CONSIDERATIONS ON THE USE OF NEON-HYDROGEN DOUBLE CHAMBERS

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ABSTRACT

This report is intended as an introduction to the advantages and limitations of the double chamber technique in the proposed NAL 25-foot bubble chamber. It is argued that the technique will be useful for both strong and weak interaction studies.

I. INTRODUCTION

Hydrogen track-sensitive targets have now been successfully operated within neon bubble chambers at DESY, BNL, and Rutherford, in the latter laboratory in an actual physics experiment. Generally one can operate with hydrogen and about a 50-50 neon-hydrogen mixture or with deuterium and almost pure (95%) neon. It is certainly time to examine seriously the usefulness of such devices in the 25-foot bubble chamber. It is my feeling that they are so useful that it will be rare that one should ever wish to operate the chamber in a single-chamber mode.

II. GENERAL FEATURES

A. Gamma-Ray Detection Capabilities

One will certainly be able to distinguish $0\pi^o(\eta^o)$ from $1\pi^o(\eta^o)$ from $>1\pi^o(\eta^o)$ events. This is perhaps the major single advantage. The necessity and advantages of gamma-ray detection capability were pointed out in numerous papers in the 1968 study report. Without it, it becomes very difficult to obtain useful mass resolution (for instance to distinguish $\rho^- \rightarrow \pi^-\pi^o$ and $A_1^- \rightarrow \pi^-\pi^o\pi^o$, as W. D. Walker pointed out. It is somewhat dubious whether one can sort out the gamma rays for multi $-\pi^o$ events since there are many possible combinations (3 for 4γ from $2\pi^o$ and 12 if we allow $2\pi^o$, $\pi^o\eta^o$, $2\eta^o$). Just the observation of the gammas will be of use in many cases, as a veto if in no other way, and as a useful constraint if all gammas are seen. For instance, in the above example we could distinguish the $A_1 \rightarrow \pi^-\pi^o\pi^o$ even though we could probably not sort out the decay distribution.

B. Neutron Detection Abilities

By providing a high density path of several nuclear interaction lengths, the neutron will often interact giving a visible star. As pointed out in the 1968 Summer Study, background will sometimes limit the usefulness of this, but for strong-interaction work especially, it should prove quite important.

C. Spiraling Problem

A great deal of attention has been given to the problem of tracks curling up in the chamber and confusing the pictures. This can be greatly alleviated by appropriate double chamber designs since many of these tracks will stop or be absorbed in the neon.

D. Particle Identification

The difficulty of distinguishing charged pion from kaon secondaries may be somewhat helped, since upon interacting in neon many more V's will be produced by the kaons (especially negative kaons); furthermore, the long path length of secondaries in neon (limited mainly by interaction length rather than chamber dimensions) will enable us to distinguish π and p in many instances by means of delta rays. In the CERN 1968 neutrino run, in a 1-meter propane chamber, 30% of the π tracks which were too fast for ionization distinction (ionization less than twice minimum) identified themselves by delta rays. A 10-BeV pion with a 5-foot track length in neon would identify itself by delta rays about 13% of the time. Below 5 BeV delta rays would enable one to distinguish pions and protons most of the time. Finally the extra stopping power of the neon will enable a greater number of tracks to be distinguished by ionization.

There will be some loss of measurement accuracy since the length of tracks in hydrogen will be decreased. This will tend to be small since the increase in accuracy goes as the square root of the track length if multiple scattering limits the accuracy.

The double chamber has some important advantages over a single chamber filled with a neon-hydrogen mixture if one is interested in events on hydrogen. First of all, with only about 20 mole percent neon, the event rates in neon and hydrogen are equal. Because the acceptable number of events per picture is small, most runs will probably have very few tracks (perhaps only one) per picture. The event collection rate will therefore be lower in a mixture and the background larger. The measurement accuracy will be considerably reduced in the neon-hydrogen mixture compared to a double chamber because of the greatly increased multiple scattering.

Another advantage of the double chamber over a homogeneous mixture of neon and hydrogen is that different gamma rays can separate spatially sufficiently before converting so that ambiguities concerning whether one gamma is a bremsstrahlung gamma from the other are reduced. An example of this is seen in the event sketched in Fig. 1. The gammas have separated during the long path length in hydrogen and then convert at approximately the same (large) distances from the interaction point.

