# Event anisotropy in U+U collisions

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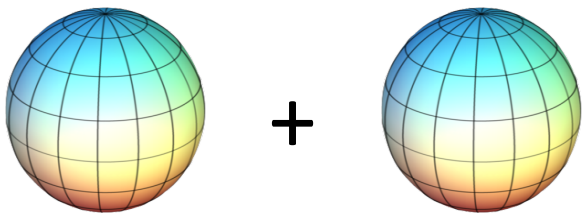
# Motivation

Au+Au Collisions



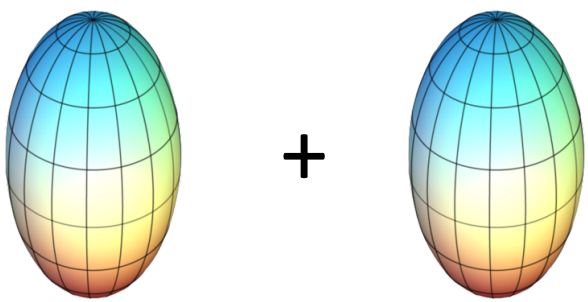
Oblate

The prolate shape of uranium nuclei provides the possibility to study

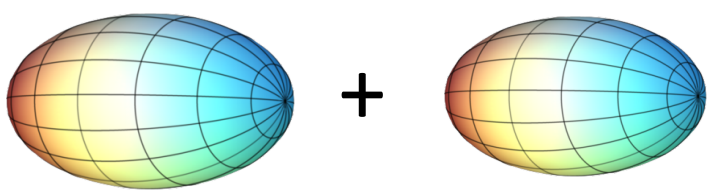
- Particle production mechanism
- Anisotropic flow
  - any difference between Au+Au and U+U?
  - separate body-body and tip-tip in U+U?
- Chiral Magnetic Effects
  - Three-particle correlator signal induced by $v_2$?
- Path-length dependence of hard probes

U+U Collisions

body-body

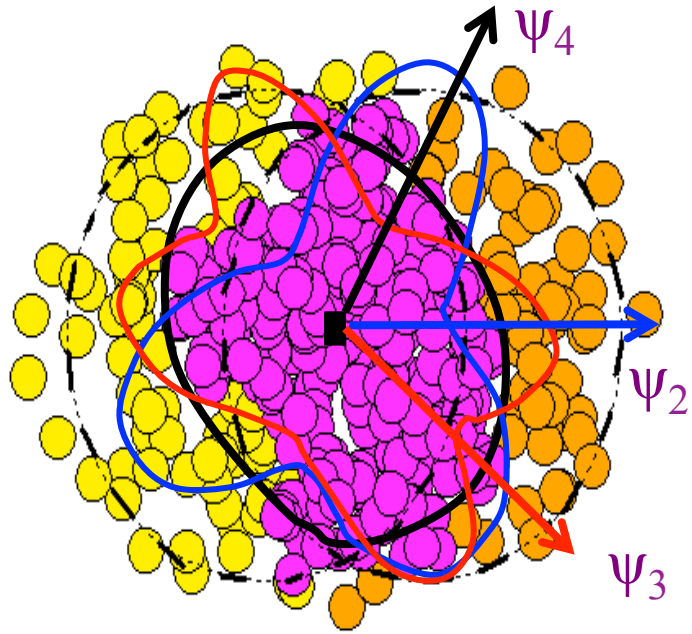


tip-tip



Prolate

# Anisotropic Flow




Initial geometry has multi-pole shape due to fluctuations

B. Alver et al, PRC 81, 054905 (2010)

$$\varepsilon_n^2 = \frac{\langle r^n \cos(n\varphi)\rangle^2 + \langle r^n \sin(n\varphi)\rangle^2}{\langle r^n \rangle^2}$$

$$\tan(n\psi_n) = \frac{\langle r^n \sin(n\varphi)\rangle}{\langle r^n \cos(n\varphi)\rangle}$$

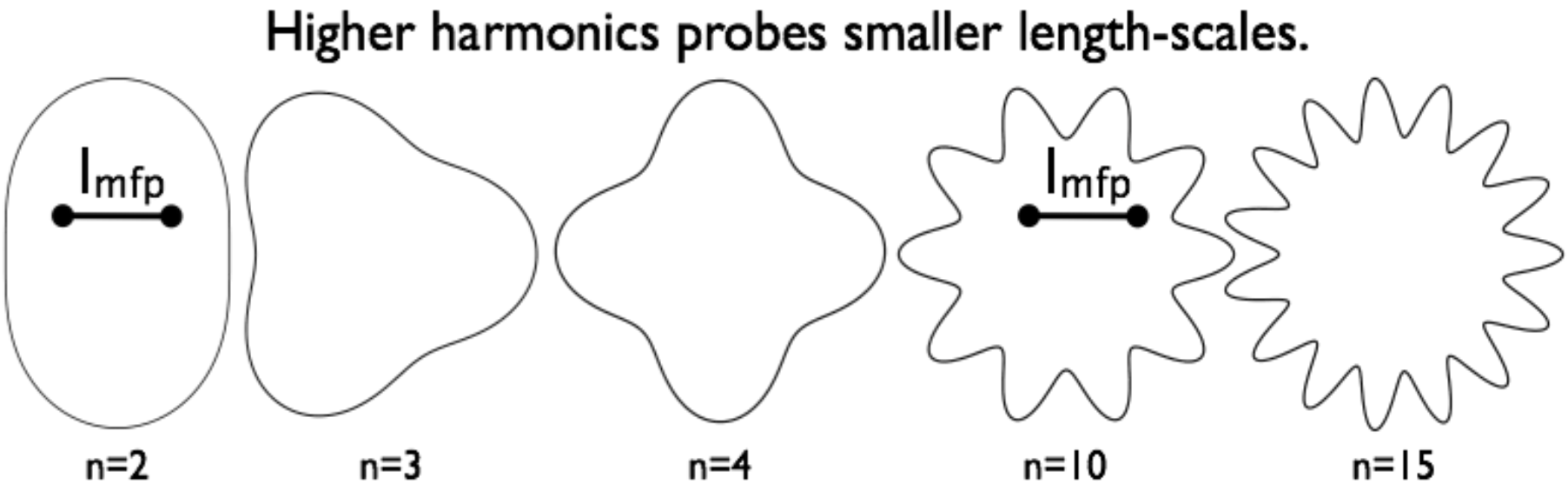
Fourier expansion of azimuthal distribution in momentum space

$$\frac{dN}{d\phi} \propto 1 + \sum_n 2\mathrm{v}_\mathrm{n} \cos n\left(\phi - \psi_n\right)$$

$$\nu_\mathrm{n} = \left\langle \cos\left[n\left(\phi - \psi_n\right)\right]\right\rangle$$

