Towards a European megaton observatory for neutrinos and proton decay

Stavros Katsanevas (IN2P3/CNRS)

Neutrino Telescopes 2009

Thanks to: A.Rubbia, F. Pietropaolo, L. Mosca, L. Oberauer, M. Marafini and A. Tonnazzo

dedicated
to
Alain de Bellefon

Borexino and Memphys
scientist
and
IN2P3/CNRS communication
officer

10^{-33} cm
proton decay
$10^{-(30-32)}$ cm
ν mass
leptogenesis

$10^{-(21-24)}$ cm
dark
matter

10^{-5} cm
archaeobiology

10^{28} cm cosmology, dark energy/matter

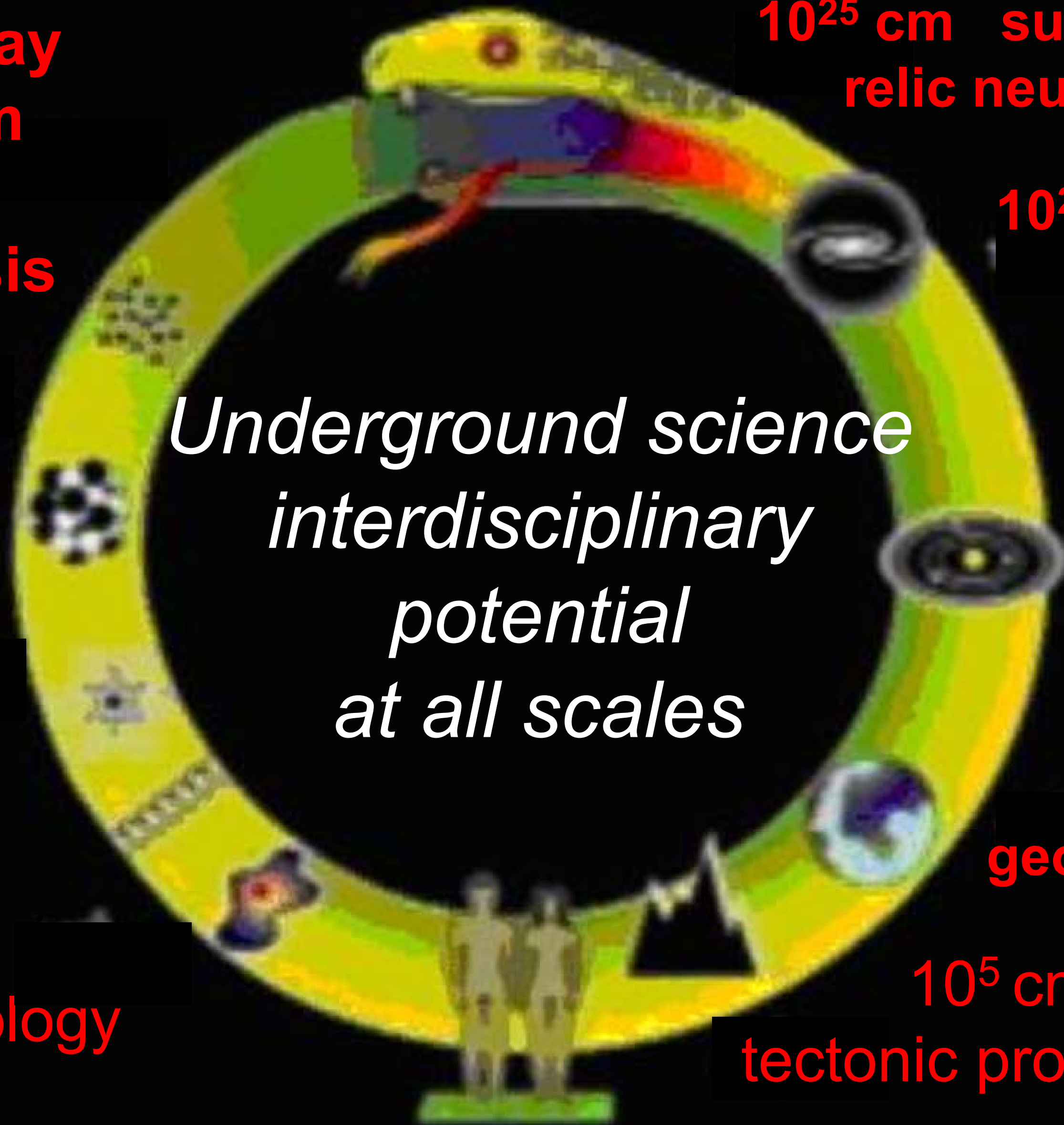
10^{25} cm supernovae
relic neutrinos

10^{22} cm galactic
Supernova
neutrinos

10^{15} cm solar
neutrinos

10^{10} cm
geoneutrinos

10^{5} cm
tectonic processes



Underground science
interdisciplinary
potential
at all scales

Megaton projects in the European Strategy for Astroparticle Physics

- **ApPEC/ASPERA** recommendation in the roadmap: "***We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the 10^5-10^6 ton scale for improved studies of proton decay and of low-energy neutrinos from astrophysical origin. The three detection techniques being studied for such large detectors in Europe, Water-Cherenkov, Liquid Scintillator and Liquid Argon, should be evaluated in the context of a common design study which should also address the underground infrastructure and the possibility of an eventual detection of future accelerator neutrino beams. <u>This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.</u>***"
- CERN initiated European Strategy Plan needs to have a CDR by 2012. SPC Strategy group with ApPEC participation (C. Spiering)
- The **European Union** has funded two EU-FP7 programs: LAGUNA and EUROnu
- Megaton projects are large scale global projects. Need world-wide collaboration. (OECD ongoing study)

European long tradition in underground science

IUS

Institute of Underground Science in Boulby mine, UK

