PROCEEDINGS

International Europhysics Conference on HEP

First Results on Au+Au Collisions at 130AGeV from the PHENIX Experiment

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Abstract: The PHENIX experiment has successfully measured reactions of Au+Au at $\sqrt{s_{NN}} = 130$ GeV. The data indicate a reaction zone with a considerably higher energy density and lower net baryon density than in previous experiments at lower energies. In high p_T particle production in central reactions a deficit is observed compared to a simple scaling from N+N collisions. This suppression is consistent with expectations from parton energy loss in a quark-gluon-plasma. Proton and antiproton p_T spectra are strongly broadened compared to lower energies and to N+N reactions.

1. Introduction

The PHENIX detector [1] at RHIC, the Relativistic Heavy Ion Collider at Brookhaven National Laboratory, is designed to measure the properties of nuclear matter at the highest temperatures and energy densities with a variety of experimental probes, and in particular to search for the predicted transition into a phase of deconfined quarks and gluons, the "quark-gluon-plasma" (QGP). The particular emphasis of PHENIX is the investigation of penetrating probes, like photons, electrons and muons.

PHENIX has measured Au+Au collisions at $\sqrt{s_{NN}} = 130$ GeV in the summer of 2000 with its central arms consisting of detectors for charged particle tracking and identification (via TOF and RICH) and electromagnetic calorimeters for transverse energy and photon and neutral meson measurements. Roughly 50% of the central detectors were instrumented in this run.

The present paper reports on first results regarding transverse energy and particle production, correlations and identified particle spectra and ratios.

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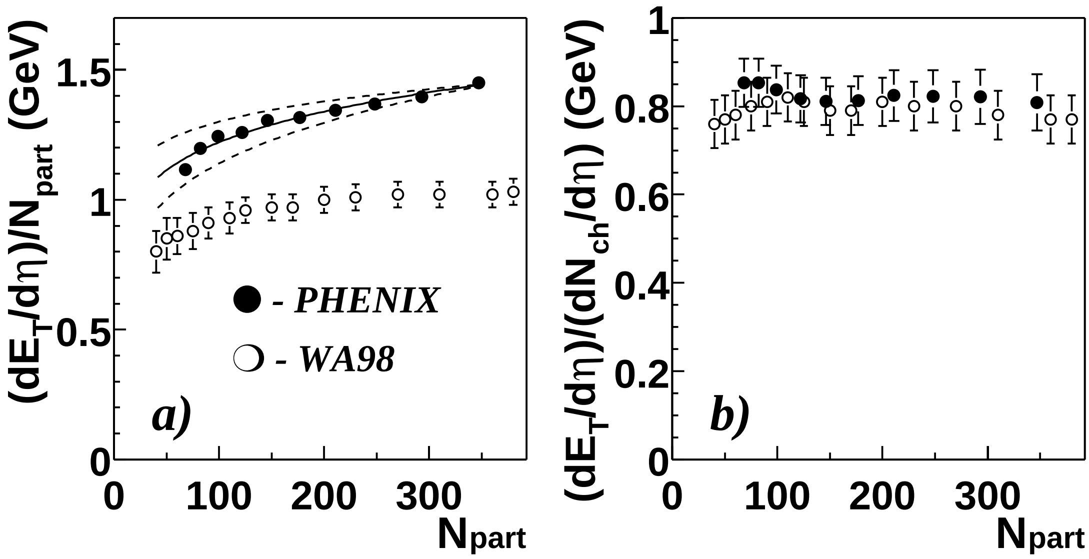

Figure 1: (a) Transverse energy density per participant $dE_T/d\eta|_{\eta=0}/N_{\rm part}$ for Au+Au collisions at $\sqrt{s_{_{NN}}}$ = 130 GeV as a function of $N_{\rm part}$, the number of participants, compared to data from WA98 [4] for Pb+Pb collisions at $\sqrt{s_{_{NN}}}$ = 17.2 GeV. (b) PHENIX $dE_T/d\eta|_{\eta=0}/dN_{ch}/d\eta|_{\eta=0}$ versus $N_{\rm part}$, including all systematic errors, compared to WA98.

2. Global Observables and Correlations

The pseudorapidity densities of the charged multiplicity and of the transverse energy have been measured at midrapidity [2, 3]. Both increase more strongly than linear with the number of participants, a behavior which has qualitatively been observed also at SPS energies [4]. However, at RHIC the increase is considerably stronger. This can be seen from Fig. 1a, which shows $dE_T/d\eta$ normalized to the number of participants. One interpretation of this observation is a more important role of hard interactions, which would rather introduce a scaling with the number of binary collisions.

In addition, it can be observed that the absolute value of $dE_T/d\eta$ is $\approx$ 50% higher at RHIC than at the SPS. In commonly used model descriptions this can be related to a higher initial energy density – within the recipe suggested by Bjorken this leads to an energy density of $\epsilon = 4.6\,{\rm GeV/fm}^3$.

The charged particle density appears to scale very similarly with system size and beam energy, leading to a constant value of E_T per charged particle (see Fig. 1b).

