Azimuthal anisotropic flow of identified hadrons in Au + Au collisions at BES-II energies at STAR

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  - Centrality dependence
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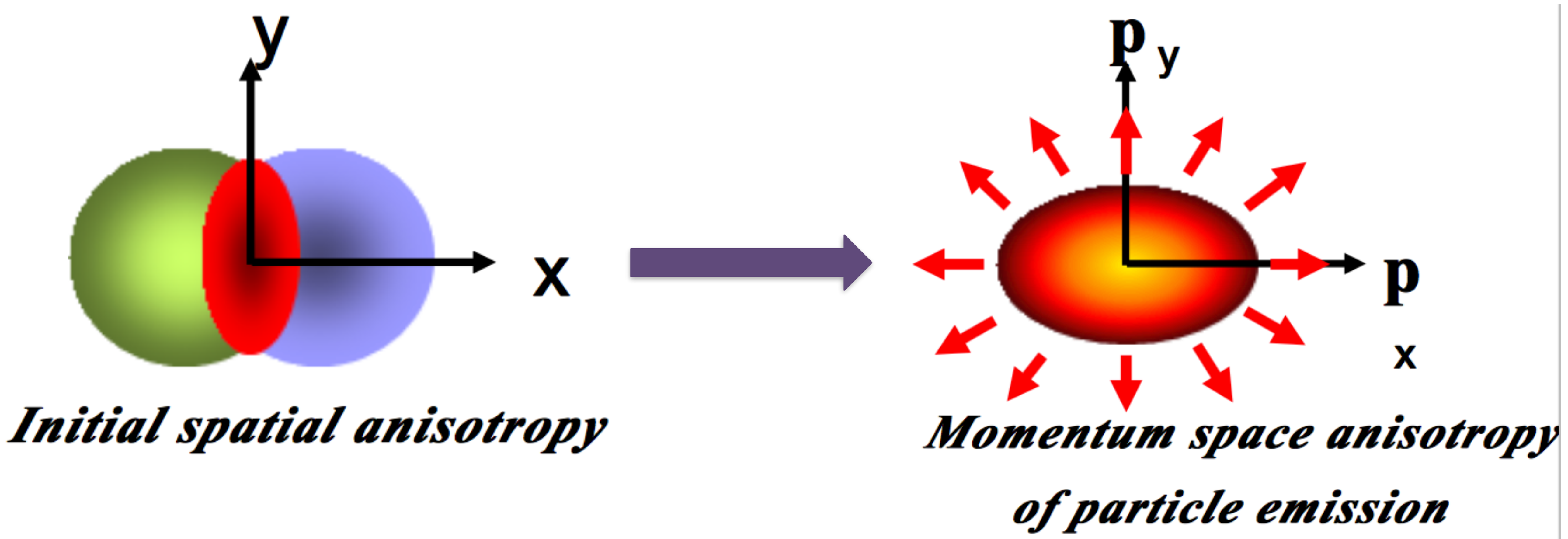
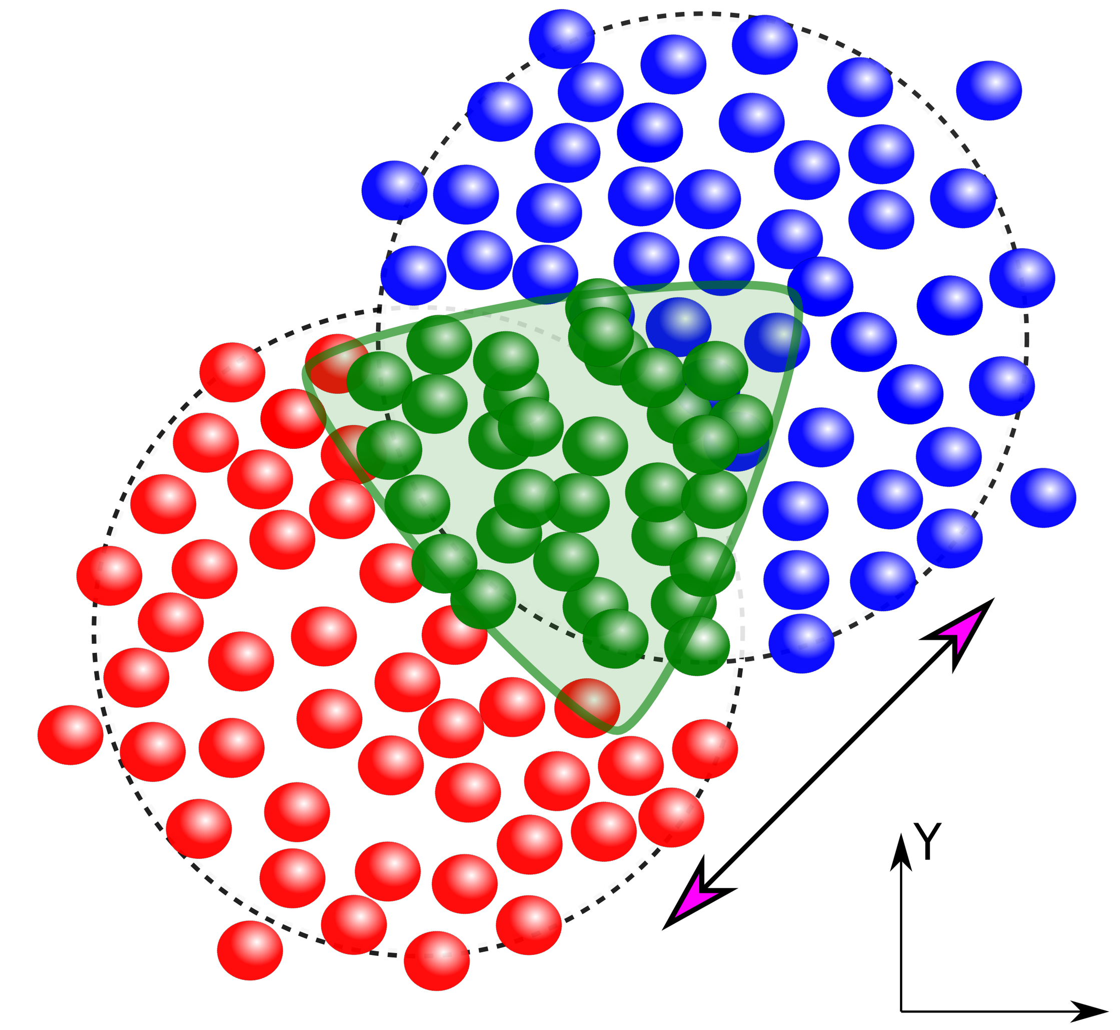
Introduction & motivation





Elliptic flow coefficient (v_2) : Initial spatial anisotropy (dominant source) + Event-by-event fluctuations

Triangular flow coefficient (v_3) : Event-by-event fluctuations in the overlap region

$$\frac{dN}{d(\phi - \Psi_n)} = N_0 \left[1 + \sum_{n=1}^{\infty} 2 v_n \cos(\phi - \Psi_n) \right]$$

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

Importance of v_2 and v_3

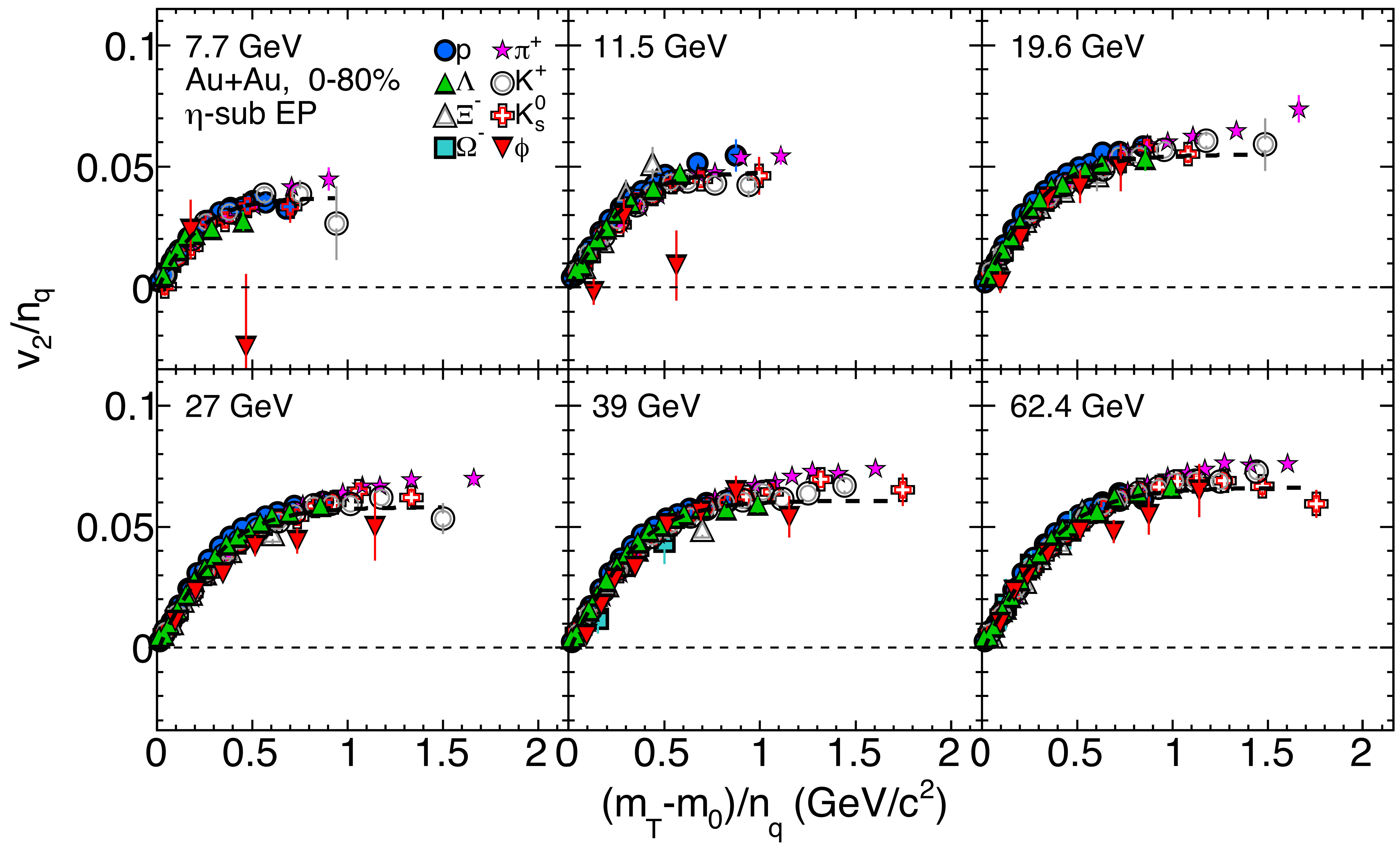
☞ Sensitive to the initial state and transport properties of the medium.

