Measurement of the $\bar{p}p$ Charge-Exchange Cross Section from 0.119 to 1.046 GeV/c

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Charge-exchange cross section for antiprotons on protons has been measured in closely spaced momentum intervals from 0.119 to 1.046 GeV/c. The regions of the reported resonances at 1936 and 2020 MeV were scanned in 10-MeV/c steps with a typical statistical error of ≈ 1% and an rms mass resolution of ± 1.5 MeV. No enhancements were observed.

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In an earlier study[1] of the charge-exchange reaction $\bar{p}p \to \bar{n}n$ we observed no structure in the vicinity of the $S(1936)$ meson, and no enhancement has been found in other formation investigations[2,3] of the reactions $\bar{p}p \to$ neutrals. In this Letter we describe new measurements of the charge-exchange reaction between 0.119 and 1.046 GeV/c with much improved energy resolution and smaller systematic uncertainty than that of Ref. 1.

The experiment was performed in the momentum-recombined branch of the low-energy separated beam LESB I at the Brookhaven National Laboratory alternating-gradient synchrotron (AGS). The apparatus is shown in Fig. 1. The incident beam was defined by scintillation counters M and S_2 and a lead-brick wall upstream of M with a rectangular hole for the beam. Antiprotons were selected from background pions and muons in the beam by means of time of flight between a hodoscope at the mass slit and the M counter, Čerenkov counter (Č) rejection of pions and muons, and pulse height in the M and S_2 counters. Contamination of the final $\bar{p}$ flux by unwanted low-mass particles was continuously monitored by a time-of-flight counter downstream of the experiment and was less than 0.2% in the vicinity of the S meson.

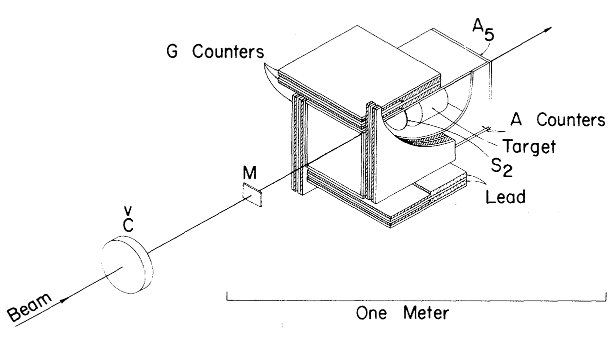

FIG. 1. Isometric projection of the apparatus.

The apparatus used in this experiment was optimized for the $\bar{p}p$ charge-exchange reaction and represented a considerable improvement over the experimental arrangement used in Ref. 1. The hydrogen target was 8 cm long in this experiment (versus 40 cm in Ref. 1), contributing about half of the overall rms center-of-mass energy resolution of ± 1.5 MeV in the vicinity of the $S(1936)$ meson[2-6] and the resonance at 2020 MeV.[7] The target was surrounded by scintillation counters (A_1–A_5) to veto $\bar{p}p$ reactions producing charged final-state particles. These in turn were surrounded by shower counters (G_1–G_4) placed upstream of the target center where they were kinematically inaccessible to n's and $\bar{n}$'s produced in charge exchange, but vetoed γ's in the backward hemisphere produced in neutral annihilations. Each shower counter consisted of two layers of lead and scintillator with each layer of lead stepped in thickness to provide a roughly constant 2 radiation lengths of γ converter over a wide range of incident angles.[8]

The product of all correction factors applied to the raw data varied smoothly in value from 1.26 at 0.121 GeV/c to 1.04 at 1.046 GeV/c and was 1.08 and 1.05 in the vicinity of the S meson and the 2020 resonance, respectively. The overall factor was composed of the following parts where the ranges are given for increasing incident momentum.

(1) n and $\bar{n}$ nuclear interactions in the hydrogen target, vacuum jacket, and A counters. This was the largest correction to the data and varied smoothly from 1.22 to 1.06, a factor of 4 smaller correction than in Ref. 1. It was calculated by means of a Monte Carlo program using the absorption cross-section parametrizations described in Ref. 1.

