Resonance Production in Au+Au Collision at STAR

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For the STAR Collaboration

WPCF – Resonance Workshop 2023

Catania (Italy), November 6-10, 2023

Supported in part by:

Outline

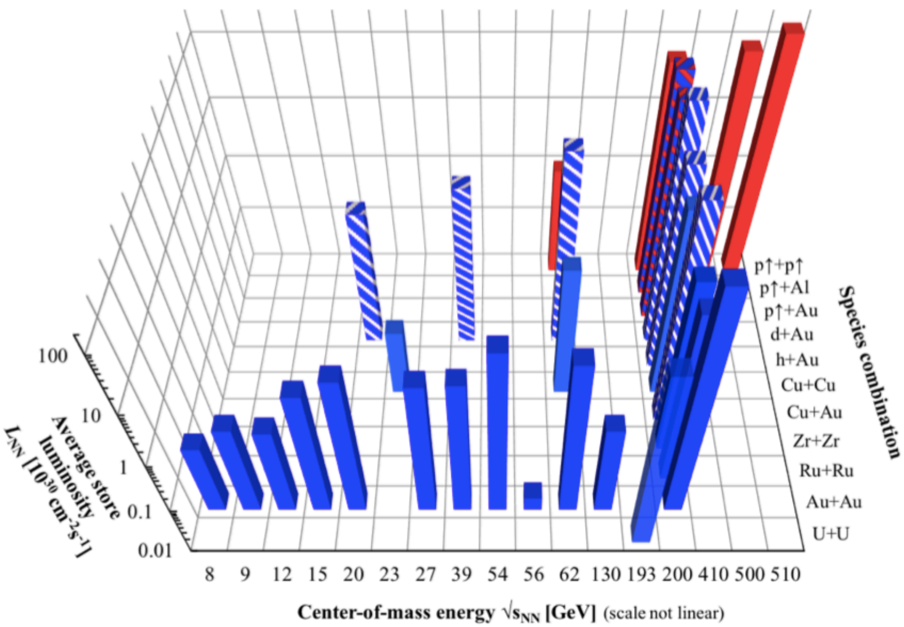
- Motivation
- The STAR Experiment
- Results

 - Invariant yields of K^{*0} and ϕ

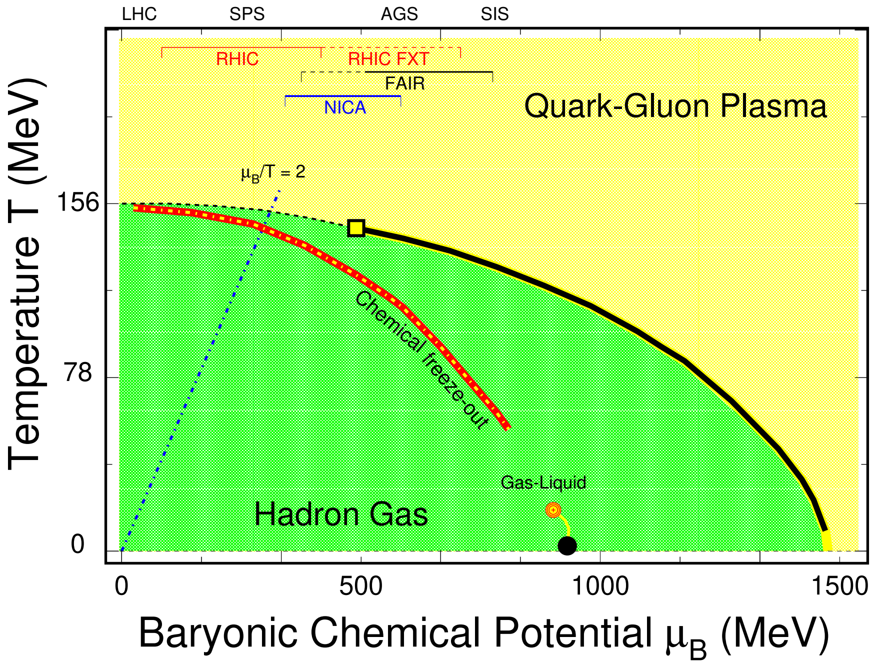
 - Anisotropic flow of ϕ
- Summary

Beam Energy Scan at RHIC

Collider Mode ($\sqrt{s_{NN}}$)= 7.7-200 GeV
Fixed Target ($\sqrt{s_{NN}}$): 3-7 GeV



The QCD phase diagram

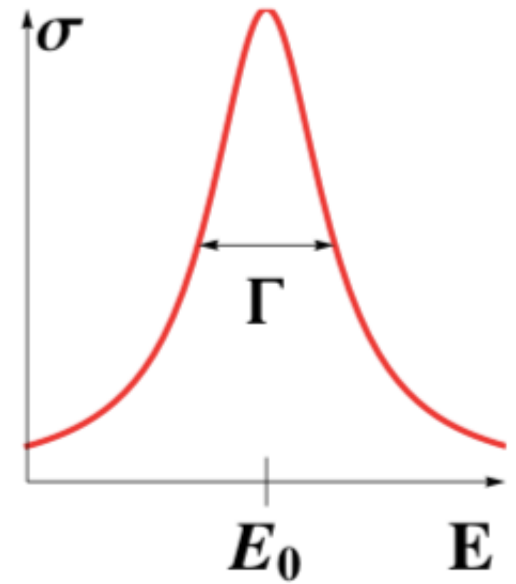


Varying beam energy varies Temperature (T) and Baryon Chemical Potential (μ_B).

Resonances

"Resonances" are short lived particles, existing for ~10^{-23} seconds

A+B $\longrightarrow$ R* $\longrightarrow$ C+D



Cross-section shape of resonance state R*
given by the **Breit-Wigner**.

- Decays through strong interaction
- **Lifetime** of resonance : $\tau = \dfrac{\hbar}{\Gamma}$

Example: ρ^0 (770), K*(892), Φ(1020), $\Sigma^{\pm}$(1385), Λ^0(1520), Ξ^0(1530)

M. Alstone et al., Phys. Rev. Lett. 6 (1961) 300.

Observation of the first resonance

First resonance particle was discovered in a bubble chamber experiment at Berkeley

RESONANCE IN THE K-π SYSTEM*

Margaret Alston, Luis W. Alvarez, Philippe Eberhard,† Myron L. Good,‡
William Graziano, Harold K. Ticho,|| and Stanley G. Wojcicki
Lawrence Radiation Laboratory and Department of Physics, University of California, Berkeley, California
(Received February 16, 1961)

In a continuation of the study of the interaction of 1.15-Bev/c K^- mesons in hydrogen by means of the Lawrence Radiation Laboratory 15-inch hydrogen bubble chamber, we now report a study of the reaction[1]

$$K^- + p \rightarrow \overline{K}^0 + \pi^- + p. \qquad \text{(A)}$$

Examples of this reaction were easily identified in those cases in which the $\overline{K}^0$ decayed into charged pions and appeared in the chamber as a two-prong interaction associated with a V. A kinematic analysis isolated 48 events of reaction (A) from other events with similar topology.[2] In only one case was the identification not unique.

one to expect a minimum of 16 events in the region $T_p \leq 15$ Mev, only three are found there. No experimental bias against very low energy protons in the K-p center-of-mass system can exist, since such protons have laboratory-system momenta of approximately 600 Mev/c, and are easily identified. The observed distribution can best be explained by a quasi-two-body reaction of the type

$$K^- + p \rightarrow K^{*-} + p, \qquad \text{(B)}$$

followed by a decay,

$$K^{*-} \rightarrow \overline{K}^0 + \pi^-. \qquad \text{(C)}$$

M. Alstone et al., Phys. Rev. Lett. 6 (1961) 300

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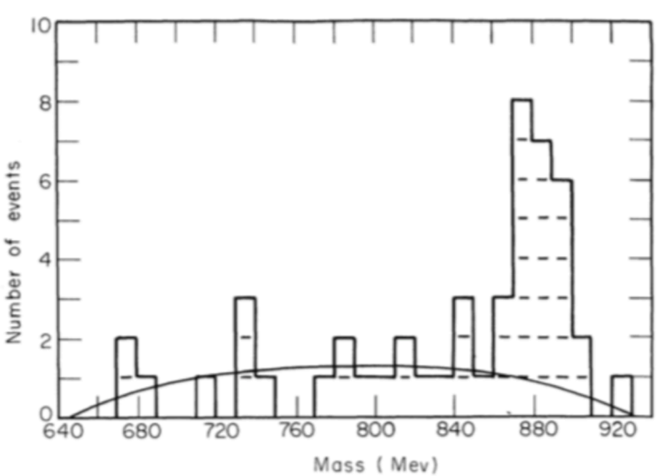

FIG. 2. Mass spectrum of the $\bar{K}^0$-π^- system. The solid line represents the phase-space curve normalized to background events.

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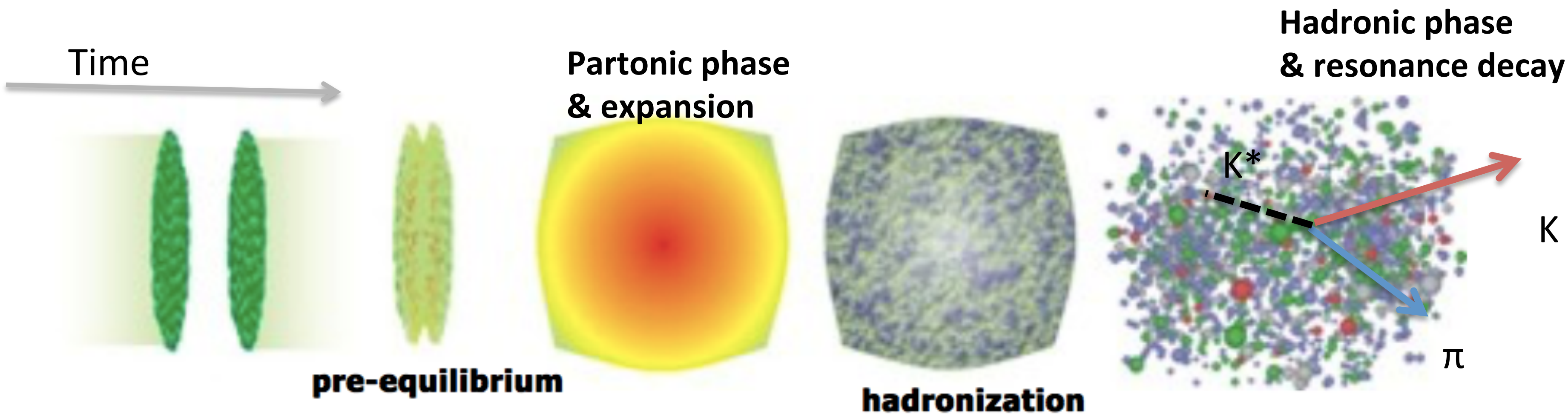
M. Alstone et al., Phys. Rev. Lett. 6 (1961) 300

