THE CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

Experimental Program

Status, Results & Prospects

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CONTENTS

- Short description of the Canfranc Underground Facility
- Current experiments and results
- Future projects

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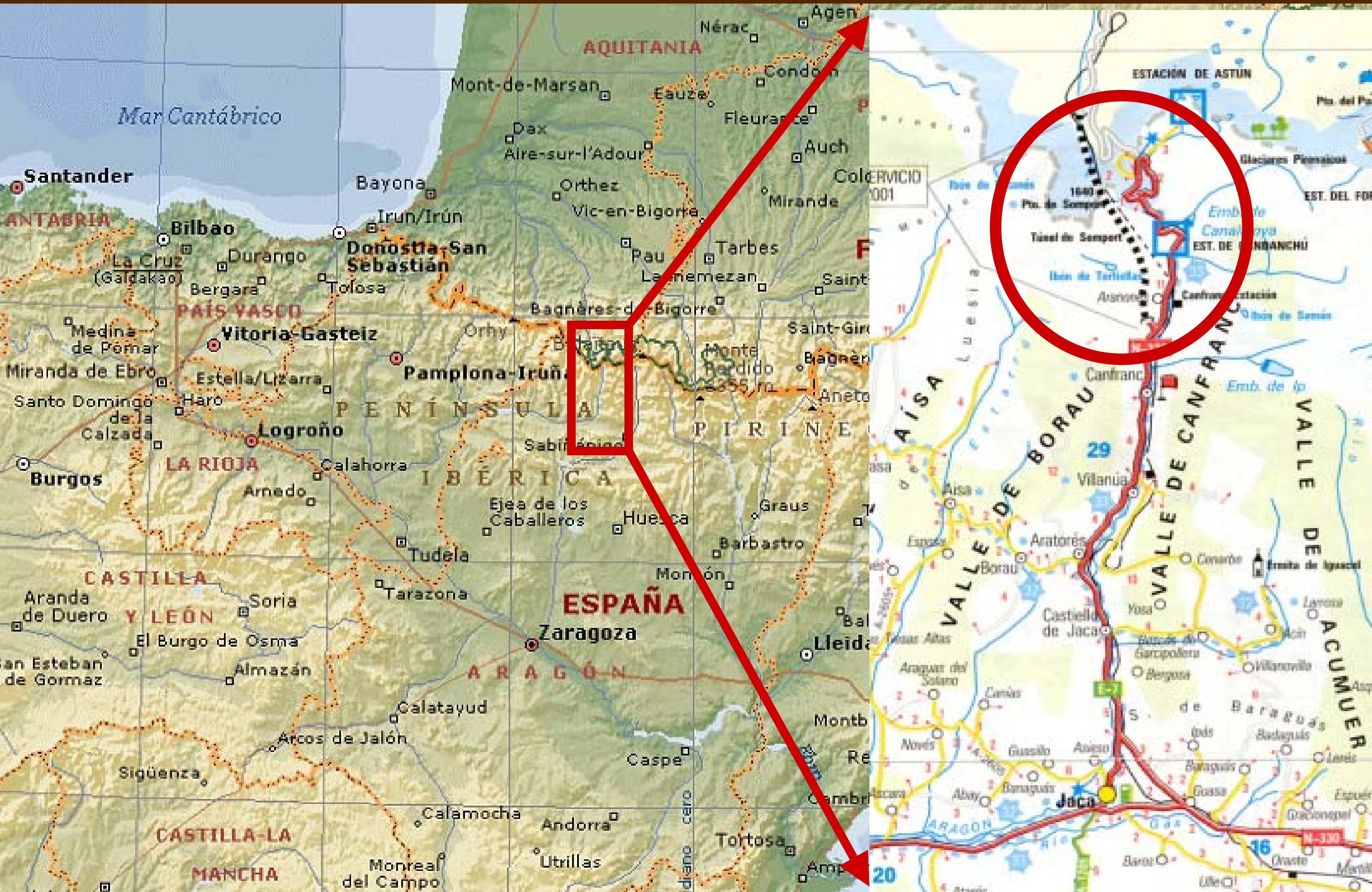
1. THE CANFRANC UNDERGROUND FACILITY

- Located in a Railway tunnel of ~8 Km long (not in use), crossing the Pyrenees (entrance at ~1080 m above sea level by the Canfranc Station).
- Set of various small facilities at different depths:
  - Two small rooms of 12 m^2 (plus two 35 m^2 x 1 m galleries) each one at 700 m.w.e.
  - One Laboratory mobile on the tracks (two trailers of 3.5 x 6 m each), at a depth from 500 to 2500 m.w.e.
  - One main Laboratory of 110 m^2 (4.5 m height) under the Tobazo mount (~2000 m), providing shielding of rock equivalent to 2450 meters of water.
  - There exist 18 galleries (~100 m x 4.5 m) connecting the recently constructed road tunnel of Somport to the Railway tunnel of Canfranc. Both tunnels go in parallel at a distance of 90 m to 150 m each other.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Santander
CANTABRIA
Bilbao
La Cruz (Galdakao)
Durango
Bergara
Tolosa
Irun/Irún
Donostia-San Sebastián
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Miranda de Ebro
Estella/Lizarra
Pamplona-Iruña
Santo Domingo de la Calzada
Haro
Logroño
LA RIOJA
Burgos
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P E N Í N S U L A
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Ejea de los Caballeros
Huesca
Tudela
Tarazona
CASTILLA Y LEÓN
Aranda de Duero
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El Burgo de Osma
Almazán
ESPAÑA
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Calatayud
Arcos de Jalón
Sigüenza
CASTILLA-LA MANCHA
Calamocha
Monreal del Campo
Andorra
Utrillas
Caspe
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Barbastro
Graus
Lleida
AQUITANIA
Nérac
Agen
Mont-de-Marsan
Eauze
Condom
Fleurance
Dax
Aire-sur-l'Adour
Auch
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VALLE DE CANFRANC
VALLE DE ACUMUER
Aísa
Villanúa
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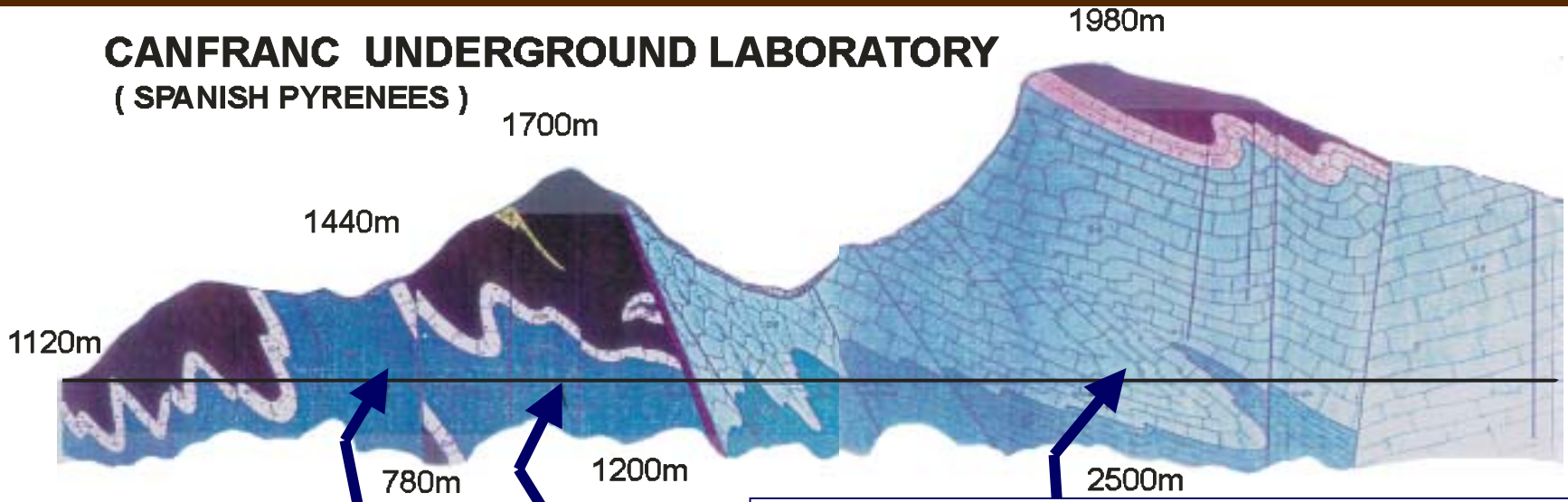
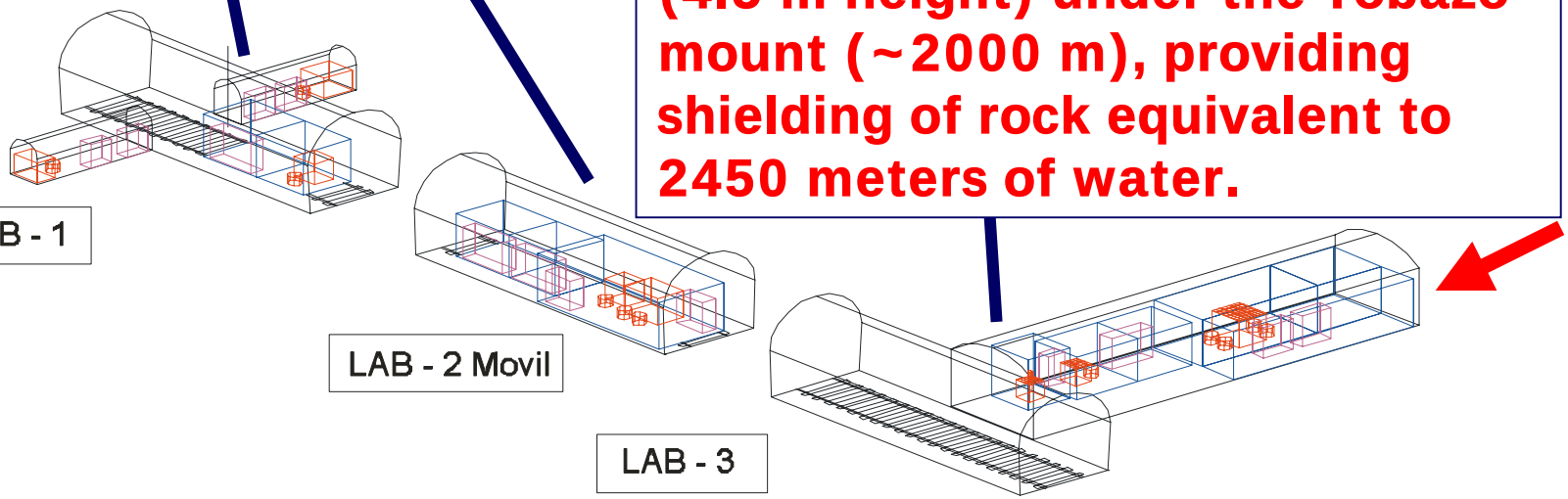
N-330

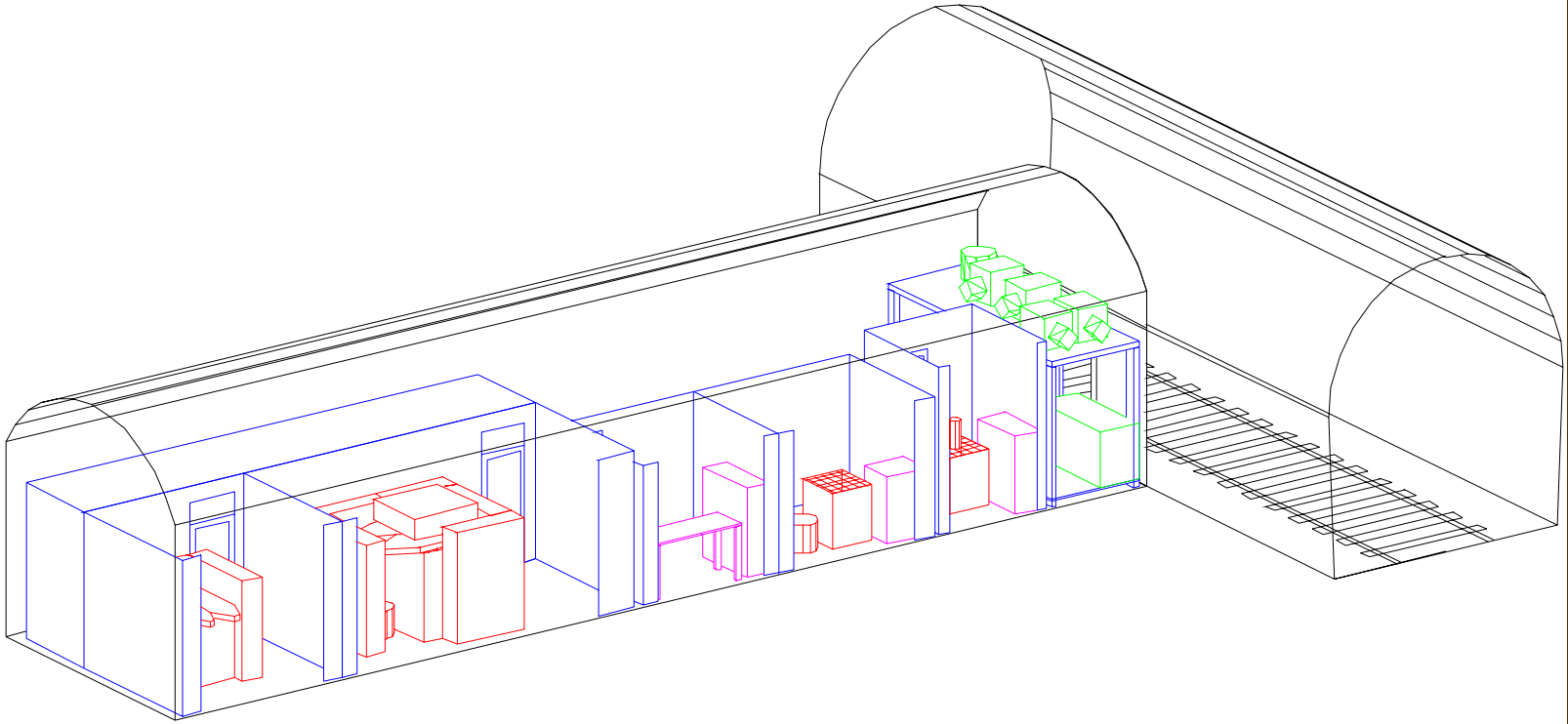
CANFRANC UNDERGROUND LABORATORY

(SPANISH PYRENEES)

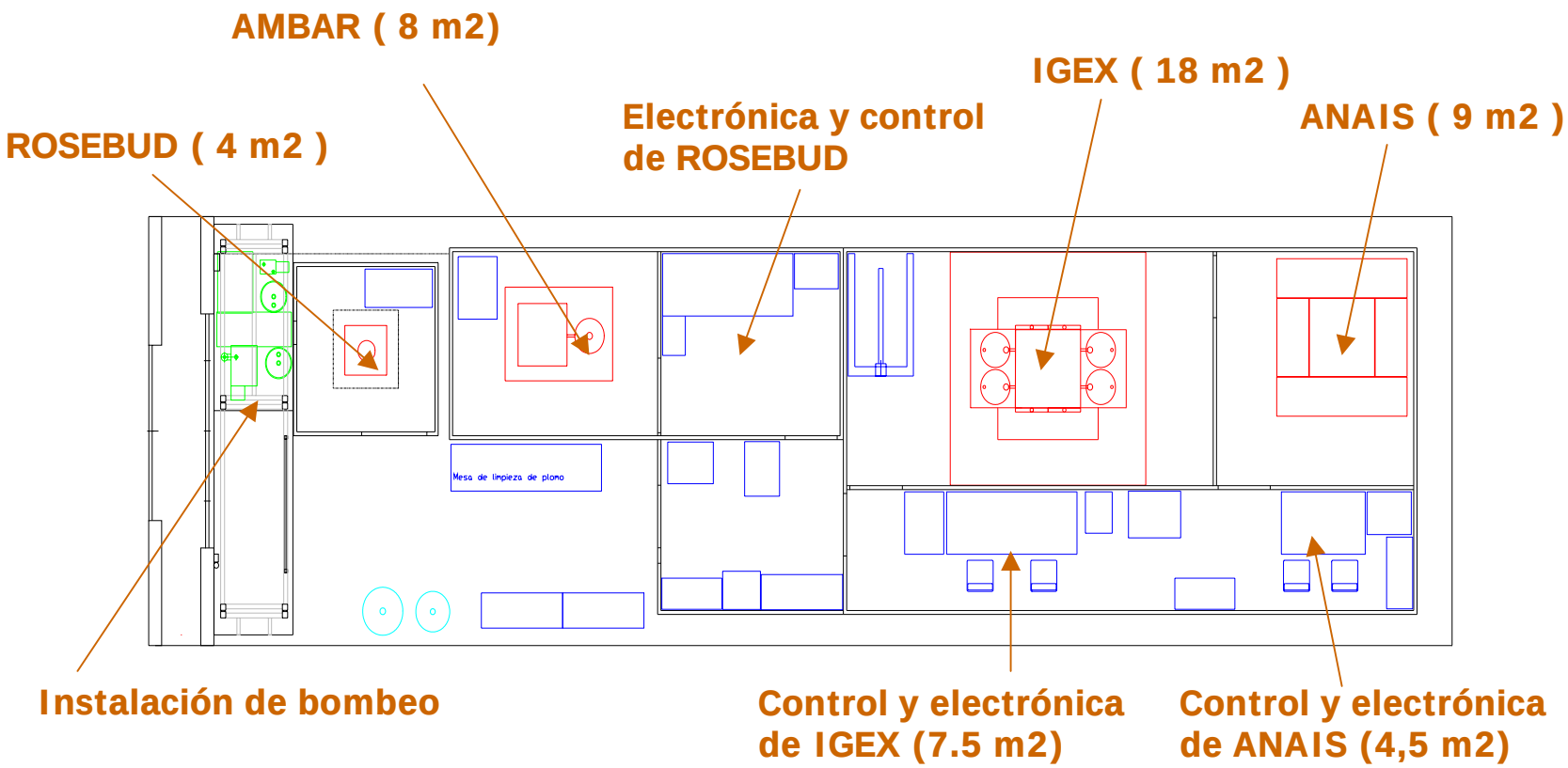


One main Laboratory of 110 m² (4.5 m height) under the Tobazo mount (~2000 m), providing shielding of rock equivalent to 2450 meters of water.

