Production of identified hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV at RHIC

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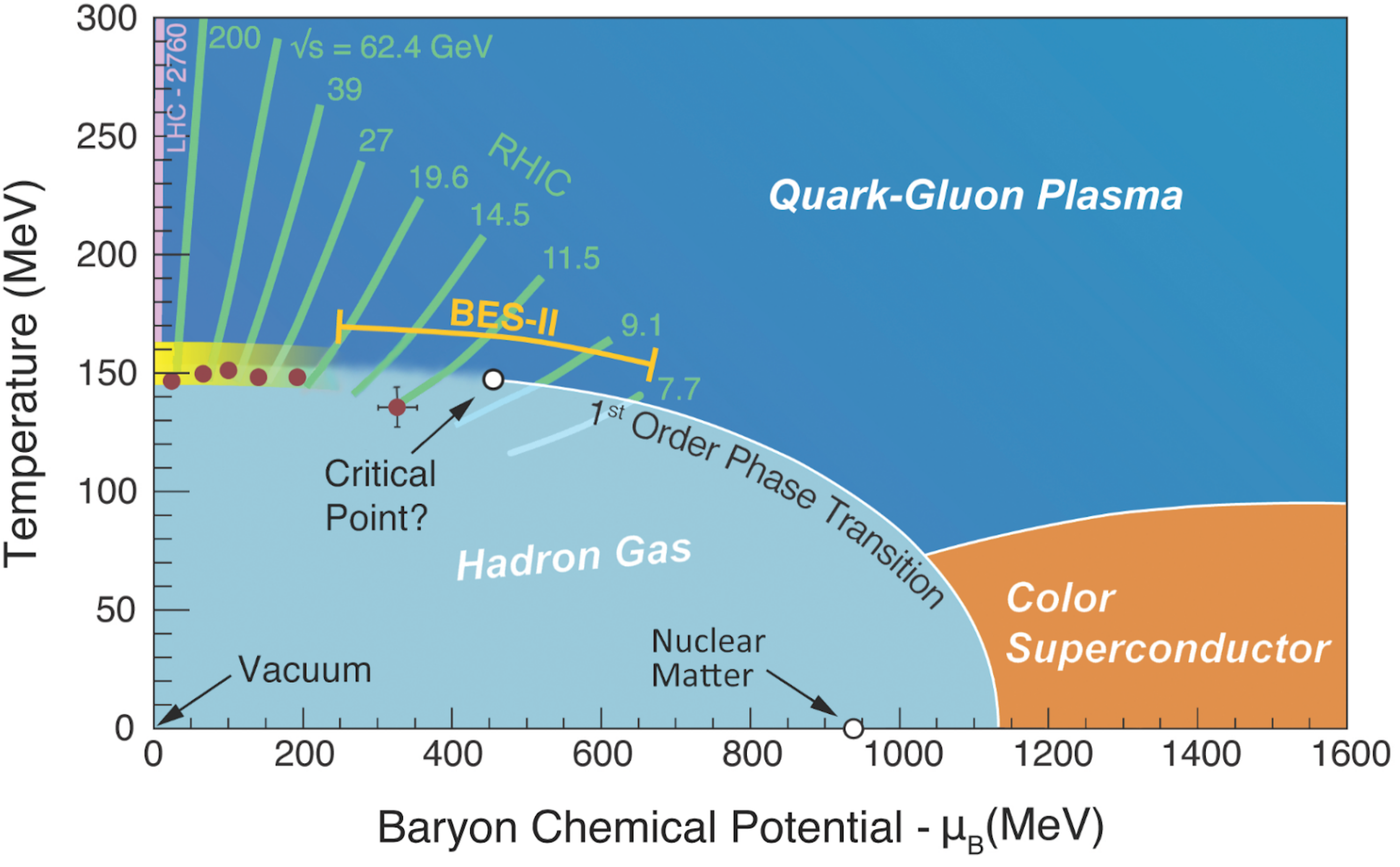
STAR

Outline

- Introduction
- STAR Experiment
- Analysis Details
- Results
- Summary

Introduction

- At very high temperature/energy density a de-confined phase of quarks and gluons is expected to form ➔ Quark-Gluon Plasma (QGP)



Xin An *et al.*, Nucl. Phys. A 1017, 122343 (2022)

RHIC BES Program:

- **To search for the predicted first-order phase transition**
- **To search for a critical end point**
- **To investigate the expected turn-off of QGP signatures**

Phase I

$\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, and 200 GeV

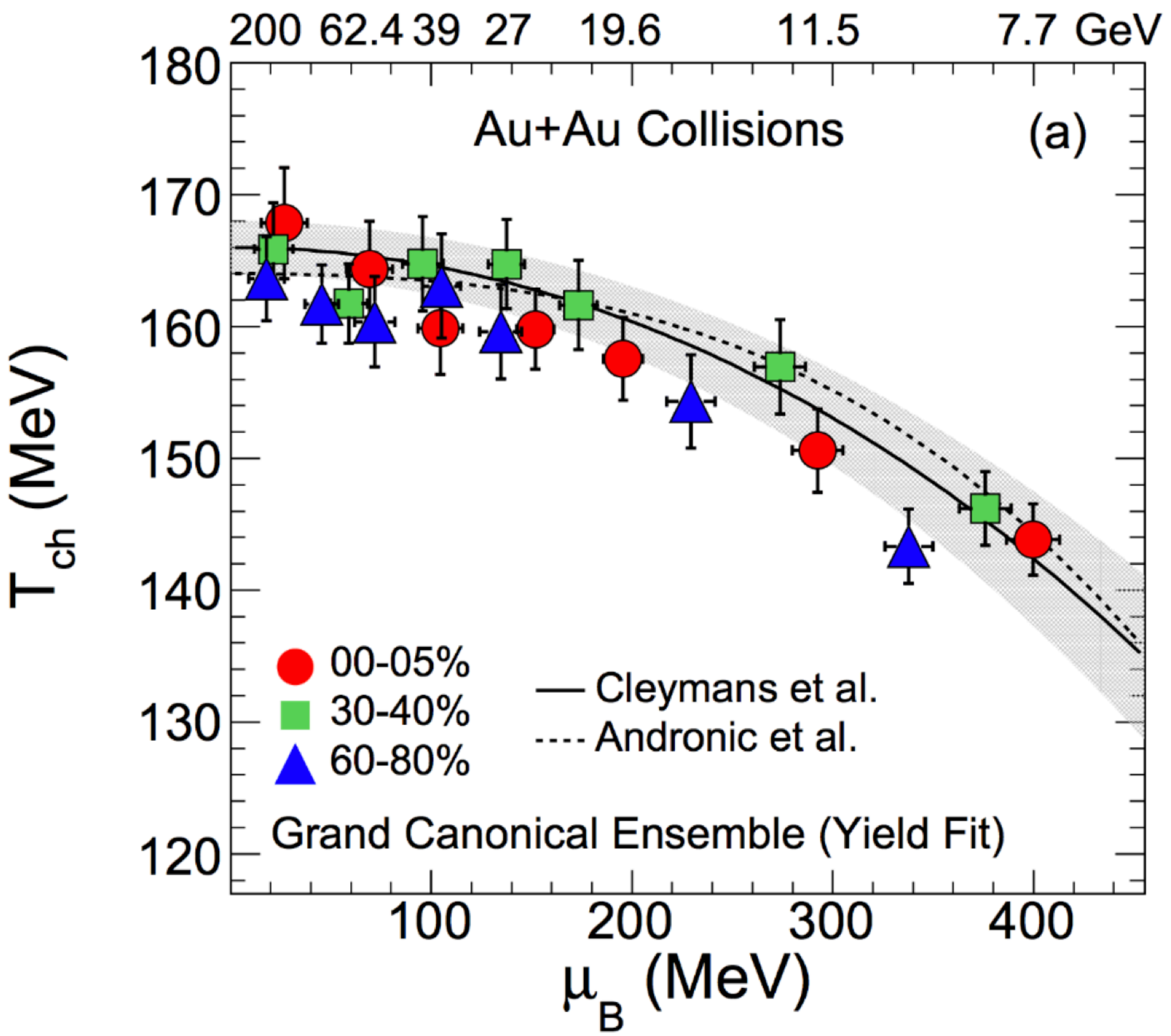
Phase II

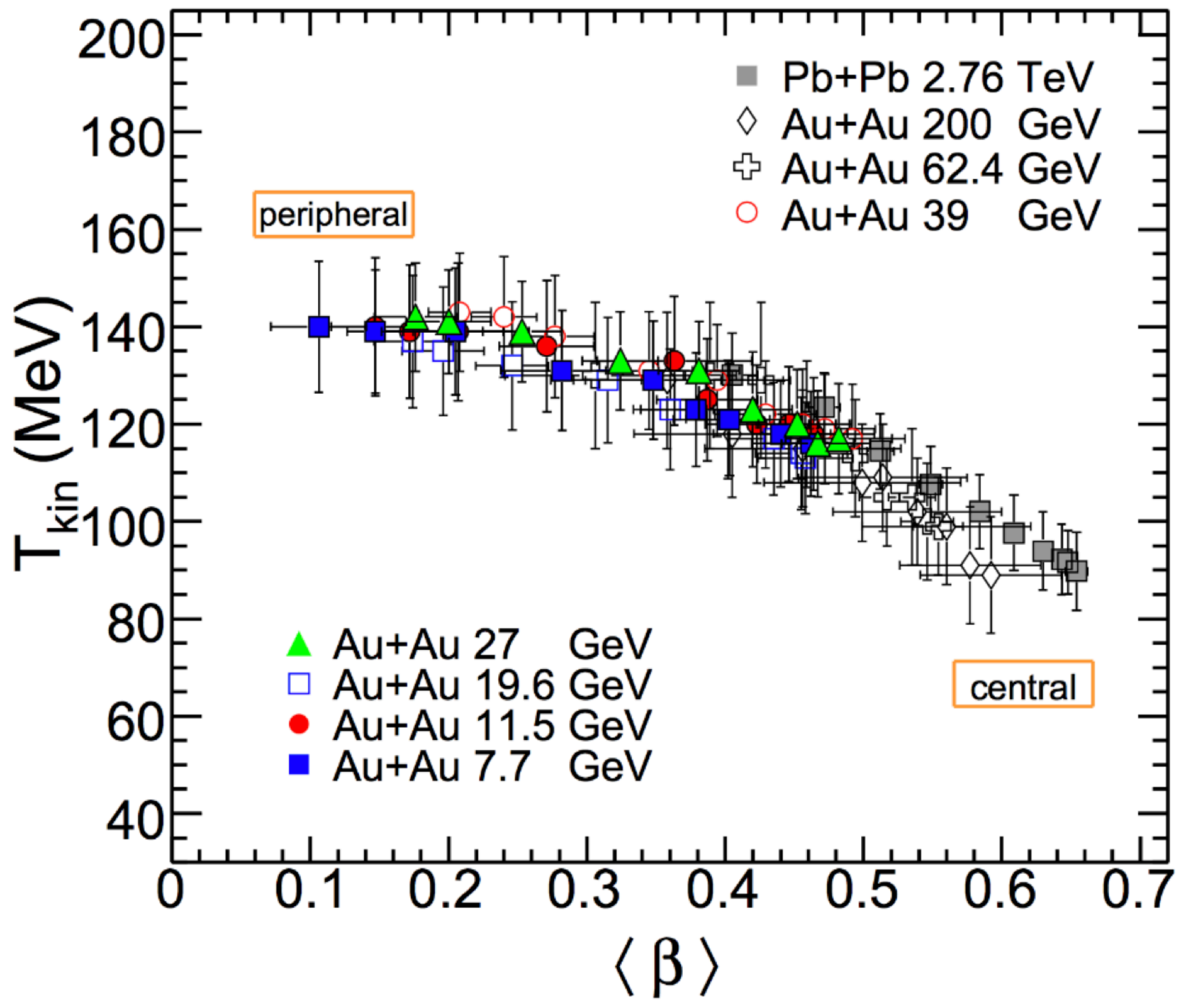
$\sqrt{s_{NN}}$ = 7.7, 9.2, 11.5, 14.6,17.3,19.6, 27 and **54.4** GeV

