Production of identified charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV using the STAR detector.

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Supported in part by:
U.S. DEPARTMENT OF ENERGY | Office of Science

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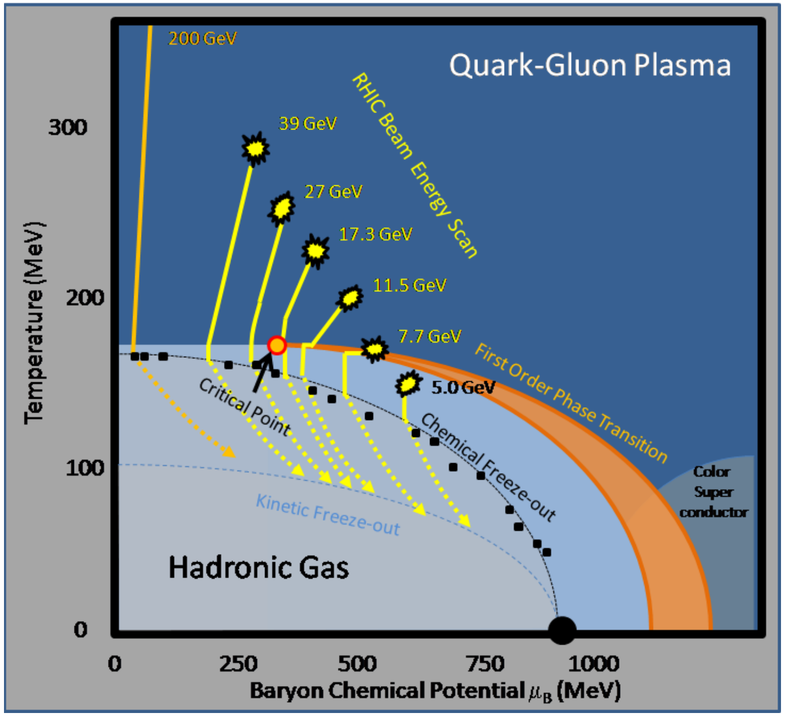
Introduction and Motivation

- **Aims of the BES Program at RHIC**
  - Study of QCD phase diagram
  - Search for the QCD critical point and first-order phase transition

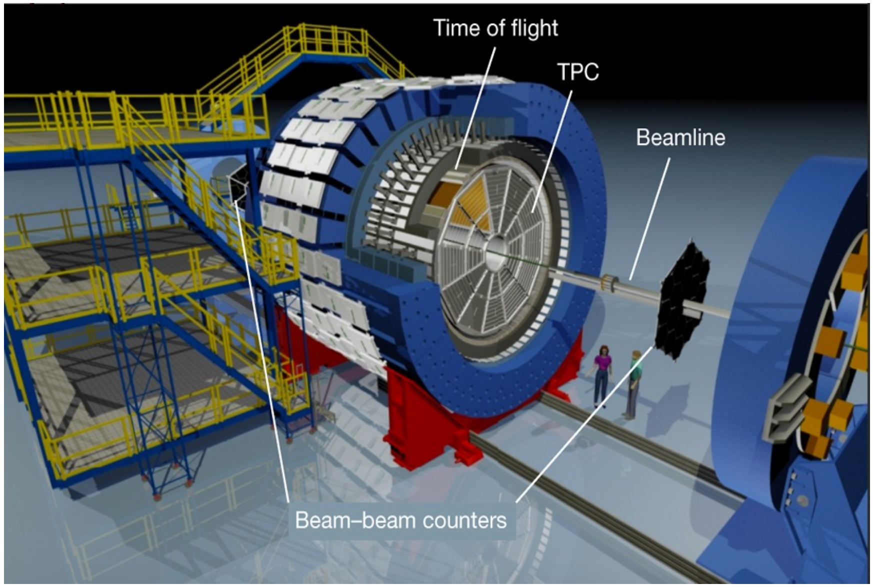
- **BES I (2010-2014)**
  - $\sqrt{s_{NN}}$ = 62.4, 39, 27, 19.6, 14.5, 11.5, 7.7 GeV

- **BES II (2017-2021)**
  - Collider mode: $\sqrt{s_{NN}}$ = **54.4, 27, 19.6, 17.3, 14.6, 11.5, 9.2, 7.7 GeV**
  - Fixed target mode: $\sqrt{s_{NN}}$ = 13.7, 11.5, 9.2, 7.7, 7.2, 6.2, 5.2, 4.5, 3.9, 3.5, 3.2, 3.0 GeV



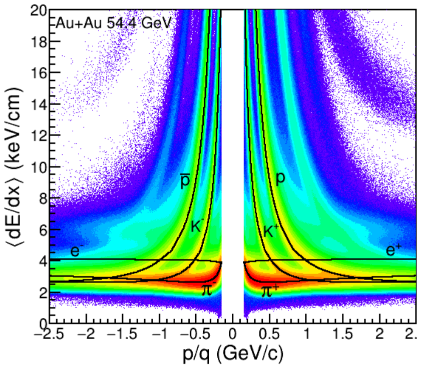
The main idea behind the BES program is to vary the collision energy and look for signatures of the QCD phase boundary and QCD critical point.

The STAR Detector

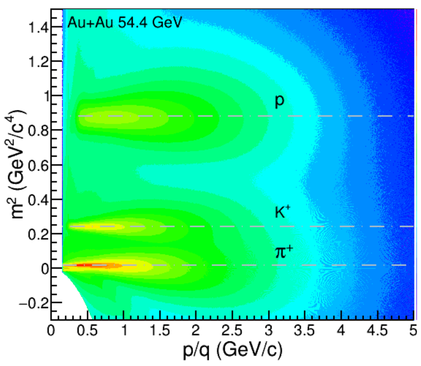


- The Solenoidal Tracker at RHIC, known as STAR, tracks the thousands of particles produced by heavy-ion collisions at RHIC.
- STAR is used to search for signatures of the Quark-Gluon Plasma (QGP).
- Particle identification for low momentum region is performed by using the Time Projection Chamber (TPC) and for high momentum region by the Time-Of-Flight (TOF) detector.

