



# **THE CANFRANC UNDERGROUND LABORATORY**

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## **PHYSICS RESEARCH PROGRAM STATUS, RESULTS AND PROSPECTS**

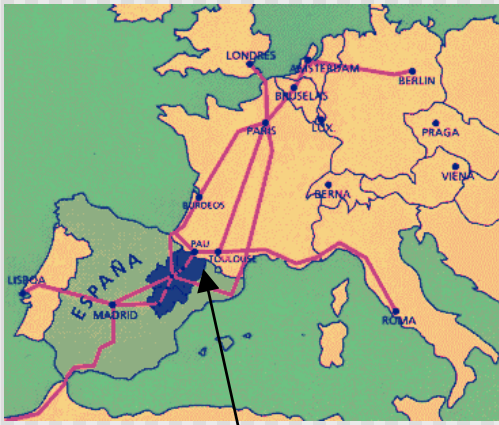


**Laboratory of Nuclear and High Energy Physics  
University of Zaragoza**

# LSC LABORATORIO SUBTERRÁNEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

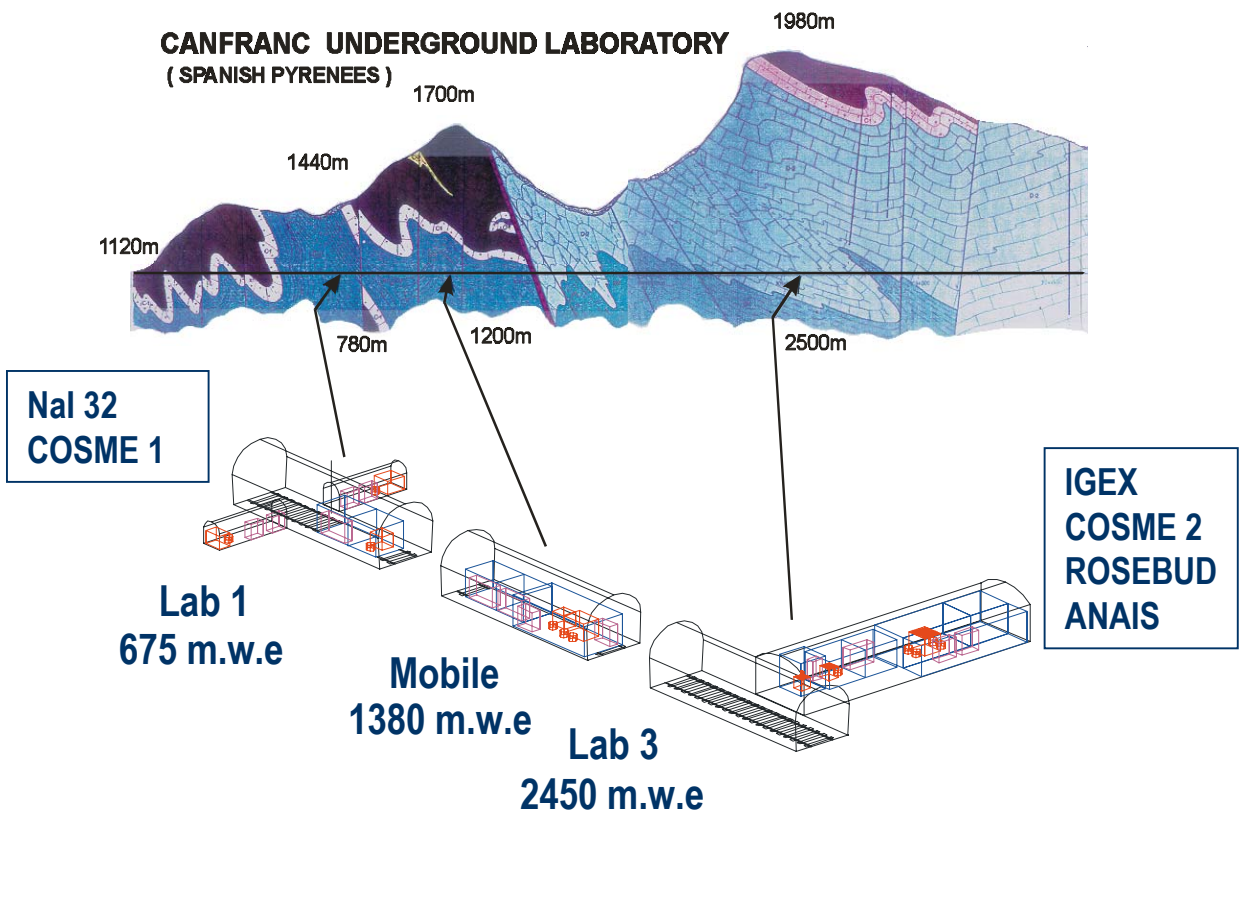
### SPAIN



Spanish Pyrenees



Railway tunnel (not in use)



# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY**

### **SPAIN**

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## **PRESENTATION AND LOCATION (I)**

The Canfranc Underground Astroparticle Laboratory (Laboratorio Subterráneo de Canfranc, LSC), is an underground scientific facility dedicated to experimental research in Fundamental Physics, Particle Physics and Astrophysics, since 1985.

It is located in the Somport Railway Tunnel (7.8 Km. long), of the Spanish Railway National Network (RENFE), which connect Spain and France across the Central (Aragonesse) Pyrenees. It consists of several small rooms located in existing service-shelters and one main experimental hall specially excavated for scientific research.

The entrance, from the Spanish side, is at the Canfranc Railway Station (at 1080 meters above sea level), after which the LSC is named. The main experimental hall of LSC is under the Tobazo mountain, 1980 meters height. The overburden at this location is 2450 m.w.e.

# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY** **SPAIN**

### **PRESENTATION AND LOCATION (II)**

**Canfranc-Estación is a small village of 526 inhabitants established around the railway station. Now the village's economy is oriented to the tourist industry because of the nearby skiing resorts of Candanchú and Astún in the Central Pyrenees.**

**There exists a few hotels and residences in Canfranc. In particular, two small and comfortable hotels located at 100m. and 200m. away from the railway tunnel entrance, wich have proven to be very convenient for stays during periods of continuous operation of the LSC experiments. However most of the stays related to Canfranc activities take place in the nearby town of Jaca. The LSC scientists are lodged in the Residence of the University of Zaragoza at Jaca.**

# **L S C LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY**

### **SPAIN**

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## **PRESENTATION AND LOCATION (III)**

The main entrance to the Valleys of the Aragonese Pyrenees is through the city of Jaca, capital of the Jacetanian region. Jaca is a small historical town of 11374 inhabitants located 18 Km. away from Canfranc in the south direction. Jaca was one of the main stops in the medieval Jacobean trail to Compostella. It has an outstanding Romanic cathedral and other architectural and historic jewels.

