Evolution of underground science in LSM

Laboratoire souterrain de Modane

From digging to modern experiments

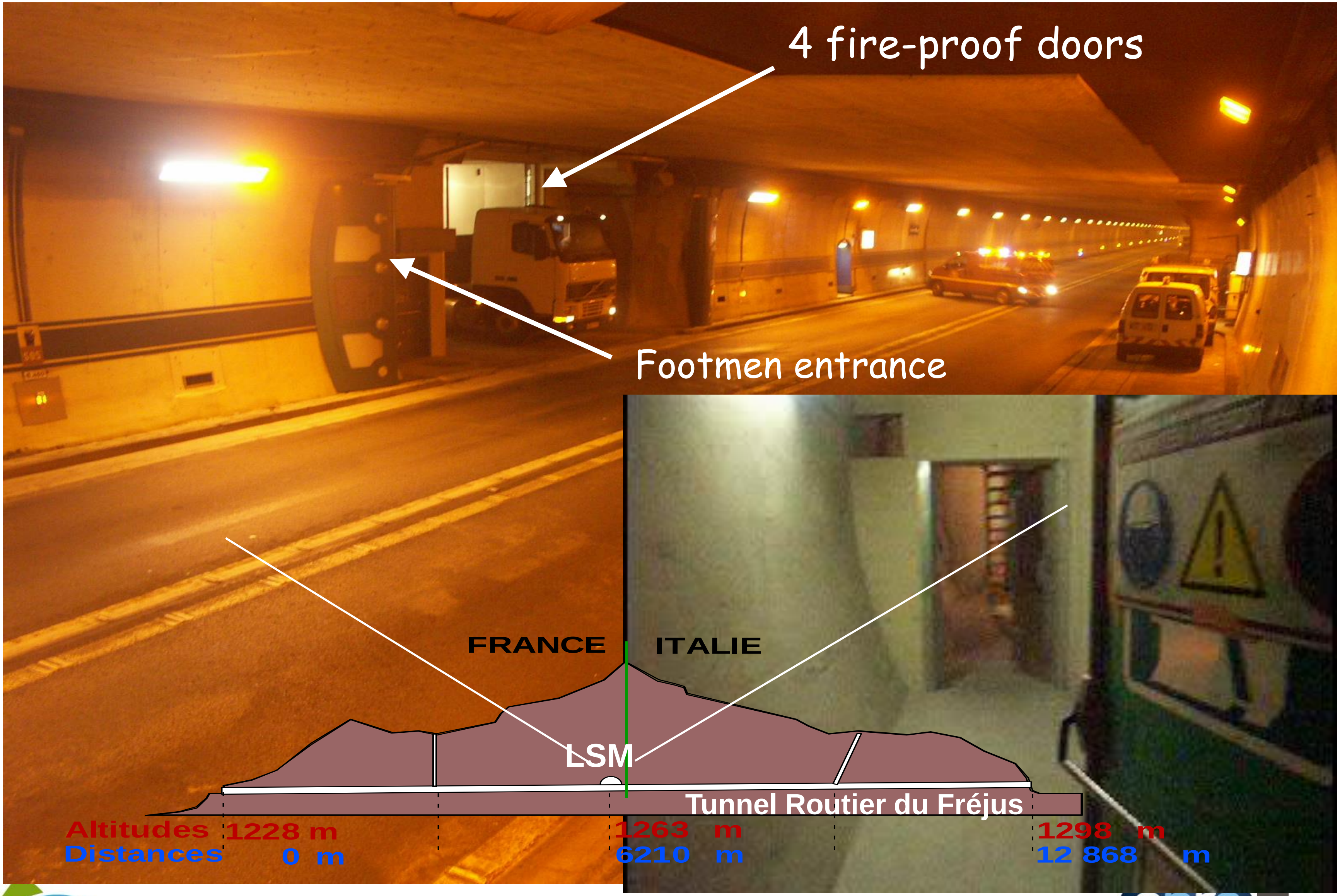
Laboratoire Souterrain de Modane

- Located in Modane
- 12 permanents
- 1000 visitors days per year
- Wide range of interdisciplinary topics
- Astroparticles, nuclear physic, environment, electronics, radioactivity measurement, biology

Laboratoire Souterrain de Modane

- Merger with Laboratoire de Physique Subatomique & Cosmologie (LPSC-IN2P3) in Grenoble
  - 70 researchers, 90 Engineers & technicians
  - Covering fields in particle & nuclear physics, astroparticle and cosmology
- LSM now becomes a « national facility » as labelled by the CNRS
  - National facility for IN2P3 / CNRS
- LSM as an national experimental facility for :
  - Fundamental Physics
    - Neutrino property determination
    - Direct Dark matter search
  - Gamma spectrometry measurement
    - 14 detectors measuring continuously
    - Open to geosciences, materials, biology and medecine
      - Actually 1000 samples measured per year
    - PARTAGe project to automatize measurments
      - Increase significantly the scope of the LSM

Location and access



History of LSM

1979 - 1981 | **1982- 1990** | **1990- 2000** | **2000 - ….**

Digging | **Proton decay** | **Prototypes** → **Experiments**

- 4 µ/m2.d
- 3500m3
- 400m2

- 15Bq/m3 Rn in air
- Radonless air 125m3/h 15mBq/m3

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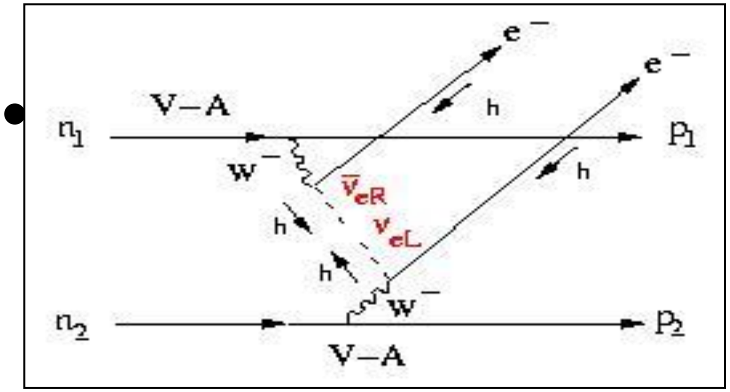
Double beta decay

