Deep Underground Facilities and Long Baseline Neutrino Experiments

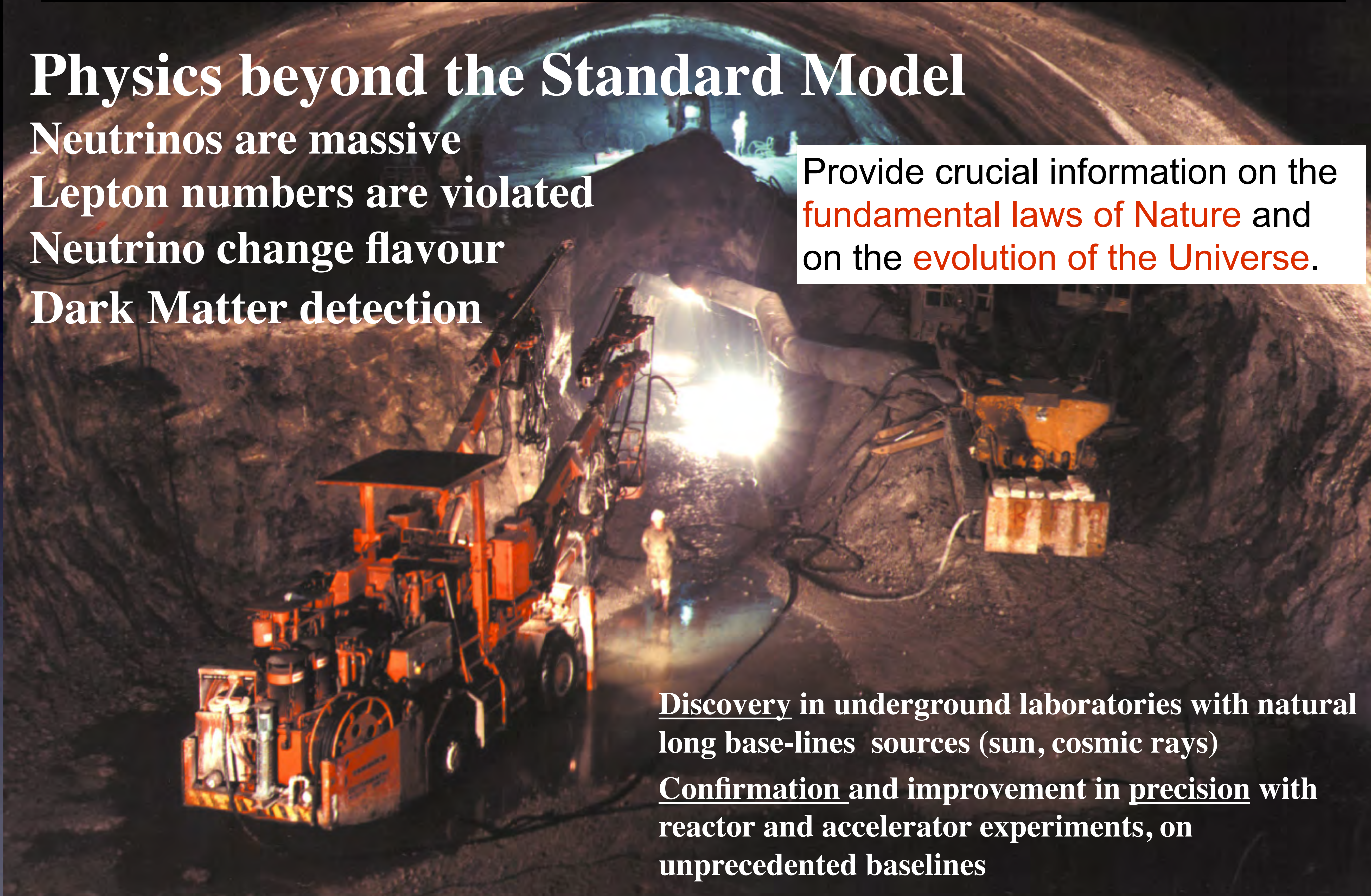
Deep Underground Science Facilities
Prospects for a next generation underground neutrino observatory on 100’000m^3 scale
Progress in Europe

André Rubbia (ETH Zurich)

BILAT USA

Symposium on Transatlantic EU-U.S. Cooperation in the Field of Large Scale Research Infrastructures
1st October 2010
CNR - Piazzale Aldo Moro, 7, 00185 Rome, Italy

Extremely rare signals. Go underground.



Physics beyond the Standard Model

Neutrinos are massive
Lepton numbers are violated
Neutrino change flavour
Dark Matter detection

Provide crucial information on the fundamental laws of Nature and on the evolution of the Universe.

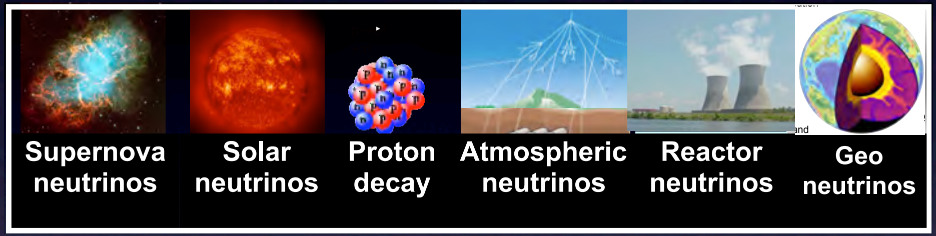
Discovery in underground laboratories with natural long base-lines sources (sun, cosmic rays)

Confirmation and improvement in precision with reactor and accelerator experiments, on unprecedented baselines

Deep underground facilities

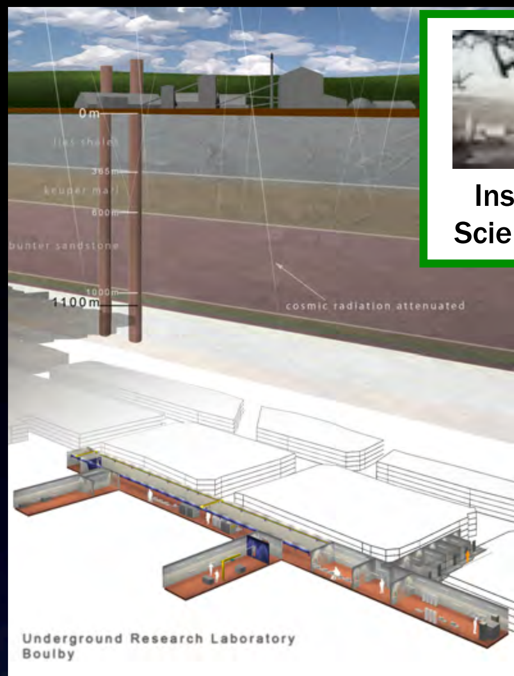
- **Deep underground laboratories are large laboratories, caverns, and cleanrooms serving the field of underground science.**
- **The main impetus is the execution of dedicated experiments studying extremely rare nuclear physics processes, which can only be studied in the absence of cosmic rays, such as:**
  - Low Energy Neutrinos Detection
  - Search for Radioactively Decaying Protons
  - Terrestrial detection of Dark Matter
  - Search for Neutrinoless Double Beta Decays
  - Study of Neutrinos from Accelerators (Neutrino Flavor Oscillations)
  - etc.

    (Cosmic rays on the Earth's surface cause backgrounds in these types of experiments, but the particles cannot penetrate great depths in rock.)



