Azimuthal Anisotropy of φ-Meson in U+U and Au+Au Collisions at RHIC

Vipul Bairathi
(For the STAR collaboration)

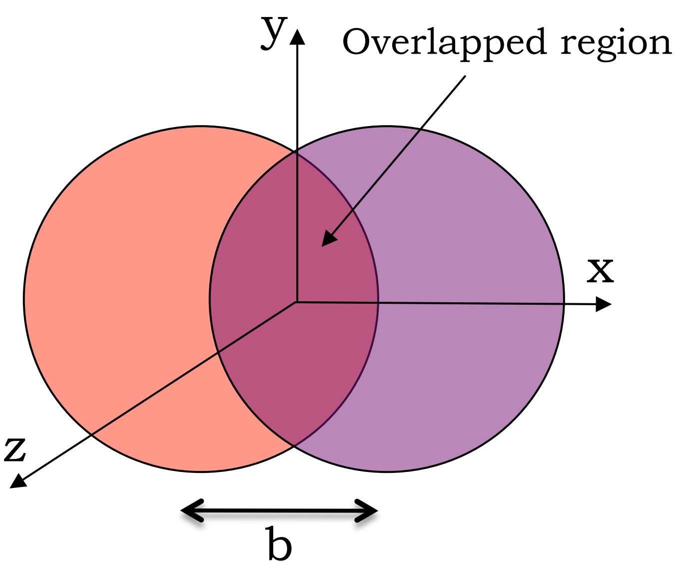
National Institute of Science Education and Research, India

Outline

- Introduction & Motivation
- STAR Experiment at RHIC
- Results
- Summary

15th Strangeness in Quark Matter
July 6-11, 2015
Dubna, Russia

Introduction: Azimuthal Anisotropy

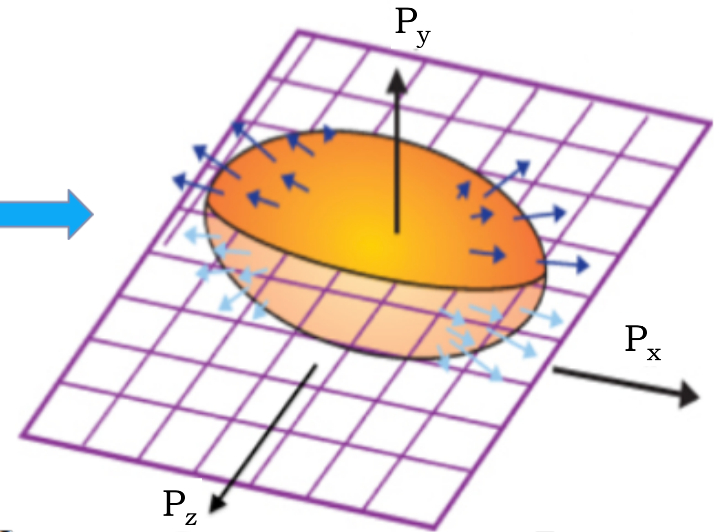


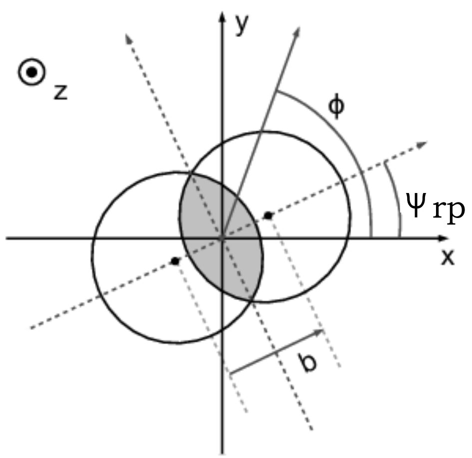
Interactions

↓

Pressure(P)

$$y > x \rightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$$





$$\frac{dN}{d\phi} \propto \frac{1}{2\pi}\left[1 + \sum_{n=1}^{\infty} 2v_n \cos\left(n(\phi - \psi_{rp})\right)\right]$$

$$v_n = \langle \cos\left[n(\phi - \psi_{rp})\right]\rangle$$

- ✓ Sensitive to early times in the evolution of the system
- ✓ Sensitive to the equation of state

P. Klob, U. W. Heinz, Nucl. Phys. A715, (2003) 653c,
A.M. Poskanzer & Voloshin, Phys.Rev. C58 (1998)

Motivation

- φ-Meson: clean probe for QGP medium
  - Small hadronic interaction cross-section
  - Long life time ~42 fm/c
    - *A. Shor, Phys. Rev. Lett. 54, 1122 (1985)*
    - *A. Sibirtsev et al., Eur. Phys. J. A29, 209–220 (2006)*
    - *Md. Nasim et al., Phys. Rev. C87(2013) 1, 014903*
- Expectations from theoretical model:
  - Hydrodynamic models suggest scaling of higher order flow harmonics with elliptic flow v_2.

