The LAGUNA design study

Deep Underground Science Facilities for ν Physics & Proton decay
Prospects for a next generation ν observatory 100 kton - 1 Mton
Progress in Europe

André Rubbia (ETH Zurich)

EuroNU week in Strasbourg
June 1-4th, 2010, Strasbourg, France

LAGUNA Design Study

Large **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics

- Objective: defining and realizing this research programme in Europe
- Participation (open): very interdisciplinary - most European physicists interested in massive detectors; geo-technical experts, geo-physicists; structural engineers; tank and mining engineers
- EC contribution: 1.7 M€ to be mainly devoted to the sites infrastructure studies (FP7 "Design Studies" Research Infrastructures LAGUNA Grant Agreement No. 212343)

21 beneficiaries in 9 countries: 9 higher education entities, 8 research organizations, 4 private companies (+4 additional universities)

Discuss and assess:
- rock engineering → feasibility
- needed infrastructure
- cost of excavation
- assembly of underground tank
- physics programme

Detector R&D to be funded at national level

WP2: Underground infrastructures and Engineering

WP3: Safety, environmental and socio-economic issues

WP4: Science Impact and Outreach

The LAGUNA Consortium
around 100 members (increasing)

The LAGUNA consortium

A. Badertscher, A. Curioni, A. Gendotti, F. Petrolo, A. Marchionni, A. Rubbia[1]
ETH Zurich (Swiss Federal Institute of Technology Zurich), 101 Rämistrasse, Zurich 8092, Switzerland

A. Ereditato, I. Kreslo, M. Messina, U. Moser
University of Bern, 4 Hochschulstrasse, Bern 3012, Switzerland

J. Maalampi, W. Trzaska, J. Suhonen
University of Jyväskylä, 9 Survontie, Jyväskylä 40014, Finland

T. Enqvist, P. Kuusiniemi, K. Rummukainen
University of Oulu, 1 Pentti Kaiteran Katu, Oulu 90014, Finland

D. Autiero, J.E. Campagne, S. Davidson, Y. Declais, J. Dumarchez, J. Marteau, M.Marafini, T. Patzak, A.Tonazzo
Centre national de la recherche scientifique, Institut National de Physique Nucléaire et de Physique des Particules (CNRS/IN2P3), 3 rue Michel-Ange, Paris 75794, France

L. Mosca, M. Zito
Commissariat à l' Energie Atomique / Direction des Sciences de la Matière, 25 rue Leblanc, Paris 75015, France

C. Buck, E. Akhmedov, M. Lindner, W. Hampel, J. Oehm, G. Raffelt, W. Rodejohann, H.Simgen, S. Schönert, J. Shreiner
Max – Planck – Gesellschaft zur Förderung der Wissenschaften e. V. 8 Hofgartenstrasse, Munich 80539, Germany

F. von Feilitzsch, M. Goger-Neff, J.C. Lanfranchi, L. Oberauer, W. Potzel
Technische Universität München, 21 Arcisstrasse, München 80333, Germany

A. Ankowski, M.Chorowski, W.Gizicki, P. Karbowniczek, J. Kisiel, J.W. Mietelsky, J. Sobczyk, M.Szarska, E. Rondio, R. Sujej, T. Szeglowski, A. Zalewska
IFJ Pan and its academic Polish partners, H.Niewodniczański Institute of Nuclear Physics PAN, Radzikowskiego 152, 31-342 Kraków, Poland

A. Bettini
Laboratorio Subterráneo de Canfranc, Plaza del Ayuntamiento no. 1, 22880 Canfranc (Huesca), Spain

A. Bueno, L. Labarga, J. Lozano
UAM and its academic Spanish partners, Universidad Autónoma de Madrid, c/Einstein no. 1; Rectorado, Ciudad Universitaria de Cantoblanco, 28049 Madrid, Spain

V. Kudryavstev, P. Lightfoot, S. Paling, M. Robinson, N. Spooner,
The University of Sheffield, New Spring House 231, Glossop Road, Sheffield S102GW, United Kingdom

S. Pascoli
University of Durham, University Office, Old Elvet, Durham DH1 3HP, United Kingdom

H. Fynbo, S. Hannestad,
University of Aarhus, 1 Norde Ringgade, Aarhus C 8000, Denmark

M. Hakala, R. Matikainen,.G Nuijten, J. Roinisto, J. Salmelainen
Kalliosuunnittelu Oy Rockplan Ltd, 2 Asemamiehenkatu, Helsinki 00520, Finland

S. Gajosinski, A. Grotowski, AMarkiewicz, W. Pytel, Z. Sadecki
KGHM CUPRUM Ltd Research and Development Centre, Pl. 1 Maja, 50-136 Wrocław, Poland

W. Bujakowsky, Z. Pilecki, J. Slizowski, K. Slizowski, K. Urbanczyk
Mineral and Energy Economy Research Institute of the Polish Academy of Sciences, Wybickiego 7, 30-950 Kraków, Poland

A. Apostu, I. Brancus,F. Chipesiu, G.C. Danil, O. Duliu, I Lazanu, R.M. Margineanu, B. Mitrica, A. Oprina, M. Pectu, C.A. Simion, A. Saftoiu, O. Sima, S. Stoica
Horia Hulubei Natonal Institute of RD for Physics and Nuclear Engineering, IFIN-HH, Magurele-Ilfov, Romania

B. Brockway, D. Gurney, M. Haworth, J. Thompson, R. Rogers
Technodyne International Ltd, Unit16, Shakespeare Business Centre Hathaway Close, Eastleigh UK SO 50 4SR, United Kingdom

G. Galvanin, M. Temussi, G. Ristaino
AGT Ingegneria Srl, Perugia, 10 A via della Pallota, Perugia 06126, Italy

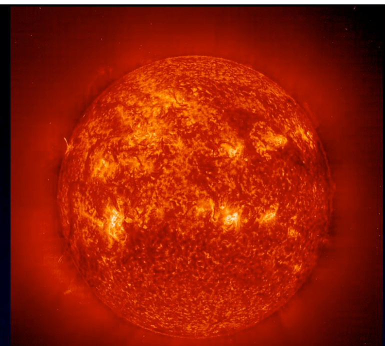
P.F. Bertola, U. Drost, U. Grasslin, A. Mordasini
Lombardi Engineering Limited, via R.Simen, Minusio CH-6648, Switzerland

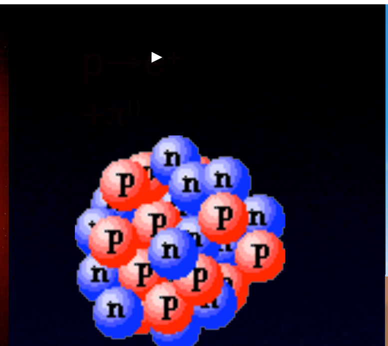
Science of LAGUNA

See Ref. D. Autiero et al., JCAP 0711 (2007) 011

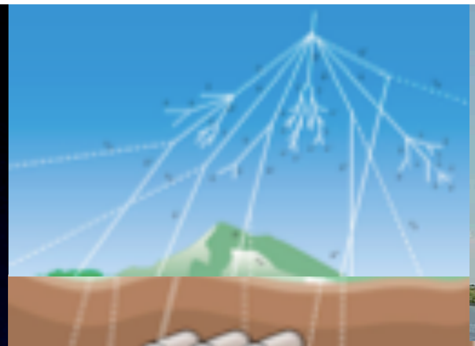
Particle Physics and Particle Astrophysics


Supernova neutrinos

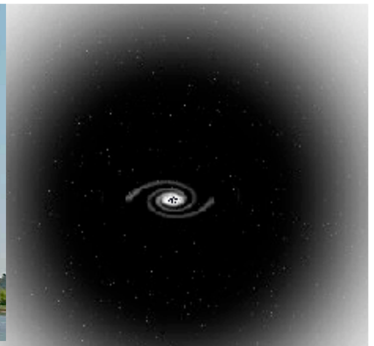

Solar neutrinos



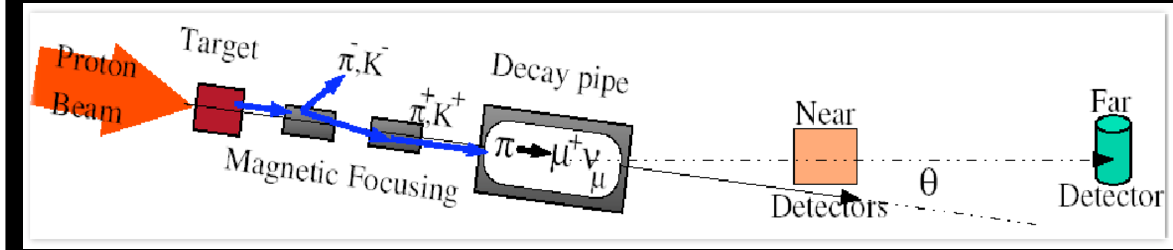
Proton decay


Atmospheric neutrinos

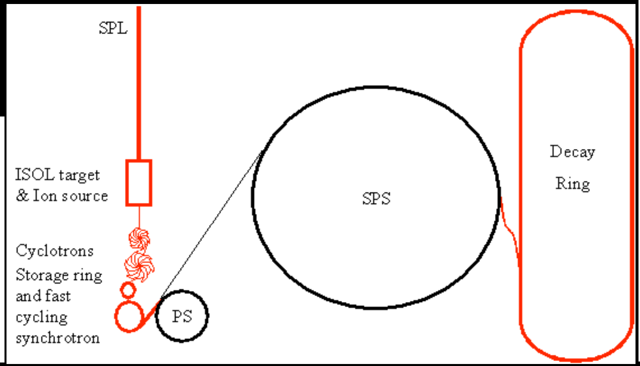

Reactor neutrinos


Dark matter

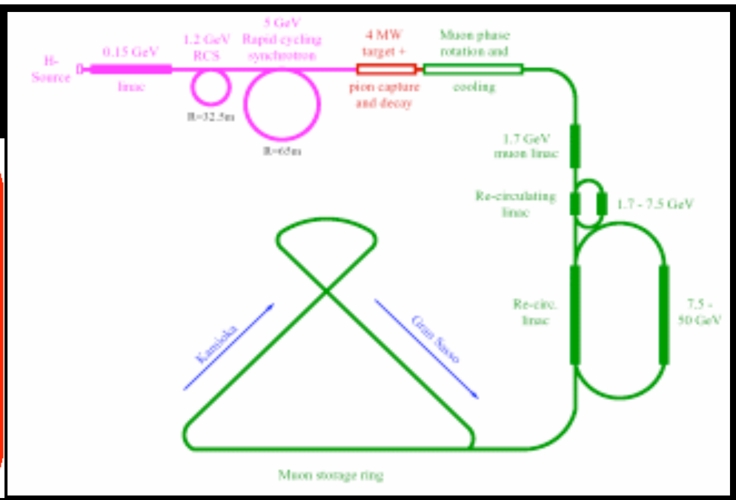
Long baseline neutrinos with accelerators



Superbeams

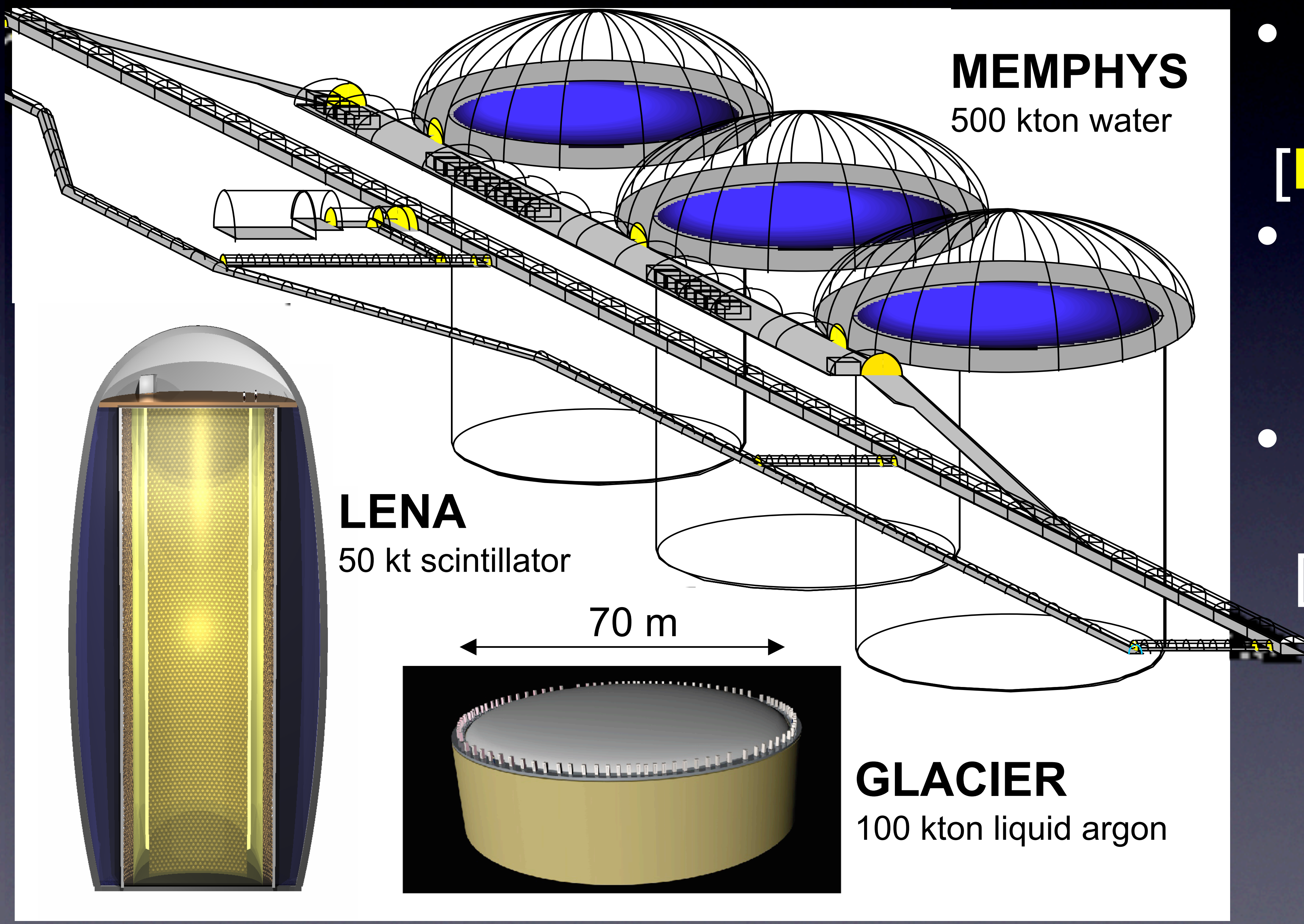


Betabeams


Neutrino factory

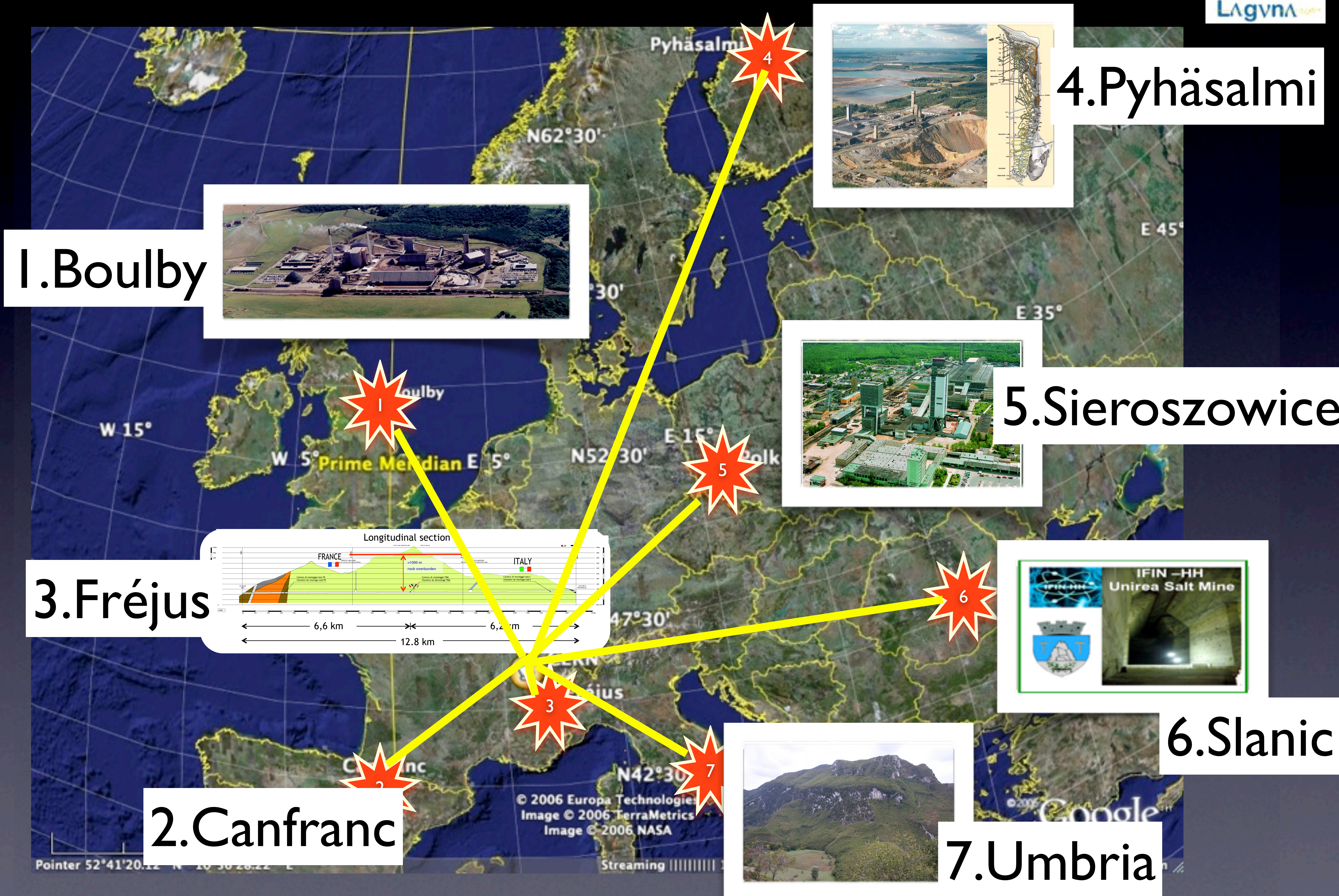
LAGUNA detector options

- **A new far detector at a new far site**
  - three options considered (MEMPHYS, LENA, GLACIER) with total mass in the range 50-500 kton

