XXV DAE-BRNS HEP SYMPOSIUM

Probing nuclear structure using elliptic flow of strange and multi-strange hadrons in isobar collisions

Priyanshi Sinha
(for the STAR Collaboration)
Indian Institute of Science Education and Research (IISER) Tirupati, India

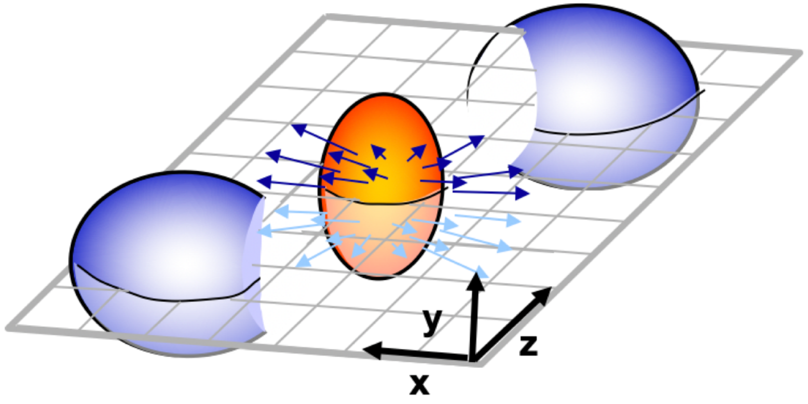
Outline

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

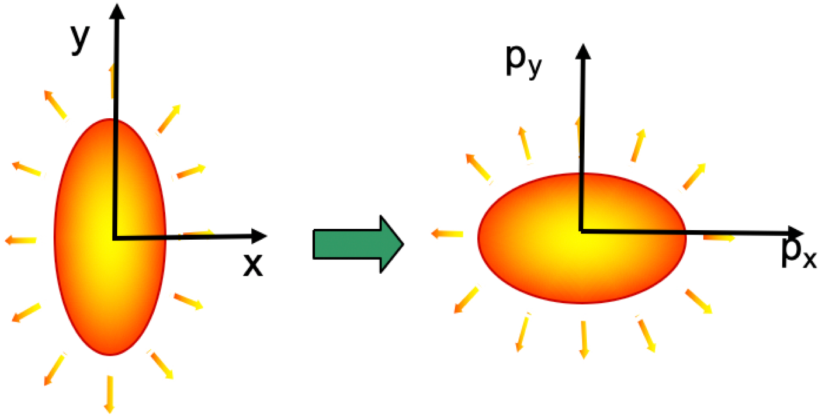
The STAR Collaboration
https://drupal.star.bnl.gov/STAR/presentations

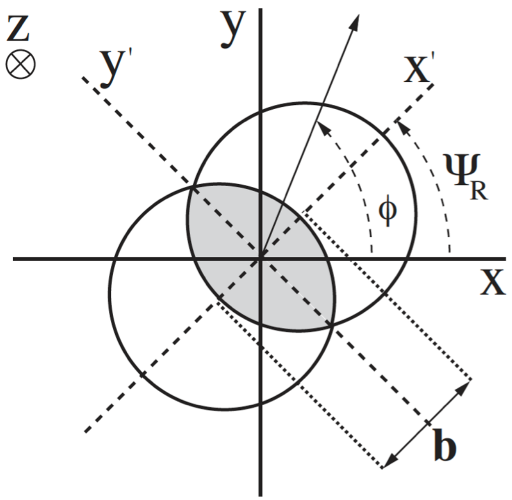
Supported in part by the U.S. DEPARTMENT OF ENERGY Office of Science

Introduction: Elliptic flow



Reaction plane: z-x plane





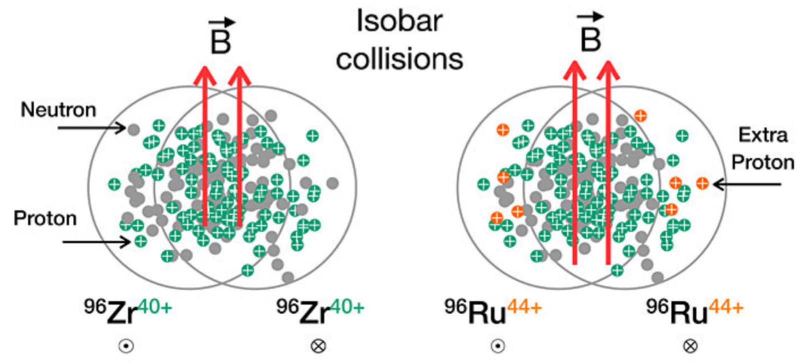
$$\frac{dN}{d\phi} \propto \frac{1}{2\pi}\left[1 + \sum_{n=1}^{\infty} 2v_n \cos(n(\phi - \Psi_R))\right]$$

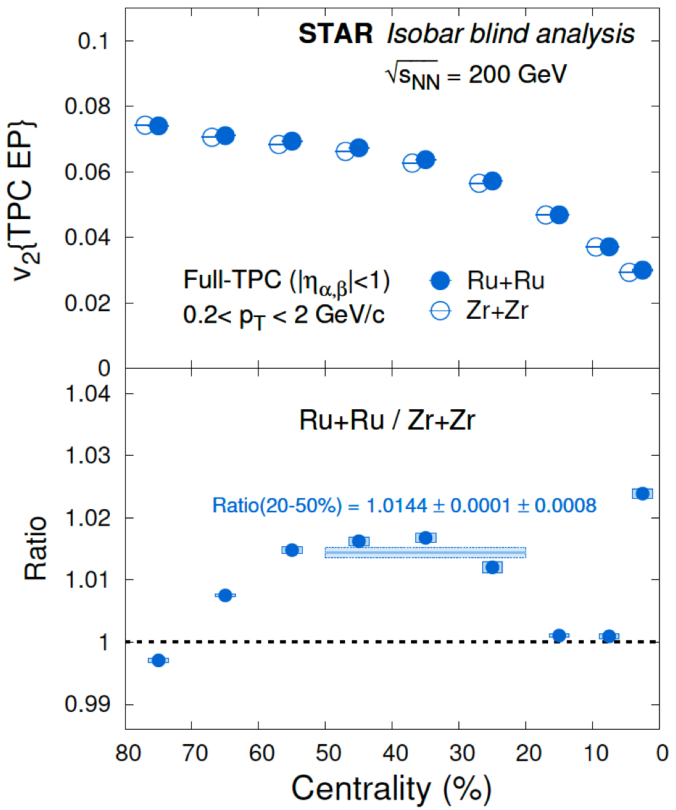
$$v_2 = \langle \cos(2(\phi - \Psi_R)) \rangle$$

- Sensitive to early times in the evolution of the system
- Useful in understanding the nuclear structure

