Underground Synergies with Astro-particle Physics: Multi-Disciplinary Studies in the World's Deep Underground Science Facilities

Overview of large cavities for different sites: Lessons from the LAGUNA project

Monday 17 December 2012 - Wednesday 19 December 2012

Durham, UK

Guido Nuijten 18.12.2012

LAGUNA - PROJECT

- **LAGUNA**
  - **Design Study: 2008 – 2010 + 1yr extension**
    Underground infrastructures and engineering
    EU, FP7-INFRASTRUCTURES, GA 212343

- **LAGUNA - LBNO**
  - **Design Study: 2011 - 2014**
    Deep Underground Facility Construction, Life Time Operation + Long Base Line Neutrino Beam
    EU, FP7-INFRASTRUCTURES, GA 284518

LAGUNA - CONTENT

LAGUNA, purpose:

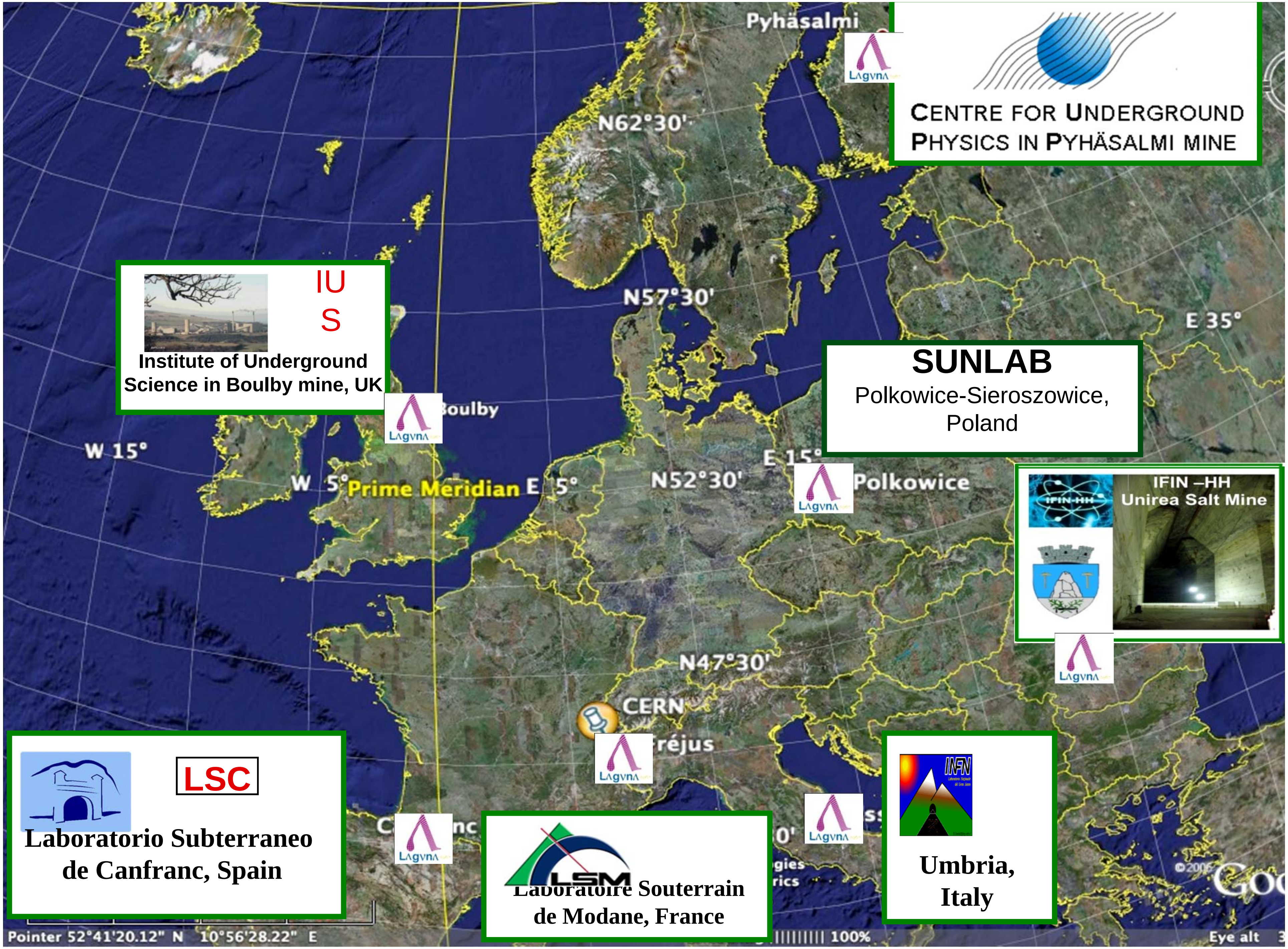
1) to study the **excavation feasibility** of the considered experiments

2) to prepare a **conceptual design** of the required underground infrastructure

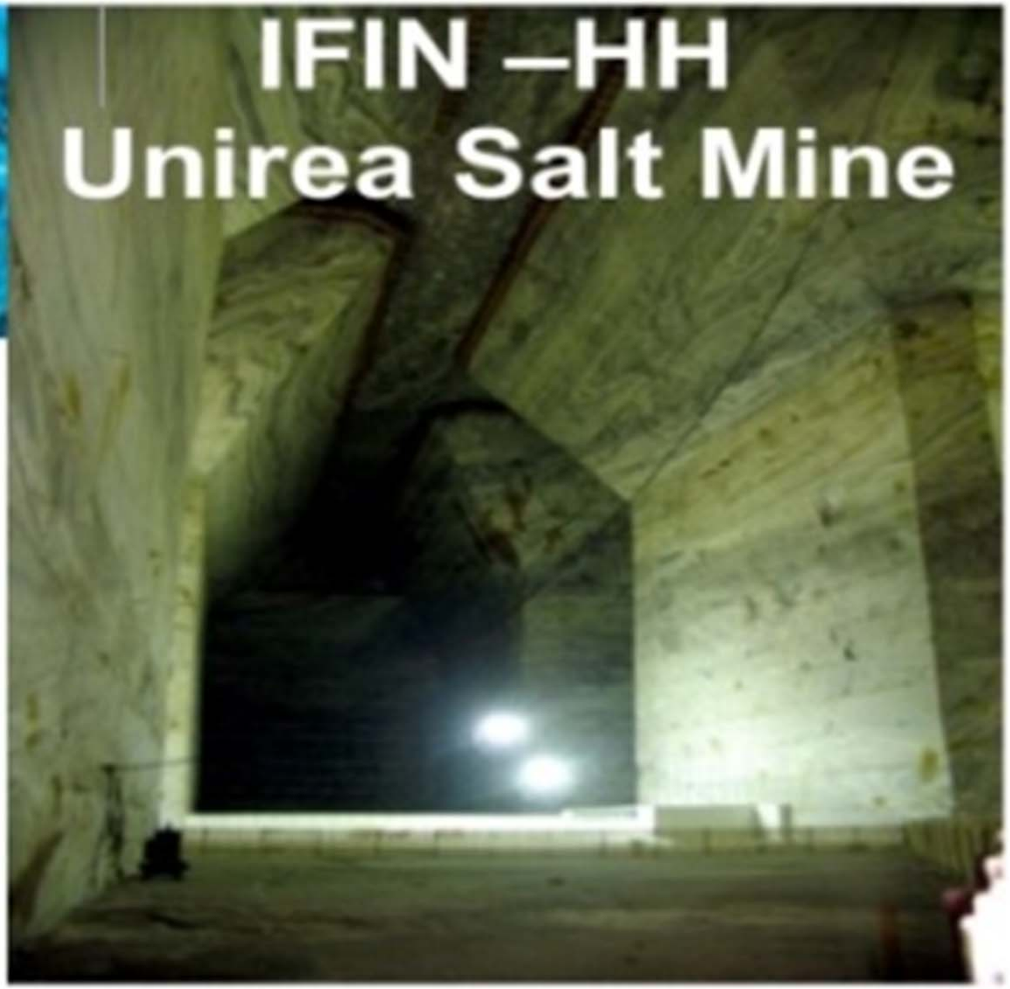
3) to **deliver** a report that allows the funding agencies to decide on the realization of the experiment and to select the site and the technology

POTENTIAL SITES

- 2.7 Slanic, Romania
- 2.6 LCS, Canfranc, Spain
- 2.5 Sunlab, Poland
- 2.4 Umbria, Italy
- 2.3 Boulby, United Kingdom
- 2.2 Modane, France
- 2.1 Pyhäsalmi, Finland

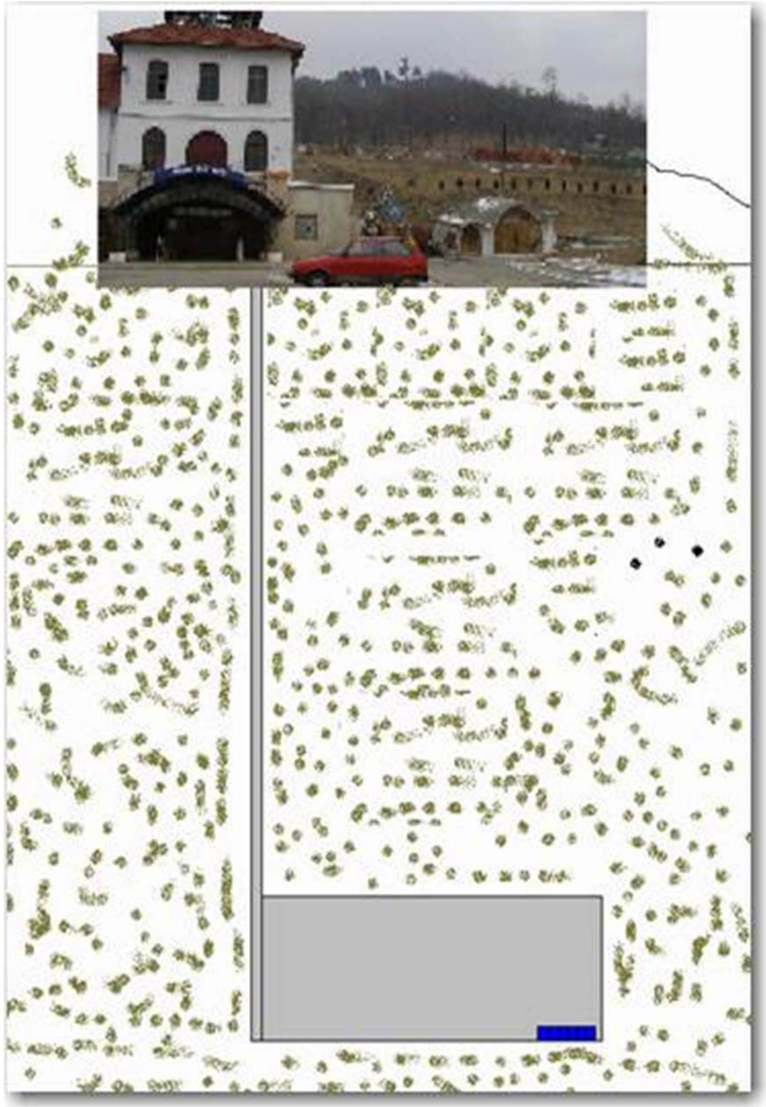

Pyhäsalmi
CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE
N62°30'
N57°30'
E 35°
IUS
Institute of Underground Science in Boulby mine, UK
Boulby
SUNLAB
Polkowice-Sieroszowice, Poland
W 15°
W 5°
Prime Meridian
E 5°
N52°30'
E 15°
Polkowice
IFIN –HH
Unirea Salt Mine
N47°30'
CERN
Fréjus
LSC
Laboratorio Subterraneo de Canfranc, Spain
LSM
Laboratoire Souterrain de Modane, France
INFN
Umbria, Italy
Pointer 52°41'20.12" N 10°56'28.22" E
100%
Eye alt

SLANIC, ROMANIA



SLANIC, ROMANIA

- The Horia Hulubei National Institute of RD of Physics and Nuclear Engineering, the University of Bucharest together with specialists from SALROM participate in FP7 Project
- In Slanic salt mine, there are already huge cavities, up to 2.9 million cubic meters, excavated at a depth higher than 600 mwe, experimentally assessed by muon flux measurement.
- The salt from Slanic deposit is very pure



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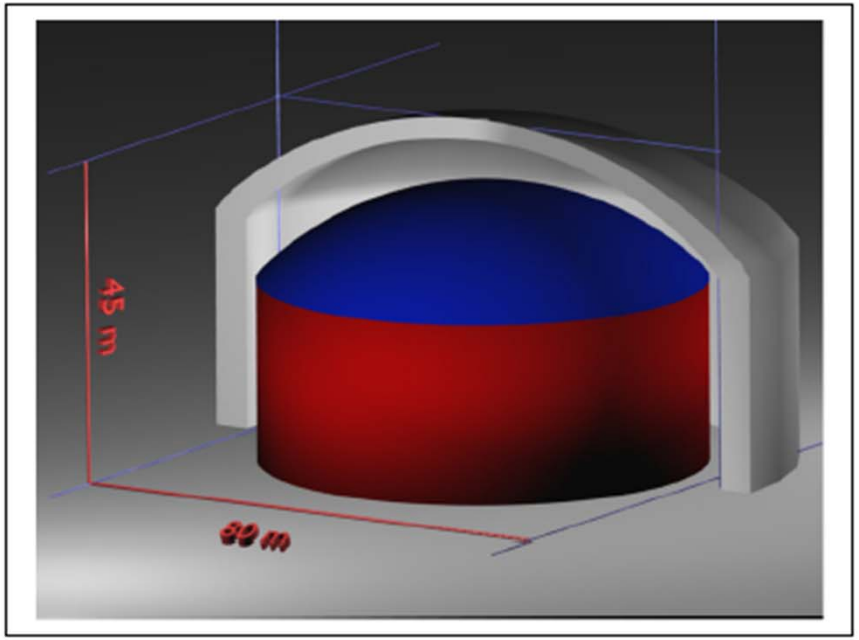
SLANIC, ROMANIA

Proposed new gallery

*If the detector will be constructed into a new gallery, than the dimensions of the gallery could have a **diameter** of up to **80 m** and **45 m height**. These dimensions offer enough space to host a tank of 72 m in diameter and 37 m height.*



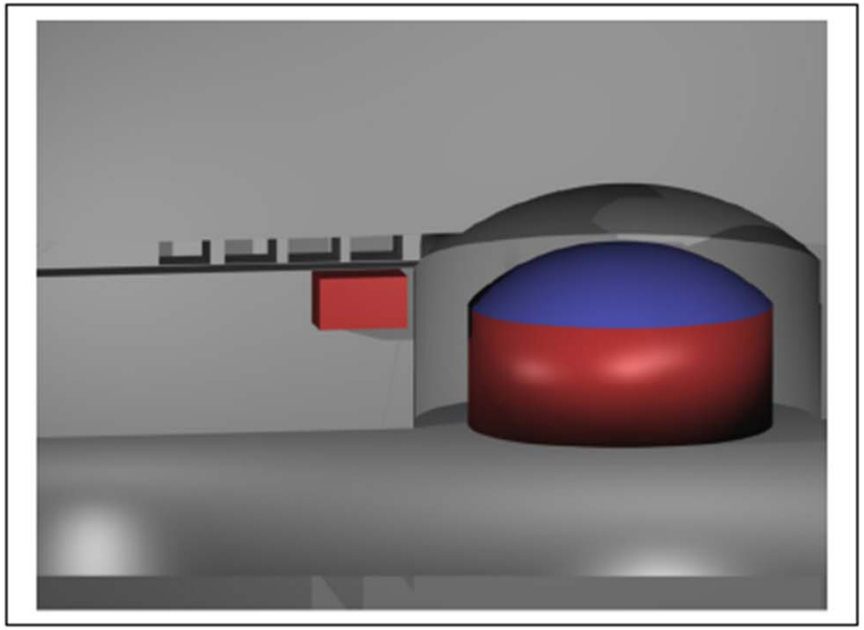


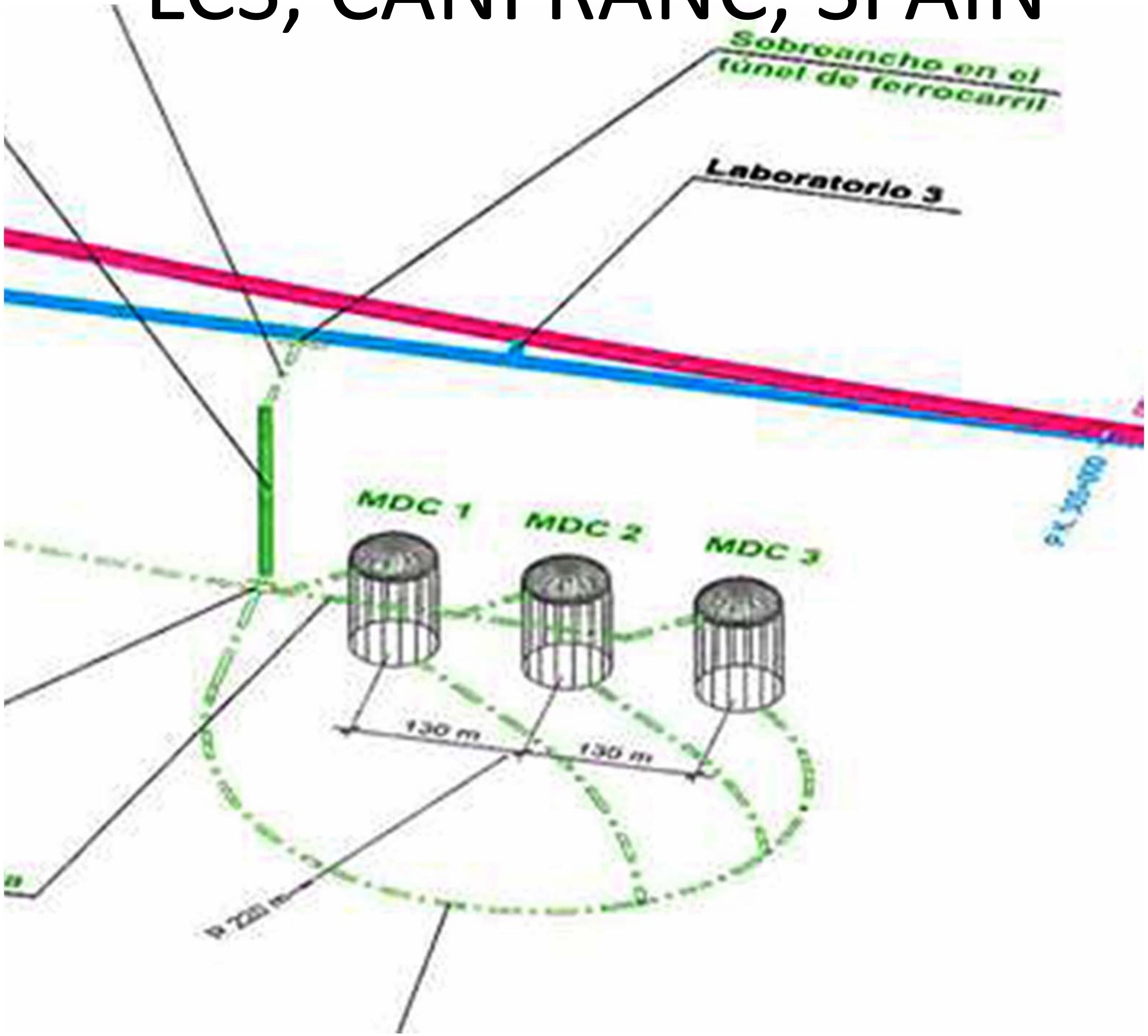
Fig. 8 The new cavern with the tank inside

SLANIC, ROMANIA

Slanic site offers several particular advantages for LAGUNA:

- Well know rock characteristics in salt
- Site depths from 300 - 350m in salt rock which are equivalent to ~1000 mwe
- Geo-mechanical studies include in-situ data and laboratory data, the salt massif is almost intact having a GSI of 98
- The salt is a valuable resource; its price on the market is 40€/ton
- Huge excavations already performed
- Good knowledge of local geological conditions in salt
- Established expertise in constructing and running an underground laboratory in a salt mine
- Existing infrastructure
- A lifetime of >50 years for a cavern of 74m in diameter and 45 m high
- A good baseline to CERN of about 1570 km
- A strong support of local and central authorities for LAGUNA at Slanic

LCS, CANFRANC, SPAIN



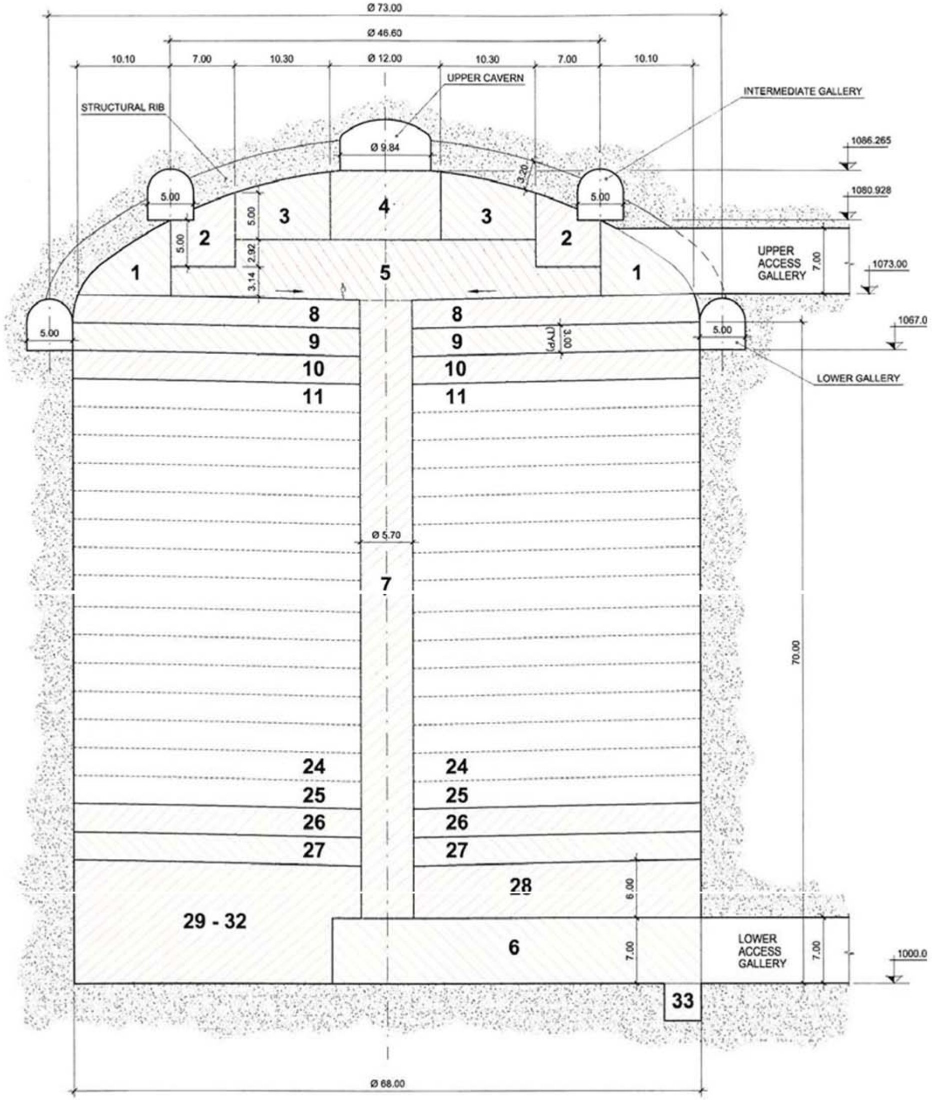
LCS, CANFRANC, SPAIN

- The Feasibility Study for Large Undeground Openings and Auxiliary Infrastructure has been carried out by a multidisciplinary team.

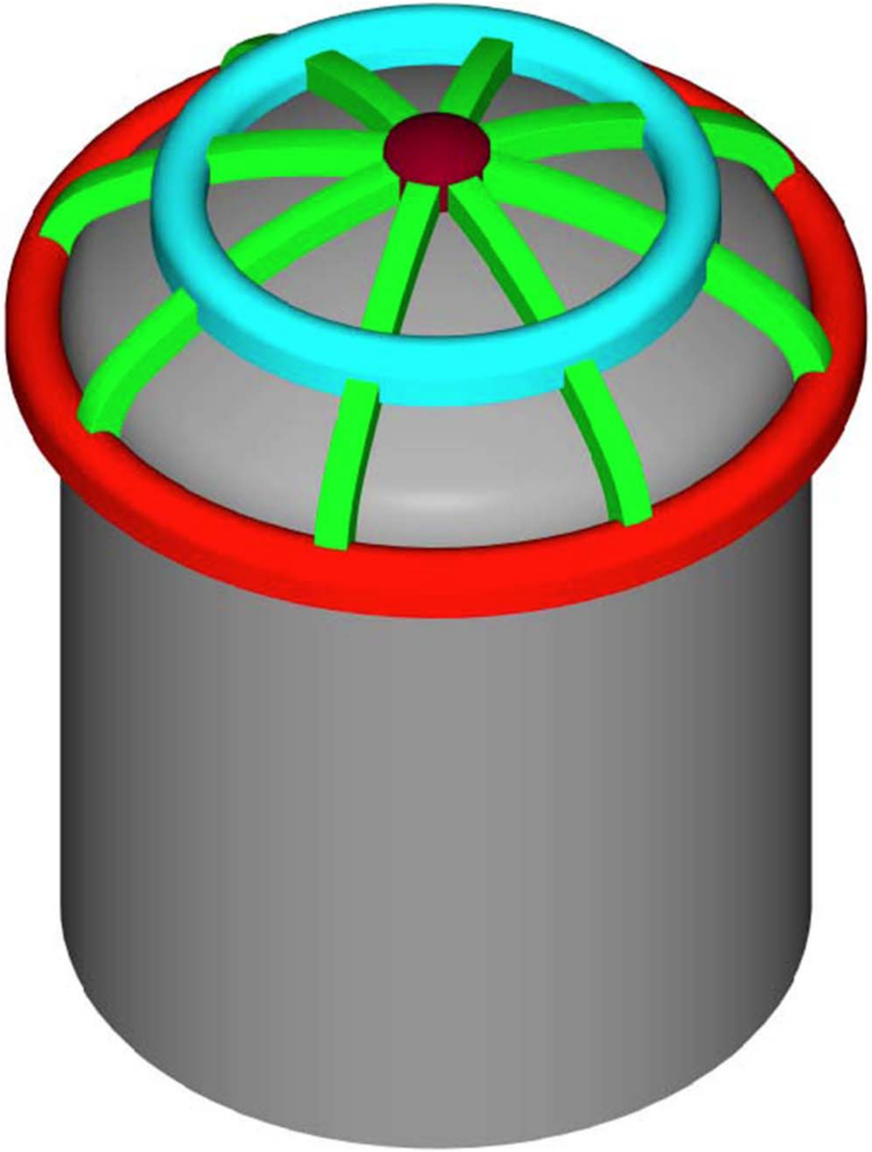
- The Contract for this Feasibility Study was awarded by the Canfranc Underground Laboratory Consortium (LSC) to IBERINSA, one of the leader engineering companies of Spain, in April, 2009.

- The team leader for the technical works development is Mr. Manuel Romana, Doctor in Civil Engineering and Professor of Rock Mechanics in the Civil Engineering School of the Universidad Politécnica de Valencia