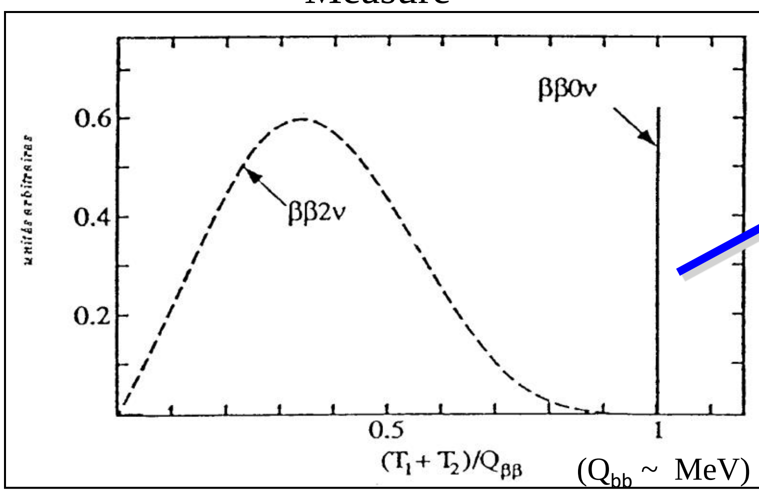
bb0n : (A,Z) $\rightarrow$ (A,Z+2)+2e$^-$



$\Leftrightarrow$

- DL = 2
- $n = \bar{n}$ Majorana's neutrino
- $m_n \neq 0$

Measure



Full electron energy

$$(T^{0\nu}_{1/2})^{-1} = C\ (Q^5_{bb})\ M^2\ \langle m_n \rangle^2$$

C : phase space factor

M : nuclear matrix element

$\langle m_n \rangle$: effective neutrino mass

$\langle m_n \rangle \Rightarrow$ mass hierarchy

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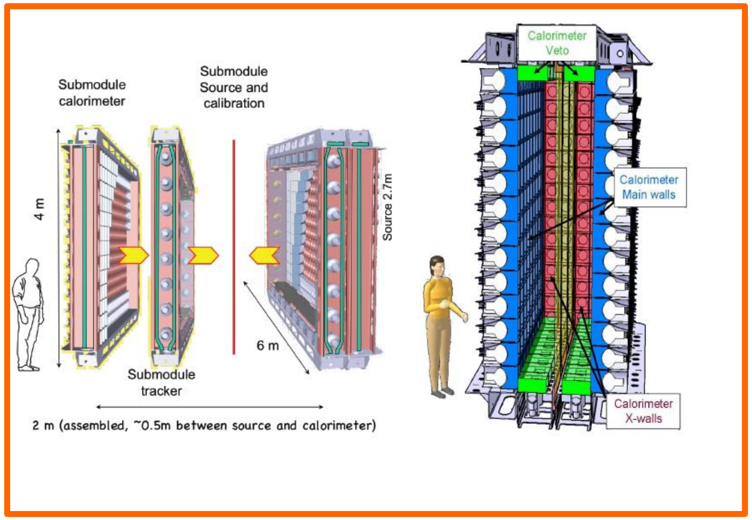
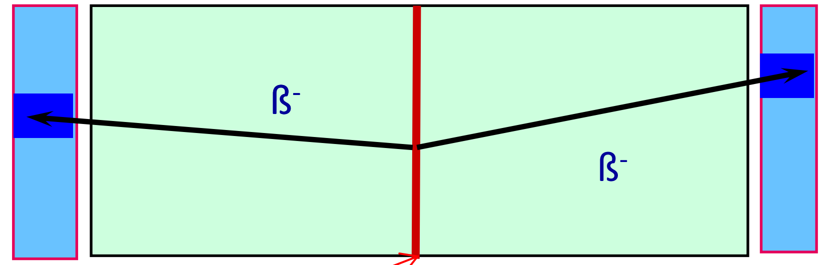
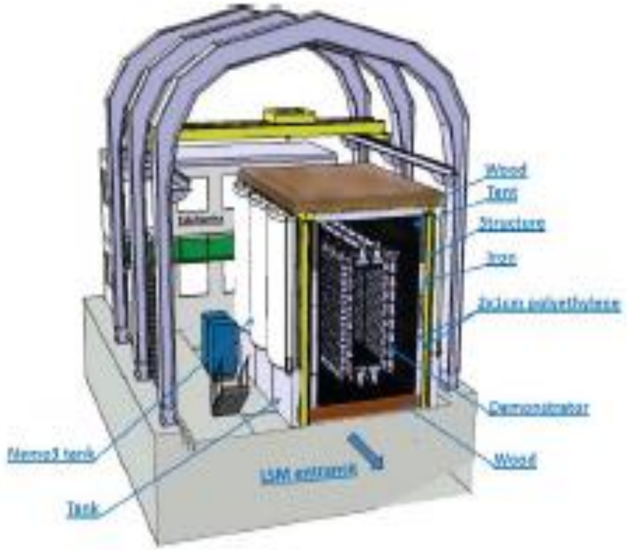
SuperNemo experiment





