

Modane Underground laboratory

F. Piquemal

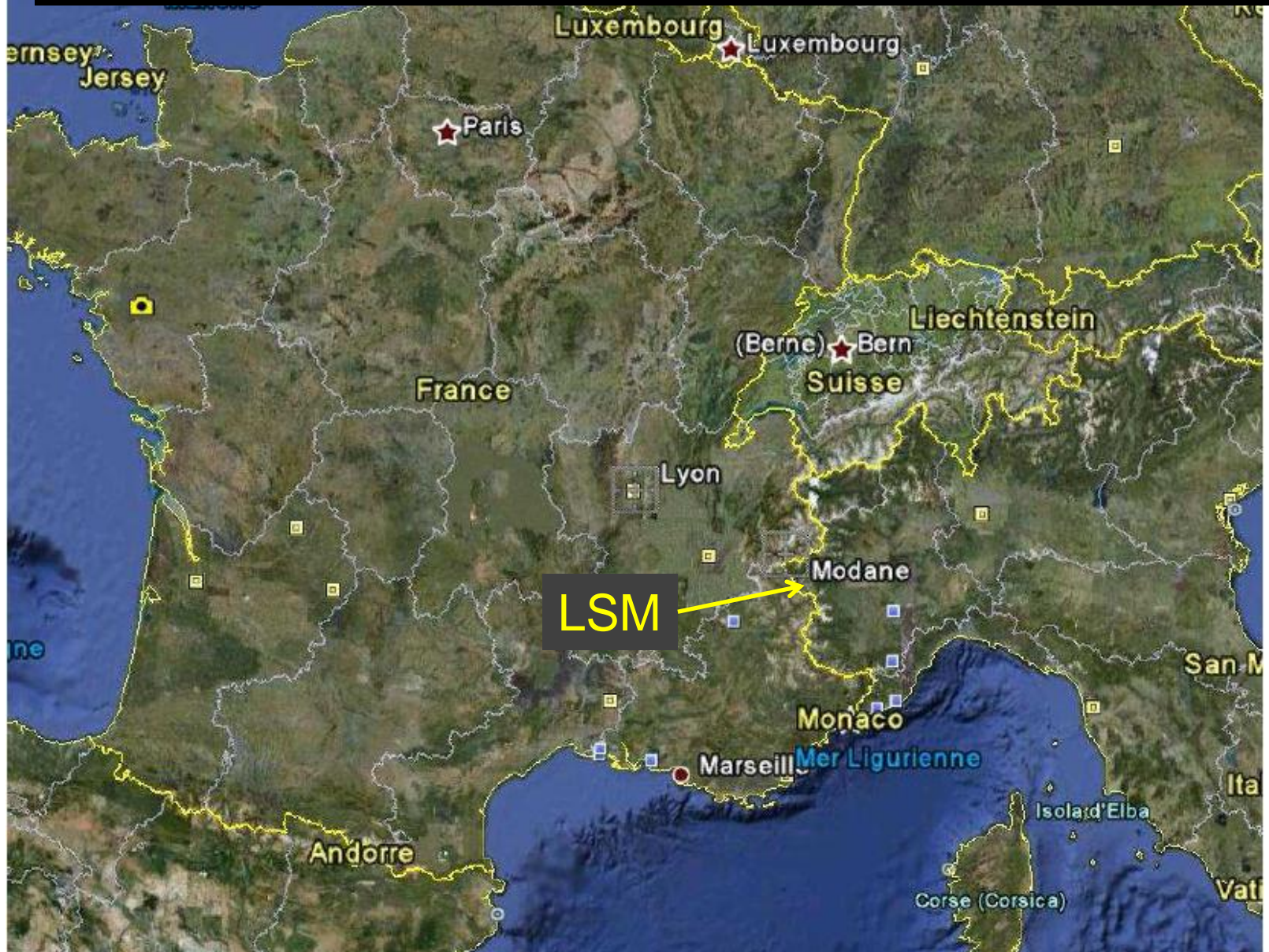
LSM CNRS/IN2P3

ASPERA UGL Workshop Zaragoza June 2011

<http://www.lsm.in2p3.fr>

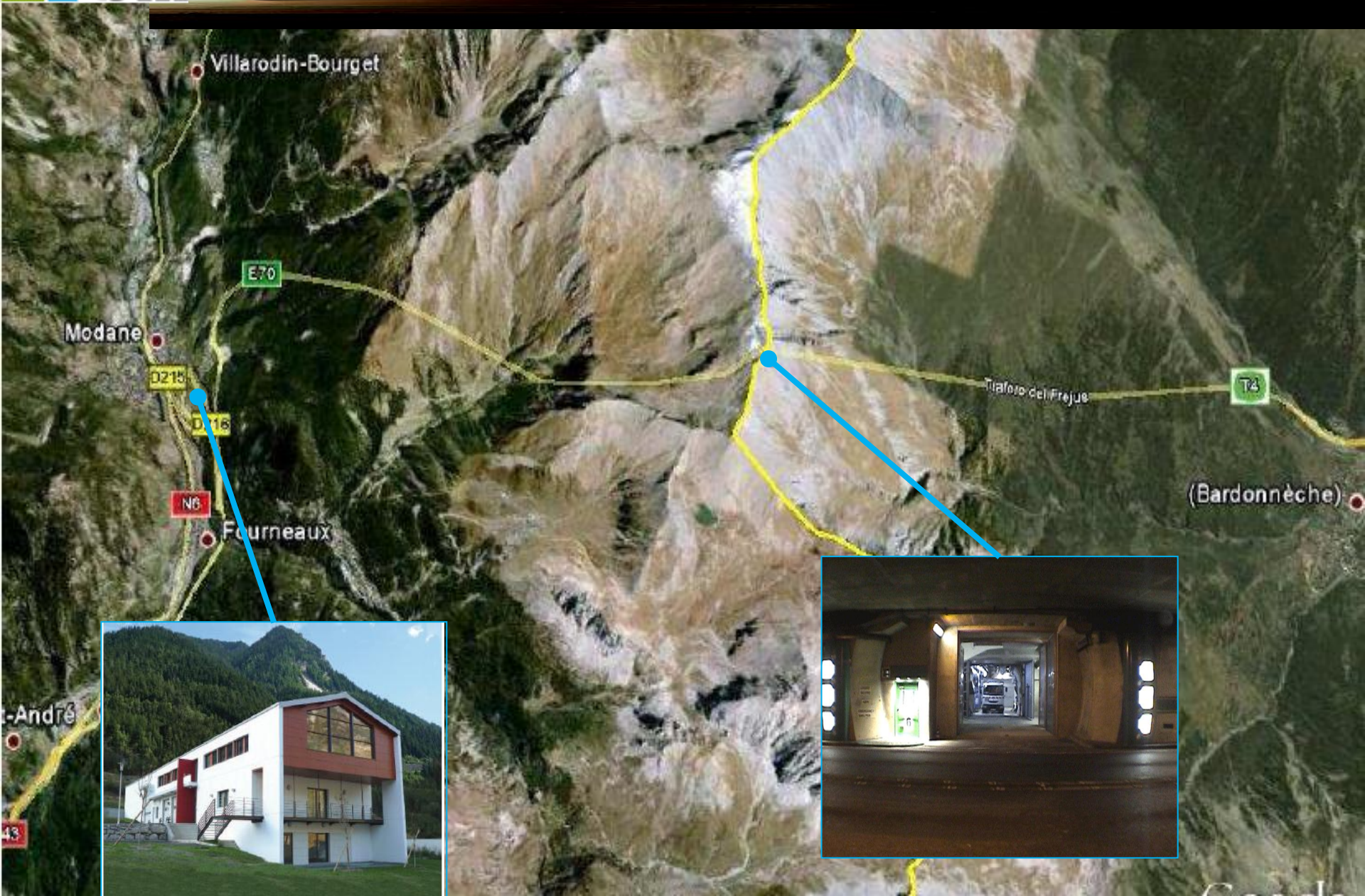


Modane underground laboratory





Modane underground laboratory





LSM: external facility

Offices, workshop, outreach space and guest rooms

Permanent exhibition for general public



2 000 visitors/year



Laboratoire Souterrain de Modane

From a particle physics experiment to a multi-science platform

1979 - 1981

1982- 1990

1990- 2000

2000 -

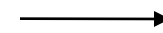


Construction

τ_p Experiment

Proton decay

Prototypes



Experiments

Neutrino: double beta decay, double EC
Dark matter
Nuclear structure

Ultra low radioactivity measurement:
Environmental sciences, applications

Logical test failures in microélectroniques



Laboratoire Souterrain de Modane

Depth: **4800 m.w.e.**

Surface: **400 m²**

Volume : **3500 m³**

Muon flux: **$4 \cdot 10^{-5} \mu.m^{-2}.s^{-1}$**

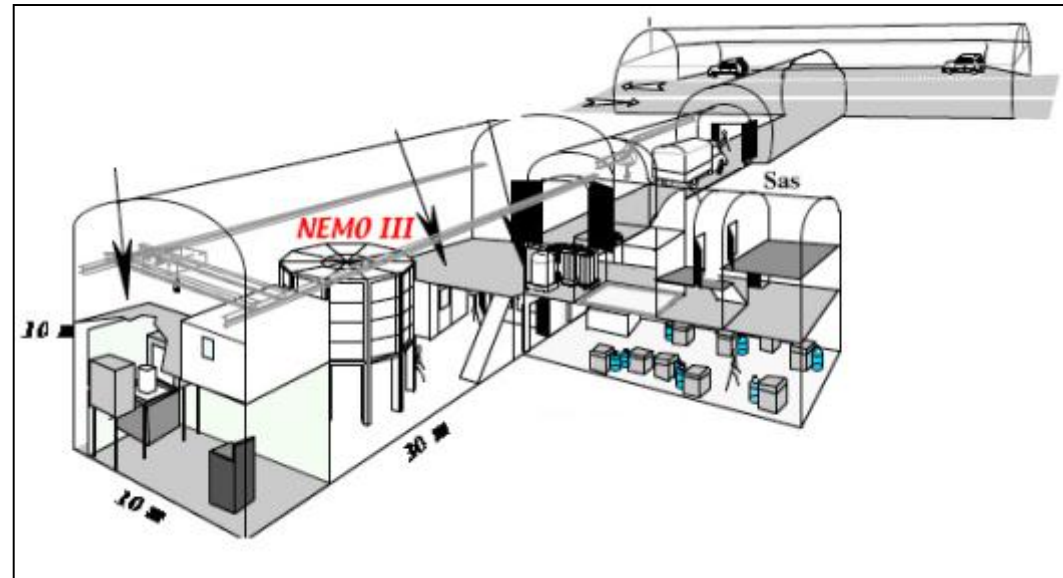
Neutrons:

Fast flux: $4 \cdot 10^{-2} n.m^{-2}.s^{-1}$

Thermal flux: $1.6 \cdot 10^{-2} n.m^{-2}.s^{-1}$

Radon: **15 Bq/m³**

Access : **horizontal**



Budget (full cost): 1 M€/yr

Staff: 3 Physicists

3 Engineers

7 Technicians

~100 users

**International associated laboratory agreement with
JINR Dubna (Russia) and CTU Prague (Czech Republic)**

Radon free air purification system

Copy from system developed by superKamiokande

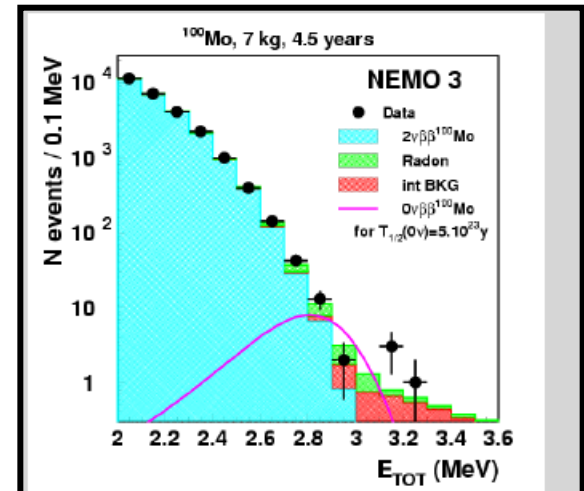
150 m³/h air 20 mBq/m³ (standard 20 Bq/m³)



Build in Czech Republic

Neutrino physics: NEMO -3

Double beta decay : Tracking + calorimeter - ^{100}Mo 7 kg



[2.8–3.2] MeV: DATA = 18; MC = 16.4 ± 1.4

$T_{1/2}(0\nu) > 1.0 \times 10^{24}$ yr at 90%CL

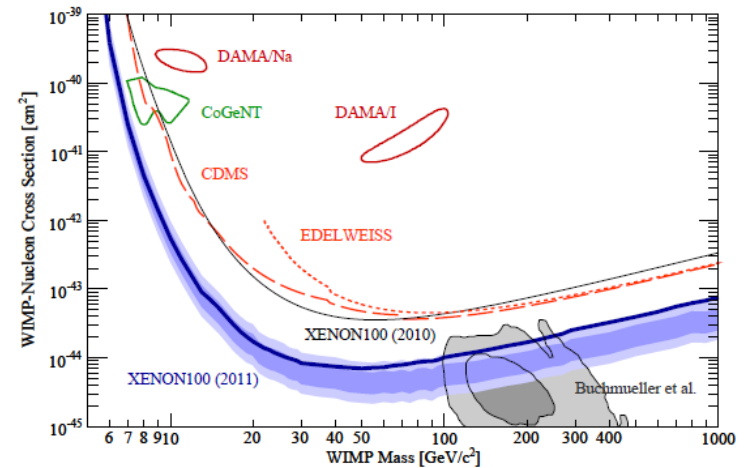
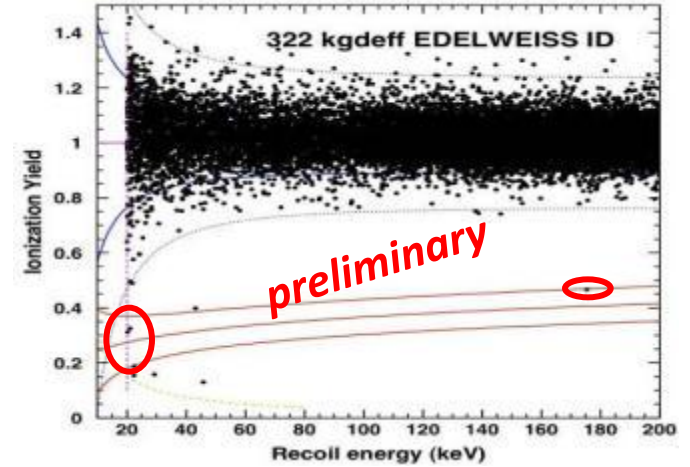
$\langle m_\nu \rangle < (0.47 - 0.96)$ eV