LCS, CANFRANC, SPAIN



MEMPHYS MDC
TYPICAL EXCAVATION PROCEDURE
SCALE 1: 250



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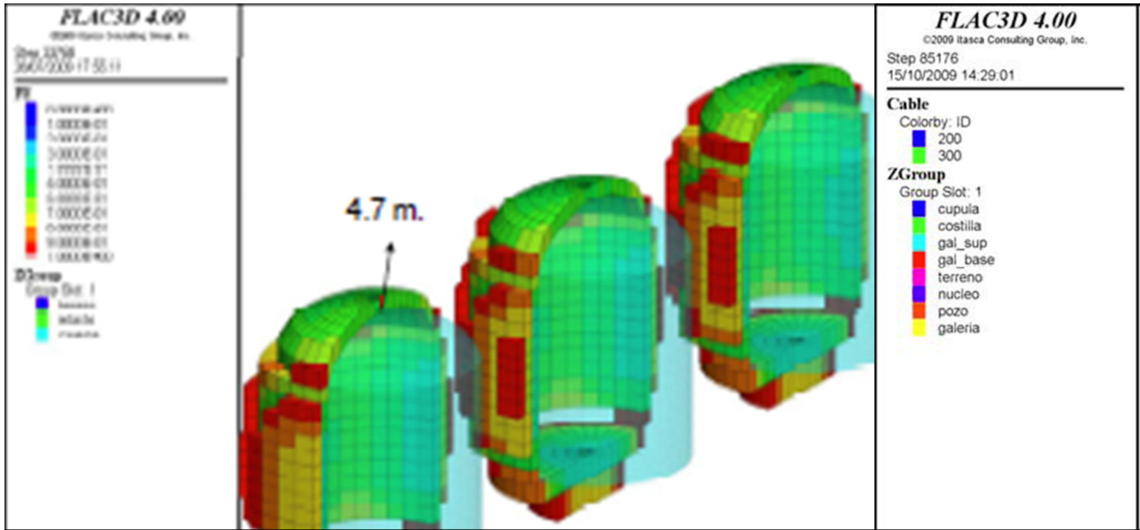
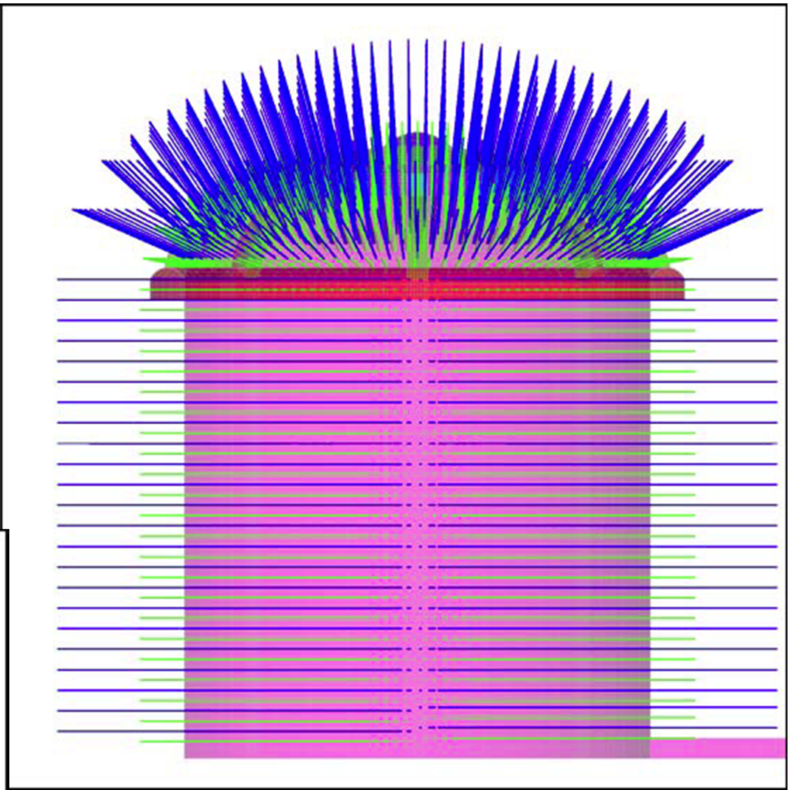
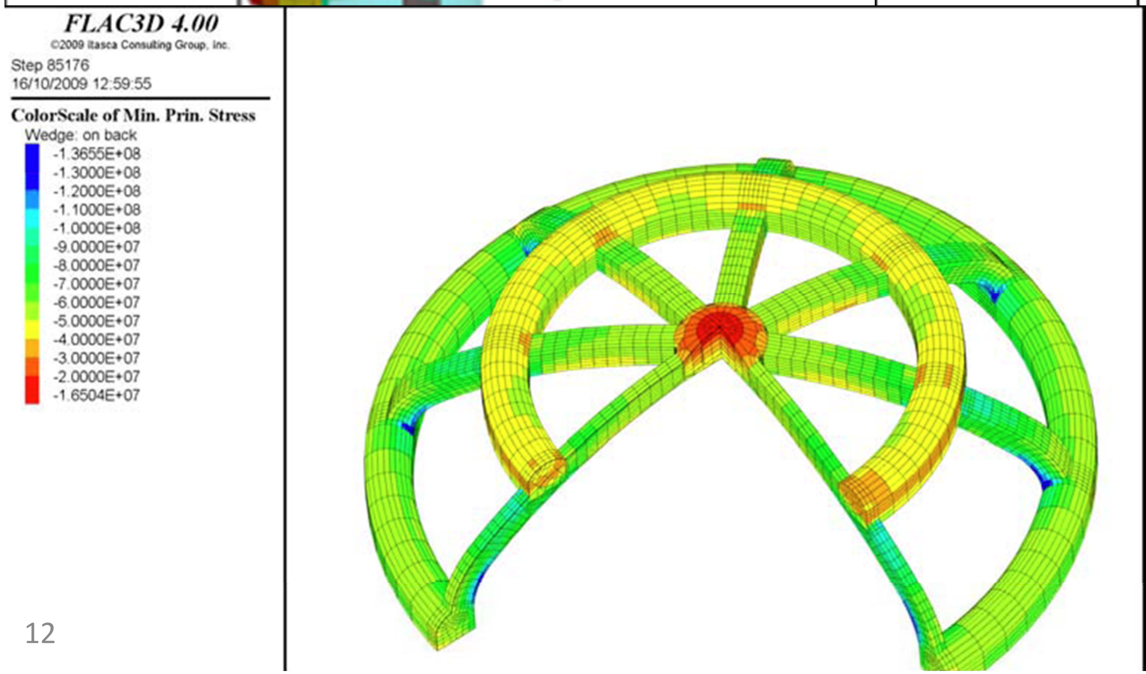
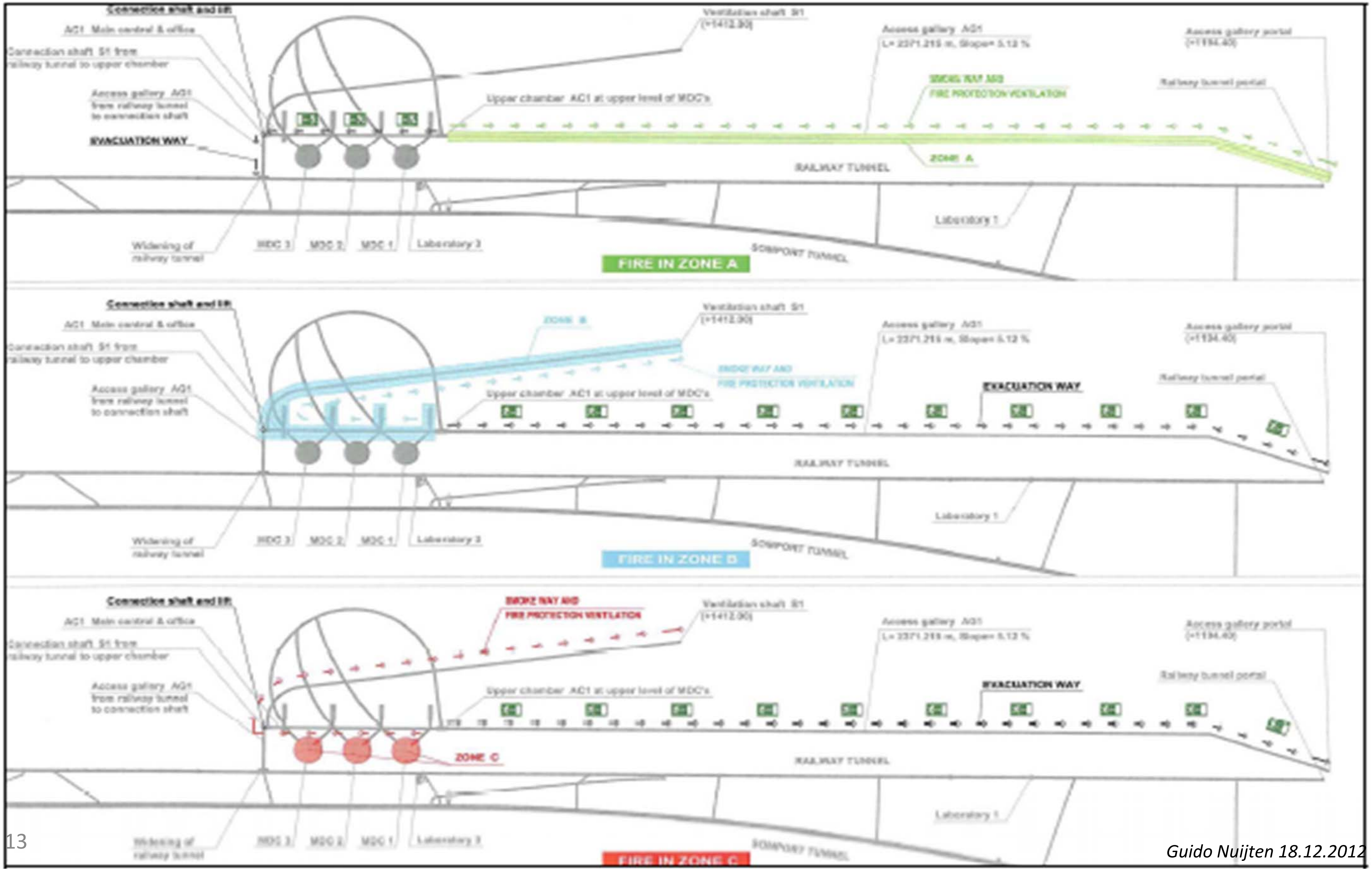
LCS, CANFRANC, SPAIN







LCS, CANFRANC, SPAIN



LCS, CANFRANC, SPAIN

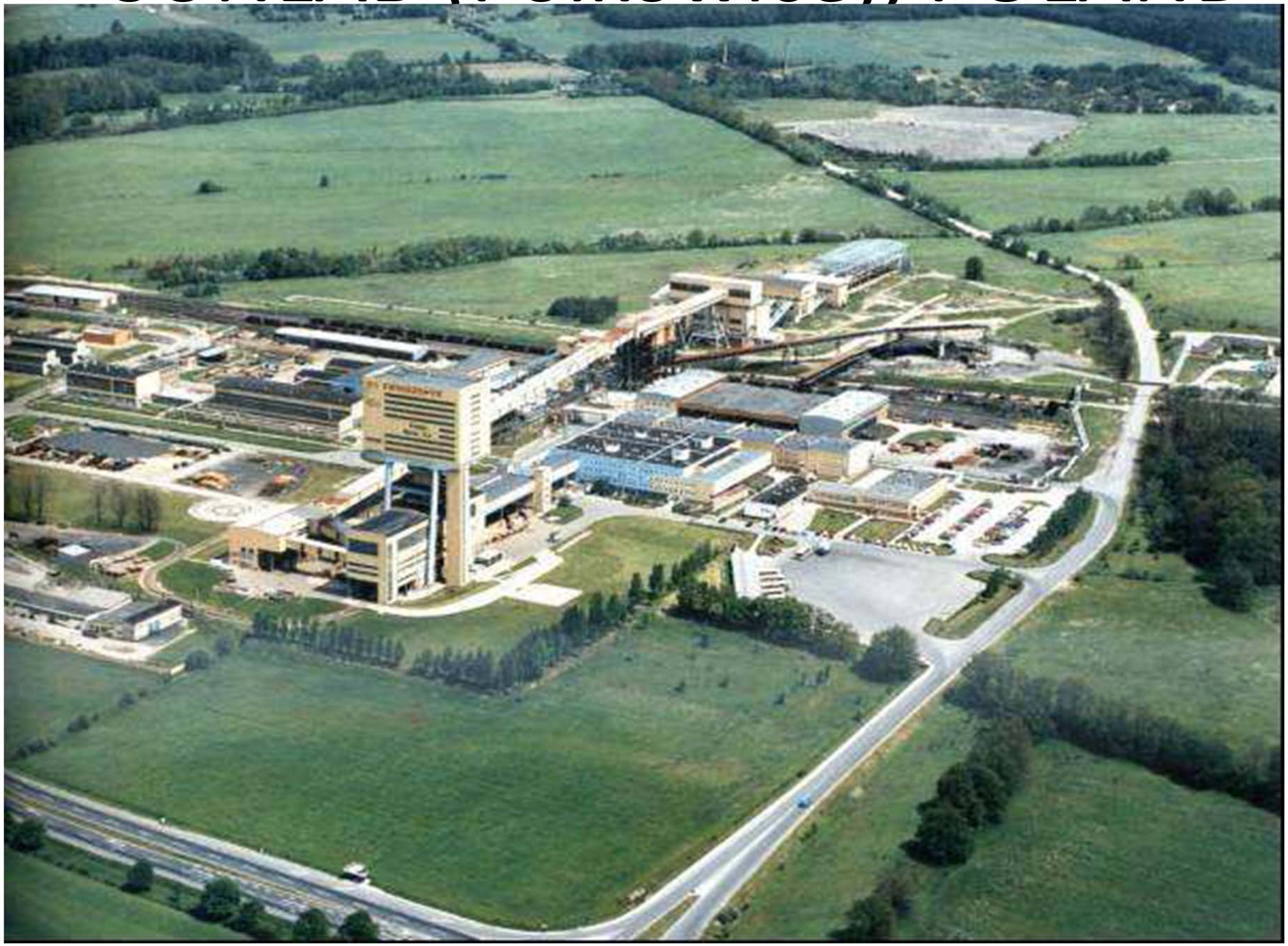
- Three detector options have been considered for the Canfranc site. The names MEMPHYS, LENA and GLACIER are those for the Water Cherenkov, Liquid Scintillator and Argon technologies.

- The general layout is similar for both MEMPHYS and LENA options, due to their location along the existing tunnel, although the Water Cherenkov experiment has been pre-designed with three large MDC´s and the LENA experiment only needs one.

- Rock cover requirements have been taken in mind in conceptual design, and allow for almost 900 m of rock overburden in both cases, the existing maximum one along the Somport Tunnel.

- In the case of the GLACIER (Argon) type, rock cover requirements are not so demanding, so the location has been selected in the aim to find the best rock quality along the tunnel, whose properties have been confirmed both with geomechanical data compiled from the excavation of the Somport tunnel face and from some selected boreholes.

SUNLAB (Polkowice), POLAND



SUNLAB (Polkowice), POLAND

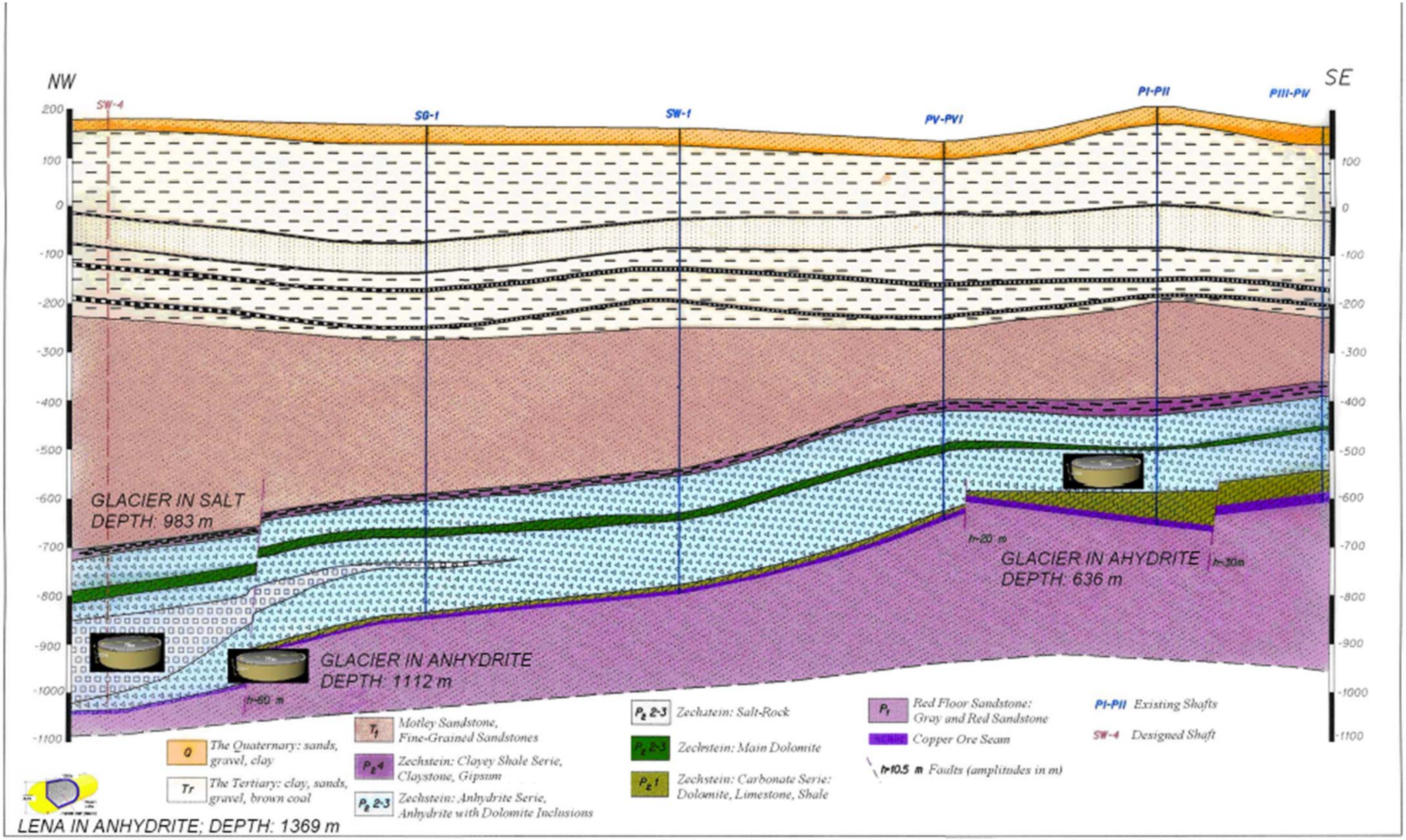
Industrial partners:

- **KGHM Cuprum CBR, Wrocław,**
- *Witold Pytel, Zbigniew Sadecki, Sławomir Hanzel, Andrzej Markiewicz, Sławomir Cygan, Piotr Mertuszka, Mirosław Raczyński*
- **Polkowice-Sieroszowice Mine**,
- *Lech Jaroń, Paweł Markowski*

Scientific partner: IGSMiE PAN, Kraków

- *Jarosław Ślizowski, Wiesław Bujakowski, Leszek Lankof, Zenon Pilecki, Kazimierz Śliwowski, Kazimierz Urbańczyk, Karolina Jaruszewska*

SUNLAB (Polkowice), POLAND



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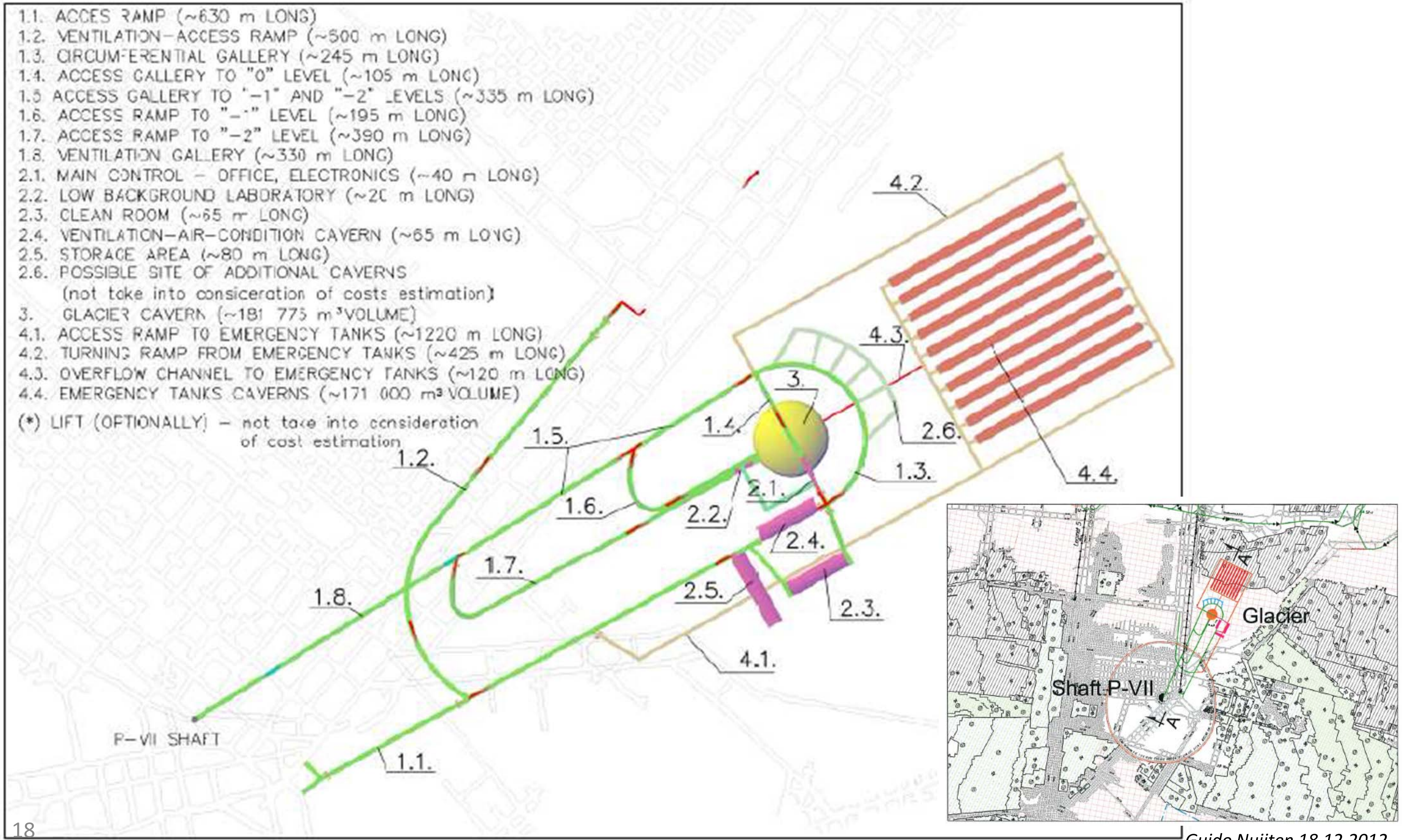

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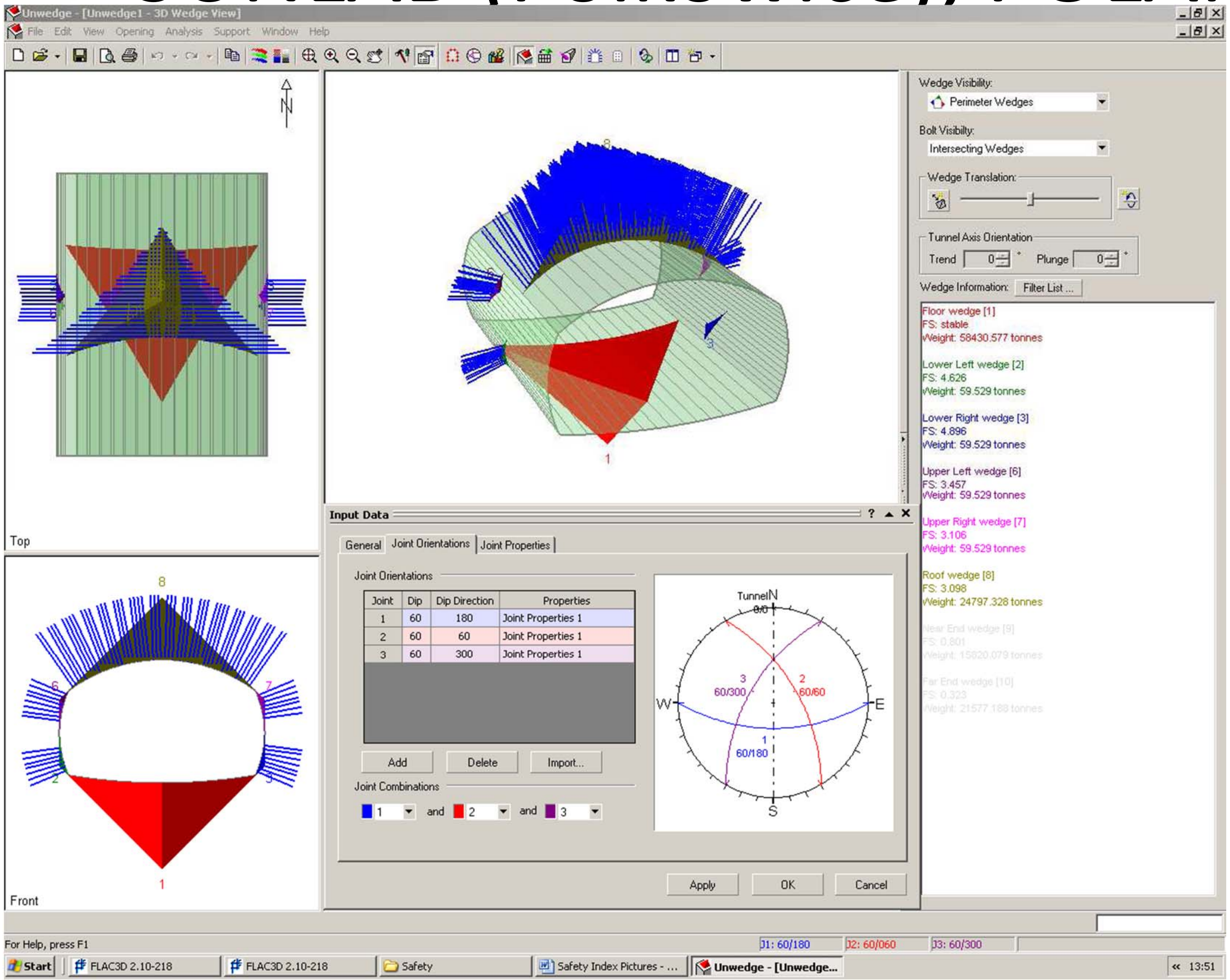

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SUNLAB (Polkowice), POLAND

Conclusions from the feasibility studies

- Anhydrite layers in Polkowice-Sieroszowice mine provide excellent conditions for locating the LAGUNA laboratory,
- Strong point of the Polkowice-Sieroszowice location are very low levels of radio-nuclides in its rocks, especially in salt.
- Polkowice-Sieroszowice mine has more than 30-years long mining tradition resulting in experience in excavation work, highly qualified mining engineers, equipment for large scale underground work.
- The mine infrastructure includes a number of large access shafts, an extended network of underground roads, ventilation system, machines for a fully mechanized extraction work and cars for the underground transport,
- Geomechanical stability of the detector chamber is guaranteed by two independent analyses made by KGHM CUPRUM CBR and by IGSMiE PAN,

SUNLAB (Polkowice), POLAND

Conclusions from the feasibility studies

- Four different locations of the laboratory, at different depths (from 600 m to more than 1300 m) and within different types of rocks (saltrock and anhydrite) have been evaluated.
- A single type of rock was required, because crossing the borders between different types of rock was considered too risky for huge, pioneer excavations of the LAGUNA caverns.
- After appropriate geomechanical and technological analyses, the thick anhydrite complex located at more than 600 m below the ground in a vicinity of the large shaft P-VII in the Polkowice-Sieroszowice mine has been selected as the best site for the LAGUNA laboratory.
- All performed studies indicate that the GLACIER type of detector fits favorably to geological and mining conditions of the Polkowice-Sieroszowice mine, mainly because this detector can be easily located in a single type of rock.

UMBRIA, ITALY

UMBRIA, ITALY

Scientific Partners:

ETH ZÜRICH .– U-BERN

Technical Partners:

AGT INGEGNERIA SRL (Perugia)

GEOINGEGNERIA SRL (Rome)

Geological Advisors:

Prof. GIORGIO MINELLI

Dott. Geol. CLAUDIO BERNETTI

UMBRIA, ITALY

- The Italian Site, unlike other sites analyzed in this Feasibility Study, is not corresponding to existing infrastructures, such as mines or tunnels;

- it has been located referring to a hypothesis of .“off-axis.” experiment using existing neutrinos beam from CERN .– Geneva to LNGS (Gran Sasso National Laboratory).

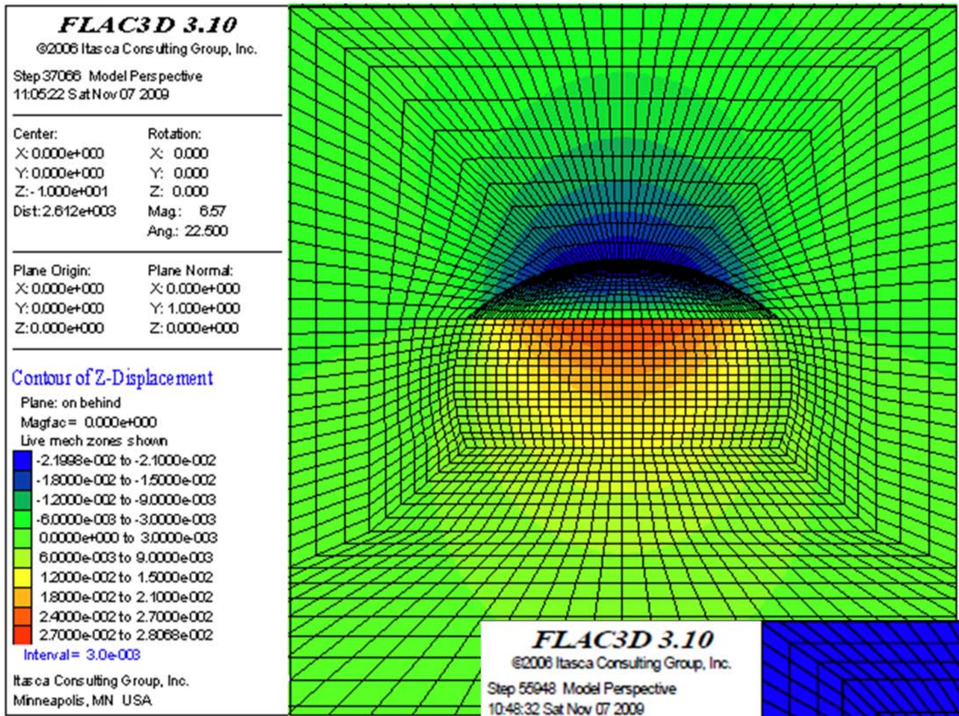
- Site features had to meet following requirements:

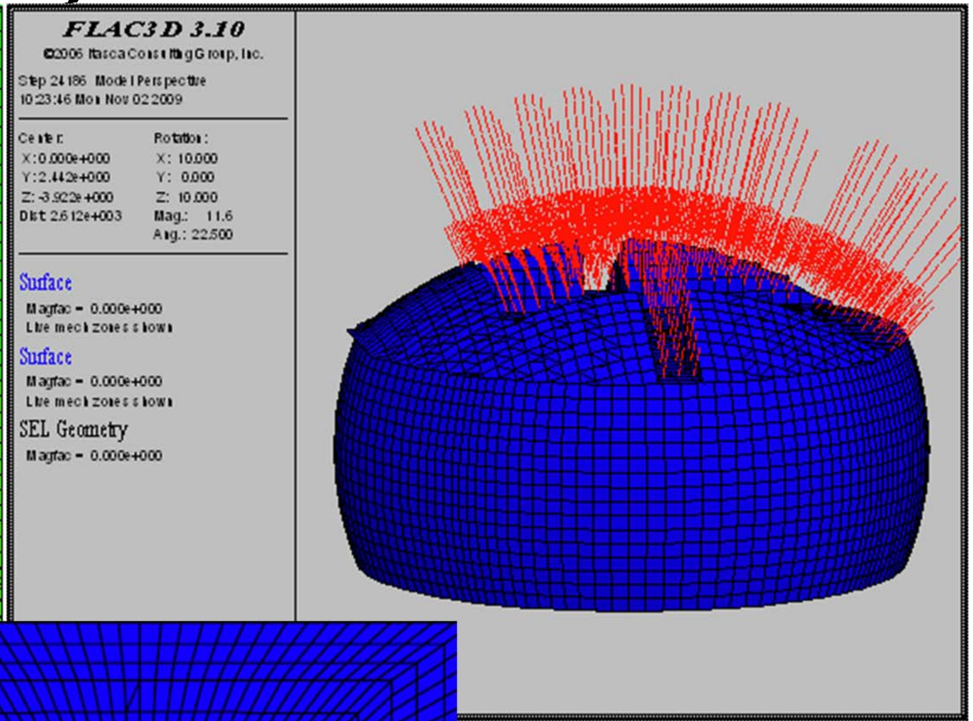
  off-axis angle w.r.t. the existing CERN/LNGS beam: about 1°;

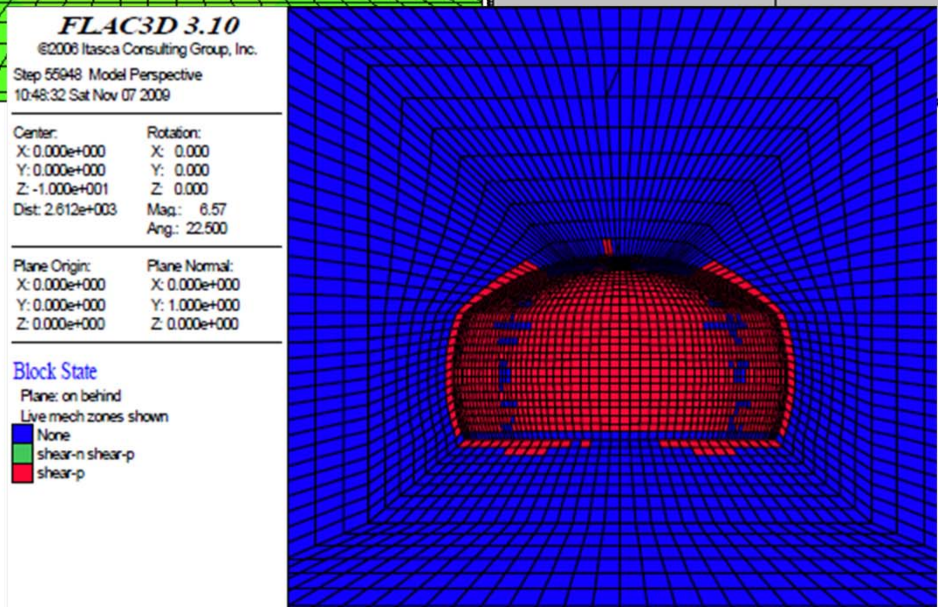
  distance from CERN: 400-800 km;

  depth: more than 400 m

UMBRIA, ITALY







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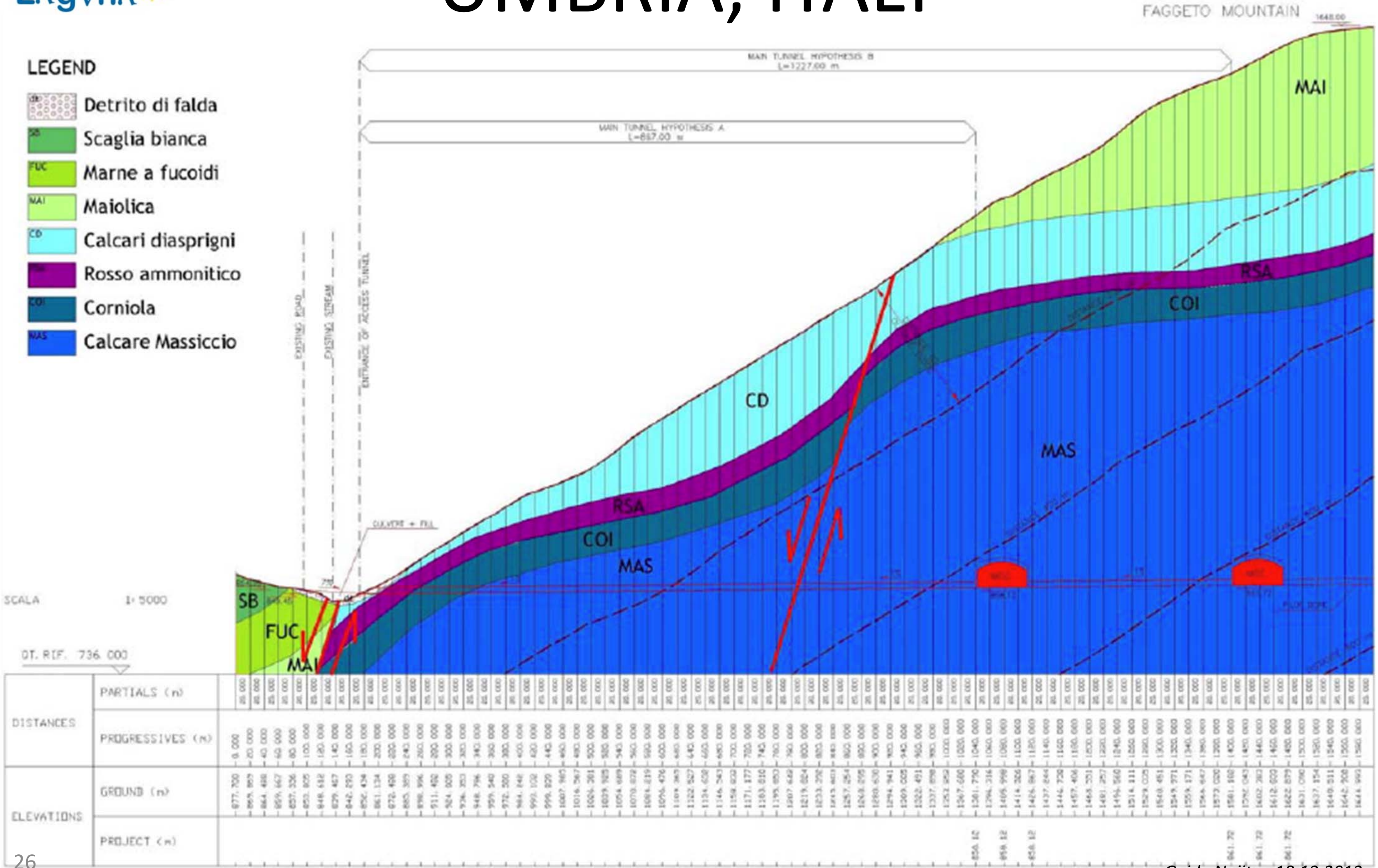

