have been used, consistent with the results of $(p, 2p)$ and $(e, e'p)$ experiments.[7-9] An inspection of Fig. 2 shows that the behavior of the observed cross sections is definitely compatible with the hypothesis of direct proton emission from the $1p$ shell in ^{12}C. Up to now we have not found evidence of direct photoprotons from the $1s$ shell, but this point will be better investigated in lighter nuclei. A more complete report on the data, including the absolute values of the cross sections and the interpretation, will be given elsewhere.

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ENERGY-DEPENDENT STRUCTURE IN BACKWARD-HEMISPHERE $\bar{p}p$ ELASTIC SCATTERING AND HIGH-MASS BOSONS*†

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We have observed a strong backward peak in the differential cross sections of backward-hemisphere $\bar{p}p$ elastic scattering in the momentum range 300-700 MeV/c. The differential cross section near 180° and near 90° shows energy-dependent fluctuations. A consistent interpretation of these fluctuations can be made in terms of direct-channel boson resonances with masses and widths $(m_\gamma, \Gamma_\gamma)$, in MeV, of (~1925, ~10) and (1945, ~20), and a state with mass greater than ~1975 MeV and width greater than 20 MeV.

Accumulating evidence suggests that boson states of mass greater than $2m_N$ exist.[1,2] There are at least three reasons for searching for such states as direct-channel resonances in the $\bar{p}N$ direct channel: (1) The mass resolution of the $\bar{p}p$ system is extremely high, so that narrow boson resonances, if they exist, can be detected. (2) By performing a phase-shift analysis the spin and parity of these states can be deduced. (3) The coupling strength of boson states to the $\bar{N}N$ channel is of intrinsic interest and can be determined.

This is a preliminary report on a $\bar{p}p$ elastic scattering in the backward hemisphere using an exposure of the Brookhaven National Laboratory 30-in. bubble chamber with five separate exposures continuously covering the region below 700 MeV/c in $\bar{p}$ momentum. Out of a total of 125 000 frames, 100 000 have been analyzed for $\bar{p}p$ elastic scattering with $\cos\theta < +0.05$. The region from 300 to 700 MeV/c has been covered. The remaining film will give additional data from 250 to 450 MeV/c. An angle template based on $\bar{p}p$ kinematics was used to select events with $\cos\theta < 0.05$ with full efficiency. Because of steep tracks this cut also selected events from 0.05 to 0.5, but with less efficiency. Cutoffs were also made by putting an upper limit on the range of the scattered $\bar{p}$ and/or a lower limit on the proton range.

There is an important class of events where the $\bar{p}$ scatters through a large center-of-mass angle giving nearly all of the incident momentum to the target protons. These $\bar{p}$'s stop in the bubble chamber and annihilate before going a visible distance from the scattering vertex appearing as odd prong events with a forward going, heavily ionizing positive track. Such events have scattering angles with $\cos\theta \lesssim -0.85$ at 300 MeV/c, $\cos\theta \lesssim -0.95$ at 500 MeV/c, and $\cos\theta \lesssim -0.99$ at 700 MeV/c. A careful search for these events has been made. They were selected both by counting prongs and by scanning for protons going in approximately the same direction as the beam. A double scan of about 1000 frames at each momentum showed that the scanning efficiency was equal for both configurations. It was 75 % for the lowest momentum exposure and 95 % for the rest of the film. For the events without a visible scattered $\bar{p}$ the ratios of 1, 3, 5 + 7 prongs are in reasonable agreement with ratios of 1, 3, 5 + 7 prongs for $\bar{p}n$ annihilation at rest.[3] This is a good check for possible biases in the selection of these events.

The selected events were measured, then computed using the DIANHASH-reconstruction kinematic-fitting system. 3934 backward elastic scatters are included in the present analysis.

The backward-hemisphere angular distributions plotted in 100-MeV/c bins are shown in Fig. 1. In three of the four momentum bins there are significant backward peaks. The shape of these peaks obviously varies considerably with momentum. We have verified that the turnover of the angular distributions near $\cos\theta = -1$ in the highest two momentum bins is not due to scanning bias. The plots of cross section versus laboratory momentum in Fig. 2 plotted for various c.m.-system angle cuts also show structure, the most prominent being the peaks centered at 440 and 520 MeV/c (statistically significant). The backward cross section also appears to rise rapidly again between 620 and 700 MeV/c. A point[3] at 1200 MeV/c is also shown indicating that the cross section decreases somewhere between 700 and 1200 MeV/c.[4] Thus, additional structure is suggested in this region. If this is due to a single state, then all that can be concluded at present is that the mass is $\gtrsim$1975 MeV and the width is $\gtrsim$20 MeV. The events with $\cos\theta$ between +0.05 and −0.05 also shows peaks at two of the same momenta. These are at 520 and 650 MeV/c. The absolute cross-section levels in these figures cannot be considered reliable to better than 20 % because of uncertainty in absolute path-length measurements.