Resonances as probe in heavy-ion collisions



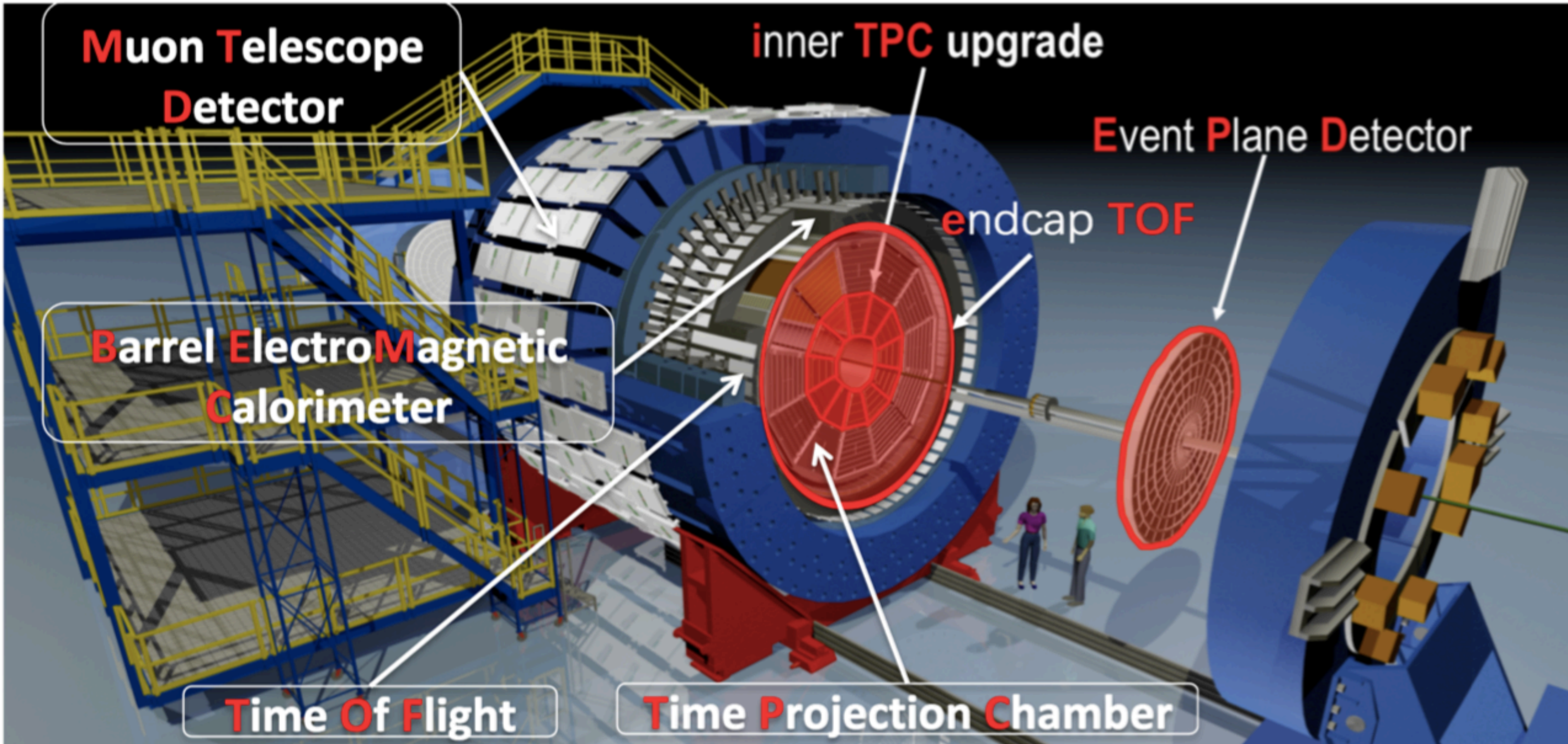
Probing partonic collectivity through ϕ

- Lifetime ~ 42 fm/c
- Early freeze-out
- Small hadronic interaction cross section

Probing hadronic phase through K*

- Lifetime ~ 4 fm/c
- Decay daughters could be affected by in-medium interaction

The STAR Experiment

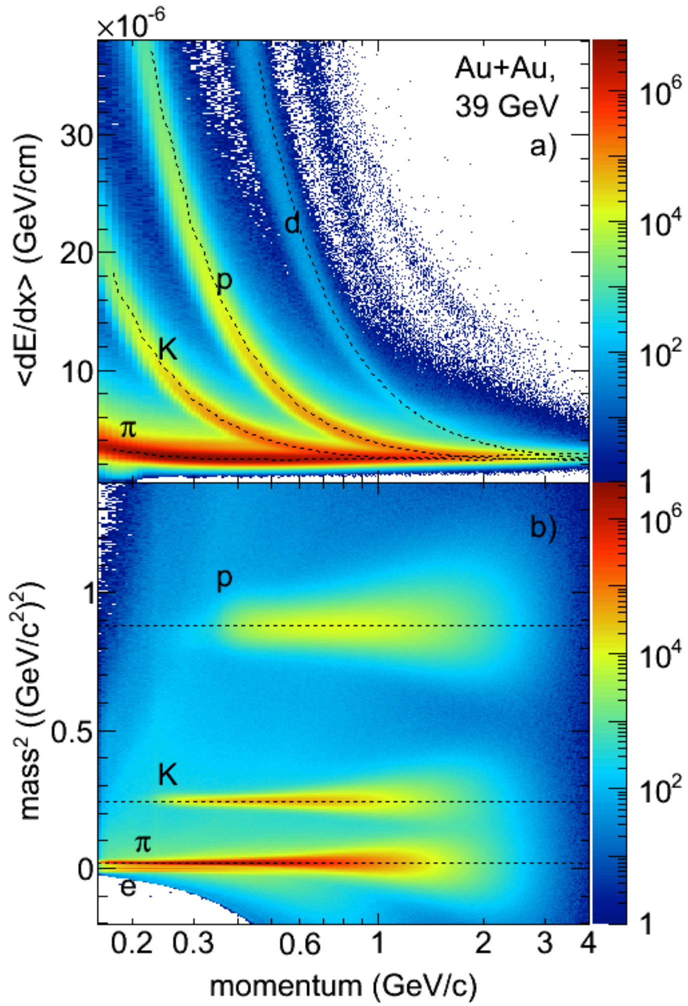


Tracking: TPC

Hadron Identification: TPC & TOF

Event Plane: TPC & EPD

Particle Identification



$\phi \longrightarrow K^+ + K^-$

Branching Ratio: ~ 0.49

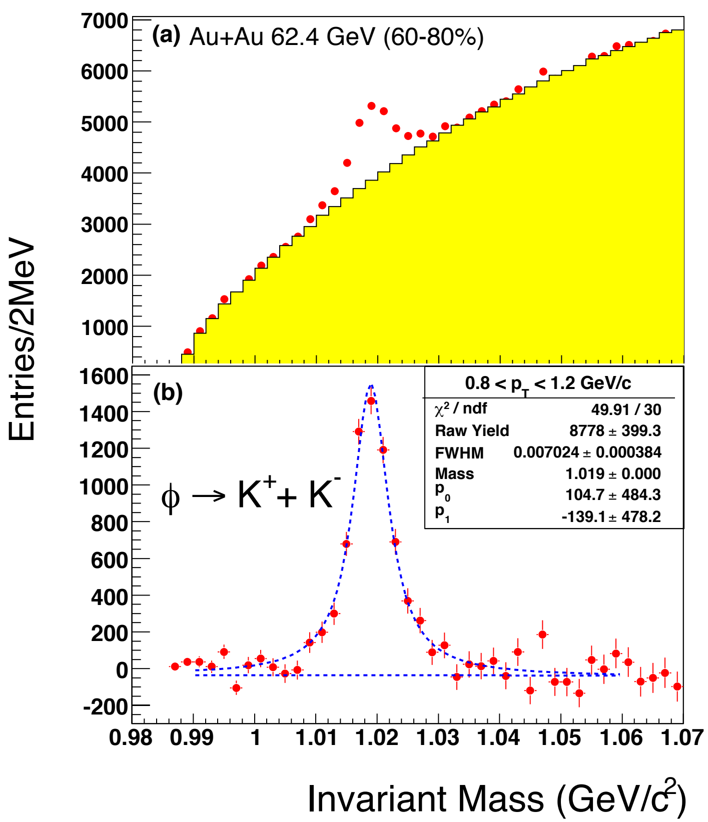
$K^{*0} \longrightarrow K^+ + \pi^-$

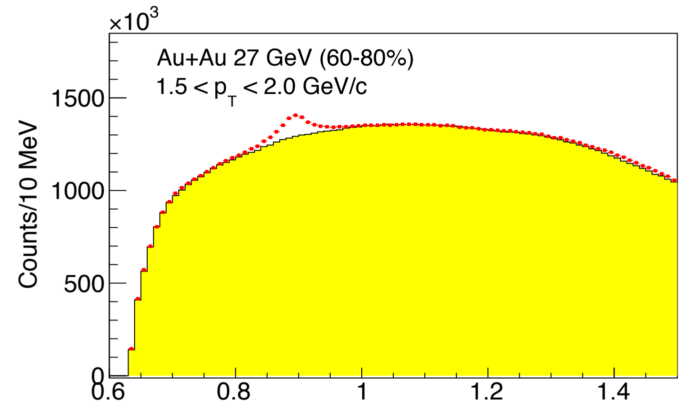
Branching Ratio: ~ 0.66

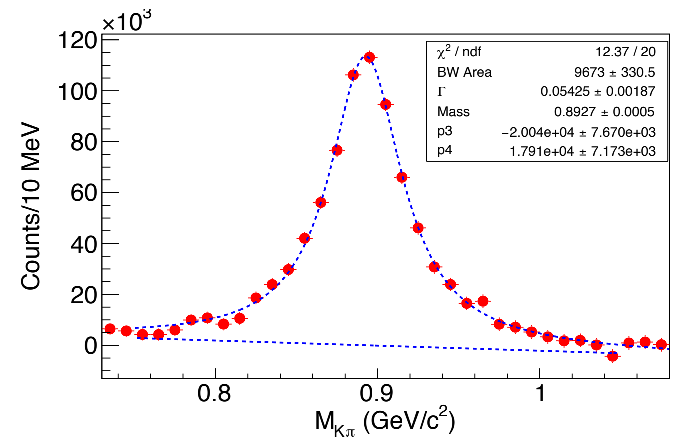
Pions and Kaons are identified using TPC and TOF detectors

K^{*0} and ϕ reconstruction

K^{*0} and ϕ reconstructed via hadronic decay channels through invariant mass method