Laboratoire Souterrain de Modane, France

LSC

Laboratorio Subterraneo de Canfranc, Spain

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

LNGS

Laboratori Nazionali del Gran Sasso, Italy

LNGS presently the largest laboratory

Coordination efforts in context of ILIAS ASPERA

Infrastructure	LNGS Gran Sasso	LSM Fréjus	LSC Canfranc	IUS Boulby	BNO Baksan	CUPP Pyhäsalmi
Year of completion	1987	1982	1986, 2005	1989	1977, 1987	1993 (2001)
Area (m^2)	13000	500	150+600	500+1000	550, 600	500-1000
Volume (m^3)	180000	3500	8000	3000	6400, 6500	100-10000
Access	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Slanted truck road
Depth (m.w.e.)	3700	4800	2450	2800	850, 4800	1050, 1444 up to 4060
Surface profile	Mountain	Mountain	Mountain	Flat	Mountain	Flat
Muon flux (m^{-2} day^{-1})	24	4	406	34	4320, 2.6	8.6 @ 4060m
Neutron flux (>1 MeV) (10^{-6} cm^{-2} s^{-1})	O (1)	O (1)	O (1)	O (1)	-, O (1)	?
Radon content (Bq/m^3)	O (100)	O (10)	O (100)	O (10)	O (100)	O (100)

LAGUNA

- **L**arge **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics
- Aimed at defining and realizing this research programme in Europe.
- It includes a majority of European physicists interested in the construction of very massive detector(s) realized in one of the three technologies using liquids: water, liquid argon and liquid scintillator.
- EC contribution: 1.7 M€ to be mainly devoted to the sites infrastructure studies to be completed by July 2010.
  21 beneficiaries in 9 countries: 9 higher education entities, 8 research organizations, 4 private companies (+4 additional universities). Coordinator A. Rubbia

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

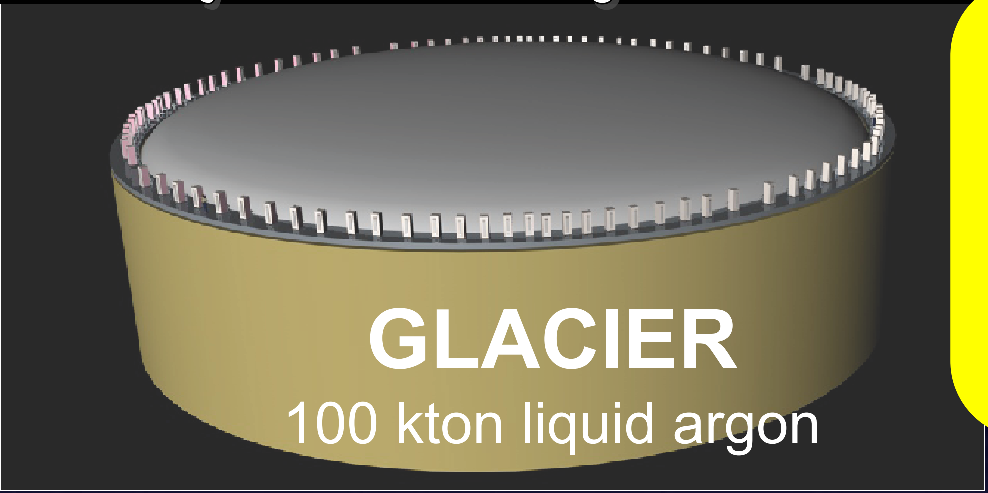
	Title
WP2	Underground infrastructures and Engineering
WP3	Safety, environmental and socio-economic issues
WP4	Science Impact and Outreach

