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POLARIZATION AT SMALL ANGLES IN ELASTIC $\bar{p}p$ AND $\bar{p}C$ SCATTERING AT 550 MeV/c

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ABSTRACT

Results are reported on the azimuthal asymmetry of antiprotons of ~ 550 MeV/c, doubly scattered at small angles from protons and carbon. The measured asymmetries are small, statistically compatible with zero, and give polarization parameters smaller than those foreseen by some NN potential models.

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For our investigation of proton-antiproton elastic scattering at LEAR (experiment PS172) it is important to know the analysing power of carbon for antiprotons. A large analysing power of carbon for $\bar{p}$'s would be extremely helpful in the study of $\bar{p}$ interactions, opening up the possibility of producing a polarized $\bar{p}$ beam by scattering, and also of analysing the $\bar{p}$ polarization in a carbon polarimeter [1]. At energies of about 150 MeV, pp and pC scattering are characterized by large values of the polarization (about 0.2 and 0.4, respectively, at 10° lab. angle), but the corresponding information for antiprotons is extremely scanty with proton targets [2], and is non-existent for nuclei. Calculations [3] indicated small values for the $\bar{p}$ C analysing power, mainly because of the strong absorption due to the annihilation channel, but lack of precise $\bar{p}$ p (and $\bar{p}$ n) data as input to the nuclear model calculation prevented precise estimates.

In this spirit we have carried out a double scattering measurement on elastic $\bar{p}$ p and $\bar{p}$ C scattering at small angles using the available 600 MeV/c beam, the objective being to detect polarization effects.

Figure 1a shows the layout of the beam, whose main characteristics are as follows:

- i) The extracted LEAR beam can be swept in the horizontal plane with the first two bending magnets so as to hit the carbon scatterer (located at a focal point F_1) at an angle varying from -9° to +9°;
- ii) the symmetric layout achromatically refocuses the beam produced in the carbon scatterer on to the liquid-hydrogen target at F_2 ;

- iii) the large angular acceptance, ± 18 mrad horizontally and ± 36 mrad vertically, gives a reasonable intensity in the scattered beam (0.54×10^{-3} per incident $\bar{p}$ at $\pm 8^\circ$);
- iv) there is good momentum resolution, $\Delta p/p = \pm 1\%$, rejecting $\bar{p}$'s inelastically or quasi-elastically scattered from the carbon target.

The momentum of the LEAR beam was 610.8 MeV/c, and 5.22 g.cm^{-2} of carbon was used as the scatterer. The measurement was performed only at one production angle, $\pm 8^\circ$, owing to lack of beam time. The beam position at F_1 was monitored continuously, using a multiwire proportional chamber (MWPC) with horizontal and vertical sense wires (1 mm spacing), and also a scintillation counter, B_0 .

The beam signal was obtained from three thin (0.5 mm) scintillators B_0 , B_1 , and B_2 , the last one defining a beam spot of 1 cm maximum diameter. The narrow beam coincidence completely rejected the contamination ($\lesssim 10^{-3}$) of pions from the carbon scatterer (the time-of-flight difference was 63 ns). Incident $\bar{p}$'s were measured in two sets of horizontal and vertical MWPCs, PC1 and PC2, with 1 mm wire spacing.

The second scatter was in either a liquid-hydrogen target or a carbon polarimeter (fig. 1b). The hydrogen target was 4 cm diameter and 95 mm long [4]. The carbon polarimeter consisted of two telescopes of three sets of horizontal and vertical MWPCs, with 2 mm wire spacing, separated by a 5.25 g.cm^{-2} carbon slab. A box of counters S_{1-5} surrounded the hydrogen target, except for i) a hole at the top, where the target was suspended from a reservoir, ii) a 6 cm diameter hole at the beam entrance, and iii) a 10 cm diameter hole at the beam exit.

The time information of the counters S was recorded on tape, so that in the analysis the annihilation events in the target could be identified. The pulse amplitude and the time information of the scintillation counter P (4 mm thick, with a 9 cm $\varnothing$ hole), was also stored on tape for later identification of $\bar{p}$'s scattered from the hydrogen target.

