

# **Scintillating bolometers for Neutrinoless Double Beta Decay**

Margherita Tenconi

CSNSM and Université Paris-Sud



# Neutrinoless Double Beta decay



violation of lepton number conservation: possible only if  $\nu \equiv \bar{\nu}$  (Majorana particle)

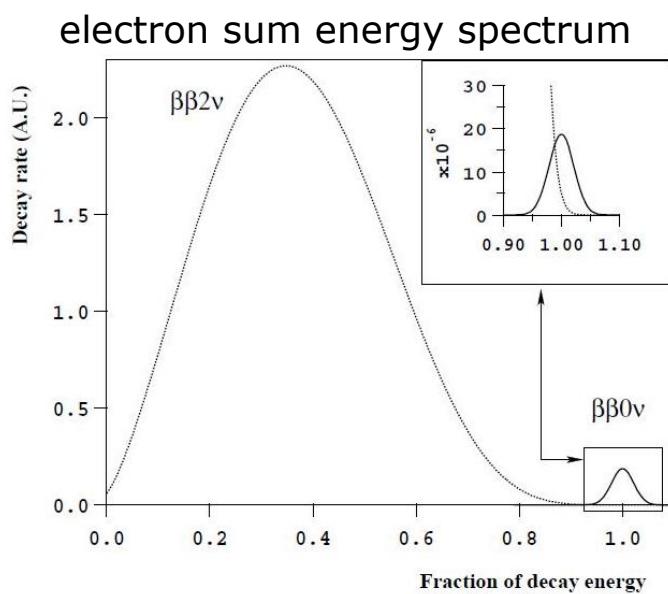
$$[T_{1/2}^{0\nu}]^{-1} = G(Q, Z) |M_{\text{nucl}}|^2 \langle m_\nu \rangle^2$$

decay rate

phase space for the final states

nuclear matrix element

- majorana effective mass
- mass eigenstates hierarchy



$$T_{1/2}^{0\nu} = 4.17 \times 10^{26} \left( \frac{f}{A} \right) \sqrt{\frac{M \cdot t}{B \cdot \Delta E}} \epsilon_{\Delta E} \text{ [years]}$$