- 82 Se source
- Extreme radiopurity requirement
- Special granularity to obtain the source



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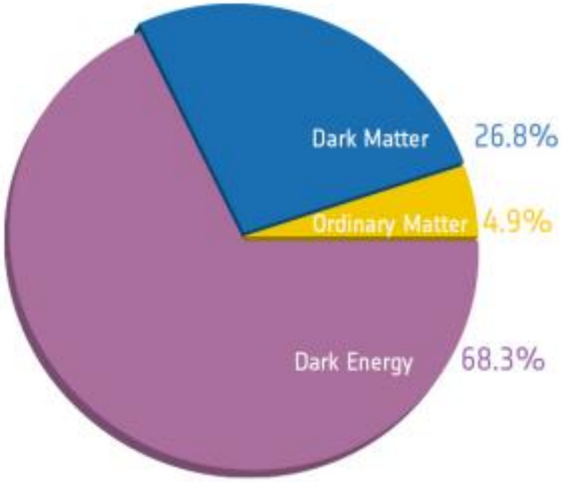
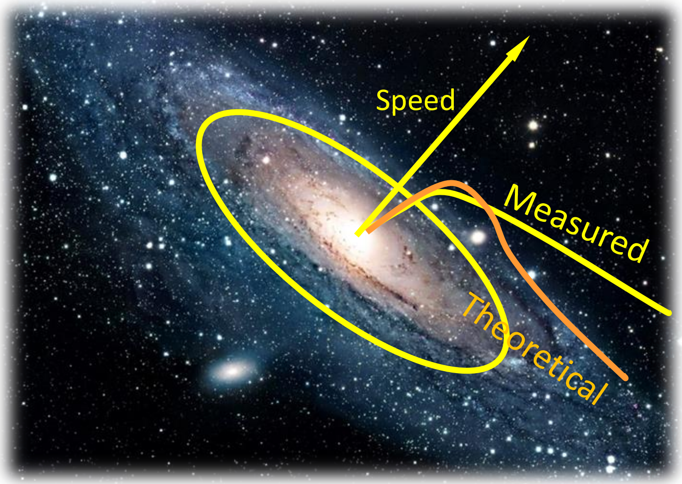
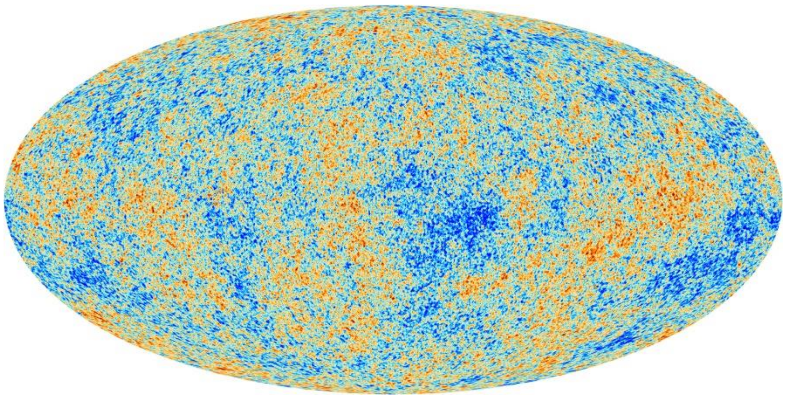
Dark matter search

- Major physics goal
- Direct detection would answer to a lot of question
- WIMP candidate is a target for underground detection



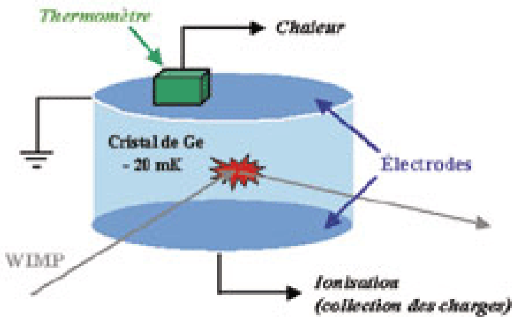


CMB anisotropy



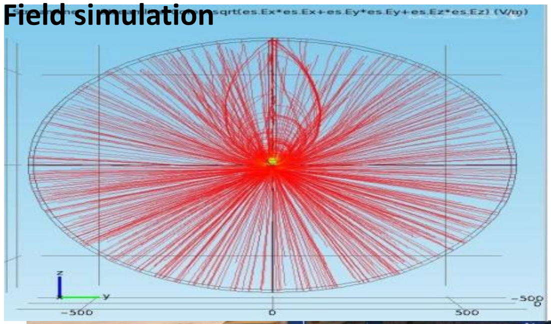
Dark matter search

- Edelweiss



- NEWS

Field simulation



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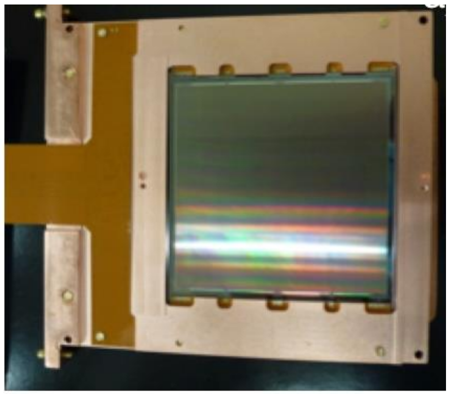
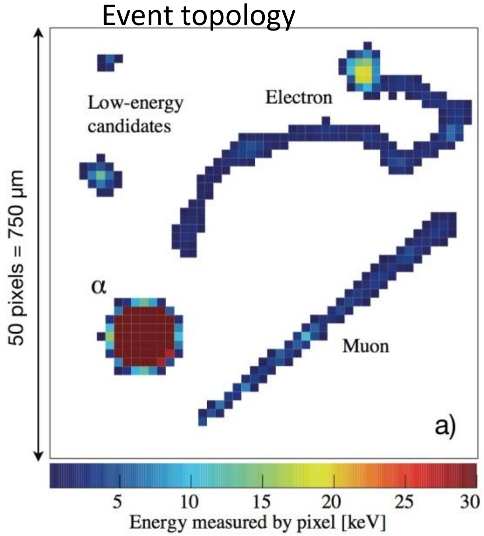
Dark matter search

