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PROPOSAL FOR A NARROW BAND BEAM NEUTRINO EXPERIMENT IN BEBC FILLED WITH DEUTERIUM, RUN PARASITICALLY WITH WANF COUNTER NEUTRINO EXPERIMENTS AND HADRON EXPOSURES IN BEBC

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1. Introduction

One of the main objects of this experiment is the detailed study of neutrino interactions with protons and neutrons. This can best be done using BEBC filled with deuterium in combination with a narrow band neutrino beam. The use of a narrow band beam is of crucial importance, since only with it can the neutrino energy for inclusive and semi-inclusive processes be determined for the full range of the kinematic variables q^2 and ν. To make full use of the narrow band neutrino beam, we propose that this experiment be run parasitically with WANF counter experiments. The possibility of running parasitically with hadron experiments in BEBC by double-pulsing BEBC is anticipated. We stress that most of the physics program outlined below cannot be done by other means and will definitely not be done at NAL by 1977-1978.

2. Physics

A. Charged Current Interactions $\left(\nu \begin{matrix} N \\ P \end{matrix} \to \mu^- \begin{matrix} X^+ \\ X^{++} \end{matrix}\right)$

1.) Total Cross-sections on Proton and Neutron Targets

In the true scaling region theories make different predictions for the total cross sections on protons $\sigma(\nu P)$ and neutrons $\sigma(\nu N)$ as a function of energy, depending on the nature of the constituents in the nucleon. A test of these models is a measurement of the ratio $\sigma(\nu N)/\sigma(\nu P)$. In this experiment this ratio will be determined free of systematical uncertainties due to the neutrino spectrum or nuclear contamination.

For the measurement of total cross-sections it will be necessary to determine the neutrino energy for every event in the full range of the relative energy transfer $y = \nu/E$. For a given radial position of the event in the chamber the energy regions in the ν_π- and ν_K peaks are well separated due to the kinematics of the beam. Using this information, events due to ν_K will be determined for energy transfer values up to $y \lesssim 0.6$ simply by the muon energy. For $y \gtrsim 0.7$ they will be recognized using the energy of the charged hadron shower. In the small kinematic region in which the energy of the event will be ambiguous the energy will be determined using transverse momentum balance[1]. This method has to be sensitive enough only to discriminate between the ν_π- and ν_K-peaks. It should be stressed that any studies of inclusive and semi-inclusive processes using wide band beams in light target liquids depend solely on this method.

The number of events which will be obtained are given in the following table.

<u>EVENT RATES</u>

10^{13} ppp, NBB Neutrino Run, D_2, 500 000 pictures

radius of used volume	pion peak		kaon peak	
	Events	Energy range GeV	Events	Energy range GeV
r<0.4m	650	50 - 80	200	160 - [illegible]
0.4<r<0.8m	2300	30 - 50	1900	140 - [illegible]
total	7200	10 - 80	5400	110 - [illegible]

It will be possible to separate events on protons and neutrons in deuterium without systematic contamination, using charge balance and the spectator method. There will be an overlap of neutron and proton events due to mis-identified spectator protons but it will be negligible at our energies (30-80 and 150-190 GeV). Effects due to final state interactions involving both nucleons will be determined utilizing angular cuts on the spectator proton and using the results of the neutrino experiment in hydrogen[2)].

2.) Differential cross-sections and Sum Rules

It will be possible to measure the differential cross-sections $d\sigma/dx$ and $d\sigma/dy$ for proton and neutron targets separately. Here the use of a narrow band beam is of great advantage, since the study of y-distributions in wide band neutrino beams is very difficult due to the rapidly falling neutrino spectrum. From these, important information regarding sum rules and structure functions can be extracted.

Sum rules involving the difference $F_i(\nu P) - F_i(\nu N)$ can only be studied in liquids, in which proton and neutron events can be separated over the full range of x. From a fit to the y-distributions it is possible to obtain integrals of the type $\int F_i(\nu_N^P)dx$. With this the Adler sum rule, in particular, can be tested:

$$\int \frac{dx}{x} \left(F_2^{\nu N}(x) - F_2^{\nu P}(x)\right) \approx 2$$

Since this rule has been derived under very general assumptions, independent of parton models, it is of the greatest importance to check it at SPS energies. The high energy involved allows us to investigate the rule to x-values down to $x_o = 0.003$ using only events in the scaling region ($Q^2 > 1 (GeV/c)^2$, $\nu_o = 190$ GeV). A quark parton model[3] indicates that at such small values of x the sum rule will be 90% saturated. We emphasize that theories involving charm predict quite different values for the sum rule for energies above the threshold for the production of charmed particles. Thus it is important to determine the value of the rule both for events in the ν_π-peak ($\langle E \rangle = 50$ GeV) and the ν_K-peak ($\langle E \rangle = 160$ GeV).

Combining the data from this experiment with those from the Neon-experiment[4], it will be possible to determine $F_2^{\nu N}(x)$, $F_2^{\nu P}(x)$, $F_3^{\nu N}(x)$, $F_3^{\nu P}(x)$ and hence the parton momentum distributions in the proton and neutron.