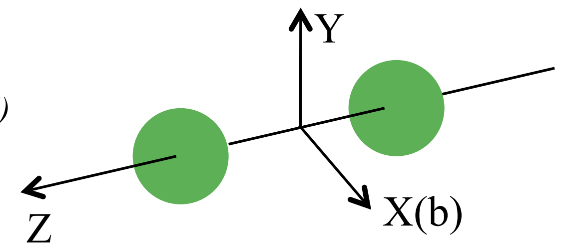
$$v_4/v_2^2 = 0.5 \qquad v_3/v_2 = constant\ at\ high\ p_T$$

  - According to Dynamic coalescence model

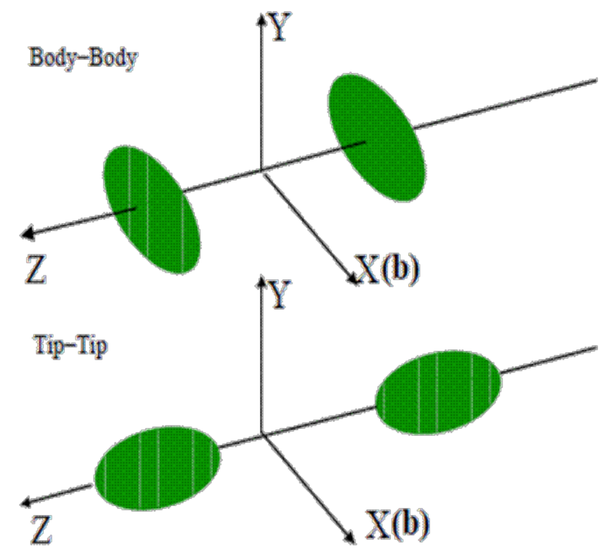
$$\frac{v_{4,M}(2p_T)}{v_{2,M}^2(2p_T)} \approx \frac{1}{4} + \frac{1}{2}\frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}, \quad \text{for mesons}$$

    - *C. W. Chen and C. M. Ko, Phys. Rev. C 73, 044903 (2006)*
- Comparison between U+U and Au+Au collisions:
  - Deformed shape of Uranium nuclei leads to different type of initial configurations like Body-Body, Tip-Tip and Body-Tip.
  - Higher particle density in U+U compared to Au+Au collisions at the same center of mass energy.