isotopic abundance

active mass

time

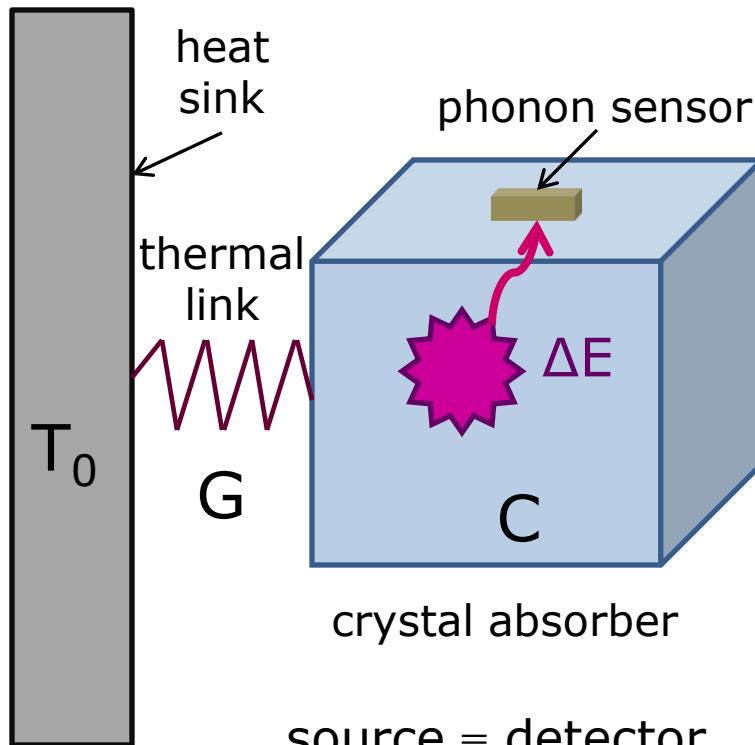
efficiency

atomic mass

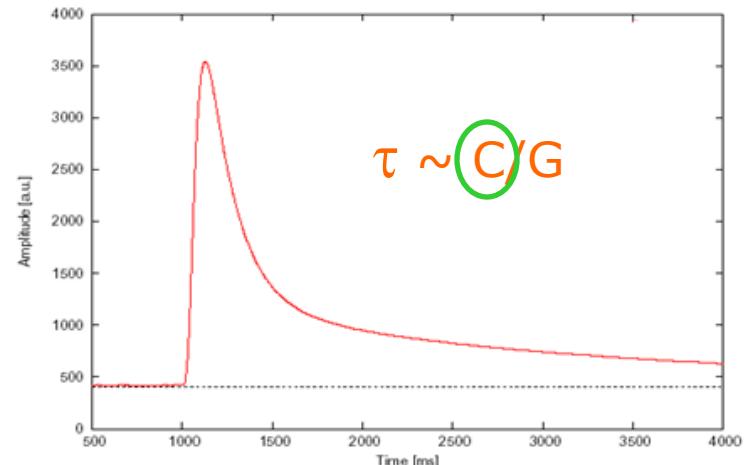
background

energy resolution

# Bolometric technique



$$\Delta T(t) = \Delta E / C \exp(-t/\tau)$$

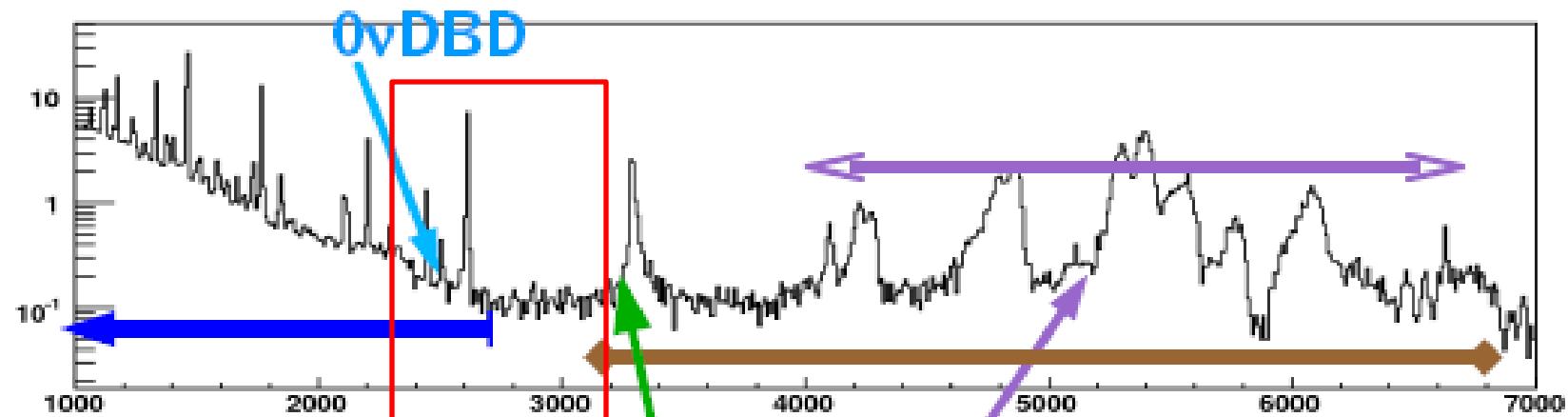


- ✓ High masses
- ✓ Good energy resolution
- ✓ High efficiency
- ✓ Different absorber materials

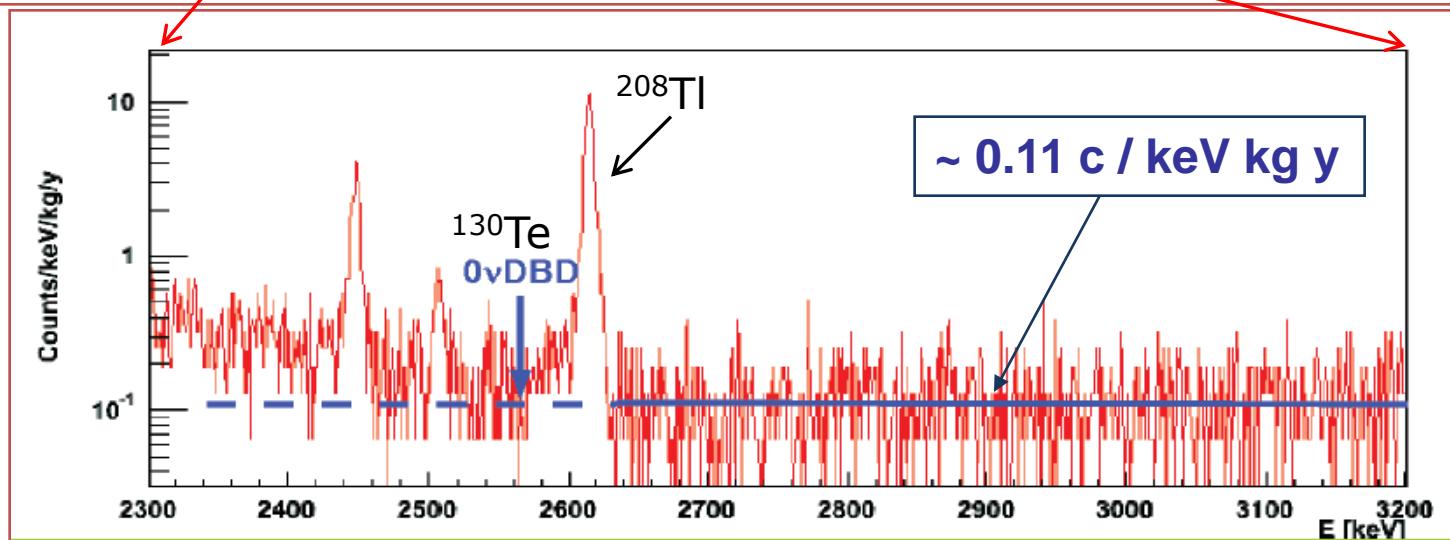
- ✗ No event reconstruction
- ✗ Cryogenic temperatures

