Laboratoire Souterrain de Modane – participation of the Czech Republic (LSM-CZ)

LM2018107

Rastislav Hodák (IEAP CTU in Prague) on behalf of

Responsible institutions:

- Institute of Experimental and Applied Physics, Czech Technical University in Prague (IEAP CTU in Prague)
- National Radiation Protection Institute (SÚRO)

LSM-CZ: from 2012 is included in the Roadmap of the Czech LRIs

Day with particle and astroparticle research infrastructures, October 17, 2022, Prague

LSM operated by: CNRS (IN2P3), l'Université Grenoble Alpes (Laurent Derome, Jules Gascon)

International advisory board: Nigel Smith (director of SNOLAB, Canada); Sean Paling (director of Boulby underground lab.); Stefan Schoenert (spokesperson of LEGEND experiment, TU Munich); Elena Aprile (spokesperson of XENON experiment, Columbia University)

Financial support of LSM operating costs: a) FR: 300 kEUR (without investments); b) CR: 70 kEUR (in 2020); c) JINR: 57 kEUR; d) SR: 20 kEUR

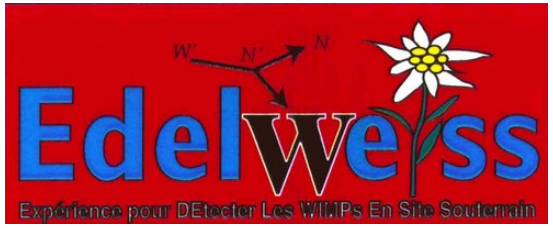
LSM-CZ annual fee: 2016 = 914 kCZK, 2017 = 500 kCZK, 2018 = 500 kCZK, 2019 = 500 kCZK, 2020 = 789 kCZK, 2021 = 700 kCZK, 2022 = 700 kCZK

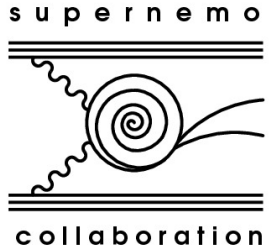

LSM – surface building

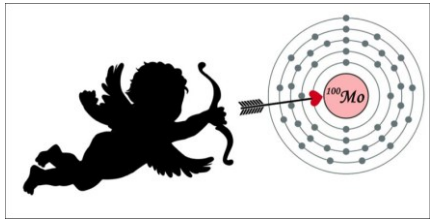
LSM – view from Fréjus tunnel

Laboratoire Souterrain de Modane (LSM, France) - RI devoted to multidisciplinary fundamental and applied research in ultra-low background conditions.

- deepest underground laboratory in Europe (4 800 m.w.e., cosmic ray flux 4 muons/m^2/day → μ suppression 10^6)
- direct search for **dark matter** - EDELWEISS, NEWS-G, DAMIC-M, MIMAC
- study of **neutrino properties** in **0νββ**: **mass** and **nature of neutrino** - SuperNEMO, CUPID-Mo, TGV, BINGO
- **environment studies** (radioactivity of samples from seas, sediments, aerosols
- **microelectronics** (tests of chips), „single count effect“ research
- **radiobiology** in „ZERO DOSE“ environment (human/rodent cell cultures in conditions with extremely low levels of background ionizing radiation)
- **geoscience** (detection of geo-neutrinos from radioactive decays), **archeology** (radionuclide dating), **climatology** (dating of lake sediments for climate changes)
- **nuclear safety, radiation emergency, nuclear forensic** (trace radionuclides analysis, e.g. in aerosol in the vicinity of nuclear power plants)







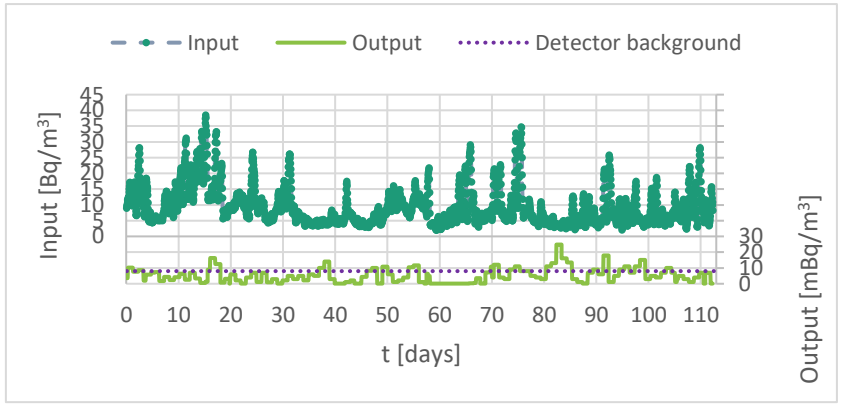
Financial support (LM2018107):