$\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7, 9.2, 11.5

and 13.7 GeV (FXT)

Introduction





Chemical freeze-out

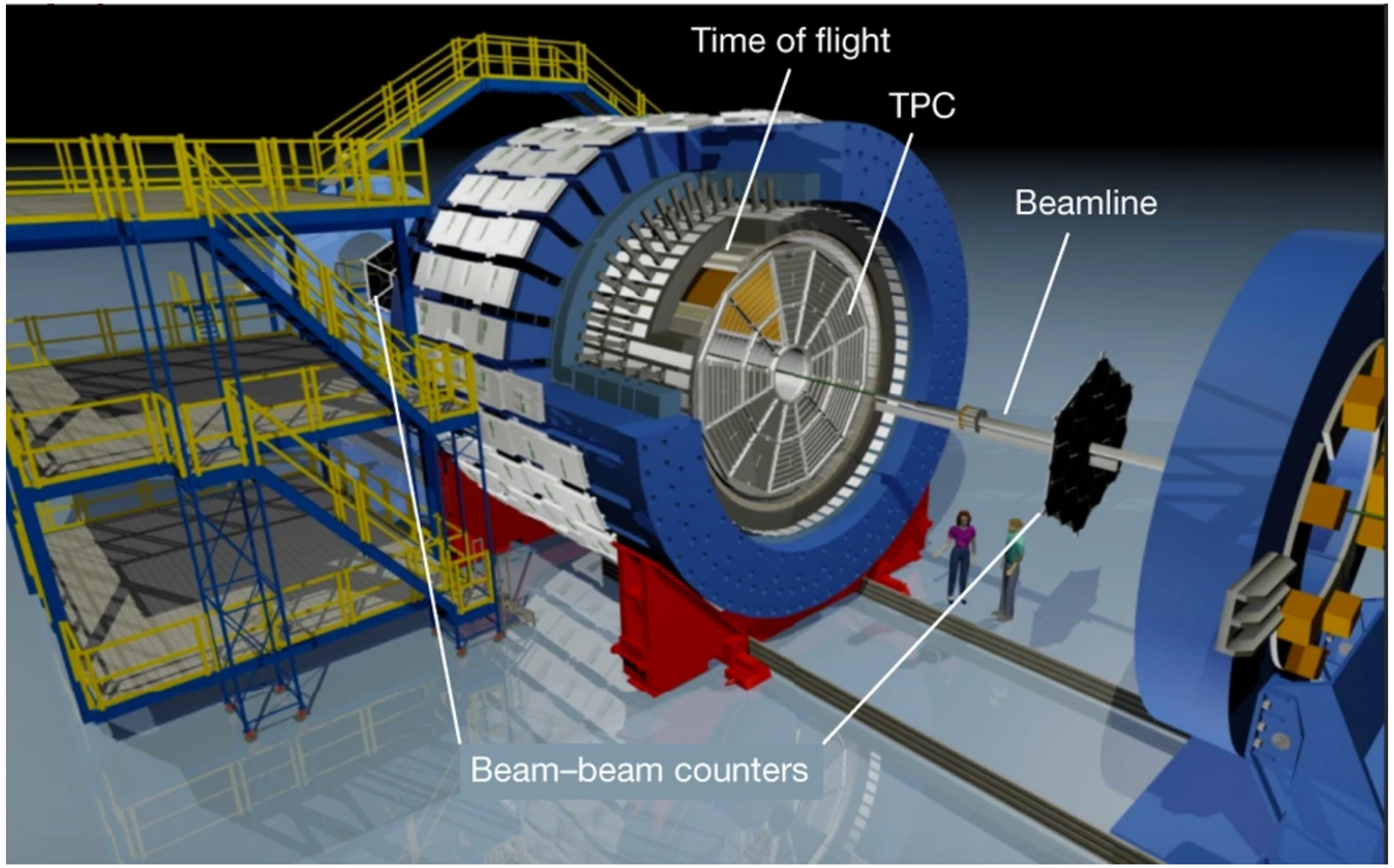
- Weak centrality dependence of T_{ch}
- Centrality dependence of μ_B at lower energies

Kinetic freeze-out

- Central collisions → lower value of T_{kin} and larger radial flow velocity <β>
- Stronger radial flow velocity at higher energy, even for peripheral collisions

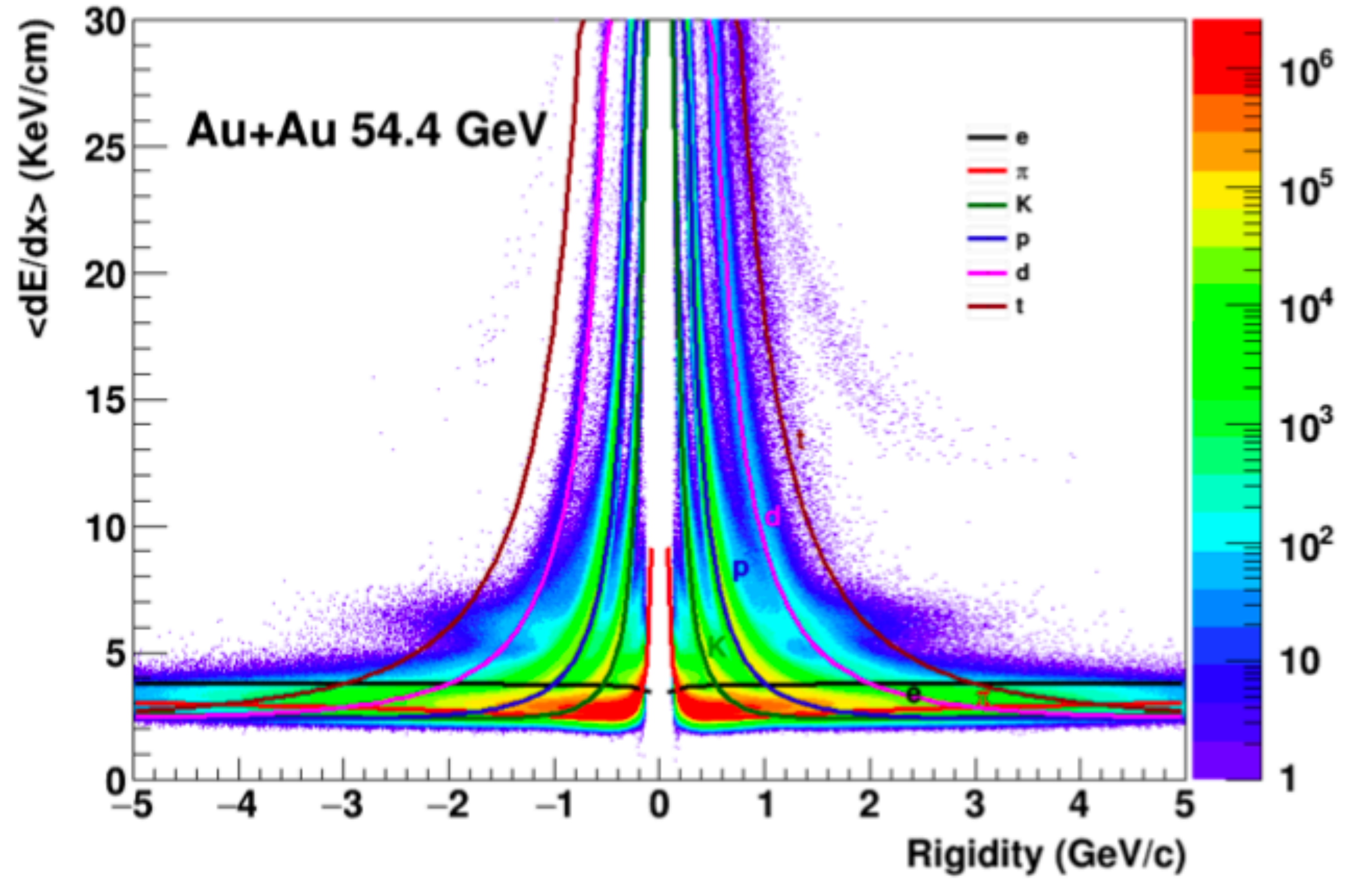
STAR, PRC 79, 034909 (2009)
ALICE, PRC 88, 044910 (2013)

