Eur. Phys. J. C (2005)
Digital Object Identifier (DOI) 10.1140/epjc/s2005-02247-4

THE EUROPEAN
PHYSICAL JOURNAL C

Neutral pion production in d-Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Received: 9 February 2005 / Revised version: 1 April 2005 /
Published online: 8 July 2005 –

Abstract. In this paper, preliminary results are presented on high p_T inclusive neutral pion measurements in d-Au collisions at $\sqrt{s_{NN}} = 200$ GeV in the pseudo-rapidity range $0 < \eta < 1$. Photons from the decay $\pi^0 \to \gamma\gamma$ are detected in the Barrel Electromagnetic Calorimeter of the STAR experiment at RHIC. The analysis of this first BEMC hadron measurement is described in detail. The results are compared to earlier RHIC findings. Furthermore, the obtained π^0 invariant differential cross sections show good agreement with next-to-leading order (NLO) perturbative QCD calculations.

PACS. 25.75.−q

1 Introduction

After five years of data taking, exciting new observations have been made at the Relativistic Heavy Ion Collider at Brookhaven National Laboratory. The high center-of-mass energy ($\sqrt{s_{NN}} = 200$ GeV) opens up the hard scattering regime which is accessed by the measurements of particle production at large transverse momentum. These particles originate from parton fragmentation in the early stage of the collisions. Hence, the scattered partons can be used to probe the produced medium of strongly interacting matter.

A significant suppression of high p_T hadron production relative to a simple binary collisions scaling from proton-proton has been observed in central Au-Au collisions at RHIC [1]. Additionally, it was found that jet-like correlations opposite to trigger jets are suppressed and that the azimuthal anisotropy in hadron emission persists out to very high transverse momenta [2–4]. In contrast, no suppression effects were seen in d-Au collisions [5], which provide an important control measurement for the effects in cold nuclear matter. The d-Au measurements have led to the conclusion that the observations made in Au-Au are due to the high density medium produced in such collisions. The most probable explanation to date is parton energy loss from induced gluon radiation (jet quenching) in the extremely dense medium. For a recent review see [6].

To quantitatively understand the existing modification from cold nuclear matter, precise measurements of identified hadrons at high p_T in d-Au are required. The STAR Barrel Electromagnetic Calorimeter (BEMC) allows high transverse momentum measurements of π^0, η mesons and direct photons and may contribute to the identification of ρ mesons. We present preliminary measurements of neutral pion production in d-Au collisions.

2 The STAR electromagnetic calorimeter

The STAR detector [7] is one of the two large-scale experiments at RHIC. The detection of photons is performed using the BEMC [8]. This detector is one of the current upgrades of the STAR experiment. For the RHIC Run III, 50% of the BEMC was installed and operational, covering an acceptance of $0 < \eta < 1$ (deuteron direction) and full azimuth. At the end of 2004, 35% of the other half of the detector ($-1 < \eta < 0$) was installed. The last stage of installation will be finished in 2005. The STAR detector utilizes the BEMC as a leading particle trigger to study high p_T hadron production (e.g. π^0 and η) as well as rare probes (jets, direct photons and heavy quarks) over a large acceptance range.

The BEMC is a lead-scintillator sampling calorimeter with a depth of 21 radiation lengths and an inner radius of 220 cm. The calorimeter covers a total area of 60 m^2 and is divided into 120 modules. Each one of the EMC modules consists of 40 towers of granularity $(\Delta\eta, \Delta\phi) = (0.05, 0.05)$. Two layers of gaseous shower maximum detectors (SMD), located approximately at a depth of 5 X_0 inside the calorimeter module, measure the lateral extension of an electromagnetic shower and the position with high resolution $(\Delta\eta, \Delta\phi) = (0.007, 0.007)$. The hadron/$\gamma$ discrimination (e.g. π^0/γ) is significantly improved by measuring the longitudinal shower shape of the tower cluster with a pre-shower detector (PSD) located within the first two layers. The dynamic range of the BEMC for photon detection is approximately 1 – 25 GeV/c taking into account the discrimination of high transverse momentum photons from merging decay photons.

Beam test results [9] provide the absolute energy calibration, whereas the relative calibration is obtained from the peak position of minimum ionizing particles (mostly charged hadrons) on a tower-by-tower basis [10]. Moreover, an overall gain calibration was obtained by comparing the momentum of electrons identified in the TPC with the energy deposited in the BEMC. The intrinsic energy resolution due to sampling fluctuations is $\delta E/E \approx 16\%/\sqrt{E}$.