Au+Au Collision

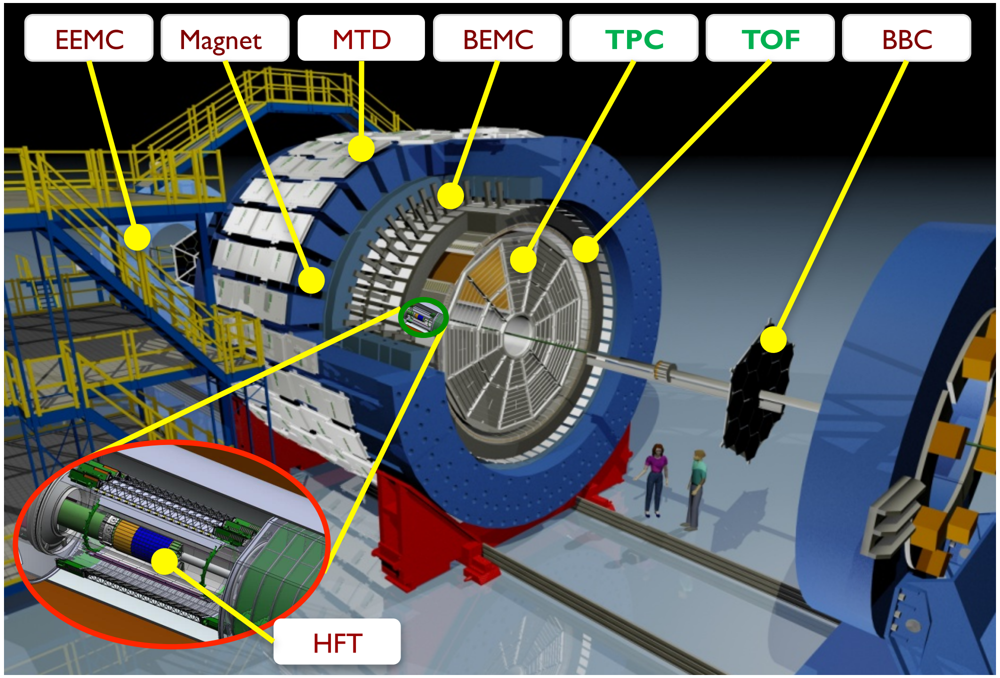


U+U Collision



- *Md. Rihan Haque et al., Phys.Rev. C85 (2012) 034905*

STAR Experiment at RHIC



Particle Identification

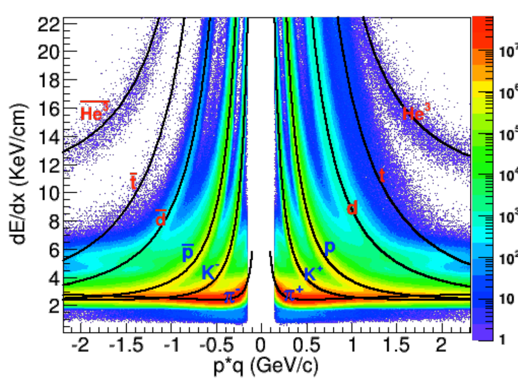
- STAR TPC detector:
  - Pseudo-rapidity: $-1.0 < \eta < 1.0$
  - Identifies kaon upto p = 0.65 GeV/c

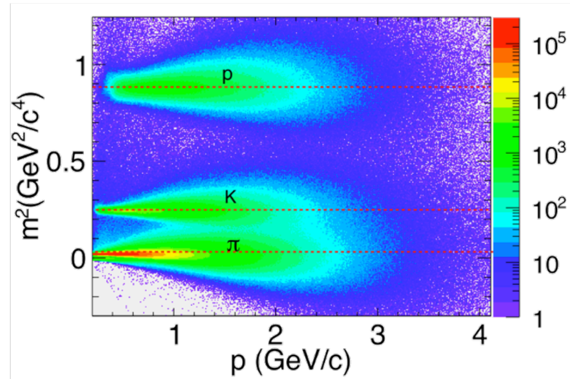
$$-\langle \frac{dE}{dx} \rangle \sim A\left(1+\frac{m^2}{p^2}\right) \qquad N\sigma = \frac{1}{R} \times \log\left(\frac{dE/dx_{measured}}{dE/dx_{theory}}\right)$$

- STAR ToF detector:
  - Pseudo-rapidity: $-0.9 < \eta < 0.9$
  - Identifies kaon for $0.65 < p < 1.6$ GeV/c

$$< t > = \frac{L}{\beta} \qquad \frac{1}{\beta} = \sqrt{1 + m^2/p^2}$$

- STAR detector has:
  - Magnetic Field 0.5 Tesla
  - Uniform Acceptance in $|\eta| < 1.0$ and $(0,2\pi)$ azimuthal angle





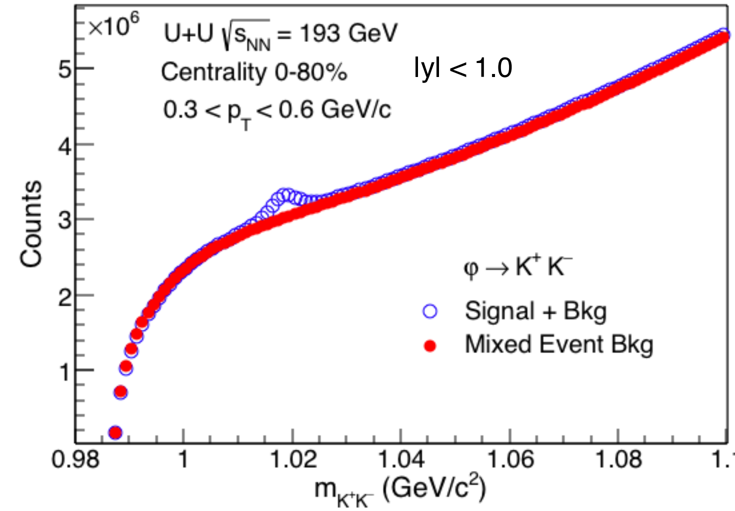
- *M. Anderson et al., Nucl. Instrum. Meth. A 499 (2003) 659*
- *W. J. Llope et al., Nucl. Instrum. Meth. A522 (2004) 252-273*

φ-Meson Signal Extraction

- φ-Meson decay: $\varphi \rightarrow K^{+} K^{-}$ (BR 48.9%)
- φ-Meson signal reconstruction using invariant mass technique

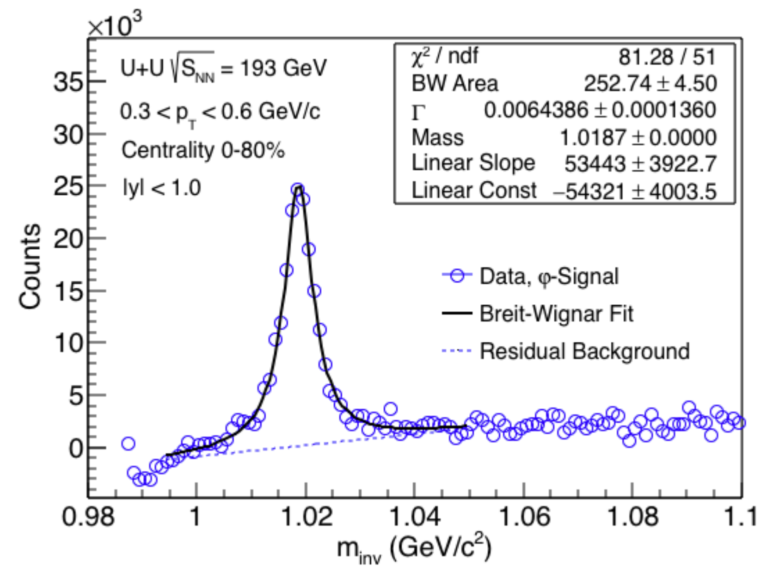
$$M_{\varphi} = \sqrt{(E_{K^+} + E_{K^-})^2 - (\vec{p}_{K^+} + \vec{p}_{K^-})^2}$$

