Azimuthal anisotropy measurement of multi-strange hadrons in Au+Au collision at $\sqrt{s_{NN}} = 27$ and 54.4 GeV at STAR

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Strangeness in quark matter, 2021

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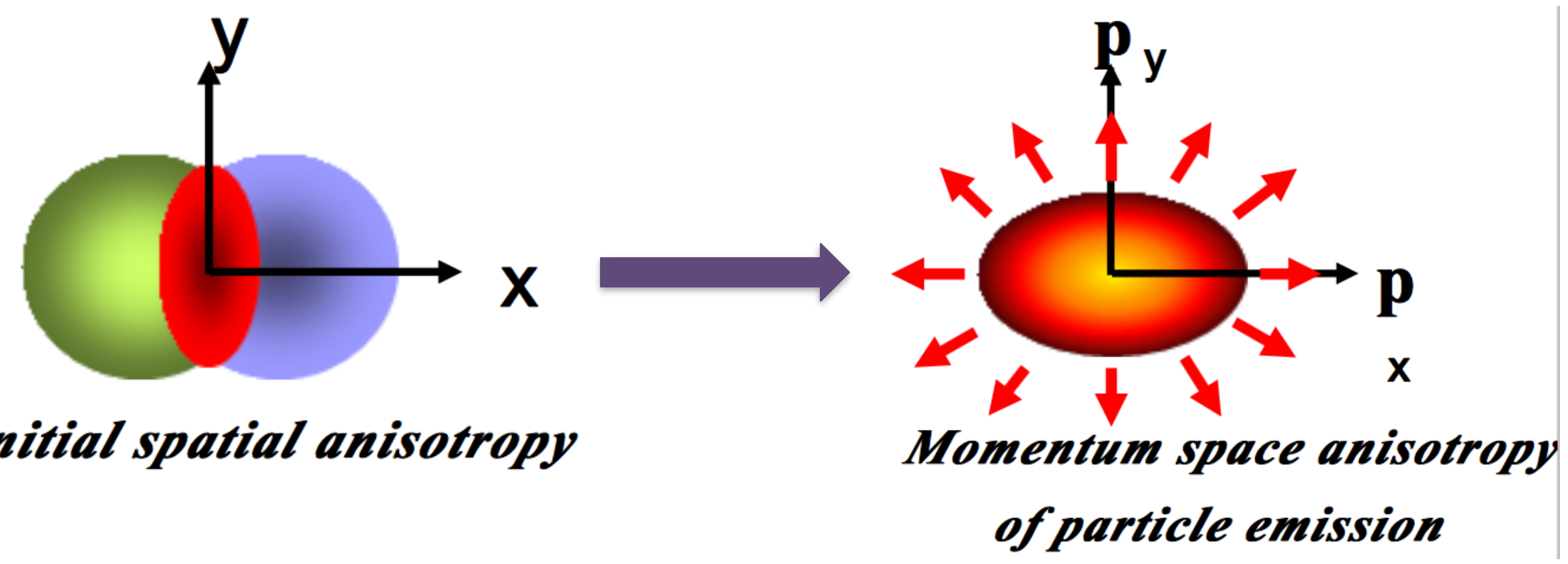
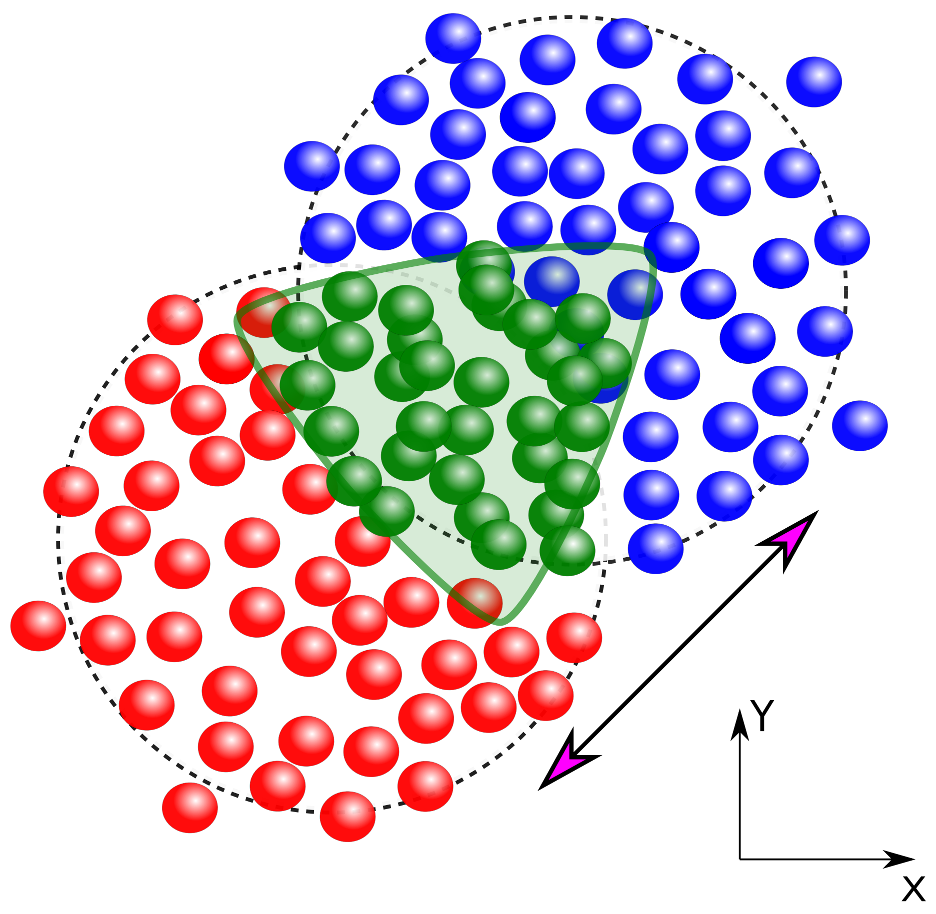
Introduction

What is azimuthal anisotropy ?





