FNAL PROPOSAL NO. 398

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A PROPOSAL FOR A FURTHER STUDY OF MUON NUCLEON INELASTIC SCATTERING AT FERMILAB

BY THE

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COLLABORATION

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II. Introduction

We propose a further investigation of inelastic muon-nucleon scattering employing the muon spectrometer built by the E-98 collaboration. Specifically we propose:

1. To extend measurements of inclusive muon inelastic scattering cross-sections to higher incident energies and thereby study the nucleon structure in kinematic regions not hitherto reached.
2. To identify hadrons and thereby measure $\pi/K/p$ ratios as a function of kinematic variables and charge dependence.
3. To extend our measurements of vector meson production to higher energies.
4. To investigate the target fragmentation region.

This proposal follows naturally from the program of E-98. Data taking in that experiment has been completed and analysis is proceeding. It is clear that we have accomplished a measurement of the structure functions for proton and neutron for q^2 up to 30 (GeV^2), ν up to 130 GeV, and ω up to 200. We have results on hadron spectra, hadron charge ratios, and the production of the ρ and $\rho'(1,600)$ vector mesons. We have studied the physics of these processes as functions of various kinematic variables such as q^2, ν, x, and t. These results will be available for both H_2 and D_2 targets. We also have results on total photo-nucleon absorption cross sections for photon energies from 90 to 130 GeV.

III. Physics Objectives

The specific objectives that we propose are:

1. To extend the measurement of muon inclusive scattering cross-sections to values of ν and q^2 not reached in E-98. This can be done by running with a beam of higher energy, specifically 225 GeV. The consequences are, first, that the ν range of the data can be extended up to 205 GeV and, second, that the statistics in the high q^2 data will be improved significantly. The improvement is best shown in Fig. 1 where the integrated number of events is plotted against q^2. Two curves are drawn, one for E-98, the other for this proposal, both using a H_2 target. The proposed runs will yield about 6,000 events from H_2 and 12,000 from D_2 for q^2 greater than 10 GeV^2.

The data on the inclusive cross-section will yield:

a) Values of νW_2. Compared to E-98, the range of q^2 will be extended from 30 GeV^2 to 50 GeV^2, and ν from 130 GeV to 205 GeV. The accuracy will be 5 to 10%, depending on binning. This determination depends on assuming a value of R, the ratio of scalar to transverse virtual photon cross-sections.

b) Values of R. These can be obtained from the overlapping (q^2,ν) regions of the proposed 225 GeV runs and the 100 and 150 GeV data of E-98. These overlap regions exist for q^2 greater than 1 GeV^2 and ν in the range 10 to 130 GeV.

The precision expected for R is such that if its value is 0.2 then there will be errors of about 0.2 in bins such as

$$1 < q^2 < 3 \quad \text{and} \quad \nu = 115\text{-}130 \text{ Gev}$$

$$3 < q^2 < 10 \quad \text{and} \quad \nu = 100\text{-}130 \text{ Gev}$$

c) Values of the total photon-nucleon cross-section by extrapolation to $q^2 = 0$. This proposal would yield measurements for photon energies from 175 to 205 GeV (E-98: 90 to 130 GeV). The precision will be better than 5%. It is a very interesting question as to whether this cross section rises with energy.

2. To identify, the downstream hadrons by the use of a gas threshold Čerenkov counter hodoscope.

Results from lower energy electroproduction experiments indicate that $K^+/\pi^+ \simeq 1$ and $K^-/\pi^- \simeq 0$ for $x > 0.5$. Preliminary results from E-98 indicate that the charged hadron ratio h^+/h^- is close to 1 for low x and increases as x approaches 1. Moreover there is an indication that this ratio increases with q^2 near $x = 1$. These results raise many interesting questions. By identification of downstream particles we expect to find the ratios K^+/π^+, K^-/π^-, π^+/π^-, p/π^+ and their variation with kinematic variables. E-98 has about 15,000 hadrons, accompanying events with $q^2 > 1 \text{ GeV}^2$ from H_2. The proposed experiment would yield about 45,000 hadrons from H_2 and 90,000 from D_2.

