Status of the AMoRE experiment searching for neutrinoless double beta decay of ^{100}Mo

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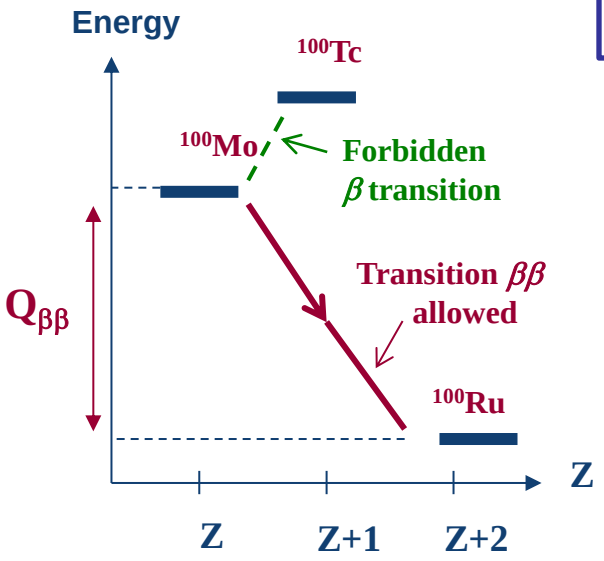
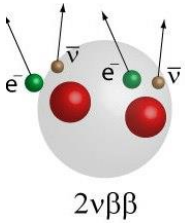
Neutrinoless double beta decay

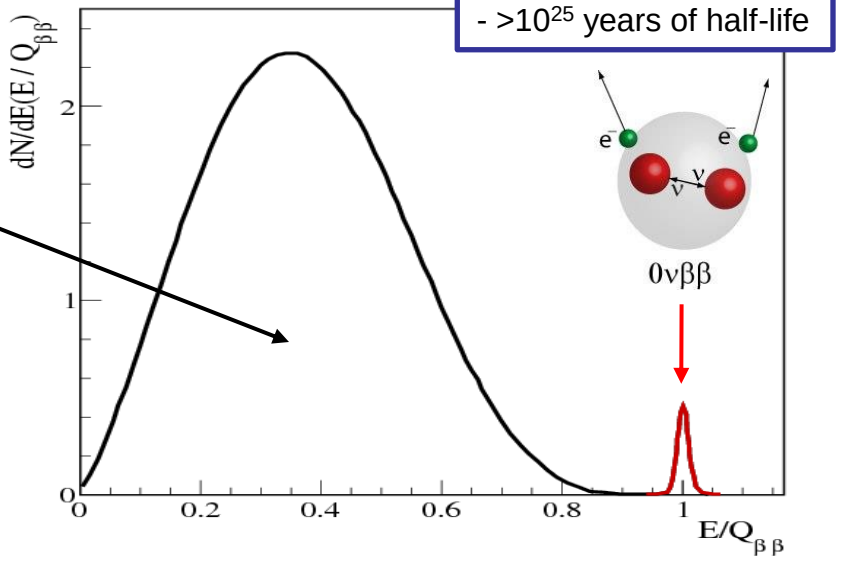
The goal of the AMoRE (**A**dvanced **Mo**-based **R**are process **E**xperiment) project is to search for neutrinoless double beta decay ($0\upsilon\beta\beta$) of ^{100}Mo using Mo-based scintillating crystals and low-temperature sensors.



2ν ββ decay
- 2nd order beta decay
- Rare nuclear decay
- (>10^{18} years of half life)

0ν ββ decay
- Massive neutrino
- Majorana particle
- Beyond the SM model
- >10^{25} years of half-life





$$(T^{0\nu}_{1/2})^{-1} = G_{0\nu}(Q_{\beta\beta}, Z)\,|M_{0\nu}|^2 < m_{\beta\beta} >^2$$

G : Phase space factor (~$Q_{\beta\beta}^5$)
M : Nuclear Matrix Element

$(Z, A) \rightarrow (Z+2, A) + 2e^- + 2\text{anti-}\nu_e$ ($\Delta L = 0$, conserved)
$(Z, A) \rightarrow (Z+2, A) + 2e^-$ ($\Delta L = 2$, violated)

AMoRE Collaboration

Advanced Mo based Rare process Experiment

8 countries, 18 Institutes, ~90 collaborators

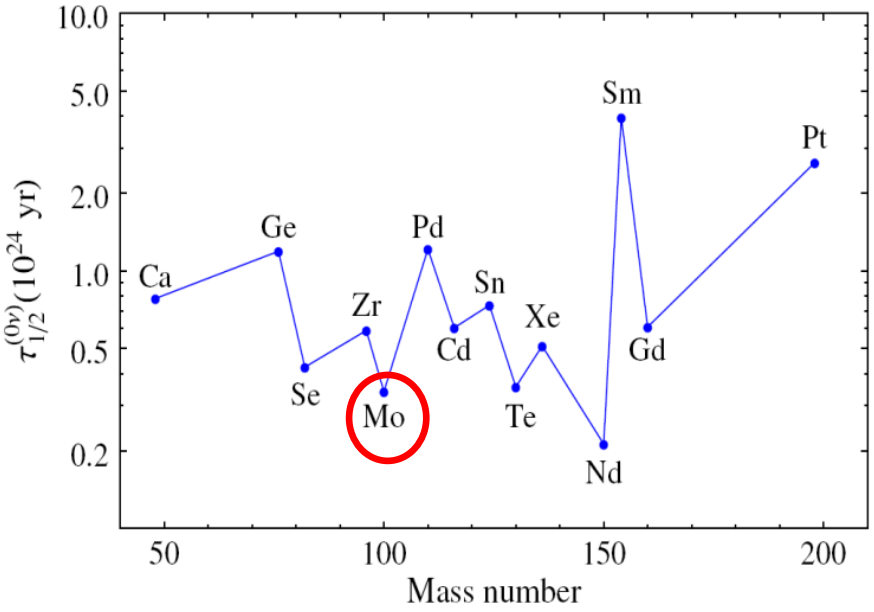
Choice of ^{100}Mo

Candidates	$Q_{\beta\beta}$(MeV)	N.A. (%)
^{48}Ca→^{48}Ti	4.271	0.187
^{76}Ge→^{76}Se	2.040	7.8
^{82}Se→^{82}Kr	2.995	9.2
^{96}Zr→^{96}Mo	3.350	2.8
^{100}Mo→^{100}Ru	3.034	9.6
^{110}Pd→^{110}Cd	2.013	11.8
^{116}Cd→^{116}Sn	2.802	7.5
^{124}Sn →^{124}Te	2.228	5.64
^{130}Te→^{130}Xe	2.533	34.5
^{136}Xe→^{136}Ba	2.479	8.9
^{150}Nd→^{150}Sm	3.367	5.6

Phys. Rev. C 53, 695 (1996)

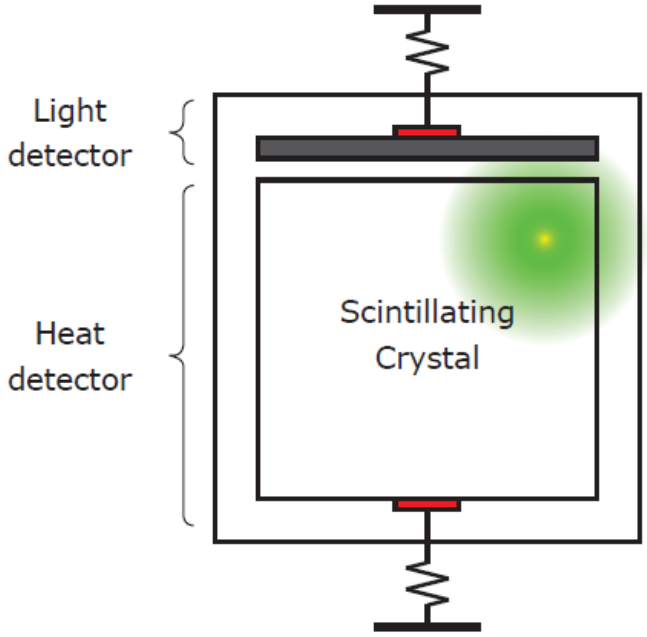
- High Q-value (3.034 MeV)
- High natural abundance (9.6 %)
- Relatively short theoretically predicted half-life (0νββ)

