REMARKS ON THE "QUASI-ELASTIC" DIFFRACTION SCATTERING OF HIGH-ENERGY PROTONS

B.T. Feld,
CERN and M.I.T.

The most recent results in the experiments of Cocconi, et al.[1], utilizing improved energy resolution and a CH_2 - C subtraction technique, indicate that the most remarkable feature - the independence of the separation between the elastic and quasi-elastic peaks on the incident proton energy - remains. (The more recent experiments have all been performed at the same lab. angle of 56 mrad, so that the independence on scattering angle has not been checked.) Furthermore, the positions of the peaks, and their splitting, continue to be in excellent agreement with the assumption (Feld and Iso[2]) that they correspond to the quasi-elastic excitation of the two $T = 1/2$ nuclear isobars observed in pion-nucleon scattering. Thus, despite the success of Drell and Hiida (as reported at this Conference by Baker[3]) in computing a quasi-elastic peak, corresponding to the diffraction scattering of the projectile proton by a virtual pion in the cloud surrounding the target nucleon, the "isobar excitation" hypothesis still remains as a possible (and, kinematically, most probable) explanation of the observations.

The rest of these remarks will be predicated on the assumption that the isobar excitation hypothesis will be required to account for the observations of Cocconi and co-workers[1]. With this assumption, the kinematical features of the isobar excitation process are summarized in the accompanying Fig. 1 and Tables I and II.

Table I

Kinematical features of quasi-elastic excitation of π-N isobars in p-N collisions

	Isobar Characteristics										
	elastic $\Delta = 0$		$(3, 3^+)$ $\Delta = 0.32$			$(1, 3^-)$ $\Delta = 0.62$			$(1, 5^+)$ $\Delta = 0.80$		
u	Δp_1	q_1	δ_0	Δp_2	q	δ_0	Δp_2	q	δ_0	Δp_2	q
2.0	0.006	0.12	0.25	0.40	0.24	0.50	0.81	0.50	0.64	1.05	0.70
3.0	0.015	0.17	0.18	0.38	0.20	0.36	0.77	0.33	0.48	1.02	0.45
5.0	0.044	0.29	0.13	0.37	0.28	0.27	0.77	0.30	0.36	1.04	0.33
10	0.179	0.51	0.086	0.37	0.57	0.18	0.79	0.55	0.25	1.07	0.55
15	0.404	0.90	0.069	0.37	0.89	0.15	0.79	0.85	0.20	1.08	0.84
20	0.719	1.20	0.060	0.37	0.99	0.13	0.79	0.88	0.18	1.09	1.22
25	1.124	1.50	0.053	0.37	1.35	0.12	0.80	1.27	0.16	1.10	1.33

u : total incident p-energy.

Δp_1 : energy loss for elastic p-N scattering.

Δp_2 : splitting between the elastic and quasi-elastic peaks.

δ_0 : longitudinal "3-momentum" transfer in the c.m.s..

q : invariant "4-momentum" transfer in the scattering process.

All energies and momenta in units of the proton mass M.

The lab. system angle Θ between M and the beam direction = 0.06 rad.

See Fig. 1 and Table II for relationship between quantities.

<u>Table II</u>

Relations between kinematical quantities
defined in Fig. 1 and Table I

$m_\pi = 0.146 \; m_p$ $M^* = M + \Delta$ $\Delta p = \Delta p_1 + \Delta p_2$ $q^2 = (\vec{p} - \vec{p}')^2 - (u - u')^2$	For elastic scattering one has the special case $M^* = M$ i.e. $\Delta = 0$ and $\delta_0 = 0$, $\Delta p = \Delta p_1$
For small angles Θ one has approximately $q \to p\Theta \approx q_1$ $\delta_0 \to \frac{\Delta(1 + \frac{1}{2}\Delta)}{2p_0}$ $\Delta p_2 \to \Delta(1 + \frac{1}{2}\Delta) \begin{Bmatrix} 0.37 \\ 0.81 \\ 1.12 \end{Bmatrix}$	

A number of features are immediately evident:

1. The constancy of Δp_2 (vs. u): In particular, the Δp_2 for the two higher isobars correspond, to within the experimental uncertainties, to the observations.

2. The progressive decrease of δ_0 with increasing projectile energy. On the assumption that the maximum internal angular momentum transfer is $\simeq \delta_0 R \simeq \delta_0/\mu$, this might account, at least in part, for the failure

to observe the $(3, 3^{+})$ resonance in the experiments at CERN ($u = 10$-25) in contrast to its strong excitation in the Brookhaven experiments ($u = 2$-5).

3. On the other hand, the above-mentioned difference between the Brookhaven and CERN observations could be accounted for on the assumption that isobar excitation results from a one-pion exchange; this mechanism has been applied by Selove to account, in a rather convincing fashion, for the Brookhaven observation. On the one-pion exchange hypothesis, the isobar excitation cross-section would fall off as u^{-2}.

