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LOW TEMPERATURE DETECTORS

# Neutrinoless double beta decay searches with enriched $^{116}$CdWO$_4$ scintillating bolometers

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## Neutrinoless double beta decay

- **Two neutrino double beta decay**, allowed by the Standard Model (SM), is the rarest decay ever observed.

$$(A,Z) \rightarrow (A,Z+2) + 2e^- + 2\overline{\upsilon}$$

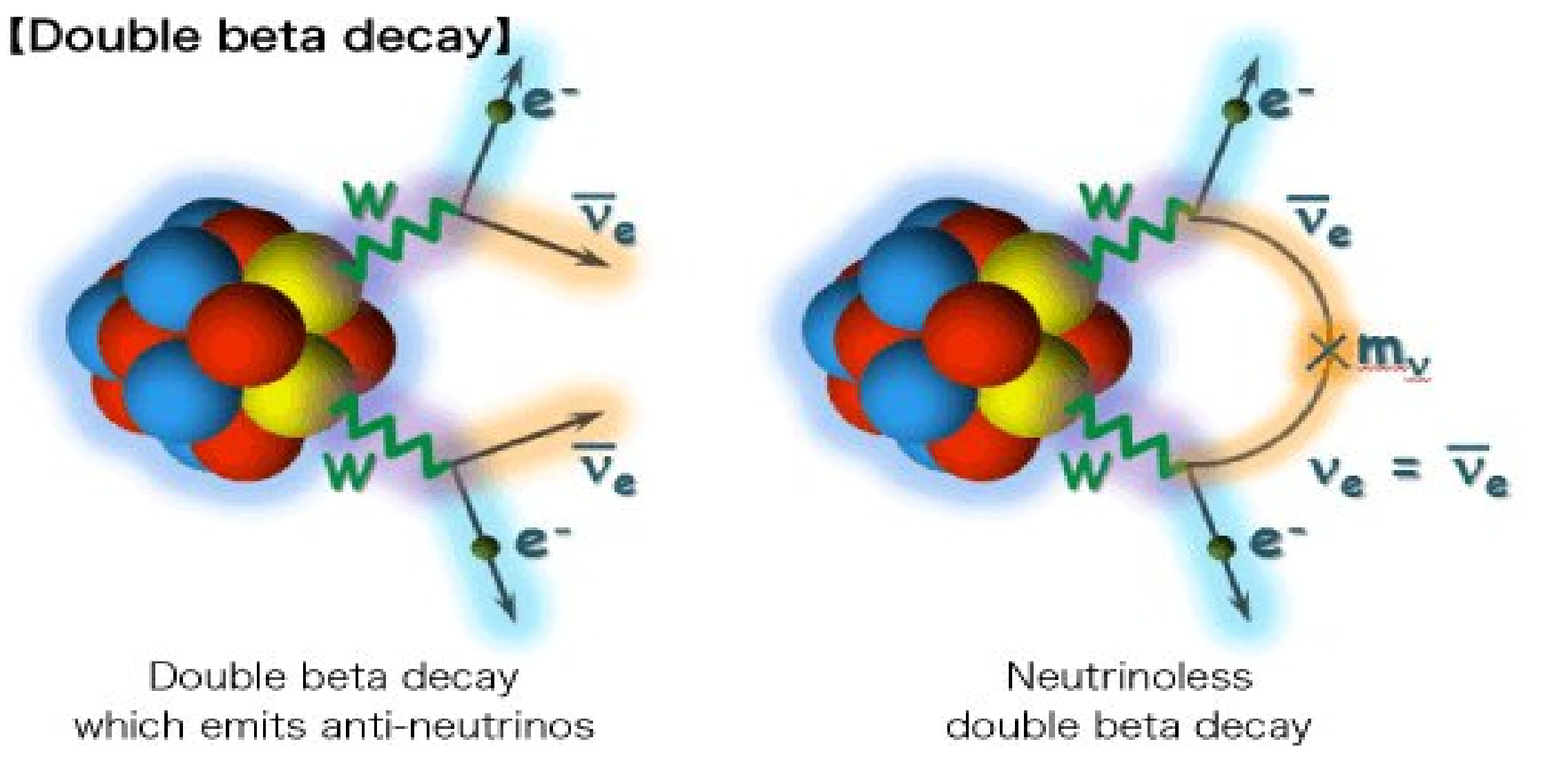
Half-life: $T_{1/2}(2\upsilon\beta\beta) \sim 10^{18}-10^{24}$ **years.**