Three asymmetries were measured: $A_C(8^\circ) \cdot A_H(\theta_H)$ and $A_C(8^\circ) \cdot A'_C(\theta_C)$ in a 'scattered beam' condition, and $A_H(\theta_H) \cdot A'_C(\theta_C)$ in a 'direct beam' condition. The first two were recorded simultaneously, using $\bar{p}$'s scattered at 8° from the first carbon target, and alternating the sign of the beam production angle at each one-hour spill. The momentum resolution of the beam line ensured that the first scattering on carbon was elastic. A total of 4.5×10^6 events were written on tape, 0.6×10^6 of which were with no hydrogen in the target (ET data) so as to measure the background from the target flask.

The third asymmetry was measured sending the direct $\bar{p}$ beam into the liquid-hydrogen target, looking for $\bar{p}$'s scattered both from hydrogen and from the carbon slab in the polarimeter. Counter P in the trigger selected events with $\theta_H \geq 4^\circ$; the carbon slab had a 5 cm $\varnothing$ hole around the beam to minimize background. In order to have, in the hydrogen target, $\bar{p}$'s of the same momentum as in the first two measurements, the first carbon scatterer was left in the beam to act as a degrader, with a factor of 2 loss in intensity. The $\bar{p}$ momentum in the first scatterer ranged from 608 to 560 MeV/c, in the liquid-hydrogen target from 556 to 542 MeV/c, and in the carbon slab of the polarimeter from 540 to 480 MeV/c. There were 6.3×10^8 useful incident $\bar{p}$'s which resulted in 1.5×10^6 events on tape, 10^5 of which were in ET conditions. The analysing power of the polarimeter, A'_C , may be

different from A_C because of the presence of inelastic and quasi-elastic events. Inelastic $\bar{p}$ events give a negligible contribution [5] at our angles.

Most annihilation events in the second carbon scatterer were rejected in the analysis, by the requirement of one and only one track in each relevant telescope. The contamination of annihilation events giving one prong in the polarimeter could be estimated, since in many cases a second prong was detected by counter P in the $A_C A'_C$ data. These events were found to have zero asymmetry as expected, and thus can only dilute the asymmetry. The remaining contamination could be calculated from geometry and known $\bar{p}d$ multiplicities (table 1), and the measured values of A'_C corrected accordingly.

Annihilations in hydrogen were flagged by prompt signals in the S counters. Using the information from the P counter, we found that the residual contamination from annihilation in the elastic $\bar{p}$ sample was less than 1.4%.

The analysis required a single track in each relevant telescope and tracks intersecting within errors in scatterers. Angular distributions take the form $(1 + A_1 A_2 \cos \varphi)$, where φ is the azimuthal angle between the two scattering planes. Conservative cuts were made, requiring full cylindrical symmetry for every event in detector acceptance. The ET events were checked to have zero asymmetry. Moreover, scatters from the empty target were mostly from carbon and showed a characteristic peak at small angles, and our data on $A_C A'_C$ are statistically compatible with zero. Therefore, to obtain A_H we have divided the measured asymmetry by the factor $(F - E)/F$, the percentage of hydrogen events in the FT sample, as given in table 2.

The azimuthal asymmetries measured in the various conditions are reported in fig. 2. Data points are given only at angles where the

annihilation correction to A'_C (see table 1) was smaller than $\sim 15\%$. The lines show predictions based on three different models used to generate the $\bar{p}p$ and $\bar{p}n$ amplitudes, namely: the optical model developed by Daum et al. [6] from an earlier model of Frahn and Venter [7] to reproduce their $\bar{p}p$ data [6, 8]; the model of Dover and Richard [9]; and the 'Paris' potential model [10]. The $\bar{p}C$ amplitudes have been evaluated using the model of Osland and Glauber [11] as in Ref. [3]. In this model the polarization A_C depends mainly on the isospin-averaged forward slope of the elementary spin-orbit scattering amplitude (the contribution of the amplitudes involving the spin degrees of freedom of the target nucleons is negligible for a heavy zero-spin nucleus such as carbon).

