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Analysis of Isobar Production in p+p at 28.5 BeV*

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The production of isobars at several energies up to ~30 BeV in highly peripheral p+p and p+D reactions has been investigated recently with counters and spark chambers.^{1,2} These experiments determined the missing-mass spectrum in the reactions p+p → p(fast in the laboratory) + (missing mass), by measuring the momentum of the fast proton. The missing-mass spectrum revealed enhancements which were interpreted as nucleon-pion isobars. An enhancement centered at ~1400 MeV was prominent at all energies studied. The only other experimental evidence for a 1400 MeV resonance besides these high-energy proton experiments, comes from π-N phase-shift analysis.³

The purpose of our experiment is to study isobar production in a bubble chamber (80" BNL H₂ chamber), where it is possible to see the charged decays of the isobars and thus determine the quantum numbers of possible resonant states. We are particularly interested in investigating the 1400 enhancement which, according to the phase shift analysis, should be a P₁₁ resonance. A total of 75,000 pictures have been taken at 28.5 BeV.

To date we have processed approximately 1500 two-prong and 500 four-prong events. Since isobar production seems to be highly peripheral,² we have selected our sample by requiring that a

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stopping proton be identified. A measurement of the stopping-proton momentum and angle gives us approximately the same resolution as the counter experiments which detected the fast proton, since the following processes are mirror images of each other

- (A) $p+p \rightarrow p \text{ (fast)} + \text{(missing mass)}$
- (B) $\quad \quad \rightarrow p \text{ (slow)} + \text{(missing mass)}$

By "missing Mass" is meant the invariant mass of all outgoing particles except the stopping proton.

Our results can be summarized as follows:

1) First consider reactions of type B in the two-prong events. Fig. 1 is a plot of the range of the stopping proton vs its angle with respect to the beam direction. A specific value for the "missing mass" results in a curve on this plot which is insensitive to the beam momentum. In Fig. 1 we can see a well defined cluster of points which correspond to the elastic scattering events in our sample. The spread in the distribution is a result of our finite measuring resolution. No other prominent features show up in this plot, except that a scanning loss of events with range $< 3.5\text{cm}$ is apparent. Few events occur with range $> 40\text{cm}$ since the tracks leave the chamber without stopping.

2) A plot of the "missing mass" from reaction B for two-prong events is made with $\Delta^2 < 0.16 (\text{BeV}/c)^2$ (Fig.2), and with $0.04 < \Delta^2 < 0.16$ (Fig.3). It may be inferred that a broad peak occurs in the region centered at 1400 MeV if one can believe that there is a significant dip in the distribution at about 1150 BeV which separates the "1400" peak from the elastics. We can also infer from the width of the elastic distribution that our resolution is about ± 100 MeV.

3) Plots of the "missing mass" for four-prong events similar to the previous plots for two-prongs are shown in Fig. 4 ($\Delta^2 < 0.16$) and Fig. 5 ($0.04 < \Delta^2 < 0.16$). If we take the width of the 1400 from Anderson et al.² as $\Gamma = 180$ MeV, and our resolution to be ± 100 MeV, we must look for a band in missing mass of width ~ 300 MeV representing the 1400. The counter results also imply that the contribution of the 1238 and 1512 resonances at low momentum transfer can be neglected at our energy. The presence of the 1400 is not obvious here, which indicates that the 1400 decays less frequently by the inelastic than the elastic mode.

4) We make one-constraint fits to our two-prong events with the hypothesis $p+p \rightarrow p + (p + \pi^0)$ or $p + (n + \pi^+)$. If we select events whose effective mass lies in the 300 MeV band mentioned above for both the $(p + \pi^0)$ and $(n + \pi^+)$ systems, we can infer the isotopic spin of a possible resonance in the 1400 MeV region from the ratio of $(n + \pi^+)$ to $(p + \pi^0)$ interpretations. After making appropriate cuts to exclude ambiguous events, we find 26 $(n + \pi^+)$ and 17 $(p + \pi^0)$ cases, resulting in a ratio of $(n + \pi^+)/ (p + \pi^0) = 1.5 \pm 0.3$. A ratio of 2:1 is predicted for $T=1/2$, and 1:2 for $T=3/2$; hence our results are consistent with the prediction of a $T=1/2$ state from phase-shift analysis.³

5) The four-prong $p\pi^+p\pi^-$ four-constraint events were investigated for possible single- and double-isobar production. A total of 96 events whose χ^2 probability was ≥ 0.01 were used. In Fig. 6 we have plotted the effective mass for all $p\pi^+$ combinations (a), and all $p\pi^-$ combinations (b). We note from the histograms that the 1238 resonance seems to be strongly produced in both modes, but no other isobars are indicated. There were also 9 events where the 1238 was produced as $p\pi^+$ and $p\pi^-$ simultaneously. This is an interesting result since there is little suggestion of

1238 production at ~ 30 BeV in single isobar production (i.e. $p+p \rightarrow p+N^*$) from the counter experiments. The latter have sufficient statistics to resolve a 1238 if it exists. However, we note from $p+p$ experiments at $\sim 3-5.5$ BeV^{4,5} that $N^*(1238) + (\text{nucleon})$ is about 5 to 10 times as great as final states involving $N^*(1238) + (\text{Nucleon} + \text{pion})$ where the $(\text{Nucleon} + \text{Pion})$ may or may not be an isobar.

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2. E.W. Anderson, et al., Phys Rev Letters 16, 855 (1966).
3. For a discussion of 1400 resonance from phase shift analysis for example, reports by Peyrou and Dalitz from Proceedings of Oxford Conference, 1965.
4. p+p at 3.6 MeV/c E.L. Hart et al., Phys. Rev. 126, 747 (1962). and G.A. Smith et al., Phys. Rev. 123, 2160 (1961).
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Figures

1. Range vs. angle of stopping proton. Smooth curves represent traces that are followed if the "missing mass" particle is 938, 1238, 1400, 1512, 1688 MeV.
2. "Missing Massing" distribution computed from beam momentum and momentum of stopping proton for 2-prong events ($\Delta^2 < 0.16$).
3. Same as 2 with a $0.04 < \Delta^2 < 0.16$ cut.
4. Same as 2 but for 4-prong events.
5. Same as 4 but with a $0.04 < \Delta^2 < 0.16$ cut.
6. a) Effective mass of all $p+\pi^+$ from 4-prong events.
b) Effective mass of all $p+\pi^-$ from 4-prong events.

BEY

MISSING MASS

5' 6' 7' 8' 9' 10' 11' 12' 13' 14' 15' 16' 17' 18' 19' 20' 21' 22' 23' 24' 25'

FIG. 2
 MISSING MASS (TWO-PRONG)
 $\Delta^2 < .16$

0.75

MISSING MASS

5.2 4.2 3.2 2.2 1.2 0.2 1.5 1.8 1.4 1.6 1.5 1.4 1.3 1.2 1.1 0.2 1.9 1.8 1.7 1.6 1.5 1.4 1.3 1.2 1.1 1.0 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0.0

$\Delta^2 < 0.16$

MISSING MASS (FOUR-PROJ.)

Fig 4

BEV

MISSING MASS

1.5 1.4 1.3 1.2 1.1 1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 .0 2.0 2.1 2.2 2.3 2.4 2.5

2
4
6
8
10

$$.04 < \Delta^2 < .16$$

MISSING MASS (Four-Proton)

FIG. 5

NUMBER OF EVENTS

FIG. 6

(a)

(b)

SUM OF (a) + (b)

EFFECTIVE MASS (P+T) MEV

EFFECTIVE MASS (P+T) MEV