Jaca is connected by road and train with the nearby main towns of Huesca (70 Km.), Zaragoza (148 Km.) and Pamplona (111 Km.). Barcelona and Madrid are at distance of 341 Km. and 451 Km. respectively. There exists international airports at Madrid, Barcelona, Pamplona and Zaragoza.

Lodging and recreational facilities typical of a small Spanish town can be found in Jaca. The University of Zaragoza (35000 students), has there an University Residence with a capability of lodging 160 people. A Summer University Campus is maintained at Jaca since 1923 devoted to the Summer Schools Courses of the University of Zaragoza.



# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY** **SPAIN**

### **CARACTERISTICS OF THE UNDERGROUND SITE (I)**

- **Set of various small facilities at different depths.**
- **Located in a Railway tunnel of ~8 Km. long (not in use), crossing the Pyrenees (entrance at ~1080 m. above sea level).**
- **Two small rooms of 12 m<sup>2</sup> (plus two 35 m<sup>2</sup> 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 mwe.**
- **One main Laboratory of 110 m<sup>2</sup> (4.5 m. height) under the Tobazo mount (~2000 m), providing shielding of rock equivalent to 2450 meters of water.**
- **Also set of 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.**
- **Current infrastructure of the site: water, electric power (independent direct supply to the Lab.); telephonic link; air conditioning and thermalization; air extraction and forced ventilation in/from outside; intaking-air gallery directly connected with outside the tunnel; ambient radon control; low temperature facility (12-20 mK); antivibrational cabin; faraday cages; Labs. impermeabilized; floor reinforced for supporting heavy shielding; bench for electroforming copper; tons of archaeological lead; bench of ultralow background Ge detectors for radiopurity measurements.**

# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY** **SPAIN**

### **CARACTERISTICS OF THE UNDERGROUND SITE ( II )**

- **Access: trucks, Lab' vehicle, personnel,... have an easy access to the Laboratory' door by using either the railway or the road tunnels.**
- **Other facilities of the LSC include, outside the Tunnel, a prefabricated hut used for meetings, conference room, computing and networking. A small building of the Spanish Railways National Network, at the disposal of the scientist of the LSC, is used for storage and mechanical workshop.**
- **Although of small size, the space that LSC has available for  $2\beta$  decay and Dark Matter experiments is similar to that used in other underground facilities, because in this type of research the experimental set-ups are of rather moderate dimensions.**

### CARACTERISTICS OF THE UNDERGROUND SITE ( III )

- **Composition of the rock and average density: calize rock (mainly calcium carbonate,  $\rho \sim 2.7 \text{ g/cm}^3$  plus + traces of quartz,  $\rho \sim 2.6 \text{ g/cm}^3$ ).**
- **Some physical parameters:**
  - ◆ **Muon flux:  $\phi_{\mu} = 2 \times 10^{-7} \mu/\text{cm}^2\text{s}$**
  - ◆ **Radon: Variable. 50-100 Bq/m<sup>3</sup> in Lab.**
  - ◆ **Ambient photon flux:  $\phi_{\gamma} \sim 2 \times 10^{-2} \gamma/\text{cm}^2\text{s}$**
  - ◆ **Neutrons:  $\phi_n \sim \text{a few} \times 10^{-6} \text{ n/cm}^2\text{s}$  depending on energy**



# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY**

### **SPAIN**

## **FINANCEMENT AND USERS**

- **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). The tunnel is operated by the University of Zaragoza (Laboratory of Nuclear and High Energy Physics). Other funding contributions come from the University of Zaragoza, the TMR Program of the European Union and the Regional Government of Aragon. Other punctual contributions are that of the DOE (USA) and NFS (USA), the INFN (Italy) and IN2P3 (France) and INR and ITEP from Russia.**
- **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).**

# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY**

### **SPAIN**

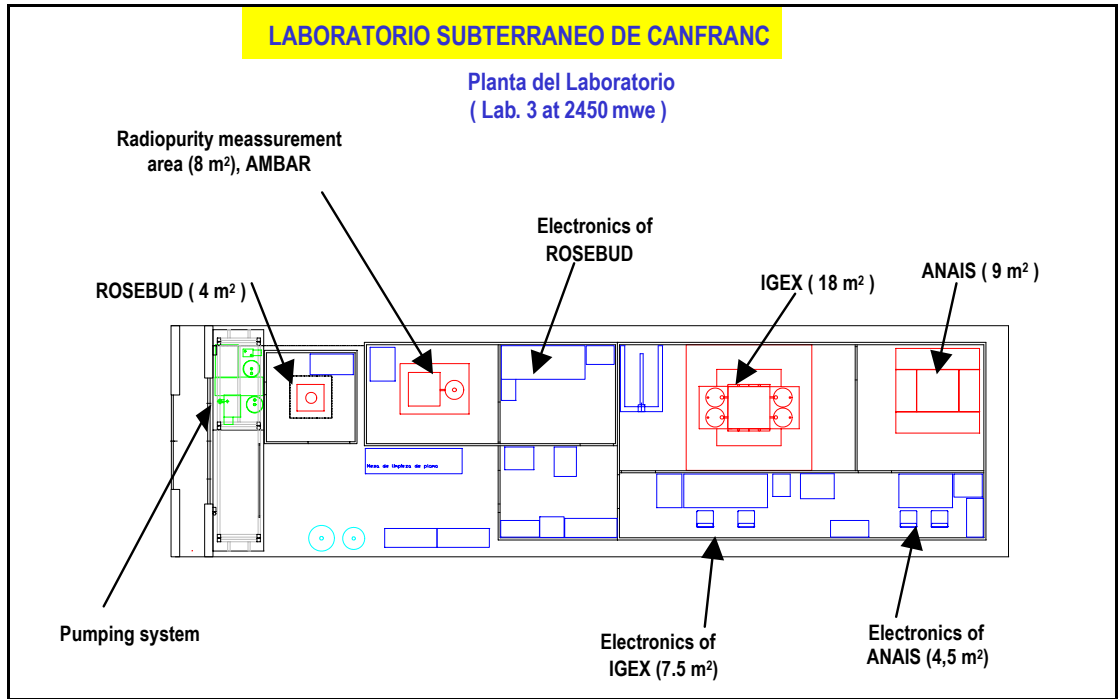
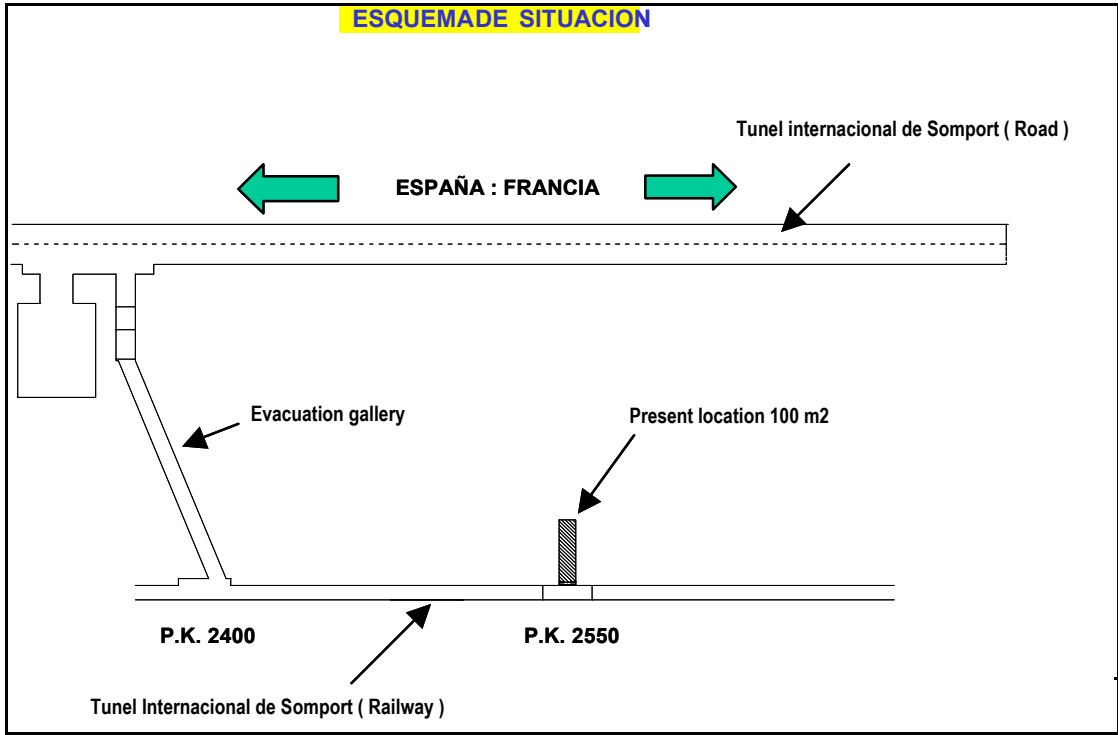
## **PHYSICS RESEARCH**

