



# ZMO detectors at CSNSM / Modane

D.V. Poda

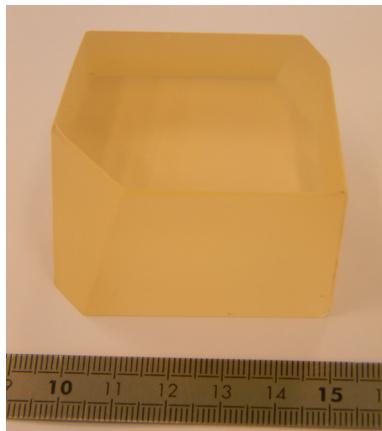
CSNSM, 91405 Orsay, France

Thanks to LUMINEU and EDELWEISS Collaborations

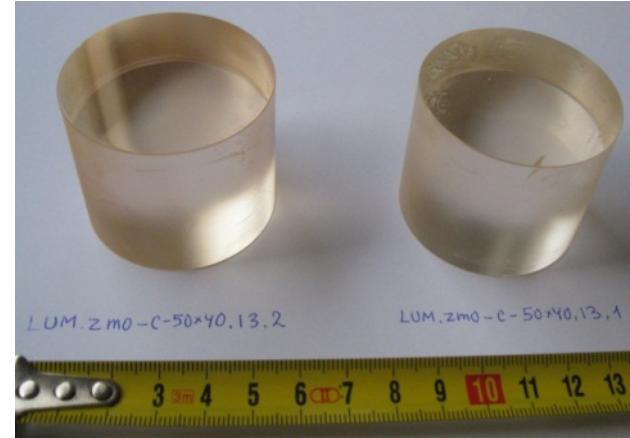
# Zinc molybdate crystals

## Crystals with natural Mo composition

Precursor of LUMINEU program (313 g)

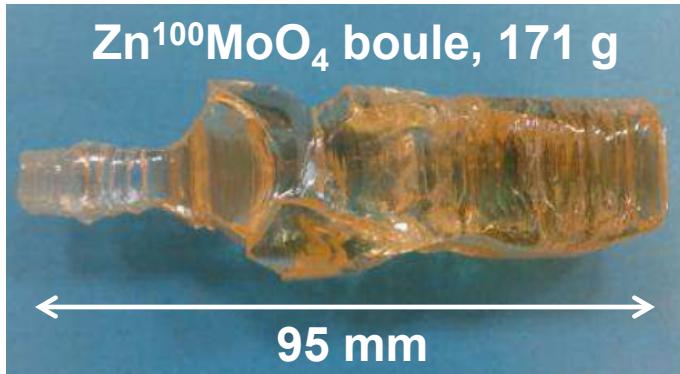


Advanced quality crystals (334 and 336 g)

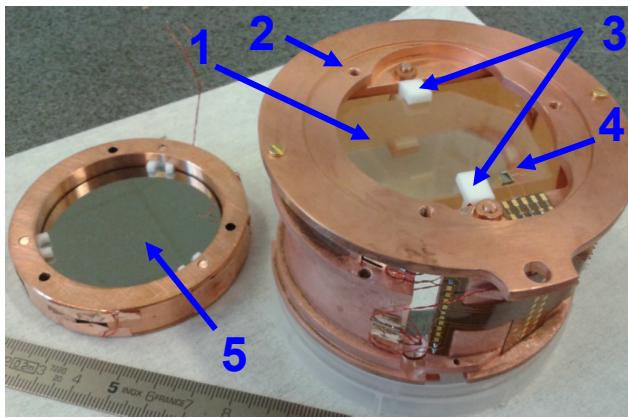


## Crystals enriched in $^{100}\text{Mo}$

$\text{Zn}^{100}\text{MoO}_4$  boule, 171 g

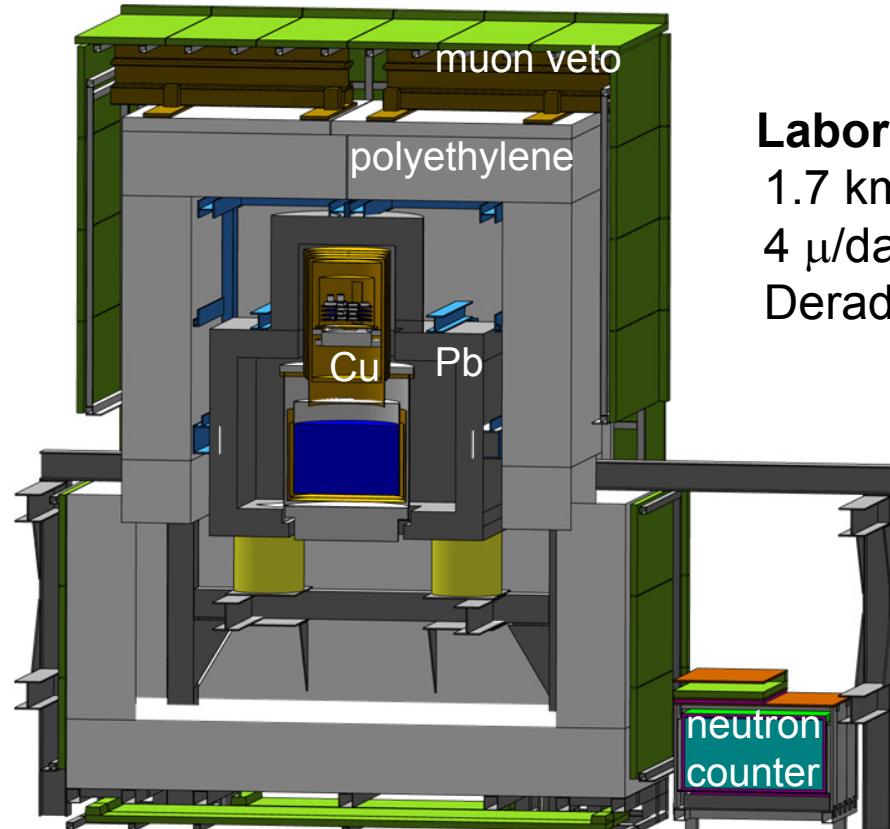
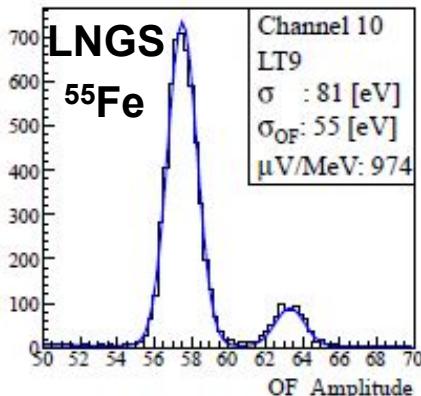


# 313 g ZnMoO<sub>4</sub> bolometer in the EDELWEISS set-up



## ZnMoO<sub>4</sub> scintillating bolometer

- (1) 313 g ZnMoO<sub>4</sub> crystal grown in NIIC (Novosibirsk, Russia)
- (2) Cu holder of the detector
- (3) PTFE supporting elements
- (4) Two NTD thermistors
- (5) Two Ge light detectors



## EDELWEISS set-up

### Laboratoire Souterrain de Modane (LSM, France)

1.7 km rock overburden (4.8 km w.e.)  
4  $\mu$ /day/m<sup>2</sup>; 10<sup>-6</sup> n/day/cm<sup>2</sup> (>1 MeV)  
Deradonized air supply (~30 mBq)

#### Cryostat (50 liters)

15 Ge bolometers

1 ZnMoO<sub>4</sub> bolometer

#### Passive shield

Pb – 20 cm

Polyethylene – 50 cm

#### Detection $\mu$ / n / Ra

Muon veto

Neutron counter

Radon counter

#### Data taking

14 bit ADC

2 kHz sampling rate

Pulse profile  $\approx$  2 s

Working  $T$  was 19 mK

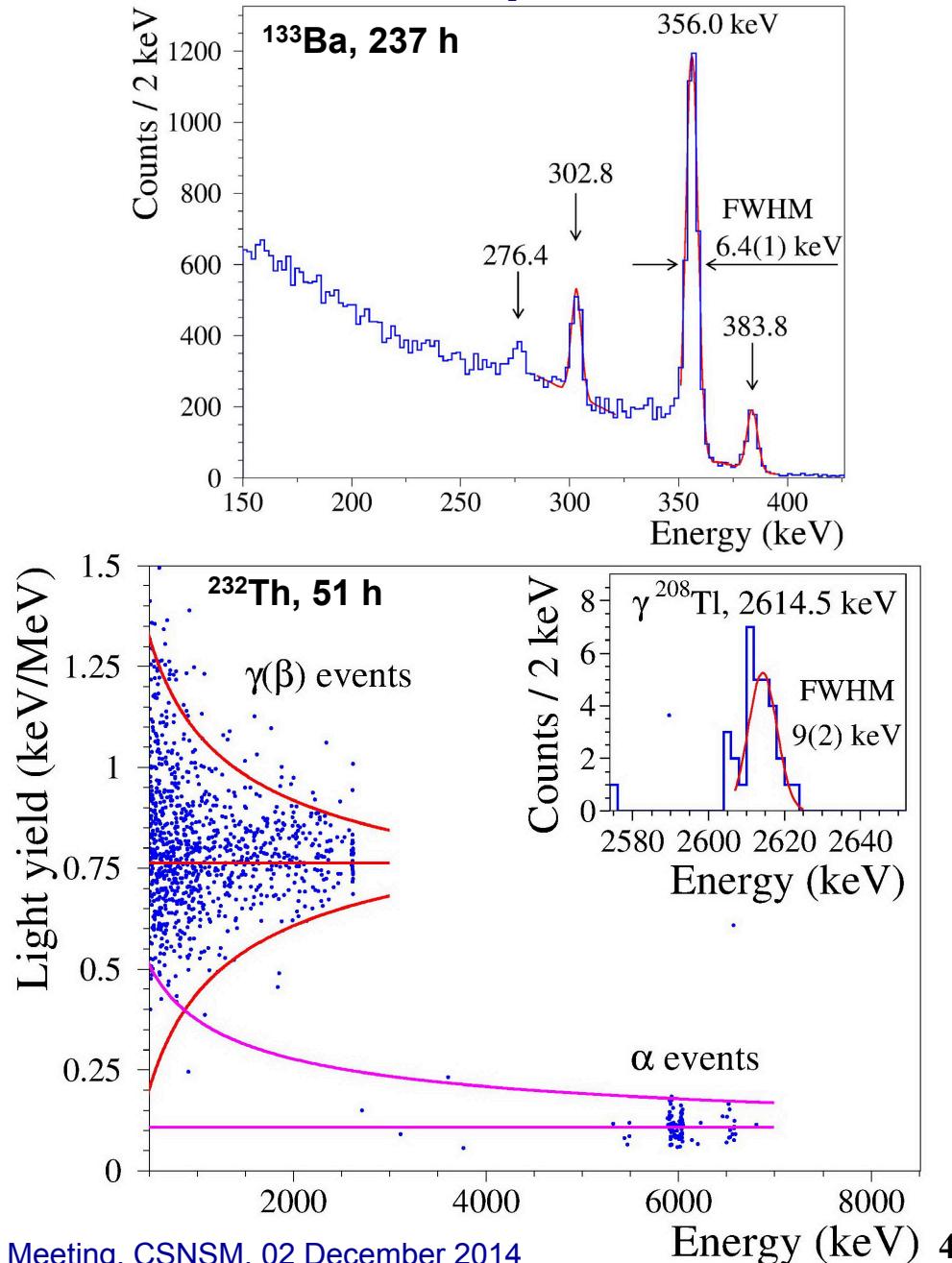
# General performances of 313 g ZnMoO<sub>4</sub> bolometer

