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PURE SPIN TOTAL CROSS SECTIONS

by

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PURE SPIN TOTAL CROSS SECTIONS*

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ABSTRACT

Measurements of the pure spin total cross sections in the NN system are described. Evidence for a dibaryon resonance interpretation of the structure in the $I=1$ cross sections at $P_{LAB} \approx 3$ GeV/c is discussed. New data on the total cross section difference for longitudinal beam and target in the $I=0$ system are presented.

INTRODUCTION

Two major topics will be discussed in this talk. These topics deal with structure observed in pure spin total cross sections and various pp elastic scattering parameters between $P_{LAB} = 1$ and 11.75 GeV/c. The first topic deals with the $I=1$ or pp case, to which a total of roughly 6 months running time was devoted by several experimental groups at the Argonne ZGS during the past few years. A considerable amount of theoretical work has been done to try to understand the observed structures near 1.2, 1.5 and 2.0 GeV/c. In particular, evidence for a dibaryon interpretation of this structure will be discussed. The second topic deals with the $I=0$ case, where preliminary data from this past August and September will be presented.

Before describing the data and its interpretation, consider briefly some motivation for these experiments. In the past, some of the first quantities measured at a new high energy proton accelerator were the spin-averaged total cross sections. Families of resonances have been found in this way in the πp and the $K^+ p$ systems. The understanding of these resonances, that is, their quantum numbers and their classification into families or multiplets, would have been considerably hampered if there were no easy way to experimentally distinguish particles according to charge (π^+ , π^0 , π^-) or according to particle type (p , π^+ , K^+). The spin quantum number is unimportant for πN and $K^+ N$ total cross sections because the pions and kaons are spin -0 particles and because the strong interactions conserve parity to high accuracy. On the other hand, spin is important in the NN case, but until recently only spin-averaged total cross sections were measured. Thus, there is a good possibility that the physics may be easier to understand if the total cross sections for pure spin states were measured.

For the NN system, there are three independent total cross sections which can be measured. In terms of pure spin total cross sections, the measured quantities are

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$$\begin{aligned}
\sigma^{\text{Tot}} &= 1/2 [\sigma^{\text{Tot}}(\vec{\uparrow}) + \sigma^{\text{Tot}}(\vec{\downarrow})] \\
&= 1/2 [\sigma^{\text{Tot}}(\uparrow\downarrow) + \sigma^{\text{Tot}}(\downarrow\uparrow)] \\
\Delta\sigma_T &= \sigma^{\text{Tot}}(\uparrow\downarrow) - \sigma^{\text{Tot}}(\downarrow\uparrow) \\
\Delta\sigma_L &= \sigma^{\text{Tot}}(\vec{\uparrow}) - \sigma^{\text{Tot}}(\vec{\downarrow})
\end{aligned}$$

where σ^{Tot} is the spin-averaged total cross section, previously measured at many accelerators. The quantity $\Delta\sigma_T$ is the difference in total cross sections for beam and target transversely polarized. It has been measured by the Michigan^{1,2} and the Rice^{3,4} groups at the Argonne ZGS. The quantity $\Delta\sigma_L$ is the difference in total cross sections for beam and target longitudinally polarized (the arrows denote the spin directions in the lab frame). It has been measured in a series of measurements by the Argonne in-house polarization group at the ZGS. The physicists who have been involved in the $\Delta\sigma_L$ experiments are: I. P. Auer, A. Beretvas, E. Colton, W. R. Ditzler, H. Halpern, D. Hill, K. Nield, B. Sandler, H. Spinka, N. Tamura, G. Theodosiou, D. Underwood, R. Wagner, Y. Watanabe and A. Yokosawa^{5,6,8,9} with assistance in the Legendre analysis and interpretation by K. Hidaka and many others.