Such total yields appear generous but are essential if the possible increase of h^+/h^- with q^2 at x near one (a low yield region) is to be investigated. In addition, this yield must be divided into two sections with different Čevenkov gas filling, one to allow separation of π from K and p, the other to allow separation of p from π and K.

3. To extend measurements of vector-meson production.

The results from E-98 have shown the expected diffractive production of ρ^0-mesons by the virtual photon. There is also evidence of diffractive production of the ρ' (1,600). For E-98 there are about 1,000 ρ-mesons and 50 ρ' mesons. The runs proposed will yield about 2,000 ρ-mesons and 100 ρ' mesons in the ν range, 175 to 205 GeV, providing an interesting extension to the E-98 data.

In addition, the installation of cylindrical chambers around the target will allow detection at all azimuths of the recoil when the target is a proton. This adds an extra constraint and permits a check of the cuts which reveal vector meson events.

4. To extend the acceptance for charged hadrons. Some additional MWPC's will be placed inside the Cyclotron magnet. For E-98 the low energy cutoff for charged forward hadrons was 7 GeV. The new MWPC's will lower this limit to about 2 GeV. As a result data about hadrons will be available to very small values of x. This will make possible a comparison with Feyman's $dx/_x$ distribution law at x near zero.

5. To begin investigations in the target fragmentation region.

We propose to surround the target with cylindrical MWPC's which will measure the direction of the charged component. This will allow measurement of charged particle multiplicities and direction correlations in the target fragmentation region.

IV. Experimental Configuration - General Description

The experimental configuration remains similar to the one employed in E-98. Figure 2 is a schematic of the proposed layout of the apparatus. The main components can be summarized as follows:

i) Beam tagging system and beam trigger.

ii) Hydrogen/deuterium target surrounded by cylindrical MWPC's used to detect charged particles emitted at large angles.

iii) 1M X 1M MWPC's to detect forward-produced charged particles.

iv) Chicago Cyclotron magnet for momentum analysis of forward-produced charged particles.

v) Wire Spark chambers downstream of the cyclotron magnet to detect charged particles.

vi) Two banks of scintillation counters (horizontal) and (vertical) to select in-time charged tracks.

vii) Čerenkov counter hodoscope to permit the separation of π's, K's, and protons.

viii) Lead-glass hodoscope to permit the detection, identification and energy analysis of photons and electrons produced in the forward direction.

ix) Steel hadron absorber, 8 feet thick.

x) Muon spark chambers to identify scattered muons. In-time muon tracks are determined by two scintillation counter hodoscopes MV and MH which are also used in the trigger.

V. Description of the Elements of the Improved Muon Scattering Spectrometer

To achieve the physics goals described in this proposal, some significant modifications to the E-98 spectrometer are needed. We present here a descript-ion of the components and of the modifications. The overall experimental configuration is shown in Figure 2.

1) The Muon Beam

We propose to run the beam at the highest possible energy, preferably 225 GeV. Any future increase of muon energy and/or intensity can only improve the experiment. In particular the present ratio of halo/beam, and the 50% anticipated increase of this ratio due to an increase in muon energy, is manageable both in the trigger and in the data analysis. Of course a reduction in halo will alway improve the data acquisition, speed the analysis, and reduce the dead time.

2) The Muon Beam Tagging System

The E-98 muon beam hodoscopes and MWPC's will be used to measure the momentum and angle of the incident muon. The only changes are: (i) the addition of some MWPC's to provide redundancy in the tagging system; (ii) the removal of the scintillation trigger counters - the beam hodoscope elements in fast OR will perform their function; (iii) the replacement of beam hodoscope elements downstream of the 1E4 magnet with scintillator of 2 mm thickness instead of the present 6 mm, and (iv) the installation of helium bags in the muon laboratory upstream of the target.

These changes will achieve a reduction by a factor of 3 of the material in the beam between 1E4 and the target. This should reduce the target empty rate. The "scraper" vetos between the magnets in enclosure 104 will be retained.

