

Elliptic flow of strange and multi-strange hadrons in isobar collisions at $\sqrt{s_{NN}} = 200$ GeV

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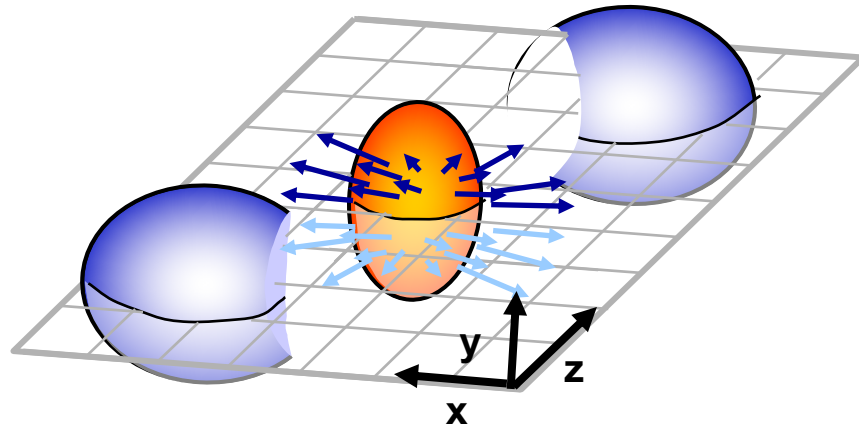
(for the STAR Collaboration)

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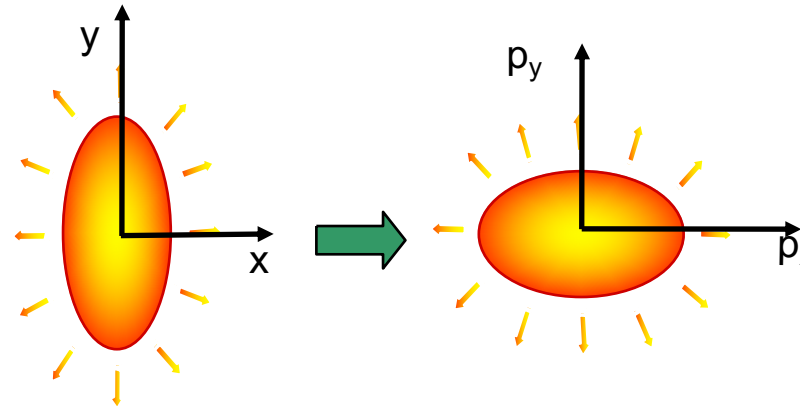
Outline

- Introduction
- STAR experiment at RHIC
- Results
 - Elliptic flow of strange and multi-strange hadrons
 - System size dependence
- Summary

Introduction: Elliptic flow



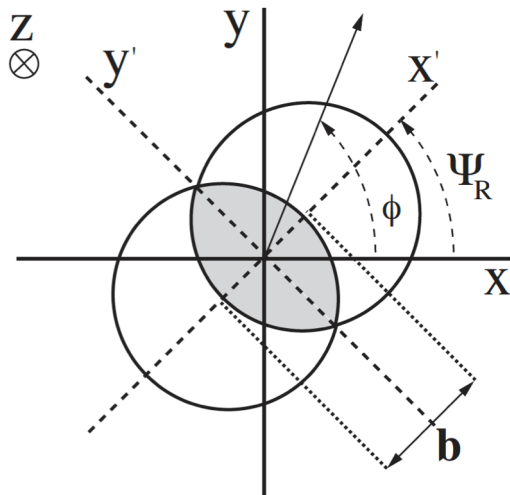
Reaction plane: z-x plane



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

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

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



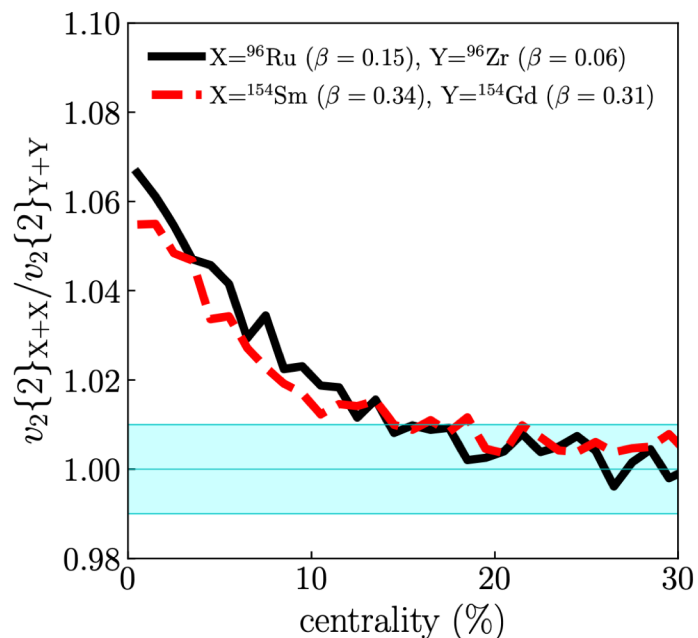
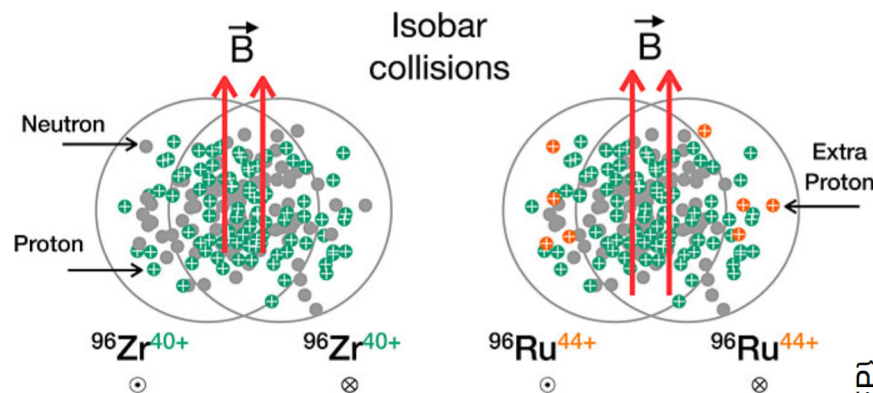
Motivation

- Study of elliptic flow in isobar collisions may help in understanding the deformation of the colliding nuclei

- Elliptic flow of strange and multi-strange hadrons, having lower hadronic cross-section, gives direct information on initial state anisotropies

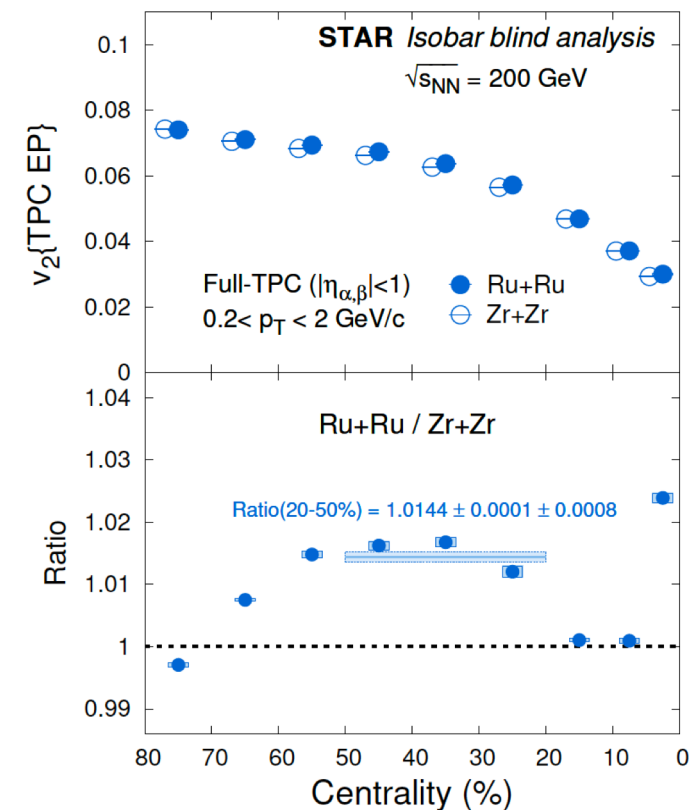
Check if:
$$\frac{(v_2)_{\text{Ru+Ru}}}{(v_2)_{\text{Zr+Zr}}} \stackrel{?}{=} 1$$

