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A COORDINATED APPROACH TO A BEAM DUMP EXPERIMENT AT FNAL USING THE 15' BUBBLE CHAMBER AND THE E-310 DETECTOR

15' Bubble Chamber

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310 Detector

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Abstract

We propose a simultaneous bubble chamber and counter exposure to the flux of particles from the beam dump when directly bombarded with 400 GeV protons. The scheme of S. Mori transporting the protons in vacuum from the front of Neuhall to the dump insures a low background from halo. The versatility of the detectors allow a search for new phenomenon such as prompt neutrinos, axion production and new neutrinos produced in the dump.

12 pgs.

I. Proposed Running Conditions

A) The 15 ft. chamber filled with as high a concentration of Ne as practicable ∿ 47% atomic.

B) EMI - 2 plane.

C) Proton energy of 400 GeV or higher.

D) Modification of target tube and decay pipe to permit the primary proton beam to be transported in vacuum to the water cooled beam dump at the end of the decay tube.

E) Greater than 10^{18}p on target (50,000 pix @ 2×10^{13}ppp).

F) It is feasible to complete the modifications according to a schedule which will permit the running of this experiment after the removal of the Quadrupole Triplet. A description of the proposed scheme is included as Appendix A.

II. Introduction

There is an obvious paradox in trying to justify an experiment to study unknown phenomena. One can only gamble on reasonably possible sources in the search for new phenomena; however, a few simple questions can be asked:

1) How far beyond known processes can the experiment explore?

2) Is the nature of the techniques broad enough so that several different phenomenological properties could be utilized to detect a new process?

3) Are there poorly understood phenomena or processes which could conceivably be detected under some assumptions in this exploratory experiment?

The following discussion attempts to speak briefly to these three questions.

Item 1. To the authors' knowledge only three proton beam dump experiments have been done at FNAL energies to a level below a few percent of the normal neutrino rates.* (During E-28, about one thousand pictures were taken without the target and the proton beam impinging on the beam dump downstream. All of the dozen neutrino interactions observed were consistent with the background from proton interactions in the air and window.) In December, 1977 an experiment was performed at the SPS at CERN. An exposure of about 2×10^{17} protons on target with a geometry similar to that proposed for this experiment was obtained. Although the analysis is not yet complete we understand there may be anomalies in the ratios of events containing μ^-, μ^+, e^+, e^-.

The level that can be reached by this proposed experiment is given in subsequent sections for several different processes, however, in general this experiment will be a factor 3-10 more sensitive than the previous experiments.

Item 2. The bubble chamber filled with neon could, with the existing 2 plane EMI, constitute one of the most versatile instruments for exploration of new phenomena, combining excellent detection of electrons and electromagnetic phenomena, high strange particle detection efficiency (μ° and Λ° decays), excellent analysis facility for the hadronic component and excellent muon/hadron discrimination. We will discuss in section II the importance of these characteristics.

*See Appendix B for a report on a recent target-out measurement for E310.

Furthermore, the proven E-310 detector provides a massive target which couples excellent muon identification and measurement with a smaller, high resolution liquid calorimeter.

There are at least four phenomena that could conceivably produce neutrinos at the target that could be separated from ν_μ neutrinos from π-μ decays, namely; (A) the decay of charmed states, (B) direct production of a new heavy particle at the target which decays into leptons and which could explain the observed direct production of leptons in strong interactions, and (C) a heavy lepton which would probably have its own neutrino and possibly related to the anomalous tri-leptons.and (D) the production of an axion at the target and subsequent interaction of the axion in the neutrino detector.

III. Phenomenological Methods Used to Detect New Phenomena

There are many parameters which might be used in searching for new phenomena, but it seems most likely that the following parameters would be the most fruitful:

A) Ratio of ν_μ/ν_e interactions.

B) Ratio of $\nu_\mu/\bar{\nu}_\mu$ and $\nu_e/\bar{\nu}_e$ interactions.

C) Strange particle production in the neutrino interactions.

D) Di-leptons (μe and $\mu\mu$) and tri-leptons.

E) High energy x and y distributions of the events.

F) Absolute number of neutrino events.

In order to make a discussion of the above six items quantitatively meaningful, it is useful to estimate the background of normal ν_μ neutrino interactions that would be expected from π-μ decays in the proton target. This calculation will be given in detail in the next section.

IV. Number of ν_μ Interactions from Neutrinos from the Target.

The estimate of this number of ν_μ interactions, called $N(\pi$-$\mu)$, will be based on the results from E-28. The data from E-28 are as follows:

Liquid: 20% neon

proton flux: 5×10^{12}ppp

proton energy: 300 GeV

2 element horn focussing

Neutrino interactions in Fv/per picture = 1/12

For this proposed experiment, the following assumptions will be made.

