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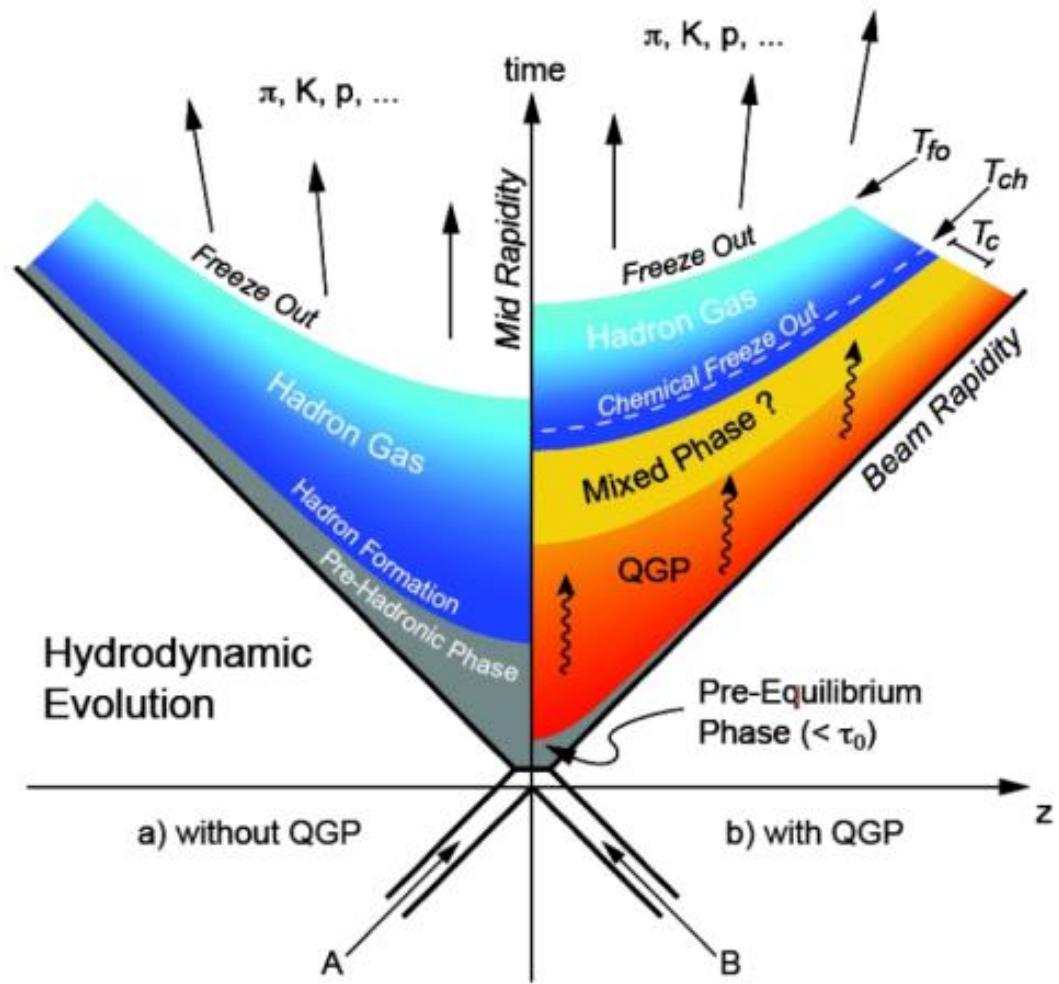
PHENIX results on identified hadron production in small and large collision systems

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for the PHENIX collaboration

Collision evolution



QGP – is a state of matter which exists at extremely high temperature and/or density.
 $(T \sim 170 \text{ MeV}, \rho \sim 1 \text{ GeV/fm}^3)$

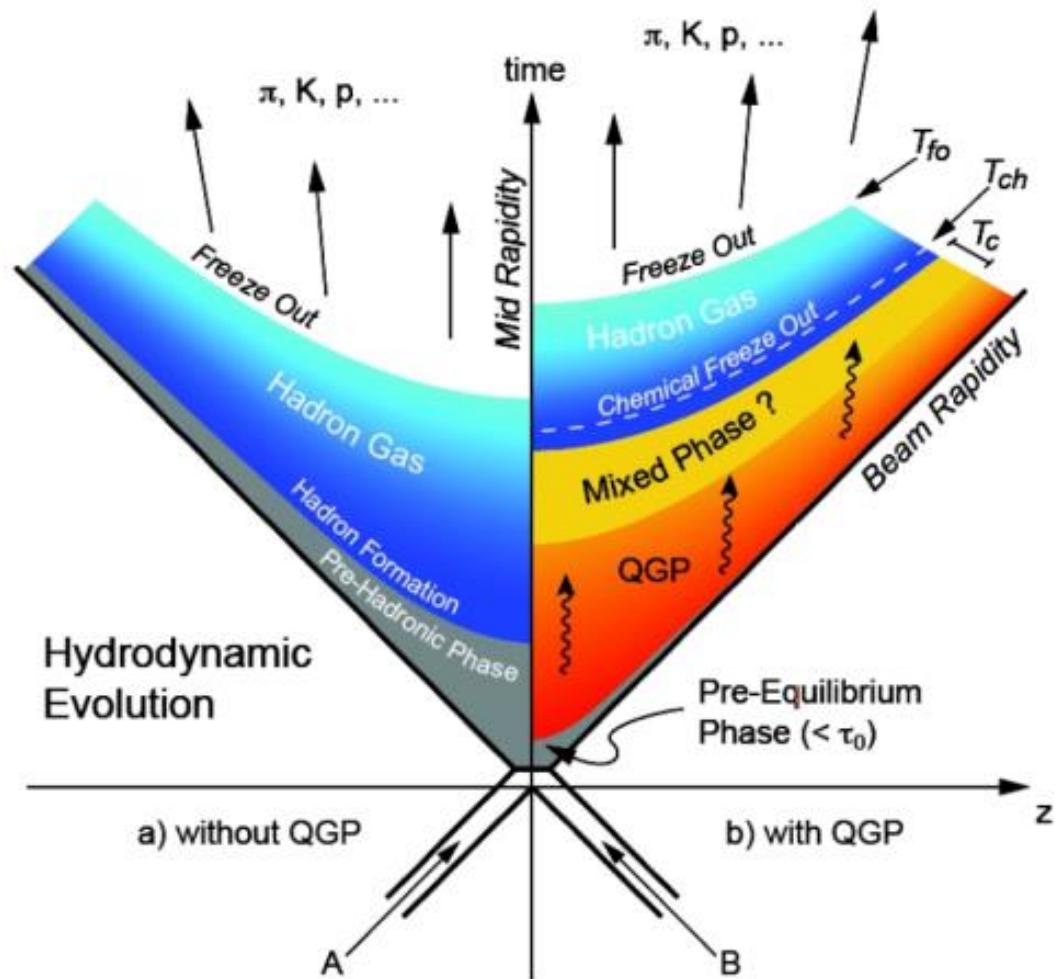
Signatures of QGP formation

- Strangeness enhancement
- Jet quenching
- Baryon enhancement
- Elliptic flow
- Charm production

Cold-Nuclear matter effects

- Multiple-parton scattering
- Modification of the initial parton distribution functions (PDFs)

Collision evolution



Hadronization of the QGP medium at the critical temperature

- Transition from a deconfined medium composed of quarks, antiquarks and gluons to color-neutral hadronic matter
- The partonic degrees of freedom of the deconfined phase convert into hadrons, in which partons are confined

No first-principle description of hadron formation

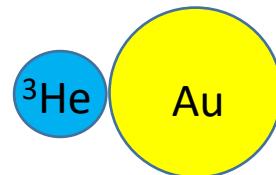
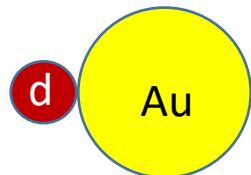
Non-perturbative problem, not calculable with QCD

Collision systems

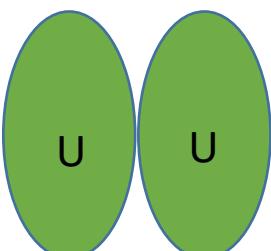
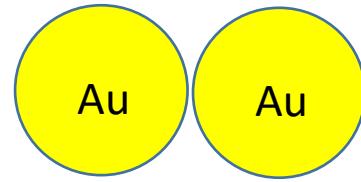
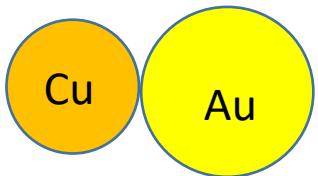
- Reference collisions:
p+p



- Small collision systems:
p+Al, d+Au, $^3\text{He}+\text{Au}$
Cold Nuclear Matter effects
QGP effects?



