$CdWO_4$ scintillating bolometers to search for $0\nu\beta\beta$ decay of ^{116}Cd

GDR Neutrino online meeting
23-24/11/2020
Dounia Helis

Outline

- Neutrinoless double beta decay and ^{116}Cd
- Tests of $^{116}CdWO_4$ as scintillating bolometers
- Performances of $^{116}CdWO_4$ at LSM and LSC
- $0\nu\beta\beta$ sensitivity with $^{116}CdWO_4$ at LSM
- Low energy threshold $CdWO_4$ scintillating bolometer
- Conclusion and prospect

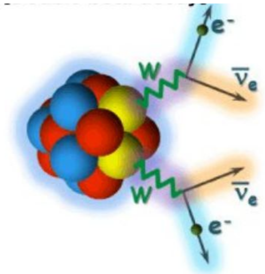
Neutrinoless double beta decay in a nutshell

Two neutrino double beta decay

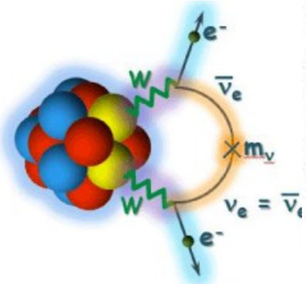
- Allowed by the Standard Model (SM) and observed experimentally for 11 nuclei
- $(A,Z) \rightarrow (A,Z+2) + 2e^{-} + 2\nu_e$
- Rarest decay observed $T_{1/2} \sim 10^{18}$-10^{24} yr

Neutrinoless double beta decay

- Forbidden by the SM, violates the lepton number by 2
- $(A,Z) \rightarrow (A,Z+2) + 2e^{-}$
- $T_{1/2} > 10^{24}$-10^{26}yr
- Never observed yet



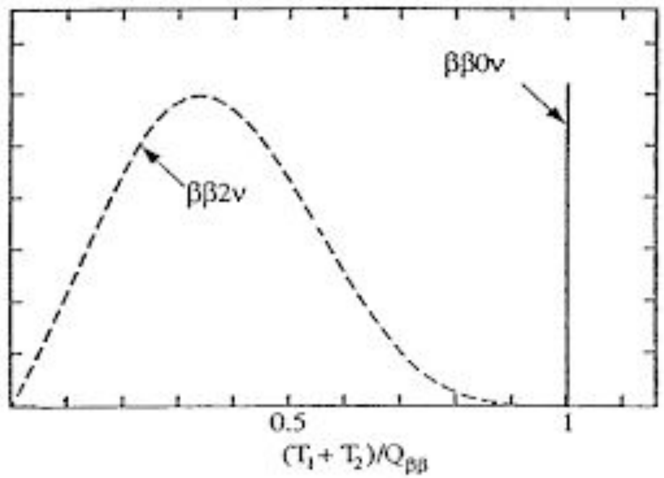
Double beta decay which emits anti-neutrinos



Neutrinoless double beta decay

What are we looking for ?

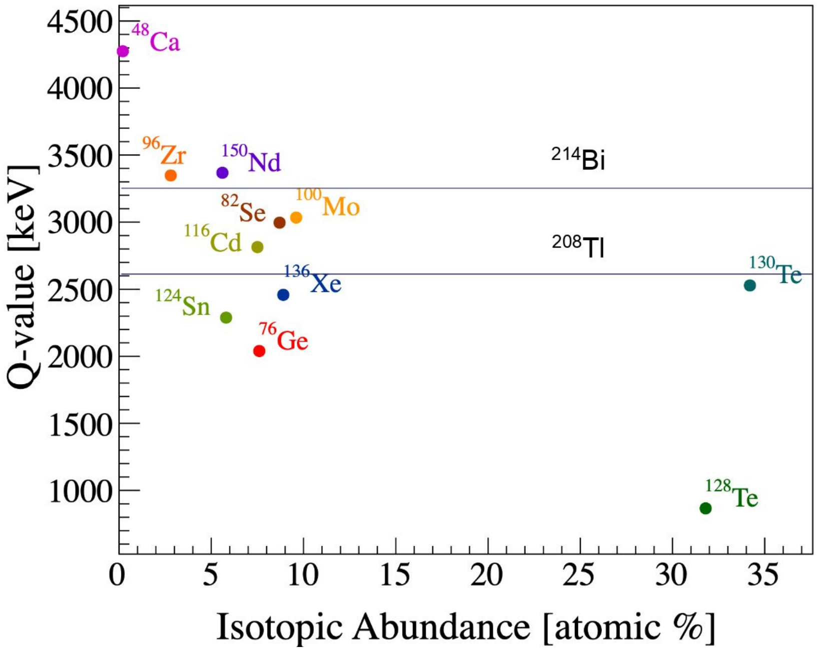
A peak over an almost flat background



^{116}Cd brief ID as a $0\nu\beta\beta$ decay candidate

- ★ Q value of the decay 2813.5 keV
- ★ Isotopic abundance **I.A. = 7. 5 %**
- ★ **Possibility of enrichment** with centrifugal method
- ★ It is possible to embed ^{116}Cd in **$CdWO_4$ crystals** which are well known scintillators