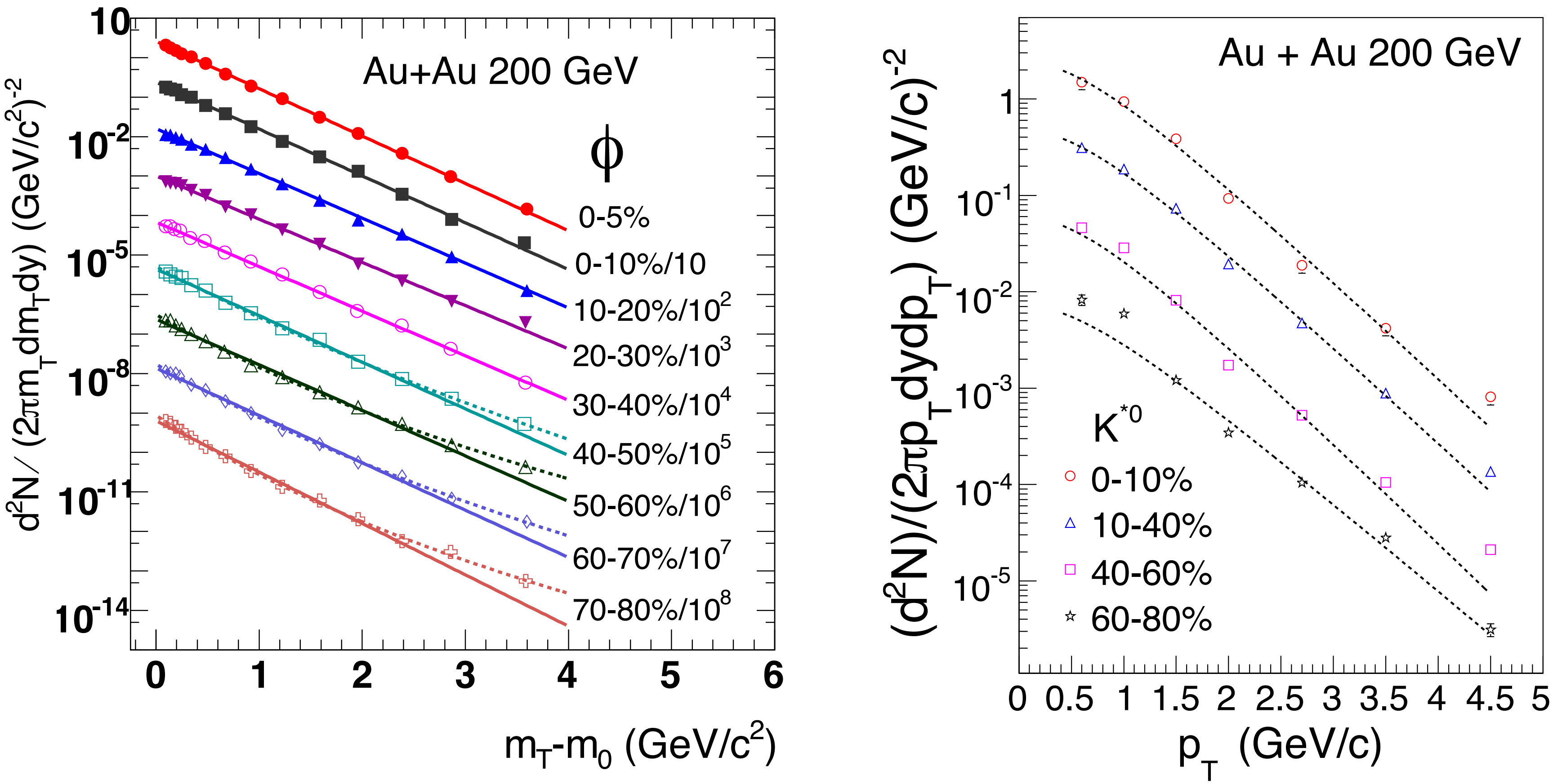


The signal is fitted with a Breit-Wigner function plus a linear residual background after mixed event background subtraction.

Phys. Rev. C **79** (2009) 64903 (STAR)

Measurement at Top RHIC Energy

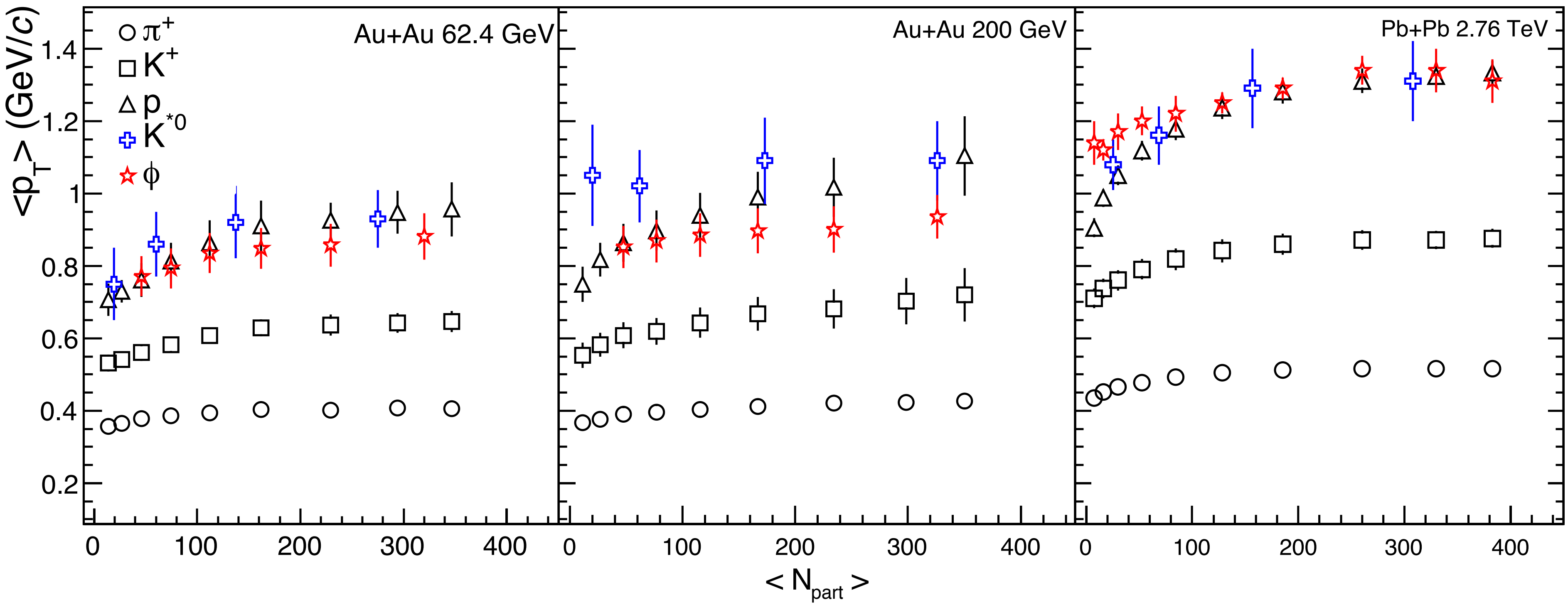
ϕ and K^{*0} spectra at 200 GeV



- Spectra is fitted with Levy fit
- Fit functions used to extrapolate yields in unmeasured regions

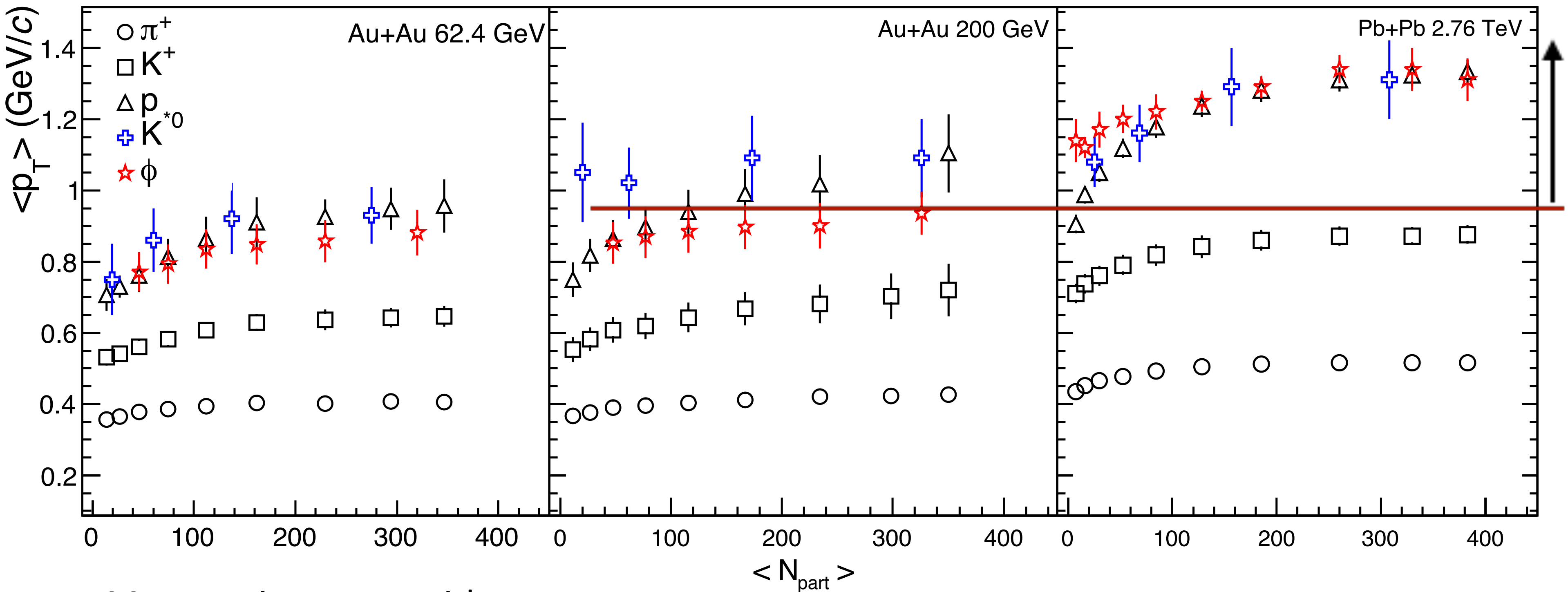
Phys. Rev. C **79** (2009) 64903 (STAR)   Phys. Rev. C **84** (2011) 34909 (STAR)

Mean transverse momentum at top RHIC and LHC energies



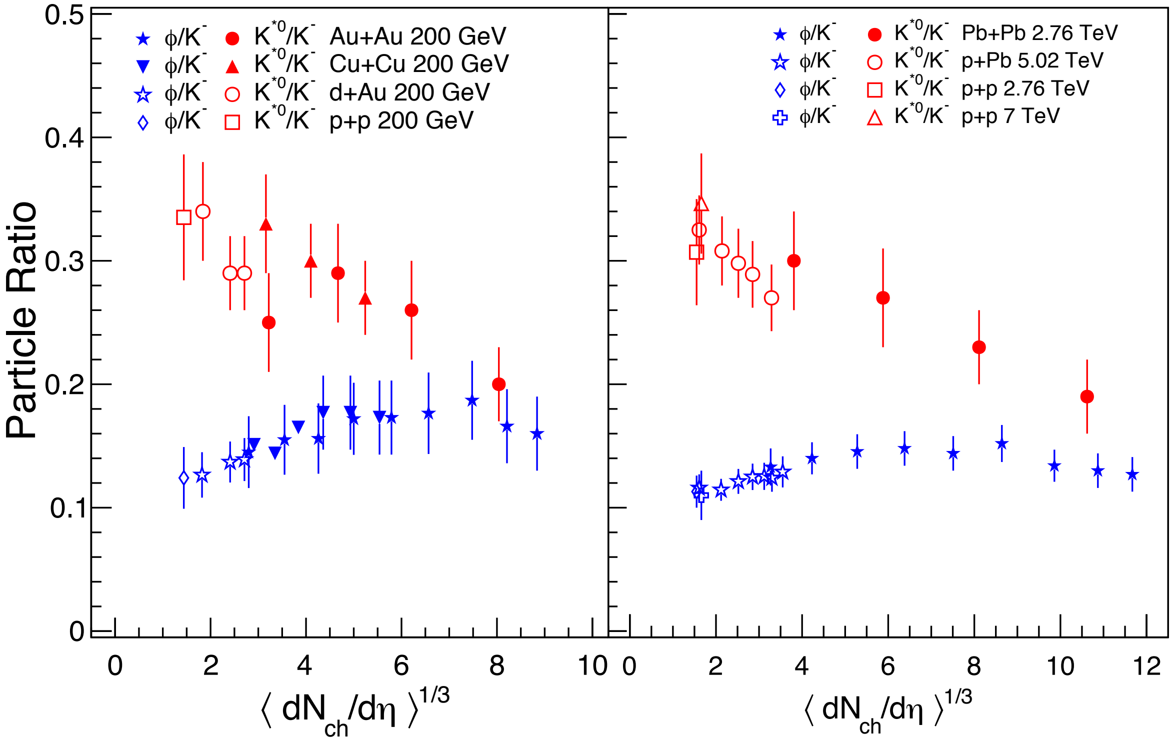
Phys. Rev. C 84 (2011) 034909 (STAR)
Phys. Rev. C 79 (2009) 064903 (STAR)
Phys. Rev. C 79 (2009) 034909 (STAR)
Phys. Rev. C 91 (2015) 024609 (ALICE)
Phys. Rev. C 88 (2013) 044910 (ALICE)