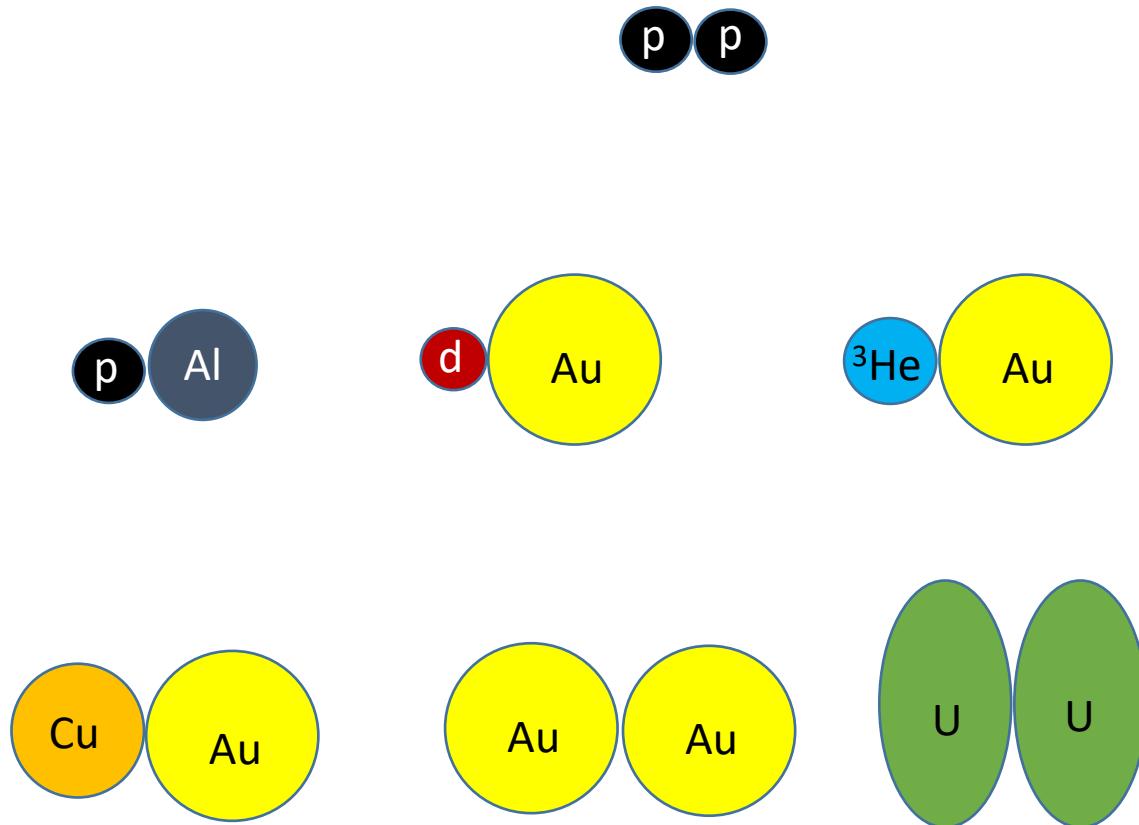
- Large collision systems:
Cu+Au, Au+Au, U+U
Cold Nuclear Matter effects
QGP effects



Nuclear modification factors (R_{AB})

- Study of collective effects that affect particle invariant p_T spectra
- Calculated according to the formula:

$$R_{AB}(p_T) = \frac{1}{N_{coll}} \frac{d^2 N_{AB}(p_T)/dydp_T}{d^2 N_{pp}/dydp_T}$$



PHENIX

(Pioneering High Energy Nuclear Interaction eXperiment)

Detectors in the central spectrometer arms
 $(|\eta| < 0.35)$

Charged Particle Tracking & Momentum measurements:

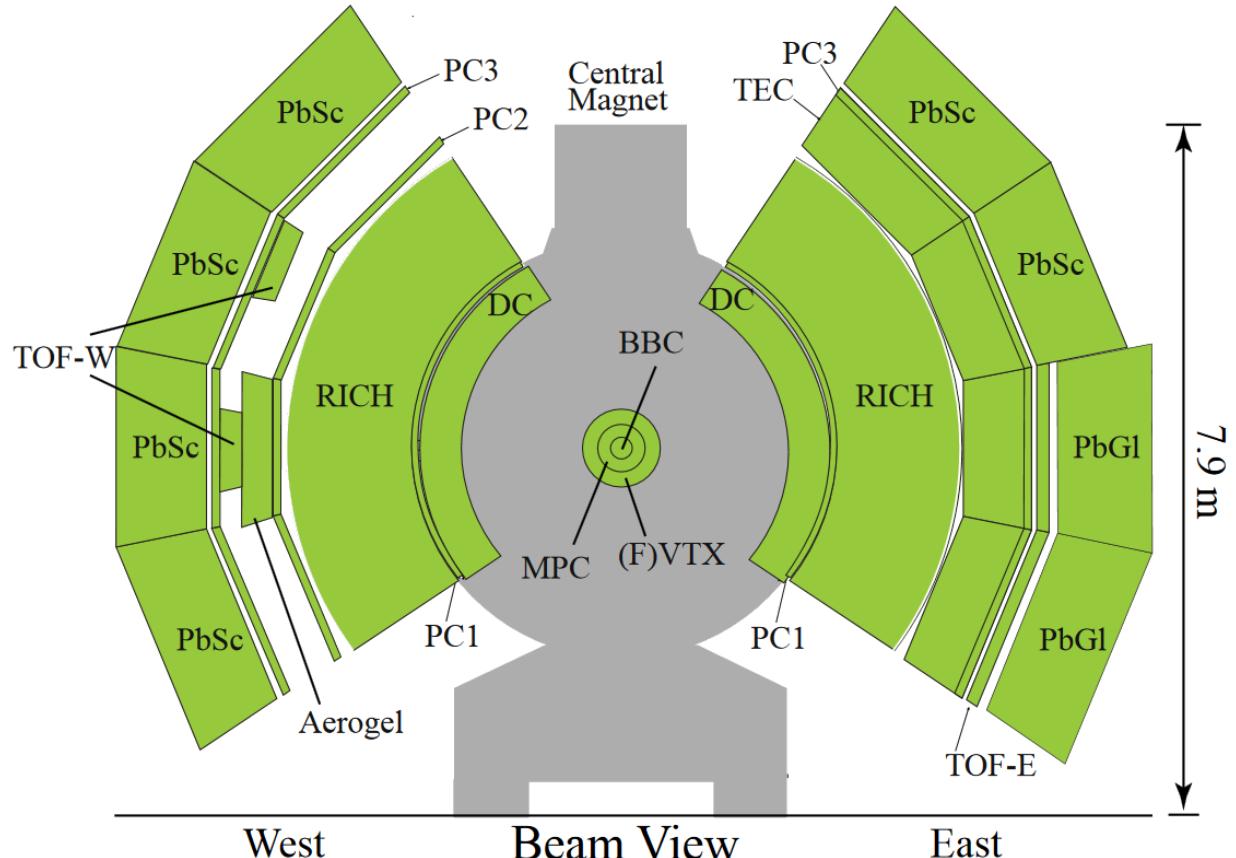
- Drift-Chambers (DC) and first layer of pad chambers (PC1)

Identification of charged hadrons:

