Antiproton Production in 11.7 AGeV/c Au+Au Collisions from E866

Hiroyuki Sako
Institute of Physics, University of Tsukuba
1-1-1 Tennoudai, Tsukuba, Ibaraki, 305 Japan

for the E866 Collaboration:
BNL-UCBerkeley-UCRiverside-Columbia-INS(Tokyo)-Kyoto-LLNL-Maryland-MIT-
Tokyo-Tsukuba-Yonsei

ABSTRACT

We present antiproton production in 11.7 AGeV/c Au+Au collisions measured in a wide transverse-mass coverage from the AGS-E866 experiment. We show indications for strong absorption effects of antiprotons in Au+Au collisions through comparison with p+A and Si+A collisions, and centrality dependence in Au+Au collisions.

1. Introduction

Antiproton production in elemental nucleon-nucleon collisions in the AGS energies (10–20 AGeV) is suppressed because of the nearby creation threshold energy (6.5 GeV). In heavy ion collisions, some fraction of initially produced antiprotons are absorbed by nucleons later. The visible antiproton yields are results of subtle interplay between the initial production and the absorption. An observation of antiproton enhancement should be an indication of the cooperative processes such as the quark-gluon-plasma (QGP) [1,2,3], or hadronic multi-step processes [4,5]. On the other hand, an observation of strong suppression could be a signature of high baryon densities [3,6].

The previous experimental results in p+A and Si+A collisions show that antiproton yields are proportional to the number of projectile participants ($N_{proj}$). There has been no clear signal observed for antiproton absorption. Two pictures have been proposed for antiproton production; one is the first collision model with very weak absorption [7] and the other is hadronic multi-step processes with absorption with free $NN$ absorption cross sections [8]. In the heavier system of Au+Au, the maximum baryon density is predicted to reach about 10 times as high as the baryon density in the normal nucleus [6,9]. We investigate if we observe the absorption effect in such a high baryon density condition where a strong absorption effect is expected.
2. Experimental Setup

The AGS-E866 experiment is aimed at studies of particle production in $10 - 12$ AGeV/c Au+Au collisions. The E866 spectrometer consists of two arms; the Henry Higgins spectrometer, which has been used in the E802 and E859 experiments, and the Forward Spectrometer, which was built newly for E866 for the forward angle coverages. In this analysis, we used the data taken in the Forward Spectrometer. The Forward Spectrometer has a 5 msr solid angle and covers polar angles from 6 to about 28 degrees in the laboratory frame. The Forward Spectrometer consists of two dipole magnets (FM1 and FM2), two tracking stations (FT1+TPC1+FT2 and FT3+TPC2+FT4), each of which consists of a TPC with two drift chambers on both sides, and a time-of-flight counter (FTOF). The kinematic coverage of antiprotons with the Forward Spectrometer is about $1 < y < 2$ in rapidity ($y$), and $m_t < m_0 + 1.2 \ [\text{GeV/c}^2]$ in transverse mass ($m_t$), where $m_0$ is the antiproton mass. The interaction trigger (INT) is defined as an event with the charge number of beam remnants lower than a threshold, which is determined by the zero-degree Čerenkov counter (Bull’s Eye) located 9.5-m downstream the target. The zero-degree calorimeter (ZCAL) is positioned in the zero-degree direction 11-m downstream the target. It is used in the off-line analysis to define the centrality of collision events by measuring the total kinetic energy of projectile spectators.

3. Data Analysis

We have analyzed about 15 million Au+Au collision events taken in 1994. The Au beam energy in 1994 was 11.7 AGeV/c. Distributions of negative charged particles which passed various track selection cuts are shown in Fig. 1. We have applied an asymmetric particle-identification (PID) cut for antiprotons in the mass-square vs momentum plane, in order to suppress background contamination of $\pi^-$ and $K^-$ at momentum higher than 3 GeV/c. The PID cut is shown as solid lines in Fig. 1. The asymmetric cut extends the PID momentum limit up to 4.5 GeV/c. The number of final antiproton candidates is about 800.

After the antiproton PID cut, we have obtained invariant differential cross sections in the rapidity vs transverse mass plane in minimum bias events (INT events), and with centrality cuts. For the centrality cuts, we used the energy spectrum of ZCAL, after the background subtraction using empty target runs. We defined the centrality as the trigger cross section between zero ZCAL energy and given ZCAL energy, normalized to the total INT trigger cross section of 5.25 barn. We used four centrality windows; 0 – 10 %, 10 – 30 %, 30 – 50 %, and 50 – 100 % (zero corresponds to the most central event), so that the number of antiproton candidates in each window is roughly same.

4. Results and Discussions

We estimated the beam energy correction to compare antiproton yields at different beam energies, using antiproton production cross sections in p+p collisions. Fig. 2 shows antiproton production cross section in the p+p interaction as a function of $\sqrt{s} - 4m$. Because few data points exist at the beam momentum lower than 15 GeV, we used the following
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parametrization as proposed in Refs. [12,13];

\[
\sigma_{p\rightarrow \bar{p}}(\sqrt{s}) = a(\sqrt{s} - 4m)^b \text{ [mb]},
\]

where \( a = (1.064 \pm 0.039) \times 10^{-2}, \ b = 1.947 \pm 0.189 \) are obtained from the fit to data. We defined the beam energy correction as the ratio of Eq. 1 at two different beam energies.

