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

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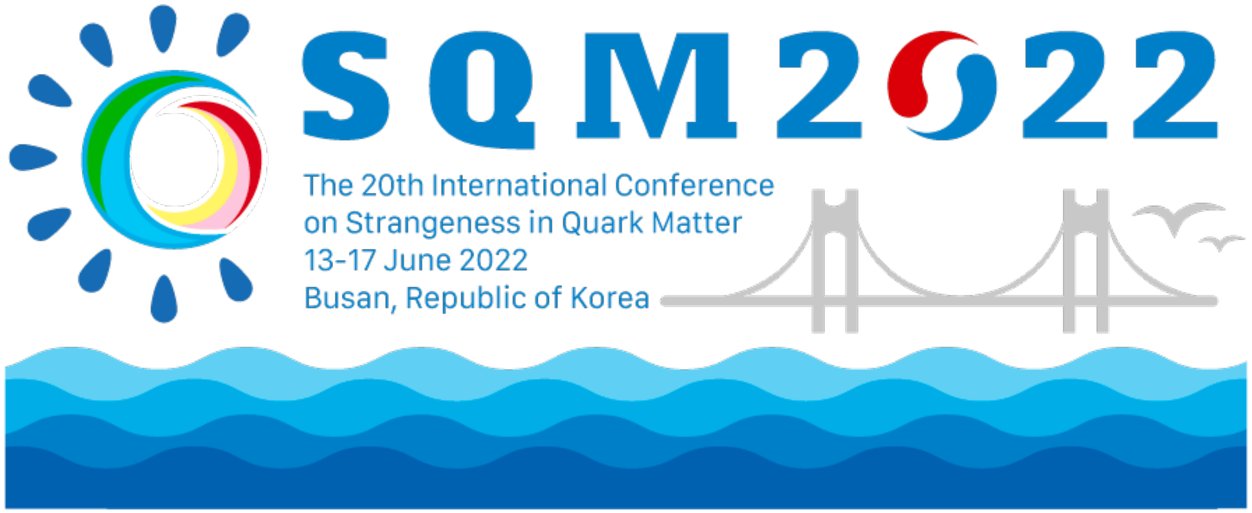

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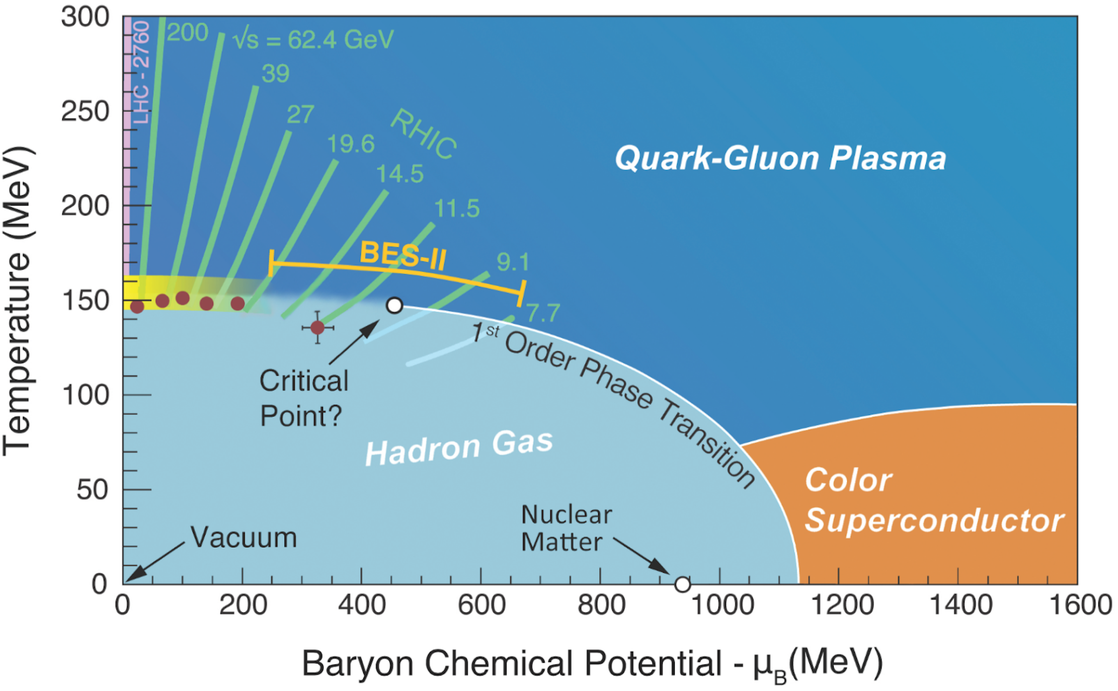
https://drupal.star.bnl.gov/STAR/presentations

Outline

- **Introduction**
- **STAR Experiment**
- **Analysis Details**
- **Results**
  - p_T spectra and dN/dy
  - Particle ratios
  - Kinetic freeze-out parameters
- **Summary**

Introduction

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



P Sorensen, Journal of Physics: Conference Series 446, 012015 (2013)

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

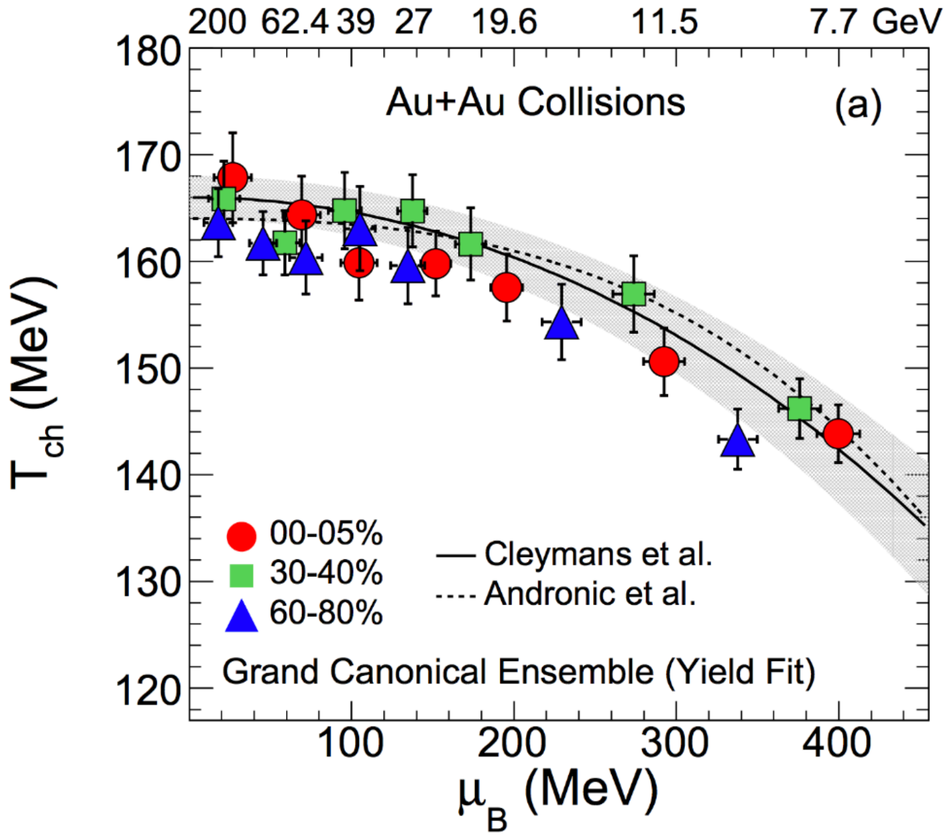
$\sqrt{s_{NN}}$ = 7.7, 11.5, 14.5, 19.6, 27, 39, 62.4, and 200 GeV

Phase II

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

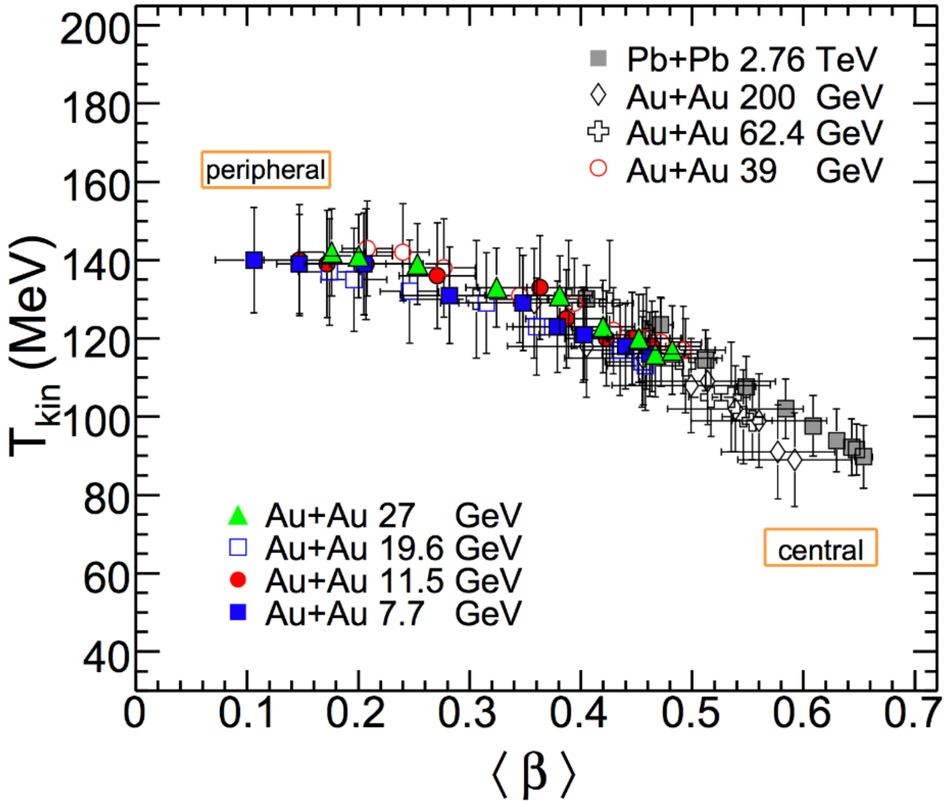
$\sqrt{s_{NN}}$ = 3.0, 3.2, 3.5, 3.9, 4.5, 5.2, 6.2, 7.2, 7.7, 9.2, 11.5, and 13.7 GeV (FXT)

Introduction



✓ **Chemical freeze-out**

- Weak centrality dependence of T
- Clear centrality dependence of μ_B at lower energies

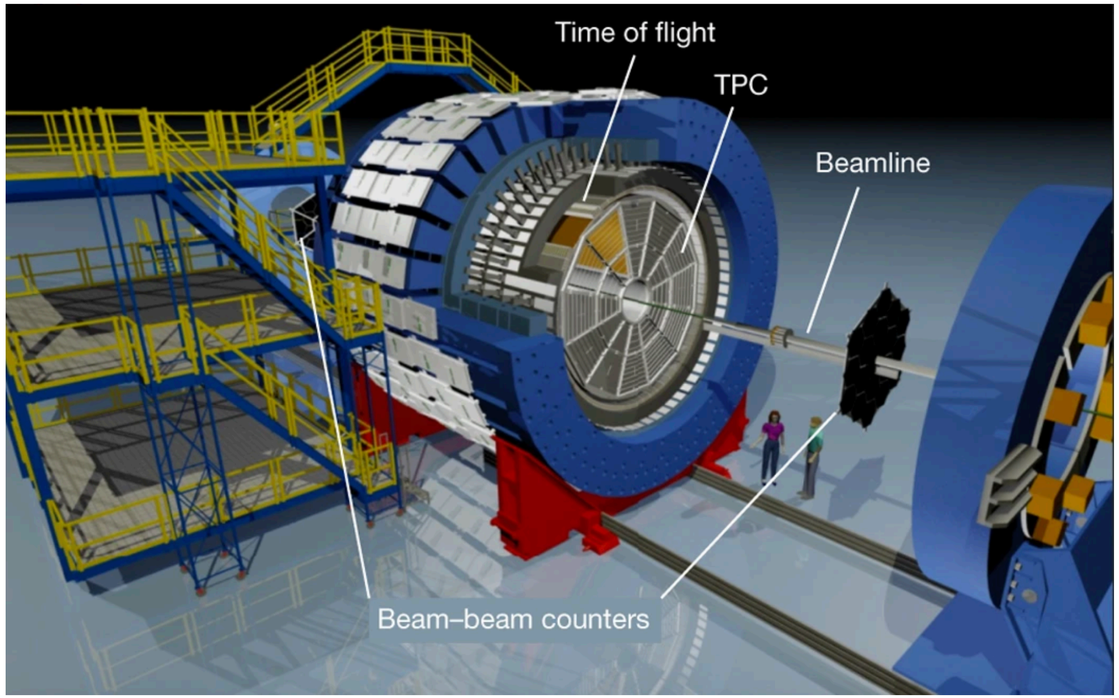


✓ **Kinetic freeze-out**

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

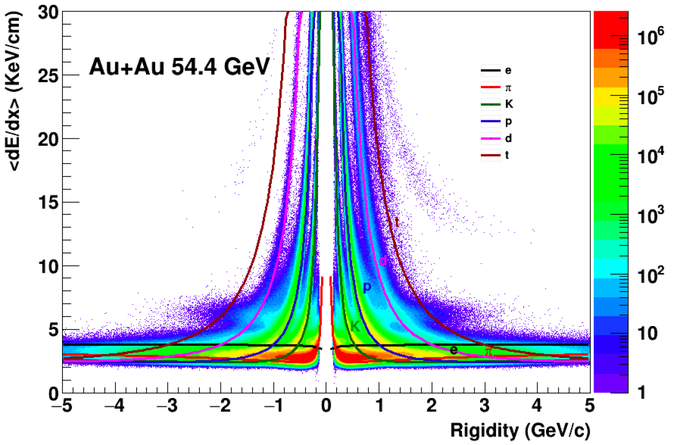
J. Cleymans et al., Phys. Rev. C 73, 034905 (2006)

