# Weak absorption of antiprotons during their production by protons with 10 GeV/*c* in Be, Al, Cu, and Au nuclei

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We have measured the emission of antiprotons and $\pi^-$ mesons from nuclei of Be, Al, Cu, and Au irradiated with protons of momentum 10 GeV/*c*. Comparison with theoretical values indicates a weak absorption of antiprotons by the nuclei in which they were formed.

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1. Studies of the emission of antiprotons from nuclei have been stimulated mainly by the search for optimal conditions for antiproton beams in accelerators. The systematic study of this phenomenon has its own interest. For momenta $< 1$ GeV/*c*, the total cross section for interaction of an antiproton with a nucleon exceeds 100 mb, in which annihilation is the basic channel. We may, therefore, expect that slow antiprotons will be produced preferentially at the edge of the nucleus, and the ratio $R_A$ of antiproton and $\pi^-$ meson emission will diminish with increasing $A$. It was noted[1] that in studying the emission of strongly interacting particles from nuclei, we may hope to find the effect of the finite formation length[2–4] for these particles in a nuclear material.

We measured the ratio $R$ for antiprotons emitted from Be, Al, Cu and Au targets irradiated with protons having an energy of 10 GeV. The measurements were carried out on the ITEF proton synchrotron for nine momentum values in the 0.57–1.85 GeV/*c* range at an antiproton emission angle of 188 mrad. Under these same conditions we measured the value of $d^2\sigma/dp\,d\Omega$ for $\pi^-$ mesons. Knowing both values, we obtained the differential antiproton production cross section $d^2\sigma/dp\,d\Omega$.

The measurements were made by conventional techniques. The internal accelerator targets were thin foils of Be, Al, Cu and Au. The magnetic channel allowed the particle momentum to be determined to within 2–3%. Particle identification was based on measurements of their speed (using the DISK Cerenkov counter), flight time and ionization losses in scintillation counters.[5] A description of the technique will be given in a separate paper. We should note that measurements of antiproton emission were carried out in other papers (see, e.g., Refs. 6–8), but measurements for different nuclei at momenta $<4$ GeV/*c* were first carried out in this work.

The experimental results are given in Fig. 1. The indicated errors included statis-

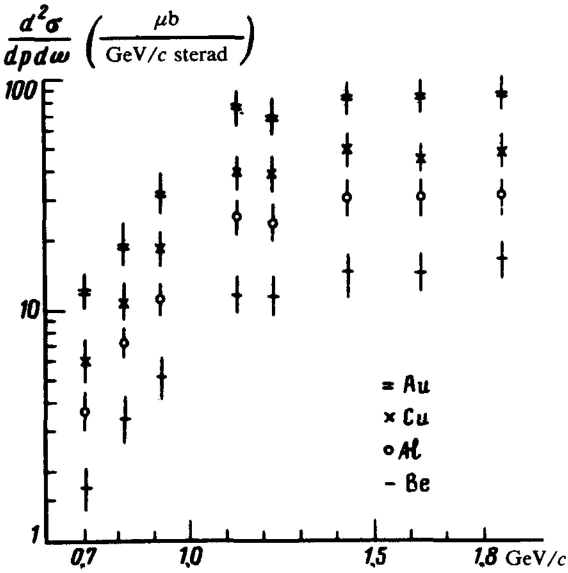

FIG. 1. Dependence of antiproton production cross section $d^2\sigma/dp\,d\Omega$ on momentum $p$.

tical and systematic errors, but they do not include the 15% error in monitoring the initial proton beam. Figure 2 shows the ratio $\kappa$ of the differential antiproton production cross sections for nuclei of Al, Cu and Au and the Be nucleus for a momentum of 0.71 GeV/$c$. Corresponding ratios for other momenta have similar values.

2. We assume that the initial proton travels a certain distance in the nucleus and it interacts at a point $x$, while the secondary particle ($\bar{p}$ or $\pi^-$ meson) is formed at a distance from the point $x$. If multi-step processes are neglected, then the ratio of inclusive emissions of secondary particles 2 at small angles to the nucleus and a nucleon is equal to

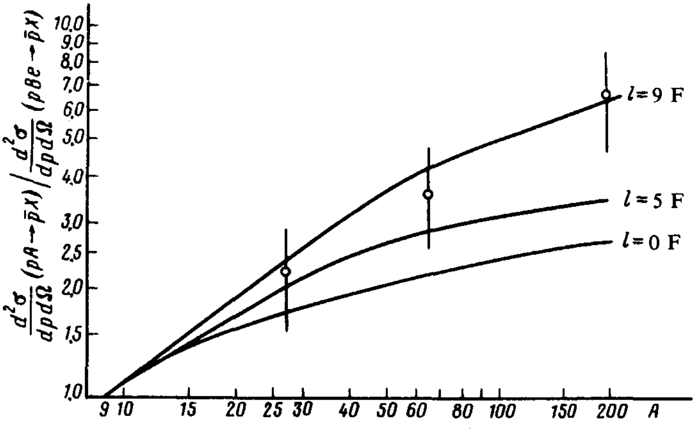

FIG. 2. Dependence of ratio of antiproton production cross section $\kappa = (d^2\sigma/dp\,d\Omega)_A/(d^2\sigma/dp\,d\Omega)_{Be}$ on the target nucleus atomic number $A$. Solid curves are calculated from Eq. (1).