50,000 pictures with 2×10^{13} ppp = 10^{18} total exposure

Ep = 400 GeV

Fill 47% Neon

Standard beam dump at the end of the decay pipe.

The effect of the horn in E-28 is a factor of 12.

These data permit an estimate of the normal neutrinos from the target.

ν_μ/pix E-28	horn	Ne ratio	proton flux	p energy factor	solid angle

$$N(\pi-\mu) = (50{,}000)\ (\tfrac{1}{12}) \times (\tfrac{1}{12}) \times (\tfrac{47}{20}) \times \left[\frac{2 \times 10^{13}}{5 \times 10^{12}}\right] \times (\tfrac{4}{3}) \times 2 \times F$$

where F is a suppression factor due to the dense target.

Here F = (decay probability of π in target)/(decay probability in decay tunnel).

To estimate F we assume the decay probability in tunnel to be about 1/5 The decay in the target can be estimated as follows. The effective mean-free path is about twice the absorption length which means $\lambda_{eff} \approx 55$ cm.

For $\beta\gamma = 1$ the decay length is $2.6 \times 10^{-8} \times 3 \times 10^{10} = 800$ cm. For a pion of 40 GeV, the decay length is $L_o = 800 \times \frac{40}{.14} = 2.3 \times 10^5$ cm. The probability of decay is then the ratio of $55/2.3 \times 10^5 = 2.4 \times 10^{-4}$. This then gives the suppression factor F

$$F = 2.4 \times 10^{-4}/1/5/e = 3 \times 10^{-3}$$

The suppression for kaon decay is roughly the same since the reduced production rate compensates for the shorter lifetime. This factor F is one of the important numbers and could be changed by using targets of different densities.

If a bare target of ~ 1 absorption length were used with the normal decay tunnel we would have expected

$$N \text{ of } \nu_\mu \text{ int.} = 50{,}000\ (\tfrac{1}{12})(\tfrac{1}{12})(2.3)(4)(\tfrac{4}{3})(2) = 8500$$

neutrino interactions. This number will be useful in evaluating the level of sensitivity of this experiment.

With a thick beam dump target (many m.f.p.) the expected number of normal ν_μ interactions is

$N(\nu_\mu)$ background ≈ 25 events in the 15' bubble chamber

$N(\nu_\mu)$ background = 300 events in the E-310 detector

V. Sensitivity of Various Types of Production Processes

Case I. Electron Neutrinos from Target

Now suppose that two electron neutrino events were observed from decays in the target (we might expect 25 x 2% $\lesssim$ 0.5 event) and wish to know what ratio of electrons/π's this corresponds to at the target (assume 1 ν_e per electron). Since ∿ 1/5 of the π's decay in the tunnel, 2 ν_e events would correspond to

$$\frac{2}{8500} \times \left(\frac{1}{5}\right) = 0.5 \times 10^{-4}$$

Thus if the "direct lepton production" at the target had a value of e^+/π^+ of 0.5×10^{-4}, this would contribute 2 events. Thus we can test whether the direct lepton production by hadrons involves a neutrino.

Case II. Ratio of $\nu_\mu/\nu_e \equiv R(\mu^+/e^+)$

The preceding numbers would yield (assuming μ-e universality)

$$R(\mu^+/e^+) = \frac{5+2}{2} = 3.5$$ instead of the value of 50 expected from normal neutrinos from π and K decays in the target.

Case III. Ratio of $\nu_\mu/\bar{\nu}_\mu$

The expected ratio of ν_μ interactions to $\bar{\nu}_\mu$ interactions from π decays in a bare target should be about $\frac{1}{12}$. In the run of 50,000 pictures we would expect a few $\bar{\nu}_\mu$ events.

However, if direct lepton processes from the target involve neutrinos then one would expect equal numbers of ν_μ and $\bar{\nu}_\mu$. So in part B there would be 8 $\bar{\nu}_\mu$ events.

It should be pointed out that the neutrinos from this type of source may have relatively low energy. The bubble chamber filled with neon is an outstanding tool for electron neutrino interaction for visible ν energies as low as 0.8 GeV. The E-310 detector could not identify the leptons in such events, but these events would be recorded as anomalous neutral current events in the liquid calorimeter.

