Max-Planck-Institute for Physics
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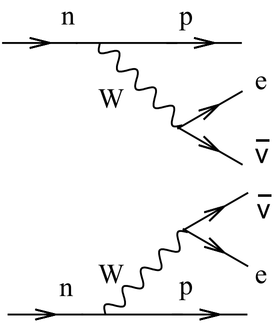
Search for neutrinoless double beta decay with scintillating bolometers

Nahuel Ferreiro Iachellini

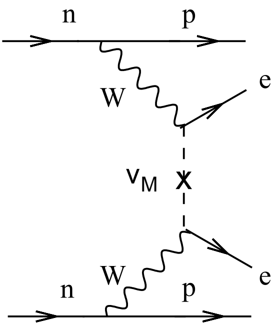
Double Beta Decay

Rare transition among isobaric elements:

$$(A, Z) \Longrightarrow (A, Z \pm 2)$$



(a) 2vDBD



(b) 0vDBD

- 2νDBD: useful for testing nuclear models

$$\frac{1}{T^{2\nu}_{1/2}} = G^{2\nu}(Q,Z)|M^{2\nu}|^2$$

$G^{2\nu}(Q,Z) \Rightarrow$ phase space of outgoing leptons
$M^{2\nu} \Rightarrow$ Nuclear Matrix Element

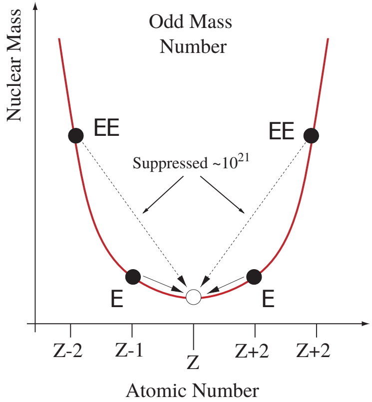
- 0νDBD: fundamental physics, if observed would prove the Majorana nature of neutrinos.

$$\frac{1}{T^{0\nu}_{1/2}} = G^{0\nu}(Q,Z) \mid M^{0\nu} \mid^2 \left(\frac{\langle m_{ee}\rangle}{m_e}\right)^2$$

The measurement of $T^{0\nu}_{1/2}$ would be a measurement of neutrino mass.

Nuclei for DBD study? Weizsäcker's formula for binding energy:

$$E(Z,A) = a_v A - a_s A^{2/3} - a_c \frac{Z(Z-1)}{A^{1/3}} - a_A \frac{(A-2Z)^2}{A} + \delta(Z,A)$$



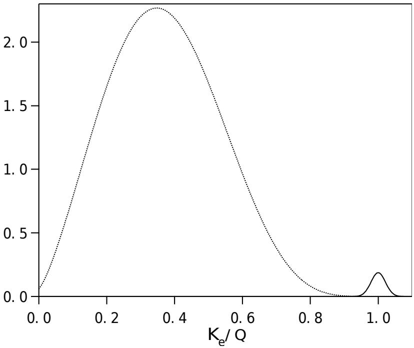
Experimental signature

Large half-lives $T_{1/2} \approx 10^{18} - 10^{21}$ years.

- Due to the rarity of the process high sensitive detectors are required
- Sensitivity for spotting 0νDBD peak over a background B:

$$S^{0\nu} = \log 2\, T\epsilon \frac{N_{\beta\beta}}{n_B} \propto \epsilon \sqrt{\frac{MT}{B\Delta}}$$

- Constraints similar to those in DM search



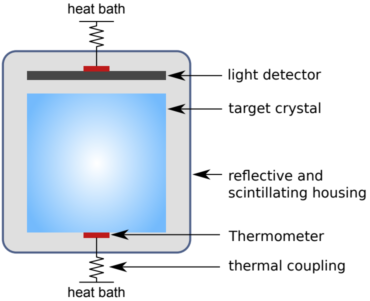
Nuclei for DBD study? $S^{0\nu} \propto \epsilon \sqrt{\frac{MT}{B\Delta}}$:

Parent Isotope	i.a. Rosman '98 [atomic %]	Q-value Audi '03 [keV]	$T^{2\nu}_{1/2}$ Measured [years]
^{48}Ca	0.187	4274	$4.4^{+0.6}_{-0.5} \times 10^{19}$
^{76}Ge	7.61	2039	$(1.5 \pm 0.1) \times 10^{21}$
^{82}Se	8.73	2995.5	$(0.92 \pm 0.07) \times 10^{20}$
^{96}Zr	2.8	3347.7	$(2.3 \pm 0.2) \times 10^{19}$
^{100}Mo	9.63	3035	$(7.1 \pm 0.4) \times 10^{18}$
^{116}Cd	7.49	2809	$(2.8 \pm 0.2) \times 10^{19}$
^{128}Te	31.74	867.9	$(1.9 \pm 0.4) \times 10^{24}$
^{130}Te	34.08	2530.3	$6.8^{+1.2}_{-1.1} \times 10^{20}$
^{136}Xe	8.87	2462	$(2.11 \pm 0.21) \times 10^{21}$
^{150}Nd	5.60	3367.7	$(8.2 \pm 0.9) \times 10^{18}$

$$S^{0\nu} \propto \epsilon \sqrt{\frac{MT}{B\Delta}}$$

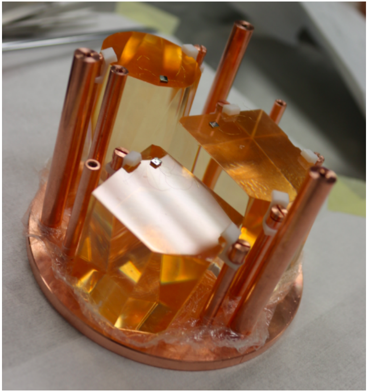
CRESST-like detectors are feasible for double beta decay purposes

- In principle $\mathrm{CaWO_4}$ could study the DBD in ^{48}Ca
- Unfortunately $^{48}\mathrm{Ca}$ is poorly abundant (0.187%) and its enrichment would cost billions
- Other crystals can be chosen $(\mathrm{ZnMoO_4, ZnSe, CdWO_4 ...})$
- Scintillation allows to reject α which are nothing but background



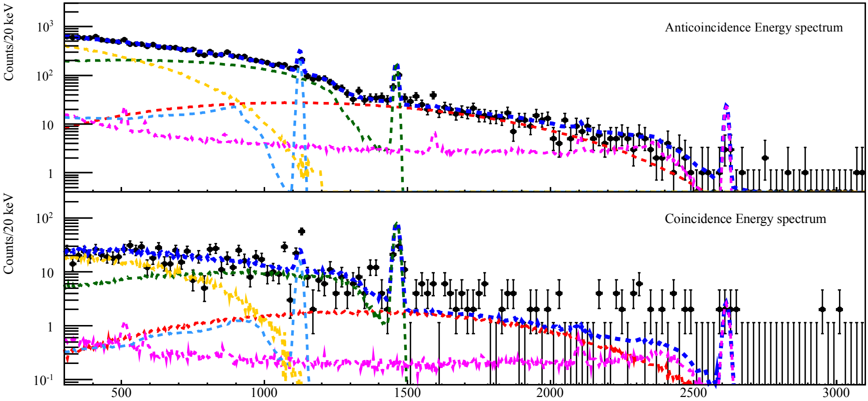
$ZnMoO_4$ crystals show the peculiar possibility to reject α background by means of shape analysis (no light channel)

- Three crystals operated as bolometers
- $\sim$0.8Kg for 36days (1.3Kg day of ^{100}Mo)
- Coincidence - anticoincidence analysis to improve background reconstruction



Background reconstruction - $T^{2\nu}_{1/2}$

$\text{bkg} = 2\nu + {}^{208}\text{Tl} + {}^{40}\text{K} + {}^{65}\text{Zn} + {}^{210}\text{Pb}-{}^{210}\text{Bi}$



$T^{2\nu}_{1/2}$ and $T^{0\nu}_{1/2}$ sensitivity

Bolometric measurement of $^{100}\mathrm{Mo}$ half-life[1]:

$$T^{2\nu}_{1/2} = (7.15 \pm 0.37(stat) \pm 0.66(syst)) \times 10^{18} \text{ years}$$

In agreement with the result obtained by NEMO[2] (the most accurate available):

$$T^{2\nu}_{1/2} = (7.11 \pm 0.02(stat) \pm 0.54(syst)) \times 10^{18} \text{ years}$$

Predicted sensitivity for 10Kg of $\mathrm{ZnMoO_4}$ with α-rejection for 1 year (CL 68%)

$$T^{0\nu}_{1/2} > 1.14 \times 10^{24} \text{ years}$$

[1] L. Cardani *et al.*, J. Phys. G **41**, 075204 (2014)

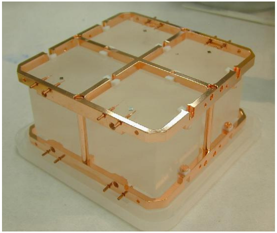
[2] R. Arnold *et al.*, First results of the search of neutrinoless double beta decay with the NEMO 3 detector, Phys.Rev.Lett. 2005