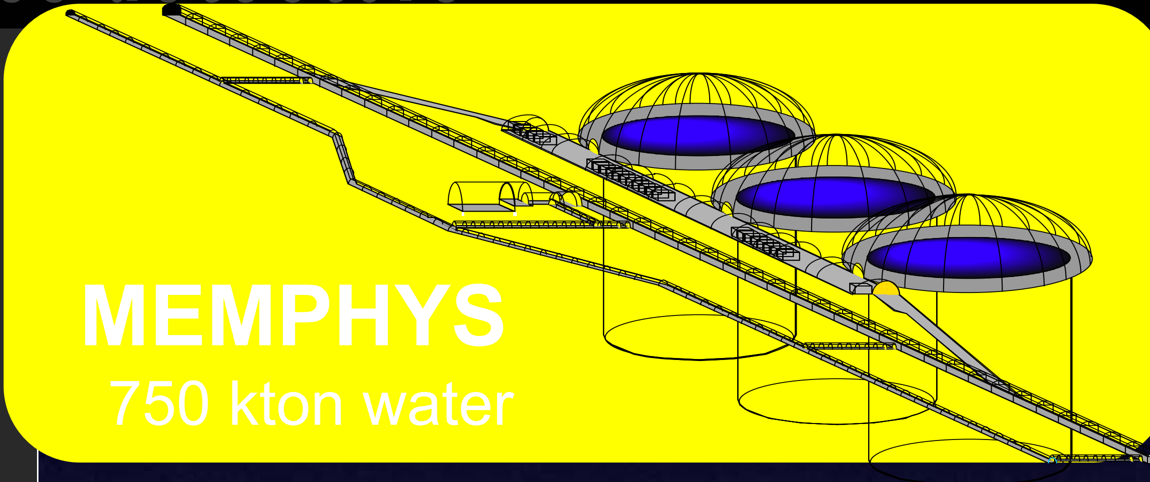
Detector R&D with national funds

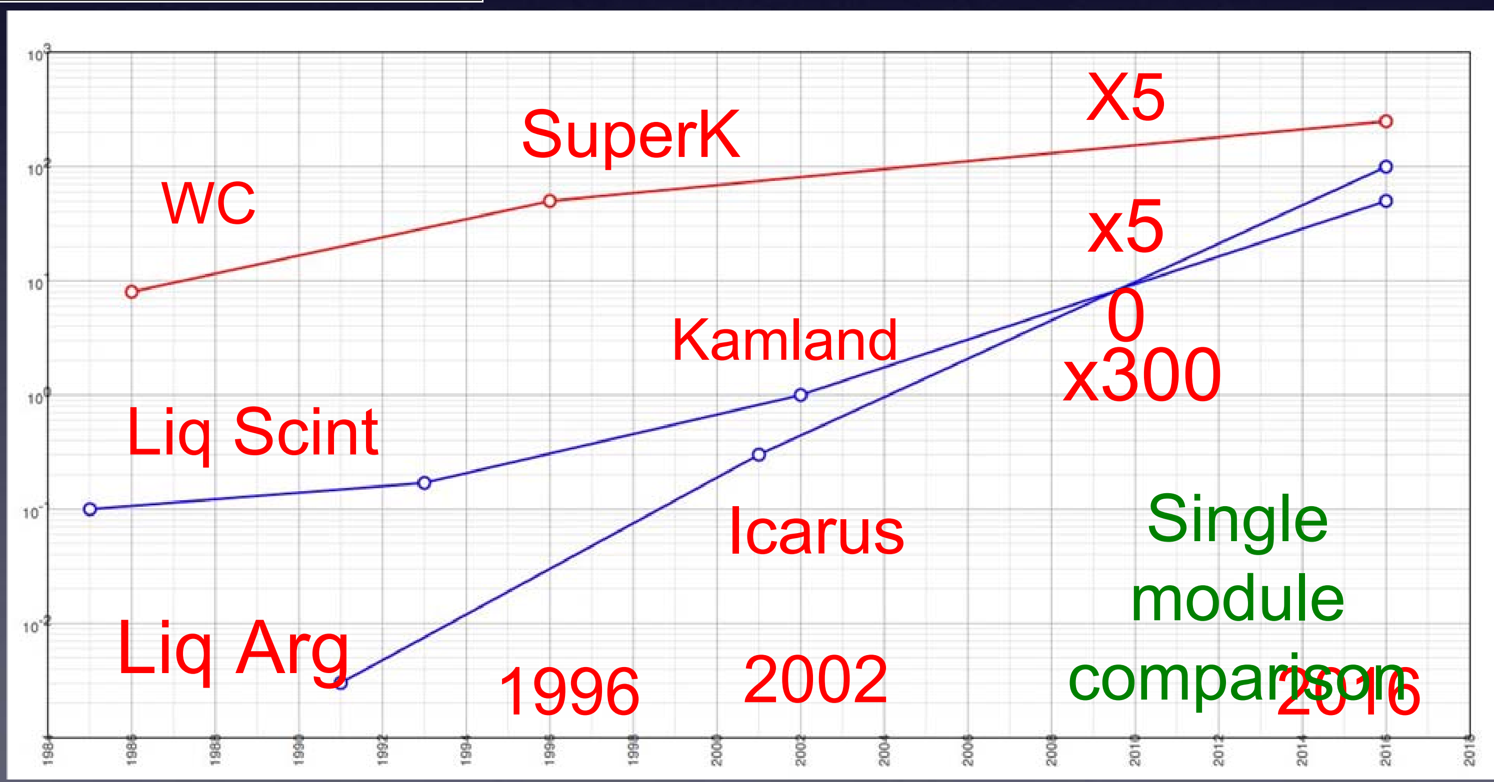
Basic infrastructure requirements

	MEMPHYS	LENA	GLACIER
Overburden	>4000 mwe (preliminary)	>4000 mwe	>600 mwe
#tanks	3 to 5	1	1 preferred (if not, take 2)
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
Geomechanical stability	>50 years	>50 years	>50 years
Temperature of liquid	≈13 °C	8 - 18 °C	87 K
Radon	<40 Bq/m3	<40 Bq/m3	--