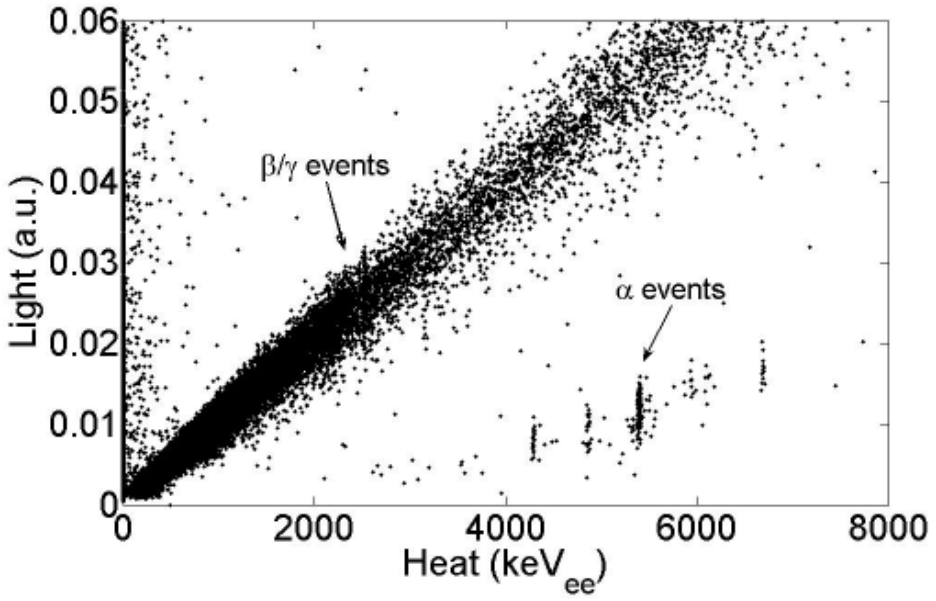
Phys. Rev. Lett. 109, 042501 (2012)



Detector concept for the AMoRE experiment

$^{40}Ca^{100}MoO_4$ (source = detector)
+ Metallic Magnetic Calorimeter (MMC, low temperature detector)





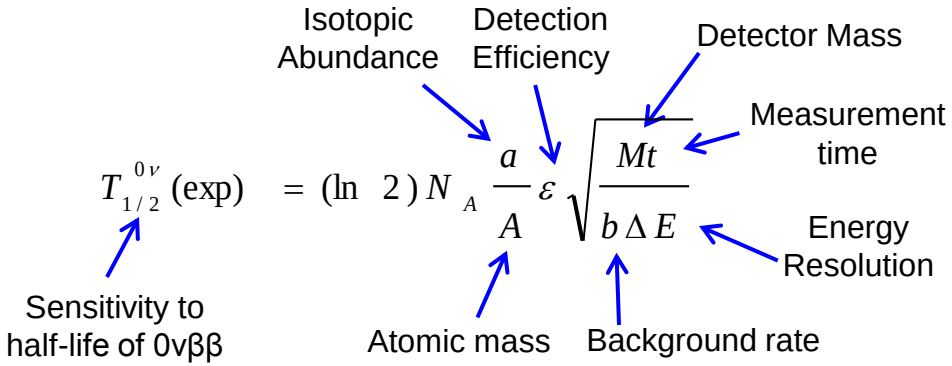
"Source = detector" approach
- High detection efficiency
- High energy resolution

MMCs
- Fast response, high energy resolution, wide operating temperatures

Simultaneous measurement of heat and light
- Particle discrimination for rejection of α-induced background

AMoRE sensitivity to $0\nu\beta\beta$

Sizeable background case



$$T_{1/2}^{0\nu}(\mathrm{exp}) = (\ln 2)\, N_A \frac{a}{A} \varepsilon \sqrt{\frac{Mt}{b\,\Delta E}}$$

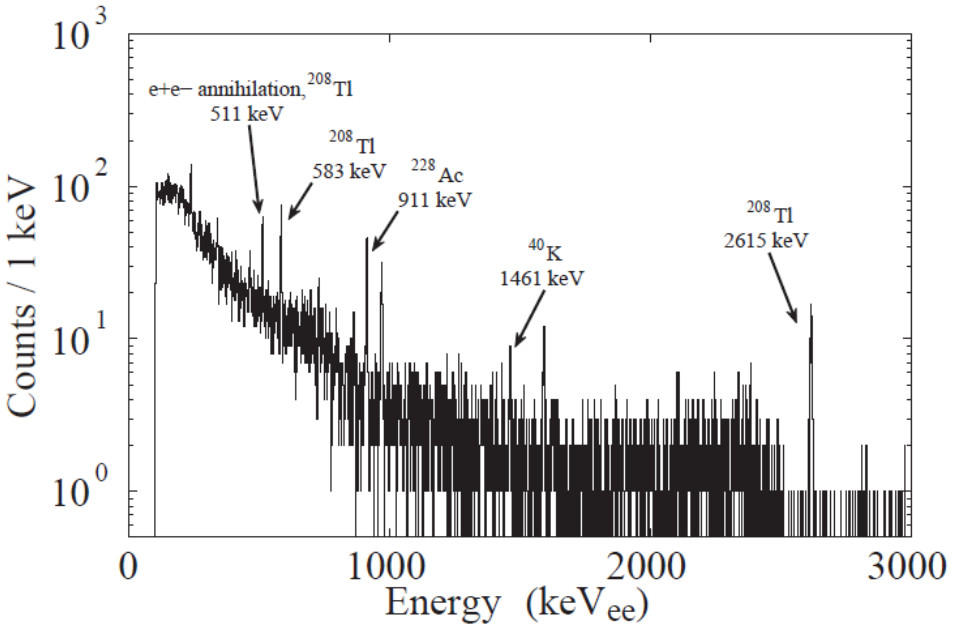
"Zero" background case

$$T_{1/2}^{0\nu}(\mathrm{exp}) = (\ln 2)\, N_A \frac{a}{A} \varepsilon M t$$

AMoRE project towards "zero"-background conditions:

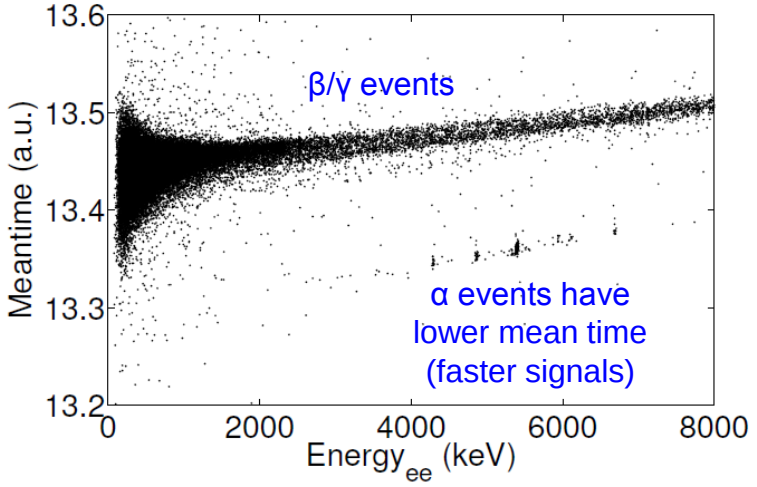
- Reduction of the background
  - α-background rejection with particle discrimination (heat and light measurement)
  - less than 0.001% of depleted ^{48}Ca (natural abundance: 0.157%, $Q_{\beta\beta}$=4.271 MeV)
  - low levels of internal and external backgrounds
- High energy resolution with MMCs
- High detection efficiency with "source = detector" approach
- Detector mass
  - enrichment of ^{100}Mo above 96%