3) The Liquid Hydrogen/Deuterium Target

The present E-98 liquid target assembly will be used. The target support frame will be replaced by a new one (already built, and presently stored in the Muon Laboratory) to allow installation of the cylindrical proportional chambers around the target. The outside housing of the target needs to be rebuilt using thinner flanges, etc, to reduce the amount of material through which particles must pass.

4) The Cylindrical MWPC's

A set of four coaxial cylindrical MWPC's will be installed to surround the liquid hydrogen/deuterium target. These chambers have a diameter of 0.3, 0.5, 0.75 and 1.0 meter, and have 3 sets of coordinate readout each. One chamber, 0.3 m in diameter and 1 m long, has been built and is now under test at EFI. The tooling and fabrication techniques have been fully developed. It should be pointed out, that some of the muon halo close to the beam will be passing through the chambers, parallel to the anode wires. Because of the short live-time of proportional chambers we do not anticipate this to be a problem.

5) The 1m X 1m MWPC's

The EFI MWPC's will remain in their present location, 8 modules with individual x or y readout between the target and the Chicago Cyclotron magnet, and one module with both x and y readout near the center of the Chicago Cylotron magnet. Twelve 1 m X 1 m MWPC planes are under construction at the University of Illinois. The chambers will be wound at Harvard. They will be installed inside the magnet to measure the momentum of those hadrons which are now curved into the magnet-yoke. These chambers will extend the full momentum measurement of hadrons considerably.

6) Drift Chambers

Harvard University is developing drift chambers of various kinds. They will be available for incorporation into the spectrometer if required.

7) The Wire Spark Chambers

The EFI 2m X 4m shift register readout chambers (12 wire planes) and the Harvard 2m X 6m magnetostrictive readout chambers (8 wire planes) will remain close to their E-98 locations.

8) The Čerenkov Counter Hodoscope

The University of Oxford has constructed an 18-cell Čerenkov hodoscope, which is shown in Figure 3. Each cell has a 20" X 40" section of a spherical mirror, a light-collecting cone, and a 5" diameter photo-multiplier tube. The output signals are directly connected to ADC's for pulse height analysis.

At present, the counter is assembled, with mirrors aligned, and is stored in the Muon Laboratory. It will be installed between the 2m X 4m and the 2m X 6m wire spark chambers. It is estimated that an adequate π/K separation can be achieved below particle momenta of 30 GeV/c using a nitrogen radiator. For K/p separation freon can be used.

9) The Hadron Hodoscopes

The hodoscopes G (horizontal elements) and H (vertical elements) will remain in the same position as for E-98 and the only change will be to add extra elements to H so that it covers the full width of the active area of the 2m X 6m magnetostrictive chambers. This change will allow H, rather than G, to be used in the trigger. The scintillator elements in H are shorter than G, so this change will decrease the trigger resolving time.

10) Lead-Glass Hodoscope

We plan to install a 10 X 10 element Pb-glass hodoscope of 1m X 1m in size to measure the forward going electrons and photons. This device should help to eliminate the uncertainties in electron identification experienced in E-98. It will measure major parts of the radiative corrections directly. A detector of this modest size will cover most of the area of interest. The area can be extended by adding some less expensive shower detectors. We plan to remove the module of 2m X 4m magnetostrictive spark chambers at present located between the lead brick wall and the hadron absorber. In addition the lead wall will be partially dismantled to accommodate the lead-glass hodoscope.

11) Muon Identification

We propose to retain most of the present muon identification equipment. The 8 feet steel absorber, made of the Rochester Cyclotron, will be used to stop all the hadrons. The muon traversing the steel will be identified by sets of sparks in the 2m X 4m magnetostrictive chambers behind the shield. Further identification of the muon will be done using two scintillation counter hodoscopes, M_V and M_H, which will be used for triggering as well as in-time track specification. We expect to reduce some counter lengths in order to tighten the timing and reduce the random coincidence rate.

VI. Trigger

The present E-98 trigger, with some modifications, is adequate for the experiment.

During the last running period of E-98 with a liquid hydrogen target, the ratio of target full to target empty was approximately 3 to 2. This undesirable target empty rate can be traced to random coincidences and to the large amount of material in the beam line before the target.

