Results of identified pions, protons and antiprotons up to transverse momentum of 12 GeV/c from STAR

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Heavy ion collisions at RHIC create a hot and dense medium that exhibits novel properties. Study of these properties and hadronization mechanisms of the medium requires identified particle results over wide transverse momentum (p_T) range. We present STAR results of identified charged pions, protons and antiprotons up to transverse momentum of 12 GeV/c in Au+Au, pp and d+Au collisions at the $\sqrt{s_{NN}} = 200$ GeV. Spectra, ratios, and nuclear modification factors, and their comparisons to jet fragmentation, partonic energy loss, and coalescence/recombination models are discussed.

1. INTRODUCTION

Ultra-relativistic heavy ion collisions provide a unique environment to study particle production mechanisms in nuclear matter under extreme conditions of high temperature and energy density. Experimental observations show that the medium created in such conditions is opaque, dense, and exhibits a variety of novel properties. Understanding of these properties and hadronization mechanisms in general requires identified particle results over a wide p_T range, as different mechanisms govern hadron formation in different kinematic regions. At sufficiently large p_T particle production in ultra-relativistic heavy ion collisions is dominated by jet fragmentation. At low p_T the system can be well described by hydrodynamical models [1]. Particle production between these momentum regimes may arise from an interplay between different mechanisms [2–5]. Measurements pions and protons (the two particle species most abundantly produced) across all three momentum regions enable us to study the transition between different hadronization mechanisms (such as, for example, jet fragmentation and possible coalescence from the medium).

2. DATA ANALYSIS

The measurements reported here ware carried out at RHIC by the STAR experiment. The STAR detector consists of several detector subsystems in a large solenoid magnet, including a time projection chamber (TPC) and a time of flight detector (TOF), both of which were used for this analysis.

*For the full list of STAR authors and acknowledgments, see appendix 'Collaborations' of this volume.

Measurements from the following data samples are reported here: minimum bias Au+Au events collected at $\sqrt{s_{NN}} = 200$ GeV in Run-4 and minimum bias d+Au (Run-3) and pp (Run-2) events at the same energy. The Au+Au minimum bias data sample was subdivided into different centrality bins, where collision centrality was determined from the measured charged particle multiplicity at mid-rapidity $|\eta| < 0.5$.

At low p_T particle identification is achieved by the traditional dE/dx technique [6]. The identification is now extended by a TOF measurement combined with TPC dE/dx to intermediate p_T (up to 5 GeV/c) [7], and by the relativistic rise of dE/dx ("rdE/dx") to high p_T (up to 12 GeV/c for minimum bias Au+Au data sample, and up to 10 GeV/c for different centrality bins of Au+Au data, d+Au and pp events, limited by current statistics).

Above 3 GeV/c the separation between pions and protons is more than twice our dE/dx resolution, allowing statistical identification of charged pions, protons and antiprotons. The analysis is complicated by insufficient (about one σ or less) separation between kaons and protons. We use our neutral kaon measurements and K^+/K^- ratio at low momentum to estimate charged kaon yields and additionally constrain the fit. Additional details about the analysis technique can be found in [8]. Charged pion, proton and antiproton spectra are obtained from the raw particle yields extracted from the multi-gaussian fits and are corrected for detector acceptance and tracking efficiency.

3. RESULTS

3.1. Antiparticle to particle ratios

With the measurements of charged pion, proton and antiproton spectra we address the p_T dependence of relative particle production via particle ratios. Our π^-/π^+ ratio is

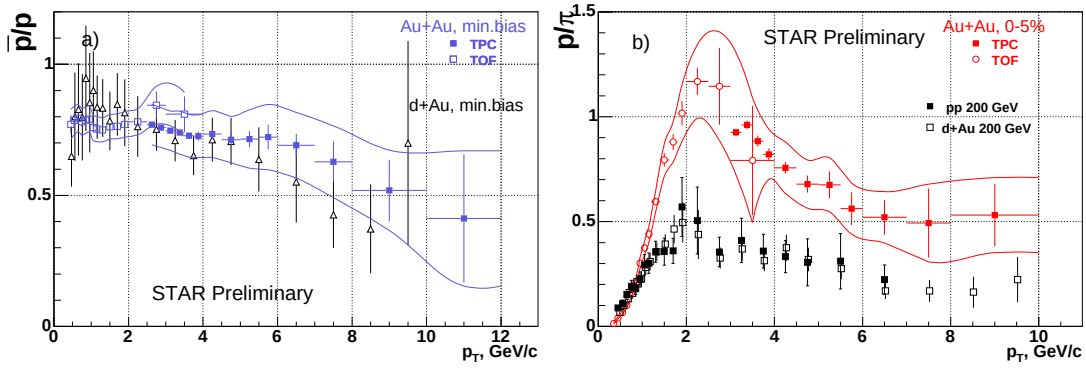

Figure 1. a) $\bar{p}/p$ ratio for minimum bias Au+Au and d+Au data as function of p_T; b) p/π as function of transverse momentum for 5% most central Au+Au and minimum bias pp and d+Au (black symbols) collisions. Colored bands represent combined statistical and systematic uncertainties for Au+Au data. For pp and d+Au data those uncertainties are shown as error-bars.

consistent with unity and independent of p_T for all data samples/centrality bins studied. $\bar{p}/p$ measurements at the intermediate p_T are similar to those at low p_T (Figure 1a). For all systems (Au+Au, pp and d+Au) our measurements show a decrease in the $\bar{p}/p$ ratio

at high p_T. The p_T dependence of the $\bar{p}/p$ ratio shown in Figure 1*a* contradicts pQCD inspired models, which predict a stronger decrease in the ratio over all p_T [9,10].

