Measurements of strange and multi-strange hadrons elliptic flow in isobar collisions at RHIC by STAR

Vipul Bairathi
(for the STAR Collaboration)
Instituto de Alta Investigación, Universidad de Tarapacá, Arica, Chile

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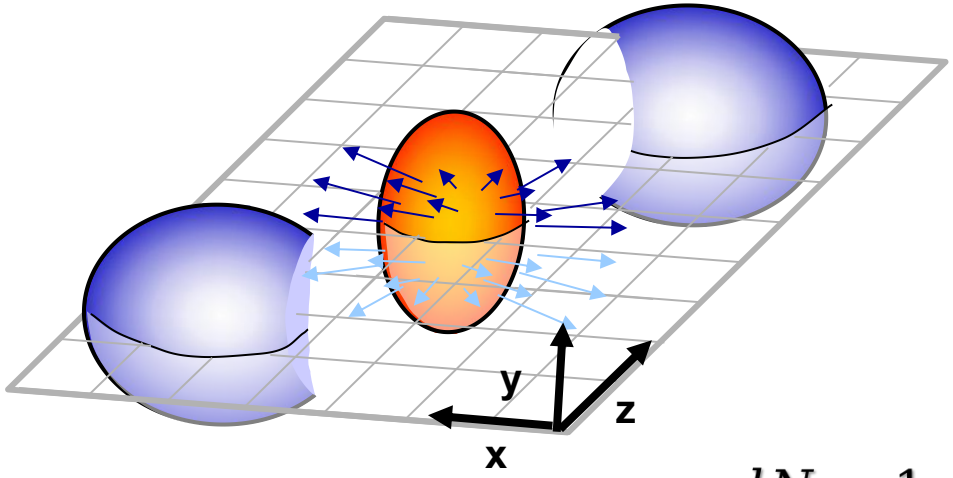
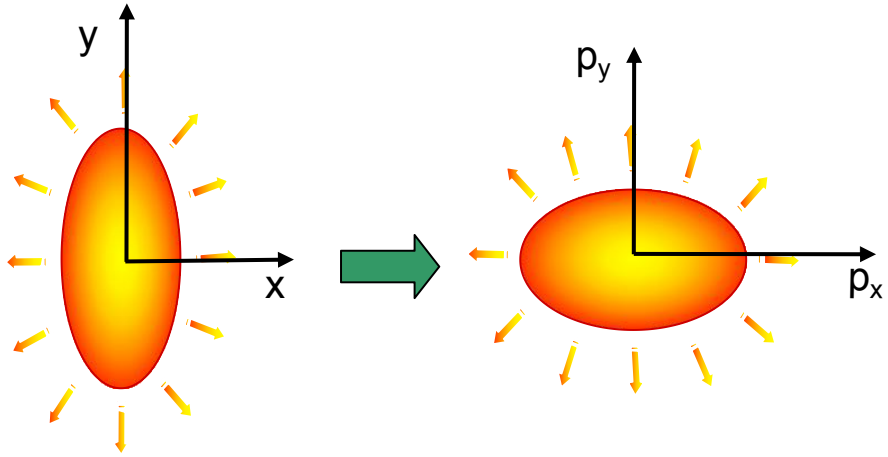
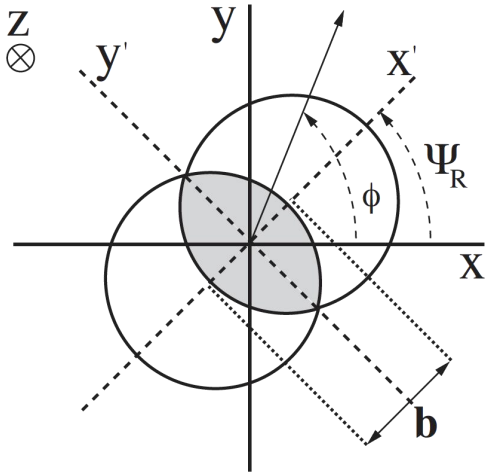
Introduction: Elliptic flow





Reaction plane: xz plane



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

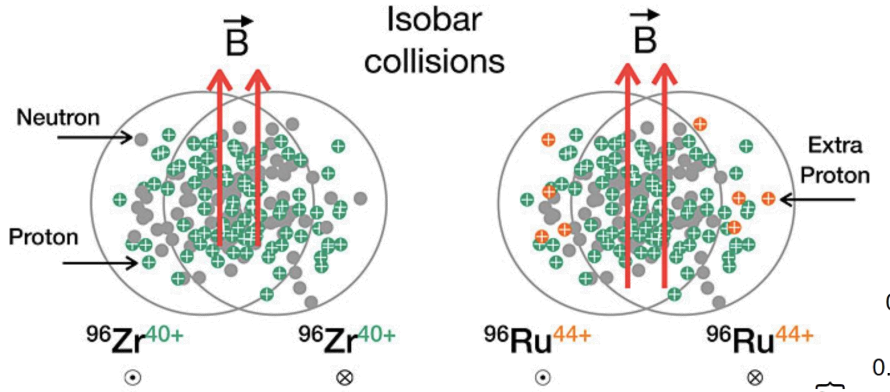
$$v_n = \langle \cos\left(n(\phi - \Psi_R)\right) \rangle$$

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

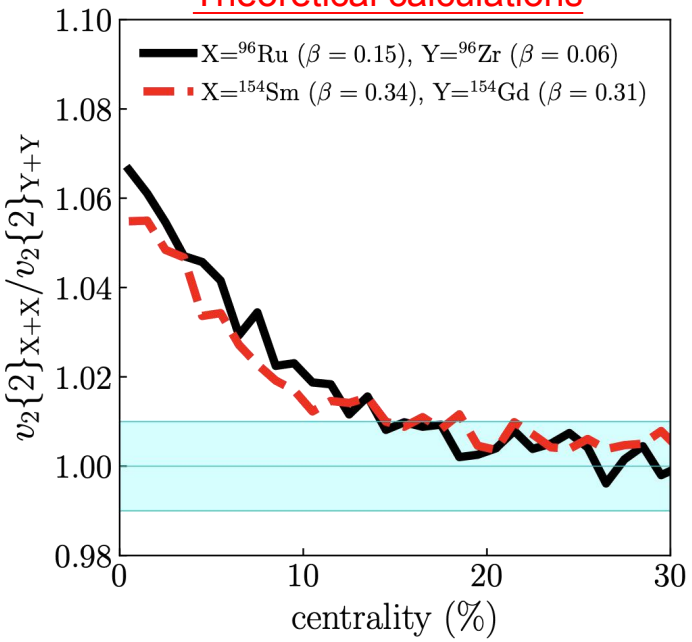
Probe of the early (partonic) stage of the collision