TPC

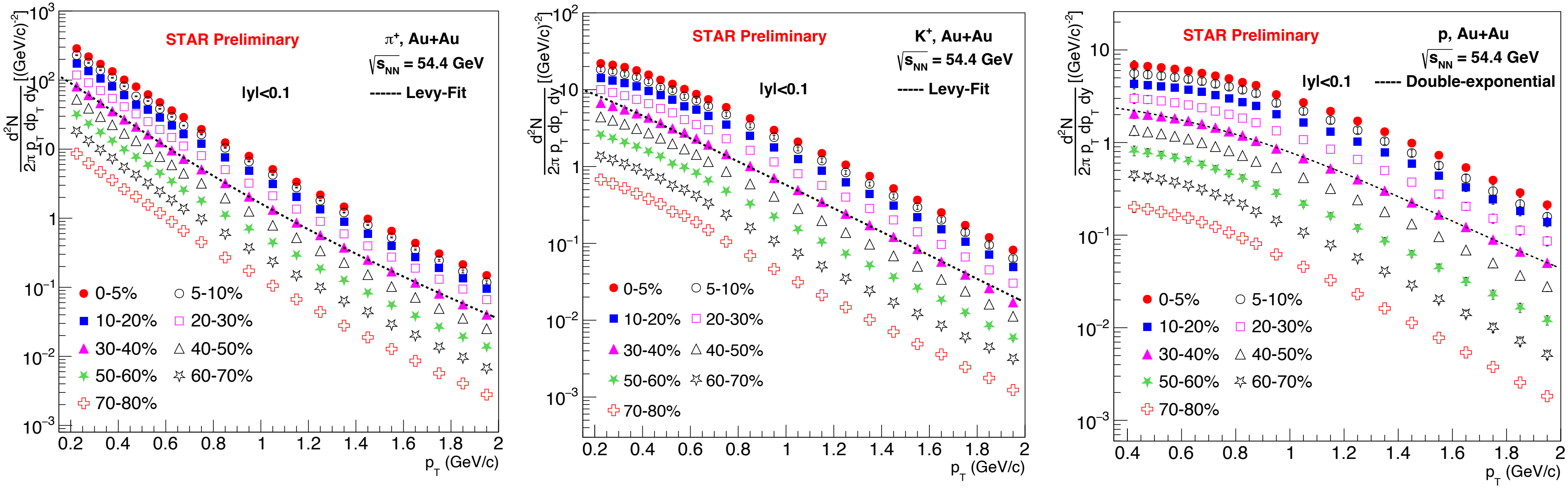


TOF



Detector→ Particle ↓	TPC (p_T range)	TOF (p_T range)
$\pi^{\pm}$	0.2 - 0.7 GeV/c	0.7 - 2.0 GeV/c
$K^{\pm}$	0.2 - 0.7 GeV/c	0.7 - 2.0 GeV/c
p and $\bar{p}$	0.4 – 0.9 GeV/c	0.9 - 2.0 GeV/c

Transverse Momentum Spectra



- Levy function:

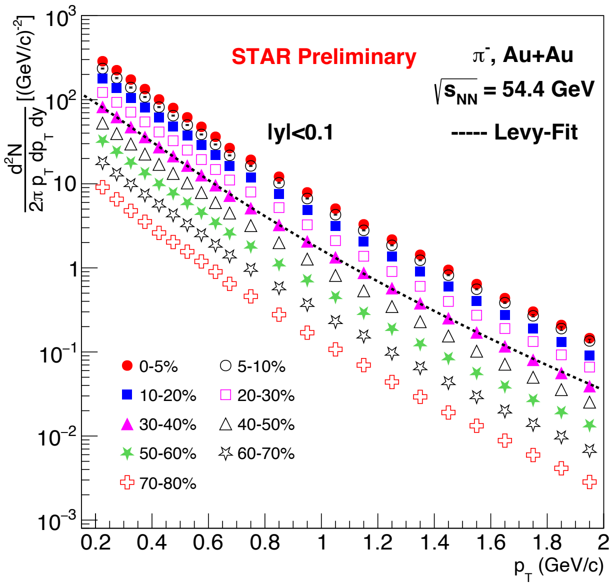
$$\frac{d^2N}{dydp_T} = \frac{(n-1)(n-2)}{nT[nT+m(n-2)]} \times \frac{dN}{dy} \times p_T \times \left(1 + \frac{m_T - m}{nT}\right)^{-n}$$

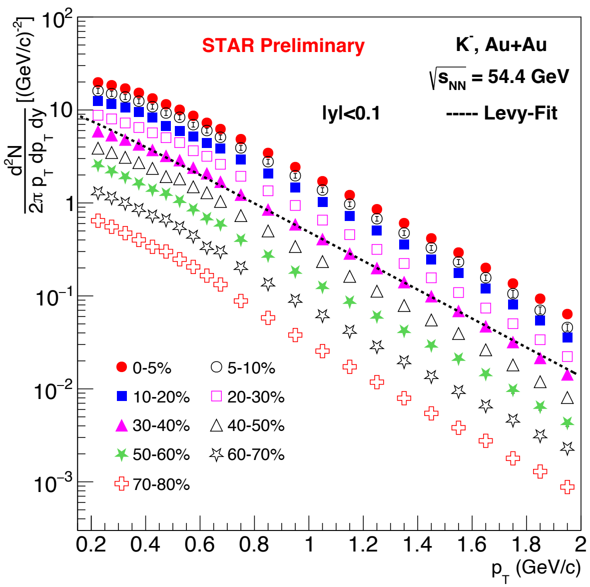
- Double-exponential:

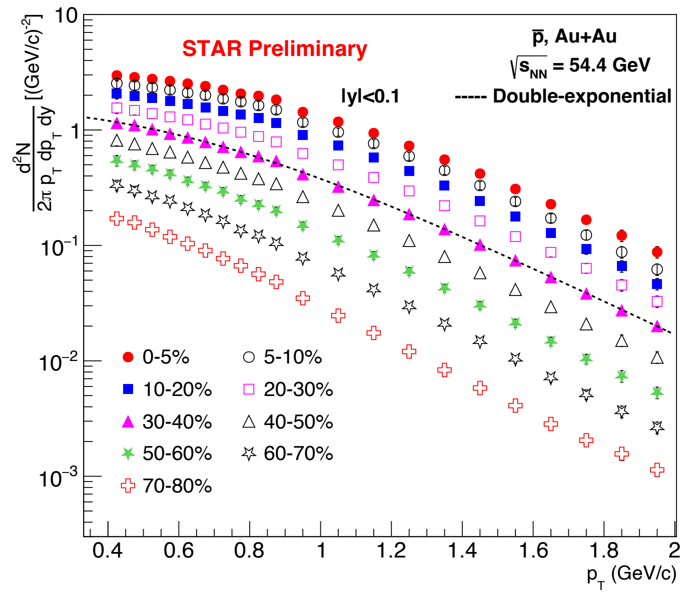
$$\frac{d^2N}{2\pi p_T dp_T dy} = A_1 e^{-p_T^2/T_1^2} + A_2 e^{-p_T^2/T_2^2}$$

- Transverse momentum spectra show a clear centrality dependence for π^+, K^+ and p.

Transverse Momentum Spectra







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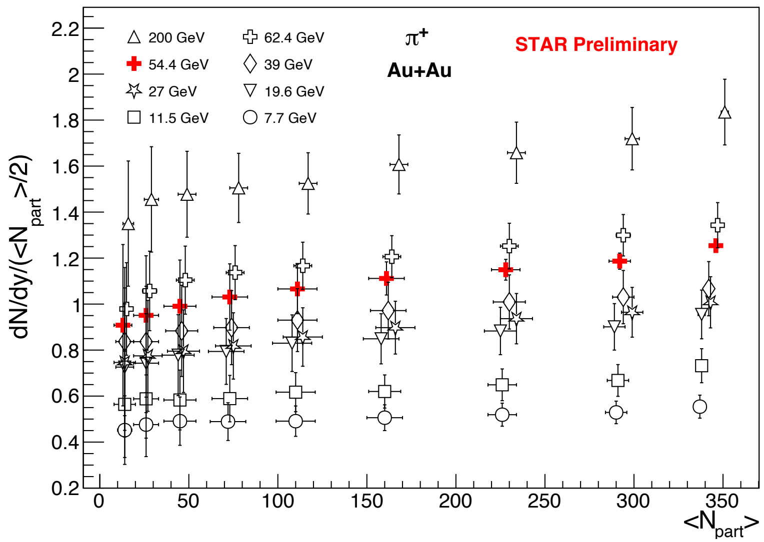
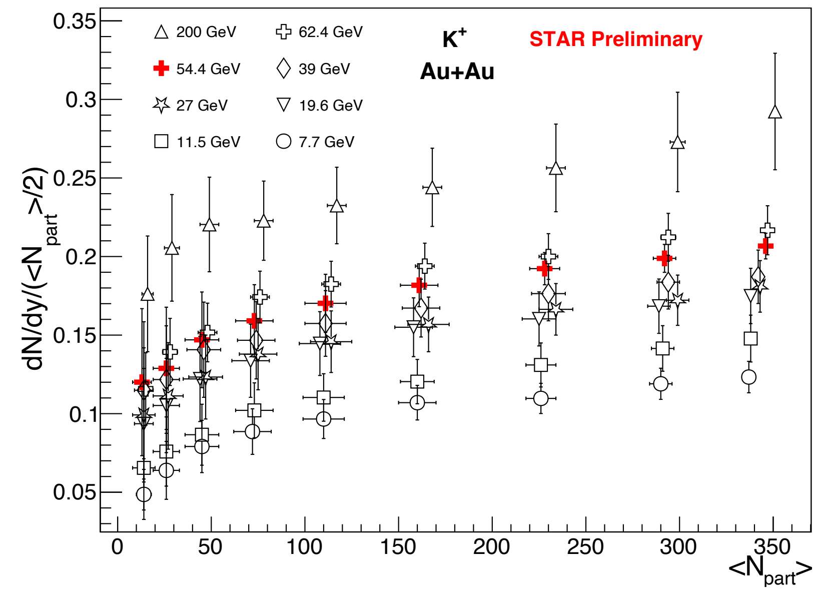
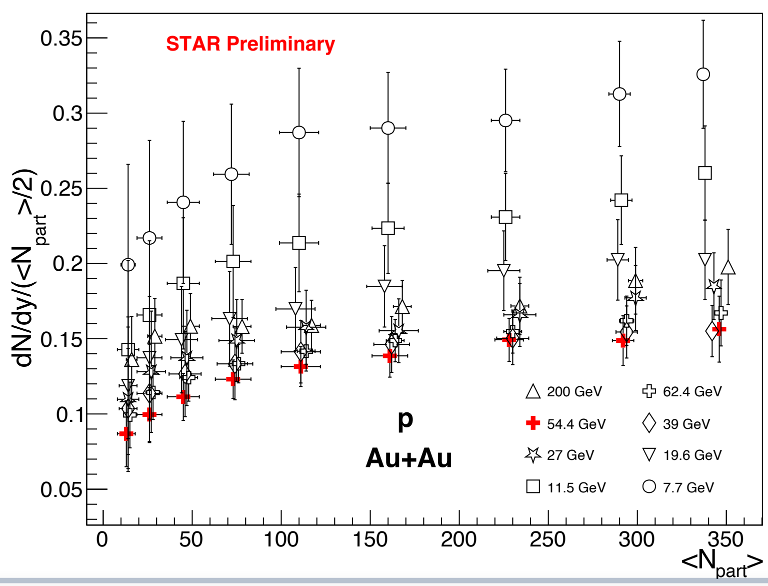
- Transverse momentum spectra show a clear centrality dependence for π^-, K^- and $\bar{p}$.

