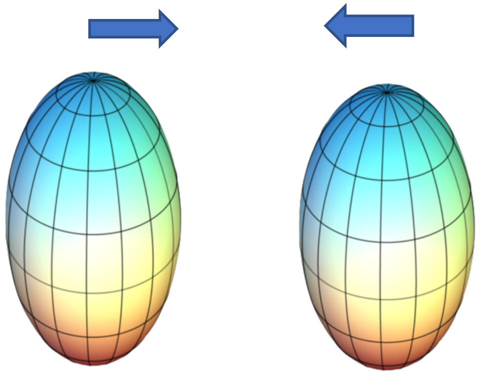
Usually from:
BNL nuclear data center
https://www.nndc.bnl.gov/
Or calculations e.g. [Möller, Sierk, Ichikawa, Sagawa, **1508.06294**]

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

Nuclei are randomly oriented in space.



Tip-Tip: Smaller R and $\boldsymbol{\varepsilon}_2$



Body-Body: Larger R and $\boldsymbol{\varepsilon}_2$

1. $\boldsymbol{\varepsilon}_2$ and system size depend on the deformation factor
2. $\boldsymbol{\varepsilon}_2$ is bigger in larger system: Tip-Tip vs. Body-body
3. $\langle p_T \rangle \propto 1/R$ and $v_2 \propto \boldsymbol{\varepsilon}_2$: **Anti-correlation 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!

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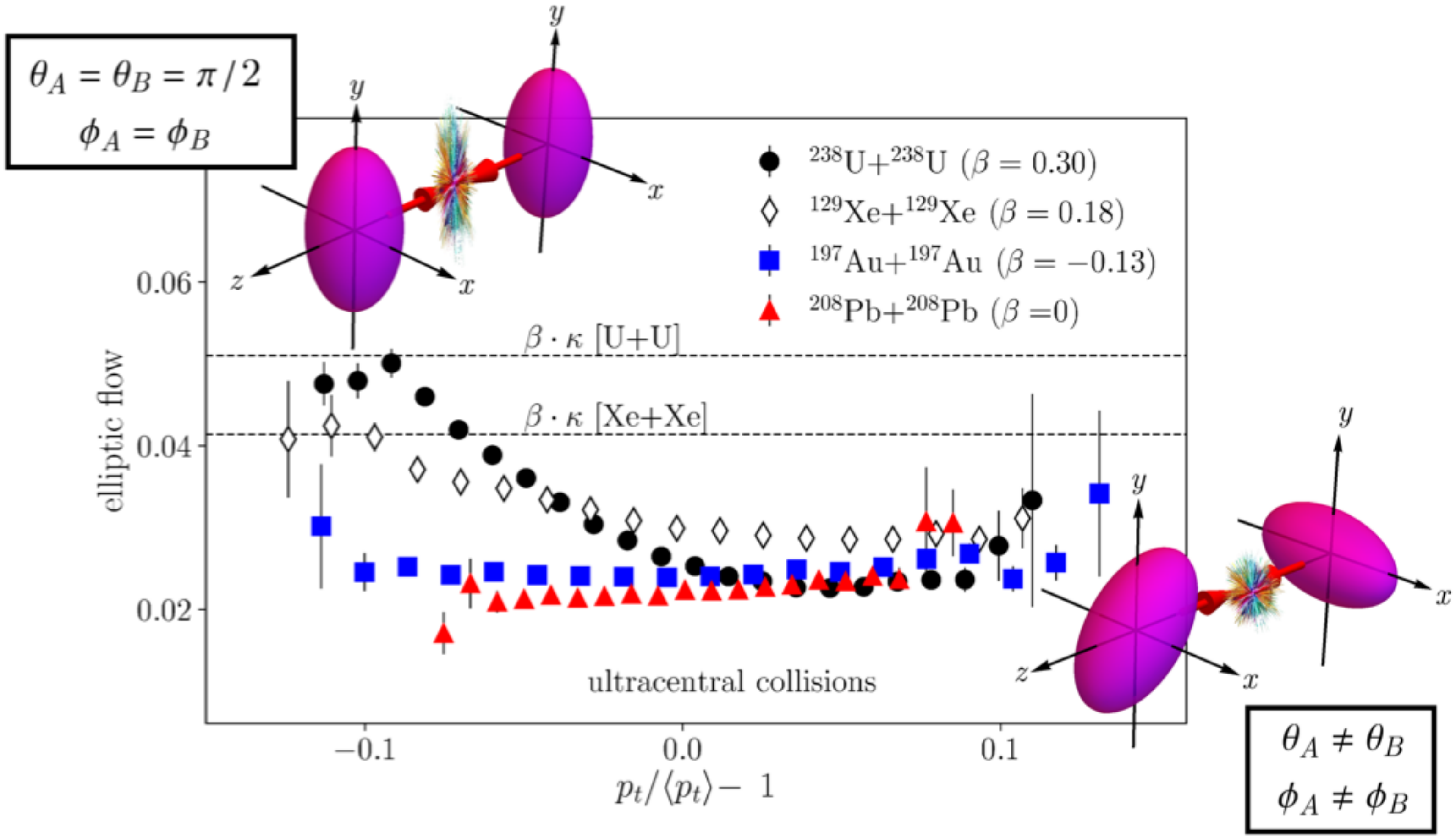
v_2 vs $\langle p_T \rangle$

Giuliano Giacalone, 1910.04673



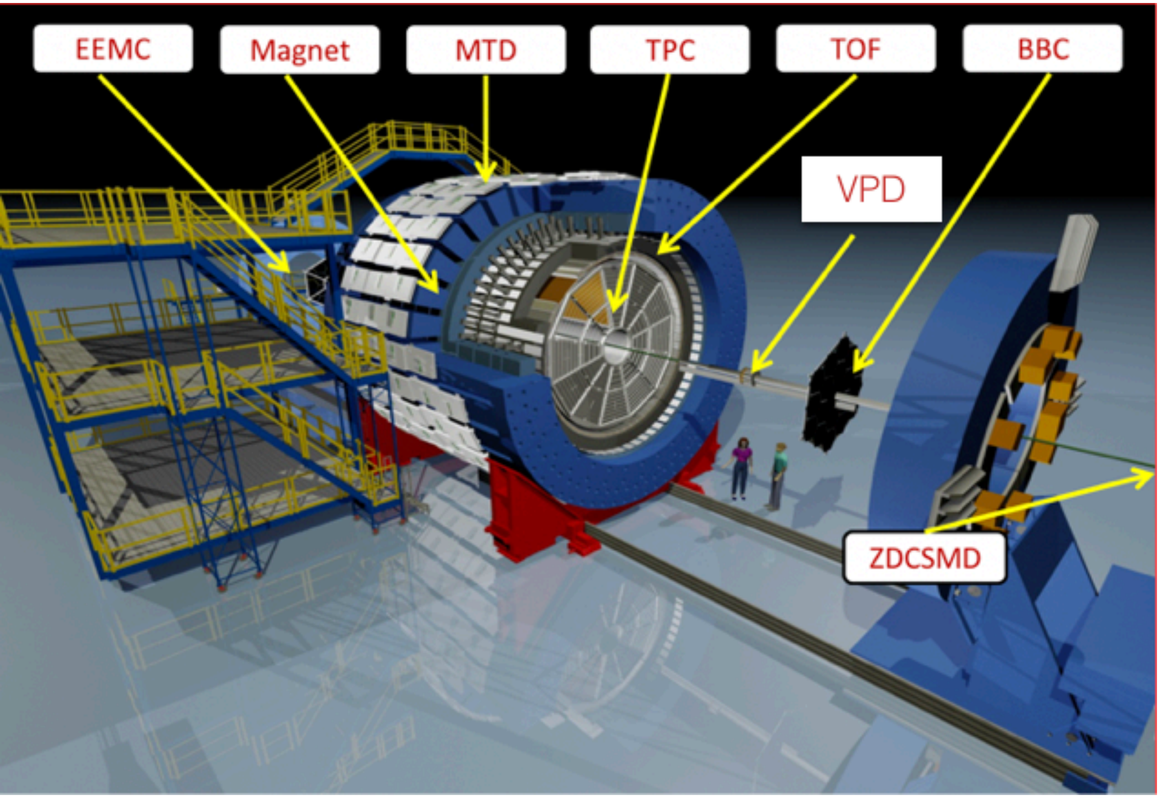
$$\frac{\bar{p}_t}{\langle \bar{p}_t \rangle} - 1 = -3c_s^2\left(\frac{R}{\langle R \rangle} - 1\right)$$