- Background reconstruction using mixed event technique



- Invariant mass distribution of φ-Meson signal fitted with Breit-Wigner + 1st order polynomial.

$$\frac{dN}{dm_{inv}} = \frac{A\Gamma}{(\mathrm{m_{inv}} - \mathrm{m_0})^2 + \frac{\Gamma^2}{4}} + B(m_{inv}) + C$$



PDG: m_{φ}= 1019.46 +/- 0.019 MeV, Γ = 4.266+/- 0.03 MeV

Analysis Method

- **Φ-Ψ_n binning method**
  - φ-meson yield as a function of ϕ-ψ_n is fitted with the following function for different p_T ranges.

$$\frac{dN}{d(\phi-\psi_n)} = A\left(1+\sum_{i=2}^{n} 2v_i \cos(\phi-\psi_i)\right)$$

--(1)

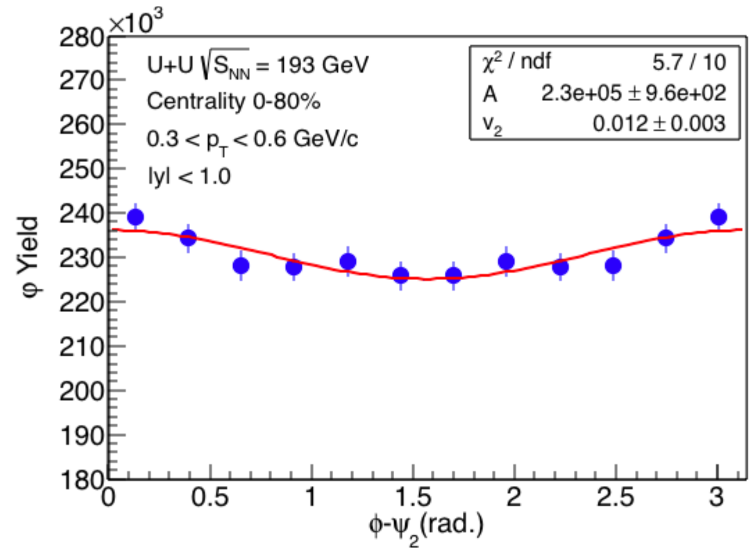
- **Invariant mass method**
  - Ratio α calculated from invariant mass distribution of φ-meson signal and signal + background.

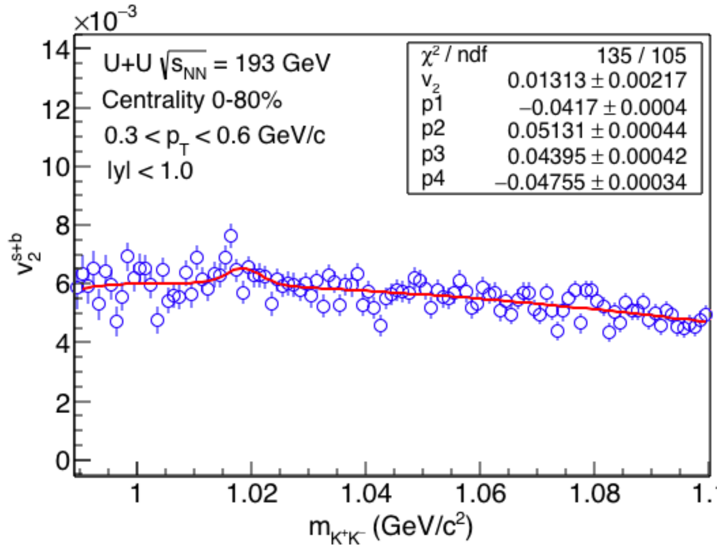
$$\alpha(m_{inv}) = \frac{Sig(m_{inv})}{(Sig+Bkg)(m_{inv})}$$

$$v_n^{S+B}(m_{inv}) = \alpha(m_{inv})v_n^{Sig} + [1-\alpha(m_{inv})]v_n^{Bkg}$$

--(2)

  - v_n^{Bkg} is parameterized using 3rd order polynomial function.