- 2020 budget 9 628 000 CZK (appr. 360 kEUR) – 65% personnel costs, 27% operating costs, 8% fee
- 2021 budget 9 176 000 CZK
- 2022 budget 8 994 000 CZK

Fees to LSM: in period of 2016-2022 = 4 603 000 CZK (appr. 184 kEUR, 26 kEUR/year)

Infrastructure at LSM:

1) **Anti-radon facility** - providing 130 m^3/h of air with Rn activity < 10 mBq/m^3 (reduction factor ~ 1000)
 - successful technology transfer to industry (ATEKO company produced several such facilities for ~ 80 MCZK)
 - original setup was dismounted in 2014 (Hodak R. et al., J. Phys. G 46 (2019) 115105)
 - LSM-CZ financed new anti-radon facility (250 m^3/h) for LSM:
 Part 1: ATEKO (air drier, cooling unit and vessel for charcoal) = 122 kEUR
 Part 2: ATEKO (charcoal, isolation….) = 17,7 kEUR
 Still missing: compressor and installation will be ensured by LSM



2) Three ultra-low background HPGe detectors

OBELIX 600 cm^3, e.g. first detection of extremely low radionuclide concentration on filters in vicinity of Czech nuclear PP (ETE EDU) (Brudanin V. B. et al., JINST 12 (2017) P02004)

IDEFIX 600 cm^3, efficiency 165%

SURO 500 cm^3, efficiency 125%

3) Low radon clean room ("ZERO DOSE" radiation environment, class ISO 5)

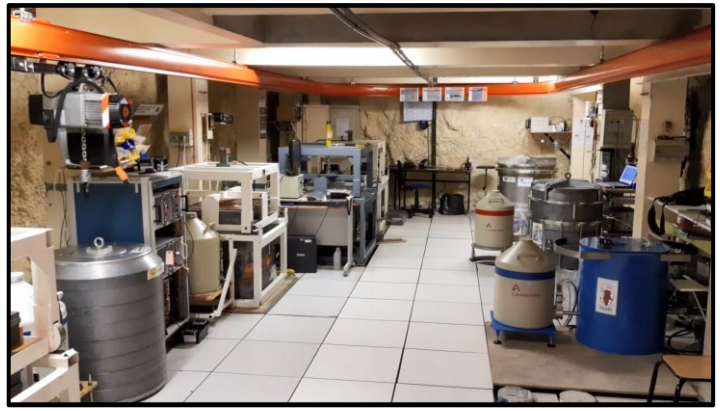
– built by company CRAC (Stekl I. et al., Frontiers in Public Health 8 (2021) 589891)

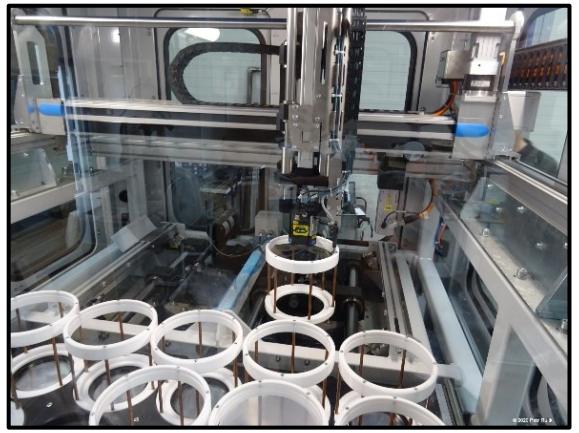
– we finished first test with frozen cells – analysis still ongoing

– currently relocation is in progress because of installation of new 0vββ decay experiment BINGO (^{100}Mo/^{130}Te).

