$K^*(892)$ meson production in heavy and small collision systems at $\sqrt{s_{NN}} = 200$ GeV

S. Antsupov[1], Ya.Berdnikov[1], D.Kotov[1], D.Larionova[1] for the PHENIX collaboration

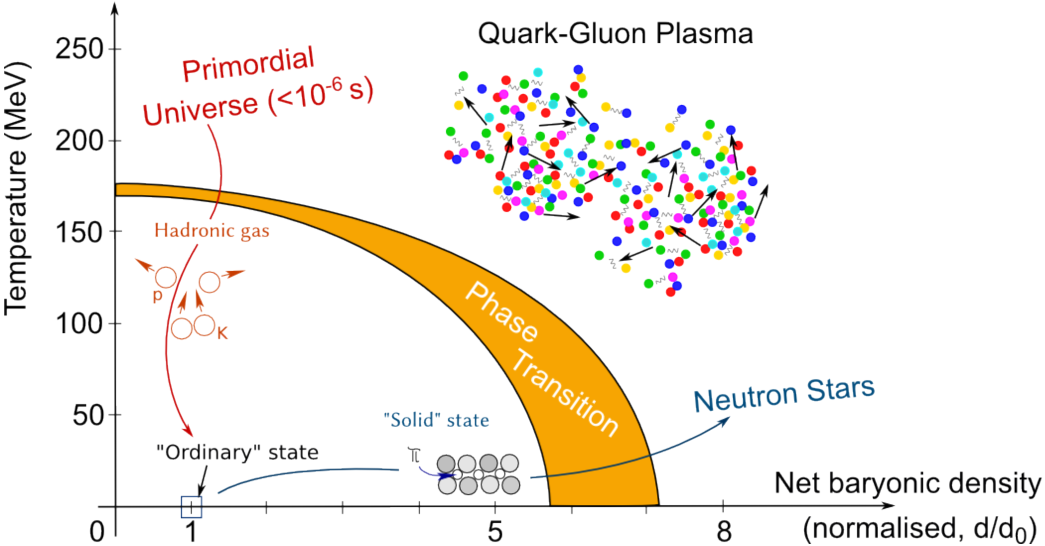
[1]Peter the Great St.Petersburg Polytechnic University

July 2, 2025

We acknowledge support from Russian Ministry of Education and Science, state assignment for fundamental research (code FSEG-2025-0009)

A Physics Experiment at RHIC

Introduction



Introduction

Strangeness enhancement

The gluon density in QGP is higher than in hot hadronic gas. This increased density enhances the production of strange quarks through the process of gluon fusion.

Jet quenching

High-energy partons that make up jets lose energy more efficiently when passing through QGP compared to hot hadronic gas. This increased energy loss results in a decrease in the production of particles with high transverse momentum p_T.

Both strangeness enhancement and jet quenching are expected to be observed in heavy collision systems at $\sqrt{s_{NN}} = 200$ GeV. This is due to energy densities greatly surpassing QGP phase transition threshold estimates.

Central collisions of small systems at $\sqrt{s_{NN}} = 200$ GeV are expected to reach energy densities just above the QGP phase transition threshold. This is why QGP is expected to be produced at least in a form of small droplets. Therefore small collisions serve as important probe for the determination of minimum conditions required for the formation of QGP. In such collisions strangeness enhancement and jet quenching are expected to manifest even if small amount QGP is created.

