Azimuthal anisotropic flow measurements of (multi-)strange hadrons in Au+Au collisions in BES-II energies at STAR

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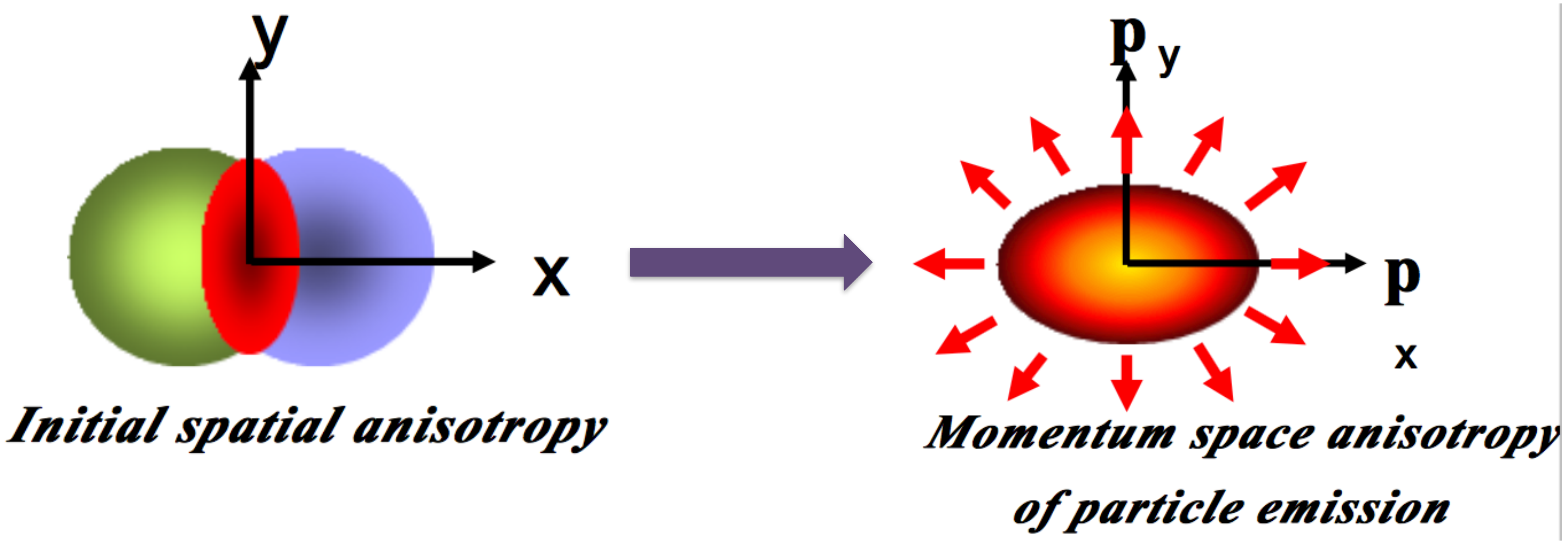
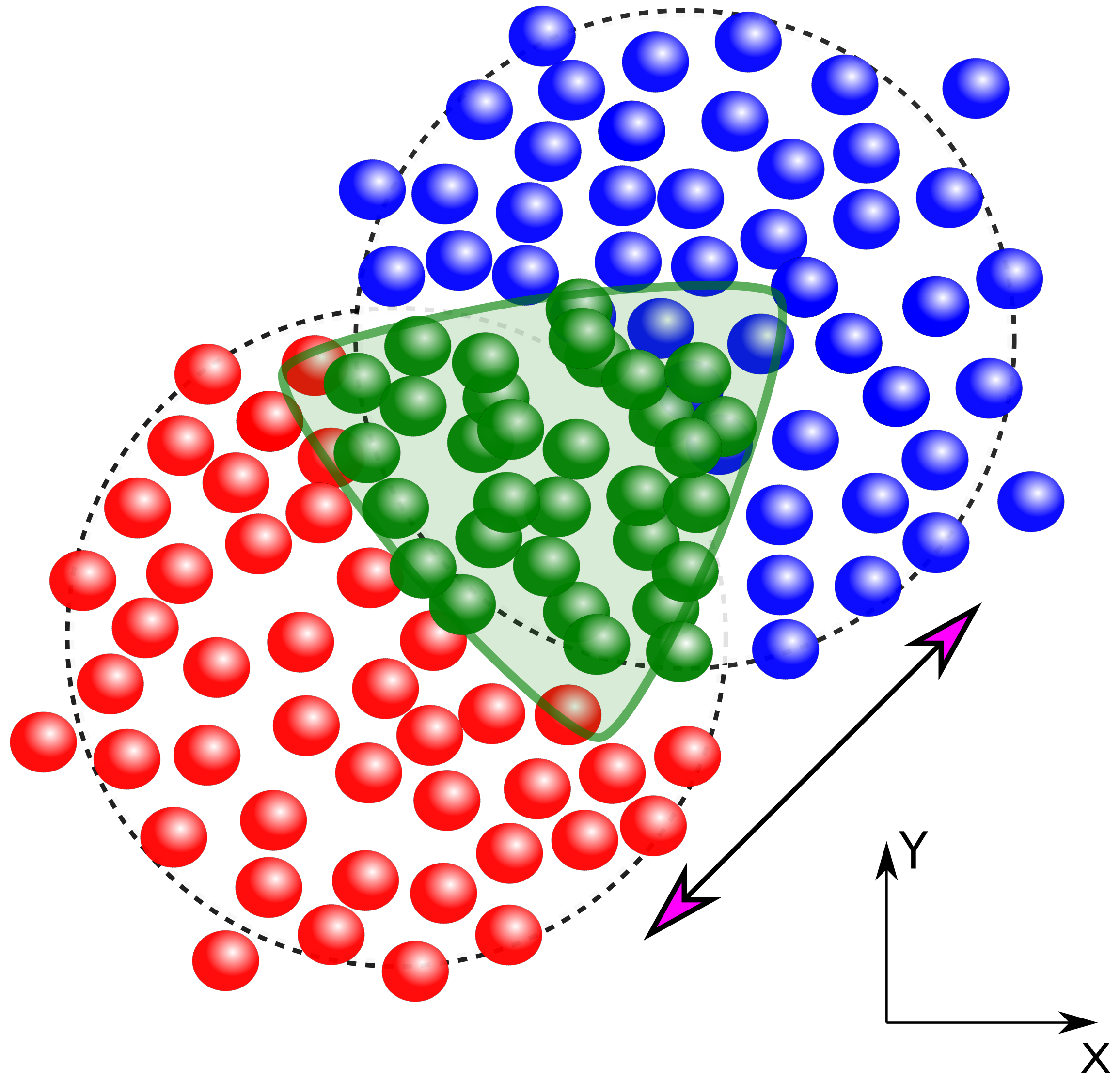
Introduction

What is azimuthal anisotropy ?





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

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

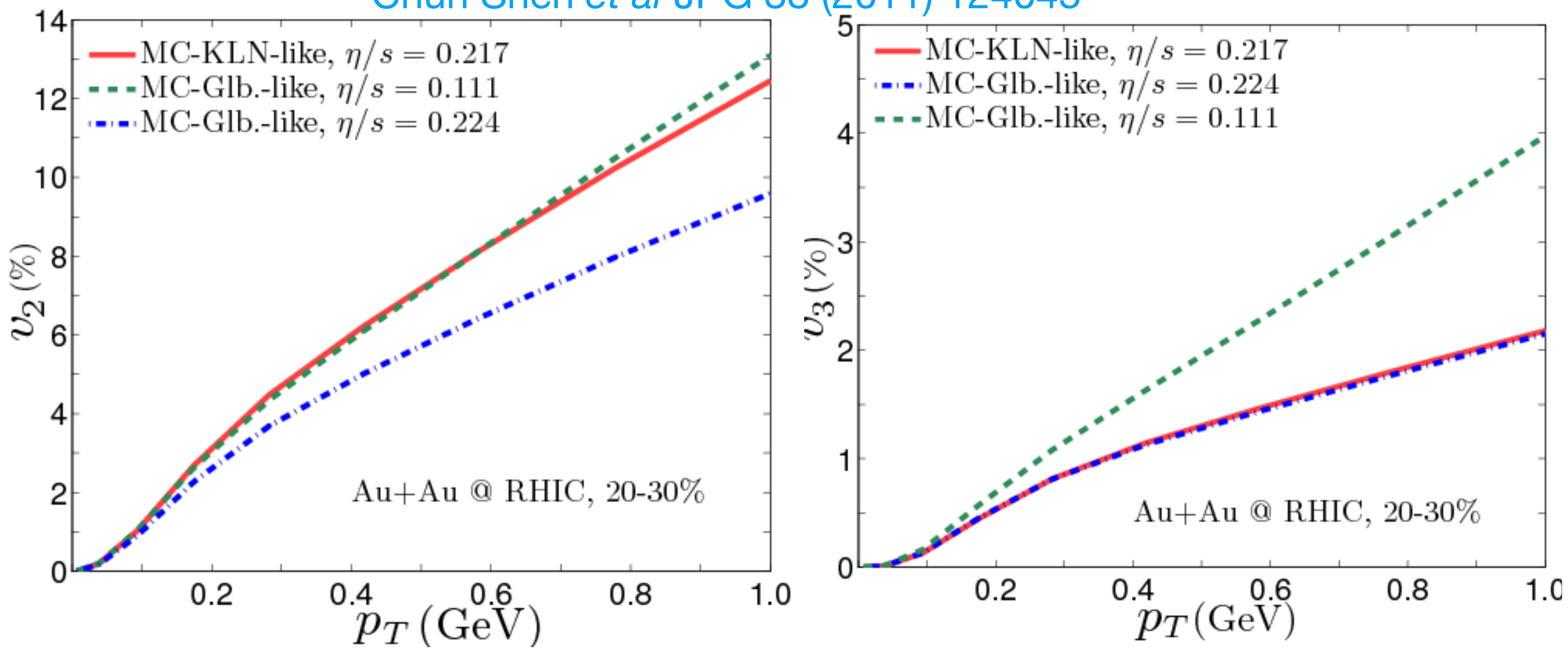
$$\frac{dN}{d(\phi - \Psi_n)} = N_0 \left[1 + \sum_{n=1}^{\infty} 2 v_n \cos(\phi - \Psi_n) \right]$$

