Development of Scintillating Bolometers for the Search of the Neutrinoless Double Beta Decay

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The Importance of the $0\nu$DBD

- $\nu$: Dirac or Majorana?
- (Only) if $\nu$ is a Majorana particle ($0\nu$DBD can happen)
- Not allowed by SM; up to now never observed $T_{1/2}^{0\nu} > 10^{24}$ y

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

Nuclear process: emission of two $e^-$ without $\nu$

If we plot the sum of the energies of the two $e^-$ we expect a monochromatic peak at the $Q$-value of the decay
The Bolometric Detectors

- A bolometer can be considered as an “ideal” calorimeter operated at cryogenic temperatures (~10 mK).

- It can be sketched as absorber + sensor.

- An energy release in the absorber gives rise to a temperature increase (read by the sensor).

- They can be grown with the isotope of interest (e.g., TeO$_2$ for $^{130}$Te) → source = detector.

![Diagram of bolometer and typical bolometric pulse](image)
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Which advantages?
- Excellent resolution (5 keV @ 2615 keV)
- Good efficiency (>80%)
- Radio-pure --> low intrinsic background
- Scalability
The Sensitivity

\[ S_0 \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}} \]

- i.a. = isotopic abundance
- \( A \) = mass number
- \( \varepsilon \) = detector efficiency
- \( M \) = mass [kg]
- \( T \) = measurement time [y]
- \( \Delta E \) = energy resolution [keV]
- \( b \) = background [counts/keV/kg/y]
The Sensitivity

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S_{0,\nu} \propto \varepsilon \frac{i.a.}{A} \sqrt{\frac{M \cdot T}{\Delta E \cdot b}}
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- **i.a.** = isotopic abundance
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For Bolometers: how can we improve?

- **ε** > 80%
- **M** ~ 1 ton
- **T** ~ 5 y
- **ΔE** ~ 5 keV
- **b** ~ 10^{-2} counts/keV/kg/y
The Challenge for Background Reduction

- The detectors are located in deep underground laboratories

LNGS
(Laboratori Nazionali del Gran Sasso)
3650 m.w.e.

Muon flux: \((2.58 \pm 0.3) \times 10^{-8} \mu/(s \text{ cm}^2)\)

Neutron flux [<10MeV]: \(\approx 4 \times 10^{-6} \text{n/(s cm}^2)\)
F. Arneodo et al., Il Nuovo Cim. 112A, 819, 1999

Gamma flux: \(\approx 0.73 \gamma/(s \text{ cm}^2)\)

- Proper shielding and vetoes
- Development of proper cleaning/storage procedures

- Ultimate limit given by the contaminations of the detector itself!
The Cuoricino Experiment

- Largest bolometric experiment ever realized
- Study of $^{130}\text{Te} \rightarrow ^{130}\text{Xe} + 2\text{e}^-$
- 40.7 kg of TeO$_2$ (11.6 kg of $^{130}\text{Te}$)
- Limit: $m_{\beta\beta} < 300 \div 710$ eV
- Study of the background: main problem surface $\alpha$ contaminations of the materials!

Black = background measurement
Green = calibration measurement (normalized on $^{208}\text{Tl}$ peak)
The Solution: Scintillating Bolometers

- $\alpha$ and $\beta/\gamma$ can release a similar heat in the bolometer but they emit a different amount of light --> we detect heat + light

- The $\alpha$ background can be eliminated!

- Our light detector is a thin germanium slab operated as bolometer

- Unfortunately, TeO$_2$ does not scintillate, so we need to grow other crystals....
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- Unfortunately, TeO$_2$ does not scintillate, so we need to grow other crystals....
- A large $Q$-value provides a further background reduction (less $\beta/\gamma$ contributions at higher energies)
- However, we need also a large isotopic abundance!
The LUCIFER Experiment

- **Baseline for the LUCIFER project:** ZnSe

- **Study of $^{82}\text{Se}$ decay**

- $Q$-value = 2995 keV

- i.a. $\sim 9.2\%$ but enrichment feasibility proved!

- ZnSe has a large LY ($\sim 7$ keV/MeV)

- Good energy resolution

- Radio - pure

- Array of scintillating bolometers

- R & D on different crystals to find the best candidate for a large mass experiment

*Wednesday, February 15, 2012*
Current Activity...

- The first tests for the “official” ZnSe production begun a few weeks ago
- Several tests are needed to characterize and understand the ZnSe features
- I’m involved in the assembly and operation of the ZnSe bolometers (LNGS)
- I’m analyzing the first results of these runs: internal contaminations, background rejection power, resolution and so on...
...R&D on Possible Alternatives

ZnMoO$_4$

(arXiv:1202.0238)

- Promising candidate for the study of $^{100}$Mo
- $Q$-value $\sim 3034$ keV
- i.a. $\sim 9.7\%$
ZnMoO₄

(arXiv:1202.0238)

- This crystal has a low LY (is this a problem for larger crystals?)
- Good energy resolution
- High radio-purity
- Different pulse shape for α and β/γ
...R&D on Possible Alternatives

TeO$_2$

(Astropart. Phys. 35 (2012) 558)

- Test on a small TeO$_2$ crystal: first detection of Cerenkov light
- The detected light is not enough BUT
- TeO$_2$ is a well known bolometer and its performances are already optimized
- 1000 crystals already @ LNGS, ready for the CUORE experiment
R&D on Possible Alternatives

\[ TeO_2 \]

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- So...more tests on reflecting foil and light detectors must be performed
Conclusions and Perspectives

- The background reduction is one of the main issues for (0ν)DBD physics.
- The LUCIFER experiment will study the (0ν)DBD of $^{82}$Se by means of ZnSe bolometers.
- Thanks to the scintillating bolometers technique, we will achieve a very low background counting rate ($\sim 10^{-3}$ counts/keV/kg/y) in the energy region of interest -- a competitive sensitivity on $m_{\beta\beta}$ ($\sim 100$ meV).
- I will characterize the ZnSe detectors by means of bolometric and optical measurements, performed in the cryostats of Roma and Gran Sasso laboratories.
- At the same time, I will follow a parallel R&D activity on other possible candidates for the study of the (0ν)DBD.