Type of measurements	Livetime
Calibration by <sup>133</sup> Ba	<b>546 h</b>
Calibration by <sup>232</sup> Th	<b>70 h</b>
Background	<b>305 h</b>

	Precursor ZMO	
	LSM [1]	LNGS [2]
<b>Mass (g)</b>	<b>313</b>	<b>329</b>
$R_{\text{work}} (\text{M}\Omega)$	<b>1.51</b>	<b>0.63</b>
$A_s (\mu\text{V}/\text{MeV})$	<b>106</b>	<b>16</b>
<b>FWHM<sub>bsl</sub> (keV)</b>	<b>3.3</b>	<b>3.6</b>
$\tau_{\text{Rise}} (\text{ms})$	<b>21</b>	<b>13</b>
$\tau_{\text{Decay}} (\text{ms})$	<b>66</b>	<b>60</b>
<b>LY (keV/MeV)</b>	<b>0.77</b>	<b>1.54</b>

[1] D.V. Poda, to appear in Proc. ICHEP-2014.

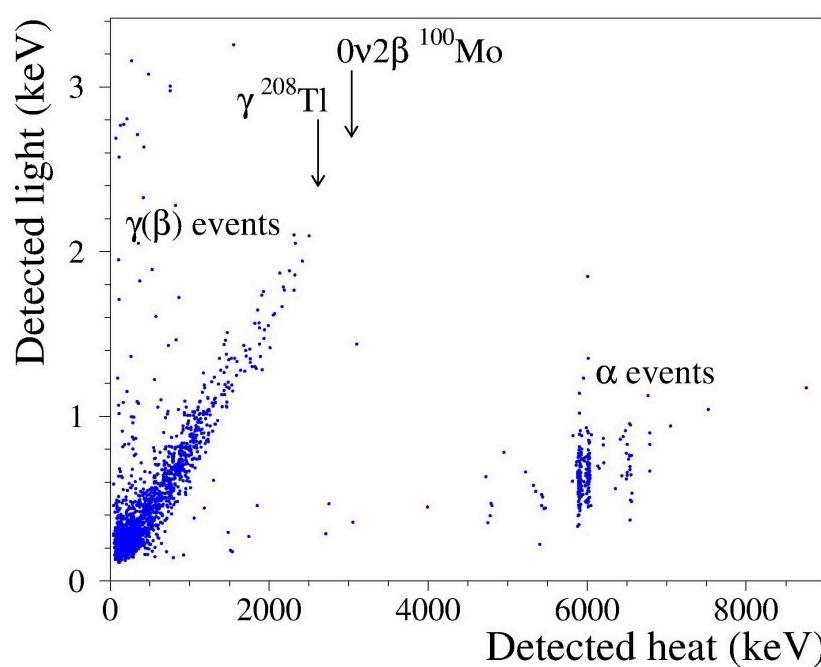
[2] J. Beeman et al., EPJC 72, 2142 (2012).



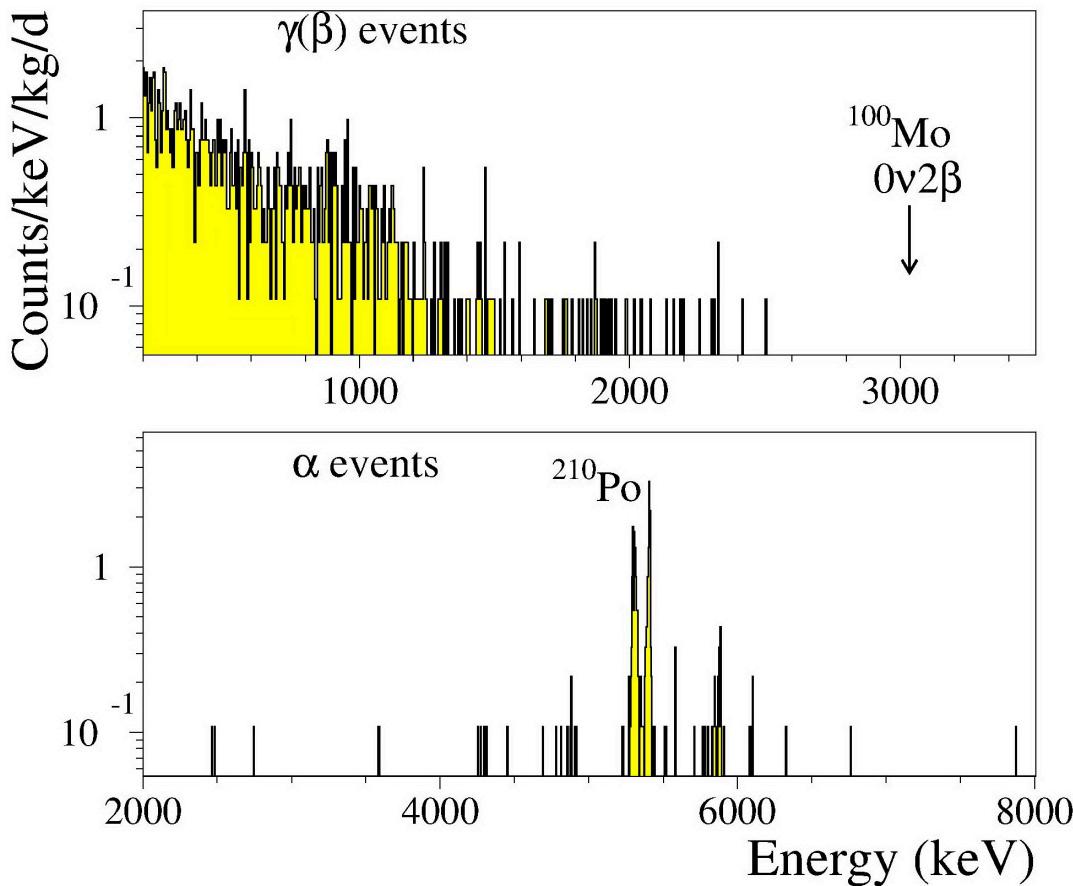
# Background measurements with ZnMoO<sub>4</sub> precursor

ZnMoO<sub>4</sub> 313 g, Background, 141 h, LSM

Heat-vs-Light scatter-plot



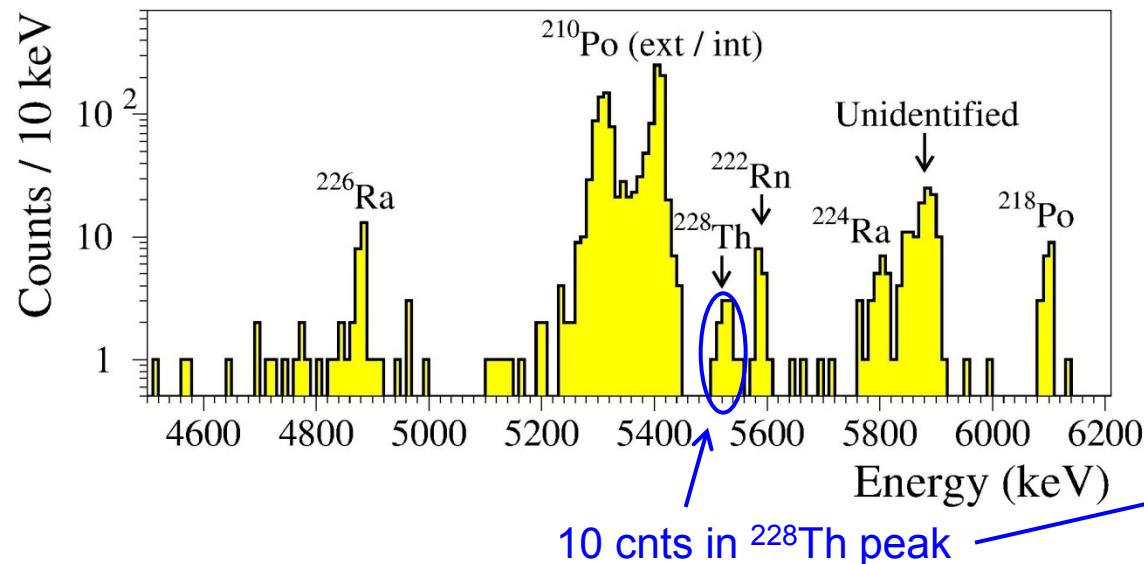
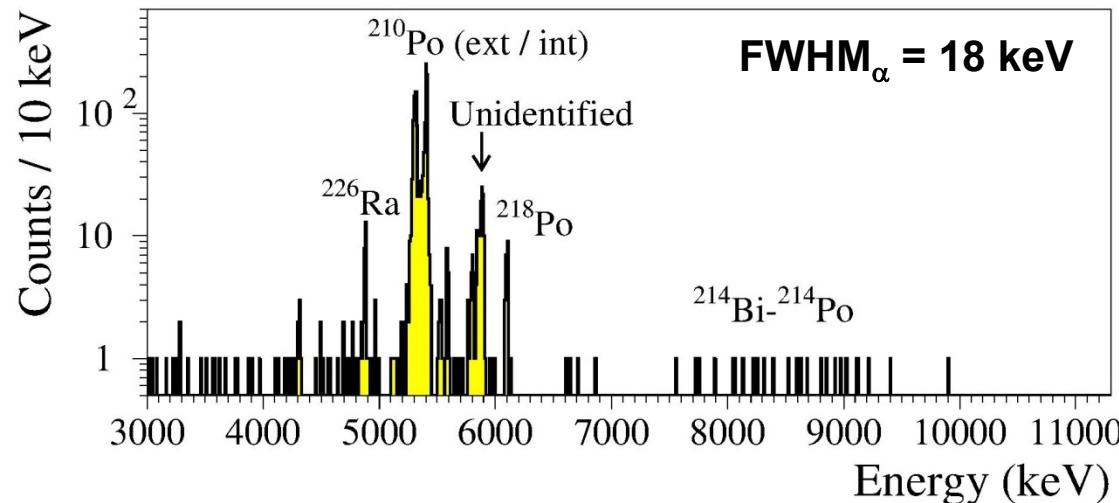
Selected  $\gamma(\beta)$  and  $\alpha$  background