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

Motivation

Why v_2 and v_3 are important ?

Chun Shen *et al* JPG 38 (2011) 124045



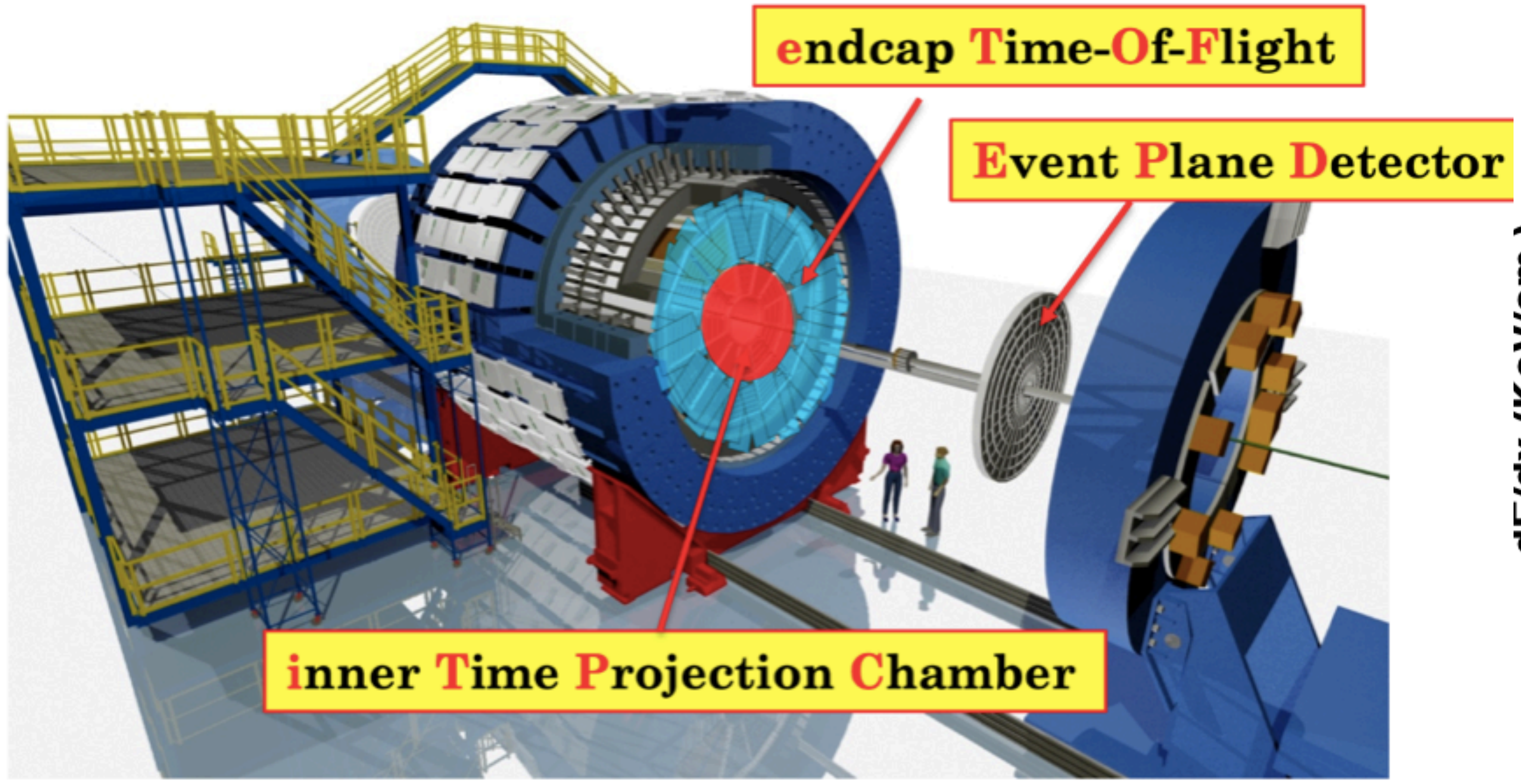
- ☞ Sensitive to the initial state and transport properties of the medium.
- ☞ Simultaneous measurements of v_2 and v_3 are important to constrain the models.

Why strange and multi-strange hadrons ?

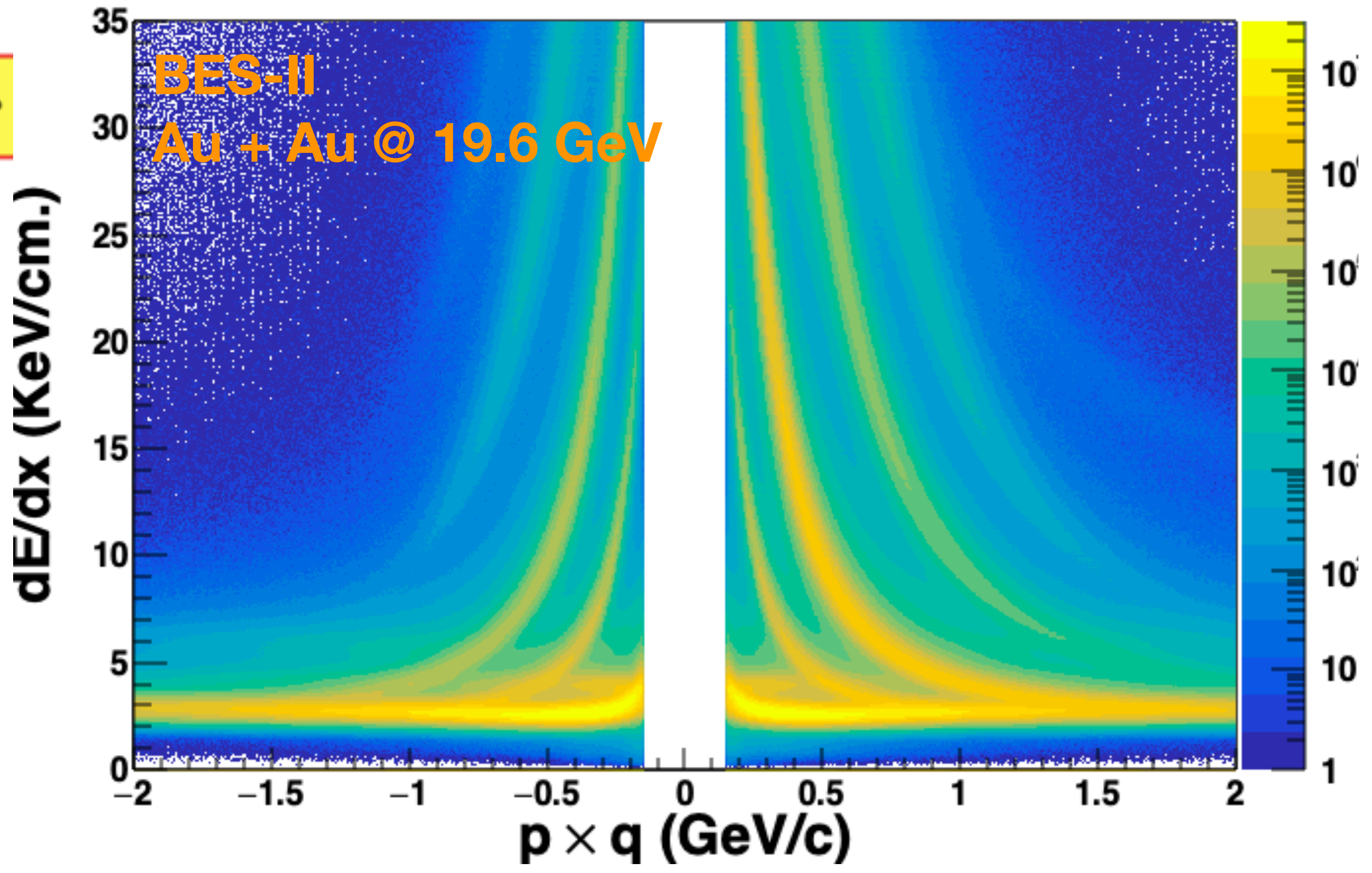
- ☞ Small hadronic interaction cross sections.
- ☞ Early freeze-out compared to other hadrons.