☞ Measurements of v_2 and v_3 are important to constrain the models. C. Shen *et al* JPG 38 (2011) 124045

Introduction & motivation

Results from RHIC BES-I

STAR Phys. Rev. C 93 (2016) 14907

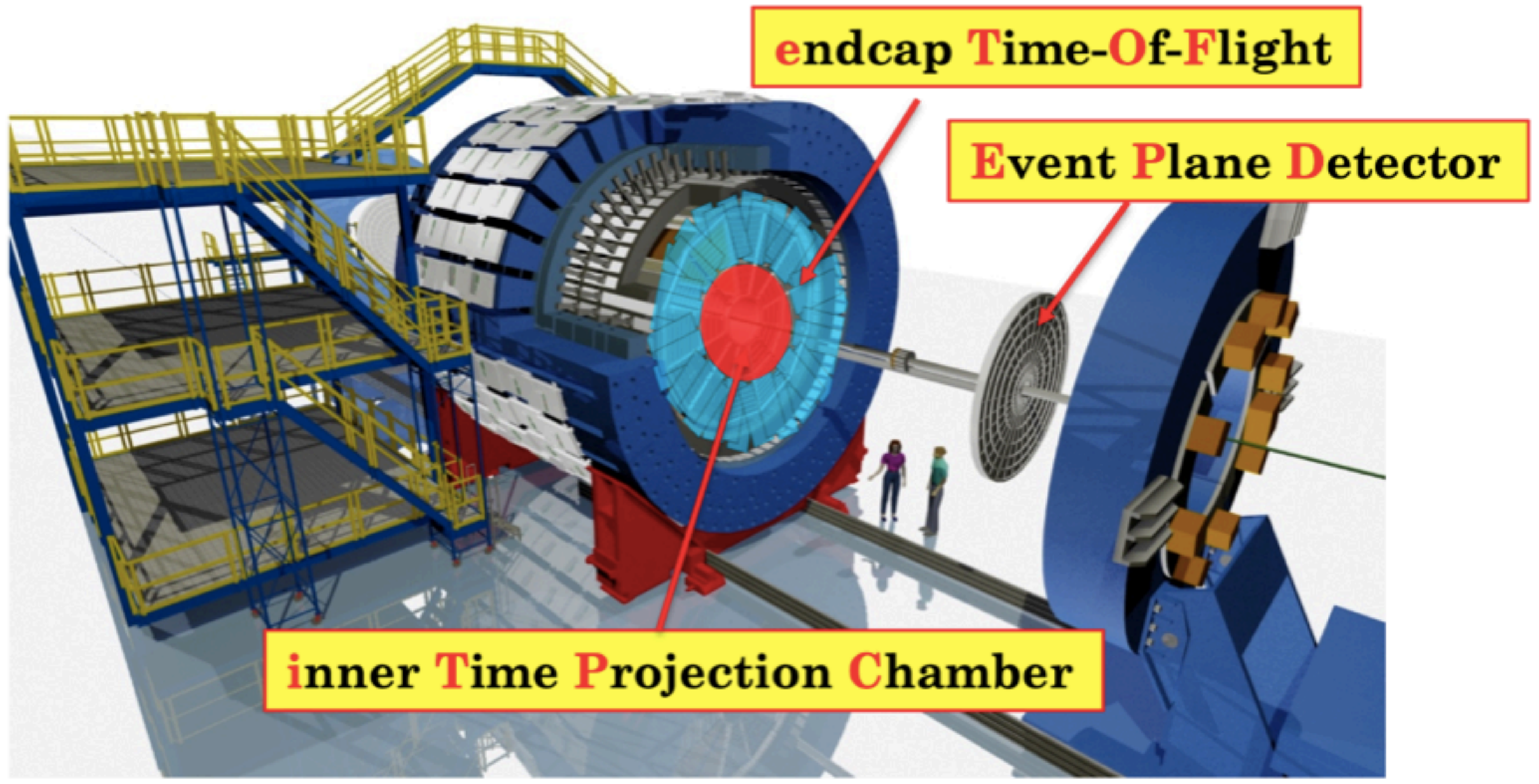


☞ ϕ mesons seem to deviate from the NCQ scaling at $\sqrt{s_{NN}} < 19.6$ GeV.

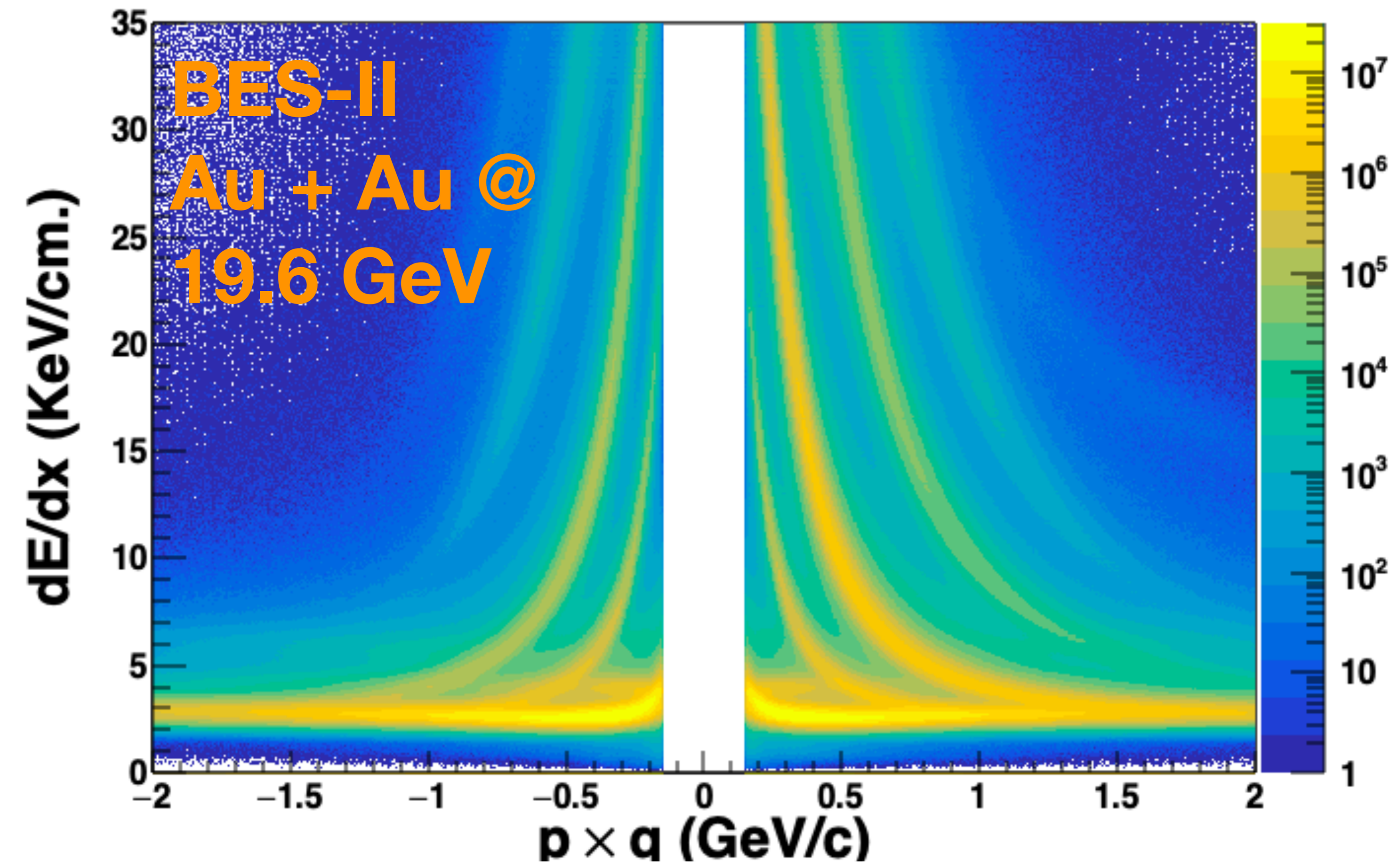
☞ But statistics is not significant to draw any conclusion.

★ High Statistics data from BES-II enable us to measure v_2 and v_3 of multi-strange hadrons and φ mesons with high precession specifically at low energy regime.

