

Anisotropic flow measurements of identified hadrons in Au+Au collisions in BES-II energies at STAR

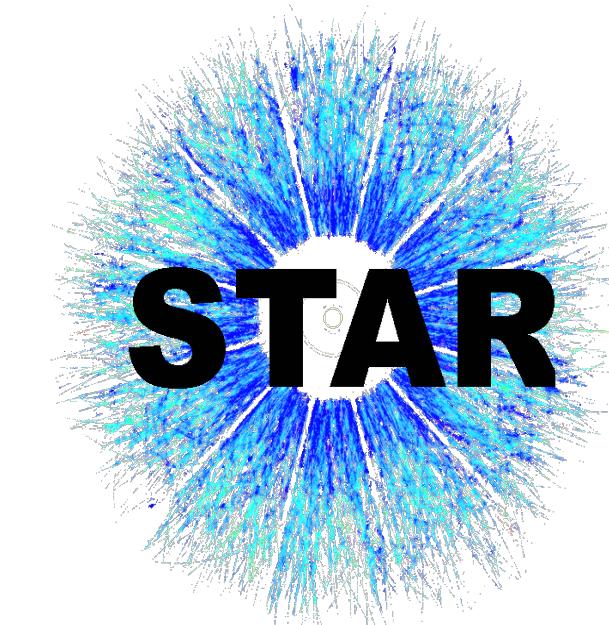
Prabhupada Dixit
(for the STAR collaboration)

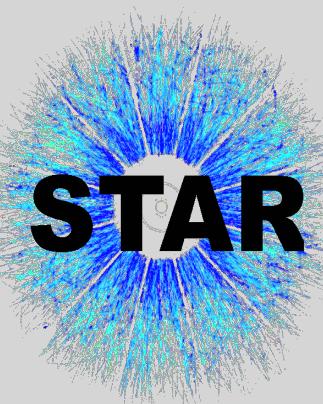
Indian Institute of Science Education and Research (IISER), Berhampur

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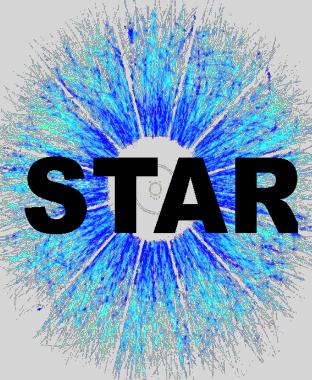
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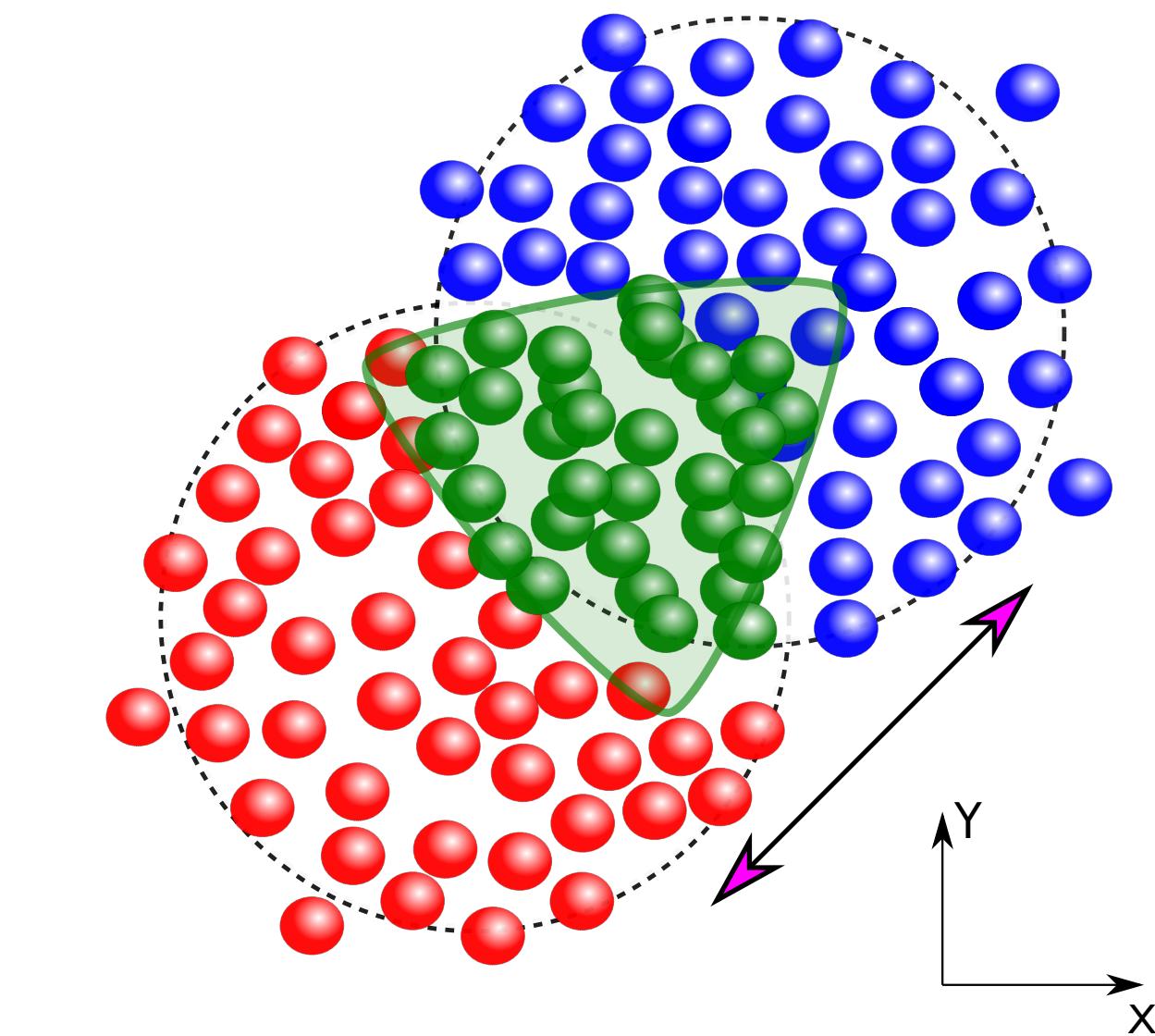
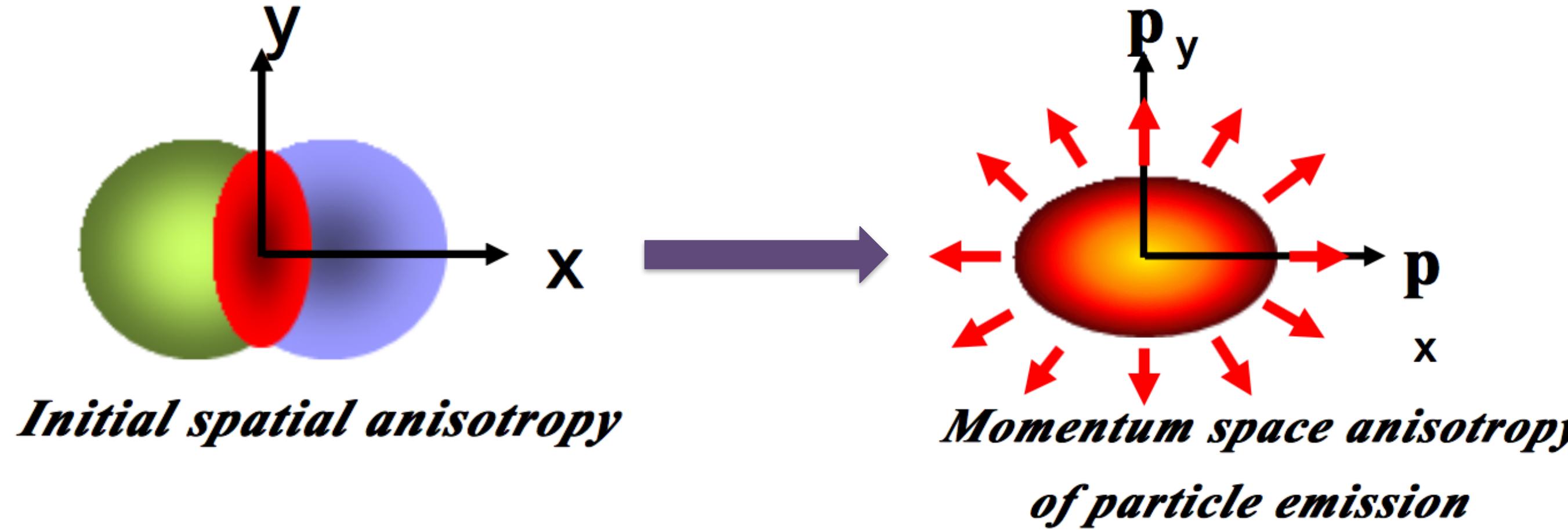
Outline

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- ❖ Motivation
- ❖ STAR detectors
- ❖ Analysis details
- ❖ Results
 - ★ p_T dependence of v_n
 - ★ Centrality dependence
 - ★ NCQ Scaling
- ❖ Summary



Introduction

What is azimuthal anisotropy ?