STAR, Nucl. Phys. A757, 102 (2005)

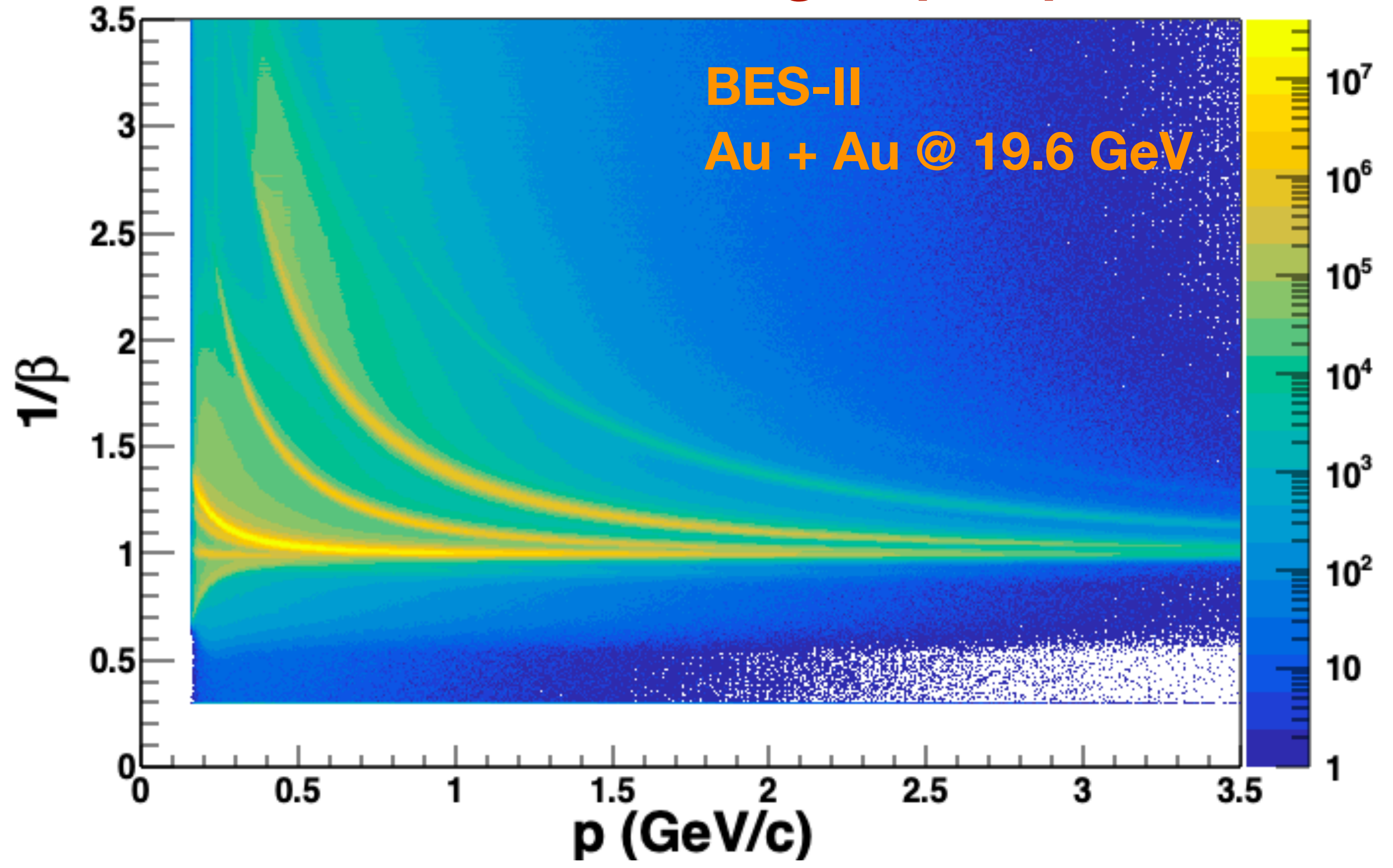
STAR detectors



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.

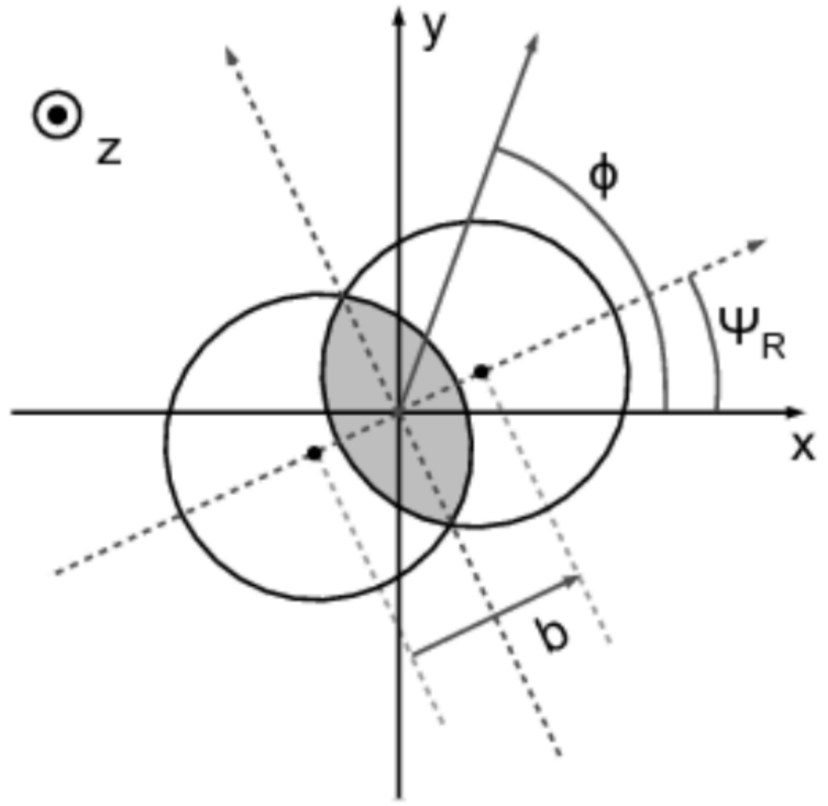
Data set information for this analysis:

- System: Au+Au
- Year: 2019 (BES-II data)
- Collision energy: 19.6 and 14.6 GeV
- #Events: ~380M (19.6 GeV) & ~270M (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 determination

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

$$Q_x = \sum_i w_i \cos(n\phi_i) \qquad Q_y = \sum_i w_i \sin(n\phi_i)$$

Where the weight factor $w_i = p_T \times \phi$-weight.

