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Evidence of Final-State Suppression of High-p_T Hadrons in Au + Au Collisions Using d + Au Measurements at RHIC

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Abstract. Transverse momentum spectra of charged hadrons with $p_T < 6$ GeV/c have been measured near mid-rapidity ($0.2 < \eta < 1.4$) by the PHOBOS experiment at RHIC in Au + Au and d + Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The spectra for different collision centralities are compared to $p + \bar{p}$ collisions at the same energy. The resulting nuclear modification factor for central Au + Au collisions shows evidence of strong suppression of charged hadrons in the high-p_T region (> 2 GeV/c). In contrast, the d + Au nuclear modification factor exhibits no suppression of the high-p_T yields. These measurements suggest a large energy loss of the high-p_T particles in the highly interacting medium created in the central Au + Au collisions. The lack of suppression in d + Au collisions suggests that it is unlikely that initial state effects can explain the suppression in the central Au + Au collisions.

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1 Introduction

In the theoretical analysis of particle production in hadronic and nuclear collisions, a distinction is often made between the relative contributions from "hard" parton-parton scattering processes and "soft" processes. The contribution from hard processes is expected to grow with increasing energy and to dominate particle production at high transverse momentum. Collisions of heavy nuclei offer ideal conditions to test our understanding of this picture, as "hard" processes are expected to scale with the number of binary nucleon-nucleon collisions N_{coll}, whereas "soft" particle production is expected to exhibit scaling with the number of participant nucleons N_{part}. In Glauber-model calculations, N_{coll} scales approximately as $(N_{part})^{4/3}$. For Au + Au collisions at the Relativistic Heavy Ion Collider (RHIC) energies, it has been predicted that the yield and momentum distribution of particles produced by hard scattering processes may be modified by "jet quenching", i.e. the energy loss of high momentum partons in the dense medium [1,2].

The data for Au + Au collisions at $\sqrt{s_{NN}} = 200$ GeV were collected using the PHOBOS two-arm magnetic spectrometer [3] at RHIC. The spectrometer arms are each equipped with 16 layers of Silicon sensors, providing charged particle tracking both outside and inside the 2T field of the PHOBOS magnet. The primary event trigger and event selection were provided by two sets of 16 scintillator counters. For d + Au collisions at $\sqrt{s_{NN}} = 200$ GeV an additional of array silicon detectors weas used in the event selection. The array consisted of a central single-layer Octagon barrel detector and the three single-layer forward Ring detectors located on either side of the interaction point. In addition, two higher level trigger conditions were used which utilized two rings of ten Cerenkov counters and two arrays of horizontal segmented scintillator hodoscopes. The yields of charged hadrons produced in Au + Au and d + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV are presented as a function of collision centrality and transverse momentum p_T.

2 Observation of suppression of high-p_T particles in Au + Au at $\sqrt{s_{NN}}$ = 200 GeV

The charged hadron distribution produced in the 0–15% most central Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV is presented in Fig. 1. The distribution illustrates a "bulk" and "tail" which can be related to "soft" processes and "hard" parton-parton scattering respectively. It should be kept in mind, however, that there is no clear separation between "hard" and soft processes. This is why analysis as a function of centrality and transverse momentum is required for better understanding of charged particle production.

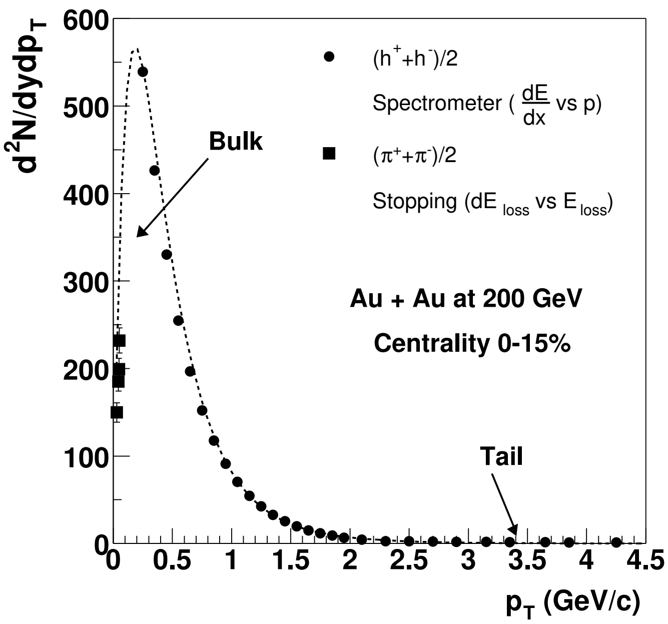

Fig. 1. Charged hadron distribution as a function of transverse momentum p_T for the 0–15% most central Au + Au collisions at $\sqrt{s_{NN}}$ = 200 GeV. The systematic errors are not shown.