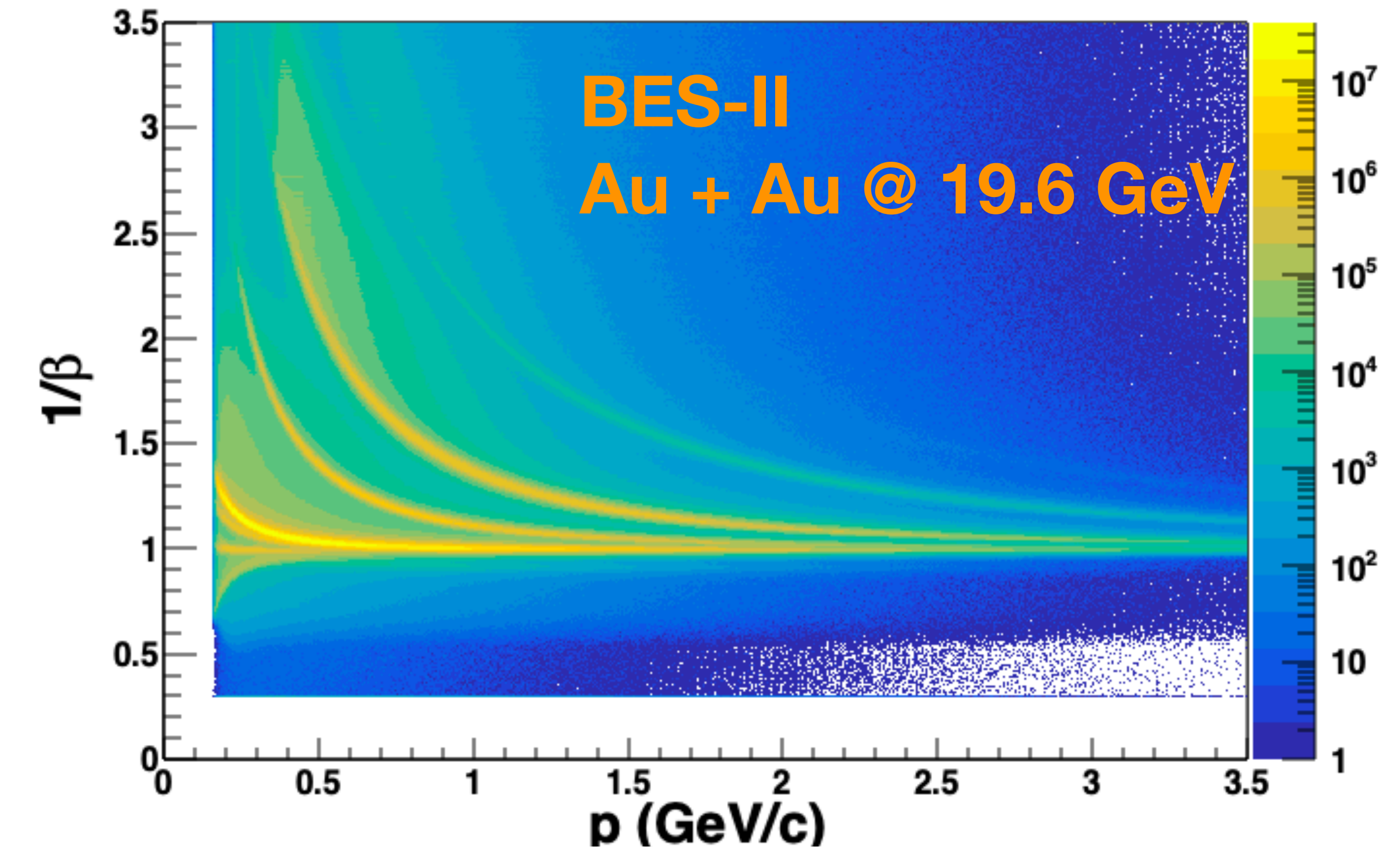
STAR detectors and particle identification



Time Projection Chamber (TPC)



Time of Flight (ToF)

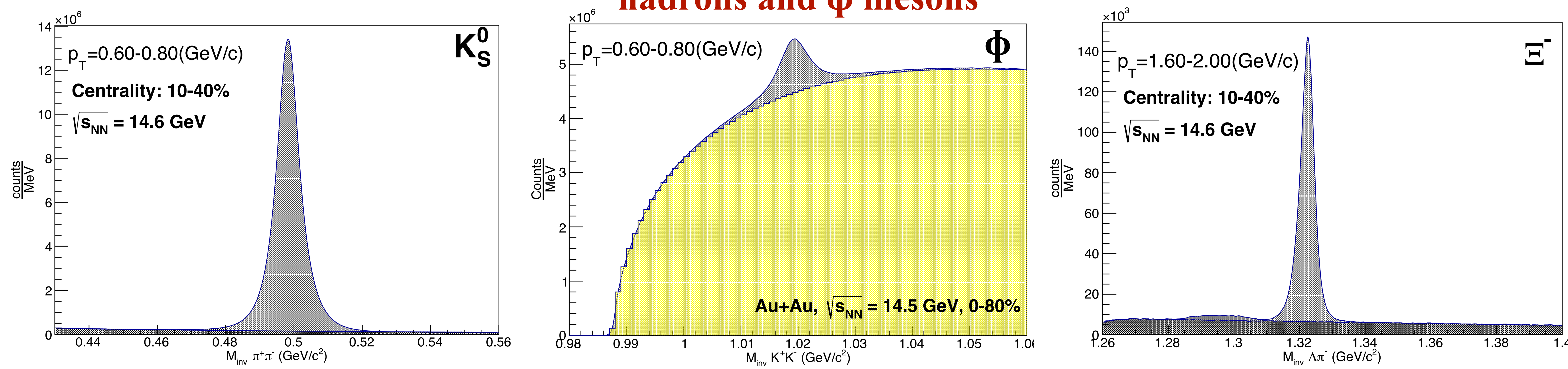


- Full azimuthal coverage
- Excellent particle identification capability

BES-II upgrades

- iTPC upgrade: Larger pseudorapidity coverage ($-1.5 < \eta < 1.5$)
- Better dE/dx and momentum resolution.
- Better track quality.

Reconstruction of (multi-)strange hadrons and ϕ mesons



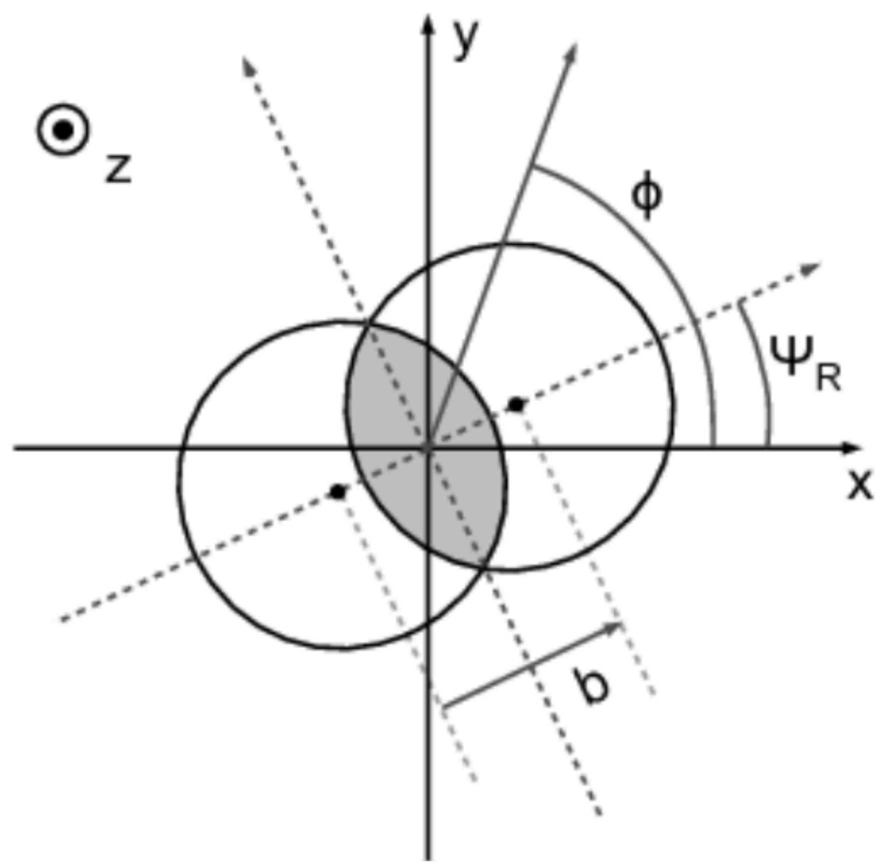
Data set information for this analysis:

- System: Au+Au
- Year: 2019 (BES-II data)
- Collision energy: 19.6 and 14.6 GeV
- #Events: ~380M (19.6 GeV) & ~400M (14.6 GeV)
- Source of systematic uncertainty: Variation of analysis cuts e.g. collision vertex selection cuts, particle identification cuts, quality track selection cuts etc.

Analysis details

The n^{th} order flow coefficient is given by

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

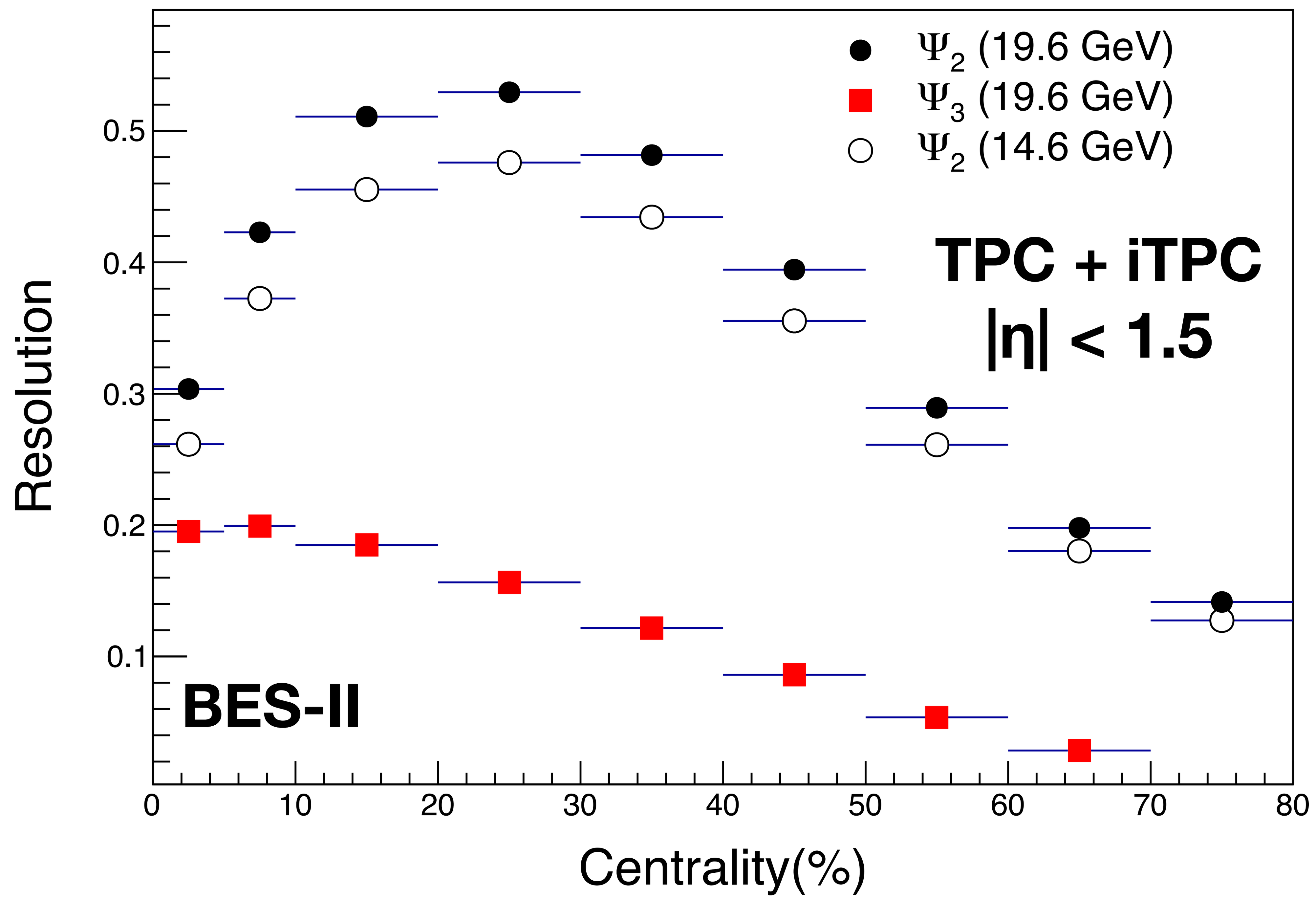


- The reaction plane of the collision can not be determined directly from the experiment.
- The event plane is used as a proxy for the reaction plane.

