New Insight into Antiproton Production and Reabsorption Using Proton-Nucleus Collisions at the AGS

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Antiproton ($\bar{p}$) yields are presented for proton-nucleus collisions, with targets Be, Cu, and Au, at beam momenta of 12.3 and 17.5 GeV/c. In addition to target size and beam momentum, the number of projectile collisions ν, as derived from the number of "grey" tracks (slow protons and deuterons), is used to disentangle the $\bar{p}$ reabsorption from the production. By quantifying the amount of reabsorption of the $\bar{p}$ within the nucleus as a function of ν, the annihilation within the nucleus is estimated and compared to the free annihilation cross section. Preliminary results on antilambda ($\bar{\Lambda}$) production as a function of ν are also presented for comparison.

1. Introduction

Sub-threshold $\bar{p}$ production as well as an apparently reduced $p - \bar{p}$ annihilation cross section in the nucleus have been under debate since the discovery of the $\bar{p}$ and until recently [1–8]. The observation of enhanced antimatter production has been proposed as a signature of the Quark Gluon Plasma [9]. Due to the annihilation of antibaryons in baryon-rich nuclear matter, it has also been proposed to use $\bar{p}$ yields as a measure of the baryon density in heavy ion collisions [10]. These interesting prospects for using antibaryons to help determine the properties of the hot, dense phase in a heavy ion collision require a deeper understanding of both the production and reabsorption of the $\bar{p}$ within the nucleus. Proton-nucleus collisions provide a cleaner environment for testing $\bar{p}$ production and reabsorption within the nucleus than heavy ion collisions. In this paper, we present measurements of $\bar{p}$ production in p+A collisions at the AGS that may help address the questions of production and reabsorption in the nucleus.

2. Data Reduction

The E910 apparatus has been described elsewhere [11]. The time-of-flight (TOF) wall, used to identify the $\bar{p}$, is located approximately 8 m from the target and covers approximately $5{\times}2$ m^2. Using the measured times of flight to identify particles, the $\bar{p}$ band is

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well separated from the pions and kaons up to 3.5 GeV/c. Momentum dependent cuts on the number of standard deviations of the measured TOF from the expected TOF of a proton are applied. To reduce background in the identified $\bar{p}$ sample, we apply cuts on the particle's ionization energy loss in the TPC and the measured photoelectrons in the Cerenkov detector. Quality cuts on the hits on the TOF include a cut on the difference in horizontal position between a projected track and the center of the hit TOF slat and a cut on the energy deposited on the TOF slat. Tracks are matched to the TOF wall with a 90±5% efficiency. We estimate and subtract a momentum-dependent background of approximately 5%. Feeddown from $\bar{\Lambda}$ in our $\bar{p}$ sample is estimated to be less than 5%. The data have been acceptance corrected within our $y - p_T$ coverage, and corrected for the efficiencies of the cuts mentioned above. All results are shown within our $y - p_T$ coverage, $y = (1, 2)$ and $p_T = (10, 800)$ MeV/c.

3. Measured Antiproton Yields

The $\bar{p}$ yields are shown in Fig. 1. We observe a strong increase in p+Au $\bar{p}$ yields from beam momentum 12.3 to 17.5 GeV/c as expected, since production of $\bar{p}$ near threshold should depend sensitively on the available phase space. Although the likelihood of producing a $\bar{p}$ may be greater in a larger nucleus [12], the likelihood of reabsorption is also greater in the presence of more baryons. These two countervailing effects can be studied by investigating the target dependence of $\bar{p}$ yields. Results for Be, Cu, and Au at beam momentum 12.3 GeV/c are also shown in Fig. 1.

