Measurement of charged hadron production in relativistic ion collision systems

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For the PHENIX collaboration
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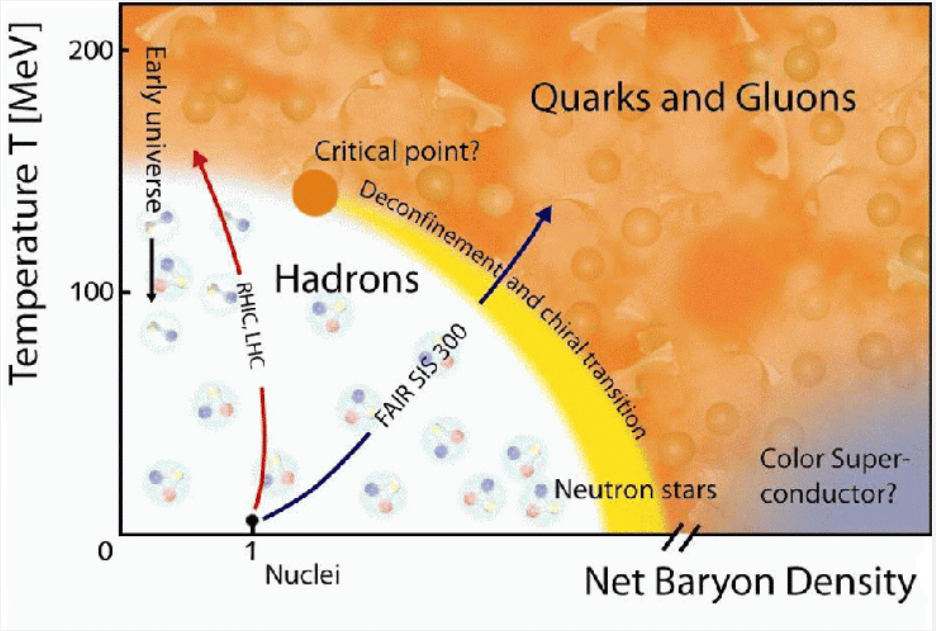
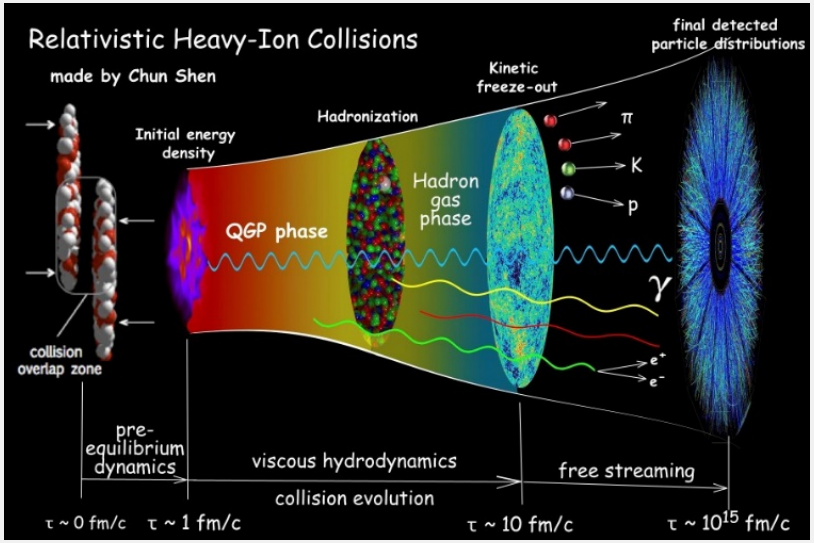
Quark-Gluon Plasma

QGP – is a state of matter which exists at extremely high temperature and/or density. This state is thought to consist of asymptotically free strong-interacting quarks and gluons, which are ordinarily confined inside atomic nucleons or other hadrons.



