LUCIFER: A Scintillating Bolometer Array for the Search of Double Beta Decay

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DBD 2011

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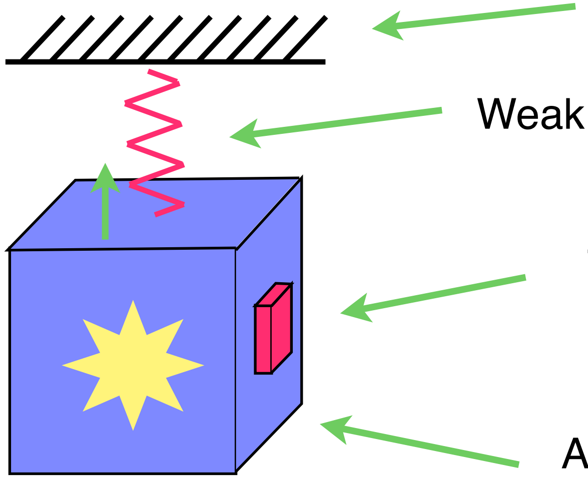
Bolometers for DBD search

- Well established technology
  - DBD source embedded in a crystal cooled down at few mK
  - (Only) energy measured via temperature variation $\Delta T = E/C$ induced by particle energy release
  - Need very low heat capacity (dielectric, diamagnetic): TeO_2: $\Delta T \sim 0.1$ mK/MeV

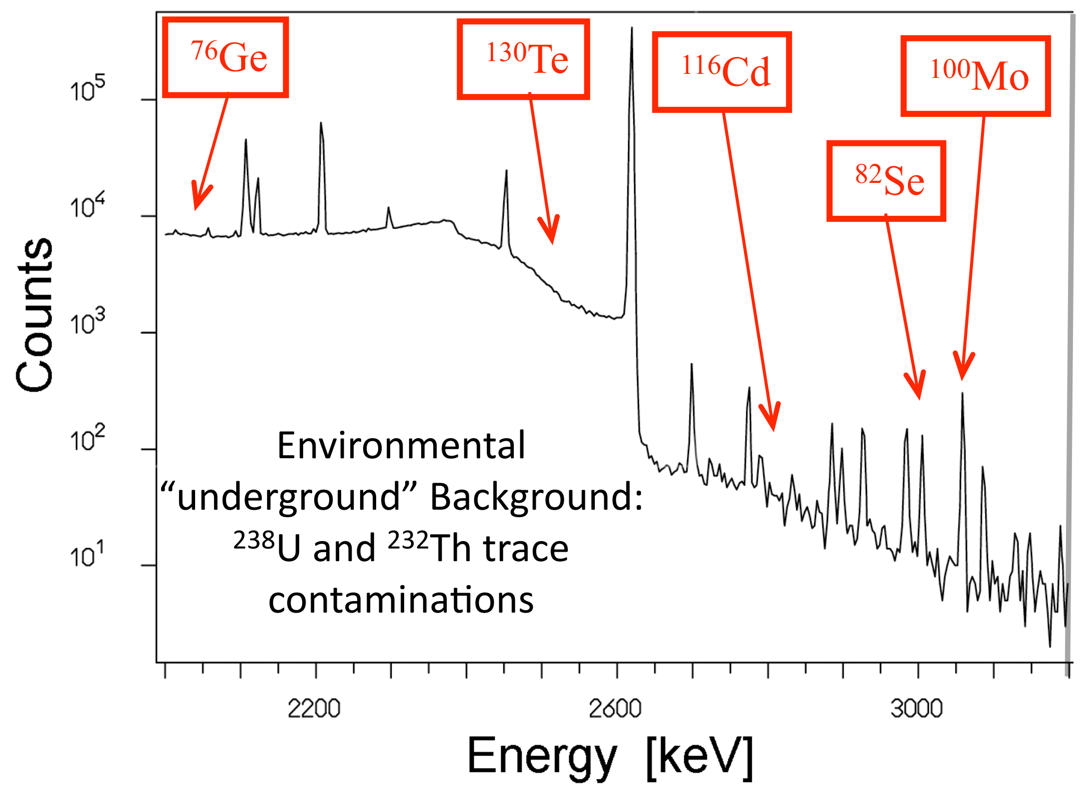


  - TeO_2: excellent energy resolution (~0.3% @ 2-3 MeV) and massive detector
  - low background ~few $\cdot 10^{-2}$ cts/keV/kg/y
- Need ~10^{-3} cts/keV/kg/y to access inverted hierarchy

The isotope choice

- The possibility to use different candidates depends on:
  - capability to grow large radio-pure crystals with good mechanical and thermal properties
  - isotopic abundance and cost/easiness enrichment
- All isotopes tested as bolometer in crystalline form with the exception of ^{136}Xe and ^{150}Nd

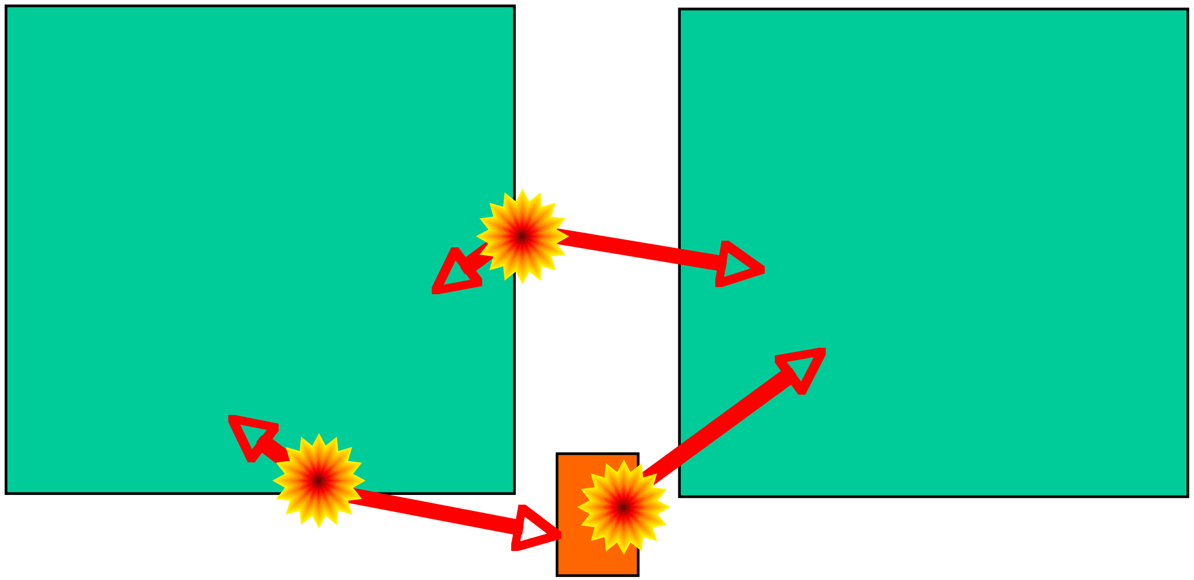
$\beta\beta$ Decay Reaction	Isotopic Abundance [atomic %]	Q-value [keV]
^{48}Ca→^{48}Ti	0.2	4274
^{76}Ge→^{76}Se	7.6	2039
^{82}Se→^{82}Kr	8.7	2996
^{96}Zr→^{96}Mo	2.8	3348
^{100}Mo→^{100}Ru	9.6	3034
^{116}Cd→^{116}Sn	7.5	2809
^{124}Sn→^{124}Te	5.8	2288
^{128}Te→^{128}Xe	31.8	866
^{130}Te→^{130}Xe	34.2	2528
^{136}Xe→^{136}Ba	8.9	2458
^{150}Nd→^{150}Sm	5.6	3368



