The study of identified charged-hadron production at PHENIX

Stony Brook University

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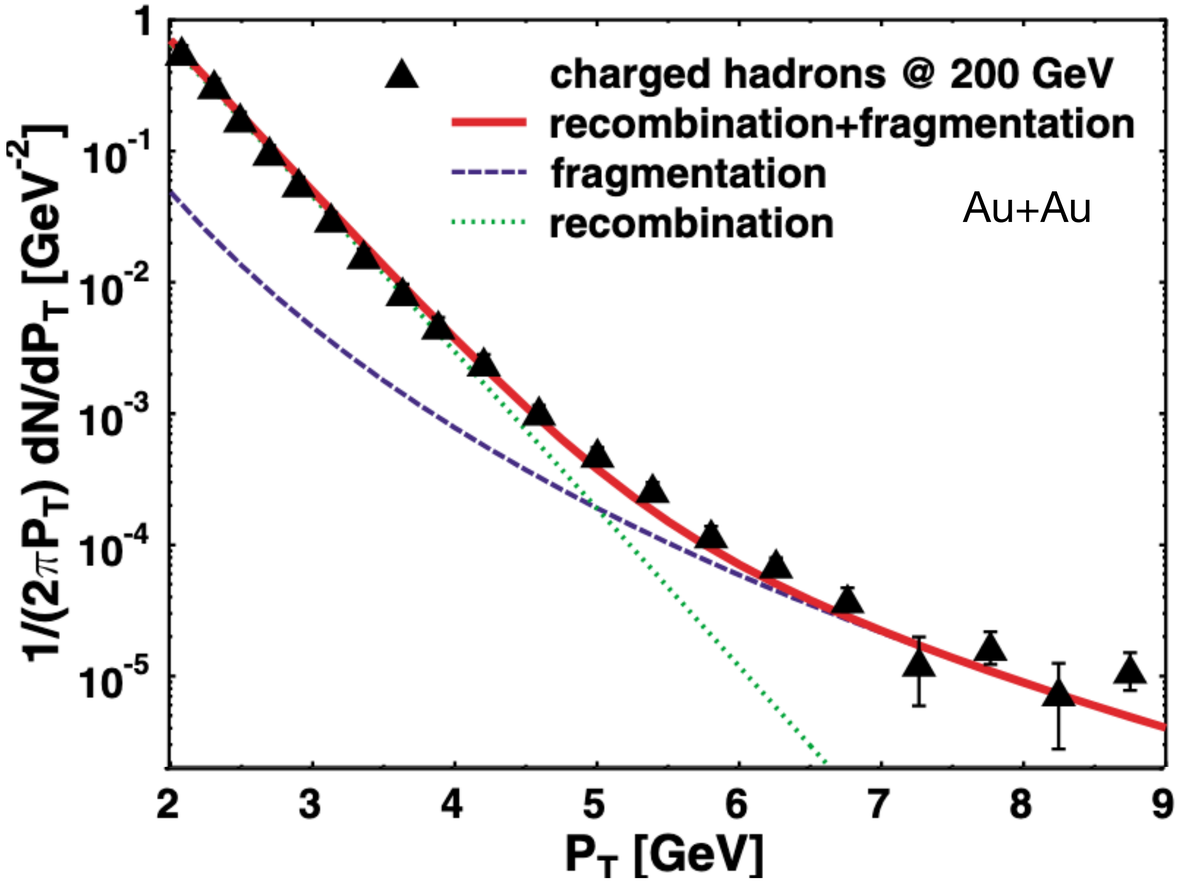
Mariia Mitrankova for the PHENIX collaboration
Stony Brook University

PHENIX

Invariant spectra shape



- Low p_T region -
  exponential shape of the spectra (recombination)
- Higher p_T region -
  power-law shape of the spectra (fragmentation)

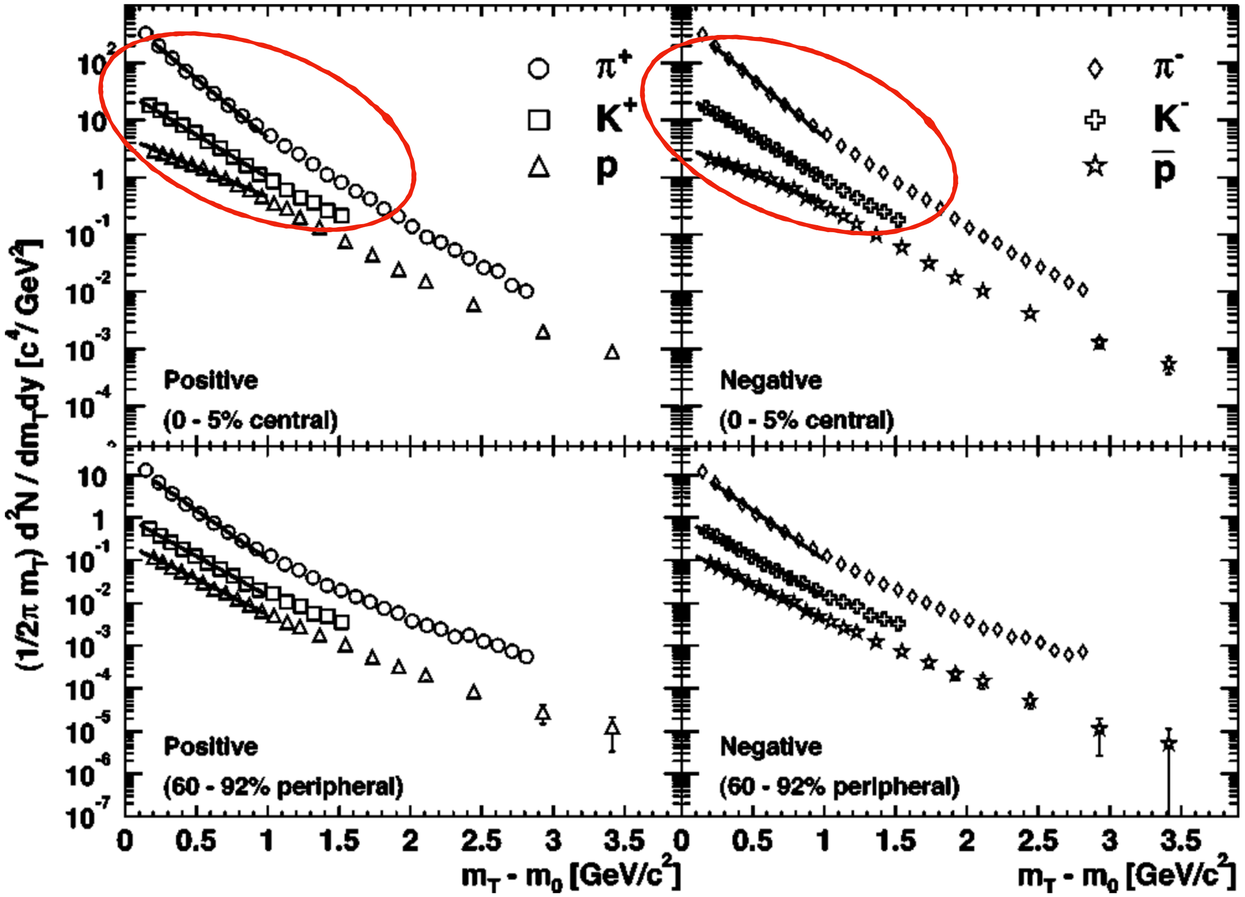
- Additionally, it is customary to plot the invariant yields as a function of the transverse mass