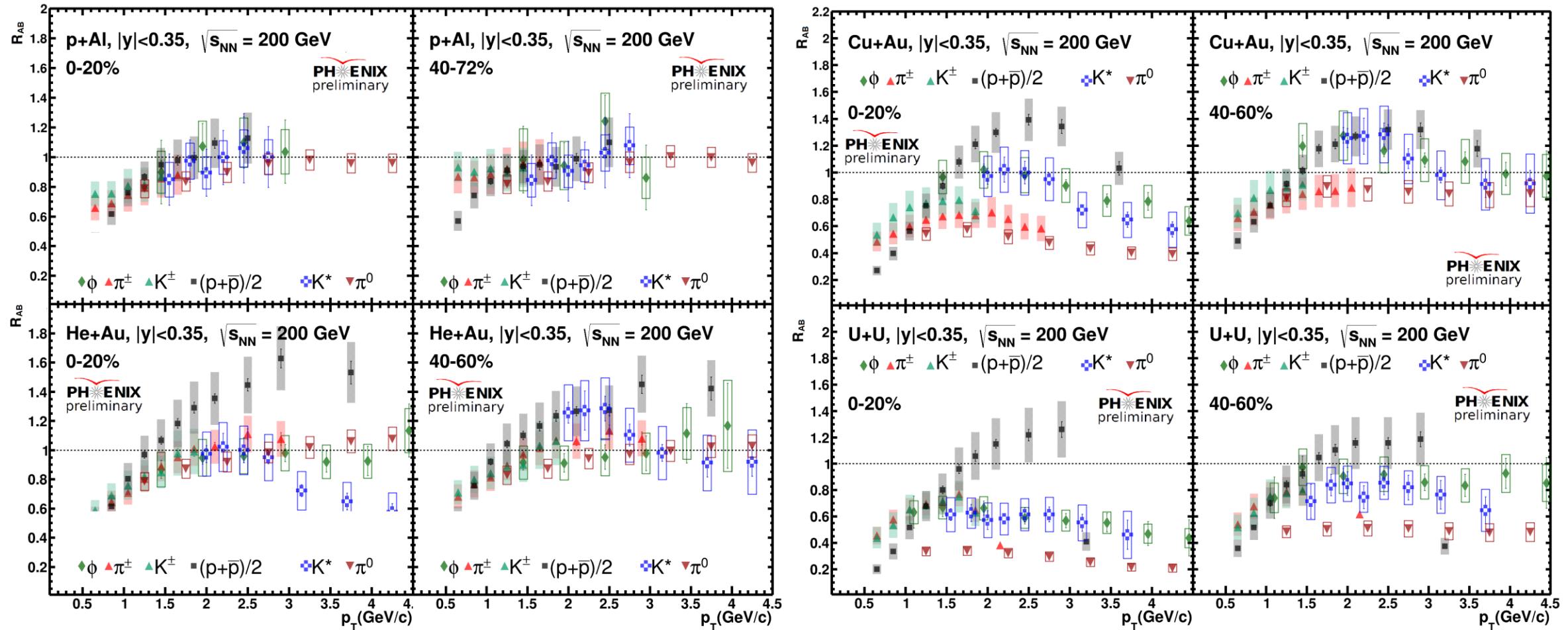
- Time-of-Flight (TOF) with start signal from the Beam-Counters (BBC)

Centrality identification:

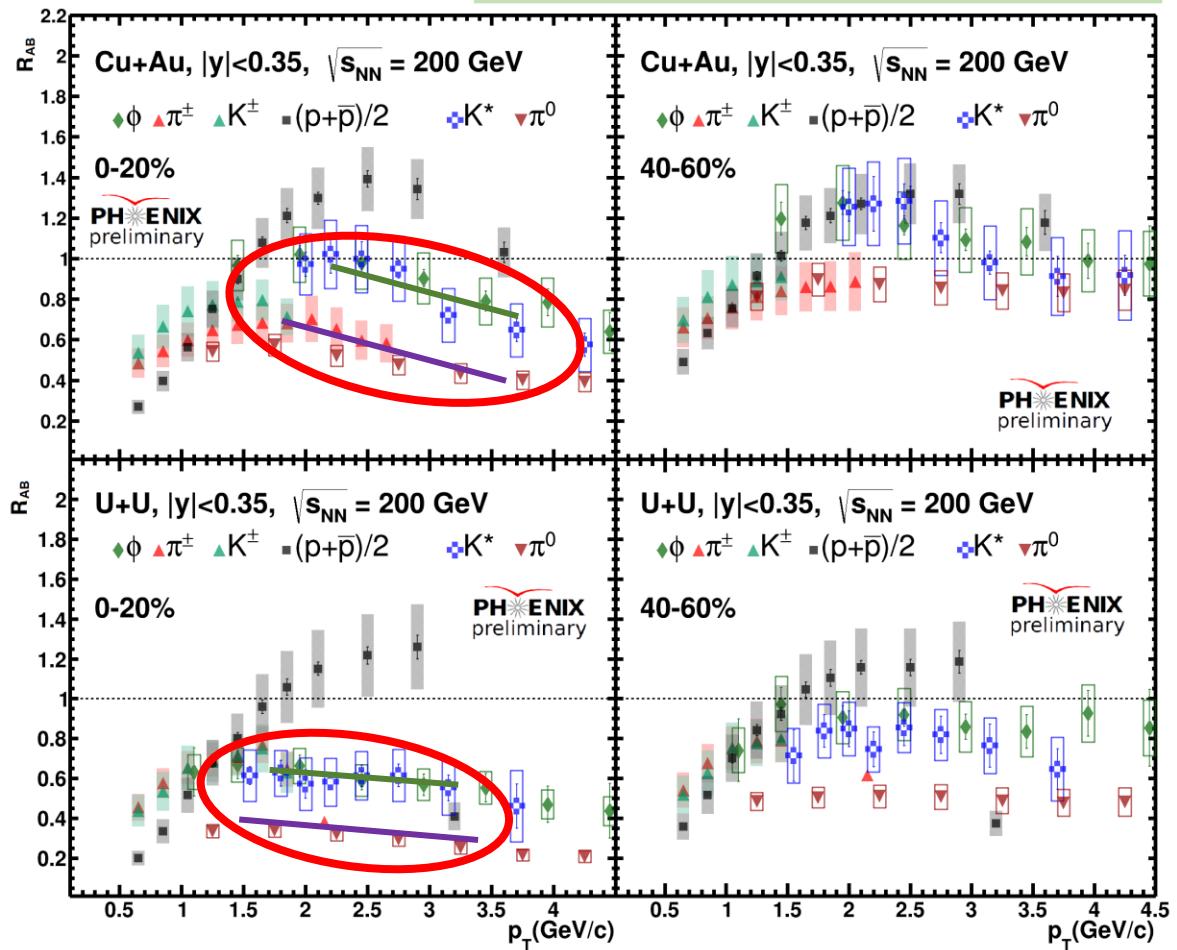
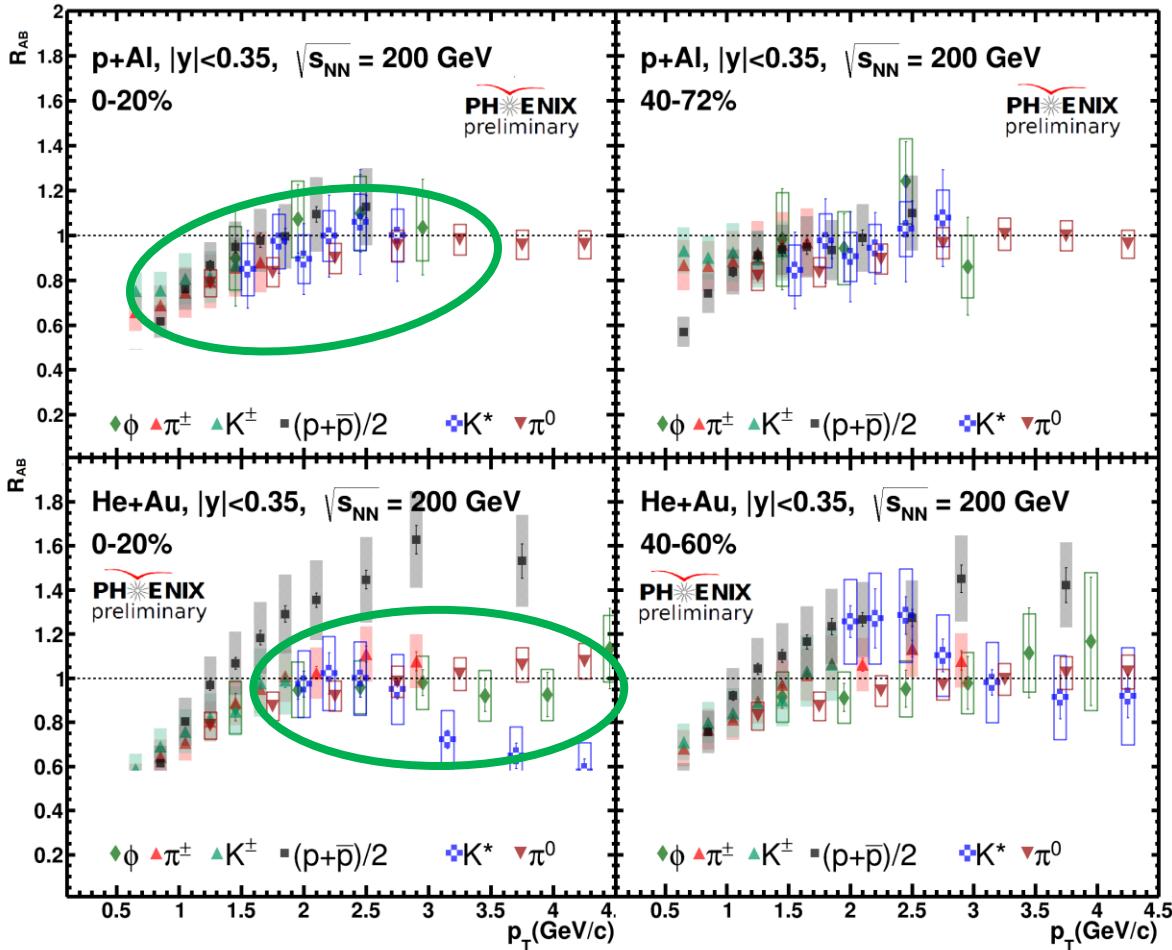
- BBC detectors (beam-beam counters)



