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EXTERNAL VERSUS INTERNAL MUON IDENTIFICATION IN THE 15-FOOT BUBBLE CHAMBER

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ABSTRACT

Two methods for identifying muons from neutrino interactions in the 15-foot bubble chamber are compared: the first uses a 1-m thick lead plate inside a neon filling and the second uses optical spark chambers interspersed with walls of concrete external to the bubble chamber.

INTRODUCTION

Previous summer studies[1] have emphasized the importance of muon identification in studying neutrino interactions in a bubble chamber. Several of the NAL proposals submitted thus far have mentioned muon identification, and two[2, 3] have explicitly described methods for achieving this goal, one internally and the other externally. The purpose of this note is to outline the two methods and list some of the advantages and disadvantages of each.

CHARGED PION DECAY

NAL Proposal 53[2] uses a lead plate 1-m thick (~ 6 interaction lengths) inside a liquid-neon filling. The approximate orientation is shown in Fig. 1. The plate is tilted slightly so that charged particles passing through the lead can be detected and momentum-analyzed on either side. The interaction length in neon is L = 85 cm so that the fraction of charged pions that decay into muons before interacting either in neon or in lead is approximately

$$F = L/\lambda,$$

where

$$\lambda = (p/m)\tau_0 c,$$

and where p is the pion momentum, m the pion mass, τ_0 the pion lifetime, and c the velocity of light.

The authors of NAL Proposal 53 estimate that there will be typically 0.5 m of pion track before a decay occurs, and that momentum change can be used to eliminate roughly half the pion decays simulating muons. The effective decay path is then

$$L_{Ne} = 83 \text{ cm}/2 = 0.42 \text{ m}.$$

The decay angle (~ 5-30 mrad) is probably too small to be detected with confidence in neon. In particular reactions, however, kinematic fitting and various cuts of the angular and momentum distributions may reduce the probability for mistaking pion identity by more than one order of magnitude.

In NAL Proposal 9 optical spark chambers are interspersed with walls of heavy concrete external to the bubble chamber as indicated schematically in Fig. 2. The hadrometer consists of 20 such walls, each 25 cm thick, for a total of 14 collision lengths. The collision length in hydrogen is about 4 m so that roughly half the pions will interact and be identified in hydrogen. Of those which decay, perhaps three-fourths can be identified by momentum change so that the effective decay path in hydrogen is approximately

$$L_{H_2} = \frac{1}{2} \times \frac{1}{4} \times 2 \text{ m} = 0.25 \text{ m}.$$

If a quantameter is used immediately after the hydrogen (hybrid system), those pions (one-half) that do not interact or decay in hydrogen must pass through one collison length of lead and will be attenuated by another factor of $1/e = 1/2.7$. The additional effective decay length in passing through the quantameter is then

$$L_Q = \frac{1}{2} \times \frac{1}{2.7} \times \frac{1}{2} \text{ m} = 0.09 \text{ m}.$$

The quantameter is followed by a drift space of about 1 m in which the additional effective decay length is

$$L_D = \frac{1}{2} \times \frac{1}{2.7} \times 1 \text{ m} = 0.18 \text{ m}.$$

Pions then enter the first concrete wall of the hadrometer, which contributes about 0.36 m (1 collision length) in which additional decays can occur:

$$L_H = \frac{1}{2} \times \frac{1}{2.7} \times 0.36 \text{ m} = 0.07 \text{ m}.$$

The total effective decay length is then

$$L_{Hybrid} = 0.59 \text{ m}.$$

The result for the hadrometer alone (no quantameter) is

$$L_{Hadrometer} = 1.18 \text{ m}.$$

The probabilities for mistaking a decaying pion for a muon in the three cases considered are summarized in Table I.

EFFECTIVE VOLUME AND SOLID ANGLE

The 1-m thick lead plate shown in Fig. 1 has a radius of about 1 m. The front edge is near the center of the bubble chamber so that the plate intercepts a cylindrical volume of about

$$V_{Ne} = \pi (1\ m)^2 \times 2\ m$$

$$= 6\ m^3.$$

(The estimate of 15 m^3 given in NAL Proposal 53 appears to be optimistic.) The quantameter and hadrometer described in the hybrid proposal have dimensions larger than the diameter of the bubble chamber so that the volume in this case is[4]

$$V_{Hybrid} = V_{Hadrometer} = 30\ m^3.$$

In each of these cases, smaller fiducial volumes would be defined for specific experiments. Roughly speaking, however, the useful volume for internal muon detection in neon appears to be about one-fifth of that for external muon detection with hydrogen.

