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Proc. 10th Workshop on Nuclear Dynamics
Snowbird, Utah
January 16-21, 1994

Conf-940169--7
BNL-60480

Antiproton production at 0 degrees for Si + A and Au + A Collisions at the AGS

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ABSTRACT

We present results on antiproton production obtained in the AGS experiments E858 and preliminary results of E878. The yields of antiprotons in Si + A collisions are shown to scale with the number of first collisions. The rapidity distributions for all targets (Au, Cu and Al) and both beams (Si at 14.6 GeV/c and Au at 11. GeV/c) have gaussian shapes peaking at y_{NN} and with similar standard deviations. From E878 we report a difference in the shape of the antiproton rapidity distributions obtained from two samples of the data populated with central and peripheral events respectively. In Au induced reactions the A dependence of the antiproton yields is small.

1. Introduction

The AGS experiment, E858, and its subsequent upgrade, E878, were proposed as high rate studies of the production of long-lived negative secondaries in reactions of heavy ion beams and nuclear targets. Both experiments were implemented in existing AGS beam lines, transforming them into double focusing spectrometers that measured negative or positive secondaries at zero degrees in the laboratory frame within a small momentum bite.

The beam fluence exceded 10^8 ions/spill for the Si beam runs. A redundant system of two ion-chambers upstream of the target, and a secondary particle telescope (SPT) made of three scintillator paddles aligned so as to view the target within a small solid angle, were used to monitor the beam intensity. For E878, several improvements were implemented at the target area; a multiwire proportional chamber upstream of the target to monitor the position of the beam as it impinges on the target. A quartz fiber hodoscope was also placed upstream and close to the target to provide another measurement of the beam position on the target, and finally, a second SPT set was placed upstream of the target making the same angle with the beam as the first one.

Figure 1 is a schematic of the instrumented AGS A3 line used for the E878 experiment. The E858 was implemented in the A1 line but the detector setup is similar. The spectrometer has $\Delta\Omega \approx 200\mu sr$ centered around zero degrees and a $\pm 3\%$ momentum bite.

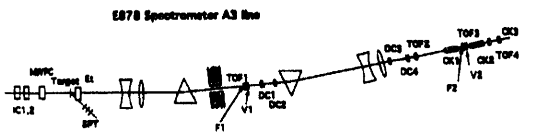

Fig. 1: Experimental layout showing the instrumented A3 AGS beam line.

The best technique for particle identification in such a long spectrometer is the measure of time of flight. Both experiments had redundant systems to measure the time of flight. The first TOF station was placed at the first focus F1 30 meters downstream of the target and just after a collimator that defines the momemtum bite of the spectrometer. This first TOF counter was a scintillator paddle viewed by two photomultipliers. A second focus is formed 25 meters downstream of the first one, and there, another time of flight counter made of a single scintillator paddle viewed by two photomultipliers was installed. Two other TOF counters were placed close to the second focus in order to make redundant measurements. During E858 these additional time of flight stations were made of a single scintillator paddle viewed by two PMT's, and later in E878, they were upgraded to five scintillator paddles covering the same area in order to remove ambiguities in cases where more than one particle was present in the line.

All the PMT's from these TOF counters had their pulse height as well as their time information recorded, providing information about the time of flight as well as the charge of the detected particle. From that information, and the value of the tuned rigidity of the beam line, the mass of the particles can be infered. Figure 2 shows the mass distribution at 6.4 GeV/c measured during the E858 run. The entries to this histogram are tracks in the spectrometer that had consistent time of flight measured with two pairs of TOF stations and information from the tracking system indicating that these particles were produced in the target and were transported by the beam line all the way to the second focus region.

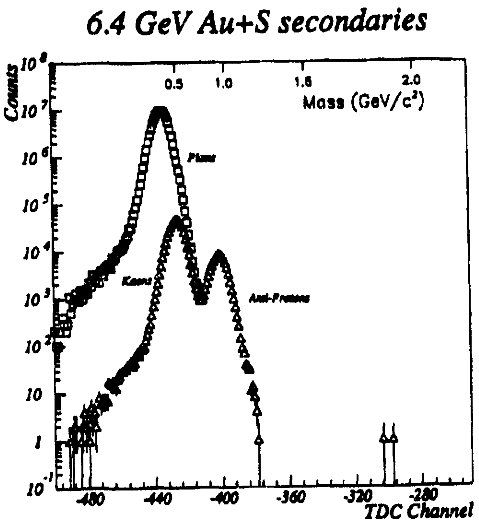

Fig. 2: TOF spectra for the negative secondaries at 6.4 GeV/c produced in 14.6 AGeV Si+Au collisions during the E858 run. Information from the Cerenkov counters was used to identify the pions

