Azimuthal anisotropy of strange hadrons in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV

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Outline

- Introduction & Motivation
- STAR Experiment at RHIC
- Results
  - Azimuthal anisotropy of strange hadrons
- Summary

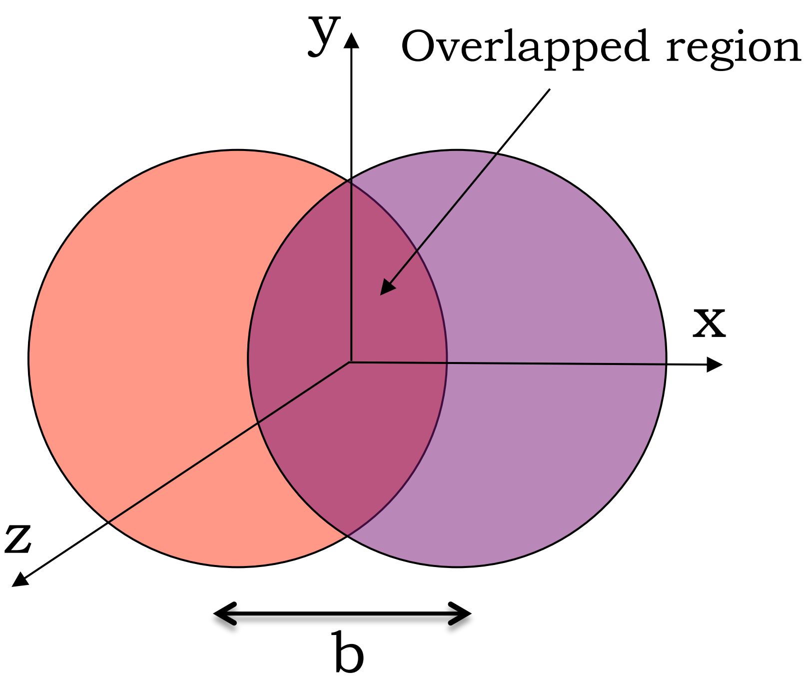
17th International Conference on Strangeness in Quark Matter

Universiteit Utrecht

10-15 July 2017

Utrecht, the Netherlands

Introduction: Azimuthal Anisotropy

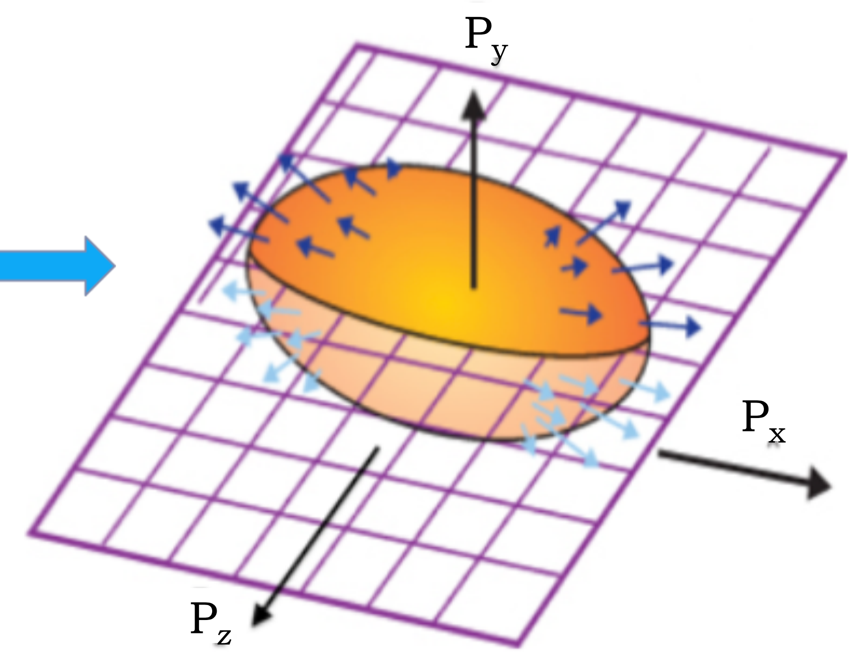


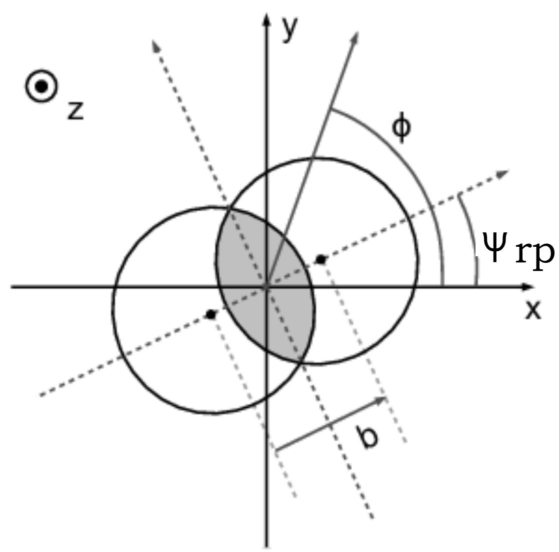
Interactions

↓

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

Probe of the early (partonic) stage of the collision

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

Motivation

Expectations from theoretical models:

- Hydrodynamic models suggest scaling of higher order flow harmonics with elliptic flow v_2

$$\frac{v_3}{v_2} = constant\ at\ high\ p_T \qquad \frac{v_4}{v_2^2} \approx 0.5$$

- **C. Lang , N. Borghini, Eur. Phys. J. C (2014) 74:2955**

- According to dynamic coalescence model

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

$$\frac{v_{4,B}(3p_T)}{v_{2,B}^2(3p_T)} \approx \frac{1}{3}\left(1 + \frac{v_{4,q}(p_T)}{v_{2,q}^2(p_T)}\right), \quad \text{for baryons}$$

for strange quarks

$$v_{4,q}(p_T)/v_{2,q}^2(p_T) \approx 0.85$$

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

NCQ scaling:

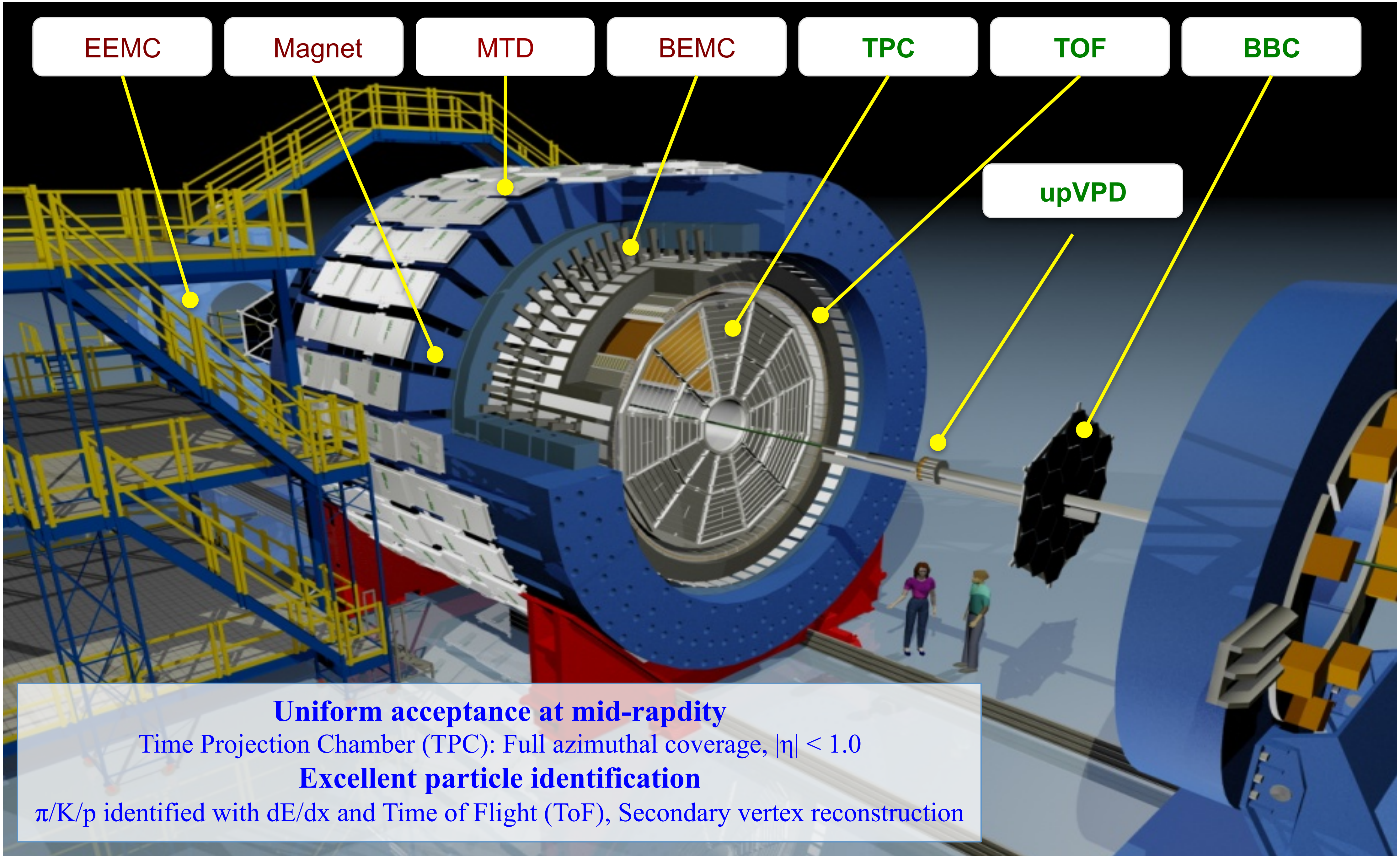
- Number of constituent quark scaling of v_n is an indication of collectivity developed during the partonic stage of heavy-ion collision.

- **B. I. Abelev et al. (STAR Collaboration) Phys. Rev. C 77, 054901 (2008)**
- **Adam, J., Adamová, D. et al. (ALICE collaboration), JHEP (2016), 164**

U+U collisions:

- Higher particle density in central U+U collisions than in Au+Au collisions at same center of mass energy

STAR Experiment at RHIC



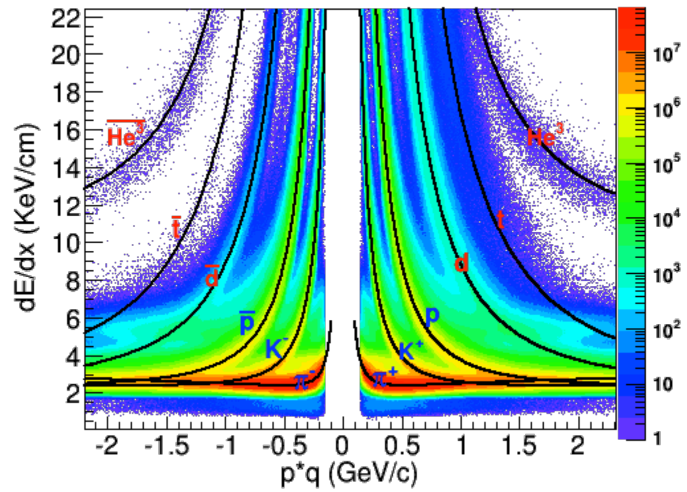
Uniform acceptance at mid-rapdity

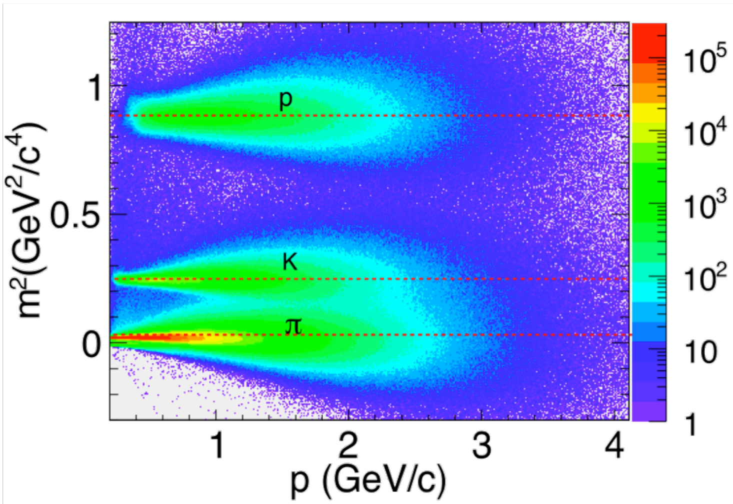
Time Projection Chamber (TPC): Full azimuthal coverage, $|\eta| < 1.0$

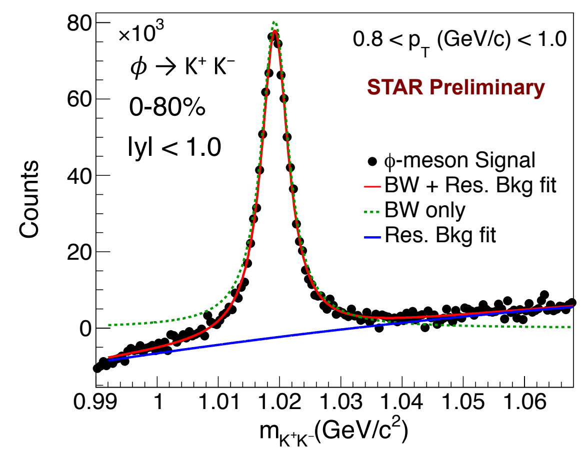
Excellent particle identification

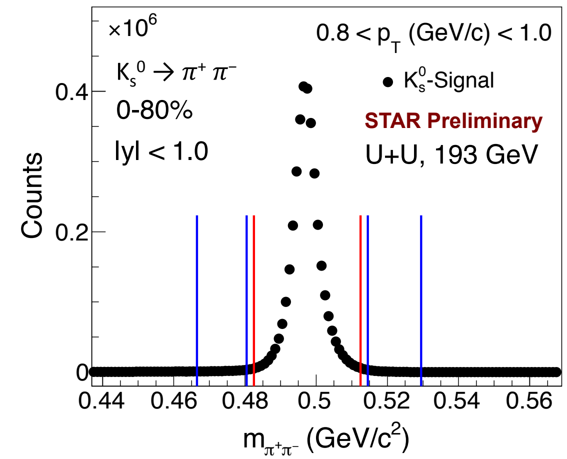
π/K/p identified with dE/dx and Time of Flight (ToF), Secondary vertex reconstruction

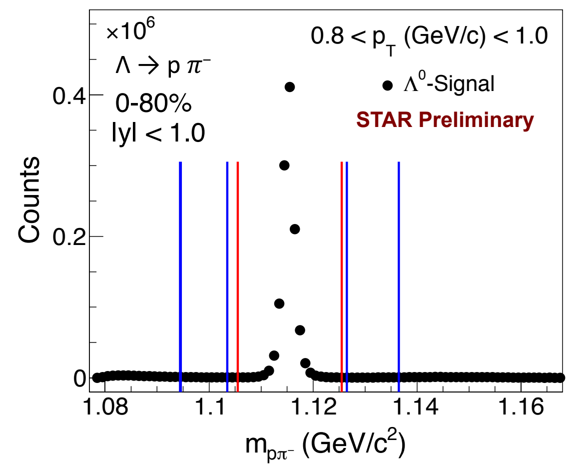
Particle identification and Reconstruction