Large expertise gathered in Cuoricino (2003-2008), CUORE

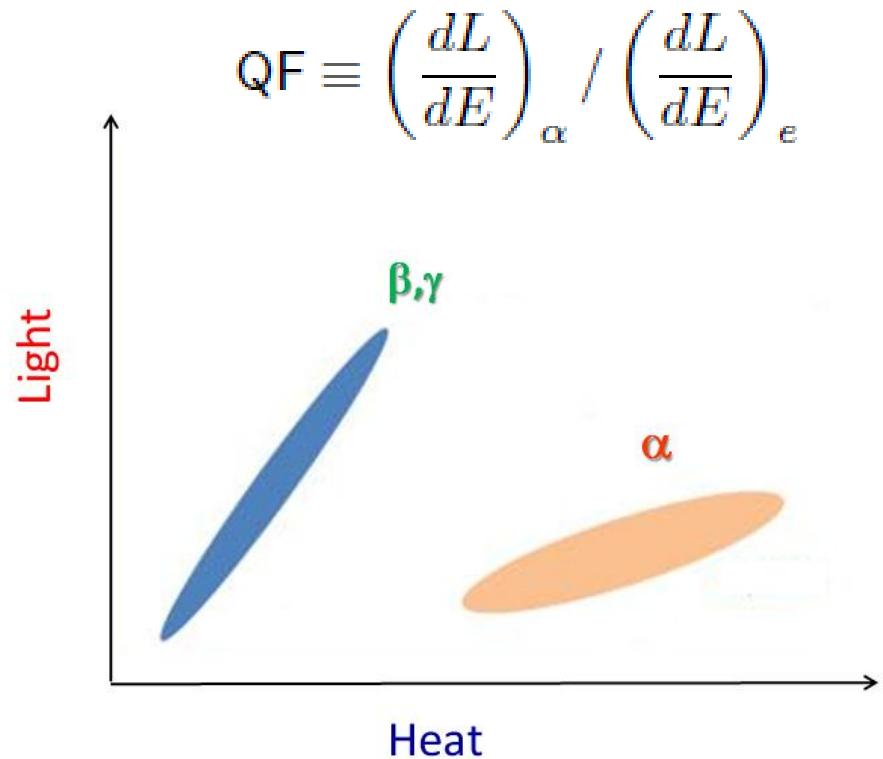
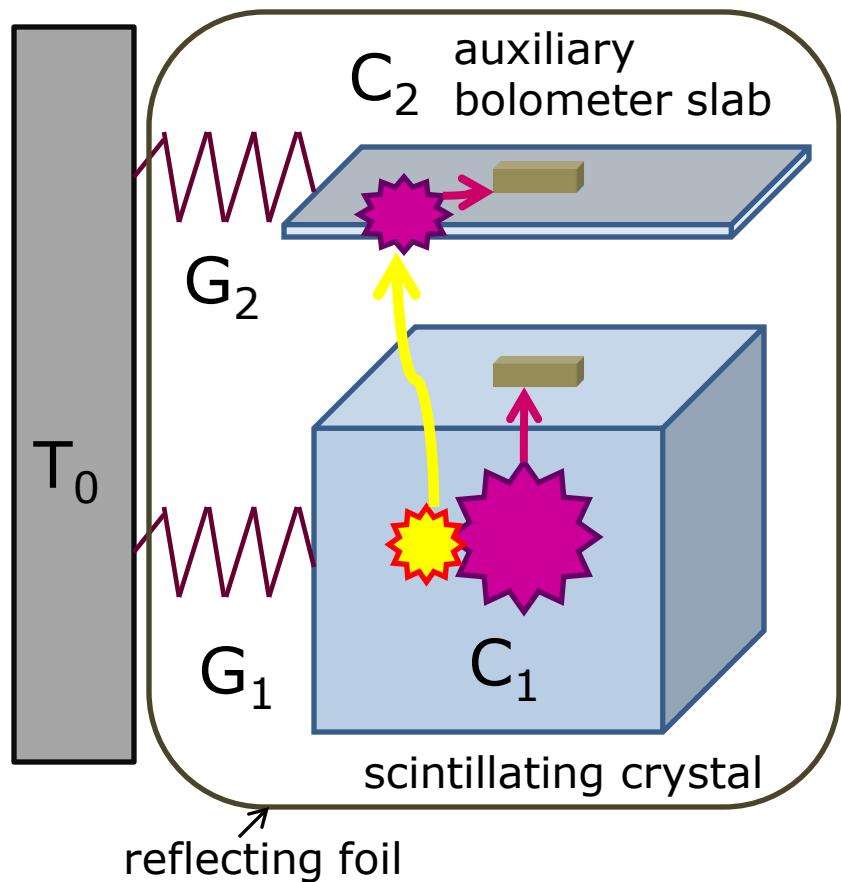
# Cuoricino background and alpha radioactivity



Alpha region, dominated by  $\alpha$  peaks  
(internal or surface contaminations)



