LSM

The laboratory

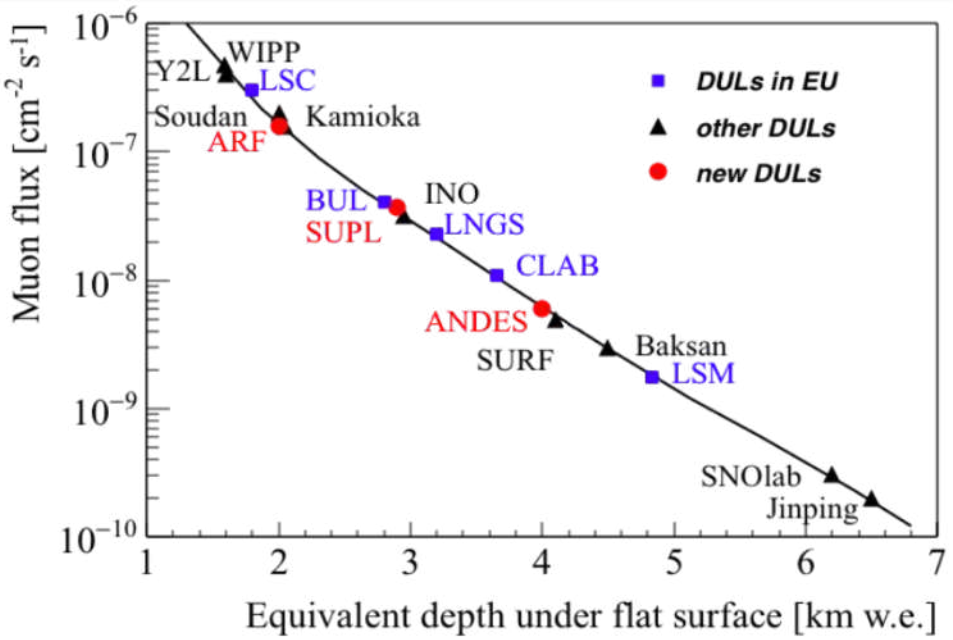
The Science program

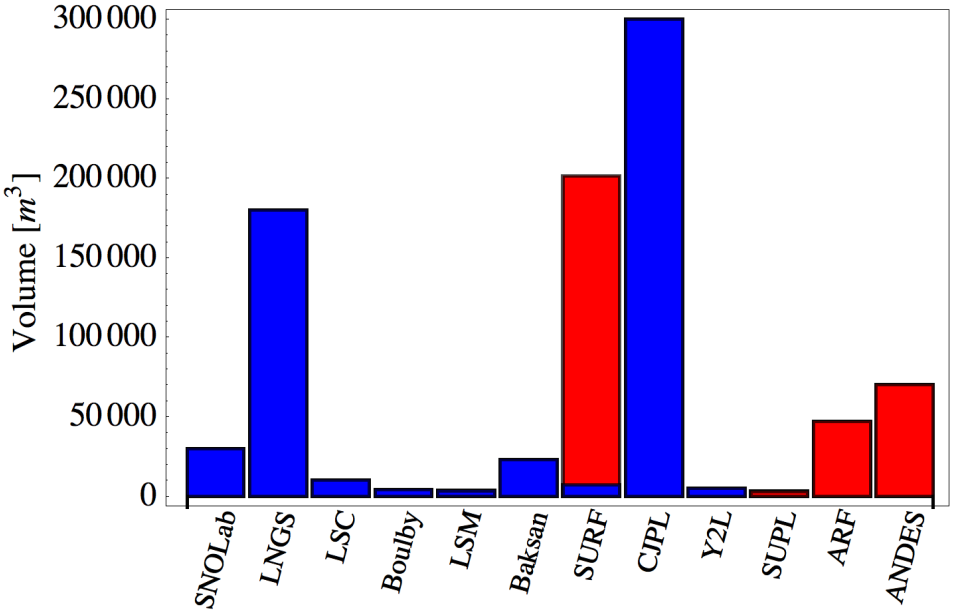
Scientific Director: Jules Gascon
(Université Lyon 1 + CNRS/IN2P3)
Director of Operations: Christophe Vescovi
(CNRS/IN2P3/LPSC)

LSM: a deep underground lab in Europe

- *Deepest* site in Europe dedicated to Astropart., Nuclear & Particle Physics
- 4800 m.w.e: Muon Flux reduced by >10^6 relative to surface (/5.5 LNGS)
- *Flexible access* (hall accessible to trucks up to 9m);
- *Small* experimental surface: 400 m^2

  cf: Canfranc 600 m^2, Boulby 1700 m^2, SNOLAB 5350 m^2, Gran Sasso 180000 m^2
- Natural radioactivity due to Radon <5 less than LNGS et LSC

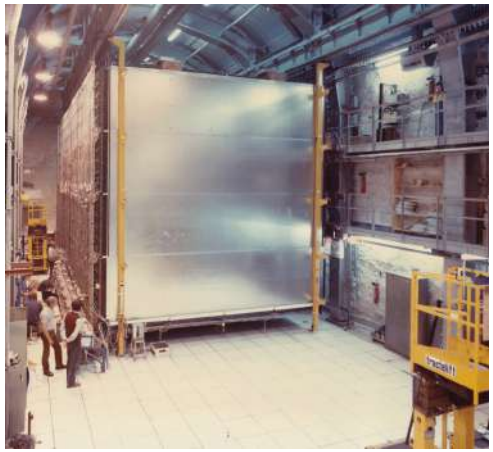




Laboratory History

- CNRS-CEA (1981-2016), CNRS-UGA(Grenoble University) (2016-2018)
- Fusion with LPSC/Grenoble (CNRS-UGA) in 2019

1979-1981 Construction → **1982-1990 Experiment on τ_p** → **1990-2000 Prototypes**