- System size dependence of the azimuthal anisotropy by comparing isobars, Cu+Cu, Au+Au and U+U



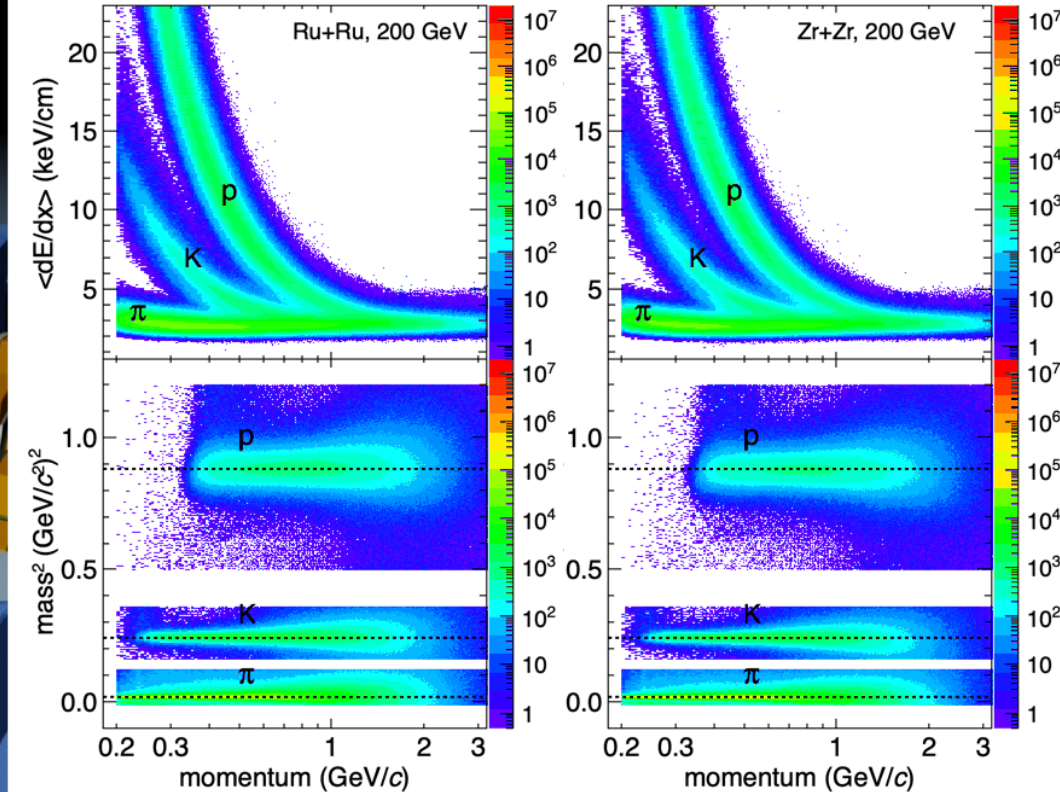
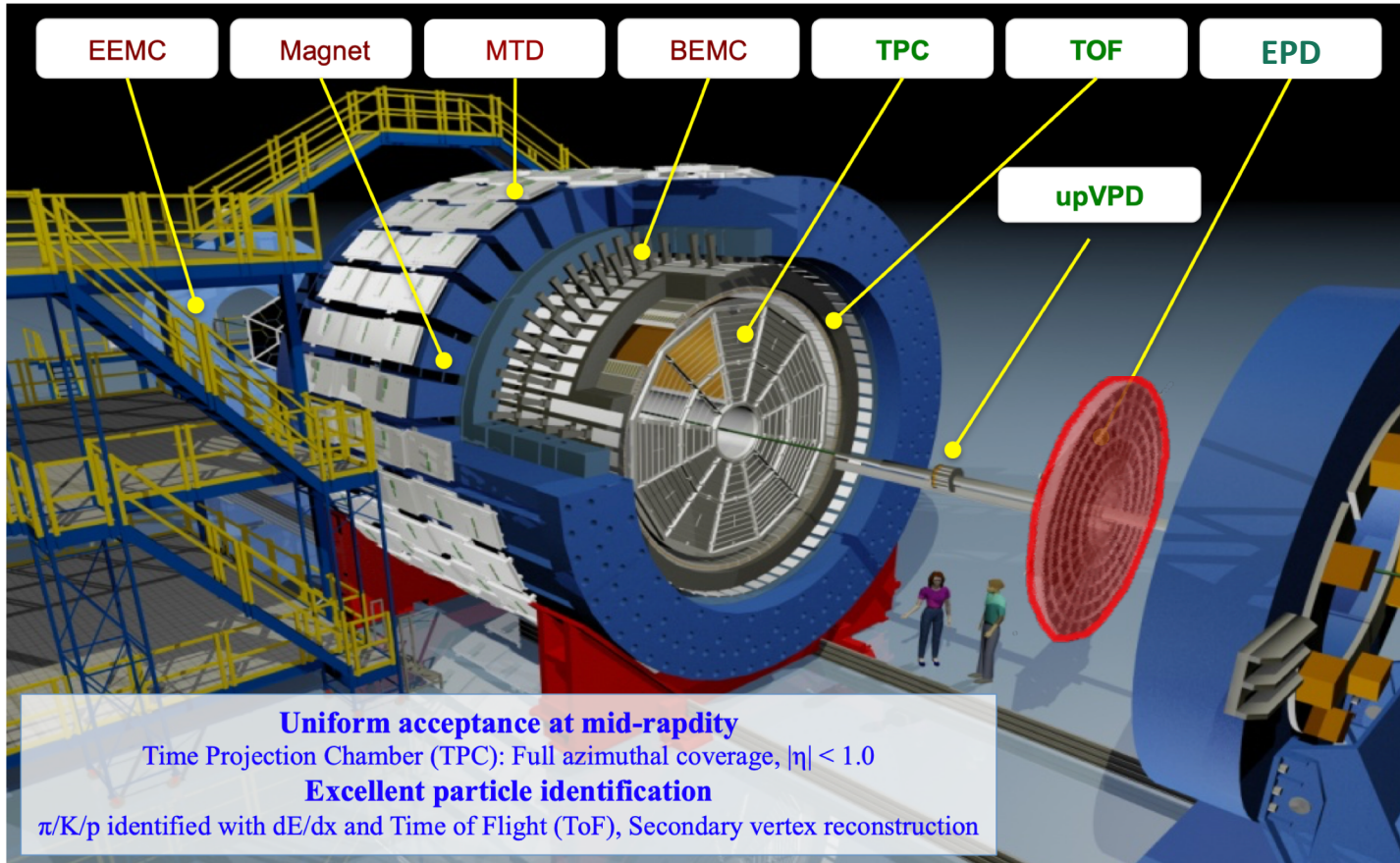
G. Giacalone, J. Jia, and V. Somà,
Phys. Rev. C 104, L041903 (2021)

Vipul Bairathi



M. S. Abdallah et al. (STAR Collaboration),
Phys. Rev. C 105, 14901 (2022)

STAR experiment



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

- Systematic uncertainty sources: Event and track selections, Topological selection, Functional fitting for yield extraction

