Status of the LUCIFER experiment: results and prospects

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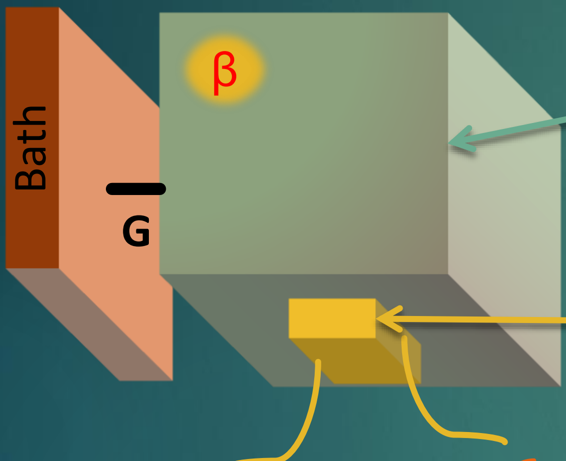
GDR NEUTRINO 2014

Orsay – 17th June 2014

The bolometric technique

Bolometer = absorber + sensor



$\Delta E \rightarrow \Delta T = \Delta E / C$ — When energy is released in the absorber, there is a temperature change in the absorber itself

$\Delta T \rightarrow \Delta R \rightarrow \Delta V$ — Heat propagates to the sensor, changing its resistance → signal

Very low working temperature (~10mK)

- ✓ To reduce the heat capacity C
- ✓ To be sensitive to the temperature variation due to a 0νββ event (0.1 mK/MeV → 1 mV/MeV)

- ✓ The energy released in the absorber creates phonons. Low energy needed to producing a phonon → high energy resolution
- ✓ The resolution is limited by the statistical fluctuations of the phonons exchanged with the bath through the thermal conductance G → $\Delta E_{rms} \sim (K_B T^2 C)^{1/2}$
- ✓ $\Delta T(t) = E/Ce^{-t/\tau}$ with $\tau = C/G$ thermal decay time → slow signals (~0.5 s)

Bolometers

Bolometers have proven to be very good detectors for 0νββ experiments aiming to investigate the inverted hierarchy region of neutrino masses ($m_{\beta\beta}$< 50meV)

- ✓ ability to sustain large source masses
  → large amount of the appropriate 0νββ candidate isotope
- ✓ excellent energy resolution (FWHM ~0.2-0.5 % above 2.5MeV)
  → to separate the 0νββ peak from the background, in particular the one coming from the 2νββ

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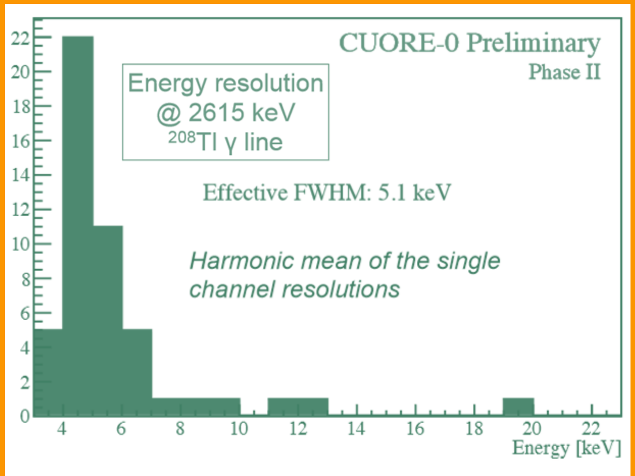

CUORE-0 preliminary*

	0νββ region cnts/(keV kg y)	2700-3900 keV	ε(%)
Cuoricino	0.153 ± 0.006	0.110 ± 0.001	83
CUORE-0	**0.063 ± 0.006**	**0.020 ± 0.001**	78

