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APS physics

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

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Outline

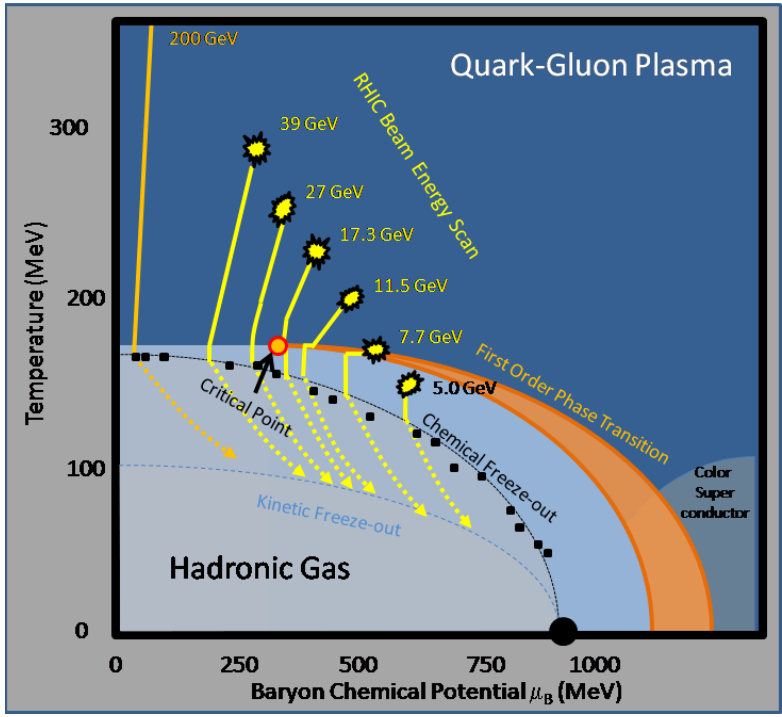
- Introduction and Motivation
- The STAR Detector
- Data Set and Particle Identification
- Results
  - ➢ Transverse momentum spectra
  - ➢ Particle yields and ratios
  - ➢ Kinetic freeze-out parameters
  - ➢ Bjorken energy density
- Summary

Introduction and Motivation

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

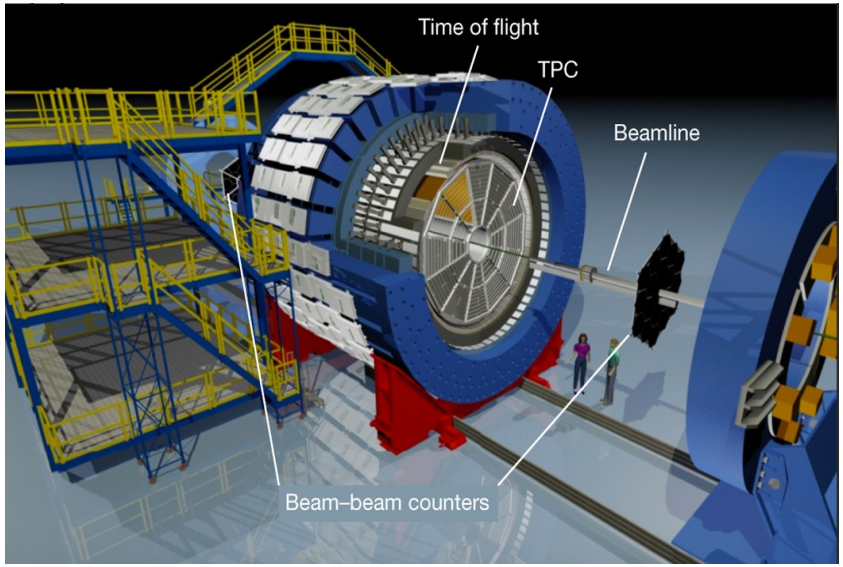
- **BES I (2010-2014)**
  - $\sqrt{s_{NN}}$ = 62.4, 39, 27, 19.6, 14.5, 11.5, 7.7 GeV