- DAMIC-M

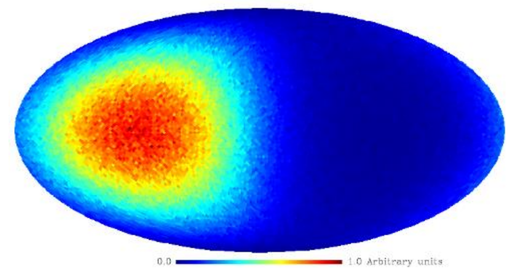


Event topology



- MIMAC
  - Directional recoil

Galactic coordinates

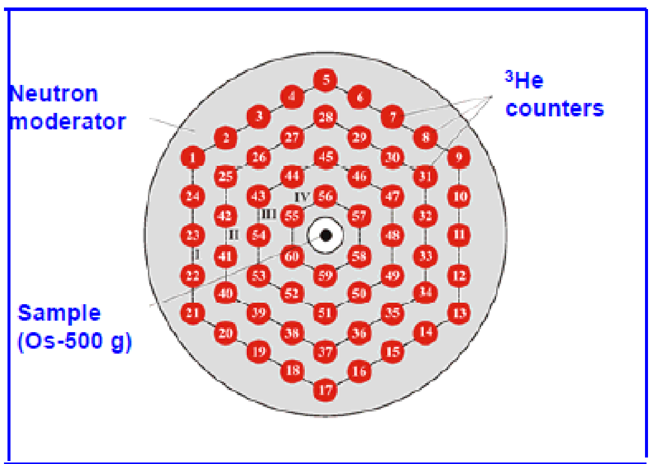


SHIN

- Super heavy element with half life >^{238}U
- Z=108 targeted with self fission producing >5n

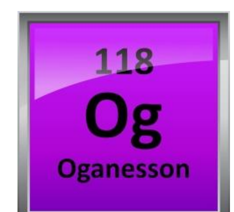
Nuclear physics
Super Heavy Element In nature
SHIN (osmium ore surrounded by 3He neutron detectors)

Events	Single	Double	Triple	Quadruple
Measured 550g Os	1 ev/ minute	1 ev./ 10days	2 events	1 event
Random events (100µs)		2 ev/ year	0 ev/ year	0 ev./ year



From these results, we can deduce an upper limit of 10^{-14}g/g for the concentration of EKA-Os super-heavy element in Osmium (with a sample of 550 g sample of Os and assuming a half-life of ~ 10^9 years for this EKA-Os)

This leads to a limit of the mean concentration of EKA-Os of 10^{-22}g/g in the earth crust



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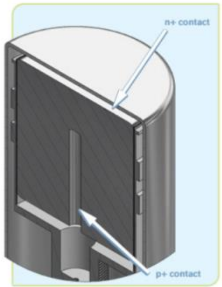
Low radioactivity constraints

- Requirement on material below mBq
- Strong pressure on analytical capabilities
- Increased number of pieces and longer time
- Main measurement performed by gamma ray spectrometry
- Constant effort took place in LSM to develop ultra low background germanium
- Expected 24 HPGe by 2020

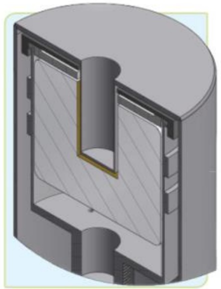
High purity germanium

- Semi conductor crystal cooled down to 77 K
- Sample at room temperature
- Sensitive to gammas from 20keV up to 3MeV
- Non destructive measurement
- Sensitive to muons and cosmic activation
- Different detectors adapted to samples shape

