High p_T suppression vs system size and energy

Truls Martin Larsen, Niels Bohr Institute University of Copenhagen,
for the BRAHMS Collaboration

High p_T particles probe the medium created in nucleus-nucleus collisions. The high p_T partons will suffer jet quenching in the medium before it hadronizes. The number of high p_T partons is proportional to the number of hard scatterings in the collision. Indirect measurement of the energy loss (relative to the number of hard scatterings) of the partons can be studied in the nuclear modification factor, R_{AA}. Studying the R_{AA} as a function of collision energy, rapidity and system size will constrain models that try to describe these collisions. Here we will present nuclear modification factors from Au-Au and Cu-Cu collisions at $\sqrt{s_{NN}} = 62.4$ GeV and compare these with Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV.

The RHIC has now collided light, intermediate and heavy mass nuclei at several different center of mass energies. Au-Au collisions at maximum energy, $\sqrt{s_{NN}} = 200$ GeV have revealed features consistent with a strongly interacting QGP [1]. By studying and comparing collisions between light and heavy nuclei, one can learn about the matter created. In particular it is of interest to compare collisions between lighter and heavier systems for the same number of incoherent parton collisions.

In asymmetric collision at RHIC (d-Au at $\sqrt{s_{NN}} = 200$ GeV) the interplay between initial and final state effects has been seen [2–5]. At mid-rapidity there is Cronin enhancement of high p_T particles, while there is suppression at forward rapidities. Cronin enhancement is related to the initial state effects, while suppression comes from the medium created, the final state effects. The strength of the enhancement changes as a function of rapidity in d-Au collisions, but the inital state effect plays the most important role. Symmetric Au-Au collisions show final state effects. There is suppression both at mid and forward rapidity. At mid-rapidity comparison of these asymmetric collisions with symmetric collisions of Au-Au at the same energy show that high p_T particles are suppressed in Au-Au with a factor of 3-5 compared to d-Au. This can be interpreted in the direction that the parton distribution function of the Au nucleus is not the source of the suppression seen in the Au-Au collision.

This article will study the suppression of the high p_T particles further, from mid-rapidity to forward rapidity, varying the colliding nuclei, Cu-Cu and Au-Au, and center of mass energy with the BRAHMS detector.

The BRAHMS experiment consists of two movable spectrometers, which covers $-0.1< \eta <3.5$ [6], and a set of global detectors. Here we will present data taken in narrow pseudorapidity bins at 0, 1, 2 and 3. At mid-rapidity the BRAHMS detector can measure unidentified hadrons up to $p_T \sim 6$ GeV/c, and at forward rapidities up to $p_T \sim 5$ GeV/c.

The data have been divided into 4 different centrality classes: 0-10%, 10-20%, 20-40% and 40-60% of the total cross section. Invariant yields for charged hadrons was constructed for the different pseudorapidity bins, and centralities. The yields were corrected for efficiency and acceptance. No decay corrections have been applied.

QCD predicts that the number of high p_{T} particles should scale with the number of hard scatterings in a collision (incoherent binary collisions between partons). This motivated measurement of the nuclear modification factor: $R_{AA}(\eta, p_{\mathrm{T}}) = \left(\frac{d^2N^{AA}}{\langle N_{bin}^{AA}\rangle dp_T d\eta}\right) / \left(\frac{d^2N^{pp}}{dp_T d\eta}\right)$ This requires measurement of p+p collisions at the same energy as the nucleus-nucleus collisions. BRAHMS has measured p+p collisions from mid to forward rapidity at $\sqrt{s_{NN}} =$ 200 GeV. At $\sqrt{s_{NN}} = 62.4$ GeV, the ISR has measured p+p collisions at mid-rapidity and we have used a parameterisation based on these data [7].

Another way to search for the scaling between the number of incoherent binary collisions and high p_{T} particles is to compare yields from different centralities. This has the advantage that the medium created at different centralities is the same, and should then cancel. It is known as the central to peripheral ratio: $R_{cp} = \left(\frac{d^2N^{AA}_{0-10\%}}{\langle N^{AA}_{0-10\%}\rangle dp_T d\eta}\right) / \left(\frac{d^2N^{AA}_{40-60\%}}{\langle N^{AA}_{40-60\%}\rangle dp_T d\eta}\right)$ Measuring this ratio might eliminate uncertainties of using a parametrization of the ISR data. It is also intrinsically easier to measure, since both data sets are measured at the same time. Many systematic errors therefore cancel. At forward rapidities there are no p+p collision measurements and we can only measure the R_{cp}. Here the central yield corresponds to 0-10% and the peripheral yield to 40-60%.