4) Automatic system for charging of samples for HPGe detectors

– using radon-free atmosphere





LSM-CZ (from 2012): **Czech Technical University in Prague**
National Radiation Protection Institute
Charles University
Nuclear Physics Institute of the CAS

- 41 team members (29 IEAP, 9 NRPI, 1 ChU, 2 NPI) (15 experienced scientists, 10 early-stage researchers, 3 engineers, 3 technicians, 2 PhD and 4 undergraduate students, 4 administrative staff)
- total number of FTE on Czech side = **10.05**
- cooperation on construction and operation of experimental and infrastructural facilities in the LSM
- construction of **home infrastructure** in **Czech Republic** (detector technologies - 2 patents for scintillating detectors, technology for Rn removing from air, low radon clean room)
- more information: lsm.utef.cvut.cz

Home infrastructure for testing of LSM technologies

1) Radon infrastructure

- testing anti-radon facility (providing 20 m^3/h of air with Rn activity < 10 mBq/m^3) in SÚRO
- testing low radon clean room in SÚRO
- sensitive Rn detectors (e.g. volume of 50 liters) and radon concentration line (100 mBq/m^3)
- testing radon chamber in SÚRO (range 10 mBq/m^3 till 1 GBq/m^3)

2) Low background detection infrastructure

- sensitive HPGe detectors in low background environment (gamma and alpha spectrometry, whole body counter for internal contamination) in SÚRO
- ultra sensitive detection technology with pixel detectors - determination of ^{137}Cs and ^{90}Sr in water samples (<1 mBq/l) to study vulnerability of hydrogeological districts in radiation accident

3) Radiobiology and radioecology infrastructure

- radiobiological SÚRO and NRI research laboratories equipped with automated analysis of DNA damage METAFER, incubators, irradiation facility for cells experiments
- on-site experimental facilities for radionuclide migration (soil, plants)

Motto: Intensive growth of interest in deep underground laboratories (extension of research programs, more users, new underground facilities)

LSM-CZ has outstanding cost/benefit ratio:

A) Scientific results (users, WOS)

- articles and conference proceedings: 98 in 2009-2014, 135 in 2016-2020 (93 articles, 42 conference contributions),
- total number of citations = 1080 (2016-2020 articles).

B) Education, international cooperation

a) PhD theses (data only for France and CR): 13 in France and 3 in Czech Republic (2016-2020, one of them in so-called “thèse en cotutelle” among France-Slovakia-Czech Republic)

b) international conference MEDEX (Nuclear Matrix Elements, Prague 2017, 2019, 2022, 2023, ...)

c) organization of collaboration meetings (SuperNEMO, COBRA, in future LEGEND…).

d) summer schools (Pontecorvo Neutrino school: Prague 2017, Sinaia in Romania 2019 – 80-90 students, cooperation with MFF UK, Comenius Univ. in Bratislava, CIFRA Romania, JINR – postponed)

e) researchers from abroad came to CR (due to cooperation with LSM):

- two researchers from Japan (J. Terasaki and Y. Orikasa - theoreticians)
- four researchers from Slovakia (R. Hodák, M. Macko, I. Hupka, V. Palušová)
- one researcher from Ukraine (O. Veselská) after finishing PhD in Lyon (France) became member of the team (common activities with Jose Busto (CPPM, Marseille))

C) Strong influence on fundamental research and applications in CR

a) in physics: SuperNEMO demonstrator (2νββ, 0νββ in ^{82}Se), special decay modes of ββ processes (excited states, EC/EC decay, etc.), participation in collaborations - LEGEND 200 and 1000 (^{76}Ge), PICO (DM), group of theoreticians in IEAP (development of ββ decay theory)

b) fundamental and applied research in biology and radioecology: behavior of cells in ZERO DOSE environment, long-term storage of cells in ZERO DOSE environment, radionuclide residues in nature…

c) general R&D of technologies (detectors, nuclear safety and emergency preparedness, forensic analysis): detection of ultra-low concentration in the vicinity of nuclear power plants, undeclared nuclear release worldwide (Masson O. et al., PNAS 116 (2019) 16750), detection techniques for low background experiments

D) Cooperation with industrial partners based on our R&D for LSM: (commercial impact)

a) NUVIA a.s. (scintillation detectors to LSM 440 kEUR; muon veto for the Fermilab and CERN project 485 kEUR; MoEDAL-MAPP 105 kEUR; automatic system for HPGe detectors)

b) ATEKO (anti-radon facility - deliveries for more than 3.2 MEUR into several deep underground laboratories in the world)

c) CRAC (two low radon clean rooms, Utility Model awarded, 240 kEUR)

d) Neutron or lead shielding, low-radioactive steel constructions, radon sensors – in total 80 kEUR

Selected plans for the next 5 years

A) Infrastructure

a) continuous support for already installed infrastructural equipment at LSM and home

b) new infrastructure devices:
   i) recycling system for Rn removal from He/Ar gas (ATEKO: estimated price = 288 kEUR);
   ii) installation of anti-radon facility (LSM or ATEKO: estimated price = 33 kEUR)

c) active participation in the LSM extension and EU cooperation (APPEC initiative to join 4 EU deep underground laboratories into common RI)