To study the evolution of the spectra with centrality in detail, we divide the data by a fit to the measured p_T-distribution in proton-antiproton collisions at the same energy [4]. The $p + \bar{p}$ data were translated into the PHOBOS acceptance using PYTHIA, following the procedure described in Ref. [5]. Fig. 2 shows the yields divided by $\langle N_{\rm part}\rangle/2$ for the mid-peripheral bin ($\langle N_{\rm part}\rangle = 65 \pm 4$) and the most central bin ($\langle N_{\rm part}\rangle = 344 \pm 11$) scaled by a fit to the measured p_T-distributions in proton-antiproton collisions. The brackets indicate the systematic uncertainty in the Au + Au data (90% C.L.). The largest contributions to the systematic uncertainty are the overall tracking efficiency, independent of p_T, and the p_T-dependent momentum resolution and binning correction. The proximity of the tracking to the collision vertex ensures that the contamination by seconday particles and feed-down particles is small. Therefore the correction factor and the uncertainty are aslo small. Similarly, the high granularity and resolution of the tracking planes leads to a small uncertainty in the rate of "ghost" tracks.

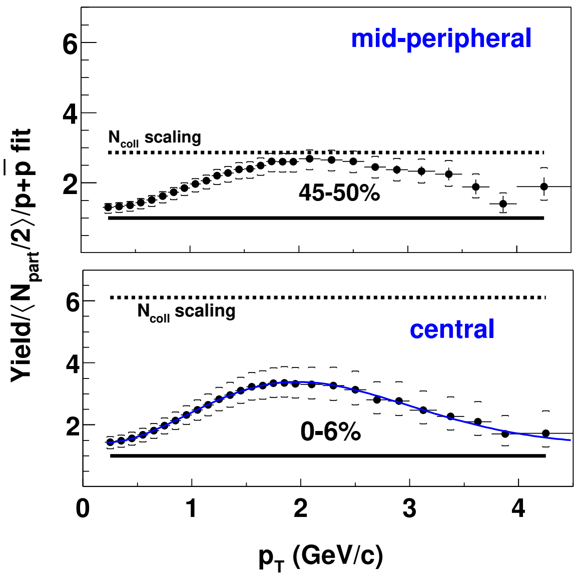

Fig. 2. Ratio of the yield of charged hadrons as a function of p_T for the most peripheral bin ($\langle N_{\rm part}\rangle = 65 \pm 4$, upper plot) and the most central ($\langle N_{\rm part}\rangle = 344 \pm 11$, lower plot) scaled by $\langle N_{\rm part}\rangle/2$ and normalized to a fit of proton-antiproton data. The dashed (solid) line shows the expectation of $N_{\rm coll}$($N_{\rm part}$) scaling relative to $p + \bar{p}$ collisions. The brackets show the systematic uncertainty of the Au + Au data.

As has been shown previously [6,7], the yield per participant pair in Au + Au collisions at these centralities is significantly larger than in proton-antiproton collisions at the same energy. We also observe that in the mid-peripheral Au + Au collisions with $\langle N_{\rm part}\rangle = 65$ (corresponding to impact parameter $b \sim 10$ fm), the spectral shape is already strongly modified from that in $p + \bar{p}$ collisions. It is worth noting that the ratio $\frac{\langle N_{\rm coll}\rangle}{\langle N_{\rm part}/2\rangle}$ increases by a factor of almost three from $p + \bar{p}$ to the mid-peripheral Au + Au collisions studied here. For the highest p_T, the yield for central events is significantly smaller than expectations based on $N_{\rm coll}$-scaling.

3 Absence of suppression of high-p_T particles in d + Au at $\sqrt{s_{NN}}$ = 200 GeV

The d + Au measurement at higher energies is motivated by results from Au + Au collisions at $\sqrt{s_{NN}}$ = 130 and 200 GeV. In this collisions, the expected scaling of hadron production with the number of binary nucleon-nucleon collisions at p_T from 2 to 10 GeV/c is strongly violated [8–10]. This effect had been predicted as a consequence of the energy loss of high-p_T partons in the hot and dense medium formed in Au + Au collisions [11]. The interpretation of the Au + Au data relies on the understanding of initial state effects, including gluon saturation [12], which can be investigated with the d + Au data presented here. By studying the spectra as a function of collision centrality, we can control the effective thickness of nuclear matter traversed by the incoming partons.