STAR Experiment

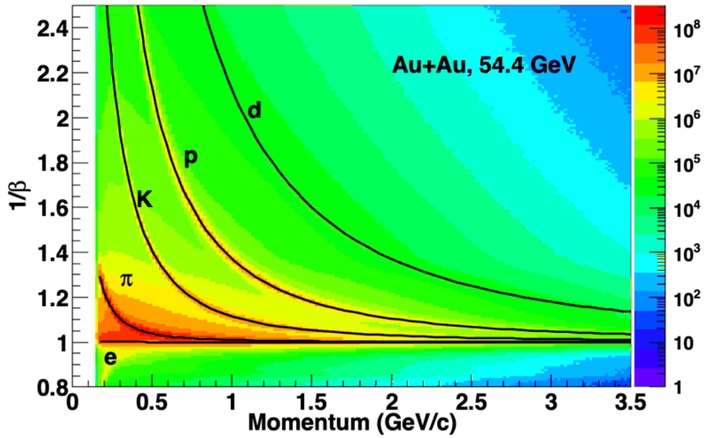


- Two main detectors used for particle identification

Time Projection Chamber (TPC)



Time of Flight (TOF)



Dataset:

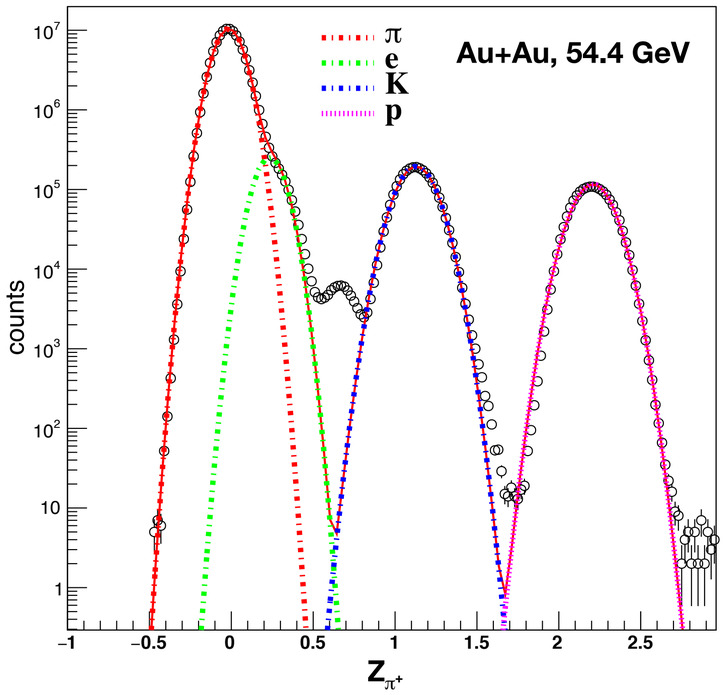
- Large coverage 0 <ϕ< 2π, |η| < 1.0
- Excellent particle identification capabilities (TPC and TOF)
- Uniform acceptance at mid-rapidity

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

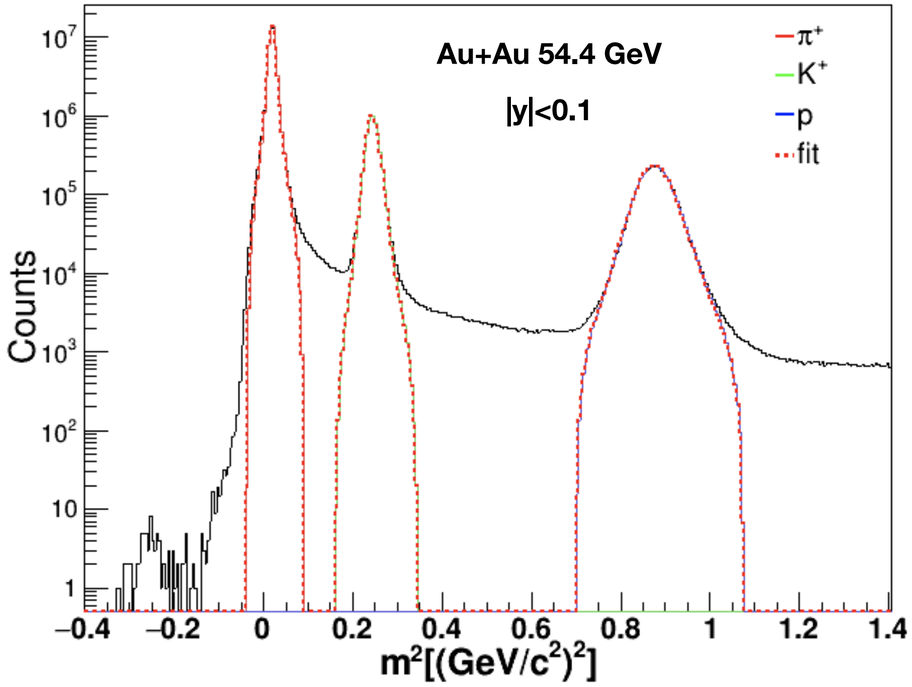
STAR, Phys. Rev. C **96,** 44904 (2017)

Particle Identification

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



0.50 < p_T (GeV/c) < 0.60



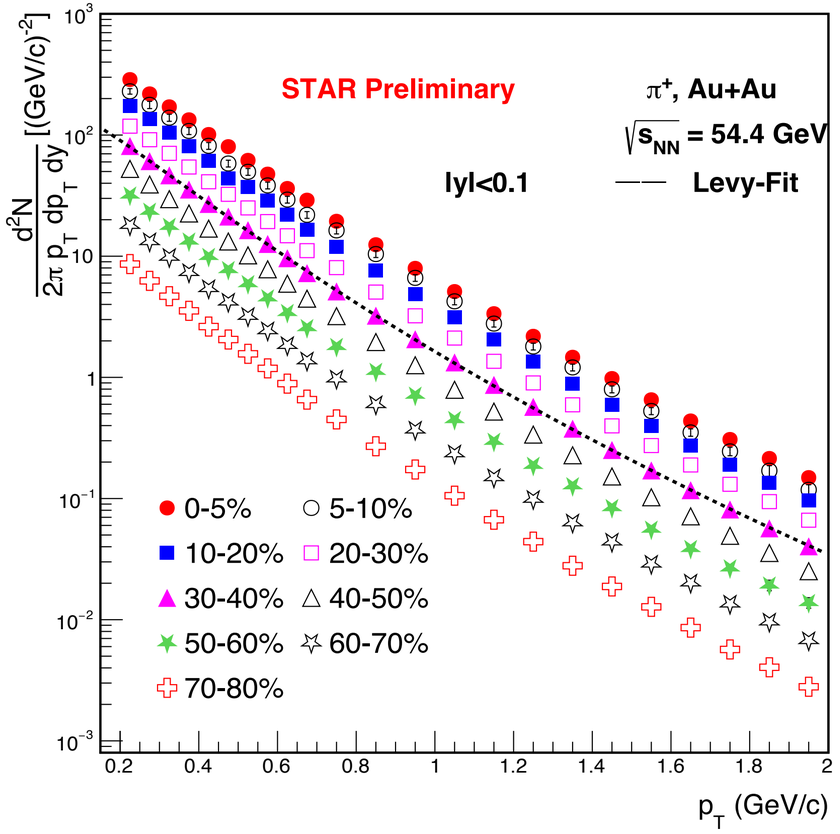
- Particles are identified using dE/dx information from TPC. <dE/dx>$_{theory}$ is calculated using Bichsel function

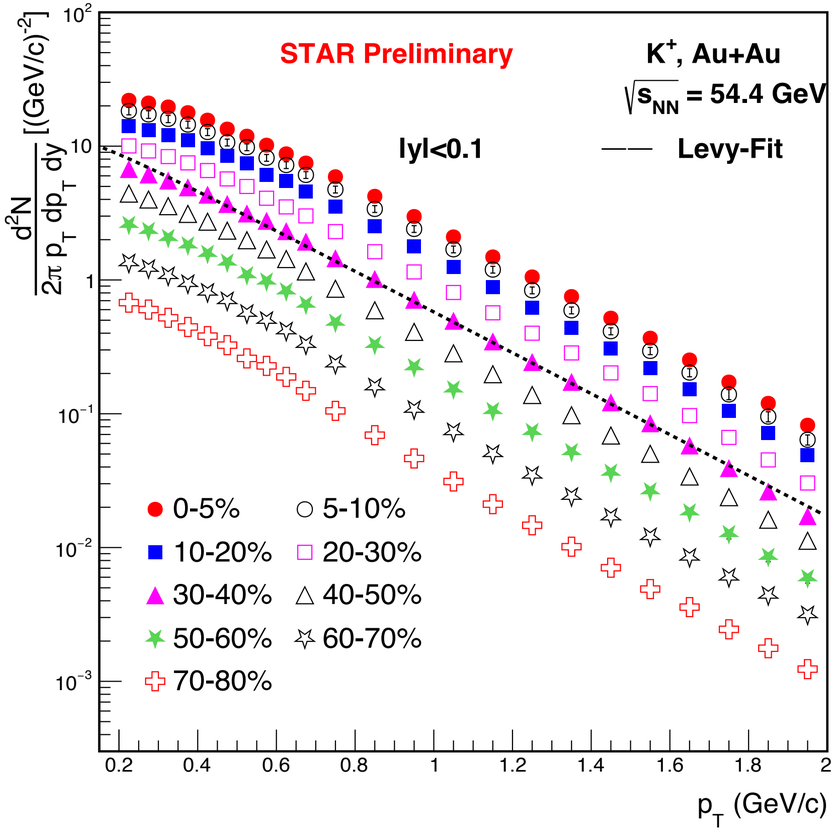
$$z_i = \ln\left(\frac{\langle dE/dx\rangle_{measured}}{\langle dE/dx\rangle_{theory}}\right)$$

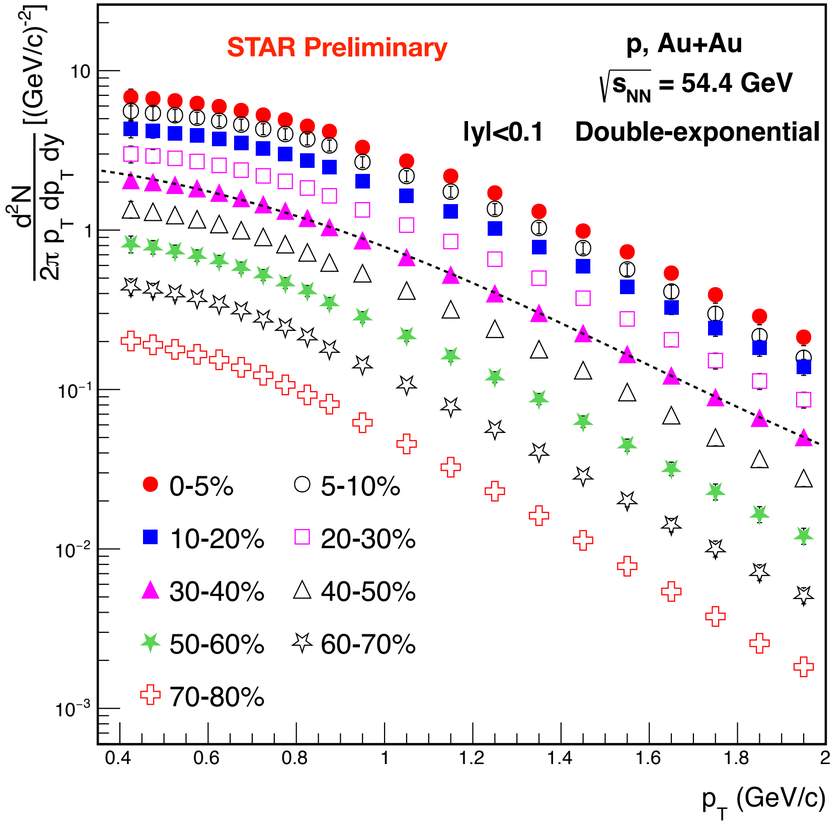
- m^2 information from TOF is used for identifying high p_T particles $m^2 = p^2\left(\left(\frac{1}{\beta}\right)^2 - 1\right)$

