Measurement of high-p_T $\pi^{\pm}$, $p(\bar{p})$ spectra in Au+Au collisions at $\sqrt{s_{NN}}$ = 19.6 GeV with the STAR experiment

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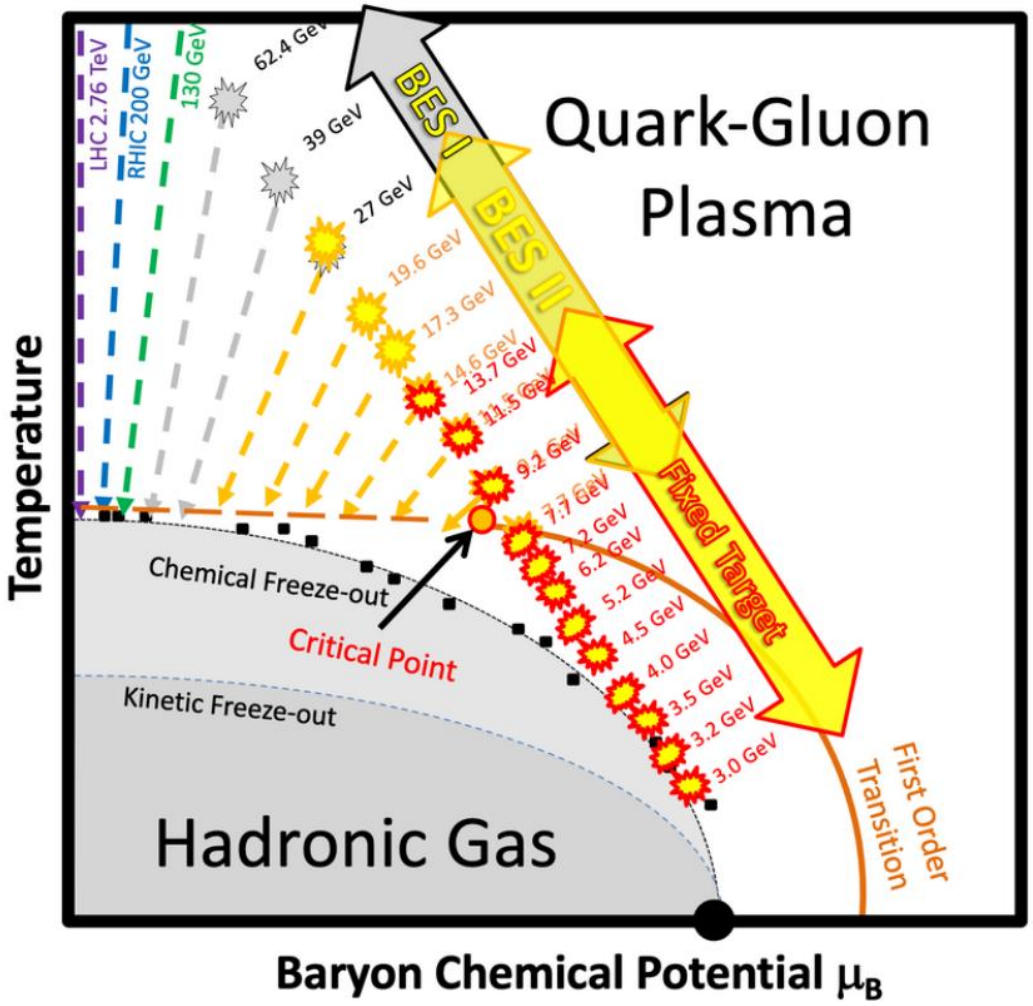
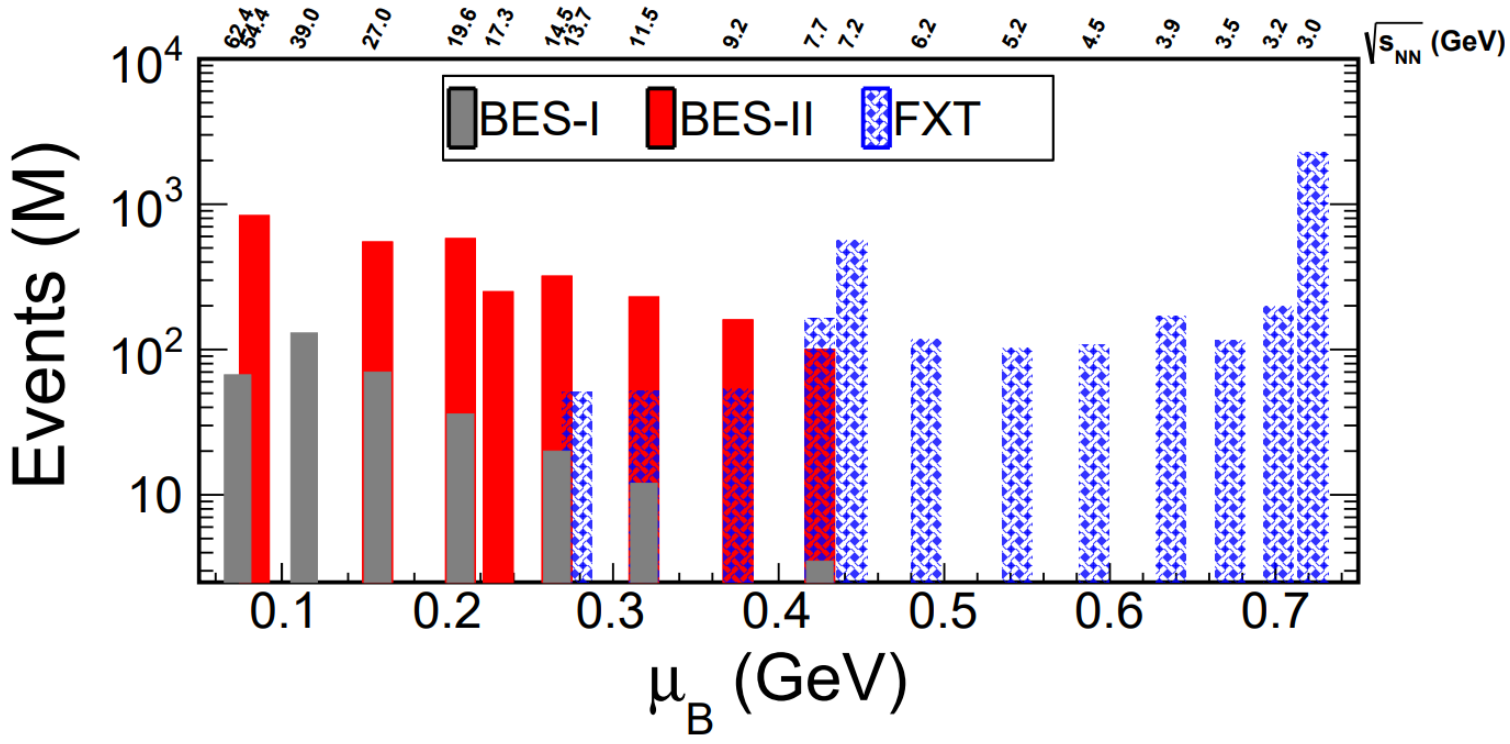
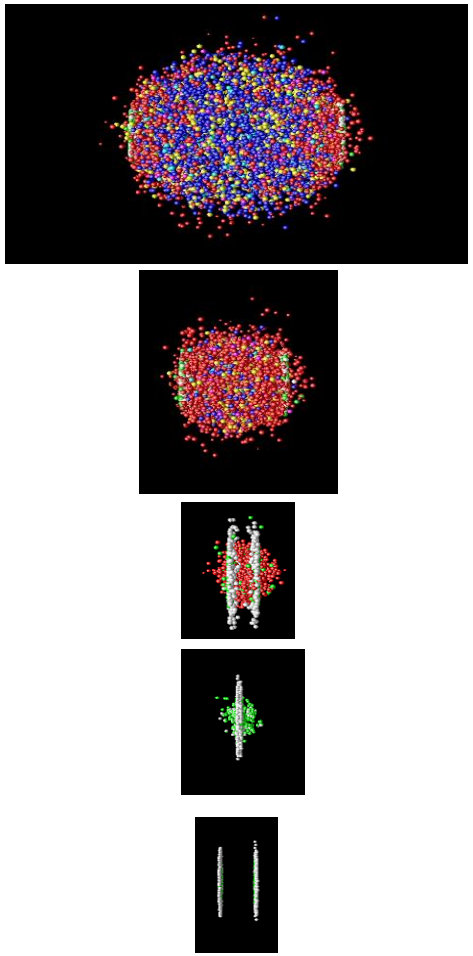
Probe QCD phase diagram with Beam Energy Scan