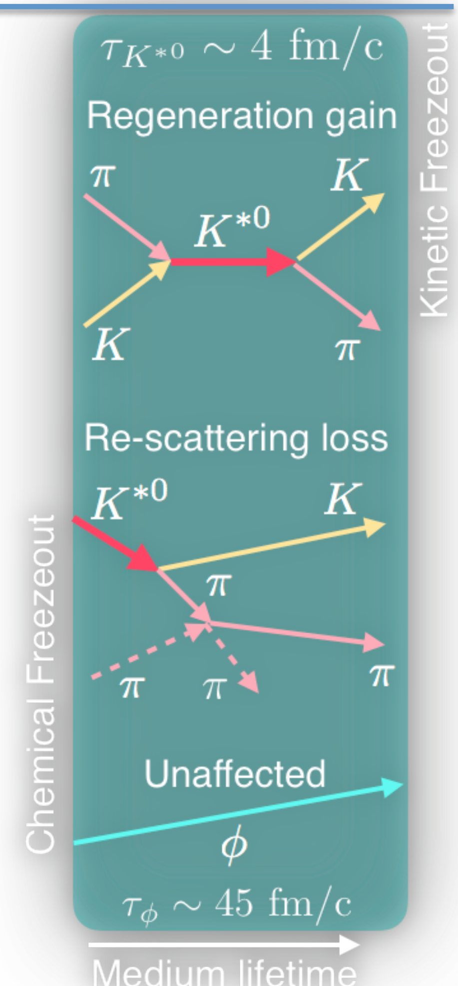
Mean transverse momentum at top RHIC and LHC energies



- Mean p_T increases with mass
- Mean p_T of K* and ϕ close to proton (similar mass)
- Mean p_T at LHC > Mean p_T at RHIC, consistent with increased radial flow at LHC

Particle ratios (K*^{0}/K- and ϕ/K-) at top RHIC and LHC energies





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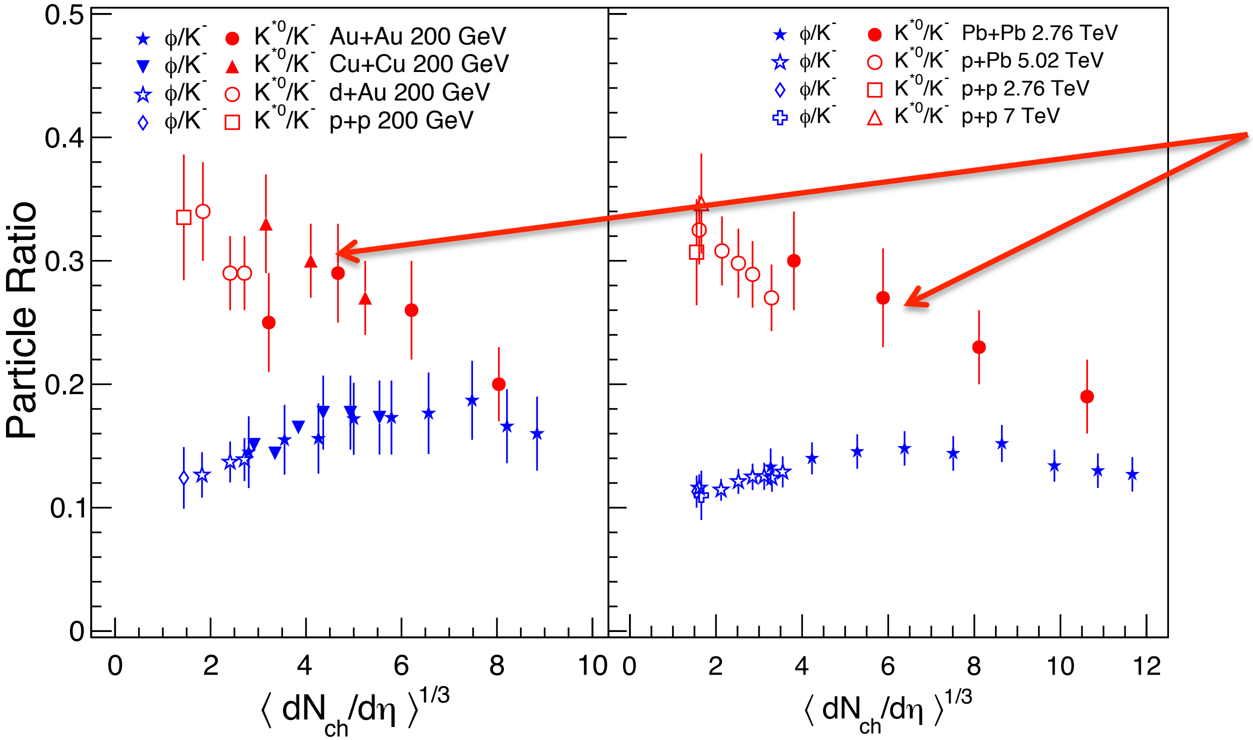
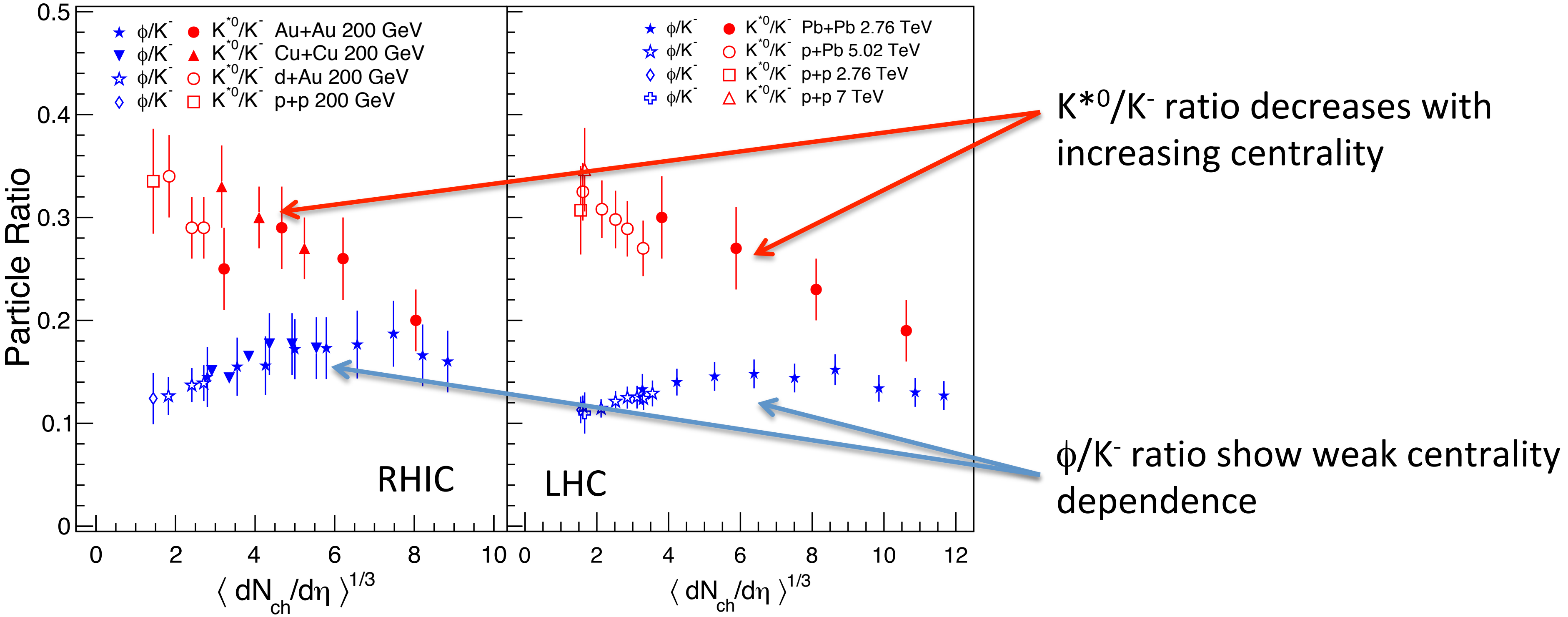
Particle ratios (K^{*0}/K^- and ϕ/K^-) at top RHIC and LHC energies



K^{*0}/K^- ratio decreases with increasing centrality

Particle ratios (K^{*0}/K^- and ϕ/K^-) at top RHIC and LHC energies



Dominance of hadronic re-scattering in central A+A collisions

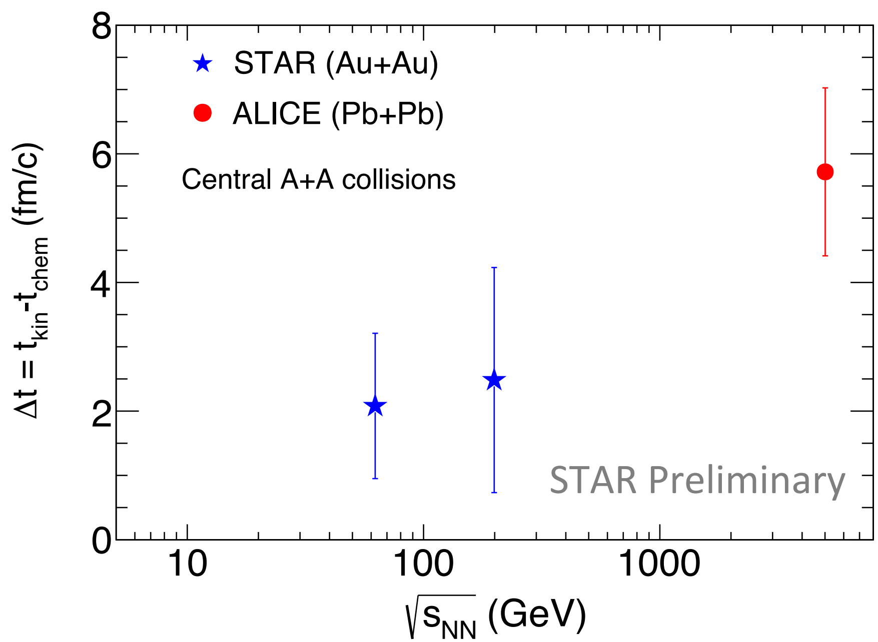
Lower limit of hadronic phase lifetime

$(K^{*0}/K)_{kin} = (K^{*0}/K)_{chem} \times e^{-\Delta t/\tau}$

Where, Δt = lower limit of hadronic phase lifetime (t_{kin} - t_{chem})

Assumptions:

- $(K^{*0}/K)_{kin} \approx (K^{*0}/K)_{AA}$
- $(K^{*0}/K)_{chem} \approx (K^{*0}/K)_{pp}$
- No regeneration

