PLANS FOR NEUTRINO EXPERIMENTS WITH THE 12 FT BUBBLE CHAMBER AT THE ZGS

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Introduction

It has been obvious for some years that studies of neutrino interactions in a pure hydrogen or deuterium target are necessary for a further experimental advance of the subject, and a proposal was made in June, 1964,[1] to build a 12 ft. hydrogen bubble chamber for use at the 12.5 GeV ZGS. The chamber was funded in the fiscal 1965 budget and is now nearing completion.

Design and Status of Chamber

The chamber is a flat cylinder with a vertical axis as shown in Figure 1.[2] The visible volume viewed by four cameras is about 3.9 m in diameter and 1.9 m high containing 20 m^3 of hydrogen or deuterium. The total volume of the chamber is 26 m^3. At present all the major components are on site at Argonne and the assembly of the chamber in the magnet is proceeding.

The magnetic field of 18 Kg is provided by a superconducting magnet in an iron yoke.[3] The magnet was operated to its design field in December, 1968.

The first tests of the chamber with hydrogen are expected in the spring of 1969, and the systems should be ready for the first neutrino experiment with the chamber filled with deuterium before the end of 1969.

Neutrino Beam

The two other ingredients of a neutrino experiment are a high intensity accelerator and a suitable beam. Figure 2 shows the quarterly mean beam intensity in the ZGS since the first operation and also the peak intensity. For a neutrino experiment with a single user, one can expect an intensity closer to the peak value. Fast extraction is done with a pulsed magnet and an energy loss target. The extraction efficiency is measured to be $> \sim 50\%$ and the spill time can be up to 200 μ sec. With no flat top the repetition rate of the ZGS is 2 secs.

The focussing horn we will use is the one designed and built for the spark chamber experiment carried out at the ZGS.[4] It is placed 36 m upstream of a 13 m thick muon filter. The whole complex is downstream of the second extracted proton area at the ZGS.

Flux Determination

For monitoring the neutrino flux we will use an array of scintillation counters in the downstream end of the filter to measure the flux above 1.5 to 2 GeV, but we will rely on an accurate beam survey for determinations of the low energy flux.

An extensive survey of pion production from 12.5 GeV proton collisions on Be was made several years ago.[5] More recent measurements[6] in a limited angular and momentum range have given higher cross sections by about a factor of two over the early data. We are scheduled to make an extensive survey this spring in which we also hope to measure the attenuation lengths for the secondary particles in Be.

Neutrino Spectrum and Event Rates

The neutrino and antineutrino fluxes expected in the experiment are shown in Figure 3 based on the old beam survey[5] which probably gives absolute values 1.5 to 2 times too low. A comparison with the proposed experiment using the 7 ft. chamber at BNL[7] shows that the ν flux in the ANL arrangement is higher below 1 GeV neutrino energy. Taking into account the larger volume of the 12 ft. chamber, the elastic event rate per proton will be much higher at ANL. The inelastic events with a cross section rising linearly as the neutrino energy will be better studied at BNL.

Using a fiducial volume of 17 m^3 and 10^{12} protons incident on the horn target, 10^6 pictures will give the following number of events for a ν experiment in deuterium assuming a flux 1.5 times higher than given in Figure 3.

	Reaction	Events
(1)	$\nu + n \rightarrow \mu^- + p$	1200
(2)	$\nu + n \rightarrow \mu^- + p + \pi^o$	120
(3)	$\nu + n \rightarrow \mu^- + n + \pi^+$	60
(4)	$\nu + n \rightarrow \mu^- + p + \pi^+$	540

The estimate of the number of elastic events comes from the theoretical cross section, whereas for the single pion production we used the excitation function measured in the recent CERN propane chamber experiment.

Expected Results

The events listed above will be seen as 2 prongs with or without a spectator proton (reactions 1 - 3) or 3 prong (reaction 4). Knowing the angles of the incident neutrino, they may be separated from one another kinematically.

