Bolometric light detectors for Neutrinoless Double Beta Decay search

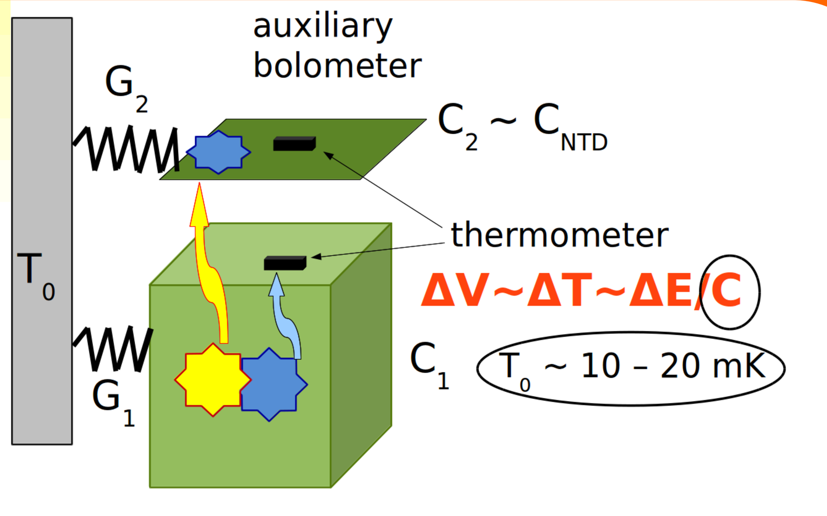
M. Tenconi[a,*] on behalf of the Orsay[a]-Kyiv[b]-Insubria[c,d] group

[a]Centre de Spectrométrie Nucleaire et de Spectrométrie de Masse, CNRS and Université Paris-Sud, F-91405 Orsay
[b]Institute for Nuclear Research, MSP 0368 Kyiv, Ukraine
[c]Università dell'Insubria, Dipartimento di Fisica e Matematica, I-22100 Como, Italy
[d]Istituto Nazionale di Fisica Nucleare, Sezione di Milano-Bicocca, I-20126 Milano, Italy

* tenconi@csnsm.in2p3.fr

Introduction

Neutrinoless Double Beta Decay (0νDBD) is a mechanism playing a key role in particle physics, presently being the only known feasible way to determine the Majorana nature of the neutrino and providing in addition an evaluation of its effective mass and hierarchy of mass eigenvalues. The bolometric technique has already proved to be a powerful method in this field, allowing to build large mass scale experiments and retaining at the same time high efficiencies and energy resolutions. By means of double read-out of phonon and scintillation signals produced by particle interactions, it is possible to discriminate gamma/beta events from those induced by alphas, which are a dangerous source of background in the energy region of interest for many candidate isotopes. This can be accomplished using scintillating bolometers, where the photons produced in the main scintillating crystal absorber are collected by a light detector: another auxiliary bolometer, in the form of a thin slab opaque to the emitted light.



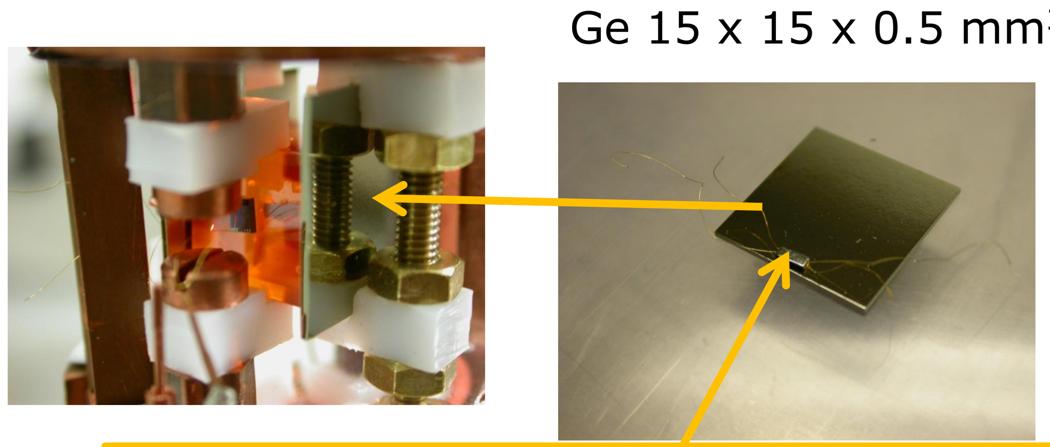
Main Goal - Optimize the performances of Ge light detectors: sensitivity, energy resolution, reproducibility.

Experimental Methods

Light detectors concerned in this work are made up of an ultrapure Ge absorber, held in a copper frame by PTFE pieces; the temperature sensor is a Ge Neutron Transmutation Doped thermistor (NTD), glued on the absorber's surface with spots of Araldite epoxy glue.
The detectors are cooled down to very low temperatures, in a range from 15 to 30 mK, by means of a dilution refrigerator.
Calibration is performed by means of a ^{55}Fe source, placed in front of the Ge absorber, emitting X-rays peaking at 5.9 and 6.4 keV.
In some tests, the Ge absorbers are placed in front of a scintillating crystal, sometimes irradiated with external sources, so as to probe the alpha/gamma discrimination capability of the whole scintillating bolometer setup and its energy resolution. The scintillating crystals considered in our tests are ZnSe (interesting for 0νDBD candidate isotope ^{82}Se) and $ZnMoO_4$ (^{100}Mo) whose emission spectra peak at around 645 nm and 625 nm respectively.

Different types of setups were tested, changing: absorber dimensions and thickness, PTFE arrangement, NTD type and size.

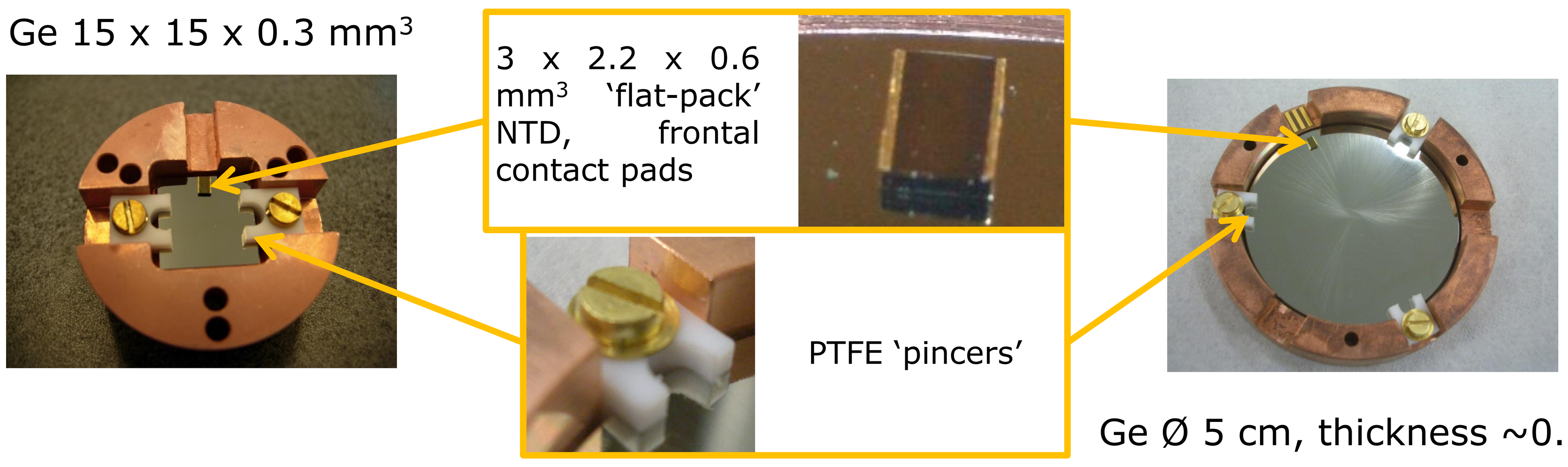
Ge 15 x 15 x 0.5 mm^3



3 x 1 x 0.6 mm^3 'T-shaped' NTD, lateral contact pads

Absorbers are held trasversally by slit PTFE pieces. The light detector is not separable from the rest of the setup.