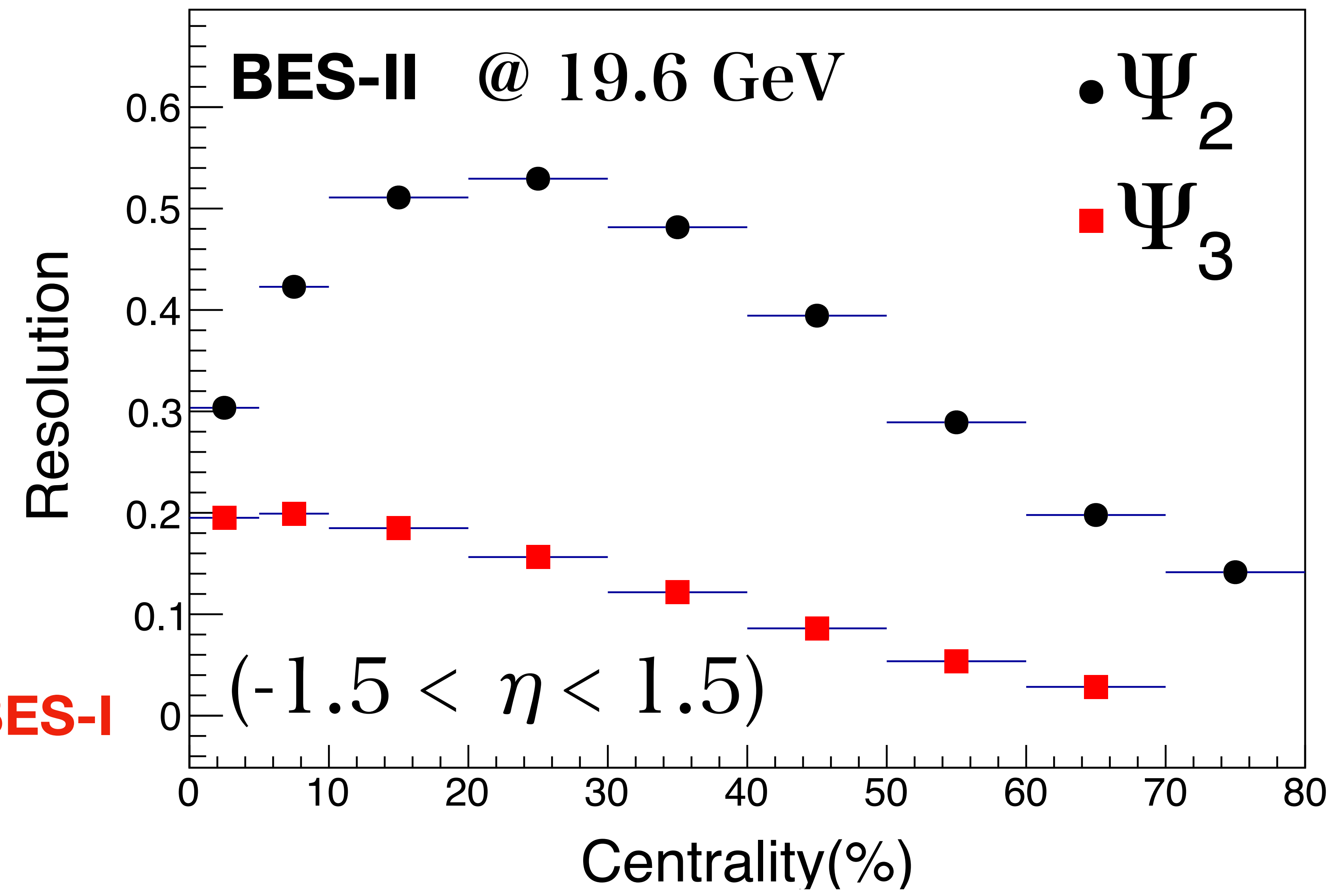
ϕ-weight: accounts for the azimuthal acceptance correction of the detectors.

Event plane resolution

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

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

Ψ_A ($-1.5 < \eta < -0.05$) and Ψ_B ($0.05 < \eta < 1.5$) two sub-event planes.



⋆ Ψ_2 resolution in BES-II is about 10% higher than BES-I

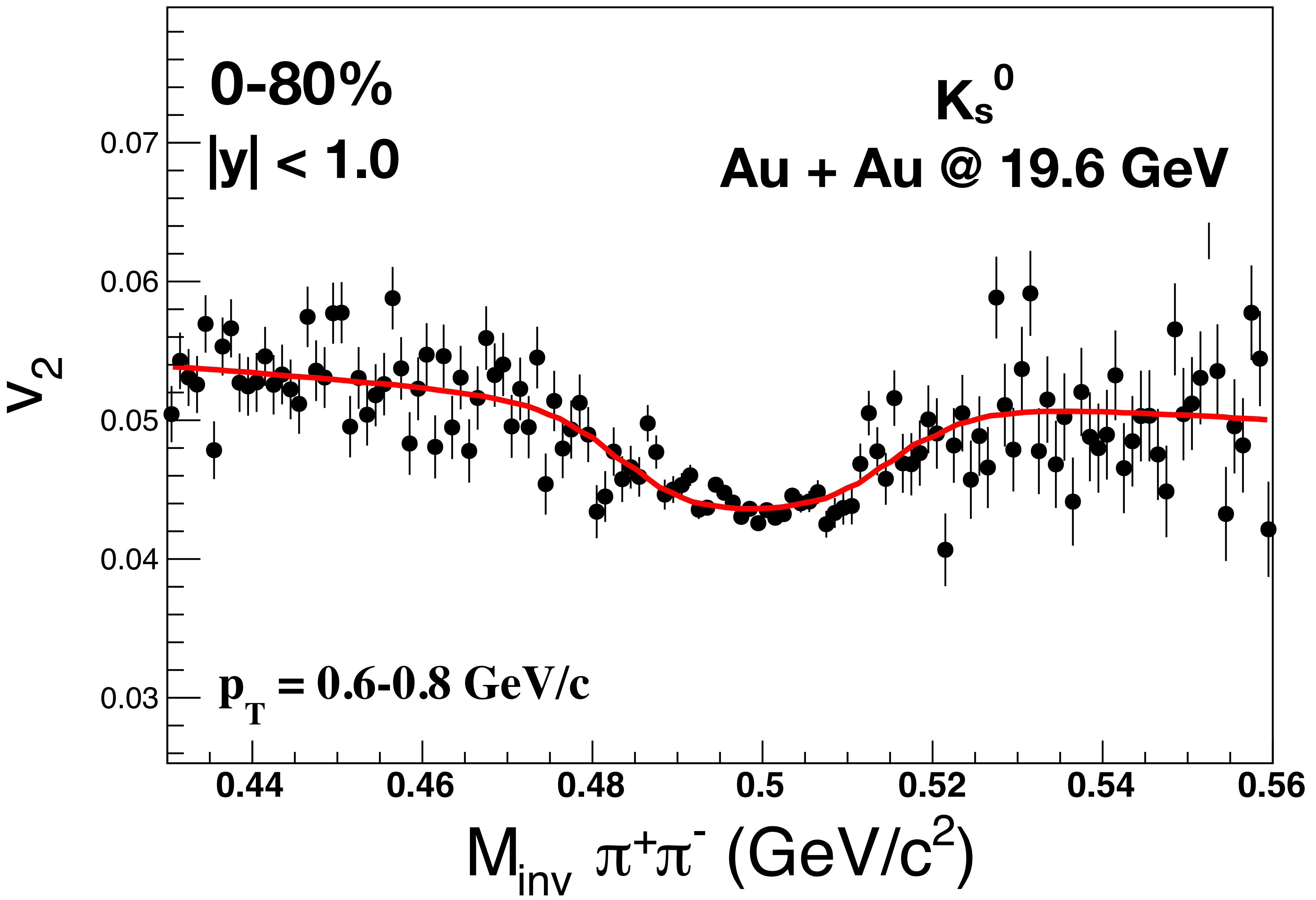
A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)