- **Easy access to great depths opens new frontiers in geomicrobiology, geosciences, and mining engineering, making deep underground laboratories multidisciplinary facilities.**

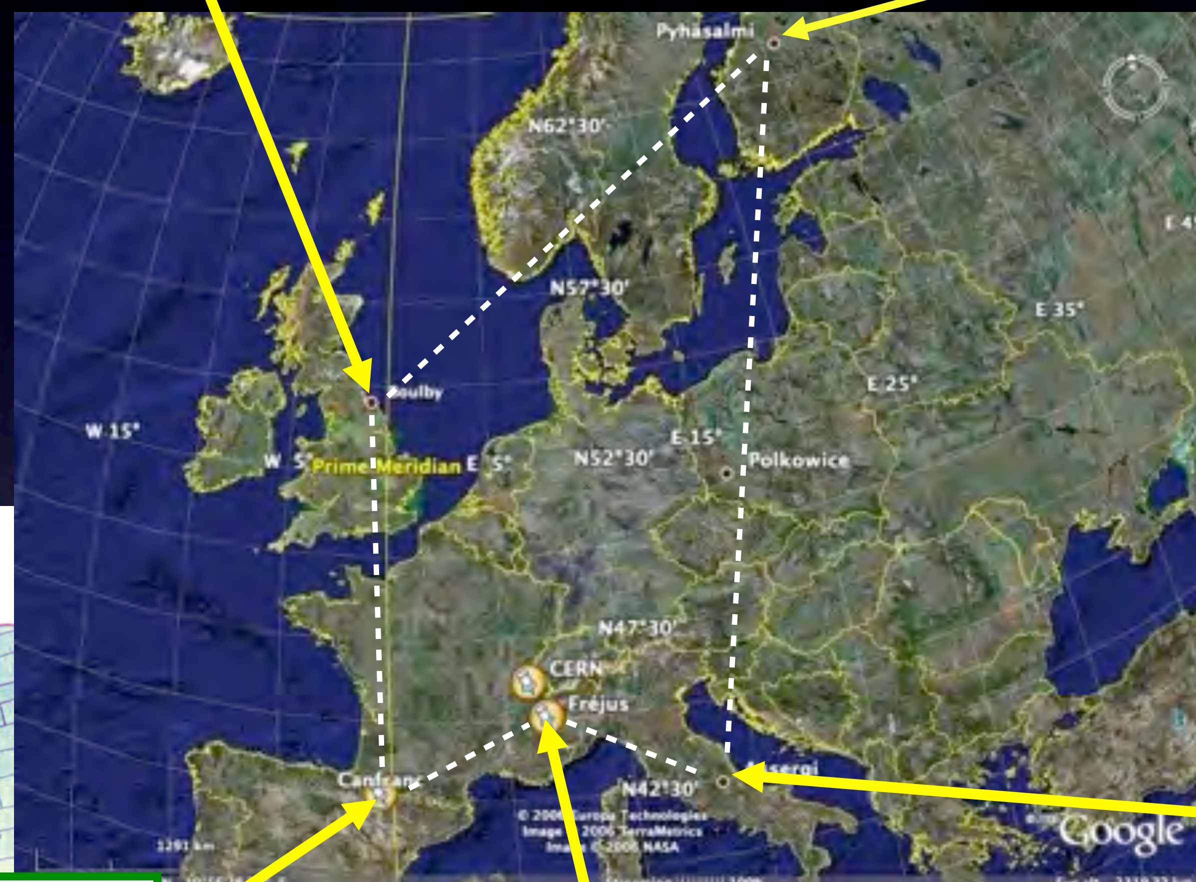
Present European underground labs

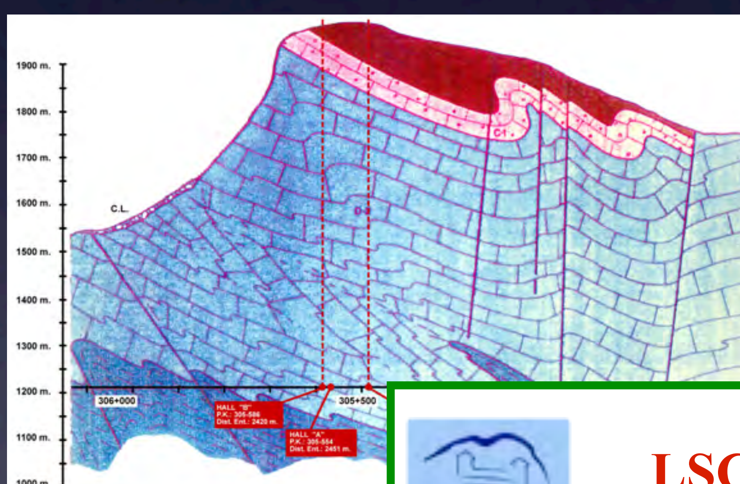


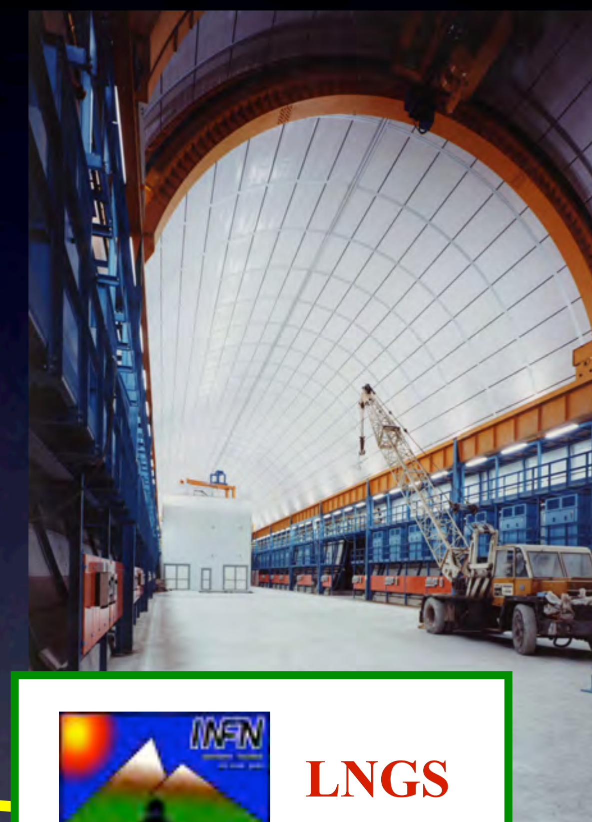
IUS

Institute of Underground Science in Boulby mine, UK

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE







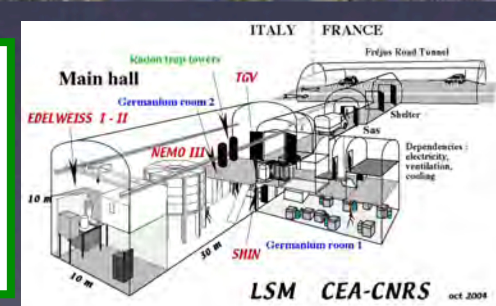
LNGS

Laboratori Nazionali del Gran Sasso, Italy

LSC

Laboratorio Subterraneo de Canfranc, Spain

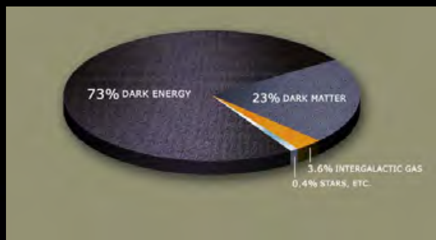
Laboratoire Souterrain de Modane, France



Western Europe hosts five national operating underground laboratories. They are linked and coordinated via ApPEC (& ILIAS).

