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Measurement of the $\bar{p}p$ charge exchange cross section below 1 GeV/c*

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ABSTRACT

No definite evidence for structure is found in the $\bar{p}p \rightarrow \bar{n}n$ cross section between 269 and 965 MeV/c. From these results limits are deduced on properties of the narrow enhancement reported in the $\bar{p}p$ total cross section at 475 MeV/c.

There have been many claims[1] for narrow boson resonances near $\bar{N}N$ threshold, a mass region where structure, called the S meson, was first reported[2] some nine years ago, but never confirmed.[3] The clearest of the recent evidence comes from the formation experiment of Carroll et al.[1] where an 18 mb bump was observed in the $\bar{p}p$ total cross section at a mass of 1932 MeV (475 MeV/c lab momentum) with a width of 9 MeV. Since then, a narrow effect at this mass has been reported in a bubble chamber study of $\bar{p}d$ reactions.[4] In addition, two other bubble chamber experiments indicate substantial, albeit conflicting, structure in the backward $\bar{p}p$ elastic differential cross section over the momentum range from 400 to 650 MeV/c.[5,6] From the theoretical side, calculations based upon one-boson exchange potentials derived from the NN interaction and suitably modified for $\bar{N}N$ suggest that there should be many (about 20) bound states and resonances in the vicinity of threshold;[7] further theoretical interpretation of the enhancement found in the $\bar{p}p$ total cross section in terms of such an $\bar{N}N$ resonance has recently been advanced.[8]

Here we report the results of a counter experiment done in the Brookhaven AGS low-energy separated beam in which the partial cross section for $\bar{p}p$ charge exchange was measured at 22 momenta from 269 to 965 MeV/c with a typical point-to-point precision of about 1%. The apparatus, originally designed to study $K^-p \to \bar{K}^o n$ and modified for $\bar{p}p \to \bar{n}n$, is shown in Fig. 1. The incident beam was defined by scintillation counters M and S_2. Background mesons in the beam were rejected by time of flight between M and a counter S_1 placed at the mass slit 5 meters in front of M, by a threshold Čerenkov counter C, and by pulse height in M. Contamination of the $\bar{p}$ signal was always less than 0.5%. A veto box consisting of counters $A_1 \ldots A_5$ detected all reactions except those yielding neutral final states, while counters $G_1 \ldots G_5$ detected gamma rays converted by approximately one radiation length of lead placed between the A and G counters. The signature for a charge exchange reaction was an incident antiproton, $\phi = S_1 \cdot M \cdot S_2 \cdot \bar{C}$, with no signal in either the A or G counters, $\phi \cdot \bar{A} \cdot \bar{G}$. Empty target rates, typically 5% of full rates, were measured at each momentum and subtracted.

Monte Carlo calculations were made to correct the cross sections. The important corrections were: 1) attenuation of the $\bar{p}$ beam through the 16-inch liquid hydrogen target (1.10 to 1.18), and 2) interaction of $\bar{n}$ or n in the hydrogen target or the AG veto box surrounding the target (1.24 to 1.56). Antinucleon cross sections in hydrogen for the above corrections were obtained from the measured $\bar{p}p$ and $\bar{p}d$ cross sections over this momentum range.[1] Since there have been no measurements of the absorption cross sections for $\bar{n}$ in carbon and lead at these momenta, extrapolations based on the optical model were made using data at higher momenta.[9] A visibility factor f_v, as introduced by Bricman _et al_.[10] to represent the fraction of interactions producing a detectable signal in a counter, was assigned to the $\bar{n}$ and n interactions in lead and scintillator: For $\bar{n}$ interactions in lead and scintillator, and for n interactions in scintillator we used $f_v = 1$; for n interactions in lead we adopted the parametrization of Bricman.

The angular distributions for the charge-exchange reaction required for the Monte Carlo calculations were obtained from bubble chamber experiments.