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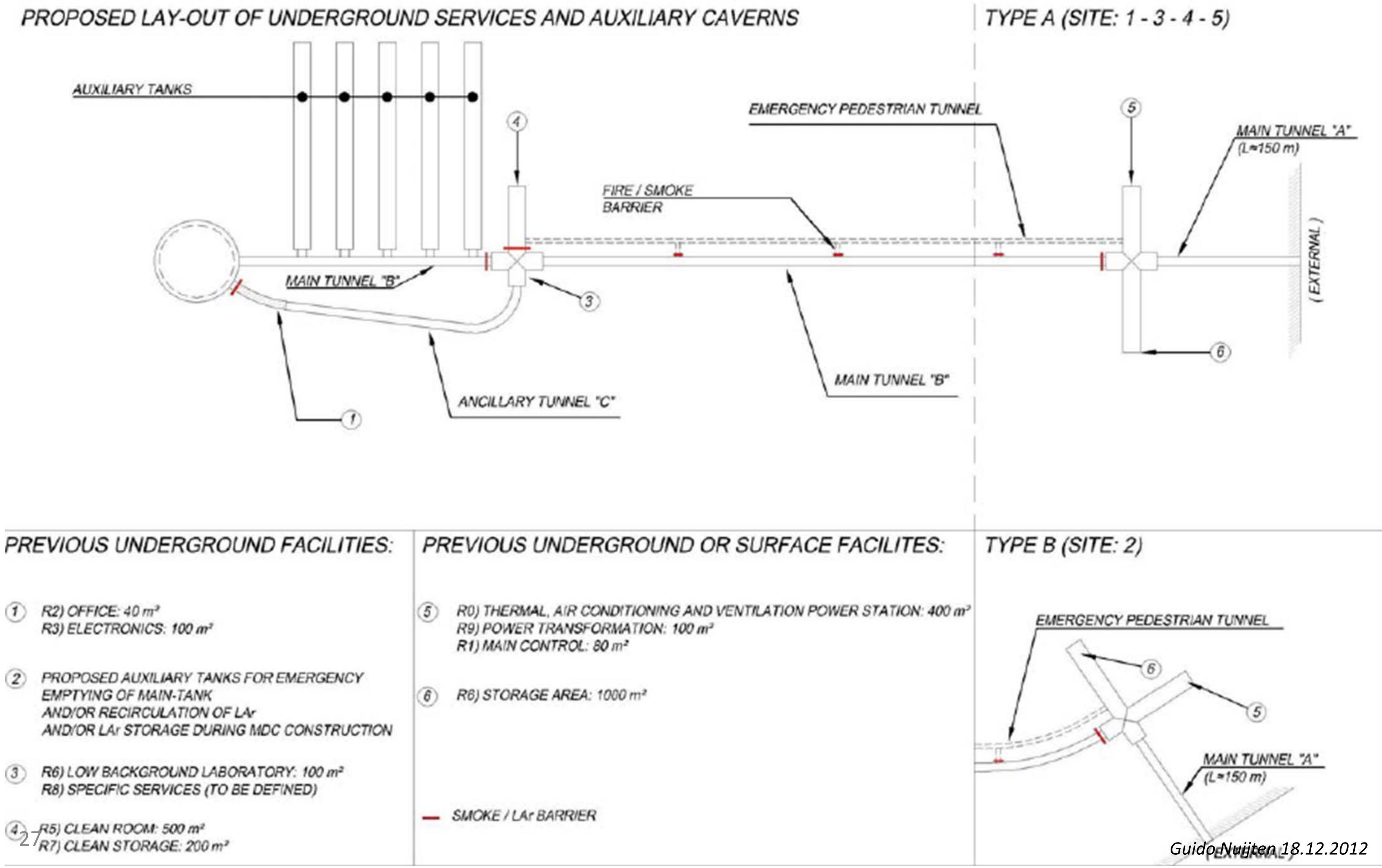

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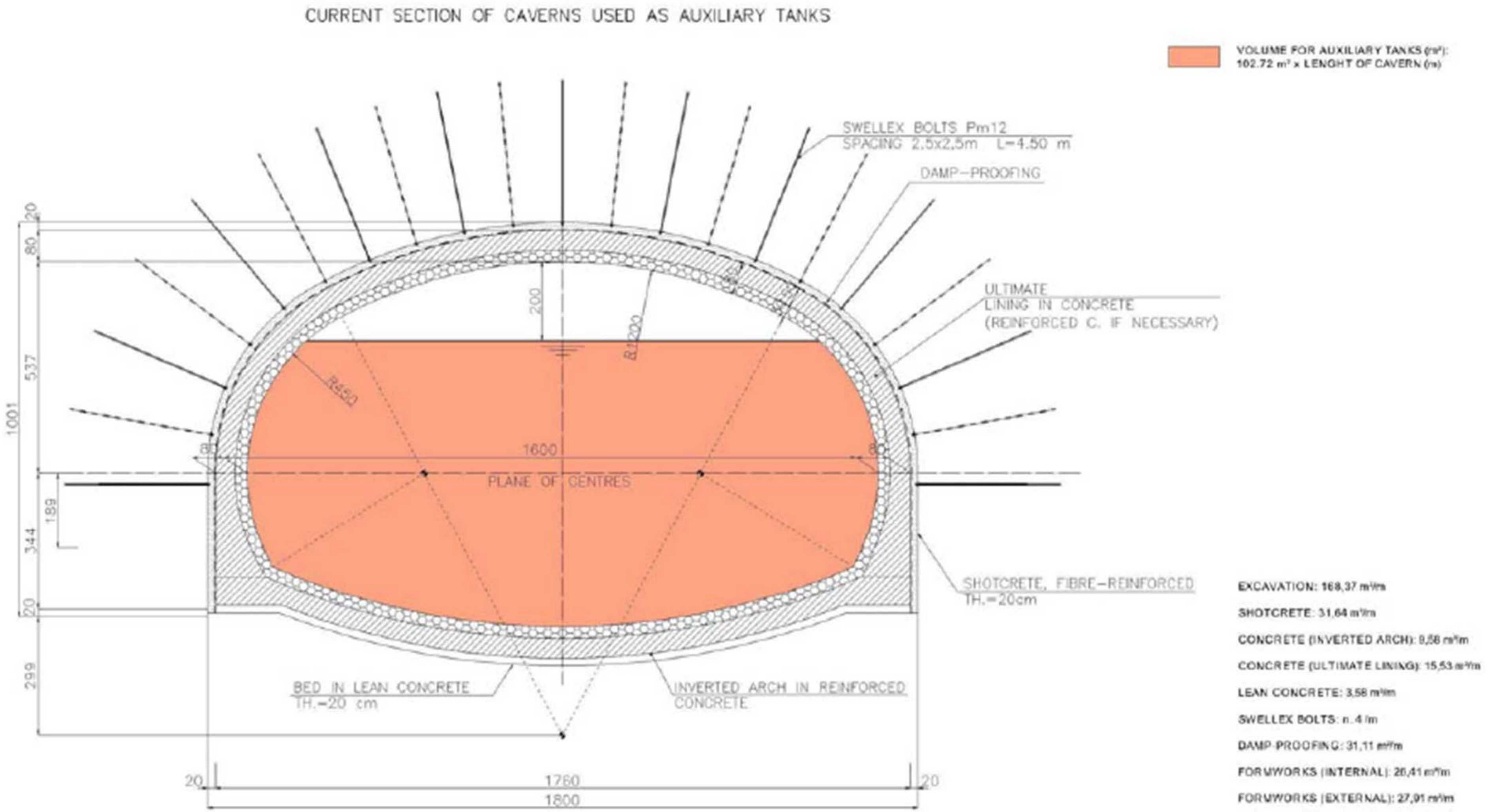


UMBRIA, ITALY

Conclusions

- This is a first assessment of Technical / Geological & Geotechnical issues concerning LAGUNA Project.
- No significant show-stoppers have been identified. Not expected preferential joint sets, as the material is a massive rock without well defined primary structures.
- For LAGUNA Project purpose and considering MDC dimensions (almost 100 m scale), the rock mass has .– practically .– isotropic characteristics.
- Only further investigations on in-situ rock can give trustworthy data for a wedge stability analysis (assessment of dip/strike of joints due to local tectonic features).
- With available data and basing on our work experience, a reasonable structure bearing potential wedges has been designed.
- Nevertheless, waiting for further and significant data, could be assessed a estimate of further costs (grid more close / anchors more long).

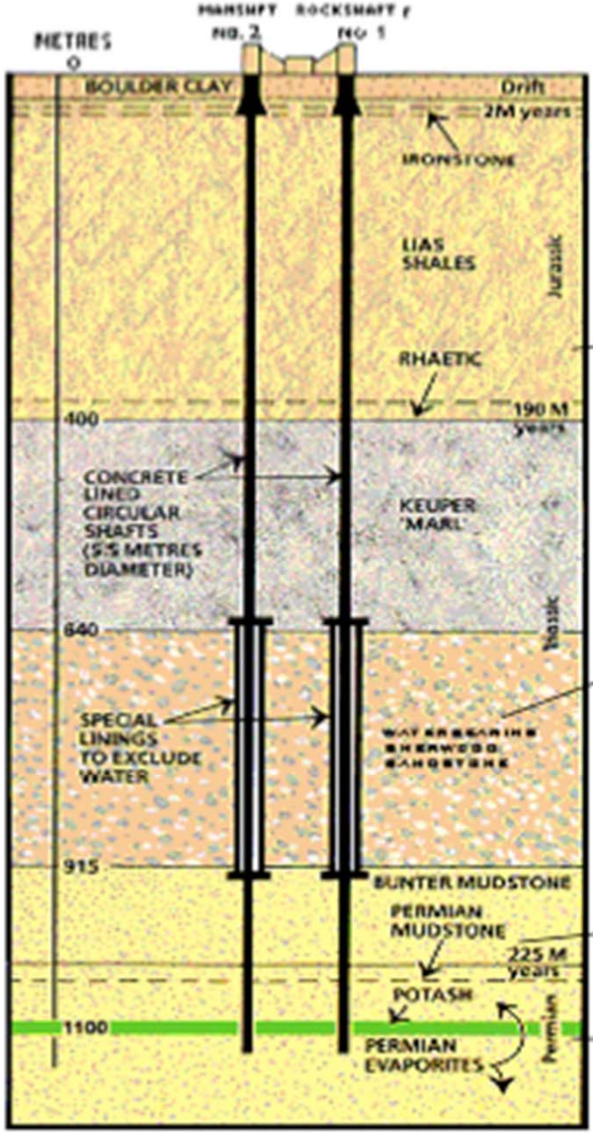
BOULBY, UNITED KINGDOM

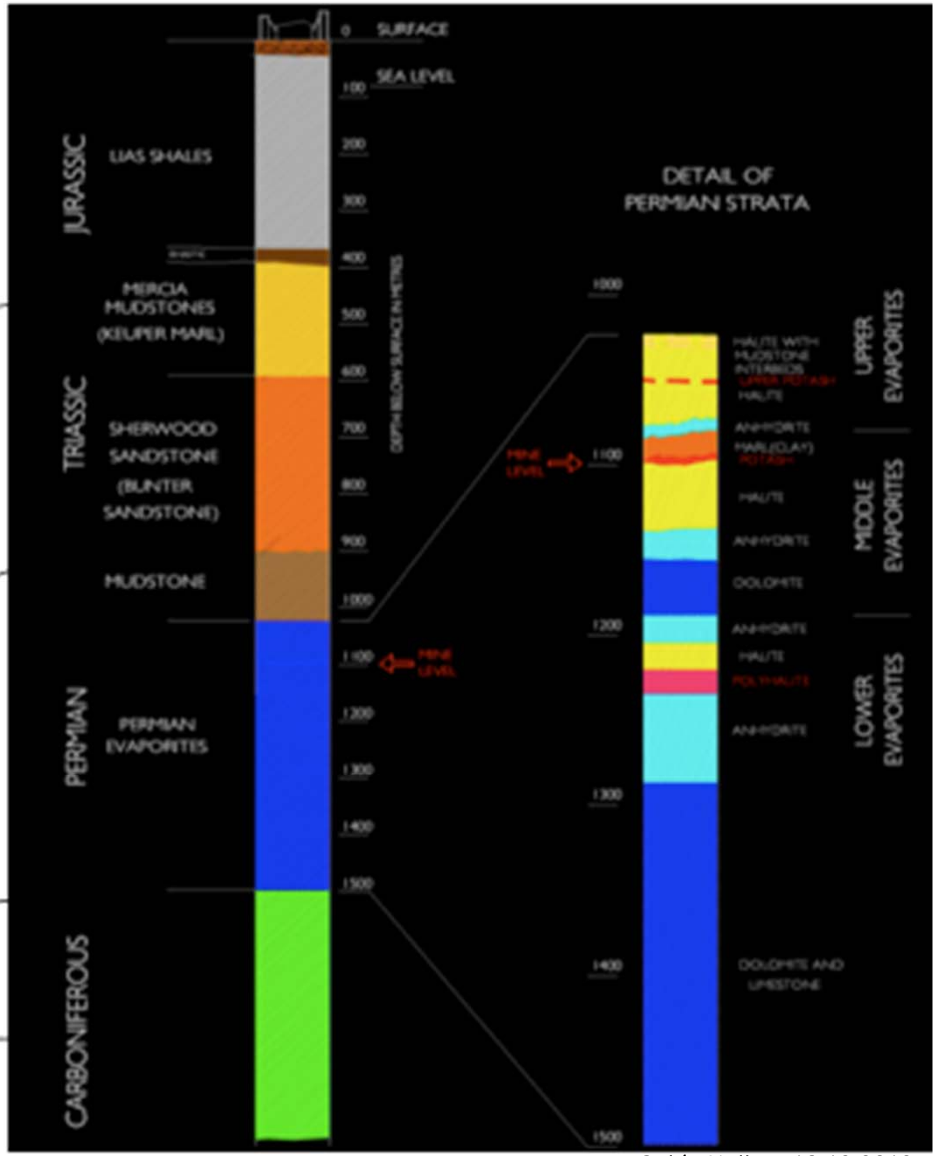
BOULBY, UNITED KINGDOM

Boulby DS contains information and work from many people involved in or connected with the LAGUNA project at Boulby.

- Cleveland Potash Ltd. (CPL)
- Alan Auld Ltd.
- AMCO Ltd.
- SES Holdings Ltd.
- Tees Valley RDA
- University of Durham
- Nottingham University
- STFC / University of Sheffield
- University of York
- University of Sussex
- Department of Civil and Structural Engineering (University of Sheffield)
- Department of Physics and Astronomy (University of Sheffield)

BOULBY, UNITED KINGDOM





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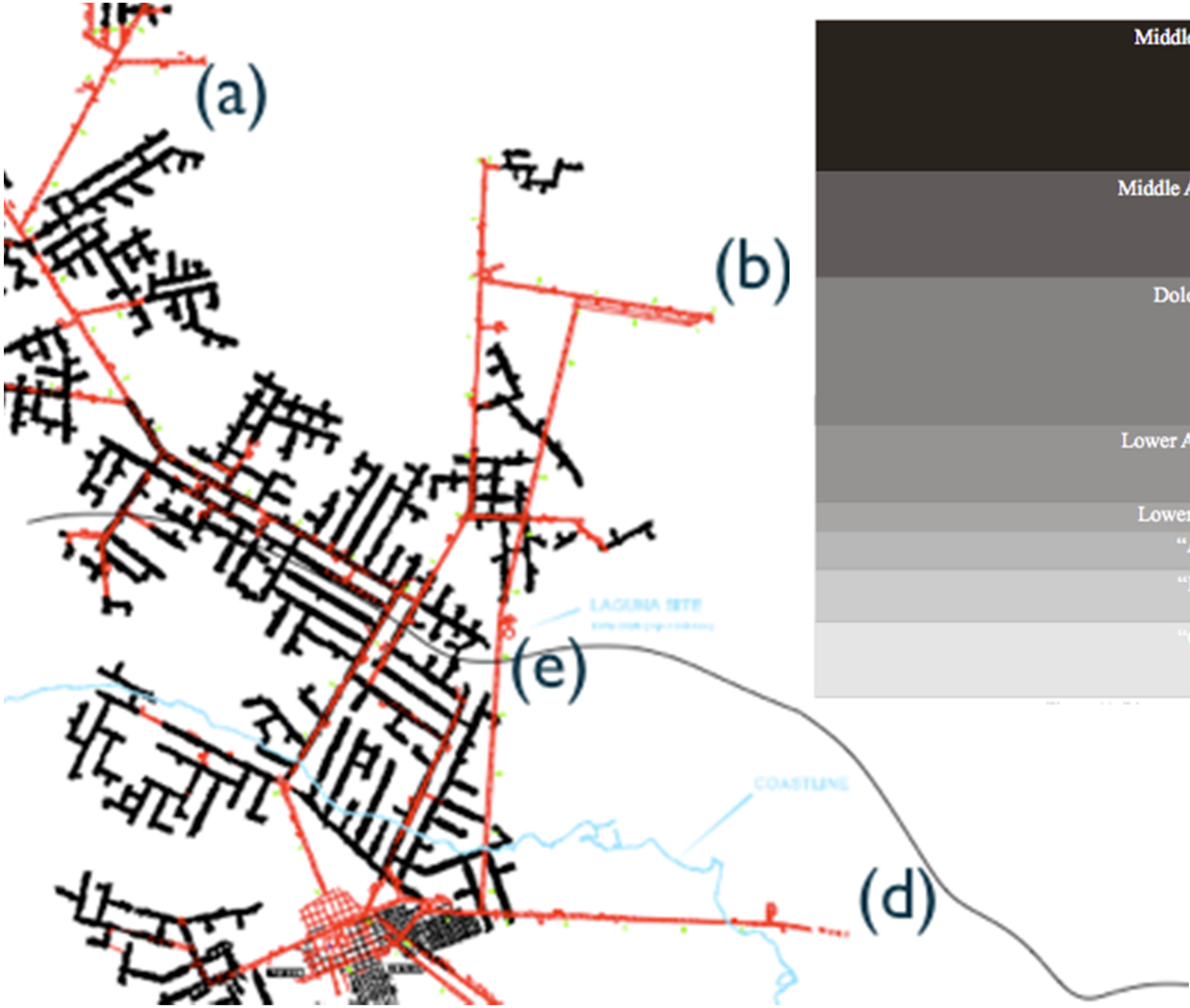
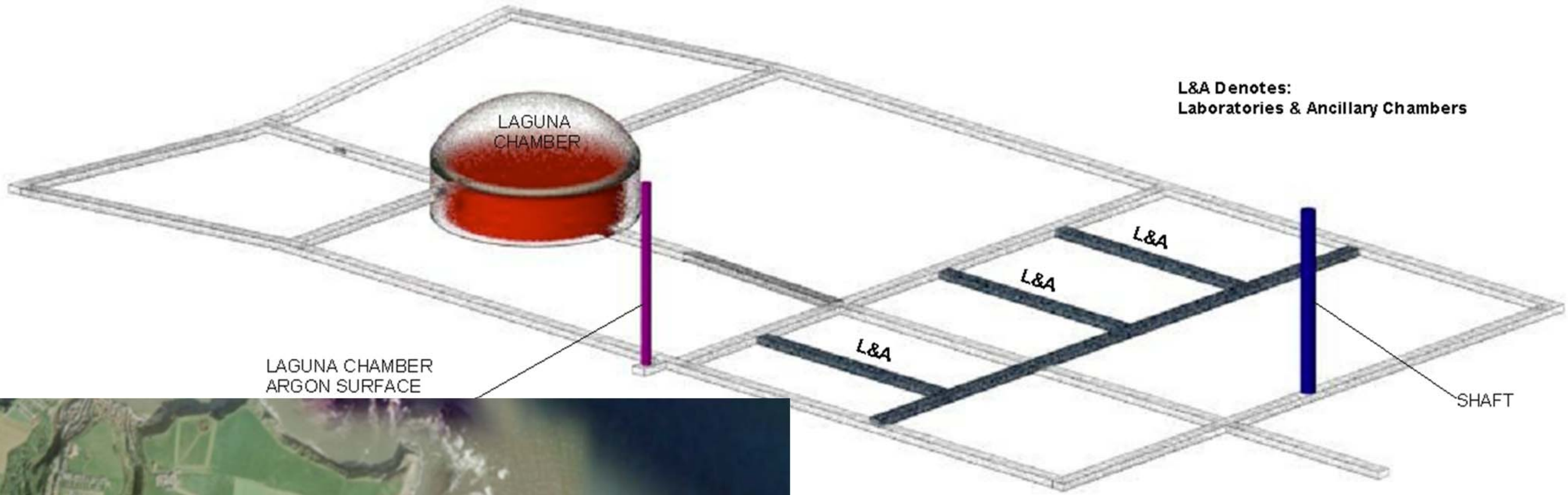
BOULBY, UNITED KINGDOM

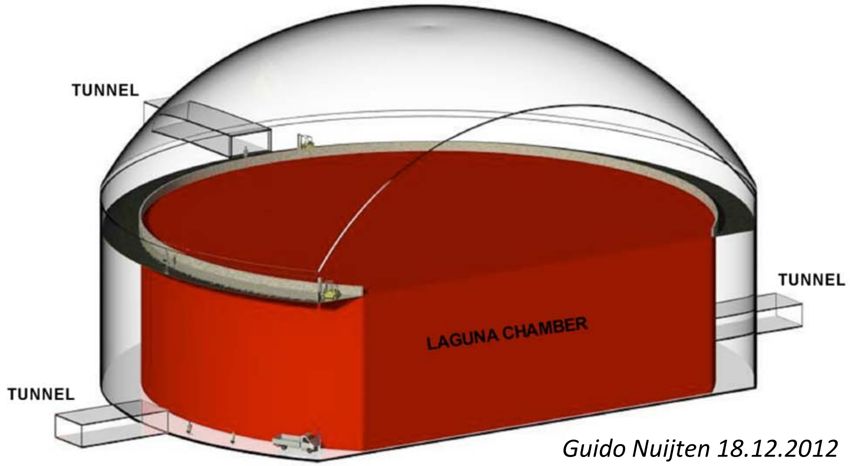


BOULBY, UNITED KINGDOM

- All detector options are included.
- However, to provide focus and a baseline for study more detailed analysis has been undertaken for GLACIER , with some extrapolation used from this for LENA and MEMPHYS.
- Participation by Boulby recognises that as a working mine with an estimated 50 year long term future and over 20 years experience at hosting successful particle astrophysics projects,
- Boulby offers some unique characteristics well suited to LAGUNA.
- The mine company CPL, regional and national authorities, STFC, RDAs OneNE and Yorkshire Forward,
- Universities and the local public back participation.

BOULBY, UNITED KINGDOM



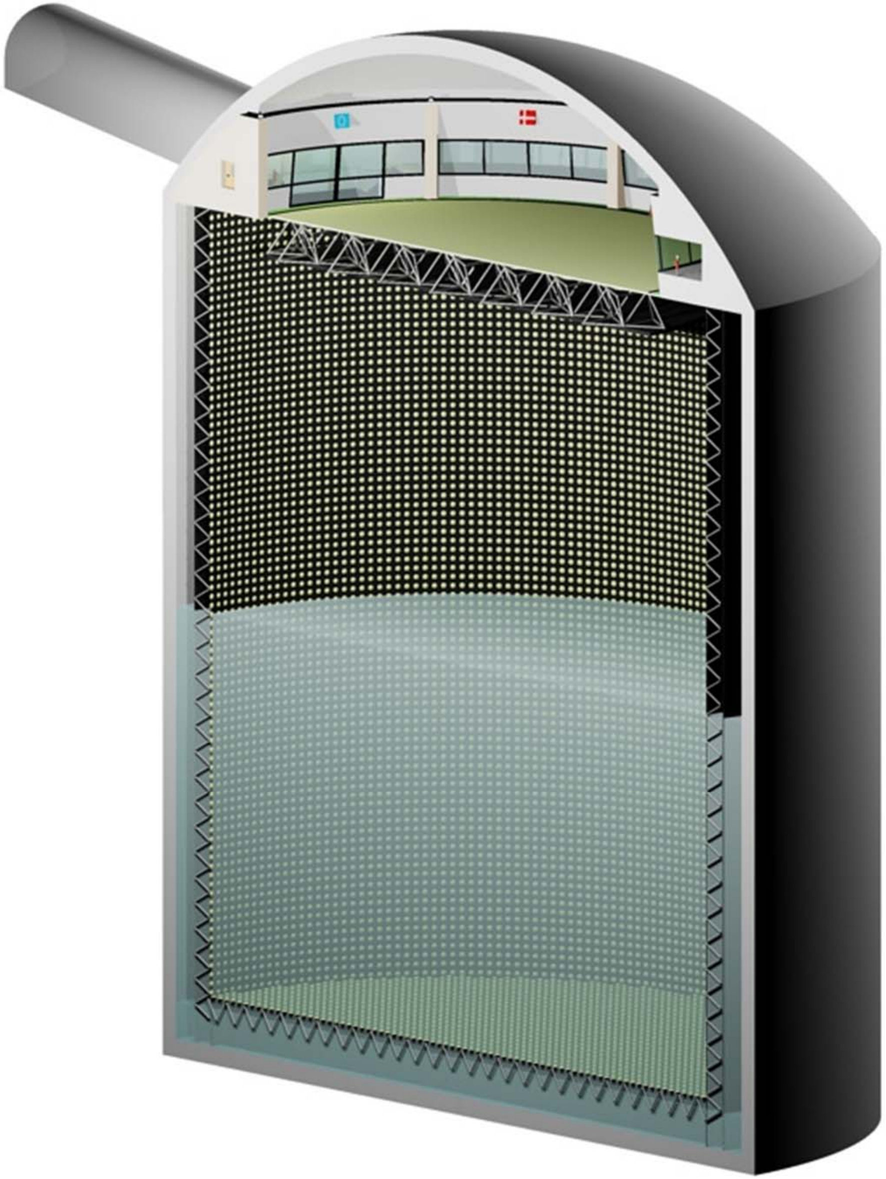


BOULBY, UNITED KINGDOM

Summary of important technical points of LAGUNA at Boulby

- Well know rock characteristics in strong **dolomite and anhydrite**
- Site depths from **900m - 1500m** in hard dolomitic rock with minimal seismic activity
- Geo-mechanical **in-situ data** from within the rock-mass, not just bore-holes
- Good rock disposal routes **underground or through mine infrastructure**
- Huge in-house rock excavation capacity **(~5Mtons/year)**
- Experience of **liquid transfer** via 1.1 km vertical pipeline, at 200,000 tonnes per year

LSM, FRÉJUS, FRANCE



LSM, FRÉJUS, FRANCE

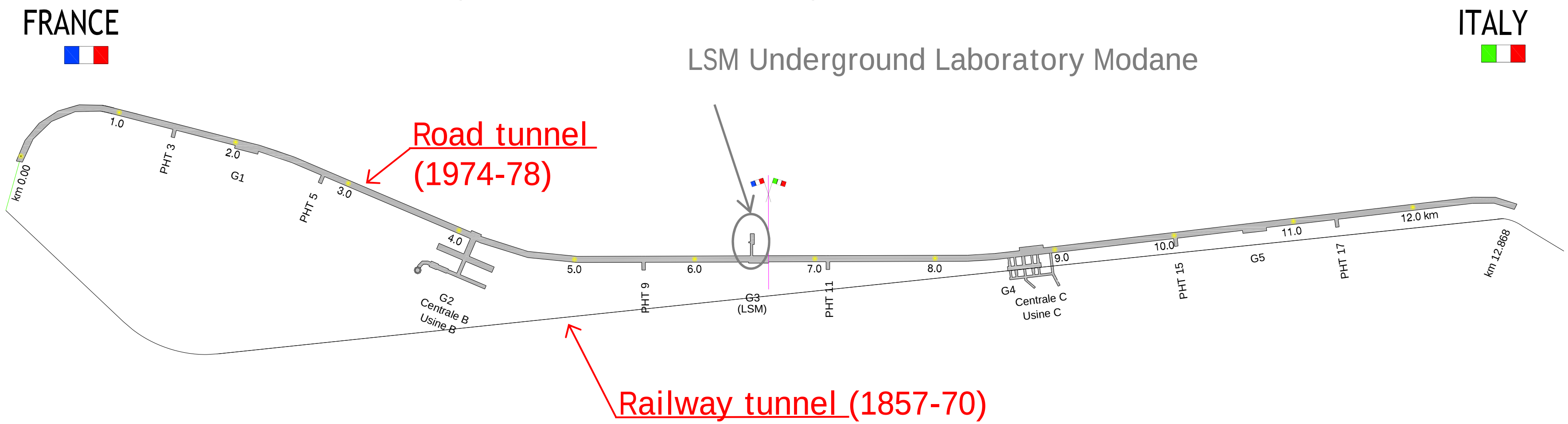
Industrial partner:

- **Lombardi Engineering Ltd.**

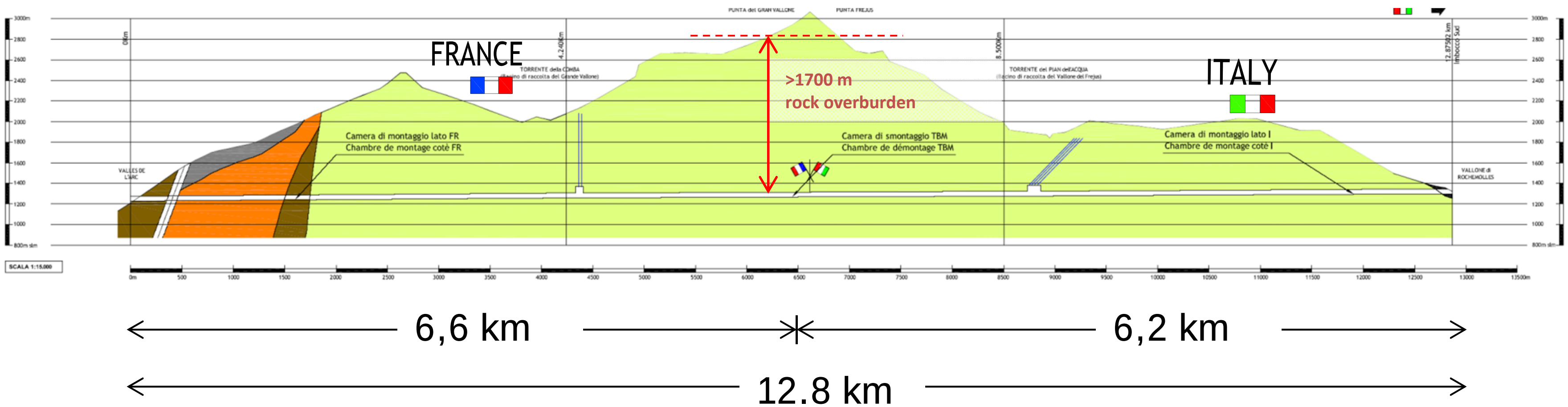
Background

- **IN2P3** (Institut National de Physique Nucléaire et de Physique des Particules) of **CNRS** (Centre National de la Recherche Scientifique) and **IRFU** (Institute of Research into the Fundamental Laws of the Universe) of **CEA** (Commissariat à l'Énergie Atomique) participate in the selection of best LAGUNA project site, proposing the Fréjus site candidature, wherein an underground laboratory (Laboratoire Souterrain de Modane, **LSM**) is already present

LSM, FRÉJUS, FRANCE



Longitudinal section (Road tunnel)



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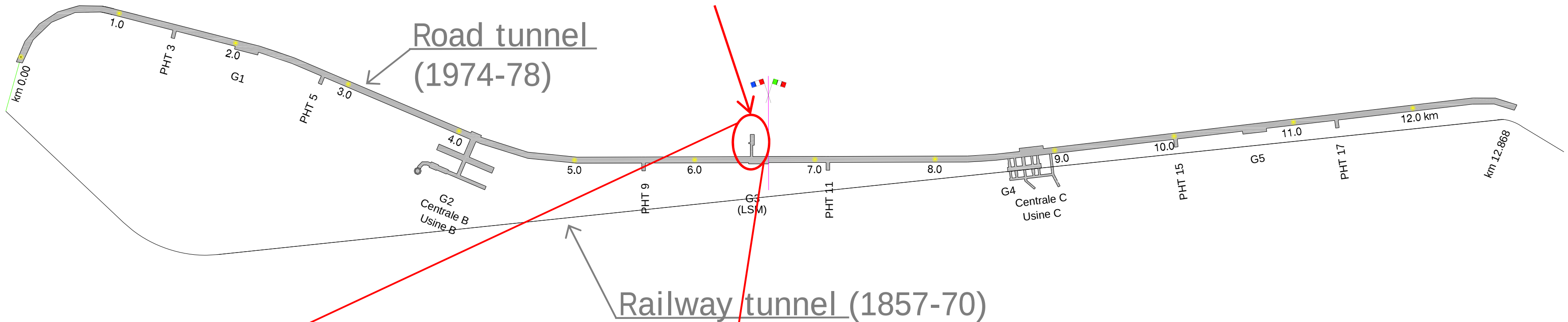
ROCKPLAN

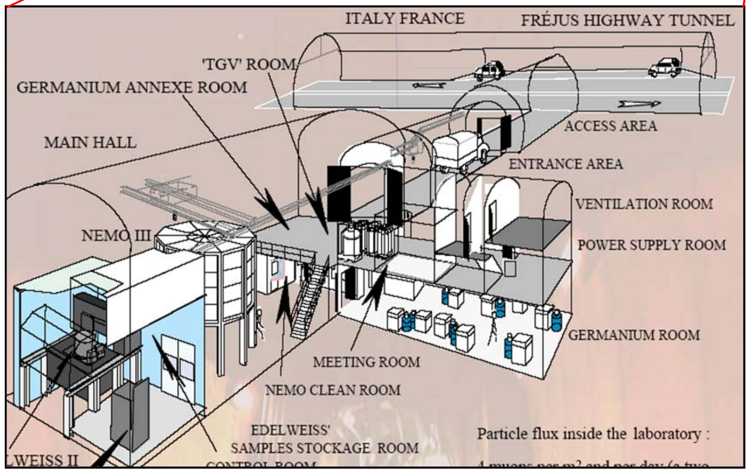
LSM, FRÉJUS, FRANCE

FRANCE

ITALY

LSM Underground Laboratory Modane





LSM is a cavity of about 3′500 m^3 located close to chainage 6+500 of Fréjus Road Tunnel in French territory

LSM is the deepest European underground laboratory (4’800 m.w.e.)

