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Measurement of $\Delta\sigma_L$ in proton-proton scattering between 300 and 800 MeV

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We have measured the difference between proton-proton total cross sections for parallel and antiparallel longitudinal spin states $[\Delta\sigma_L = \sigma^{tot}(\rightleftarrows) - \sigma^{tot}(\rightrightarrows)]$ at 13 incident energies between 300 and 800 MeV, which cover the region of possible $^1D_2$ and $^3F_3$ diproton resonances. The present experiment has strongly confirmed the structure previously observed at the Argonne Zero Gradient Synchrotron. No additional narrow structure has been found.

Since the striking structure in $\Delta\sigma_L$ in proton-proton scattering was observed,[1] there have been many measurements in the region of the postulated dibaryon resonances.[2] On the basis of recent measurements of various spin observables in proton-proton scattering, Hoshizaki has obtained an indication of dibaryon resonances in the $^3F_3$ (2.22 GeV) and $^1D_2$ (2.17 GeV) waves in his phase-shift analysis.[3] Recent results of phase-shift analysis by Arndt *et al.* also indicate the existence of these two resonances.[4] Beside the proton-proton system, several experiments which favor the existence of dibaryon resonances in the γ-d and π-d channels have been reported as well.[5]

The motivation of the present experiment was to search for additional narrow structures. The possibility of additional narrow structure has been suggested,[6] and cannot be ruled out by the existing data. Finer energy steps than those of the previous data were used so as to more accurately estimate the mass and width of the two known diproton resonances. A further motivation of the present experiment was to check the previous $\Delta\sigma_L$ data, because (i) the initial $\Delta\sigma_L$ values measured at the Argonne Zero Gradient Synchrotron (ZGS) were questioned by Bugg[7] and (ii) these data might have some normalization error due to the possibility of systematic errors in the measurement of the beam polarization caused by low-energy depolarizing resonances in the ZGS.

The measurements reported here were performed at 13 energies between 300 and 800 MeV using the longitudinally polarized beam of the Los Alamos Meson Physics Facility (LAMPF). After acceleration by the linear accelerator, the spin of the vertically polarized H^- beam was rotated into the longitudinal direction by a superconducting solenoid followed by three dipole magnets and a stripper foil.[8] This scheme has the great advantage that the beam direction and position can be kept fixed independent of beam momentum without moving any magnets or experimental apparatus. The average beam intensity was usually $<10^4$ p/sec, with a duty factor of 9% at 800 MeV and 3% at other energies. The beam polarization was $>80\%$ during the runs and was monitored with a liquid-hydrogen polarimeter [consisting of a bending magnet, a 7-in.-long liquid-hydrogen target, and scintillator telescopes (up, down, left, and right)]. The direction of the beam spin was flipped once a minute at the H^- source.

The target material was propanediol ($C_3H_8O_2$) with a length of 5.5 cm and a diameter of 2 cm. Typical values of the target polarization were around 80%; the polarization was monitored continuously during the runs. The experimental setup is shown in Fig. 1.

A conventional transmission technique was used for the measurement. Incident protons were defined by three sets of counters ($S0$, $S1$, $S2$) and two halo-veto counters (BA). Proportional wire chambers ($P1$, $P2$, $P3$) were used for sampling measurements of the beam profile. The $S1$ and $S2$ counters were segmented into left, right, up, and down counters in order to monitor and control beam position correlated with spin reversal to an accuracy of a few μm. For the unambiguous identification of each event, and the correction for rate-dependent effects, fast-logic setups were used to reject any event in which there was more than one incident particle within 50 nsec. The transmitted protons were detected with 10 transmission counters (T_i) with radii which varied from 5 to 23 cm. The distance from the target to the transmission counter was changed at each momentum to cover the same elastic momen-