The momentum of the ANL neutrino beam is ideally suited to the study of reaction (1) ("elastic"), since in this momentum region (0.5 - 1.5 GeV) the differential cross section, $\frac{d\sigma}{dq^2}(k_\nu, q^2)$, exhibits the most structure. This is shown in Figure 4. The shape of $\frac{d\sigma}{dq^2}$ is determined by the hadron weak interaction current which couples to the leptonic current in the matrix element. This current is believed to be of the form:

$$J_a = \psi_p \{F_V \gamma^a + \frac{i\mu F_V}{4m}(\gamma^a\gamma^\beta - \gamma^\beta\gamma^a) q^\beta + \lambda F_A \gamma^a \gamma^5 - \frac{ib}{m} F_p \gamma^5 q^a\} \psi_n$$

The experiment is insensitive to the presence of the fourth term — "induced pseudo scalar term". The form factors, F_A and F_V are assumed to be of the form:

$$F_{A,V} = \left(\frac{1}{1 + \frac{q^2}{M^2_{A,V}}} \right)^2$$

It is predicted by the Conserved Vector Current hypothesis, (CVC), that $\mu = 3.71$ and $M_V = 0.84$ GeV. These values come from the relationship with the nucleon form factors in electromagnetic interactions and are therefore very precise predictions. While certain low energy decays satisfy the CVC predictions within errors (10%), no definite confirmation has been possible previously for reactions in which q^2 is significantly greater than zero. This is the backbone of present weak interaction theory and confirmation from this experiment is vital. M_A is not predicted, but previous experiments at CERN have suggested that $\frac{M_A}{M_V} = 1.0 \pm 0.3$.

The analysis of the "elastic" events will use the maximum likelihood method. Taking our expected flux and differential cross section we have investigated the error matrix that we would get in a fit to these form factors, the constant μ and flux correction factors. This analysis shows that the experiment will answer the following questions:

1) assuming the CVC value for μ and a 10% error on the flux estimate, what is the value of M_V? (M_A being a free parameter.) The error would be $\pm$ 0.10 GeV;

2) assuming in addition the CVC value of M_V, what is the value of M_A? The error would be $\pm$ 0.04 GeV.

If instead the absolute flux was unknown, the errors would be 50% higher. In this case the flux is measured by the value of the differential cross section at $q^2 = 0$.

Much less is known about the inelastic channels 2, 3, 4. There is indication that the process is dominated by N^* (1238) production. This has three consequences:

a) the ratio of the cross sections for channels 2, 3, 4 are 2:1:9
b) the nucleon-pion mass distribution should be characteristic of the N^* (1238)
c) the nucleon-pion angular distribution should correspond to the decay of the N^*.

None of these features has been demonstrated very convincingly in other experiments so far, either because of small statistics or because of interpretation problems in production on complex nuclei. There is also the prediction of $\frac{d\sigma}{dq^2}$ at $q^2 = 0$ based on the partially conserved axial vector current (Adler) and the consequences of CVC which in this case relates N^* production by neutrinos to N^* electroproduction. An analysis of the form factors may be made as in the "elastic" reaction — of course, the value of any flux correction factors has to be the same.

The cross section for other channels will be small at our energy, and we do not anticipate a great contribution from studies of the inelastic events.