$$m_T = \sqrt{p_T^2 + m^2}$$

Identified charged hadron production

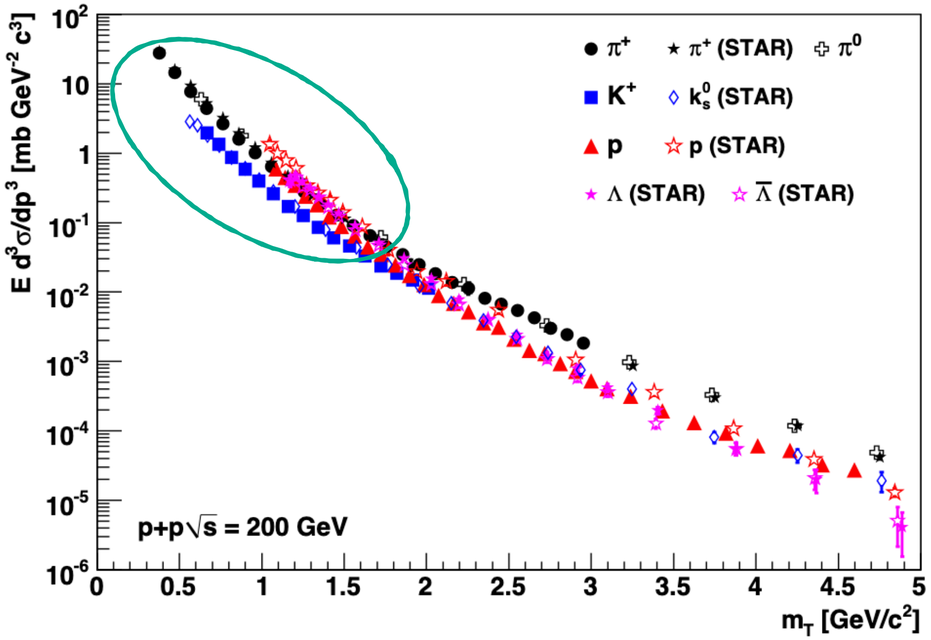
$\pi^{\pm}, K^{\pm}, p, \bar{p}$. Previous results in $p+p$ and Au + Au collisions

Au + Au, $\sqrt{s_{NN}} = 200$ GeV



PRC 69, 034909, 2004

$p + p$, $\sqrt{s_{NN}} = 200$ GeV



PRC 83, 064903, 2011

- $p + p$ – same shape of the spectra for π, K, p
- Au+Au – different shape of the spectra for π, K, p at $p_T < 2$ GeV/c

The model of radially expanding thermalized systems

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

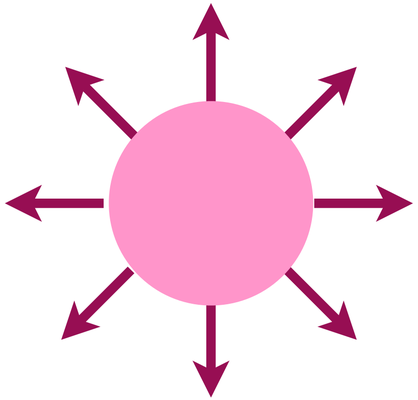
$$\langle E_{kinetic} \rangle = \langle E_{thermal} \rangle + \langle E_{collectiv} \rangle$$