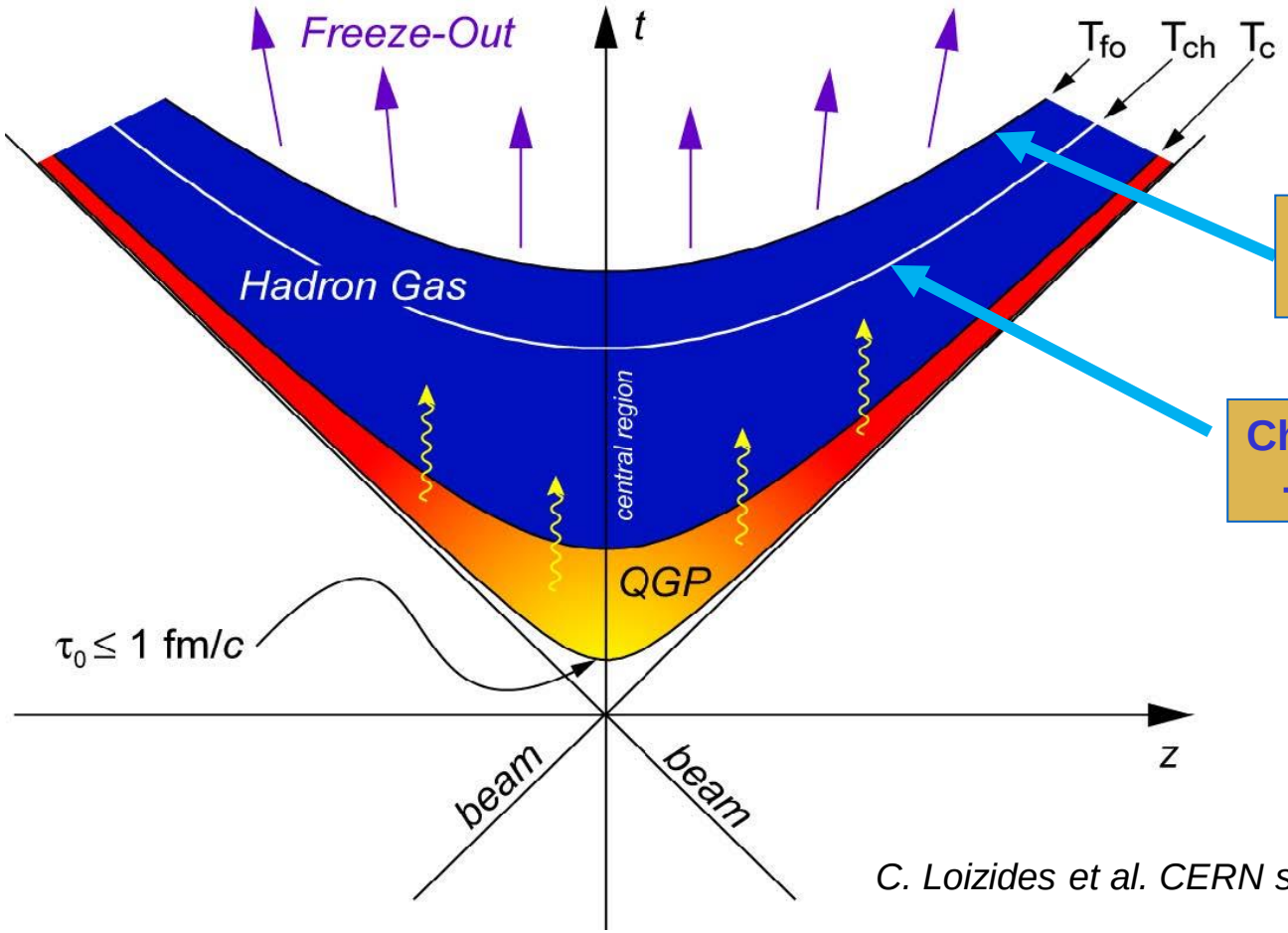




- QGP is an extreme state of nuclear matter in which quarks and gluons are deconfined.
- Beam Energy Scan phase II program maps QCD phase diagram with high precision.

Final state particle production reveals bulk properties





Kinetic Freeze-out
--- elastic scatterings cease

Chemical Freeze-out
--- inelastic scatterings cease

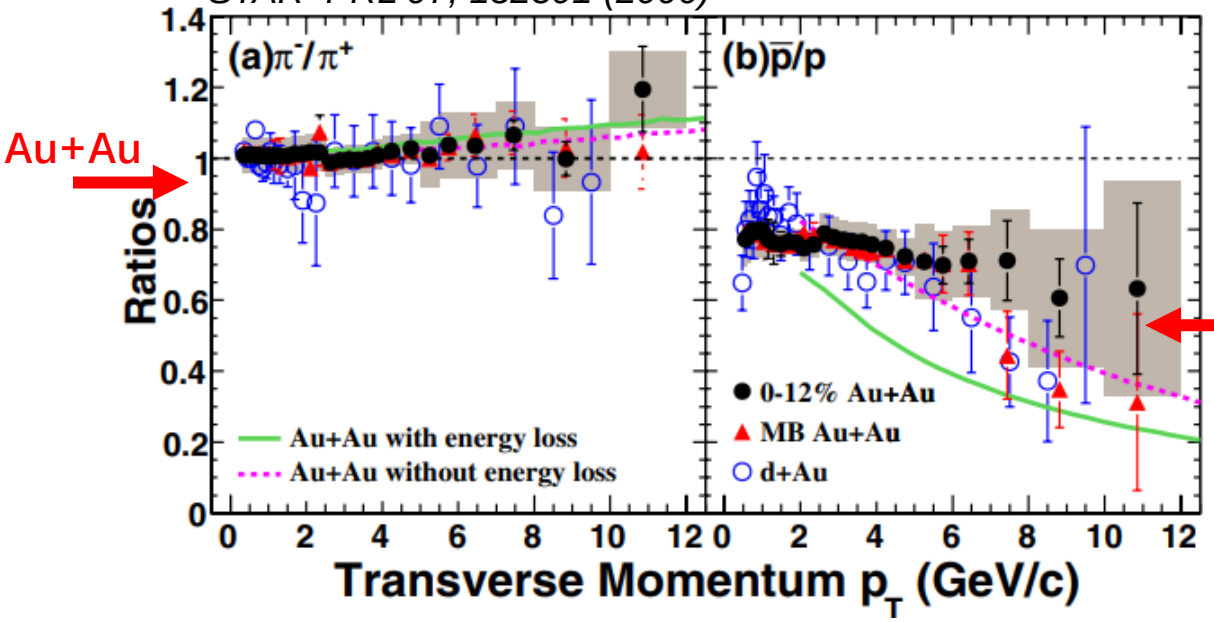
C. Loizides et al. CERN summer student programme 2016

p_T spectra	→	Kinetic freeze-out temperature, radial flow velocity
Integrated yields	→	Chemical freeze-out temperature, chemical potential μ_B

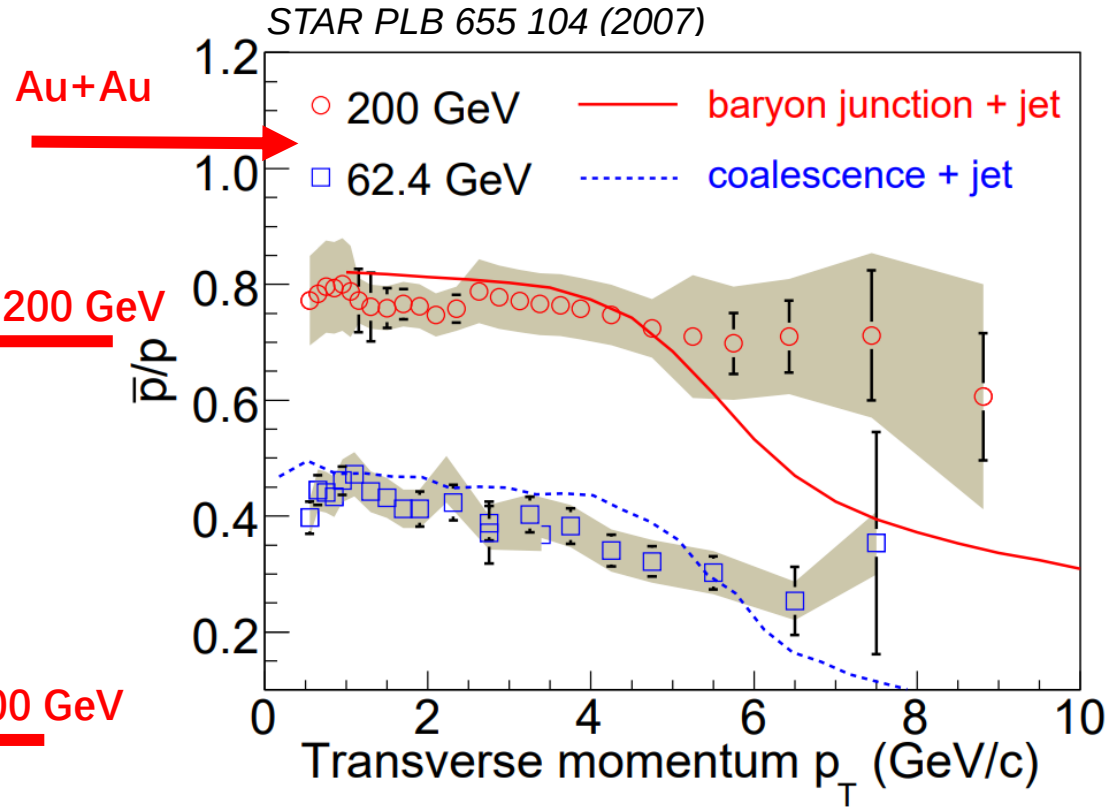
← Particle spectra measurements

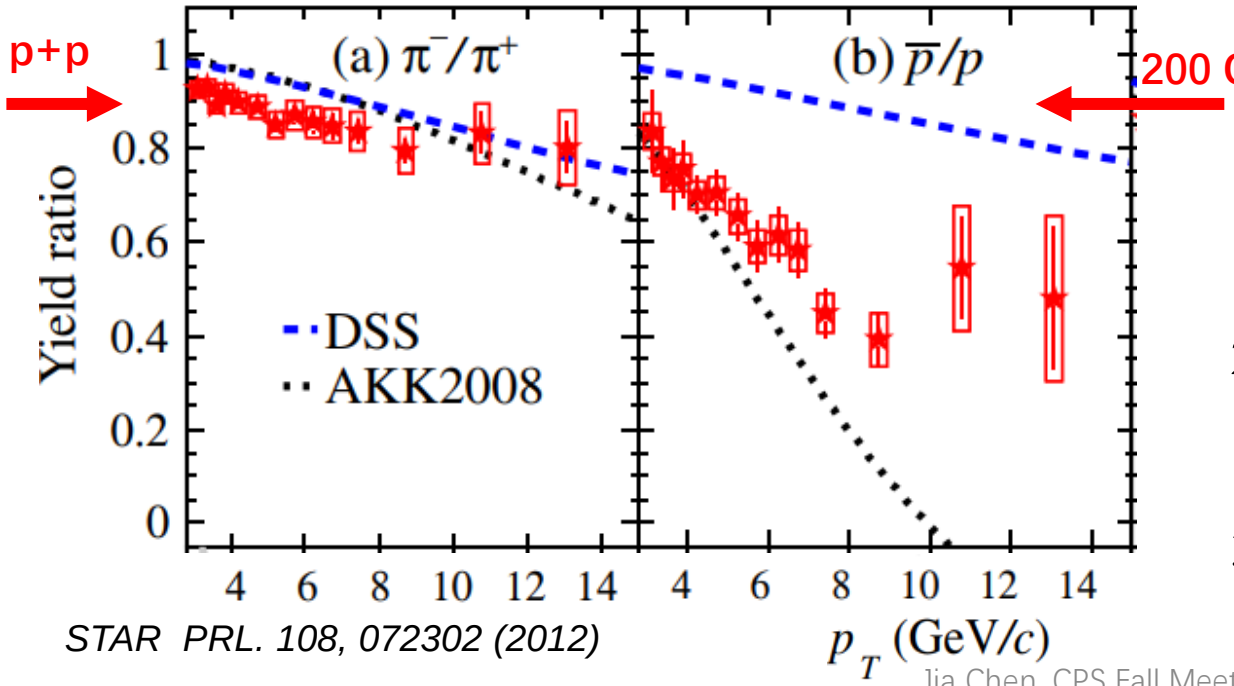
Particle ratio towards high p_T distinguishes production mechanisms