- **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

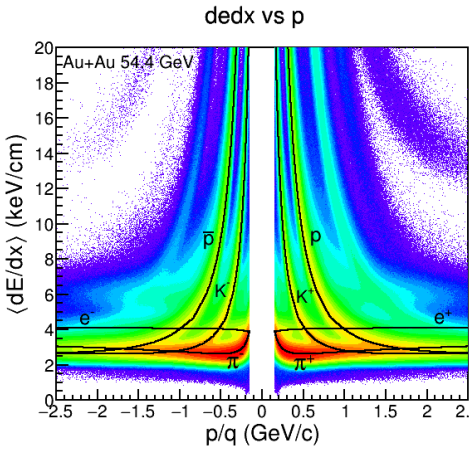


The main idea behind the BES program is to vary the collision energy and look for the signatures of the QCD phase boundary and QCD critical point.

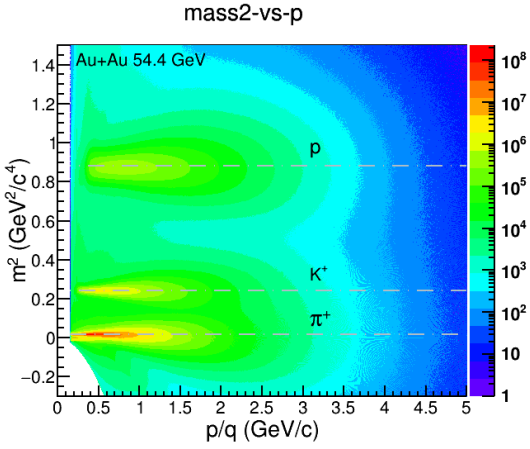
The STAR Detector



TPC Detector



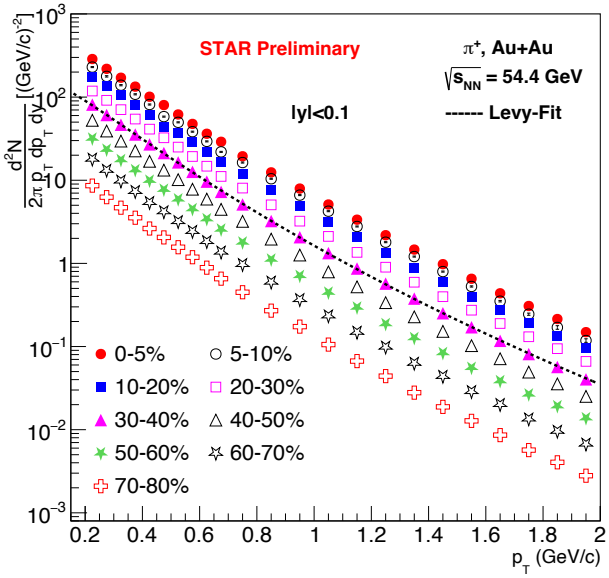
TOF Detector

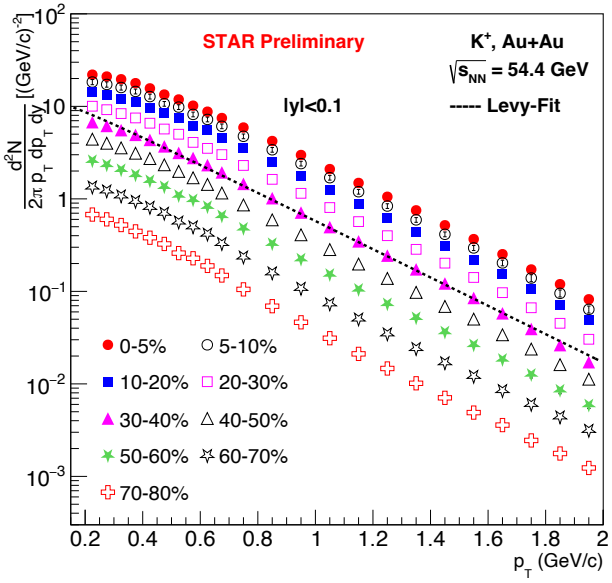


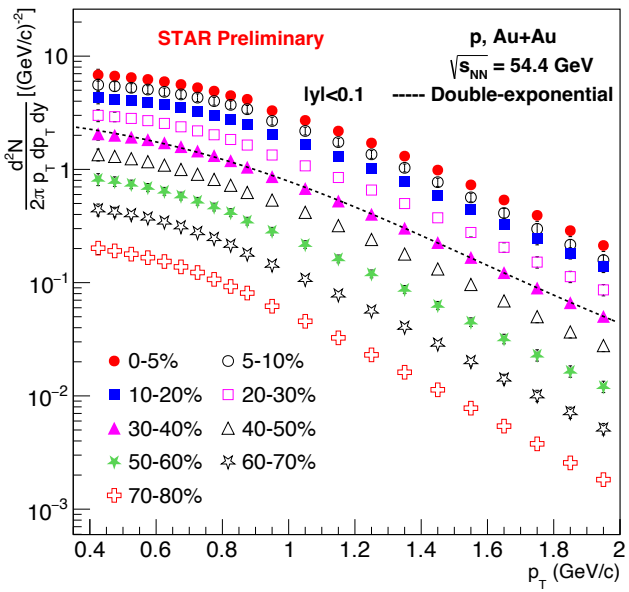
- The Solenoidal Tracker at RHIC, known as STAR, tracks the thousands of particles produced by heavy-ion collisions at RHIC.
- STAR is used to search for signatures of the formation of matter that RHIC was designed to create: the Quark-Gluon Plasma.
- Particle identification (PID) for low momentum region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