- Gain ~ 100 if $Q_{\beta\beta}$ > 2615 keV common highest γ line (^{208}Tl) with BR ~36% in Th chain

The α problem

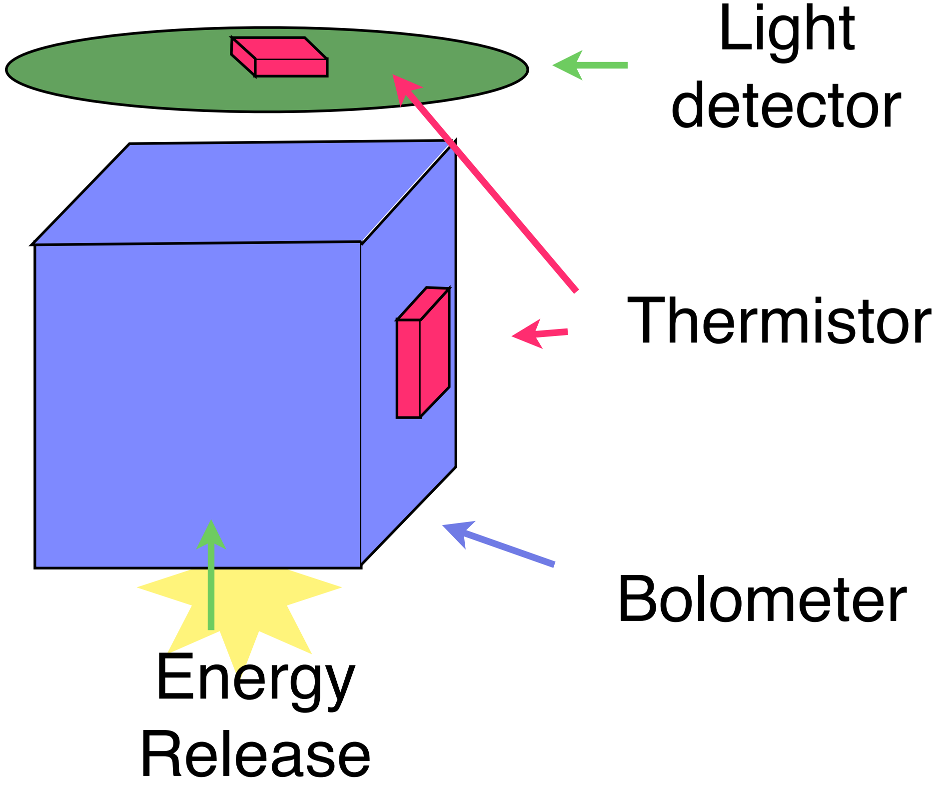
- Bolometers are fully sensitive, up to detector surface ⇒ no dead layer
- Surface contamination of the bolometers themselves or of the materials surrounding them emitting α particles gives a continuum background in the Region of Interest

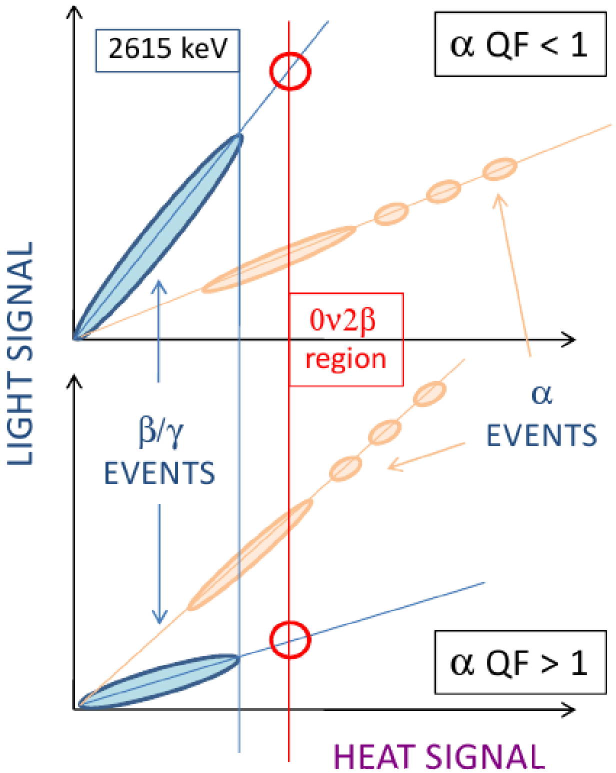


- Very difficult to reduce this background below 0.05 cts/keV/kg/y below and above 2615 keV
  - need α rejection >98% to reach 10^{-3} cts/keV/kg/y

The solution

- Scintillating bolometers: use different α/γ light emission for background discrimination
- The light detector: a thin opaque bolometer facing a polished side of the main bolometer





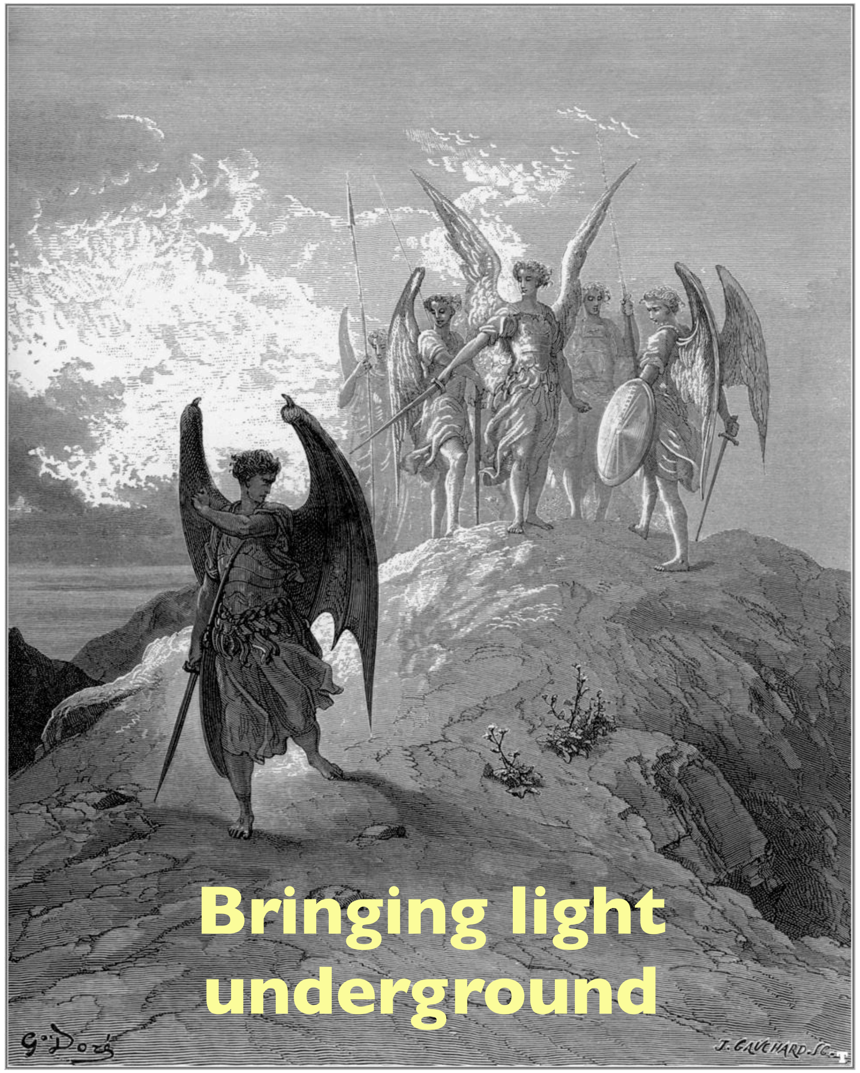
- The experimental basis of this technique was the R&D activity performed by S.Pirro at LNGS in the framework of the Bolux(INFN), ILIAS-IDEA (EC WP2-P2) program

