FERMILAB-Proposal-0521

Update

Fermilab Proposal No. 521

Scientific Spokesman:

J.C. Vander Velde
Randall Laboratory
University of Michigan
Ann Arbor, MI 48109

DILEPTON PRODUCTION BY NEUTRINOS IN DEUTERIUM

(15-Foot Bubble Chamber Proposal)

J.W. Chapman, C.T. Coffin, B.P. Roe, R.T. Ross,
A.A. Seidl, D. Sinclair, J.C. Vander Velde

University of Michigan

J.R. Albright, R.N. Diamond, S. Hagopian,
V. Hagopian, J.E. Lannutti

Florida State University

October 1976
Revised December 1977

17pp.

ABSTRACT

We propose 200,000 pictures with a broad-band neutrino beam using a system of metal plates in the 15-foot bubble chamber with EMI to detect dileptons produced by neutrinos in deuterium. Bremsstrahlung in the plates by primary electrons will greatly increase the detection efficiency for dilepton events. Conversion in the plates of gammas from π° decays will aid in the kinematical reconstruction of complete events in the search for the primary source of the dileptons. Neutron/proton cross section ratios can be directly measured as a function of Bjorken X in order to investigate the elemental quark content of these new processes. If an additional upstream plate of different materials can be available the A dependence of neutrino-produced hadron systems can be studied.

INTRODUCTION

The discovery of neutrino induced dilepton events at Fermilab[1,2,3] is one of major importance. The primary source for these events is still uncertain. We propose to make a direct measurement of the separate neutron and proton production rates and hopefully also learn more about the true origin of these events (be it new particles or whatever) through the application of kinematic constraints available in production on deuterium.

The rate for dilepton production (in a heavy neon-hydrogen mix) has been measured[4] as

$$\frac{\nu N \to \mu^- e^+}{\nu N \to \mu^-} = .005 \pm .002 \text{ (for } P_e > 0.3 \text{ GeV/c)}$$

and

$$\frac{\nu N \to \mu^- e^-}{\nu N \to \mu^- e^+} = 0.2 \pm 0.1 \text{ (for } P_\mu > 10 \text{ GeV/c, } P_e > 1 \text{ GeV/c).}$$

The CITFR and HPWFR experiments find trimuon events at the rate

$$\frac{\nu N \to \mu^- \mu^+ \mu^-}{\nu N \to \mu^- \mu^+} \sim 0.03 \text{ (for } P_\mu > 4 \text{ GeV/c).}$$

Further 15-foot bubble chamber results indicate that

$$\frac{\bar{\nu} N \to \mu^+ e^-}{\nu N \to \mu^- e^+} \lesssim 0.07 \text{ (for } P_e > 0.3 \text{ GeV/c).}$$

There is a myriad of possible explanations of these effects, involving charmed particles, $c\bar{c}$ pairs, heavy leptons (charged and neutral) produced singly, in pairs, and in sequential decays.

The WA1 (Steinberger) experiment at CERN is now studying these (muonic) processes and will soon have more accurate rates. It is going to be difficult to sort out the underlying mechanisms because WA1:

a) does not see electrons, b) has a $P_{min} \geq 4$ GeV/c cut on the muon, c) does not see strange particles, d) does not have separate p and d targets.

We note that the currently popular explanations of these multilepton events all involve one or more missing neutrinos in the decay of a heavy lepton or charmed particle. Thus a direct measure of the heavy particle masses will probably not be possible in these events. To sort out the basic processes one must rely on other handles, such as:

1) spectra for both e's and μ's down to low momentum,

2) associated strange particle rates,

3) associated missing transverse momentum,

4) separate rates for p and n targets,

5) measurements of missing masses (see Appendix A).

This proposal accomplishes all of these objectives, whereas the present WA1 experiment accomplishes none of them. That the WA1 experimenters plan to put in p and d targets upstream of their apparatus adds incentive for us to carry out our proposed experiment as soon as possible. We also point out that these rare $\mu^- e^+$ events are identified on the scanning table so that the analysis of this aspect of the experiment can be done very rapidly.

