Antiparticle to particle ratios and identified hadron spectra in Cu+Cu and Au+Au collisions

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Abstract. New results on antiparticle to particle ratios in Cu+Cu and Au+Au collisions at √sNN = 62.4 and 200 GeV from the PHOBOS experiment at RHIC are presented. Transverse momentum spectra of pions, kaons, protons and antiprotons from Au+Au collisions at √sNN = 62.4 GeV close to mid-rapidity are also discussed. Antiparticle to particle ratios are found to be remarkably independent of the collision centrality in both colliding systems. The collision energy dependence of the p/p ratios is very significant in Cu+Cu collisions. Baryons are found to have substantially harder transverse momentum spectra than mesons. The pT region in which the proton to pion ratio reaches unity in central Au+Au collisions at √sNN = 62.4 GeV fits into a smooth trend as a function of collision energy. The observed particle yields at very low pT are comparable to extrapolations from higher pT for kaons, protons and antiprotons. The net proton yield at mid-rapidity is found to be proportional to the number of participant nucleons in Au+Au collisions at 62.4 and 200 GeV energies.

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1. Introduction

The antiparticle to particle ratios of hadrons are important observables of heavy ion collisions, and have been extensively studied since the very beginning of RHIC operations [1, 2]. They are more precisely measurable than invariant cross sections, and provide quantitative input to models concentrating on the hadro-chemistry of the collisions, such as statistical thermal models. Antiproton to proton ratios and net proton yields provide information on baryon transport and baryon production in these ultra-relativistic collisions, and are relevant quantities to estimate the fraction of the total collision energy that is available for particle production [3].

The presented identified hadron spectra at $\sqrt{s_{NN}} = 62.4$ GeV extend the energy range for which the contributions of different particle species to the inclusive charged hadron spectra are known, bridging a gap between 17.2 and 130 GeV. Invariant cross sections at very low $p_T$, net proton yields and baryon enhancement in the intermediate $p_T$ range (reported earlier in [4, 5, 6]) are studied in Au+Au collisions at 62.4 GeV.

The sensors in the two arms of the PHOBOS silicon spectrometer are arranged into layers [7]. The particles with $p_T$ measured to be less than 200 MeV/c range out in these layers. Particle ratios are measured in the 0.2 < $p_T$ < 0.8 GeV/c range in the spectrometer, and the identified spectra analysis uses the time-of-flight detector as well, extending the $p_T$ reach to 3 GeV/c.

The acceptance corrections of the particle ratios are cancelled by changing the polarity of the magnetic field: the ratios are formed from the yields of the positive and negative particles with similar trajectories corresponding to the same bending direction, but to opposite magnetic polarity. Ratios in each bending direction and spectrometer arm are evaluated separately and averaged, at the same time providing a handle on the systematic errors. The ratios are corrected for absorption in the beam-pipe and in the detector materials, secondary particle production and feed-down from weak decays, based on detailed Monte Carlo simulations. The size of the latter correction is only 1-2%, since the first silicon layer is positioned within 10 cm from the interaction point, thus allowing good rejection of tracks from displaced vertices.

2. Results

The preliminary $\pi^-/\pi^+$, $K^-/K^+$ and $\bar{p}/p$ ratios in p+p, Cu+Cu and Au+Au collisions are presented in figure [1] as a function of the number of participants in the collision [8]. The comparison of different collision energies (left panel) shows that the $\bar{p}/p$ ratios are strongly energy dependent in Cu+Cu collisions (similarly to collisions of heavier ions). There is only an insignificantly small, if any, decrease of the $\bar{p}/p$ ratio observed with increasing collision centrality at both energies. On the right panel, the same ratios in p+p, Cu+Cu and Au+Au collisions are compared at 200 GeV, where again, almost no variation of the $\bar{p}/p$ ratio with centrality is visible. This observation challenges theoretical expectations about baryon stopping in collisions with varying
Impact parameter. These comparisons are being extended to 62.4 GeV where the ratios are further away from unity, possibly leaving more room for measurable variations.

