Hadron production in small systems

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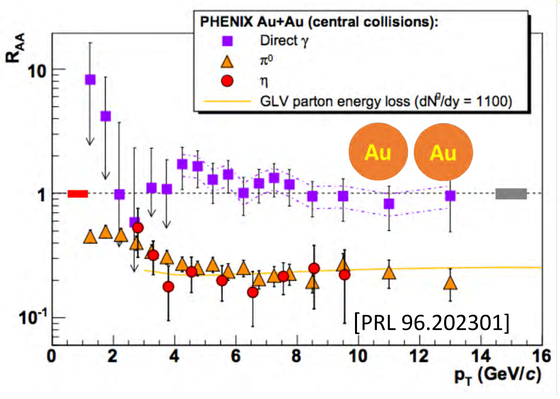
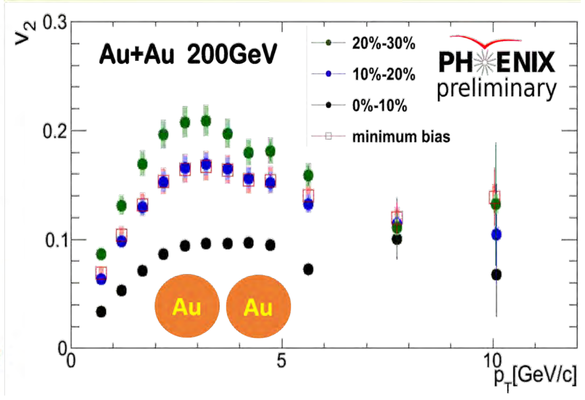
Au+Au, d+Au and the QGP

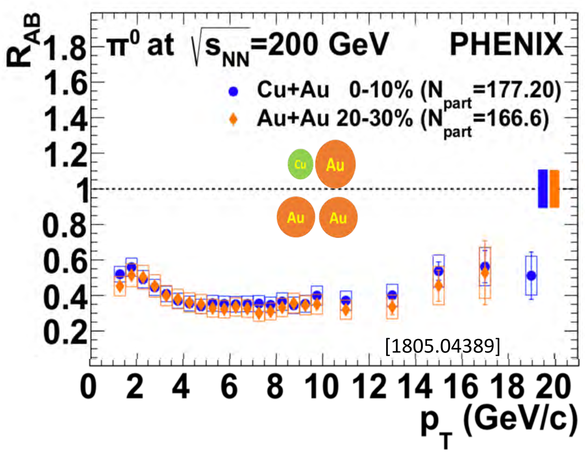
The two classic signatures of the Quark Gluon Plasma (QGP) were a suppression of π^0s due to energy loss as the hard parton passed through fireball and a strong elliptic flow. The strength of the elliptic flow indicated that the QGP was a strongly interacting liquid with $\eta/s=1/4\pi$ that behaved collectively. Direct photons in Au+Au collisions experienced no suppression implying that scaling with N_{binary} was correct.

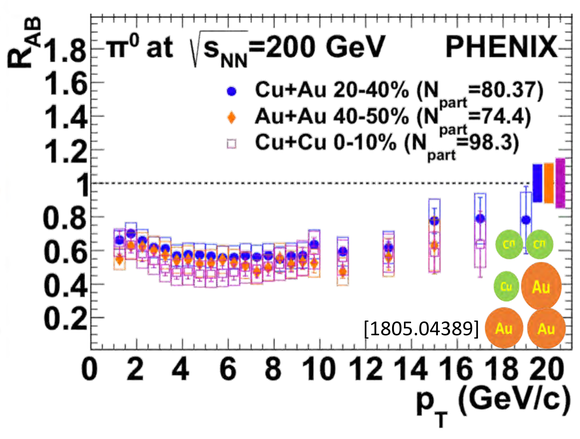


R_{AA} in central Au+Au collisions for π^0, η and γ showing the suppression for hadrons, and lack of suppression for direct γ.