$$T = T_0 + \langle u_t \rangle^2 \cdot m_0$$

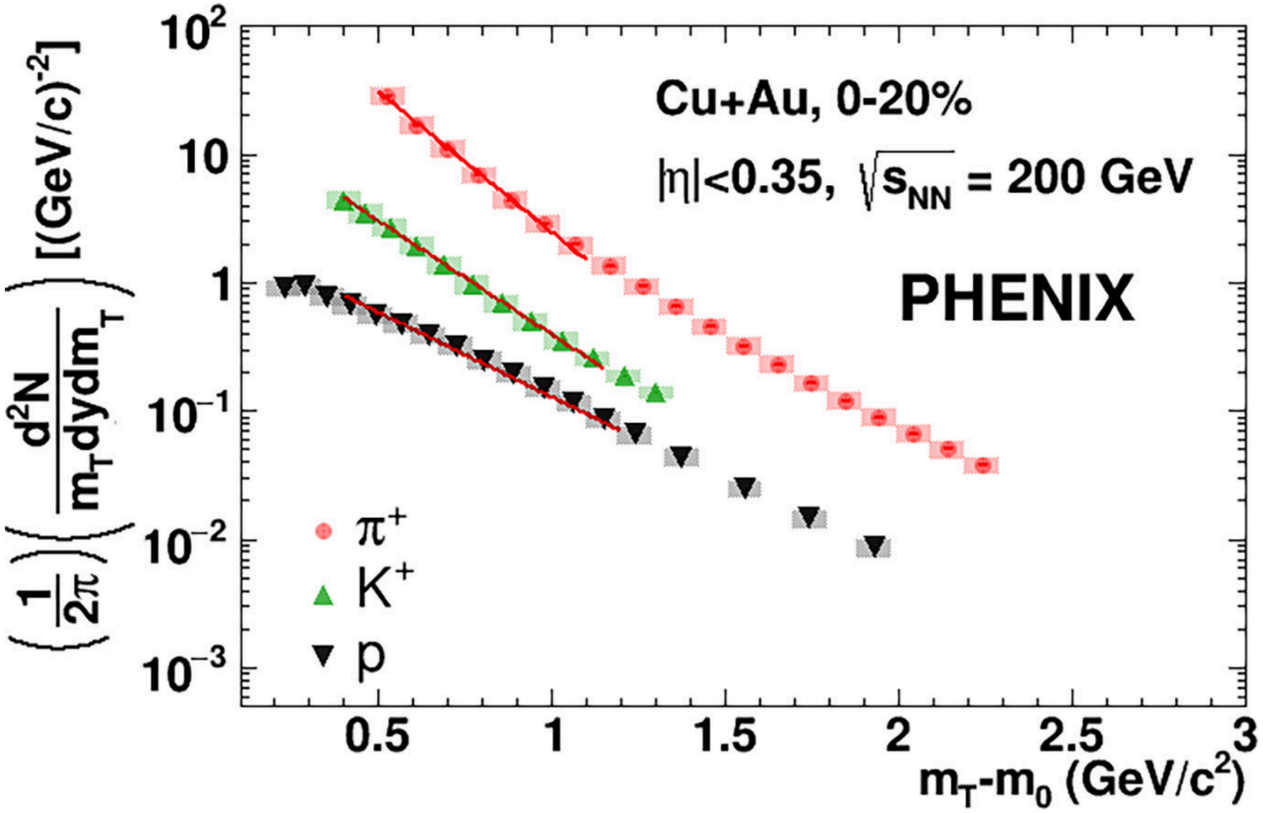
T_0 – kinetic freeze out temperature

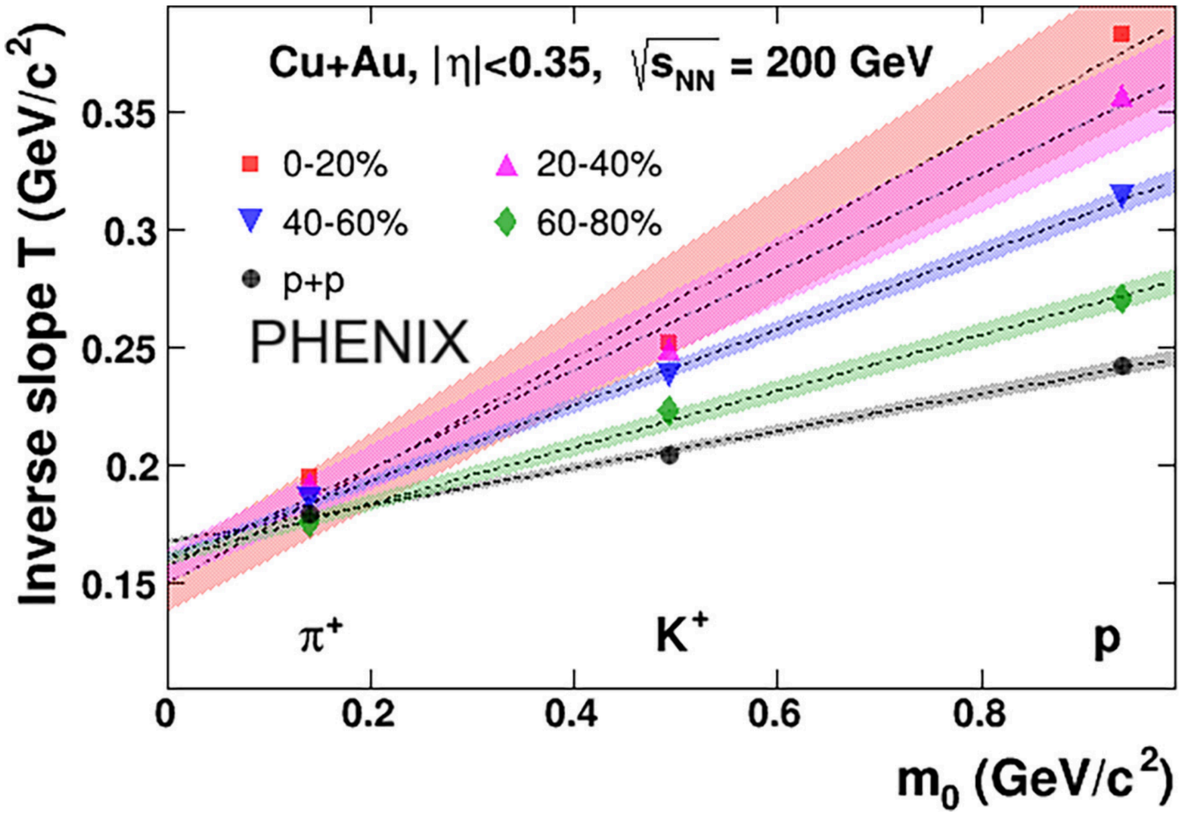
$\langle u_t \rangle$ – average collective velocity

Radial flow



Invariant m_T spectra



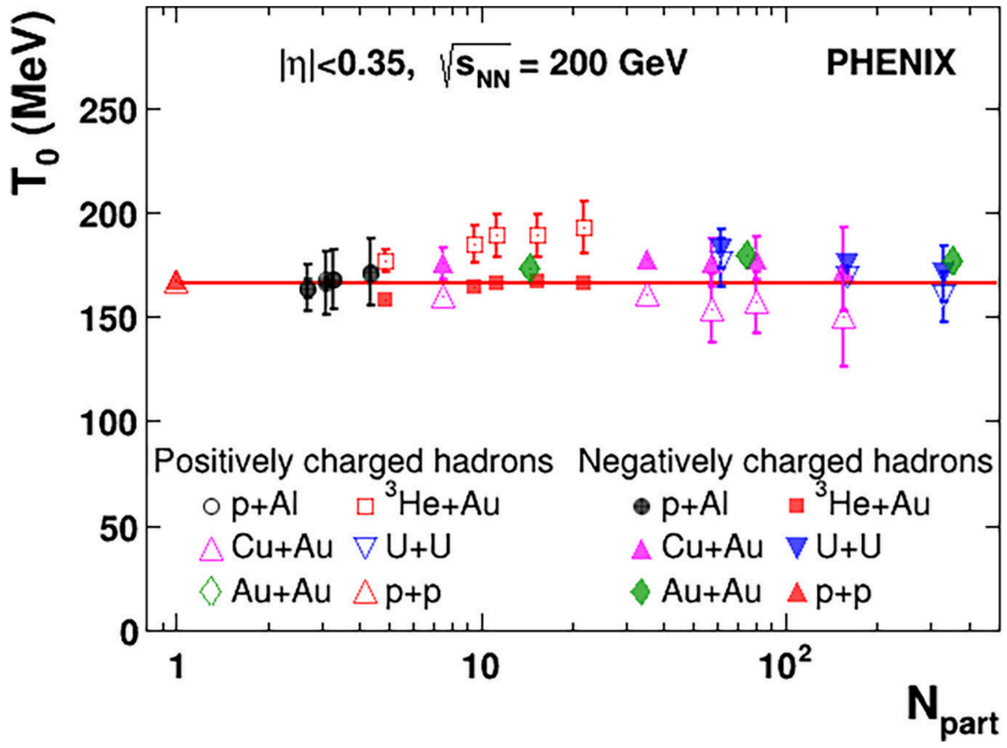


$$\frac{1}{\pi m_T}\frac{d^2N}{dm_T dy} = \frac{1}{2\pi T(T+m_0)} \cdot A \cdot exp\frac{-(m_T - m_0)}{T}$$

$$T = T_0 + \langle u_t \rangle^2 \cdot m_0$$

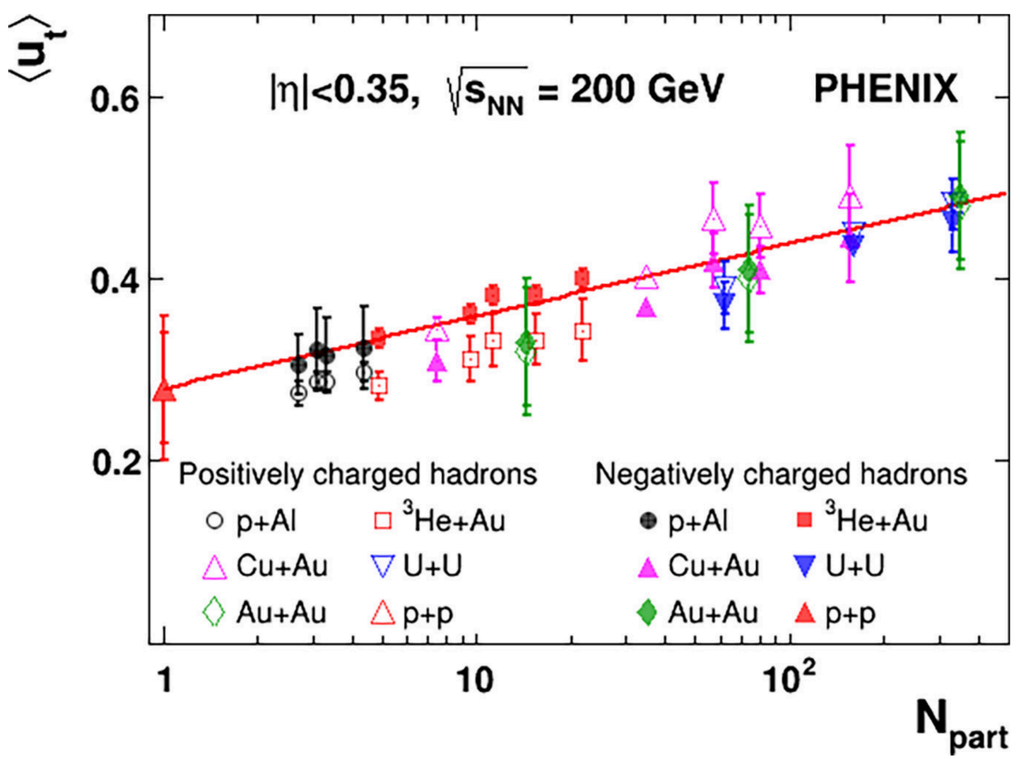
Thermodynamic parameters

Kinetic freeze out temperatures and average collective velocities as a function of number of participants



$$T_0 \approx 166 \pm 2 \text{ MeV}$$

$$\langle u_t \rangle \left(N_{part} \right) \approx p_1 \cdot \log p_2 \cdot N_{part}$$