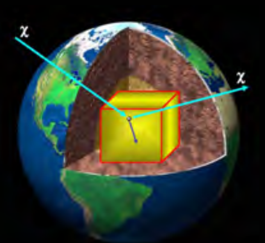
Large underground experimental halls

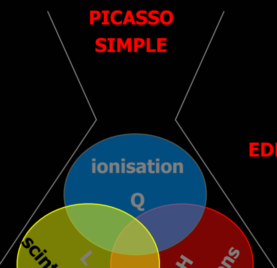
Underground science in expansion



Direct Dark Matter searches

And axions of course…





XENON, ZEPLIN_III
ArDM, WARP

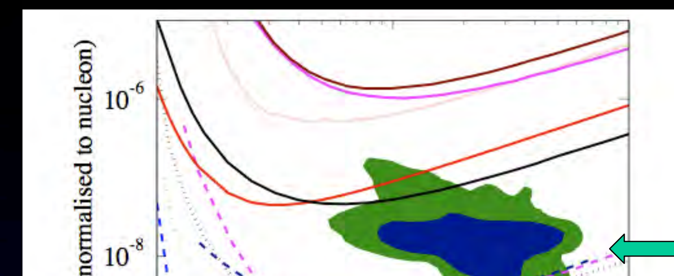
DAMA/LIBRA, ZEPLIN I
ANAIS

Roadmap encourages large consortia of ton-sc

- EDELWEISS, CRESST =>EURECA
- XENON, ArDM => DARWIN
- Design studies financed by ASPERA

ASPERA

Dark Matter Searches



Present
1 event/ 100 kgdays

Next 3 years (2010-2012)
1 event/10^{3-4} kgdays
XENON100/WARP140/
EDELWEISS-II/CDMS-II

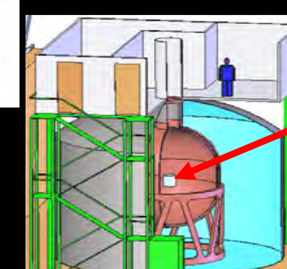
2013-2015
1 ton detector material
1-10 events/tonyear

✓Dark Matter

Ton scale dark matter detectors

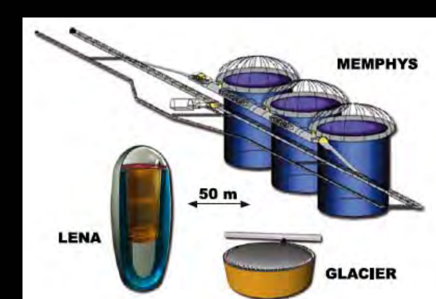
✓Neutrino mass

100Kg/ton neutrino mass detectors



✓Proton decay, neutrino properties and low energy neutrino astrophysics

Megaton scale detectors

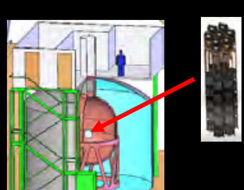


ASPERA

Neutrino mas

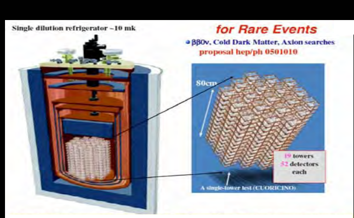
…ass searches

$0\nu\beta\beta$ decay: in operatio



GERDA (I-II and

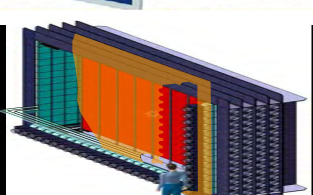
Ge diodes in liquid nitroge
Implemented in phases (1
Results phase I: 2011, pha



CUORE

Bolometer of TeO_2 (^{130}Te 203 kg)
Operation 2011, full detector in 2013

or R&D in EXO, Cobra, NEXT, Lucifer, …

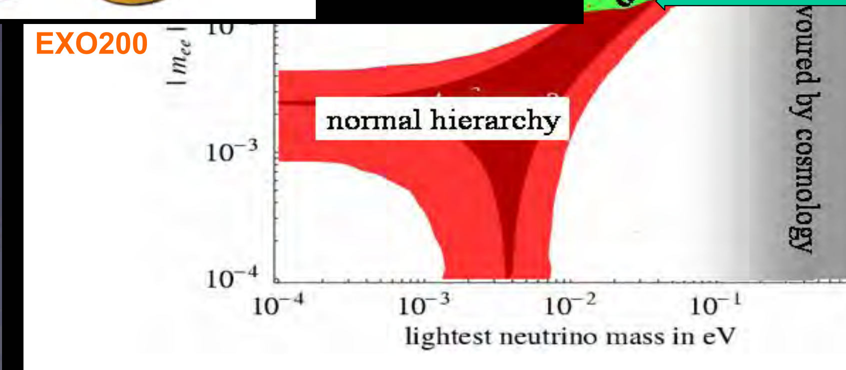


SuperNEMO

20 modules of a tracko-calo,
100 kg of ^{82}Se or ^{150}Nd

First module in 2012 (=GERDA I)

