PRODUCTION OF NUCLEON ISOBARS IN PROTON-PROTON COLLISIONS*

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The isobar model of pion production has developed from the work of Watson,[1] Peaslee,[2] Lindenbaum and Sternheimer,[3] and Mandelstam,[4] and has been supported by experimental work in both nucleon-nucleon[5-9] and pion-proton[10, 11] collisions. In this model it has been assumed that the process of meson production proceeds through two stages, first the production of an isobar (a nucleon in an excited state) and secondly the decay of the isobar to a normal nucleon and a π meson. Calculations have been made[3] on the basis of this model by assuming that the probability for producing an isobar of given mass can be related to the variation of cross section with energy for the (3/2, 3/2) resonant state of the π-p system. Because of the finite width of this resonance there is a distribution of possible values of the isobar mass with a maximum probability at 1.23 Bev, given by the resonant pion kinetic energy of 195 Mev, and leading in p-p collisions to a corresponding maximum in the energy spectrum of the protons recoiling in the production process. Experimentally this peak should be superimposed upon a fairly smooth distribution of energies representing decays of the isobar by the proton mode and should contain 3/14 of all the protons observed.

We have investigated the validity of the isobar model by observing the momentum spectrum of inelastically scattered protons from p-p collisions with the arrangement shown in Fig. 1. The external proton beam from the Cosmotron was focussed at the center of a 15-in. long liquid hydrogen target. The momentum spectrum of protons emerging at 4.8° to the incident beam was determined using an analyzing magnet and a counter telescope, giving a momentum resolution of ±3.4%. It was unnecessary to discriminate against pions since these were kinematically excluded from the momentum region of interest. The incident proton beam was monitored by a thin argon-filled ionization chamber which was placed in front of the target.

Incident proton energies of 1.04, 1.20, 1.35,

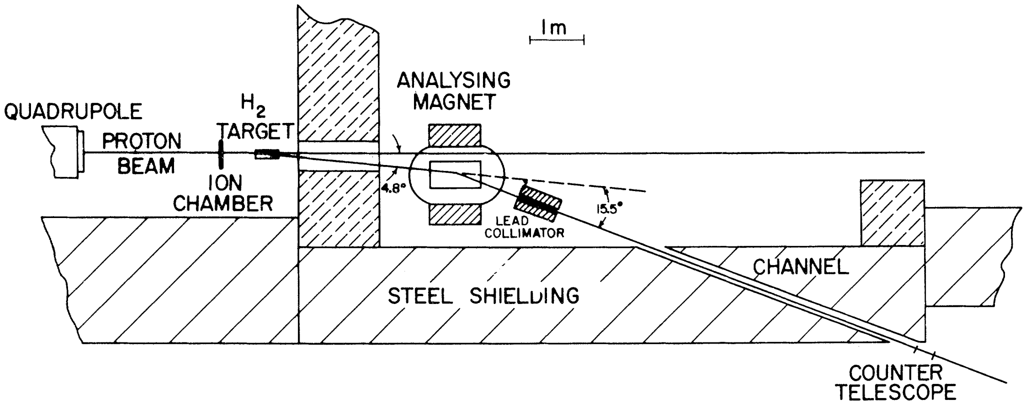

FIG. 1. Experimental arrangement.

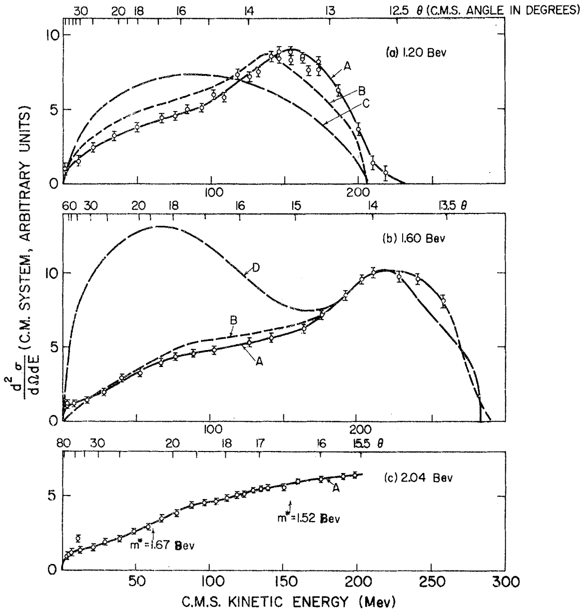

FIG. 2. Center-of-mass energy spectra of inelastically scattered protons from p-p collisions at (a) 1.20, (b) 1.60, and (c) 2.04 Bev. Curves A fit the experimental points, curves B are spectra expected for single meson production from the isobar model, curve C is the three-body phase space factor, and curve D is the predicted spectrum from the isobar model for one- and two-meson production in the ratio of their observed production cross sections. The center-of-mass angle of observation is shown above each section.