* O. Cremonesi, 06/06/2014, Neutrino 2014 @Boston, USA

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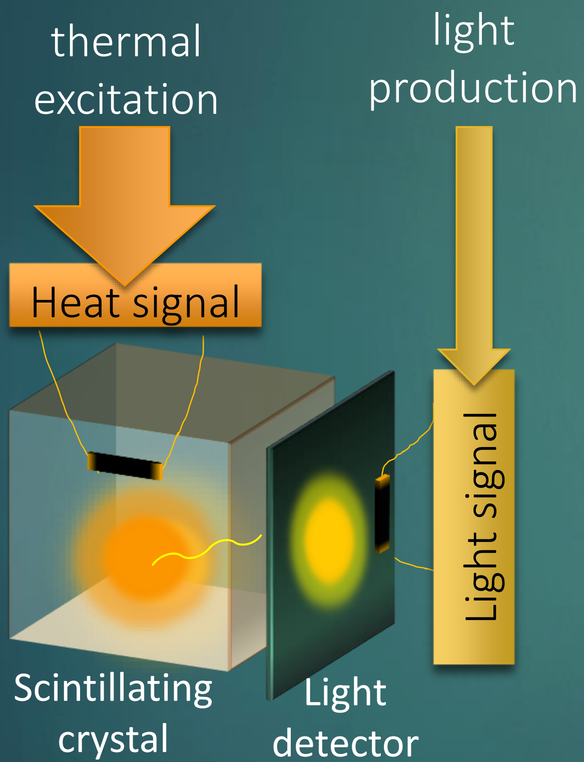
  → large amount of the appropriate $0\nu\beta\beta$ candidate isotope
- ✓ excellent energy resolution (FWHM ~0.2-0.5 % above 2.5MeV)
  → to separate the $0\nu\beta\beta$ peak from the background, in particular the one coming from the $2\nu\beta\beta$
- ✓ possibility to exploit the simultaneous collection of heat and light
  → low backgrounds in the region of interest

Scintillating bolometers

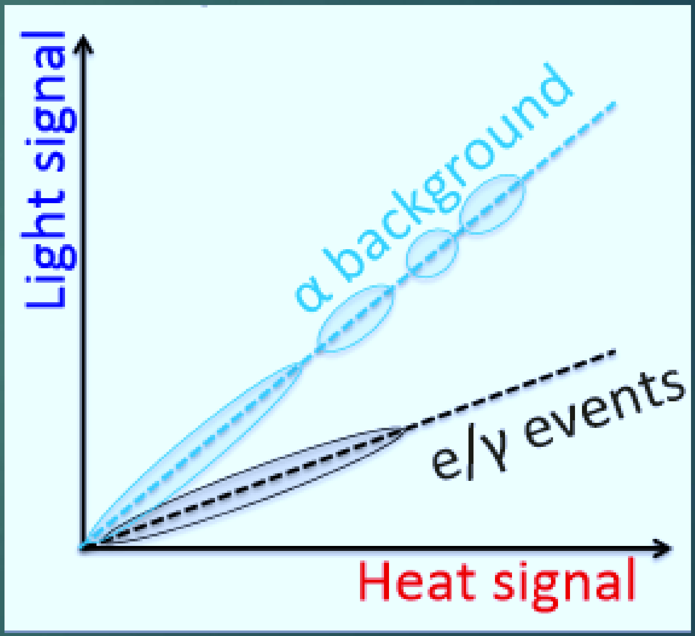
The release of energy in a scintillating crystal follows two channels



Different light output produced by α or β/γ events with same energy

$$QF = \frac{\alpha\ light}{\beta/\gamma\ light}$$

Simultaneous read-out of the energy deposed in the main crystal and the scintillation light allows the discrimination of signal events from the α bkg



The LUCIFER experiment

Low-background Underground Cryogenic Installation for Elusive Rates

A scintillating bolometers array to search for the 0νββ decay of candidates with a Q_{value} higher than 2.6 MeV

α and β/γ event discrimination thanks to the double read-out

outside the natural γ radioactivity range: αs are the dominant disturbing background sources

LUCIFER will search for the 0νββ of ^{82}Se/^{100}Mo using ZnSe/$ZnMoO_4$ scintillating compounds