1. Structure in the I=1 NN System

In the past, before the measurement of pure spin total cross sections, there was no convincing evidence for a dibaryon in the pp system. Below the π -production threshold at $P_{\text{LAB}} = 0.77$ GeV/c, there is no indication of a dibaryon resonance (except the deuteron) from phase shift analyses in either the pp or pn systems. There are no peaks in $\sigma^{\text{Tot}}(pp)$ comparable to those produced by the low lying resonances in $\sigma^{\text{Tot}}(\pi p)$ or $\sigma^{\text{Tot}}(K^-p)$. The rapid rise in $\sigma^{\text{Tot}}(pp)$ near 1.2 GeV/c has been interpreted as a threshold effect from the $N\Delta$ channel (see Fig. 1). (The threshold for $pp \rightarrow NN\pi\pi$ is 1.22 GeV/c, for $pp \rightarrow N\Delta$ (1236) is 1.28 GeV/c, for $pp \rightarrow NN^*$ (1400) is 1.74 GeV/c, and for $pp \rightarrow \Delta\Delta$ is 2.12 GeV/c.) For these reasons and others, the pp system was considered "exotic" and without resonances.

The three I=1 total cross sections are shown in Fig. 1. The measurements employed the standard "good geometry" transmission technique. The experimental details for $\Delta\sigma_T$ and $\Delta\sigma_L$ are described in Refs. 1-6, 8, 9. Spin effects are seen to be a sizeable fraction of σ^{Tot} at low energies and to exhibit striking structure as a function of P_{LAB} . The $\Delta\sigma_L$ results between 2.75 and 5.0 GeV/c and at 11.75 GeV/c are preliminary. Additional measurements of $\Delta\sigma_T$ between 1.1 and 2.75 GeV/c, reported at this conference by T. Mulera,⁴ have recently been performed by the Rice University group. Their preliminary data confirms the structure previously seen in $\Delta\sigma_T$.

Fig. 1. PP Total Cross Section. The $\Delta\sigma_T$ results are from Refs. 1-4 and the $\Delta\sigma_L$ data (solid triangles) are from Refs. 5, 6, 8. Preliminary $\Delta\sigma_L$ results are shown as open triangles. (See also Fig. 6 and Ref. 4.)

The pp total cross sections can be expressed in terms of partial waves as follows:

$$\begin{aligned}\Delta\sigma_T &\sim \text{Singlet} - \text{Triplet} \quad (J=L\pm, \text{ even}) \\ \sigma^{\text{Tot}}(\vec{z}) &= \sigma^{\text{Tot}} + 1/2 \Delta\sigma_L \\ &\sim \text{Singlet} + \text{Triplet} \quad (J=L\pm 1, \text{ even}) \\ \sigma^{\text{Tot}}(\vec{z}) &= \sigma^{\text{Tot}} - 1/2 \Delta\sigma_L \\ &\sim \text{Triplet} \quad (J=L, \text{ odd}) + \text{Triplet}' \quad (J=L\pm 1, \text{ even}),\end{aligned}$$

where Singlet refers to a sum of positive contributions from spin-singlet ($S=0$) partial waves and Triplet refers to a sum of positive contributions from $S=1$ partial waves. Note that a resonance in a spin-singlet partial wave would be characterized by a peak in $\Delta\sigma_T$ or $\sigma^{\text{Tot}}(\vec{z})$ or $\Delta\sigma_L$. Likewise, a resonance in a spin-triplet $J=L$ partial wave would be characterized by a peak in $\sigma^{\text{Tot}}(\vec{z})$ or a dip in $\Delta\sigma_L$. Structure caused by either spin-singlet or $J=L$ spin-triplet partial waves may be easier to see in $\Delta\sigma_L$ than in $\sigma^{\text{Tot}}(\vec{z})$ or $\sigma^{\text{Tot}}(\vec{z})$ because the coupled triplet ($J=L\pm 1$) partial wave contributions somewhat cancel in $\Delta\sigma_L$.

A. Structure Near 1.5 GeV/c

One of the most striking features of the data is the deep dip in $\Delta\sigma_L$ near 1.5 GeV/c. If the pure spin total cross sections are computed from σ^{Tot} and $\Delta\sigma_L$, it appears that the structure occurs in $\sigma^{\text{Tot}}(\vec{z})$ but not in $\sigma^{\text{Tot}}(\vec{z})$ or $\Delta\sigma_T$ (see Fig. 2). As described above, this behavior is characteristic of partial waves with $S=1$, $J=L\text{-odd}$.

There are also indications of structure near 1.5 GeV/c in the elastic channel. The total elastic cross sections seems to show a bump near that momentum. The polarization parameter averaged over the range $0.1 < |t| < 0.2$ (GeV/c)² is shown in Fig. 3. All data shown were collected by one group¹⁰ in order to minimize any systematic differences between the points. The differential cross section in this t -range changes slowly with lab momentum. Since the polarization times the differential cross section ($Pd\sigma/d\Omega$) contains contributions from spin-triplet terms only, then the rapid change in polarization indicates structure in the $S=1$ partial waves near 1.5 GeV/c.