STAR Experiment

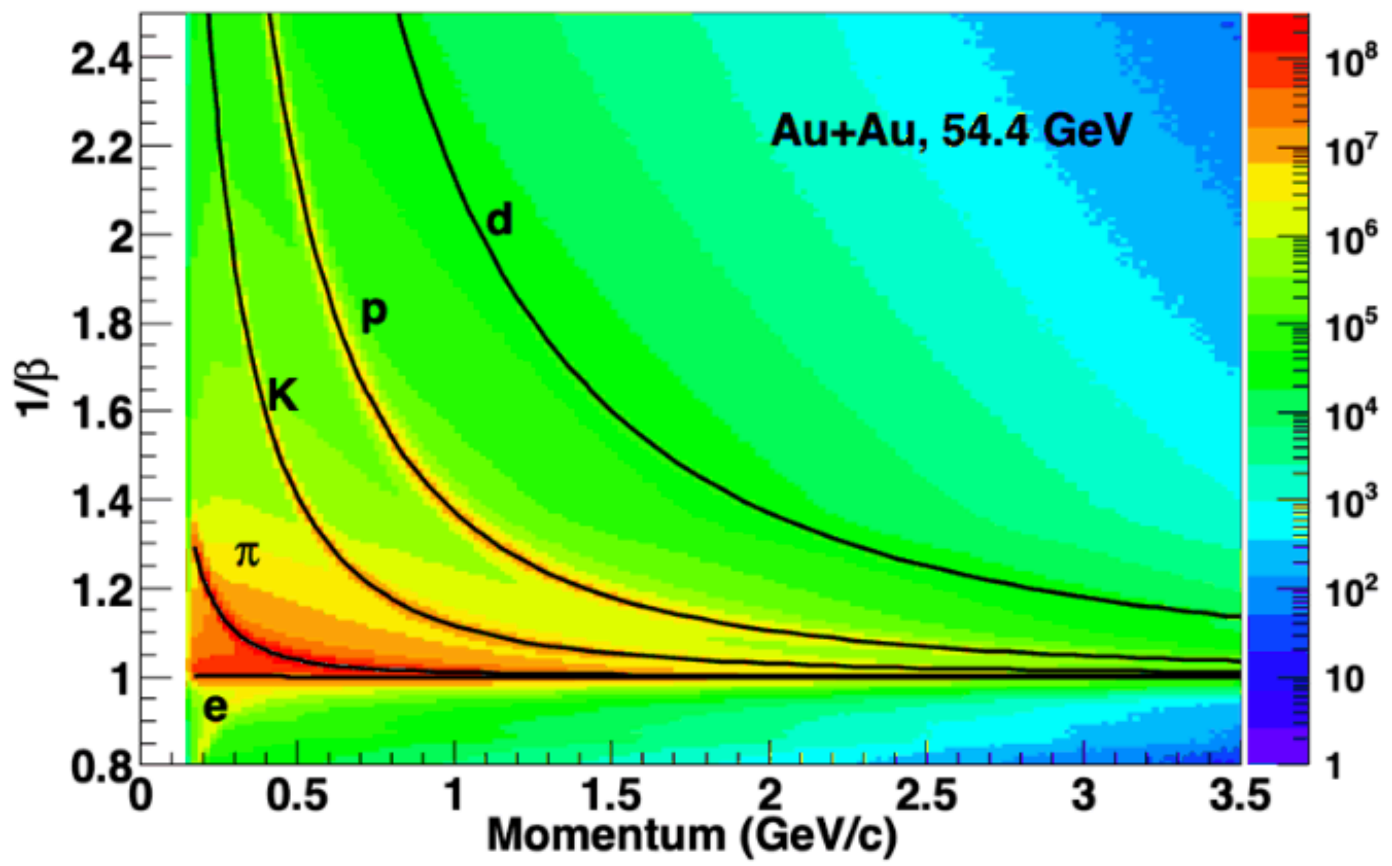


Two main detectors used for particle identification:

TPC (Time Projection Chamber)



TOF (Time of Flight)



- Large coverage in ϕ $(0,2\pi)$ and η $(-1,1)$
- Excellent particle identification at low p_T using TPC and at intermediate p_T using TOF
- Uniform acceptance at mid-rapidity

Dataset: Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV (2017)

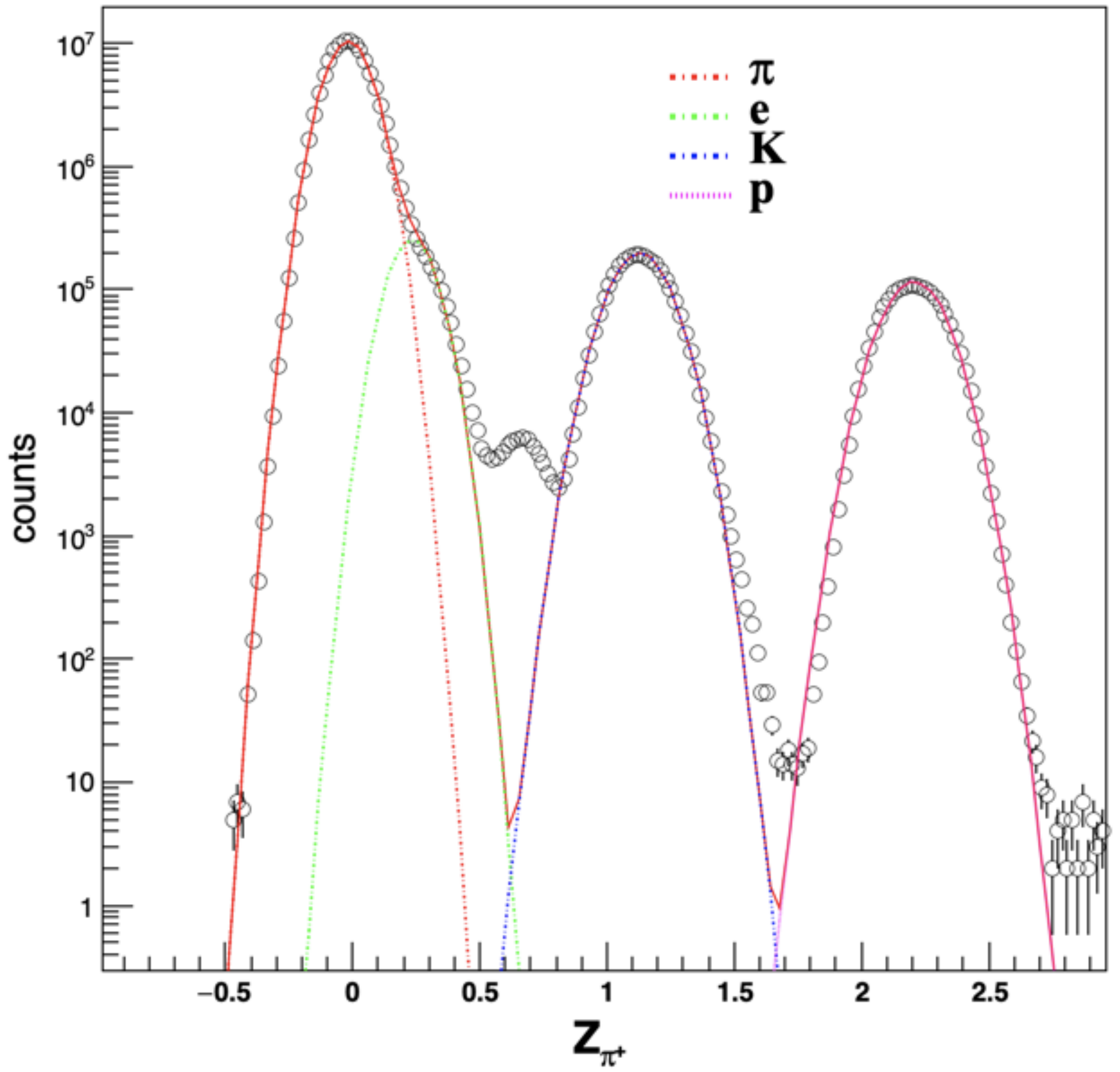
Particle Identification

- Particle identification → <dE/dx> information from TPC
- $\langle dE/dx \rangle_{theory}$ is calculated using Bichsel function
- m^2 information from TOF is used for identifying p_T > 0.8 GeV/c particles

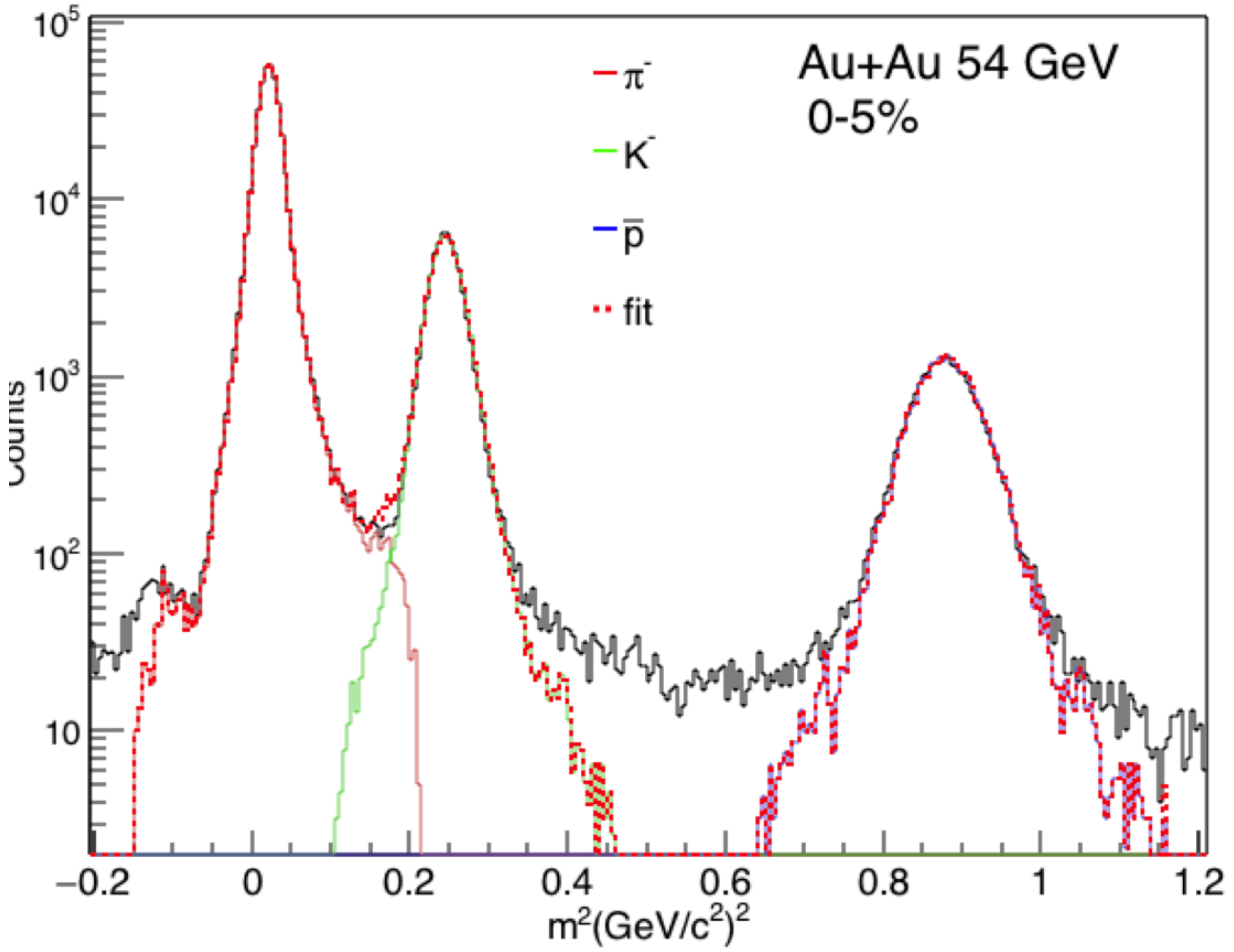
TPC p_T range → $\pi^{\pm}$ and $K^{\pm}$: 0.2-0.7 GeV/c ; p: 0.4-0.8 GeV/c