$K^*(892)$ quark content

$K^{*0}(892) - u\bar{s}$
$\bar{K}^{*0}(892) - \bar{u}s$

$K^*(892)$ lifetime

$\approx 1.3 \cdot 10^{-23} s$

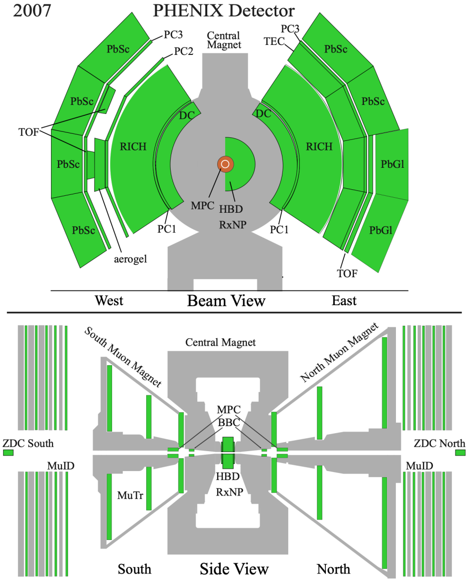
$K^*(892)$ decay mode

$K^{*0}(892) \to \pi^{\pm} K^{\mp}$
$\bar{K}^{*0}(892) \to \pi^{\pm} K^{\mp}$

Analysis workflow

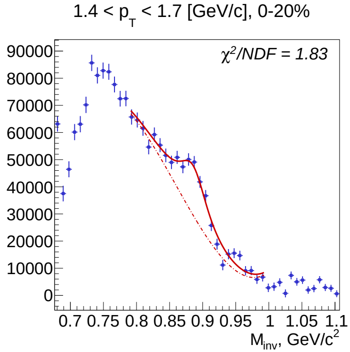
1. Extraction of charged hadrons from the raw data from PHENIX experiment.
2. Formation of invariant mass distribution from extracted charged hadrons and extraction of the signal of $K^*(892)$.
3. Estimation of $K^*(892)$ reconstruction efficiency using Monte-Carlo (MC).
4. Estimation of $K^*(892)$ invariant p_T spectra, R_{AB}, R_{CP}.

Experimental apparatus

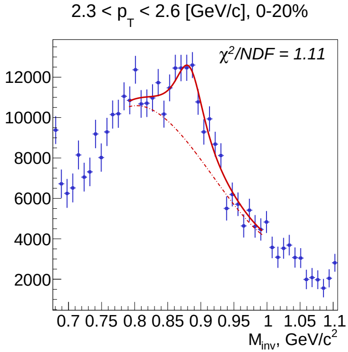


- BBC and ZDC detectors were used for the determination of even centrality
- DC-PC1 subsystem was used for reconstruction of tracks of charged particles and their momenta
- TOFe, TOFw, EMCal (PbSc) were used for particle identification via the time-of-flight measurements
- PC3, PC2, TOFe, TOFw, EMCal (PbSc, PbGl) were used for improved tracking of charged particles

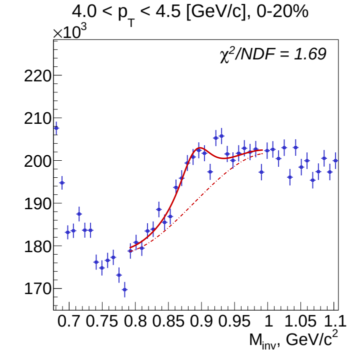
$K^*(892)$ signal extraction in Au+Au@200



(a) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $1.4 < p_T < 1.7$ range



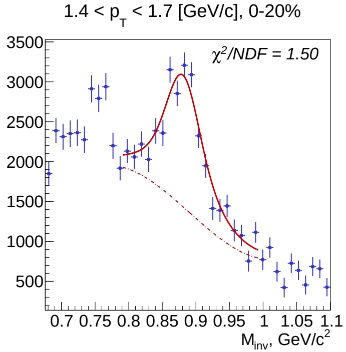
(b) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $2.3 < p_T < 2.6$ range



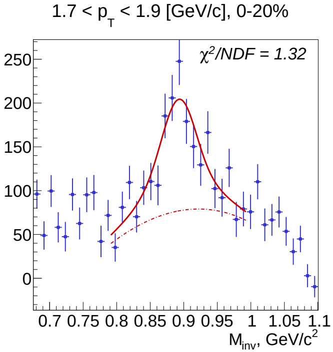
(c) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $4.0 < p_T < 4.5$ range

- Red solid line - foreground (Relativistic Breit-Wigner) + background approximation
- Red dashed line - background approximation