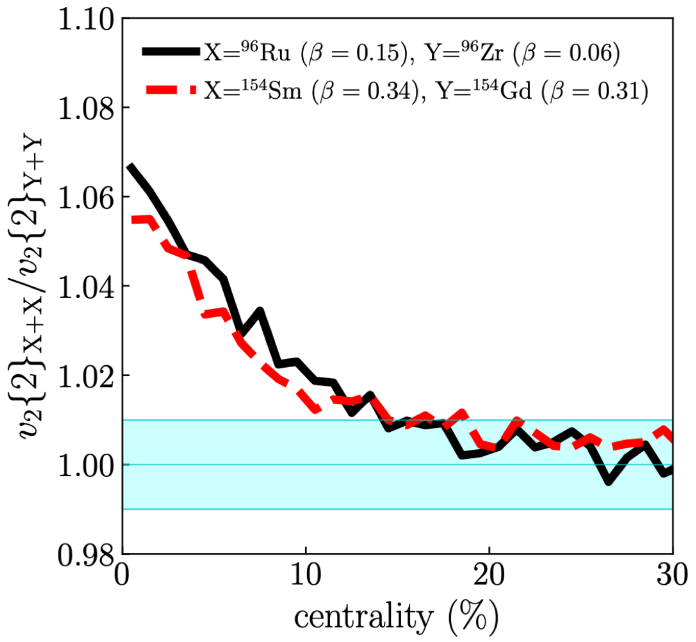
A. M. Poskanzer & S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)

Motivation





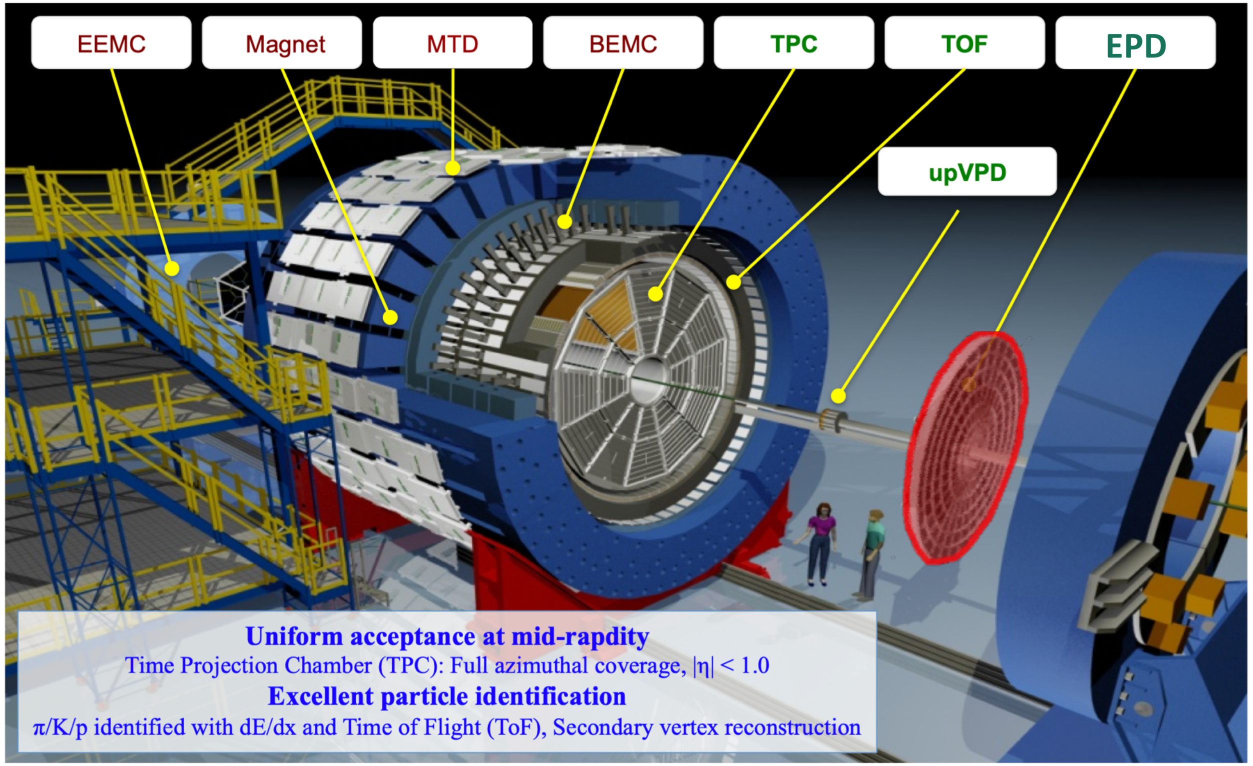
M. S. Abdallah et al. (STAR Collaboration), Phys. Rev. C 105, 14901 (2022)