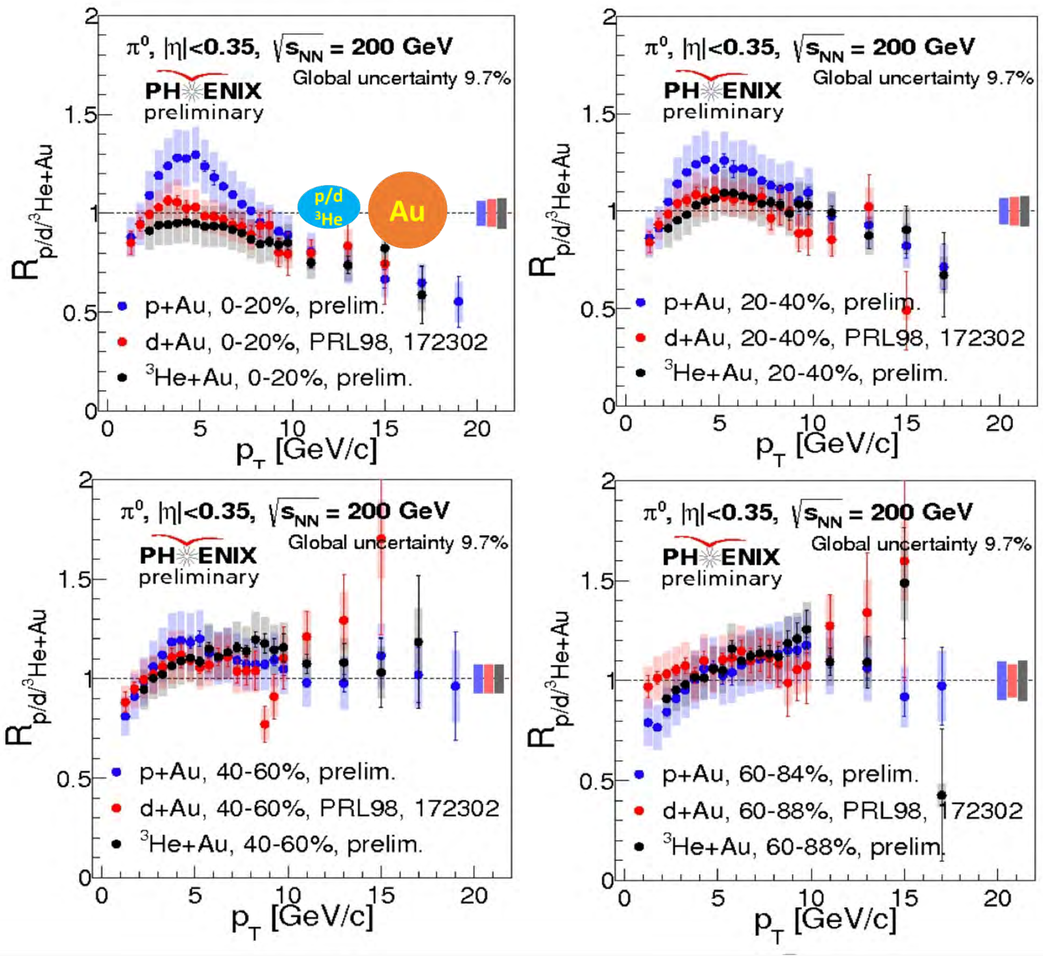
Elliptic flow in Au+Au collisions





R_{AA} scales with N_{part} as can be see when Cu+Cu, Cu+Au, and Au+Au data is plotted as a function of N_{part}.

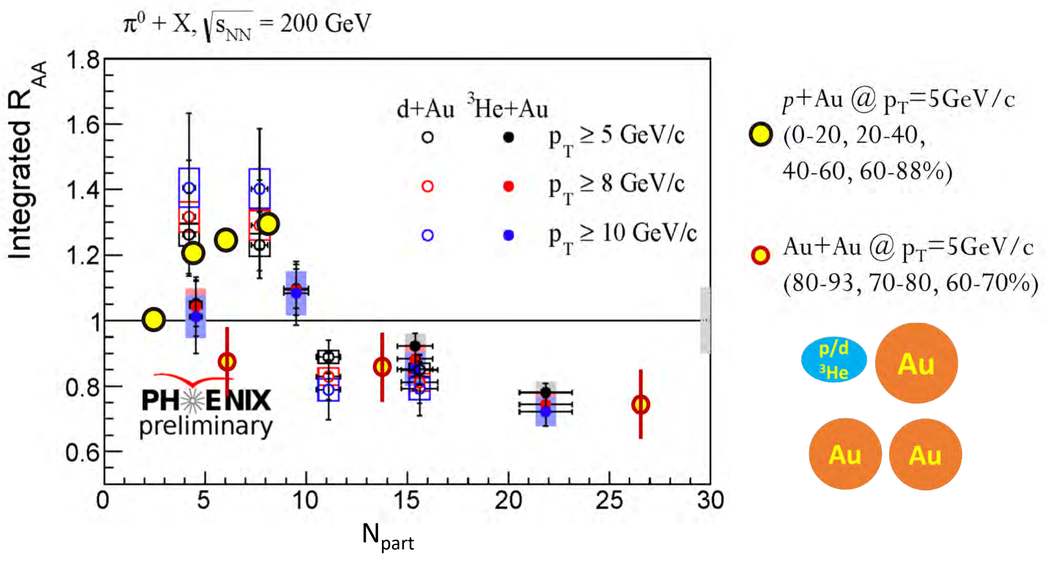
$R_{AA}(\pi^0)$ in small systems: p+Au, d+Au, ^{3}He+Au



R_{AA} of all three systems are similar at high p_T(> 10GeV) and show a suppression in central events.