Light hadron R_{AB} in small and large systems

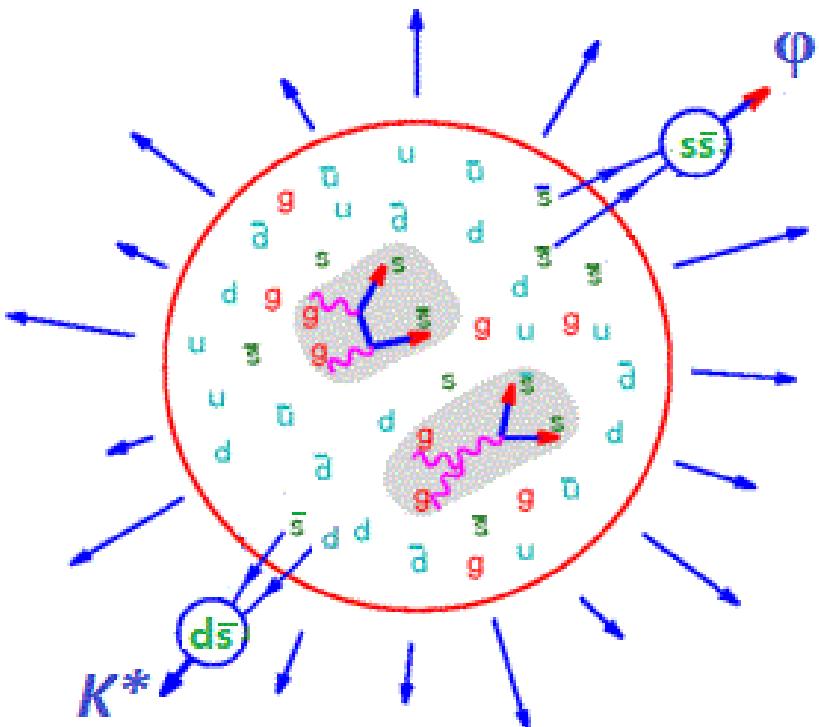
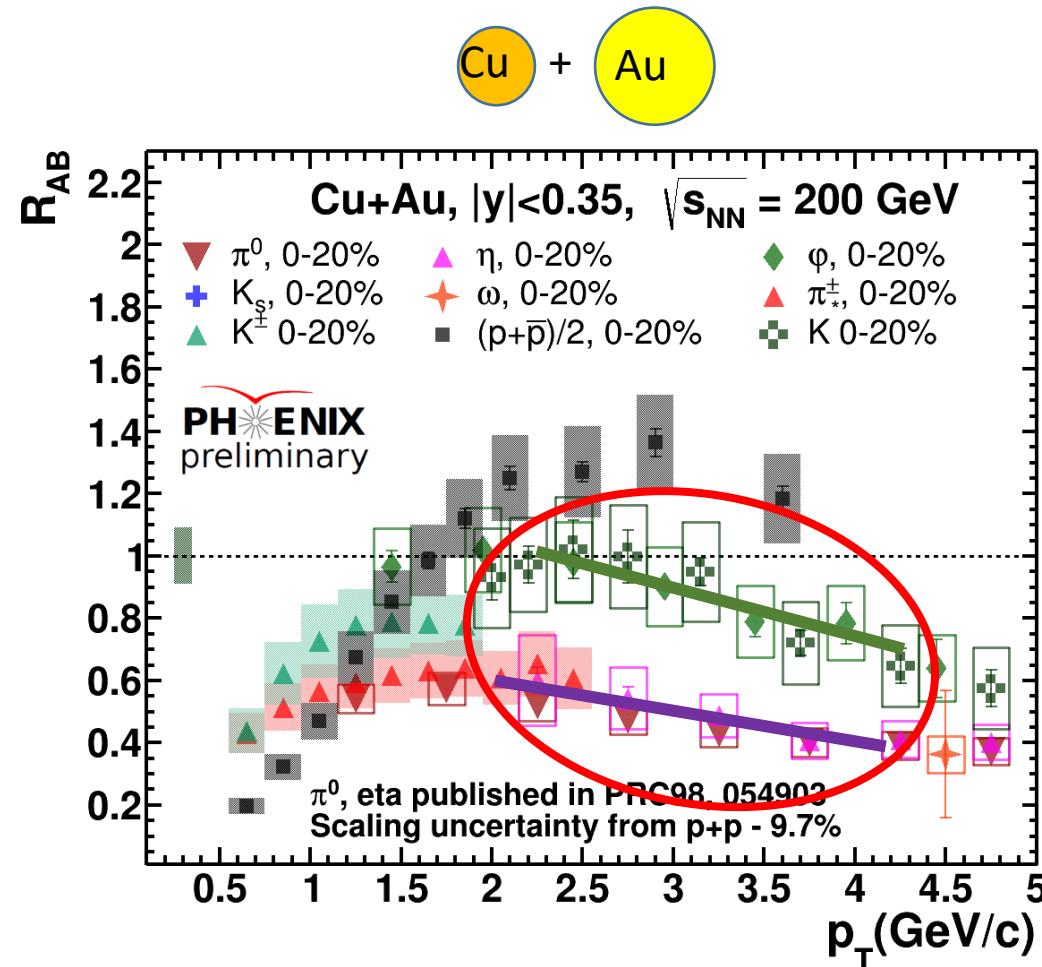


