HARD SCATTERING AT RHIC: WHERE WE'VE BEEN, WHERE WE'RE GOING

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Recent measurements of high transverse momentum hadrons at RHIC have suggested a suppression of jets in nuclear collisions due to energy loss of the scattered partons. Current theoretical understanding of the mechanism for this energy loss indicates that the gluon density created in these collisions may be $\sim$20 times larger than in ordinary nuclear matter. I will review recent results from the RHIC experiments and develop a clear picture of what, exactly, we know about the suppression of high transverse momentum hadrons from the first two RHIC runs. In addition, I will discuss plans for the third RHIC run and beyond and highlight the measurements that will need to be made to quantify the suppression and further develop our theoretical understanding.

1. Introduction

Hard scattered partons are an important probe of the matter created in heavy-ion collisons. Because the hard scattering event occurs early in the evolution of the collisions ($\tau < 1$ fm/c), the scattered partons can be affected by the evolution of the surrounding QCD matter, particularly if this matter passes through a deconfined phase. The scattered partons will be sensitive to the medium primarily through the mechanism of energy loss, resulting in a reduction of the energy available to the parton when it fragments into hadrons. This phenomenon has been predicted to lead to a suppression of particles with large transverse momentum in heavy-ion collisions at the Relativistic Heavy Ion Collider [1]. In heavy-ion collisions it is not possible to to identify jets directly due to the large particle multiplicity

*This work supported by a grant from the U.S. Department of Energy

of the overall event. However, it is possible to identify jets through the use of leading particles and particle correlations.

2. Hadron Suppression at High p_T

All four RHIC experiments have measured charged partcile spectra from Au+Au collisions at $\sqrt{s_{NN}} = 130$ and 200 GeV, with measurements for unidentified hadrons extending out to almost $p_T = 12$ GeV/c [2,3]. All of these measurements show a suppression of high transverse momentum hadrons in central collisions when compared to data from p+$\overline{p}$ collisions measured by the UA1 collaboration (suitably scaled by the number of binary collisions and the energy difference). The PHENIX detector is also capable of reconstructing the decay of the π^0 meson to two photons using the electromagnetic calorimeter in both central arms. Using the measured production of π^0 mesons in both pp and Au+Au collisions, we can construct a ratio known as the "nuclear modification factor" R_{AA}.

$$R_{AA}(p_T) = \frac{1/N d^2N^{AA}/dp_T d\eta}{< N_{binary} > d^2N^{pp}/dp_T d\eta} \tag{1}$$

The number of binary collisions for a given centrality class $< N_{binary} >$ is estimated using a Glauber model of the nuclear overlap. In the (niave) limit that a nucleus-nucleus collision can be though of as a superposition of independent nucleon-nucleon collisions, the nuclear modification faction at high p_T should be unity.

The measured nuclear modification factor for neutral pions is shown in Figure 1. There is a significant suppression of high transverse momentum π^0 mesons observed in Au+Au collisions, consistent with substantial energy loss of the scattered partons [4]. A similar suppression was observed in data taken at $\sqrt{s_{NN}} = 130$ GeV [3]. Models of energy loss that incorporate the expansion of the system indicate the energy loss in the matter created in heavy-ion collisions at RHIC may be as much as fifteen times larger than the energy loss of a comparable parton in ordinary nuclear matter [5]. Since the energy loss is proportional to the gluon density, this implies the gluon density created in a heavy ion collision is more than an order of magnitude larger than in cold nuclei.

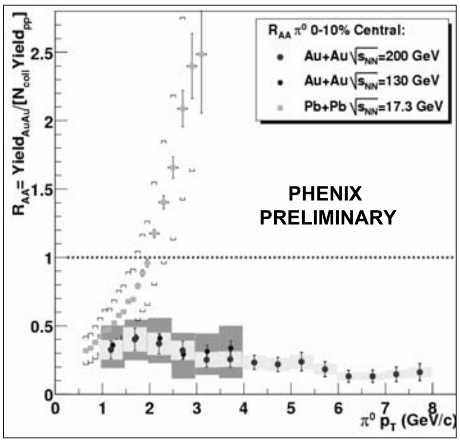

Figure 1. The nuclear modification factor R_{AA} for neutral pions in central collisions measured in the PHENIX apparatus, for both $\sqrt{s_{NN}} = 130$ GeV and $\sqrt{s_{NN}} = 200$ GeV collisions. Data from the CERN SPS is also shown, where initial state parton scattering dominates energy loss, producing an enhancement in the R_{AA} ratio above 2 GeV/c. The error bars on the PHENIX data are statistical, while the shaded bands indicate the systematic error.