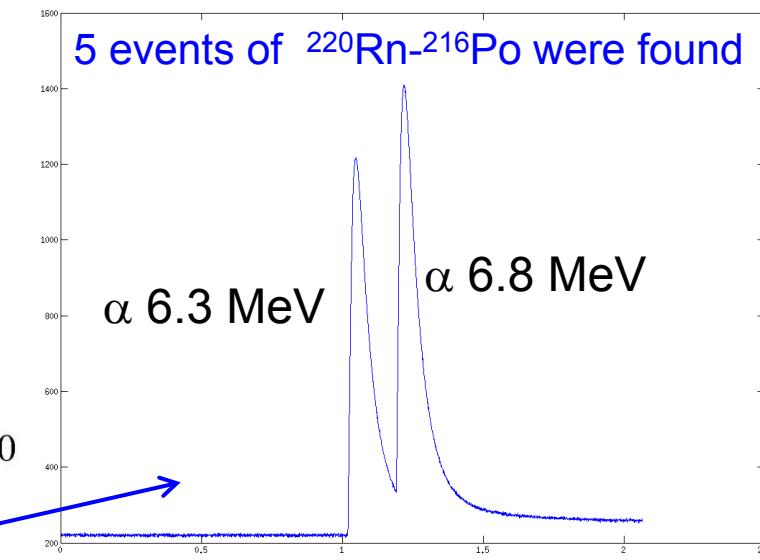
# Alpha background of 313 g ZnMoO<sub>4</sub> crystal

Radiopurity of even LUMINEU precursor is very high

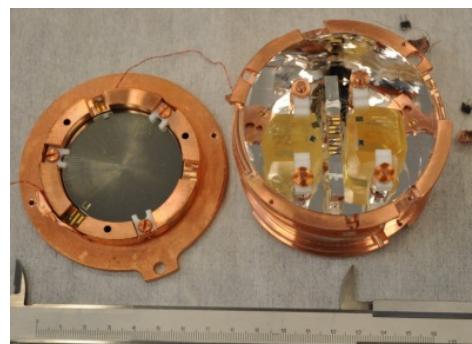
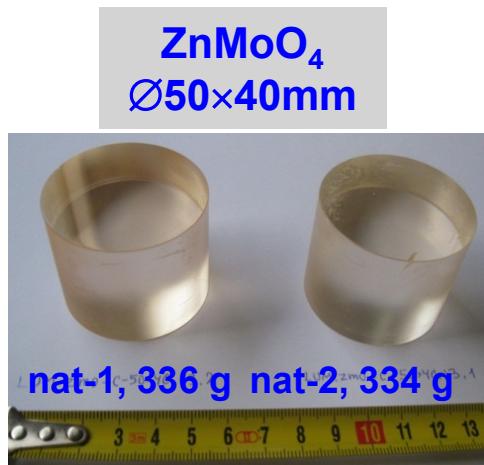
ZnMoO<sub>4</sub> 313 g,  $\alpha$  spectrum, 851 h, LSM



- $^{210}\text{Po}$  ( $620 \mu\text{Bq/kg}$ ),  $^{226}\text{Ra}$  ( $26 \mu\text{Bq/kg}$ ) and  $^{228}\text{Th}$  ( $10 \mu\text{Bq/kg}$ ) are observed
- Only limits ( $\sim 5\text{-}15 \mu\text{Bq/kg}$ ) were set for other  $\alpha$  radionuclides of U/Th
- Sub-chain of  $^{226}\text{Ra}$  ( $^{226}\text{Ra}-^{222}\text{Rn}-^{218}\text{Po}-^{214}\text{Bi}-^{214}\text{Po}$ ) is observed in equilibrium, as it is expected
- The presence of  $^{228}\text{Th}$  is confirmed by observation of short-lived  $\alpha$ -active daughters ( $^{220}\text{Rn}-^{216}\text{Po}$ )



# New ZMO-based scintillating bolometers for LUMINEU



## New LUMINEU bolometers

- ZnMoO<sub>4</sub> and Zn<sup>100</sup>MoO<sub>4</sub> crystals
- Copper holders
- PTFE supporting elements
- NTD temperature sensors
- Heating elements
- Ge photodetectors

## Detectors developing

- Deep purification [1,2] natural and enriched (99% <sup>100</sup>Mo) molybdenum
- Crystal growth using advanced technique based on low-thermal-gradient Czochralski method (high crystal yield ~85%, low irrecoverable losses of Mo <4%)
- Construction of scintillating bolometers from new crystals and Ge-based light detectors (photodetectors, Zn<sup>100</sup>MoO<sub>4</sub> array were tested with good performances at CSNSM)

[1] L. Bergé et al., JINST 9, P06004 (2014).

[2] A.S. Barabash et al., EPJC 74, 3133 (2014).

# Aboveground test of Zn<sup>100</sup>MoO<sub>4</sub> array at CSNSM

Zn<sup>100</sup>MoO<sub>4</sub> show bolometric properties similar to ZnMoO<sub>4</sub> detectors



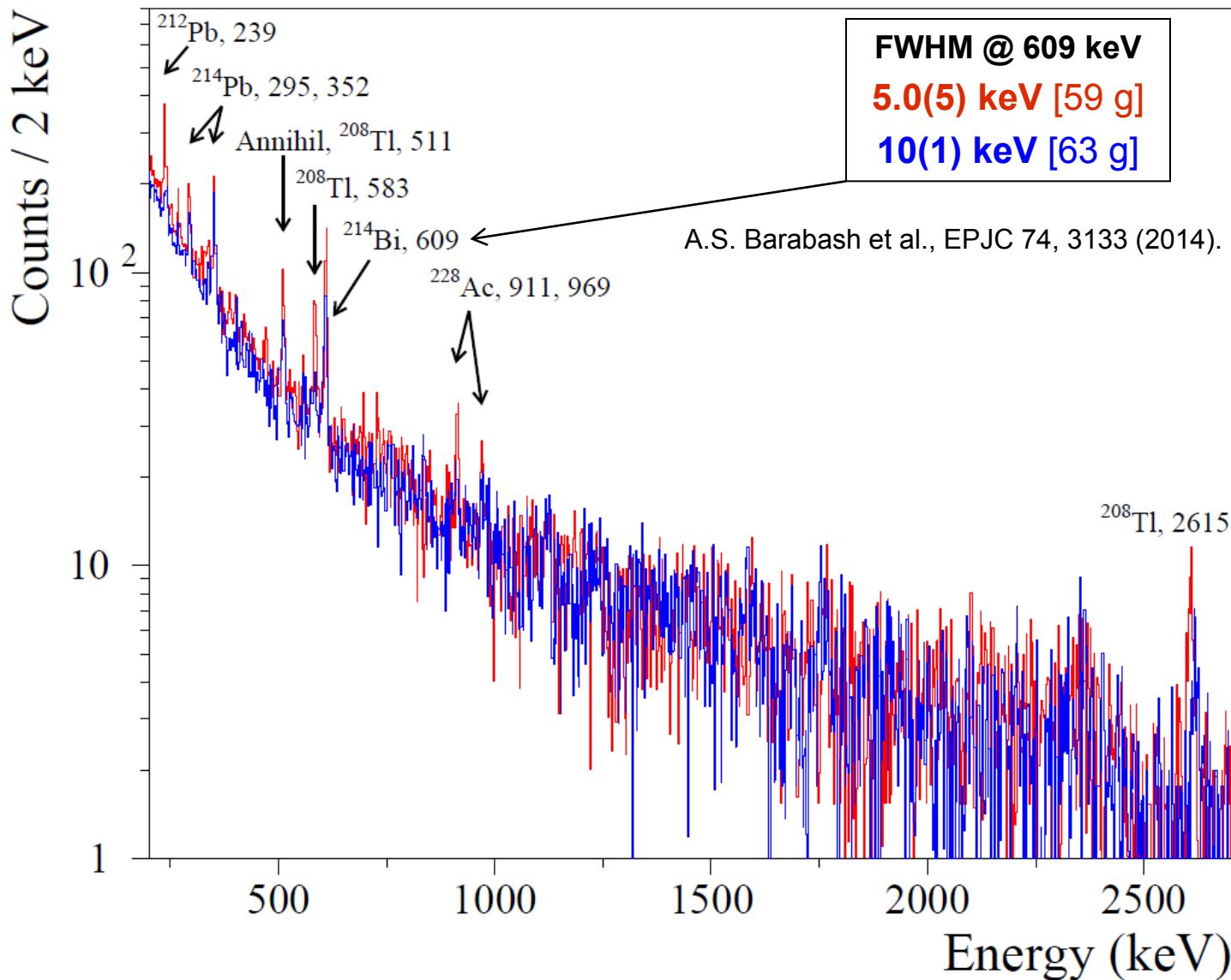
- Pulse tube cryostat with a high power dilution refrigerator
- DC readout low noise electronic in a Faraday cage
- Stream data recorded by 16 bit ADC with 10 kHz sampling rate
- Working  $T$  in mK (time of run): 13.7 (18 h), 15 (5 h), 19 (24 h)
- Calibration by means of <sup>232</sup>Th source and environmental  $\gamma$ 's