The same figure also points up some of the disadvantages of this device. The gammas could point not only to the interaction but also to 5 or 10 feet of other track of this event. If there were a secondary interaction, it might not be clear at which vertex the gamma(s) pointed. For a 40 mb total cross section, 10 feet of track would produce a secondary interaction 40% of the time. Of course, by using the strength of the 4c fits one could in many cases distinguish between the ambiguities. Sometimes, however, multiple ambiguities would make this difficult and one would be forced to accept only samples with no secondary interactions, thus considerably cutting down on the event rate. Other cases would probably simply prove intractable by this method. It should be noted, however, that for most of these situations neither a hybrid detector nor a single chamber filled with a neon-hydrogen mixture seems to offer a large improvement over the double chamber.

Another related difficulty is that almost every track will interact in the neon creating secondaries, gammas, and generally obscuring things. Figure 1 shows that this is mitigated by the fact that the gammas go forward while the charged particles, though initially forward, are bent out of the way. This tendency is, in fact, general because particles are produced at small angles and because of the high bending power of the 40-kG field. At energies high compared to 30 BeV or for events in which one particle retains most of the primary energy this separation will be decreased.

We shall next consider the usefulness of these devices in three broad areas: strong interactions in general, neutrino interactions, and coherent production.

III. STRONG INTERACTIONS

The radiation length in neon is about one foot and in the 50% neon-hydrogen mixture about two feet.

If we want about 5 radiation lengths in the forward direction to have good efficiency, we might consider an inner chamber perhaps 14 feet long. For strong interactions, one does not need large lateral dimensions since sidewise going particles tend to be of low energy. The narrower the hydrogen part is made, the less trouble spiraling will give. This part clearly needs more thought but perhaps an inner chamber of about 6-ft diameter by 14-ft long would be reasonable.

If it proves to be very difficult to make an inner chamber, even a diaphragm dividing the chamber into a 14-foot hydrogen front part and an 11-foot neon rear part would give many of the double chamber advantages since the high-energy gamma rays will go forward and the vast majority of the phase space of π^0 decay corresponds to these forward-going high-energy gamma rays.

This arrangement would not prevent spiraling nor would it generally be able to distinguish peripherally produced Σ^0 from Λ^0, since these would be low energy, yielding low-energy and often wide-angle decay gamma rays.

It should be noted that background problems may be severe for distinguishing low-energy gamma rays in a full double chamber, since they do not "point" as accurately to the interaction as do high-energy gammas and one may be bothered by stray gammas. It may be necessary to have some shielding at the chamber entrance.

We consider what energy range we will want to explore with this device. At the present time we have explored in detail with bubble chambers only the energy range up to about 4 BeV/c and are in the process of exploring the 4-8 BeV/c range in detail. It would seem at present that the region above 12 BeV/c and certainly that above 20 BeV/c will still be largely unexplored when the 25-foot bubble chamber would come into operation. At energies much above 40-50 BeV/c, the secondaries will often not be bent far away from the forward direction, and interactions of the secondaries in the neon will clutter the film and seriously impair the gamma-ray detection efficiency. Hence this device will probably be useful for strong interactions in the range around 15-40 BeV/c.

Next we can ask what cross-section sensitivity we will have. We would want a small number of interactions per picture and there will be confusion in sorting out gammas and neutrons. We assume two interactions per picture. Furthermore, we must ask that the secondaries not interact in the first 7 feet of track length, so that we can make accurate track measurements and so that the gamma rays have only one origin to point to. As can be seen in Fig. 1, the gammas could point to the first several feet of secondary track as well as to the origin. For 4 charged secondaries and a 30 mb cross section this eliminates about 2/3 of the events. A million picture run would give about $2 \times 1/3 \times 10^6$ events. If the total cross section is about 30 mb this gives ~ 20 events/microbarn. This means, as expected, that one cannot look at rare events but is a respectable sensitivity to get an overall view of the strong interactions.

The fitting accuracy problems have been discussed last summer and the first part of this summer. It seems clear that with visible gamma rays, the accuracy should be reasonably good. Walker has argued that regions away from the center of the chamber will have problems due to being out of focus. In the double chamber arrangement, the part needing accurate measurements is the hydrogen part, located in the center region of the chamber. This should help alleviate the problem for strong interaction utilization of the chamber. Because of the different shape of the double chamber needed for neutrino physics (see next section) this argument does not apply for neutrino work.