The main lines of Physics Research at Canfranc are Neutrino Physics (in particular Double Beta Decay) and Dark Matter Searches (in particular the direct detection of galactic WIMPs, Weak Interacting Massive Particles).

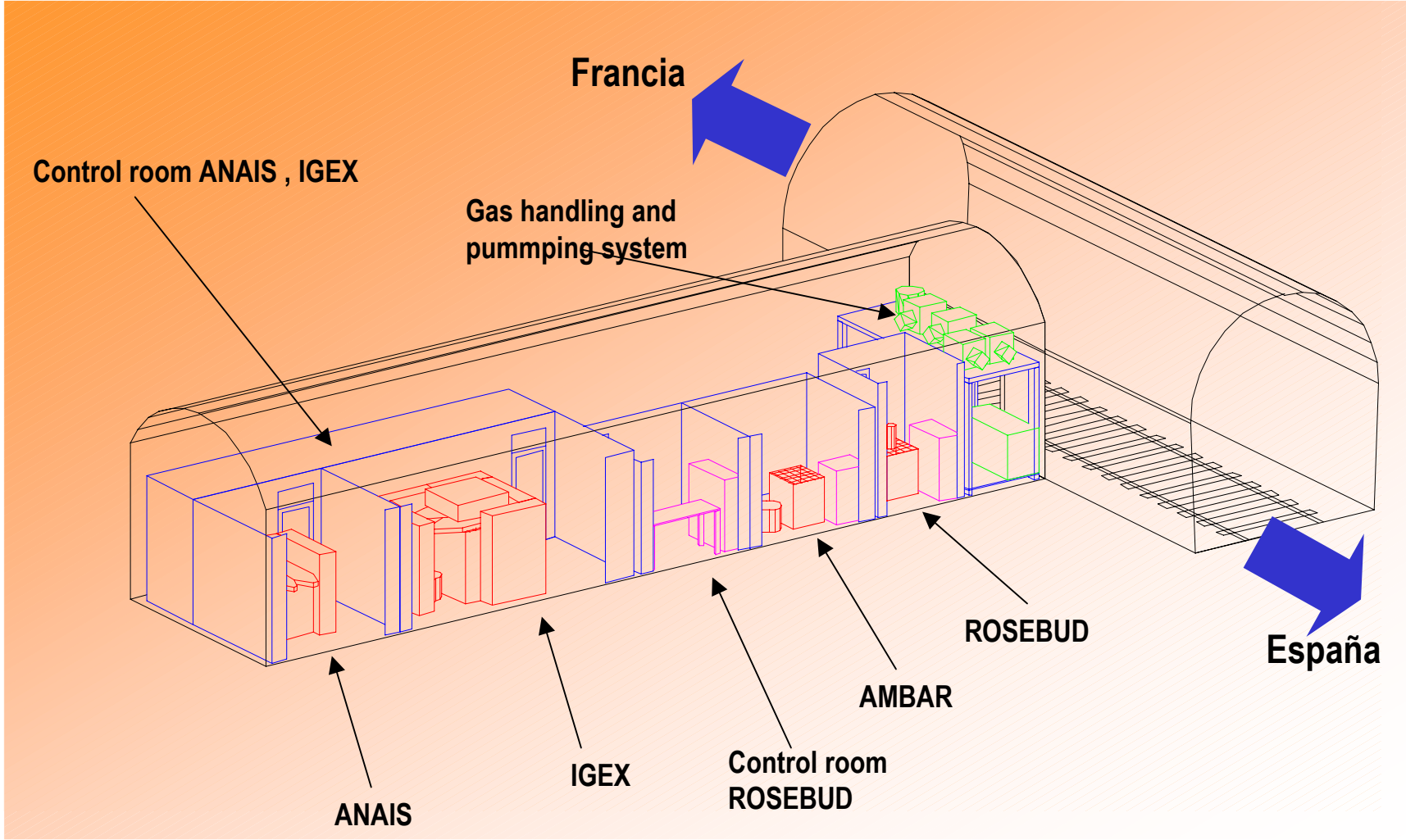
Typical experiments already performed or being currently in operation at LSC are:

- Decay of  $\text{Ge}^{76}$  to excited states ( $2\beta/\gamma$  coincidence experiment)
- Double positron decay of  $^{87}\text{K}\gamma$
- 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  $\beta$ )
- 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)

# Canfranc Underground Laboratory



# Canfranc Underground Laboratory



# L S C LABORATORIO SUBTERRANEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY SPAIN

### EXPERIMENTS

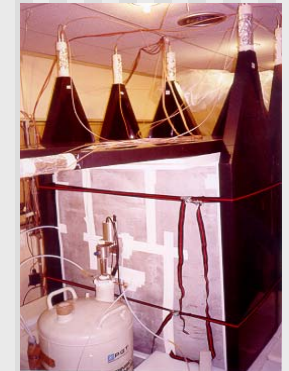
- **IGEX –  $2\beta$**  (*Experiment Completed. Analysis in Progress*)  
Search for Double Beta Decay of Ge-76, with a set of 6.3 Kg of enriched 76 Germanium.