The corrected charge-exchange cross section is displayed in Fig. 2 as a function of the mean laboratory interaction momentum, and is listed in Table I. Errors shown are statistical only. We estimate the systematic uncertainty in overall normalization to be ±5%. There is an additional ±5% uncertainty at the lowest three momenta (where anti-protons stop in the target) due to a 0.5% uncertainty in the beam momentum. At the highest momentum our value agrees within 5% with the Stony Brook-Wisconsin counter experiment,[11] and at lower momenta with several bubble chamber results[12,13] as shown in Fig. 2. The general shape of the momentum dependence of our results is in reasonable agreement with the calculations of Bryan and Phillips,[14] although our absolute value is some 40% higher.

Within the momentum resolution of our experiment, which is indicated at several momenta in Fig. 2, there is no evidence for narrow structure. In particular, there is no enhancement near 475 MeV/c where Carroll <u>et al</u>.[1] have reported an 18^{+6}_{-3} mb bump in the $\bar{p}p$ total cross section with a width of 9^{-3}_{+4} MeV. If it is assumed that the observed structure arises from a resonance in a pure spin and isospin state, then

$$\Delta\sigma_T = \pi\lambda\!\!\!^{-2}(2J + 1)\ x/2 \quad , \tag{1}$$

where $x = \Gamma_{\bar{N}N}/\Gamma_T$ is the elasticity of the resonance $(0 \leqslant x \leqslant 1)$, and J is the spin. With $\Delta\sigma_T = 18$ mb, this yields $x(2J + 1) = 1.56$. $J = 0$ is thus excluded by unitarity. For charge exchange, assuming that there is no background in the same state, the corresponding expression for the cross-section enhancement is

$$\Delta\sigma_c = \pi\lambda\!\!\!^{-2}(2J + 1)\,(x/2)^2 \quad . \tag{2}$$

A reasonable upper limit to the unobserved enhancement in our experiment is 0.5 mb. This estimate assumes a width of 9 MeV and includes unfolding of our momentum resolution. From Eq. (2) we then find $x^2(2J + 1) < 0.086$. Combining this with the total cross section result, the spin J of the resonance would have to assume an improbably large value of 14. Instead, in Fig. 2 we exhibit the enhancement expected for $J = 4$, a value suggested from the Regge trajectory of $\rho(765)$, $A_2(1310)$, and g(1680). With this spin, to be consistent with our upper limit of 0.5 mb, the corresponding bump in the total cross section could be no higher than 10 mb, some 2.6 standard deviations lower than quoted.

Alternatively, the structure expected in charge exchange could be strongly suppressed if there were degenerate or nearly degenerate resonances of the same J^{PC} in both I = 1 and I = 0. Although this may seem an unlikely possibility, it is perhaps more consistent with the equal bumps observed in $\bar{p}p$ and $\bar{p}d$ total cross sections[1] than is the usual assumption of a pure I = 1 resonance. In fact, such an approximate degeneracy of resonances is predicted for $J^{PC} = 2^{-+}$ near this mass by the $\bar{N}N$ potential model of Bogdanova et al.[7]

For $J < 4$, the assumption of negligible nonresonant background of the same spin-parity as the resonance becomes questionable. Abandoning this assumption, a resonant amplitude $[x/(\epsilon - i)]$ and a nonresonant background $(B = B_R + iB_I)$ will interfere to yield a structure $[x^2 + 2x(B_I + \epsilon B_R)] / (\epsilon^2 + 1)$. Here $\epsilon = 2(E_r - E)/\Gamma_T$. Thus a negative B_I will suppress the enhancement, and if sufficiently large can even produce a dip at resonance; averaged over the resonance, B_R will yield no net enhancement. The shallow depression from 400-500 MeV/c suggested by our data might be interpreted as such a dip. None of the amplitudes of the Bryan-Phillips potential leads to such large destructive interference; however, detailed reliance on the model is perhaps unjustified.