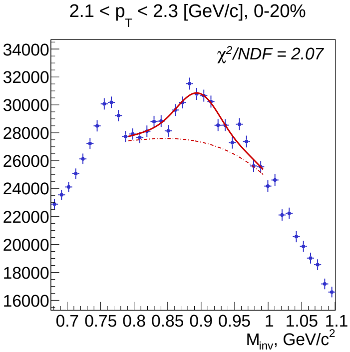
$K^*(892)$ signal extraction in He+Au@200



(a) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $1.4 < p_T < 1.7$ range



(b) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $1.4 < p_T < 1.7$ range



(c) $K^{\pm}\pi^{\pm}$ invariant mass distribution in 0-20% centrality class in $1.9 < p_T < 2.1$ range

- Red solid line - foreground (Relativistic Breit-Wigner) + background approximation
- Red dashed line - background approximation

$K^*(892)$ invariant p_T spectra estimation

Reconstruction efficiecny was estimated using Monte-Calro (MC) with the following formula:

$$\epsilon = \frac{N_{reconstructed}}{N_{generated}} \tag{1}$$

Where

- $N_{generated}$ - number of generated $K^*(892)$ particles in MC,
- $N_{reconstructed}$ - number of reconstructed $K^*(892)$ particles in MC.

We then estimated the $K^*(892)$ invariant p_T spectra with the use of the following formula:

$$\frac{1}{2\pi p_T}\frac{d^2N}{dydp_T} = \frac{1}{2\pi p_T \epsilon}\frac{d^2Y_{raw}}{dydp_T} \tag{2}$$

Where

- Y_{raw} - raw yield of $K^*(892)$ in the experiment,
- y - rapidity.

$K^*(892)$ invariant p_T spectra in Au+Au@200 and He+Au@200

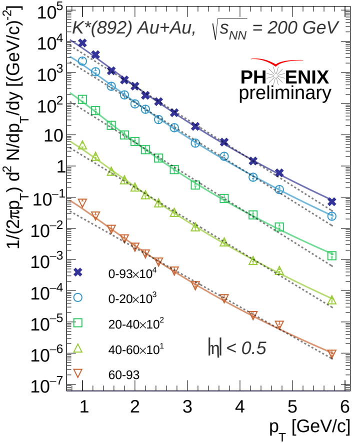


Figure: $K^*(892)$ invariant p_T spectra in Au+Au at $\sqrt{s_{NN}} = 200$ GeV. Dashed lines - exponential fits, solid lines - Levy fits.

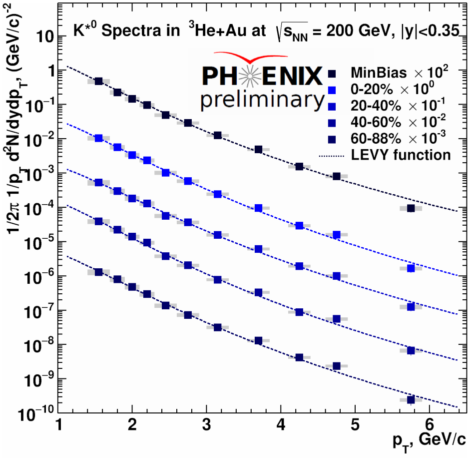


Figure: $K^*(892)$ invariant p_T spectra in He+Au at $\sqrt{s_{NN}} = 200$ GeV.

Au+Au@200: $0.9 < p_T < 6.5$ GeV/c
He+Au@200: $1.4 < p_T < 6.5$ GeV/c
Au+Au@200 & HeAu@200: 5 centrality classes

Nuclear modification factors R_{AB} estimation

We estimated $K^*(892)$ R_{AB} with the use of the following formula:

$$R_{AB} = \frac{1}{N_{coll}} \frac{1/2\pi p_T \; d^2N_{AB}/dydp_T}{1/2\pi p_T \; d^2N_{pp}/dydp_T} \tag{3}$$

Where

- N_{coll} - average number of nucleon-nucleon collisions in A+B collision,
- $1/2\pi p_T \; d^2N_{AB}/dydp_T$ - invariant p_T spectra in A+B collision,
- $1/2\pi p_T \; d^2N_{pp}/dydp_T$ - invariant p_T spectra in p+p collision.