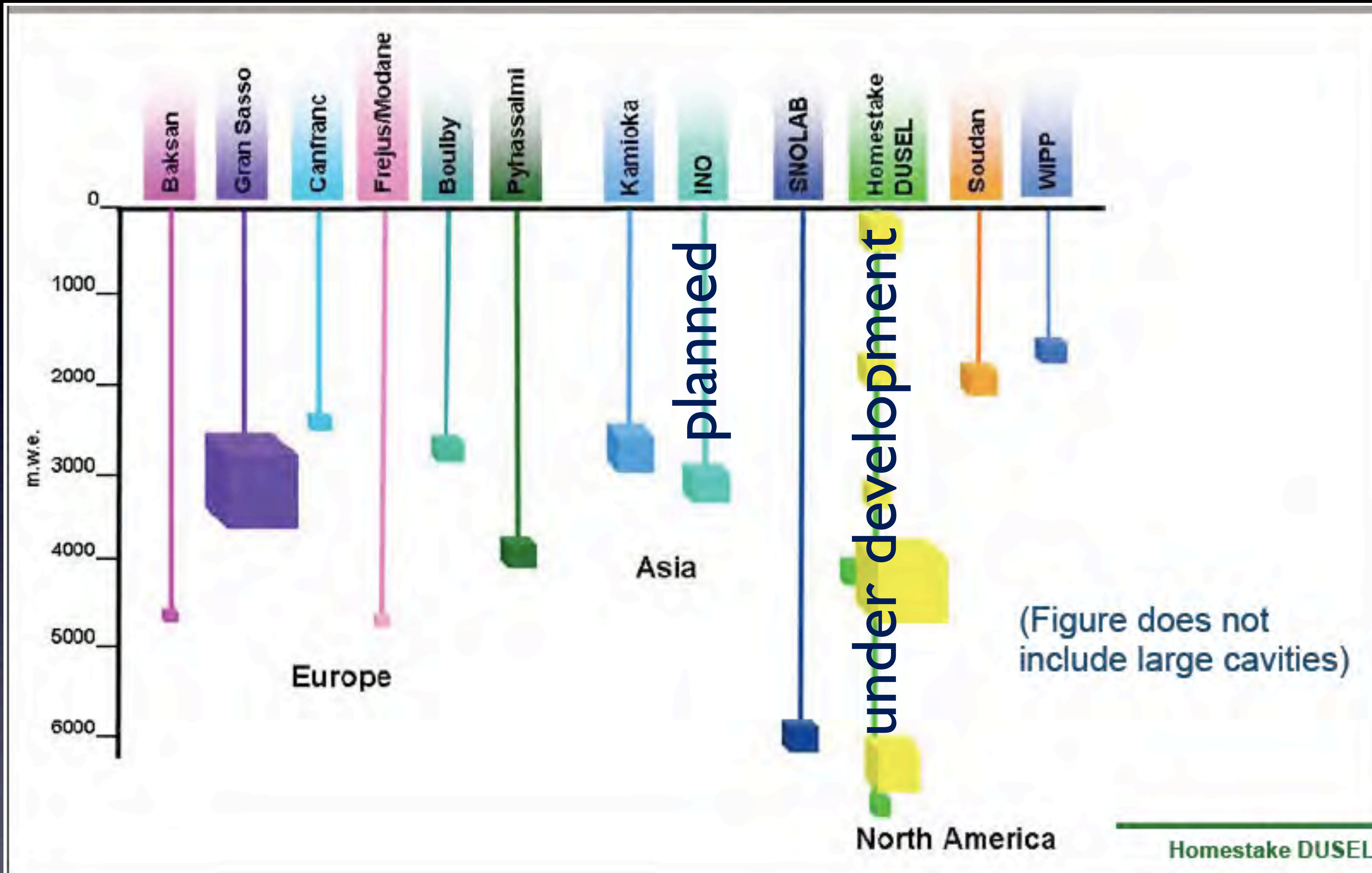
EXO200



1-10 counts/year*ton

0,1-1 count/year*ton

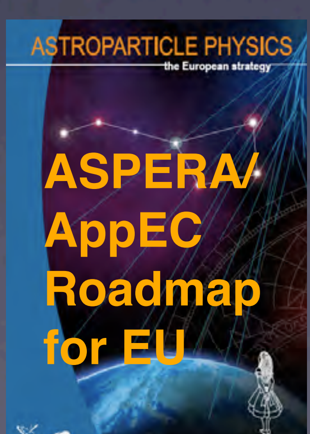
Deep Underground Labs in the world



Europe enjoys today a leading position in underground science with five national underground laboratories. LNGS is the largest in the world.

A new giant neutrino observatory in Europe ?

- **Advances in low energy neutrino astronomy and direct investigation of Grand Unification require the construction of very large volume underground observatories.**
- There is currently no such infrastructure in Europe able to host underground instruments of this size, although five national underground laboratories with high technical expertise are currently operated with leading-edge smaller-scale underground experiments.
- A pan-European infrastructure able to host underground instruments with volumes at the 100’000 m^3 scale will provide new and unique scientific opportunities in low energy neutrino astronomy and Grand Unification physics.
- This field of research is at the forefront of particle and astro-particle physics and is the subject of intense investigation also in North America and Asia. Such an infrastructure in Europe would attract scientists from all over the world and ensure that Europe will continue to play a leading and innovative role in the field.



“recommend that a new large European infrastructure is put forward as a future international multi-purpose facility on the 100-1000 ktons scale for improved studies of proton decay...”

➡ **LAGUNA project**

European LAGUNA project

Large Apparatus for Grand Unification and Neutrino Astrophysics

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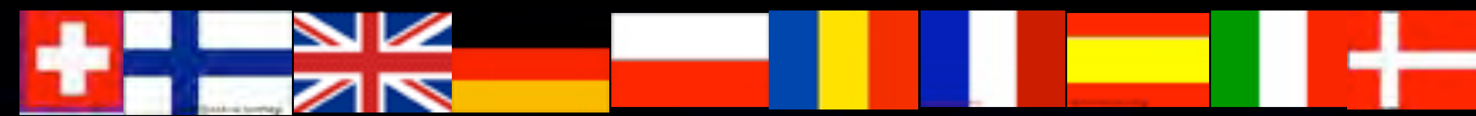


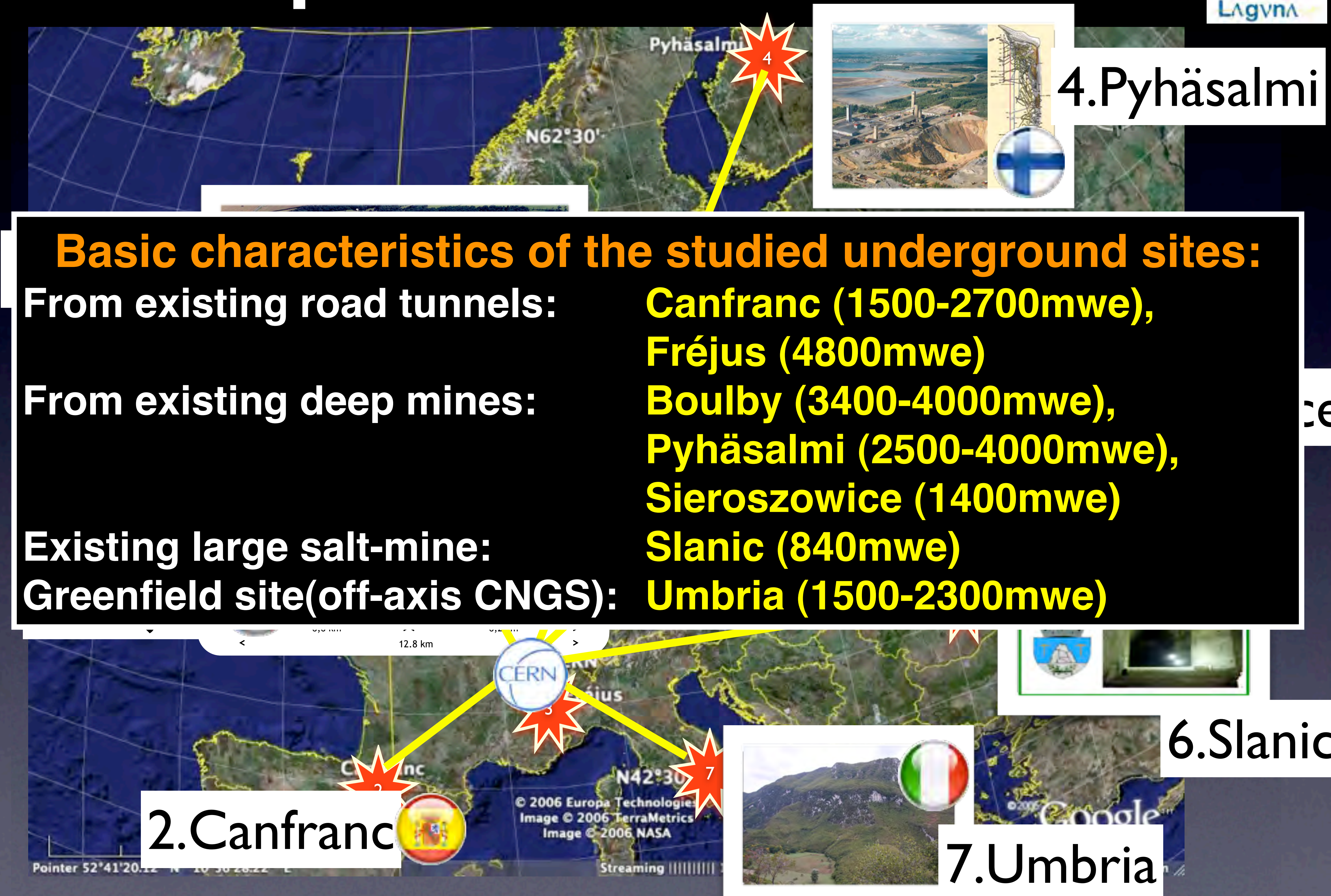
- European physicists interested in massive neutrino detectors; geo-technical experts, geo-physicists; structural engineers; tank, rock mechanical&underground and mining engineers
- about 100 members
- 28 institutions
- 10 countries
- multidisciplinary
- academic and industrial partners