(2) $\bar{p}$ beam absorption in liquid hydrogen. This correction was applied to the full-target antiproton flux and multiplied the full-target cross section by a factor which ranged from 1.07 to 1.02, one-fifth the correction required in Ref. 1.

(3) Neutral annihilations which were not vetoed. This correction, which was calculated using a Monte Carlo program with parametrizations for γ detection in the shower counters described in Ref. 1, was made in two parts: $\bar{p}p \to 2\pi^0$ events were generated with the angular distribution given by Dris[9] for all incident $\bar{p}$ momenta and $\bar{p}p \to 3\pi^0$ events were generated according to phase space throughout the momentum range of the experiment. To a good approximation, the distributions of photons detected by the apparatus for events producing 6 γ's could be calculated with the assumption of a constant single-photon detection efficiency. With use of a statistical model of $\bar{p}p$ multipion annihilation branching fractions provided by Vandermeulen[10] and the assumption that a constant photon detection efficiency could be used for annihilations producing more than 6 γ's, an overall inefficiency for vetoing neutral annihilation events was found to be approximately constant and the correction factor used was a constant 0.981.

Two other reactions which could contaminate the sample are $\bar{p}p \to K_L{}^0 K_L{}^0$ and $\bar{p}p \to \bar{n}n\pi^0$. Cross sections for the former reaction have been measured over a substantial part of our momentum range and are small.[11] The magnitude of the increase in measured cross section due to the latter reaction was estimated from the $\bar{p}p \to \bar{p}p\pi^0$ data of Burns *et al.*[12] and isospin considerations[13] to be linearly rising above threshold to about 30 μb at 1.046 GeV/c. The correction factor for both these reactions which was applied to the data varied between 0.999 and 0.995.

(4) The curved ends of the hydrogen target provided different path lengths for beam particles at different distances from the beam axis. This constant normalization factor of 0.985 was calculated from an x-ray picture of the target and beam-profile information obtained from wire chambers in a previous experiment.[14]

The beam momentum was established by time of flight at ten momenta between 0.440 and 1.008 GeV/c and was everywhere within 0.8% and typically within 0.5% of the momenta calculated from magnet settings and dE/dx values for materials in the beam line. The momentum bite was measured by a range curve to have an rms spread of ± 0.7%, in agreement with Monte Carlo calculations of the beam acceptance.

No systematic shifts were observed outside of statistics in repeating data points at different times. Empty-target rates were typically 25% of full-target rates throughout the experiment.

The corrected cross sections are tabulated in Table I and shown in Fig. 2 along with the data of Ref. 1 with statistical errors. The data of this experiment are well within the overall 5% systematic errors quoted with the earlier data and probably differ in the middle of the momentum range because of the correction-factor dependence on the uncertain $\bar{p}p \to \bar{n}n$ angular distributions in the earlier experiment. Reasonable agreement also exists with the data of Cutts *et al.*[15] The curve is a parametrized least-squares fit to the data between 0.249 to 0.903 GeV/c with an explic-

TABLE I. Cross-sections versus $\bar{p}$ lab momentum.