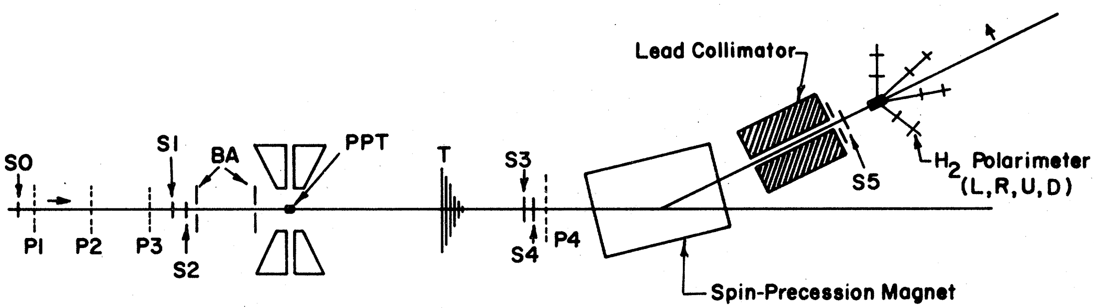

FIG. 1. Schematic view of experimental setup.

tum-transfer (t) region of the scattering with $|t|_{max} \cong 0.02$ $(\mathrm{GeV}/c)^2$ and $\Delta t = -0.002$ $(\mathrm{GeV}/c)^2$ between counters. The efficiency of each counter was continuously monitored during the runs by means of a highly redundant coincidence logic and was normally > 0.999. Delayed coincidences were used to estimate the accidental rates. The scaler data were recorded on magnetic tape typically every fourth pulse of the beam (sometimes every pulse) for off-line rejection of those anomalous beam pulses which could produce a false asymmetry.

The total-cross-section difference $\Delta\sigma_L(t_i)$ for the ith transmission counter is obtained by

$$\Delta\sigma_L(t_i) = (A/P_T P_B)\ln(R_i^+/R_i^-) \quad ,$$

where $R_i^\pm$ is the fraction of the incident particles which is transmitted through the target and detected with counter T_i for parallel (+) and antiparallel (−) spin states; P_T and P_B are the target and beam polarization and A is the target constant for free protons; the $R_i^\pm$ were corrected for counter efficiencies and accidental coincidences, and the $\Delta\sigma_L(t_i)$ were corrected for Coulomb-nuclear interference.[9] The value of $\Delta\sigma_L$ is obtained by extrapolating the $\Delta\sigma_L(t_i)$'s to $t=0$ at each energy. Because of strong correlations between the $\Delta\sigma_L(t_i)$, a straight-line fit of $\Delta\sigma_L(t_i)$ was made with the full covariant error matrix[10] to evaluate $\Delta\sigma_L$. Figure 2 shows the $\Delta\sigma_L(t_i)$ vs t_i with fitted lines at several energies.

Numerical values of $\Delta\sigma_L$ and the slope parameter $d[\Delta\sigma_L(t)]/dt$ are given in Table I.

The quoted errors are due to the counting statistics and also beam-polarization uncertainty including the normalization. The measurements of the analyzing power of the polarimeter were performed by means of the quench method to accuracies of 1–2% at each energy.[11] The overall normalization error of the present data set is 2.8%, and is due to the normalization error of the target-polarization measurement (1.8%) and the uncertainty of the target constant (2.2%) (free-proton density). The spread in beam energy due to energy loss in the target was ±5 to ±7.5 MeV, depending on incident energy, and the uncertainty in central energy was 2 to 3 MeV.

Because the raw asymmetry is very small (an asymmetry of 1×10^{-4} corresponds to 1.2 mb in $\Delta\sigma_L$), many checks were made to avoid any systematic error in the course of the experiment. These include the following.

(1) Measurements of $\Delta\sigma_L$ with zero target polarization were carried out several times at each energy, and measurements with vertically or horizontally polarized beam were made at several energies. The results were consistent with zero within the statistical errors (< 1 mb).