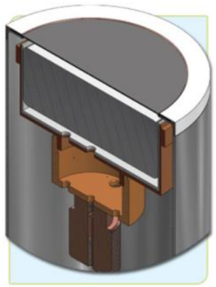
Coax

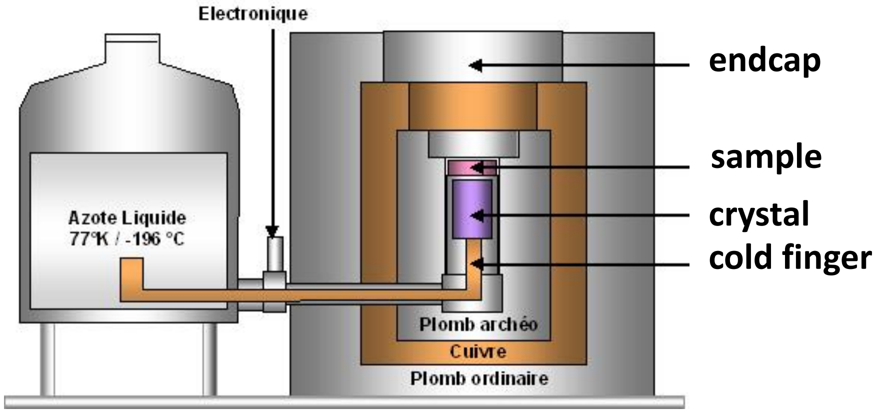


Well



Planar





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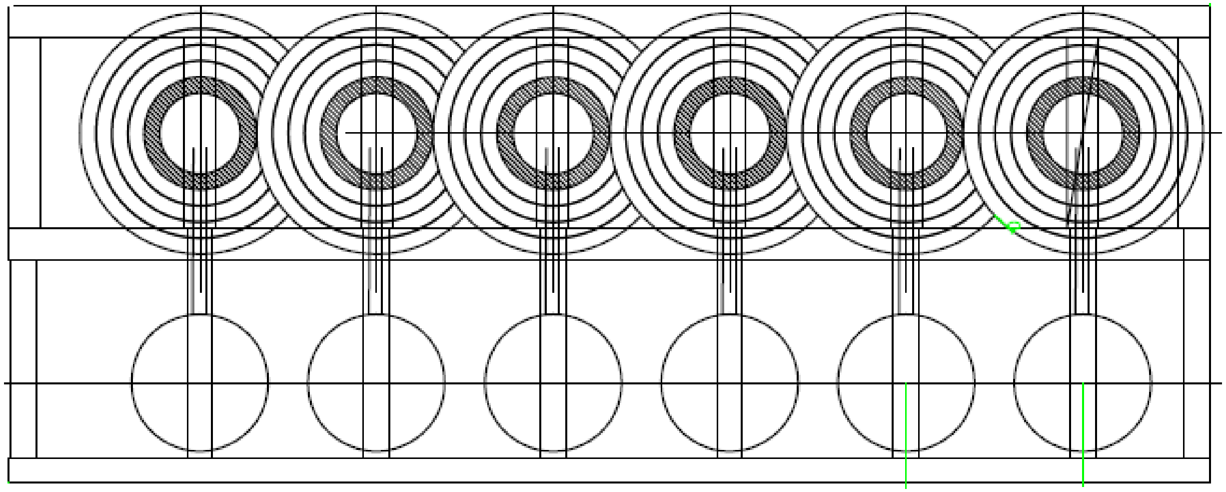
Future of measurement at LSM

- PARTAGe project
  - Combining shields in common walls



- Robotisation
- Optimisation of measurement time based on the radiopurity objectives

Germanium detector

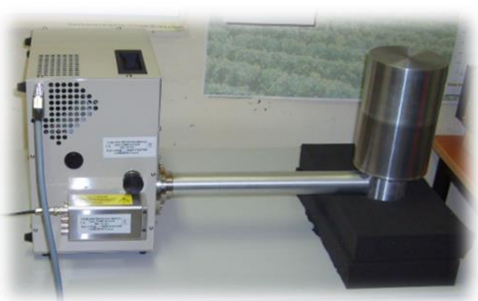
- Example of detection limits

Mafalda : (our swiss army knife)

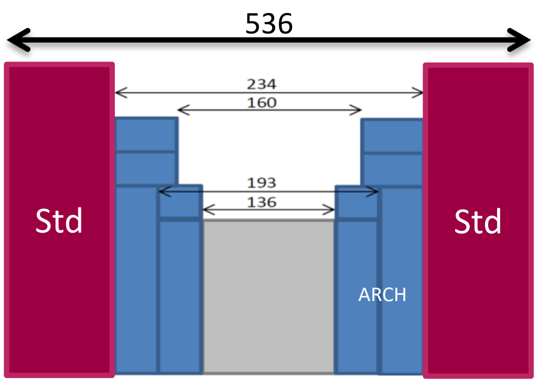
- Size 150 cc – 43,1%
  - Φ 80mm h 31,7mm
- Resolution
  - 122 keV 920 eV
  - 1,33MeV 1,97keV
- Background
  - Integral 115±3,5 count/day
  - 133 c/kg
  - Peaks
  - 46,5 keV 1,49 ± 0,37 c/d [210Pb]
  - 75 keV 3,6 ± 0,62c/d [Pb]

$$\text{limit (Bq)} = \frac{1{,}43 + 2{,}36\sqrt{1{,}36 + bdf \times t}}{\varepsilon(m)\, m\, t}$$

$$\varepsilon = \frac{detected}{emitted}$$



Shielding



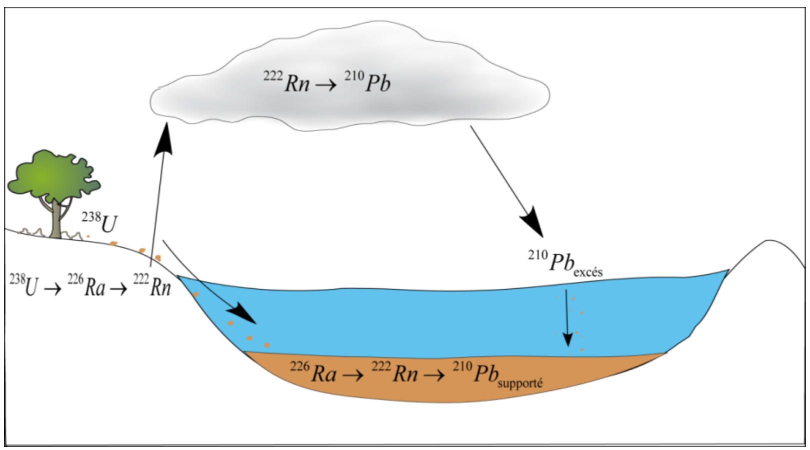
Silicon wafer measurement
700 000s 650g

Nucleide		Bq/kg
210Pb	<	1,58E-02
^{226}Ra	<	1,27E-03
238U	<	6,27E-03
228Ra	<	3,82E-03
228Th	<	8,66E-04