$v_2$ (elliptic flow) has been well studied in experiments and model calculations

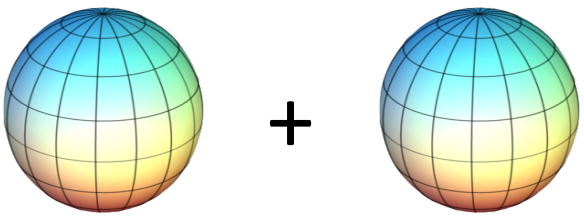
# Anisotropic Flow




- Sensitive to initial state fluctuations and hydrodynamic evolution
- Provide valuable information to study the evolution of the system
- Different harmonics may have different sensitivity to the medium properties( i.e. η/s)
- Use the full spectrum of harmonics to maximally constrain the models

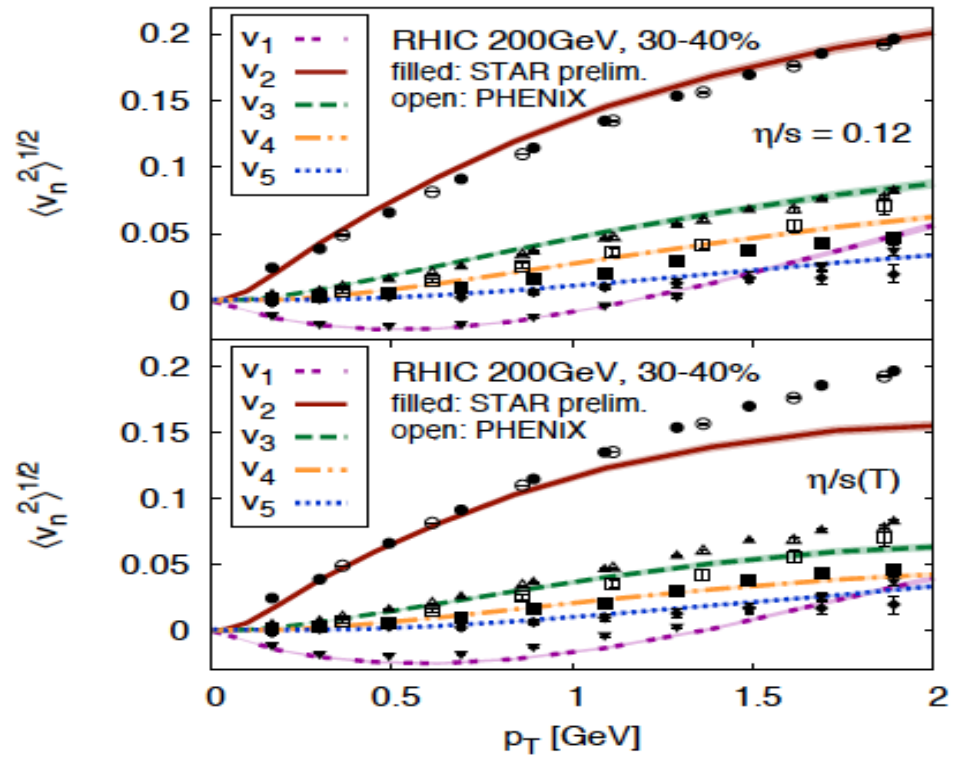
# Anisotropic Flow

Au+Au Collisions

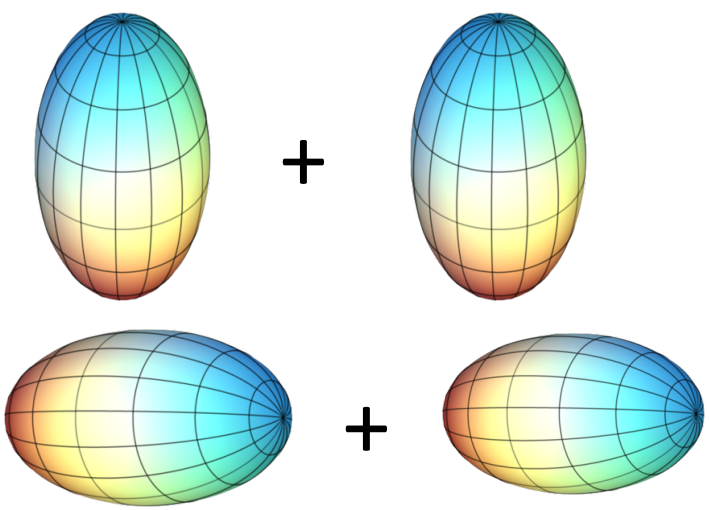


Oblate

Phys. Rev. Lett. 110, 012302,(2013).