Event plane resolution

$$R_n = \langle \cos n(\Psi_n - \Psi_R)\rangle$$

Experimentrally, $R_n(sub) = \sqrt{\langle \cos n(\Psi_A - \Psi_B)\rangle}$



Event plane determination

$$\Psi_n = \frac{1}{n}\tan^{-1}\left(\frac{Q_y}{Q_x}\right)$$

$$Q_x = \sum_i w_i \cos(n\phi_i)$$

$$Q_y = \sum_i w_i \sin(n\phi_i)$$

To minimize non-flow correlation

★ **Sub-event plane method is used to calculate v_n.**

★ **η gap of 0.1 is taken between two sub-event planes Ψ_A (-1.5 < η < -0.05) and Ψ_B (0.05 < η < 1.5).**

★ **To calculate v_n of a particle in negative η region, event plane from positive η side is used and vice versa.**

The weight factor $w_i = p_T \times \phi$-weight.

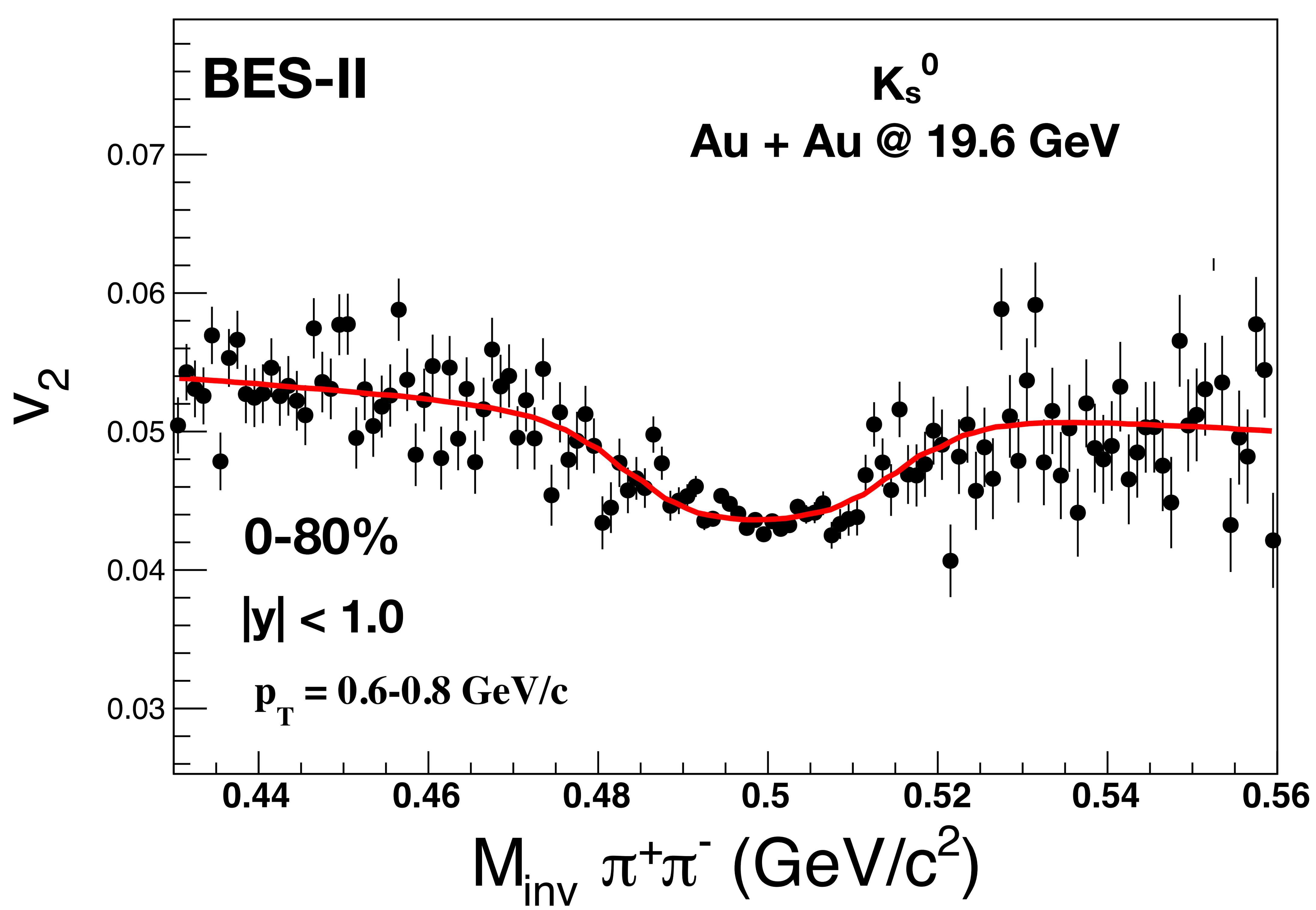
ϕ-weight: accounts for the azimuthal acceptance correction of the detectors.