Projected megaton class detectors







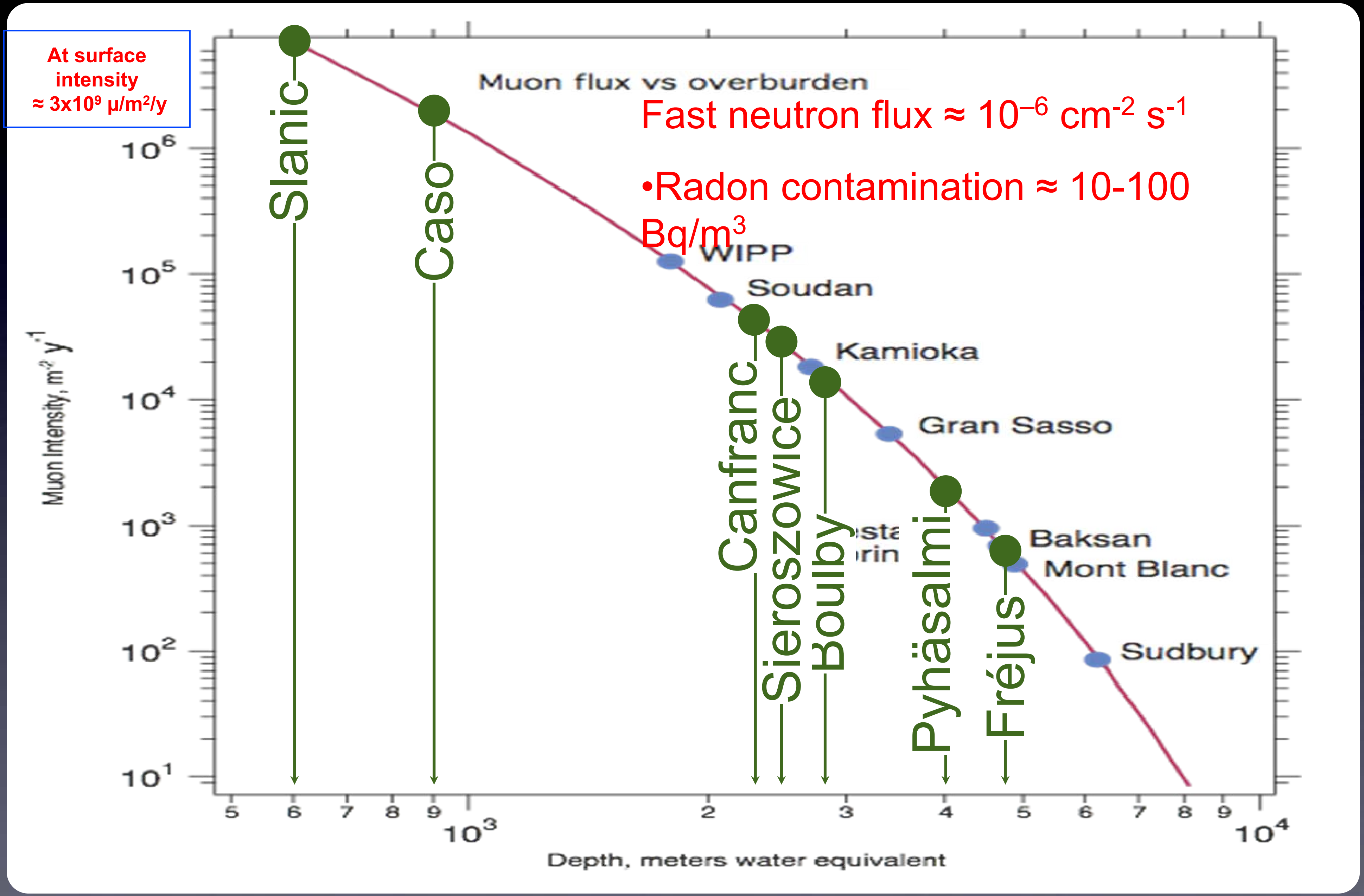
Possible localizations of the future large underground laboratory

Candidate sites

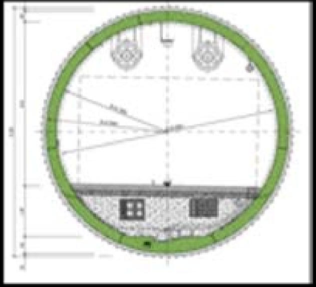
1. Boulby, UK
2. Canfranc, Spain
3. Fréjus, France
4. Pyhäsalmi, Finland
5. Sieroszowice, Poland
6. Slanic, Romania
7. Caso "green fields" Italy