References

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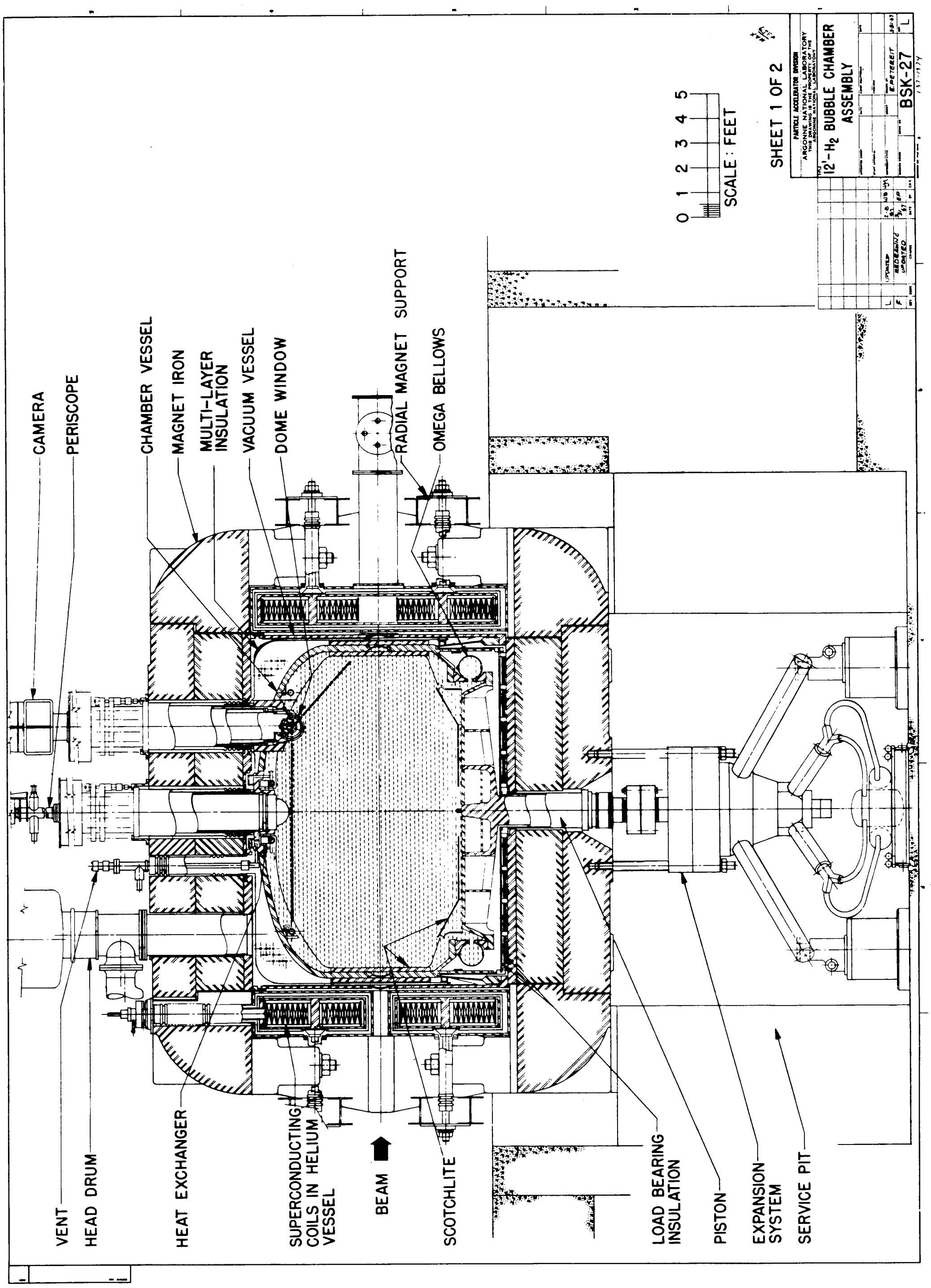
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PERISCOPE
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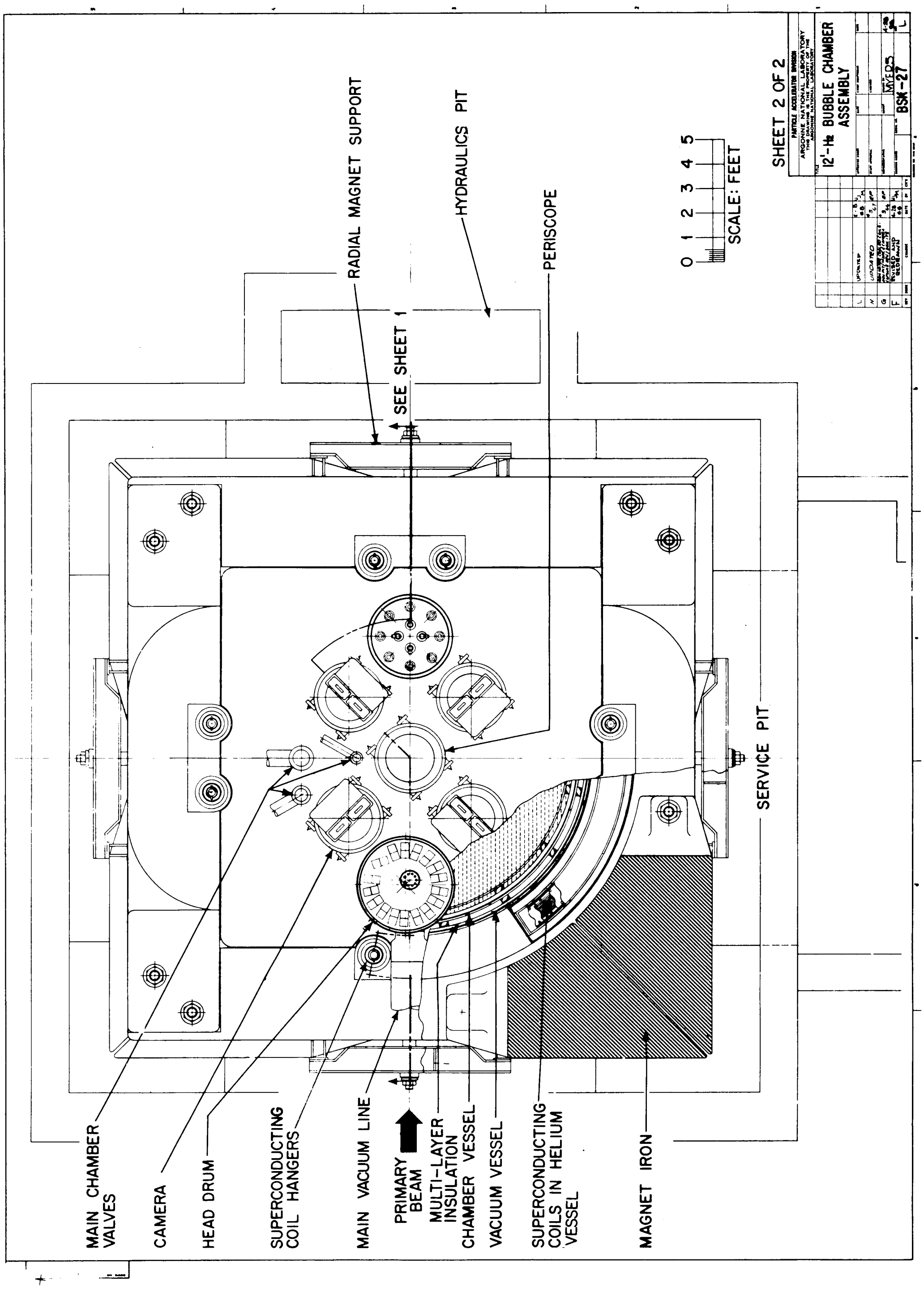
MAGNET IRON
MULTI-LAYER INSULATION
VACUUM VESSEL
DOME WINDOW
RADIAL MAGNET SUPPORT
OMEGA BELLOWS
VENT
HEAD DRUM
HEAT EXCHANGER
SUPERCONDUCTING COILS IN HELIUM VESSEL
BEAM
SCOTCHLITE
LOAD BEARING INSULATION
PISTON
EXPANSION SYSTEM
SERVICE PIT
0 1 2 3 4 5
SCALE : FEET
SHEET 1 OF 2
ARGONNE NATIONAL LABORATORY
12'-H_2 BUBBLE CHAMBER ASSEMBLY
BSK-27