P. Klob, U. Heinz, Nucl. Phys. A715, (2003) 653c; A.M. Poskanzer & S.A. Voloshin, Phys. Rev. C 58 (1998) 1671

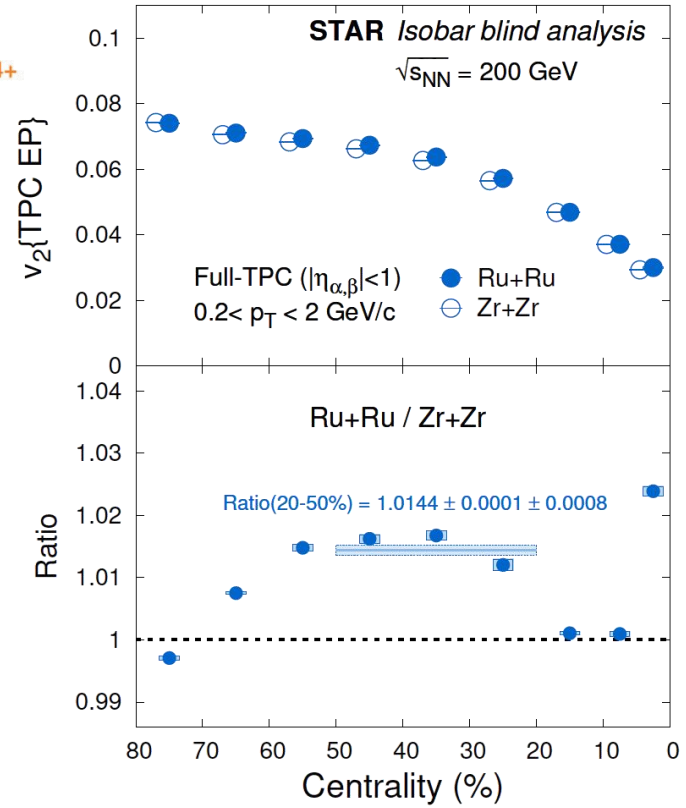
Motivation



Theoretical calculations



Experimental measurements



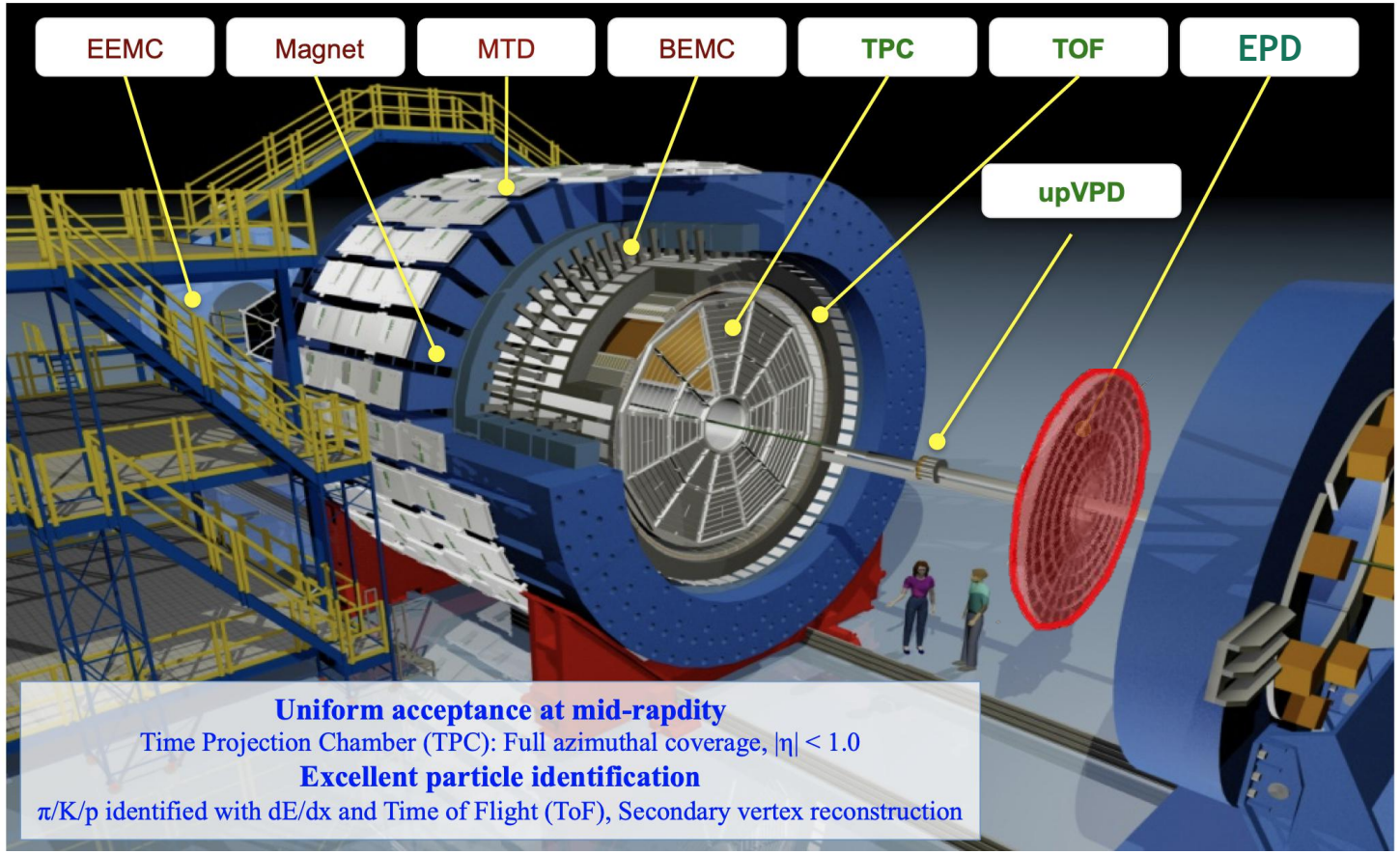
- Elliptic flow of (multi-)strange hadrons provide information on initial state anisotropies.
- Study of elliptic flow in isobar collisions may help in understanding the deformation of the colliding nuclei. for (multi-)strange hadrons, one can check the ratio between the two isobar system:

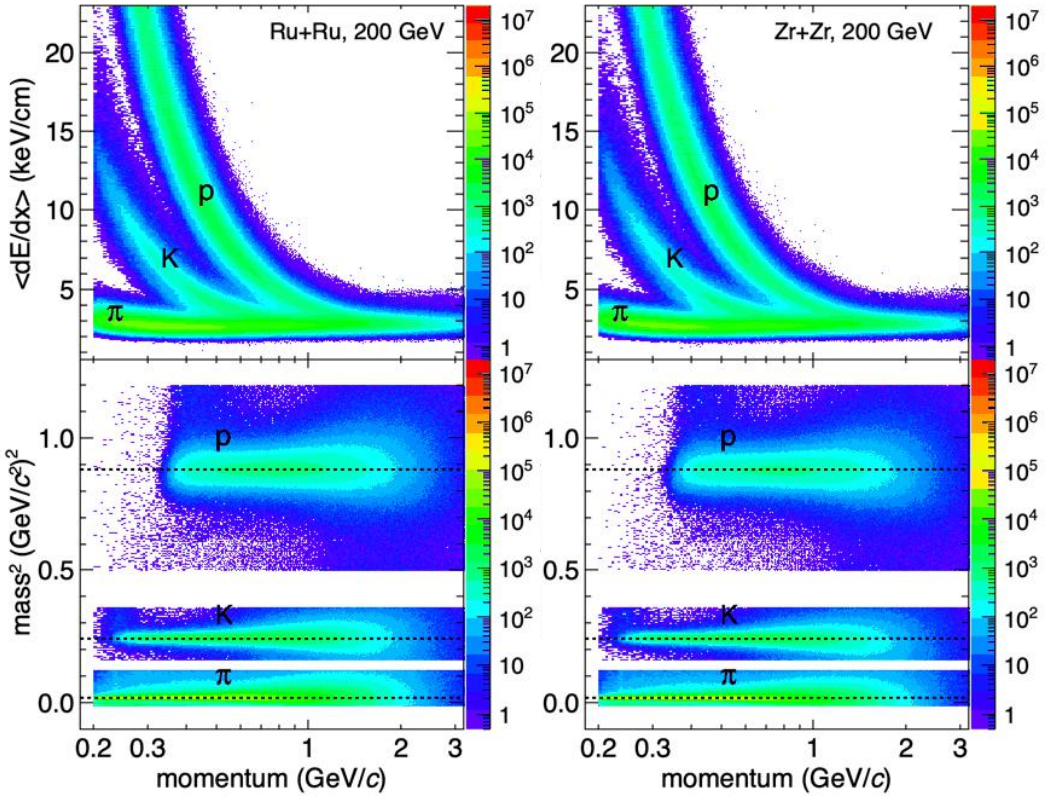
$$\frac{(v_2)_{Ru+Ru}}{(v_2)_{Zr+Zr}} \stackrel{?}{=} 1$$

- Comaprison of elliptic flow among systems with different nuclear size can help in understanding system size dependence of the azimuthal anisotropy

G. Giacalone et al., Phys. Rev. C 104 (2021) L041903, M. S. Abdallah et al. (STAR), Phys. Rev. C 105 (2022) 14901

STAR experiment





Dataset: Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV (2018)