Centrality Dependence of Particle Yields

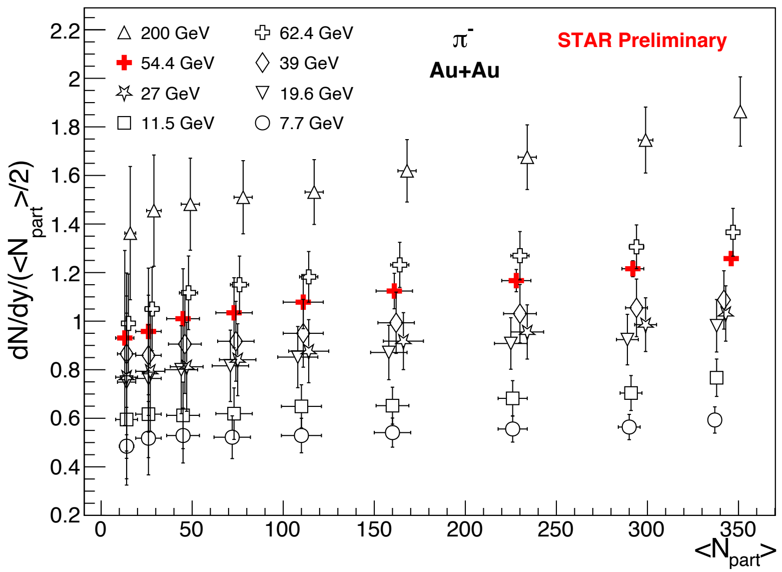


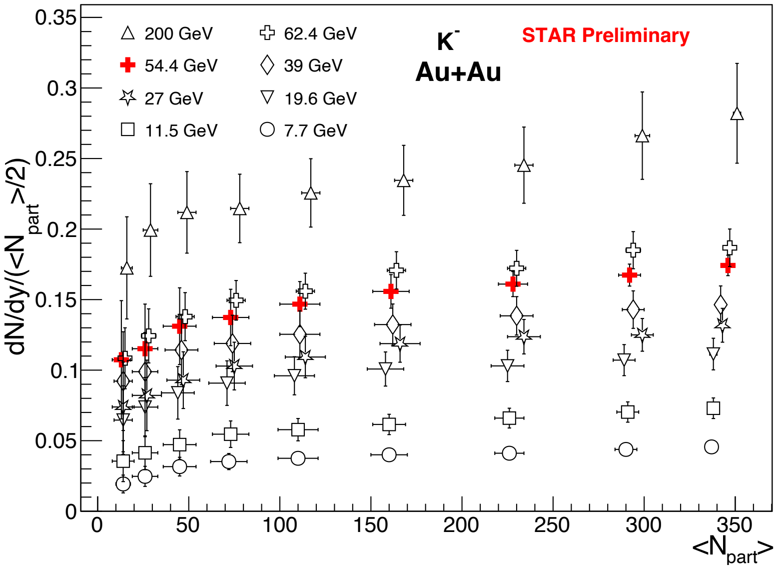


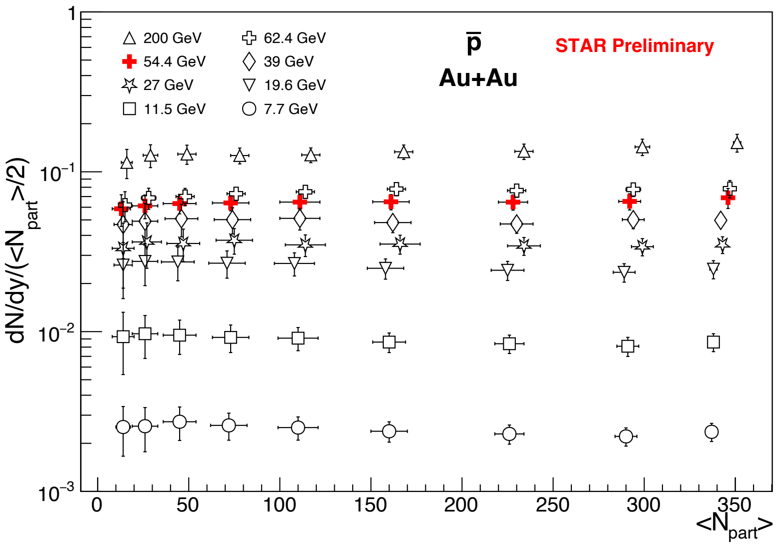


- Normalized yields for π^+ and K^+ show clear energy and centrality dependence.
- The observed energy trend for p is due to the interplay between pair production and baryon stopping.