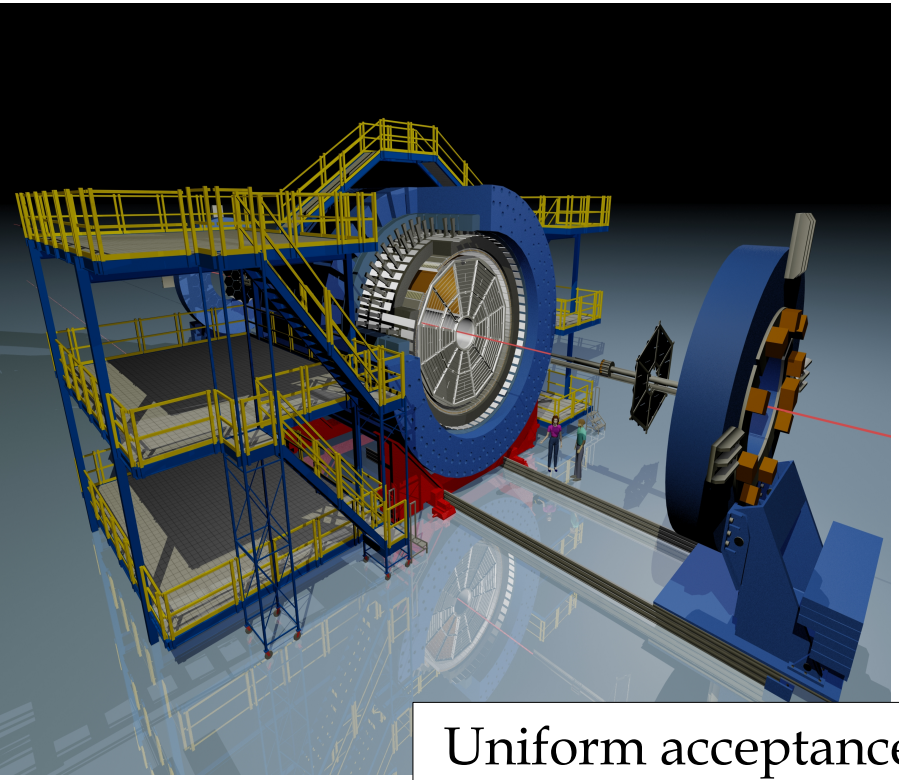

U+U Collisions

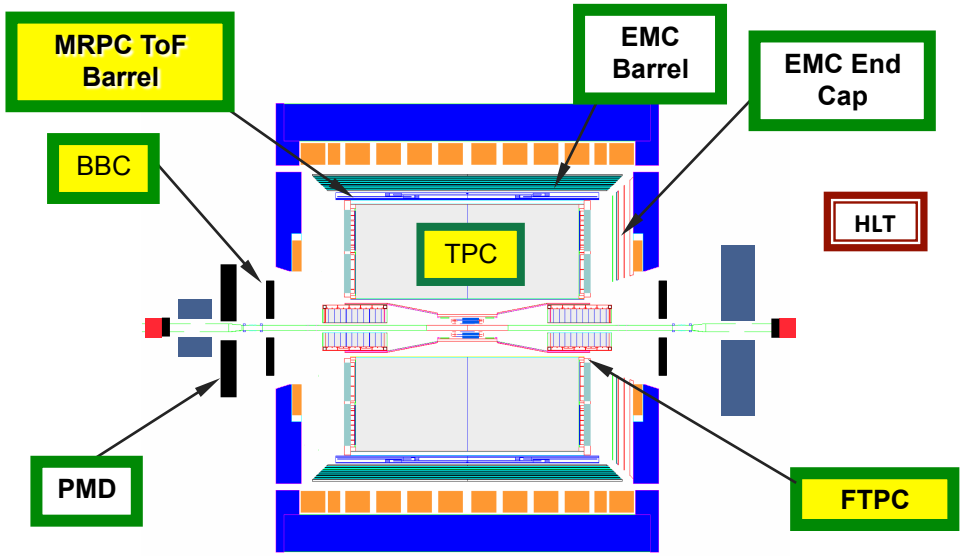


Prolate

Do we expect to see similar description of UU data ? (i.e. similar η/s )

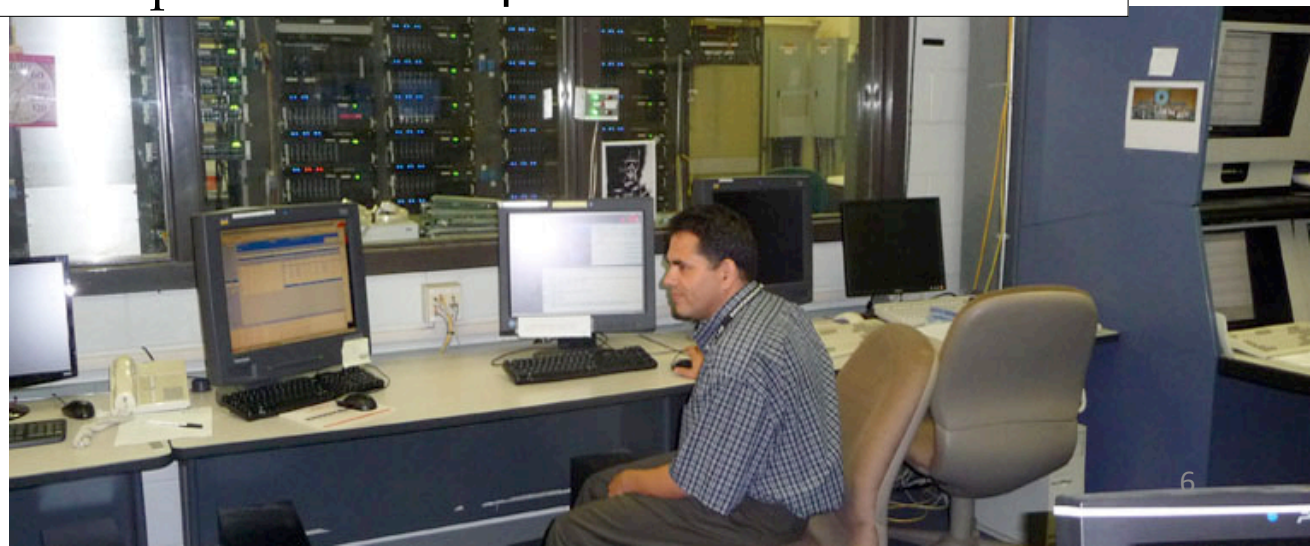
# The Solenoid Tracker At RHIC (STAR)






Uniform acceptance in $-1 < \eta < 1$ & $2\pi$ in azimuth

STAR is composed of 57 institutions from 12 countries, with a total of 533 collaborators



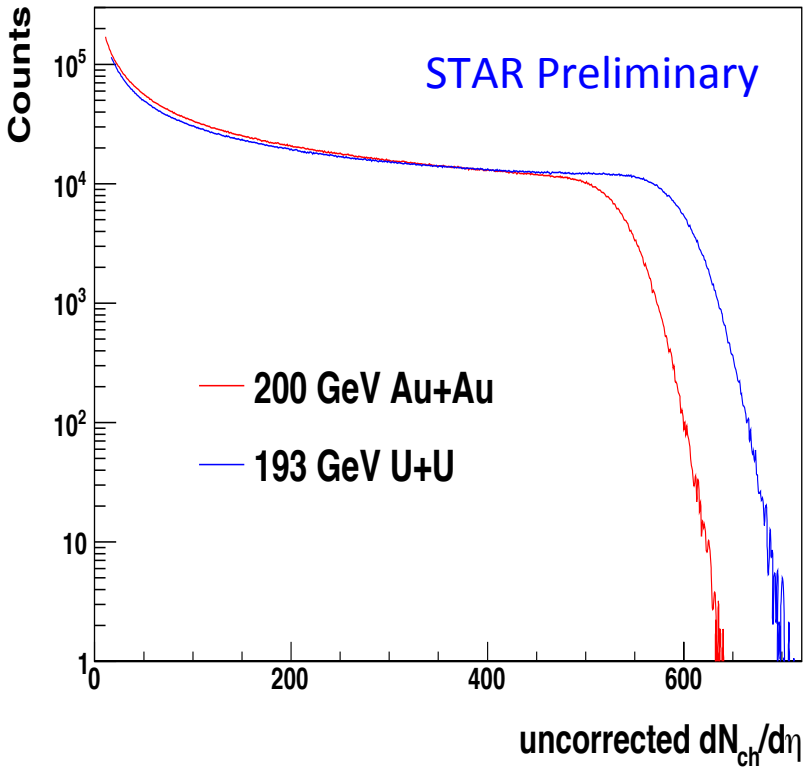
# Particle production

We often assume multiplicity depends partially on the number of participants and partially on the number of binary collisions