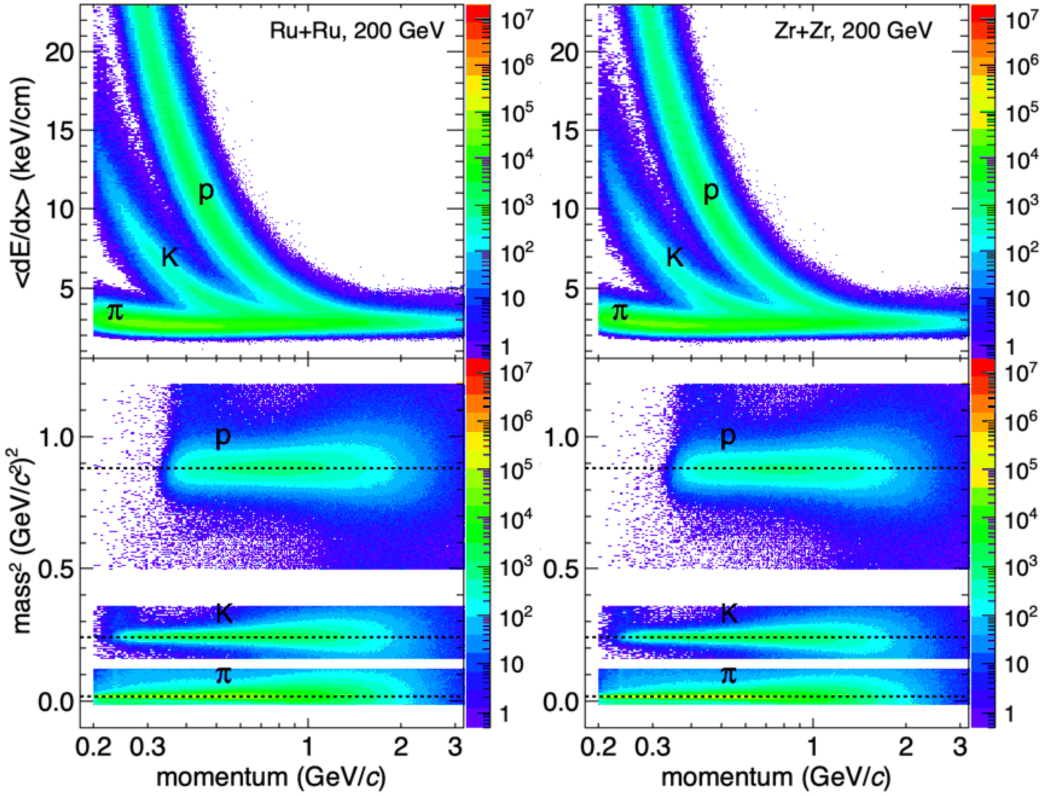


G. Giacalone, J. Jia, and V. Somà, Phys. Rev. C 104, L041903 (2021)

- Study of elliptic flow in isobar collisions may help in understanding the difference in deformation of the colliding nuclei
- Elliptic flow of strange and multi-strange hadrons gives direct information on initial state anisotropies
- System size dependence of the azimuthal anisotropy by comparing $^{238}_{92}$U, $^{197}_{79}$Au, $^{96}_{44}$Ru, $^{96}_{40}$Zr, $^{63}_{29}$Cu

STAR experiment





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

- Particle selection using TPC and TOF
- 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 :

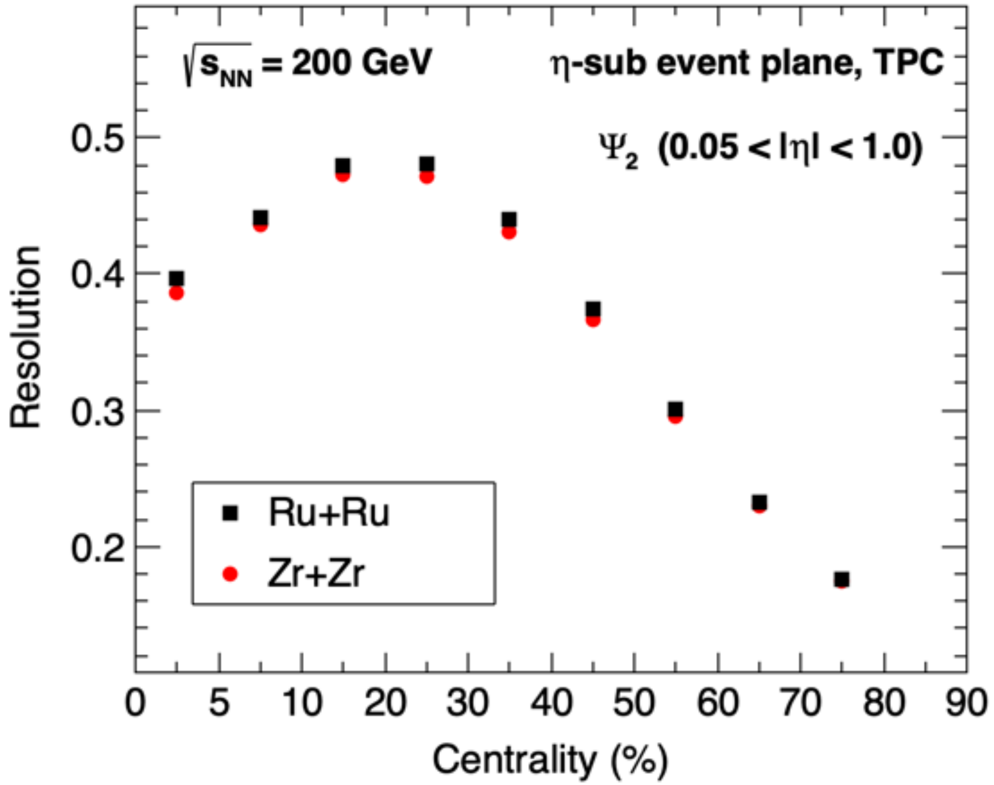
$$\Psi_2 = \left[\tan^{-1}\left(\frac{\sum_i w_i \sin(2\phi_i)}{\sum_i w_i \cos(2\phi_i)}\right)\right]/2$$

- Event plane calculated in two different pseudo-rapidity windows 'a' (-1.0 < η < -0.05) and 'b' (0.05 < η < 1.0)

- The event plane resolution:

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

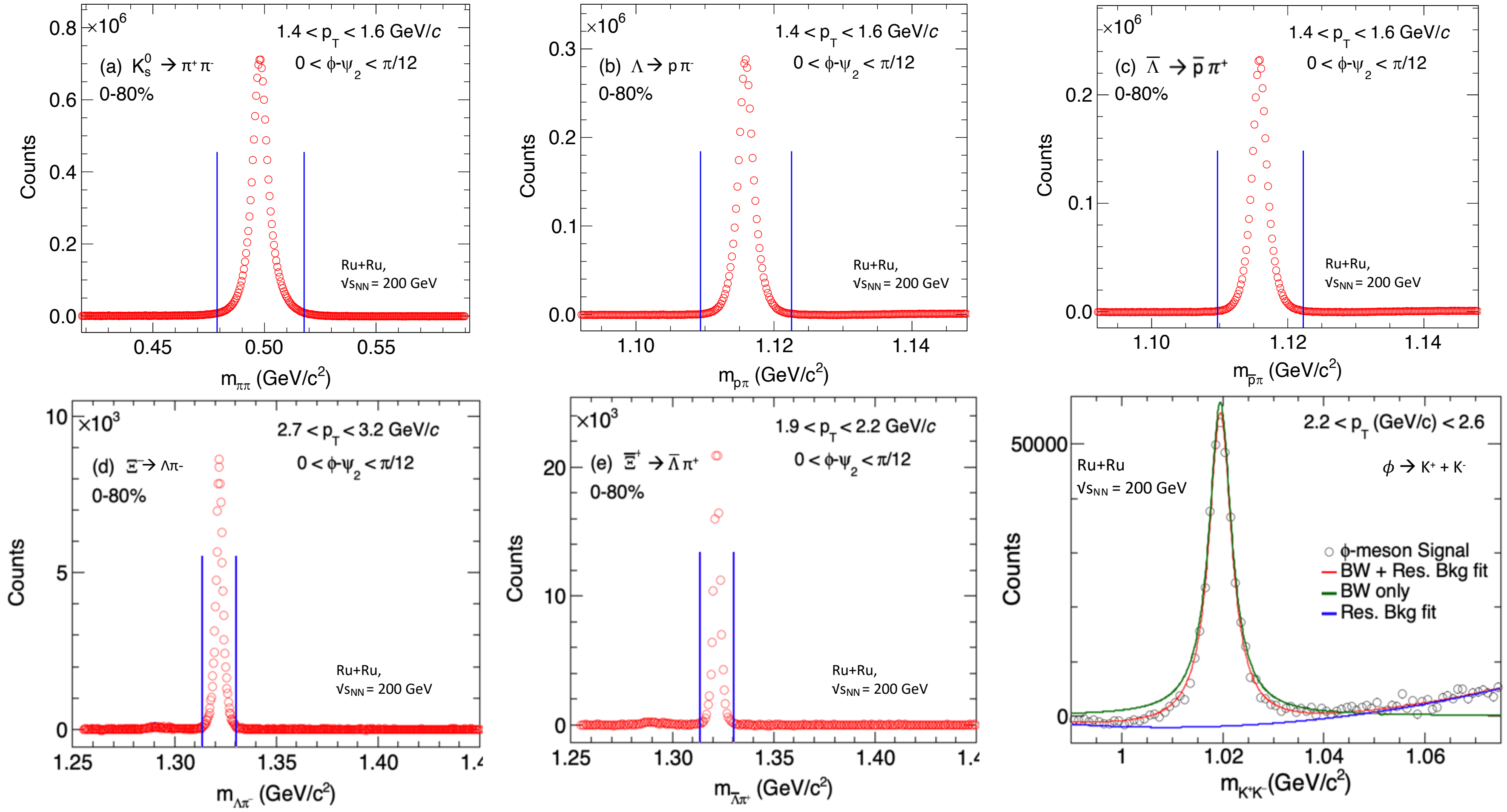
- Resolution correction is applied to obtain the final v_2