Analysis details

v_n measurements for (multi-)strange hadrons and ϕ mesons

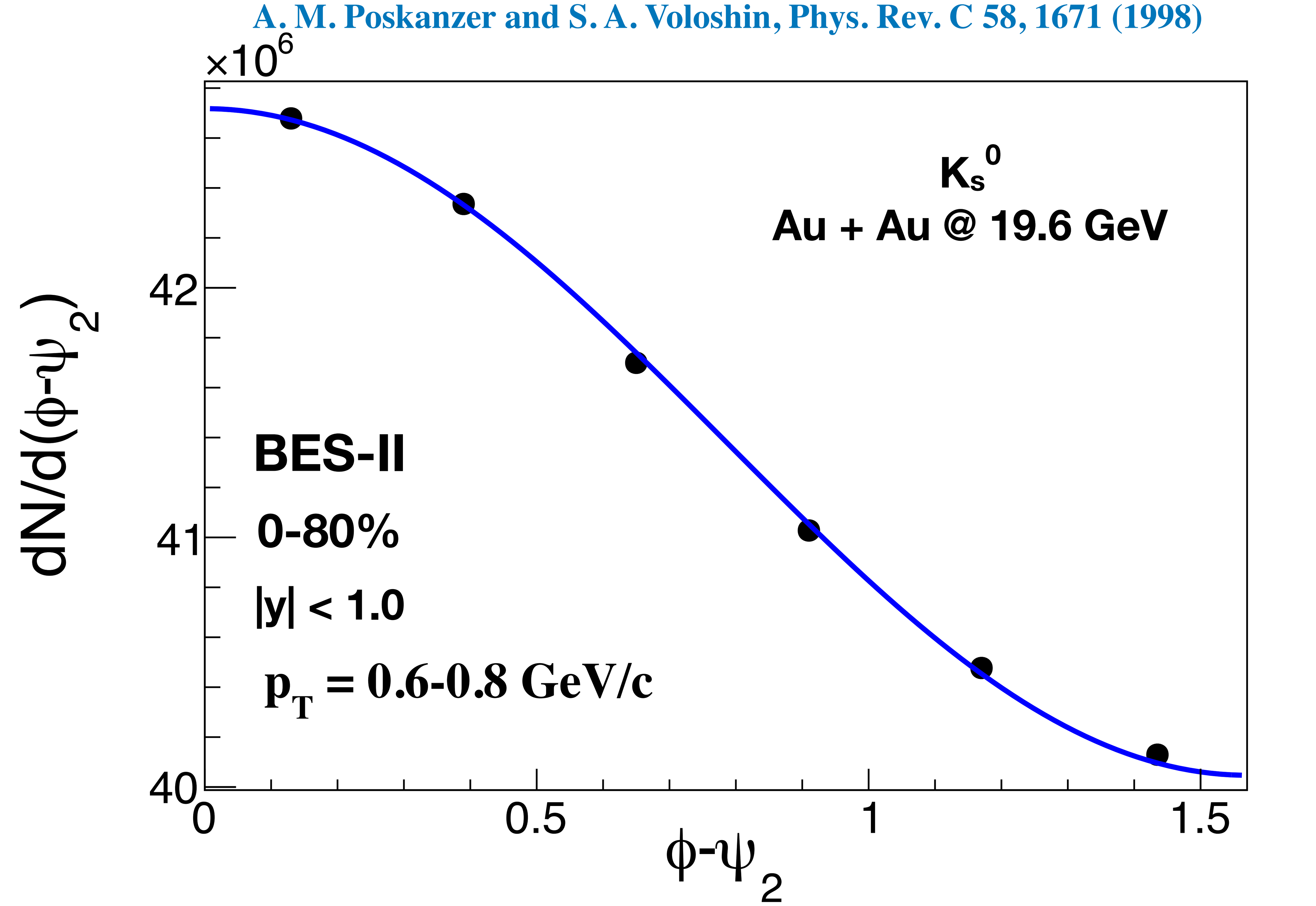
Invariant mass method

N. Borghini and J.-Y. Ollitrault, Phys. Rev. C 70, 064905 (2004)



Event plane method

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

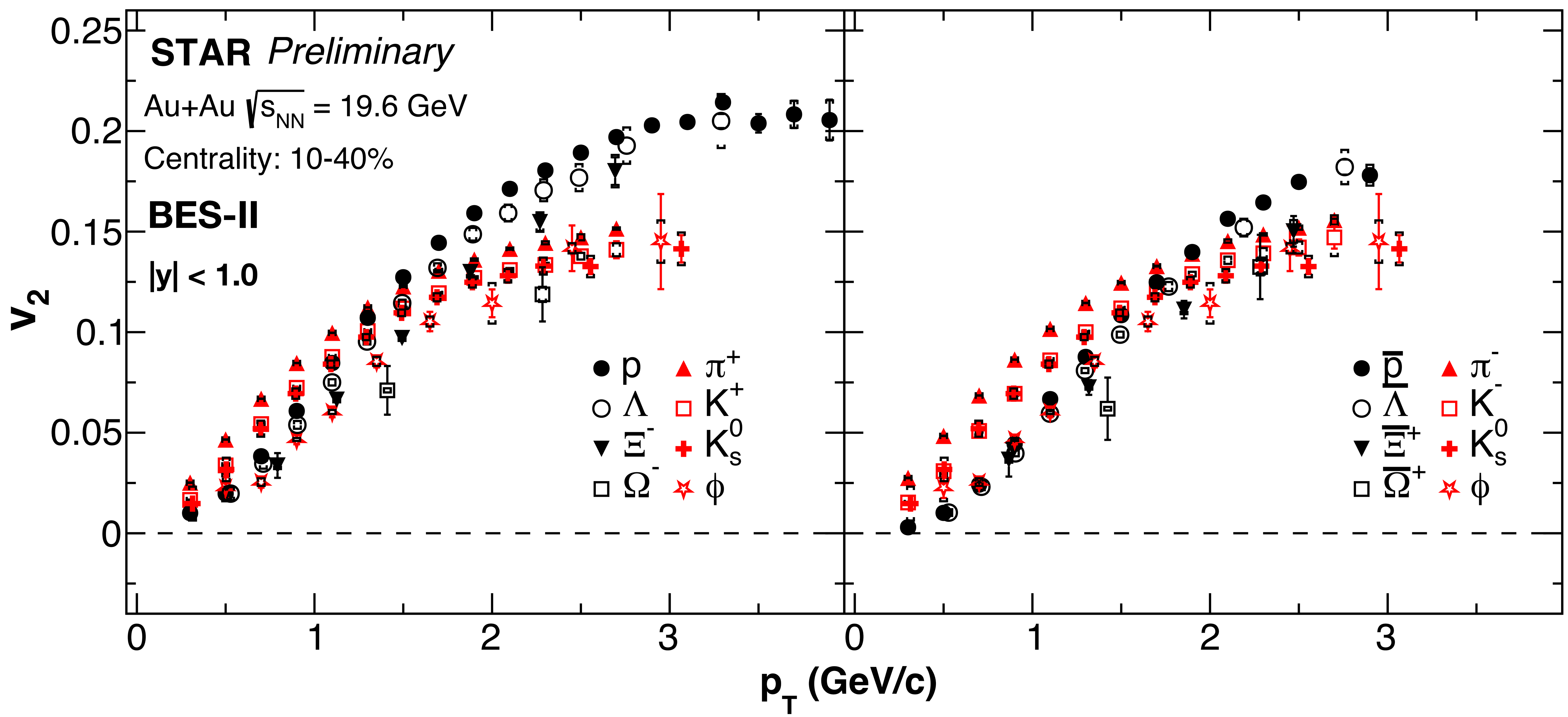


$$v_n^{S+B}(M_{inv}) = \langle cos\left[n(\phi-\psi_n)\right]\rangle = v_n^S \frac{S}{S+B}(M_{inv}) + v_n^B \frac{B}{S+B}(M_{inv})$$

$$\frac{dN}{d(\phi-\psi_n)} = \frac{N_0}{2\pi}\left(1+2v_n\cos n(\phi-\psi_n)\right)$$

$$v_n^B(M_{inv}) = p_0 + p_1 M_{inv}$$

Results: p_T dependence of v_2 @19.6 GeV

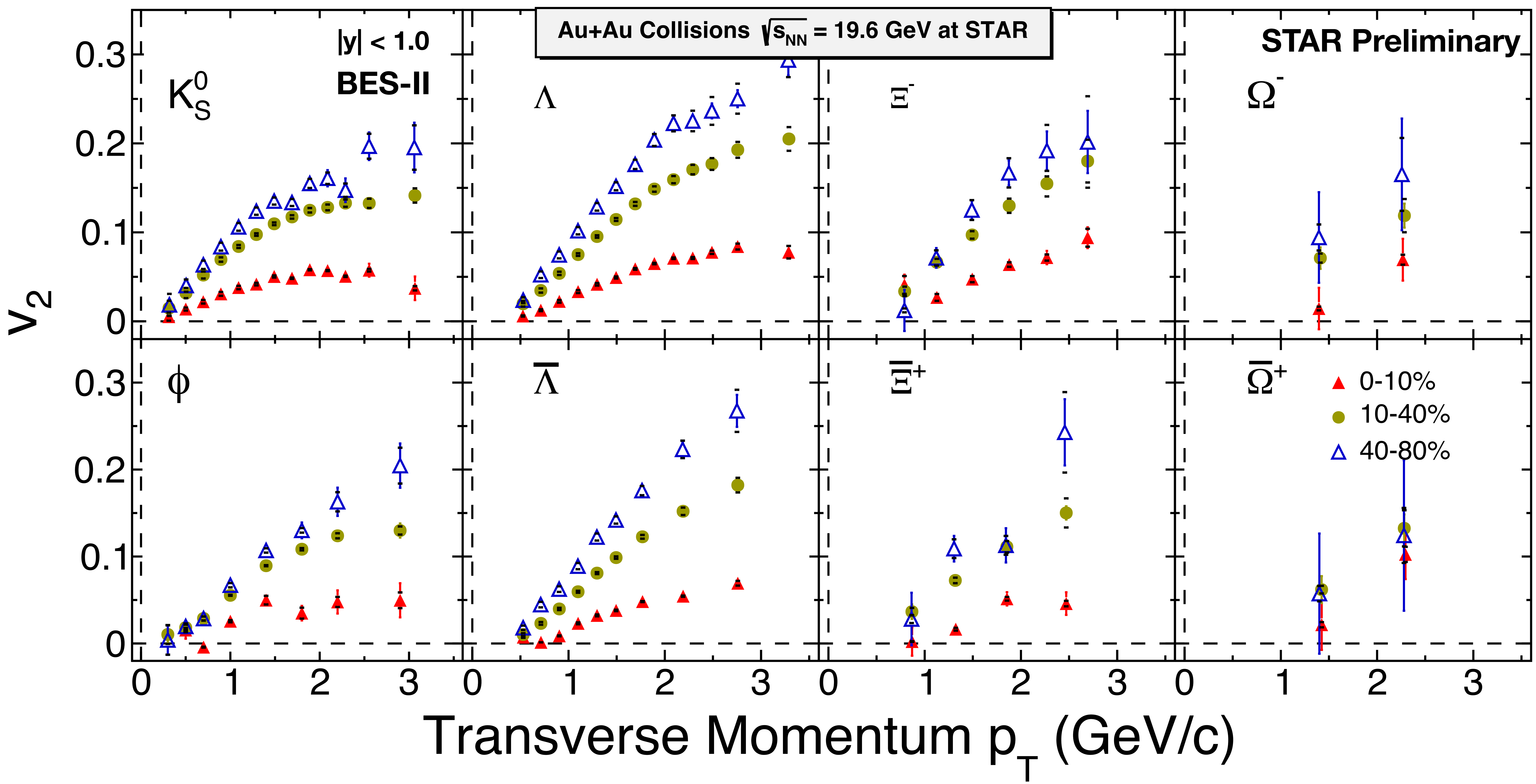


☞ Mass ordering observed in the low p_T region (p_T < 1.5 GeV/c) : Radial flow

☞ Baryon to meson separation observed in the high p_T region : Quark coalescence

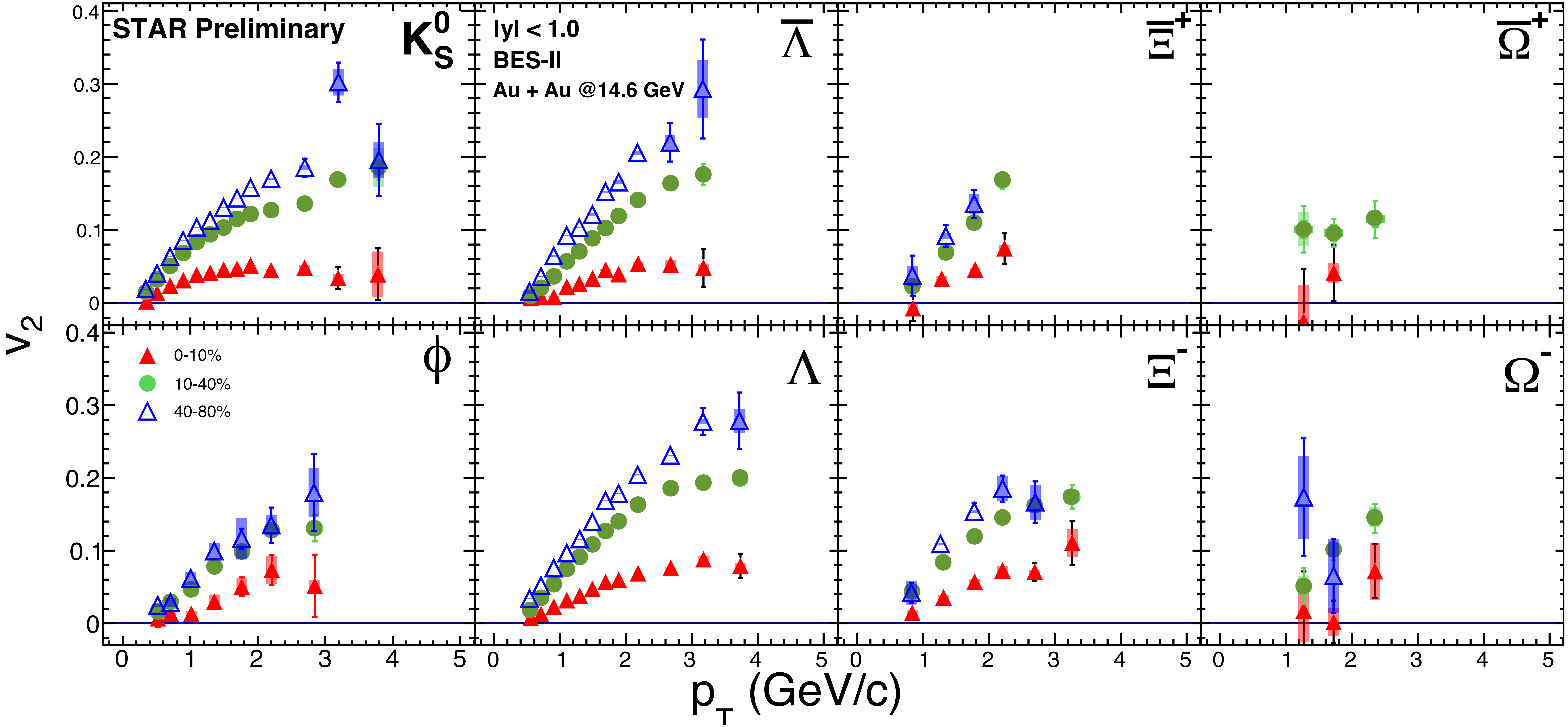
⭑ **The statistical errors are reduced by a factor of ~3 compared to BES-I.**