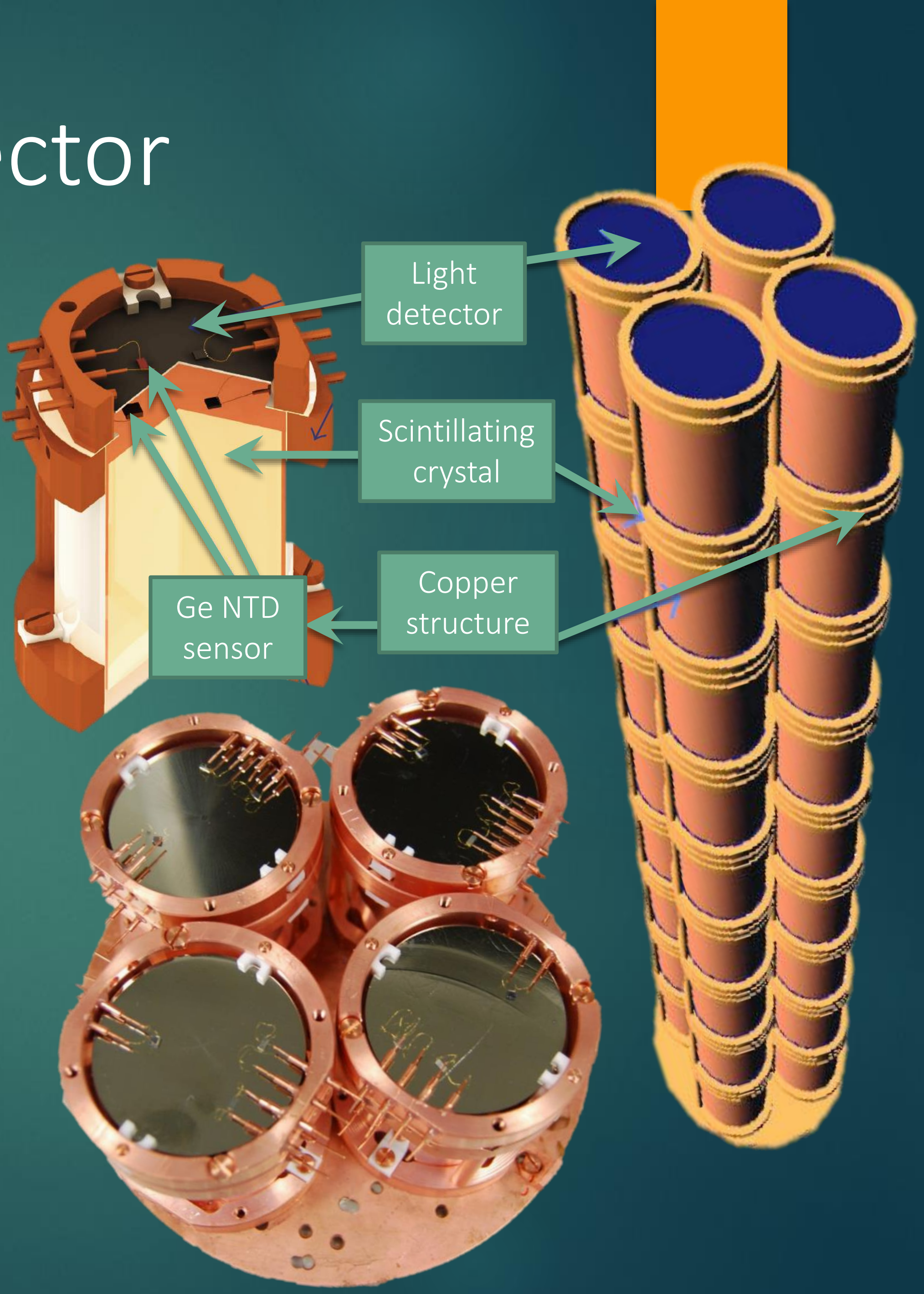
A complete elimination of αs for these candidates can lead to specific bkg levels of ~ 10^{-3} c/(keV·kg·y) or lower

The LUCIFER detector

- ✓ LUCIFER baseline: 36 ZnSe crystals enriched at 95% for ~15kg of total isotope mass
- ✓ light detectors sandwiched between two crystal floors
- ✓ in the CUORE-0 cryostat @ LNGS
- ✓ R&D on $ZnMoO_4$ crystal for a 10kg experiment in collab* with LUMINEU

**MoU between INFN, IN2P3 & ITEP*

	ZnSe	$ZnMoO_4$
0νββ isotope	^{82}Se	^{100}Mo
Q-value [kev]	2995	3034
Useful material	56%	44%
$LY_{\beta/\gamma}$ [keV/MeV]	6.5	1.5
QF_α	4.2	0.2



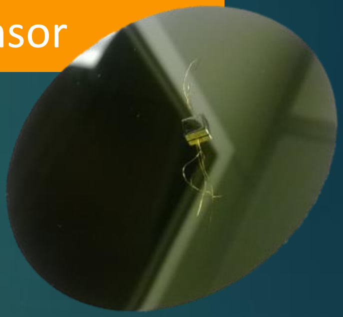
Light Detectors

LUCIFER light detectors = Ge slabs, operating as bolometers

- ✓ Opaque semiconductors → sensitive over a wide range of γ wavelengths
- ✓ Radiopure crystals