2.1 Event trigger

In the minimum bias trigger a neutron signal was required in the Zero Degree Calorimeter (ZDC) in the Au beam direction resulting in an acceptance of $(95 \pm 3)\%$ of the d-Au hadronic cross section. To enhance the high p_T range, two high tower triggers (HT1 and HT2) were used with an energy threshold of 2.5 GeV and 5 GeV for the highest EMC cluster energy, respectively. The tower occupancy is in the order of a few percent for d-Au events, and the high tower trigger efficiency is nearly 100%.

3 Neutral pion analysis

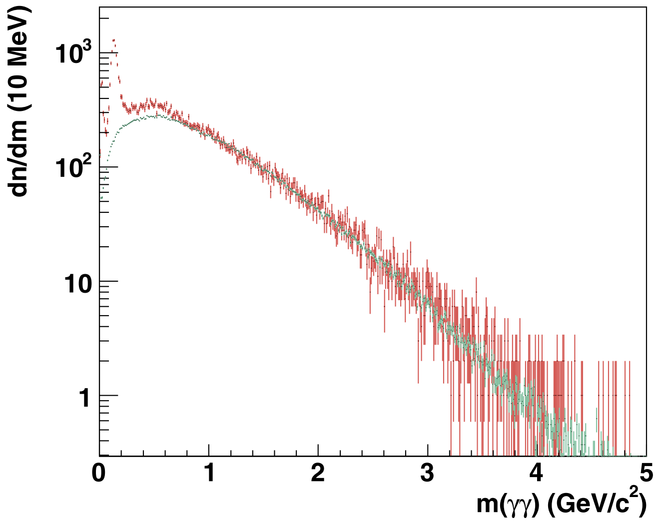
As mentioned in Sect. 2, the installed component of the BEMC was used for this analysis, resulting in a coverage of $0 < \eta < 1$ and full azimuth ($\Delta\phi = 2\pi$). The STAR Time Projection Chamber (TPC) [11], which is situated in front of the BEMC, has full azimuthal coverage and an acceptance of $|\eta| < 1.2$ for collisions in the STAR detector centre. The TPC provides particle identification and precise measurement of the charged particle trajectories in a 0.5 Tesla solenoidal magnetic field. In this analysis, it is used as a charged particle veto.

For the analysis presented in this paper, 10 M d-Au events were used after event quality cuts (main vertex coordinate (beam axis) within 80 cm of the TPC centre). Neutral pions were reconstructed in the decay channel $\pi^0 \to \gamma\gamma$ (branching fraction 98.8%) by calculating the invariant mass of all pairs coming from neutral clusters in the calorimeter which do not have a TPC track pointing at them. Furthermore, a cut on the two-particle energy asymmetry was imposed: $|E_1 - E_2|/(E_1 + E_2) \leq 0.5$.

At present, the full calibration of the calorimeter and the search for noisy and dead towers is in progress. To perform a neutral pion analysis at this stage, a sub-sample of good towers was selected. The quality of the individual towers was checked using the π^0 invariant mass distribution. The towers are tagged according to the decay photon with the highest energy. While determining the gain for a given tower from π^0 peaks it is assumed that the error from the yet uncalibrated towers used as partners for the invariant mass analysis cancel on average. Only those towers were used which have a well defined π^0 signal above the combinatorial background. A Gaussian fit to the π^0 signal has to have a relative mass and width error of less than 30% and 50%, respectively. By this method, approximately one third of all towers was used for the present analysis. The acceptance correction takes this into account. The π^0 peak position of all good towers was used to perform an additional tower gain correction (7% on average).

In Fig. 1, the resulting invariant mass distribution of neutral cluster pairs is shown. A clear signal is observed with a RMS width of 28 MeV/c^2. The background from random pairs was estimated by two different methods. First, a second-order polynomial was fitted to the invariant mass distribution outside the peak region (full curve in the bottom panel of Fig. 1). With the second method, the background is estimated using the event mixing technique. The event mixing distribution, which is shown in the lower histogram in the plots of Fig. 1, follows the data in the range 0.8–5 GeV/c^2. At lower invariant mass the excess can be attributed to the tail of the π^0 peak and a contribution from the η signal ($m_\eta = 547.3$ MeV/c^2). The peak observed at $m < 0.05$ GeV/c^2 stems from cluster splittings in the EMC towers.

