High-p$_T$ Results from the STAR Experiment at RHIC*

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High-p$_T$ measurements in relativistic heavy ion collisions provide a unique set of tools to investigate the early stages of the collision. In this paper we report the high-p$_T$ measurements of inclusive hadron spectra, azimuthal anisotropies and two particle correlations performed by the STAR detector for 200 GeV Au+Au, p+p and d+Au collisions at RHIC. The results suggest that the phenomena observed uniquely in central Au+Au collisions are due to strong final state interactions in the hot and dense medium created in such collisions.

One of the main goals in the study of heavy ion collisions at relativistic energies is the understanding of the matter behavior at extreme temperature and densities conditions. QCD calculations predict that a phase transition from hadronic matter to a deconfined plasma of quarks and gluons may occur in such conditions [1]. Energetic partons propagating through the medium are expected to loose energy [2] and the magnitude of the energy loss is strongly dependent on the gluon density of the medium. Hard scattering of partons occurs early in the collision. In this case, partons emerging from such collisions probe the early phase of the evolution of the system and may provide important information about the characteristics of the hot and dense matter that is created. The hard scattering and subsequent fragmentation of these partons usually generates jets of correlated hadrons. In a clean, low multiplicity event it is possible to reconstruct the jet, making it possible directly to measure the parton characteristics. In a high multiplicity event, as the one originated from central Au+Au collisions, the soft background makes the jet reconstruction impossible. In this case, indirect studies of parton hard scattering, such as high-p$_T$ single hadron spectra and high-p$_T$ azimuthal correlations, may reveal important information about the propagating parton. Parton energy loss in the medium softens the fragmentation of jets, leading to a suppression of the high-transverse momentum hadrons [3]. Several high-p$_T$ results from RHIC have already been reported [4-11] and are consistent with large partonic energy loss in high energy density matter. This paper reports the results from the data taking with the STAR detector [12] for the Au+Au, p+p and d+Au systems at GeV. Details of the analysis can be found in Ref. [4,7-11].

The invariant yields for charged hadrons $(h^+ + h^-)/2$ at mid-rapidity are found in Fig. 1. Each curve represents a different centrality selection with different scale factors for clarity purposes. Event centrality selection is made using the uncorrected number of primary tracks with number of fit points larger than 10 in the pseudorapidity range of $|\eta| < 0.5$. The bottom curve is the yield obtained for p+p collisions. Spectra are corrected for tracking efficiency, background and momentum resolution [9]. The errors indicated include both statistical and systematic uncertainties and are visible only in the high momentum region.

In order to understand any modification in the spectra due to nuclear effects we compare the Au+Au spectra with the one obtained from p+p collisions using the nuclear modification factor:

$$R_{AA}(p_T) = \frac{d^2N^{AA}/dp_T d\eta}{T_{AA} d^2N^{NN}/dp_T d\eta} \quad (1)$$

where T_{AA} accounts for the nuclear collision geometry [4]. Fig. 2 shows $R_{AA}(p_T)$ for different centrality selections. The horizontal dashed lines represent the expected value obtained from a Glauber model [4] if the Au+Au yield is scaled with the number of binary collisions N_{bin} or the number of participants N_{part}. The gray bands represent their respective systematic errors, including both the model and p+p normalization uncertainties. In this figure the high-p$_T$ hadron spectrum is suppressed by a factor 4-5 in central Au+Au collisions with respect to p+p collisions. In this figure it is also shown pQCD-I calculations [13] and the influence of each nuclear effect separately. The absolute scale of the energy loss for central collisions is a fit parameter while the dependence with p_T and centrality is constrained by the theory. Initial state effects such as shadowing and the Cronin effect [14] do not account for the strong suppression observed in the data. This suppression can be explained only when a partonic energy loss in the dense medium component is included in the calculation. The calculation agrees very well with the data if the initial parton density in central collision is set to be 15 times that of cold nuclear matter. In this figure we also show calculations from pQCD-II [14] that was used to predict a p_T-independent suppression factor in the high-p$_T$ region of the figure.