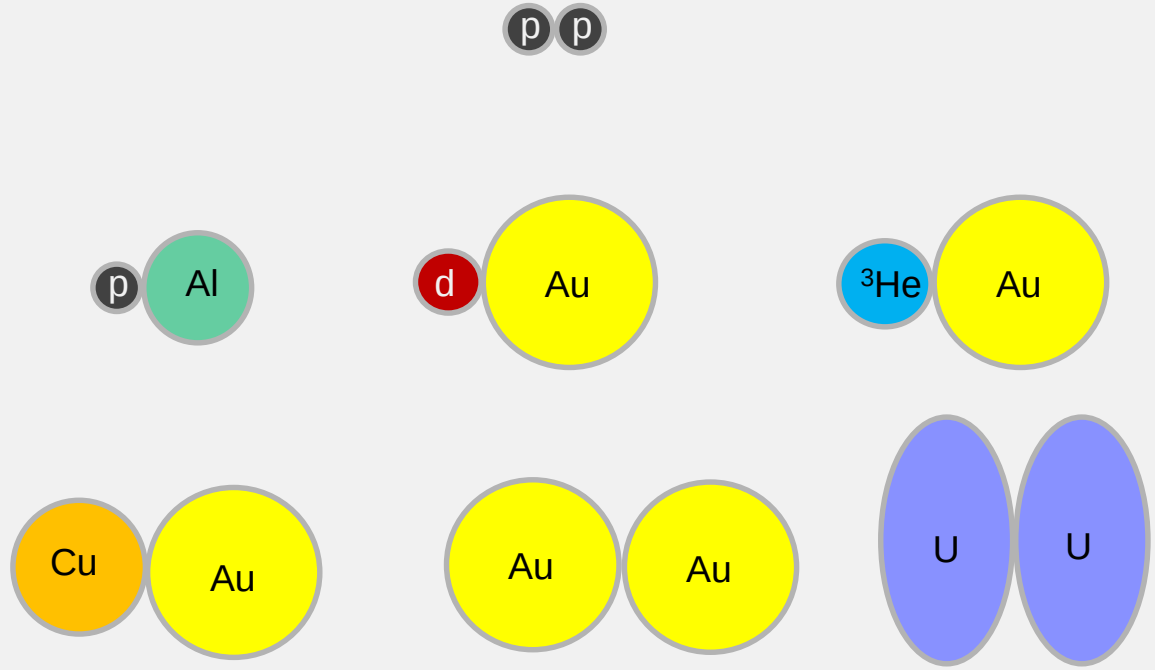


Collision Systems

1. Reference collisions:
   p+p

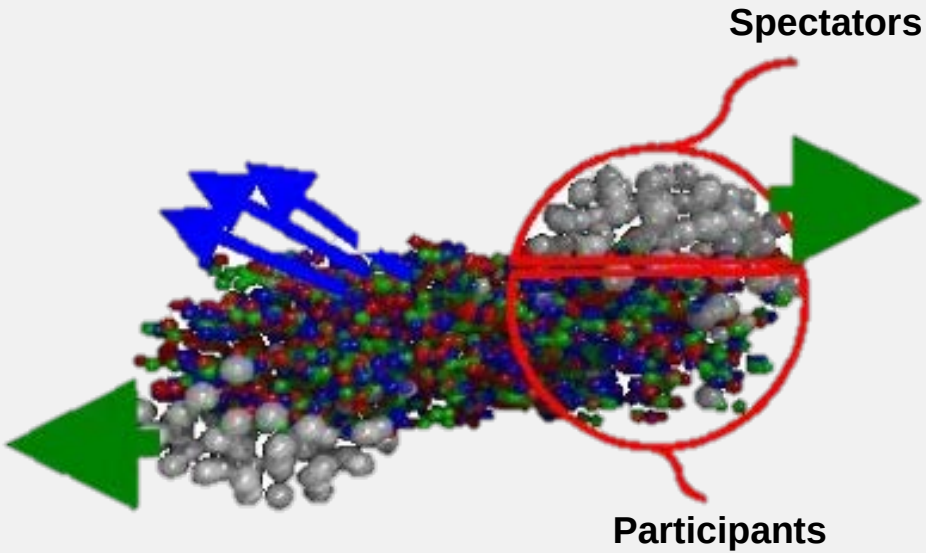
2. Small collsion systems:
   p+Al, d+Au, ^{3}He+Au
   Cold Nuclear Matter effects
   QGP effects

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



Centrality

Measurements of charged particles multiplicity with the BBC ($3.0 < |\eta| < 3.9$)



- Centrality characterized by
  N_{part}: Number of nucleons which suffered at least one inelastic nucleon-nucleon collision
  N_{coll}: Number of inelastic nucleon-nucleon collisions

- N_{part} and N_{coll} from Glauber calculations

PHENIX

(Pioneering High Energy Nuclear Interaction eXperiment)

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

Charged Particle Tracking & Momentum measurements:

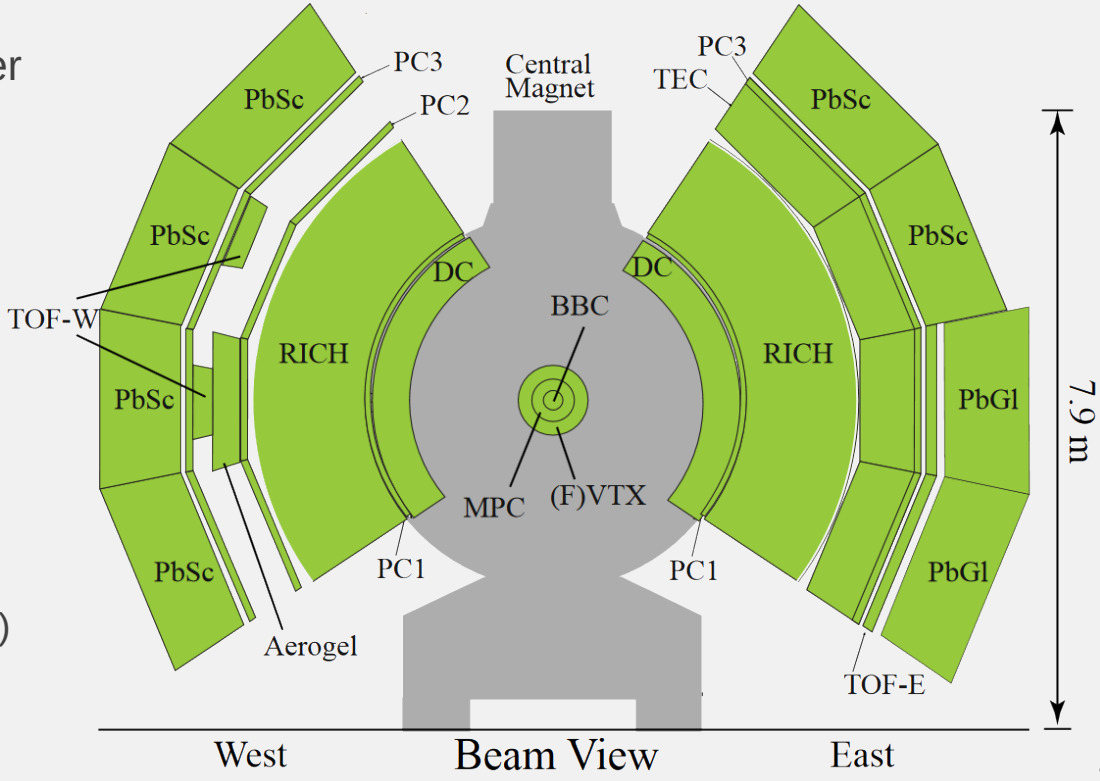
- Drift-Chambers (DC) and first layer of pad chambers (PC1)

Identification of charged hadrons:

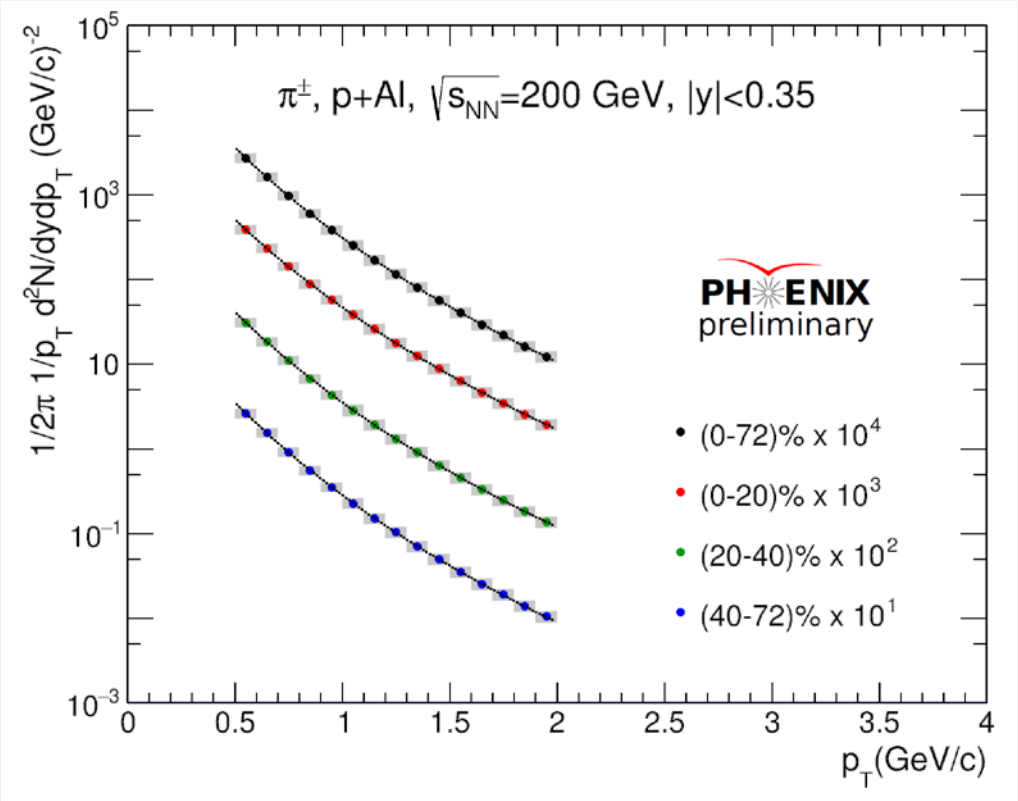
- Tine-of-Flight (TOF) with start signal from the Beam-Counters (BBC)

Centrality identification:

- BBC detectors (beam-beam counters)



Invariant spectra



The lines are Levy function fits.