- *A. M. Poskanzer and S. Voloshin, Phys. Rev. C58(1998) 1671–1678*
- *N. Borghini and J. Y. Ollitrault, Phys. Rev. C70 (2004) 064905,*

Event Plane Resolution

- Event plane angle defined as

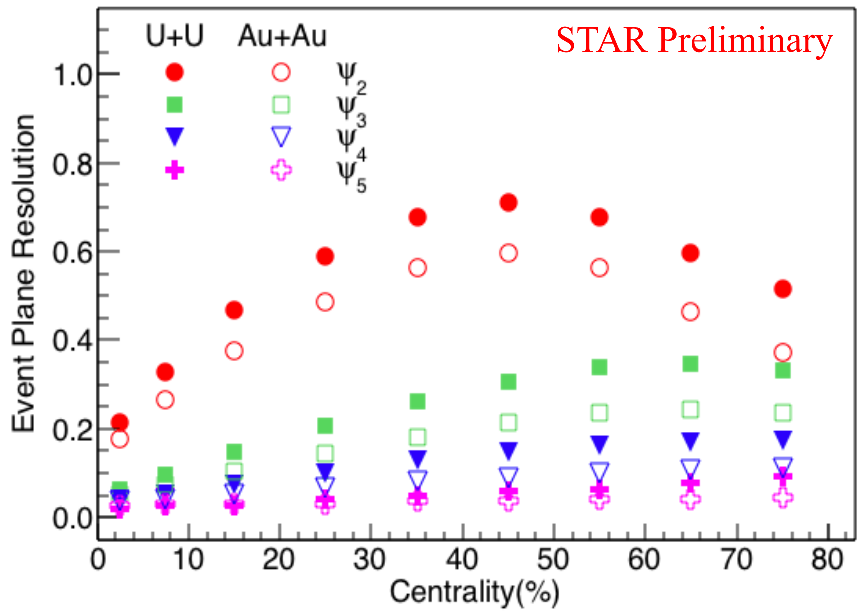
$$\psi_n = \left(\tan^{-1}\left[\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right]\right)/n$$

- Event plane angle Ψ_n is calculated in two different windows 'a' ($0.05 < \eta < 1.0$) and 'b' ($-1.0 < \eta < -0.05$).

- Event plane resolution then given by:

$$R = \sqrt{\cos n(\psi_n^a - \psi_n^b)}$$

- Resolution correction has been done for small centrality bins for each event.

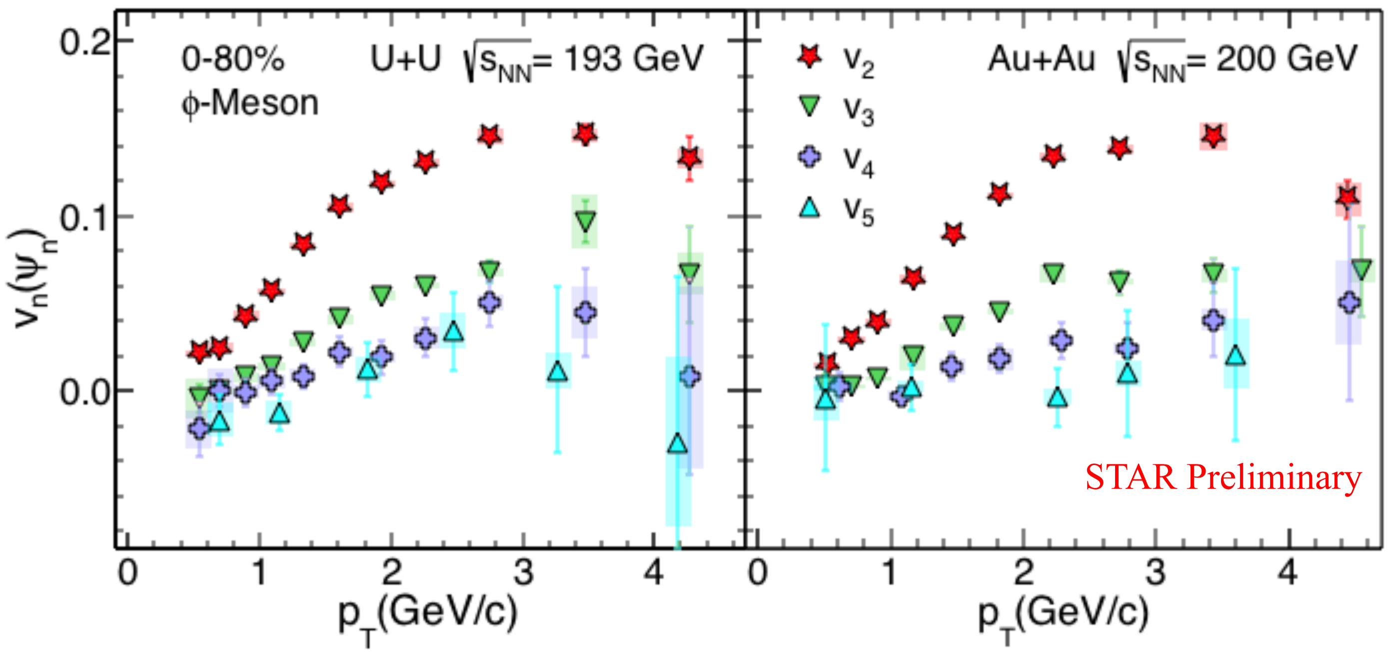


R(U+U) > R(Au+Au)

multiplicity(U+U) > multiplicity(Au+Au)