A preliminary analysis of identified pion interferometry has been performed [5]. While longitudinal radii are slightly larger than at lower energies, there appears to be no beam energy dependence in the transverse radii – they are on the order of $R_T = 3 - 6\,{\rm fm}$ depending on transverse momentum, similar to measurements at the SPS. It is presently unclear, whether a potentially larger source might be masked by stronger collective flow effects.

Preliminary results of analyses of azimuthally anisotropic flow [6] identify a strong elliptic component v_2, larger than at SPS energies. The values increase with transverse momentum and are close to expectations from hydrodynamical calculations.

3. Particle Ratios and Spectra

Preliminary results of the ratio of antiprotons to protons have been obtained as $\bar{p}/p = 0.64 \pm 0.01 \pm 0.08$ with only very little dependence on centrality or on p_T. This is a much lower net baryon density than at the SPS. While it does not yet imply the "baryon-free" limit, there are for the first time more baryons produced in the reaction than have been brought in by the colliding nuclei.

Momentum spectra of various particle species have been investigated. Most interestingly, PHENIX is able to measure particle spectra out to very high p_T, where particle production from hard scattered partons should become more and more important [7].

Fig. 2 shows transverse momentum spectra of charged particles (a) and neutral pions (b) for central and peripheral reactions. The data are compared to extrapolations of spectra from N+N collisions to the energy and effective number of collisions of the present measurements. While these extrapolations agree with the data at high p_T in peripheral reactions, they overpredict the spectra in central reactions.

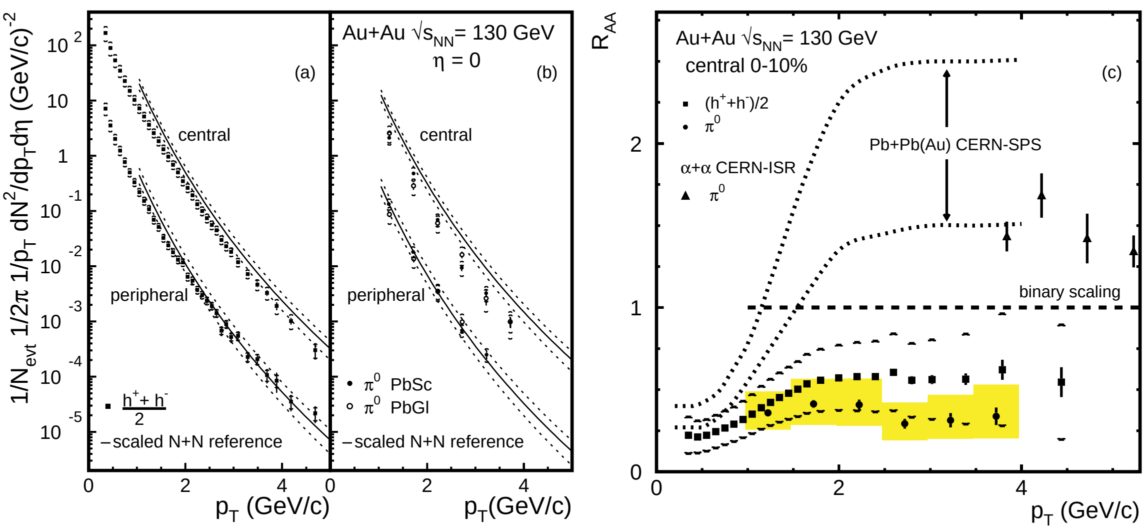

Figure 2: Yields per event at mid-rapidity for (a) charged hadrons and (b) neutral pions as a function of p_T for 60–80% (*lower*) and 0–10% (*upper*) event samples. Shown for reference are the yields per collision in N+N collisions, of charged hadrons and neutral pions respectively, each scaled up by $\langle N_{binary} \rangle$ for the class. (c) The ratio R_{AA} for charged hadrons and neutral pions in central Au+Au collisions. Also shown for reference are the ratio of inclusive cross sections in $\alpha + \alpha$ compared to p+p at $\sqrt{s_{NN}} = 31$ GeV (CERN-ISR) and semi-inclusive spectra from central Pb+Pb, Pb+Au compared to p+p collisions at $\sqrt{s_{NN}} = 17$ GeV (CERN-SPS).

This striking observation is born out more explicitly in Fig. 2c where the *nuclear modification factor*:

$$R_{AA}(p_T) = \frac{(1/N_{evt})\ d^2N^{A+A}/dp_T d\eta}{(\langle N_{binary}\rangle/\sigma_{inel}^{N+N})\ d^2\sigma^{N+N}/dp_T d\eta}. \tag{3.1}$$

is displayed as a function of transverse momentum. This ratio is expected to be one for a scaling with the number of binary collisions as in the most naive picture of hard processes. In central reactions of Au+Au at 130AGeV R_{AA} is significantly below one for charged particles and for neutral pions. This *nuclear modification* is very different from the one known at lower energies where it is dominated by the anomalous enhancement (also known as “Cronin-effect”). In reactions at the SPS and the ISR R_{AA} was observed to be larger than one as indicated in the figure. The suppression observed points to a qualitatively new effect in the present measurement. It has been suggested [8] that this observation might be explained by the energy loss of primarily produced partons via medium induced gluon radiation, which should be much stronger in a quark-gluon-plasma.