In order to be able to study the ratios of different particle yields or $p_T$ integrated $dN/dy$ rapidity densities, one has to measure invariant spectra of identified particles as well. Figure 2a summarizes the measured $p_T$ spectra of charged hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. Different rows correspond to three classes of centrality (expressed as the percentile of the total inelastic Au+Au cross section, starting with the 15% most central collisions in the top row). A smooth evolution of the spectra with centrality can be observed, with the proton spectrum being harder than the meson spectra, similar to results at higher collision energies [4, 9]. Figure 2b compares the $\pi^+\pi^-$, $K^+K^-$ and $p\bar{p}$ spectra to the cross sections measured at very low $p_T$. A blast wave fit is applied to the higher $p_T$ data points (solid lines), and extrapolated to low $p_T$ (dashed lines). The extrapolation is in good agreement with the kaon and (anti)proton yields (the fit does not take into account resonance production which populates the low $p_T$ region with pions).

The proton and antiproton spectra can be integrated over $p_T$, with only a small extrapolation of the yield to the unmeasured low and high-$p_T$ region. Figure 2c shows the integrated yield, $dN/dy$, of the net protons ($\bar{p} - p$) close to mid-rapidity at 62.4 [8] and 200 GeV [4] collision energies. In both cases, the net proton yield is approximately proportional to $N_{part}$, which does not meet expectations of increasing amount of baryon stopping with increasing centrality. According to figure 1 the $\bar{p}/p$ ratio does not depend strongly on centrality, thus the $\bar{p}$ and $p$ yields are also proportional to $N_{part}$ to a good approximation.

The less steeply falling proton $p_T$ spectrum dominates over the mesons at higher $p_T$ values, and at 200 GeV collision energy, even the antiproton yield can exceed the pion
Particle ratios and identified hadron spectra from PHOBOS

Figure 2. (a) Invariant cross sections of identified hadrons in Au+Au collisions at \(\sqrt{s_{NN}} = 62.4\) GeV. Positives are plotted in the left, negatives in the right column. (b) Invariant cross sections of \(\pi^+ + \pi^-\), \(K^+ + K^-\) and \(p + \bar{p}\) including the very low \(p_T\) data in the most central class. (c) Net proton yield close to mid-rapidity as a function of \(N_{\text{part}}\) in Au+Au collisions at \(\sqrt{s_{NN}} = 62.4\) and 200 GeV.

yield at high \(p_T\) \[5\]. The phenomenon may be important to identify the relevant degrees of freedom and to study the energy loss of partons in the medium created in a heavy ion collision. To illustrate the baryon dominance at high \(p_T\), the fraction of protons among all positive hadrons \((p/h^+)\) and the fraction of antiprotons among all negative hadrons \((\bar{p}/h^-)\) are plotted in figure 3a, for central Au+Au collisions at 62.4 GeV. The \(p/h^+\) ratio approaches 1/2 around 2.5–3 GeV/c (dashed line), which indicates that the proton yield becomes dominant over both the \(\pi^+\) and \(K^+\) yields.

Figure 3b illustrates the evolution of the ‘baryon dominance’ with collision energy. For central heavy-ion (Au+Au or Pb+Pb) collisions at the AGS, SPS and RHIC accelerators, the approximate \(p_T\) value at which the invariant cross sections of protons and positive pions at mid-rapidity approach each other is plotted. Data (with the percentile of most central events) are taken from the E802 \[10\] (4%), NA44 \[11\] (3.7%), NA49 \[12\] (5%), PHENIX \[4, 6\] (5%) and PHOBOS (15%) experiments. A remarkably smooth collision energy dependence of the ‘crossing’ \(p_T\) value is observed. At low energies, the abundance of produced pions is naturally low compared to high collision energies, while baryon number conservation ensures that a significant fraction of the large number of initial state protons are found in the final state, thus the invariant yields of protons and positive pions become comparable already at low \(p_T\). With increasing energy, this \(p_T\) value grows, mainly due to the approximately logarithmically increasing
Figure 3. (a) $p/h^+$ (closed symbols) and $\bar{p}/h^-$ (open symbols) ratios as a function of $p_T$ in Au+Au collisions at $\sqrt{s_{NN}} = 62.4$ GeV. (b) The $p_T$ value where the proton and $\pi^+$ invariant yields become equal in central Au+Au (Pb+Pb) collisions, as a function of $\sqrt{s_{NN}}$. All data have been corrected for feed-down from weak decays (see text for references).

number of produced pions. Our new result at 62.4 GeV fits smoothly into the trend established by earlier experiments.

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