# Scintillating bolometry



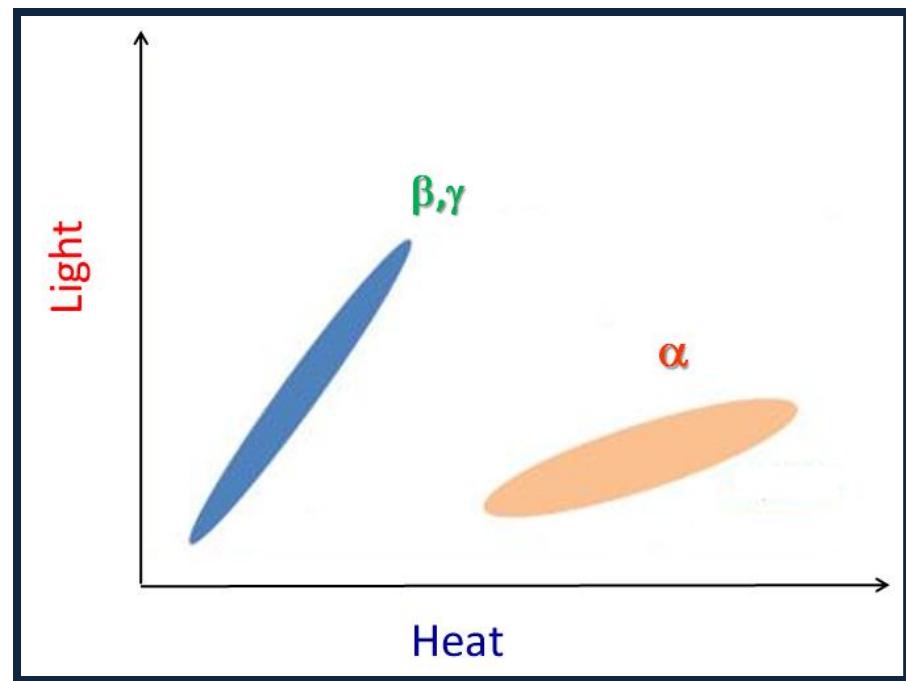
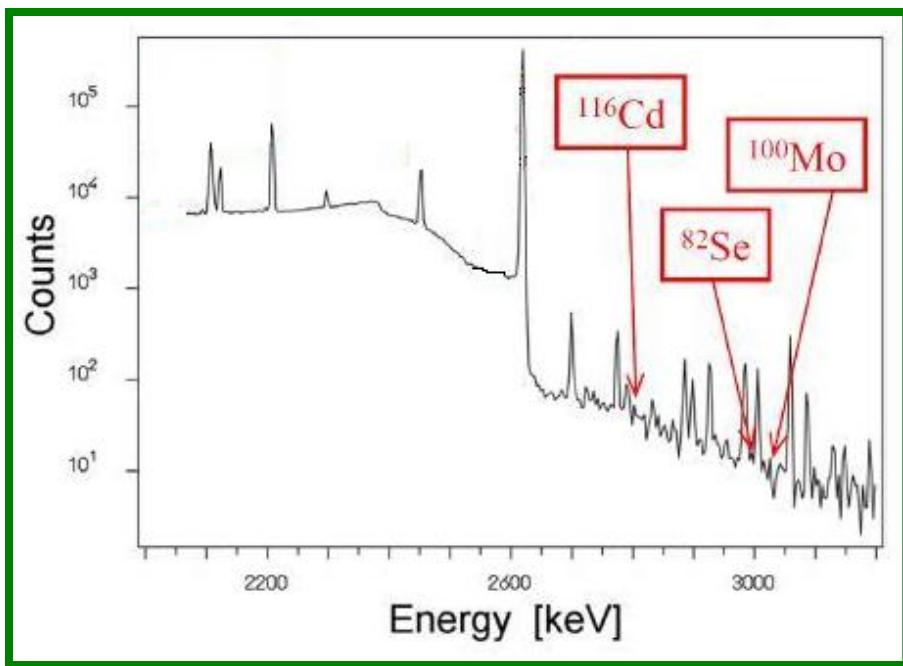
**Double read-out: heat + light → alpha rejection**

# Next-generation experiments goal

High Q-value isotope



Double read-out: plot of coincidence events



**Background rate  $\leq 1$  count/(keV · ton · year)**

# 0νDBD candidate isotopes and absorber materials

Isotope	Q-value [keV]	I.A. %	Tested crystal absorbers ( <u>good scintillators</u> )
<sup>76</sup> Ge	2039	7.8	Ge
<sup>130</sup> Xe	2479	8.9	-
<sup>130</sup> Te	2527	33.8	TeO <sub>2</sub>
<b><sup>116</sup>Cd</b>	2802	7.5	<u>CdWO<sub>4</sub></u> , <u>CdMoO<sub>4</sub></u>
<b><sup>82</sup>Se</b>	2995	9.2	<u>ZnSe</u>
<b><sup>100</sup>Mo</b>	3034	9.6	<u>ZnMoO<sub>4</sub></u> , <u>PbMoO<sub>4</sub></u> , <u>CaMoO<sub>4</sub></u> , <u>SrMoO<sub>4</sub></u> , <u>CdMoO<sub>4</sub></u> , <u>Li<sub>2</sub>MoO<sub>4</sub></u> , <u>MgMoO<sub>4</sub></u>
<b><sup>96</sup>Zr</b>	3350	2.8	ZrO <sub>2</sub>
<b><sup>150</sup>Nd</b>	3367	5.6	-
<b><sup>48</sup>Ca</b>	4270	0.187	<u>CaF<sub>2</sub></u> , <u>CaMoO<sub>4</sub></u>

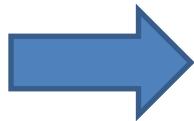
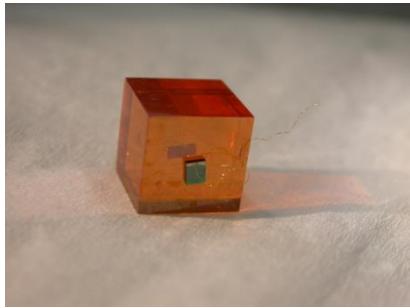
ZnSe => LUCIFER - funded as ERC Advanced Grant project (2010-2015)

ZnMoO<sub>4</sub> => LUMINEU - funded as ANR blanc project (2013-2016)