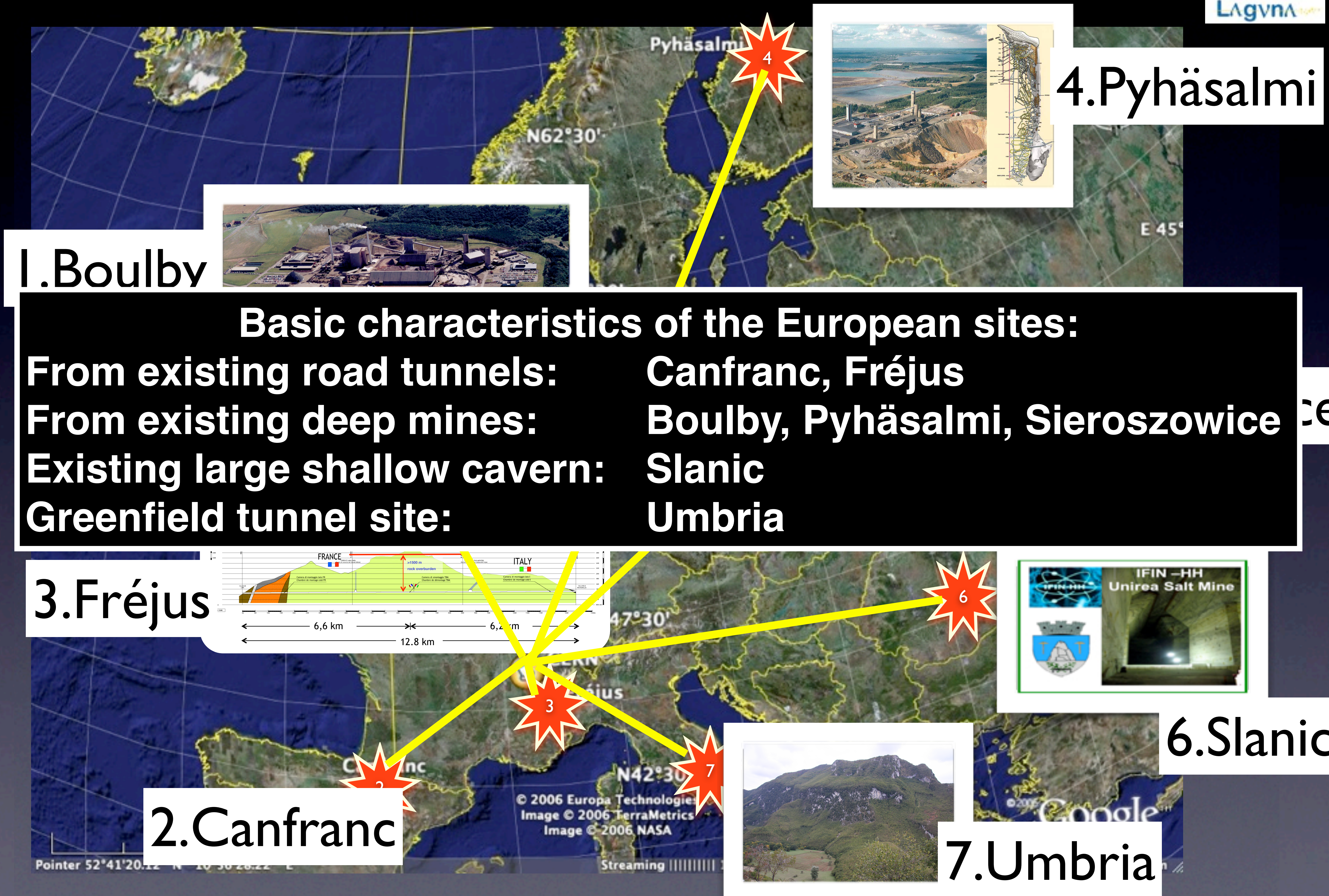


- Water Cerenkov [**MEMPHYS**]
- Liquid scintillator [**LENA**]
- Liquid Argon TPC [**GLACIER**]

7 potential sites



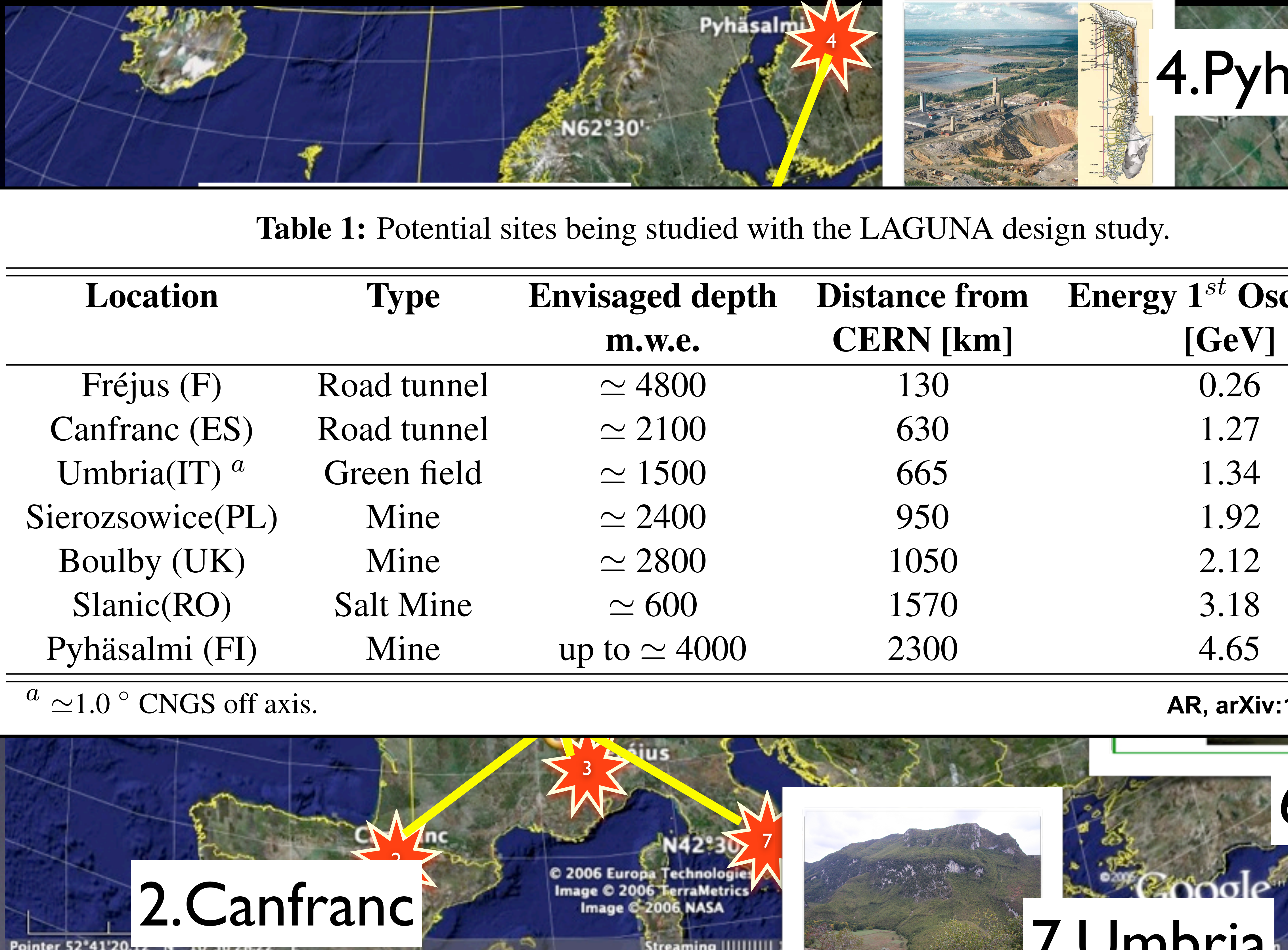
7 potential sites



Basic characteristics of the European sites:

From existing road tunnels:	**Canfranc, Fréjus**
From existing deep mines:	**Boulby, Pyhäsalmi, Sieroszowice**
Existing large shallow cavern:	**Slanic**
Greenfield tunnel site:	**Umbria**

7 potential sites



4.Pyhäsalmi

Table 1: Potential sites being studied with the LAGUNA design study.

Location	Type	Envisaged depth m.w.e.	Distance from CERN [km]	Energy 1^{st} Osc. Max. [GeV]
Fréjus (F)	Road tunnel	$\simeq$ 4800	130	0.26
Canfranc (ES)	Road tunnel	$\simeq$ 2100	630	1.27
Umbria(IT) [a]	Green field	$\simeq$ 1500	665	1.34
Sierozsowice(PL)	Mine	$\simeq$ 2400	950	1.92
Boulby (UK)	Mine	$\simeq$ 2800	1050	2.12
Slanic(RO)	Salt Mine	$\simeq$ 600	1570	3.18
Pyhäsalmi (FI)	Mine	up to $\simeq$ 4000	2300	4.65

[a] $\simeq$1.0 $^{\circ}$ CNGS off axis.

AR, arXiv:1003.1921

6.Slanic

2.Canfranc

7.Umbria

7 potential sites

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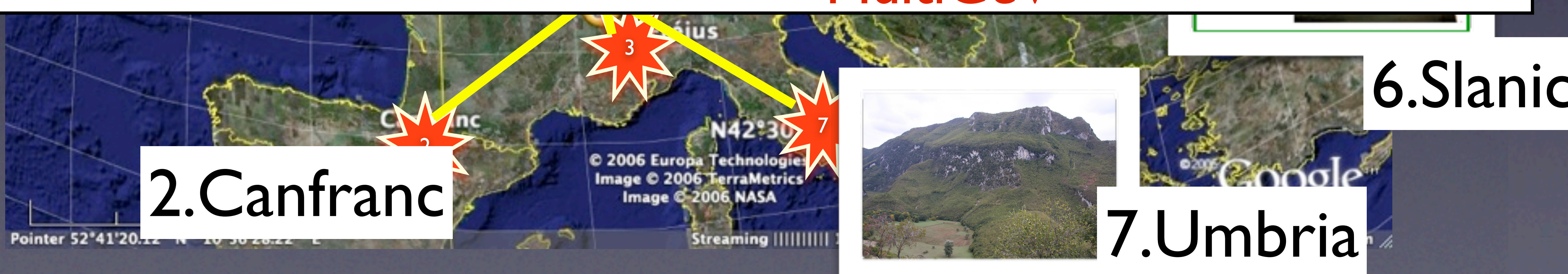
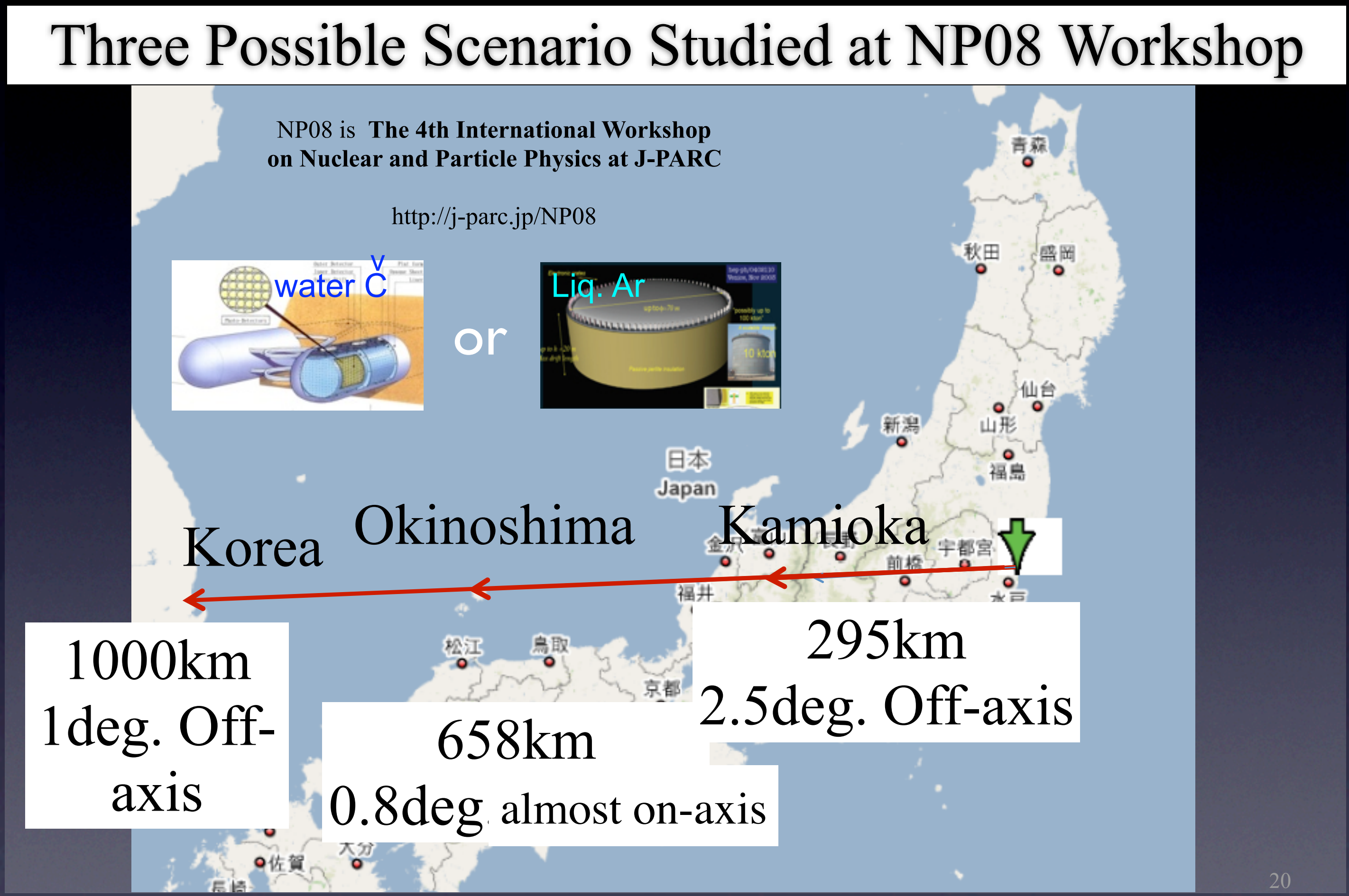
MultiGeV

AR, arXiv:1003.1921



Synergies with worldwide programs

Future at JPARC



FNAL-DUSEL (USA)

Basic ingredients considered:

- very high intensity beams (> 1 MW)
- a new very large far underground neutrino detector based on Water Cerenkov or Liquid Argon technology ("megaton-scale")

LAGUNA and superbeams

Requires a high energy and high intensity proton driver for baselines longer than CERN-Fréjus ➠ HP-PS(2)

Table 2: Expected pot per year [1e19] for different machine scenarios. $E_{tot} \equiv E_p \times N_{pot}$ corresponds to the total amount of energy deposited on the target per year, which is a relevant quantity to estimate neutrino event rates.

	PS+SPS	SpS RF upgrade	SPL+PS2+ SPS new RF	SPL + PS2	New HP-PS	Booster + RCS 4 MW
Machine param.	[33]			[35]	this paper	[37]
Proton energy E_p	400 GeV			50 GeV		30 GeV
$ppp(\times 10^{13})$	4.8	7	10	12.5	25	10
T_c (s)	6	7.2	4.8	2.4	1.2	$(8.33\text{Hz})^{-1}$
Beam power (MW)	0.5	0.6	1.3	0.4	1.6	4
Global efficiency	0.8	0.8	0.8	1.0	1.0	1.0
Beam sharing	0.85	0.85	0.85	0.85	0.85	1.0
Running (d/y)	200	200	200	200	200	200
N_{pot}/yr $(\times \mathbf{10^{19}})$	**9.4**	**11.4**	**24.5**	**77**	**300**	**1437**
$E_{tot} \equiv E_p \times N_{pot}$ $(\times 10^{22}$ GeV·pot/yr)	4	4.5	10	4	15	43
E_{tot} increase compared to CNGS	$\times 2$	$\times 2$	$\times 4$	$\times 2$	$\times 5$	$\times 16$

AR, arXiv:1003.1921

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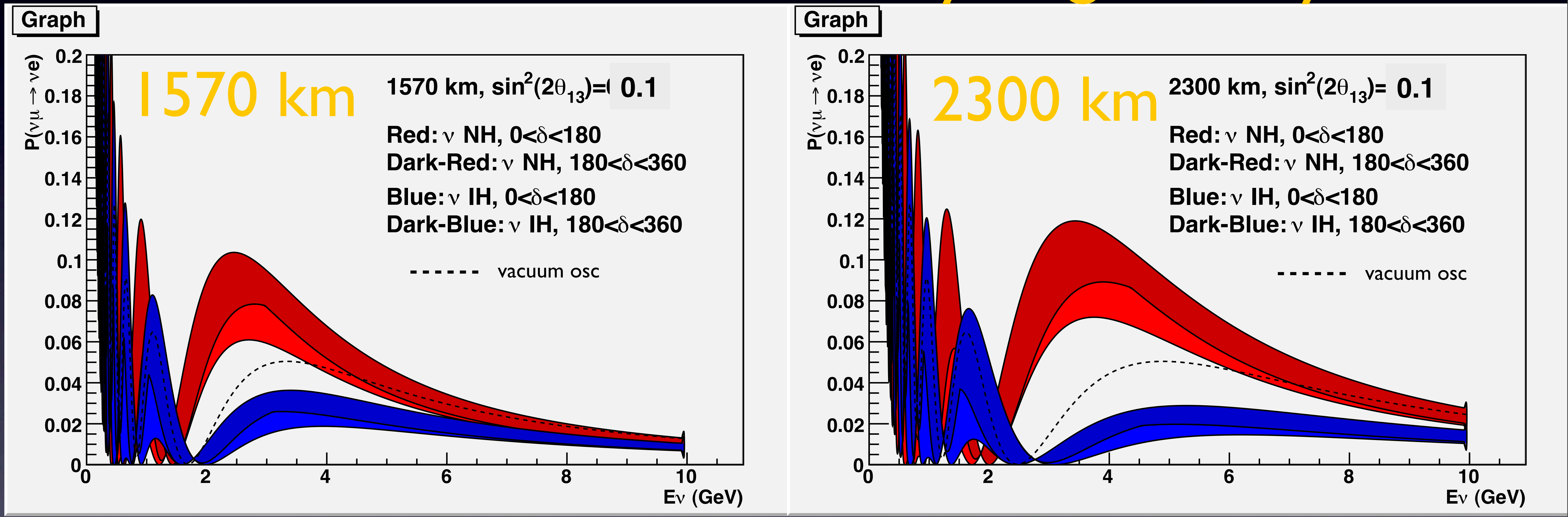
"substantial"

AR, arXiv:1003.1921

Opportunities of long baselines

CERN-Slanic & CERN-Pyhäsalmi offer very long baselines not considered elsewhere in the world ➠ unique physics opportunities in Europe