Event plane method

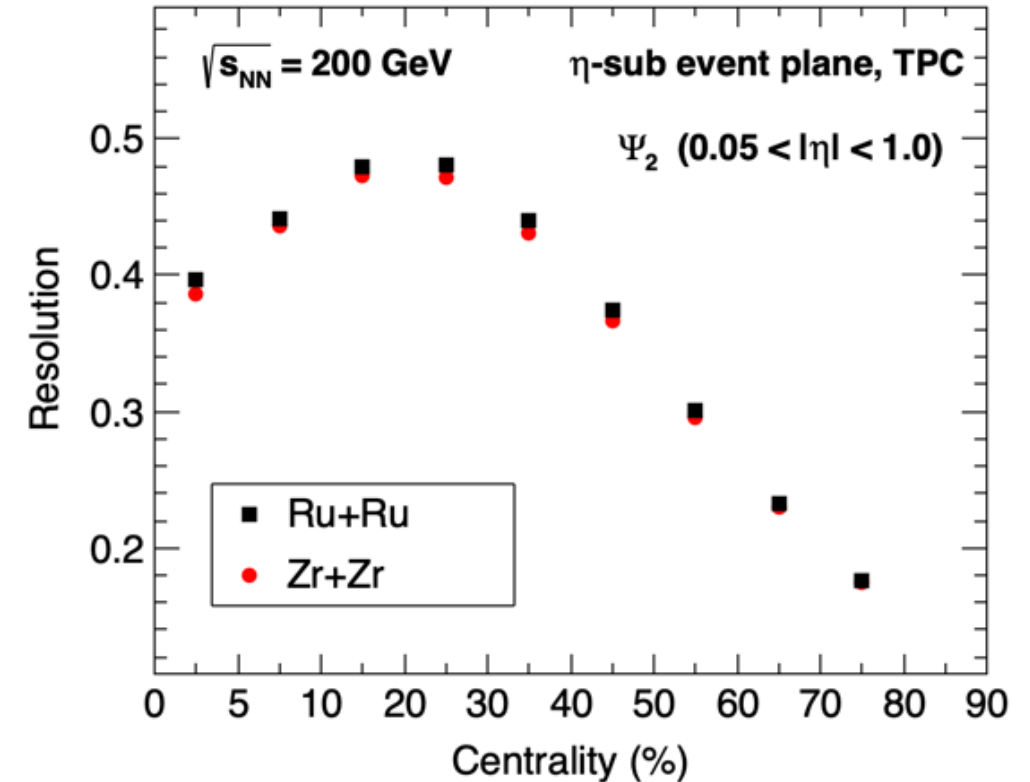
- Azimuthal angle of event plane is defined as :

$$\Psi_2 = \left[\tan^{-1} \left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)} \right) \right] / 2$$

- Event plane has been calculated in two different pseudo-rapidity windows 'a' ($-1.0 < \eta < -0.05$) and 'b' ($0.05 < \eta < 1.0$)
- The event plane resolution using η -sub event approach :

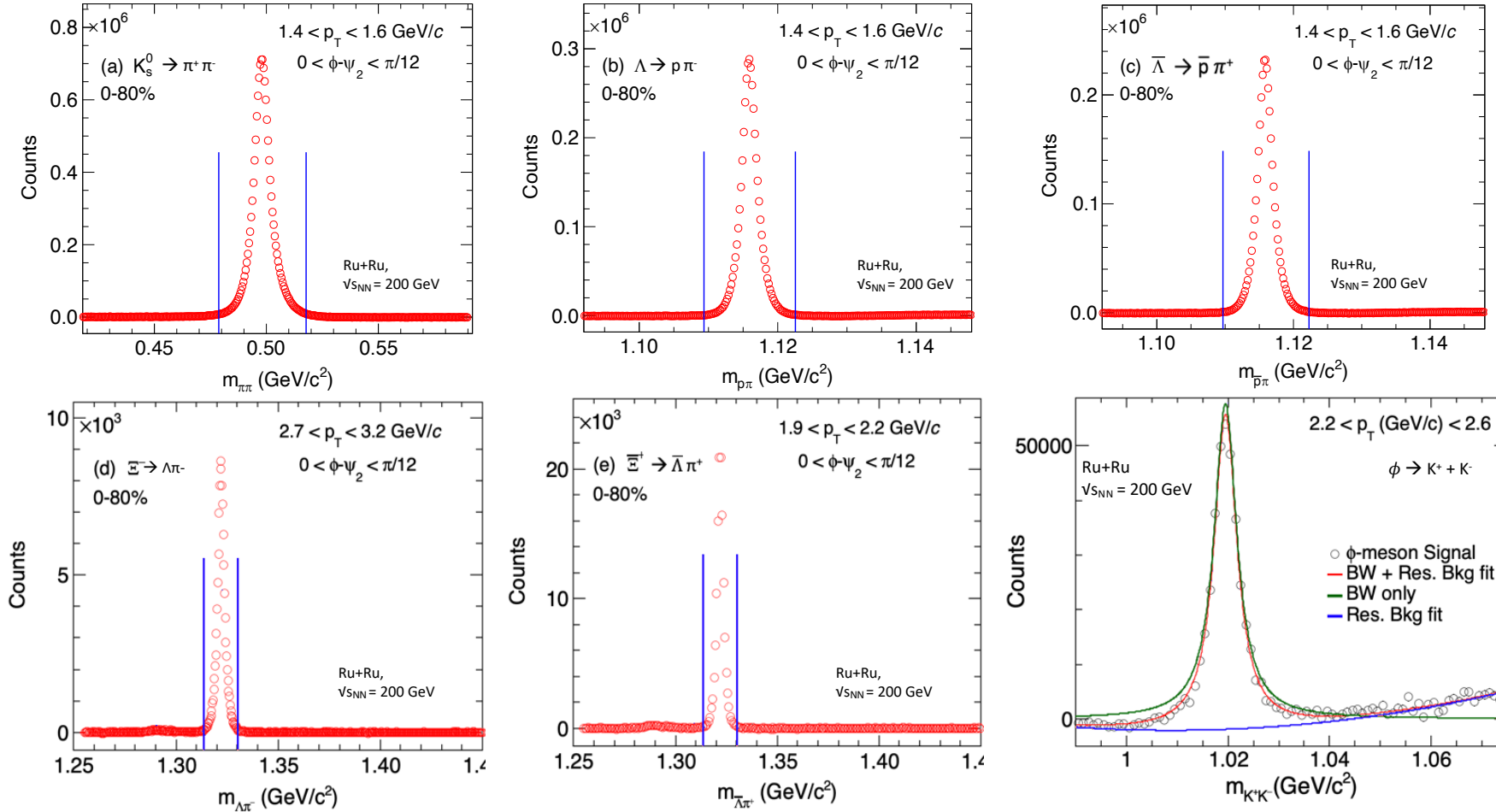
$$R = \sqrt{\langle \cos 2(\Psi_2^a - \Psi_2^b) \rangle}$$

