High-p_T Neutral Pion Production
in Heavy Ion Collisions at SPS and RHIC

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Abstract

Transverse momentum spectra for neutral pions have been measured by the WA98 experiment in $\sqrt{s_{nn}}$=17.3 GeV Pb+Pb collisions at the CERN SPS and by the PHENIX experiment in $\sqrt{s_{nn}}$=130 GeV Au+Au collisions at RHIC. The neutral pion yields in central collisions for both reaction systems are compared to scaled transverse momentum spectra for nucleon-nucleon reactions at the respective energy. At SPS energies neutral pion production at high p_T is enhanced compared to the n+n reference while at RHIC a significant suppression of high-p_T neutral pions is observed.

1 Introduction

In heavy ion reactions particle production at high transverse momentum is expected to result from parton scatterings with large momentum transfer. In n+n reactions these hard scatterings dominate particle production above $p_T \approx$ 2 GeV/c [1]. Hard scattering in heavy ion collisions will occur in the early stage of the reaction, well before a quark-gluon plasma is expected to form. Thus, fast partons produced in hard scatterings interact with the extended medium that is subsequently produced in a heavy ion reaction. The interaction of partons with hot and dense nuclear matter leads to an energy loss of the partons. This parton energy loss is considered as a potential signature of a quark-gluon plasma formation since the energy loss in a medium of deconfined quarks and gluons is expected to be higher than in hadronic matter [2].

An observable consequence of parton energy loss is the suppression of hadron production at large transverse momenta relative to a baseline expectation in the absence of energy loss. The construction of this baseline necessarily relies on model assumption. For the description of hard scattering processes the nucleons of the two colliding nuclei can be approximated as incoherent superpositions of partons. In this picture the particle yields in a heavy ion reaction are expected to scale with the number N_{coll} of inelastic nucleon-nucleon

collisions, since the cross-section for hard processes is small. Thus, the results on neutral pion production are presented in terms of the following ratio of invariant yields $E\,d^3N/dp^3$:

$$R_{AA} = \frac{E\frac{d^3N}{dp^3}(p_T)|_{AA} \,/\, N_{coll}}{E\frac{d^3N}{dp^3}(p_T)|_{nn}} \tag{1}$$

This ratio is usually denoted as the nuclear modification factor. In the absence of nuclear modifications to hard scattering R_{AA} will be unity.

Calculations based on perturbative QCD are a second possibility for the construction of a baseline expectation. These calculations usually also phenomenologically model the multiple initial scatterings of the partons in a A+A reaction. By just comparing the hadron yield in A+A reaction with the scaled n+n reference, as in equation 1, the effect of multiple parton scattering is not taken into account. Multiple parton scattering can explain the enhancement of high-p_T hadron production in p+A reactions relative to a N_{coll}-scaled n+n reference. This anomalous enhancement is usually referred to as the Cronin-effect. In order to fix the strength of initial parton scattering in the modeling of A+A reactions data for p+A reactions at the same energy are very important.

2   Neutral Pion Spectra at SPS and RHIC

The WA98 experiment at the CERN SPS and the PHENIX experiment at RHIC reconstruct neutral pions on a statistical basis via their decay into two photons. The photon detector LEDA of the WA98 experiment consists of 10.080 lead glass modules and covers the pseudorapidity interval $2.3 < \eta < 3.0$. After the last WA98 data taking in 1996 the WA98 lead glass detector was brought from CERN to the Brookhaven National Laboratory and is now part of the PHENIX experiment. PHENIX consists of two separate electromagnetic calorimeters: the lead glass detector (PbGl) and a lead-scintillator (PbSc) sampling calorimeter. Both detectors cover the pseudorapidity interval $-0.35 < \eta < 0.35$. The PbGl and PbSc data were analyzed separately. Figure 1 shows the agreement of the final π^0 spectra [4].

The number N_{coll} of inelastic binary nucleon-nucleon collisions in WA98 and in PHENIX is determined within a Glauber model framework [5, 6]. The Glauber-model is based on a purely geometric picture of a nucleus-nucleus collision: Nucleons travel on straight-line trajectories and a collision between two nucleons takes place if their distance in the plane transverse to the beam axis is smaller than a certain value given by the inelastic nucleon-nucleon
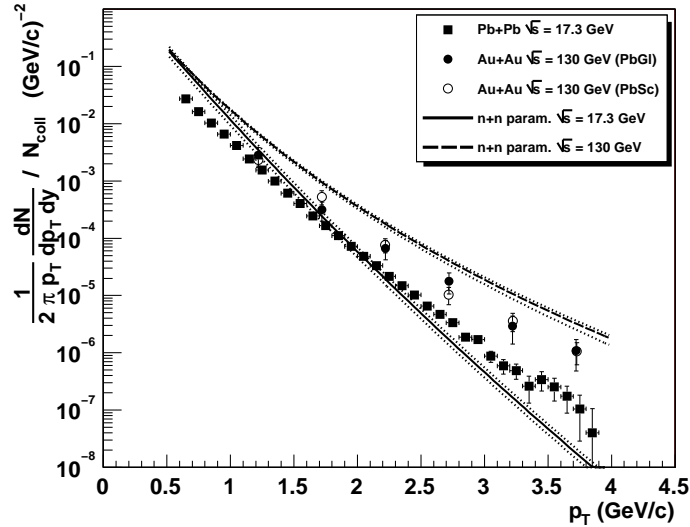
Figure 1: Neutral pion transverse momentum spectra in central Pb+Pb reactions at the CERN SPS and in central Au+Au reactions at RHIC. The yields are normalized to the respective number of binary nucleon-nucleon collisions. The data are compared to parameterizations of neutral pion spectra in nucleon-nucleon collisions. The estimated uncertainties of these parameterizations are indicated by the dotted lines.