LUCIFER

Low-background Underground Cryogenics Installation For Elusive Rates

ERC-2009-AdG 247115

Lucifer is a Latin word (from the words *lucem ferre*), literally meaning "light-bearer", which in that language is used as a name for the dawn appearance of the planet Venus, heralding daylight.



Principal Investigator:
F. Ferroni

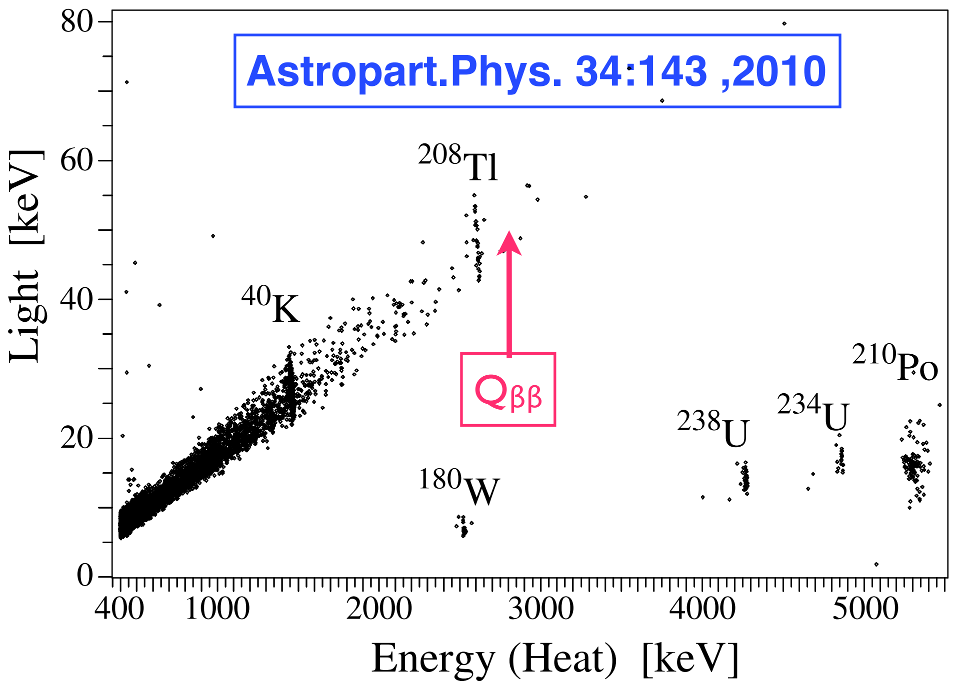
Co- Investigator:
A.Giuliani

Coordinator: S.Pirro

The candidates: $CdWO_4$

	$Q_{\beta\beta}$ (keV)	Useful material (% weight)	LY (keV/MeV)	QF
$CdWO_4$	2809	32	~17	~0.16

- Pro:
  - ~0.5 kg crystal successfully tested
  - very good crystal quality
  - high light yield

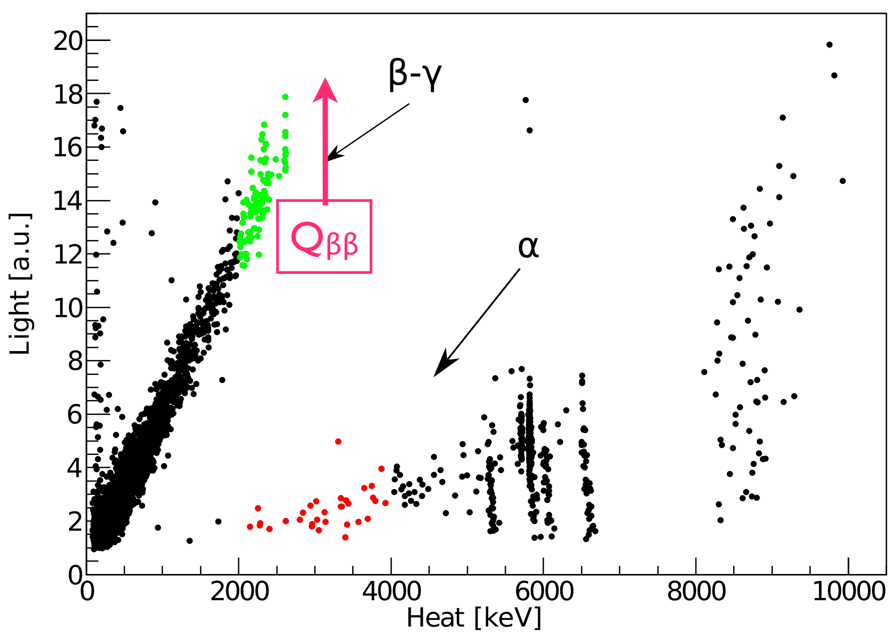


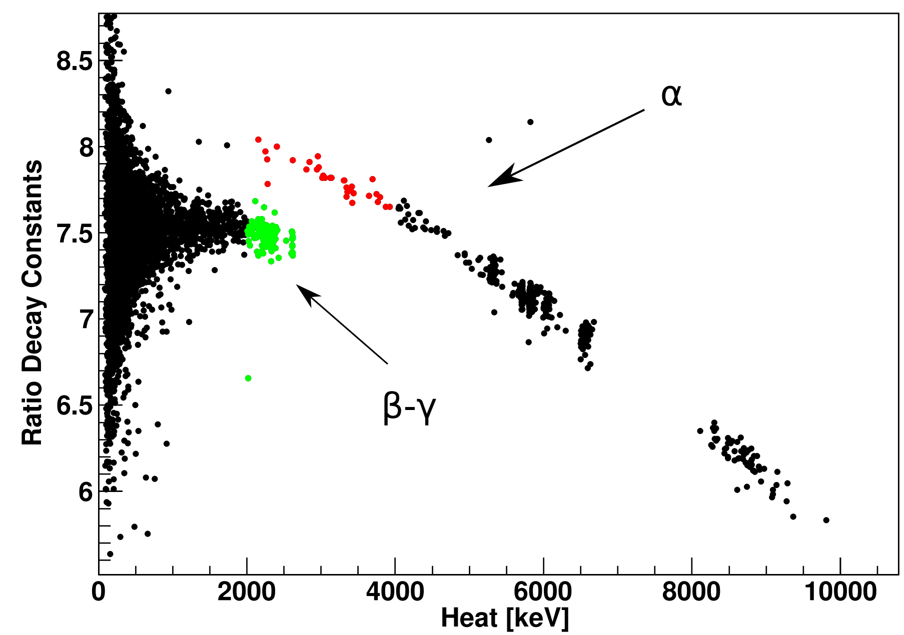
- Cons:
  - only 32% of useful material
  - ^{113}Cd (huge neutron cross section) ⇒(n,γ) reaction ⇒ possible continuum γ background