Analysis details

v_n measurements

Invariant mass method

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

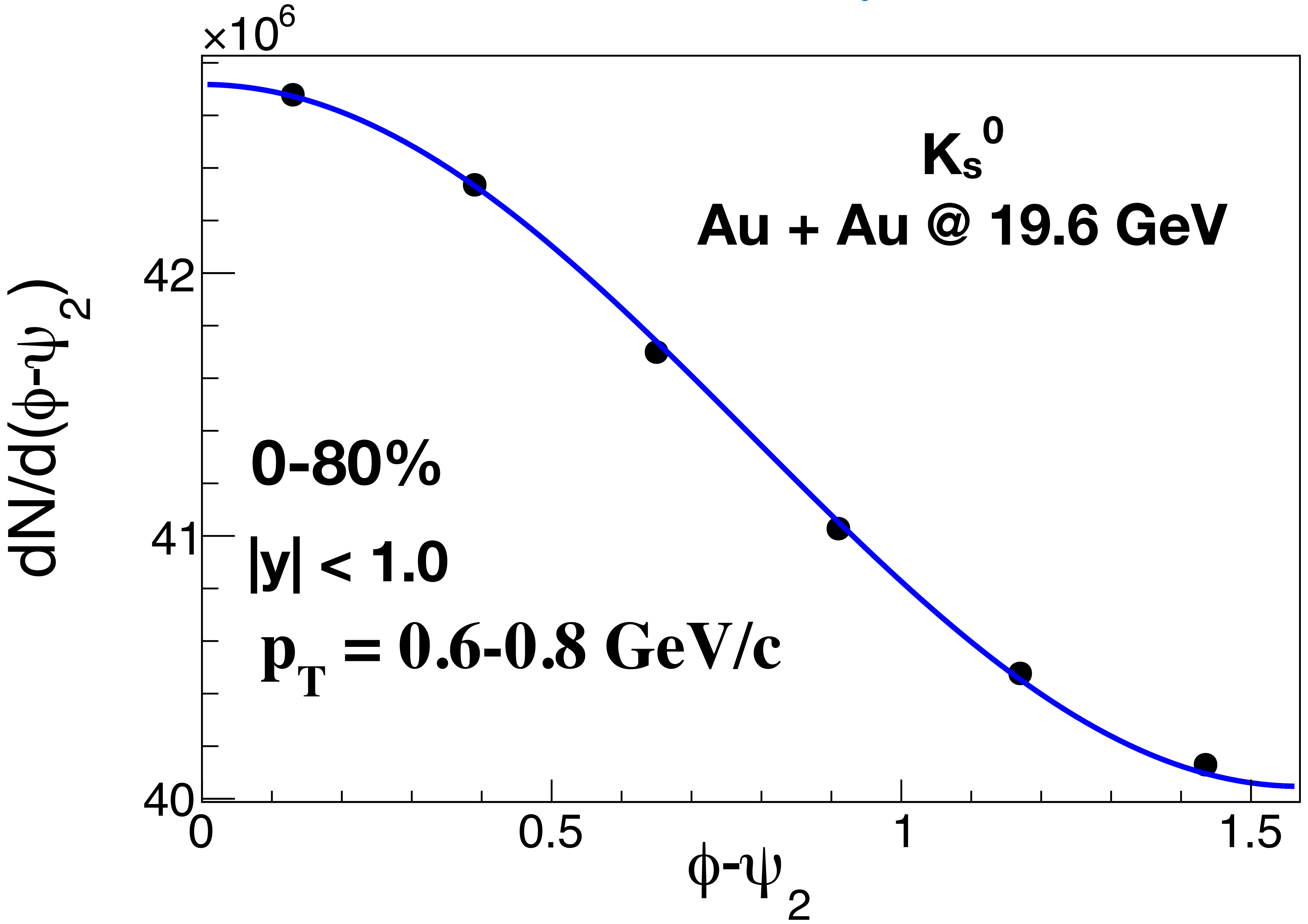


$$v_n^{S+B}(M_{inv}) = \langle cos\left[n(\phi - \psi_n)\right]\rangle = v_n^S \frac{S}{S+B}(M_{inv}) + v_n^B \frac{B}{S+B}(M_{inv})$$

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

Event plane method

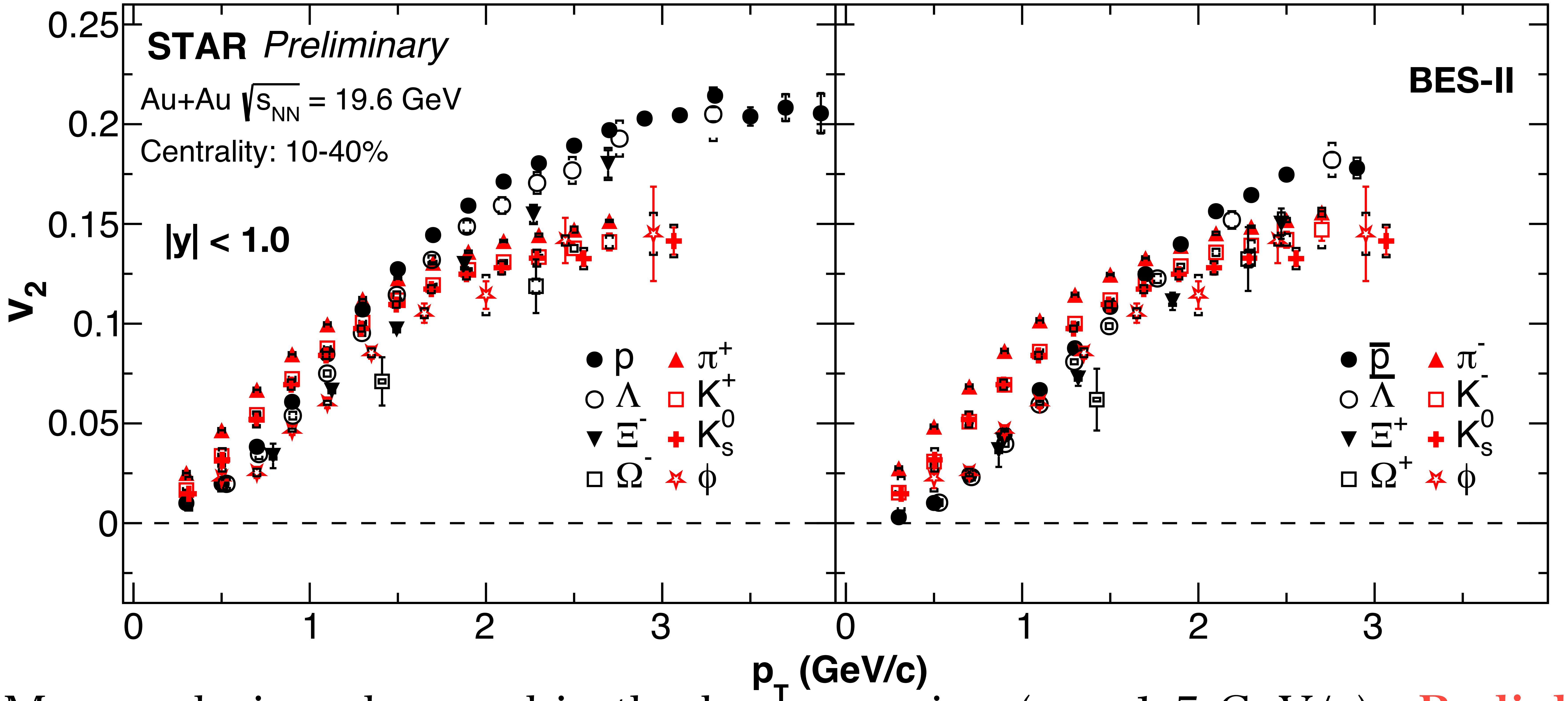
A. M. Poskanzer and S. A. Voloshin, Phys. Rev. C 58, 1671 (1998)



$$\frac{dN}{d(\phi - \psi_2)} = \frac{N_0}{2\pi}\left(1 + v_2 \cos 2(\phi - \psi_2)\right)$$

Results

p_T dependence of v_2



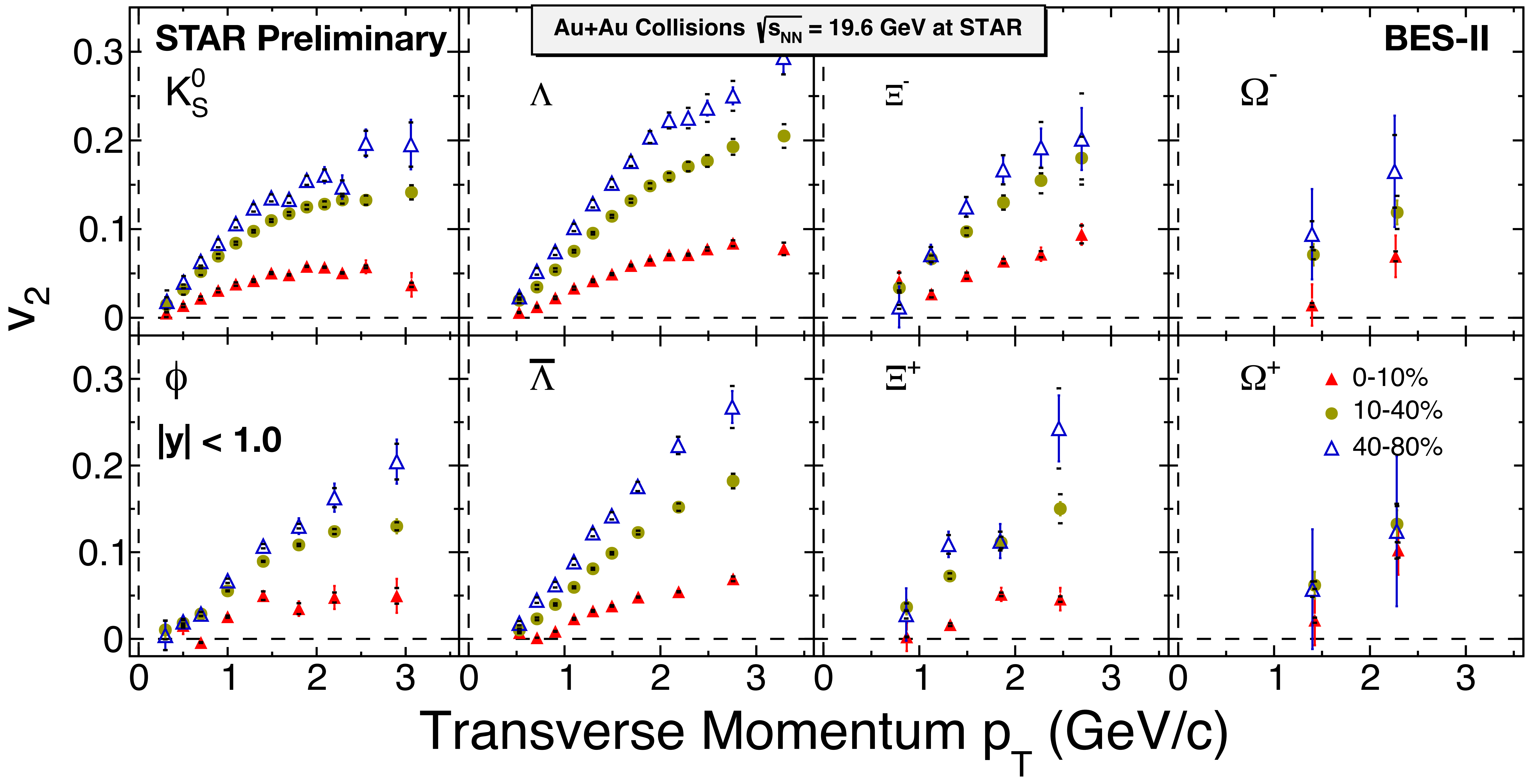
☞ Mass ordering observed in the low p_T region ($p_T < 1.5$ GeV/c) : Radial flow