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

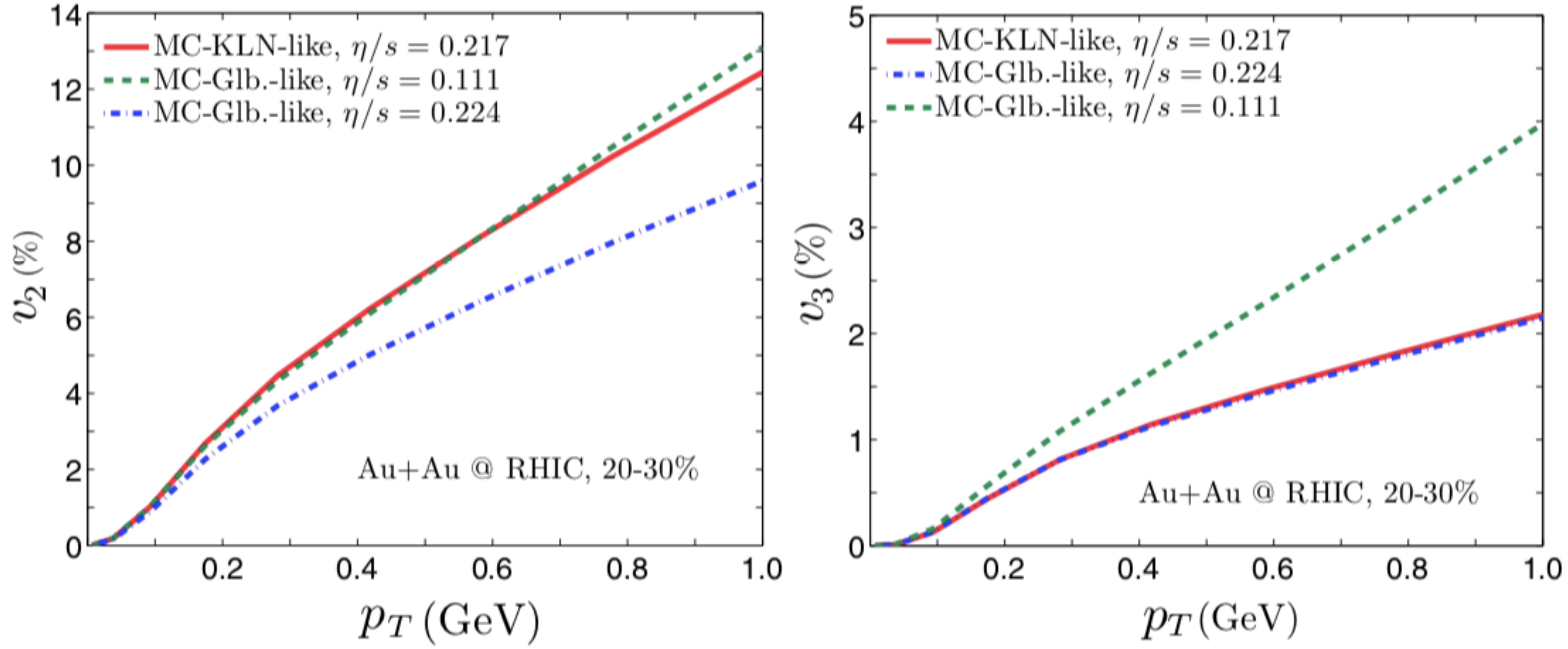
Triangular flow coefficient (v_3) : Event-by-event fluctuations in the overlap region

$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}[1 + 2v_1\cos(\phi - \Psi_R) + 2v_2\cos 2(\phi - \Psi_R) + ...]$$

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

Motivations

Why v_2 and v_3 are important ?



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

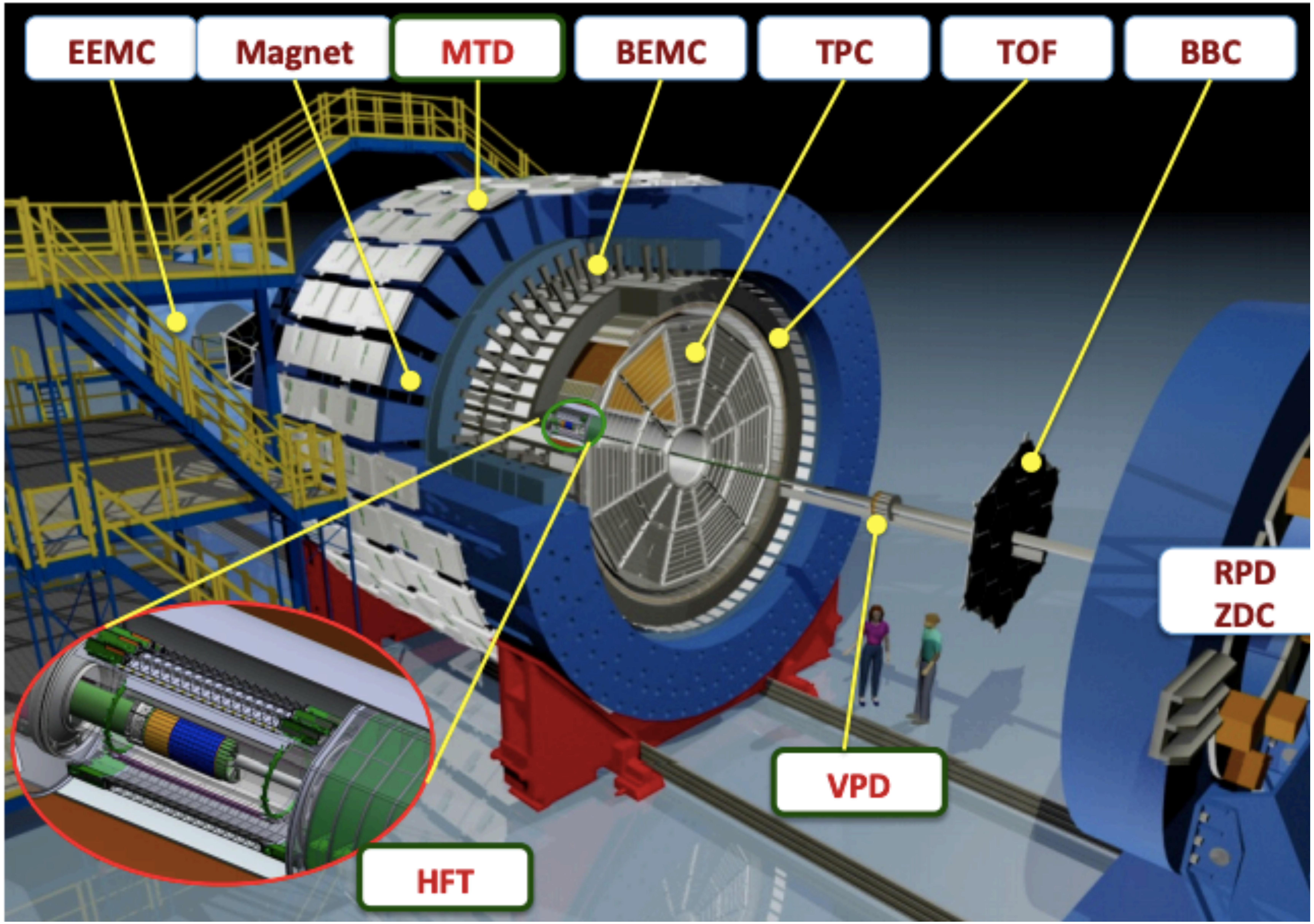
Simultaneous measurements of v_2 and v_3 are important to constrain η/s

Why multi-strange hadrons ?

- Early freeze out
- Small hadronic interaction cross section

→ Least affected by the hadronic phase of the system

STAR detectors



- Uniform Acceptance
- Full Azimuthal Coverage
- Excellent Particle Identification Capability

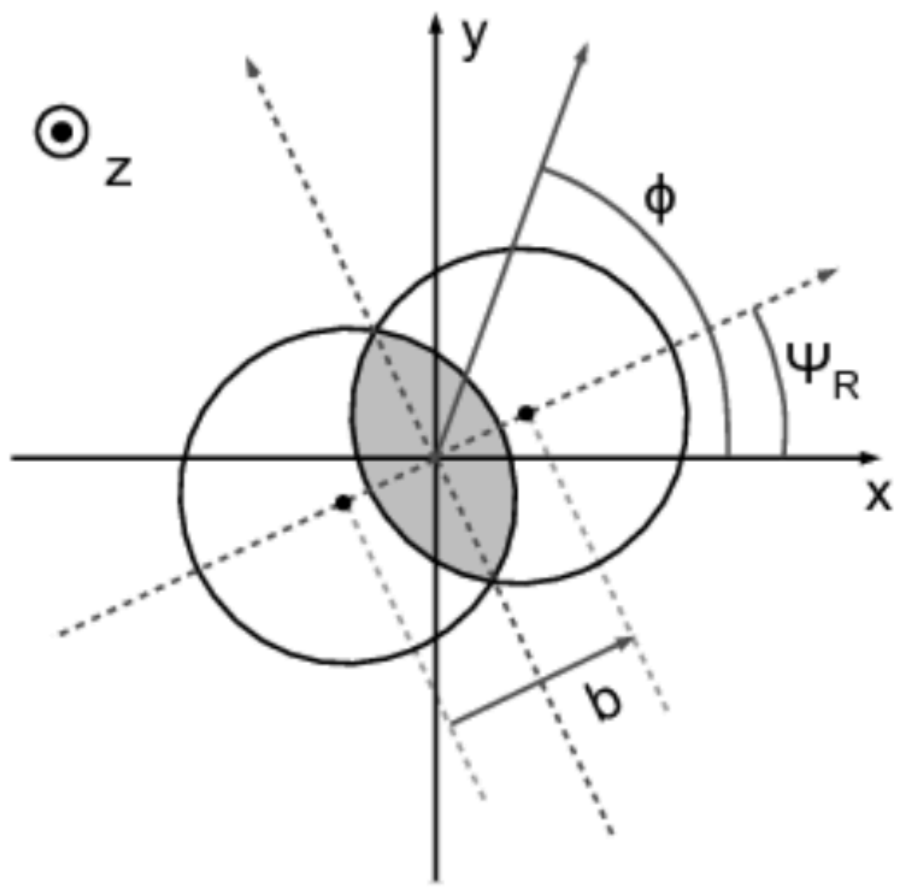
DATA SETS (Au+Au)