The yields per event obtained from both subtraction methods were extracted in $p_{\rm T}$ bins (width of 0.5 GeV/c for minimum bias and 1 GeV/c for high tower triggered events) by integrating the background subtracted mass distribution in a range $\pm 3\sigma$ around the π^0 peak. The mean values were used for further analysis and the difference contributes 10–15% to the systematic uncertainties. Further background studies will decrease this systematic error contribution in the future. The signal-to-background ratio increases from 1 to 8 between $p_{\rm T} = 1$ and 4 GeV/c.



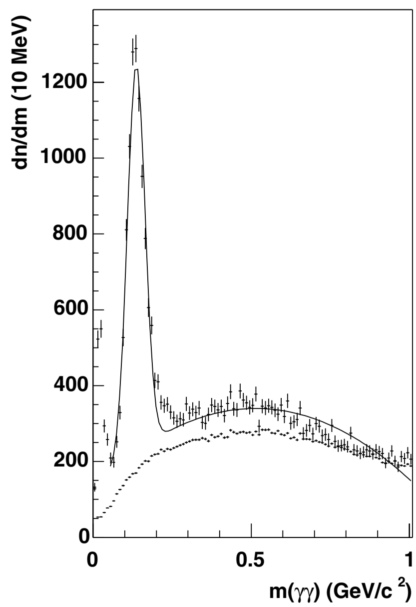


Fig. 1. Invariant mass distribution of neutral pion candidates in minimum bias d-Au collisions at $\sqrt{s_{\rm NN}} = 200$ GeV (top). A detailed view of the range 0–1 GeV/c^2 is shown on the bottom panel. The full line is a Gaussian plus second order polynomial fit. The histogram is obtained from event mixing. The relative mass resolution is ≈ 20%

Corrections for reconstruction losses (quality cuts) and detector efficiencies were calculated with Monte-Carlo simulations using the STAR detector geometry and reconstruction software. A correction for the unmeasured trigger fraction, which is expected to be a few percent, is not applied. Losses due to cluster density effects and contributions from weak decays of K^0 mesons are not corrected for, but are expected to be small. The high tower trigger spectra are normalized using pre-scaling factors obtained from the ratios of the BEMC cluster transverse energy distributions in the overlap region. The overall systematic errors related to efficiency, yield extraction, pre-scaling factors,

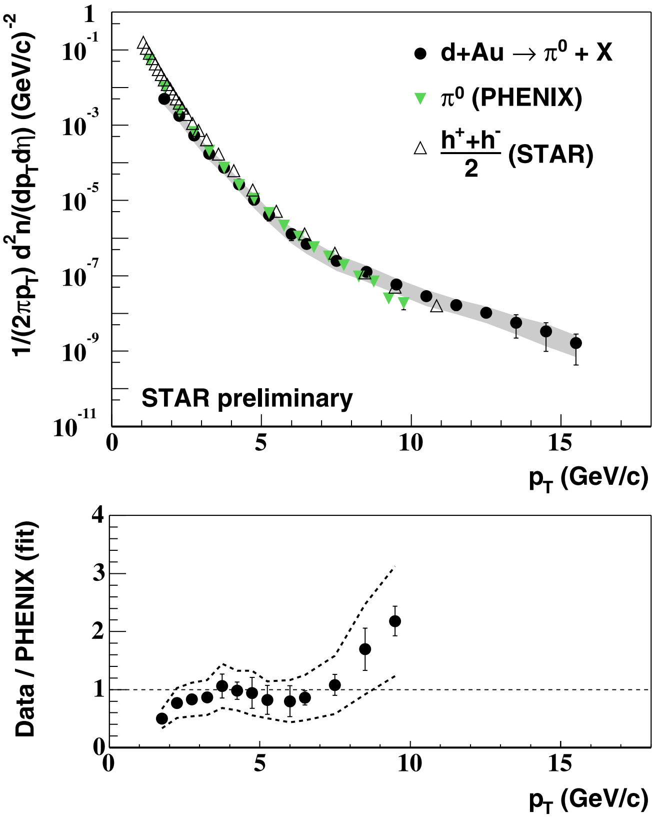


Fig. 2. Inclusive p_T distribution for neutral pions in d-Au collisions at $0 < \eta < 1$ (full circles). The error bars (shaded band) represent the statistical (systematic) uncertainties. Previous STAR measurements of the charged hadron cross section are shown by the open triangles, and the full triangles show π^0 results from PHENIX. The lower plot shows the ratio between the d-Au data and a fit of the PHENIX results, with the dashed lines indicating the systematic errors on the data