10.1088/1748-0221/6/08/P08011

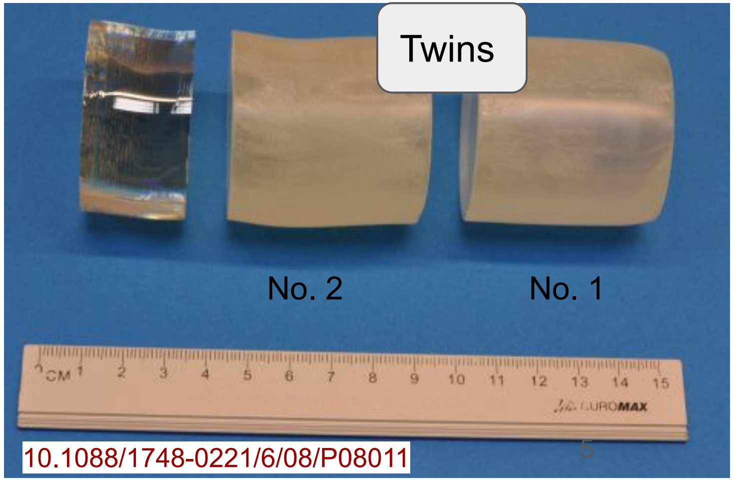


State of art of ^{116}Cd 0νββ experiments

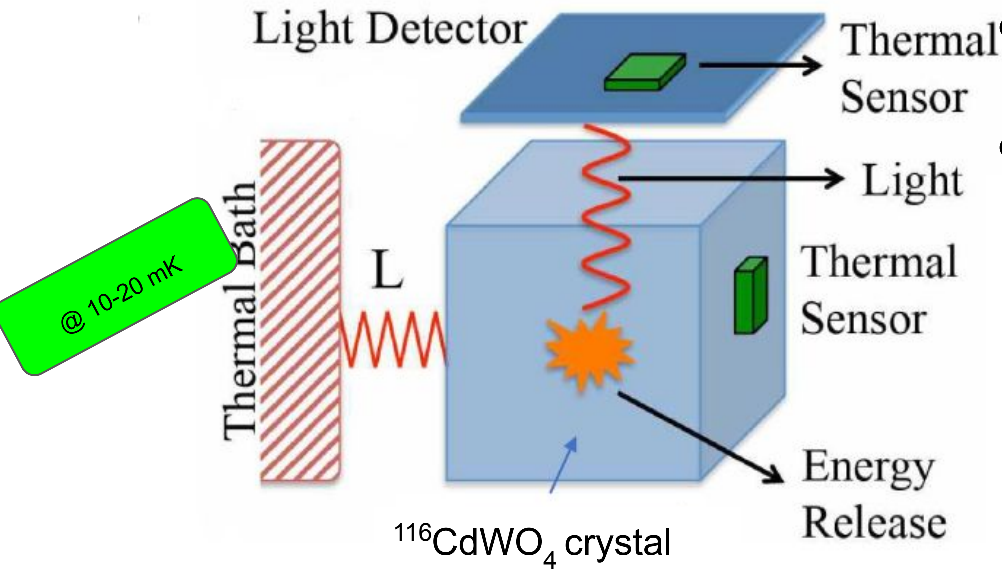
Experiment	Detection technology	Limit on $T_{1/2}$ at 90% CL
Solotvina at Solotvina underground lab in Ukraine	enriched $^{116}CdWO_4$ (~83%) crystal scintillators	1.7 x 10^{23} years https://doi.org/10.1103/PhysRevC.68.035501
NEMO-3 at LSM in France	^{116}Cd foils (~93%) with tracking calorimetric technology	1.0 x 10^{23} years https://doi.org/10.1103/PhysRevD.95.012007
Aurora at LNGS in Italy	enriched $^{116}CdWO_4$ (~82%) crystal scintillators at room temperature	2.2 x 10^{23} years https://doi.org/10.1103/PhysRevD.98.092007

The Aurora experiment used two $^{116}CdWO_4$ crystals (total mass 1.162 kg) as scintillation detectors.

We used the two crystals from Aurora as cryogenic scintillating bolometers. The sample $^{116}CdWO_4$ No. 1 was installed in the EDELWEISS cryostat and $^{116}CdWO_4$ No. 2 was installed in the CROSS cryostat.

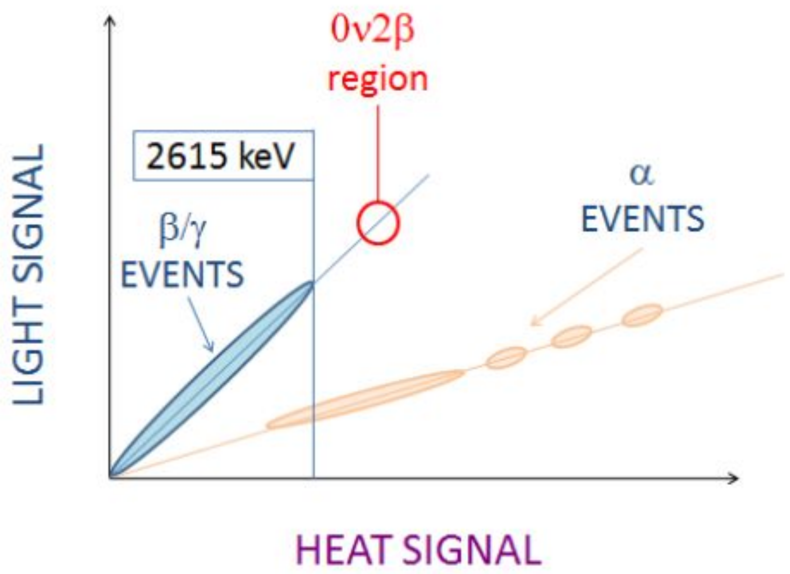


Scintillating bolometers



thermal sensor: **Neutron Transmutation Doped Ge (NTD-Ge)**

- Bolometer⟹high energy resolution
- Double readout⟹ particle ID and full α/β(γ) separation
- Source=detector⟹ high efficiency

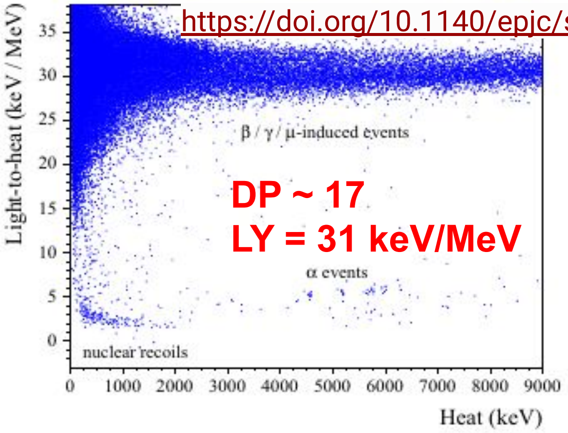


$^{116}CdWO_4$ scintillating bolometers

Motivation

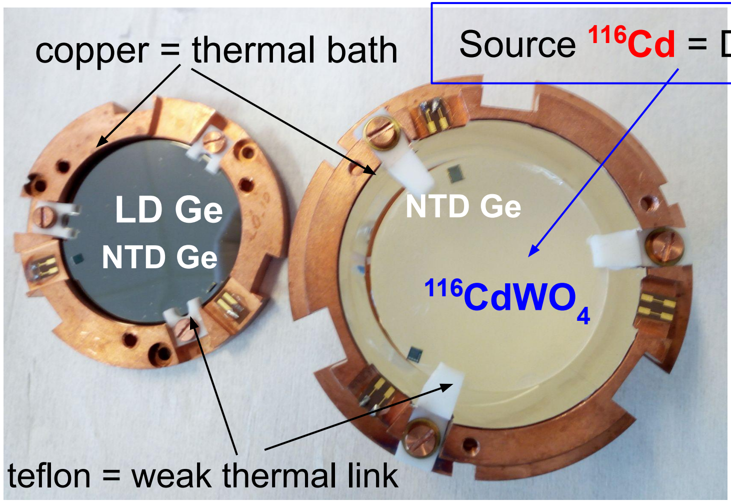
First bolometric test of **34 g $^{116}CdWO_4$** above ground at IJCLab (ex CSNSM) in 2016

https://doi.org/10.1140/epjc/s10052-016-4331-2

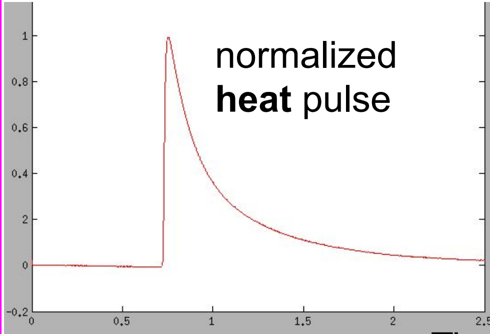


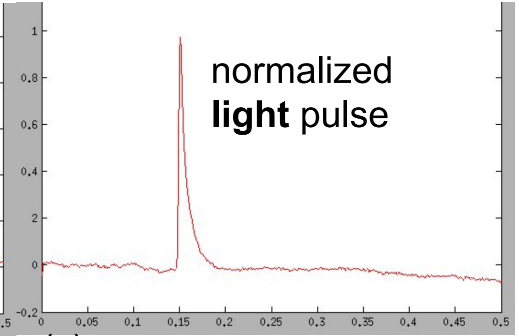
Excellent performances achieved and high radiopurity