TOF p_T range → $\pi^{\pm}$ and $K^{\pm}$: 0.7-2.0 GeV/c ; p: 0.8-2.0 GeV/c

|y|<0.1, 0.25 < p_T (GeV/c) < 0.30



|y|<0.1, 0.8 < p_T (GeV/c) < 0.9

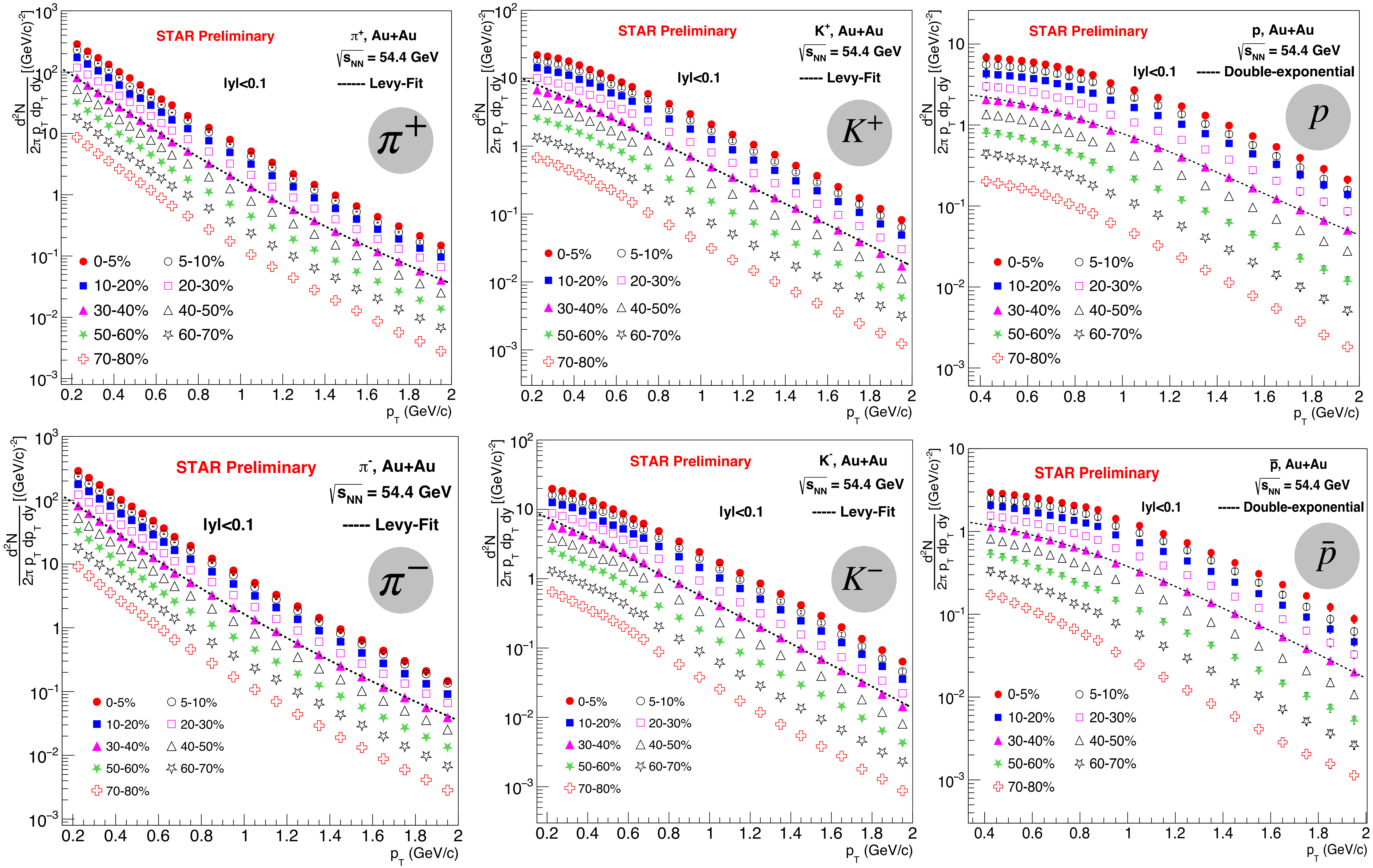


$$z_i = \ln\left(\frac{\langle dE/dx \rangle_{measured}}{\langle dE/dx \rangle_{theory}}\right)$$

H. Bichsel Nucl. Instr. Meth. A 562, 154 (2006)

$$m^2 = p^2\left(\frac{1}{\beta^2} - 1\right)$$

Transverse momentum (p_T) spectra



- Levy Function

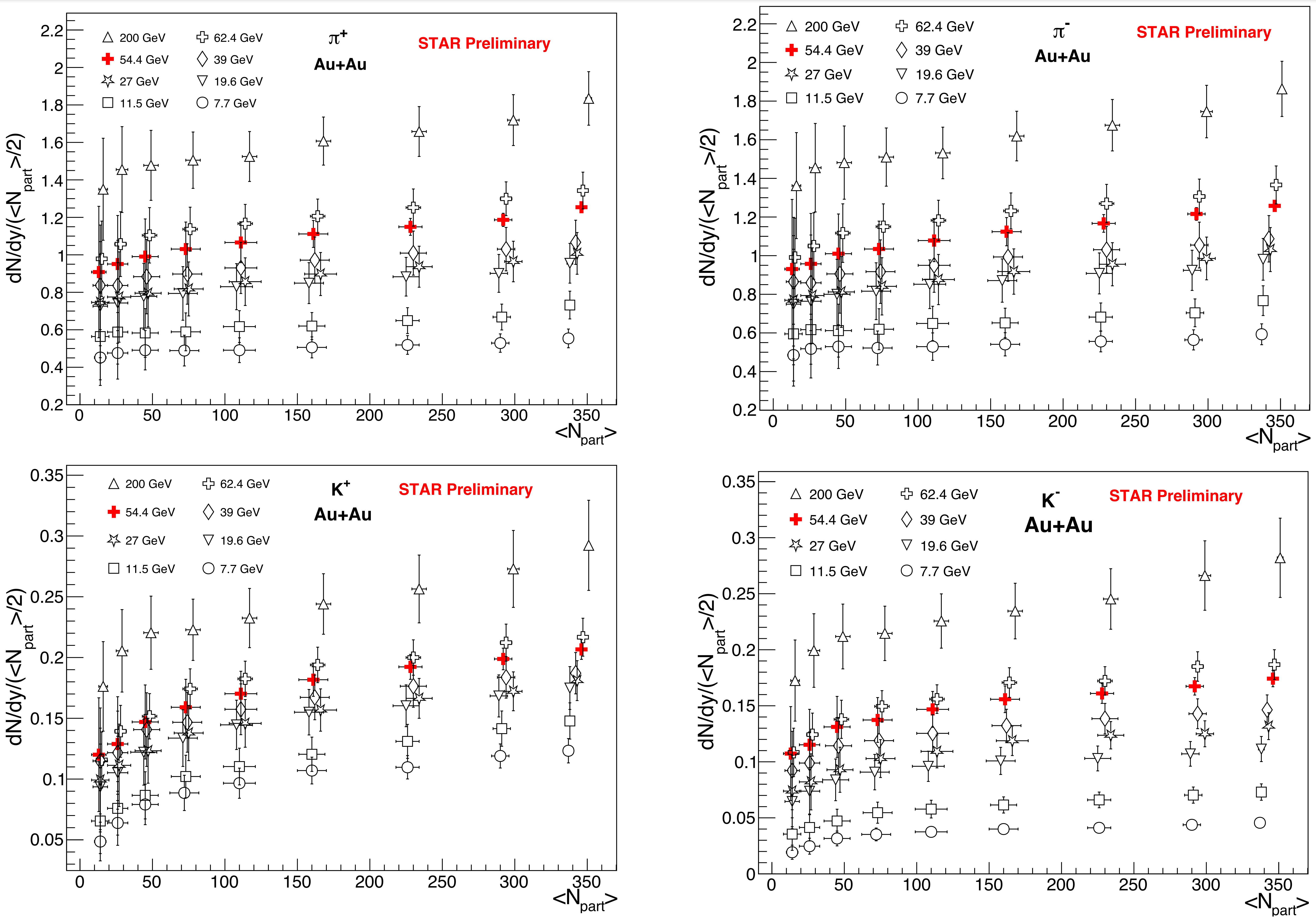
$$\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT+m(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1+\frac{m_T-m}{nT}\right)^{-n}$$

- Double exponential

$$\frac{d^2N}{2\pi p_T dp_T dy} = A_1 e^{-p_T^2/T_1^2} + A_2 e^{-p_T^2/T_2^2}$$

- p_T spectra of particles and antiparticles show a clear particle species and centrality dependence

