Recent Heavy Ion Results from PHENIX

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The Relativistic Heavy Ion Collider, RHIC, has begun operation just over 10 years ago. Over this period, the PHENIX Collaboration has accumulated a wealth of results that provide an increasingly detailed picture of the hot and dense medium produced in central heavy ion collisions at RHIC. This contribution reviews some of PHENIX's recent results from the heavy ion runs, and their impact within the context of what has been learned at RHIC.

1 Introduction

The first decade of RHIC running has brought both big surprises and the confirmation of some theoretical expectations. One such theoretical success was the prediction, initially made for p+p collisions and later for heavy ions, that a highly energetic parton produced in the first instants of the collision could lose energy, and perhaps even be fully absorbed, as it traversed the hot colored medium created in the collision. Many experimental observables focus on the evaluation of this "jet quenching" mechanism at RHIC, from the single particle spectra and their suppression when compared to the appropriately scaled p+p measurement, to di-hadron correlations and the new attempts at full jet reconstruction in the difficult high-multiplicity heavy ion environment. All of these have contributed to establish that jet quenching is indeed happening at RHIC, but the mechanisms involved are yet to be determined, and only the full complement of measurements, as well as a move towards increased precision, both experimental and theoretically, will be able to resolve this issue.

2 Single particle spectra

Single particle transverse momentum spectra can be used as tools to study the suppression of high-momentum partons via the measurement of the Nuclear Modification Factor, denoted as R_{AA}, and defined as follows:

(1)

PHENIX has measured R_{AA} for a wide range of particle species, collision energies and even colliding pairs (Au+Au, Cu+Cu, and d+Au). The two key observations were that a factor of 5 suppression was reached for light mesons in the most central Au+Au collisions for $pT > 3$, and that no such effect was seen in d+Au collisions, indicating that jet-quenching is a final state effect that takes place in the medium created in A+A collisions. The full range of PHENIX

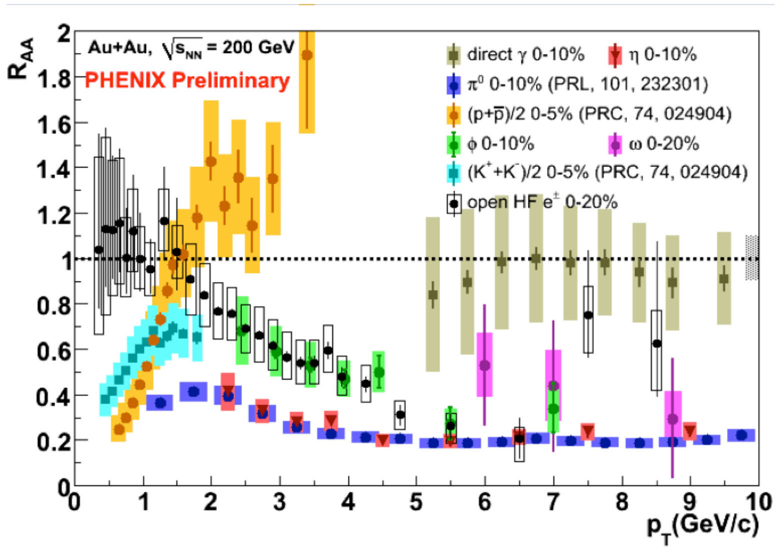


Figure 1: (color online)

measurements for central Au+Au collisions is presented in Fig.1. Several interesting trends are worth noting:

- η: the recently published η R_{AA} covers nearly the full pT range of the original π^0 measurement, and shows that the two results are nearly identical, despite the different mass and flavor compositions of the η and π^0. From the experimental point of view, the η measurement suffers from fewer systematic uncertainties at high-pT, given that the two photons that result from its decay are well separated enough to be independently resolved in the PHENIX electromagnetic calorimeter up to pTs of, unlike the π^0, which starts to be affected by these merging effects at pTs of about 20 GeV. This difference implies that with future larger data samples, such as the one from recent Run-10, will allow the pT range of the RAA measurement to be extended via the η.