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

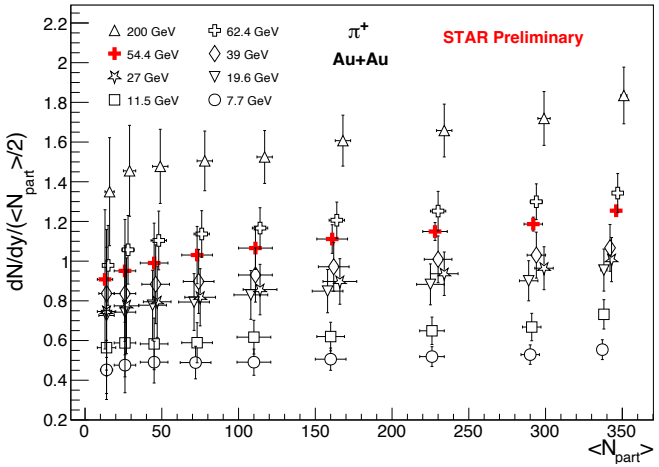


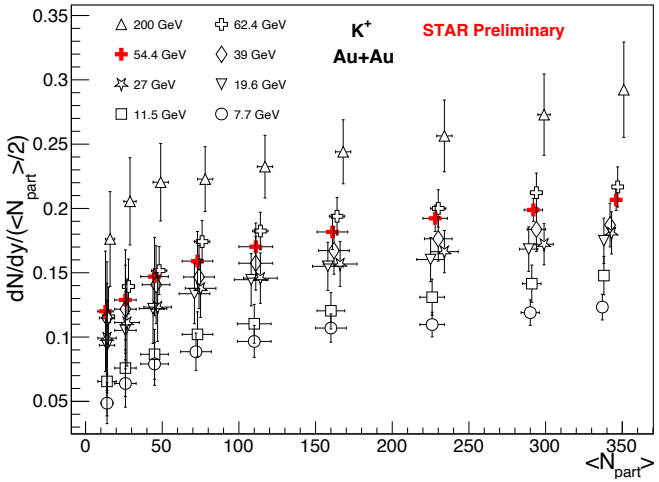


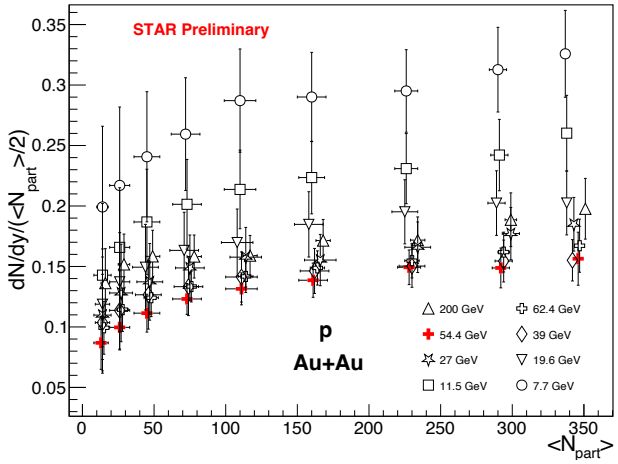


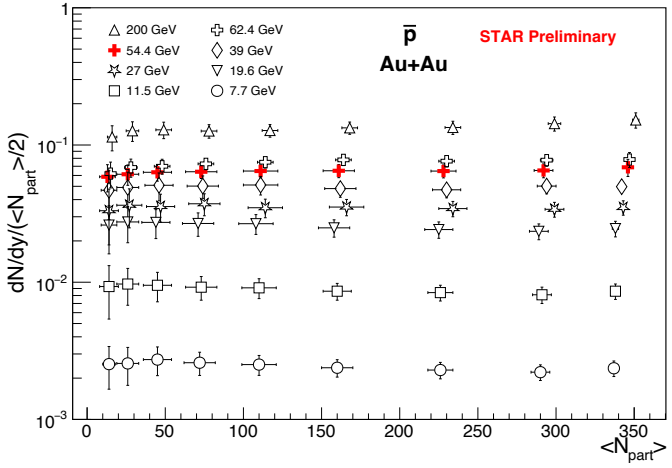
- Transverse momentum spectra show clear centrality and p_T dependence for π^+, K^+ and p.
- Similarly, the transverse momentum spectra were obtained for π^-, K^- and $\bar{p}$ and similar trend was observed.