LSM, FRÉJUS, FRANCE

Situation at Fréjus (a posteriori):

In situ large scale tests

Modulus of elasticity E_{din}=15 GPa

Compressive strength σ_c=15/4 MPa

Excavation of road tunnel

Convergence monitoring

Extension of failure zone around tunnel

Discontinuities (number, orientation, quality)

Others properties

Water inflow

Rock mass temperature

Back analysis

Rock mass properties

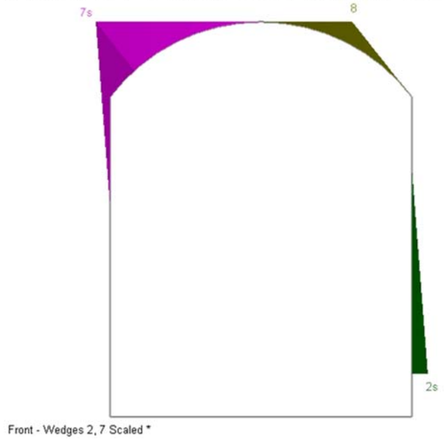
Reduction of uncertainties

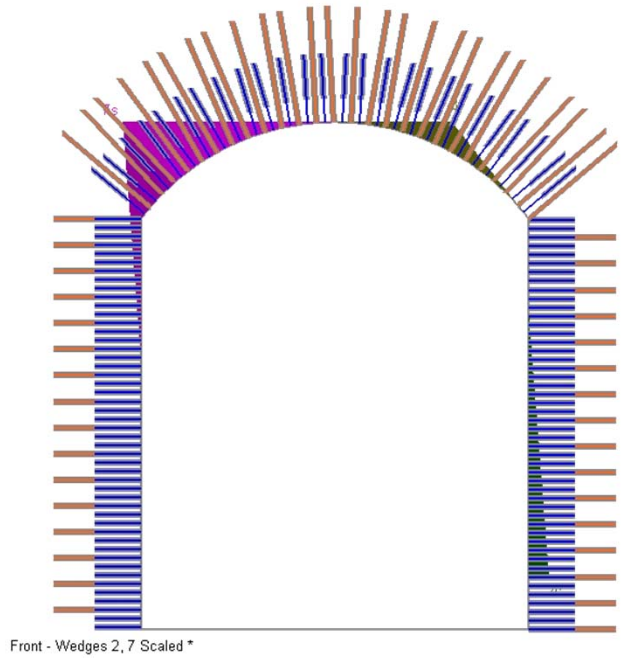
Advantage of Frejus:

Intensive analysis of tunnel behaviour during construction (and well documented)

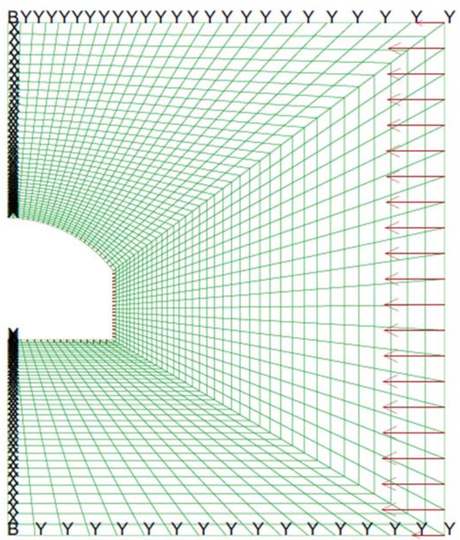
LSM, FRÉJUS, FRANCE

1. Analysis of the effect of discontinuities on wedge stability (→**preliminary support**)





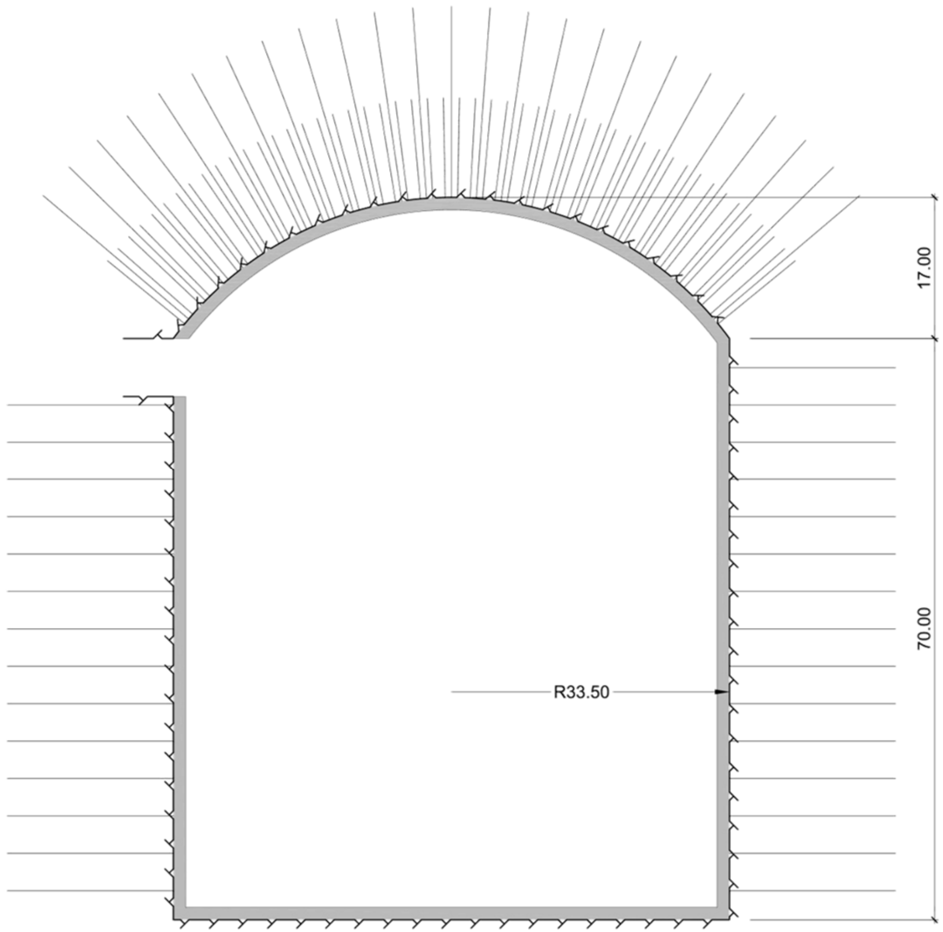
2. Analysis of time dependent displacements (→**final lining**)



Models of continua

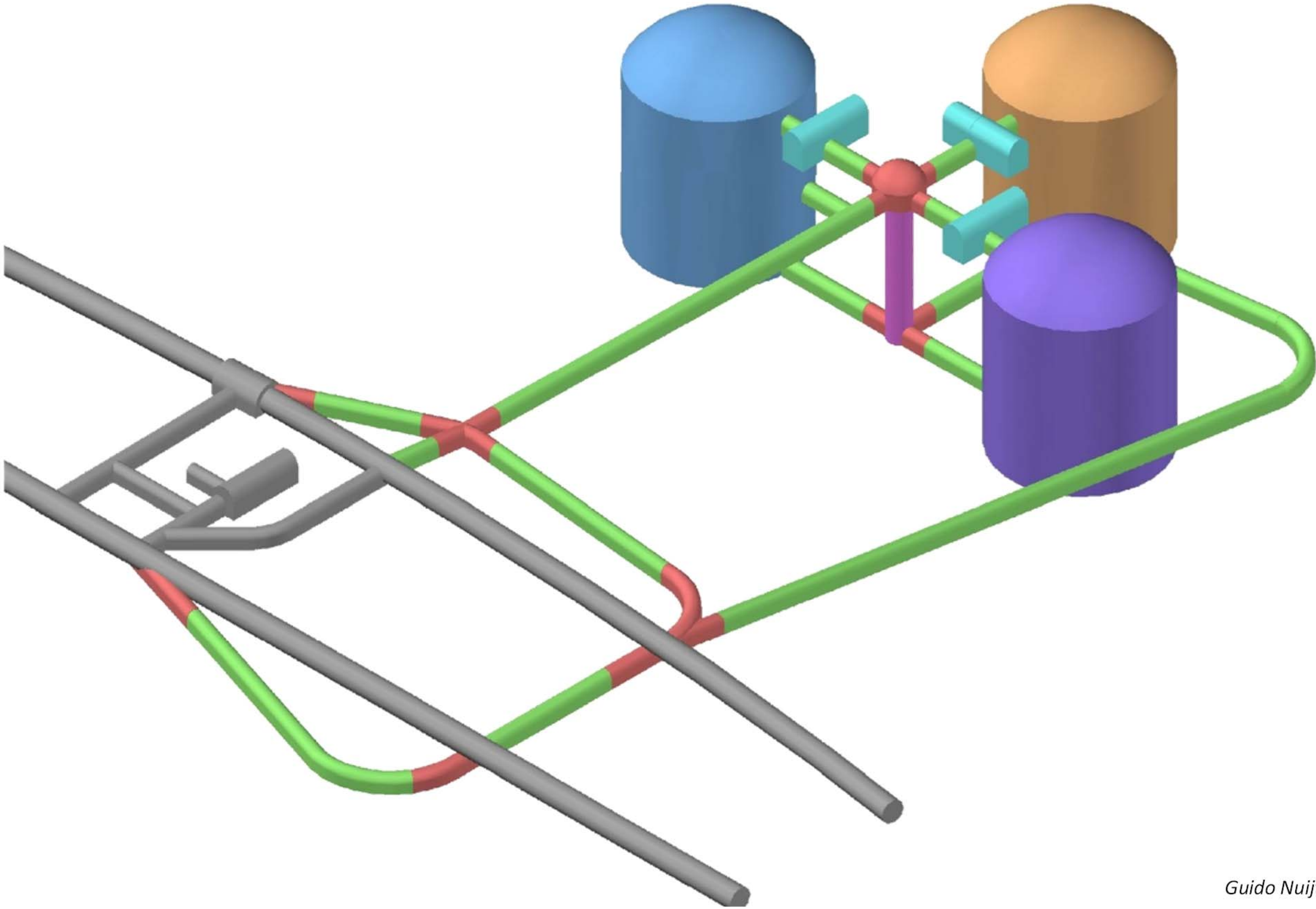
LSM, FRÉJUS, FRANCE

MEMPHYS – Final lining



- Thickness: **1.5 m** (roof and vertical wall)
- Thickness of the lower part (15 m) increased to **2.3 m**

LSM, FRÉJUS, FRANCE

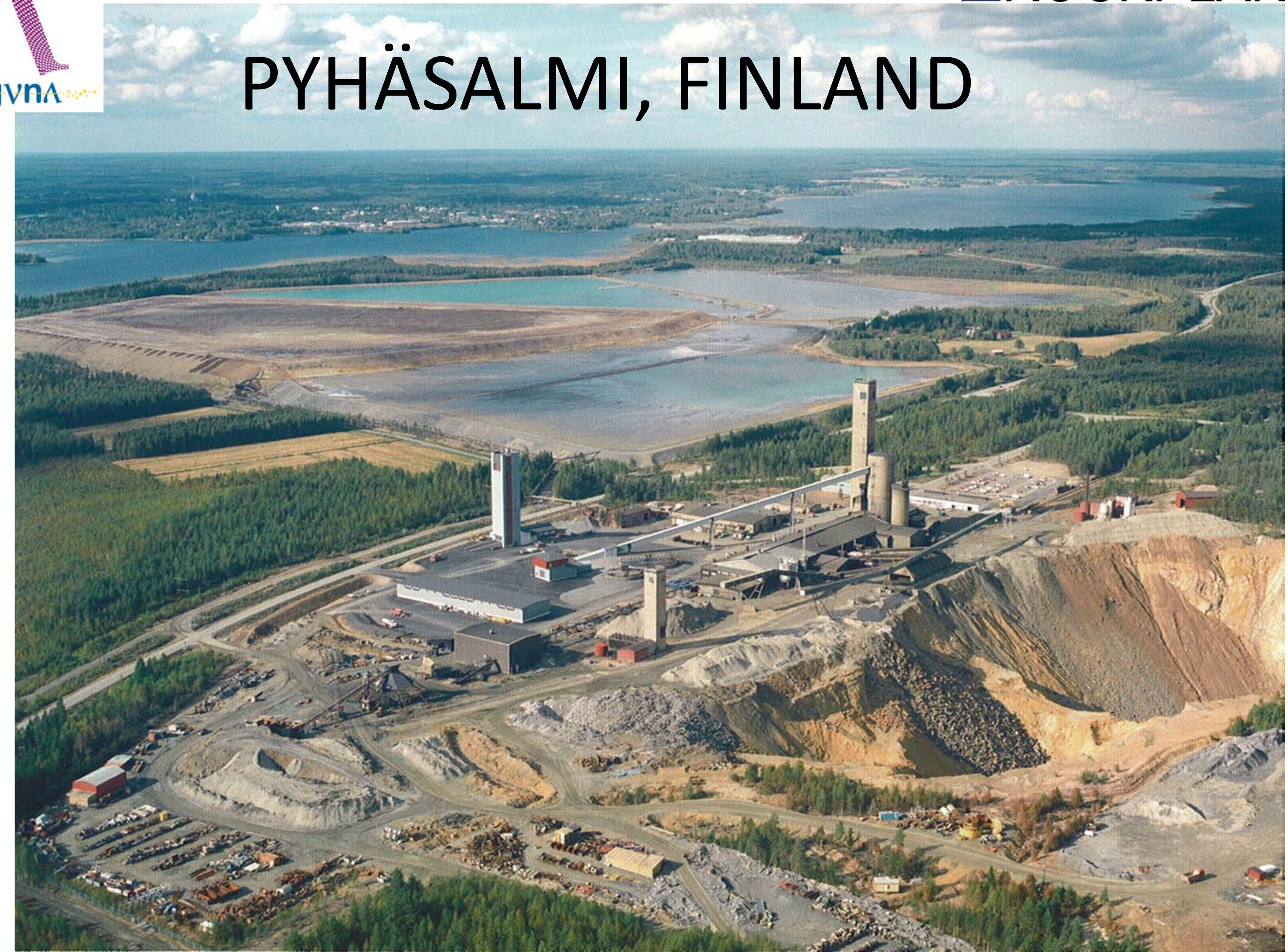


LSM, FRÉJUS, FRANCE

General conclusions

- The Frejus site allows to host all the detectors options proposed within LAGUNA, i.e. GLACIER, LENA and MEMPHYS.
- The rock mass behavior was deeply investigated (during highway tunnel and now safety tunnel) allowing to minimize the uncertainties and the risks related to the realization of further underground cavities.
- The excellent quality of the rock, with the appropriate amount of plasticity, allows the excavation of very large cavities at a depth of 4800 m w.e., which is the deepest in Europe (for an underground laboratory).
- The Fréjus safety tunnel, presently under construction, provides an optimal and completely safe access to the site during both construction and operation (whole life-time, e.g. 50 years).
- The Frejus rescue team, permanently in service, ensure the highest safety support both in the tunnel and in the laboratory.
- The accessibility of the Frejus site is excellent (by road or train from many international cities as Torino, Chambery, Lyon, Genève, Milano, Paris).

PYHÄSALMI, FINLAND

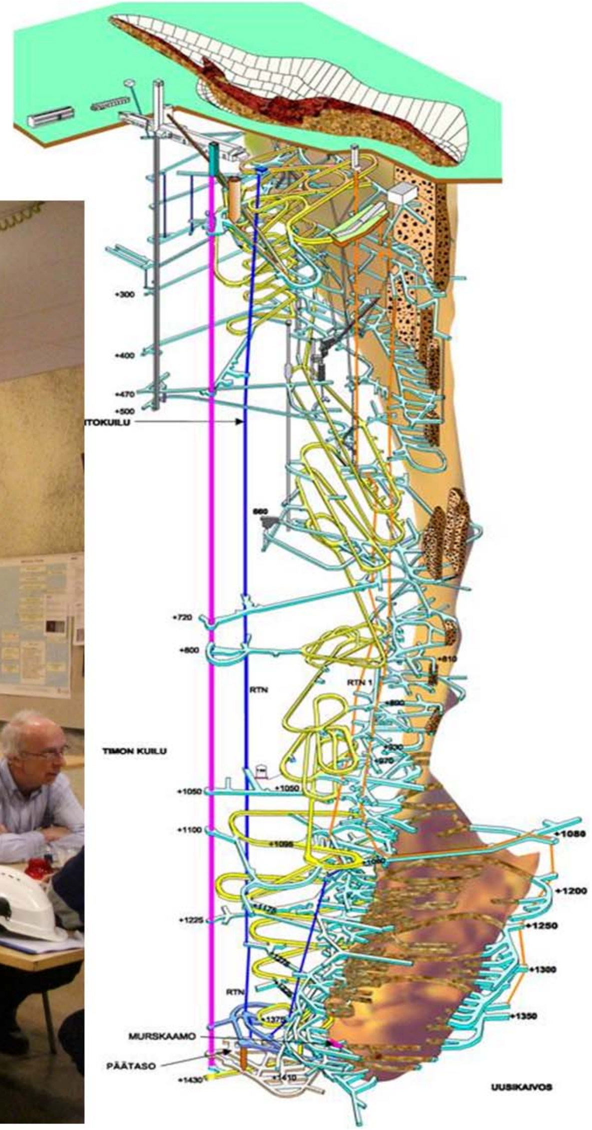


PYHÄSALMI, FINLAND

- Designer
  Rockplan

- in co-operation with
  University of Oulu
  University of Jyväskylä
  CUPP, Centre for Particle Physics, Pyhäsalmi
  Pyhäsalmi Mine (Inmet)

PYHÄSALMI, FINLAND



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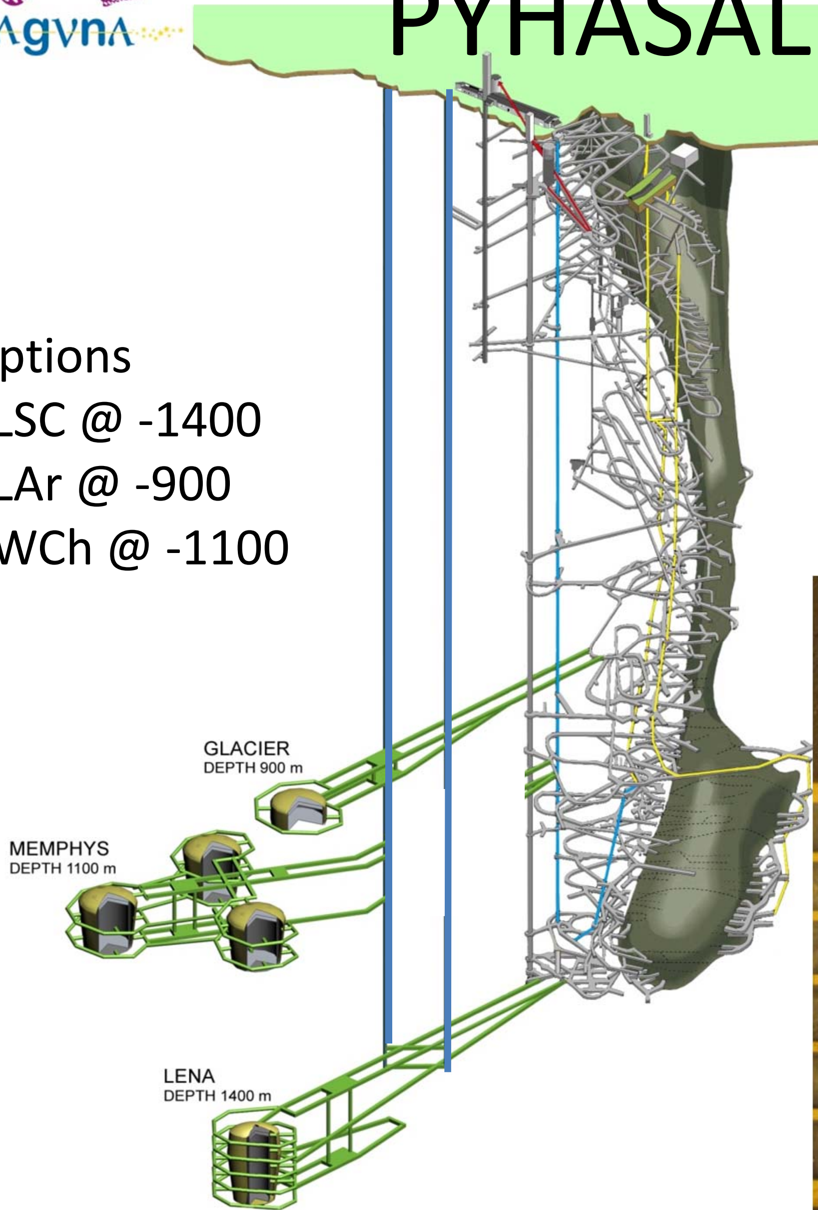
PYHÄSALMI, FINLAND

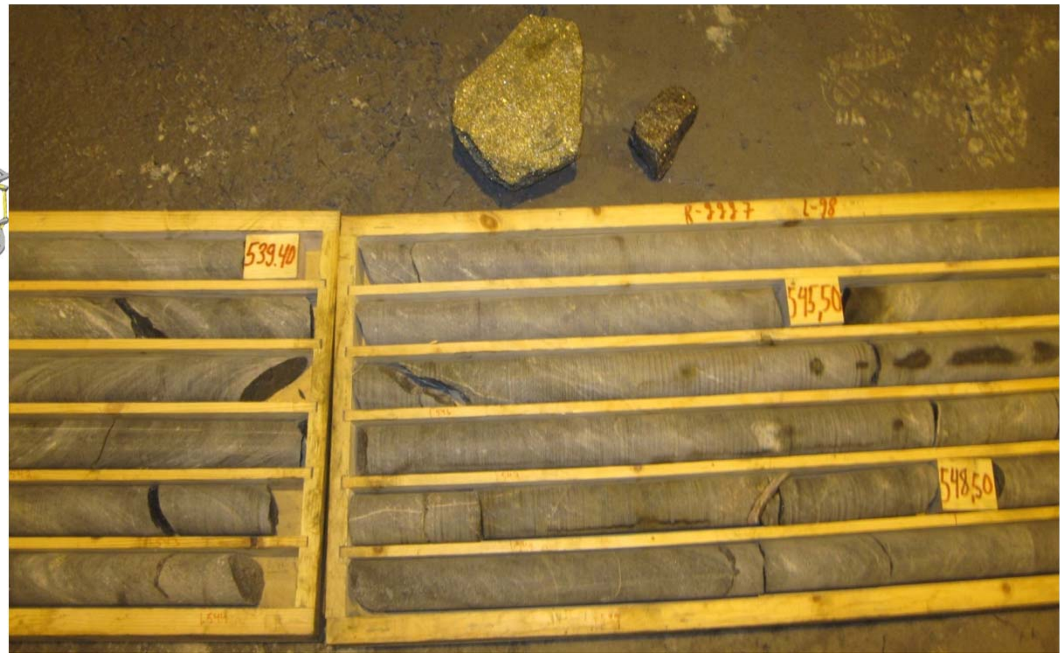
PYHÄSALMI, FINLAND

Very intact rock:
average RQD: 99.67
Joint density: 1 crack / 2m
Locally pegmatite dike encountered

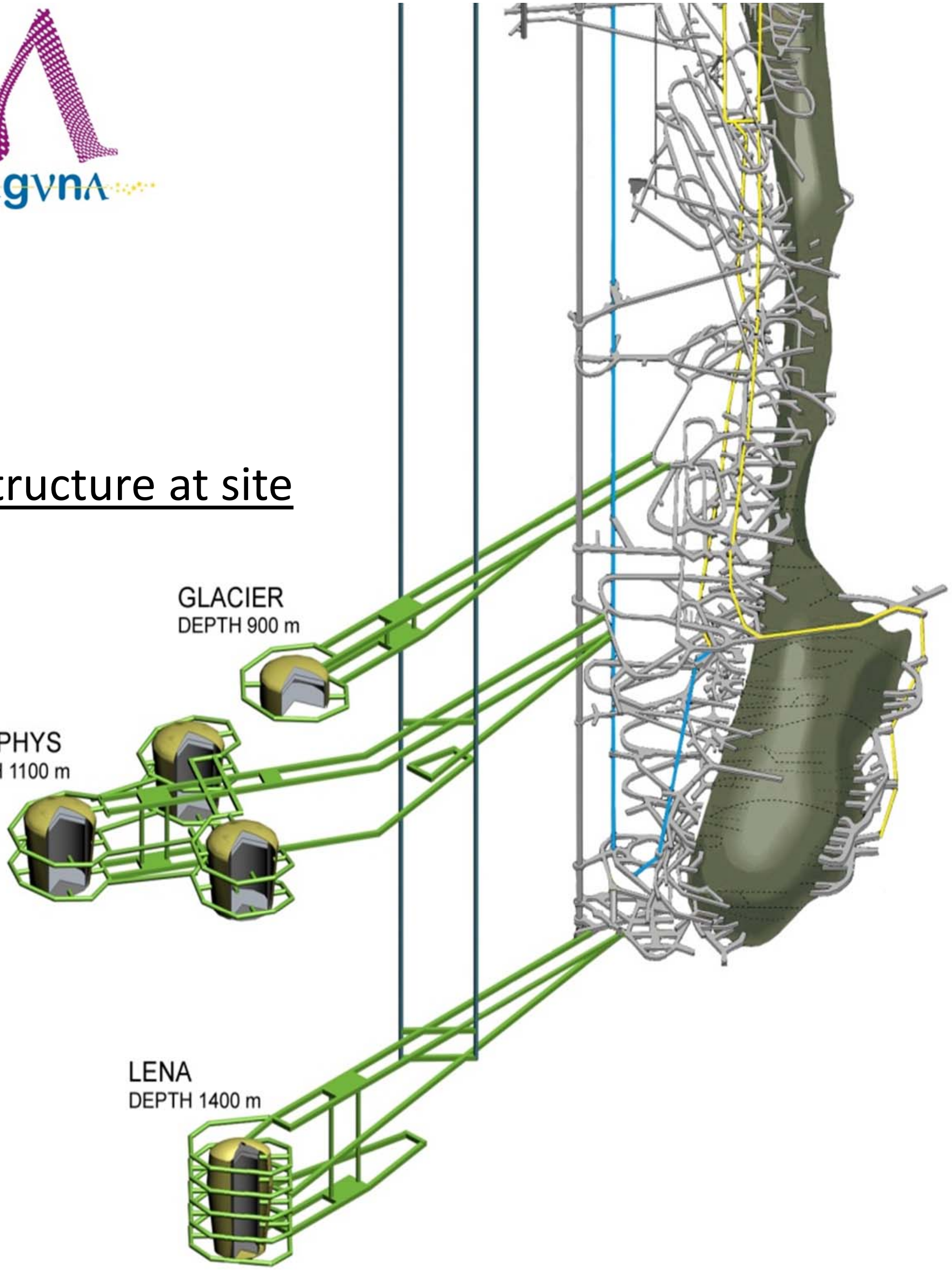
Uniaxial compressive strength of intact rock is 200-250 MPa (29,000-36,000psi)

