The 39th Winter Workshop on Nuclear Dynamics

Identified charged hadron and ϕ-meson production in small and large collision systems

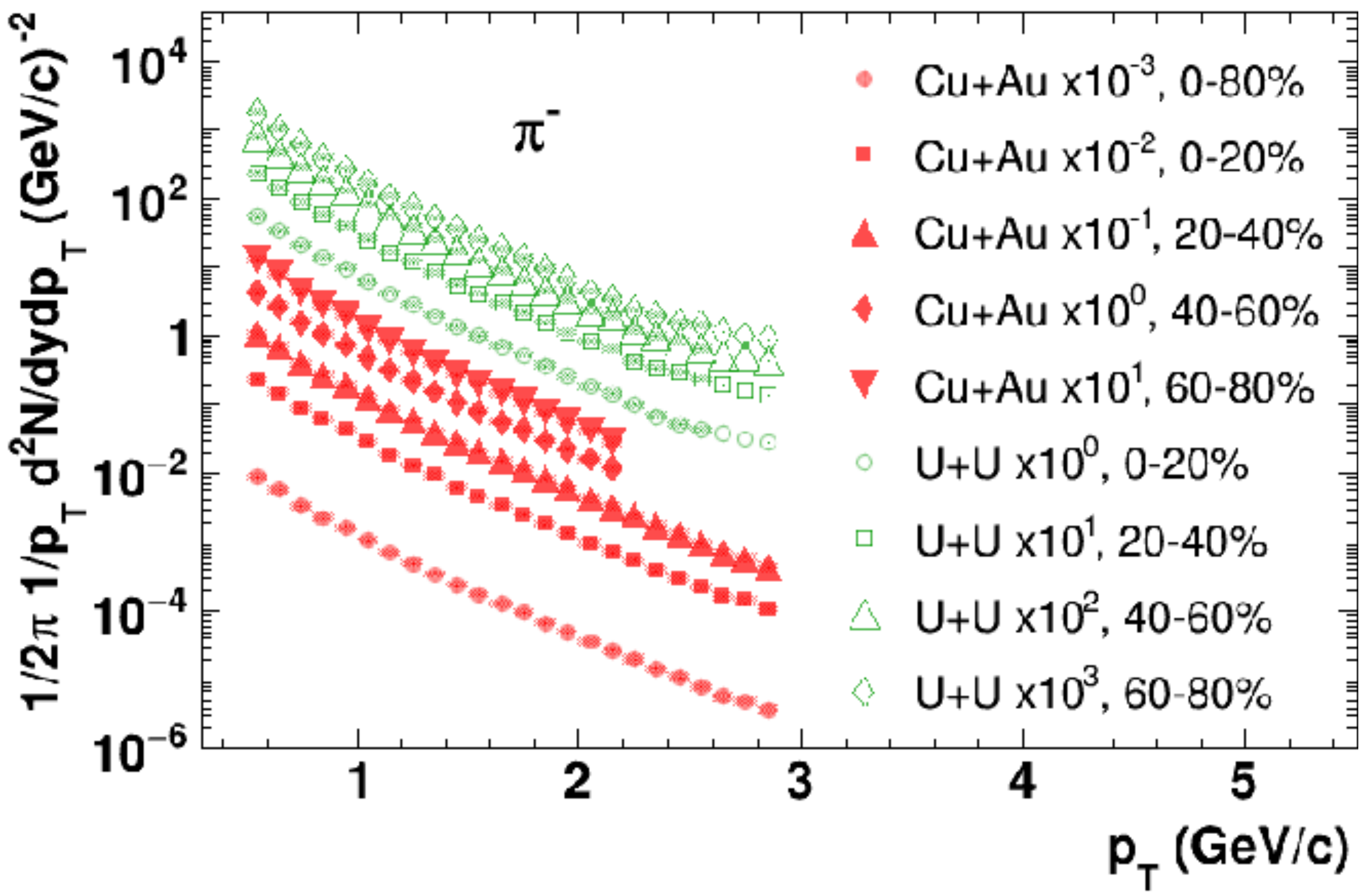
Vassu Doomra (for the PHENIX collaboration)
Stony Brook University

Stony Brook University

PHENIX

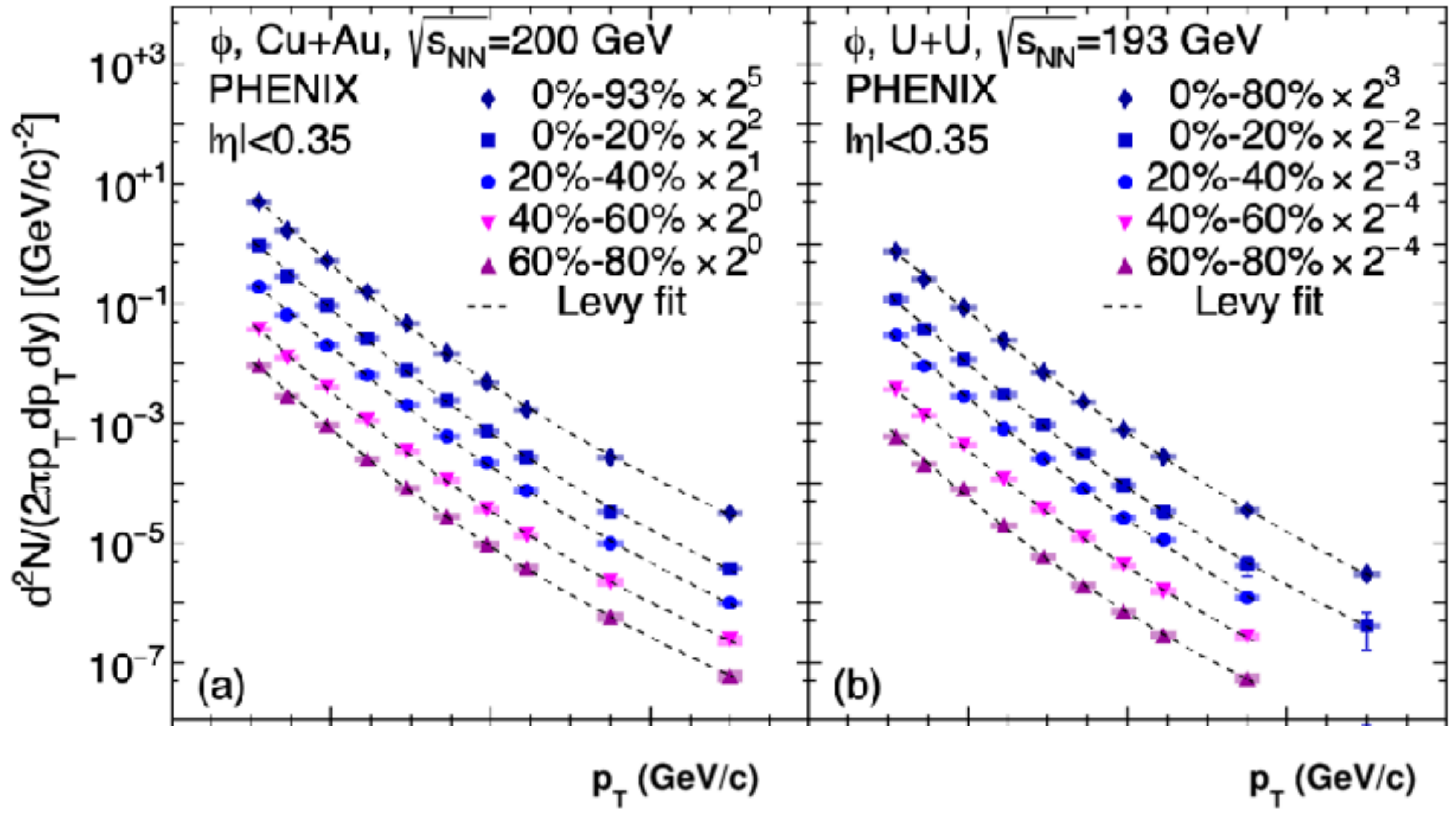
Index

- $\pi/K/p$ production in small and large collision systems



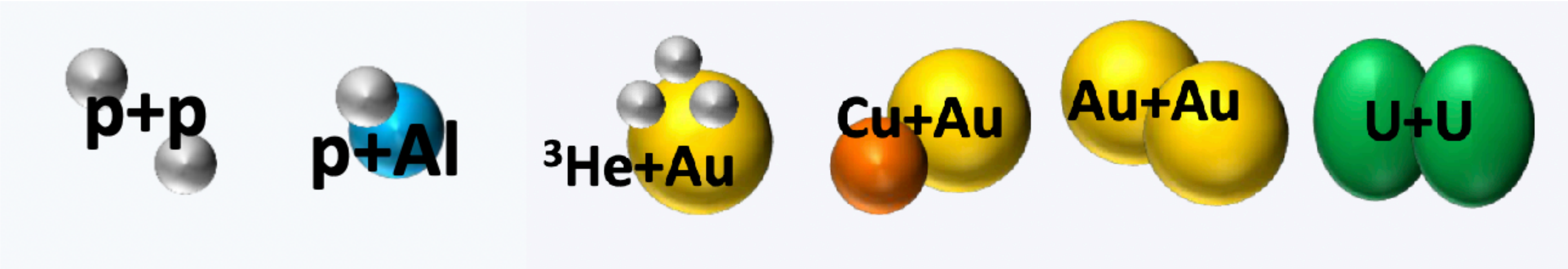
arXiv:2312.09827

- ϕ-meson production in small and large collision systems



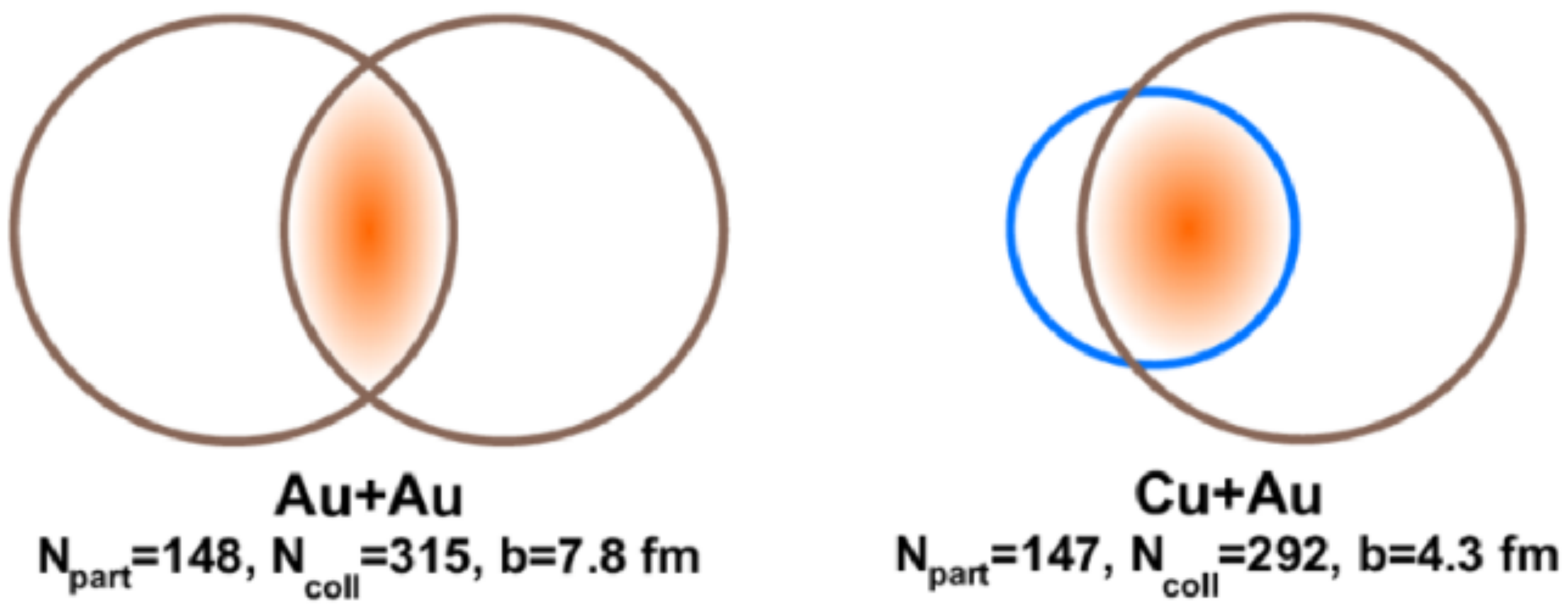
Phys. Rev. C 106, 014908 (2022)
Phys. Rev. C 107, 014907 (2023)