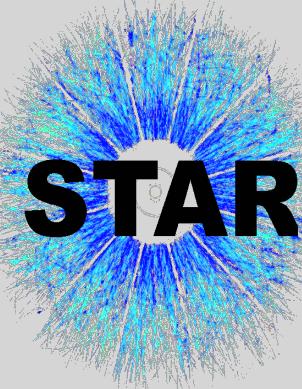


Elliptic flow coefficient (v_2) : Medium response to the initial spatial anisotropy (dominant source) + Event-by-event fluctuations

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

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

Where R is the resolution of the nth order event-plane



Motivation

Quark coalescence model of hadronization

R. J. Fries, B. Müller, C. Nonaka, and S. A. Bass, Phys. Rev. C 68, 044902 (2003)

$$v_2^{\text{hadron}}(p_T) = n \times v_2^{\text{quarks}}(p_T/n)$$

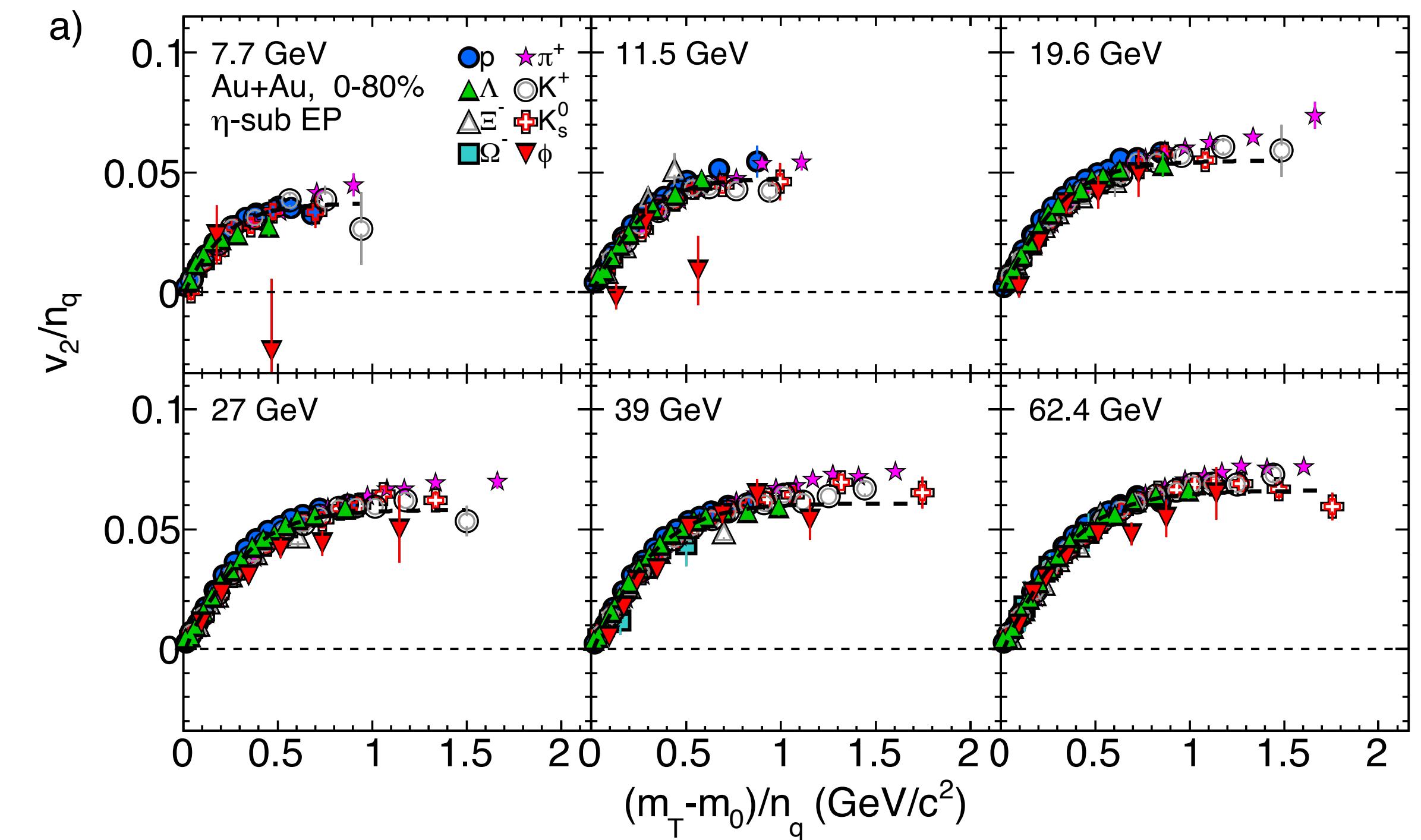
Where n is the number of constituent quarks of the hadron

$v_2^{\text{hadron}}/n \rightarrow v_2 \text{ of constituent quarks}$

Number of constituent quark scaling \rightarrow Partonic collectivity

Results from RHIC BES-I

STAR Phys. Rev. C 88 (2013) 14902



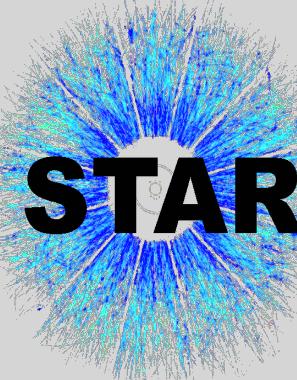
👉 ϕ mesons seem to deviate from the NCQ scaling at $\sqrt{s_{\text{NN}}} < 19.6 \text{ GeV}$.

Domination of hadronic degrees of freedom?

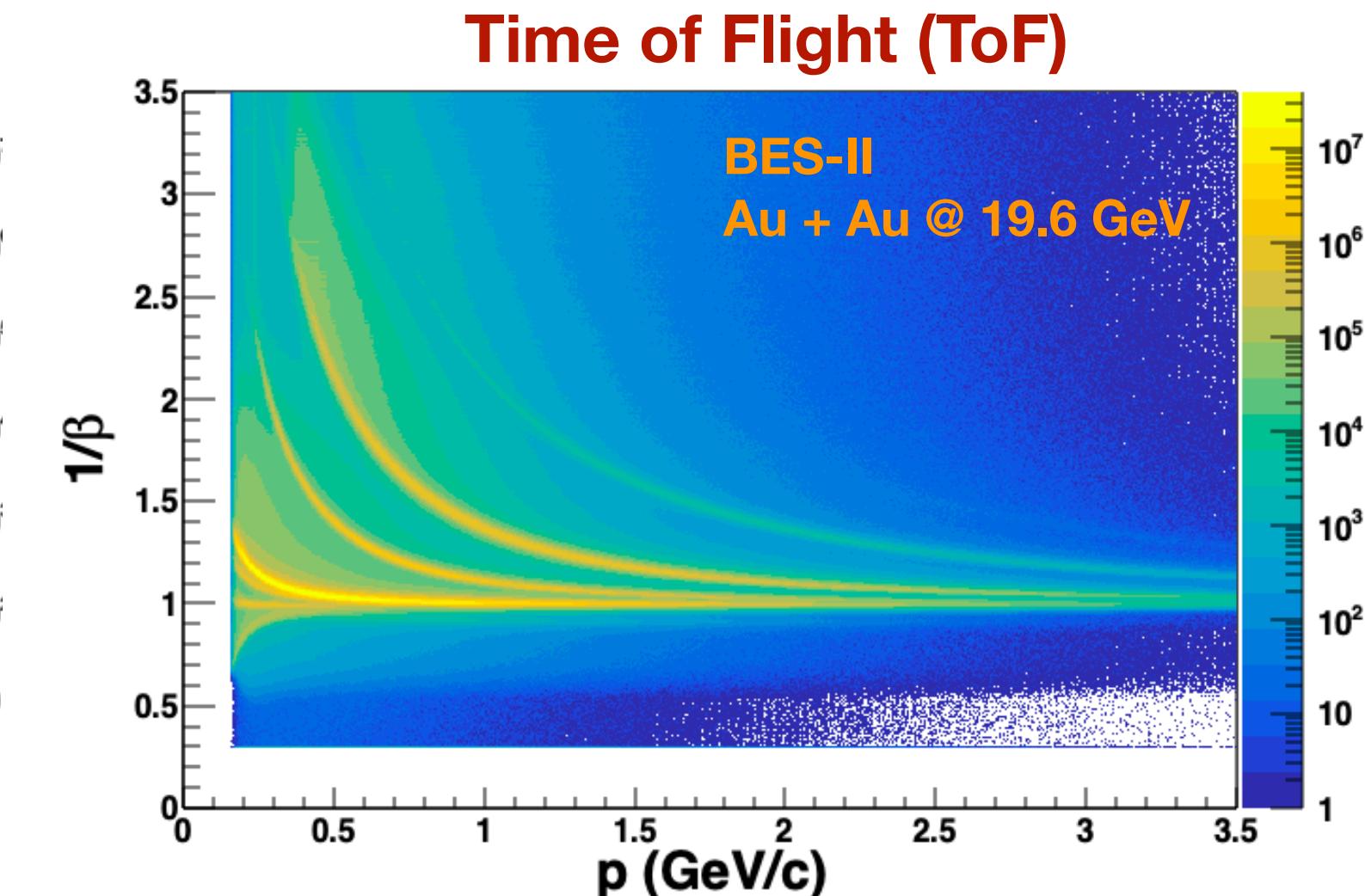
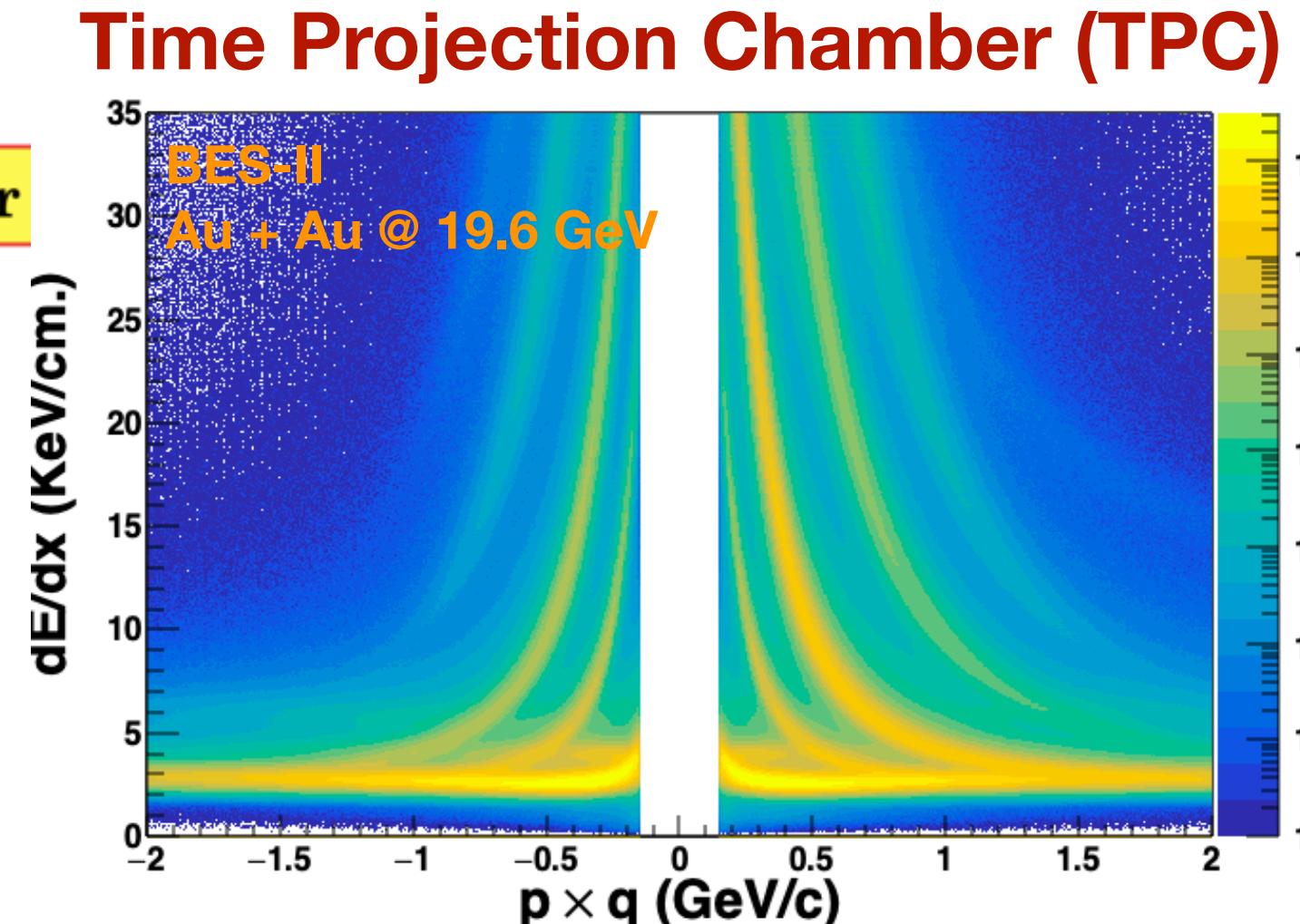
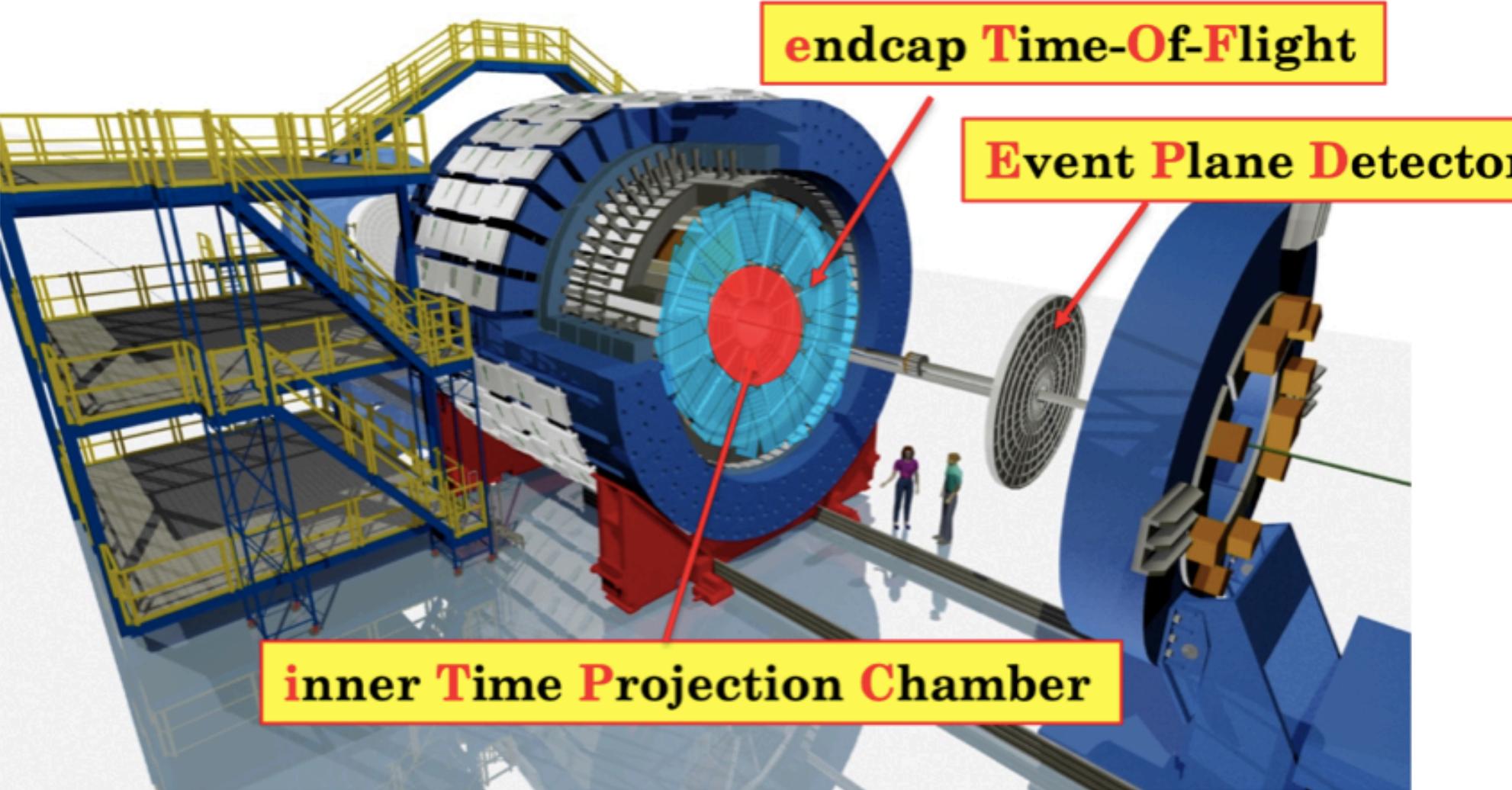
Turn off of QGP ?