Options
- LSC @ -1400
- LAr @ -900
- WCh @ -1100





rastructure at site



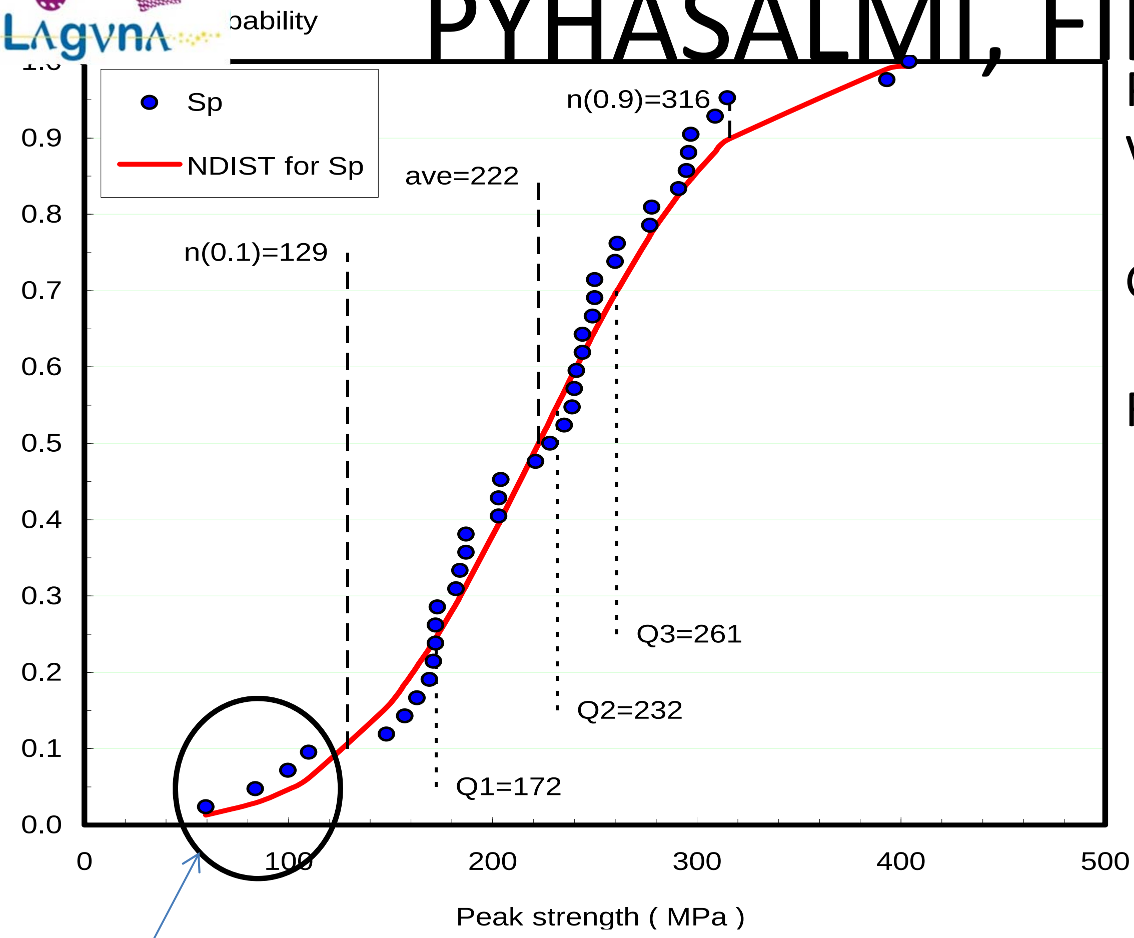
Main purpose of the infrastructure

- ***Sufficient*** *(to conduct the experiment)*
- ***Efficient*** *(cost & process effectiveness)*
- ***Safe*** *(during all phases)*

Main aspects of the infrastructure

- *good excavation strategy*
- *efficient rock disposal*
- *no disturbance with hosting site*
- *sufficient fresh air inlet*
- *effective outlet of return air*
- *safety*
- *supply routes for construction*
- *storage of material*
- *quality control of material at the vicinity*
- *supply route (pipe lines) for liquids*

PYHÄSALMI, FINLAND



Peak Strength of Mafic and Felsic Volcanites (intact) **σ_{ci} = 232 MPa**

Geological Strength Index = 77

Rock mass strength **σ_{cm} = 132 MPa**

Note: Pegmatite dykes (intact) σ_{ci} = 110 MPa to be avoided

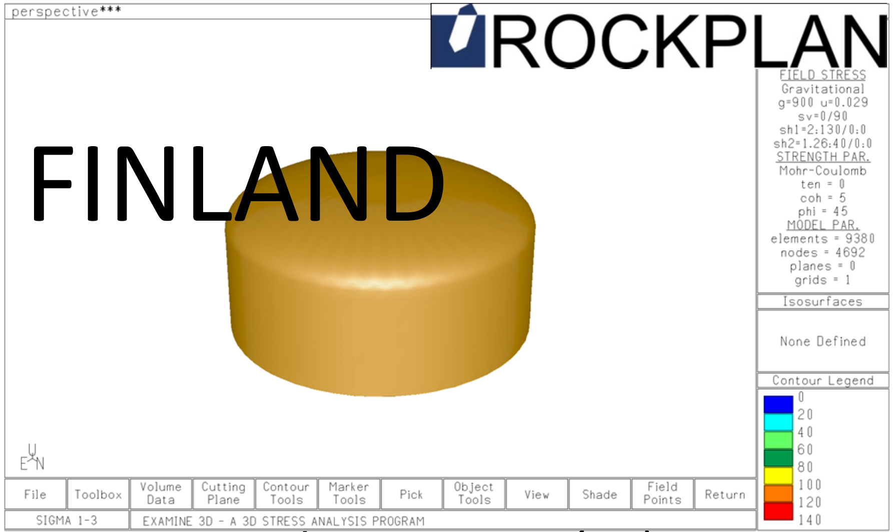
measurements and stress failure observations confirms
*Rock mass strength **σ_{cm} = 132 MPa***

PYHÄSALMI, FINLAND

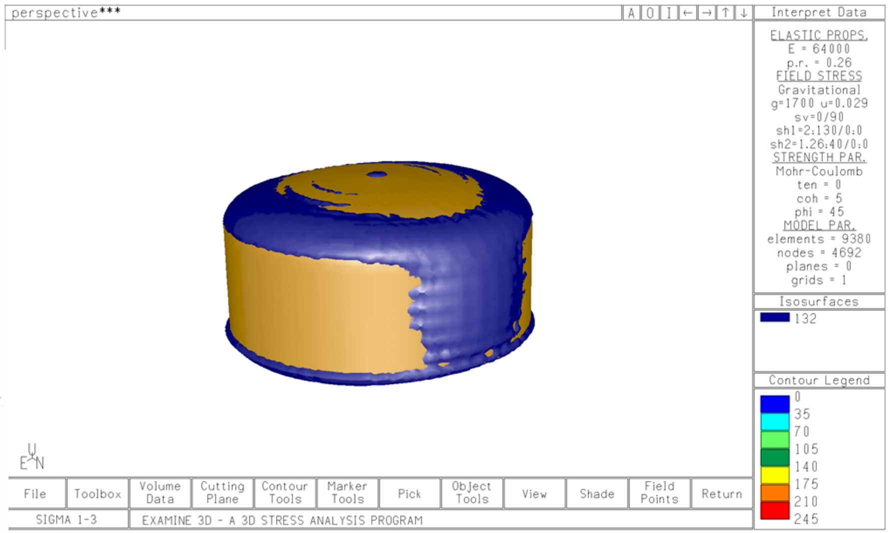
In situ stress (before excavation)

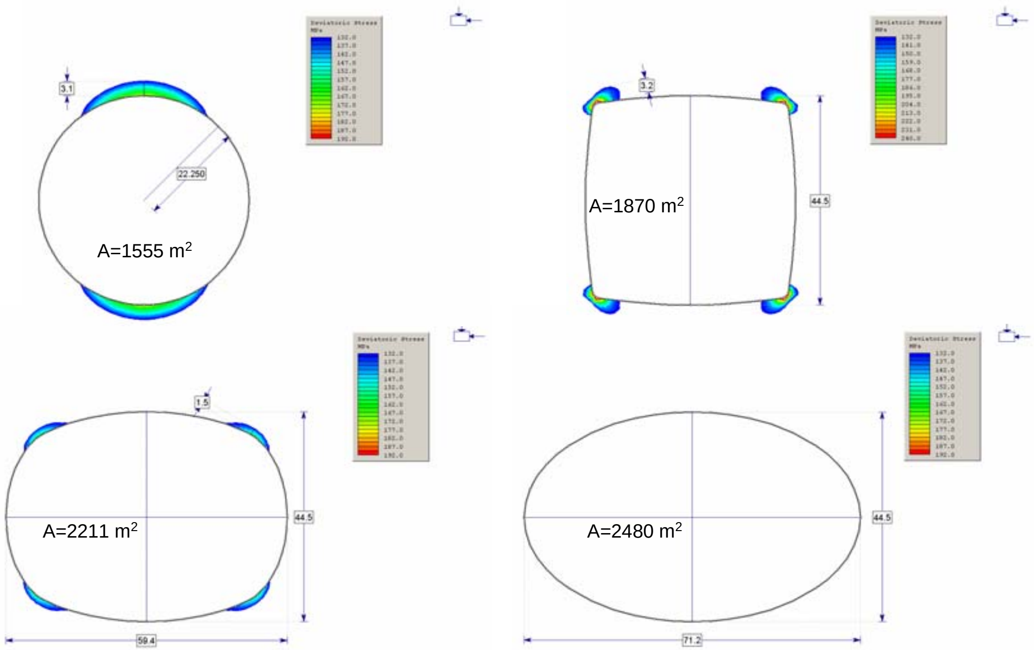
Depth (m)	*σ_{H1} (MPa)*	*σ_{h2} (MPa)*	*σ_{v} (MPa)*
900	52	33	26
1100	64	40	32
1400	81	51	41
2000	116	73	58

Major principal stress is horizontal and bearing to N-W (310° clockwise from N).



GLACIER results at -900m (up) & -1700m (down)





LENA results at -1450m (left)

PYHÄSALMI, FINLAND

General conclusions

- Within Finland the Pyhäsalmi Mine offers the best location for this purpose, as it is the deepest present location in Finland 1400 meters below surface.
- Pyhäsalmi Mine has expressed its interest to be chosen as one of the locations for the underground laboratory as stated in the memorandum of understanding between the Mine and LAGUNA parties in Finland
- Pyhäsalmi is located in the municipality of Pyhäjärvi in the middle of Finland, 450 km north of Helsinki and 150 km south of Oulu
- LAGUNA has received a very positive support from the municipality of Pyhäjärvi as well from the local region Northern Ostrobothnia.
- A part from the scientific involvement by the Universities of Jyväskylä and Oulu, also the University of Helsinki, the Helsinki Institute of Physics and the Finnish Academy have shown to be interested in the LAGUNA project.
- The national government of Finland and members of the House of Parliament have been informed and their response, although unofficial, is genuine positive.

PYHÄSALMI, FINLAND

Technical / rock engineering conclusions

- Finland is known for its Precambrian stable hard bedrock. The hard and very old bedrock of Finland provides by far one of the best locations in Europe to locate any of the LAGUNA laboratories deep under the ground.

- Finland has high expertise and good experience in designing and construction of large, complex underground excavations and constructions.

- Pyhäsalmi Mine has a suitable low temperature of surrounding rock. The temperature is only a moderate 16°C at 900m and about 23°C at 1400m depth.

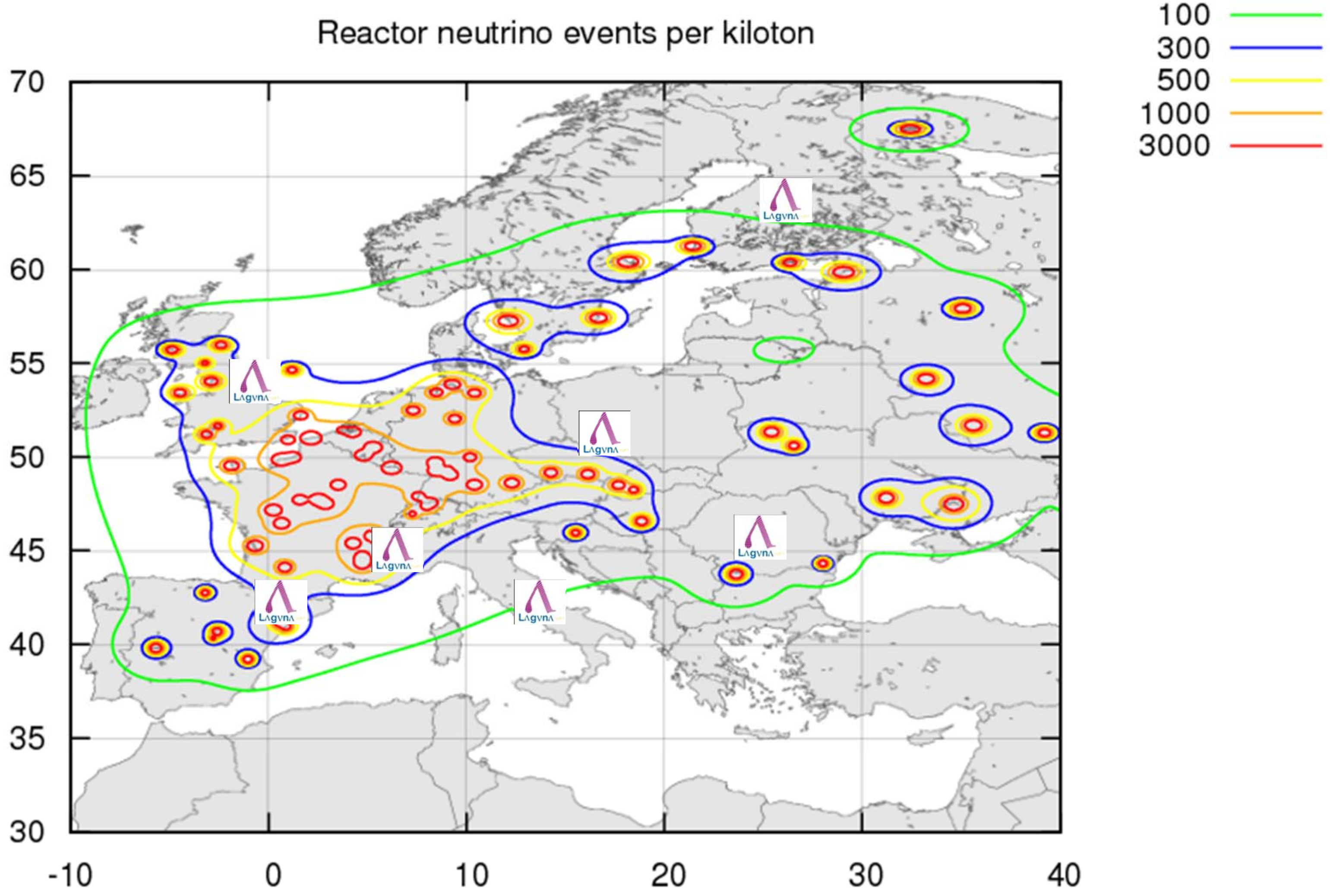
- Finland is also known for its tectonically stable bedrock. Earthquake zones are absent at the vicinity, therefore earthquakes occur extremely rarely and their magnitude may be neglected.

PYHÄSALMI, FINLAND

Technical / rock engineering conclusions

- The Mine has one decline, one main transport hoist shaft and one ventilation shaft. The present underground infrastructure only needs to be enlarged with a ventilation shaft and it provides a perfect layout to conduct excavation as well construction and filling of the tank.
- On surface there is an excellent rail yard and with good rail and road connections to the harbor in Kokkola. Construction of the tunnels can be started directly at the depth desired due to excellent existing infrastructure as well on surface as below surface.
- Pyhäsalmi has no challenges how to dispose excavated rock as all excavated rock can be handed over to the Mine and will be disposed underground.
- Pyhäsalmi Mine has very suitable hydrological conditions. The deep rock is nearly completely dry and there aren't any rock formations, that show time related deformations (like creep of salt or anhydrite)

COMPARING OF SITES



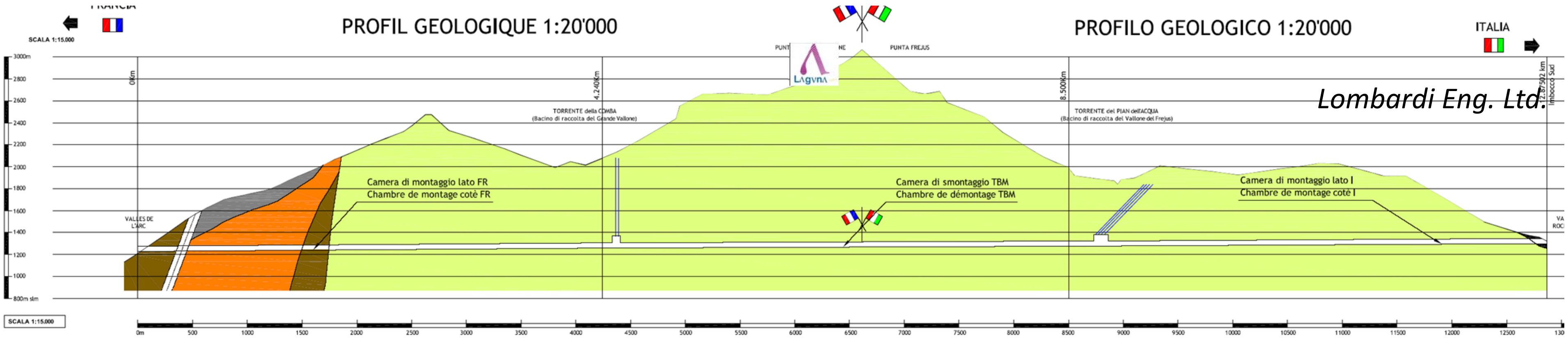
Clearance from nuclear plants to avoid reactor neutrino events

Guido Nuijten 18.12.2012

COMPARING OF SITES

Sufficient depth to reduce muon flux at the laboratory

France (1500m overburden)

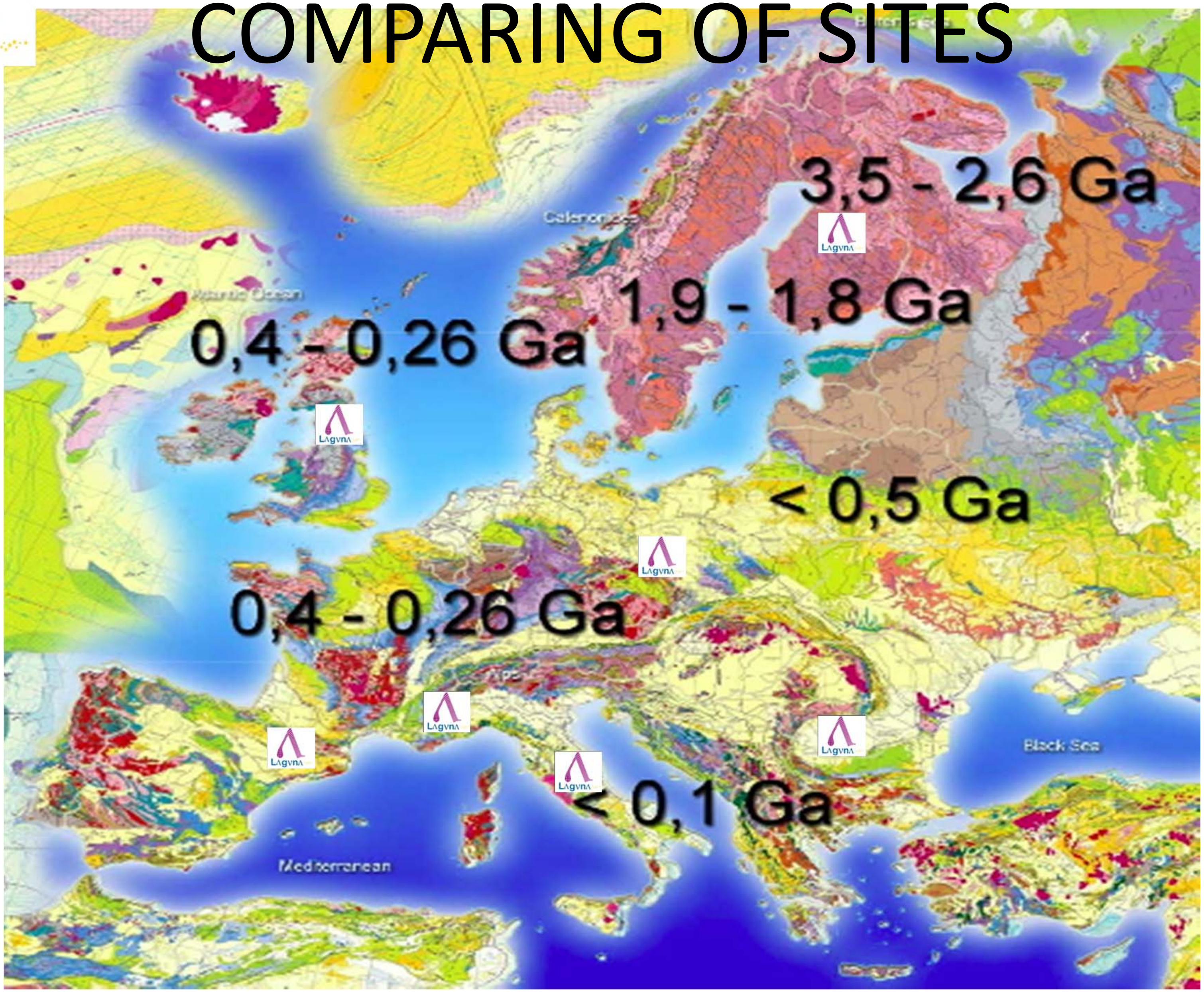


Other sites:
- Finland: sufficient depth for all three considered
- Spain: sufficient depth for Glacier + Memphys (Lena almost)

- UK: sufficient depth for Glacier (Lena almost)

- Poland: sufficient depth for Glacier
- Romania: sufficient depth for Glacier
- Italy: sufficient depth for Glacier

COMPARING OF SITES



Guido Nuijten 18.12.2012

COMPARING OF SITES

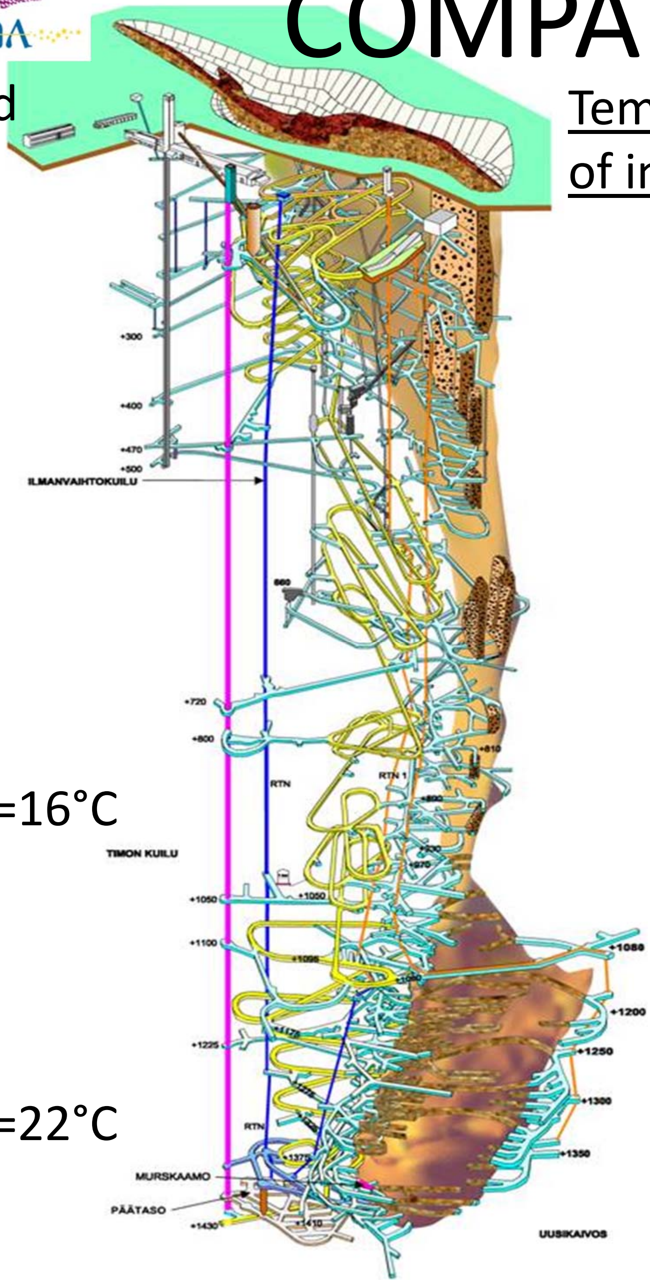
Intact Rock Strength		*average (MPa)*	*rock behavior*
Pyhäsalmi Finland		**232 (Mafic and Felsic Volcanites)**	**elastic + risk of spalling**
Frejus	France	**70** (Calc schists)	ductile plastic deformation large deformation + creep
Boulby	United Kingdom	**85** (Upper / Lower anhydrite) **180** (Dolomite, only 35 m thick layer)	elasto-plastic behavior (yield) failures on the boundary
Umbria	Italy	**100** (Limestone, estimated)	ductile plastic deformation
Sc-Polkowice - Poland		**43** (Salt rock) **124** (Anhydrite)	high level of creep brittle elasto-plastic behavior
Canfranc	Spain	**65** (Calcareous slate or limestone)	elasto-plastic deformation
Slanic	Romania	**28** (Massive Salt)	elastic (due to shallowness)
Kamiokande - Japan		**149** (Amphibolite and gneiss)	
Homestake – USA		**111** (Rhyolite) **115** (Amphibolite) *http://arxiv.org/ftp/arxiv/papers/1108/1108.0959.pdf*	

LAGVNA

ROCKPLAN

COMPARING OF SITES

Finland



T=16°C

T=22°C

Temperature conditions of in-situ rock

Romania

Other sites:

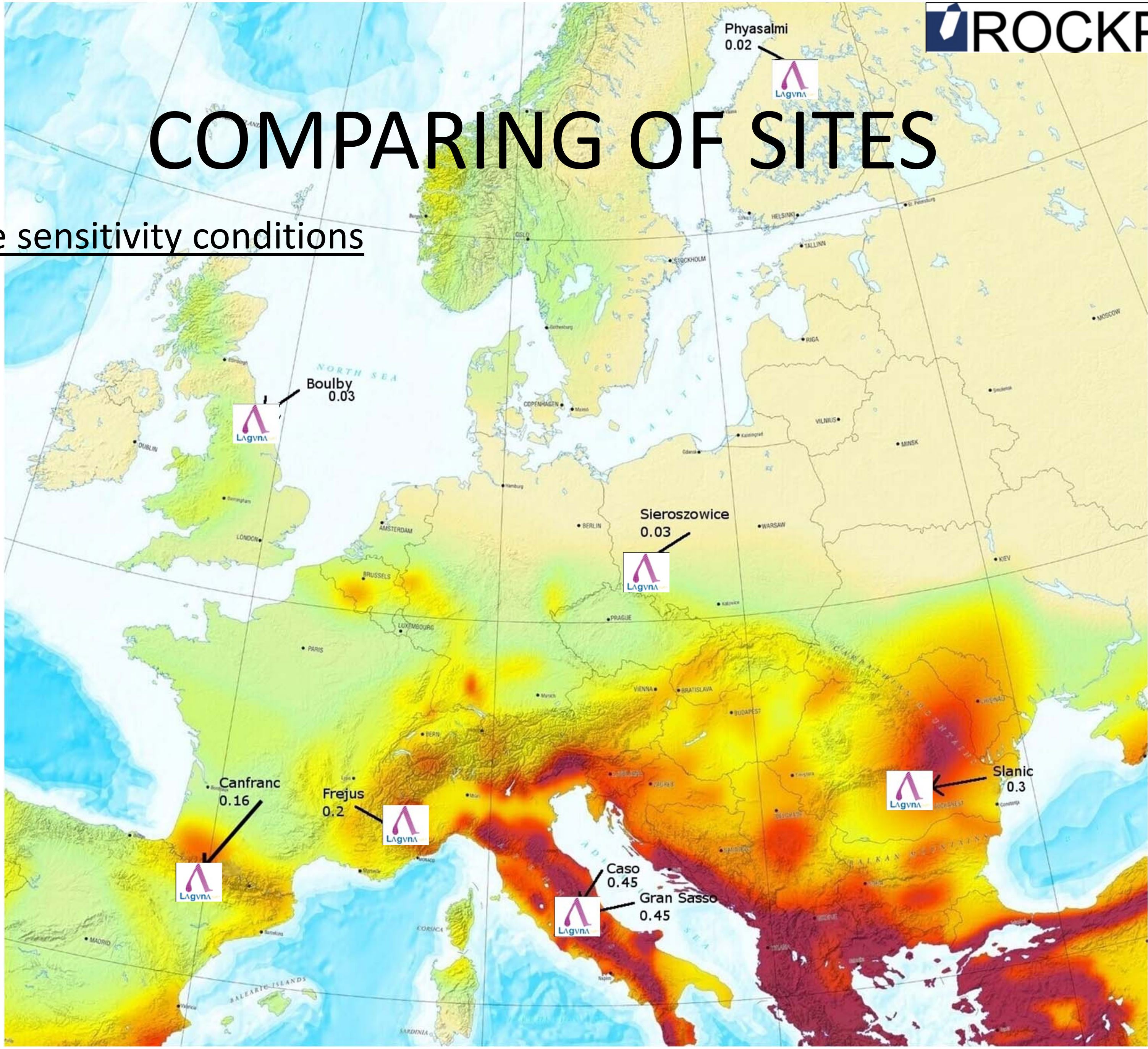
- Italy:
  estimated to be cool (14°C)

-France & Spain:
  warm, around 25°C maybe more

- UK & Poland:
  very warm 28 to 44°C

COMPARING OF SITES

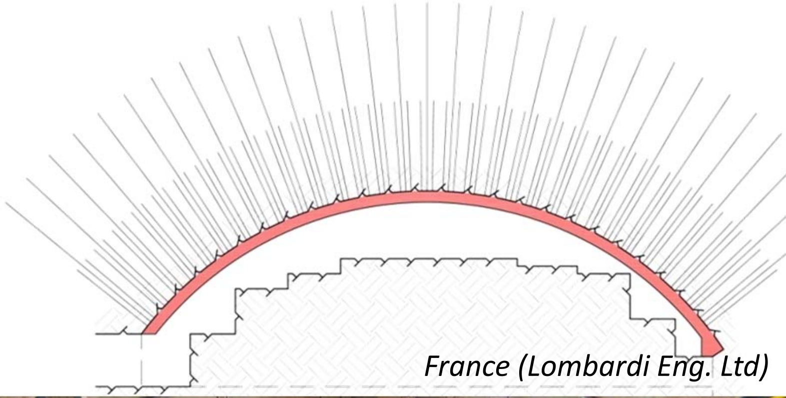
Earthquake sensitivity conditions



COMPARING OF SITES

Rock reinforcements (solutions presented)

Site	*reinforcements*
2.1 Finland	rock bolts + shotcrete + wire mesh
2.2 France	rock bolts + shotcrete + concrete final lining (1,5 to 2,3m)
2.3 United Kingdom	rock bolts *+ analyses to be finalized*
2.4 Italy	rock bolts + shotcrete + concrete final lining
2.5 Poland	polyester-glass bolts + wire mesh *+ analyses to be finalized*
2.6 Spain	pre bolting from pilot tunnels + rock bolts + shotcrete & final lining
2.7 Romania	fibre bolts + shotcrete



France (Lombardi Eng. Ltd)

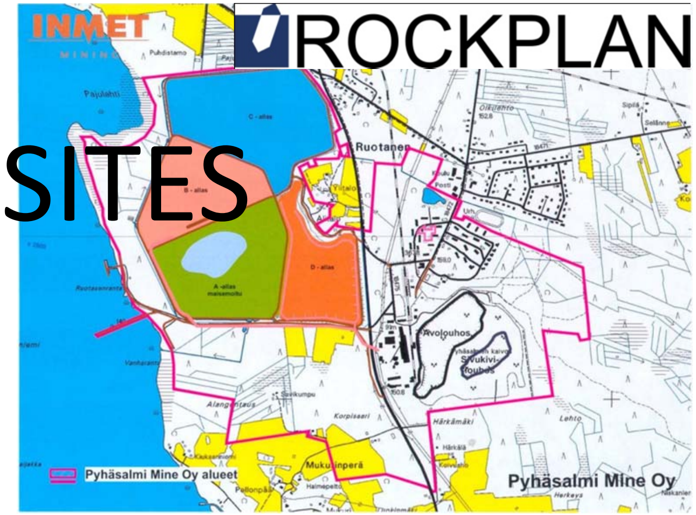
Shotcrete lining at -1430m in the maintenance hall in Pyhäsalmi, Finland)

COMPARING OF SITES

Site	*rock disposal*
2.1 Finland	directly delivered to the mine, that uses it for stoping (max. 250.000 m^3 /yr)
2.2 France	to be transported outside the tunnel + environmental regulations of the disposal site
2.3 United Kingdom	transported to surface and further by rail *present working system*
2.4 Italy	to be transported somewhere *(not yet analyzed)*
2.5 Poland	may be used for filling, may be transported to surface
2.6 Spain	to be transported outside the tunnel + environmental regulations of the disposal site
2.7 Romania	Salt is sold for a good price

Rock disposal solutions presented

COMPARING OF SITES



Pyhäsalmi, Finland

Present infrastructure at surface

Site	*rail line*	*rail yard*	*harbor connection*	*space for surface infra*	*main roads*
2.1 Finland	yes	yes	150 km	yes	yes
2.2 France	yes	no	200 km	?	yes
2.3 United Kingdom	yes	yes	1 km	yes	no
2.4 Italy	no	no	100 km	?	?
2.5 Poland	?	?	400 km	yes	no
2.6 Spain	yes	no	150 km	?	yes
2.7 Romania	no	no	250 km	yes	no