The accidentals will be reduced by using shorter hodoscope elements, in particular by having H instead of G in the trigger and by shortening some of the elements in the M_H hodoscopes.

The material in the beam line before the target will be minimized by the removal of most of the scintillator downstream of the 1E4 magnet, and by the use of a thinner target housing (see Section IV.2)

A schematic of the proposed trigger arrangement is shown in Figure 4. The basic trigger is formed from an incident beam particle passing through trigger counter T1 and six muon beam hodoscopes B1-B6, in coincidence with a muon leaving the beam and passing through the H and M hodoscopes. The veto counters VS ensure that beam particles pass cleanly through the apertures of bending magnets in enclosute 104. The halo veto counters VH reject intime particles far away from the muon beam from triggering the apparatus. The beam veto hodoscope, K, insures that detected muons have left the beam.

VII. Assignment and Status of Major Modifications and Additions

The successful prosecution of this experiment requires that the Fermilab as well as the orginators of the proposal assume certain responsibilities.

A. We request Fermilab to-

1) Install the new target stand. It is now stored in the Muon Laboratory.
2) Supply additional electronic equipment consisting mainly of power supplies, and ADC's for the lead glass and Čerenkov hodoscopes. This will be requested from PREP.

B. The University of Chicago is responsible for supplying-

1) Cylindrical MWPC's. One of these is built and now under test at EFI. Construction of the remainder await approval by the N.S.F.
2) 1 m X 1 m lead-glass hodoscope. Again construction is contingent on N.S.F. approval.

C. Harvard University will -

1) Provide a new thinner target housing. A request for approval to install this item will be sent to the Neutrino Laboratory.
2) If required, make available drift chambers which are now under construction at Cambridge.

D. Oxford University is responsible for-

1) Čerenkov hodoscope. This is built and stored in the Muon Laboratory. It has yet to be tested.

2) Hodoscope changes. New parts will be made at Oxford and brought here for installation.

E. The University of Illinois will supply-

1) Twelve 1 m X 1 m MWPC planes. These modules are now under construction at Urbana and will be wound at Harvard.

VIII. Requests for Preparation and Beam Time

1) Access to the Muon Laboratory will be required in order to implement the proposed improvements and to restore the E-98 apparatus to its muon scattering configuration following its present use for hadron experiments. We estimate that the time required is as follows:

    a) Modification of scintallation hodoscopes, 3 weeks.
    b) Installation and testing of Čerenkov hodoscope, 8 weeks. (This will be subject of a separate letter).
    c) Installation of lead-glass, 5 weeks.
    d) Installation of target and stand, commissioning of target, 6 weeks in all.
    e) Installation of cylindrical MWPC, 5 weeks.
    f) Re-establishing other equipment, 6 weeks.
    g) Installation of shims on quadrupoles in Enclosure 103, 3 weeks.

    Some of these things can be done at the same time. Some items will require parasitic beam time for testing.

2) We request two periods of running at the highest momentum available, preferably 225 GeV. We require a total of 2×10^{11} muons each for μP and μD scattering. In terms of intensities currently available, each run could be completed in 400 hours of real beam time. Specifically we have assumed a beam of 10^6 μ's per pulse, 500 pulses per hour. The yields shown in Figure 1 are calculated with an assumed data-taking efficiency of 50%, in accordance with our past experience.

Figure Captions

Fig. 1 Integrated yield of events having squared four-momentum transfer greater than q^2 as a function of q^2.