- Resolution correction is applied to obtain the final v_2



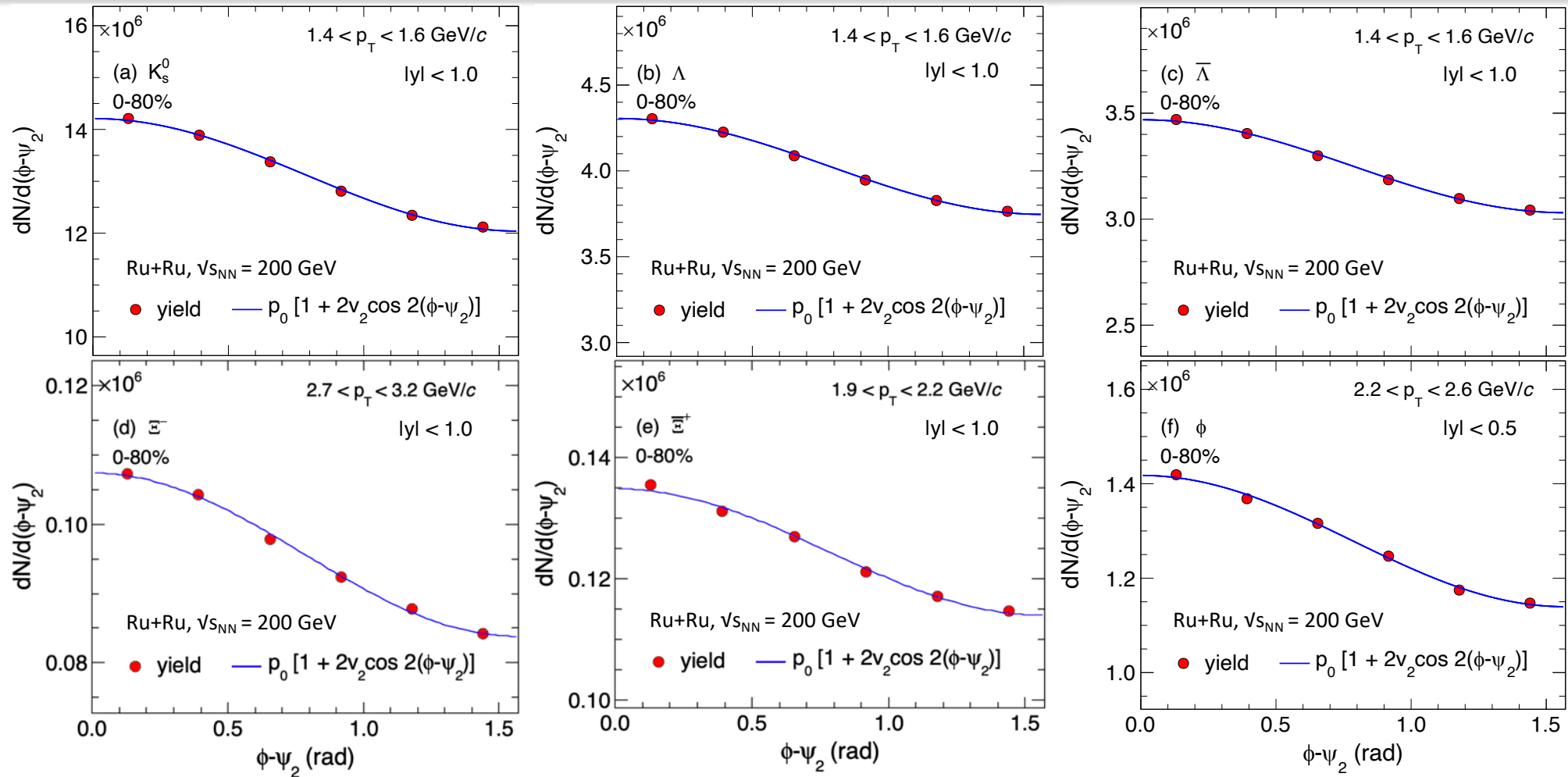
*Statistical error within marker size

Particle reconstruction



- K_S^0 , ϕ , Λ , and Ξ have been reconstructed using invariant mass method; topological cuts using Helix method
- Background reconstruction using event-mixing method for ϕ -mesons and rotational method for K_S^0 , Λ , and Ξ

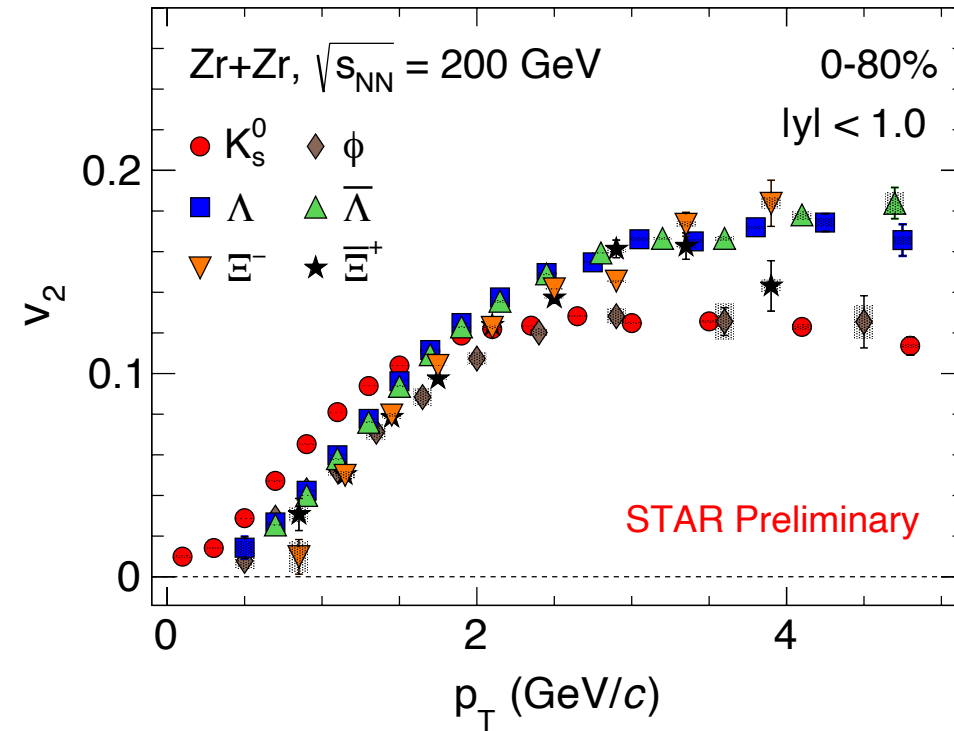
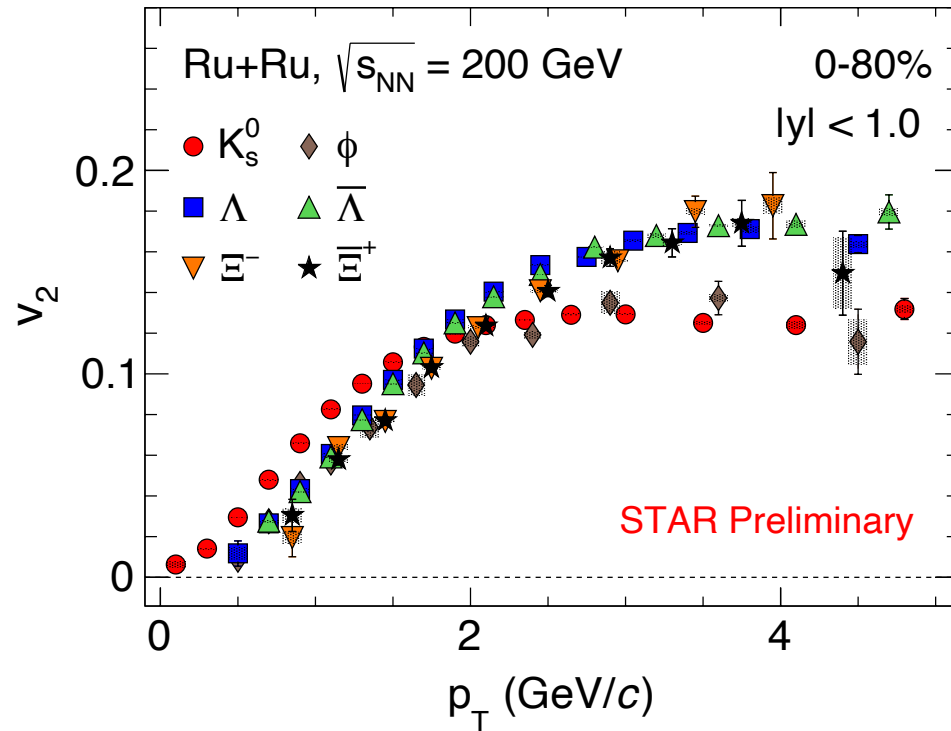
Flow analysis method



Event plane method:

- Particle raw-yield as a function of $\phi - \Psi_2$ is fitted with a Fourier fit function for different p_T ranges to extract v_2 coefficients