CPV and mass hierarchy degeneracy

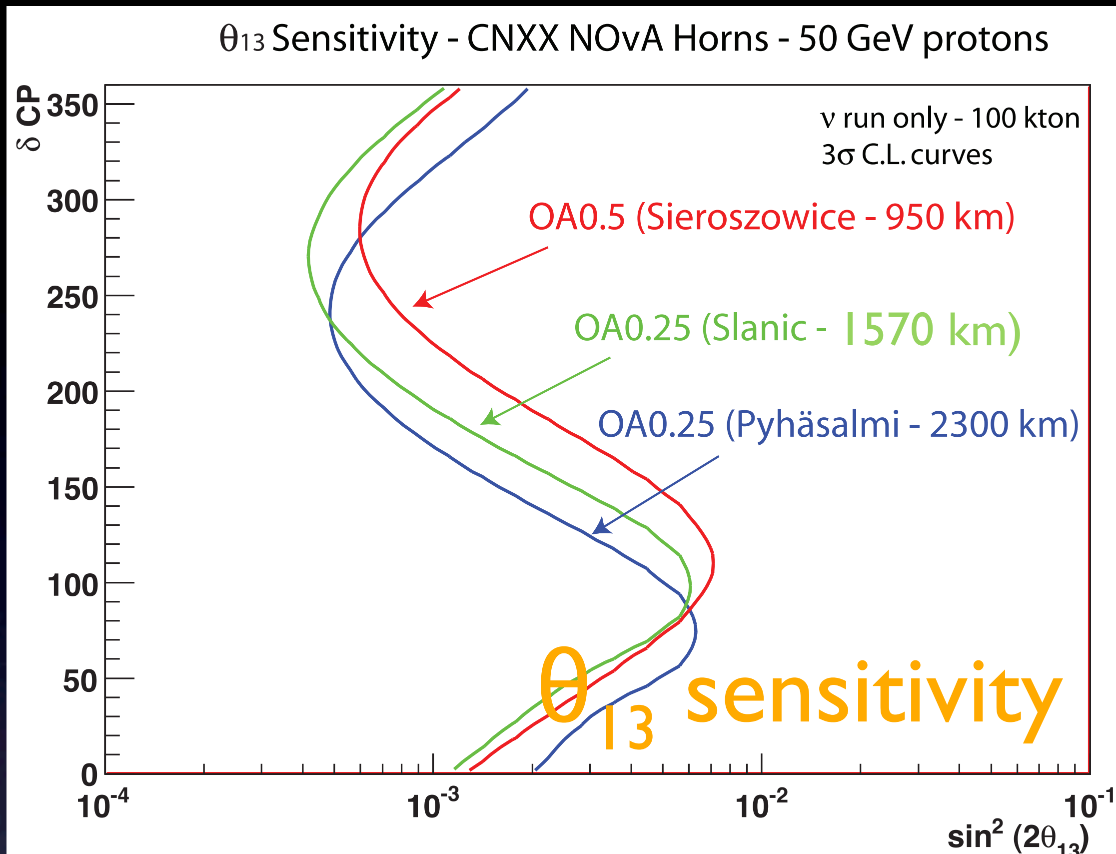


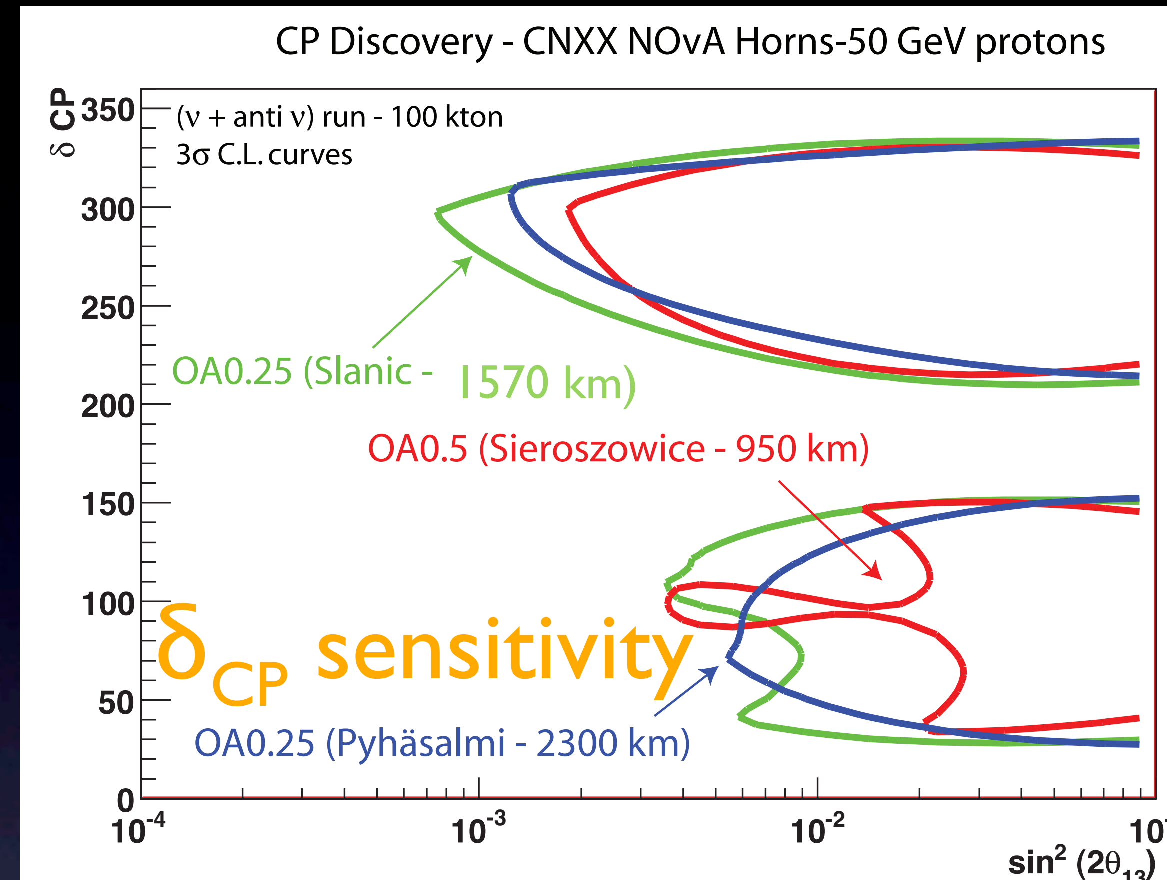
Determine CPV and mass hierarchy and resolve degeneracies and so-called "π-transit" effect

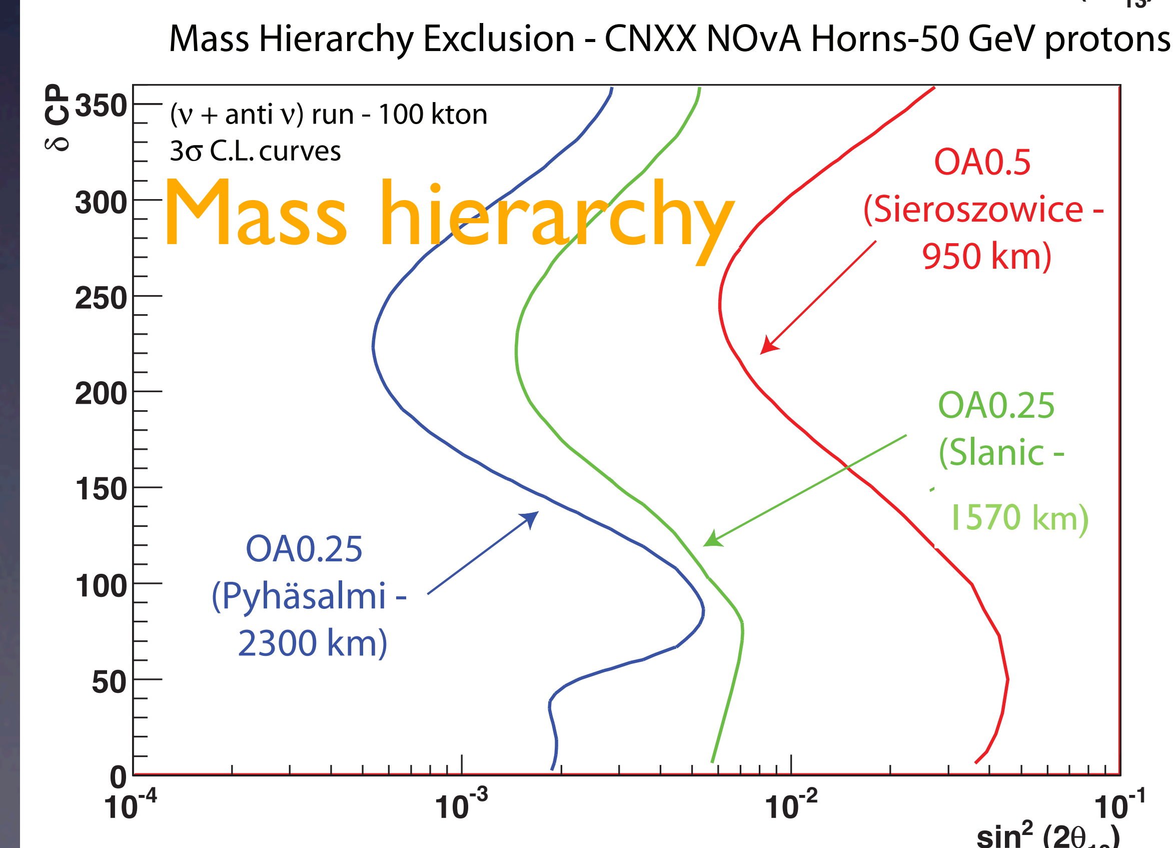
See e.g. arXiv:0908.3741v1 for "Magic 2500 km baseline"

LAGUNA and HP-PS(2)

AR, arXiv:1003.1921







100 kton LAr
5 yrs ν
3 x 10^{21} pots/yr @ 50 GeV

100 kton LAr
5 yrs ν + 5 yrs $\bar{\nu}$
3 x 10^{21} pots/yr @ 50 GeV

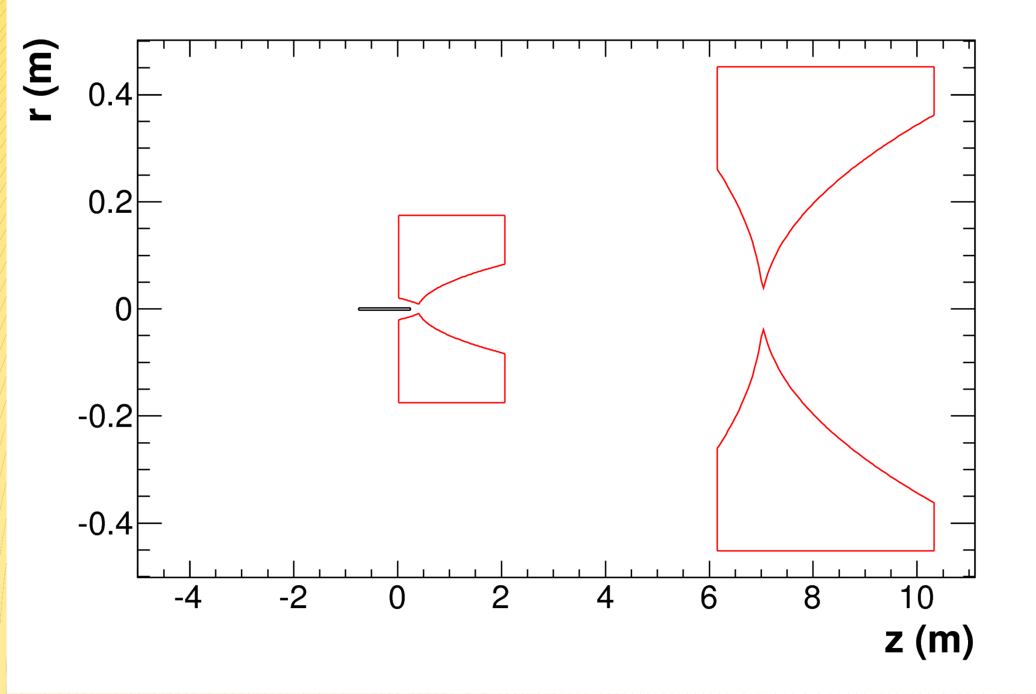
(sensitivities computed with preliminary horn designs & GLOBES)

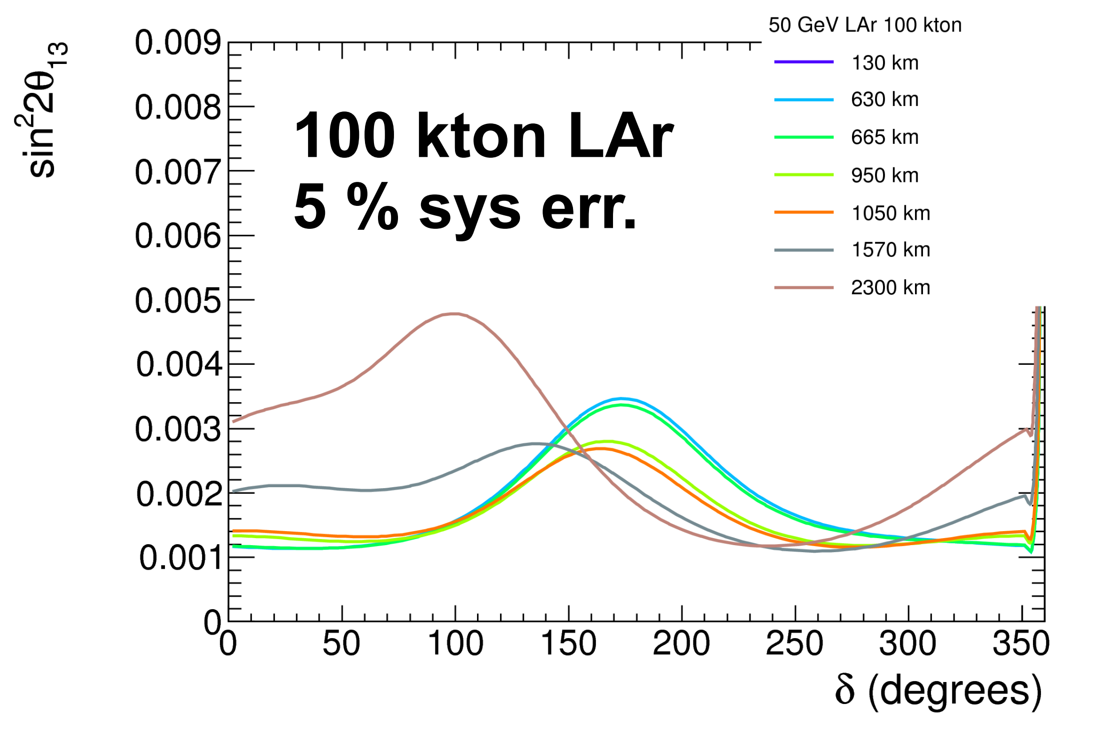
Full GEANT4 simulations of fluxes

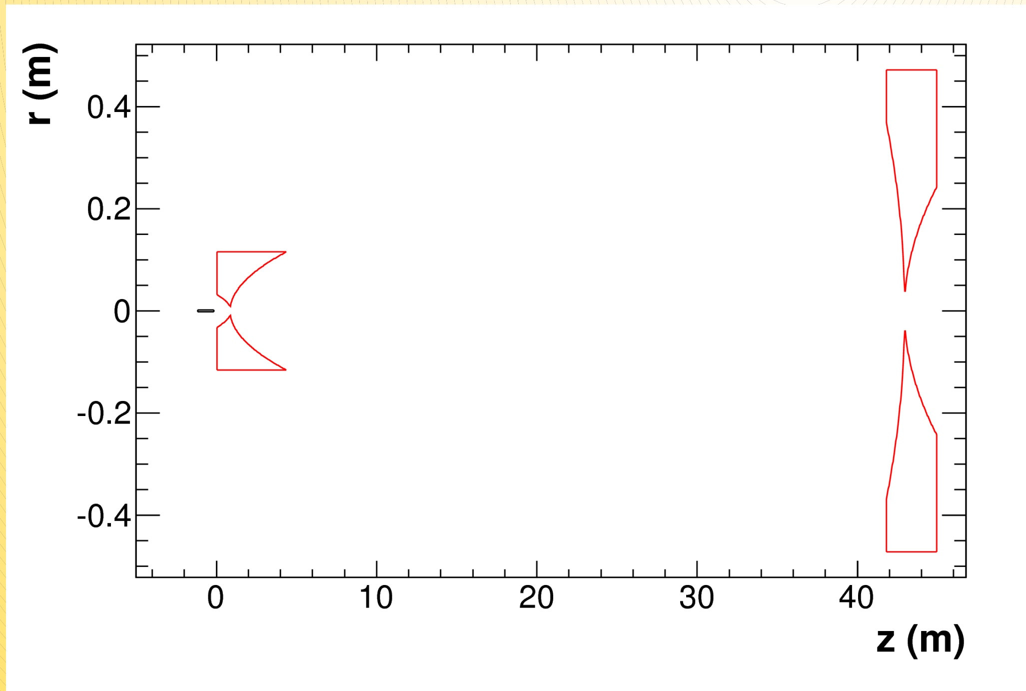
A. Longhin

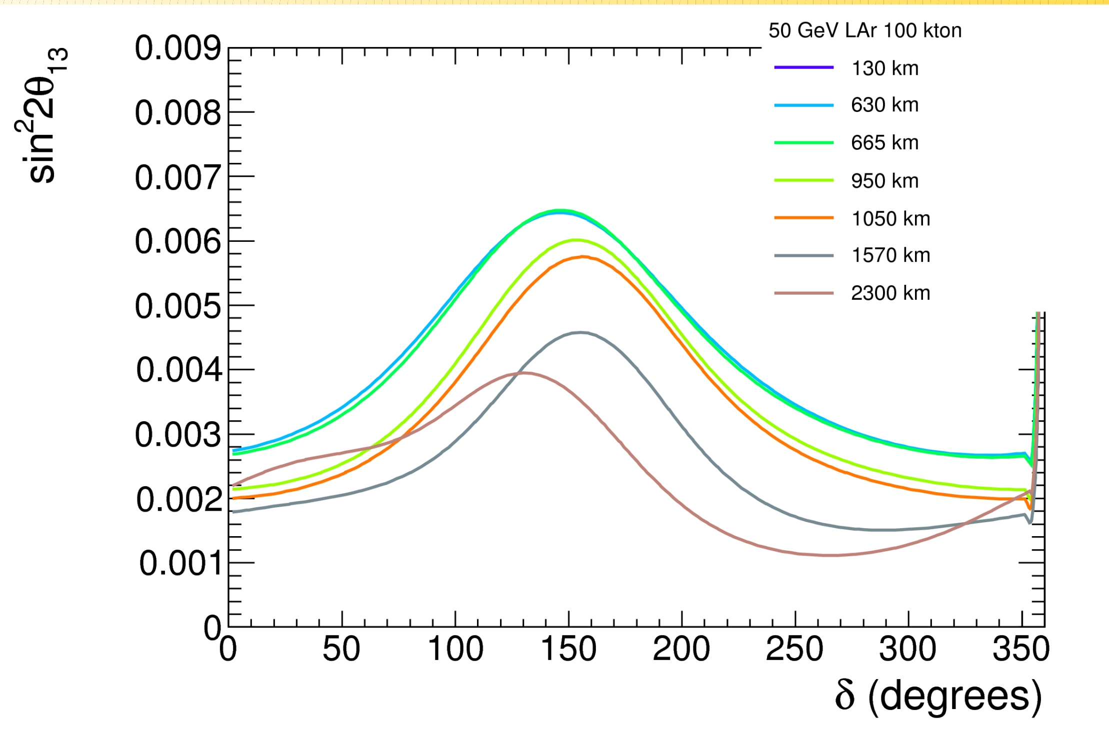
The GEANT4 simulation and optimization tools are being used to study Super Beams from a 50 GeV proton driver ("HP-PS2") to LAGUNA sites equipped with a 100 kton LAr detector

study ongoing within the LAGUNA-WP2 (physics)