Statistical error within marker size

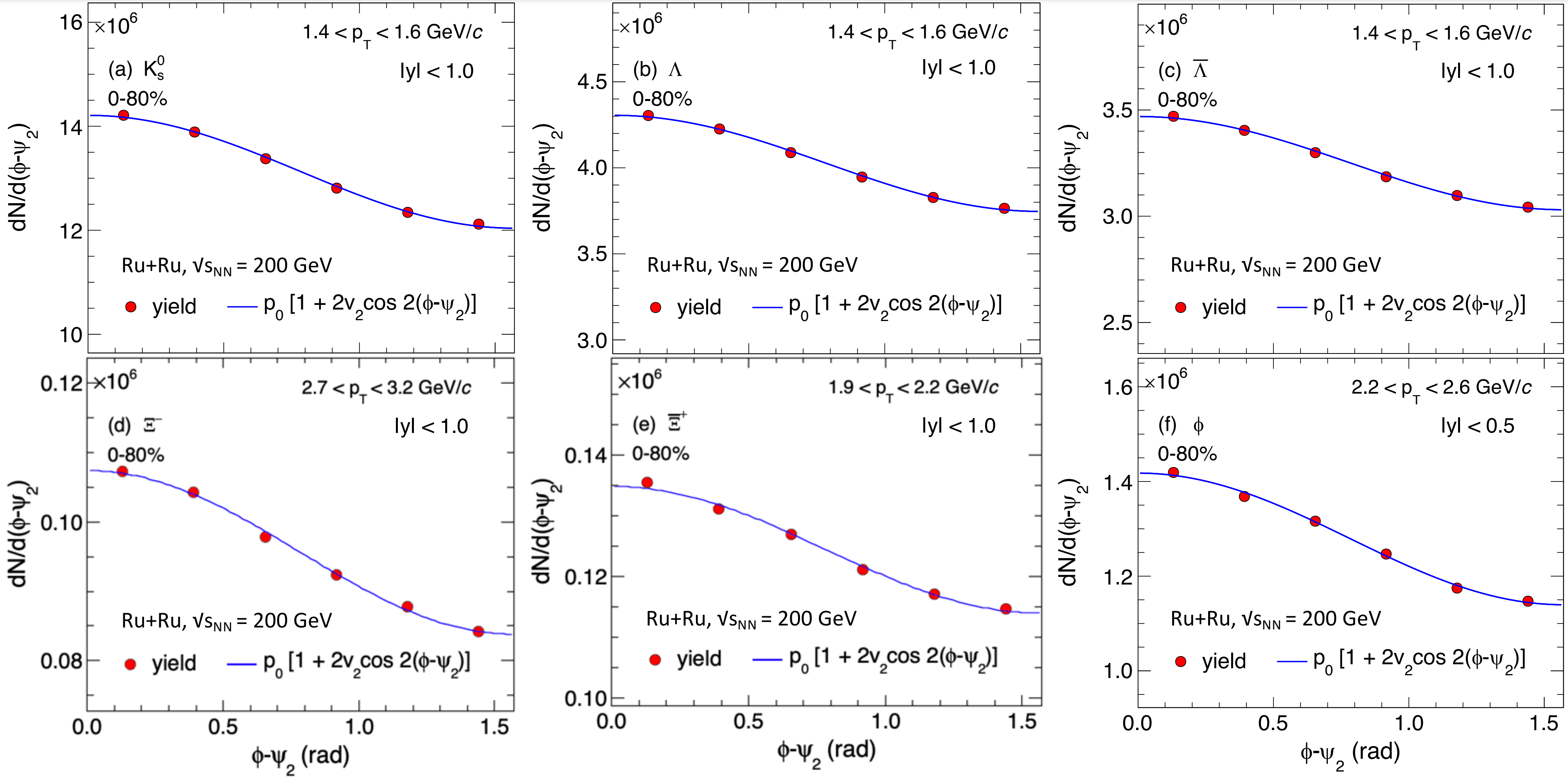
A. M. Poskanzer & S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)

Particle reconstruction



- Reconstructed using invariant mass method; topological cuts using Helix method for K_s^0, Λ, and Ξ
- Background reconstruction using event-mixing method for ϕ-mesons and rotational method for K_s^0, Λ, and Ξ

