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Observation of a new structure in the difference between the *pp* total cross sections for antiparallel and parallel longitudinal spin states

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We have measured the difference between the *pp* total cross sections for parallel and antiparallel longitudinal spin states at beam momenta of 2.75, 2.92, 3.25, and 3.48 GeV/*c*. These results reveal possible new structure in this momentum range.

We reported previously on measurements of the difference between the *pp* total cross sections for parallel and antiparallel spin states, $\Delta\sigma_L = \sigma^{\text{tot}}(\rightleftarrows) - \sigma^{\text{tot}}(\rightrightarrows)$, using a longitudinally polarized beam and target up to 6.00 GeV/*c* (Refs. 1 and 2). The data, including the estimated Coulomb-nuclear (CN) interference process, of Ref. 1 are shown in Fig. 1. The dip and peak structures have been interpreted as evidence for the formation of diproton resonances $B_1^2(2.14)$ with a quantum state of $^1D_2$ and $B_1^2(2.22)$ with $^3F_3$ state.[3] We attempted to look for additional $\Delta\sigma_L$ structure in the momentum region higher than those previously found. We measured $\Delta\sigma_L$ at $p_{\text{lab}} = 2.75$, 2.92, 3.25, and 3.48 GeV/*c*.

The experiment was performed at Argonne National Laboratory using a polarized proton beam from the Zero Gradient Synchrotron (ZGS). The experiment was similar to that previously reported.[1] It was performed with a simultaneous measurement of the spin-spin correlation parameter $C_{LL} = (L,L;0,0)$ (Ref. 4). The incident proton beam, defined by the coincidence of three scintillation counters, was attenuated as it was transmitted through the polarized proton target and finally passed through a transmission-counter (T-counter) array.

The beam polarization was reversed each spill, thus, providing well-matched running conditions for positive and negative polarization. The average beam polarization P_B was 70%. The proton beam at the target was approximately 1×1 cm^2 in cross section. The beam intensity was $\sim 10^5$ per pulse.

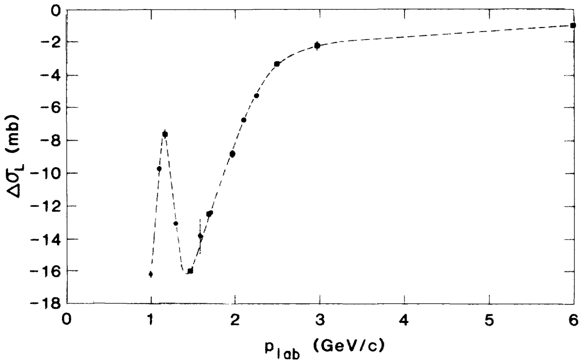

FIG. 1. $\Delta\sigma_L$ vs p_{lab} up to 6 GeV/*c* from previous data, Ref. 1(c). [The Coulomb-nuclear (CN) interference correction was included.] The dashed curve is only to guide the eye.

The magnetic field of the polarized proton target (PPT) was 2.5 T and was aligned to produce a purely L-type target. The target was $2 \times 2 \times 8$ cm^3 ethylene glycol doped with $K_2Cr_2O_7$ and maintained at ~ 0.4 K. Polarization was produced by microwave spin pumping and was continuously monitored via a NMR system. For the free protons in the target, the average polarization p_T was 85%. Other experimental details are described in the report of our previous measurements.[1]

The results obtained are shown in Fig. 2 along with some of the previous data.[1] The errors shown are purely statistical; systematic errors are estimated to be 6% of $\Delta\sigma_L$. We have neglected Coulomb-nuclear interference effects, which depend on spin-spin correlations. We believe these effects are small.[1(c)]

Although the statistics are not compelling, a new peak structure is indicated at around 2.75 GeV/*c* as shown in Fig. 2. Clearly we need to measure a few more points to clarify the energy dependence of $\Delta\sigma_L$ in this energy region. We note that the Saturne II data point[5] at $T = 2.433$

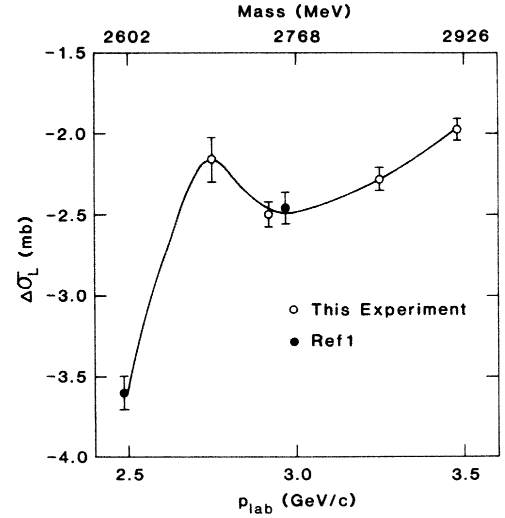

FIG. 2. The $\Delta\sigma_L$ dependence on p_{lab} from 2.49 to 3.48 GeV/*c*. The errors shown are statistical only. Line drawn is only to guide the eye.