2. Data Analysis

A complete description of the data reduction can be found in ref. 1 and ref. 2. The total number of triggers recorded during the E858 run in the Spring of 1989 was 10^6 events, and taking into acount the scaledown pion signal, that represents some $5 \times 10^8 \pi^-$, a million K^-, some 3×10^5 antiprotons, and two antideuteron candidates.

A prominent result from E858 were the two antideuteron candidates at p=6.1 GeV/c ref. 2. This translates into a measured invariant cross section of 40 nb/GeV^2. In the same reference an attempt was made to estimate the production rate of antideuterons using a coalescence model from ref. 3. The measured antiproton cross sections were used in that calculation in order to be consistent, and the result at p=6.1 GeV/c turned out to be $4 \times 10^{-4} mb/GeV^2$, which is a factor of 10 larger than the measured value.

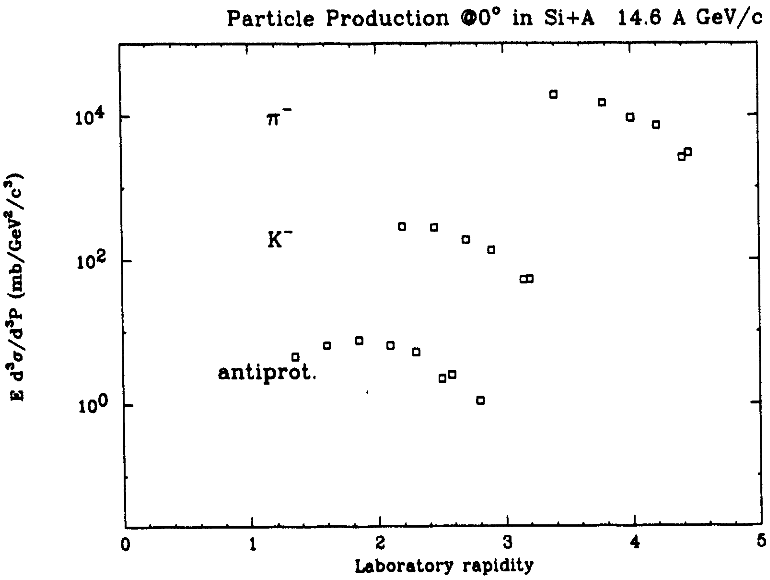

Fig. 3: Invariant cross sections for negative pions, kaons and antiprotons as functions of the laboratory rapidity. The negative secondaries were produced in 14.6 AGeV Si+Au collisions during the E858 run.

Figure 3 shows a sample of the invariant cross sections measured in E858, These cross sections are shown as functions of the laboratory rapidity, for π^-, K^- and antiprotons produced with the silicon beam incident on a gold target. As can be seen the acceptance of this experiment is quite forward for pions and kaons, but the measured antiprotons produced at midrapidity can be compared to the other heavy ion experiments at the AGS. Such comparison was made and is summarized in the following table where the quantity compared is the number of antiprotons per event at y=1.6 and $p_T = 0$:

Comparison to other AGS experiments			
E814	E859 Central	Estimated E859 Min. Bias.	E858
0.0035 ± 0.0006	0.0068 ± 0.002	0.0027 ± 0.0008	0.0027± 0.0003

The number of antiprotons per collision from E814 was obtained from ref. 4 after dividing their result by the total Si + Au cross section equal to σ = 3750 mb. The comparison to the E859 used data from ref. 6 and was made by extrapolating the invariant cross sections as functions of the transverse mass at y=1.6 to $p_T = 0$. These cross sections were extracted from a sample of central events. In order to make the comparison to minimum biased events from E858 the result of the extrapolation of E859 data was multiplied by 0.4 This conversion factor of 0.4 was extracted from ref. 5 as the ratio of antiproton yield in minimum biased events to the one from central events. More recent results from E859 indicate that this ratio can be equal to 0.5. And finally the E858 numbers were extracted from ref. 1 As can be seen in the table above, all three experiments agree within the error of their measurements.