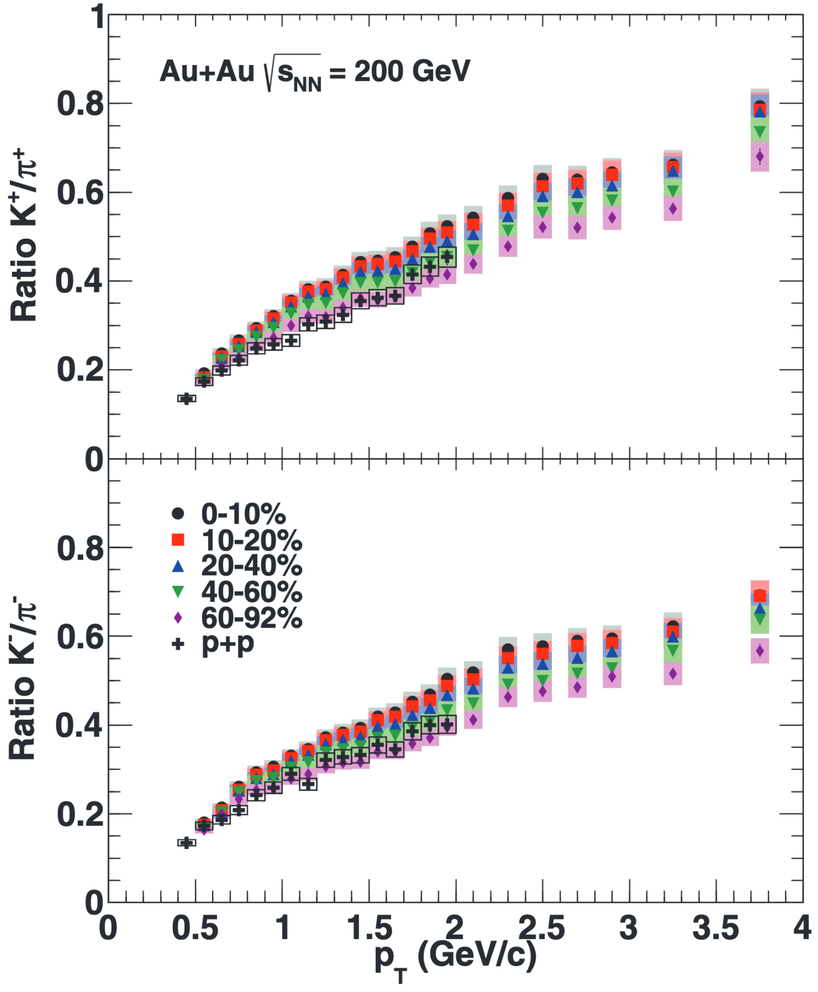
$$p_1 = 0.0345 \pm 0.0003,\ p_2 = 3196 \pm 342$$

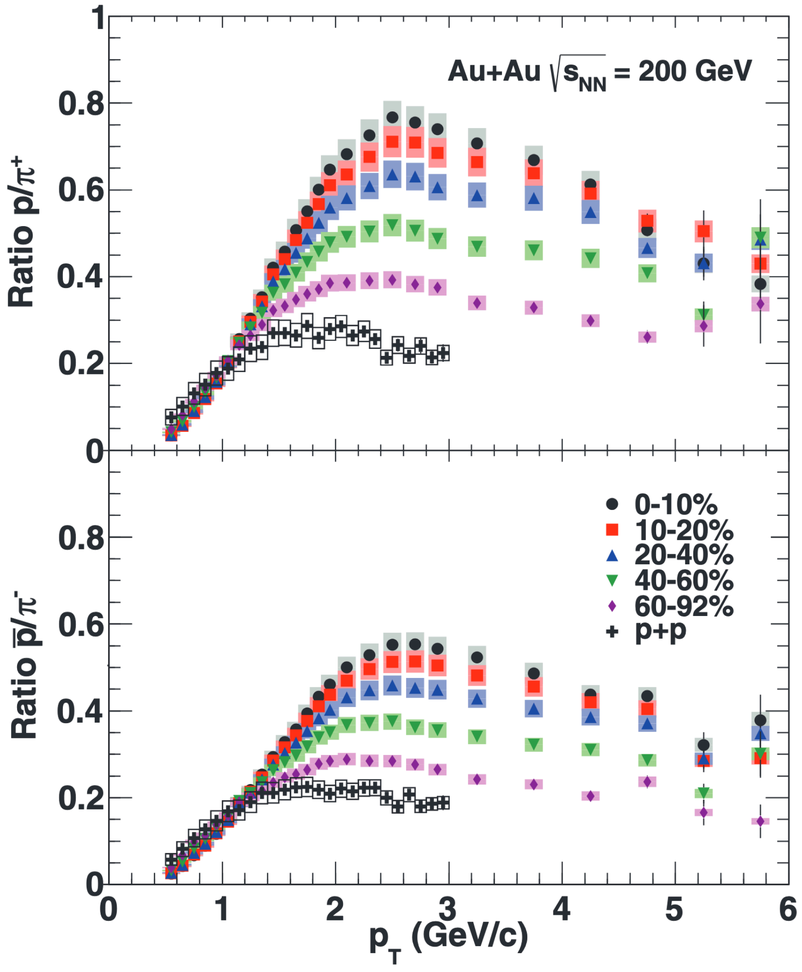
Error bars represent sums of systematic, statistic and fit uncertainties