Do not have significant statistics in BES-I to make any conclusion.

High statistics measurement under improved detector conditions in BES-II will shed light on this low energy region.



STAR detectors



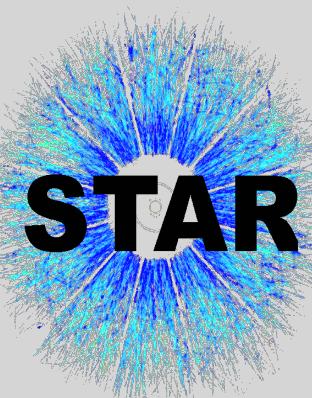
- Full azimuthal coverage
- Excellent particle identification Capability

BES-II iTPC upgrades

- 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 after cuts: ~380M (19.6 GeV, $|V_z| < 70$ cm.) & ~400M (14.6 GeV, $|V_z| < 140$ cm.)



Analysis techniques

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

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

Event plane determination

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

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

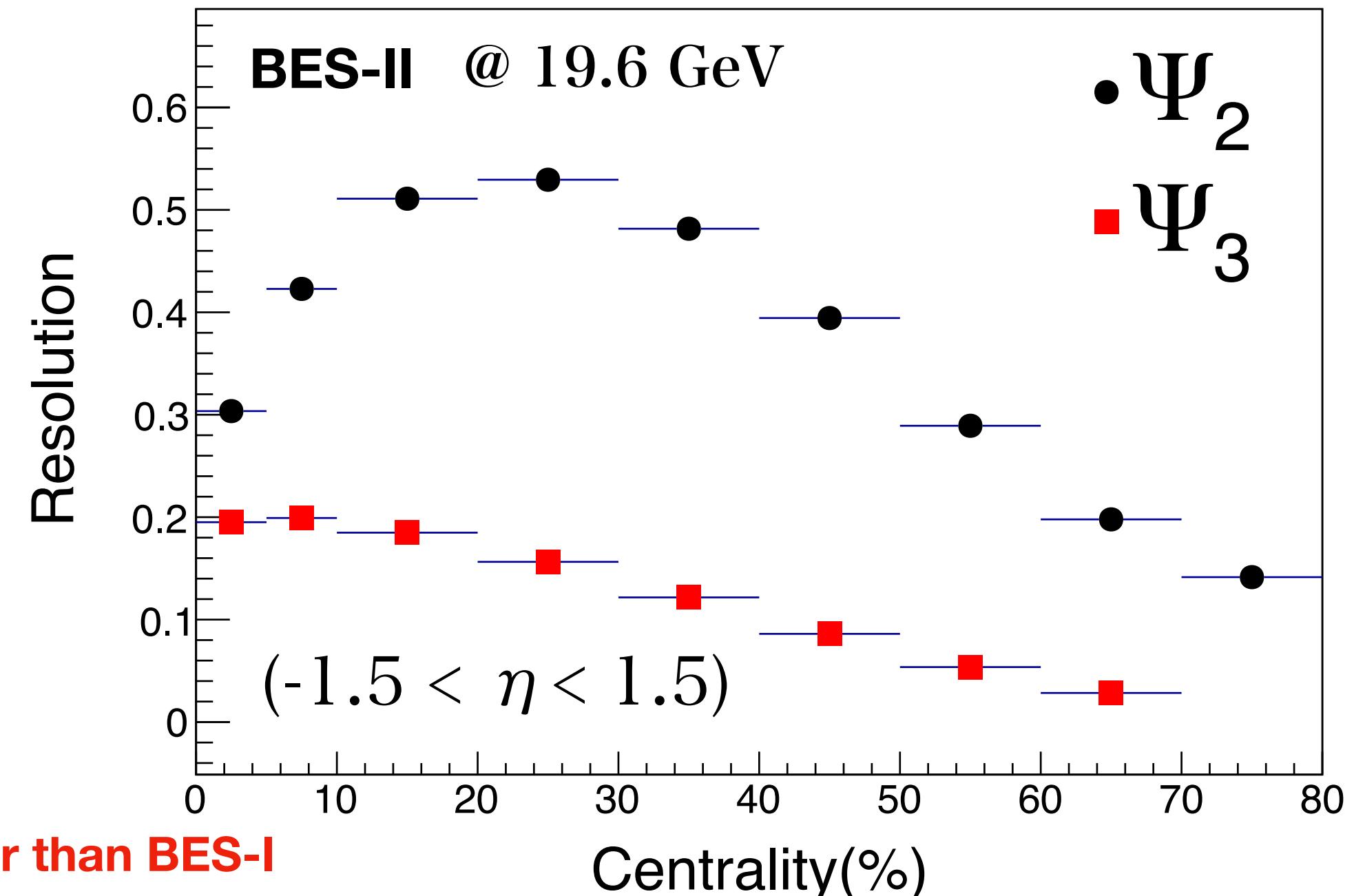
Where the weight factor $w_i = p_T \times \phi\text{-weight}$.

