VI. Other Physics

The primary intent of this proposal as emphasized above is to carry out a definitive long baseline neutrino oscillation search in the region of the oscillation parameters suggested by the anomaly in the atmospheric neutrino data. If successful in reaching a positive result, the experiment would answer long standing questions concerning neutrino mass and mixing and open a new avenue to physics beyond the standard model. It is therefore desirable to perform the experiment as well as possible, and this has been the guiding principle in its design.

Nevertheless, it should be recognized that the new neutrino beam facility discussed in Section II B would also make possible other unique neutrino scattering experiments of fundamental importance. We briefly discuss here one such experiment primarily to provide the physics motivation for it. Detailed design would require more elaboration than is appropriate here.

A. Neutrino Magnetic Moment, Anomalous and Charge Radius-Anapole Moment, and Extra Z'-bosons.

An experiment to measure the precisely normalized absolute cross section of the reaction $\nu_\mu e^- \to \nu_\mu e^-$ with small statistical error and high angular resolution, when compared with the accepted Electroweak Theory (Standard Model) prediction, would lead to valuable searches for intrinsic properties of neutrinos other than mass and mixing, and for physics beyond the Standard Model.

We show in Table 1 the current limits on possible magnetic moments of neutrinos. One sees that laboratory based limits lag significantly behind those derived from astrophysics measurements which, while probably roughly correct, are indirect and require substantial inductive reasoning to extract them. There is a large theoretical literature relating to the possible existence of a neutrino magnetic moment, much of it attempting without appreciable success to dissociate neutrino mass from neutrino magnetic moment. Accordingly, significant improvement in laboratory searches for a neutrino magnetic moment, even without a positive result, would complement the neutrino oscillation searches, and aid in the formation of a complete picture of the intrinsic properties of neutrinos. Neutrino mass and a directly measurable neutrino magnetic moment are properties beyond those attributed to neutrinos in the Standard Model.

The charge radius-anapole moment of neutrinos is related to the magnetic moment in that all may be considered as the source of neutrino coupling to the electromagnetic field and the

Laboratory	$\mu_{\bar{\nu}_e} < 4 \times 10^{-10}\mu_B$ $\mu_{\nu_\mu} < 9.5 \times 10^{-10}\mu_B$
Stellar cooling $(\gamma \rightarrow \nu\bar{\nu})$	$\mu_\nu < 1.1 \times 10^{-11}\mu_B$
Red giants	$\mu_\nu < (2-3) \times 10^{-12}\mu_B$
Nucleosynthesis $(\nu_L e \rightarrow \nu_R e)$	$\mu_\nu < 0.5 \times 10^{-10}\mu_B$
SN1987A	$\mu_\nu < (10^{-13} - 10^{-12})\mu_B$
Standard model (Dirac mass)	$\mu_\nu < 3 \times 10^{-19}(\frac{m_\nu}{1eV})\mu_B$

Table 1: Limits on neutrino magnetic moments. From P. Langacker, " Testing the Standard Model," Proc. 1990 Theoretical Advanced Study Institute in Elementary Particle Physics, Ed. M. Cvetic and P. Langacker, World Scientific, 1990 (p. 892).

Feynman diagrams describing their influence on neutrino-electron scattering are similar. The charge radius-anapole moment occur to a good approximation as a gauge invariant quantity—indeed, as a radiative correction in the Standard Model— and is expected to contribute to $\nu - e$ scattering at a level just below that set by present experimental limits, approximately $10^{-32}cm^2$ [1]. To the extent that confirmation of the precise magnitude of calculated radiative corrections by experiment is a desirable test of the validity of gauge theories—witness the attempts to go to higher loop corrections, i.e., higher orders of α_{QED}, through more and more refined measurements of $g-2$ for the charged leptons—so determination of the charge radius of the neutrino would directly test our understanding of radiative corrections in the Electroweak Theory. A deviation could point to an anomalous charge radius induced by new physics.

Still other issues of importance which may be addressed in $\nu_\mu e^- \rightarrow \nu_\mu e^-$ scattering are those of extra Z'-bosons beyond the known Z^0 at $m(Z^0) = 91.18$ GeV, and extra fermions [2]. We use as illustration here extra neutral Z bosons because, in general, extra intermediate vector bosons (IVB)—beyond the Standard Model (SM) W and Z—are universal in grand unification theories (GUTs) beyond SU(5). They arise naturally because the extension from the SM to GUTs introduces larger gauge groups with more group generators and more IVBs. Relatively low mass IVBs might, however, develop masses in the TeV range by other than usual Higgs fields.

There are effectively two extra free parameters in the SM with an extra Z boson, provided the relative fermion couplings are constrained by the underlying non-Abelian gauge group. This allows for many possibilities which are discussed in detail in Ref. [2], some of which are best searched for by other experimental means, e.g., e^+e^- collisions or parity violating atomic physics measurements. There are also a number of extra Z-boson types for which measurement of $\sigma(\nu_\mu e^-)$ would be either the sole means of access or one strongly competitive with other means.

As remarked above, improved searches for anomalous electromagnetic properties of the ν_μ or extra Z-bosons will require precise measurement of $\sigma(\nu_\mu e^-)$. This would be possible in the imaging Cherenkov counter D1 in which the momentum and angle of the recoiling electron would be directly measured with good accuracy and the event rate would be high. For example, D1 would have angular resolution (limited by multiple scattering) similar to that of the E-734 detector [3] and a substantially higher rate. Normalization would be provided by quasielastic events in D1 and D3. Many of the uncertainties involved in the E-734 normalization would not occur in D1 and D3 because of the larger mass of the detectors, the larger distance of the detectors from the beam origin, and the almost monochromatic beam with little high energy tail at 1.5 degrees.

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