Bolometer	Zn <sup>100</sup> MoO <sub>4</sub> [1]	ZnMoO <sub>4</sub> [2]
<b>Mass (g)</b>	<b>59</b>	<b>63</b>
<b><math>T_{\text{work}}</math> (mK)</b>	<b>13.7</b>	<b>13.7</b>
<b><math>R_{\text{work}}</math> (<math>M\Omega</math>)</b>	<b>1.54</b>	<b>1.82</b>
<b><math>A_s</math> (<math>\mu\text{V}/\text{MeV}</math>)</b>	<b>87</b>	<b>96</b>
<b>FWHM<sub>bsl</sub> (keV)</b>	<b>1.4</b>	<b>1.8</b>
<b><math>\tau_{\text{Rise}}</math> (ms)</b>	<b>9.0</b>	<b>5.5</b>
<b><math>\tau_{\text{Decay}}</math> (ms)</b>	<b>46</b>	<b>26</b>
<b>LY (keV/MeV)</b>	<b>1.01</b>	<b>0.93</b>
		<b>1.8</b>

[1] A.S. Barabash et al., EPJC 74, 3133 (2014). [2] M. Mancuso et al., JLTP 176(2014)571.

# Aboveground test of Zn<sup>100</sup>MoO<sub>4</sub> array at CSNSM

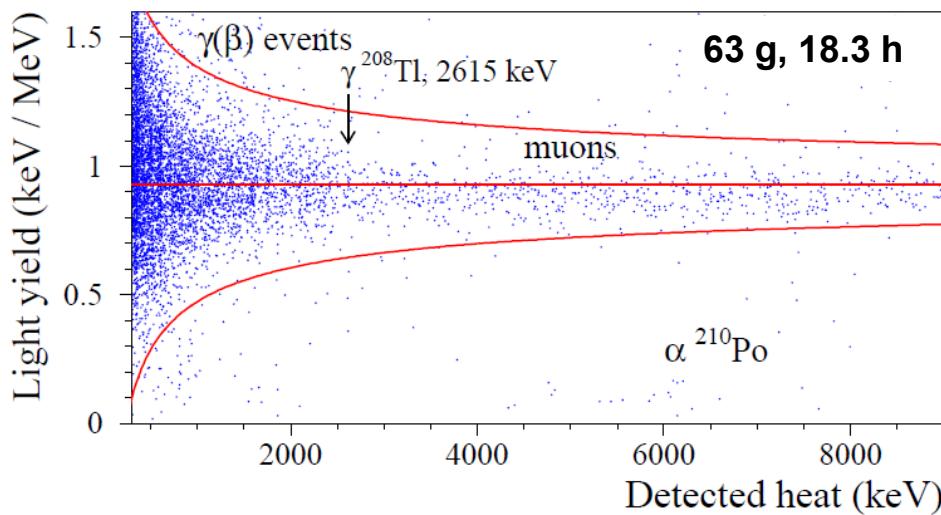
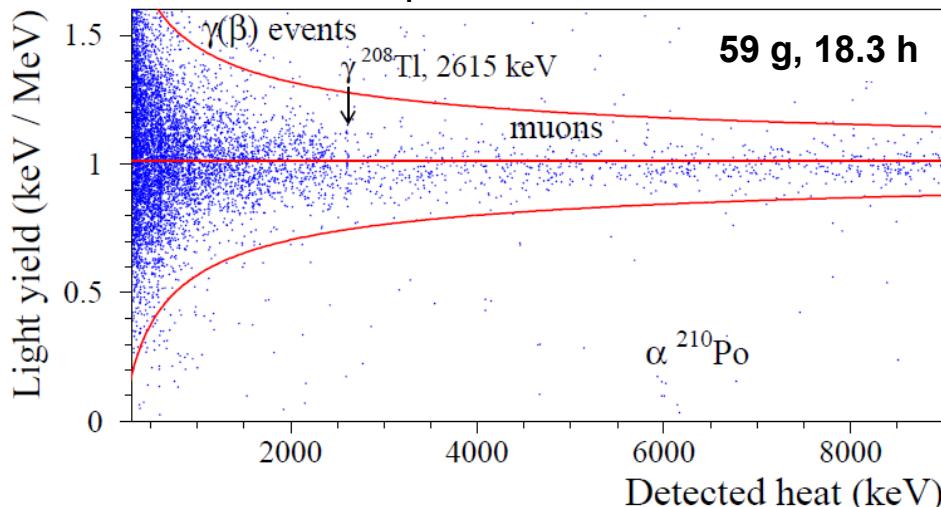
Both Zn<sup>100</sup>MoO<sub>4</sub> bolometers show good performance



# Aboveground test of Zn<sup>100</sup>MoO<sub>4</sub> array at CSNSM

Encouraging radiopurity of the Zn<sup>100</sup>MoO<sub>4</sub> crystals

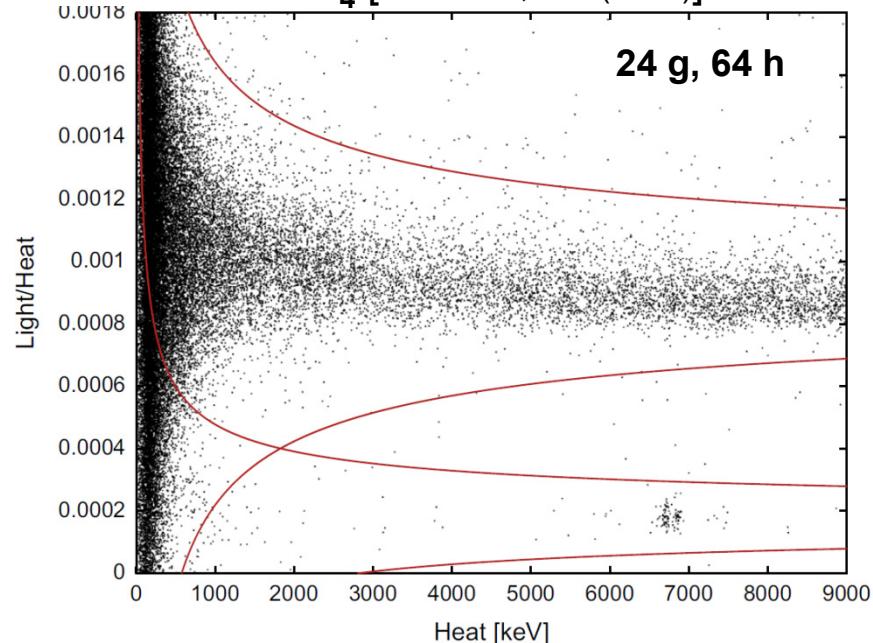
Zn<sup>100</sup>MoO<sub>4</sub> [EPJC 74, 3133 (2014)]



Activity of  $^{210}\text{Po} \sim 1 \text{ mBq/kg}$

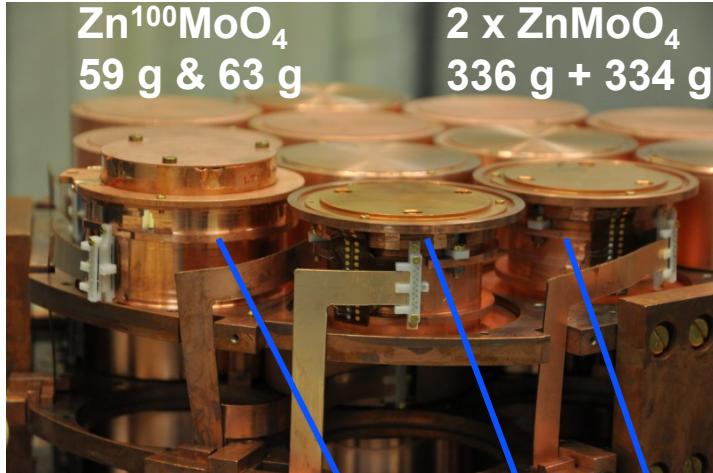
Total  $\alpha$  activity  $\sim (3\text{-}5) \text{ mBq/kg}$

ZnMoO<sub>4</sub> [NIMA 729, 856 (2013)]