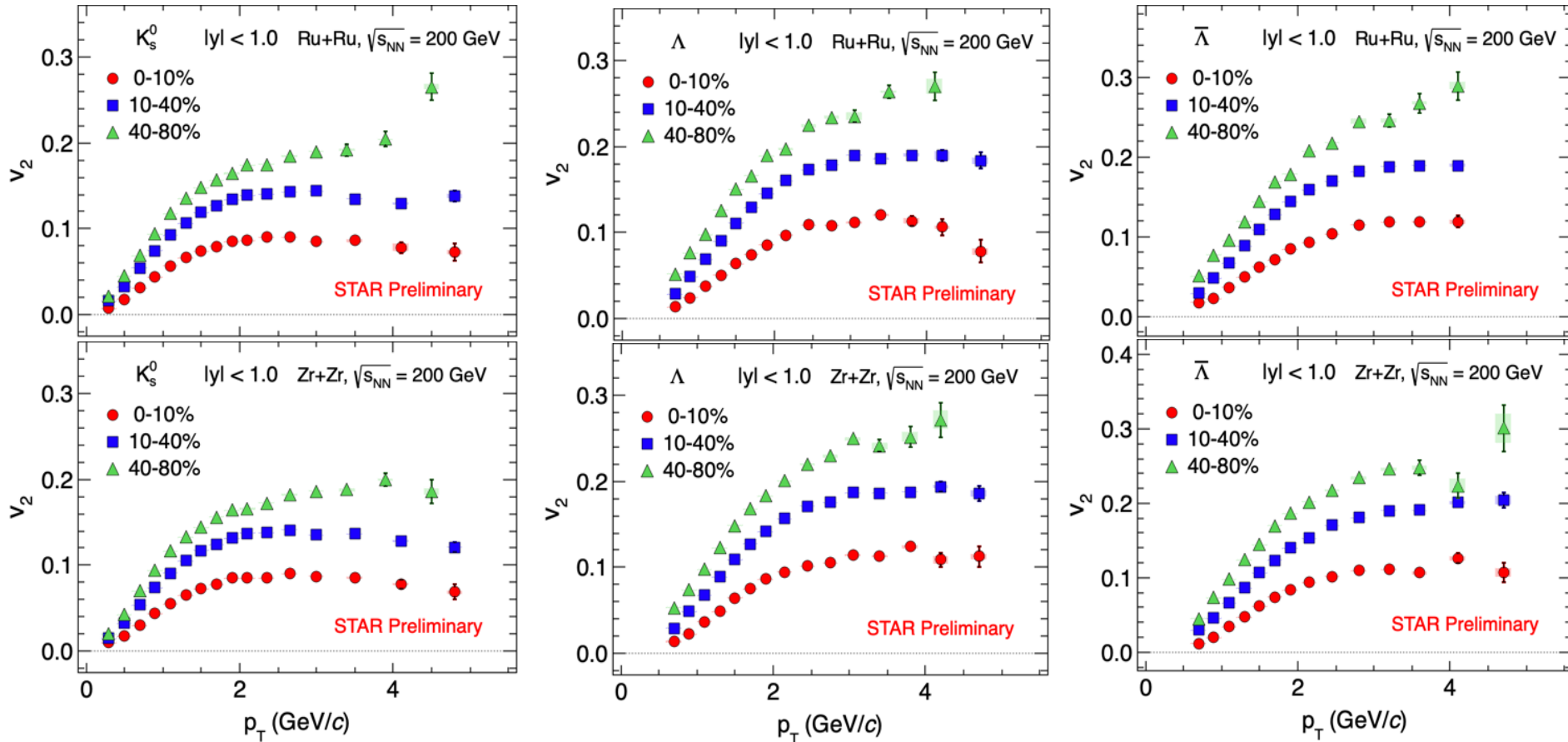
Results: Elliptic flow



**Vertical bars indicate statistical error and shaded boxes denote systematic errors*

- v_2 shows a mass ordering at low p_T in isobar collisions
- Baryon-meson splitting at intermediate p_T region (> 2 GeV/c)
- v_2 values have similar p_T dependence in minimum bias Ru+Ru and Zr+Zr collisions

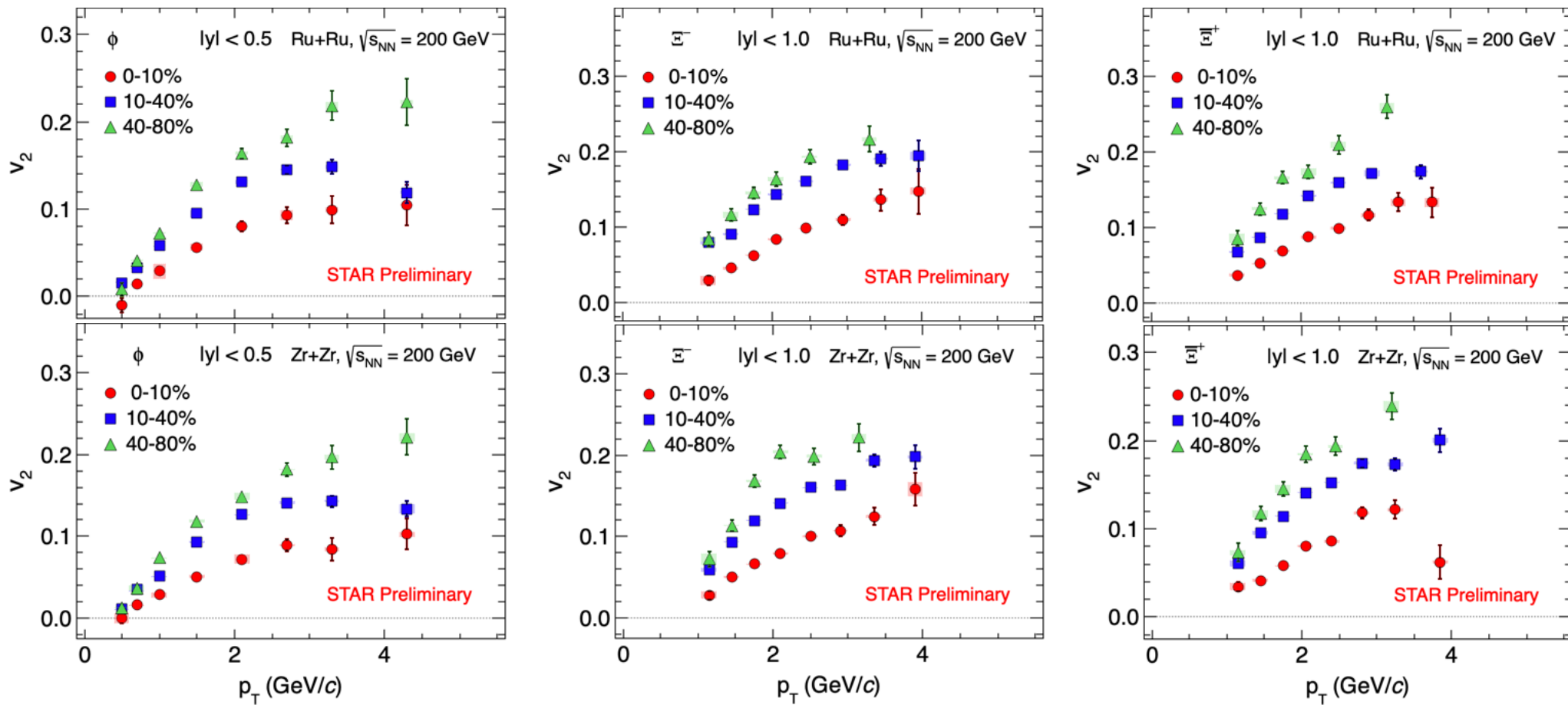
Centrality dependence of $v_2(p_T)$



*Vertical bars indicate statistical error and shaded boxes denote systematic errors

- Strong centrality dependence is observed for v_2 of K_s^0 , Λ , and $\bar{\Lambda}$, in both Ru+Ru and Zr+Zr collisions
- $v_2(p_T)$ increases from central to peripheral collisions

