MAX-PLANCK-INSTITUT FÜR KERNPHYSIK

International PhD Summer School on Neutrinos
Here, There & Everywhere

Chiral EFT Treatment of Neutrinoless Double Beta Decay with Majoron Emission

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Motivation

Neutrinos are massive particles: Extension of SM

Two possible types of masses:

Dirac

$$m(\bar{\nu}_L \nu_R + \bar{\nu}_R \nu_L)$$

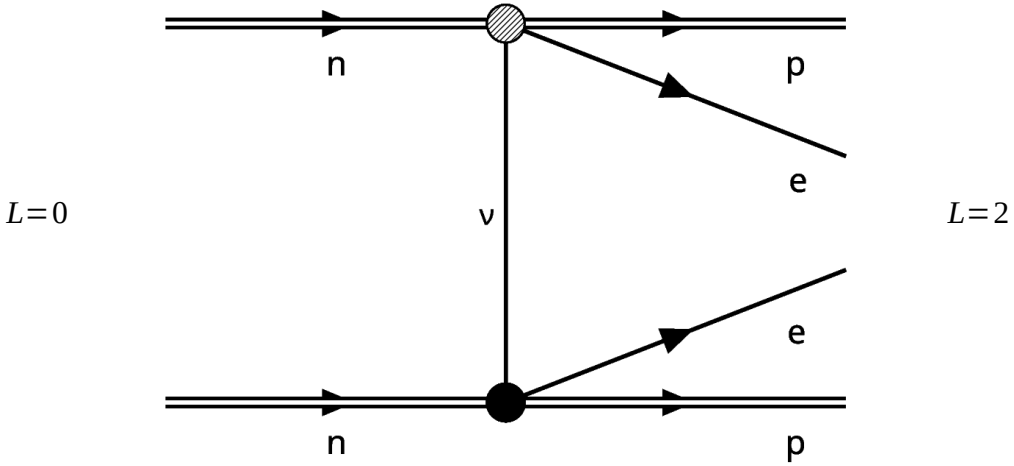
Majorana

$$\frac{m}{2} \nu_L^T C^\dagger \nu_L + h.c.$$

Lepton flavour is not conserved ⇨ Maybe lepton number is not conserved either

Motivation

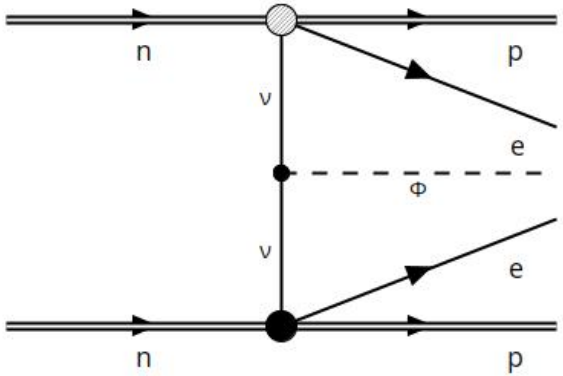
Neutrinoless double beta decay ($0\upsilon\beta\beta$) is one of the most popular tests of lepton number conservation:



0υββ with Majoron emission

$U(1)_{B-L}$ global symmetry: The Goldstone boson that occurs from spontaneous breaking of this symmetry is the Majoron

Depending on the paper one is reading, the Majoron can have different features (e.g. massless or light)



Chiral EFT treatment

Approximate chiral symmetry of QCD:
For idealized massless quarks (u, d, s) there is a chiral flavour symmetry

$$SU(3)_L \times SU(3)_R$$

Chiral perturbation theory:

- Constructed with Lagrangian that is consistent with this symmetry (among others like parity)
- Uses the most general Lagrangian

⇨ Can describe interactions between pions and between pions and nucleons

⇨ Moreover it can be applied to few nucleon systems

⇨ Makes sense to apply it to $0\upsilon\beta\beta$ (two nucleons)

Chiral EFT treatment

For $0\upsilon\beta\beta$ without Majoron emission extensive treatment exists already