[Collaboration: University of Zaragoza, University of South Carolina, Pacific Northwest National Laboratory, Institute for Nuclear Research (Baksan) and ITEP (Moscow).]



- **IGEX – DM** (*Experiment Running*)  
Search for non Baryonic Dark Matter (WIMPS) with an enriched (2 Kg) Germanium Crystal.

[Collaboration: University of Zaragoza, University of South Carolina, Pacific Northwest National Laboratory, Institute for Nuclear Research (Baksan) and ITEP (Moscow).]



- **COSME 2** (*Experiment Completed*)  
Search for WIMPS and axions with a small natural abundance Ge Crystal.

[Collaboration: University of Zaragoza, USC, PNNL.]

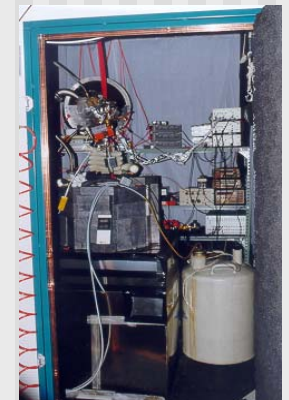


- **Nal-32 / ANAIS** (*Experiment Running*)  
Search for annual modulation of WIMP signals with a set of Nal scintillators.

[Collaboration: University of Zaragoza.]

- **ROSEBUD** (*Experiment Running*)  
Search for WIMPS with bolometers of Al<sub>2</sub>O<sub>3</sub>, Ge and CaWO<sub>4</sub>.

[Collaboration: University of Zaragoza and Institut d' Astrophysique Spaciale (Orsay).]



# LS C LABORATORIO SUBTERRÁNEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

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## IGEX-2 $\beta$

### Objective:

To investigate the double beta decay of  $^{76}\text{Ge}$ .

### Rationale:

In the Standard Model of Particle Physics neutrinos and antineutrinos are supposed to be massless and different particles, but there are no fundamental argument for that prejudices. On the contrary, recent strong evidences (from solar and atmospheric neutrinos observations) conclude that neutrinos have indeed finite masses and that they mix between their three flavours. On the other hand, no experimental evidence exists so far of whether neutrinos are equal (Majorana) or different (Dirac) that their antineutrinos.

A Neutrinoless Double Beta Decay would imply that neutrinos are Majorana particles and that they have non-zero masses.

The International Germanium Experiment search for such rare decay since 1990 with three detectors of  $^{76}\text{Ge}$  (enriched up to 86%), of a total mass of 6.3 Kg.

### Results 2000:

From a total exposure of 116.75 mole-years (8.87 Kg y of Ge-76) (of wich PSD has been applied only to 52.51 fiducial mole-years), the neutrinoless half-life lower bound (90% C.L.) obtained from the complete data set (with and without) PSD, is

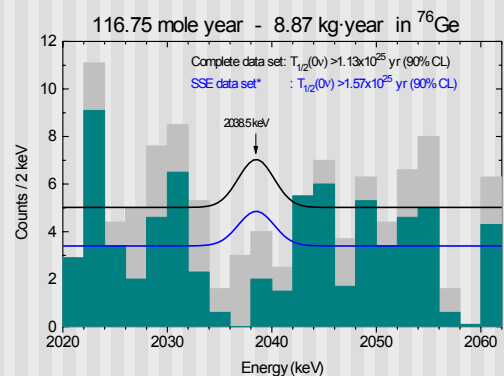
$$T_{1/2}^{0\nu} \geq 1.57 \times 10^{25} \text{ years}$$

providing a Majorana neutrino mass limit

$$\langle m_1 \rangle < (0.33 \sim 1.31) \text{ eV}$$

depending on the theoretical nuclear matrix element used. The measured two-neutrino half-life is

$$T_{1/2}^{2\nu} = (1.5 \pm 0.2) \times 10^{21} \text{ years}$$





# LS C LABORATORIO SUBTERRÁNEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

### SPAIN

## IGEX-DM

### Objective:

Direct Search for WIMP dark matter.

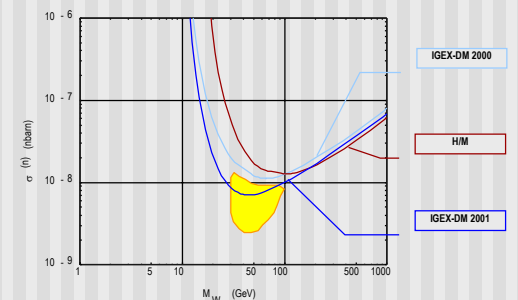
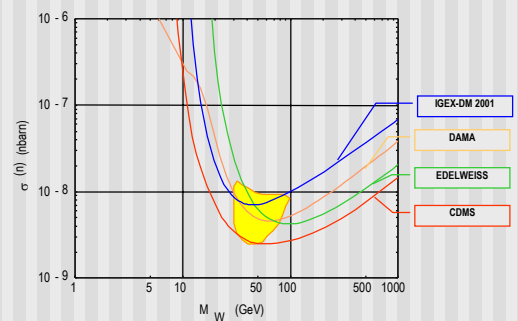
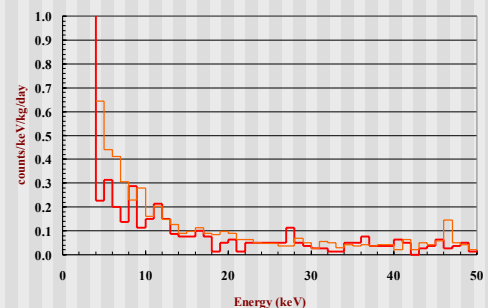
### Rationale:

Experimental evidences and robust arguments conclude that most of the matter of the Universe is dark and mainly of non-baryonic nature. WIMPs (Weak Interacting Massive Particles) and axions are favourite candidates for such non-baryonic components of the dark matter.

WIMPs could be detected through the nuclear recoil produced by the WIMP elastic scattering off the nuclei of a suitable detector. WIMPs non relativistic ( $v \sim 10^{-3}c$ ) and heavy ( $m \sim \text{GeV-TeV}$ ) can produce a small nuclear recoil (1-100 KeV), at a very small event rate ( $10^{-10}$  counts per Kg. of target detector and day). Ultrasensitive detectors of low energy threshold, and very low radioactive background are needed for intend such detection. IGEX is using one detector of 2.1 Kg. (Energy threshold of 4 KeV), and of a very low background (of  $2 \times 10^{-1}$  to  $10^{-2}$  c/KeV Kg day from 4 to 50 KeV) in a direct search for WIMPs.