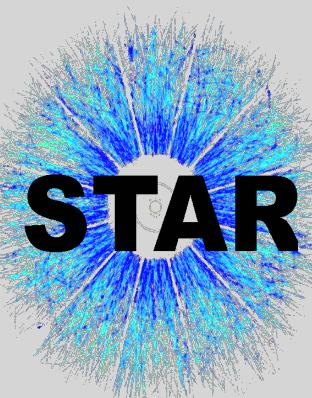
$\phi\text{-weight}$: accounts for the azimuthal acceptance correction of the detectors.

Event plane resolution

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

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



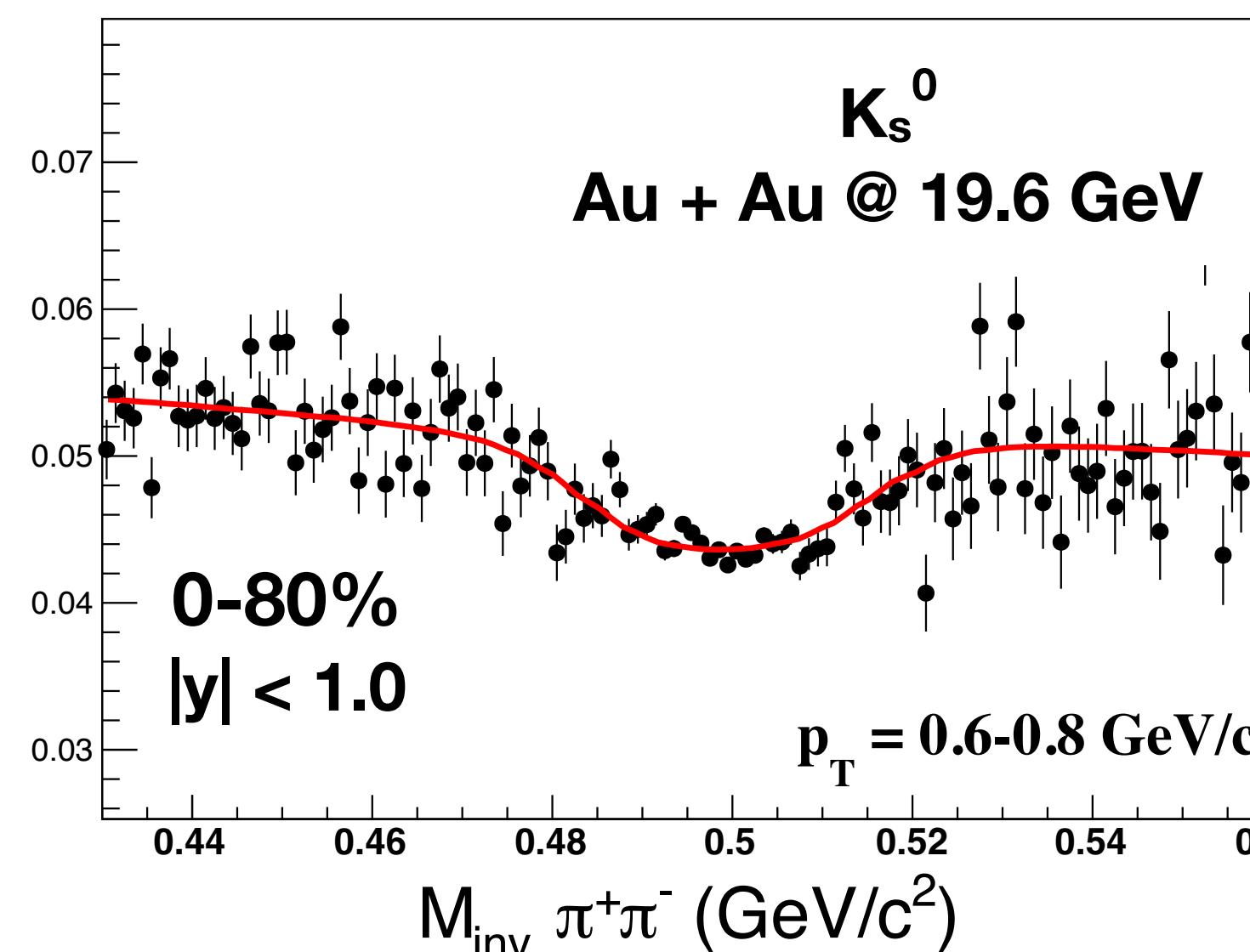
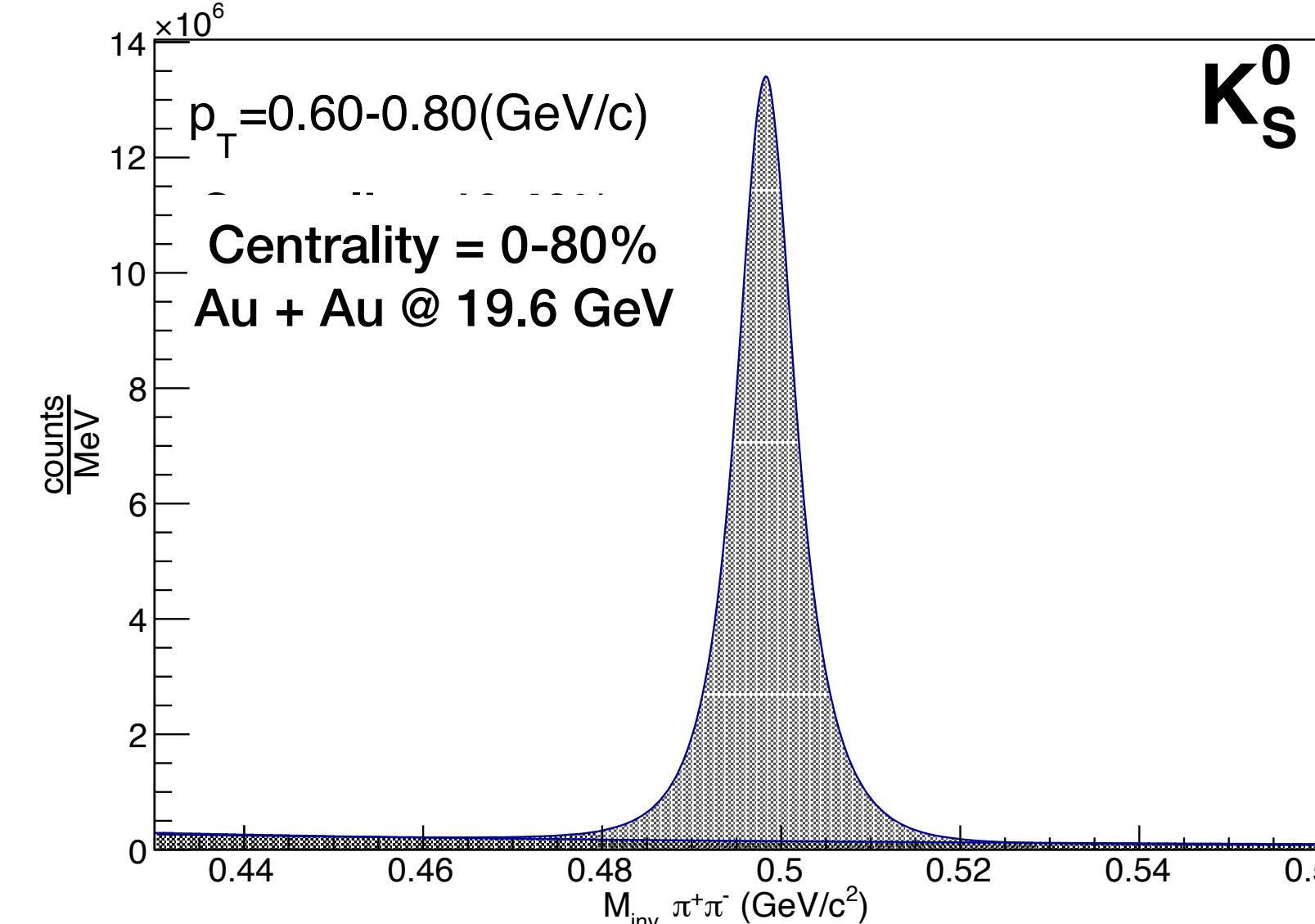


Analysis techniques

V_n measurements

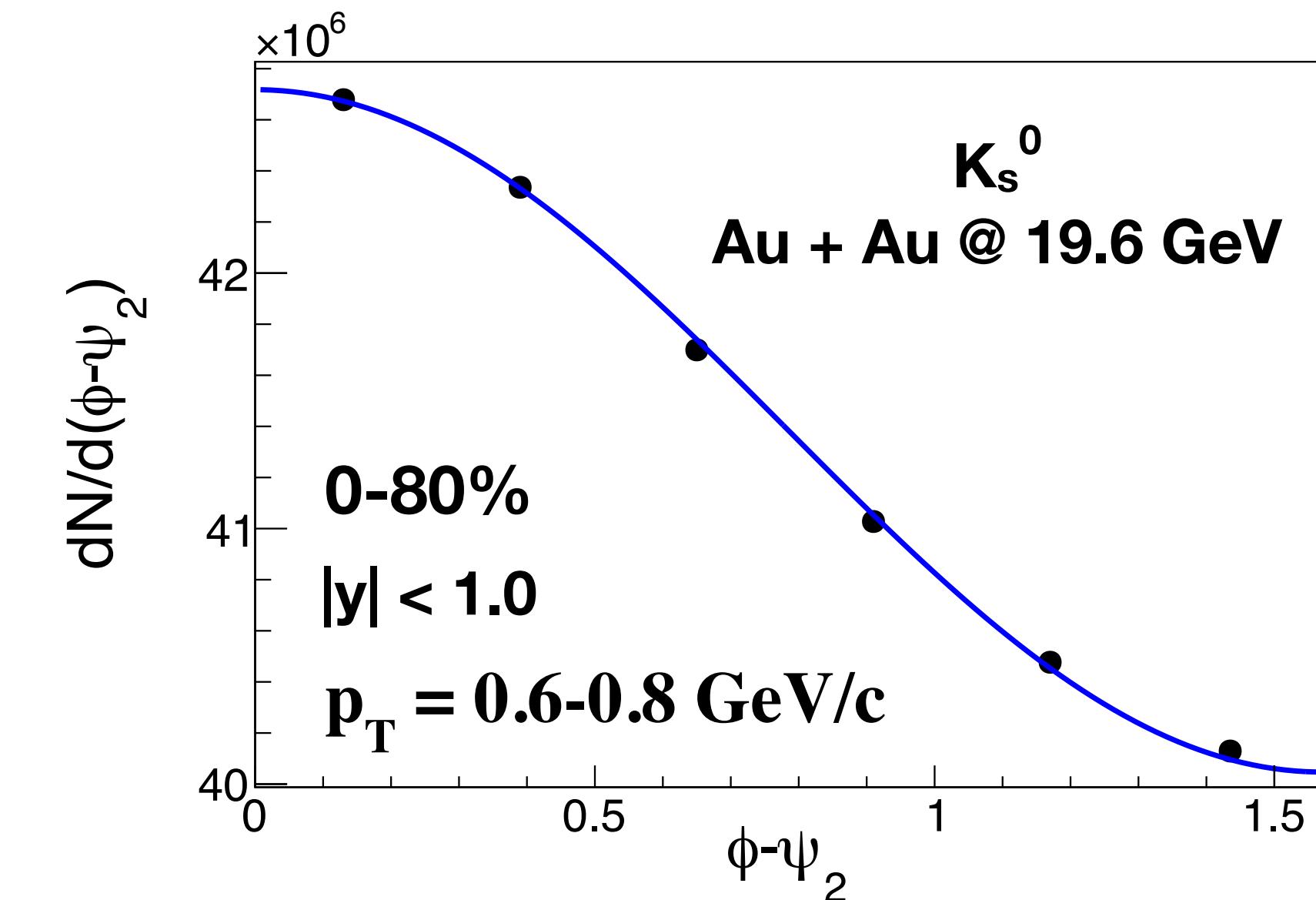
Invariant mass method

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)