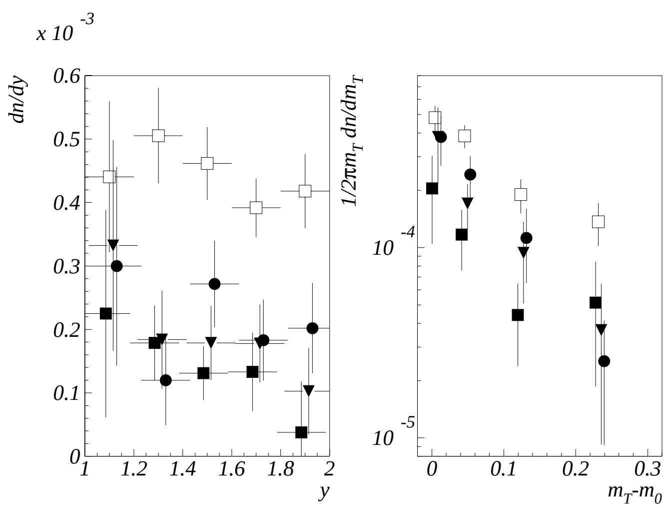

Figure 1. Beam momentum and target dependence of rapidity densities (left) and transverse mass densities (right). The open squares are 17.5 GeV/c p+Au yields, solid squares are 12.3 GeV/c p+Au, solid triangles are 12.3 GeV/c p+Cu, and solid circles are 12.3 GeV/c p+Be.

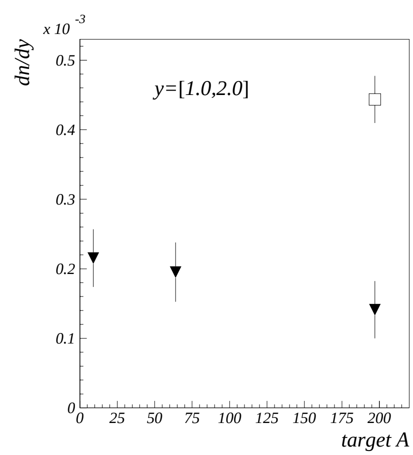

Figure 2. Integrated rapidity density as a function of target A. The triangles are yields from 12.3 GeV/c beam momentum, and the open square is 17.5 GeV/c.

Figure 2 shows the integrated rapidity densities for all four data sets. The yields decrease from p+Be to p+Au collisions by 34 ± 22%.

4. Reabsorption of the Antiprotons

By characterizing collision "centrality," E910 can provide new insight into $\bar{p}$ absorption. Events are characterized by the mean number of collisions ν that the projectile undergoes within the nucleus (as determined by the number of "grey" tracks N_g) [11]. The ν dependence of the mean $\bar{p}$ multiplicity in 17.5 GeV/c p+Au collisions is shown in Fig. 3. A preliminary measurement of the mean $\bar{\Lambda}$ multiplicity as a function of ν is also shown in Fig. 4. The mean multiplicity of both tends to decrease as ν increases. Although not convincingly significant, the increase from $N_g = 0$ to $N_g = 1$ in the mean $\bar{p}$ yield may be evident of a contribution to production beyond the first p+N collision. The increase is more pronounced in the mean $\bar{\Lambda}$ yield versus ν and thus strengthens the evidence for production beyond a first collision model. With the following assumptions, we quantify the "effective" absorption cross section in the nucleus and show that it is greatly reduced relative to the free $p - \bar{p}$ annihilation cross section. The first assumption is that the $\bar{p}$ is predominantly produced in the first p+N collision. Since the beam energy is near the production threshold, this is generally assumed to be true at AGS energies [13]. If there are contributions to production beyond $\nu = 1$, as we have conjectured, they are not large enough to change our conclusion dramatically. The second assumption is that the $\bar{p}$ follows the path of the projectile through the nuclear matter. This is also a reasonable assumption because we observe strongly forward-peaked angular distributions for the $\bar{p}$. Then the survival probability of the $\bar{p}$ can be described by the following equation (although one should note that a formation time is not taken into account by this description),

$$\sigma(pA \to \bar{p}X) = \sigma(pp \to \bar{p}X) e^{-\frac{\sigma_{abs}}{\sigma_{pN}}(\nu-1)}. \qquad (1)$$

Since the value ν plotted on the x-axis of Figs. 3 and 4 is simply an average value, $\bar{\nu}(N_g)$, and each value of N_g actually has a distribution of ν values associated with it, $P_{N_g}(\nu)$, we fold the above exponential with $P_{N_g}(\nu)$. We determine σ_{abs} by fitting with,

$$\sigma(pA \to \bar{p}X) = \sigma(pp \to \bar{p}X) P_{N_g}(\nu) e^{-\frac{\sigma_{abs}}{\sigma_{pN}}(\nu-1)}. \qquad (2)$$