Results: Centrality dependence of v_2 @19.6 GeV



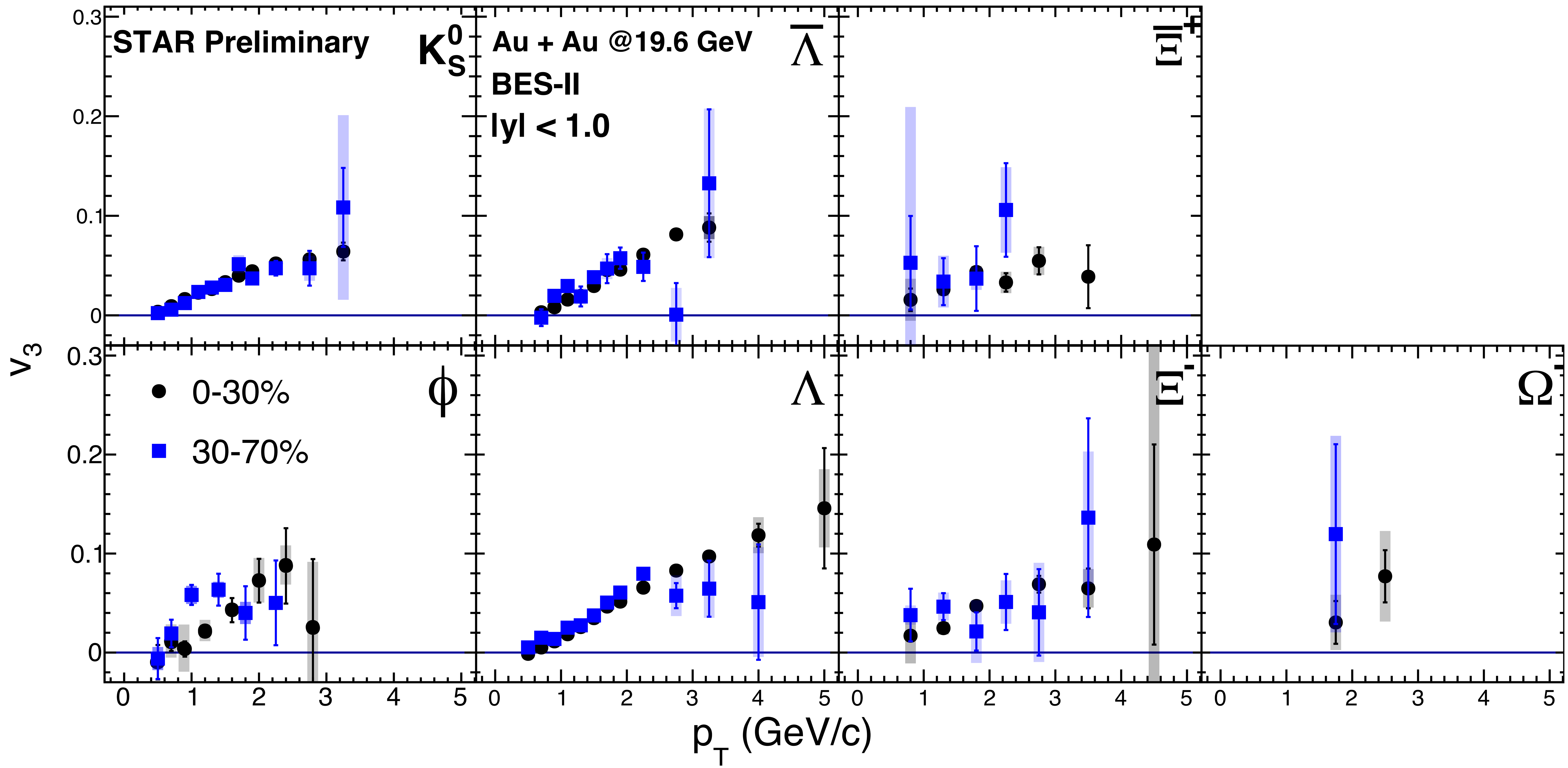
☞ Strong centrality dependence of v_2 → Spatial anisotropy is a dominant cause for v_2

Results: Centrality dependence of v_2 @14.6 GeV



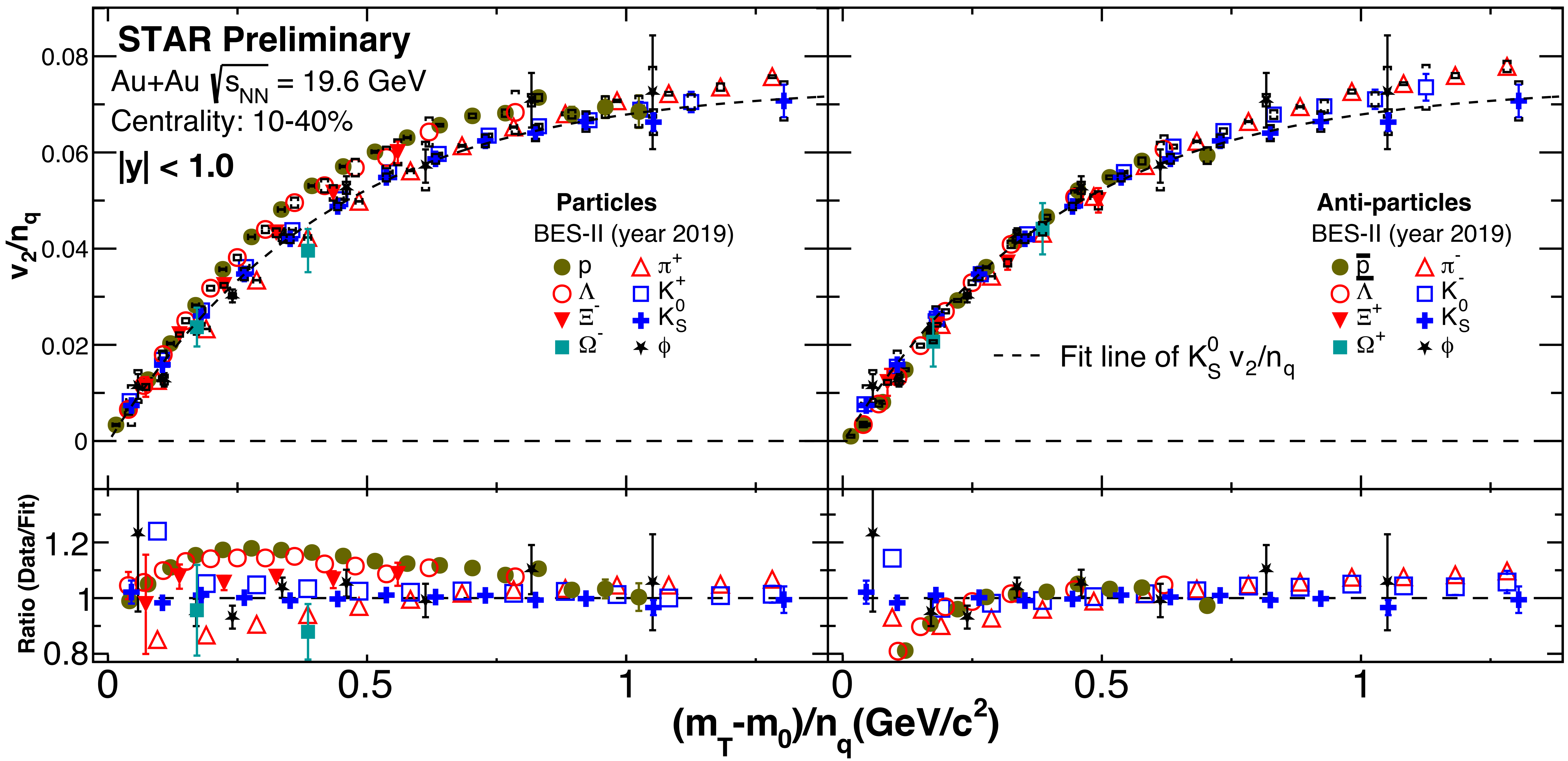
☞ Strong centrality dependence of v_2 → Spatial anisotropy is a dominant cause for v_2

Results: Centrality dependence of v_3 @19.6 GeV



☞ Weak centrality dependence of v_3 → Event-by-event fluctuation is a dominant cause for v_3