STAR PRL 97, 152301 (2006)



STAR PLB 655 104 (2007)

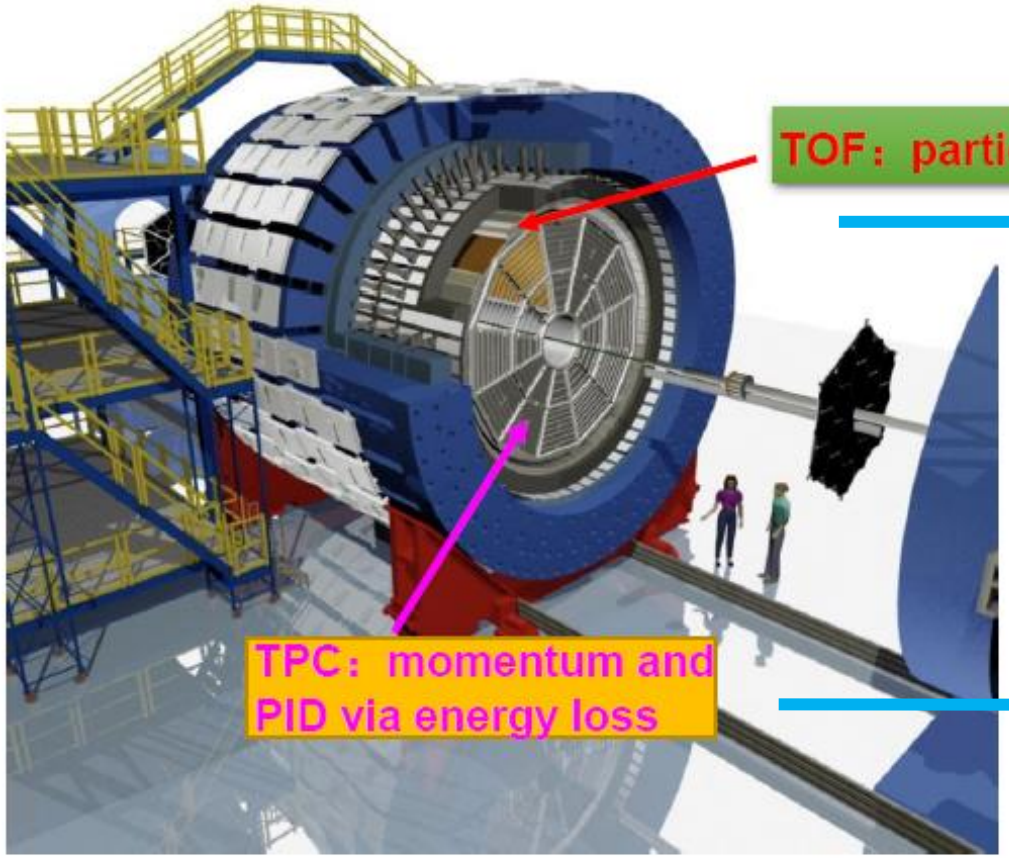


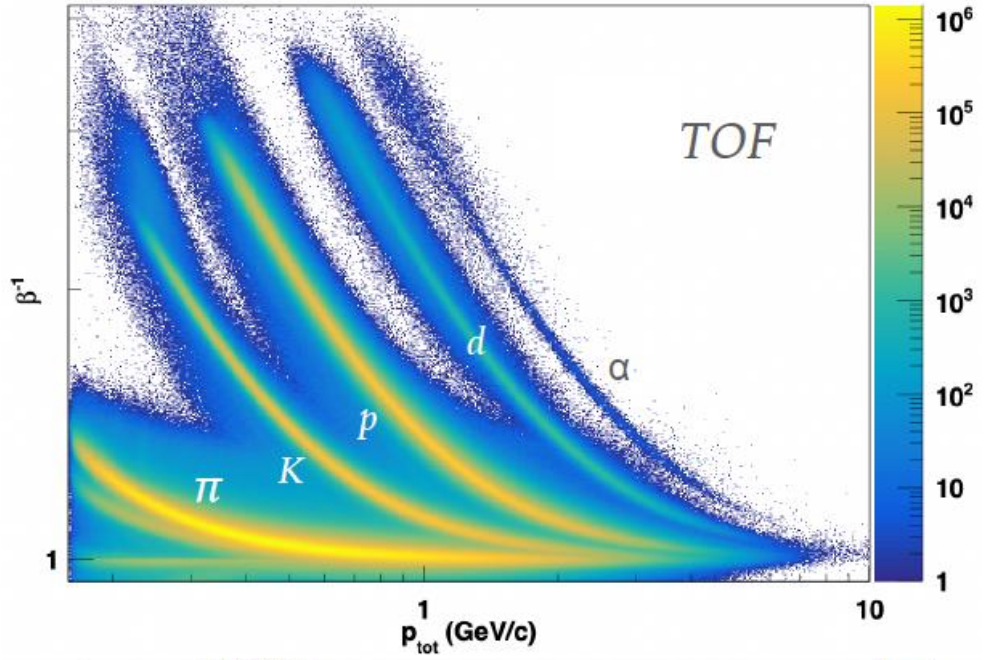


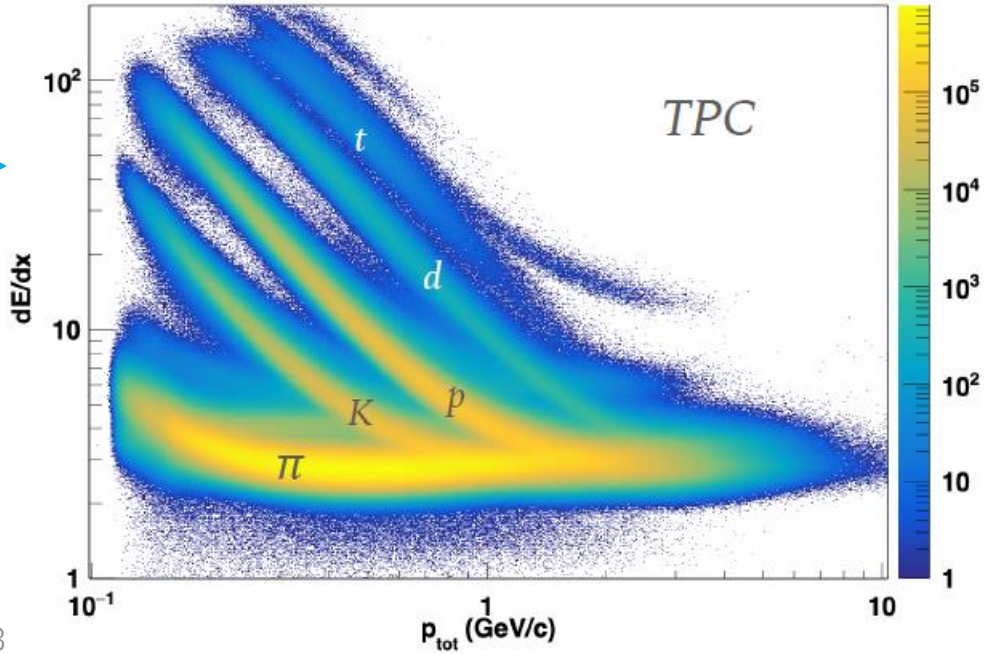
STAR PRL. 108, 072302 (2012)

1. Particle yield ratios vs p_T vary with different collision centralities, energies, and systems.
2. Particle ratios at high p_T region provide better constraint on model assumptions, however the existing data are limited by statistics
3. BES-II with x10 BES-I statistics can help