Approximately 3.6 B events have been analysed

Event plane method

- 2nd harmonic event plane angle is defined as:

$$\Psi_n = \frac{1}{n}\tan^{-1}\left\{\frac{\sum_i w_i \sin(n\phi_i)}{\sum_i w_i \cos(n\phi_i)}\right\}; \quad \text{for } n = 2$$

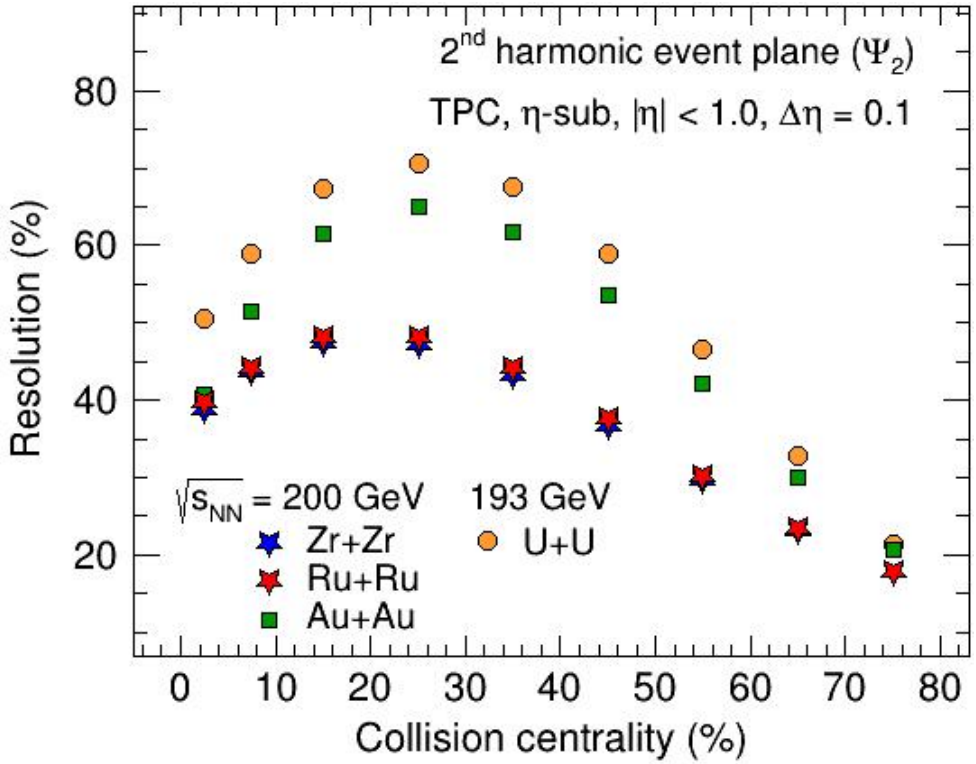
- Event plane angle calculated in two different η windows

  (a) $-1.0 < \eta < -0.05$ and (b) $0.05 < \eta < 1.0$

- The event plane angle resolution:

$$R = \sqrt{\cos 2\left(\Psi_2^a - \Psi_2^b\right)}$$

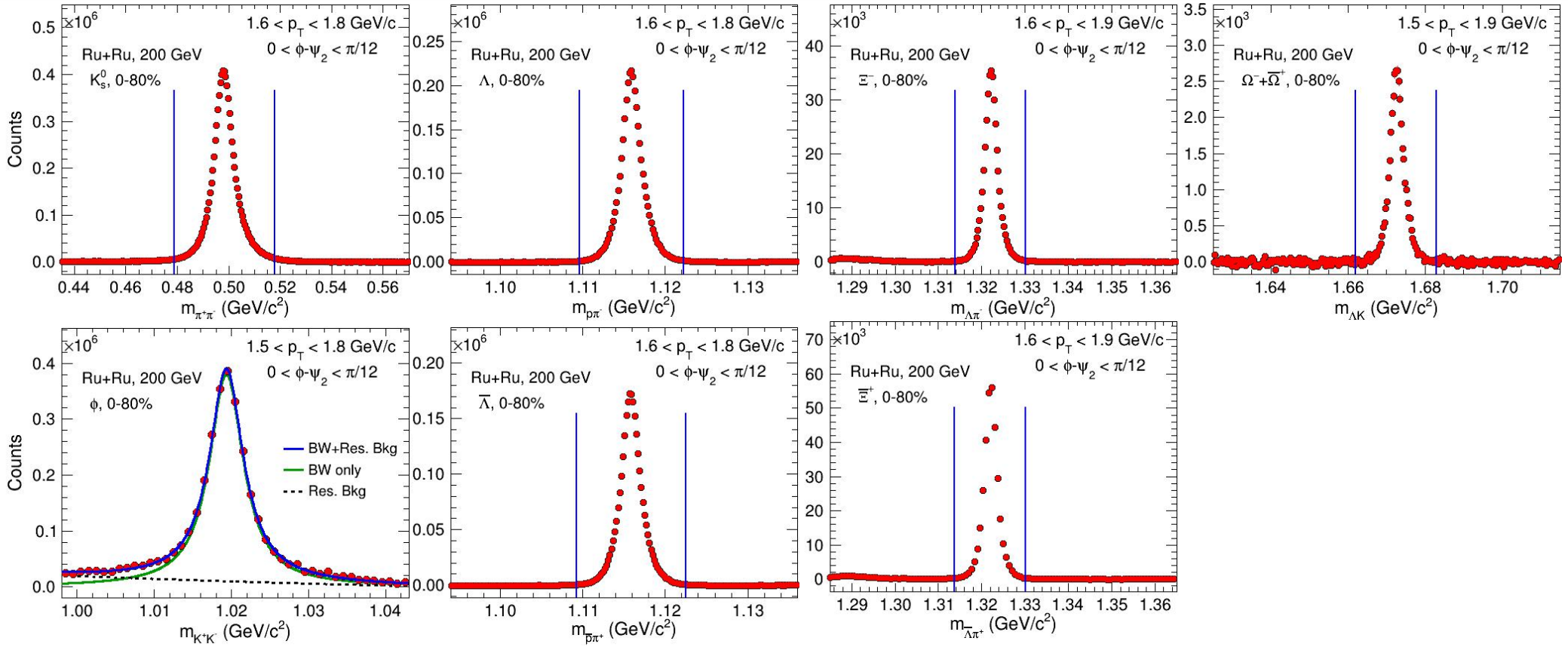
- Resolution correction applied to obtain the final v_2