Test of two massive crystals (0.6 kg each)



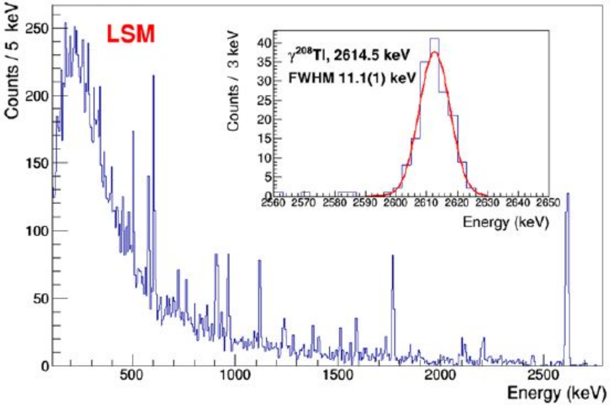
Detector response

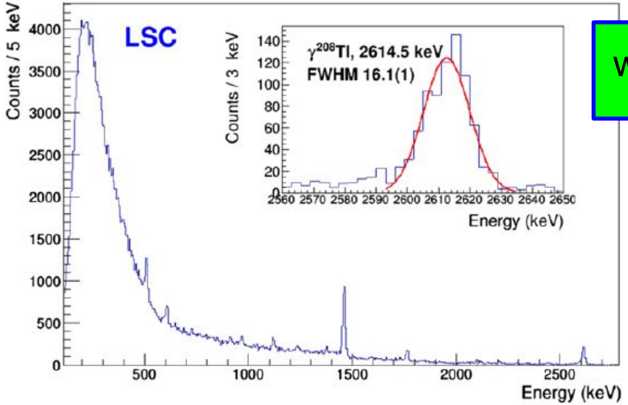




Time (s)

Performances of $^{116}CdWO_4$ scint. bolometers

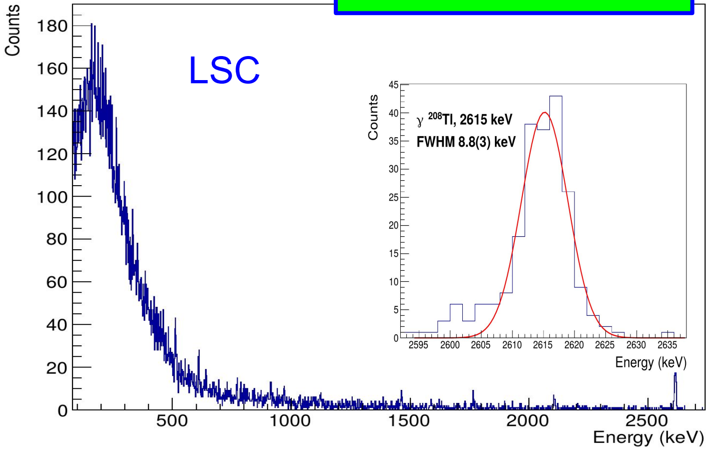




without suspension

$^{116}CdWO_4$ No. 2 at LSC

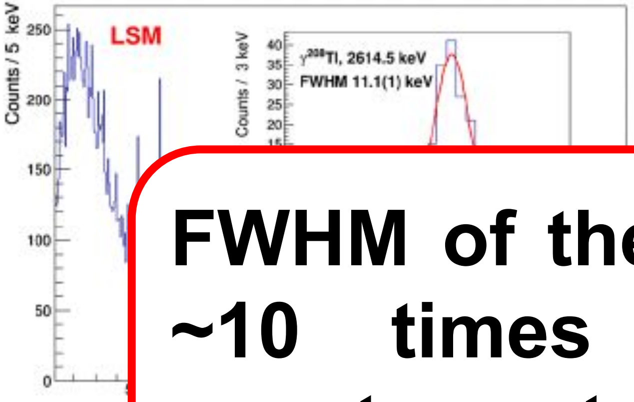
with suspension

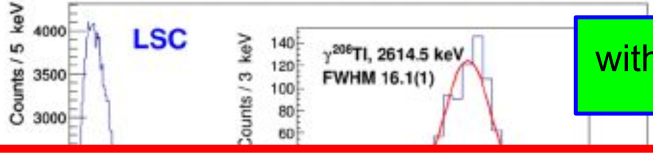


https://doi.org/10.1007/s10909-019-02315-2

Performances	at LSM 20.7 mK	at LSC w.o suspension 10 mk	at LSC with suspension 12 mK
$FWHM_{baselne}$(keV)	2.3	10	3.1
$FWHM_{2615}$(keV)	11	16	9

Performances of $^{116}CdWO_4$ scint. bolometers





without suspension

LSC

ension

FWHM of the scintillating bolometers is ~10 times better then scintillating counters at 2.6 MeV within the Aurora experiment