The candidates: $ZnMO_4$

	$Q_{\beta\beta}$ (keV)	Useful material (% weight)	LY (keV/MeV)	QF
$ZnMO_4$	3034	44	~1	~0.2

- Pro: good pulse shape discrimination on main (heat) bolometer **Astropart.Phys. 34:797 ,2011**
- Cons: poor light yield ,only small crystals (~30 g) up to now **JINST 5:P11007,2010.**



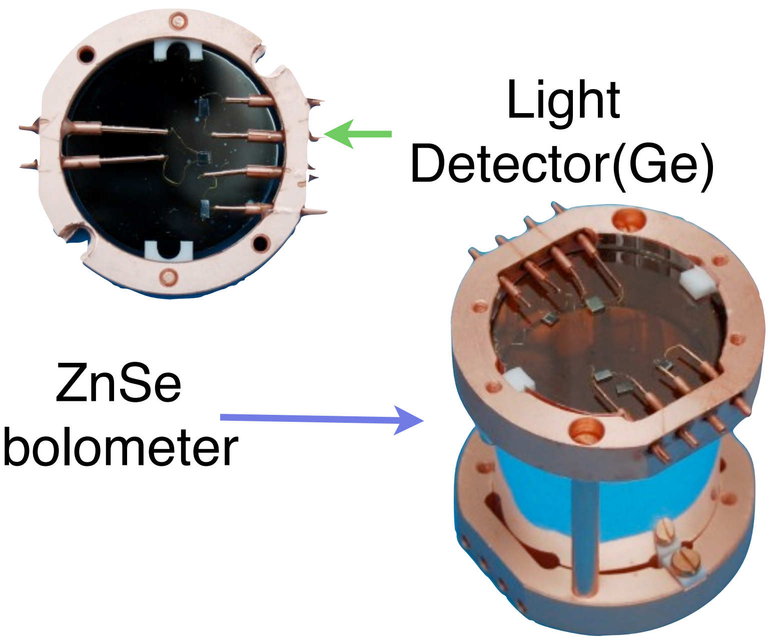


The candidates: ZnSe

	$Q_{\beta\beta}$ (keV)	Useful material (% weight)	LY (keV/MeV)	QF
ZnSe	2995	56	~7	~4

Astropart.Phys. 34:344 ,2011

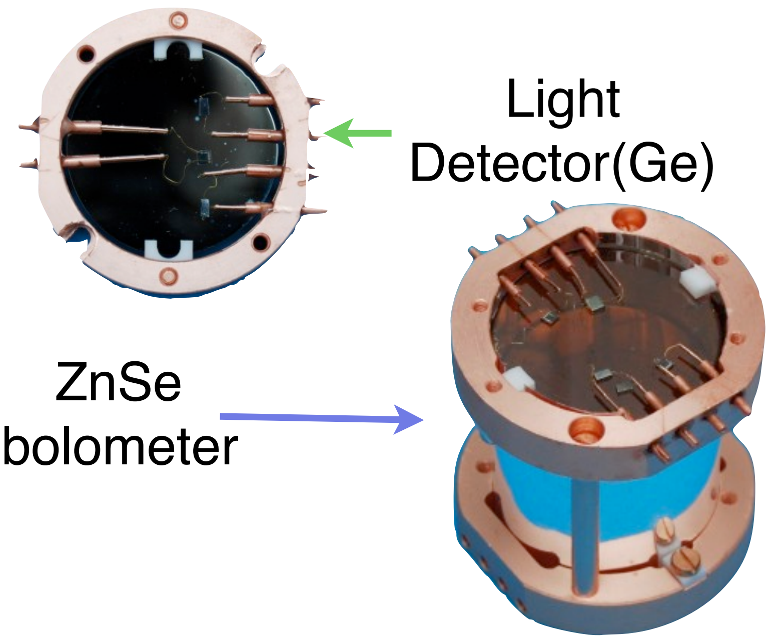
- Pro:
  - ~340 g crystal successfully tested
  - good light yield and radio-purity
  - pulse shape discrimination on light detector
  - the most mass effective