The numerous differential cross section and polarization data in this momentum range were fit with Legendre polynomials as a function of angle:⁷

$$\begin{aligned}d\sigma/d\Omega &= (1/k_{\text{cm}})^2 \sum A_N P_N(\cos\theta) \\ Pd\sigma/d\Omega &= (1/k_{\text{cm}})^2 \sum B_N P_N^1(\cos\theta)\end{aligned}$$

Fig. 2. Pure Spin pp Cross Sections. The curves are to guide the eye.

The coefficients A_N and B_N can be related to individual partial waves. The variation of the coefficients with momentum indicates that the partial wave 3F_3 is probably responsible for the structure seen in the polarization (Fig. 3). This partial wave ($S=1, J=L=3=\text{odd}$) is consistent with the structure observed in $\Delta\sigma_L$ and $\sigma^{TOT}(\hat{n})$ as described before.

At the same time the $\Delta\sigma_L$ data were taken, the elastic scattering parameter C_{LL}

$$C_{LL} = [d\sigma/dt(\hat{n}) - d\sigma/dt(\hat{\bar{n}})] / [d\sigma/dt(\hat{n}) + d\sigma/dt(\hat{\bar{n}})]$$

was measured near $\theta_{c.m.} = 90^\circ$ for momenta between 1 and 3 GeV/c.¹¹ (Additional data up to 5 GeV/c were recently measured, but the C_{LL} analysis is not yet complete.) It was shown^{11,12} that the rapid change in $C_{LL}(90^\circ)$ with P_{LAB} is consistent with a Breit-Wigner resonance in the 3F_3 partial wave and a slow variation of the other partial waves near 1.5 GeV/c.

Fig. 3. Polarization in pp Elastic Scattering (from Ref. 10).

From the experimental results described, assuming the structure in $\Delta\sigma_L$ near 1.5 GeV/c is caused by a dibaryon resonance, then its properties are

Mass	~ 2260 MeV
Width	~ 200 MeV
Charge	2
J^P	3^-
Elasticity	$\sim .2$

where the mass, width and elasticity are approximate values only. These parameters were obtained by a fit to the shape of $\Delta\sigma_L$ and were used to check the behavior of $C_{LL}(90^\circ)$ ^{11,12}

Additional evidence on the structure in $\Delta\sigma_L$ near 1.5 GeV/c is available from fixed -t dispersion relations by Grein and Kroll.^{13,14} They define amplitudes F_2 and F_3 whose imaginary parts are

$$\text{Im}F_2 = - (P_{LAB}/4\pi) \Delta\sigma_T$$

$$\text{Im}F_3 = (P_{LAB}/4\pi) \Delta\sigma_L .$$

Grein and Kroll use phase shift predictions at low energies, the measured $\Delta\sigma_T$ and $\Delta\sigma_L$ values between 1 and 6 GeV/c and some assumptions

about the high energy behavior to obtain $\text{Im}F_2$ and $\text{Im}F_3$ as a function of momentum. The real parts of F_2 and F_3 are then computed from dispersion relations. The amplitude $[-P_{\text{cm}}^2 (F_2 + F_3)/P_{\text{LAB}}]$, which contains no spin-singlet contributions, is displayed in an Argand diagram¹⁴ in Fig. 5a. The minus sign is included since the structure seems to occur in $\sigma^{\text{Tot}}(\frac{1}{2})$ and since $\text{Im}F_3 \sim \sigma^{\text{Tot}}(\frac{1}{2}) - \sigma^{\text{Tot}}(\frac{3}{2})$. A clear resonance-like behavior is seen in Fig. 5a. With the assumption that this behavior is caused by a dibaryon resonance, Grein and Kroll obtain a slightly larger mass and width and a slightly smaller elasticity (assuming $J=3$ for the resonance) than discussed above.