c_s^2=0.19: Speed of Sound

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

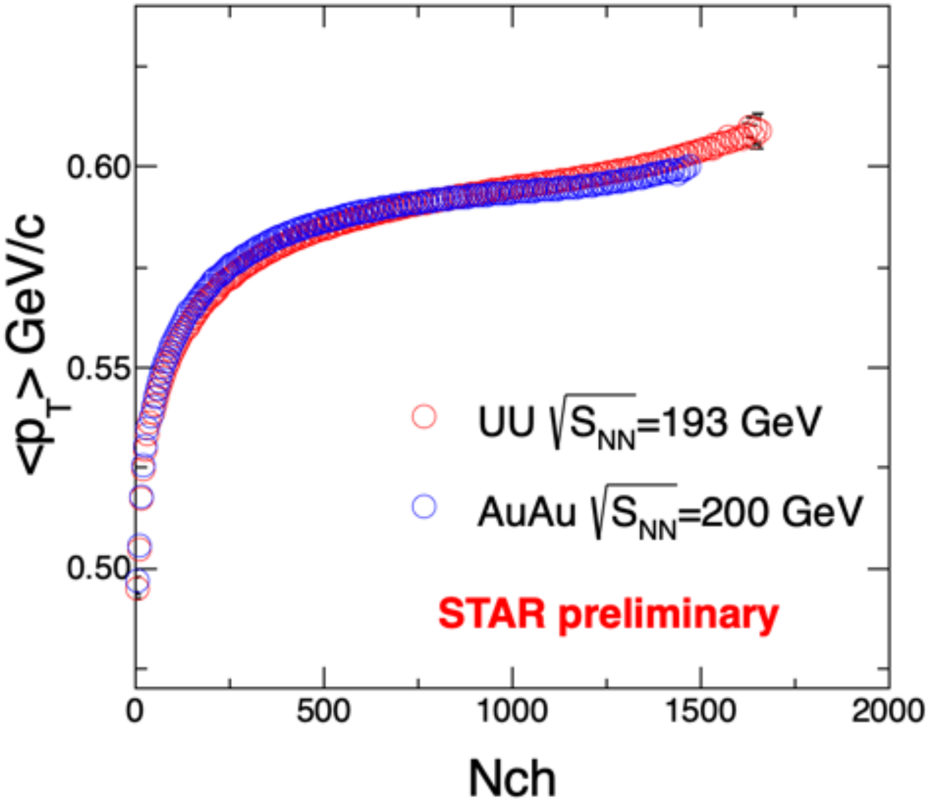
2. Uranium nuclei is largely deformed comparing with Au nuclei. An anti-correlation between elliptic flow and $\langle p_T \rangle$ is expected in ultra central UU