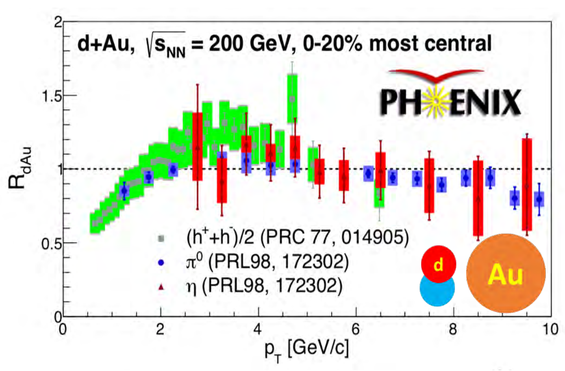
- May be a sign of energy loss?
- Cronin type enhancement in p+Au at low p_T,
- System ordering at low p_T in central collisions: $R_{pAu} > R_{dAu} > R_{HeAu}$

Integrated R_{AA}: p+Au, d+Au, ^{3}He+Au, Au+Au

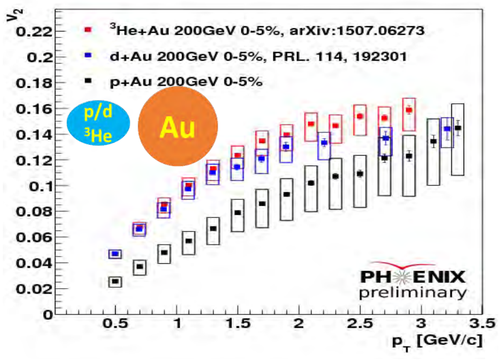


- For N_{part}<10 system ordering: pAu~dAu>HeAu> AuAu
- At N_{part} >10 all 3 small systems converge to the same integrated R_{AA} as Au+Au
  → Indication of hot matter for N_{part} >10 (a QGP?)

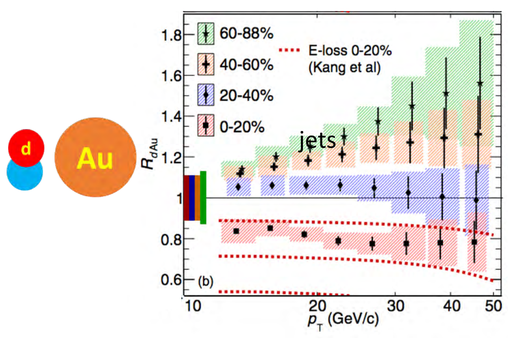
Hadrons in d+Au collisions showed no suppression, seeming to fulfill the expectation that no QGP was formed. Collisions in small systems such as p+Au and d+Au could act a a baseline against which Au+Au collisions could be compared. Hence long range correlations in the highest N_{ch} p+p events seen by CMS were a surprise [JHEP 1009, 091]. Shortly thereafter, a non-zero elliptic flow in d+Au collisions was seen at RHIC. It became important to look at the suppression of hadrons in simple systems more carefully.



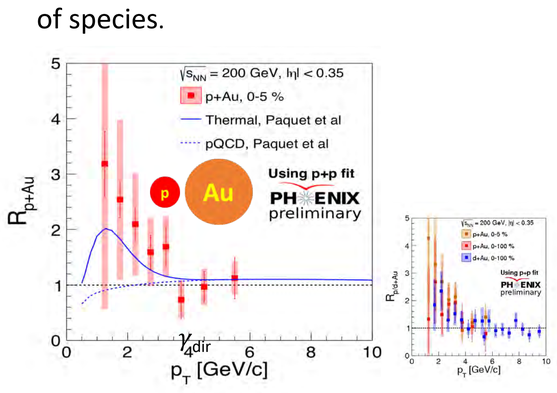
R_{dAu} for π^0, η and charged hadrons showing no suppression. Note that data goes only to p_T=10 GeV.



Surprisingly, small systems showed a strong flow (v_2) signal.
→Look more carefully at R_{AA}. The versatility of RHIC allows for collisions with a variety of species.



The R_{dAu} of jets at pt >10 GeV showed strong centrality dependence with central collisions showing a suppression. Note that the data covers p_T >10 GeV.
→What do hadrons do?



R_{pAu} for direct photons in simple systems (p+Au) is unity for p_T>4 GeV. Enhancement at low p_T similar to Au+Au, perhaps thermal?
→ photon yield scales with N_{binary}. The nucleus behaves as a simple collection of nucleons for direct photons.

Summary

- p/d+Au systems no longer represent a baseline with which we compare Au+Au collisions.
- At forward rapidities, R_{pAu}, R_{dAu} and R_{HeAu} are similar at high p_T and show suppression in central events.
- The integrated R_{AA} of the three colliding systems converge to the R_{AA} of Au+Au for Npart>12.
  - System ordering of R_{AA} for Npart<12: $R_{pAu}>R_{dAu}>R_{HeAu}>R_{AuAu}$
- Does the R_{AA} data confirm the hypothesis from flow measurements that we have a QGP in small systems?
  - Hydro models can reproduce small system flow results.
  - Are there models including a QGP which can reproduce the small system R_{AA} results?
  - Models which only include cold nuclear matter effects should also be compared with the data.

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