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The NAL 30 M^3 Bubble Chamber External Muon Identifier*†

F. A. Harris
Department of Physics and Astronomy
University of Hawaii
Honolulu, Hawaii 96822

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The Hawaii-LBL collaboration has accepted the responsibility of building an external muon identifier[1] (EMI) behind the 15' bubble chamber at NAL. Neither the bubble chamber nor the EMI have yet become operational, so it is impossible to report any physics results at this time. It might be useful, however, to discuss how well the EMI should work, particularly in light of the review at this conference by D. H. Perkins of neutrino physics at CERN and NAL. Of special interest at the present time is the possibility of neutral current interactions ($\nu p \to \nu$ + hadrons), as indicated by preliminary results from a CERN-Gargamelle experiment.[2] Muon identification is extremely important in these experiments to show that no muons are produced in the reaction. Muon identification is also extremely important in bubble chamber experiments involving deeply inelastic neutrino scattering, heavy lepton searches, intermediate vector-boson searches, and studies of four Fermion interactions.

The basic idea of the EMI is to use a single plane of multiwire proportional chambers (MWPC) to detect the positions of particles emerging from an absorber behind the 15' bubble chamber. The incident direction and momentum are determined by analyzing the bubble chamber film. By extrapolating the trajectory through the magnetic field, it is possible to predict where each particle should intersect the plane of MWPC's. In this case, the copper coils of the super-conducting

Helmholz magnet plus additional zinc stacked between these coils comprise the main absorber, as is shown in Fig. 1. Muons will appear in a region near the predicted intersection, and the size of the region necessary to contain a given fraction of the incident muons can be calculated by taking into consideration the uncertainties in the incident direction and momentum as well as the multiple Coulomb scattering in the absorber. Hadrons, on the other hand, undergo nuclear interactions which means that their reaction products will usually scatter outside the muon acceptance region. No attempt is made to completely contain the hadron secondaries in the absorber.

A test of this method of muon identification[3] was made at the LBL Bevatron. A beam of pions or muons, defined by a conventional range telescope, was incident on an iron absorber of variable thickness followed by multiwire proportional chambers. For each iron thickness, the fraction of the incident pions remaining in a circle calculated to be large enough to contain 96% of incident muons was determined. The results can be summarized as follows: A single multiwire proportional chamber following only 50 cm of iron (3.9 collision lengths) can reject pions with 96 ± 1% efficiency while accepting 96% of the incident muons. This result is expected to be insensitive to energy above a few GeV, since hadron-nucleous cross sections are nearly constant above a few GeV. The combined radial thickness of the copper coils, vacuum tank and bubble chamber walls, plus one radius of liquid hydrogen will be equivalent to approximately 3.9 collision lengths.

Also very important to the question of overall efficiency is the geometric acceptance for detecting muons. The fraction of muons accepted depends on how many MWPC modules are on the back of the bubble chamber vacuum tank. Each module is approximately one meter square and covers a solid angle of approximately $17^{o} \times 17^{o}$. Initially, from 20 to 30 modules will be mounted. The geometric efficiency has been calculated using a simple parton model to give the angular distribution for inelastic scattering. Neutrino interactions are generated uniformly over a suitable fiducial volume, and the muons are extrapolated through the field out to a cylindrical radius of 3.3 meters. The calculated efficiency as a function of neutrino energy is shown in Fig. 2 for various assumed areas and configurations of MWPC modules. Proposal 9B[4] calls for 50 modules, which would cover a solid angle of approximately 90^{o} vertically $\times$ 180^{o} horizontally. It can be seen that the efficiency is less for deeply inelastic events with $x, y > 0.5$ ($x = \frac{Q^2}{2M\nu}$, $y = \frac{\nu}{E}$). Fig. 2 underestimates the identification efficiency since it does not take into consideration low momentum muons (less than 2 GeV) that become trapped in the magnetic field inside the bubble chamber and are identified by their non-interaction in the liquid hydrogen itself.

Not only does the muon detection efficiency decrease for the deeply inelastic events, but also the probability of misidentifying the muon increases because of the increasing hadron multiplicity. It is possible, though, to get very high identification efficiency by selecting a suitable sub-sample of events. This can be shown by an example in which we make the following simplifying assumptions:

1) There is one and only one muon produced in the basic neutrino interaction;
2) The charge of the muon is known from the type of interaction; i.e., $\nu + p \rightarrow \mu^- +$ hadrons;
3) Hadrons and muons have equal probability of hitting or missing the MWPCs.

If we restrict our data sample to events where one and only one particle is identified as a muon (hits inside the muon circle), then the probability of misidentification can be seen in Table 1 to be a function of how many trajectories extrapolate to miss the MWPCs. If we require that no trajectories miss, then we can obtain a very low probability of misidentification, even for very high hadron multiplicities. Muon identification can be quite accurate for deeply inelastic scattering, where we postulate beforehand that we expect to see one and only one muon. It is important to cover as large a solid angle as possible behind the 15' bubble chamber with MWPCs not only to increase the muon acceptance but also to increase the muon identification efficiency.