Case IV. Strange Particle Production

In both ν_e and ν_μ interactions the frequency of observed associated K_1° decay is about 0.04 while in charm related ν_μ interactions the visible K_1° production rate is 0.3 (20x normal rate). If a new type of neutrino produces a "charmed" state, the probability of an associated K_1° is very high. Indeed if in the proposed run there were as few as 2 events with K_1° decays, clearly some "new" phenomena must have been involved. Two events with K_1° would correspond to a production ratio R_N at the target for a new type of particle

$$R_N \; (2/.3)/8500 = 8. \times 10^{-4}$$

Case V. Di-leptons and Tri-leptons

Suppose that some of the tri-leptons which were observed in E-310 are due to a new type of neutrino coming directly from the targets. With the requirement that the lepton energy exceed 4 GeV the observed rate is $\sim 5 \times 10^{-4}$ $\mu\mu\mu$/cc. If one can extend minimum detectable lepton momentum (as in the bubble chamber) to $E_\ell \gtrsim 0.8$ GeV this rate may increase by a factor ~ 2 making it $\sim 10^{-3}$. Only about one third of the total neutrinos produced by a bare target have energies greater than 100 GeV. Using this factor one would expect the number of tri-leptons might be

$$N(\mu\mu e) = 10^{-3} \times 8500/3 \sim 2 \text{ or } 3$$

Including the detection efficiency for electrons, this will still yield a few events. There might be a few trimuons in the E-310 apparatus under the same assumptions.

The detection efficiency for dileptons is extremely good by this combination of detectors. We estimate it is excess of 70% for μμ, ee and μe. So any direct source of particles leading to dileptons can be detected at the level of 10^{-3} or 10^{-4} compared to pion production.*

VI. Summary

The coordinated employment of the E-310 neutrino detector and the 15' Bubble Chamber can provide a sensitive and important search for new phenomena involving neutrinos. An exposure of 10^{18} protons on target using the beam configuration suggested by S. Mori would allow a broad based search for new particles which are produced at a level 10^{-3} - 10^{-4} of normal pion production. The exciting and often unexpected results of the past few years - not to mention the rumored CERN experience - make this an opportune time for such an important search.

*The interaction of axions in the detector can result in unusual dimuon events or dielectron events with zero opening angle between the leptons. This is an example of a unique signature for a new phenomena produced in the beam dump which increases the level of sensitivity of the search.

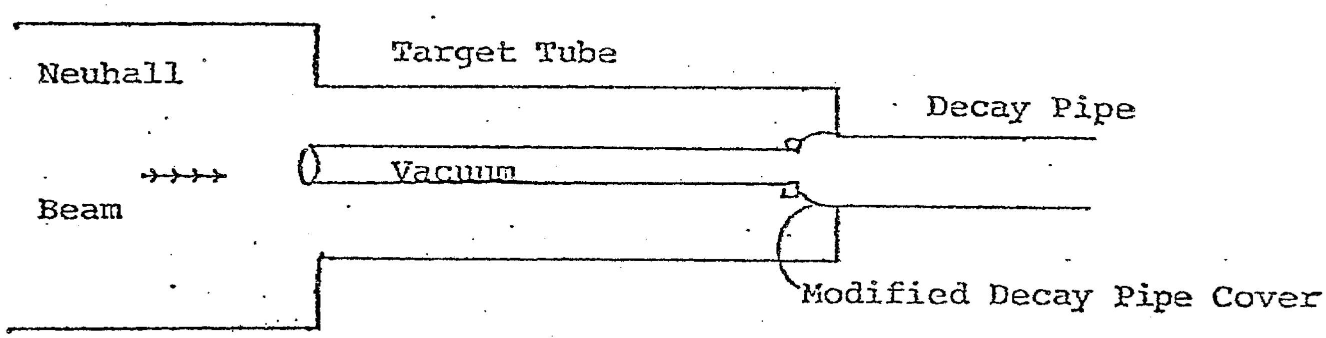
November 15, 1977

TO: D.THERIOT

FROM: S.MORI S Mori

SUBJECT: DUMP EXPERIMENT

The following arrangement seems to be a clean and efficient way to do a dump experiment:



Compared to the arrangement to put a dump in the Target Tube, this scheme gives about twice larger flux at the 15' B.C. area. We estimate that it can be ready in two to three months after we get a "go ahead" order.

