First results of CUPID-0

Stefano Pirro - INFN-LNGS
CUPID-0 Collaboration
Scintillating Bolometers: rudiments of operation

A Bolometric Light Detector is a fully active a particle detector

The time response of a BLD is the same of a standard bolometer 0 (ms)

The QE of a BLD could, probably, be close to 1 but it is rather difficult to measure it

Operating Temperatures for massive detectors: 10÷30 mK
The Lucifer Grant (2010-2015) was dedicated to R&D to be finalized in one enriched demonstrator made of enriched scintillating crystals in the order of few kg of enriched material. During the R&D several crystals containing $^{82}\text{Se}$, $^{100}\text{Mo}$, $^{116}\text{Cd}$ were tested an also the tiny Cherenkov light from a (non scintillating) TeO$_2$ was measured.
LUCIFER Low-background Underground Cryogenics Installation For Elusive Rates

isotope: $^{82}\text{Se}$, $^{100}\text{Mo}$, $^{116}\text{Cd}$

material: ZnSe, ZnMoO$_4$, CdWO$_4$

choice: Choice induced by non availability on the market (2012) of $^{100}\text{Mo}$ and $^{116}\text{Cd}$

From 2016 this activity is funded by INFN under the INFN-CUPID Project. For this reason, LUCIFER is called now CUPID-0, the first demonstrator in view of CUPID.
LUCIFER: the forerunner of CUPID

Cuore Upgrade with Particle IDentification

CUPID-0 will be the first enriched bolometer $\beta\beta$ experiment that will demonstrate the background rejection achievable for hybrid $\beta\beta$ scintillating bolometers.
Bolometric Light Detectors

In case of scintillating crystals, even in case of “bad” scintillators (Light Yield ≈ 0.05 %), the scintillation light at $Q_{\beta\beta}$ results of the order $O(1\ \text{keV})$. This amount of energy release can be “easily” readout by standard thermistor-based bolometers.

The light detector is a Ge thin wafer equipped with a small thermistor.

These devices are calibrated through an ionizing $^{55}\text{Fe}$ sources.

R&D mounting setup

JW Beeman et al. JINST 8(2013) P07021

CUPID-0 detector


$^{55}\text{Fe}$

5.9

6.5

$\text{RMS}_{\text{baseline}}$ [eV] $\tau_r$ [ms] $\tau_d$ [ms]

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<tbody>
<tr>
<td>LD Top-1</td>
<td>32.5 ± 0.5</td>
<td>1.68</td>
<td>5.15</td>
</tr>
<tr>
<td>LD Top-2</td>
<td>39.3 ± 0.7</td>
<td>1.91</td>
<td>5.75</td>
</tr>
<tr>
<td>LD Top-3</td>
<td>57.1 ± 0.8</td>
<td>1.71</td>
<td>3.41</td>
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<tr>
<td>LD Bot-1</td>
<td>43.9 ± 0.7</td>
<td>1.83</td>
<td>5.45</td>
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<tr>
<td>LD Top-4</td>
<td>37.8 ± 0.6</td>
<td>1.66</td>
<td>5.23</td>
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<tr>
<td>LD Top-5</td>
<td>112.2 ± 2.0</td>
<td>1.81</td>
<td>9.17</td>
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<tr>
<td>LD Top-6</td>
<td>65.7 ± 1.0</td>
<td>1.88</td>
<td>10.96</td>
</tr>
<tr>
<td>LD Bot-6</td>
<td>46.1 ± 0.7</td>
<td>1.82</td>
<td>5.39</td>
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$\langle \sigma \rangle = 55\ \text{eV} \sim 25\ \gamma$
The mechanical configuration of the CUPID-0 tower was designed by the LNGS Mechanical workshop and 3D printing service. Driving Idea: minimize frame mass, type of pieces, use only certified (large slab) copper.