Measured values are clearly smaller than predicted. Since the overall set of data is compatible with the hypothesis $A_C = A'_C = 0$ ($\chi^2 = 19.8$ for 20 degrees of freedom), the disagreement could be mainly in A_C . Indeed a different nuclear model calculation indicates smaller values for A_C [12]. On the other hand, if the Glauber theory is reliable, it is also possible that both A_H and A_C are small, or that there is a cancellation between $\bar{p}p$ and $\bar{p}n$ amplitudes.

The data presented in fig. 2 can be described by assuming a linear dependence of the polarization parameters on the angles -- quite a reasonable assumption at these small angles -- namely $A_H = \alpha_H \theta_H$ and $A_C = \alpha_C \theta_C$. From the three asymmetries we find

$$\alpha_C \alpha_H = (-58 \pm 120) \times 10^{-6} \quad \text{from 27,170 useful events,}$$

$$\alpha_C \alpha'_C = (39 \pm 41) \times 10^{-6} \quad \text{from 180,542 useful events,}$$

and

$$\alpha_H \alpha'_C = (-16 \pm 52) \times 10^{-6} \quad \text{from 97,246 useful events,}$$

when θ is given in degrees. If we take $A_C = A'_C$, all the data can also be used to evaluate a single χ^2 , and to estimate confidence intervals for α_C and α_H , as shown in fig. 3. The slope predictions for the three models are also indicated, and the corresponding confidence levels are smaller than 10^{-7} . As is apparent from the figure, α_H and α_C are strongly correlated, and as soon as α_C is diminished, the bounds on α_H become looser and looser. We consider it quite important to measure A_C at a higher $\bar{p}$ beam momentum, where higher transverse momenta at the first scattering are accessible, thus increasing the sensitivity of the measurement.

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Table 1

The fraction of annihilation in the second carbon scatterer

$\theta_{\text{carbon}} (^{\circ})$	8 ± 1.5	11 ± 1.5	14 ± 1.5	17 ± 1.5
Scattered beam	0.024	0.041	0.078	0.16
Direct beam	0.056	0.096	0.17	0.32

Table 2

The fraction (F-E)/F of hydrogen events in full target data

$\theta_{\text{hydrogen}} (^{\circ})$	4.5 ± 1.5	7.5 ± 1.5	10.5 ± 1.5	13.5 ± 1.5
(F-E)/F	0.73	0.79	0.89	0.94

Figure captions

- Fig. 1 : Schematic layout of the beam (a) and of the apparatus (b); D_{1-4} are bending magnets; Q_{1-7} quadrupoles; C_H and C_V horizontal and vertical collimators; B_{0-2} , S_{1-5} , and P scintillators; PC_{0-8} multiwire proportional chambers.
- Fig. 2 : Results for the three asymmetry measurements $A_C(8^\circ) \cdot A_H(\theta_H)$, $A_C(8^\circ) \cdot A'_C(\theta_H)$, and $A_H(\theta_H) \cdot A'_C(\theta_C)$. Also shown are predictions from the optical model of Frahn and Venter [6, 7] (full lines), from the model of Dover and Richard [9] (dashed lines), and from the 'Paris' potential model [10] (dash-dotted lines). Following the notation of ref. [6], in the optical model we have assumed $R = 1.365$ fm, $d = 0.38$ fm, $\mu^+ = 0.4$, $\mu^- = -0.3$, $\epsilon = 0.1$. The Glauber theory [11] has been used to evaluate the $\bar{p}C$ amplitudes, as in ref. [3].
- Fig. 3 : Constant χ^2 level curves for all the asymmetry data of fig. 2. The minimum value of χ^2 is $\chi_m^2 = 18.7$, for 18 degrees of freedom. Also shown are the predictions for (α_C, α_H) using the three models of fig. 2. ($\square$ optical model [6, 7], Δ Dover and Richard [9], $\circ$ 'Paris' [10]).

Fig. 1

Fig. 2

Fig. 3