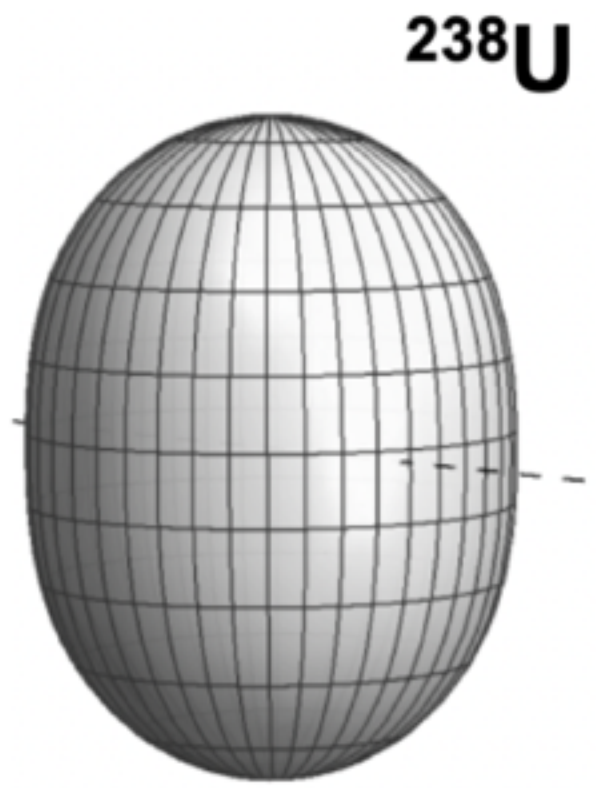
$\pi/K/p$ production in small and large collision systems



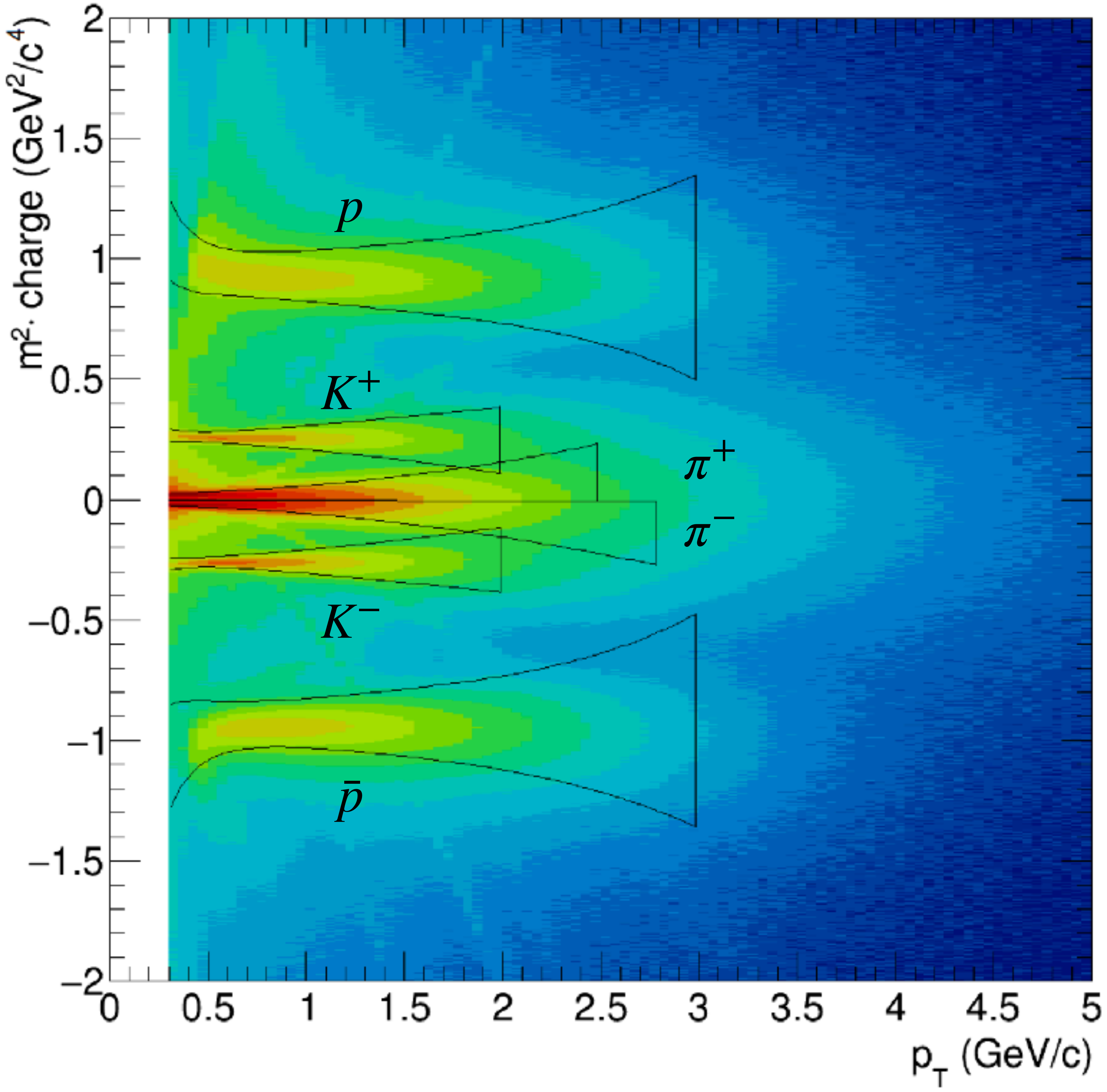
Cu+Au and U+U Collisions are special!

- Cu+Au —> asymmetric system of heavy nuclei.
- Collisions of uranium nuclei, which are highly deformed, provide different collision configurations depending on their orientation relative to the reaction plane.
- Comparing to symmetric systems, the nuclear-overlap region in Cu+Au and U+U collisions has additional asymmetry along the impact-parameter orientation.



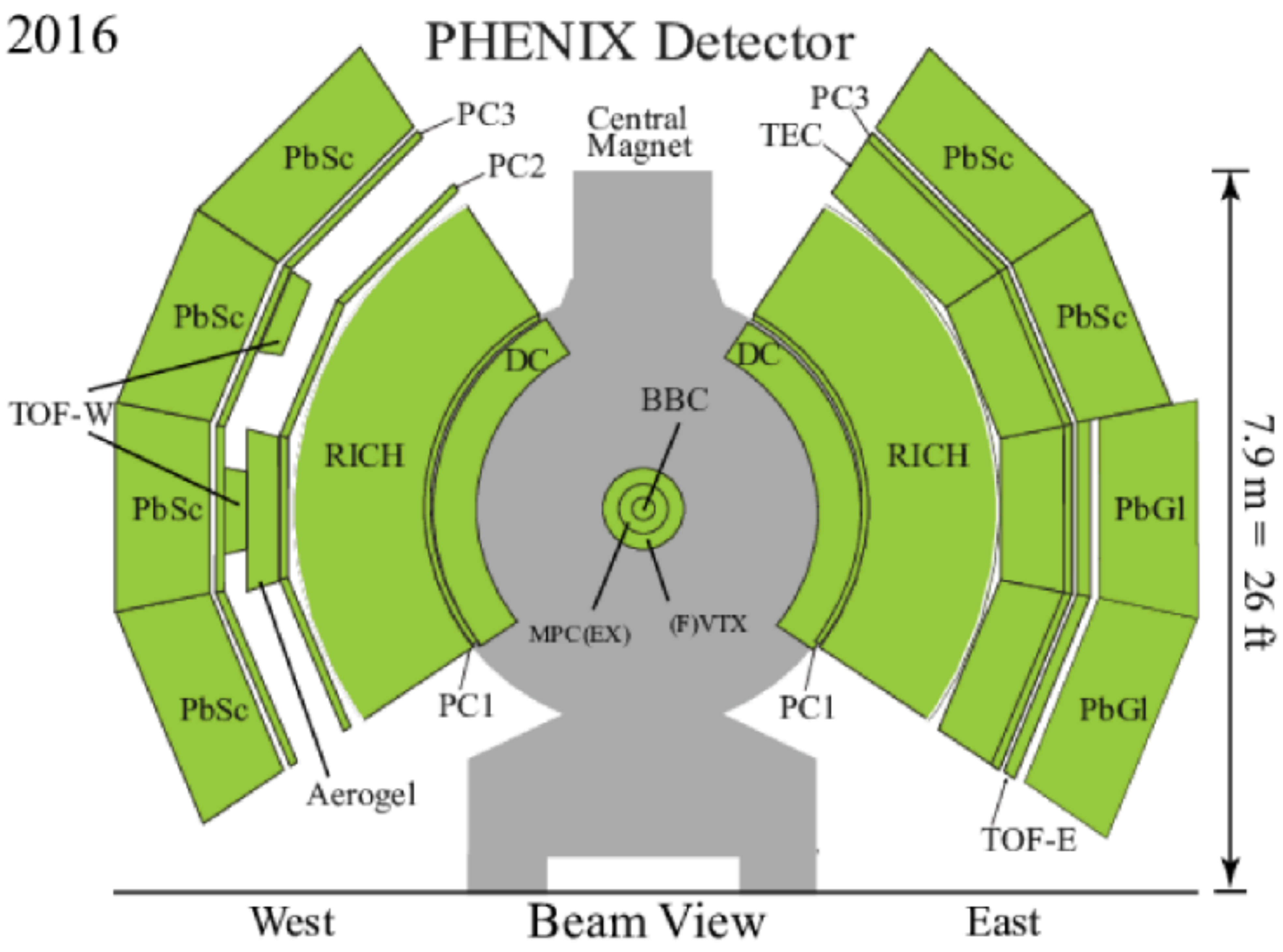


Hadron Identification using TOF

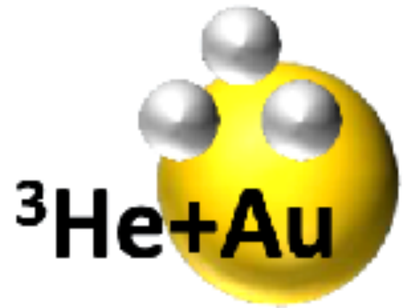


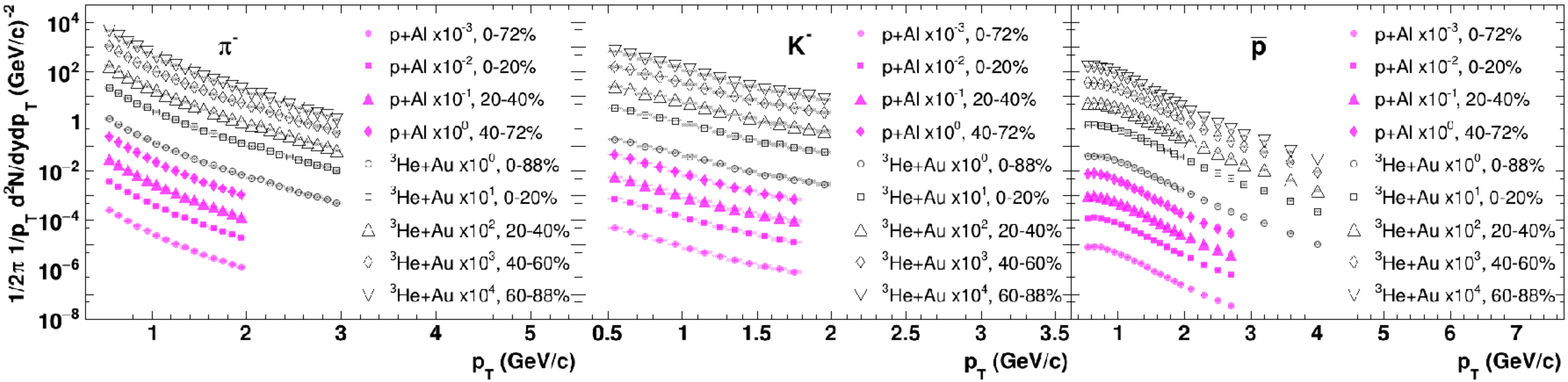
The particles invariant mass in terms of the momentum and it's Time of Flight is given by

$$m^2 = p^2\left[\left(\frac{T}{L}\right)^2 - 1\right]$$

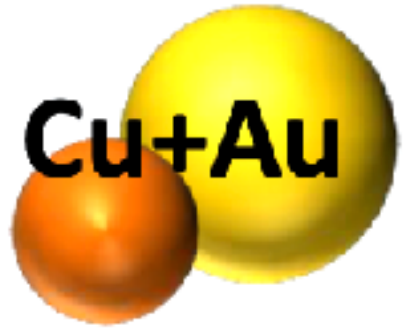


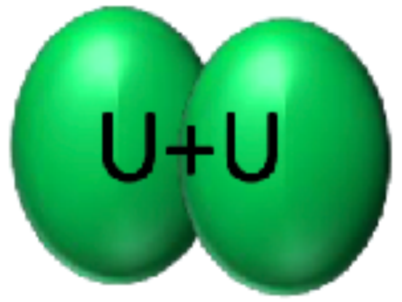
The invariant transverse momentum spectra

