Production of pions, kaons, and (anti-)protons in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV at RHIC

Krishan Gopal (for the STAR Collaboration)
Indian Institute of Science Education and Research (IISER) Tirupati, India
• Introduction

• STAR Experiment

• Analysis Details

• Results
  - $p_T$ spectra and $dN/dy$
  - Particle ratios
  - Kinetic freeze-out parameters

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

**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

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

**Phase I**

\[ \sqrt{s_{NN}} = 7.7, 9.2, 11.5, 14.6, 17.3, 19.6, 27 \text{ and } 54.4 \text{ GeV} \]

**Phase II**

\[ \sqrt{s_{NN}} = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7, 9.2, 11.5, \text{ and } 13.7 \text{ GeV (FXT)} \]
✓ Chemical freeze-out
- Weak centrality dependence of $T$
- Clear centrality dependence of $\mu_B$
  at lower energies

✓ Kinetic freeze-out
- Central collisions $\rightarrow$ lower value of $T_{\text{kin}}$
  and larger collectivity $<\beta>$
- Stronger collectivity at higher energy, even for peripheral collisions.

• Two main detectors used for particle identification

Time Projection Chamber (TPC)  Time of Flight (TOF)

• Large coverage $0 < \phi < 2\pi$, $|\eta| < 1.0$
• Excellent particle identification capabilities (TPC and TOF)
• Uniform acceptance at mid-rapidity

Dataset:
• Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV (2017)
• Number of events $\sim 513$ M
• Particles studied: $\pi^\pm$, $K^\pm$, $p$ and $\bar{p}$

• Particles are identified using dE/dx information from TPC. $<\text{dE/dx}>_{\text{theory}}$ is calculated using Bichsel function

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

• $m^2$ information from TOF is used for identifying high $p_T$ particles

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

Transverse Momentum Spectra

- $p_T$-spectra of particles ($\pi^+$, $K^+$, and $p$) show a clear particle species and centrality dependence

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

- Double exponential:
  $$A_1 e^{-p_T^2/T_1^2} + A_2 e^{-p_T^2/T_2^2}$$
Transverse Momentum Spectra

- $p_T$-spectra of particles ($\pi^-$, $K^-$, and $p$) show a clear particle species and centrality dependence.

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

- Double exponential:
  \[
  A_1 e^{-p_T^2/T^2_1} + A_2 e^{-p_T^2/T^2_2}
  \]
Pion ($\pi^-$, $\pi^+$) yields show centrality and energy dependence.

STAR Preliminary
Kaon ($K^-, K^+$) yields show centrality and energy dependence.
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

- $\pi^-/\pi^+$ ratio is close to unity for all centralities
- $K^-/K^+$ ratio does not depend on centrality and is lower than unity $\Rightarrow$ associate production
- Antiproton-to-proton ratio decreases with increasing centrality $\Rightarrow$ baryon stopping
• $K^-/\pi^-$ ratio increases with increasing energy
• $K^+/\pi^+$ ratio is maximal at 7.7 GeV and then decreases → associated production dominance at lower energies
• $\bar{p}/\pi^-$ ratio increases with increasing beam energy
• $p/\pi^+$ ratio decreases with increasing energy $\rightarrow$ more baryon stopping at lower energies
Particle ratios for 54.4 GeV data are consistent with the energy dependence trend observed at AGS, SPS, RHIC, and LHC energies
Transverse momentum spectra are fitted simultaneously with BW model to extract $T_{\text{kin}}$ and $<\beta>$.
Kinetic freeze-out
- $T_{\text{kin}}$ and $\langle \beta \rangle$ show anti-correlation
- $T_{\text{kin}}$ and $\langle \beta \rangle$ for 54.4 GeV show similar trend as other RHIC energies
Summary

- Transverse momentum spectra for $\pi^\pm$, $K^\pm$, $p$ and $\bar{p}$ have been studied in Au+Au collisions at $\sqrt{s_{NN}} = 54.4$ GeV using STAR data.

- Normalized particle yield $(dN/dy)/(<N_{\text{part}}>/2)$ shows clear centrality and energy dependence.

- Centrality dependence of particle ratios is consistent with the trend observed at other RHIC energies.

- $K^-/\pi^-$, $\bar{p}/\pi^-$ increase, whereas $K^+/\pi^+$ and $p/\pi^+$ ratios decrease with increasing energy, and are consistent with world data trend.

- $T_{\text{kin}}$ and $<\beta>$ show anti-correlation as observed at other energies.
Thank you for your attention
Au+Au, $\sqrt{s_{NN}} = 54.4$ GeV

0-5%

STAR Preliminary

\[ \frac{1}{N} \frac{d^2N}{d\eta dp_T} \text{ (GeV/c)} \]

$\pi^-$, $\pi^+$
$K^-$, $K^+$
$\bar{p}$, $p$

-BGBW
• $p_T$ spectra of particles ($\pi^+$, $K^+$, and $p$) show a clear $p_T$ and centrality dependence
Transverse Momentum Spectra

\* p_T -spectra of anti-particles (π-, K-, and \( \bar{p} \)) show a clear p_T and centrality dependence

\[ \frac{d^2N}{dp_T^2} \sim \left( \frac{GeV}{c} \right)^{-2} \]

\[ N \sim 10^{-10} \]

\[ T_p = 3 - 10 \]

\[ S_NN = 54.4 \text{ GeV} \]

\[ |y| < 0.1 \]

\[ \text{Levy-Fit} \]

\[ \text{Double-exponential} \]

\[ \text{STAR Preliminary} \]

14/06/2022

Krishan Gopal-SQM 2022