https://doi.org/10.1103/PhysRevD.98.092007

Performances	at LSM 20.7 mK	at LSC w.o suspension 10 mk	at LSC with suspension 12 mK
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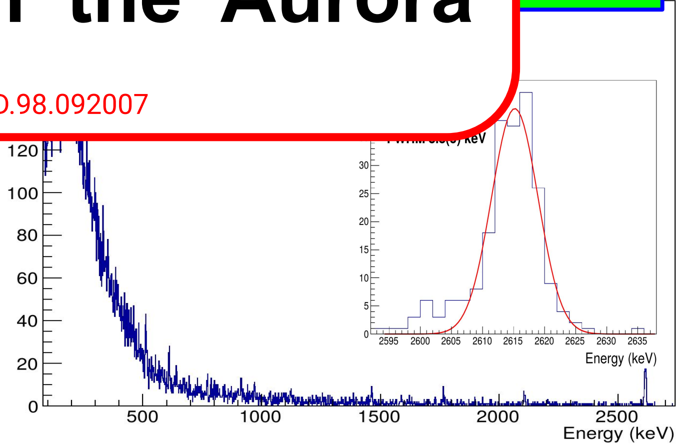
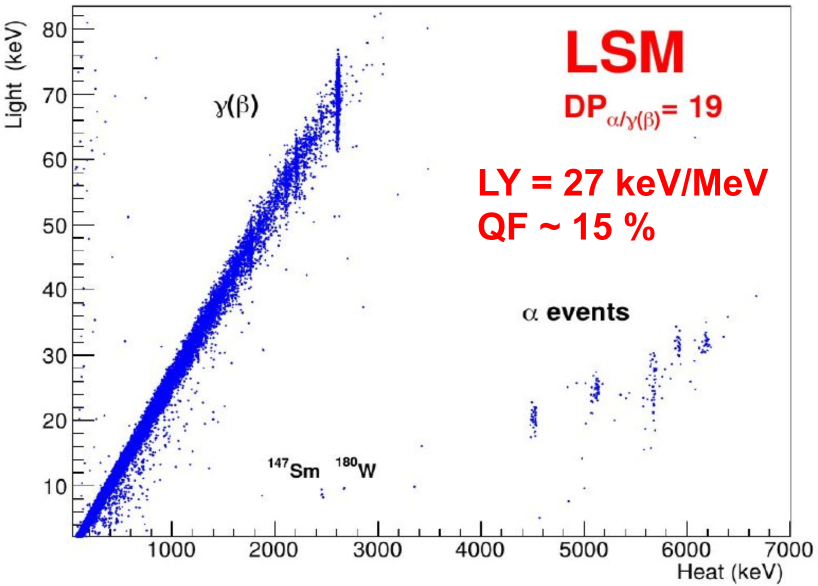
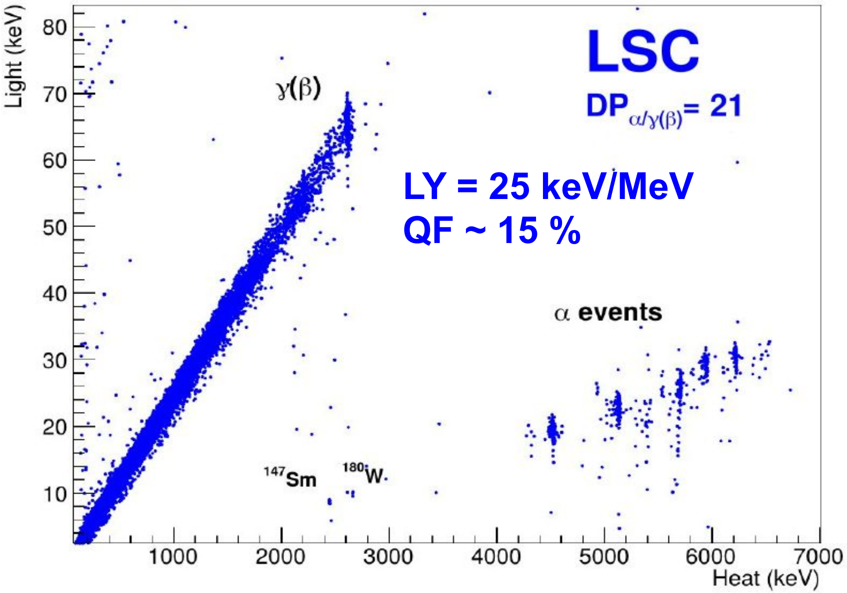


Performances of $^{116}CdWO_4$ scint. bolometers





Performance	No. 1 at LSM	No. 2 at LSC w.o suspension	No. 2 at LSC with suspension
LD $FWHM_{baseline}$ (keV)	0.15	0.36	0.22

https://doi.org/10.1007/s10909-019-02315-2

Radiopurity of $^{116}CdWO_4$ crystal

Scintillating bolometers

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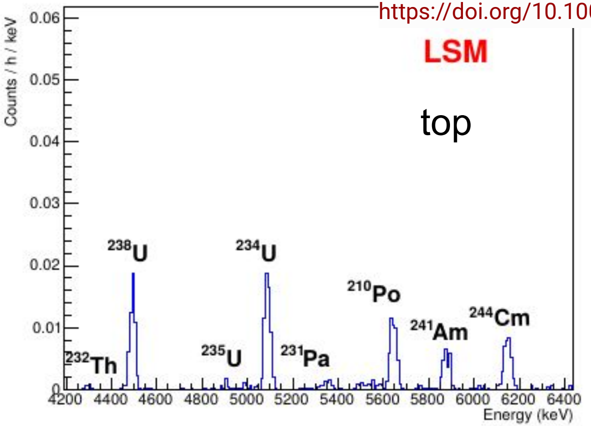
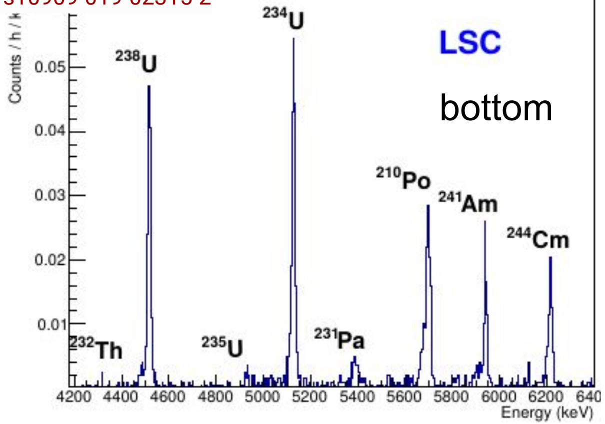
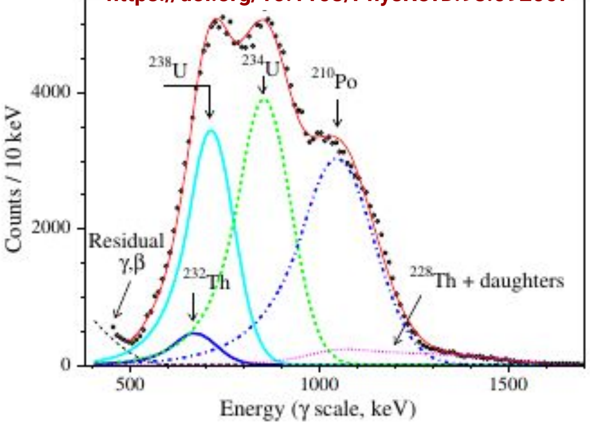