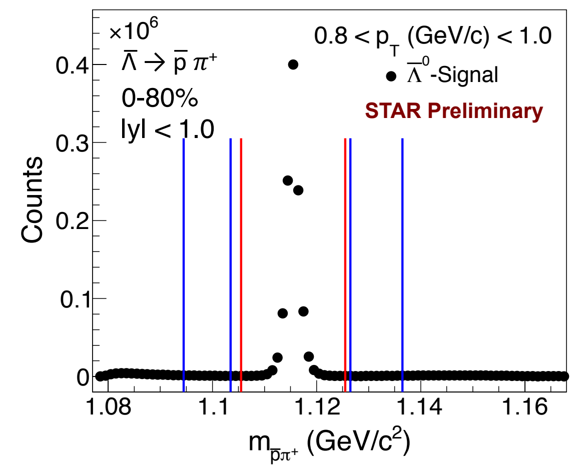












❖ Error bars are statistical uncertainties only

- Signal reconstruction using invariant mass technique $$M_{inv} = \sqrt{(E_1 + E_2)^2 - (\vec{p}_1 + \vec{p}_2)^2}$$
- Background reconstruction using various techniques. Event-mixing technique for ϕ-meson, like-sign technique for K_s^0, Λ.
- Long-lived particles (K_s^0, Λ) are reconstructed from their decay products using topological cuts.

Event Plane Resolution

- Event plane angle is defined as

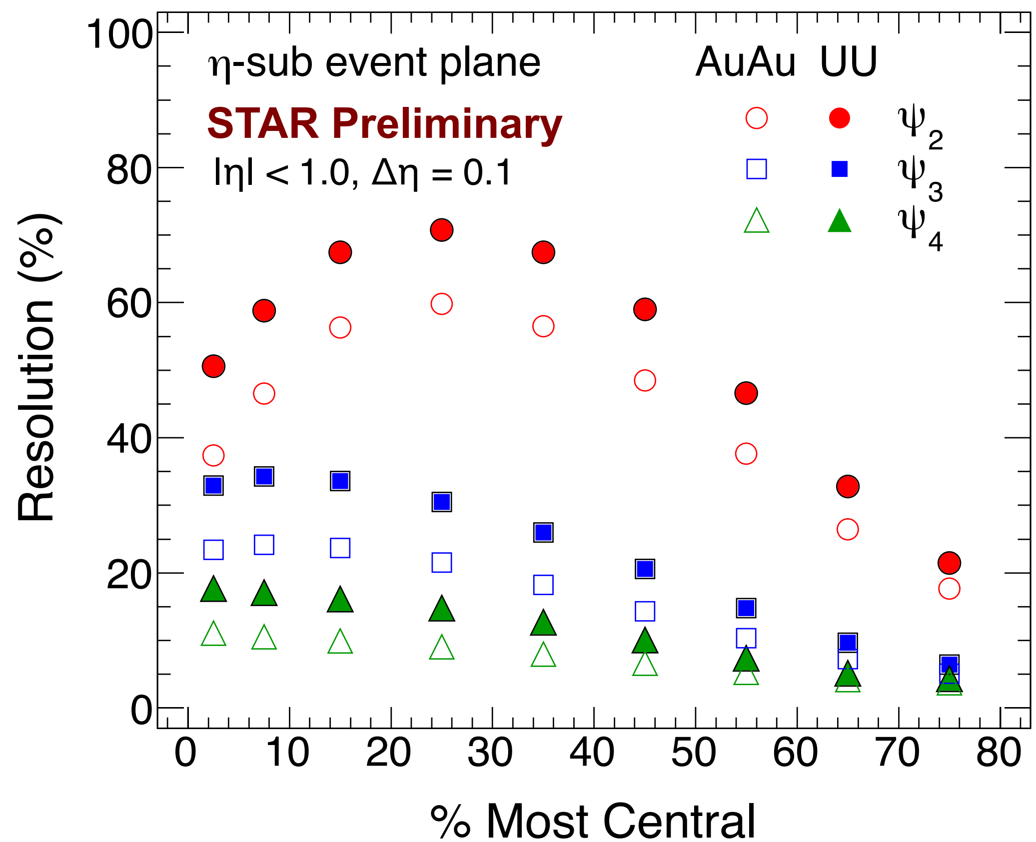
$$\psi_n = \left(\tan^{-1}\left[\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right]\right)/n$$

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

- Hence, the event plane resolution is given by:

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

- Resolution correction is applied for each 5%- or 10%-wide centrality bin separately for each event.



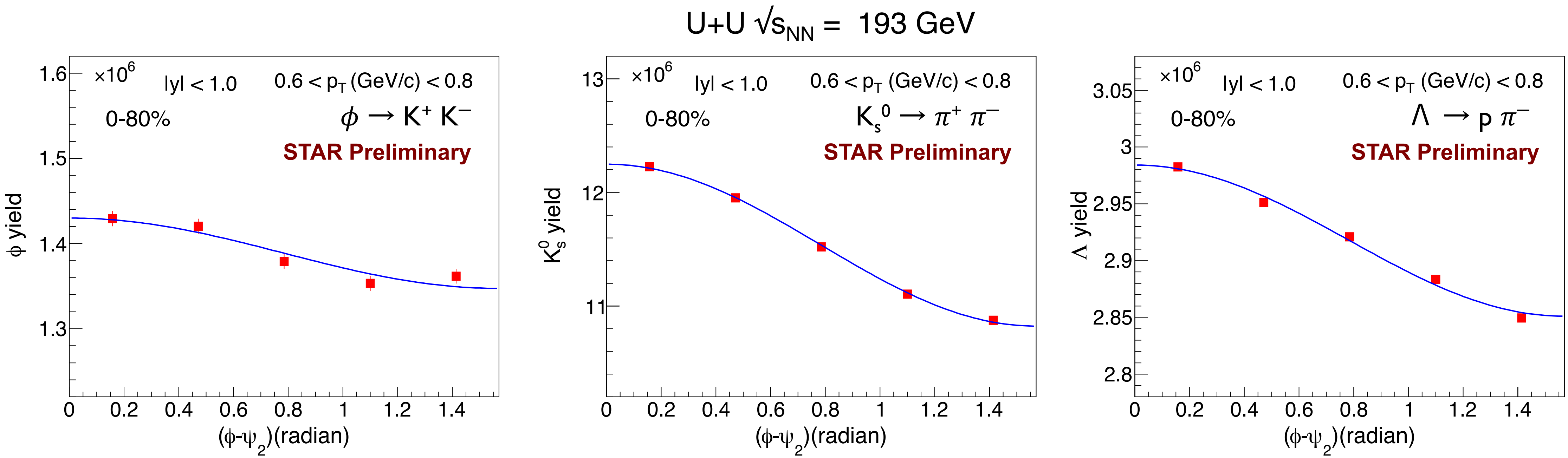
Multiplicity (U+U) > Multiplicity (Au+Au)

⬇

Resolution (U+U) > Resolution (Au+Au)

