Exp. Methods in Astroparticle Physics (SS 2020) - Problem sheet 13

Tutorial: Arnulf Barth (arnulf.barth@kip.uni-heidelberg.de)

Deadline for this sheet: Thu, 23.07.2020

Neutrinoless double-beta decay

13.1 Neutrinoless double-beta decay *5+1 Points*

The (total) lepton number might not be a conserved quantity, which would be demonstrated by observing the neutrinoless double-beta decay.

a) Explain the mechanism leading to a neutrinoless double-beta decay involving light Majorana neutrinos.

b) Express the relation between the half-life and the effective Majorana neutrino mass $m_{\beta\beta}$.

c) Write down the PMNS matrix in case of Majorana neutrinos (factorized into four 3×3 matrices), and express $m_{\beta\beta}$ as a function of the mixing matrix elements and m_1, m_2, and m_3.

Taking into account the value of the mixing angles and squared mass differences Δm_{ij}^2 obtained from neutrino oscillation measurements in the limit of a very small lowest mass eigenstate $m_1 \simeq 0\,\mathrm{eV}$, calculate:

e) the range in variation of $m_{\beta\beta}$ in the case of normal ordering

f) the range in variation of $m_{\beta\beta}$ in the case of inverted ordering

g) (Optional) how $m_{\beta\beta}$ can be approximated in the case of a quasi-degenerate limit for the mass eigenstates.

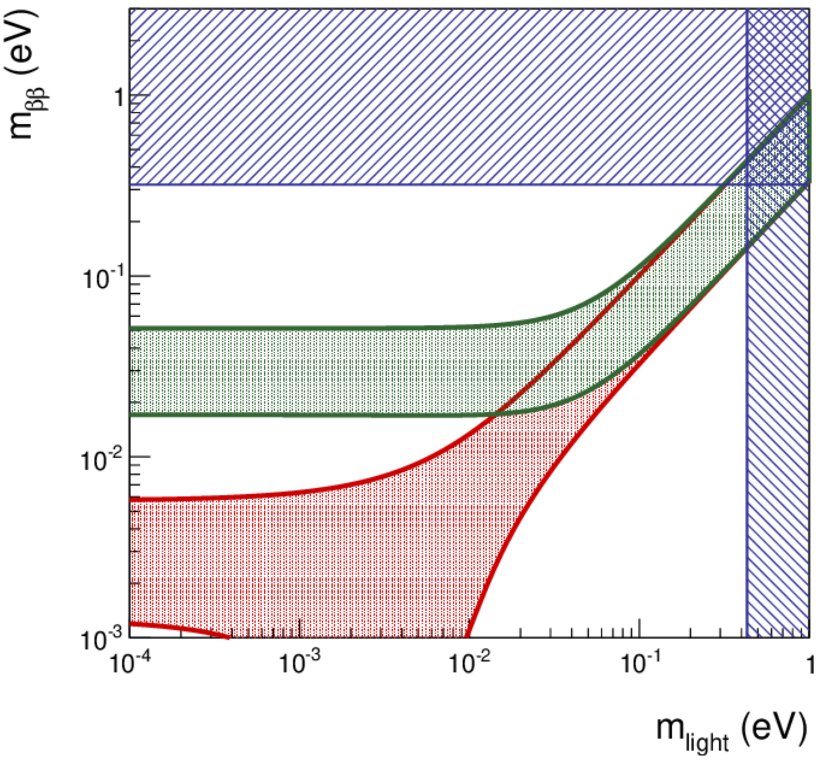

Figure 1: The effective neutrino Majorana mass, $m_{\beta\beta}$, as a function of the lightest neutrino mass, m_{light}. The green band corresponds to the inverted ordering of neutrino masses, whereas the red one corresponds to the normal ordering. The region where normal and inverted ordering overlap corresponds to the quasi-degenerate limit. The blue regions are exclusions from cosmological bounds and $0\nu\beta\beta$ constraints. *From: Gómez-Cadenas, Juan J. et al. "NEXT, high-pressure xenon gas experiments for ultimate sensitivity to Majorana neutrinos." JINST 7(11), 2012*

13.2 The GERDA experiment *5 Points*

In the case of massive Majorana neutrinos, the process of a neutrinoless double-beta decay ($0\nu\beta\beta$) of the form $X\,(Z, A) \rightarrow Y\,(Z+2, A) + 2\mathrm{e}^-$ is allowed and could be observable by experiments.

a) How can $0\nu\beta\beta$ events be recognized in an experiment?

The GERDA experiment is designed to search for $0\nu\beta\beta$ in $^{76}\mathrm{Ge} \rightarrow {}^{76}\mathrm{Se} + 2\mathrm{e}^-$ by using high purity germanium detectors. A brief overview of the experiment can be found here:
https://arxiv.org/abs/1909.02726.

b) What is the natural abundance of ^{76}Ge? If one were to test for a half-life of 10^{25} years of the $0\nu\beta\beta$-decay, what is the mass m_{Ge} of Ge that needs to be monitored to have a chance to observe 5 events in one year?

c) Explain the expression "zero background limit" in relation to $0\nu\beta\beta$ experiments.

d) What is the dependence of the sensitivity of an experiment to test a given half-life on the exposure ($m_{\mathrm{Ge}} \times t$) in case of zero background?

e) Which background could compromise the "zero background limit", and how has the GERDA experiment been designed to remove the majority of the background contributions?

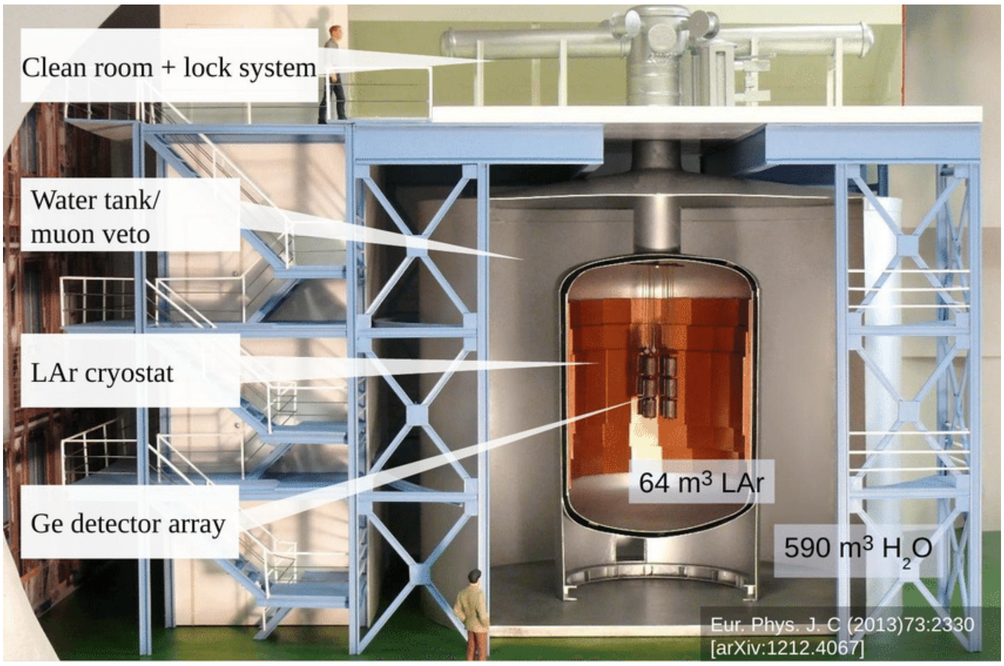

Figure 2: Schematic of the GERDA experiment