LAGUNA – LBNO: CONTENT

<u>LAGUNA-LBNO, purpose:</u>

1) Deep Underground Facility Construction, **TANK** construction + **LIQUID** infrastructure, optimized **LAYOUT + LOGISTICS**

2) Detector, Liquid handling, Life Time Operation, Costs & Risks

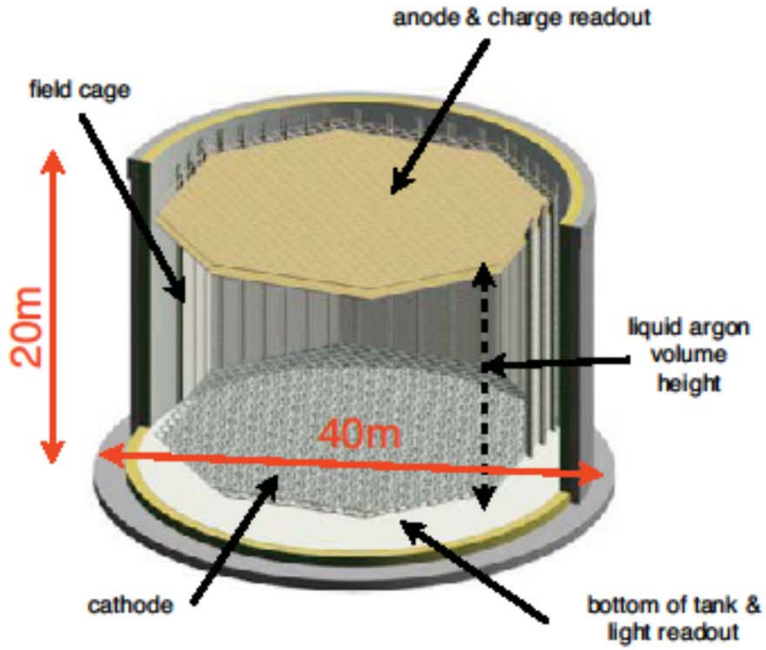
3) Long Base Line Neutrino Beam

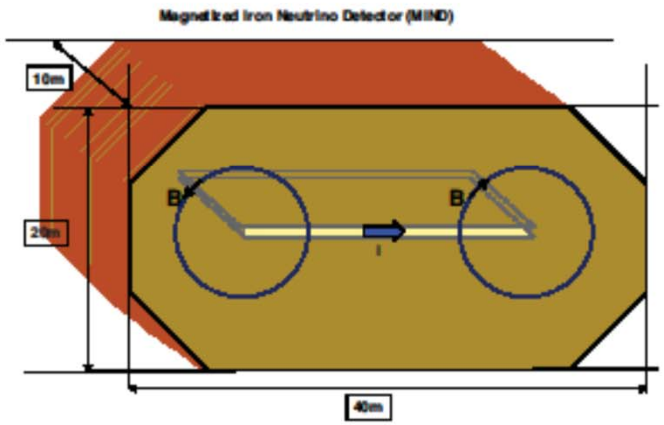
<u>POTENTIAL SITES & EXPERIMENTS</u>

- Modane, France
  - WCh
- Pyhäsalmi, Finland
  - LAr
  - LSc
  - MIND (not part of LL)
  - CN@PY (BEAM)

Far underground detectors

- **20 kton double phase LAr LEM TPC (GLACIER): best detector for electron appearance measurements with excellent energy resolution and small systematic errors**
  - Exclusive final states, low energy threshold on all particles
  - Excellent ν energy resolution and reconstruction ability from sub GeV to a few GeV, from single prong to high multiplicity
    - ➡ Suitable for spectrum measurement with needed wide energy coverage
  - Excellent π^0/electron discrimination
    - ➡ Wide band On-Axis beam is tolerable
- **35 kton magnetized Muon Detector (MIND): conventional and well-proven detector for muon CC, and NC**
  - muon momentum & charge determination, inclusive total neutrino energy
  - rsμ/wsμ with Neutrino Factory
  - 3cm Fe plates, 1cm scintillator bars, B=1.5-2.5 T

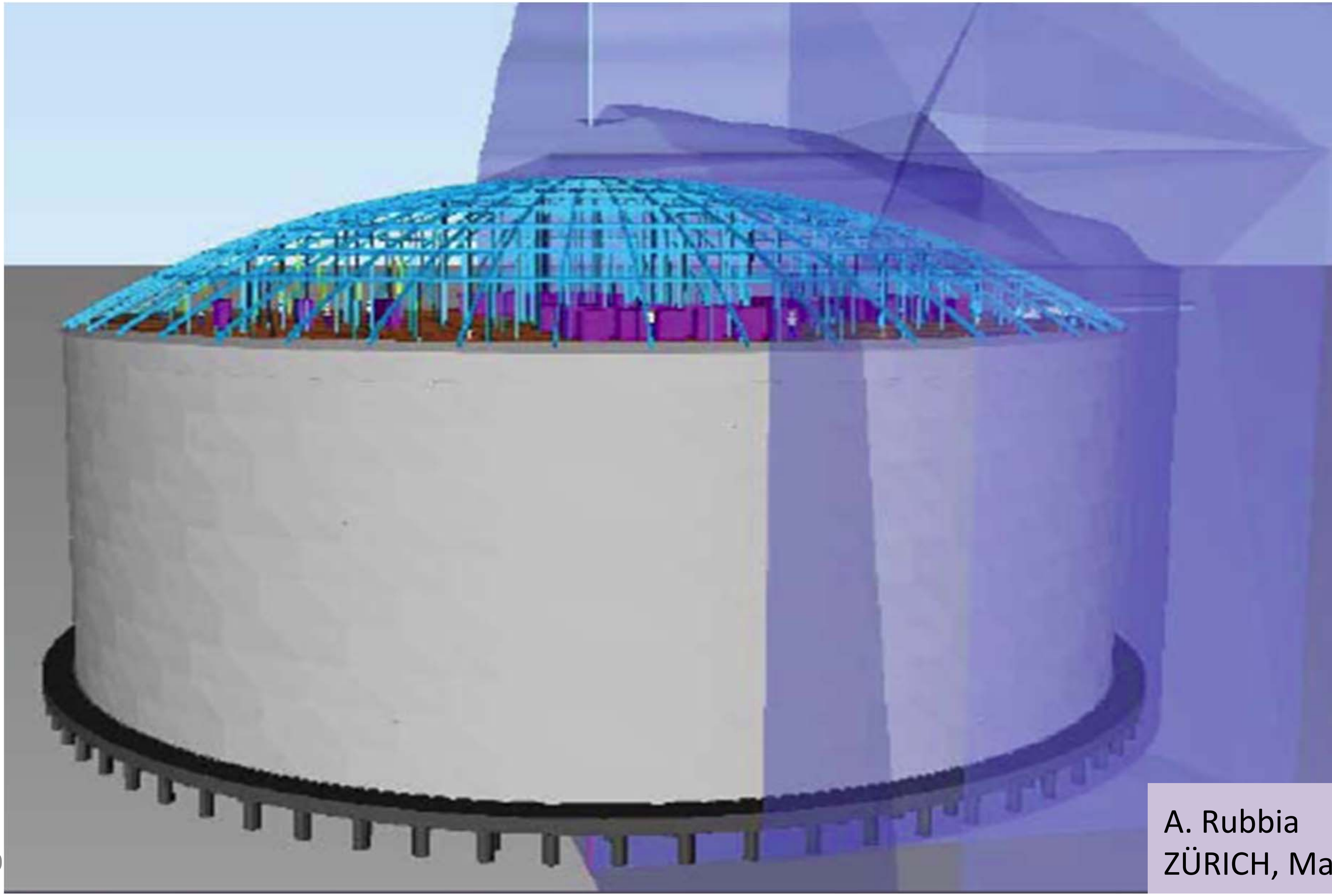




A. Rubbia
ZÜRICH, March. 2011

LAGUNA – LBNO

- LAr: 1 (PROTO) / 20 / 50 / 100 kTON



A. Rubbia
ZÜRICH, March. 2011

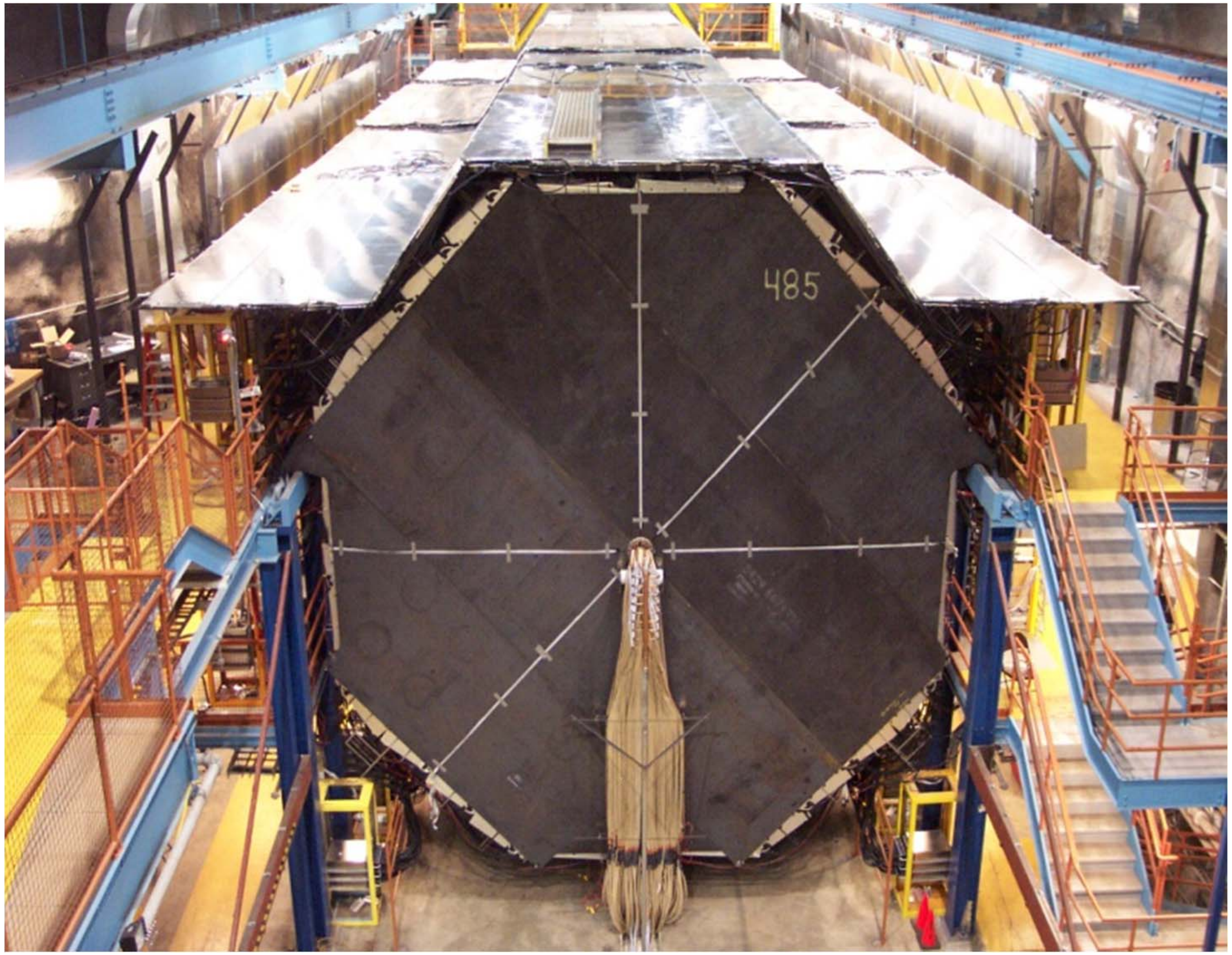
LAGUNA – LBNO

- LAr: 1 (PROTO) / 20 / 50 / 100 kTON

			20 kton	50 kton	100 kton
fiducial volume for beam neutrino events		kton	20	48	98
active volume	d1	mm	33000	51000	72000
active volume	h1	mm	20000	20000	20000
inner tank diameter	d2	mm	37000	55000	76000
inner tank argon height	h2	mm	22000	22000	22000
outer tank diameter	d3	mm	39000	57000	78000
bottom-lar	h3	mm	24000	24000	24000
bottom-top	h4	mm	25000	25000	25000
GAr phase	h4-h3	mm	1000	1000	1000
HV-GND distance radial	(d2-d1)/2	mm	2000	2000	2000
cathode-bottom	h2-h1	mm	2000	2000	2000
isolation thickness	d3-d2	mm	2000	2000	2000
bottom isolation thickness	h3-h2	mm	2000	2000	2000
total volume argon		m3	2.37E+04	5.23E+04	9.98E+04
total mass argon		kton	33	73	140
active volume		m3	1.71E+04	4.09E+04	8.14E+04
active mass		kg	2.39E+07	5.72E+07	1.14E+08
		kton	24	57	114
ratio active / total			72%	78%	82%
ratio fiducial / total			59%	66%	70%

LAGUNA – LBNO

- MIND 35kT: Magnetized Iron Neutrino Detector



Example from MINOS, Soudan, USA
(size 8x8m)
(depth 30m)

For Pyhäsalmi
Size 20x40m
Depth 10m

A. Weber
OXFORD, OCT. 18. 2011

LAGUNA – LBNO

- LSc: 50 kTON

Authors: Lothar Oberauer, Patrick Pfahler, Michael Wurm

M. Wurm
HAMBURG, 4.9. 2012

LAGUNA – LBNO

- LSc: 50 kTON

Item			25 kt	50 kt
cavern: short axis	D_{cs}	mm	44600	44600
cavern: long axis	D_{cl}	mm	70000	71200
cavern: height	H_c	mm	70000	120000
concrete tank: inner diameter	D_{ti}	mm	36000	32000
concrete tank: inner height	H_{ti}	mm	40000	100000
concrete tank: wall thickness	d_{tw}	mm	600	600
scintillator: total volume		10^3 m^3	40.7	80.3
scintillator: total mass		kt	35.0	69.1
active volume: diameter	D_{ls}	mm	32000	28000
active volume: height	H_{ls}	mm	36000	96000
scintillator: active volume		10^3 m^3	28.9	59.1
scintillator: active mass		kt	24.9	50.8
ratio: active/total			71%	74%
cavern volume (bottom to tank height)		10^3 m^3	92.7	219.6
tank volume		10^3 m^3	43.5	86.6
outer water volume		10^3 m^3	49.2	133.0

M. Wurm
HAMBURG, 4.9. 2012

LAGUNA – LBNO

Extraction from LSS2, target in North Area

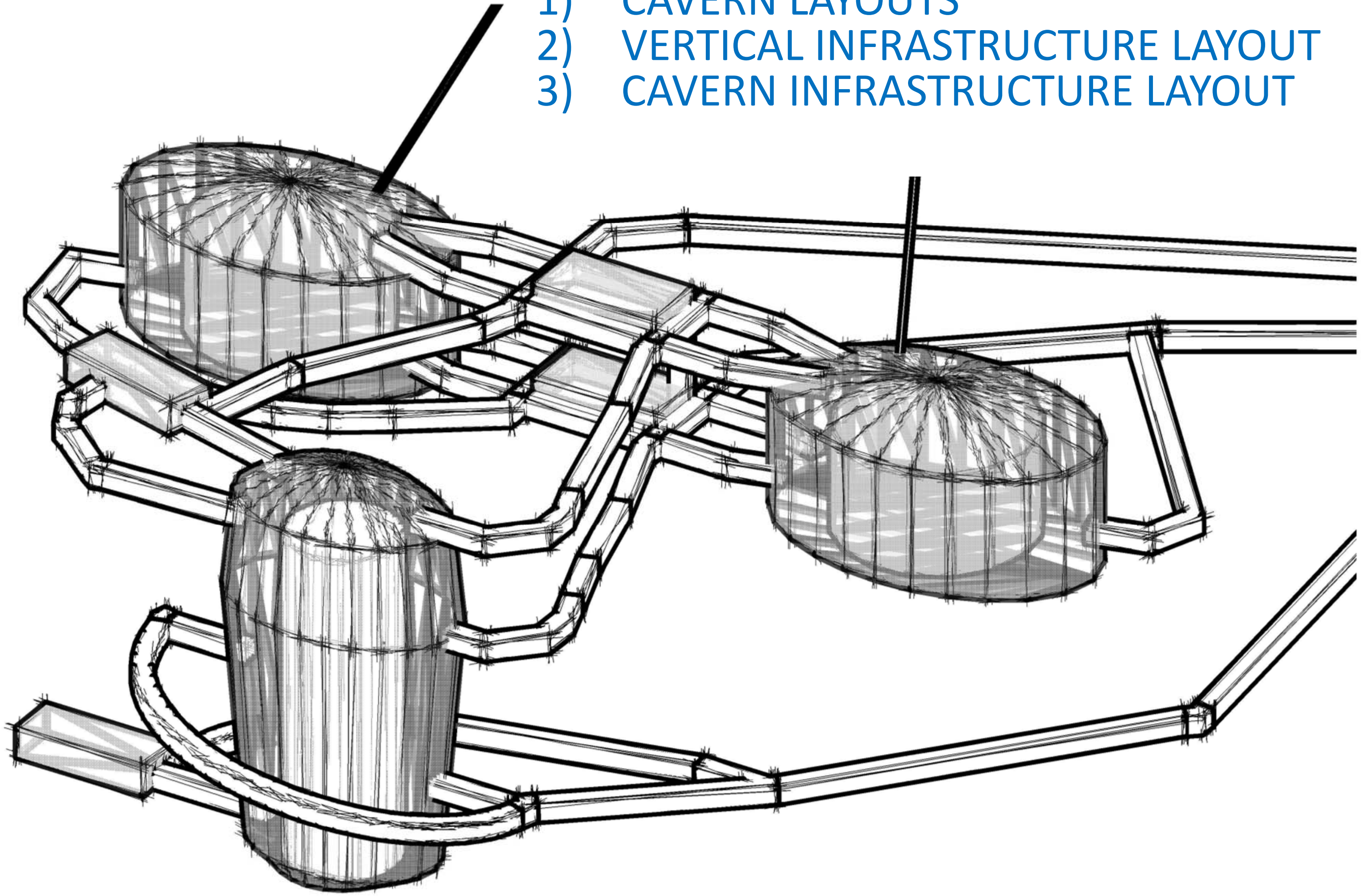
I.Efthymiopoulos
CERN, OCT. 2. 2012

LAGUNA – LBNO

- INFRASTRUCTURE + EXCAVATION

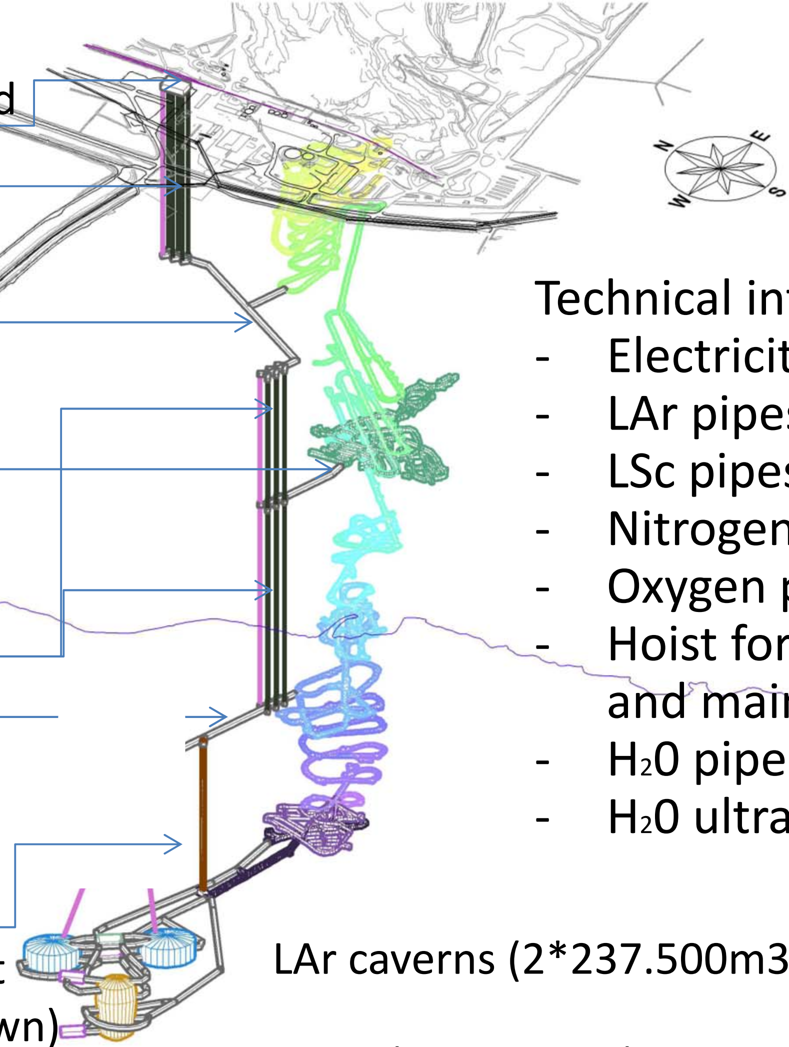
LAGUNA-LBNO: LAr + LSc LAYOUT @ PYHÄSALMI

1) CAVERN LAYOUTS
2) VERTICAL INFRASTRUCTURE LAYOUT
3) CAVERN INFRASTRUCTURE LAYOUT



AXONOMETRIC VIEW, LAr AND LSc SKETCH FROM SOUTH - WEST
2.7.2012

Pyhäsalmi Mine & LAGUNA-LBNO underground infrastructure



Surface connection next to rail yard, road connection and parking places

Technical infra shaft connection D3,1m
Surface to -375

Shaft yards and horizontal tunnel connection at -375

Shaft yards and horizontal tunnel connection at -675 + shaft drainage

Technical infra shaft connection D3,1m from -375 via -675 to -1100

Shaft yards and horizontal tunnel connection at -1100

Technical infra shaft connection D3,1m from -1100 to -1400 + additionally outlet during excavation and construction (brown)
LAr vents (pink) 2*D0,7m

Technical infra shaft:
- Electricity
- LAr pipes
- LSc pipes
- Nitrogen pipes
- Oxygen pipes
- Hoist for installation and maintenance
- H_2O pipes
- H_2O ultra pure pipes

LAr caverns (2*237.500m3)

LSc cavern (254.700m3)

Total LAr+LSc underground infrastructure (879.000m3)

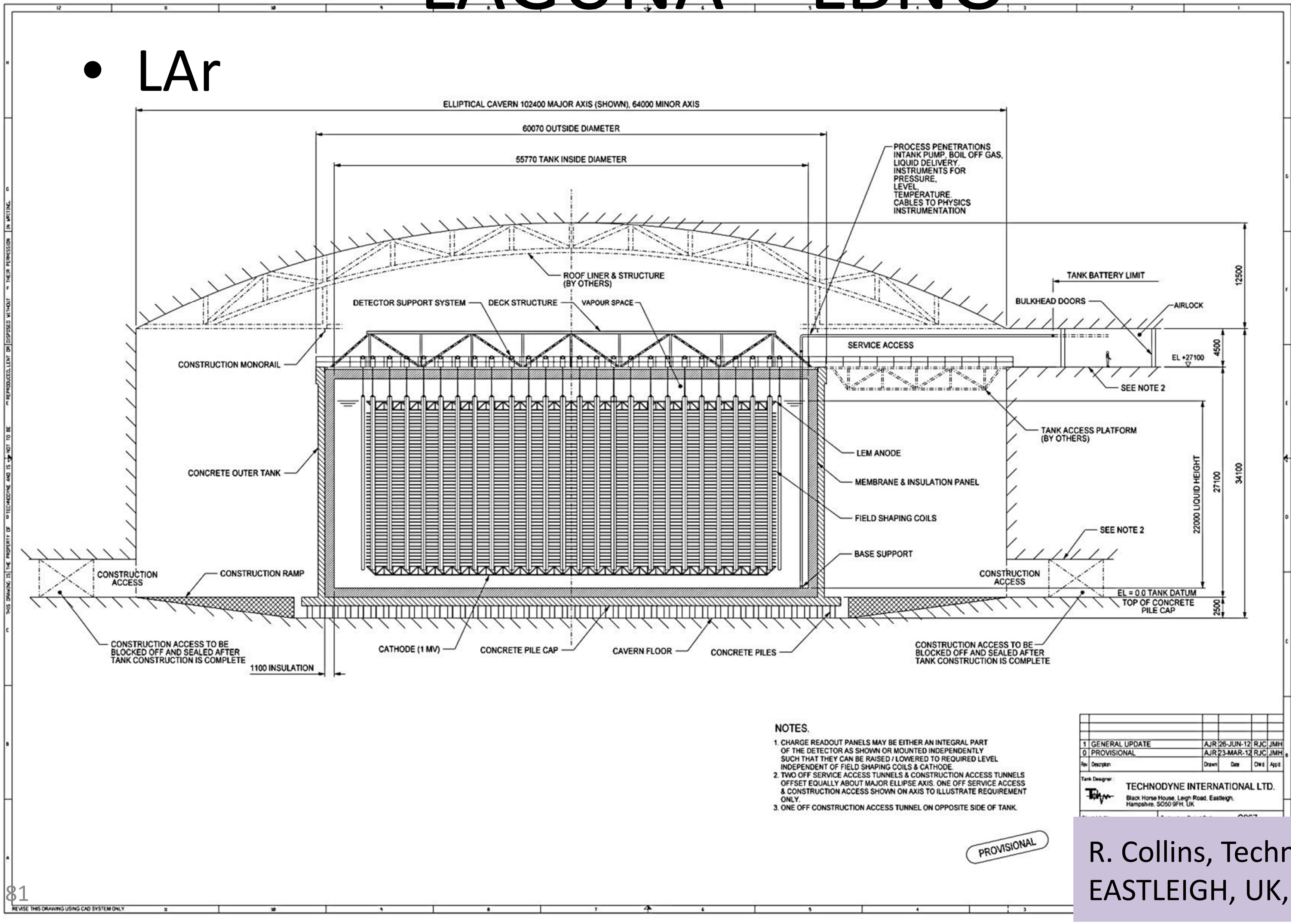
AXONOMETRIC VIEW, SOUTH - WEST
2.7.2012

LAGUNA – LBNO

- CONSTRUCTION (CONCRETE + STEEL)
  - LAr membrane tank
    - CONCRETE TANK
    - STEEL LINING
    - INSULATION
  - LSc concrete tank
    - CONCRETE TANK
    - STEEL INNER LINING
    - PUR MEMBRANE OUTER LINING
  - MIND

LAGUNA – LBNO

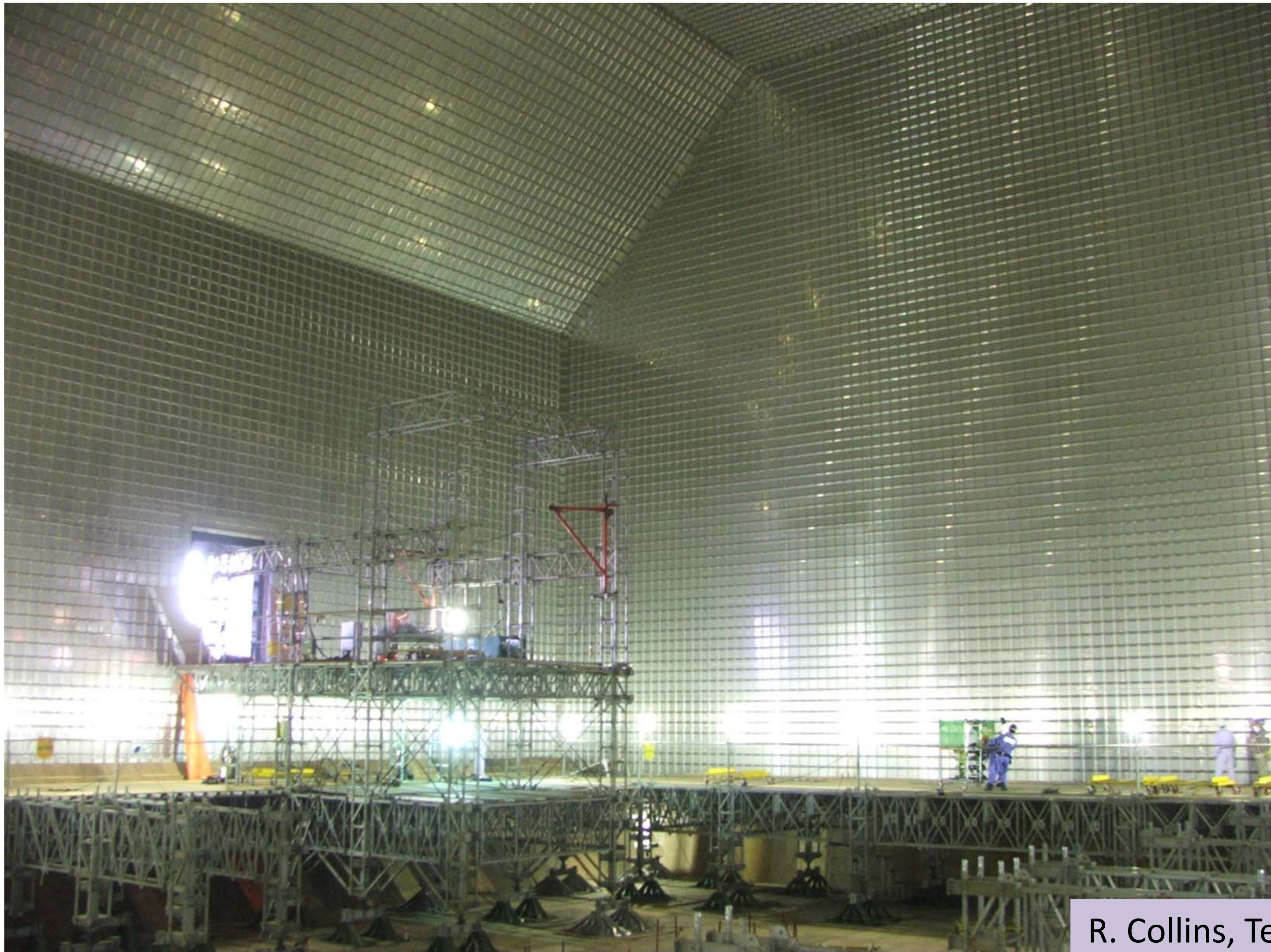
- LAr



R. Collins, Technodyne
EASTLEIGH, UK, 7.2012

Technodyne International Limited

Review Robustness of Membrane Technology

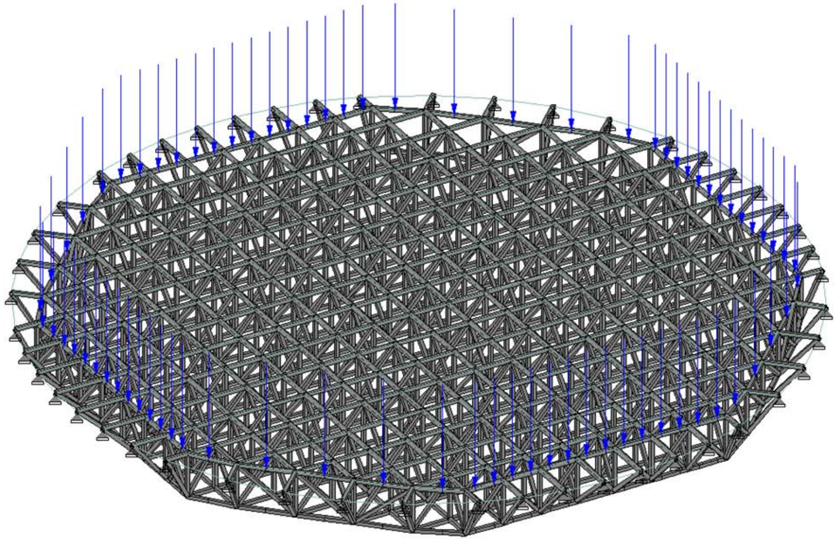


R. Collins, Technodyne
EASTLEIGH, UK, 7.2012

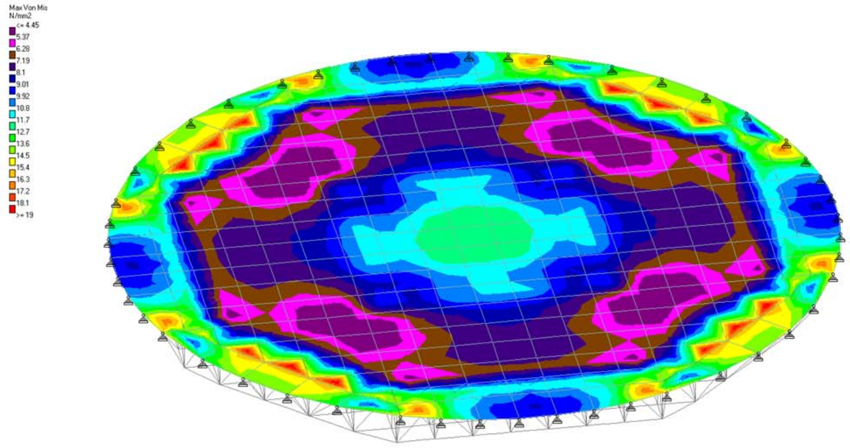
Technodyne International Limited

GLACIER LAr Tank Design Update 2

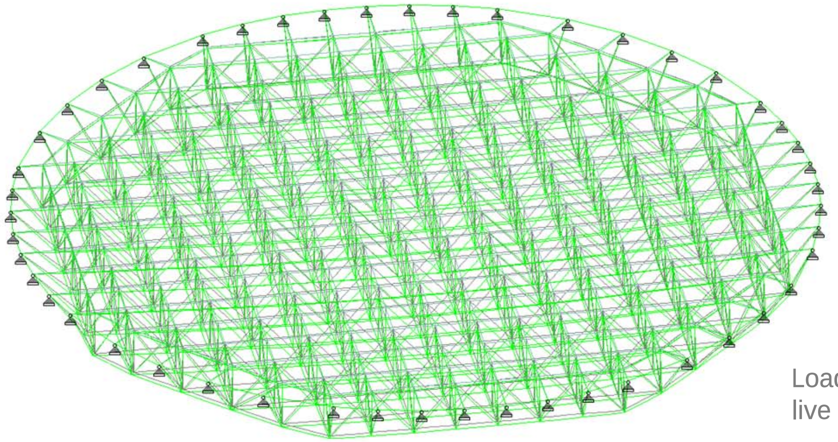
Revised Deck Design (100ktonne)