B) Science

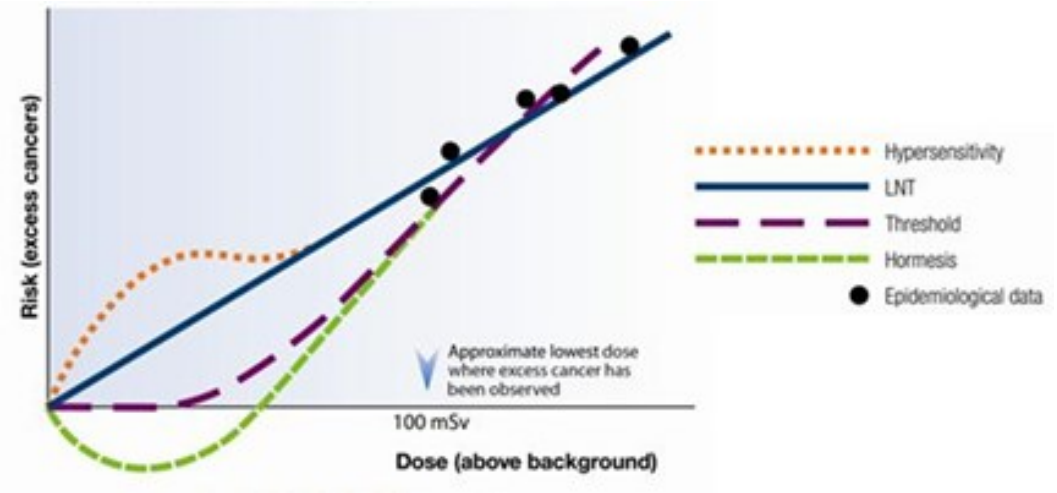
a) SuperNEMO experiment
   - delivery of neutron shielding (PE sheets, 250 pieces) → done
   - tender for steel frame for iron shielding (4 offers, 2-3 mil. CZK)
   - calibration and operation of the detector
   - data processing (2 students from CTU under the supervision of M. Macko)

b) measurement of 2vββ decay into excited states of ^{82}Se: by HPGe detector OBELIX (6 kg of enriched material)

c) TGV experiment: 2vEC/EC decay of ^{106}Cd, construction of completely new setup (detector, electronics)

d) Biological studies

- biological effects of low doses: To this day, biological effects of low doses of IR remain unclear. Non-linear cellular responses, such as adaptive response or genome instability, occur at low doses of radiation but disappear at higher doses. The studies of cell behavior in low and extremely low radiation background are necessary to describe the basic mechanisms of DNA damage induction and repair together with epigenetic signaling and cell communication. The results should provide insight into the basic mechanisms of DNA damage repair initiation, which are essential for assessing the toxicity of low radiation doses and the definition of a modern radiation protection system.



- long-term storage of biological materials: Special attention in the project should be devoted to intensive collaboration with biologists and medical experts – to save for long-term genetic materials (e.g. umbilical cord blood or eggs) to suppress the influence of cosmic rays. It is a quickly increasing market (in the USA on the annual level of several billions USD). After scientific proof of this important idea (suppression of cosmic ray damages on genetic samples, low radiation background storage equipment) it is new and unique investment opportunity. It underlines importance of deep underground laboratories including the need for space enlargement.

Summary (structured issues required by MEYS):

a) RI LSM attracts progressive multidisciplinary fundamental and applied science (neutrino physics, dark matter, biology, ecology and radioecology, radiation & nuclear forensic analysis, nanoelectronics) based on international cooperation

b) unique portfolio of technology services such as ZERO DOSE environment, removing radon from air and gases, testing of new detection technologies, HPGe ultra-low sensitivity ~ mBq/kg (for selection of non-radioactive components and materials, trace radionuclides analysis...)

c) datasets on ultra-low background shielding materials (e.g. Roman lead)

d) unique cost benefit (low cost vs. important results – in 5 years 135 published results, 1080 citations)

e) training of Czech early carrier researchers and students in attractive areas (16 PhD theses only in France and CR)

f) strong cooperation with technological industrial partners and transfer of technologies (4.5 MEUR for CR companies)

g) cooperation and knowledge transfer to National Regulation Authority (innovative emergency preparedness, forensic analysis…)

International Peer Review Evaluation: organized by MEYS in 2021:

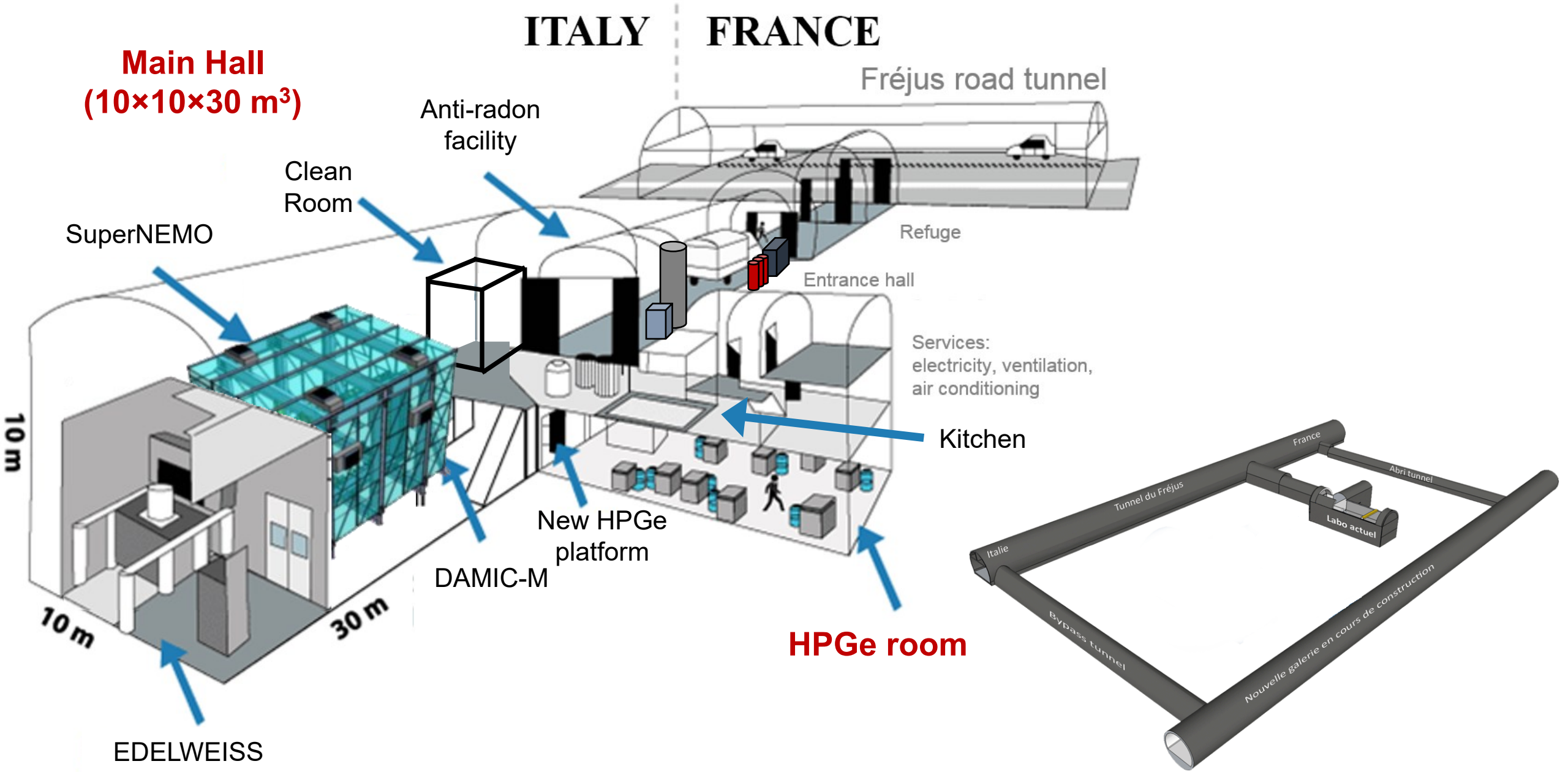
→ LSM-CZ received grade 4 and stays in Roadmap of LRIs of the Czech Republic (2023 - 2026)

- **APPEC (Astroparticle Physics European Consortium):**
  Initiative for a European Laboratory of Deep Underground Science (distributed RI, LNGS, LSC, LSM and Boulby)

- **Double Beta Decay APPEC Committee Report:**
  Recommendation 5. The European deep underground laboratories should provide the required space and infrastructure for next generation double beta decay experiments. A strong level of coordination is required among European laboratories for radiopurity material assays and low background instrumentation development in order to ensure that the challenging sensitivities of the next generation experiments can be achieved on competitive timescales.