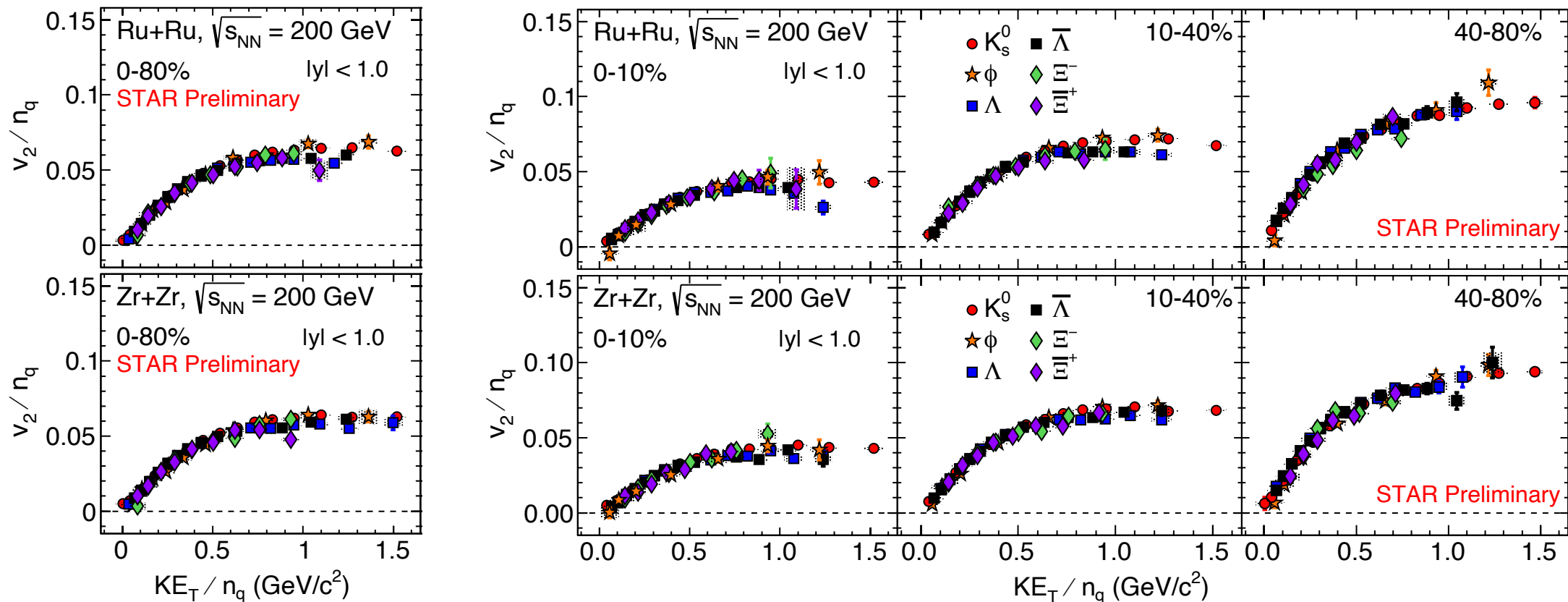
Centrality dependence of $v_2(p_T)$



*Vertical bars indicate statistical error and shaded boxes denote systematic errors

- Strong centrality dependence is observed for v_2 of ϕ , Ξ^- , and Ξ^+ in both Ru+Ru and Zr+Zr collisions
- $v_2(p_T)$ increases from central to peripheral collisions

NCQ scaling



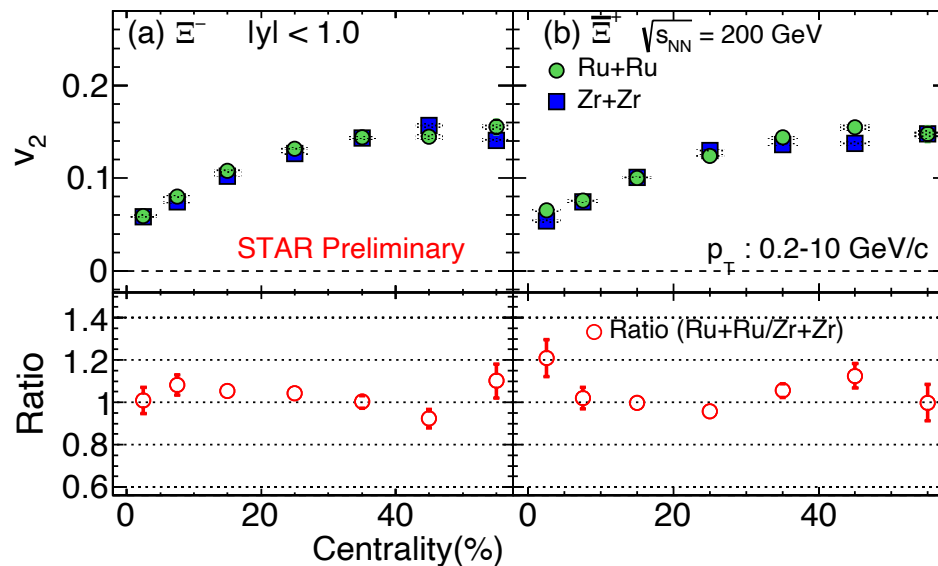
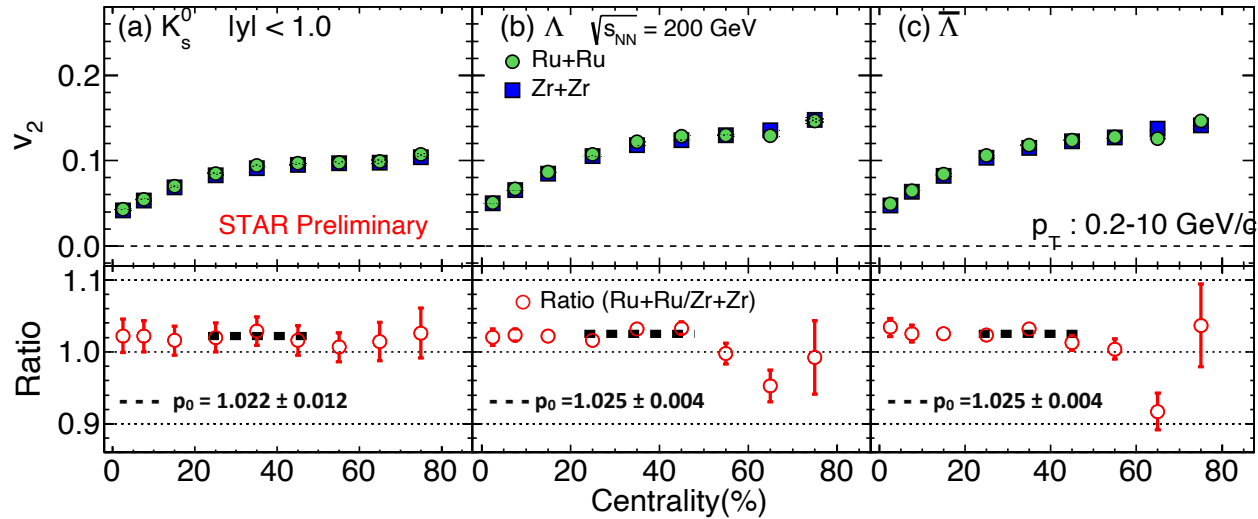
n_q = Number of constituent quarks, 3 for baryons and 2 for mesons ; Transverse kinetic energy (KE_T) = $m_T - m_0$

➤ NCQ scaling of v_2 holds good within 10% uncertainties in both Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV

→ Indicative of partonic collectivity in the system

*Vertical bars indicate statistical error and shaded boxes denote systematic errors