Light hadron R_{AB} in small and large systems

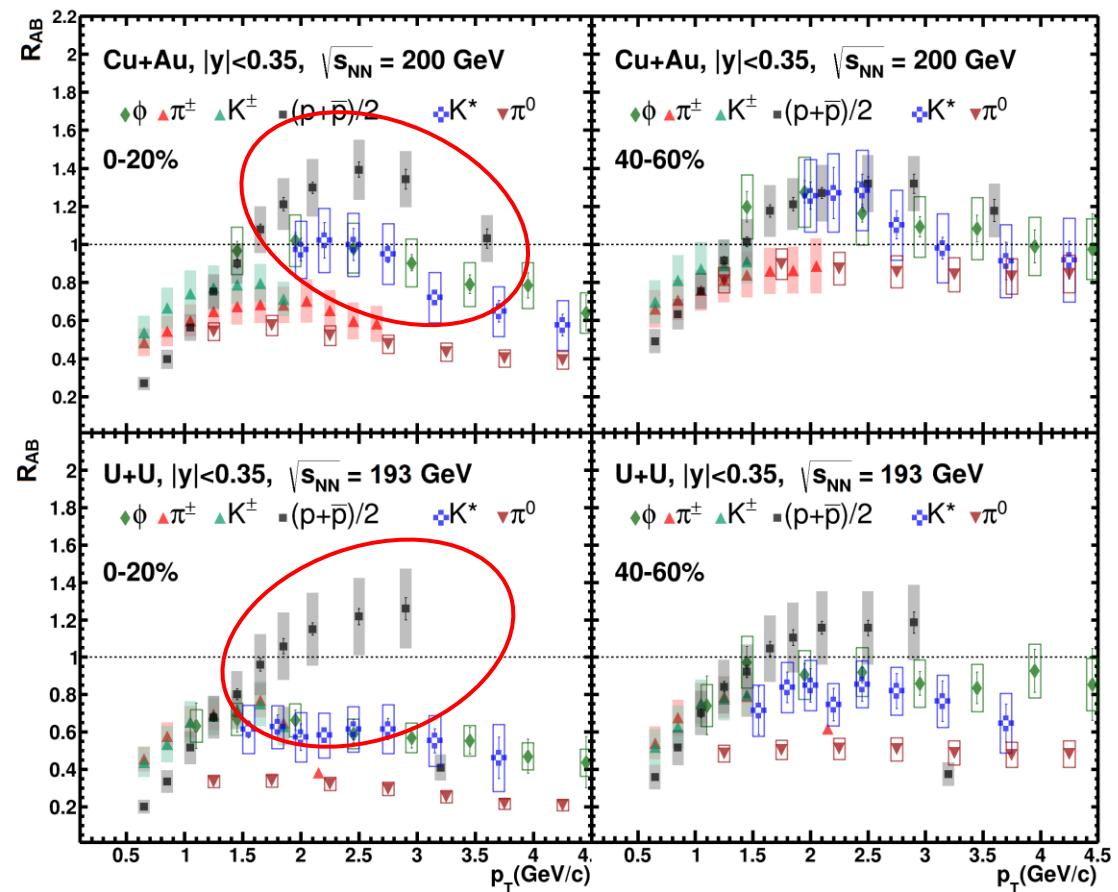
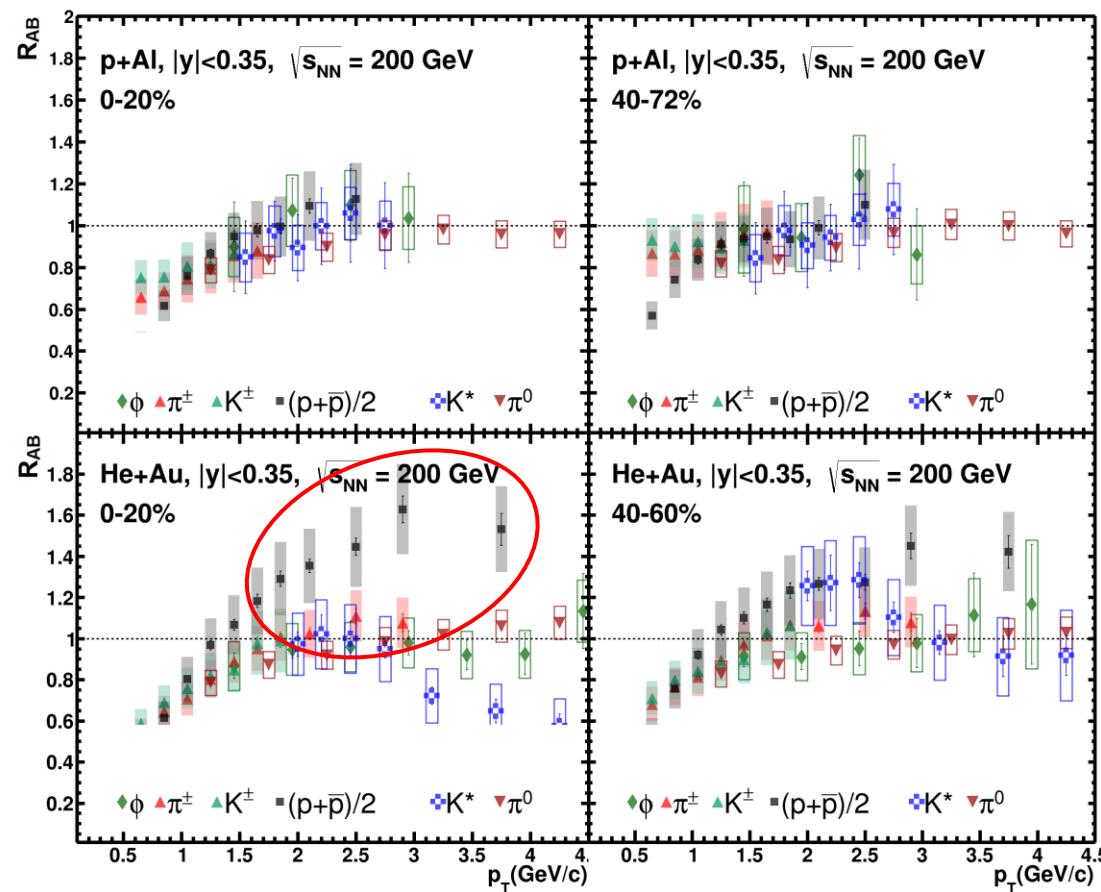


$$R_{AB}^\phi < R_{AB}^p, m_\phi \approx m_p$$

Strangeness enhancement

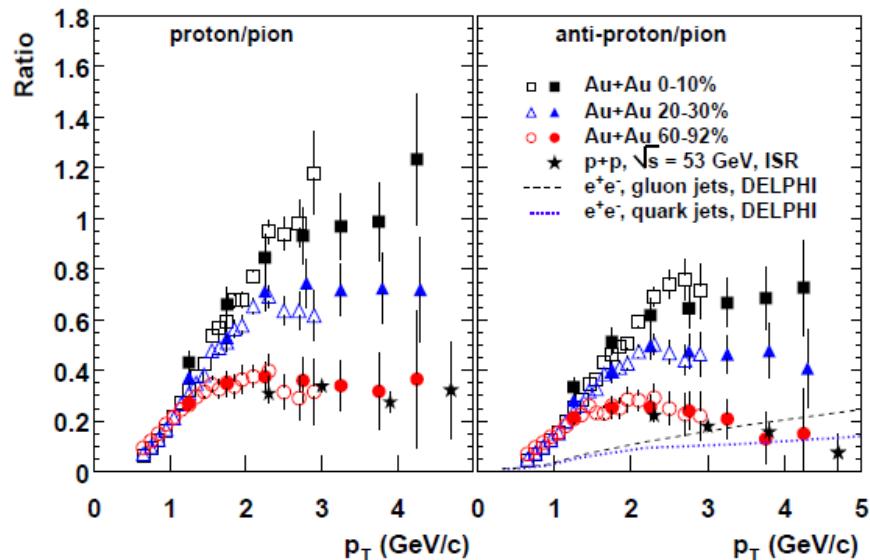


Light hadron R_{AB} in small and large systems

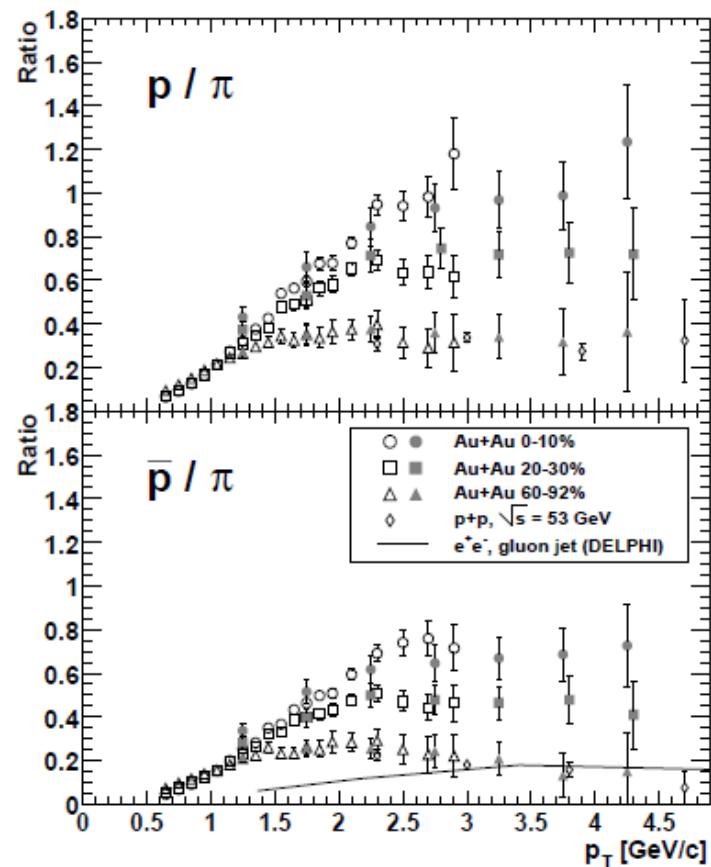


Baryon enhancement

Baryon Puzzle - Anomalous large ratio of protons (3 quarks) to π -mesons (2 quarks) yields in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV discovered by PHENIX