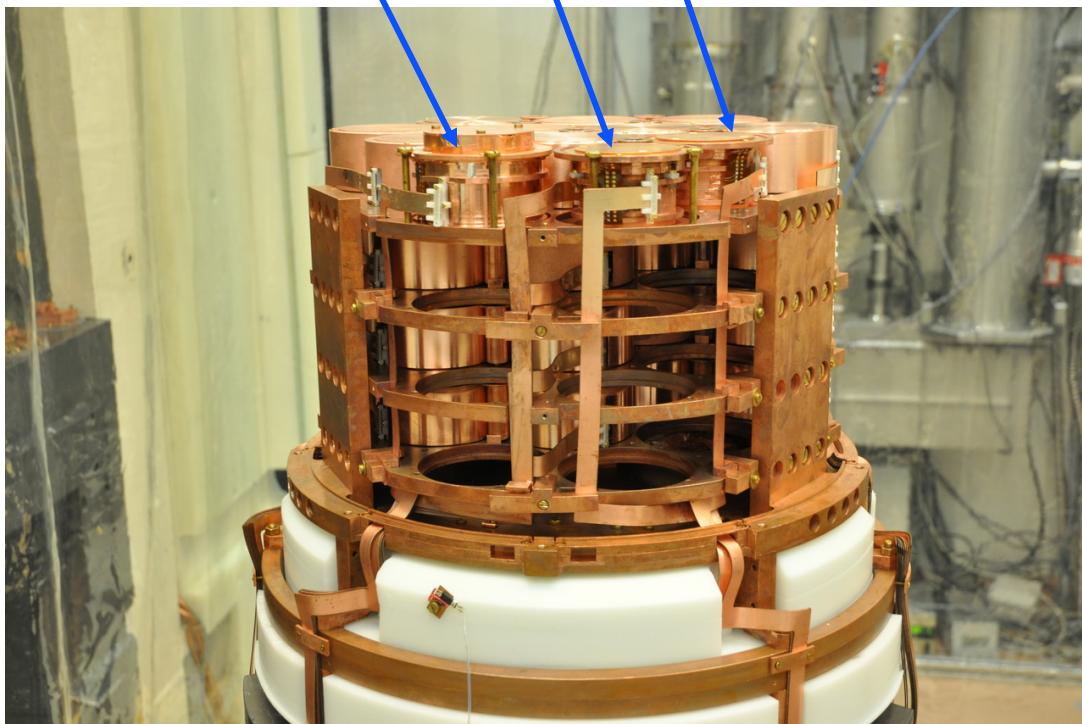
$^{232}\text{Th}$	$^{232}\text{Th}$	$\leq 0.5$
$^{228}\text{Th}$	$^{228}\text{Th}$	$\leq 0.8$
$^{235}\text{U}$	$^{227}\text{Ac}$	$\leq 0.5$
$^{238}\text{U}$	$^{238}\text{U}$	$\leq 1.0$
	$^{234}\text{U}$	$\leq 0.8$
	$^{230}\text{Th}$	$\leq 0.8$
	$^{226}\text{Ra}$	$\leq 0.8$
	$^{210}\text{Po}$	8(1) (mBq/kg)
Total $\alpha$ activity		22 (2)

# New LUMINEU detectors in the EDELWEISS set-up



## New assembling in EDELWEISS set-up

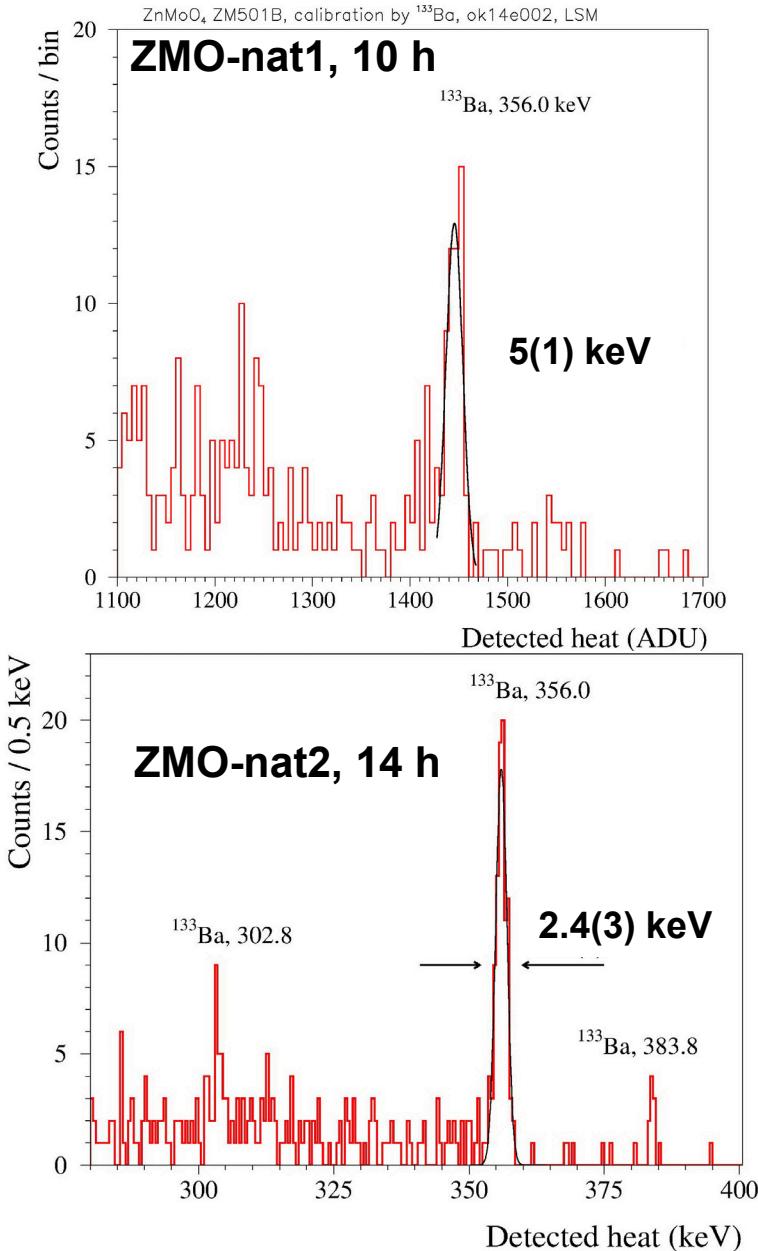
- $\text{Zn}^{100}\text{MoO}_4$  scintillating bolometers array
- 2 scintillating bolometers based on advanced  $\text{ZnMoO}_4$  crystals
- 36 germanium bolometers 800 g each



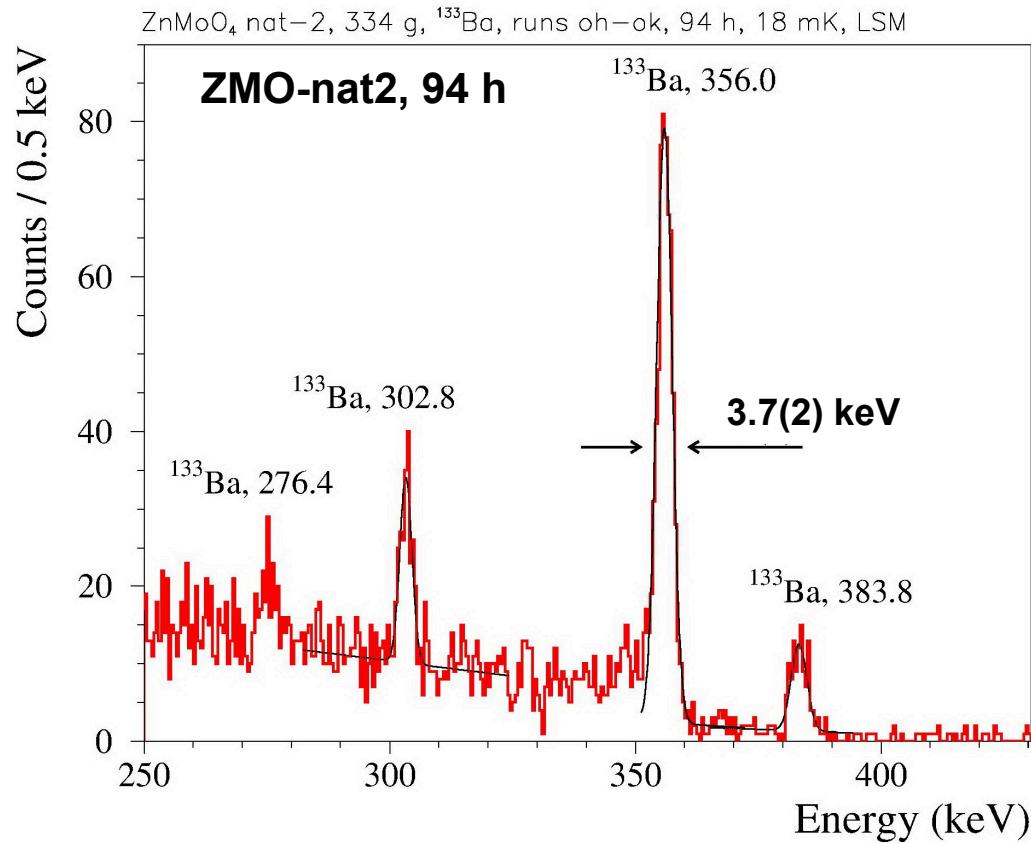
## New features

- Polyethylene at 1 K plate
- NOSV copper screens
- Individual low bg Kapton
- Implementation of device for thermal response control (from middle of October)
- New bolo-boxes (16 bit ADC, 1 kHz sampling rate)
- Base temperature 18 mK