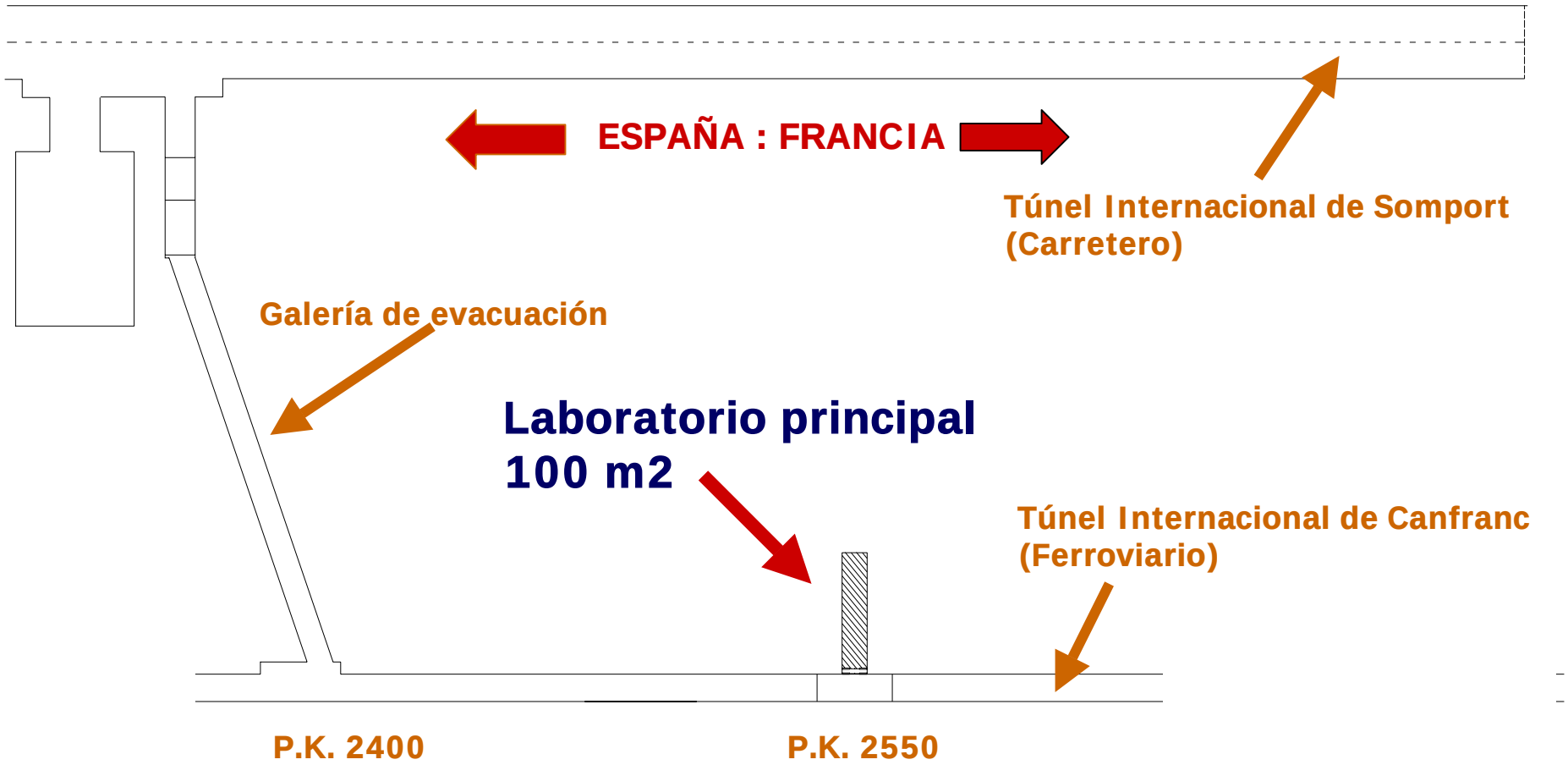




LABORATORIO SUBTERRANEO DE CANFRANC
Planta del Laboratorio Principal
(Lab. 3 a 2450 mwe)



ESQUEMA DE SITUACION



EXPERIMENTAL PARAMETERS

Depth (max.): ~ 2500 meters of water equivalent (m.w.e.)

Composition of the rock and average density: limestone, mainly calcium carbonate, $\rho \sim 2.7$ g/cm^3 plus traces of quartz, $\rho \sim 2.6$ g/cm^3)

Muon flux: $\phi_\mu = 2 \times 10^{-7}$ μ/cm^{2}s

Radon: Variable, 50-100 Bq/m^3 in Laboratory

Ambient photon flux: $\phi_\gamma \sim 2 \times 10^{-2}$ γ/cm^{2}s

Neutrons: $\phi_n \sim$ a few x 10^{-6} n/cm^{2}s depending on energy

CURRENT INFRASTRUCTURE OF THE SITE

- Independent electric power supply to the Lab.
- Telephonic link
- Air conditioning and thermalization
- Air extraction and forced ventilation in/from outside
- Low temperature facility (12-20 mK)
- Antivibrational cabin and Faraday cages
- Floor reinforced for supporting heavy shielding
- Tons of archaeological lead
- Bench of ultra-low background HpGe detectors for radiopurity measurements

FINANCEMENT

The research infrastructures built in the tunnel, the investments on experimental equipment, the running costs and other scientific activities of the LSC are financed by the Spanish National Programs of High Energy Physics, and of Particle Physics and Accelerators of the **Ministry of Science and Technology (MCyT).**

Other funding contributions come from the **University of Zaragoza**, the TMR Program of the **European Union** and the Regional **Government of Aragon.**

Punctual contributions are that of the **DOE (USA)** and **NSF (USA)**, the **INFN (Italy)** and **IN2P3 (France)** and **INR and ITEP from Russia.**

USERS

More than fifty scientists from twelve institutions from eight countries have participated in the LSC Scientific Program (Argentina, Armenia, France, Italy, Portugal, Russia, Spain and USA).

Laboratory of Nuclear and High Energy Physics, University of Zaragoza, (Spain)
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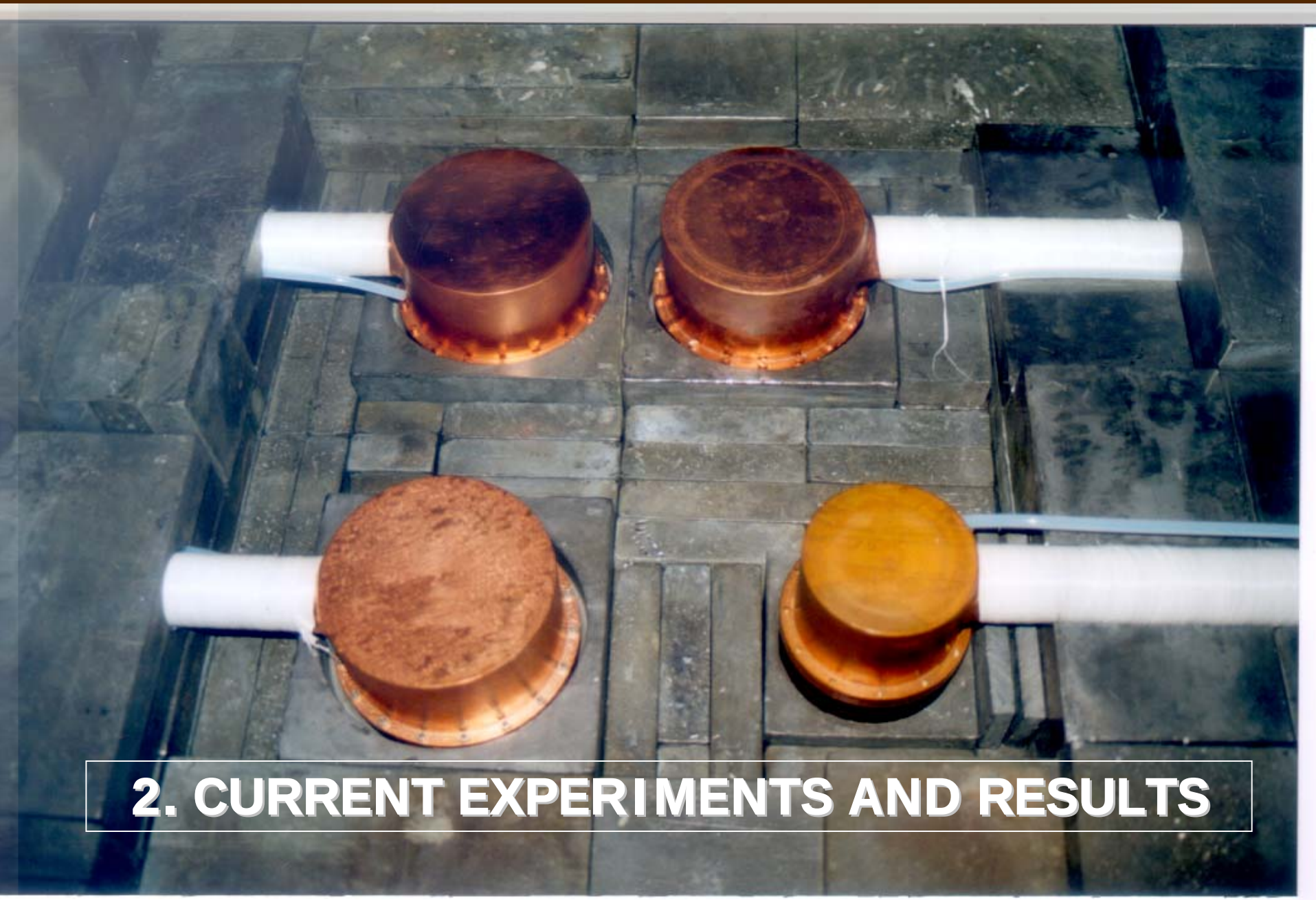


2. CURRENT EXPERIMENTS AND RESULTS

MAIN LINES OF PHYSICS RESEARCH AT CANFRANC

☆ Neutrino Physics

Double Beta Decay

IGEX- 2β-decay, $^{76}Ge2\beta/\gamma$, $^{78}Kr2\beta^{+}$-decay
CUORICINO (LNGS)

☆ Dark Matter searches

Direct detection of galactic WIMPs

COSME1, COSME2, IGEX-DM, NaI-32, ANAIS
ROSEBUD I, ROSEBUD II

☆ Solar axions searches

Bragg scattering on crystals

COSME2, SOLAX

Helioscopes

CAST

EXPERIMENTS ALREADY PERFORMED OR BEING CURRENTLY IN OPERATION AT LSC

- Decay of Ge76 to excited states ($2\beta/\gamma$ coincidence exp.)
- Double positron decay of 78Kr
- Looking for WIMPs of low mass (COSME-1)
- Search for annual modulation of WIMPs signals with scintillators (NaI-32)
- Detection of solar axions through Bragg-scattering (COSME-2)
- Looking for WIMPs with a small natural Ge detector (COSME-2)
- Double Beta Decay of Ge-76 (IGEX-2 β)
- Direct search for WIMPs with an enriched Ge detector (IGEX-DM)
- Direct search for WIMPs with thermal detectors (ROSEBUD-I)
- Search for WIMPs with scintillating bolometers (ROSEBUD-II)
- Search for annual modulation of WIMP signals with large masses of NaI (ANAIS)

Double Beta Decay Searches at the Canfranc Underground Laboratory

DBD is an unique Laboratory to investigate:

Lepton number Symmetry

Neutrino vs. Antineutrinos

Are they equal (Majorana) or different (Dirac)?

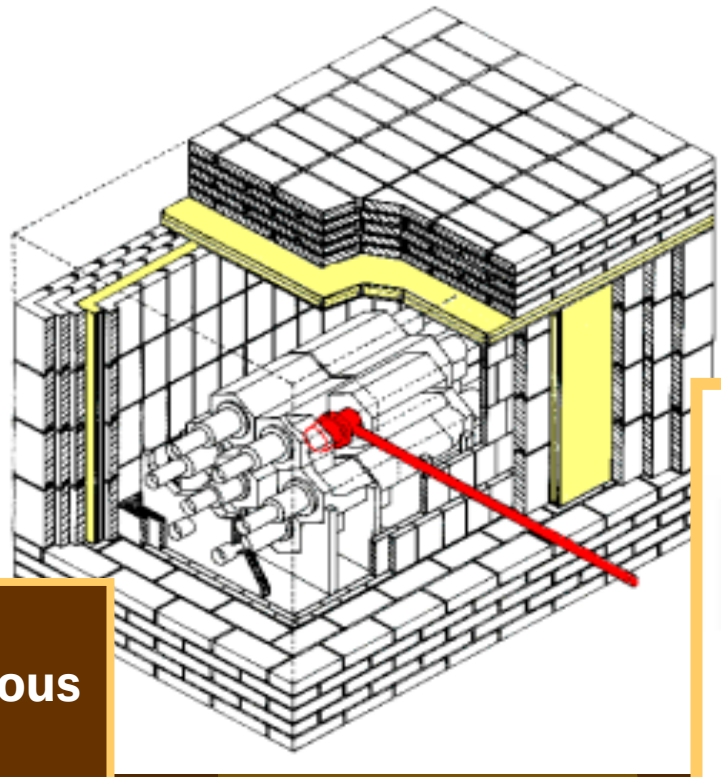
Massive Neutrinos / Neutrino mass scale

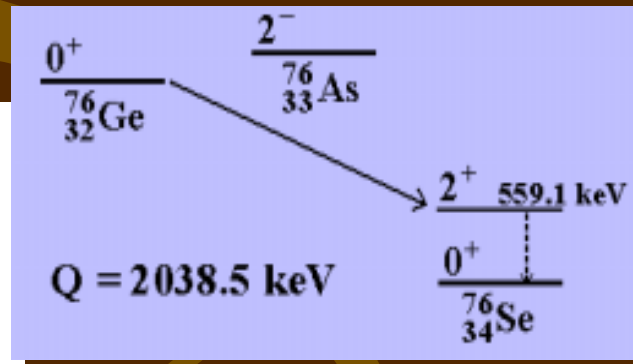
VIEWS ON A NEW LANDSCAPE IN PARTICLE PHYSICS

Nuclear 2Beta decay is a subject seventy year old, always in the front page, which is now in its most relevant period

2β/γ coincidence experiment

Decay of Ge76 to excited states





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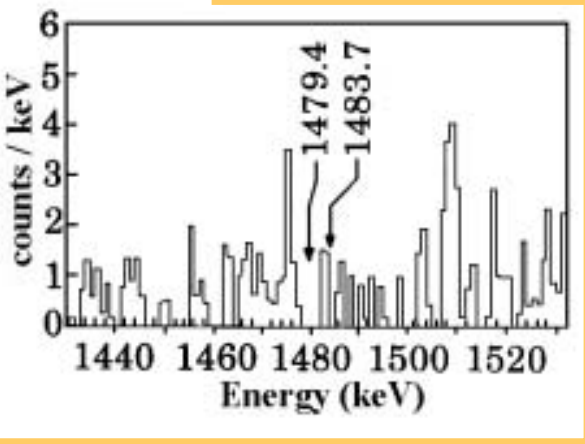
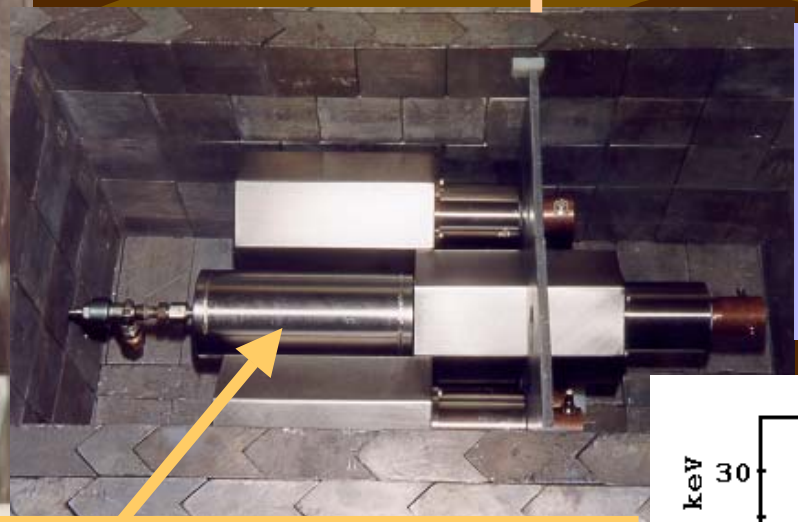