$$N_{ch} = n_{pp} * [x N_{coll} + (1-x) N_{part}/2].$$

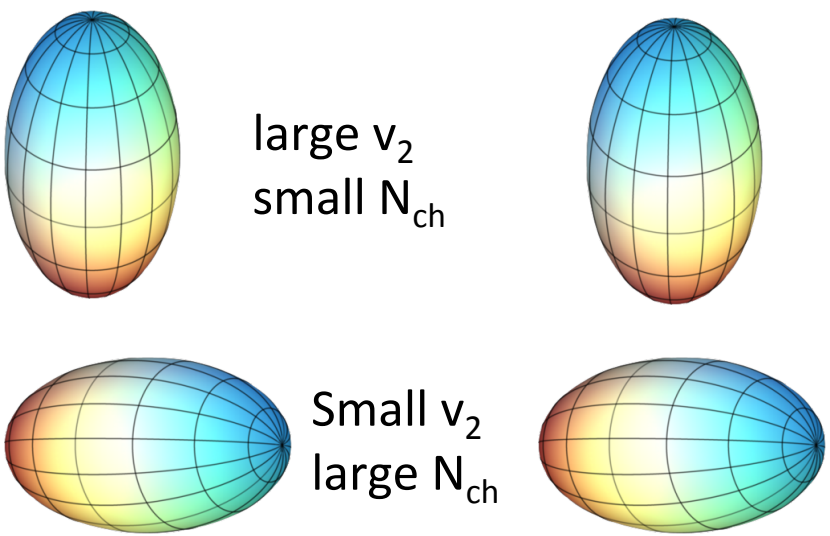
A larger system produces more particles ?

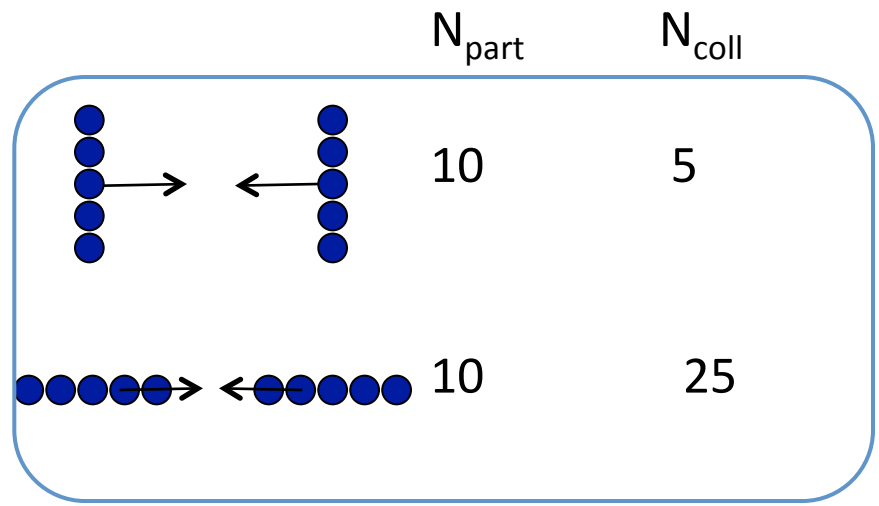
Yes ! Multiplicity distribution well fitted by the MC Glauber



# Particle production

Central U+U collisions, ideal testing ground for particle production:



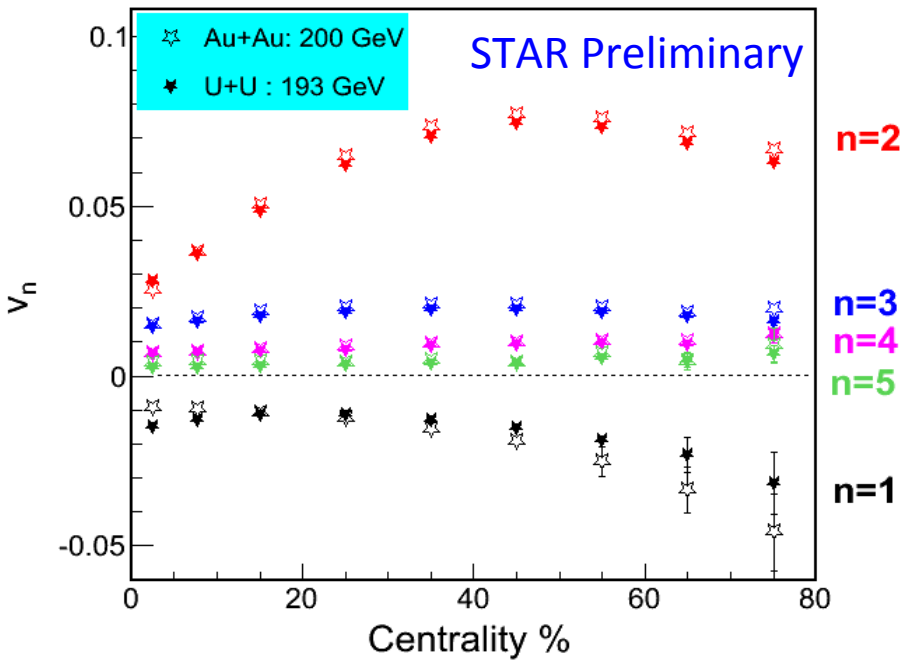

Zero Degree Calorimeters (ZDC)were used to trigger on spectator neutrons.