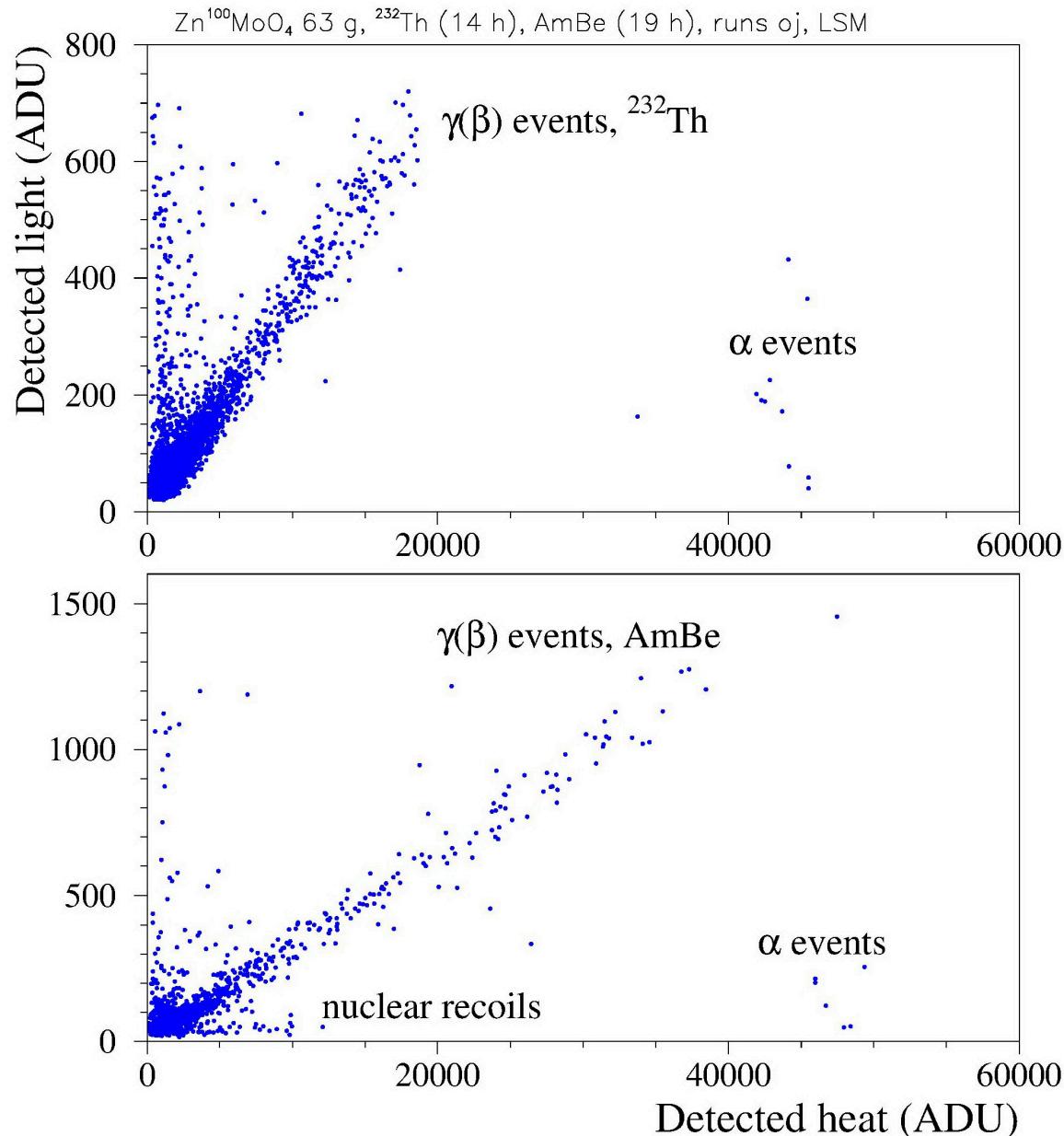
# Advanced ZnMoO<sub>4</sub>: Calibration by <sup>133</sup>Ba



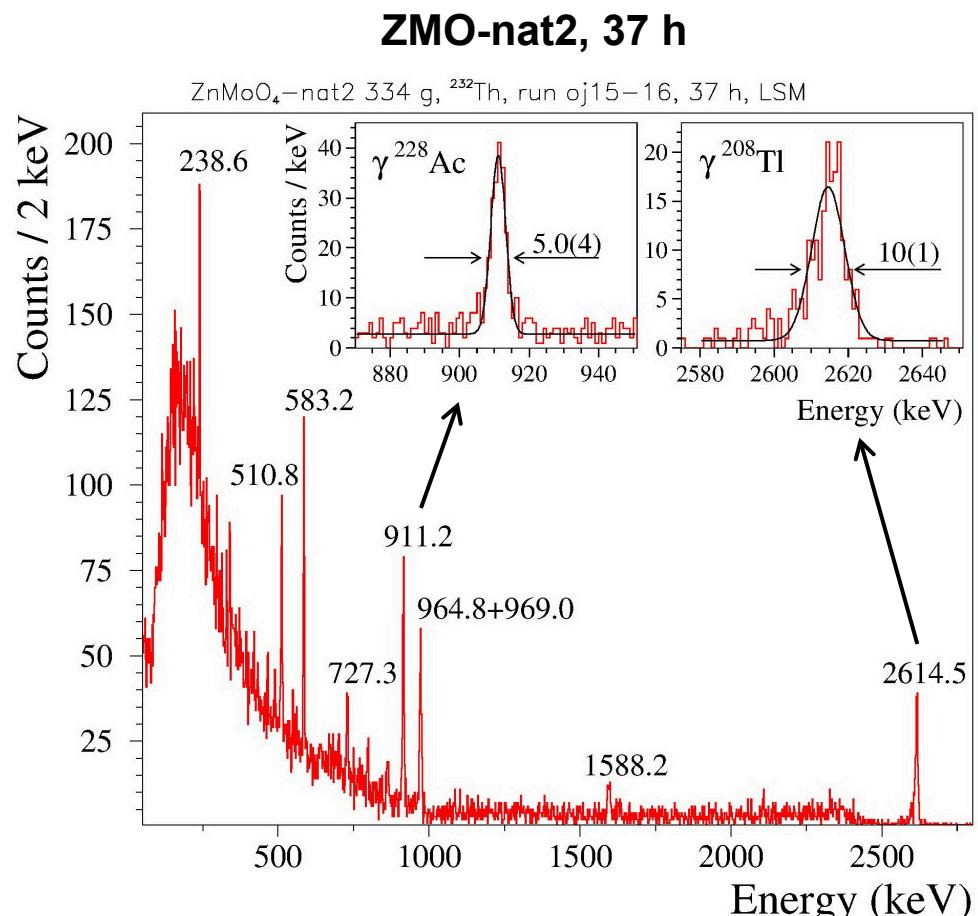
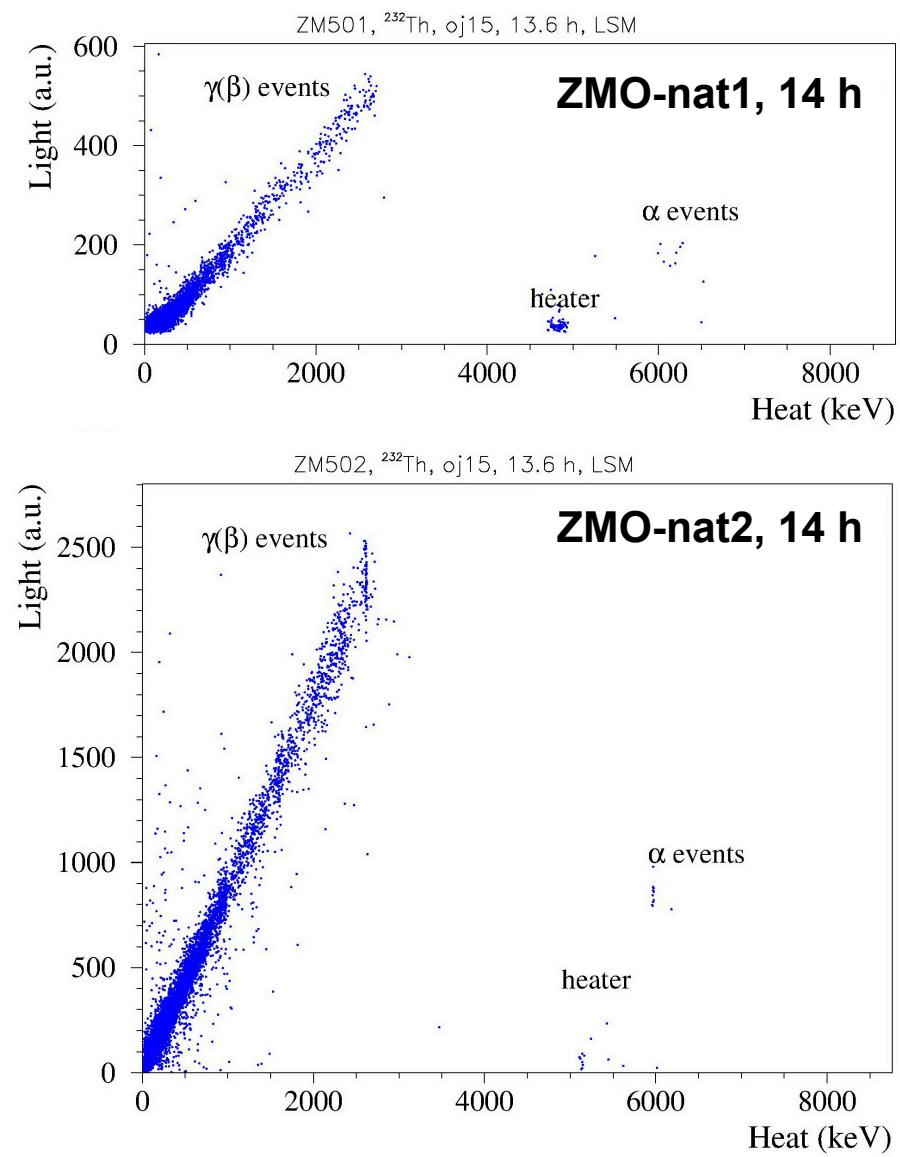
Excellent spectrometric performances