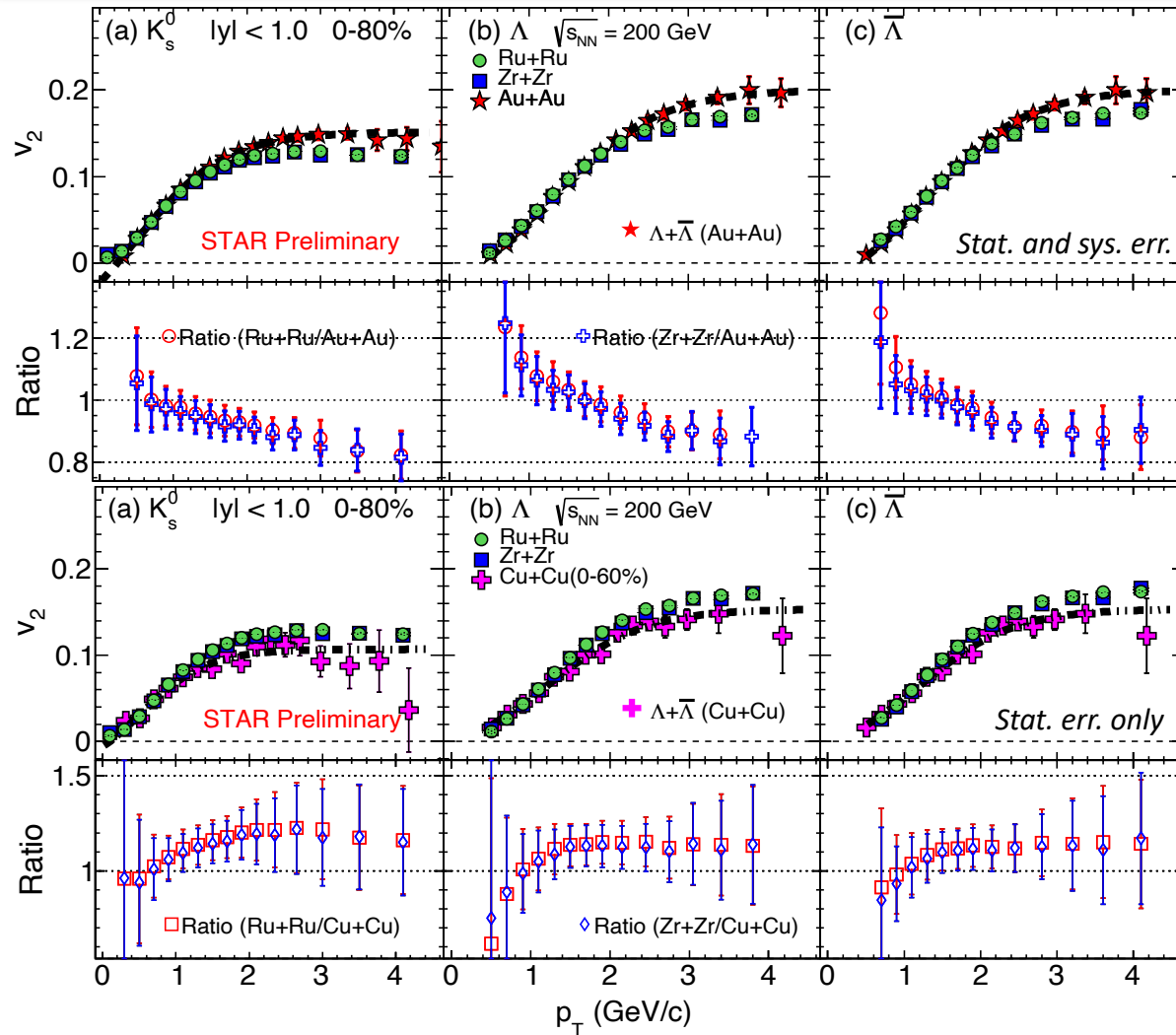
v_2 vs centrality



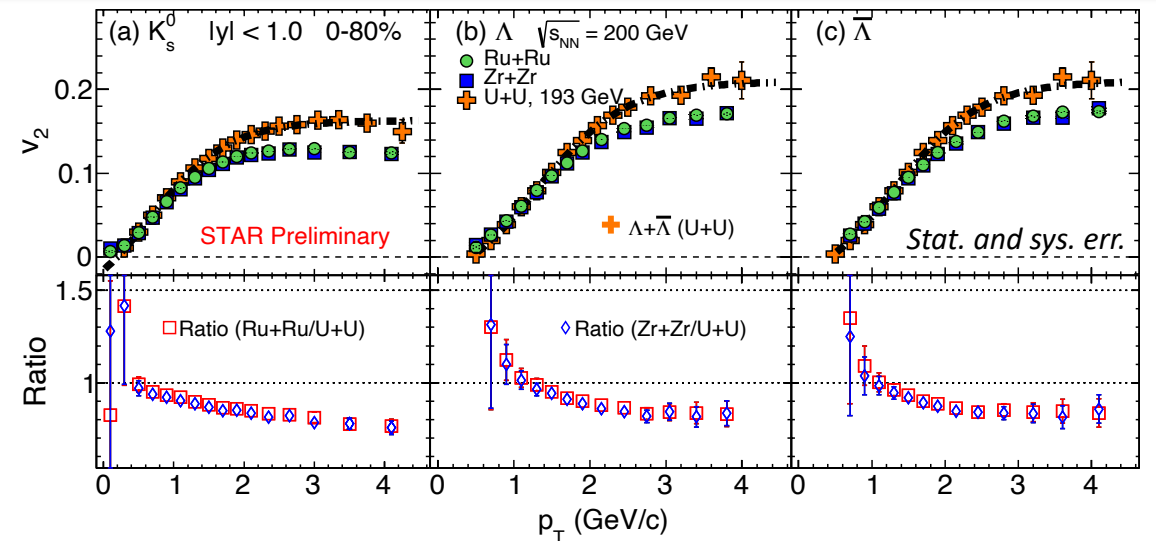
- p_T -integrated elliptic flow increases from central to peripheral collisions
- Ratios of v_2 between Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV for K_s^0 , Λ and $\bar{\Lambda}$ seem to deviate from unity by $\sim 2\%$ at central and mid-central collisions
 → May indicate nuclear shape and structure difference between the two isobars

*Vertical bars indicate statistical error and shaded boxes denote systematic errors
 *Error in the ratio includes statistical and systematic uncertainties

System size dependence (strangeness)



B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 77, 054901 (2008)
 B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 81, 044902 (2010)



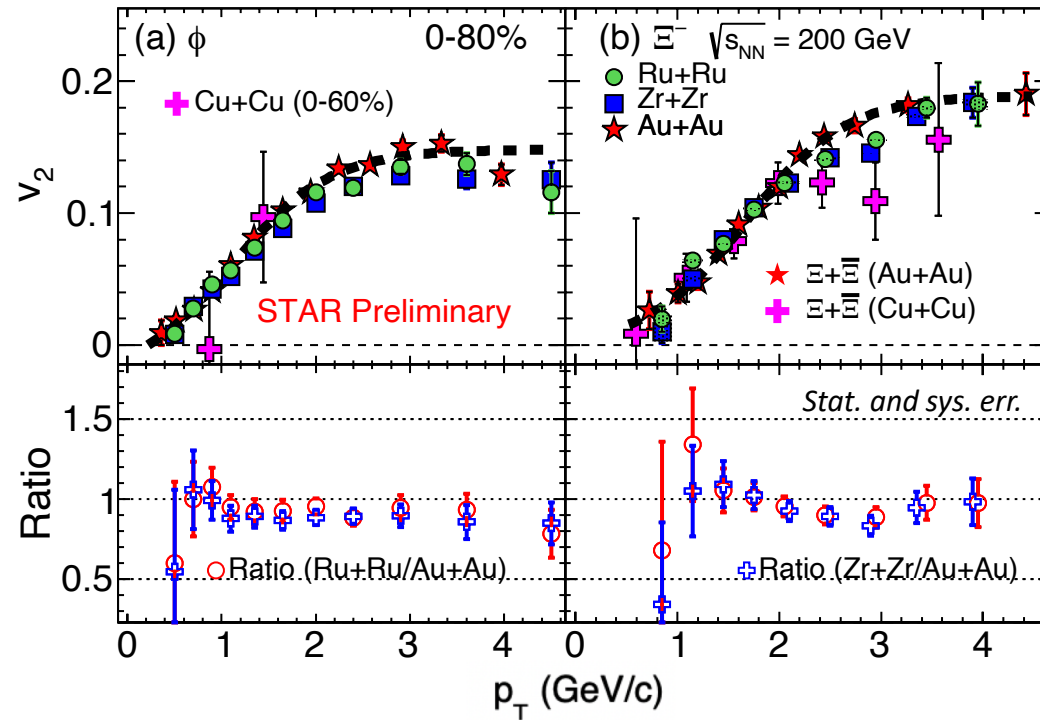
M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 103, 064907 (2021)

$$\text{Fitting function : } f_{v_2}(n) = \frac{an}{1 + e^{-(p_T/n-b)/c}} - dn$$

n : number of quarks; a, b, c, d : free parameters

- v_2 of K_s^0 , Λ , and $\bar{\Lambda}$ in isobar collisions is smaller than those in $^{197}\text{Au}+^{197}\text{Au}$ and $^{238}\text{U}+^{238}\text{U}$ collisions at higher p_T
- v_2 in isobar collisions is higher compared to those in $^{63}\text{Cu}+^{63}\text{Cu}$ collisions at higher p_T , but their ratios seem to be unity within current uncertainties