A question that must clearly be explored much further is, what is the physics interest in events between 15-40 BeV/c, at a sensitivity of 20 events/μb, with the ability to look at events with 0, 1, and possibly 2 missing neutrals and with some limited capability of distinguishing mass of secondaries by means other than fitting? I will give here only two examples. In the Regge model with absorptive cuts, one has had great success recently in fitting reactions. Nonetheless, certain problems remain. For instance in fitting $\pi p \to \omega \Delta$ at 8 BeV/c and below, using only a rho pole and cut, some of the ω density matrix elements have the wrong sign and it can be shown that no amount of fiddling with simple parameters of the theory can change it. It is supposed that this discrepancy comes from either s channel effects or from an ignored helicity flip part in the elastic cross section used in calculating the absorptive cut. These effects should both decrease as the energy increases. At about 30 BeV, the $\omega\Delta$ cross section will be approximately 1/2 of its value at 8 BeV and should still be capable of being analyzed. Furthermore, the t dependence should change with energy in a calculable way due to a different s dependence of the cut and pole terms. One can obtain important tests of the model and perhaps information on whether s channel effects are still important.

Tests of the multi-Regge model can be made with three body and quasi-three body final states. I am told that 20-40 BeV will be an important energy range for examining this idea.

Neither of the above theories may still exist next year, much less in four years from now. I consider them only to indicate that this energy region is valuable for the analyses of some current theories and that it therefore probably will be valuable for the examination of the current theories of four years hence.

IV. NEUTRINO INTERACTIONS

The CERN 1-meter chamber was run in a neutrino beam in 1967. In terms of interaction and radiation lengths, this chamber is slightly larger than the proposed NAL 25-foot chamber filled with hydrogen and we can make use of some experience gained there. In analyzing elastic cross sections, contamination from events with a missing π^o was a problem. For deuterium runs, fitting can greatly reduce this when the spectator is seen. However, the spectator will be seen only about one third of the time. Furthermore, to the contemplated accuracy of this new generation of experiments, the π^o contamination will probably remain a problem.

One always wishes to examine total cross sections to the highest available energies. In the CERN chamber, at CERN neutrino energies, 25% of the energy transferred to strongly interacting particles in inelastic events went into unseen neutrals; I would not expect this number to decrease greatly at higher energies. This means that there was a considerable uncertainty in the energy of the neutrino producing an individual event. Since the variation of this ratio could not be studied as a function of energy, systematic errors were introduced. This introduced a large uncertainty in the CERN experiment on the cross-section points above 5 BeV. The reason is that the neutrino flux is falling quite rapidly in this region and a small change in apparent energy produces a large change in apparent cross section. For instance, omitting the correction for the unseen neutrals in the CERN experiment changes the total ν cross sections above 4 BeV by a factor of two. It is clear that to get accurate total cross sections, one needs to detect most of the energy of the interaction.

The inelastic events in the CERN neutrino experiment were analyzed as a function of E_ν and q^2, the 4-momentum transferred to the muon. An uncertainty in E_ν introduces the same percentage uncertainty into q^2. For the small statistics of the CERN experiment, these uncertainties were probably tolerable, but they will seriously impair the analyses of the larger statistics of NAL experiments.

In the reaction $\bar{\nu} \rightarrow \mu^+ n$, it will be crucial to see a neutron star in neon since otherwise one has only a 0c fit. However, as pointed out in other reports,[1] the background neutrons may cause a severe problem for this reaction even with neon. Furthermore, there are many reactions one would wish to examine which involve several strongly interacting particles in the final state (N^* form factors, vector meson production, multiple meson states) and for these the arguments proceed exactly as in the case of the strong interactions with one additional feature: the path length in neon will often allow one to decide which particle is the muon (or electron).

This point will be very important, especially for $\bar{\nu}$ experiments. For ν experiments at low energies, the charge balance is unfavorable for producing many π^-. This is not as true for $\bar{\nu}$ at low energies (producing π^+) and will be true for neither γ or $\bar{\nu}$ at higher energies. Hence there will be considerable confusion unless neon is used or spark chambers placed in back of the chamber (or both).