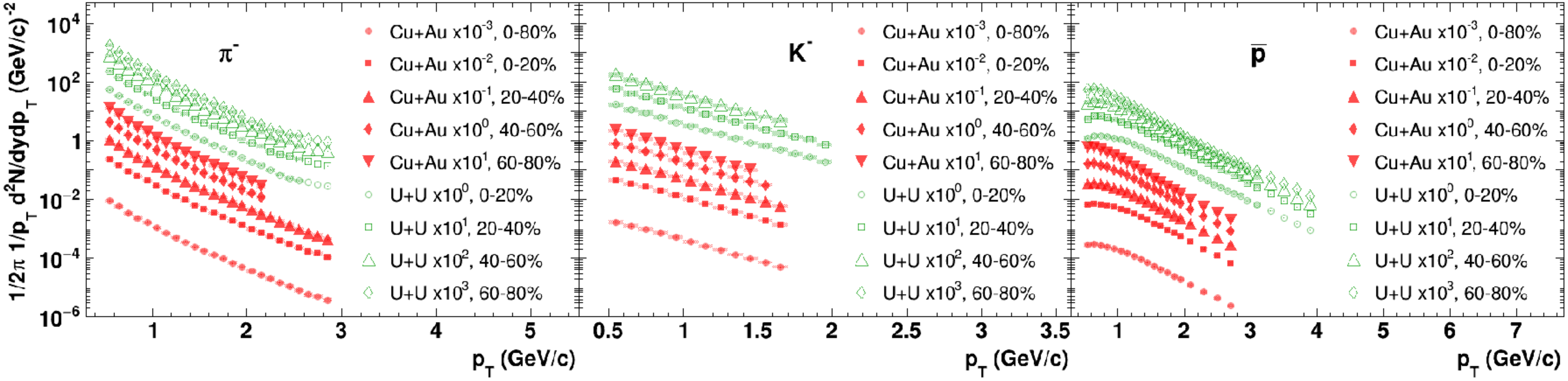




The invariant transverse momentum spectra

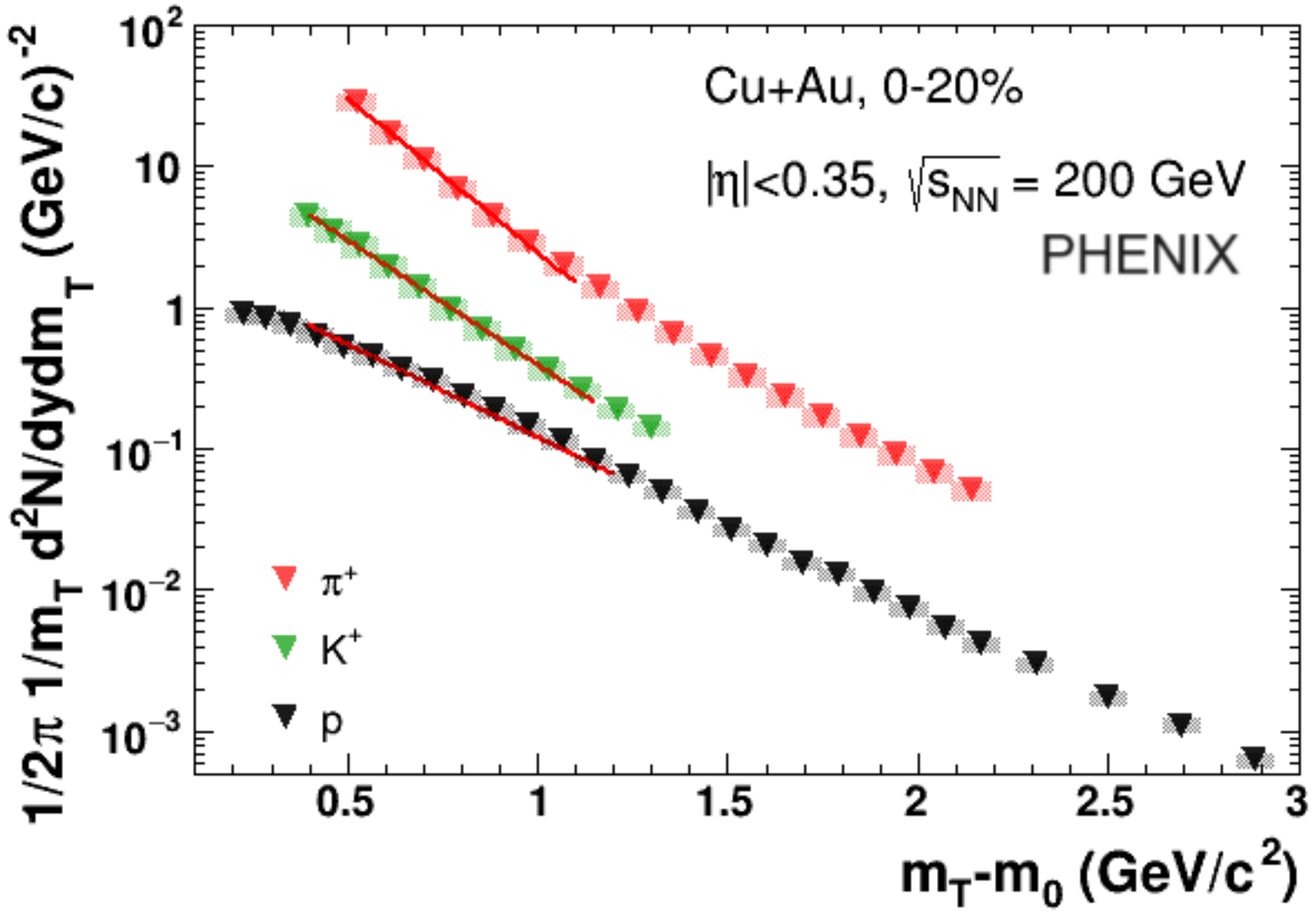




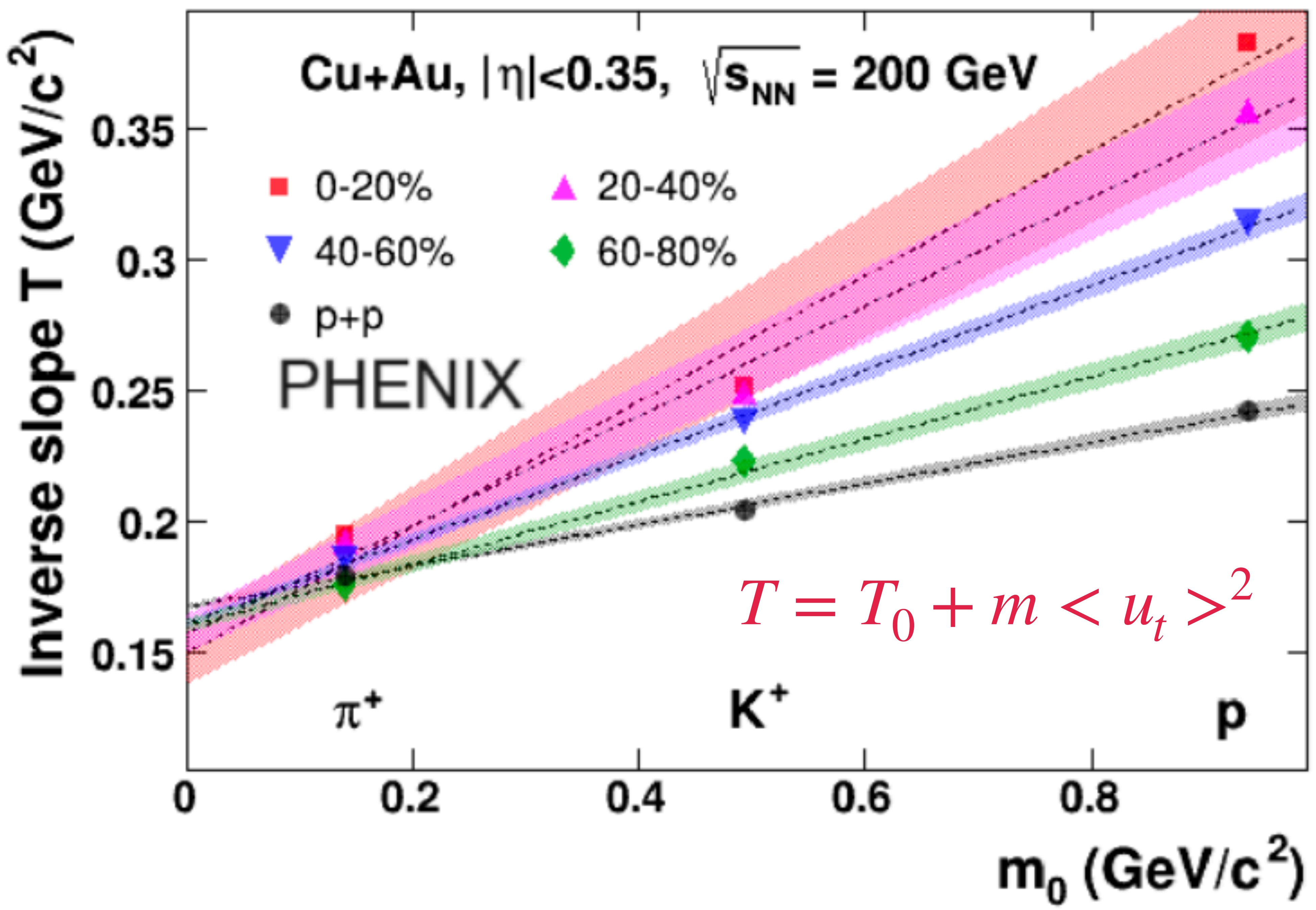


Transverse Mass Spectra

$\pi/K/p$ p_T - spectra have different shapes and in order to quantify these differences we look at the transverse-mass spectra



$$\frac{1}{2\pi m_T}\frac{d^2N}{dm_T dy} = \frac{A}{2\pi T(T+m_0)}\exp\left(-\frac{m_T-m_0}{T}\right)$$