Centrality Dependence of Particle Yields



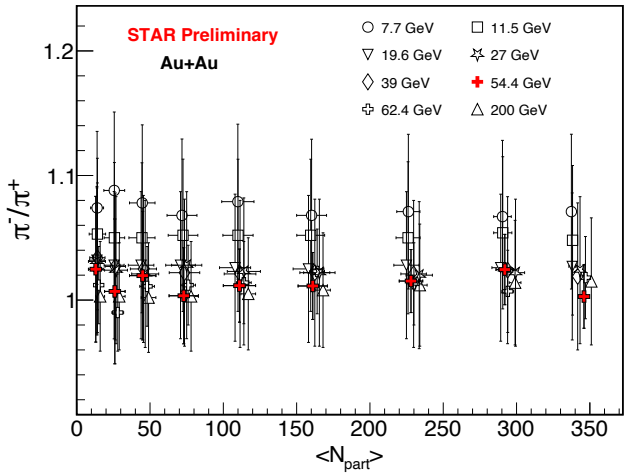


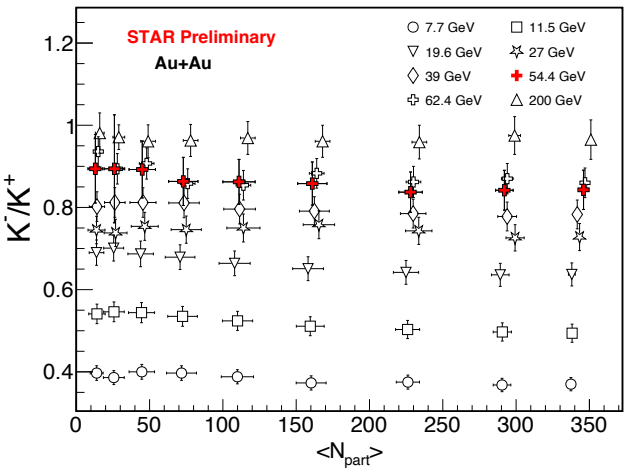


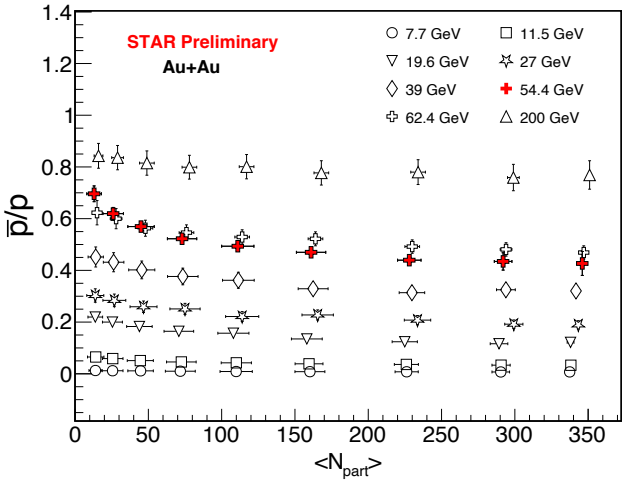


- Normalized yields for π^+ and K^+ show clear energy and centrality dependence.
- The normalized yield for p show clear centrality dependence. The observed energy trend is due to the interplay between pair production and baryon stopping.
- Normalized yield for $\bar{p}$ shows clear energy dependence but not centrality dependence.