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

Transverse Momentum Spectra



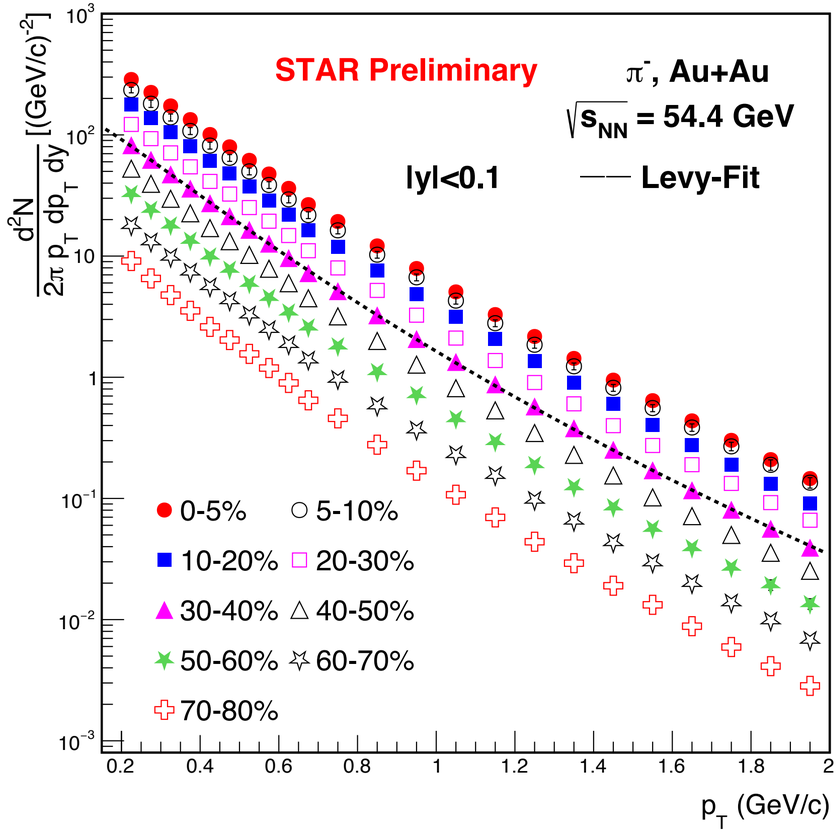


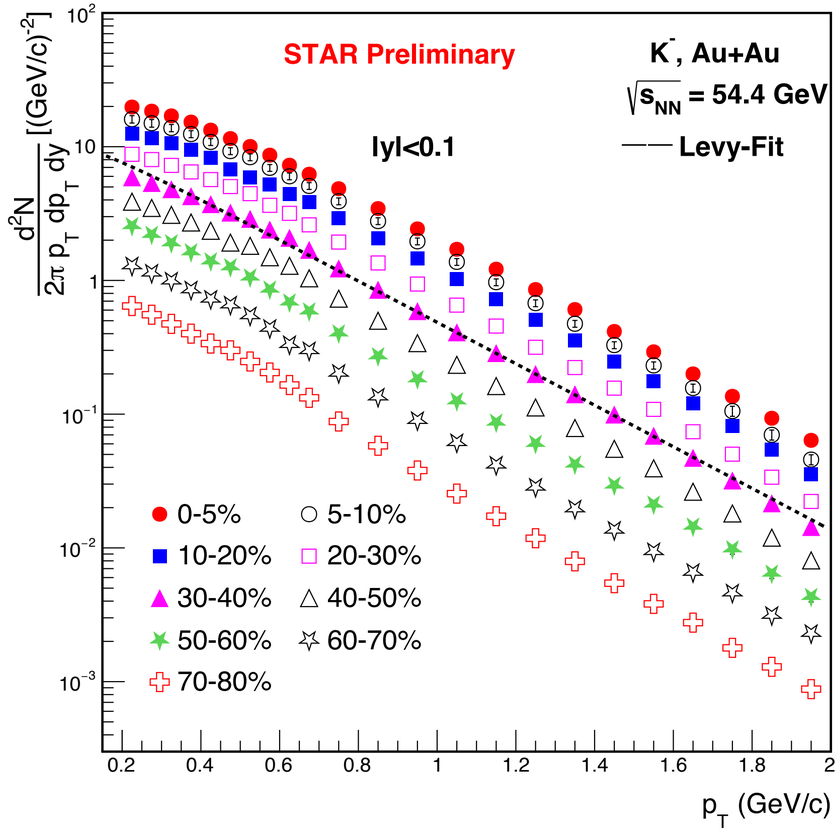


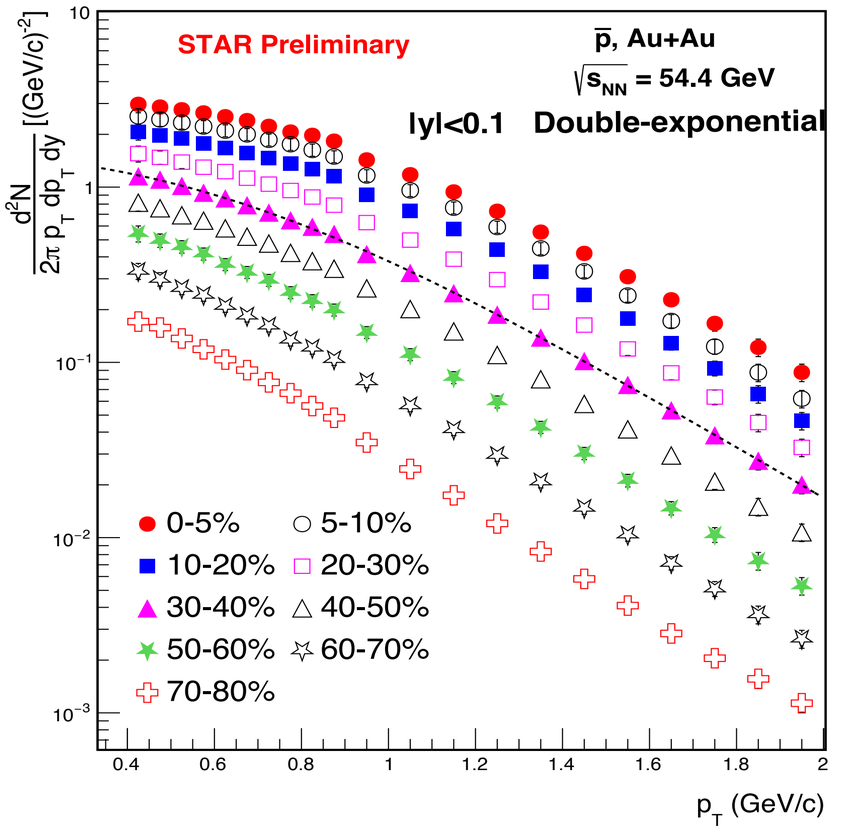
- p_T -spectra of particles (π^+, K^+ , and p) show a clear particle species and centrality dependence

  - Levy function : $$\frac{\mathrm{d}^2N}{\mathrm{d}y\mathrm{d}p_\mathrm{T}} = \frac{(n-1)(n-2)}{nT[nT+m(n-2)]} \times \frac{\mathrm{d}N}{\mathrm{d}y} \times p_\mathrm{T} \times \left(1+\frac{m_\mathrm{T}-m}{nT}\right)^{-n}$$
  - Double exponential : $A_1 e^{-p_T^2/T_1^2} + A_2 e^{-p_T^2/T_2^2}$

Transverse Momentum Spectra







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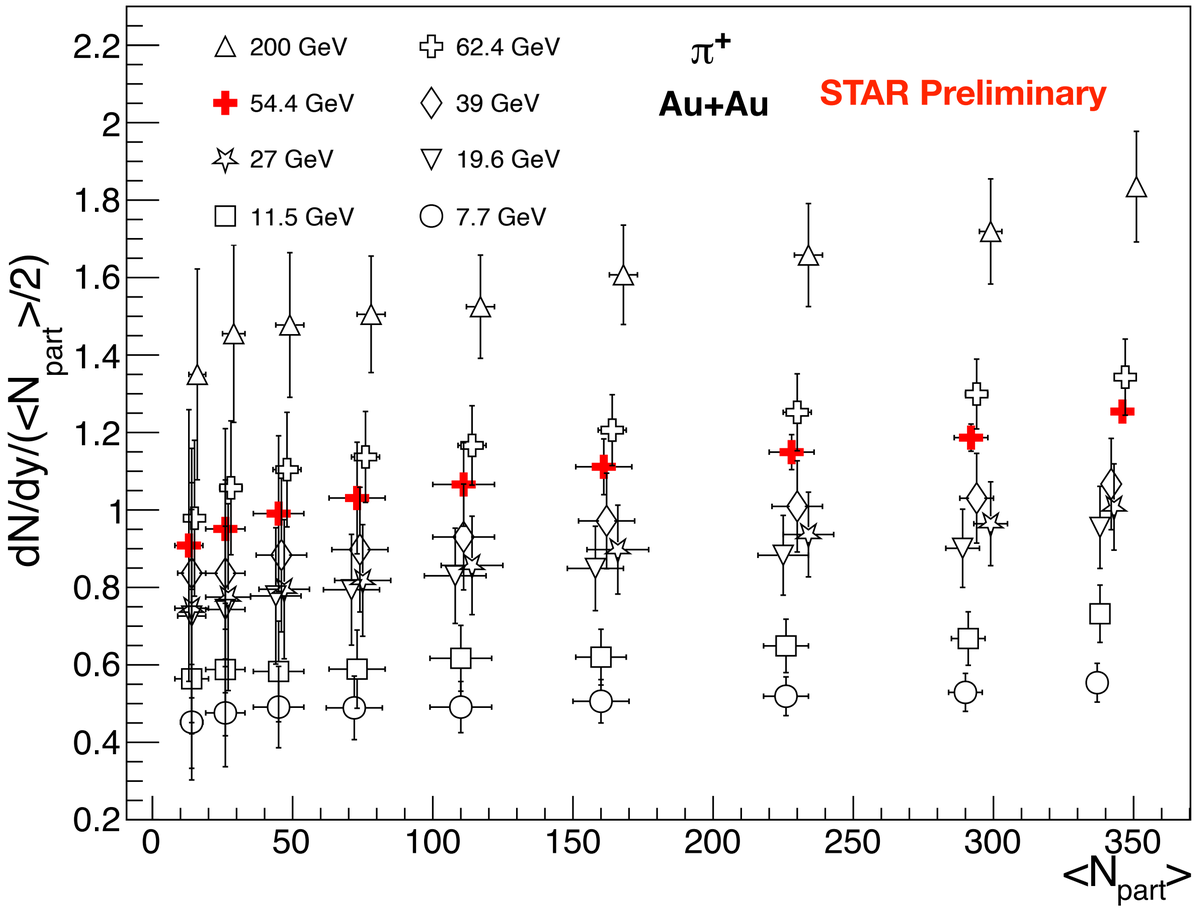
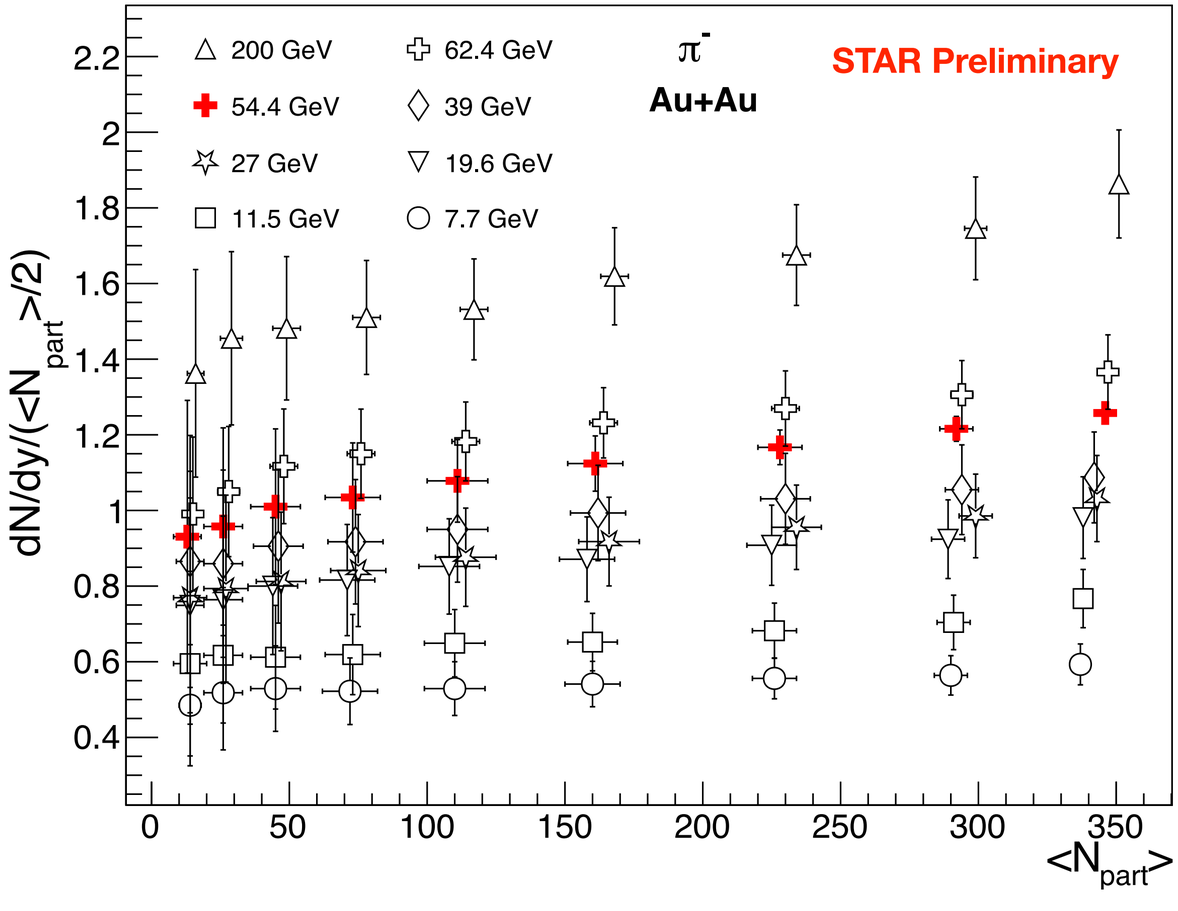
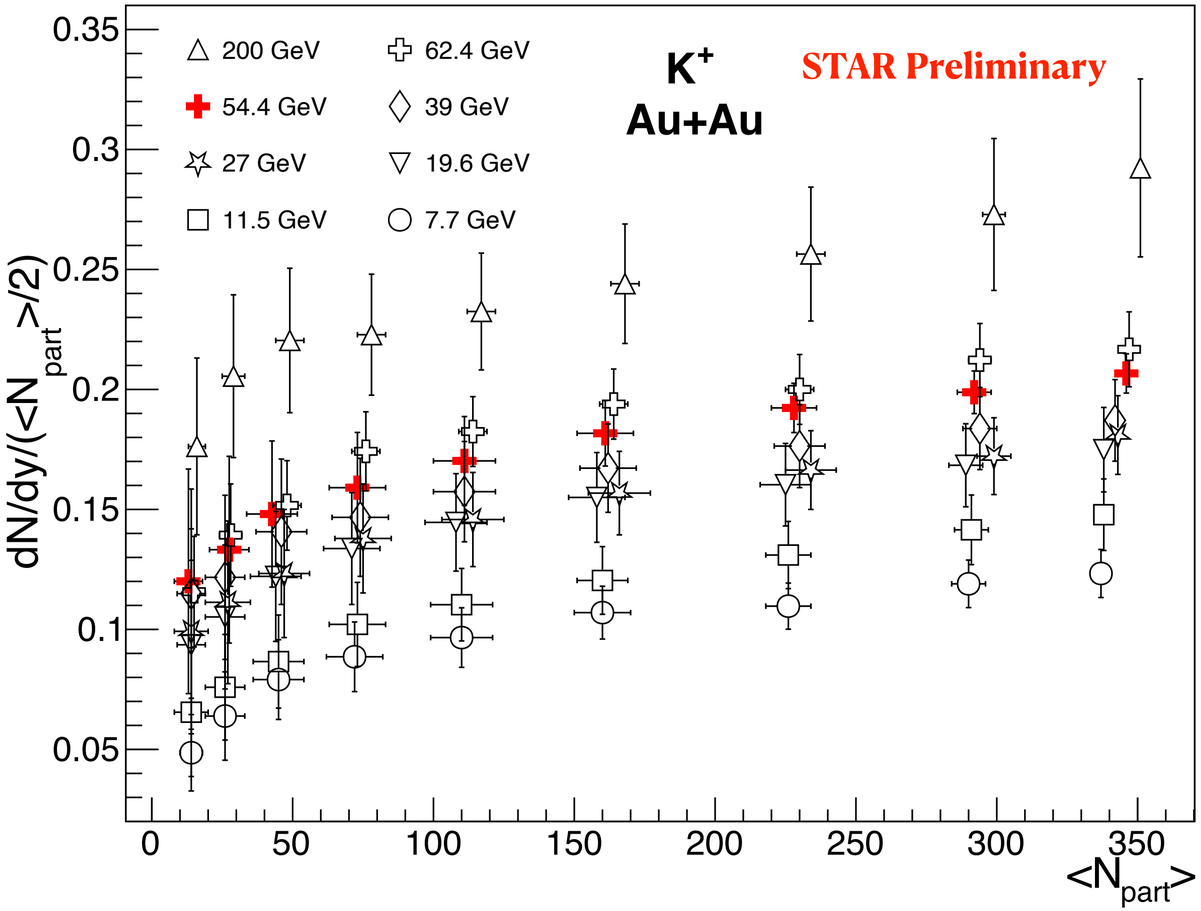
p_T-integrated Yield (dN/dy)