- *A. M. Poskanzer & S. A.Voloshin, Phys.Rev. C58 (1998) 1671-1678*
- *Hiroshi Masui, A. Schmah arXiv:1212.3650(2012)*

Results: Flow Harmonics(v_n)

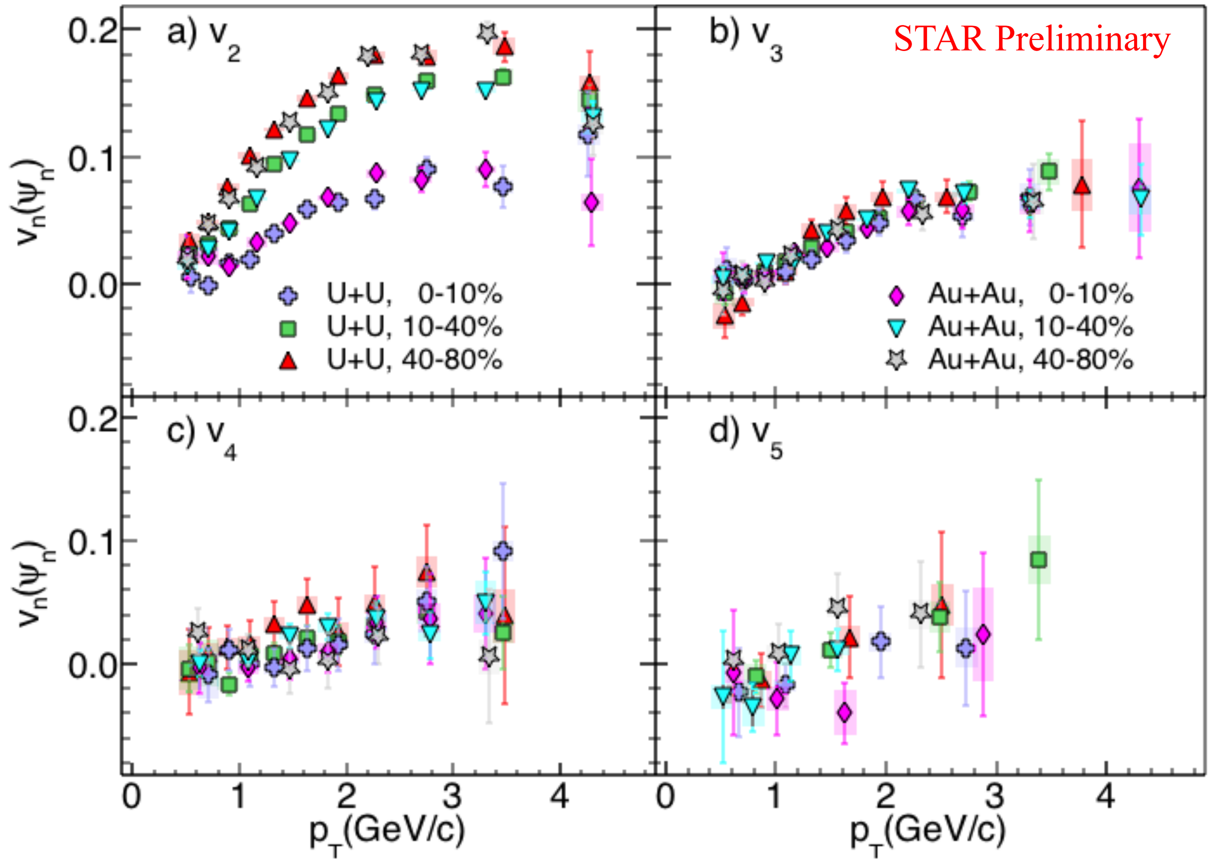


- Statistical errors are shown by vertical lines.
- Systematic uncertainties has been done by varying different analysis cuts(e.g. collisions vertex position, dca to the primary vertex and number of fits points for reconstruction of the tracks etc.).
- Systematic errors on v_n are calculated using rms deviation relative to v_n values and it is shown by bands.

Minimum bias collisions

- ✓ v_n values for φ-meson are of similar order in U+U and Au+Au collisions for 0-80% centrality.
- ✓ v_n for φ-meson have similar p_T dependence in U+U and Au+Au collisions for 0-80% centrality.
- ✓ φ-meson $v_2 > v_3 > v_4 > v_5$ for both U+U and Au+Au collisions.