http://www.laguna-science.eu/

***Objective*: defining and realizing this research programme in Europe**

Seven pre-selected EU sites

Seven pre-selected EU sites

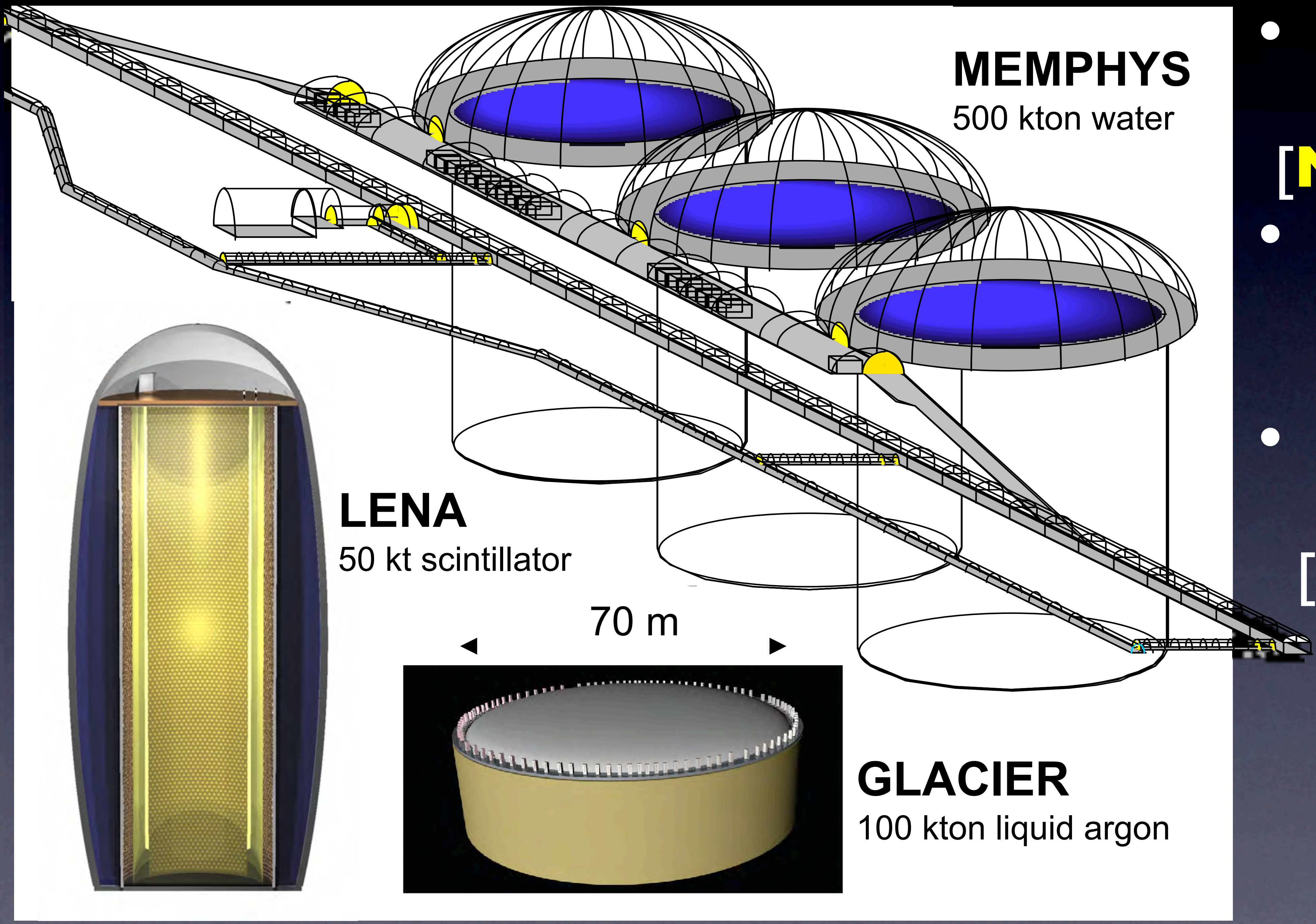


Basic characteristics of the studied underground sites:

From existing road tunnels:	Canfranc (1500-2700mwe), Fréjus (4800mwe)
From existing deep mines:	Boulby (3400-4000mwe), Pyhäsalmi (2500-4000mwe), Sieroszowice (1400mwe)
Existing large salt-mine:	Slanic (840mwe)
Greenfield site(off-axis CNGS):	Umbria (1500-2300mwe)

Detector technology options

- **Next generation deep underground neutrino observatory**
  - Three technology options considered (MEMPHYS, LENA, GLACIER) with total active mass in the range 50’000-500’000 tons



- Water Cerenkov [**MEMPHYS**]
- Liquid scintillator [**LENA**]
- Liquid Argon TPC [**GLACIER**]

LAGUNA at work (2008-2011)

FP7 "Design Studies" Research Infrastructures
LAGUNA Grant Agreement No. 212343

Typical questions addressed

- assessment of strengths and weaknesses
- rock mechanics of caverns
- design of tanks in relation to sites
- overburden vs. detector options
- transport, access, delivery of liquids
- safety e.g. tunnel vs. mine
- environment e.g. rock removal
- relative costs

WP2: Underground infrastructures and Engineering

WP3: Safety, environmental and socio-economic issues

WP4: Science Impact and Outreach

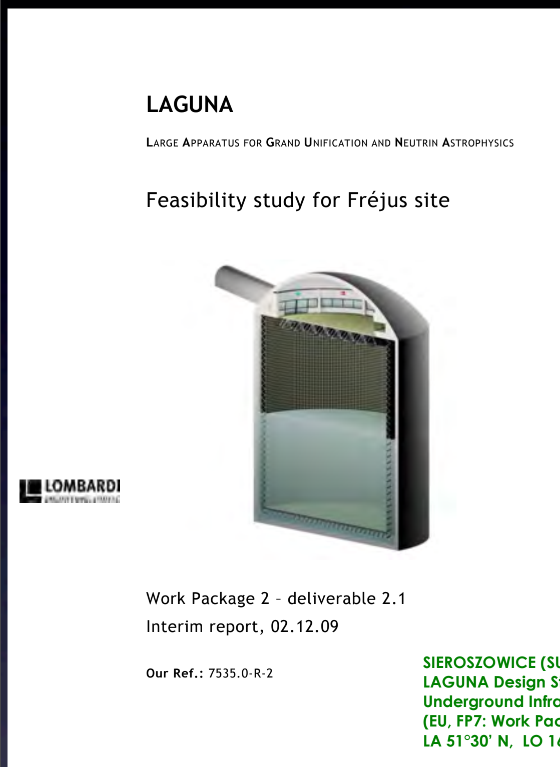
Site visits and meeting

- sites work together on common areas

Several technical reports

Interim site-dependent geotechnical reports: delivered!