K/π and p/π ratios

Previous results in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

PRC 88, 024906, 2013





$p_T > 1.5$ GeV/c

Enhancement of p/π values

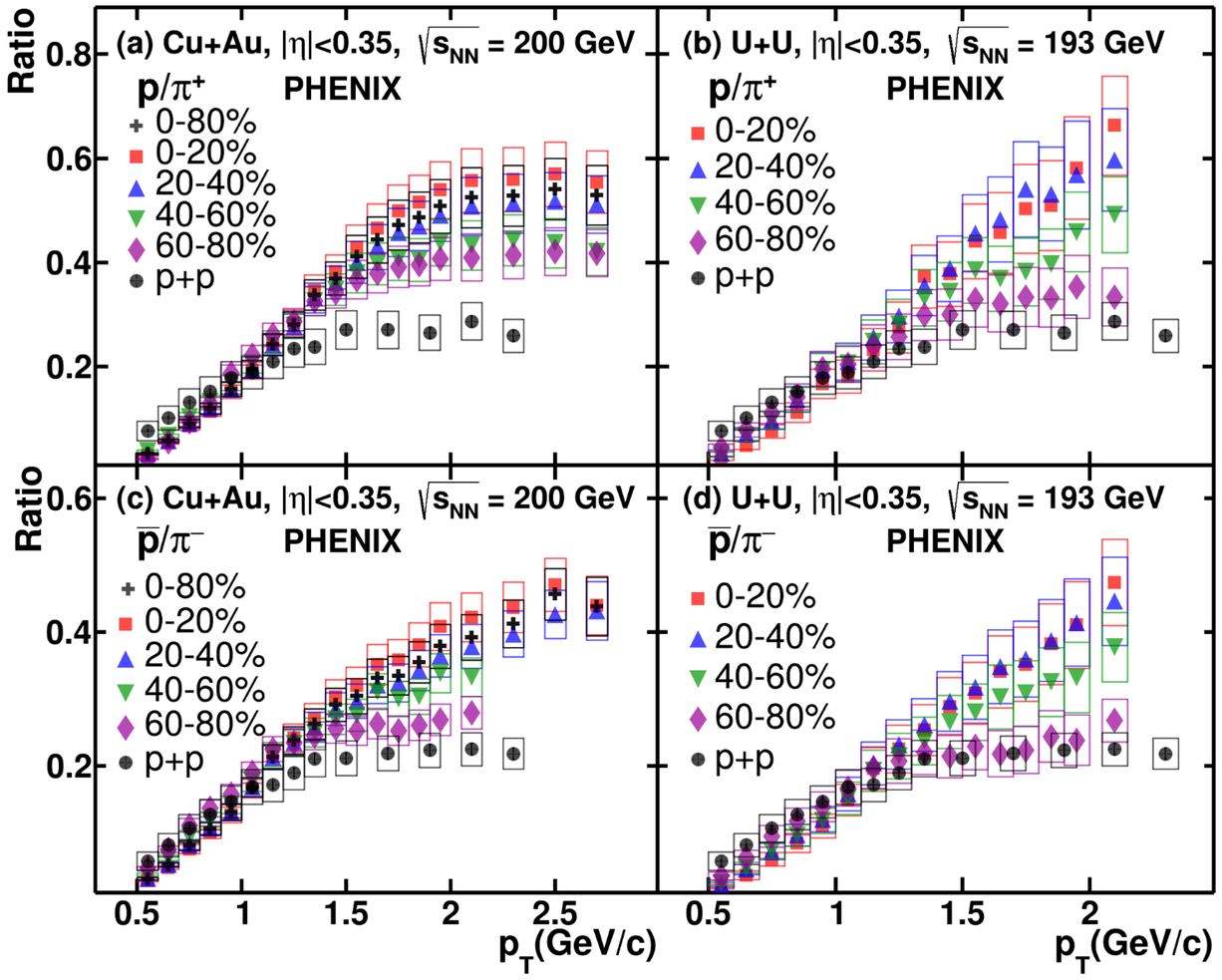
The p/π reach the value of 0.8

~ 2.5 larger than in $p + p$

- p/π – strong centrality dependence
- K/π – weak centrality dependence

p/π ratio in large collision systems

Cu+Au and U+U

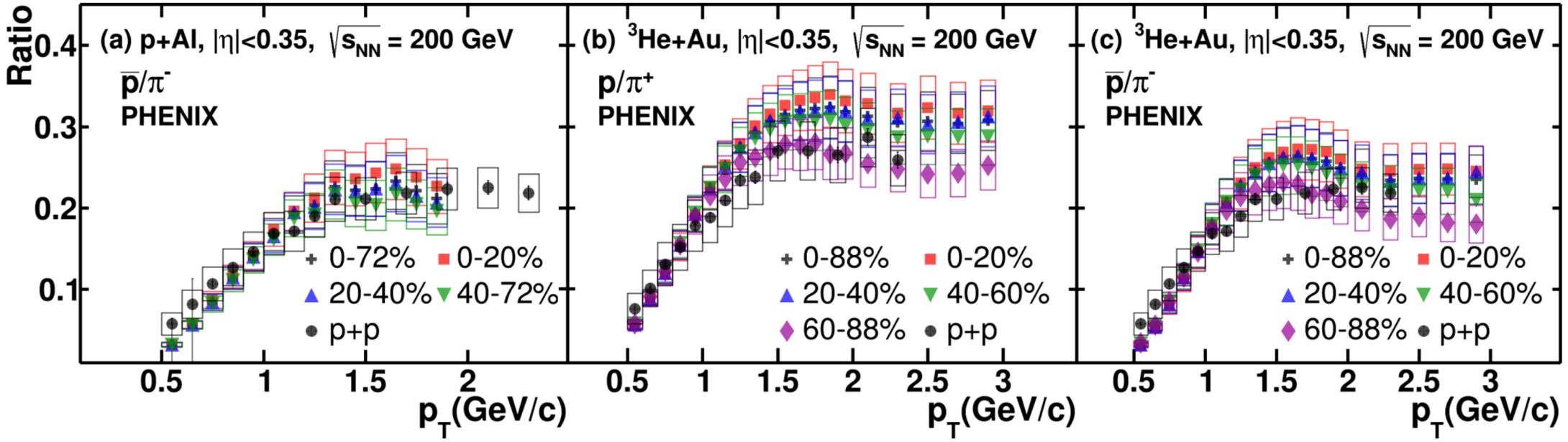


Large collision systems

- In central collisions p/π ratios reach the values of ≈ 0.6
- In peripheral collisions p/π ratios < 0.4
- Behavior of p/π ratios observed in Cu + Au and U + U collision systems can be qualitatively described using recombination models

