TeV MAJORANA NEUTRINO DISCOVERY POTENTIAL AT THE ELECTRON COLLIDER

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Abstract. Heavy Majorana neutrinos may well provide key features for the understanding of the Standard Model neutral lepton spectrum. The Electron Linear Collider can give critical evidence towards their discovery. No presently available data exclude their existence at the TeV mass level.

INTRODUCTION

An attractive way to explain the near masslessness of the observed three neutrinos is the possible existence of right-handed singlet neutrino fields with masses that have eluded detection in production processes. We have argued [1,2] that the reaction $e^-e^- \to W^-W^-$ is capable of providing conclusive evidence for being mediated by t- and u-channel exchange of such singlet states. In the present paper, we give the parameter space accessible to the discovery of these states in the light of limitations imposed by rare decay limits at low energies. We also note that recent arguments that the existence of such states is precluded by the non-observation of neutrinoless double beta decay is unfounded at the level of sensitivity of existing detection capabilities.

DISCOVERY PROCESS

As it turns out, the cross-section for W^- pair production in e^-e^- collisions (see Fig. 1) is sizeable only if both incoming electrons are left-handed. The free choice of chiral couplings accessible by the ease of producing highly polarized electron beams and of inverting their helicities is at the basis of the search we proposed. The cross-section is

$$\frac{d\sigma}{d\cos\theta} = \frac{G_F^2}{8\pi}\left|\sum_N \frac{U_{eN}^2}{m_N}\right|^2 s^2 \qquad \text{for } m_W \gg \sqrt{s} \gg m_N. \tag{1}$$

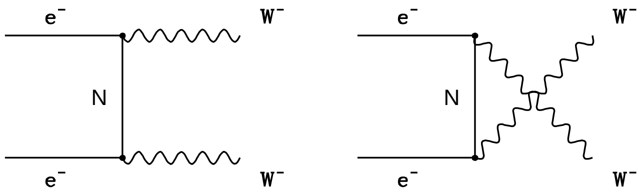

FIGURE 1. Feynman diagrams for the process $e_L^- e_L^- \to W^- W^-$.

It leads to sizeable counting rates at the Linear Collider, and to spectacular, unmistakable final states:

$$W^- W^- \quad \left.\begin{array}{ll} \to & e^-\mu^-(\tau^-) + p_{\perp miss}, \\ \to & \mu^-\mu^-(\tau^-) + p_{\perp miss}, \\ \to & \tau^-\tau^- + p_{\perp miss} \\ \to & e^-(\mu^-,\tau^-) + \text{jet}, \\ \to & \text{jet} + \text{jet}, \end{array}\right\} \tag{2}$$

where the jets reconstruct to the W mass.

The counting rates are, of course, determined by cross-section (1) and the available luminosities. The mixing parameters U_{eN} in this expression are the relevant Yukawa couplings of W, e, N and the directional cosines. Note that any suspicious signal can be checked by a helicity reversal of one or both incoming beams.

Remarkably, the cross-section has a strong energy dependence $\sim s^2$, which gives direct information on the masses of the exchanged heavy neutrinos. The couplings are bounded by low-energy non-observation of rare muon and tau decays which could, in principle, also be mediated by these heavy singlets. Figure 2 illustrates the permitted parameter space for reaction (1) in terms of these quantities.

COMPATIBILITY WITH NON-OBSERVATION OF NEUTRINOLESS DOUBLE BETA DECAY

Classically, neutrinoless double beta decay of such easily accessed isotopes as ^{76}Ge has been viewed as the discovery process for the Majorana character of the neutrino mass term. As is well known, limits on the observation of this process are proportional to the mass for light neutrinos, but to 1/m for heavy masses. This relationship has recently been misused by arguments that the non-observation of this process not only puts very low limits on light Majorana masses (recall that, at mass = 0, there is no difference between Dirac and Majorana masses), but also that it excludes the existence of heavy neutrinos in the mass range we are discussing here [3,4].

The reason for the non-applicability of the non-observation argument for the case at hand is the very fact that the exchange of very heavy masses in the double beta decay process is heavily suppressed by the factor $1/m_N$ we mentioned above: On