Since destructive interference in charge exchange will result in constructive interference in elastic scattering, we may deduce further limits on the resonance in the presence of this background complication if we also consider the evidence from $\bar{p}p$ elastic scattering. The bubble-chamber data of Amaldi <u>et al</u>.[15] show no enhancement within large statistical uncertainty and we may place a reasonable upper limit $\Delta\sigma_e < 4$ mb for a possible elastic enhancement. Decomposing B_I into isospin amplitudes, we may, with the aid of Eq. (1) together with the unitarity constraint $(B_I)_{0,1} \geqslant 0$, write

$$J + 1/2 \geqslant (\Delta\sigma_T)^2 \Big/ \pi\lambda\!\!\!^-{}^2(\Delta\sigma_e + \Delta\sigma_c) \qquad (3)$$

Taking $\Delta\sigma_T = 18^{+6}_{-3}$ mb, $\Delta\sigma_e = 4$ mb and $\Delta\sigma_c = 0$, we conclude that $J \geqslant 3^{+3}_{-1}$. Thus, such an interpretation cannot be excluded on the basis of present experimental evidence although $J = 1$ seems unlikely.

The neutral annihilation cross section was measured simultaneously in this experiment by the signature $\phi \cdot \bar{A} - \phi \cdot \bar{A} \cdot \bar{G}$, and the corrected cross sections are tabulated in Table I.[16] We estimate the overall normalization uncertainty to be ±20%. The sum of our charge exchange and neutral annihilation cross sections agree well with the topological zero-prong cross sections as measured in bubble-chamber experiments.[15] Again, no structure is apparent in regions where resonances have been reported.

In conclusion, our lack of confirmatory evidence for an $\bar{N}N$ resonance at 1932 MeV can be reconciled with the total cross section results if a) a high spin $J > 4$ is assigned to the resonance, b) it consists of approximately degenerate $I = 1$ and $I = 0$ resonances of the same J^{PC}, or c) a substantial imaginary nonresonant background of opposite isospin is present in the same J^{PC}. This experiment per se establishes an upper limit $x^2(2J + 1) < 0.086$ for a single resonant state without background.

