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INELASTIC PROTON-PROTON SCATTERING AND NUCLEON ISOBAR PRODUCTION

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This letter reports the results of measurements of inelastic proton-proton scattering at a fixed laboratory angle of 60 mrad for incident proton momenta in the range 3.6 to 11.8 GeV/c. Momentum spectra of positively charged particles emitted at a fixed laboratory angle of 60 mrad were measured using a magnetic spectrometer¹⁾ of resolution better than 1%.

Targets of CH₂ and C were bombarded alternately by the internal beam of the CERN proton synchrotron. The momentum spectra of the secondaries from p-p collisions were obtained from the CH₂ and C spectra by subtraction, using the Be⁷ activity of the targets and the measured values²⁾ of the Be⁷ cross section to obtain absolute cross sections. The elastic p-p cross sections obtained are in reasonable agreement with those found in other experiments^{3,4)}.

Figure 1 shows nine momentum spectra of positive particles emitted at 60 mrad in p-p collisions. (The elastic scattering peaks have been omitted).

The main features of the spectra will be discussed in terms of nucleon isobar production, namely the process

N^* being a resonant pion nucleon state. The positive particles detected in this experiment have momenta just below that of the elastic peak and are either scattered protons resulting from excitation of the target nucleon or protons from the decay of excited incident protons. The background from π^+ may be neglected in the region explored as is shown by the experiment of Melissinos et al.⁵⁾ at 3.7 GeV/c incident momentum.

The following qualitative statements may be made about the spectra of Fig. 1:

- a) A peak corresponding to the excitation of the target nucleon to the $(3/2, 3/2)$ resonant state of mass 1.24 GeV is observed at incident proton momenta, p_0 , between 3.60 and 7.68 GeV/c. The intensity of the peak decreases with increasing momentum until it is submerged by the background at $p_0 = 8.94$ GeV/c.
- b) Two peaks of higher mass are seen for $p_0 \geq 4.47$ GeV/c and traces of the less massive of these are probably present also for $p_0 = 3.60$ and 4.10 GeV/c. The peaks grow more prominent with increasing incident momentum.
- c) The position of the peak nearest to the $(3/2, 3/2)$ state changes with the incident momentum. A hint of this behaviour may be seen in the data of Chadwick et al.⁶⁾ at 2.9 and 3.7 GeV/c. The mass corresponding to the centre of the peak changes from 1.4 GeV for $p_0 = 3.60$ GeV/c to 1.51 GeV for $p_0 \geq 6.23$ GeV/c where it can be assigned to the $(1/2, 3/2)$ pion-nucleon resonance of mass 1.512 GeV. Its interpretation

for lower values of p_0 will be discussed below. The centre of the third peak remains close to a mass of 1.69 GeV for all incident momenta and it is therefore assigned to the $(1/2, 5/2)$ pion-nucleon resonance of mass 1.688 GeV.

In spite of the clear resolution of the isobar peaks a quantitative measurement of the cross sections for the resonance production is rendered difficult by the large and variable continuum of cross section under the peaks. A one pion exchange model calculation by E. Ferrari⁷⁾ for $p_0 = 3.60$ and 4.10 GeV/c shows that fair estimates of isobar production by a single neutral pion exchange are obtained from the area enclosed by the peaks. The residue of the cross section is found by Ferrari to be well accounted for by the contributions from decaying isobars and from multi-pion production.

Guided by Ferrari's calculated spectra an attempt has been made to resolve quantitatively the cross sections for the nucleon isobar peaks. This is indicated by the dotted curves in Fig. 1. It must be stressed, however, that since the shape of the background spectra changes drastically with increasing p_0 , this procedure is rather ill defined. The cross sections deduced are shown in Fig. 2. They should be reliable to within $\pm 50\%$.

Another ambiguity appears in the determination of the cross section of the $(1/2, 3/2)$ state where the position of the peak shifts with p_0 . The cross section for this state has been measured in two ways,

- 1) including only the part of the peak centred at a mass of 1.512 GeV and with a width of about 130 MeV;
- 2) including the whole broad bump from a mass of about 1.35 to 1.60 GeV.

The two cross sections obtained from methods 1 and 2 are represented in Fig. 2 by vertical dotted lines joining the two values.