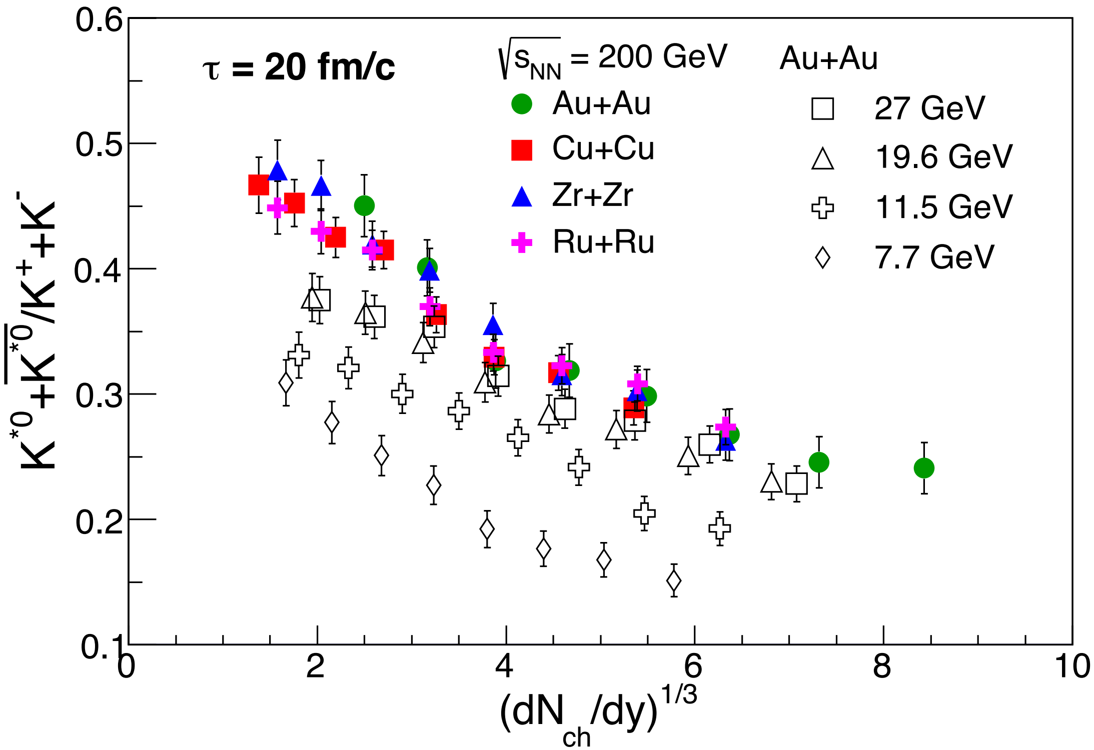


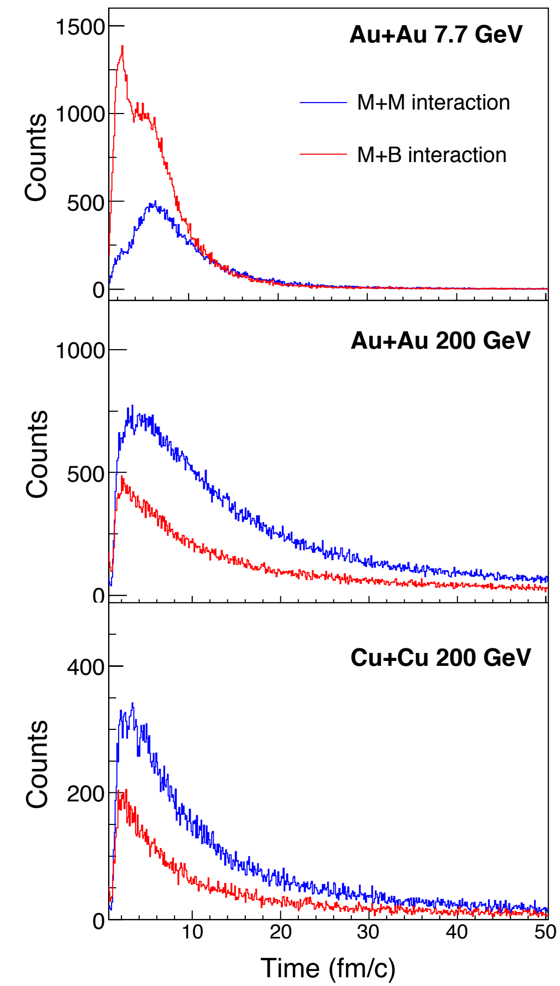
Smaller Δt at RHIC compared to LHC

Phys.Lett.B 802 (2020) 135225 (ALICE)
Phys. Rev. C 84 (2011) 034909 (STAR)
Zhangbu Xu. J. Phys. G 30 (2004), S325--S334
S. Singha, et al. Int. J. Mod. Phys. E 24 (2015) 05, 1550041

Measurement at BES Energies

K*⁰/K ratio from UrQMD model



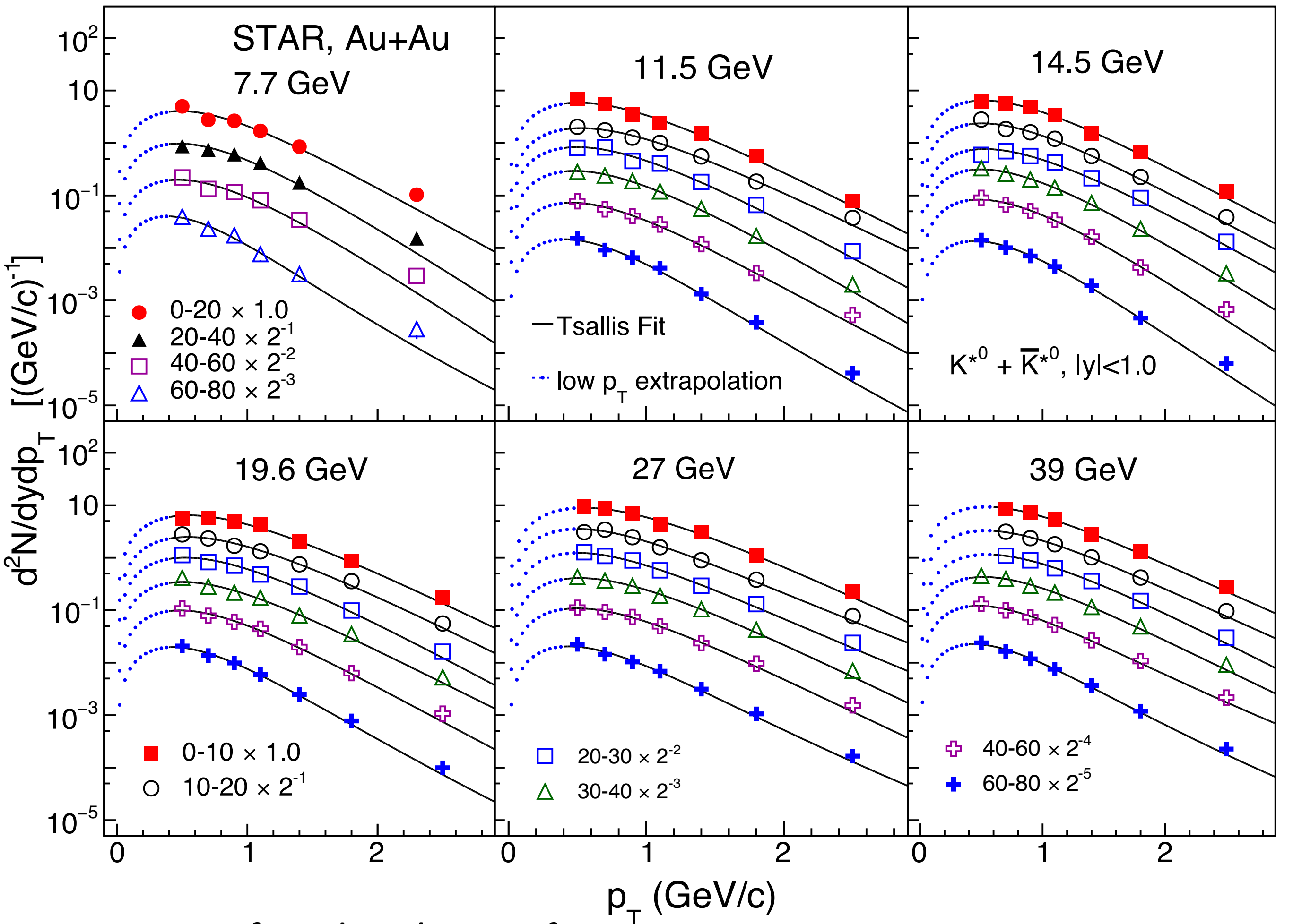


UrQMD predicts breaking of multiplicity scaling at BES energies

A.K. Sahoo et al, arXiv : 2307.06661

K^{*0} spectra at BES energies

BES-I

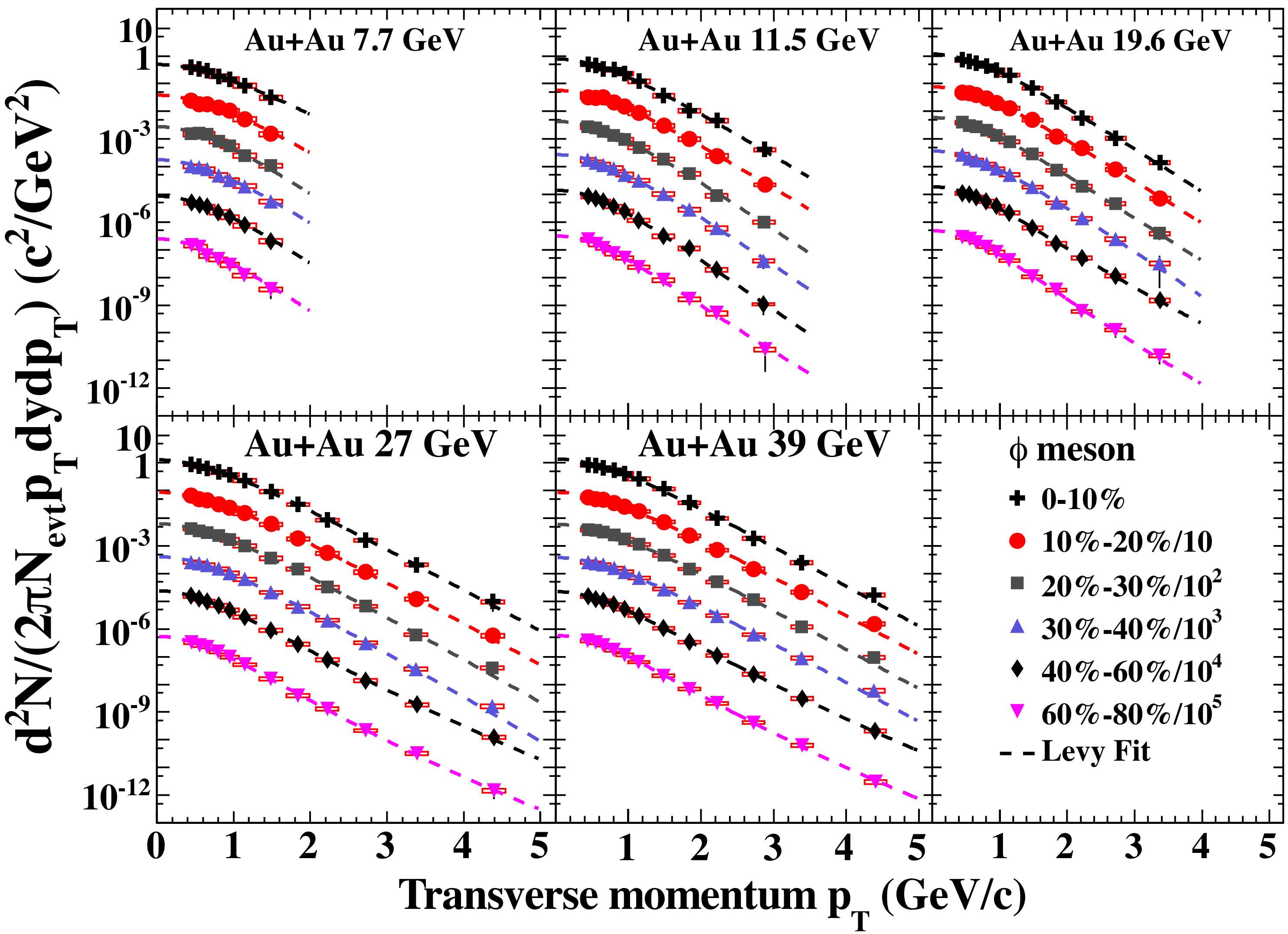


- Spectra is fitted with Levy fit
- Fit functions used to extrapolate yields in unmeasured regions