- The trends of π^- and K^- yields were similar to their corresponding anti-particles.

Centrality Dependence of Particle Ratios

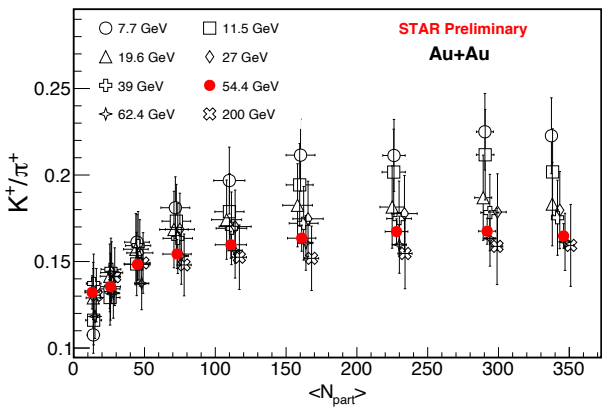


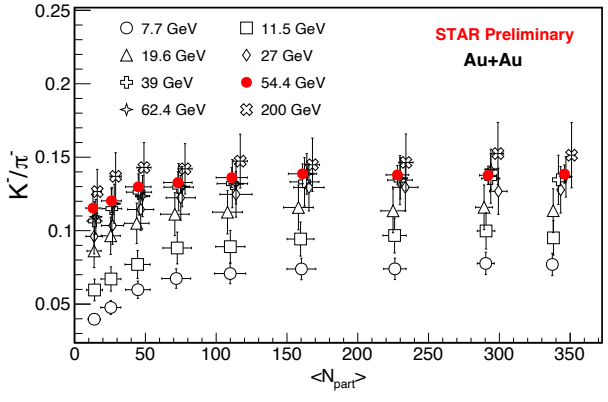


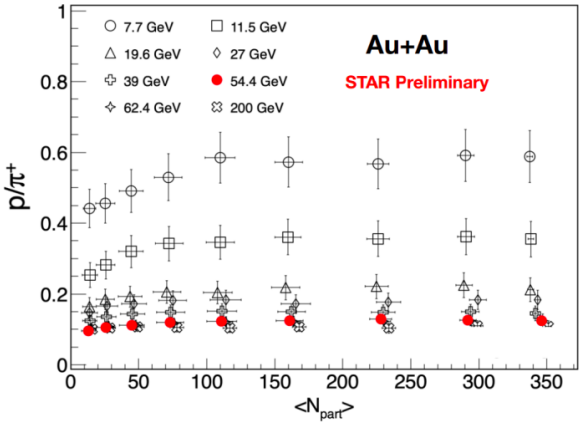


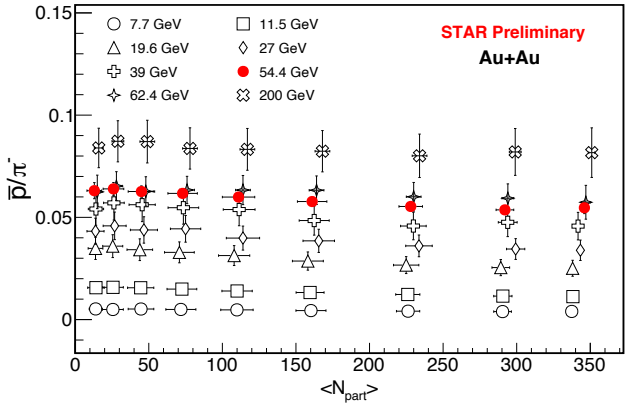
- π^-/π^+ ratio is close to unity for all the centralities.
- K^-/K^+ ratio shows clear energy dependence but weak centrality dependence.
- $\bar{p}/p$ ratio shows energy dependence. The ratio decreases as we move towards central collisions which could be due to the baryon stopping.

