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(Draft)

FUTURE EXPERIMENTAL CONSIDERATIONS FOR THE H.L.B.C.

Now that ~ 500 events have been analysed in a freon filled chamber and a general picture of high energy interactions obtained, it has become apparent that several specific lend themselves immediately for a more detailed study.

These specific reactions will be discussed from an experimental point of view, especially with regard to a study using a heavy liquid chamber.

The elastic reaction and form factors

The elastic reactions

$$\nu_\mu + n \rightarrow \mu^- + p$$
$$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$$

are considered to be well describable theoretically, and if one makes certain assumptions on CVC, G-symmetry, time invariance and negligible pseudo-scalar terms, the cross-section and four-momentum distribution depends only on the choice of the axial vector form-factor : the ν and $\bar{\nu}$ cross-sections differing only by the vector axial vector interference term. Ideally the most sensitive way of determining the axial vector form-factor is to obtain the difference between the ν and $\bar{\nu}$ cross sections. In fact if one has an accurate knowledge of the flux a good determination of the vector form-factor can be obtained at the same time.

Experimentally, however, difficulties arise. In the case of a $\bar{\nu}$ experiment in hydrogen one has difficulty in distinguishing an elastic event from an inelastic event containing a neutron and any number of π^0's. To overcome this difficulty a very efficient lead plate system must be used. With existing chambers, this would make the production region uninterestingly small.

In propane, a $\bar{\nu}$ experiment has added difficulties. As N^* production is of the same order as the elastic process, many of the π^- produced will be absorbed in the carbon nuclei giving no visible products, thus appearing as elastic $\bar{\nu}$ events.

Therefore at present the most reliable experiments concerning form-factors will be carried out using ν_μ beams, all elastic products being charged.

Before discussing in detail future ν_μ elastic experiments it is perhaps instructive to review the present position of the elastic data as obtained in freon.

In freon, the major difficulty is the extraction of the true elastic sample from the non-pionic sample. This is because the 1π production via N^* is of the same order as the elastic process and many pions are absorbed in the parent nucleus. Fortunately π^+ absorption takes place mainly on a deuteron system within the nucleus, giving rise mainly to two protons, and hence a multiproton event. However, the fraction of absorbed pion events not giving protons cannot be estimated.

Monte-Carlo programmes have shown that to make a multiproton event from a true elastic event is highly improbable and that the number of expected absorbed pion events is of the same order as the multiproton events.

Thus in freon we have concluded that the best definition of an elastic event is o one with only 0,1 proton above 30 Mev, leaving a sample of 54 events above 1 Gev. The energy cut-off is enforced to eliminate neutron and in-coming charged particle background and also to ensure that the elastic cross section is energy independent. A value of M_A can be obtained from the shape of the q^2 distribution and also independently from the event rate if the ν flux is known. The fit obtained to the q^2 distribution is very good and the estimate from the flux agrees well with this estimate. A combined fit gives $M_A = .78 \begin{smallmatrix} + .16 \\ - .20 \end{smallmatrix}$ Gev, the errors being purely statistical. It is difficult to estimate the pionic contamination of this sample, however, we have rejected 59 non-pionic events from this region. From the total non-pionic sample one obtains M_A = 1.17 Gev. Thus if the residual contamination is $\sim$ 20 o/o, then a systematic error $\sim$ .1 Gev is possible i.e. a little less than statistical. However, using this result, the experimental differential energy cross section or ν energy spectrum (they are complementary) disagree somewhat with prediction. This indicates that one is correctly estimating the total flux but with the wrong energy dependence. No matter what the cause, be it statistical, horn, or cross section, the question should be resolved. If so then four times the present statistics in freon is required. Other proposed runs in propane will also contribute to this problem, but at about 1/3 the rate.

To improve on the present situation from a point of view of form-factors ~50 free neutron elastic events must be obtained.

The obvious instrument is of course a deuterium filled chamber. With present conditions i.e. 1×10^{12} protons/pulse, 3 sec. rep. rate, 23 metre shielding then for liquid deuterium and above 1 Gev, the elastic event rate/$0{\cdot}4\ m^3$ will be $1.5/10^{17}$ protons or .43 events/day. A second type of free neutron target available is deuterated propane. Here, experimental technique is more complex, consisting of recognizing free neutron events by means of charge and momentum balance. Of this sample ~35 o/o of the events will be from carbon. However, this background can be found easily from a ν run in propane. The necessity of this background subtraction reduces the statistical weight of the free neutron sample by about one half. With present conditions, the expected rates for free neutron events above 1 Gev will be :

3 events/10^{17} protons or .87/day
(also 1.83 elastic carbon events/day)

N^* production

The N^* production cross section has been predicted, and in fact shown in the freon experiment, to be of the same order as the elastic process.