Above-ground measurements (with a wet DR)

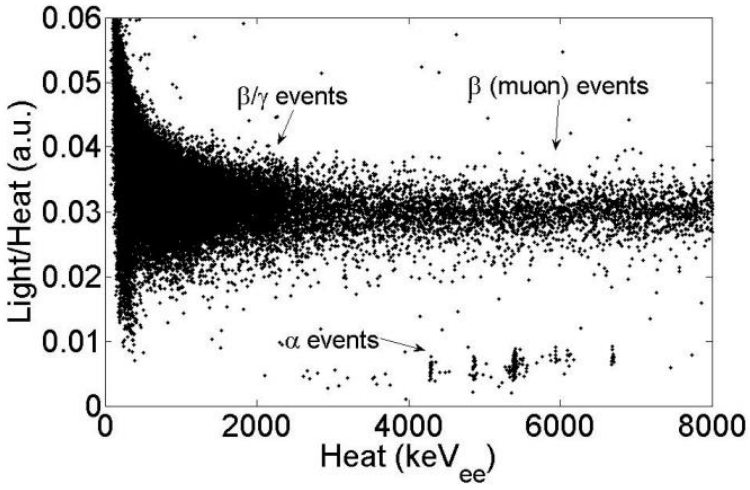


- Energy spectrum obtained with a ^{232}Th source at 10 mK
- FWHM energy resolution: 8.7 keV @ 2.6 MeV (Region of interest: 3.034 MeV)

Pulse shape discrimination from heat signals

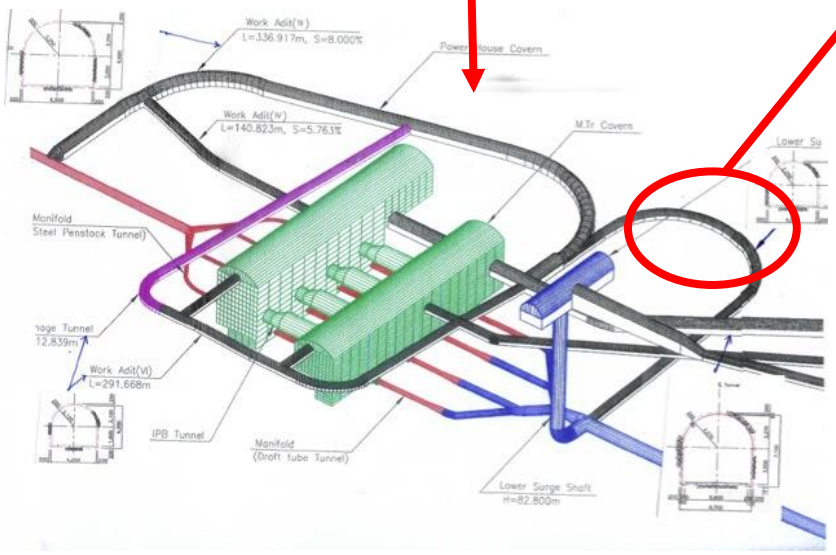


Particle discrimination by light-heat ratio

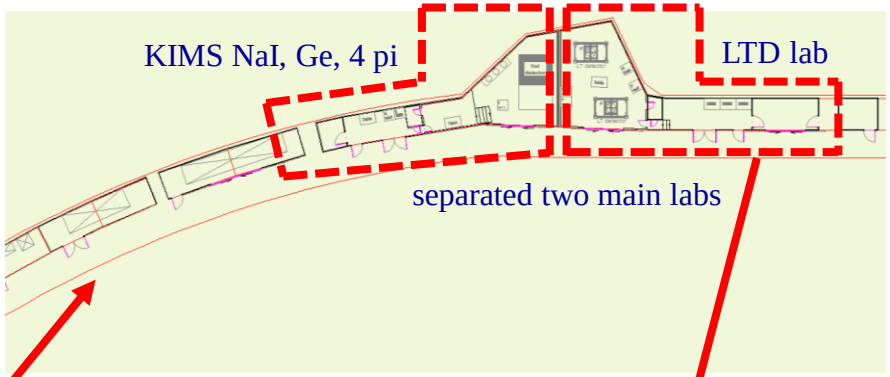


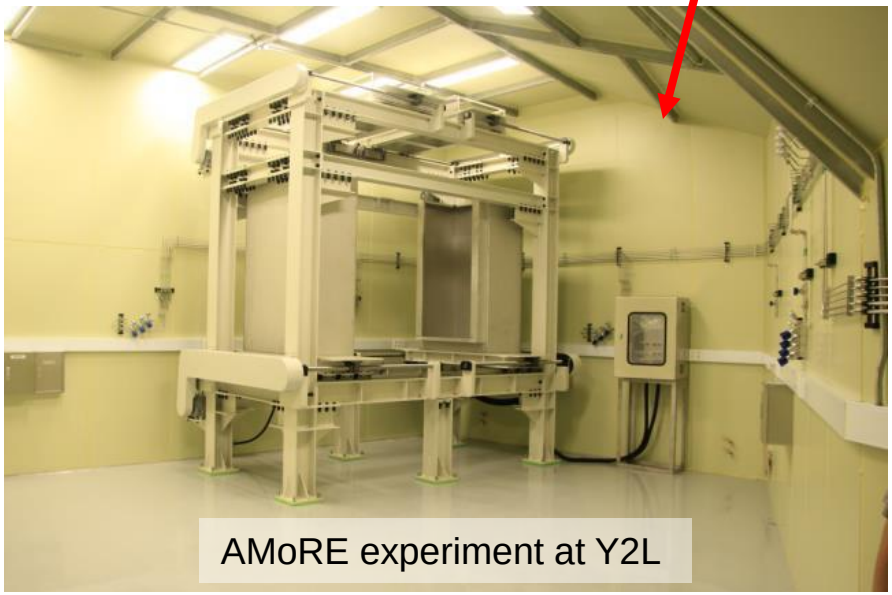
Yangyang underground laboratory (Y2L, South Korea)

Yangyang pumped storage Power Plant
Minimum vertical depth : 700 m
Access to the lab by car : around 2 km

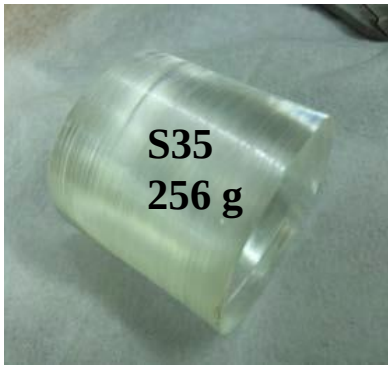


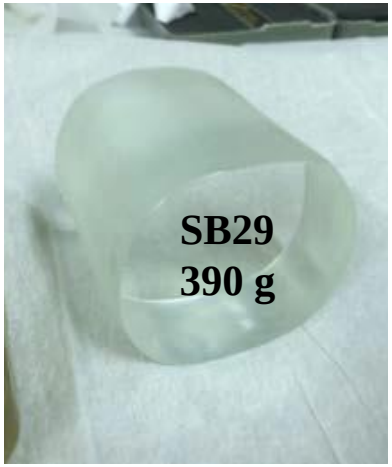
Experiments
- KIMS : dark matter search experiment
- AMoRE : neutrinoless double beta decay search experiment