System size dependence (multi-strangeness)



$$\text{Fitting function : } f_{v_2}(n) = \frac{an}{1 + e^{-(p_T/n-b)/c}} - dn$$

n : number of quarks; a, b, c, d : free parameters

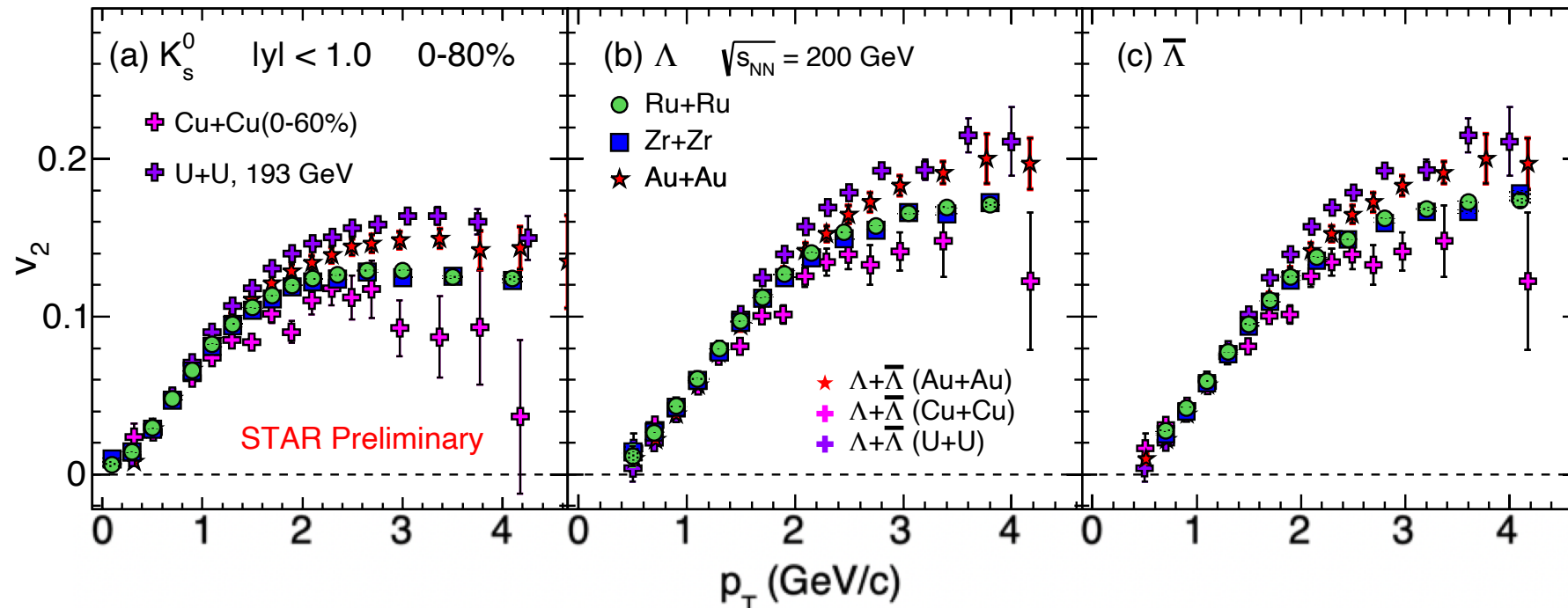
- v_2 of ϕ and Ξ is similar in the measured p_T range for different collision systems within uncertainties

B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 77, 054901 (2008)
 B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 81, 044902 (2010)
 L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 116, 062301 (2016)

- Elliptic flow of K_s^0 , Λ , $\bar{\Lambda}$, ϕ , and Ξ has been measured using event plane method for Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV
- Strong centrality dependence of v_2 for all particles has been observed
- NCQ scaling holds good within 10% uncertainties for all particles in all centralities for the isobar collisions
- Elliptic flow ratio for Ru+Ru over Zr+Zr seems to show a deviation of nearly 2% in central and mid-central collisions
 - Maybe related to nuclear shape and structure difference between the two isobars
- v_2 of strange hadrons in isobar collisions
 - At high p_T : Smaller compared to Au+Au and U+U collisions, and larger compared to Cu+Cu collisions
 - At low p_T : Similar for all collision systems studied

Thank you for your attention!

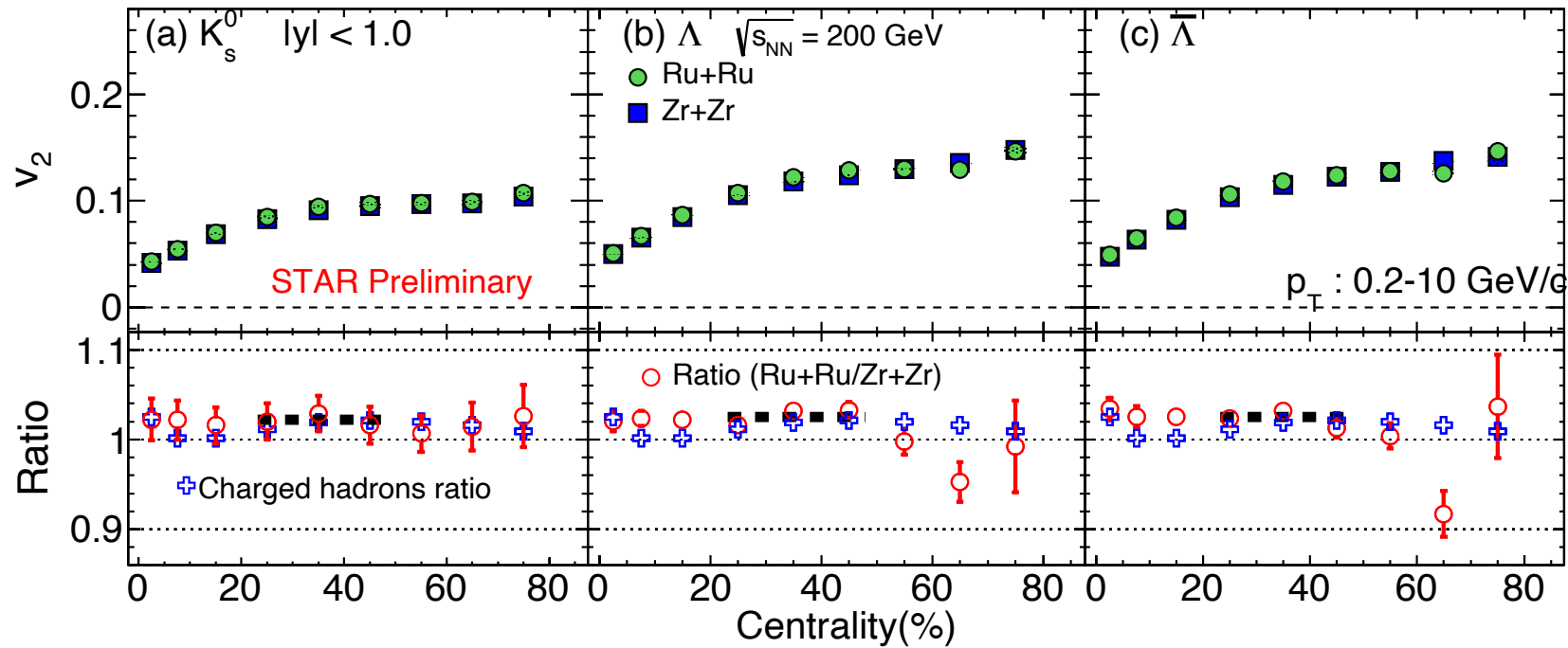
System size dependence (strangeness)



- v_2 of K_s^0 , Λ , and $\bar{\Lambda}$ in isobar collisions is smaller than in $^{197}\text{Au}+^{197}\text{Au}$ and $^{238}\text{U}+^{238}\text{U}$ collisions at higher p_T
- v_2 in isobar collisions is larger as compared to $^{63}\text{Cu}+^{63}\text{Cu}$ collisions at higher p_T

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M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 103, 064907 (2021)

v_2 vs centrality



*Vertical bars indicate statistical error and shaded box denote systematic errors

*Error in the ratio includes statistical and systematic uncertainties

- p_T -integrated elliptic flow increases from central to peripheral collisions
- Ratio of v_2 between Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}} = 200$ GeV for charged hadrons are comparable within the current uncertainties

M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 105 (2022) 14901