Fermilab Proposal No. 521

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DILEPTON PRODUCTION BY NEUTRINOS IN DEUTERIUM

(15 foot Bubble Chamber Proposal)

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October 1976

ABSTRACT

We propose 200,000 pictures using a system of metal plates in the 15 foot bubble chamber with EMI to detect dileptons produced by neutrinos in deuterium. Conversion in the plates of gammas from π° decay 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. Using plates of different materials will allow the A dependence of neutrino interactions to be studied.

INTRODUCTION

The discovery of neutrino induced dilepton events at Fermilab[1,2,3] is one of major importance. At this point the primary source of these events is not known, nor is their production rate on free protons or neutrons. 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 deuterons.

THE PLATE SYSTEM

An integral feature of the proposal is a system ofnine 0.9 cm steel plates interspersed through the chamber with a spacing of 30 cm. A detailed description of the plate system and optics has been given in a recent proposal by J. P. Berge et al[4]. We suggest a slight modification. Each plate is 0.5 radiation lengths and .07 nuclear interaction lengths. Hence they provide excellent electron identification and also supplement the EMI in hadron/muon discrimination. The plates provide $e^{\pm}$ identification equivalent to that of a heavy neon-hydrogen mixture while at the same time allowing the study of production on free deuterons.

We propose that one of the two upstream plates be made of a low A material, such as aluminum and that the other be made of a high A material, such as tungsten. The same 0.9 cm thickness for Al plates represents 0.1 radiation lengths and 0.03 interaction lengths. For the tungsten plate A 0.5 cm thickness would be used corresponding to 1.4 radiation lengths and .05 interaction lengths.

There are several good physics reasons for the plates:

(1) Directly produced $e^{\pm}$ can be found with high efficiency ($\sim$ 95%), and with low background (a few %; see Appendix A). One can also use the plates to search for dilepton production in the neutral current. The reaction $\nu d \to \nu e^{+} x$ should be detectable and separable from the $\bar{\nu}_e d \to e^{+} x$ 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-NeH_2 experiment[12].

(2) Gammas from π° convert with high probability ($\sim$ 90%) and can be reconstructed to give π° momenta to an accuracy of $\sim \pm$ 10%[4]. This is important in the kinematical reconstruction of events since π°'s are the main source of neutral momentum in the hadronic system. Hence one gets more accurate values for 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 a K_2°. Of course one also now has access to a whole new class of exclusive processes involving particles with one or more π° in their decays ($\rho^{\pm} \to \pi^{+}\pi^{\circ}$, $\omega^{\circ} \to \pi^{+}\pi^{-}\pi^{\circ}$, $B^{+} \to \omega^{\circ}\pi^{+}$, $D^{\circ} \to \bar{K}^{\circ}\pi^{\circ}$ (?), $F^{+} \to \eta^{\circ}\pi^{+}$ (?)). If such particles are produced then it is important to know the precise exclusive channels, including the target in which the production occurs[5]. The recent discovery at SLAC of new narrow particles decaying into $K\pi$, $K\pi\pi$, $K\pi\pi\pi$, and $\bar{\Lambda}\pi\pi\pi$ at Fermilab[6] give a sense of urgency to such an investigation as we are proposing (not to mention the turn-on of BEBC at the SPS).

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

(3) Measurements made in experiment E180 in a H_2-Ne mixture in the 15 ft. bubble chamber indicate that the $\bar{\nu}n$ and $\bar{\nu}p$ cross sections may become equal at high energies, especially at low x and high y[7]. The x, y, E_ν dependences of the n/p 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 $\bar{\nu}$ this would eliminate the b quark model (with $q=\frac{-1}{3}$). It will be very interesting in fact to check this ratio for both ν and $\bar{\nu}$ to examine models such as the b quark model or Gerstein's 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. These final state interactions can be studied by using plates of different materials. Differences between $\bar{\nu}$ and pion interactions in the H_2-Ne have already been observed[8] and studies of the dependence on atomic number A may lead to an understanding of how hadronic matter propagates through nuclear matter. Also 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 other 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.

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:

$$\nu + T \rightarrow A + B$$

where

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

ν = a neutrino with <u>unknown energy</u> E_ν.

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

$B \rightarrow$ 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).

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, $-\Sigma P_x > 5$ GeV/c cut on visible momentum.