V+A: $T_{1/2}(0\nu) > 5.4 \times 10^{23}$ yr at 90%CL

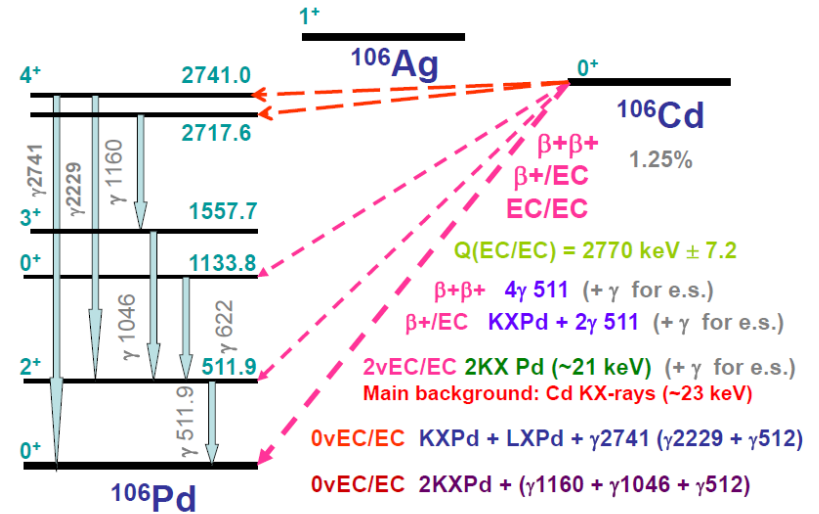
Majoron: $T_{1/2}(0\nu) > 2.1 \times 10^{22}$ yr at 90%CL

Dark matter: EDELWEISS

Bolometric technique: Heat + Ionization Ge crystals - 40 kg

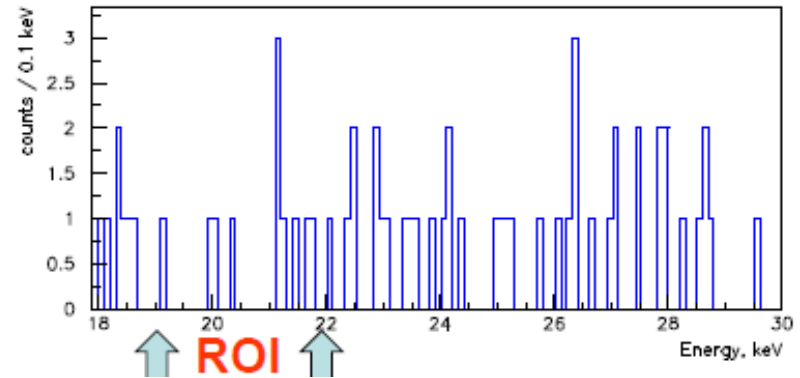
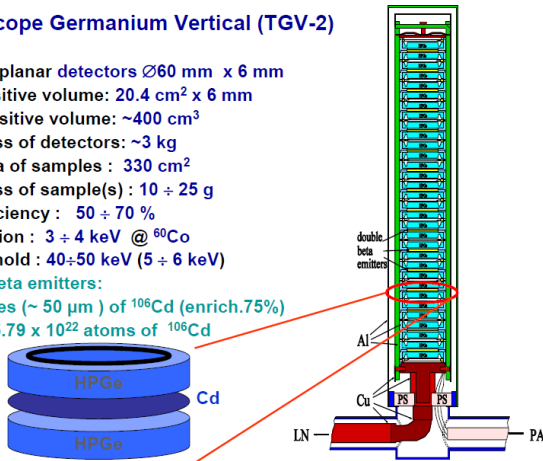


TGV II experiment



Telescope Germanium Vertical (TGV-2)

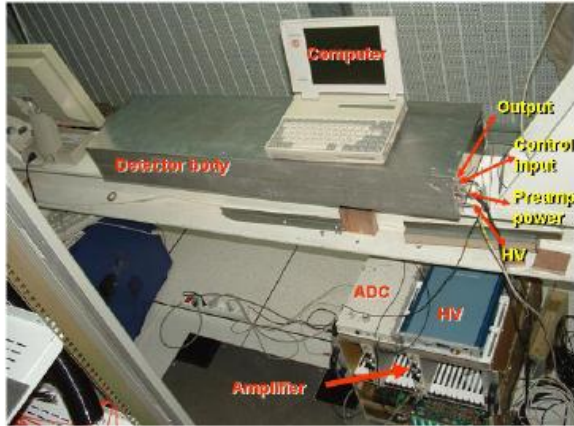
- 32 HPGe planar detectors $\varnothing 60 \text{ mm} \times 6 \text{ mm}$
- with sensitive volume: $20.4 \text{ cm}^2 \times 6 \text{ mm}$
- Total sensitive volume: ~400 cm^3
- Total mass of detectors: ~3 kg
- Total area of samples : 330 cm^2
- Total mass of sample(s) : 10 \div 25 g
- Total efficiency : 50 \div 70 %
- E-resolution : 3 \div 4 keV @ ^{60}Co
- LE-threshold : 40 \div 50 keV (5 \div 6 keV)
- Double beta emitters:
- 16 samples (~ 50 μm) of ^{106}Cd (enrich.75%)
- 13.6 g ~ 5.79×10^{22} atoms of ^{106}Cd



$$T_{1/2}^{2\nu\text{EC}/\text{EC}} (^{106}\text{Cd}) = 4.5 \times 10^{20} \text{ y (77\% C.L.)}$$

$$T_{1/2}^{2\nu\text{EC}/\text{EC}} (^{106}\text{Cd}) > 4.2 \times 10^{20} \text{ y (90\% C.L.)}$$

Neutron detectors at LSM



^3He counters



Sphere TPC



Gd loaded liquid scintillator

Support from ILIAS TARI for the 3 detectors

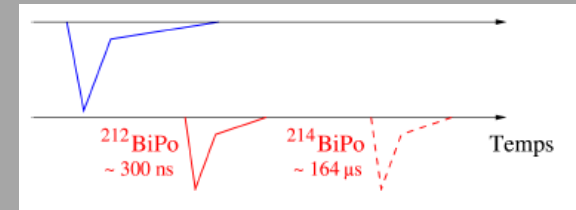
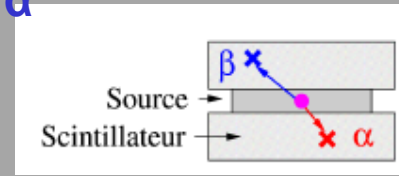
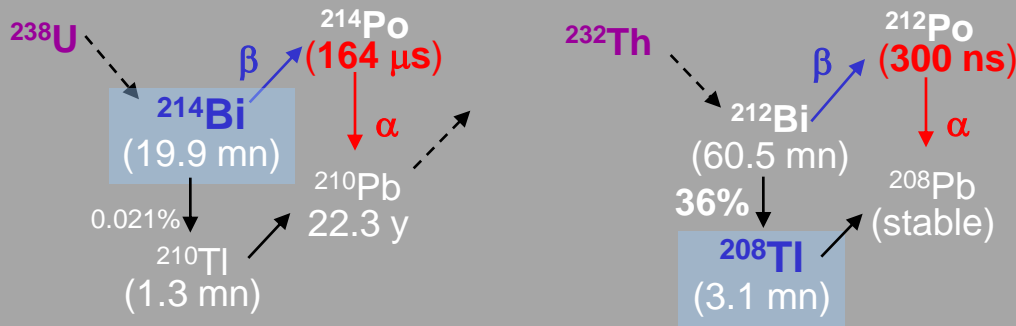
Radon detectors – sensitivity ~ 1 mBq/kg
(electrostatic collection of radon daughters)
Saga University (Japan) and Dubna (Russia))



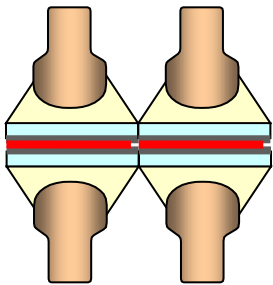
SuperNEMO BiPo prototypes

Objectives :to mesure $^{208}\text{Tl} < 2 \mu\text{Bq/kg}$ & $^{214}\text{Bi} < 10 \mu\text{Bq/kg}$ in $\beta\beta$ source foil in 1 m

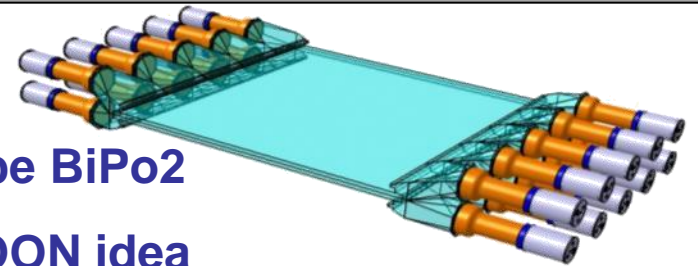
Principle: Detection of BiPo coincidence : β + delayed α



Prototype BiPo 1



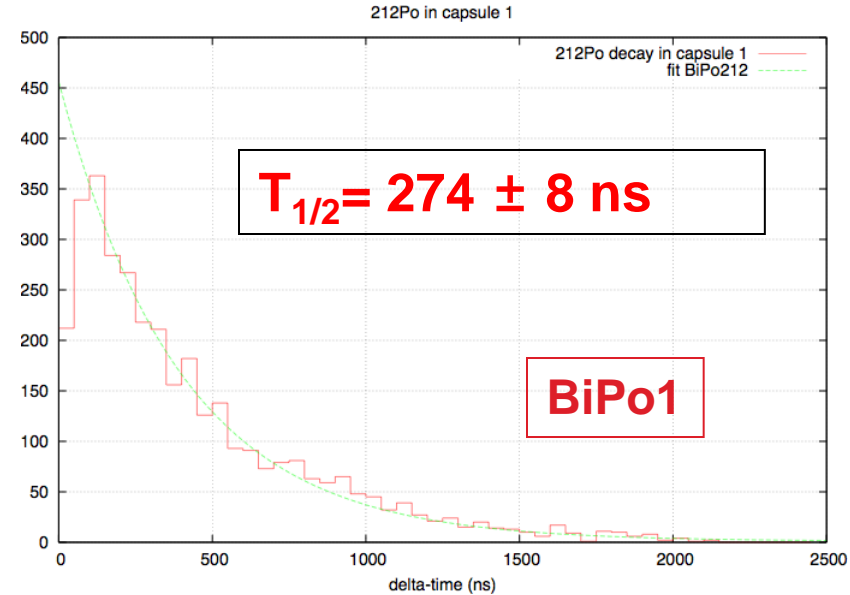
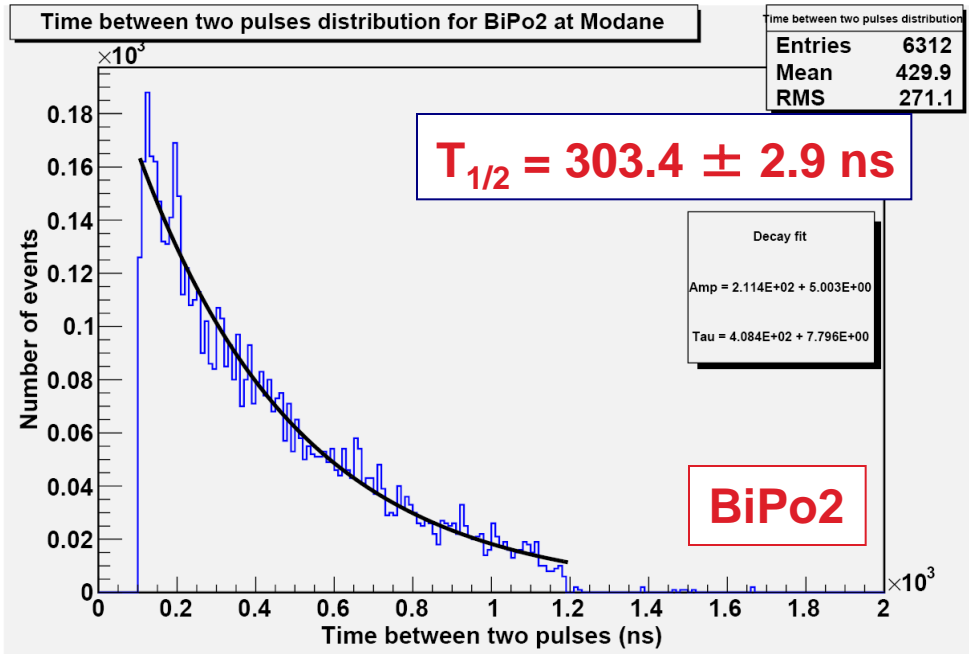
Prototype BiPo2
from MOON idea



Data taking since July 2008

❖ ^{212}Po decay constant measurement :

The lifetime of the ^{212}Po (299 ns) has been measured in BiPo1 (2 scintillator versions) and BiPo2 using a calibrated Aluminium foil.