Nuclear modification factors R_{AB} in Au+Au and He+Au at $\sqrt{s_{NN}} = 200$ GeV

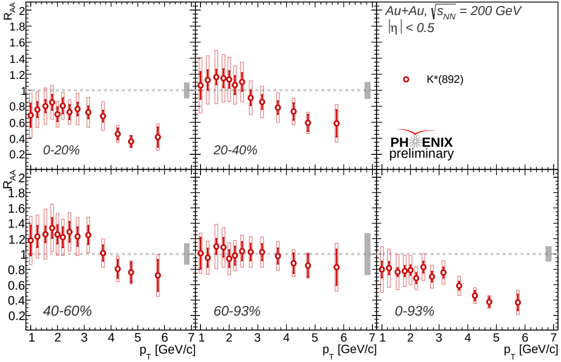


Figure: $K^*(892)$ R_{AA} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

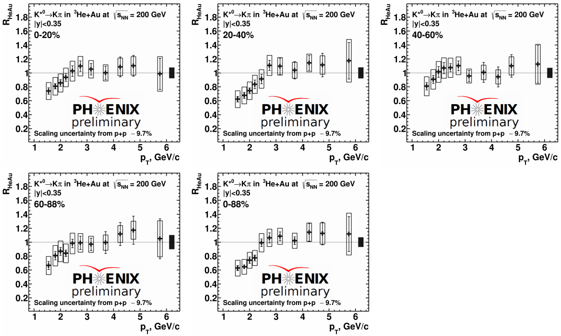


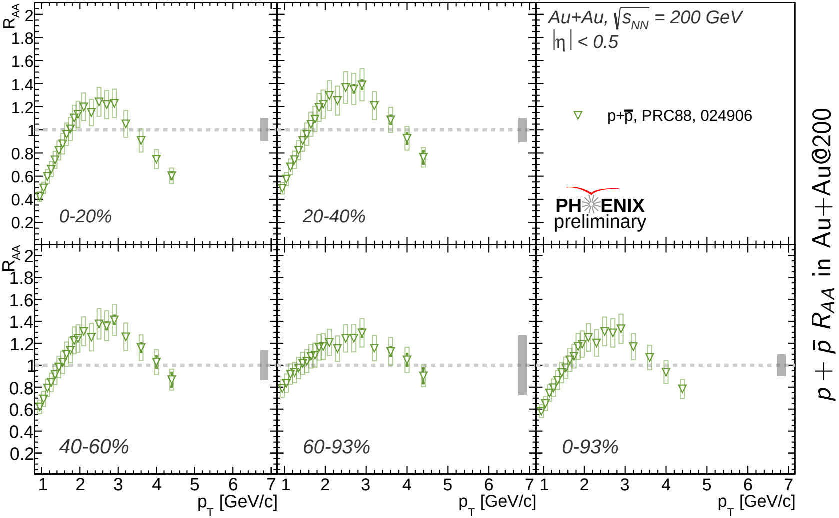
Figure: $K^*(892)$ R_{AB} in He+Au at $\sqrt{s_{NN}} = 200$ GeV