**ZnSe 78 %
Cu 22%
PTFE 0.1%**
CUPID-0 Construction

The detectors were assembled in the Low Rn content Dark Side clean room @LNGS

14-Oct-2016
The fully mounted CUPID-0 detector
CUPID-0: Location and main features

24 Zn$^{82}\text{Se}$ bolometers, for a total mass $\approx 5.1 \text{ kg of } ^{82}\text{Se}$
2 ZnSe bolometer $\approx$400 g each, not enriched in $^{82}\text{Se}$
$Q_{\beta\beta}(^{82}\text{Se}) = 2998 \text{ keV}$

Light detectors high purity Ge wafers with antireflecting coating
Thermal sensors made with NTD thermistors
Detector assembled in 5 towers in Cuoricino/CUORE-0 cryostat
Total active mass of the detector $\approx$10.5 kg

CUPID-0 is installed in the Old Mibeta-Cuoricino-CUORE-0 dilution refrigerator placed in the Hall A of LNGS

Some upgrades were done on the cryogenic system:
- New double pendulum system to reduce vibrational noise
- Upgrade of the radon abatement system to reduce $^{214}\text{Bi}$
- Improvements in the injection line of the mixture
- New cryostat wiring to measure up to 120 detectors
- A completely new FE electronics

https://www.lngs.infn.it/en/cupid
The SR-0 enabled us to fix several bugs of electronic and SW. After the stop we implemented few major changes.

The SR-1 started 3 June 2017 we presently have (Physics+Calibrations) > 93 %
It is clear that the abrupt difference between the baseline resolution of the detector and the effective energy resolution @2615 keV is due to the non perfect quality of the crystals.

Energy resolutions are still (slightly) improving…
Light Detectors at first glance

LDs work extremely good.

- Presently we cannot give the actual performance since, for obvious reasons, no $^{55}\text{Fe}$ sources were mounted on CUPID-0.

- Nevertheless the performances can be inferred by roughly looking at the S/N ratio at the scintillation signal @2615 keV: it is very good for all the detectors.

- Moreover, the discrimination factor evaluated on internal $\alpha$-lines is completely satisfying.

Different Scintillation signal for $\alpha$ and $\beta/\gamma$

![Graph showing scintillation signal for alpha and beta/gamma](image)

Shape parameter of scintillation [a.u.]

Internal $\alpha$'s

$^{228}\text{Th}$ Calibration

Energy [keV_{ee}]

Total Background Spectrum, no cuts

$^{65}\text{Zn} - \text{EC}$

$^{40}\text{K}$

$2\nu \sim 8000 \text{ c/keV/kg/y (or \sim 7200 events)}$

exposure $= 0.9 \text{ kg x y}$

bin width $= 8 \text{ keV}$

$^{208}\text{TI}$
Cut efficiency of the order of ~93%. Will slightly increase after optimization of the coincidence jitter time (in progress).
A not negligible background is induced by internal contamination belonging to the \(^{232}\)Th chain, through the decay of \(^{208}\)Tl with Q-Value of 5 MeV. The decay is preceded \((T_{1/2} \approx 3 \text{ min})\) by the \(\alpha\)-decay of \(^{212}\)Bi, with Q-value 6.2 MeV.

Dead time \(\sim 6\%\) due to the presence of the \(^{218}\)Po line. We will increase the LT by optimizing the energy window.
Total cut efficiency of SR-0 is 87 % (evaluated at $^{65}\text{Zn}$ -1135 keV). We are working to reach a cut efficiency >90%.
Conclusions

✓ The $\alpha$-rejection technique works at best

✓ The SR-0 shows the extremely low background in the $2\nu$ region

✓ The first background in the 0vDBD $^{82}\text{Se}$ is promising

✓ The first reliable evaluation of the BI will be released as soon as our background model will be ready and the statistics has increased at least by a factor three (September)
The CUPID-0 collaboration

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BACKUPS
The “final” decision of the LUCIFER detector was due, finally to the market availability of enriched material. At that time (2010-2011) we didn’t succeed to get any kind of feedback from Russia.

The only “feasible” producer was, therefore, URENCO in Holland. URENCO did not have any kind of production line of Mo-isotopes (due to the not-easy to handle- gas phase of Mo isotopes), so that \textbf{the only possibility was }^{82}\text{Se} \text{ (that is enriched through the standard Hexafluoride technique)}

The contract for the delivery of 10+5 kg $^{82}\text{Se}$ was signed in mid 2011. The price for the production was fixed at 70kEuro/kg @> 95 % i.a.