Load case 51 – Vacuum, self-weight, live load and sensor loads – Max von Mises plate stress



Load case 50 – Pressure, self-weight, live load and sensor loads



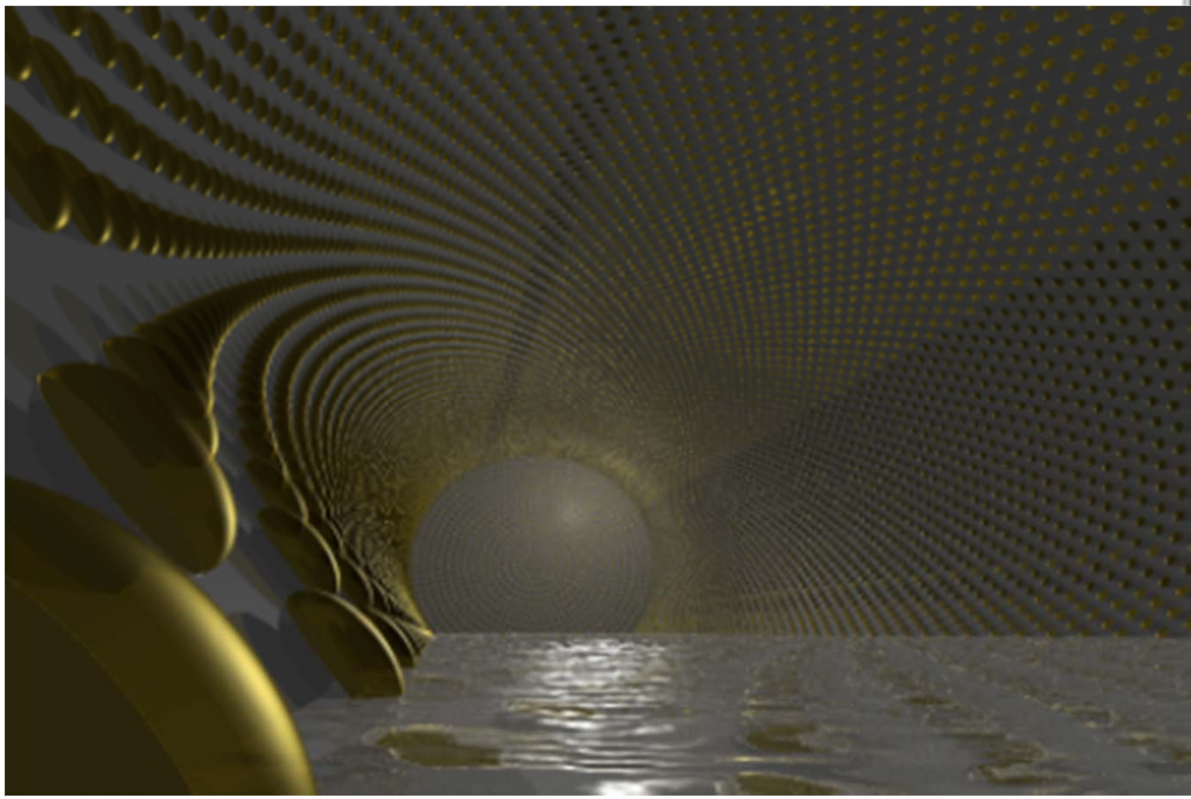
Load case 51 – Vacuum, self-weight, live lo

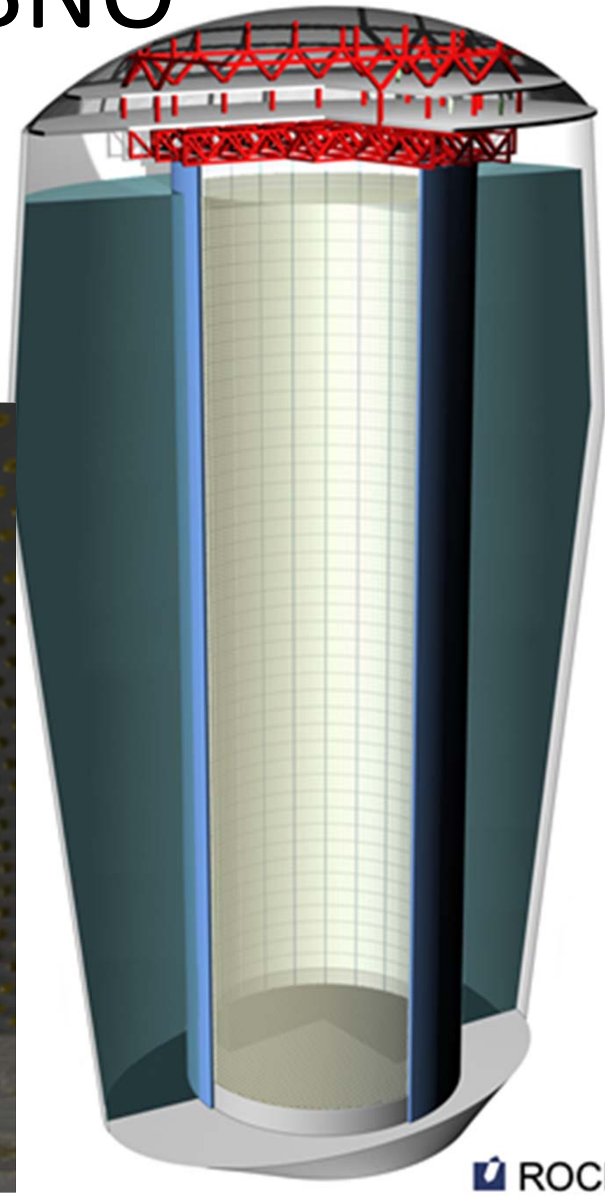
R. Collins, Technodyne
EASTLEIGH, UK, 7.2012

ROCKPLAN

LAGUNA – LBNO

- LSc





ROCKPLAN

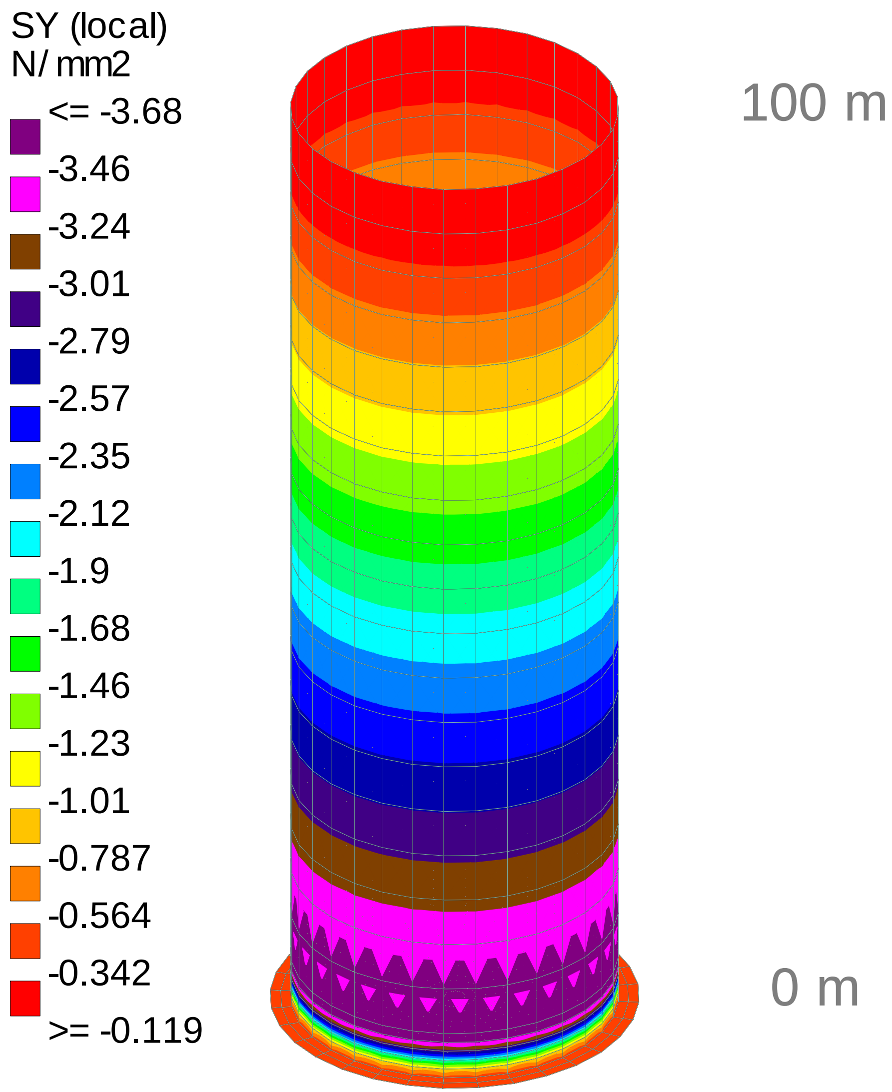
Guido Nuijten 18.10.2012

Finite Element Analysis of Concrete Tank - 1

Service Hoop Compressive Stress (N/mm²)

Inside Full of Oil with Specific Gravity 0.86

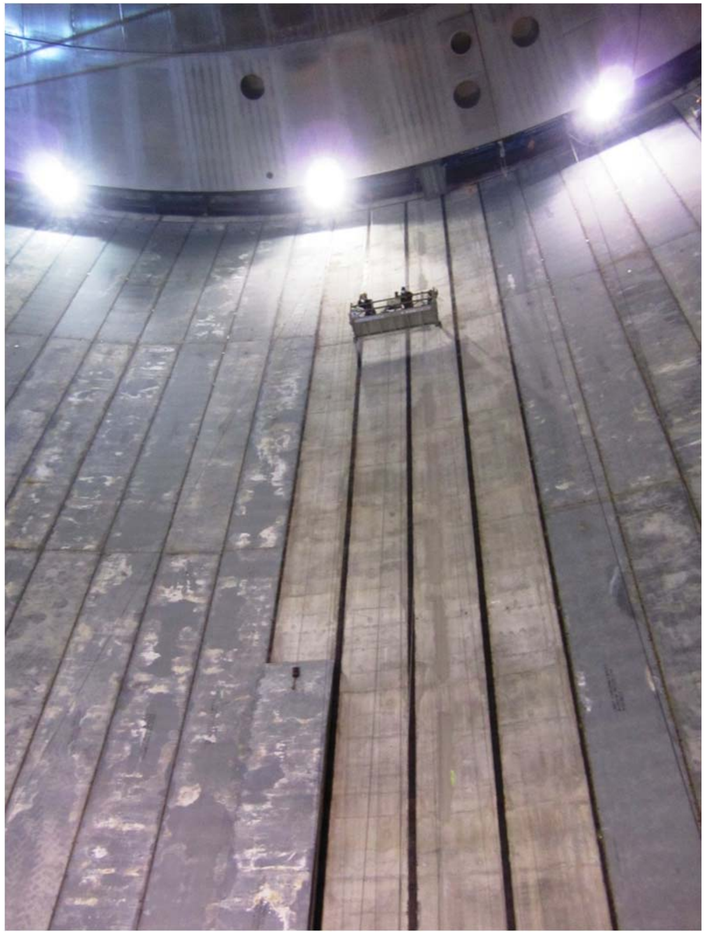
External Space Filled with Water with Specific Gravity 1.0



Technodyne International Limited

LENA LSc Tank Design Update 2

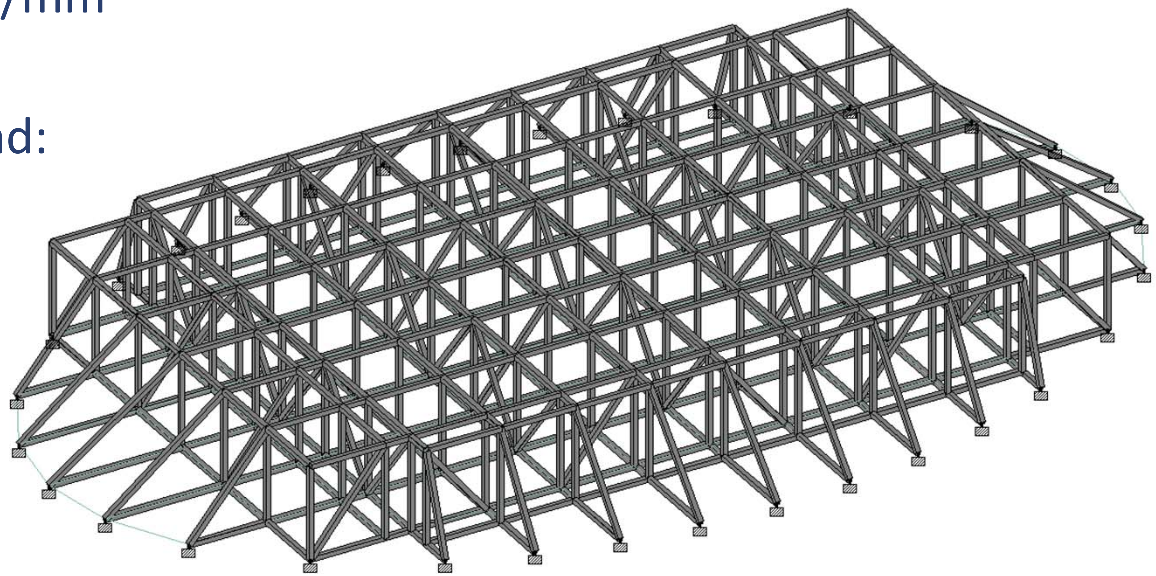
Design of Stainless Steel Lining



R. Atkinson, Technodyne
EASTLEIGH, UK, 7.2012

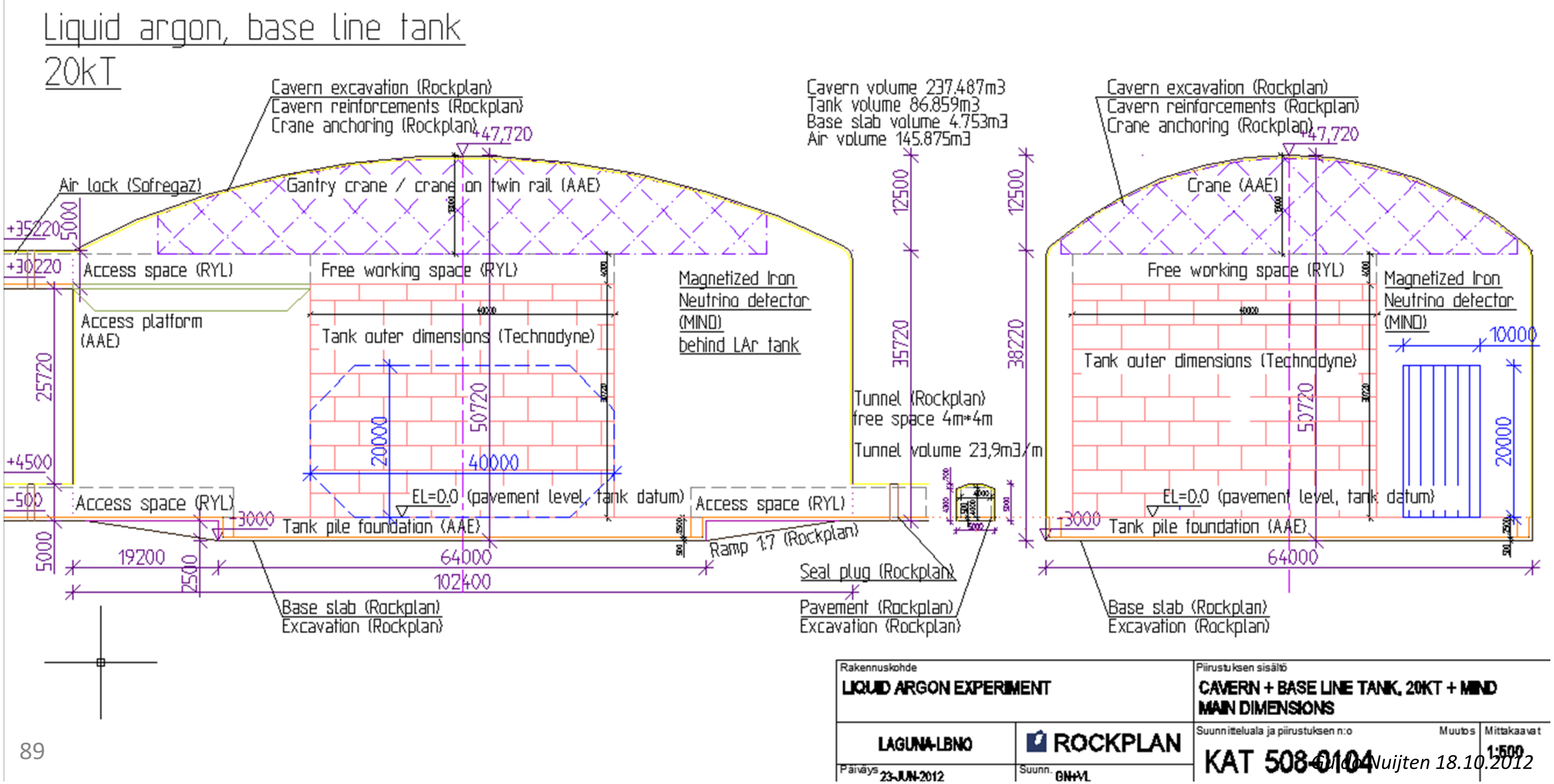
LENA LSc Tank Top Lower and Upper Deck Design

- Upper Deck basic design
- Loads:
- Self weight
- Muon Veto: 0.00049 N/mm^2 (bottom of deck only)
- Equipment and live load: 0.0017 N/mm^2
- Hoist Load: -323730 N (point load see below)

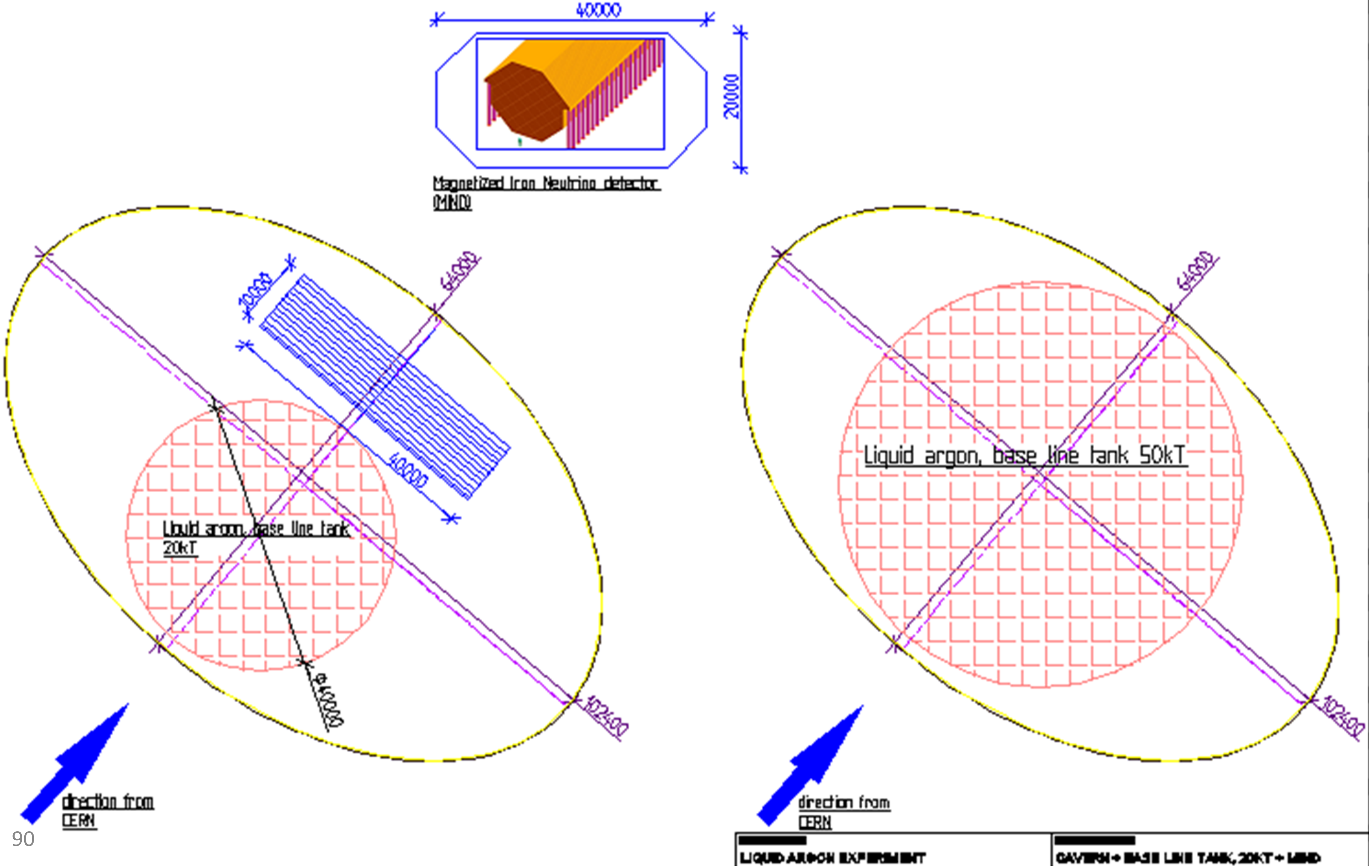


LAGUNA – LBNO

- MIND (behind the 20 kT LAr)



LAGUNA – LBNO

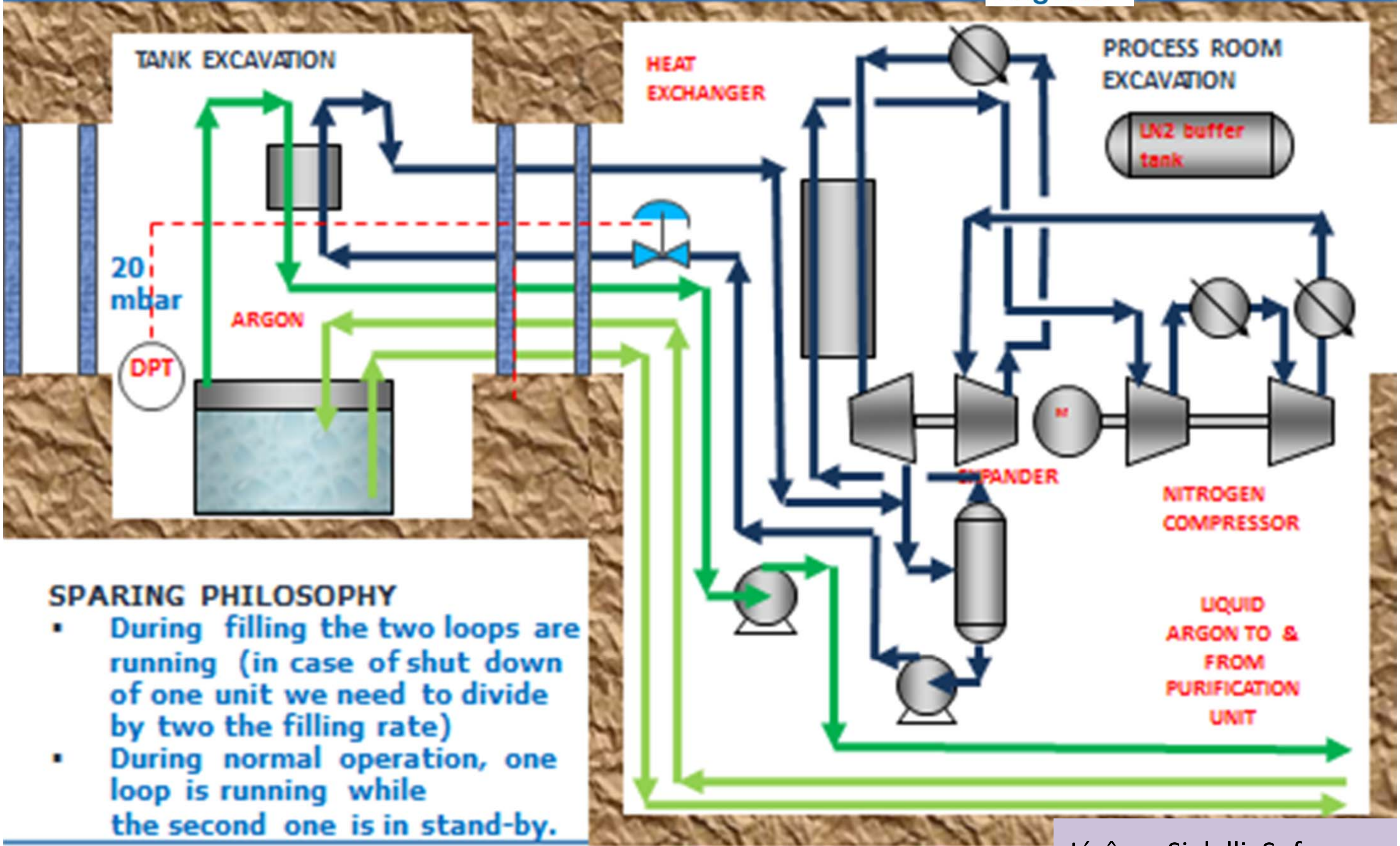

40000
20000
Magnetized Iron Neutrino detector
(MIND)
10000
40000
64000
Liquid argon, base line tank
20kT
Φ40000
102400
direction from
CERN
Liquid argon, base line tank 50kT
64000
102400
direction from
CERN
[redacted]
LIQUID ARGON EXPERIMENT
[redacted]
CAVERN + BASE LINE TANK, 20KT + MIND

LAGUNA – LBNO @ PYHÄJÄRVI

– LIQUID INFRASTRUCTURE + LIQUID HANDLING

- Pipe lines
- Purification plants
- Temporary storages on surface

LIQUID ARGON: BOIL OFF LIQUEFACTION



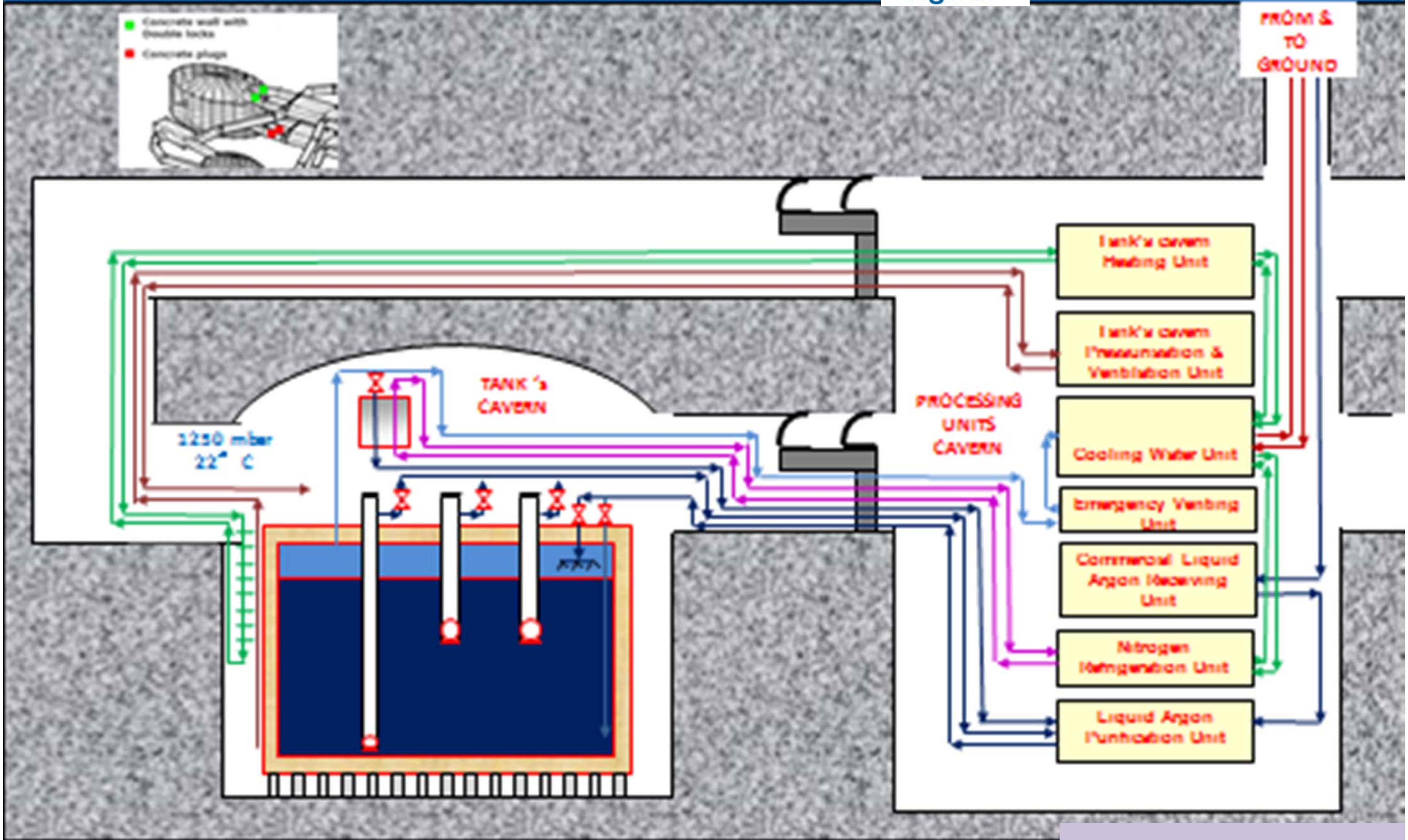
SPARING PHILOSOPHY

- During filling the two loops are running (in case of shut down of one unit we need to divide by two the filling rate)
- During normal operation, one loop is running while the second one is in stand-by.