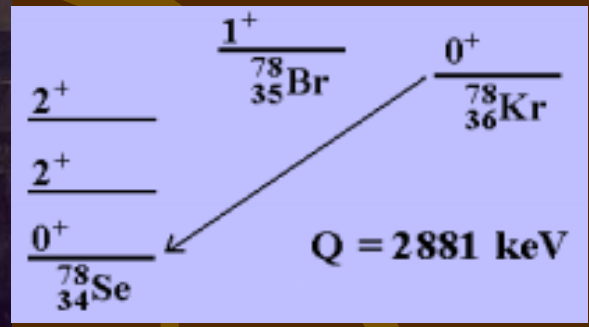
Ge coincidence spectrum (NaI window of 2.35σ around 559.1 keV)

Background 3 times better than the previous experiment at Frejus

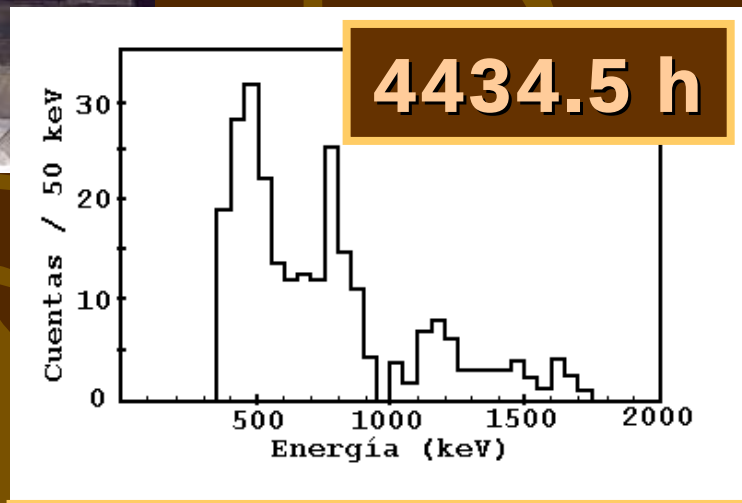
No accumulation of counts at 1483.7 keV. The former Frejus peak is not due to any 2β decay process (95% C.L.)

Krypton experiment
Double positron decay of Kr78





High pressure, high resolution chamber filled with Kripton gas enriched up to 94% in Kr78



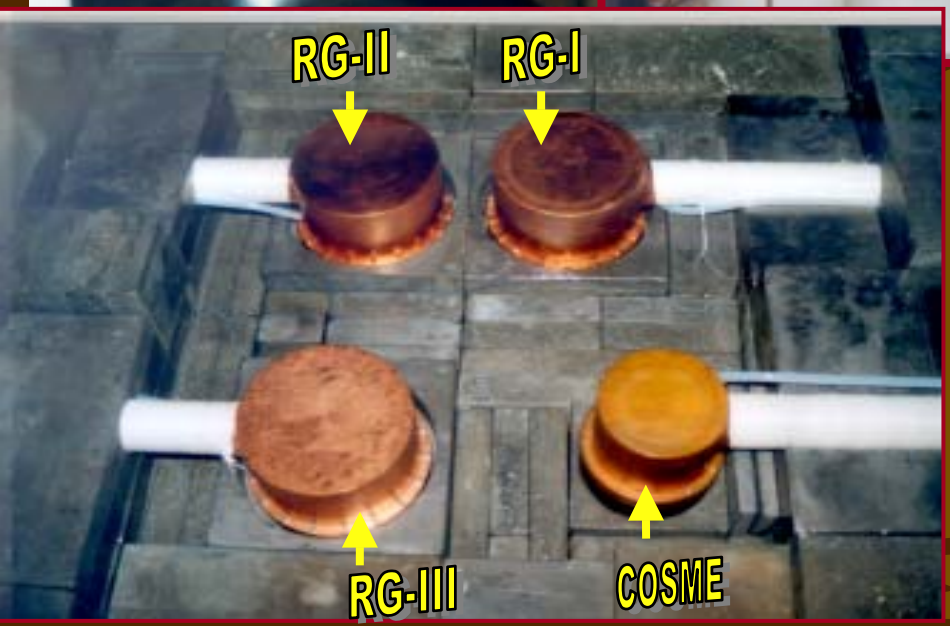
Coincidence spectrum between the IC signal and two 511 keV gammas in the scintillators (energy window of 2.35σ)

$T_{1/2}$ ($EC\beta^+$)0ν > 5.1×10^{21} y

$T_{1/2}$ ($EC\beta^+$)2ν > 1.1×10^{20} y

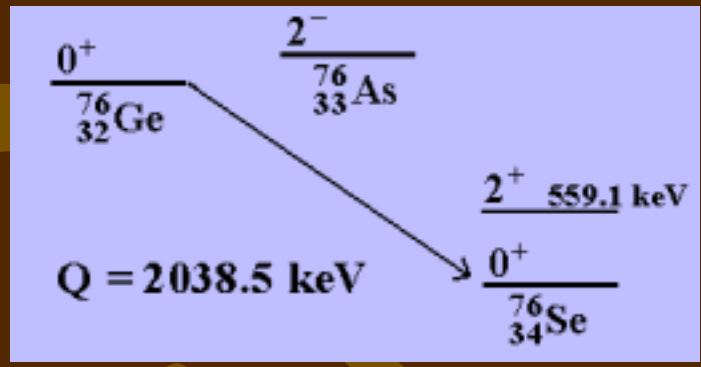
$T_{1/2}$ ($\beta^+\beta^+$)[2ν&0ν] > 1.1×10^{20} y

(68% C.L.)



IGEX-2β
Double beta decay of Ge76

The IGEX Experiment at Canfranc



Phase II

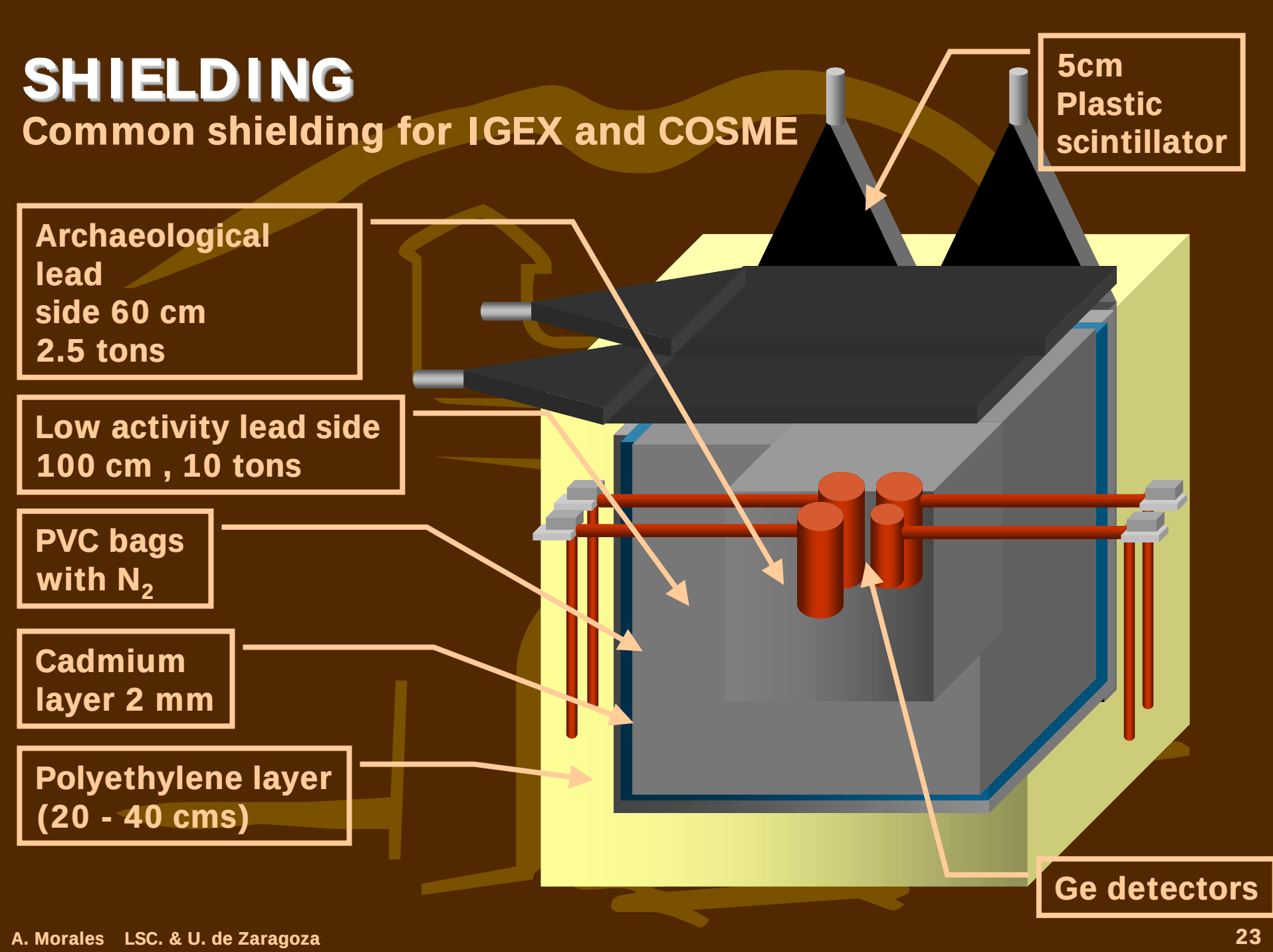
- 3 germanium detectors of 2 kg total mass each, enriched to 86 % in ^{76}Ge.
- Copper parts in the cryostat are produced by special techniques to eliminate Thorium and Radium impurities.
- Feedback resistor placed close to the crystal for low noise-capacitance effects, but separated by roman lead disk 2.5 cm thick.
- Rest of front-end electronics placed outside the shield.

Preamplifiers modified for Pulse Shape Discrimination.

Phys. Rev. C 59 (1999) 2108

SHIELDING

Common shielding for IGEX and COSME



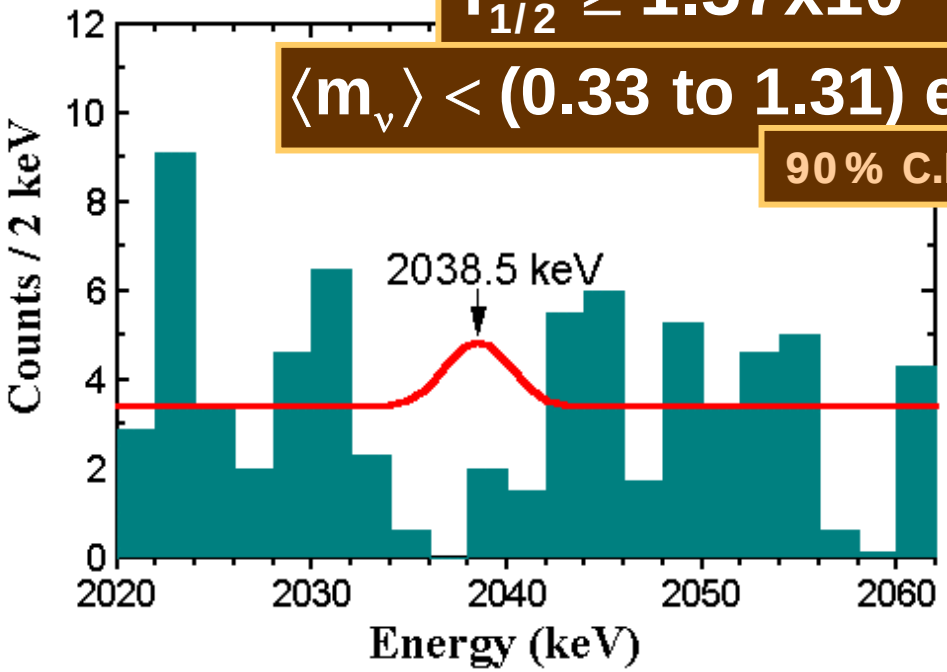
IGEX 2-β

116.75 mole-years (8.87 kg y of ^{76}Ge)

$T^{0\nu}_{1/2} \geq 1.57 \times 10^{25}$ y

$\langle m_\nu \rangle < (0.33 \text{ to } 1.31)$ eV

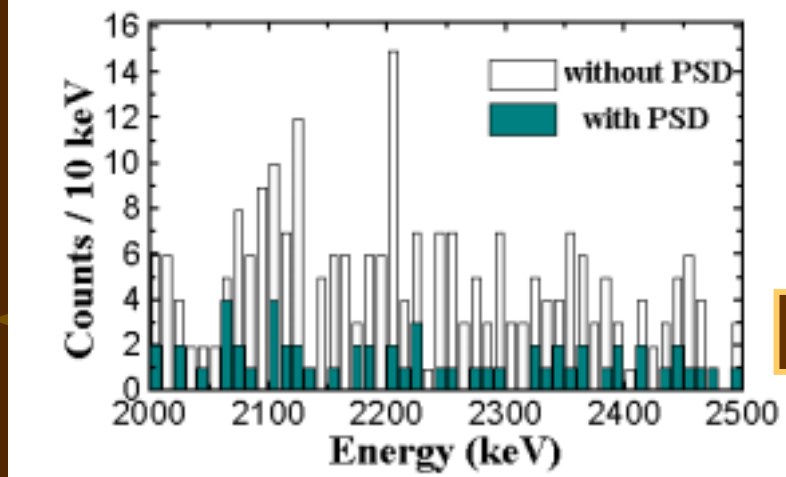
90 % C.L.



Two neutrino decay

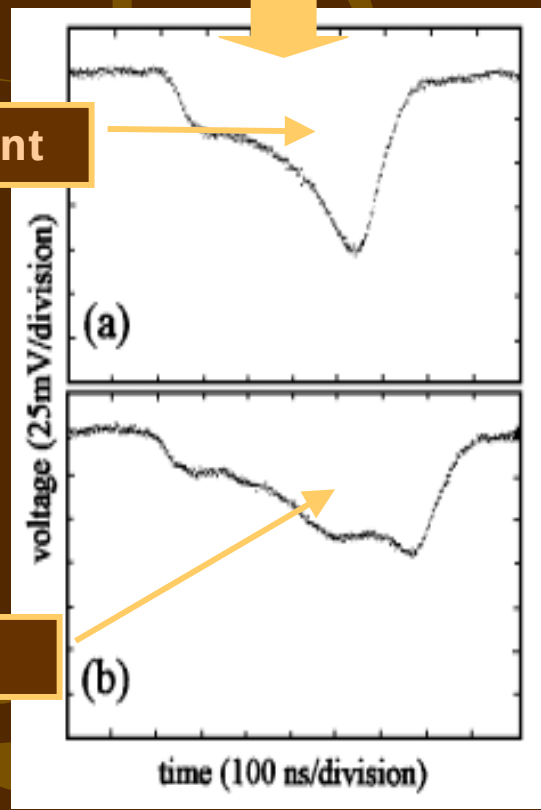
$T^{2\nu}_{1/2} = (1.5 \pm 0.2) \times 10^{21}$ y

Pulse Shape Discrimination



Single-site event

Multi-site event

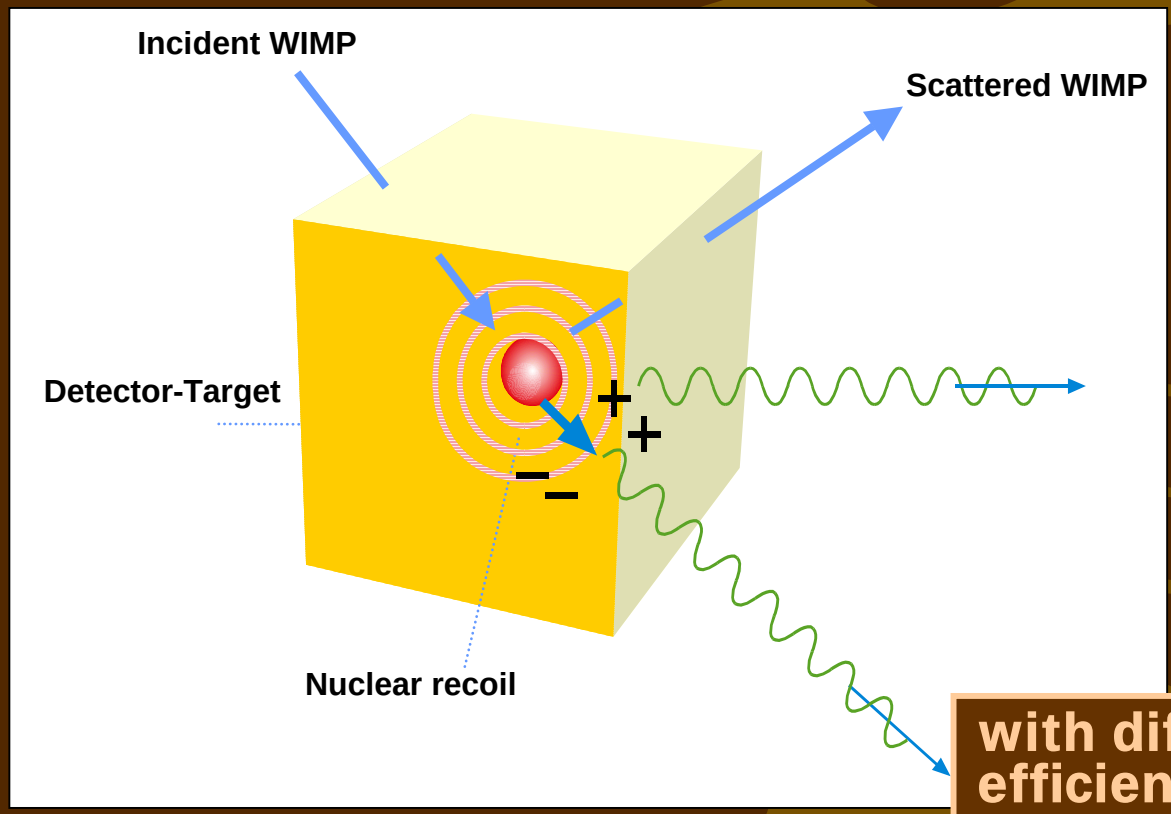


WIMP Direct Searches at the Canfranc Underground Laboratory

Objective:

To attempt the detection of the nuclear recoil produced by a WIMP scattering of a nuclear target

How to detect (directly) WIMP particles of the halo:



Energy deposit due to WIMP - Nucleus elastic scattering appears as

Heat

Ionization

Scintillation

with different degree of efficiency (Quenching factors).