Au+Au@200: $0.9 < p_T < 6.5$ GeV/c

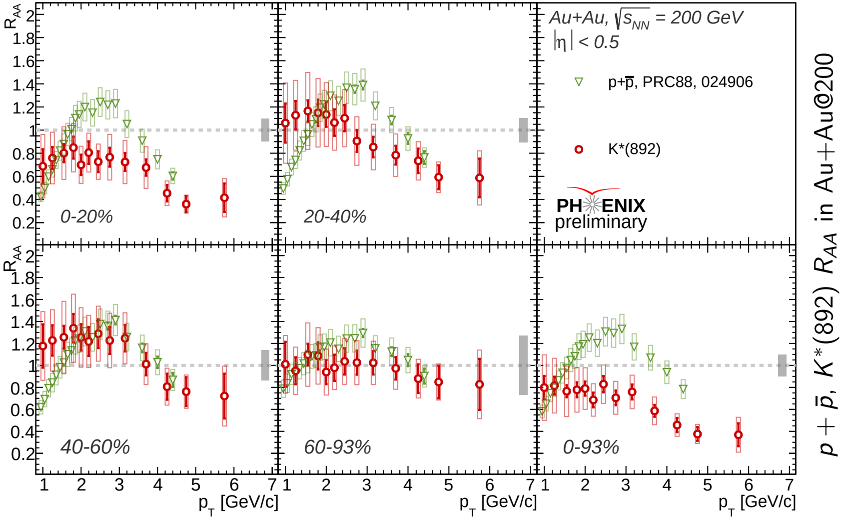
He+Au@200: $1.4 < p_T < 6.5$ GeV/c

Au+Au@200 & HeAu@200: 5 centrality classes

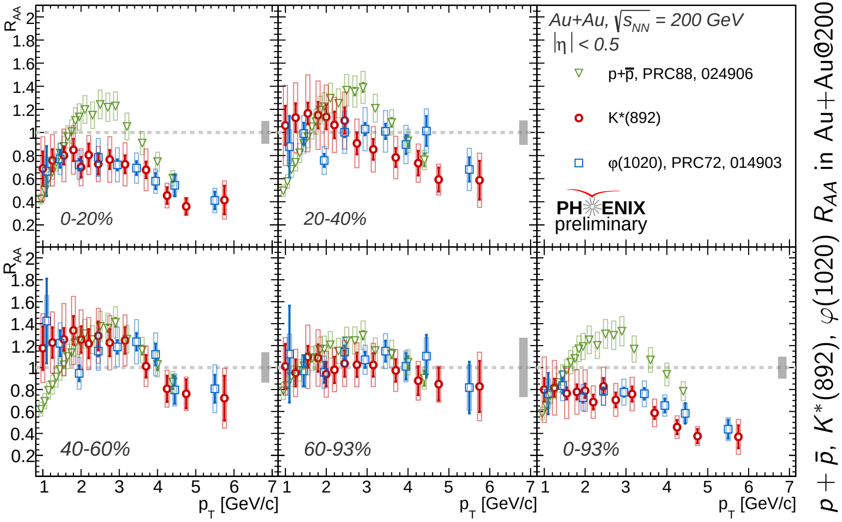
Nuclear modification factors R_{AA} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



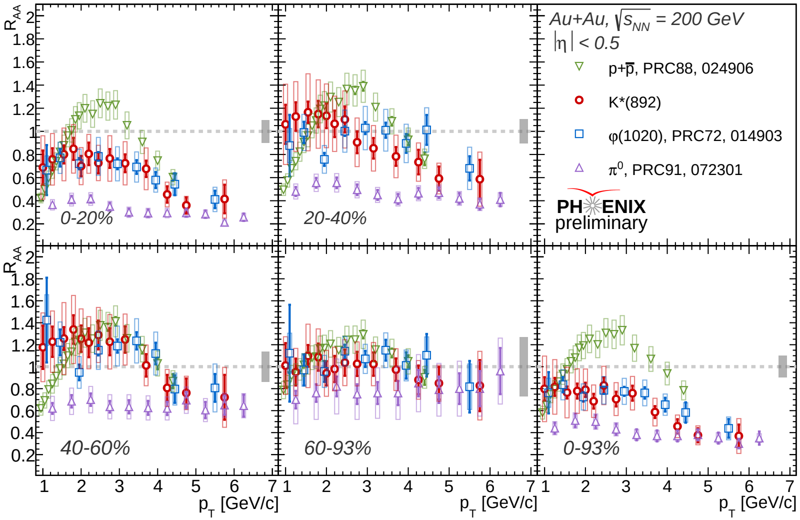
Nuclear modification factors R_{AA} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



Nuclear modification factors R_{AA} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