The $^{82}\text{Se}$ production went on rather smooth. After the delivery of the first 5 kg, we recognized a trace contamination of the enriched metal beads both in U and Th. URENCO therefore developed in 2014 a \textbf{small vacuum distillation set-up} to decrease the contamination (also of Na and S used for the $^{82}\text{SeF}_{6}$ to $^{82}\text{Se}$ metal conversion)

<table>
<thead>
<tr>
<th></th>
<th>Se(Enr.)</th>
<th>Se(enr-Dist.)</th>
<th>Se(enr-Dist.)</th>
<th>Zn (nat)</th>
<th>Zn (nat)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>[mBq/kg]</td>
<td>[mBq/kg]</td>
<td>[g/g]</td>
<td>[mBq/kg]</td>
<td>[g/g]</td>
</tr>
<tr>
<td>$^{238}\text{U} / ^{226}\text{Ra}$</td>
<td>&lt;0.41</td>
<td>&lt; 0.11</td>
<td>&lt; 9.0 $10^{-12}$</td>
<td>&lt; 0.066</td>
<td>&lt; 5.4 $10^{-12}$</td>
</tr>
<tr>
<td>$^{232}\text{Th} / ^{228}\text{Th}$</td>
<td>1.4 ± 0.2</td>
<td>&lt; 0.11</td>
<td>&lt; 2.6 $10^{-11}$</td>
<td>&lt; 0.036</td>
<td>&lt; 8.9 $10^{-12}$</td>
</tr>
<tr>
<td>$^{40}\text{K}$</td>
<td>3 ± 1</td>
<td>&lt; 0.99</td>
<td>&lt; 3.2 $10^{-8}$</td>
<td>&lt; 0.38</td>
<td>&lt; 1.2 $10^{-8}$</td>
</tr>
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</table>
Background consideration: the “old” cryostat

This is not the Holy Shroud, but the drawing of the old Oxford Cryostat hosting CUPID-0. The construction materials were selected, but with radioactive prescriptions of 30 years ago……
The crystals were polished in the Low Rn Dark Side Clean Room @LNGS

Background spectrum of three Zn$^{82}$Se crystals before and after the surface polishing with Ultrapure SiO$_2$ powder.
Environmental “underground” Background: $^{238}\text{U}$ and $^{232}\text{Th}$ trace contaminations

Surface and Bulk contaminations

CUORICINO $\alpha$ Background
ZnSe crystals shows an “inverse” QF, i.e. $\alpha$-particles scintillate more than $\beta/\gamma$'s (C. Arnaboldi et al., Astrop. Phys. 34(2011))

The $\alpha$-induced background is recognized through two independent measurements: 1) the decay time of the scintillating signal 2) the different scintillation yield between $\alpha$ and $\gamma/\beta$ particles (the “usual” light Vs Heat scatter plot)

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**ZnSe crystals and $\alpha$ discrimination**

**2) Light Vs Heat scatter Plot**

- "Ionization coincidences" between Ge light detector and ZnSe
- Smeared $\alpha$-source
- $^{208}$TI calibration source

**1) Decay time of the scintillation light**

- $\beta/\gamma$ scintillation
- $\alpha$-scintillation
- Direct ionization

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JW Beeman et al., JINST 8 (2013) P05021

TeO$_2$... Not TeO$_2$... This is the problem !!!

CUPID

TeO$_2$

Pros

✓ Well defined and known compound
✓ Large commercial crystal production
✓ High reproducibility

✓ $Q_{\beta\beta}$ above 2516 keV
✓ $\alpha$ Id is straightforward
✓ Enriched material already pure
✓ Crystal growth yield can reach 85%

Cons

✓ $Q_{\beta\beta}$ below 2516 keV
✓ $\alpha$ and surface ID needs extremely performing technologies
✓ Crystals yield is presently low (30%)

✓ Not commercial crystals
✓ Larger enrichment price
✓ Not yet proved crystal growth reproducibility (demonstrator)