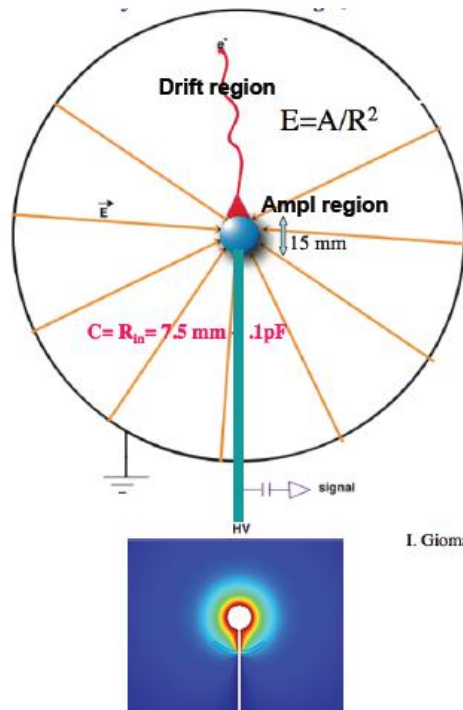


The Bi-Po events measurement principle has been validated with the prototypes

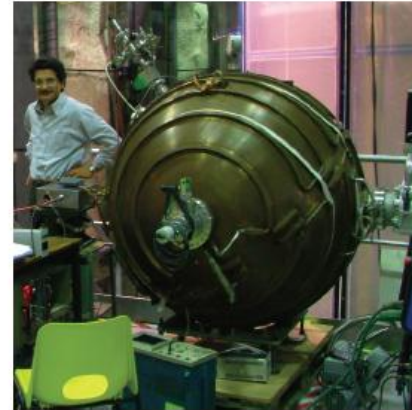
Surface background measurement :

- ▶ $A(^{208}\text{Tl})_{\text{BiPo1}} \sim 1.5 \mu\text{Bq}/\text{m}^2$
(258 days. m^2 @ LSM)

Spherical Proportional Counter

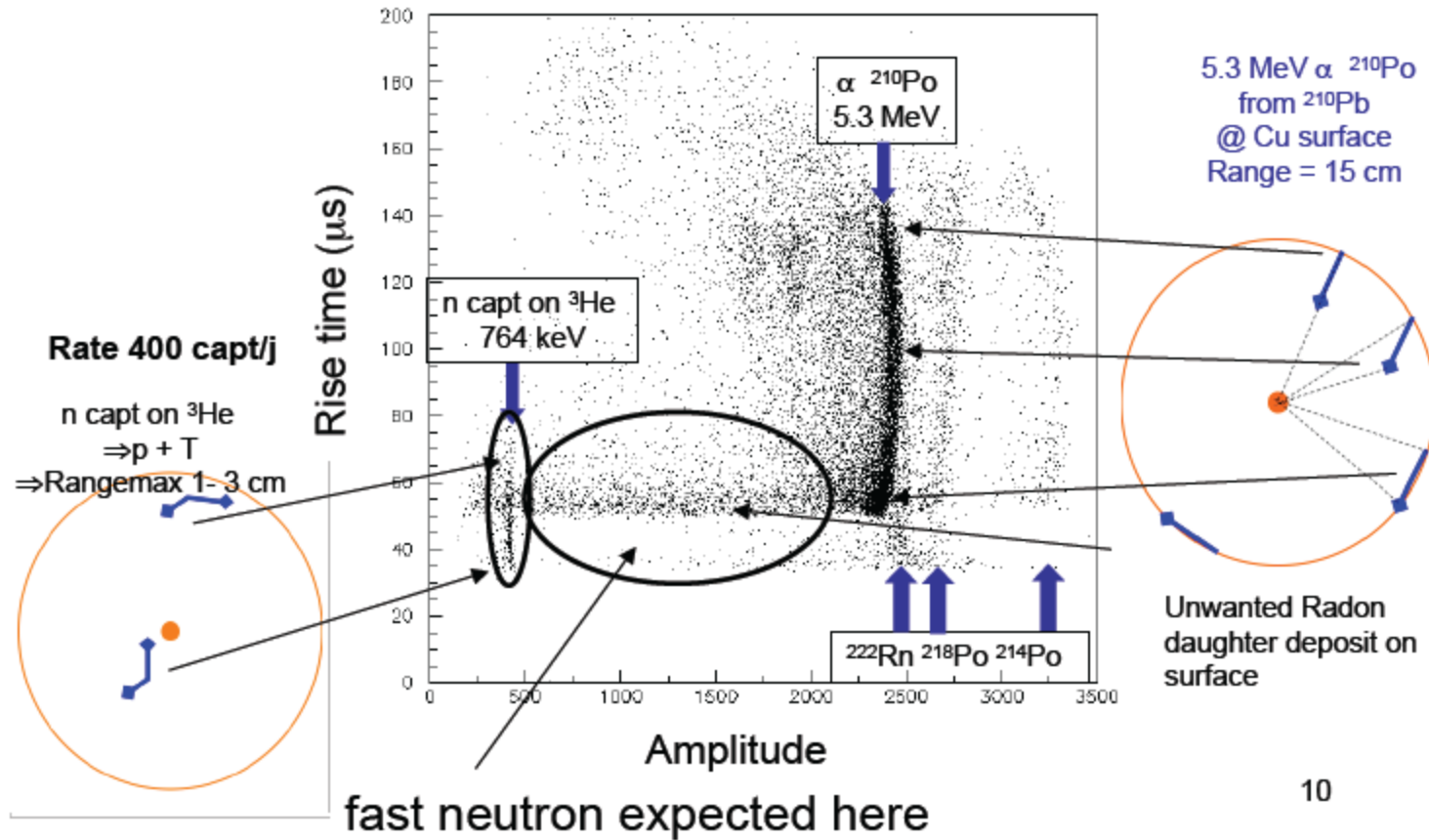


- Low threshold (low C)
- Fiducial selection (risetime)
- Flexible (P, gaz)
- Robust
- Simple/cheap
- 2 LEP cavity tested 1.3 m \varnothing



- High (5 MeV) and low energy (< keV) measurements
- Applications
 - Low neutron flux (thermal & fast) ($\sim 10^{-6}$ /cm²/s) : prototype
 - Low radioactive contaminant gaz measurements
 - Neutrino coherent scattering
 - SN detectors network
 - Dark matter detection ?

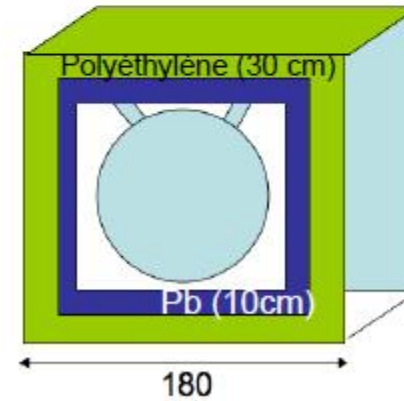
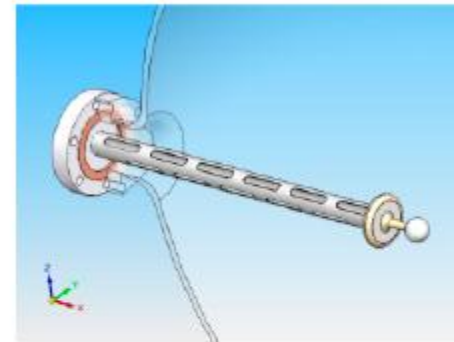
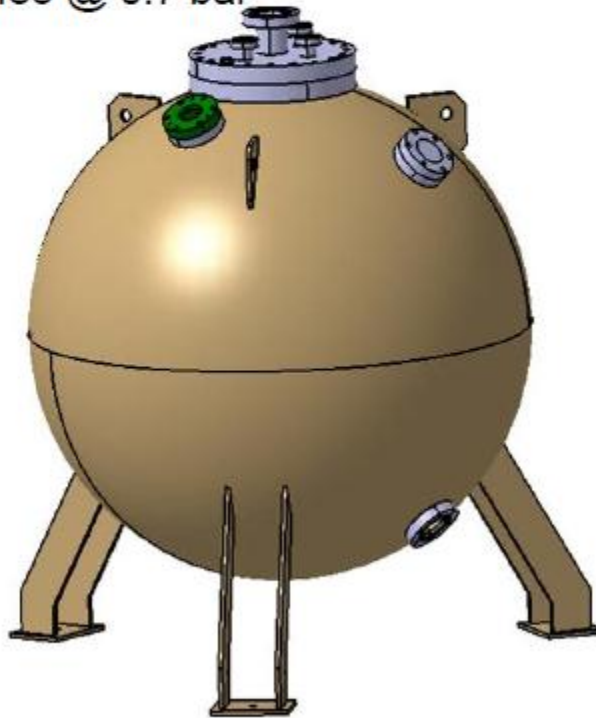
Run at LSM - Ar/CH₄ + 3g ³He 200 mb



Low activity project : SEDINE

- Sphere of 60 cm diameter in low activity Cu and steel
- Low activity material + low Rn emanation

-2 kg Ar @ 10 bar
 -10 g He3 @ 0.7 bar



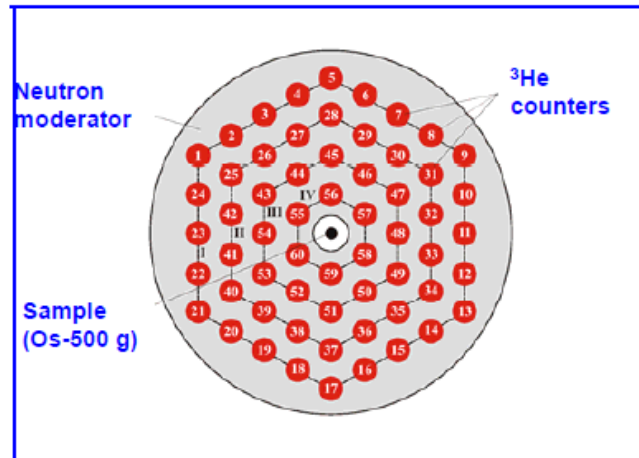
Other experiments

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 (100 μs)		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 $\sim 10^9$ 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

Soon

MIMAC prototype (Dark matter TPC for DM directional detection)

MEMPHYNO prototype for megaton – scale cherenkov detector



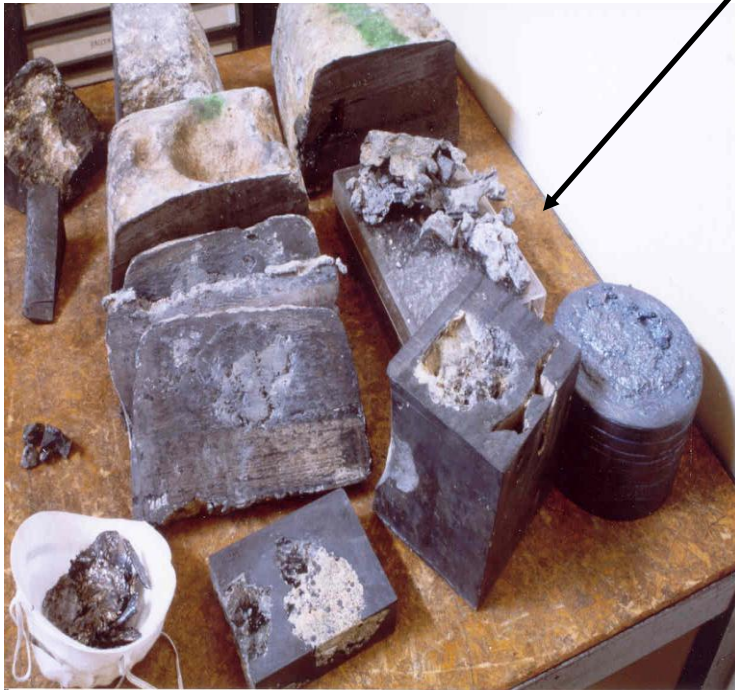
Low radioactive measurements

**13 HPGe from 6 different laboratories of CNRS, CEA, JINR Dubna
CTU Prague are available at LSM**

- Material selection for astroparticle physics,
- Environnemental researches (oceanography, climate, retro-observation,....)
- Environmental survey
- Applications (wine datation, salt origin,...)
- Developements of Ge detector (ILIAS)