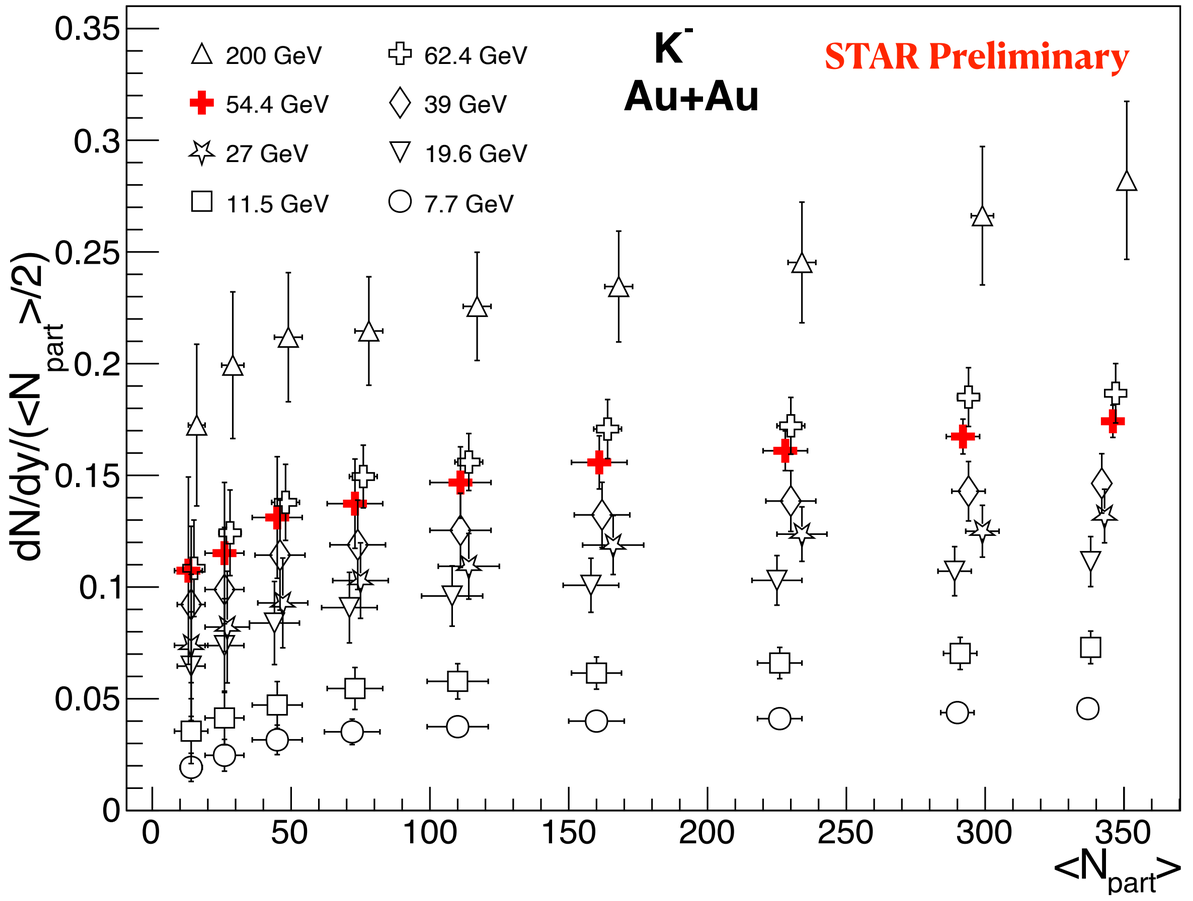




- Pion (π-,π^+) yields show centrality and energy dependence

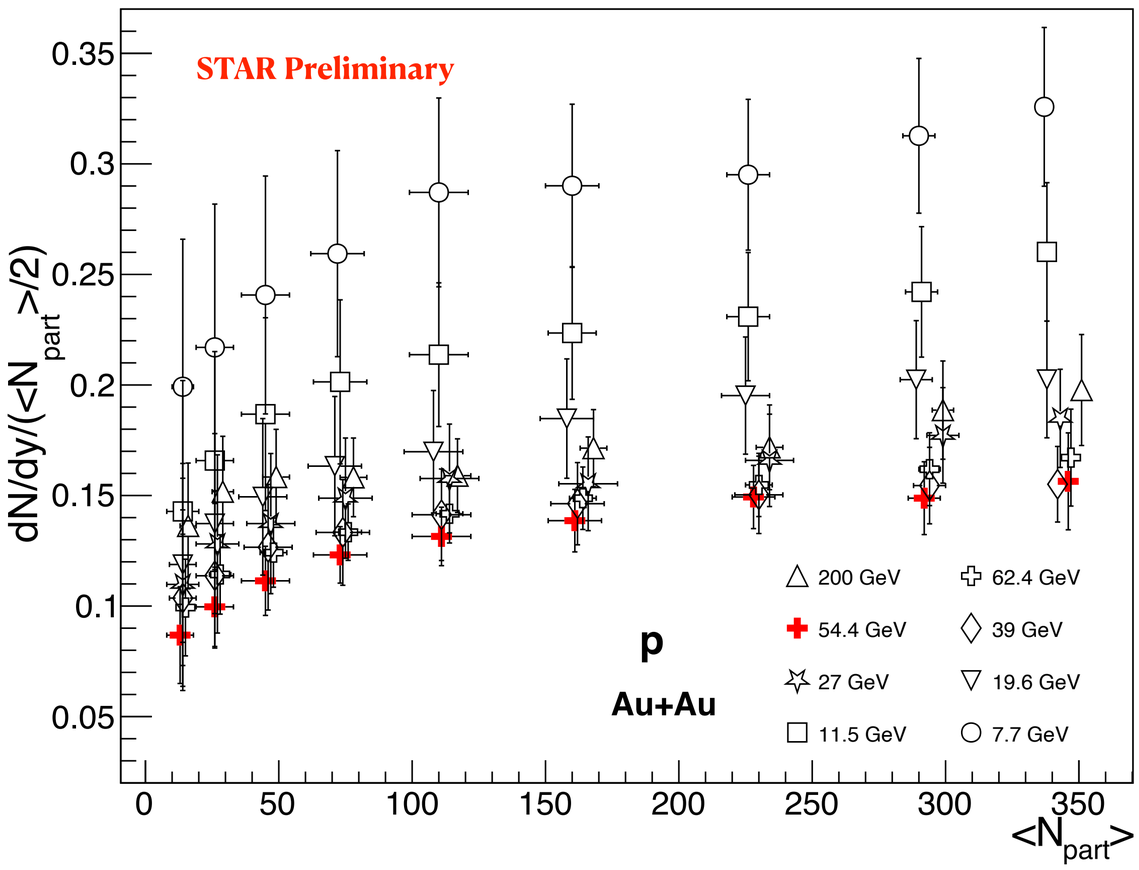
p_T-integrated Yield (dN/dy)