Centrality Dependence of Particle Yields

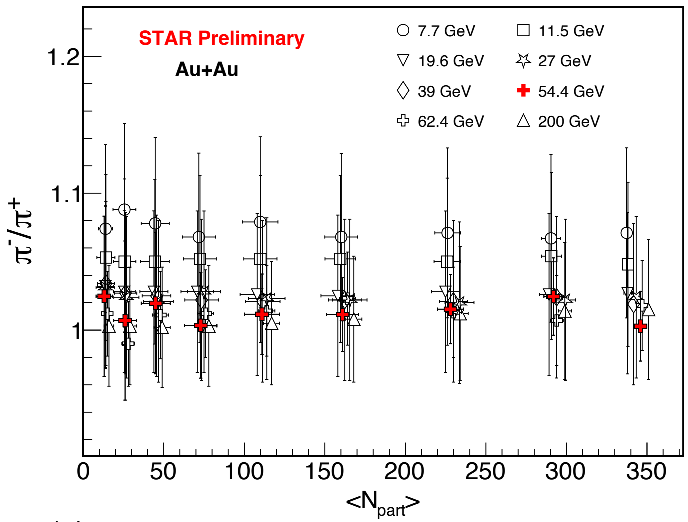


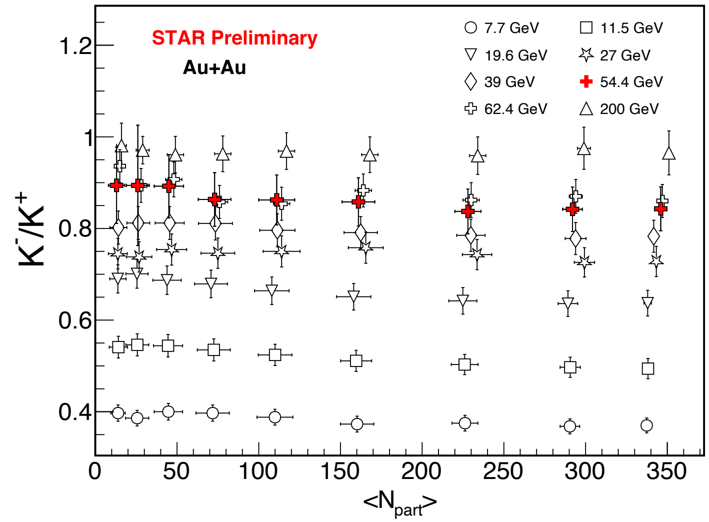


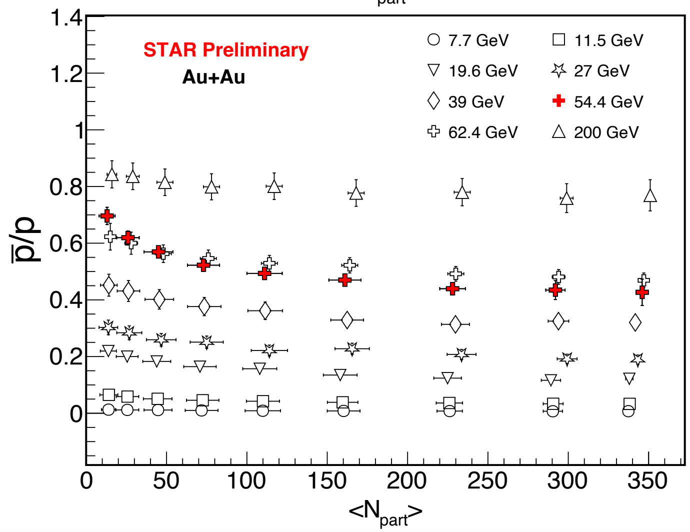


- The trends of π^- and K^- yields show clear energy and centrality dependence.
- Normalized yield for $\bar{\mathrm{p}}$ shows clear energy dependence but not centrality dependence.

