

# Nuclear Modification Factors at Forward Rapidity in Au-Au and CuCu collisions at $\sqrt{s_{NN}} = 62.4$ GeV

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**Abstract.** Data from Au-Au, Cu-Cu and p+p collisions at  $\sqrt{s_{NN}} = 62.4$  GeV have been collected by the BRAHMS experiment from rapidity 0 to 3.1. Nuclear modification factors,  $R_{AA}$  at forward rapidity, with  $p_T$  up to  $\sim 2$  GeV, which corresponds to more than half of the available kinetic energy, are presented together with results from mid rapidity for Au-Au and Cu-Cu collisions. They will also be shown as a function of centrality.

Jet quenching in heavy ion collisions at the RHIC top energy has been a central indicator of the creation of strongly interacting quark gluon matter. In heavy ion collisions at  $\sqrt{s_{NN}} = 200$  GeV, strong suppression of high  $p_T$  particles is observed, saturating from  $p_T \simeq 4$  and  $\sim 20$  GeV. Through the study of  $d - Au$  collisions at the same energy it has been established that the suppression is a final state effect, thought to be due to quark energy loss in the medium. The medium the partons go through have a high density of colour charges, and the partons can loose energy through gluon emission. The energy loss will then be proportional to  $L^2$ . These measurements show a strong contrast to earlier proton-nuclei and nucleus-nucleus collisions, performed at SPS and FERMILAB [1, 2, 4] at  $\sqrt{s_{NN}} \simeq 20 - 30$  GeV, where an enhancement of the yield of the high  $p_T$  particles was seen. The enhancement is due to  $p_T$  broadening from multiple scatterings of the partons as they traverse the cold matter of the nucleon [3]. To get a better understanding of these mechanisms the RHIC community has carried out a program of measurements at an intermediate energy,  $\sqrt{s_{NN}} = 62.4$  GeV, with various system sizes. Measuring the nuclear modification factor as a function of centrality and pseudorapidity will give information on the matter created in the fireball.

This article presents the first BRAHMS results of collisions of Au-Au, Cu-Cu and p+p at  $\sqrt{s_{NN}} = 62.4$  GeV, as a function of pseudorapidity and centrality. The BRAHMS experiment has earlier performed such measurement at the RHIC top energy, and data has now also been collected, from mid- to forward rapidity, at  $\sqrt{s_{NN}} = 62.4$  GeV. The nuclear modification factor for a light system, Cu-Cu, as well as a heavy system, Au-Au, will be presented here.

The BRAHMS experiment consists of two movable magnetic spectrometers, covering  $-0.1 < \eta < 3.5$ , and a set of detectors to determine the multiplicity of charged particles and the interaction point [7]. For the p+p collisions additional Čerenkov

radiators, positioned around the beam pipe at  $-3$  m,  $1.8$  m and  $3$  m away from the nominal interaction point, were used to determine the point of interaction, with a resolution of  $\sim 2$  cm. From dedicated runs, it was determined that their coverage of the total cross section was 12 mb out of the 36 mb. This information was used when the minimum bias transverse momentum spectrum was calculated.

The nuclear modification factor is given as:

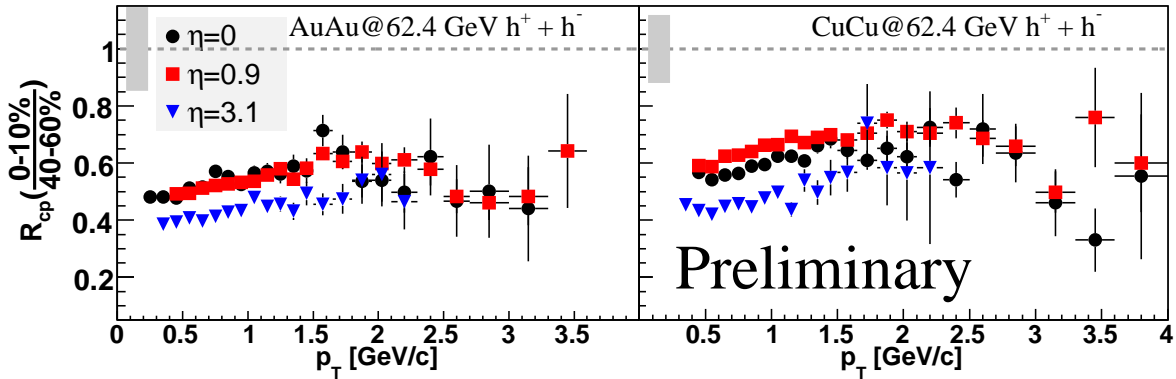
$$R_{AA}(\eta, p_T) = \left( \frac{d^2 N^{AA}}{\langle N_{bin}^{AA} \rangle dp_T d\eta} \right) \cdot \left( \frac{d^2 N^{pp}}{dp_T d\eta} \right)^{-1} \quad (1)$$