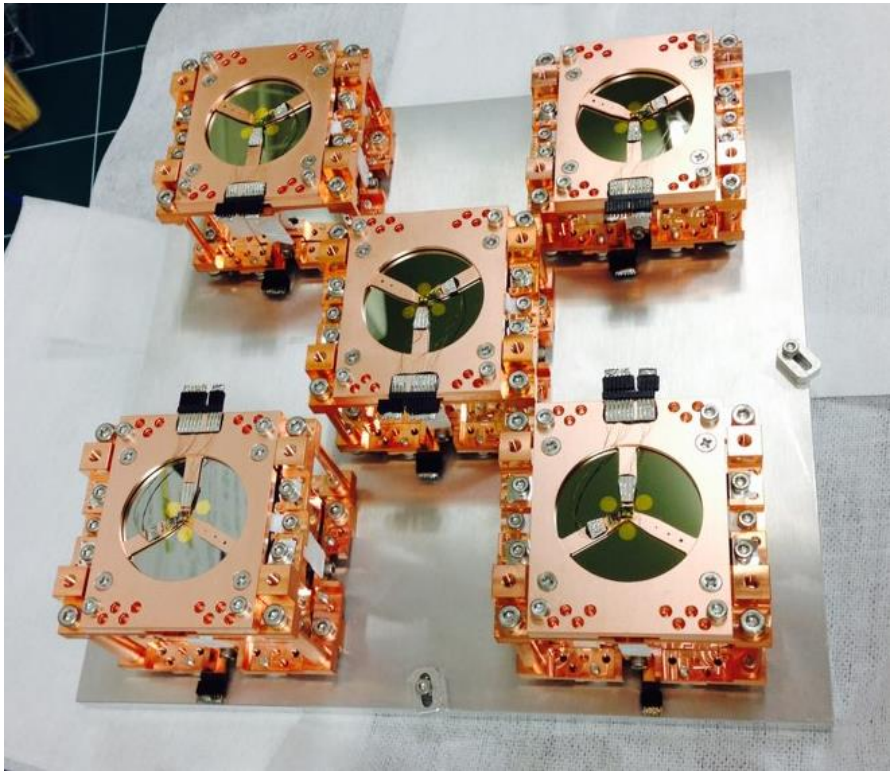

AMoRE experiment at Y2L

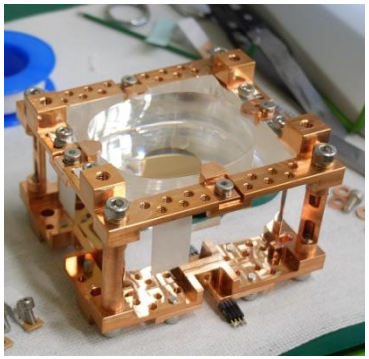
$^{40}Ca^{100}MoO_4$ Crystals for AMoRE-Pilot