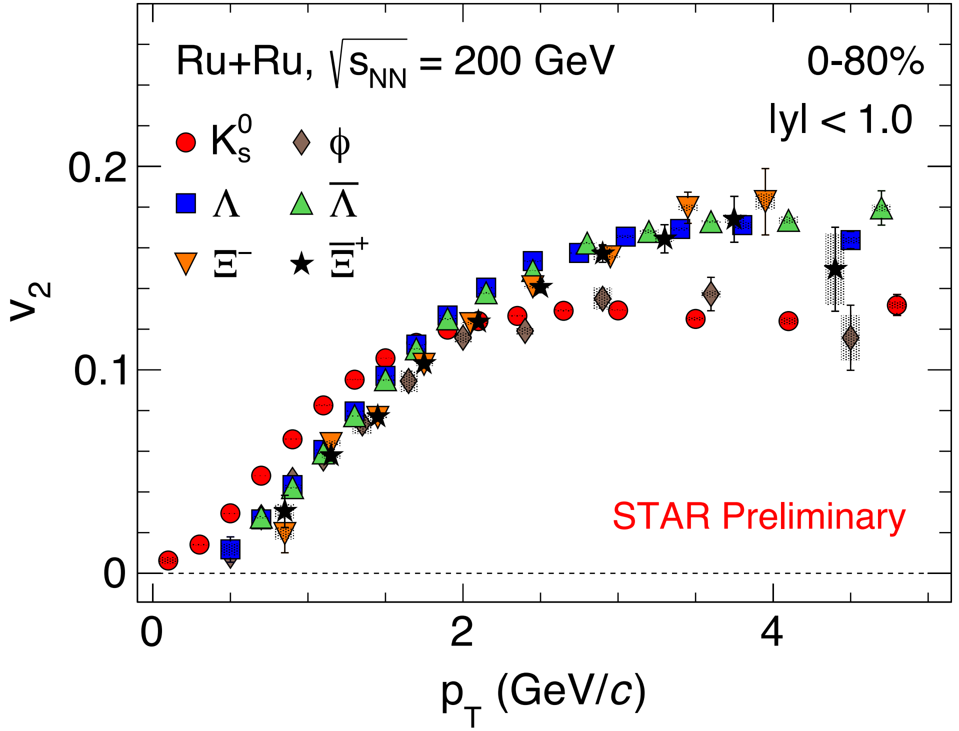
Flow analysis

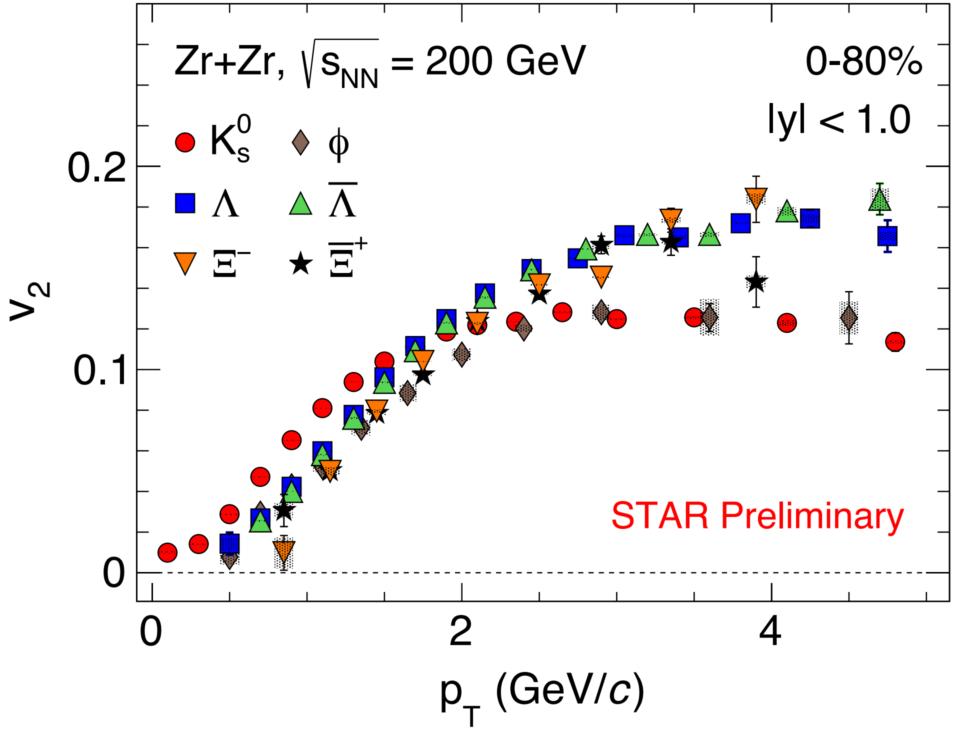


Event plane method:

- Particle raw-yields as a function of ϕ - Ψ_2 are fitted with a Fourier function for different p_T ranges to extract v_2 coefficients