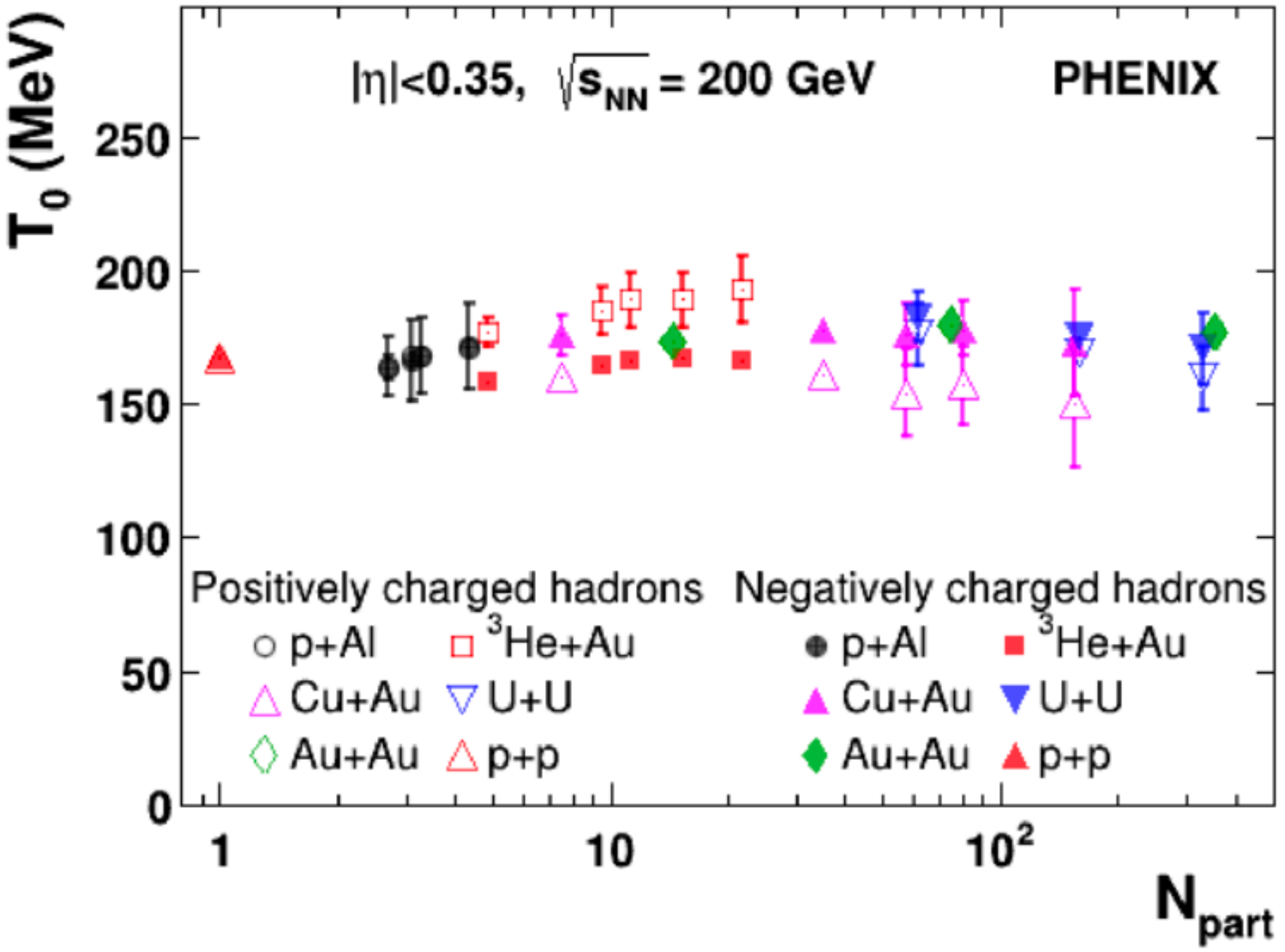
$T = T_0 + m < u_t >^2$

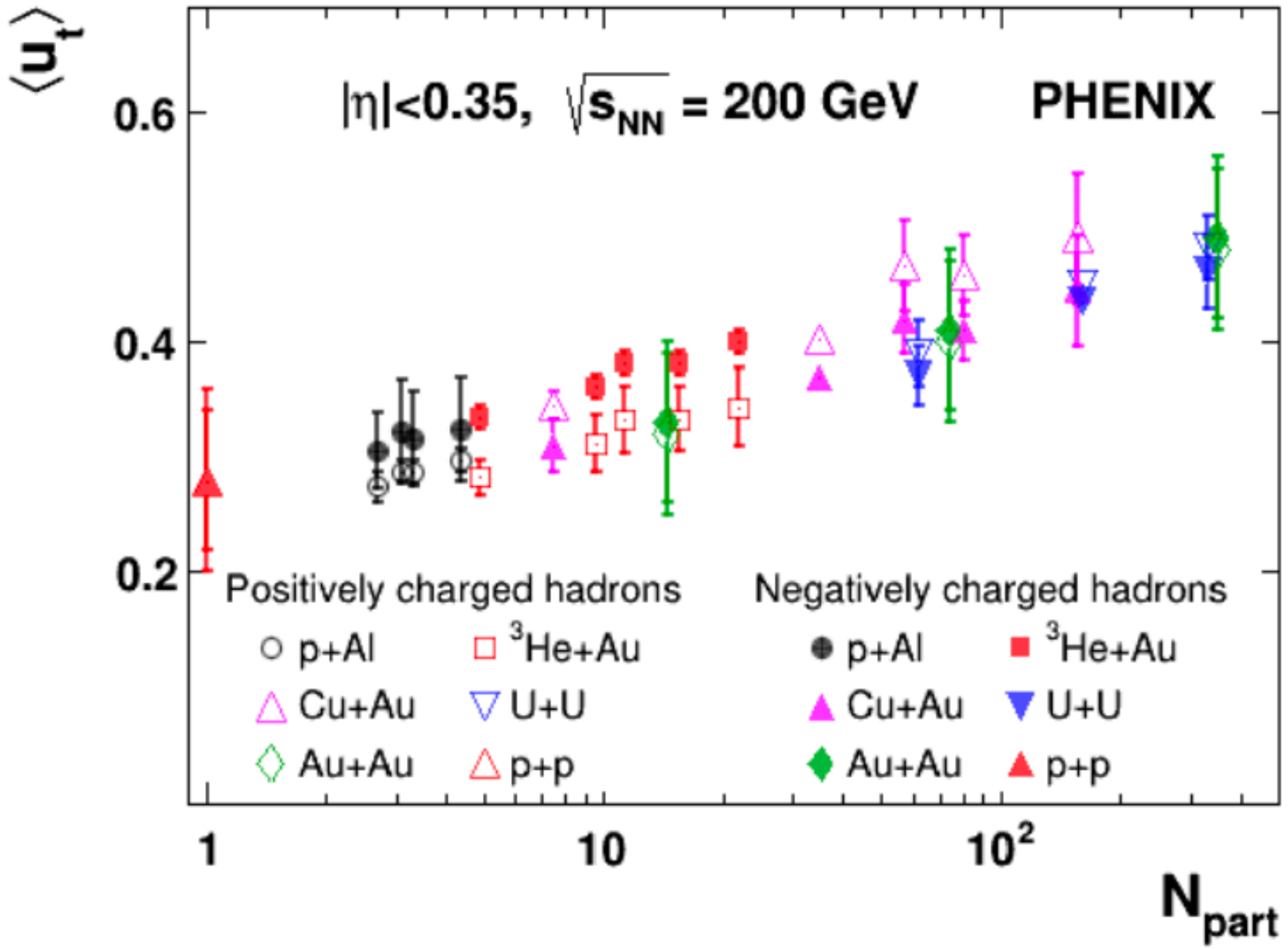
The inverse slope parameter exhibits a dependence on the hadron mass!

Can be interpreted as the freeze-out temperature

$$T = \boxed{T_0} + m\boxed{< u_t >^2}$$

Average collective velocity of all particle species

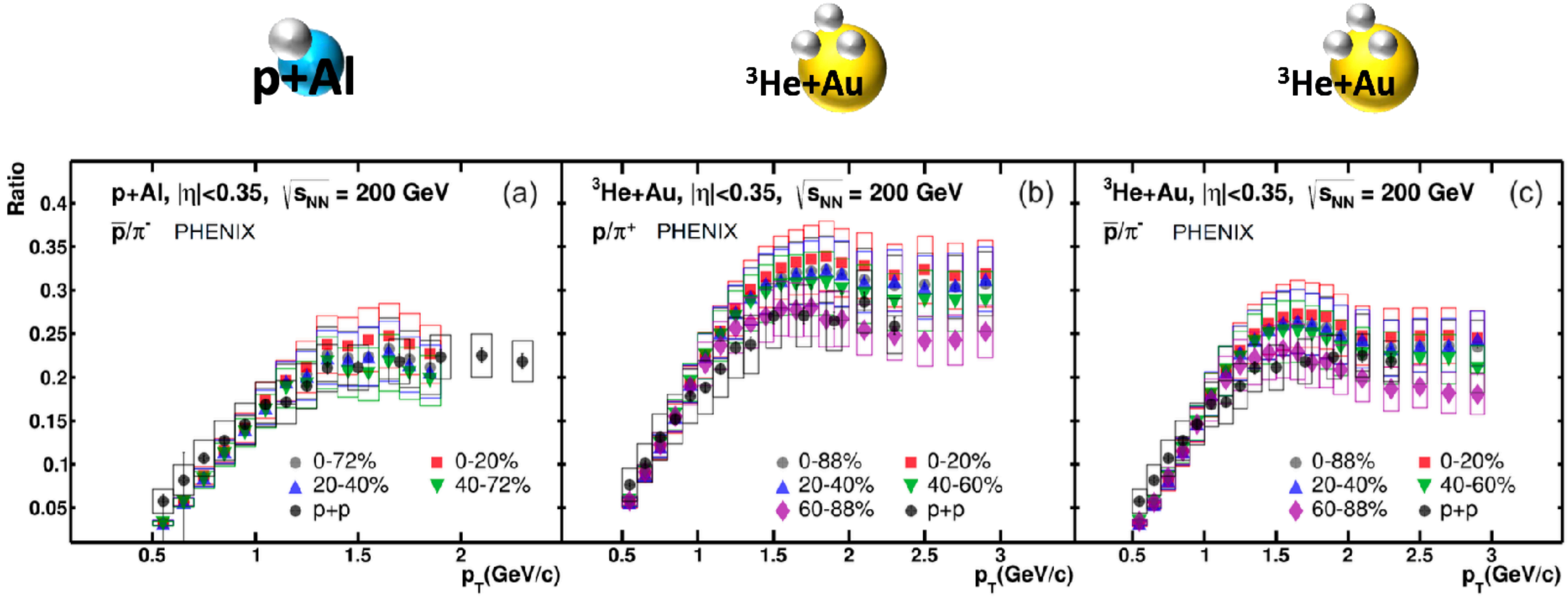




The freeze-out temperature is approximately independent of N_{part} within uncertainties!

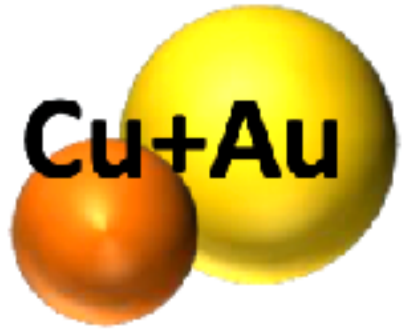
Collective effects are more pronounced in collisions characterized by large N_{part} than in collisions with small N_{part}.