Finally Hoshizaki has performed a phase shift analysis for $P_{\text{LAB}} = 1.1$ to $3 \text{ GeV}/c$. The input data include many elastic scattering results, the total cross sections σ^{Tot} , $\Delta\sigma_T$, $\Delta\sigma_L$, the results of Grein and Kroll's dispersion analysis, and some theoretical inputs for the behavior of the high spin partial waves. He concludes that the results indicate the existence of a diproton resonance in the 3F_3 partial wave (and possibly in the 1D_2 partial wave at a lower momentum). He obtains a slightly smaller mass and width and the same elasticity as quoted above for the 3F_3 resonance. Further details will be given by the next speaker (N. Hoshizaki).

B. Structure Near 1.2 GeV/c

The sharp peak in $\Delta\sigma_L$ near $1.2 \text{ GeV}/c$ is possibly associated with a 1D_2 dibaryon resonance according to Hoshizaki's phase shift analysis. Its properties would be

Mass	$\sim 2170 \text{ MeV}$
Width	$\sim 50 - 100 \text{ MeV}$
J^P	2^+
Elasticity	~ 0.1

A spin-singlet resonance would be expected to appear as a peak in $\Delta\sigma_T$ and $\sigma^{\text{Tot}}(\frac{1}{2})$ as well as in $\Delta\sigma_L$. There is an indication of a rise in $\Delta\sigma_T$ (see Fig. 1 and Ref. 4) as the momentum decreases to about $1.2 \text{ GeV}/c$, as would be expected. However, in this momentum range $\sigma^{\text{Tot}}(\frac{1}{2})$ is changing rapidly (see Fig. 2) and no peak is apparent. It is possible that the rapid rise in the total cross section, which is usually associated with the opening of the $N\Delta$ channel (also fed from the 1D_2 partial wave), might conceal any resonant structure in $\sigma^{\text{Tot}}(\frac{1}{2})$.

Additional arguments, similar to those used for the structure near $1.5 \text{ GeV}/c$, cannot be made in this case. The Legendre coefficient analysis of $Pd\sigma/d\Omega$ gives no information on the 1D_2 partial wave since $Pd\sigma/d\Omega$ contains contributions from spin-triplet partial waves only. In addition, Grein and Kroll¹³ find no evidence for a resonance near $1.2 \text{ GeV}/c$ from their dispersion relation analysis of the forward amplitudes. There appears to be structure in $C_{LL}(90^\circ)$ and possibly in $C_{LL}(73^\circ)$ near $1.2 \text{ GeV}/c$ (see Fig. 4), but additional

Fig. 4. The pp Elastic Scattering Parameter C_{LL} vs. P_{LAB} . The results shown are from fits to the data presented in Ref. 11. The curves are to guide the eye.

Fig. 5. Argand Diagram for the Amplitudes. $[-P_{cm}^2(F_2 + F_3)/P_{LAB}]$ and $[-P_{cm}^2 F_2/P_{LAB}]$ from Ref. 14. Spin-singlet terms are absent in a) and spin-triplet $J=L$ terms are absent in b).

measurements of both elastic and inelastic spin parameters would be very useful to clarify the nature of the structure in $\Delta\sigma_L$ and $\Delta\sigma_T$ near 1.2 GeV/c.

There have been a number of theoretical papers which have attempted to explain the behavior of $\Delta\sigma_T$ and/or $\Delta\sigma_L$ or which have criticized the dibaryon resonance interpretation.¹⁵⁻¹⁸ These models require a large contribution to $\Delta\sigma_L$ from the elastic channel

$$\Delta\sigma_L^{el} = -2 \int C_{LL} (d\sigma/d\Omega) d\Omega$$

for $P_{LAB} \approx 2$ GeV/c. Kroll¹⁴ estimates $\Delta\sigma_L^{el}$ to be -6 to -8 mb at 1.47 GeV/c from the measured C_{LL} data¹¹ and from results at $\theta=0^\circ$ from the dispersion analysis. This estimate is inconsistent with the values required by some of the inelastic models.

Criticisms of the dibaryon interpretation of the structures near 1.2 and 1.5 GeV/c (Refs. 18-21 and other references cited) have been raised before the $\Delta\sigma_T$, $\Delta\sigma_L$ and/or C_{LL} results were published. These results may invalidate some of the criticisms. In particular, the C_{LL} data contradict the predictions of the "modified phase shift analysis" of Ref. 18.