Final joint report on potential European sites: soon


LAGUNA

LARGE APPARATUS FOR GRAND UNIFICATION AND NEUTRIN ASTROPHYSICS

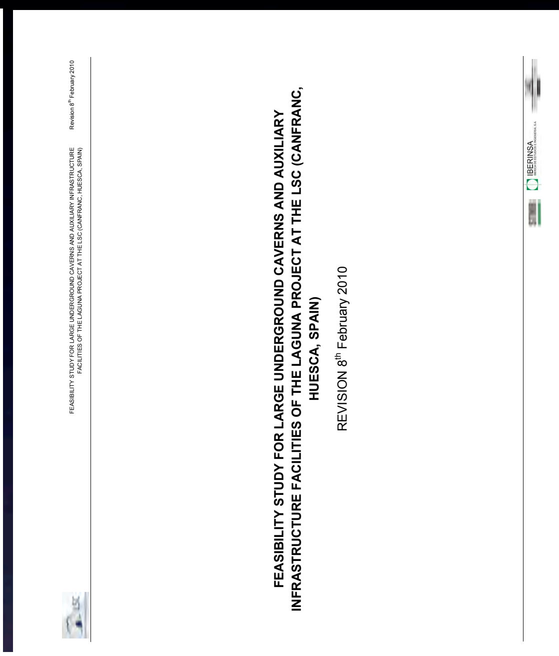
Feasibility study for Fréjus site

LOMBARDI

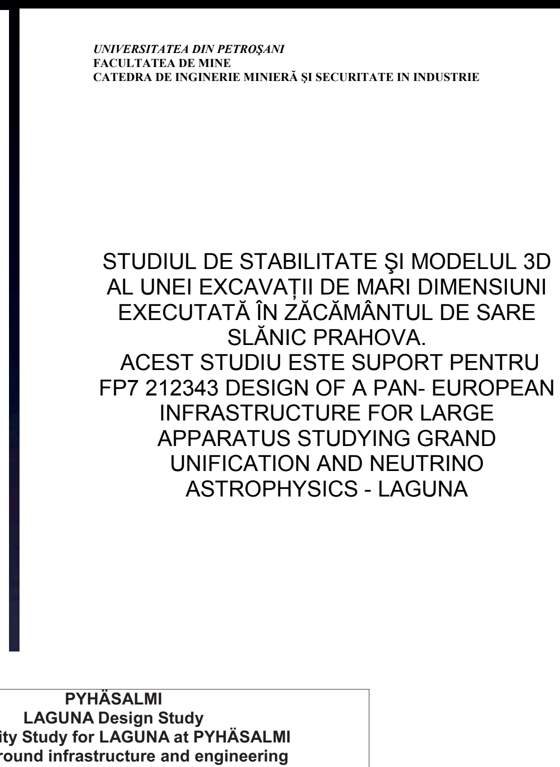
Work Package 2 - deliverable 2.1

Interim report, 02.12.09

Our Ref.: 7535.0-R-2


FEASIBILITY STUDY FOR LARGE UNDERGROUND CAVERNS AND AUXILIARY INFRASTRUCTURE FACILITIES OF THE LAGUNA PROJECT AT THE LSC (CANFRANC, HUESCA, SPAIN)

REVISION 8th February 2010

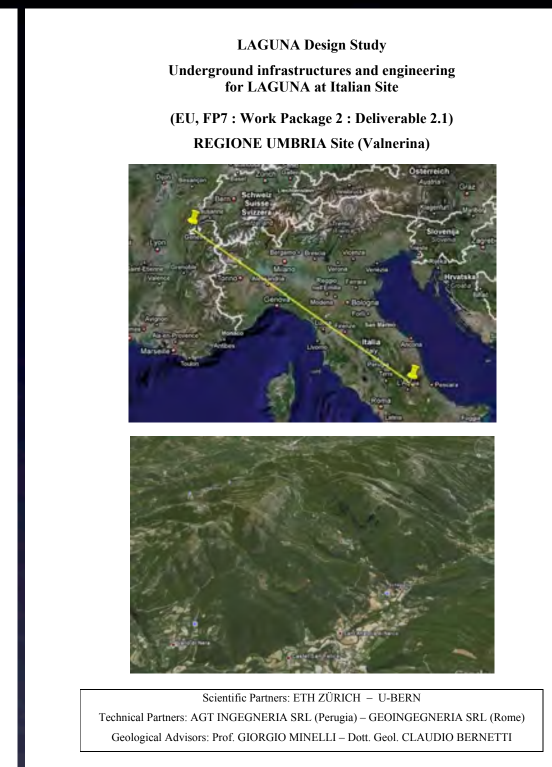

UNIVERSITATEA DIN PETROŞANI

FACULTATEA DE MINE

CATEDRA DE INGINERIE MINIERĂ ŞI SECURITATE IN INDUSTRIE

STUDIUL DE STABILITATE ŞI MODELUL 3D AL UNEI EXCAVAŢII DE MARI DIMENSIUNI EXECUTATĂ ÎN ZĂCĂMÂNTUL DE SARE SLĂNIC PRAHOVA.

ACEST STUDIU ESTE SUPORT PENTRU FP7 212343 DESIGN OF A PAN- EUROPEAN INFRASTRUCTURE FOR LARGE APPARATUS STUDYING GRAND UNIFICATION AND NEUTRINO ASTROPHYSICS - LAGUNA


LAGUNA Design Study

Underground infrastructures and engineering for LAGUNA at Italian Site

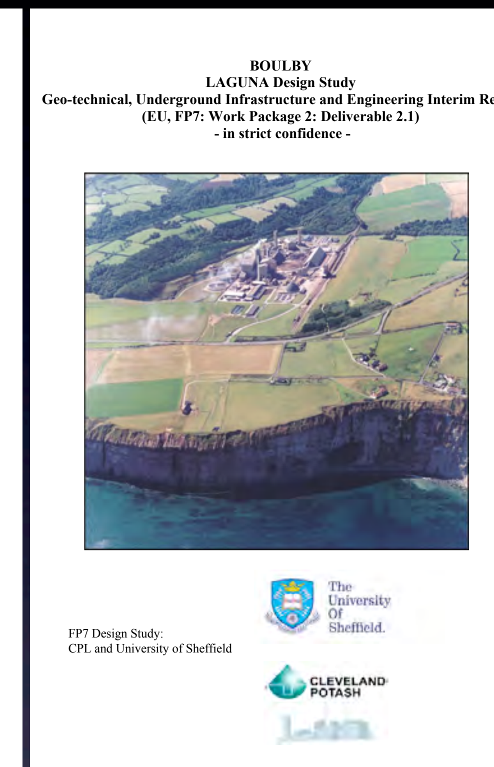
(EU, FP7 : Work Package 2 : Deliverable 2.1)

REGIONE UMBRIA Site (Valnerina)

Scientific Partners: ETH ZÜRICH – U-BERN

Technical Partners: AGT INGEGNERIA SRL (Perugia) – GEOINGEGNERIA SRL (Rome)

Geological Advisors: Prof. GIORGIO MINELLI – Dott. Geol. CLAUDIO BERNETTI


BOULBY

LAGUNA Design Study

Geo-technical, Underground Infrastructure and Engineering Interim Report

(EU, FP7: Work Package 2: Deliverable 2.1)

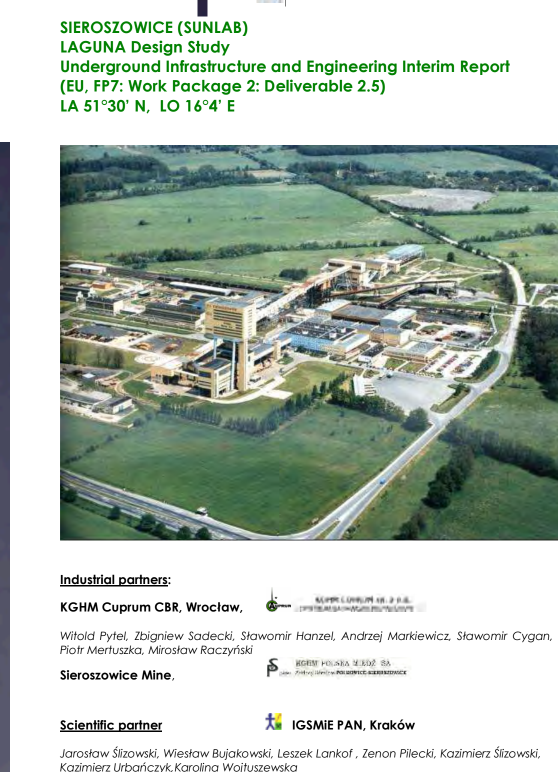
- in strict confidence -

FP7 Design Study:

CPL and University of Sheffield

The University Of Sheffield.