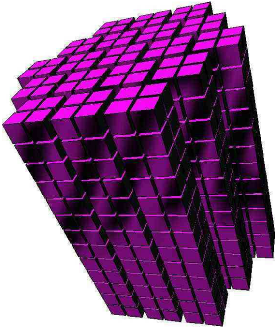
Current scenario

CUORE: Search for 0νDBD with $\mathrm{TeO_2}$ crystals array

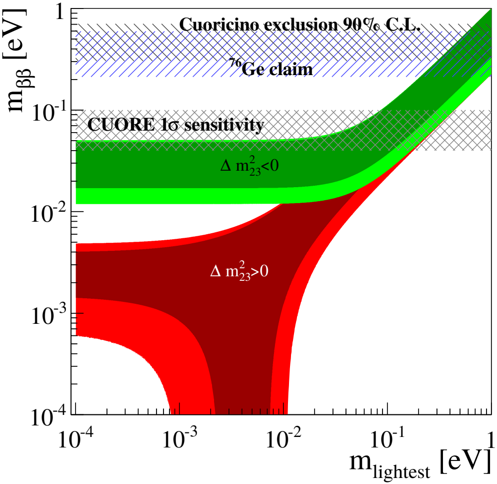
Specifics:

- 988 $\mathrm{TeO_2}$ crystals operated at $\sim$10mK.
- Expected background in ROI 10^{-2} counts/keV/kg/y, mainly due to degraded αs from surface contaminations and materials faced to the detectors.
- Expected sensitivity 2×10^{26} years, or $40 - 100 meV$ for $\langle m_{ee} \rangle$ for 5 years of exposure (it would span part of the inverted hierarchy).
- $\mathrm{TeO_2}$ does not scintillate $\Rightarrow$ no active background rejection?



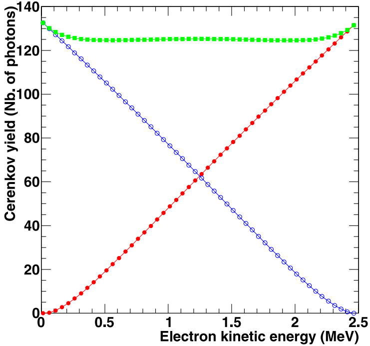


The picture from neutrino oscillations



TeO_2 are non scintillating crystals, but:

- They are transparent to light in the 350nm-IR region
- The refraction index ($n \simeq 2.4$) seta threshold for Cherenkov light emission:
  1. beta 50 keV
  2. α 400MeV
- ~350eV of light predicted for ROI beta events (regardless detection efficiency)

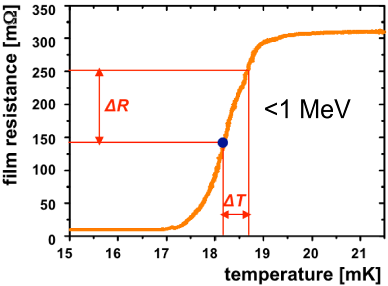


The Cherenkov photons are expected to be 350nm-650nm (2.0-3.5eV)

Experimental approach

Which thermometer best suits?

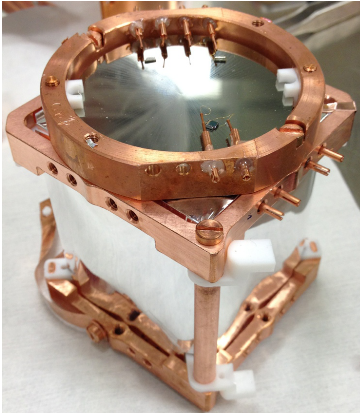
- TESs show great performances for the low energy region (some eV of baseline resolution), but their production is rather difficult and no mass production available
- NTDs (Neutron Trasmutation Doped) offer less sensitivity compared to TES but they are easy to be produced in series with standard performances. Baseline resolution $\sim$ several hundreds eV for Light Channel



Cerenkov light in $\mathrm{TeO_2}$

A recent measurement[3] achieved to quantify the Cherenkov light emitted by beta particles in $\mathrm{TeO_2}$ using NTDs thermometers:

- The amount of light emitted is $\sim$100eV at 0νDBD region, below the level of NTDs noise. This result is roughly 50% of the predicted one (self-absorption?)
- TES sensors should fulfill the required sensitivity to achieve event by event tagging and hence background rejection



[3] N. Casali *et al.*, arXiv:1403.5528 [physics.ins-det]