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A SPARK-CHAMBER SYSTEM WITH VERY LARGE HYDROGEN TARGETS FOR NEUTRINO EXPERIMENTS: PRELIMINARY TECHNICAL CONSIDERATIONS

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1. Need for Larger Hydrogen-Containing Systems.

Present plans for the study of neutrino interactions in hydrogen center around the proposed 25-ft hydrogen bubble chamber. The volume of that chamber is 100 m^3 (7 metric tons), of which perhaps 70 (5 tons) constitute the useful fiducial volume. When and if constructed, it will be by far the largest bubble chamber ever built. Its size presents very great difficulties; there is considerable doubt among the experts as to how well it will work, and even some residual fear that perhaps it may not work at a satisfactory level at all.

Mammoth though it may appear, in at least one sense the chamber is too small. This became clear in the course of the 1968 summer study when attention was turned to the rate at which useful data will be accumulated and the amount of accelerated beam necessary to obtain useful data. Considering the available neutrino flux and the expected cross sections, the chamber is not large enough to minimize the data cost, that is, the sum of the accelerator time cost and the bubble chamber operating cost for a given number of events. Since the accelerator cost is dominant, a larger detector is required; but in the

present state of bubble chamber technology one does not dare to take a larger step than the present one even assuming no financial limitations.

As matters stood in the 1968 summer study, the total neutrino event rate in the chamber even with rather optimistic assumptions about focusing essentially the entire neutrino spectrum into a beam, would not exceed 0.5 events per pulse. Of these events, about half will result from neutrinos of 5 GeV or less. Studies on events produced by neutrinos of, say, 10 GeV or more will yield a total rate of 0.1 per pulse. Antineutrino events will be down by another factor of 3 to 10. In his report, Snow[1] estimated that 10^5 or more pulses would be needed to do a "minimal" experiment on elastic neutrino interactions and 2.5×10^6 for a minimal experiment on recoil proton polarization (these are with a deuterium target). For hydrogen, the corresponding antineutrino elastic experiment, if one requires the scattered neutron to be detected, requires 2.5×10^6 pictures even without polarization measurements. To do the antineutrino production of lambdas, it takes 2.5×10^6 pictures to obtain 1000 visible lambda events in each of five momentum bins.

A 2.5-million picture experiment probably represents at least half a year's operation of the accelerator with the bulk of the beam going to produce neutrinos. A year's operation of the accelerator costs about $40 million (excluding new equipment), and of the bubble chamber about $4 million. It seems worthwhile, therefore, to reexamine the possibilities of designing neutrino detection systems that use spark chambers

and very large but relatively inexpensive hydrogen targets. Although such systems have been suggested,[2] no extended discussion of the attendant problems seems to exist. This may be due in part to the conceptual difficulties of designing an adequate system and in part to the lack of a good case for the physics that such a system would make accessible. As a first approximation, let us take Snow's figures as representing such a prima facie case and turn our attention to spark-chamber technology to see whether it is equal to the task.

2. Specifications.

We define the design objective as a system using hydrogen targets with thin walls in which reconstruction of vertices in hydrogen will be sufficiently accurate to allow kinematic reconstruction; in which the variation of sensitivity with track direction (anisotropy) is not great enough to seriously affect the data; in which it should at the very least be possible to identify muons and electrons and hopefully other particles as well; and to detect recoil neutrons. In addition, we consider it highly desirable that the system be modular so that a small working system can be tested that will allow eventual expansion to the 100-ton size which bubble chambers are unlikely to reach and which would make possible the exploration of many processes otherwise inaccessible. The system should be capable of attacking from the beginning a reasonably large area of neutrino physics and consequently will require good event-recognition capabilities.