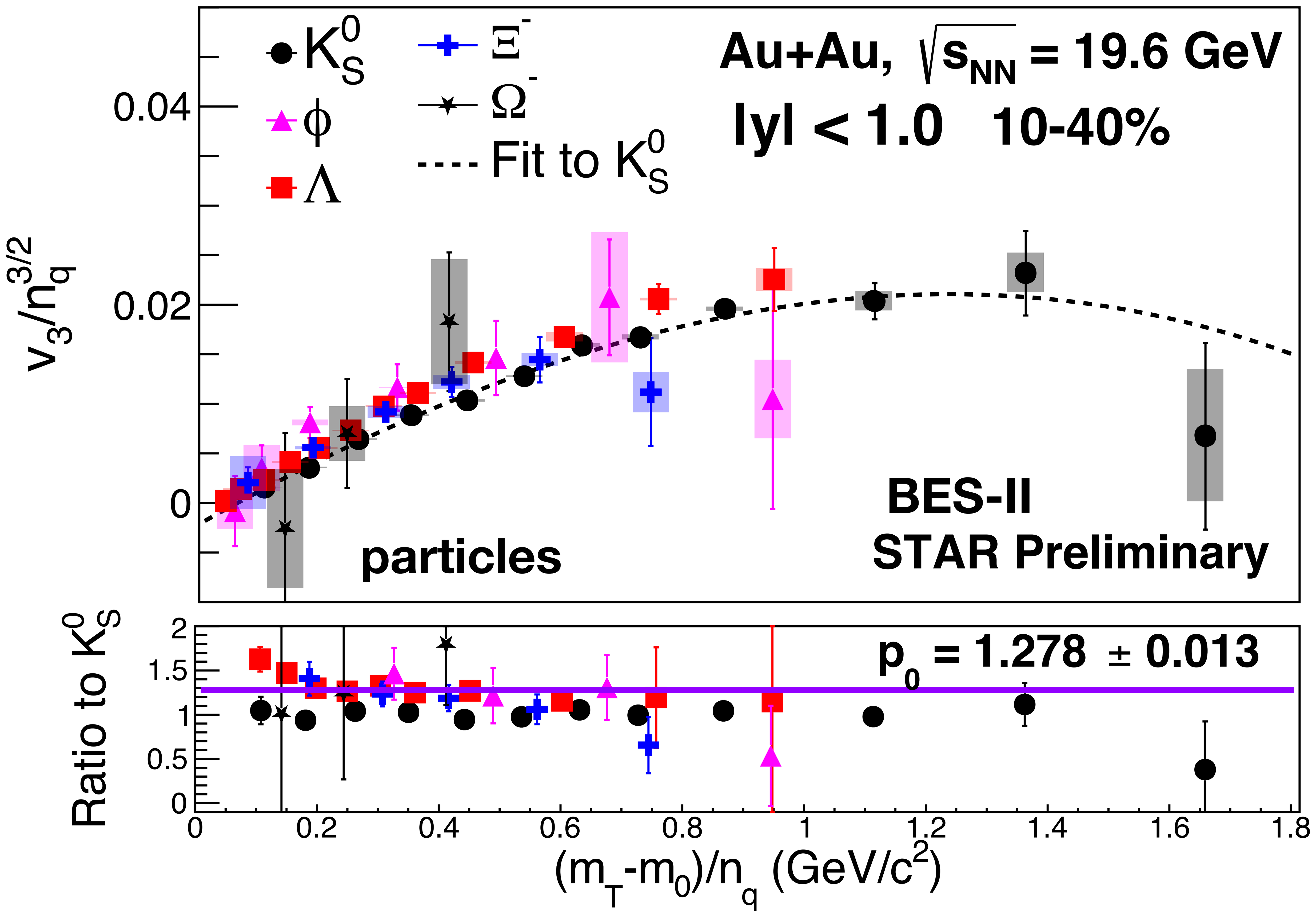
Results: NCQ scaling in v_2 @19.6 GeV

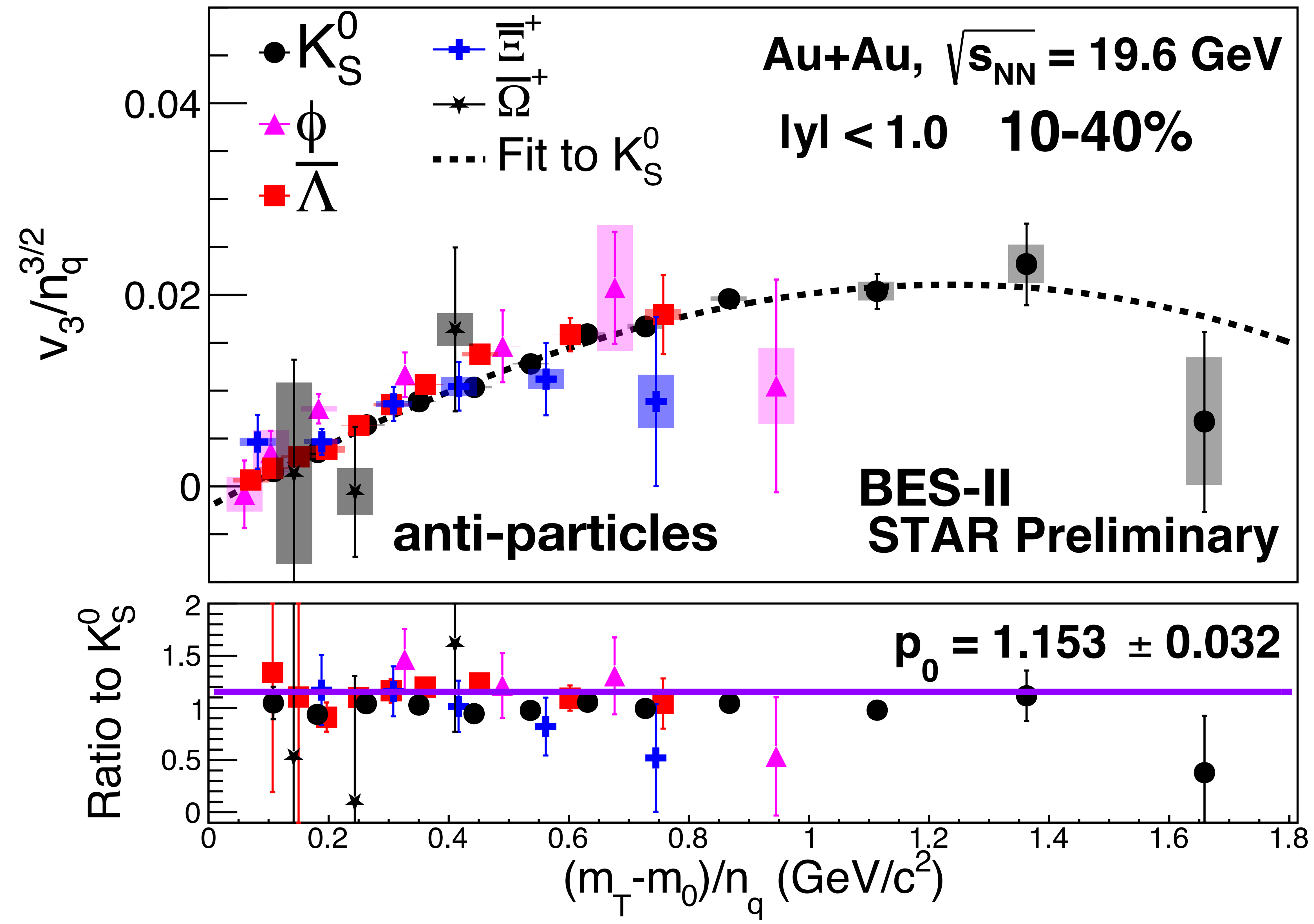


☞ The scaling for v_2 holds within 20% for particles and within 10% for anti-particles (except at low p_T for $\overline{\Lambda}$ and $\overline{p}$)

↳ Partonic collectivity in the initial stage of the system and hadronization via coalescence.

