Search for the S Meson

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(Received 9 January 1980)

Total and annihilation cross sections for $\bar{p}p$ and $\bar{p}d$ have been measured over the momentum range 355–1066 MeV/c at closely spaced momenta and with good energy resolution. No evidence is seen for the narrow structure reported by other experiments in the vicinity of 500 MeV/c. The present measurements indicate a broader enhancement in this region, which, if interpreted as a resonance, would have a height of ~3 mb and a width of ~20 MeV. This structure appears only in the $\bar{p}p$ data.

PACS numbers: 14.40.–n, 13.75.Cs

Four formation experiments have so far reported narrow structures ranging in width from 3 to 9 MeV in $\bar{p}p$ cross sections at the mass of the so-called $S(1936)$ meson. In a transmission experiment, Carroll *et al.*[1] reported an 18-mb bump in the $\bar{p}p$ total cross section—a 10% effect—and a comparable enhancement in the $\bar{p}d$ total cross section as well. Two bubble chamber experiments[2,3] have observed similar effects while another counter experiment[4] found narrow structure at a slightly higher mass in the charged annihilation cross section and in elastic scattering. The somewhat disparate parameters for the S claimed by these experiments are summarized in Table I. From the theoretical side, interest in narrow $\bar{N}N$ states (sometimes referred to as baryonium) has emerged both from $\bar{N}N$ potential models[5] and from conjectures about states composed of diquarks and antidiquarks,[6] thereby adding impetus to experimental observations.

Having seen no indication for the S meson in our previous measurements of $\sigma(\bar{p}p\to\bar{n}n)$,[7,8] and $d\sigma(\bar{p}p\to\bar{p}p)/d\Omega$ at 180°,[9] we have remeasured the $\bar{p}p$ and $\bar{p}d$ total cross sections in an experiment specifically designed for the study of narrow resonances at low $\bar{p}$ momenta.

The experiment took place in beam LESB I at the Brookhaven alternating-gradient synchroton (AGS) and was performed in the same manner as that of Carroll *et al.*,[1] namely, by the transmission technique whereby the total cross section is obtained by extrapolation of the cross sections measured by a series of counters of diminishing size to one subtending zero solid angle. A major difference between the experiments was that our target and transmission counters were thinner than theirs, each presenting only $\frac{1}{4}$ as much of the stopping power to the antiproton beam. Since the range $R\sim p^{3.3}$, this permitted us to descend 1.5 times lower in momentum, to 350 MeV/c at the target center, before annihilations due to antiprotons stopping in the transmission counters

TABLE I. S-meson parameters as obtained in formation experiments.

Experiment	P (MeV/c)	M (MeV)	Γ (MeV)	$\Delta\sigma_T$ (mb)	$\Gamma\Delta\sigma_T$ (MeV-mb)	$\Delta\sigma_{el}$ (mb)
Carroll *et al.*	475	1932 ± 2	9^{+4}_{-3}	18^{-3}_{+6}	162 ± 25	
Chaloupka *et al.*	491	1936 ± 1	$8.8^{+4.3}_{-3.2}$	10.6 ± 2.4	93 ± 22	7.0 ± 1.4
Bruckner *et al.*	505	1939 ± 3	$\leqslant4$	9 ± 2	36 ± 9	4 ± 2
Sakamoto *et al.*	489	1936 ± 1	2.8 ± 1.4	15 ± 4	41 ± 23	
This experiment	505 ± 7	1939 ± 2	22 ± 6	3.0 ± 0.7	66 ± 24	0.5 ± 1.0

and light guides began to seriously impair the proper functioning of the apparatus. The shorter target also improved our c.m. energy resolution so that at the reported S meson (~ 500 MeV/c), the rms value was ± 1.5 MeV.[8] Whereas the beam used in Ref. 1 was defined by wire chambers, we used a counter telescope whose final element was a thin (1.6-mm) counter placed directly upstream of the target in order to ensure that all particles defined as antiprotons did indeed traverse the target. Accidentals were negligible. Our extrapolation employed three of four $\frac{1}{4}$-in.-thick counters maintained at fixed momentum transfers, 49, 68, and 80 MeV/c, while theirs used five out of a total of ten counters. Both experiments covered approximately the same momentum-transfer region. A further improvement in our experiment came from the use of a charged-particle veto box surrounding the target except along the beam axis. We were therefore able to measure simultaneously the cross section for charged annihilations plus large-angle elastic scattering as well as the total cross section. The veto box was also usefully placed in anticoincidence with the transmission counters so that we could extrapolate the elastic scattering as well as using the more conventional method employed by Ref. 1 of extrapolating all particles projected in the forward direction. As they should, both methods extrapolate to nearly the same total cross section.