Results: Elliptic flow

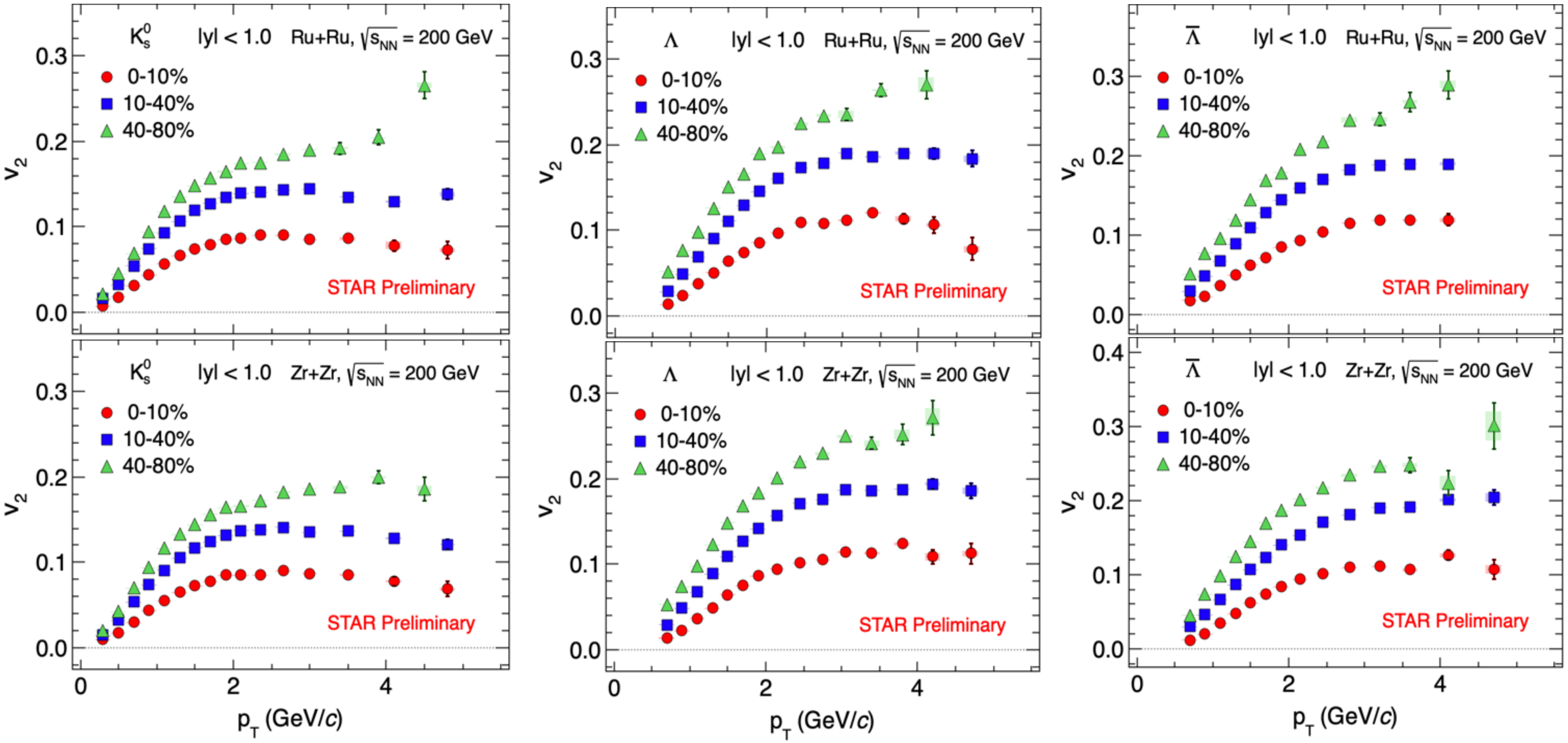




**Vertical bars indicate statistical error and shaded boxes denote systematic errors*

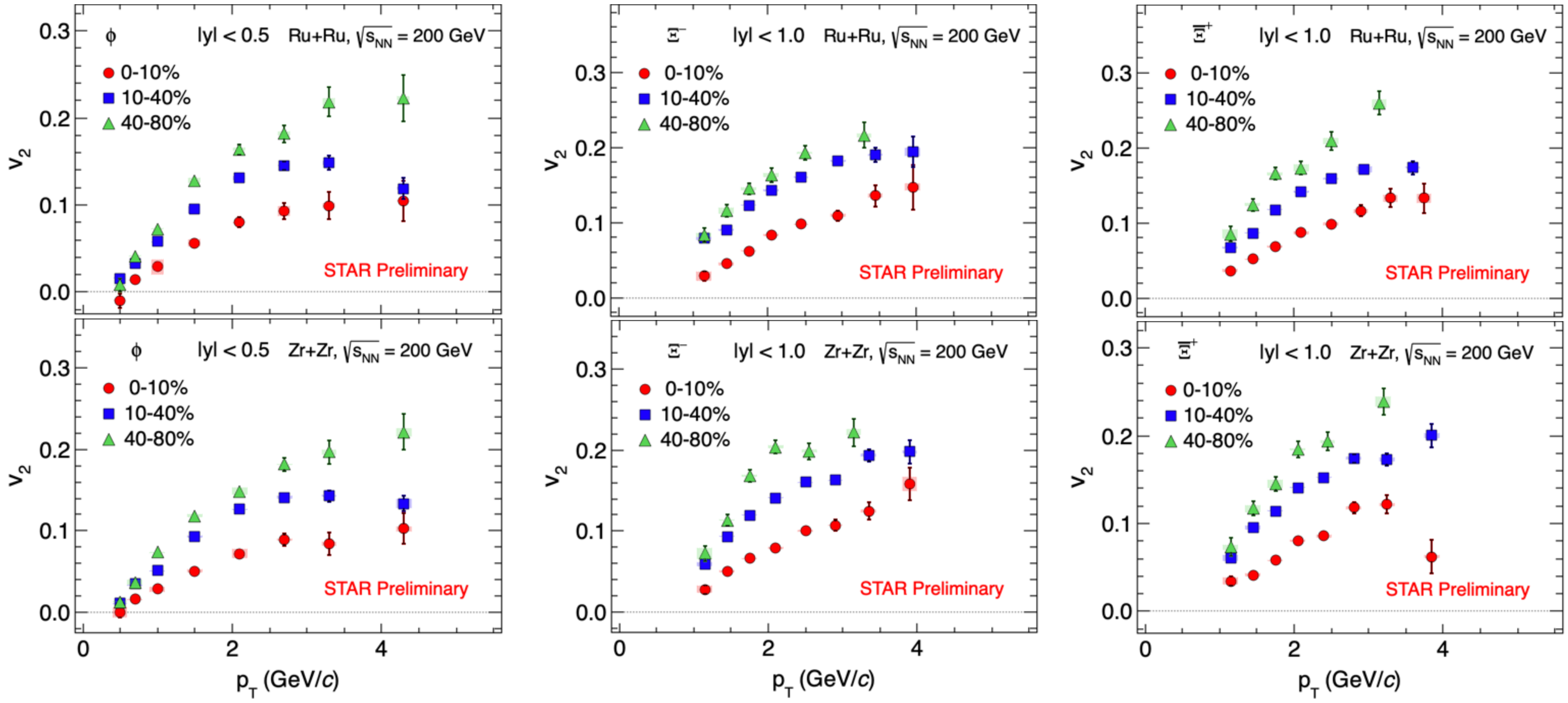
- v_2 shows a mass ordering at low p_T in isobar collisions
- Baryon-meson splitting at intermediate p_T region (> 2 GeV/c)

Centrality dependence of $v_2(p_T)$



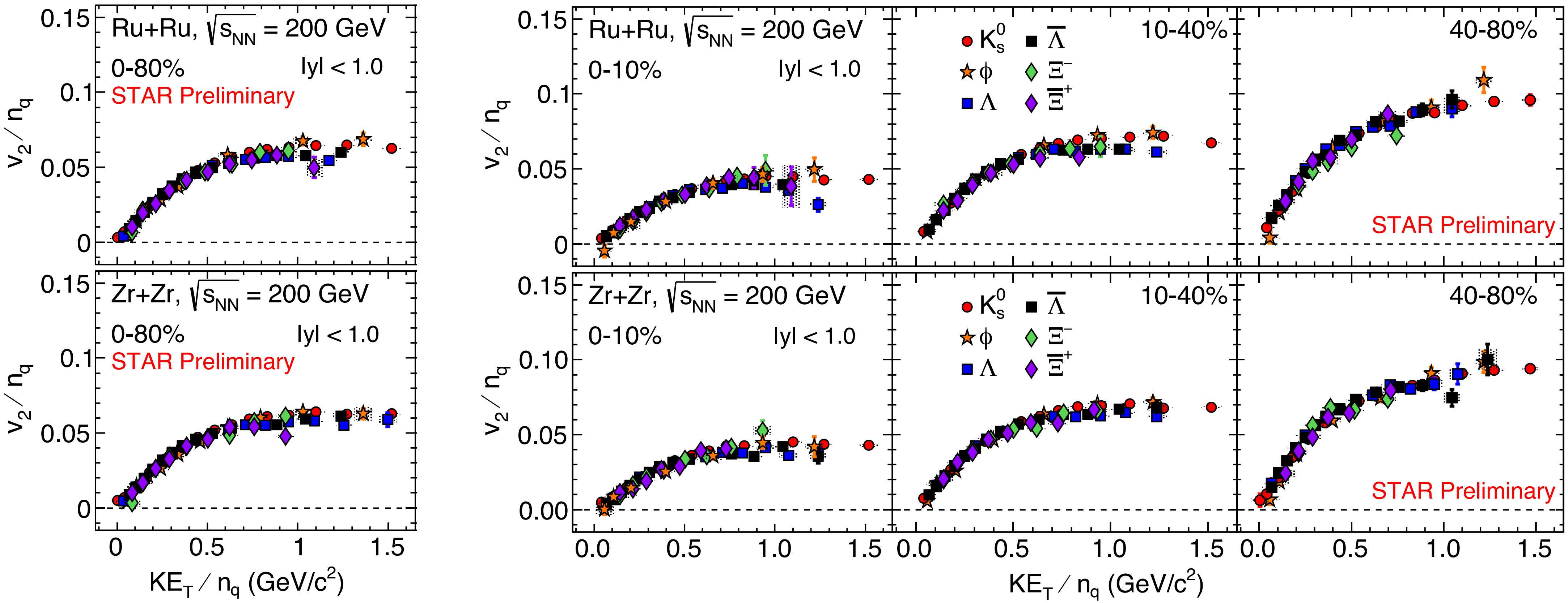
- Strong centrality dependence is observed for v_2 of K_s^0, Λ, and $\bar{\Lambda}$, in both Ru+Ru and Zr+Zr collisions
- v_2 (p_T) increases from central to peripheral collisions