The interpretation of dibaryon resonances is described in terms of SU(6) in Ref. 22, in terms of the MIT bag model in Refs. 23, 24 in terms of the πNN system with the π forming a Δ with both nucleons in Ref. 25, and in a quark-cluster model in Ref. 26.

C. Structure Near 2.0 GeV/c

The peak in $\Delta\sigma_T$ near 2.0 GeV/c has been confirmed and more accurately defined by recent measurements of the Rice University group.⁴ Although there is no apparent structure in $\Delta\sigma_L$, there is a hint of a shoulder occurring around 2.1 GeV/c in $\sigma_L^{tot}(z)$, and structure is again seen in C_{LL} (Fig. 4). As discussed before, the behavior of $\Delta\sigma_T$ and $\sigma_L^{tot}(z)$ is characteristic of spin-singlet partial waves ($1D_2$, $1G_4$, $1I_6$, ...).

Grein and Kroll¹³ find resonance-like structure in the spin-singlet partial waves near 2.0 GeV/c. The Argand diagram for the amplitude $(-P_{cm}^2 F_2/P_{LAB})$ is shown in Fig. 5b. Recall that the imaginary part of the amplitude F_2 is proportional to $\Delta\sigma_T$, and $\Delta\sigma_T$ contains no contribution from spin-triplet $J=L$ partial waves. The mass and width derived by Grein and Kroll from the results in Fig. 5b are

$$\begin{array}{ll} \text{Mass} & \sim 2390 \text{ MeV} \\ \text{Width} & \sim 100 \text{ MeV} \end{array}$$

A spin of 4 is conjectured, which gives an elasticity of ≈ 0.1 . If the structure in $\Delta\sigma_T$ near 2.0 GeV/c is caused by a spin-singlet partial wave, a Legendre coefficient analysis of $Pd\sigma/d\Omega$ (which contains no contributions from $S=0$ partial waves) would not help

to determine the resonance quantum numbers. However, $J=4$ or the $1G_4$ partial wave is consistent with the behavior of the C_{LL} data, since the $1G_4$ contribution to C_{LL} should vanish at $\theta_c^m = 70.1^\circ$. The data indicate a considerably stronger variation of C_{LL} with momentum at 90° than at 73° .

The Rice group collected data on the elastic scattering parameter

$$C_{NN} = [d\sigma/dt(\uparrow\uparrow) - d\sigma/dt(\uparrow\downarrow)]/[d\sigma/dt(\uparrow\uparrow) + d\sigma/dt(\uparrow\downarrow)]$$

at several momenta near 2.0 GeV/c. Their preliminary results⁴ and data at other energies^{27,28} indicate a substantial variation of C_{NN} with angle and energy. Their new results should considerably assist phase shift analyses near 2.0 GeV/c; however additional data are probably required to completely understand the nature of the structure in $\Delta\sigma_T$.

D. High Energy Behavior of $\Delta\sigma_L$

Various predictions of the high energy behavior of $\Delta\sigma_L$ have been made, all assuming dominance of an A_1 -like (unnatural parity) exchange. One such prediction by Berger, Sorenson and Irving²⁹ is shown in Fig. 6. They predict

$$\Delta\sigma_L \sim (P_{LAB})^{\alpha-1}$$

with $\alpha = -0.19$. Grein and Kroll¹³ assumed a similar behavior with $\alpha = -0.15$ as input to their dispersion relation calculation for the F_3 amplitude. Finally, Stacey³⁰ gives a more complicated expression which is numerically very close to the values of Grein and Kroll at ZGS energies. All three predictions give $\Delta\sigma_L \sim -0.5$ mb at $P_{LAB} = 11.75$ GeV/c, which agrees with the preliminary experimental value (Fig. 1). The predictions differ by almost a factor of 2 at 100 GeV/c. Stacey also gives a model independent way to obtain the pure unnatural parity exchange amplitudes from the $\Delta\sigma_L$ and $\Delta\sigma_T$ values. He concludes that the $\Delta\sigma_L$ values near 5 GeV/c contain a substantial ($\sim 30\%$) natural parity exchange contribution.