GeV is consistent with our data at $p_{\mathrm{lab}} = 3.25$ GeV/c.

To study the behavior in terms of the partial scattering amplitudes, the data on the dimensionless quantity $(k^2/4\pi)\Delta\sigma_L$ are plotted in Fig. 3 as a function of the center-of-mass energy, where k is c.m. momentum.

In terms of s-channel helicity amplitudes,[6]

$$\phi_1 = \langle + + \mid + + \rangle ,$$

$$\phi_2 = \langle - - \mid + + \rangle ,$$

$$\phi_3 = \langle + - \mid + - \rangle ,$$

$\Delta\sigma_L$ can be expressed as

$$\Delta\sigma_L = (4\pi/k)\mathrm{Im}[\phi_1(0) - \phi_3(0)] \tag{1}$$

and the spin-averaged cross section as

$$\sigma^{\mathrm{tot}} = (2\pi/k)\mathrm{Im}[\phi_1(0) + \phi_3(0)] . \tag{2}$$

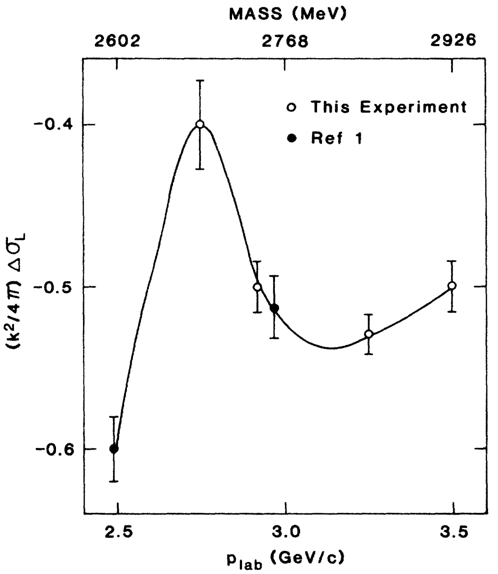

FIG. 3. A plot of $(k^2/4\pi)\Delta\sigma_L$. Line drawn is only to guide the eye.

When the helicity amplitudes are decomposed into partial waves,[7]

$$\mathrm{Im}\phi_1(0) = \frac{1}{k}\sum_J \mathrm{Im}\{(2J+1)R_J + (J+1)R_{J+1,J} + JR_{J-1,J} + 2[J(J+1)]^{1/2}R^J\} , \tag{3}$$

$$\mathrm{Im}\phi_3(0) = \frac{1}{k}\sum_J \mathrm{Im}\{(2J+1)R_{JJ} + JR_{J+1,J} + (J+1)R_{J-1,J} - 2[J(J+1)]^{1/2}R^J\} , \tag{4}$$

where R_J is the spin-singlet partial wave with $J = L =$ even, R_{JJ} and $R_{J\pm 1,J}$ are spin-triplet waves with $J = L =$ odd and $J = L \mp 1 =$ even, respectively, and R^J is the mixing term. [Note that $R_J = (\eta_J e^{i2\delta_J} - 1)/i2k$, and similarly for triplet waves[6].]

If the bump in $(k^2/4\pi)\Delta\sigma_L$ is considered to be due to a resonance, the mass is about 2700 MeV with a width of less than 80 MeV and an elasticity, η, of more than 0.10 for R_J assuming $J=0$ or for $R_{J+1,J}$ as one can see from Eqs. (1), (3), and (4) along with Fig. 3.

Earlier, structure near 2700 MeV was observed in the spin-spin correlation parameter $C_{LL} = (L,L;0,0)$ in p-p elastic scattering around $\theta_{\mathrm{c.m.}} = 90°$ (Ref. 4). Also a strong energy dependence including a shoulder around the 2700-MeV mass region has been observed in a plot of $k^2 C_{NN}(d\sigma/d\Omega)$, where $C_{NN} = (N,N;0,0)$, and $\theta_{\mathrm{c.m.}} = 90°$ (Ref. 8).

Polarization measurements for $p^{\uparrow}p \to d\pi^+$ from $T_p = 1.0$ to 2.3 GeV carried out at Saclay revealed a structure near $T_p \approx 1.9$ GeV (near 2700-MeV mass).[9]

Many attempts have been made to explain the nucleon-nucleon structure as threshold effects using various models. However, these attempts have not seemed very successful as was discussed in Ref. 4.

We note that the cloudy bag model[10,11] predicts six-quark state resonances, and in particular an s-wave state near the 2700-MeV mass with ~50 MeV width[10] may be consistent with the new structure.

It is highly desirable to measure both $\Delta\sigma_L$ and $\Delta\sigma_T$ in this mass region with smaller energy steps (≈ 20 MeV).

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