Analitycal power for interdiciplinarity

- Possibility to measure a wide range of nucleides
- Used in many environmental datation

Relative datation



$$({}^{210}Pb)^{t}_{ex} = ({}^{210}Pb)^{0}_{ex} \times e^{-\lambda t}$$

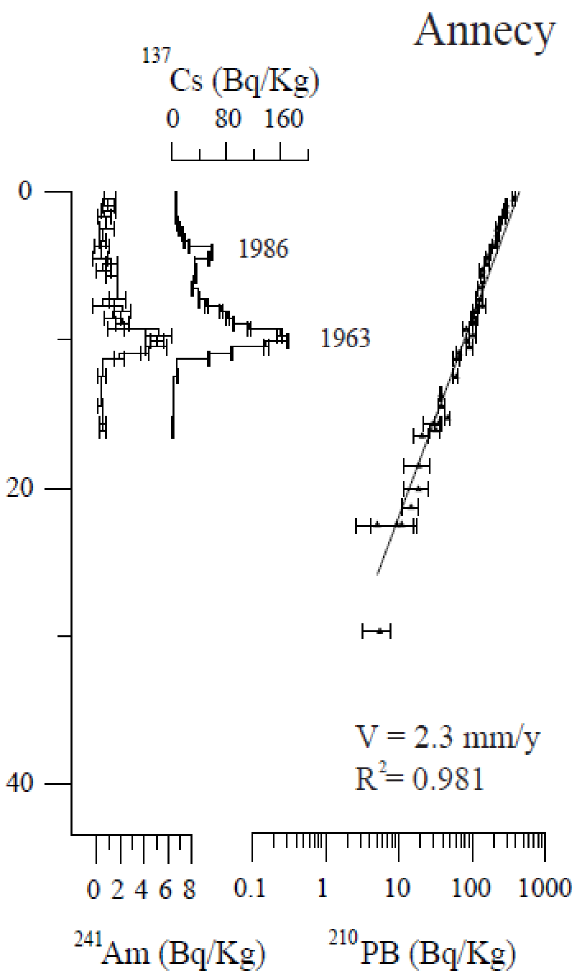
$$Ln({}^{210}Pb)^{t}_{ex} = -\lambda \frac{z}{V} + Ln({}^{210}Pb)^{0}_{ex}$$

Absolute datation

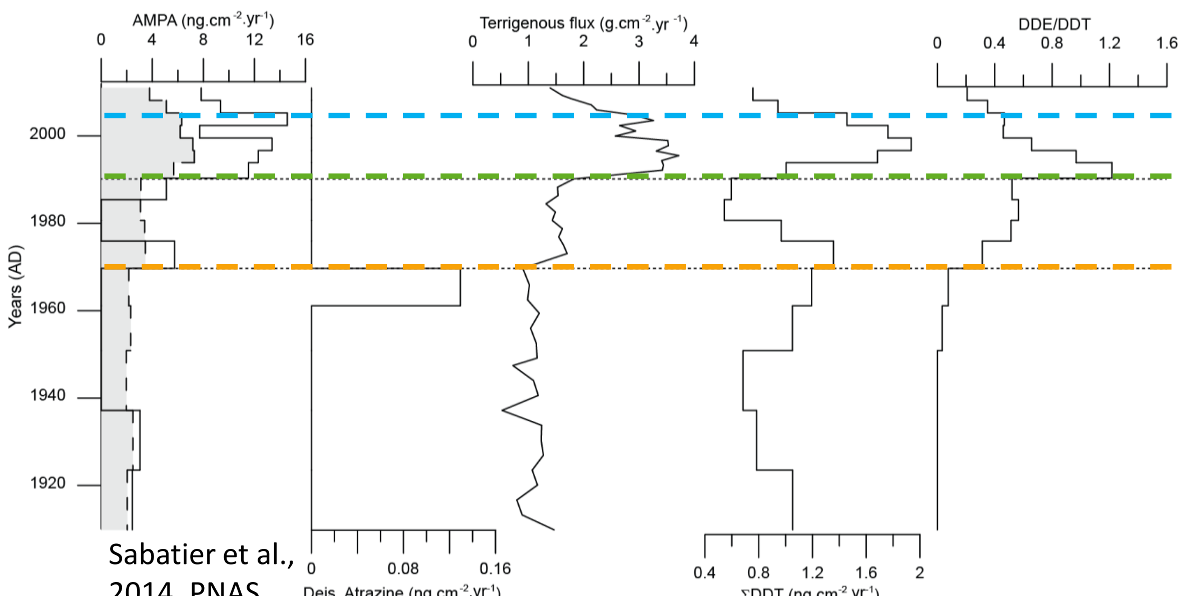
^{137}Cs + ^{241}Am
1963

^{137}Cs only
1986

Lake survey



- 210Pb gives the sedimentation rate
- Confirmed by artificials nucleides
- Allowing to reconstruct the history of a lake without archives