Centrality Dependence of Particle Ratios

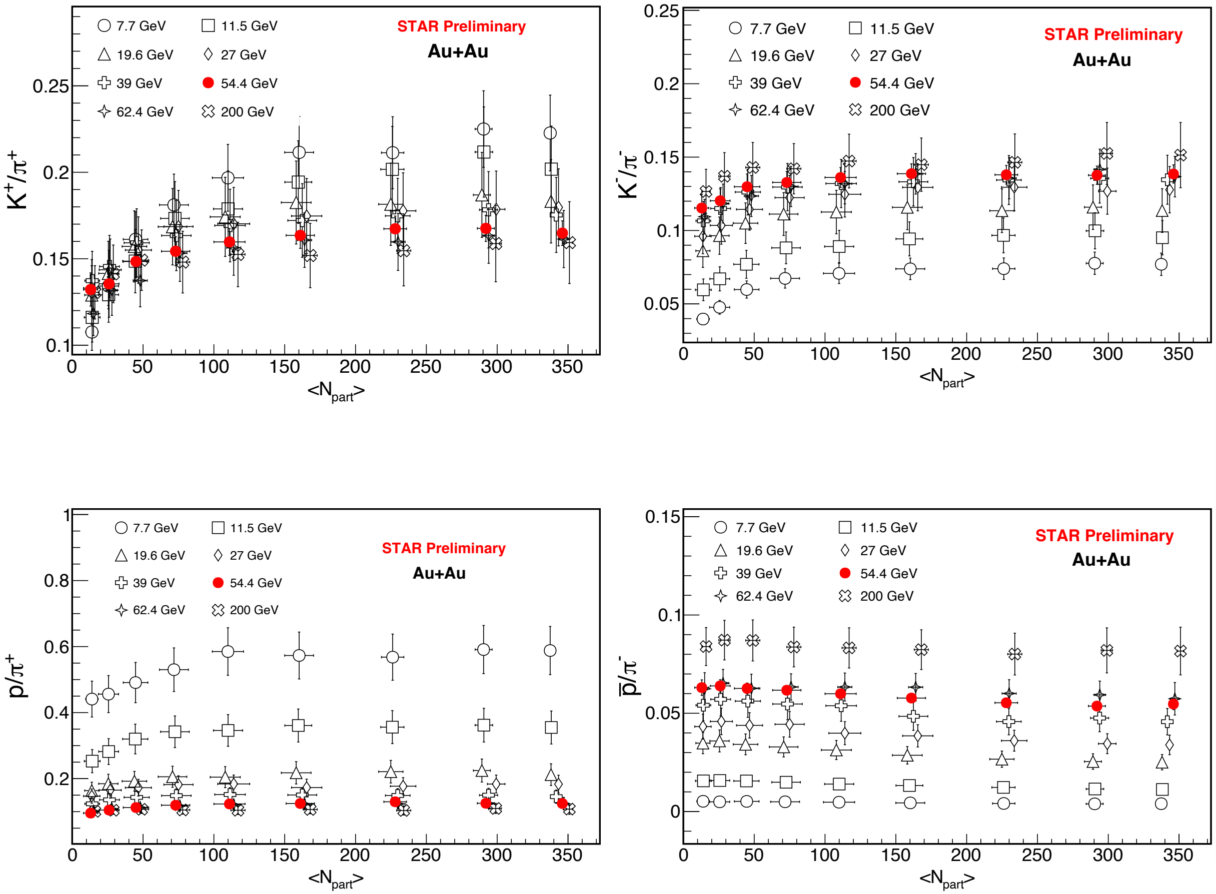






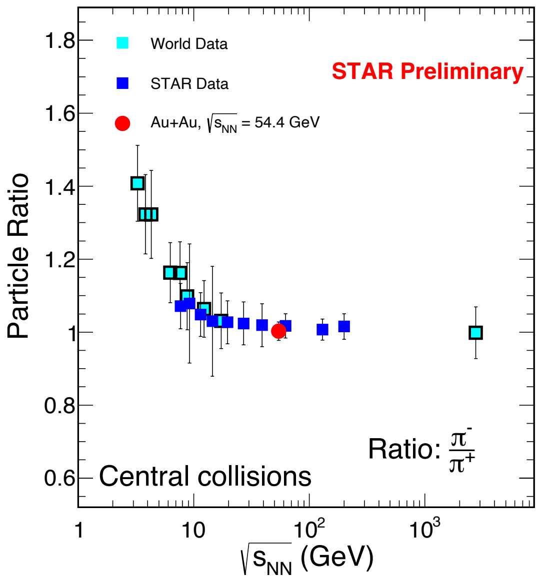
- π^-/π^+ ratio is close to unity for all the centralities.
- $\mathrm{K}^-/\mathrm{K}^+$ ratio shows clear energy dependence but weak centrality dependence.
- The observed trend of $\bar{\mathrm{p}}/\mathrm{p}$ is due to the interplay between baryon stopping and pair production.