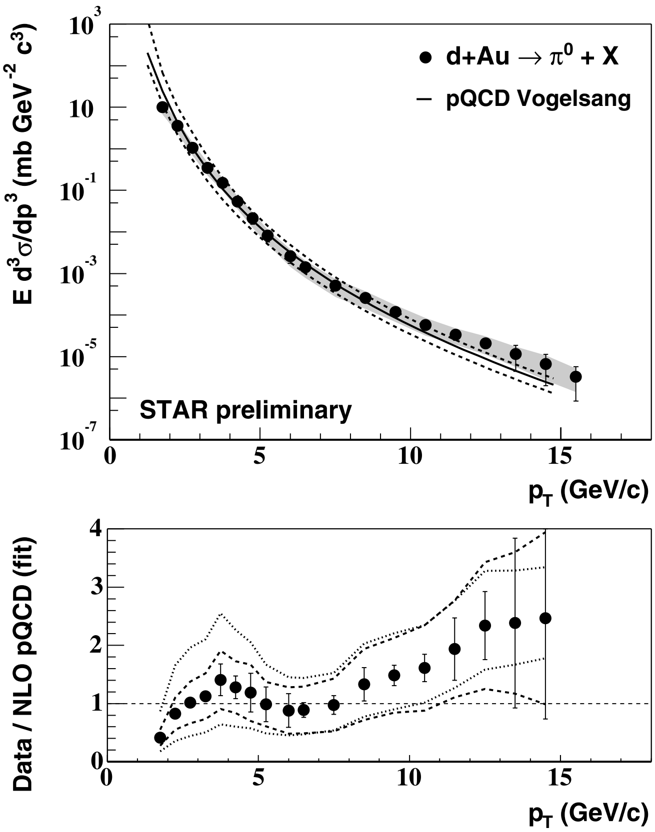


Fig. 3. The invariant differential cross section (full circles) compared to NLO pQCD calculations (full line). The factorization scale uncertainty is indicated by dashed lines. The lower plot shows the ratio between the data and the theory curve. The dashed lines indicate the systematic errors on the data while the dotted ones represent different factorization scales

and energy calibration are estimated to be 30% (50%) for transverse momenta below (above) 9 GeV/c.

3.1 Results and conclusion

The inclusive p_T distribution for neutral pions is plotted in Fig. 2. The yields up to 6 GeV/c are from minimum bias events while above 6 (9.5) GeV/c the entries are from HT1 (HT2) triggered events. For the different trigger samples, the yields have an overlap of one point in the p_T spectrum and agree within errors. It is seen from Fig. 2 that π^0 mesons are presently measured up to $p_T \approx 16$ GeV/c. The obtained p_T spectrum is compared with previous STAR measurements on charged hadron cross sections [5] and with PHENIX results on neutral pion production [12]. Except for the lowest p_T point, the data show reasonable agreement within 10–20%.

Figure 3 shows the invariant differential cross section which is obtained by multiplication of the measured yields with the hadronic cross section in d-Au collisions ($\sigma^{\mathrm{dAu}}_{\mathrm{hadr}} = 2.21 \pm 0.09$ b) [5]. The normalization uncertainty is 10%. The results are compared to next-to-leading order (NLO) pQCD calculations [13] done using the CTEQ6M set of nucleon parton distribution functions [14] and the nuclear parton densities in the gold nucleus from [15]. In this calculation, the factorization scale was identified with p_T (full line) and is varied by a factor two to estimate the scale uncertainties (dashed lines). The fragmentation functions are taken from [16]. The Cronin effect is not included in the calculations. The measurements are, within errors, consistent with the calculation up to $p_T = 15$ GeV/c.

Acknowledgements. We thank the RHIC Operations Group and RCF at BNL, and the NERSC Center at LBNL for their support. This work was supported in part by the HENP Divisions of the Office of Science of the U.S. DOE; the U.S. NSF; the BMBF of Germany; IN2P3, RA, RPL, and EMN of France; EPSRC of the United Kingdom; FAPESP of Brazil; the Russian Ministry of Science and Technology; the Ministry of Education and the NNSFC of China; Grant Agency of the Czech Republic, FOM and UU of the Netherlands, DAE, DST, and CSIR of the Government of India; Swiss NSF; and the Polish State Committee for Scientific Research.

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