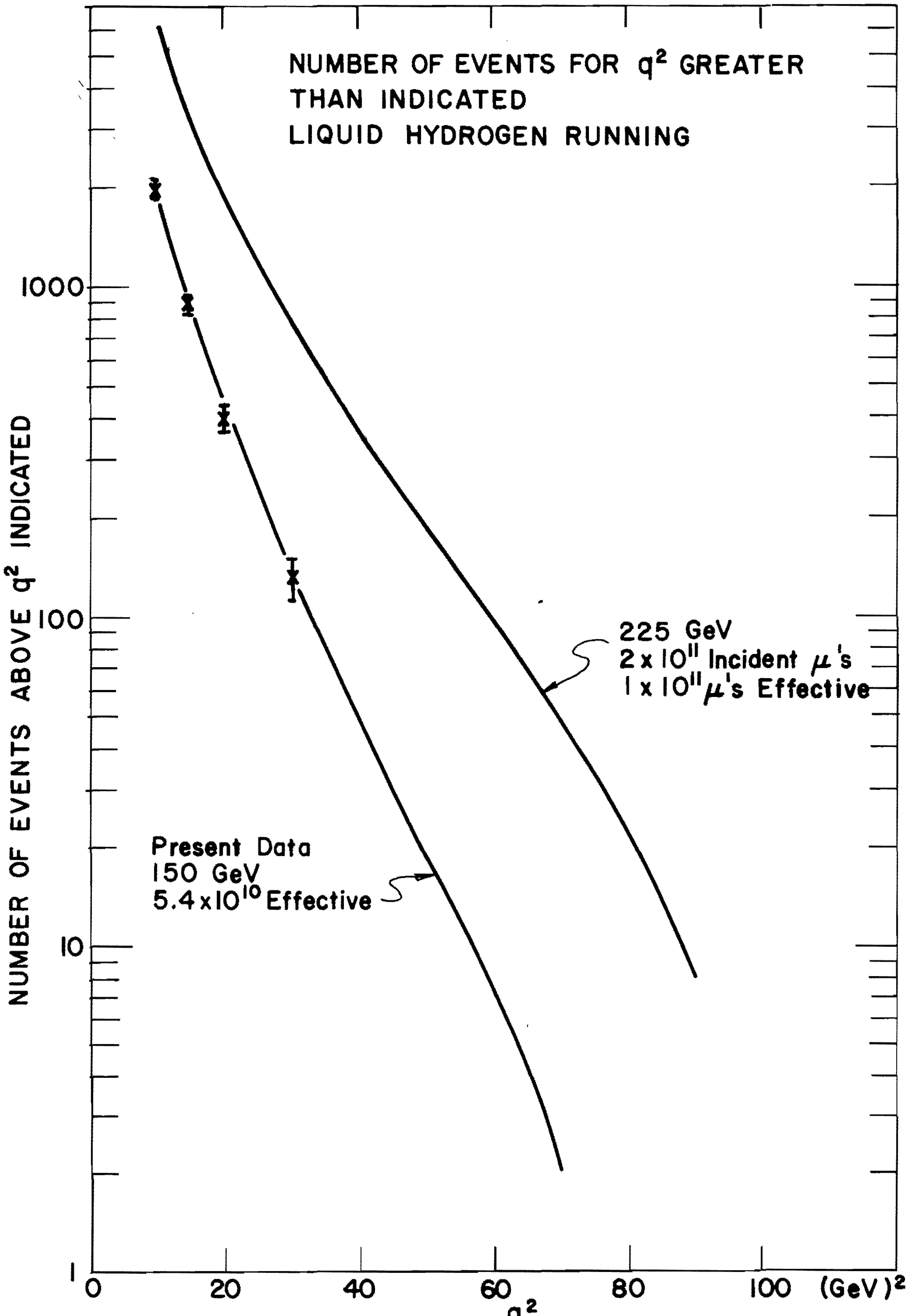
1) Hydrogen results from E-98.

2) Proposed running for hydrogen.

Fig. 2 Proposed layout of apparatus.

Fig. 3 Gas threshold Čerenkov counter hodoscope.

Fig. 4 Simplified trigger logic.