1.60, 1.74, and 2.04 Bev were used. The spectra of inelastically scattered protons, transformed into the center-of-mass system for three of these energies, are shown in Fig. 2. At the first two energies mentioned above, the elastically scattered protons were within the momentum range of the spectrometer but these are not shown in the figure. The statistical error in the number of counts was less than ± 1% over most of the momentum range covered; the errors shown represent an estimate of beam monitor fluctuations. The background counting rate, obtained from an empty target, was almost constant except at momenta close to that of the elastically scattered protons and equal to about 17% of the counting rate obtained from a full target in the region of the maximum in the inelastic scattering.

The theoretical curves B and D in Fig. 2(a) and 2(b) were calculated by Sternheimer[12] assuming an isotropic distribution for the production and decay of the isobar but without folding in the experimental resolution. The agreement between the experimental curve A and the calculated curve B at 1.20 Bev [Fig. 2(a)] is sufficiently good to give strong support to the isobar model. There is no agreement with the distribution predicted on a statistical basis (curve C). The peak in curve B indicates an isobar mass of 1.19 Bev which, when compared with the value 1.23 Bev obtained from π-p scattering data, is a bit outside our estimated experimental uncertainty. Similar shifts are observed at 1.04, 1.35, and 1.60 Bev incident energies, giving masses of 1.19, 1.18, and 1.21 Bev, respectively.

At 1.6 Bev [Fig. 2(b)] the experimental spectrum A agrees well with the theoretical curve B, calculated for single meson production only, which is surprising because the known ratio for double to single meson production is 0.5 ± 0.3 at this energy[8] so that protons from the double production process should add to the spectrum to give curve D. This discrepancy seems to imply a radical difference in the angular distributions of the two processes so that the single production recoils predominate at smaller angles. It is possible that the introduction of appropriate angular distributions into the theory would account for some of the disagreement shown in Fig. 2(a), but probably would not explain the shift in the peak.

In addition to the 3/2, 3/2 resonance so clearly evident in our data, previous work on pion photoproduction[13, 14] and pion-nucleon scattering[15, 16] has indicated the existence of additional resonances. The first two belong to the $T = 1/2$ system and correspond to total masses of 1.52 and 1.67 Bev. If these new states are interpreted as isobars they should be formed in p-p collisions; in fact the Clebsch-Gordan coefficients for the production of "recoil" protons together with $T = 1/2$ isobars give them a statistical weight relative to "decay" protons of 3, as compared with 3/11 for the $T = 3/2$ isobar case.

The expected positions of peaks in the proton spectrum for an incident energy 2.04 Bev are shown by arrows in Fig. 2(c), which gives the experimental results at this energy. There is no evidence for production of these isobars, either at this or at the lower energies investigated.

It is proposed to observe these spectra at several more angles and higher incident energies in order to investigate the angular distribution of the isobar production and to continue searching for the formation of higher mass isobars.

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NEUTRINOS EMITTED IN β DECAY AND μ CAPTURE*

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Lee and Yang have recently drawn attention to the possibility that the neutrinos ν_1, ν_2, emitted in μ^- capture and β^+ decay, respectively,

$$\mu^- + p \rightarrow n + \nu_1,$$
$$(A,Z) \rightarrow (A,Z-1) + e^+ + \nu_2, \qquad (1)$$

may not be identical particles.[1] Indeed, if the absence of the photodecay $\mu \rightarrow e + \gamma$ is to be reconciled with the intermediate vector boson theory[2] of weak interactions, then it must be assumed that:

(a) the helicity of ν_1 is the same as the helicity of ν_2;

(b) ν_1 and ν_2 must differ in some internal coordinate which may, perhaps, be the analog for leptons of the "strangeness" of hyperons and K mesons.

After the discussion by Lee and Yang had appeared, it was reported that an attempt to measure the helicity of the μ^- emitted in π^- decay had yielded no definite result.[3] Therefore, since the helicity of ν_1 is still an open question, it is of some interest to examine the consequences of an assumption alternative to (a), namely:

(a′) ν_1 and ν_2 are created with opposite helicities in μ^- capture and β^+ decay, respectively.

Let us suppose that the coupling of leptons to bare nucleons is $V-A$, both for β decay and μ capture.[4] Since the helicity of ν_2 in (1) is negative,[5] the interaction Hamiltonian is

$$\mathcal{H}_\pm = (\bar{\psi}_p \gamma_\lambda (g_V + g_A \gamma_5) \psi_n)[(\bar{\psi}_\mu \gamma_\lambda (1 \pm \gamma_5) \psi_{\nu_1}) + (\bar{\psi}_e \gamma_\lambda (1 + \gamma_5) \psi_{\nu_2})] + \text{H.c.}, \qquad (2)$$

where the positive sign corresponds to assumption (a) and the negative to (a′). From the conservation of spin and momentum in π decay,

$$\pi^- \begin{array}{l} \nearrow \mu^- + \bar{\nu}_1 \\ \searrow e^- + \bar{\nu}_2 \end{array} \qquad (3)$$

(for clarity we shall only consider the π^-), it follows that $\mathcal{H}_-$ implies the same branching ratio of the $(\pi - e)$ mode to the $(\pi - \mu)$ mode as does $\mathcal{H}_+$; this theoretical ratio is in agreement with the experimental value.

Consider now the $\pi - \mu - e$ chain: the only established experimental facts are[5]: