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(Presented by Robert W. Birge)

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In an SU3 supermultiplet the difference in mass between the various isotopic spin multiplets is typically of the order of 100 MeV. This mass splitting is believed due to the violation of SU3 symmetry by part of the strong interaction, and is accurately described by the Gell-Mann-Okubo mass formula.[1]

The mass splitting within an isotopic-spin multiplet is determined by the electromagnetic interaction and is of the order of 10 MeV. By assuming SU3 symmetry and neglecting the effects of the violation due to the strong interactions, one can relate the mass splitting in different isotopic-spin multiplets of the same supermultiplet with the formula $m = m_0 + aQ + bQ^2$. In the baryon octet, for example, the prediction[2] that $m(\Xi^-) - m(\Xi^0) = m(\Sigma^-) + m(\Sigma^+) + m(p) - m(n) = 6.7 \pm 0.5$ MeV has been experimentally confirmed.[3]

In the $3/2^+$ decuplet, whose members are $N^*(I=3/2,\ Y=1)$, $Y^*(I=1,\ Y=0)$, $\Xi^*(I=1/2,\ Y=-1)$, and $\Omega^-(I=0,\ Y=2)$, the following relationships are predicted:[4]

$$m(N^{*++}) - m(N^{*-}) = 3[m(N^{*+}) - m(N^{*0})]$$
$$m(N^{*0}) - m(N^{*-}) = m(Y^{*0}) - m(Y^{*-})$$
$$m(N^{*+}) - m(N^{*0}) = m(Y^{*+}) - m(Y^{*0}) .$$

Recently a group at CERN[5] has reported a mass difference $\Delta m(Y^*) = m(Y^{*-}) - m(Y^{*+}) = 17 \pm 7$ MeV while a Berkeley group[6] has measured $\Delta m(Y^*) = 4.4 \pm 2.2$ MeV. In the "Tadpole" theory of Coleman and Glashow,[8] b=0 (equal splitting), and the N^* becomes the member of the decuplet most sensitive to Electromagnetic mass splittings; the Y^* measurements implying mass differences $\Delta m(N^*) = m(N^{*-}) - m(N^{*++}) = 25 \pm 10$ MeV and 6.6 ± 3.3 MeV, respectively. However, "nontadpole" contributions to the mass splittings cannot be neglected and alter these predictions.[8,9]

Okubo has recently pointed out that, because of electromagnetic mass splitting, the Gell-Mann—Okubo mass formula is valid only for particles with the same charge from each mulitplet.[7] In particular the mass of N^{*-} is required for the comparison $m(\Omega^-) - m(\Xi^{-*}) = m(\Xi^{-*}) - m(Y^{-*}) = m(Y^{-*}) - m(N^{-*})$.

We report here a measurement of $\Delta m(N^*)$, using the two reactions

$$n + n \rightarrow n + p + \pi^- \qquad \text{(907 events)} \qquad (1)$$

and

$$p + p \rightarrow n + p + \pi^+, \qquad \text{(791 events)} \qquad (2)$$

which are known to procede almost entirely via N^{*-} and N^{*++} production respectively in our energy region. In general, for these three-body final states the peak in the π-nucleon effective mass distribution does not coincide with the mass of the resonance (defined as the energy at which the phase shift goes through 90 deg in π-nucleon scattering); the apparent shift in the resonance energy depends upon the reaction mechanism (e.g., single-pion exchange), and on the interaction energy in reactions (1) and (2). In consequence, a valid comparison of N^* masses requires that thé different charge states be produced in charge symmetric reactions at the same energy, under identical experimental conditions. The reactions were simultaneously achieved at the same energy by the interactions of 3.68-GeV/c deuterons with deuterium in the Brookhaven National Laboratory's 20-inch bubble chamber.