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TABLE I

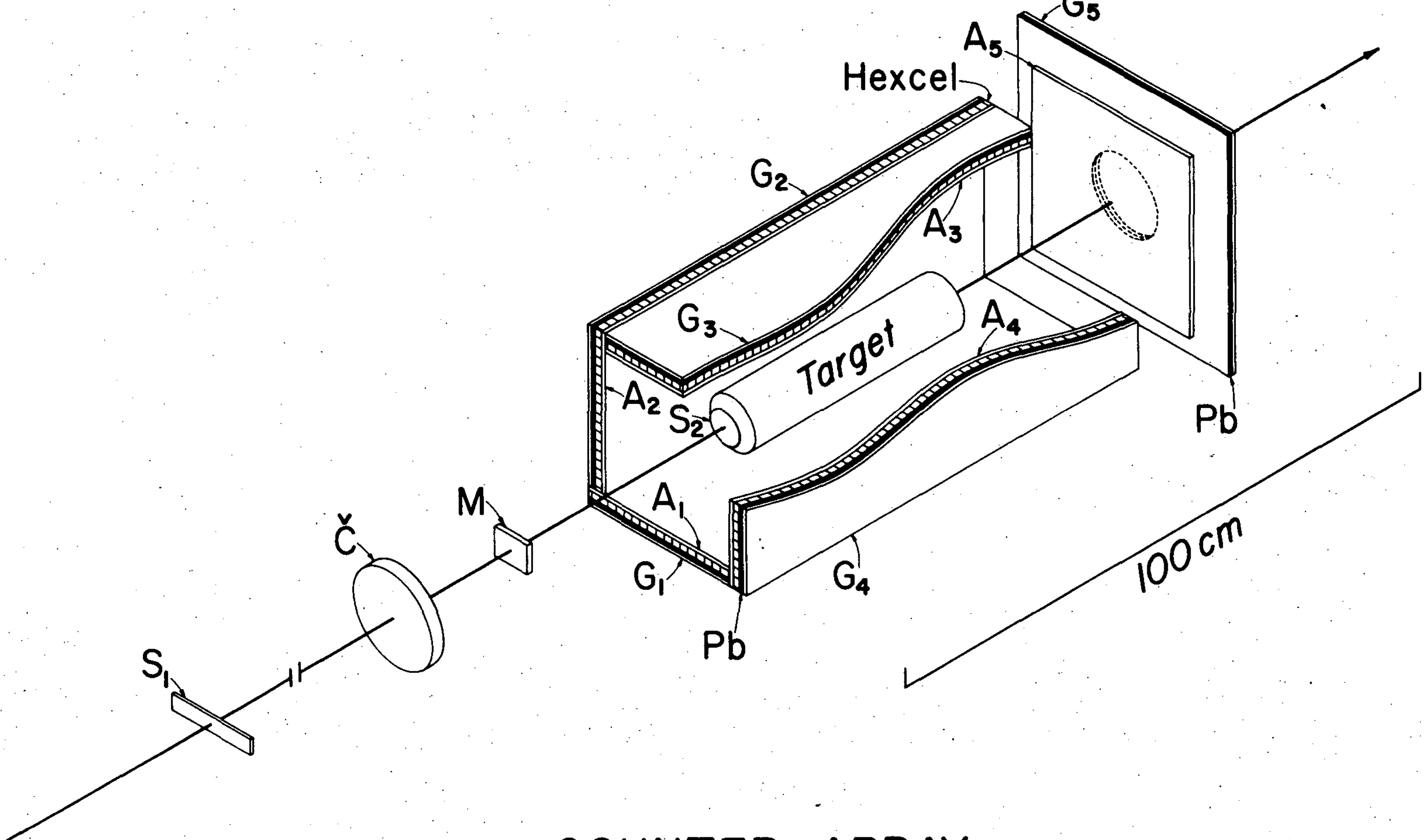
Cross Sections vs $\bar{p}$ Lab Momentum

$\bar{p}$ Momentum (MeV/c)		Cross section (mb)	
Mean	RMS Resol.	Charge exchange	Neutral annihil.
269	58	17.37±0.62	---
297	64	16.46±0.50	---
323	68	15.89±0.31	---
366	50	15.56±0.19	5.32±0.19
408	38	14.62±0.13	4.54±0.13
444	31	14.05±0.13	4.38±0.12
475	27	13.55±0.10	3.89±0.09
504	24	13.32±0.11	3.65±0.11
532	22	12.67±0.09	3.59±0.08
558	20	12.26±0.12	3.09±0.10
583	18	11.72±0.11	3.27±0.09
608	17	11.33±0.11	3.07±0.09
632	16	10.86±0.09	2.89±0.08
655	16	10.47±0.11	2.88±0.09
678	15	10.32±0.08	2.68±0.07
723	14	9.61±0.07	2.63±0.07
767	13	9.02±0.07	2.54±0.06
810	13	8.64±0.09	2.35±0.08
849	13	8.21±0.06	2.38±0.05
888	12	7.83±0.08	2.44±0.08
927	12	7.46±0.07	2.14±0.07
965	12	7.34±0.05	2.26±0.05

Figure Captions

Fig. 1 Isometric projection of the apparatus. G_5 and its lead converter have 5-inch-diam holes through which the beam passes.