Sabatier et al., 2014, PNAS

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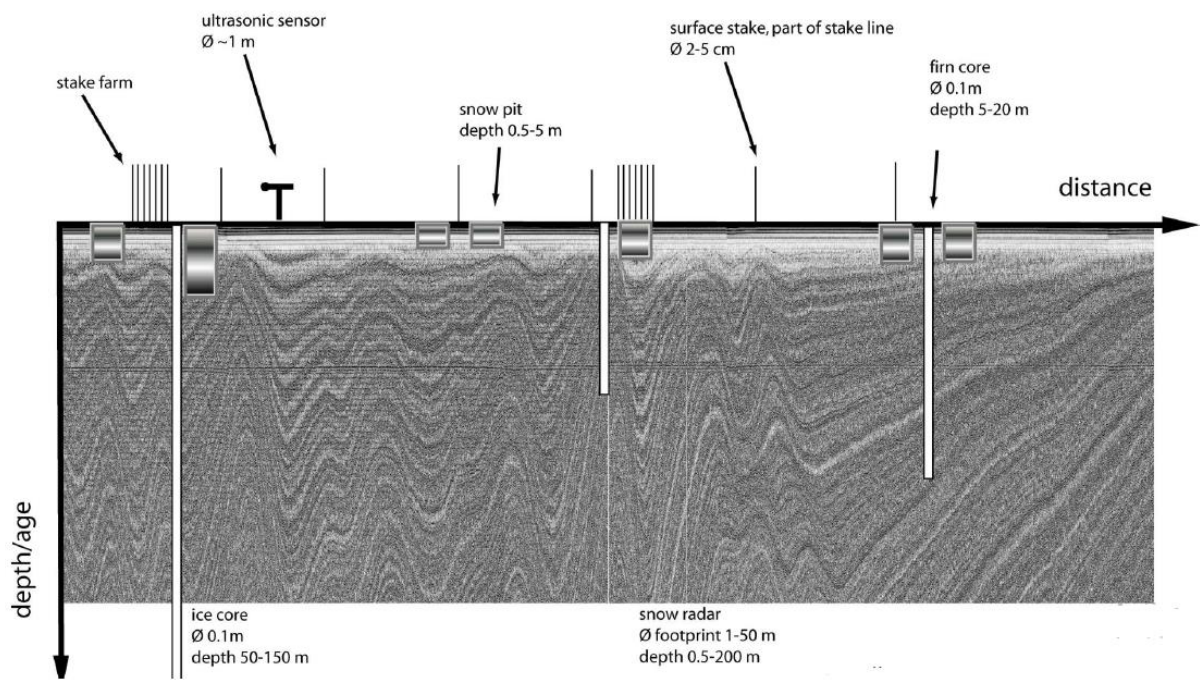
Ice survey

- Datation of ice core in antartica
- Calibration of radar
- Temporal marker for climate change
- 2 days measure needed in underground lab



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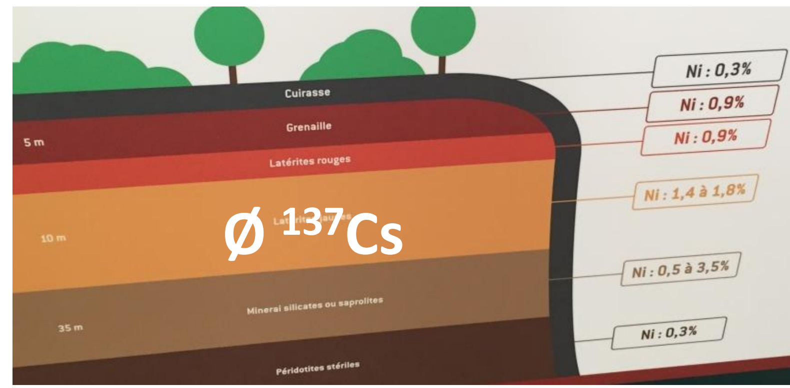
Erosion survey

Sources of sediment in mining catchments of New Caledonia

Two main sources of sediment to the main river

Non-mining tributaries

Mining tributaries



- Discrimination of contributions of both types of tributaries based on their activities in natural/artificial radionuclides
- Quantification using mixing models
- Analysis of sediment cores collected in the delta to reconstruct changes in source contributions with time

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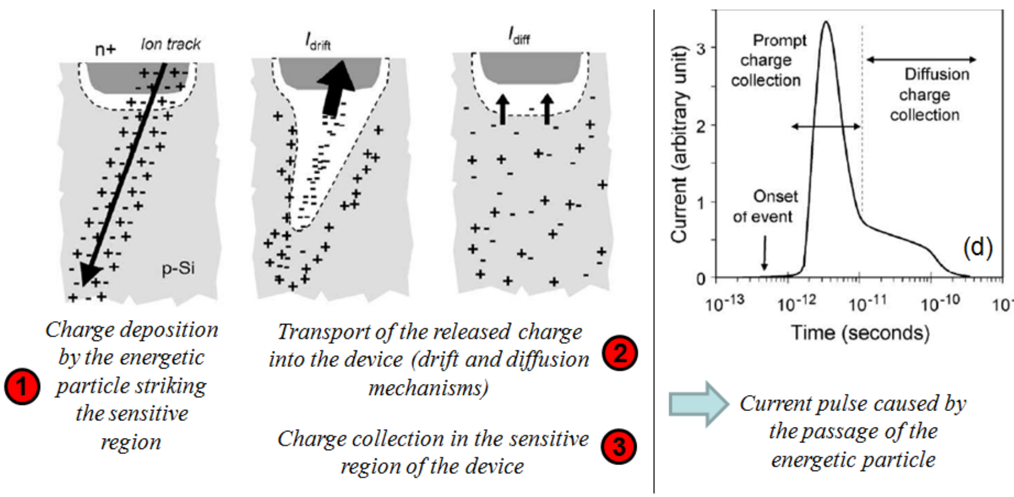
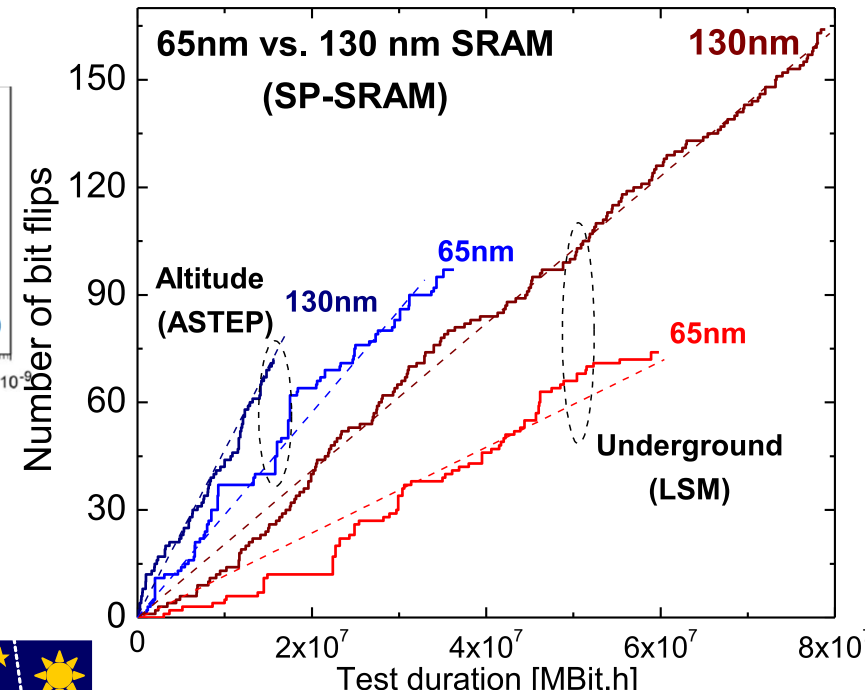
CNRT Nickel & son environnement