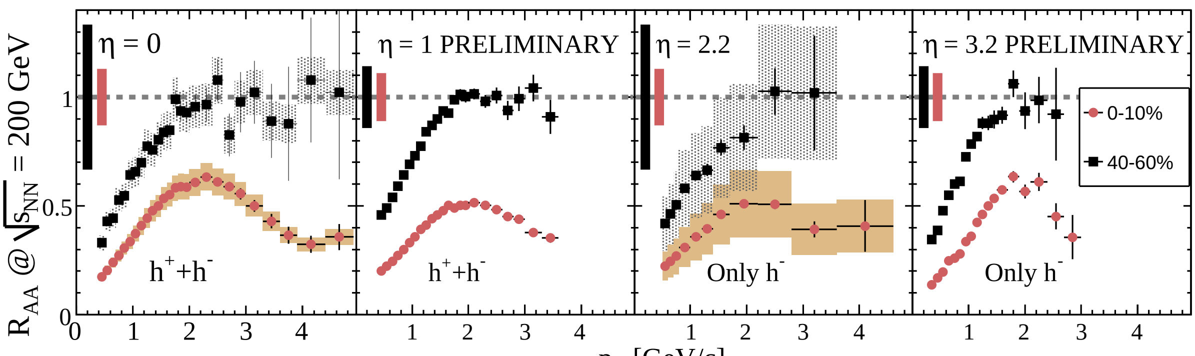

Figure 1. R_{AA} in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The $\eta = 0$ and 2.2 panels are from [8]. The shaded error bars around the points are systematic errors. The $\eta = 1$ and 3.2 panels only show statistical errors and are preliminary results. The R_{AA} at $\eta = 2.2$ and $\eta = 3.2$ are only negative hadrons. The shaded bar at 1 show the errors on the scale.

Figure 1 shows R_{AA} for Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The behaviour of the R_{AA} is similar at all pseudorapidities. The central collisions show suppression when p_{T} is higher than 2 GeV/c, while the R_{AA} for peripheral collisions approches unity for $p_{\mathrm{T}} > 2$ GeV/c. At mid-rapidity the suppression factor is about ~ 3. As suggested by the last points at $\eta = 0$, the suppression saturates at this value, which have been measured by PHENIX from $p_{\mathrm{T}} \sim 4$ GeV/c up to $p_{\mathrm{T}} \sim 10$ GeV/c for neutral pions [9]. The R_{AA} does not appear to depend on the rapidity at this energy. Figure 2 show that Au-Au