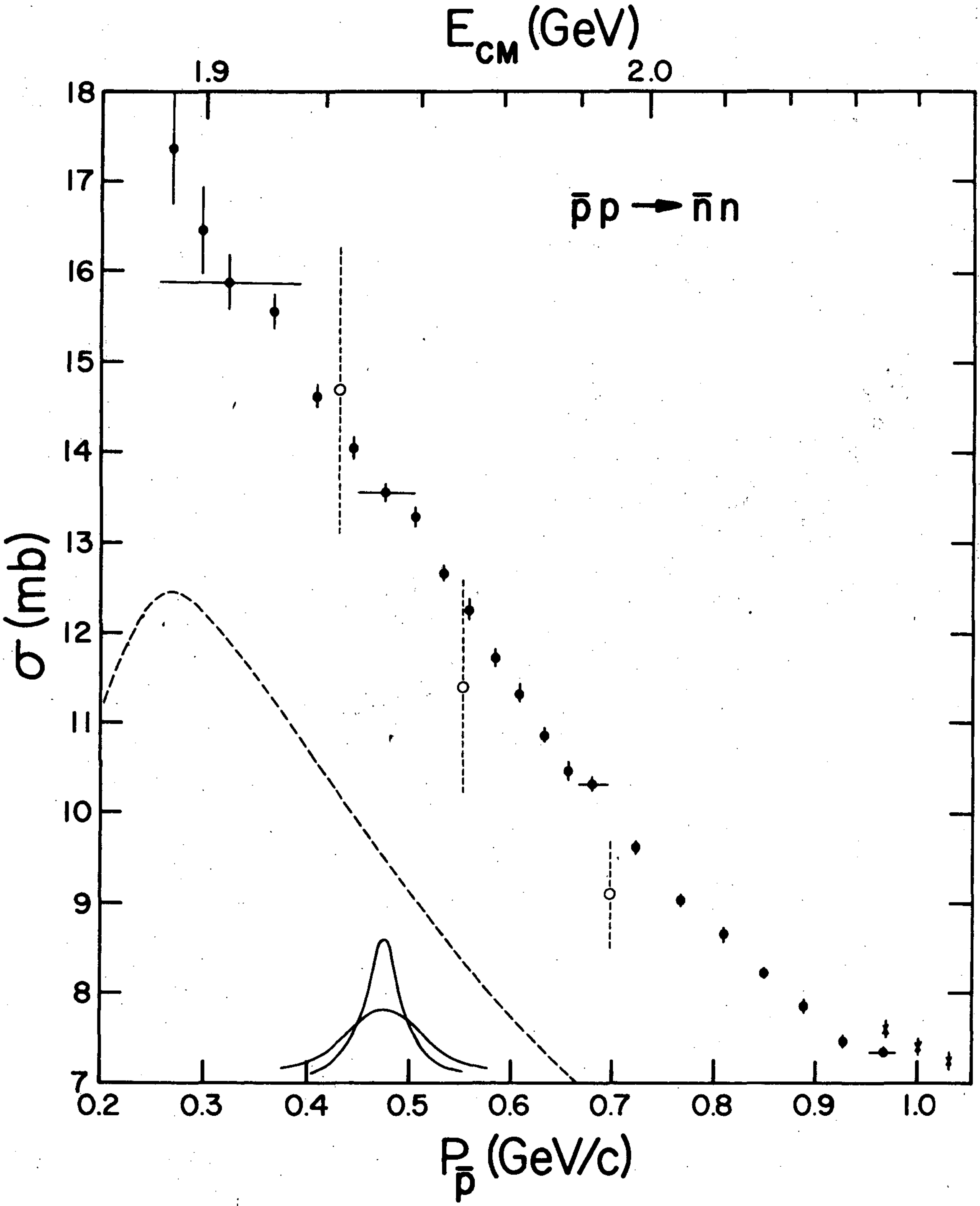
Fig. 2 Cross section for the reaction $\bar{p}p \to \bar{n}n$ vs lab momentum. The full points are from this experiment. The open circles are bubble chamber points of Refs. 12, 13 and crosses are from Ref. 11. The dashed curve is a theoretical calculation of Bryan and Phillips.[14] The resonance curve at 475 MeV/c is calculated from the total cross section results of Ref. 1 assuming J = 4, and is shown with and without our resolution folded in.



COUNTER ARRAY

XBL 755-1432

Fig. 1



XBL 756-3306

Fig. 2

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