Results: NCQ scaling in v_3 @19.6 GeV



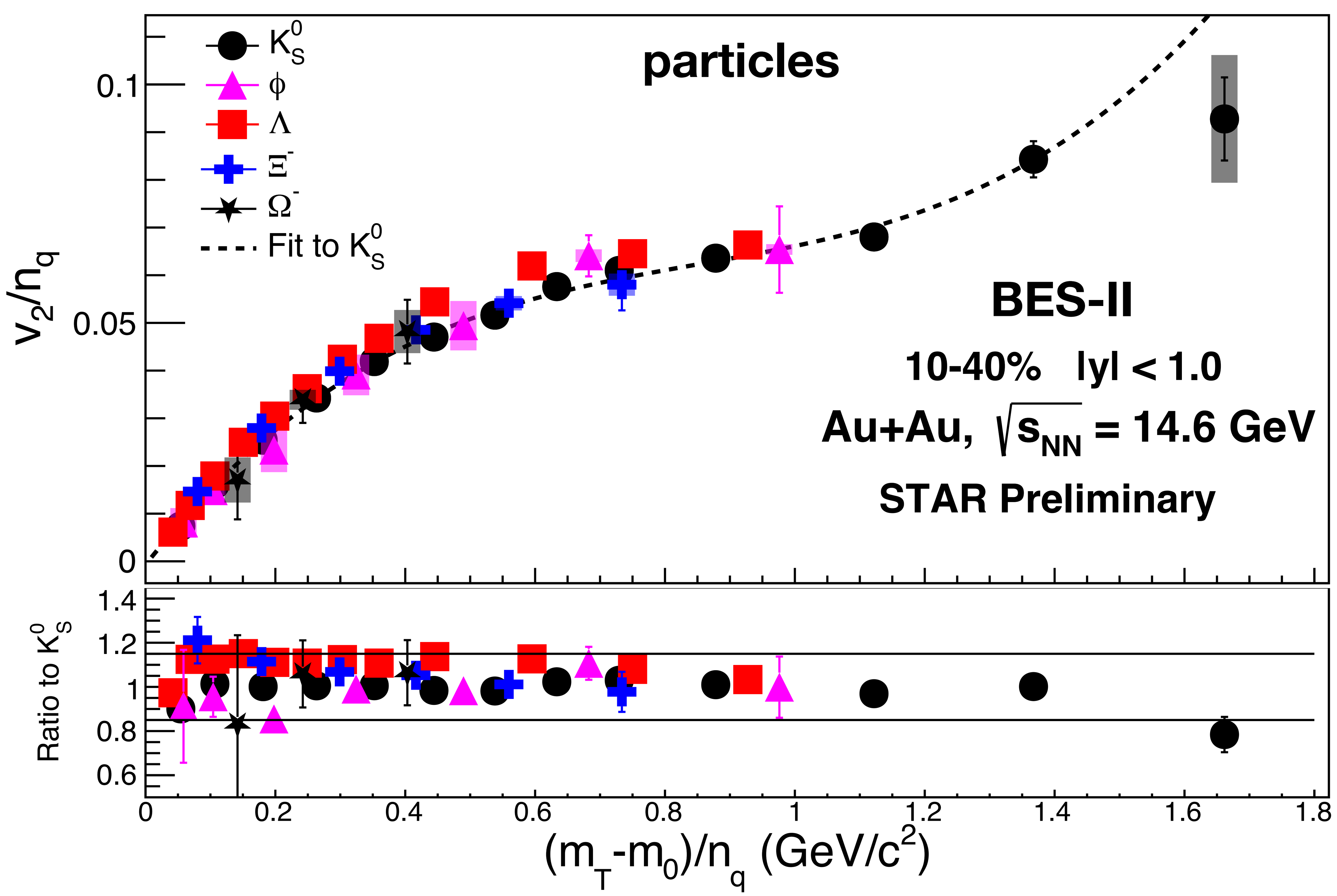


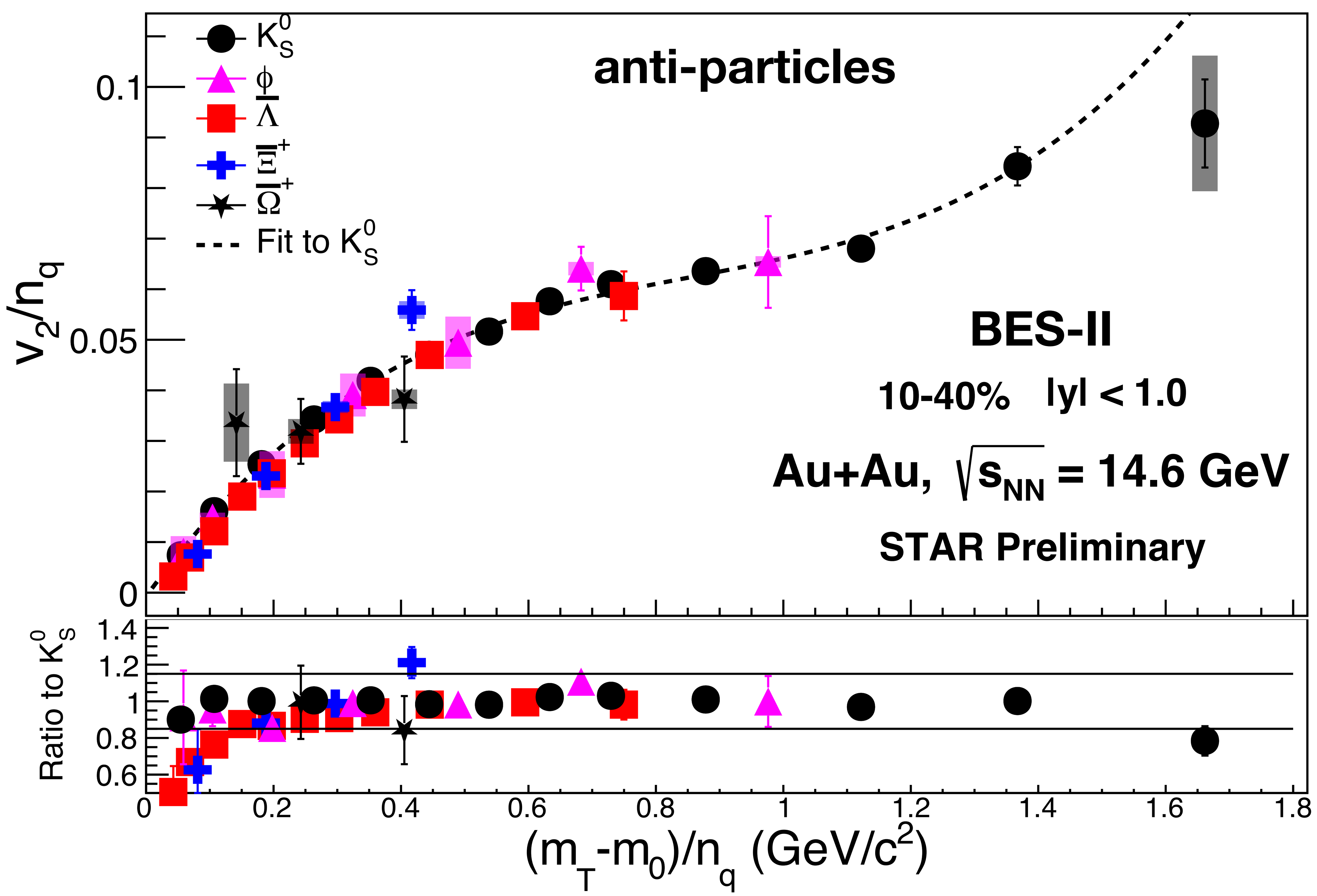
⋆ p_0 is the parameter from the simultaneous 0th order polynomial fit to the ratios.

☞ The modified scaling for v_3 holds within 30% for particles and within 15% for anti-particles.

PHENIX Phys. Rev. C 93, 051902 (2016)

Results: NCQ scaling in v_2 @14.6 GeV





- ☞ The scaling for v_2 holds within 15% for the (multi-)strange hadrons except low p_T $\bar{\Lambda}$.
- ☞ ϕ mesons are following the NCQ scaling at 14.6 GeV.
- ☞ The rising trend in the K_S^0 v_2 at $(m_T - m_0)/n_q > 1$ GeV/c^2 may arise due to the non-flow contribution. Non-flow estimation is underway.

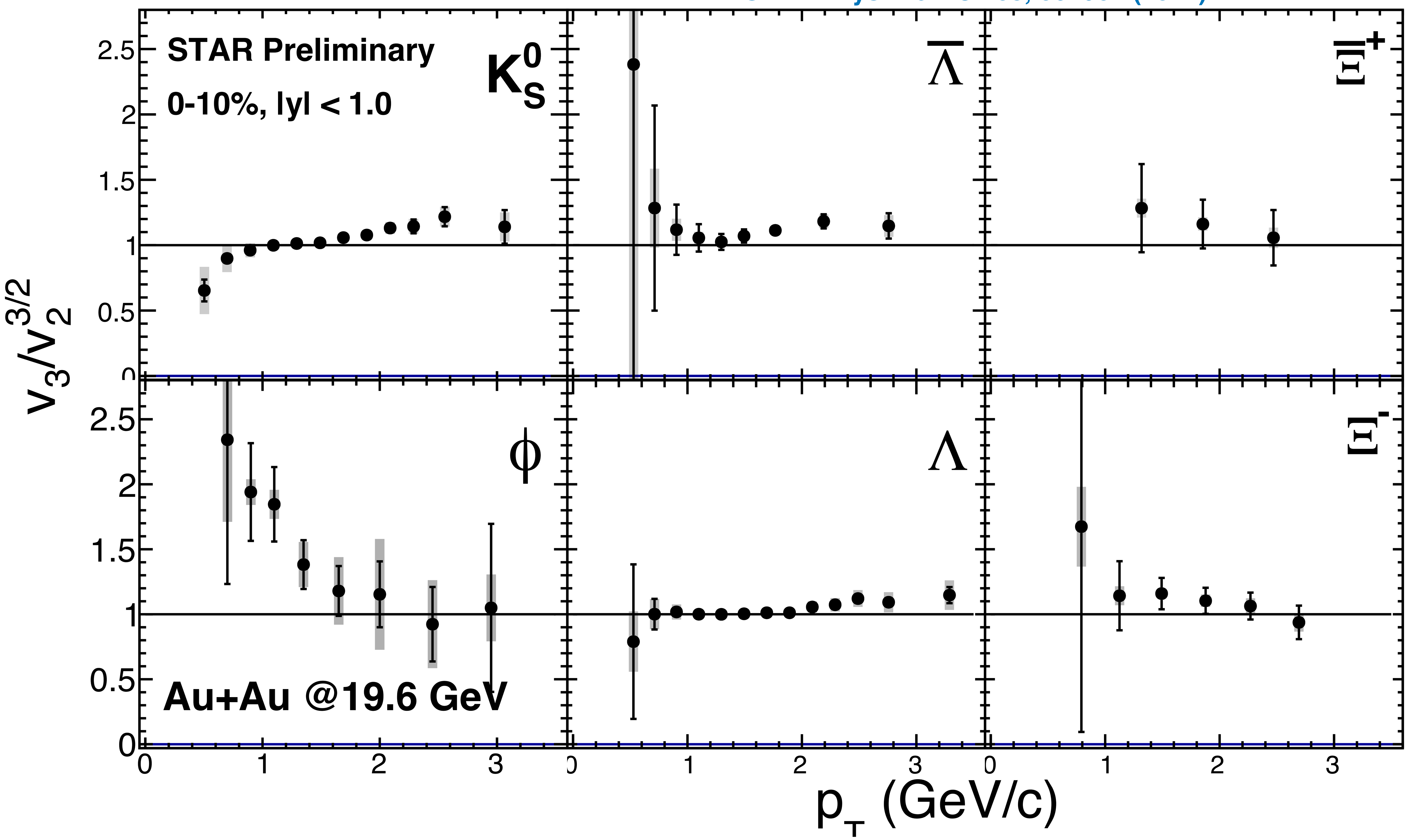
⭑ See S. Zhou's talk for light hadrons v_2 at 14.6 GeV

Results: $v_3/v_2^{3/2}$ ratio @19.6 GeV

Correlation between v_3 and $v_2^{3/2}$

Previous RHIC measurements suggests that $v_n \propto v_2^{n/2}$

STAR Phys. Rev. Lett. 92, 062301 (2004)
PHENIX Phys. Rev. Lett. 105, 062301 (2010)
STAR Phys. Rev. C 103, 064907 (2021)



- ☞ The ratio $v_3/v_2^{3/2}$ shows non-trivial p_T dependence.
- ☞ $v_3/v_2^{3/2}$ ratios are sensitive to the initial state fluctuations and transport properties of the medium.

E. Retinskaya et al. Phys. Rev. C 89, 014902 (2014)

Summary

☞ Using high statistics BES-II data, precise measurements of v_2 of identified hadrons in 19.6 and 14.6 GeV Au+Au collisions have been presented, with improved statistical significance by a factor of 3 compared to BES-I.

☞ New results of v_2 and v_3 of (multi-)strange hadrons and ϕ mesons are presented.

p_T dependence of v_2

☞ Confirmation of usual trend of mass ordering in v_2 at low p_T and baryon-meson separation at high p_T in low energies at 19.6 GeV using strange and multi-strange hadrons.

Centrality dependence of v_n

☞ Strong centrality dependence of v_2 : initial spatial anisotropy is a dominant cause for v_2.

☞ Weak centrality dependence of v_3: event-by-event fluctuation is a dominant cause for v_3.

NCQ scaling

☞ The NCQ scaling holds for both particles and anti-particles.

☞ The scaling holds for ϕ mesons at 14.6 GeV.

☞ The scaling suggests the collectivity in the partonic phase of the system and hadronization via quark coalescence.

$v_3/v_2^{3/2}$ ratio

☞ The ratio shows weak dependence of p_T above $p_T > 1.0$ GeV/c.

☞ Can be used to constrain the initial state fluctuations and η/s of the medium.

Thank you …