2. Structure in the $I=0$ NN System

The second topic to be covered deals with the $I=0$ system. The shape of the spin-averaged total cross section is again smooth, just as in the pp case (see Fig. 9). Data from several experimental groups are shown,³¹⁻³³ and it can be seen that systematic errors are sizeable. This is also the case for the $\Delta\sigma_L$ ($I=0$) results. The rise in the spin-averaged total cross section occurs at a somewhat higher energy than in the pp case. Thresholds for the various inelastic channels are the same as in the $I=1$ case except that the $N\Delta$ channel, which was suspected to be the cause of the structure in $\sigma_{Tot}(pp)$ and $\Delta\sigma_L(pp)$ near 1.5 GeV/c, cannot occur in $I=0$. In particular, threshold effects are not the cause of structure observed near 1.5 GeV/c in the $I=0$ channel.

Before describing the data, consider a few relevant experimental details. Unfortunately, there are experimental problems at the ZGS with the use of either a polarized neutron or longitudinally polarized deuteron beam incident on a polarized target. It is also impossible to make a target of free neutrons, that is neutrons not bound in some nucleus. Therefore, the experiment used a beam of polarized protons from the Argonne ZGS and precessed the proton spin to the longitudinal direction. The polarization direction was reversed on alternate pulses, which greatly assisted in reducing systematic errors. The target material was partially deuterated ethylene glycol. Thus the target neutrons are not free, but are bound inside a deuteron. Most of the experimental runs had either the deuterons polarized or both the free protons and the deuterons polarized.

The number of incident protons was counted with three scintillators in the beam. Rejection of particles that would miss the target was performed with various beam veto counters. A set of circular scintillators, located about 2m downstream of the target, recorded the number of charged particles as a function of the solid angle subtended. The number of noninteracting beam particles transmitted through the target was determined for the two beam spin directions by extrapolating the counts in the circular scintillators to zero solid angle. The difference in pure spin total cross sections, $\Delta\sigma_L$, was then computed.

In order to extract the $I=0$ total cross section difference $\Delta\sigma_L(I=0)$, a number of subtractions and corrections were required. First, for runs in which both free target protons and deuterons were polarized, $\Delta\sigma_L(pp)$ was subtracted to give the directly measured quantity $\Delta\sigma_L(pd)$. These values agreed well with $\Delta\sigma_L(pd)$ for runs where only the deuterons in the target were polarized. Alternately, both $\Delta\sigma_L(pp)$ and $\Delta\sigma_L(pd)$ could be extracted using all the runs and the known target polarizations for protons and deuterons. The values of $\Delta\sigma_L(pp)$ from this method of analysis are compared to previous measurements in Fig. 6. Most of the new measurements were performed at energies where $\Delta\sigma_L(pp)$ data already existed. As can be seen, the agreement is quite good, which gives added confidence in the $\Delta\sigma_L(pd)$ results.

The preliminary results of $\Delta\sigma_L(pd)$ are given in Fig. 7 along with the spin-averaged total cross section $\sigma^{Tot}(pd)$. These data are quite smooth and featureless compared to the pp case. Errors shown are statistical only. At present, systematic errors are estimated to be $\pm 10-15\%$, due mainly to the target polarization uncertainty. These errors may be reduced after we perform a more refined data analysis. Note that $\sigma^{Tot}(pd)$ shows more structure than $\Delta\sigma_L(pd)$.

We have had to rely on some theory to extract $\Delta\sigma_L(pn)$ from the $\Delta\sigma_L(pd)$ results. In the simplest approximation

$$\Delta\sigma_L(pd) \approx \Delta\sigma_L(pp) + \Delta\sigma_L(pn) \quad .$$

Fig. 6. $\Delta\sigma_L(pp)$ vs. P_{LAB} . The solid circles are data from Refs. 5, 6, 8 and the open triangles are preliminary results using a polarized proton target. The open circles are preliminary $\Delta\sigma_L(pp)$ values measured with a partially deuterated target at the same time as the $\Delta\sigma_L(pd)$ results. The dashed curve at low energy is to guide the eye, and the solid curve at high energy is a prediction from Ref. 28.

Fig. 7. pd Total Cross Sections. The values of $\sigma^{Tot}(pd)$ are from Refs. 31-33. All errors shown are statistical only. Systematic errors for the $\Delta\sigma_L(pd)$ results are ± 10 -15%.