Reaction (1) was selected from events with three outgoing charged particles-- p, p, π^-. The apparent charge unbalance indicates that a proton of less than 90 MeV/c emerged, and this was clearly the spectator nucleon in the target deuteron. These events were constrained to the reaction

$$dn \rightarrow pp\pi^- n, \qquad (3)$$

assuming that the target neutron was at rest. Events with $\chi^2 \leqslant 3$, for which the neutron was not a spectator from the beam deuteron were called n-n interactions. The $(\pi^- n)$ effective mass was computed from the unconstrained variables in Eq. (3). This means that the neutron momentum is uncertain by ±90 MeV/c, in addition to the usual measurement errors. The average shift in the (π^-n) effective mass due to this effect is 0.6 MeV.

Reaction (2) was selected by looking for $dd \to p\pi^+nnn$ interactions with two emergent charged particles, $p\pi^+$. Events in which the proton momentum was consistent with its being a high-energy or low-energy spectator were excluded. The remaining events were constrained to the hypothesis $pp \to p\pi^+n$, with an incident 3.68/2-GeV/c proton and a target proton at rest. Because of the Fermi momenta of the interacting protons, the acceptance criterion on these events was raised to $\chi^2 \leq 10$. However the (π^+p) effective mass was computed from the unconstrained, measured parameters, and hence is not influenced by the uncertainty in the interaction energy.

Figure 1 shows the invariant mass plots M_{π^-n} and M_{π^+p} for the two reactions. To determine the positions of the peaks we first subtracted the reflection from N^{*0} and N^{*+} in the ratio 1:9, and then fit the curves with an S-wave Breit-Wigner (B. W.) formula multiplied into phase space (PS). For comparison with the usual πp scattering parameters, we also fit them with a P-wave Breit-Wigner formula

$$N \propto \frac{1}{q^2}\left[\frac{\Gamma^2}{(M_{N^*} - M_{\pi N})^2 + (\Gamma/2)^2}\right] \quad \text{(PS)},$$

where

$$\Gamma = \gamma^2 \left\{ 2\left(\frac{qa}{\hbar}\right)^3 \Big/ \left[1 + \left(\frac{qa}{\hbar}\right)^2\right] \right\} .$$

The results, shown in Table I, give a mass difference $\Delta m(N^*) = -0.6 \pm 5.0$ MeV.

Errors may possibly arise from (a) selection criteria or (b) systematic errors in magnetic field and beam momentum. For group (a), to test if

Table I. Masses, widths, and mass differences for N^*.

		S-wave B. W. formula	P-wave B. W. formula
Mass	N^{*-}	1218.6 ± 3.5	1226.4 ± 3.6
	N^{*++}	1219.2 ± 3.5	1227.4 ± 4.0
Width	N^{*-}	$\Gamma = 124 \pm 11$	$\gamma^2 = 77 \pm 8$
	N^{*++}	$\Gamma = 127 \pm 12$	$\gamma^2 = 77 \pm 10$
$\Delta m(N^*)$		-0.6 ± 5.0	-1.0 ± 5.4

reactions (1) and (2) as selected sampled the same configurations, we plotted the pion- and nucleon-momentum spectra for each reaction. These plots, Figs. 2 and 3, respectively, show no obvious differences. Because we use only 3-prong events in reaction (1), and hence exclude low-energy target neutrons with momentum greater than about 90 MeV/c, we allow a smaller range of center-of-mass energies than in reaction (2). However the requirement of a fit to reaction (2) has the effect of excluding high Fermi momenta. This and the coincidence of the momentum spectra lead us to believe that there is no bias here.

Since the N^* mass measured in reaction (1) is determined with a missing neutron, while that measured in reaction (2) is determined with two charged prongs, systematic errors of type (b) can simulate a mass difference. As a check, we measured the missing mass in reaction (3) and obtained 940.9 ± 3 MeV. The mean measured momentum of protons that met our high-energy spectator criteria was 1836 ± 5 MeV, in good agreement with half the beam momentum of 3.68 GeV/c as determined from magnet-current settings. These considerations together with the wellknown magnetic-field distribution in the chamber gives us confidence in our result.

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FIGURE LEGENDS

Fig. 1. Normalized invariant mass distributions for $\pi^- n$ and $\pi^+ p$ in the reactions $nn \to np\pi^-$ and $pp \to np\pi^+$ respectively.