Particle identification at STAR





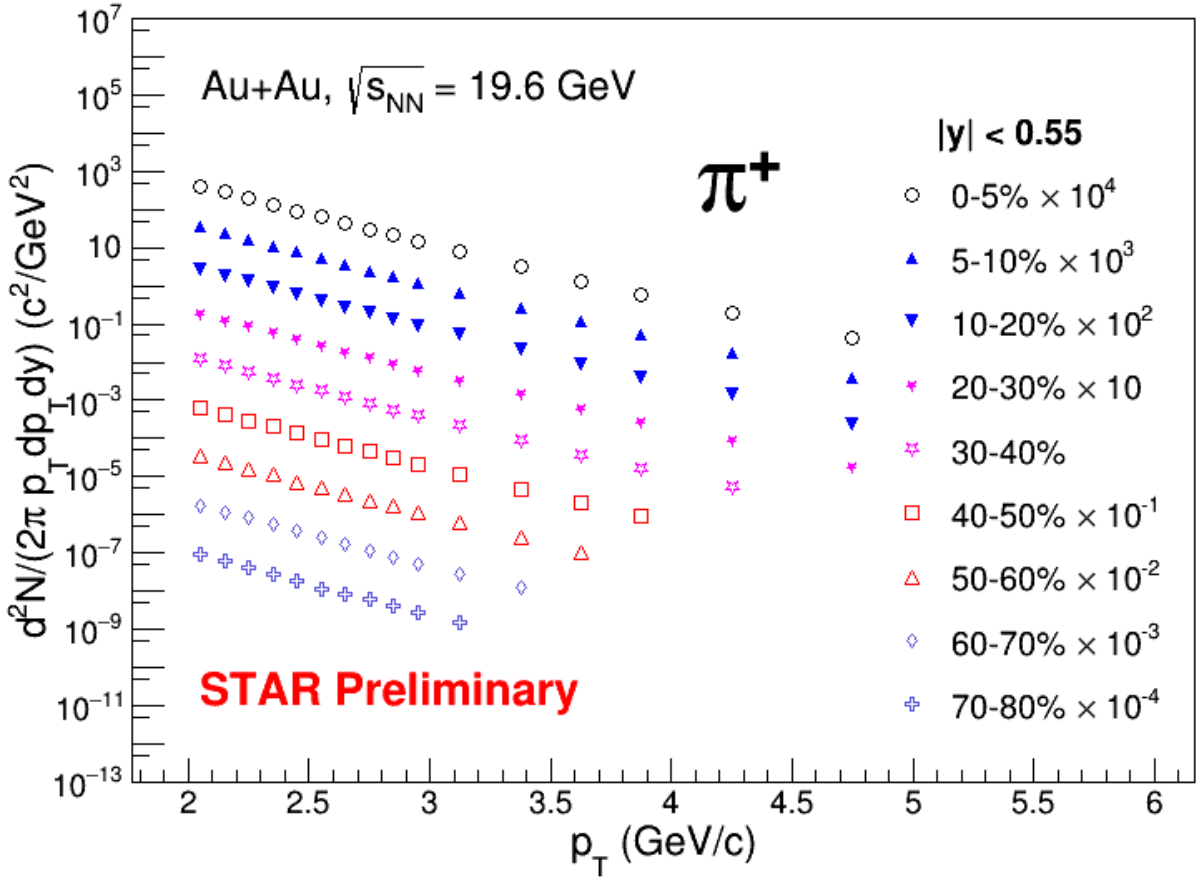


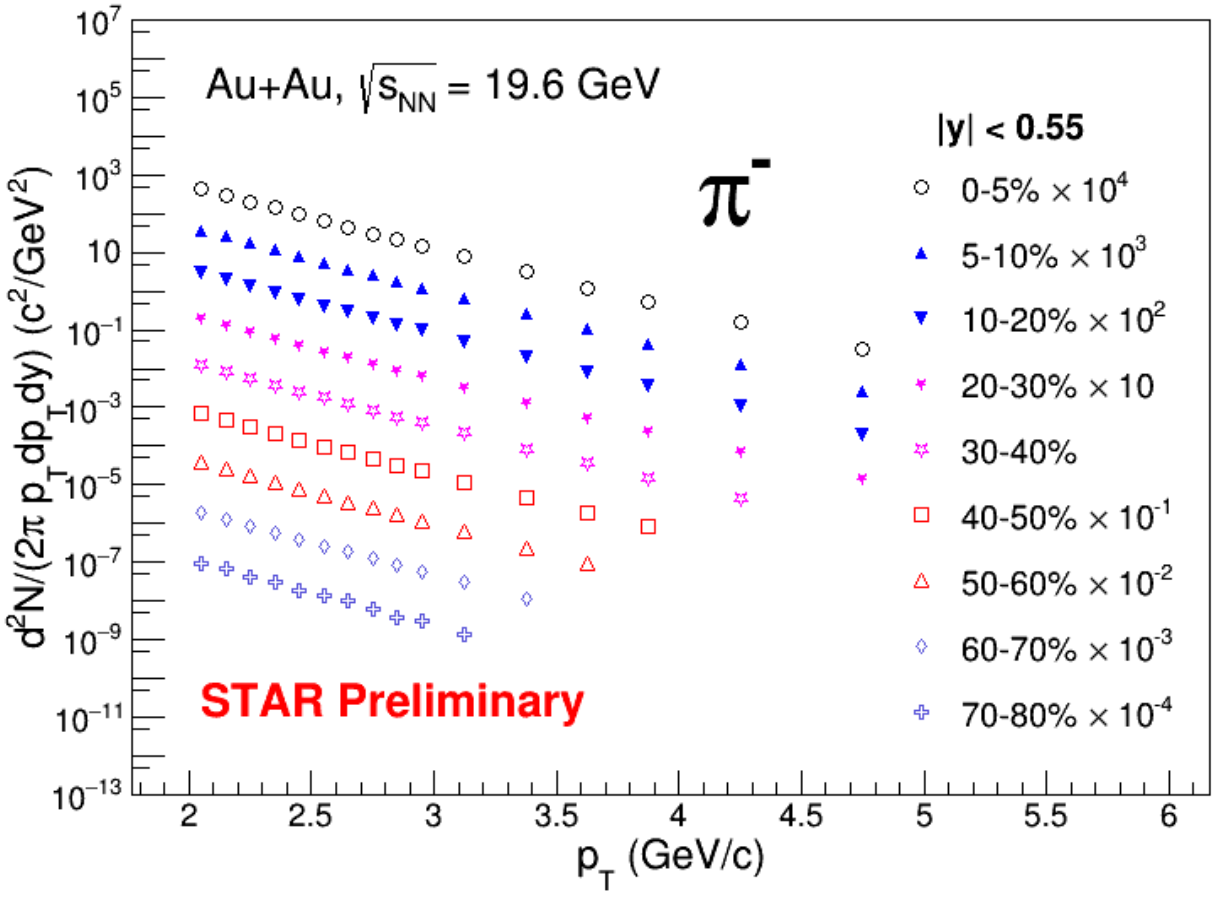
Time Projection Chamber(TPC)

Time-Of-Flight(TOF)