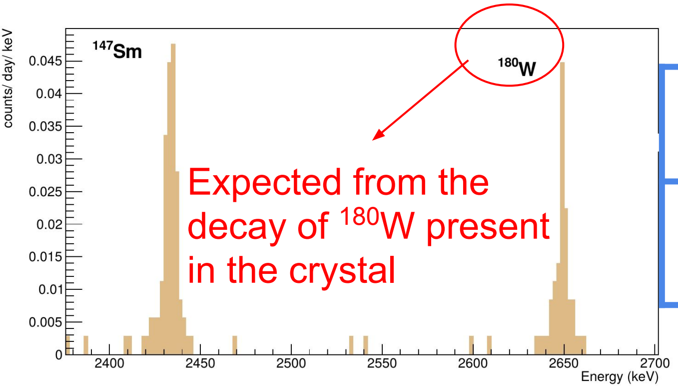


Scintillating counters

https://doi.org/10.1103/PhysRevD.98.092007



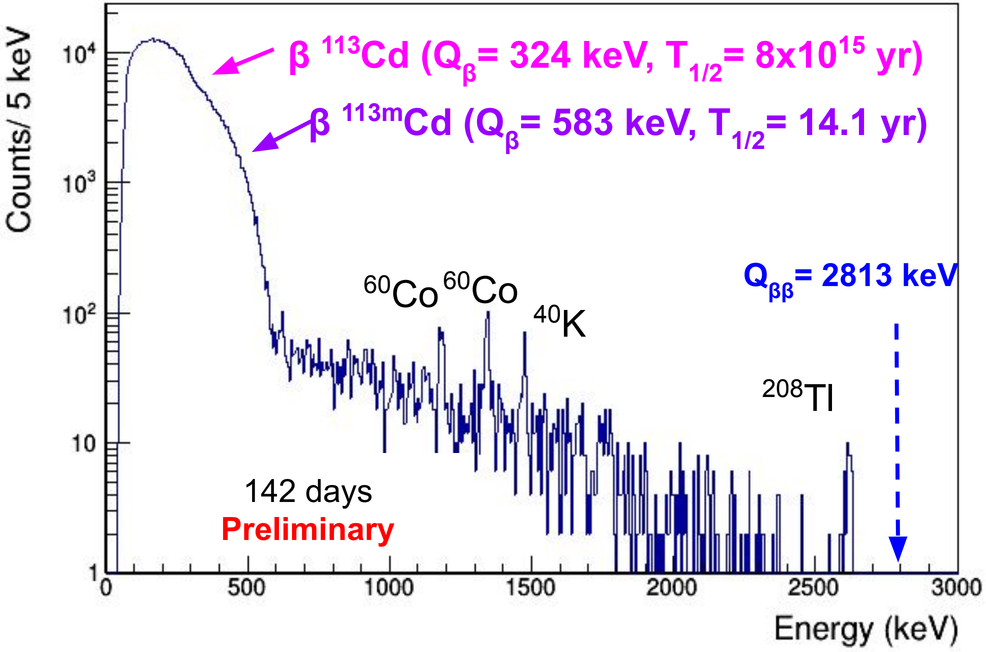
Thermal quenching ~ 6%



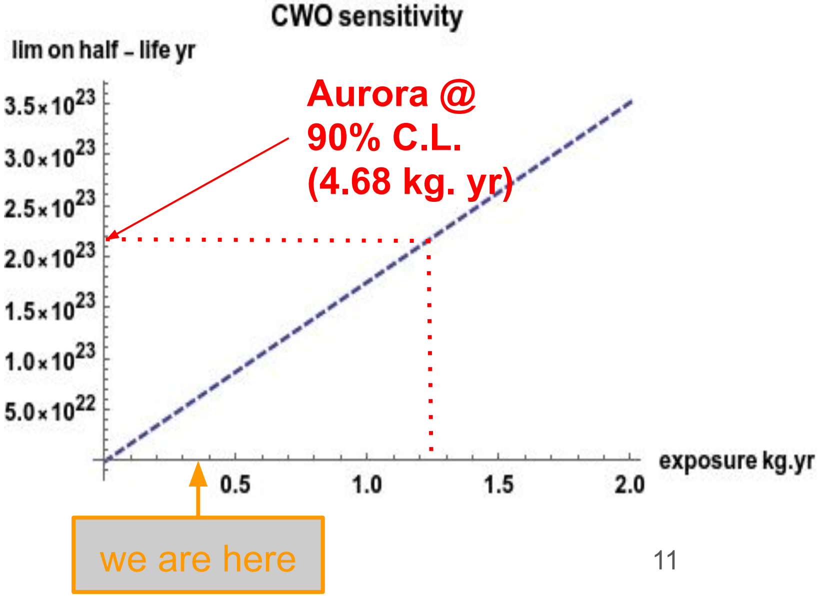
Radioactivity of the crystals

element	^{147}Sm	^{180}W	^{241}Am	^{244}Cm	^{232}Th	^{238}U	^{235}U
activity (mBq/kg)	0.018	0.009	0.18	0.21	0.011	0.41	0.29

$0\nu\beta\beta$ sensitivity with $^{116}CdWO_4$ at LSM



- Data production and analysis finalization is on going
- **Total expected exposure ~ 0.36 kg.y** (March 2019 to July 2020)
- No event in the ROI (142 days)



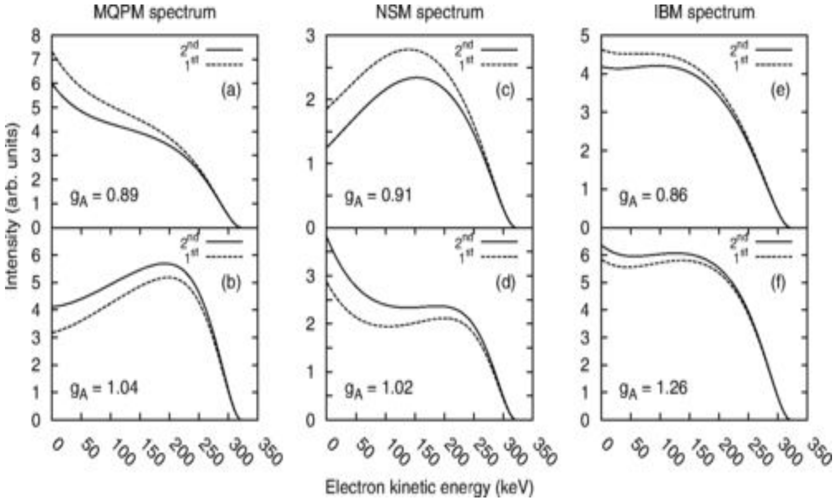
It is possible to set the same limit as Aurora with only 1.3 kg.yr

Low energy threshold $CdWO_4$ scintillating bolometer

- **g_A can be quenched** => the sensitivity to $0\nu\beta\beta$ decay will change
- **How to measure the g_A^{eff}?** in the spectral shape of highly forbidden beta decays
- The Spectral Shape Method: different values of g_A give different spectral shapes.