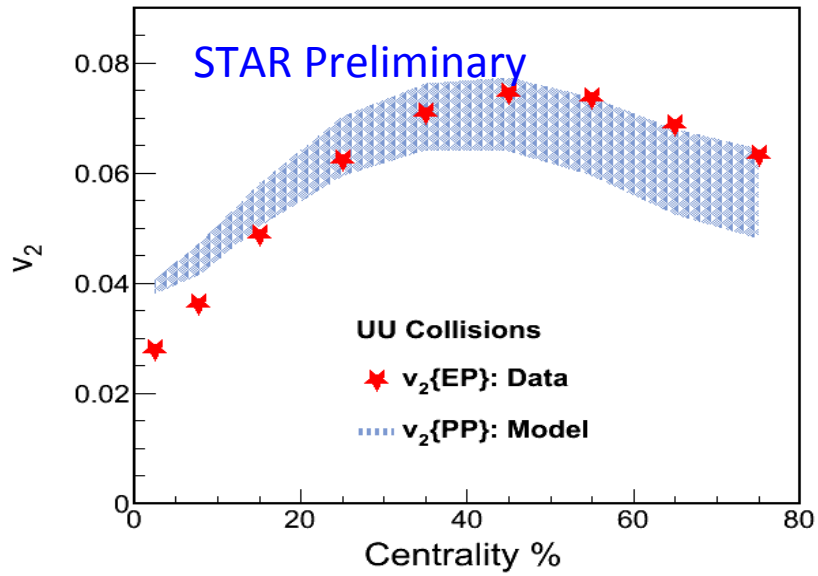
Is larger $v_2$ associated with lower $N_{ch}$?

# Centrality dependence

Au+Au Results: QM2012, STAR Collaboration

H. Masui et. al, Phys. Lett. B 679, 440(2009)

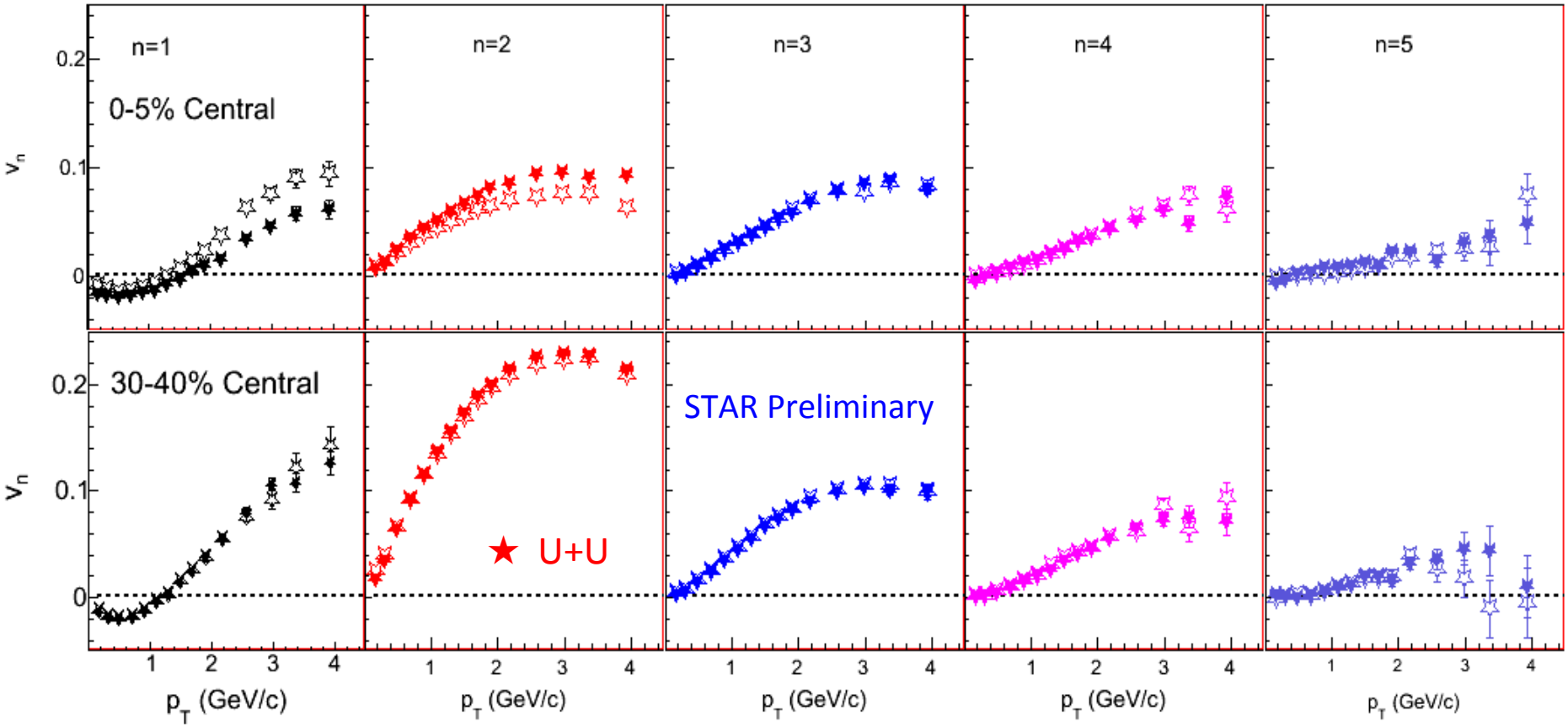


- $v_n$ integrated in $0.15<p_T<2$ GeV/c.
- Centrality dependence is week for all other harmonics except n=2
- $v_2$ in U+U central collisions is not as large as predicted based on MC Glauber based approach