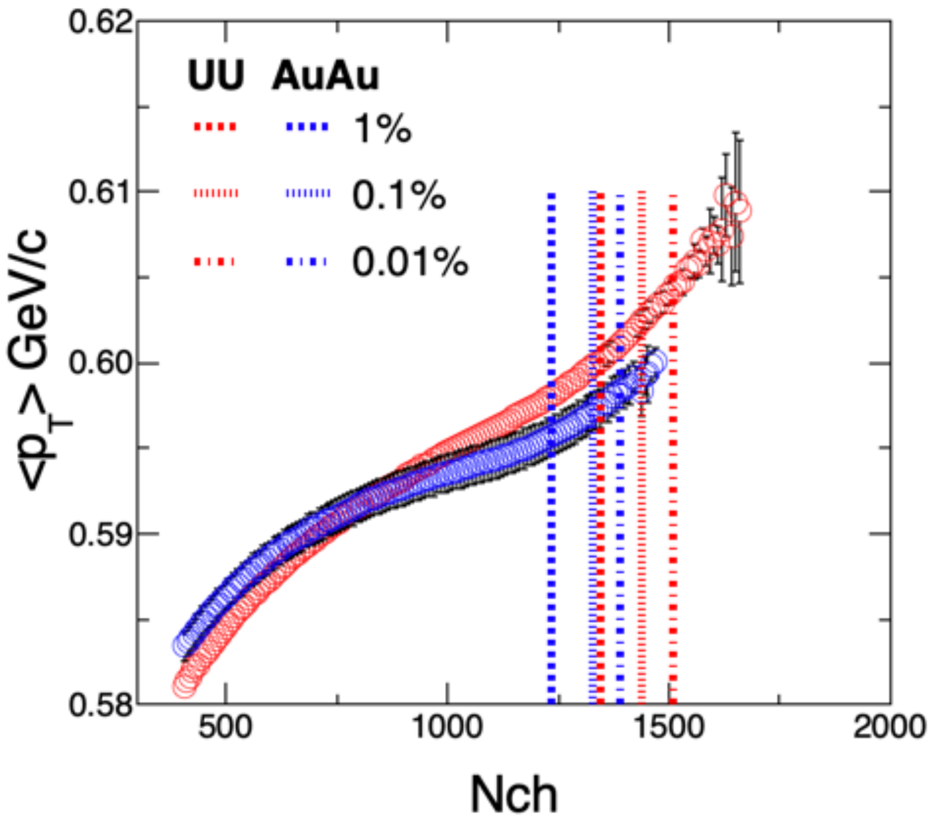
STAR Detector



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

$<p_T>$ vs Nch

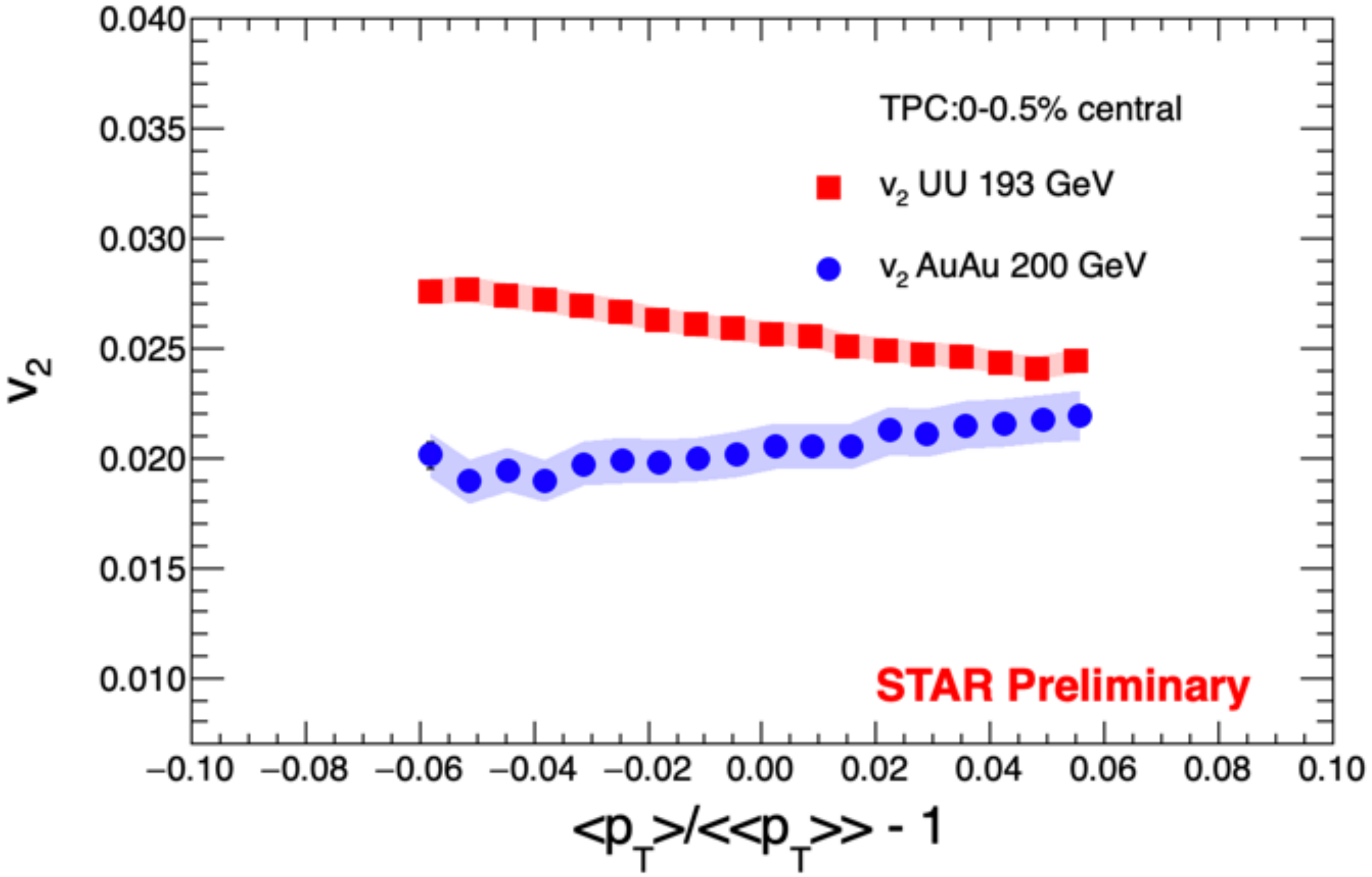




$<p_T>$ increasing trend becomes sharper in ultra-central AA collisions

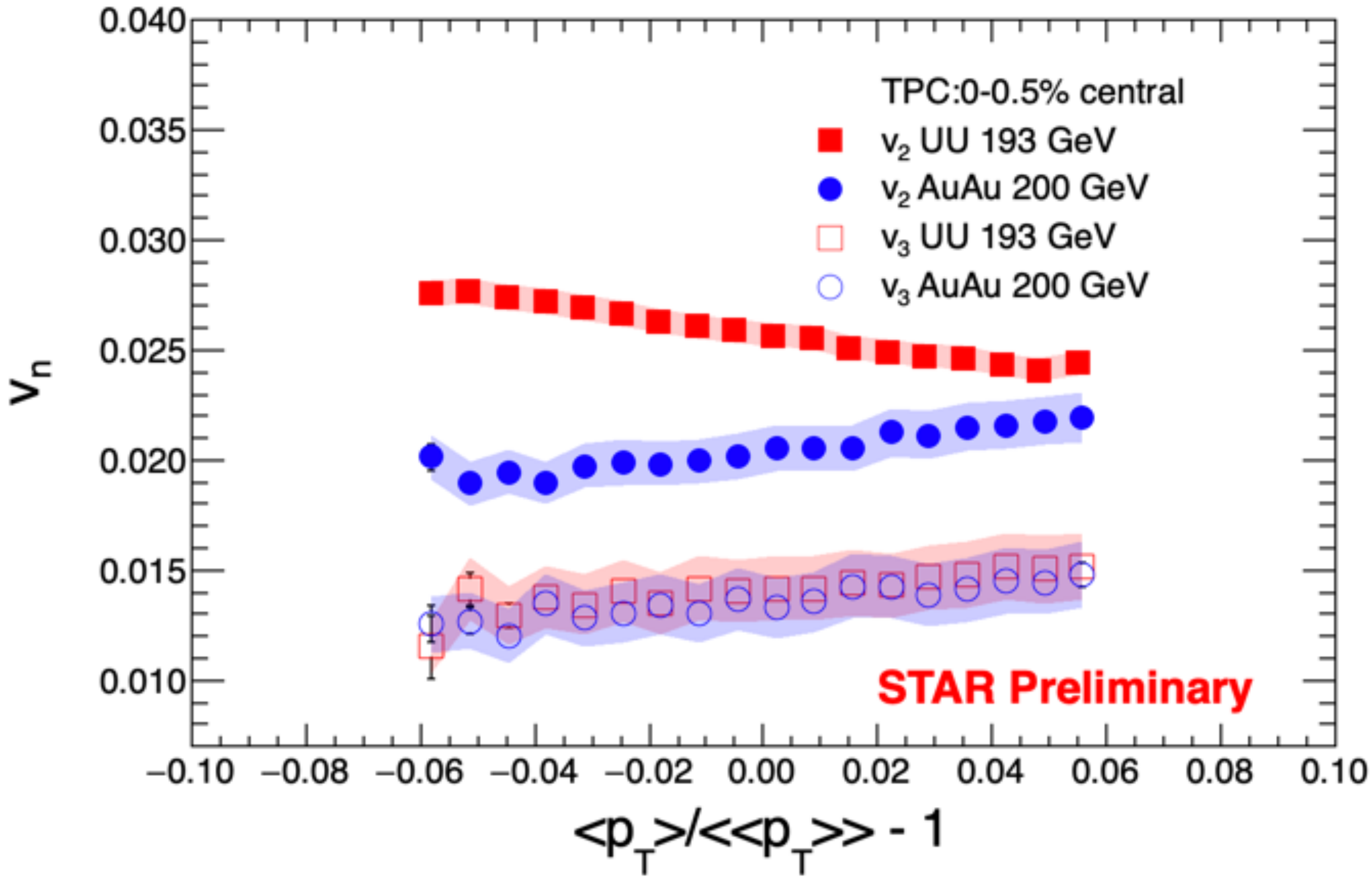
It indicates a tight correspondence between $<p_T>$ and system size, and will be useful to extract the speed of sound (C_s) of fireball

V_2 vs $<p_T>$



A negative correlation is observed between v_2 and $<p_T>$ in top 0.5% UU collisions while not in AuAu

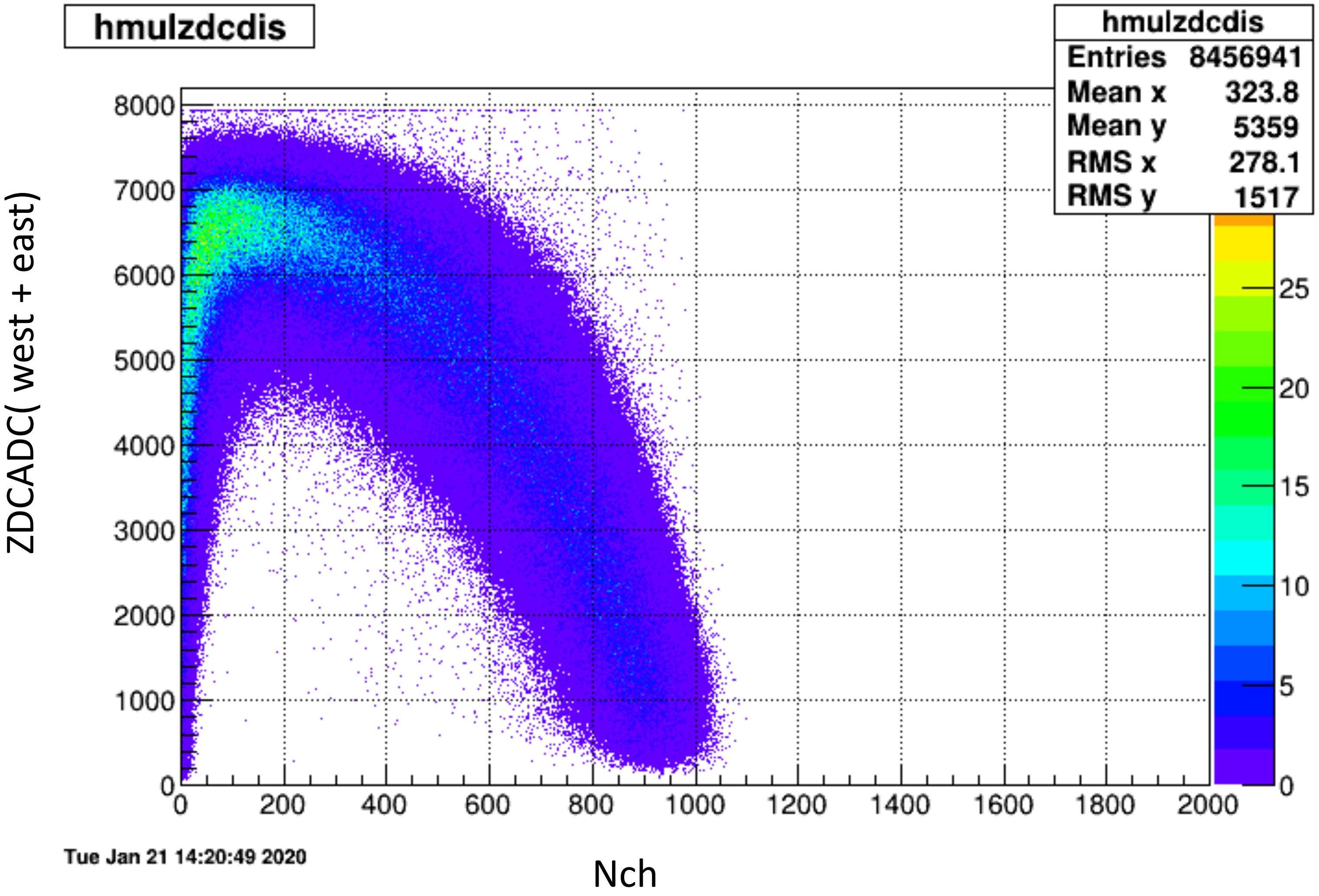
V_3 vs $<p_T>$



A negative correlation is observed between v_2 and $<p_T>$ in top 0.5% UU collisions while not in AuAu