The invariant cross sections as functions of the laboratory rapidity corresponding to each of the targets (Au, Al and Cu) are well described by gaussian shapes (ref. 7). For all three targets the distributions peak at the nucleon-nucleon center of mass rapidity, y_{NN}, and they all have standard deviations around $\sigma = 0.51 \pm 0.03$. These distributions are much wider than a simple proton-antiproton pair production from nucleon-nucleon interactions. A simple phase space calculation for this mechanism produces distributions with a width of some $\sigma \approx 0.35$. It was investigated if Fermi motion could account for the widening of the distribution, and found that, to do so, the Fermi momentum distribution would have to have a Fermi level P_F greater than 500 MeV/c (ref. 7).

The yield of antiprotons at $p_T = 0$, (calculated in this case as the area under the gaussian fit to the dN/dy distributions obtained with different targets) scales with the number of first collisions in an unbiased Si + A reaction.

3. The E878 Au + Au data

E878 has an integrated flux on target of some 5×10^{12} ions. The number of detected antiprotons was 1.2×10^5. Among the positive secondaries the sample of heavy particles is considerable; 2.2×10^5 deuterons, 6×10^3 tritons, 6×10^3 ^3He, and some 300 alpha particles.

Besides the data collected with the Silicon beam, E878 has a good data sample obtained with the gold beam at 11. GeV/c during the fall of 1993. In what follows, some preliminary results are presented for proton distributions collected during the portion of the run when the magnets of the beam line had their polarities set so as to transport positive secondaries produced at the target. The sample of positive particles ranges from pions, kaons and protons to heavier fragments like ^3He and alpha particles. A more detailed presentation of antiproton distributions is also included.

Figure 4 shows the invariant cross section of protons as a function of the laboratory rapidity. The sample of data used to extract this cross section does not have any condition on the centrality of the reaction and should be considered as minimum bias. In the same graph a cross section calculated from simulated protons using the ARC model (see ref. 8) is presented. The impact parameter of the simulated events ranges from zero to some 20 fm making it a minimum biased sample. As can be seen in the figure, the model agrees well with the measured data.

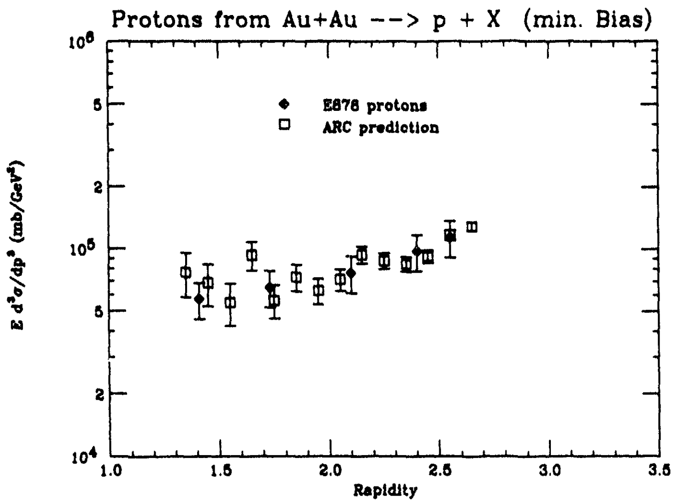

Fig. 4: Invariant cross section of protons produced by the Au beam at 11. GeV/c incident on a Au target. This cross section is shown as a function of the laboratory rapidity. No conditions on the centrality of the event were imposed on the data, these are minimum biased events

Figure 5 shows the minimum biased invariant cross section for antiprotons produced by the gold beam incident on a gold target as function of the laboratory rapidity. The statistical errors are smaller than the symbols used to display the results. The E878 collaboration is presently analysing these data and the present results have an assigned systematic error of some 15 to 20 % because there are still some uncertainties in the normalization of each measurement; the acceptance of beam line has been fixed as a constant for all the used tunes, the effects of multiple scattering, beam energy loss and absorption of secondaries in the target continue to be worked. A more thorough analysis will certainly smooth the results.