$\bar{p}$ Momentum (MeV/c) Mean	RMS Resolution	Charge Exchange Cross Section(mb)	$\bar{p}$ Momentum (MeV/c) Mean	RMS Resolution	Charge Exchange Cross Section(mb)
119		8.32 ± .65	651	6	11.02 ± .12
131		16.57 ± .88	662	6	10.71 ± .12
208	44	17.37 ±1.03	673	6	10.63 ± .13
249	29	16.91 ± .68	684	6	10.25 ± .12
277	23	15.13 ± .87	694	6	10.39 ± .12
308	18	15.56 ± .48	705	6	10.10 ± .07
355	12	15.09 ± .22	715	6	10.19 ± .11
385	10	14.77 ± .19	726	6	9.93 ± .11
414	9	14.65 ± .20	737	6	9.78 ± .11
442	8	14.17 ± .15	747	6	9.66 ± .21
455	7	14.11 ± .25	758	6	9.48 ± .10
468	7	13.56 ± .14	768	6	9.45 ± .09
479	7	13.51 ± .17	779	6	9.26 ± .10
492	7	13.52 ± .12	789	6	9.11 ± .09
505	6	13.52 ± .13	799	6	8.98 ± .09
516	6	13.17 ± .12	810	6	8.88 ± .05
528	6	13.17 ± .14	820	6	8.75 ± .08
539	6	12.74 ± .09	831	6	8.50 ± .08
551	6	12.53 ± .14	841	6	8.48 ± .08
563	6	12.50 ± .11	862	7	8.23 ± .06
574	6	12.33 ± .12	882	7	8.05 ± .09
585	6	12.30 ± .12	903	7	7.83 ± .08
596	6	11.87 ± .12	923	7	7.87 ± .08
608	6	11.72 ± .11	944	7	7.61 ± .08
619	6	11.45 ± .13	964	7	7.38 ± .08
630	6	11.59 ± .13	1005	7	7.29 ± .07
640	6	11.17 ± .11	1046	8	7.32 ± .08

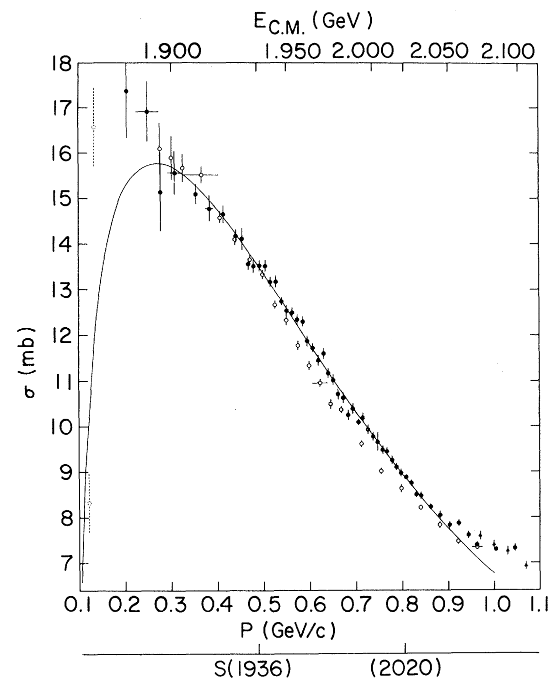

FIG. 2. Cross section for the reaction $\bar{p}p \to \bar{n}n$ vs lab momentum. The open circles are from our earlier experiment (Ref. 1), the closed circles are from this experiment, and the triangles are from Ref. 15. The vertical error bars are statistical and do not include the 3–5% overall systematic error. The curve is a parametrized fit to the data given in Eq. (1) in the text. For the closed circle data above 0.450 GeV/c, the horizontal error bars are smaller than the circles. The points with dashed error bars occur at momenta where the incident antiprotons stop in the target and, because of the 0.1 GeV/c threshold and rapidly rising cross section for charge exchange, large uncertainties exist in the mean interaction momentum.

it threshold factor and is given by

$$\sigma = 17.34[1-(0.10/P)^2]^{1/2} \times [1-0.45P+2.0P^2] \quad (1)$$

with a χ^2 per degree of freedom of 1.07 for this momentum range. We estimate that the overall systematic error is less than 3% at high momenta and 5% at the lowest momenta with a point to point uncertainty of less than 1%.

The data exhibit a rapid rise from threshold ($p_{\bar{p}} = 0.099$ GeV/c), a smooth falloff to about 0.950 GeV/c, and a flattening out above 0.950 GeV/c. We find no evidence for either the S meson or the 2020 resonance in this reaction. Our results are in reasonable agreement with the charge-exchange cross section obtained from the potential-model calculation of Bryan and Phillips.[1,16]

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