- ϕ: results for the ϕ spectra and R_{AA}, measured using several different techniques, have also recently been published. It is interesting that while clearly suppressed, phi mesons only reach the suppression level of the pi0 and eta at pT¿5, and also that they seem to follow a similar pT evolution trend as other strange particles and even heavy-flavor electrons.

- heavy-flavor electrons: one of the big surprises at RHIC, even after the observation of jet quenching, was that the suppression for electrons resulting from heavy-flavor electrons (see X for the details of the measurement technique) was almost as strong as that observed for light mesons, despite the fact that heavy-flavor quarks were not expected to couple strongly to the medium. This strong coupling is one of the aspects of jet quenching that has attracted considerable theoretical attention, but no clear resolution. Some of the most promising calculations invoke AdS/CFT stuff.

- direct photons: the direct photons serve also as a control measurement, as they are not expected to interact with the medium, it comes as no surprise that their measured R_{AA} value is one. At higher pT, not shown, there are hints of a deviation from unity, which can be due to contributions from isospin effects and/or fragmentation photons.

3 Azimuthal Asymmetry

Even within measurements of single particle spectra, it is possible to obtain a more differential picture of jet quenching by looking at the azimuthal dependence of the suppression, relative to the reaction plane. The reaction plane is formed by the impact parameter vectors of the two colliding nuclei. The almond shaped region created by their overlap is thinnest in-plane and thickest out-of-plane. Therefore, since all proposed jet quenching mechanisms have a path-length dependence built-in (though the strength of this dependence varies across models), it should be possible to identify different suppression levels between high-pT particles that emerge along the reaction plane and perpendicular to it. Figure X shows a sample of the PHENIX results for azimuthally-dependent R_{AA}, in- and out-of-plane, together with corresponding model comparisons. The best agreement so far is obtained by a AdS/CFT inspired calculation, which corresponds to a path-length dependence proportional to l^3, the strongest dependence considered.

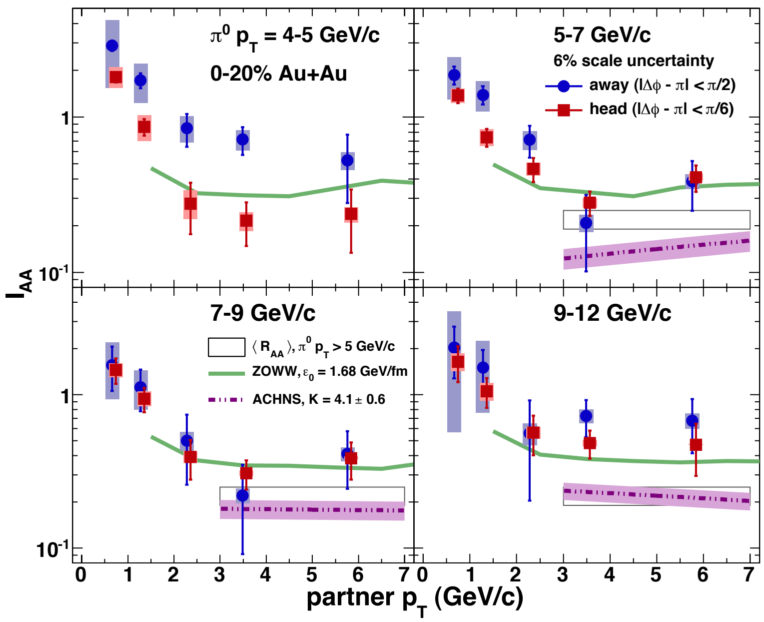
4 Di-hadron Correlations and $\gamma-$jet

When studying di-hadron correlations, the focus is again on finding deviations from the two-peak distribution that is attributed to back-to-back jets in p+p collisions. Since jets are expected to be modified by the medium in A+A collisions, these modifications should be apparent in the shapes and yields of the two peaks when compared to p+p, and able to be more differentially analyzed than in single particle spectra studies. Di-hadron correlations are built by requiring a (typically high-p_T) trigger particle, and pairing it with every other track (within a given p_T range) in the event. After correcting for acceptance and azimuthal correlations due to elliptical flow, a correlation function is obtained, and the yields and shapes of near-side and away-side peaks can be extracted.