THE PLATE SYSTEM

The plate system now being developed for the 15-foot bubble chamber at Fermilab consists of 4 plates of stainless steel each 1.3 cm. thick separated by 25 cm. at the median plane. The first plate is to be located some 57 cm. downstream of the chamber center, leaving an unobstructed fiducial volume of ~12 m^3. Some results on the A dependence of neutrino reactions can be obtained by comparing events produced in the steel with events produced in the deuterium, but it is hoped that an additional "A plate" composed of equal weights of aluminium, steel, and tantalum can be installed in the upstream part of the chamber at some future date to facilitate a more systematic study of A-dependent effects.

The present plate system contains 3 radiation lengths in total and also 4 nuclear interaction lengths. Hence it provides excellent electron identification and nicely supplements the EMI in hadron/muon discrimination. The plates provide $e^{\pm}$ identification nearly equivalent to that of a heavy neon-hydrogen mixture while at the same time allowing the study of production on free deuterons.

There are several good physics reasons for the plates: 1) Directly produced $e^{\pm}$ can be found with high efficiency (~95%) for events produced upstream of the plates and with at least 50% efficiency for events occurring between the plates. The background, as described in Appendix B, is a few percent. One can also use the plates to search for dilepton production via the neutral current. The reaction $\nu_\mu d \to \nu_\mu e^+ X$ should be detectable and separable from the $\nu_e d \to e^+ X$ background. The deuterium production kinematics will make this separation cleaner than in a similar neon exposure. The rate for this process is unknown, but there is a "hint" of such events in a recent ν-N_eH_2 experiment.[4]

2) Gammas from $\pi°$ decays convert high probability (~90%) and can be reconstructed to give $\pi°$ momenta to an accuracy of ~±10%.[5] This is important in the kinematical reconstruction of events since $\pi°$'s are the main source of neutral momentum in the hadronic system. As a result one gets more accurate values of x, y, E_ν in individual events and the accuracy on missing masses, etc., is also increased. Moreover, if there is a large missing transverse momentum in the event it most probably is due either to a neutrino or to a K_2^o. Of course one also now has access to a whole new class of exclusive processes involving particles with one or more $\pi°$'s in their decays, eg. $\rho^\pm \to \pi^+\pi°$, $\omega° \to \pi^+\pi^-\pi°$, $B^+ \to \omega°\rho^+$, $D° \to \bar{K}°\pi°$(?), $F^\pm \to \eta°\pi^+$(?). If such particles are produced then it is important to know the precise exclusive channels, including the target in which the production occurs.[6] The discoveries of new narrow particle decaying into $K\pi$, $K\pi\pi$, $K\pi\pi\pi$ at SLAC[7] and into $\bar{\Lambda}\pi\pi\pi$ at Fermilab[8] give a sense of urgency to such an investigation as we are proposing. Some evidence for the production of these new particles in neutrino induced reactions has already been reported.[9]

The plates can also be used to purify the sample of elastic neutrino events, $\nu n \to p\mu^-$ and $\nu p \to \pi^+ p\mu^-$, by indicating with high probability the existence of γ-rays from $\pi°$ decays.

3) Measurements made in experiment E180 in a light N_e-H_2 mix in the 15-foot bubble chamber indicate that the $\bar{\nu}n$ and $\bar{\nu}p$ cross

section may become equal at high energies, especially at low x and high y. The x, y, E_ν dependence of the n/p cross section ratio are important to know. For instance, within the quark picture $\sigma_{\nu n}-\sigma_{\nu p}$ should have only a valence quark contribution, whereas $2\sigma_{\nu p}-\sigma_{\nu n}$ should have only a sea quark contribution. Thus the effects of these separate parts of the baryon wave function can be studied. If the n/p ratio were to become one at high energy for $\bar{\nu}$ the b quark model (with q=-1/3) would be eliminated. It will be very interesting to check this ratio for both ν and $\bar{\nu}$ in order to examine such models as the b quark model or Gerstein's[11] model in which the sea contribution rises with energy (a result also predicted as a consequence of asymptotic freedom). More work is needed on this question and deuterium provides a cleaner target because final state interactions are considerably reduced.