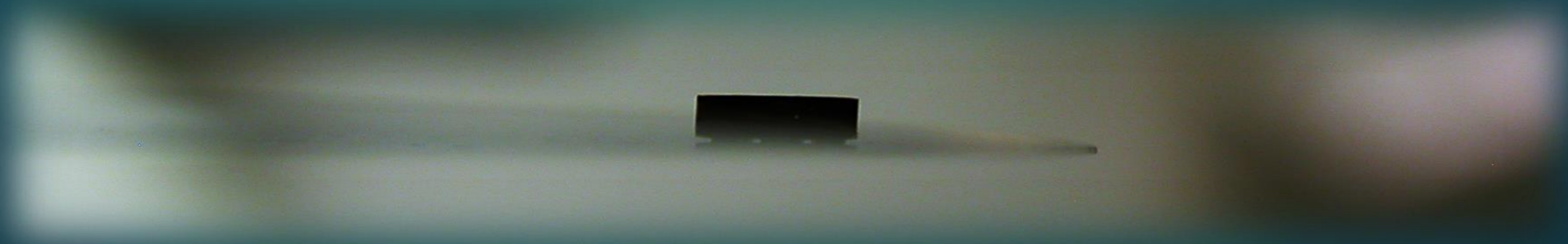
- ✓ $\varnothing = 44$ mm
- ✓ thickness = 180 μm
- ✓ grown using Czochralski technique

- ✓ NTD Ge thermistor as temperature sensor

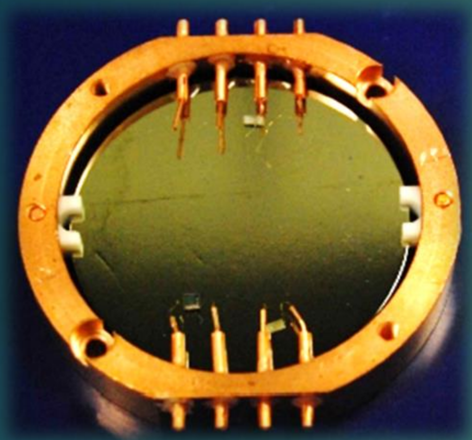


Light collection increased with a SiO_2 dark layer deposited on the surface of the Ge crystal *(JW Beeman, et al. NIM-A, vol. 709, pp 22-28, 2013)*

Several tests were carried on to investigate the performances of Ge light detectors in terms of signal amplitude, energy resolution and signal time development to identify the best working conditions