v_3 and $<p_T>$ correlation are positive and similar in AuAu and UU collisions

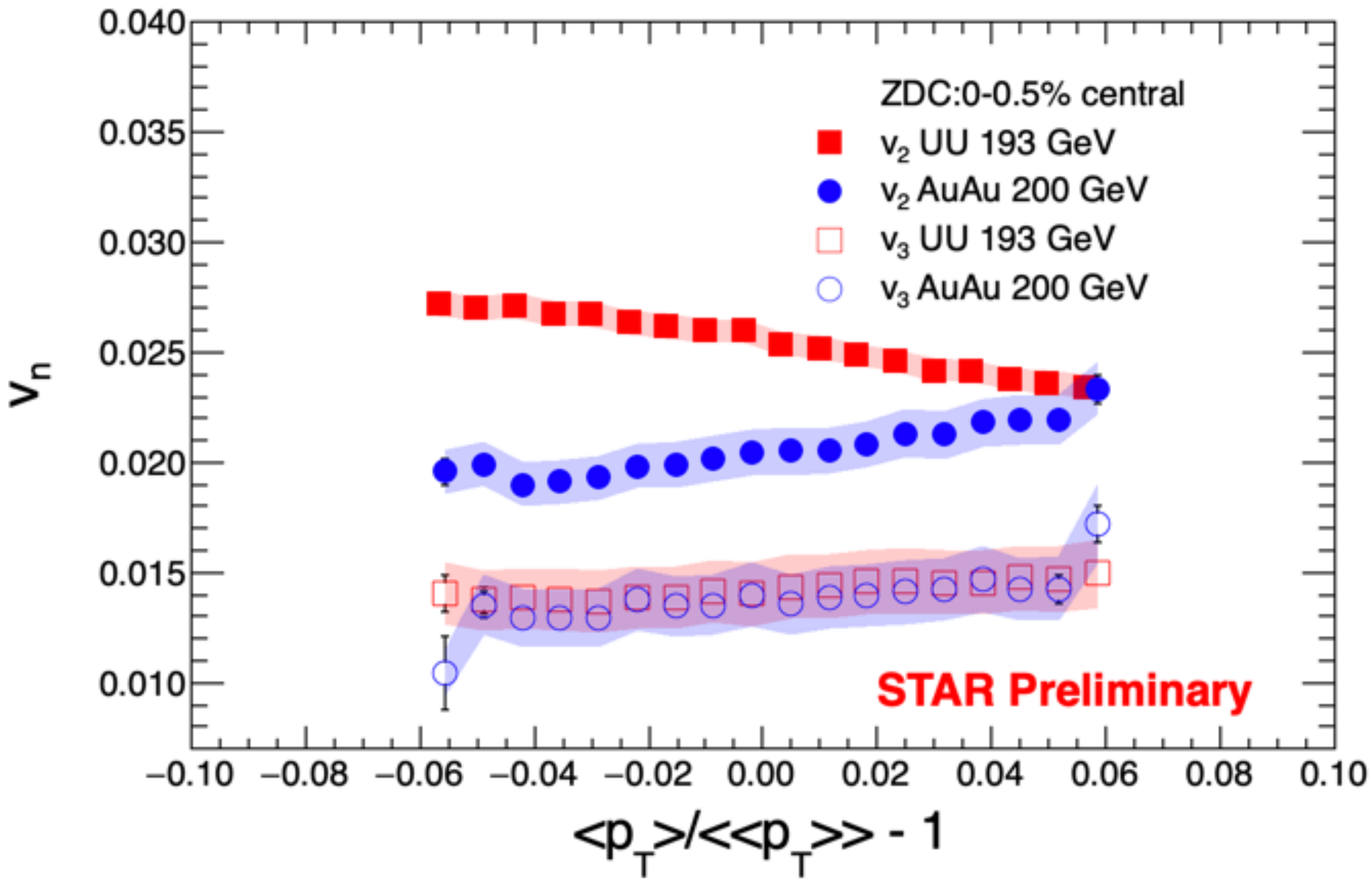
Centrality From ZDC



0.5% centrality from ZDC:

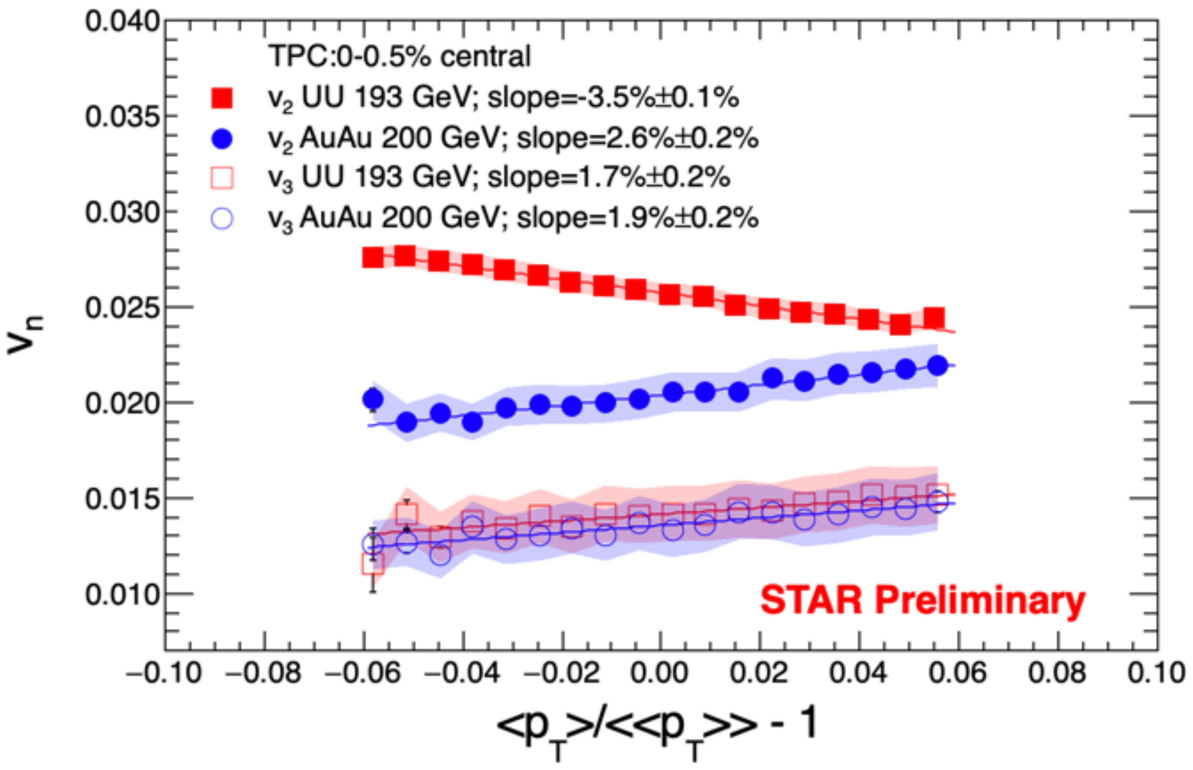
ZDCW> 497 && ZDCE>497

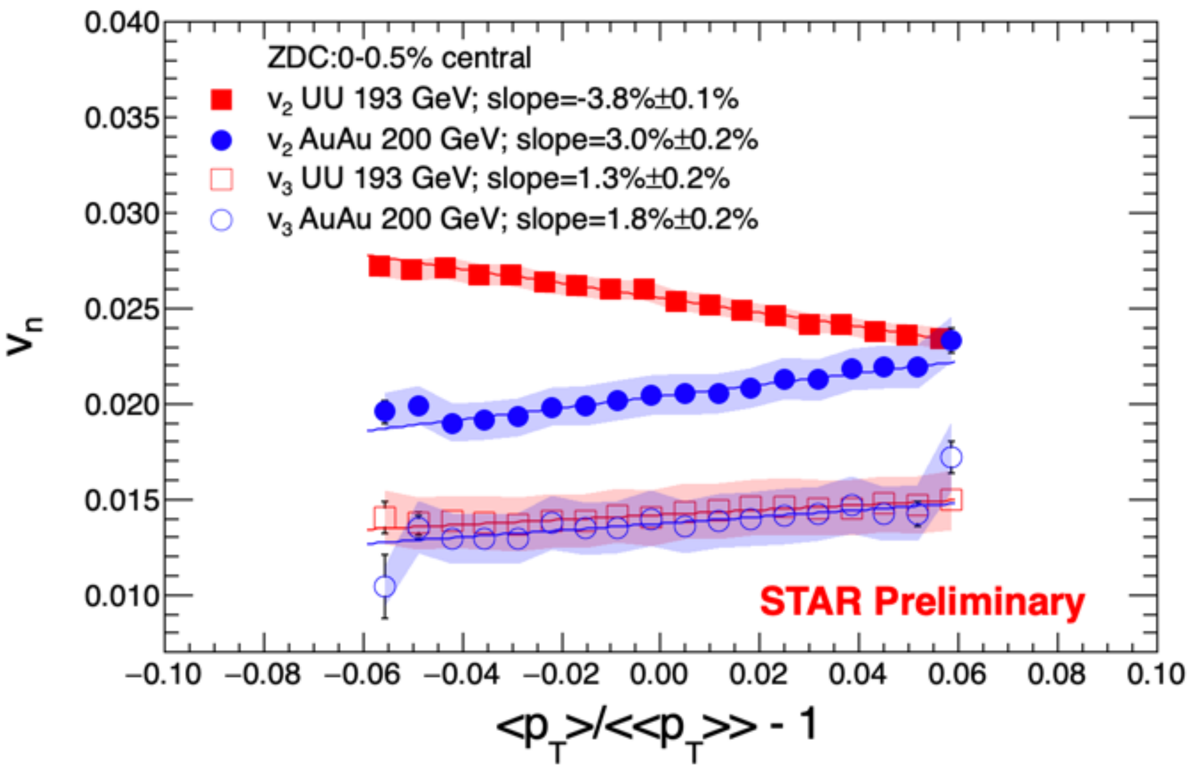
TPC Centrality vs ZDC Centrality(I)



Similar behavior is observed from centrality defined by ZDC energy as that defined by TPC Nch