1708.09390, 1806.02780

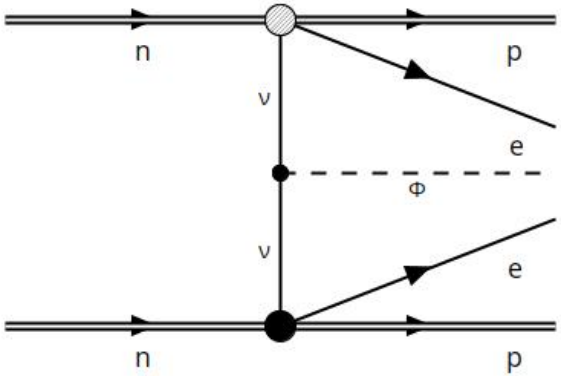
Also the case with sterile neutrinos has been treated

2002.07182

Goal: Similar treatment including the Majoron; maybe including sterile neutrinos

Ingredients

- Matrix element
  - Concentrate on long-range contribution
  - Standard mechanism for $npe\upsilon$ coupling
  - Two different couplings for $\upsilon\upsilon\phi$



- Phase space
  - Phase space consists of integral factors and of part that comes from the electron trace
  - Also factor from electron wave function expansion
  - Phase space differs for different kinds of double-beta decay

From these it is possible to get the half-life or the (differential) decay rate!

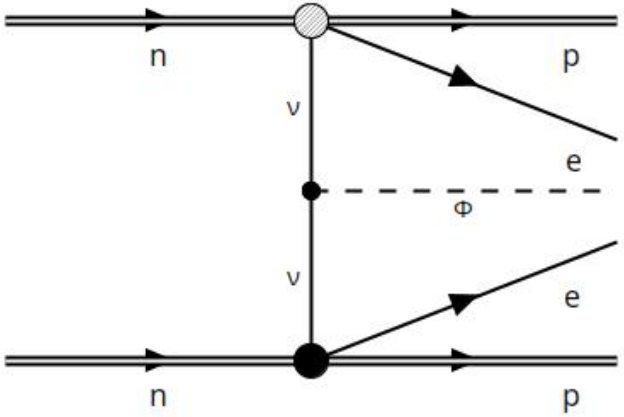
Matrix Element

$npe\upsilon$ vertex

- For now: standard mechanism
- In chiral EFT the operator is

$$O \sim G_F \overline{u_L}\, \gamma^\mu d_L\, \overline{e_L}\, \gamma_\mu\, \nu$$

- In principle there are a lot of different operators possible for this vertex in chiral EFT