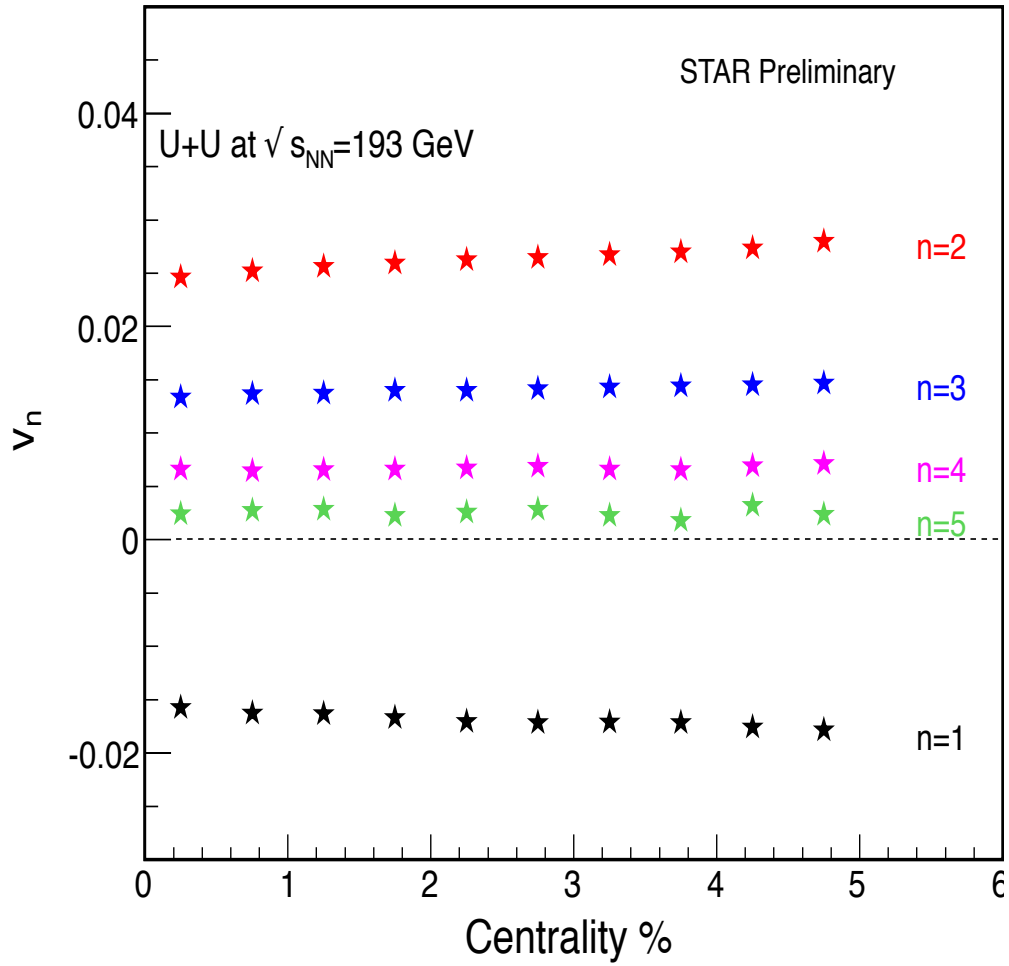
# Transverse momentum($p_T$) dependence

Au+Au Results: QM2012, STAR Collaboration




- $v_1$ crosses zero above $p_T$> 1.2 GeV/c
- $v_n$ for U+U collisions is similar to that of Au+Au Collisions except n=1 and 2 at central collisions

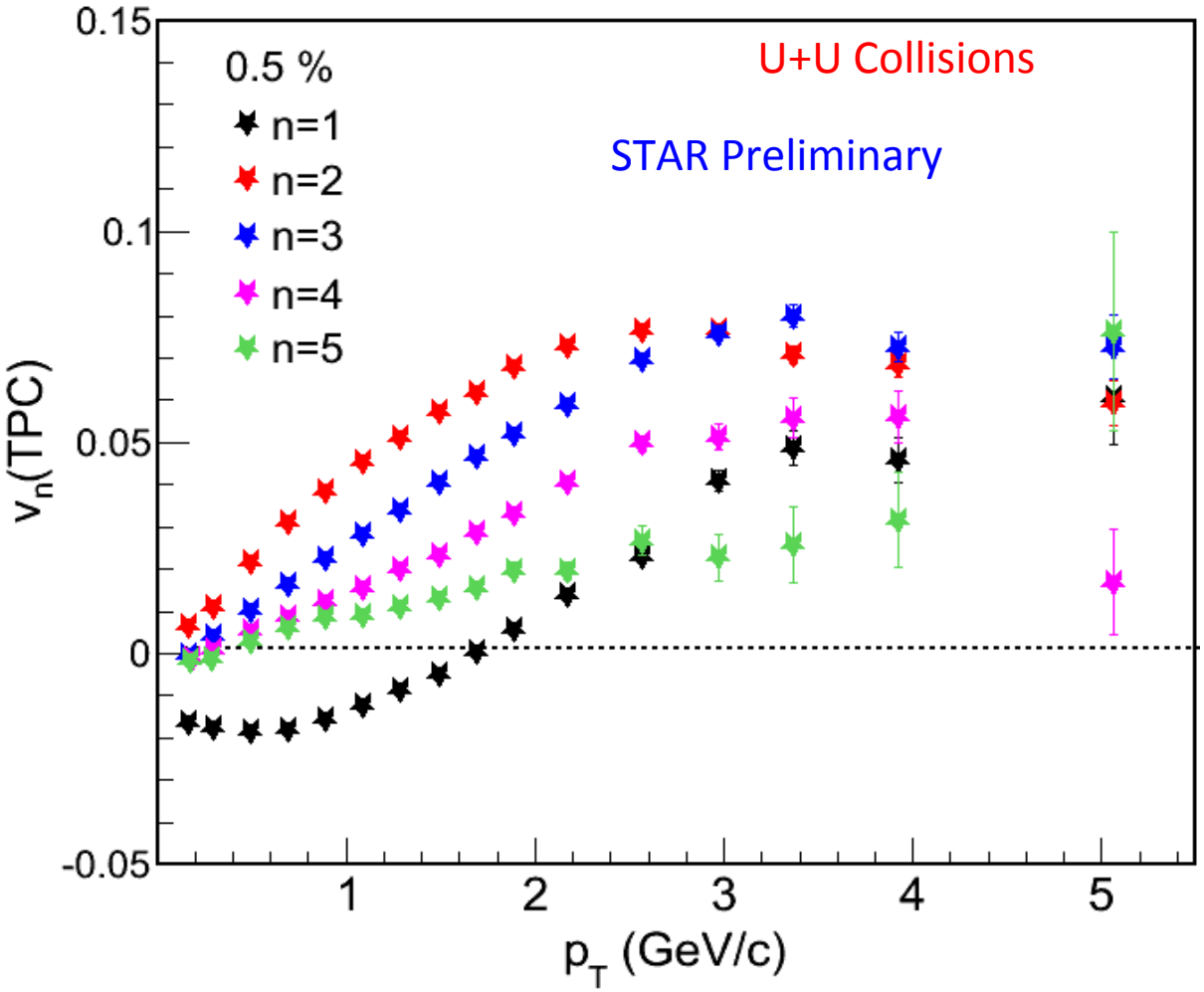
# Flow harmonics for ultra central events: $v_n$ as a function of centrality




| Centrality | Uncorrected $dN_{ch}/d\eta$ at \|eta\|<0.5 |
|---|---|
| 5.0% | 523 |
| 4.5% | 531 |
| 4.0 % | 538 |
| 3.5 % | 446 |
| 3.0% | 554 |
| 2.5 % | 562 |
| 2.0 % | 570 |
| 1.5 % | 580 |
| 1.0 % | 591 |
| 0.5 % | 606 |

$p_T$ ($0.15 < p_T < 2$) integrated $v_n$: $v_2$ changes slightly, other harmonics are almost constant