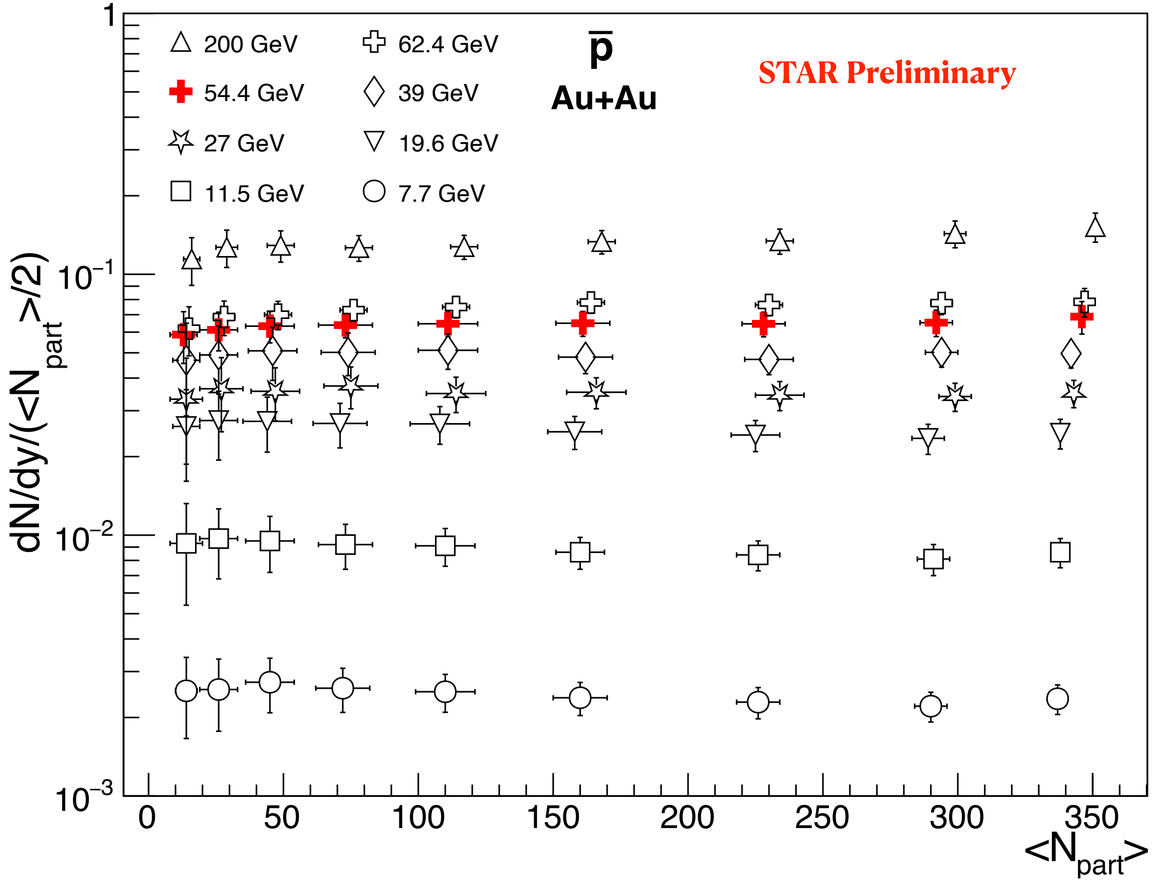




- Kaon (K^-,K^+) yields show centrality and energy dependence

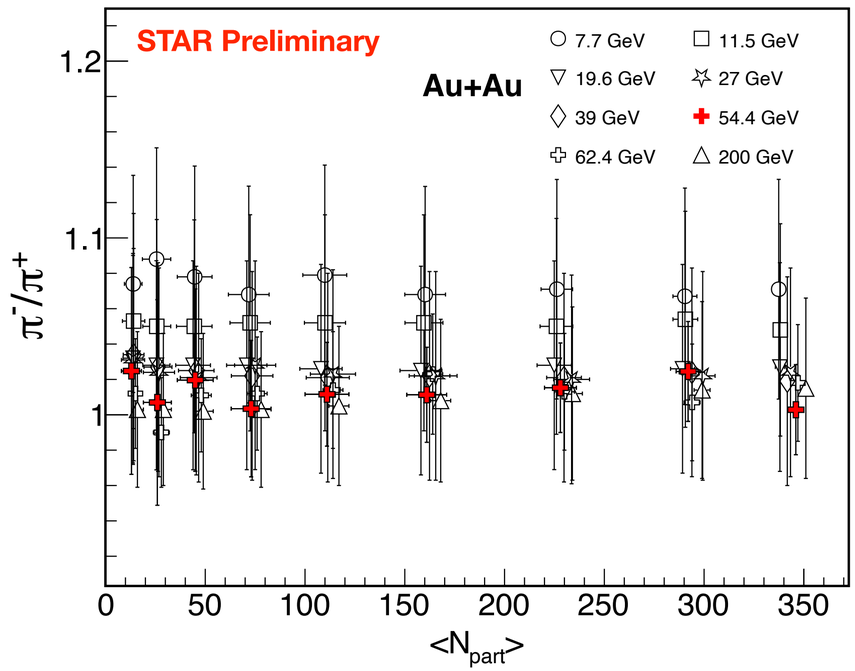
p_T-integrated Yield (dN/dy)

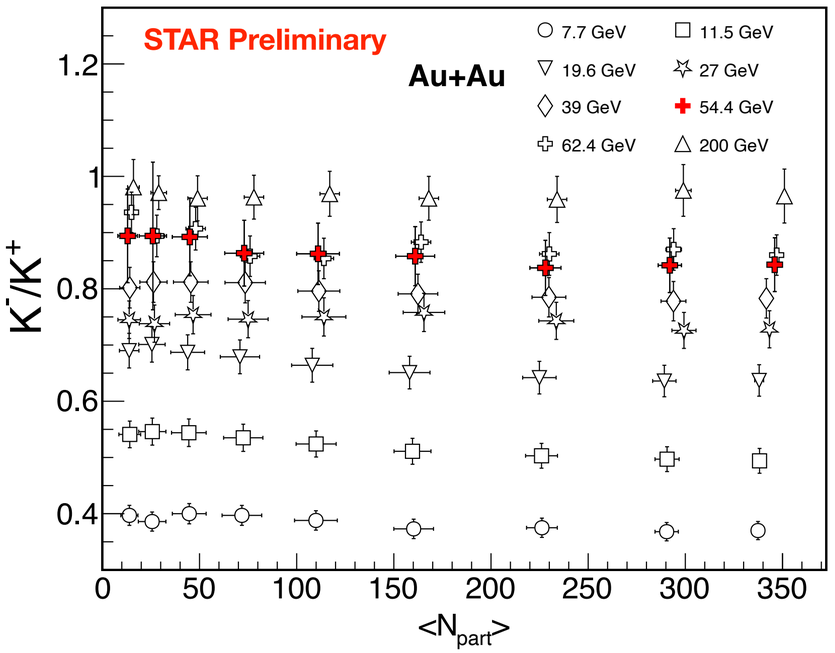


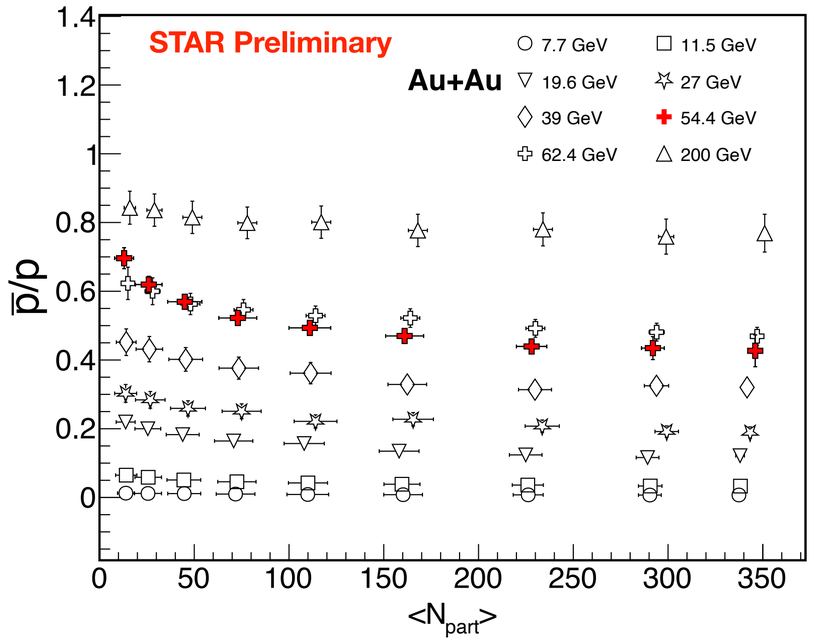


- Normalized yield for proton shows a clear centrality dependence, and reaches a minimum around 54.4 GeV due to the interplay of pair production and baryon stopping
- Normalized yield for anti-proton shows a clear energy dependence

Centrality Dependence of Particle Ratios

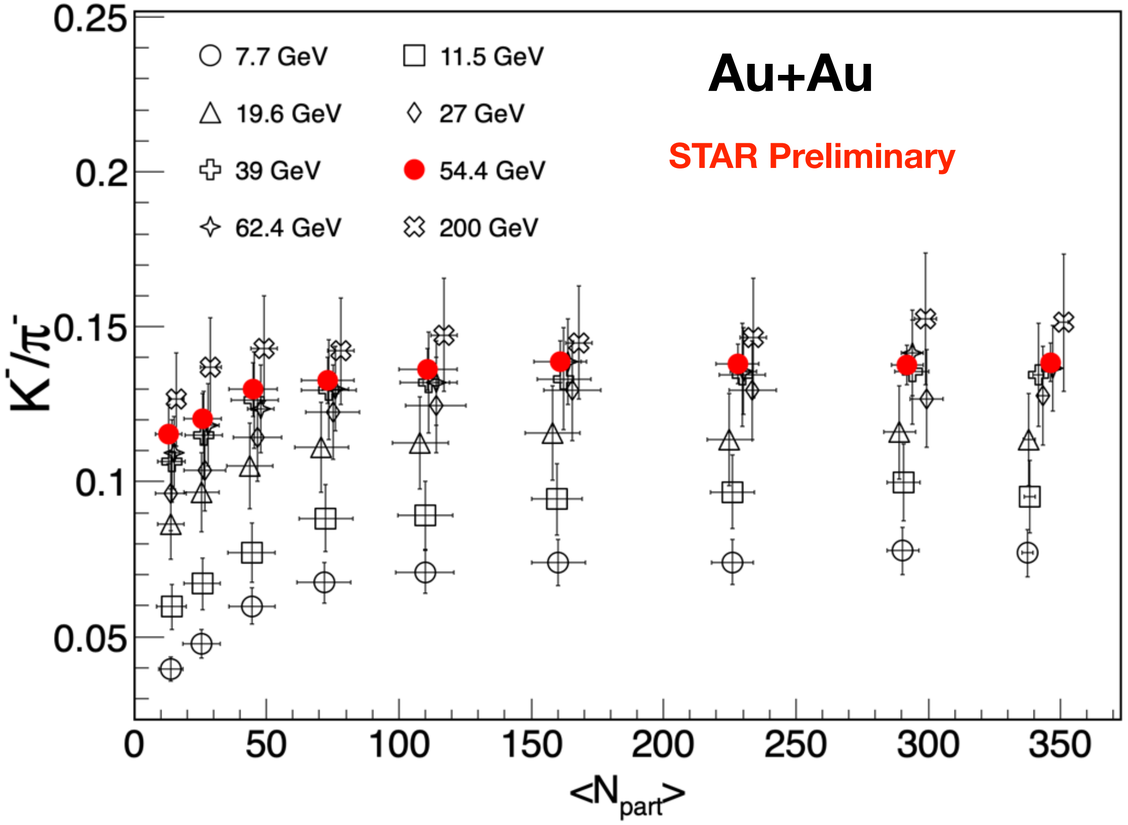


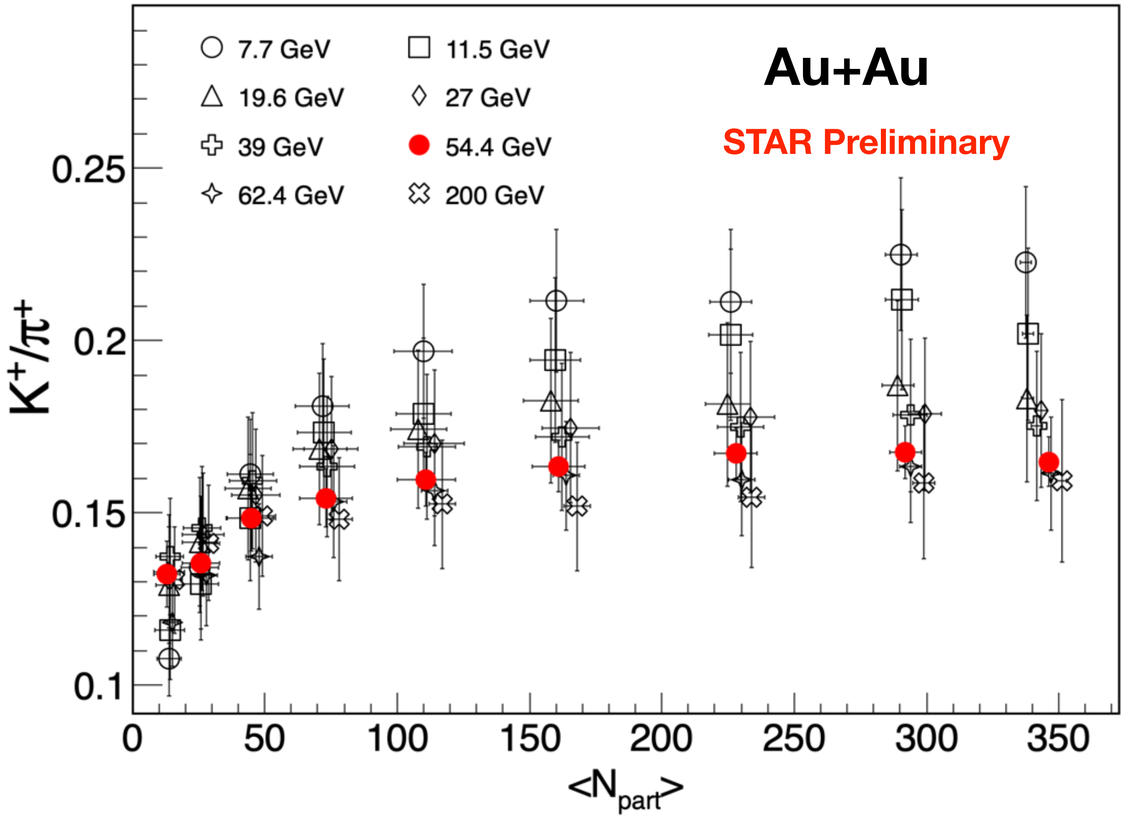




- π^-/π^+ ratio is close to unity for all centralities
- K^-/K^+ ratio does not depend on centrality and is lower than unity ➔ associate production
- Antiproton-to-proton ratio decreases with increasing centrality ➔ baryon stopping