Hence for ν experiments one normally would wish to operate in a double chamber mode. Since we are interested in ν events in hydrogen or deuterium, we want hydrogen in a large fraction of the chamber volume, and a flat or v-shaped diaphragm would seem most appropriate (Fig. 2).

Ten feet is 5 radiation lengths for 50% neon and about 2-1/2 interaction lengths. Hence most of the time the muon will identify itself. For deuterium fills pure neon may be used, for which the numbers are 10 r.l. and 5 interaction lengths.

The interactions taking place in the neon part of a double chamber will often not be useless since there are many things that can be done with neutrino reactions in heavy nuclei. For instance $\nu Z \rightarrow \mu\mu\nu Z$ may be observable. At the 1968 summer discussions D. Cline[2] suggested putting the 12-foot chamber filled with neon behind the 25-foot chamber filled with hydrogen specifically to get neon reactions. A double chamber would be an alternative to this plan.

V. COHERENT PRODUCTION

This is included as a separate topic since one may wish to operate in a triple chamber mode here. If we wish to use a neon target but measure momenta accurately, we may wish to use hydrogen to measure the momenta. If the small neon target were 2 feet long, then outgoing tracks pass through about 1 foot of neon (Fig. 3). For an 8 BeV/c track, this corresponds to a multiple scattering projected angle of 2 mrad or $p\Delta\theta \sim 0.02$ BeV/c. This is not an unreasonable value if gamma rays are detected.[3]

EPILOGUE

The above report is report is presented as an introduction to double chamber capabilities and to stimulate further study during the conference. There are a great many problems, difficulties, and subjects for further discussion, but if this device proves feasible, I think there is an enormous amount of physics information which can be obtained from the 25-foot chamber. Two final points might be mentioned. The cost of a neon filling is not now included in the 25-foot chamber proposal. This cost should certainly be added to the proposal. Secondly, for strong-interaction physics the chamber is going to want to be operated in a multipulsing mode. For this to be done with least disturbance to counter experiments, it would be highly desirable to develope a "fast" (0. 5 msec) beam extraction system which could operate with the debunched internal beam so several pulses could be taken off during flattop.

REFERENCES

[1]R. D. Sard, Cosmic Ray Backgrounds in Neutrino Experiments, National Accelerator Laboratory 1969 Summer Study Report SS-15, Vol. II.

[2]D. Cline, Study of the Four Fermion Weak Interactions and Exotic Beta Decays Using ν Scattering on High Z Materials, National Accelerator Laboratory 1968 Summer Study Report B.1-68-76, Vol. I, p. 247.

[3]W. D. Walker, On the Use of a Hybrid Bubble Chamber in the 100-BeV Region, National Accelerator Laboratory 1968 Summer Study Report A.3-68-100, Vol. III, p. 299.