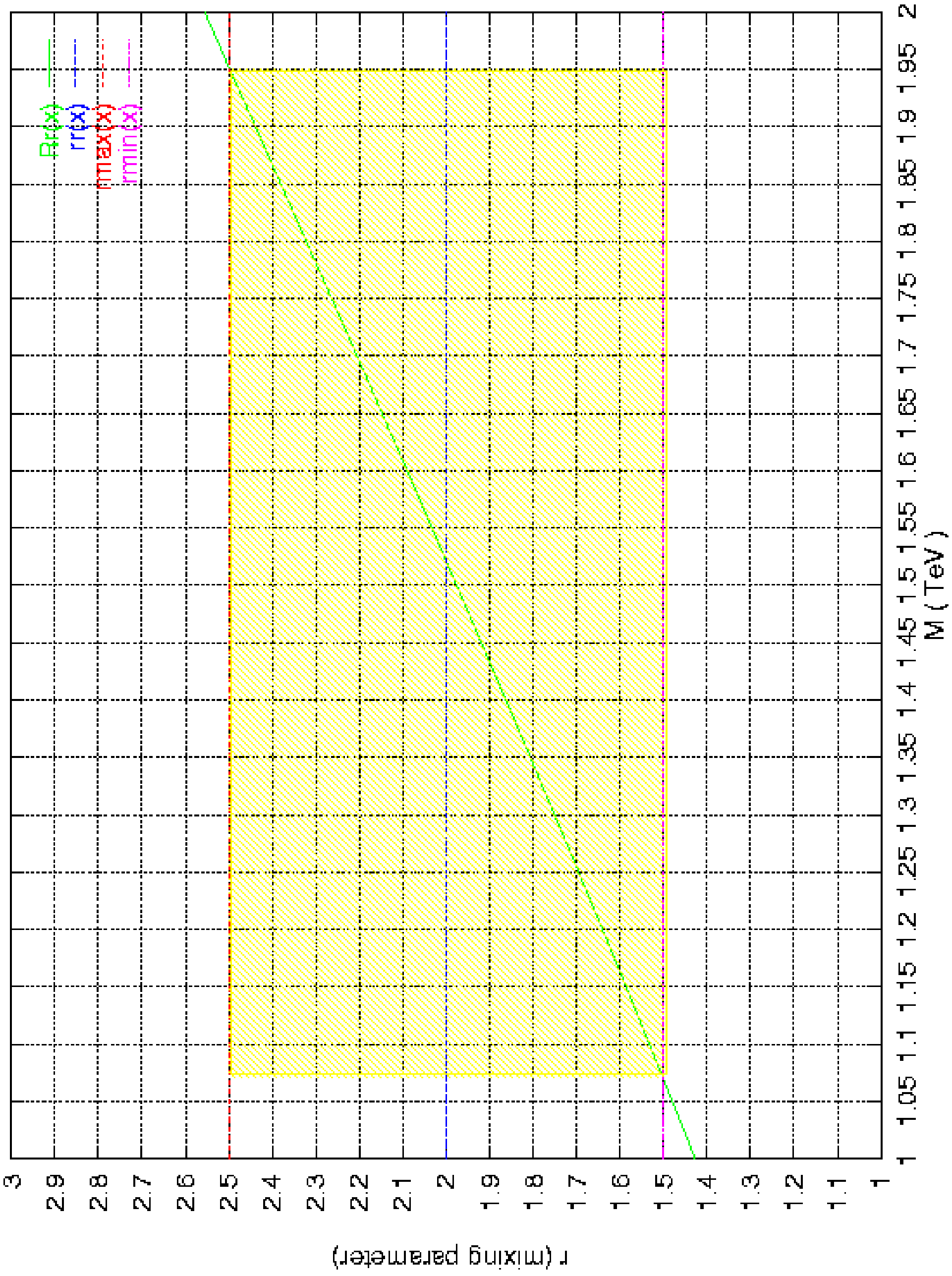

FIGURE 2. Discovery potential for a heavy neutrino flavor in the coupling and mass parameter space r, M. The range corresponding to $1.5 \leq r \leq 2.5$ is shown as shaded region. The mixing parameter r is defined, in terms of $|U_{eN}|^2$ of eq. (1), by $|U_{eN}|^2 = r(2 \times 10^{-4})$.

the quark level, Fig. 3 shows that the double beta decay graph implies that two d quarks from two different neutrons inside the parent nucleus have to approach to within $1/m_W$ in order to exchange the particle we are searching for: the color Coulomb wall, however, provides a hard core repression against this process. We have shown that the constraints on the close approach of the two d quarks by their parent nucleons as well as by the nuclear configuration winds up depressing the effective Lagrangean term by factors that preclude the observation of such processes initiated by the exchange of TeV-level Majorana neutrinos [5,6].

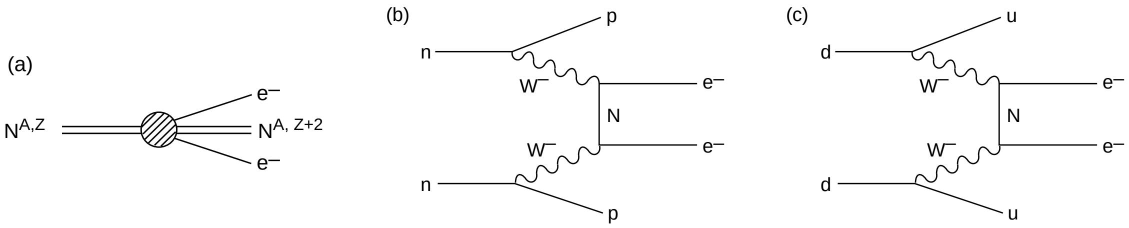

FIGURE 3. a) Generic graph for neutrinoless double beta decay; b) details of heavy neutrino exchange in a), shown on the nucleon level; c) same as b), but on the quark level. Given that the locality scale is set by m_W^{-1}, the latter is the most relevant graph.

CONCLUSION

We summarize by urging the early configuration of the Linear Collider in the e^+e^- and e^-e^- versions with low overhead costs for the changeover from one mode to the other in a short time, and by pointing out that the very promise of giving decisive evidence towards the resolution of one of the basic conundrums of our Standard Model ought to be seen as one more signature task for the accelerator that our community is likely to agree on as our next major international construction effort.

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