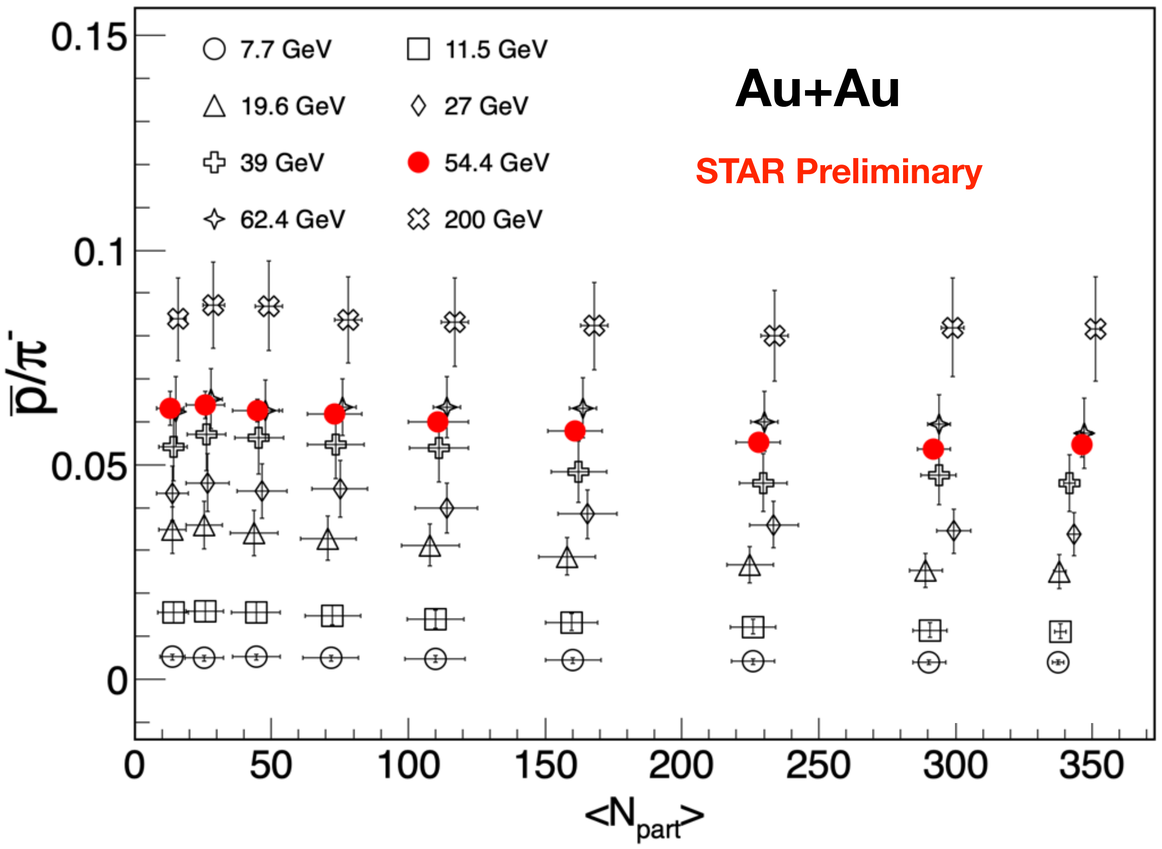
Centrality Dependence of Particle Ratios

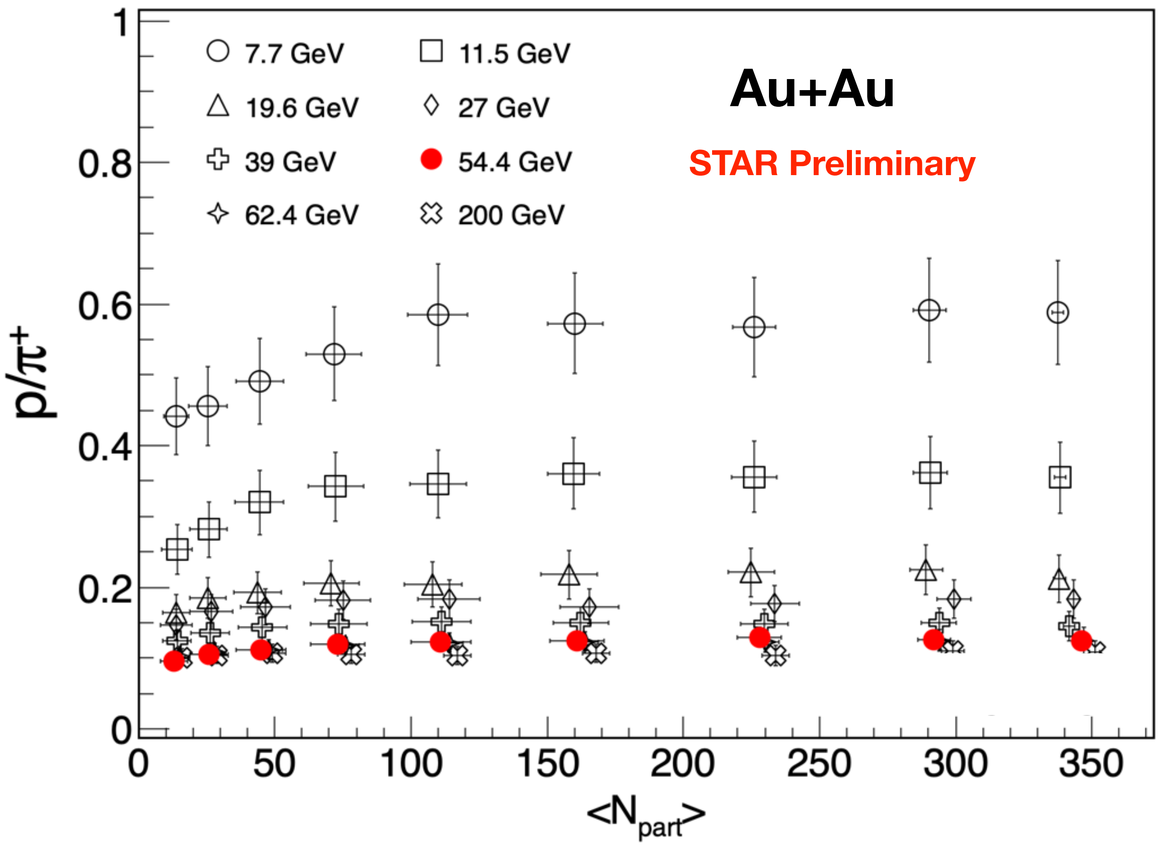




- K^-/π^- ratio increases with increasing energy
- K^+/π^+ ratio is maximal at 7.7 GeV and then decreases ➔ associated production dominance at lower energies

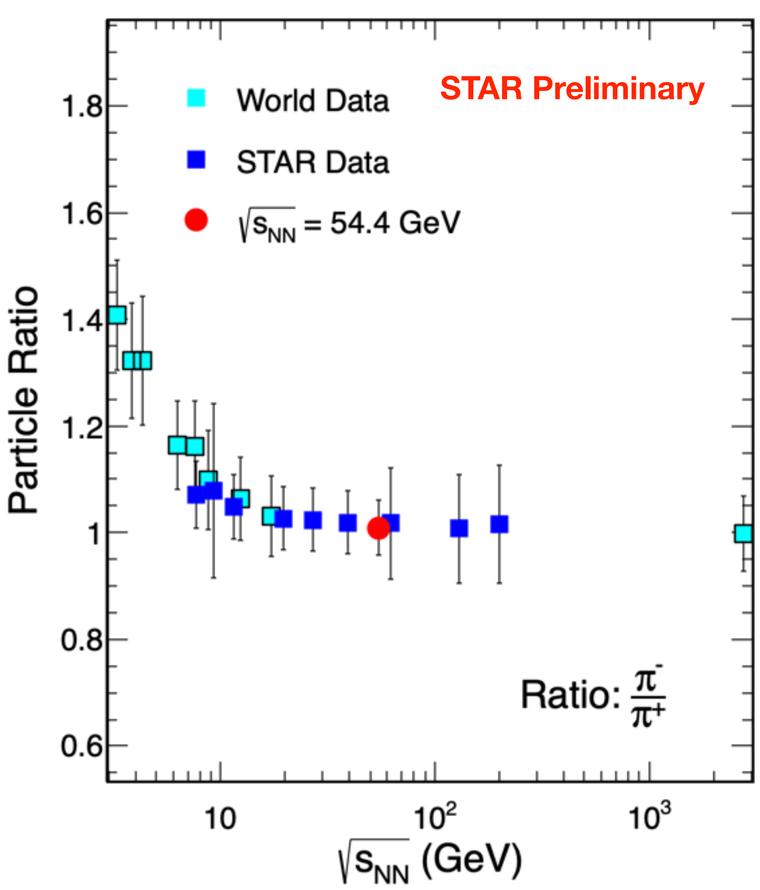
Centrality Dependence of Particle Ratios

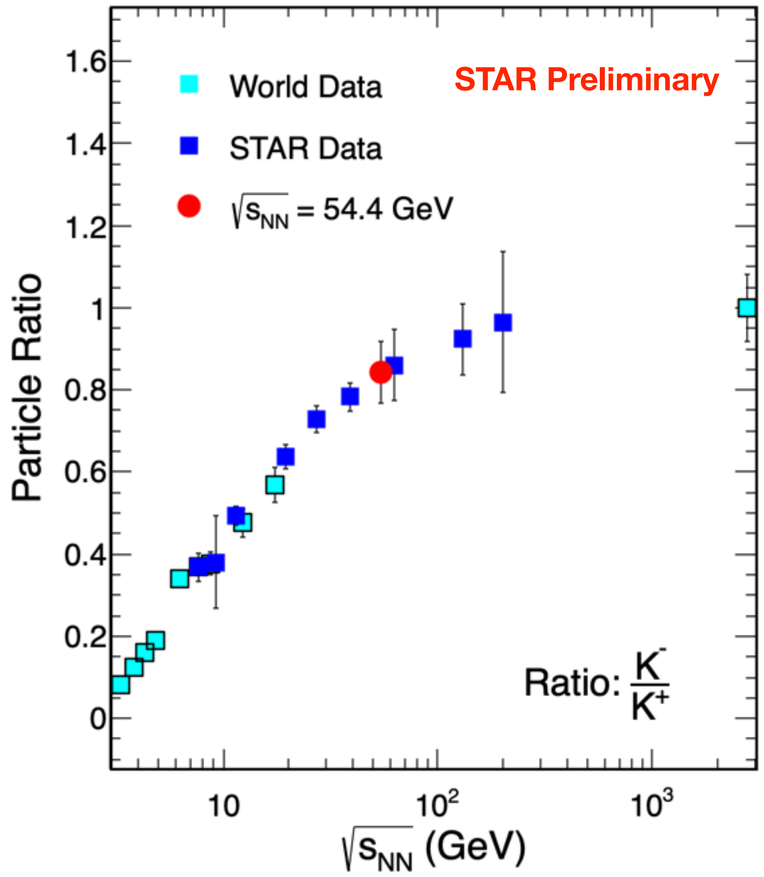


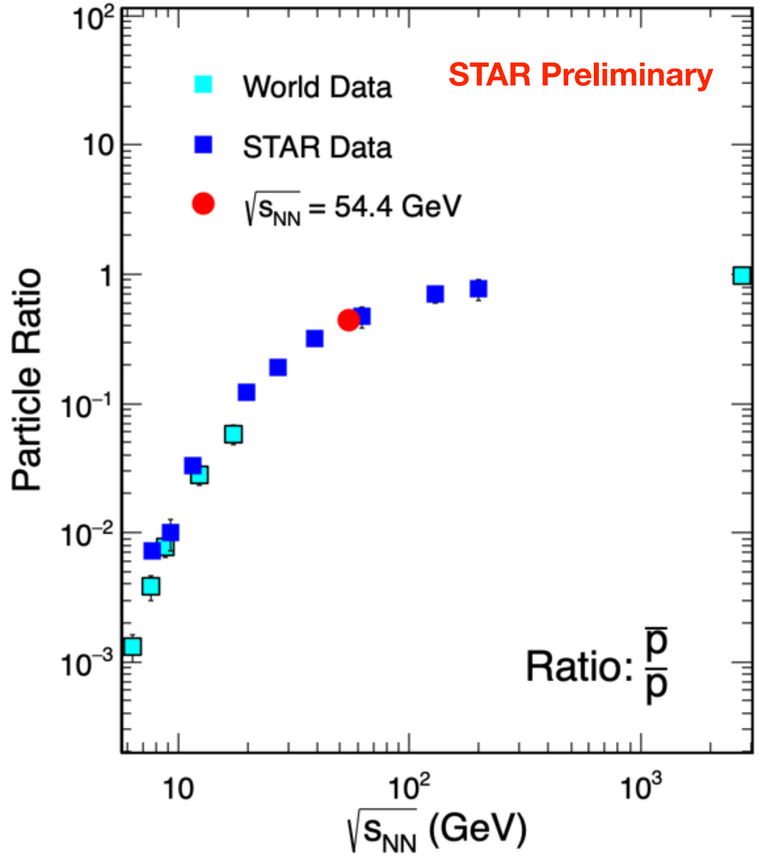


- $\bar{p}/\pi-$ ratio increases with increasing beam energy
- p/π^+ ratio decreases with increasing energy ➔ more baryon stopping at lower energies