dE/dx: ionization energy loss per unit length

$\pi^{\pm}$ spectra in different centralities

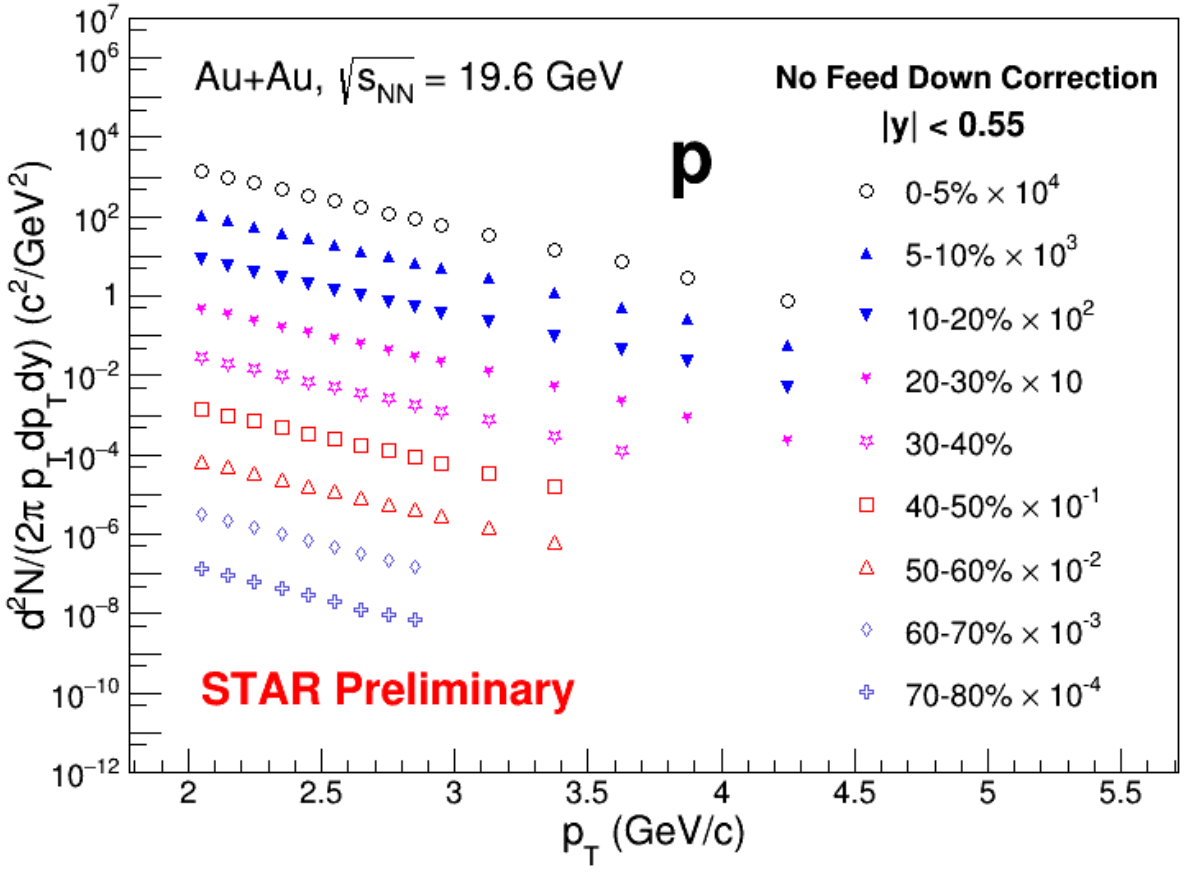


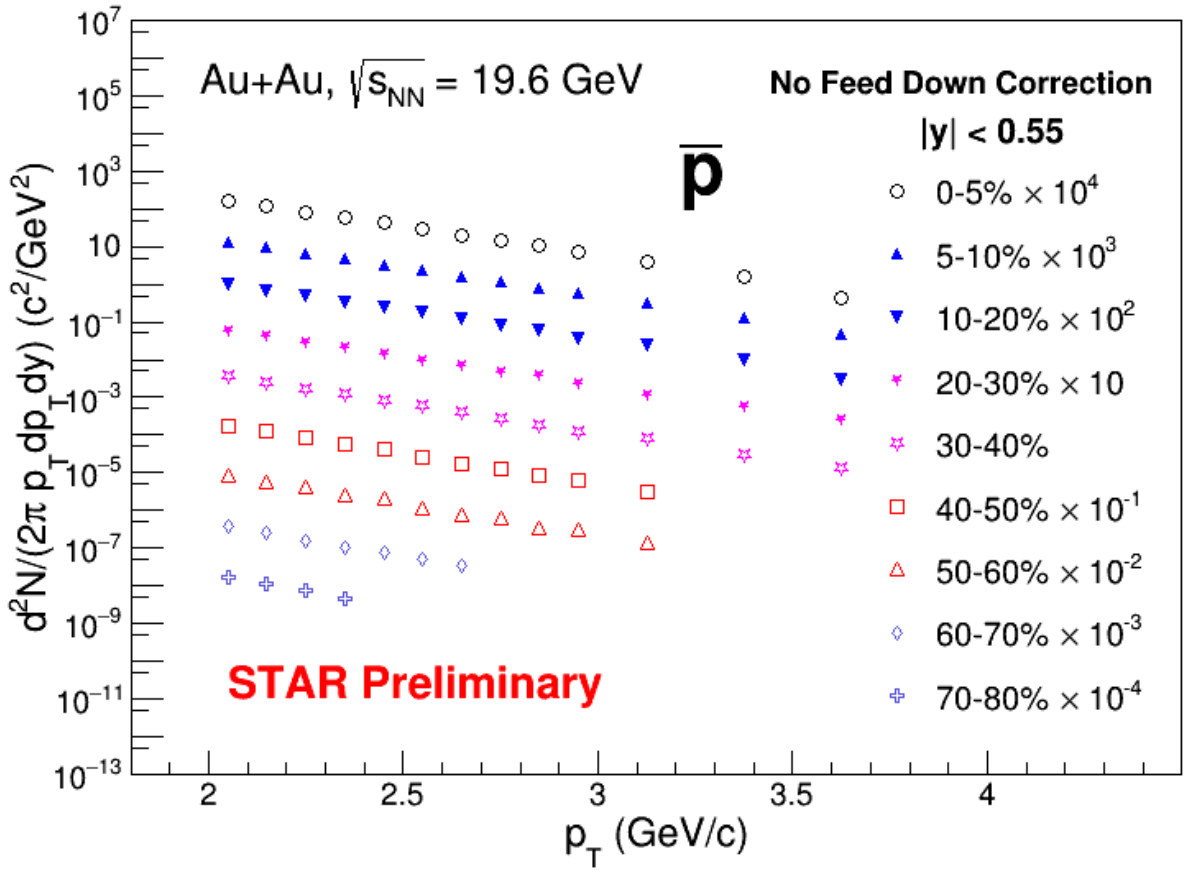


p_T spectra in mid-rapidity (|y|<0.55) are extended to higher p_T region

Statistical and systematic uncertainties are added in quadrature

$p(\bar{p})$ spectra in different centralities



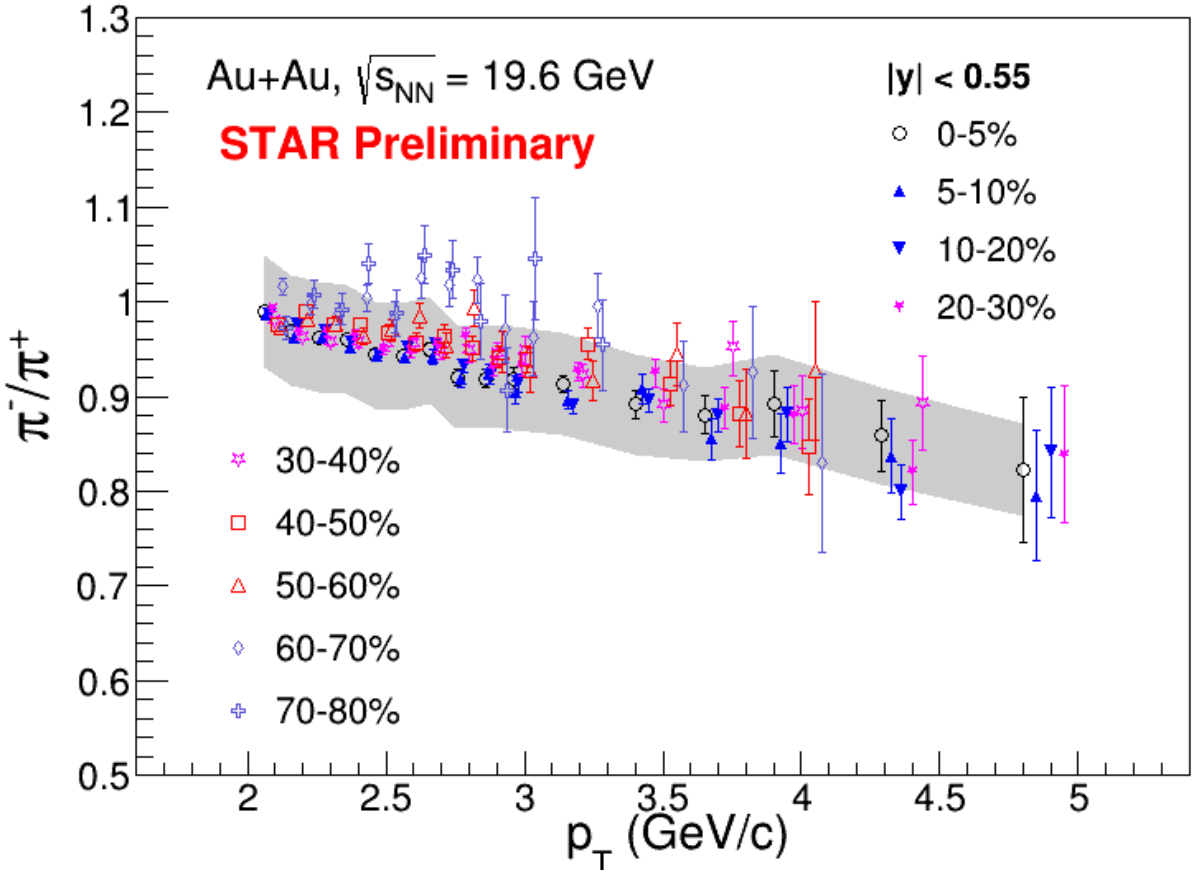


p_T spectra in mid-rapidity (|y|<0.55) are extended to higher p_T region

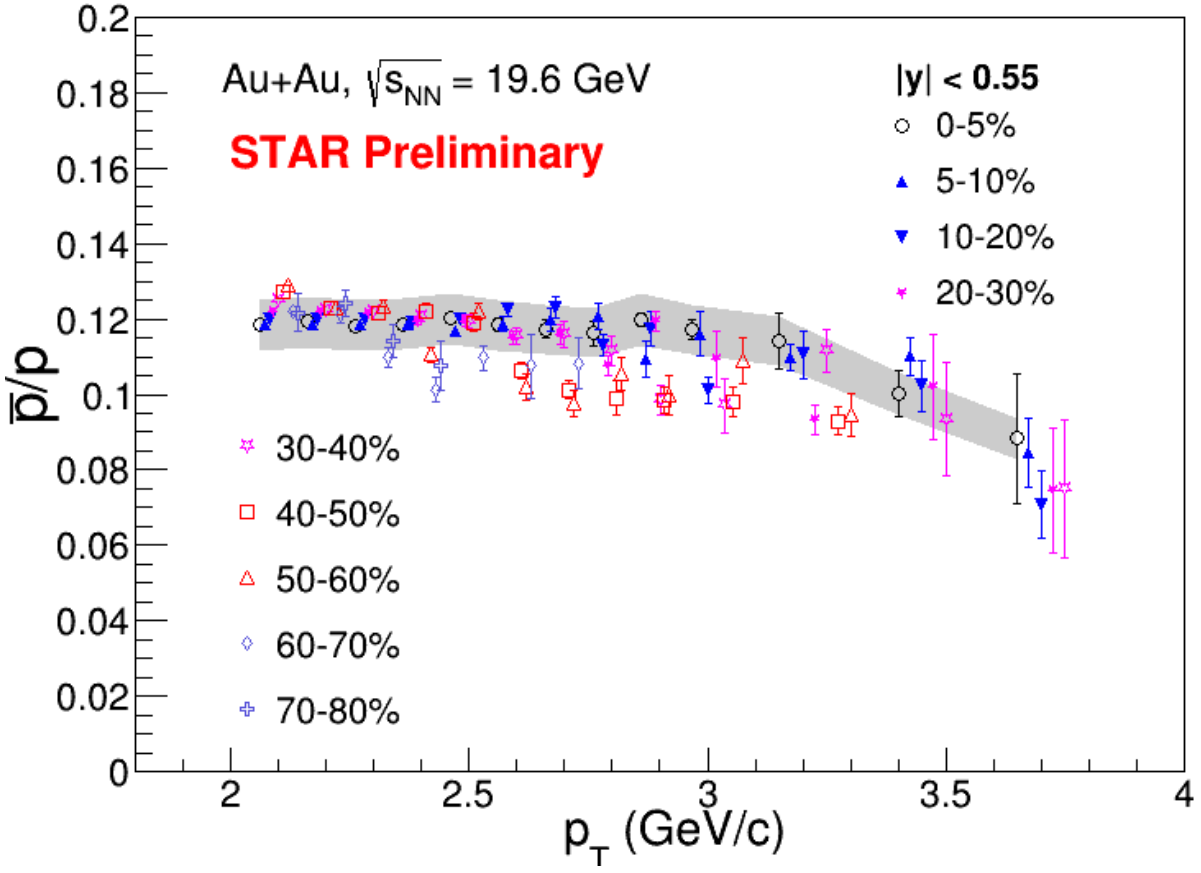
Statistical and systematic uncertainties are added in quadrature

Centrality dependence of particle ratio

No obvious centrality dependence within uncertainties in π^-/π^+ and $\bar{p}/p$ ratios