$\sqrt{s_{NN}}$	#events	Year
27 GeV	~ 300M	2018
54.4 GeV	~600M	2017

Particles in mid-rapidity ($|\eta| < 1$) region are used for analysis.

Analysis method

$v_n = \langle \cos n(\phi - \Psi_R) \rangle$ Ψ_R is the azimuthal angle of the reaction plane.



- The true 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

$$\psi_n = \frac{1}{n} \tan^{-1}\left(\frac{Q_{ny}}{Q_{nx}}\right),$$

$$Q_n \cos(n\psi_n) = Q_{nx} = \sum_{i=1}^{M} w_i \cos(n\phi_i),$$

$$Q_n \sin(n\psi_n) = Q_{ny} = \sum_{i=1}^{M} w_i \sin(n\phi_i),$$

Resolution

$\Psi_n \neq \Psi_R$

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

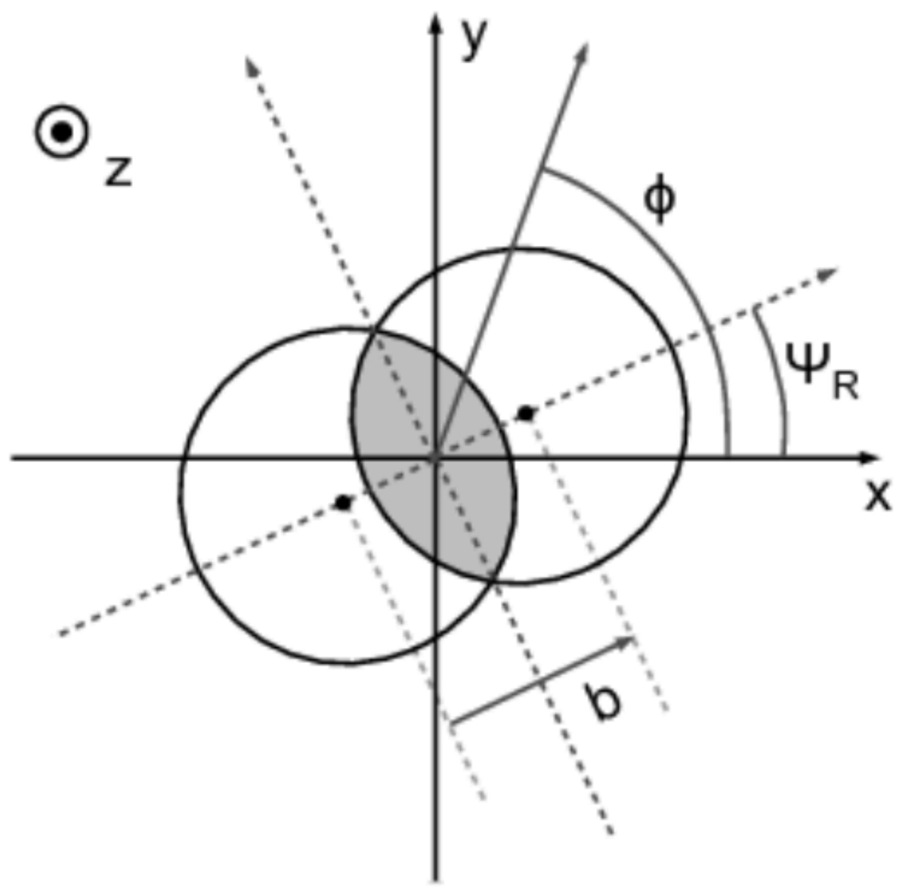
$$R_n(sub) = \sqrt{\langle \cos n(\Psi_A - \Psi_B) \rangle}$$

Ψ_A ($-1.0 < \eta < -0.05$) and Ψ_B ($0.05 < \eta < 1.0$) two sub-event planes.

Analysis method

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

Ψ_R is the azimuthal angle of the reaction plane.



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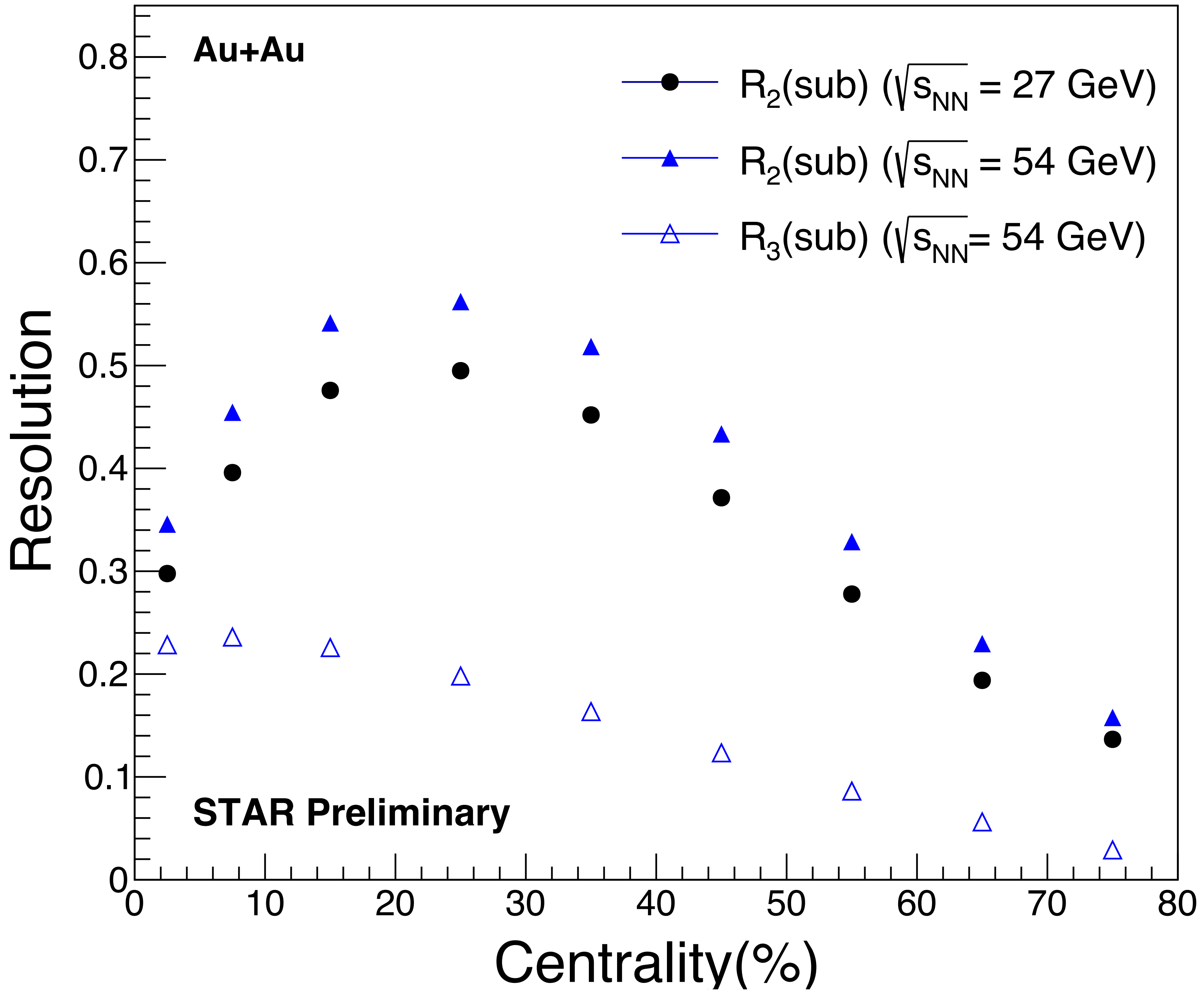
Resolution