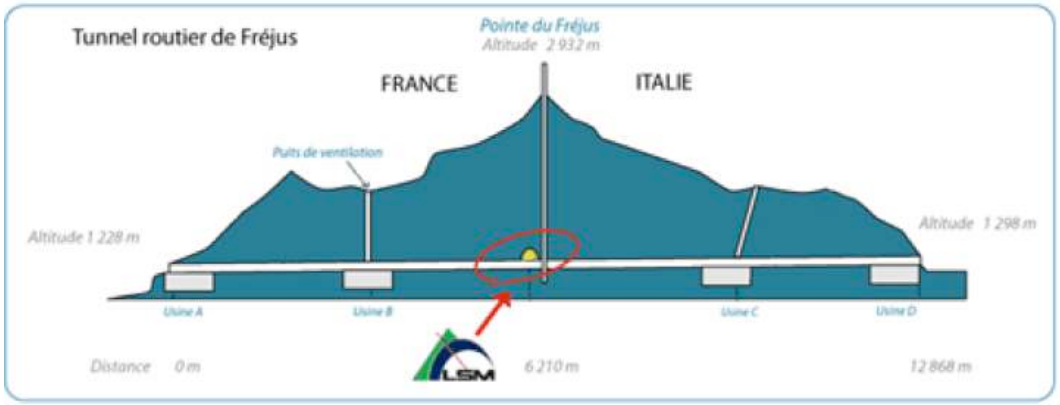
→ **2000-2020 : rich experimental program**




Two sites

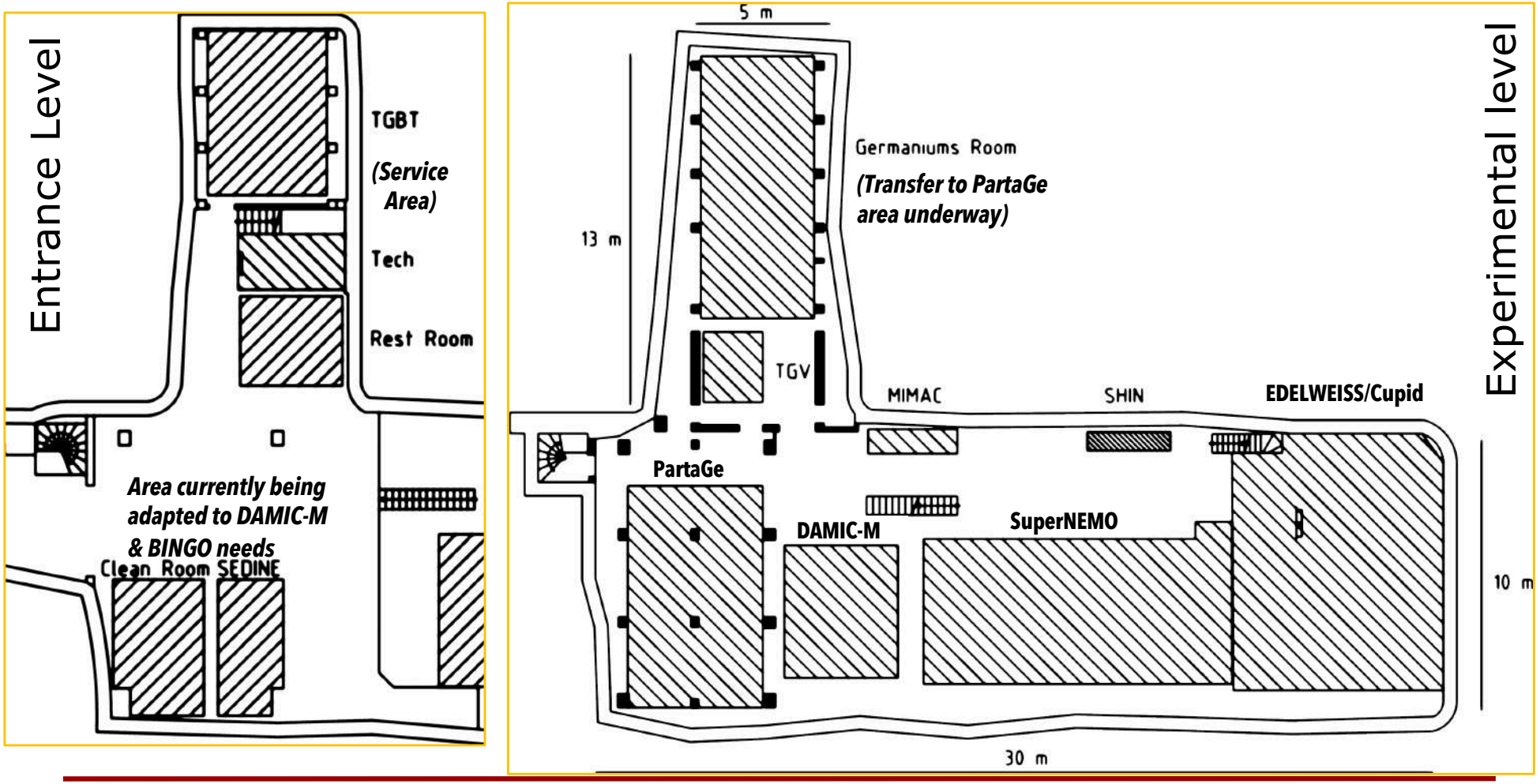
- 145 km from Grenoble
- Surface building
  - Built in 2009, with strong local + regional support
  - Offices, garage, museum open to the public

- Experimental site
  - Midway point of the 12 km Fréjus tunnel between France and Italy



LSM Floor plan (ca 2020)