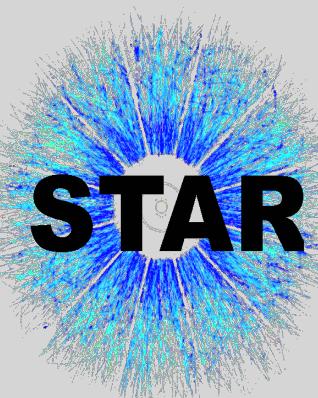


$$v_n^{S+B}(M_{inv}) = v_n^S \frac{S}{S+B}(M_{inv}) + v_n^B \frac{B}{S+B}(M_{inv})$$

$$v_n^B(M_{inv}) = p_0 + p_1 M_{inv} \quad v_n^S \rightarrow \frac{v_n^S}{R_n}$$

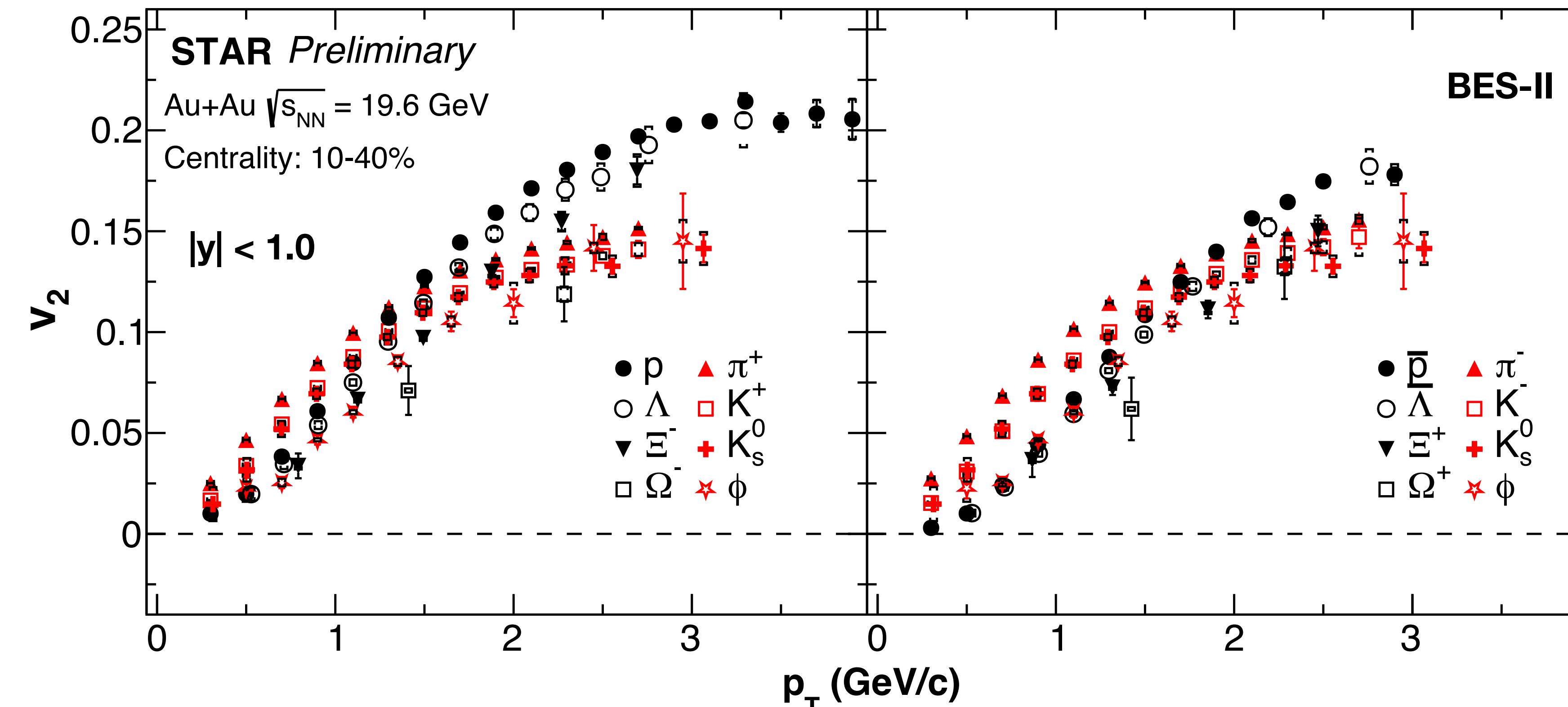
$$\frac{dN}{d(\phi - \psi_n)} = \frac{N_0}{2\pi} (1 + v_n^{obs} \cos n(\phi - \psi_n))$$

$$v_n = \frac{v_n^{obs}}{R_n(sub)}$$



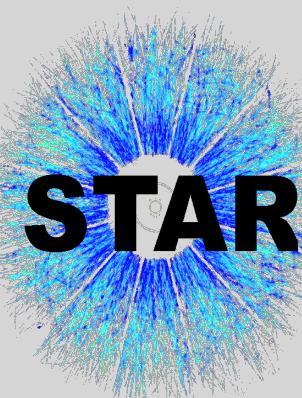
Results

p_T dependence of v_2



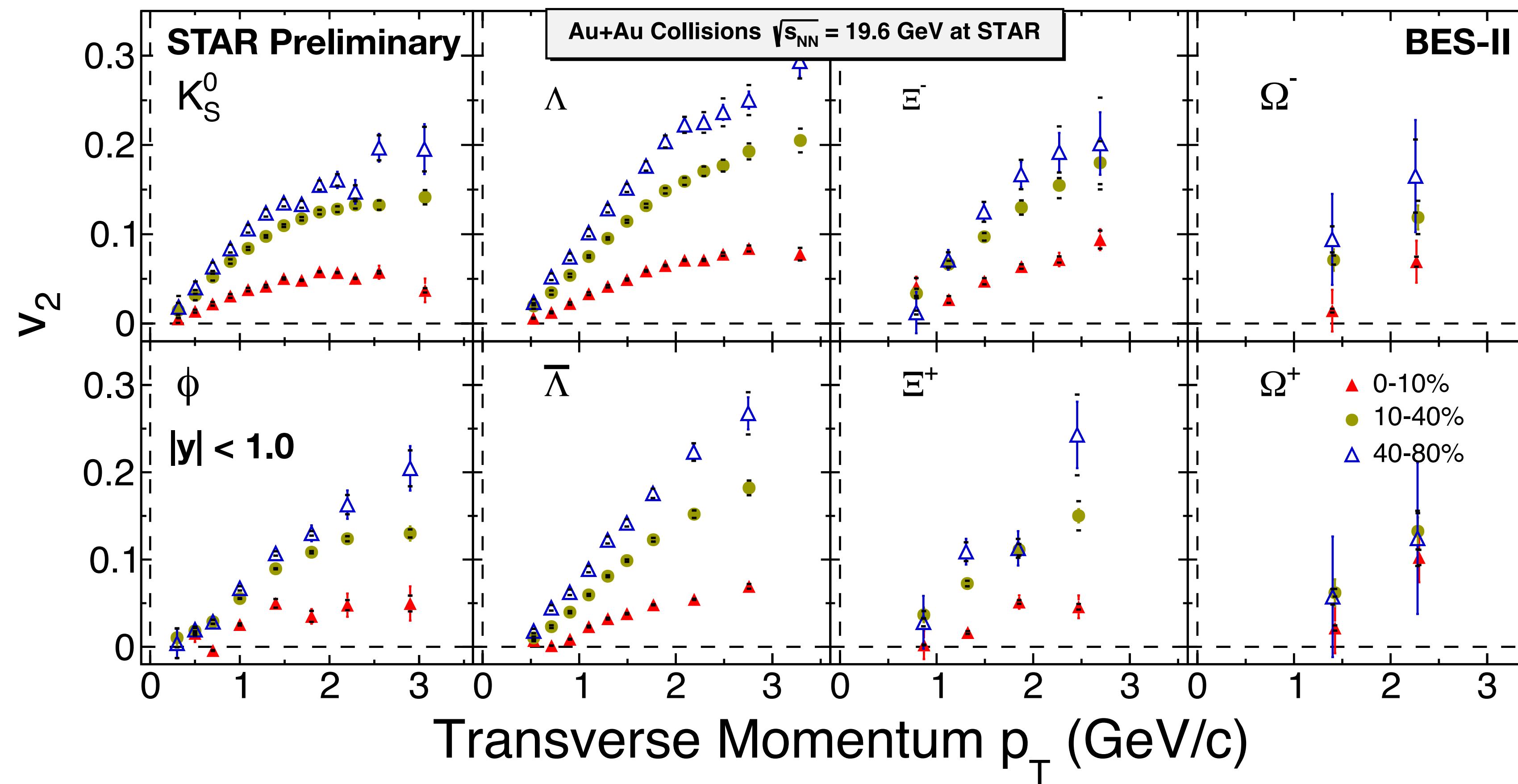
- ☞ Mass ordering observed in the low p_T region ($p_T < 1.5 \text{ GeV}/c$) : **Radial flow**
- ☞ Baryon to meson separation observed in the high p_T region : **Quark coalescence**

★ The statistical uncertainties are reduced by a factor of ~3 compared to BES-I.