4) If and when the A plate becomes available the final state interactions can be studied. Differences between $\bar{\nu}$ and pion interactions in the N_e-H_2 mixture have already been observed[12] and studies of the A dependence may lead to an understanding of how hadronic matter propagates through nuclear matter. In addition, a non-linear A dependence of the total neutrino cross section might indicate a finite mass for the W boson, or at the very least, can be an important step in understanding how the W boson couples to hadrons.

THE DEUTERON TARGET

The main reason for choosing a deuteron target is the determination of cross sections on quasi-free neutrons.

This is essential to our eventual understanding of dilepton production. Deuterium also has some nice properties:

1) The unseen spectator momentum is generally low enough so that setting it equal to zero does not appreciably alter the kinematic fitting procedure.

2) Neutron/proton cross section ratios can be directly determined in a single experiment without the need for independent flux determinations. Experience with high energy hadron beams in deuterium indicates that in about 15% of the interactions both nucleons are active participants. The remaining 85% can be divided into neutron-spectator and proton-spectator interactions. For neutrino interactions the separation should be even cleaner since prescattering by the beam and rescattering by the produced lepton can be neglected. For dilepton and other exotic channels such as charmed particle production, it is by no means *a priori* clear what the n/p ratios will be. It will depend on whether the production is primarily diffractive or primarily off valence quarks, for example.

3) For charged current interactions one gets about three times as many events in deuterium as in an equivalent hydrogen exposure.

EVENT RATES

We give in Table I some typical rates for the more interesting reactions we propose to study. We assume 200,000 pictures, 1.3×10^{13} ppp, 400 GeV protons on target, and $\Sigma P_x >$ 5 GeV/c cut on total visible longitudinal momentum.

TABLE I

Inclusive C.C.	$\nu p \to \mu^- X$	9000
	$\nu p \to \mu^- X$	~18000†
Dilepton C.C. & N.C.	$\nu d \to \mu^- e^+ X$	~ 320
	$\nu d \to \nu e^+ X$	~ 100?
	$\nu d \to \mu^- \mu^+ K^\circ_s X$	~ 300[y]
Elastic	$\nu n \to \mu^- p$	~ 600†[13]
	$\nu e^- \to \nu e^-$	~ 6[z]
Single pion C.C.	$\nu n \to \mu^- p \pi^\circ$	~ 350†[14]
	$\nu n \to \mu^- n \pi^+$	~ 250†[14]
	$\nu p \to \mu^- p \pi^+$	700
Inclusive N.C.	$\nu n \to \nu x$	~ 2700
	$\nu p \to \nu x$	2700
Total neutrino events in deuterium		32000[x]

† Rate extrapolated from low energy data.

x There will be an additional ~28000 events occurring in the steel plates. If an A plate is added there would be another ~10000 events divided equally among the various materials.

y If selecting on K°_s events gives a highly enriched sample of dileptons then the EMI can be used to find dimuon events in that sample.

z This is an average taken from references 17 and 18.

REFERENCES

1. A. Benvenuti *et al.*, Phys. Rev. Lett. 34, 1199, 1203, and 1249 (1976).
2. B.C. Barish *et al.*, Phys. Rev. Lett. 36, 939 (1976).
3. J. van Krogh *et al.*, Phys. Rev. Lett. 36, 710 (1976).
4. C. Baltay *et al.*, Phys. Rev. Lett. 39, 62 (1977).
5. J.P. Berge *et al.*, Proposal to Study Neutrino Interactions in Hydrogen and Nuclei with an Internal Target and Converter System in the 15-Foot Bubble Chamber (April 1976).
6. See for example Chen, Henyey, and Kane. In particular the B° reaction tests for second class currents which has so far not been observed.
7. I. Perruzzi *et al.*, Phys. Rev. Lett. 37, 569 (1976).
8. B. Knapp *et al.*, Phys. Rev. Lett. 37, 882 (1976).
9. N. Samios, 1977 SLAC Summer Institute.
10. R.N. Diamond, University of Michigan Research Note, UM 76-3.
11. S.S. Gerstein, Rapporteur talk, International Conference on High Energy Physics, Tblisi (1976).
12. J. Loos, R. Diamond, private communication.
13. S.J. Barish *et al.*, Reaction $\nu d \to \mu^- p p_s$, Symposium on Lepton and Photon Interactions, Stanford University (August 1975).
14. S.J. Barish *et al.*, Study of the Isospin Properties of Single-Pion Production by Neutrinos, Phys. Rev. Lett. 36, 179 (1976).
15. If there is only a neutrino missing then in principle the