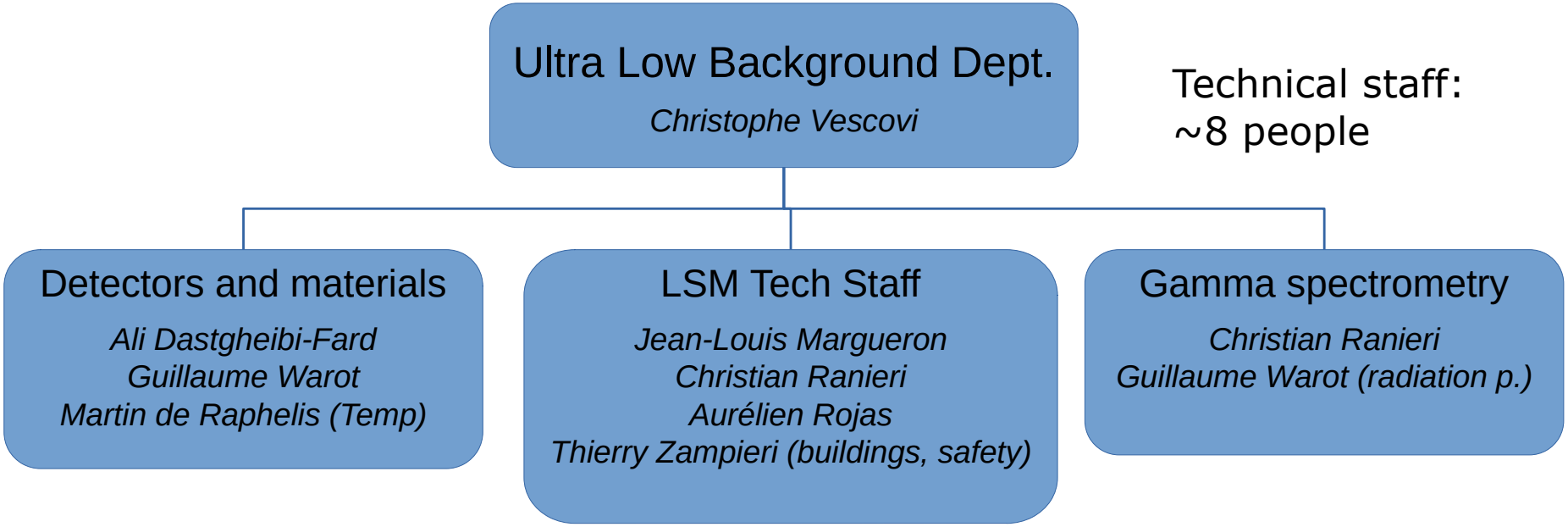
- Tight occupation of available 400 m^2
- Plans to install 180 m^2 mezzanine level (over the crane access) above expt. level



LSM Status and Missions

- Since 2019: national platform of CNRS/IN2P3, hosted by the CNRS+UGA laboratory LPSC (Grenoble)
  - Merging LSM (~10 personnel) with LPSC (~200 personnel) improved administrative & technical support, and improved link with Grenoble University *(infrastructure support)*
  - National status of LSM ensured by nomination of Scientific Director by IN2P3
  - LSM included 2022 by French Ministry on its national list of Research Infrastructure
- **Platform for Subatomic/Astroparticle physics**
  - Hosting fundamental physics experiments, in particular those supported by IN2P3
  - Host R&D and detector physics for future generation experiments, with larger detector arrays being deployed in larger DUL
  - Provide technical support to experiments
- **Germanium detector platform**
  - Measurement of very low activities in samples
  - Technological development for very-low activity measurements
- **Opening to multidisciplinary applications**
  - Host small experiments / measurements that can benefit from the exceptional low-radioactivity environment and the staff expertise in this domain *(ex: biology)*

LSM Organization

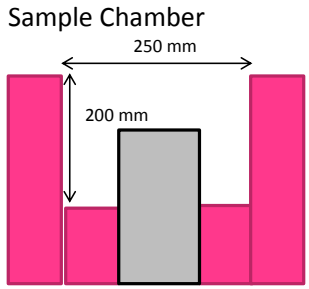


- Director of operation (C. Vescovi, LPSC)
- Scientific director (J. Gascon, Lyon University + CNRS/IN2P3)
- LSM Steering committee includes CNRS/IN2P3 & Université Grenoble Alpes
- LSM External Strategic Council: A. Iani (LNGS), S. Paling (Boulby), S. Schönert (TUM), N. Smith (Triumf) ... *importance of DUL coordination in strategy discussion*
- No physicists in staff. *Scientific coordination of French efforts in Deep Underground Physics via DUPhy "Groupe de Recherche" (GDR): (https://gdrduphy.in2p3.fr/)*

Germanium platform

- ~16 Ge for very-low background material assays
  - For experiments based at LSM (SuperNEMO, EDELWEISS, CUPID-Mo) or for other experiments (ex: JUNO)
  - *Agreement with LNGS for measurement of ECEC decay of ^{82}Se (6 kg) to excited state on large (600 cc) Obelix Ge*
  - Large program for Earth Sciences (sediment and ice core sample datation), environmental safety (CEA) and Biology

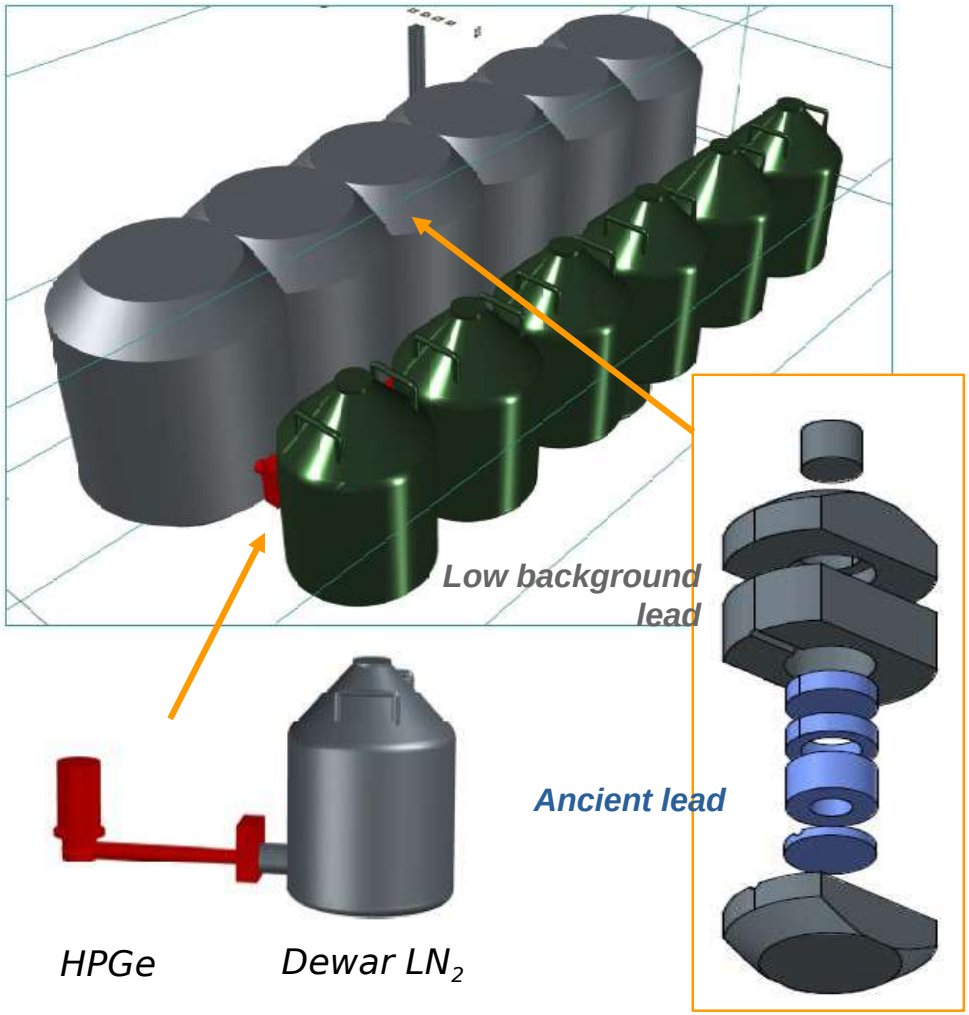
- Academic and industrial partners
  - IRSN, CEA, CENBG, IP2I, LSCE (Université Paris-Saclay, CEA, CNRS), EDYTEM (CNRS, Université Savoie Mont-Blanc), JINR Dubna (Russia), UTEF Prague and SURO (Czech Republic)