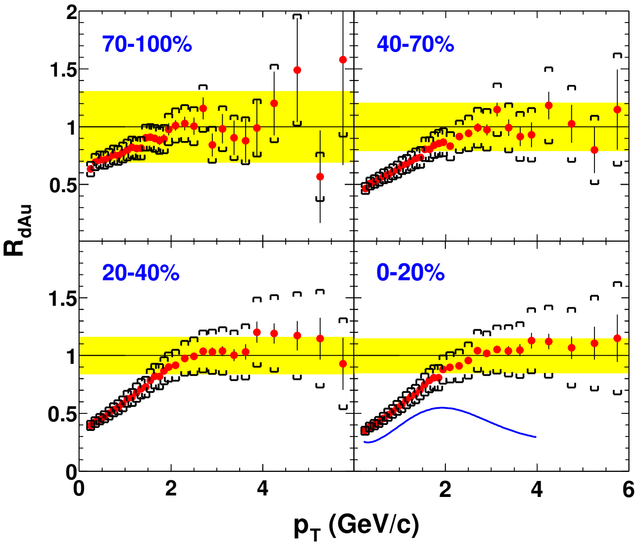

Fig. 3. Nuclear modification factor R_{dAu} for d + Au collisions as a function of p_T for four centrality bins. In the most central bin (0–20%), the spectral shape for central Au + Au data relative to $p+\bar{p}$ (UA1) is shown for comparison as a solid line. The shaded area shows the uncertainty in R_{dAu} due to the systematic uncertainty in $\langle N_{coll} \rangle$ and the UA1 scale error (90% C.L.). The brackets show the systematic uncertainty of the d + Au spectra measurement (90% C.L.).

In Fig. 3 we present the nuclear modification factor R_{dAu} as a function of p_T for each centrality bin, defined as:

$$R_{dAu} = \frac{\sigma_{p\bar{p}}^{inel} d^2N_{dAu}/dp_T d\eta}{\langle N_{coll}\rangle d^2\sigma(\mathrm{UA1})_{p\bar{p}}/dp_T d\eta}$$

Consistent with our Glauber calculation, we used $\sigma_{p\bar{p}}^{inel} =$ 41 mb. A value of $R_{dAu} = 1$ corresponds to scaling of the yield as an incoherent superposition of nucleon-nucleon collisions. For all centrality bins, we observe a rapid rises of R_{dAu} from low p_T, leving off at p_T of $\sim$ 2 GeV/c. For comparison, we also plot the results from central Au + Au collisions at the same energy [10] in the lower right panel of Fig. 3 as a solid line. The average number of collisions undergone by each participating nucleon in the central Au + Au collision is close to 6, similar to that of each nucleon from the deuteron in a central d+Au collision. For central Au + Au collisions, the ratio of the spectra to $p+\bar{p}$ rise rapidly up to $p_T = 2$ GeV/c, but falls far short of collision scaling at larger p_T, in striking contrast to the behavior for central d + Au collisions. Predictions for the evolution of R_{dAu} from semi-peripheral collisions with $\langle N_{coll}\rangle \sim 6$ to central collisions were made in two qualitatively different models.

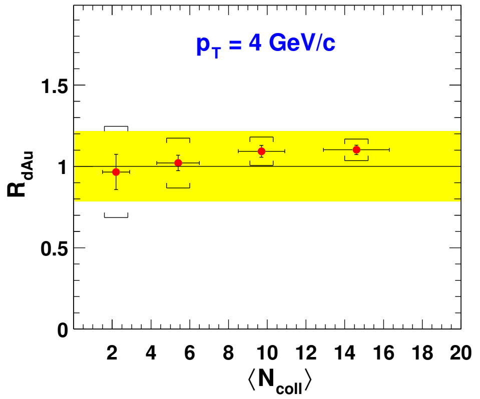

Fig. 4. Nuclear modification factor for R_{dAu} as a function of centrality at $p_T = 4$ GeV/c. The brackets indicate the point-to-point systematic error, dominated by the uncertainty in the number of collisions for each centrality bin. The shaded band shows the overall scale uncertainty. Systematic errors are at 90% C.L.

A perturbative QCD calculation [13] predicted an increase in the maximum value of R_{dAu} at $p_T \sim 3.5$ GeV/c by 15%. In contrast, a decrease in R_{dAu} by 25–30% over the same centrality range is predicted in a parton saturation model [12]. The centrality evolution of R_{dAu} is shown in Fig 4, where the points were obtained from a fit to the p_T dependence of R_{dAu} in each centrality bin. From Fig 4 corresponding to transverse momentum $p_T = 4$ GeV/c, we extract the ratio $\frac{R_{dAu}(N_{coll}=14.6)}{R_{dAu}(N_{coll}=5.4)} = 1.08 \pm 0.06$ (the systematic uncertainty corresponds to 15–20% at 90% C.L.). Our data disfavor the prediction from the parton saturation model. The lack of suppression in d + Au collisions suggests that it is unlikely that initial state effects can explain the suppression in the the central Au + Au.

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