$$(T^{0\nu}_{1/2})^{-1} = G^{0\nu} g_A^4 |M^{0\nu}|^2 < m_{\beta\beta} >^2$$

https://doi.org/10.1103/PhysRevC.95.024327



https://doi.org/10.1103/PhysRevC.95.024327

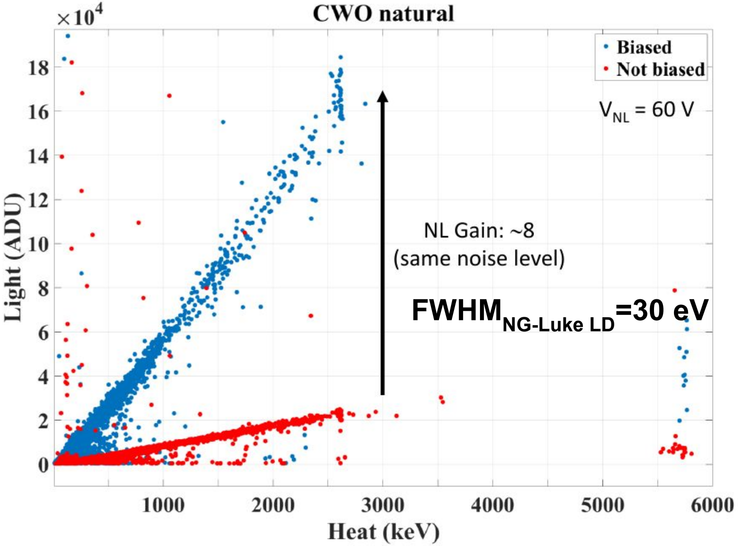
Investigation of the four-fold forbidden β decay in ^{113}Cd. This decay is not masked by other lower order of forbiddenness or allowed beta decays

We are using a natural $CdWO_4$ crystal (12.5% of ^{113}Cd) as a scintillating bolometer at LSC to perform a measurement of g_A.

Low energy threshold $CdWO_4$ scintillating bolometer

Neganov-Luke Ge LD enhances the scintitllation gain by applying a biais

Natural $CdWO_4$ crystal of 433 g. I.A =12.2% of ^{113}Cd
$T_{1/2}(^{113}Cd)=8x10^{15}$ yr

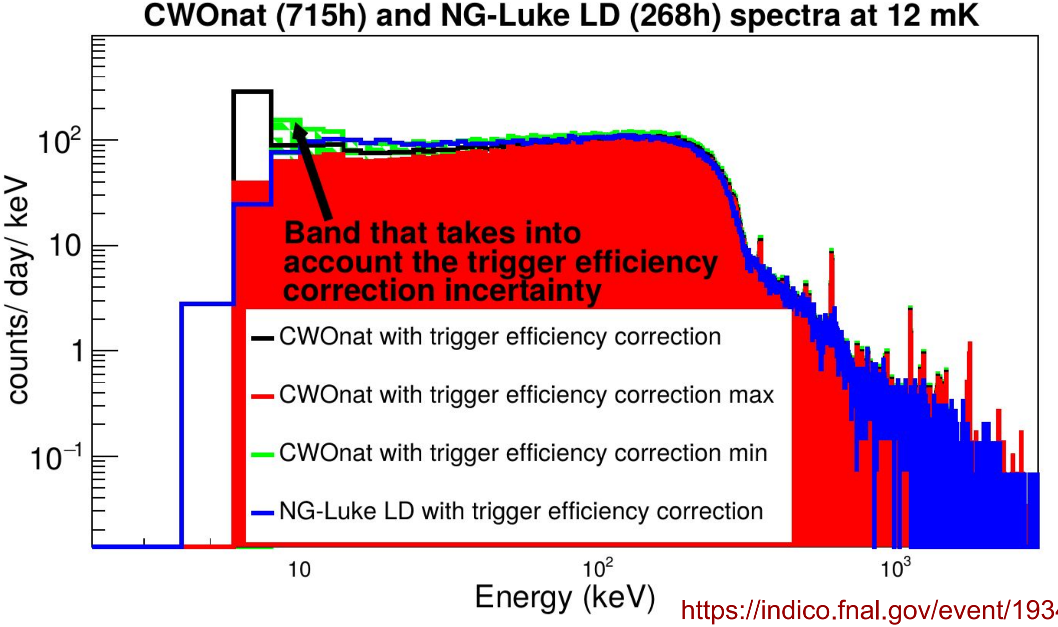


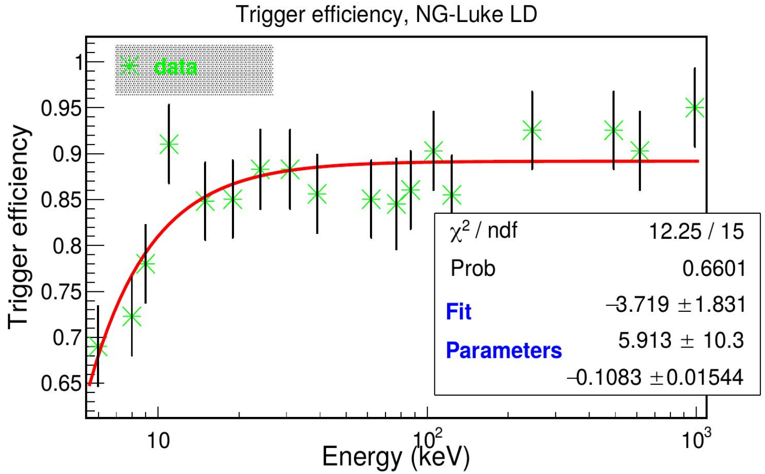
Crystal's main Performances

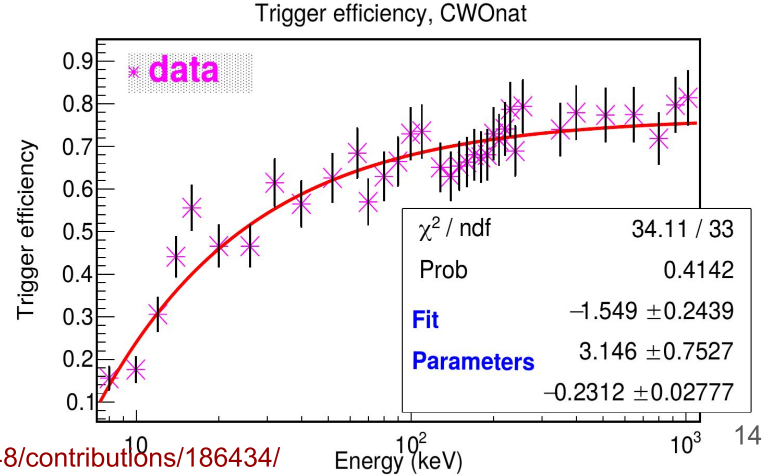
$FWHM_{CWOnat}$(noise) = 3.2 keV
$FWHM_{CWOnat}$(2.6 MeV) =8.9 keV
LY = 14.7 keV/MeV

Low energy threshold $CdWO_4$ scintillating bolometer

We performed a trigger efficiency analysis to correct the experimental spectrum at low energy







https://indico.fnal.gov/event/19348/contributions/186434/

Conclusions and prospects

- Two massive enriched $^{116}CdWO_4$ crystals (~ 0.6 kg each) were operated successfully as scintillating bolometers for the first time

- The twin scintillating bolometers were installed at LSM and LSC underground laboratories

- The detectors showed very good performances in both underground laboratories in terms of energy resolution (9-16 keV FWHM at 2.6 MeV), PID (~ 20 σ) and high radiopurity