Fig. 2. Normalized momentum distributions for neutrons and protons in the reactions $nn \to np\pi^-$ and $pp \to np\pi^+$ respectively.

Fig. 3. Normalized momentum distributions for π^- and π^+ in the reactions $nn \to np\pi^-$ and $pp \to np\pi^+$ respectively.

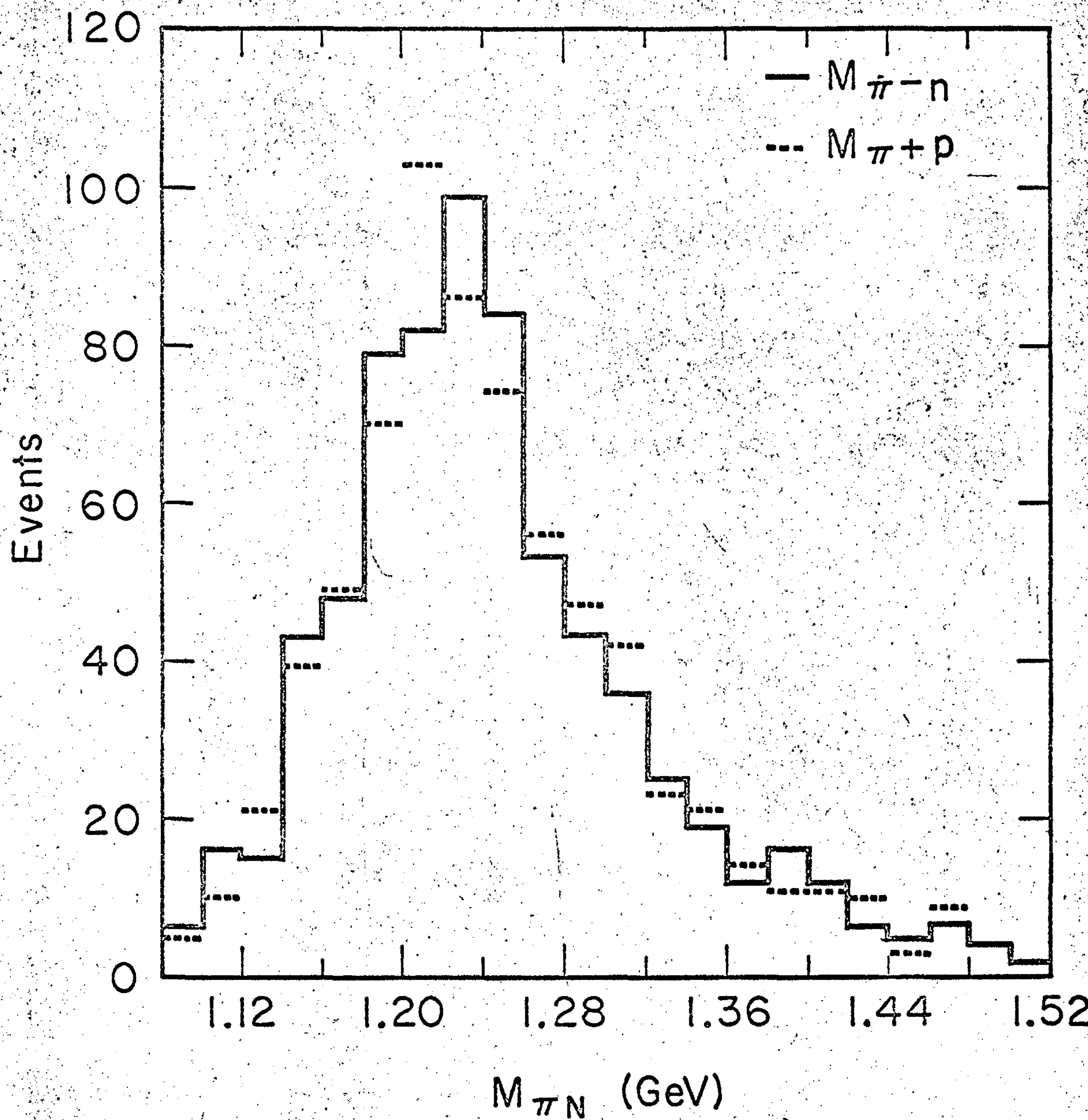

Fig. 1

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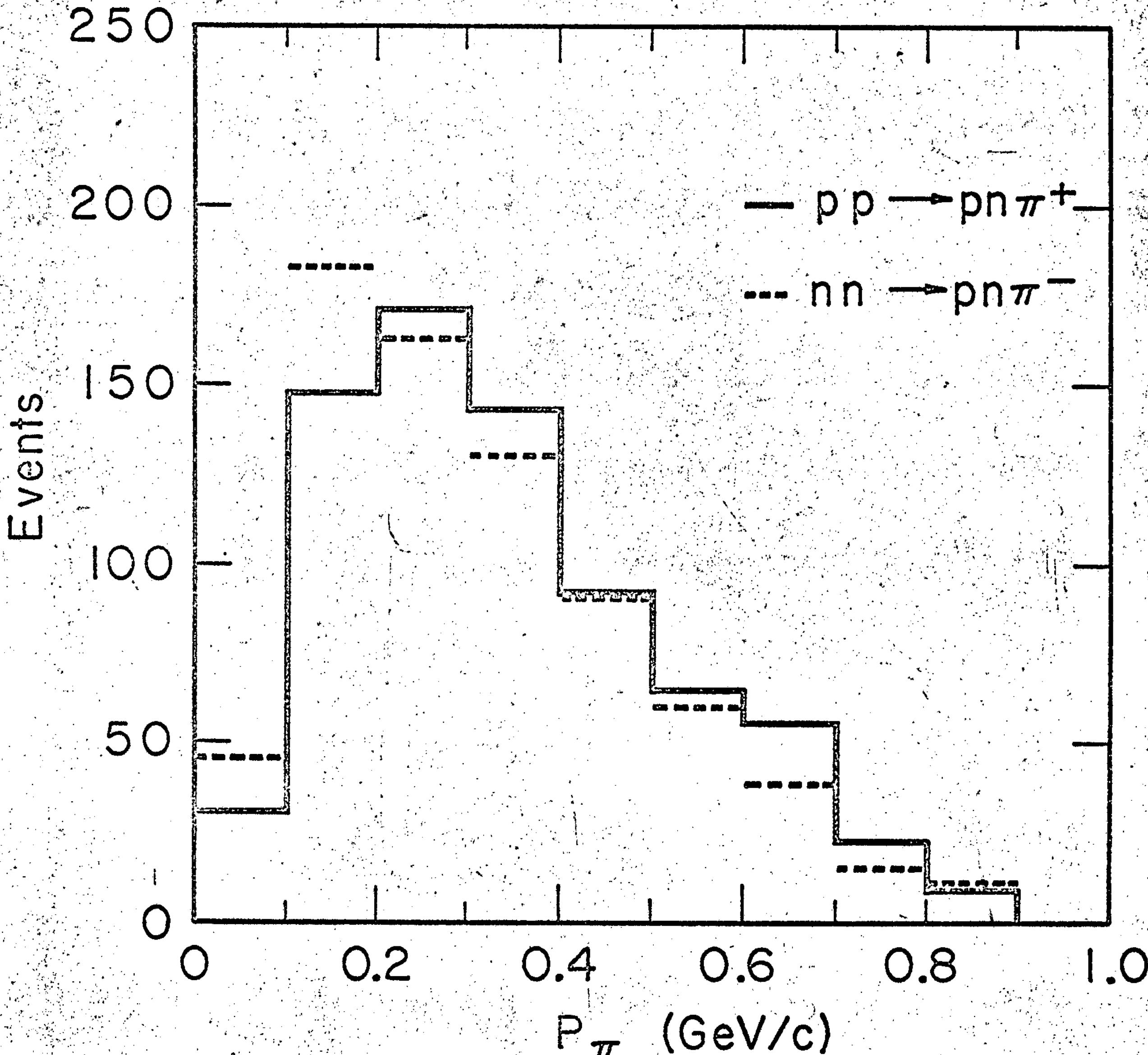