*The complete list of STAR collaborators can be found in Ref.[10]

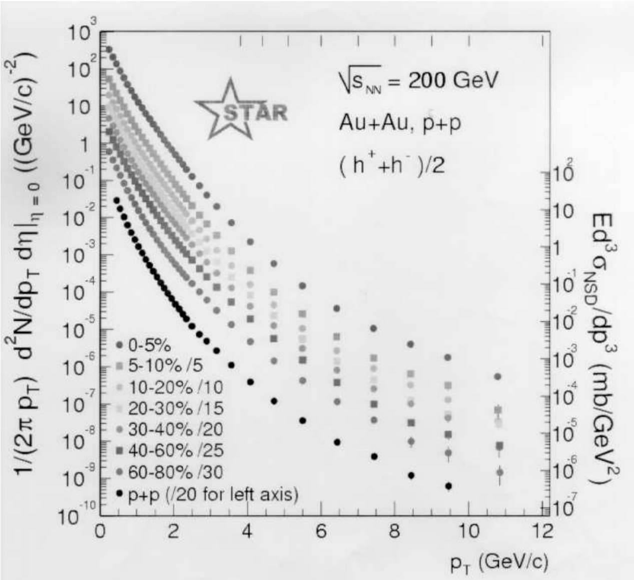

Figure 1. Invariant cross section for charged hadrons in the region of $|\eta| < 0.5$ for Au+Au and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV. Each curve represents a different centrality selection.

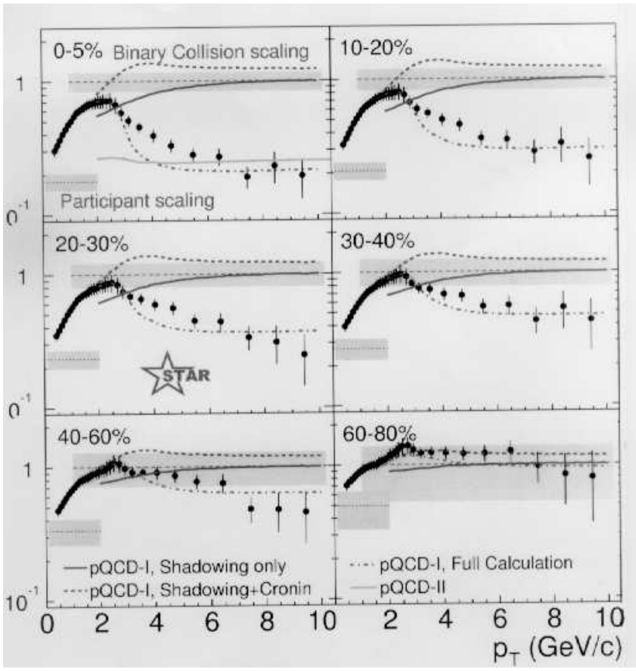

Figure 2. $R_{AA}(p_T)$ for charged hadrons in the region of $|\eta < 0.5$ for different centralities. Error bar include both statistical and systematic uncertainties. Calculations are described in the text.

When the reaction zone has a spatial anisotropy, pQCD predicts a strong coupling of momentum and coordinate space in the case of existence of partonic energy loss in the medium due to high initial gluon densities. This can be easily understood with a nave view that partons propagating through a larger path length would loose more energy than others propagating through a shorter one. This leads to initial spatial anisotropies that are transferred to momentum space. These momentum anisotropies can be quantified using the second Fourier component (v_2) of the high-p$_T$ hadrons azimuthal distribution with respect to the reaction plane. Details of this analysis can be found in Ref. [7].

Fig. 3 shows v_2 as a function of the transverse momentum for mid-central Au+Au collisions. We observe a finite value of v_2 up to $p_T = 12$ GeV/c, well into the pQCD regime, which makes the interpretation in terms of partonic energy loss quite interesting.

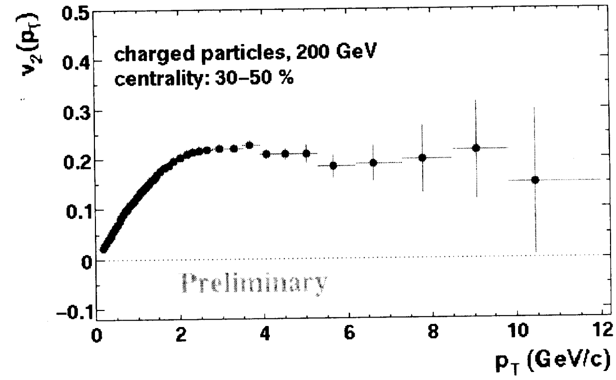

Figure 3. Azimuthal anisotropy v_2 for charged hadrons as a function of the transverse momentum for mid-central Au+Au collisions. The results are still preliminary.