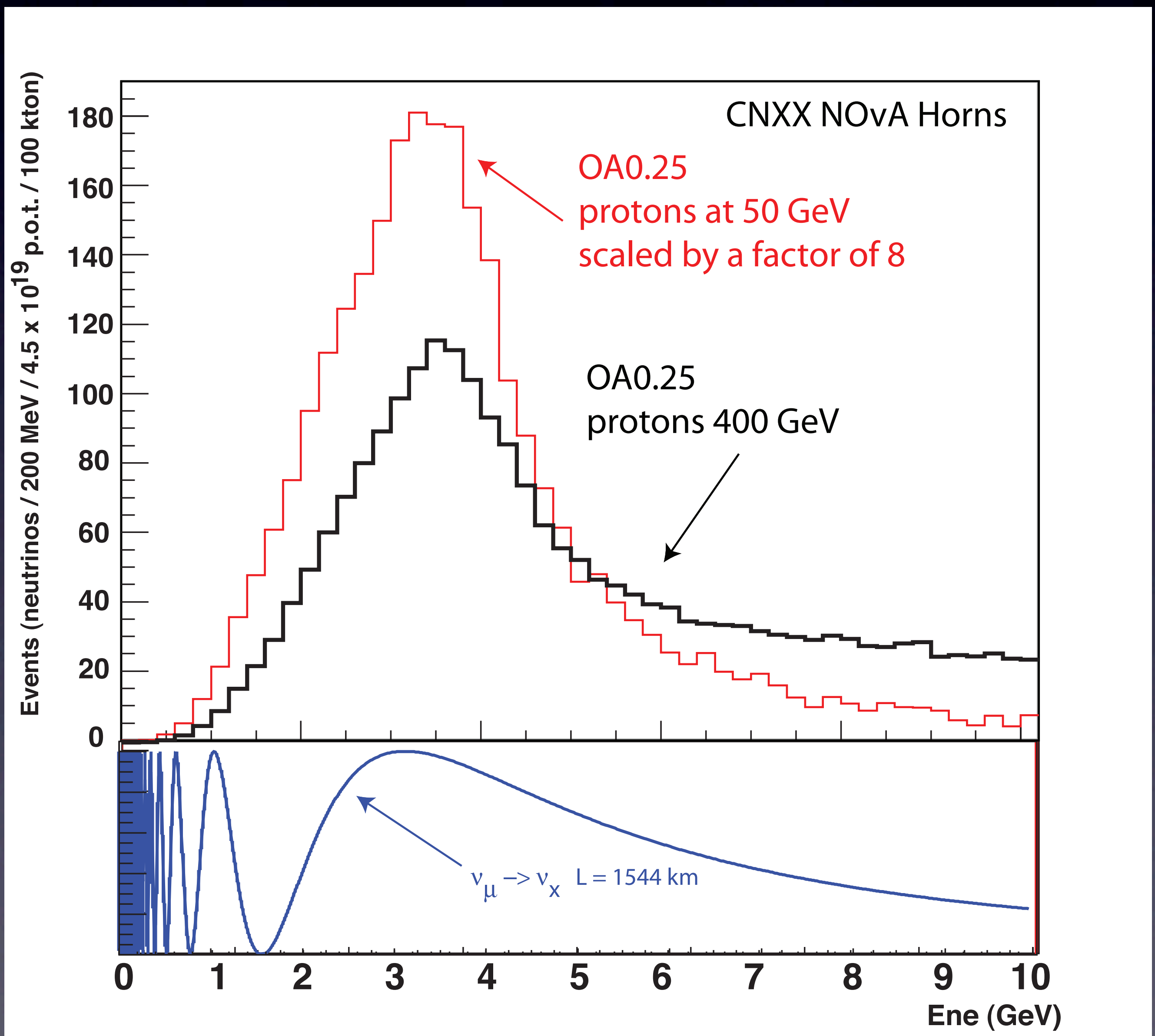


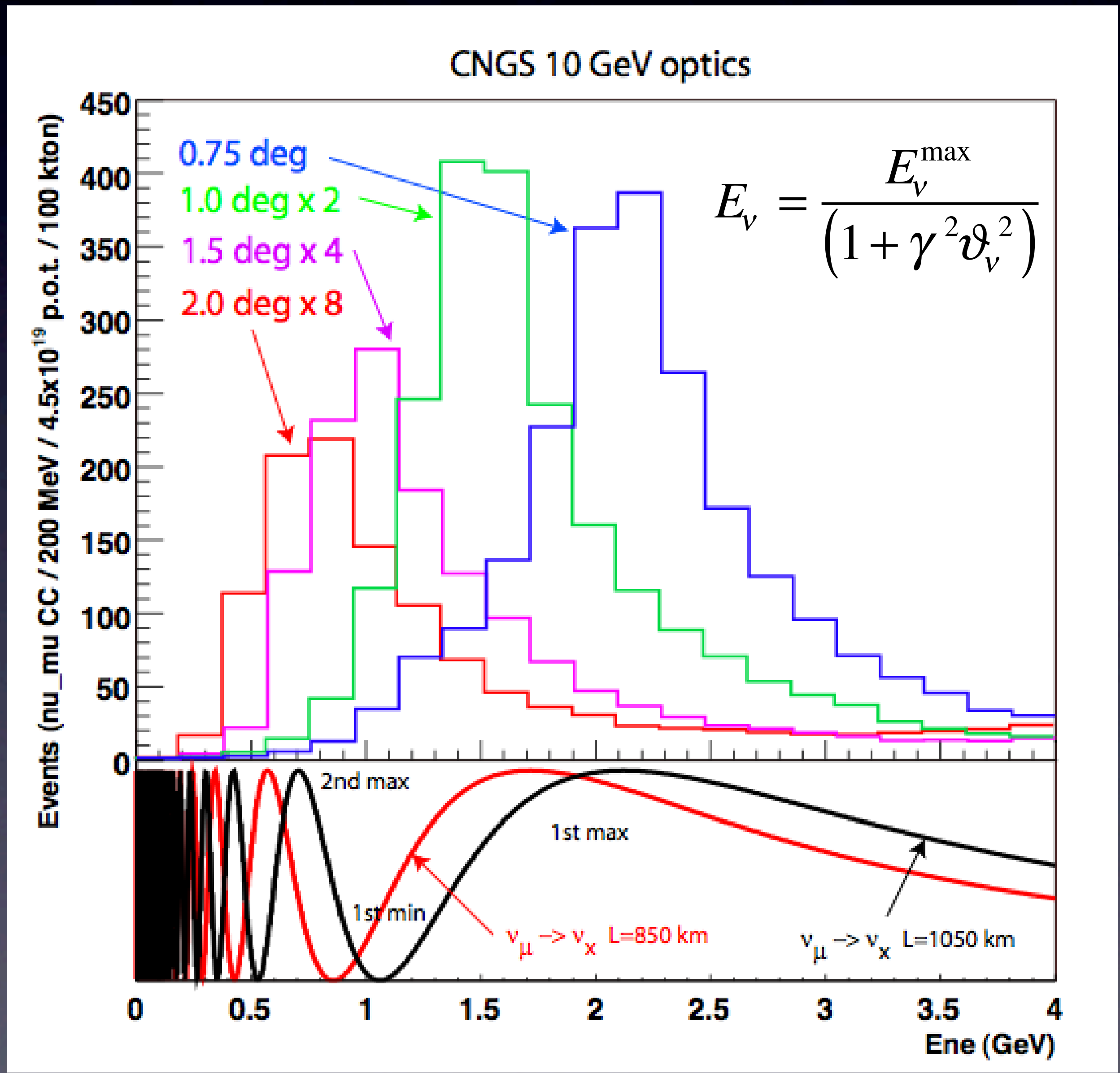




Considering a staged scenario

- We can consider both options:
  - 400 GeV protons from SpS with PS2 as new injector
  - 50 GeV protons from an intensity upgraded PS2 (HP-PS(2))
- Neutrino flux scaling: (pot @ 50 GeV) ≈ 8x (pot @ 400 GeV)





New ν line ➠ must be designed to sustain several MW beam power

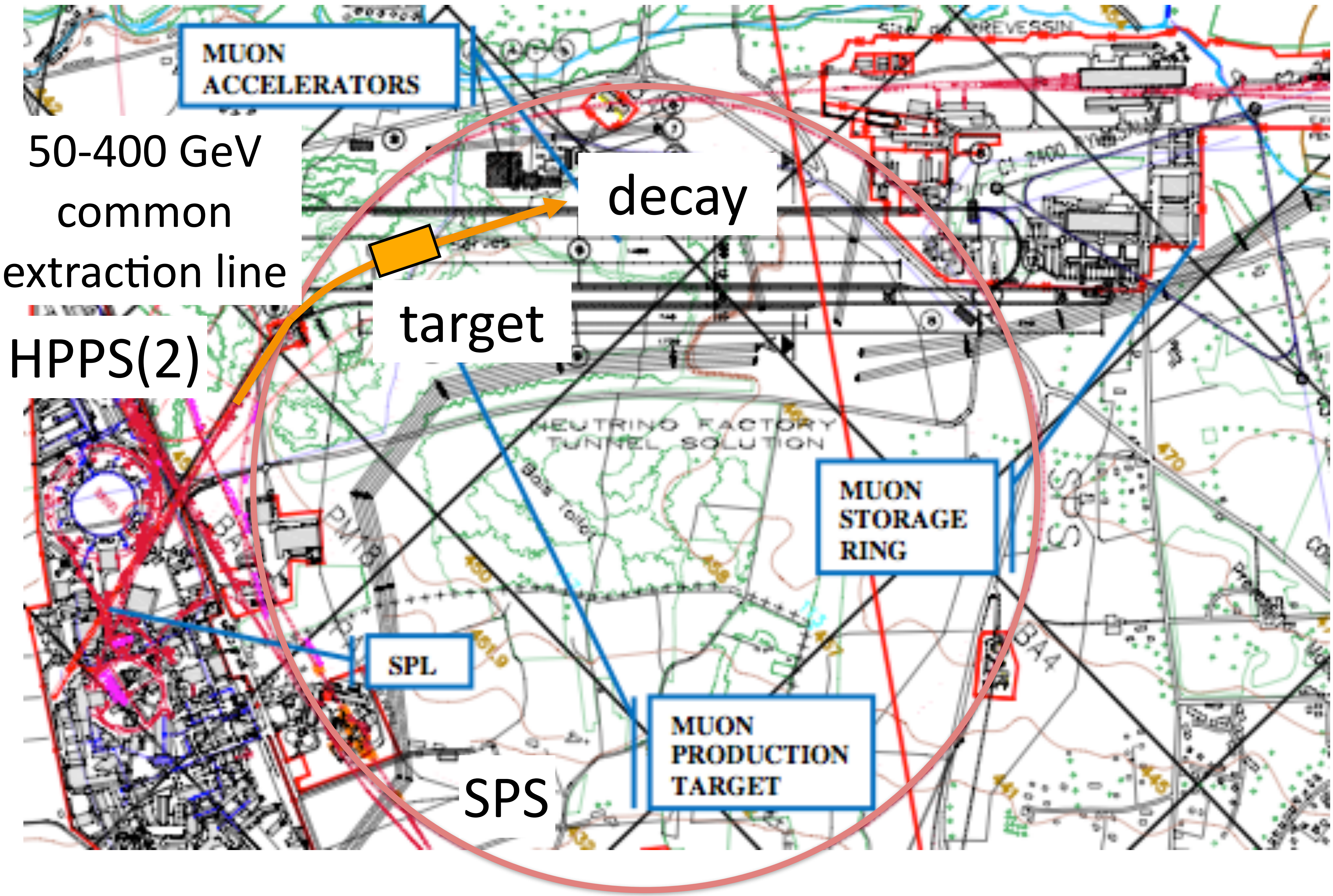
Event rates at Pyhäsalmi vs Okinoshima

At L=2300 km the first maximum is above tau production threshold yielding a copious number of (QEL) tau events

	Neutrino horn polarity				Antineutrino horn polarity			
Distance/OA	ν_μCC ($\bar{\nu}_\mu$CC)	ν_eCC ($\bar{\nu}_e$CC)	$\nu_\mu \to \nu_e$ ($\bar{\nu}_\mu \to \bar{\nu}_e$)	$\nu_\mu \to \nu_\tau$ ($\bar{\nu}_\mu \to \bar{\nu}_\tau$)	ν_μCC ($\bar{\nu}_\mu$CC)	ν_eCC ($\bar{\nu}_e$CC)	$\nu_\mu \to \nu_e$ ($\bar{\nu}_\mu \to \bar{\nu}_e$)	$\nu_\mu \to \nu_\tau$ ($\bar{\nu}_\mu \to \bar{\nu}_\tau$)
J-PARC , 30 GeV protons , 1.66 MW								
Okinoshima **658 km** 0.76 deg	17010 (619)	138 (12)	26 (0.4)	1.5 (0.2)	1817 (4627)	32 (31)	1.3 (5.4)	0.5 (0.4)
CNXX NUMI-ME-like horns , 400 GeV SPS protons , 2.4$\times 10^{20}$ **pot/year**								
Pyhäsalmi **2300 km** 0.25 deg	12393 (449)	73 (10)	26 (0.3)	297 (16)	738 (4808)	15 (25)	1.2 (4.1)	28 (115)
CNXX NUMI-ME-like horns , 50 GeV HPPS2 protons , 3$\times 10^{21}$ **pot/year**								
Pyhäsalmi **2300 km** 0.25 deg	10655 143	72 3	47 0.2	80 3	596 2906	9 19	1.8 5.5	14 16

Table 1: Charged current (CC) event rate calculated for J-PARC assuming the T2K optics and for CNXX using a NUMI-ME-like realistic focusing, normalized for one year and a liquid Argon detector with a mass of 100 kton. We assume for the mixing angles $\tan 2\theta_{12} = 0.45$, $\theta_{23} = \pi/4$ and $\sin^2 2\theta_{13} = 0.002$.

Combined SPS and HPPS(2) scenario



LAGUNA and beta-beams

β-beams and LAGUNA

A β-beam is produced from boosted, radioactive-ion decays
$\Rightarrow$ a pure ν_e ($\bar{\nu}_e$) beam.

P. Zucchelli, Phys. Lett. B **532**, 166 (2002).

Several different combinations of ions, boosts, baselines and exposures have been studied:

Low-γ beam: **J. E. Campagne, M. Maltoni, M. Mezzetto and T. Schwetz, arXiv:hep-ph/0603172**

- 100γ ^{18}Ne and 100γ ^{6}He ions.
- 440 kton WC detector at Fréjus (130 km).
- Combine with a super-beam (SPL).
- Short baseline limits hierarchy sensitivity - use atmospheric ν as well.

T. Li,
LAGUNA Canfranc meeting

Intermediate-γ beam: **D. Meloni, O. Mena, C. Orme, S. Palomares-Ruiz and S. Pascoli, arXiv:0802.0255**

- 450γ ^{18}Ne ions.
- 50 kton LAr detector at Boulby (1050 km).
- Very sensitive to exposure.

High-γ beam: **C. Orme, arXiv:1004.0939**

- 570γ ^{18}Ne and 350γ ^{6}He ions.
- 50 kton LAr at Slanic (1570 km) or Pyhäsalmi (2300 km).
- Combine with a second baseline and detector (500 kton WC) at Canfranc (650 km) to improve hierarchy sensitivity.

LAGUNA at work (2008-2010)

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

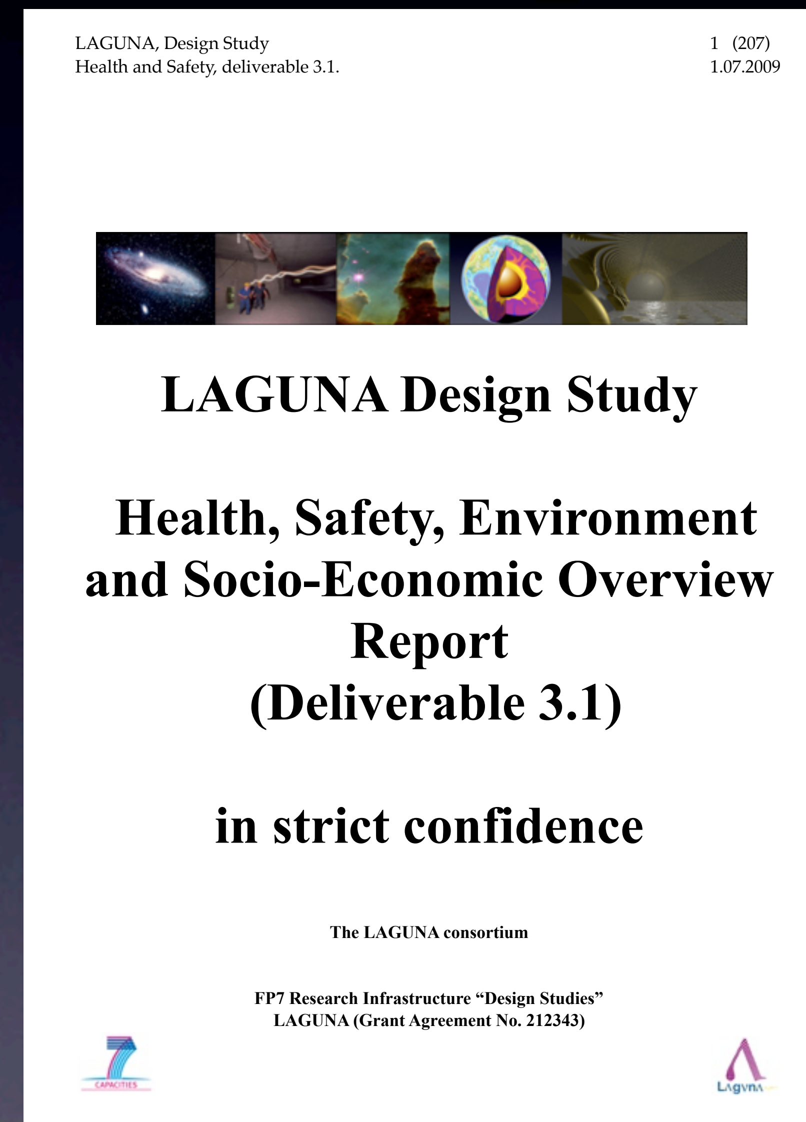
Site visits and meeting

- sites work together on common areas

16 deliverables (2008-2010)

Interim safety, socio-economic, environmental report: July 2009

- 207 pages, delivered on schedule
- report on the Health and Safety issues for each of the seven LAGUNA sites
- list of local authorities and responsible entities and establish contact with them
- address basic environmental issues
- address impact on local area
- identify potential show-stoppers


LAGUNA, Design Study
Health and Safety, deliverable 3.1.