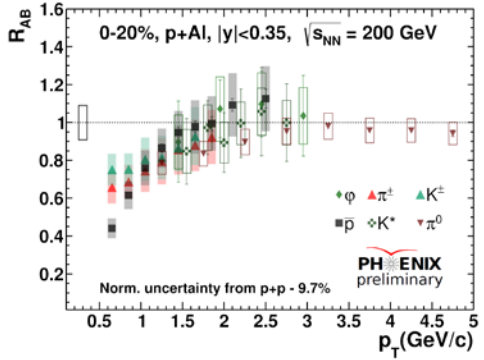
Nuclear modification factors

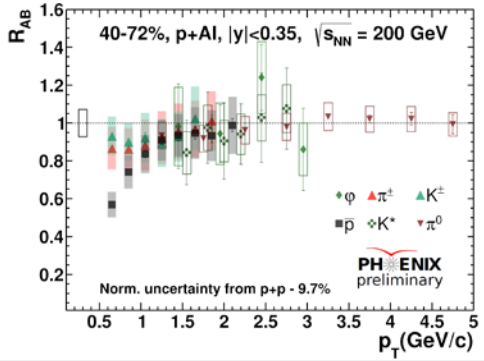
To measure the modification of the spectrum of produced particles in heavy-ion collisions relative to the spectrum in p+p collisions, nuclear modification factors (R_{AB}) are employed:

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

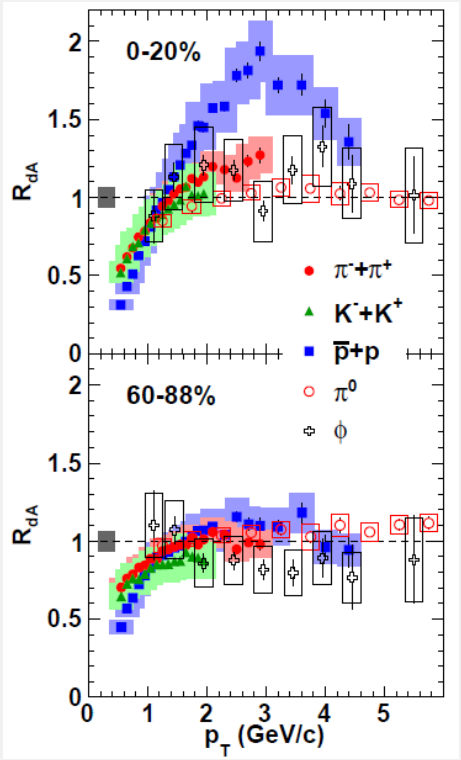
Light hadron R_{AB} in p+Al, d+Al and ^{3}He+Au

p+Al

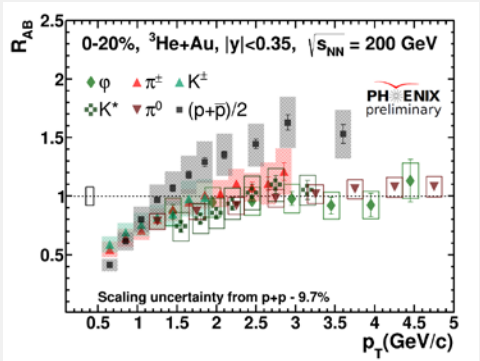


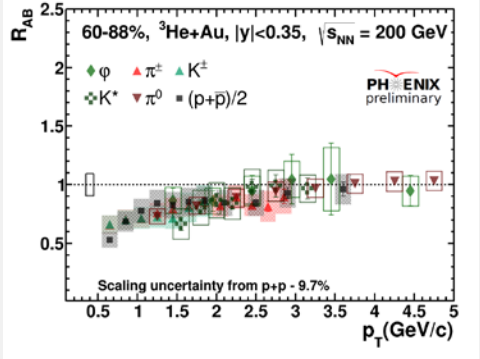


d+Au



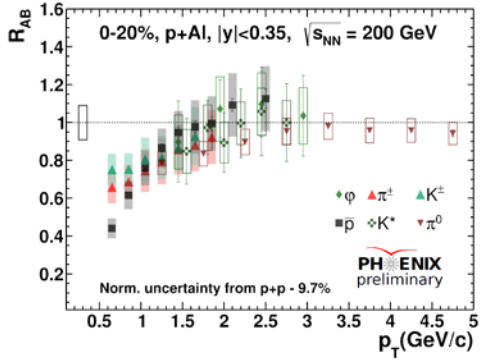
^{3}He+Au

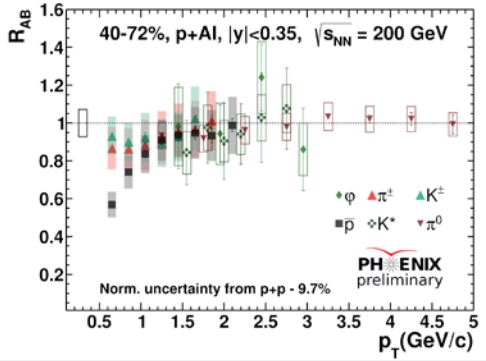




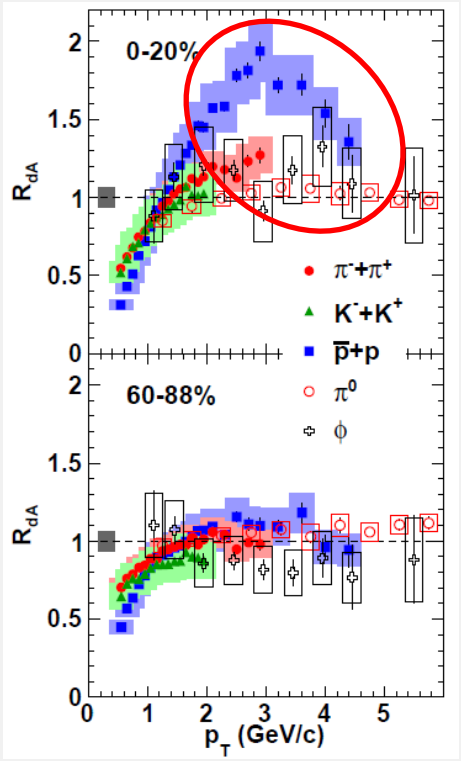
Light hadron R_{AB} in p+Al, d+Al and ^{3}He+Au