# Flow harmonics for ultra central events: $v_n$ as a function of $p_T$



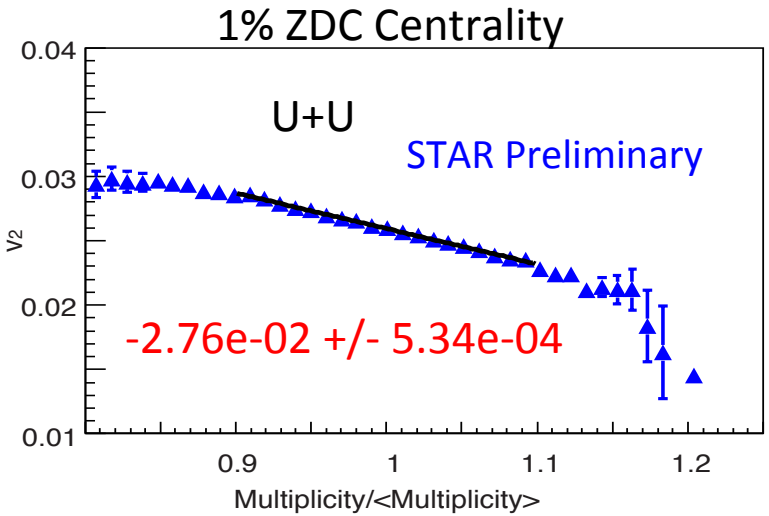

- $v_2$ is still dominant harmonics at low $p_T$ (< 2 GeV/c) at ultra central(0-0.5%) collisions

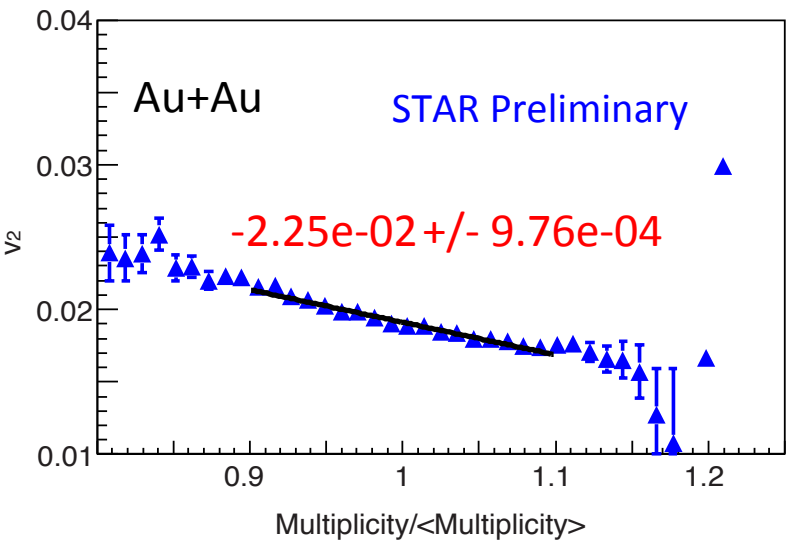
- At intermediate $p_T$ (3-5 GeV/c) range, $v_3 \sim v_2$ and $v_1 \sim v_4$ in ultra central collisions

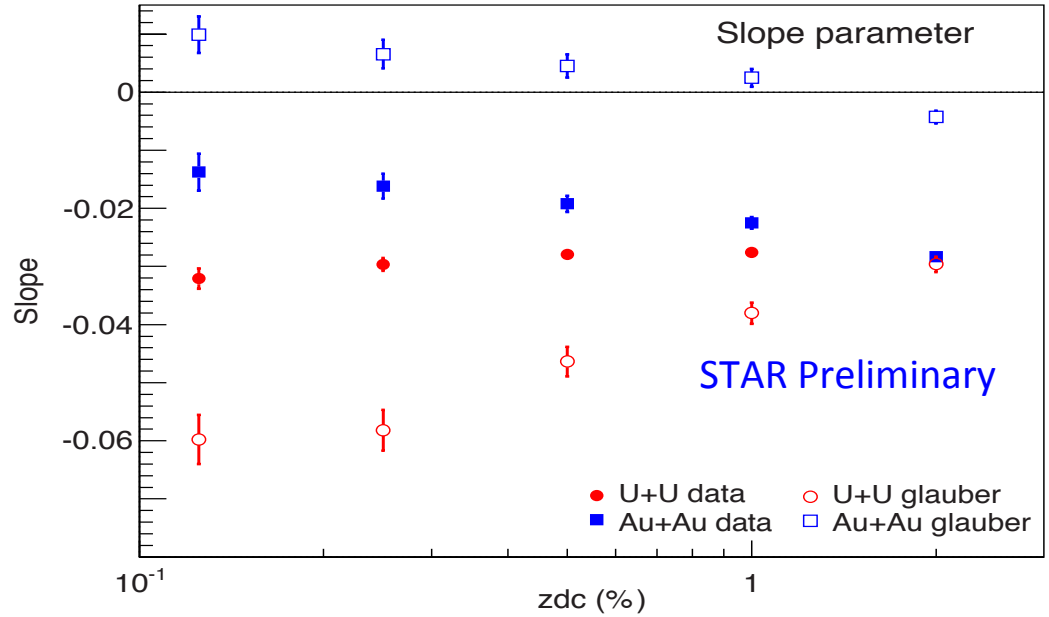
Transverse momentum dependence of 0.5% central collisions

# Can we see a difference between Au+Au and U+U?

Use of normalized multiplicity cancels out multiplicity independent efficiency



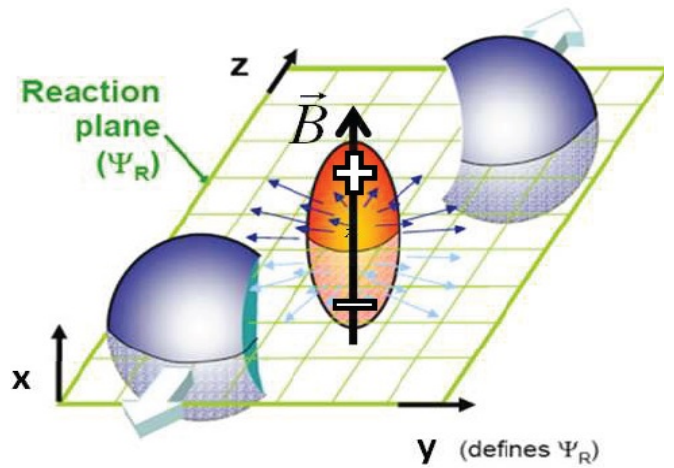




- The U+U $v_2$ shows a stronger multiplicity dependence.
- A linear fit for $v_2$, the slope parameter
- The differences in the slope parameters between Au+Au and U+U increase in more central collisions
- Compare with eccentricity calculated from glauber simulations( scaled down 0.2 for UU and 0.25 for AuAu to match the experimental $v_2$ )