Ge 15 x 15 x 0.3 mm^3



3 x 2.2 x 0.6 mm^3 'flat-pack' NTD, frontal contact pads

PTFE 'pincers'

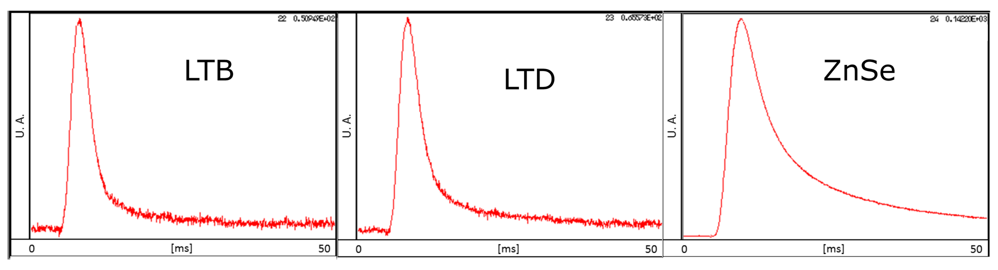
Ge Ø 5 cm, thickness ~0.25 mm

The light detector is actually an indipendent device, coupled to its own copper holder which can be mounted, dismounted and integrated into different setups, without compromising its original configuration.

Results

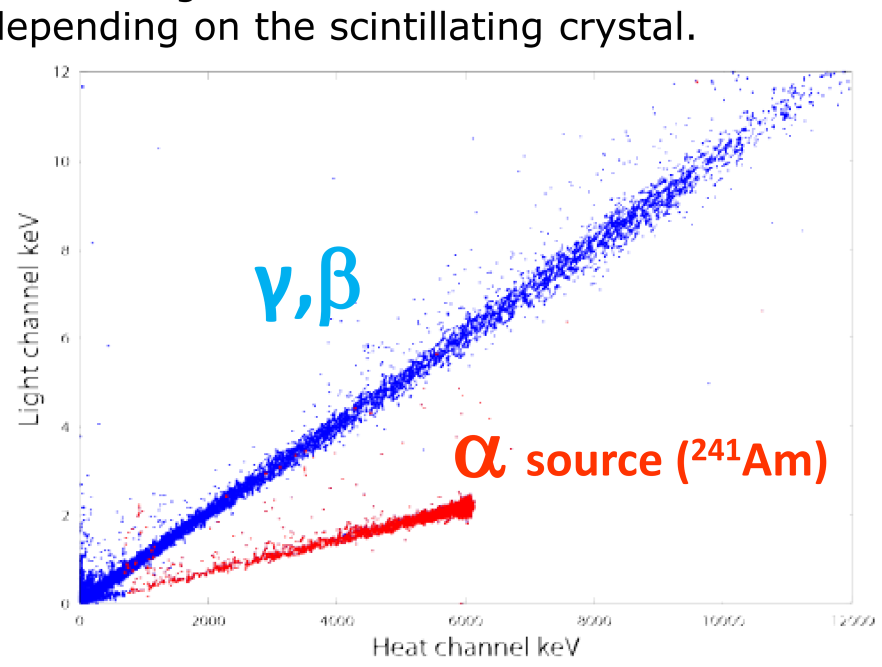
Coupling to scintillating crystals

Small light detectors (15 x 15 mm^2 Ge absorbers), coupled to small ZnSe (~5 g) and $ZnMoO_4$ (~5 g and ~24 g) crystals, were operated aboveground (University of Insubria - Como and CSNSM - Orsay).



Example of a coincidence on the 5 g ZnSe crystal and on the two auxiliary light detectors (Como run).

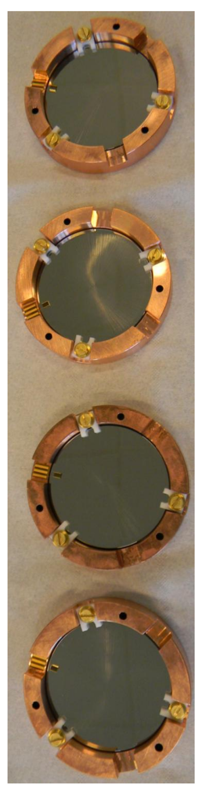
In all these tests, a good separation between gamma/beta and alpha events was achieved: the two bands can be clearly discriminated in the scatter plot of the coincidences on the main scintillating crystal and the auxiliary bolometer.
In the energy region of interest, relative light yields range from a few keVs to tens of keVs, depending on the scintillating crystal.