➠ *prepare for site selection, define criteria*

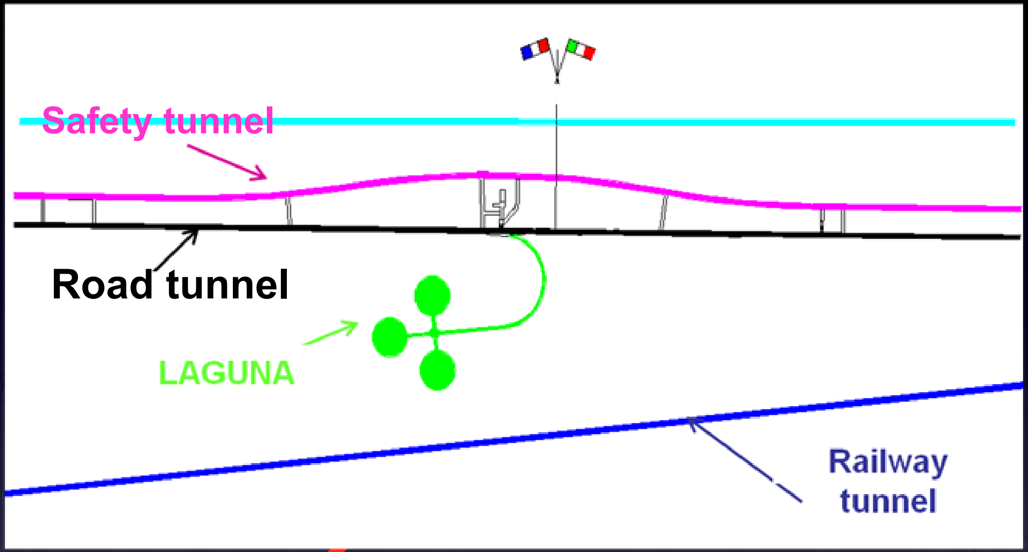
Cosmogenic backgrounds, depth

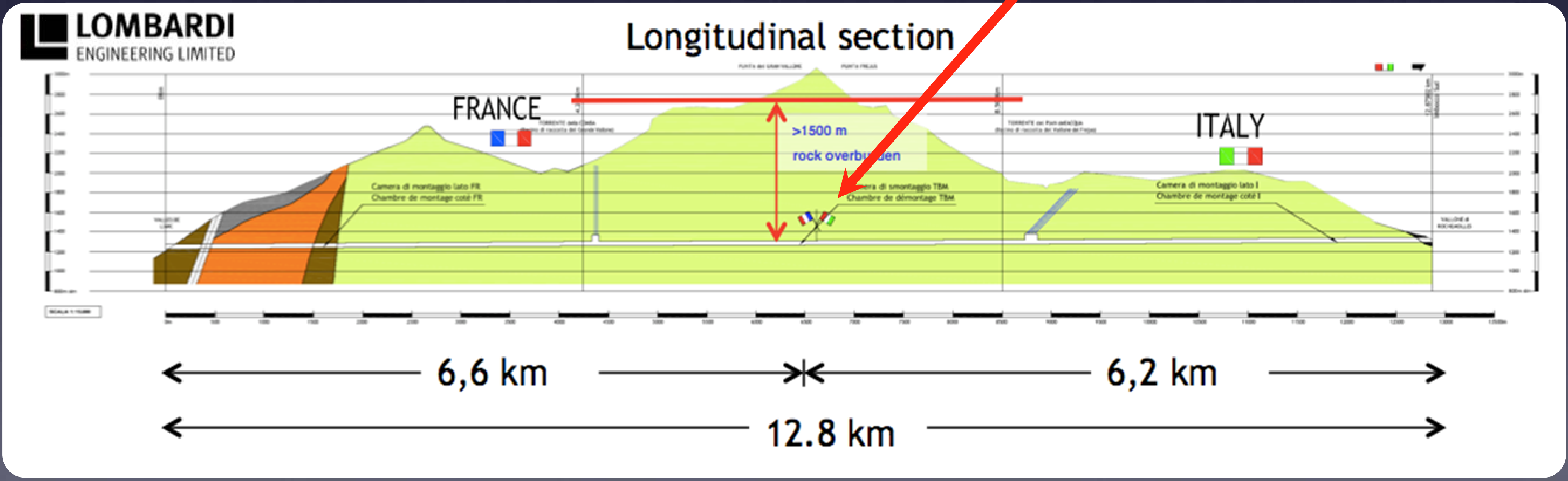


Site Study Ia : Fréjus



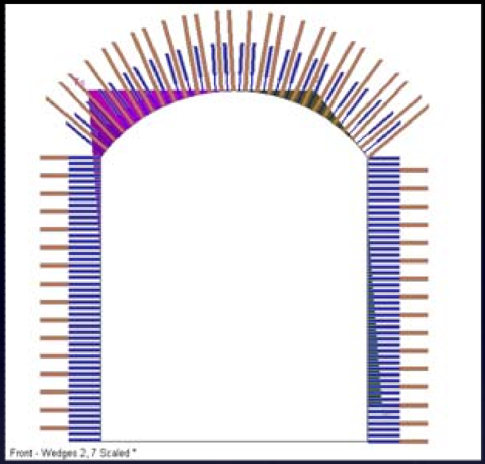
- Operability of new safety tunnel by 2014
- Planned 60'000 m3 LSM extension decision by the end of 2010.
  - 3.5 months excavation
- Megaton extension could use the safety tunnel for the rock debris evacuation
- First site study by STONE (2005) influential.