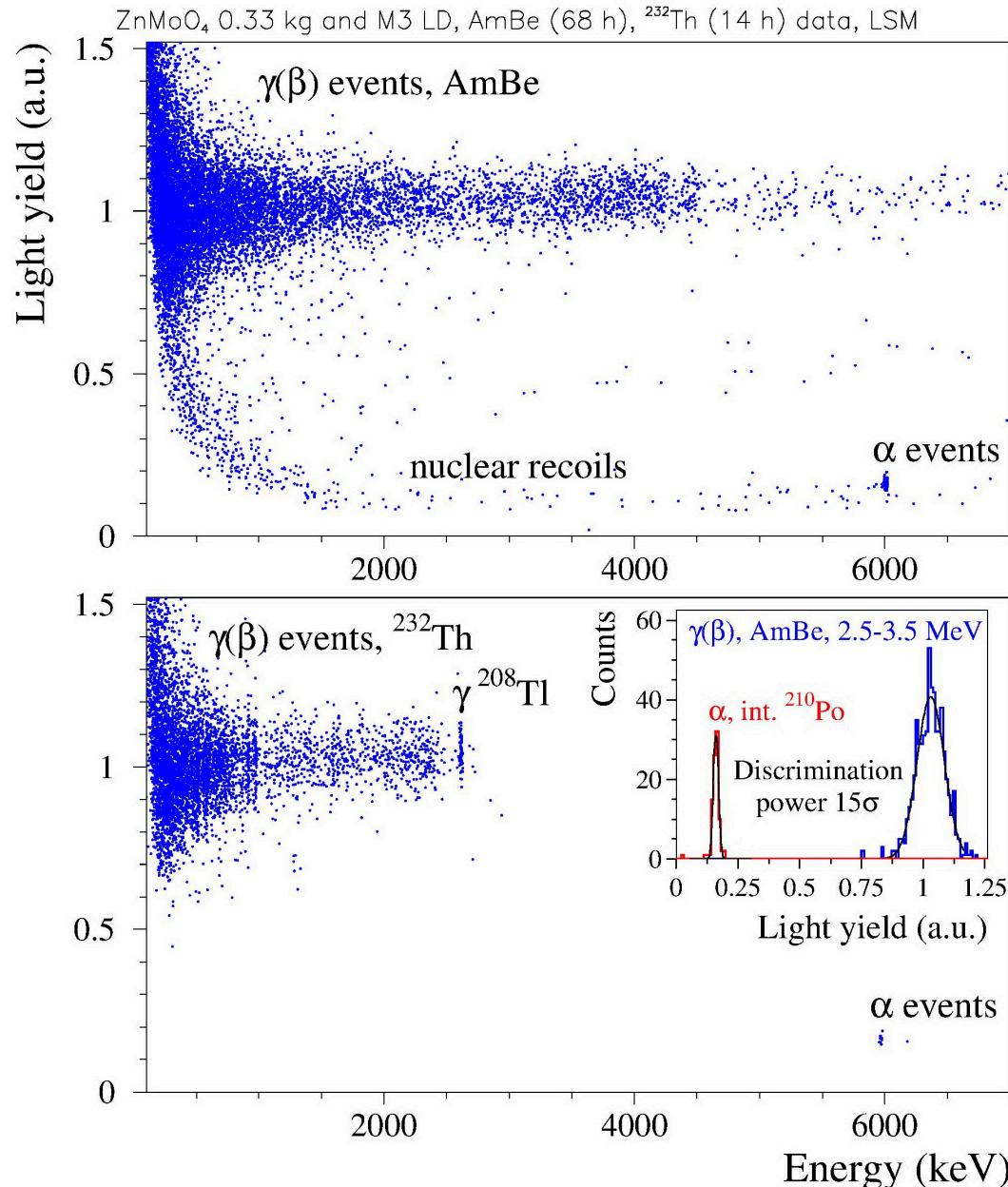
# Zn<sup>100</sup>MoO<sub>4</sub>: Calibration by <sup>232</sup>Th and AmBe



# Advanced ZnMoO<sub>4</sub>: Calibration by <sup>232</sup>Th



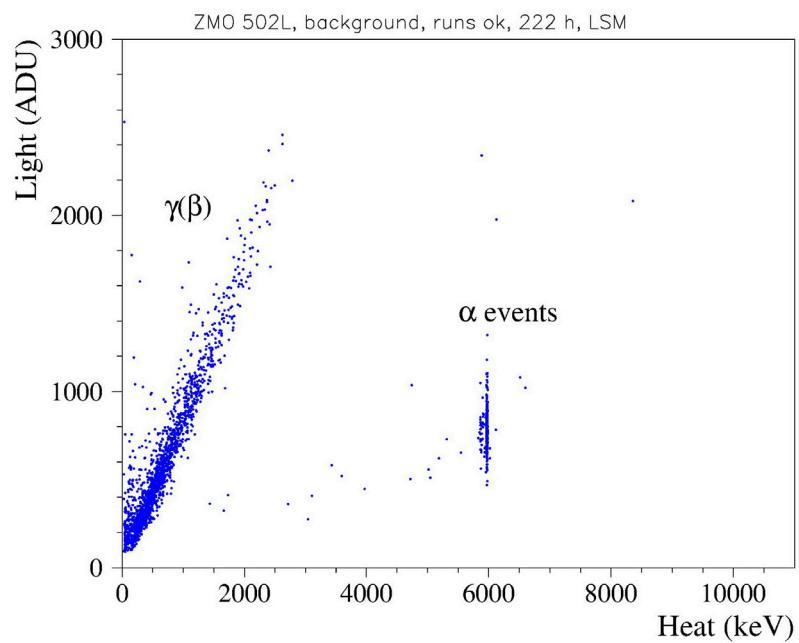
# Advanced ZnMoO<sub>4</sub>: Calibration by <sup>232</sup>Th and AmBe



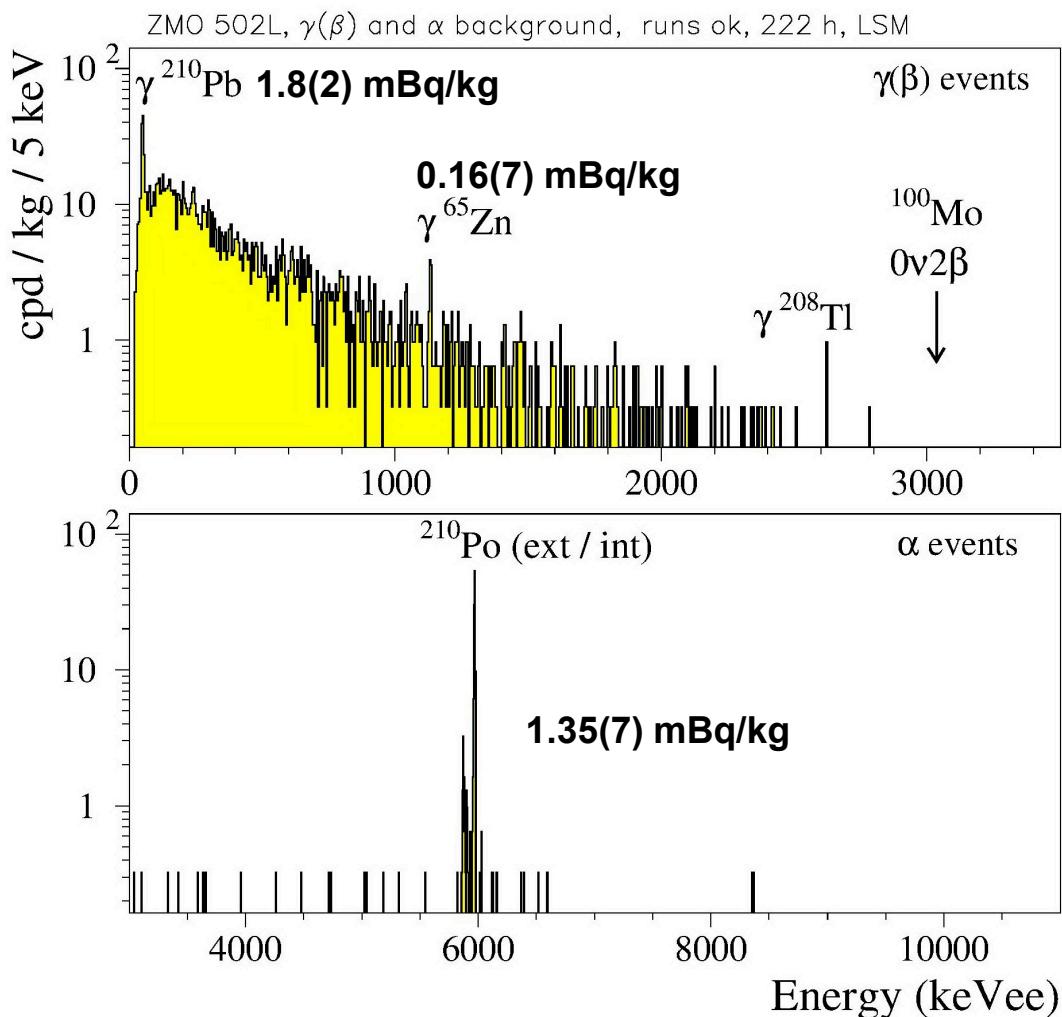
# Background measurements with advanced ZnMoO<sub>4</sub>