The horizontal and vertical angles for the quantameter and hadrometer proposed, measured from the center of the bubble chamber, are 90° × 90°. The center of the useful volume for neon with 1-m lead plate is about 1 m upstream of the plate, which has a 1-m radius and thus also subtends horizontal and vertical angles of order 90° × 90°. Neglecting the magnetic field, then, the solid angles for muon identification are comparable in the two proposals.

MAGNETIC FIELD

The short distance from the neutrino vertex in neon to the 1-m thick lead plate is a major advantage when the effect of the 30-kG magnetic field is taken into account. The total deflection angle versus muon momentum is plotted in Fig. 3 assuming the field extends over 2.5 m (vertex at the center of the bubble chamber). The figure suggests that external muon identification will not be effective for muon energies below about 4 GeV. Below about 1 GeV, muons are captured in the magnetic field and can be identified in this way. Assuming the muon has typically half the neutrino energy, external muon identification becomes effective for neutrino energies above 8 GeV. An important point is that tracks observed in the bubble chamber can be traced through the quantameter and hadrometer. Thus, particles outside the hadrometer acceptance are clearly distinguished and are not misidentified (i.e., one knows when positive identification of a track is possible).

SUMMARY

The advantages and disadvantages of the internal and external methods of muon identification as proposed are listed in Table II. The internal method allows fewer decays and is not insensitive to muons in the range 1-4 GeV, although muons of about 1 GeV do not penetrate the 1-m lead plate. On the other hand, momentum measurements are severely degraded in neon as compared to hydrogen, and the fiducial volume is reduced by the lead plate in neon by a factor of 5, essentially nullifying the factor of 10 rate advantage frequently attributed to neon. Both systems allow π^0 and neutron detection so that total cross sections and deep-inelastic interactions can be studied.

REFERENCES

[1] D. D. Jovanovic, R. Palmer, and B. Roe, Muon Detectors after the 25-Foot Chamber, National Accelerator Laboratory 1969 Summer Study Report SS-69, Vol. II, p. 207.

[2] C. Baltay, R. B. Palmer, and N. P. Samios, Search for the Intermediate Boson, Lepton Pair Production, and a Study of Deeply Inelastic Reactions Utilizing High Energy Neutrino Interactions in Liquid Neon, National Accelerator Laboratory Proposal 53, 1970.

[3] M. L. Stevenson et al., Proposal for a High-Energy Neutrino Experiment in the NAL 30 m^3 H_2, D_2 Bubble Chamber, National Accelerator Laboratory Proposal 9, 1970.

[4] We assume a long decay path and muon shield in Area 1 (1400 m + 1400 m, for example) in which case the neutrino events would be distributed throughout the 30 m^3 bubble-chamber volume.

Table I. Misidentification in Percent.

p_π(GeV)	λ(m)	Ne-Pb 0.42 m/λ	hybrid 0.59 m/λ	hadrometer alone 1.18 m/λ
1	55.6	0.76	1.1	2.1
2	111	0.38	0.53	1.1
5	278	0.15	0.21	0.42
10	556	0.08	0.11	0.21

Table II Relative Advantages of Neon-Lead Plate and Quantameter Systems.

Neon with 1-m Lead Plate

Advantages	Disadvantages
low-energy muon sensitivity	fiducial volume reduced 1/5
lower decay probability	±20% error in E_ν
π^0 energy in neon	performance of bubble chamber?
neutron energy in neon	difficulty in viewing
neon density (× 10)	modifications to bubble chamber
all data on film	conflict with hadron runs
no external field map	downtime to install plate
π^0 photon angles in neon	cost of neon ($900 K ?)
	cost of lead plate ($300 K ?)

Hybrid (Quantameter Plus Hadrometer)

Advantages	Disadvantages
H_2 or D_2 target	muons of 1-4 GeV are missed
full 30 m^3 volume	larger decay probability
±5% error in E_ν	timing, triggering, backgrounds?
π^0 energy in quantameter	modifications to bubble chamber
neutron energy in hadrometer	must merge spark-chamber and bubble-chamber data
π^0 photon angles in quantameter	detailed external field map
	cost of hybrid ($1040 K ?)