How the EMI is to be used depends on the type of experiment that we wish to perform. In order to demonstrate the existence of events with no muons produced in the final state (neutral-current events), it would be necessary to increase the area of the muon circle to, say, the 99.9% acceptance level and limit the event sample to those events where all the bubble chamber trajectories extrapolate into the MWPCs. The probability of a hadron faking a muon is now high, but the probability of not identifying a real muon is on the level of 0.1%. A conclusive experiment could be performed by restricting the data sample to rather low multiplicity events and correcting the observed rate for hadrons accidentally faking muons.

At the present time, five MWPC modules are being tested in place on the back of the bubble chamber. The remaining modules are being constructed in Berkeley, where most of the chamber[5] and readout system[6] development has taken place. Additional modules will be mounted as they are completed over the course of the next few months.

Initial testing of the system will use the 15' bubble chamber hadron beam, which is being brought into the area for the first time. A total of four chambers will be mounted in line; two in front and two in back of the bubble chamber. The readout system, which is located on the balcony of Neutrino Laboratory A, will write raw data on magnetic tape. Offline analysis will provide us with detailed information on chamber resolution and efficiency. Online displays, possible at reduced beam intensity, will be useful during the tuning of the beamline.

References

1. NAL Proposal 155, "Development and Test of an External Muon Identifier for the 30 m^3 Bubble Chamber," by R. J. Cence, F. A. Harris, S. I. Parker, M. W. Peters, V. J. Stenger, and D. E. Yount (University of Hawaii), and A. Barbaro-Galtieri, J. Marriner, F. Solmitz, and M. L. Stevenson (LBL); V. Z. Peterson, Proceedings of the 1973 International Conference on Instrumentation for High Energy Physics at Frascati, Italy; "HYBRID Bubble Chamber Detection of Neutrino Events: The External Muon Identifier."
2. Neutral currents were discussed in great detail by D. H. Perkins in Lecture 2 of the 5th Hawaii Topical Conference in Particle Physics.
3. F. A. Harris, S. I. Parker, V. Z. Peterson, D. E. Yount, and M. L. Stevenson, Nucl. Instr. and Meth. 103, 345 (1972). ("Muon Identification Using Multiwire Proportional Chambers")
4. NAL Proposal 9B, "Proposal to Study Neutrino Interactions in the 30 m^3 NAL Bubble Chamber with an External Muon Identifier," R. J. Cence, F. A. Harris, S. I. Parker, M. W. Peters, V. J. Stenger, and D. E. Yount (Hawaii), and A. Barbaro-Galtieri, J. Marriner, F. Solmitz, and M. L. Stevenson (LBL).
5. "EMI Development: Half-Meter Proportional Chamber Test Results," by S. I. Parker and R. Jones. Available as LBL Report 797, Hawaii Report UH-511-122-72, or NAL TM-359.

6. "Digitizing Electronics for the EMI Multiwire Proportional Chambers," E. Binnall, F. Kirsten, K. Lee, and C. Nunnally, LBL Report 798 or NAL TM-360.

Table 1. Probability (%) of misidentifying the μ^- in $\nu + p \rightarrow \mu^- +$ hadrons for a restricted event sample where only one trajectory hits inside the 96% muon acceptance circle.

Number of Negatively Charged Hadrons*	Number of Negatively Charge Trajectories that Extrapolate to Miss the MWPCs							
	0	1	2	3	4	5	6	7
1	.2	4						
2	.3	4	7.7					
3	.4	4	7.7	11.1				
4	.6	4	7.7	11.1	14.3			
5	.7	4	7.7	11.1	14.3	17.2		
6	.8	4	7.7	11.1	14.3	17.2	20	
7	.9	4	7.7	11.1	14.3	17.2	20	22.6

*Hadrons identified by interactions in bubble chamber are excluded.

