PHENIX measurement of high $p_T$ particles in Au+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract.

We present new results on the production of charged hadrons and neutral pions in Au+Au and d+Au collisions at $\sqrt{s_{NN}} = 200$ GeV, measured within the PHENIX experiment. We observe the opposite centrality dependence when comparing the two collision systems: an increase with centrality compared to the binary scaled yield from p+p collisions in d+Au and a decrease with centrality in Au+Au.

1. Introduction

The production of hadrons with large transverse momentum ($p_T$) is dominated by the fragmentation of quarks and gluons, produced in parton-parton scatterings with large momentum transfer $Q^2$. The production cross section for this hard scattering depends on the initial distribution of partons in the colliding species, the elementary parton-parton cross section and the fragmentation process of partons into hadrons.

In absence of any medium effects the production of high $p_T$ particles in Au+Au and d+Au collisions should be comparable to the production in p+p after scaling with a geometrical factor which reflects the increased number of scattering centers. The geometrical factor for a given centrality is usually expressed in terms of the nuclear overlap function $T_{AB}$ or the number of binary nucleon-nucleon collisions $N_{coll}$. The comparison of different colliding species or centralities to the p+p reference is done with the nuclear modification factor:

$$R_{AB} = \frac{d^2N_{AB}/dydp_T}{T_{AB} \cdot d^2\sigma_{pp}/dydp_T}. \quad (1)$$

If the model of geometrical scaling from p+p to other colliding species is valid, the nuclear modification factor should be unity above a certain $p_T$ where hard scattering is dominant. In contrast to this expectation the results for Au+Au collisions at the Relativistic Heavy Ion Collider (RHIC) showed a suppression of up to a factor of five in the nuclear modification factor [1 2].

§ For the full PHENIX Collaboration author list and acknowledgments, see Appendix ”Collaborations” of this volume.
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It has been suggested that the observed suppression is a result of parton energy loss in a dense medium like the quark-gluon plasma \cite{3, 4}. However, with only $Au+Au$ collisions it is hardly possible to distinguish between final state effects and effects of cold nuclear matter at $\sqrt{s_{NN}} = 200$ GeV (initial state effects).

Initial state effects can influence the particle production in various ways. A modification of the parton distribution function in a nucleus can result in a suppression or enhancement of particle production, depending on the momentum fraction $x$ of the scattered parton (shadowing or anti-shadowing). Multiple soft scattering of incoming nucleons or partons leads to an enhancement at intermediate $p_T$ (Cronin Effect). Such effects are also present in $d+Au$ collisions, while no large volumes with increased energy density are formed. These reactions have been studied in early 2003 at the Relativistic Heavy Ion Collider (RHIC) and first results have been published in \cite{5}, showing the absence of suppression in minimum bias reactions at mid-rapidity.

The examination of $d+Au$ collisions also tests whether more exotic phenomena, e.g. the possible formation of a Color Glass Condensate (CGC) in the initial state at $\sqrt{s_{NN}} = 200$ GeV can be responsible for the observed suppression in central $Au+Au$ collisions. In this case the nuclear modification factor in $d+Au$ should also show a decrease with centrality and a $R_{AB}$ below unity in central $d+Au$ collisions \cite{6}.

2. Data analysis and results

The data we present were collected in two different RHIC runs. In 2001–2002 $Au+Au$ collisions at $\sqrt{s_{NN}} = 200$ GeV and in early 2003 $d+Au$ collisions at the same energy were studied. The PHENIX central arm detectors used in this analysis provide a solid angle coverage of $\Delta \eta = 0.7$ and $\Delta \phi = \pi$. They have the capability of identifying neutral pions and charged hadrons over a broad momentum range \cite{7, 8}.

Neutral pions are reconstructed via their $2\gamma$ decay channel, using an invariant mass
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Figure 3. Centrality dependence of the nuclear modification factor in $Au+Au$ (left) and $d+Au$ (right) collisions.

The data set used for the $\pi^0$ analysis in $Au+Au$ consists of 30 M minimum-bias events and a newly incorporated data set of high-energy photon triggered events which corresponds to an additional 50 M minimum-bias events. The enlarged data set extends the $p_T$ reach up to 10 GeV/c (see Fig. 4) for all centralities compared to the result in [1]. In the analysis of the $d+Au$ run 16 M minimum-bias events have been combined
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with an equivalent of 100 M minimum-bias events from a high-$p_T$ photon triggered data set, resulting in the measurement of $\pi^0$'s up to 10 GeV/$c$.

Charged particles are tracked through the PHENIX central arms by Pad Chambers and Drift Chambers. Particle momenta are reconstructed by their deflection in an azimuthaly symmetric magnetic field with a precision of $\delta p/p \simeq 1\% \oplus 1\% \cdot p/(\text{GeV}/c)$ using tight matching criteria in the Pad Chambers to reduce the background. The data sets analyzed were 27 M minimum-bias events in Au+Au and 12 M events in d+Au, which allows to study unidentified charged particles in a broad momentum range (See Fig. 2 and [2]).

To calculate the nuclear modification factor the PHENIX p+p $\pi^0$ spectrum is used [9]. In case of the charged particles these data were scaled by a factor of 1.6 to account for the known abundance of total charged particles over $\pi^0$'s and combined with the data from UA1 for charged hadrons [10]. The result for different centralities is shown in Fig. 3 for Au+Au and d+Au. In very peripheral collisions charged particle and neutral pion yields are consistent with the expectation from binary scaling in both colliding systems. Going to more central collisions the suppression gets stronger in Au+Au, in contrast to the situation in d+Au where the particle production is enhanced compared to the expectation from binary scaled p+p. Another interesting observation in central collisions is the difference between charged hadrons and neutral pions in both colliding systems. This is mainly due to an anomalous $p/\pi$ ratio at intermediate $p_T$. For further discussion see also [11].

3. Conclusion

We have presented results on the centrality dependent production of neutral pions and charged hadrons in d+Au and Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. The d+Au measurement provides the baseline for effects of cold nuclear matter at mid-rapidity for this energy. The absence of suppression in d+Au collisions shows that the suppression observed in central Au+Au collisions cannot be attributed to initial state effects, like shadowing or the formation of a Color Glass Condensate. The observation supports the picture of a medium induced energy loss.

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