A fit was made to the measured points using a gaussian distribution and the result gave a peak position at 1.56 ± 0.1 units of rapidity or practically the NN center of mass rapidity. The width of this distribution obtained from the fit is equal to 0.5 ± 0.1 very similar to the width of the rapidity distributions of antiprotons in Si + A measured during the E858 runs. Eventhough these results are similar, it has to be pointed out that the available energy in the nucleon-nucleon center of mass is different for these systems. (E878 has reported the same measurement obtained during a short run in 1992 ref. 11. The wider rapidity distribution of antiprotons obtained from that run may be related to a higher momentum of the beam (11.7 GeV/c)) In the same figure the measured points were reflected around y_{NN} because the Au + Au is a symmetric system. The reflected points are displayed as open symbols, and it can be seen that wherever there is an overlap the discrepancy falls within the assigned systematic error.

An attempt was made to characterize the A dependence of the antiproton yields in the Au + A reactions. In order to reduce the effects of corrections not yet completed, ratios of yields are presented as functions of the laboratory rapidity. The cross sections

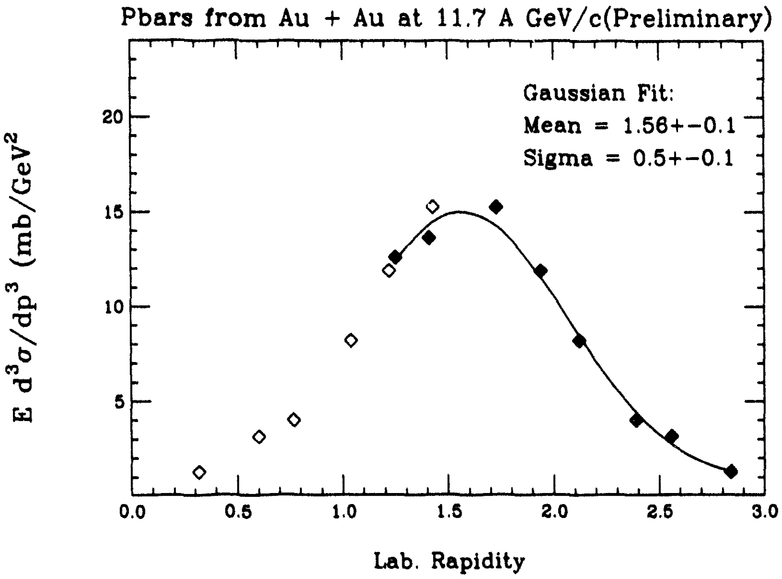

Fig. 5: Minimum biased invariant cross section for antiprotons produced in Au + Au reactions at 11. GeV/c.

used to calculate these ratios did not have a correction for beam energy loss in the targets. Figure 6 shows the following ratios: $\frac{Au}{Al}$ and $\frac{Au}{Cu}$. Within most of the range of measured rapidities, these two ratios are very similar and equal to roughly 1.2 indicating a weak dependence in the A of the target.

Among the new detectors added to E878, the so called Multiplicity Detector constitutes a major improvement because it characterizes the centrality of the event. This counter was designed to detect gamma rays produced by the decay of neutral pions. Each cell of this counter consists of 1/4 of an inch of Pb as converter, the same thickness of quartz radiator and finally high rate, square face photomultipliers (Hamamatsu 2248). The thickness of the converter was chosen so that in average each count correspond to one neutral pion. These detectors were arranged in two rings of 14 modules each making 40 and 60 degrees with the beam. The time information from each module is recorder in a multihit TDC system and the extracted information is the number of modules that have hits with time related to events recorded in the main spectrometer. This detector is also sensitive to charged particles with $\beta > 0.68$. Monte Carlo simulations indicate that this contribution accounts for 30% of the total multiplicity.

Two sets of events can be defined by requiring that the number of modules with hits in the Multiplicity Detector be greater than 20 (this set will be called the central events set) and less than 5 (these events are called peripheral)

It is estimated that the central events set represents a 10 % of the total cross section and the peripheral ones correspond to the 30 % most peripheral collisions.