Phys. Rev. C **107** (2023) 34907 (STAR)

ϕ spectra at BES energies

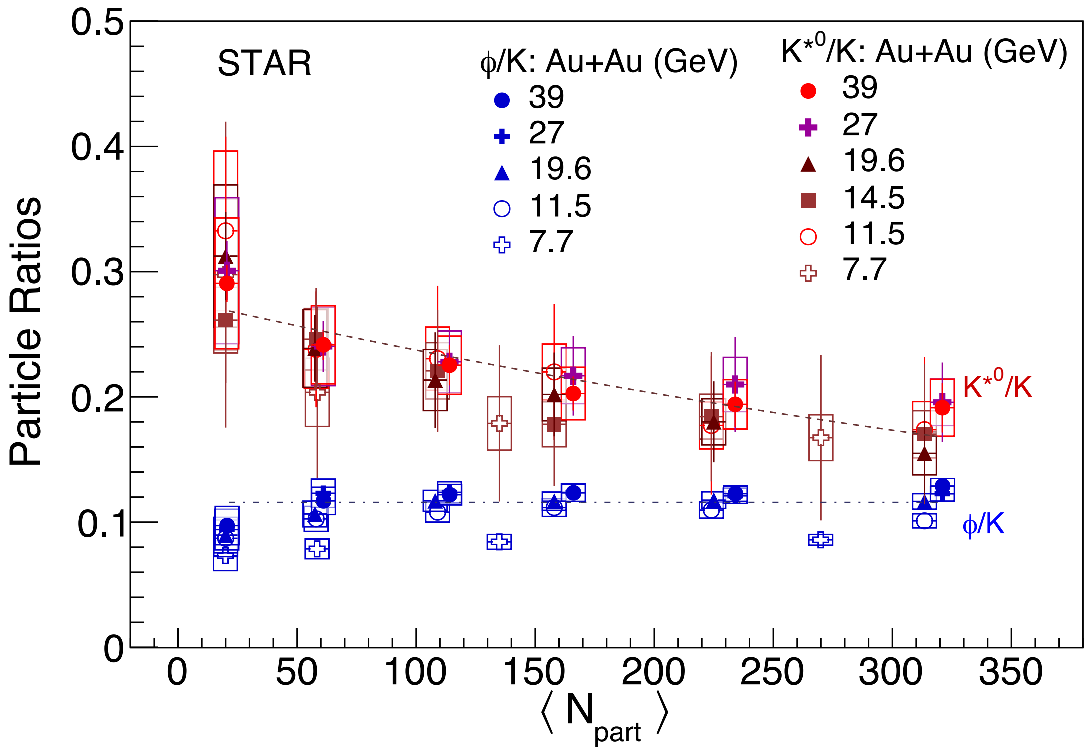
BES-I



Phys. Rev. C 93 (2016) (R) 21903 (STAR)

Particle ratios (K^{*0}/K and ϕ/K) at BES energies

BES-I



ϕ/K ratio : Weak centrality dependence

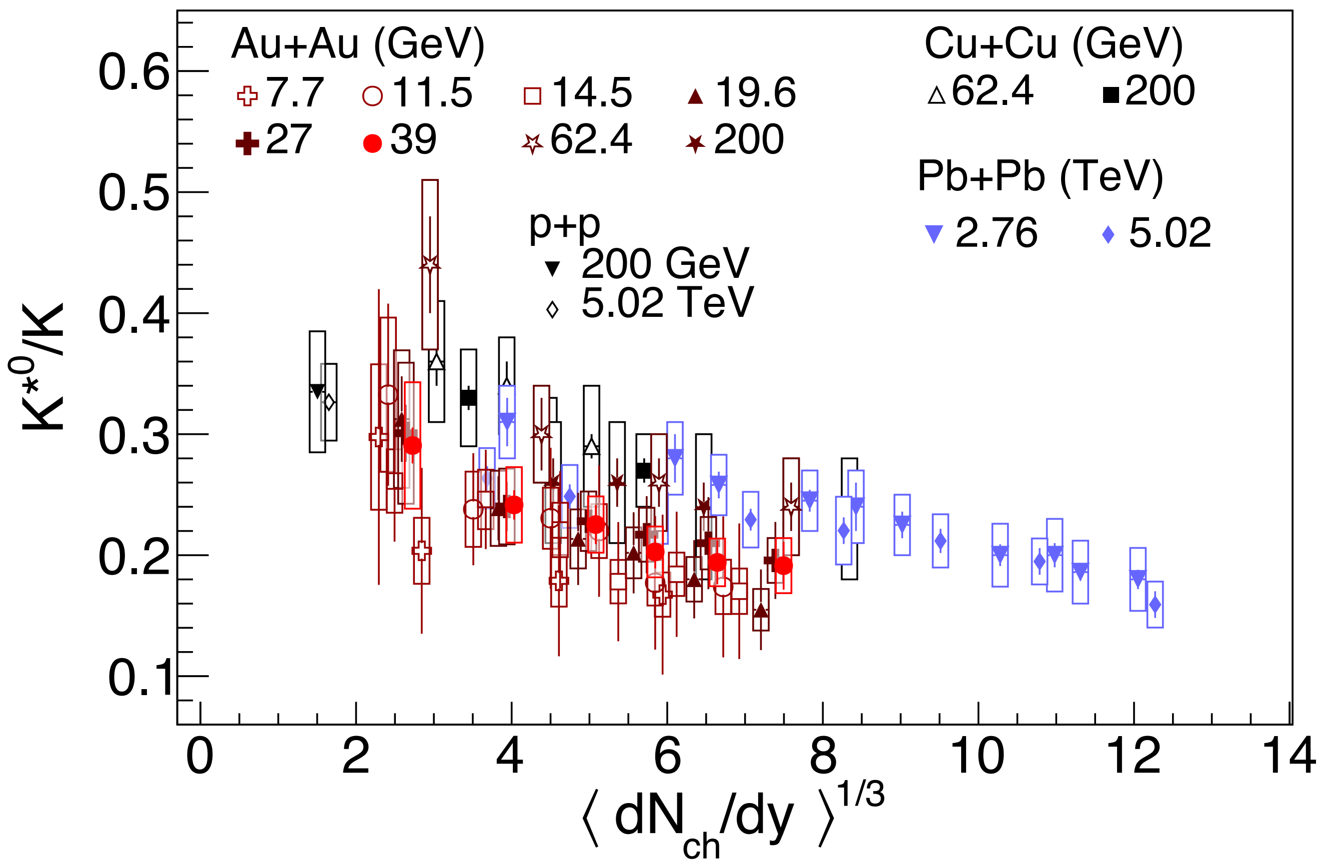
K^{*0}/K ratio: decreases with increasing centrality, more re-scattering in central collisions

Indicating dominance of hadronic re-scattering in central Au+Au collisions

Phys. Rev. C **107** (2023) 34907 (STAR)

K^{*0}/K ratio : Multiplicity Dependence

BES-I

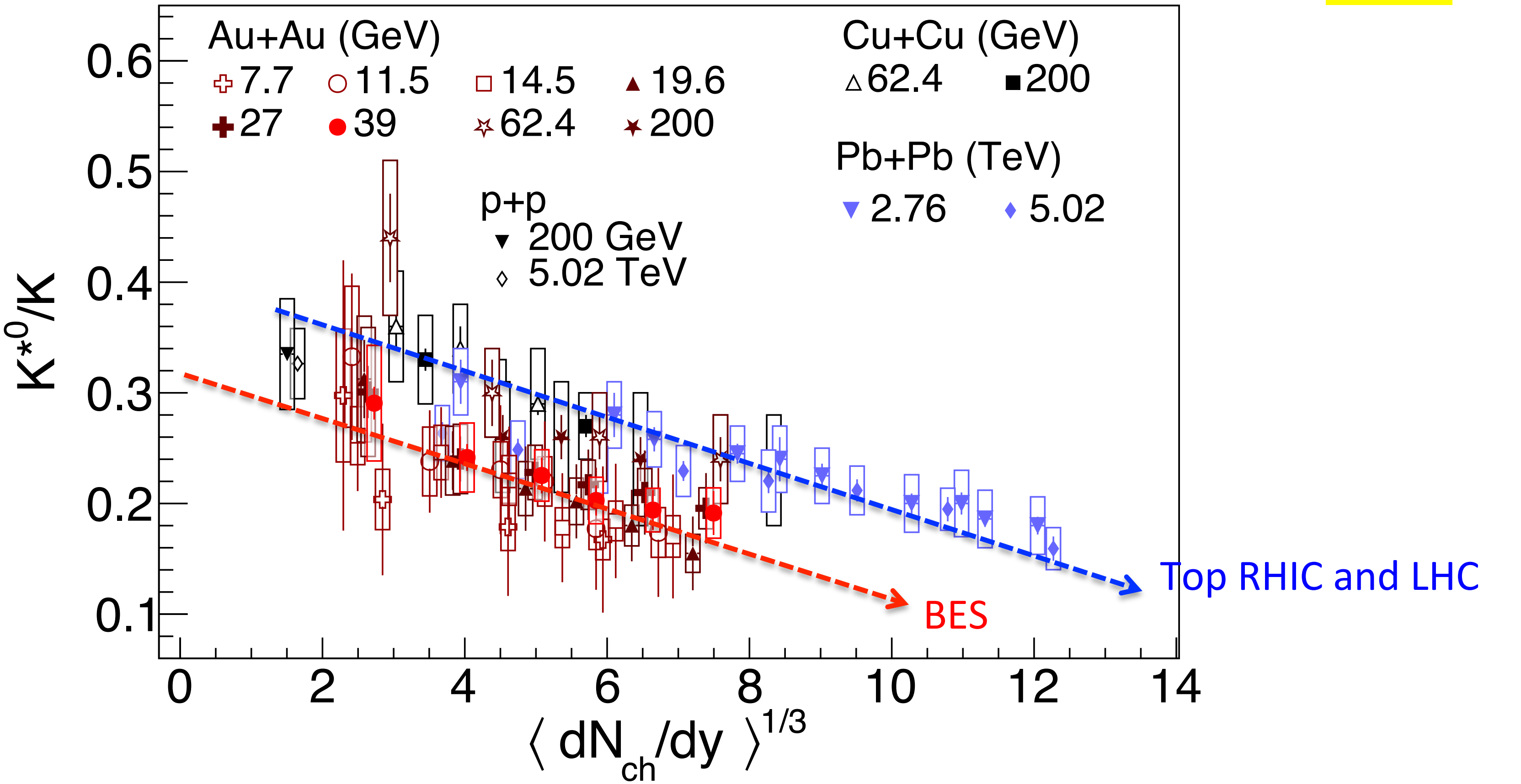


K^{*0}/K ratio: decreases with increasing multiplicity

Phys. Rev. C **107** (2023) 34907 (STAR)