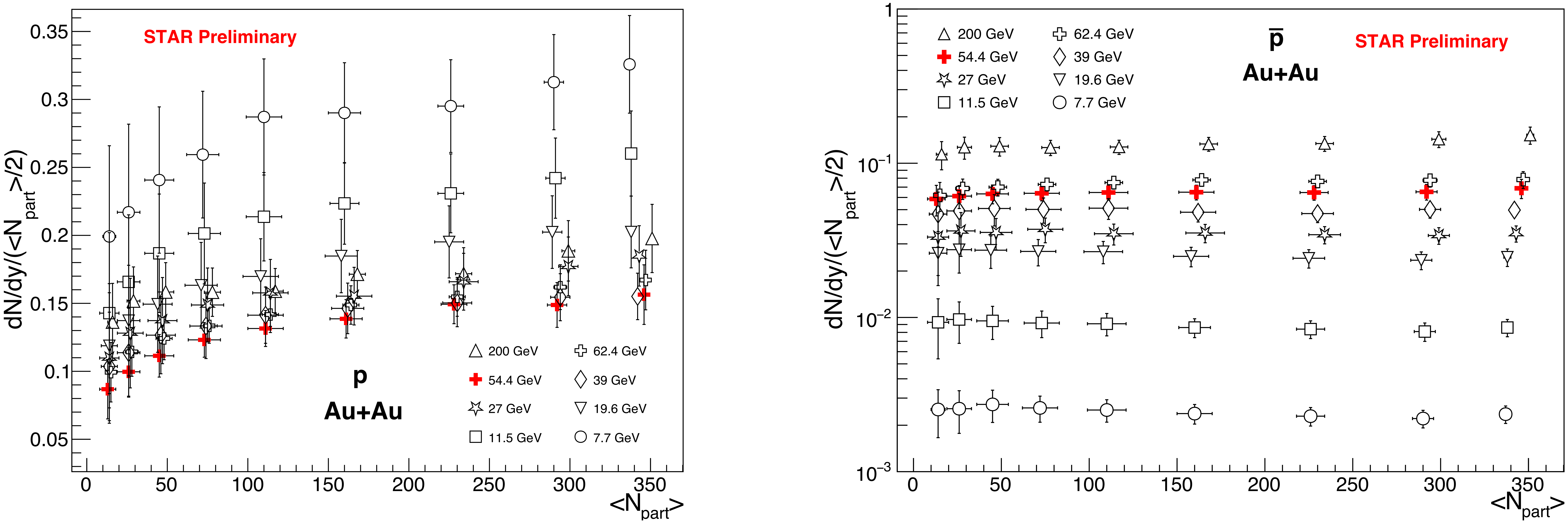
p_T-integrated yield



- Normalized pion and kaon yields increase with centrality and collision energy

STAR, PRC 79,034909 (2009); STAR, PRC 81, 24911 (2010); STAR, PRC 96, 044904 (2017); STAR, PRC 101, 24905 (2020)