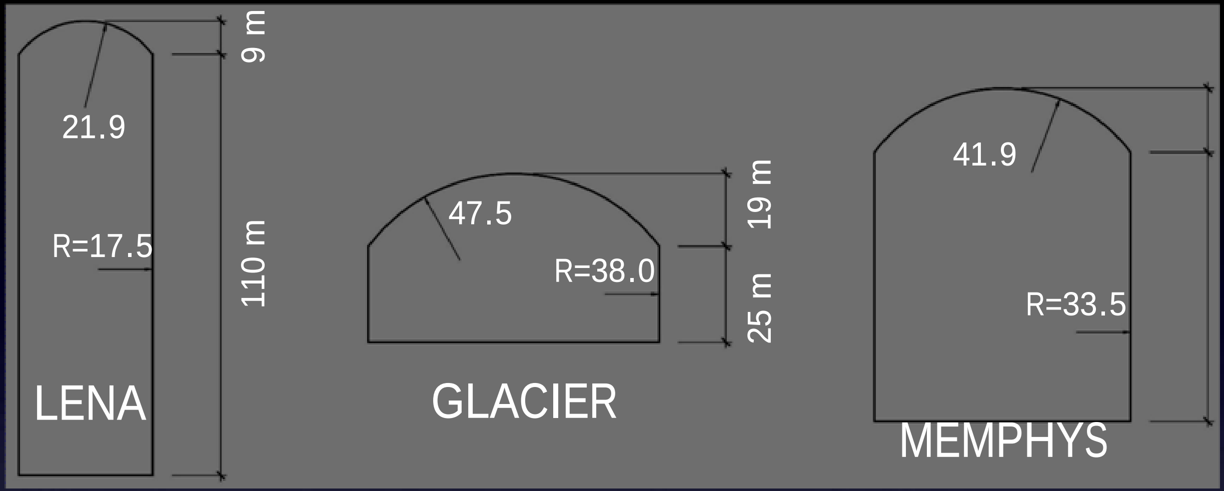




Site Study Ib : Fréjus

LOMBARDI ENGINEERING LIMITED





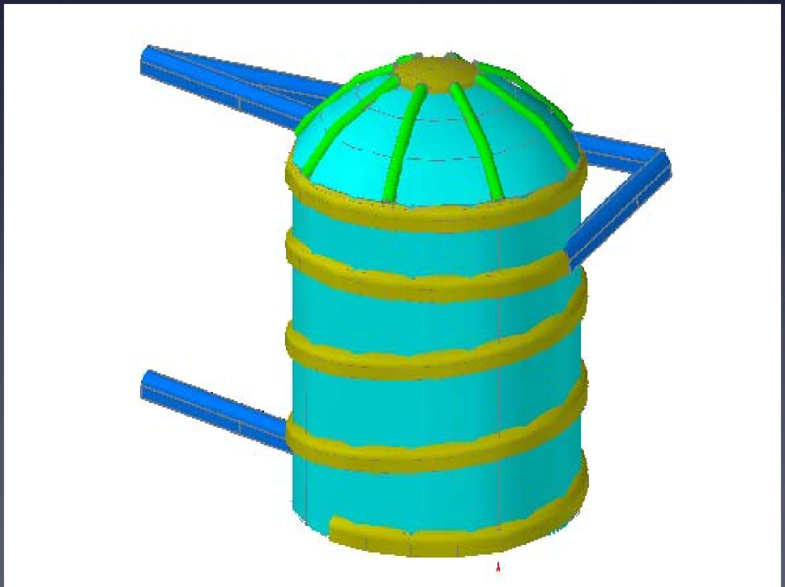
•Fréjus optimum for large caverns. Not too plastic not too hard.

•The construction of the large excavations for the 3 detector types of Laguna is feasible. The overall stability of the cavern is assured. A support is however required for wedge stability.

1. For Glacier it is possible to built a unique large tank. The division into 2 smaller tanks can reduce the total construction costs of the caverns.