cross section. The inelastic nucleon-nucleon cross section increases from $\sigma_{nn} \approx$ 30 mb at CERN SPS energies ($\sqrt{s} = 17.3$ GeV) to $\sigma_{nn} \approx 40$ mb at the RHIC energy of $\sqrt{s} = 130$ GeV.

The neutral pion yields in central Pb+Pb collisions at $\sqrt{s_{nn}} = 17.3$ GeV and in central Au+Au collisions at $\sqrt{s_{nn}} = 130$ GeV are shown in Figure 1 [3, 4]. The yields are normalized to $N_{coll}^{WA98} = 651 \pm 65$ and $N_{coll}^{PHENIX} = 905 \pm 96$, respectively. The measured π^0 spectra are compared to results for nucleon-nucleon reactions. The n+n references is a parameterization that is based on an interpolation of existing data to the respective center-of-mass energy [3, 4]. One observes that the π^0 spectrum in n+n reactions at the RHIC energy is significantly flatter than the corresponding spectrum at the CERN SPS energy. The curvature of the π^0 spectrum in A+A reactions, however, changes only moderately when going from SPS to RHIC.

Figure 2 shows the ratio R_{AA} as defined in equation 1. The PHENIX PbGl and PbSc results were averaged for this plot. A striking difference between the results for the SPS and RHIC energy can be seen. The ratio R_{AA} for $\sqrt{s_{nn}} = 17.3$ GeV is qualitatively in line with expectations from the Cronin effect: R_{AA} increases with p_T and the neutral pion yield increases stronger than N_{coll} above $p_T \approx 2$ GeV/c. At $\sqrt{s_{nn}} = 130$ GeV, however, R_{AA} is basically
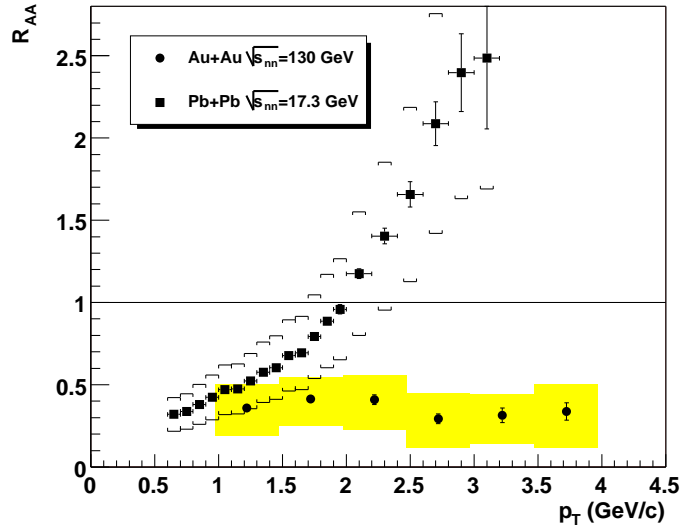
Figure 2: The ratio R_{AA} as defined in equation 1 for neutral pion spectra at CERN SPS and RHIC energy. For the WA98 data points the error due to the uncertainty of the n+n reference and due to the uncertainty of N_{coll} is indicated by brackets. The errors bars of the PHENIX data points indicate the statistical errors. The systematical errors, indicated by shaded areas, include the uncertainties of the n+n reference and of N_{coll}.

flat. Moreover, R_{AA} is significantly below unity over the entire p_T range. Thus, high-p_T neutral pion production at RHIC energies is suppressed compared to the N_{coll}-scaled n+n reference.

One can now replace the n+n reference by the N_{coll}-normalized π^0 spectrum measured in peripheral A+A collisions. This is depicted in Figure 3. The number of binary nucleon-nucleon collisions for the peripheral samples are $N_{coll}^{WA98} = 30 \pm 5$ and $N_{coll}^{PHENIX} = 20 \pm 6$. Figure 3 indicates that the N_{coll} normalized peripheral π^0 spectrum at RHIC is very similar to the respective n+n spectrum. In contrast, the comparison of the SPS results in Figure 2 and Figure 3 shows that the shape of the π^0 spectrum changes significantly when going from n+n to peripheral Pb+Pb collisions with $N_{coll} \approx 30$.