The cross sections for production of the $(3/2, 3/2)$ state are shown in Fig. 3 together with equivalent data from Chadwick et al⁶). The latter data were angular distributions, taken at fixed incident momenta, while those of the present experiment were taken at a fixed laboratory angle. The cross section, $\frac{d\sigma}{dt}$, decreases strongly with increasing incident momenta for fixed four-momentum transfer t .

Excitation of the $(1/2, 3/2)$ and $(1/2, 5/2)$ states has been previously observed and discussed by several authors^{3,6}). As is seen in Fig. 2 the production cross sections for these two states have essentially the same t dependence, markedly different from that of the $(3/2, 3/2)$ state.

As a conclusion it appears that the production cross section of the $(3/2, 3/2)$ state decreases much more rapidly with increasing t than those for the isotopic spin $1/2$ states. The difference in behaviour of the isotopic spin $1/2$ and $3/2$ states may be associated with the necessity for exchange of isotopic spin 0 and 1 respectively in the production processes.

The peak corresponding to the $(1/2, 3/2)$ state appears shifted towards lower mass at low incident momenta. Two possible explanations for such a shift are listed below.

- 1) From kinematics the proton spectrum from the decay of high-energy $(3/2, 3/2)$ states should produce a ledge on the high-momentum side of the $(3/2, 3/2)$ peak. The results of Ferrari's calculation exhibit this behaviour. A similar situation holds for the $(1/2, 3/2)$ state. If the angular distribution of the decay protons from this state is strongly peaked forward, the resulting decay spectrum may show a sharp maximum at a mass lower than that of the isobar itself. This would particularly be the case for lower incident momenta, where the decay spectra cover only narrow momentum bands.
- 2) The shift could also be explained by the existence of a new nucleon isobar of mass about 1.4 GeV. If the excitation of this isobar were to decrease with increasing energy and momentum transfer in a way similar to that of the $(3/2, 3/2)$ state, the peak would gradually be replaced by that due to the $(1/2, 3/2)$ isobar, giving the impression of a continuous shift from a mass of 1.40 to 1.51 GeV.

The existence of an isobar state at a mass of 1.40 GeV would imply that the energy spectrum of the pion-nucleon total cross section should show a bump at about 420 MeV pion kinetic energy. Recent data of Bareyre et al ⁸⁾ exhibit a shoulder in the $\pi^- - p$ total cross section at a pion energy corresponding to a mass of about 1.40 GeV. No such structure is observed in the $\pi^+ - p$ cross section. This total cross section result tends to reinforce the proposal of the existence of a new pion-nucleon resonant state of mass 1.40 GeV. The results of Bareyre et al, of course, lead to an isotopic spin assignment of $1/2$. The apparent rapid decrease with respect to t in the bump observed at a mass of 1.40 GeV in the present experiment leads to a prejudice for isotopic spin $3/2$ by comparison with the $(3/2, 3/2)$ excitation. Further observations at smaller angles and higher energies can, perhaps throw more light on this problem.

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FIGURE CAPTIONS

- Figure 1 : Momentum spectra of inelastically scattered protons from p-p collisions, (lab system). Arrows indicate the momenta of the incoming protons, p_0 . One scale shows the missing mass, M^* , with the positions of the proton (elastic peak) and the three first nucleon isobars indicated. A second scale shows the square of the four-momentum transfer, $-t$. The dotted lines show how the cross sections for the production of the $(3/2, 3/2)$ isobar have been obtained. The elastic peaks that come at a momentum approximately equal to p_0 are omitted as they are from 25 to 50 times higher than the inelastic ones.
- Figure 2 : Cross sections, $\frac{d\sigma}{dt}$, for production of the $(3/2, 3/2)$, $(1/2, 3/2)$ and $(1/2, 5/2)$ nucleon isobars in p-p collisions as a function of t . All points shown, also those for the elastic cross sections, were obtained at a laboratory angle of 60 mrad. The significance of the vertical dotted lines is explained in the text.
- Figure 3 : Cross sections, $\frac{d\sigma}{dt}$, for production of the $(3/2, 3/2)$ isobar in p-p collisions as a function of t . The data for $p_0 = 2.9$ and 3.7 GeV/c are taken from Chadwick et al⁶).

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Fig.1

Fig. 2

Fig. 3