where  $\langle N_{bin}^{AA} \rangle$  is the number of partons collisions in one of the colliding nucleons go through. The results presented here will use a parametrisation of the transverse momentum spectra from ISR [8] at midrapidity,  $\eta = 0$  and  $0.9$ , and BRAHMS own p+p spectra at  $\eta = 3.1$ . These data were collected at the same magnetic field settings as the heavy ion data in order to minimize systematic errors. The parametrisation of the ISR  $p_T$  spectra has an estimated uncertainty of about  $\sim 20\%$ .

Another quantity one can study is the central-to-peripheral ratio:

$$R_{cp} = \left( \frac{d^2 N_{0-10\%}^{AA}}{\langle N_{0-10\%}^{AA} \rangle dp_T d\eta} \right) \cdot \left( \frac{d^2 N_{40-60\%}^{AA}}{\langle N_{40-60\%}^{AA} \rangle dp_T d\eta} \right)^{-1} \quad (2)$$

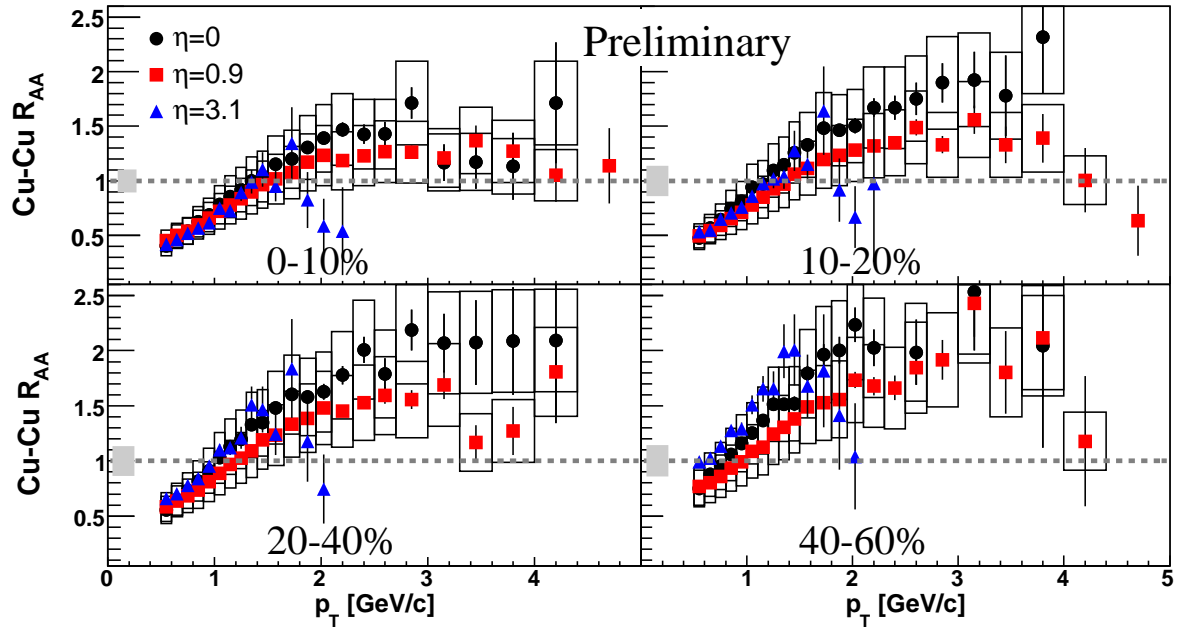
The central,  $0 - 10\%$ , and peripheral,  $40 - 60\%$   $p_T$  spectra are both taken at the same time, and is therefore largely free of systematic errors.



**Figure 1.**  $R_{cp}$  in Au-Au and Cu-Cu collisions at  $\sqrt{s_{NN}} = 62.4$  GeV for charged hadrons. The shaded bar at 1 show the error on the scale.