Hadrometer (No Quantameter)

Advantages	Disadvantages
H_2 or D_2 target	E_ν not fully measured
full 30 m^3 volume	poor π^0 identification
no modifications to bubble chamber	poor neutron identification
	larger decay probability
	muons of 1-4 GeV are missed
	must merge spark-chamber and bubble-chamber data
	detailed external field map
	cost of hadrometer alone ($430 K ?)

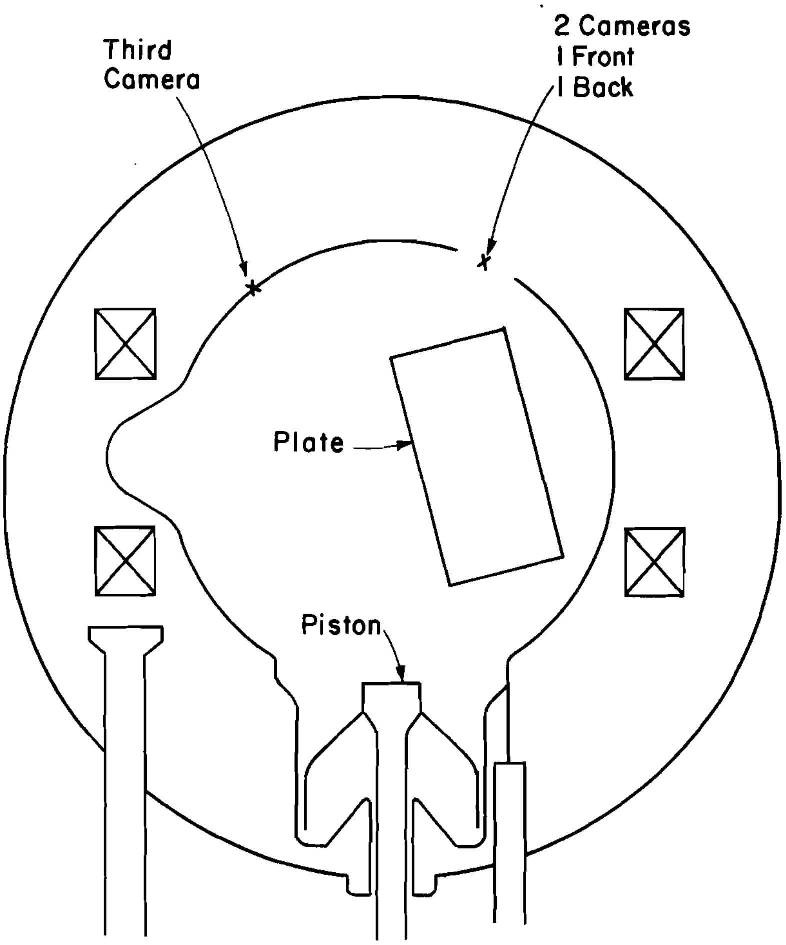
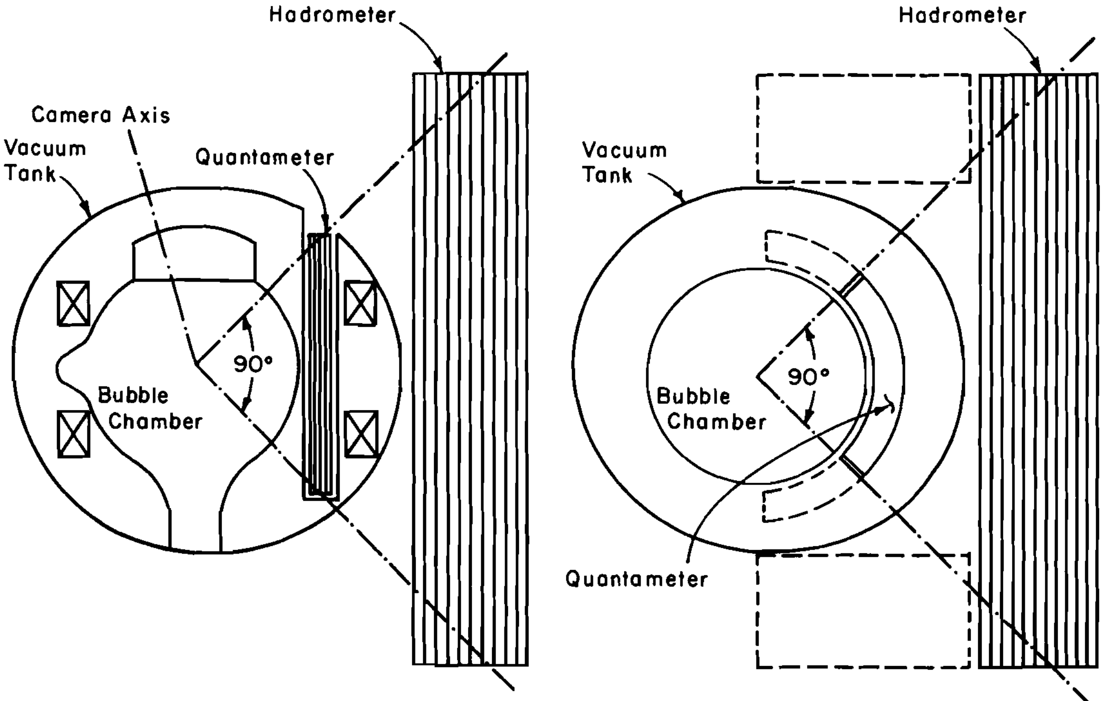