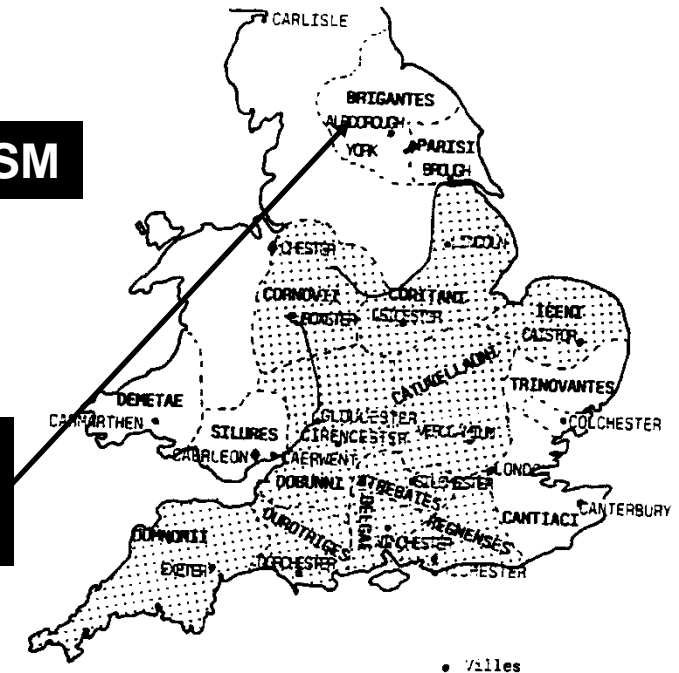
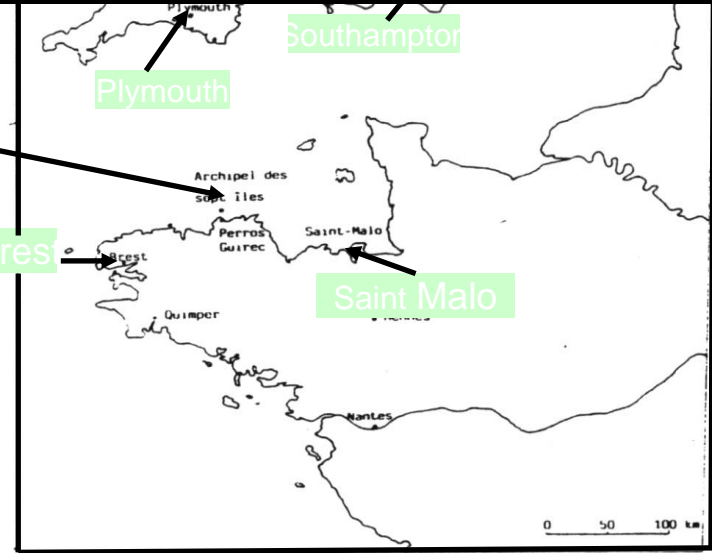
Archeological lead

Roman wreck with 271 lead lingots



Celtic runes on the lingots
(14C ⇒ 4ème siècle)

12 tons at LSM





Low radioactive measurements

In Europe, even remote mountain landscapes are man-made

Noisetier

Epicéa

Pin cembro

Sapin

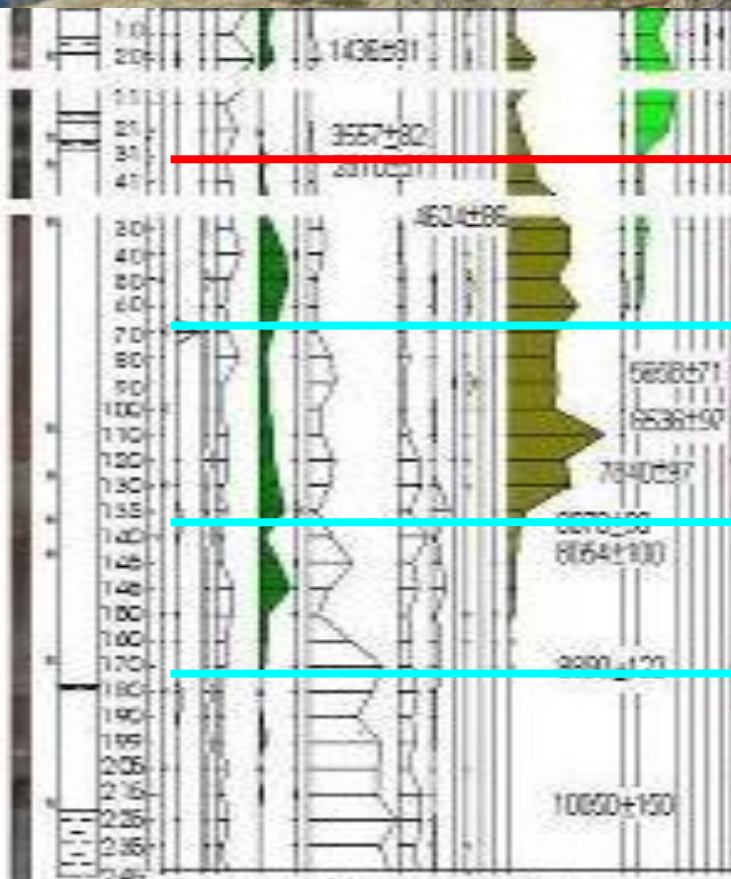
Pollen data, Villy, Haute Savoie, 2250m asl

**Open space:
deforestation**

First forest opening
(human or climate?)

Closing of the
forest space

Forest
reconquest



Epicéa

3600 cal. BP

Pin cembro

5600 cal. BP

Epicéa Sapin

Pin cembro

8000 cal. BP

Sapin

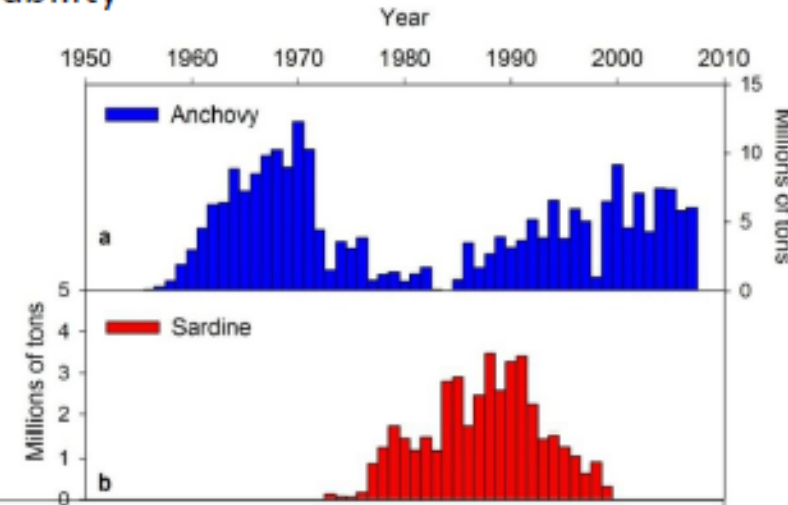
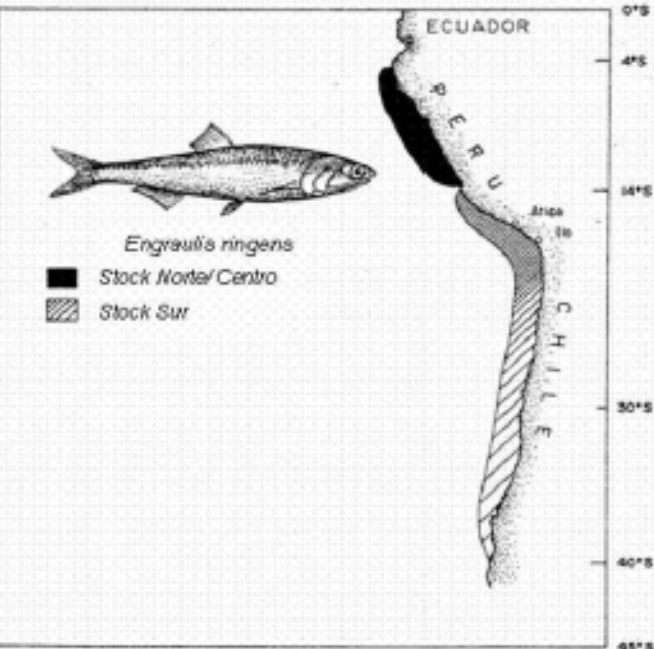
Pin cembro

8900 cal. BP

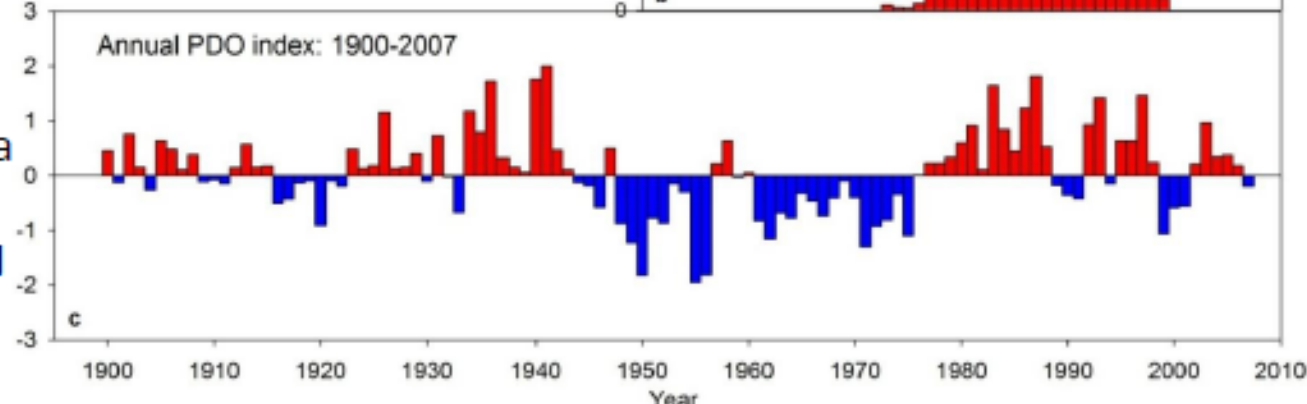
Noisetier

The Humboldt Upwelling Ecosystem is characterized by strong ENSO variability and the highest pelagic fish productivity

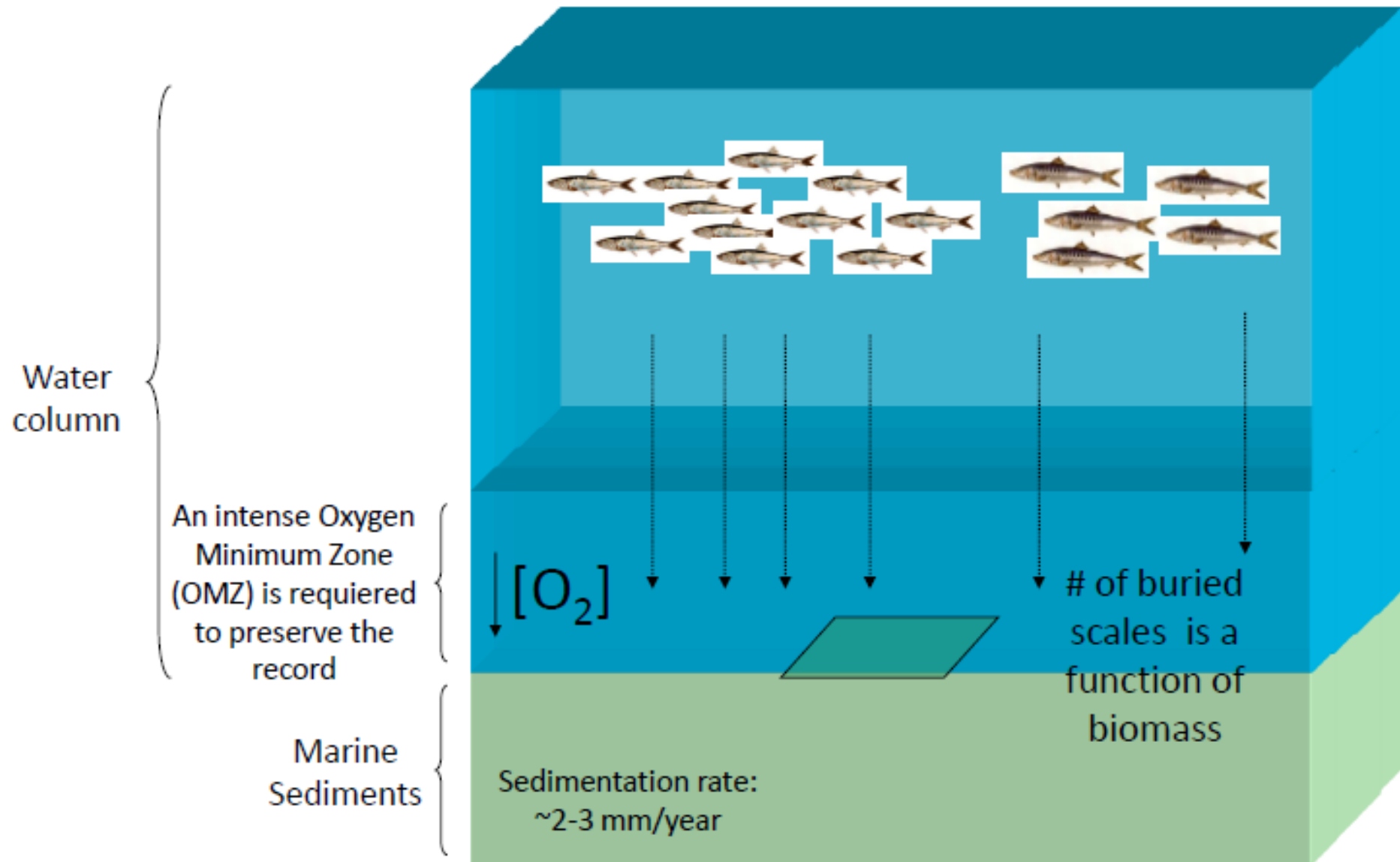
- Continuous coastal upwelling throughout the year
- The northern Humboldt Current System off Peru presently produces about 10% of the world fish catch based primarily on anchovy.
- Anchovy and sardine landings show strong annual and decadal biomass variability



The Pacific Decadal Oscillation (PDO) Index is defined as the leading principal component of North Pacific monthly sea surface temperature variability (poleward of 20N for the 1900-93 period).