# ZnSe bolometers

Crystals grown by ISC Kharkhov, Ukraine

$\sim 5 \text{ g}$

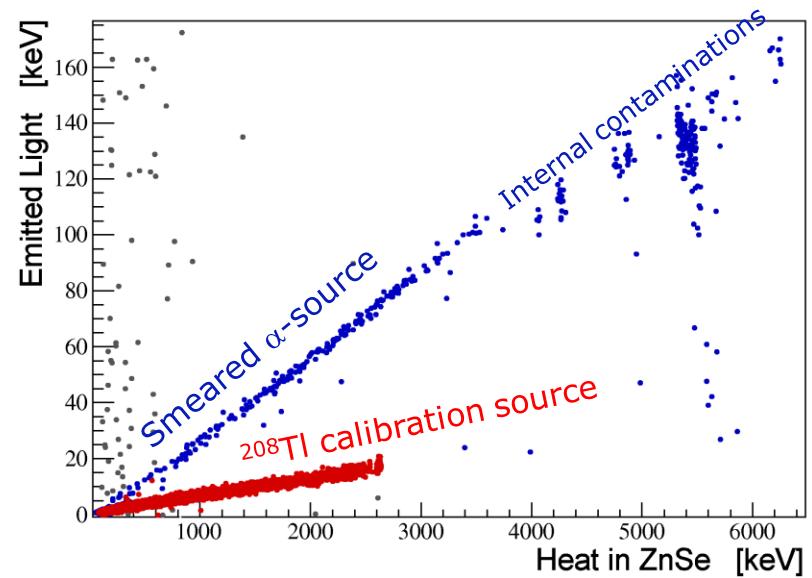
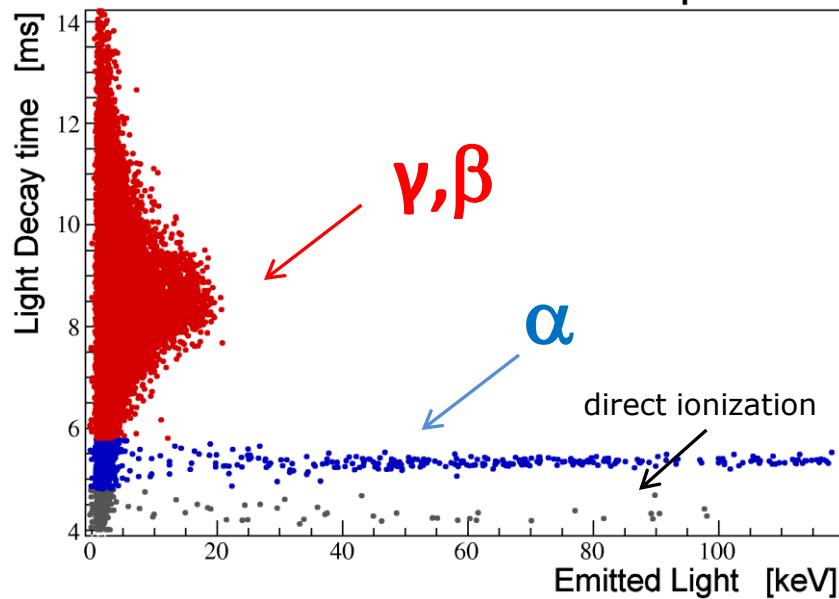


$LY \sim 7.4 \text{ keV/MeV}$

$QF > 1$

483 g

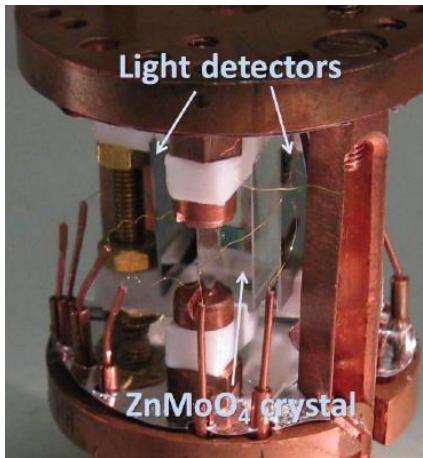
LUCIFER: preliminary results at LNGS



LUCIFER pilote experiment:  $\sim 10 \text{ kg}$  enriched material

# ZnMoO<sub>4</sub> bolometers (1)

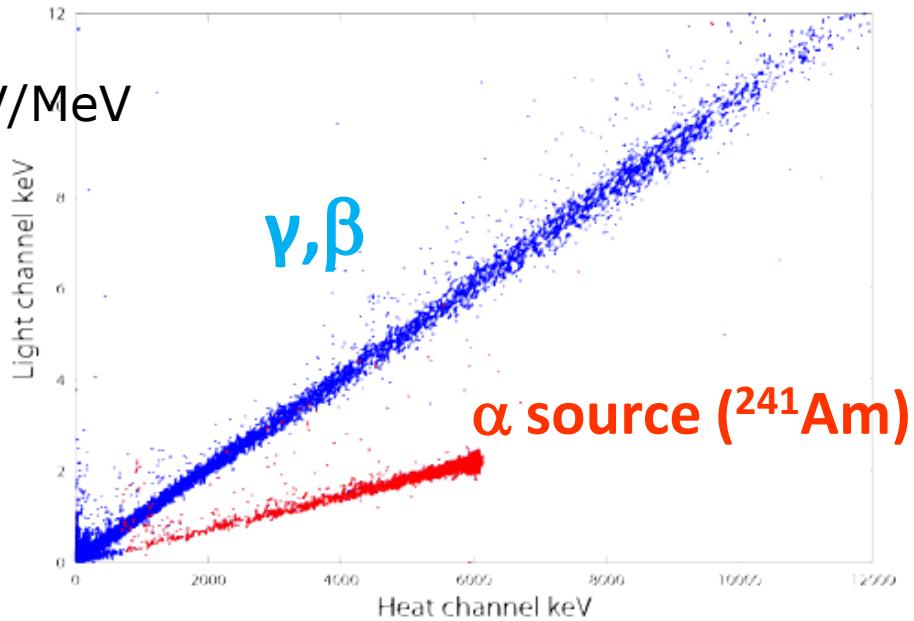
Crystals grown by NIIC Novosibirsk, Russia