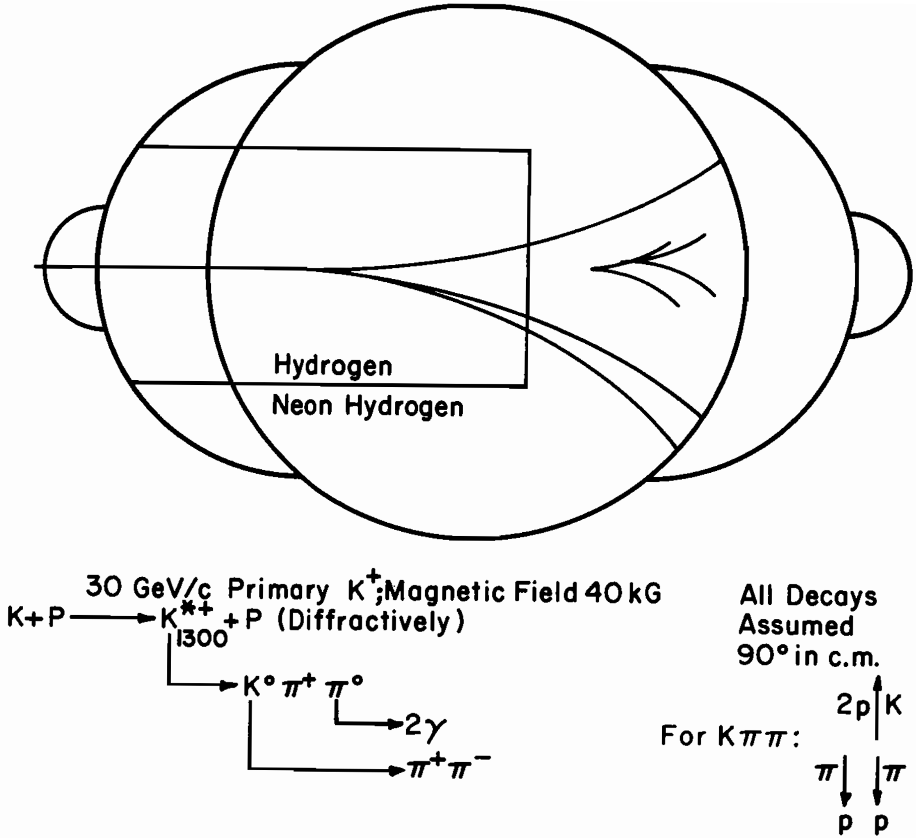

Fig. 1. Simulated kaon interaction in track-sensitive target.

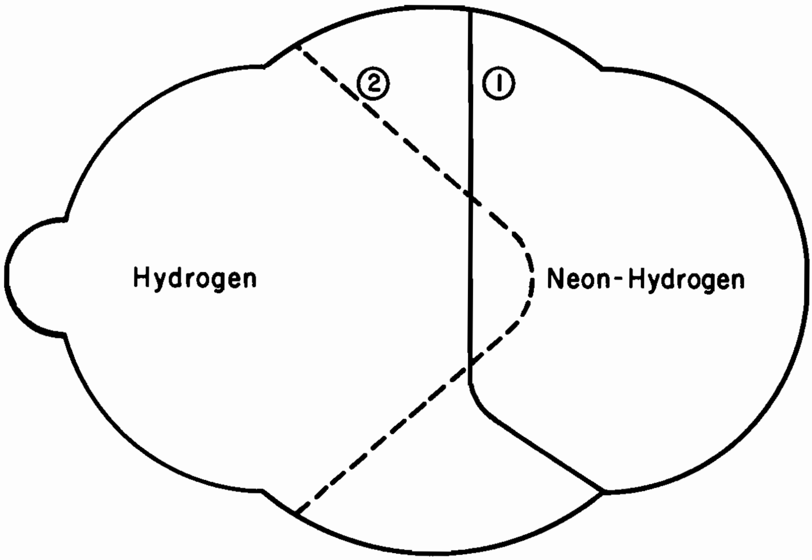

Fig. 2. Possible methods for dividing the chamber into two separate regions with different fillings.

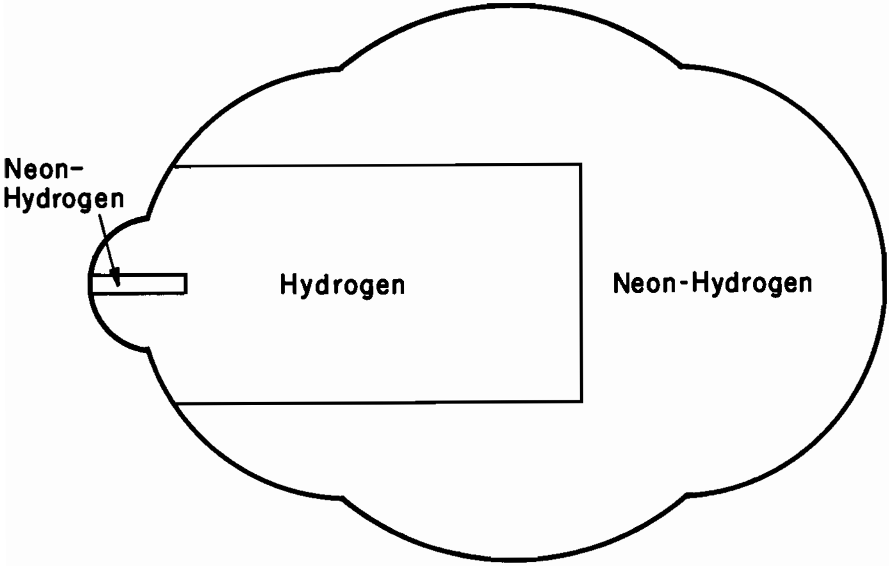

Fig. 3. Possible threefold separation, with a small heavy target region in addition to the hydrogen-filled track-measuring region.