### Results 2001:

After an exposure of 80 Kg day, IGEX-DM has excluded WIMP-nucleon cross-section (for spin-independent interactions), above  $7 \times 10^{-6}$  pb for masses from 20 to 200 GeV. That is the best exclusion ever obtained with these type of detectors. The IGEX exclusion contour enters, by the first time, the DAMA region without using discrimination mechanisms to reject the background, but relying only in the raw ultralow background achieved in the experiment.



# LSC LABORATORIO SUBTERRÁNEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

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### Nal-32 and ANAIS

#### Objective:

Search for annual modulation in the WIMP signal.

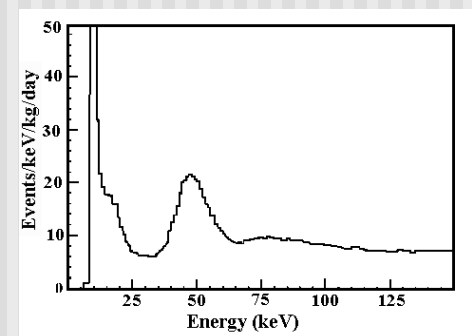
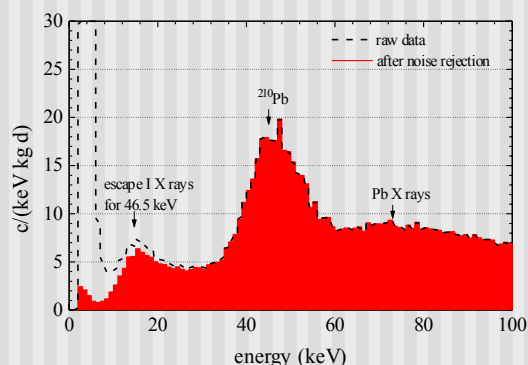
#### Rationale:

Nal32 (finished) and ANAIS are large mass scintillator experiments planned to investigate the seasonal modulation effects of galactic WIMPs, induced by the variations in the relative velocity between the Earth and the halo. A set of three NaI(Tl) scintillators of 10.7 kg each were used in Nal32, while ANAIS will consist of up to 10 of these crystals. A prototype is being developed in an attempt to obtain the best conditions regarding the energy threshold and the radioactive background.

#### Results:

The analysis of the data corresponding to 1342.8 kg day of exposure in Nal32 did not show any indication of annual effects. The nonobservance of such modulation was used to derive more stringent bounds on WIMP-nuclei cross-sections than those derived from the standard method.

The first results from the prototype of ANAIS (2069.85 kg day) are promising, since the rejection of noise using pulse shape discrimination techniques allows to reduce the energy threshold down to 4 keV.



# LS C LABORATORIO SUBTERRÁNEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY

### SPAIN

## ROSEBUD

### Objective:

Direct search for WIMPs with cryogenic detectors.

### Rationale:

WIMPs, beside axions, are favourite candidates for the non-baryonic dark matter. WIMPs would be directly detected by measuring the energy transferred to a nucleus recoiling after their elastic scattering.

The specific feature of low temperature detectors is the measurement of this low recoil energy (some keV) through the subsequent temperature increase of the absorber (~ $\mu$ K if the operation temperature is a few mK). Advantages of this new detector technology are:

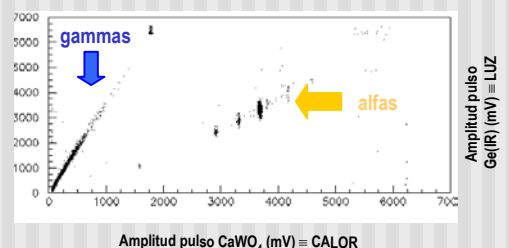
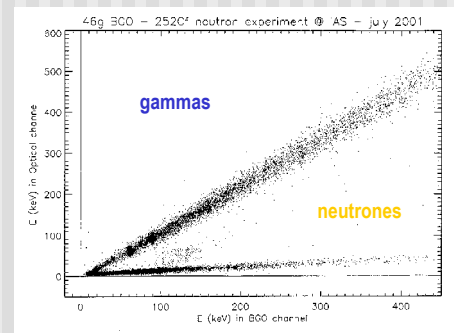
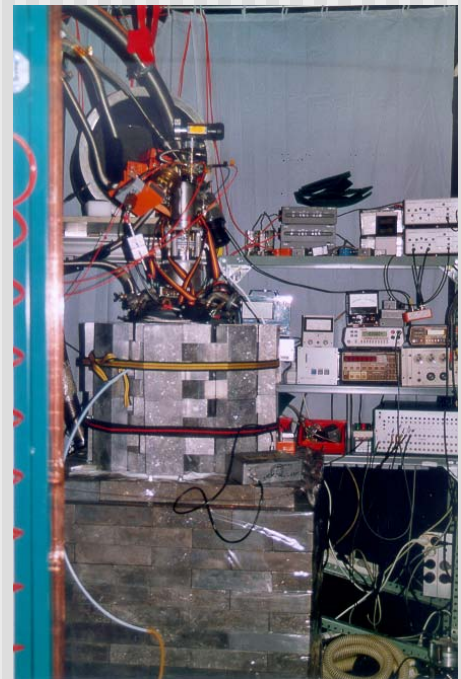
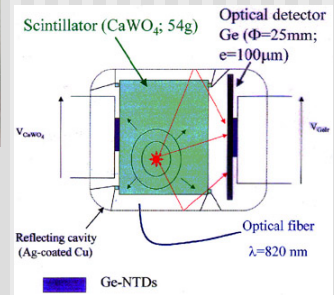
- The wide choice of absorbers.
- The low energy threshold and good energy resolution achievable.
- Feasibility of discrimination techniques (nuclear recoil versus electron events).

In the first phase of the experiment only sapphire (25 and 50g) was used as absorber, being the main goal to reduce the radioactive background in the unfriendly cryogenic environment (down to about 5 events/kg/keV/day at 100 keV at the end of 1999).

### Results:

Bolometers of Ge (67g),  $Al_2O_3$  (50g) and  $CaWO_4$  (54g) have been operated in Canfranc. For the first time three different absorbers worked in the same radioactive environment.

Very good expectations come from the first underground heat-scintillation discrimination with a medium mass  $CaWO_4$  absorber. In a short measurement no recoil events were observed and  $\alpha$  contamination was clearly discriminated from  $\gamma/\beta$  background. Previous test in Paris showed the discrimination of recoils with a neutron source. Currently, BGO is also under test for discrimination purposes.