p+Al

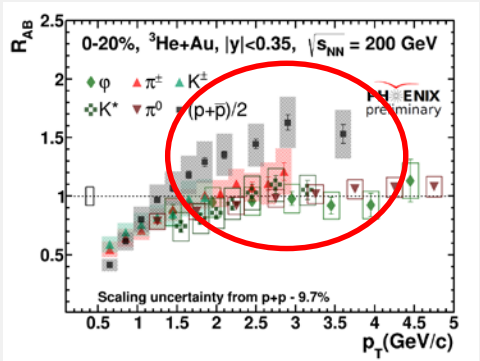


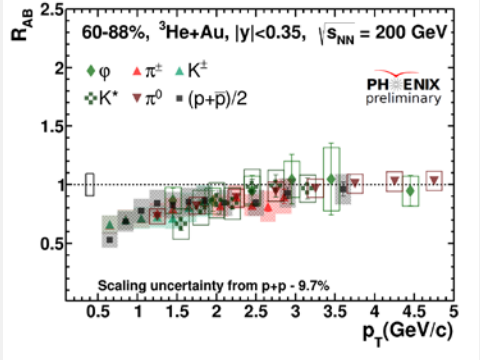


d+Au

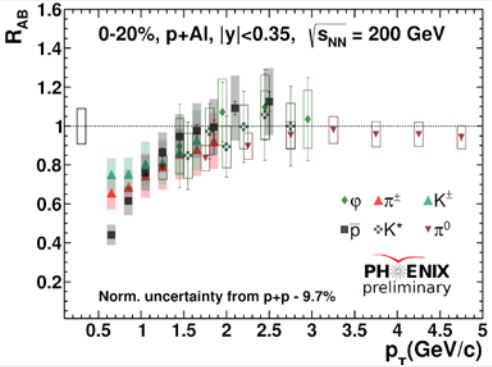


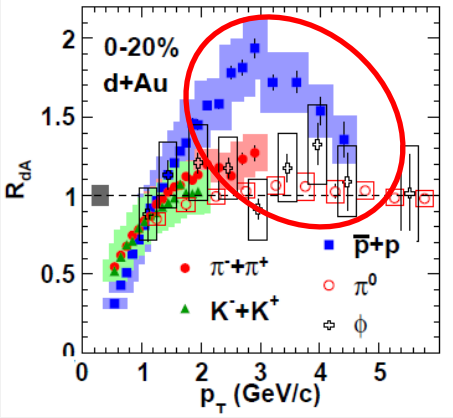
^{3}He+Au

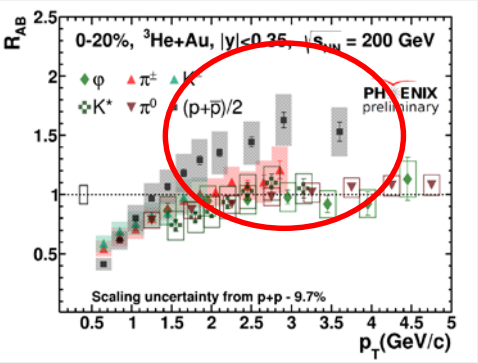


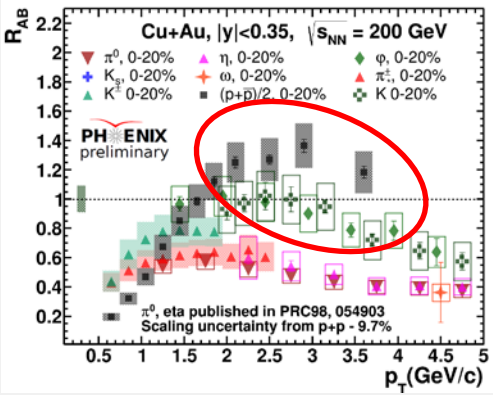


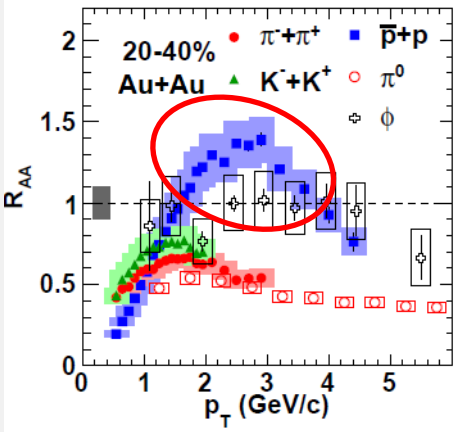
Light hadron R_{AB} in small and large systems