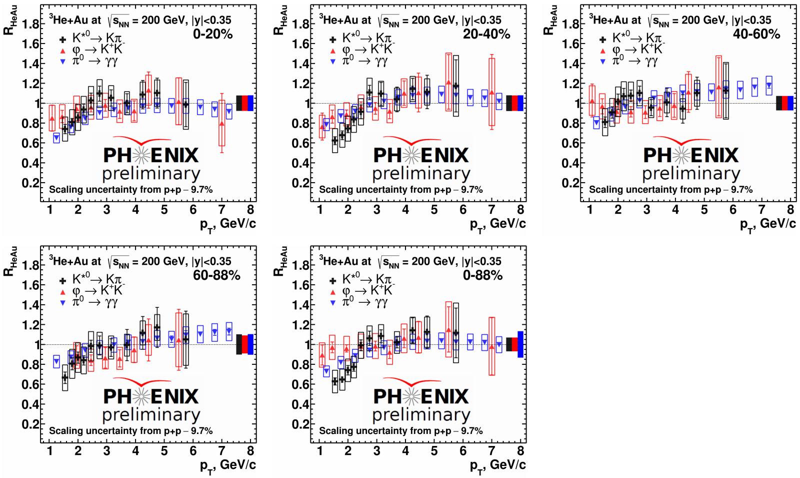


Nuclear modification factors R_{AA} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



$p+\bar{p}$, $K^*(892)$, $\varphi(1020)$, & π^0 R_{AA} in Au+Au@200

Nuclear modification factors R_{AB} in He+Au at $\sqrt{s_{NN}} = 200$ GeV



$K^*(892)$, $\varphi(1020)$, & π^0 R_{AB} in He+Au@200

Nuclear modification factors R_{CP} estimation

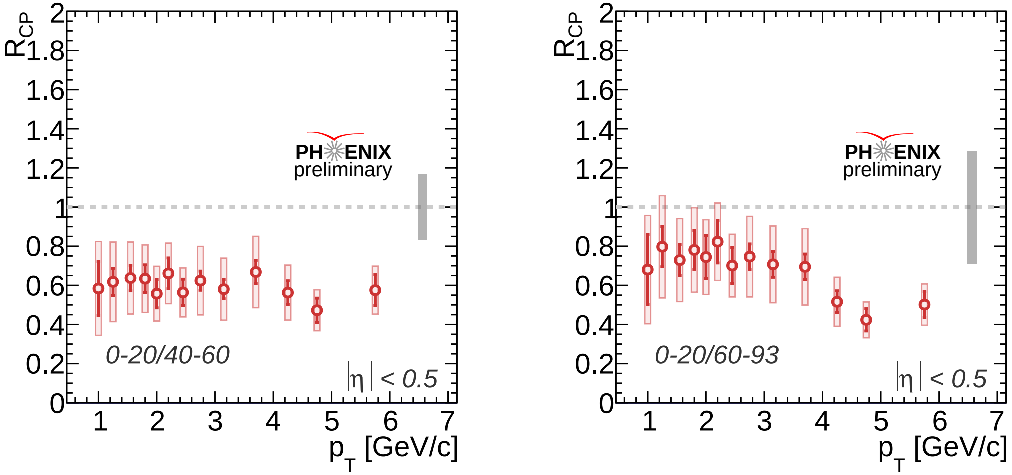
We estimated $K^*(892)$ R_{CP} with the use of the following formula:

$$R_{CP} = \frac{N_{coll}^{peripheral}}{N_{coll}^{central}} \frac{1/2\pi p_T \ d^2 N_{AB}^{central}/dydp_T}{1/2\pi p_T \ d^2 N_{AB}^{peripheral}/dydp_T} \quad (4)$$