The Canfranc Dark Matter Search Program measure the ionization, the scintillation, the heat, and the heat + light, according to various techniques and using several types of detectors

Ionization

IGEX-DM

Ge

U. Zaragoza / South Carolina / PNNL / INR / ITEP Collaboration

Scintillation

ANAIS

NaI

U. Zaragoza

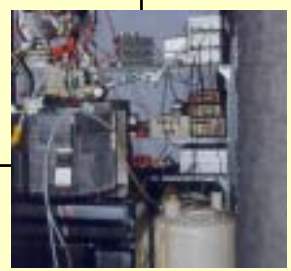
CANFRANC EXPERIMENTS
WIMP
detection techniques

Heat

ROSEBUD-I

Al_2O_3
Ge
$CaWO_4$

U. Zaragoza / IAS Orsay Collaboration



Heat + Light

ROSEBUD-II

$CaWO_4$
BGO

U. Zaragoza / IAS Orsay Collaboration

Methods

1. Comparison of expected signal rate with recorded (raw) background:

- Derivation of exclusion plots $\sigma^p(m)$:

  -Particle Dark Matter candidates interacting coherently with target nuclei, with nucleon cross-section σ^p (for mass m) which give rates above the recorded (background) rate are excluded.

  IGEX-DM (Ge), ROSEBUD-I (Al_2O_3, $CaWO_4$), ANAIS (NaI).

2. Looking for distinctive signals

- Annual modulation of the WIMP signal

  a)NaI-32 (Completed)

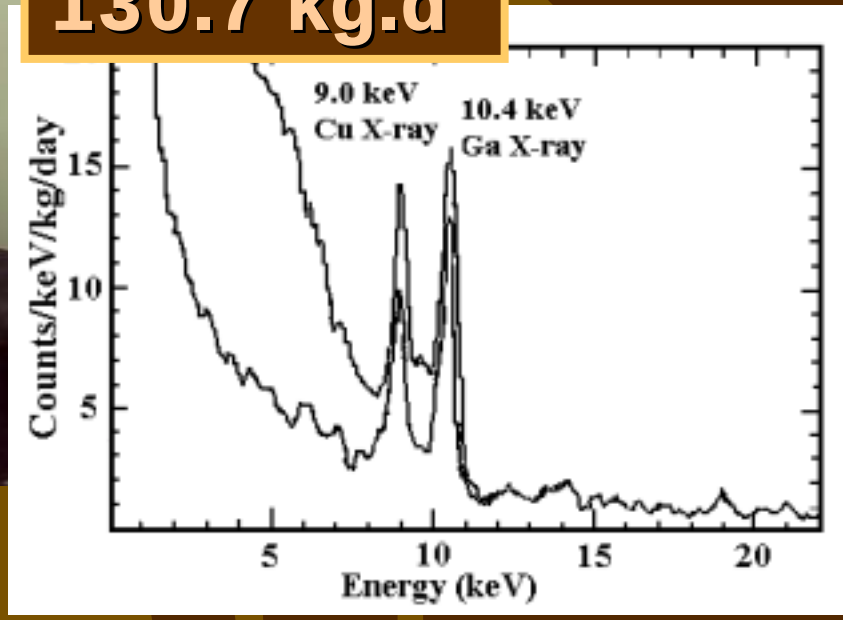
  b)ANAIS (Annual Modulation Search with NaIs). Prototype tested. Set of 10 detectors (107 kg of NaI) being mounted.

- Recoil rate dependence on the nuclear target (nuclear mass A and spin J). Explored with cryogenic detectors.
ROSEBUD, (Rare Objects SEarch with Bolometers UndergrounD) (Al_2O_3, Ge, $CaWO_4$, BGO).

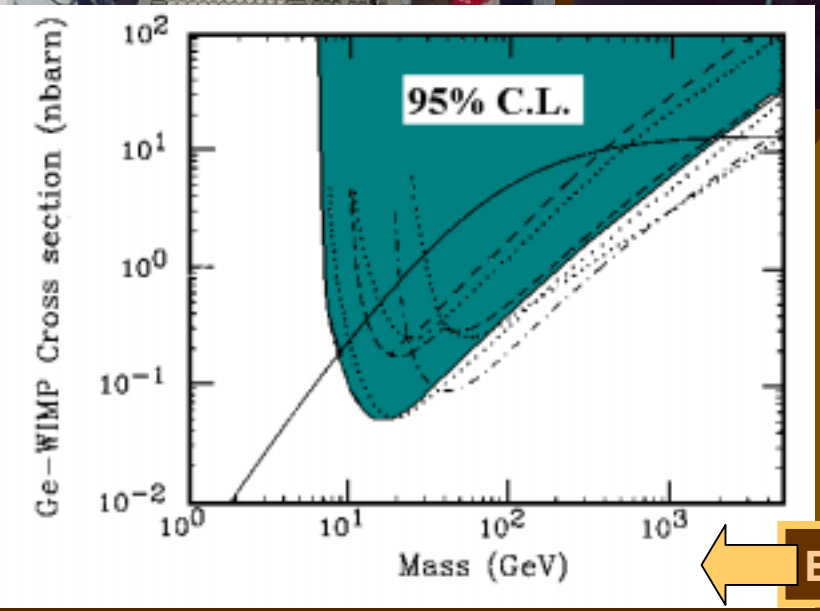
Looking for WIMPs of low mass

COSME-1

130.7 kg.d



COSME spectrum (with and without filtering microphonics & electronic noise)

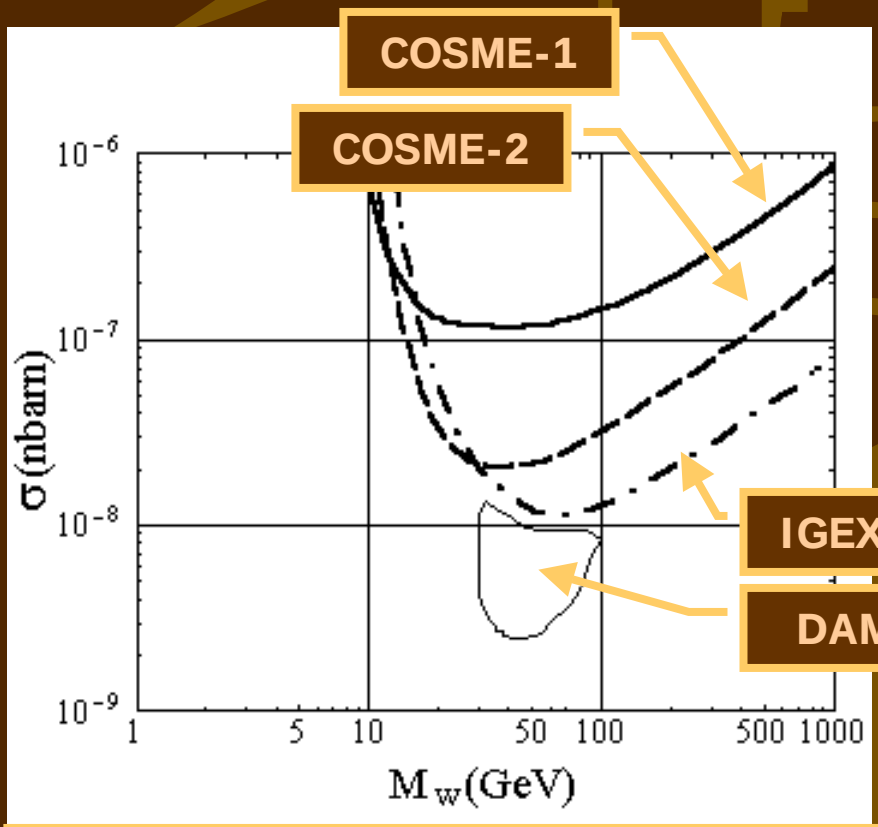


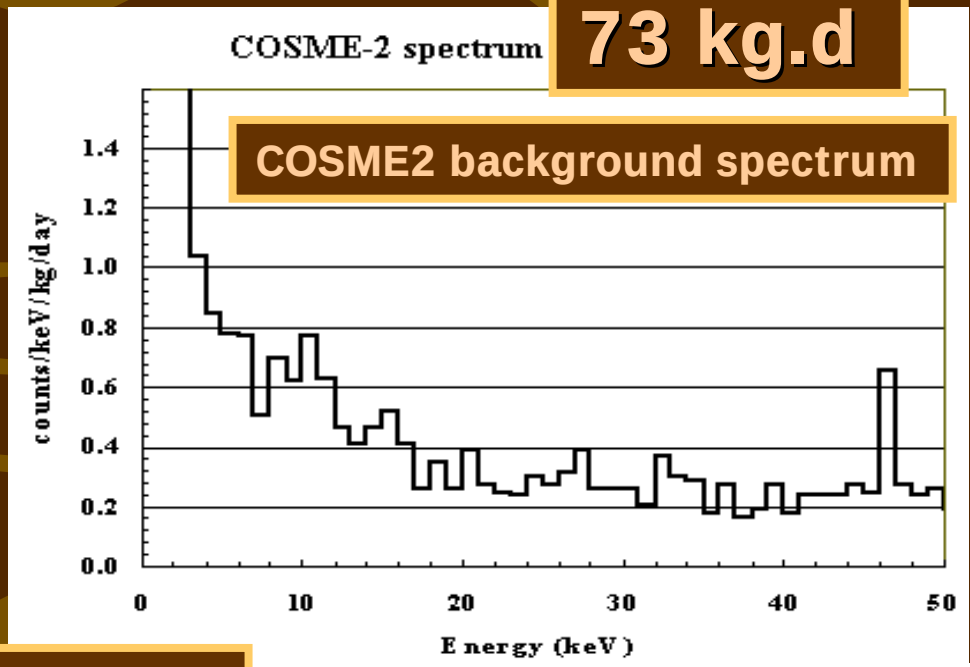
Exclusion plot for spin independent interactions

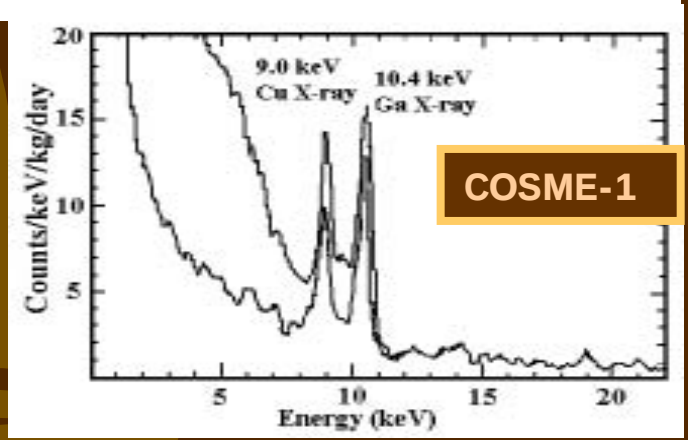
COSME 2

Looking for WIMPs with a small natural Ge detector

73 kg.d







Exclusion plots for spin dependent interactions

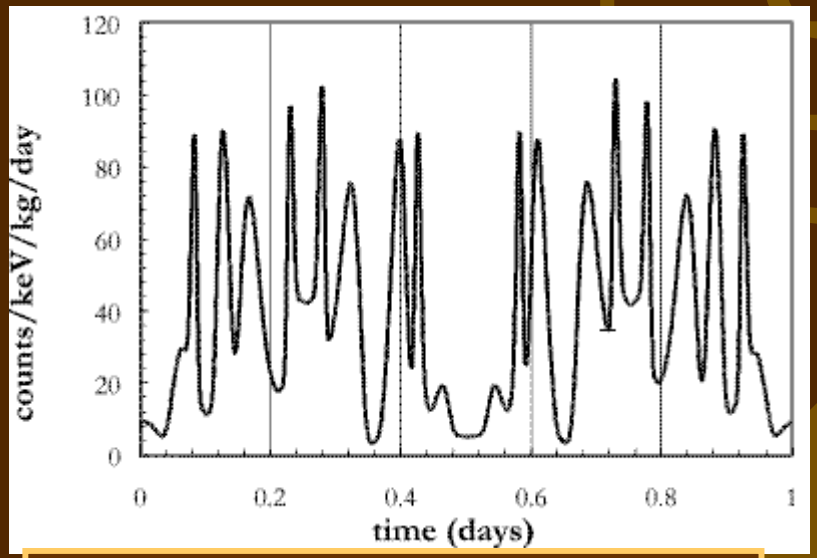
COSME 2

Detection of solar axions through Bragg-scattering

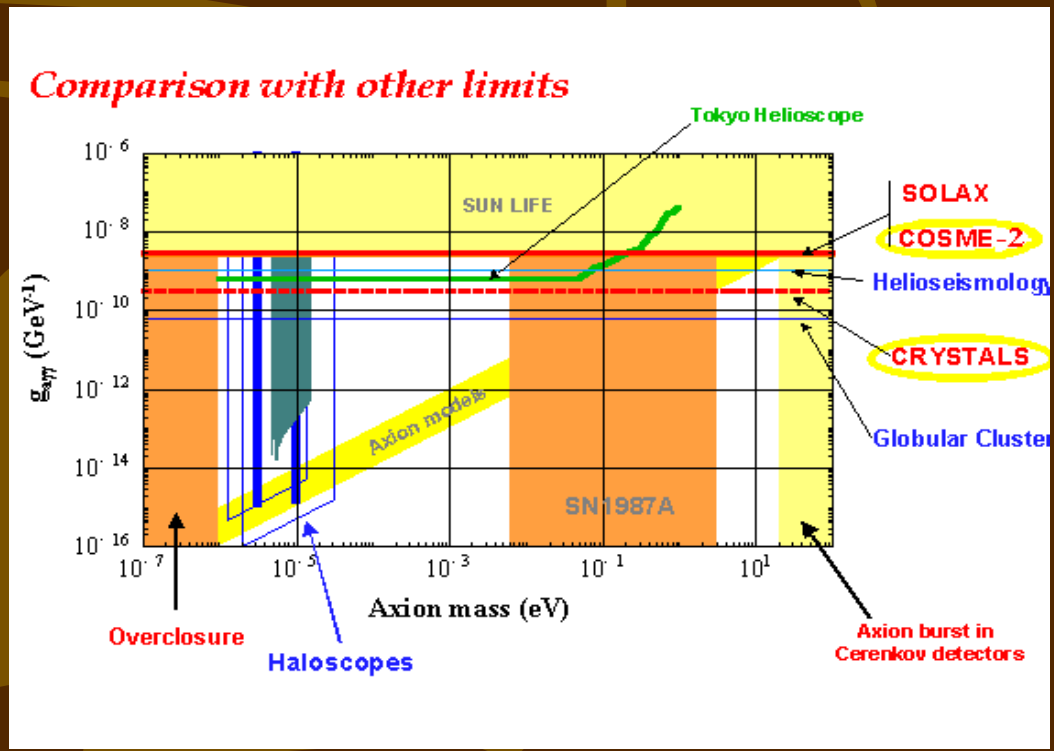
Primakoff conversion inside the crystal electric field

$$g_{a\gamma\gamma} < 2.8 \times 10^{-9}\ GeV^{-1}$$

At 95% C.L.