π^-/π^+ ratios slightly decrease at higher p_T



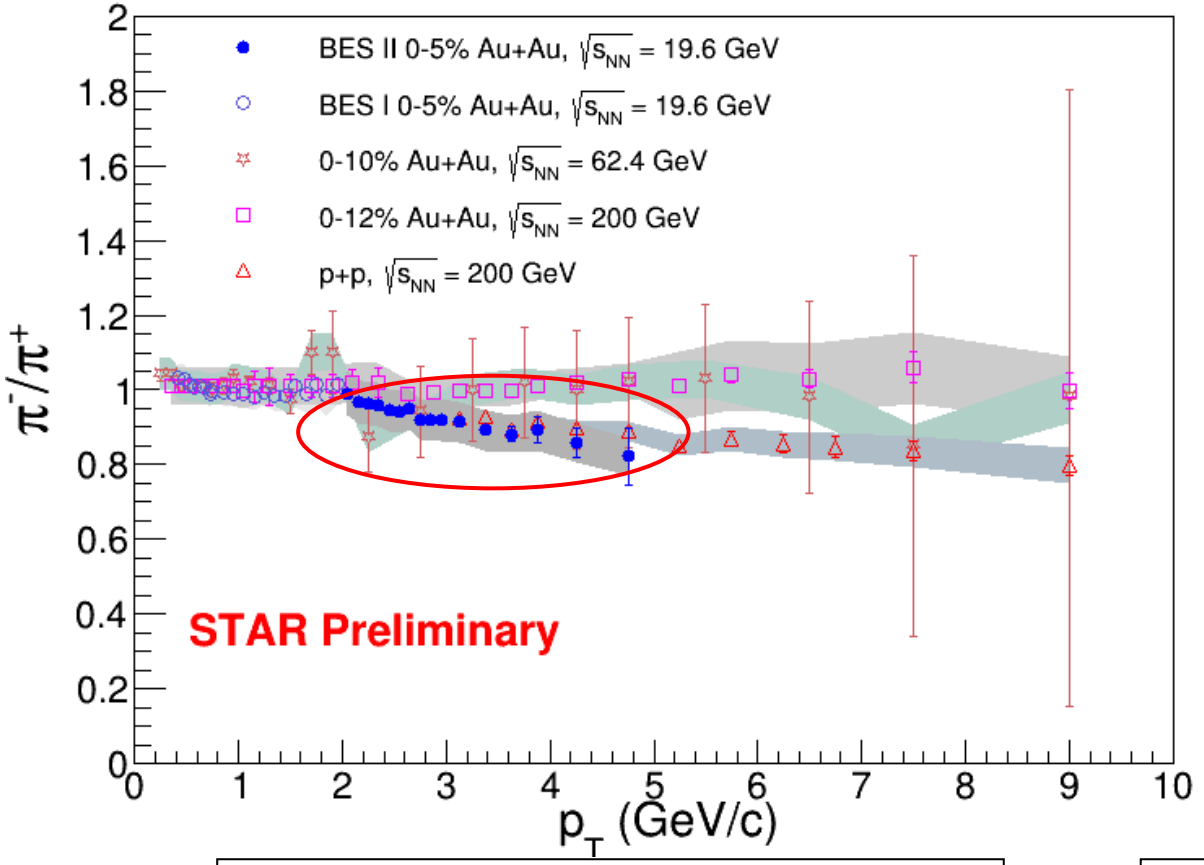
No obvious p_T dependence within uncertainties in $\bar{p}/p$ ratios

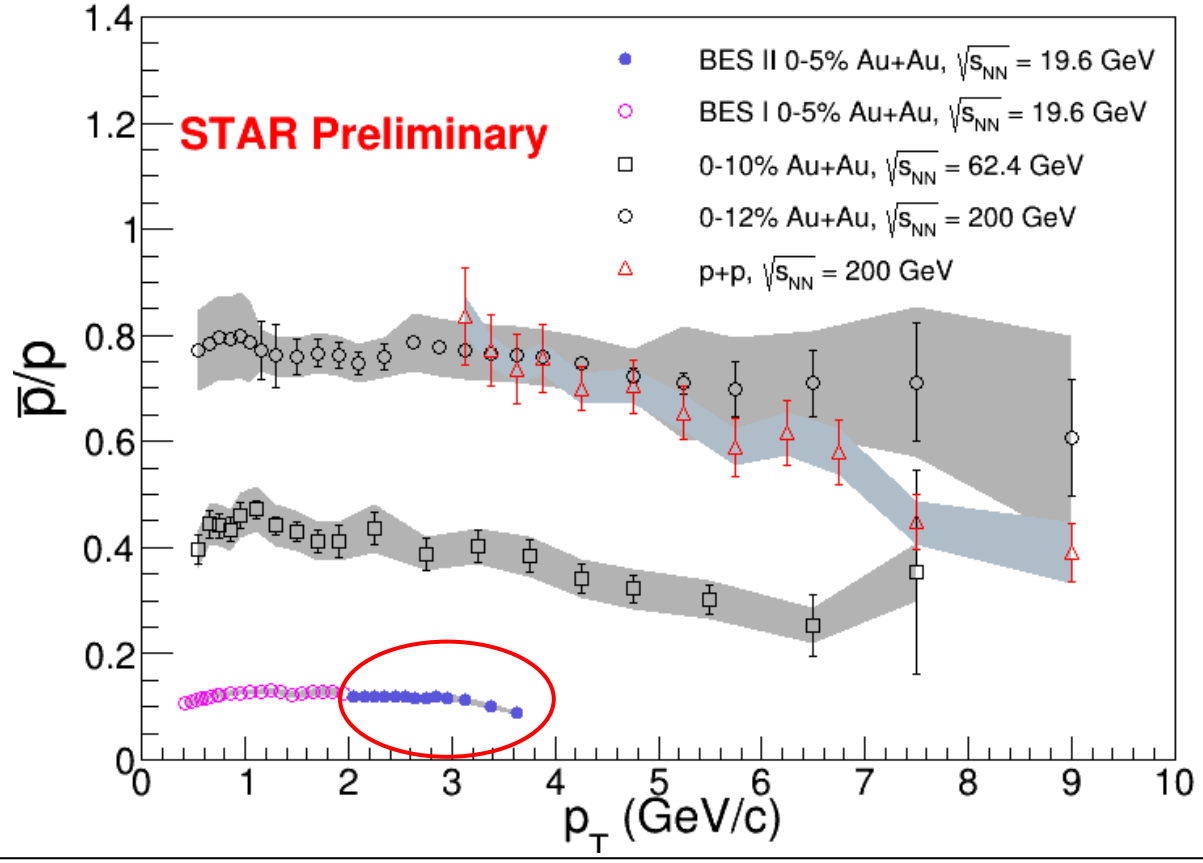
The shaded band only reflects the systematic uncertainties in 0-5% centrality class.

Collision energy dependence of particle ratios

The shaded band reflects the systematic uncertainties.

Need theoretical model prediction for Au+Au @19.6GeV





No obvious energy dependence within uncertainties in π^-/π^+ ratios

$\bar{p}/p$ ratio decrease with decreasing collision energy: different contribution from jet fragmentation and/or constituent quark coalescence/recombination and/or baryon junctions to spectra of different collision energy at higher p_T

STAR BESII new data achieved high precision for pion and proton spectra with $p_T > 2$ GeV/c

Extract kinetic freeze-out properties with TBW model

Non-extensive Tsallis statistics

$$\exp(-\frac{m_T}{T}) \Rightarrow [1+\frac{(q-1)m_T}{T}]^{-1/(q-1)}$$

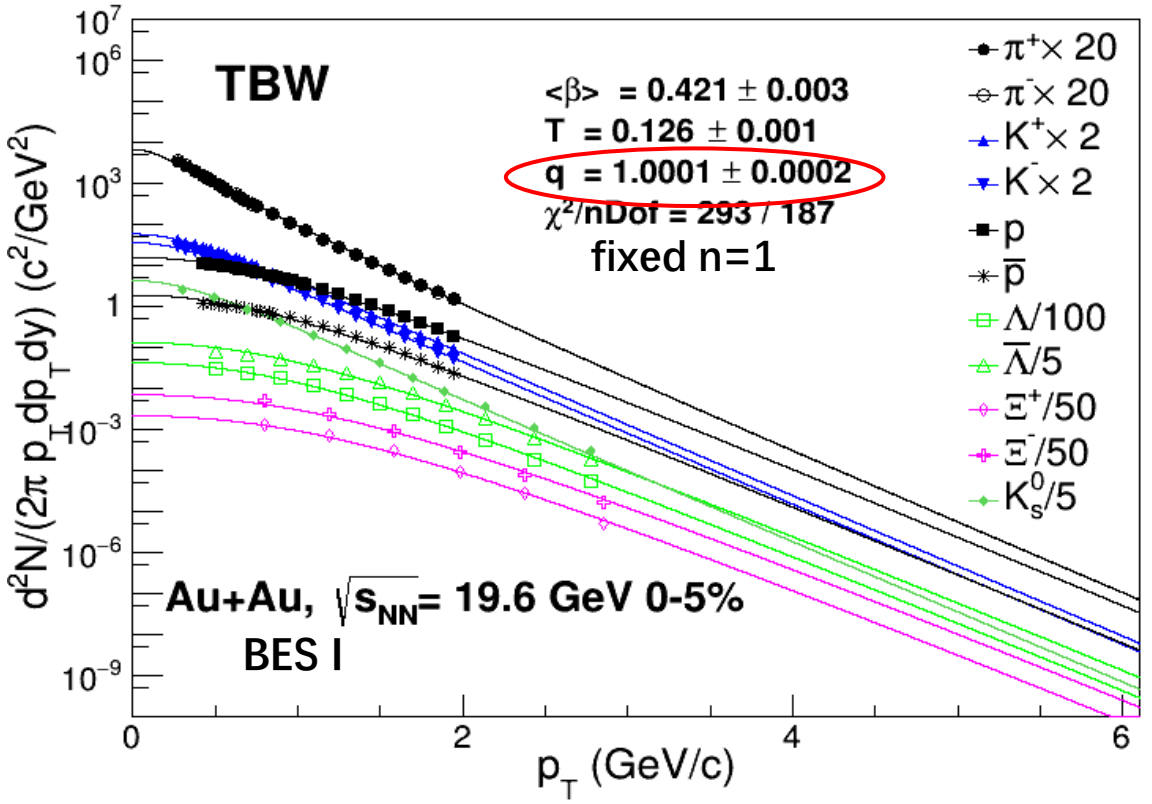
Particle spectra in TBW:

$$\frac{dN}{m_T dm_T} \propto m_T \int_{-Y}^{+Y} \cosh(y)dy \int_{-\pi}^{+\pi} d\phi \int_0^R rdr$$

$$\{1+\frac{q-1}{T}[m_T \cosh(y)\cosh(\rho) - p_T \sinh(\rho)\cos(\phi)]\}^{-1/(q-1)}$$

$$\beta(r) = \beta_S(\frac{r}{R})^n \qquad \text{fixed n=1}$$

Radial flow velocity <β>, Temperature and nonequilibrium degree (q−1) determined by fit to spectra