Analysis method

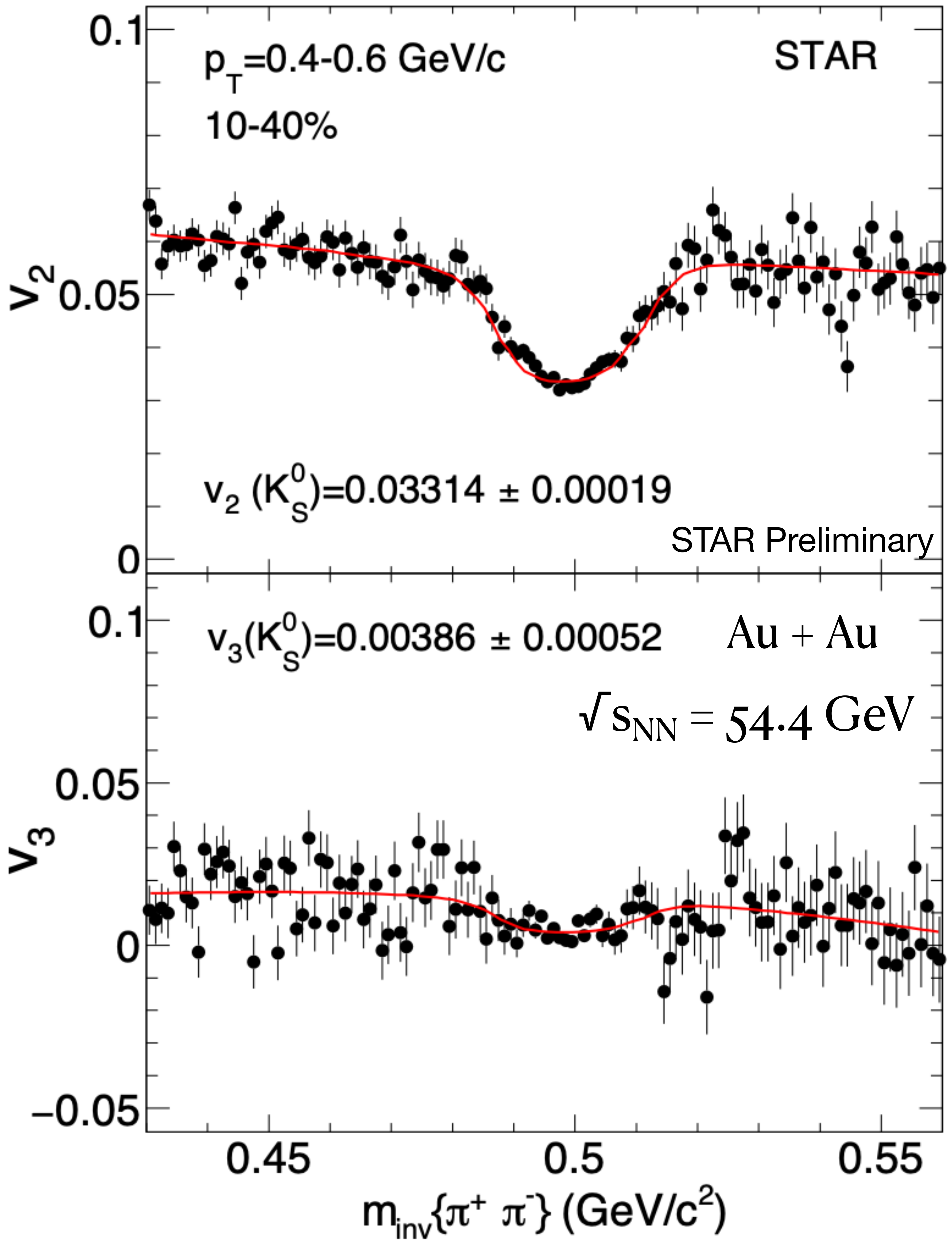
Invariant mass method for v_n

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

We assume