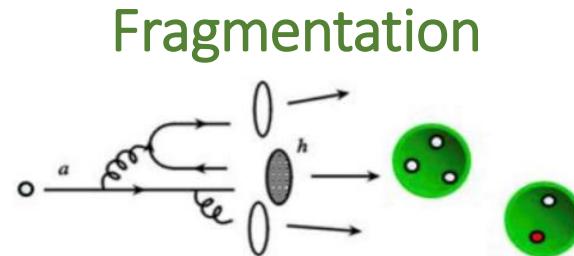
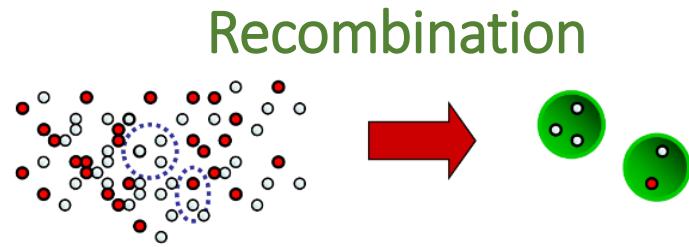
PHENIX collaboration, Phys.Rev.Lett.91:172301,2003



PHENIX collaboration, Phys.Rev.C69:034909,2004

Strong centrality dependence of p/π ratios
Recombination model of QGP hadronization

QGP hadronization



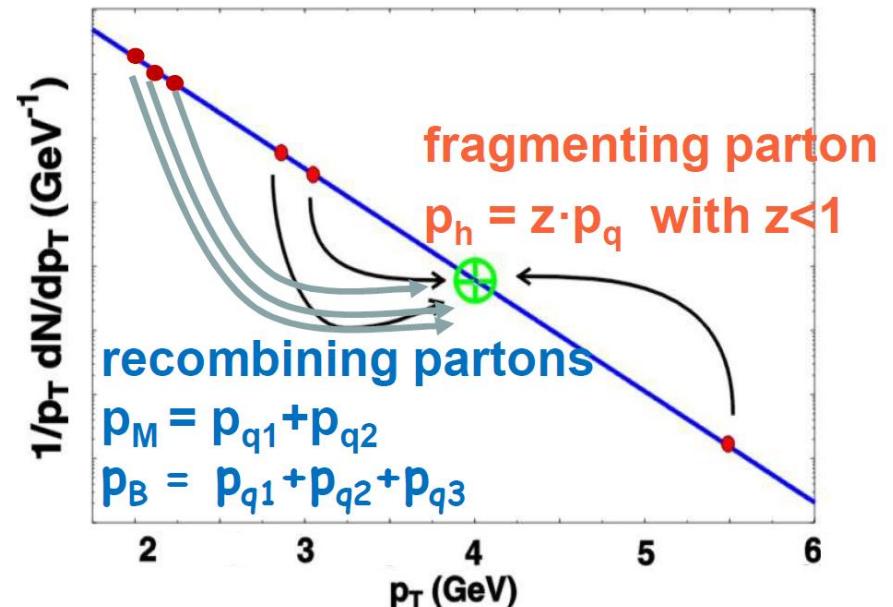
Phase space at the hadronization is filled with partons

- Single parton description may not be valid anymore
- No need to create $\bar{q}q$ pairs via splitting/string breaking
- Partons that are “close” to each other in phase space (position and momentum) can simply recombine into hadrons

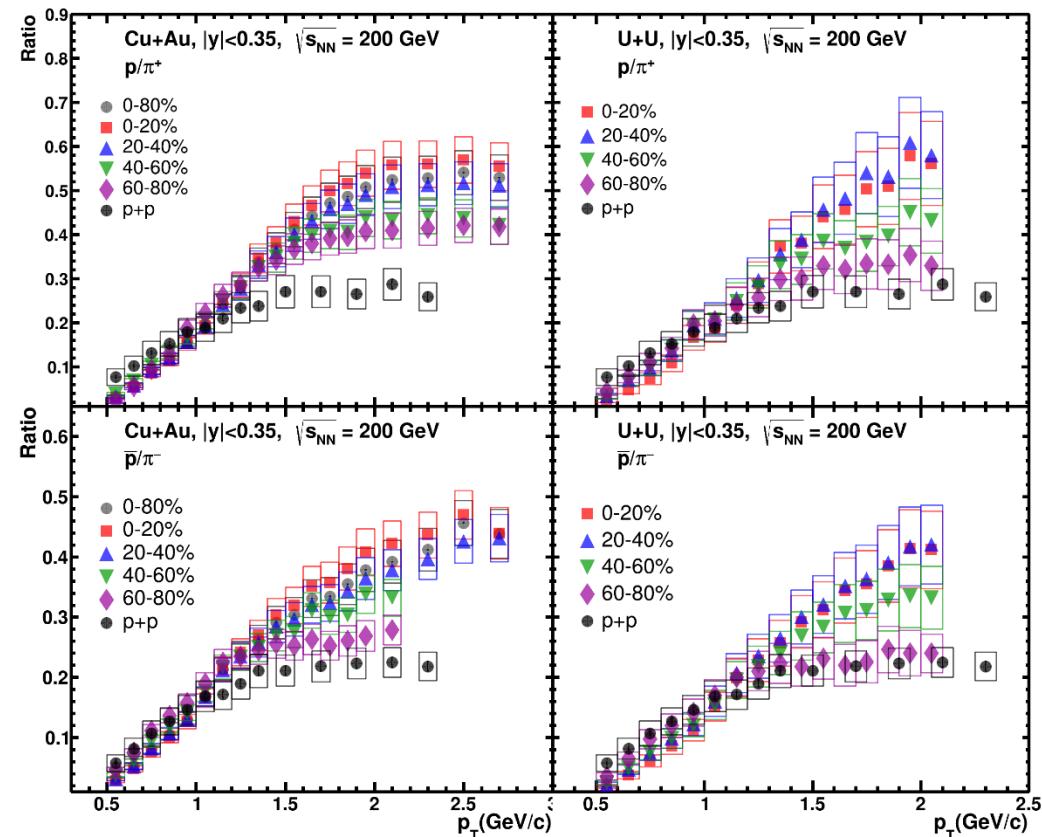
Recombination and Fragmentation are competing mechanisms at the intermediate p_T range

Baryon puzzle was explained in the frame of recombination models, so baryon enhancement can be used as a tool for exploring small systems