Fish scales buried in marine laminated sediments can provide a record of population variability of small pelagic fishes prior to the development of the fisheries



Low radioactive measurements

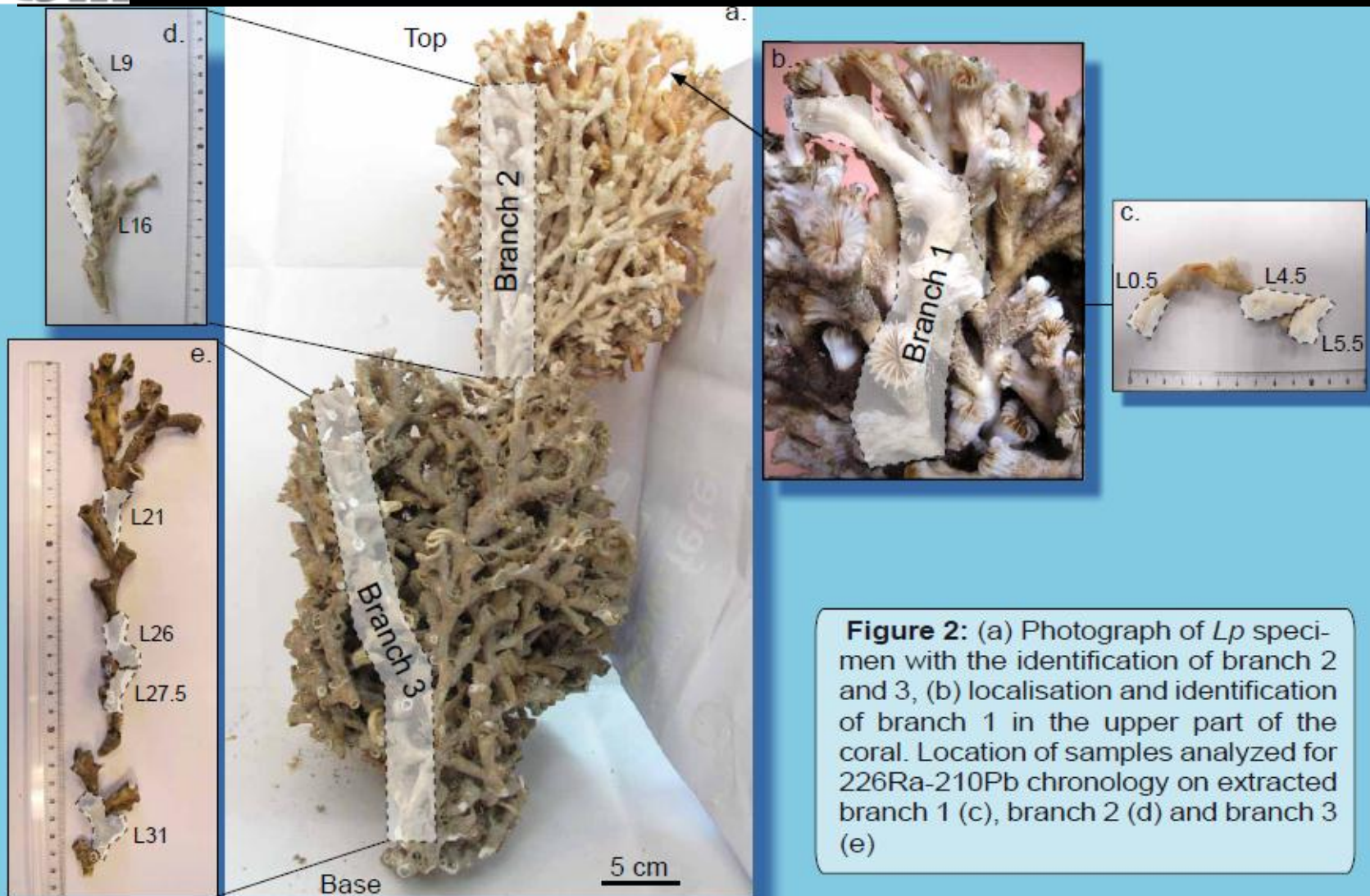
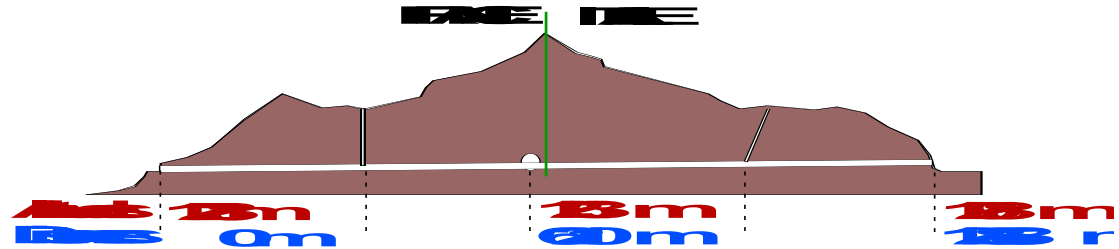


Figure 2: (a) Photograph of *Lp* specimen with the identification of branch 2 and 3, (b) localisation and identification of branch 1 in the upper part of the coral. Location of samples analyzed for ^{226}Ra - ^{210}Pb chronology on extracted branch 1 (c), branch 2 (d) and branch 3 (e)

Deep-sea Coral are useful archives to study seasonal, interannual and decadal paleoclimate changes using ^{120}Pb , ^{226}Ra , ^{230}Th , ^{14}C

Fukushima measurements

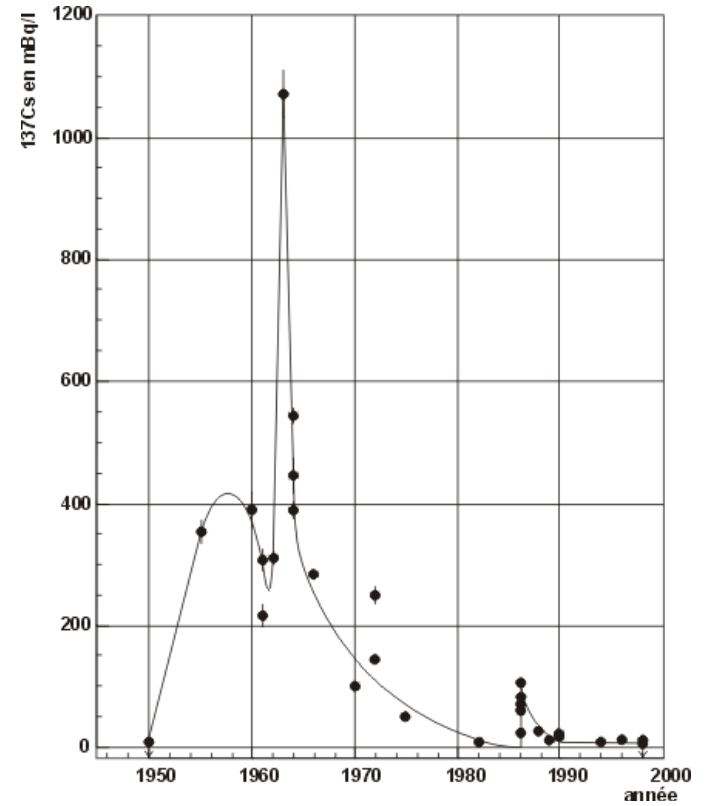


Air renewal : ~5 000 m³/h

4 filters in parallel → measurement of one filter (after one or few days exposure)
by gamma spectroscopy

Period of exposure	Air flow (m ³)	Activities (μBq/m ³)					
		¹³¹ I	¹³² I	¹³² Te	¹³³ I	¹³⁴ Cs	¹³⁷ Cs
25/03-27/03	78374	250±12+50		3.5±0.7		7.3±1.2	5.6±0.9
28/03	37534	200±52		<1.6		<2.5	<2.4
29/03	23952	144±38		<2.2		<3.5	<3.3
30/03	28303	415±108		<1.6		19±3	17±3
31/03-01/04	36584	260±68		2.4±0.5		26±4	24±4
02/04-03/04	84064	522±136		5.8±1.2		34±6	30±5
04/04	33080	123±32		<1.4		8.7 ±1.5	8.2±1.4
05/04	31562	336±87		<1.5		10±2	9±2
06/04	31381	119±31		<2.0		<1.8	<1.8
07/04	31339	129±37		<0.7		9±2	9±1
08/04-10/04	91140	72±19		<0.8		3.5±0.6	1.4±0.2
11/04	28295	100±26		<2.4		7.6±1.3	4.0±1.4
12/04	35238	103±27		<1.9		12.9±2.2	7.9±2.7
13/04	35914	137±36		<2		20±3	15±5
14/04	33049	118±31		<0.2 ?		5.1±0.9	12±2
15/04-18/04	106027	51±13		<0.2		8.3±1.7	8.1±1.6

Table 1: Activities of the product isotopes ¹³¹I, ¹³²I, ¹³⁴Cs, ¹³⁷Cs measured at the Modane Underground Laboratory in the periods given in column 1. The air flow corresponds to the air passing through the filter during the exposure period. Statistical and systematic uncertainties are presented separately. Limits are given at 95% CL according to [2].



137Cs measurement

(Ph. Hubert CENBG)

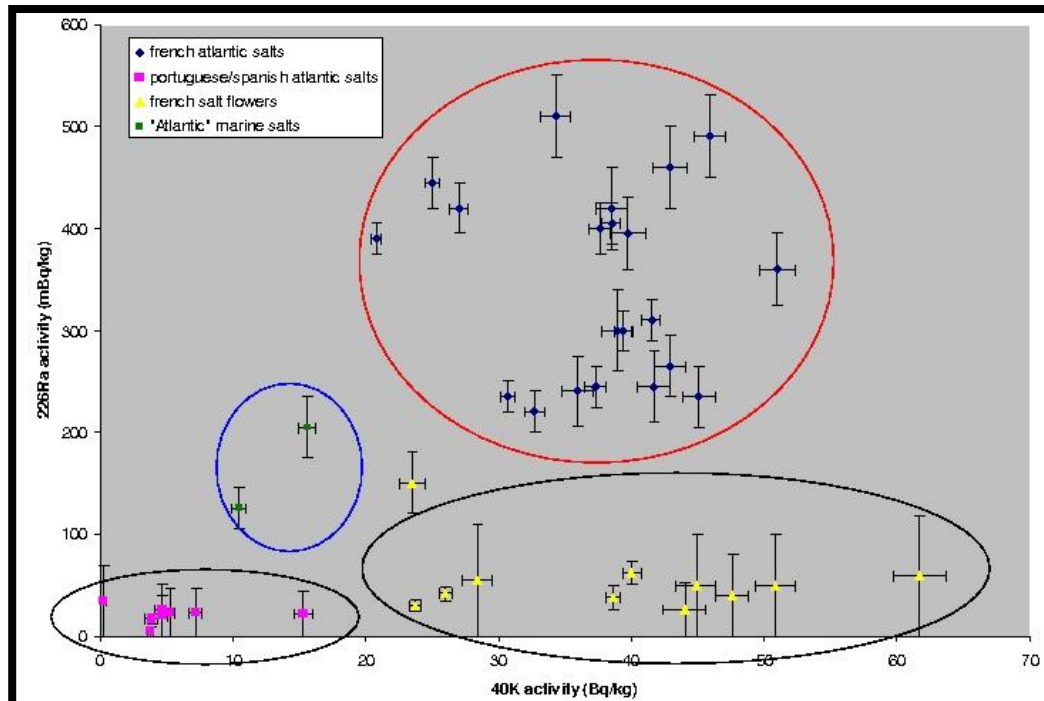


Applications: origin of marin salts



Appellation for Guerande salt

**True or Fake Guerande salt
can be distinguished by
natural radioactivity**





Biology

Modeling the impact of radiation on living cells: Geant4 DNA

Validation: need for relevant observables to characterize biological systems

- Cell survival rate
- DNA single or double strand breaks
- Molecular biology: genomic mutations, gene expression

Experimental protocol: compare observables after controlled radiation exposure

- In normal lab conditions
- After beam irradiation (γ , e^- , p , α)
- **Need for a reference point at zero-radiation: Modane**