Current Ge facility upgrade: PARTAGe

- More efficient use of space
- Can increase up to 22 HPGe
- Shielding optimisation
- Ease of LN_2 refill
- Common Rn-free air tent

- 11 detectors transferred so far



Other facility upgrade: Radon trapping

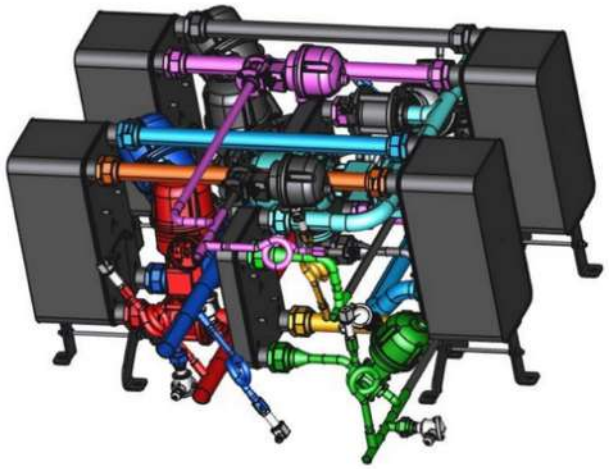
Cf C. Vescovi presentation

Existing facility

- First one installed in a DUL in 2005):
- Initially, 120 m^3/h flow of air with 15 mBq/m^3 Rn concentration (~ /1000 ambient).
- Flow now reduced to 120 m^3/h, reliability: upgrade under way

Upgrade:

- Staged approach to reach flow of 250 m^3/h in time for SuperNEMO and DAMIC-M runs + reduce electricity & cooling needs



Design study for optimized refrigeration system

Summary of 2021 activities for experiments

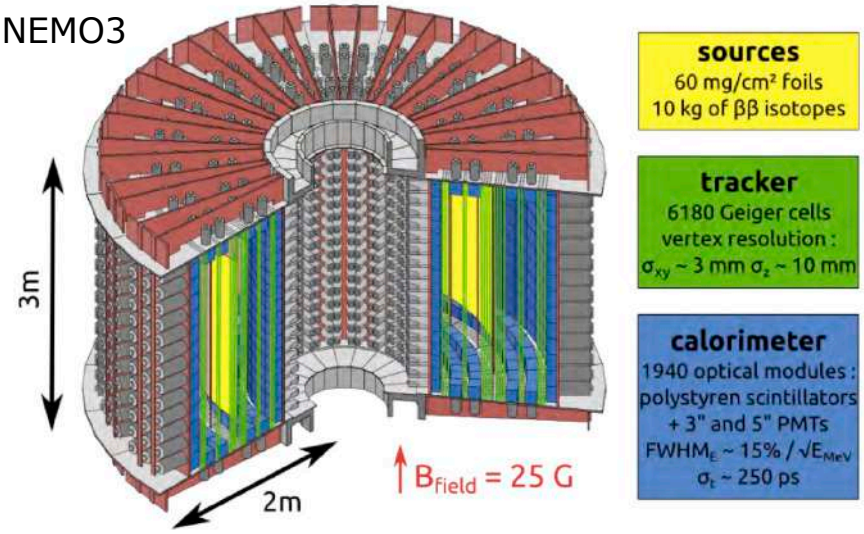
- Program focused on development of new techniques ("demonstrator") and low-mass WIMP searches: *well adapted to LSM constraints (small space) and strong point (lowest muon rate in EU, easy road/truck access, proximity to French labs)*

LSM Experiment	Domain	Technique	Collaboration	Activities in 2020-2021
CUPID-Mo	$\beta\beta0\nu$	Cryogenic LiMoO	France, Russia, Germany, Italy, USA, Chine, Ukraine	Physics exploitation. No futher runs in EDELWEISS-III cryostat.
SuperNEMO	$\beta\beta0\nu$	Tracko-Calo	France, UK, Russia, Japan, USA, Czech Rep., Slovakia	Commissionning ongoing. Delays in the shield installation
BINGO	$\beta\beta0\nu$	Cryogenic	France	Installation of cryostat to start end of 2022
Obelix 82Se	ECEC2ν	Ge ionisation	France, Italy, Russia, Czech Rep.	Counting of 6 kg enriched 82Se sample from LNGS started in january 2022: ECEC2ν to excited states
TGV	$\beta\beta0\nu$	Ge ionisation	Russia	Detector upgrade delayed by covid & war
DAMIC-M	DM	Si CCD	France, USA, Canada, Switzerland, Denmark, Spain, Brasil, Argentina	Installation started in 2020, Test chamber data started in 2022, physics in 2023
EDELWEISS	DM	Ge Cryogenic	France, Russia, Germany	Physics exploitation. No furter runs in EDELWEISS-III cryostat
CRYOSEL	DM	Ge Cryogenic	France	EDELWEISS detector R&D using BINGO cryostat
MIMAC	DM	TPC Direct.	France	No runs in 2021
NEWS-G	DM	Spherical gas detecor	France, Canada, USA, Greece, UK	Plans for SEDINE detector tests in new shielding