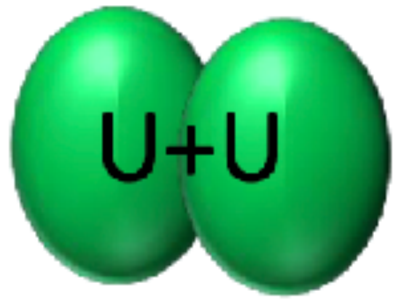
p/π - Ratio in small collision systems

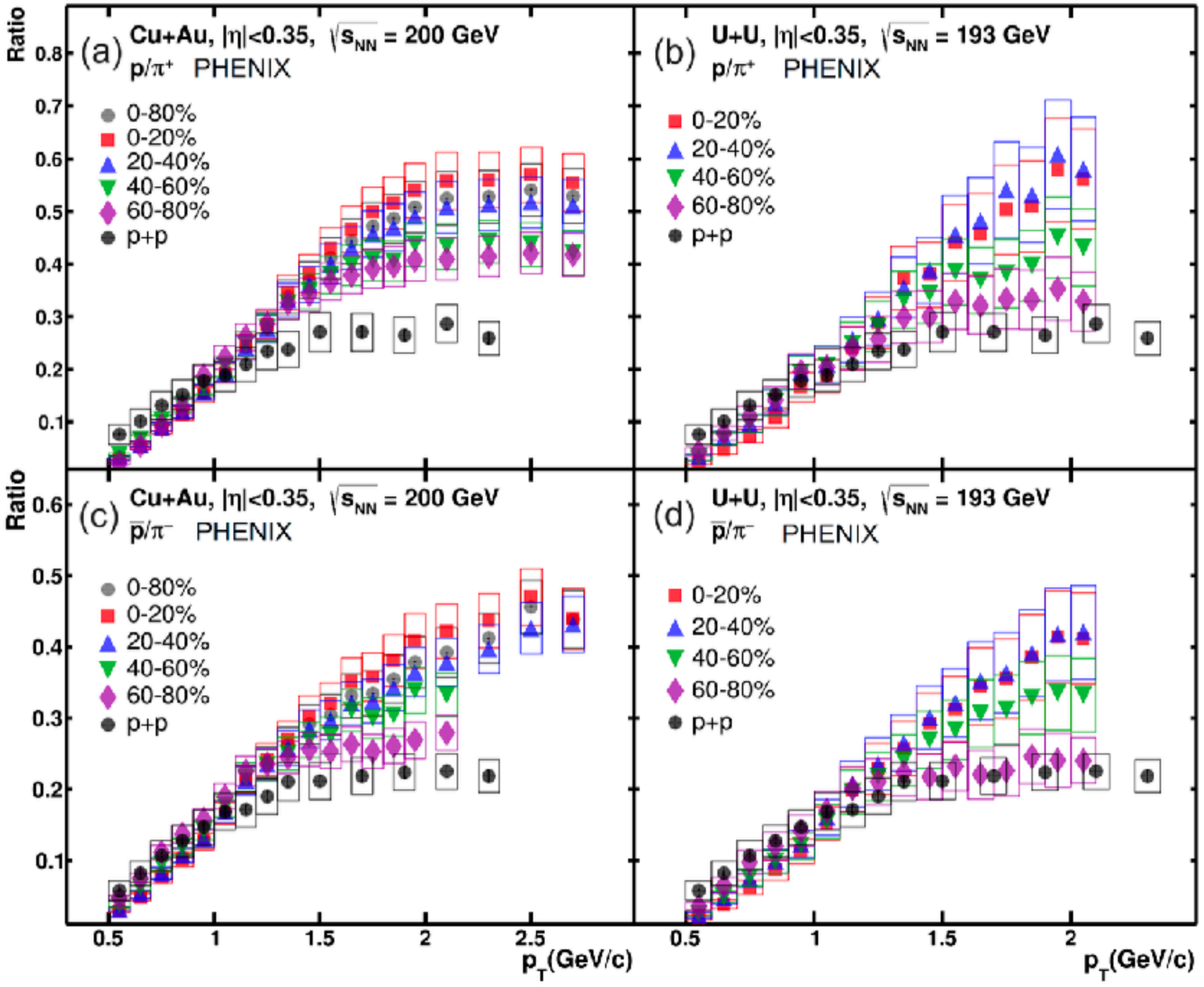


In small collision systems (p+Al, ^{3}He+Au), the values of p/π ratios are similar to those measured in p+p collisions within uncertainties.

p/π - Ratio in large collision systems

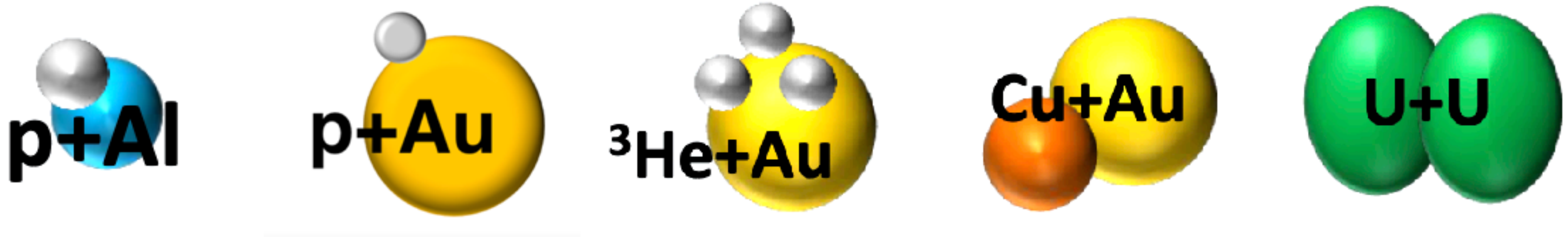






- In central Cu+Au and U+U collisions the p/π ratio is nearly twice as large as in the p+p case.
- However these ratios seems to agree, within uncertainties, to those from p+p when we move to peripheral collisions.

ϕ-meson production in small and large collision systems



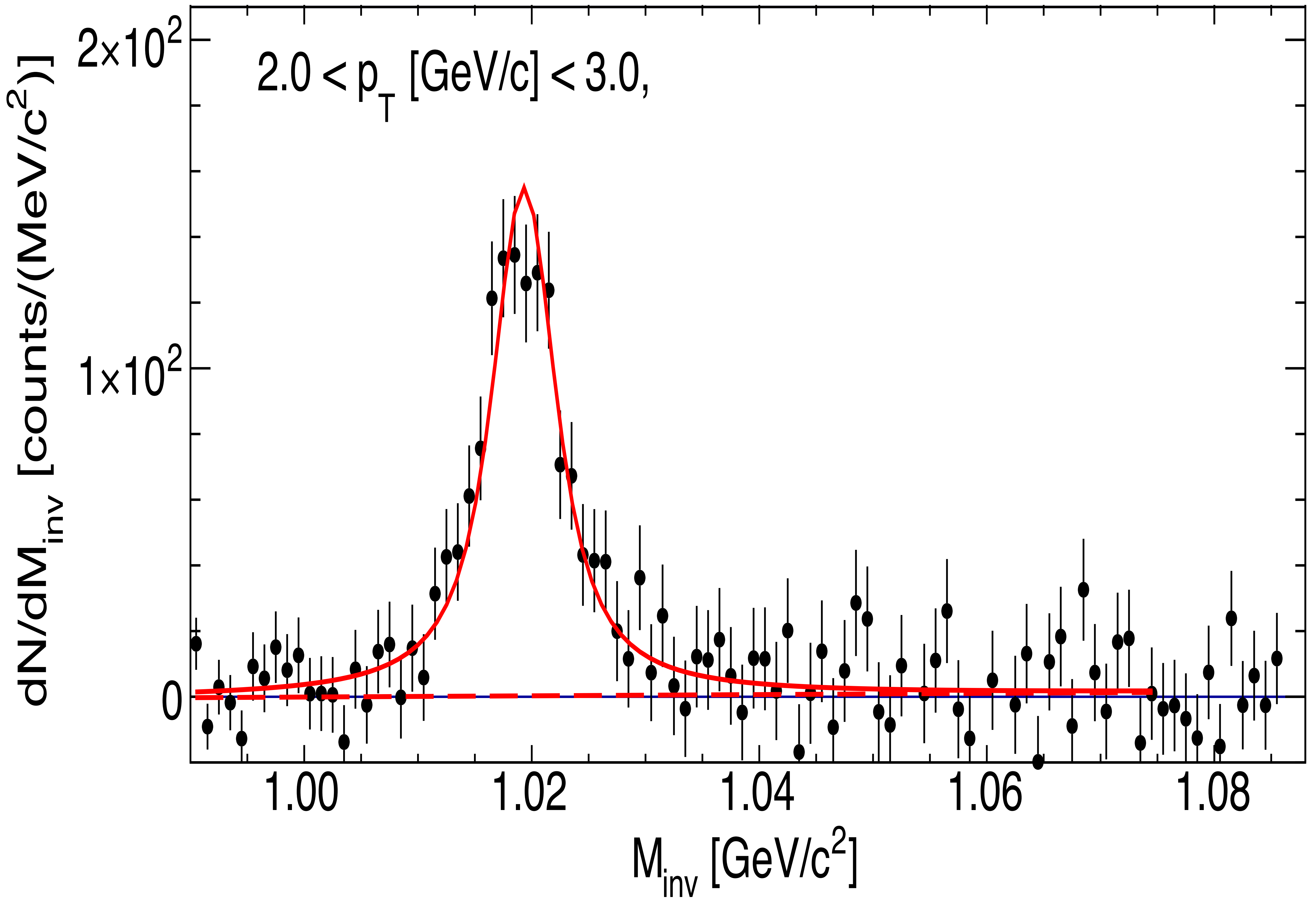
Why ϕ-meson?

- Lowest bound state of $s\bar{s}$

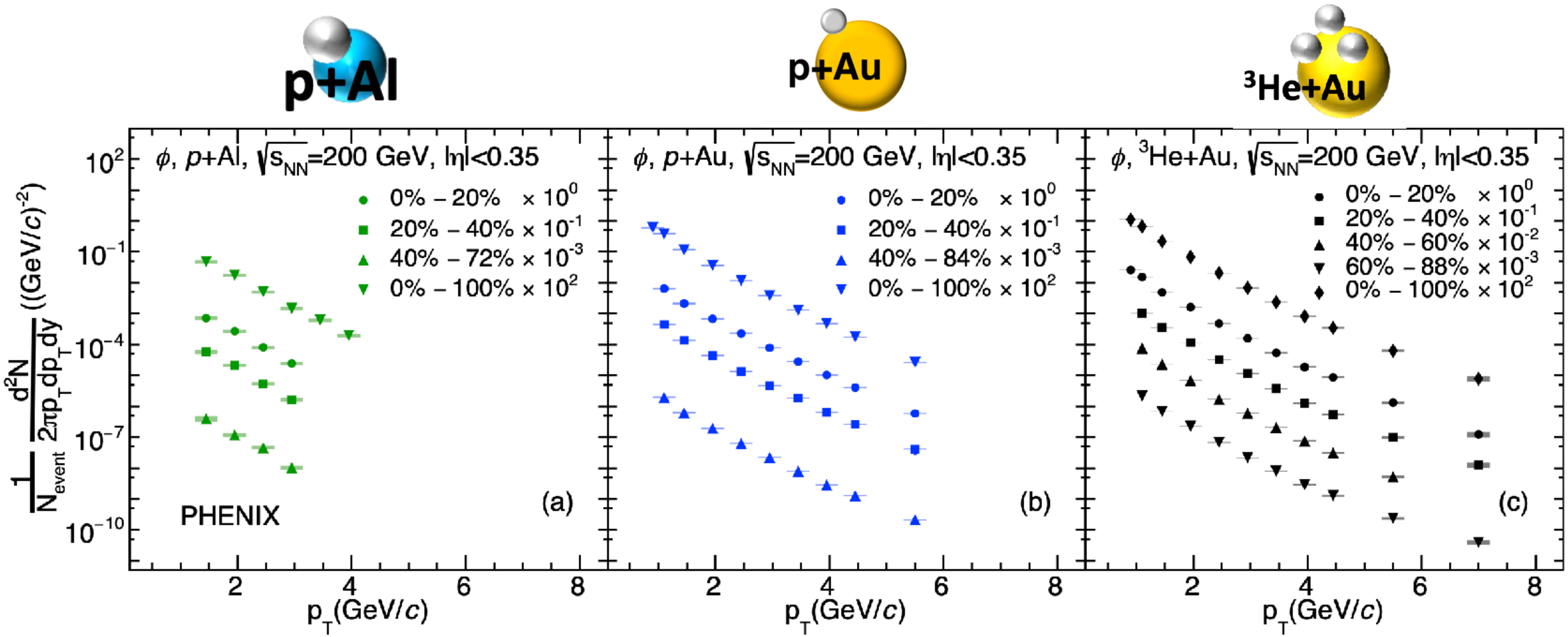
- ϕ lifetime >> τ^{QGP} . Mostly decays outside the fireball.