N^* production, in a target containing equal numbers of neutrons and protons, should have the charge states in the proportion $9\ \pi^+ p : 2\ \pi^0 p : 1\ \pi^0 n$. Hence the observation of a $5 : 1$ π^+/π^0 ratio in single pion events is conclusive evidence for N^*. Other methods of showing N^* production are the calculation of the π - nucleon invariant mass and, as the N^* should be aligned along the ν, μ momentum bisector, the π nucleon angular distribution. Finally a calculation of the mass of the recoiling system using the energy of the event and the μ momentum.

In heavy liquid only the last of these methods can be considered seriously, because of the high interaction probability of the π and nucleon in the parent nucleus, and because of energy loss this method still contains biases towards low values of recoil mass. An estimate of the actual cross section is however difficult and uncertain.

As we have mentioned Monte-Carlo programmes show that probably all the multiproton events are in fact due to absorbed one pion events(and also 2 π events). Adopting this procedure a N^* cross section can be calculated which is roughly in agreement with prediction, but having the same type of discrepancy as the elastic cross section, thus tending to support the theory of incorrect spectral shape.

If one knows the flux and spectrum an accurate determination of the N^* cross section can be made using only proton targets. Here only the $N^{*++}_{3/2\,3/2}$ will be produced and recognized by means of the π p invariant mass and angular distributions. From experience gained in freon it is estimated that ~ 100 free proton events above 1.5 Gev will be needed.

If this experiment is done in a hydrogen chamber one expects the following rates.

Present conditions Events/ .4 m^3 H_2

N^{*++} > 1.5 Gev

1.3 events/10^{17} protons or .35 events/day

The experiment, however, lends itself well to a propane chamber. Here, free proton events would be recognized by means of charge and momentum balance and with these criteria a contamination of ~ 16 o/o carbon events is expected.

Rates

N^{*++} > 1.5 Gev

2.5 events/10^{17} or .7 events/day

Strange particle production by $\bar{\nu}$

Hyperons are expected to be produced only by $\bar{\nu}$ according to the $\frac{\Delta S}{\Delta Q} = +1$ rule. Our present results with freon are in complete agreement with this prediction (Phys. Letters 281, 12, 1964, NPA/Int. 64-36).

This production can be considered as inverse β decay as is the elastic reaction and N^* production, and thus have a similar energy distribution i.e. 90 o/o below 5 Gev.

If the production takes place in freon, as will the March run, one must appreciate the secondary interactions modifying the primary process. 20 o/o of the strange particles will produce hyper and crypto fragments. Most of the Σ^- will interact or charge exchange and Y^* will be seen as Λ^0 half the time because of π absorption.

The combined production processes are calculated to be between $5 \sim 15$ o/o of the combined elastic and N^{*-} cross section.

Thus with present conditions the most optimistic strange particle production in freon will be

3 events/10^{17} protons or .9 events/day

Thus with a 3 weeks run a rough estimate of the total cross section should be obtained.

However, in hydrogen and propane the rates are so low that only when very large chambers exist along with much increased fluxes it will be possible to study form-factors.

Total inelastic cross section and multipion channels

The results in freon have indicated a marked rise in total inelastic cross section with energy. The statistics are quite small, especially above 5 Gev. This total cross section is adequately studied on complex nuclei and all the experiments previously discussed will add statistics for the process. The optimum running conditions for these experiments are however with a low energy beam; but essentially the flux between 3 and 7 Gev remains unchanged. If the very high energy events are to be studied then a horn must be specifically designed for them and a separate high energy experiment carried out.

A detailed study of the various channels found in the inelastic events has proved impossible due to secondary interaction of the pions, and free nucleon events must be used.

All theoretical predictions on these channels, such as peripheral ρ, ω, η production, have yielded far too small a cross-section and it is possible that it is due to the production of higher N^*'s.

To obtain all charge states a deuterium target should be used. If channels other than completely charged are to be studied with a deuterium chamber then a very efficient plate system must be used.