Centrality Dependence of Mixed Ratios



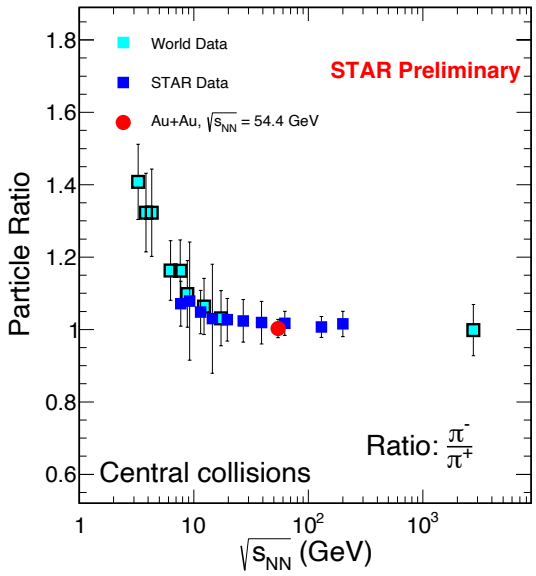


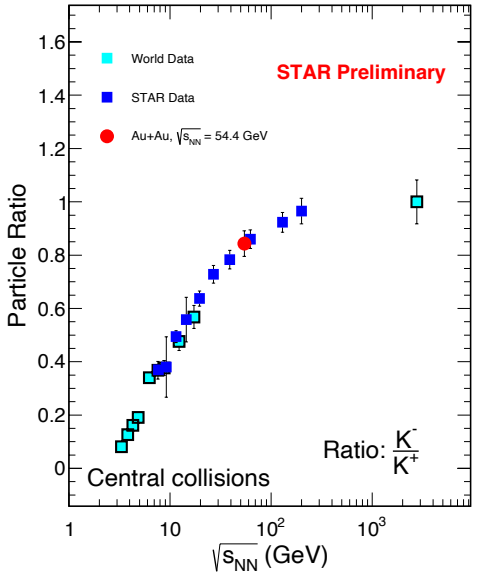


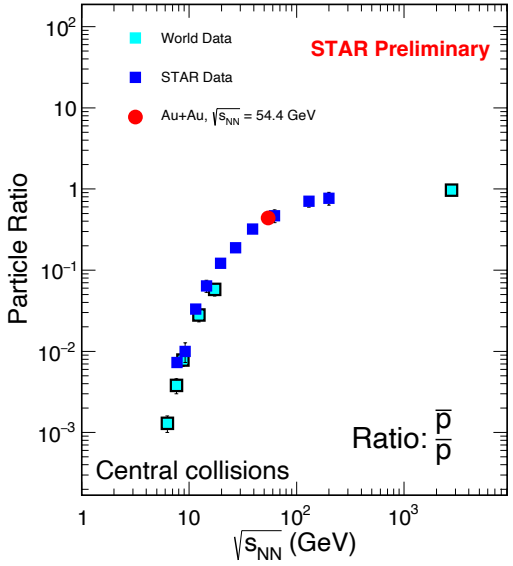


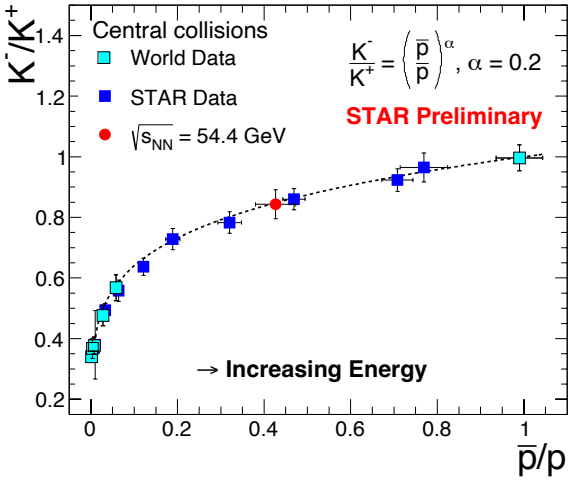
- K^+/π^+ ratio is maximal at 7.7 GeV due to associated production which is a result of large baryon stopping at low energies.
- K^-/π^- ratio increases with increasing energy.
- p/π^+ ratio decreases with increasing energy due to larger baryon stopping at lower energies.