PHENIX has recently published results on yield and shape modification for di-hadrons where the trigger particles are identified π^0 with transverse momentum in the range $4-12$ GeV/c and the associated particles are charged hadrons with $p_T = 0.5 - 7$ GeV/c. The near-side shape in Au+Au collisions is found to be consistent with the one observed in p+p, over the full range of trigger and associated p_T. The near side yield, however, is . The away-side modification can be quantified by measurements of I_{AA}, the ratio of the conditional jet pair yield in a given $\Delta\phi$ range in A+A to the same yield in p+p), shown in Figure 2.

5 Jet Reconstruction

A recent advance in the study of jets and energy loss at RHIC is the use of full jet reconstruction algorithms, developed originally for p+p environments, in the analysis of heavy ion events. PHENIX has pursued these studies using a Gaussian filter algorithm, which has been applied to p+p and Cu+Cu collisions so far. The advantage of the Gaussian filter over traditional jet reconstruction algorithms resides in its ability to reject fake jets originating from the large soft



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background at RHIC. Fluctuations in the underlying even can also produce fake jets, which are removed by requiring a minimum energy in the jet core. This fake rejection scheme has been shown to be effective in heavy ion collision environments using HIJING. Figure 4 shows the jet R_{AA}, obtained from the jet reconstruction measurements for Cu+Cu and p+p collisions in PHENIX. For comparison, the R_{AA} for π^0 is also shown.

6 Summary and Outlook

7 Bibliography

Some examples are given below [1, 2, 3]. Note that there should be a (non-breaking) space before `\cite`, obtained in LaTeX by typing `~`.

References

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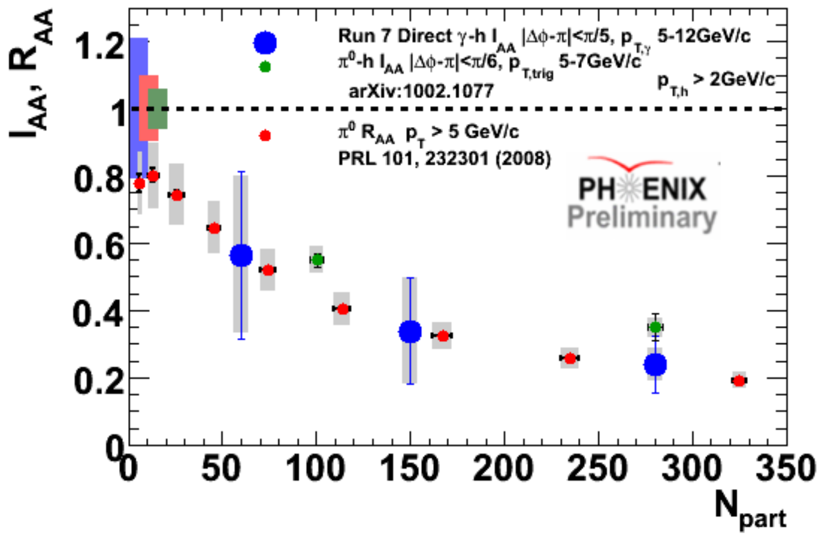

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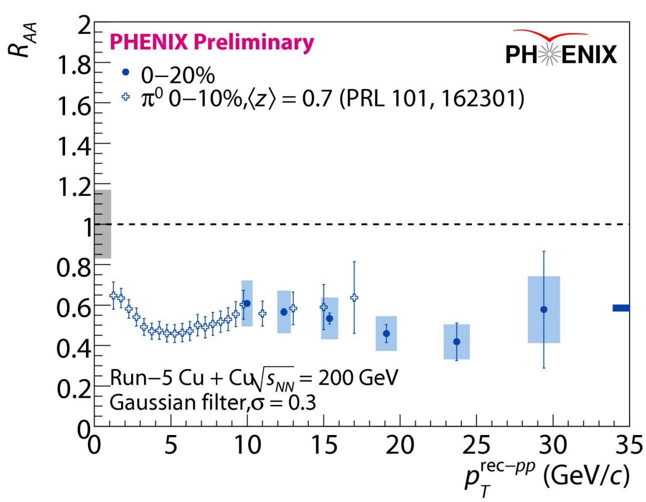

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