LAGUNA-LBNO
LAr-Process Facilities

Jérôme Sialelli, Sofregaz
Genève, Oct. 2012

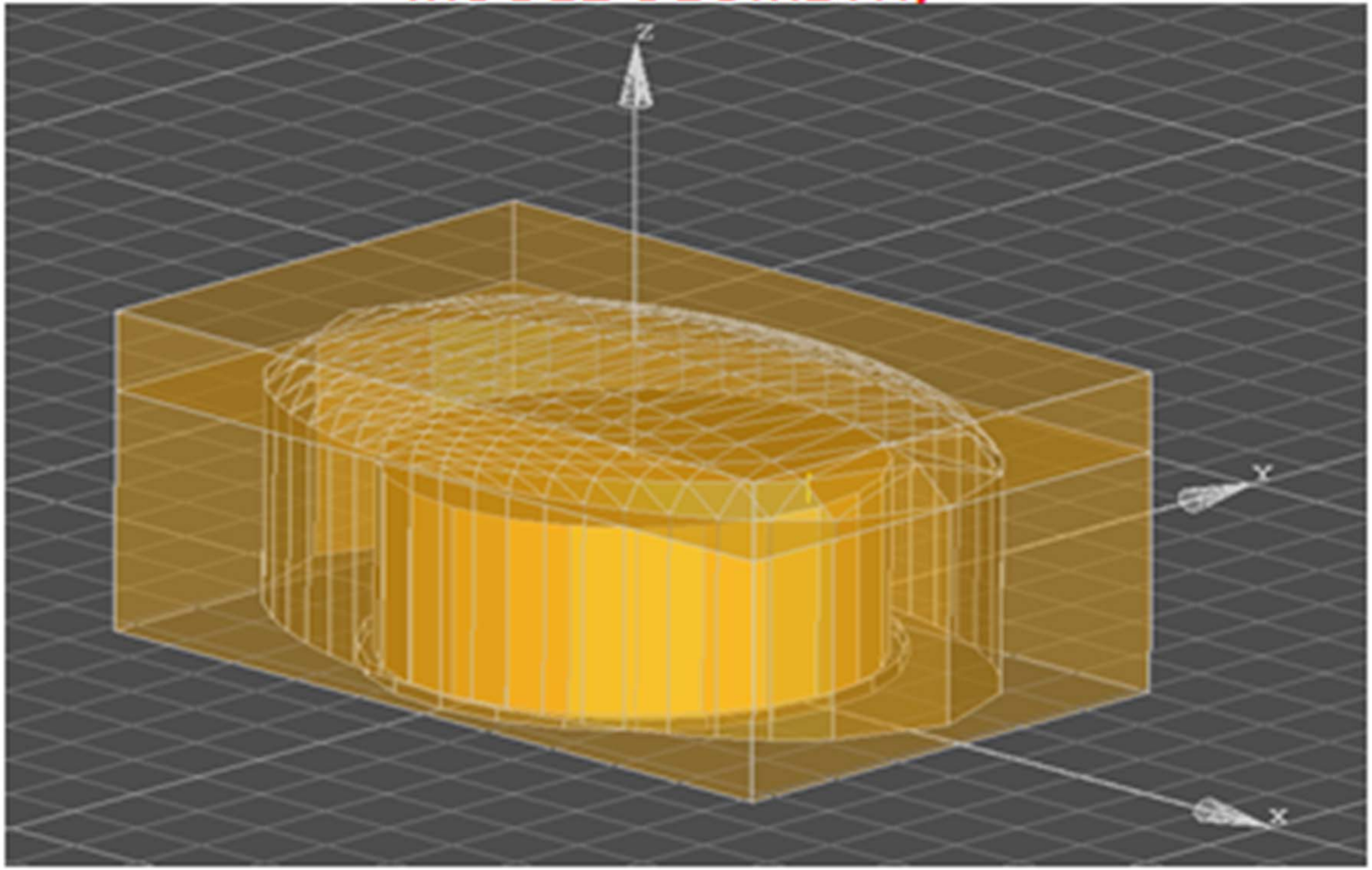
BELOW GROUND FACILITIES



Jérôme Sialelli, Sofregaz
Genève, Oct. 2012

LARGE BREAK

MODEL GEOMETRY



Ioannis Papazoglou,
Demokritos, Greece
Genève, Oct. 2012

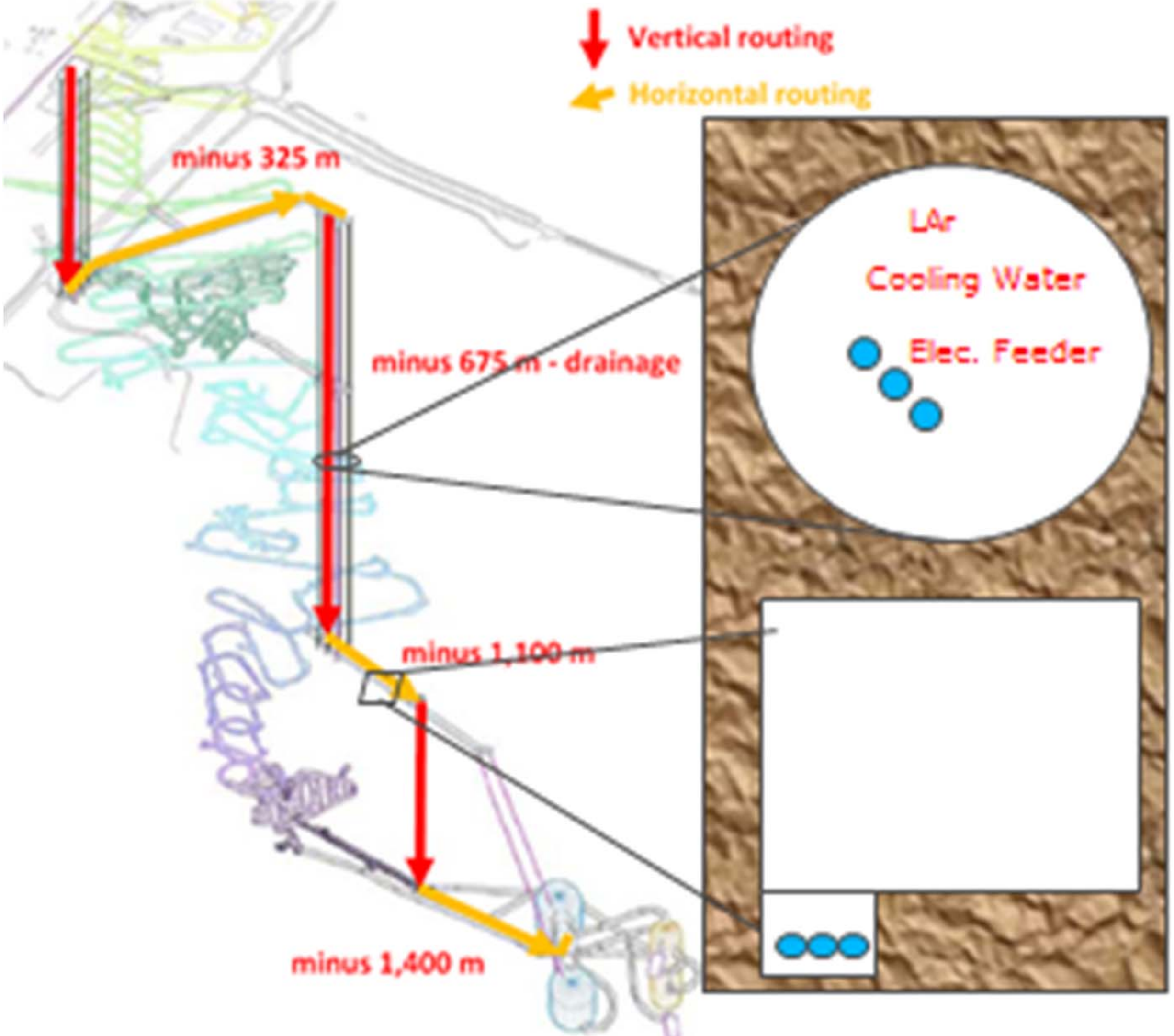
•GRADATION OF LEAKS LINER TANK

ROCKPLAN Sofregaz LAgUNA

type of leak	Liquid argon leak flow m3/s	Effect on people on tank deck	without specific borehole to surface	with borehole to surface	probability tank*year
instantaneous release of total inventory	infinite	possible death of people on deck, from 14m fall into Lar or congelation , deck reinforcement is broken	cavern and other caverns are left	*cavern is left , work go on on other caverns*	5*E-6
major failure	16	with valve opened around 35 second opened to let air enter tank, tank doesn't implode people have 20 minutes to leave the cavern, after death by lack of oxygen or cold	cavern and other caverns are left	cavern is left , work go on on other caverns	1*E-4
minor failure	1,5	people have 3,7 hours to leave the cavern	cavern and other caverns are left	cavern is left , work go on on other caverns	8*E-5
hole 10mm diameter	0,0016	people leave the cavern which is full of under 0°C argon	cavern and other caverns are left	cavern is left , work go on on other caverns	1*E-4 !!
flow evacuable by evaporative water cooling system	0,000833333	people leave the cavern which is full of gaseous argon at ambient temperature (heat required 115kW .	cavern is left , work go on on other caverns	cavern is left , work go on on other caverns	?
Limit of normal ventilation of cavern	1,85E-05	people stay in the cavern	experience go on	experience go on	?

Didier Fernique, Sofregaz
Genève, Oct. 2012

INTERCONNECTING FACILITIES



Functional requirements:

1. Interconnecting piping & wiring from above ground to below ground (piping & wiring):
2. Exhaust air coming from below ground cooling system

Installation:

1 => Hanged pipes in for vertical potion & rack for horizontal ones.

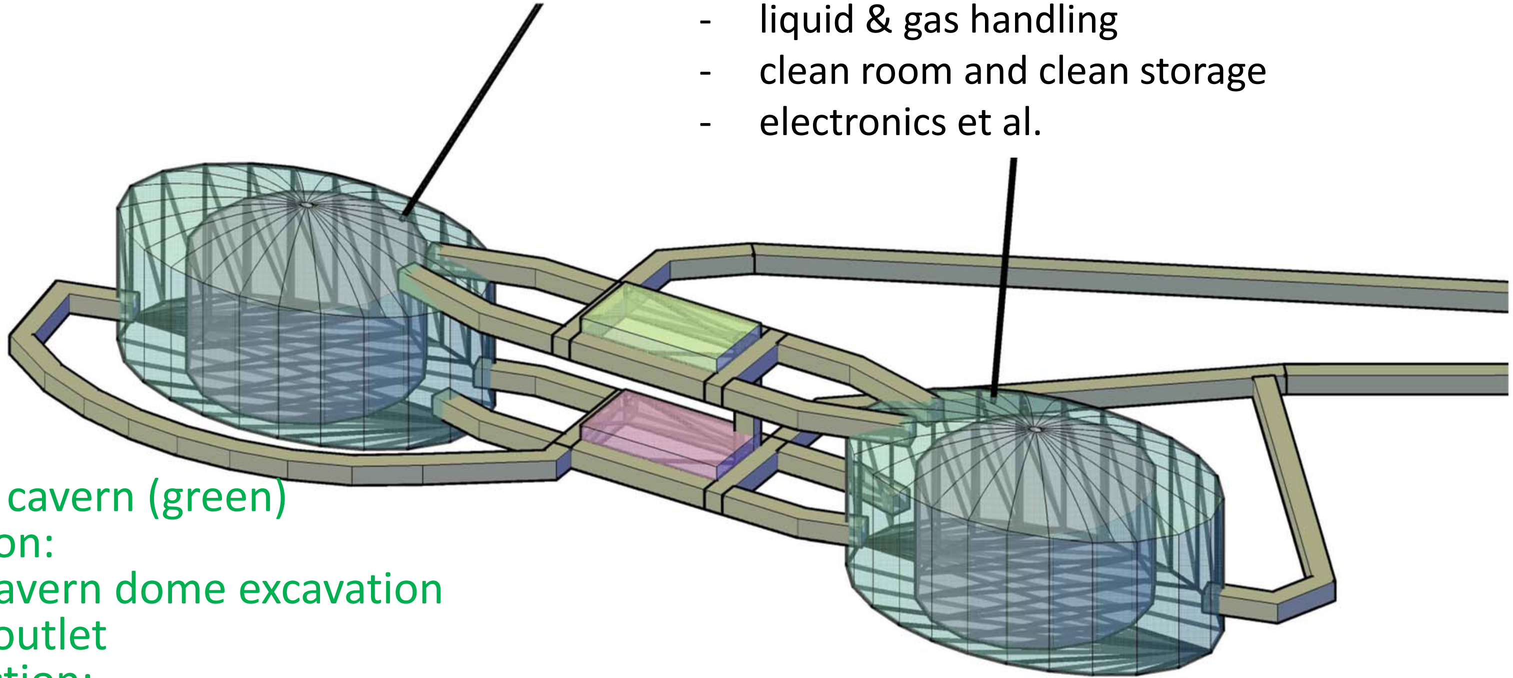
2 => Same shaft for vertical portions & same gallery for horizontal portions.

Jérôme Sialelli, Sofregaz
Genève, Oct. 2012

LAr LAYOUT @ PYHÄSALMI

ROCKPLAN

Main Detector Cavern MDC (in operation):
- equipment space/room
- liquid & gas handling
- clean room and clean storage
- electronics et al.



Upper auxiliary cavern (green)
during excavation:
- access for cavern dome excavation
- ventilation outlet

during construction:
- supply for roof construction

during operation:
- processing, electrical and control room
- power transformation
- ventilation power room

Lower auxiliary cavern (magenta)
during excavation:
- access to cavern invert
- ventilation inlet to caverns
- equipment storage

during construction:
- supply for tank construction

during operation:
- pump installation
- safety and emergency rooms

AXONOMETRIC VIEW, LAr SOUTH - WEST
2.7.2012

PURIFICATION OF LSC IN OPERATION

Then to go from top of cavern to surface a piston pump:

Geometric head : 1,400m

Head drop (16.4%): 2100 x 16.4% = 344m

So 1,744m or 144 bar

Pump power 100kW.

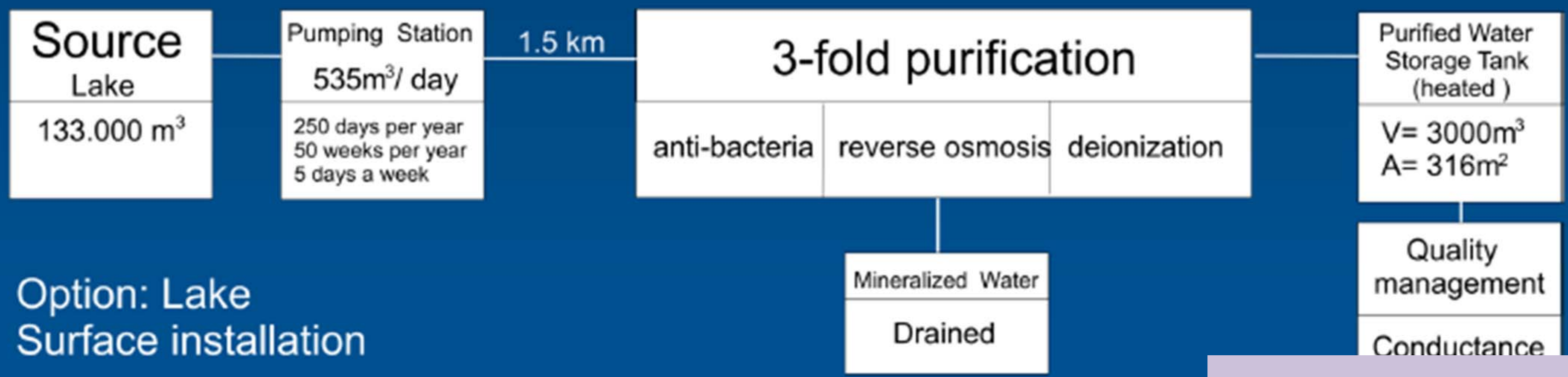
If pump is used only to go to surface for purification, purified product (water or LSC) go back to tank simultaneously so level is constant there is no need to empty the 2 products.

If emptying of LSc is required to go inside tank , water must be removed simultaneously and if we don't want to use the same pump half time for LSc and half time for water , a second identical pump will be required for water.

Jérôme Sialelli, Sofregaz
Genève, Oct. 2012

Pure water production line

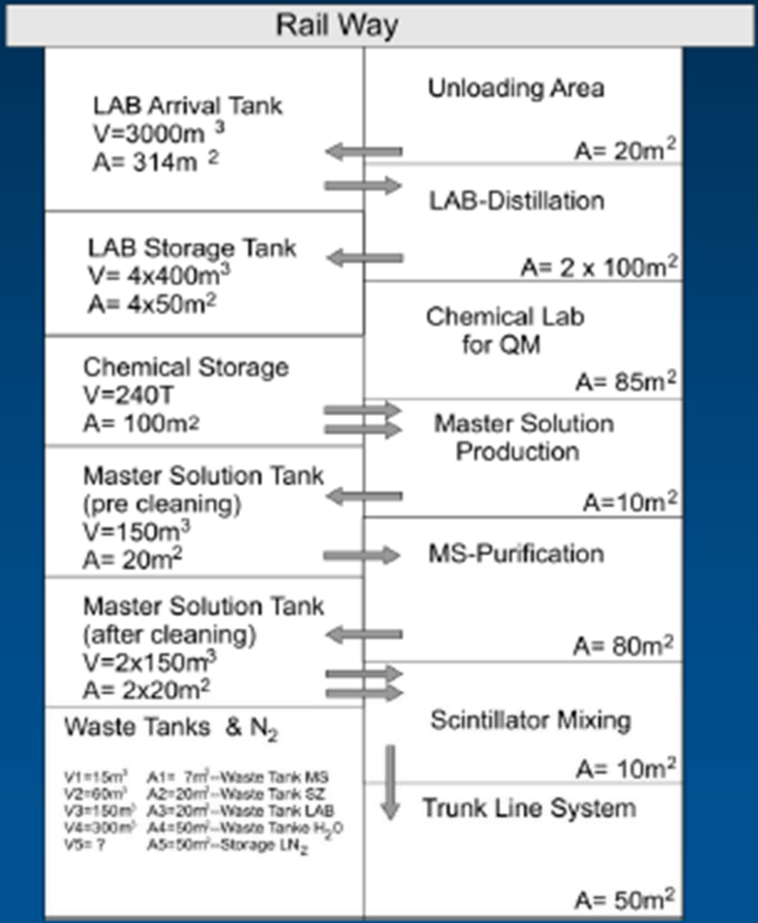
- Aim:
  - Production of 133.000 m^3 pure water within 1 year
  - Cleanliness: optical transparent (long term stable)
  - Sources: lake / mine

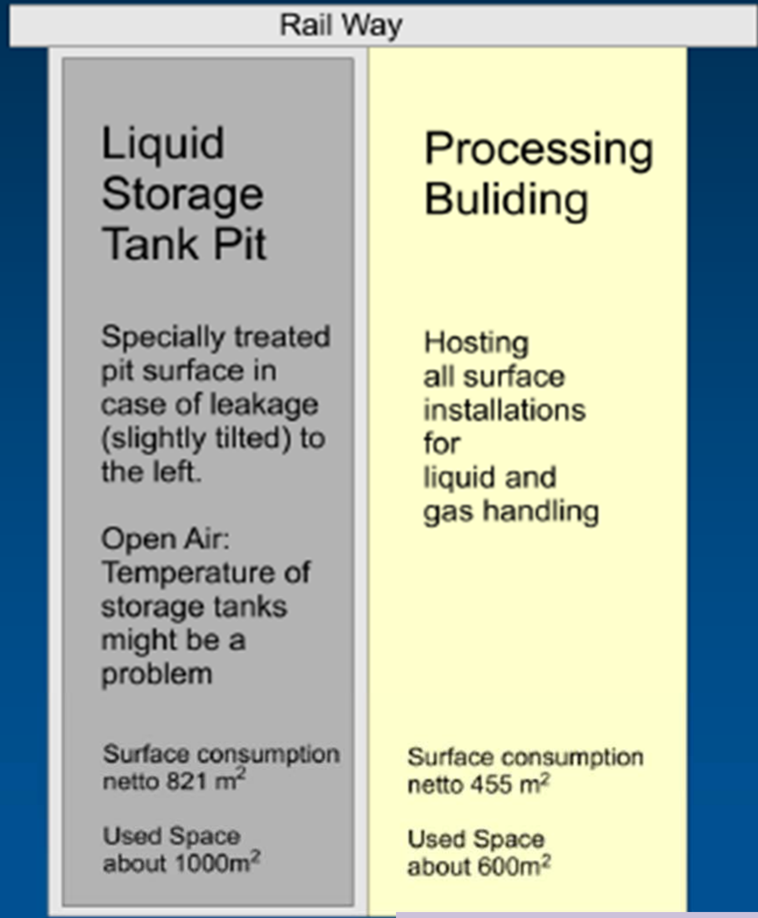


Option: Lake
Surface installation

Lothar Oberauer
TU München, 4.2012

Spatial needs on the surface





Lothar Oberauer
TU München, 4.2012

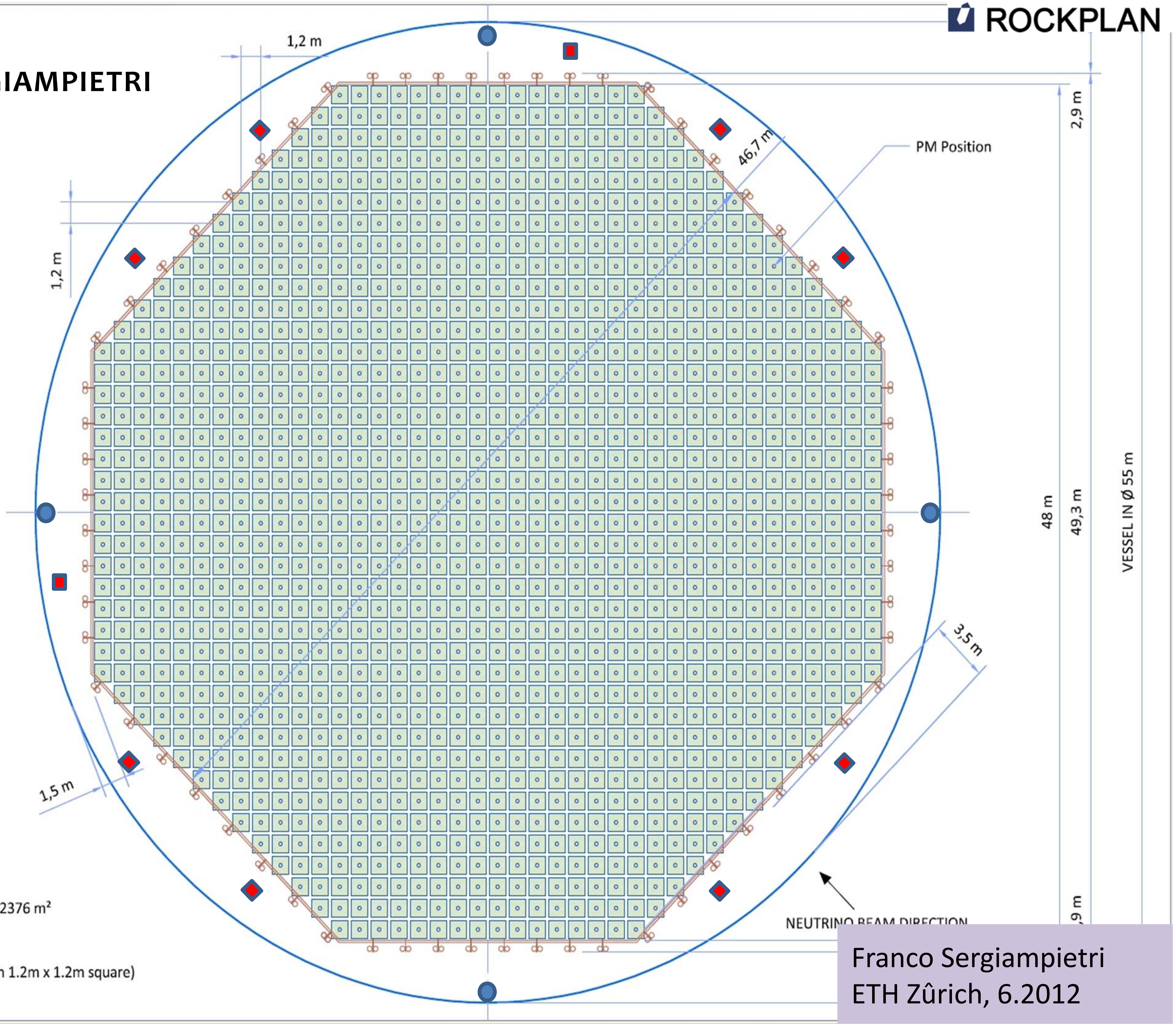
LAGUNA – LBNO @ PYHÄJÄRVI

– Detectors

- LAr:
- LSc:
- MIND:
- BEAM: CERN to Pyhäsalmi

Lagvna

…of …ERGIAMPIETRI



50 KT

Scale 1:300

Øin(LAr) = 55 m → S(LAr50) = 2376 m²

Scintillation Light Read Out

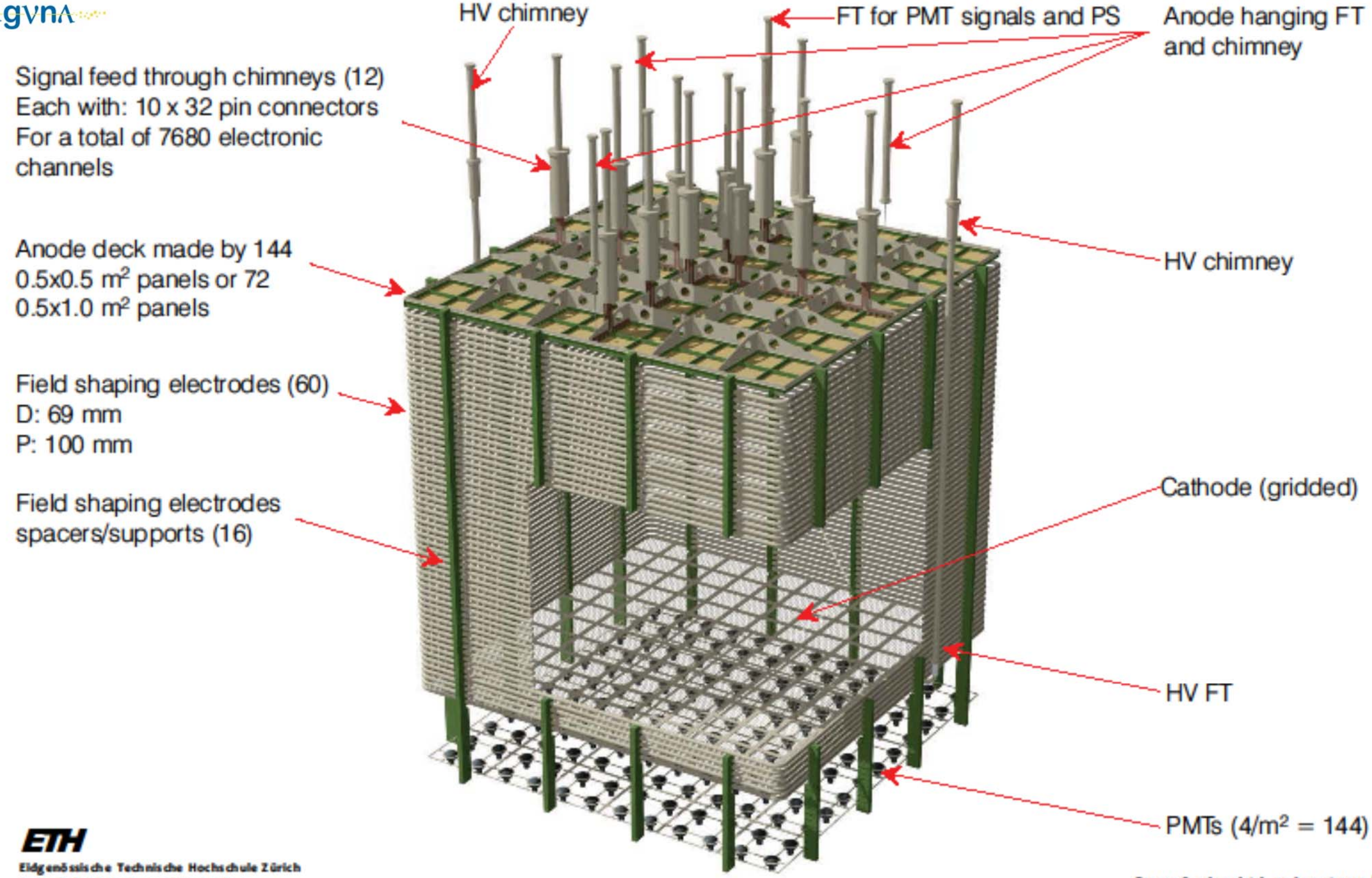
Active Area =1'855 m² → 78%

1'288 Photomultipliers (1 each 1.2m x 1.2m square)

Franco Sergiampietri
ETH Zûrich, 6.2012

ROCKPLAN

LAGUNA LAr Prototype at CERN - Inner detector



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology

Franco Sergiampietri, 20 August 2012, 7

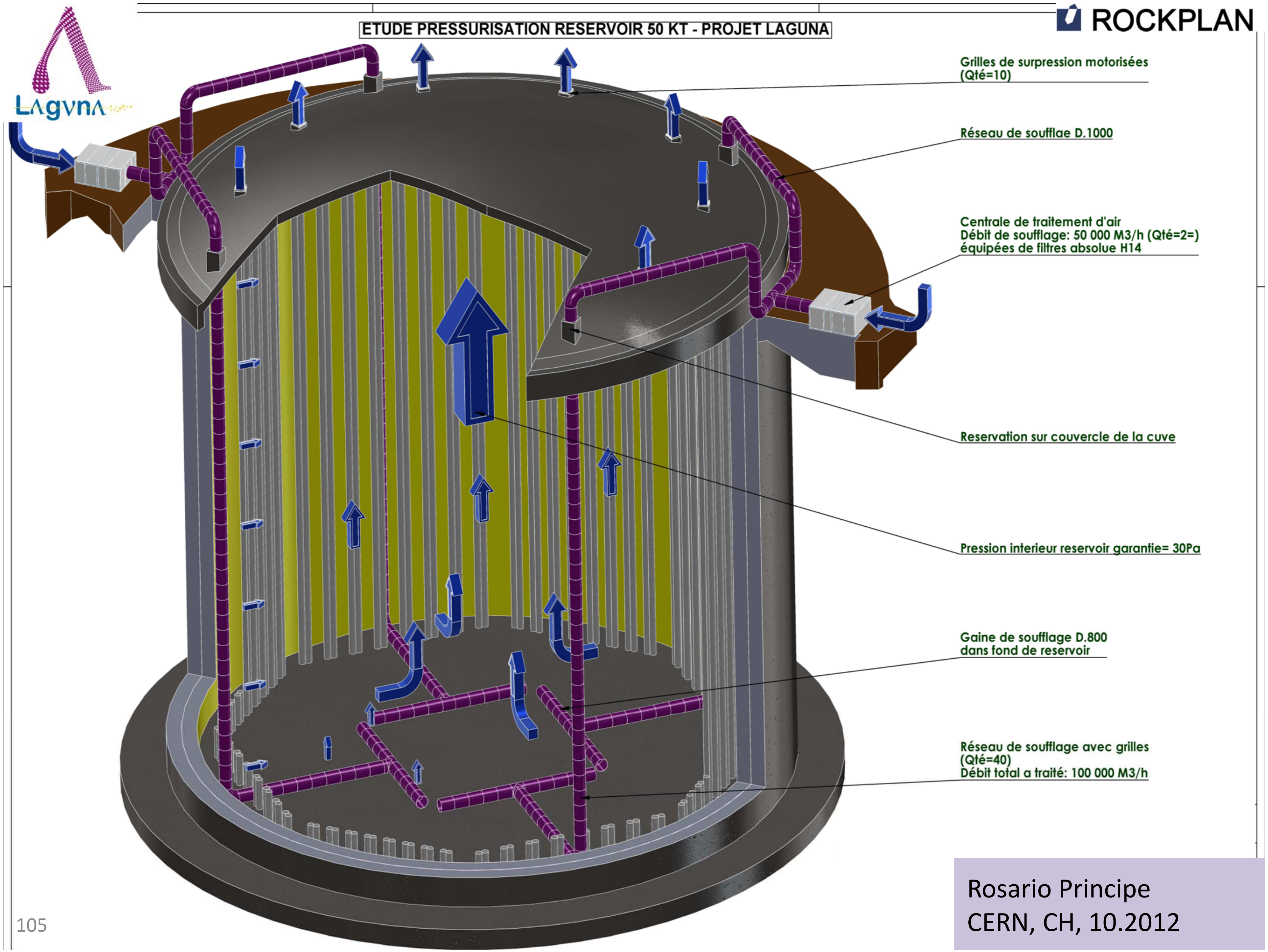
Franco Sergiampietri
ETH Zûrich, 10.2012

ROCKPLAN

O 14644-1 STANDARDS

Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air

Rosario Principe
CERN, CH, 6.2012



Rosario Principe
CERN, CH, 10.2012