- $\bar{p}/\pi^-$ ratio increases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

Energy Dependence of Particle Ratios





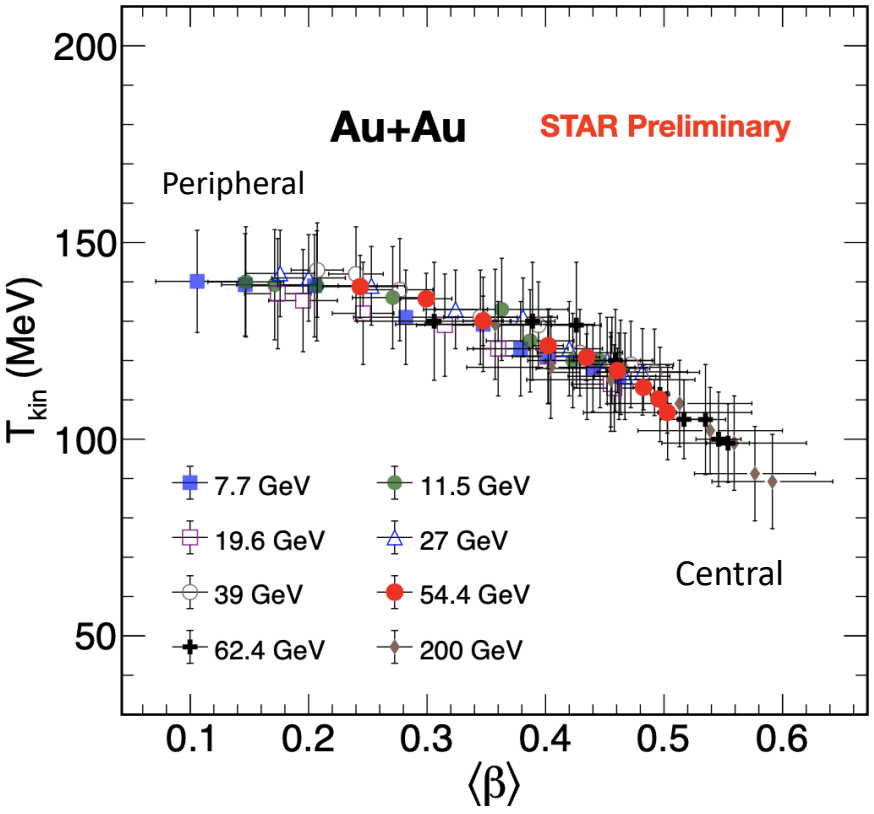




- The anti-particle to particle ratios measured at 54.4 GeV follow the world data trend.
- Correlation between K^-/K^+ and $\bar{p}/p$ ratio
  - ➢ Follows the power-law behaviour.
  - ➢ Shows how the kaon production is related to net-baryon density.