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

Flow Analysis Method



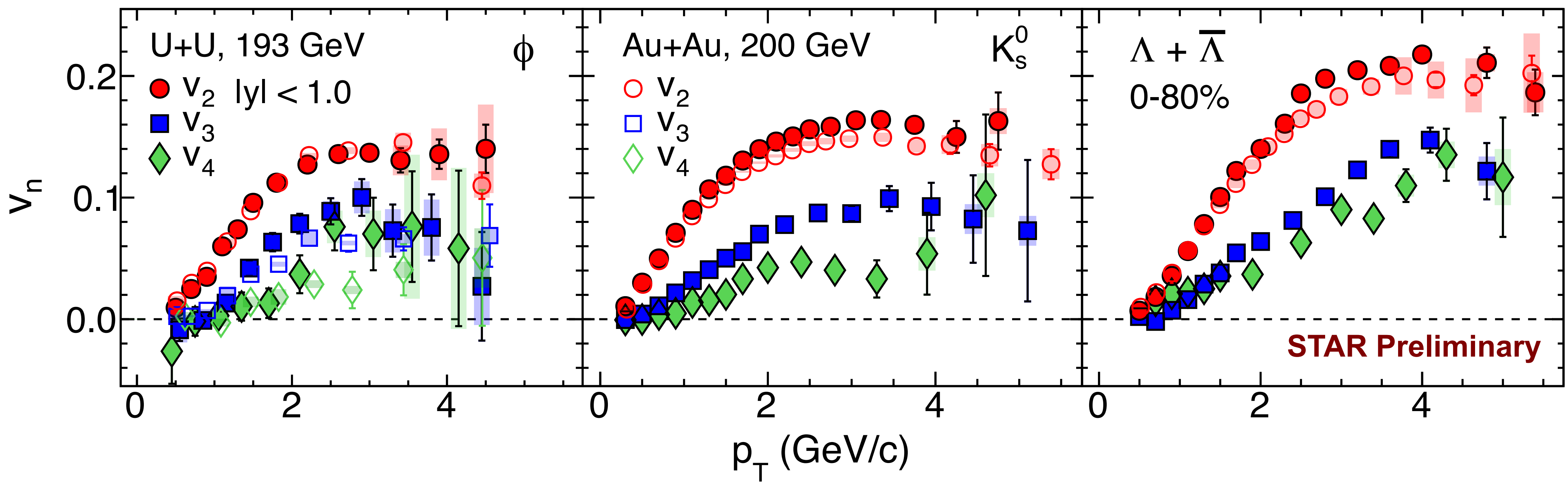
ϕ-ψ_n binning method :

- Particle raw-yield as a function of ϕ-ψ_n is fitted with the following function for different p_T ranges to extract v_n coefficients.

$$\frac{dN}{d(\phi-\psi_n)} = A\,(1 + \,2v_n \cos\, n(\phi-\psi_n))$$

- *A. M. Poskanzer and S. Voloshin, Phys. Rev. C58(1998) 1671–1678*

Results: Flow harmonics v_n



- *Au+Au 200 GeV: B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 77, 054901 (2008)*

❖ *Statistical and systematic uncertainties are shown by vertical lines and bands, respectively.*

❖ *Data are not feed-down corrected, which is expected to be small based on AuAu results at* $\sqrt{s_{NN}}$ *= 200 GeV.*

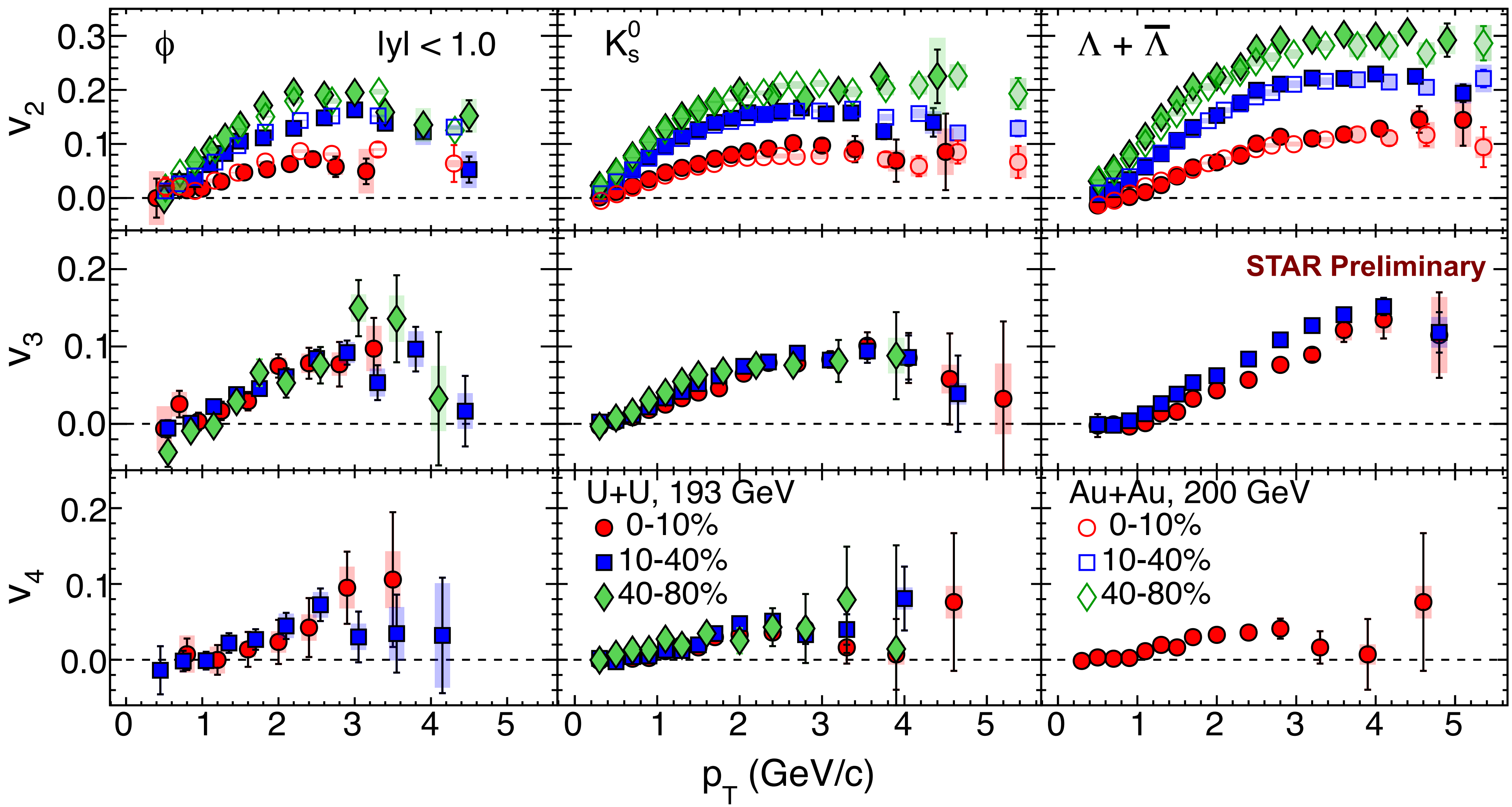
Minimum Bias collisions

✓ $v_2 > v_3 > v_4$ for ϕ, K_s^0 and Λ in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV.

✓ v_n values are of similar order in U+U and Au+Au collisions for 0-80% centrality.

✓ v_n values have similar p_T dependence in U+U and Au+Au collisions for 0-80% centrality.