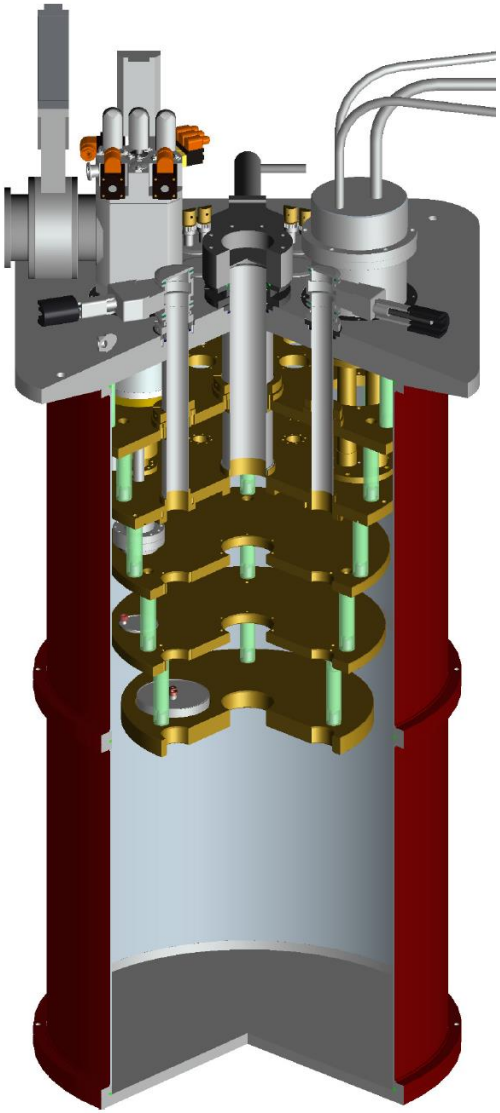


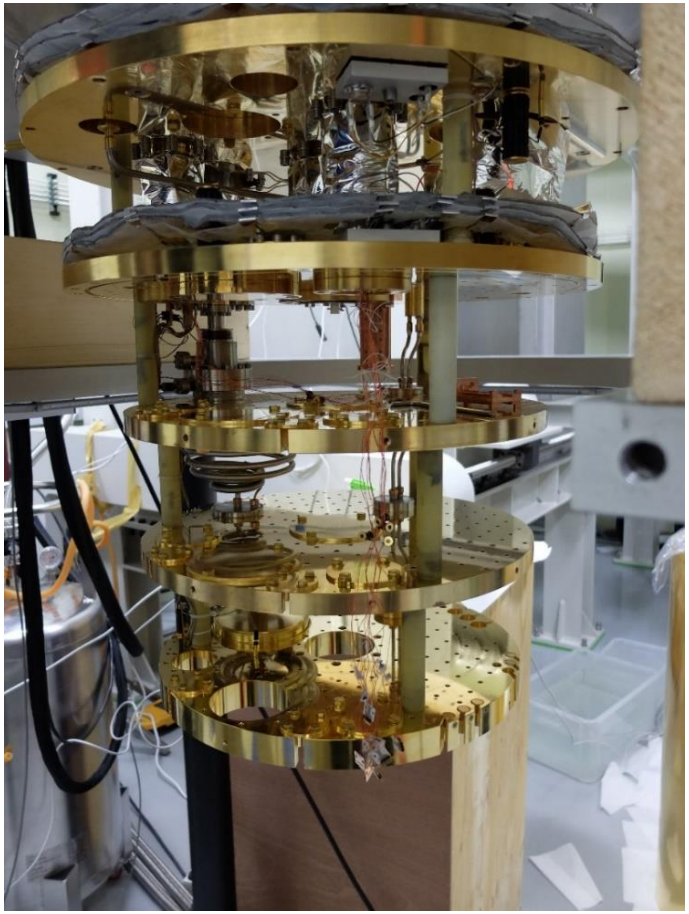
Total mass of crystals ~ 1.5 kg

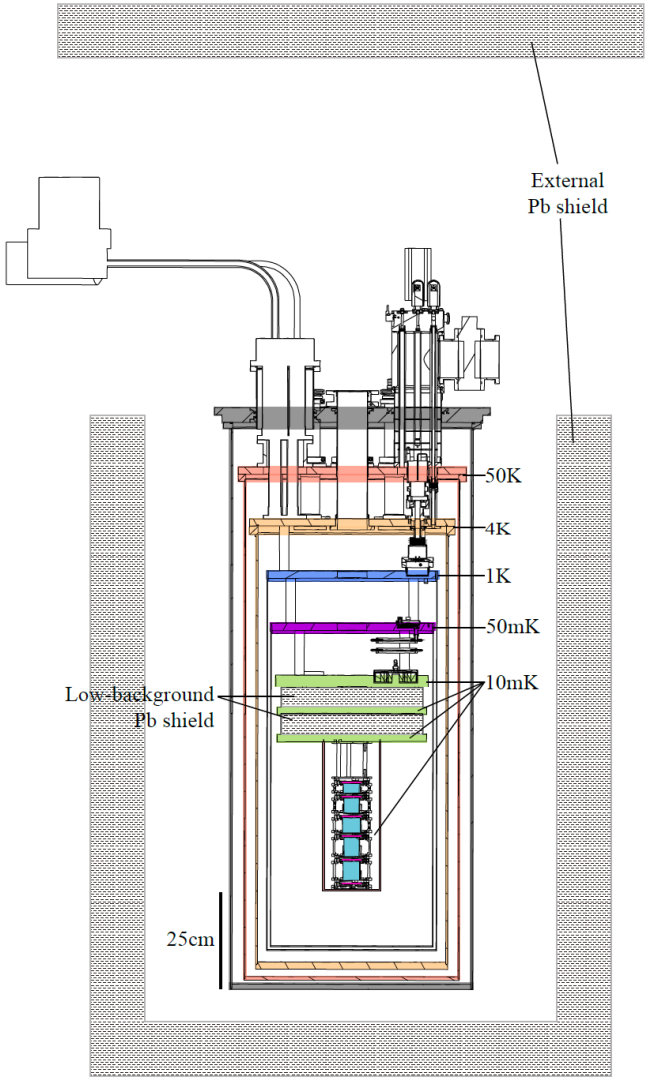




Cryostat: Cryogen Free Dilution Refrigerator (CFDR)

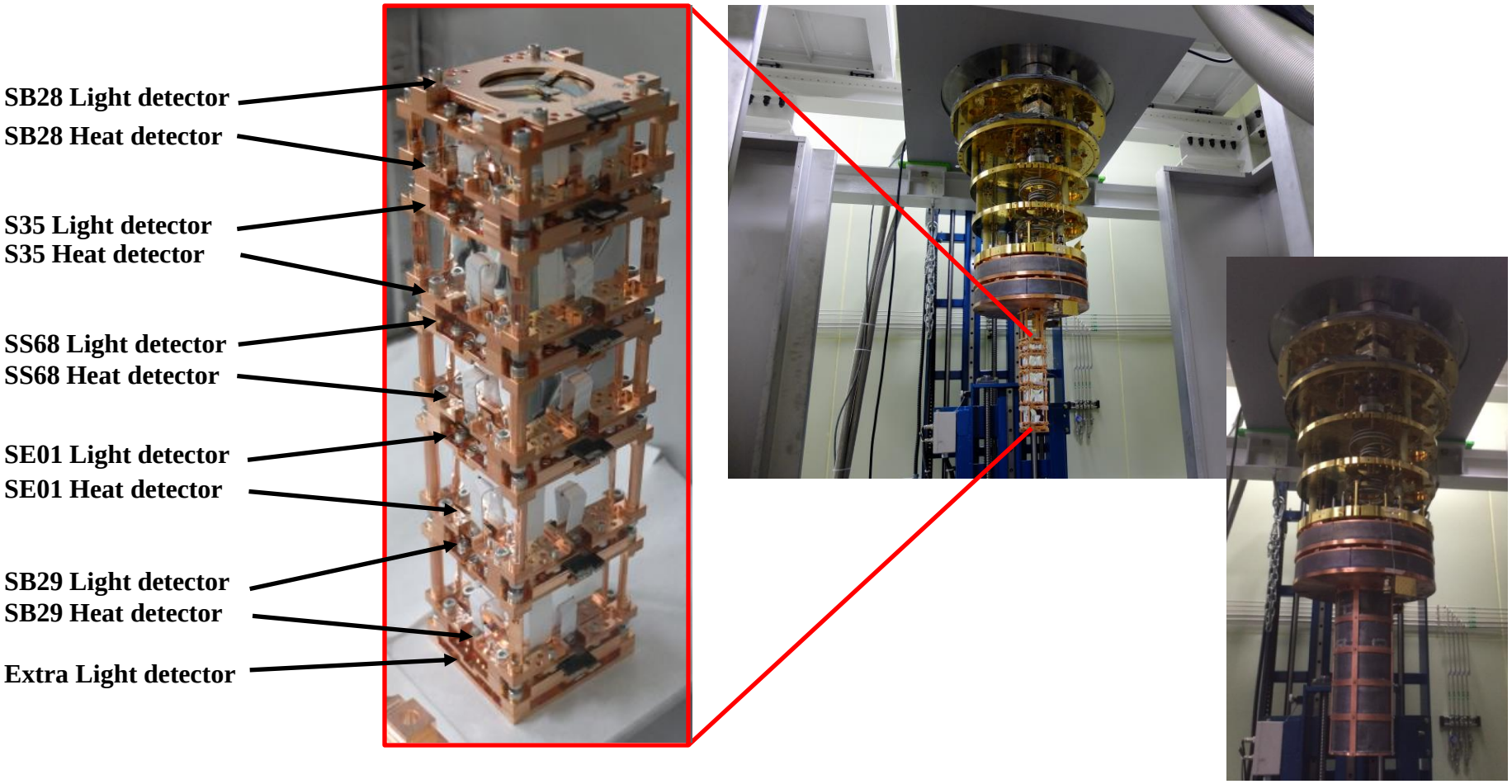






AMoRE-Pilot detector configuration

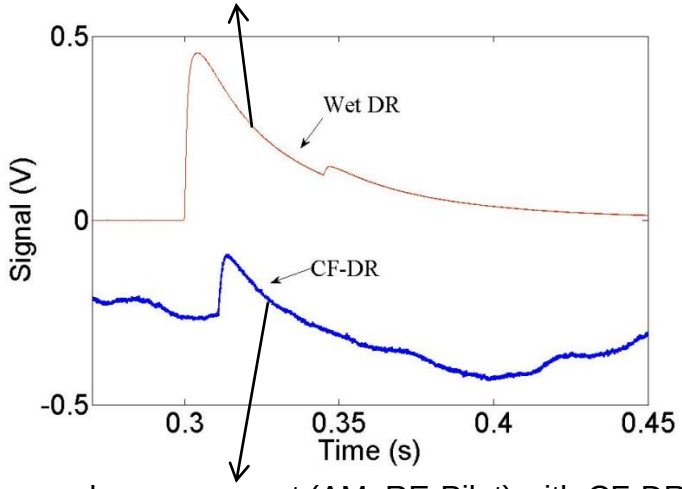
5 crystals: SB28, S35, SS68, SE01, SB29
5 phonon detectors + 6 photon detectors



AMoRE-Pilot runs

- AMoRE-Pilot consists of several runs (a new run being started after an experimental setup upgrade) : run-1 and run-2 have been achieved and run-3 will run later this year
- Measurements performed at temperatures from 10 mK to 40 mK: background and calibration measurements
- Current main goals:
  - ➢ Reduction of the vibration noise (coming mostly from the pulse tube refrigerator of the CF-DR)
  - ➢ Reduction of the background coming from external sources (detector setup, cryostat…)

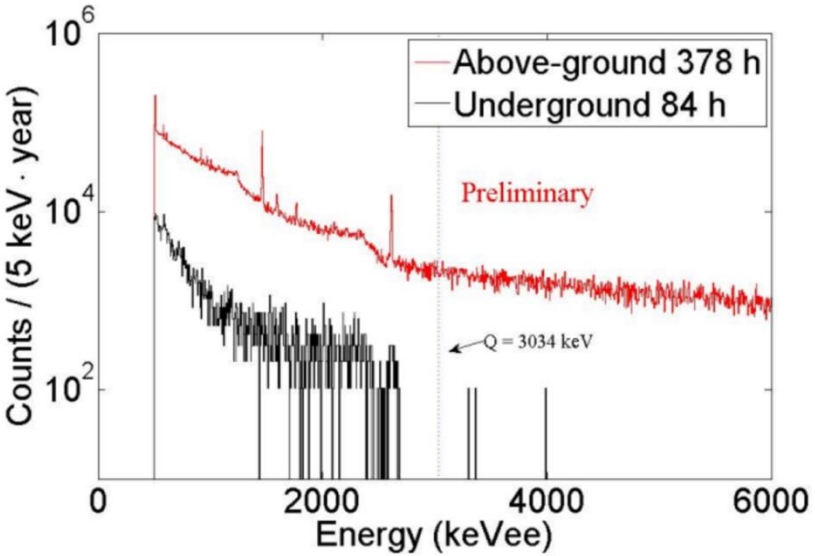
Above-ground measurement (prototype) with wet-DR



