Antiproton yield in the collision of carbon nuclei with copper nuclei at energy of 3.65 GeV/nucleon

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The antiproton yield in the collision of relativistic nuclei has been measured for the first time. The ratio of the antiproton yield to the yield of negative pions with a momentum 0.8 GeV/c and production angle of 24° in the laboratory frame has been found to increase appreciably as a result of collision of carbon nuclei with copper nuclei in comparison with the production in the proton-nucleus collision at the same energy per beam nucleon.

The search for new phenomena resulting from the collision of relativistic nuclei has recently included attempts to measure the yield of rare particles. The yield of K^+ and K^- mesons has been measured previously.[1] The yield of antiprotons has heretofore been measured only for proton-nucleus interactions.[2,3] In a nucleus-nucleus collision at 2.1 GeV/nucleon only the upper limit of the antiproton production has been determined.[4] The cross section for the production of antiprotons at energies below the production threshold in nucleon-nucleon interaction can be assumed to be sensitive to the collective and multiquark effects produced in the collision of nuclei. Our purpose in this experiment, therefore, was to measure the antiproton yield under kinematic conditions close to those in the experiments on proton-nucleus collisions.

In this letter we present the results of measurement of the yield of 0.8-GeV/c antiprotons at an angle of 24° in the laboratory frame in the collision of 3.65-GeV/nucleon carbon nuclei with copper nuclei.

The measurements were carried out in the magnetic channel of the "KASPII" apparatus consisting of two dipole magnets and four quadrupole magnets situated at the extracted beam of the relativistic nuclei of the JINR high-energy laboratory.[5] The time-of-flight method with a 7-m baseline was used. To suppress pions, muons, and electrons, we analyzed ΔE in the three scintillation counters and we imposed selection criteria with use of two Čerenkov counters made of a material equivalent of Plexiglas, which operated under conditions of total internal reflection of light from fast particles. All counters were calibrated using protons and π^+ mesons. The suppression factor of pions in each ΔE channel was approximately 8, the total suppression of fast particles by Čerenkov counters was about 800, and the total recording efficiency of protons was 93%.

In the measurements we used in 20-g copper target and a primary beam with intensity 5×10^8 carbon nuclei per cycle. In estimating the cross section we introduced corrections for the meson decay, for the absorption and annihilation in the target and the detector and for the multiple scattering along the entire channel. The antiproton annihilation cross sections were taken from Ref. 6. The total correction for annihilation was 2.75.

To determine the probability for the passage of protons through each magnetic dipole of the channel, we disrupted the balance of parts I and II of the channel with respect to the sign of the forming particles. In adjusting the channel to antiprotons the first magnet was found to pass protons at 2×10^{-4} level and the second magnet transmitted protons at the 1.3×10^{-5} level of the number of protons when the channel had positive polarity. The proton background was therefore about 3×10^{9}, which is three orders of magnitude lower than the measured effect.

The time-of-flight particle spectra for the positive and negative channel polarities are shown in Fig. 1. The solid histogram in Fig. 1b corresponds to the rejection of pions and kaons by the Čerenkov counters and ΔE analysis in the two scintillators and the dashed histogram corresponds to the same situation in the case of an additional ΔE analysis in the third scintillator. Nine events corresponding to the antiproton transmission were thus recorded. The measured value of the ratio $N_{\bar{p}}/N_{\pi}$ is $(1.35\pm0.45)\times10^{-6}$. After introducing the corrections the ratio of the double differential cross sections is $(4\pm1.5)\times10^{-6}$. Using the pion production cross sections,[1] we find the invariant cross section for the antiproton production

$$\sigma_{inv} = 6.3 \pm 2\ \mu\text{b}\cdot\text{GeV}^{-2}\text{sr}^{-1}\cdot\text{s}^{3}.$$