 Ann. Rev. Nucl. Part. Sci. 2008. V. 58. P. 177-205



The ratios of p/π in Cu+Au and U+U collisions

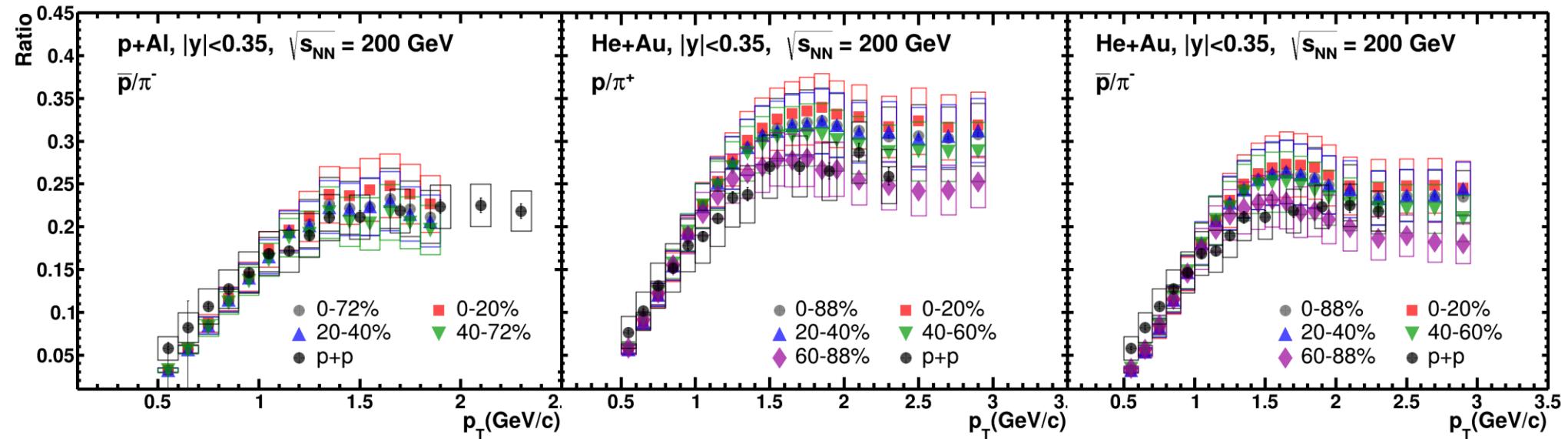


$$(p/\pi)_{Cu+Au,U+U}^{0-20\%} \gg (p/\pi)_{p+p}$$

$$(p/\pi)_{Cu+Au,U+U}^{60-80\%} \approx (p/\pi)_{p+p}$$

Centrality dependence

The ratios of p/π in p+Al and He+Au collisions



$$(p/\pi)_{Cu+Au,U+U}^{All centr.} \approx (p/\pi)_{p+p}$$

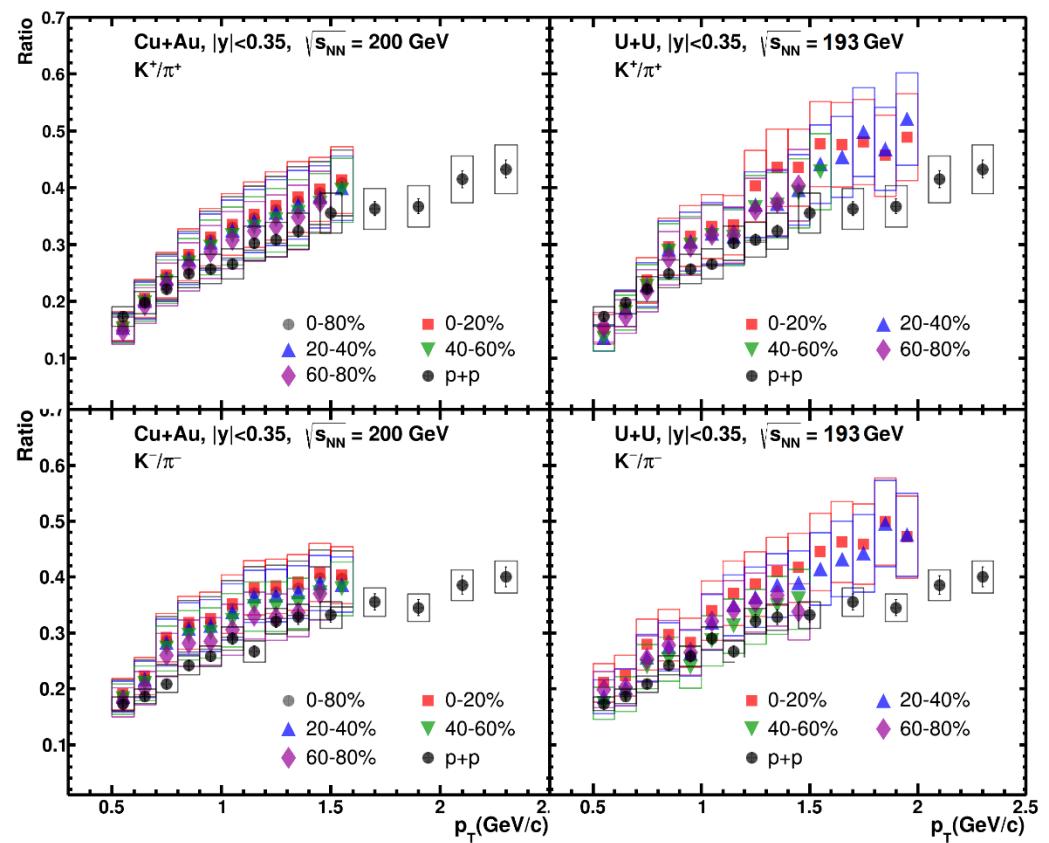
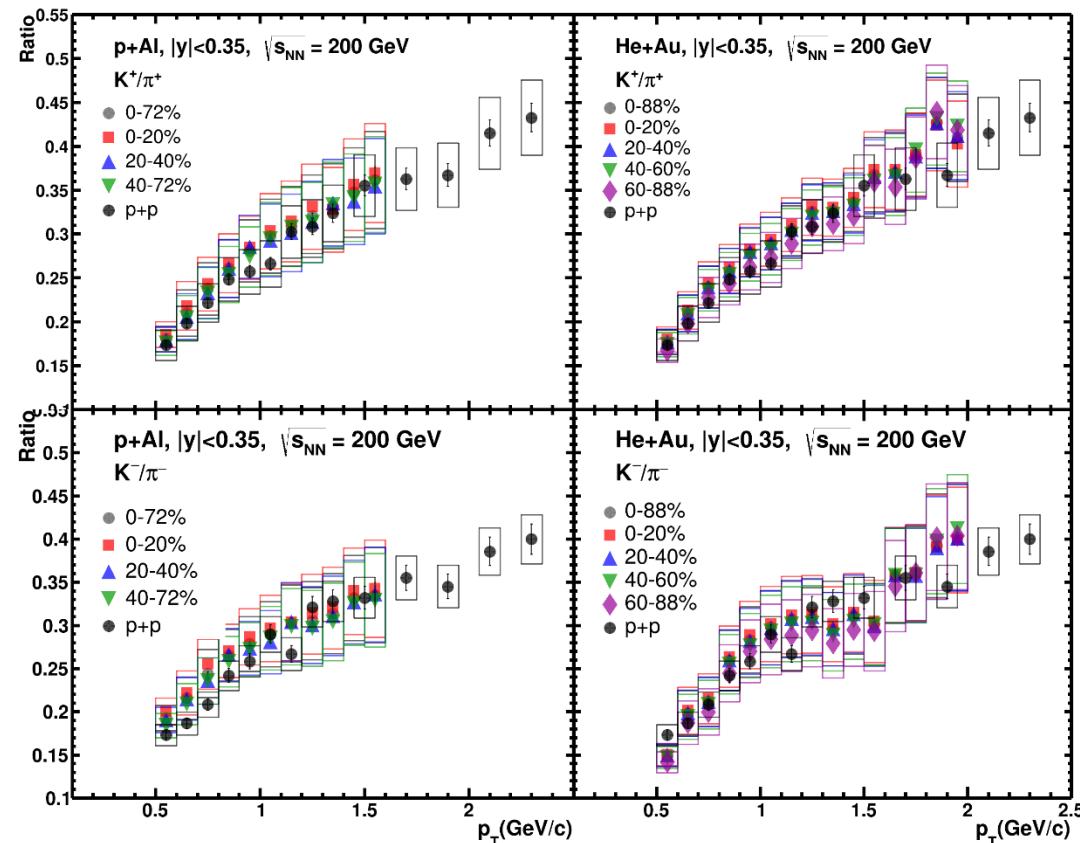
No centrality dependence in p+Al collisions