Centrality dependence



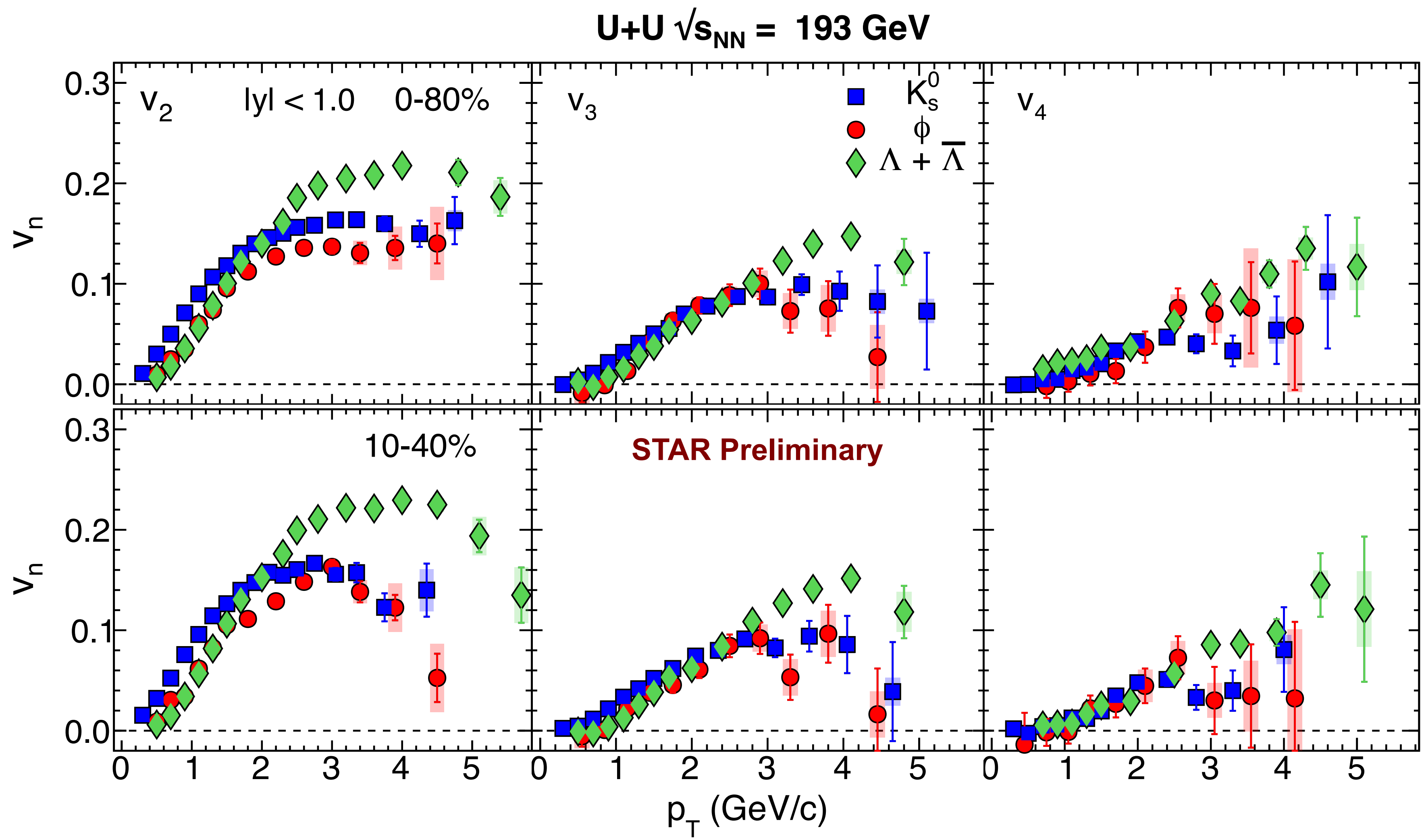
- *Au+Au 200 GeV: B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 77, 054901 (2008)*

✓ v_2 of ϕ, K_s^0 and Λ in U+U and Au+Au collisions are comparable for different centralities.

✓ Strong centrality dependence is observed for v_2 of ϕ, K_s^0 and Λ in both U+U and Au+Au collisions.

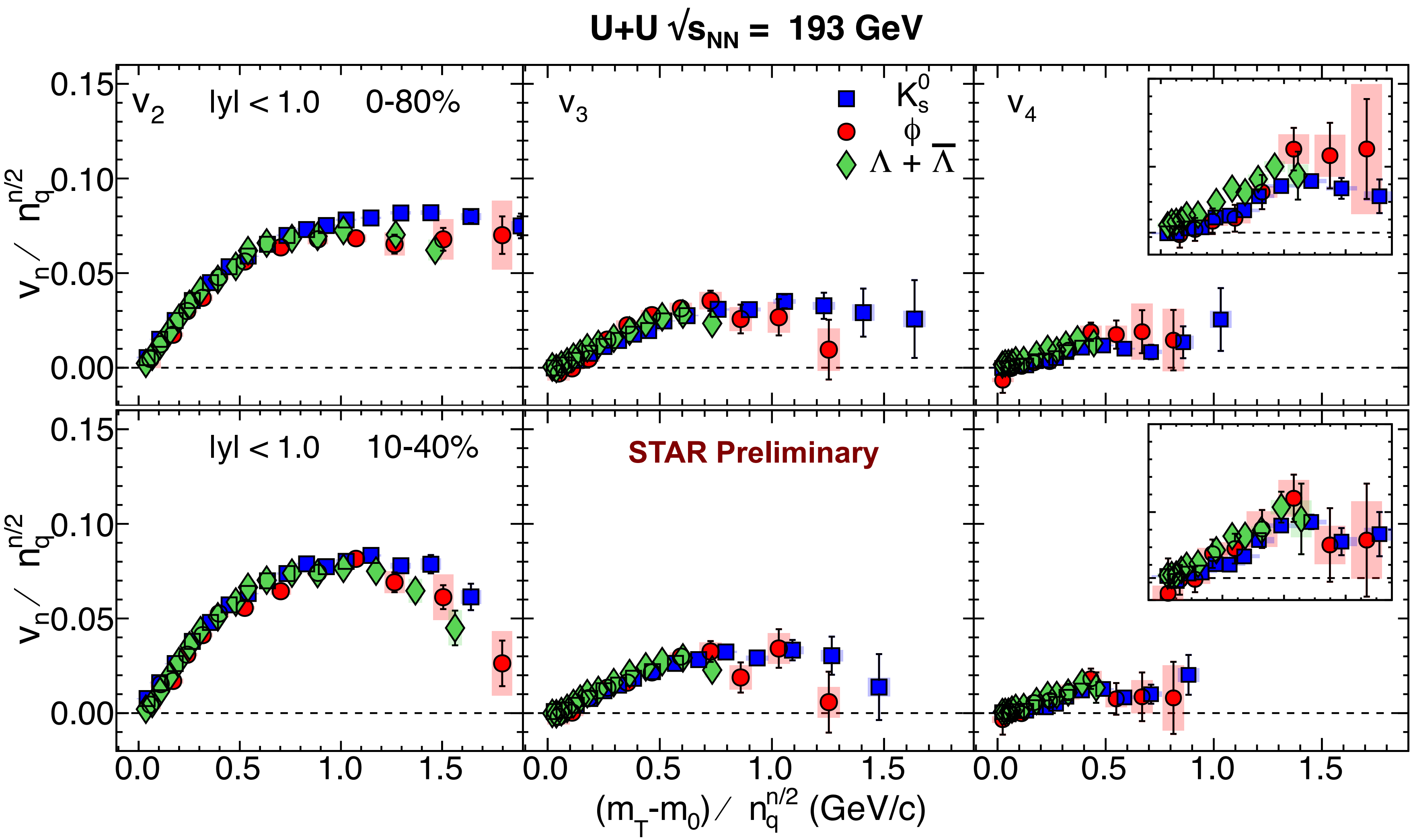
✓ Both v_3 and v_4 show a weak centrality dependence in U+U collisions.