p/π ratio in small collision systems

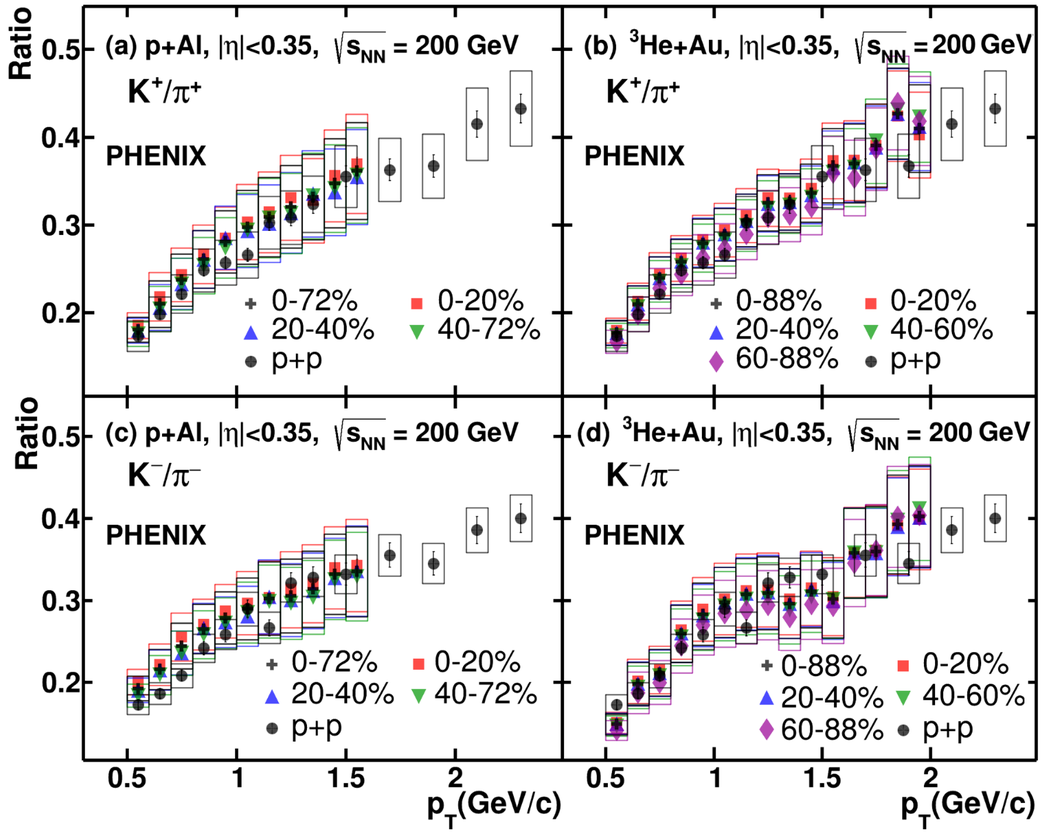
p+Al and ^{3}He+Au

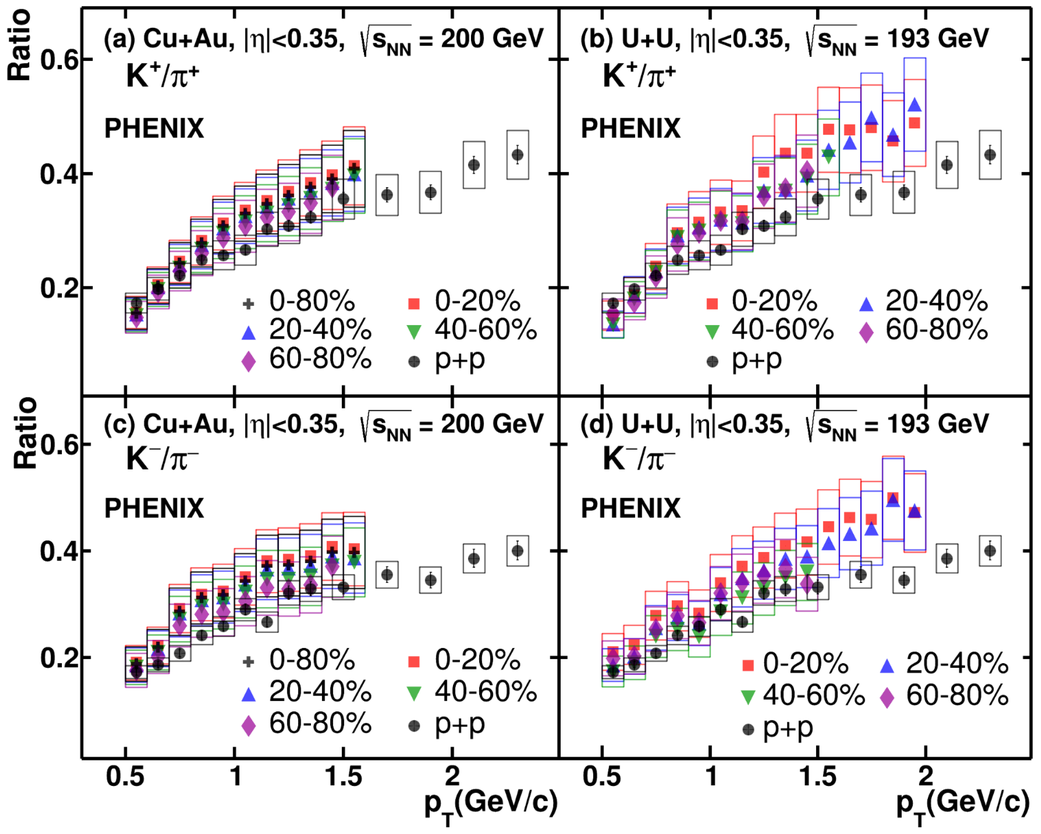


- The values of p/π ratios $\approx$ the values of ratios in $p + p$
- ^{3}He + Au - Modest centrality dependence, similar to that observed in d + Au collisions
- p + Al - The values of p/π ratios in all centrality classes consistent with the ones in $p + p$

K/π ratios in small and large collisions

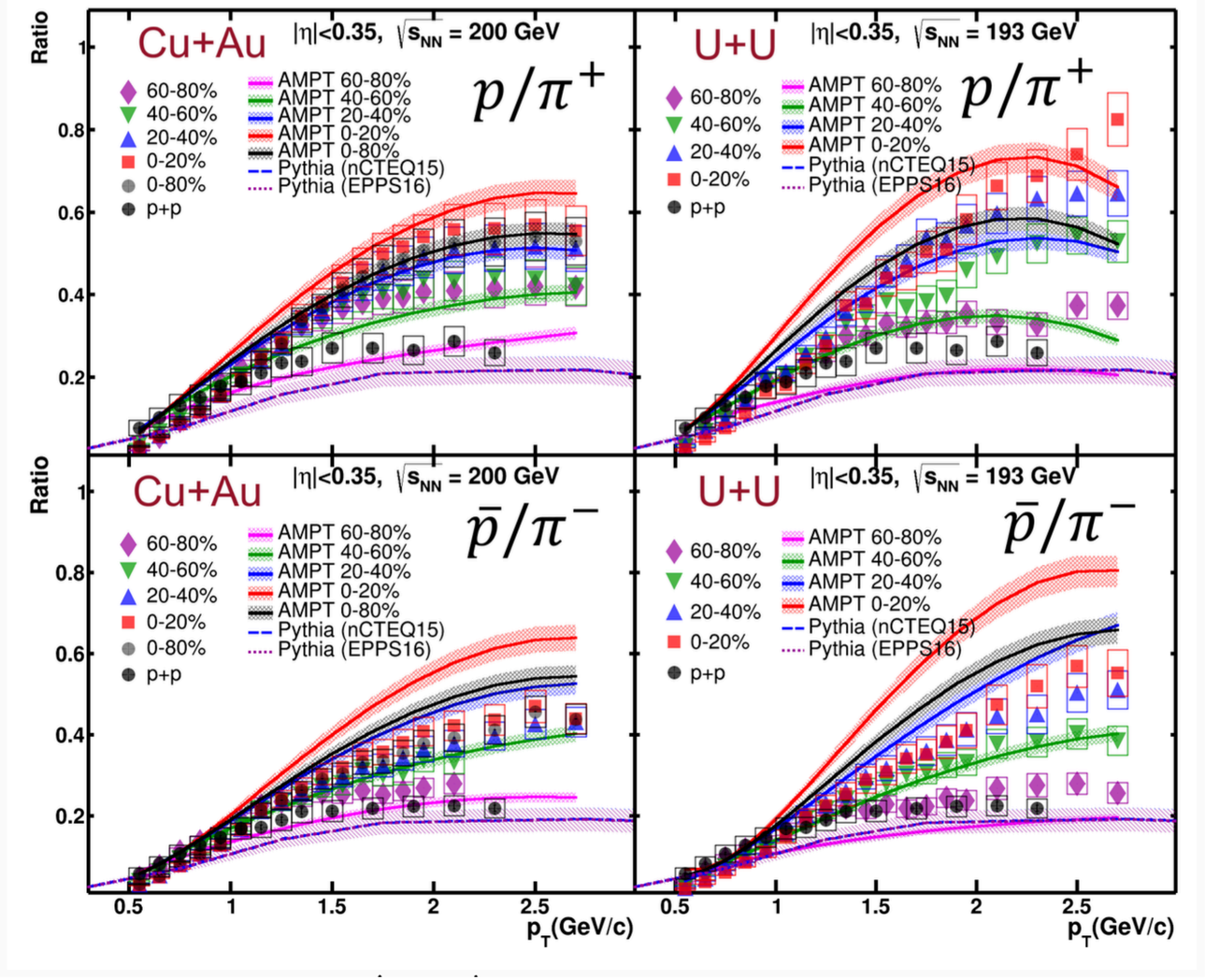
p+Al , ^{3}He+Au, Cu+Au, and U+U





- The values of K/π ratios show a modest centrality dependence, which is insignificant within systematic uncertainties
- The centrality dependence of K/π ratios in d + Au and Au + Au collisions was attributed to a strangeness-enhancement effect