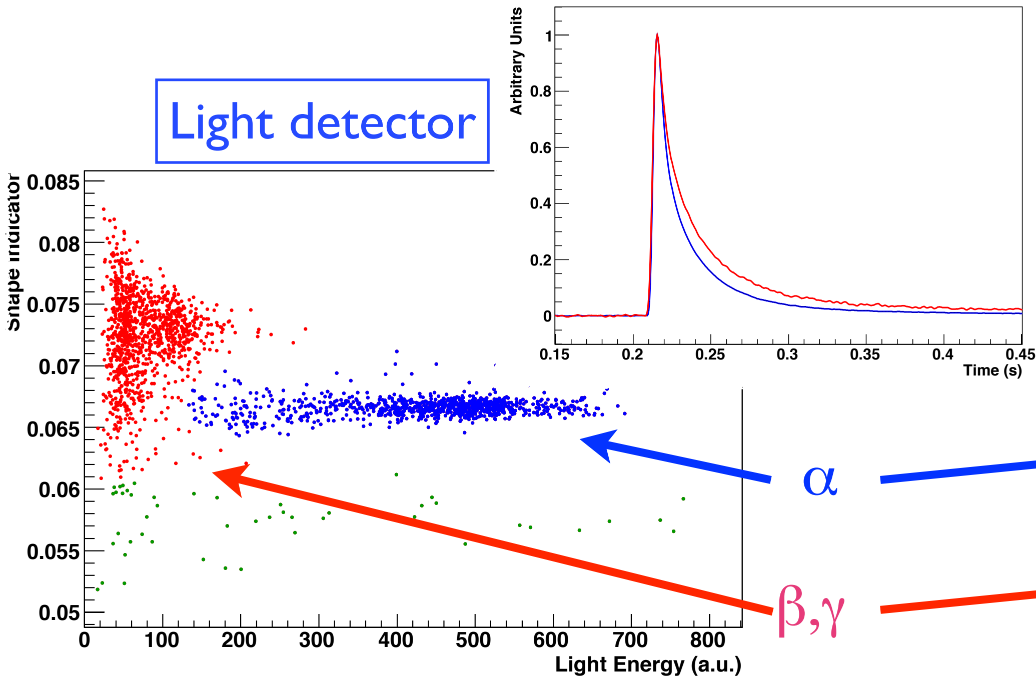


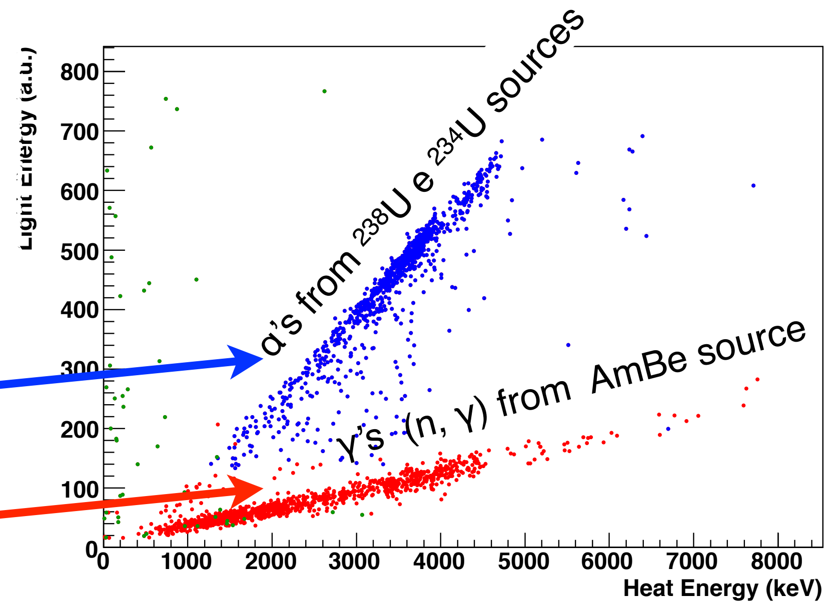
- Cons:
  - inverted Quenching Factor!
  - crystal production: not yet solid protocols and reproducibility issue

The candidates: ZnSe

- No explanation for the inverted Quenching Factor.
- Discarded hypotheses:
  - ZnSe self-absorption
  - Light collection efficiency
  - Light detector transparent to certain wavelengths







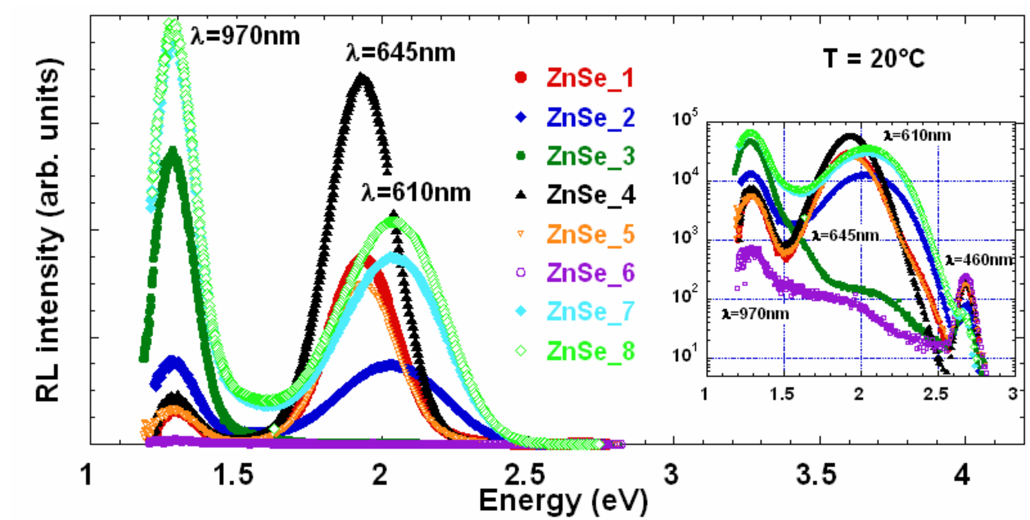
The scintillating candidates

	$Q_{\beta\beta}$ (keV)	Useful material (% weight)	LY (keV/MeV)	QF
$CdWO_4$	2809	32	~17	~0.16
$ZnMO_4$	3034	44	~1	~0.2
ZnSe	2995	56	~7	~4

