LUCIFER: Neutrinoless Double Beta Decay search with scintillating bolometers

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OUTLINE

- DBDOv physics
- Tools for the DBDOv search
- Scintillating Bolometers
- LUCIFER proposal
- LUCIFER R&D
- Conclusions
DBDOv

- 2nd order nuclear weak decay
- not allowed in the SM
- $t_{1/2}$ expected $> 10^{25}$ y

If observed:

- the neutrino is a Majorana particle: $\nu_e \equiv \bar{\nu}_e$
- $\Delta L = 2$, lepton number violation

Neutrino mass measurement:

$$\frac{1}{T_{DBD0\nu}^{1/2}} = G_{0\nu}(Q, Z) |M^{0\nu}|^2 m_{\beta\beta}^2$$
What are we looking for??

Monochromatic signal @ Q-value

\[ S_{0\nu} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}} \]

**i.a.** : isotopic abundance

**A** : atomic mass number

**M** : source mass

\[ O(1000 \text{ kg}) \]

**T** : live time \( O(5 \text{ y}) \)

**\Delta E** : FWHM in the ROI

\[ O(\sim \text{keV}) \]

**b** : bkg in the ROI

\[ O(0.01 \text{ c/keV/kg/y}) \] ...
The pursuit of DBDOν

... but if b is very low... “zero background approach”...

\[ S_{0ν} \propto \varepsilon \frac{i.a. \cdot M \cdot T}{A} \]

... this background level is achievable:

- high energy resolution  => bolometric technique
- removing sources of background  => material selection
- background discrimination  => heat - light

SCINTILLATING BOLOMETERS
Scintillating Bolometers

A bolometric device able to measure phonon (heat) and photon (light) excitations produced in an absorber by a single radiation interaction.


A. Alessandrello et al., Nuclear Physics B 28 (1992) 233-235
DBDOv candidates

- high isotopic abundance (or easy enrichment)
- achievable radiopurity
- suitable for the experimental technique

There is no "natural golden isotope"
Background issue

Main source of background in the ROI:
- Surface contaminations (unknown sources)
- Mainly degraded alphas from surfaces of “passive materials” (e.g. Copper, Teflon, ...)

See E. Guardincерri’s talk

Solution: Particle Discrimination
Discrimination Power

By means of the double (heat-light) read-out
=> particle discrimination $\alpha - (\gamma, \beta)$ is possible

$\gamma @ 2615$ keV

Research Proposal (B1) LUCIFER 2009

L. Gironi et al., Optical Materials, 31 (2009) 1388-1392
LUCIFER
Low-background Underground Cryogenics Installation For Elusive Rates

Principal Investigator: Fernando Ferroni
Co-Investigator: Andrea Giuliani

ERC-2009-AdG 247115

The experimental basis for LUCIFER is the R&D activity performed by S. Pirro at LNGS, in the framework of the programs:

- BOLUX funded by INFN - CSN5
- ILIAS - IDEA funded by the European Commission (WP2 - P2)
Isotope choice

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Q-value [keV]</th>
<th>Useful material</th>
<th>LY [keV/MeV]</th>
<th>QF [a.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{1}\text{CdWO}_4$</td>
<td>2809</td>
<td>32%</td>
<td>17.6</td>
<td>0.19</td>
</tr>
<tr>
<td>$^{2}\text{ZnMoO}_4$</td>
<td>3034</td>
<td>44%</td>
<td>1.4</td>
<td>0.16</td>
</tr>
<tr>
<td>$^{3}\text{ZnSe}$</td>
<td>2995</td>
<td>56%</td>
<td>7.4</td>
<td>4.2</td>
</tr>
</tbody>
</table>

$^{113}\text{Cd}$ : high neutron cross section
natural beta emitter

Lucifer baseline: $\text{ZnSe}$

Active isotope: $^{82}\text{Se}$
Decay: $^{82}\text{Se} \rightarrow ^{82}\text{Kr} + 2\text{e}^-$
Q-Value: 2995 keV
Abundance: 9%

1 C.Arnaboldi et al., arXiv:1005.1239
2 Research Proposal (B1) LUCIFER 2009
3 Research Proposal (B1) LUCIFER 2009

Courtesy of L. Gironi
Various ZnSe

<table>
<thead>
<tr>
<th>Crystal name</th>
<th>Crystal color</th>
<th>Mass [g]</th>
<th>LY [keV/MeV]</th>
<th>QF$_{\alpha}$ [a.u.]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small</td>
<td>Yellow</td>
<td>37.5</td>
<td>1.3</td>
<td>4.4</td>
</tr>
<tr>
<td>Large</td>
<td>Red</td>
<td>120</td>
<td>7.5</td>
<td>4.2</td>
</tr>
<tr>
<td>Huge</td>
<td>Orange</td>
<td>337</td>
<td>4.6</td>
<td>3</td>
</tr>
</tbody>
</table>

Different Colors => Stoichiometry problems (?)
Different LY => Surface treatment (?)

C. Arnaboldi et al, arXiv:1006.2721

Courtesy of L.Gironi
**STRUCTURE**

Cryostat possible location: ex-Cuoricino cryostat @ LNGS

**Tower:**
12 single modules

**Single module:**
4 ZnSe crystals and 1 light detector

Research Proposal (B1) LUCIFER 2009
SENSITIVITY

Sensitivity of ZnSe scintillating bolometer experiments
(background ~ $10^{-3}$ counts/keV/kg/y)

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$\langle m_{ee} \rangle \sim 52-65$ meV

$T = 5 \, \text{y}$

$b = 10^{-3}$ counts/keV/kg/y

$\Delta E = 5$ keV

a.i. = 95%

$M = 31.7$ kg (17.6 kg $^{82}$Se)

NME =

J. Mendez et al. arXiv:0801.3760;
F. Simkovic et al. Phys.Rev. C77 (2008);
SENSITIVITY

Sensitivity of ZnSe scintillating bolometer experiments (background $\sim 10^{-3}$ counts/keV/kg/y)

- $\langle m_{ee} \rangle \sim 52-65$ meV
- $T = 5$ y
- $b = 10^{-3}$ counts/keV/kg/y
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NME =

LUCIFER R&D

- Light Detector optimization (Si - Ge)
- Crystal Growth optimization
- Crystal Enrichment
- Bolometers optimization

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Data taking: 2014
CONCLUSIONS

• In DBD0v is mandatory the bkg reduction

• Zero background approach can be achieved with double read-out

• Scintillating bolometers are a perfect tool

• ...still some work to do for LUCIFER

• Data taking foreseen in 2014

... stay tuned