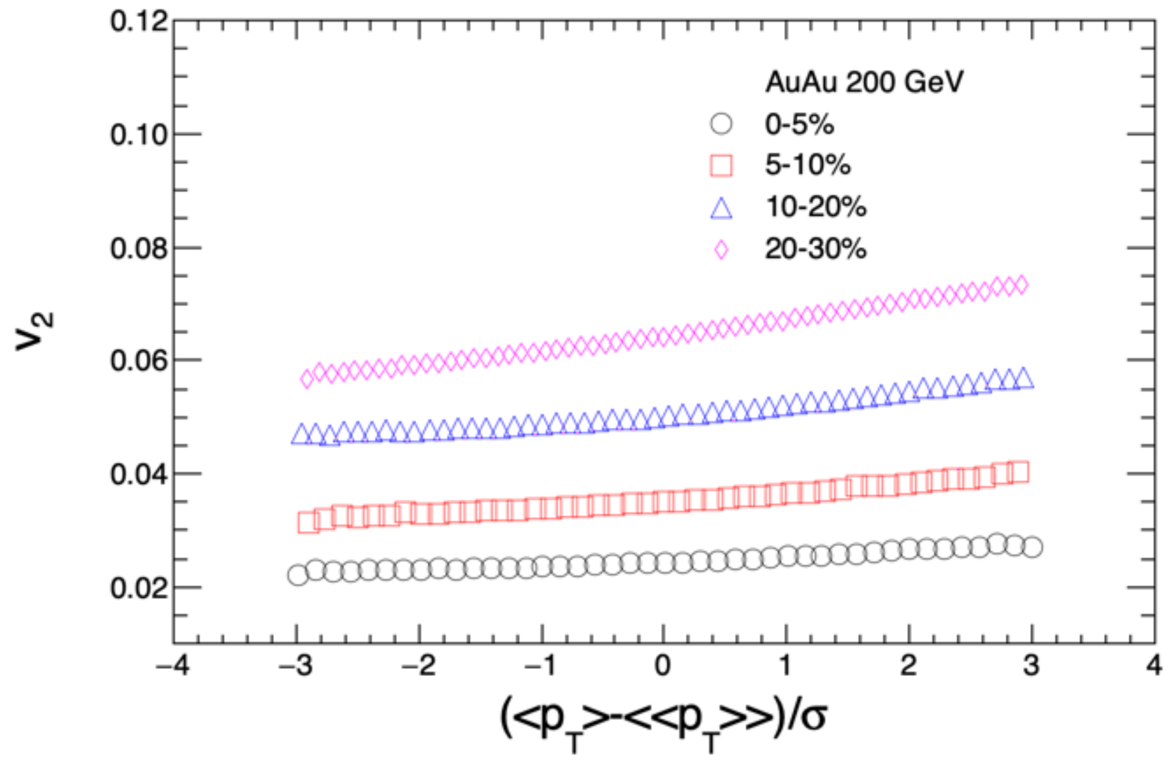
TPC Centrality vs ZDC Centrality(II)

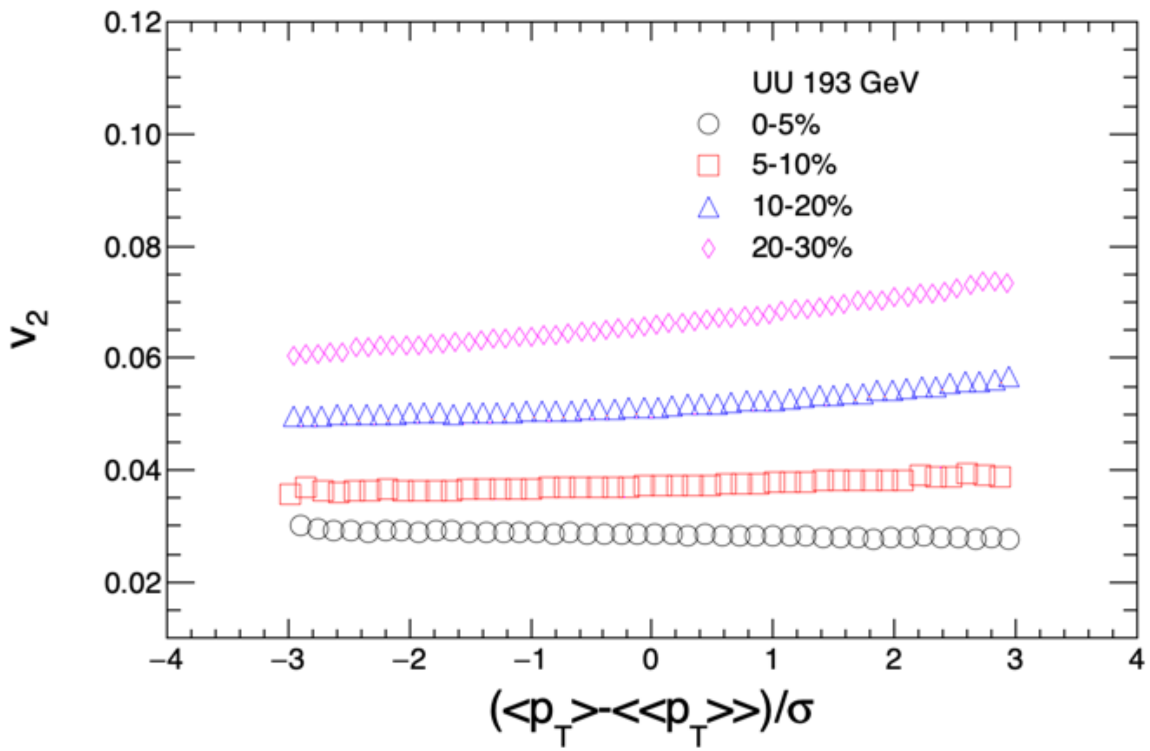




	System	TPC Centrality	ZDC Centrality
V_2 slope	UU	-3.5%±0.1%	-3.8%±0.1%
V_2 slope	AuAu	2.6%±0.2%	3.0%±0.2%
V_3 slope	UU	1.7%±0.2%	1.3%±0.2%
V_3 slope	AuAu	1.9%±0.2%	1.8%±0.2%

Centrality Dependence



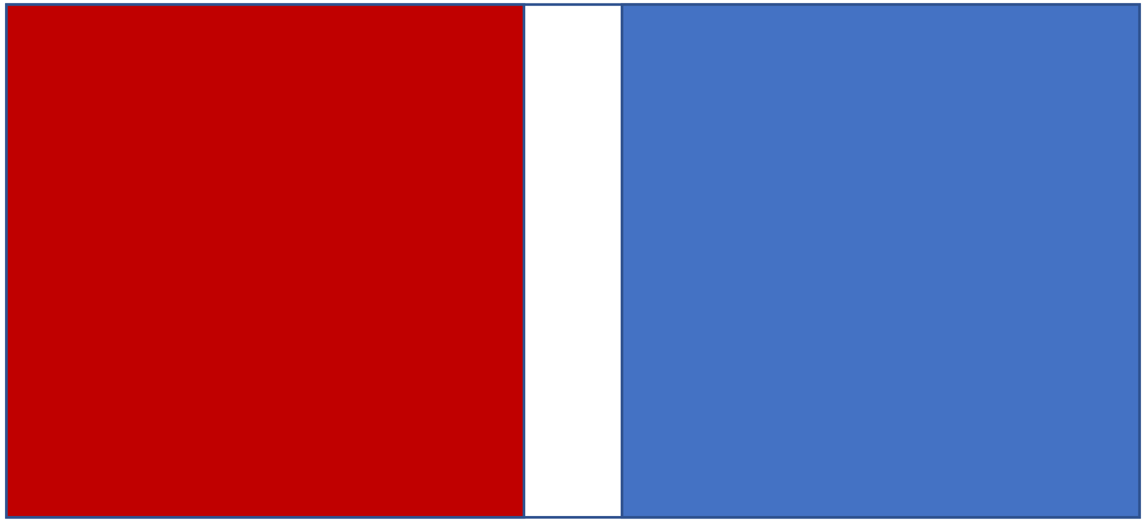


Beside ultra-centrality, the slope between AuAu and UU are also different in other centralities.