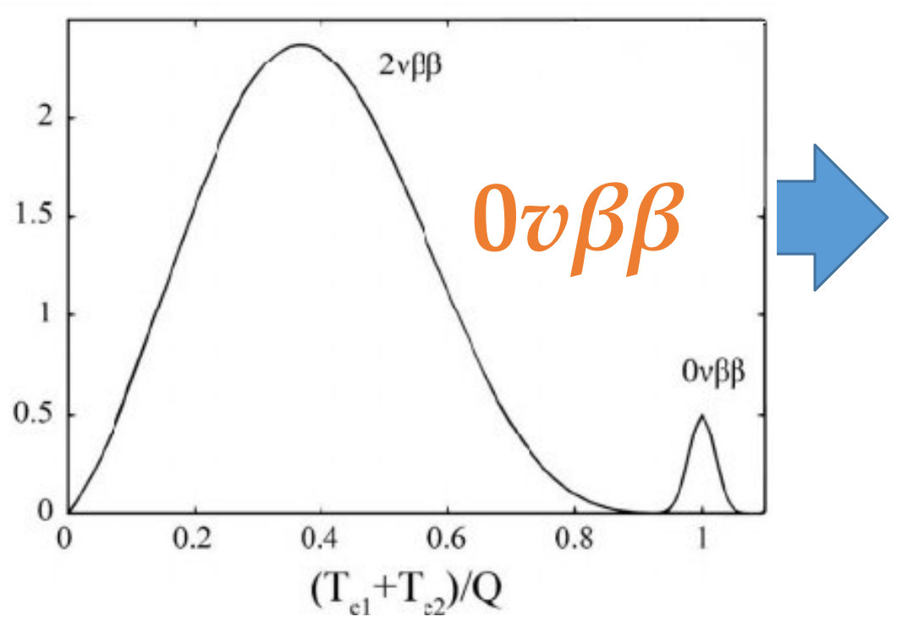
- **Neutrinoless double beta decay $0\upsilon\beta\beta$** is a very rare nuclear transition, not yet observed. It is forbidden by the SM.

$$(A,Z) \rightarrow (A,Z+2) + 2e^-$$

Limits on the half-life: $T_{1/2}(0\upsilon\beta\beta) > 10^{24}-10^{26}$ **years.**