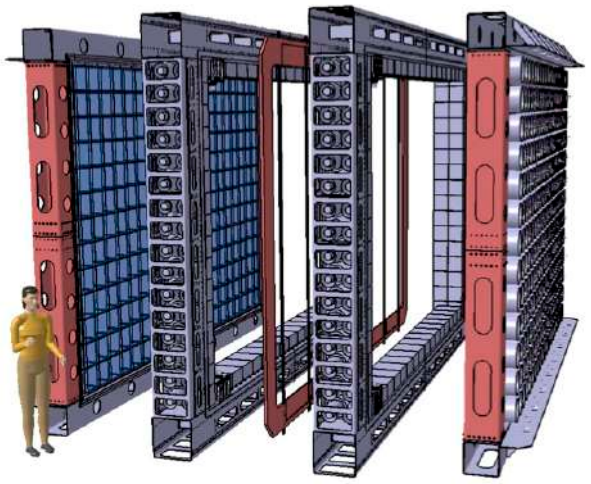
$\beta\beta0\nu$: NEMO3 -> SuperNEMO

- Unique tracko-Calorimeter detection of neutrinoless double-beta decay for the identification of the two electron tracks
  - Detailed characterization and reduction of non-$\beta^-\beta^-$ backgrounds
  - Ideal for the study of non-standard decay models
- NEMO3 (2000-2011): at the time, best ^{100}Mo limit based on 46 kg.y (7 kg target), and best limit on 4 other isotopes
- *SuperNEMO demonstrator: 7 kg ^{82}Se target in more modular design (to assess possibility of future extension in a larger UL)*

NEMO3



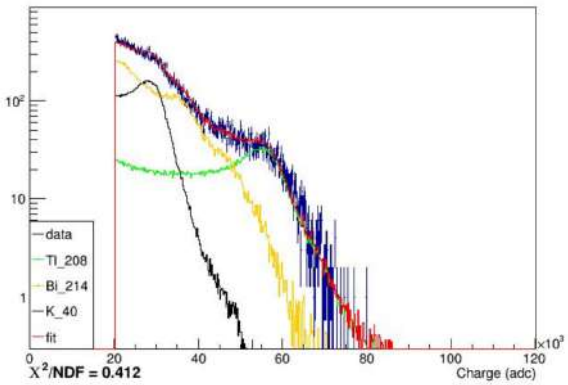
SuperNEMO module



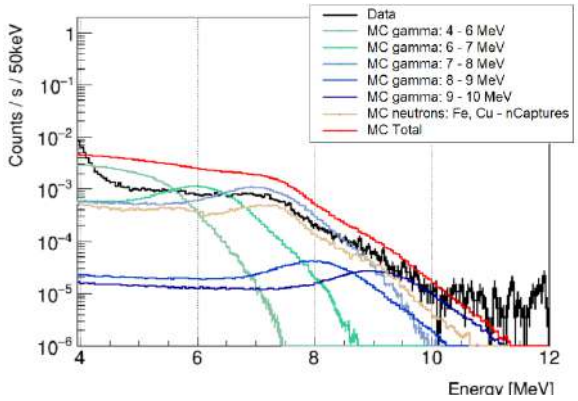
$\beta\beta0\nu$: SuperNEMO update

- Installation delayed by COVID
- Commissioning of calorimeter (2019) & tracker (2021)
- Next: installation of iron and polyethylene shields, and of radon tent

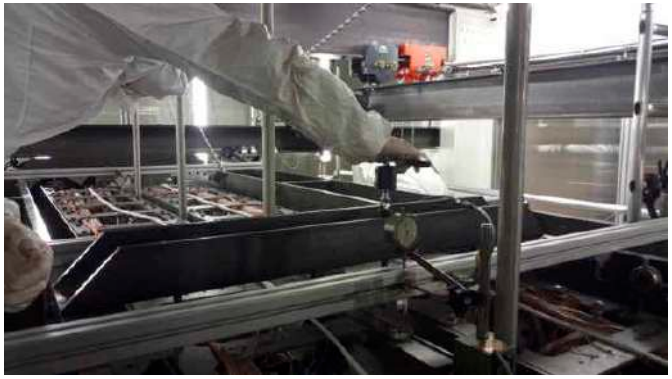
Optical module spectrum ≤ 2.6 MeV with MC fit ^{40}K + ^{214}Bi + ^{208}Tl

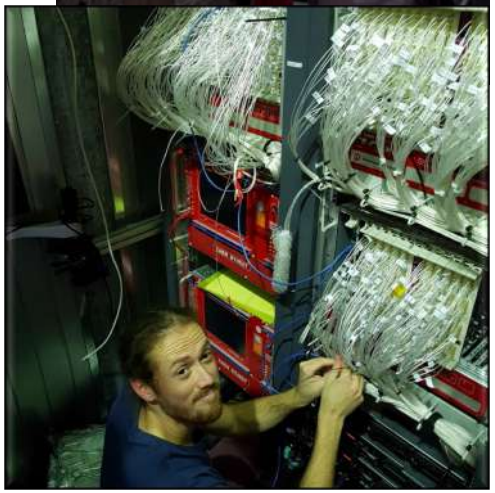


LSM published ambient flux (γ+n) vs SuperNEMO calorimeter-only data



- Publication of ambient neutron+gamma flux calorimeter-only data
- Data taking to start in 2023





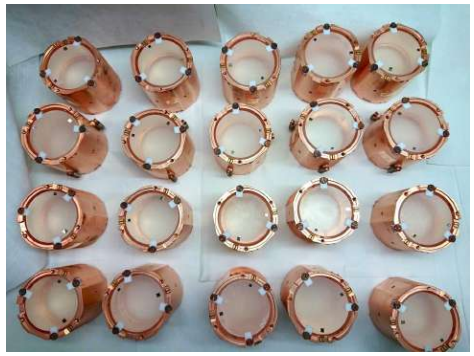
$\beta\beta0\nu$: CUPID-Mo

- 19-month common run with EDELWEISS (2018/12–2020/07)
  - Cryogenic (22mK) detectors
  - 20 crystals x 0.21 kg Li_2MoO_4
- Physics throughout the COVID!
- Best ^{100}Mo limit obtained with a limited exposure of 1.47 kg.y only (arxiv:2202.08716):