However, deviations from this simple approximation occur because the neutron can be shadowed by the proton when the incident particle strikes the deuteron, and also because the neutron is moving inside the deuteron; termed Fermi-motion. C. Sorensen³⁴ derived a formula relating $\Delta\sigma_L(pn)$ with the quantities $\Delta\sigma_L(pd)$, $\Delta\sigma_L(pp)$, $\sigma^{Tot}(pn)$, $\sigma^{Tot}(pp)$ and the real parts of the forward pp and pn amplitudes within the framework of Glauber theory (see also Ref. 35). Since the $I=0$ forward amplitudes are poorly known, especially the real parts, an approximation was made to extract $\Delta\sigma_L(pn)$. The real parts of all forward amplitudes were assumed to be zero for the data shown. (More refined Glauber corrections will be made in the future.) Simple corrections were applied for the D-state of the deuteron wave function. In order to account for Fermi-motion effects, the $\Delta\sigma_L(pp)$ values were averaged for the momentum distribution of the proton inside the deuteron. The results are shown in Fig. 8. The features in both $\sigma^{Tot}(pn)$ and $\Delta\sigma_L(pn)$ are smeared by Fermi-motion of the neutron inside the deuteron. Statistical errors are shown; however systematic errors from the corrections and target polarization uncertainty are larger than the statistical errors.

Finally, $\Delta\sigma_L(I=0) = 2\Delta\sigma_L(pn) - \Delta\sigma_L(pp)$ is shown in Fig. 9. Recall from Fig. 7 that $\Delta\sigma_L(pd)$ is smooth. Therefore, the peak in $\Delta\sigma_L(I=0)$ and $\Delta\sigma_L(pn)$ at 1.5 GeV/c arises from the subtraction of $\Delta\sigma_L(pp)$. Fermi-motion effects cannot smear $\Delta\sigma_L(pp)$ sufficiently to make the peak in $\Delta\sigma_L(I=0)$ disappear, because the smear is typically ± 100 MeV/c in P_{LAB} . It is also believed that the refined analysis of the shadowing or Glauber corrections, especially taking the real parts of the forward amplitudes into account, and the D-state corrections will change the values of $\Delta\sigma_L(I=0)$ in a smooth and slowly varying manner. Therefore, it appears that there is a striking peak in $\Delta\sigma_L(I=0)$ near 1.5 GeV/c. As mentioned previously, this structure cannot be caused by the $N\Delta$ channel, since it cannot contribute to $I=0$.

If the $I=0$ total cross sections are expressed in terms of partial waves, then

$$\Delta\sigma_T \sim \text{Singlet} - \text{Triplet } (J=L\pm 1, \text{ odd})$$

$$\sigma^{Tot}(\vec{s}) \sim \text{Singlet} + \text{Triplet } (J=L\pm 1, \text{ odd})$$

$$\sigma^{Tot}(\vec{s}) \sim \text{Triplet } (J=L, \text{ even}) + \text{Triplet}' (J=L\pm 1, \text{ odd})$$

in the same notation as that used for the $I=1$ case. A peak in $\Delta\sigma_L(I=0)$ would be characteristic of a spin-singlet partial wave or waves, 1P_1 and/or 1F_3 . Unfortunately, additional information is lacking at this time. Polarization data for $I=0$ do not cover wide angular ranges, and thus a Legendre coefficient analysis is not possible. Furthermore, $Pd\sigma/d\Omega$ only contains contributions from spin-triplet terms. If the structure in $\Delta\sigma_L(I=0)$ is caused by spin-singlet partial waves, $Pd\sigma/d\Omega$ would not assist the identification of quantum numbers. Contributions from spin-singlet terms

Fig. 8. pn Total Cross Sections. The values of $\sigma^{\text{Tot}}(\text{pn})$ are from Refs. 31-33. Errors on the $\Delta\sigma_L(\text{pn})$ data are statistical only. Simple corrections for shadowing, for the D-state of the deuteron and for Fermi-motion of the proton have been applied (see the text). All cross sections are smoothed by Fermi-motion of the neutron in the deuteron target. The curve is a guide to the eye.

Fig. 9. $I=0$ Total Cross Sections. (See the caption for Fig. 8.)

are isolated in the quantity $\Delta\sigma_T + \sigma^{\text{Tot}}(\frac{1}{2})$; unfortunately $\Delta\sigma_T(I=0)$ has not been measured. Although it appears there is remarkable structure in $\Delta\sigma_L(I=0)$, the interpretation is unclear until additional data are available in the $I=0$ system.

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