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

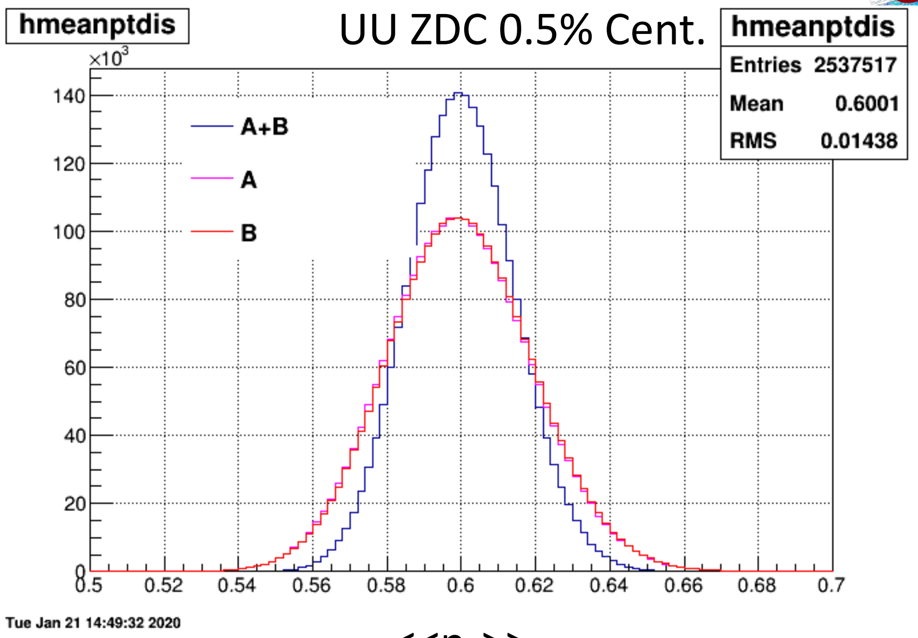
Two Subevent Method

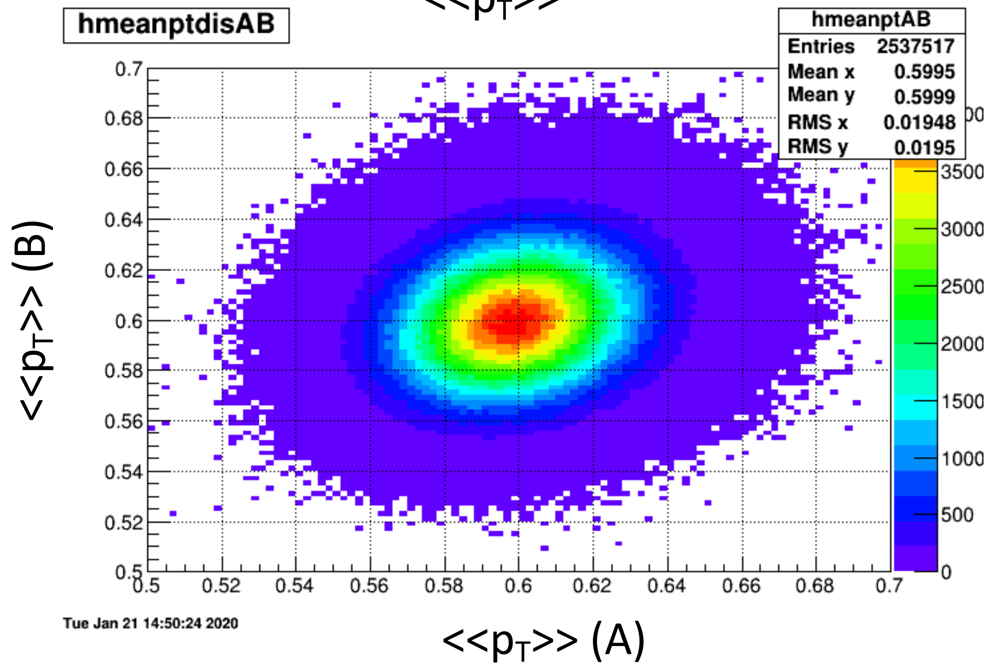
A(-1.0<η<-0.1) B(1.0>η>0.1)



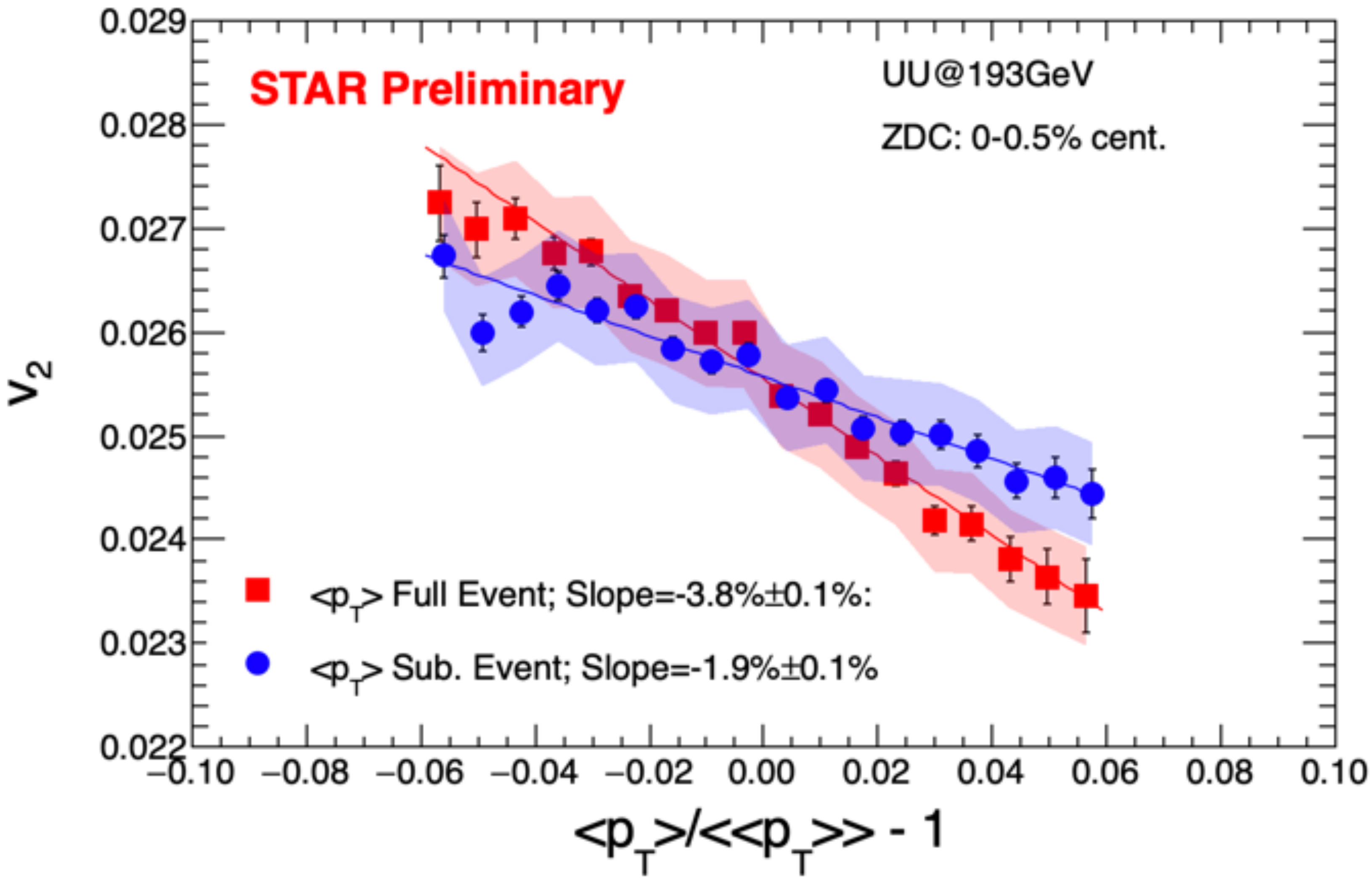
$$\langle V_{nn} \rangle = \langle Q_{n,A} \times Q^*_{n,B} \rangle$$