TABLE I

Reaction		Number of Events
Inclusive C.C.	$\nu p \rightarrow \mu^- x$	9000
	$\nu n \rightarrow \mu^- x$	~ 18000 †
Dilepton C.C. and N.C.	$\nu d \rightarrow \mu^- e^+ x$	~ 320
	$\nu d \rightarrow \nu e^+ x$	~ 100 ?
	$\nu d \rightarrow \mu^- \mu^+ K^\circ_s x$	≈ 300 y
Elastic	$\nu n \rightarrow \mu^- p$	~ 600 † ‡
	$\nu e^- \rightarrow \nu e^-$	~ 35
Single pion C.C.	$\nu n \rightarrow \mu^- p \pi^\circ$	~ 350 † *
	$\nu n \rightarrow \mu^- n \pi^+$	~ 250 † *
	$\nu p \rightarrow \mu^- p \pi^+$	700
Inclusive N.C.	$\nu n \rightarrow \nu x$	~ 2700
	$\nu p \rightarrow \nu x$	2700
Total neutrino events in deuterium		32,000 x

† Rate extrapolated from low energy data

‡ Reference 9

* Reference 10

x There will be an additional 60,000 events of which ~ 52,000 are in steel, ~ 5000 in tungsten, and ~ 3000 in Aluminum.

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.

REFERENCES

(1) A. Benvenuti et al., Phys. Rev. Letters 34 419 (1975), 35 1199, 1203, and 1249 (1976).

(2) B. C. Barish et al., Phys. Rev. Letters 36 939 (1976).

(3) J. van Krogh et al., Phys. Rev. Letters 36 710 (1976).

(4) J. P. Berge et al., Proposal to Study Neutrino Interactions in Hydrogen and Nuclei with an Internal Target and Converter System in the 15 ft. Bubble Chamber (April 1976).

(5) See for example Chen, Henyey and Kane, Nucl. Phys. (To be published). In particular the B° reaction tests for second class currents and has so far not been observed.

(6) I. Peruzzi et al., Phys. Rev. Letters 37 569 (1976).
B. Knapp et al., Phys. Rev. Letters 37 882 (1976).

(7) R. N. Diamond, University of Michigan Research Note, UM 76-3.

(8) J. Loos, R. Diamond, private communication.

(9) S. J. Barish et al., Reaction $\nu d \rightarrow \mu^- p p_s$, Symposium on Lepton and Photon Interactions, Stanford University (August 1975).

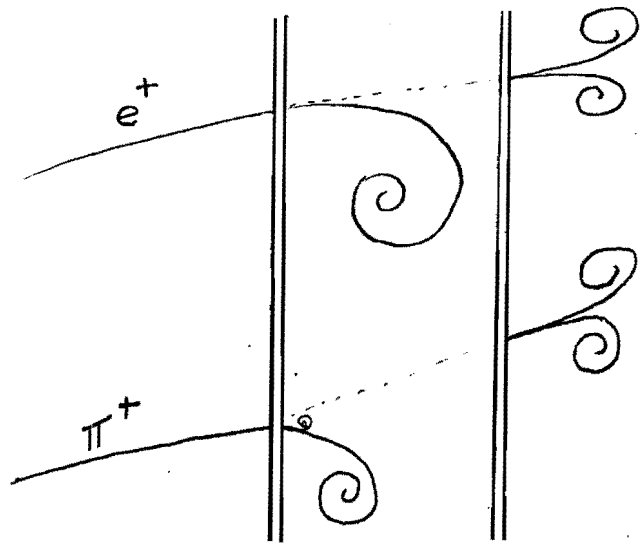
(10) S. J. Barish et al., Study of the Isospin Properties of Single-Pion Production by Neutrinos, Phys. Rev. Letters 36 179 (1976).

(11) If there is only a neutrino missing then in principle the event can be reconstructed with a "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 the beam energy, is often quite large.

(12) LBL-CERN-Hawaii-Wisconsin Collaboration, "Neutrino Interactions with $e^+\mu^+$ and multiple K°'s", Preprint CERN/EP/Phys. 76-38.

APPENDIX A

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 = σ ($\pi^+ n \rightarrow \pi^{\circ} p$) (.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 $\pi^+ \rightarrow e^+$ 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

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

and

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

2) CITFR and HPWFR find trimuons at the rate

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

3) The 15-foot Bubble Chamber results indicate

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

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 explanationsof 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.