Uncertainties on experimental data represent quadratic sums of statistical and systematic uncertainties

G. Wilk et al. EPJA 40, 299 (2009)

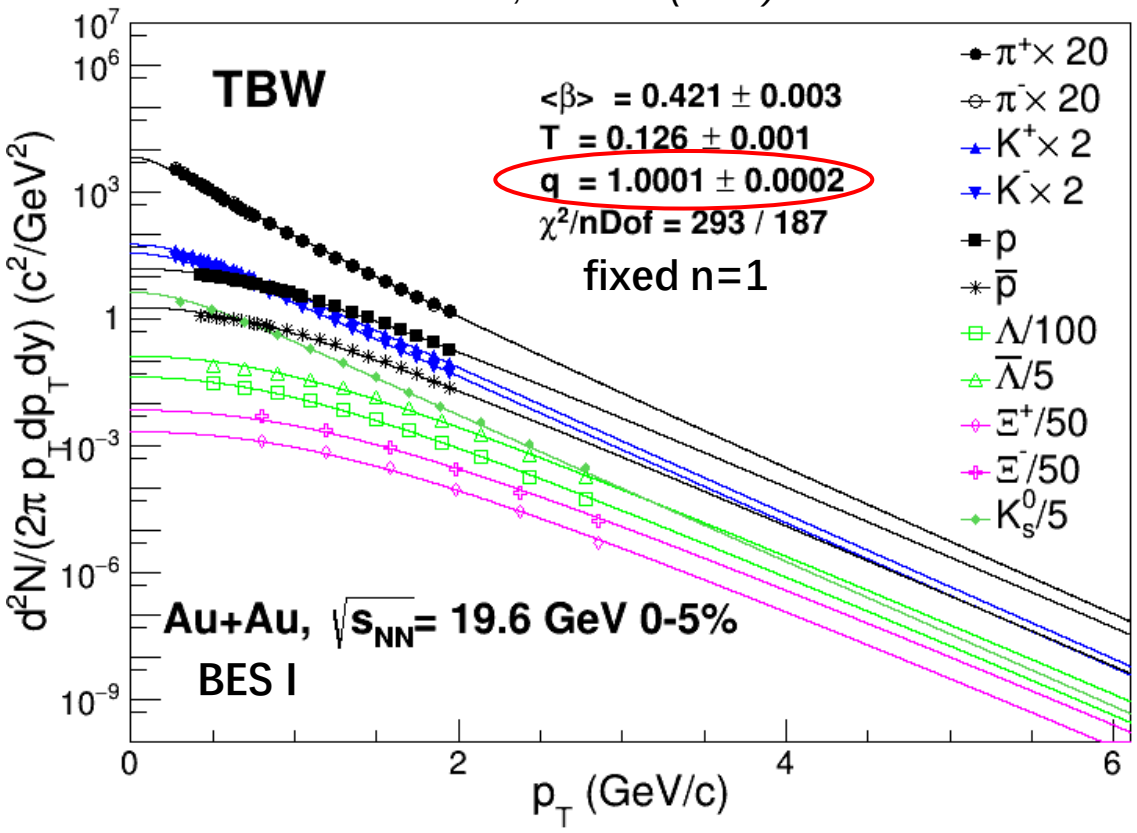
C. Tsallis, J. Stat. Phys. 52, 479 (1988)

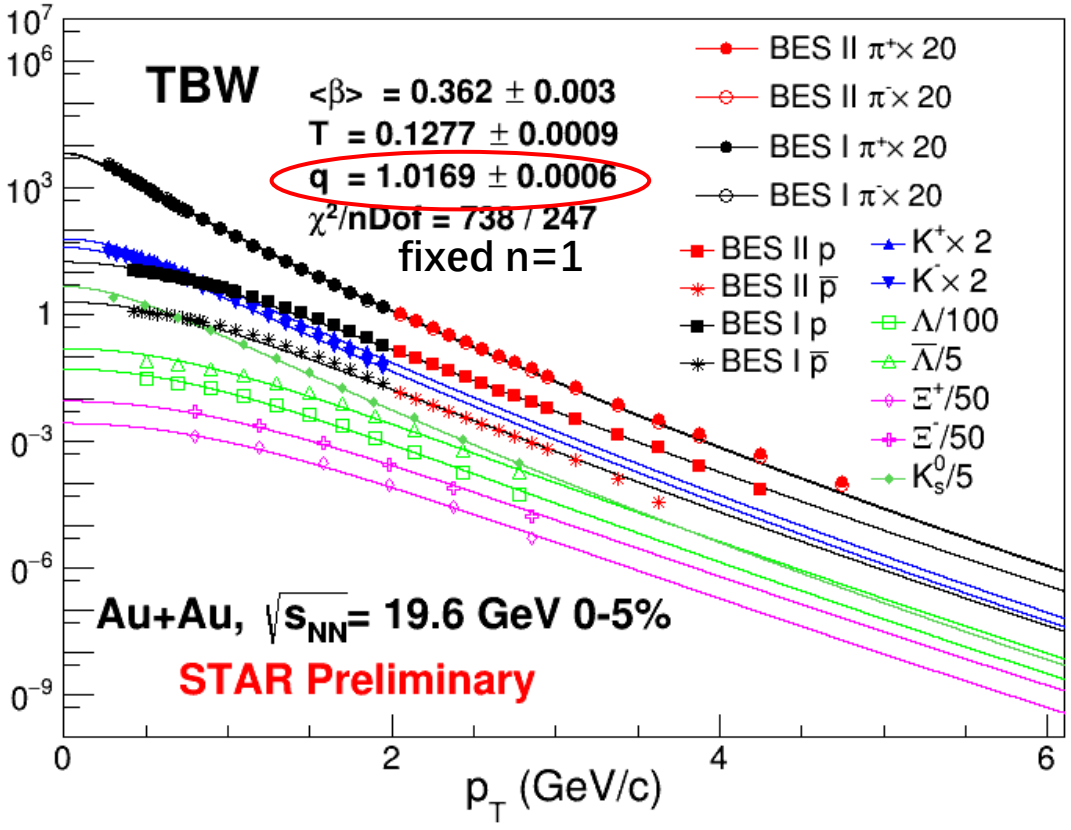
Z. Tang et al. *PRC 79, 051901 (R) (2009)*

J. Chen et al. PRC 104, 034901 (2021)

Extract kinetic freeze-out properties with TBW model

STAR PRC 96, 044904 (2017)
J. Chen et al. PRC 104, 034901 (2021)





STAR BESI results only

STAR BESI and BESII (pion and proton spectra with $p_T > 2$ GeV/c) results

STAR BESII new data achieved high precision for pion and proton spectra with $p_T > 2$ GeV/c

Larger nonequilibrium degree (q−1): sizable contribution to the pion and proton spectra at higher p_T from non-equilibrium source

Summary

- New measurement of $\pi^{\pm}$ and $p(\bar{p})$ spectra at higher p_T are performed in Au+Au collisions at 19.6 GeV with BESII data.
- The p_T and energy dependence of particle ratios are studied.
  - π^-/π^+ ratio slightly decrease at higher p_T and no obvious p_T dependence in $\bar{p}/p$ ratios.
  - No obvious energy dependence for π^-/π^+ ratios and $\bar{p}/p$ ratio is found to decrease with decreasing collision energy.
- Study the kinetic freeze-out properties with this new measurement at higher p_T region.
  - Sizable contribution to the pion and proton spectra at higher p_T from non-equilibrium source.

Thank You

Back up

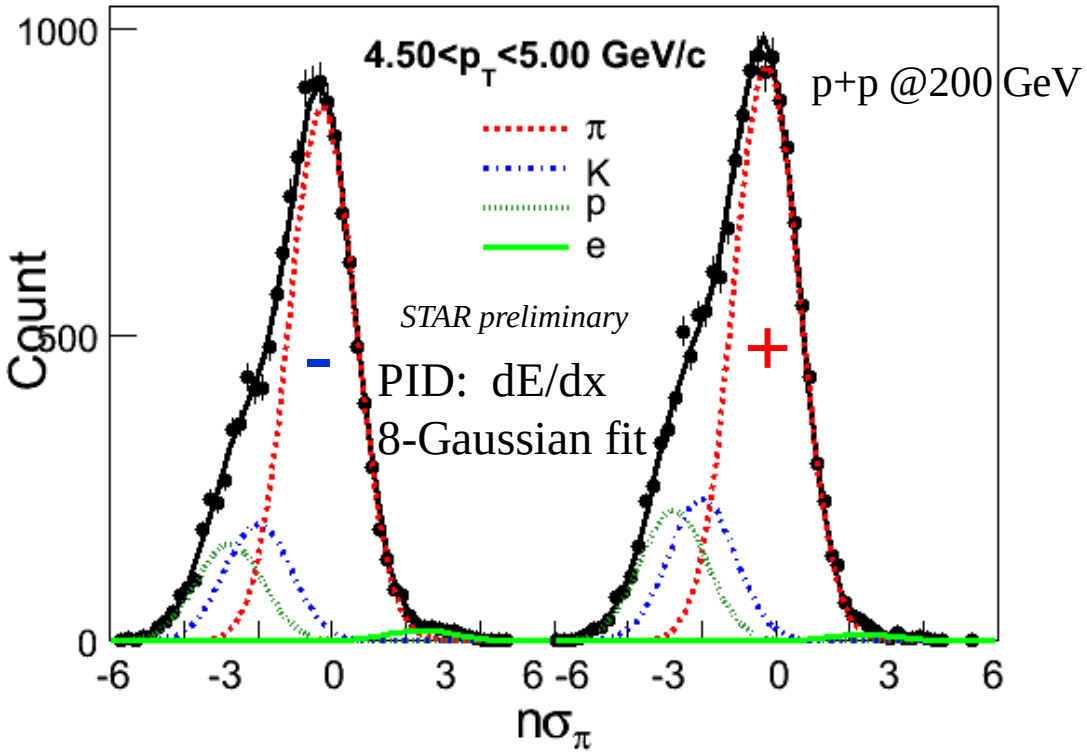
Analysis overview

Goal: $\pi^{\pm}$, $p(\bar{p})$ spectra and ratio
Collision : Au+Au @19.6 GeV
Year: 2019
Trigger : Minimum Bias
Statistics: ~600 Million events
Transverse momenta of measurement: TPC
PID : $\pi^{\pm}$:TPC with TOF cuts
$p(\bar{p})$:TOF with TPC cuts

dE/dx re-calibration needed!