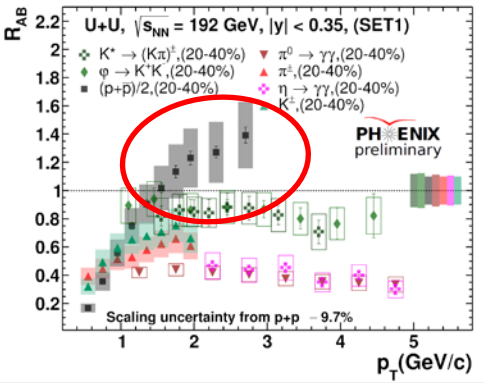




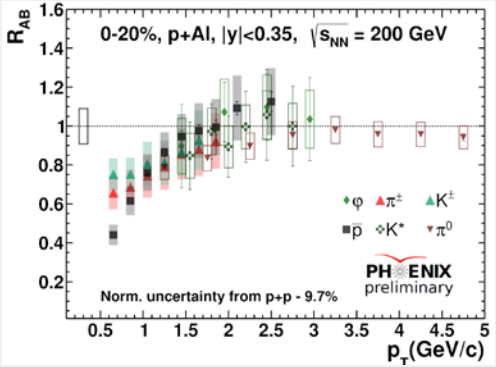


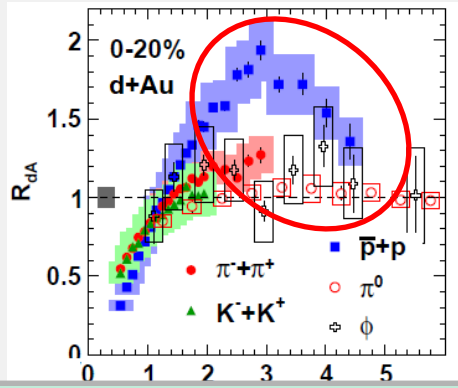


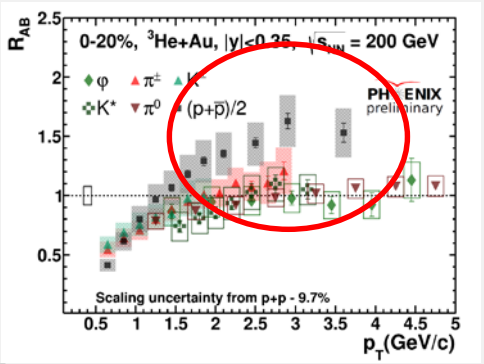




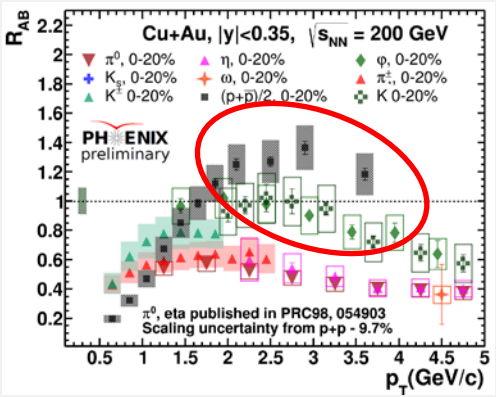
Light hadron R_{AB} in small and large systems

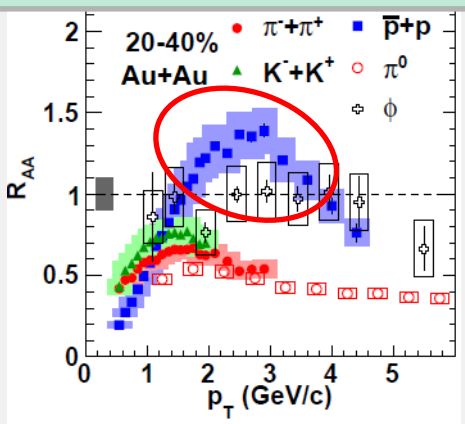


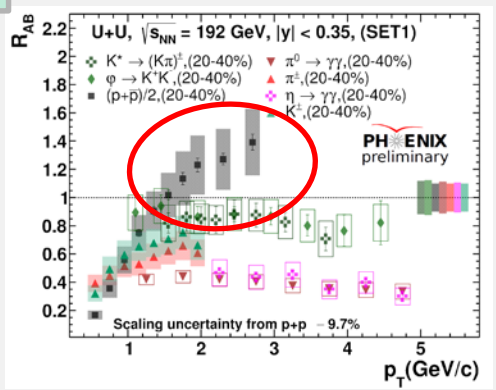




Baryon Puzzle: $R_{AB}^{\varphi} < R_{AB}^{p}$, $m_{\varphi} \approx m_p$

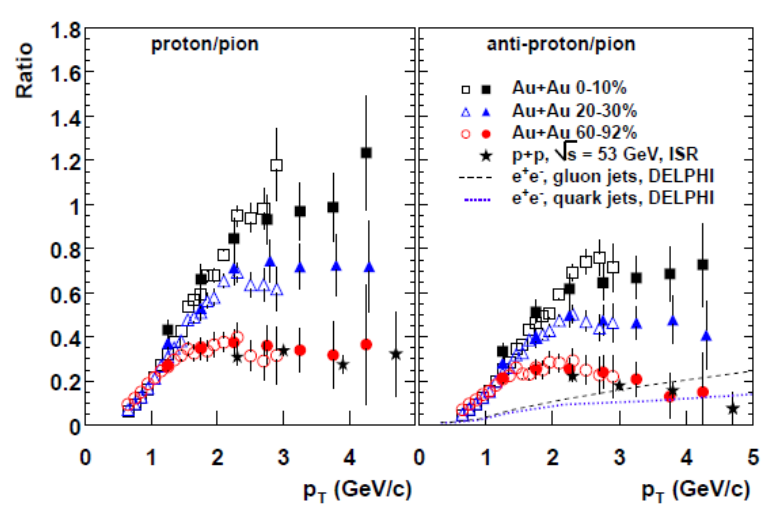




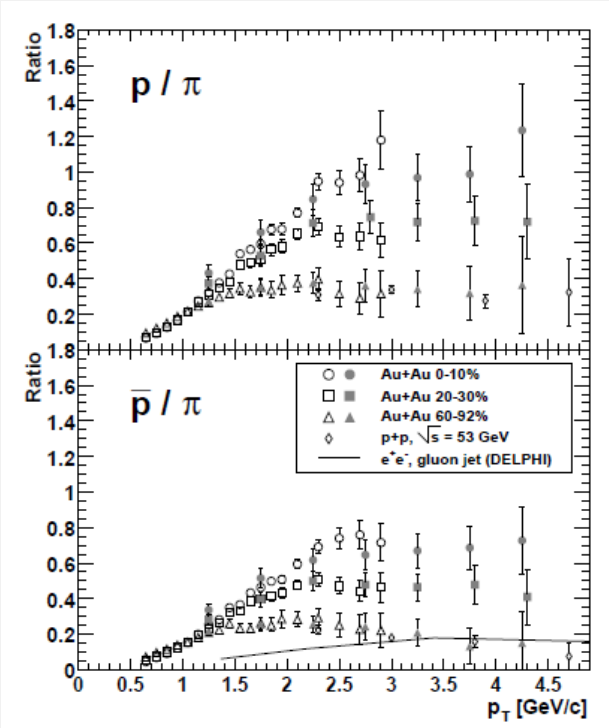


Baryon enhancement

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



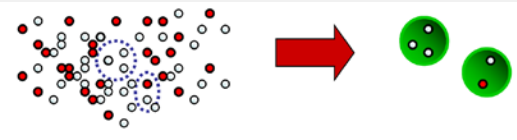
PHENIX collaboration, Phys.Rev.C69:034909,2004

Strong centrality dependence of p/π ratio

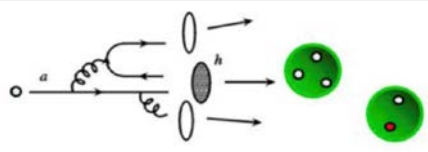
Recombination model of QGP hadronization

QGP Hadronization

Recombination



Fragmentation

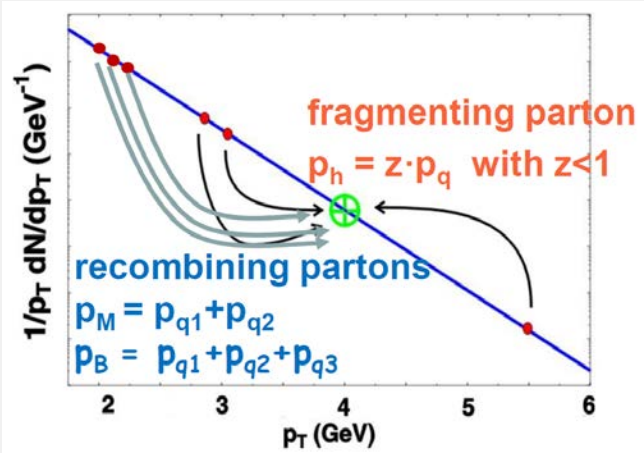


Phase space at the hadronization is filled with partons

- 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 vs. fragmentation:

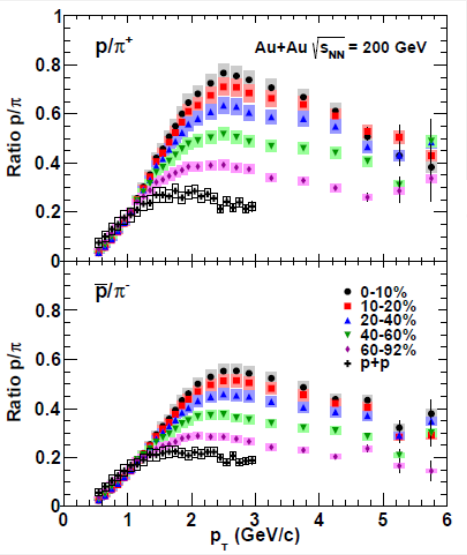
- Competing mechanisms
- Recombination naturally enhances baryon/meson ratios at intermediate p_T

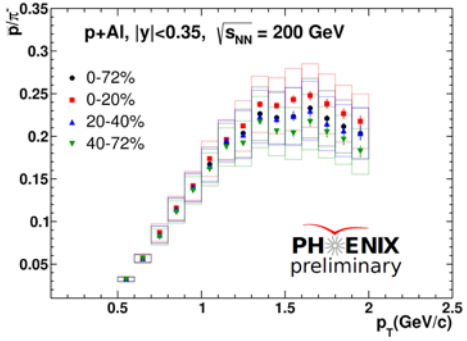


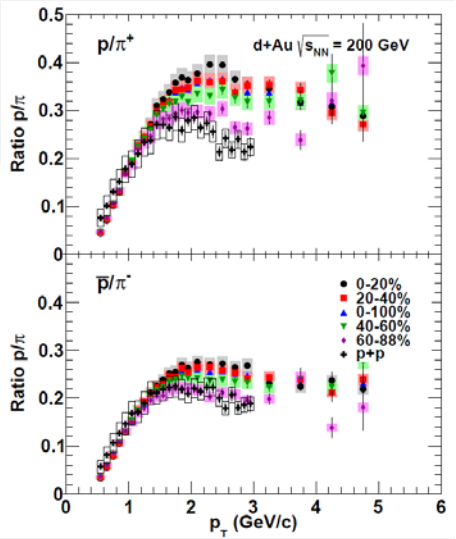
Baryon puzzle was successfully explained in the frame of recombination models, so baryon enhancement can be used as tool for exploring small systems