- Baseline crystal for LUCIFER: **ZnSe**

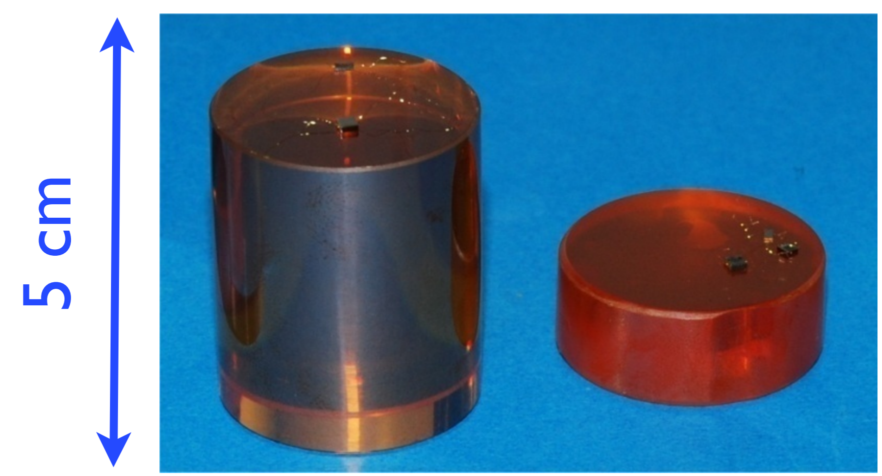
ZnSe

- Luminescence properties well known



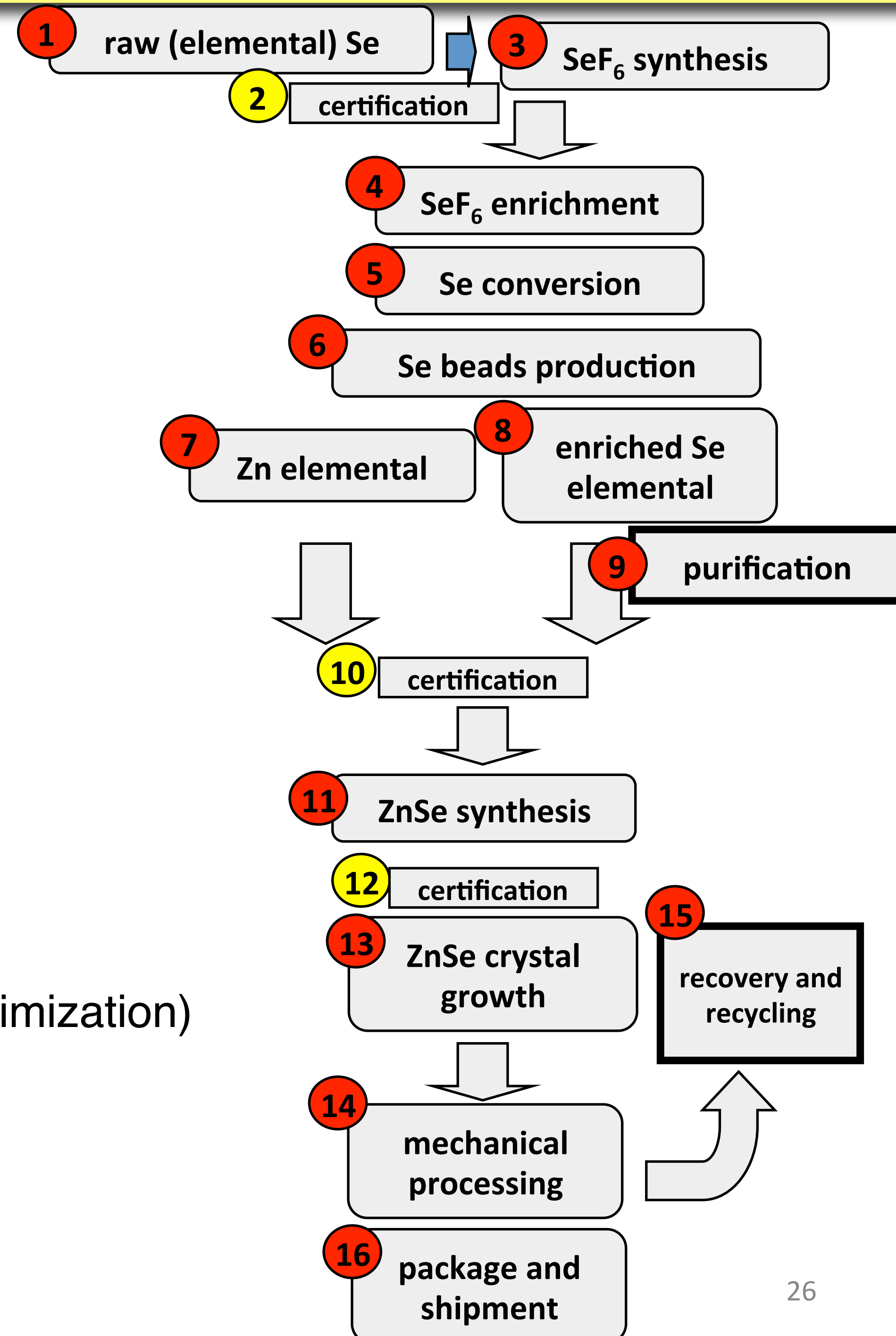
- Crystal growth known:
  - Bridgman technique at 1525° C
  - high twining tendency
  - high volatility: stoichiometry control

- Effort focused on:
  - enrichment
  - ZnSe synthesis
  - efficient crystal growth



ZnSe production

- Need radio-chemical pure Se
  - ICPMS measurements
- Enrichment (URENCO)>95%
  - Chemical problems in Se conversion (mainly reagent contamination)
- Beads (powder not good for crystal)
  - require dedicated instruments (HPGe gamma spectroscopy)
  - Purification (99.999%)⇒zone refining
- Synthesis of ZnSe
  - High or low temperature method (yield optimization)
- Growth of ZnSe crystal
  - Avoid twining and reach reproducibility

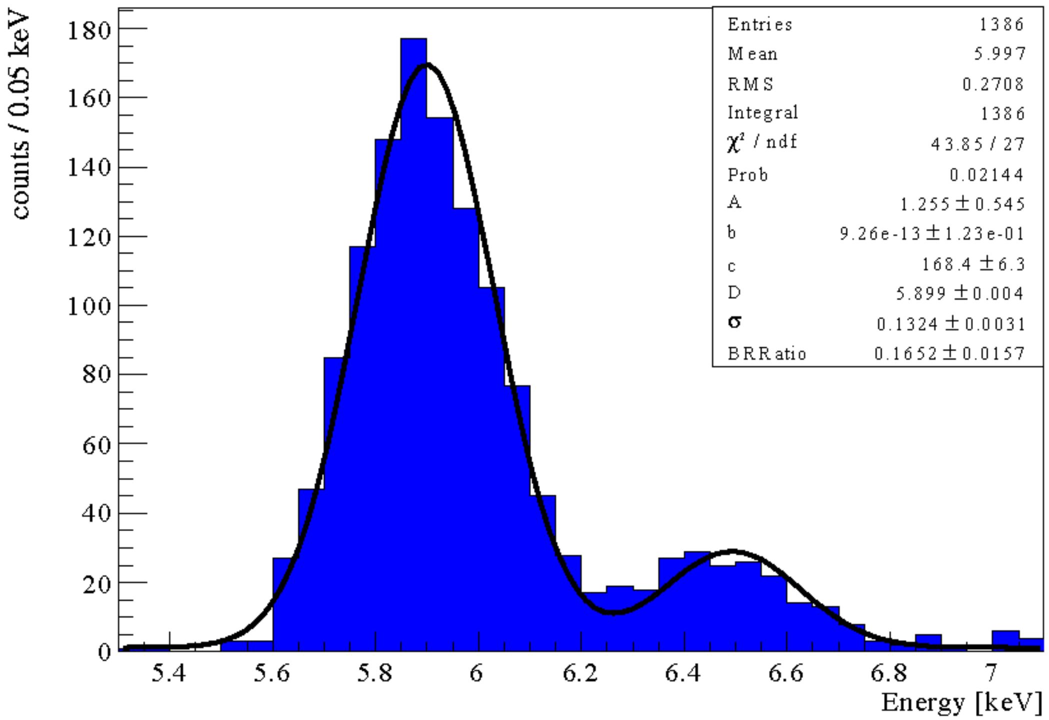


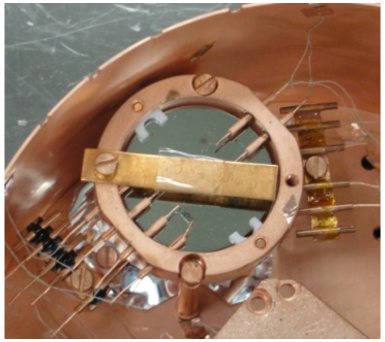
Light detectors

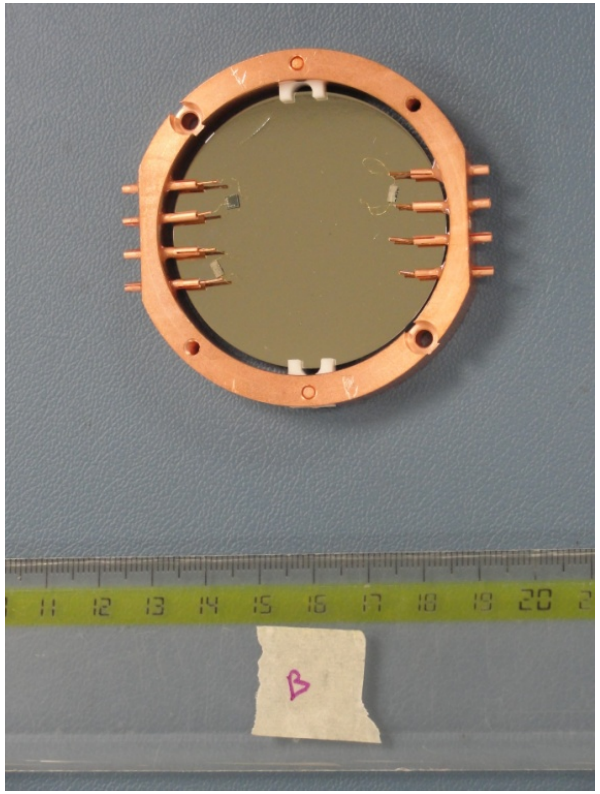
- Light Detectors are generally pure Germanium disks (thickness 0,3-1 mm)