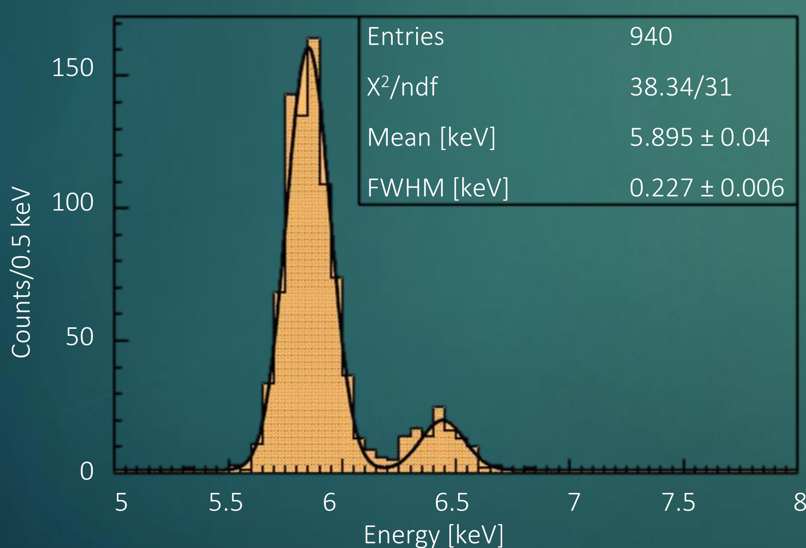


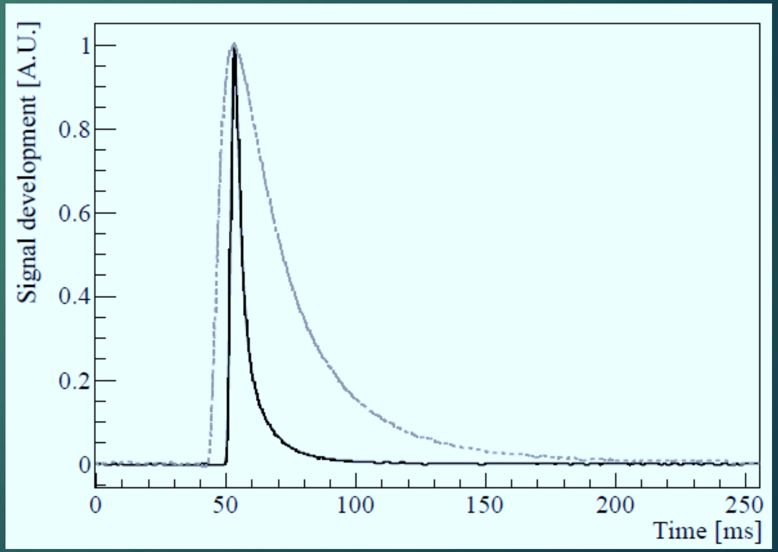
Light detectors



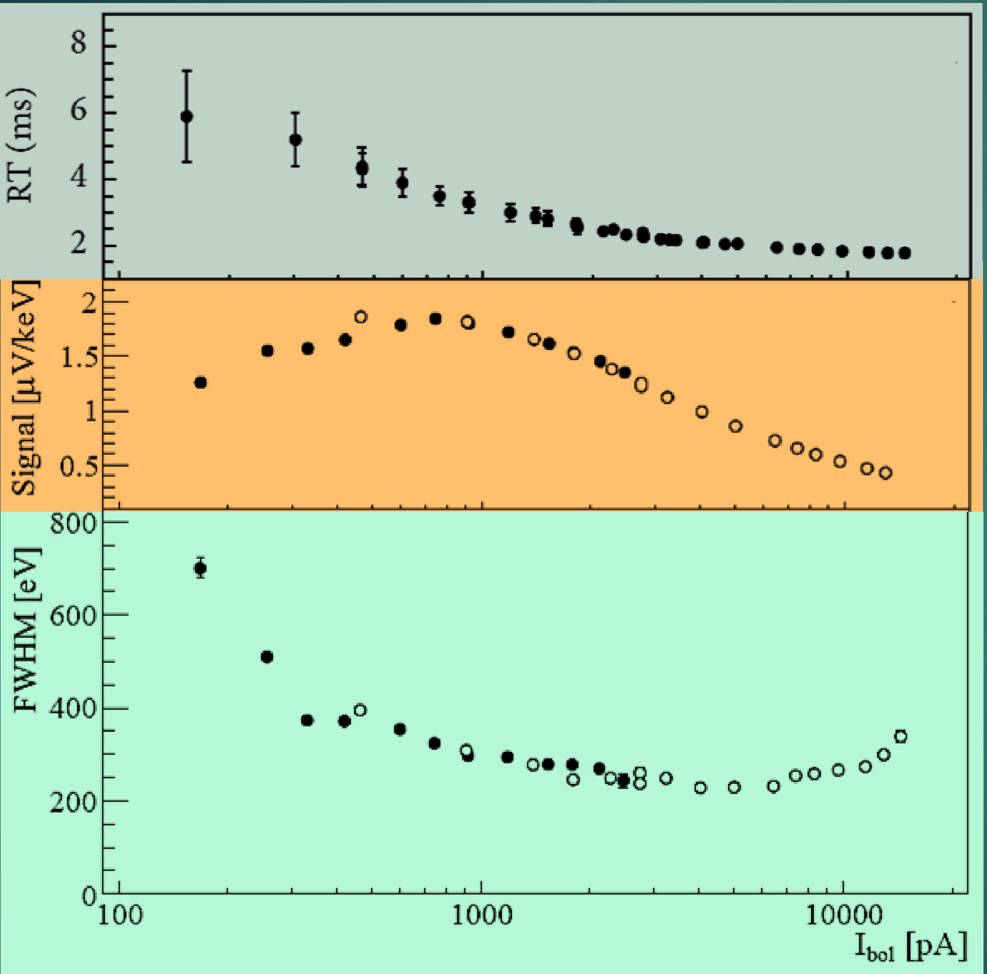
To allow proper calibration of the LD a ^{55}Fe source, producing two X-rays at 5.9 and 6.5 keV, is used

→ comparable with tipical light signals produced in scintillating bolometers (order of ~10 keV)





Light detectors



●=11GΩ Load resistance; ○ = 2G Ω Load resistance

- ✓ LD performances dependence on the applied bias current
  Best values: 2–7nA. At higher currents signal to noise ratio limited by **preamplifier noise**

- ✓ LD performances uninfluenced by the value of the load resistance
  → LDs not affected by Johnson noise