☞ 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

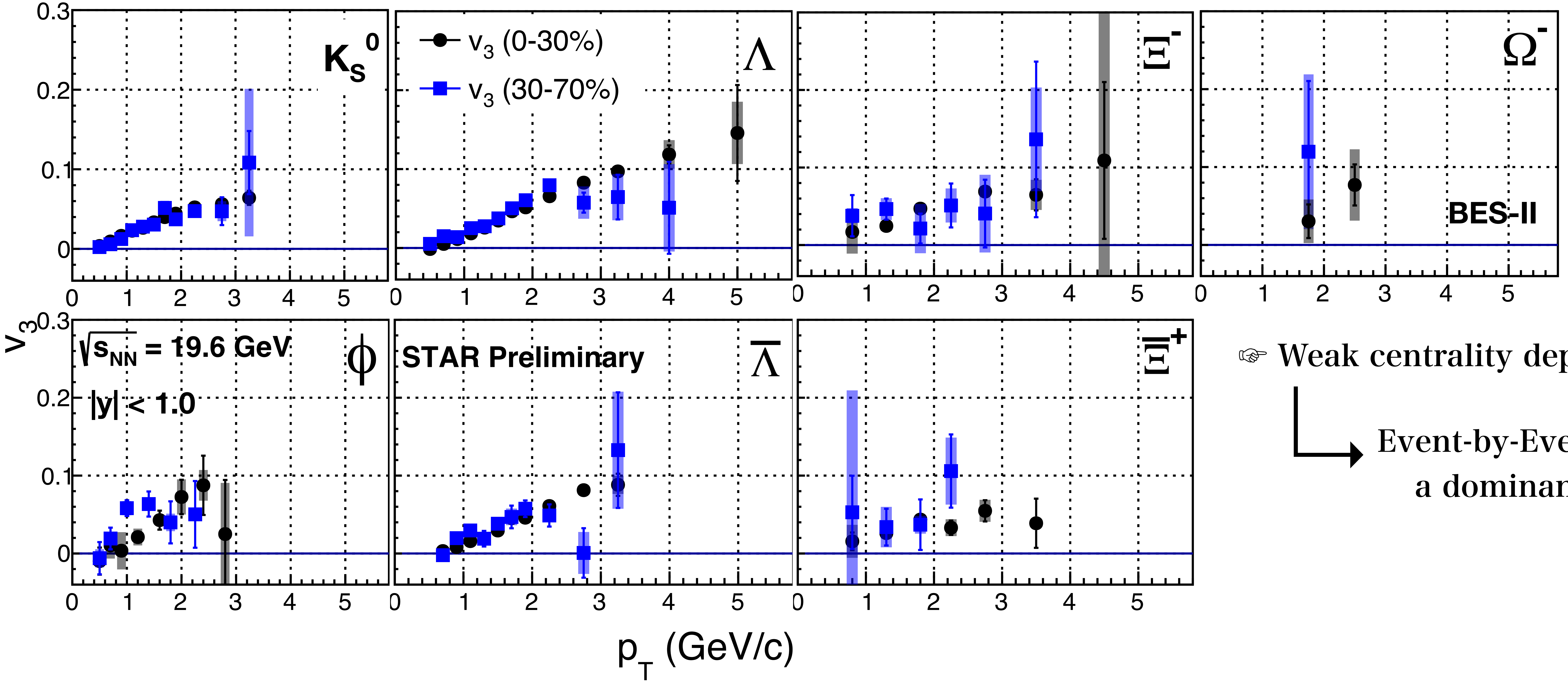


☞ Strong centrality dependence of v_2

Spatial anisotropy is a dominant cause for v_2

Results

Centrality dependence of v_3

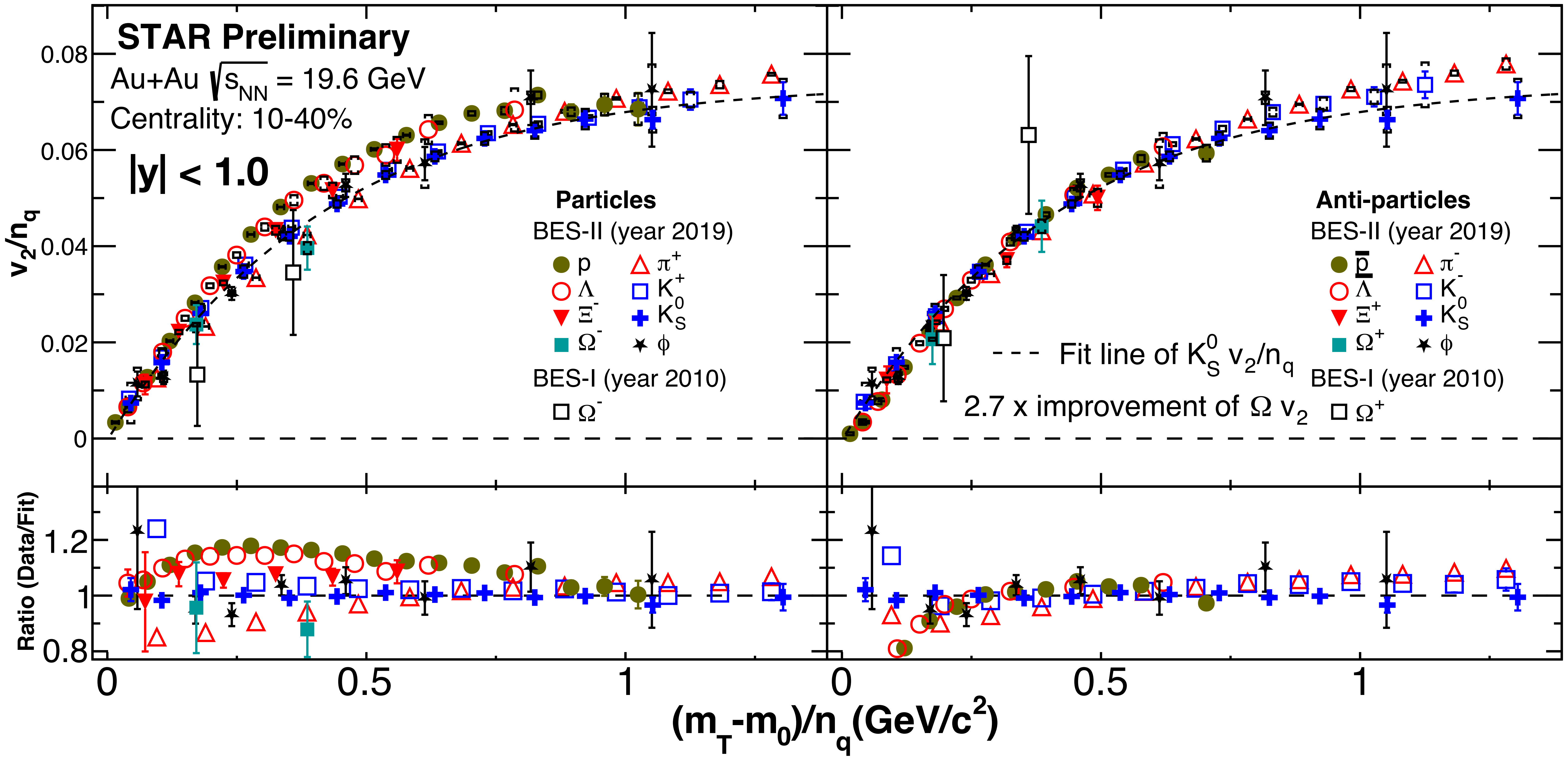


☞ Weak centrality dependence of v_3

→ Event-by-Event fluctuation is a dominant cause for v_3