In order to understand better the origin of the high-p$_T$ hadrons we looked for jet-like structures within the events analyzed. As mentioned earlier, jet reconstruction is nearly impossible in central Au+Au collisions due to the enormous soft background present in the events. In this case, we searched for azimuthal correlations between high-p$_T$ particles. It is known, from N+N collisions that the jet cone has a typical width of $\Delta\eta \sim 0.5 - 0.7$. To extract the jet-specific structures we compared the azimuthal correlations for pseudorapidity intervals of $\Delta\eta < 0.5$ and $\Delta\eta > 0.5$. In addition to the correlations due to jets, it is expected that the azimuthal correlations also show a structure due to an elliptic flow anisotropy of single particles with respect to the reaction plane that needs to be taken into account in order to isolate the jet-like correlations. Fig. 4 shows the azimuthal correlations for a trigger particle with $4 < p_T^{trigger} < 6$ GeV/c and all associated particles in the event with $2 < p_T < p_T^{trigger}$ GeV/c, for two Au+Au centrality selections and p+p collisions at $\sqrt{s_{NN}} = 200$ GeV. In order to compare the correlations observed in Au+Au with p+p collisions a simple model was adopted where the measured v_2 and a constant background are added to the p+p measurement. Details can be found in Ref. [8]. The well pronounced peak at small $\Delta\phi$ is suggestive of jets. The peaks at large $\Delta\phi$ for p+p and peripheral Au+Au suggest the presence of back-to-back jet-like structure, not present in central Au+Au.

The suppression of back-to-back jets, the strong suppression of the inclusive hadrons in central Au+Au collisions and the finite v_2 at high-p$_T$ suggest a picture in which hadrons with $p_T > 3 - 4$ GeV/c are mostly fragments of hard-scattered partons that strongly interact with the nuclear medium. The observed hadrons result preferentially from partons generated on the periphery of the nuclear collision zone and heading outwards. In this picture, the inclusive yield is suppressed relative to the binary scaling expectation and also explains the finite v_2 observed at high-p$_T$. This

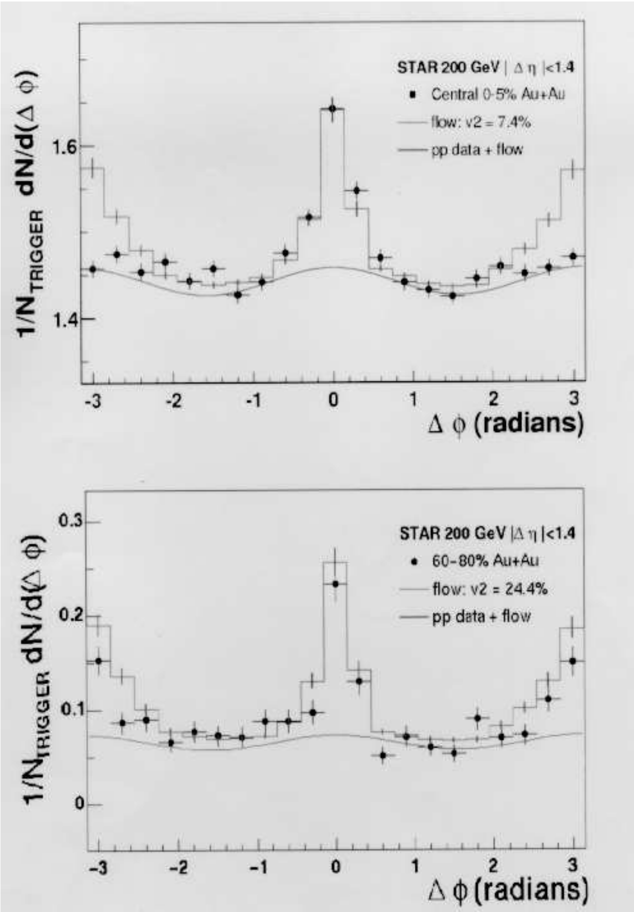

Figure 4. Azimuthal correlations for Au+Au collisions for two different centrality selections. The histogram is the measurement for p+p collisions in which the measured v_2 for Au+Au and a constant background is added in order to compare it with the Au+Au measurement.