(2) The dependence of $\Delta\sigma_L$ on the beam position

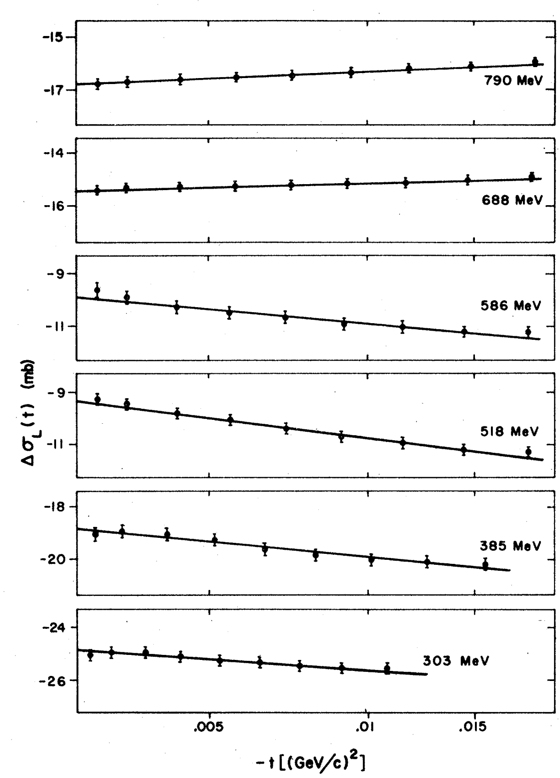

FIG. 2. $\Delta\sigma_L(t)$ vs t. The solid lines represent the fitted straight line to these data. The $\Delta\sigma_L(t)$ at the smallest $|t|$ was not used for the fit.

and intensity was also investigated. It was found to be insensitive to variation of the beam position, but serious problems were observed at high beam intensities. For data taking runs, the beam intensity was kept less than 300 kHz instantaneous rate where no such effects were found. During off-line analysis, pulses with more than 1 MHz instantaneous beam rate were rejected.

(3) Several tens of runs were taken at each energy. The distribution for the value of $\Delta\sigma_L$ from each run was consistent with the statistically expected distribution.

(4) At 485, 535, and 790 MeV, the measurements were made twice. The second measurements were made a few months after the first ones with different target beads. The results were consistent with each other within errors as shown in Table I.

Figure 3 shows the present results compared with the previous ZGS data. These data are quite consistent except for the previous 1.2-GeV/c point,[12] and firmly establish the anomalous structures which have been interpreted as evidence of the existence of $^1D_2$ and $^3F_3$ dibaryon resonances. No obvious additional structure was observed.

We note that the peak and dip shown in Fig. 3 completely vanish when resonant partial-wave amplitudes of $^1D_2$ and $^3F_3$ by Arndt *et al.*[4] are subtracted from the $\Delta\sigma_L$ data as illustrated by a dotted line in Fig. 3. However, we cannot conclude that there are no resonances between the $^1D_2$ and $^3F_3$ energies. For

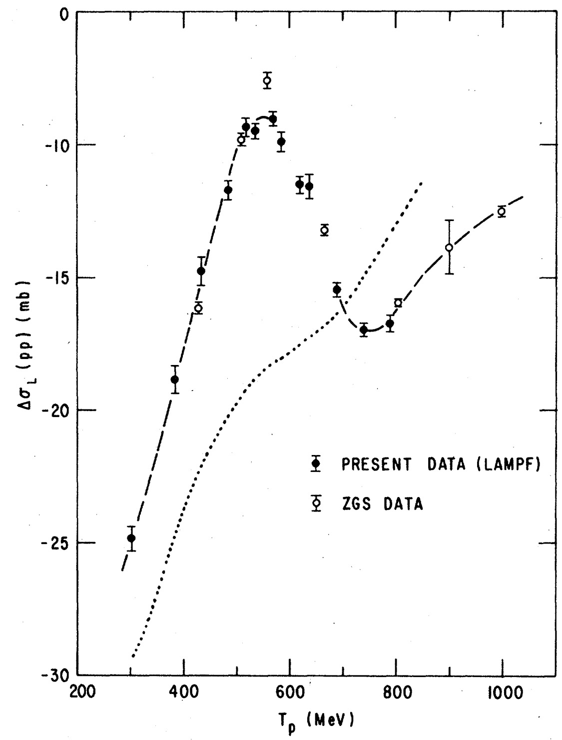

FIG. 3. Energy dependence of $\Delta\sigma_L(pp)$. The dashed line is only to guide the eye. The dotted line is obtained when resonant amplitudes $^1D_2$ and $^3F_3$ are subtracted from the original $\Delta\sigma_L$ data.