LY  $\sim 1.5$  keV/MeV

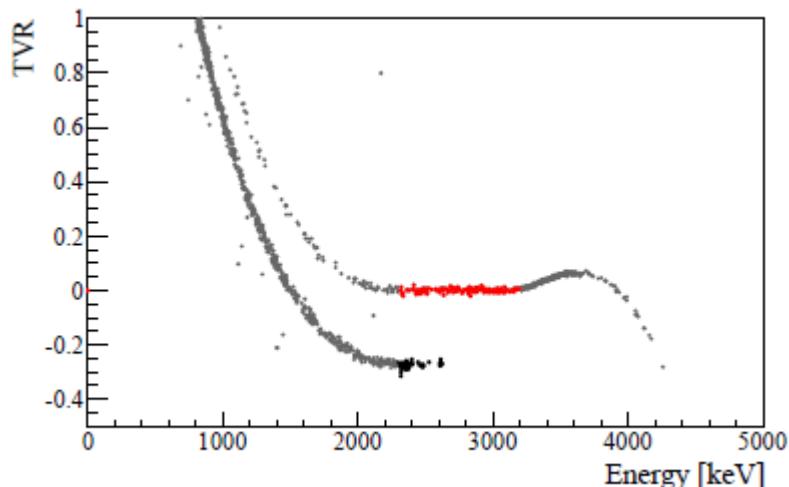
QF  $\sim 0.2$

5 g crystal



Orsay-Kiev-Insubria group  
Phys. Lett. B 710 (2012) 318

Energy resolutions on heat channels  $\sim$  few keV FWHM



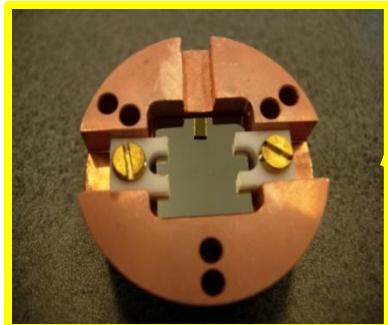
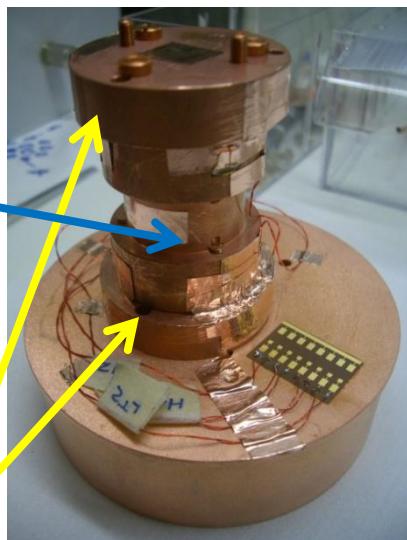
27 g crystal

pulse shape discrimination  
on heat channel

LNGS-Roma group  
Astropart. Phys. 35 (2012) 813

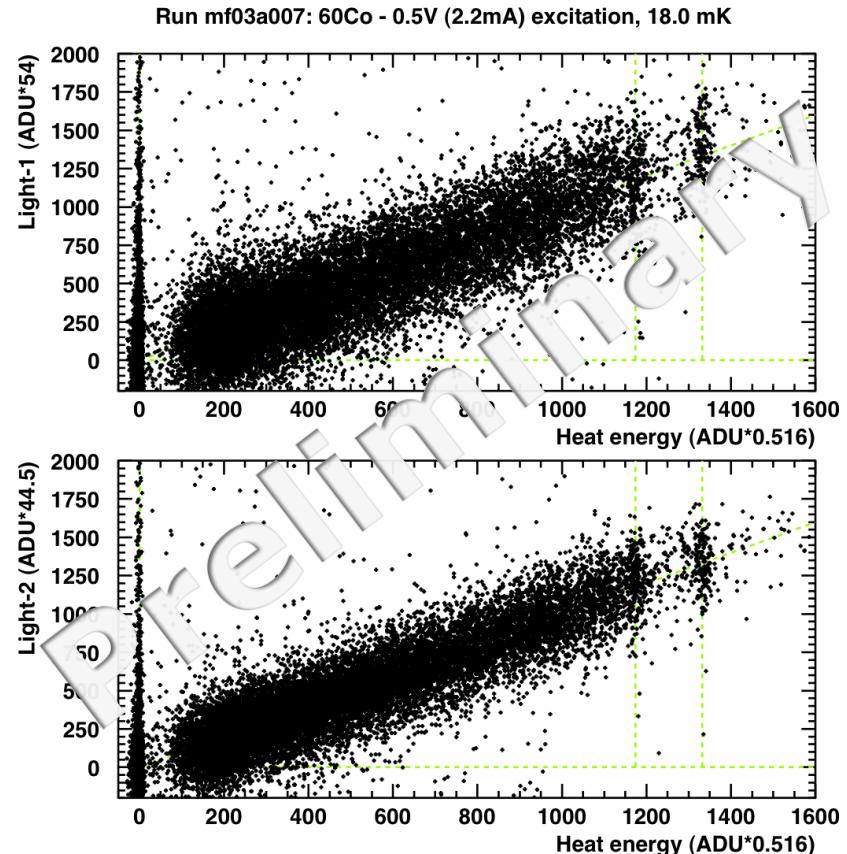
## ZnMoO<sub>4</sub> bolometers (2)