typical example of the temporal pattern expected along one day

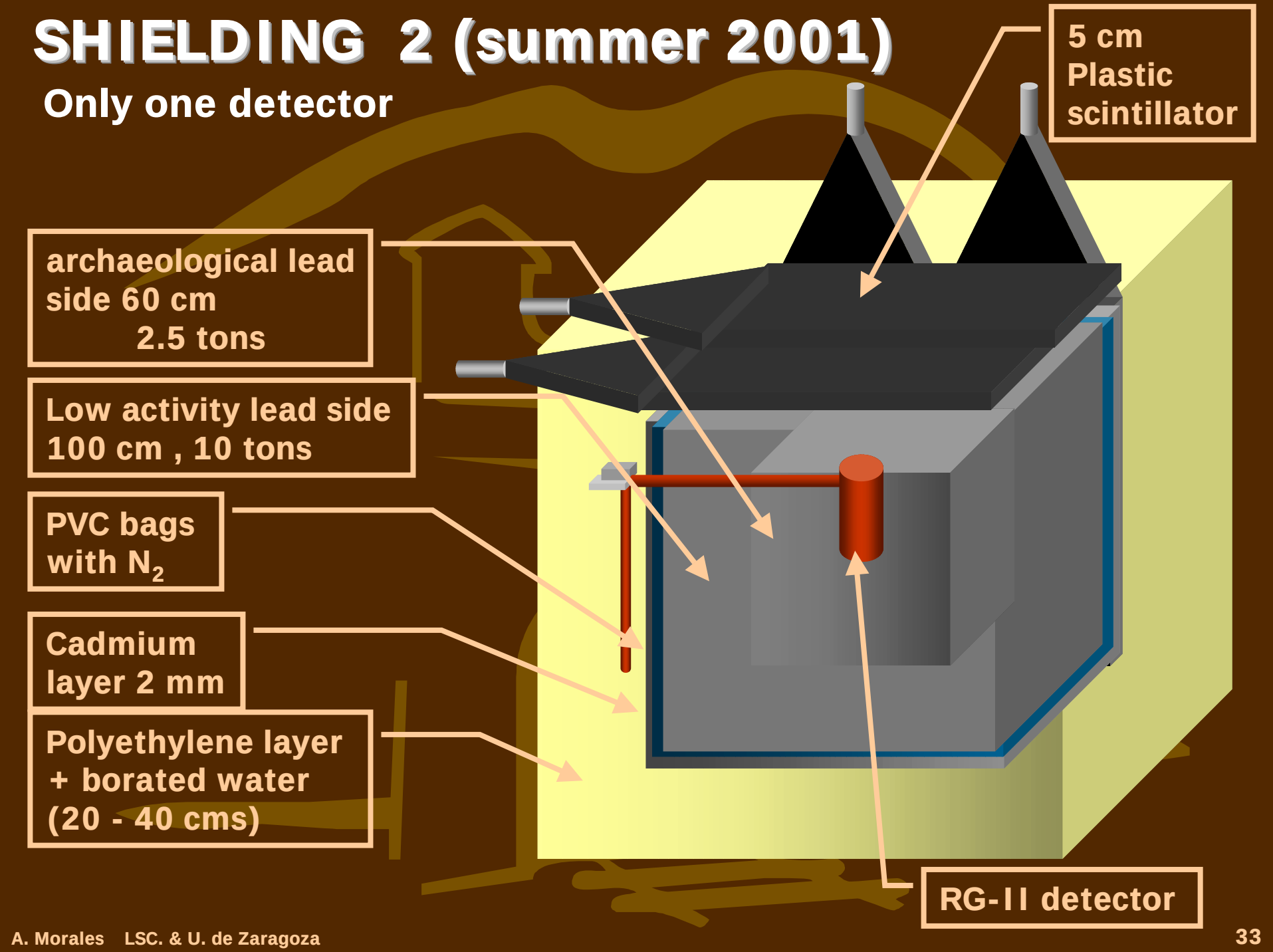


IGEX-DM

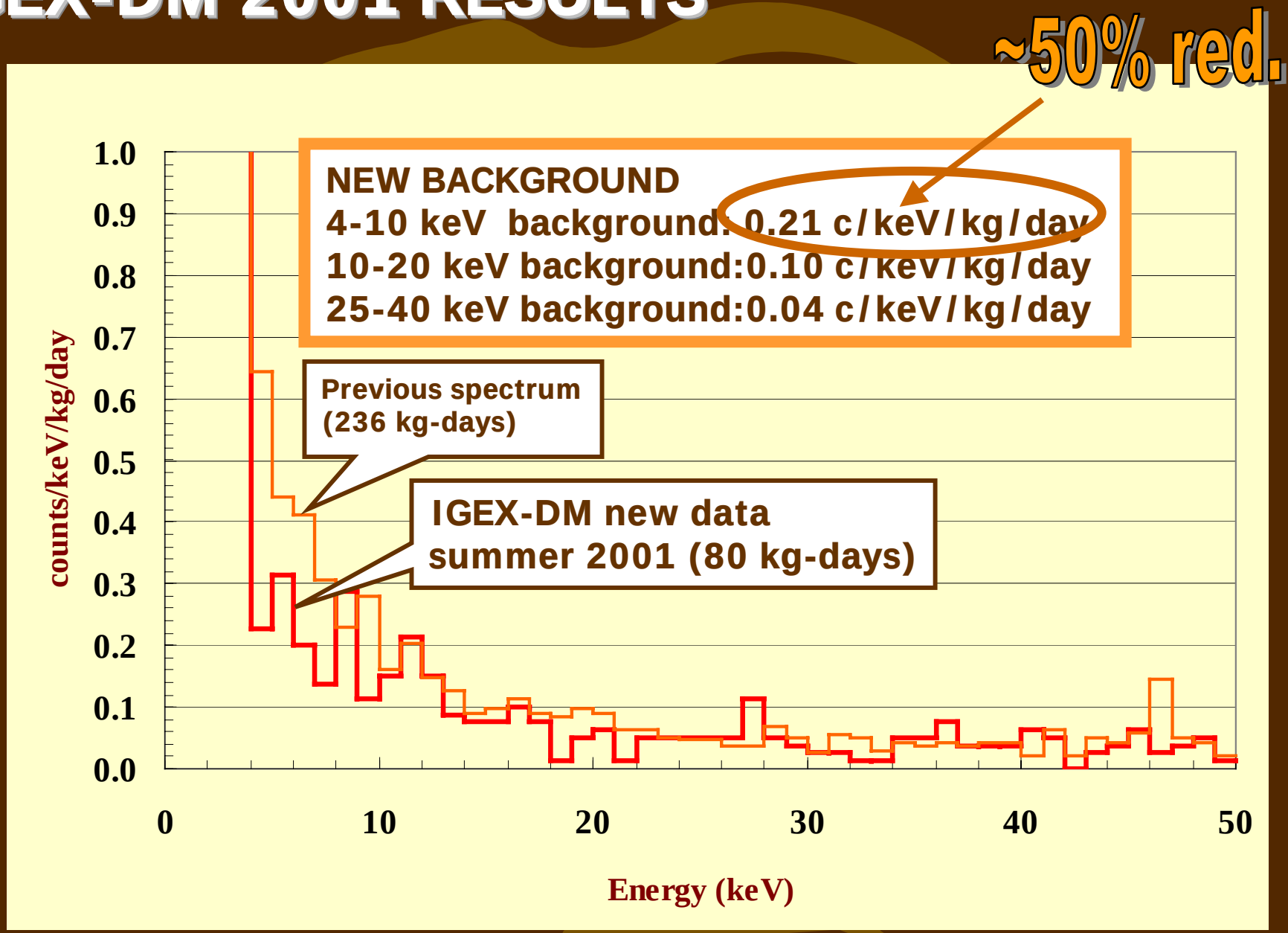
Direct search for WIMPs with an enriched Ge detector

SHIELDING 2 (summer 2001)

Only one detector

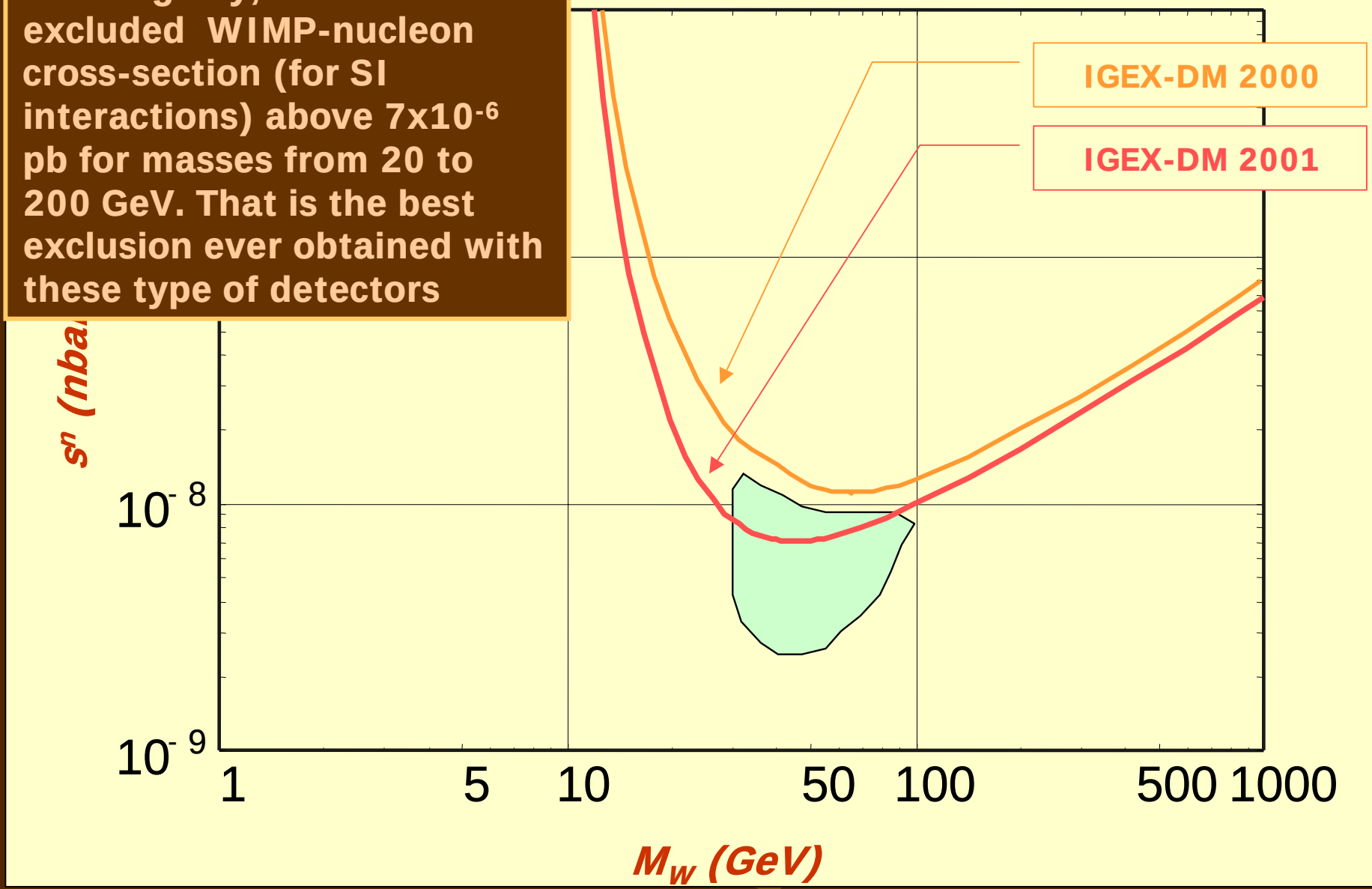


IGEX-DM 2001 RESULTS



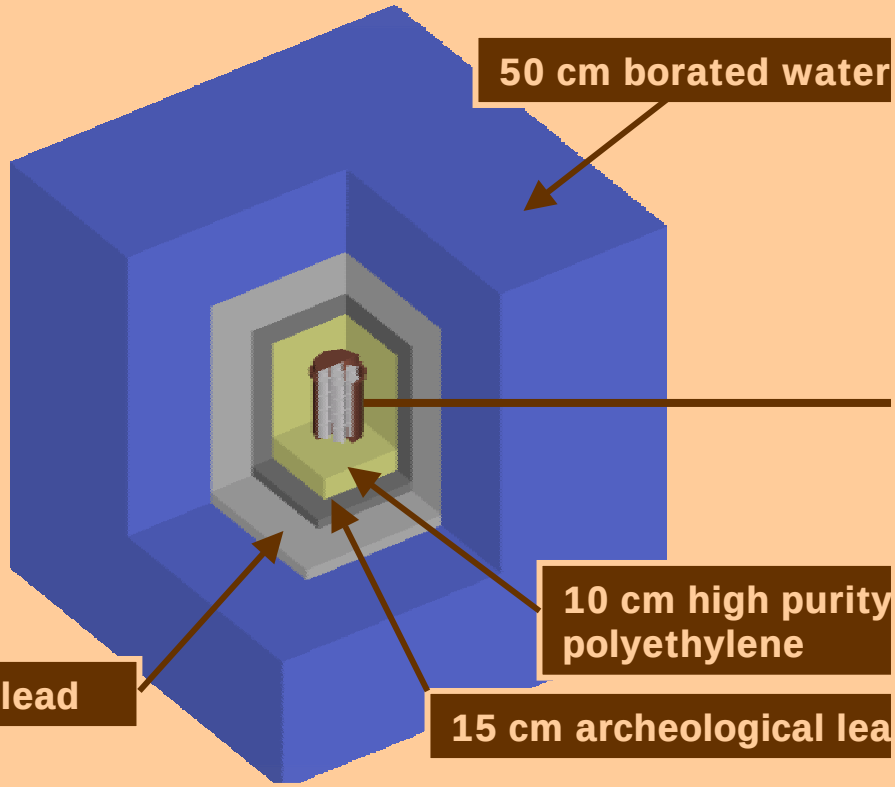
IGEX-DM 2001 EXCLUSION

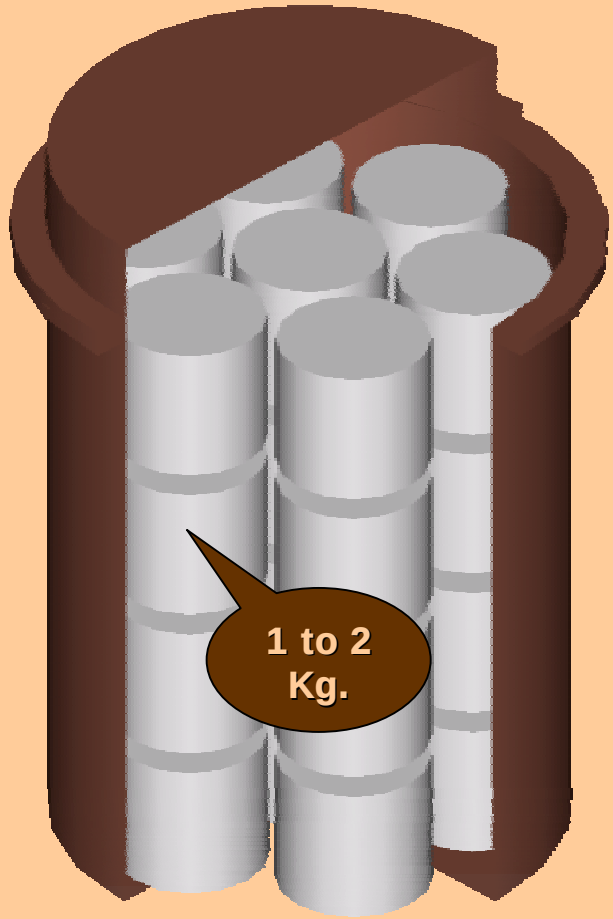
In 80 kg day, IGEX-DM has excluded WIMP-nucleon cross-section (for SI interactions) above 7×10^{-6} pb for masses from 20 to 200 GeV. That is the best exclusion ever obtained with these type of detectors



GEDEON

- ✓ Set of Germanium crystals in one cryostat
- ✓ IGEX Technology
- ✓ 30 Kg total mass in 1st stage. 60 Kg 2nd stage
- ✓ Background of 2 - 5 x 10^{-3} c/keV.Kg.day is expected
- ✓ Annual modulation can be searched (Astrop. Phys. 14, 33





