The new CROSS Cryogenic Underground (C2U) facility: an overview

P246

E. Olivieri for The CROSS Collaboration

We present the CROSS (Cryogenic Rare-event Observatory with Surface Sensitivity) Cryogenic Underground (C2U) facility installed at the Laboratorio Subterranéo de Canfranc (Spain). It consists of a low-radioactivity, pulse-tube-cooled dilution refrigerator where scintillating macro-bolometers are run and read out via low-noise room-temperature electronics, to study the neutrino-less double-beta decay of ^{100}Mo, ^{130}Te or ^{116}Cd.

Since the commissioning (mid-2019), we performed three long-living runs (up to 5 months duration), operating several detectors which reported superior performances in terms of stability, running duty-cycle and energy resolutions. The C2U facility is about to be upgraded with 1) an extension of the present internal/external shielding, 2) the installation of an anti-radon system, 3) a muon veto.

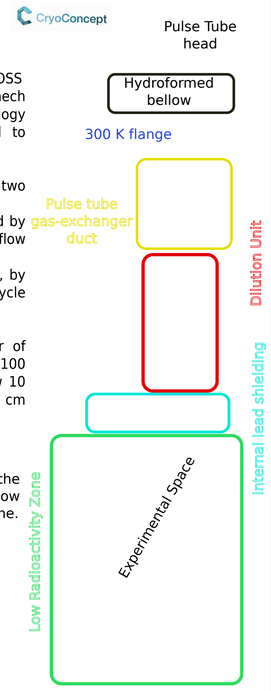
Cryostat description...

The low radioactivity cryostat of CROSS (Cryoconcept) is equipped with a Cryomech PT415 pulse-tube. A special technology (Ultra Quiet Technology) is employed to mitigate the pulse tube vibrations.

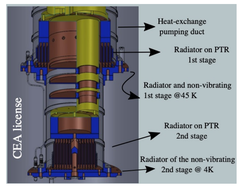
The cooling process take place in two phases:
- precooling: from 300 K to 4 K obtained by circulating a ^{3}He/^{4}He mixture at high flow rate (17 mmol/s)
- standard cooling: from 4 K to 10 mK, by using a dilution unit closed-cycle (condensation at 2 mmol/s).

The dilution unit has a cooling power of about 6 uW at 20 mK and 340 uW at 100 mK, and can reach temperatures below 10 mK over an experimental volume of 600 cm length and 30 cm diameter.

The pulse tube head is coupled to the cryostat via a supple hydro-formed bellow and is firmly kept by a tripode rigid frame.



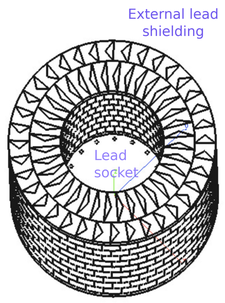
The pulse tube cold stages are thermally linked to the cryostat cold stages by gas loaded exchangers which prevent any mechanical contacts.



...and shielding

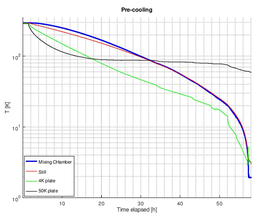
The cryostat is mechanically referenced to the floor: it is tighten to a 10 ton lead-brick loaded platform. Bricks constitute the low radioactivity external lead-shielding (25 cm thick) which protects the internal experimental volume from the external radioactivity.

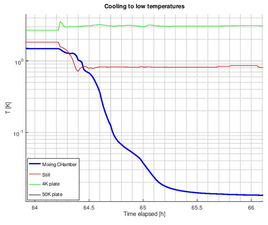
An internal lead socket (120 kg weight), cooled down to temperatures as low as 800 mK, shields the experimental volume from the dilution unit and cryostat upper parts (no low radioactivity materials). From below, the experimental volume is protected by a 25 cm thick lead socket.



Cooling down

The cryostat cools down to 4 K without any exchange gas: 120 kg of internal lead-copper shielding plus few tens of kg of low temperatures detectors/holders are ready in 55 hours to be further cooled down 10 mK.

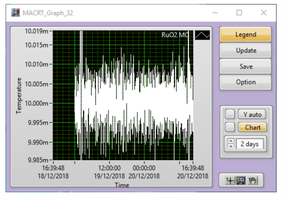




In few hours the detectors reach the 20 mK temperature region and are ready to study. The Mixing Chamber temperature is stabilized around 12 mK with temperature fluctuation within 10 uK. The best detector working point is searched and noise optimization studies begin...