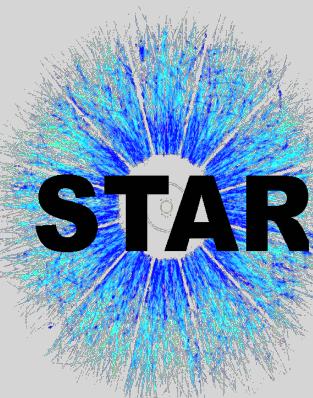


Results

Centrality dependence of v_2

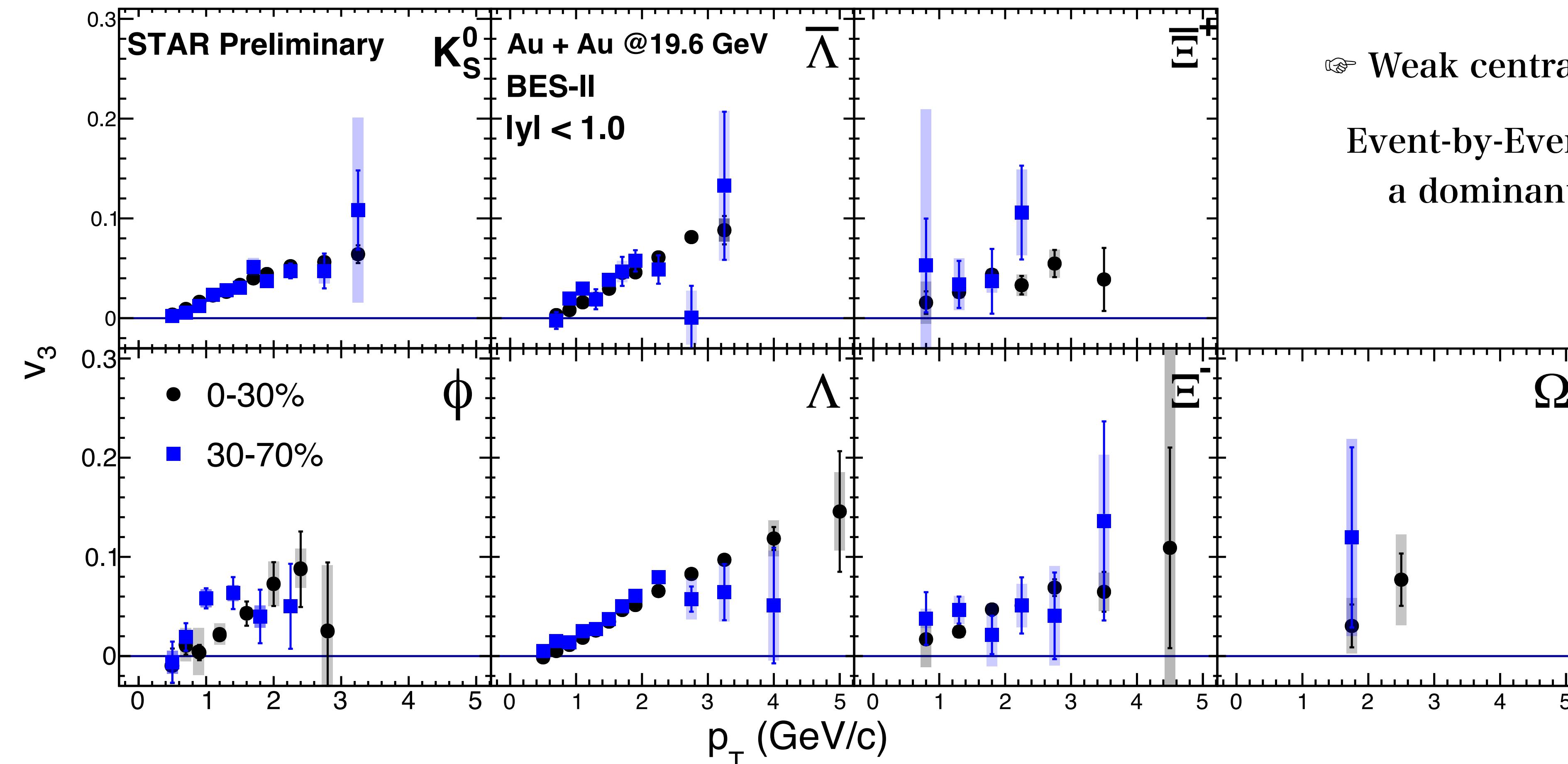


Strong centrality dependence of v_2
Spatial anisotropy is a dominant cause for v_2

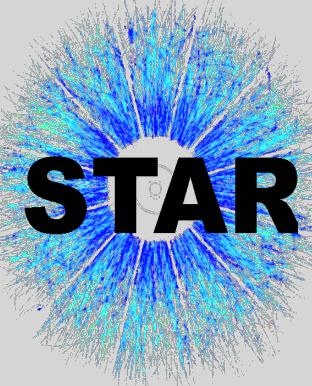


Results

Centrality dependence of v_3

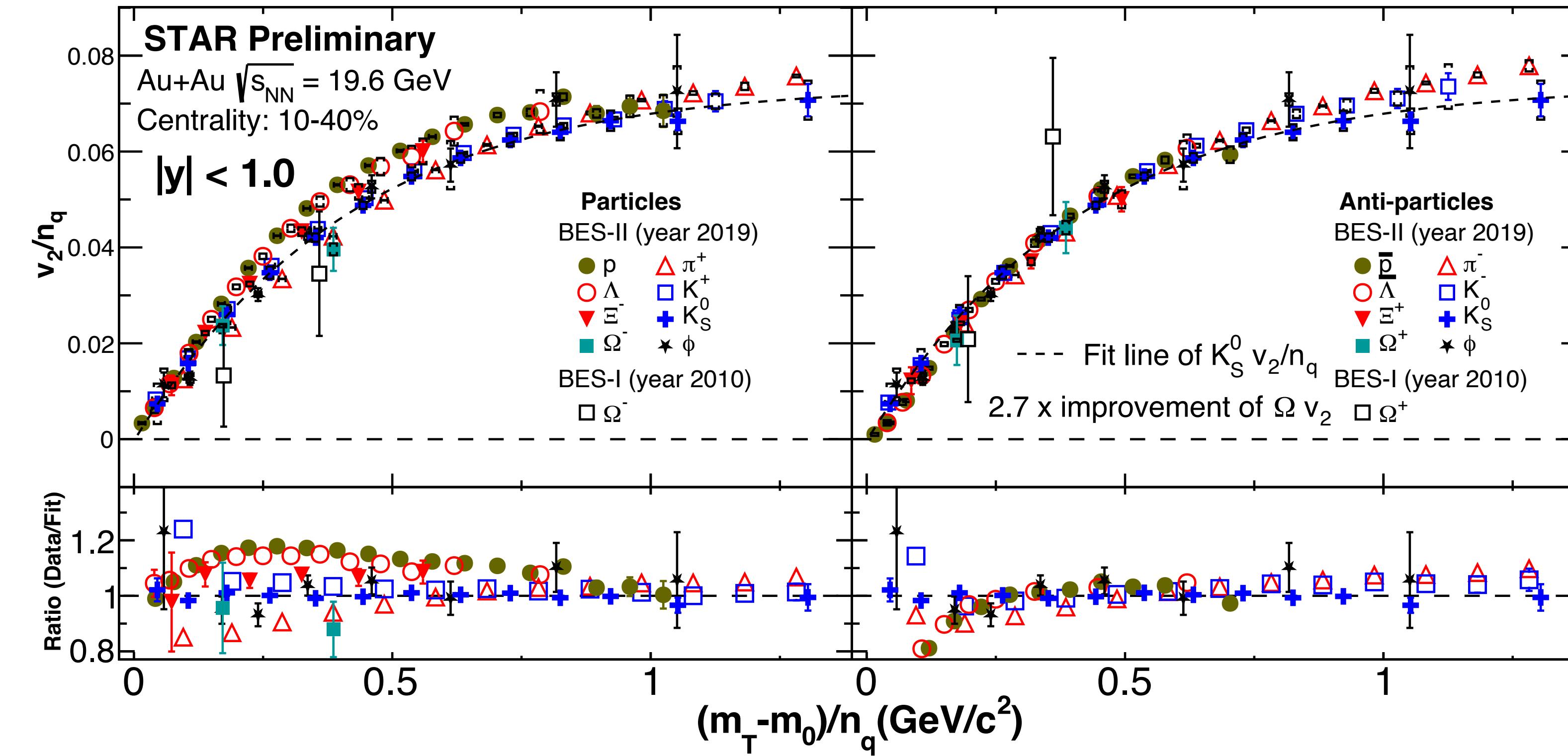


Weak centrality dependence of v_3
Event-by-Event fluctuation is
a dominant cause for v_3