It can occur only if neutrinos are **Majorana particles.**



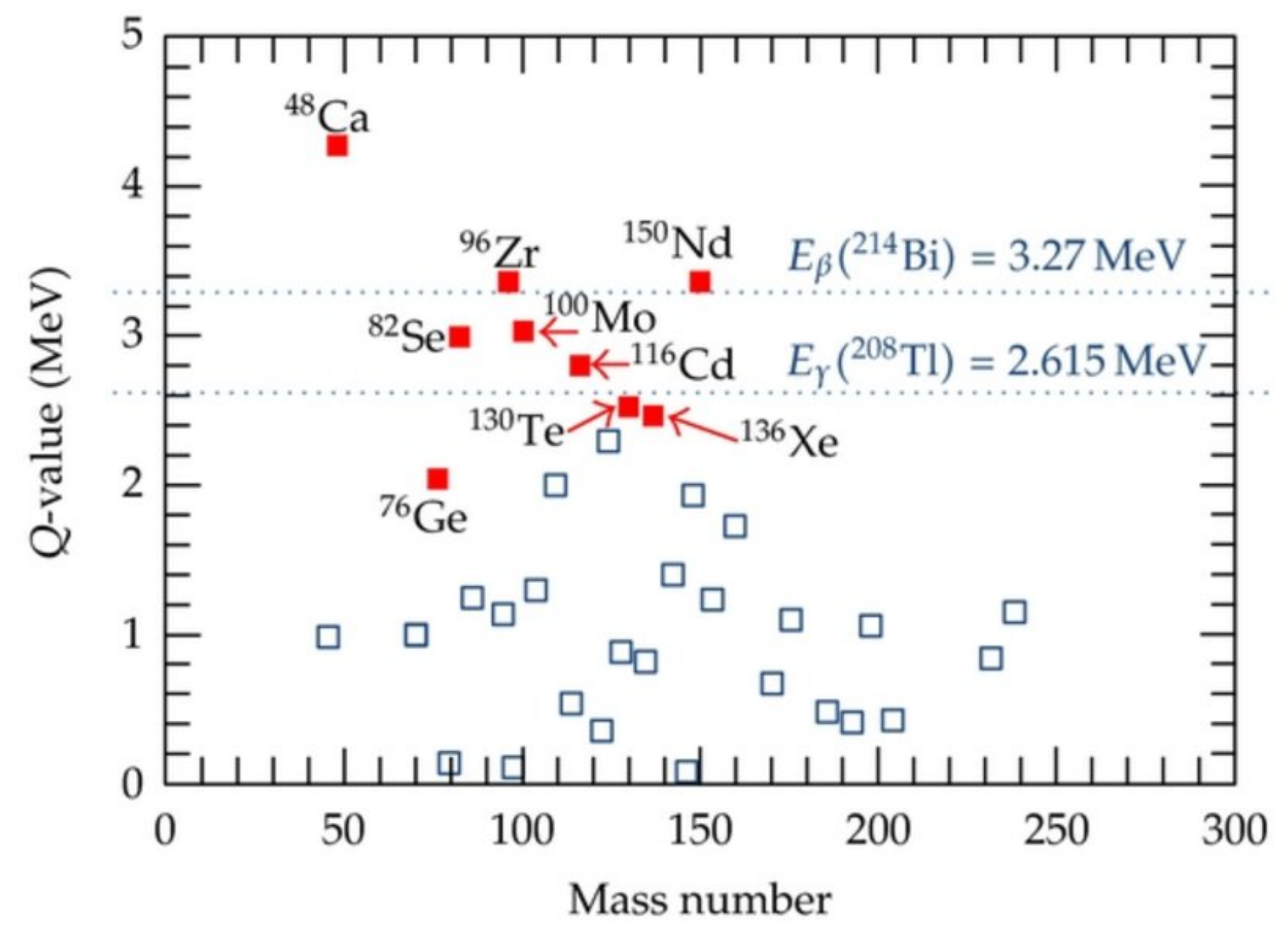


- **Lepton number violation.**
- $\overline{\upsilon} = \upsilon$
- **Fix the neutrino mass hierarchy.**

### What element for such a decay ?

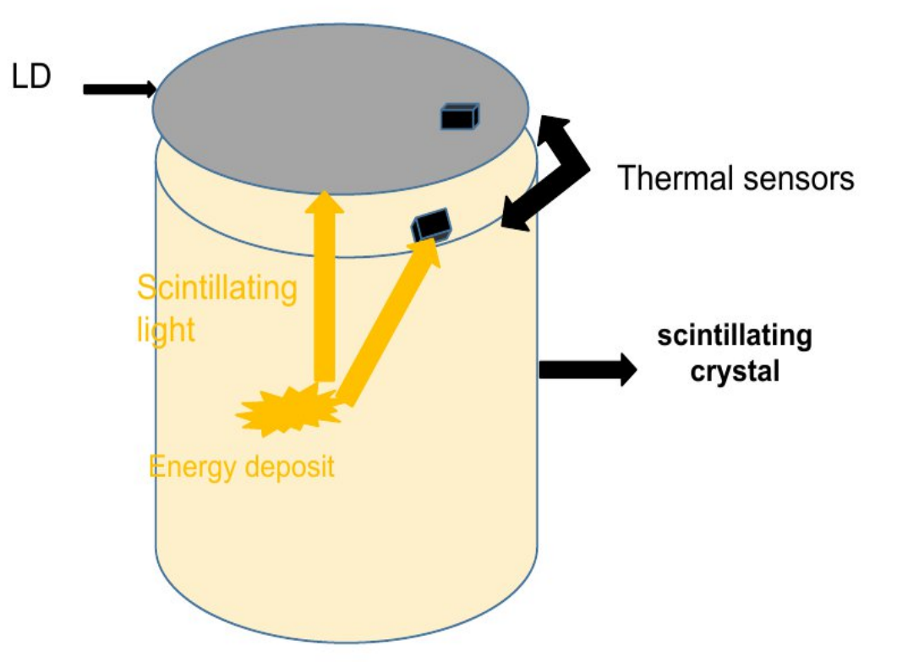