Figure 7 shows the invariant yield of antiprotons from the Au + Au collisions

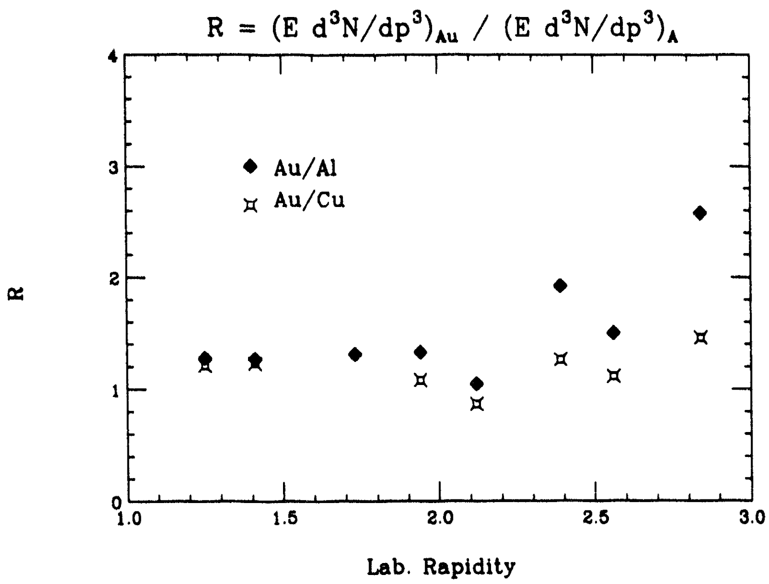

Fig. 6: Ratios of yields of antiproton per event as a function of the laboratory rapidity in Au + A collisions at 11. GeV/c. The statistical errors are smaller that the display symbols.

as functions of the laboratory rapidity. The upper panel shows this distribution for the set of central events, and the lower panel the one corresponding to the peripheral events. It should be made clear that the units of the y axis in these plots are arbitrary because the analysis of these data is still in its preliminary stages. The remarkable feature in these distributions is the fact that they have different widths. The peripheral events, with a $\sigma = 0.35$ seem to be indicating a simple proton-antiproton pair production mechanism, and the central events point to some additional process that would have widened the distribution. Some models of antiproton production that are in wide use in the field, like RQMD ref. 9 and ARC ref. 10, contend that baryon resonances as intermediate states or the screening of the antiprotons by copious number of pions that render annihilation less probable, are important in shaping the observed antiproton spectra.

4. Summary

AGS experiments E858 and E878 were designed as high rate measurements of antiproton production in heavy ion reactions, as well as a search for antideuterons and stable negatively charged exotic particles. The present work reports the following results obtained in the E858 experiment: The yield of antiprotons scales with the number of first collisions and the rapidity dsitributions of antiprotons with $p_T = 0$ for all targets used have the same gaussian shape peaking at y_{NN} and having a standard deviation of $\sigma = 0.51 \pm 0.03$. An agreement between E858 and the other two AGS experiments that measured antiprotons is reported.

Preliminary results from experiment E878 were presented. A very interesting

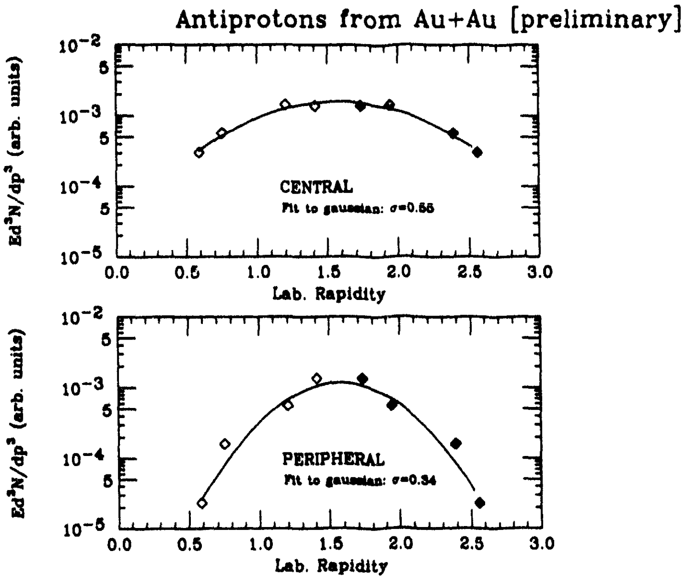

Fig. 7: Invariant yields of antiprotons per event as functions of rapidity. The upper panel correspond to the central events selected by a high number of E_T modules with hits. The lower panel is the same distribution but this time, it was extracted from the sample of peripheral events. The statistical are smaller than the symbols used to display tha data.

difference in the shape of the rapidity distribution of antiprotons appears between samples of events defined as central and peripheral. These samples of data are defined by the multiplicity of hits measured with the new Multiplicity Detector.

This work was supported in part by grants from the U.S. Department of Energy, and the joint U.S. - Japan agreement on high energy physics. We acknowledge the help of the AGS operators and staff for facilitating the data taking.

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