Fig. 1a


RADIAL MAGNET SUPPORT
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SHEET 2 OF 2
ARGONNE NATIONAL LABORATORY
12'-H2 BUBBLE CHAMBER ASSEMBLY
BSM-27
SERVICE PIT
MAIN CHAMBER VALVES
CAMERA
HEAD DRUM
SUPERCONDUCTING COIL HANGERS
MAIN VACUUM LINE
PRIMARY BEAM
MULTI-LAYER INSULATION
CHAMBER VESSEL
VACUUM VESSEL
SUPERCONDUCTING COILS IN HELIUM VESSEL
MAGNET IRON

Fig. 1b

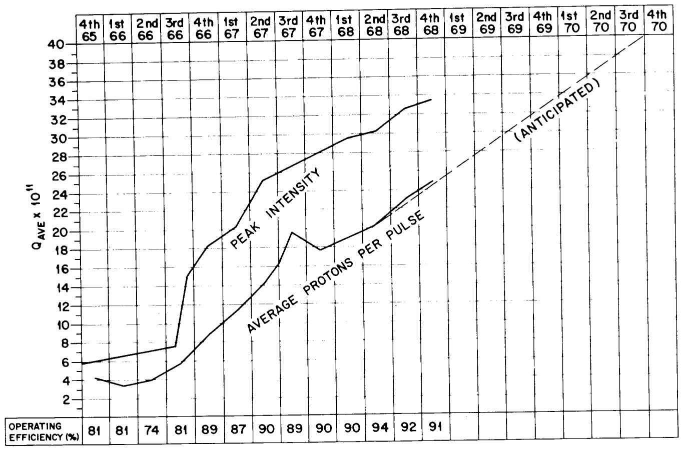

Fig. 2

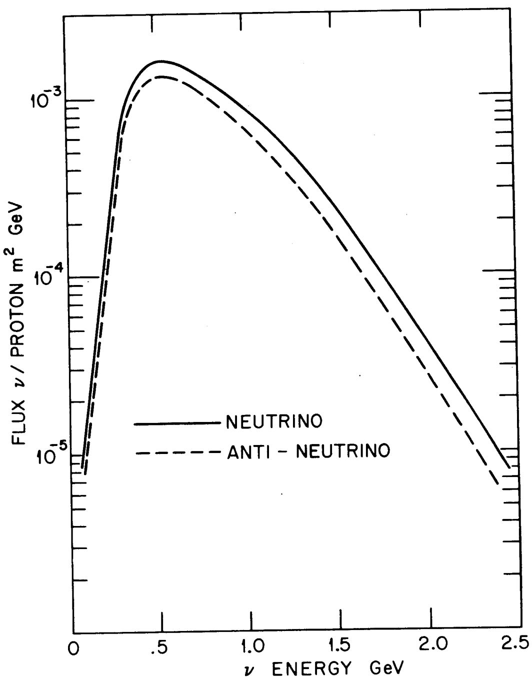

Fig. 3

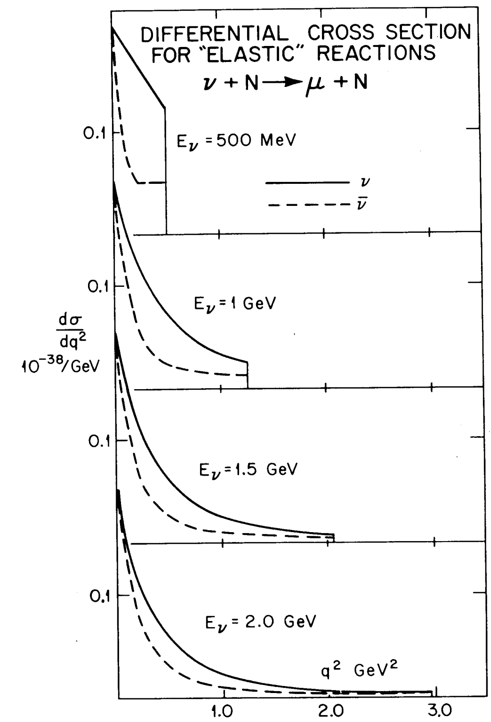

Fig. 4