Where

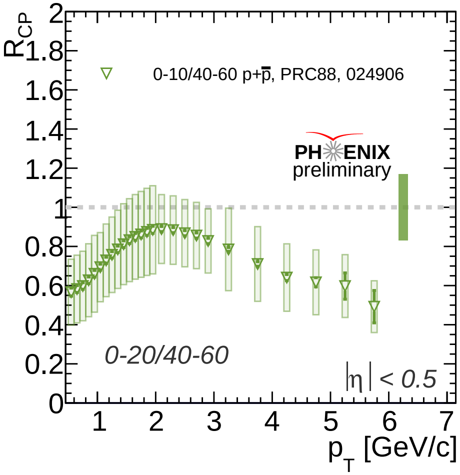
- $N_{coll}^{central}$, $N_{coll}^{peripheral}$ - average number of nucleon-nucleon collisions in A+B collision in central and peripheral centrality classes respectively,
- $1/2\pi p_T \ d^2 N_{AB}^{central}/dydp_T$, $1/2\pi p_T \ d^2 N_{AB}^{peripheral}/dydp_T$ - invariant p_T spectra in A+B collision in central and peripheral centrality classes respectively.

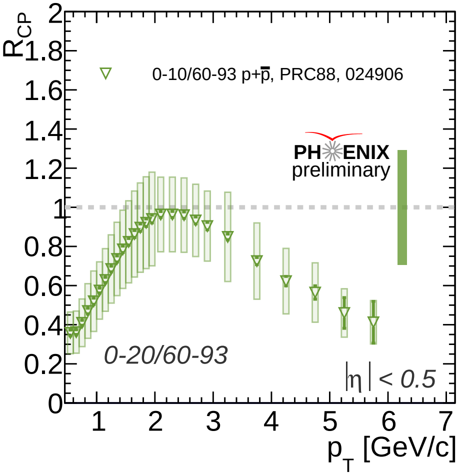
Nuclear modification factors R_{CP} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



$K^*(892)$ R_{CP} in Au+Au@200
Au+Au@200: $0.9 < p_T < 6.5$ GeV/c

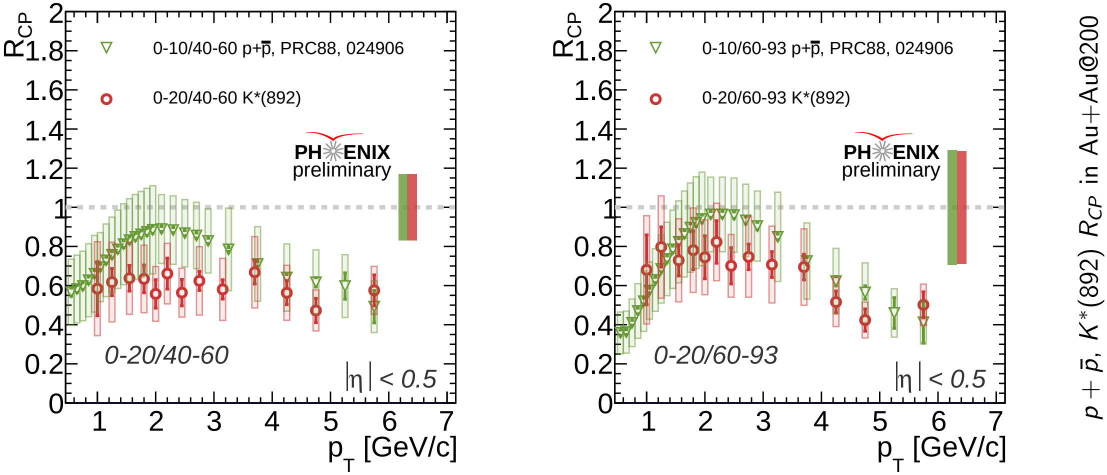
Nuclear modification factors R_{CP} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