NUMBER OF EVENTS FOR q^2 GREATER
THAN INDICATED
LIQUID HYDROGEN RUNNING
225 GeV
2×10^{11} Incident μ's
1×10^{11} μ's Effective
Present Data
150 GeV
5.4×10^{10} Effective
NUMBER OF EVENTS ABOVE q^2 INDICATED
1000
100
10
1
0
20
40
60
80
100
(GeV)^2
q^2

Fig.1

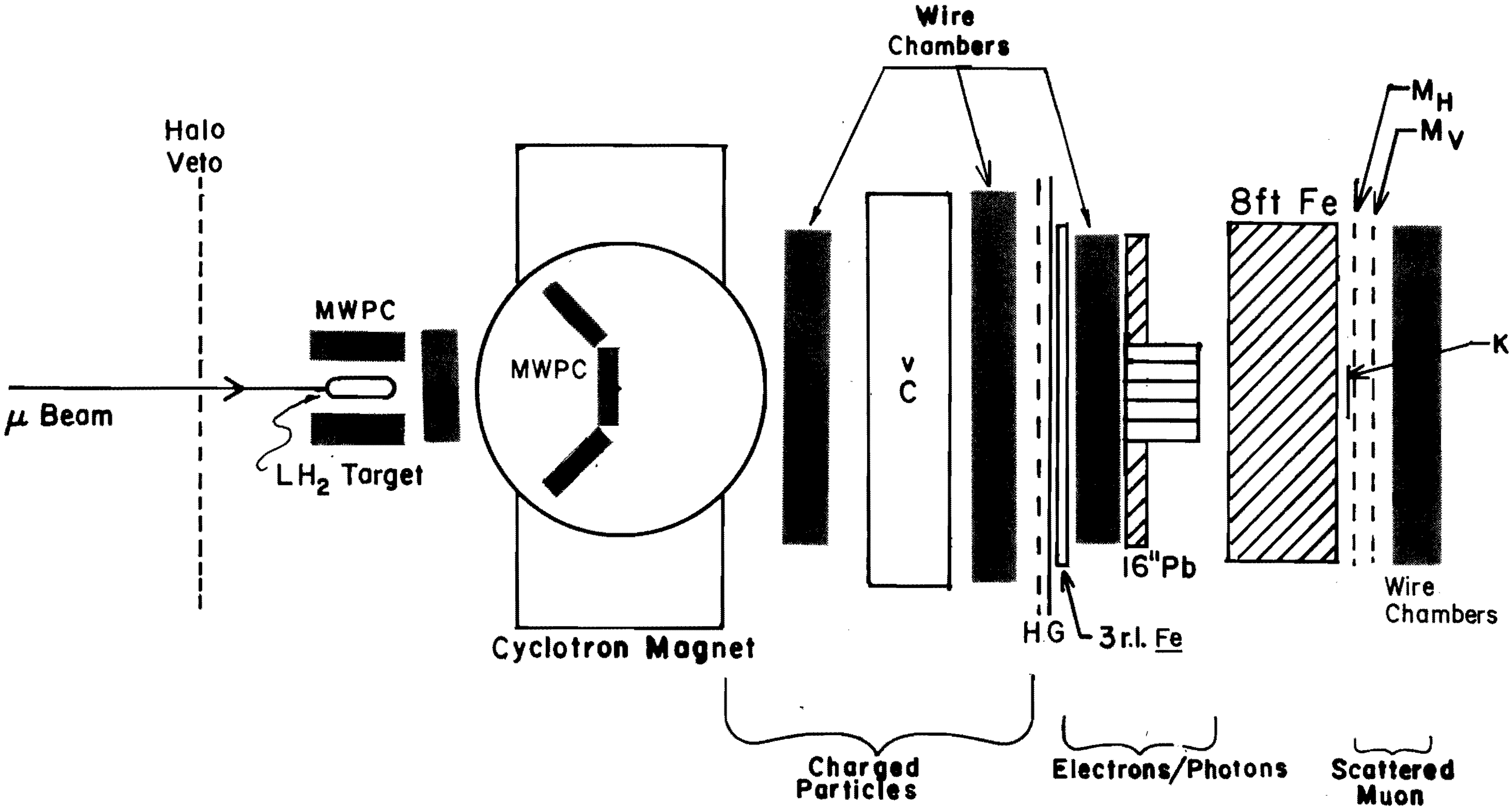

Wire Chambers
Halo Veto
MWPC
MWPC
μ Beam
LH2 Target
Cyclotron Magnet
C
8ft Fe
MH
MV
K
16"Pb
HG
3 r.l. Fe
Wire Chambers
Charged Particles
Electrons/Photons
Scattered Muon

