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Low Energy Antiproton Interaction Studies at Brookhaven

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Abstract

Results on antiproton quasielastic scattering on Al, Cu and Pb for two incident momenta 514 and 633 MeV/c are presented. Differential cross sections for these reactions were combined with other published data and analyzed with a nonrelativistic optical model. Absorption cross section results from our experiment are in good agreement with predictions from our optical model fits. Preliminary results are presented from $\bar{p}$ elastic scattering on hydrogen for the forward angular region in the momentum range from 360 to 652 MeV/c. We obtain small values of the ratio of the real to imaginary part of the forward scattering amplitude in this momentum interval.

1. Introduction

We are presenting results from an antiproton experiment at the Brookhaven National Laboratory AGS in the low energy separated beam line. The main purpose of the experiment was to study $\bar{p}p$ interaction in the region of the putative S meson. During a period of several months, various data runs with a hydrogen target were carried out with incident momentum of 360 to 652 MeV/c. The momentum settings were chosen to give overlapping bins from the energy loss in the hydrogen target.

The purpose of the experiment was to study the momentum dependences of the following topics:

- a) total cross section
- b) elastic differential cross section
- c) annihilation cross section
- d) the ratio of the real to imaginary part of the forward scattering amplitude.

In addition, we made a short excursion into nuclear physics and ran 20 hours with antiprotons on Al, Cu and Pb targets at 514 and 633 MeV/c. Data were taken for

- a) quasielastic differential cross section
- b) absorption cross section.

Our results on the nuclear quasielastic scattering, preliminary results on σ_{abs} on nuclei and preliminary results on the ratio of the real to imaginary parts of the forward scattering amplitude are presented.

2. Experimental Layout

The experimental setup is shown in Fig. 1. The partially separated beam was tagged electronically with S1, S2 and S3 used as both time of flight and dE/dx counters. In addition, a lucite Cerenkov counter $\bar{C}$ provided a pion veto. The resulting antiproton beam identification was 99% pure and was used as the experimental trigger. The incoming beam was measured in four triplet drift chambers (DC1-12) each consisting of an x, u and v plane. The outgoing scattered particle was measured in 18 doublet drift chambers (DC13-30), six each for x, u and v.

Fig. 1. Experimental layout.

The scattered particle also passed through one of two hodoscopes, H1 and H2 in Fig. 1. Each of these hodoscopes consisted of two orthogonal sets of elements, with a square hole in the center of H1, to allow more precise measurement of the forward going particles. The photomultipliers on all of the elements had their time of flight and pulse heights recorded. A minimum of three photomultipliers was required to distinguish between outgoing pions from annihilations and elastically scattered antiprotons.

Both the time of flight and the pulse height were used to identify the antiprotons with a resulting tagging efficiency of about 95% per plane. Time of flight distributions are shown in Figure 2. Further details of both the time of flight and pulse height criteria are given in Ashford et al. (1984).

3. Quasielastic $\bar{p}$ Nucleus Scattering

A summary of the various nuclear physics runs is shown in Table I.

Fig. 2. Time of flight distribution for forward secondary tracks in the downstream hodoscope.

Table I

TRIGGER TOTALS AND TARGET THICKNESSES

<u>Target</u>	<u>Thickness (cm)</u>	<u>Total Triggers</u>	
		<u>514 MeV/c</u>	<u>633 MeV/c</u>
Aluminum	0.299	144,680	145,932
	0.686	72,361	73,531
Copper	0.099	145,445	146,511
	0.284	72,737	72,932
Lead	0.081	145,656	146,557
	0.244	71,385	73,265

To help understand systematics we made measurements with two target thicknesses for each nucleus. The differential cross sections determined from the two thicknesses were in agreement at angles greater than three times the mean multiple scattering angle expected for the thick target. We therefore merged the thick and thin target data in that region and used the thin target data alone in the forward region. Typical differential cross section results are shown in Fig. 3; additional distributions are shown in Ashford et al. (1984).

Fig. 3. The quasi-elastic angular distribution for copper at 633 MeV/c.

We analyze the elastic cross sections in terms of a nonrelativistic optical potential model. We take the potential to be of the form

$$V_{\text{opt}}(r) = -V_0 f_R(r) - iW_0 f_I(r)$$

where f_R and f_I have the Woods-Saxon shape

$$f_{R,I}(r) = \left[1 + \exp \left(\frac{r - R_{R,I}}{a_{R,I}} \right) \right]^{-1}$$

We therefore have six parameters to fit, the two strengths V_0 and W_0 , the two radii R_R and R_I , and the two diffuseness parameters a_R and a_I . We have included in our analysis recent data for ^{12}C , ^{27}Al and ^{63}Cu at energies about 110, 150 and 190 MeV from Nakamura et al. (1984) and for ^{12}C at 46.8 MeV from Garreta et al. (1984). In principle the sizes of the nuclei can be determined from the diffraction minima in the pure elastic differential cross section. It is important to note, however, that the data of Ashford et al. (1984) and Nakamura et al.

(1984) are quasielastic rather than pure elastic scattering. Since the outgoing tracks in these experiments are not momentum analyzed the data include inelastic scattering to low lying nuclear states.