Using deuterated propane as target allows an efficient study of completely charged channels and if 14 % freon is added π^0's will also be detected. However reactions giving neutrons can never be studied without the use of a very large propane chamber.

Conservation Laws

In the freon experiment we have obtained the following results.

1) Lepton Conservation

$$\frac{\text{Number of events with } \mu^+}{\text{Number of events with } \mu^-} < \begin{array}{l} 3.5\ \%\ \text{ for elastic events} \\ 8\ \%\ \text{ for inelastic events} \end{array}$$

$(E_{vis} > 1 \text{ GeV})$

2) Two Neutrinos

$$\frac{\text{Number of events with } e^-}{\text{Number of events with } \mu^-} < 2\ \%\ \text{ for elastic and inelastic events}$$

$E_{vis} > 1 \text{ GeV}$

3) Neutral Lepton Currents

$$\frac{\Sigma(\nu+p \longrightarrow \nu+p)}{\Sigma(\nu+n \longrightarrow \mu^-+p)} < 20\ \%\ \ (E_{proton} > 250 \text{ MeV})$$

$$\frac{\Sigma(\nu+N \longrightarrow N'+n\pi+\nu)}{\Sigma(\nu+N \longrightarrow N'+n\pi+\mu^-)} < 12\ \%\ \ (E_{n\pi} > 1 \text{ GeV})$$

The upper limit set for the possible violation of $\nu\mu \neq \nu e$ is very small and only a much increased statistics could improve the situation, whatever the detector. For the question of the conservation of μ^- (against μ^+), the only improvement will be obtained using hydrogen and a $\bar{\nu}$ beam. In this case an elastic event is a single μ^+ and can be distinguished kinematically from the neutron background. The presence of single μ^- would give a limit of the violation.

If neutral currents are to be investigated further then much effort must be put to reduction of the neutron flux.

Conclusions

From the above discussion it is concluded that after the chamber has completed the $\overline{\nu}$ exploratory run and the X_2 commitments then it would be valuable to consider the following possibilities.

1) Propane filled chamber running in a low energy beam with 17 metre iron shielding and 1·5 sec. repetition rate.
   Aim : to study mainly N^* production and improve spectral and inelastic knowledge.

2) Deuterated propane filled chamber running in same low energy beam, if possible with heavy shielding.
   Aim : to study mainly elastic form-factors and to improve on N^* , inelastic and spectral knowledge.

H. Burmeister
D.C. Cundy
G. Myatt
M. Paty
K. Schultze.

Type of event	Primary nucleon	Secondary hadrons 1)	Possible liquids 2)			
			C_3H_8	C_3D_8	H_2	D_2
elastic	n	p		X		X
1 π	p	+p	X	X	X	X
	n	op		XF		XP
		+n		L		XP
2 π	p	+op	XF	XF	XP	XP
		++n	L		XP	XP
	n	+on				+P
		+-p		X		X
		oop		XF		+P
3 π	p	+oop	XF	XF	+P	+P
		++-p	X	X	X	X
		++on	L	L	+P	+P
	n	+oon		L		+P
		++-n		L		XP
		ooop		XF		+P
		o+-p		XF		XP

Table 1(a)

ν - reactions

Type of event	Primary nucleon	Secondary hadrons 1)	C_3H_8	C_3D_8	H_2	D_2
elastic	p	n			XP	XL
1 π	p	-p	X	X	X	X
		on	L	L	+P	+P
	n	-n		L		XP
2 π	p	-op	XF	XF	XP	XP
		oon	L	L	+P	+P
		+-n	L	L	XP	XP
	n	--p		X		X
		-on		XF		XP
3 π	p	-oop	XF	XF	+P	+P
		-+-p	X	X	X	X
		ooon	L	L		
		o+-n	L	L	+P	+P
	n	--op		L		XP
		-oon		L		+P
		-+-n		L		XP
Hyperons	p	Λ^o	X	X	X	X
		Σ^o	XF	XF	XP	XP
	n	Σ^-		X		X
Y^*	p	Y^{*o}	XF	XF	XP	XP
	n	Y^{*-}		X		X

Table 1(b)

$\bar{\nu}$ - reactions

1) +, -, o stands for π^+, π^-, π^o

2) X well measurable
\+ with low accuracy
L in a large chamber
F with freon
P with lead plates