TABLE I. $\Delta\sigma_L$ for various incident energies.

T_p (MeV)	$\sqrt{s}$ (MeV)		$\Delta\sigma_L$ (mb)	Slope (mb/GeV^2)	C−N correction (mb)
302.9	2022		−24.86 ±0.49	−65.5 ±11.9	2.19
384.6	2060		−18.84 ±0.54	−110.3 ±10.7	1.69
434.4	2082		−14.75 ±0.54	−145.3 ±14.7	1.49
485.0[a]	2105		−11.53 ±0.47	−126.8 ±11.8	1.31
			−12.02 ±0.59	−144.3 ±19.1	1.31
		av.	−11.73 ±0.37	−132.6 ±10.0	1.31
518.4	2120		−9.36 ±0.34	−132.4 ±9.2	1.15
535.4[a]	2127		−9.68 +0.44	−141.5 ±13.5	1.07
			−9.38 ±0.36	−113.5 ±10.1	1.07
		av.	−9.51 ±0.28	−126.6 +8.3	1.07
569.6	2143		−9.03 ±0.26	−103.0 ±7.1	0.89
586.3	2150		−9.90 ±0.37	−91.5 +10.0	0.81
619.8	2164		−11.51 ±0.32	−41.2 ±8.4	0.67
636.8	2172		−11.59 ±0.43	−32.1 ±10.6	0.56
688.0	2194		−15.43 ±0.27	25.9 ±5.3	0.56
739.5	2216		−16.96 ±0.24	47.4 ±4.6	0.56
790.1[a]	2237		−15.30 ±0.57	60.5 ±12.0	0.58
			−16.96 ±0.33	49.4 ±7.8	0.58
		av.	−16.72 ±0.39	53.8 ±6.6	0.58

[a]At 485, 535, and 790 MeV, the measurements were made twice with different target beads. The third line gives the average of the two measurements.

example, two or more partial waves may cancel each other in $\Delta\sigma_L$ concealing possible structure. In particular, $^3P_0$ and $^3P_2$ partial waves resonating in this energy range might explain the behavior of polarization data[2] at $\theta_{c.m.}=63°$ and $(C_{NN}-C_{LL})$ data[13] at $\theta_{c.m.}=90°$; both sets of data have no contribution from either $^1D_2$ or $^3F_3$ partial waves. This situation will be clarified soon when more C_{LL} and C_{SL} data become available

The slope parameter of the straight-line fit is related to C_{LL} for forward p-p elastic scattering (including Coulomb-nuclear interference region) and other reactions (mainly $pp \rightarrow d\pi^+$). Our results shown in Table I indicate that it has a minimum around 500 MeV and changes sign at 650 MeV. Such a strong energy dependence of the slope parameter indicates a rich structure in the energy dependence of C_{LL}. We are investigating the interpretation of these data further.

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[13]V. A. Efimovyh *et al.*, Phys. Lett. 99B, 28 (1981); authors concluded that there is no structure in $(C_{NN}-C_{LL})$ at $\theta_{c.m.}=90°$ with respect to the incident momentum. However, when one plots $k^2(d\sigma/d\Omega)(C_{NN}-C_{LL})$ so that we can directly examine the partial-wave scattering amplitudes we observe a sharp structure at around 1.25 GeV/c (see Ref. 14). The structure may be explained by resonating $^3P_0$ and $^3P_2$ partial waves. Efimovyh *et al.* examine $^3P_0$ or $^3P_1$ partial waves as a resonance candidate, referring to A. Yokosawa, Argonne Reports No. ANL-HEP-CP-80-01 and ANL-HEP-CP-80-07 (unpublished). Unfortunately, that particular part of the reports by Yokosawa should be corrected due to the latest information from phase-shift analyses (Ref. 4).

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