- A competitive limit on the $0\nu\beta\beta$ of decay ^{116}Cd could be set with only 1.3 kg.yr of exposure (to be compared with 4.68 kg.yr with scintillating counters)

- A background model is under study and development for the natural $CdWO_4$ to extract the effective value of g_A

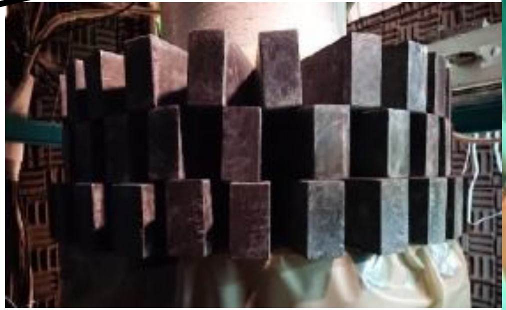
Back-up slides

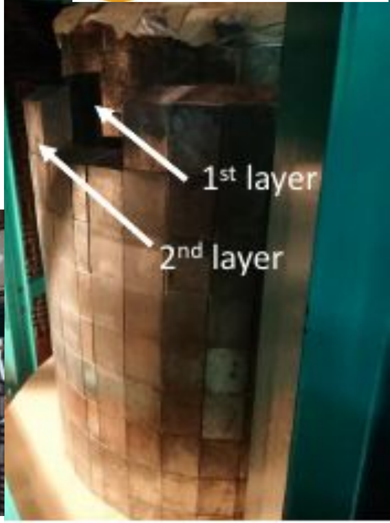
$^{116}CdWO_4$ scint. bolometers in underground laboratories

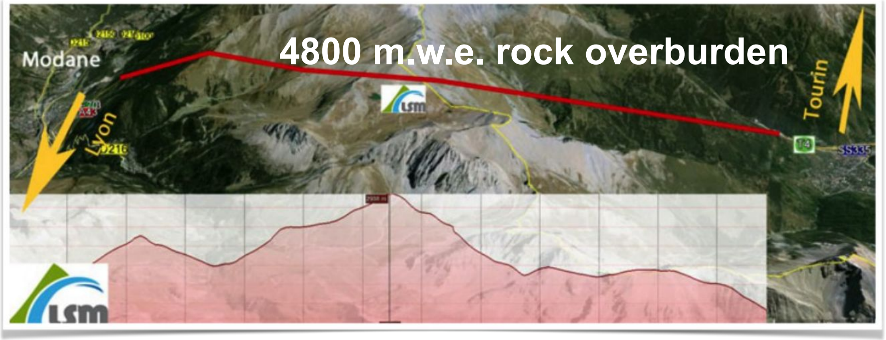
$^{116}CdWO_4$ No. 1

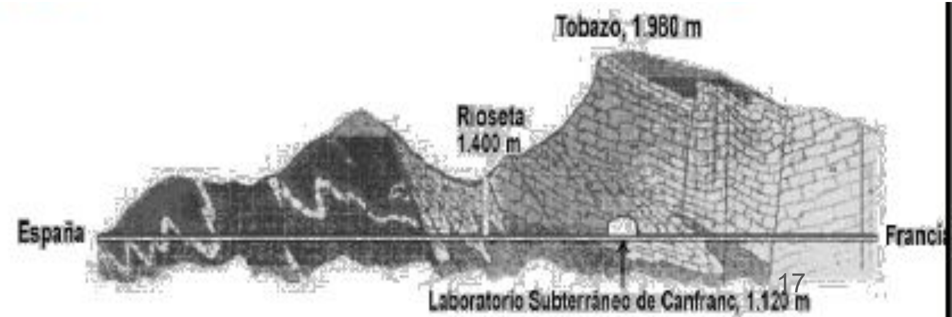
$^{116}CdWO_4$ No. 2

Commissioning in April 2019
The final setup is not finished yet (complete lead shielding, radon box, muon veto,..)







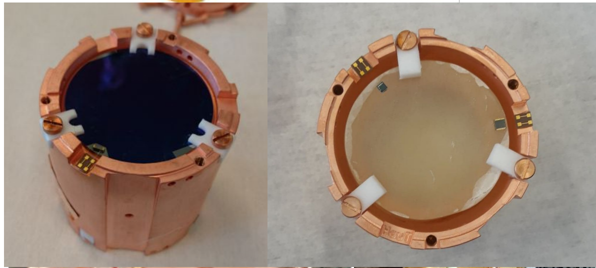


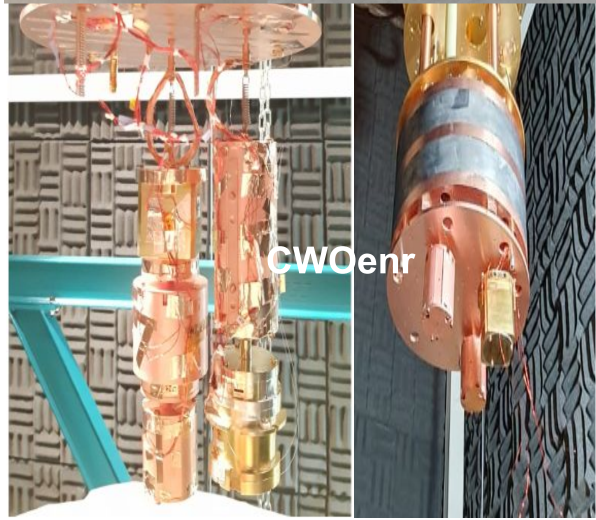
Laboratoire Souterrain de Modane

Laboratorio Subterráneo de Canfranc

Massive $^{116}CdWO_4$ scintillating bolometers in underground laboratories

LSM, France	LSC, Spain
$^{116}CdWO_4$ No.1 ∅45x47 mm ~ 580 g **Ge LD** ∅44x0.17 mm SiO	$^{116}CdWO_4$ No.2 ∅45x47 mm ~ 582 g **Ge LD** ∅44x0.17 mm SiO
EDELWEISS suspended tower 03/2019 to 07/2020 20.7-22 mK	**CROSS** No suspension 04-07/2020 Suspended tower 12/2019 to 04/2020 10-18 mK
Complete shielding anti-radon system muon veto	**Not completed shielding** no anti-radon system no muon veto