K^{*0}/K ratio : Multiplicity Dependence

BES-I



K^{*0}/K ratio: decreases with increasing multiplicity

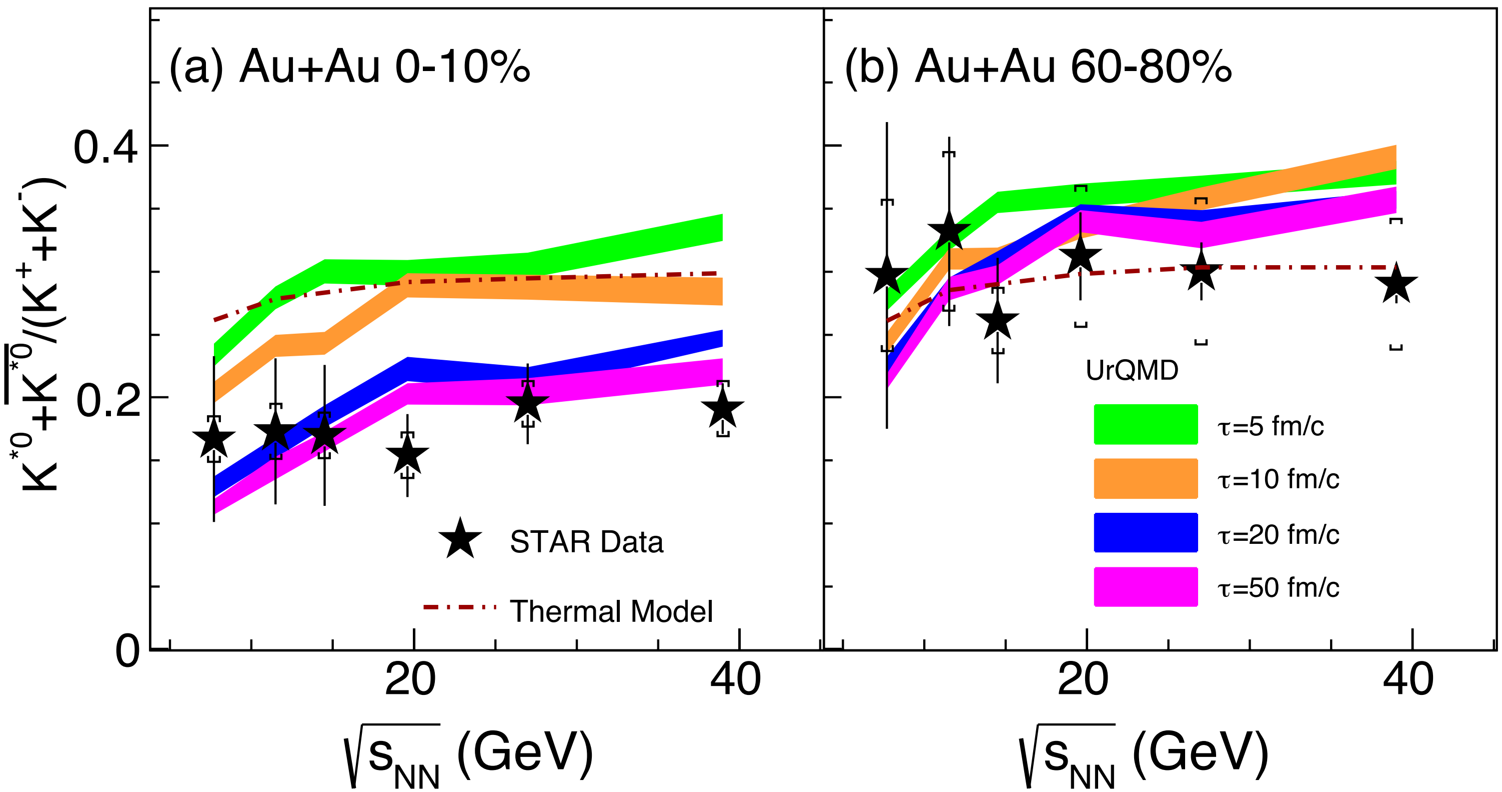
Ratios at BES do not seem to follow multiplicity scaling with top RHIC and LHC energies.

Precise measurement are needed to confirm.

Phys. Rev. C **107** (2023) 34907 (STAR)

K^{*0}/K Ratio: Model Comparison

BES-I

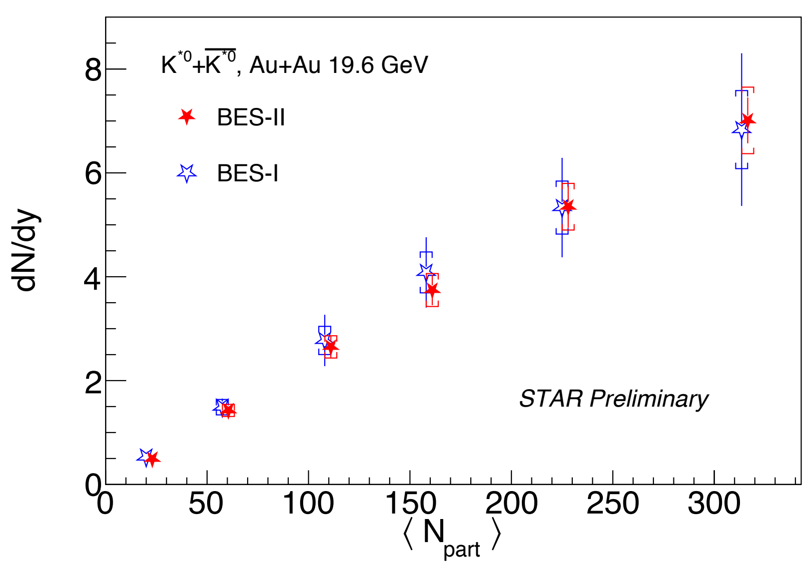


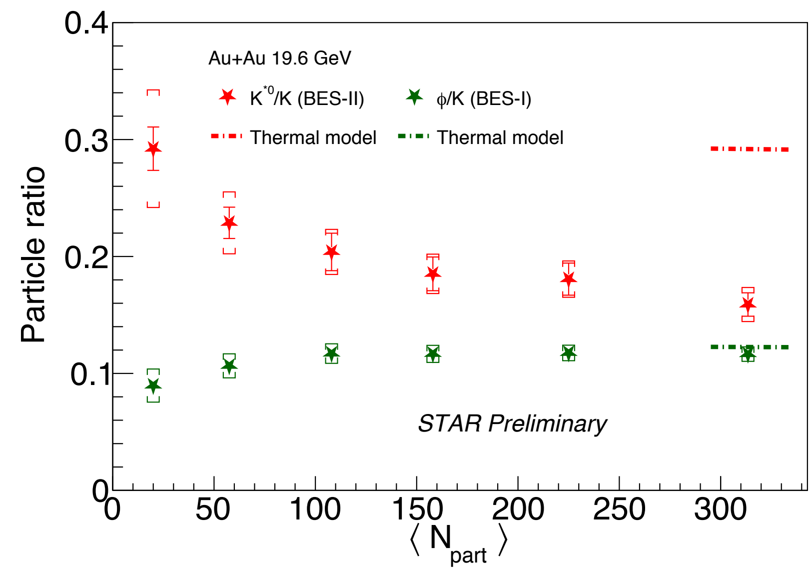
- Thermal model explains K^{*0}/K in peripheral collisions, but overestimates the ratio in central collisions
- UrQMD with longer hadronic phase is needed to explain K^{*0}/K in central collisions

A.K. Sahoo et al, Phys. Rev. C **108**, (2023) 044904 Phys. Rev. C **107** (2023) 34907 (STAR)

Particle ratio from BES-phase II data

Au+Au @ 19.6 GeV, BES-II



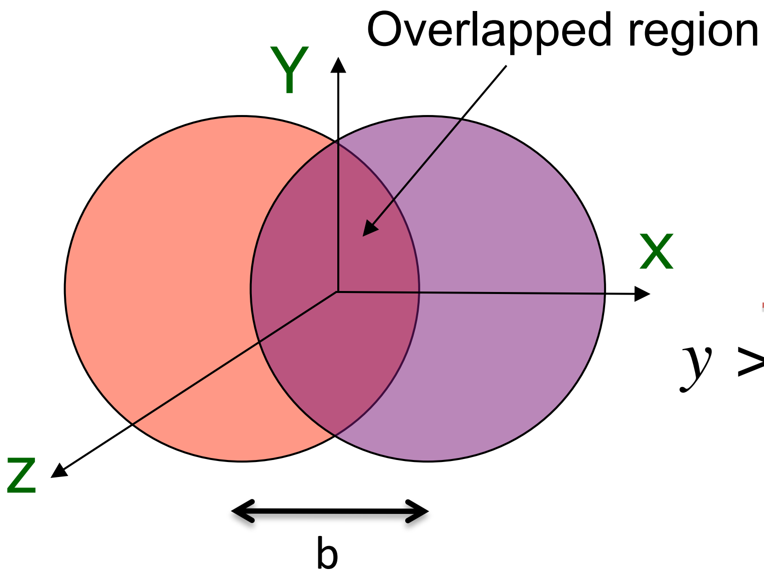


- $(K^{*0}/K)_{central} < (K^{*0}/K)_{peripheral}$

Precise measurement at BES-II confirms the dominance of hadronic re-scattering in central Au+Au collisions

Probing Partonic Collectivity Using ϕ Meson

Collectivity in heavy-ion collisions

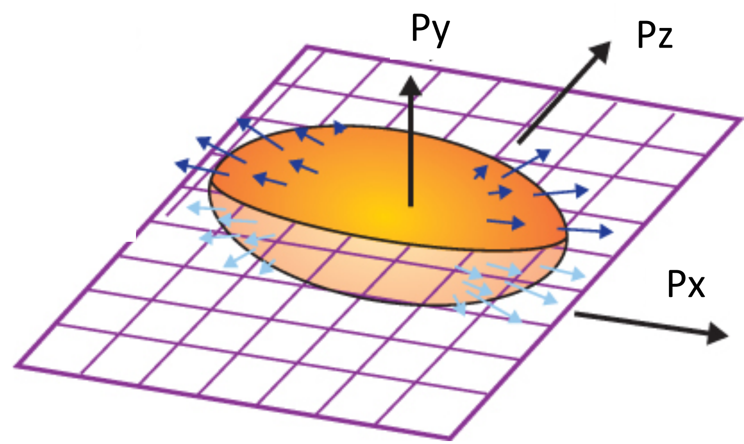


Interactions

↓

Pressure (P)

$$y > x \longrightarrow \frac{\partial P}{\partial x} > \frac{\partial P}{\partial y}$$