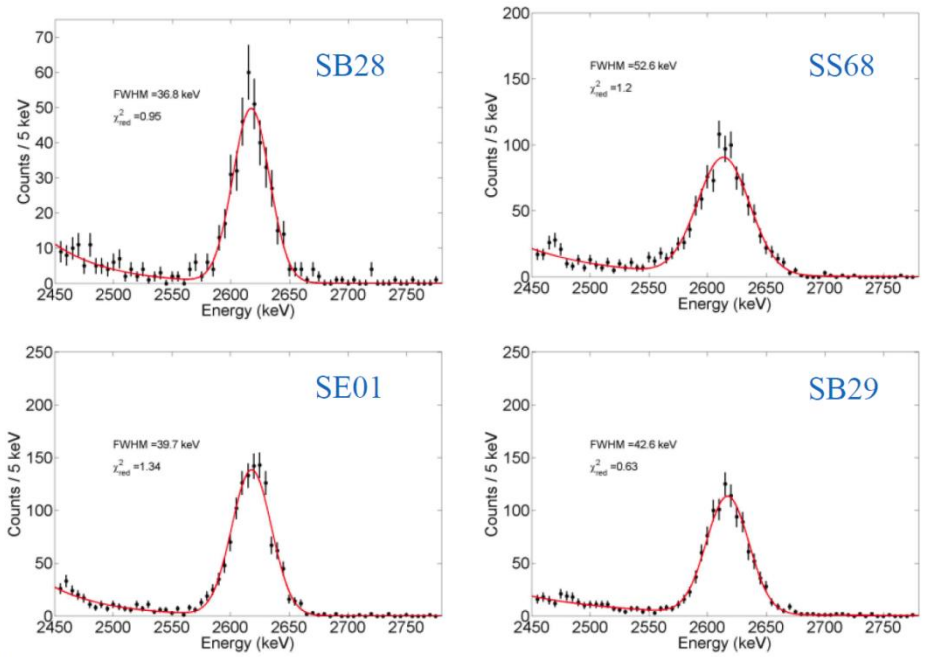
Underground measurement (AMoRE-Pilot) with CF-DR

The level of noise observed when using a CF-DR is significantly higher than when using a wet DR due to the pulse tube refrigerator of the CF-DR inducing a large amount of vibration noise

AMoRE-Pilot run-1 measurements

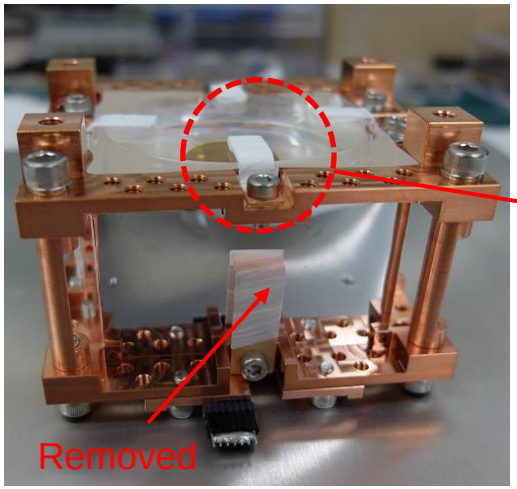


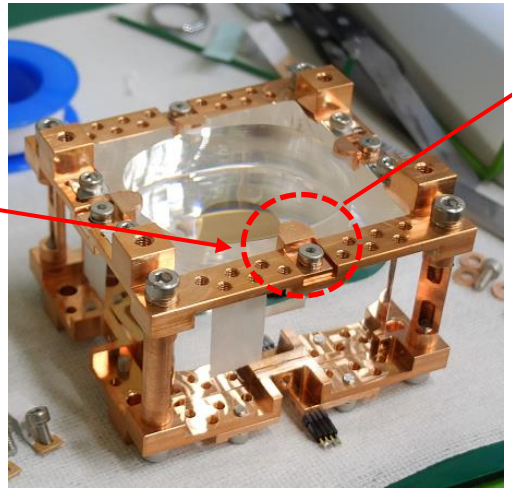
FWHM energy resolution from run-1
(S35 not available)

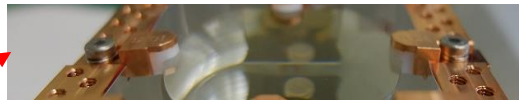


- Muon band was suppressed
- S35 phonon channel was not working
- Large vibration noise

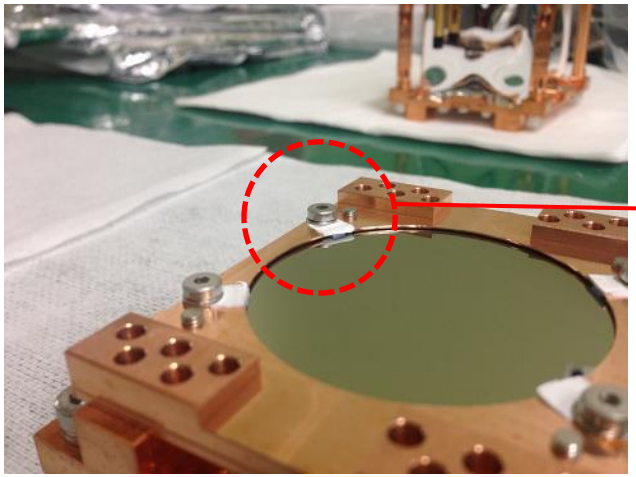
Vibration reduction in the setup of AMoRE-Pilot run-2

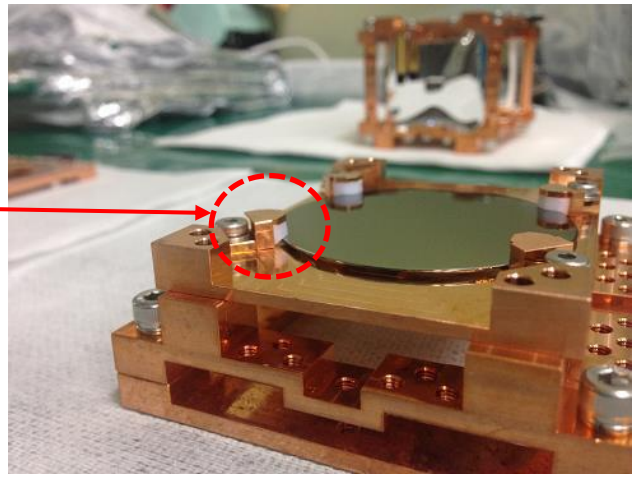






Heat detectors:
phosphor bronze springs were replaced by newly designed teflon springs