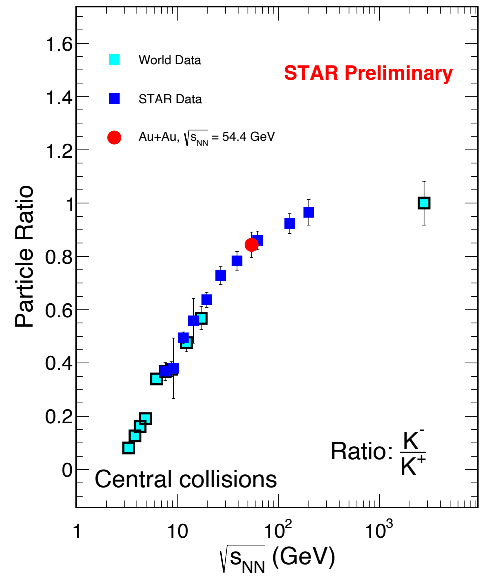
Centrality Dependence of Mixed Ratios

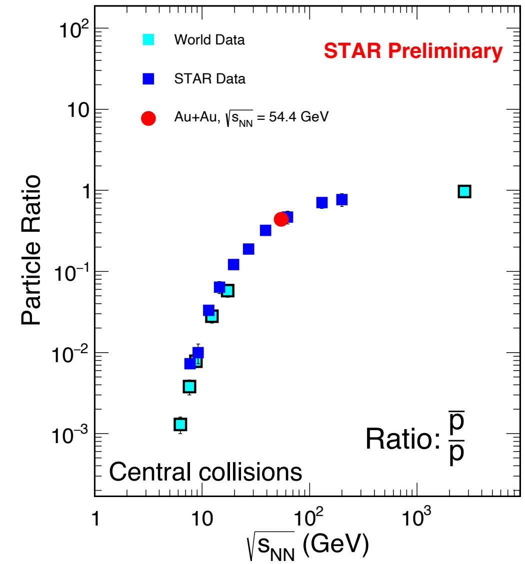


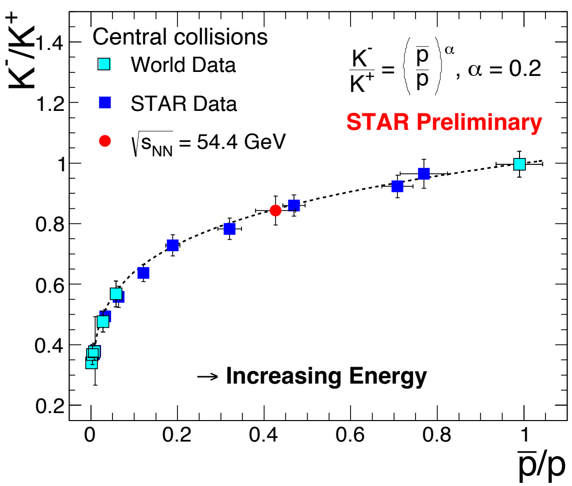
- K^+/π^+ ratio is maximal at 7.7 GeV due to associated K^+ production which is a result of large baryon stopping at low energies.
- K^-/π^- ratio increases with increasing energy.
- p/π^+ ratio decreases with increasing energy due to larger baryon stopping at lower energies.
- $\bar{p}/\pi^-$ ratio increases with increasing energy and shows little centrality dependence.

Energy Dependence of Particle Ratios





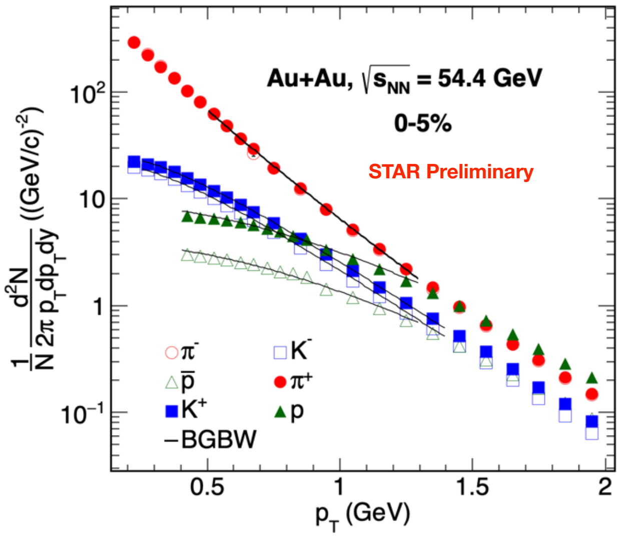


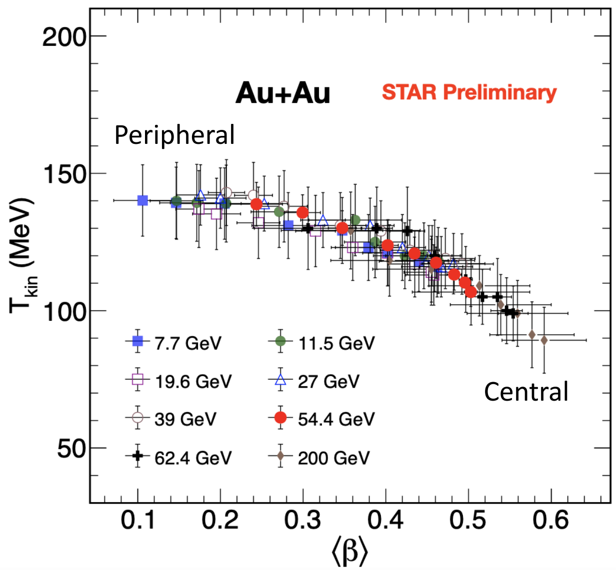


- The anti-particle to particle ratios measured at 54.4 GeV follow the world data trend.
- At 54.4 GeV π^-/π^+ ratio is close to unity, K^-/K^+ ratio is close to 0.8 and $\bar{p}/p$ ratio is close to 0.4.
- Correlation between K^-/K^+ and $\bar{p}/p$ ratio
  - ➢ Follows power-law behaviour.
  - ➢ Shows how the kaon production is related to net-baryon density.

BRAHMS: PRL 90, 102301 (2003), J. Cleymans et al. ZPC 57, 135 (1993), B. Abelev et al. (STAR Collaboration), Phys. Rev. C 81, 24911 (2010), L. Adamczyk et al. (STAR Collaboration), Phys. Rev. C 96, 044904 (2017), J. Adam et al. (STAR Collaboration), Phys. Rev. C 101, 24905 (2020)

Kinetic Freeze-Out Parameters





BLAST-WAVE MODEL

- Transverse momentum distribution is described by

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

I_0 and K_1 = modified Bessel functions

$$\rho(r) = \tanh^{-1}\beta$$

β = transverse radial flow velocity

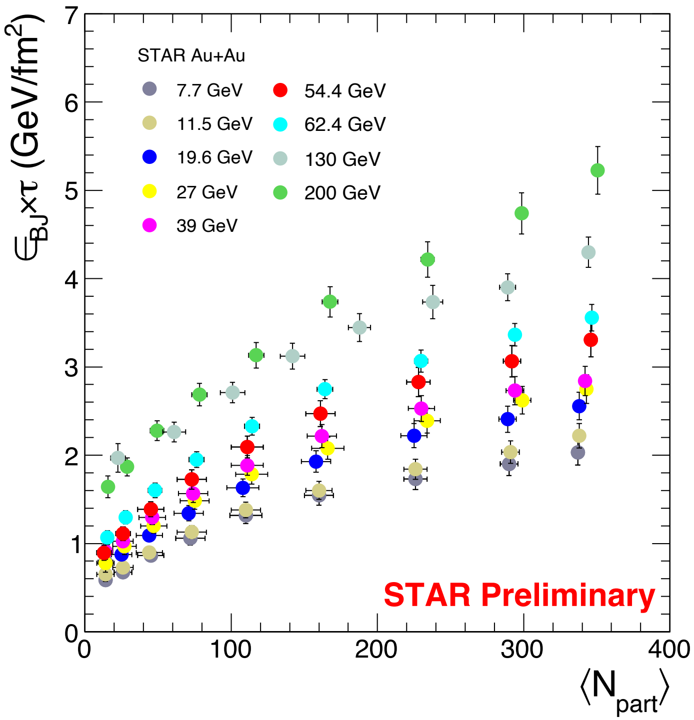
T_{kin} = kinetic freeze-out temperature.