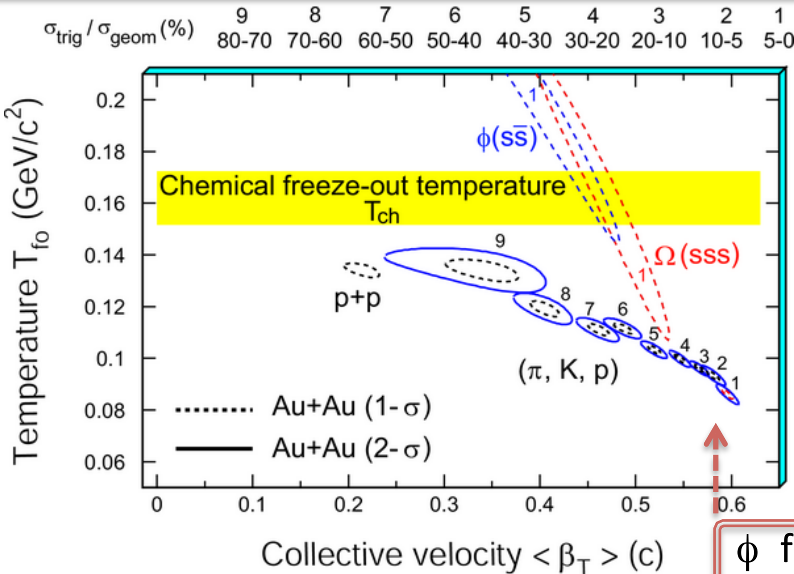
$$E\frac{d^3N}{dp^3} = \frac{1}{2\pi}\frac{d^2N}{p_T dp_T dy}[1 + 2v_1\cos(\phi - \Psi_R) + 2v_2\cos 2(\phi - \Psi_R) + ...]$$

v_1 – Directed flow

v_2 – Elliptic flow

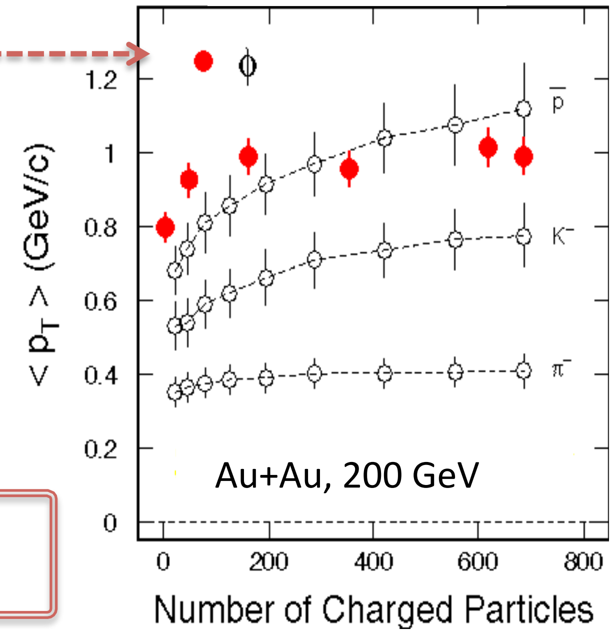
Sensitive to initial dynamics

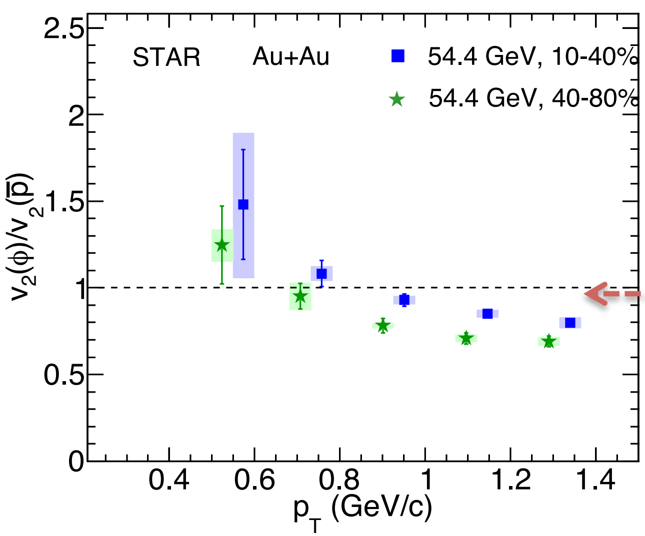
ϕ mesons v_2: Probe to Partonic Collectivity



ϕ freezes out at higher temperature than π,k,p

$<p_T>$ of ϕ is almost independent of centrality unlike anti-protons





ϕ v_2 less affected by hadronic interaction compared to anti-proton

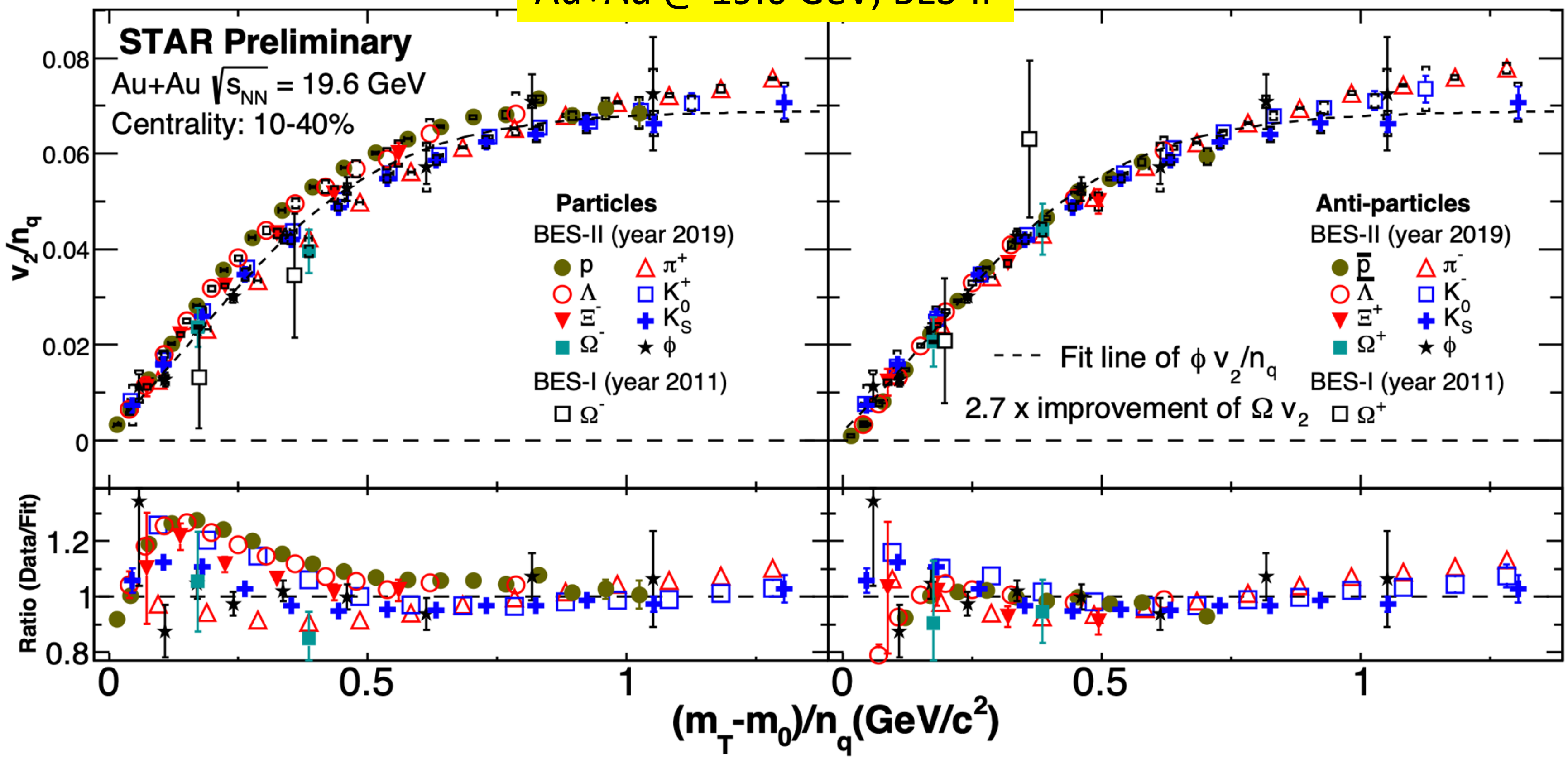
- Indicates possibly ϕ decouples early in the interaction
- Clean probe to partonic collectivity

Phys. Rev. C 107, (2023) 024912 (STAR)

Phys. Lett. B 612 (2005) 181 (STAR)

NCQ Scaling of Elliptic Flow

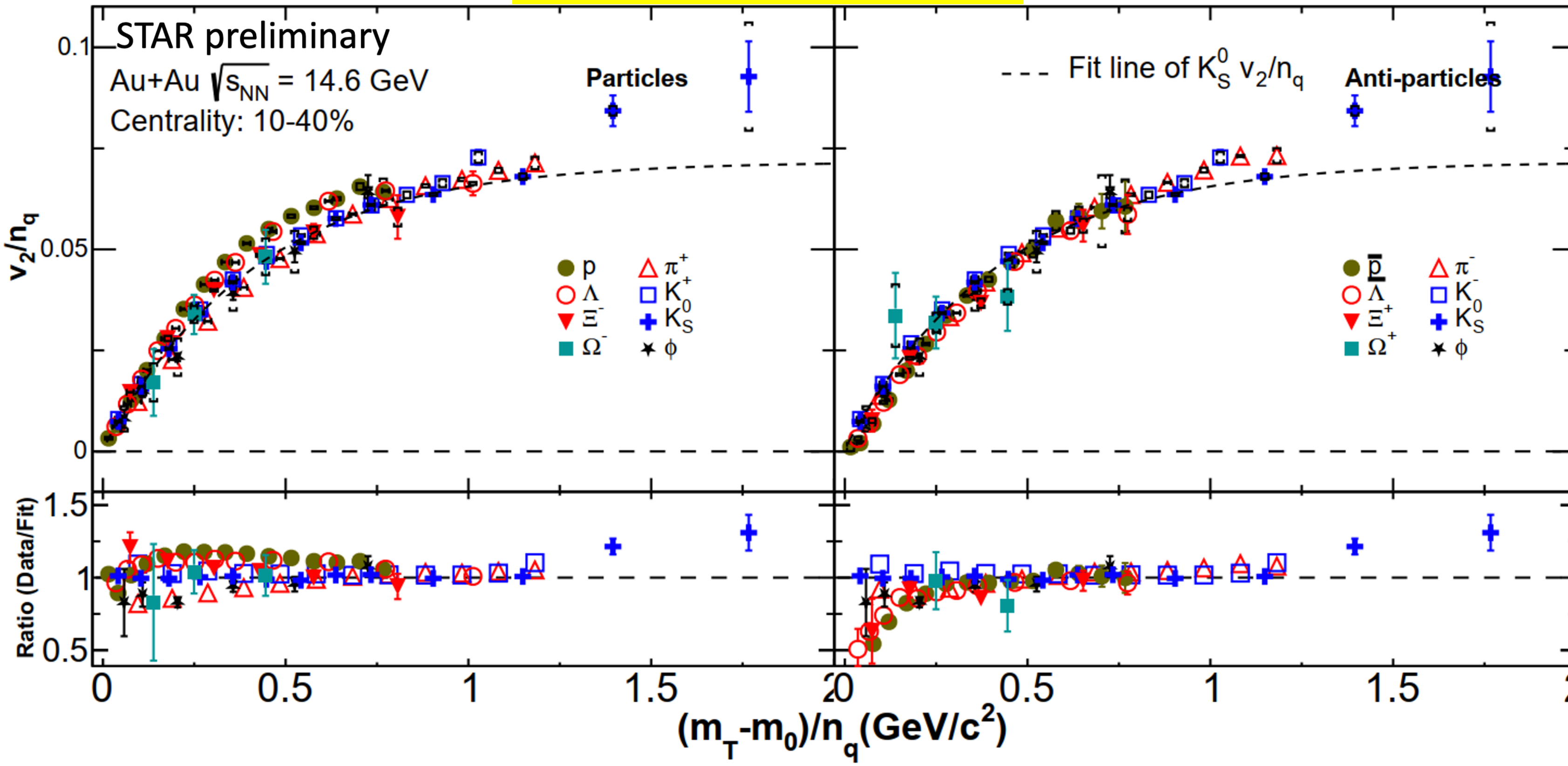
Au+Au @ 19.6 GeV, BES-II



- ϕ meson v_2 follow NCQ scaling with other hadrons.

NCQ Scaling of Elliptic Flow

Au+Au @ 14.6 GeV, BES-II



- φ meson v_2 follow NCQ scaling with other hadrons.

Evidence of partonic collectivity at 14.6 and 19.6 GeV.

Summary

Invariant Yield:

- K^{*0}/K ratio in central Au+Au collisions is smaller than in p+p and peripheral Au+Au collisions
- ϕ/K ratio shows weak centrality dependence

Consistent with hadronic re-scattering for resonances with short lifetime

Elliptic Flow:

- Elliptic flow of ϕ mesons follow NCQ scaling with other hadrons at 14.6 and 19.6 GeV

Evidences of partonic collectivity at 14.6 and 19.6 GeV.

Thanks.