Fig. 3 shows antiproton invariant differential cross sections in inclusive events. Since the \(\text{INT}\) cross section is 5.25 barn while the total geometrical cross section in \(\text{Au+Au}\) collisions is 6.85 barn [15], we lose about 23\% of most peripheral events. The cross sections were obtained in minimum bias events (\(\text{INT}\) events), and corrected for antiproton yield in the most peripheral events by 8\%. Cross sections at kinematically reflected rapidities with respect to the nucleon-nucleon center-of-mass rapidity of 1.6 are consistent within statistical errors. Antiproton yields at \(p_t \approx 0\) measured by two other experiments at AGS, E886 and E878 are also shown in the figure. To E878 data, we have applied the beam energy correction of 1.4 using Eq. 1. Agreements of these data with E866 data are good within errors. Fig. 4 shows antiproton invariant differential yields in four centrality windows. The inverse slope parameter increases as going to the central events from 0.17 GeV/c\(^2\) in central 50 - 100\% events to 0.24 GeV/c\(^2\) in central 0 - 10\% events.

Next, we have compared antiproton yields in p+A and Si+A collisions with those in \(\text{Au+Au}\) collisions with the beam energy correction. In order to describe different collision systems and centralities, we used the number of projectile participants (\(N_{\text{proj}}\)). We estimated \(N_{\text{proj}}\) using FRITIOF version 1.7, in a range of impact parameters converted from trigger cross sections at each centrality range. Fig. 5 shows antiproton's \(dN/dy\) multiplied by the energy correction for p+A, Si+A collisions at 14.6 AGeV/c, and \(\text{Au+Au}\) collisions at 11.7 AGeV/c as a function of \(N_{\text{proj}}\). As mentioned above, antiproton yields in p+A and Si+A collisions are on a straight line (dashed line). On the other hand, the ratio of antiproton yields in \(\text{Au+Au}\) collisions to the line are only 60\% to 30\%, from the most peripheral events to the most central events, and the ratio decreases as going to the central events. This suggests strong antiproton absorption in \(\text{Au+Au}\) collisions, compared to in p+A and
Si+A collisions, and also that the effect is stronger as going to the central events.

Next, we have compared the centrality dependence in Au+Au collisions among various particle species. For the comparison, we used the ratios of the particle yields to π⁻ yields, because the ratios may reduce systematic effects depending on the centrality. Fig. 6 shows ratios of rapidity densities, \( p/π⁻, \bar{p}/π⁻, K⁺/π⁻ \) and \( π⁺/π⁻ \), as a function of \( N_{\text{proj}} \). The order of increase of the ratios as going to the central events is \( K⁺/π⁻ > K⁻/π⁻ > p/π⁻ > π⁺/π⁻ > \bar{p}/π⁻ \). Only \( \bar{p}/π⁻ \) decreases as going to the central events, in contrast to other particle ratios. This is another signature suggesting that the antiproton absorption is stronger as going to the central events in Au+Au collisions.

The above two experimental results suggest strong absorption effects in Au+Au collisions. Lastly, we have attempted comparison of antiproton yields with a cascade model, RQMD [18]. In RQMD, antiproton production is characterized by initial production in hadronic multi-step processes and absorption with the free \( N\bar{N} \) annihilation cross sections [8]. RQMD predicts that about 98% of initially produced antiprotons are absorbed in central Au+Au collisions. Fig. 7 shows comparison of antiproton’s \( dN/dy \) with by the beam energy correction in p+A, Si+A, and Au+Au collisions. RQMD reproduces overall tendencies of antiproton yields from p+A to Au+Au collisions within 50%.

5. Summary

We have studied antiproton production in 11.7 AGeV/c Au+Au collisions using the Forward Spectrometer in the E866 experiment. Indications for strong absorption effects of antiprotons were observed in Au+Au collisions through comparison with p+A and Si+A collisions, and centrality dependence in Au+Au collisions. RQMD reproduces overall tendencies of antiproton yields from p+A to Au+Au collisions.
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7. References


Figure 5: Antiproton's $dN/dy$ multiplied by the energy correction, $\frac{\sigma_{pp}^{-1}(14.6\text{AGeV}/c)}{\sigma_{pp}^{-1}(p)}$, for p+A, Si+A collisions at 14.6 AGeV/c, and Au+Au collisions at 11.7 AGeV/c as a function of $N_{\text{proj}}$. The insert shows the enlarged plot for p+A data. Data are taken from Ref. [16] for p+A, from Ref. [17] for Si+A, and from this analysis for Au+Au. The rapidity ranges are $1.1 < y < 1.7$ for p+A and Si+A collisions, and $1.0 < y < 1.6$ for Au+Au, respectively, so that both ranges are $y_{\text{nn}} - 0.6 < y < y_{\text{nn}}$. The energy correction for Au+Au is 2.1.

Au+Au 11.7 GeV/c (1.2 < y < 2.0)

Figure 6: Ratios of rapidity densities, p/π−, p/π−, K±/π− and π+/π−, as a function of N_{proj} in the rapidity range of 1.2 to 2.0. Error bars are statistical only.

Figure 7: Antiproton’s dN/dy multiplied by the energy correction in p+A, Si+A, and Au+Au collisions for E802 and E866 data (left) and RQMD (right). The rapidity ranges are 1.1 < y < 1.7 for p+A and Si+A collisions, and 1.0 < y < 1.6 for Au+Au collisions, respectively. RQMD calculations from p+A and Si+A are taken from Ref. [8]. RQMD calculations for Au+Au collisions were done with RQMD Version 2.1, and the beam energy correction of 2.1 is applied, which is the same value as for the experimental data.