Uncertainty in the path length per MeV/c of beam momentum can give rise to spurious fluctuations and is a potential problem in this experiment. However, if the fluctuations are due to path-length misestimate, then the structure should be qualitatively the same at all angles. As shown in Fig. 2 the structure is clearly angle dependent. The expected energy resolution in this experiment is less than 10 MeV over the entire momentum range.

Two possible explanations of this structure are that it is due to the existence of a few high-mass boson resonances that couple to the $\bar{p}p$ direct channel, or of many overlapping resonances giving rise to statistical or Ericson fluctuations.

The hypothesis that the dip-bump structure

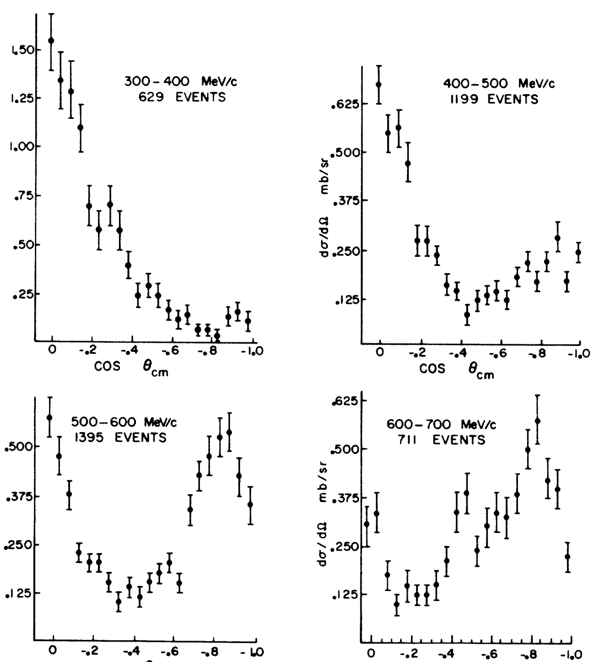

FIG. 1. Differential cross section for backward-hemisphere $\bar{p}p$ elastic scattering below 700 MeV/c. The momentum bins are 100 MeV/c wide.

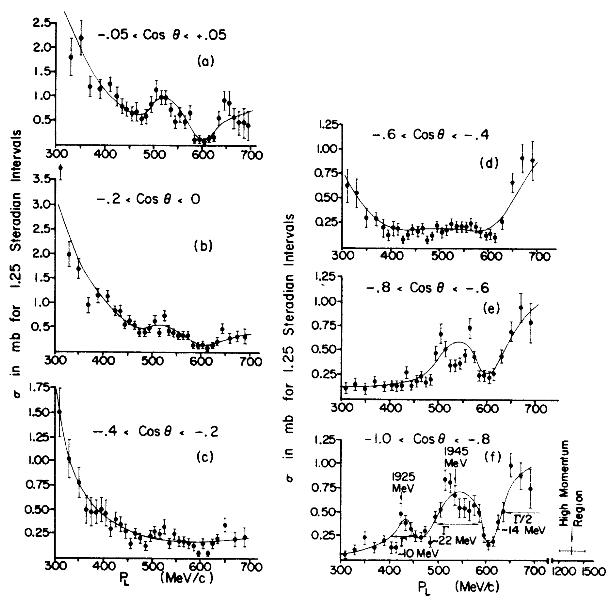

FIG. 2. Energy dependence of the differential cross section for various $\cos\theta$ cuts. Curves are drawn through the data to guide the eye and are not fits to the data. The cross section at ~1300 MeV/c was obtained from Ref. 4.

seen in Fig. 2 is due to the process $\bar{N}N \to$ boson $\to \bar{N}N$ is made plausible by the observation of similar fluctuations in $d\sigma/d\Omega$ for $\cos\theta \sim 0$ and for $\cos\theta$ near -1.0. In absence of background, boson states which couple to even angular-momentum states in the $\bar{N}N$ system would cause nonvanishing cross sections at both 90° and 180°, whereas boson states resulting in odd angular-momentum states would contribute only to 180° scattering. In Fig. 2 it can be seen that the 550-MeV/c enhancement appears to be present both near 90° [Fig. 2(a)] and near 180° [Fig. 2(f)] suggesting even l for the $\bar{N}N$ system. The cross section rise near 700 MeV/c is also reflected in the 90° and 180° scattering. Apparently the 430-MeV/c enhancement is not present at 90°, suggesting that this state comes from odd l in the $\bar{N}N$ system. In the large-angle bins the background under the peaks appears to be quite small and suggests that interference between background and the resonance scattering might be unimportant.