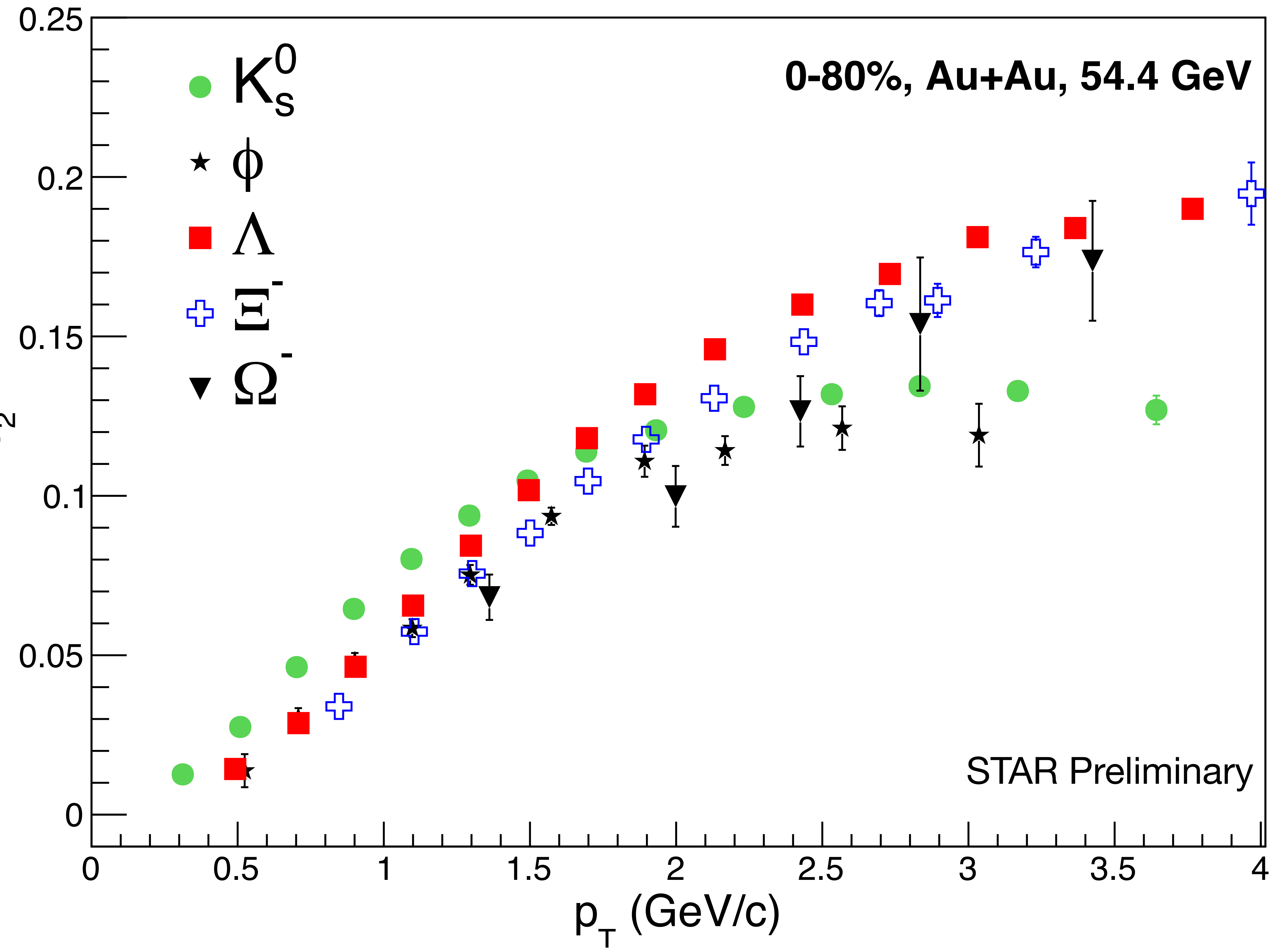
$$v_n^B(m_{inv}) = p_0 + p_1 m_{inv}$$

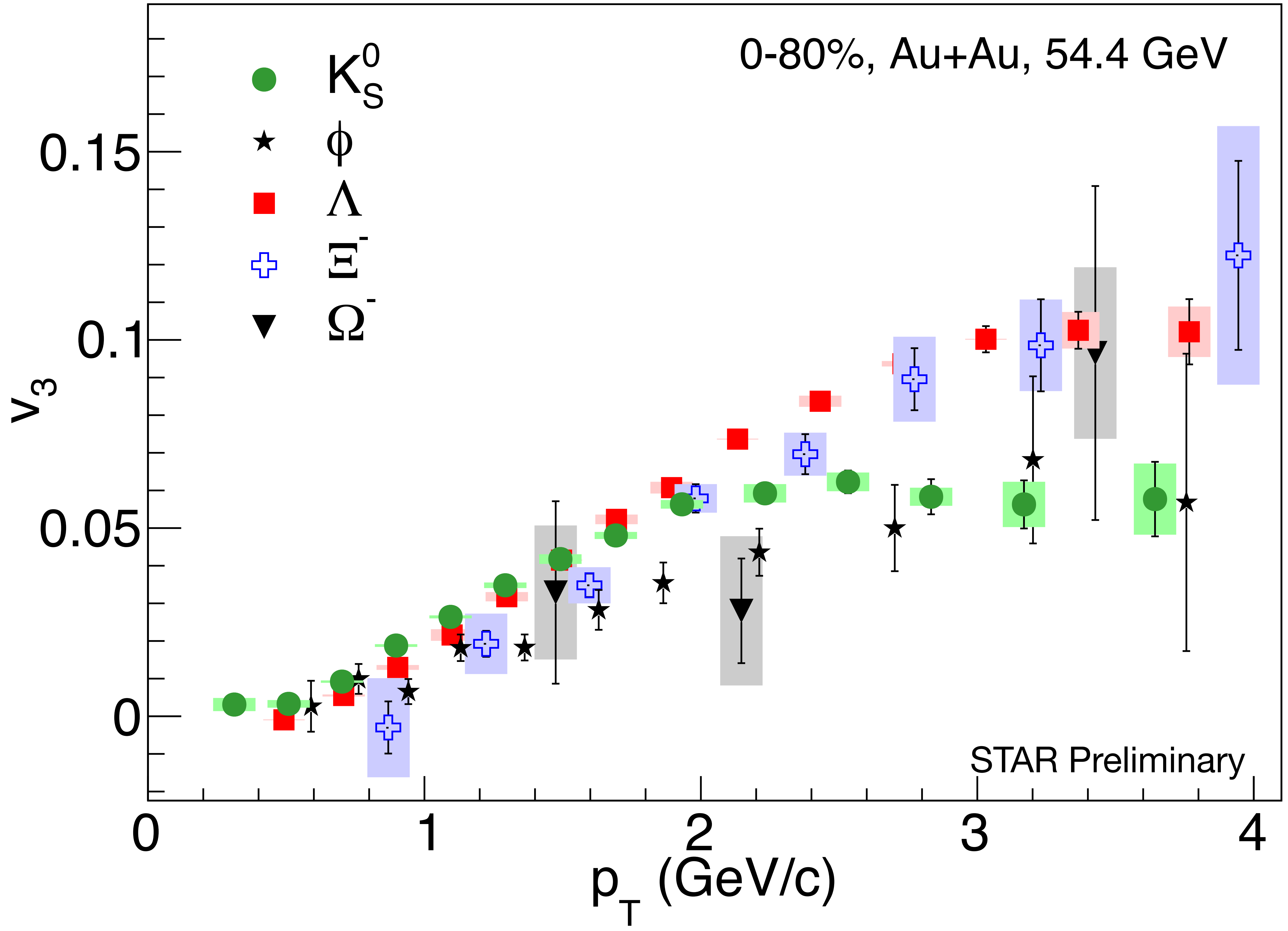
N. Borghini and J.-Y. Ollitrault
Phys. Rev. C 70, 064905 (2004)