4. However, the plausibility of a one-pion exchange dominance is brought into the strongest doubt by the values of the 4-momentum transfer, q, required by the kinematics of the isobar excitation process. Thus, the values of q, required in the energy range of the CERN experiments, are $\approx 7\mu$, a range of values in which it is extremely doubtful that a single-meson exchange process should be dominant.

5. Assuming, then, that the CERN observations correspond to isobar excitation, it is much more likely that the nucleon is "absorbed" more-or-less uniformly over a range of impact parameters, b, extending all the way from 0 to $R \approx 1/\mu$. This suggests that it may be more appropriate to describe the quasi-elastic scattering in a fashion analogous to the description of diffraction elastic scattering by means of the "optical" model. I have considered such a description[4)]; in the following, some of the more recently derived consequences of this model are summarized:

(a) The optical description of elastic scattering starts with a "phase-shift" analysis of the scattering cross-section (spin-independent)

$$\left(\frac{d\sigma}{d\Omega}\right)_d = \frac{1}{k^2}\left|\sum_{\ell=0}^{\infty}(2\ell+1)(1-\eta_\ell)\,P_\ell(\cos\Theta)\right|^2 . \qquad (1)$$

Assuming that $a_\ell \equiv (1-\eta_\ell) \simeq 1$ in the range $0 < \ell < kR$, and $a_\ell = 0$ for $\ell > kR$, we obtain the usual diffraction scattering formula

$$\frac{d\sigma}{d\Omega} \simeq k^2 R^4 \left[\frac{J_1(kR\Theta)}{(kR\Theta)} \right] \quad . \tag{2}$$

In exactly the same way, a "phase-shift" analysis may be made for the cross-section for the reaction

$$N + N \rightarrow N^* + N \quad . \tag{3}$$

Thus, neglecting spin, the cross-section for excitation of the $(3, 3^+)$ isobar $(\Delta J = 1^+)$ becomes

$$\frac{d\sigma}{d\Omega} \simeq \frac{1}{k^2} \left| \sum_{\ell=0}^{\infty} \sqrt{2\ell + 1}\; b_\ell \; Y^1_\ell(\Theta, \varphi) \right|^2 \quad . \tag{4}$$

and gives, for the same approximations

$$\frac{d\sigma}{d\Omega} \simeq \bar{b}^2 \; k^2 R^4 \left[\frac{1}{X^2} \left(\int_0^X J_0(x)dx - X \; J_0(X) \right) \right]^2 \tag{5}$$

with

$$X = kR\Theta \; ,$$

a distribution which, starting at 0 for $X = 0$, shows the characteristic features of a diffraction phenomenon.

(b) The assumption of "step-functions" for a_ℓ and b_ℓ (constant for $0 < \ell \leq kR$, 0 for $\ell > kR$) is clearly unrealistic. However, a smoother variation of the scattering amplitudes with ℓ may be assumed, say Gaussian, or exponential, or even $\sim (\ell^2 + L_0^2)^{-n}$, in which case the main effect will be to smooth out the secondary maxima and minima predicted by Eqs. (2) and (5), without influencing too strongly the distribution in the main diffraction peak. The problem of the appropriate choice of the variation of a_ℓ with ℓ has been discussed in a number of contributions (cf.[5]) relating to diffraction elastic scattering.

(c) The effect of nucleon spin on the kinematics of elastic and quasi-elastic scattering can also be taken into account[6]. The main effect is to smooth out the angular distribution, even assuming a sharp absorption boundary, owing to the appearance of terms in the angular distribution corresponding to different values of the change in orbital angular momentum ($\vec{J} = \vec{L} + \vec{S}$).

6. Perhaps the most important effect of the nucleon spins is in leading to the possibility that the scattered (elastically or quasi-elastically) nucleon might emerge polarized. We have investigated this problem in some detail. The main conclusions are the following:

(a) Polarization, both in the elastic and in the quasi-elastic scattering, could result from a "spin-orbit" interaction. Such polarizations have been observed at lower projectile energies.

(b) However, even if the above mechanism does not operate, there is another possible, and more interesting, source of polarization of the scattered nucleon. This would result from a final-state "spin-spin" interaction between the product proton and isobar - i.e. from a difference (in phase) between the amplitudes for production of $N + N^*$ in the two possible states of the total spin $S = S^* \pm \frac{1}{2}$. Such effects can be large - $P > 50\%$ at appropriate angles of scattering - and could provide a mechanism for investigating the interaction between nucleons and isobars.