3.2. Relative baryon production

The p_T dependence of $\bar{p}/\pi$ and p/π ratios provides more insights into what has become known as the "baryon-meson puzzle". The results presented in Figure 1*b* confirm the reported anomalously high production of protons and antiprotons in the intermediate momentum range. After reaching a maximum at approximately 2-3 GeV/c the ratios then fall off at higher transverse momentum. The p/π ratio shows that approximately equal amounts of baryons and mesons are produced in central Au+Au collisions in the momentum range of $2 < p_T < 4$ GeV/c. This is significantly higher than the corresponding measurement in elementary pp collisions (also shown in Figure 1*b*), and pQCD result of $p/\pi \approx 0.2$ [11]. The observed baryon enhancement in the intermediate p_T range shows a centrality dependence, with higher relative baryon production in more central collisions.

Different theoretical models predict a variety of non-fragmentation contributions to baryon production in the intermediate p_T range. Various mechanisms for baryon production such as gluon junctions (Soft+Quench) [2], recombination [3,4] and quark coalescence [5] result in an enhancement of baryons with respect to mesons in those models. The models also predict a rather rapid fall off of those contributions at higher p_T. Since the models predict similar trends for p/π with p_T, their discrimination will require higher precision data than we presently have.

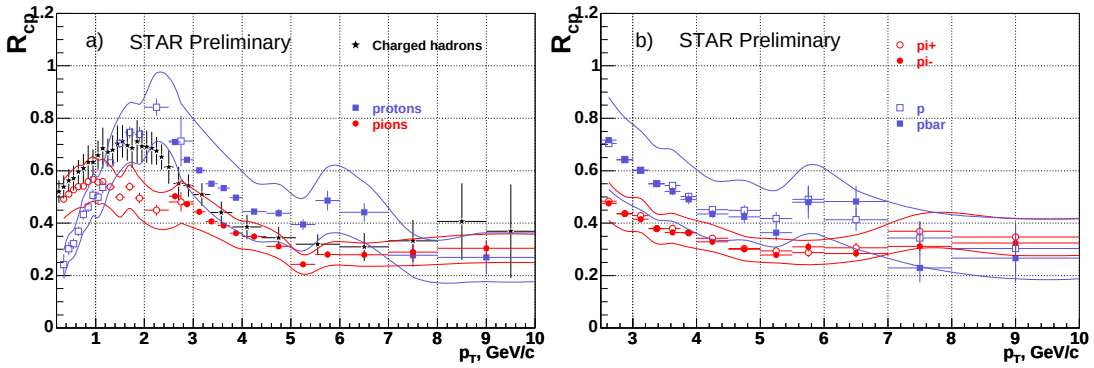

Figure 2. R_{CP} for the 5% most central collisions, normalized by the peripheral 60-80% collisions, as function of p_T. In *a)* particle and antiparticle spectra are added together to increase statistics. Black symbols show R_{CP} for inclusive hadrons [12]. *b)* shows particles and antiparticles rdE/dx measurements separately. The bands show combined statistical and systematic errors; the systematic uncertainties for pions and protons are strongly correlated.

3.3. Nuclear modification factor

Figure 2 shows the nuclear modification factor R_{CP} for pions and protons in the 5% most central collisions, normalized by the peripheral 60-80% collisions. Our measurements show a stronger suppression for pions than protons in the intermediate p_T range. Such difference in R_{CP} was also observed in our strange baryon and meson measure-

ments [13]. The baryon-meson dependence of R_{CP} at intermediate p_T contradicts the expectations from parton energy loss followed by jet fragmentation in vacuum, and favors the coalescence/recombination scenario.

In the high p_T region, where jet fragmentation dominates, one should expect similar values of R_{cp} for charged hadrons, pions, and protons. Our measurements indicate that this is indeed true at sufficiently high transverse momentum. Over the wide p_T range measured we do not observe difference in R_{CP} between particles and antiparticles.

4. CONCLUSIONS

In summary, we have presented first measurements of identified charged pions, protons and antiprotons at high transverse momentum in Au+Au, d+Au and pp collisions from RHIC. We extended our previous measurements up to transverse momentum of 12 GeV/c. Studies of the p_T dependences of particle ratios and nuclear modification factors yielded the following main results: 1) π^-/π^+ ratio shows no p_T-dependence and is consistent with unity for all systems measured; 2) the $\bar{p}/p$ measurement is found to be independent of p_T at low p_T, and decrease at high p_T; 3) baryon production, relative to meson production, is found to vary strongly with p_T. It increases at low p_T, reaching a maximum at about 2 GeV/c, and decreases at high p_T. The baryon over meson enhancement at intermediate p_T is stronger in more central Au+Au events. Nuclear modification factors, similar between particles and antiparticles, show strong baryon-meson splitting at intermediate p_T, which diminishes at high p_T. The measured features at intermediate p_T are consistent with the presence of multi-parton particle formation mechanisms beyond the framework of parton energy loss followed by standard jet fragmentation.

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