Biologists, computer scientists
Physicists, chemists

Geant4 DNA



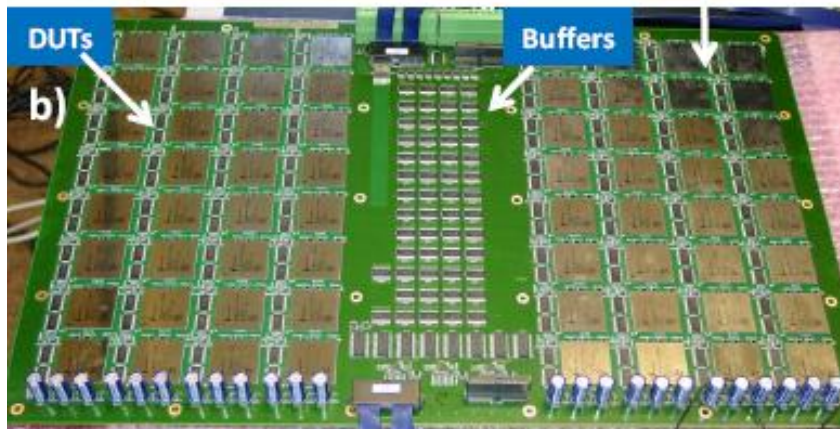
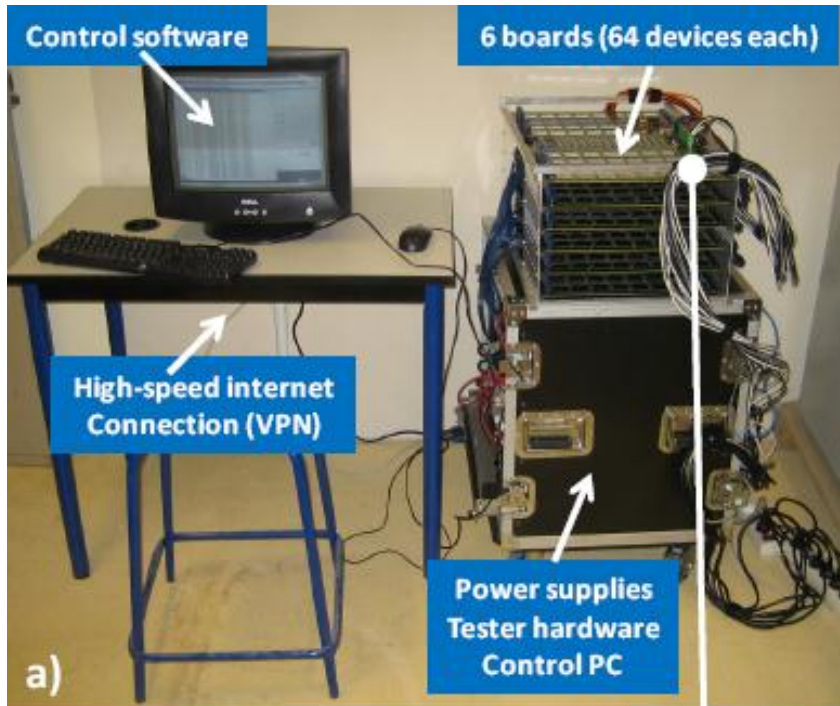
Biology: LSM for reference

- ✦ **In normal lab conditions, cultures are exposed to 10 Millions cosmic rays per day per square meter**
 - Low but significant radiation exposure

- ✦ **In Modane, down to 4 cosmic rays per day per square meter**

- ✦ **Goal: study evolution of model organisms in radiation free environment**
 - Bacteria life cycle
 - Mutation rate
 - Localization of gene mutations, gene expression
 - DNA breaks

Micro-electronics test failures



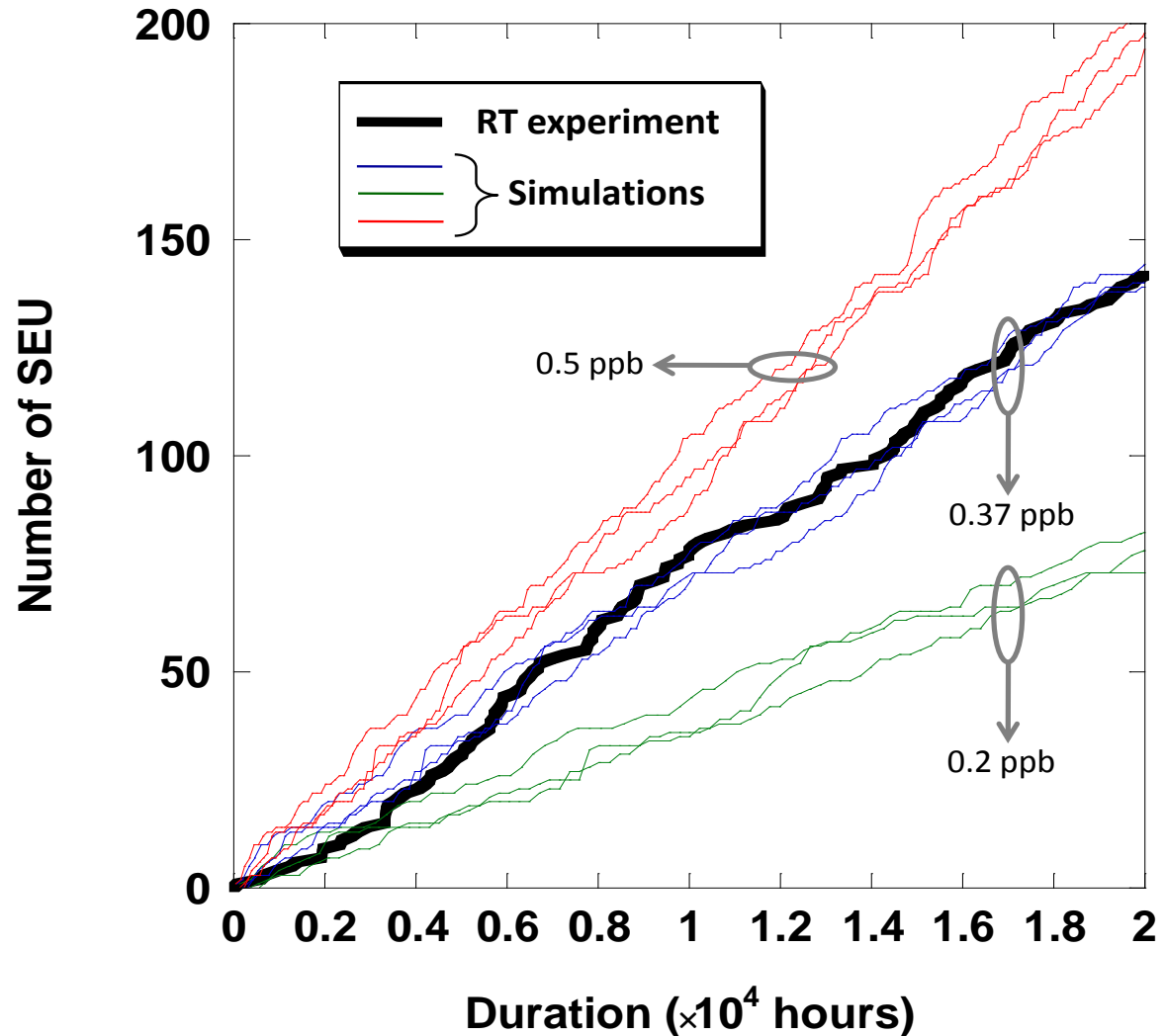
Les neutrons et les rayonnements alpha de la radioactivité naturelle sont la source d'erreurs dans les circuits de microélectronique

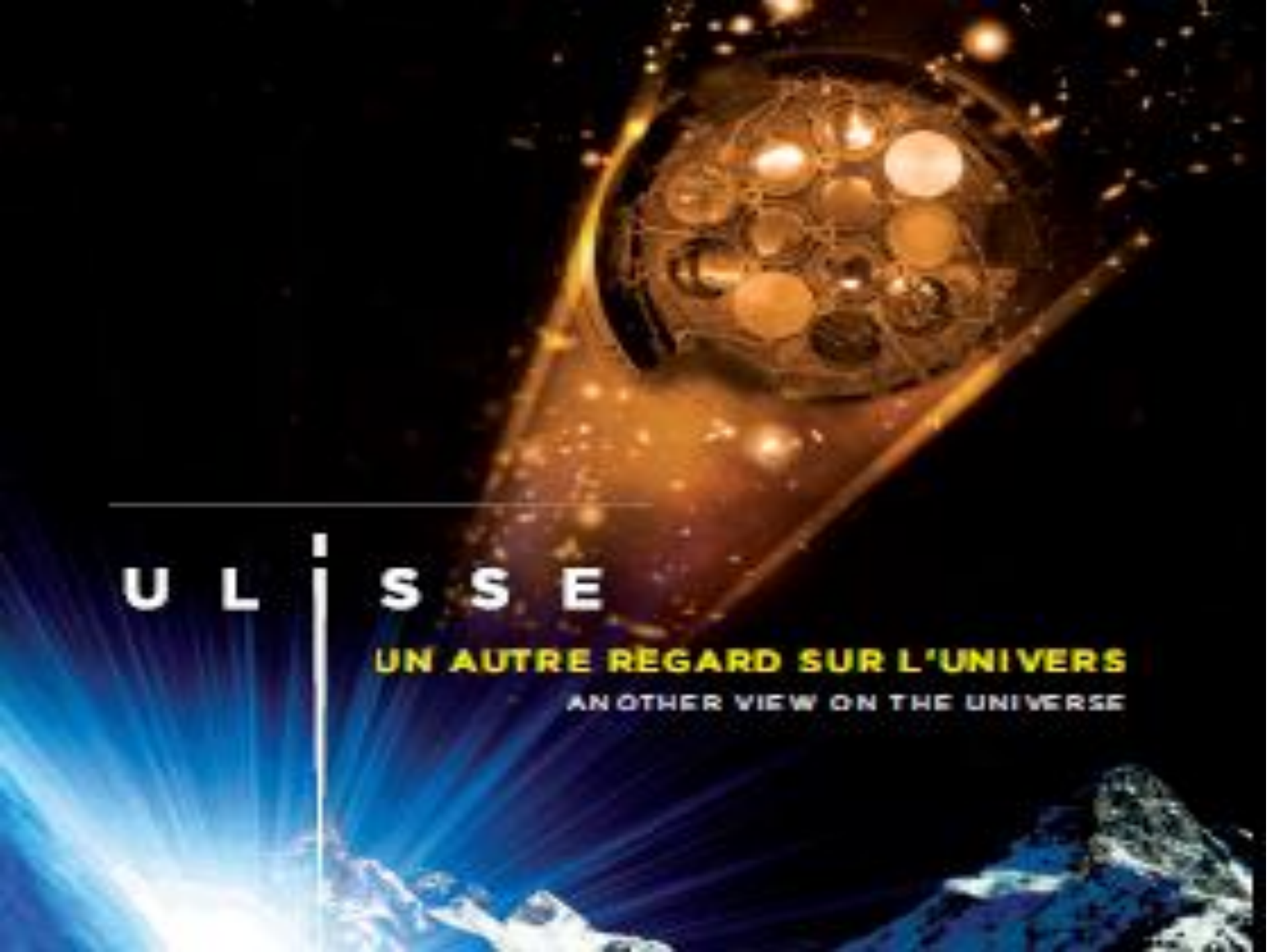
L'utilisation de matériaux « radioactifs » peut entraîner des incidents industriels majeurs

Le LSM est laboratoire de référence pour la norme internationale JEDEC en microélectronique

Monte-Carlo Simulation of Underground Experiments

- Up to 20,000 h of cave characterization
- α -SER reevaluated to 2079 FIT/MBit
- Monte-Carlo simulation gives a contamination level by ^{238}U impurities of 0.37 ppb
- Very good agreement with wafer-level characterization (alpha emissivity) in the range [0.2-0.5] ppb



The background of the image shows the Ulysses spacecraft in space. The spacecraft is a complex structure with a large, circular instrument bay at the top, containing several smaller instruments. It is positioned in the upper right quadrant, with a bright, glowing trail of light extending from it towards the bottom left. The background is a dark, star-filled space with a prominent blue and white nebula or comet tail in the lower left corner. The overall color palette is dominated by dark blues, blacks, and oranges from the spacecraft's instruments.

U L | S S E

UN AUTRE REGARD SUR L'UNIVERS

AN OTHER VIEW ON THE UNIVERSE

In 2006, the project of a safety galery along the Fréjus roadway tunnel started to be realistic.