Fig. 2

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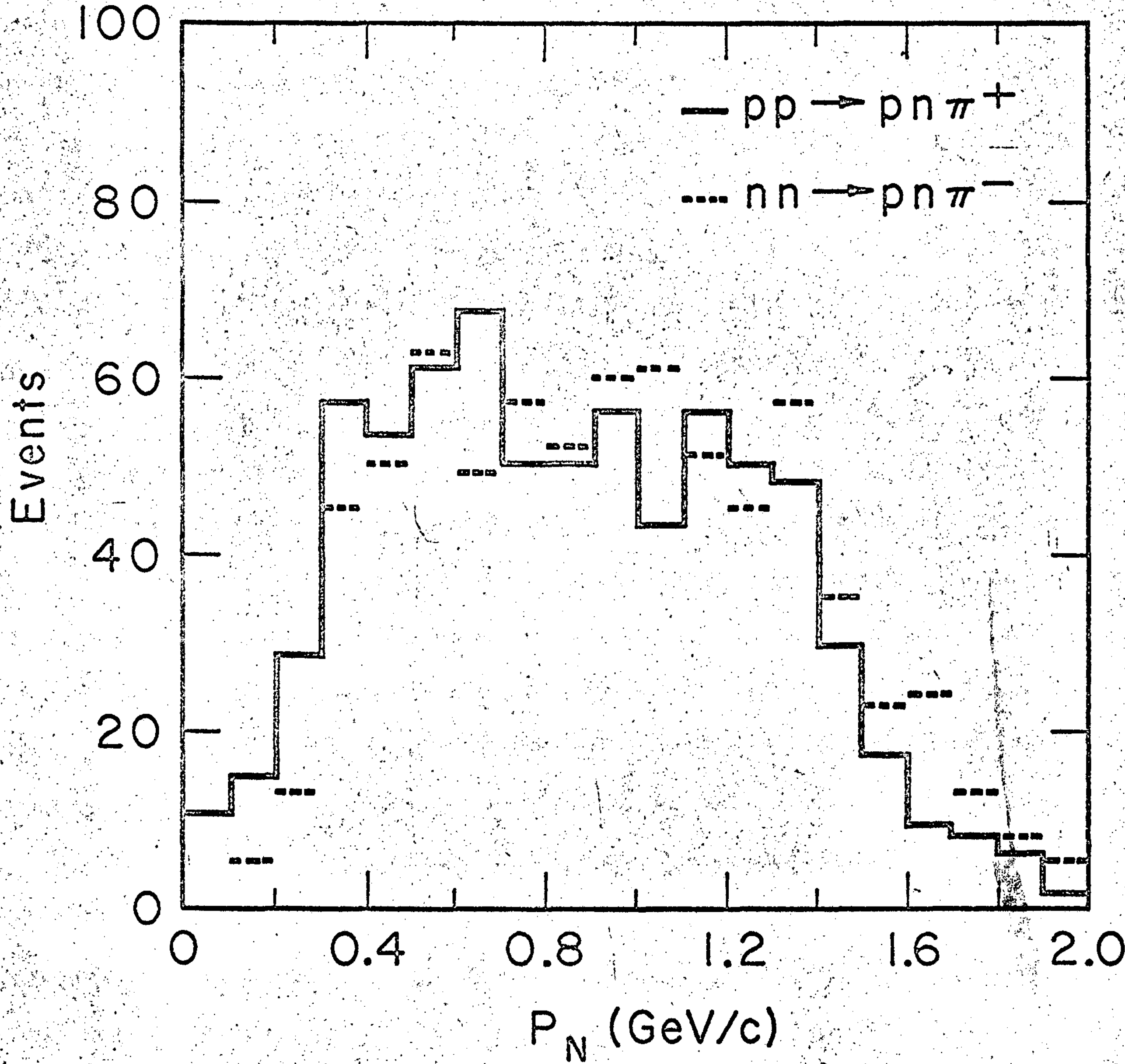

Fig. 3

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