**$0\nu\beta\beta$** is energetically possible for 35 nuclei, **but only 9** fulfill theses criteria:

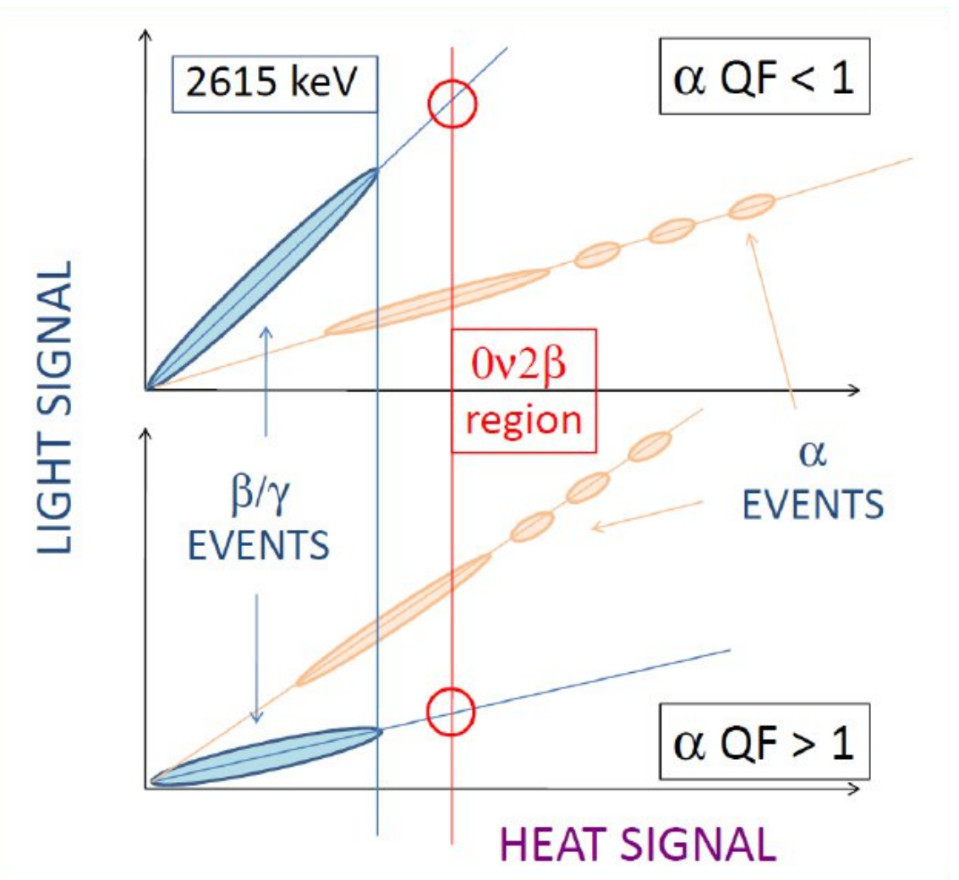
- ✓ Q-value of the transition has to be higher then the end point of natural gamma radioactivity (2615 keV $\gamma$ of $^{208}$Tl).
- ✓ Large isotopic abundance.
- ✓ Possibility of enrichment.
- ✓ Favorable predictions on the half-life.