A.M. Poskanzer & S.A. Voloshin, Phys. Rev. C 58 (1998) 1671

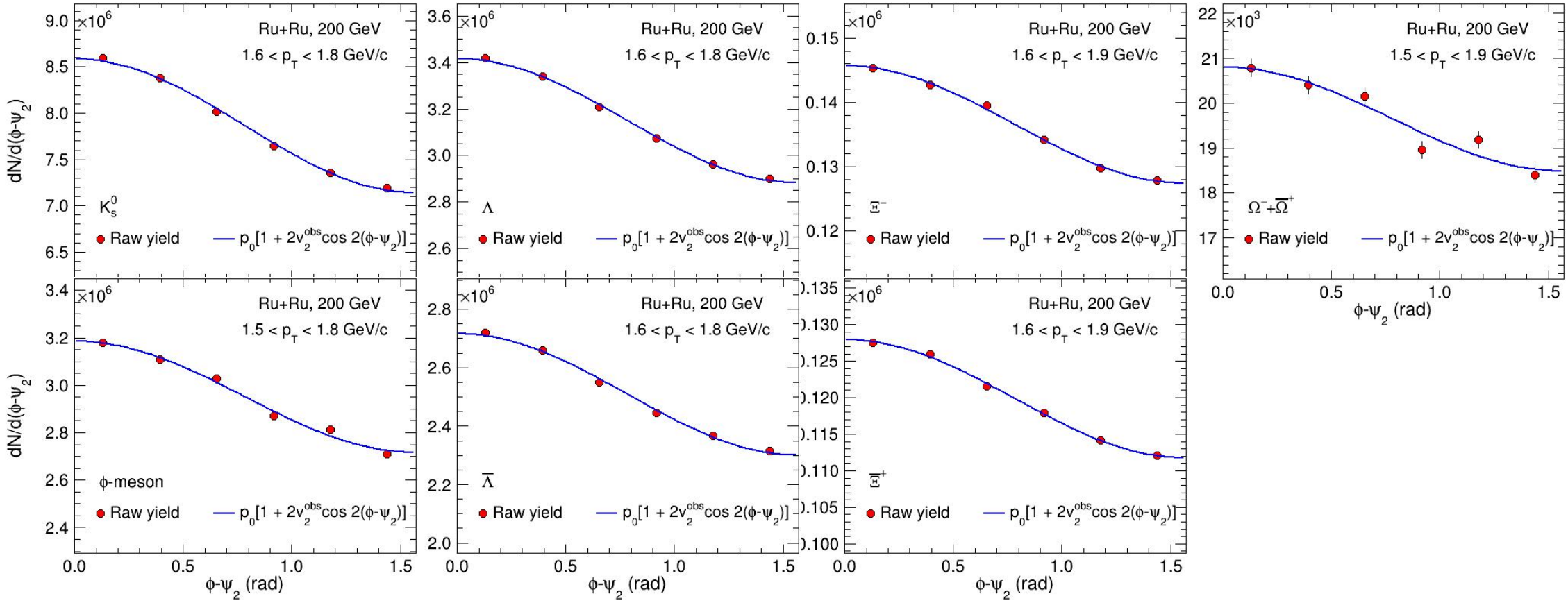
B. I. Abelev et al. (STAR), Phys. Rev. C 77 (2008) 054901;
M. S. Abdallah et al. (STAR) Phys. Rev. C 103 (2021) 064907

Particle identification



- K_s^0, ϕ, Λ, Ξ, and Ω have been reconstructed from their decay products using invariant mass technique.
- Background reconstruction using Event-mixing method for ϕ-mesons, rotation method for K_s^0, Λ, Ξ, and Ω.
- Signal extracted using bin counting within ±3σ of the invariant mass peak for weak-decay particles and using Breit-Wigner fit for ϕ-mesons.

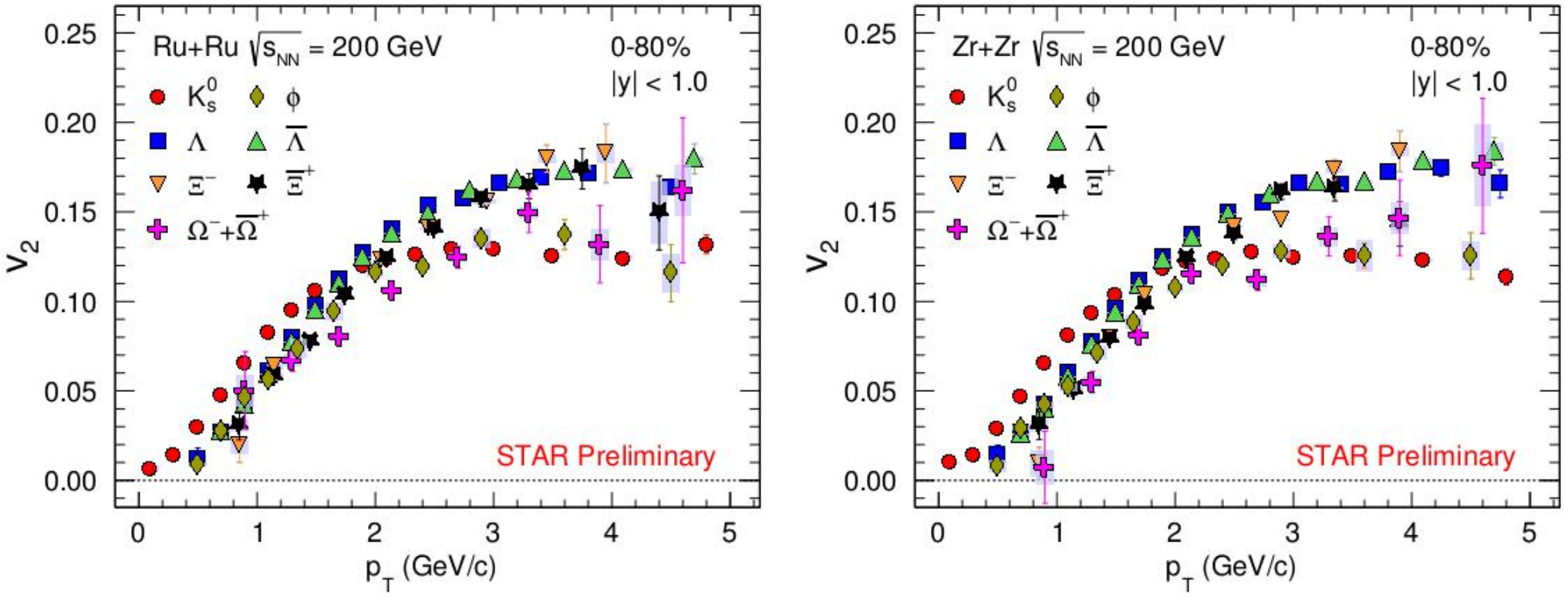
Flow analysis method



Event plane method:

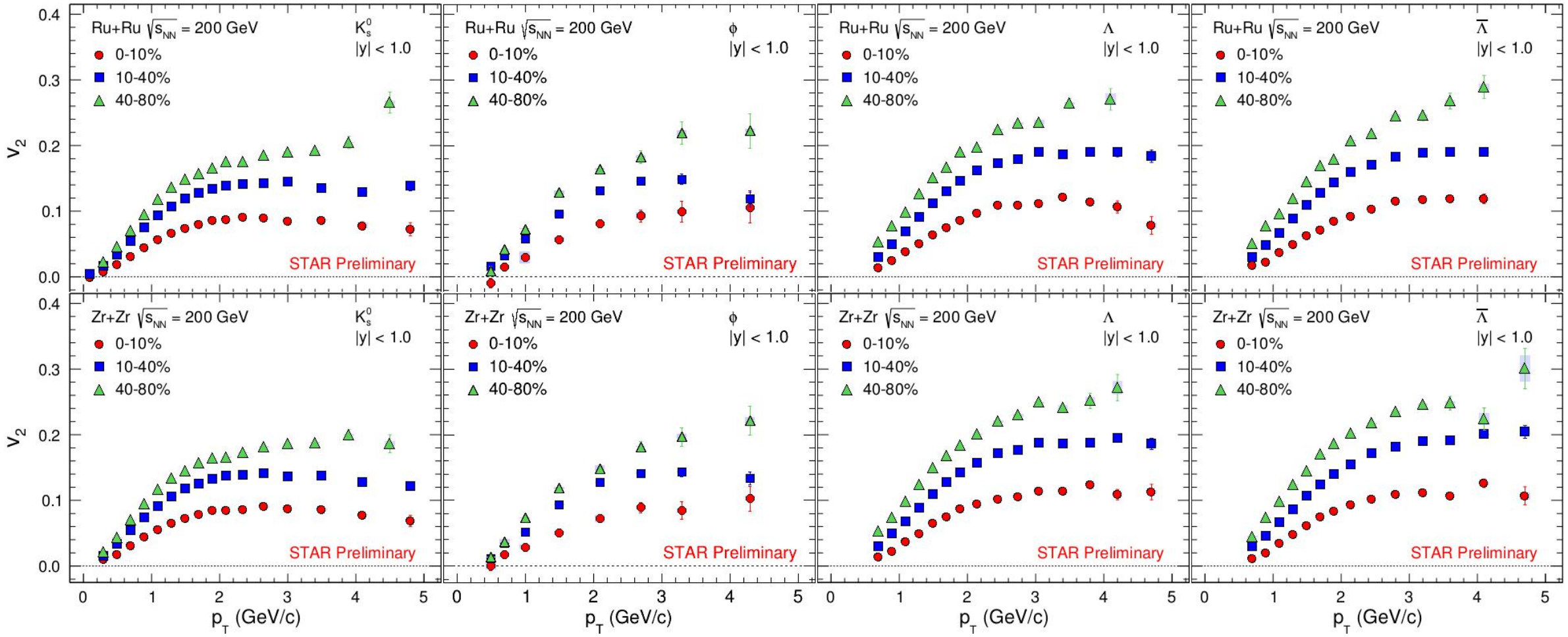
- Particle raw-yield as a function of ϕ-Ψ_2 is fitted with a function for different p_T ranges to extract observed v_2 coefficients.