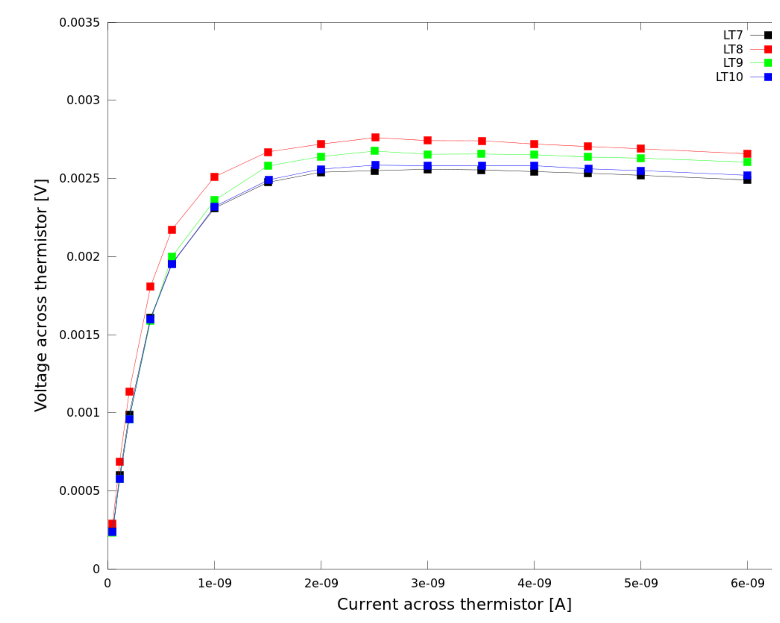


Light yield detected by Ge light detectors as a function of the phonon energy deposited in the 5 g $ZnMoO_4$ scintillating crystal (Orsay run).

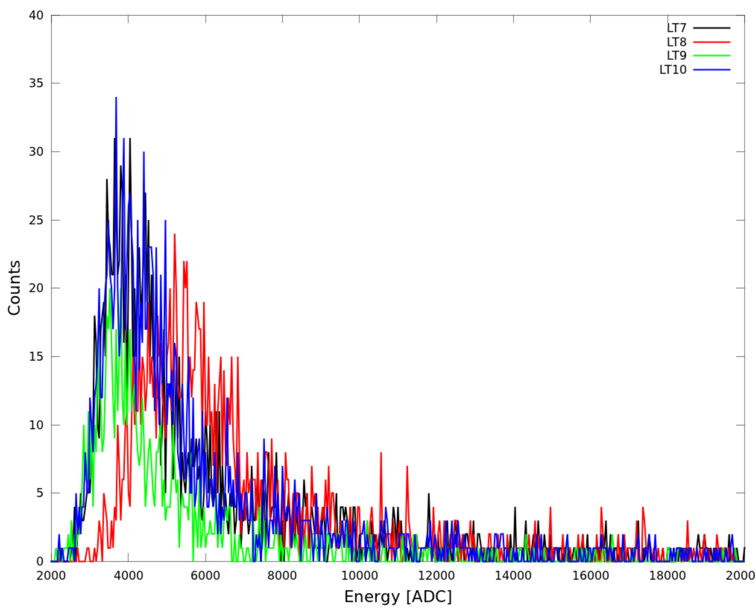
Reproducibility of large detectors

A tower of four identical large light detectors was assembled and tested at CSNSM: absorbers are 5 diameter Ge disks, ~250 μm thick. These detectors will be used in the LUCIFER program and on large $ZnMoO_4$ crystals.





Static behaviour: V-I curves show a good reproducibility of thermal coupling.



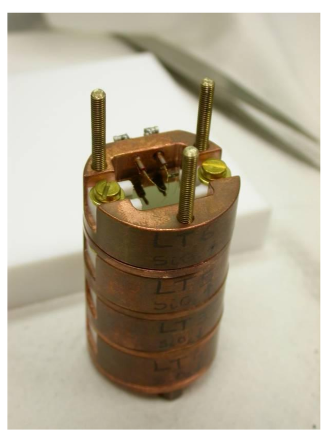
Spectrum of muon coincidences in ADC: the detector responses are comparable. Baseline noise values are largely spread due to channel-dependent microphonic noise.