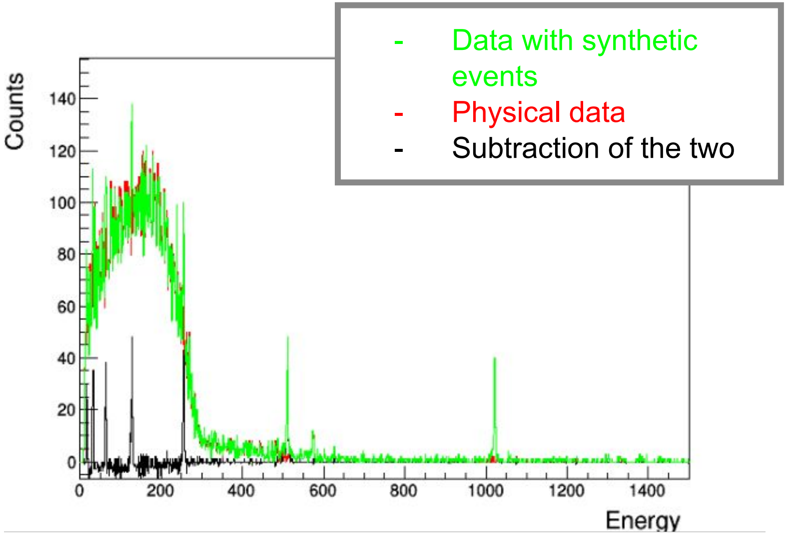


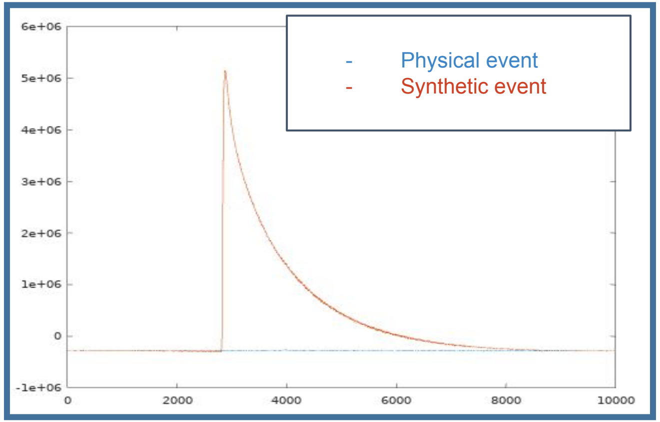


Trigger efficiency measurement

1. *Inject synthetic event,* based on an average pulse of physical event scaled to a given energy, in the stream data
2. Process and analyse the data with the synthetic pulses as physical data
3. Subtract the data with synthetic event from the physical data
4. Compute the integral of each peak that corresponds to the injected events

This work is done on the light and on the heat channel

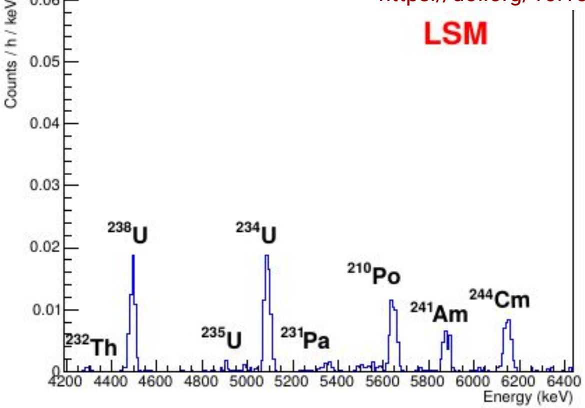


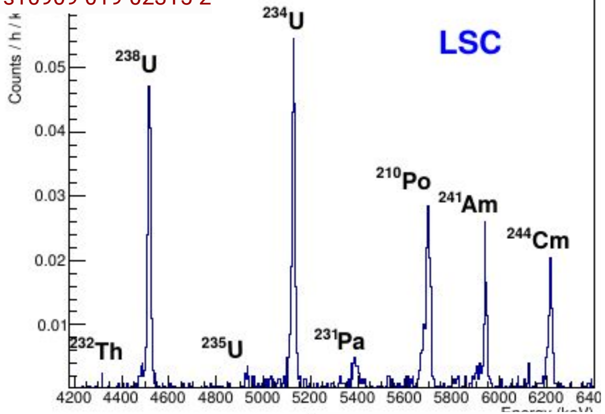


Radiopurity of $^{116}CdWO_4$ crystal

Scintillating bolometers

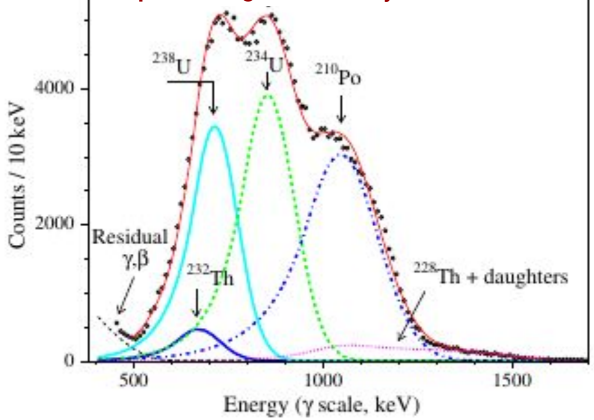
https://doi.org/10.1007/s10909-019-02315-2



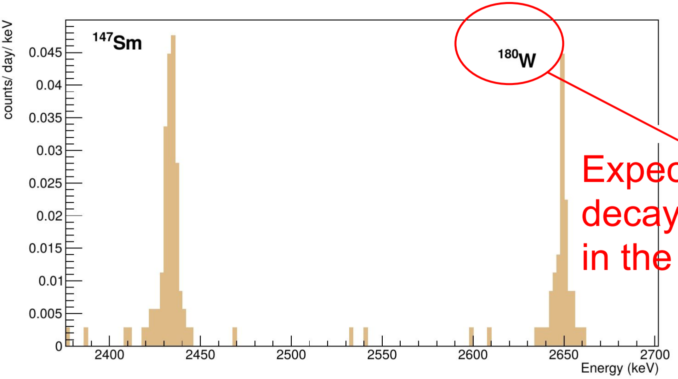


Scintillating counters

https://doi.org/10.1103/PhysRevD.98.092007



Thermal quenching ~ 6%



Expected from the decay of ^{180}W present in the crystal

Chain	Nuclide	Activity (mBq/kg) No. 1 at LSM	No. 2 at LSC	Present work Weighted mean	Present work Combined value	Aurora [15]
	^{147}Sm	0.018(3)	0.019(5)	0.018(3)	0.018(2)	
	^{180}W	0.009(2)	0.010(4)	0.009(2)	0.009(2)	
	^{241}Am	0.12(1)	0.24(2)	0.14(1)	0.18(1)	
	^{244}Cm	0.19(2)	0.24(1)	0.23(1)	0.21(1)	
^{232}Th	^{232}Th	0.010(4)	0.013(4)	0.012(3)	0.011(2)	0.07(2)
^{238}U	^{238}U	0.29(2)	0.53(3)	0.36(2)	0.41(2)	0.58(4)
	^{234}U	0.32(6)	0.48(3)	0.45(3)	0.40(3)	0.60(1)
	^{210}Po	0.27(2)	0.34(2)	0.305(14)	0.30(1)	0.70(4)
^{235}U	^{235}U	0.021(2)	0.038(8)	0.022(2)	0.029(4)	
	^{231}Pa	0.037(6)	0.067(9)	0.046(5)	0.052(5)	