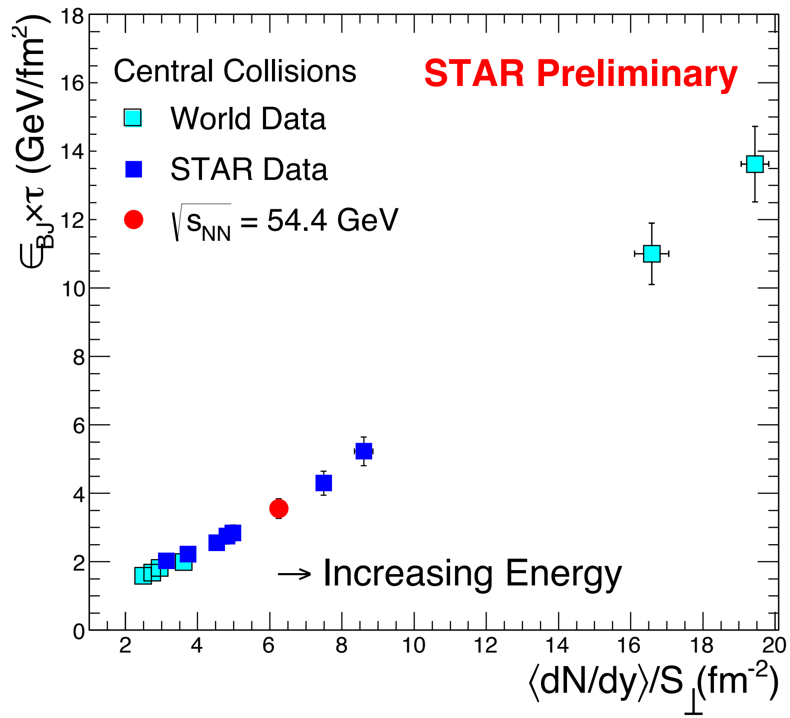
- The transverse momentum spectra are fitted simultaneously for $\pi^{\pm}, \mathrm{K}^{\pm}, \mathrm{p}$ and $\bar{\mathrm{p}}$ to obtain the freeze-out parameters.

- T_{kin} and β are anti-correlated to each other.

Bjorken Energy Density

- Bjorken energy density, ϵ_{BJ}, represents the initial energy density in the central rapidity region after the two nuclei pass each other. $\epsilon_{BJ} = \frac{dE_T}{dy} \times \frac{1}{S_\perp \tau}$, where, $\frac{dE_\perp}{dy} \approx \frac{3}{2}\left(\langle m_\perp \rangle \frac{dN}{dy}\right)_{\pi^\pm} + 2\left(\langle m_\perp \rangle \frac{dN}{dy}\right)_{K^\pm, p, \bar{p}}$, $S_\perp$ is the transverse overlap area of two colliding nuclei and τ is the formation time.





- The value of $\epsilon_{BJ} \times \tau$ increases with increasing centrality and also with increasing collision energy.

M. Petrovici, A. Pop, arXiv:2209.08828
PHENIX Collaboration, PRC 93, 024901 (2016)
M. Petrovici, A. Lindner, A. Pop, M. Târzilă, and I. Berceanu PRC 98, 024904 (2018)
STAR Collaboration, PRC 79 (2009) 034909

Summary

•Transverse momentum spectra of $\pi^{\pm}, \mathrm{K}^{\pm}, \mathrm{p}$ and $\bar{\mathrm{p}}$ in 54.4 GeV Au+Au collisions using the STAR data have been studied.

•**Centrality dependence of particle yields and ratios:**

➢ Normalized $\pi^{\pm}, \mathrm{K}^{\pm}$ and p yields increase with increasing number of participating nucleons. For $\bar{\mathrm{p}}$ there is no clear centrality dependence.

➢ π^{-}/π^{+} and $\mathrm{K}^{-}/\mathrm{K}^{+}$ ratios show weak centrality dependence. $\bar{\mathrm{p}}/\mathrm{p}$ ratio decreases from peripheral to central collisions.

➢ K^{+}/π^{+}, K^{-}/π^{-} and p/π^{+} ratios increase from peripheral to central collisions while $\bar{\mathrm{p}}/\pi^{-}$ ratio shows weak centrality dependence.

•**Energy dependence of particle ratios:**

➢ $\pi^{-}/\pi^{+}, \mathrm{K}^{-}/\mathrm{K}^{+}$ and $\bar{\mathrm{p}}/\mathrm{p}$ at 54.4 GeV are in trend with other energies. At 54.4 GeV π^{-}/π^{+} ratio is close to unity, $\mathrm{K}^{-}/\mathrm{K}^{+}$ ratio is close to 0.8 and $\bar{\mathrm{p}}/\mathrm{p}$ ratio is close to 0.4.

➢ The correlation between $\mathrm{K}^{-}/\mathrm{K}^{+}$ and $\bar{\mathrm{p}}/\mathrm{p}$ ratio follows power-law behaviour.

•**Kinetic freeze-out:** T_{kin} and β are anti-correlated and follow the trend of other energies.

•**Bjorken energy density:**

➢ Increases with increasing centrality and also with increasing collision energy.

Thank you for your attention!