CLEVELAND POTASH


SIEROSZOWICE (SUNLAB)

LAGUNA Design Study

Underground Infrastructure and Engineering Interim Report

(EU, FP7: Work Package 2: Deliverable 2.5)

LA 51°30' N, LO 16°4' E

Industrial partners:

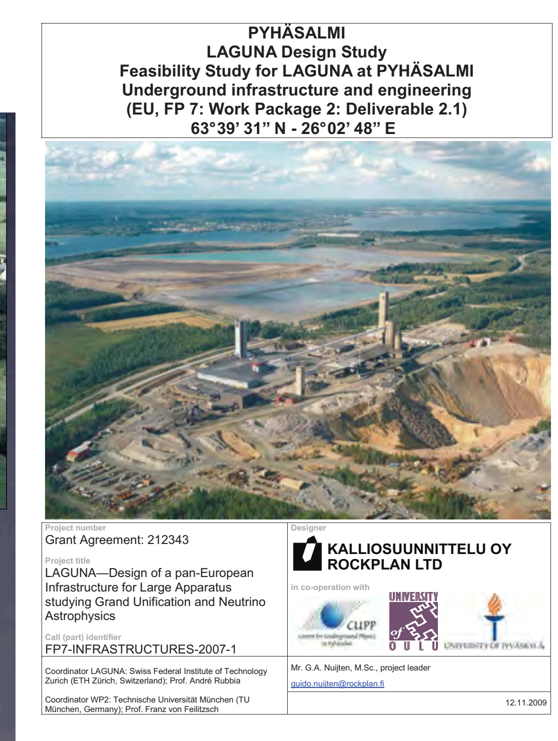
KGHM Cuprum CBR, Wrocław,

Witold Pytel, Zbigniew Sadecki, Sławomir Hanzel, Andrzej Markiewicz, Sławomir Cygan, Piotr Mertuszka, Mirosław Raczyński

Sieroszowice Mine,

Scientific partner — **IGSMiE PAN, Kraków**

Jarosław Ślizowski, Wiesław Bujakowski, Leszek Lankof , Zenon Pilecki, Kazimierz Ślizowski, Kazimierz Urbańczyk,Karolina Wojtuszewska


PYHÄSALMI

LAGUNA Design Study

Feasibility Study for LAGUNA at PYHÄSALMI

Underground infrastructure and engineering

(EU, FP 7: Work Package 2: Deliverable 2.1)

63°39' 31" N - 26°02' 48" E

Project number Grant Agreement: 212343 Project title LAGUNA—Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics Call (part) identifier FP7-INFRASTRUCTURES-2007-1	Designer KALLIOSUUNNITTELU OY ROCKPLAN LTD in co-operation with CUPP UNIVERSITY of OULU
Coordinator LAGUNA: Swiss Federal Institute of Technology Zurich (ETH Zürich, Switzerland); Prof. André Rubbia Coordinator WP2: Technische Universität München (TU München, Germany); Prof. Franz von Feilitzsch	Mr. G.A. Nuijten, M.Sc., project leader guido.nuijten@rockplan.fi 12.11.2009

- more than 1200 pages
- large amount of information and details
- healthy competition among sites
- publicly available

Preliminary LAGUNA findings

1. All the pre-selected sites appear technically and environmentally feasible, so there are several options (unlike in Japan or now USA), though not all sites are interested in all detector options.
2. It appears technically feasible to excavate the desired underground caverns and infrastructures, to build the necessary tanks underground, and to fill them with the desired liquids.
3. The liquid procurement with the needed quantities is feasible for all sites and for all liquids (Water, LAr, LScint), although it might take several calendar years to reach the full *in-situ* procurement.
4. The cost of the excavation, although non-negligible, is not the dominant cost of the project. In order to proceed towards a technology choice, a better understanding of the costs of the full detector design and construction including their instrumentation for the three detector options is essential.
5. Studies indicate that some European options offer potential physics and/or technical advantages that need to be specially and carefully confronted with other options worldwide.
6. The physics goals play a dominant role in selecting the site !

LAGUNA-LBNO

Attention is needed to the US and Japan LBL situation and requires more concrete considerations of the perspectives of long baseline neutrino oscillations within the LAGUNA programme.

- **LBNE is proceeding with both water and LAr with a baseline that is fixed to 1300 km. It needs a new beamline and at least one far detector. The beam power will be 700 kW until ProjectX is operational (>2020?).**
- **Japan has an existing J-PARC beam with an upgrade plan to 1.66MW (>2014) and two fixed possibilities for the baseline (Kamioka @ 300km and Okinoshima @ 658 km).**

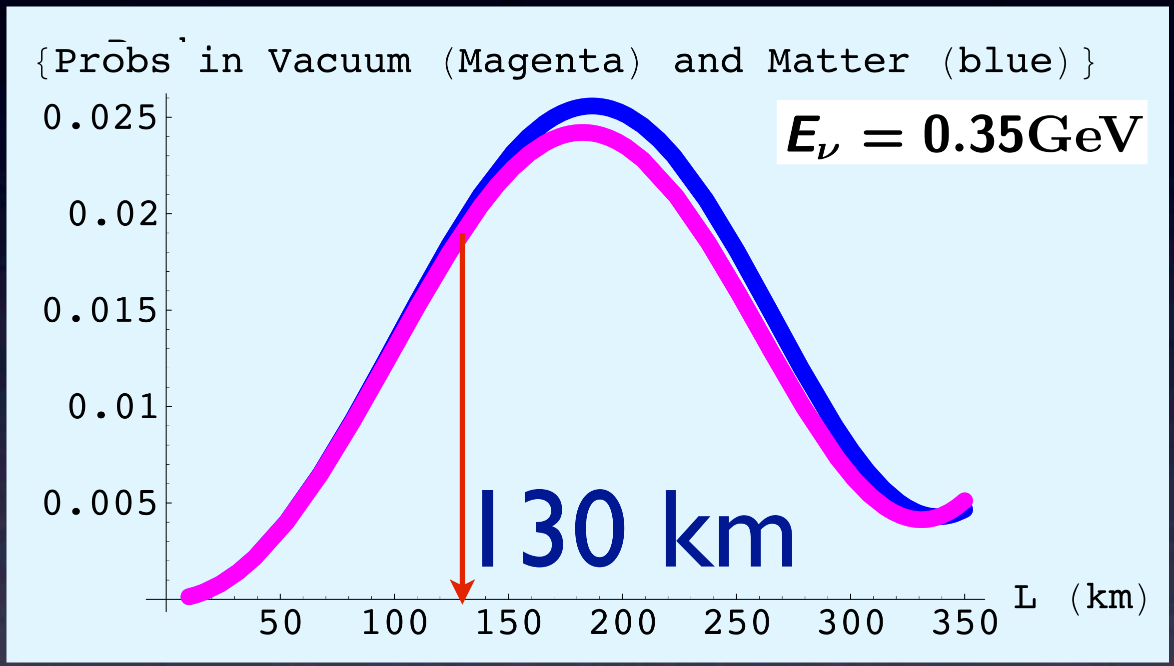
Europe has *a priori* the benefit of more flexibility in choice of both beam and baseline, and detector technology. We focus on three options where CERN-LAGUNA can be competitive:

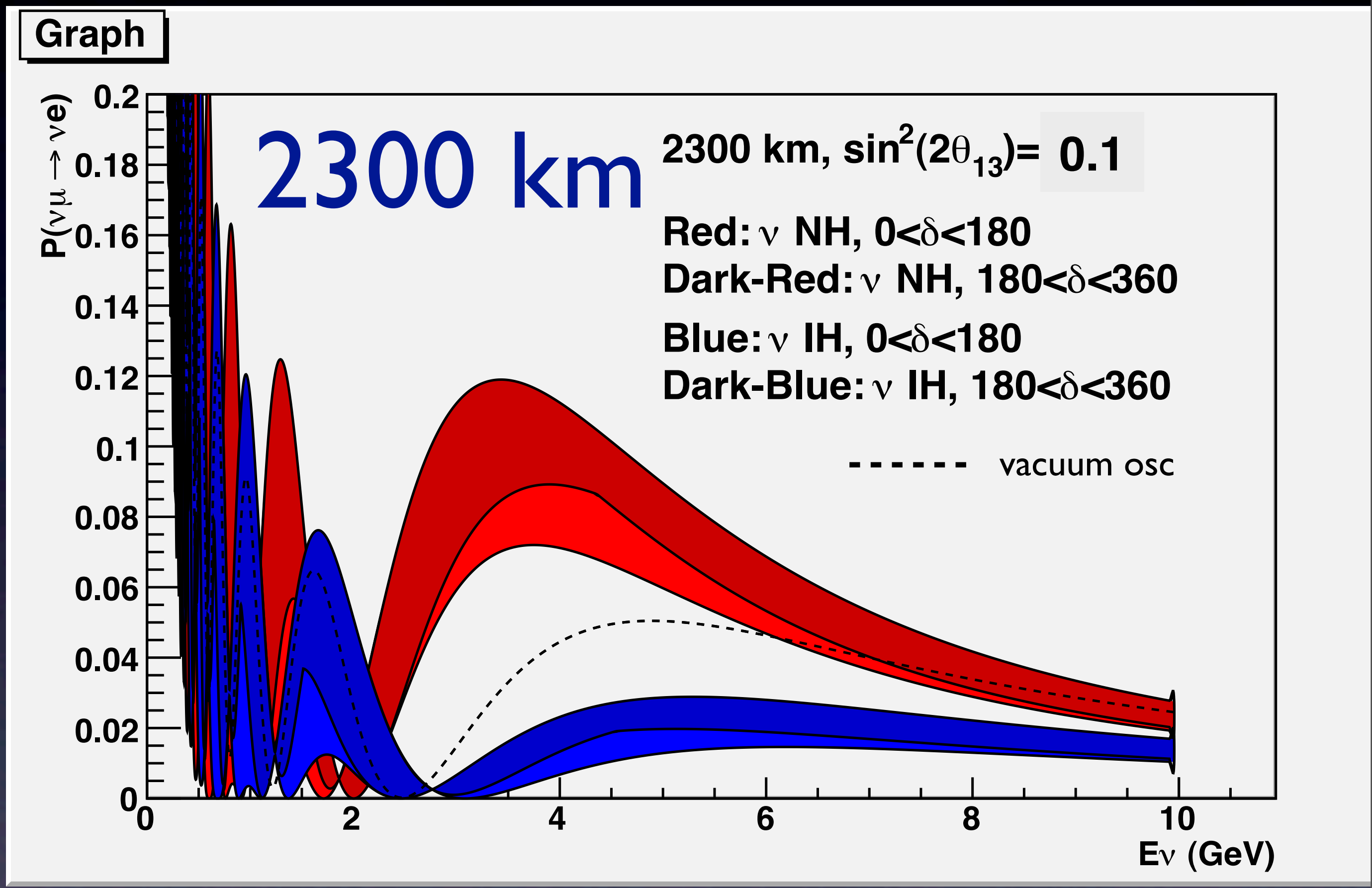
(a) existing CNGS beam ➠ Umbria (or LNGS') 650-732km
(b) shortest baseline, no matter effect ➠ Fréjus 130km
(c) longest baseline, matter effect ➠ Pyhäsalmi 2300 km

Very short/long baseline concept

CERN-Fréjus offers a very short baseline not considered elsewhere in the world ➠ unique physics opportunities in Europe

CERN-Pyhäsalmi offers a very long baseline not considered elsewhere in the world ➠ unique physics opportunities in Europe





Determine CPV by comparison of neutrinos/antineutrinos in absence of competing matter effects

need very low energy beam and huge (WC) detector

Adequate baseline/energy for betabeam

Determine CPV and mass hierarchy by spectrum measurement and resolve degeneracies and so-called “π-transit” effect

arXiv:0908.3741v1 for “Magic distance”

Adequate baseline for neutrino factory

LAGUNA-LBNO FP7 DS ?

Planned submission as FP7 Design Study - Call 2010

Work Packages

WP1 : Management, Outreach, International relations

WP2 : Detector R&D and Design, Cost Estimation including Underground Construction, and Large Volume Magnetization

WP3 : Definition of Detector Operation and Liquid Processes - Project Lifetime Costs and Safety

WP4 : Conventional Neutrino Beams from CERN to LAGUNA and Conceptual Design of Near Detectors

WP5 : Underground Science and Physics Potential

The CERN laboratory plans to participate to the study for what concerns the feasibility of the neutrino beam (WP4). The far underground observatory, including its astroparticle physics programme, remains in the domain of the LAGUNA consortium.

LAGUNA - Schedule

Paper Design Study (EU funded):	2008-2011
Categorize the sites and down-select:	July 2010
Study detector design and beam options (LAGUNA-LBNO ? call end 2010):	2011-2013
Critical decision	2014 ?
Phase 1 excavation-construction:	2015-2020 ?
Phase 2 excavation-construction:	>2020 ?

Timeline matched to a new potential CERN neutrino beams in >2016

Conclusions

Growing worldwide interest and activities on next-generation underground large neutrino and proton decay detectors, requiring both new sites and detector technologies

Europe enjoys today the most experience in underground science and sites
Within LAGUNA it has a well defined roadmap & timeline
- a large amount of technical expertise has been gathered to reach the conclusions and a strong collaboration has developed since 2008
- no obvious geo-technical show-stoppers so far - but several challenges (e.g. cost of deep underground construction, liquid procurement, financing...)
- prioritize sites in 2010, study perspectives for LBL, detector technology choice

Big range of CERN baselines are feasible (130 km - 2300 km)
- includes possibility of very short and very long baselines
- LAGUNA timeline matched to potential superbeam from CERN

It is clear that Europe has great relevant infrastructure and expertise to build LAGUNA, we can benefit from this
- LAGUNA mainly towards a European research infrastructure but strongly linked to projects world-wide that consider same physics goals (future J-PARC and LBNE). Worldwide coherence and coordination is the only winning strategy for a project of this scale.