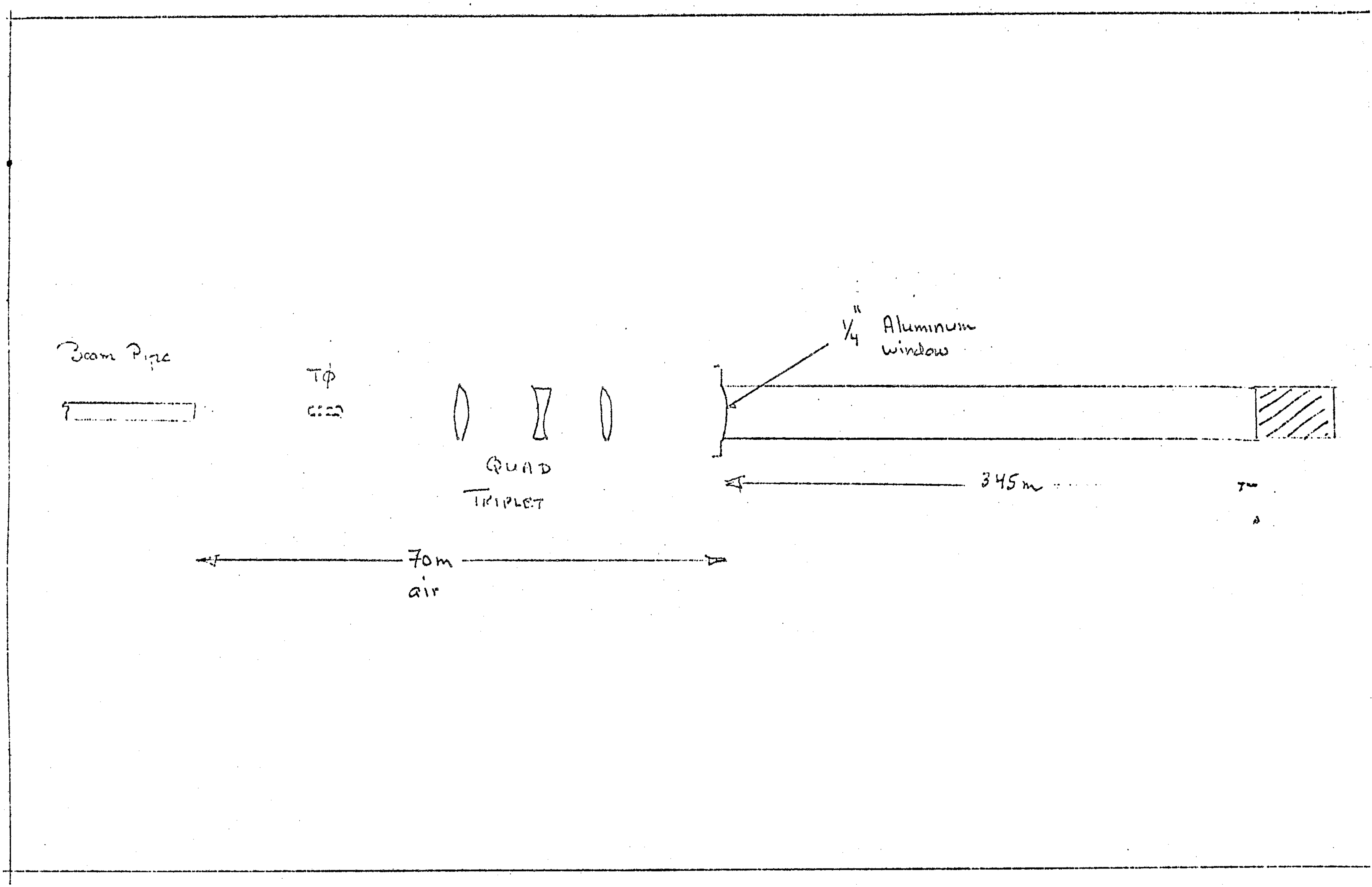
SM:dla
cc: J.Peoples
T.Yamanouchi
R.Stefanski

S. Mori suggests that the vacuum pipe be extended upstream so that the entire path through Neuhall will be in vacuum. He also finds that a more detailed investigation of the schedule indicates the entire modification can be accomplished in less than or about one month.

Appendix B Background Tests for Beam Dump Experiment

During a series of tests for E-310 in early January (1973), the target in the NØ line was removed. The E-310 detector was used to measure trigger rates and to record neutrino induced events in order to make a determination of the characteristics of the non-target background arising from extraneous material in the NØ line. The relevant part of the NØ beam is shown in Fig. 1. With the target removed, the remaining material amounts to approximately 70 m of air and the 1/4" aluminum vacuum window of the decay pipe. (The very thin titanium window at the end of the proton beam pipe may be neglected.) This introduces .12 absorption lengths into the proton beam. One therefore expects a rate, relative to the target (1 absorption length) being in the beam, of 29%. We have measured the relative rates for a variety of triggers in the E-310 detector to be 32 ± 3%. This result is consistent with all the background coming from the air and aluminum in the NØ line.

The film taken during this test has also been scanned. We see no evidence for an increase in the rate of obviously non-neutrino induced events. The measured hadron energy distribution in the neutrino interactions, however, is peaked at ~lower energy. This is indicated by the presence of a broadband, non-focused component to the target and background.


Beam Pipe
TΦ
QUAD
TRIPLET
70m
air
1/4" Aluminum
window
345m