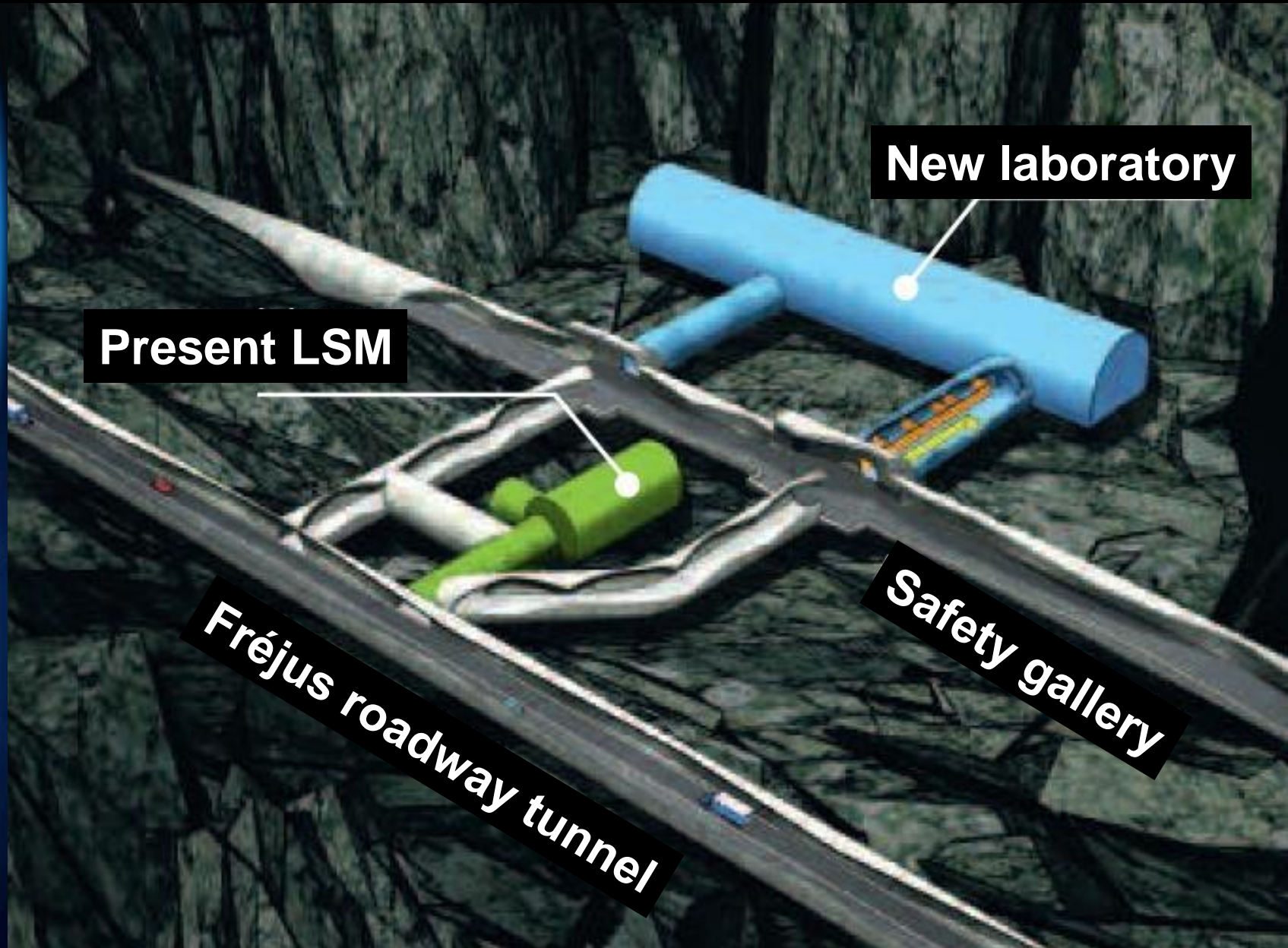
An unique opportunity

- Deepest site in Europe (4800 mwe)
- Known and « good » site (low convergence, dry, stiff rock)
- Central location in Europe, easy access (plane, train car)
- 23 years experience in running such platform
- Independent, convenient, safe, horizontal access
- European Roadmap new projects
- Integration of project to tunnel company planning and constraints
- Performed pre study : moderate cost

Scientific Motivations : To be able to host the next generation of neutrino and dark matter experiments

To develop the multi-disciplinarity aspects of the laboratory

LSM Extension project



Present LSM

New laboratory

Fréjus roadway tunnel

Safety gallery

LSM Extension project



COUPE TYPE SALLE A

SECTION EXCAVÉE 375 m²

SECTION UTILE 320 m²

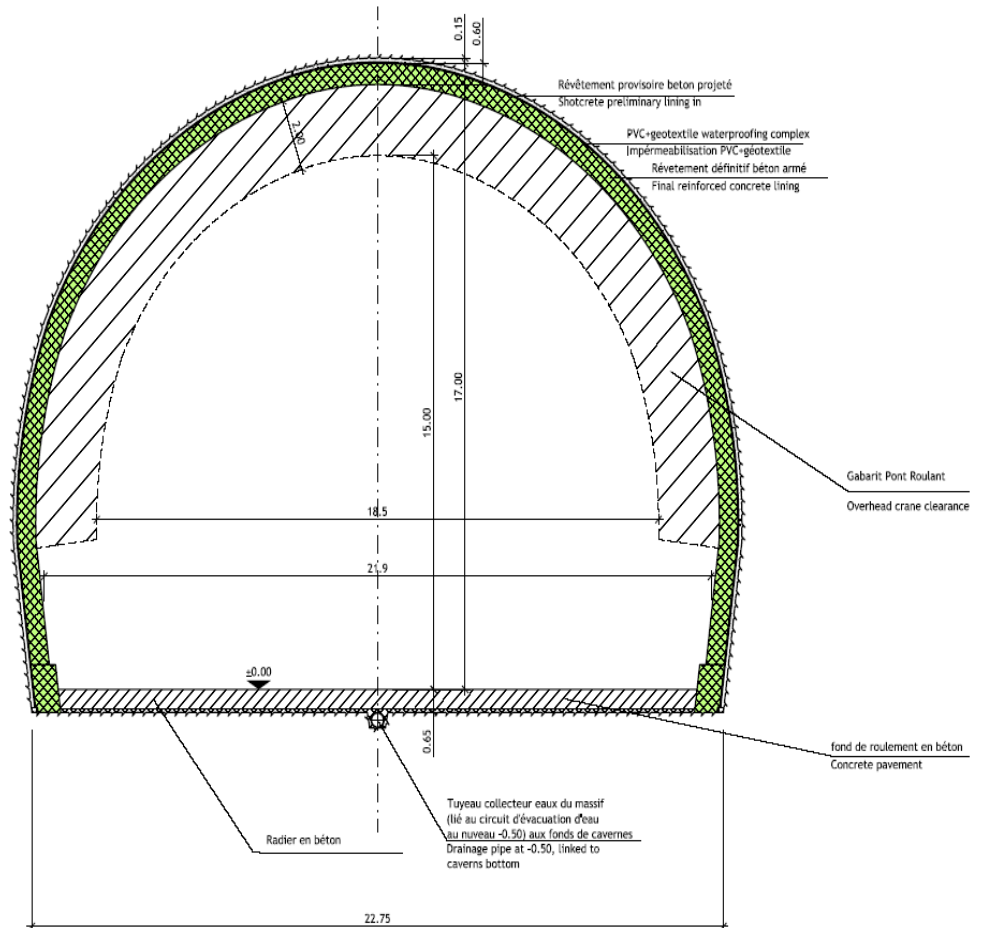
1:100

CAVERN A CROSS SECTION

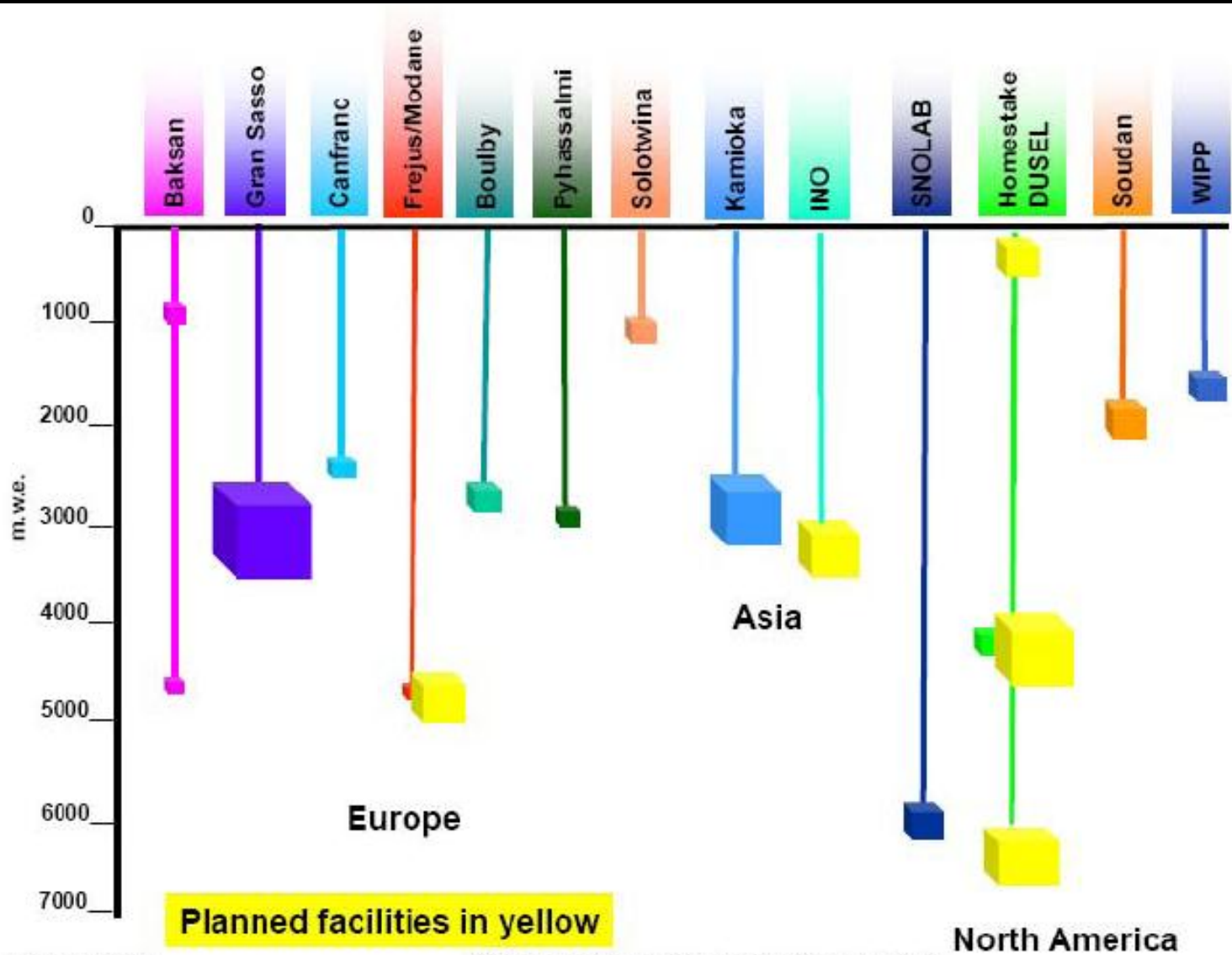
EXCAVATED AREA 375 m²

INTERNAL CLEARANCE 320 m²

1:100



Comparison of Underground Labs



International call for letter of interest June 2008
12 LoI received and one Expression of Interest

Neutrino (DBD)

SuperNEMO (tracko-calorimetry method)
COBRA (solid TPC)

Dark matter:

EURECA (Bolometers)
DARWIN (noble liquid) EoI
MIMAC (TPC)
ULTIMA (Superfluid ^3He)

Double EC

TGVIII Double EC (pixelized detector)
Double EC with Ge detectors

R&D for proton decay and neutrino physics
MEMPHYNO

Supernovae neutrinos:

TPC sphere

Logical test failure

Low background techniques

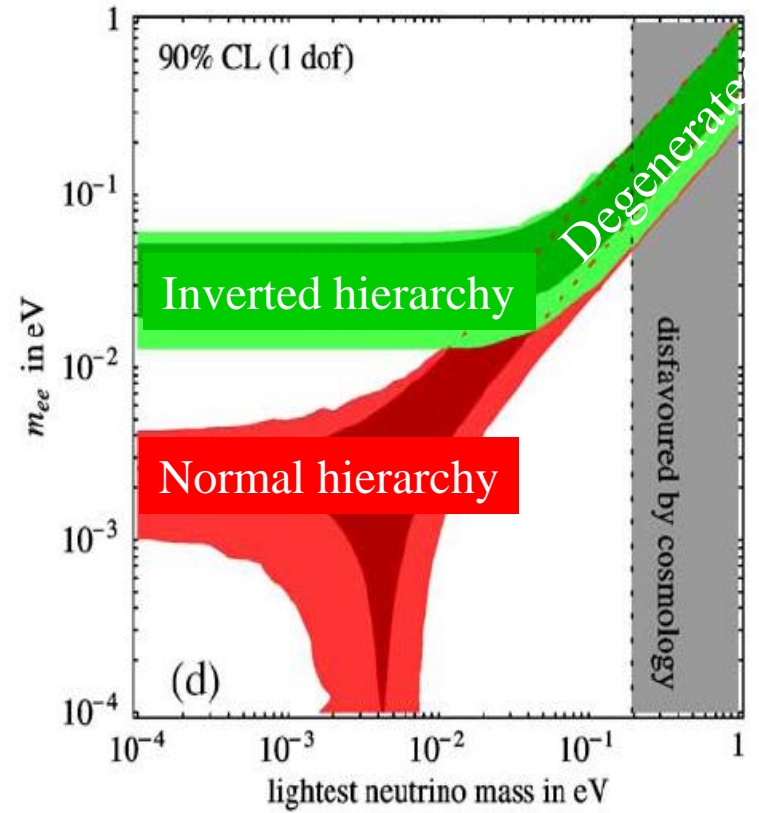
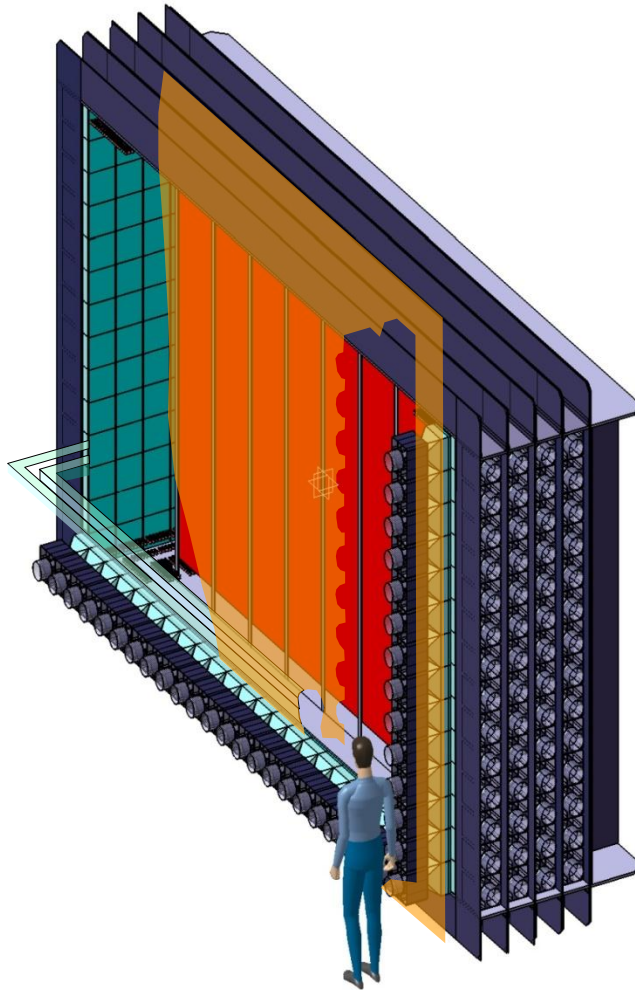
:Environmental measurement
Sediment in alpine lakes