- $\phi \rightarrow K^+K^-$ with a branching ratio of $48.9 \pm 0.5\%$

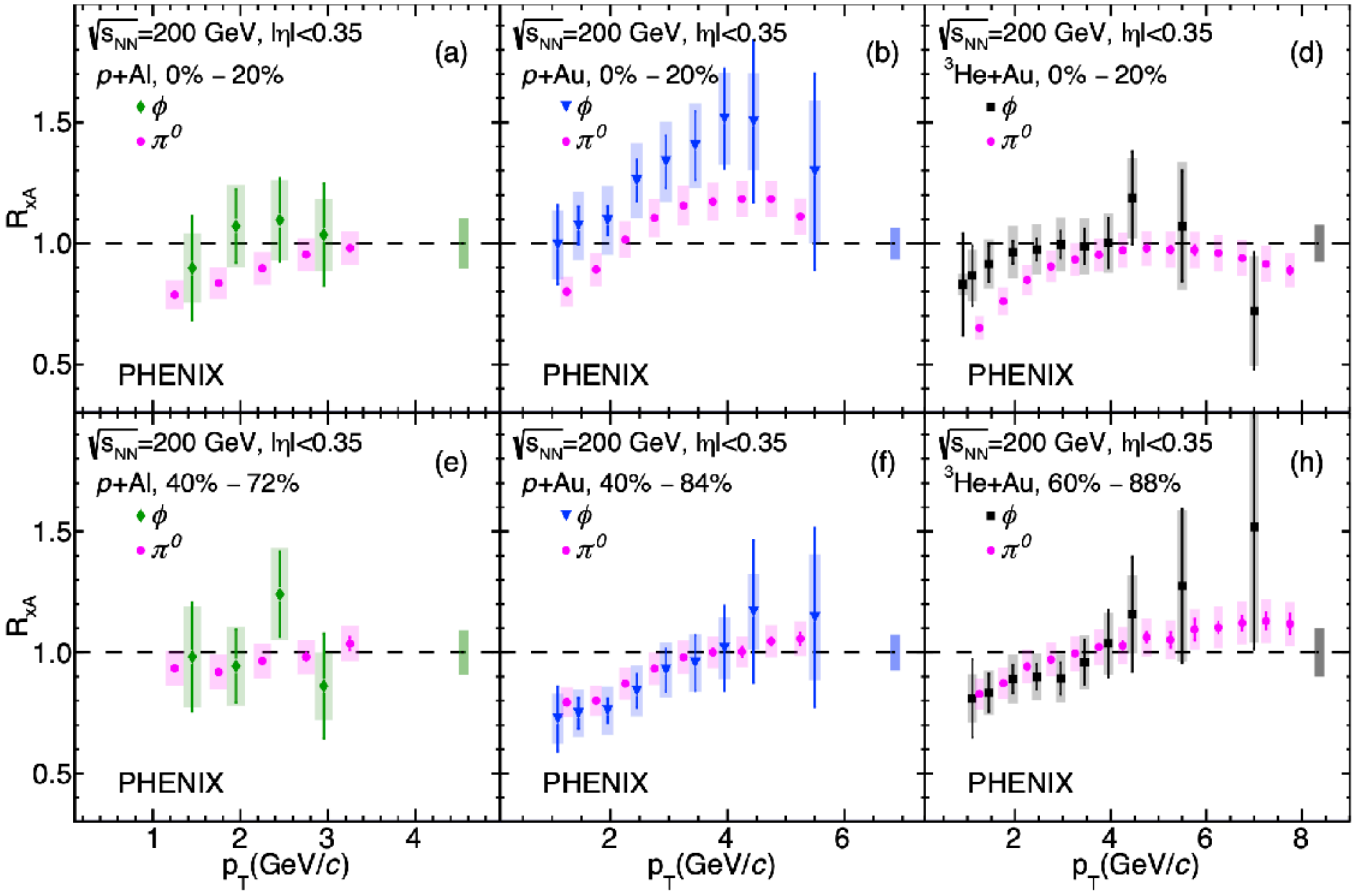
- Measurements of the ϕ-meson p_T spectra in various collision systems can contribute to the understanding of strangeness enhancement, along with energy loss and coalescence.



The invariant transverse momentum spectra

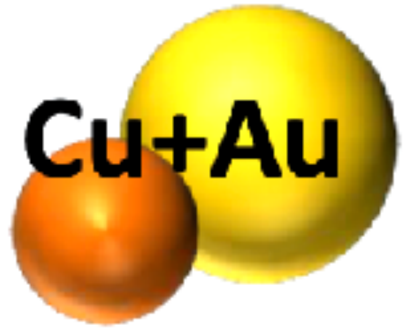


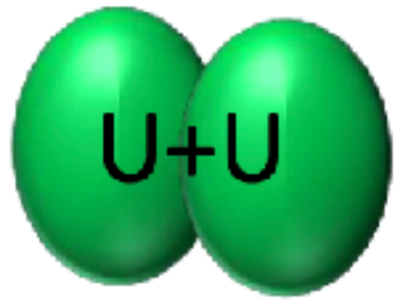
R_{AB} - Nuclear Modification factor

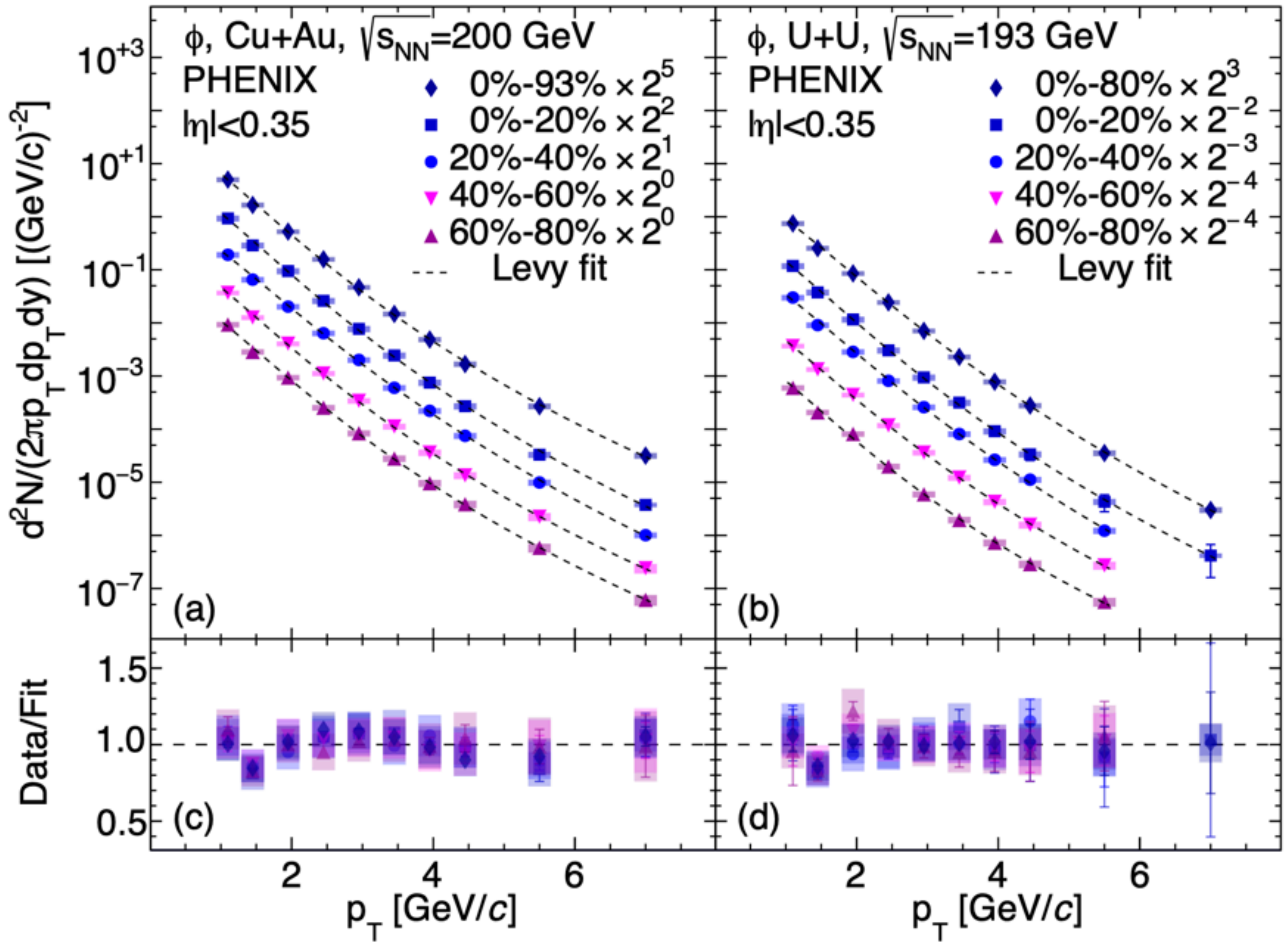


The ϕ meson production in the most central collisions shows a trend to less suppression or larger enhancement than the π^0 meson production at moderate p_T, however it cannot be concluded due to large systematic uncertainties.

The invariant transverse momentum spectra







- Utilizing the $\phi \rightarrow K^{+}K^{-}$ with the Kaon identification using DC and TOF in the East Arm.

- The dashed lines represent the Levy-function fits

$$\frac{1}{2\pi p_T}\frac{d^2N}{dp_T dy} = \frac{1}{2\pi}\frac{dN}{dy}\frac{(n-1)(n-2)}{nT(nT+m_\phi(n-2))}\times$$
$$\times\left(1+\frac{\sqrt{{p_T}^2+m_\phi^2}-m_\phi}{nT}\right)^{-n}$$

R_{AB} - Nuclear Modification factor

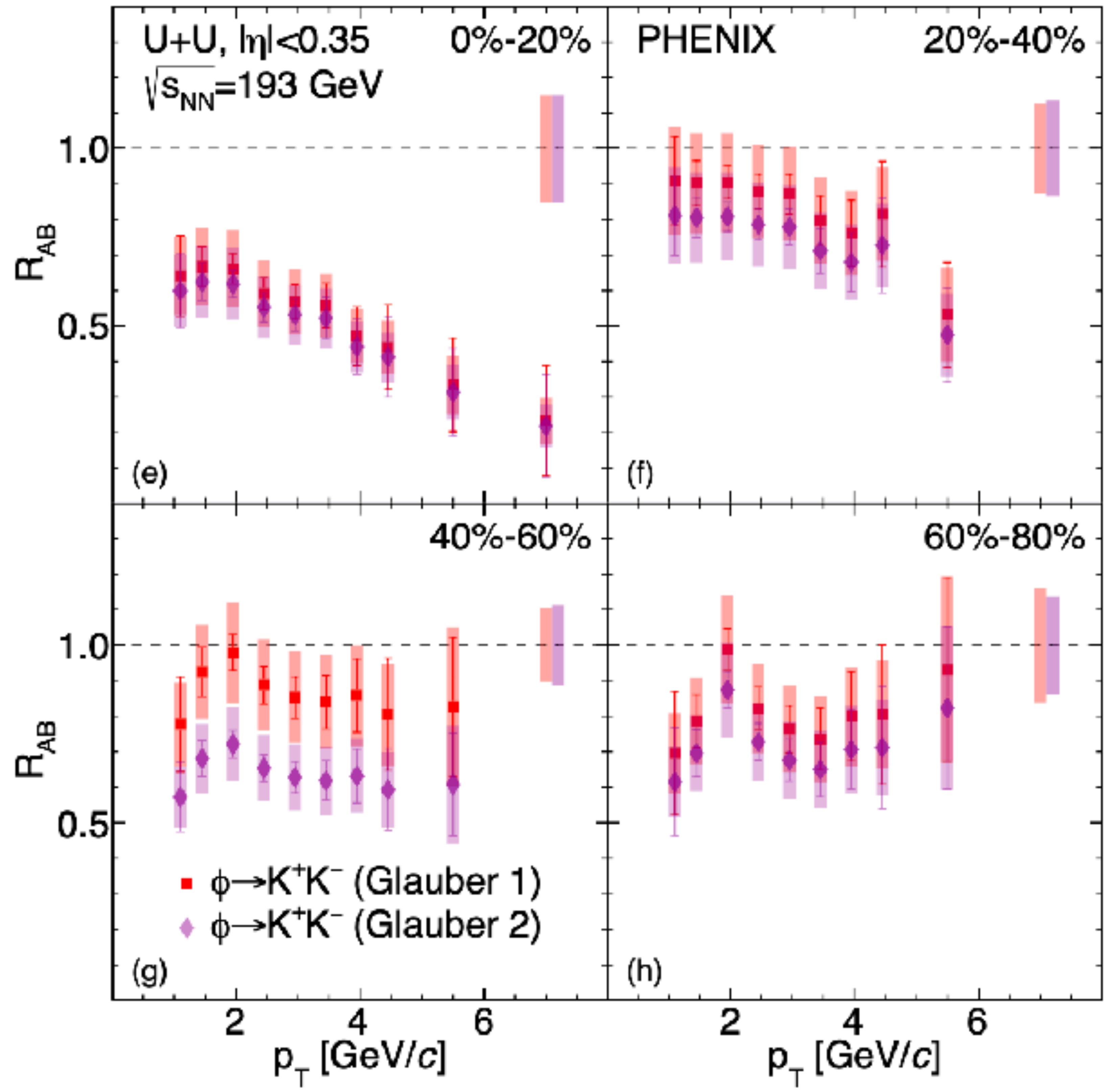
For asymmetric ^{238}U, the θ-dependent Woods-Saxon density distribution is used:

$$\rho(r,\theta)/\rho_0 = \frac{1}{1+\exp\left[(r-R'(\theta))/a\right]}$$

$$R'(\theta) = R(1+\beta_2 Y_2^0(\theta) + \beta_4 Y_4^0(\theta))$$

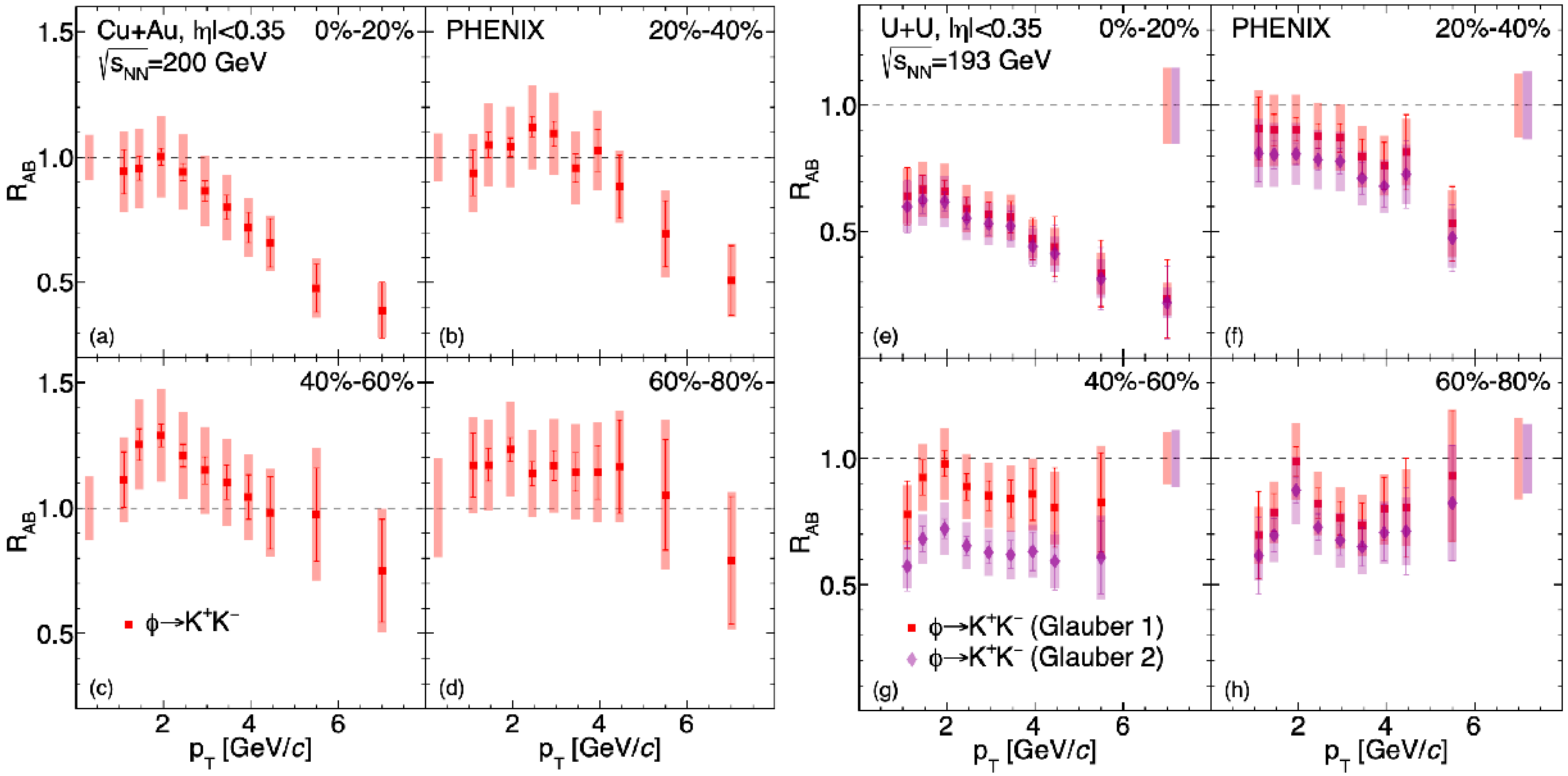
TABLE I. Parameters for the Woods-Saxon distributions used for U+U Glauber Monte-Carlo simulations.

Parameter	Glauber 1 [31]	Glauber 2 [32]
R (fm)	6.81	6.86
a (fm)	0.60	0.42
β_2	0.280	0.265
β_4	0.093	0



Glauber 1 and Glauber 2 corresponds to two different parameterizations of Woods-Saxon Distribution used in MC.

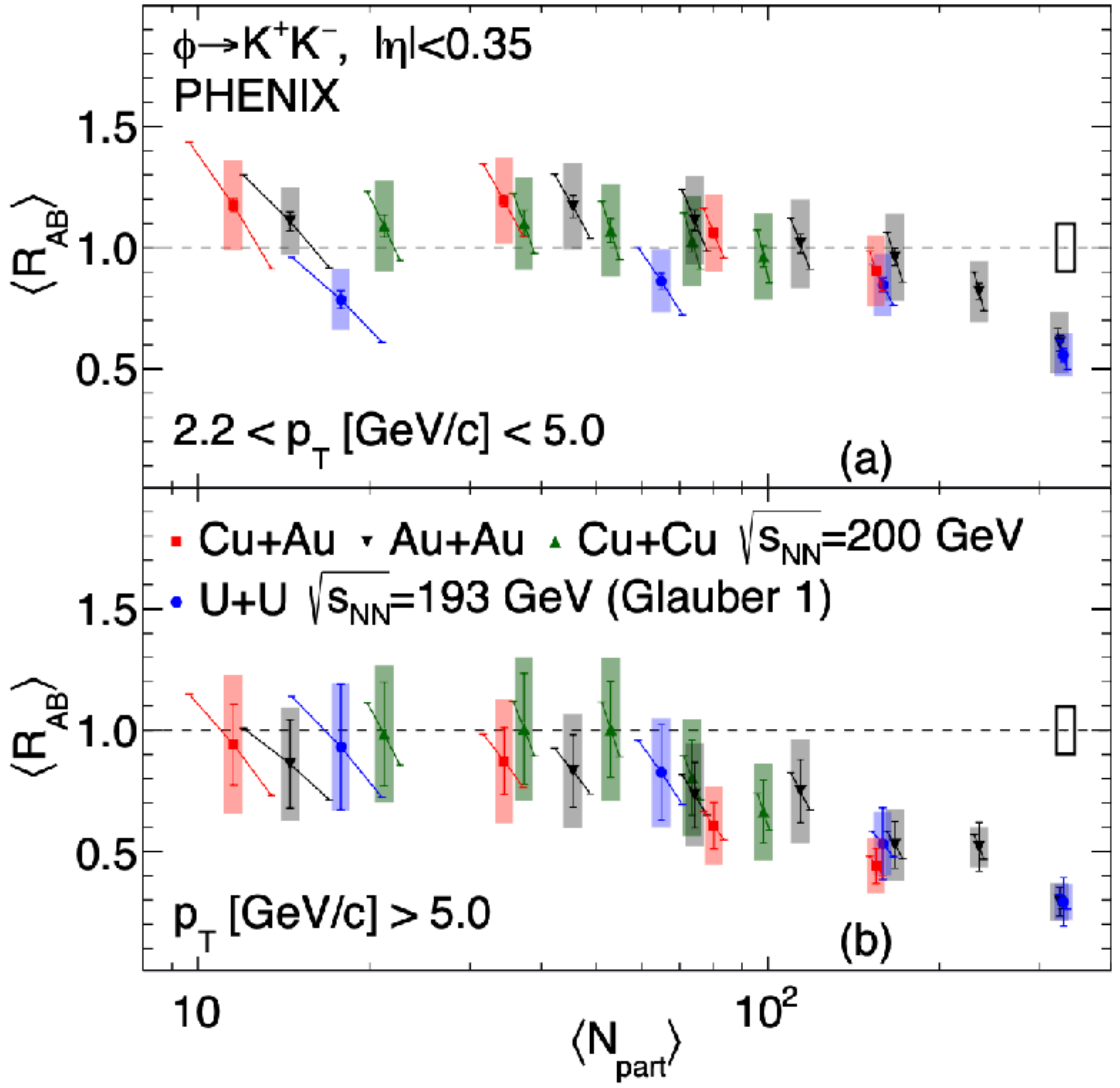
R_{AB} - Nuclear Modification factor



- In central and semi-central Cu+Au and U+U collisions at high p_T > 5 GeV/c we see suppression.
- And this suppression decrease when moving to more peripheral collisions.

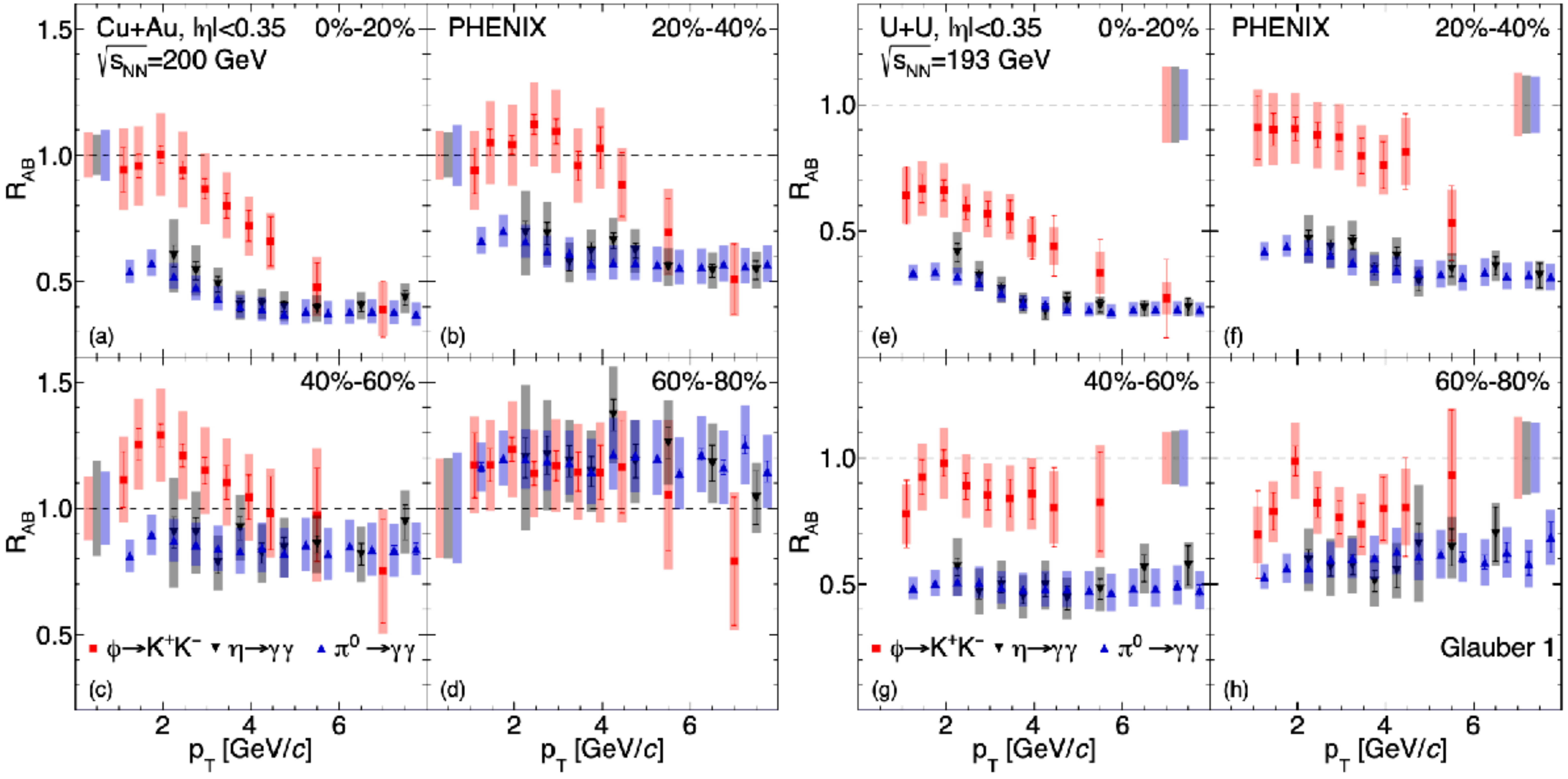
Glauber 1 and Glauber 2 corresponds to two different parameterizations of Woods-Saxon Distribution used in MC.