A two-parameter fit, $A + B(1 + bt/2)t$, to the data from the three counters was used, where b term represents a small correction due to the falling elastic differential cross section $\sim e^{bt}$; b is conveniently approximated[10] by $b = (3 + 1P)^2$ from experiments performed at larger t.

Since the data with use of the veto box yield the forward elastic differential cross section which provides a further check on the experiment, we use this method in our quoted results although both give essentially the same answer. Corrections have been made for contributions to the cross section arising from Coulomb scattering and from the Coulomb-nuclear interference.[11] These corrections lower the extrapolated cross section by several millibarns.

The charged annihilation cross sections, obtained by placing the veto box in coincidence with beam $\bar{p}$'s, also contained $\bar{p}$ elastic scatters at angles greater than 38° in the laboratory, as well as recoil protons from scattering with sufficient momentum to escape from the target (~ 250 MeV/c). There are also small uncorrected contribu-

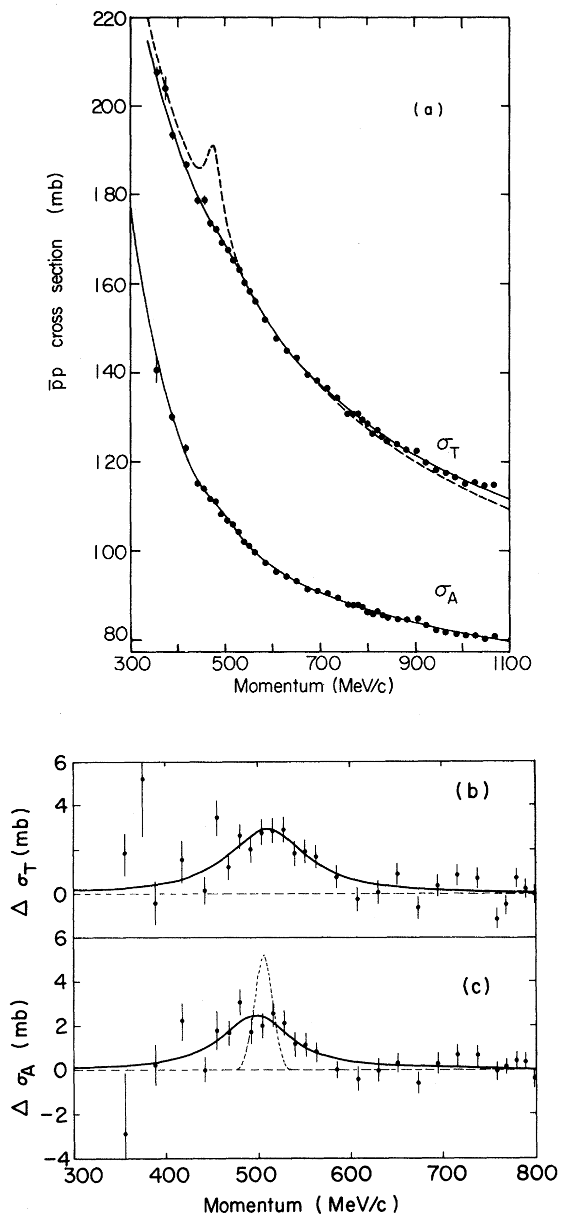

FIG. 1. (a) The $\bar{p}p$ total and "charged annihilation" cross sections measured by this experiment. The solid curves are best fits to our data using the parametrizations described in the text. The dashed line represents the data of Ref. 1. The "charged annihilation" cross section is uncorrected for large-angle elastic scattering and neutral interactions as described in the text. (b) The background-subtracted total cross section and our fit which yields $P_0 = 510 \pm 6$ MeV/c, $\Gamma = 101 \pm 28$ MeV/c, and $\Delta\sigma_T = 3.0 \pm 0.7$ mb. (c) The background-subtracted "charged annihilation" cross section and our fit which yields $P_0 = 497 \pm 9$ MeV/c, $\Gamma = 90 \pm 42$ MeV/c and $\Delta\sigma_A = 2.5 + 0.8$ mb shown as a solid line. The dashed line represents the fit to the data of Ref. 4.