- Performances are evaluated on the ^{55}Fe doublet: 5.9 & 6.5 keV x-Ray

  - Good energy resolution: σ~130 eV
    theoretical resolution σ~80 eV





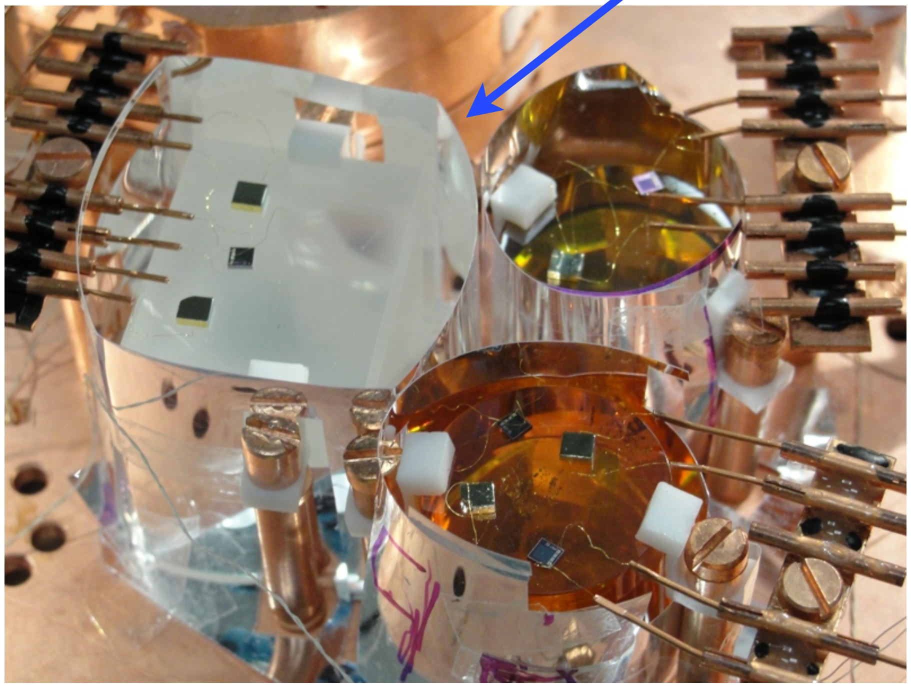


LD test: TeO_2 Cerenkov light

- TeO_2 bolometers don't scintillate: detection of Cerenkov light
- Cerenkov threshold: 50 keV for β, α below threshold ⇒ particle discrimination