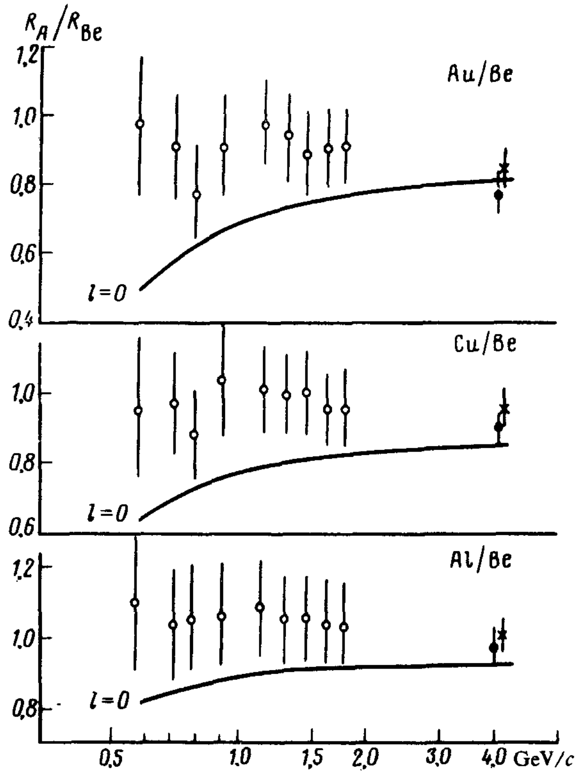

FIG. 3. Dependence of ratio $R_A/R_{Be}$ on antiproton momentum: ○—our result $P_0 = 10$ GeV/$c$, $\theta = 188$ mrad; ×—$P_0 = 24$ GeV/$c$, $\theta = 87$ mrad;[8] ●—$P_0 = 24$ GeV/$c$, $\theta = 17$ mrad.[8]

$$\frac{\dfrac{d^2\sigma}{dpd\Omega}(pA \to 2x)}{\dfrac{d^2\sigma}{dpd\Omega}(pN \to 2x)} = \int d^2b \int_{-\infty}^{\infty} \exp\left[-\sigma_1 \int_{-\infty}^{x} \rho(b,z)dz\right] \exp\left[-\sigma_2 \int_{x+l}^{\infty} \rho(b,z)dz\right] \rho(b,x)dx\,. \tag{1}$$

Here $\sigma_1$ and $\sigma_2$ are the total cross sections for the inelastic interactions of the initial proton and secondary particle, respectively, $\rho$ is the nuclear density normalized to $A$, and $b$ is the "impact parameter." We used the Saxon-Woods nuclear density distribution with the following values of the parameters $(R,a)$ for nuclei of Be, Al, Cu and Au, respectively (in Fermi): (2.0; 0.5), (2.8; 0.614), (4.28; 0.57) and (6.38; 0.527). The cross section $\sigma_1 = 30$ mb, and the cross section $\sigma_2$ for antiprotons of momentum 0.71 GeV/$c$ is equal to 90 mb.

Figure 2 shows results of calculations according to Eq. (1) for different formation lengths $l$. We see that for $l = 0$ there is poor agreement between calculation and experiment, at least for gold. The best agreement is reached for finite formation lengths $l \approx 5$–9 Fermi. This conclusion also follows for other values of antiproton momenta.

3. Let us consider the experimental data concerning the variation of the ratio of the emission of antiprotons and $\pi^-$ mesons with their momenta. The ratio $R_A/R_{\mathrm{Be}}$ is shown in Fig. 3 for nuclei of Al, Cu and Au (along with data for antiprotons and $\pi^-$ mesons with momentum 4 GeV/$c$, produced by 24-GeV protons[8]); it reveals that $R_A/R_{\mathrm{Be}}$ is independent of momentum. The secondary particles will always be effectively generated in a layer of thickness $\sim 1/\rho\sigma_2$, and the probability of their emission from the nucleus is $W \sim \sigma(pN \rightarrow 2x)/\sigma_2$. Thus,

$$\delta = \frac{(\bar{p}\text{ emission}/\pi^-\text{-emission) on nucleus}}{(\bar{p}\text{ emission}/\pi^-\text{-emission) on nucleon}} \sim \frac{\sigma_{\pi^- N}}{\sigma_{\bar{p}N}}$$

should decrease with decreasing secondary particle momentum, since the cross section $\sigma_{\bar{p}N}$ increases and the cross section $\sigma_{\pi^- N}$ decreases with decreasing momentum. The solid line in Fig. 3 shows the values for $R_A/R_{\mathrm{Be}}$ computed from Eq. (1) for $l = 0$. We note that the possible contribution of secondary processes for ions is larger than that for antiprotons, and taking this condition into account would further increase the observed discrepancy between theory and experiment for $l = 0$.

4. The experimental data therefore indicate that the secondary antiprotons with momentum $\gtrsim 0.6$ GeV/$c$ interact weakly with nuclear matter "at the moment of creation." This result is unexpected. It may be understood, provided we assume that antiprotons are formed from point antiquark-partons, while time is required[1,4] in order for the latter to be fused, surrounded with their own "sea," and to have begun to interact with the nucleus.

A fundamentally different explanation for the observed effects might be contained in the fact that the bulk of created antiprotons is formed during the decay of heavy meson resonances 20 meV in width,[9] whose cross section in the nucleus is small ($\sim 15$ mb). However, this hypothesis does not seem very probable to us.

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