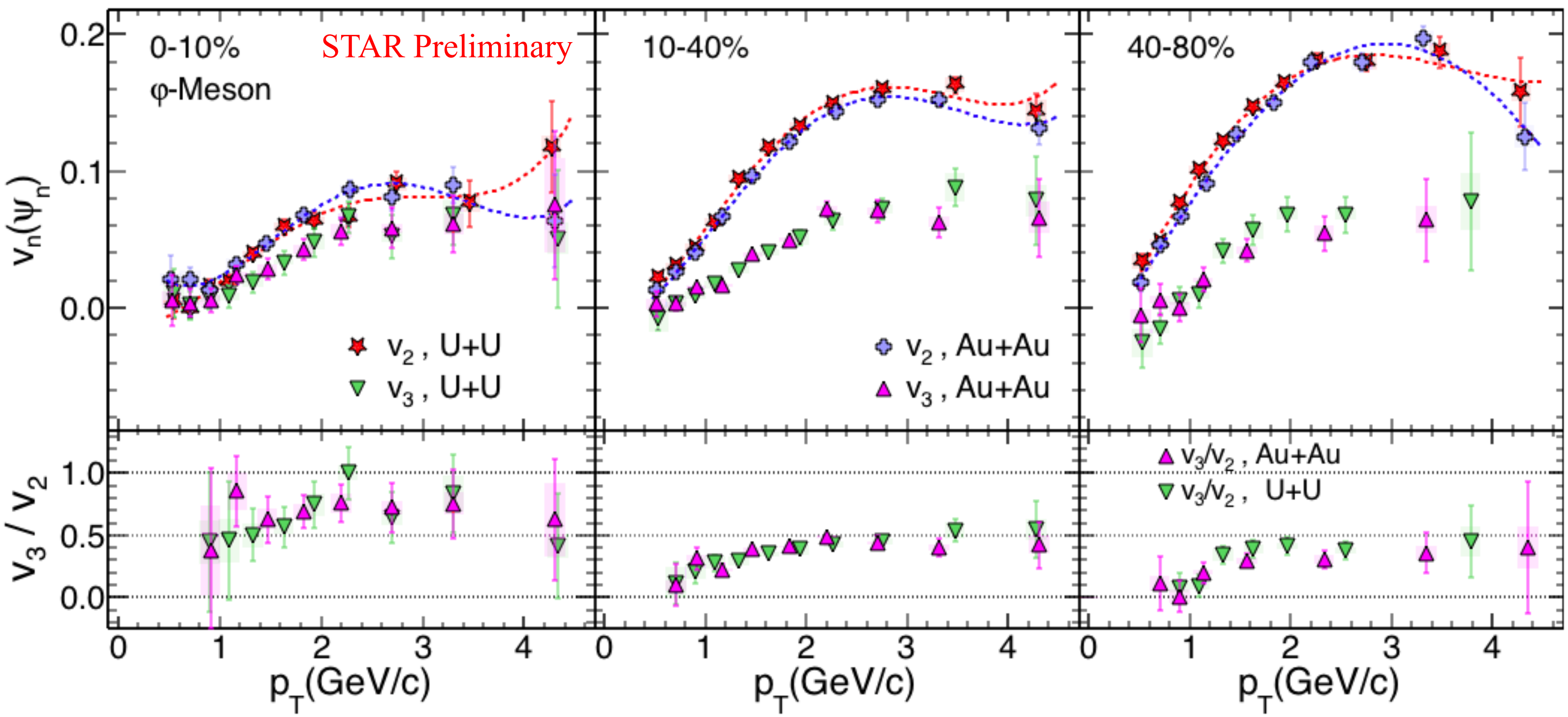
Result: Centrality dependence



Statistical errors are shown by vertical lines and systematic errors are shown by bands.

- ✓ v_n of φ-meson for U+U and Au+Au collisions are comparable for different centralities.
- ✓ v_2 of φ-meson shows strong centrality dependence in both U+U and Au+Au collisions.
- ✓ v_3, v_4 and v_5 doesn't show clear centrality dependence.