In one fit, the first data point is not included (because of the initial increase in yield from $N_g = 0$ to $N_g = 1$), and in the second fit, the $N_g = 0$ point is included. The parameter, σ_{abs}/σ_{pN}, resulting from the fit is 0.23 $\pm$ 0.09 when neglecting the first data point in the fit, and 0.13 $\pm$ 0.05 when including it. Taking the more conservative estimate of 0.23 and assuming σ_{pN} to be 30 mb, one obtains an absorption cross section, σ_{abs}, of 6.9 $\pm$ 2.7 mb. At $p = 2.5$ GeV/c, the mean measured momentum of the $\bar{p}$ sample we detect, this is approximately 1/5 of the free annihilation cross section [12], σ_{ann}. The large discrepancy between σ_{abs}, as derived from our model, and σ_{ann} suggests a modification of the $p - \bar{p}$ annihilation cross section within the nuclear medium. Figure 4 shows a very similar dependence of the mean $\bar{\Lambda}$ yield on ν. Fitting with the same function that was used for the $\bar{p}$ yields, the extracted fit parameter is 0.22 $\pm$ 0.04. The effective absorption cross section is thus the same (within errors) for $\bar{\Lambda}$ as for $\bar{p}$. This suggests an intermediate state that emerges from the nuclear medium as a $\bar{p}$ or a $\bar{\Lambda}$.

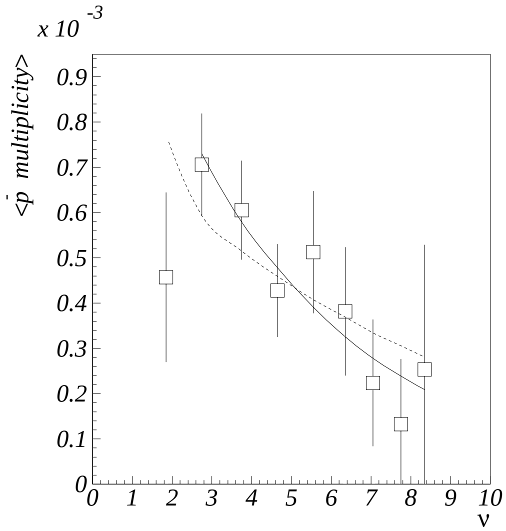

Figure 3. Dependence of mean $\bar{p}$ yield on ν. The solid line is the result of the fit neglecting the first point ($N_g = 0$ bin), and the dashed line includes the first point.

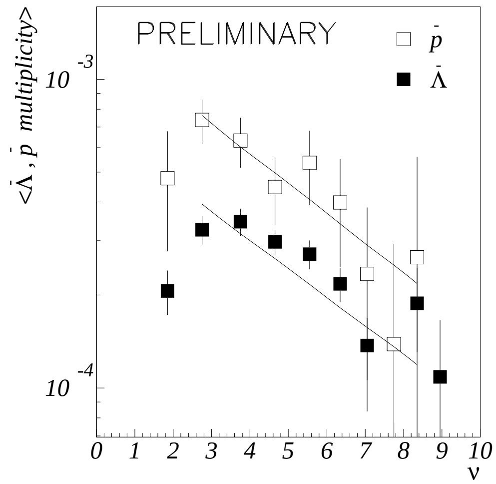

Figure 4. Dependence of mean $\bar{p}$ yield and mean $\bar{\Lambda}$ yield on ν (semi-log scale). The open squares denote the $\bar{p}$ data and the solid squares denote the $\bar{\Lambda}$ data.

5. Conclusions

We have found that, at AGS energies, the $\bar{p}$ yields dramatically increase with beam momentum and moderately decrease with increasing target size. We have found evidence that even at these beam momenta, near the production threshold of the $\bar{p}$ and the $\bar{\Lambda}$, there is production beyond the first p+N collision for the $\bar{\Lambda}$, and a similar behavior for the $\bar{p}$ is not excluded. Finally, the "effective" absorption cross section, calculated within the context of a simple model, is significantly reduced relative to the free $p - \bar{p}$ annihilation cross section. The similarity between the calculated absorption cross sections for $\bar{p}$ and $\bar{\Lambda}$ may indicate the presence of a single intermediate state which leads to both final states.

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