Université de la Nouvelle-Calédonie

Electronic SER test

- Sensitivity of electronic to ionising radiation
- At sea level neutron and alpha contribution
- LSM reference point in JEDEC standard for 0 neutron





Adapted after Baumann, ***IEEE Trans. Device Mater. Reliab***. 5, 305-316 (2005)

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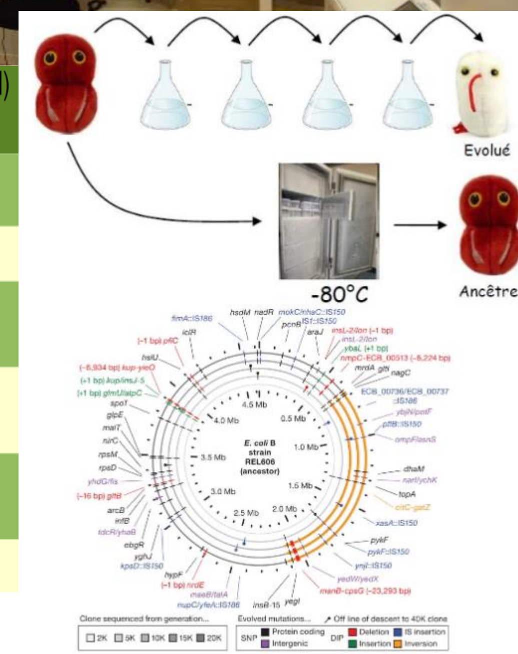
Biology at LSM

- Evolution driven by radiation
- Comparison between surface and underground bacteria culture 800 generations harvested

Source	Measurement Method	LPC Clermont (nGy/day)	Modane (nGy/day)	Modane (shielded) (nGy/day)
γ background	Dosimeter measurement (rate varied by 10%)	2400	480	15
Muon flux	From theory	460	0	0
Potassium-40 (γ)	Simulations based on concentration	0.4	0.4	0.4
Potassium-40 (β)	Simulations based on concentration	74.4	74.4	74.4
Carbon-14 (β)	Simulations based on concentration	0.02	0.02	0.02
Total		2935	555	90



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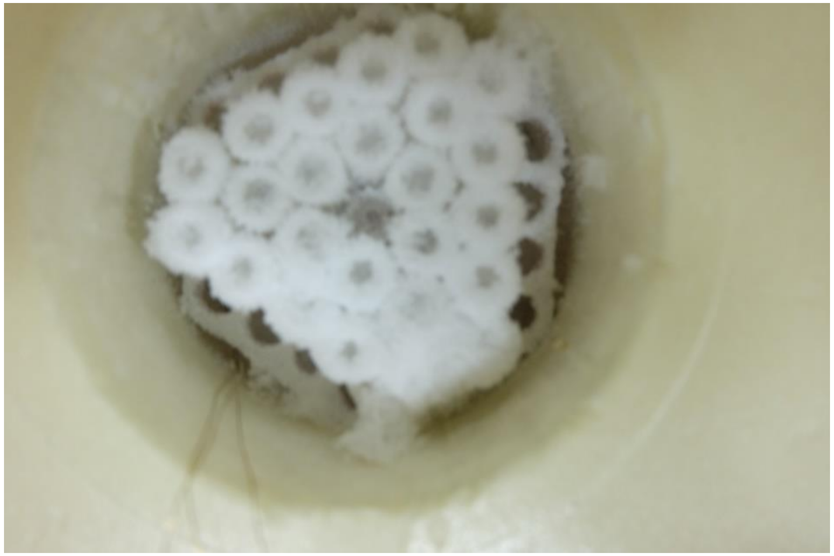
Stem cell storage

- LSM-pasteur institute collaboration
- Funded by interdisciplanary mission from CNRS
- Allowed to test a stem cell storage shielded from natural radioactivity and terrestrial cosmic rays
- Patented solution
- Publication in progress
- Industrial prototype in

development



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Institut Pasteur

Conclusion

- Underground labs are designed for large scale fundamental physics
- Unique environment find always a use sometimes unforeseen at digging
- Leaves room for interdisciplinary program at moderate cost
- New fields and discoveries made possible by the access to low level radiation environment