Energy Dependence of Particle Ratios

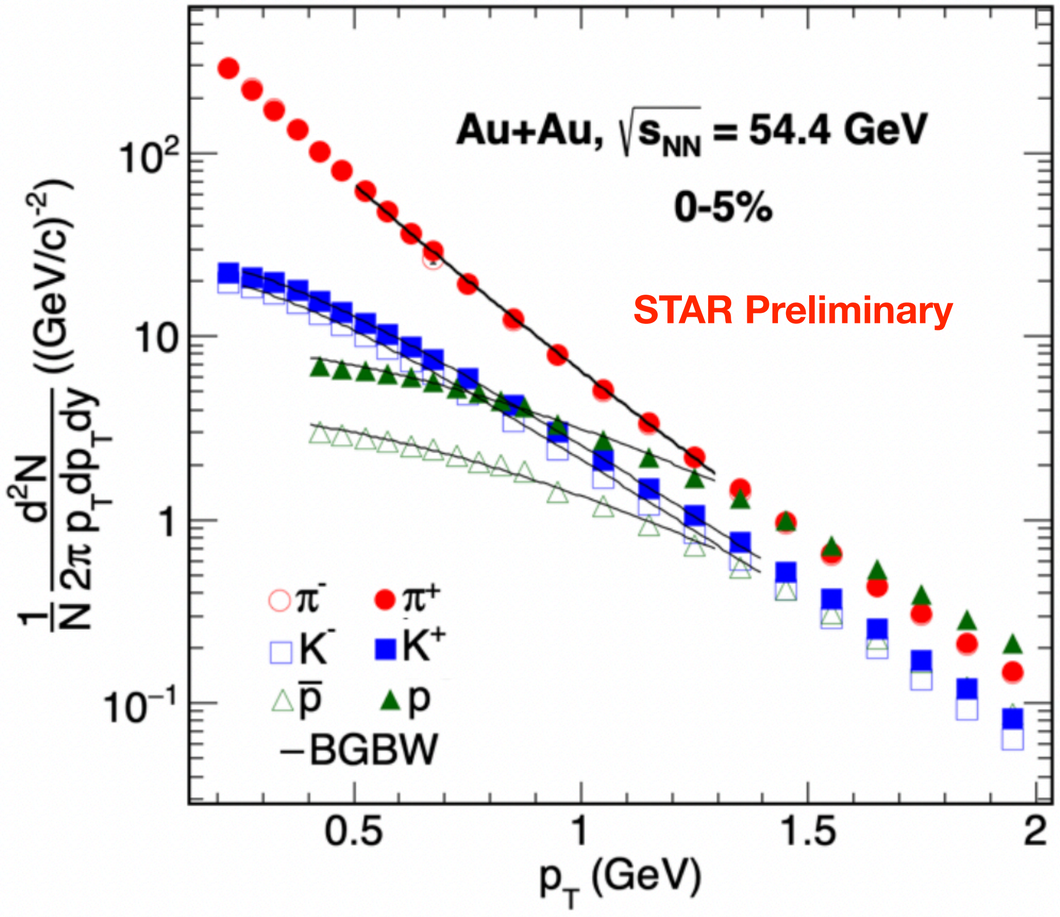






- Particle ratios for 54.4 GeV data are consistent with the energy dependence trend observed at AGS, SPS, RHIC, and LHC energies

Kinetic Freeze-out: Blast-Wave Model



Blast-Wave Model : Hydrodynamic inspired 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

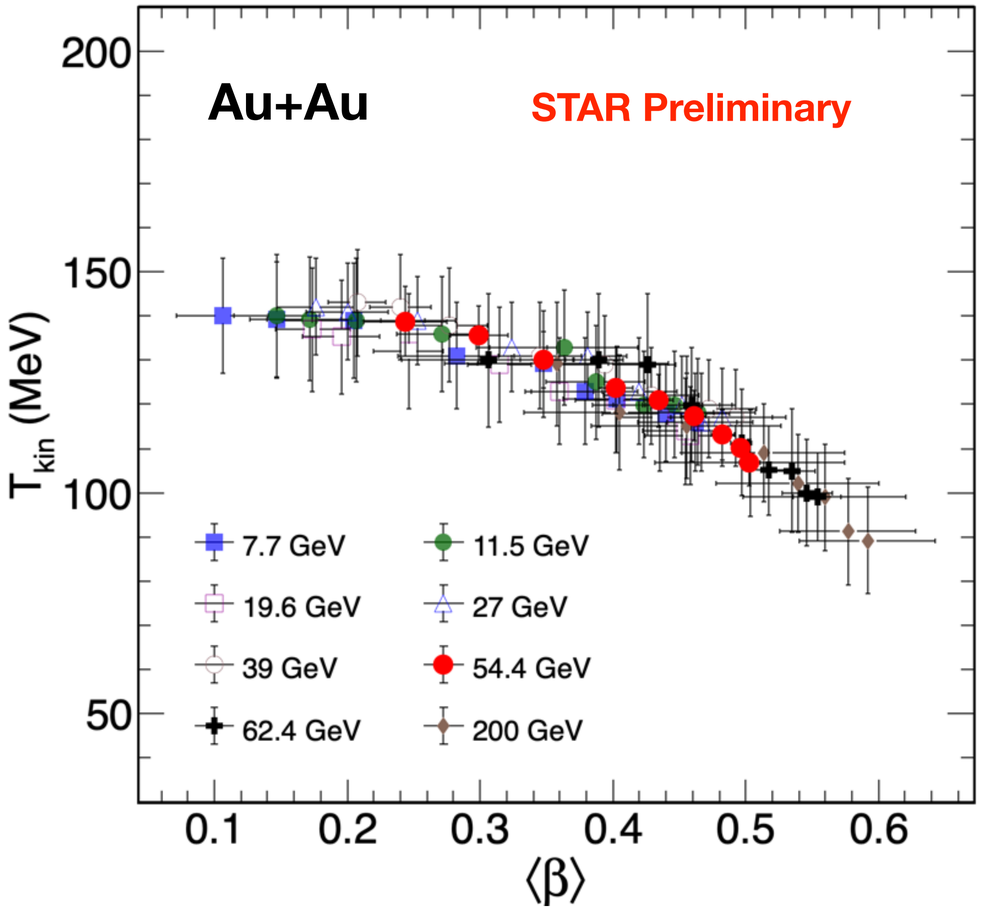
$\rho(r) = \tanh^{-1}\beta$

β = Transverse radial flow velocity

T_{kin}: Kinetic freeze-out temperature

Transverse momentum spectra are fitted simultaneously with BW model to extract T_{kin} and $\langle\beta\rangle$

Kinetic Freeze-out Parameters



✓ **Kinetic freeze-out**

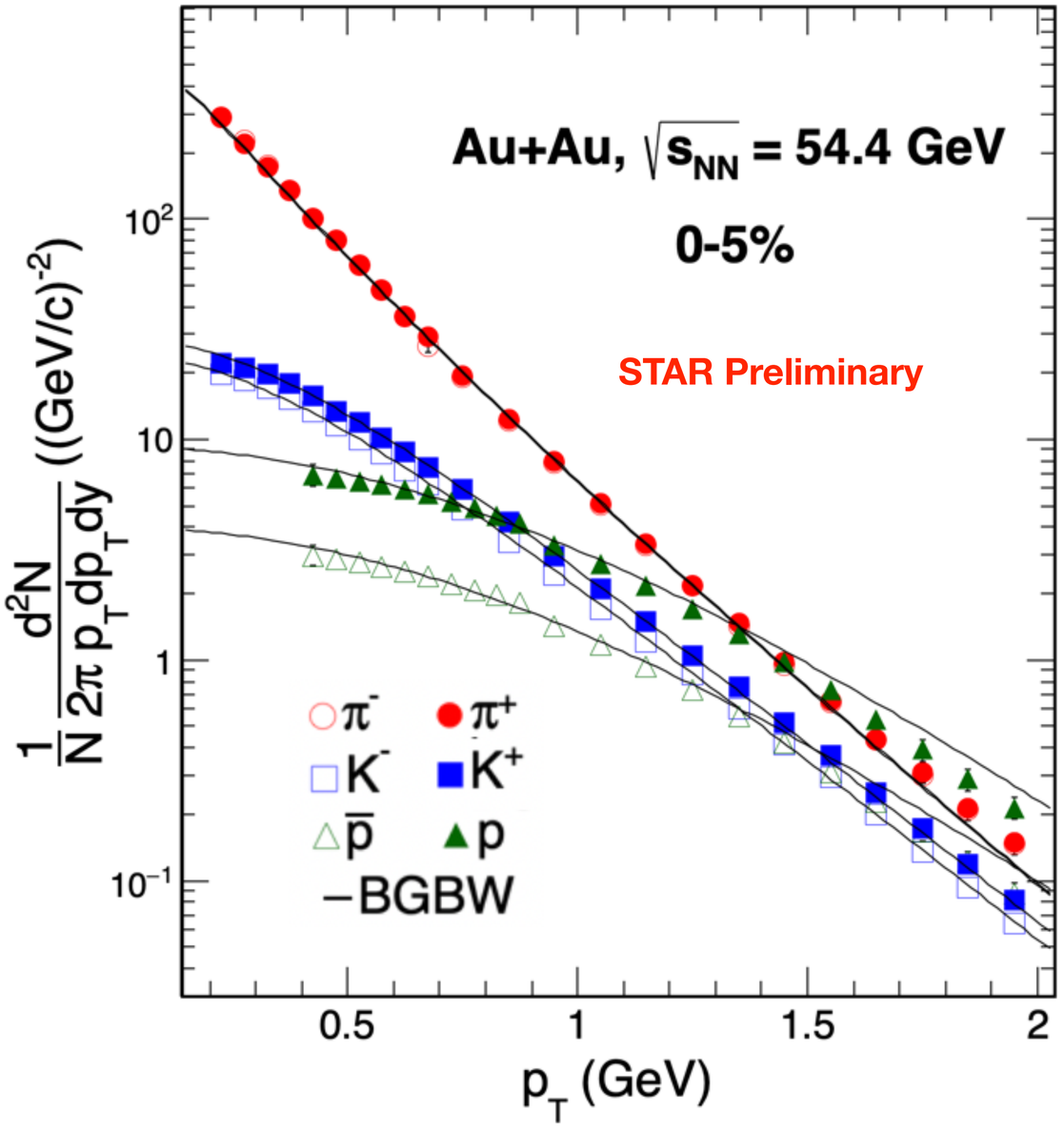
- T_{kin} and <β> show anti-correlation
- T_{kin} and <β> for 54.4 GeV show similar trend as other RHIC energies

Summary

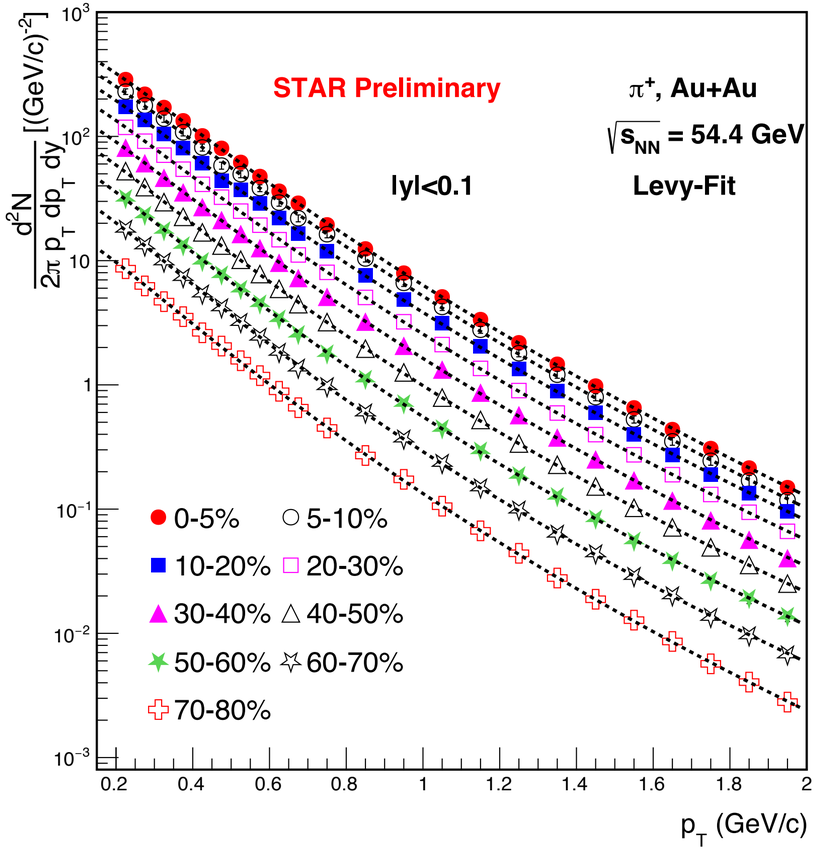
- Transverse momentum spectra for $\pi^{\pm}$, $K^{\pm}$, p and $\bar{p}$ have been studied in Au+Au collisions at $\sqrt{s_{NN}}$ = 54.4 GeV using STAR data
- Normalized particle yield (dN/dy)/(<N_{part}>/2) shows clear centrality and energy dependence
- Centrality dependence of particle ratios is consistent with the trend observed at other RHIC energies
- K^-/π^-, $\bar{p}/\pi^-$ increase, whereas K^+/π^+ and p/π^+ ratios decrease with increasing energy, and are consistent with world data trend
- T_{kin} and <β> show anti-correlation as observed at other energies