3. Particle Correlations

For almost all particles produced in the collision ($p_T < 2.5\ GeV/c$), the observed elliptic flow (characterized by the Fourier coefficient v_2) is consistent with a hydrodynamic expansion of the colliding system coupled with the anisotropic initial overlap of the two nuclei [6]. The matter in this low momentum region is dominated by soft, non-perturbative QCD interactions and participates fully in the hydrodynamic expansion. However, energy loss combined with the anisotropic shape of the nuclear overlap region would also induce a nonzero v_2 parameter for these high momentum particles [7]. The STAR and PHENIX collaborations have measured a large elliptic flow parameter as a function of centrality out to large transverse momenta [8,9]. The measured v_2 is close to the maximal elliptic flow possible for a source that is opaque, and all that is observed is surface emission [10].

The correlation of partciles in azimuthal angle in a narrow range of pseudorapidity is sensitive to the correlation of hadrons arising from the fragmentation of a scattered parton. The STAR and PHENIX collaborations have measured particle correlations near $\phi = 0^o$ and $\phi = 180^o$ in relative angle that have properties consistent with jet fragmentation [11,12].

STAR in particluar has demonstrated the disappearance of the far-side jet as a function of centrality, consistent with the formation of a gluon-dense medium in central collisions.

4. Future Measurements

The RHIC Run-3 physics program will center around collisions of deuterons with Au nuclei. These measurements will provide a strong baseline conparison for many of the physics observabled measured by the RHIC experimental collaborations. For hard scattering, d+Au collisons will allow a measurement of the enhancement in R_{AA} at high p_T due to multiple scattering of the incident partons. This enhancement is overpowered by the suppression in Au+Au collisions, but an understanding of the enhancement is necessary in order to be able to quantify the overall effect.

Subsequent runs at RHIC with Au ions at full luminosity will allow high statistics measuremnts of charm production. Recent measurements of single inclusive electrons from the PHENIX collaboration [13] may indicate the heavier quarks may not suffer as strong an energy loss as lighter quarks, offering another potential tomographic probe. This may be especially important matter created is almost opaque to light quarks, as is suggested by current measurements from the RHIC experiments.

References

1. X.-N. Wang and M. Gyulassy, Phys. Rev. Lett. **68** 1480 (1992); M. Gyulassy and M. Plümer, Phys. Lett. **B243** 432 (1990).
2. C. Adler *et. al*, Phys. Rev. Lett **89**, 202301 (2002) and talk by C. Jorgensen *et. al*, Proceedings of Quark Matter 2002, Nantes, to be published in Nucl. Phys. A
3. K. Adcox *et. al*, Phys. Rev. Lett **88**, 022301 (2002).
4. PHENIX Collaboration, talk by S. Mioduszewski *et. al*, Proceedings of Quark Matter 2002, Nantes, to be published in Nucl. Phys. A.
5. E. Wang and X.-N. Wang, hep-ph/0202105.
6. PHENIX Collaboration, talk by T. Chujo *et. al*, Proceedings of Quark Matter 2002, Nantes, to be published in Nucl. Phys. A.
7. M. Gyulassy, I. Vitev and X.-N. Wang, Phys. Rev. Lett. **86** 002537 (2001).
8. C. Adler *et. al*, Phys. Rev. C **66**, 034904 (2002).
9. K. Adcox *et. al*, Phys. Rev. Lett **89**, 212301 (2002).
10. E. Shuryak, Phys. Rev. C **66**, 027902 (2002).
11. C. Adler *et. al*, nucl-ex/0210033.
12. PHENIX Collaboration, talk by M. Chiu *et. al*, Proceedings of Quark Matter 2002, Nantes, to be published in Nucl. Phys. A.
13. K. Adcox *et. al*, Phys. Rev. Lett **88**, 192303 (2002).