Results: Elliptic flow $v_2(p_T)$



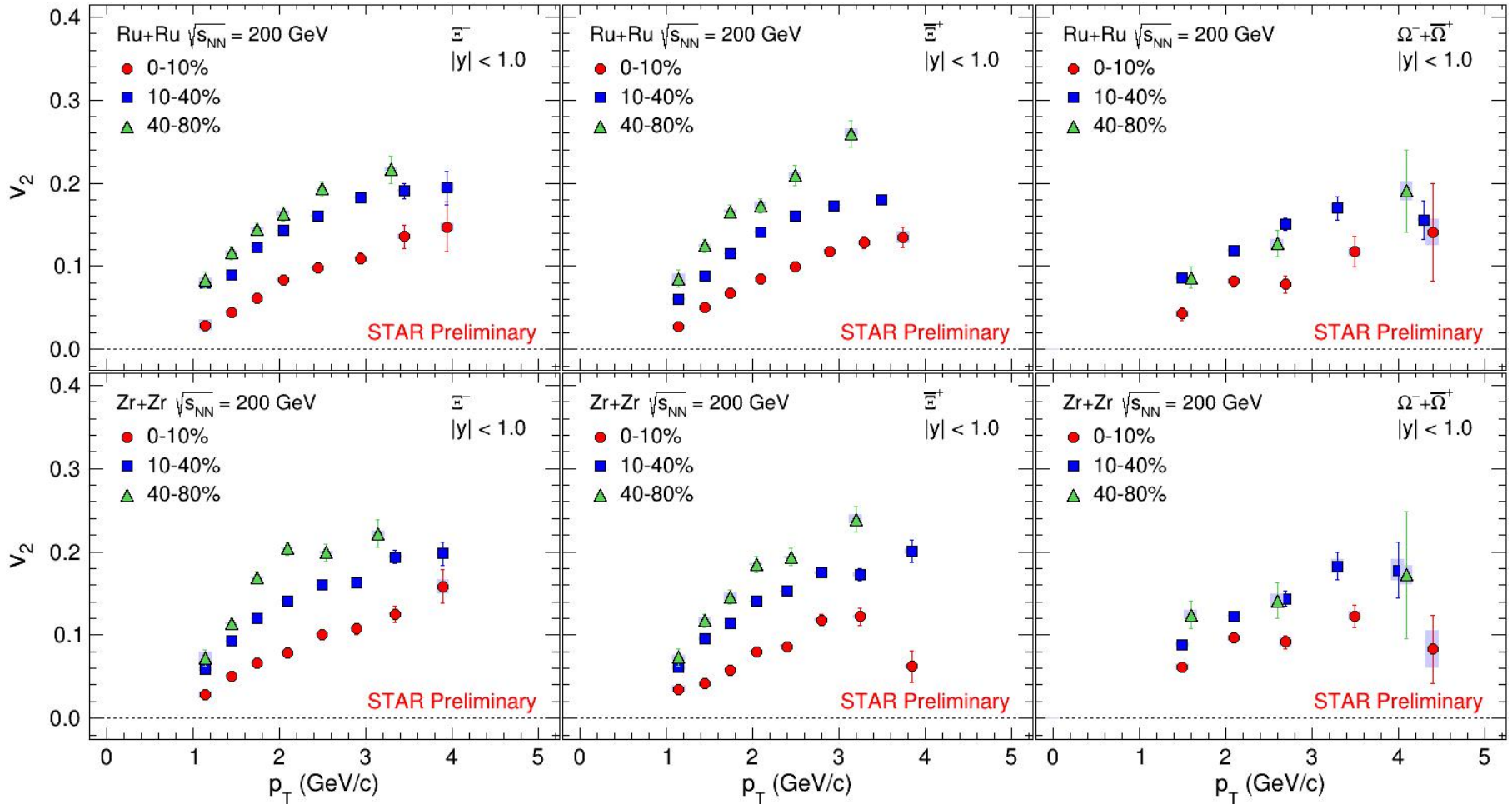
- Elliptic flow v_2 shows a particle mass ordering at low p_T for minimum bias isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV.
- Splitting of flow coefficients between baryons and mesons at intermediate p_T region is observed.
- A similar p_T dependence is observed in both Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV.

Centrality dependence of $v_2(p_T)$



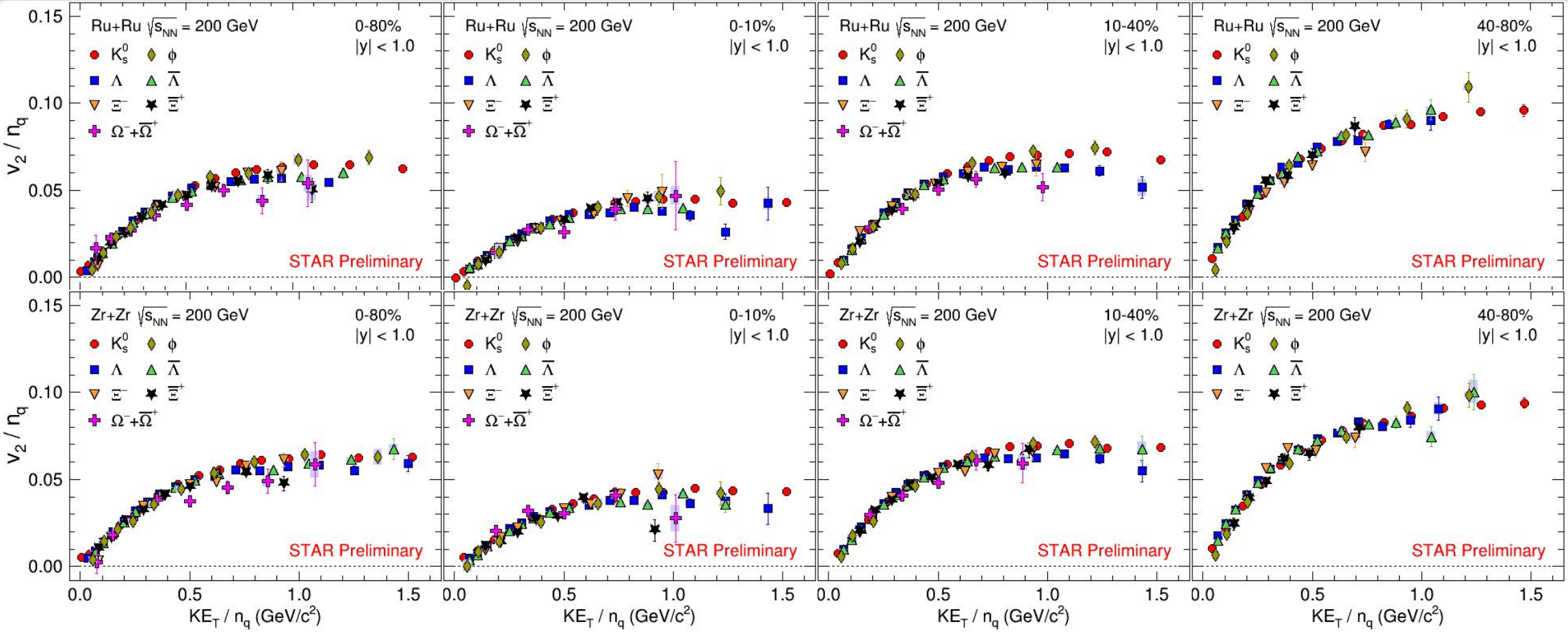
Elliptic flow $v_2(p_T)$ increases from central to peripheral collisions showing strong centrality dependence which indicate effect of initial eccentricity in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV.