Particle mass dependence



- ✓ Particle mass dependence of flow coefficients (v_n) is observed in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV. Statistical and systematic uncertainties are shown by vertical lines and bands, respectively.
- ✓ Smaller mass particle has larger flow for p_T < 2 GeV/c.
- ✓ Splitting of flow coefficients between baryons and mesons for p_T > 2 GeV/c is observed.

NCQ scaling



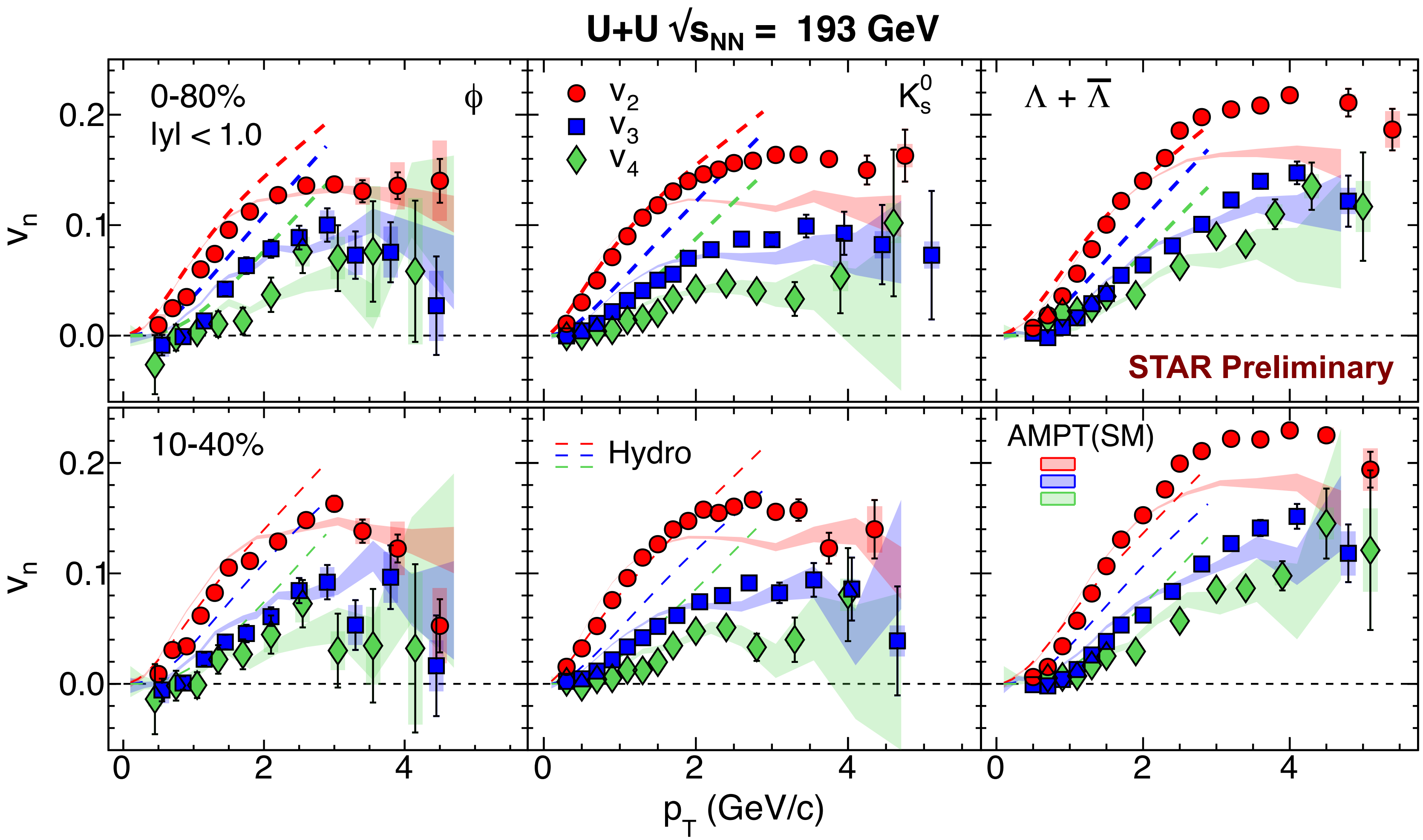
❖ *Statistical and systematic uncertainties are shown by vertical lines and bands, respectively.*

n_q = Number of constituent quarks 3 for baryon, 2 for meson

$m_T = \sqrt{(p_T^2 + m^2)}$

✓ Flow coefficients (v_n) divided by powers of number of constituent quarks ($n_q^{n/2}$) follow a single curve within uncertainties in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV.

Comparison with models



- *Hydro calculations are done by V. Roy from NISER, India*
- *Statistical and systematic uncertainties are shown by vertical lines and bands, respectively.*

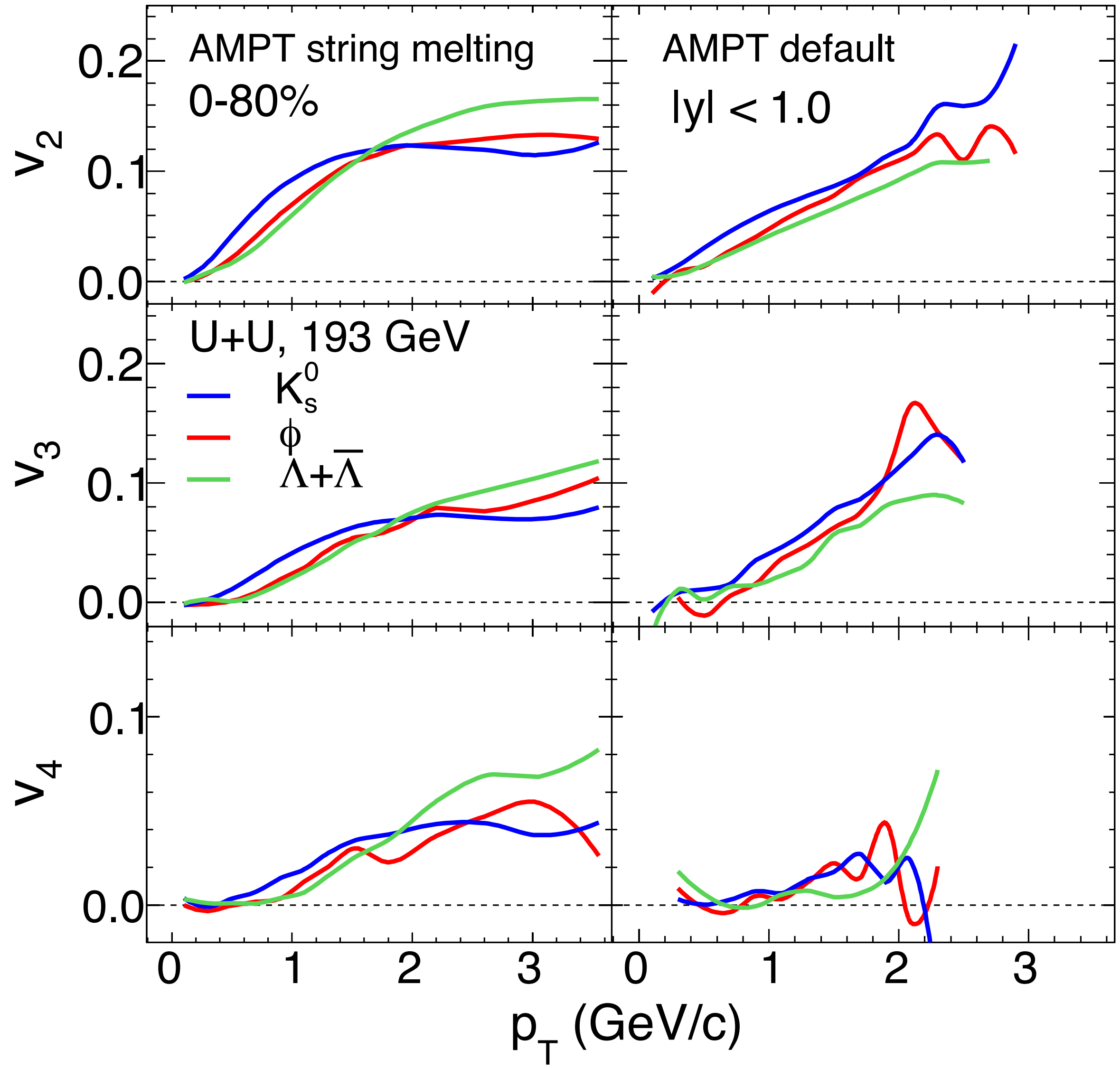
✓ AMPT(string melting) model with 3 mb Parton cross-section describes the data at low p_T (< 2.0 GeV/c).