3   Comparison to pQCD calculations

A pQCD calculation from Wang described in [7] is compared to the central π^0 spectrum for Pb+Pb collisions at $\sqrt{s_{nn}} = 17.3$ GeV/c in Figure 4a. In the range around $m_T - m_0 \approx 2.5$ GeV/c^2 the pQCD calculation overpredicts the experimental data by around 30%. In a recent publication also Lévai et al. compare their pQCD calculations to WA98 data [8]. In agreement with Wang's
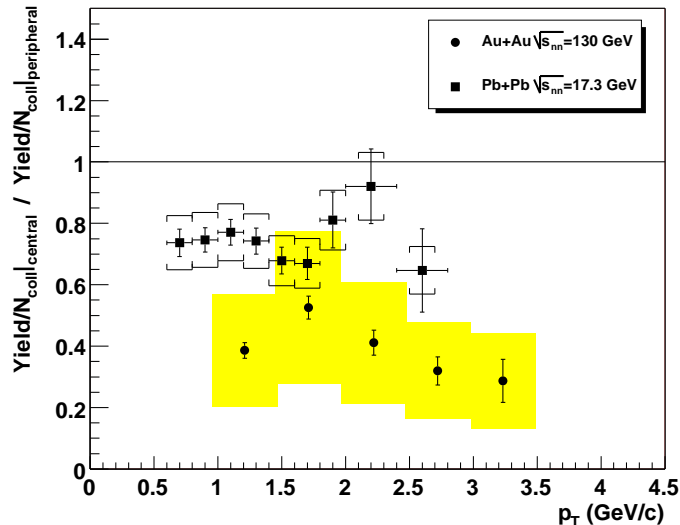
Figure 3: Ratio of central and peripheral π^0 spectra at SPS and RHIC energy. Each spectrum is normalized to the number of n+n collisions.

calculation they find that their pQCD calculation predicts more neutral pions at high p_T than actually measured. Thus, one can conclude that a possible parton energy loss effect ("jet quenching") is not ruled out at SPS energies.

Figure 4b shows a comparison of the PHENIX neutral pion spectrum in central Au+Au collisions with a pQCD calculation from Wang [9]. The standard pQCD calculation without parton energy loss effects clearly fails to describe the data points. By introducing a parton energy loss parameter a reasonably description of the data can be reached. In [9, 10] it is argued that when the expansion of the fireball is appropriately taken into account the energy loss of $dE/dX = 0.25$ GeV/fm in an expanding system effectively corresponds to a much higher energy loss in a static system. This implies that the energy loss in the initial fireball produced in a A+A collision at RHIC is significantly higher than in cold nuclear matter.

References

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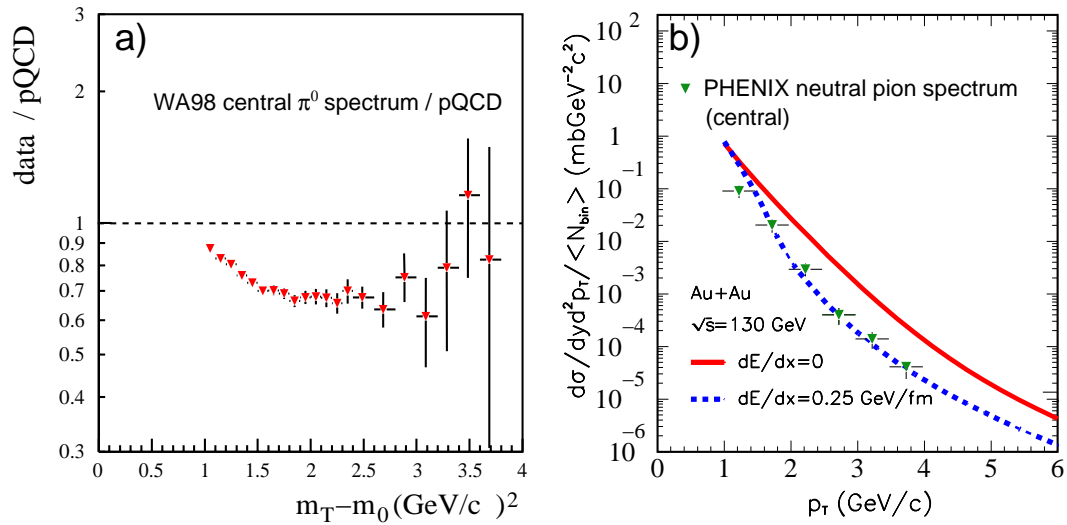[3] M.M. Aggarwal et al., WA98 collaboration, nucl-ex/0108006;

Figure 4: Comparisons of neutral pion spectra measured in central Pb+Pb collisions at the CERN SPS and in central Au+Au collisions at RHIC with pQCD calculations from X.N. Wang [7, 9]. The left panel (a) shows the ratio of the WA98 central neutral pion spectrum to the pQCD calculation. At RHIC energies (b) the differences between the standard pQCD calculation without parton energy loss and data are so significant that the spectra themselves can directly be compared on a logarithmic scale.

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