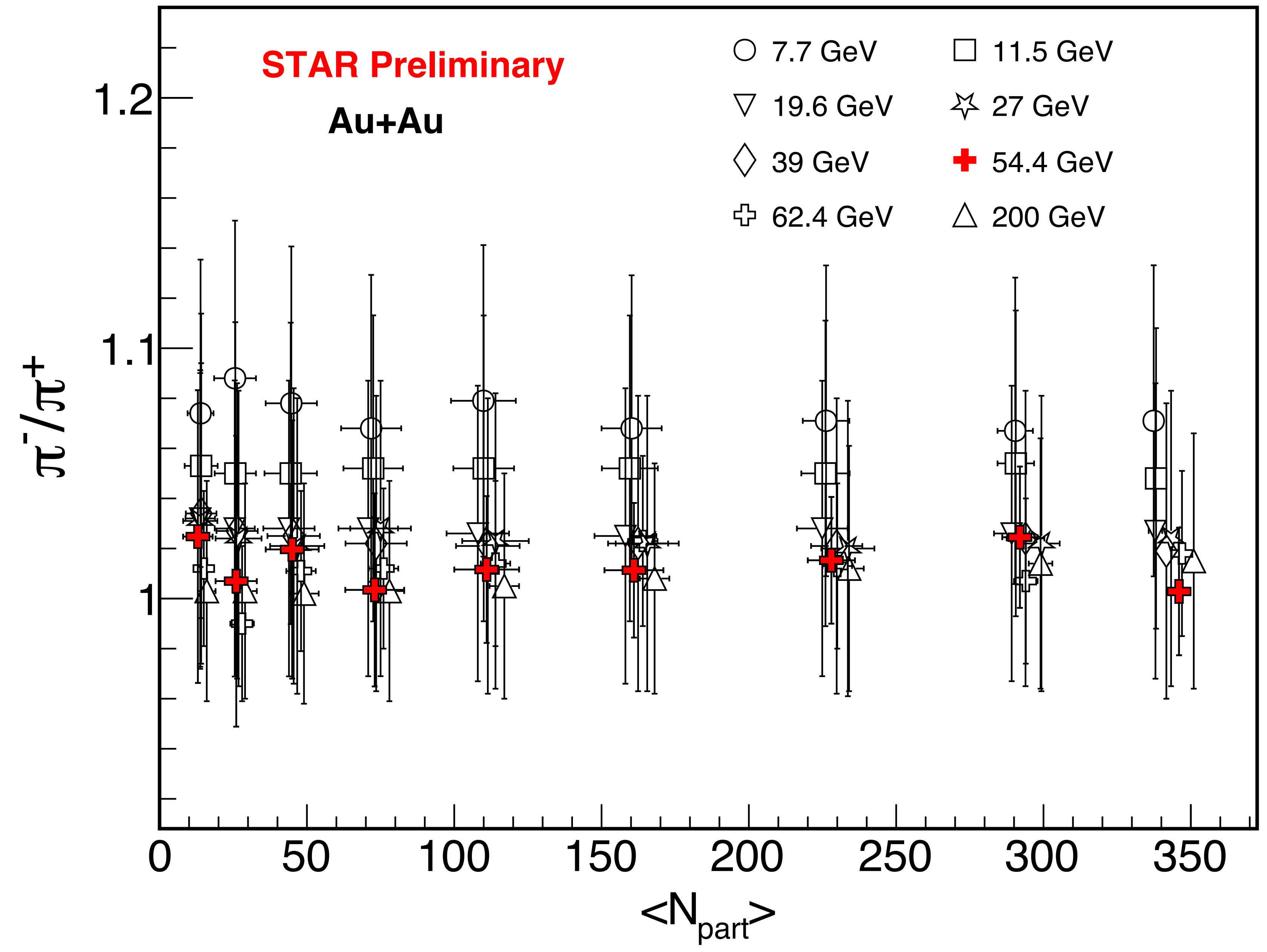
pT-integrated yield

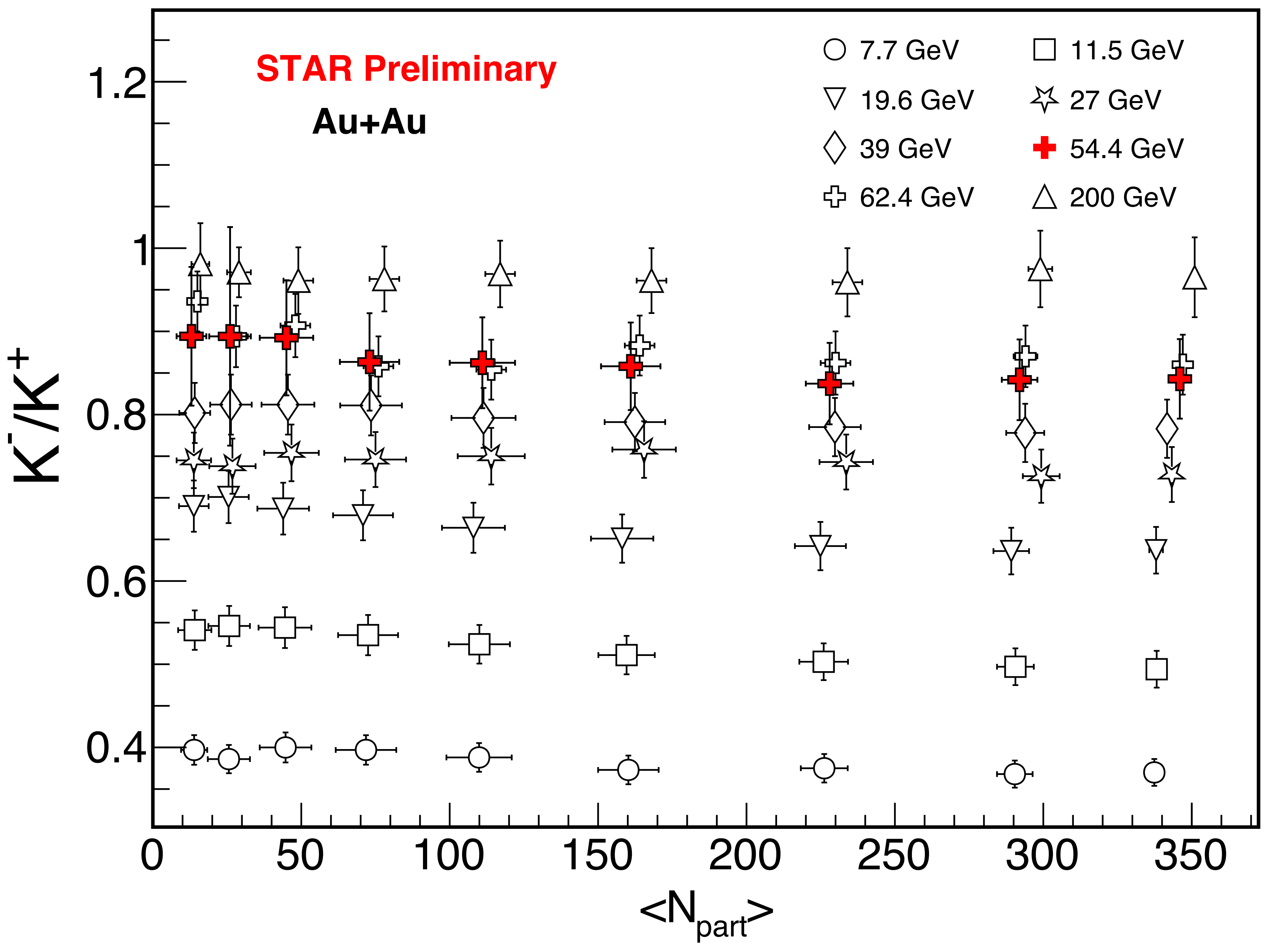


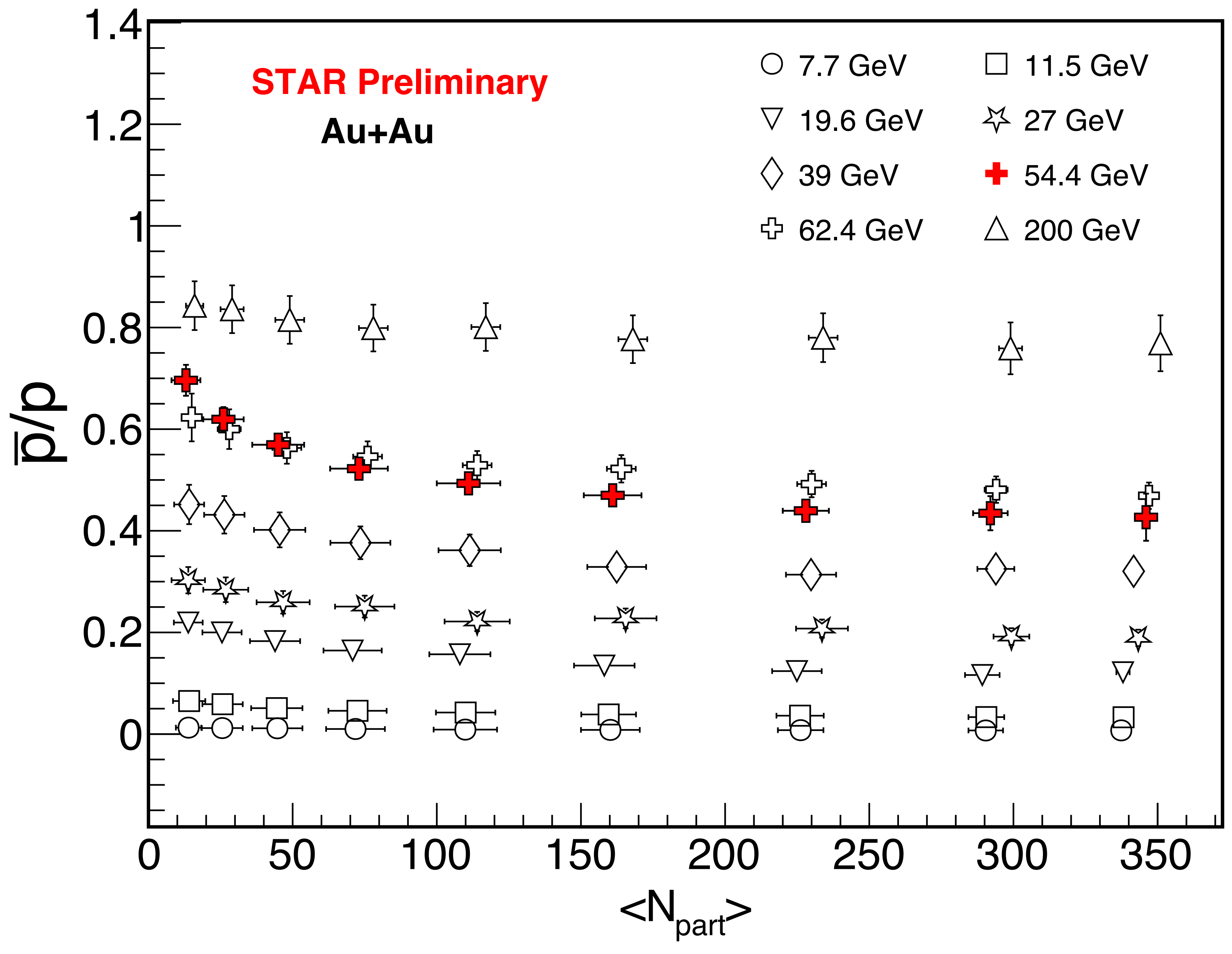
- Normalized yield for proton shows a clear centrality dependence, and reaches a minimum around 54.4 GeV due to the interplay of pair production and baryon stopping