Fig. 2

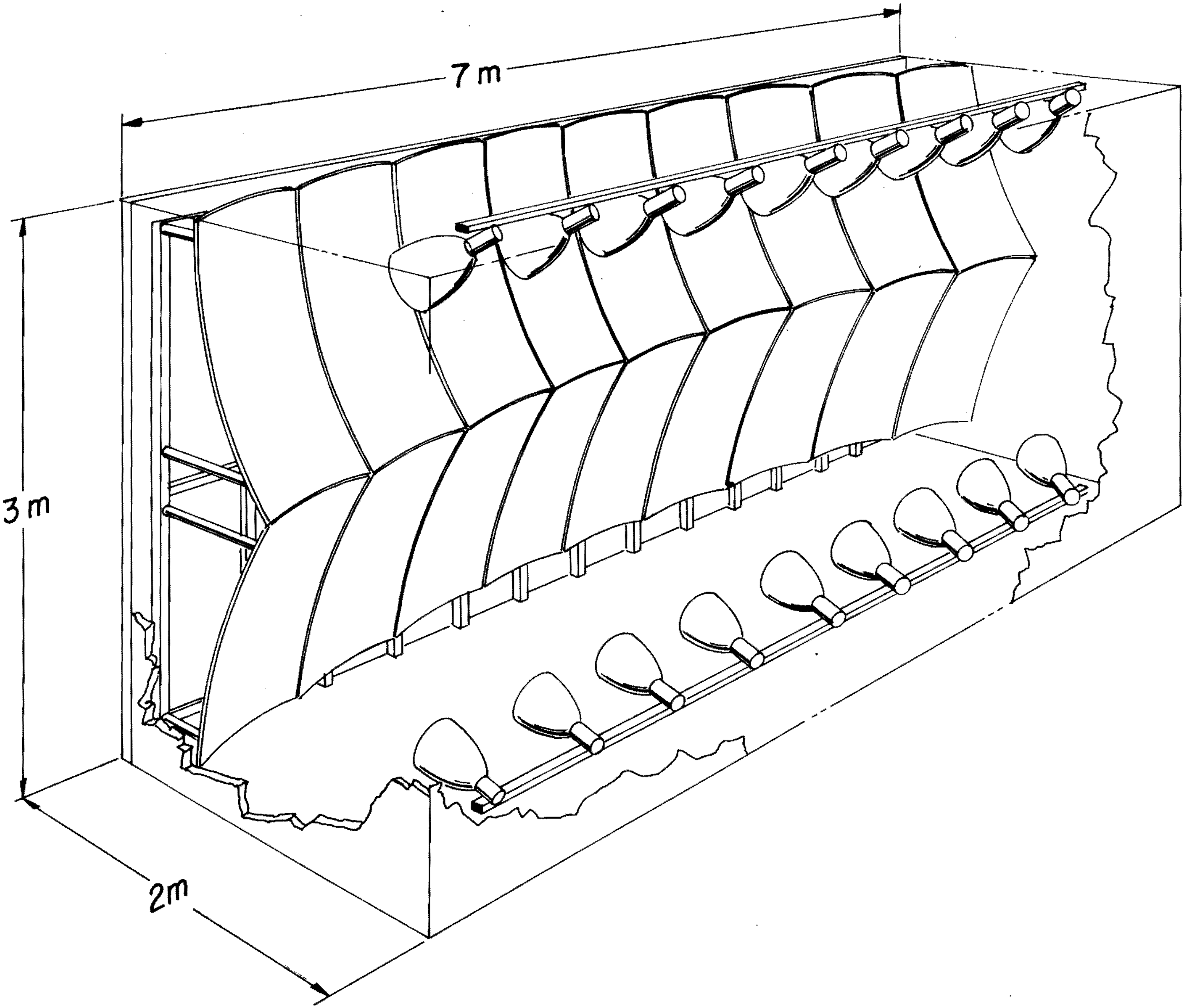
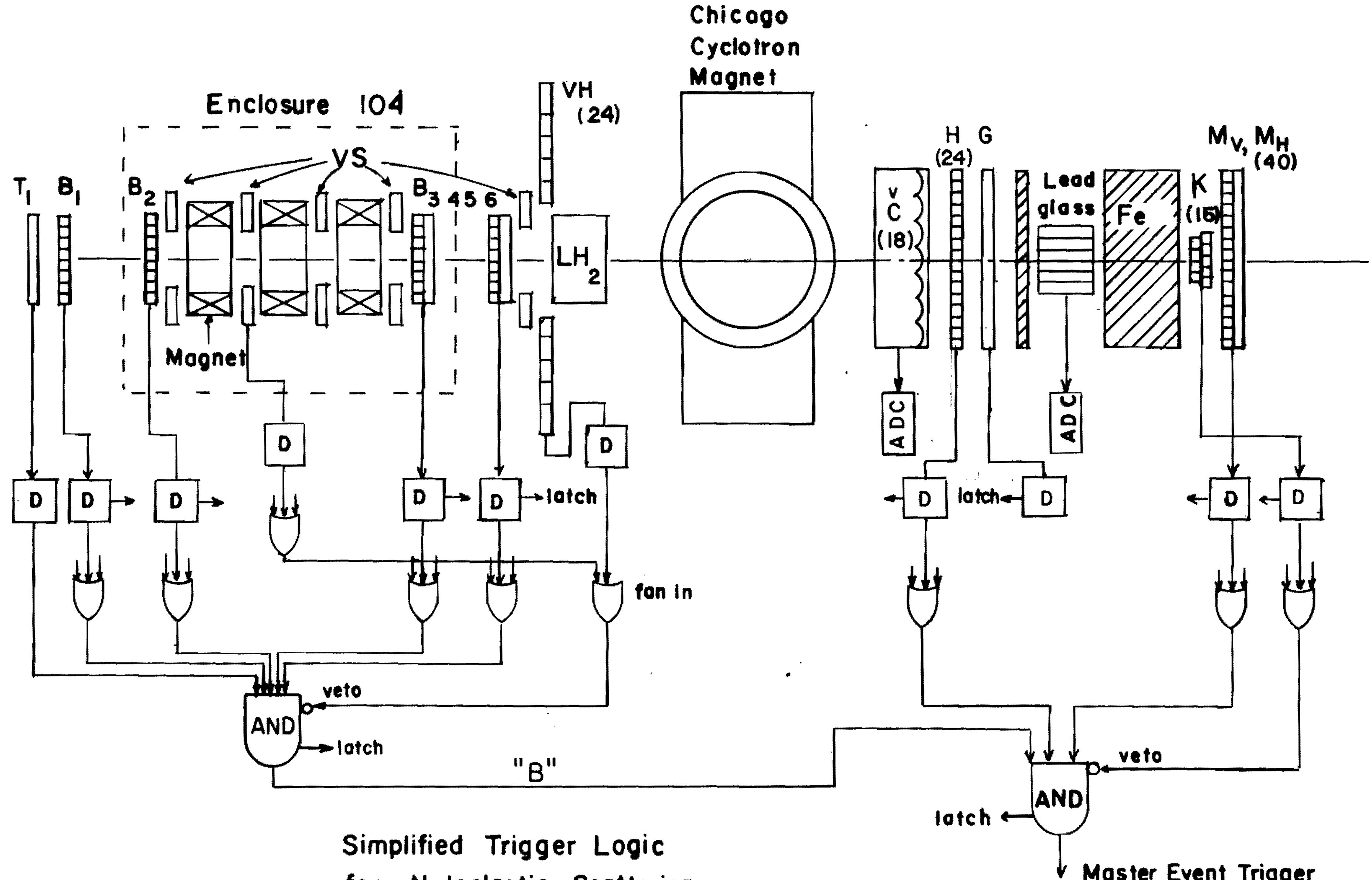


Fig. 3



Simplified Trigger Logic
for μN Inelastic Scattering

Fig. 4