Centrality dependence of $v_2(p_T)$



Elliptic flow $v_2(p_T)$ increases from central to peripheral collisions showing strong centrality dependence which indicate effect of initial eccentricity in isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV.

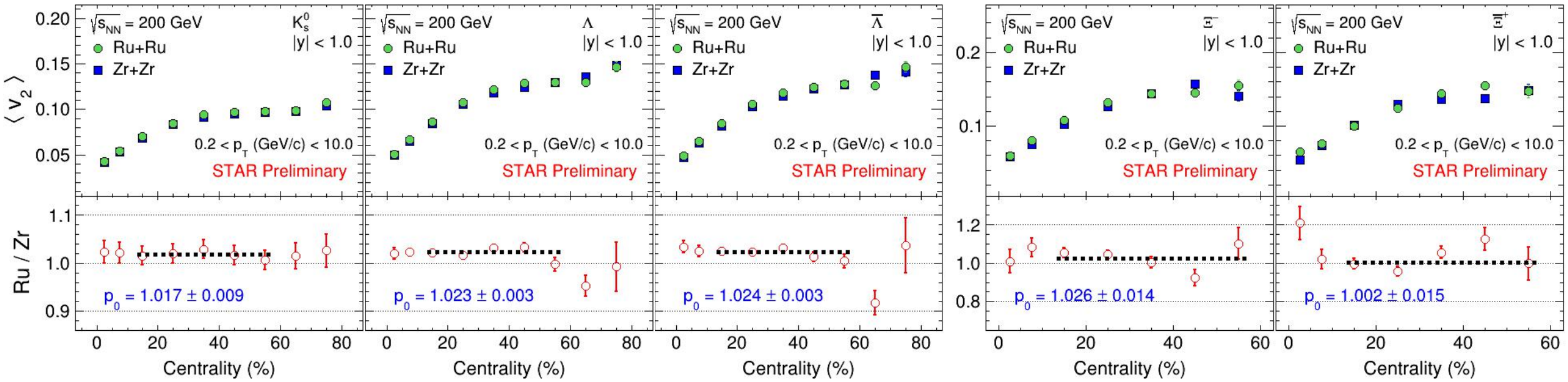
Constituent quarks scaling



n_q = Number of constituent quarks (3 for baryons and 2 for mesons); Transverse kinetic energy (KE_T) = $m_T - m_0$

- NCQ scaling hold good to ±10% within uncertainties in both Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV.
- Elliptic flow (v_2) scaled by number of constituent quarks falling on a universal curve, indicating partonic collectivity.

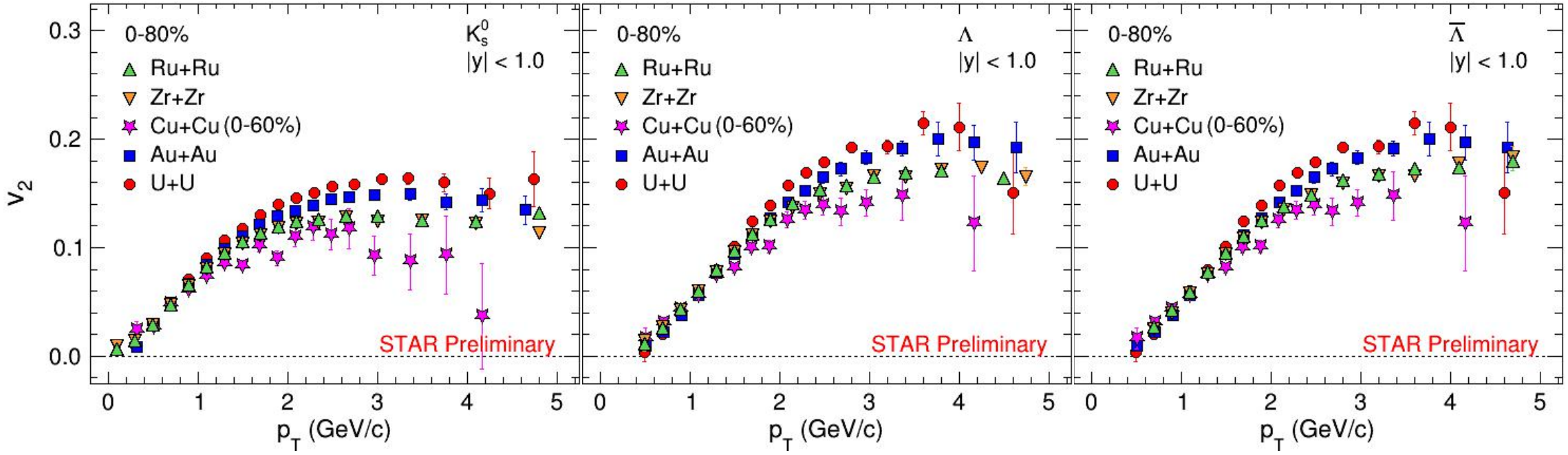
Integrated v_2



- p_T -integrated elliptic flow $\langle v_2 \rangle$ for strange and multi-strange hadrons increases from central to peripheral collisions.
- Ratio of integrated v_2 between Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV for strange hadrons (K_s^0, Λ, and $\overline{\Lambda}$) show deviation from unity by 2% wtih a significance >= 2σ (for K_s^0) and > 5σ (for Λ and $\overline{\Lambda}$) in mid-central (10-60%) collisions.

Indication of larger nuclear deformity in Ru nuclei than in the Zr nuclei

System size dependence (strange)



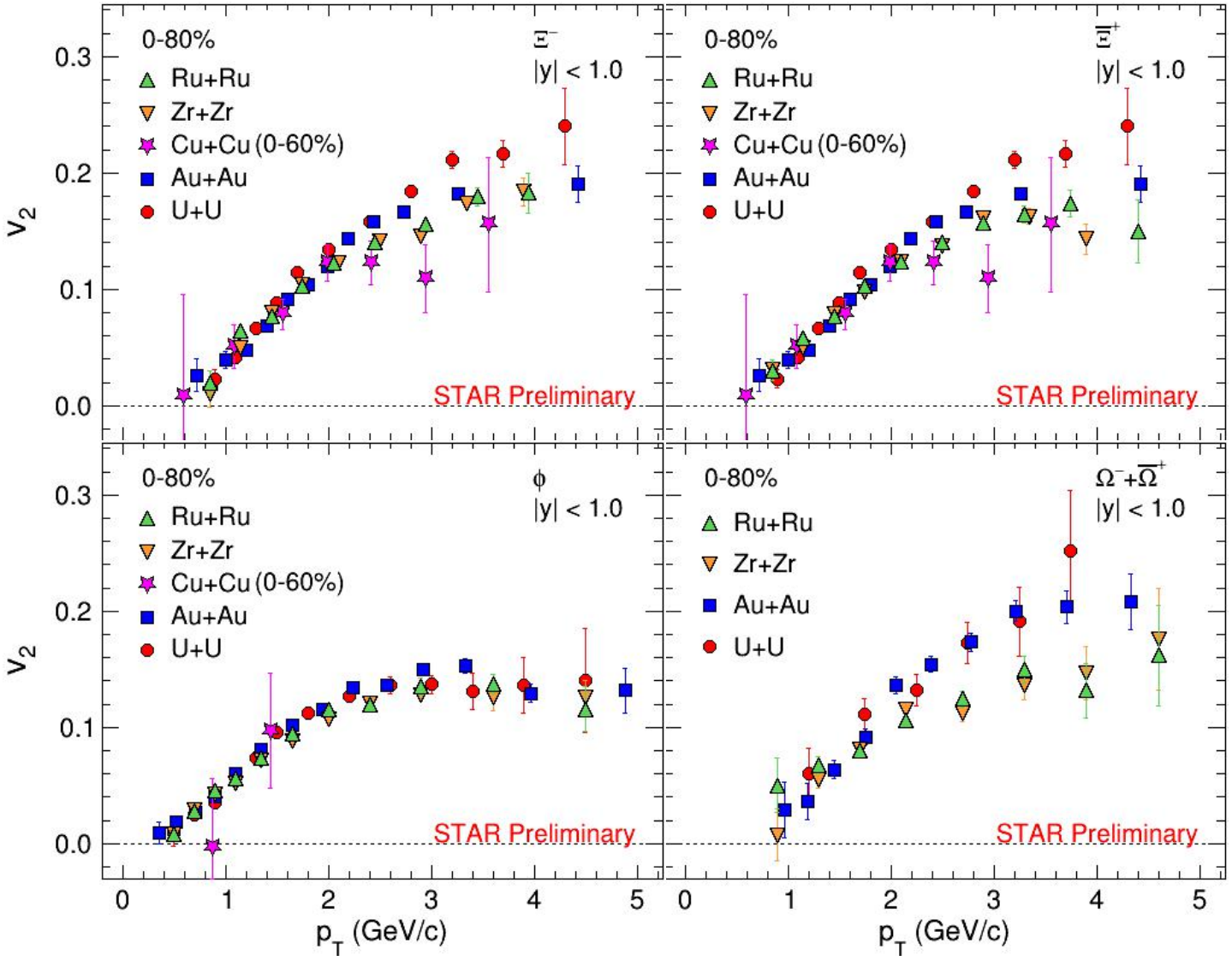
** Error bars are combined statistical and systematic uncertainties*

