A general parametrization for the long-range part of neutrinoless double beta decay [†]

H. Päs [*], M. Hirsch, S.G. Kovalenko [‡], H.V. Klapdor–Kleingrothaus

Max–Planck–Institut für Kernphysik,
P.O. Box 103980, D–69029 Heidelberg, Germany

ABSTRACT

Double beta decay has been proven to be a powerful tool to constrain $B-L$ violating physics beyond the standard model. We present a representation for the long–range part of the general $0\nu\beta\beta$ decay rate allowed by Lorentz–invariance. Combined with the short range part this general parametrization in terms of effective $B-L$ violating couplings will provide the $0\nu\beta\beta$ limits on arbitrary lepton number violating theories.

1. General Formalism

We consider the long–range part of neutrinoless double beta decay with two vertices, which are pointlike at the Fermi scale, and exchange of a light neutrino in between. The general Lagrangian can be written in terms of effective couplings ϵ^α_β, which correspond to the pointlike vertices at the Fermi scale so that Fierz rearrangement is applicable:

$$\mathcal{L} = \frac{G_F}{\sqrt{2}}\{j^\mu_{V-A}J^\dagger_{V-A,\mu} + {\sum_{\alpha,\beta}}' \epsilon^\beta_\alpha j_\beta J^\dagger_\alpha\} \tag{1}$$

with the combinations of hadronic and leptonic Lorentz currents of defined helicity $\alpha,\beta = V-A, V+A, S+P, S-P, T_L = 2TP_L, T_R = 2TP_R$ and the usual left– and right handed projectors $P_{L/R} = \frac{1\mp\gamma_5}{2}$. The sum runs over all contractions allowed by Lorentz–invariance, except for $\alpha = \beta = V-A$. Evaluating "on axis" one assumes only one of the ϵ^β_α unequal zero and arrives at a general double beta decay amplitude proportional to

$$T(\mathcal{L}_{(1)}\mathcal{L}_{(2)}) = \frac{G_F^2}{2}T\{j_{V-A}J^\dagger_{V-A}j_{V-A}J^\dagger_{V-A} + \epsilon^\beta_\alpha j_\beta J^\dagger_\alpha j_{V-A}J^\dagger_{V-A} + (\epsilon^\beta_\alpha)^2 j_\beta J^\dagger_\alpha j_\beta J^\dagger_\alpha\}. \tag{2}$$

While the first term corresponds to the standard model (SM) like neutrino exchange and the 3rd term $\sim (\epsilon^\beta_\alpha)^2$ can be neglected, only the 2nd term is phenomenological interesting. For this term one has to consider two general cases:

1) The leptonic SM $V-A$ current meets a left–handed non SM current j_β with $\beta = S-P, T_L$. This contribution is proportional to the unknown neutrino Majorana mass $m_\nu \leq\sim 0.5eV$, for which no lower bound exists. Therefore no limits on the parameters ϵ^β_α can be derived.

2) The leptonic SM $V-A$ current meets a right–handed non SM current j_β with $\beta = S+P, V+A, T_R$. This contribution is proportional to the neutrino momentum $q \simeq p_F \simeq 100MeV$ with the nuclear Fermi momentum p_F, and thus will produce stringent limits on ϵ^β_α.

[†] Talk presented by H. Päs at the Erice School on Nuclear Physics, 19th course "Neutrinos in Astro, Particle and Nuclear Physics", Erice, Italy, 16-24 September 1997

[*] present address: Laboratori Nazionali del Gran Sasso (INFN), 67010 Assergi (AQ), Italy;
E-mail: Heinrich.Paes@mpi-hd.mpg.de

[‡] On leave from Joint Institute for Nuclear Research, Dubna, Russia

Taking these considerations into account, we are left with three interesting contributions discussed in the following sections. With the present half-life limit of the Heidelberg–Moscow experiment $T_{1/2}^{0\nu\beta\beta} > 1.1 \cdot 10^{25} y^1$ and

$$[T_{1/2}^{0\nu\beta\beta}]^{-1} = (\epsilon_\alpha^\beta)^2 G_{0k} |ME|^2 \tag{3}$$

where G_{0k} denotes the phase space factors defined in[2] and $|ME|$ the nuclear matrix elements, limits on the ϵ_α^β can be derived.

2. Calculational details and preliminary limits

2.1. *SM meets $j_{V+A} J^\dagger_{V+A}$ and $j_{V+A} J^\dagger_{V-A}$*

This contribution has been considered already in the context of left–right symmetric models.[2,3] For sake of completeness we repeat the results here in our notation: $\epsilon^{V+A}_{V+A} < 8.2 \cdot 10^{-7}$, $\epsilon^{V+A}_{V-A} < 4.5 \cdot 10^{-9}$.

2.2. *SM meets $j_{S+P} J^\dagger_{S+P}$ and $j_{S+P} J^\dagger_{S-P}$*

Under some assumptions[4] one gets

$$ME^{S+P}_{S+P} = ME^{S+P}_{S-P} = \frac{4}{R^2 m_e^2} \mathcal{M}_1^{(\nu)} \tag{4}$$

with the nuclear radius R and $k = 1$ determining the phase space factor. Inserting the numerical value of the matrix element $\mathcal{M}_1^{(\nu)} = 2.1$, which has been calculated in the QRPA approach in,[5] one derives $\epsilon^{S+P}_{S+P} = \epsilon^{S+P}_{S-P} < 1.2 \cdot 10^{-8}$.

2.3. *SM meets $j_{T_R} J^\dagger_{T_R}$ and $j_{T_R} J^\dagger_{T_L}$*

In the tensor part the dacay rate depends on the phase space $k = 1$ and new matrix elements not considered in the literature.[4] An estimation of their numerical values for the special case of ^{76}Ge, based on kinematic properties, yields $\epsilon^{T_R}_{T_R} < \mathcal{O}(10^{-9})$. The limit on $\epsilon^{T_R}_{T_L}$ is expected to be considerably weaker.

3. Conclusion

We have presented a general parametrization for the long range part of the neutrinoless double beta decay rate in terms of effective couplings. Combined with the short range part and contributions of derivative couplings, this parametrization will give the double beta decay constraints for arbitrary lepton number violating theories beyond the SM. A further step should include interference terms and justify the assumptions and approximations used in this work. For a more detailed discussion we refer to.[4]

Acknowledgement

H.P. is supported by a HSP/II AUFE grant of the Deutscher Akademischer Auslandsdienst (DAAD)

References

1. L. Baudis *et al.* (Heidelberg–Moscow collab.), Phys. Lett. **B 407** (1997) 219
2. M. Doi, T. Kotani, E. Takasugi, Progr. Theor. Phys. Suppl. **83** (1985) 1
3. M. Hirsch, H.V. Klapdor–Kleingrothaus, O. Panella, Phys. Lett. **B 374** (1996) 7
4. H. Päs, M. Hirsch, S.G. Kovalenko, H.V. Klapdor–Kleingrothaus, in: H.V. Klapdor–Kleingrothaus, H. Päs (Eds.): “Beyond the Desert – Accelerator and Non–Accelerator Approaches”, Proc. of the Int. Workshop on Physics beyond the Standard Model, Castle Ringberg, Germany, IOP Publishing 1998
5. M. Hirsch, H.V. Klapdor–Kleingrothaus, S.G. Kovalenko, Phys. Lett. **B 372** (1996) 181, Erratum: Phys. Lett. **B381** (1996) 488