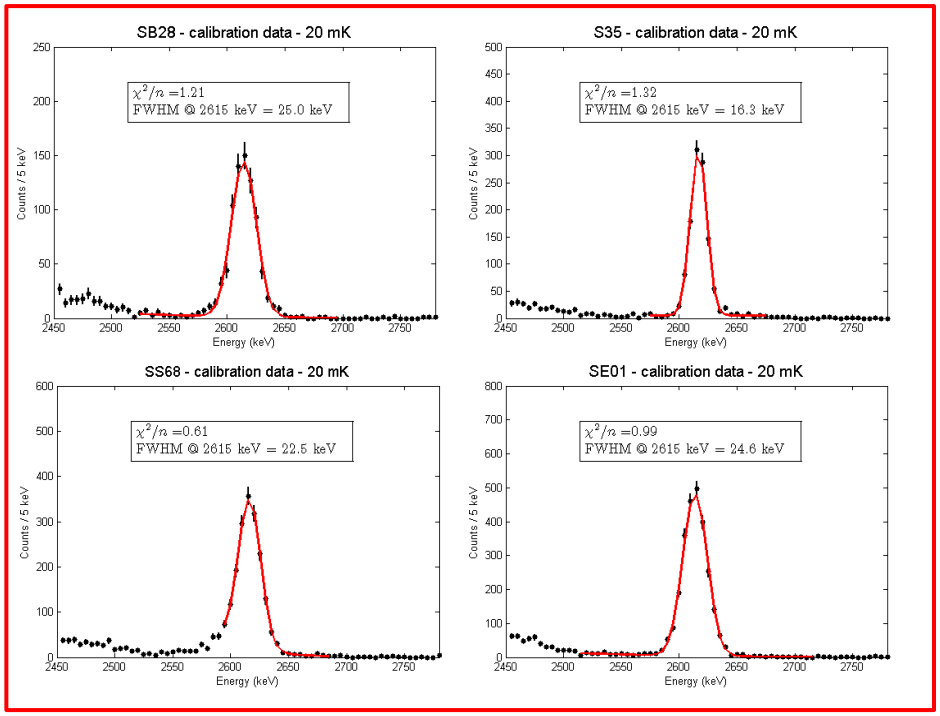




Light detectors:
new springs (teflon)

Energy resolution from AMoRE-Pilot run-2

Pilot run-2 (SB29 not available)

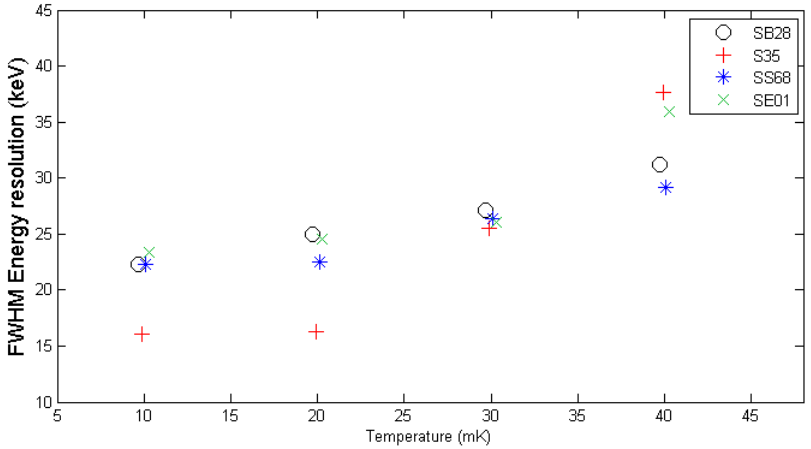


FWHM energy resolution @ 2.6 MeV, at 20 mK

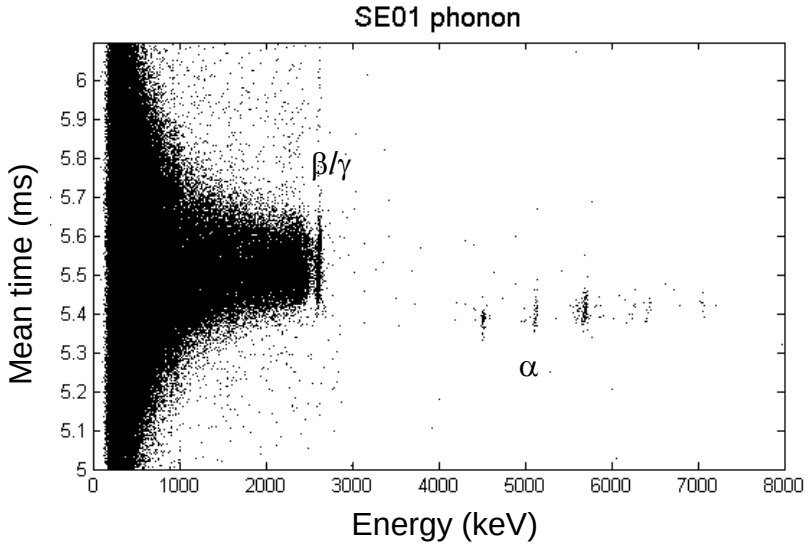
Crystals	AMoRE-Pilot run-1	AMoRE-Pilot run-2
SB28	36.8 keV	25.0 keV
S35	N/A	16.3 keV
SS68	52.6 keV	22.5 keV
SE01	39.7 keV	24.6 keV
SB29	42.6 keV	N/A

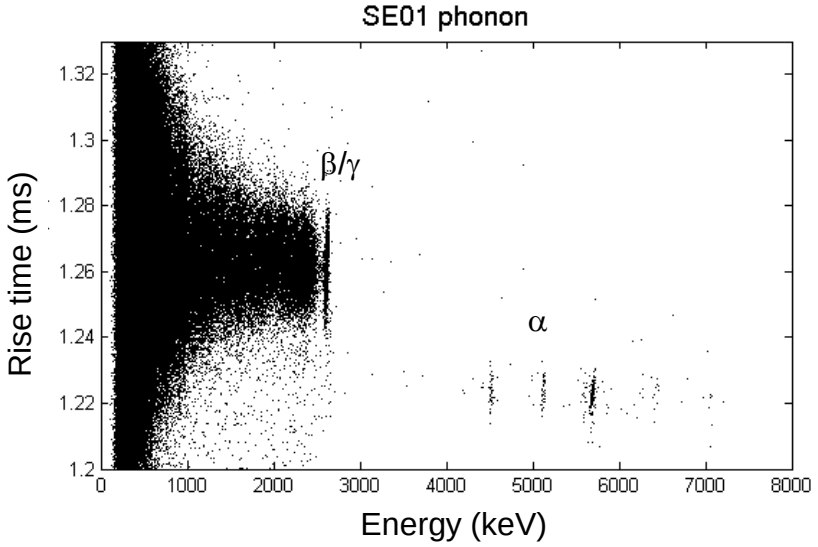
- From run-1 to run-2, the energy resolution of phonon channels have been improved through vibration reduction
- Photon channels still need more improvements

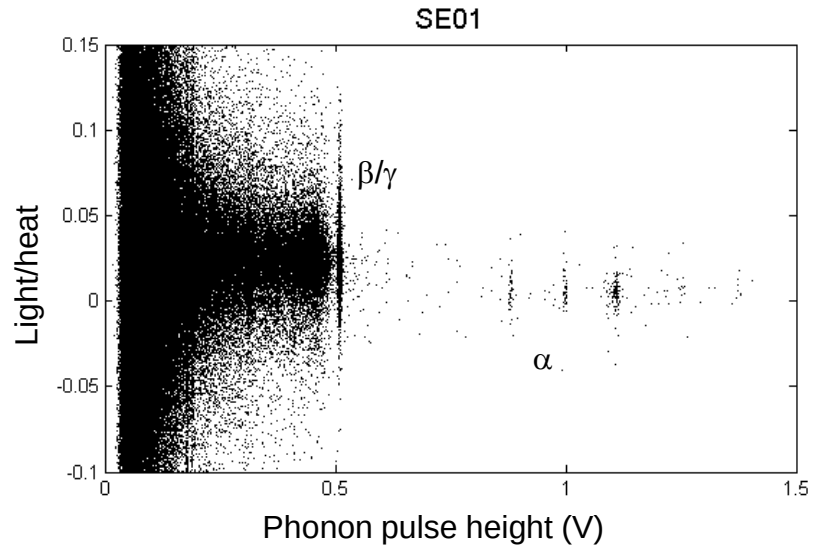
FWHM energy resolution
as a function of temperature (run-2)