- ✓ *EASY*
- ✓ *LOW-COST*
- ✓ *NO TECHNOLOGICAL CHALLENGE*

PROSPECTS OF THE CANFRANC DARK MATTER SEARCHES WITH GERMANIUM

IGEX-DM

Provided low E events are rejected

E (thr) = 4 keV

Flat 0,04 c/keV.Kg.d

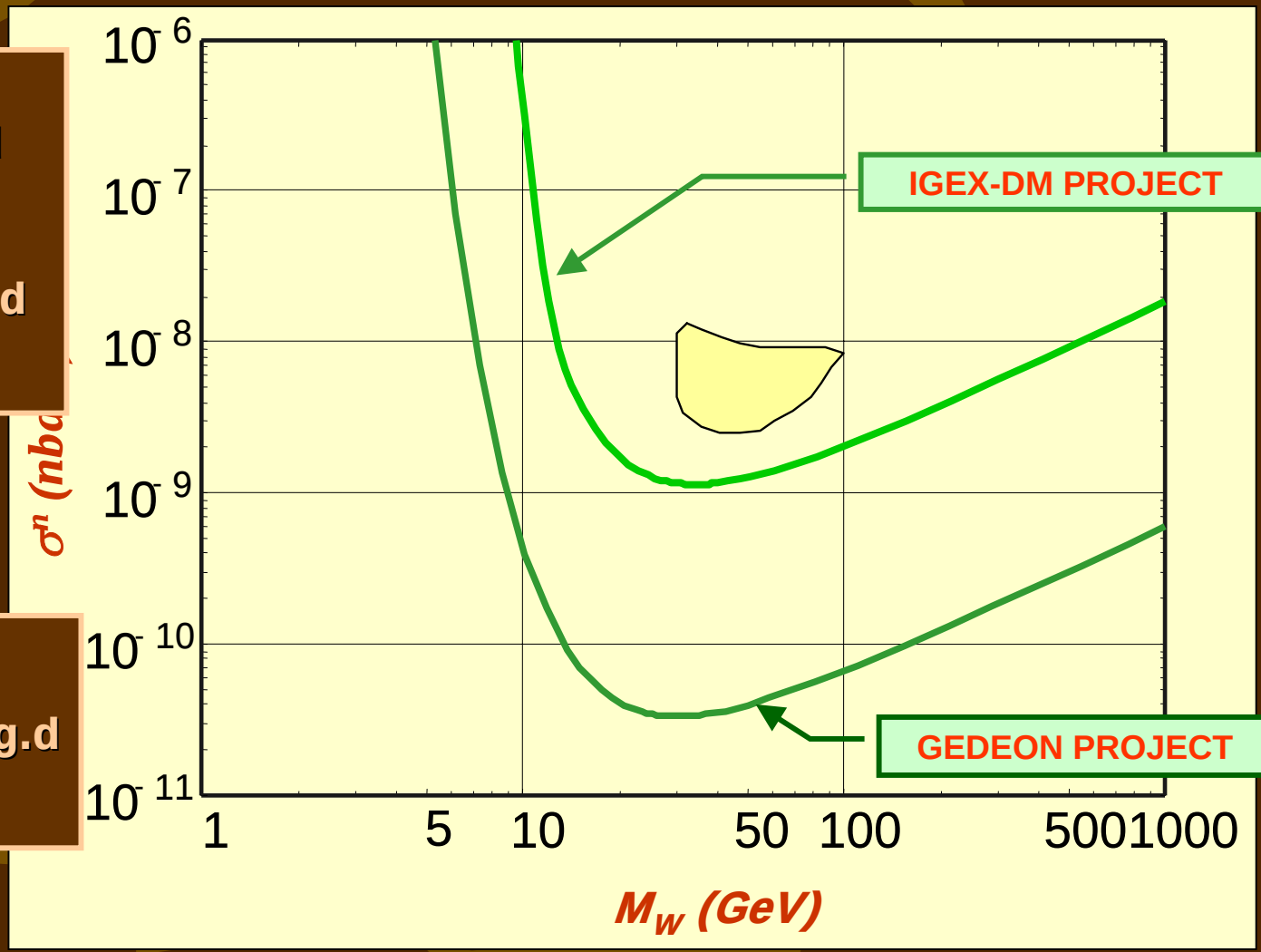
MT = 1 Kg.y

GEDEON

E (thr) = 4 keV

Flat 0,0O2 c/keV.Kg.d

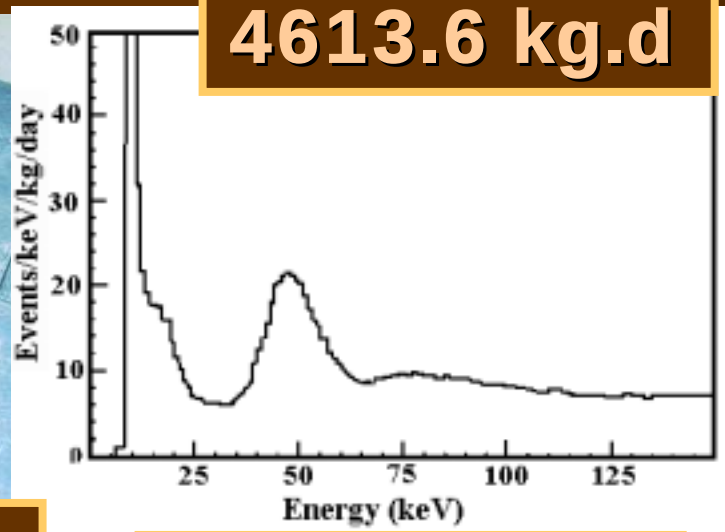
MT = 24 Kg.y



Search for annual modulation of WIMPs signals with scintillators

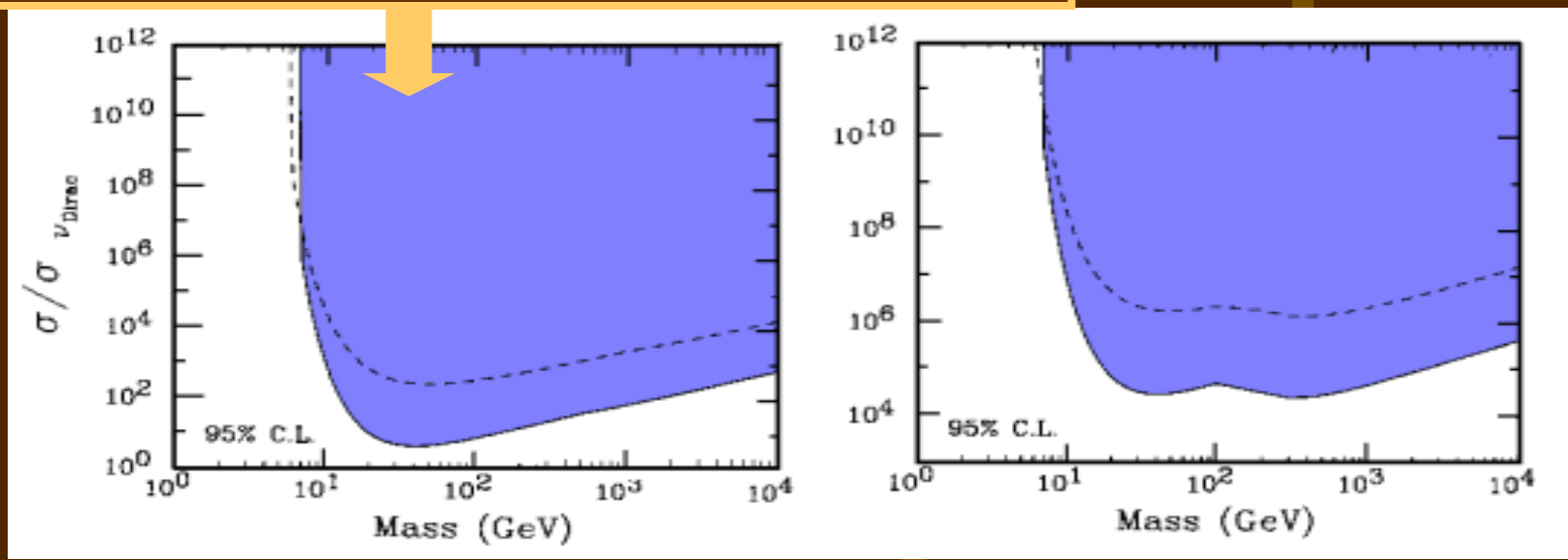
NaI-32

4613.6 kg.d

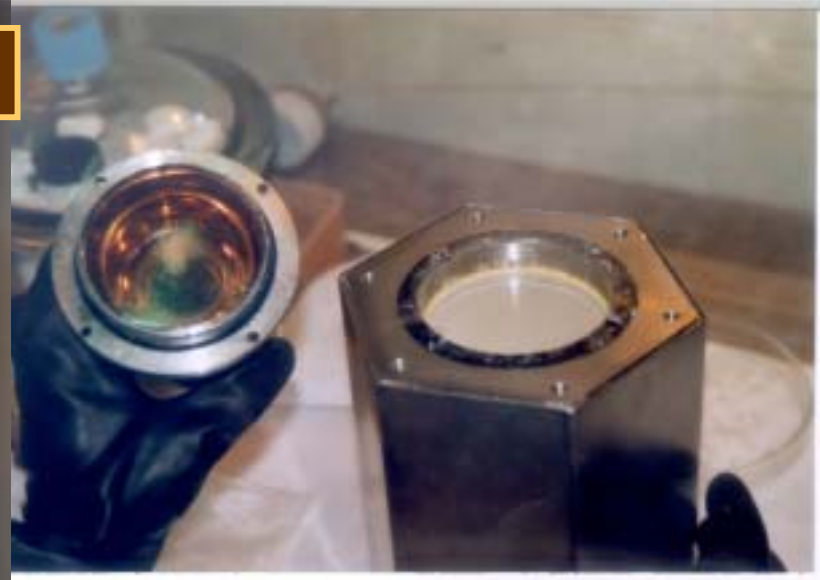


Background spectrum

Exclusion plots for coherent and spin dependent interactions in units of the Dirac neutrino c. s.



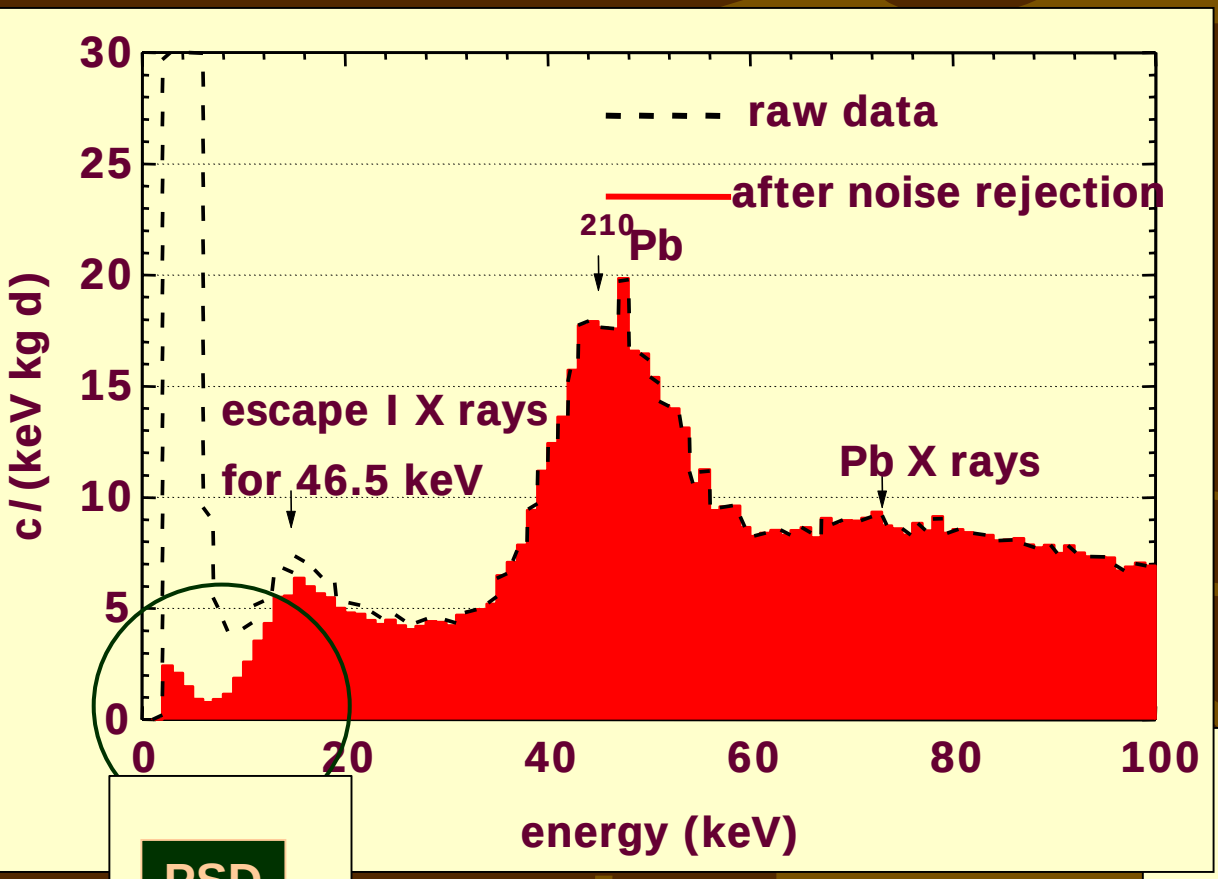
Experimental set-up of the prototype



ANAIS

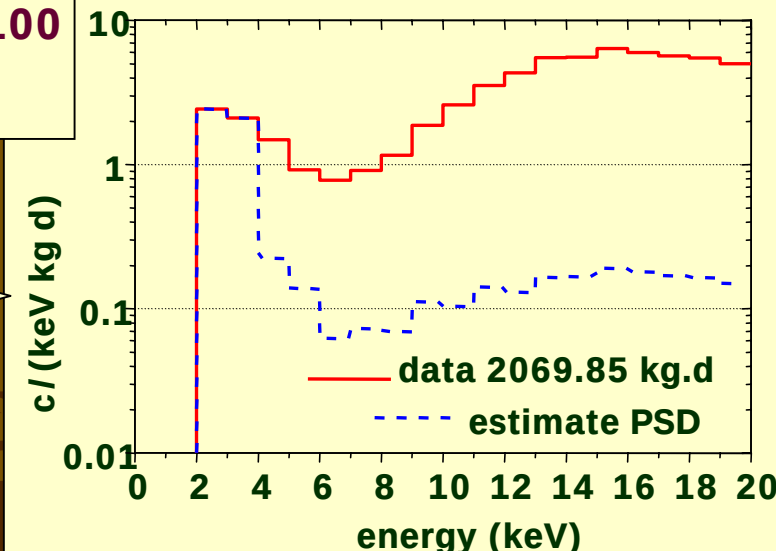
Search for annual modulation of WIMP signals with large masses of NaI

First results in 2069.85 kg.d



PSD

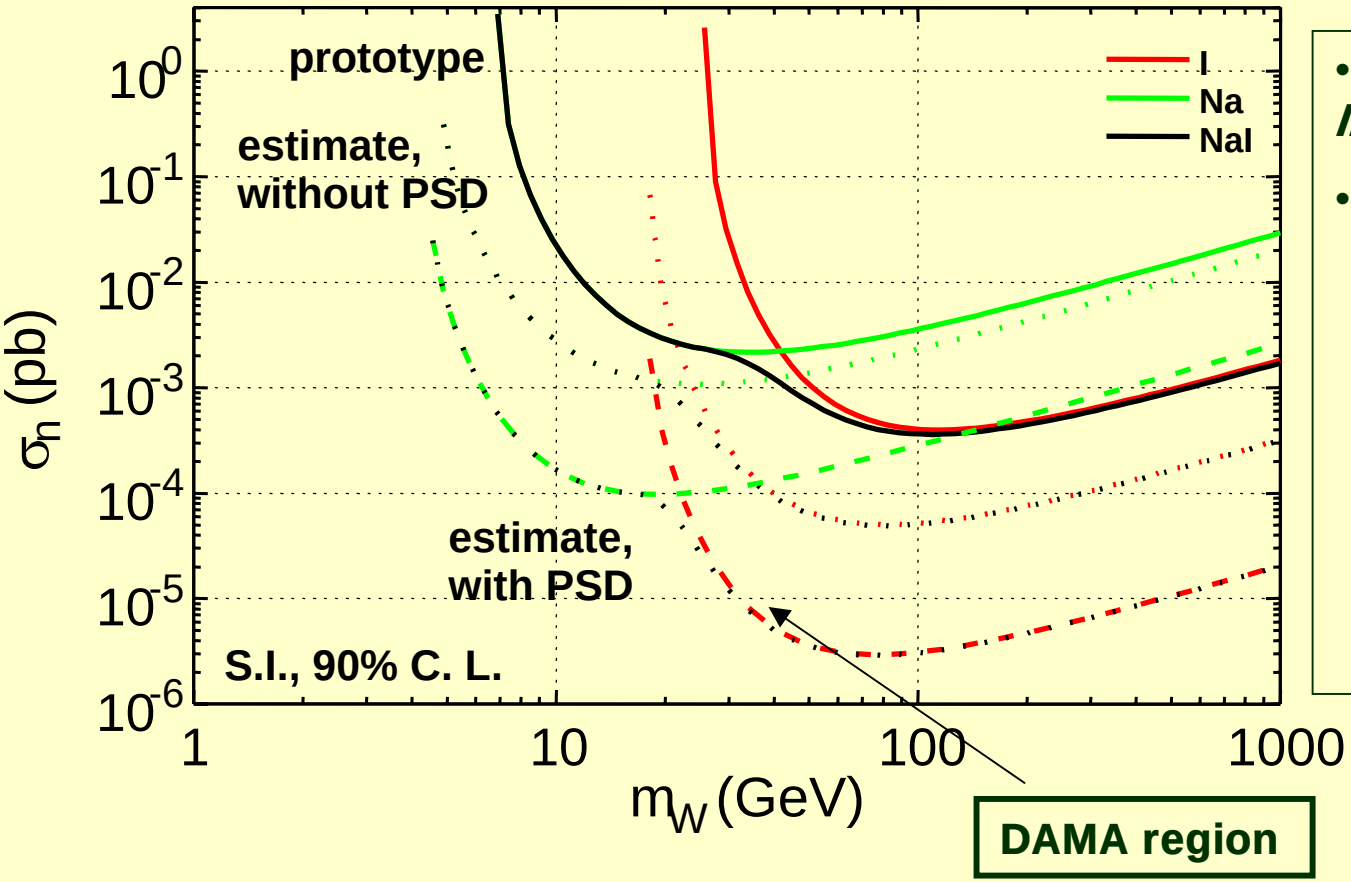
- Threshold:
  ~4 keV
- Bkg:
  1.2 c/(keV.kg.d)
  in 4-10 keV



