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ENERGY DEPENDENCE OF NUCLEAR MODIFICATION FACTORS IN Au-Au COLLISIONS AT 200 GeV AND 62.4 GeV*

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Abstract. Transverse momentum spectra of produced hadrons in ultrarelativistic nuclear collisions provide valuable information on particle production mechanisms as well as dynamics and properties of the produced matter. We will present results on inclusive charged hadrons produced in Au-Au collisions at 200 AGeV and 62.4 AGeV, in center of mass system, at mid-rapidity (y = 0). The 200 GeV p-p collisions reference data are collected also with the BRAHMS experimental set-up. The energy dependence of nuclear modification factors and central-to-peripheral factors in Au-Au and p-p collisions will be shown and discussed.

Key words: heavy ion collisions, quark-gluon plasma, high p_T suppression.

1. INTRODUCTION

Within the past several years there was an extraordinary progress on various aspects of elementary particle properties and related phenomena such as heavy ion collisions at relativistic energies [1]. From the study of nucleon-nucleon interactions it is known that when two partons undergo a scattering with large momentum transfer in the early stages of the collision, the hard-scattered partons fragment into jets of hadrons with high transverse momentum ($p_T \geq$ 2GeV/c) [2]. When the hard scattered partons traverse the hot and dense nuclear matter that is created in a high energy heavy ion collision, they may lose energy through gluon bremsstrahlung. The energy lost depends on the density of color charges in the matter which parton propagates [3]. This effect is called jet-quenching or high p_T

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suppression, and the most directly measurable consequence is the suppression of high transverse momentum hadrons in the final state.

In order to determine the high p_T hadron suppression in nucleus-nucleus collisions, the hadron p_T spectra have to be compared to the reference data from nucleon-nucleon (p-p) collisions at the same collision energy. The nuclear modification factor is defined as:

$$R_{AB} = \frac{\dfrac{\mathrm{d}N_{AB}^2}{\mathrm{d}p_T\,\mathrm{d}y}}{\left\langle N_{coll}^{AB} \right\rangle \dfrac{\mathrm{d}N_{pp}^2}{\mathrm{d}p_T\,\mathrm{d}y}}, \tag{1}$$

where $\left\langle N_{coll}^{AB} \right\rangle$ is the average number of binary collisions for a given centrality in an A-B collision. The study of this factor can reveal the underlying physics in heavy ion collisions. At low p_T ($p_T < 2$ GeV/c), where soft production dominates the measured yields, the nuclear modification factor tells about the bulk properties and is expected to scale with the number of participants, $\left\langle N_{part} \right\rangle$ and not to $\left\langle N_{coll} \right\rangle$. At high p_T and in the absence of nuclear medium efects, hard processes are expected to scale with the number of binary collisions, $\left\langle N_{coll} \right\rangle$, and consequently, $R_{AB} = 1$ (nuclear collisions are just a superposition of p-p collisions). Any deviation from unity indicate strong nuclear medium effects, such as the high p_T suppression.

If p-p collision distributions are not available or in order to remove the systematic errors introduced by the comparison of the measurements of nucleus-nucleus and p-p collisions, a diferent ratio can be constructed, called the „central-to-peripheral" ratio, R_{cp}. This ratio uses the peripheral collisions to construct the reference spectrum. The spectrum in the numerator and the denominator are both scaled with their corresponding number of incoherent binary collisions. The R_{cp} is thus defined as:

$$R_{CP} = \frac{\left\langle N_{coll}^{peri} \right\rangle}{\left\langle N_{coll}^{cent} \right\rangle} \frac{\dfrac{\mathrm{d}^2 N_{cent}}{\mathrm{d}p_T\,\mathrm{d}y}}{\dfrac{\mathrm{d}^2 N_{peri}}{\mathrm{d}p_T\,\mathrm{d}y}}, \tag{2}$$

where $\left\langle N_{coll}^{cent} \right\rangle$ and $\left\langle N_{coll}^{peri} \right\rangle$ are the average number of binary collisions in central and peripheral Au-Au collisions, respectively. Nuclear medium effects are expected to be much stronger in central relative to peripheral collisions, which makes R_{cp} another measure of these effects.

2. EXPERIMENTAL SET-UP

The data presented here were collected with BRAHMS detector system [4] from RHIC (Relativistic Heavy Ion Collider) [5]. BRAHMS (Broad RAnge Hadron Magnetic Spectrometers) consists of a set of global detectors for event characterization and two magnetic spectrometers, the mid-rapidity spectrometer (MRS) and the forward spectrometer (FS), which identify charged hadrons over a broad range in rapidity and transverse momentum. Collision centrality is determined from the charged particle multiplicity measured by a set of global detectors. Since BRAHMS is a small solid angle device, the charged particle spectra is obtained by mapping out the particle phase space by collecting data with many different spectrometer settings and various magnetic fields (mostly high magnetic field chosen in order to increase statistics at high p_T).

When combining different settings, the deviation of the single settings spectra to the final spectra are within 20% in the low p_T regions. In the high p_T region, the different settings are consistent within the statistical errors.