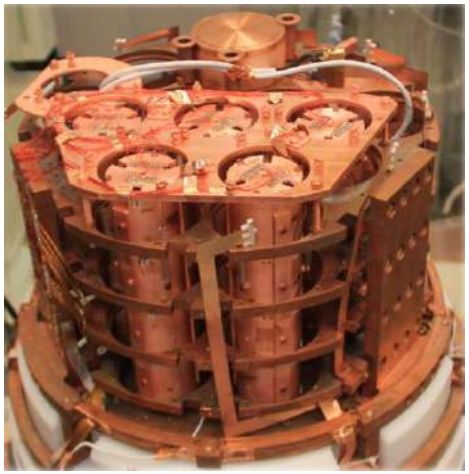
$$T_{1/2} > 1.8 \times 10^{24} y$$

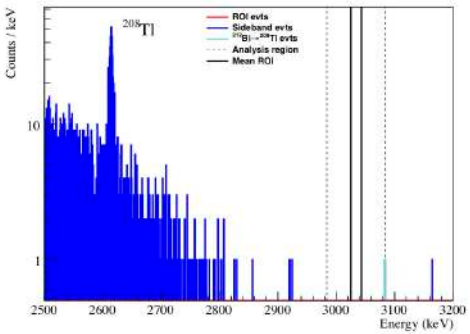
$$\langle m\beta\beta \rangle < (0.28\text{-}0.49)\ eV$$

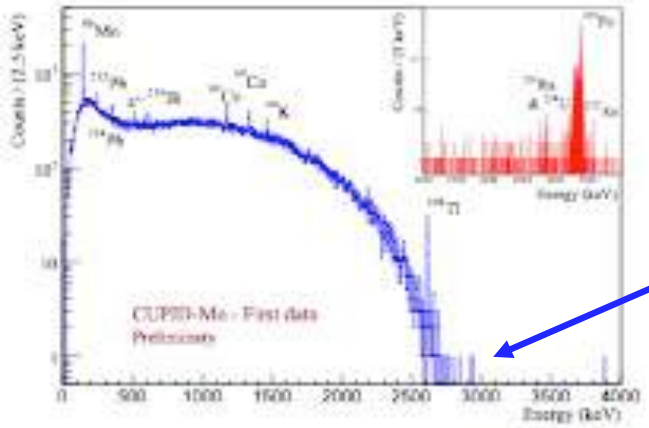
- *Key result for CUPID design*
- *Gateway for a larger French participation to CUPID*
- *Excellent example of synergy between experiments at LSM!*



CUPID-Mo (front)
EDELWEISS





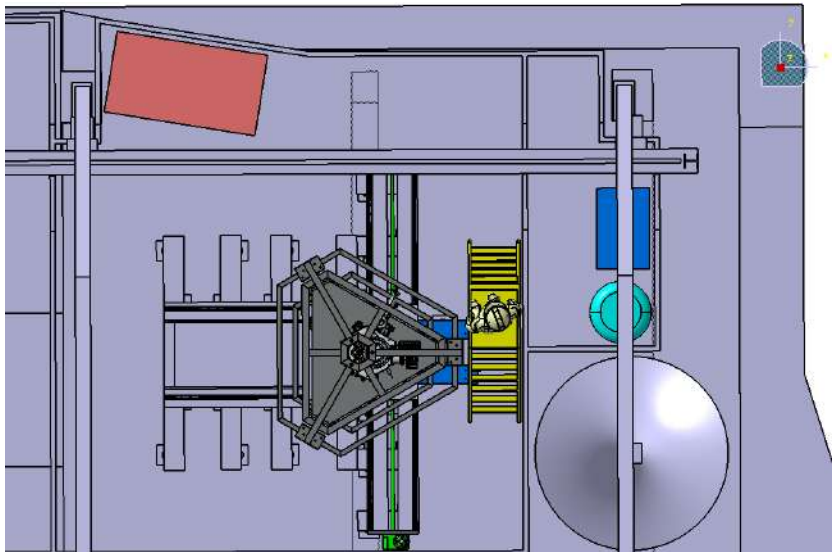


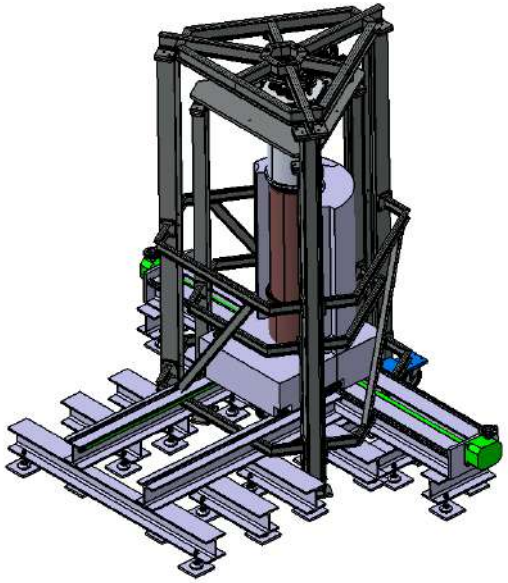
Background rejected with light detector

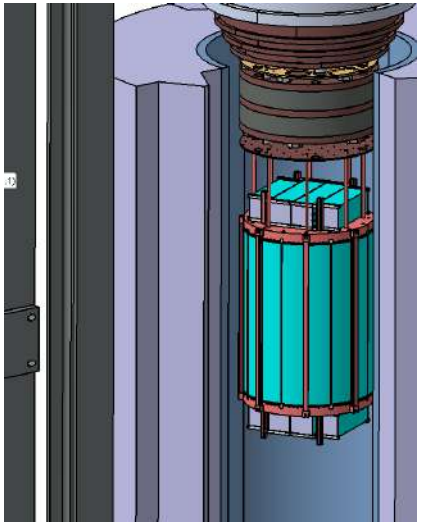
Region of interest: 3034 keV

$\beta\beta0\nu$: BINGO ERC

- Mini-BINGO demonstrator, for $\beta\beta0\nu$ searches beyond CUPID:
  - Innovation in detector support and light detector required for cryogenic detector to be scalable to higher mass & lower bkgs
  - Active cryogenic inner shield
  - ^{100}Mo and ^{130}Te targets
  - Synergy with EDELWEISS (CRYOSEL runs scheduled for 2023)
  - Clean room for new *dry* cryostat to be installed at LSM end 2022