Centrality dependence of $v_2(p_T)$



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

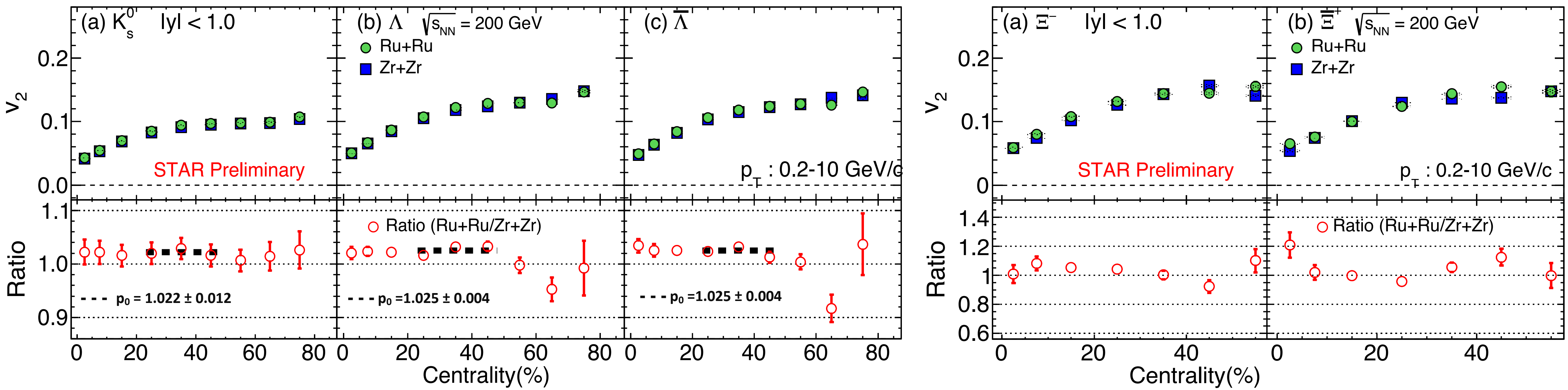
NCQ scaling



Transverse kinetic energy (KE_T) = $m_T - m_0$

- NCQ scaling holds good for (multi-)strange within 10% uncertainties in both Ru+Ru and Zr+Zr collisions
  - → Indicative of partonic collectivity in the system

v_2 vs centrality

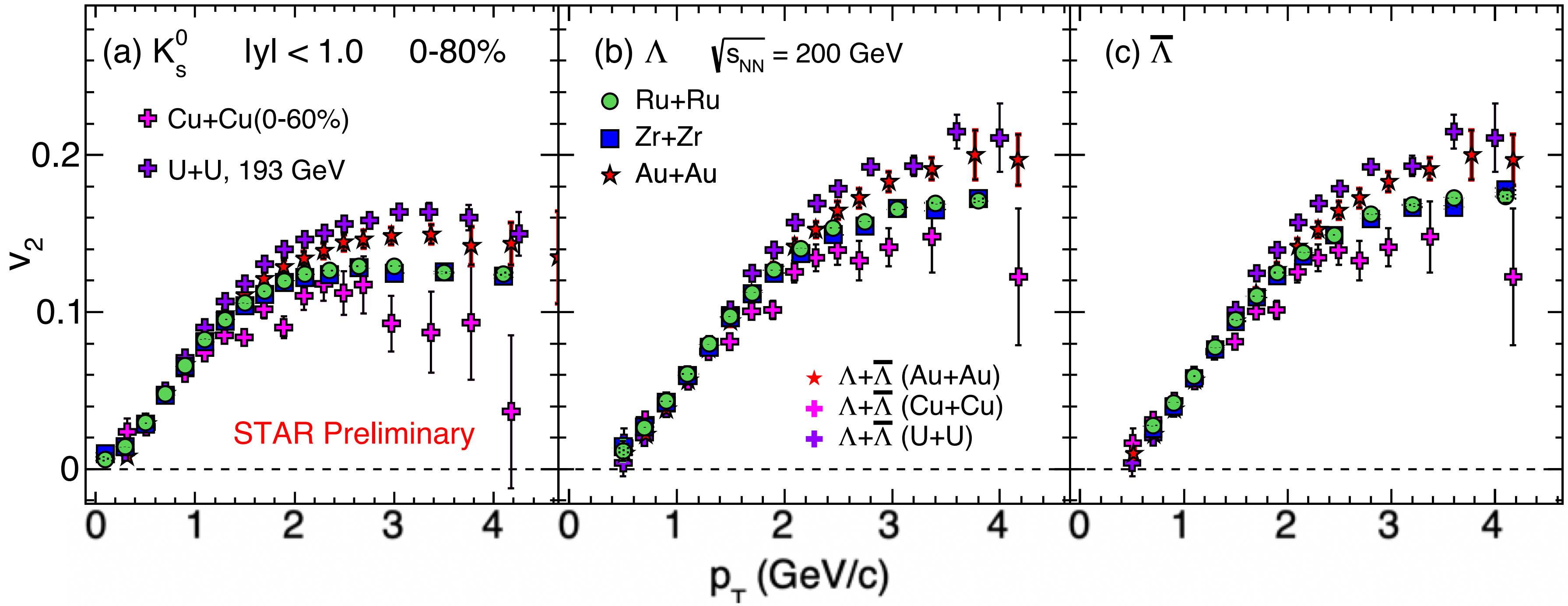


- p_T -integrated elliptic flow increases from central to peripheral collisions
- Ratios of v_2 between Ru+Ru and Zr+Zr collisions at $\sqrt{s_{NN}}$ = 200 GeV for K_s^0, Λ and $\bar{\Lambda}$ show a deviation from unity by ~2% at central and mid-central collisions