Results

p_T dependence of v_n

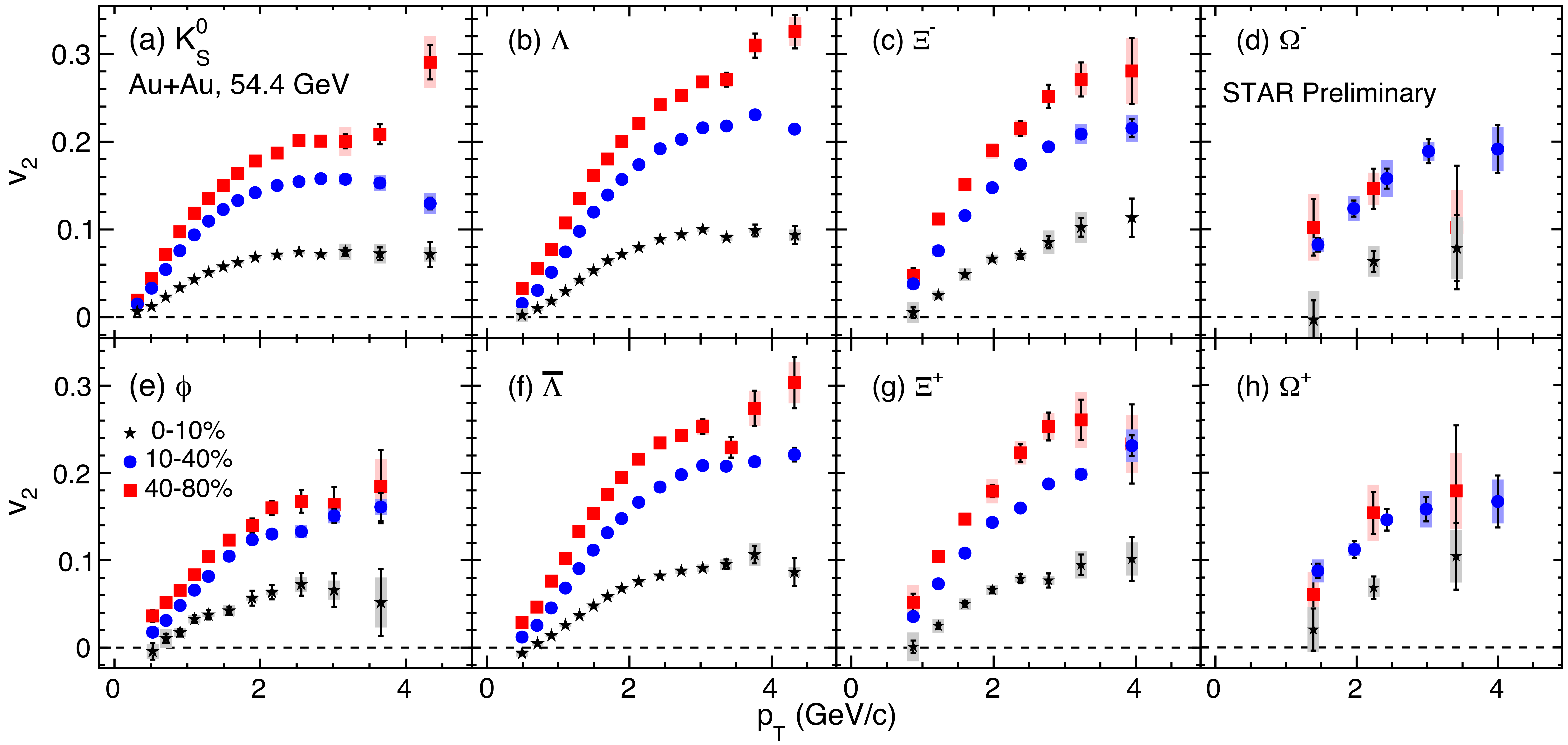




- Mass ordering observed in the low p_T region ($p_T < 2$ GeV/c) : *Radial flow*
- Baryon to meson separation observed in the region $p_T > 2$ GeV/c : *Quark coalescence*

Results

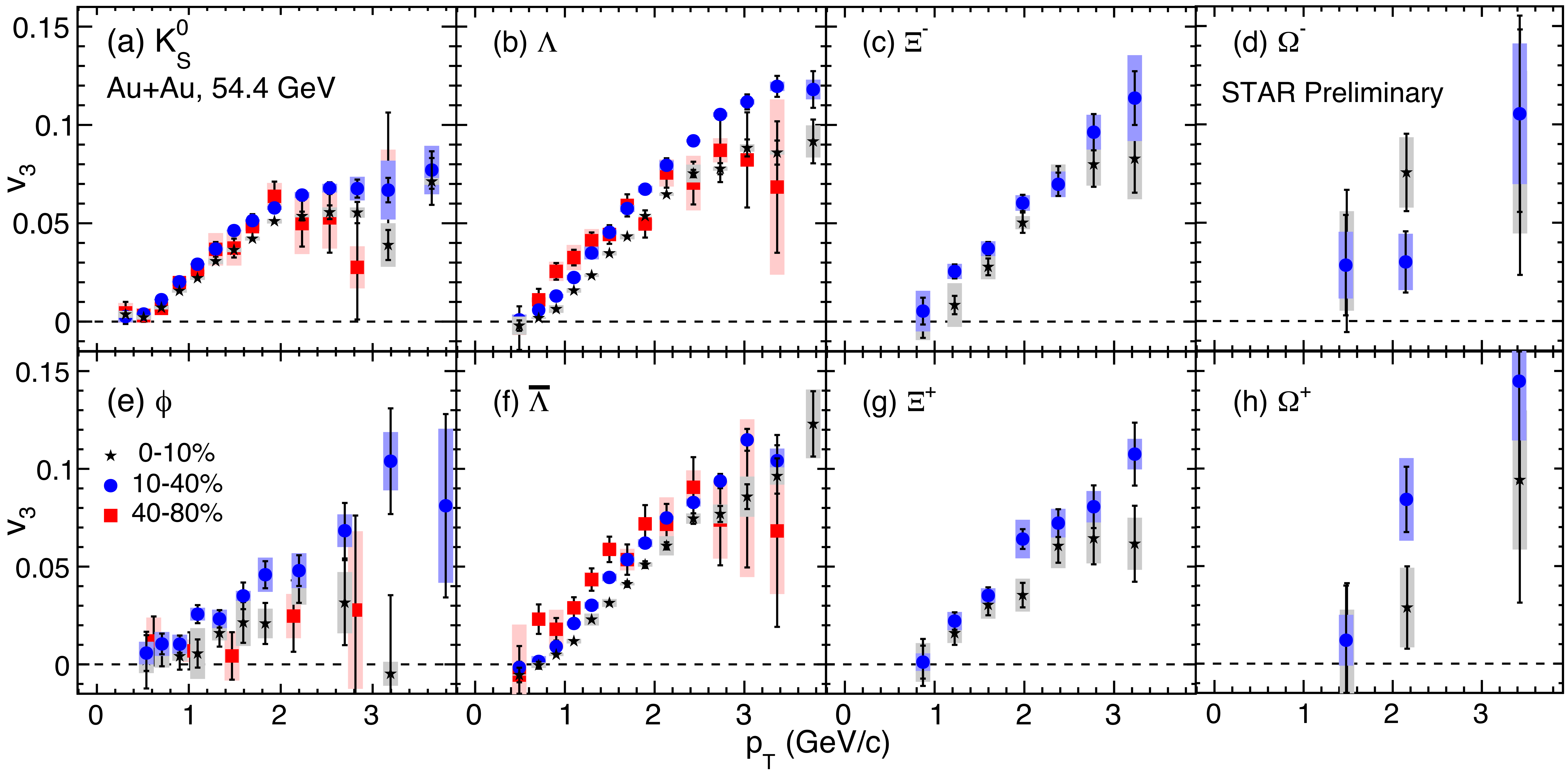
Centrality dependence of v_2



Strong centrality dependence → Initial spatial anisotropy is the dominant mechanism