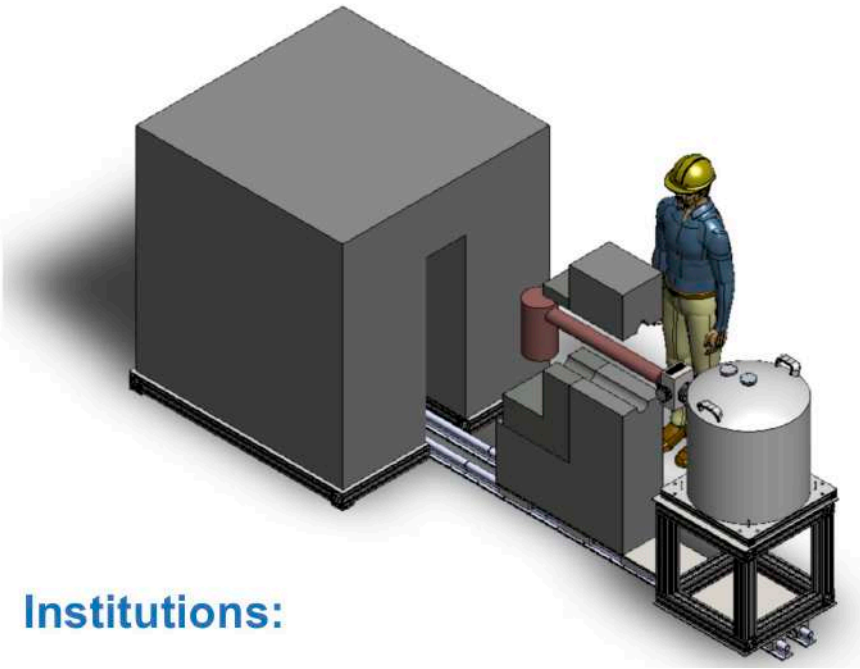






Low-mass Dark Matter: DAMIC-M

- Search for low-mass Dark Matter with skipper CCDs
  - Building on DAMIC@SNOLAB results with 40g detector array
- 1 kg Si target (50 CCDs x 20g)
  - Skipper readout: resolution < 0.1 e-
- Background goal: 0.1 DRU
  - Underground clean room for assembly
  - Second clean room for detector
  - <1 GeV WIMPs @ 10^{-42} cm^2 (SI)
  - DM-electron interactions: ~10^{-41}cm^2 for masses down to 1 MeV/c^2
- ERC Advanced Grant (May 2018) and NSF Grant (Sept. 2018)

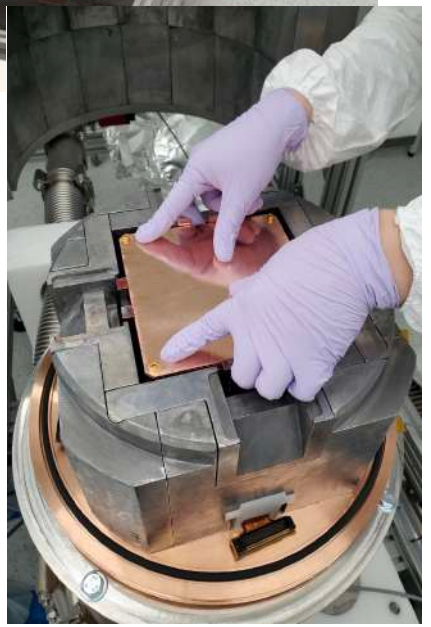


Institutions:

The University of **Chicago**, University of **Washington**, Pacific Northwest National Laboratory (**PNNL**), **SNOLAB**, Laboratoire de Physique Nucléaire et de Hautes Energies (**LPNHE**), Laboratoire de l'Accélérateur Linéaire (**LAL**), Laboratoire Souterrain de Modane/Grenoble (**LSM**), Institut de physique nucléaire d'Orsay (**IPNO**), Centre d'études nucléaires Bordeaux Gradignan (**CENBG**), Laboratoire de Physique Subatomique et des Technologies Associées (**SUBATECH**), University of **Zurich**, **Niels Bohr Institute**, University of **Southern Denmark**, University of **Santander**, Universidad Federal do **Rio de Janeiro**, Centro Atómico **Bariloche**

Low-mass DM: DAMIC-M

- Cleanroom for 2-CCD system received Feb. 2021
- Installation of Low-Background Chamber (Oct-Dec 2021), to host these two first CCDs



- 2 CCDs with skipper readout running
  - Measure dark current, ^{32}Si background, backside layer background
  - First science measurements (1 kg-day goal)
- CCD production (outside LSM) in 2022
- Preparation for a run in 2023

Low-mass DM: NEWS-G

SNO-Globe project

- Spherical detector (diam.1.4m) fabricated in France in 2018
- Installation in LSM in March 2019
- Collaboration PNNL+LSM for electrodeposition of low-radioactivity Cu + etching + passivation
- Data taking in Oct. 2019 with CH_4 target (best target for for lightest DM)
- Detector shipped at SNOLAB in Nov. 2019 for non-CH_4 runs.

SEDINE sphere (0.6m) at LSM

- Continue to use this pioneer sphere (2017 physics results @ LSM) at LSM for calibration & reference He measurements

Electrodeposition

Installation in Roman lead shield at LSM

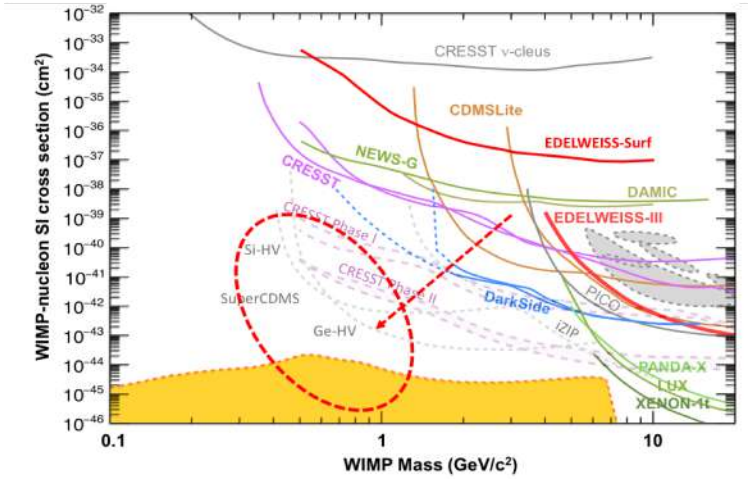
Low-mass DM: EDELWEISS

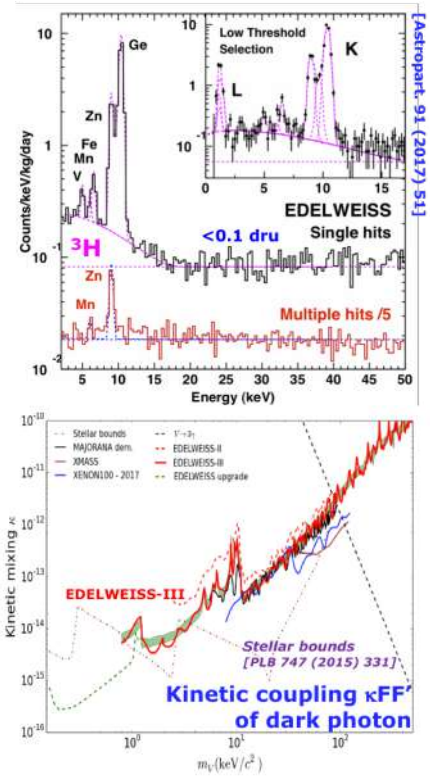
EDELWEISS-III (2010-2015)