Results

NCQ scaling at 19.6 GeV



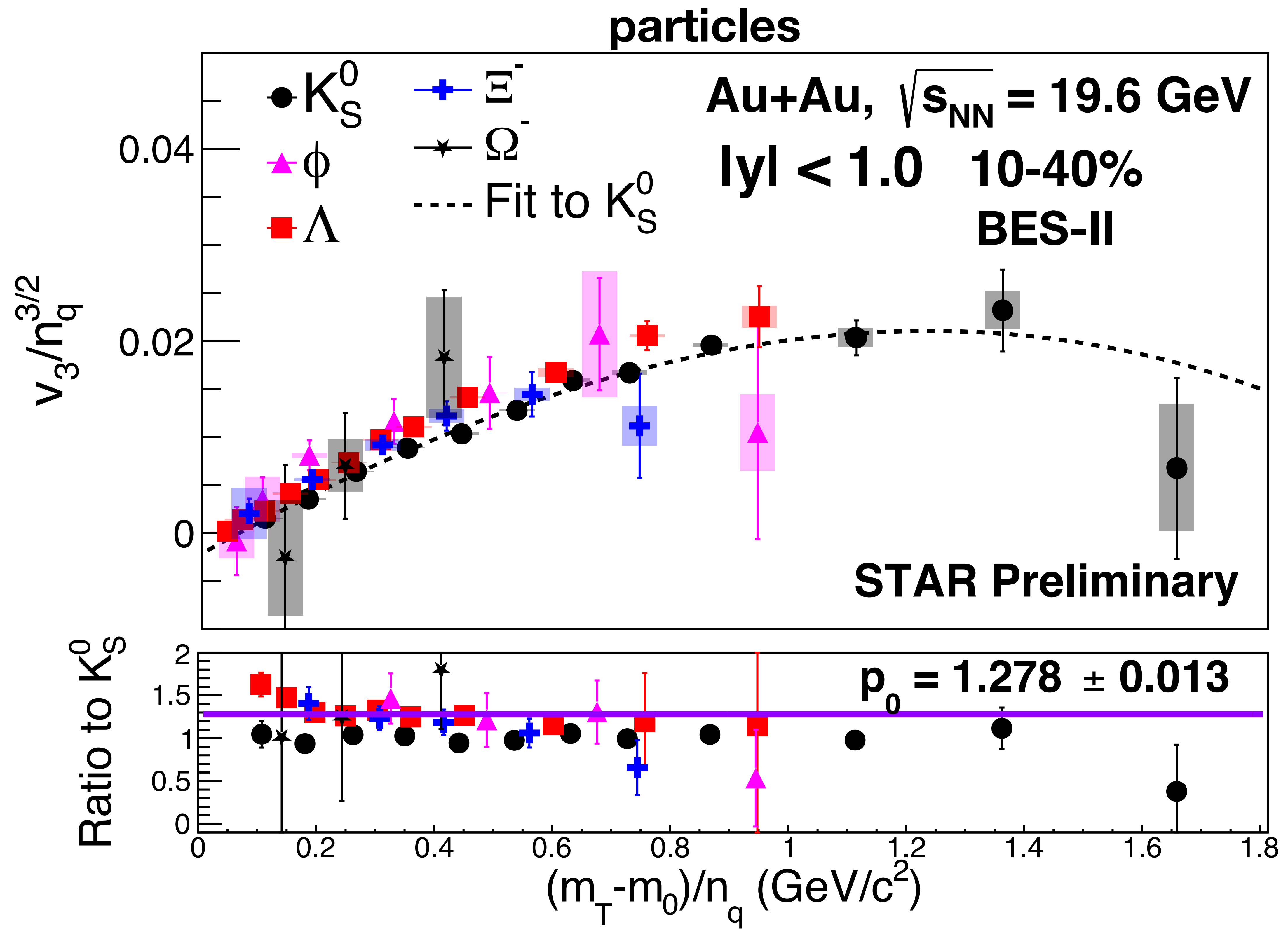
☞ The scaling for v_2 holds within 20% for particles and within 10% for anti-particles.

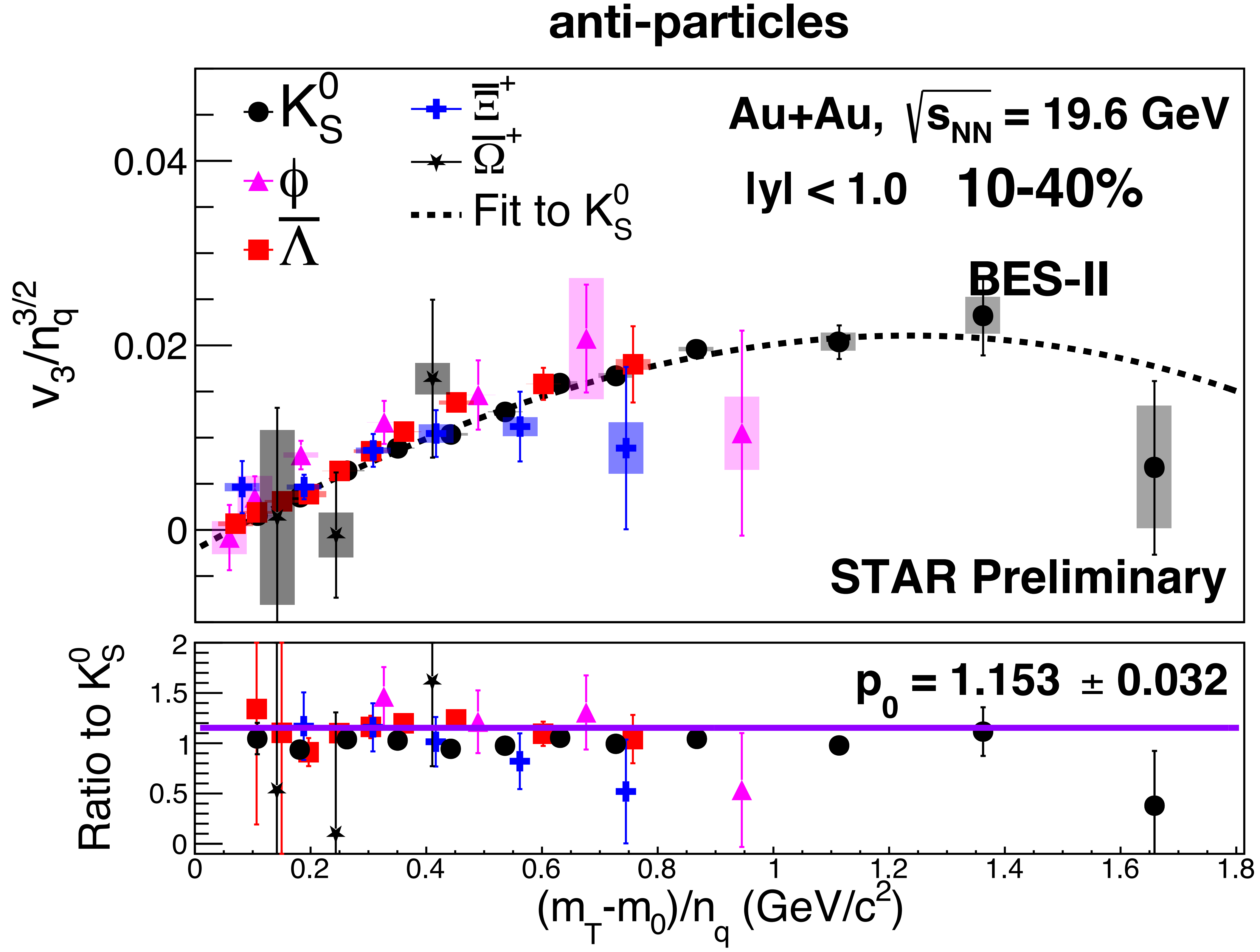
☞ Better NCQ scaling for anti-particles than particles: Contribution of transported quarks in particles.