To meet the above design objectives, several system characteristics become immediately apparent. The spark-chamber detectors must operate in thermal and hydrostatic equilibrium with the liquid hydrogen; otherwise there will be severe heat-loss problems, as well as relatively massive walls in inconvenient locations. The chambers and targets must necessarily have large areas, otherwise the requisite quantities of hydrogen cannot be accommodated. In order to reduce the volume of the system and consequently of the magnetic field required to determine momenta, the sum of spark-chamber volume plus target volume must be kept to a minimum. To avoid losing events, the targets ought to be reasonably thin. The heat load imposed by the thermal dissipation of spark energy must be tolerable. The design study must interpret these requirements quantitatively.

No data exist on the operation of spark chambers at liquid-hydrogen temperature, and this lack must certainly be remedied before serious design work can be undertaken. However, data do exist at high pressures (to 30 atmospheres) and at temperatures down to liquid nitrogen.[3-5] The results are encouraging; the behavior (efficiency, delineation) improves with increasing density as expected. Because of higher density and lower thermal velocity the diffusion of electrons in the gas should be slower (about as $T^{1/2}$) than at room temperature, and so the limiting intrinsic accuracy of delineation should improve. Streamer chambers should also work better and give more light in these circumstances.

With this in mind, let us start by postulating as a point of departure for further study a system consisting of modules, each constructed as shown in Fig. 1. The liquid-hydrogen target module, about 3 meters square and 11 cm (0.7 gm/cm^2) thick, contains a cubic meter and is made of mylar (or equivalent material) a few mils thick. To keep it flat, it is made like a sofa pillow with internal threads and button seals. The only pressure on the mylar is the hydrostatic pressure of the liquid hydrogen since the target is surrounded by helium (or He-Ne) at atmospheric pressure. At liquid-hydrogen temperature, the helium density is 15 times atmospheric. Consequently, spark-chamber gaps operated in this gas will have the efficiency and delineation characteristics of much wider gaps at room temperature; this has been verified for high-pressure room-temperature gas. Thus, even a one-cm gap should give good track delineation, and the lower limit on gap width will probably be imposed by optics. The module of Fig. 1 may therefore be any combination of wide-gap (i.e., 1 cm or more), streamer or digital sections, each with gaps that need not be much more than a cm thick. In particular, the streamer mode with higher-density gas should produce brighter tracks and would guarantee isotropic detection efficiency when that is important.

Technical points that come to mind include the following. The use of streamer-mode operation is favored over wide-gap from a thermal-load standpoint; less heat is produced in the discharge although the heat

load, ~ .01 joule per gap, is tolerable even for wide gaps. High-voltage leads must be brought into the low-temperature, vacuum-insulated volume. The spark-chamber gas must be completely free of oxidants. The entire chamber system needs a transverse magnetic field of 20 kg or more. Optical access is not easy; in some experiments, modules can be made with digitized planes to avoid optical access.

The hydrogen target modules are thin (0.7 g/cm^2) to allow slow particles to emerge and to simplify vertex reconstruction by decreasing the distance that tracks need to be extrapolated. The targets are, however, too thick to allow spectator protons from deuterium to be seen. One-prong events cannot be kinematically reconstructed unless the neutral secondary is detected; nonetheless, useful data may be obtained in such events. If the system is sufficiently large, containing many modules, the probability of gamma-ray conversion and neutron detection will increase substantially; the thin-target module favors low-energy proton detection and identification. With one-cubic-meter modules, fourteen modules make a ton and a five-ton system with seventy modules would have a total target thickness of 7.7 meters, about 0.8 radiation length and an overall length (with the design of Fig. 1) of about 19 meters.

The mode of streamer-chamber operation proposed is unconventional in that the chamber is viewed not along the electric field but transversely. Seen from this direction, the streamers are several mm

long and not as bright. However, most tracks will be along the neutrino direction, thus along the electric field and the tracks will be correspondingly brighter. A mixture of wide-gap and streamer modules may be desirable.

No serious consideration has been given to the question of magnet design. Providing a transverse field of 20 kg over hundreds of cubic meters is too big an undertaking to treat in a few words. It is certainly possible but will present a major design challenge.