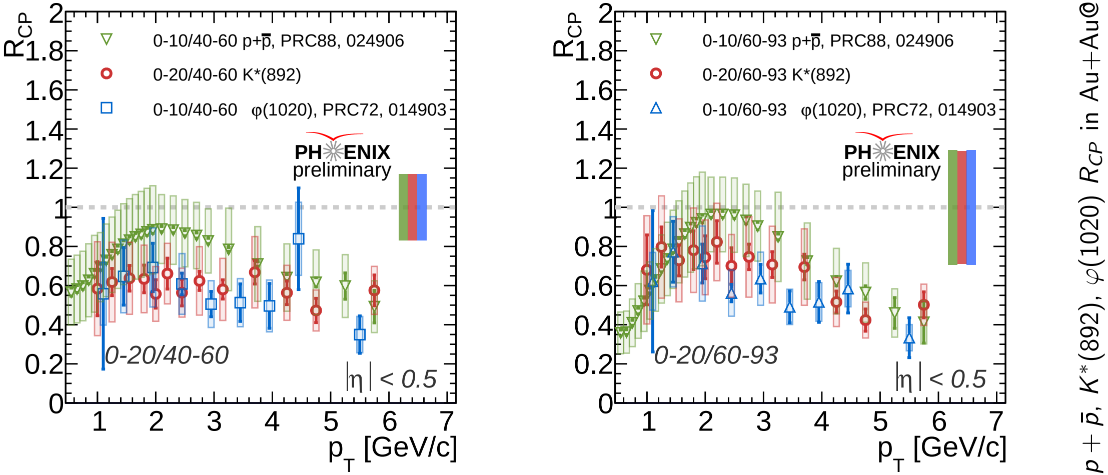


$p + \bar{p}$ R_{CP} in Au+Au@200

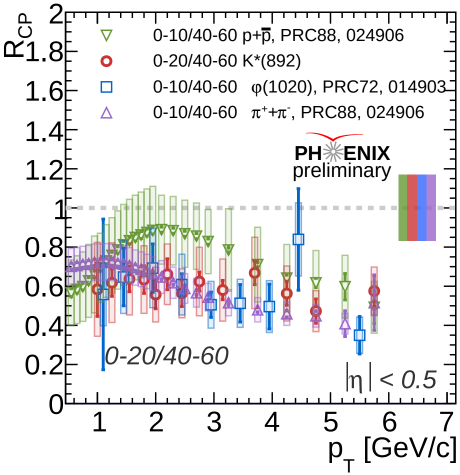
Nuclear modification factors R_{CP} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV

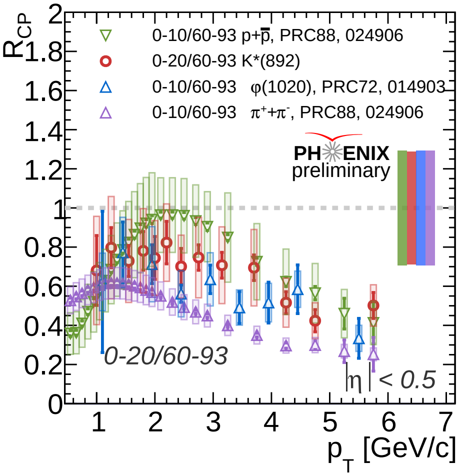


Nuclear modification factors R_{CP} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV



Nuclear modification factors R_{CP} in Au+Au at $\sqrt{s_{NN}} = 200$ GeV





$p+\bar{p}$, $K^*(892)$, $\varphi(1020)$, π^0 R_{CP} in Au+Au@200

Conclusions

- We observed that values of R_{AA} and R_{CP} for $K^*(892)$ and $\varphi(1020)$ are close and are mostly within uncertainties of each other thus the impact of effects of suppression and enhancement are similar for both $K^*(892)$ and $\varphi(1020)$.
- We observed the difference of R_{AA} and R_{CP} in Au+Au@200 between $K^*(892)$ and $p + \bar{p}$ which can be explained by the recombination models. This is because recombination models predict higher baryon yield than meson yield.
- We observed the difference of R_{AB} and R_{CP} in Au+Au@200 between $K^*(892)$ and π^0 which can also be explained by the recombination models. Recombination models predict thermal over shower partons recombination dominance for $K^*(892)$ and $\varphi(1020)$ up to 6 GeV/c in p_T due to the strangeness enhancement while the same dominance for π^0 only spans up to 3 GeV/c.
- We observed no significant difference of R_{AB} in He+Au@200 between $K^*(892)$ and π^0 even in the most central collisions, the values for both particles are mostly within uncertainties of each other. Therefore no conclusion on QGP formation can be made in He+Au@200.

Thank you for your attention!