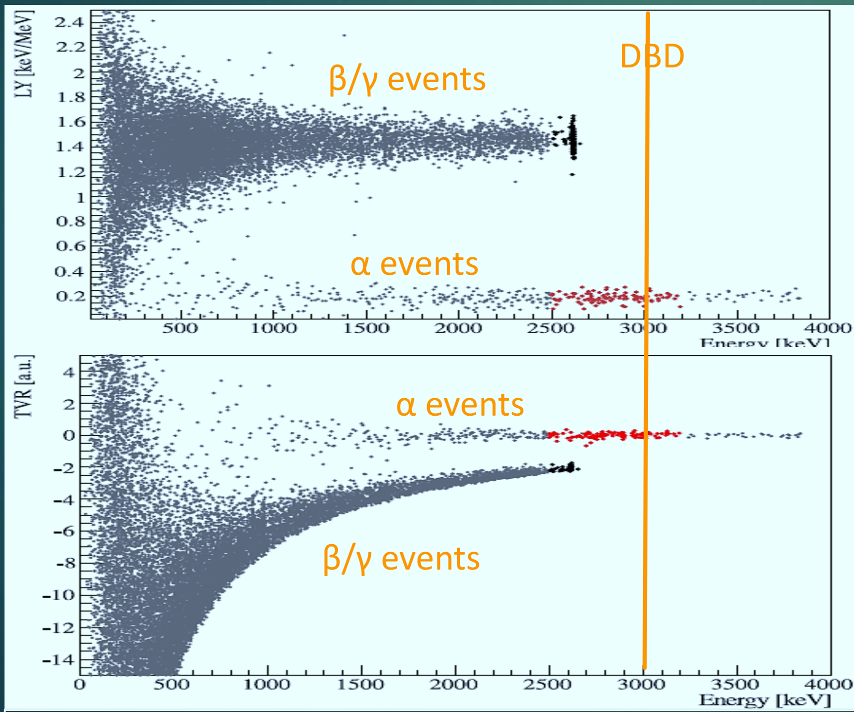
- ✓ LD performances influenced by the working temperature
  at ∼20mK FWHM is significantly better with respect to that observed at ∼ 10mK, the standard working temperature of bolometers for rare events searches

Crystal absorber - $ZnMoO_4$

Bolometric test with a 330 g $ZnMoO_4$ crystal

JW Beeman et al, Eur. Phys. J. C 72:2142 (2012)

- ✓ Excellent particle discrimination using light vs heat or the shape of the heat pulses



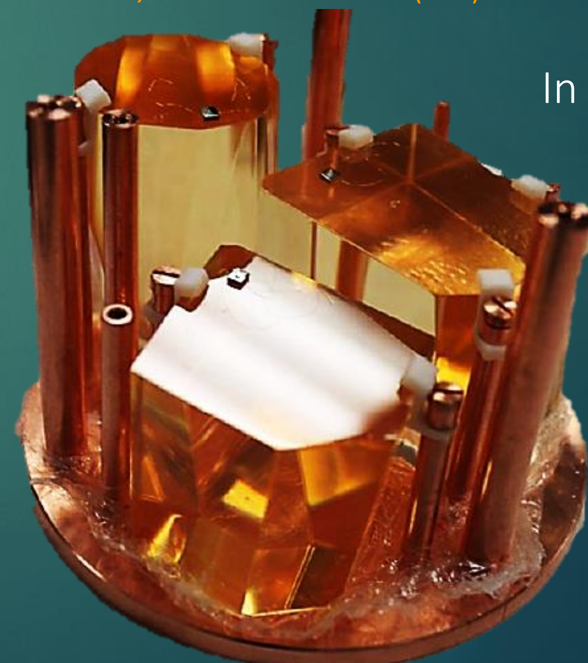
Calibration: ^{232}Th γ-source and smeared ^{238}U α-source

First bolometric measurement of 2νββ of ^{100}Mo with a $ZnMoO_4$ crystal array

L Cardani et al 2014 J. Phys. G: Nucl. Part. Phys. ***41*** *075204*

- ✓ 3 natural $ZnMoO_4$ crystals
- ✓ Total exposure 1.3 kg*d of ^{100}Mo

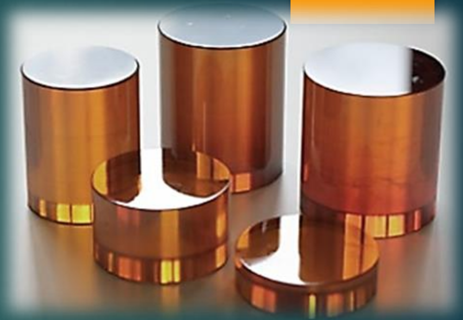
$T^{2\nu}_{1/2}$= [7.15±0.37$_{(stat)}$±0.66$_{(syst)}$]×10^{18} y