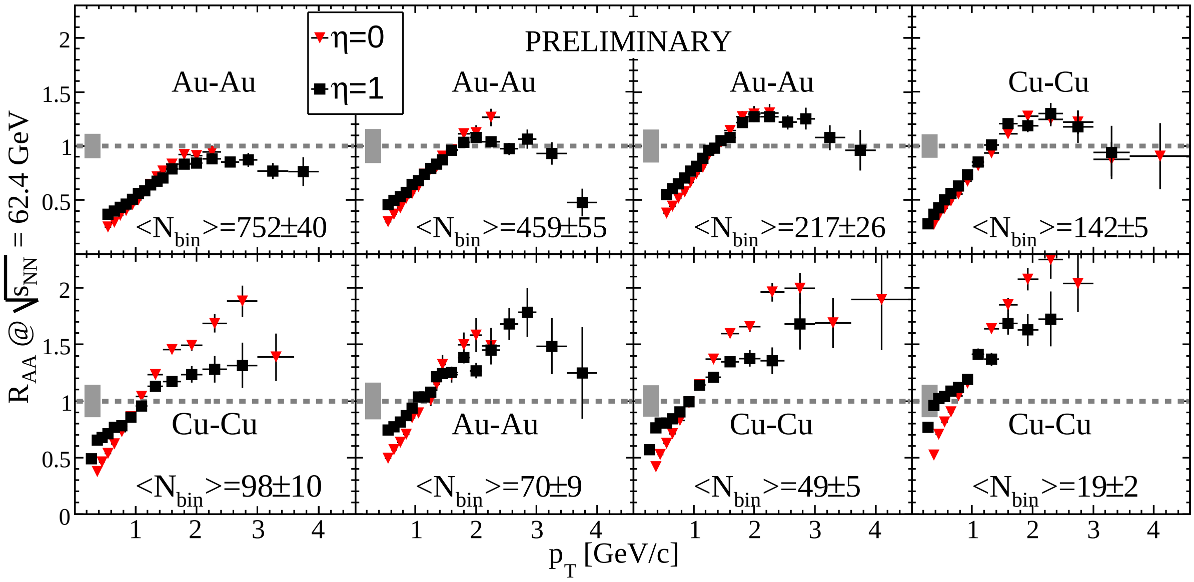

Figure 2. R_{AA} in Au-Au and Cu-Cu collisions at $\sqrt{s_{NN}} = 62.4$ GeV. The shaded bar at 1 show the errors on the scale. Only statistical errors are shown. The number of incoherent binary collisions are stated on each plot, and are arranged in decreasing order.

and Cu-Cu collisions have no significant suppression at $\sqrt{s_{NN}} = 62.4$ GeV. A Cronin enhancement appears for more peripheral collisions. The R_{AA} grows steadily as $\langle N_{bin}\rangle$ decreases.

Figure 3a, b and d shows the pseudorapidity dependence of the R_{cp} for all three different collisions. At $\sqrt{s_{NN}} = 200$ GeV there is a clear difference in the shape of the R_{cp} at forward rapidity compared to mid-rapidity. A peak is seen at $p_{\rm T} \sim 2$ GeV/c. The $\sqrt{s_{NN}} = 62.4$ GeV data also show a difference of the $\eta \sim 3$ R_{cp}, it is consitently lower than at mid-rapidity for all $p_{\rm T}$. Figure 3c shows the ratio of semi-peripheral Au-Au yield to the semi-central Cu-Cu yield. Both yields have the same average number of binary collisions. The very flat ratio shows the similarity of the Au-Au and Cu-Cu collisions.

At low energies $\sqrt{s_{NN}} = 17.2$ GeV a Cronin enhancement of high $p_{\rm T}$ particles has been seen [10,11]. This has been interperated as a $p_{\rm T}$ broadening due to multiple scattering of the partons. In central collisions at $\sqrt{s_{NN}} = 62.4$ GeV the Cronin enhancement is gone, while at $\sqrt{s_{NN}} = 200$ GeV, there is a clear high $p_{\rm T}$ suppression. The suppression depends on the mass of the particle at $\sqrt{s_{NN}} = 200$ GeV [13]. The R_{AA} at high $p_{\rm T}$, decreases with increasing energy in both central and semi-peripheral collisions. Also at $\sqrt{s_{NN}} = 62.4$ GeV, see Fig. 2 the suppression increases with increasing $\langle N_{bin}\rangle$. For this intermediate energy the Au-Au and Cu-Cu collisions shows the same feature as a function of $p_{\rm T}$ when the $\langle N_{bin}\rangle$ is the same, as can been seen in Fig. 3c. R_{cp} does not depend on collisions energy at mid-rapidity in $\sqrt{s_{NN}} = 200$ GeV and $\sqrt{s_{NN}} = 62.4$ GeV collisions, but at forward rapidity it does, see Fig. 3. One interpretation of this is that coalescense (quark recombination) [12] decreases the Cronin enhancement at forward rapidity. Another possibility is that the underlying parton spectrum changes with rapidity for the more peripheral collisions.