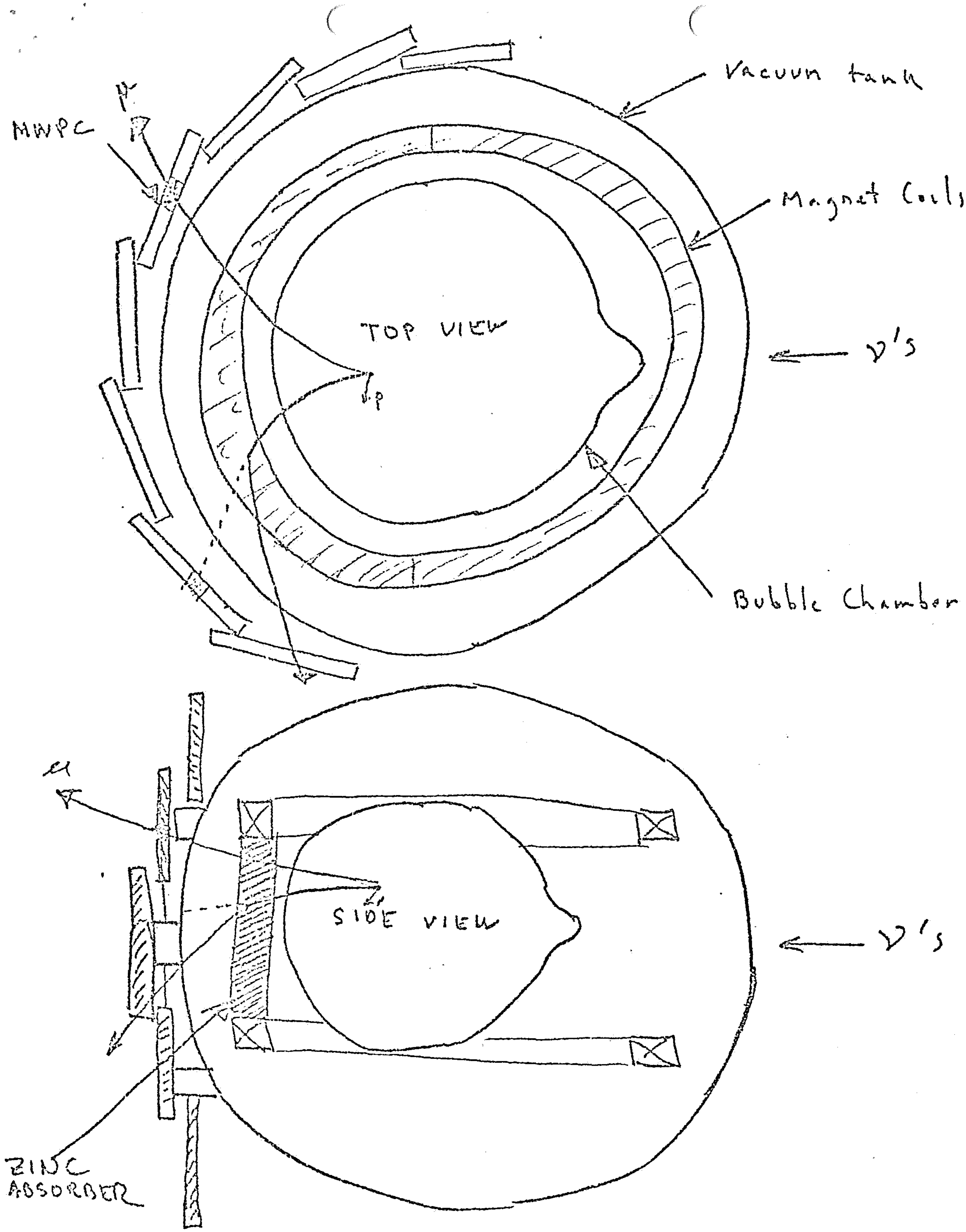
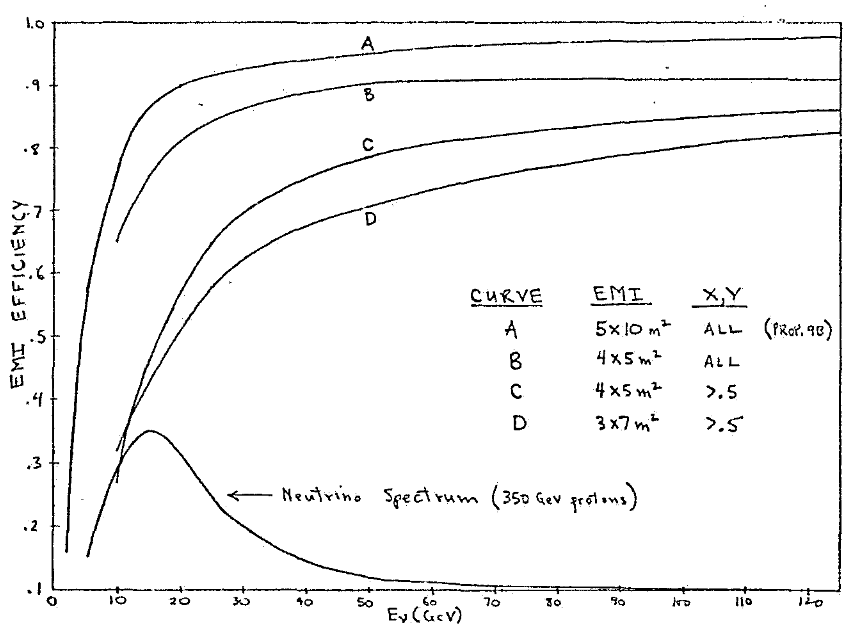

Vacuum tank
MWPC
TOP VIEW
Magnet Coils
ν's
Bubble Chamber
SIDE VIEW
ν's
ZINC ABSORBER

Fig. 1



A
B
C
D
CURVE EMI X,Y
A 5×10 m² ALL (PROP. 98)
B 4×5 m² ALL
C 4×5 m² >.5
D 3×7 m² >.5
← Neutrino Spectrum (350 Gev protons)
EMI EFFICIENCY
1.0
.9
.8
.7
.6
.5
.4
.3
.2
.1
0 10 20 30 40 50 60 70 80 90 100 110 120
Eν (GeV)

Fig. 2