## Scintillating bolometers

- A bolometer is a low temperature detector. It is composed by three main elements: an **absorber**, a **thermal sensor** and a **thermal bath.**





- If we used as absorber a **crystal which can scintillate** and we couple the absorber to an **auxiliary thin bolometer** facing the crystal which will work as a **photodetector**, we can have a **simultaneous read out** of the deposited heat and the emitted light by a particle in the crystal. This is how a **scintillating bolometer** works!
- Experiments using this technique: **CUPID-0, CUPID-Mo, AMoRE, CRESST, CROSS...**

**The double readout light and heat allows to have a full $\alpha/\beta$ separation in order to get a zero $\alpha$ background.**

## $^{116}$Cd as a $0\upsilon\beta\beta$ candidate

### Why $^{116}$Cd ?

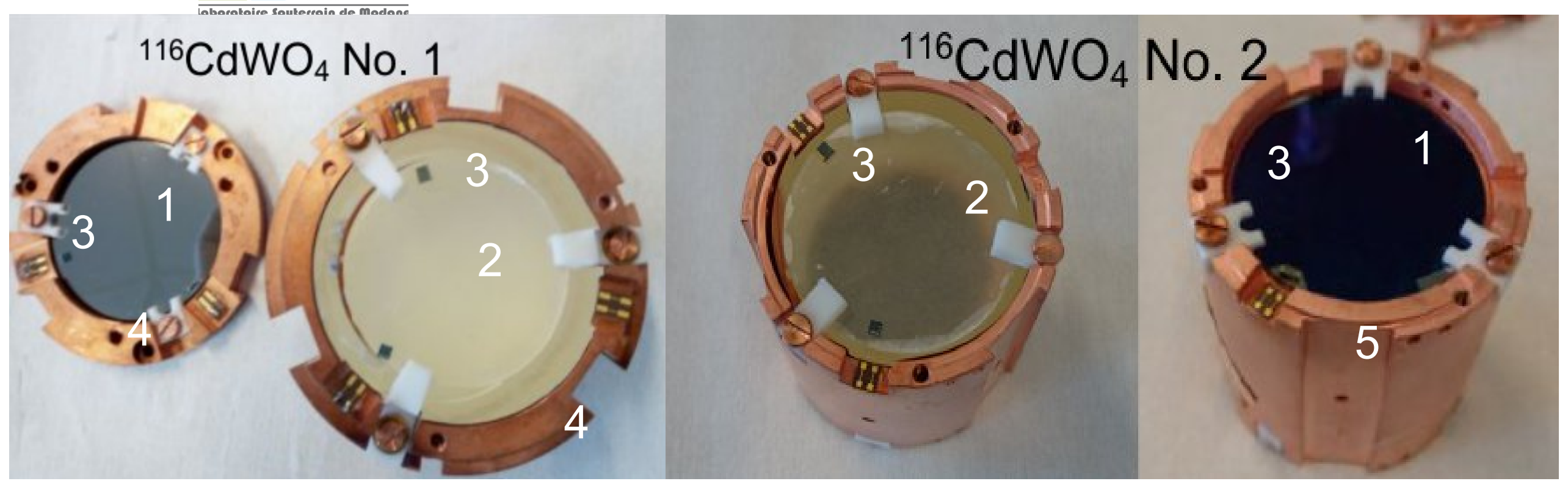
- ✓ **$^{116}$Cd** is one of the favorable candidates for $0\upsilon\beta\beta$ searches from theoretical and experimental point of view.
- ✓ Energy of the decay is **Q-value = 2813.49 keV.**
- ✓ Isotopic abundance is 7.5 %.
- ✓ **$^{116}$Cd -> $^{116}$Sn + 2e$^-$**
- ✓ Enrichable by gas centrifugation.