1 (207)
1.07.2009

LAGUNA Design Study

Health, Safety, Environment and Socio-Economic Overview Report (Deliverable 3.1)

in strict confidence

The LAGUNA consortium

FP7 Research Infrastructure "Design Studies"
LAGUNA (Grant Agreement No. 212343)

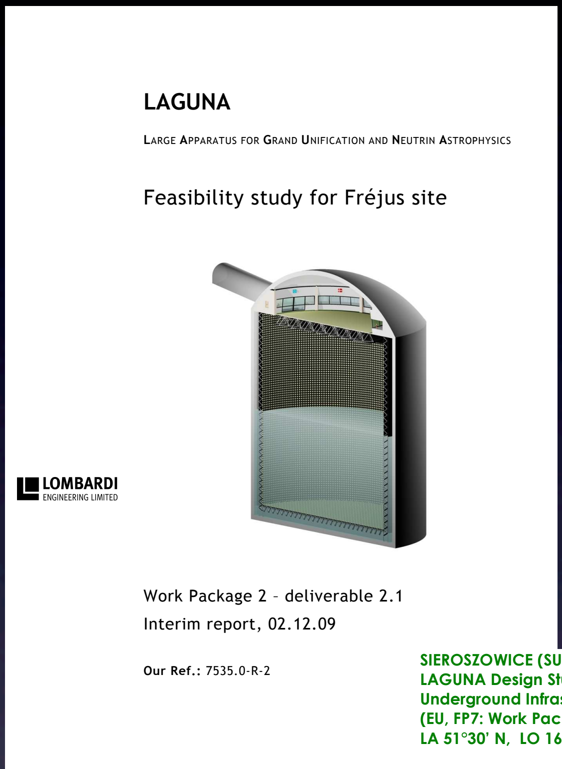
Interim geotechnical reports: May 2010
Final report: postponed to fall 2010

16 deliverables (2008-2010)

Deliverable Number 61	Deliverable Title	WP number 53	Lead beneficiary number	Estimated indicative person-months	Nature 62	Dissemination level 63	Delivery date 64
1.1	First year report	1	ETHZ	5	Report	Public	12
1.2	Final report on European underground research infrastructure and its science	1	ETHZ	10	Report	Public	24
2.1	Interim report for CUPP/ Pyhäsalmi	2	UOULU	18	Report	Public	16
2.2	Interim report for Fréjus	2	CNRS	18	Report	Public	16
2.3	Interim report for Boulby	2	USFD	18	Report	Public	16
2.4	Interim report for CNGS off-axis	2	U-Bern	10	Report	Public	16
2.5	Interim report for SUNLAB	2	IFJ PAN	18	Report	Public	16
2.6	Interim report for LSC	2	LSC	18	Report	Public	16
2.7	Interim report for IFIN-HH	2	IFIN-HH	10	Report	Public	16
2.8	Final joint report on potential European sites	2	UOULU	20	Report	Public	24
3.1	Site specific safety overview report	3	USFD	20	Report	CO	12
3.2	Final report on safety	3	USFD	20	Report	CO	24
3.3	Report on liquid procurement	3	USFD	10	Report	RE	20
3.4	Report on socio-economic impact	3	USFD	10	Report	RE	20
4.1	Deep science paper for general audience	4	IFJ PAN	20	Report	Public	24
4.2	Scientific paper for the physics community	4	IFJ PAN	20	Report	Public	24
			Total	245			

7 sites technical reports

Interim geotechnical reports: being finalized
Final joint report on potential European sites: July 2010


LAGUNA

Large Apparatus for Grand Unification and Neutrin Astrophysics

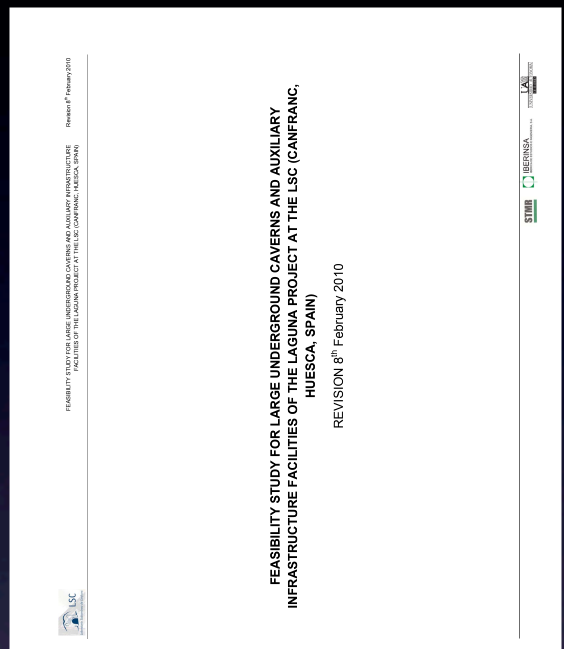
Feasibility study for Fréjus site

LOMBARDI ENGINEERING LIMITED

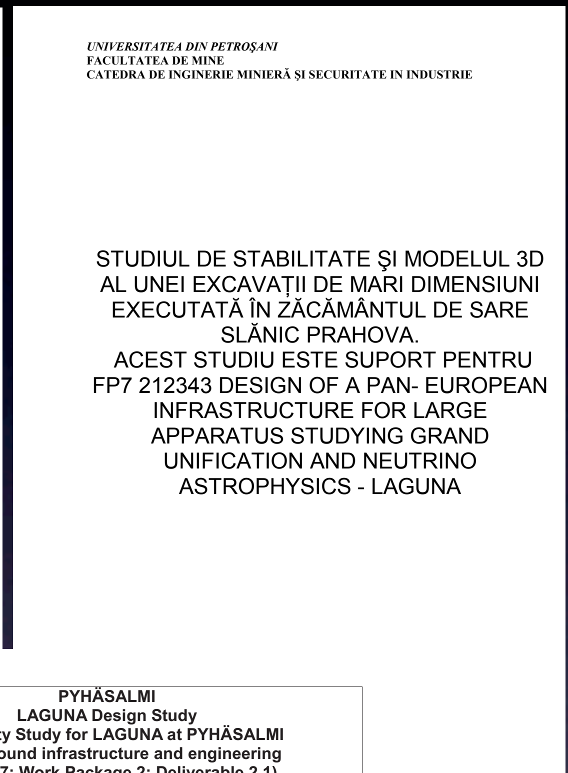
Work Package 2 - deliverable 2.1

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

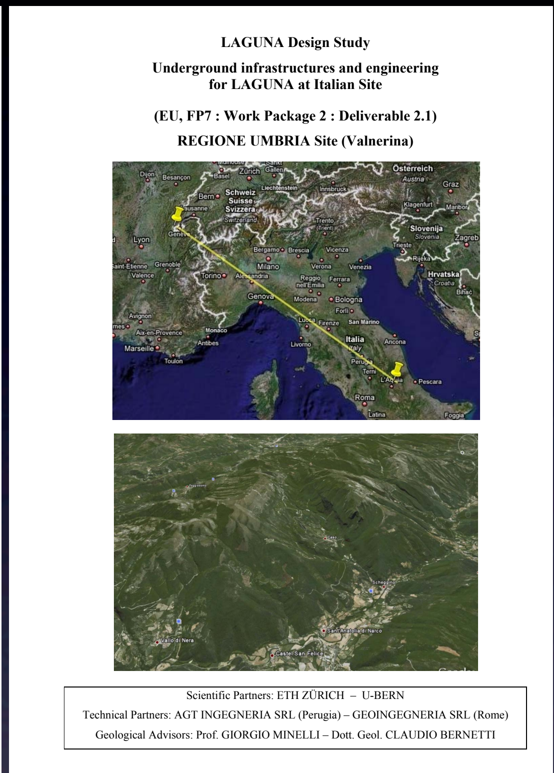

UNIVERSITATEA DIN PETROŞANI

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

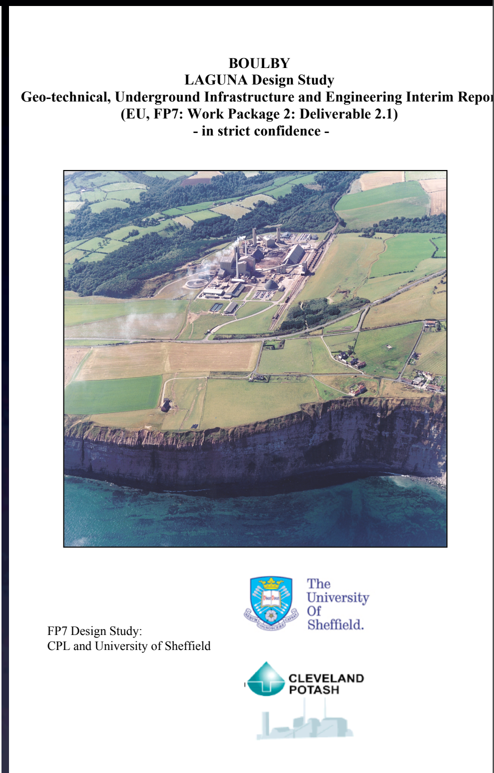
(EU, FP7 : Work Package 2 : Deliverable 2.1)

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

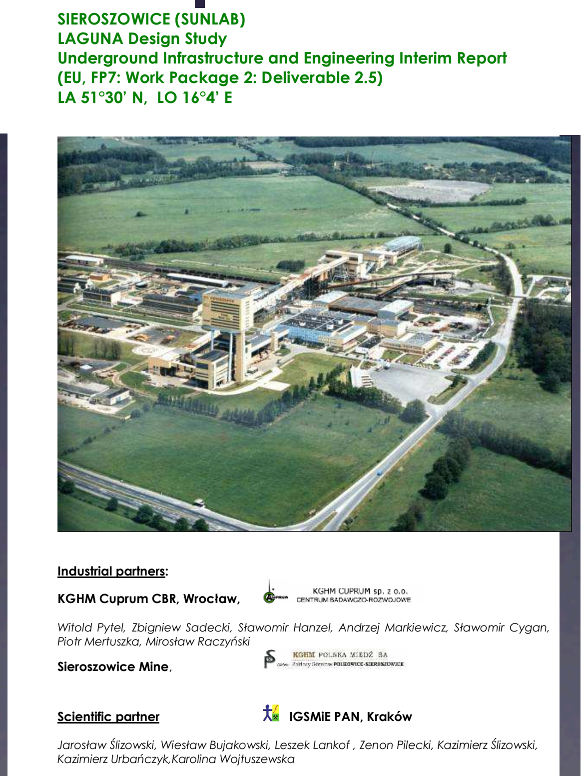
(EU, FP7: Work Package 2: Deliverable 2.1)

- 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,

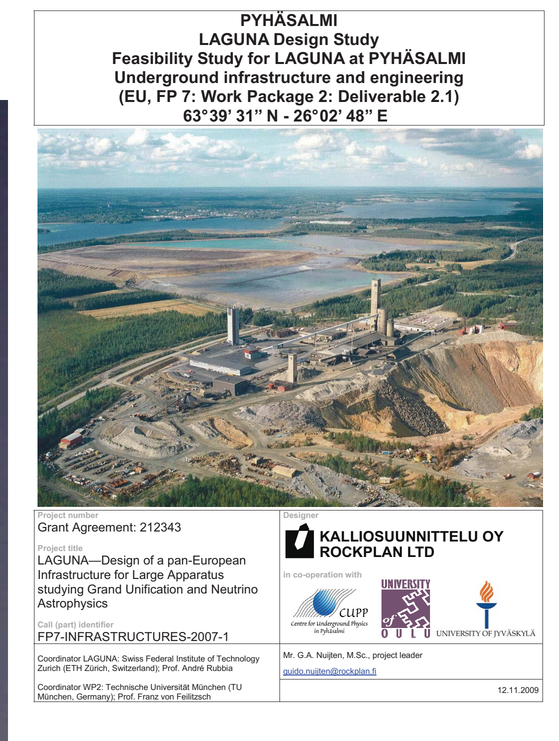
Witold Pytel, Zbigniew Sadecki, Sławomir Hanzel, Andrzej Markiewicz, Sławomir Cygan, Piotr Mertuszka, Mirosław Raczyński

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

Grant Agreement: 212343

LAGUNA—Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics

FP7-INFRASTRUCTURES-2007-1

KALLIOSUUNNITTELU OY ROCKPLAN LTD

12.11.2009

- more than 1000 pages !
- huge amount of information !
- wealthy competition among sites !
- soon publicly available

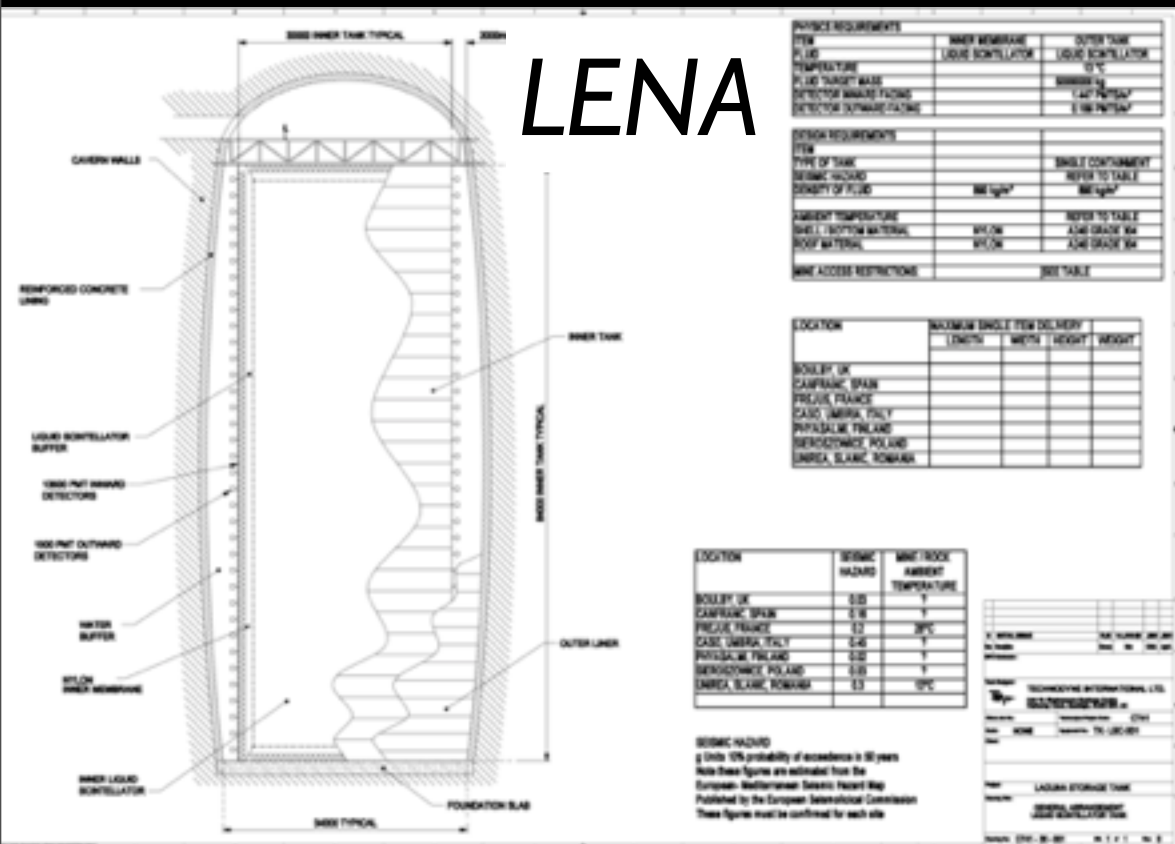
Several different options are being systematically assessed and compared

↓

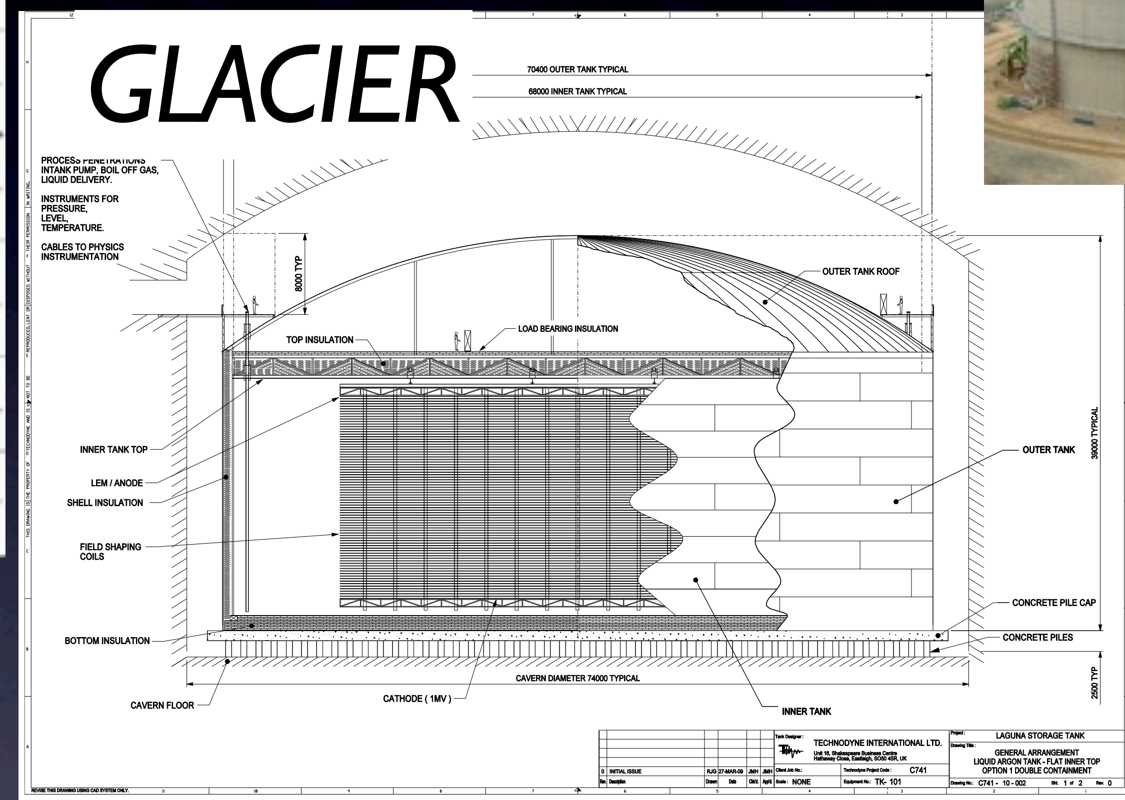
In the following I will try to illustrate a few examples