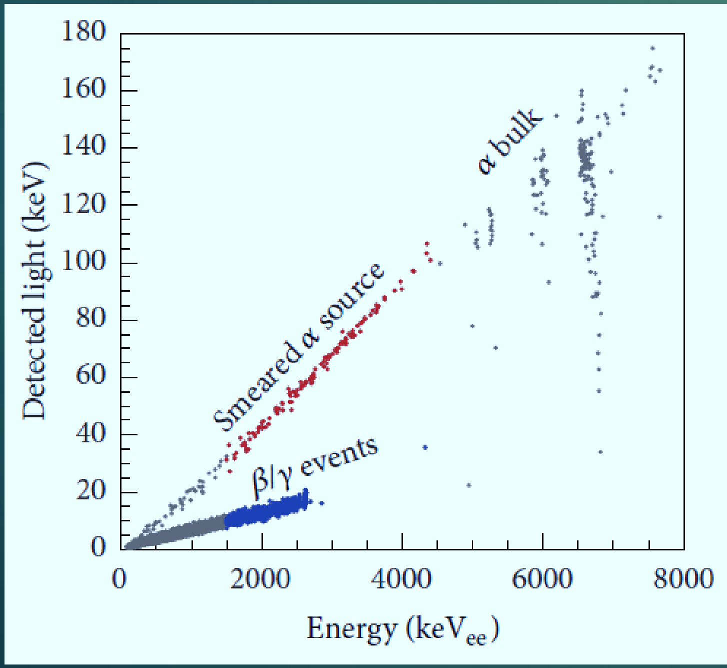
In agreement with the NEMO3 result

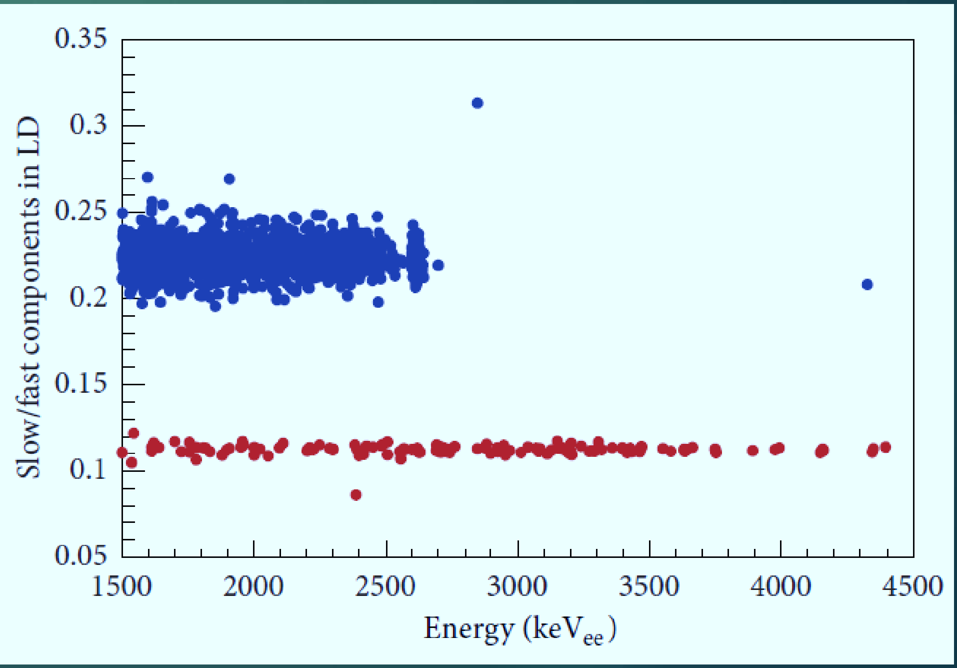
Crystal absorber - ZnSe

Characterisation of the largest ZnSe bolometer ever realized (431 g crystal) *(JW Beeman et al, 2013 JINST8 P05021)*



- ✓ FWHM energy resolution of 12.2±0.8 keV at 1461 keV and 13.4±1.3 keV at 2615 keV
- ✓ Excellent particle discrimination using Light vs. Heat or the shape of the light pulses





Crystal absorber - ZnSe

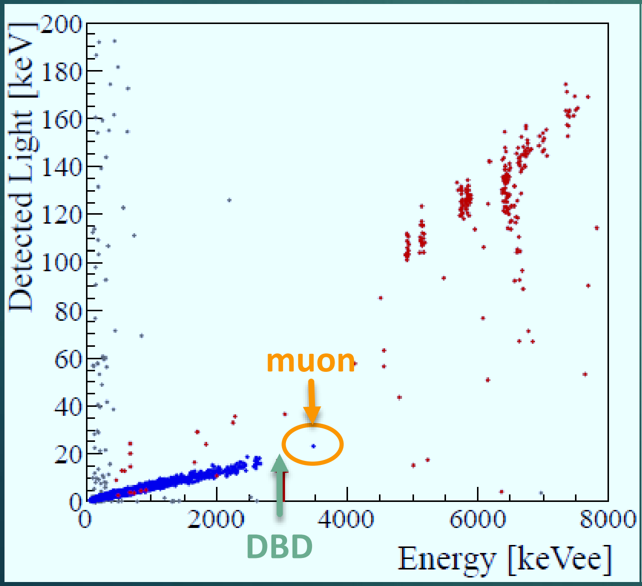
Low background measurement (t=524h)