# **LS C** LABORATORIO SUBTERRANEO DE CANFRANC

## CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY SPAIN

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### SCIENTIFIC PROJECTS

- **Short term:**
  - The enlarging of the NaI-32/ANAIS set up to 200 Kg of radiopure NaI crystals to look for annual modulation of WIMP signals.
  - ROSEBUD II: search for WIMPs with scintillating bolometers (heat + light) of  $\text{CaWO}_4$  and BGO.
  - GEDEON: a set of 30 (~1 Kg) natural Ge detectors in a common cryostat to look for WIMPS.
  - A large (1 m<sup>3</sup>) Xenon TPC (microMeGa / MWPC) with directional sensitivity to WIMP-produced nuclear recoils.
- **Long term (Possible experiments to be considered in the new –600/700 m<sup>2</sup>– experimental hall) :**
  - Gravitational waves.
  - Large arrays of detectors / crystals of enriched  $2\beta$  – decaying isotopes to look for neutrinoless decay (**Majorana**-like).
  - Measurement of low energy nuclear cross-section of astrophysical interest with small accelerator (**LUNA**-like).
  - Neutrino oscillation experiments: Atmospheric (**MONOLITH**-like). Reactor (**Kamland**-like)  
Others (?)



# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY** **SPAIN**

### **FUTURE PLANS & PROJECTS (I)**

- **To substantially enlarge its current facilities**
  - **Excavation of a new gallery of 600 m<sup>2</sup>, close to the present LSC site, in a new road tunnel parallel to the railway one at 90 m.**
  
- **To host experiments from international collaboration offering room, facilities and technical support**
  - **(EEC VI framework Program of Access to Large Scale Facilities).**

# **L S C** **LABORATORIO SUBTERRANEO DE CANFRANC**

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## **CANFRANC UNDERGROUND ASTROPARTICLE LABORATORY** **SPAIN**

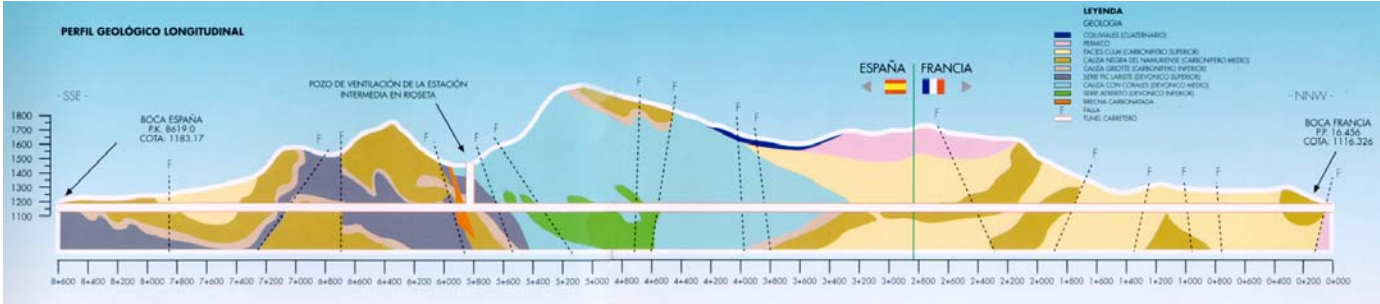
### **FUTURE PLANS & PROJECTS (II)**

**A new tunnel, connecting Spain and France has been recently constructed. It is already completed and will be open to the traffic shortly. It goes parallel to the Railway Tunnel (at ~90-150 m). Both are connected through emergency galleries.**

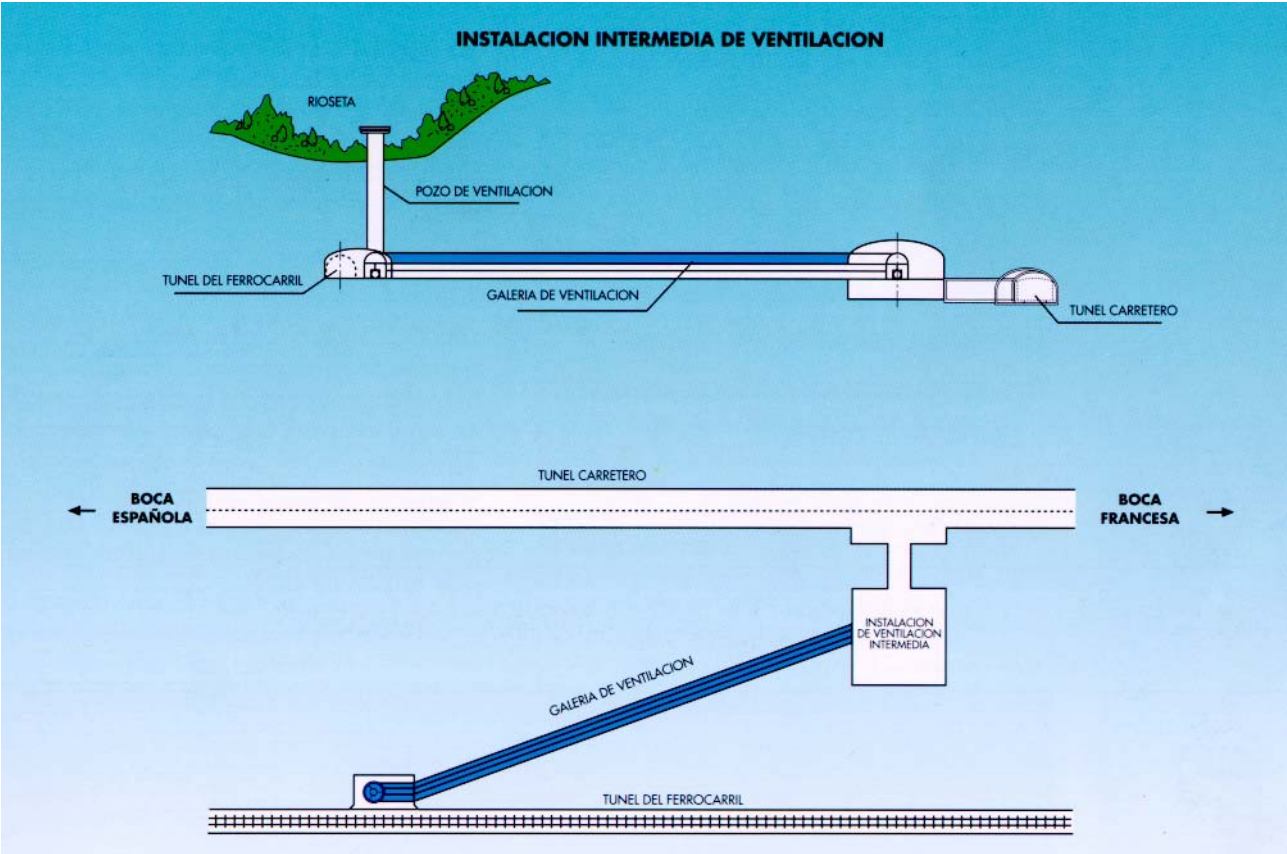
**IN THE CONNECTING GALLERY CLOSEST TO THE LSC A NEW EXCAVATION IS PLANNED (AND PRACTICALLY FUNDED) FOR THE CONSTRUCTION OF A NEW, MEDIUM SIZE, LABORATORY OF ~600-700 m<sup>2</sup> (9-10 m. HEIGHT) CONNECTED TO THE LSC. THE NEW HALL WILL BE ORIENTED TO CERN.**