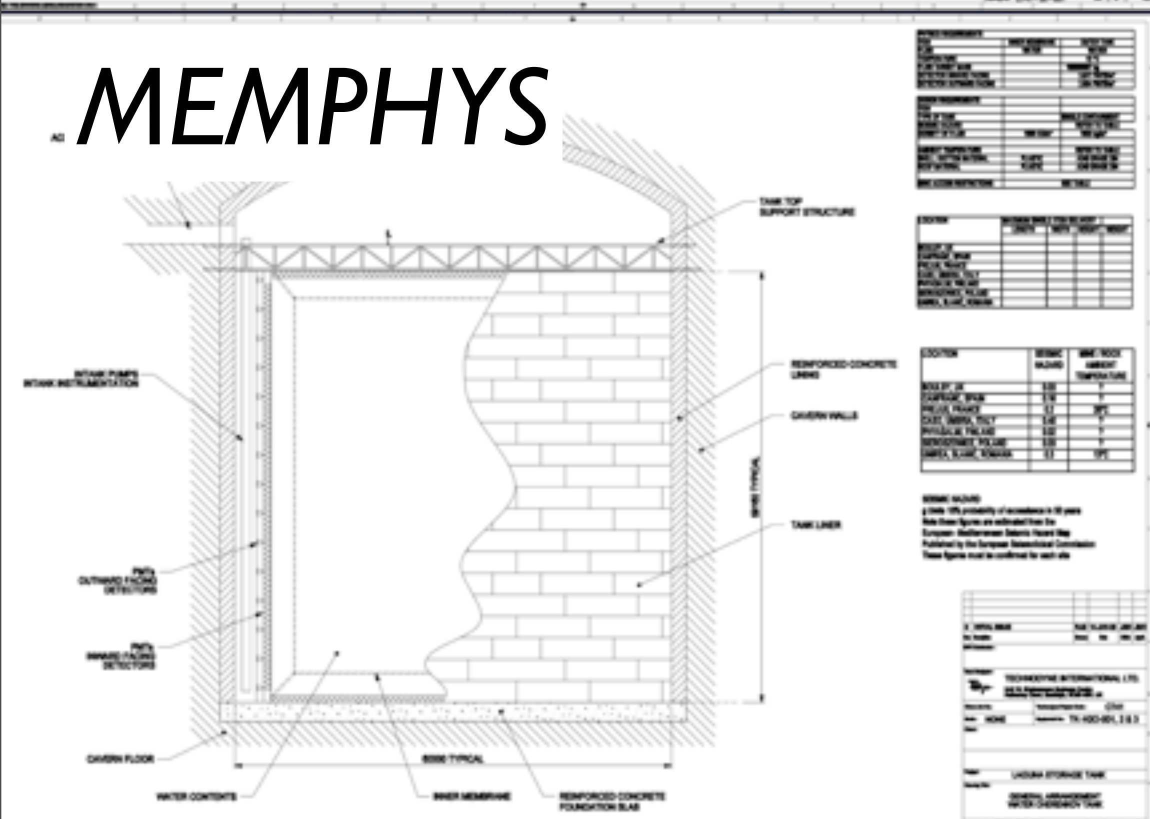
(1) Tank concepts

Engineering of large tanks becoming well understood



Designs by Technodyne Ltd





Item	MEMPHYS	Lena	Glacier
Type	Single Containment	Single Containment	Single or Double Containment
Inner Membrane	Plastic	Nylon	-
Liquid Holding Tank	Stainless Steel	Stainless Steel	Stainless Steel
Cavern Liner	Stainless Steel	Stainless Steel	9% Nickle Steel or Carbon Steel

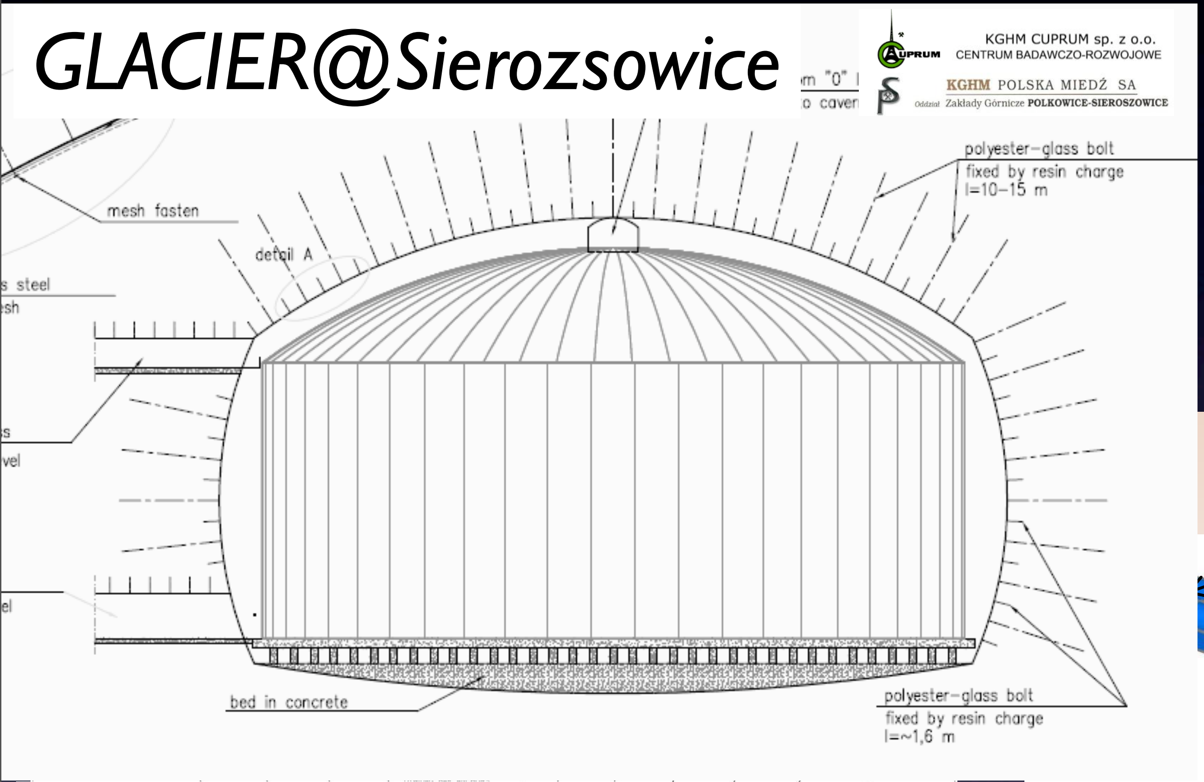
(2) Main cavern engineering

Relationship between tank design and main cavern excavation

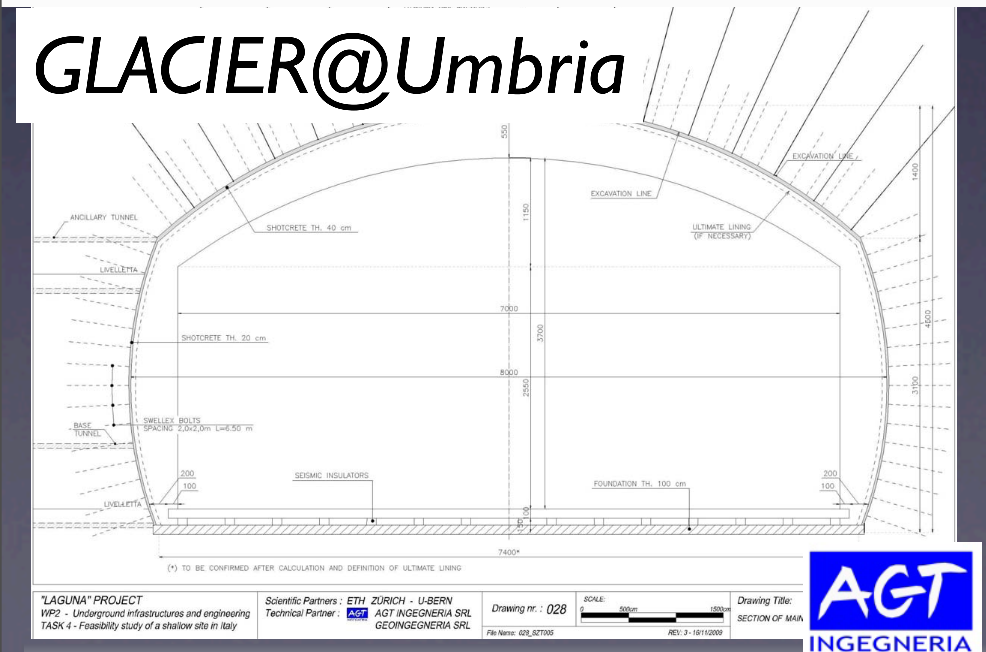
- Interaction between scientists, Technodyne Ltd. with Rockplan, Cuprum, CPL, AGT, ...

	MEMPHYS	LENA	GLACIER
Overburden	>2000 mwe	>4000 mwe	>600 mwe
#tanks	3 to 5	1	1 preferred
Dimensions of tank	cylinder 65m Ø x 65m height	SS cylinder of 30m Ø x105 m height, inside a external tank of ~ cylindrical shape, of at least 34m Ø for water-buffer.	cylinder: 72,4m Ø x 26,5m height dome: 12,7m height x 144,8m Ø
Cavern	65m Ø x 70m height + dome	Egg-shaped to house external tank	cylinder: 75,1m Ø x 26,5m height + dome