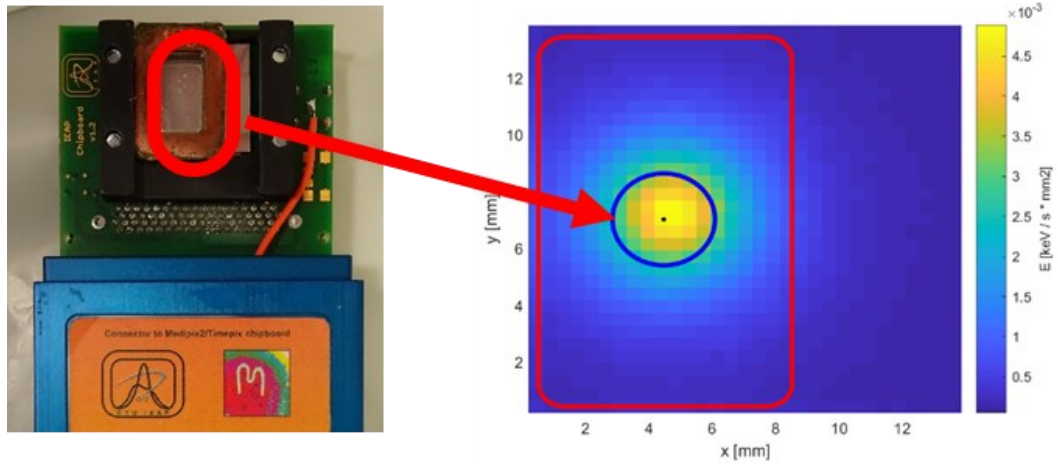
Thank you for the attention!

Backup slides


ITALY
FRANCE
Main Hall
(10×10×30 m³)
Fréjus road tunnel
Anti-radon facility
Clean Room
SuperNEMO
Refuge
Entrance hall
Services:
electricity, ventilation,
air conditioning
Kitchen
10 m
10 m
30 m
New HPGe platform
DAMIC-M
HPGe room
EDELWEISS
France
Abri tunnel
Tunnel du Fréjus
Labo actuel
Italie
Bypass tunnel
Nouvelle galerie en cours de construction

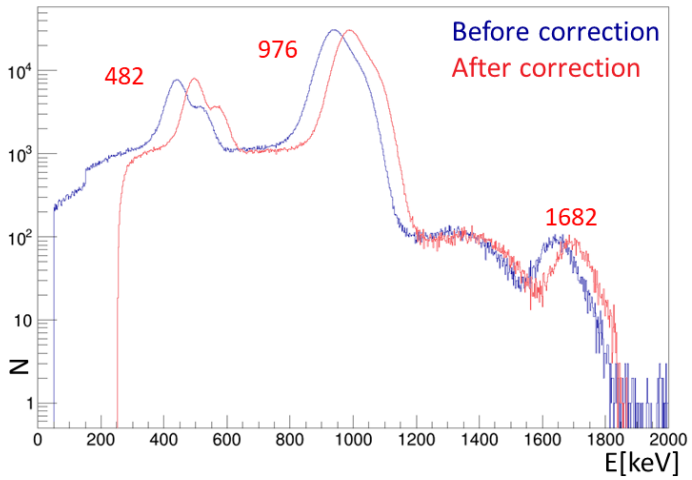
Some examples of activities of Sn Prague group

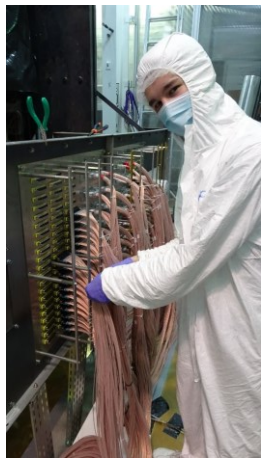
1) Miroslav Macko: in SN coll. since 2015, Junior researcher,
Activities: ^{207}Bi source mapping, measurement of ^{207}Bi source activities, MC simulations



Macko M. et al., JINST 16 (2021) T07012

2) Filip Koňařík: in SN coll. since 2020, Master student (Bc. defended in Sep. 2022)
Activity: Preparation of calibration software (^{207}Bi)