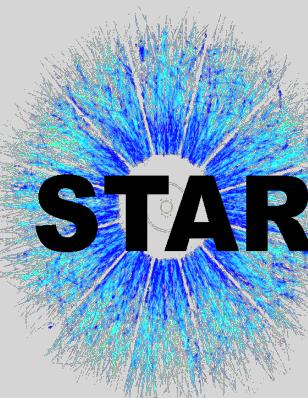
Results

NCQ scaling at 19.6 GeV



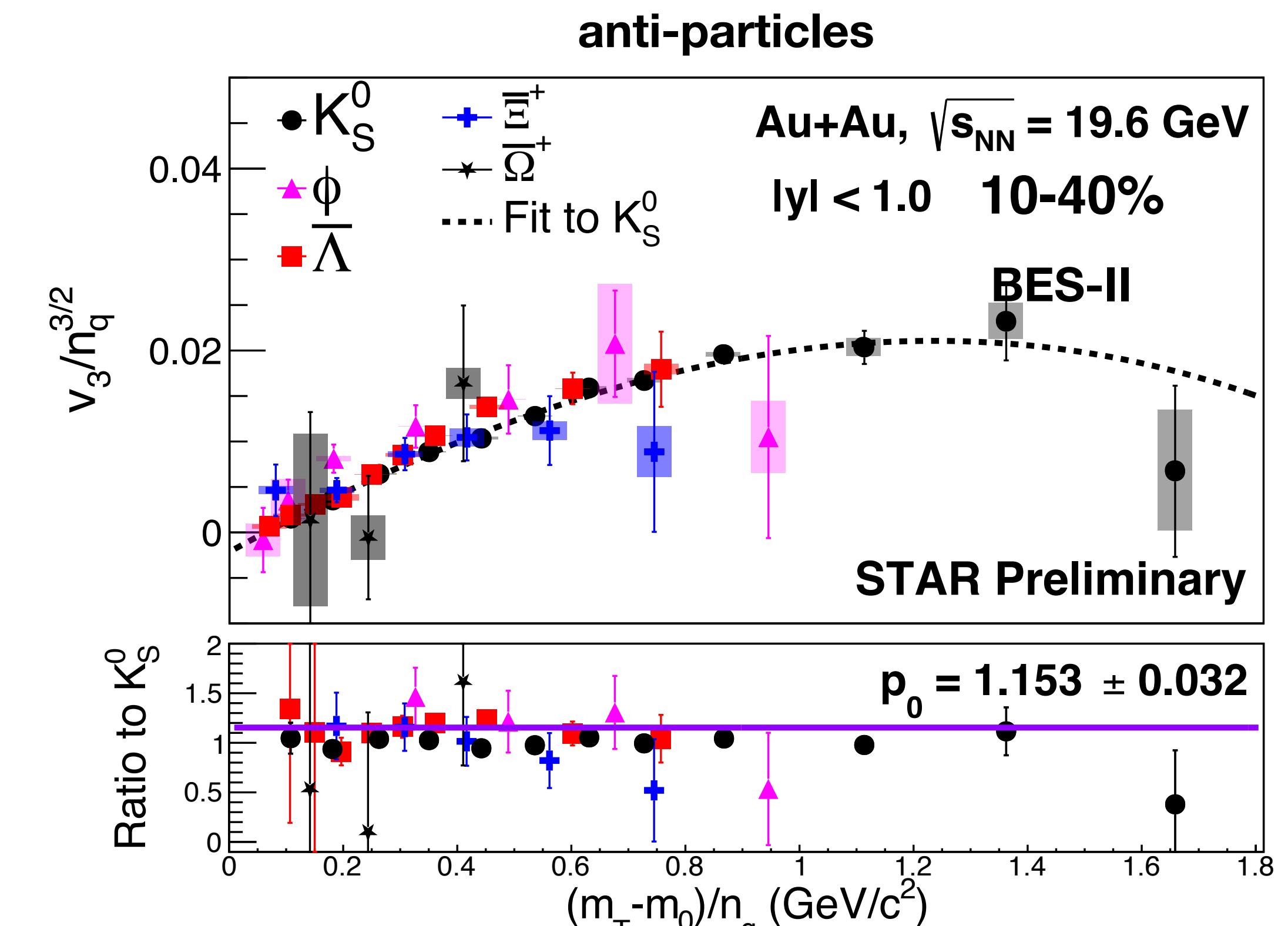
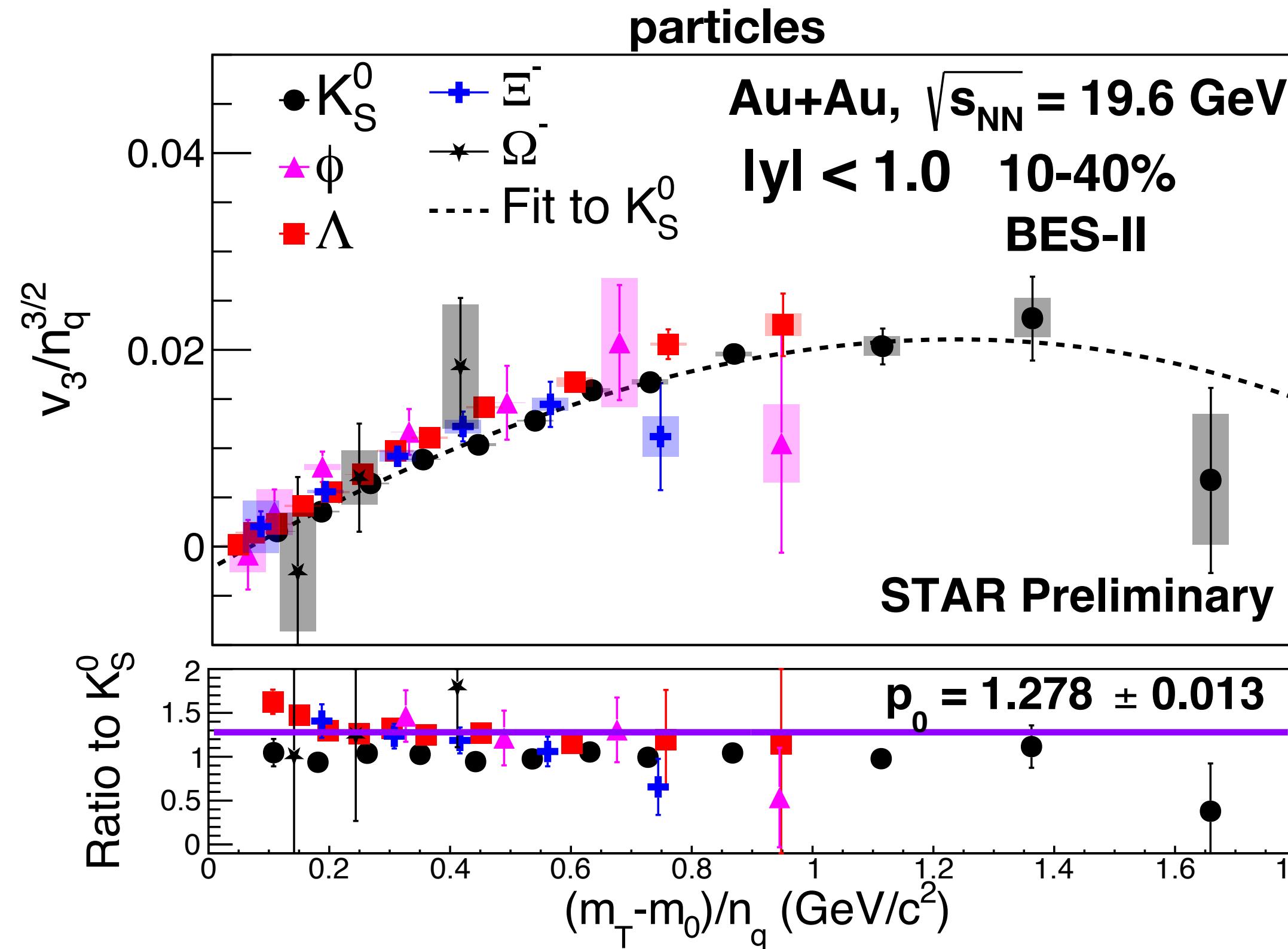
- ☞ The scaling for v₂ holds within 20% for particles and within 10% for anti-particles.
- ☞ Better NCQ scaling for anti-particles than particles: **Contribution of transported quarks in particles.**

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



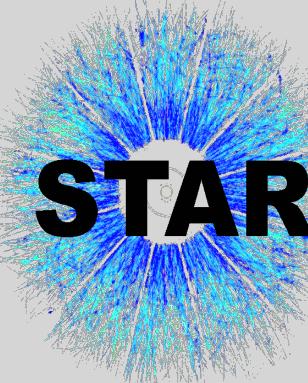
Results

NCQ scaling at 19.6 GeV



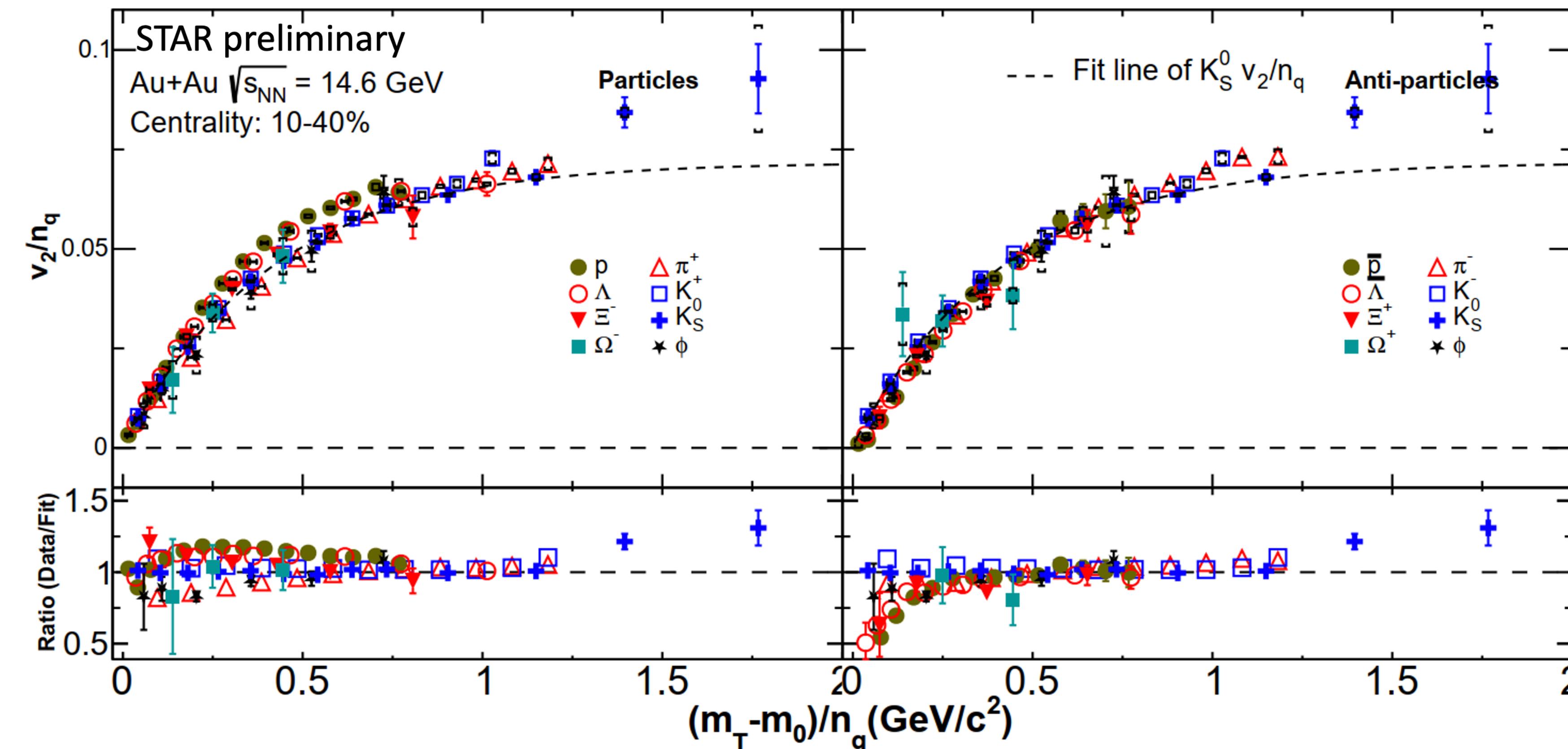
★ p_0 is the parameter from the simultaneous 0th order polynomial fit to the ratios.