event can be reconstructed with "O-C fit", i.e. the transverse component $P_\perp$ of the neutrino momentum is obtained directly from momentum balance and the beam-direction component is given by $P_{\nu x}=(P_\perp{}^2-g^2)/2g$, where $g=(E-P_x)$ for the missing neutrino (obtained directly from balancing $E-P_x$). In practice g becomes quite small so that the error in $P_{\nu x}$, and therefore also in beam energy, is often quite large.

16. P. Bosetti et al., Phys. Rev. Lett. 38, 1248 (1977).

17. F.J. Hasert et al., Phys. Lett. 46B, 121 (1973).

18. F. Bobisut et al., Neutrino Conference Aachen (1976).

APPENDIX A

SOME KINEMATICS

The following calculation illustrates why the combination of π° detection and a free production target may be extremely important.

Suppose one has the following reaction:

$$\nu + T \to A + B$$

where

T = a target of known mass T and zero momentum.

ν = a neutrino with unknown energy E_ν.

$A \to$ all detected particles with invariant mass A.

$B \to$ some undetected particles but with total invariant mass B.

Then it follows that

$$B^2 = A^2 - TW_A + S\ (1 - {}^{W_A}/T)$$

where $W_A \equiv (E - \beta P_{\parallel})_A$ depends largely on the measured lab quantities E and $P_{\parallel}$ of A and is insensitive to the overall c.m. velocity $\beta \approx 1$ (which has negligible E_ν dependence at high E_ν).

We also have

$$\beta \approx 1 - T/E_\nu$$

$$S = T^2 + 2T\ E_\nu$$

Hence $$\frac{\partial(B^2)}{\partial S} \approx 1 - {}^{W_A}/T = 1 - \left(\frac{S+A^2-B^2}{S+T^2} \right)$$

So the error in measuring the missing mass B is given by

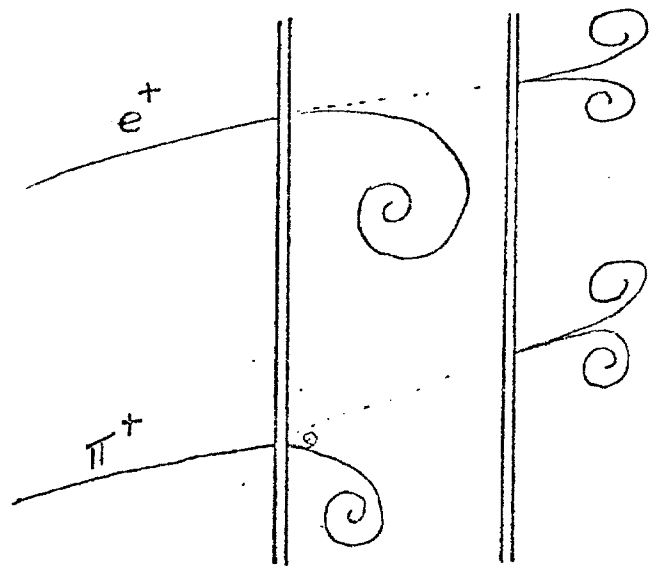
$$\delta B^2 \approx \left(\frac{\delta E_\nu}{E_\nu} \right) (T^2 - A^2 + B^2)$$

What the last equation says is that the measurement of the missing mass B is insensitive to the neutrino energy whenever the masses A and B are nearly equal. Hence, given a large enough sample of dilepton events with even a crude knowledge of the neutrino energy, it is possible to search for peaks in various missing mass combinations involving a (presumed) missing neutrino.[11]

Obviously it is necessary in such calculations that no additional particles go undetected; hence the importance of the detection of π°'s (or their absence).