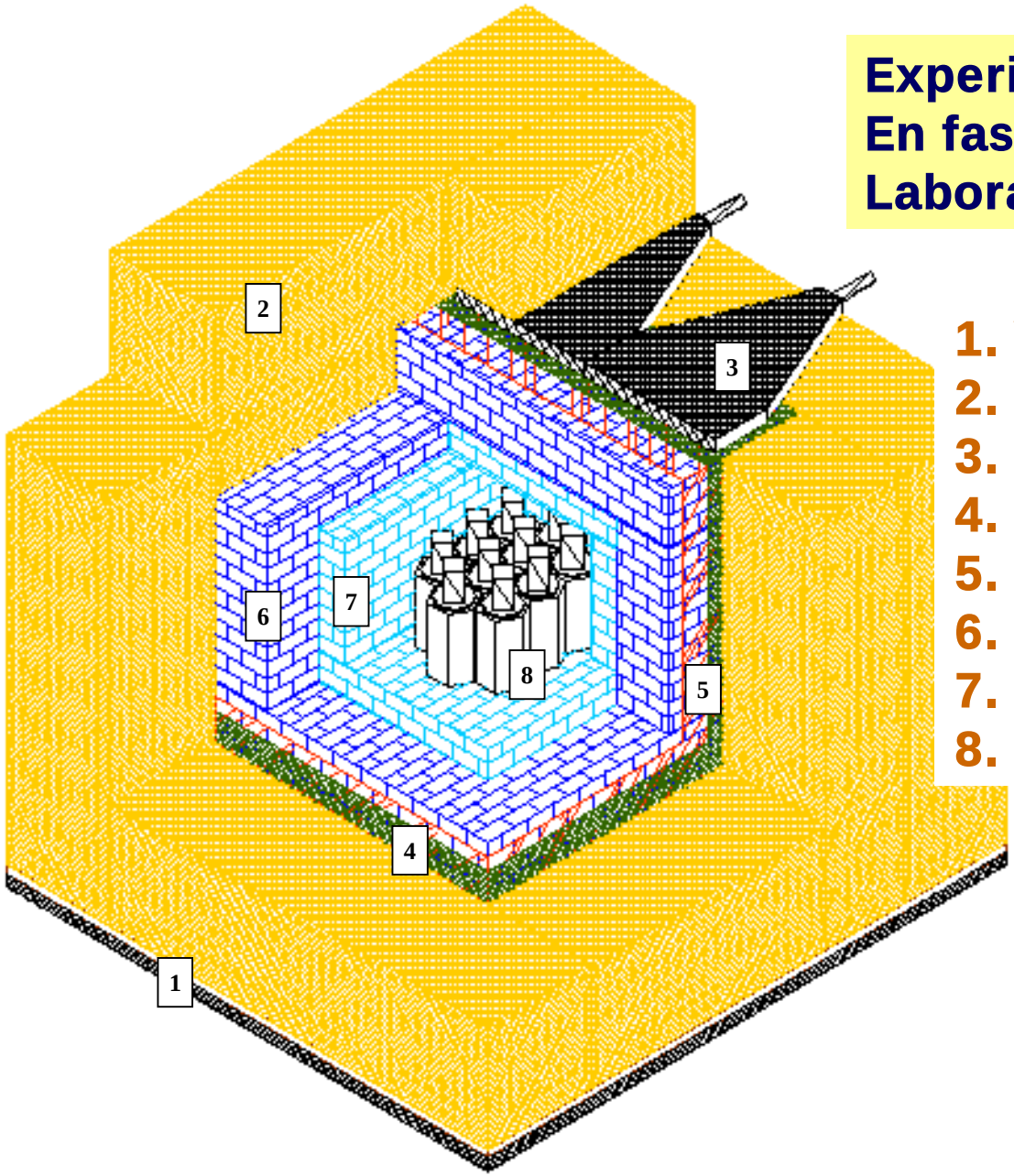
A. Morales LSC. & U. de Zaragoza

Exclusion plots for WIMPs s(mw)

Scalar Interactions SI



- Prototype *(solid line)*
- Estimate:
  - 1 c/(keV kg d) in 2-8 keV
  - 107 kg x y
  - without PSD (*dotted*)
  - with PSD (*dashed*)



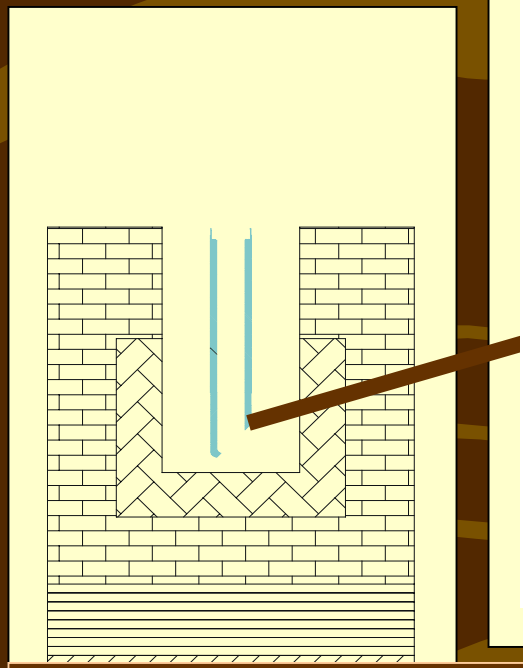
Experimento ANAIS
En fase de montaje
Laboratorio 3 (2450 m.w.e.)

1. Vibration insulator
2. 40 cm neutron shielding
3. 2 x 0.5 m2 veto
4. 2 mm Cd
5. PVC box
6. 20 cm lead
7. 10 cm roman lead
8. 10 x 10.7 Kg NaI

ROSEBUD

Rare Objects SEarch with Bolometers UndergrounD

FARADAY CAGE



EXTERNAL SHIELDING

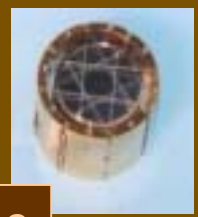
Bol 278
54g $CaWO_4$

Bol 276
Ge (IR)