- Original design (2010): > 10 GeV/c² WIMPs
- Updated objectives (2012): 5-20 GeV/c²
- *Largest mass of cryogenic Ge (30 kg)*
- Completed in 2015 with 3000 kg.d (8 kg.y)

EDELWEISS Low-mass program (2016…)

- GeV/c² -> SubGeV/c² WIMPs, <1 MeV DM-electron interactions, ~eV Dark Photons...
- *Major step forward (2018):* heat resolution improved x25 (σ=18 eV) with 33g detector





EDELWEISS Sub-GeV goals:
σ_{phonon} = 10 eV and σ_{ion} = 20 eV_{ee}

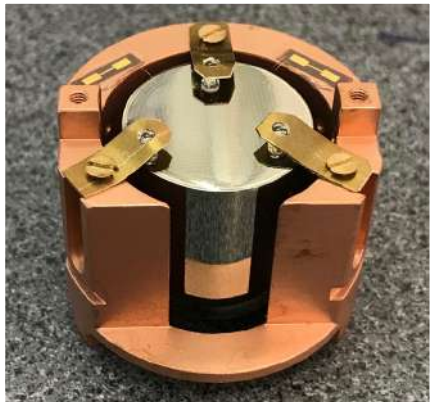
- Demonstrate event-by-event particle identification of nuclear recoils down to 1 GeV/c² with kg-size array (~10^{-43} cm²) – *developed in synergy with Ricochet*
- With Luke-Neganov gain, obtain single-electron detection capabilities (~100V needed already achieved in EDELWEISS)
- *"Building brick" for future ≫1kg contribution to SuperCDMS*

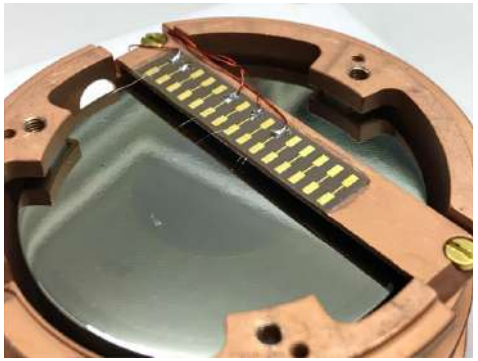
Low-mass DM: EDELWEISS

- Installation at LSM in 2018 of a new generation of smaller, low-threshold detectors
- Common physics run with CUPID-Mo
- *First demonstration of a <1 e- resolution with a massive cryogenic Ge detector*
- *Sub-MeV sensitivity to DM-electron scattering & 1 eV Dark Photons*
- *Sensitivity to WIMPs with masses <35 MeV/c²*

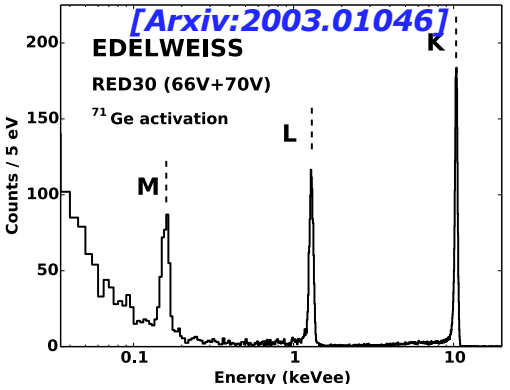
- CRYOSEL: New single-electron tag using nanowire technology TES sensor, with *excellent physics reach with 1x40 g detector to be operated in BINGO cryostat @ LSM (2023)*

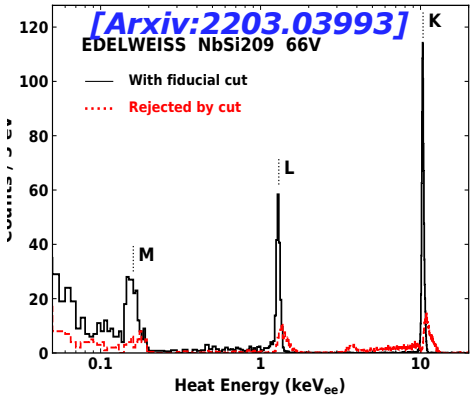
33g GeNTD

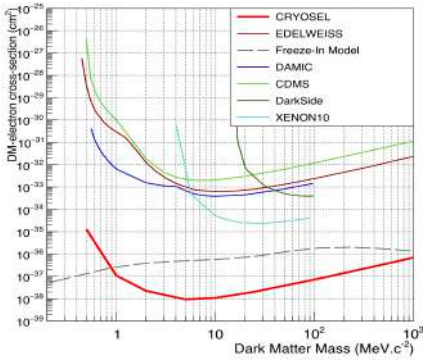


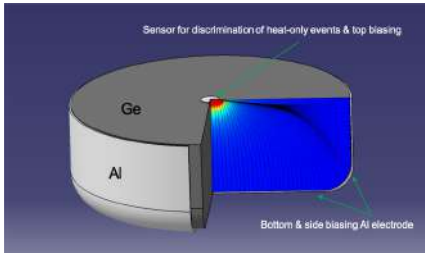


200g NbSi









CRYOSEL@LSM demonstrator: 1 month x 1 detector

Conclusion

- LSM physics program focused on experiments requiring stringent low-radioactivity requirements, and on the associated technological developments. Also open to other applications that can benefit from its depth, its expertise and its position within the French and EU landscape

- *LSM physics program has already links with larger experiments in larger DUL*

- *Looking forward an increased partnership with the EU underground laboratories*