24 g detector



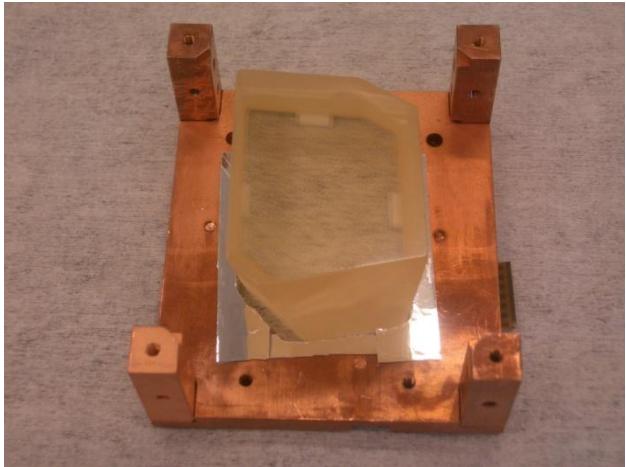
15 x 15 mm<sup>2</sup> Ge

Tested aboveground at CSNSM and afterwards successfully operated in Modane.



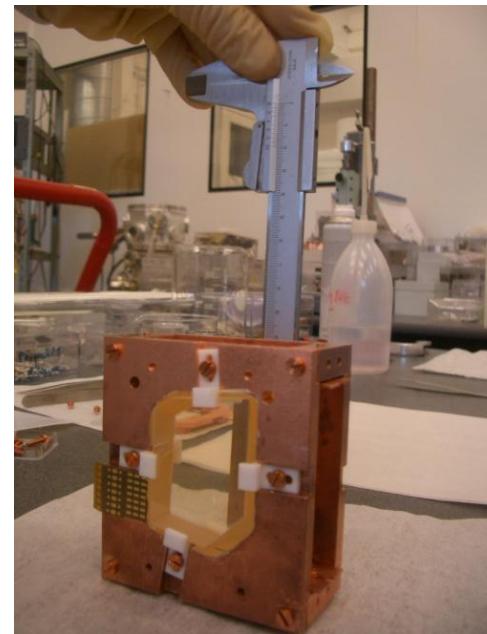
Merci à EDELWEISS

# ZnMoO<sub>4</sub> bolometers (3)



313 g crystal

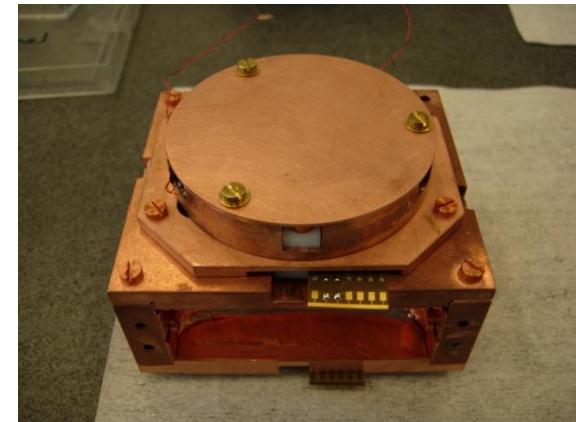
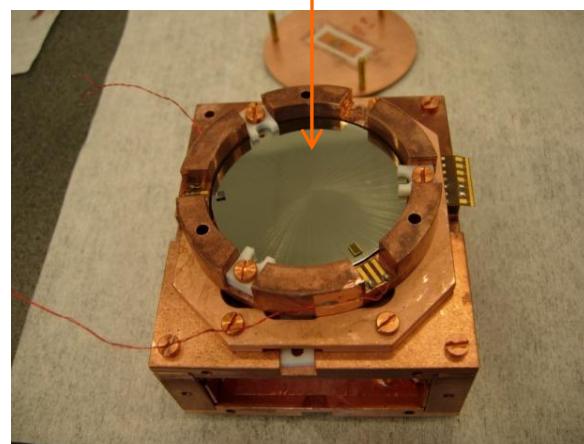
Cooling down starting  
at CSNSM, Orsay...