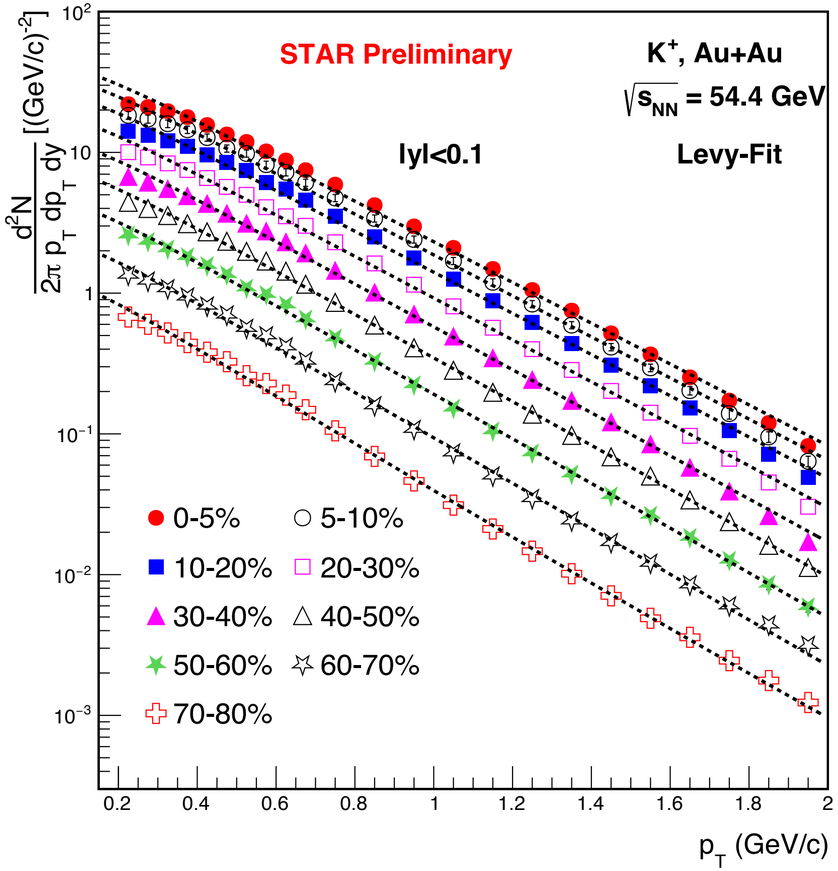
Thank you for your attention

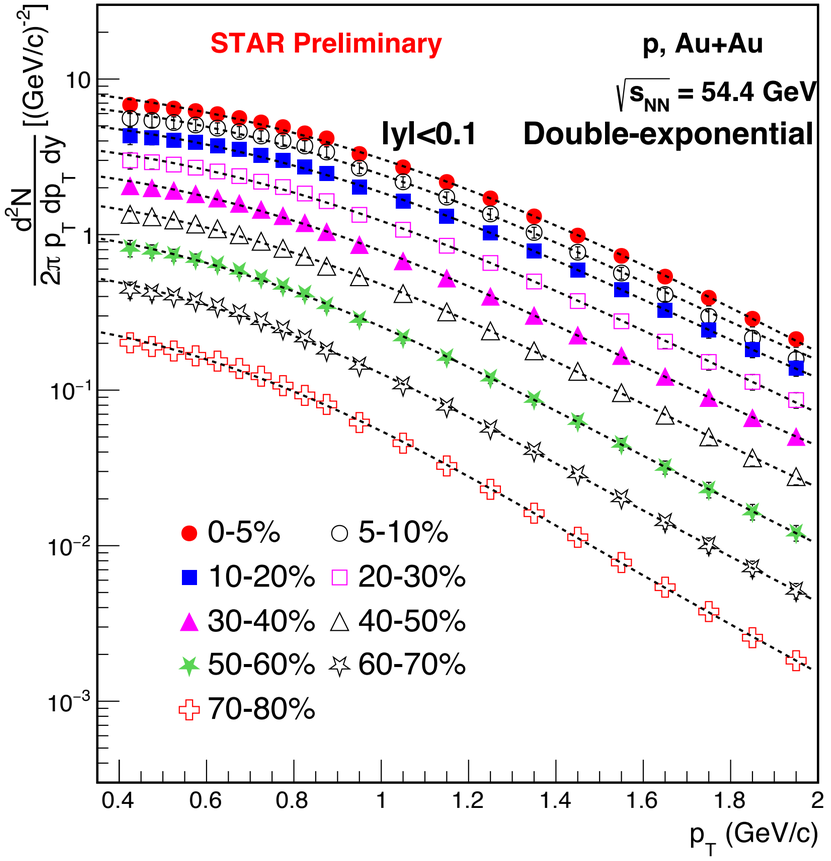
Backup


Au+Au, $\sqrt{s_{NN}}$ = 54.4 GeV
0-5%
STAR Preliminary
π^- π^+
K^- K^+
$\bar{p}$ p
–BGBW
$\frac{1}{N}\frac{d^2N}{2\pi\, p_T dp_T dy}$ ((GeV/c)$^{-2}$)
p_T (GeV)
10^2
10
1
10^{-1}
0.5
1
1.5
2

Transverse Momentum Spectra

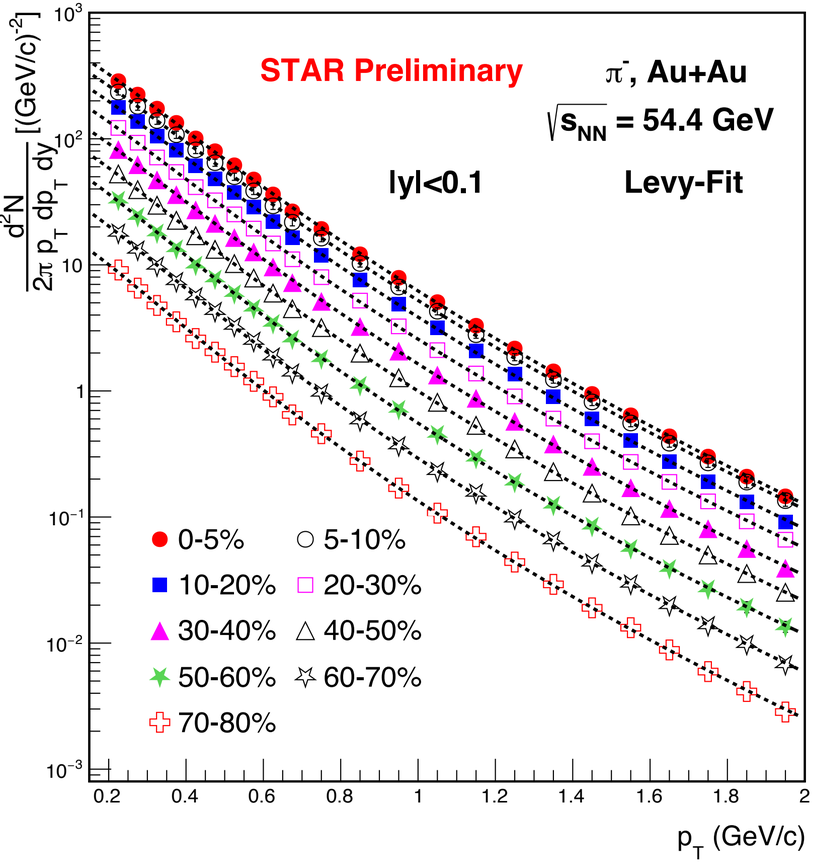


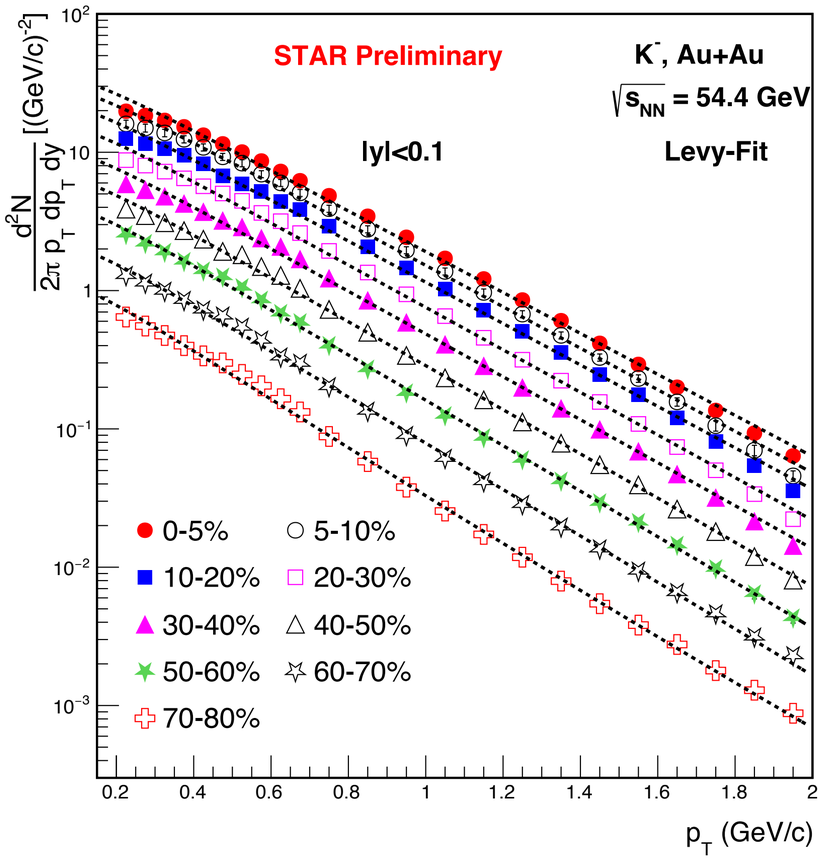


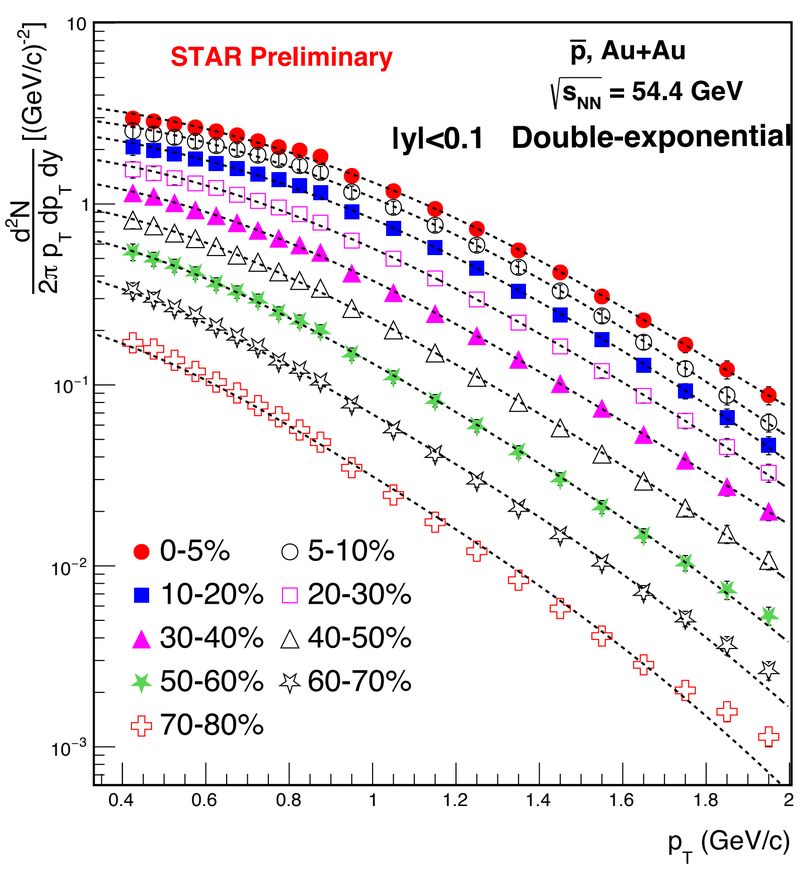


- p_T -spectra of particles (π^+, K^+ , and p) show a clear p_T and centrality dependence

Transverse Momentum Spectra







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