### Search for $0\upsilon\beta\beta$ decay of $^{116}$Cd

| Experiment | Limit on $T_{1/2}$ (years) at 90 C.L. |
|---|---|
| Solotvina with enriched $^{116}$CdWO$_4$ (~83%) crystal scintillators | 1.7 x $10^{23}$ |
| NEMO-3 in $^{116}$Cd foils with tracking calorimeter technology | 1.0 x $10^{23}$ |
| Aurora with enriched $^{116}$CdWO$_4$ (~82%) crystal scintillators | 2.2 x $10^{23}$ |

## $^{116}$CdWO$_4$ crystals as scintillating bolometers

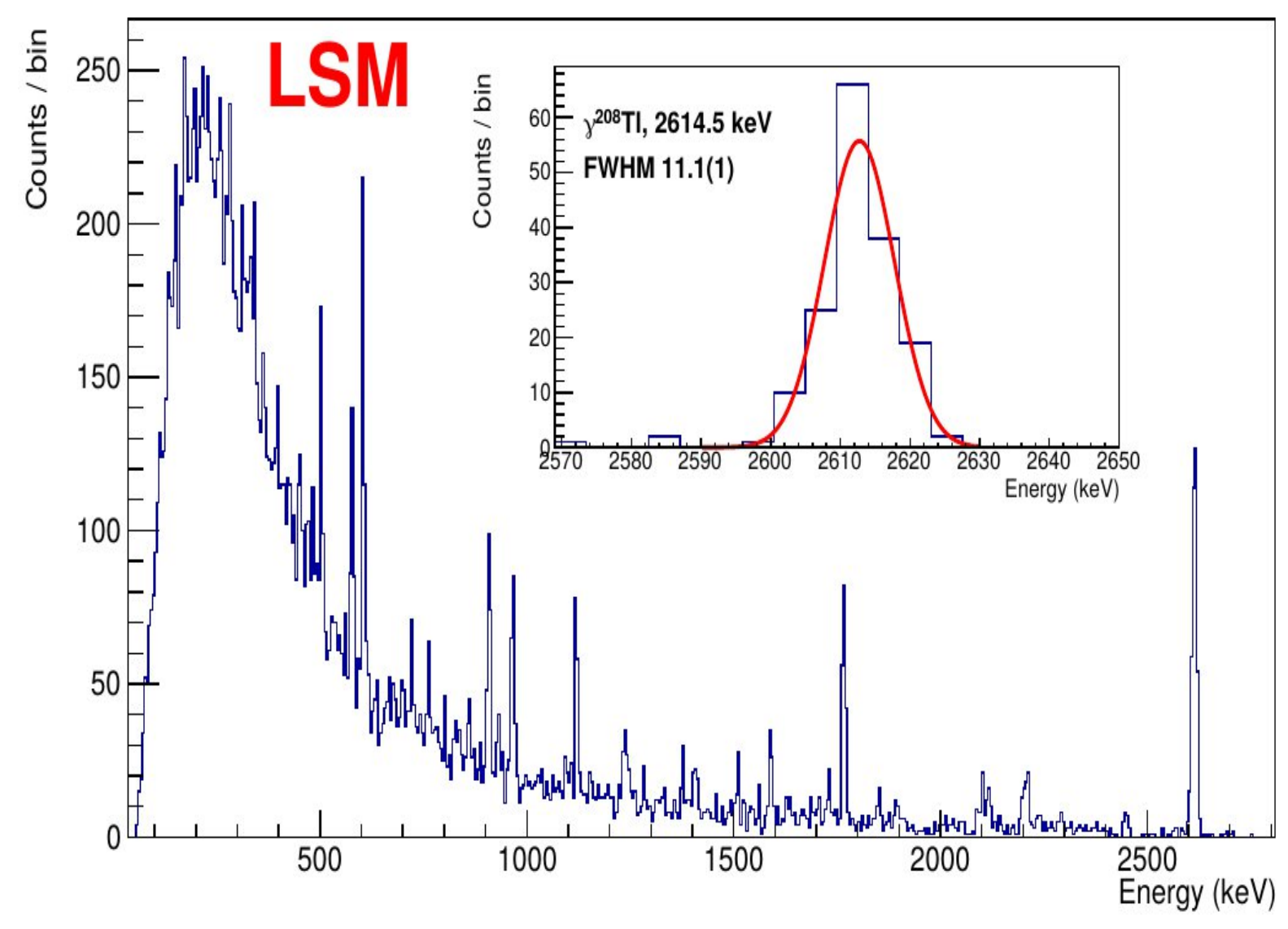
### Detector assembly



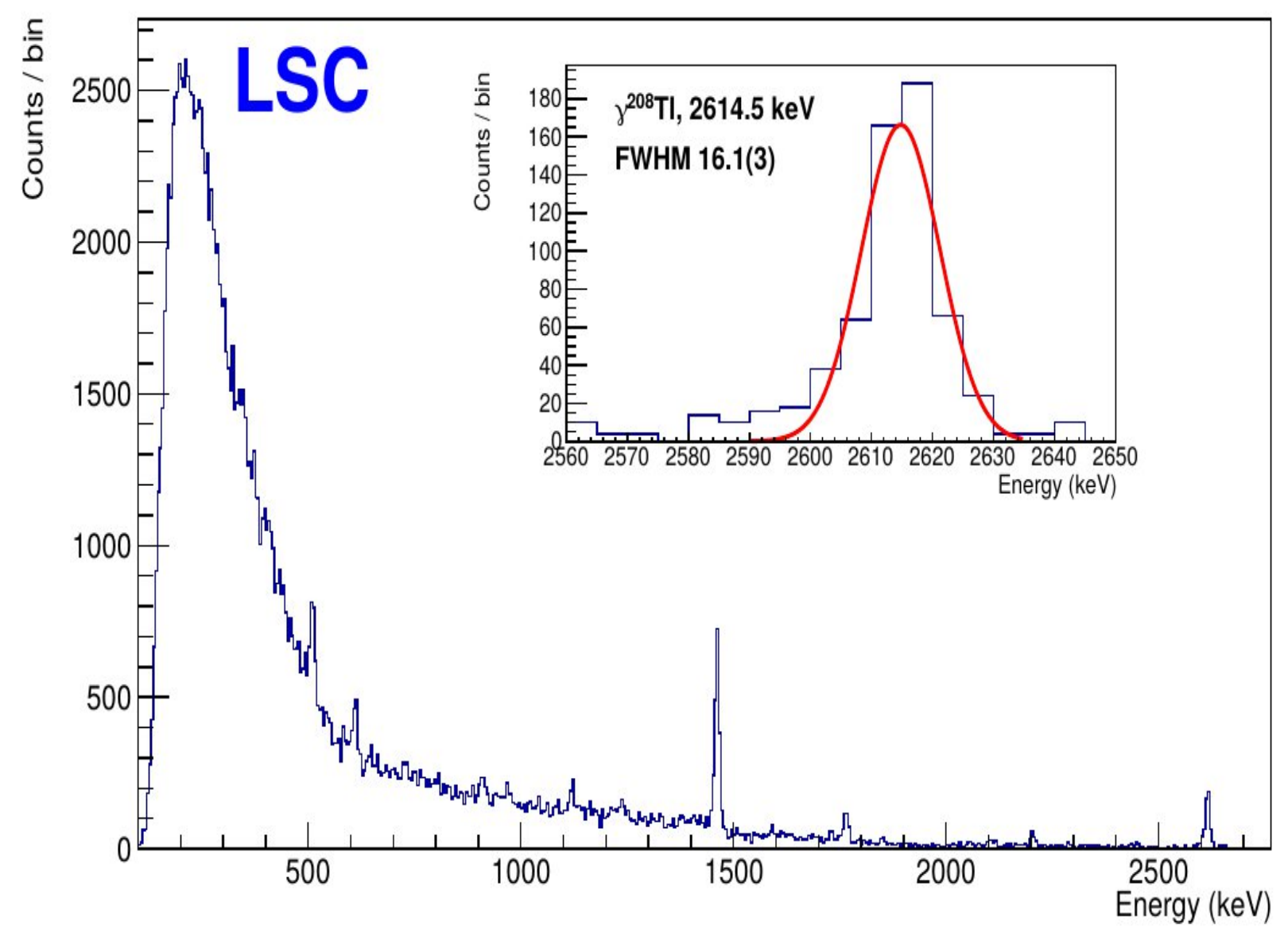
1. Ge ($\phi$44x0.17 mm) based Light detector coated with (SiO).
2. Enriched $^{116}$CdWO$_4$ crystals.
3. Thermal sensor: NTD.
4. LUMINEU style copper holder.
5. CUPID-Mo style copper holder.