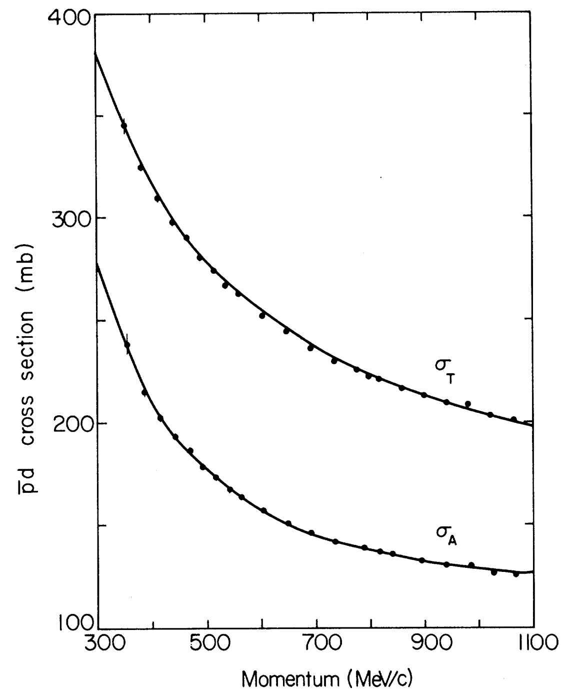

FIG. 2. The $\bar{p}d$ total and "charged annihilation" cross sections and our best fits.

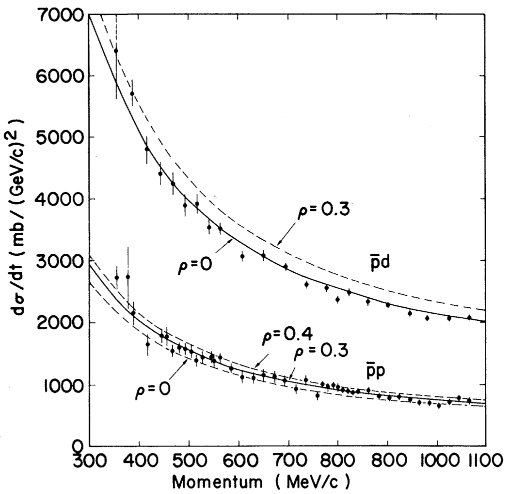

FIG. 3. The elastic differential cross sections in the forward direction for hydrogen and deuterium as obtained from the B coefficients of our fits. The lines show the expected value with use of the optical theorem and our total cross section with various values of ρ = Ref/Imf. $\rho_{\bar{p}p}$ = 0.3 and $\rho_{\bar{p}d}$ = 0.0 are consistent with a recent dispersion-relation calculation (Ref. 12). This gives independent support for use of these values to evaluate the Coulomb-nuclear interference.

tions from the reactions $\bar{p}p \to$ neutrals when the $\bar{n}$, n, or γ interact in the target or surrounding veto box. These effects increase our measured cross section by about 15% at 500 MeV/c relative to experiments[2,4] which measure only annihilations into charged mesons.

In Fig. 1(a), we display the $\bar{p}p$ total and annihilation cross sections as a function of the laboratory momentum P. The total cross section was parametrized as $\sigma_T = \alpha/P + \beta + \Delta/(\epsilon^2+1)$, where $\epsilon = 2(P_R - P)/\Gamma$ approximates the energy dependence of the resonance and the background was parametrized so that $\sigma_T P = \alpha + \beta P$. The annihilation background was observed to be a smooth but more complex function of momentum. Accordingly, this background was expressed with four parameters, $\sigma_A P = \alpha' + [\beta'(P_0 - P)^2 + \gamma]^{1/2}$; again a Breit-Wigner term was used for the resonance. The solid curves are our best fits while the dashed curve on σ_T represents the measurements of Carroll *et al.*[1] We strongly disagree with Ref. 1 concerning the magnitude and width of any resonance structure. In both our cross sections, however, there appears to be a broad and gentle enhancement, approximately coincident in mass with the narrow structure seen by Bruckner *et al.*[4] In Figs. 1(b) and 1(c), we exhibit the observed enhancements over background for the total and annihilation cross sections, respectively. Figure 1(c) also shows (dotted line) the narrow enhancement found in Ref. 4 for the annihilation cross section. It is twice as high as our annihilation cross section and much narrower, with a width less than 17 MeV/c. Inasmuch as our resolution has been measured to be 15 MeV/c full width at half maximum, our results are in clear disagreement.