Comparison to AMPT and PYTHIA model calculations



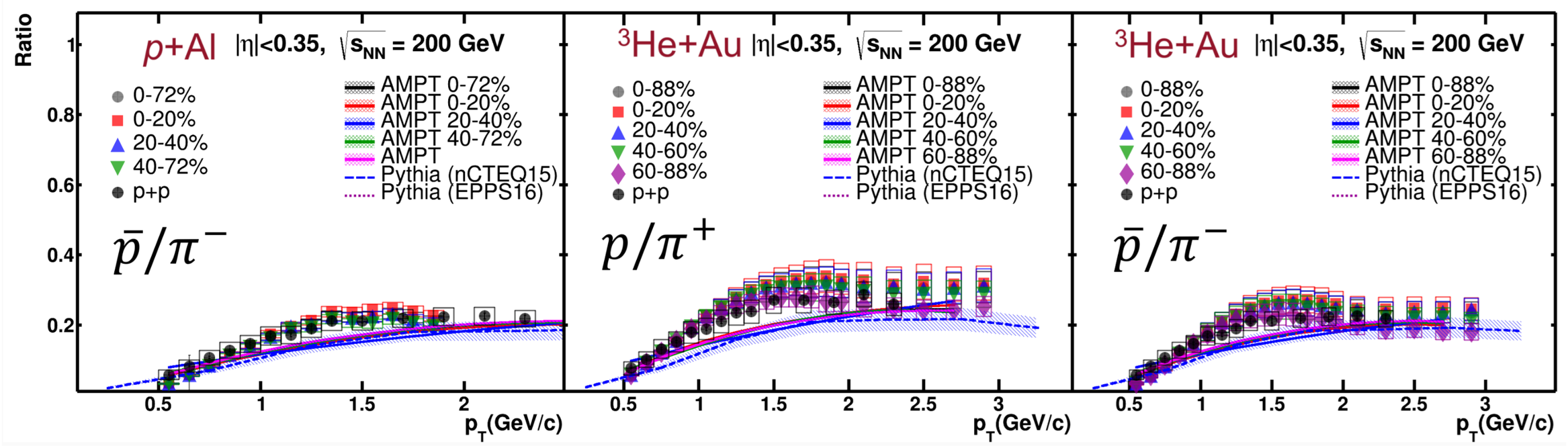
AMPT –
recombination + fragmentation

Qualitatively
(but not quantitatively) describes experimental data

PYTHIA –
fragmentation

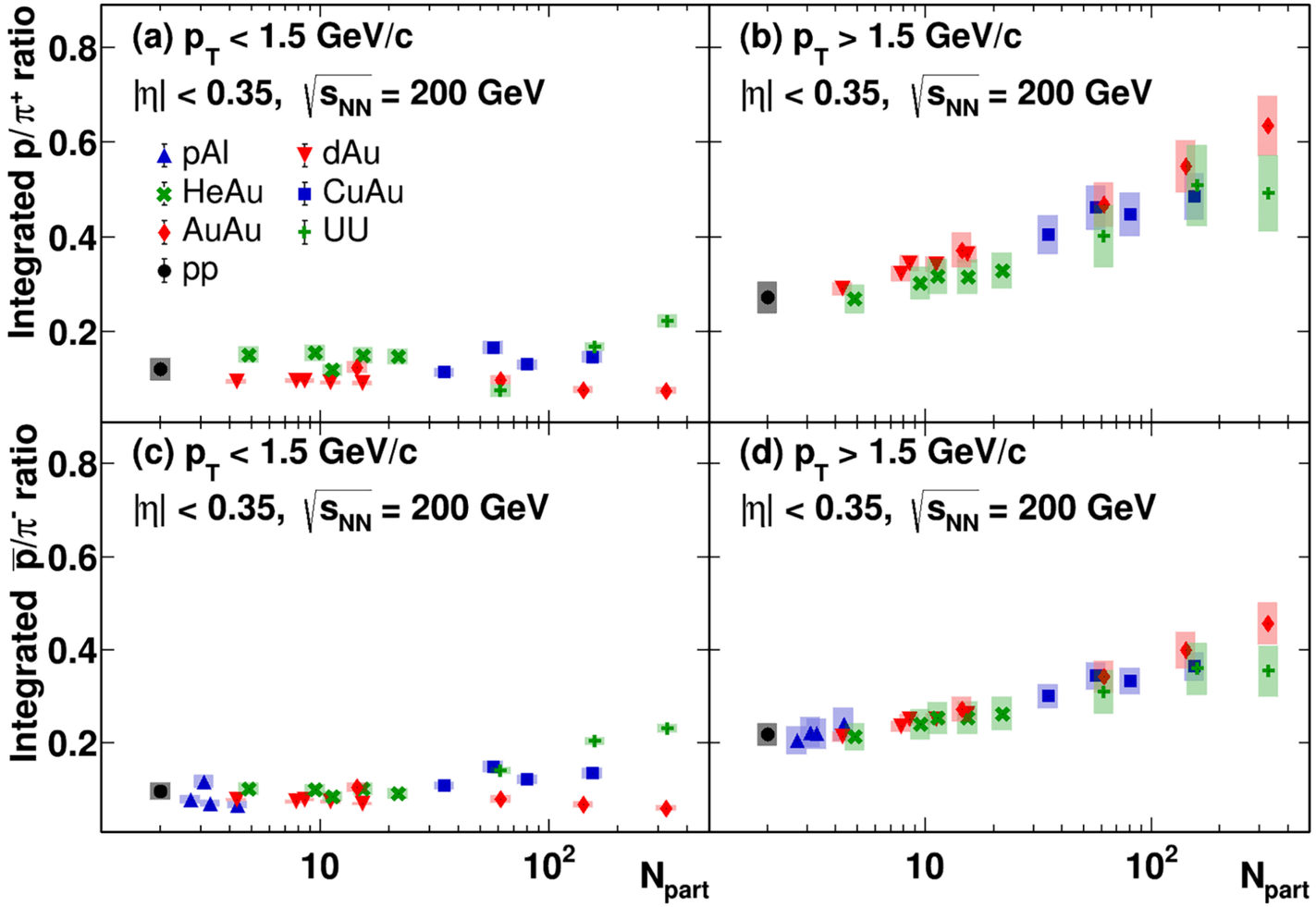
Does’t describe baryon enhancement

Comparison to AMPT and PYTHIA model calculations



- QGP signatures were observed in small collision systems
  - PHENIX Collaboration. Nature Physics, 15 (3), 2018
  - PHENIX Collaboration. Phys. Rev. C 105, 064912 (2022)
- The QGP volume is not sufficient for observation of baryon enhancement in *p*+Al collisions