- Elliptic flow $v_2(p_T)$ of strange hadrons in isobar collisions is higher than the Cu+Cu collisions at $\sqrt{s_{NN}}$ = 200 GeV and lower compared to U+U and Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV.

Elliptic flow at high p_T incresases with atomic mass number of nuclei indicating a nuclear size dependence

B. I. Abelev et al. (STAR), Phys. Rev. C 77 (2008) 054901, Phys. Rev. C 81 (2010) 044902; M. S. Abdallah et al. (STAR) Phys. Rev. C 103 (2021) 064907

System size dependence (multi-strange)

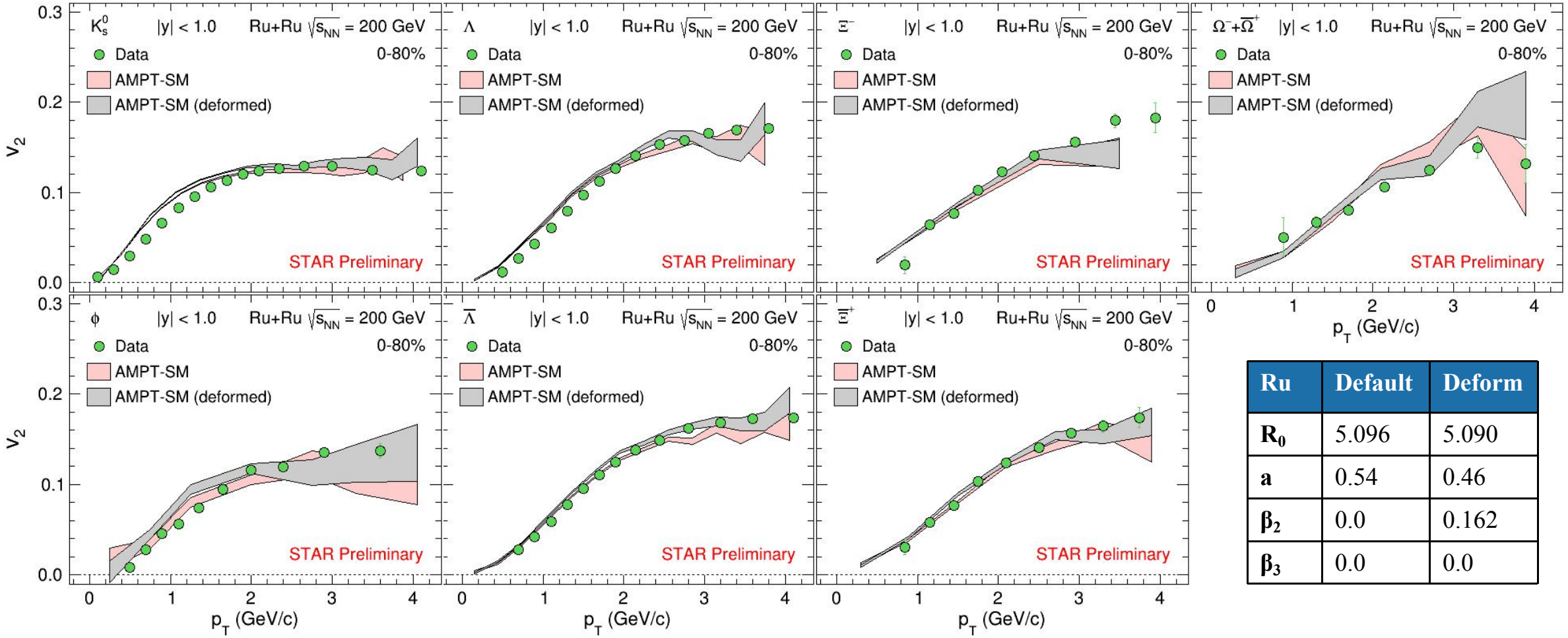


* *Error bars are combined statistical and systematic uncertainties*

Elliptic flow of multi-strange hadrons in the measured p_T range for isobar collisinos at $\sqrt{s_{NN}}$ = 200 GeV shows nuclear size dependence similar to the strange hadrons, while ϕ-meson shows weak or no system size dependence.

B. I. Abelev et al. (STAR), Phys. Rev. C 77 (2008) 054901
B. I. Abelev et al. (STAR), Phys. Rev. C 81 (2010) 044902
L. Adamczyk et al. (STAR), Phys. Rev. Lett. 116 (2016) 062301
M. S. Abdallah et al. (STAR) Phys. Rev. C 103 (2021) 064907