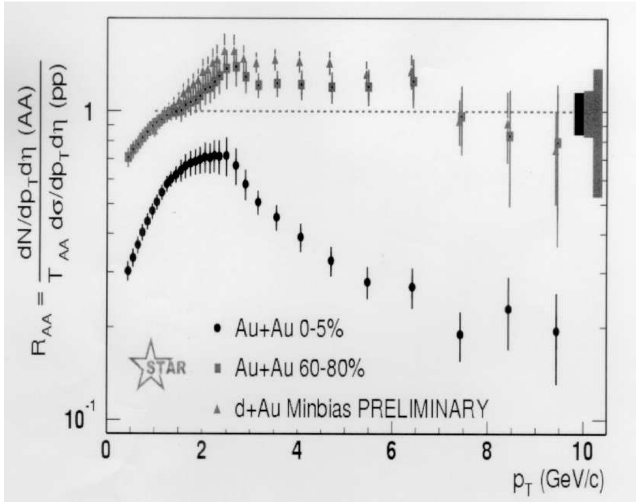

Figure 5. $R_{AA}(p_T)$ for charged hadrons in the region of $|\eta| < 0.5$ for d+Au, peripheral and central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. No evidence for hadron suppression with respect to binary scaling is observed in d+Au collisions.

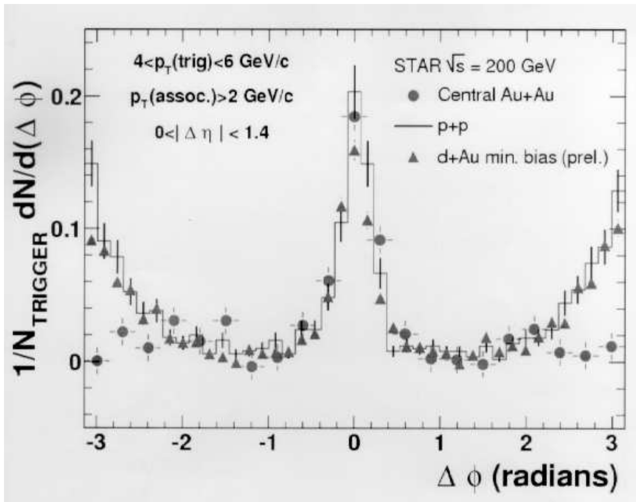

Figure 6. Azimuthal correlations for minimum bias d+Au, p+p and central Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. No evidence for back-to-back jet suppression is observed in d+Au collisions.

picture also explains the suppression of back-to-back correlations in central Au + Au, in which the parton scattered towards the nuclear collision zone is reabsorbed due to the strong interaction with the medium. Alternatively, the phenomena observed might result from initial-state effects prior to the hard scattering, such as the saturation of gluon densities in the incoming nuclei [15]. Models incorporating both pictures can describe the central Au+Au data [9]. In order separate initial and final-state effects d+Au measurements were performed. In this case it is expected that the hot and dense medium shall not be created in the collisions and only initial-state effects are present. Fig. 5 shows preliminary results for $R_{AA}(p_T)$ in d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV compared to peripheral and central Au+Au results. There is no suppression with respect to binary scaling observed. The enhancement above the binary scaling is understood in terms of the Cronin effect. Fig. 6 shows preliminary results from azimuthal correlations analysis for d+Au. Results from central Au+Au and p+p are also shown. In this case, the correlations in d+Au collisions behave like the ones observed for p+p collisions. No evidence for back-to-back suppression is observed in this case.

In summary, the study of high transverse momentum is capable of reveal important information about the early stages of the nuclear collision. STAR has measured high-p_T hadrons for Au+Au, p+p and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV at RHIC. The combined evidence observed in the high-p_T region, such as the yield suppression with respect to binary scaling, the finite azimuthal anisotropy (v_2) and the suppression of back-to-back jets, not observed in d+Au collisions strongly suggest that the phenomena observed in central Au+Au collisions are due to final-state interactions with the dense and hot medium created in the collision.

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