- Normalized yield for anti-proton shows a clear energy dependence

Centrality dependence of particle ratios

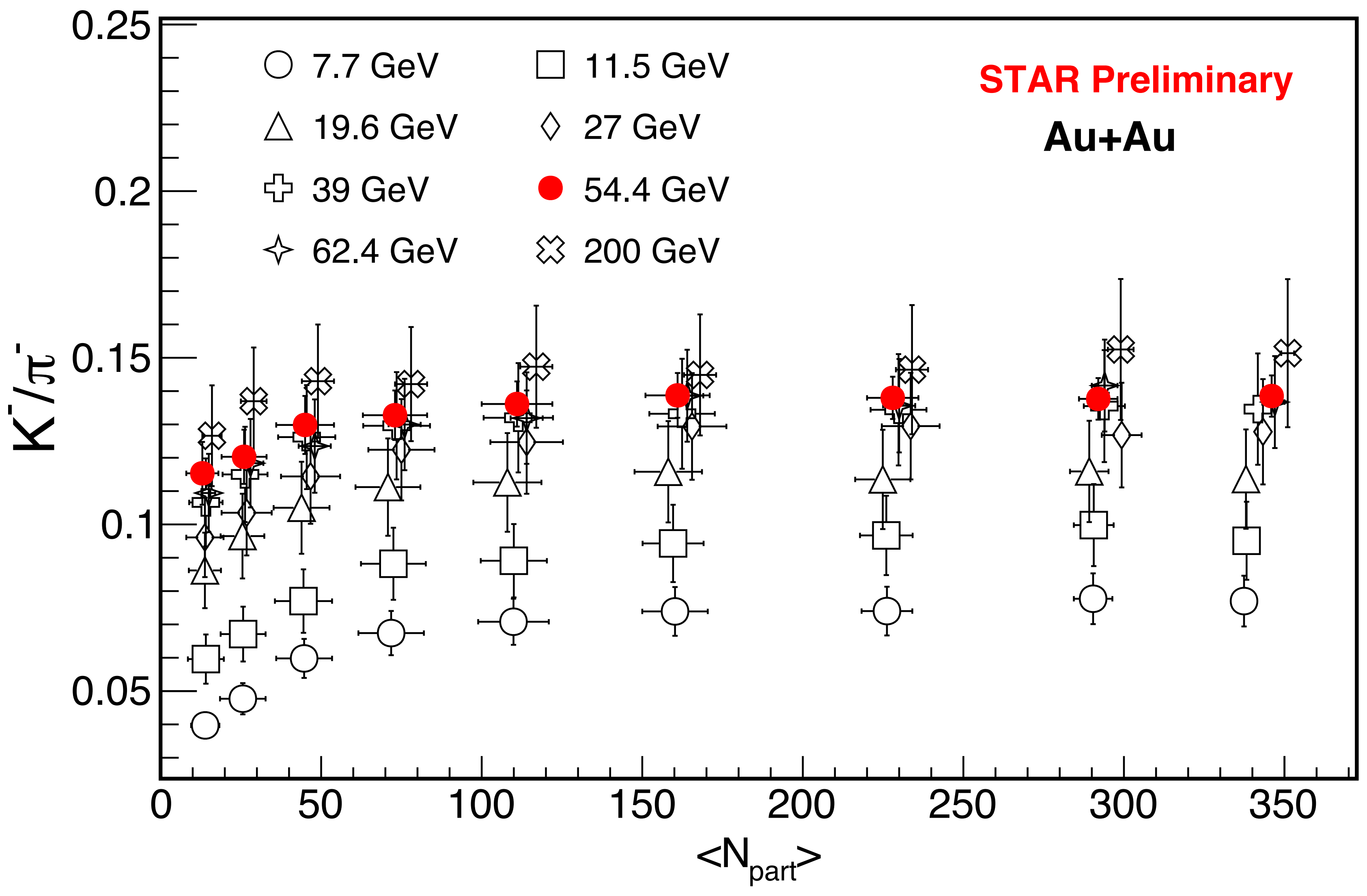


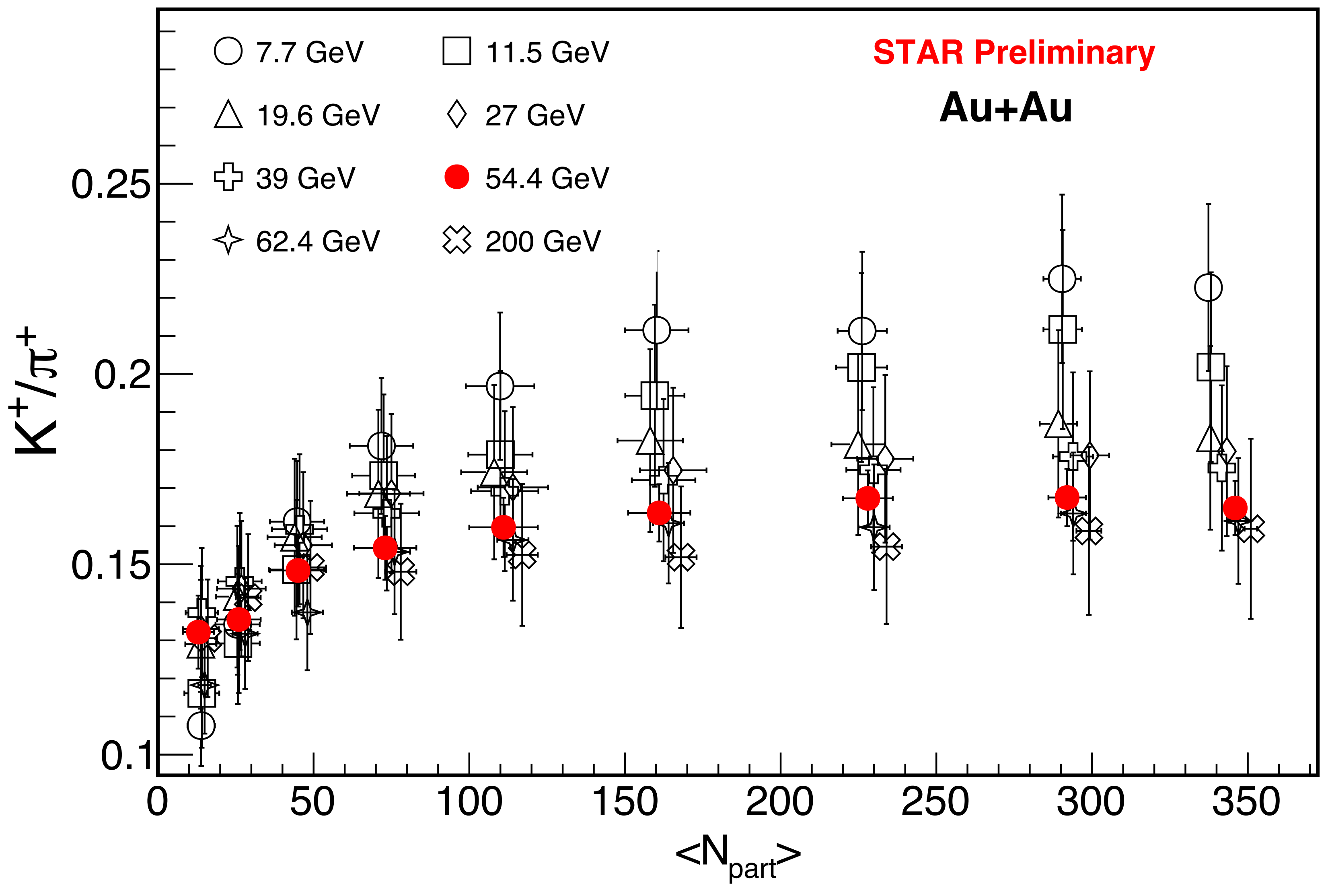


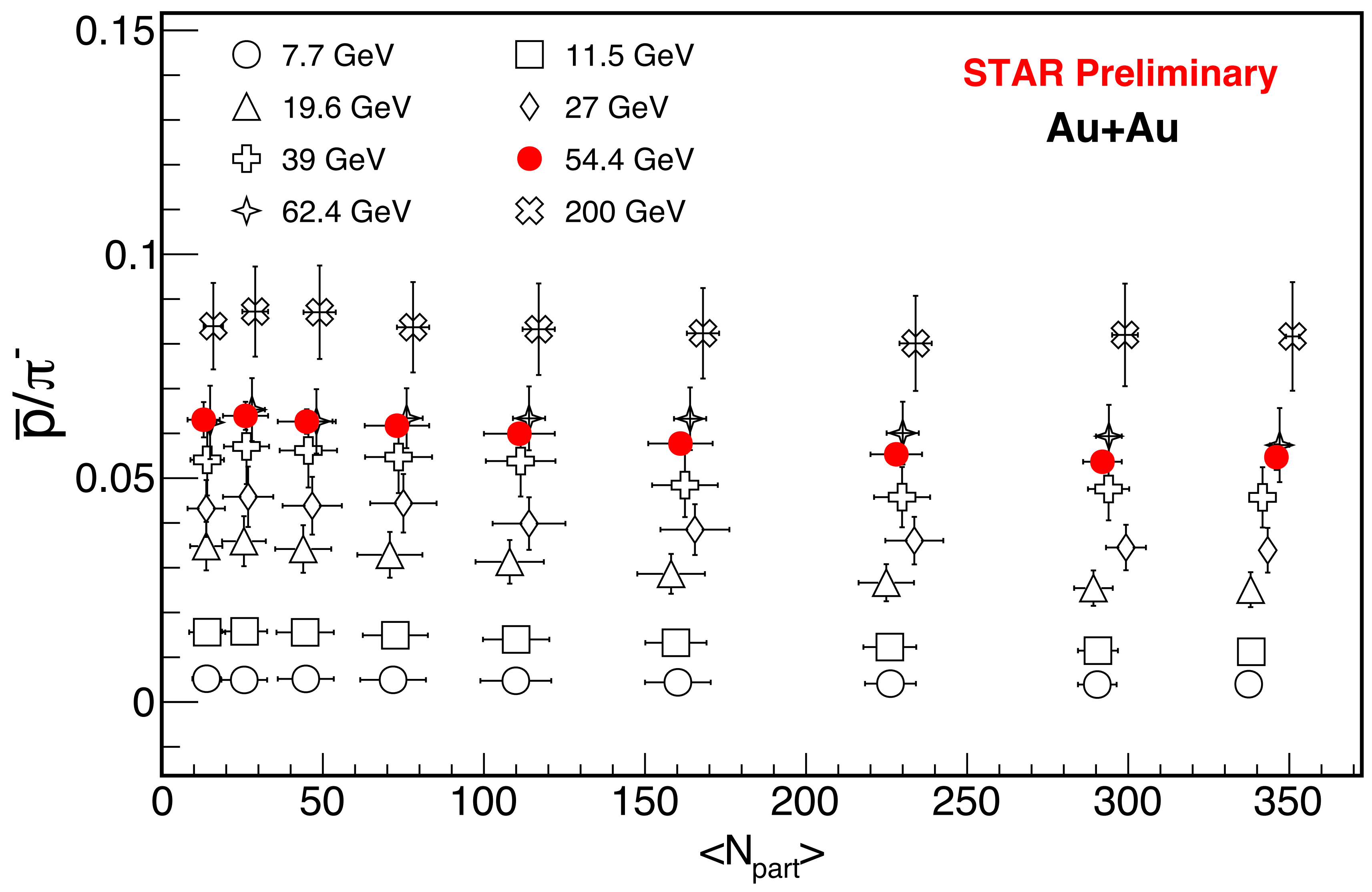


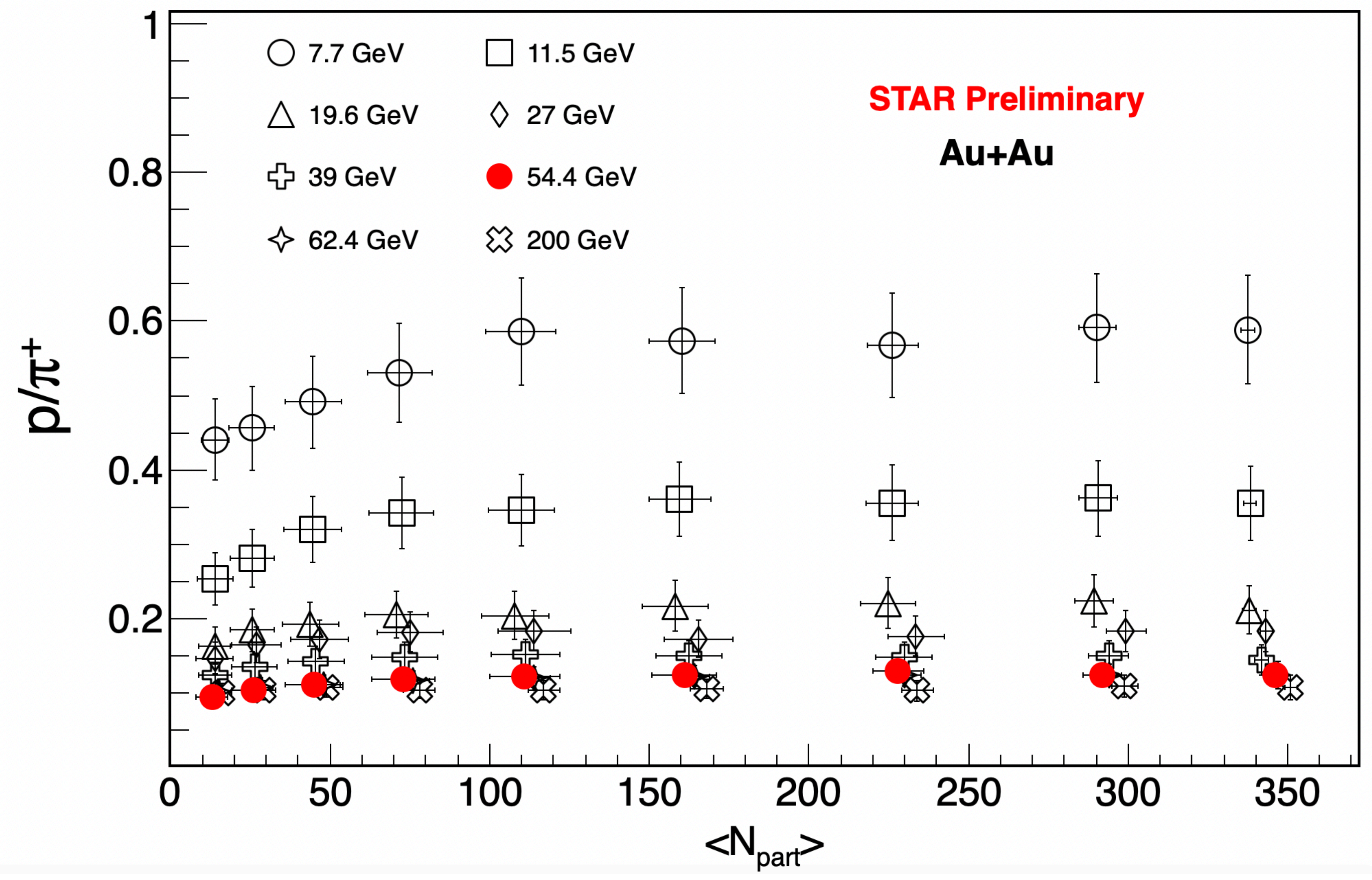
- π^-/π^+ ratio is close to unity for all centralities
- K^-/K^+ratio does not depend on centrality and is lower than unity ➔ associated production
- Antiproton-to-proton ratio decreases with increasing centrality ➔ baryon stopping

Centrality dependence of particle ratios



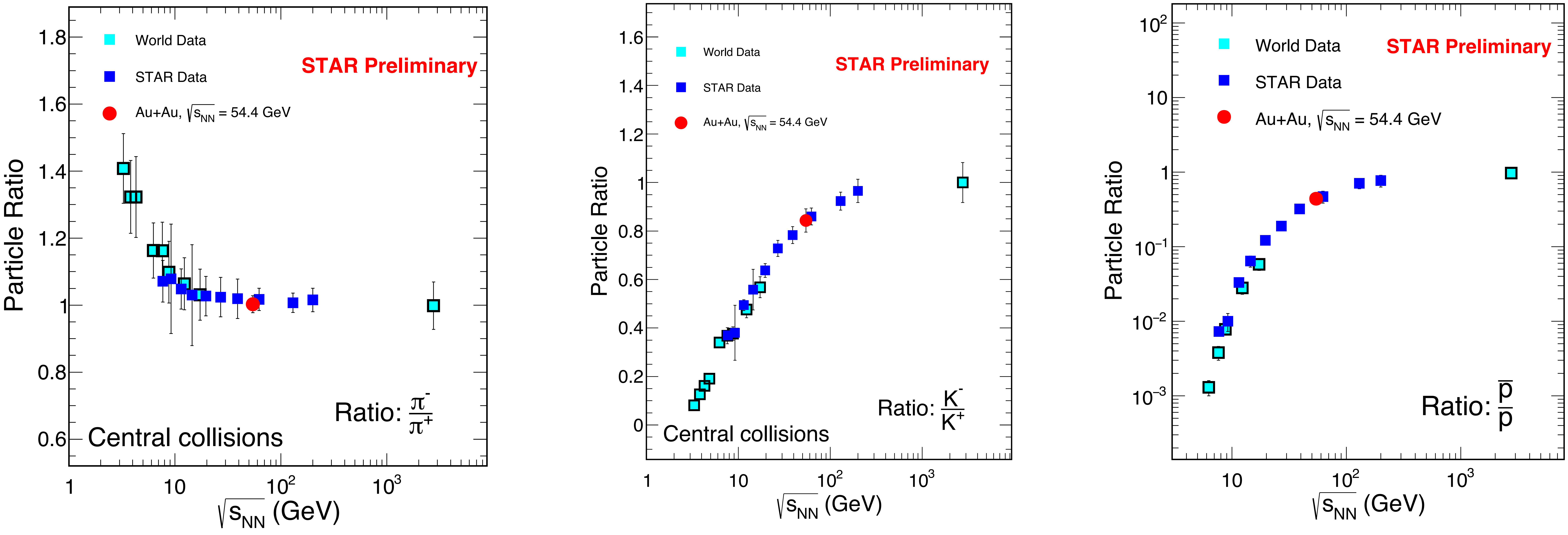






- K^-/π^- and $\bar{p}/\pi^-$ ratios increase with increasing energy
- K^+/π^+ratio is maximal at 7.7 GeV and decreases with increasing energy ➔ associated production dominant at lower energies
- p/π^+ ratio decreases with increasing energy ➔ more baryon stopping at lower energies