$$\langle\langle p_T \rangle\rangle : A, B \text{ and } A + B$$





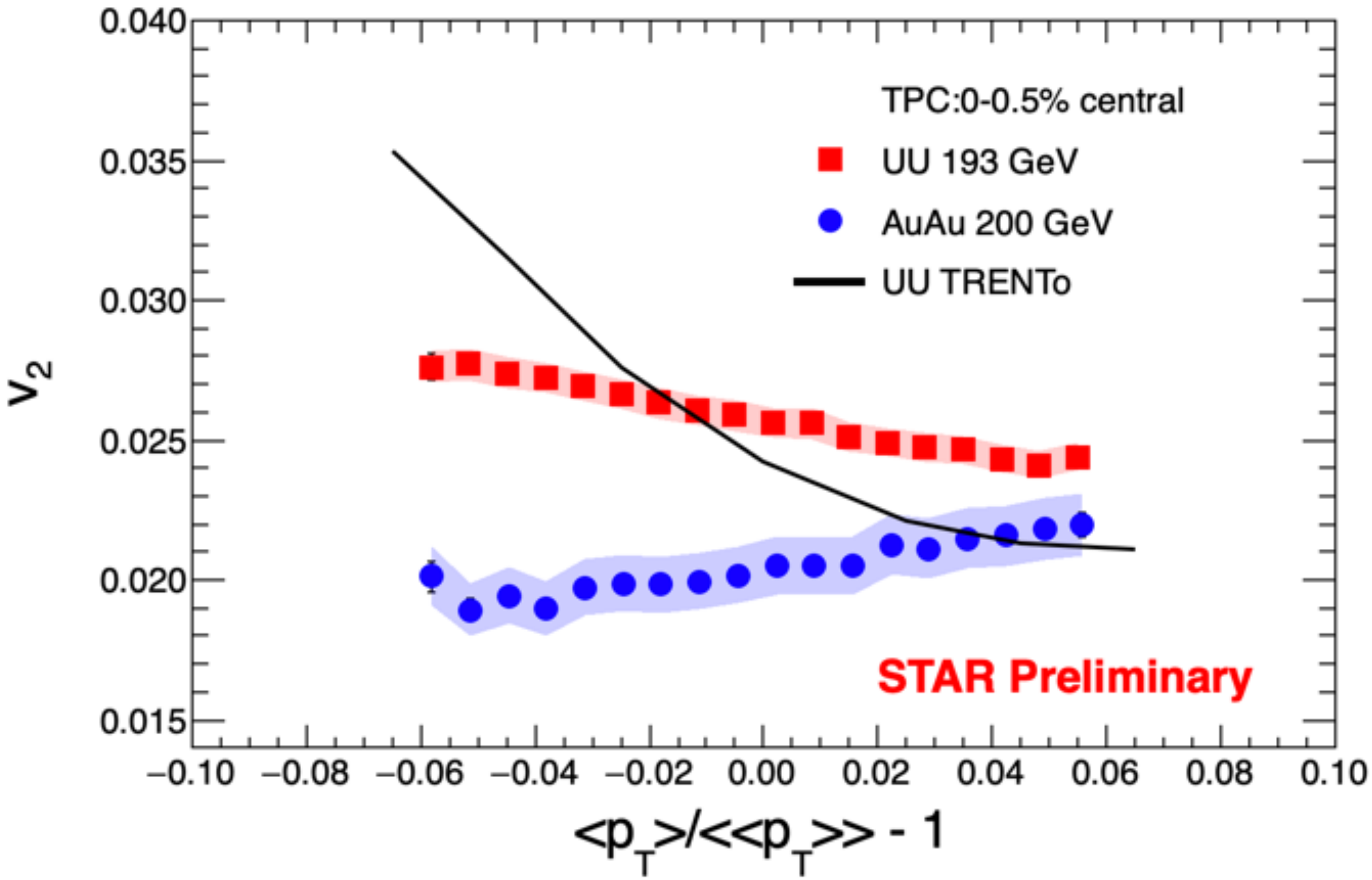
Effect of Statistical Fluctuations



The slope is a factor of two smaller of <p_T> is calculated with sub-events

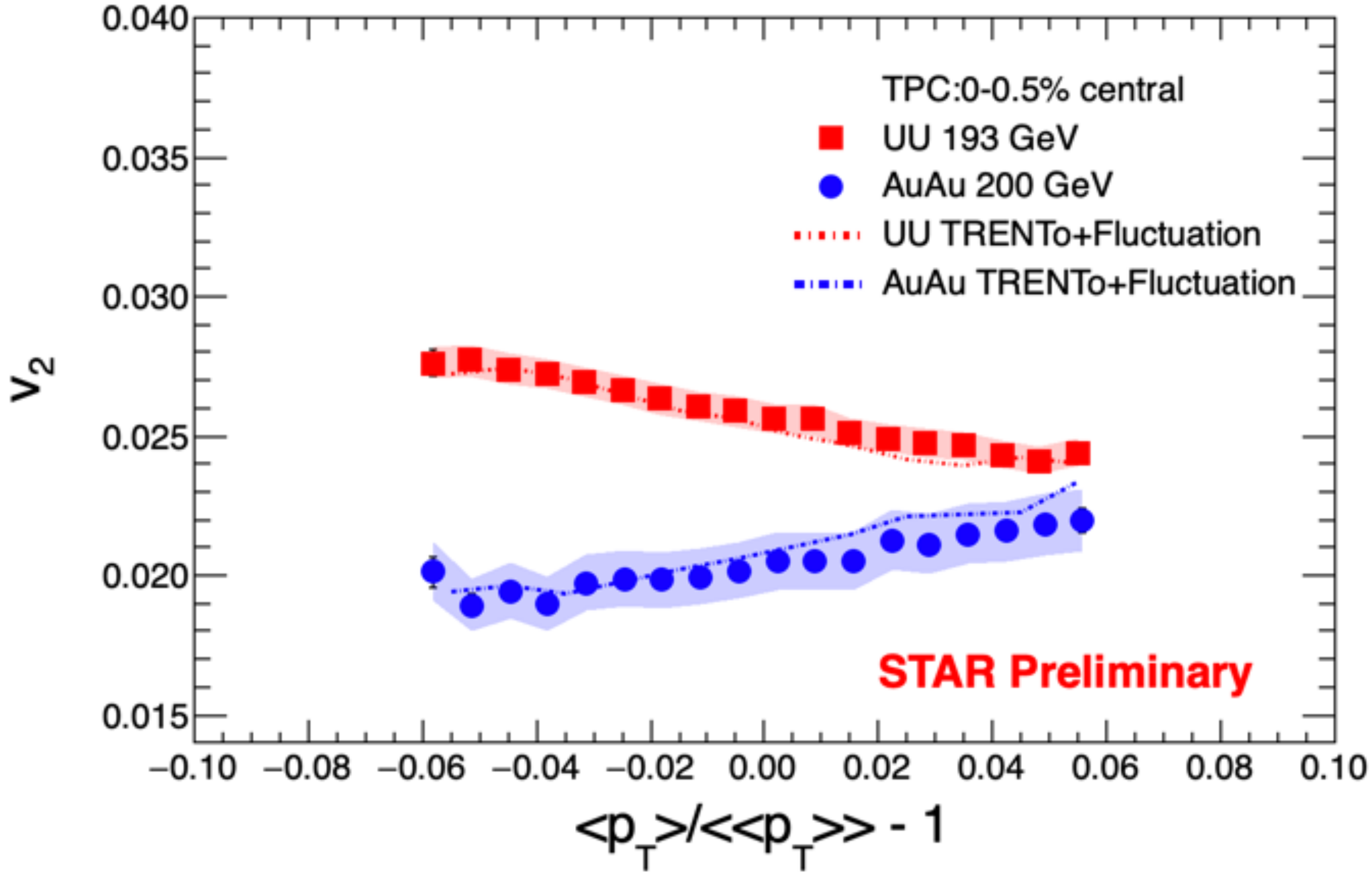
The effect of statistical fluctuations is huge!

Comparing with TRENTo



Without the statistical fluctuations, TRENto initial model over predicts the slope with β_2=0.30

Comparing with TRENTo+Fluctuation ~ v_2

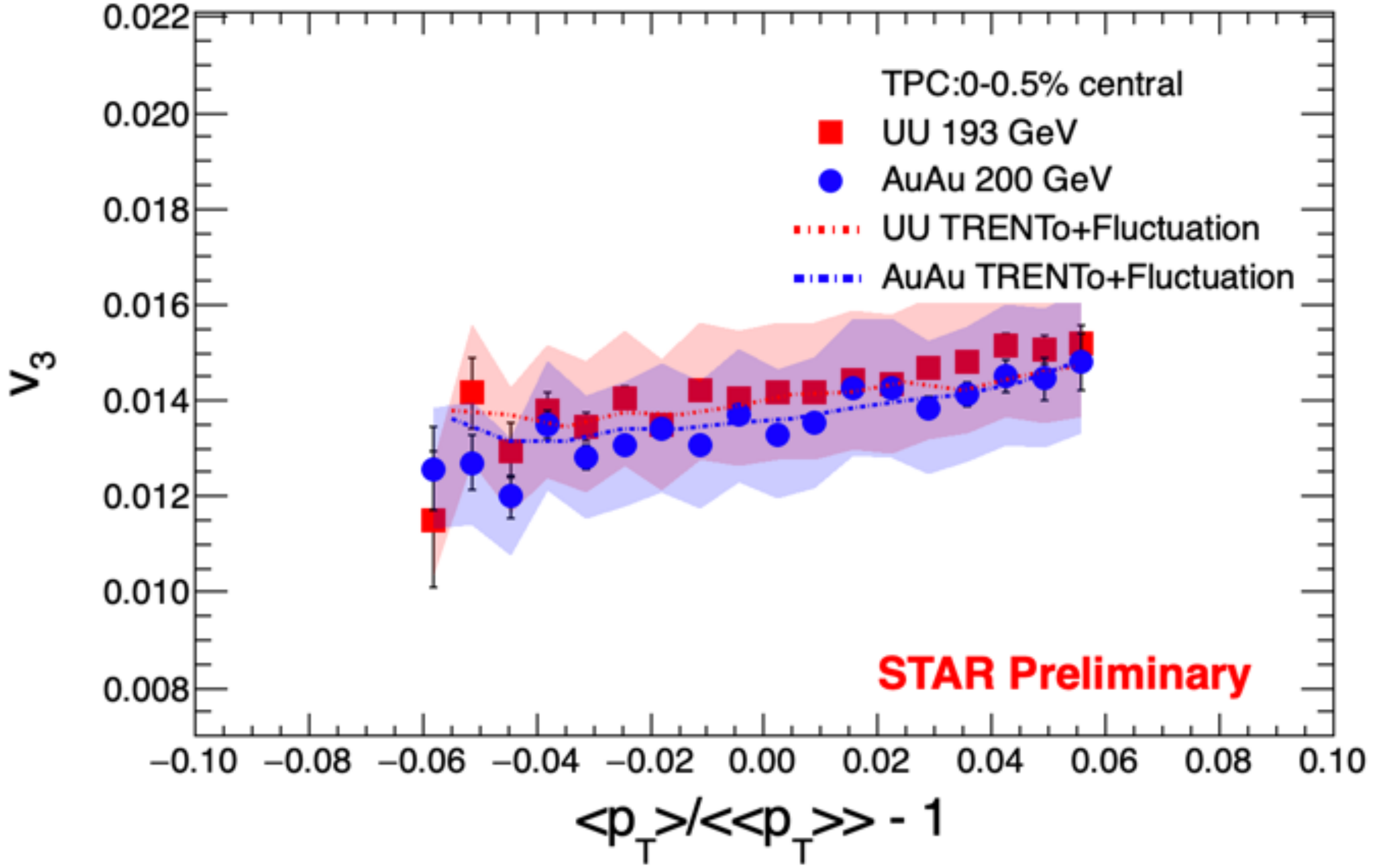


Statistical fluctuation:
$\delta\langle pt\rangle / \langle\langle pt\rangle\rangle = 0.018$
by assuming 1200 track in |eta|<1.0

Adding statistical by hand, model can re-produce the data

The statistical fluctuation is crucial!