It is known, in the case of ^{12}C , that the inelastic processes can fill in the diffraction minimum (Garreta et al., 1984). Therefore, in order to study the A dependence of the strengths of the potential we fix the well shape parameters (Auerbach, et al., 1981).

$$R_R = 1.3 A^{1/3} \text{ fm}; \quad R_I = 1.1 A^{1/3} \text{ fm};$$

and

$$a_R = a_I = 0.52 \text{ fm}.$$

We have used the program A-THREE (Auerbach, 1978) to fit the data to the above potentials. Since two of the experiments include quasielastic data, we restrict the fitted region to the forward region where the pure elastic is expected to be dominant. That limit varied between 10 to 14 degrees depending on the nucleus. In our preliminary fitting we saw no energy dependence of the strength parameters for any of the nuclei in the energy region measured. Therefore we have merged the different energies and fit each nucleus as one set of data. The resulting strength parameters, shown below, are all strongly absorptive with an attractive real well.

Table II

Optical Model Well Depth Parameters for C, Al, Cu and Pb.

	V_o (MeV)	W_o (MeV)
^{12}C	25	91
^{27}Al	24	96
^{63}Cu	27	121
^{208}Pb	25	173

We have made an estimate of the absorption cross section from our experimental data via the transmission technique and compared the results with the predictions based on these optical parameters. Using the downstream drift chambers to define a series of transmission counters subtending decreasing solid angles, we can extrapolate to zero degrees, correcting for the elastic scattering, obtain the absorption cross section. In Fig. 4 we show one of the extrapolation plots. The errors in our absorption cross sections are dominated by uncertainties in the various efficiencies and not by the extrapolation procedure. Overall, our experimental results agree with the predictions of the optical model fits to the elastic scattering data and are shown in Table III.

Fig. 4. Extrapolation plot for absorption cross section for Cu at 514 MeV/c. Total and elastic cross sections are represented by pluses and the inelastic cross section, which is the difference, is represented by crosses.

Table III

Absorption Cross Section (Barns)

<u>Element</u>	<u>P(MeV/c)</u>	<u>Global Fit</u>	<u>Experimental Results</u>
Al	514	0.73	$0.77 \pm .06$
Al	633	0.68	$0.62 \pm .05$
Cu	514	1.21	$1.42 \pm .10$
Cu	633	1.14	$1.10 \pm .10$
Pb	514	2.51	$2.1 \pm .70$
Pb	633	2.36	$1.4 \pm .25$

4. Ratio of Real to Imaginary Part of the $\bar{p}p$ Forward Scattering Amplitude

We present some preliminary results on measurements of the forward elastic antiproton scattering in hydrogen. The separation of outgoing antiprotons from annihilation pions was carried out in the same manner as was described for the nuclear data. We estimated less than 1% contamination in the forward region. Since we are studying the shape of the differential cross section, it is important for the target empty correction to take into account the different multiple scattering for the two different samples.

We have differential cross section data at 11 momenta between 360 and 652 MeV/c; a typical angular distribution is shown in Fig. 5.

Fig. 5. Forward elastic differential cross section for pp scattering. The curves represent the fits described in the text.

To extract the ratio of the real to imaginary part of the forward elastic scattering amplitude we use the standard formalism. We divide the effective scattering into three pieces, a Coulomb term, a nuclear term and an interference term. Explicitly, we have

$$\frac{d\sigma^C}{dt} = 4\pi \left(\frac{\alpha \hbar c}{\beta t} \right)^2 F(t)^2$$

$$\frac{d\sigma^I}{dt} = \frac{\alpha \sigma_{TOT}}{\beta t} \cdot F(t) \exp \left(-\frac{1}{2} bt \right) (\rho \cos \delta - \sin \delta)$$

and

$$\frac{d\sigma^N}{dt} = \frac{1}{\pi} \left(\frac{\sigma_{TOT}}{4 \hbar c} \right)^2 (1 + \rho^2) \exp (-bt)$$

where $-t$ is the four-momentum transfer, α is the fine structure constant, β is the velocity of the incident p in the laboratory, b is the slope parameter of the pp diffraction peak, $F(t)$ is the Coulomb form factor of the proton, $F(t) = (1 + t/0.71)^{-4}$, δ is the phase of the Coulomb amplitude and ρ is the ratio of the real to imaginary parts of the forward scattering amplitude. We have neglected, in this preliminary analysis, as is usually done, any spin dependent effects in the forward direction.

Rather than attempt to fit the three parameters σ_{TOT} , b and ρ , we use the parameterization for σ_{TOT} : $\sigma_{TOT} = A + B/p$ with $A = 61.2$ and $B = 53.4$ (Nakamura, et al., 1984) and only fit for ρ and b . Our fits include the effects of the angular resolution and multiple scattering. It should be noted that a change in σ_T of $\pm 2.0\%$ produces a uniform change in the fitted values of ρ and b of roughly ∓ 0.04 and $\pm 1.5 (\text{GeV}/c)^{-2}$, respectively. Scaling our data by $\pm 2.0\%$ changes ρ and b by roughly $\pm .03$ and $\mp 1.0 (\text{GeV}/c)^{-2}$.

In Fig. 6 we show our preliminary results from the fits for ρ throughout the region from 360 MeV/c to 652 MeV/c. In Fig. 7 we show the corresponding b values from these fits. Our results are consistent with small

values of ρ , between 0 to 0.2 and, with no significant structure throughout this momentum region. These results tend to be flatter than those reported by earlier experiments (Iwaski, et. al., 1981) which gave rise to speculation of high-mass pole terms in order to get agreement with dispersion relation calculations.

Fig. 6. The ratio of the real to imaginary parts of the forward scattering amplitude for pp elastic scattering.

Fig. 7. The slope of the forward pp elastic nuclear cross section.

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