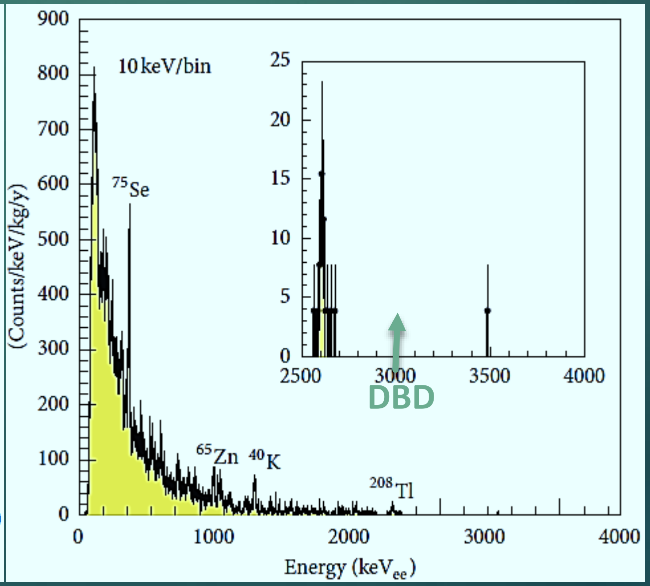
From α spectrum:

- ✓ internal contamination: 3×10^{-4} c/keV/kg/y ^{238}U and 3×10^{-3} c/keV/kg/y ^{232}Th @ROI

From β/γ spectrum:

- ✓ natural contamination of ^{40}K and ^{208}Tl
- ✓ contaminations in ^{75}Se and ^{65}Zn for the cosmogenic activation of of ^{74}Se and ^{64}Zn, not affecting the bkg in the DBD region for their short half-lives and low Q-values
- ✓ Single event above 2615 keV, likely produced by a muon interaction





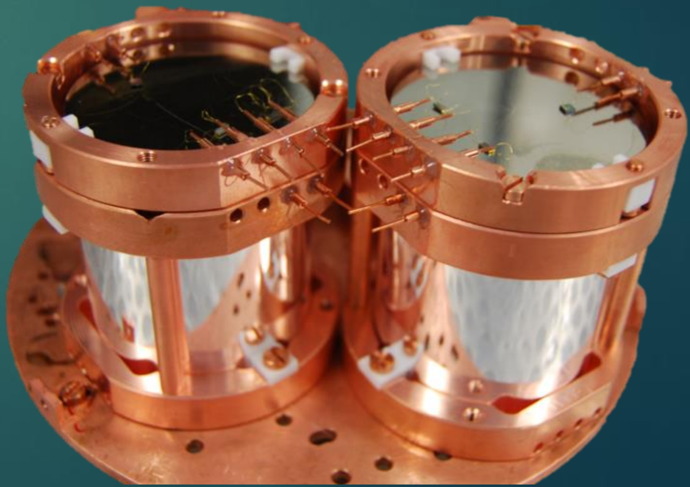
1 event in ROI in 5yrs with a 20kg detector

zero-background is achievable

Conclusions

- ✓ Bolometers have proved to be excellent detectors for 0νββ search
- ✓ Discrimination of α and β/γ events makes a background free detector possible
- ✓ LUCIFER is a next generation 0νββ experiment demonstrator using the scintillating bolometer technique
- ✓ LUCIFER goals are: bkg ≤ 10^{-3} c/keV/kg/y and FWHM ≤ 10 keV @ ROI
- ✓ LUCIFER baseline is a detector with 15kg enriched ZnSe crystal
- ✓ Further option: a 10kg enriched $ZnMoO_4$ search in collab. with LUMINEU & ITEP
- ✓ Several detector components have been defined and characterized
- ✓ LUCIFER will start in 2015

Crystal	Live time [y]	$T^{0\nu}_{1/2}$ [10^{26}y]	$\langle m_{\beta\beta} \rangle$ [meV]
ZnSe	5	0.6	65-194
	10	1.2	46-138
$ZnMoO_4$	5	0.3	60-170
	10	0.6	42-120



LUCIFER coll., Adv. High Energy Phys., (2013) 237973