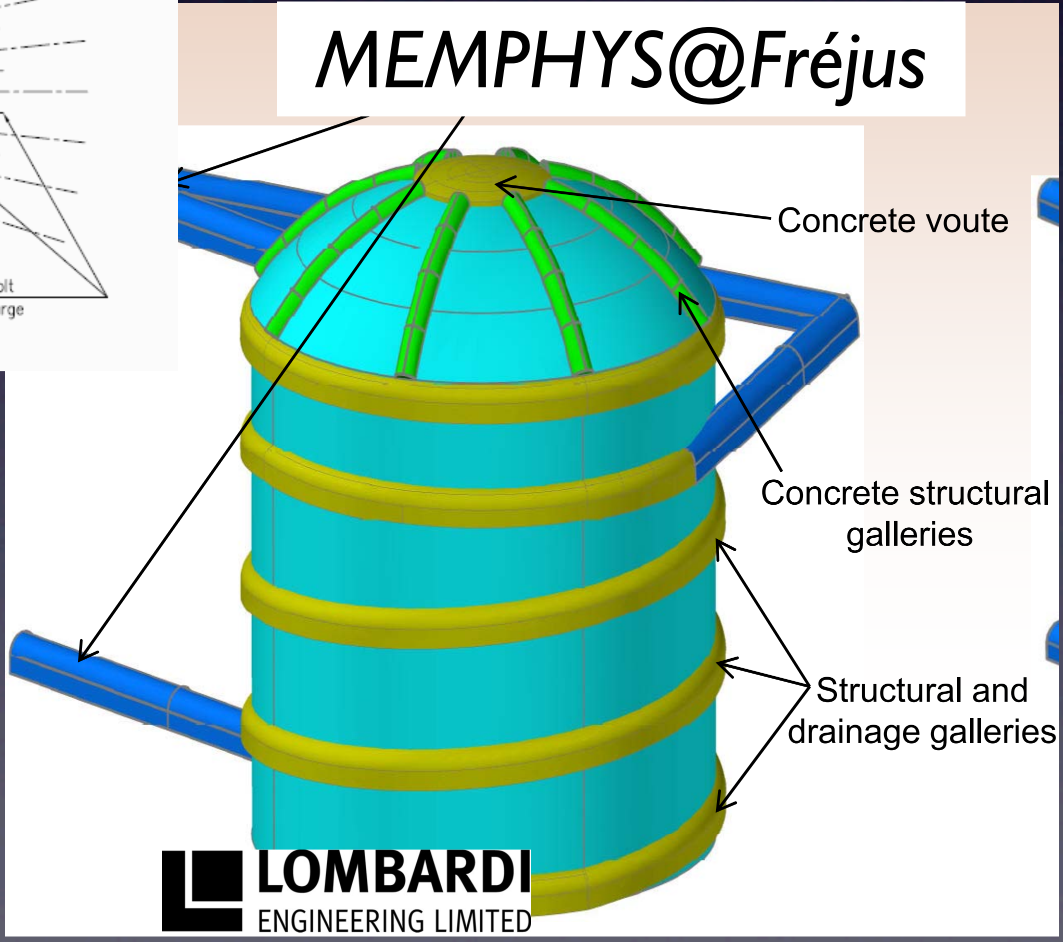
GLACIER@Sierozsowice

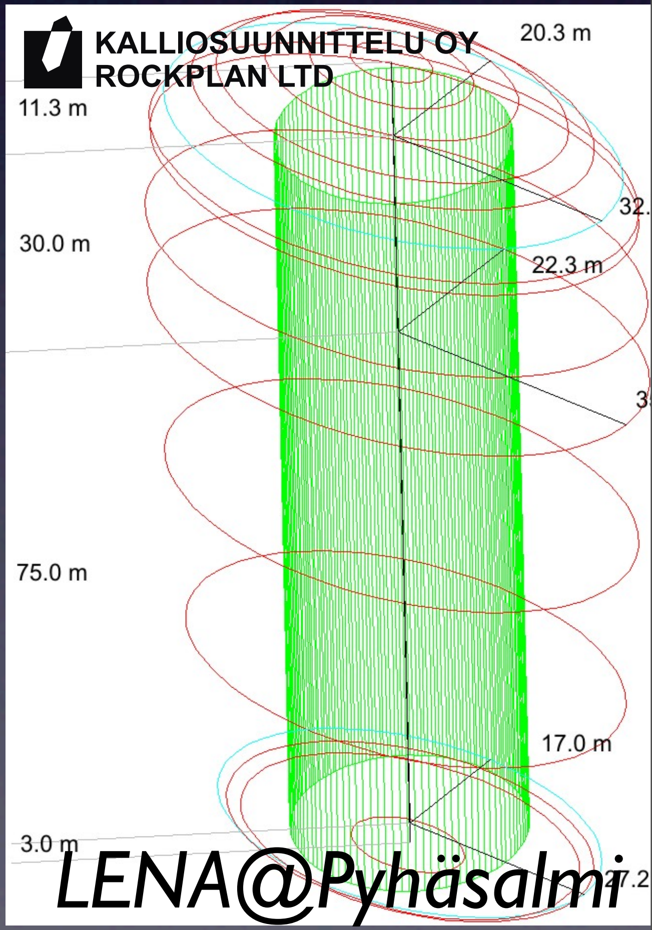


GLACIER@Umbria



MEMPHYS@Fréjus





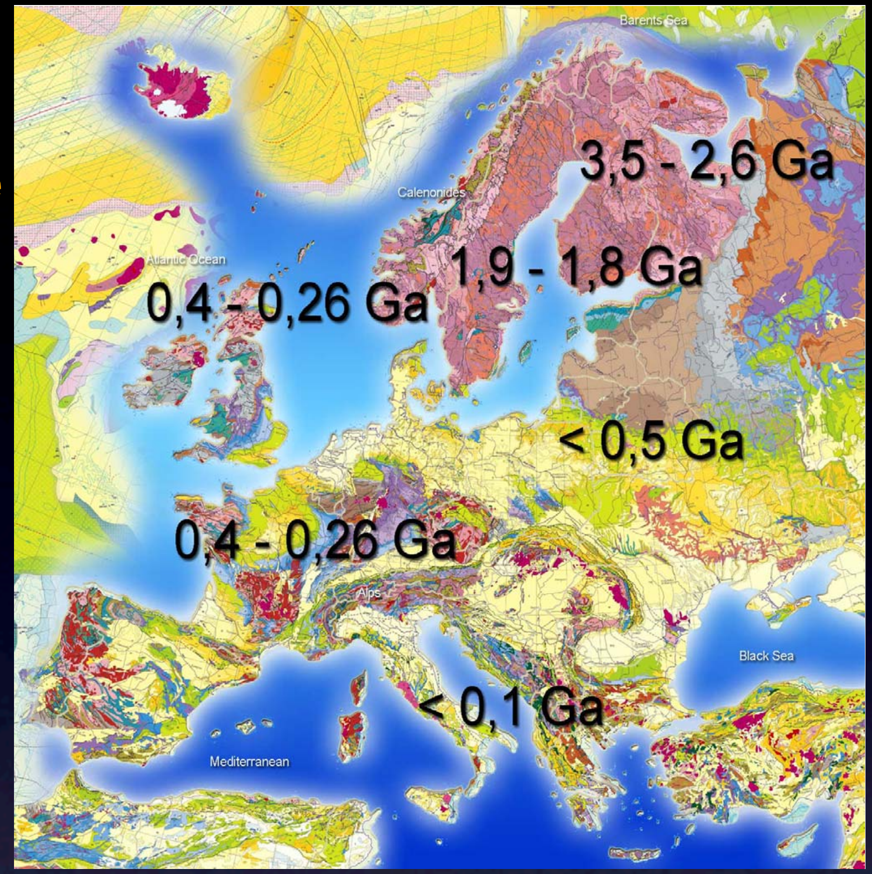
LENA@Pyhäsalmi

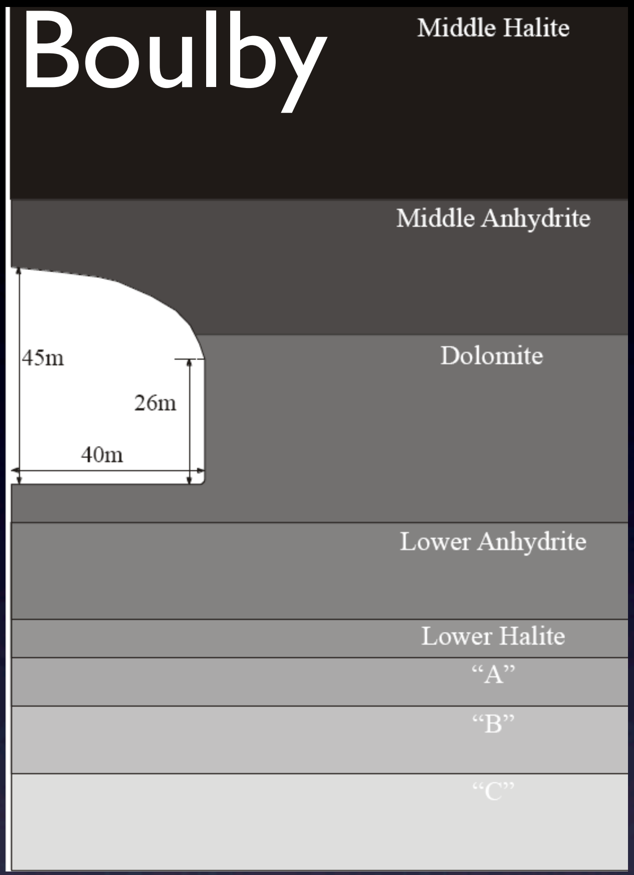
(3) Geomechanical studies

Rock data gathered for all sites

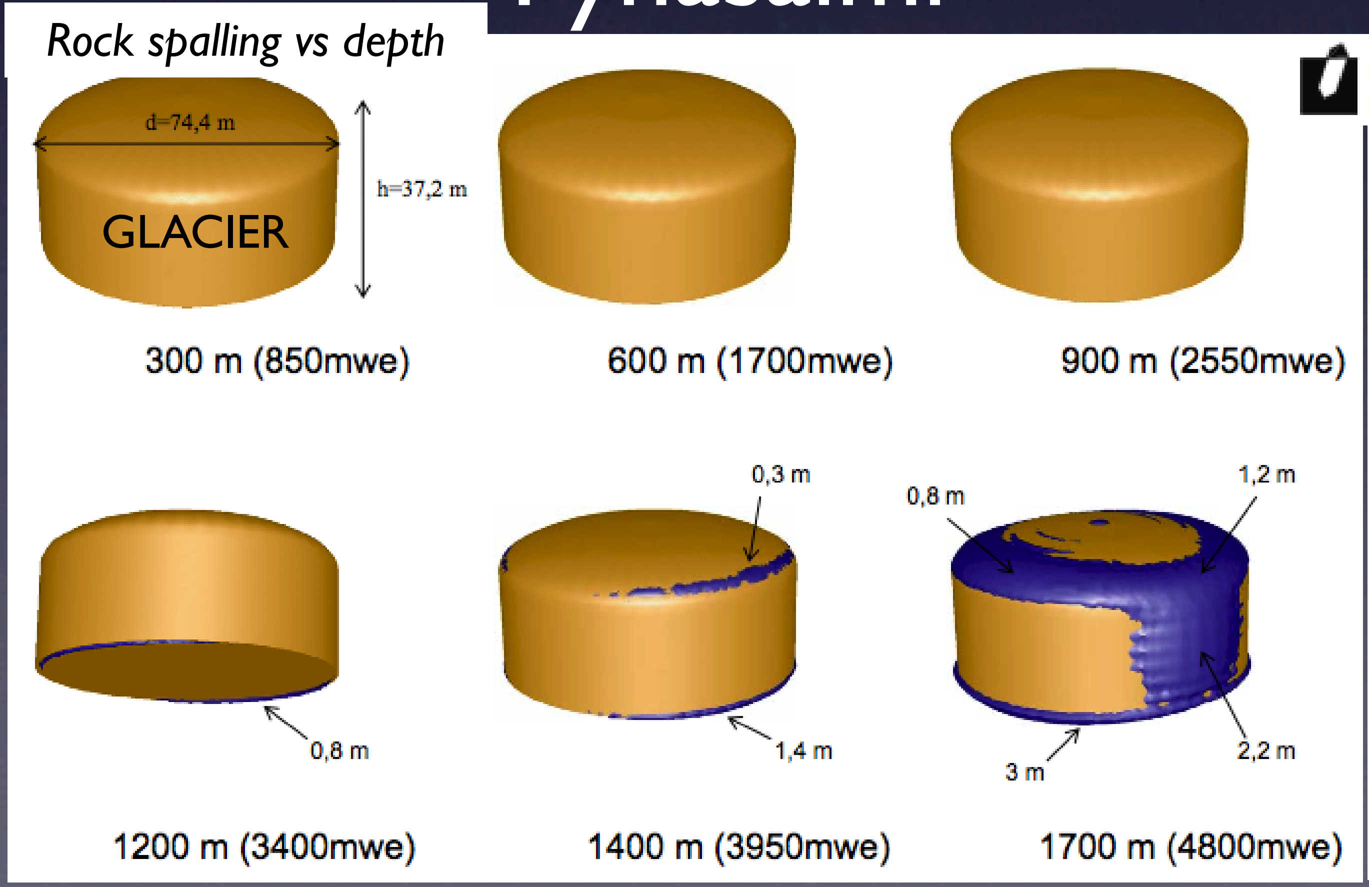
Numerical modeling based on these parameters:

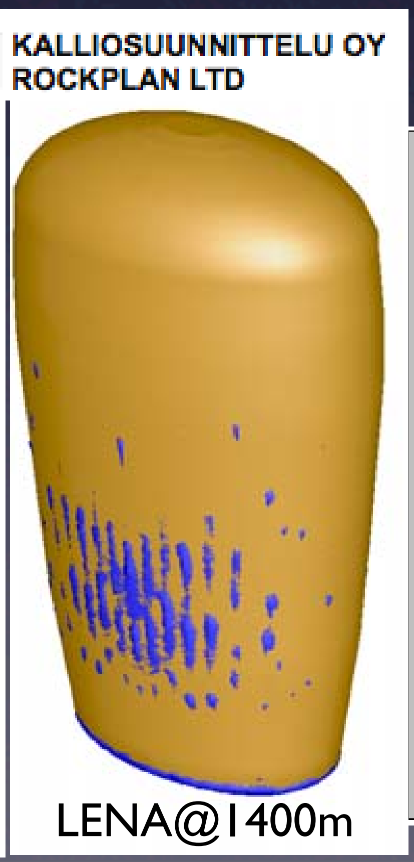
- Convergence
- Spalling
- Rock-bolting
- Mucking
- Multi-strata rock issues
- Cavern shapes

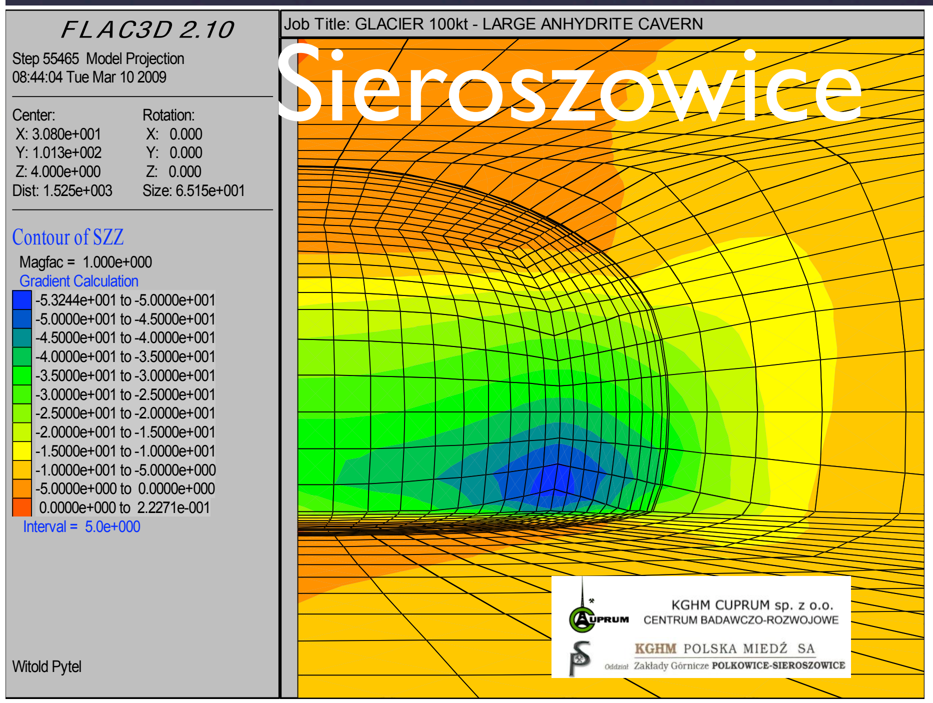




Pyhäsalmi

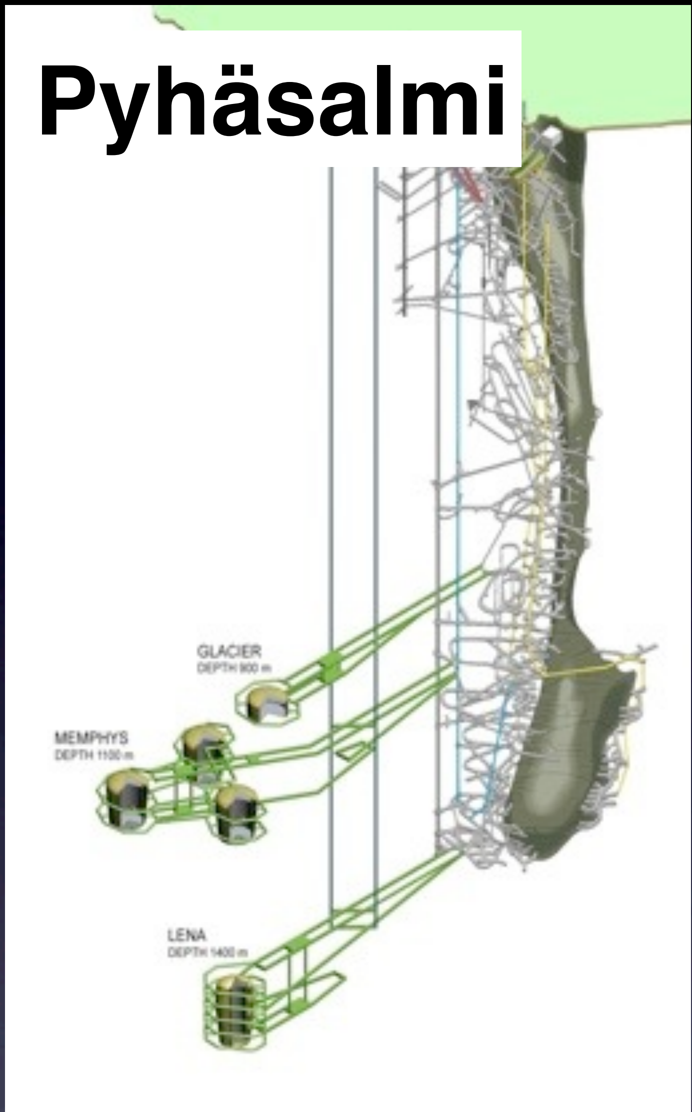


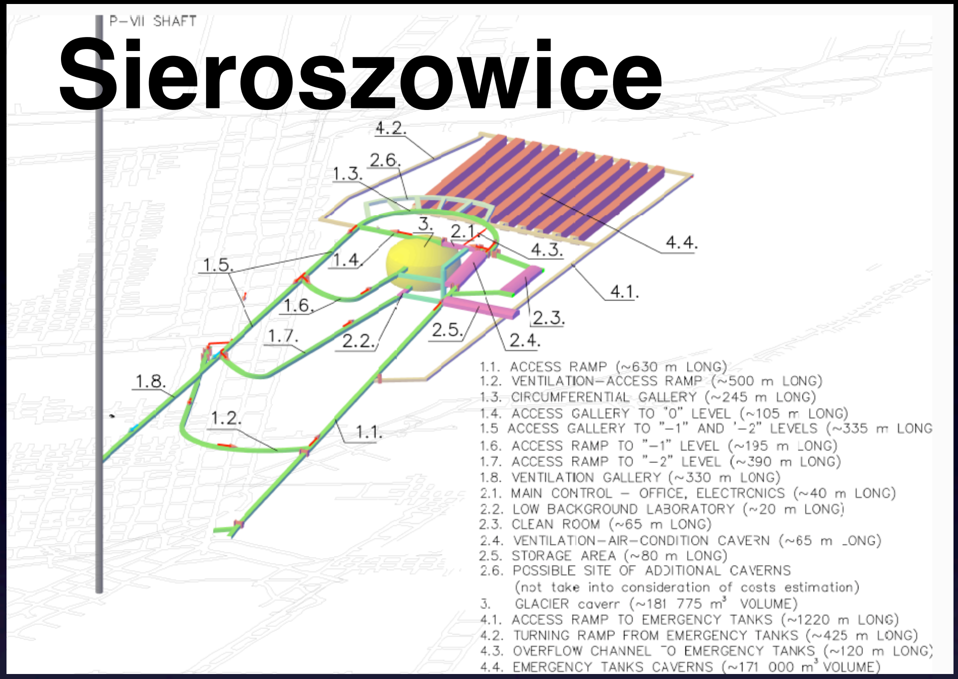


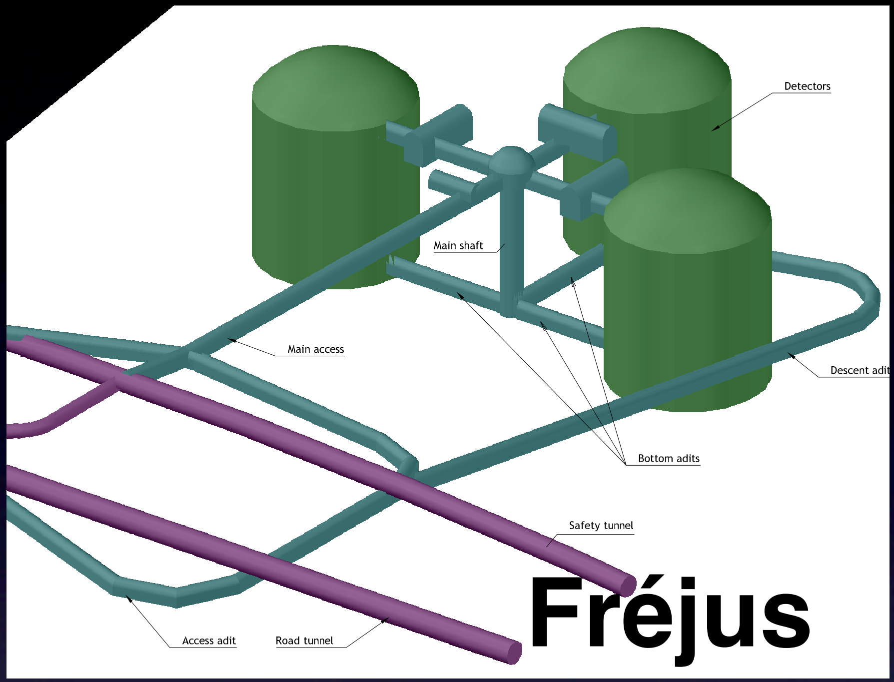


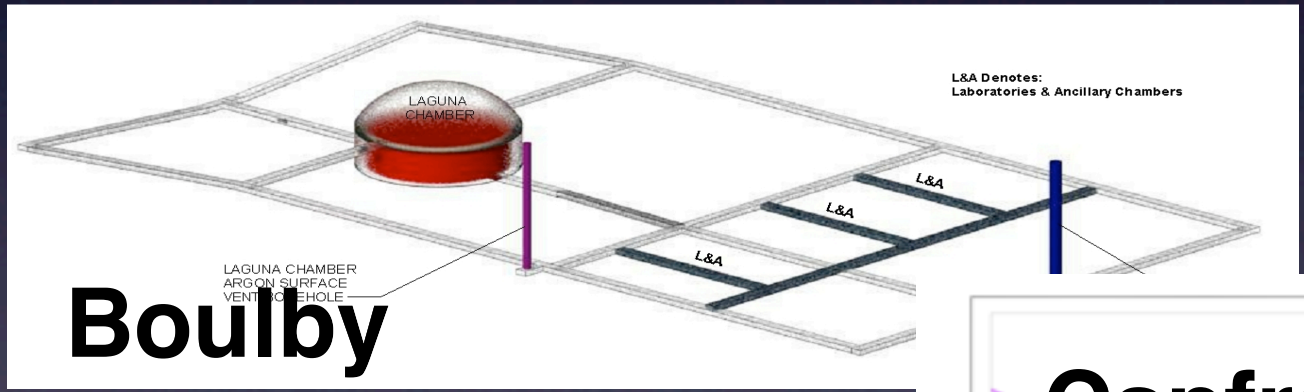
(4) Underground Layout

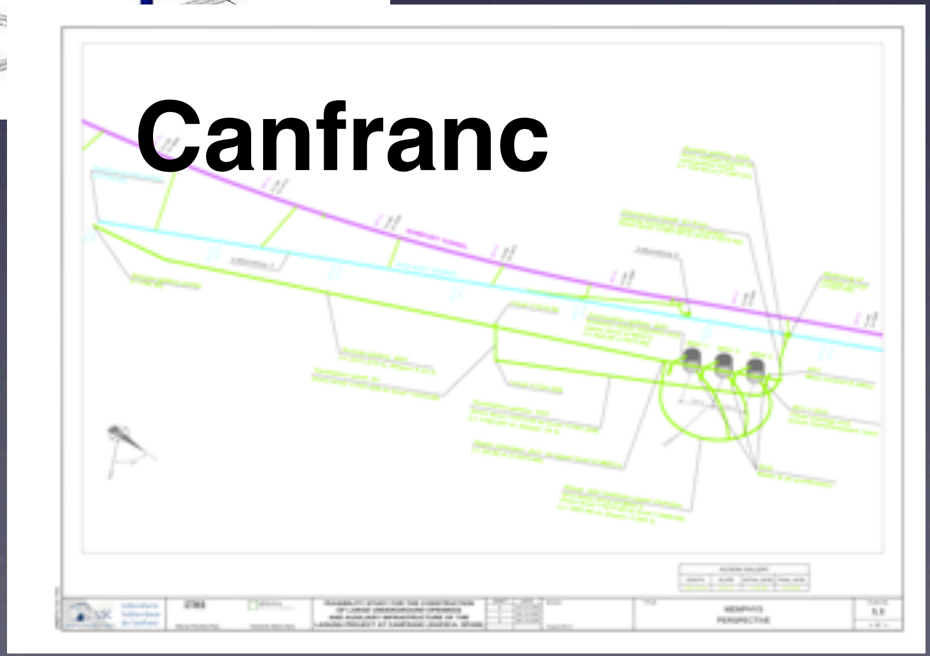
Details of layout including MDC, auxilliary caverns, access, escape routes, etc...