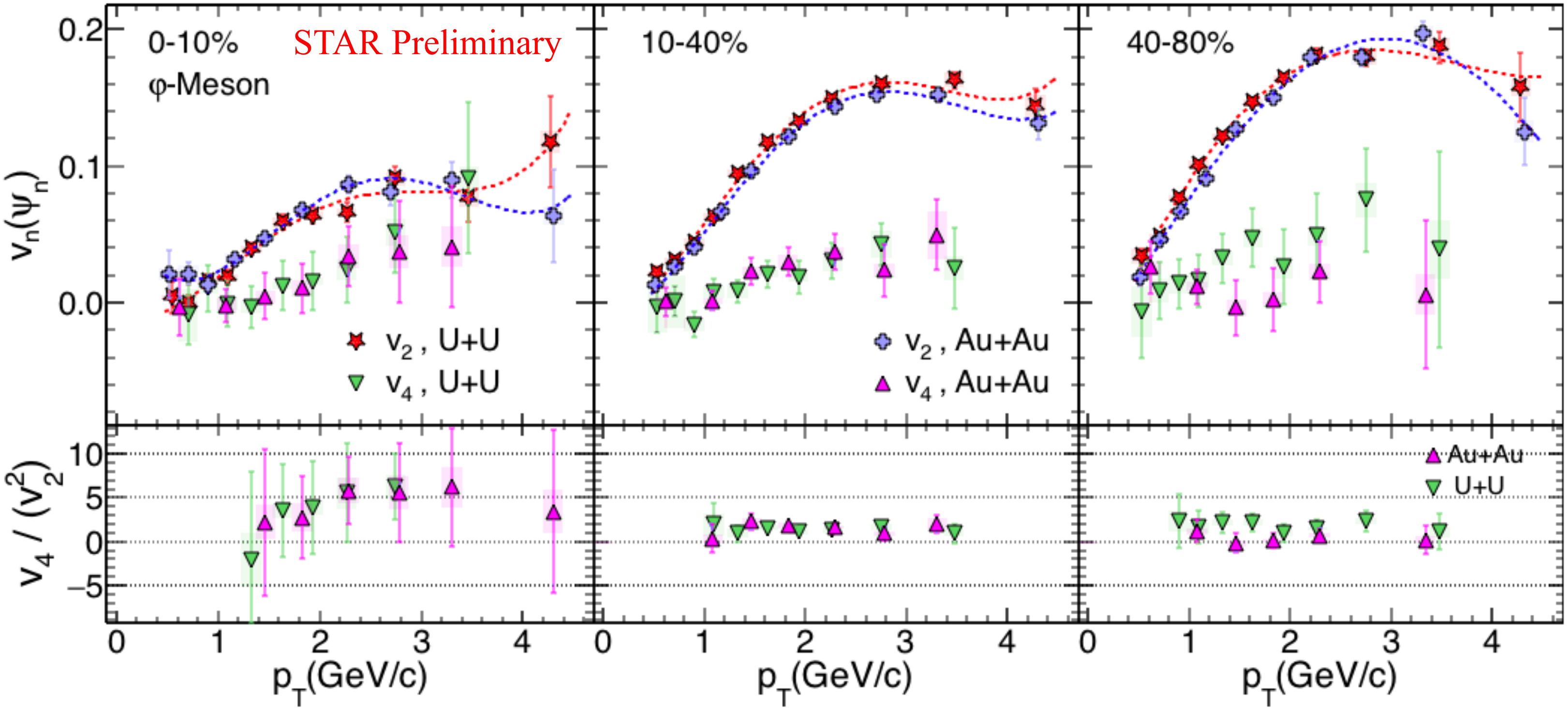
Result: v_3/v_2



✓ v_3/v_2 ratio of φ-meson for p_T > 1.5 GeV/c is constant for both U+U and Au+Au collisions and supportive of the hydrodynamic picture.

arXiv:1312.7763v1(2013) C. Lang and N. Borghini

Result: v_4/v_2^2



Ratio(v_4/v_2^2)	0-10%	10-40%	40-80%
U+U	5.096 ± 2.27	1.347 ± 0.293	1.743 ± 0.449
Au+Au	4.592 ± 2.26	1.588 ± 0.318	0.427 ± 0.451

- ✓ v_4/v_2^2 ratio of φ-meson is constant for U+U and Au+Au collisions.
- ✓ v_4/v_2^2 ratio seems to be higher for central collisions compare to peripheral collisions in both U+U and Au+Au collisions.
- ✓ v_4/v_2^2 ratio is higher than a hydrodynamic model in both U+U and Au+Au collisions.

• *C. W. Chen and C. M. Ko, Phys. Rev. C 73, 044903 (2006)*

Summary

- φ-meson azimuthal anisotropy coefficients v_n (n = 2,3,4,5) has been studied and compared between U+U and Au+Au collisions at $\sqrt{s_{NN}}$ = 193 GeV and 200 GeV, respectively.
- φ-meson v_n are comparable in both U+U and Au+Au collisions for all collision centralities.
- Strong centrality dependence for v_2 is observed and no clear centrality dependence is observed for v_3, v_4 and v_5 in both U+U and Au+Au collisions.
- v_3/v_2 ratio of φ-meson for $p_T > 1.5$ GeV/c is constant for both U+U and Au+Au collisions and consistent with the hydrodynamic model.
- The measured values of v_4/v_2^2 are higher than expected from a hydro model.
- v_4/v_2^2 ratio seems to be higher for central collisions compare to peripheral collisions in both U+U and Au+Au collisions.

Thank You