  → May indicate nuclear shape and structure difference between the two isobars

**No tracking efficiency correction since the effect would be largely cancelled*
**Error in the ratio includes statistical and systematic uncertainties*

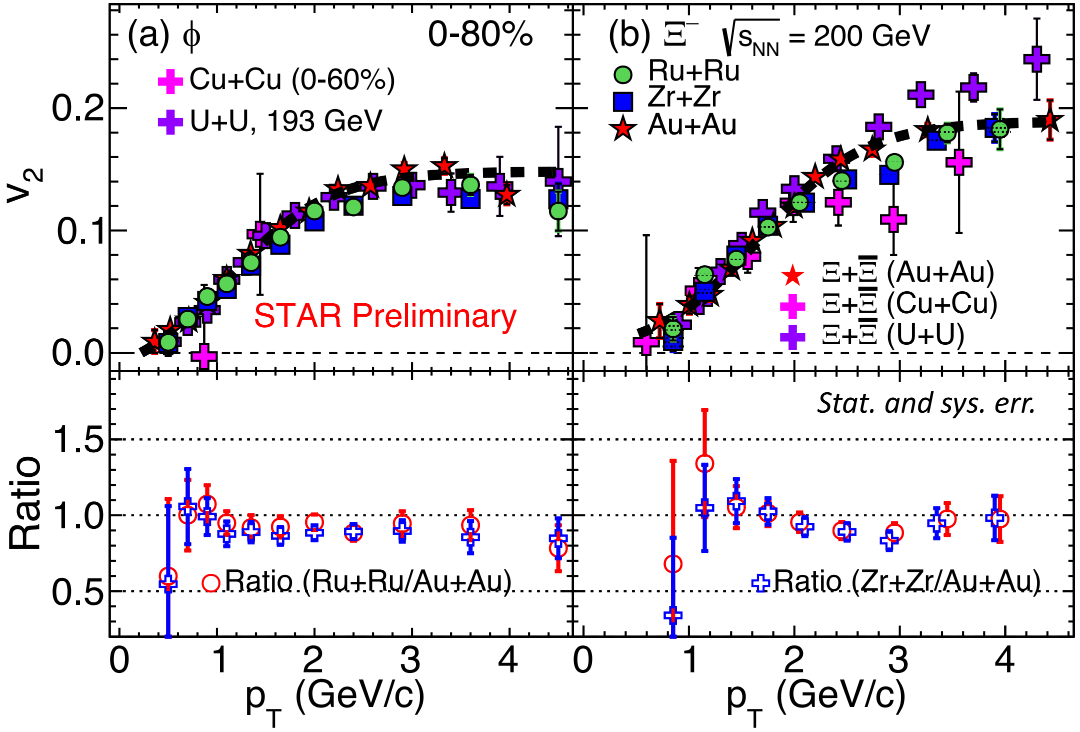
System size dependence (strange)



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

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)

System size dependence (multi-strange)



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 is similar in the measured p_T range for different collision systems within uncertainties
- v_2 of Ξ is lower than $^{238}U+^{238}U$ collisions at higher p_T

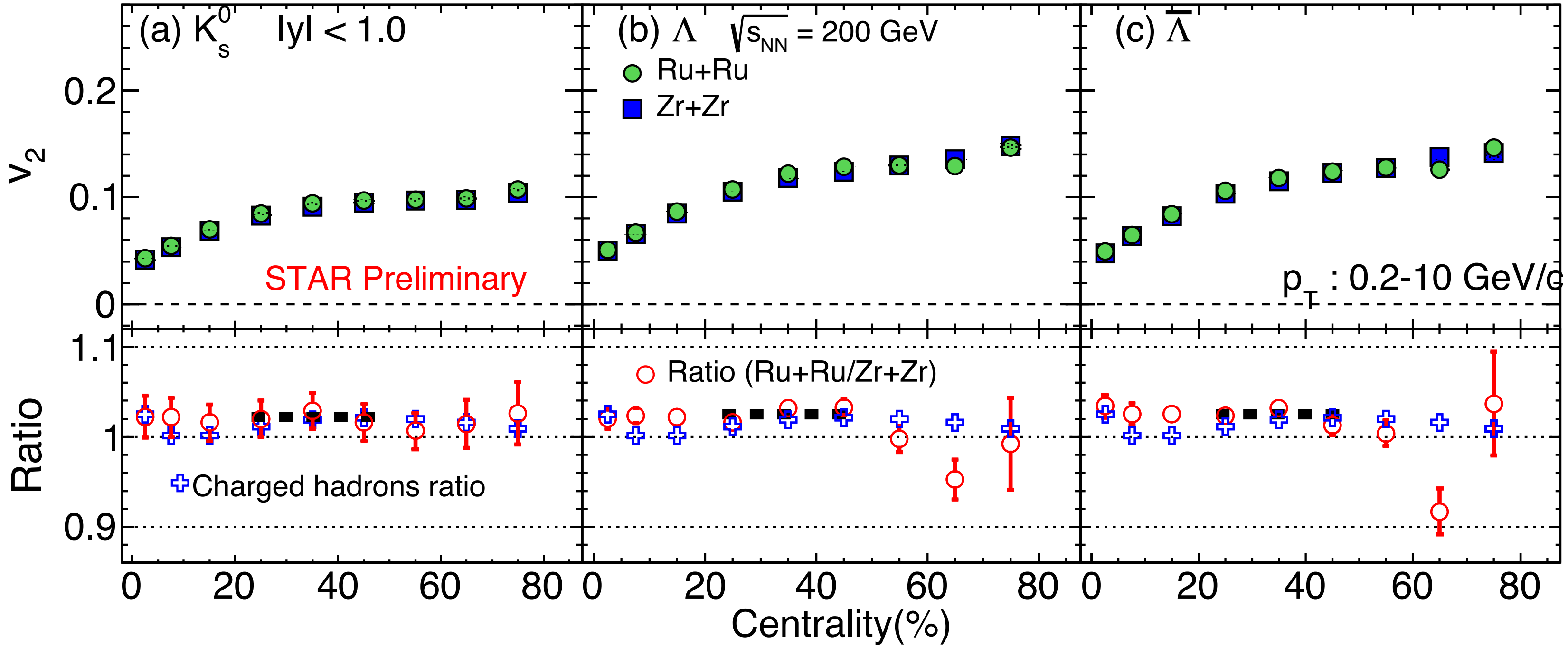
B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 77, 054901 (2008)
B. I. Abelev et al. (STAR Collaboration), Phys. Rev. C 81, 044902 (2010)
L. Adamczyk et al. (STAR Collaboration), Phys. Rev. Lett. 116, 062301 (2016)

Summary

- Elliptic flow of K_s^0, Λ, $\overline{\Lambda}$, 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 shows 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!

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