TeO_2:Sm (30 ppb ^{nat}Sm)
3.0x2.4x2.8 cm^3
116.65 g

VM2002 reflecting foil

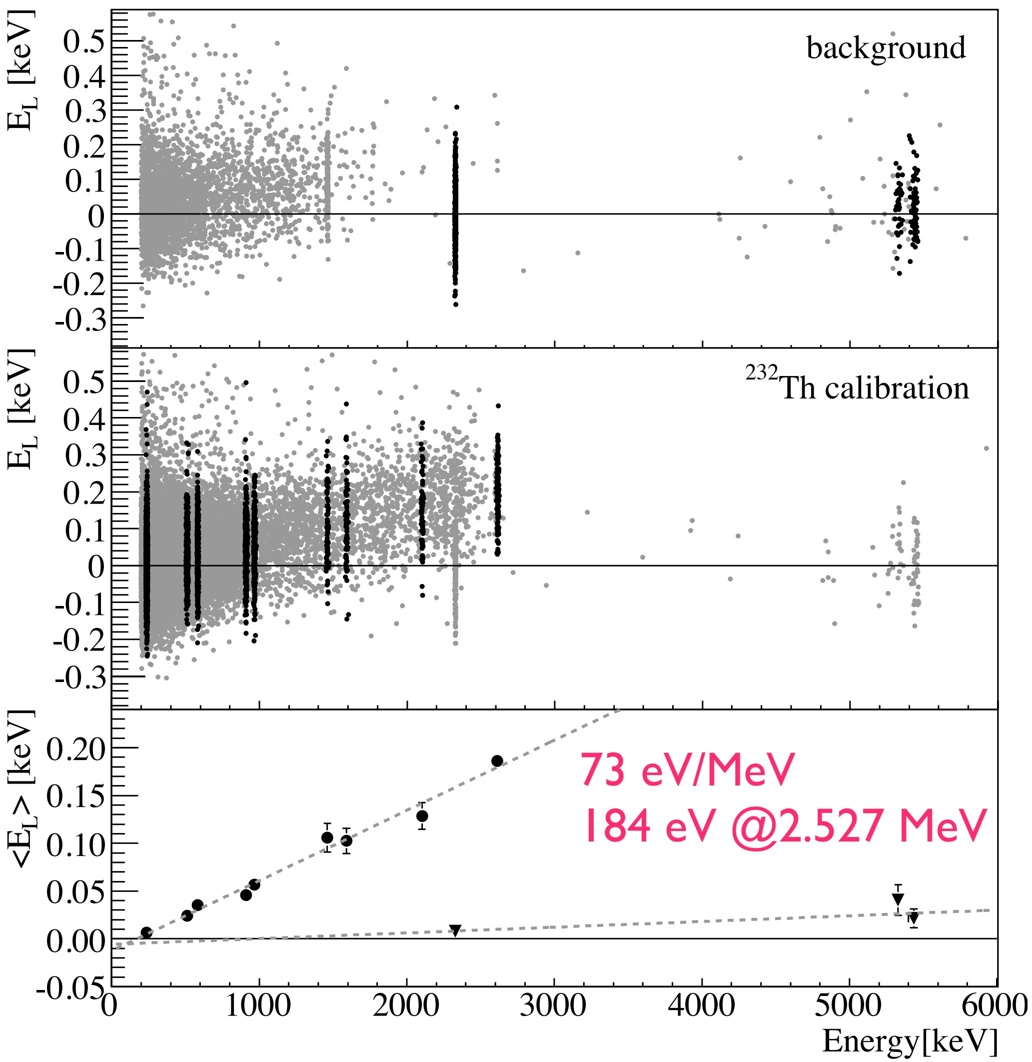


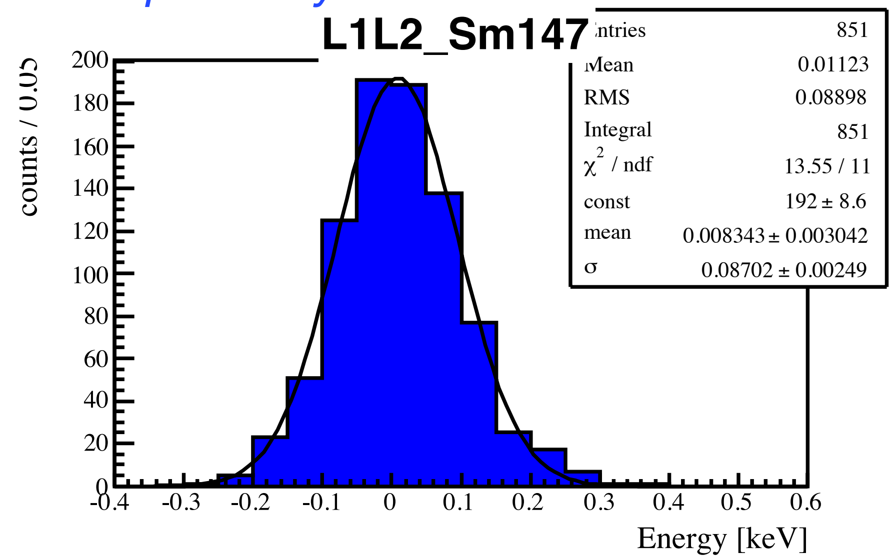
^{147}Sm: α decay at 2310 keV

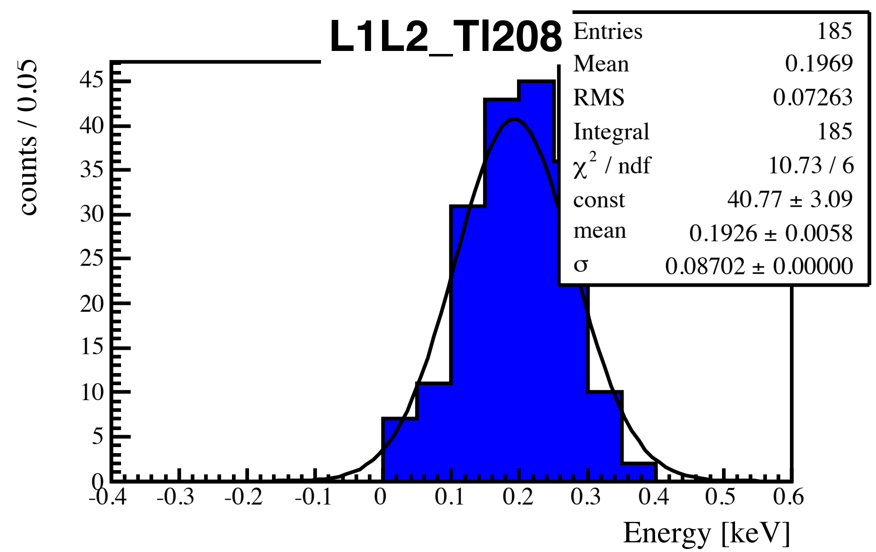
Light detector of pure Ge
66 mm diameter, 1mm thick.
One side coated with SiO_2 to increase absorption of µm wavelengths.

Results

arXiv:1106.6286 submitted to Astropart. Phys.



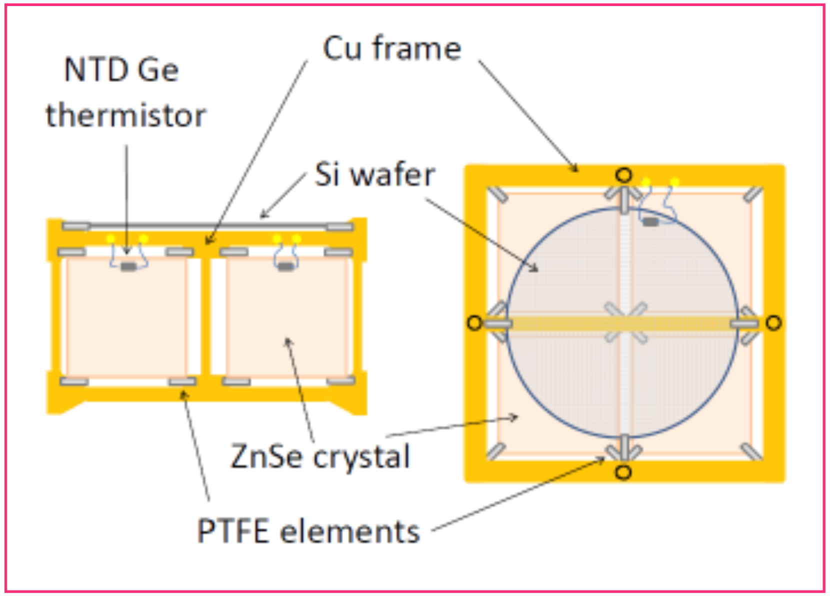


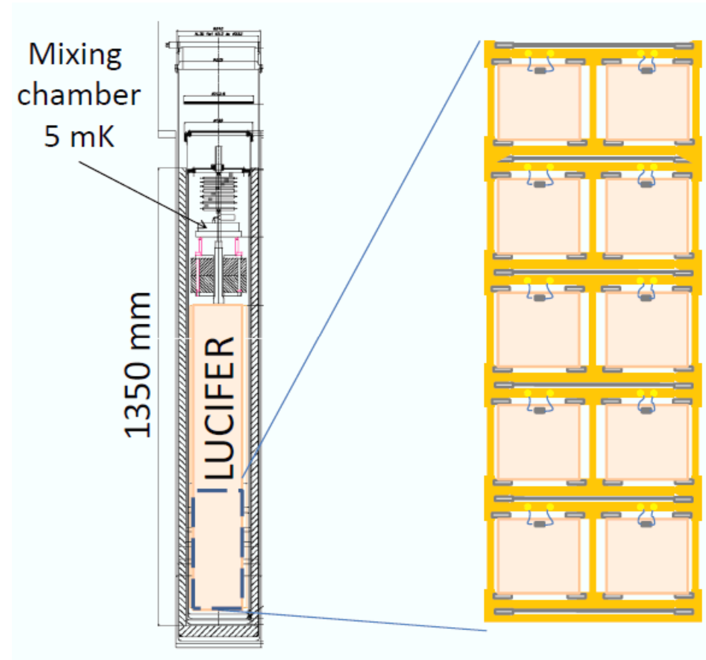


- ~2 σ separation
- R&D on going on 5x5x5 cm^3 TeO_2 crystal: light collection optimization

LUCIFER Detector

- Single module: 4ZnSe -1light detector Tower: 12 single modules





- Hosted @ Laboratori Nazionali del Gran Sasso

Preliminary

  - Equivalent vertical depth relative to a flat overburden: ~ 3.1 ± 0.2 km.w.e
  - Gamma flux:~0.73 $\gamma/(s\ cm^2)$
  - Neutron flux: ~$4 \cdot 10^{-6}$ $n/(s\ cm^2)$ below 10 MeV
  - Muon flux: $(2.58 \pm 0.3) \cdot 10^{-8}$ $\mu/(s\ cm^2)$

Conclusions

- The main challenge for a 0vDBD next generation bolometer experiment is the α background rejection to ~10^{-3} cts/keV/kg/y

- The scintillating bolometer is a promising technique
  - the LUCIFER goal is to demonstrate the feasibility of this technique on a reasonable large scale
  - but has a remarkable physics reach by itself

ZnSe	^{82}Se weight(kg)	Half life(10^{26} y)	$m_{\beta\beta}$ (meV)
baseline	**17.6**	**2.3**	**51-65**

assuming ΔE ~ 10keV, live time ~ 5 y, bkgd~10^{-3} cts/keV/kg/y

J.Mendez et al. arXiv:0801.3760;
F.Simkovic et al. Phys.Rev. C77 045503,(2008);
J.Suhonen et al. Int.J.Mod.Phys E17 1 (2008)

- Data taking foreseen in 2014