NCQ scaling : Partonic collectivity in the initial stage of the system and hadronization via coalescence.

Results

NCQ scaling at 19.6 GeV





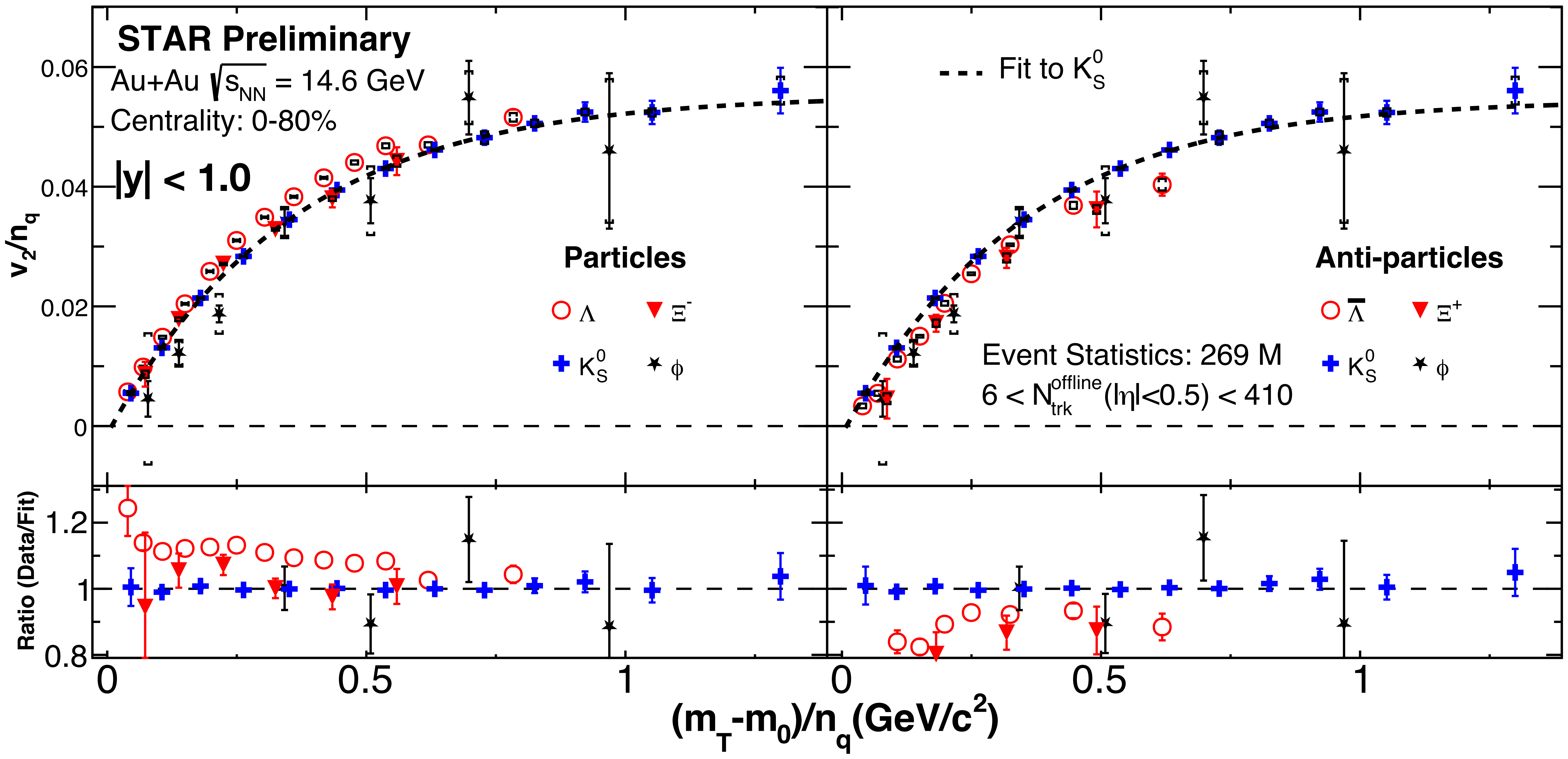
⭑ p_0 is the parameter from the simultaneous 0^{th} order polynomial fit to the ratios.

☞ 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 at 14.6 GeV



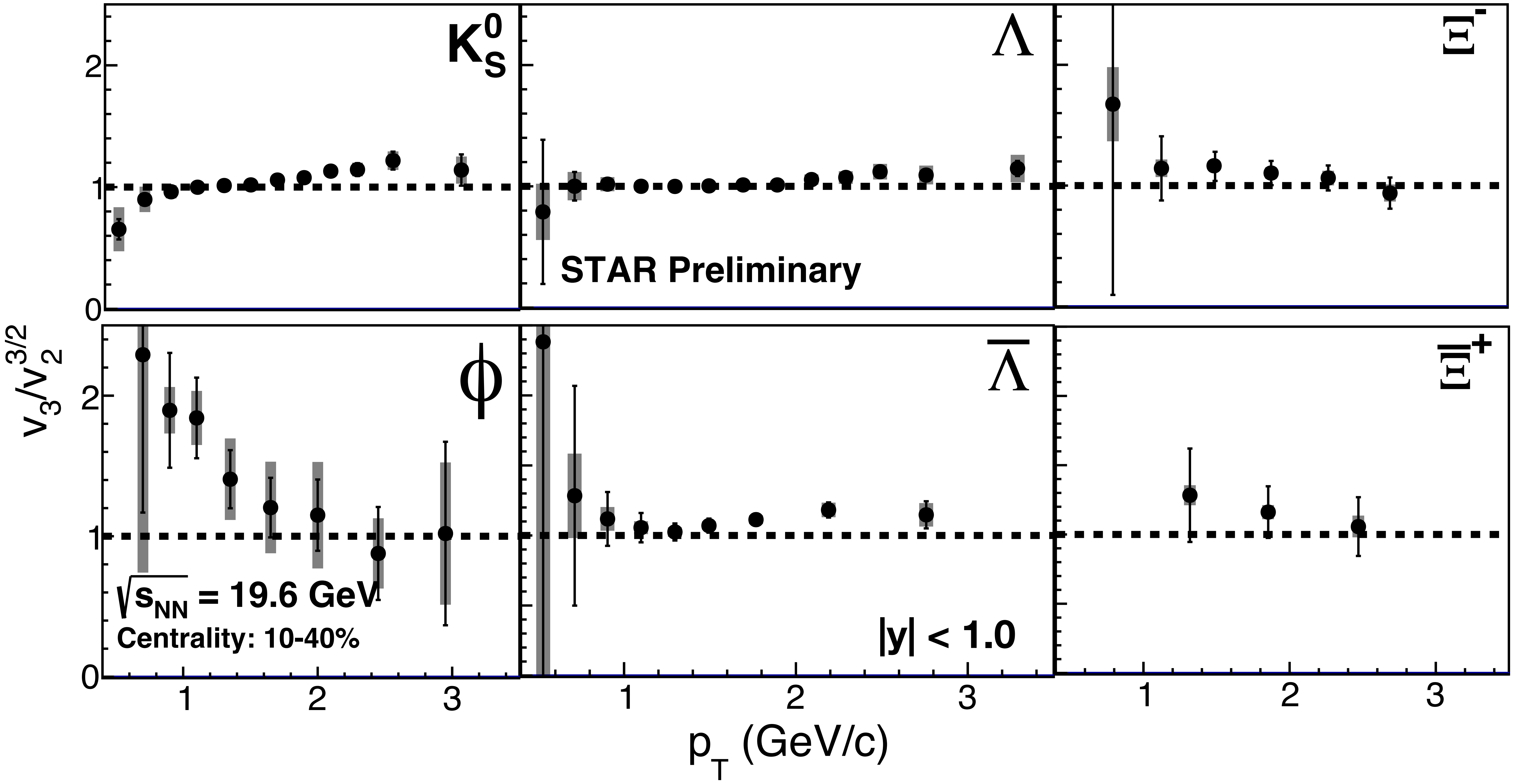
☞ NCQ scaling holds within 20%

⋆ Measurements in finer centrality bin is underway.

Results

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

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



- ☞ The ratio $v_3/v_2^{3/2}$ shows weak p_T dependence above $p_T > 1.0$ GeV/c.
- ☞ $v_3/v_2^{3/2}$ ratios are sensitive to the initial state fluctuations and transport properties of the medium.

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

Summary

p_T dependence of v_2

☞ Mass ordering at low p_T : Radial flow

☞ Bayon-meson separation at high p_T : Coalescence model of hadronization

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

☞ NCQ scaling holds: Partonic collectivity in the initial stage.

☞ The scaling is better for anti-particles than particles: Effect of transported quarks in the particles.

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