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

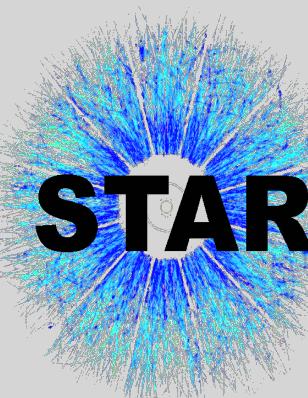


Results

NCQ scaling at 14.6 GeV

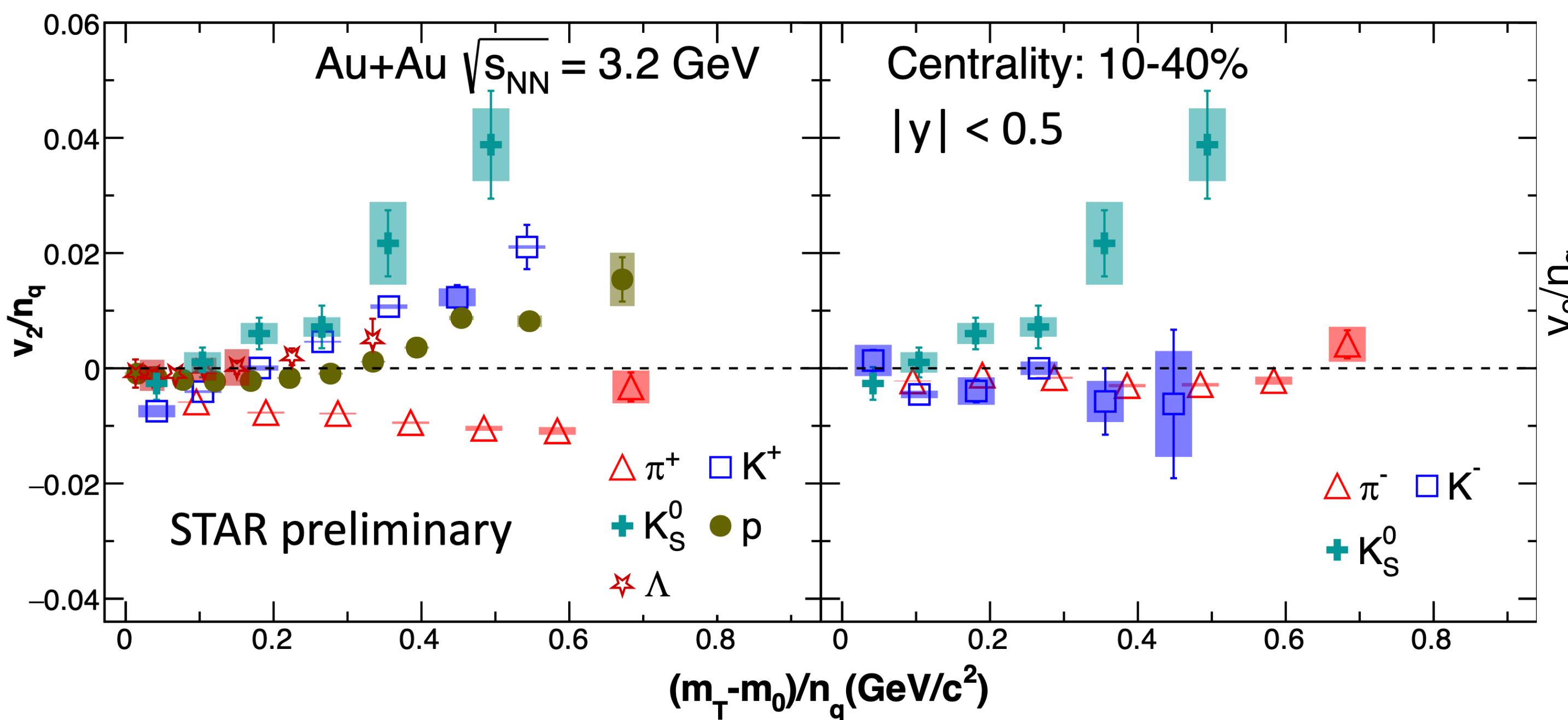


NCQ scaling holds within 15% for anti-particles and 25% for particles : Partonic dominance at 14.6 GeV

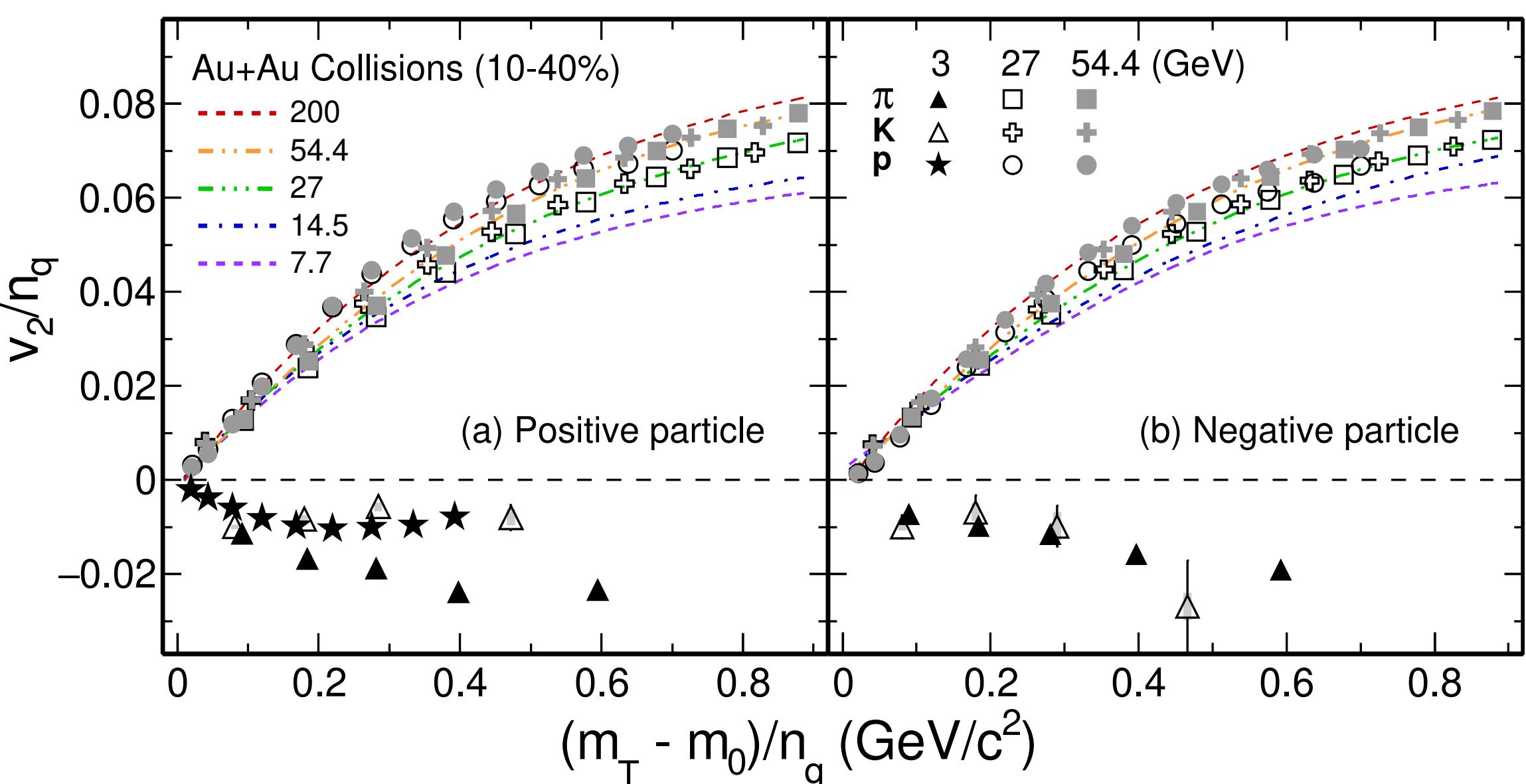


Results

Presented in QM-2023

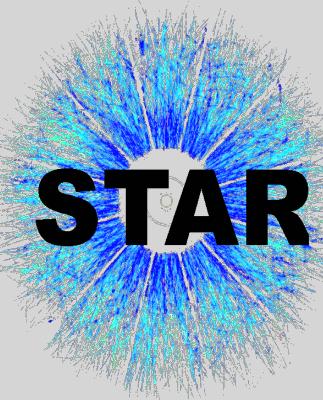


Published result at 3 GeV **STAR Phys. Lett. B 827 (2022) 137003**



Breaking of NCQ scaling at 3.2 GeV and below.

 Dominance of hadronic degrees of freedom.



Summary

p_T dependence of v₂

- ☞ Mass ordering at low p_T : Radial flow
- ☞ Bayon-meson separation at high p_T : Coalescence hadronization

Centrality dependence of v_n

- ☞ Strong centrality dependence of v₂ : initial spatial anisotropy is a dominant cause for v₂.
- ☞ Weak centrality dependence of v₃: event-by-event fluctuation is a dominant cause for v₃.

NCQ scaling

- ☞ NCQ scaling holds in 19.6 and 14.6 GeV: Partonic collectivity in the initial stage.
- ☞ Φ meson follows NCQ scaling upto 14.6 GeV.
- ☞ Hadronic dominance of the medium at 3.2 GeV.
- ☞ The scaling is better for anti-particles than particles: Effect of transported quarks in the particles.
- ☞ Ongoing measurement at lower energies (7.7 and 9.2 GeV).

Thank you ...