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



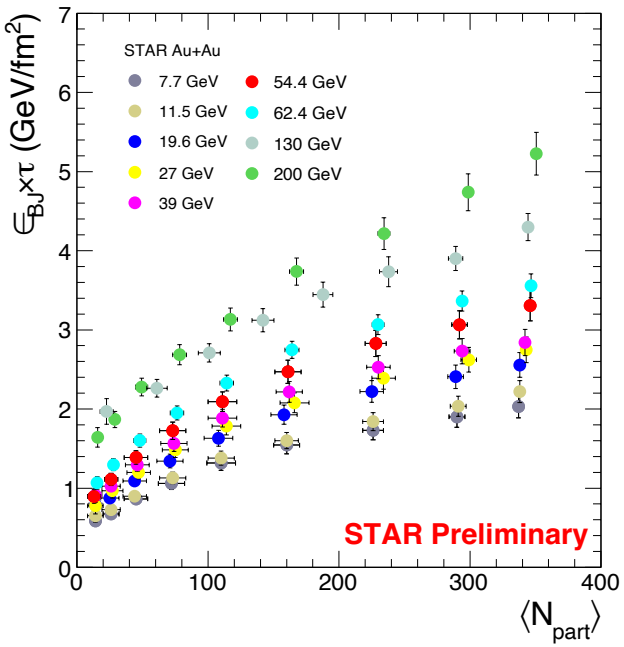
- Transverse momentum distribution is described by:

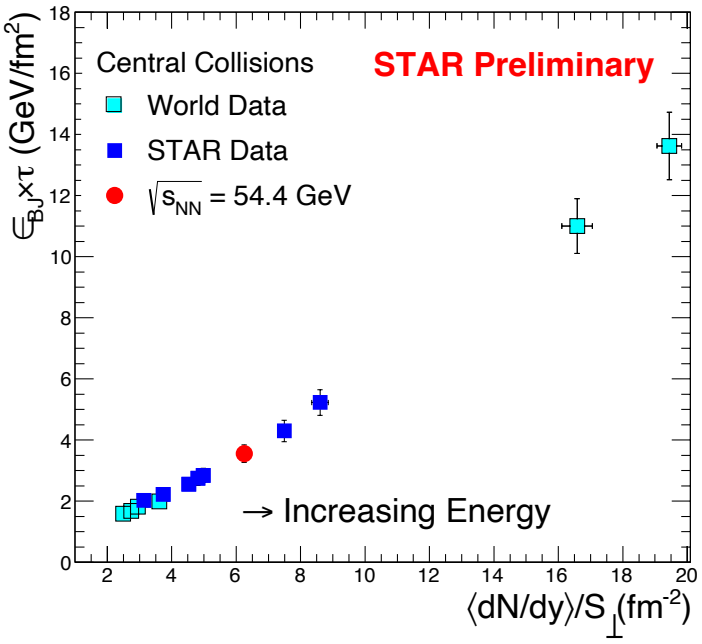
$$\frac{dN}{p_T dp_T} \propto \int_0^R r\,dr\, m_T I_0\left(\frac{(p_T \sinh\rho(r))}{T_{kin}}\right) \times K_1\left(m_T \cosh\frac{(\rho(r))}{T_{kin}}\right)$$

where, $m_T = \sqrt{p_T^2 + m^2}$, m is mass of hadron, $\rho(r) = \tanh^{-1}\beta$, and I_0 and K_1 are modified Bessel functions. β is the transverse radial flow velocity of the form $\beta = \beta_S(r/R)^n$, where β_S is the surface velocity, r/R is the relative radial position in the thermal source and n is the exponent of flow velocity profile and T_{kin} is the kinetic freeze-out temperature.

- The transverse momentum spectra are fitted simultaneously for all the particles and anti-particles to obtain the freeze-out parameters.
- T_{kin} and are anti-correlated to each other.
- T_{kin} and β follow the trend with other energies.

Bjorken Energy Density





- The Bjorken formula can be used to estimate the initial energy density in the central rapidity region after the two nuclei pass each other. ε_{BJ} is calculated as: $\epsilon_{BJ} = \frac{dE_T}{dy} \times \frac{1}{S_\perp \tau}$, 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 of QGP.

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

https://arxiv.org/abs/2209.08828v2, PRC 93, 024901 (2016),PRC 98, 024904 (2018), PRC 79 (2009) 34909

Summary

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

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

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

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

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

•**Energy dependence of particle ratios:**

➢ π^{-}/π^{+}, K^{-}/K^{+} and $\bar{p}/p$ at 54.4 GeV are in trend with other energies. 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.

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

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

•**Bjorken energy density:**

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


thank
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