2 workshops to present projects

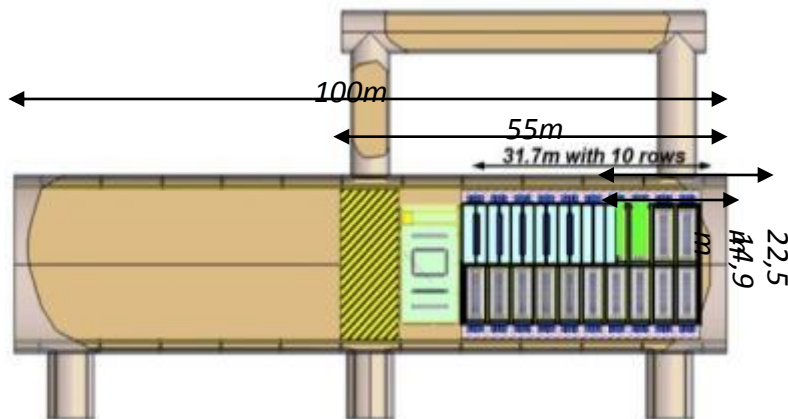
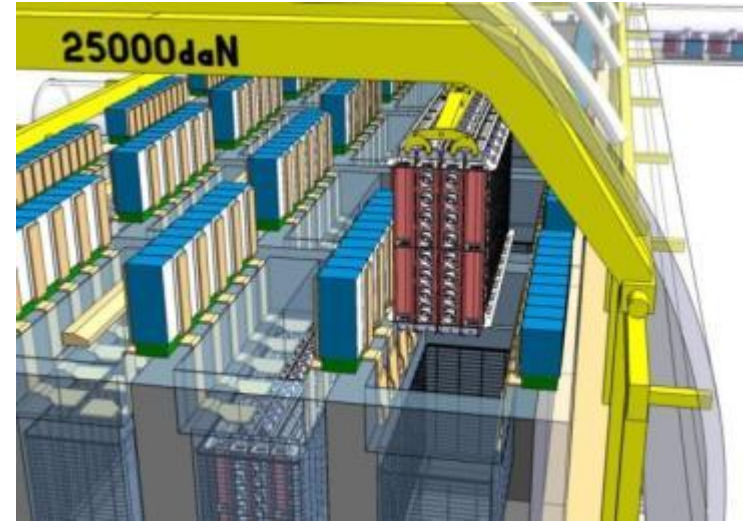
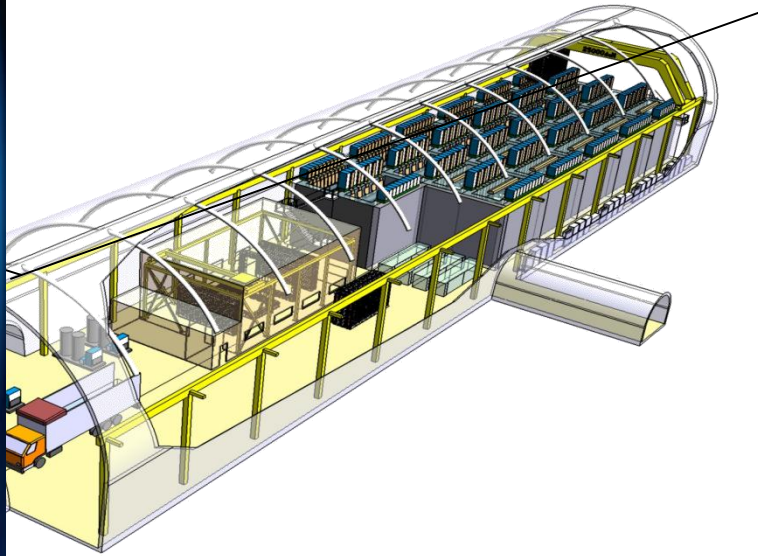
**Reviewed by an International
Scientific Advisory Committee**

SuperNEMO @LSM

Tracko-calorimeter detector 100 kg of isotopes (20 modules)



SuperNEMO @LSM

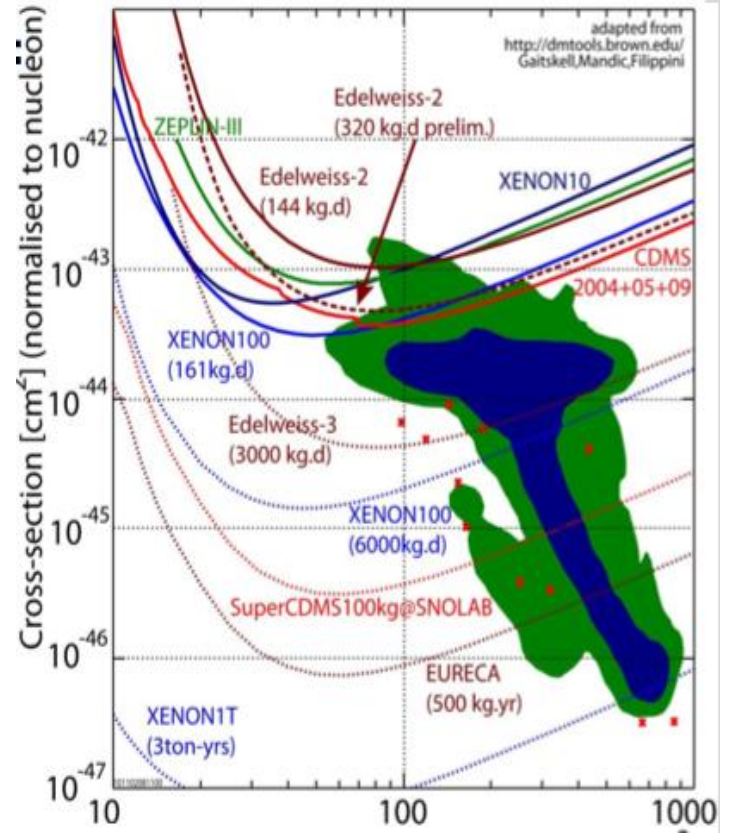
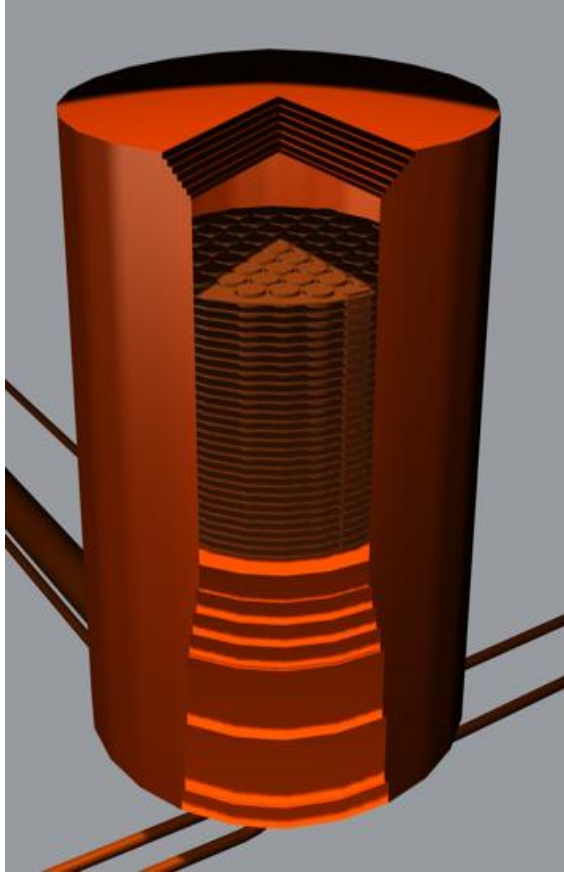


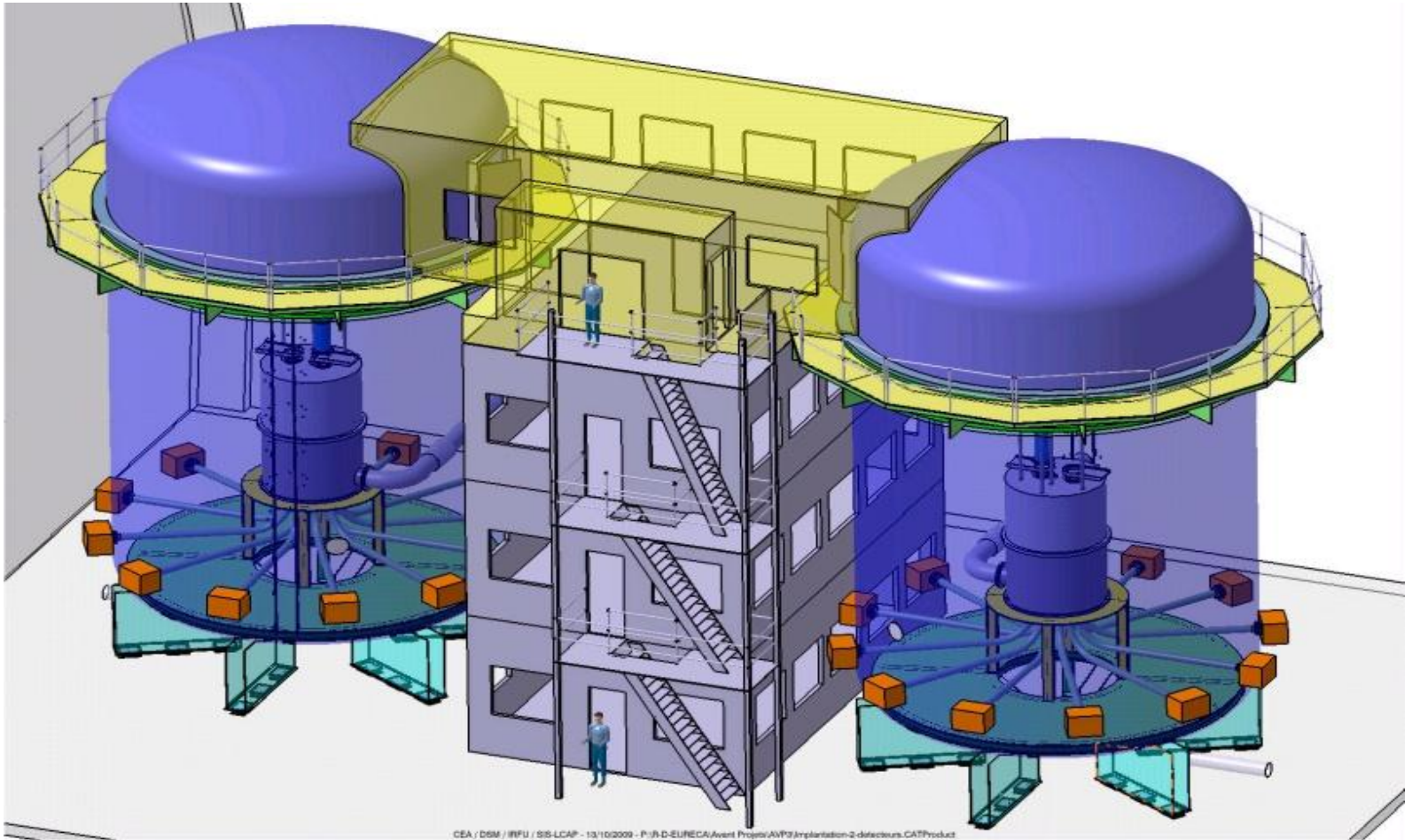
20 modules shielded by water tanks

Space requirements: 32 m X 15 m

Minimum height: 13 m

Dark matter search with 1 ton of bolometers





Dimensions : 30 m x 14 m
Height : 14 m

Ultra low platform LSM, EDYTEM (Université de Savoie), LSCE (CNRS and CEA), LGGE (U. Grenoble, CNRS), LPSC (U. Grenoble, CNRS)

Improvement of detectors for low radioactivity measurements

Material selection

Use of radioactivity for environmental research :

Oceanography : Study of metals in the ocean, studies of water columns

Retro-observation : Human effect on the environment, study of Alpin lakes

Water quality : possibility to use sediments to know the state reference for the Lake and the river as requested by EU

Studies of temperature water effect and fishing on the fish resources

Climatology

Glaciology,....

Expertises : Environmental survey

Wine datation

Salt origin,....

1st EQUIPEX call ULISSE, request 19,5 M€

Including : Civil Work (12 M€)
Equipments (3 M€)
SuperNEMO 1st Module (1,5 M€)
EURECA (1,5 M€)
MIMAC (0,5 M€)
Low radioactivity platform (1 M€)



ULISSE ranked at 61 position ex-aequo

New strategy : To find the cavity funding outside of EQUIPEX call
To submit equipments and detectors to 2nd call of EQUIPEX

A constraint is to confirm the option for the civil work before March 2012

Funding in discussion for civil work. 12 M€

Expected contribution from State, Rhône-Alpes, Savoie, CNRS and CEA

- Safety gallery work started in October 2010
- 600 m excavated, TBM will start in September

Laboratory digging end 2012

New LSM in operation mid-2014