Figure 2 shows the corresponding $\bar{p}d$ total and annihilation cross sections. No indication of an enhancement can be seen in these data around 500 MeV/c. We have fitted these cross sections in the same manner as our $\bar{p}p$ data, fixing, however, the resonance momentum at 505 MeV/c. The width, broadened by deuterium internal momentum, was also fixed at $\Gamma = 142$ MeV/c. No statistically significant enhancements emerged from this fitting procedure. Apart from deuterium corrections, an $I=0$ resonance should appear the same size in hydrogen and deuterium, whereas an $I=1$ resonance should be three times larger in deuterium. For a resonance of this width, we estimate that internal momentum smearing and Glauber shadowing will diminish the height of the observed bump by a factor of 2. Therefore, our results in deuterium are barely consistent with an $I=0$ structure but appear to exclude $I=1$.

For a pure isospin resonance, $\Delta\sigma_T = \pi\lambda\!\!\!^{-2}(2J+1)x/2$, which for our measured enhancement leads to $(2J+1)x/2 = 0.15 \pm 0.03$. The elasticity x being equal to $1 - \Delta\sigma_A/\Delta\sigma_T$, we obtain $x = 0.2^{+0.3}_{-0.2}$. This favors a spin $J=0$ or 1, although higher values are not excluded with x so poorly established by the data.

Turning now to the higher momenta, we find no evidence for a resonance at 805 MeV/c ($E_{\text{c.m.}} = 2020$ MeV), where a production experiment[12] has observed an enhancement of width 24 ± 12 MeV. Without a knowledge of the elasticity and spin of the putative resonance, there is no way to estimate the magnitude of the effect to be expected in our experiment.

The forward elastic cross section, measured in our experiment by the extrapolation slope $B = d\sigma/dt$ at $t=0$, is related to the total cross section through the optical theorem and $\bar{N}N$ dispersion relations. Figure 3 shows that we find reasonable agreement with real parts of the forward scattering amplitude obtained from a recent dispersion relation calculation.[13]

The 500- and 800-MeV/c regions have been scanned several times, always with similar results. Repeated points agree within $\frac{1}{3}\%$ which is slightly larger than the statistical uncertainty, but is about the level of stability expected from the target density and effective length. We estimate the absolute normalization uncertainty on σ_T to be $\pm 1.5\%$.

In conclusion, our data are inconsistent with those of previous formation experiments which claimed evidence for a pronounced and narrow S-meson resonance. If, on the other hand, we assume that the $\bar{p}p$ total and annihilation cross sections have, apart from resonances, simple dependences on the $\bar{p}$ laboratory momentum, then this experiment suggests a broad (~20-MeV) and gentle (~3-mb) enhancement centered at 1939 MeV and coming primarily from the annihilation reaction. It should be stressed, however, that the parameters of and even the evidence for the existence of this broad structure are sensitive to how the rapidly falling background is parametrized. In particular, a more complex background behavior such as one containing a break near 600 MeV/c could diminish the strength of evidence for a resonance.

We are grateful to D. Lowenstein and others of the Brookhaven National Laboratory AGS staff for their hospitality. We thank R. Kenney, T. Daly, and M. Long for their aid in the design and construction of the experimental apparatus and P. Madden for programming assistance. One of us (R.T.) wishes to acknowledge support from CERN and the advice and assistance of M. Ferro-Luzzi.

This work was supported by the High Energy Physics Division of the U. S. Department of Energy under Contracts No. W-7405-ENG 48, No. ER-78-S-02-4831, and No. DE-AC02-76CH00016.

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