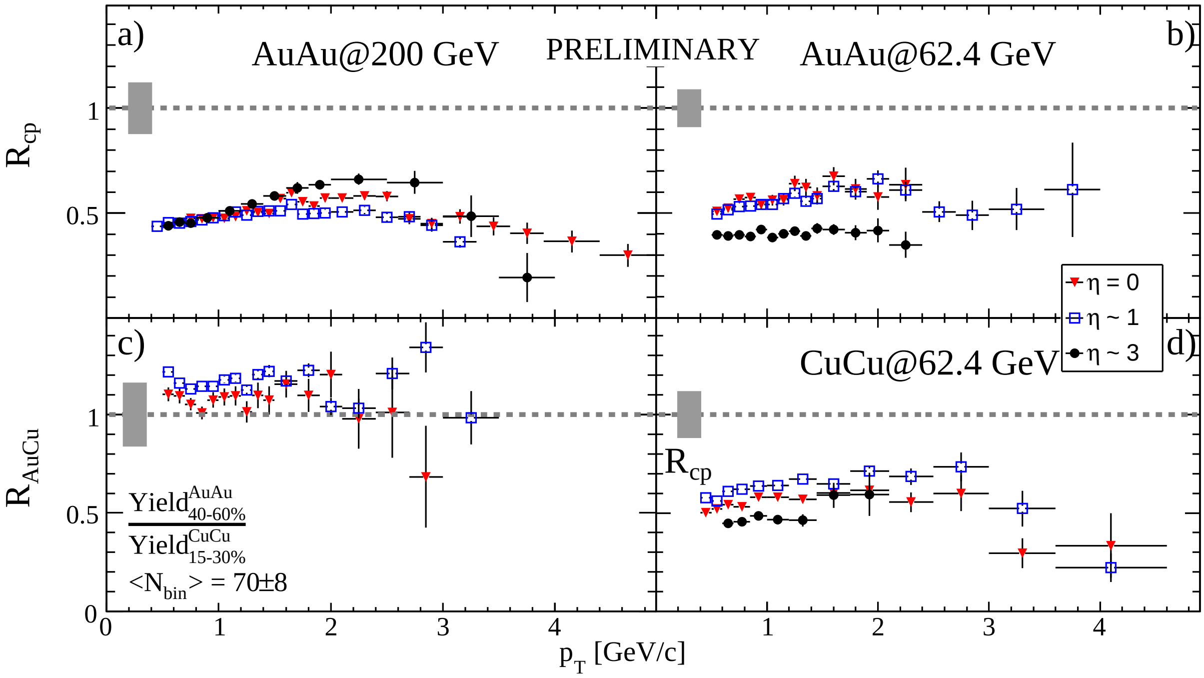

Figure 3. Panel a, b and d are central to peripheral ratio, R_{cp} for Au-Au and Cu-Cu collisions at $\sqrt{s_{NN}} = 62.4$ GeV. The shaded bar at 1 show the errors on the scale. Panel c show ratio of semi-peripheral (40-60%) Au-Au yield to semi central (15-30%) Cu-Cu yield. Most systematic errors will cancel in these ratios.

The data sets presented constrain models that include jet quenching, coalescense and/or other medium effects. An even more systematic study of the rapidity dependence can be carried out when BRAHMS has measured p+p collisions at $\sqrt{s_{NN}} = 62.4$ GeV, which is proposed in 2006. These p+p data will help us disentagle the final and inital state effects on high p_{T} particles, and enable a more thorough study of parton energy loss.

REFERENCES

1. "First Three Years of Operation of RHIC", Nucl. Phys. **A757**, Issues 1-2 (2005).
2. J. D. Bjorken, Phys. Rev. **D 27**, 140 (1983).
3. R. Baier, *et al.*, Phys. Lett. **B 345**, 277, (1995); Annu. Rev. Nucl. Part. Sci. **50**, 37 (2000).
4. M. Gyulassy and M. Plümer, Phys. Lett. **B 243**, 432 (1990).
5. BRAHMS collaboration, I. Arsene, *et al.*, Phys. Rev. Lett. **91**, 072305 (2003).
6. M. Adamczyk *et al.*, Nucl. Instr. Meth. **A499**, 437 (2003).
7. B. Alper *et al.*, Nucl. Phys. **B100**, 237 (1975).
8. BRAHMS collaboration, I. Arsene *et al.*, Phys. Rev. Lett. **91**, 072305 (2003).
9. PHENIX collaboration, S.S. Adler, *et al.*, Phys. Rev. Lett. **91**, 072301 (2003).
10. X. N. Wang, Phys. Rev. **C61**, 064910 (2000) and references therein.
11. D. d'Enterria, J. Phys. **G31**, S491 (2005); D. d'Enterria nucl-ex/0504001
12. R. C. Hwa, C. B. Yang, Phys. Rev. Lett. **93** 082302 (2004).
13. Radoslaw Karabowicz (BRAHMS collaboration), these proceedings.