✓ Dashed lines show the corresponding results from Ideal-Hydrodynamics model with LQCD+HRG equation of state.

✓ Ideal-hydro model over-predicts the data. Viscous corrections are needed to explain the data.

- ***AMPT: Z. W. Lin et al. Phys. Rev. C 72 064901 (2005)***

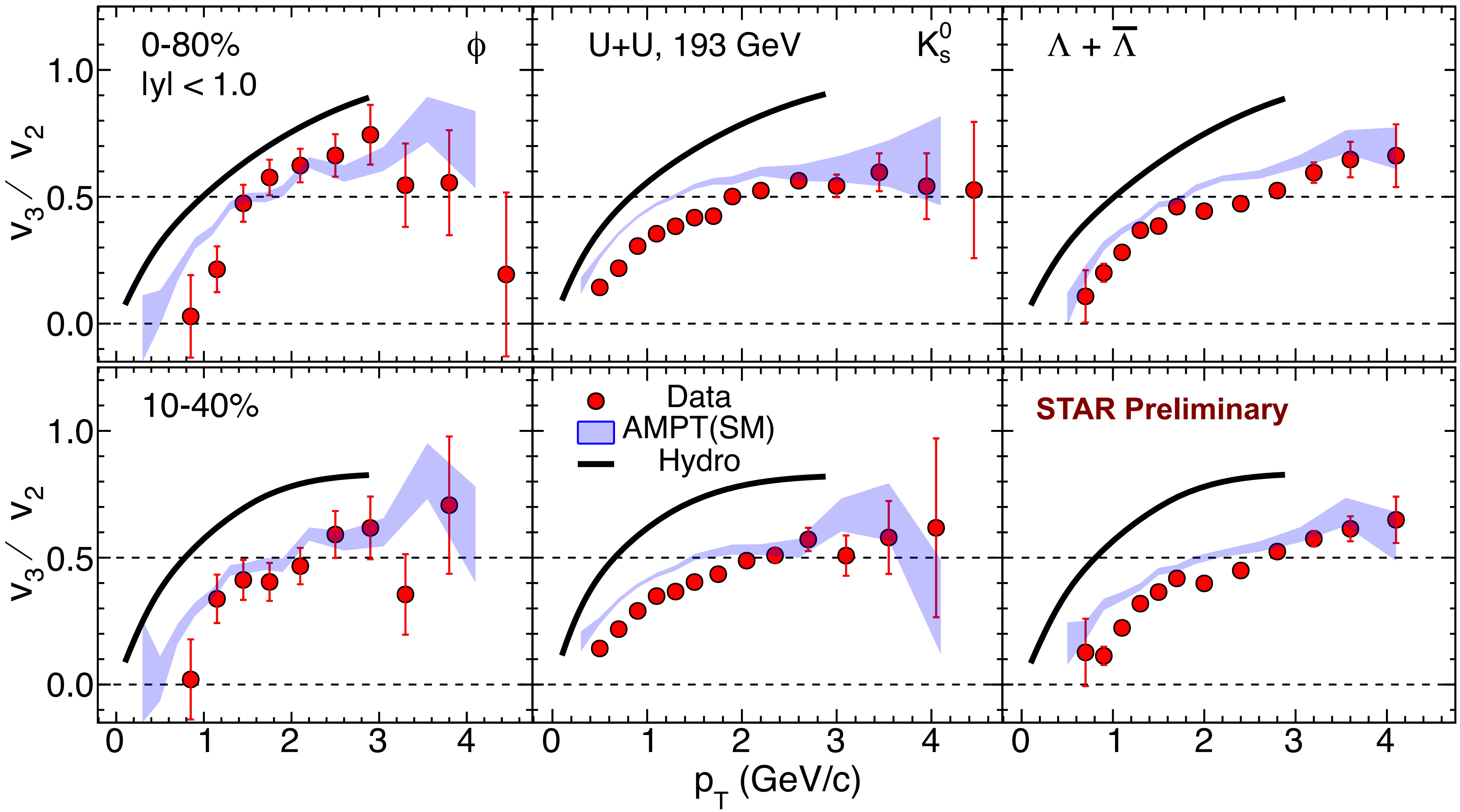
Model comparison



- ✓ AMPT model with string melting shows mass ordering of v_2, v_3 and v_4 at low p_T (< 2.0 GeV/c) and particle type flow at intermediate p_T
- ✓ AMPT model default version only shows the mass ordering of v_2, v_3 and v_4