The central-to-peripheral ratio,  $R_{cp}$  is shown in fig 1 for Cu-Cu and Au-Au collisions. The  $R_{cp}$  at  $\eta = 3.1$  is smaller than at midrapidity, but shows a similar  $p_T$  dependence. No dependence on the charge ( $h^+$  or  $h^-$ ) at forward rapidity has been seen.

The  $R_{AA}$  for Cu-Cu and Au-Au collisions at  $\sqrt{s_{NN}} = 62.4$  GeV are shown in fig 2 and 3. There is no difference between the measurements at midrapidity and at forward rapidity. The  $R_{AA}$  does not, like the  $R_{cp}$ , show any dependence in the charge ( $h^+$  or  $h^-$ ). There is more enhancement or less suppression in Cu-Cu  $R_{AA} 0 - 10\%$  compared to Au-Au  $R_{AA} 0 - 10\%$ . The same trend is seen as one goes to more peripheral collisions, indicating, as expected that the  $R_{AA}$  depends on the geometry of the system.



**Figure 2.**  $R_{AA}$  in Cu-Cu collisions at  $\sqrt{s_{NN}} = 62.4$  GeV. The midrapidity results,  $\eta = 0$  and  $0.9$ , use p+p reference spectra from ISR [8]. The systematic errors are shown as boxes around the points. The  $\eta = 3.1$  uses BRAHMS own preliminary p+p reference data taken in the exact same pseudorapidity bin. Systematic errors for these results should be  $\sim 5\%$  on the scale. The shaded bar at 1 shows the errors on the scale.

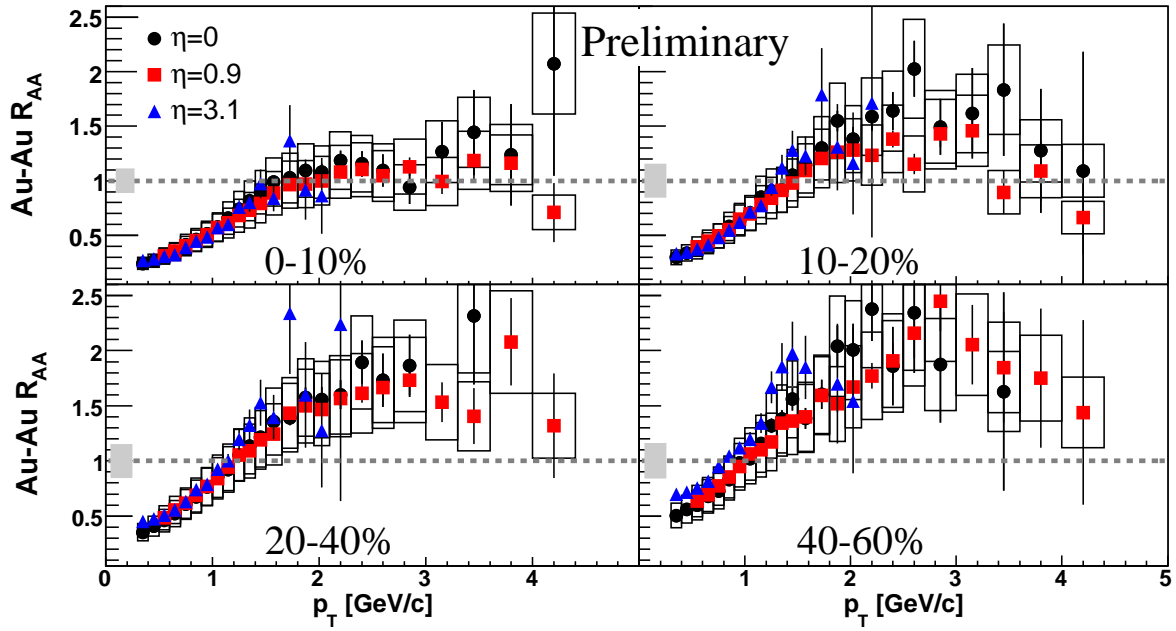
Fig 4 shows a ratio,  $R_{AuCu}$  of Au-Au spectra to Cu-Cu spectra, scaled with the number of binary collisions for their respective centralities. The shape of the ratio is very similar to the  $R_{cp}$ , but is consistent with one. The ratio becomes flat just above  $\sim 1$  GeV.