A small hint of centrality dependence in He+Au collisions

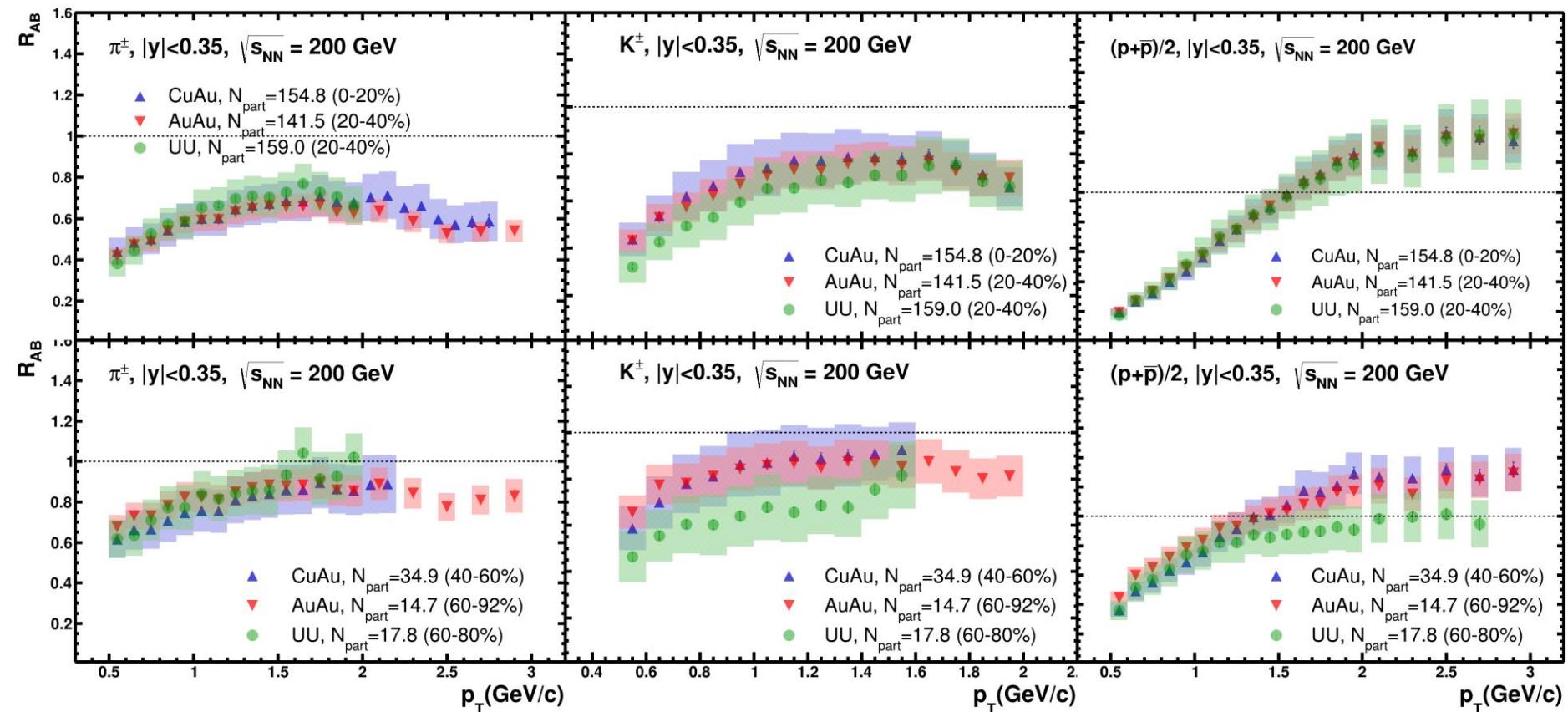
The ratios of K/π in small and large collision systems

$$(K/\pi)_{A+B}^{\text{All centr.}} \approx (p/\pi)_{p+p}$$

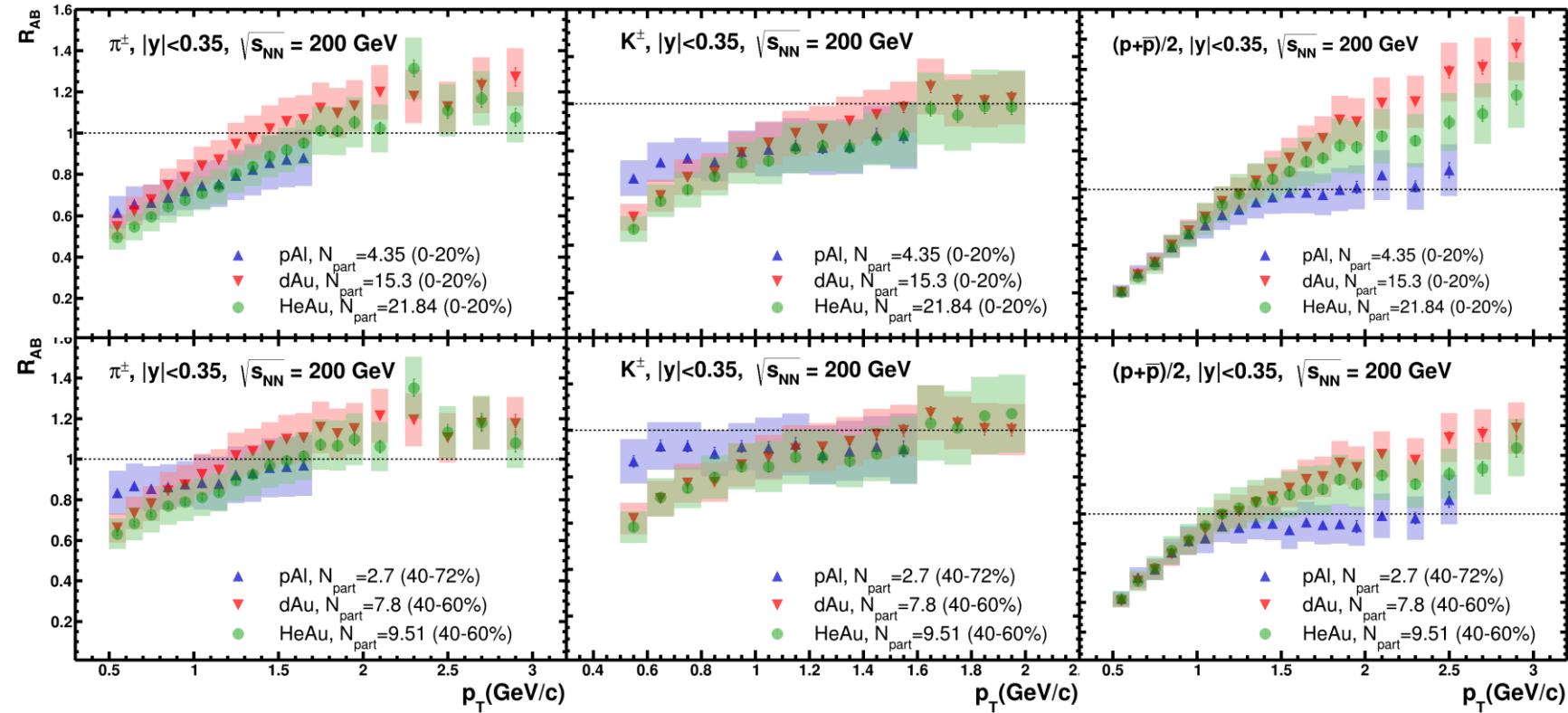
No centrality dependence



Comparison of hadron R_{AB} in large systems



Comparison of hadron R_{AB} in small systems



$R_{AB}^{\bar{p}} \approx 1$ in p+Al collisions in all centralities in the intermediate p_T range.

Flatter slope of $R_{AB}^{\pi,K}(p_T)$ in p+Al collisions than in ${}^3\text{He}+\text{Au}$ and d+Au.

Conclusion

- R_{AB} values for π^\pm and K^\pm in p+Al, ${}^3\text{He}+\text{Au}$, Cu+Au and U+U collisions at the same N_{part} values are consistent within uncertainties.
- K^\pm/π^\pm in p+p, p+Al, ${}^3\text{He}+\text{Au}$, Cu+Au and U+U are consistent within uncertainties in all centralities.
- **No evidences for strangeness enhancement in small collision systems:**

$$R_{xA}^{\varphi, K^\pm, K^*} \approx R_{xA}^{\pi^\pm, \pi^0}$$

- **Possible evidences for strangeness enhancement in large collision systems:**

$$R_{AB}^{\varphi, K^\pm, K^*} > R_{AB}^{\pi^\pm, \pi^0}$$

Conclusion

- $R_{AB}^{\bar{p}} \approx 1$ in p+Al collisions in all centralities in the intermediate p_T range.
- Flatter slope of $R_{AB}^{\pi,K}(p_T)$ in p+Al collisions than in ${}^3\text{He}+\text{Au}$ and d+Au.
- No baryon enhancement in p+Al collisions: all measured light hadron R_{AB} values are consistent in all centralities of p+Al collisions. No enhancement of \bar{p} R_{AB} values over meson R_{AB} values in p+Al collisions was observed.
- In central collisions \bar{p}/π^- in p+Al is smaller than in ${}^3\text{He}+\text{Au}$ and d+Au, but this difference disappears in peripheral collisions.

Light hadron dominant production mechanism in p+Al collisions differs from light hadron dominant production mechanism in d+Au and ${}^3\text{He}+\text{Au}$

Conclusion

Light hadron dominant production mechanism in p+Al collisions differs from light hadron dominant production mechanism in d+Au and ${}^3\text{He}+\text{Au}$

That might indicate that:

- 1. conditions in p+Al collisions are not sufficient for QGP formation**
or
- 2. the system is too small for recombination to cause a noticeable increase in proton production**

Thank you for attention!