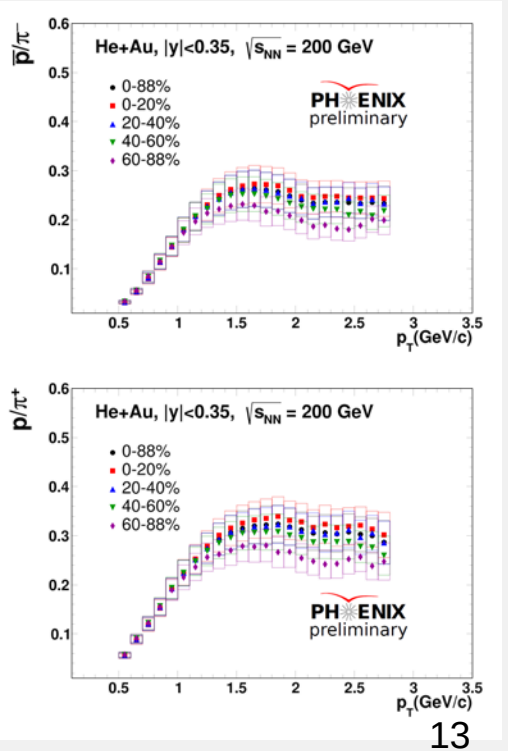
The ratio of p/π

Au+Au | **p+Al** | **d+Au** | **^{3}He+Au**



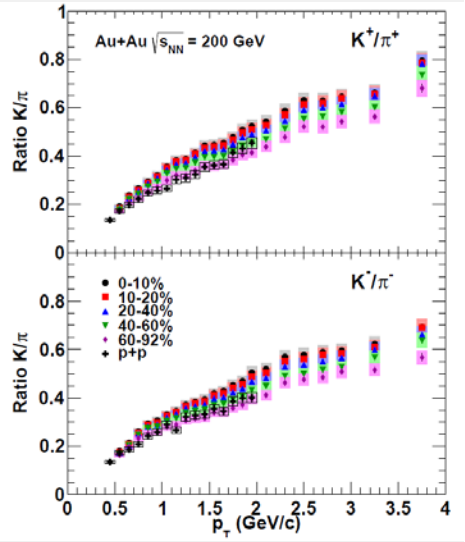


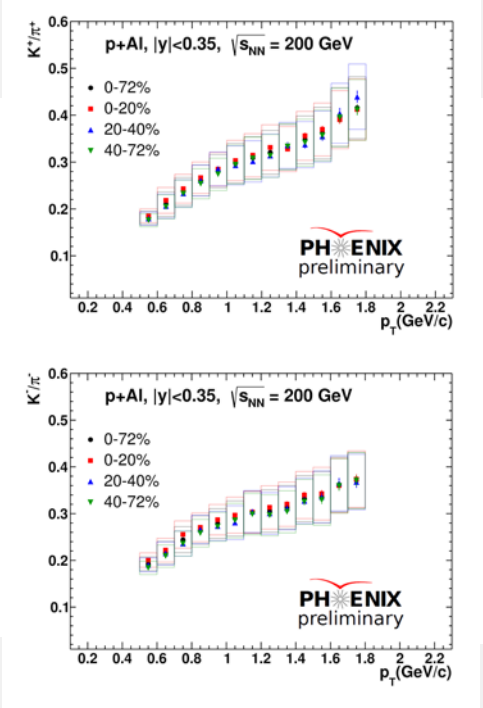


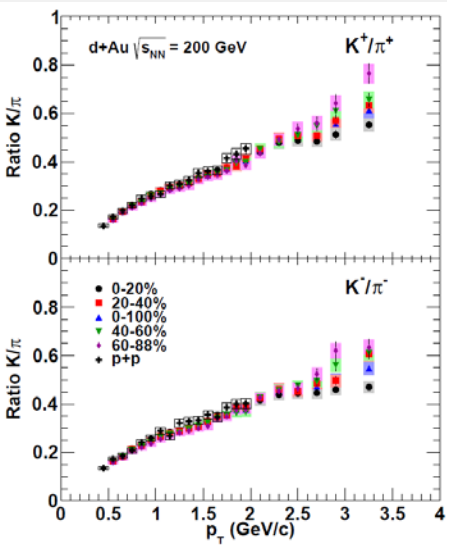


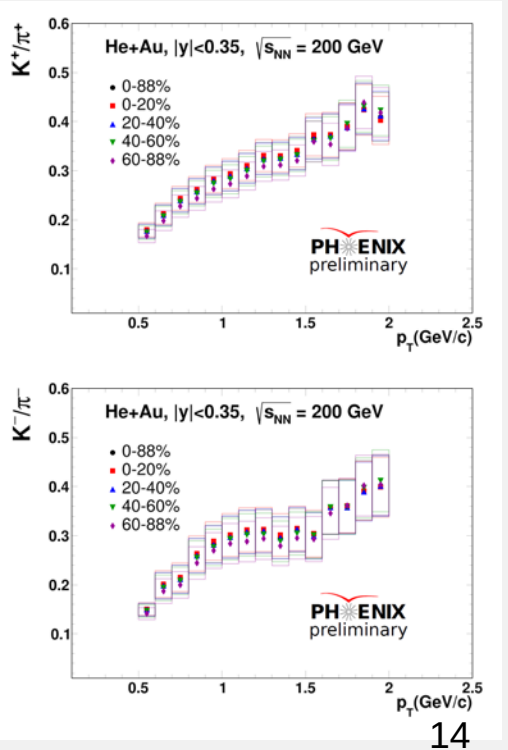
The ratio of K/π

Au+Au | **p+Al** | **d+Au** | **^{3}He+Au**

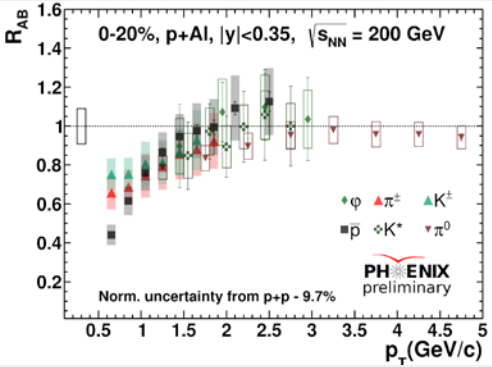


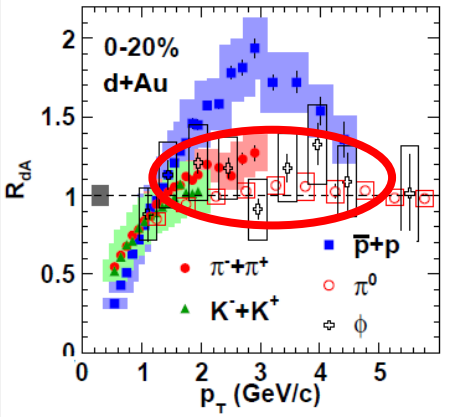


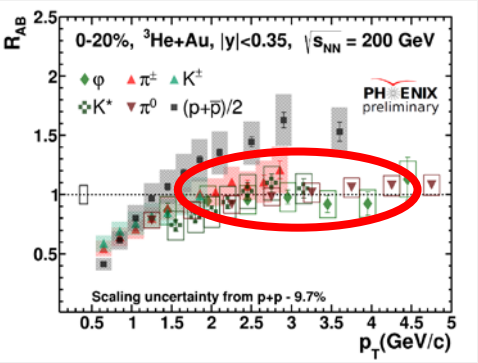


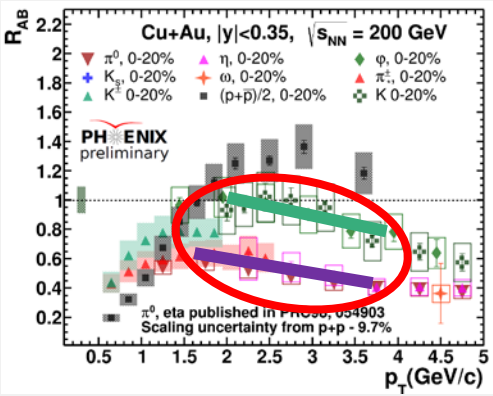


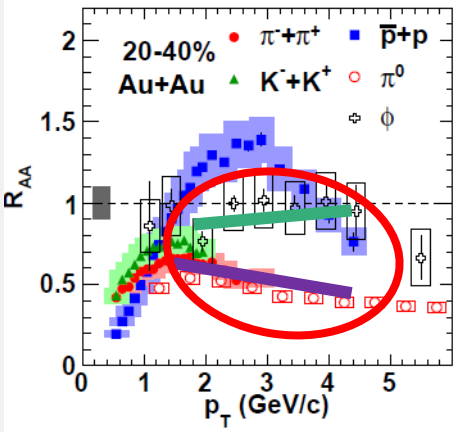
Strangeness enhancement

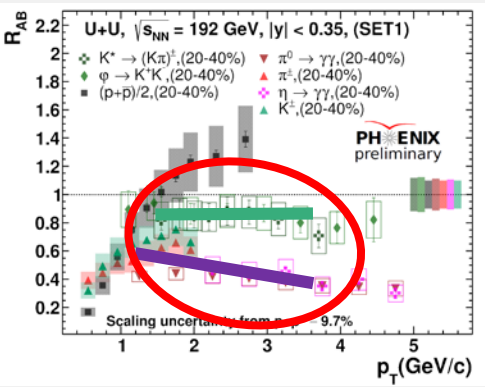






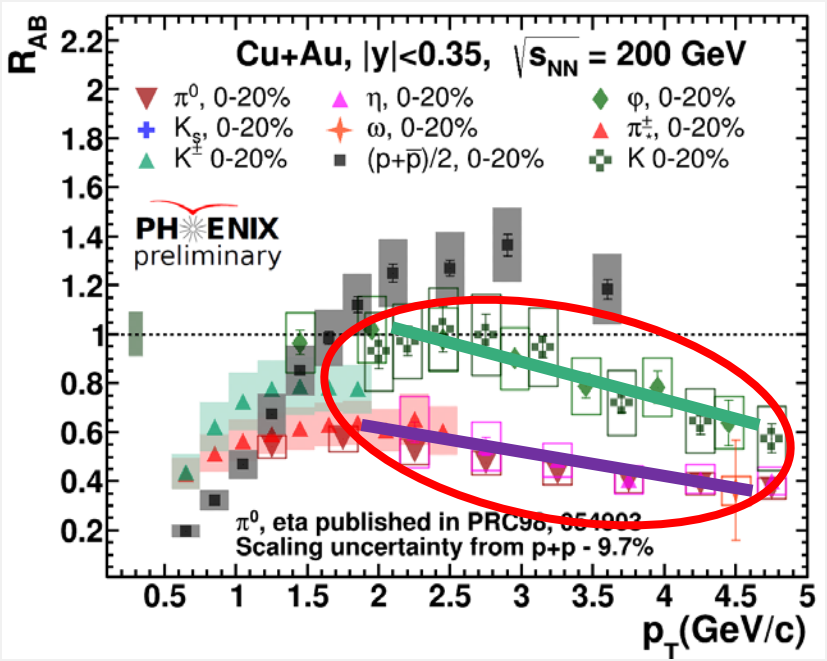


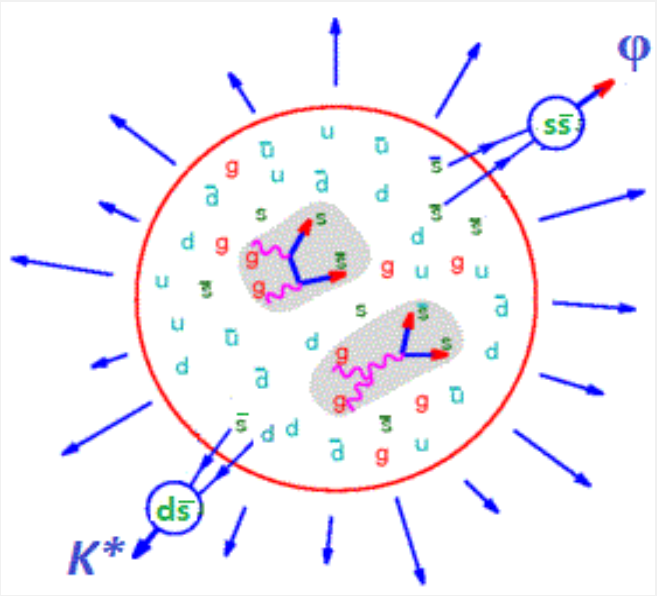




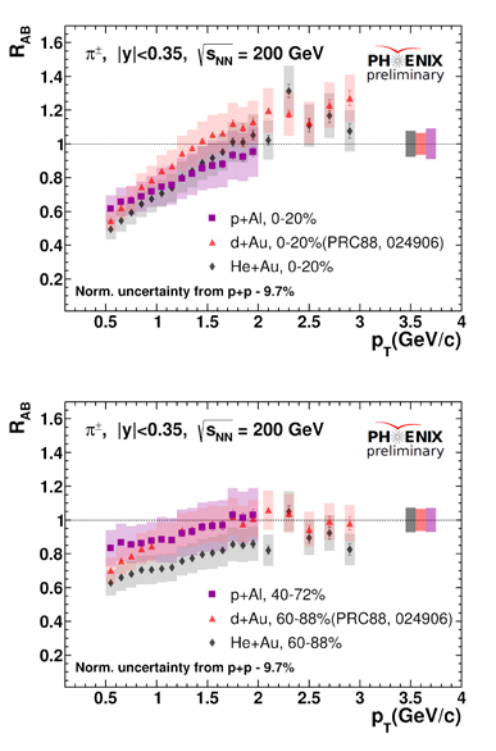
Strangeness enhancement

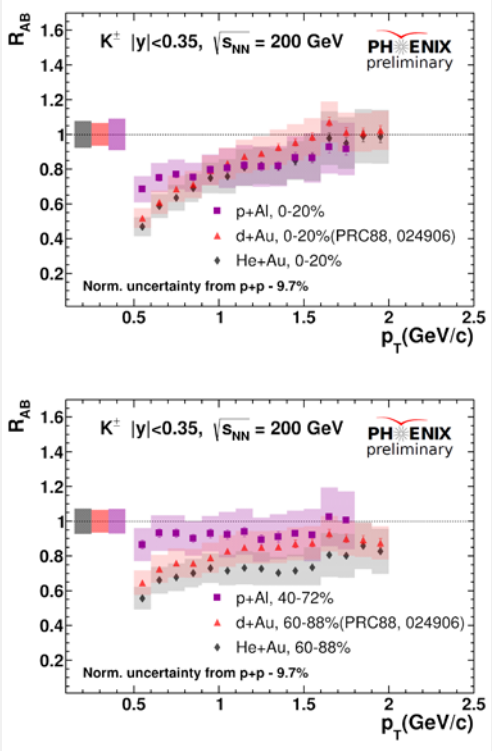
Cu + Au

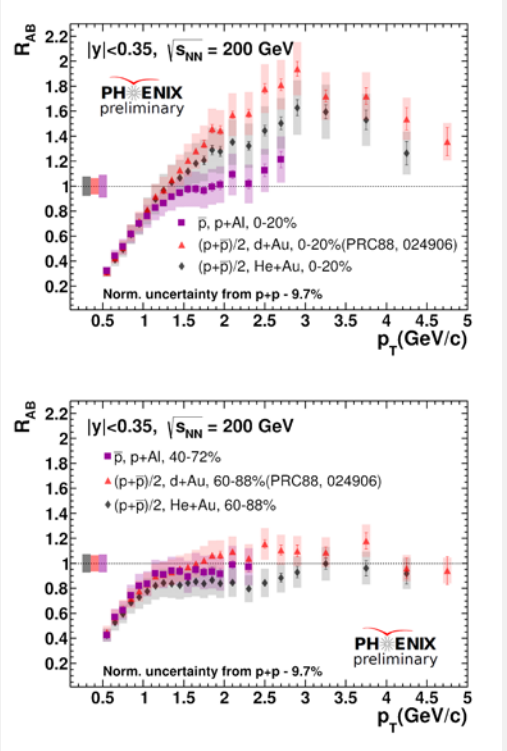




Comparison of hadron R_{AB} in light systems







Conclusion

- R_{AB} values for $\pi^{\pm}$ and $K^{\pm}$ in p+Al, ^{3}He+Au and d+Au collisions are consistent within uncertainties.

- $K^{\pm}/\pi^{\pm}$ in p+Al, ^{3}He+Au and d+Au are consistent within uncertainties.
- No strangeness enhancement in small system collisions: $R_{AB}^{\varphi,K^{\pm},K^{*}} \approx R_{AB}^{\pi^{\pm},\pi^{0}}$

Conclusion

- $\boldsymbol{R_{AB}^{\bar{p}} \approx 1}$ **in p+Al collisions** in all centralities in the intermediate p_T range.
- **Smaller slope of** $\mathbf{R_{AB}^{\pi,K}(p_T)}$ **in p+Al collisions** than in ^{3}He+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 $\bar{p}/\pi^-$ in p+Al is smaller than in ^{3}He+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}He+Au

Conclusion

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

That might indicate that:

1. condition 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

Further study is needed

Conclusion

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

That might indicate that:

1. condition 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

Further study is needed

Thank you for attention!