ZnMoO<sub>4</sub> 334 g, Background, 222 h, November 2014, LSM

Heat-vs-Light scatter-plot

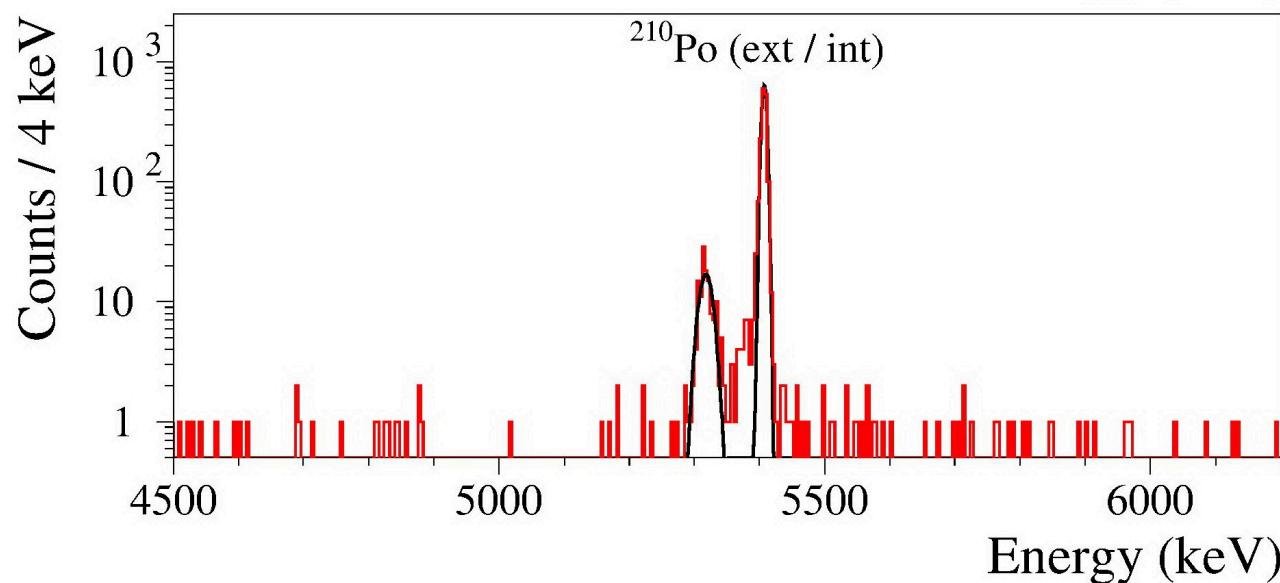
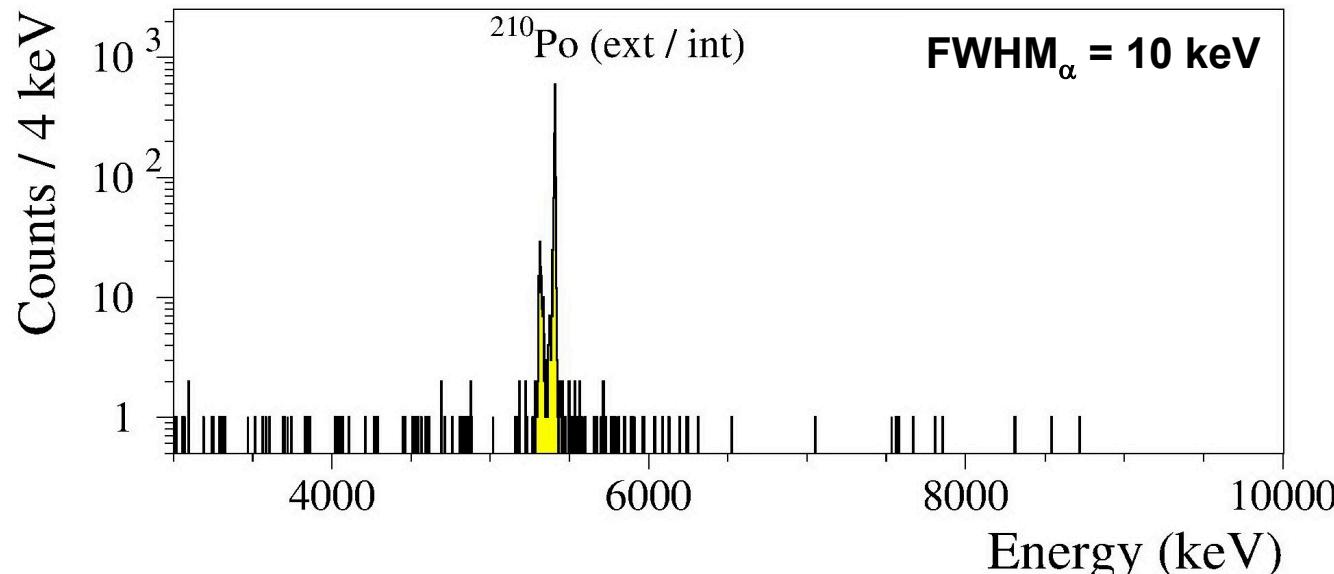


Selected  $\gamma(\beta)$  and  $\alpha$  background



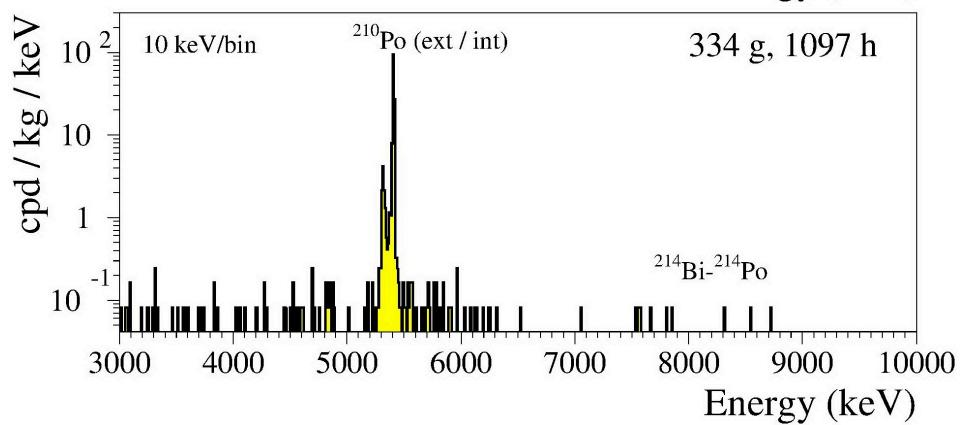
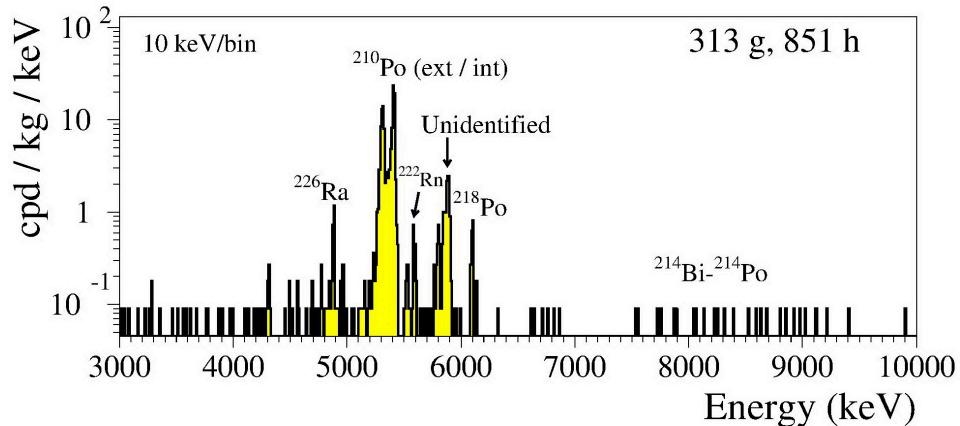
# Alpha background of advanced ZnMoO<sub>4</sub> crystal

ZnMoO<sub>4</sub> 334 g,  $\alpha$  spectrum, 1097 h, August-November 2014, LSM



# Radiopurity of ZnMoO<sub>4</sub> crystals ( $\mu\text{Bq}/\text{kg}$ )

Radiopurity of ZnMoO<sub>4</sub> crystal satisfies the LUMINEU requirements



[1] D.V. Poda, to appear in Proc. ICHEP-2014.

[2] J. Beeman et al., EPJC 72 (2012) 2142.

	Advanced ZMO		Precursor ZMO	
	LSM [1]	LSM [1]	LSM [1]	LNGS [2]
<b>232Th</b>	<b>≤ 1.4</b>	<b>≤ 10</b>	<b>≤ 5</b>	<b>≤ 8</b>
<b>228Th</b>	<b>≤ 4</b>	<b>≤ 24</b>	<b>10(3)</b>	<b>≤ 6</b>
<b>238U</b>	<b>≤ 4</b>	<b>≤ 8</b>	<b>≤ 8</b>	<b>≤ 6</b>
<b>234U</b>	<b>≤ 4</b>	<b>≤ 22</b>	<b>≤ 14</b>	<b>≤ 11</b>
<b>230Th</b>	<b>≤ 1.4</b>	<b>≤ 13</b>	<b>≤ 9</b>	<b>≤ 6</b>
<b>226Ra</b>	<b>≤ 5</b>	<b>≤ 21</b>	<b>26(5)</b>	<b>27(6)</b>
<b>210Po</b>	<b>1157(49)</b>	<b>939(52)</b>	<b>621(25)</b>	<b>700(30)</b>
<b>235U</b>	<b>≤ 3</b>	<b>≤ 10</b>	<b>≤ 7</b>	<b>-</b>
<b>147Sm</b>	<b>≤ 5</b>	<b>≤ 5</b>	<b>≤ 5</b>	<b>-</b>
<b>190Pt</b>	<b>≤ 4</b>	<b>≤ 5</b>	<b>≤ 3</b>	<b>-</b>
<b>65Zn</b>	<b>164(67)</b>	<b>-</b>	<b>-</b>	<b>-</b>

# Summary

## The technology for a single ZMO-module is well established

- Three massive  $\text{ZnMoO}_4$  crystals ( $\sim 0.3$  kg each) were used for the studies; two of them were produced from double crystallized boules grown from deep purified materials
- All  $\text{ZnMoO}_4$  detectors were successfully tested over  $\sim 1000$  h in the EDELWEISS set-up at the LSM (France); measurements with advanced crystals are in progress
- High spectrometric properties (FWHM $_{\gamma}$  up to 2.4 keV at 356 keV) and full  $\alpha/\gamma$  separation (discrimination power up to  $15\sigma$ ) are achieved

## First enriched ZMO-detector was developed and tested

- Enriched  $\text{Zn}^{100}\text{MoO}_4$  (99.5% of  $^{100}\text{Mo}$ , 0.17 kg, 84% of initial charge,  $\sim 4\%$  losses) are successfully developed
- $\text{Zn}^{100}\text{MoO}_4$  detectors ( $\sim 60$  g each) show high performance and encouraging radiopurity in aboveground test at the CSNSM (France)
- The optimization of  $\text{Zn}^{100}\text{MoO}_4$  array is ongoing in the EDELWEISS set-up to improve noise conditions

## Sufficient progress in developing of radiopure ZMO is achieved

- Approved purification procedure allows to reach high radiopurity of  $\text{ZnMoO}_4$  (in particular, activity of  $^{228}\text{Th}$  and  $^{226}\text{Ra} < 5 \mu\text{Bq/kg}$ )
- $\text{ZnMoO}_4$  radiopurity satisfies requirements of a next-generation  $0\nu2\beta$  experiment