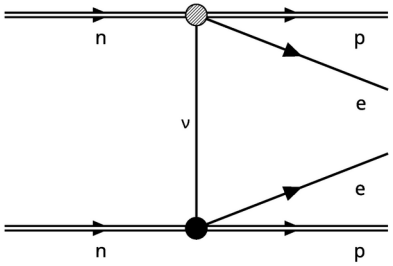
$\upsilon\upsilon\phi$ vertex

- Scalar Majoron
- Different options, with or without a γ_5

Matrix Element

Example: Case with a γ_5

One part is proportional to

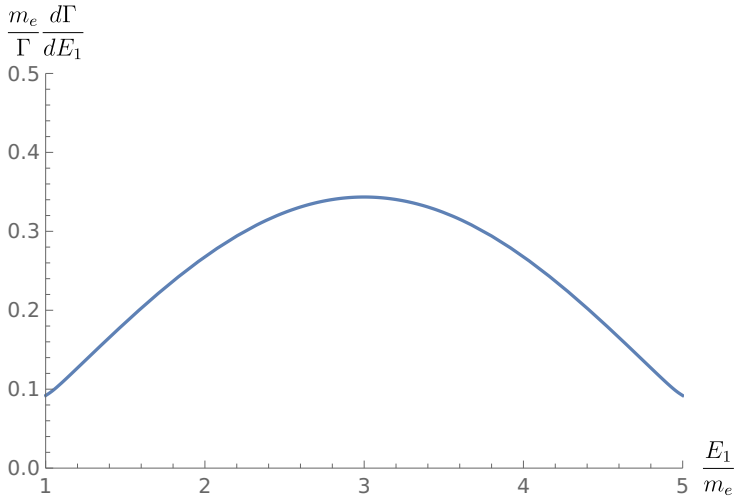


Second part is a more complicated correction

Double Beta Decay and Majorana Neutrino, *Doi, Kotani and Takasugi, 1985*

Phase Space

Phase space without Majoron for germanium



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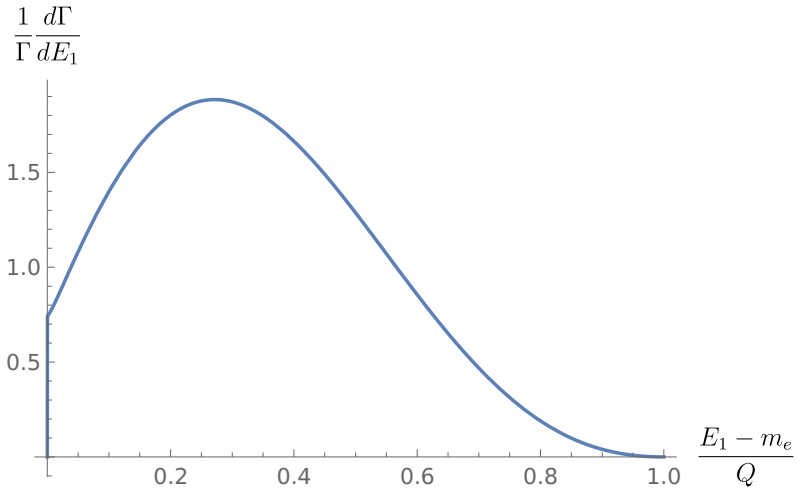
Phase space with massless Majoron for selenium



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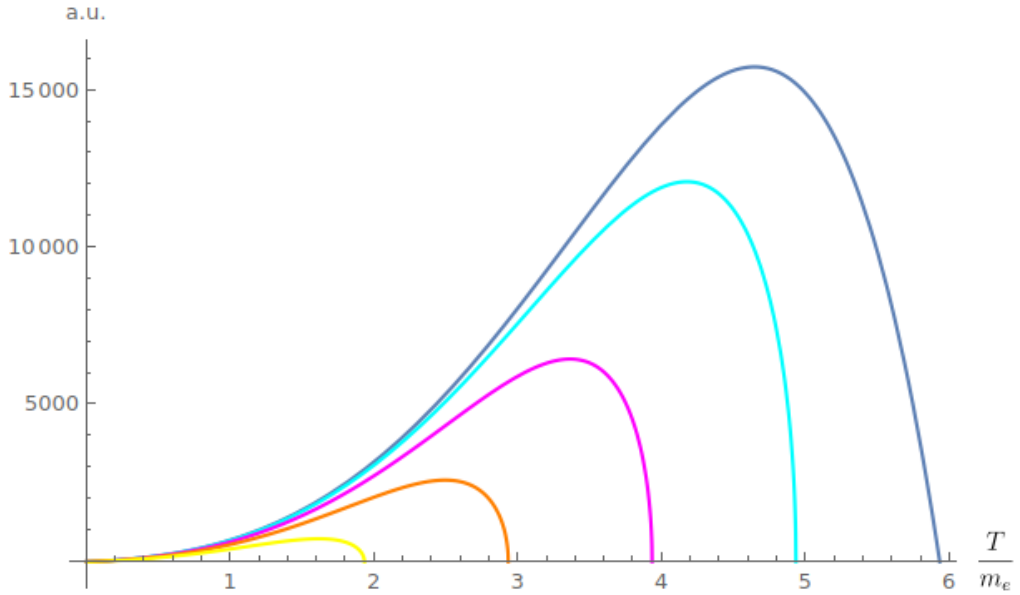
Phase Space

Phase space with massive Majoron for molybdenum



$$T = E_1 + E_2 - 2\, m_e$$

1808.08158

Summary

- $0\upsilon\beta\beta$ is a test for lepton number conservation
- $0\upsilon\beta\beta\phi$ is a variation of $0\upsilon\beta\beta$
- Both can be treated in chiral EFT
- Two parts have to be calculated: matrix element and phase space
- Outlook: Include sterile neutrinos as well

Thank you for your attention!

Sources

- Sketch neutrinos: sudonull.com/post/19063-Neutrino-oscillations-for-dummies
- All other figures I produced myself