If we assume that the interference with background is not important, the masses and full width at half-maximum widths of the two states observed below 600 MeV/c are $m_r \sim 1925$ MeV, $\Gamma \sim 10$ MeV and $m_r \sim 1945$ MeV, $\Gamma \sim 22$ MeV. In summary, comparison of the 90° and 180° cross sections suggests that the 1925 object is associated with odd l and the 1945 object is associated with even l. The absence of the 430-MeV/c enhancement in the $-0.6 > \cos\theta > -0.8$ bin in Fig. 2 indicates that the backward peak associated with this bump is quite sharp. On the other hand, the 550 bump appears to be associated with a broader backward peak. These qualitative considerations suggest that the low-mass state has negative parity and that the 550 state has positive parity and, in addition, that the spin of the low-mass state is greater than that of the 550-MeV/c enhancement. Until a better understanding of the background is accomplished, more restrictive statements cannot be made. At present it is not possible to make a connection between the enhancements observed here and other reported high-mass mesons. This is especially true because the isospin of the states has not been determined in the present experiment. However, it is interesting to note that in the CERN missing-mass spectrometer experiments, $I=1$ enhancements have been observed at 1925 MeV with a width of less than 15 MeV and at ~2000 MeV with a width of ~40 MeV.[1] There is also some possibility that the 1925-MeV state is actually at 1945 MeV.[5]

Ericson fluctuations[6] occur when there are many resonant states coupled to a system, and the spacing of these states is small compared with their average width. This is the case for compound nuclei where these fluctuations have been observed.[6] The cross sections show energy variation that has a period comparable with Γ, where Γ is the average width of the resonances. Fluctuations in differential cross sections are expected to have an average angular width equal to $1/L_{max}$ where L_{max} is the maximum angular momentum. In order to observe these fluctuations, an experiment must have energy resolution $\Delta E \ll \Gamma$ and angular resolution $\Delta\theta \ll 1/L_{max}$. If the structure observed in this experiment is due to Ericson fluctuations, then the widths of the observed backward peaks in $\bar{p}p$ elastic scattering give $L_{max} \approx 2$ for 300-600 MeV/c. It is surprising that the angular width of the peak increases with energy since L_{max} should increase with energy.

In summary, a study of backward-hemisphere $\bar{p}p$ elastic scattering in the momentum region 300-700 MeV/c indicates energy-dependent structure in the cross section as well as backward peaking of the differential cross section. Although a unique interpretation of this structure cannot be given at present, there is a strong suggestion that it is due to boson resonances coupled to the $\bar{p}p$ system. The width of these resonances is surprisingly small compared with the low-mass states like the ρ and f_0. The richness of the structure suggests that further study of low-energy $\bar{N}N$ scattering will unveil a complex boson spectrum in the mass range above ~1900 MeV.

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TEST OF TIME-REVERSAL INVARIANCE IN ELASTIC ELECTRON SCATTERING FROM THE DEUTERON*

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A test of time-reversal invariance for an electromagnetic interaction at high momentum transfer has been performed by measuring the recoil-deuteron vector polarization for the elastic scattering of electrons from an unpolarized deuteron target for an incident electron energy of 1 GeV and a recoil-deuteron four-momentum of $q = 721$ MeV/c. The value obtained for the vector polarization is $|P| = 0.075 \pm 0.088$, showing no significant T nonconservation.

The observation that K_L^0 can decay into two pions has stimulated many investigations to search for apparent CP or T nonconservation in other processes or reactions. The conjecture that the electromagnetic interactions of hadrons may be C noninvariant[1] has resulted in several proposals for tests of this hypothesis and several experiments are, in fact, in progress. These tests are quite difficult to perform to a meaningful level, and theoretical estimates for these tests are generally model dependent.[2] One such test of T invariance which has received some theoretical consideration[3] is elastic electron scattering from a nucleus with spin $>\frac{1}{2}$. In these cases, unlike the case for a spin-$\frac{1}{2}$ nucleus, there are additional form factors which violate time-reversal invariance and which are not identically required to be zero due to current conservation. These additional form factors lead to possible nonzero expectation values of T-odd correlations such as a vector polarization of the recoil nucleus. We wish to report the result of such an experiment. Specifically, we have measured the vector polarization of the recoil deuterons in the elastic scattering reaction $e^- + d \to e^- + d$ with an unpolarized target for an electron energy of 1 GeV and a recoil-deuteron four-momentum of 721 MeV/c. This reaction has the attractive feature that $\Delta I = 0$ for the isospin. The importance of testing T invariance in $\Delta I = 0$ processes has been considered by several authors.[4]

For elastic scattering from a spin-1 nucleus and with P and T conservation, the photon-nucleon vertex may be described by form factors which correspond to the charge, electric quadrupole, and magnetic dipole moments. If the requirement of T conservation is dropped, the vertex is generally described by the above three form factors plus an additional term which violates T invariance.

In terms of these form factors, the cross section for elastic e-d scattering may be written, in the first Born approximation,[3]

$$\frac{d\sigma}{d\Omega} = \frac{d\sigma}{d\Omega}\bigg|_{\text{Ruth}} [A(q^2) + B(q^2)\tan^2\tfrac{1}{2}\theta],$$

where

$$A(q^2) = F_C^{\,2} + (8/9)\eta^2 F_Q^{\,2} + B(q^2)/2(1+\eta)$$

and

$$B(q^2) = \tfrac{4}{3}\eta(1+\eta)(F_M^{\,2} + 4\eta^2 G^2)$$

and the form factors have as their nonrelativistic