Results

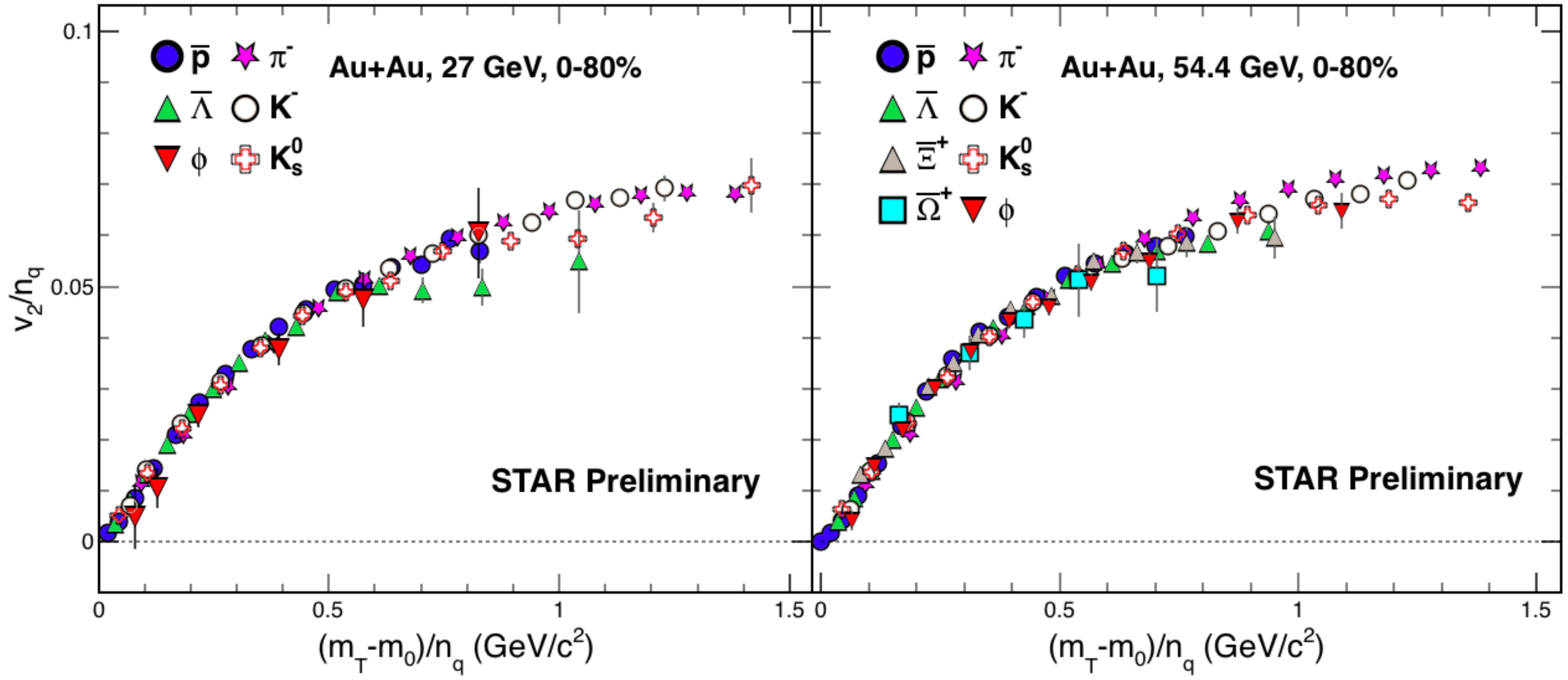
Centrality dependence of v_3

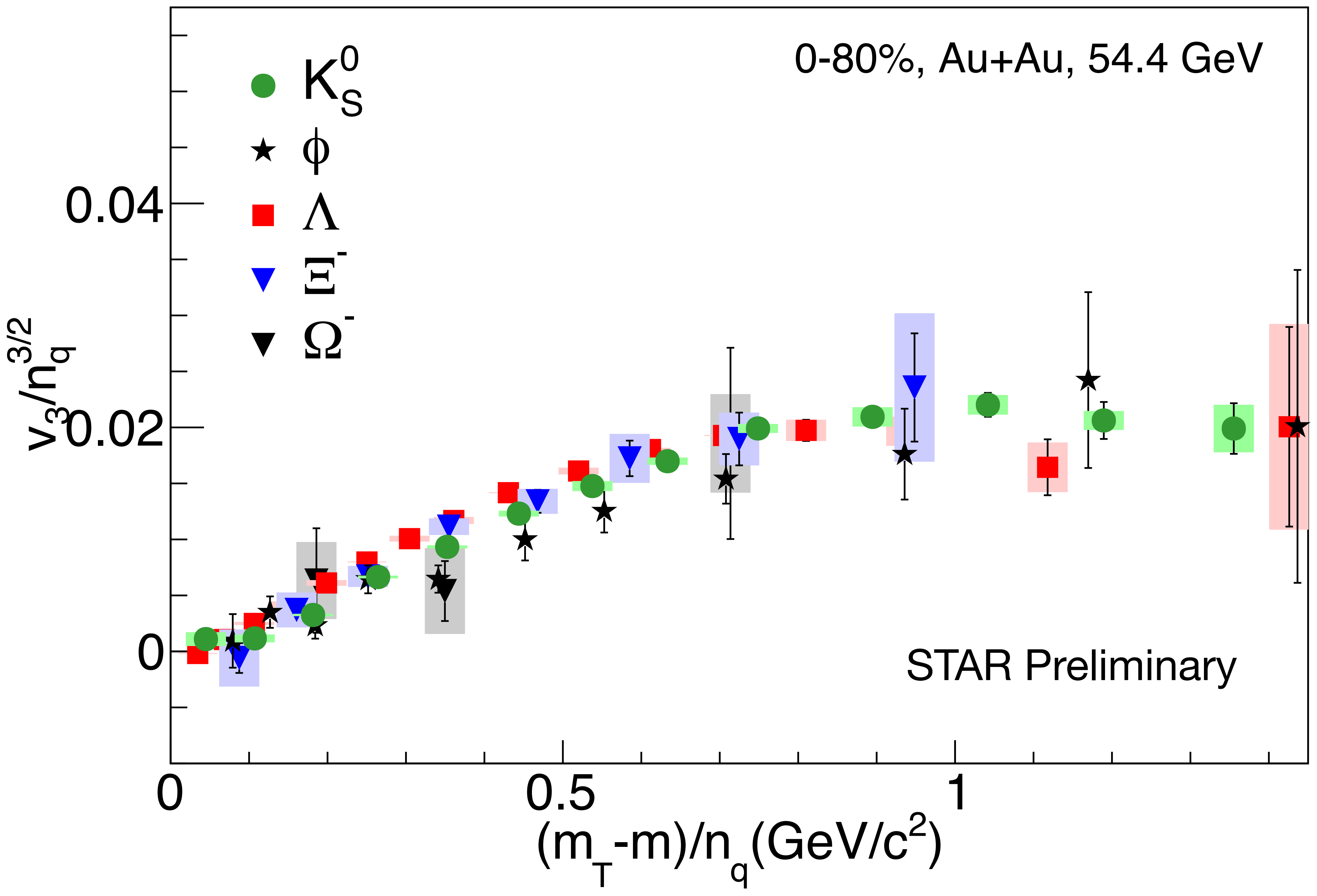


weak centrality dependence → Event-by-event fluctuation in the initial overlap region