3.) Semi-inclusive Reactions

The measurement of semi-inclusive cross-sections allows the investigation of the current fragmentation region without systematic uncertainties due to charge exchange effects in the nucleus.

From the pion multiplicity $d\sigma(\nu P \to \mu^- \pi^- X)/d\sigma(\nu P \to \mu^-$ [illegible] the Feynman current fragmentation function $D_u^{\pi^-}(z)$ will be measured. This will be superior to analyses using electroproduction, since the function $D_u^{\pi^-}(z)$ can be separated with high accuracy in neutrino interactions, whereas in electroproduction this is true only for the sum $(D_u^{\pi^-}(z) + D_d^{\pi^-}(z))$.

Drell-Yan Scaling can be tested by comparing the fragmentation function $D_u^{\pi^-}(z)$ as obtained from the ν_π- and ν_K-peaks, respectively.

B. Neutral Currents ($\nu_P^N \to \nu_{X^+}^{X^o}$)

1.) Inclusive Semi-leptonic Neutral Currents

Nothing is known at the present time about inclusive neutral current processes on neutron and proton targets. These processes will be studied in this experiment. Even though it will not be possible to determine the energy for most of such events (see below, however), the following cross-section ratios can be determined (averaged over E):

$$\frac{\sigma_o(\nu N \to \nu X^o)}{\sigma_C(\nu N \to \mu^- X^+)} = 0.2 \quad ; \quad \frac{\sigma_o(\nu P \to \nu X^+)}{\sigma_C(\nu P \to \mu^- X^{++})} = 0.3 \quad .$$

$$\frac{\sigma_o(\nu N \to \nu X^o)}{\sigma_o(\nu P \to \nu X^+)} = 1.2 \quad .$$

The numbers given correspond to the values as expected from the Weinberg-Salam model (using $\sin^2\theta_W = 0.37$).

Since the radial position of the events is known, it will be possible, however, to determine the neutrino energy even for neutral current processes, for almost half the events from the ν_K-peak. The energy ambiguity can be resolved for events having a relative energy transfer $y > 0.5$ under the assumption that less than 40% of the hadron energy goes into neutrals (which seems very reasonable). From this it should be possible to extract the total neutral current cross-section on neutrons and protons separately as a function of energy: $\sigma_o^{\nu n}(E)$ and $\sigma_o^{\nu p}(E)$. It should be noted that this is the only clean way to obtain these cross-sections other than using track-sensitive H_2- or D_2- targets in bubble chambers. Narrow band beam experiments have the added great advantage that in this region events produced by ν_K should contain a very small neutron background.

2.) Semi-inclusive Interactions

Nothing is known about the isostructure of the weak neutral current. The measurement of the ratio π^+/π^- enables one to determine its $I = 1$ and $I = 0$ content[3]. In the language of the Salam-Weinberg model this is equivalent to an independent determination of the Weinberg angle.

C. Background of Muons and Hadrons from the shielding and surrounding matter.

One of the major potential backgrounds in neutrino experiments using wide band beams at high proton intensity comes from energetic muons and hadrons produced by neutrino interactions in the shielding, the magnets etc. Thus for a wide band beam, approximately 50 muons as well as hadrons will enter the chamber. Likewise a large number of such particles will enter the EMI, making muon identification nontrivial. We point out that for a narrow band beam experiment, these backgrounds are negligible due to the small neutrino flux in the beam.

D. Technical Aspects

1.) External Muon Identifier

The physics program outlined above depends crucially on the identification of the muon, so that the EMI presently being developed at CERN is essential for both CC and NC studies.

2.) Physicists involved

Aachen : 5 physicists
CERN : 5 "
Oxford : 4 "

Flux measurement : H. Wachsmuth (CERN)
EMI : A. Grant (CERN)
H. Foeth (Aachen)

3.) Beam and Chamber requirements

Beam

Narrow band neutrino beam; proton energy 400 GeV; intensity 10^{13} ppp on target; meson momentum 200 ± 20 GeV.

Chamber

BEBC, deuterium filling, 500 000 pictures.

It is proposed that this experiment is run parasitically with WANF counter experiments. It will be possible to share the chamber with hadron experiments by double pulsing BEBC.

If deuterium would not be available, we propose to run with a hydrogen filling, since much of the physics could be achieved by running with hydrogen, and making use of the proposed narrow band experiment in Ne.[4)]

4.) Film Handling and Analysis

Due to the small number of events, measurements using automatic systems will be completed in the order of half a year.

References

1) G. Myatt, CERN/ECFA/72/4 Vol. II. p. 117.

2) Proposal to study high energy ν and $\bar{\nu}$ interactions in hydrogen at the SPS using BEBC. Aachen-CERN-Oxford Collaboration, CERN/SPSC/74-91/P25

3) R. McElhaney and S.F. Tuan, Phys. Rev. D8, 2267 (1973)

4) Proposal to study high energy neutrino interactions with a narrow band beam at the SPS, using BEBC filled with Neon. Aachen-CERN-Oxford-Collaboration, CERN/SPSC/74-88/P23.

5) Comparison of neutrino- and electroproduced pions and tests of the parton model. L.M. Sehgal, to be published.