Zero Degree Calorimeters (ZDC)were used to trigger on spectator neutrons

# Search for Local Parity Violation

$$\frac{dN_{\pm}}{d\phi} \propto 1 + 2a_{\pm} \cdot \sin\left(\phi^{\pm} - \Psi_{RP}\right)$$




A direct measurement of the P-odd quantity "a" should yield zero

$$\gamma = \left\langle \cos(\phi_\alpha + \phi_\beta - \psi_{RP}) \right\rangle$$

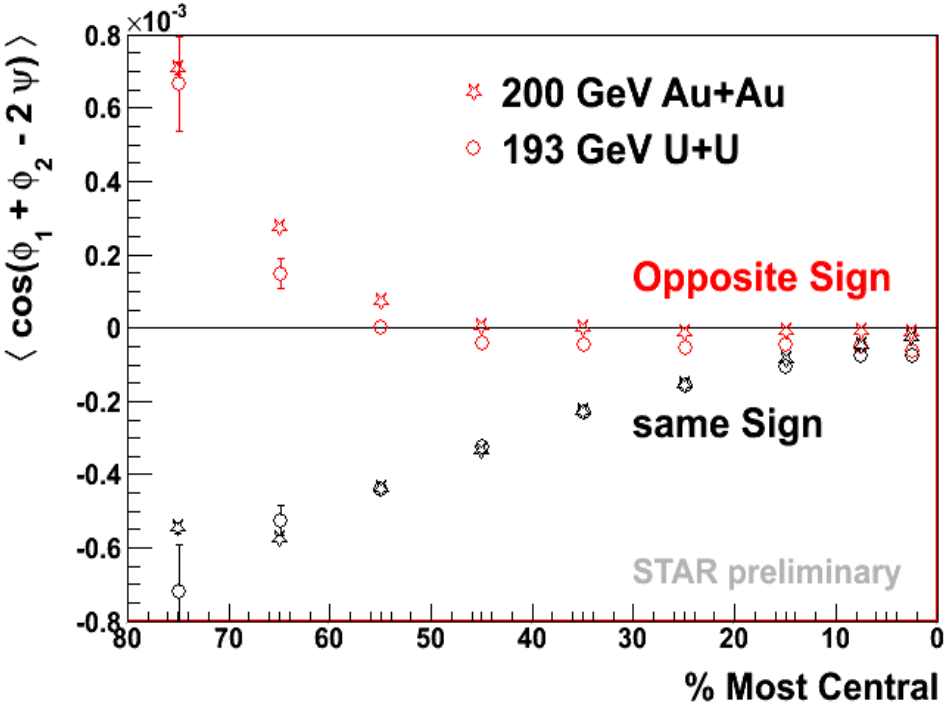
$$= \left[\left\langle v_{1,\alpha} v_{1,\beta} \right\rangle + B_{in}\right] - \left[\left\langle a_\alpha a_\beta \right\rangle + B_{out}\right]$$

*Non-flow/non-parity effects: largely cancel out*

*Directed flow:* expected to be the same for SS and OS

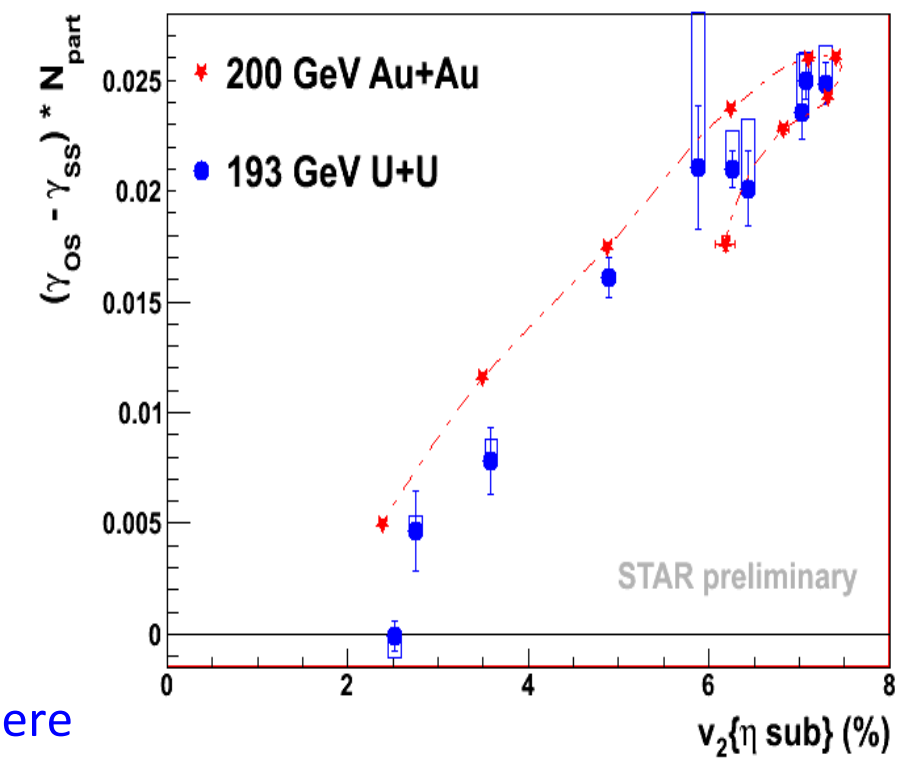
*P-even quantity: still sensitive to charge separation*

# Search for Local Parity Violation




$$\gamma = \langle \cos(\varphi_\alpha + \varphi_\beta - \psi_{RP}) \rangle$$

Consider OS-SS to be the signal.
$N_{part}$ accounts for the dilution




- The difference between OS and SS is still there in U+U, with similar magnitude to Au+Au

- A dedicated trigger with 0-1% spectator neutrons. With the magnetic field suppressed, the charge separation signal disappears while $v_2$ is still >2%

# Summary/Outlook

- Anisotropic flow
  - Difference between Au+Au and U+U?

1. For higher harmonics and mid central collisions, $v_n$\{U+U\} is similar to $v_n$\{Au+Au\}, the difference appears at central collisions(0-5% central) for $v_1$ and $v_2$.
2. The U+U $v_2$ shows a stronger multiplicity dependence for central events.
3. The differences in the slope parameters between Au+Au and U+U increase in more central collisions

- Chiral Magnetic Effects

An important systematic check for three-particle correlator was carried out in U+U. With the magnetic field suppressed, the charge separation signal disappears while $v_2$ is still >2

- Outlook:
  - separate body-body and tip-tip in U+U

# Backup slide