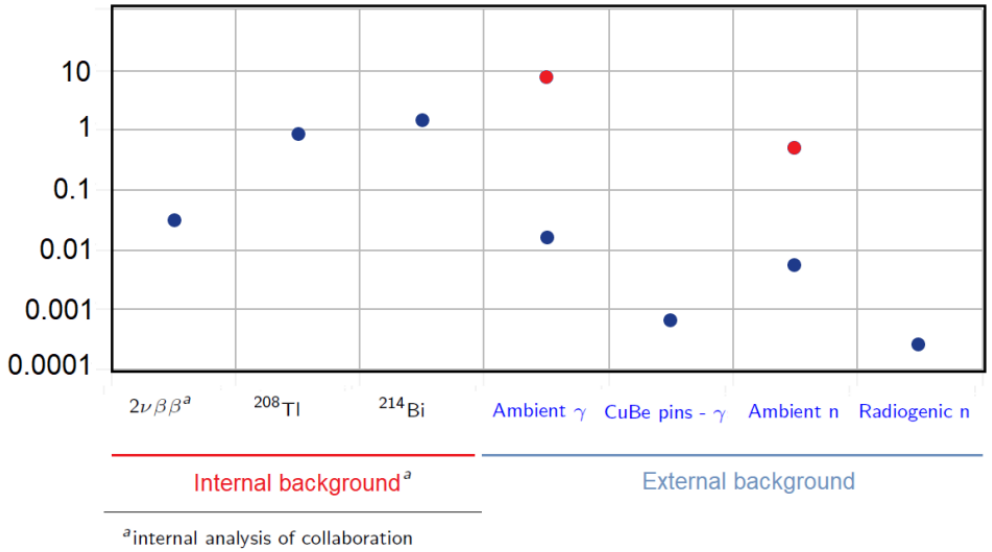


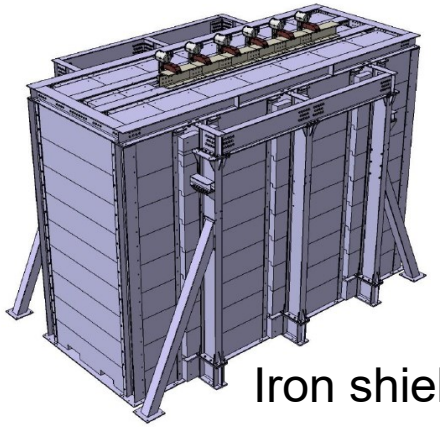


3) Veronika Palušová: in SN coll. since 2017, Junior researcher

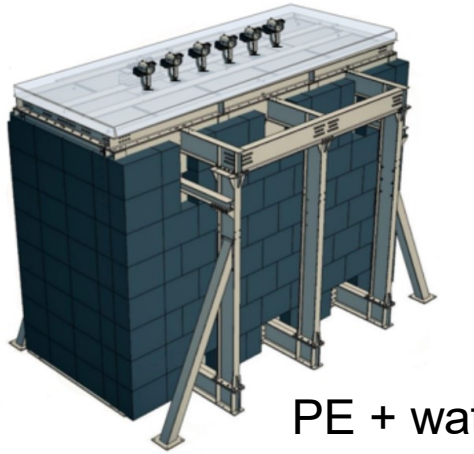
Activities: external background model, shielding proposed based on her study within PhD. thesis

Number of expected background events in the energy ROI after 2.5 years of exposure