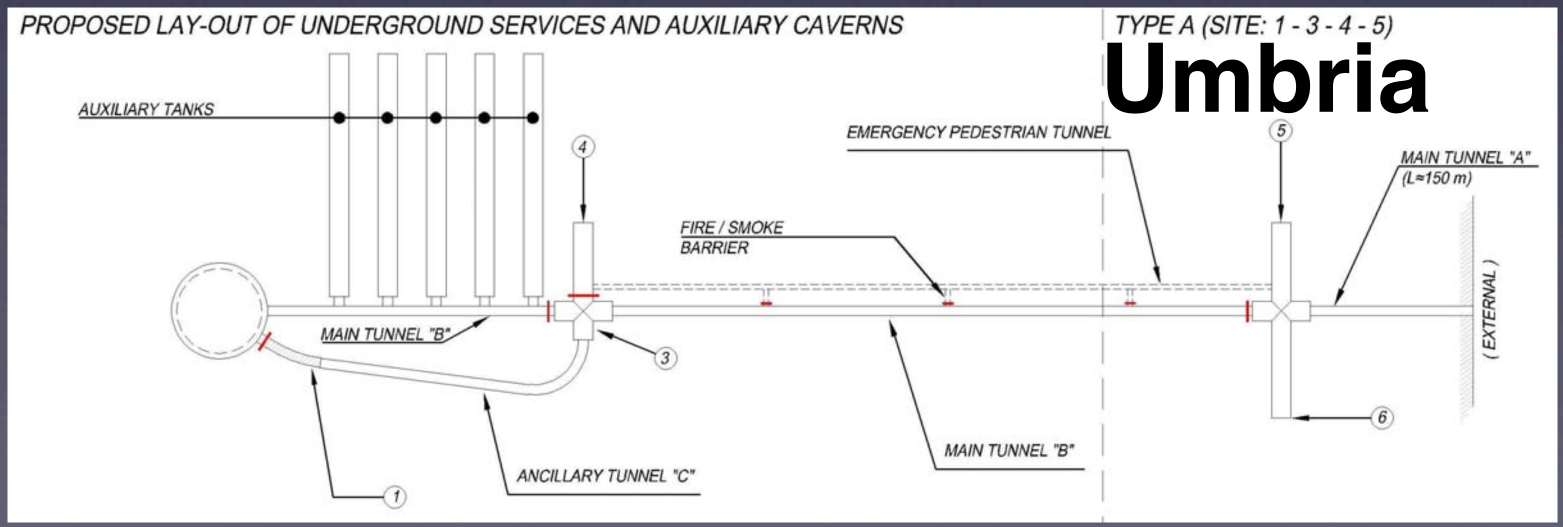




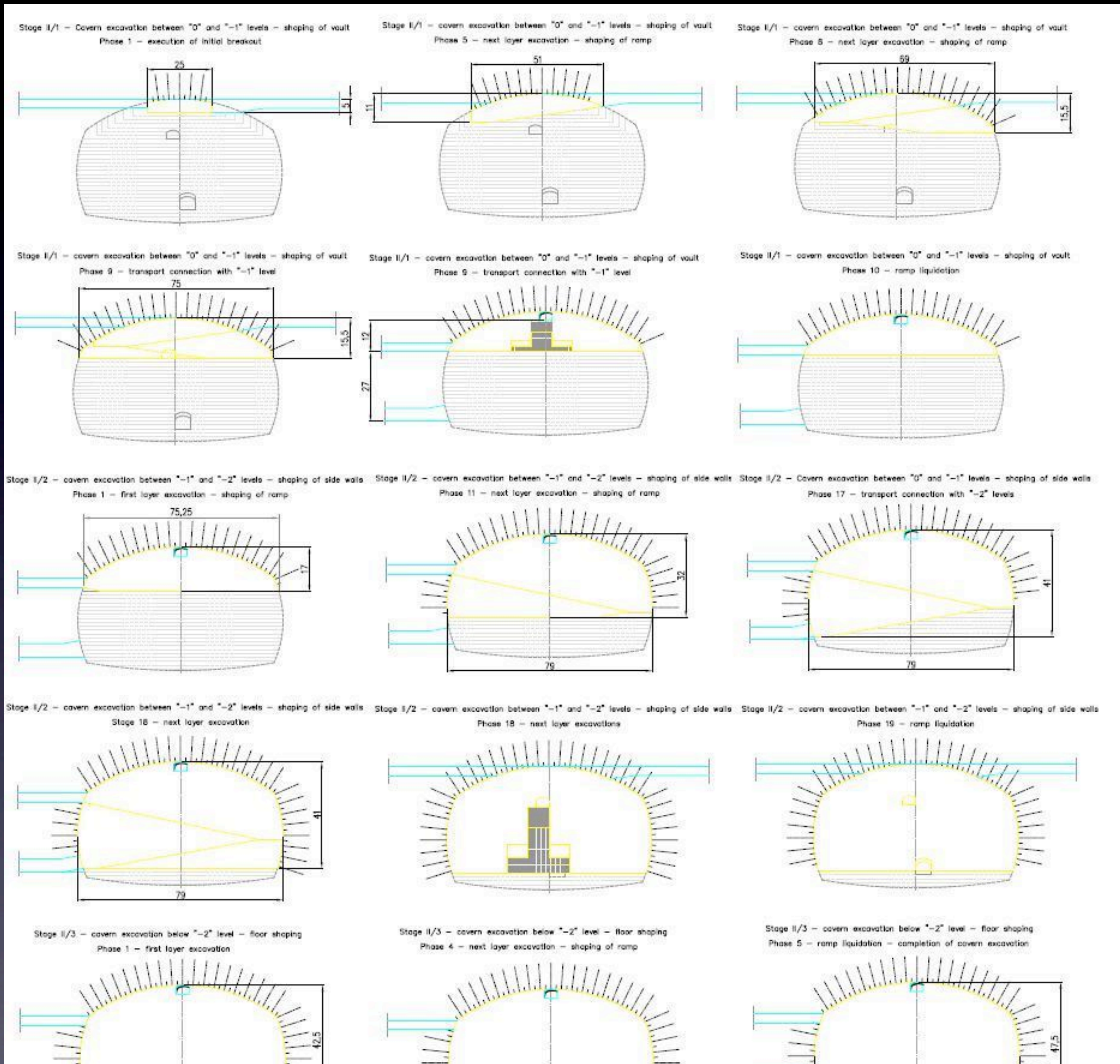








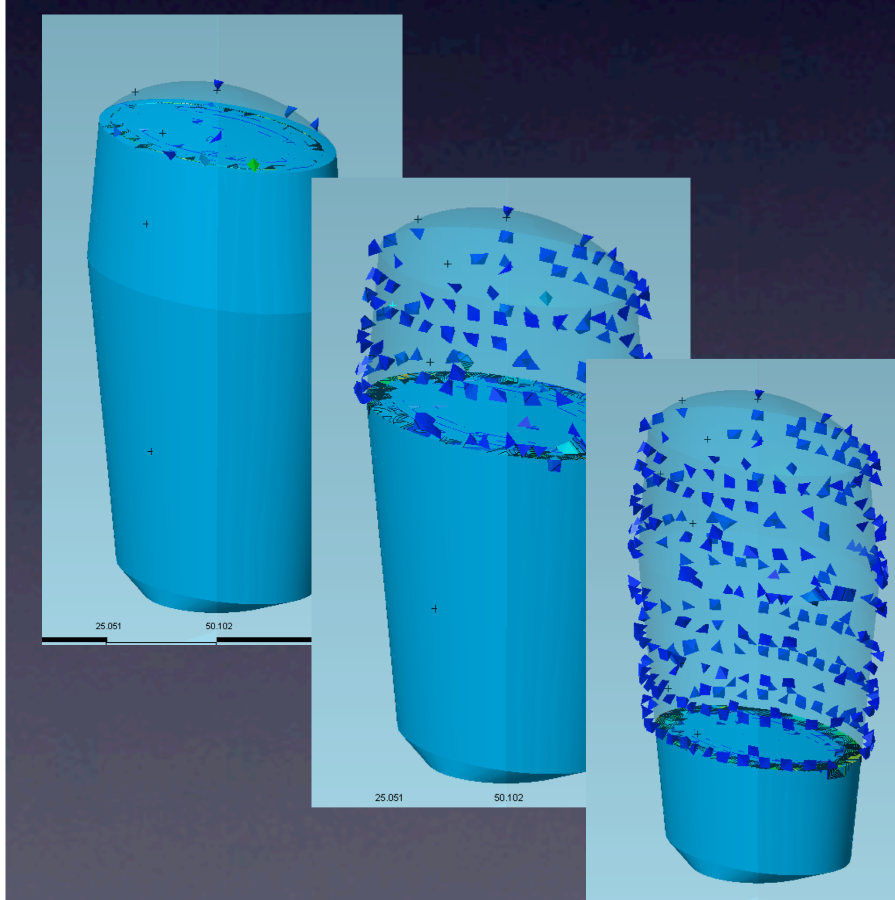
(5) Sequence of excavation



Example: GLACIER@Sieroszowice

Details of construction sequence also studied at various sites

- Rock disposal
- Geotechnical stability and safety at each stage of excavation
- Requirements for rock removal and rock bolting
- Egress routes and evacuation safety

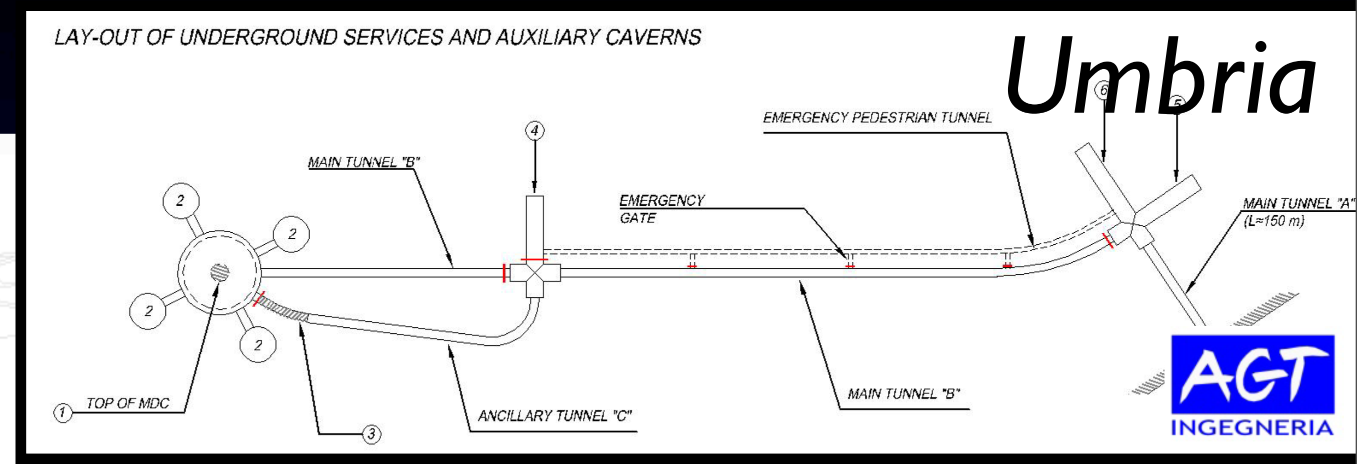


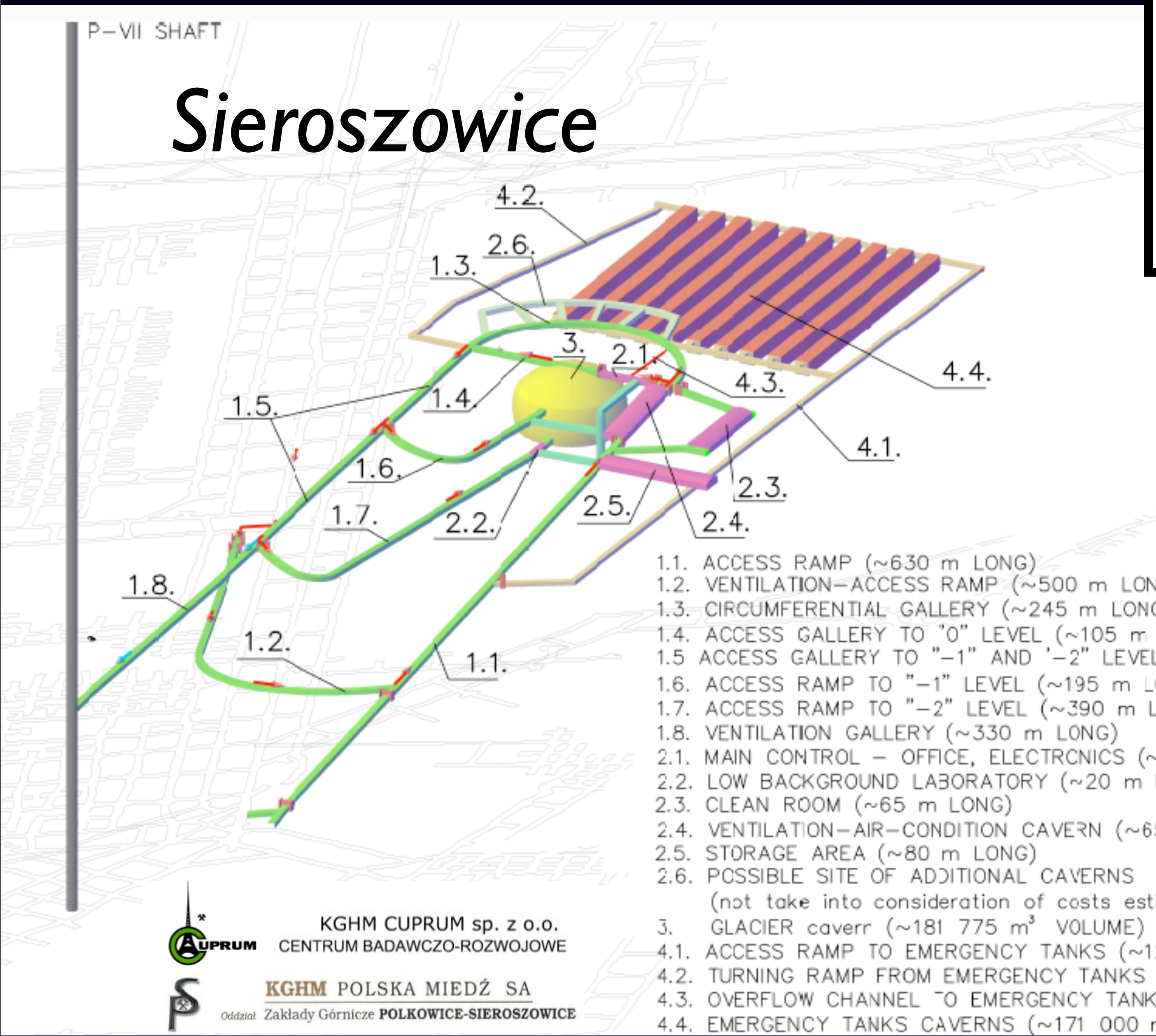
LENA@Pyhäsalmi

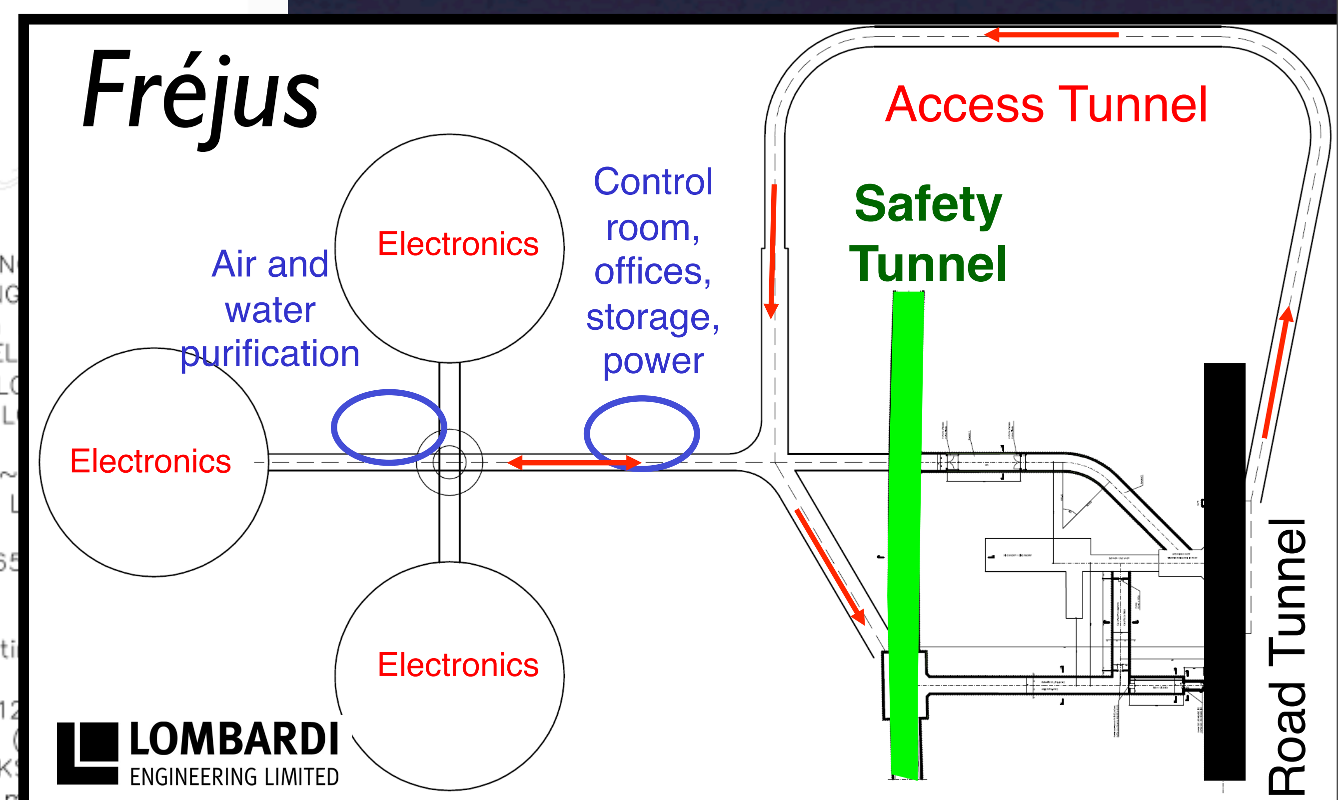
(6) Additional infrastructure

Details of ancillary laboratories, storage caverns and egress

- Design of liquid transit, storage and emergency dump
- Ancillary caverns for construction phase
- Clean rooms, electronics and mechanical workshops
- Emergency safe havens, double egress routes







(7) Costs

Cost estimation for each detector option has been divided into several sections

- Main Detector Cavern excavation and support.
- Access galleries, auxiliary caverns and ventilation facilities excavations and support.
- Installations: construction installations, underground installations and surface installations.
- Environmental measures.

- The proposed designs developed by each industrial partner for each site has been critically reviewed by other industrial partners during a series of dedicated technical meetings.
- The designs were “corrected” where necessary. Technical differences between sites remain due to local boundary conditions (quality of rock, depth, etc.)
- The unit costs were taken using reference from civil construction in the same area. Unit costs were debated at length. Differences among regions clearly exist.
- Approximate costs for site and infrastructure excavation (details in documents): GLACIER O(65M€), LENA O(75M€), MEMPHYS O(200M€) – detectors not included!

LAGUNA is about choices

- Our main goals are:
  - to study the feasibility of the considered experiments
  - to prepare a conceptual design of the required underground infrastructure
  - to deliver a report that allows the funding agencies to decide on the realization of the experiment(s) and to select the site and the technology(ies)

- The LAGUNA prioritization of the sites is based on:
  - ✓ scientific arguments (WP4)
  - ✓ technical feasibility (WP2)
  - ✓ political and environmental arguments (WP3)
  - ✓ costs

LAGUNA choices

Prioritization and down-selection to be included into next deliverables

- **Deliverable 2.8 : Final joint report on potential European sites**
- **Deliverable 1.2 : Final report on European underground research infrastructure and its science**

At present:

- GLACIER keeps several options:
  - Mine (vertical access): Pyhäsalmi, Sieroszowice, Slanic
  - Road tunnel (horizontal access): Canfranc, Umbria
  - [Okinoshima, Japan (horizontal access)]
- LENA favors Pyhäsalmi (with Fréjus as second option)
- MEMPHYS option favors Fréjus (with a 2nd potential location at Canfranc)
- Other sites are disfavored

LAGUNA - Schedule

Paper Design Study (EU funded):	2008-2010
Prioritize the sites and down-select:	July 2010
Prioritize detector options and down-select (LAGUNA-NEXT ? call end 2010):	2011-2012
Phase 1 construction (intermediate step):	2012-2016
Phase 2 construction:	>2016

Timeline matched to new potential CERN neutrino (super)beams in >2020

Conclusions

Growing interest and activities on large neutrino and proton decay detectors, both new sites and detector technologies

In Europe LAGUNA has a well defined timeline
- no obvious geo-technical show-stoppers so far - but several challenges (e.g. underground construction, liquid procurement, financing...)
- prioritize sites in 2010

Big range of CERN baselines are feasible (130 km - 2300 km)
- timeline matched to potential superbeam in >2020
- could be operated in connection with more advanced beams like beta-beams or neutrino factories (>>2020 ?)

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 should also be strongly linked to projects world-wide that consider same physics goals (J-PARC to Okinoshima and LBNE project)

ASPERA/AppEC Roadmap for EU

"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..."

Acknowledgements

- FP7 Research Infrastructure "Design Studies" LAGUNA (Grant Agreement No. 212343 FP7-INFRA-2007-1)