APPENDIX B

Background to $e^{\pm}$ Identification due to π° Production in Plates



The principal source of background that can fake an $e^{\pm}$ in the plates is illustrated in the picture above. An e^{+} identifies itself by losing a significant fraction of its energy via bremstrahlung in the plate. Correspondingly a π^{+} can charge exchange off a neutron to give an invisible proton and a π°. The π° can then decay in such a way that the two gammas can fake the brems of an e^{+}.

We can estimate this background as follows:

.07 = prob. that π^{+} will interact in a plate

50 mb = total π^{+} cross section (.5 to 1.0 GeV/c)

.5 mb = $\sigma\ (\pi^{+} n \to \pi^{\circ} p)$ (.5 to 1.0 GeV/c)

.5 = prob. that proton will not emerge from plates

1/30 = prob. that two gammas from π° will fake a brems. (This is difficult to calculate exactly but we believe 1/30 is conservative)

.2 = prob. that one gamma from π° will convert in first plate

2.5 = ave. no. of π^+ per neutrino interaction

.3 = e^+ detection efficiency per plate

.01 = e^+ production rate per neutrino interaction

Putting all these numbers together we get the following ratio of fake $\pi^+ \to e^+$ to real e^+ per event:

$$\text{Prob.} = \frac{(.07)\left(\frac{5\text{ mb}}{50\text{ mb}}\right)(.5)\ (1/30)\ \ (.2)\ (2.5)}{(.3)\ \ (.01)} = .02$$

The smallness of this estimate of background, which of course can be measured in the experiment, makes the proposed plate system look like an ideal way to detect directly produced $e^{\pm}$.

March 22, 1977
J. Vander Velde

Addendum to Proposal P521

There are several new developments in multi-lepton physics that clarify the urgency of P521:

1) E53A (Baltay, ν in heavy mix) finds

$$\frac{\nu N \rightarrow \mu^- e^+}{\nu N \rightarrow \mu^-} = .005 \pm .002 \text{ (for } P_e > .3 \text{ GeV/c)}$$

and $$\frac{\nu N \rightarrow \mu^- e^-}{\nu N \rightarrow \mu^- e^+} = .2 \pm .1 \text{ (for } P_\mu > 10. \text{ GeV/c, } P_e > 1. \text{ GeV/c)}$$

2) CITFR and HPWFR find trimuons at the rate

$$\frac{\nu N \rightarrow \mu^- \mu^+ \mu^-}{\nu N \rightarrow \mu^- \mu^+} \simeq .03 \quad (P_\mu \gtrsim 4 \text{ GeV/c})$$

3) The 15-foot Bubble Chamber results indicate

$$\frac{\bar{\nu} N \rightarrow \mu^+ e^-}{\nu N \rightarrow \mu^- e^+} \gtrsim .07 \quad (P_e > .3 \text{ GeV/c})$$

There is a myriad of possible explanations of these effects, involving charmed particles, $C\bar{C}$ pairs, heavy leptons (charged and neutral) produced singly, in pairs, and in sequential decays.

The WA1 (Steinberger) experiment at CERN is now taking data on all these (muonic) processes and will soon have much more accurate rates. However, it's going to be very difficult to sort out the underlying mechanisms. The WA1 experiment has several deficiencies: (a) They don't see electrons. (b) They have a $P_{min} = 4$ GeV/c cut on the muons. (c) They don't see V°s. (d) They don't have separate p and d targets.

We note that the currently popular explanations of these multilepton events all involve one or more missing neutrinos in the decay of a heavy lepton or charmed particle. Thus a direct measure of the heavy particle masses will probably not be possible in these events. To sort out the basic processes one must rely on other handles, such as:

1) spectra for both e's and μ's, down to low momentum
2) associated strange particle rates
3) associated missing transverse momentum
4) measurement of missing masses (see appendix of P521)
5) separate rates for p and n targets

The purpose of this note is to point out that P521 accomplishes all of these things, whereas the present WA1 experiment accomplishes none of them. (However, they plan to put in p and d targets upstream of their apparatus in about a year. This adds incentive for us to do P521 as soon as possible.)

We also point out that these rare $\mu^- e^+$ events are identified on the scanning table so that the analysis of this experiment can be carried out very rapidly.