Fig. 2c also shows that the suppression is stronger for neutral pions compared to charged particles. This might be traced to the influence of (anti)protons in the charged

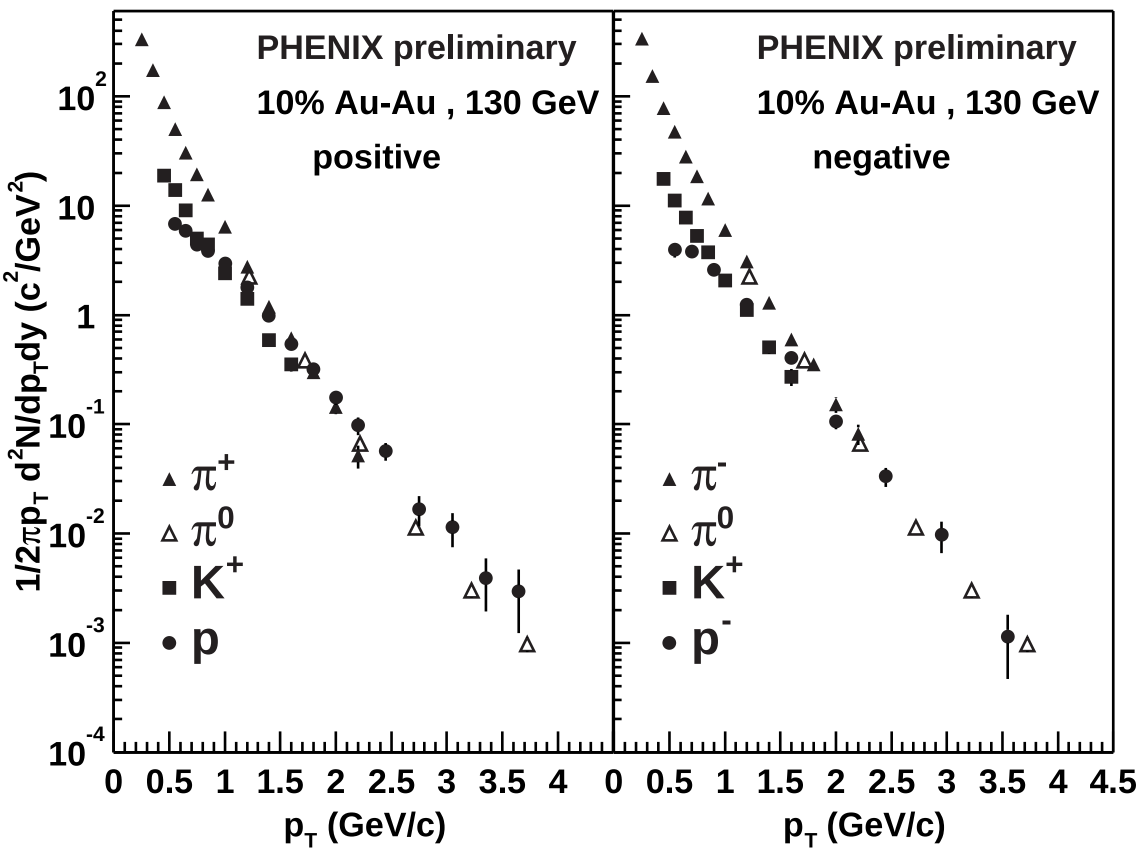

Figure 3: Transverse momentum spectra measured at mid-rapidity normalized to $|y| < 0.5$ for π^+, K^+, p (left) and $\pi^-, K^-, \overline{p}$ (right) for the 10% most central collisions.

particle spectra. Spectra of identified particles from central reactions (10%) are displayed in Fig. 3. With increasing mass of the particle the inverse slope of the spectra increases significantly. Especially the spectra of protons and antiprotons are much broader than those of pions which eventually leads to a higher yield of (anti)protons compared to pions at high p_T. Such a "crossing" of these spectra had so far not been observed in heavy ion or hadron reactions; it is also not predicted by perturbative QCD. The most likely explanation is a strong collective radial flow, which broadens the spectra of the heavier particles significantly.

4. Conclusions and Outlook

The PHENIX measurements from the first RHIC beam time indicate high energy density and low net baryon density in Au+Au collisions at 130AGeV. Strong collective flow effects are observed and suggest early equilibration. Exciting features are observed in transverse momentum spectra: (Anti)protons overshoot pions at high p_T and pions appear to be suppressed relative to expectations from binary collision scaling. The latter is consistent with an explanation by "jet-quenching", the energy loss of partons in dense matter. Other explanations have, however, not been ruled out. Comprehensive calculations are needed, taking into account also subtle modifications of nuclear effects recently observed at lower energies [9].

In the currently ongoing beam time PHENIX is measuring Au+Au collisions at the design c.m. energy of $\sqrt{s_{NN}} = 200$ GeV. The data from this run should allow to study high p_T particle production much beyond the limited momentum range of the present analysis which should help in identifying the physics mechanism responsible for the observed suppression. Furthermore, measurements of vector mesons and direct photons should be achievable.

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