Fig. 1. Chamber with neon filling and lead plate.



Side View

Top View

Fig. 2. Chamber with quantameter.

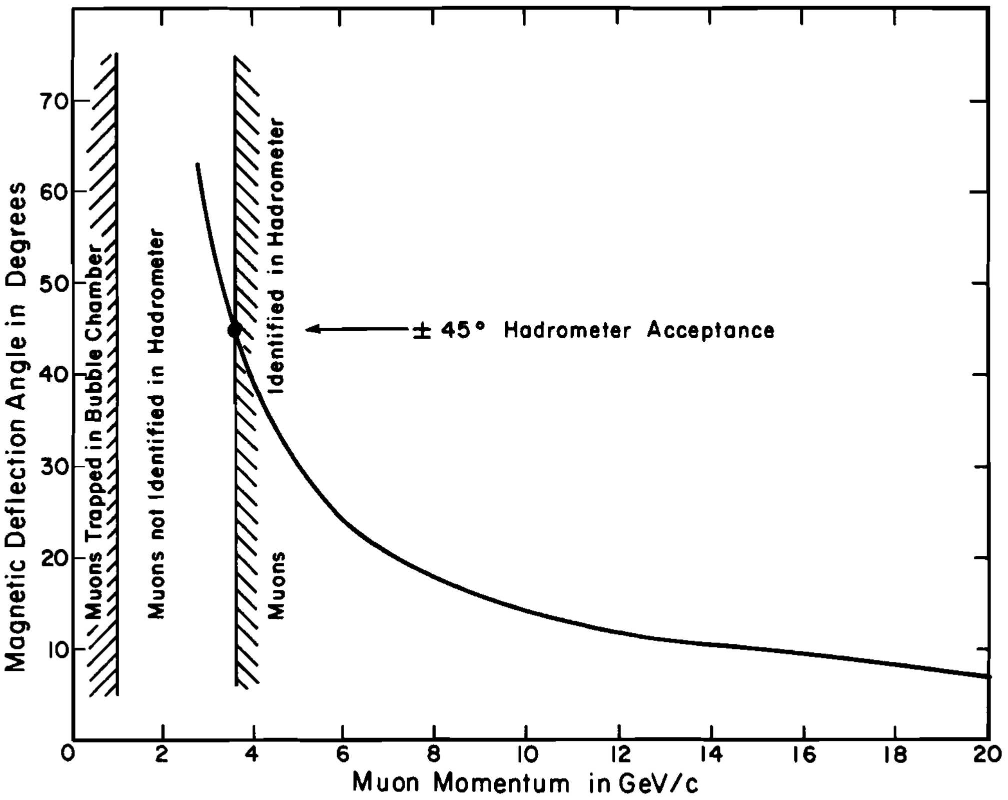


Fig. 3. Deflection of muons in the chamber magnetic field.