Conclusion

In the discussion above, we have started from the assumption that the observations of Cocconi, et al.[1], correspond to isobar excitation through a "quasi-elastic diffraction" process. This approach is perhaps contradictory or perhaps "complementary" to the "one-pion exchange" hypothesis. In any event, the experiments will eventually choose between them. Should the isobar-excitation hypothesis prove correct, observations on the angular distribution and energy dependence of the excitation process may provide additional information concerning details of the nucleon-nucleon and the nucleon-isobar interaction mechanisms.

REFERENCES

1) G. Cocconi, this conference.
2) B.T. Feld and Chikashi Iso, Nuovo Cimento (in the press).
3) M. Baker, this conference.
4) B.T. Feld, CERN internal report 1114/Th 178.
5) D.I. Blokhintsev, this session.
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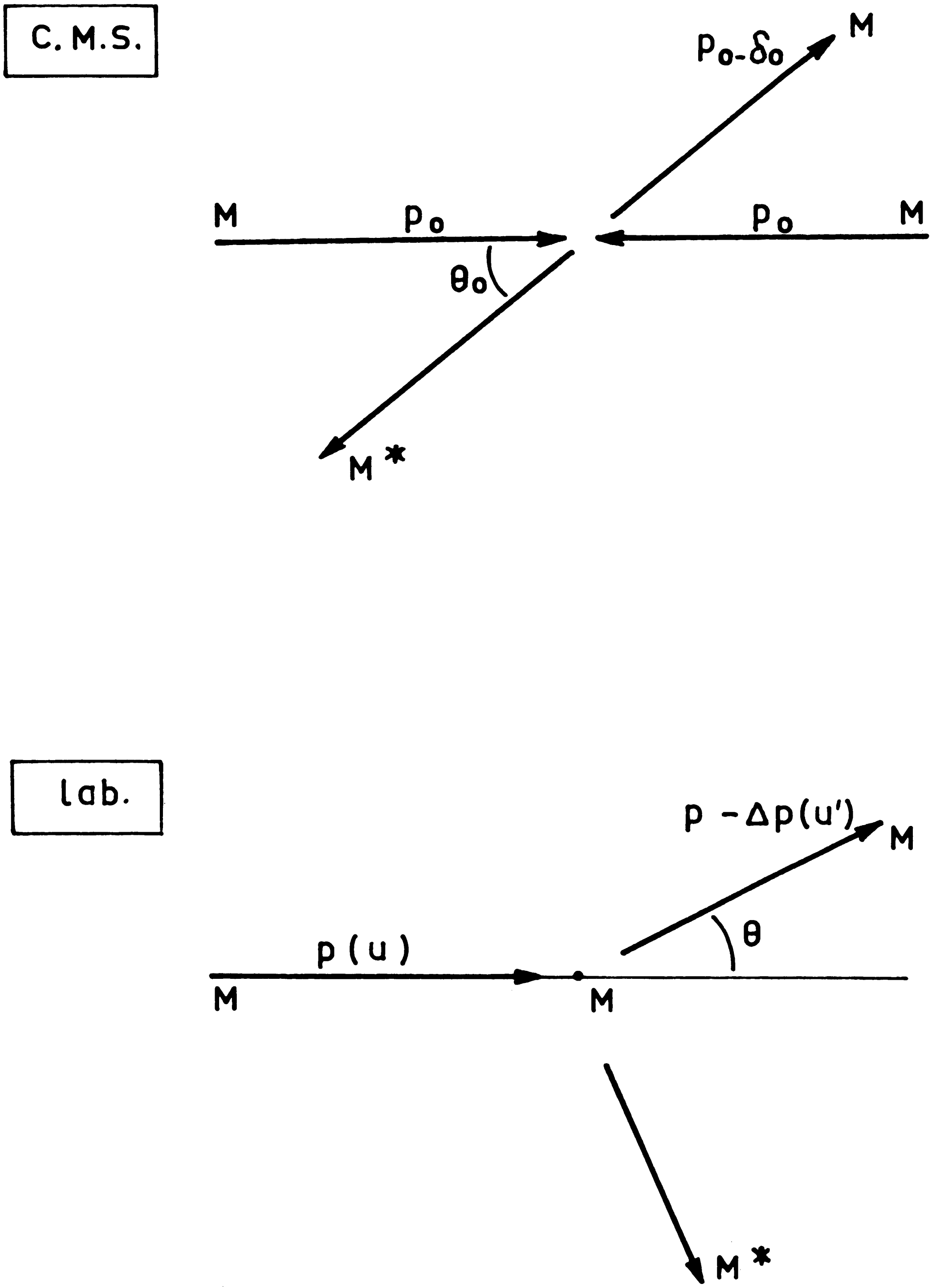

Fig. 1 Sketch of a quasi-elastic collision with isobar (mass M*) in the c.m.s. and the laboratory explaining the symbols used in Table II and in the text.

VI. ONE-MESON EXCHANGE