Iron shielding

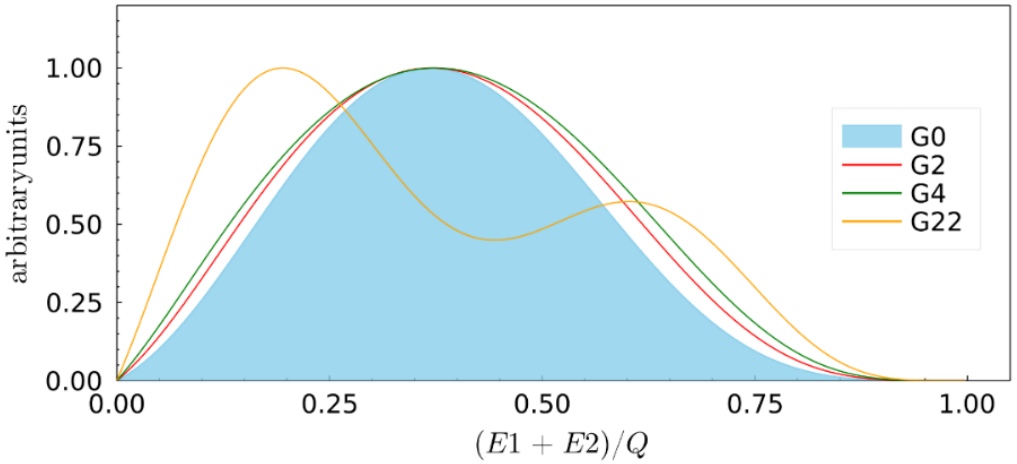


PE + water

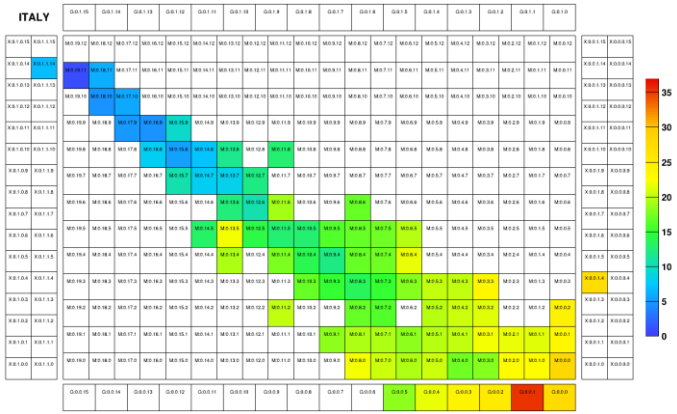
4) Maroš Petro: in SN coll. since 2021, PhD. Student

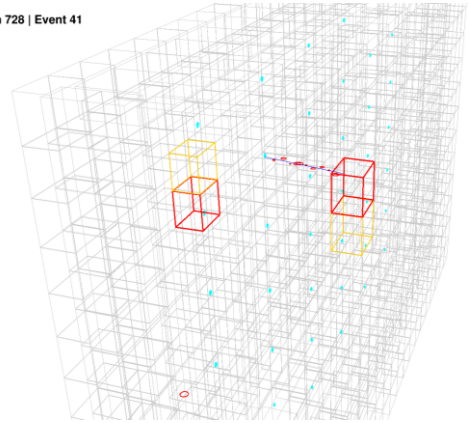
Activities: Analysis of 2vββ data, detector construction works

Theoretical $2\nu\beta\beta$ spectra

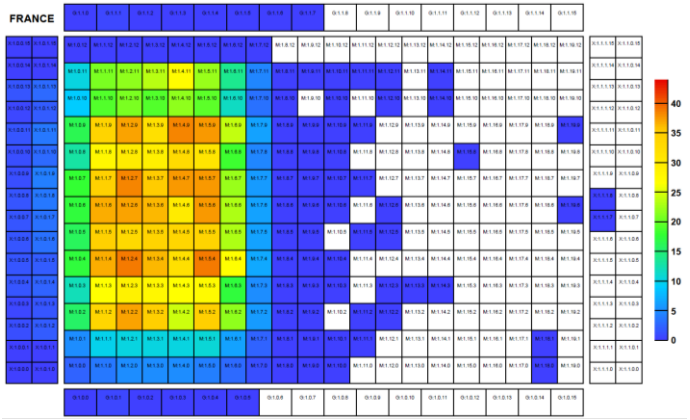


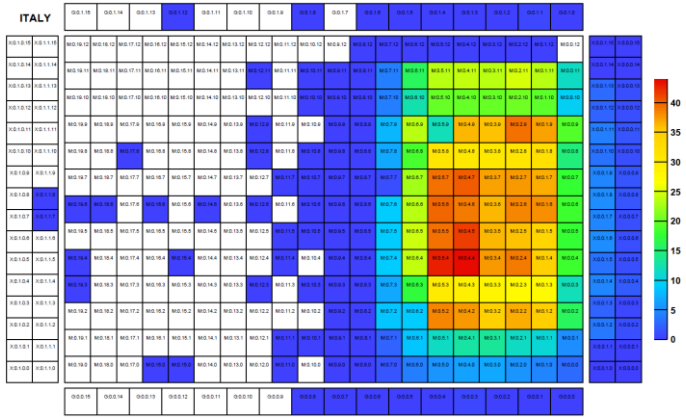
5) Tomáš Křižák: in SN coll. since 2020, Bachelor student
Activities: search for muons in data, development of track reconstruction algorithm





6) Adam Mendl: in SN coll. since 2021, Bachelor student
Activity: study of electron background from data





Electron background in main calorimeter walls with associated tracks from tracker (real data analysis, Run 728)