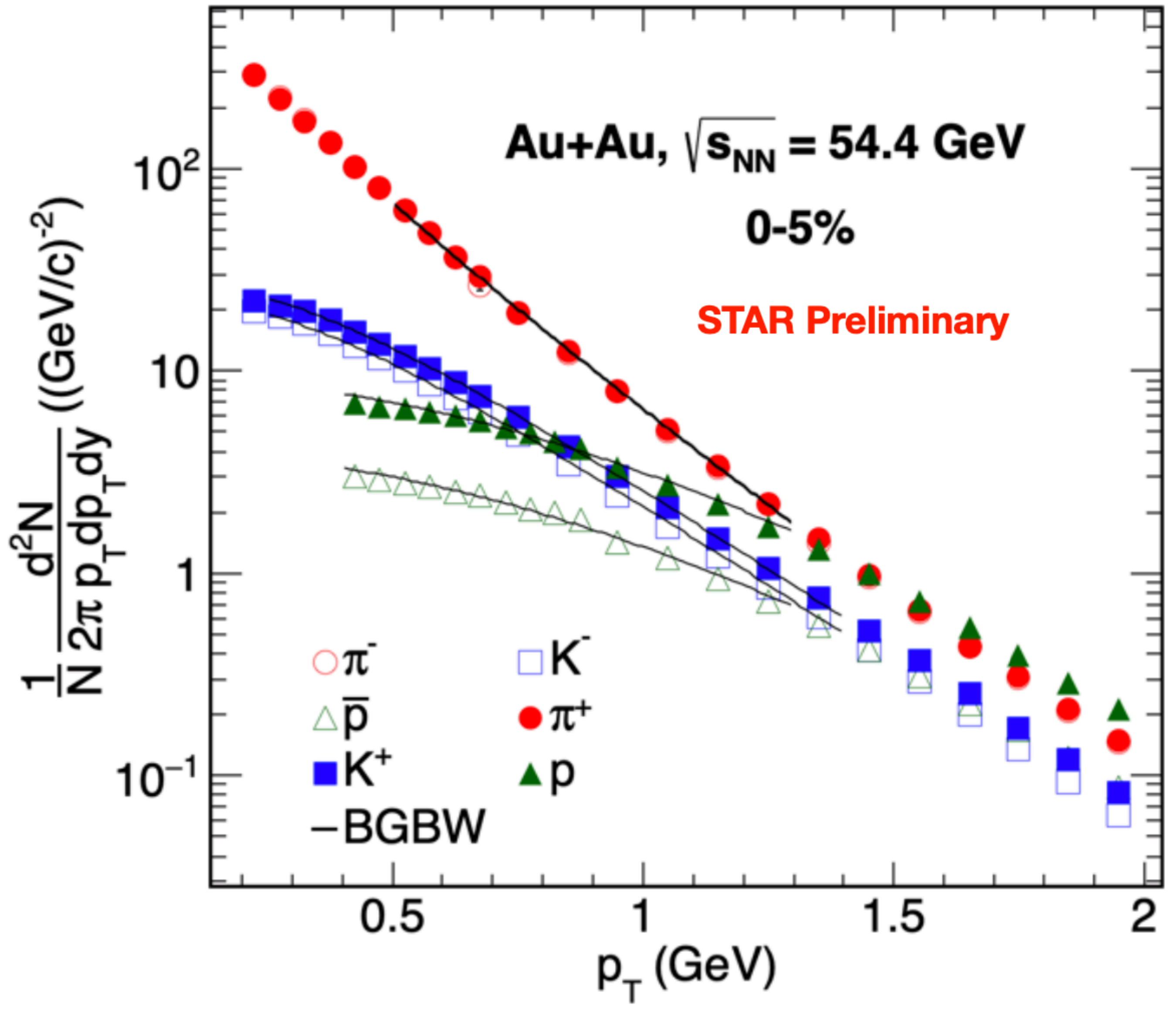
Energy dependence of particle ratios

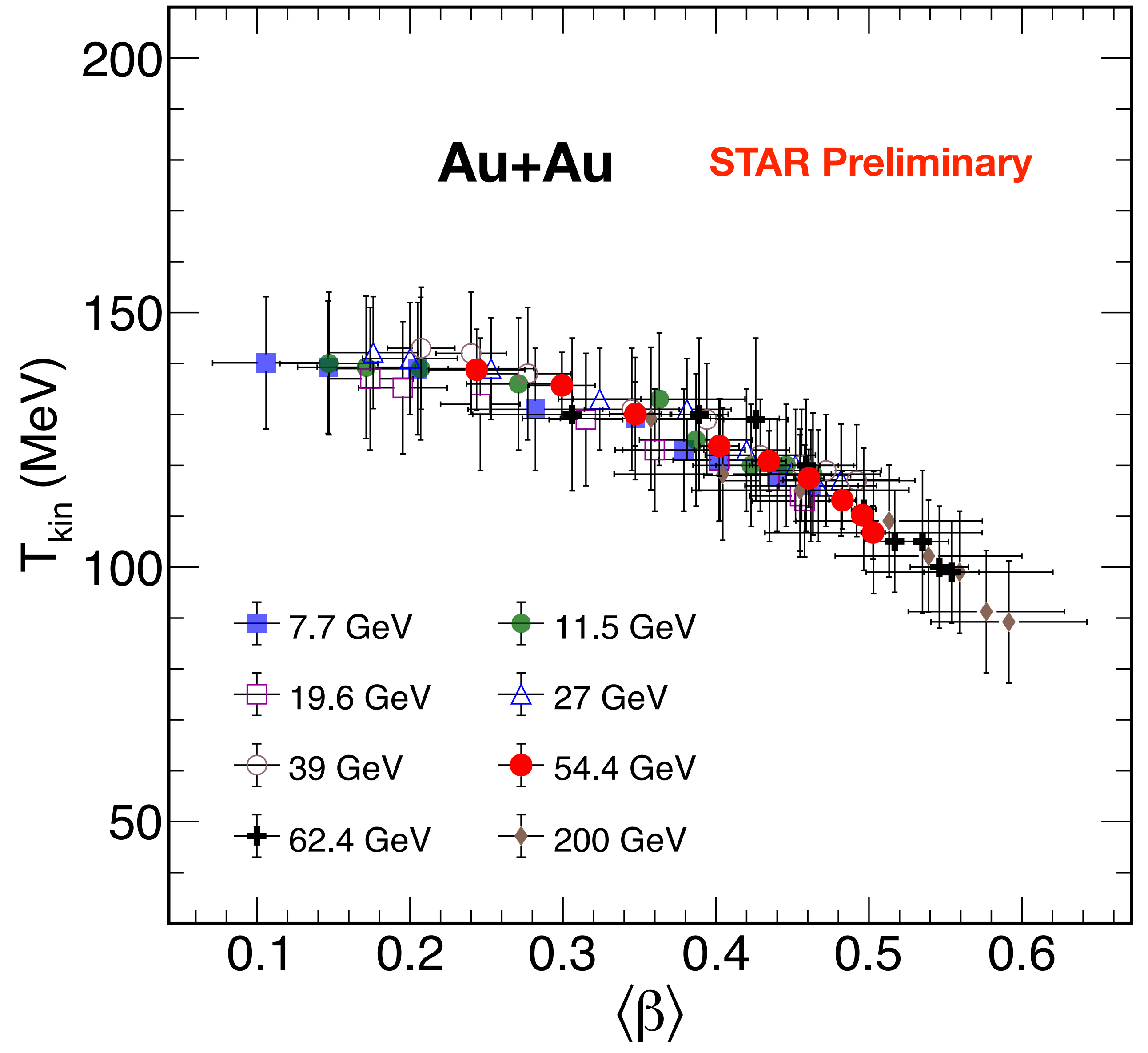


- Particle ratios for 54.4 GeV follow the collision energy dependence established by measurements from AGS, SPS, RHIC, and LHC energies

E895, PRL 88, 102301 (2002); NA49, PRC 77, 024903 (2008); STAR, PRC 96, 044904 (2017); STAR, PRC 81, 024911 (2010); STAR, PRC 79, 034909 (2009); ALICE, PRC, 88, 044910 (2013)

Kinetic freeze-out





Blast-wave model: A hydrodynamic model

$$\frac{dN}{p_T dp_T} \propto \int_0^R r\, dr\, m_T I_0\left(\frac{p_T \sinh\rho(r)}{T_{kin}}\right) \times K_1\left(\frac{m_T \cosh\rho(r)}{T_{kin}}\right)$$

I_0, K_1: Modified Bessel functions
$\rho(r) = \tanh^{-1}\beta$
β = Transverse radial flow velocity
T_{kin}: Kinetic freeze-out temperature

Kinetic freeze-out

- Central collisions ➔ lower value of T_{kin} and larger radial flow velocity $\langle\beta\rangle$
- Stronger radial flow velocity at higher energy, even for peripheral collisions

STAR, PRC 79, 034909 (2009)

Summary

- Transverse momentum spectra for identified hadrons ($\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$) have been studied in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV using STAR data
- p_T integrated normalized yields show a clear centrality and energy dependence
- Energy and centrality dependences of particle ratios are consistent with BES-I results
- Kinetic freeze-out temperature and flow velocity show anti-correlation

Thank you for your attention !!