2 NTD Ge thermistors +  
heating device



2" Ge light detector

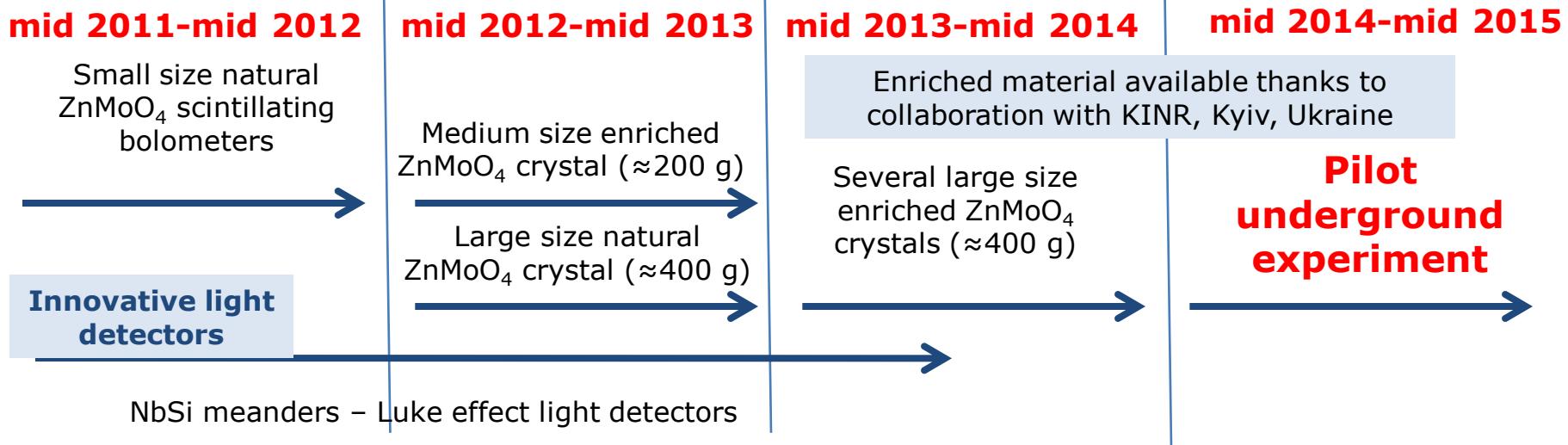


# ZnMoO<sub>4</sub> bolometers (4)

Number of ~ 400 g crystals	Total isotope mass [kg]	Half-life sensitivity [ $10^{25}$ y]	$m_{\beta\beta}$ sensitivity [meV]
4	0.676	0.53	167 - 476
40	6.76	4.95	55 - 156
2000 (nat.)	33.1	15.3	31 - 89
2000	338	92.5	13 - 36

Calculated sensitivities for 5-year-livetime, enrichment level 97%, efficiency 90%. The expected background rate is  $4 \times 10^{-4}$  counts/(keV kg y).

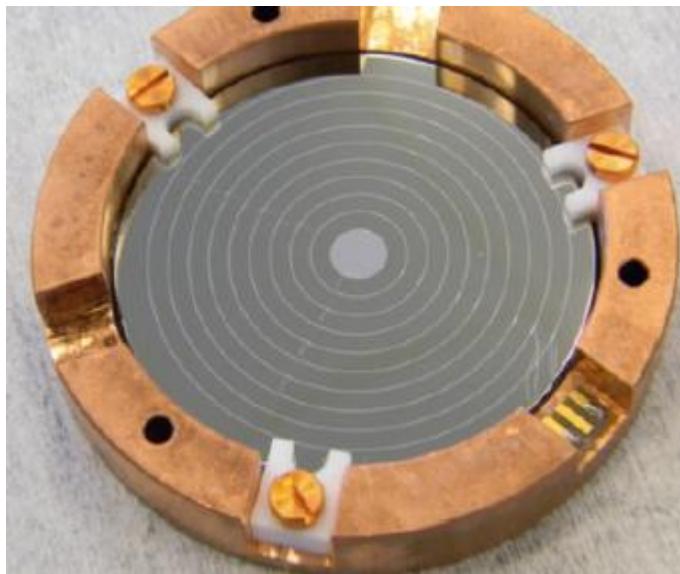
## LUMINEU schedule



# Neganov-Luke detectors

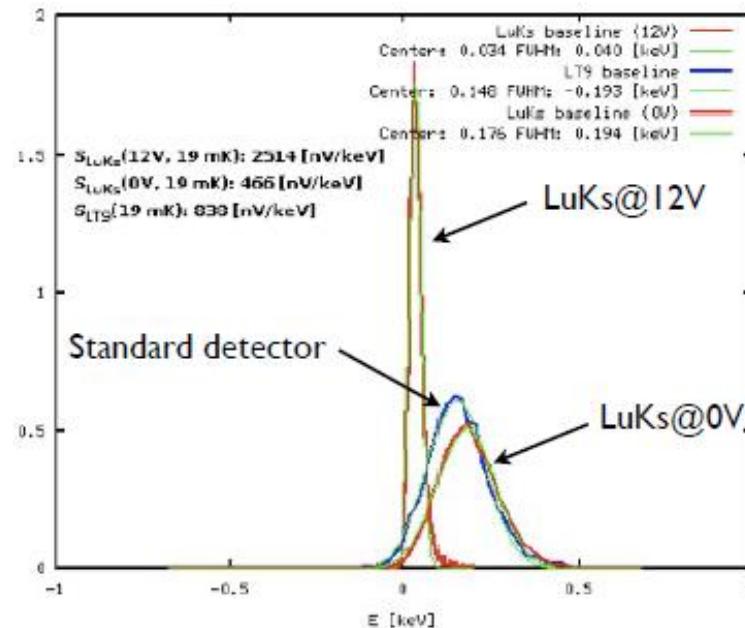
Events cause ionization → e-h pairs accelerated by an electric field → additional phonon signal

2" Ge detector, ~ 250 um thickness, 2 mm pitch Al grid  
Al evaporation, assembly and test at CSNSM, Orsay



$$G \propto V_b / \epsilon$$

Applied bias voltages up to -12 V



Sensitivity gain (0 V - -12 V)  $\sim 5.4 \Rightarrow$  baseline sigma reduces from 82.6 eV to 17 eV

# Conclusions

- Scintillating bolometers provide effective event discrimination capability by means of double read-out of heat and light signals, allowing to reject alpha particles
- This technique has the potential to reach zero background limit (100 kg y scale) in future 0νDBD experiments, probing the inverted hierarchy region
- ZnSe and ZnMoO<sub>4</sub> prototype bolometers are being tested, in view of next-generation large mass experiments
- Large crystal absorbers, close to the final absorber size, are currently being investigated
- Neganov-Luke light detectors may be useful in this framework, as less light escapes larger crystals; they may also fit in Cherenkov light detection in TeO<sub>2</sub> (M. Vignati's talk).