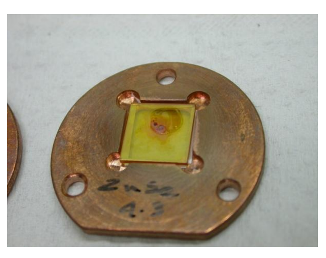
Sensitivity [μV/keV]	Baseline noise FWHM [eV]
0.79	148
1.02	133
0.80	184
0.78	1830

Preliminary

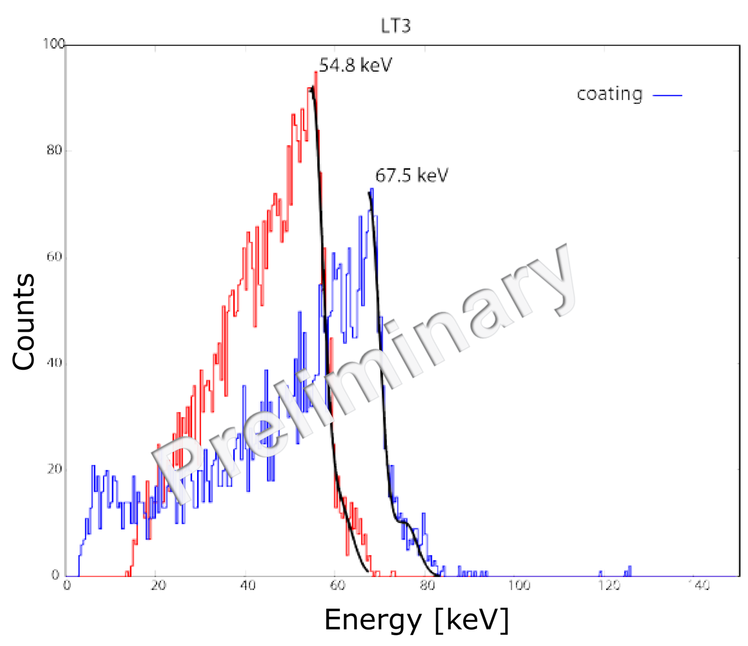
Sensitivities and baseline noise, as calculated from the optimal filtered spectra, at a base temperature of 19 mK.

Coating effect



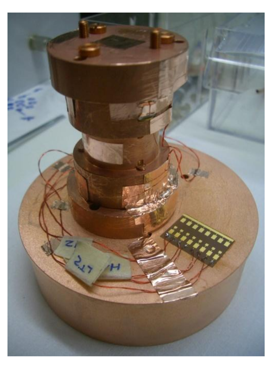


A dedicated setup was constructed in Como cryogenic lab in order to study the effect of the deposition of a thin layer of SiO_2 on the surface of Ge wafers.
Four nominally identical light detectors were assembled, the Ge absorber being coated with an approximately 70 nm thick SiO_2 layer only on one side.
Each detector was equipped with a heating device, directly glued on Ge, in order to periodically dissipate a fixed energy signal into the absorber.
Light sources were fabricated by depositing a liquid uranium solution on a thin ZnSe slab: the expected light spectrum pattern has an end point at the characteristic energy of the source, smearing at lower energies.
Two runs were performed, changing the Ge side exposed to the source.
The detector responses were compared by referring to heaters pulses and calibrated using minimum ionizing cosmic rays.



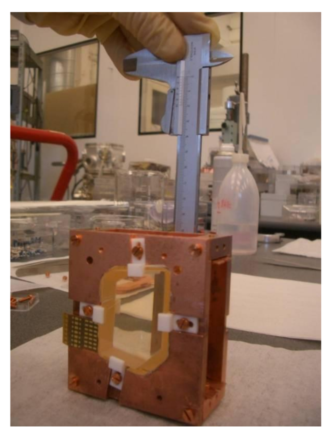
Spectra collected in the two runs. Results are reproducible and show a gain of the order of 20% in light collection efficiency due to SiO_2 coating.

Conclusions and future perspectives



The 24 g $ZnMoO_4$ detector, now in Modane.

- Measurements on small scintillating bolometer prototypes, operated aboveground, revealed good performances of Ge light detectors in terms of alpha/gamma discrimination capability. A 24 g $ZnMoO_4$ detector is currently being tested in Modane underground labs.
- The four large detectors operated in Orsay showed reproductible results in terms of static behaviour and dynamic responses in μV/keV; however, the microphonic noise is difficult to control and baseline noise levels are widely spread. One of the detectors will be coupled to a large $ZnMoO_4$ scintillating bolometer, now under construction at CSNSM.
- The results of runs performed in Como demonstrated the positive effect of SiO_2 coating on the light collection efficiency: the absorption enhancement is of the order of 20%.



The 313 g $ZnMoO_4$ crystal, now being assembled at CSNSM.