Improvement on TPC PID

Yichun Xu et al. NIMA 614:28-33 (2010)



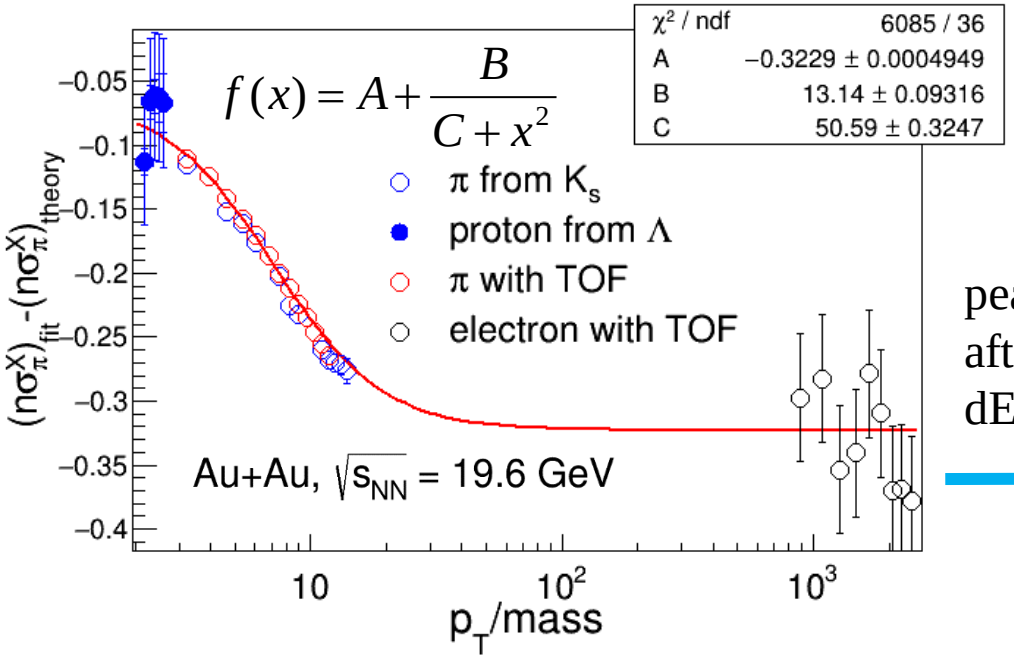
$$n\sigma_{\pi}^{X} = \frac{\log((dE/dx)_X / B_{\pi})}{\sigma_{\pi}}$$

B_{π} : <dE/dx> from the Bichsel function.
However, <dE/dx> deviate from the theoretical value.

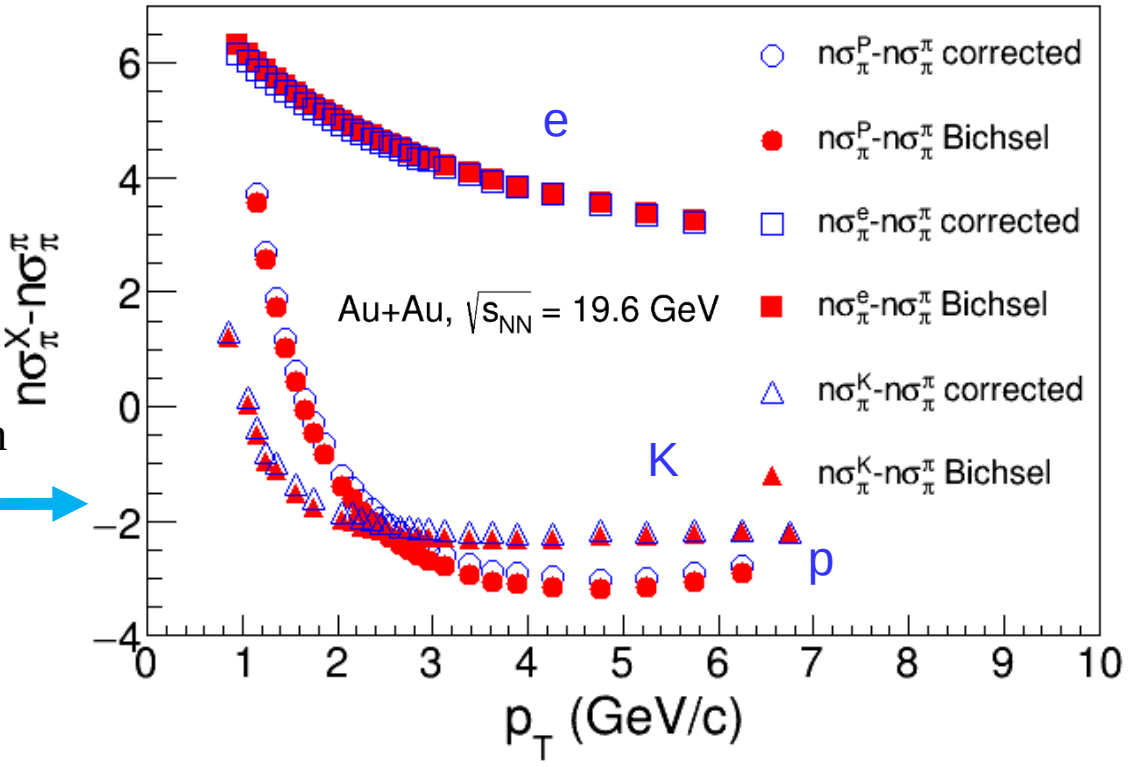
dE/dx re-calibration

Our method: pure particle sample to correct dE/dx peak position.

dE/dx deviation vs p_T /mass:



peak position after correcting dE/dx deviation



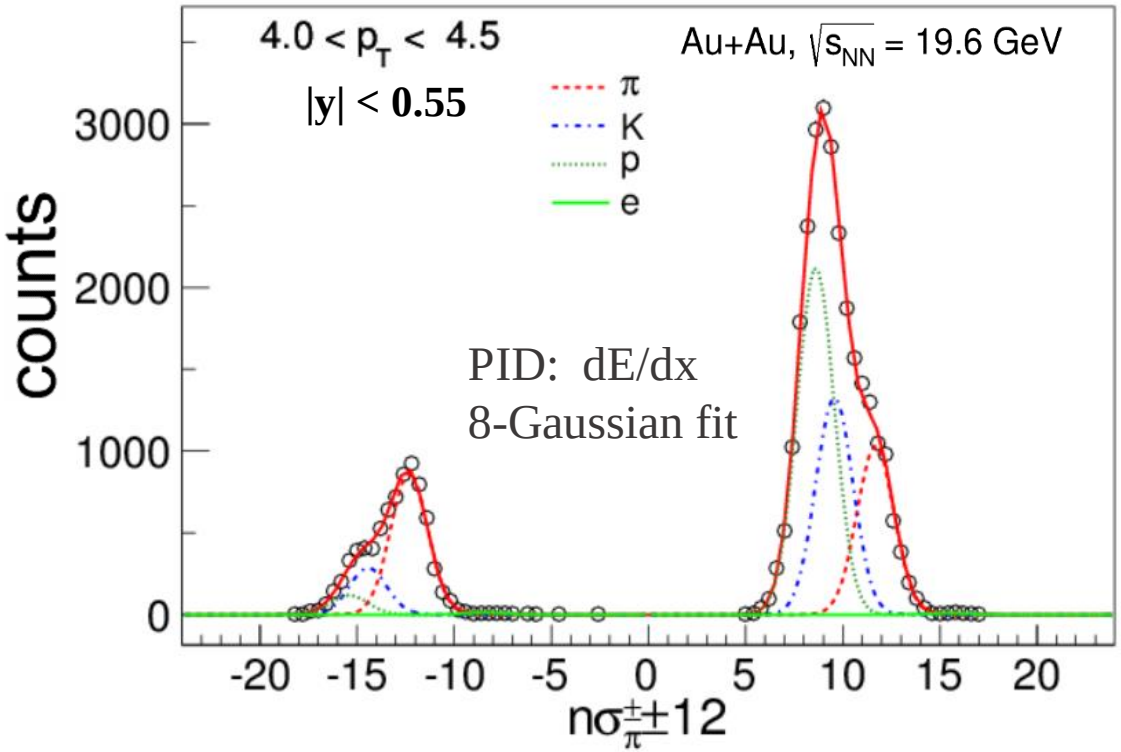
$n\sigma_\pi^X$ from pure sample:

- Pure proton and pion from (Λ,K_S) decay
- Pure electron and pion from TPC and TOF selection

Signal extraction with TPC and TOF

Pion PID : TPC with TOF

π yield from $n\sigma_\pi$ distribution after TOF π Cut $\left|\frac{1}{\beta}-\sqrt{\frac{m_\pi^2}{p^2}+1}\right|<0.03$



$$n\sigma_X = \frac{1}{\sigma_X}\log\frac{(dE/dx)_{measured}}{< dE/dx >_X}$$

Proton PID: TOF with TPC

Proton raw yield from mass square of TOF:
Student-T function Fit after TPC $n\sigma_{\text{proton}}$ < 1 Cut