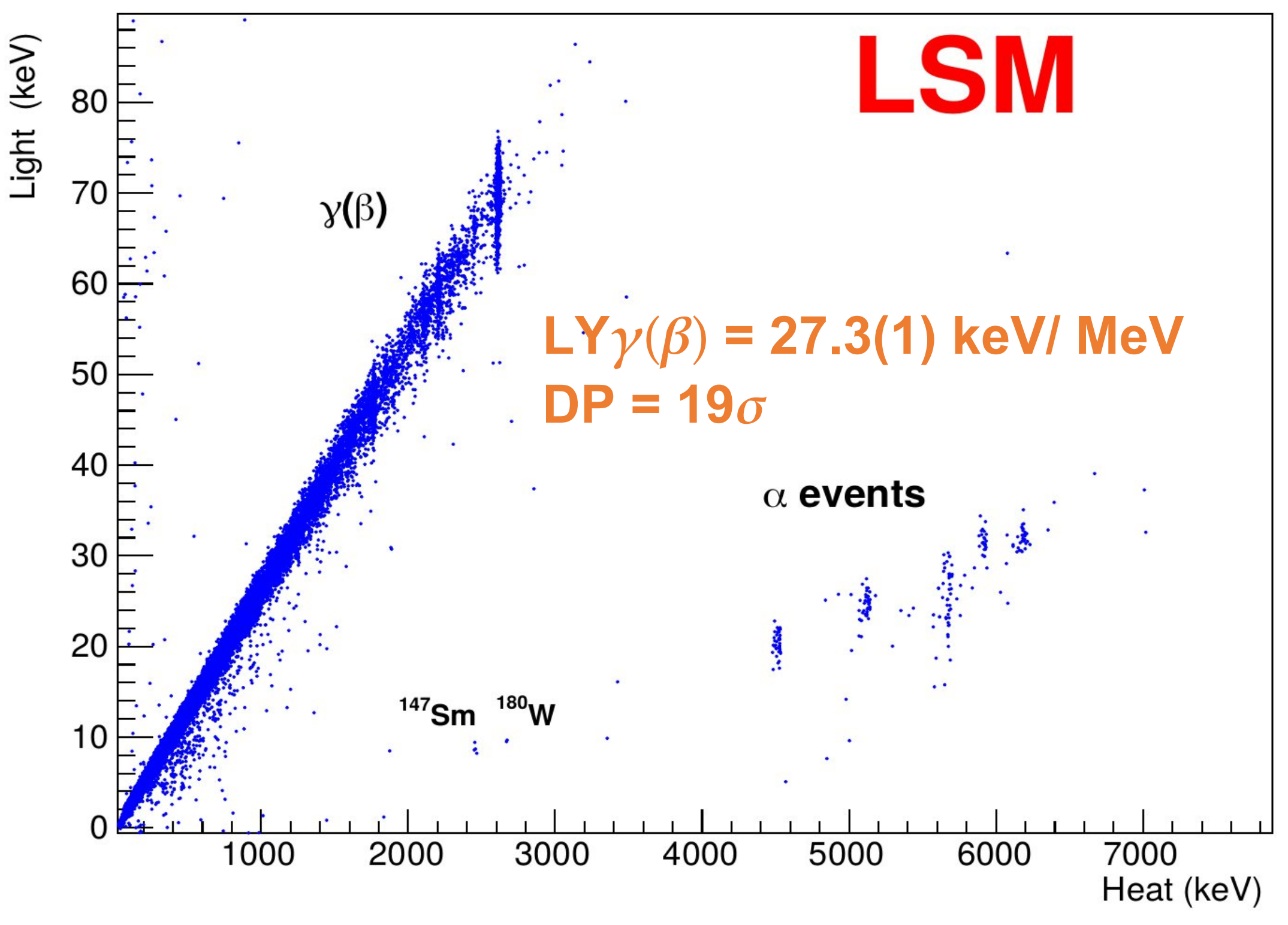
**Twin $^{116}$CdWO$_4$ crystals opperated as scintillating bolometers are installed in two underground laboratories: Laboratoire Souterrain de Modane (LSM) and Laboratorio Subterraneo de Canfranc (LSC).**