# TUNEL DE SOMPORT

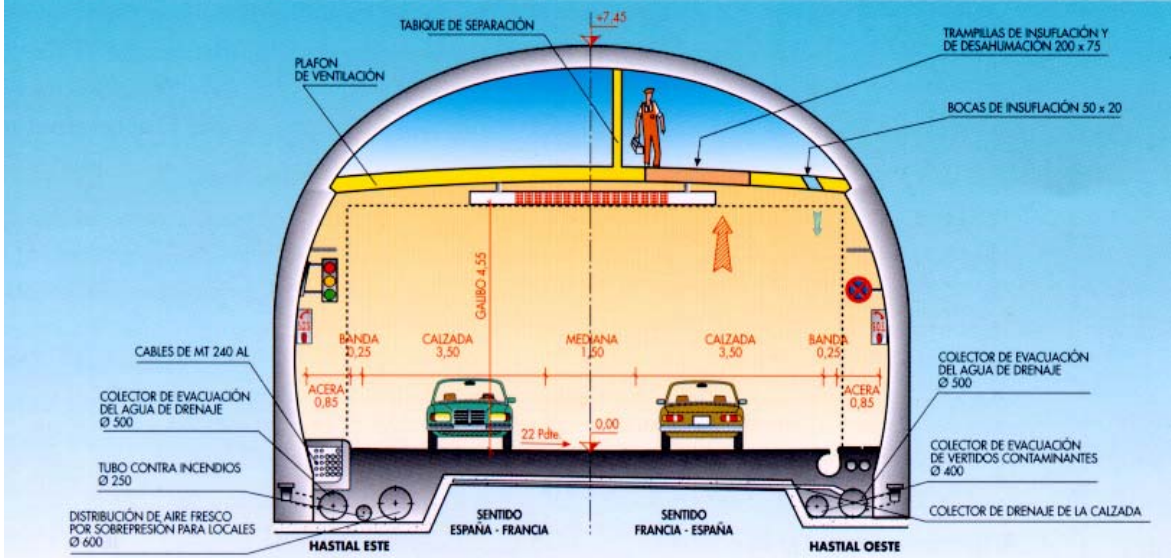


Tunnel profile



Ventilation gallery

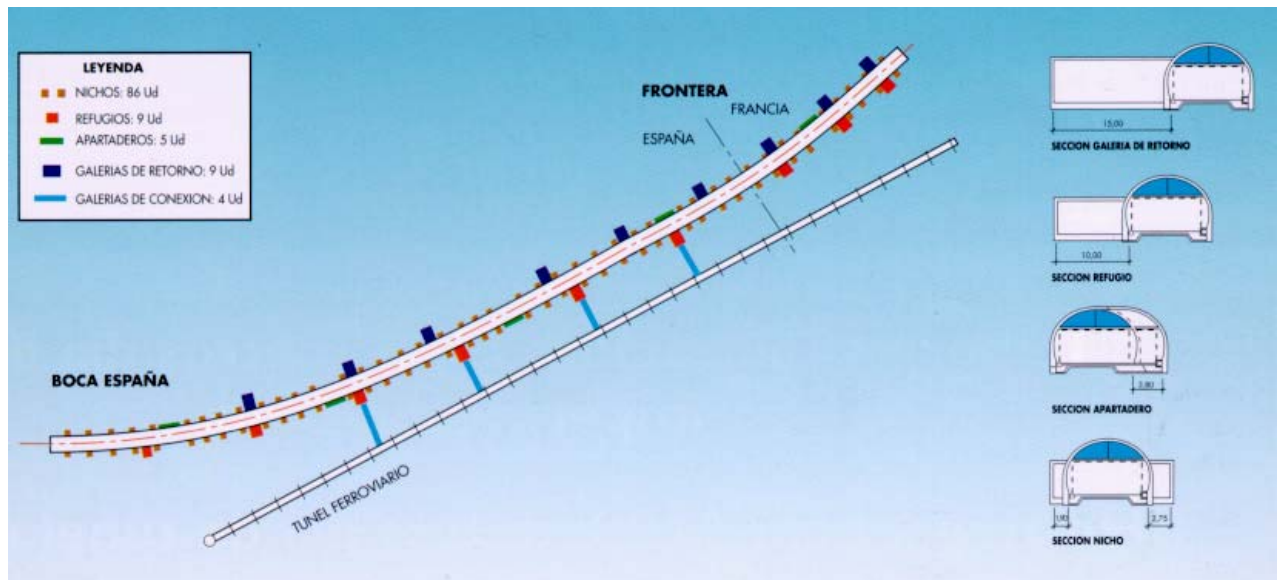
# TUNEL DE SOMPORT



Tunnel section



# TUNEL DE SOMPORT



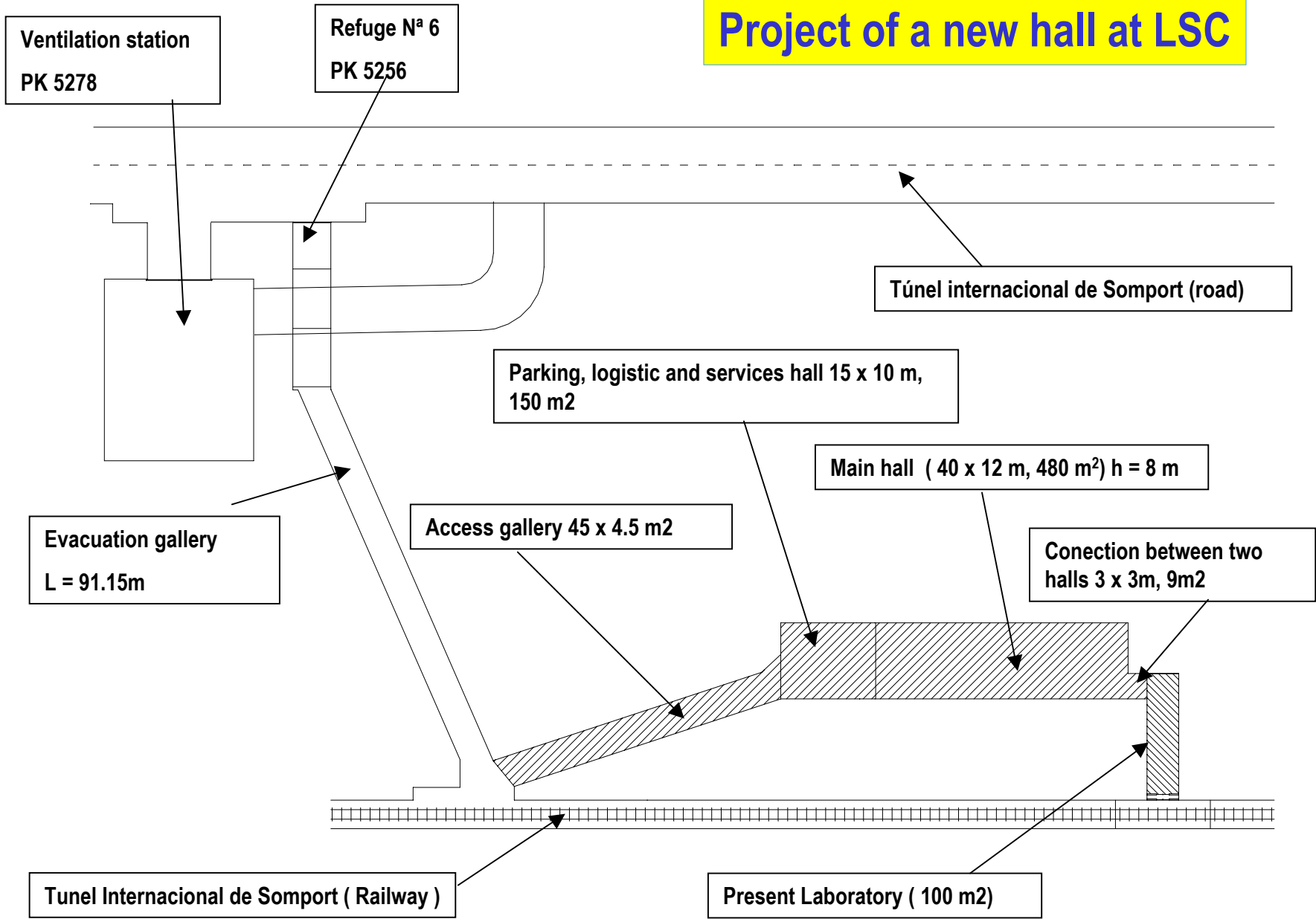
General view of the evacuation galleries



One evacuation gallery

