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PHENIX Results on Nuclear Modification of Hadron Production in Small and Large Systems

Axel Drees (for the PHENIX collaboration)[a,*]

[b] *Department of Physics and Astronomy, Stony Brook University, , New York*

E-mail: axel.drees@stonybrook.edu

The intermediate p_T region is ideal for studying hadronization and the transition from soft to hard physics. Quark mass and flavor are key ingredients in hadronization as well as elucidating the details of energy loss mechanisms in the hard sector. For this reason, it is essential to study a variety of different particle species, and PHENIX is ideally-suited for many resonance decay analyses. In this talk we present spectra and nuclear modification factors of identified particles in p+Al, p+Au, d+Au, ^{3}He+Au, Cu+Cu, Cu+Au, Au+Au, and U+U collisions at 200 GeV. Implications for hadronization and energy loss will be discussed.

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1. Introduction

Hadron spectra hold rich information about the dynamics of particle production and possible modification in a nuclear environment. We will compare hadron spectra from A+A collisions to those from properly scaled p+p collisions. Schematically, one expects at high p_T, where production is dominated by jet fragmentation, a suppression due to parton energy loss, that can reach up to a factor of 5 in central collisions. For intermediate p_T there is an enhancement due to radial flow, that depends on the particle mass and/or flavor content. The particle composition may also be altered due to strangeness enhancement.

PHENIX can measure a broad range of hadron spectra using the information from the central arm spectrometers. Key detectors used for these measurements are the central arm drift chambers for charge particle tracking, the EMcal for photon detection, and different TOF systems for particle identification. Besides the particles that can be reconstructed directly, many others can be measured via their decays. PHENIX also measured these hadrons for a broad range of collision systems from small to large size. Here we will focus on data taken at 200 GeV center of mass energy. In order to compare data from different collision systems it is common to use N_{part} or N_{coll}. N_{part} is typically associated with centrality. It stands in for the reaction volume, volume times energy density or total particle production. N_{coll} is thought to be proportional to the hard scattering probability. Though the physics interpretation is different, in Glauber calculations they are tightly correlated independent of the collision system. As we will see the modifications of hadron spectra are not driven by geometry differences. We use $p + p$ measurements as bench mark for modifications of hadron spectra heavier systems [1].

2. Heavy Ion Collisions

Fig. 1 highlights results for meson nuclear modification factors from heavy ion collisions. These are representative results from PHENIX taken from a large body of published [2–10] and preliminary data on π^0, η, ω, K_s, K^* and ϕ.

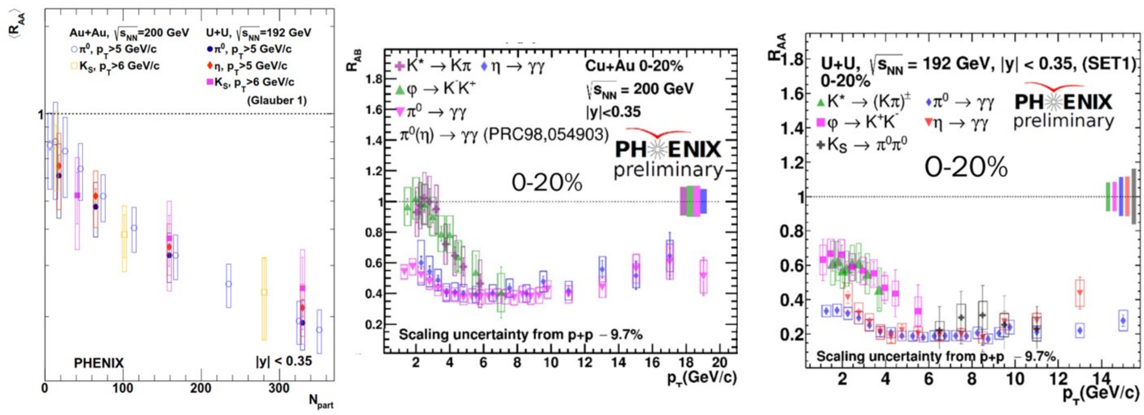

Figure 1: Representative meson R_{AA} data from various collision systems.

All data show similar trends: (i) a common suppression for mesons at high p_T, (ii) a nearly constant R_{AA} from 5 to 10 GeV/c followed by a rise, (iii) less suppression at low p_T, and (iv) a

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clear meson mass ordering at low p_T with heavier mesons being less suppressed. The suppression above 5 GeV/c is universal for all mesons and independent of the system geometry and scales with system volume or N_{part}. At lower p_T R_{AA} also scales with N_{part} but shows a clear mass ordering.

The left hand side of Fig. 2 shows proton R_{AA} for Au+Au and Cu+Au at similar N_{part}. Again R_{AA} scales with N_{part}, but now an enhancement is observed, which is not seen for ϕ and K^* mesons of almost equal mass.