• *AMPT: Z. W. Lin et al. Phys. Rev. C 72 064901 (2005)*

Ratio: v_3/v_2

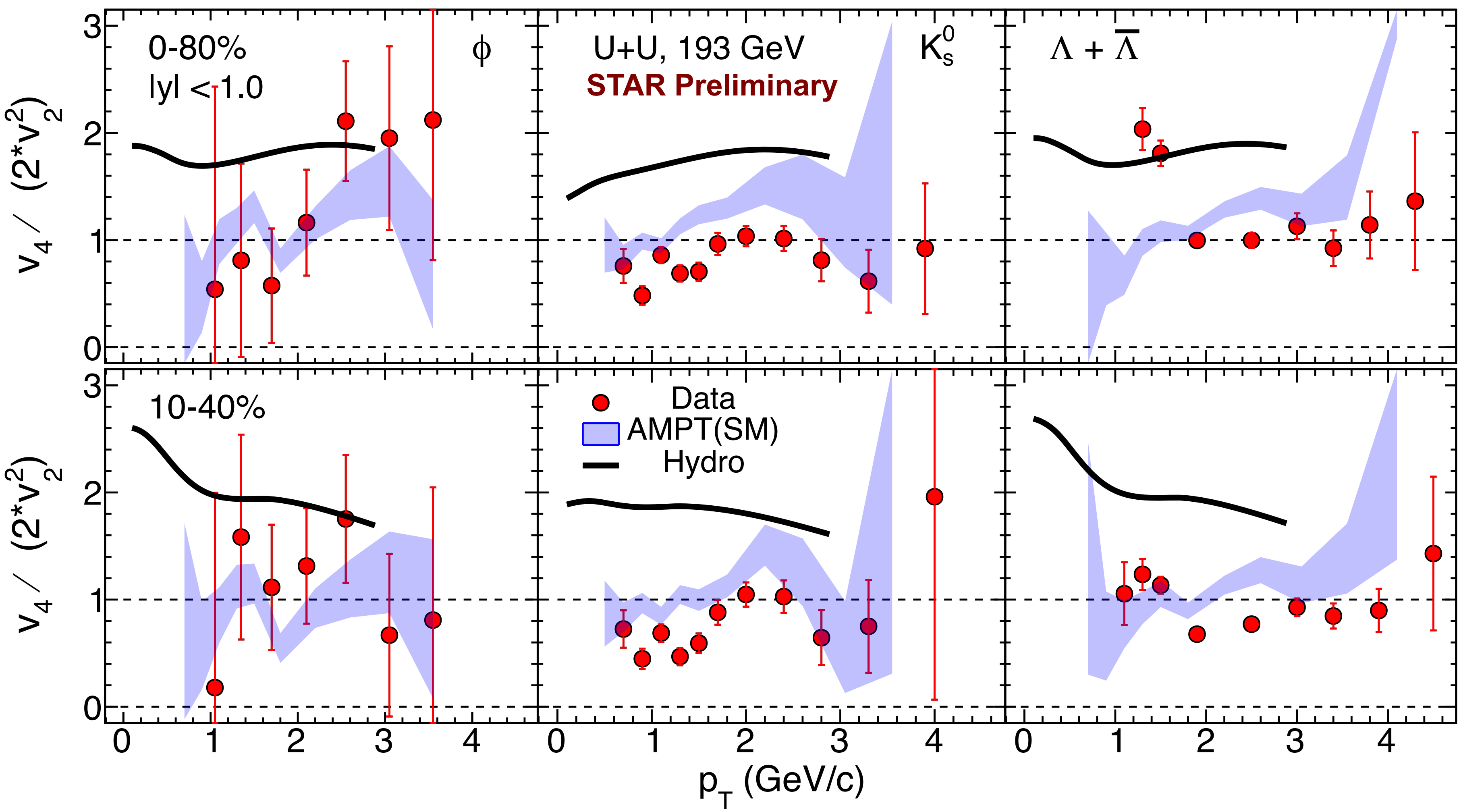


❖ *Hydro calculations are done by V. Roy from NISER, India*

✓ v_3/v_2 ratio of ϕ, K_s^0 and Λ in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV compared with AMPT and ideal-hydrodynamic model.

- ***AMPT: Z. W. Lin et al. Phys. Rev. C 72 064901 (2005)***

Ratio: v_4/v_2^2



❖ *Hydro calculations are done by V. Roy from NISER, India*

✓ $v_4/(2*v_2^2)$ ratio of ϕ, K_s^0 and Λ in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV compared with AMPT and ideal-hydrodynamic model.

- ***AMPT: Z. W. Lin et al. Phys. Rev. C 72 064901 (2005)***

Summary

- Azimuthal anisotropy coefficients v_n (n = 2,3,4) for strange hadrons has been studied and compared between U+U and Au+Au collisions at $\sqrt{s_{NN}}$ = 193 GeV and 200 GeV, respectively.

- Strong centrality dependence for elliptic flow (v_2) is observed in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV similar to Au+Au collisions.

- A weak centrality dependence is observed for higher order flow coefficients (v_3,v_4).

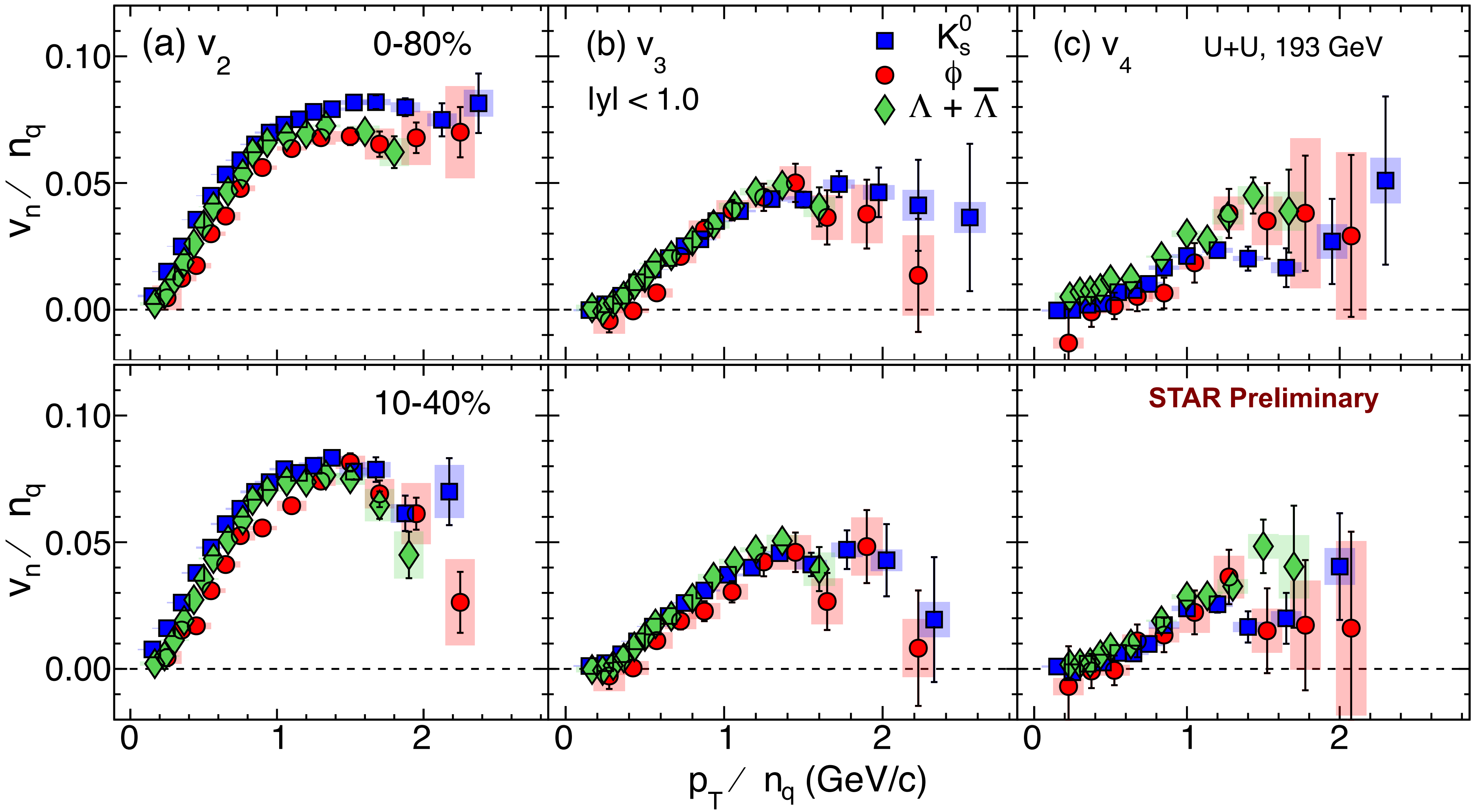
- Mass ordering of v_2, v_3 and v_4 at low p_T (p_T < 2.0 GeV/c) is observed in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV. AMPT model with string melting shows similar mass ordering of v_n and describe the data.

- Flow coefficients (v_n) divided by powers of number of constituent quarks follow a single curve within uncertainties in U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV.

Thank You!

Back-Up

NCQ scaling



 Vipul Bairathi 10/07/17