Comparing with TRENTo+Fluctuation ~ v_3



Model can reproduce v_3 slope with same parameters!

Summary

- 1. We observer that a sharper increasing trend for $<p_T>$ vs Nch in ultra-central collisions, which maybe used to extract the Cs as Hydro. predicted

- 2. The slope of v_2 vs $<p_T>$ are different between AuAu and UU due to deformations.

- 3.After adding the statistical fluctuations by hand, the TRENTo initial model can reproduce the data with deformation factor $\boldsymbol{\beta}_2$=0.30

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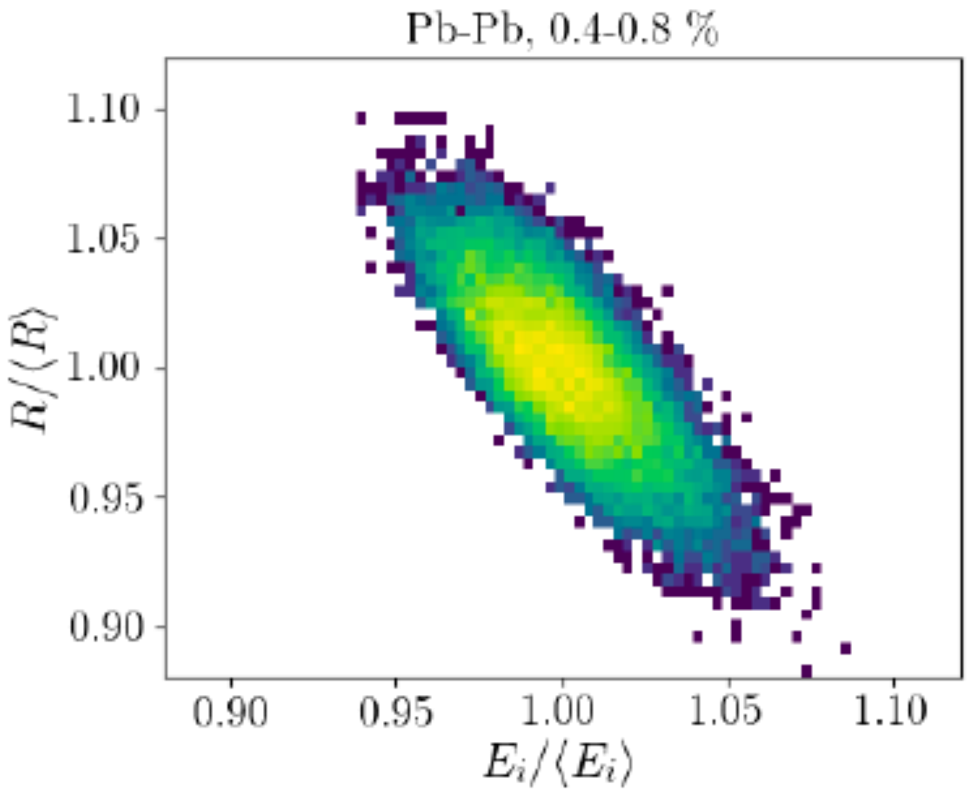
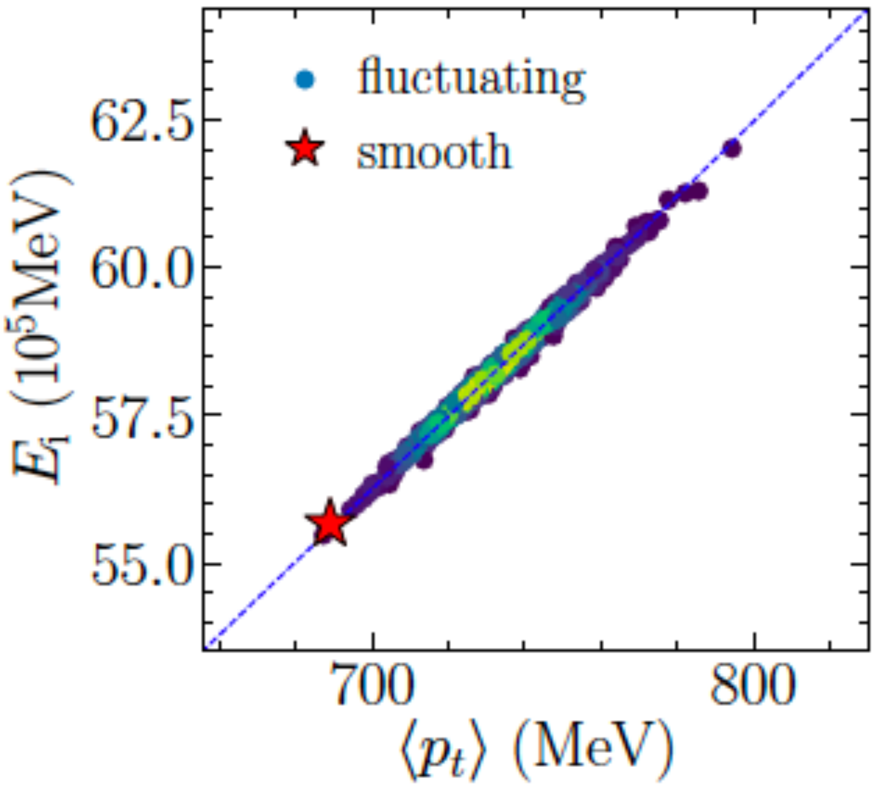
BackUp

Corresponding of <pt> vs Initial Energy E_i

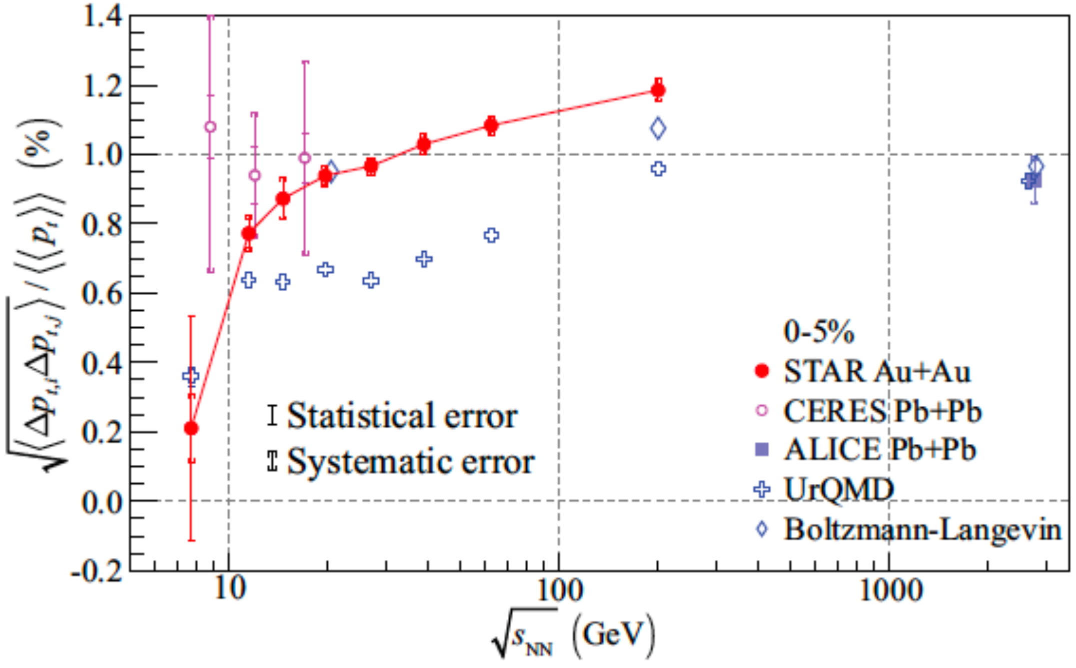




TRENTo+Hydrodynamics

Stronger corresponding of <pt> with Ei that that of <pt> with 1/R

Dynamical Fluctuation of <pt>



From TRENTo, the dynamical fluctuation of E_i

$$\delta E_i / \langle E_i \rangle = 0.03$$

From STAR, the dynamical fluctuation of <pt>

$$\delta \langle pt \rangle / \langle \langle pt \rangle \rangle = 0.012$$

$$\frac{\delta \bar{p}_t}{\langle \bar{p}_t \rangle} = 0.4 \frac{\delta E_i}{\langle E_i \rangle}$$

Statistical Fluctuation

${}^{\delta\langle pt\rangle}/_{\langle\langle pt\rangle\rangle} = 0.018$ by assuming 1200 track in |eta|<1.0

Statistical fluctuation = 1.5 dynamical fluctuation