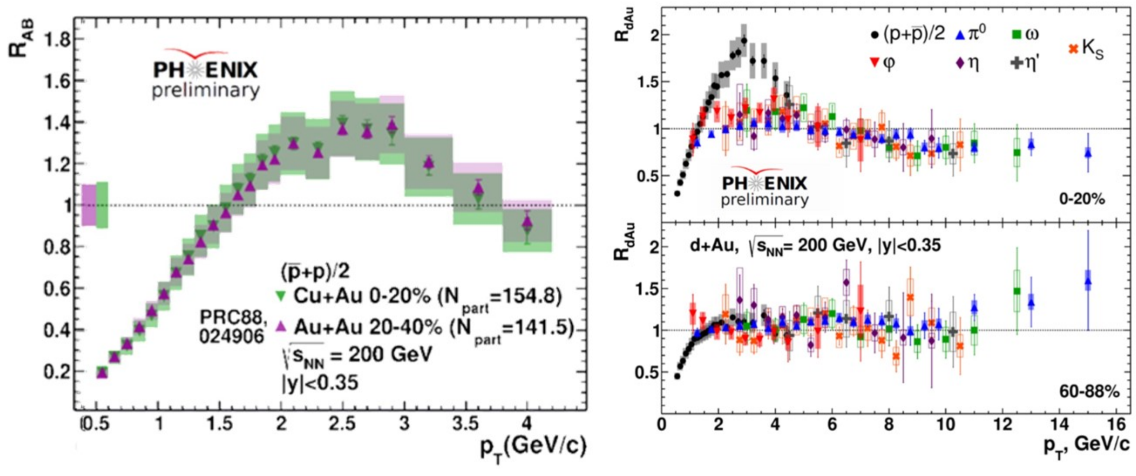

Figure 2: proton R_{AA} for large and small systems.

3. Small Systems

The right hand side of Fig. 2 gives a completion R_{dA} data, PHENIX's most extensive identified hadron data to date from small systems [4–6, 9, 11]. For central collisions all mesons show a similar modification: a Cronin peak at 4 GeV/c and a suppression for $p_T > 8$ GeV/c, while for peripheral collisions R_{dA} is consistent with unity above 2 GeV/c. Protons exhibit a larger Cronin peak in central collisions, but are consistent with mesons in peripheral collisions.

For π^0 and ϕ we have preliminary data across systems p+Al, p+Au, d+Au, ^{3}He+Au. The π^0 data are shown in Fig. 3. The nuclear modifications are different from the ones seen in heavy ion collisions. At high p_T all systems show the same modification for the same centrality class, with a suppression in central and an enhancement in peripheral collisions. At low p_T the Cronin peak in central collisions shows a clear ordering with projectile size (the smaller nucleus), and is largest for p+Au. In contrast there seems to be no modification in peripheral collisions. When R_{AB} at high p_T is compare as function of the number of collisions per projectile, collisions with Au nuclei follow the same trend. While collisions with Al are distinctly different. One can draw model independent conclusions for the underlying mechanism of the modification; it involves mostly independent interaction of each projectile and is not driven by the thickness of matter traversed by projectile.

4. Conclusion

PHENIX presented R_{AA} measurements for hadrons in Cu+Cu, Cu+Au, U+U, Au+Au at 200 GeV. We observe a universal high p_T suppression with N_{part} for all measured hadrons. This

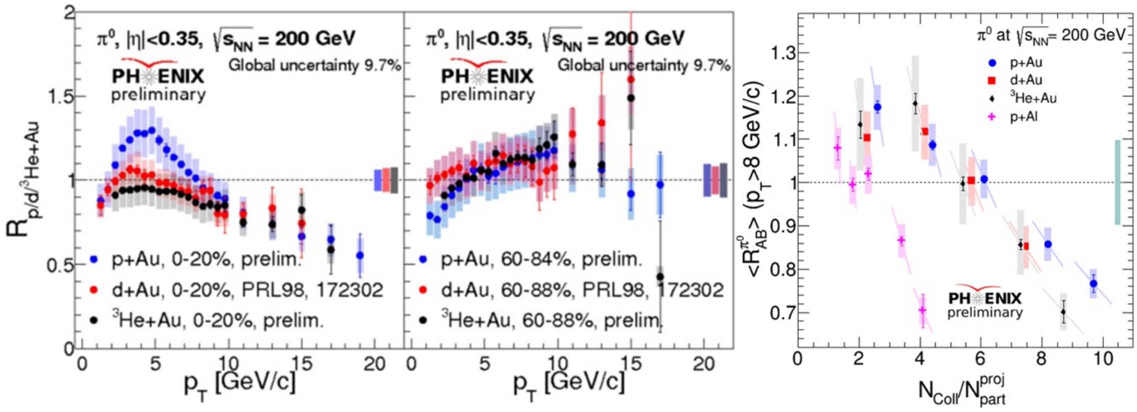

Figure 3: Small system R_{AB} for neutral pions.

indicates that jet fragmentation is not modified or modified equally for all mesons. At low p_T the meson R_{AA} exhibits mass ordering (small at low meson mass) and a common N_{part} dependence. This systematic trend is consistent with similar fireball dynamics and hadronization across systems. The modifications appear to be driven by radial flow. For protons R_{AA} is larger at low p_T than for similar mass mesons (ϕ, K^*), which underlines that mass can not be the only factor. This may point to radial flow at the parton level.

For small systems the hadron modification was shown for p+Al, p+Au, d+Au, ^{3}He+Au. In peripheral collisions the hadron R_{AB} is consistent with unity for p_T above 2 GeV/c and no clear evidence for a nuclear modification is seen. In contract central collisions exhibit clear nuclear modifications. We observe a Cronin peak around 4 GeV/c with a clear system ordering $R_{pAu} > R_{dAu} > R_{HeAu}$. It is hard to see how this could be related to radial flow in small systems. At much higher p_T a suppression is seen. It is independent of the projectile and not driven by the target thickness, therefore it is unlikely that this suppression is related to energy loss.

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