REFERENCES

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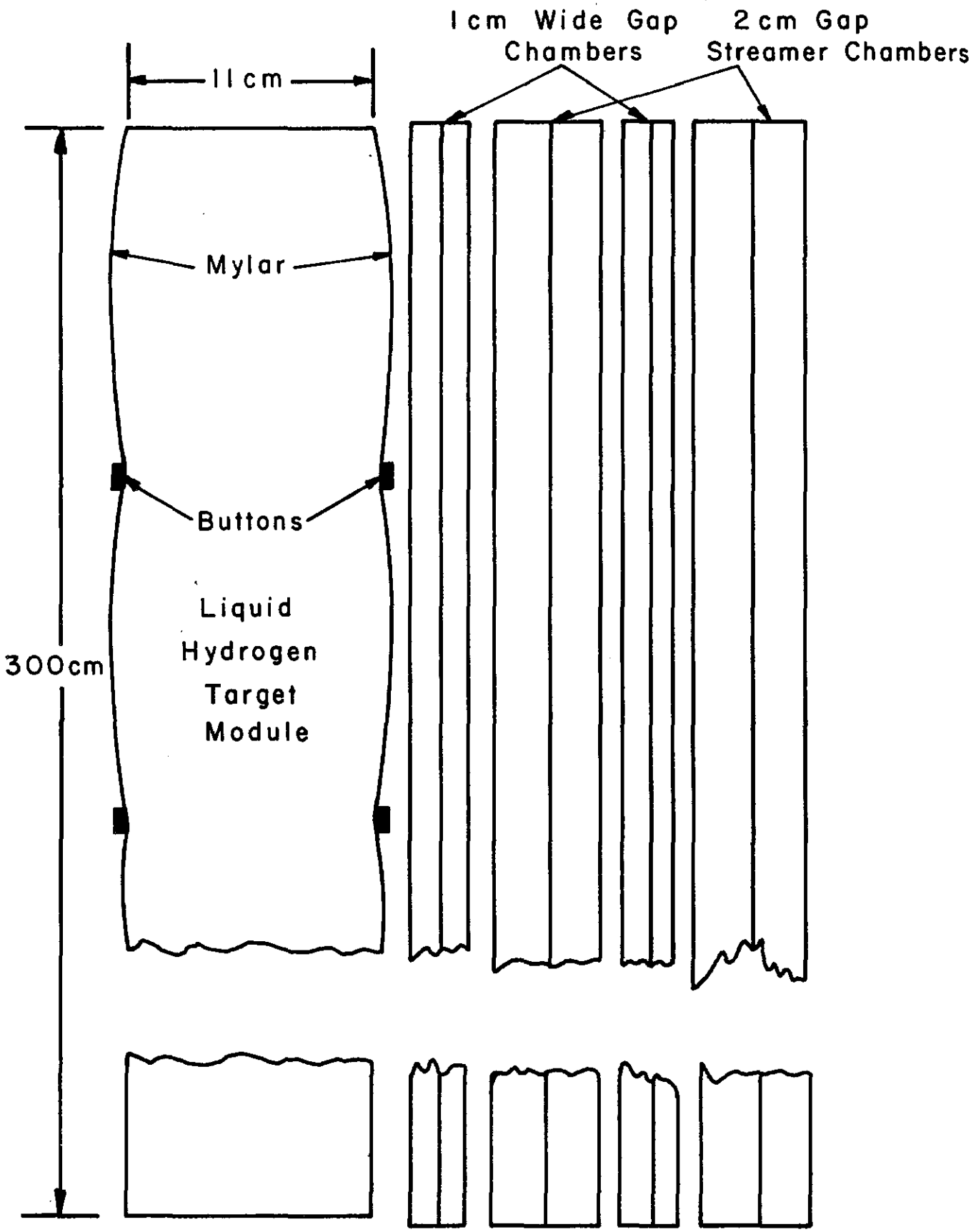

Fig. 1 Target-Spark Chamber Module