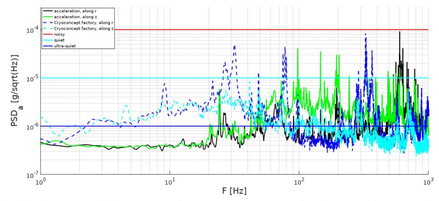
The Mixing Chamber is regulated via a PID system, which typically delivers a power of about 200 nW (5.5 uW) to stay at 10 mK (20 mK).

Temperature/noise stabilities are key parameters to perform high quality, long-living bolometric searches.

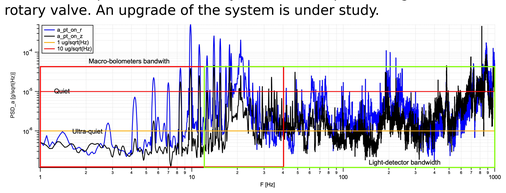


Vibration survey

We performed a campaign of "seismic" measurement at the installation site to built the best strategy to place the cryostat and decouple from environmental vibrations. Since the ground floor at LSC is an extremely calm reference frame (except human activity), the cryostat is referenced to the floor.



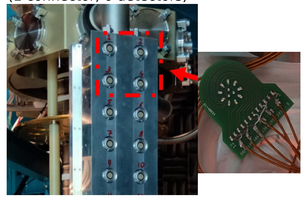
With high sensitivity accelerometers we further characterized the vibration profile of the 10 mK replica plate, where detectors are installed, with pulse tube ON/OFF. Along the radial direction r, the pulse tube high order harmonics are not totally cancelled, despite the UQT system. These residual components are mainly due to the positioning/fixation of the rotary valve. An upgrade of the system is under study.

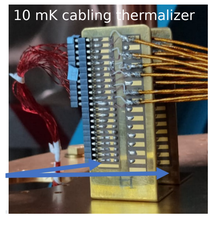


Wiring, electronics...

The cryostat is equipped with shielded, twisted pair manganin wires. The wiring goes (without any interruption) from 300 K down to 10 mK: here the conductors are thermalized via Kapton pads thermally anchored to the cold stage. The cables are thermalized at every cryostat cold stages by mechanical clamping of the shielding.

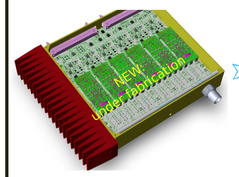
Cryostat connector box (1 connector, 6 detectors)



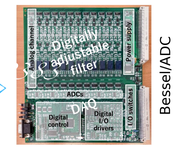


...front-end and more

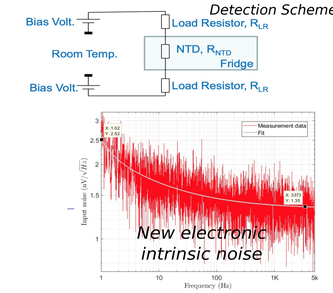
Detectors are equipped with high resistivity sensors (Ge-NTD, 1-10 Mohm resistance). The sensor signals are read by low-noise, room-temperature amplifiers. The sensor bias current circuitries (typ: 10 pA-30 nA range) is also embedded in the amplifier modules. The signals are afterwards shaped with a programmable Bessel filter and digitized with 24 bit precision ADC (+- 10.25 V dynamic range, 5kHz sampling frequency).



Front-end: 6 detectors per card, directly plugged to the cryostat connector box

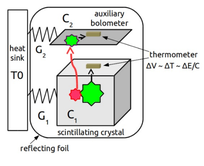


Data are streamed via ethernet packages and saved into binary files

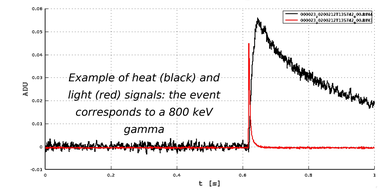


Typical bolometer...

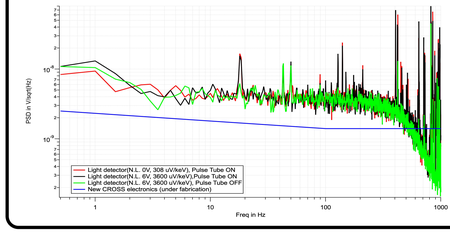
Among 6 composite heat-and-light Li_2MoO_4 detectors, 2 $CdWO_4$ (mass about 433 g and 582 g) bolometers were operated during the last 5 month run. One of these latter was operated in combination with a Neganov-Luke boosted germanium light detector. The bolometers read-outs were realized according to the scheme hereafter:



P303



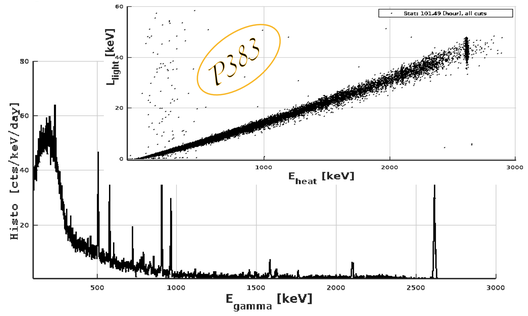
The Power Spectral Density Noise curves, in several configuration (at the working points) are shown as an example, for the germanium Neganov-Luke light detector: there are minor differences when the Pulse Tube is turned off for few minutes, which demonstrate the effectiveness of the full damping system adopted for the experiment.



The light detector reported a baseline noise (FWHM) as good as 30 eV (380 eV), with a Neganov-Luke bias of 60 V (0 V). No signs of space-charge building up was experienced over few months of operations; it was charge-reset only few times in the whole period.

The $CdWO_4$ heat channels reported about 2 keV (FWHM) baseline noise, with excellent stability in time, both in terms of noise and signal.

...performance



P383

As an exemple, we report the heat-and-light scatterplot, together with the energy spectrum, for a ^{232}Th calibration run (100 hours) of a $CdWO_4$ bolometer. Stability, baseline noise and resolution are excellent.

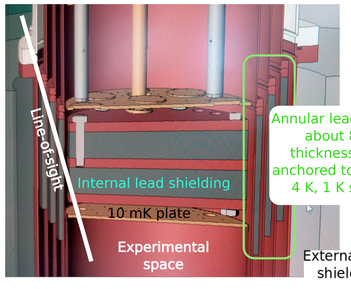
The table reports the resolutions of the several gamma line recorded. The performance remained very stable during the 5 month operation.

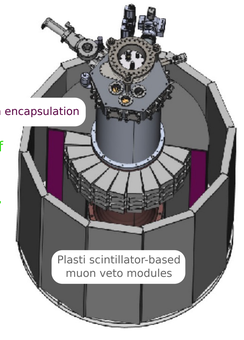
Prominent lines (γ)	Resolution (FWHM, keV)
0 keV	2.35
238 keV (^{212}Pb)	2.9
511 keV (^{208}Tl+annihil.)	4.6
583 keV (^{208}Tl)	3.8
911 keV (^{228}Ac)	5.4
964.8+969.0 keV (^{228}Ac)	6
2615 keV (^{208}Tl)	9.8 (anti-corr. widening)
Heater (6283 keV)	4.7

Prospects

The experimental space is not yet completely shielded from the external environment and line-of-sight apertures let environmental gammas striking the detectors, directly. An improved, internal (annular layers) lead shielding is under construction to reduce this component. C2U is about to be fit with an anti-radon system, connected to the LSC anti-radon facility.

A plastic-based SiPM readout muon veto is under study; it will mitigate the effect of the residual muons over the bolometers bkg.





The number of read-out channels will be progressively updated up to read 82 heat-and-light bolometers, simultaneously.

The facility will then host ^{100}Mo (16 kg mass), ^{130}Te (22 kg mass) bolometers and run as a first step for 2 years: this pilote experiment will demonstrate the CROSS tecnology capability to reach bkg index of 2×10^{-4} cts/keV/kg/y (in the ROI) and give indication of being able to go even further.

The CROSS project allows to assess a new technology for the next generation neutrino-less double beta decay experiment.

P308

- Linked Posters

P308: "*The CROSS experiment: rejecting surface events with PSD*". Presenter: *Hawraa Khalife*.

P383: "*A low energy threshold $CdWO_4$ scintillating bolometer for gA measurement*". Presenter: *Helis Dounia*.

P303: "*First results of CROSS underground measurements with massive bolometers*". Presenter: *Anastasiia Zolotarova*.

- References

I. C. Bandac et al., "*The 0ν2β-decay CROSS experiment: preliminary results and prospects*", JHEP 01 (2020), 018.

E. Olivieri et al., "*Vibrations on pulse tube based Dry Dilution Refrigerators for low noise measurements*", NIMA, 858 (2017) 73–79.

V. Novati et al., "*Charge-to-heat transducers exploiting the Neganov-Trofimov-Luke effect for light detection in rare-event searches*", NIMA 940 (2019) 320–327.

C. Arnaboldi et al., "*JFET Transistors for Low-Noise Applications at Low Frequency*", IEEE Transaction of Nucl. Sci, 51(6), (2004) 2975-2982.

CryoConcept Refrigerator: http://cryoconcept.com/