Results

NCQ scaling



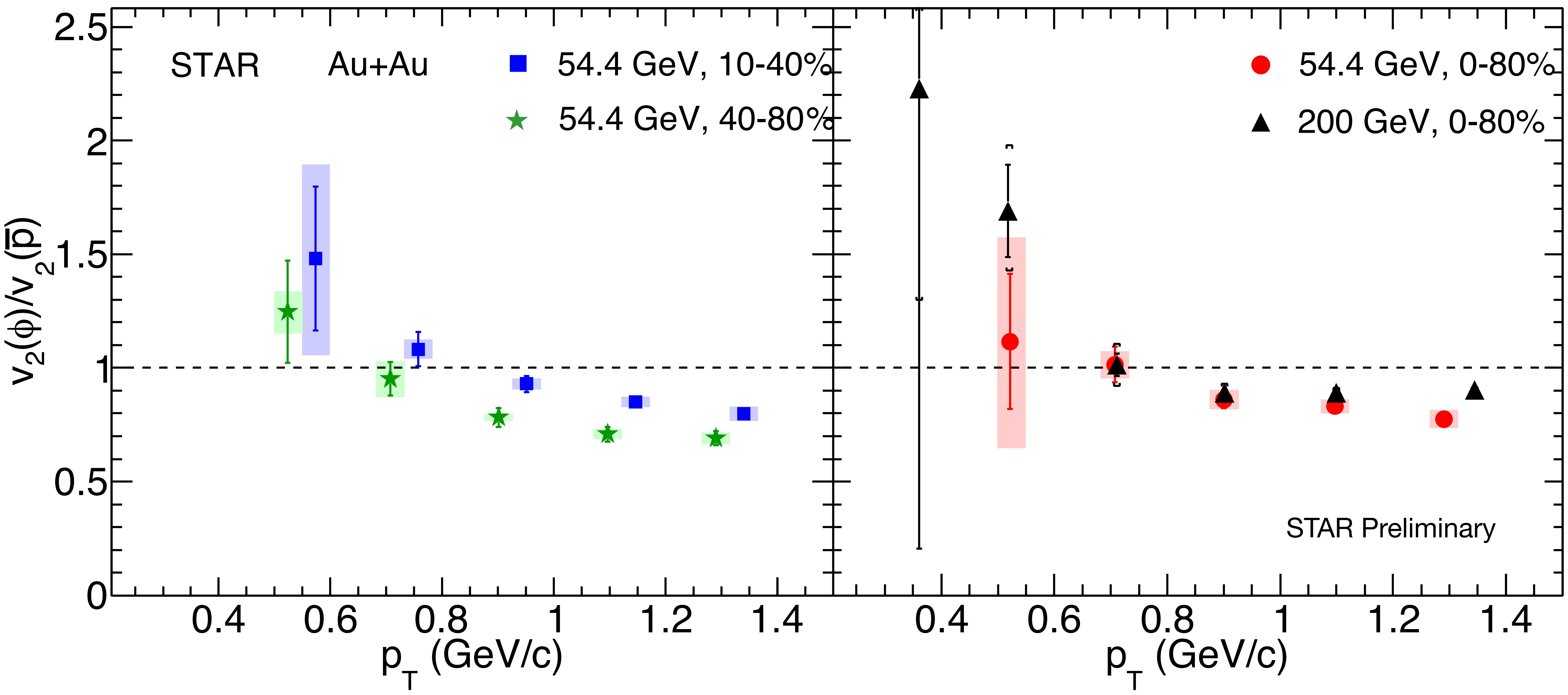


1. Quark recombination model explains the observed scaling. D. Molnar and S. A. Voloshin, Phys. Rev. Lett. **91**, 092301 (2003).

2. Multi-strange hadrons follow NCQ scaling with other light hadrons → Partonic collectivity in the initial stage.

Results

$v_2(\phi)/v_2(\bar{p})$



Ref. for 200 GeV data points : STAR PRL 116, 062301 (2016)

Hint of violation of mass ordering at low p_T → Early decoupling of **ϕ** meson from the system (less hadronic rescattering)

Tetsufumi Hirano *et al* Phys. Rev. C 77, 044909 (2008)

Summary

v_2 (at $\sqrt{s_{NN}}$ = 27 and 54.4 GeV) and v_3(at $\sqrt{s_{NN}}$ = 54.4 GeV) of multi-strange hadrons in Au+Au collisions are presented.

p_T dependence of v_n

- Mass ordering in low p_T ⟶ Radial flow
- Baryon and meson separation at high p_T ⟶ Quark recombination during hadronization

Centrality dependence of v_n

- Strong centrality dependence of v_2 ⟶ Spatial anisotropy is a dominant source for v_2
- Weak centrality dependence of v_3 ⟶ Event-by-event fluctuation in the overlap region is the cause for v_3

NCQ scaling

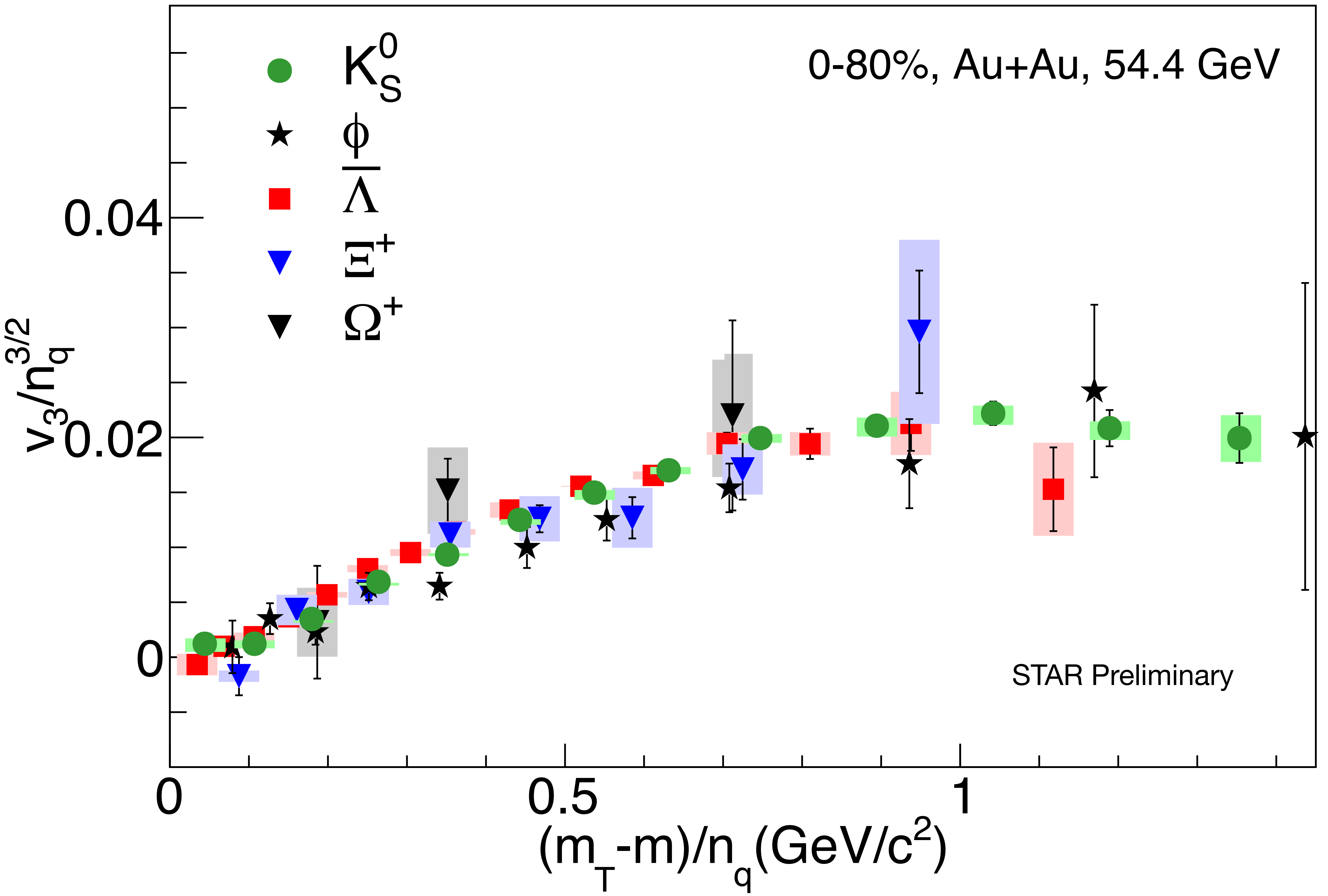
- NCQ scaling holds for both v_2 and v_3 ⟶ Signature of partonic collectivity

$v_2(\phi)/v_2(\bar{p})$

- Hint of violation of mass ordering at low p_T for $\bar{p}$ and ϕ ⟶ Small hadronic interaction cross section and early decoupling of ϕ meson from the system.

Thank you...

Backup



K^0_S
ϕ
$\overline{\Lambda}$
Ξ^+
Ω^+
0-80%, Au+Au, 54.4 GeV
STAR Preliminary
0.04
0.02
0
$v_3/n_q^{3/2}$
0
0.5
1
$(m_T\text{-}m)/n_q(GeV/c^2)$