For Au-Au collisions at  $\sqrt{s_{NN}} = 200$  GeV, BRAHMS has previously [10] shown that  $R_{AA}$  is approximately independent of pseudorapidity, over a wide range ( $0 < \eta < 3.5$ ). The new measurements of the nuclear modification factor at  $\sqrt{s_{NN}} = 62.4$  GeV have been shown to have no dependence on pseudorapidity, either. If it is the final state medium that affects the high momentum partons, the suppression/enhancement only affects the transverse momentum component, and not the longitudinal one.

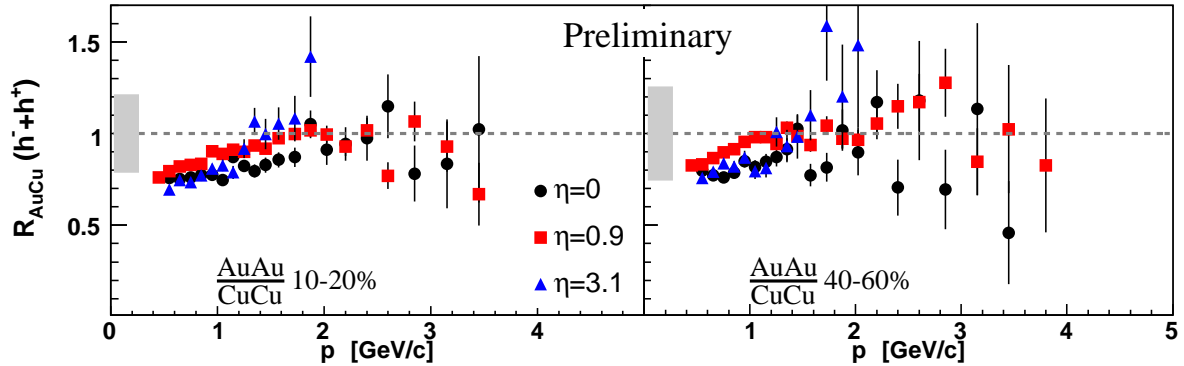
Furthermore the flatness of the ratio, from  $\sim 1$  GeV, in fig 4, shows that the enhancement or suppression strongly depends on the volume of the fireball, as expected.

## References

- [1] J. Cronin *et al*, Phys. Rev. **D11** 3105 (1975).
- [2] D. Antreasyan *et al* (CP Collaboration) Phys. Rev. **D19** 764 (1979).
- [3] X.-N. Wang, Phys. Rept. **280** 287 (1997).
- [4] M. M. Aggarwal *et al*, Eur. Phys. J **23** 225 (2002).
- [5] "First Three Years of Operation of RHIC", Nucl. Phys. **A757**, Issues 1-2 (2005).
- [6] T. Alber *et al*, Phys. Rev. Lett. **75** 3814 (1995).
- [7] M. Adamczyk *et al*, Nucl. Instr. Meth. **A499**, 437 (2003).



**Figure 3.**  $R_{AA}$  in Au-Au and collisions at  $\sqrt{s_{NN}} = 62.4$  GeV. The midrapidity results,  $\eta = 0$  and  $0.9$  see [9], The systematic are shown as boxes around the points. The  $\eta = 3.1$  uses BRAHMS own preliminary p+p reference data taken in the exact same pseudorapidity bin. The shaded bar at 1 show the errors on the scale. Only statistical errors are shown for the forward result, but they have an  $\sim 5\%$  uncertainty on the scale.



**Figure 4.** The figure shows the Au-Au  $p_T$  spectra divided by Cu-Cu spectra at  $\sqrt{s_{NN}} = 62.4$  GeV, scaled to the number of binary collisions in their respective centralities,  $R_{AuCu}$ . Left panel shows the scaled ratio of 10 – 20% centrality, and the right panel the 40 – 60%. The point to point error is statistical only, but most systematic error should cancel. The error on the scale is the shaded bar around 1.

[8] D. d’Enterria, J. Phys. **G31**, S491 (2005); D. d’Enterria Eur. Phys. J. **C43** 295 (2005).

[9] BRAHMS Collaboration, I. Arsene *et al*, Submitted to Phys. Lett. B, nucl-ex/0602018

[10] BRAHMS Collaboration, I. Arsene *et al*, Phys. Rev. Lett. **91**, 072305 (2003).