Roman lead

Bol 265
67g Ge

Bol 213
50g Al_2O_3



Ge

$CaWO_4$

Search for WIMPs with thermal and scintillating detectors

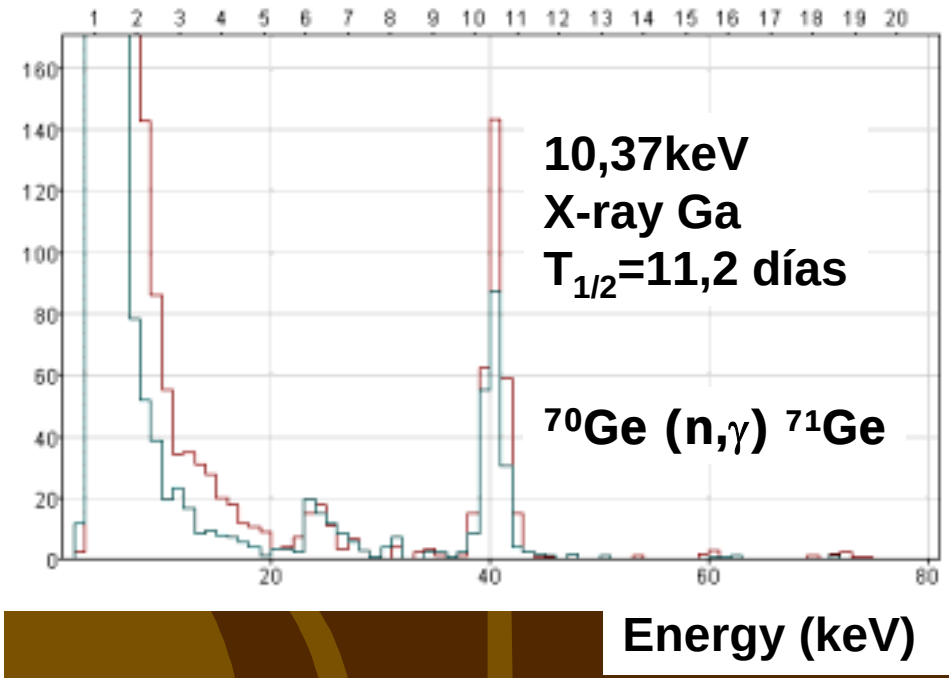
ROSEBUD Best Results 2000 in Canfranc

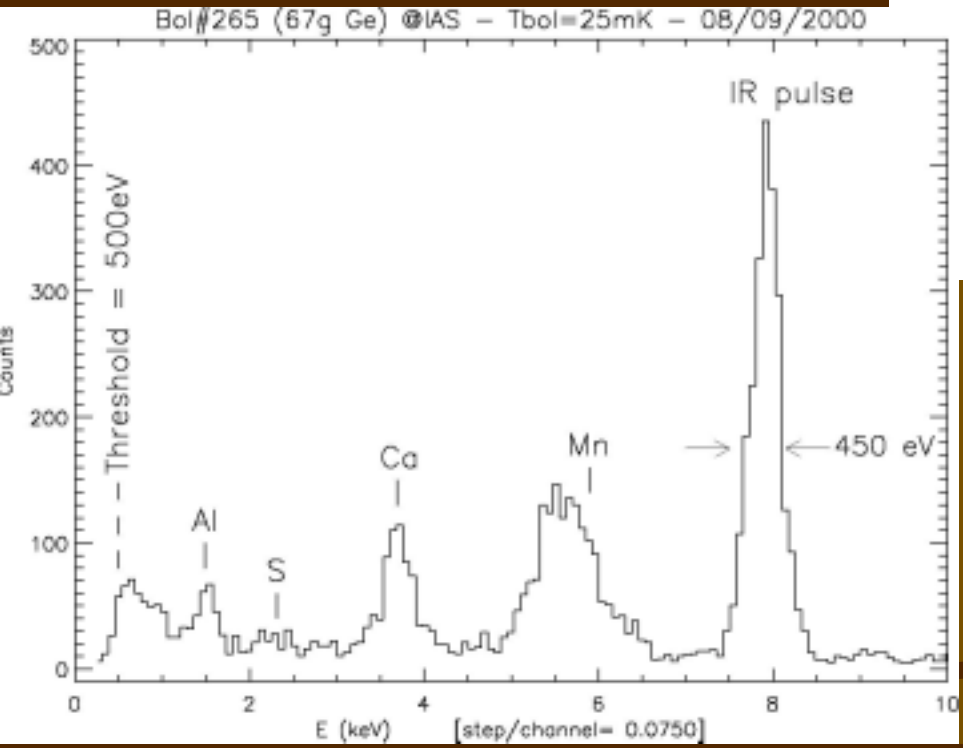
420 eV threshold in 67g Ge

1 keV threshold in 50g Al_2O_3

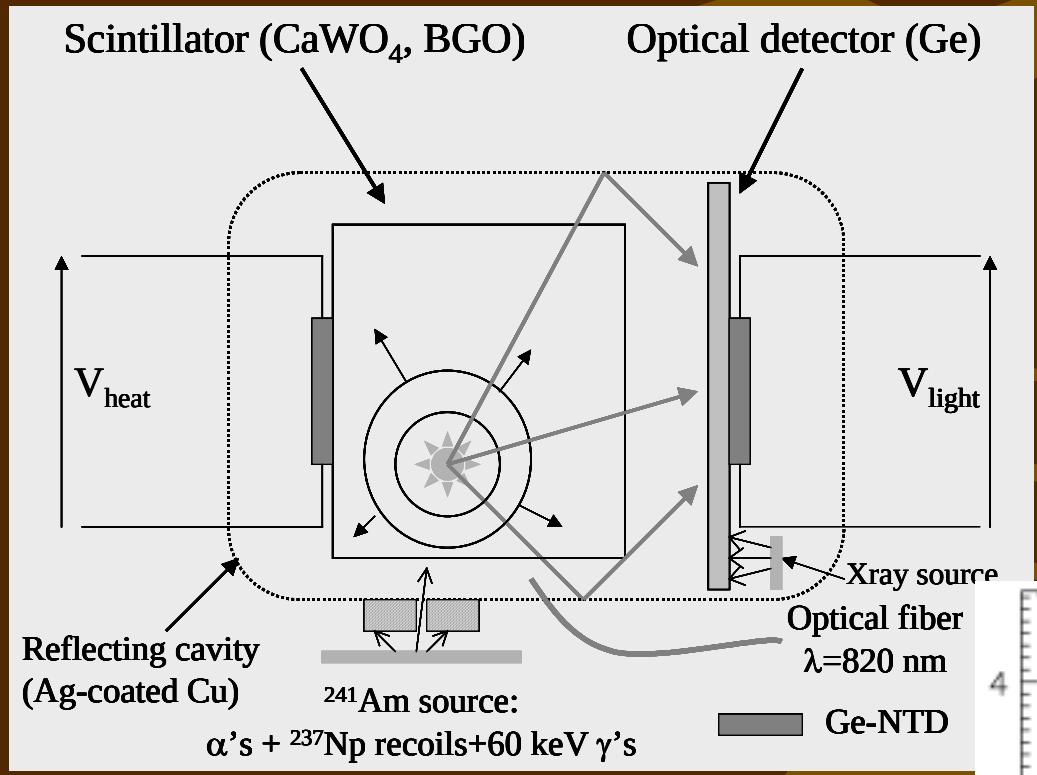
5 evts/keV/kg/day at 100 keV

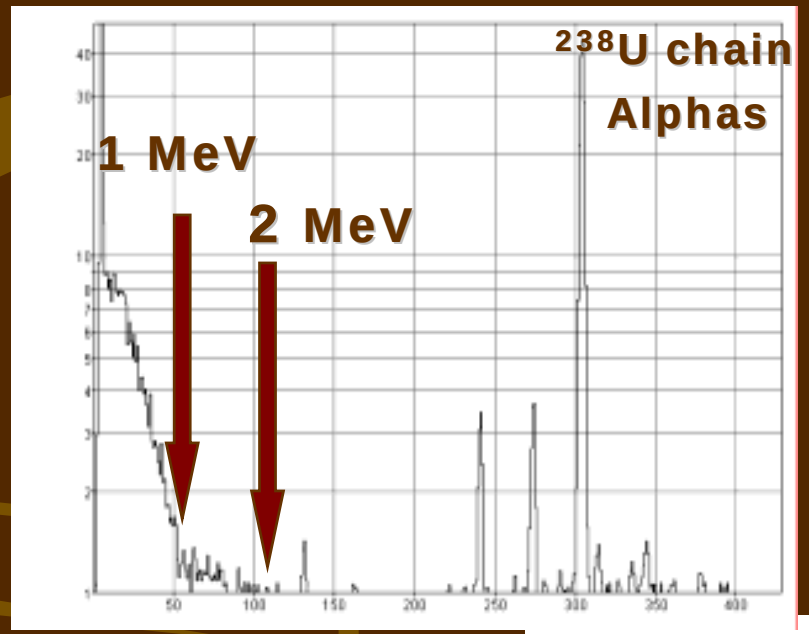
LOW ENERGY GE SPECTRUM





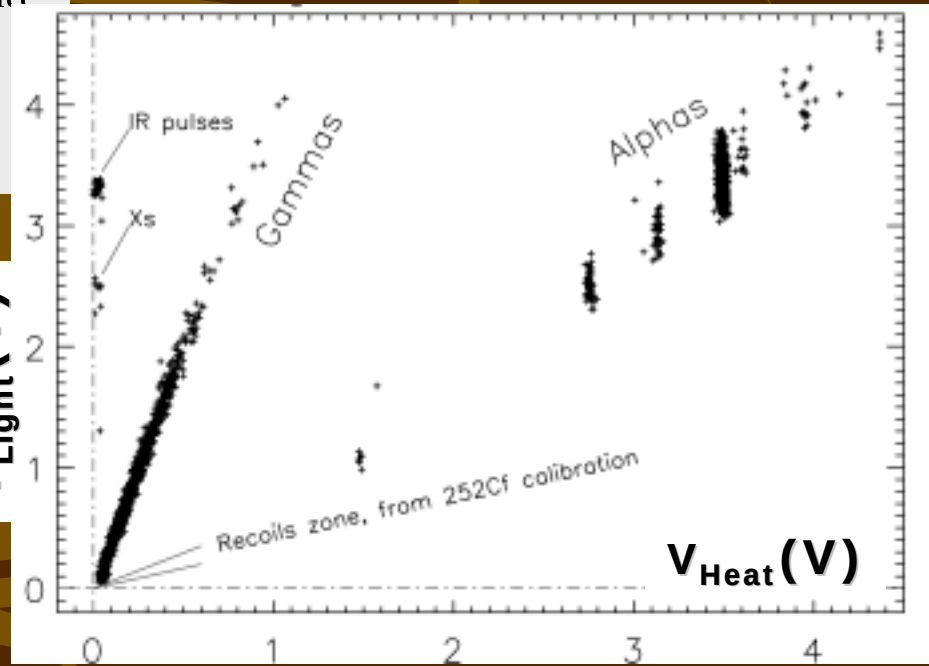
Light / Heat discrimination





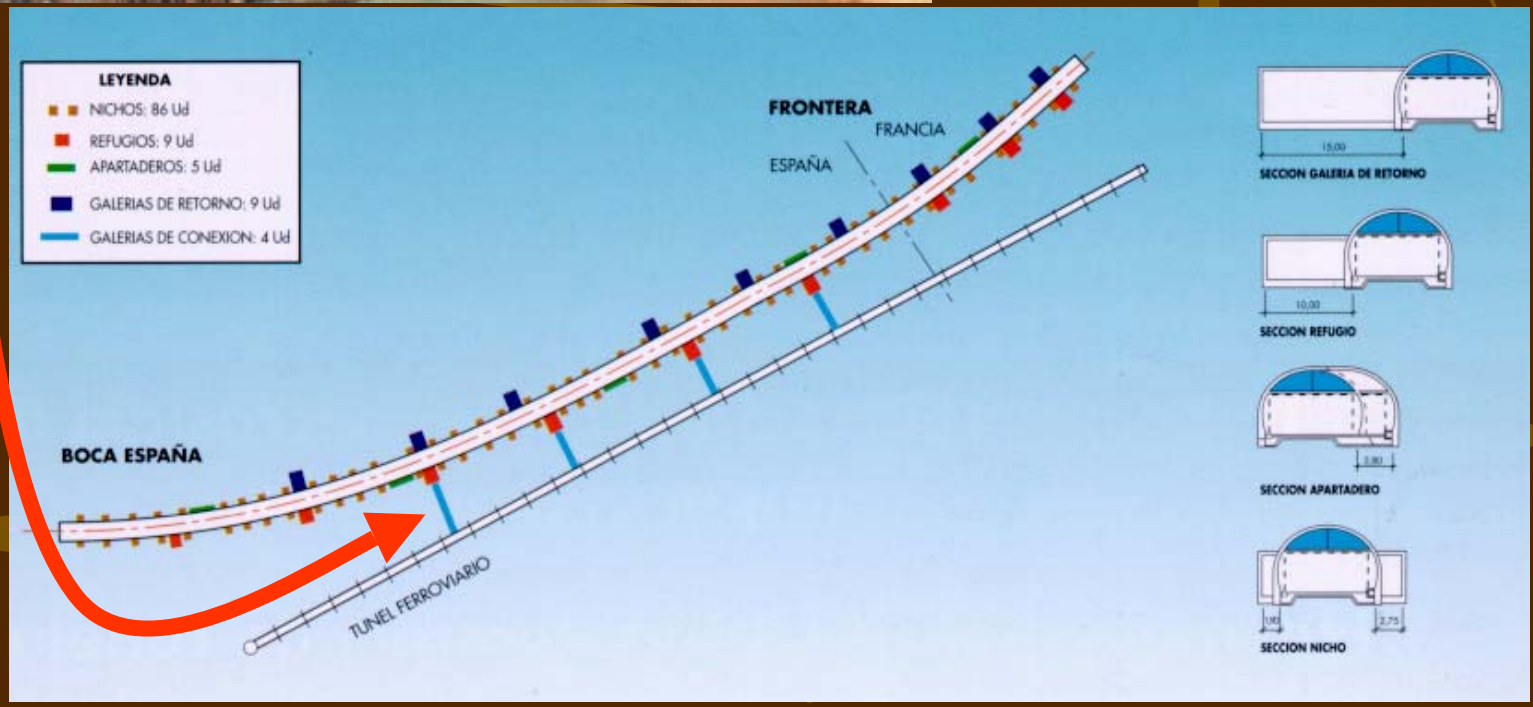
54g $CaWO_4$ 45 keV thr.
46g BGO 6,5 keV thr.

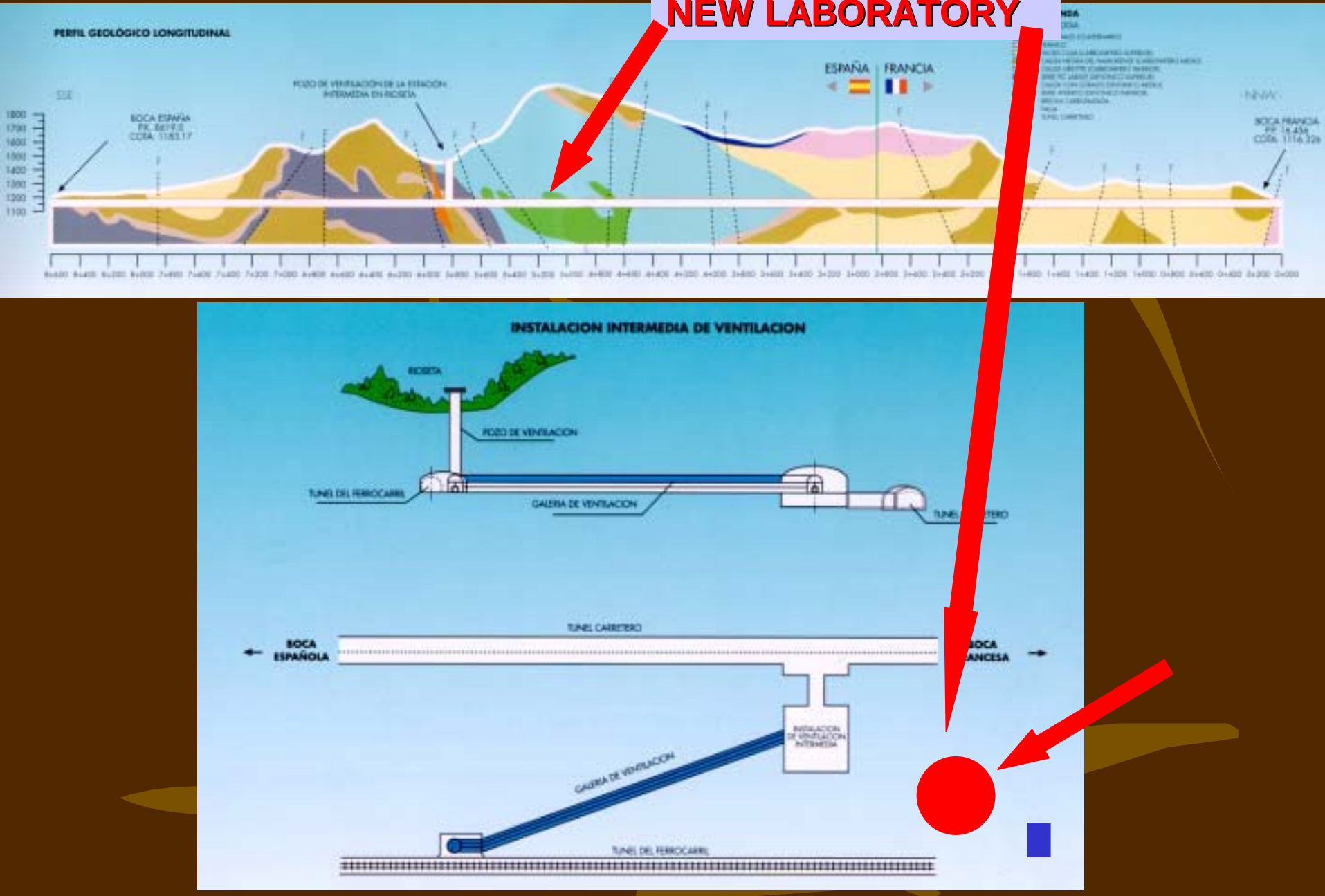
Relative light yields
γ / α / n
1 / 4 / 10



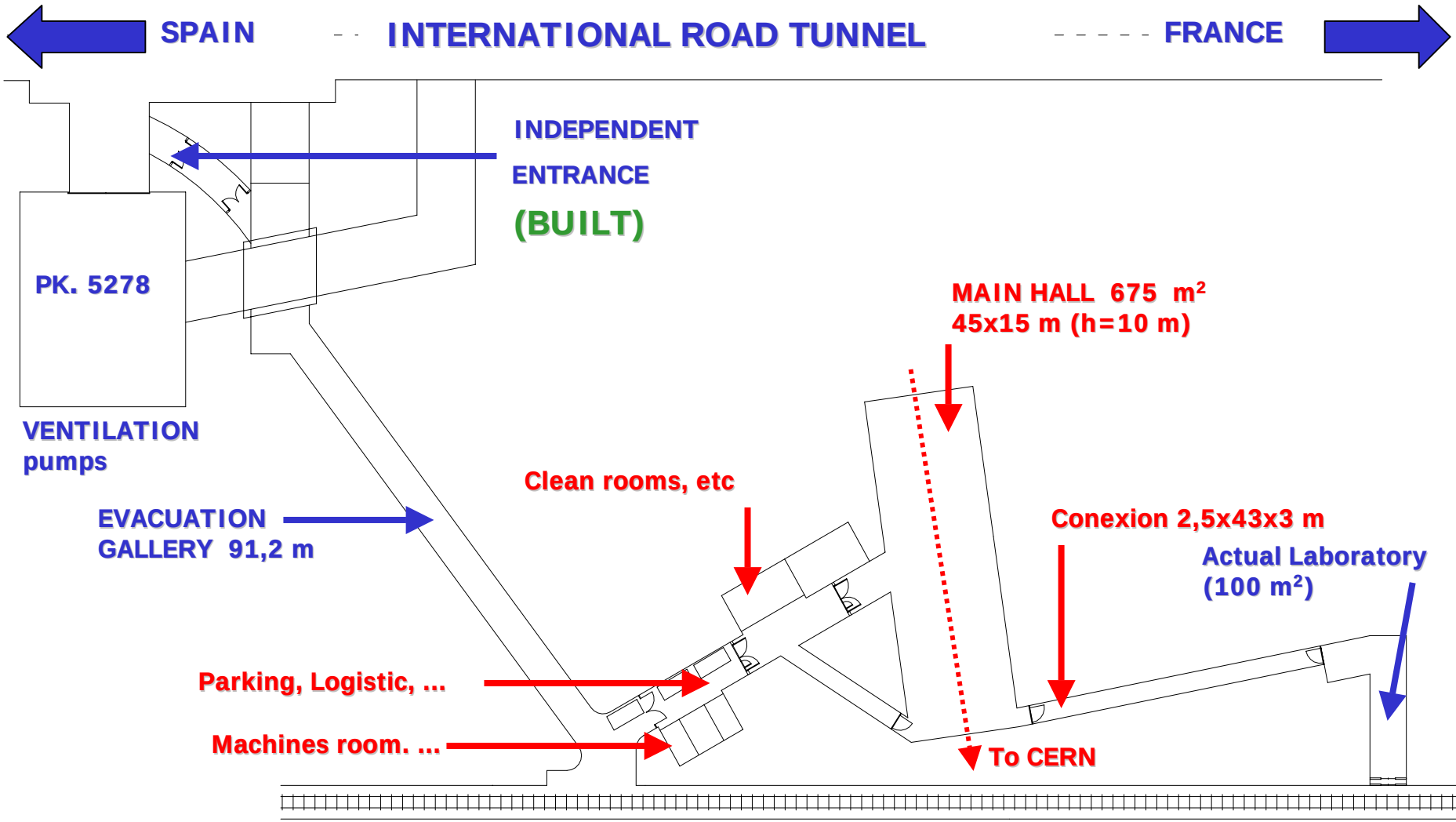
3. FUTURE PROJECTS

THE PROJECT OF A NEW LABORATORY

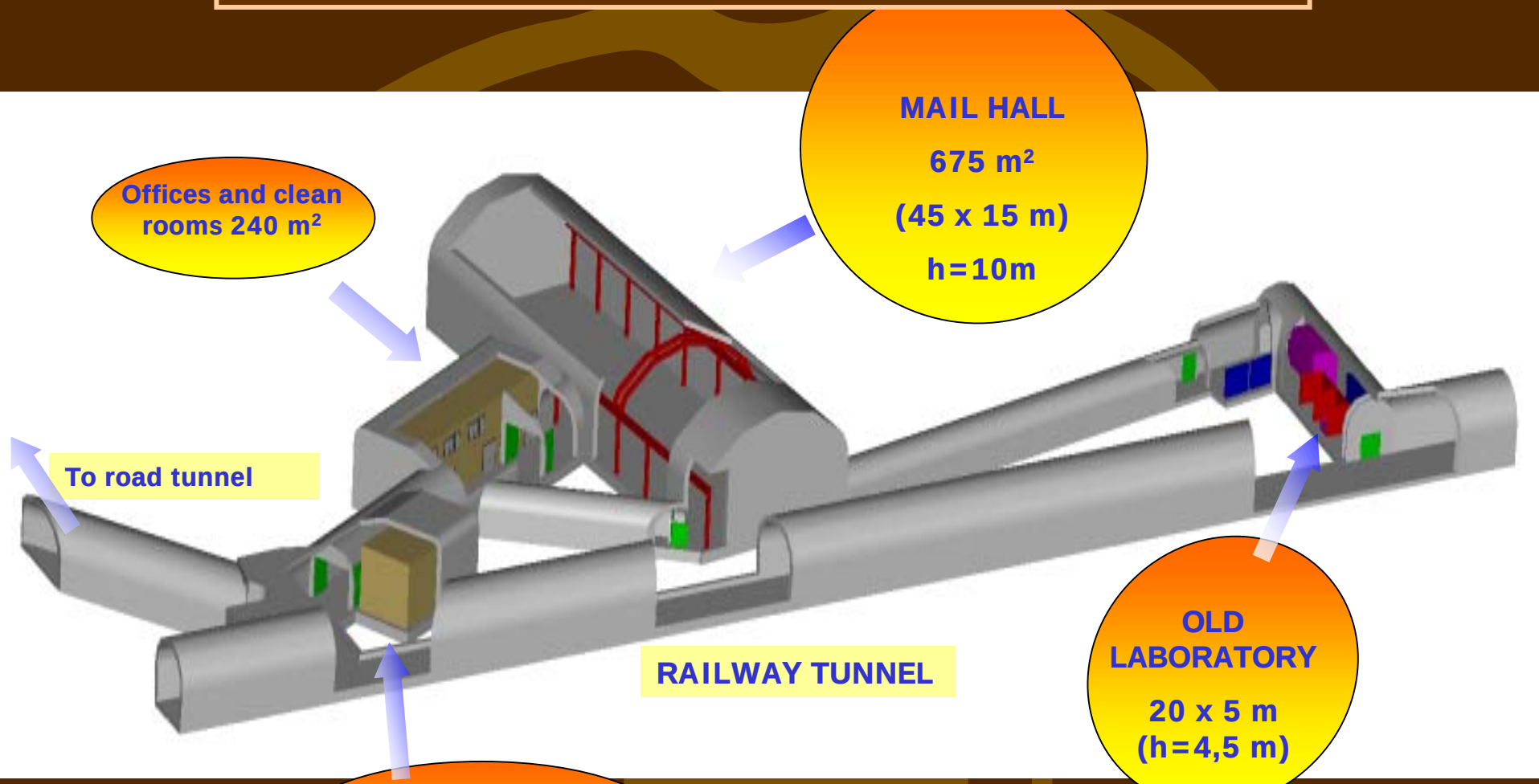

LEYENDA
NICHOS: 86 Ud
REFUGIOS: 9 Ud
APARTADEROS: 5 Ud
GALERIAS DE RETORNO: 9 Ud
GALERIAS DE CONEXION: 4 Ud
FRONTERA
FRANCIA
ESPAÑA
BOCA ESPAÑA
TUNEL FERROVIARIO
SECCION GALERIA DE RETORNO
SECCION REFUGIO
SECCION APARTADERO
SECCION NICHO


NEW LABORATORY
PERFIL GEOLÓGICO LONGITUDINAL
ESPAÑA
FRANCIA
BOCA ESPAÑA
BOCA FRANCIA
INSTALACION INTERMEDIA DE VENTILACION
RODETA
POZO DE VENTILACION
TUNEL DEL FERROCARRIL
GALERIA DE VENTILACION
TUNEL CARRETERO
BOCA ESPAÑOLA
INSTALACION DE VENTILACION INTERMEDIA

DISTRIBUTION OF THE NEW LABORATORY



NEW LABORATORY SCHEMATIC VIEW



THE CANFRANC UNDERGROUND ASTROPARTICLE NATIONAL LABORATORY

- ✓ FINANCEMENT ⇒ APROVED
- ✓ EXECUTION ⇒ ADMINISTRATIVE DEADLINES
- ✓ MANAGEMENT ⇒ DGA-UZ CONSORTIUM

PARTNERSHIP WITH

LNGS (Laboratori Nazionali del Gran Sasso. Italia)

LSM (Laboratoire Souterrain de Modane. Francia)

Boulby (Institute for Underground Science. Boulby Laboratory. UK)