Energy and System Size Dependence of Charged Hadron Transverse Momentum Spectra from Cu+Cu and Au+Au Collisions at $\sqrt{s_{NN}} = 62.4$ and 200 GeV

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Abstract. The PHOBOS collaboration has measured transverse momentum distributions of charged hadrons produced in Cu+Cu collisions at $\sqrt{s_{NN}} = 200$ and 62.4 GeV. The nuclear modification factor $R_{\text{AA}}^{N_{\text{part}}}$ is calculated relative to p+p data at both collision energies as a function of collision centrality. For the same number of participating nucleons, $R_{\text{AA}}^{N_{\text{part}}}$ is essentially the same in both systems over the full range of $p_T$ that is measured. In addition, we observe that within experimental uncertainties, the ratio of 200 GeV to 62.4 GeV Cu+Cu yields has only a moderate centrality dependence and is consistent with the value previously measured in Au+Au collisions for a broad range of $p_T$.

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1. Introduction

The yield of charged hadrons produced in Cu+Cu collisions at energies of $\sqrt{s_{NN}} = 200$ and 62.4 GeV has been measured with the PHOBOS detector at the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The data are presented as a function of transverse momentum ($p_T$) and collision centrality. The goal of these measurements is to study the modification of particle production compared to nucleon-nucleon collisions at the same energy.

This measurement was motivated by the results from Au+Au collisions for $\sqrt{s_{NN}} = 62.4$ and 200 GeV. Hadron production at these energies was found to be strongly suppressed relative to expectations based on an independent superposition of nucleon-nucleon collisions at $p_T$ of 2–10 GeV/c [11 12 13 14]. Such a suppression had been predicted to occur as a consequence of the energy loss of high-$p_T$ partons.
in the dense medium formed in Au+Au collisions [5]. This hypothesis is consistent with the observed absence of this effect in deuteron–gold collisions at the same collision energy [6-9]. The results presented here for Cu+Cu collisions at \( \sqrt{s_{NN}} = 200 \) and 62.4 GeV bridge the gap between the Au+Au and d+Au systems, allowing a unique examination of the dependence of high \( p_T \) suppression on system size.

Furthermore, it has been shown for Au+Au collisions that, within experimental uncertainty, a surprisingly clean factorization of the energy and centrality dependence of charged hadron yields exists at all measured values of \( p_T \) [10]. The Cu+Cu system allows us to explore whether this factorization persists down to a system of 20 participant nucleons or whether there is a critical size where this factorization begins to break down.

2. Technical details

The data were collected using the PHOBOS two-arm magnetic spectrometer [11]. The primary event trigger used the time difference between signals in two sets of 10 Čerenkov counters, located at 4.4 < \( |\eta| \) < 4.9, to select collisions along the beam-axis that were close to the nominal vertex position. For the analysis presented here, events were divided into centrality classes based on the total energy deposited in the octagon silicon detector, covering pseudo-rapidities \( |\eta| \) < 3.0. A full detector simulation using HIJING events [12, 13] was used to estimate \( \langle N_{\text{part}} \rangle \) for each centrality class, and the corresponding \( \langle N_{\text{coll}} \rangle \) values were obtained from a Monte Carlo Glauber calculation [12].

3. Results

It has been previously noted that the observed strong centrality dependence of \( R_{AA} \) at \( \sqrt{s_{NN}} = 200 \) GeV corresponds to a relatively small change in the yield per participating nucleon [4] and that over the same centrality range, the total yield of charged particles per participating nucleon is constant within experimental uncertainties [14]. These observations lead us to define \( R_{AA}^{N_{\text{part}}} \) in analogy to \( R_{AA} \), where now we scale the reference spectrum by \( N_{\text{part}}/2 \) rather than \( N_{\text{coll}} \).

\[
R_{AA} = \frac{\sigma_{pp}^{\text{inel}}}{\langle N_{\text{coll}} \rangle} \frac{d^{2}N_{AA}/dp_{T}d\eta}{d^{2}\sigma_{pp}/dp_{T}d\eta}, \quad R_{AA}^{N_{\text{part}}} = \frac{\sigma_{pp}^{\text{inel}}}{\langle N_{\text{part}} \rangle/2} \frac{d^{2}N_{AA}/dp_{T}d\eta}{d^{2}\sigma_{pp}/dp_{T}d\eta}. \tag{1}
\]

In Fig. 1 we explore the centrality dependence of \( R_{AA}^{N_{\text{part}}} \) at \( \sqrt{s_{NN}} = 200 \) GeV in detail. Over the range of \( p_T \) that we measure, the bulk particle production seems to depend only on the size of the system, that is the Cu+Cu and Au+Au spectra look identical for the same number of participating nucleons. This observation appears to hold at \( \sqrt{s_{NN}} = 62.4 \) GeV as well, as is shown implicitly in Fig. 2 where the ratios of spectra at two energies again coincide for the same system-size.
System size dependence of charged hadron spectra

\[ \text{Npart}_{AA} \]

\[ R = 0.55 \text{ (GeV/c)} \]

\[ T = 200 \text{ GeV} \]

\[ \text{PHOBOS Cu+Cu} \]

\[ \text{PHOBOS Au+Au} \]

\[ \text{PHENIX Au+Au} \]

\[ T_p = 1.25 \]

\[ T_p = 2.5 \]

\[ T_p = 3.38 \]

\[ T_p = 5.25 \]

\[ T_p = 6.25 \]

\[ \text{Fig. 1. Nuclear modification factor, } R_{N\text{part}}^{AA} \text{ versus } N_{\text{part}} \text{ in bins of } p_T \text{ at } \sqrt{s_{\text{NN}}} = 200 \text{ GeV for } \text{Cu+Cu (filled symbols) and } \text{Au+Au (open symbols). Systematics are shown with brackets (90\% C.L.). Data from the PHENIX collaboration are also included (open diamonds) where they have been published [2].} \]

In Fig. 2 the ratio of yields in 200 GeV to 62.4 GeV is plotted versus centrality for a range of transverse momenta. Within our experimental uncertainties, it is shown that the ratio of yields in Cu+Cu has only a moderate centrality dependence and is consistent with the Au+Au value for all measured \( p_T \).

\[ \text{Fig. 2. Ratio of yields at } \sqrt{s_{\text{NN}}} = 200 \text{ GeV to } 62.4 \text{ GeV for } \text{Cu+Cu (filled circles) and } \text{Au+Au (open circles). The ratio of yields in elementary nucleon-nucleon collisions is also shown (open squares) [15].} \]

4. Conclusions

Particle production at \( p_T > 1 \text{ GeV/c} \) in heavy-ion collisions is expected to be influenced by the interplay of many effects. This includes \( p_T \)-broadening due to initial and final state multiple scattering (the ‘Cronin effect’), the medium-induced energy loss of fast partons, as well as the effects of collective transverse velocity fields and of parton recombination [16]. Considering the significantly different geometries of Au+Au and Cu+Cu collisions with the same number of participant
nucleons, it is not obvious, \textit{a priori}, that these effects should conspire to give the same spectra in both systems over the measured $p_T$ range.

Moreover, the results presented here demonstrate, within experimental uncertainty, a surprisingly clean factorization of the energy and centrality dependence of charged hadron yields that persists for very small systems at all measured values of $p_T$. This factorization of energy and centrality is also a characteristic feature of the total and differential particle yields \[17, 14\] and of multi-particle correlation measurements such as Bose-Einstein correlations \[18\]. These observations provide further evidence of global constraints on particle production and appear to be a key feature of heavy-ion collisions that remains to be understood.

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