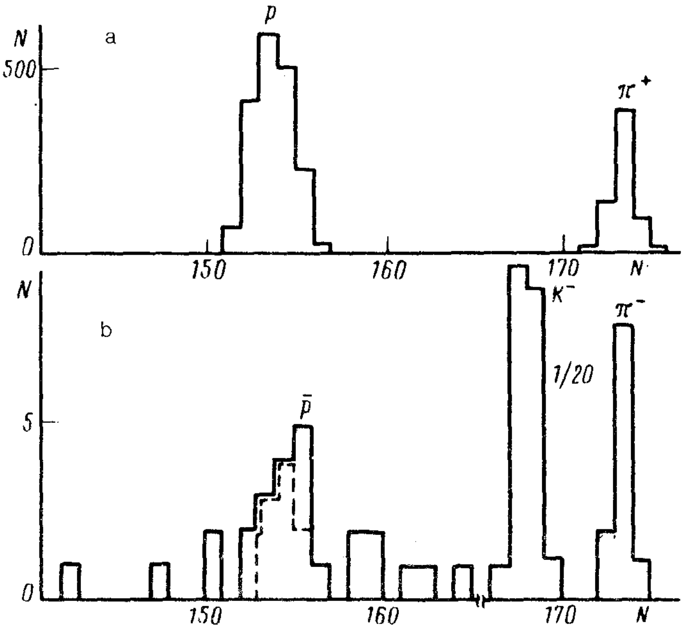

FIG. 1. Time-of-flight spectra of the particles. a—Positive pions, kaons, and protons without a rejection; b—negative pions, kaons, and antiprotons; solid histrogram—rejection by the Čerenkov counters and by two ΔE counters; dashed histrogram—additional rejection in the third ΔE counter.

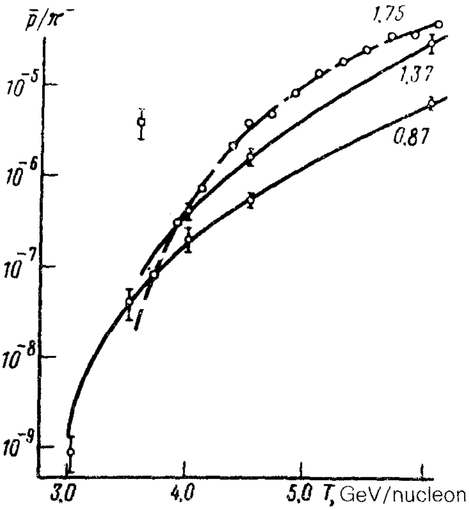

FIG. 2. Ratio of the antiproton and negative pion yield vs the kinetic energy per primary beam nucleon. The curves were plotted according to the data of Refs. 2 and 3, for a proton beam with various antiproton and pion momenta (in GeV/c) indicated at the curves. The symbol $\overline{\underline{\phi}}$ denotes the result of our experiment for a beam of carbon nuclei. A copper target was used.

Figure 2 compares the measured yield ratio $\bar{p}/\pi^-$ with the data on the production of antiprotons in the collision of protons with copper nuclei[2,3] for similar kinematic conditions, as a function of energy per nucleon of the primary beam. We see that the yield ratio $\bar{p}/\pi^-$ increases by approximately a factor of 60 in the case of nucleus-nucleus collisions. Our estimates showed that this increase cannot be explained in terms of the Fermi motion of nucleons in the incident carbon nucleus even if the production through the intermediate pion at the maximum Fermi momentum of 0.27 GeV/c is taken into account.

Qualitatively, this assertion follows also from the analysis of the antiproton production thresholds, with allowance for the Fermi motion of nucleons in nuclei. While the production threshold $\bar{p}$ in the collision of free protons is 5.63 GeV, incorporation of $P_F = 0.27$ GeV/c in the target nucleus reduces the threshold to only 4.2 GeV. As can be seen in Fig. 2, this value is inconsistent with experiment. The threshold for the production of antiprotons through the intermediate pion, $\pi N \rightarrow \bar{p}NN$, by a free nucleon is 3.7 GeV, but if P_F is taken into account, it drops to 2.9 GeV, in agreement with the data on the production of $\bar{p}$ by copper protons. Allowance for the Fermi motion in the incident nucleus, however, reduces the thresholds only slightly (to 2.7 GeV) for the given value of P_F.

In the quark-parton interaction picture[7] the observed effect may be due to the difference in the structure functions of the incident nucleon and the incident nucleus at large values of the scaling variable, which correspond to the subthreshold antiproton production. In the case of pions with the same momentum in the laboratory frame, the values of the scaling variable are small and the structure functions are nearly the same.

In the literature there are estimates of the ratio $\bar{p}/\pi^-$ in the thermodynamic treatment. In the fireball model[8] the value of 2×10^{-6} was obtained at a temperature of 100 MeV. The firestreak model[9] gives a value of $(1\text{–}2)\times10^{-5}$. The assumption of thermodynamic equilibrium upon which these models are based requires, however, further theoretical substantiation.

We have accordingly observed experimentally an appreciable increase in the ratio of the antiproton yield to the pion yield in the nucleus-nucleus collisions in comparison with the proton-nucleus collisions. The production of antiprotons in nucleus-nucleus collisions seems to be a process which makes it possible to study the collision-induced thermodyamic effects, the high-momentum component in the nuclei or the nuclear properties at short ranges, and the quark structure of nuclei.

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