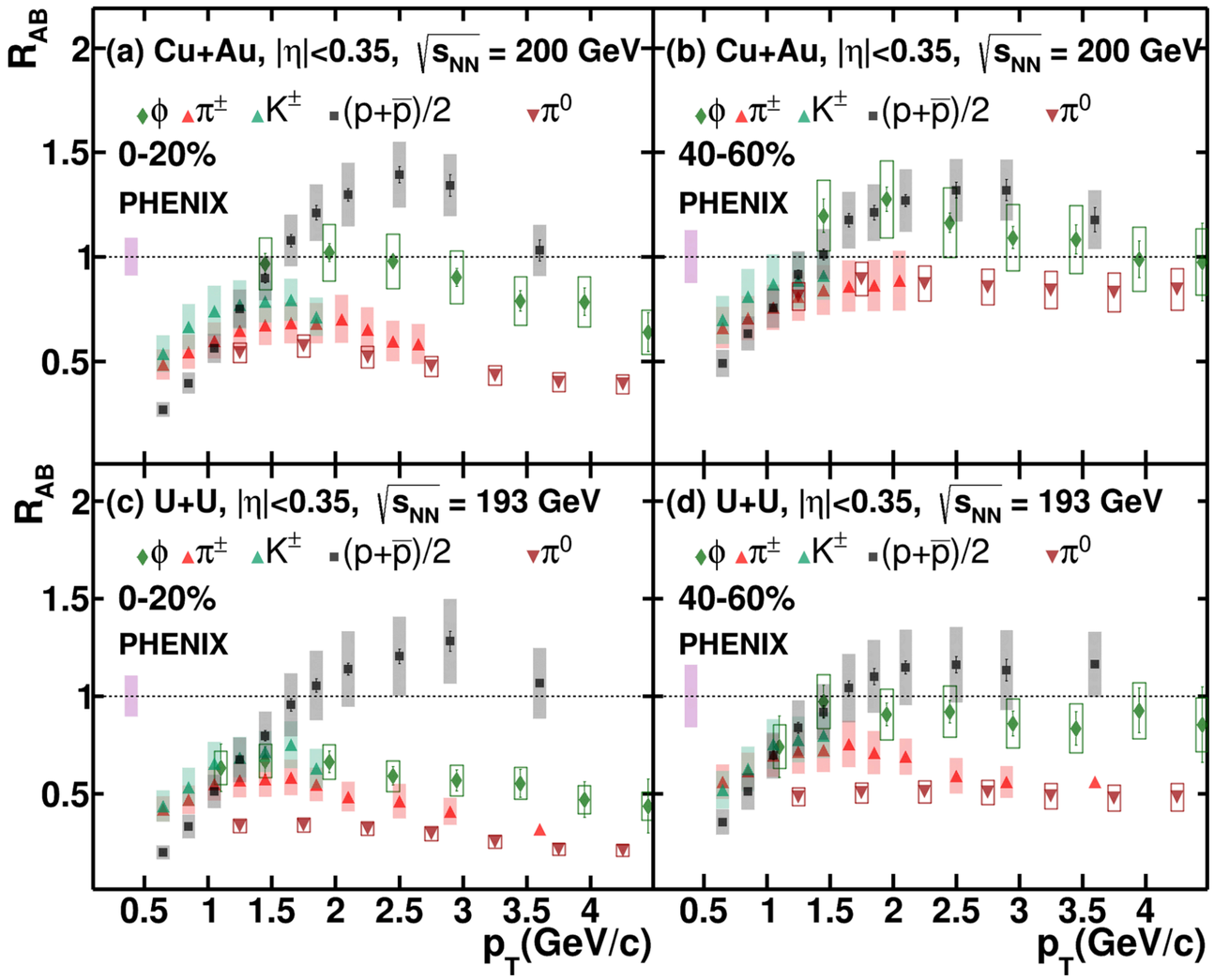
Integrated baryon to meson ratios



- Low-p_T region
  - Approximately independent of $\langle N_{part} \rangle$
- High-p_T region
  - Smoothly grow with increasing $\langle N_{part} \rangle$
- The $\bar{p}/p$ ratio ≈ 0.73 and $\pi^-/\pi^+ \approx 1$, regardless of $\langle N_{part} \rangle$ → the integrated p/π^+ ratios exceed the integrated $\bar{p}/\pi^-$ ratios
- Increase of the recombination role in particle production with increasing number of participant nucleons $\langle N_{part} \rangle$

Nuclear modification factors

Large collision systems



$$R_{AB} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2N_{A+B}}{dp_T dy} \frac{d^2N_{p+p}}{dp_T dy}$$

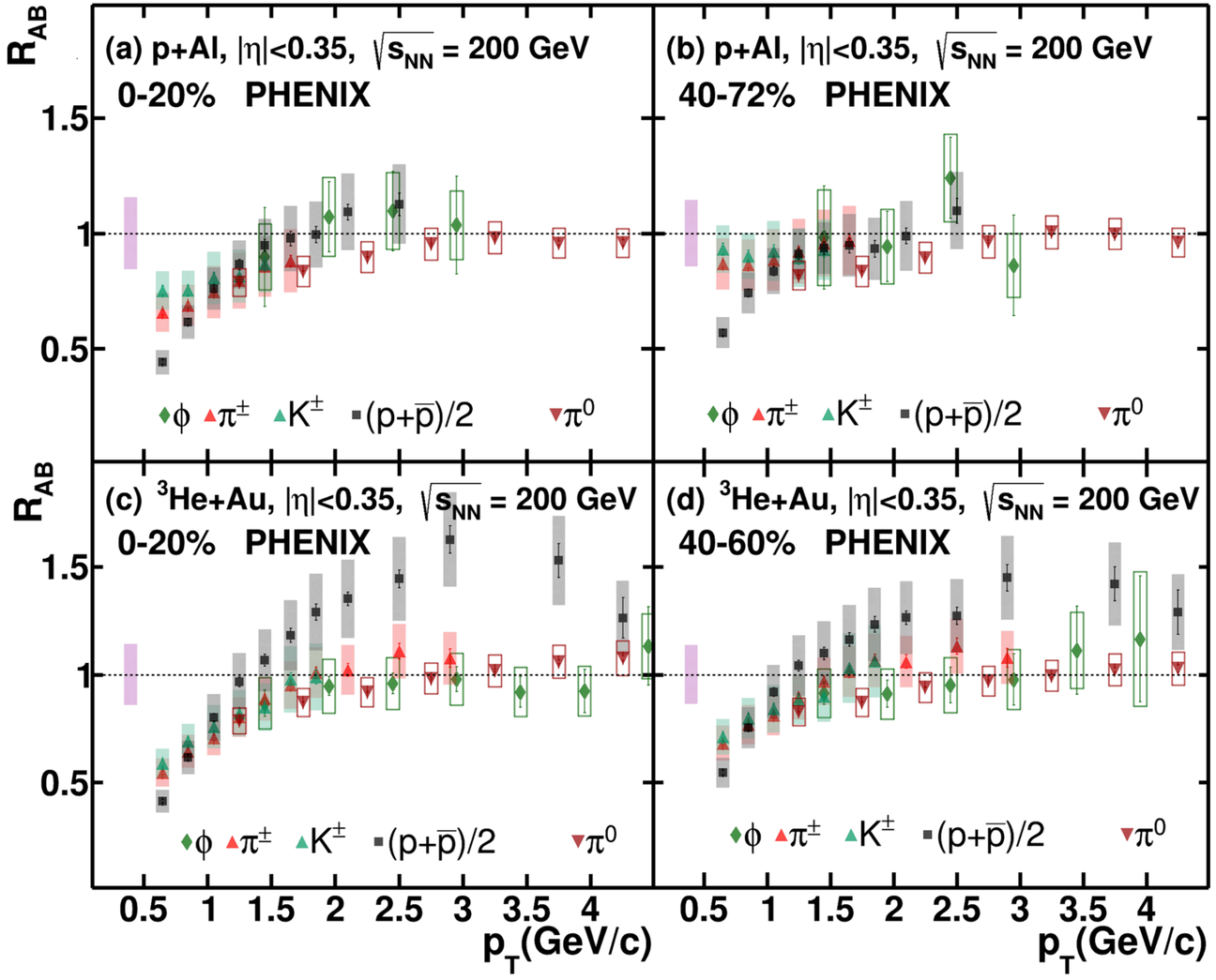
Cu + Au at $\sqrt{s_{NN}} = 200$ GeV and

U + U at $\sqrt{s_{NN}} = 200$ GeV

- **Hight** p_T
  Similar suppression for all particle species
  Energy loss
- **Intermediate** p_T
  $R_{AB}\ (p + \bar{p})/2 > R_{AB}\ \phi > R_{AB}\ \pi$
- **Low** p_T
  Similar suppression for all particle species
  Cold nuclear matter effects

Nuclear modification factors

Small systems



$$R_{AB} = \frac{1}{\langle N_{coll} \rangle} \frac{d^2N_{A+B}}{dp_T dy} \frac{d^2N_{p+p}}{dp_T dy}$$

Intermediate p_T

- $p + \mathrm{Al}$

  $R_{AB}\ (p + \bar{p})/2 \approx\ R_{AB}\ \phi \approx R_{AB}\ \pi$

- $^3\mathrm{He} + \mathrm{Au}$

  $R_{AB}\ (p + \bar{p})/2\ > R_{AB}\ \phi \approx R_{AB}\ \pi$

SUMMARY

- The values of freeze-out temperatures T_0 and average collective velocities $\langle u_t \rangle$ have been obtained
  - The T_0 values - no dependence on the collision centrality and $\langle N_{part} \rangle$ values
  - The $\langle u_t \rangle$ values - smoothly increase with increasing of $\langle N_{part} \rangle$ values
  - In collisions characterized by large $\langle N_{part} \rangle$ values collective effects are more pronounced than in collision systems with small $\langle N_{part} \rangle$ values
- Baryon enhancement in intermediate p_T range in central ^{3}He+Au, Cu+Au, U+U
- Strangeness enhancement in intermediate p_T range in Cu+Au and U+U
- Observation of signatures, that can be attributed as an evidence of QGP formation, reveal a smooth transition from small to large collision systems and the nature of this transition needs further investigation

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THANK YOU FOR YOUR ATTENTION!