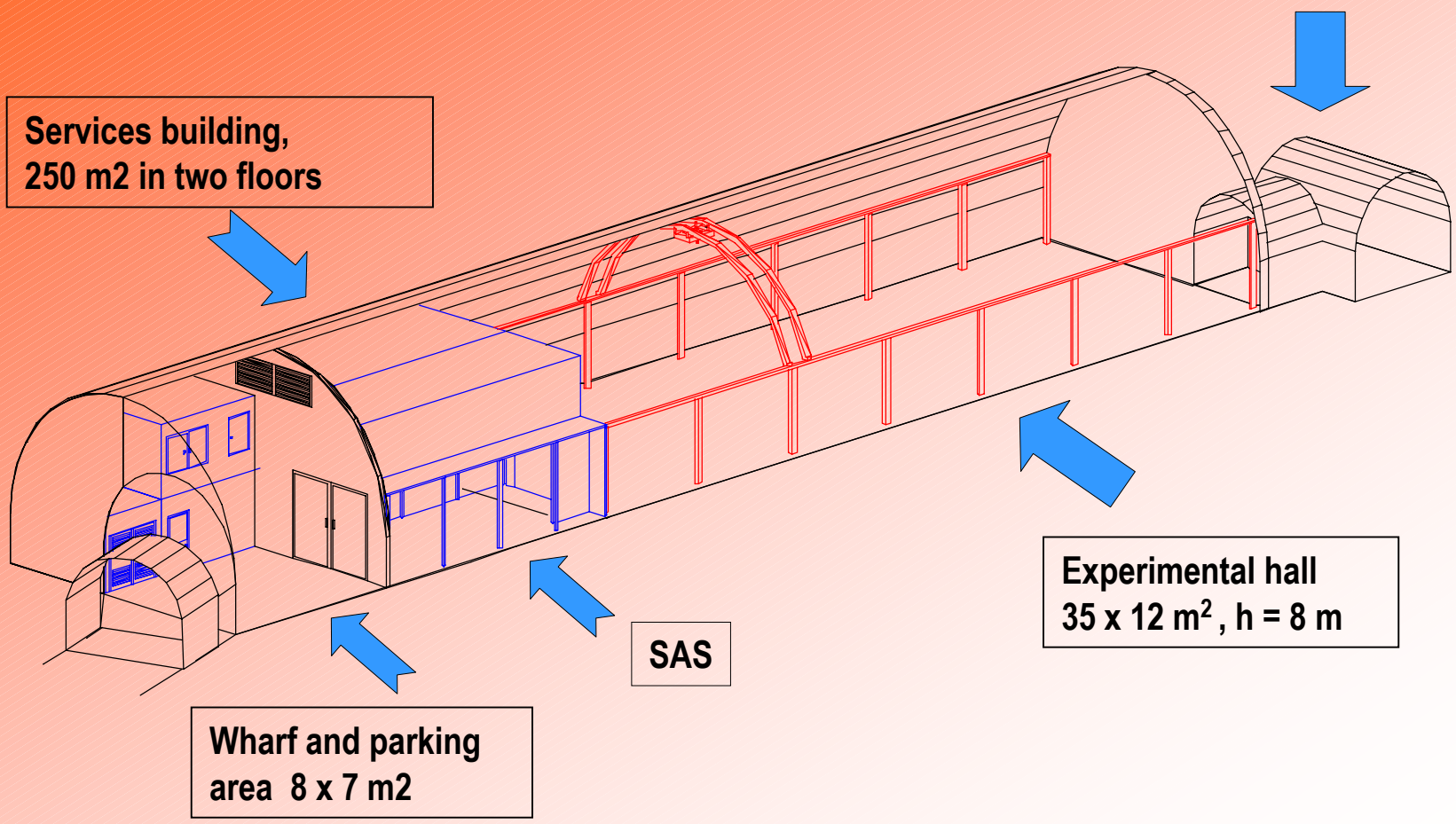


# Project of a new hall at LSC



# Project of a new hall at LSC

Present location  
of LSC



Services building,  
250 m<sup>2</sup> in two floors

Experimental hall  
35 x 12 m<sup>2</sup>, h = 8 m

Wharf and parking  
area 8 x 7 m<sup>2</sup>

SAS

# Project of a new hall at LSC