Model Comparison

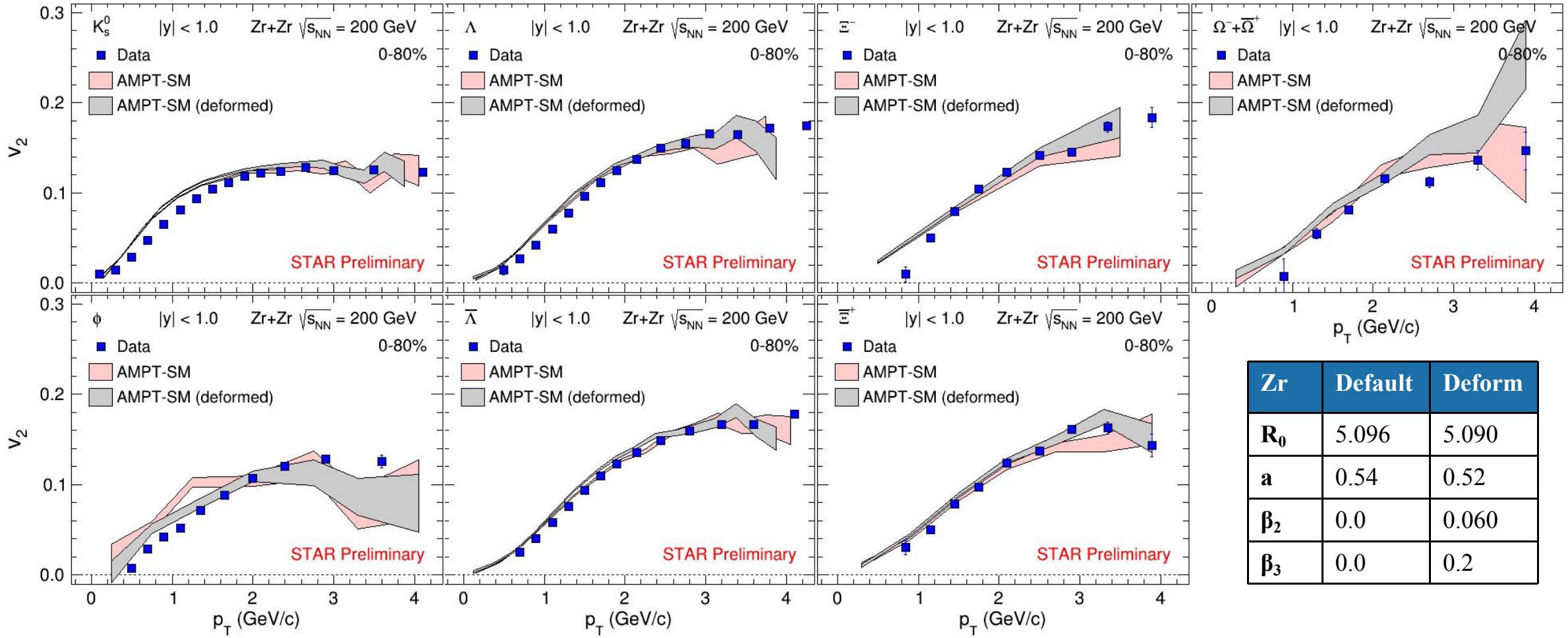


Ru	Default	Deform
R_0	5.096	5.090
a	0.54	0.46
β_2	0.0	0.162
β_3	0.0	0.0

AMPT-SM model with and without nuclear deformation are close to each other and the data in the measured p_T range for minimum-bias isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV

B. Zhang et al., Phys. Rev. C 61, 067901 (2000)
Z.-W. Lin et al., Phys. Rev. C 64, 011902 (2001), Phys. Rev. C 72, 064901 (2005)

Model Comparison



Zr	Default	Deform
R_0	5.096	5.090
a	0.54	0.52
β_2	0.0	0.060
β_3	0.0	0.2

AMPT-SM model with and without nuclear deformation are close to each other and the data in the measured p_T range for minimum-bias isobar collisions at $\sqrt{s_{NN}}$ = 200 GeV

B. Zhang et al., Phys. Rev. C 61, 067901 (2000)
Z.-W. Lin et al., Phys. Rev. C 64, 011902 (2001), Phys. Rev. C 72, 064901 (2005)

Summary

- Elliptic flow of strange (K_s^0, Λ, $\overline{\Lambda}$) and multi-strange (ϕ, Ξ, Ω) hadrons has been measured using event plane method in isobar (Ru+Ru and Zr+Zr) collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC.

Partonic collectivity:

- Strong centrality dependence and NCQ scaling of v_2 for (multi-)strange hadrons in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV
  - ► Partonic collectivity in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC

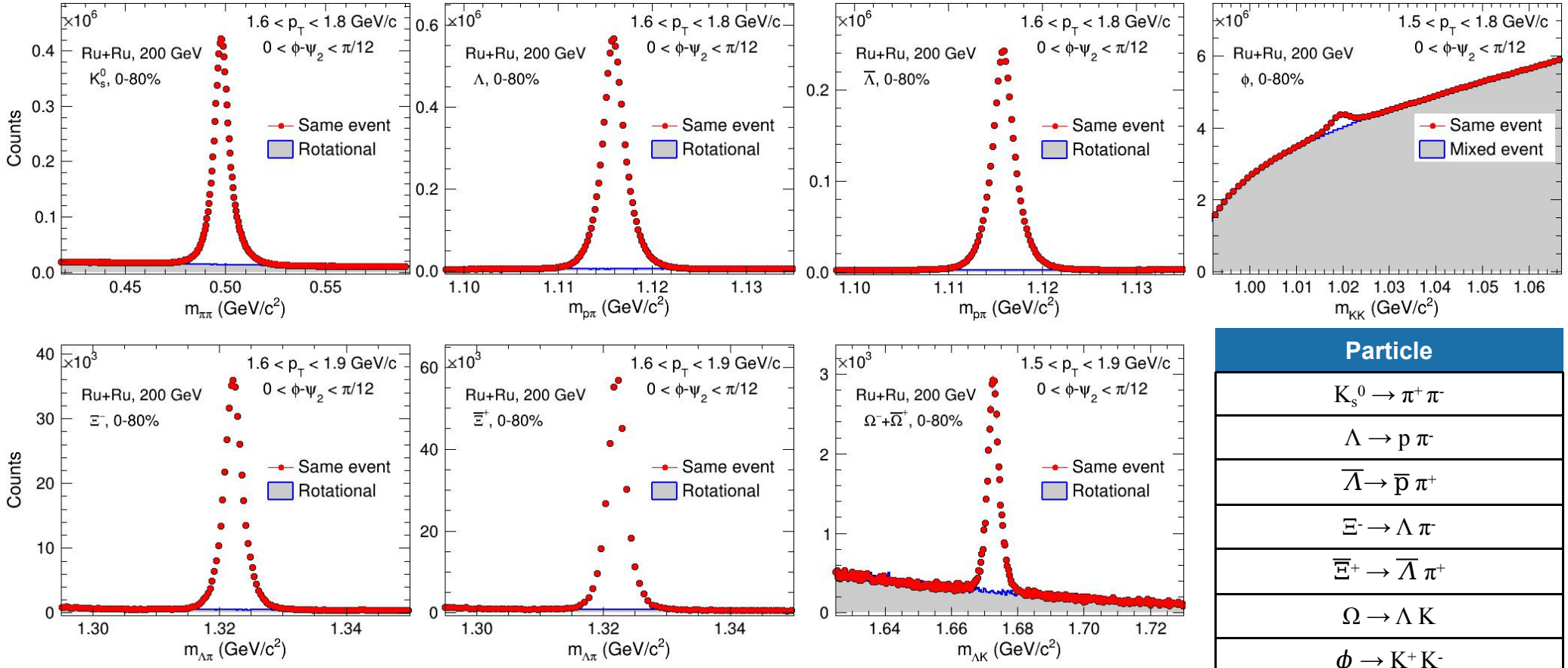
Nuclear size and deformation:

- Elliptic flow $\langle v_2 \rangle$ ratio between two isobars (Ru/Zr) shows a deviation of 2% from unity in mid-central collisions
  - ► Indicates higher deformation in Ru than in Zr nuclei
- $v_2(p_T)$ at higher p_T (> 2 GeV/c) for strange hadrons increases with increasing system size
  - ► Indicates effect of nuclear size on elliptic flow at $\sqrt{s_{NN}} = 200$ GeV

Thank you for your attention!

Backup

Particle identification



Particle
$K_s^0 \rightarrow \pi^+ \pi^-$
$\Lambda \rightarrow p\ \pi^-$
$\overline{\Lambda} \rightarrow \overline{p}\ \pi^+$
$\Xi^- \rightarrow \Lambda\ \pi^-$
$\overline{\Xi}^+ \rightarrow \overline{\Lambda}\ \pi^+$
$\Omega \rightarrow \Lambda\ K$
$\phi \rightarrow K^+ K^-$

- K_s^0, ϕ, Λ, Ξ, and Ω have been reconstructed from their decay products.
- Background reconstruction using various methods: Event-mixing method for ϕ-mesons, rotation method for K_s^0, Λ, Ξ, and Ω.

AMPT (SM) Model Parameters

AMPT (String Melting) Model:

- Parton-Parton interaction cross-section 3 mb is used.

Woods-saxon distribution: $\rho(r,\theta) = \rho_0 / \{1 + e^{[(r - R(\theta,\varphi))/a]}\}$

$$R(\theta,\varphi) = R_0[1 + \beta_2 Y_{2,0}(\theta,\varphi) + \beta_3 Y_{3,0}(\theta,\varphi)]$$

Default	R_0	a	β_2	β_3
Ru	5.096	0.54	0.0	0.0
Zr	5.096	0.54	0.0	0.0
Deform	R_0	a	β_2	β_3
Ru	5.09	0.46	0.162	0.0
Zr	5.09	0.52	0.060	0.2