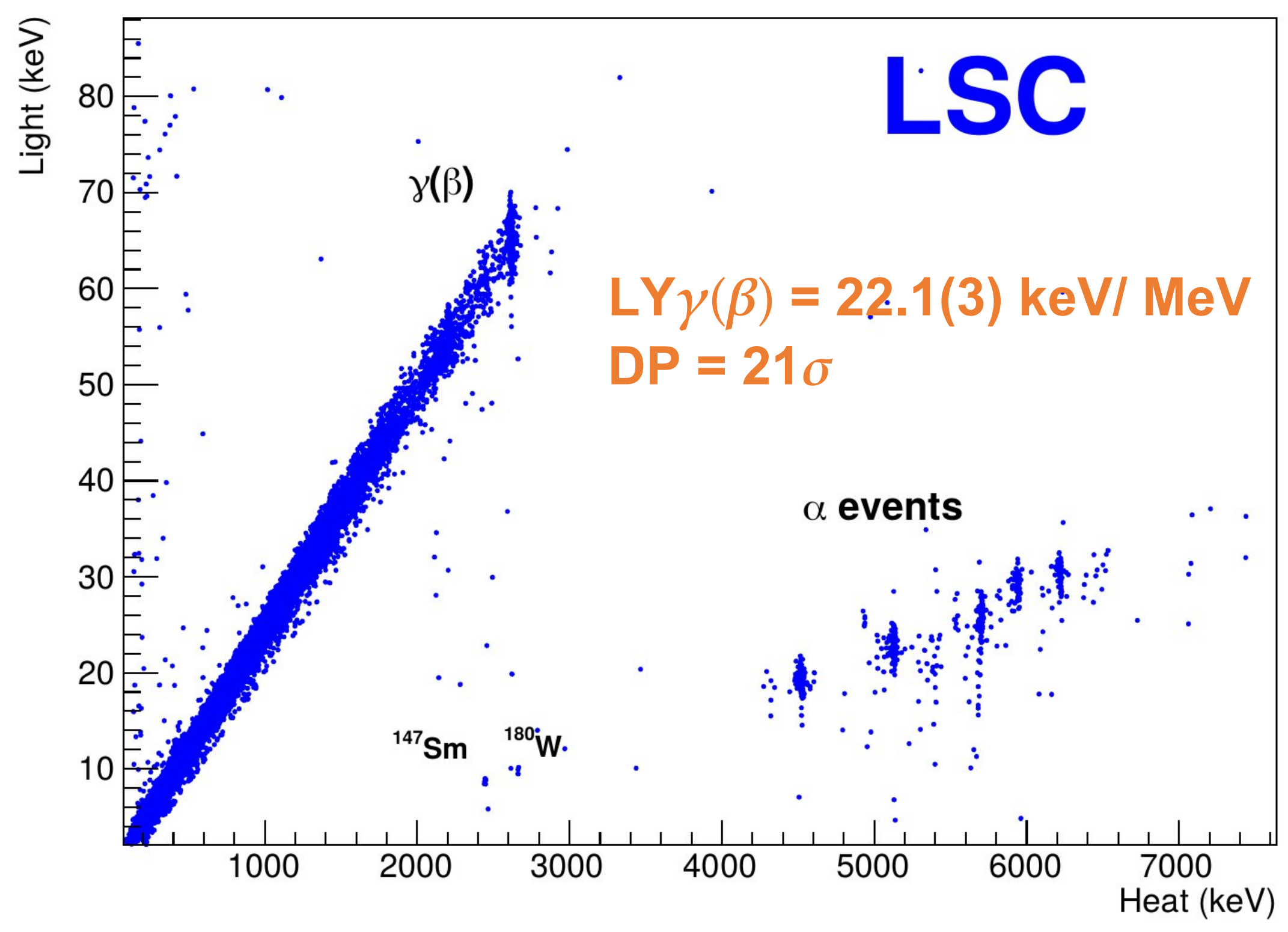
## Results of the underground test of two enriched $^{116}$CdWO$_4$ scintillating bolometers



- High energy resolution: **11.1(1) and 16.1(3) keV FWHM for $^{116}$CdWO$_4$ No.1 and No. 2 respectively**.
- Such difference can be explained: the detector No. 2 has no mechanical decoupling from the pulse tube cryostat.
- About one order of magnitude better than the energy resolution of scintillating counters based on these crystals.







**Scatter plot light versus heat shows full separation between $\gamma(\beta)$ and $\alpha$ events.**

- Two alpha contaminations in the energy range 2400--2700 keV ($\gamma$ calibration): one at 2670 keV that corresponds to the alpha decay of $^{180}$W (Q = 2515.29 keV) and the second at 2455 keV which is the alpha decay of $^{147}$Sm (Q = 2310.96 keV).
- In addition to the traces of $^{238}$U/$^{232}$Th radioactive contamination of the $^{116}$CdWO$_4$ crystals, we distinguish two other prominent peaks at 5636 keV and 5902 keV. We assume that these two populations are $^{241}$Am and $^{244}$Cm with Q = 5638 keV and Q = 5902 keV respectively.

## Conclusion

- **Promising results have been achieved with two enriched $^{116}$CdWO$_4$ crystals operated as scintillating bolometers in two different undergound facilities (LSM and LSC).**
- **$^{116}$CdWO$_4$-based bolometric technology provides high energy resolution and effective background discrimination.**
- **We have estimated the radiopurity of the crystal: we distinguish 7 alphas populations.**

### Radiopurity of the crystals

| Chain | Nuclide | Activity (mBq/kg) | | | |
|---|---|---|---|---|---|
| | | Scintillating bolometer at LSM | Scintillating bolometer at LSC | Combined | Aurora experiment |
| | $^{147}$Sm | 0.018(3) | 0.019(5) | 0.018(2) | |
| | $^{180}$W | 0.009(2) | 0.010(4) | 0.09(2) | |
| | $^{241}$Am | 0.12(1) | 0.24(2) | 0.18(1) | |
| | $^{244}$Cm | 0.19(2) | 0.24(1) | 0.21(1) | |
| $^{232}$Th | $^{232}$Th | 0.010(4) | 0.013(4) | 0.11(2) | 0.07(2) |
| $^{238}$U | $^{238}$U | 0.29(2) | 0.53(3) | 0.41(2) | 0.58(4) |
| | $^{234}$U | 0.32(6) | 0.48(3) | 0.40(3) | 0.6(1) |
| | $^{210}$Po | 0.27(2) | 0.34(2) | 0.30(1) | |
| $^{235}$U | $^{235}$U | 0.021(2) | 0.038(8) | 0.029(4) | |
| | $^{231}$Pa | 0.037(6) | 0.067(9) | 0.052(5) | |

The radiopurity of the crystal No. 1 (which was cut from the upper part of the boule) is higher because of the segregation of contaminants during the cadmium tungstate crystal growth.

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