For the Au-Au data which are presented here, the midrapidity spectrometer was positioned at 90 degrees relative to the beam axis, and measured charged hadrons are for pseudorapidity, η, in the range [-0.1, 0.1] ($\eta = -\ln(\tan(\theta/2))$, where θ is the angle of emission relative to the beam direction).

The global detectors were used for the minimum bias trigger and event characterization. This trigger selects approximately 95% of the Au-Au interaction cross section. Spectrometer triggers are also used to enhance the track sample. The IP position is determined with a precision $\sigma < 0.85$ cm by the use of beam counters (BB) placed at $z = \pm 2.2$ m from the nominal interaction point.

3. RESULTS AND DISCUSSION

The transverse momentum spectra for unidentified charged hadrons $(h^+ + h^-)/2$ measured by BRAHMS experiment in Au-Au collisions at $\sqrt{s_{NN}} = 200$ GeV and 62.4 GeV at mid-rapidity ($y = 0$) are shown in Fig.1.

The displayed spectra correspond to centralities of 0–10% (most central), 10–20%, 20–40% and 40–60% (peripheral) of the total interaction cross-section. The spectra have been corrected for acceptance of the spectrometers and for centrality dependent tracking efficiencies. All the charged hadron spectra exhibit a power law shape.

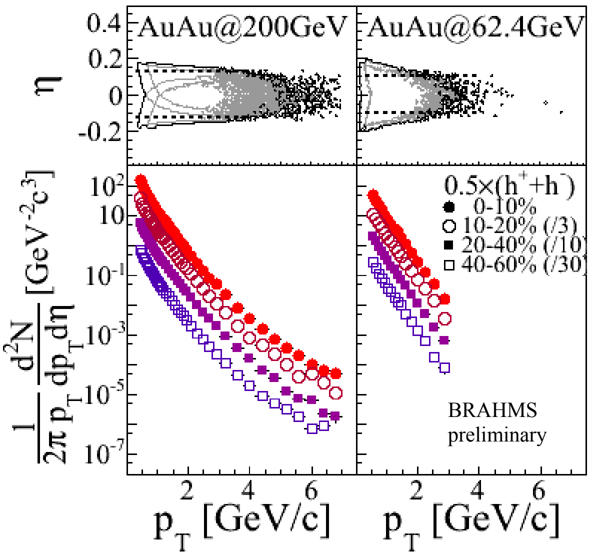

Fig. 1 – Top row: Population of experimental data in $\eta - p_T$ phase space for each setting. The dotted lines show the cuts in η that have been applied. Bottom row: Transverse momentum spectra for inclusive charged hadrons produced Au-Au collisions at 200 A GeV (left) and 62.4 A GeV (right) – both in center of mass system – at mid-rapidity (y = 0), for 0–10%, 10–20%, 20–40% and 40–60% collision centrality. For clarity, some spectra have been divided by the indicated factors.

Table 1

The number of binary collisions for different centrality classes in Au-Au collisions at $\sqrt{s_{NN}}$ =200 GeV and 62.4 GeV

Centrality (%)	N_{coll}^{200} AuAu@200GeV	$N_{coll}^{62.4}$ AuAu@62.4GeV
0-10	886±39	752±40
10-20	534±46	459±55
20-40	244±23	217±25
40-60	71±7	70±9

The number of binary collisions, N_{coll}, is not experimentally measurable quantity and it is necessary to rely on model calculations to determine the values. For BRAHMS data, the estimations are done using the HIJING events as input to a BRAG (BRAHMS GEANT) simulation with the same centrality cuts as in the analysis of real data, and with the same acceptance cuts as the global detectors. Details about the calculation of N_{coll} can be found in [6]. N_{coll} for diferent collision centralities used in this analysis are presented in the Table 1.

The nuclear modification factor, R_{AA}, as function of p_T for Au+Au collisions at η = 0 for four centrality classes (0–10%, 10–20%, 20–40% and 40–60%) is shown in Fig. 2. Because there are no diferences between R_{AA} for positive hadrons and for negative hadrons, we present the R_{AA} for $(h^{+}+h^{-})/2$. Error bars are statistical. The estimated systematic errors on the data points are indicated by the shaded boxes around the points.

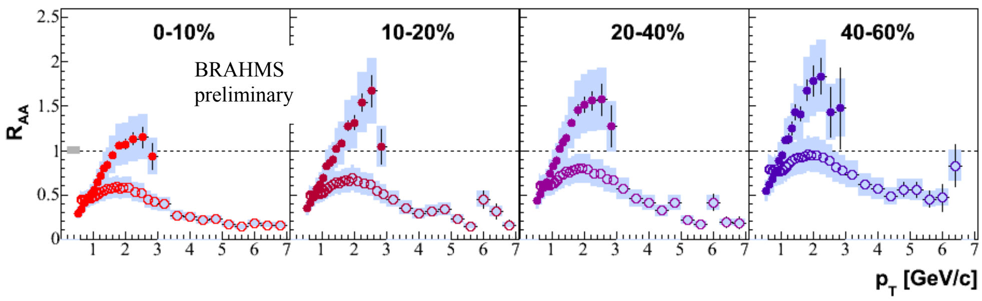

Fig. 2 – R_{AA} for the charged hadrons produced in Au-Au collisions at 200 A GeV (open symbols) and 62.4 A GeV (full symbols), both in center of mass system, at pseudorapidity $\eta = 0$ for the four centrality classes indicated. The estimated systematic errors on the data points are indicated by the shaded boxes around the points.

For all centrality classes, at low $p_{T,}$ the R_{AA} distributions in Au+Au collisions at 200 GeV increase monotically up to $p_T = 2$ GeV/c. As p_T continues to increase above 2 GeV/c, the R_{AA} values decrease showing the suppression of the charged hadron yields relative to the p-p reference. At high p_T ($p_T > 4$ GeV/c), for the most central 0–10% Au+Au collisions at 200 GeV, the charged hadron yields are suppressed by a factor of ~5 as compared with binary scaled p-p yields.

For semi-peripheral collisions (40–60% centrality), at high p_T ($p_T > 4$ GeV/c), $R_{AA}(p_T)$ values are around ~0.6–0.7, higher that the 0–10% R_{AA} values, showing less high p_T suppression. This could indicate that peripheral Au-Au collisions behave very much like a superposition of many p+p collisions, which implies less nuclear efects. As one goes to more central collisions, the strong suppression of $R_{AA}(p_T)$ below unity, evidences strong nuclear efects.

The centrality dependence of the nuclear modification factor could be explained as a consequence of medium induced energy loss of partons traversing the hot, dense medium. For the smaller system sizes (peripheral Au-Au data), the path length traversed is smaller (on average) than for the larger system (central Au-Au).

The R_{AA} measurements for Au-Au collisions at $\sqrt{s_{NN}}$ = 62.4 GeV are consistent with binary scaling at $p_T > 2$ GeV/c. Even considering the systematic errors associated with the reference p-p spectra and the normalization to N_{coll}, the R_{AA} around mid-rapidity at $\sqrt{s_{NN}}$ = 62.4 GeV is significantly above the value obtained for Au-Au collisions at $\sqrt{s_{NN}}$ = 200 GeV, showing no high p_T hadron suppression. For the intermediate p_T region, jet-quenching compensates Cronin enhancement.

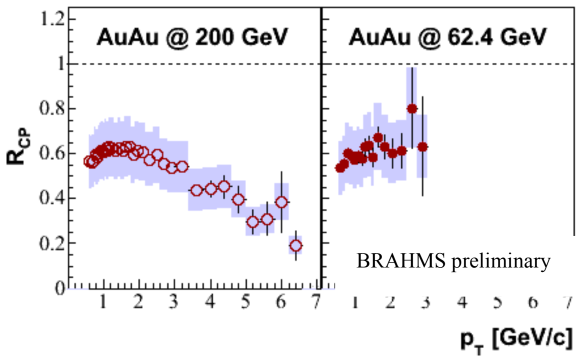

Fig. 3– R_{CP} for charged hadrons, $(h^+ + h^-)/2$, produced in Au+Au collisions at 200 A GeV (left panel) and 62.4 A GeV (right panel), both in center of mass system, at mid-rapidity ($\eta = 0$) as a function of transverse momentum. The systematic uncertainties are shown as the shaded boxes around the data points.

In order to remove the systematic error introduced by the comparison from the measurements of nucleus-nucleus and p-p collisions, we analyze the R_{CP} ratio, defined by formula (2).

Figure 3 shows the central-to-peripheral, R_{CP}, for Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV (left panel) and $\sqrt{s_{NN}}$ = 62.4 GeV (right panel) as a function of transverse momentum for $\eta = 0$. For $p_T >$ 3-4 GeV/c, the R_{CP} values are between 0.3 and 0.4, showing that in 0–10% most central $\sqrt{s_{NN}}$ = 200 GeV Au+Au collisions, the charged hadron yields are strongly suppressed as compared to semi-peripheral (40–60%) Au+Au collisions, when scaled with the number of binary collisions. The R_{CP} for $\sqrt{s_{NN}}$ = 62.4 GeV collisions exhibit similar values and is similar to the ratios that have been measured for $\sqrt{s_{NN}}$ = 200 GeV collisions. Assuming same initial state effects in peripheral and central Au+Au collisions, R_{CP} contains information only about final state effects, whereas R_{AA} ratios sample both initial and final state effects.

4. CONCLUSIONS

In summary, we have measured the transverse momentum spectra of unidentified charged hadrons in Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV and $\sqrt{s_{NN}}$ = 62.4 GeV. The results show that there is a strong, centrality dependent suppression of the production of high p_T charged hadrons in the most central Au+Au collisions at $\sqrt{s_{NN}}$ = 200 GeV relative to the pQCD expectations. The present data shows less suppression with decreasing collision energy at mid-rapidity. There is a clear difference shown between R_{AA} and R_{CP} at 62.4 AGeV.

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