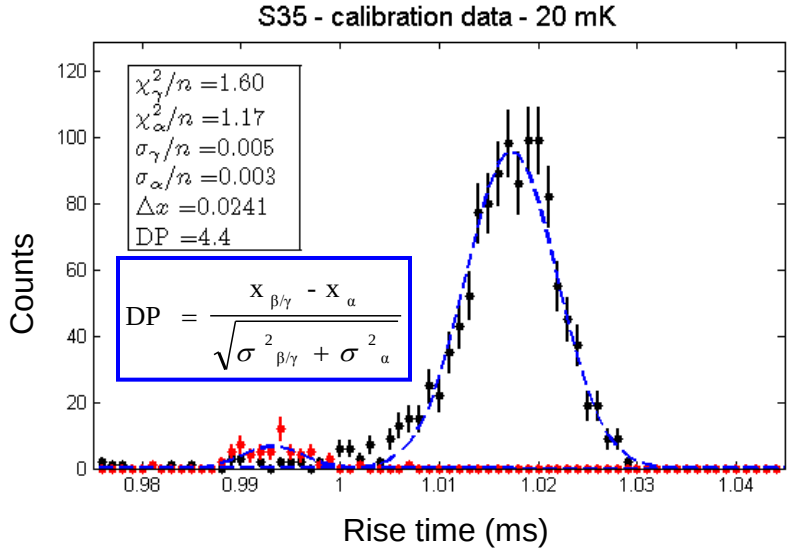


Particle discrimination from AMoRE-Pilot run-2



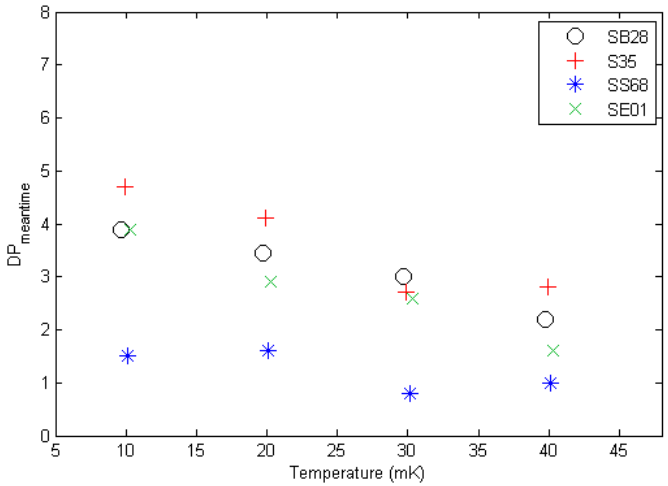




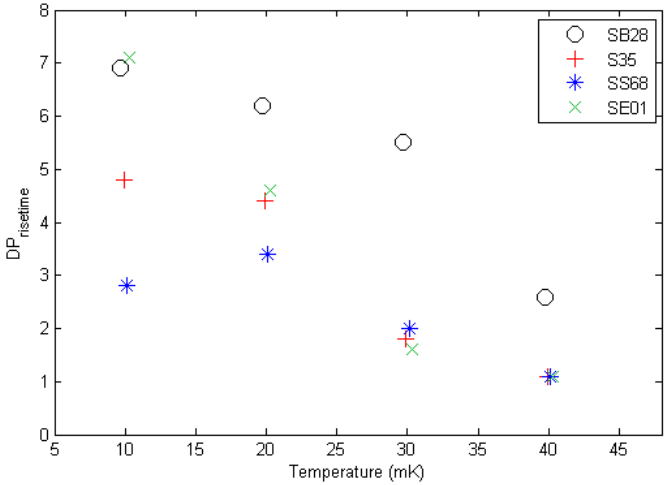


AMoRE-Pilot run-2: Discrimination Power as a function of temperature

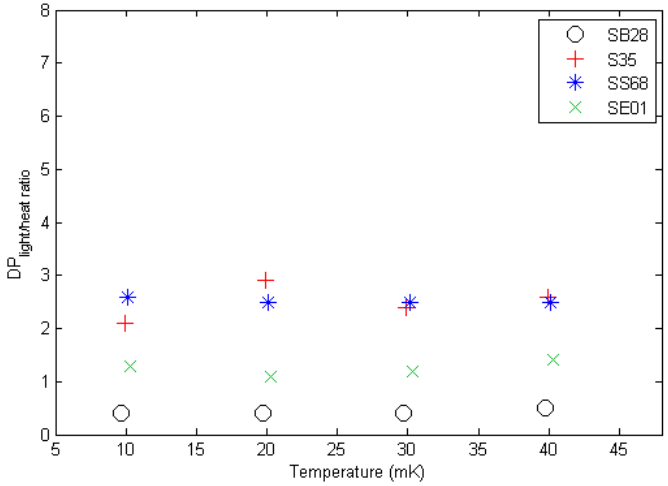
DP mean time



DP rise time



DP light/heat



$$DP = \frac{x_{\beta/\gamma} - x_{\alpha}}{\sqrt{\sigma^{2}_{\beta/\gamma} + \sigma^{2}_{\alpha}}}$$

- Performances of each particle discrimination method vary from one crystal to another
- Overall, rise time provides the highest Discrimination Power (DP)

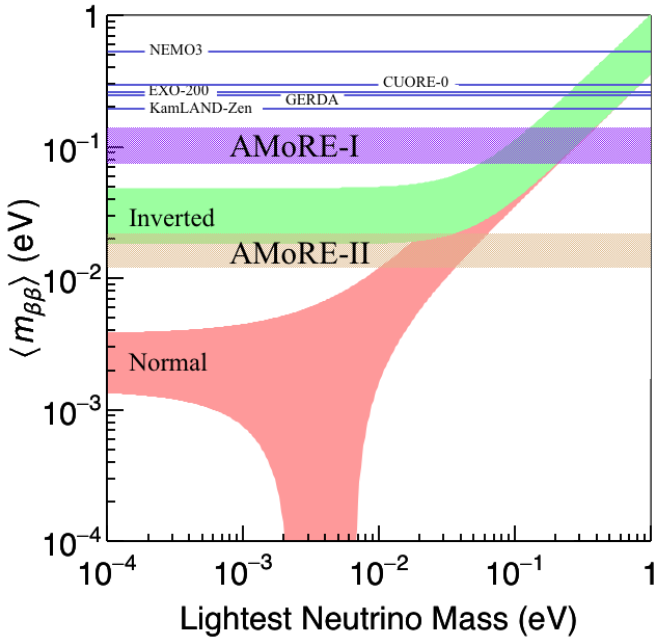
Current status of AMoRE-Pilot

- The cryostat's inner vacuum chamber which was made of Aluminium was replaced with a new low-background Copper chamber to try and reduce the ^{208}Tl background
- Further improvements on the crystal holding structures are being tested to reduce the vibration noise
- Efforts are being made to decouple the pulse tube refrigerator from the cryostat as it is the main source of vibration noise
- Several damping systems are being designed and will be tested with the AMoRE-Pilot setup
- AMoRE-Pilot run-3 measurements will reflect the improvements being made

AMoRE-I and AMoRE-II experiments

	AMoRE-Pilot	AMoRE-I	AMoRE-II
Total mass	1.5 kg ($^{40}Ca^{100}MoO_4$)	5 kg ($^{40}Ca^{100}MoO_4$)	200 kg
$T_{1/2}$ sensitivity (years)	3.2×10^{24}	2.7×10^{25}	1.1×10^{27}
m_{ee} sensitivity (meV)	210-400	70-140	12-22
Underground lab	Y2L	Y2L	New lab
Schedule	2015-2017	2017-2019	2020-…

- AMoRE-Pilot and AMoRE-I at Y2L, with $CaMoO_4$ scintillation crystals
- AMoRE-II will be carried out at a bigger lab because of the large detector volume, with decision on crystals not final yet



Thank you