A comparison with the symmetric systems



- Average R_{AB} values integrated in two p_T regions and plotted as a function of the $< N_{part} >$ which is proportional to the nuclear overlap region

- The obtained $\langle R_{AB} \rangle$ results suggest the scaling of light-hadron production with the average nuclear-overlap size, regardless of the collision geometry

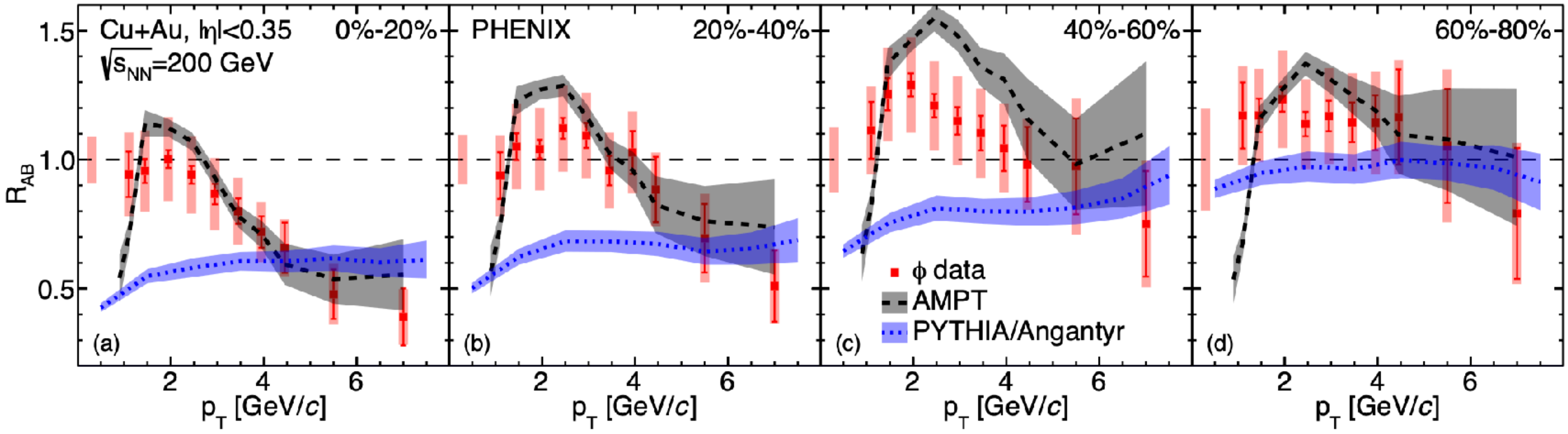


Comparisons with other light mesons.

- In central and semi-central Cu+Au and U+U collisions, at low p_T $R_{AB}^{\phi} > R_{AB}^{\pi^0,\eta}$ —> qualitatively can be explained by the interplay of strangeness enhancement and hadronization via recombination.

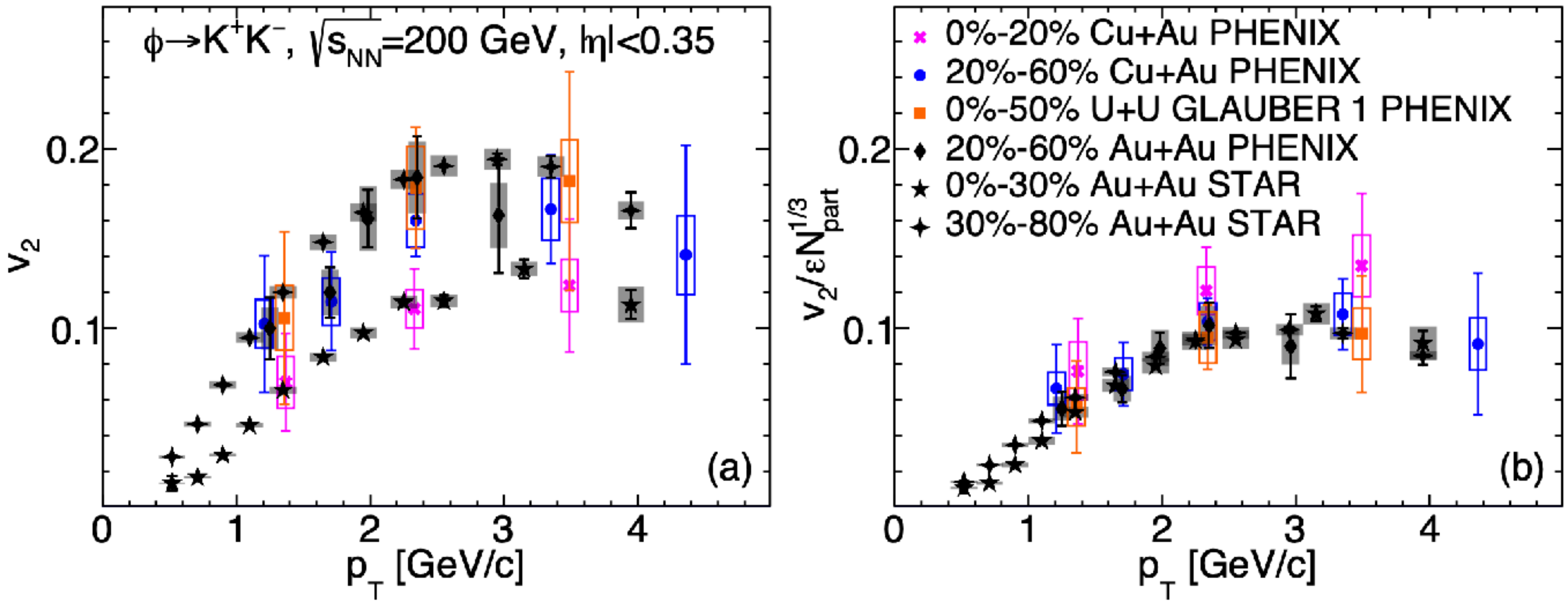
- At high-p_T there are similar levels of suppression —> consistent, within uncertainties, to the assumption of flavor-independent energy loss of pre-fragmentation partons.

Comparison with Models



This comparison shows that the ϕ-meson production measured in Cu+Au collisions is well described by the AMPT model, which assumes that the mechanism of ϕ-meson production at moderate p_T is dominated by the coalescence of $s\bar{s}$ pairs

Elliptic Flow v_2 of ϕ-mesons



- ε —> A measure of the shape of the nuclear overlap region
- $N_{part}^{1/3}$ —> A measure of the length scale of the nuclear overlap region

- The comparison of elliptic flow for ϕ mesons in symmetric and asymmetric collision systems suggests that the v_2 values follow common empirical scaling with $\varepsilon N_{part}^{1/3}$.

Summary

- Identified charged hadron production in p+Al, He+Au, Cu+Au at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV.
  - ✳ The T_0 values do not exhibit any dependence on the collision centrality and $\langle N_{part} \rangle$ values, whereas the values of $\langle u_t \rangle$ smoothly increase with increasing of $\langle N_{part} \rangle$ values.
  - ✳ In collisions with small $\langle N_{part} \rangle$ values the ratios of p/π are comparable to those measured in p+p collisions. In collision systems with large $\langle N_{part} \rangle$ values p/π ratios reach the values of ≈0.6, which is ≈2 times larger than (p/π)p+p.

Summary

- ϕ-meson production in Cu+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and U+U collisions at $\sqrt{s_{NN}}$ = 193 GeV

  - ✳It is found that features of ϕ-meson production measured in heavy-ion collisions reported by the PHENIX experiment do not depend on the shape of the nuclear-overlap region.
  - ✳The obtained ϕ-meson $\langle R_{AB} \rangle$ and $v_2 /(\varepsilon_2 N_{part}^{1/3})$ values are consistent across Cu+Cu, Cu+Au, Au+Au, and U+U collisions within uncertainties.

Thank You!

Back-Up

What have we seen until now?

Jet quenching

David d'Enterria

CERN, PH-EP, CH-1211 Geneva 23, Switzerland
LNS, MIT, Cambridge, MA 02139-4307, USA

Summary. We present a comprehensive review of the physics of hadron and jet production at large transverse momentum in high-energy nucleus-nucleus collisions. Emphasis is put on experimental and theoretical "jet quenching" observables that provide direct information on the (thermo)dynamical properties of hot and dense QCD matter.

PHYSICAL REVIEW C **68**, 044902 (2003)

Hadron production in heavy ion collisions: Fragmentation and recombination from a dense parton phase

R. J. Fries, B. Müller, and C. Nonaka
Department of Physics, Duke University, Durham, North Carolina 27708, USA

S. A. Bass
Department of Physics, Duke University, Durham, North Carolina 27708, USA and RIKEN BNL Research Center, Brookhaven National Laboratory, Upton, New York 11973, USA
(Received 12 June 2003; published 24 October 2003)

Strangeness in relativistic heavy ion collisions

P Koch [a], B Müller [b], J Rafelski [c]

Show more

+ Add to Mendeley Share Cite

https://doi.org/10.1016/0370-1573(86)90096-7 Get r

Jet Quenching —> Suppression of high-p_T hadron yields due to partonic energy loss in the hot and dense medium relative to the N_{coll} scaled p+p yields.

Strangeness enhancement —> increase of strange and hadron yields in nucleus-nucleus collisions relative to N_{coll} scaled p+p data.

Hadronization via recombination qualitatively describes strangeness and baryon enhancement.

Two parameterizations of the Woods-Saxon Distribution

For asymmetric ^{238}U, the θ-dependent Woods-Saxon density distribution is used:

$$\rho(r,\theta)/\rho_0 = \frac{1}{1+\exp\left[(r-R'(\theta))/a\right]}$$

Where

$$R'(\theta) = R(1+\beta_2 Y_2^0(\theta) + \beta_4 Y_4^0(\theta))$$

Because there is no single universally accepted parametrization of the U nucleus, we used two parameter sets.

PHYSICAL REVIEW C 102, 064905 (2020)

TABLE I. Parameters for the Woods-Saxon distributions used for U+U Glauber Monte-Carlo simulations.

Parameter	Glauber 1 [31]	Glauber 2 [32]
R (fm)	6.81	6.86
a (fm)	0.60	0.42
β_2	0.280	0.265
β_4	0.093	0

K/π - Ratio in small and large collision systems