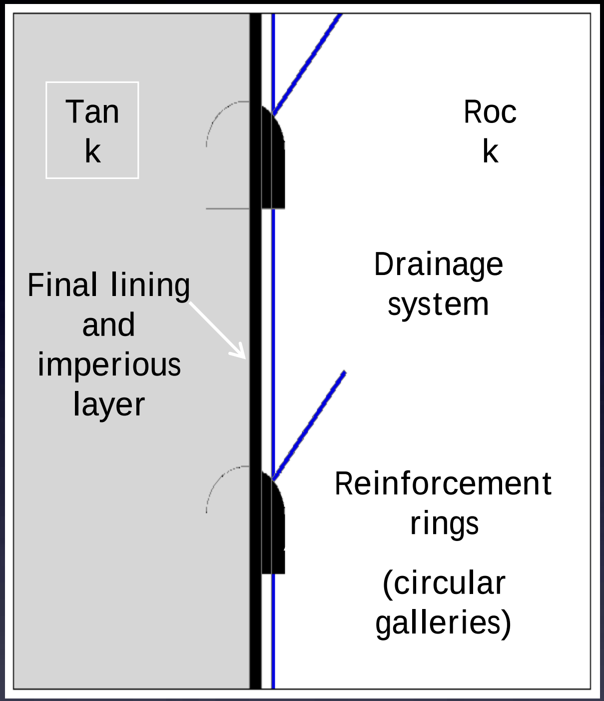
2. For Lena it is not necessary to have curved walls (at Fréjus)

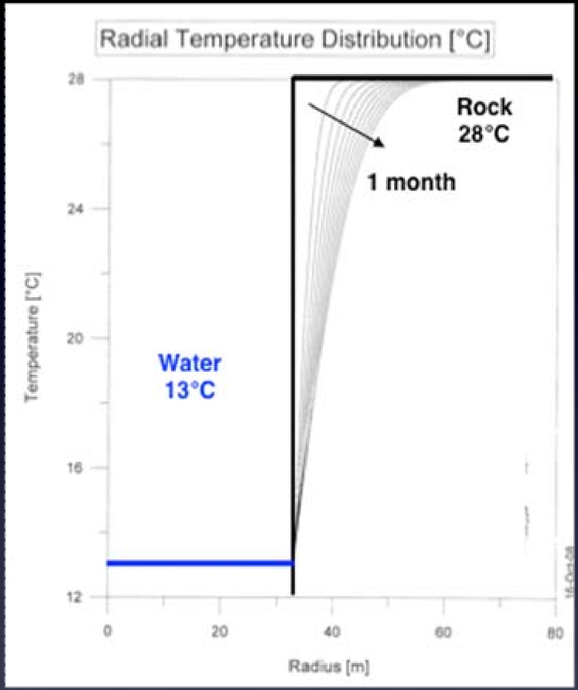
3. For Memphys the pre-excavation of the spiral gallery increases the stability of the overall cavern (the same for the dome)

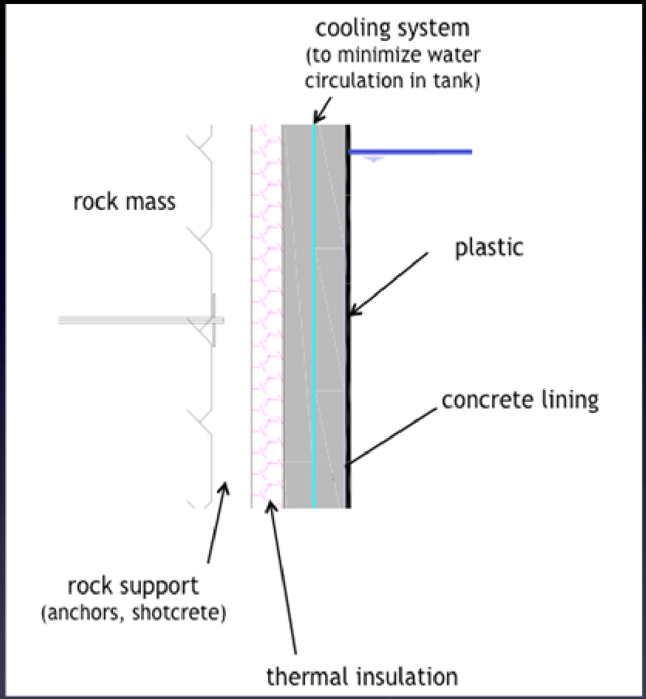


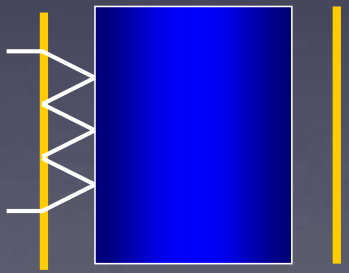
Site Study Ic : Fréjus

Conceptual tank design





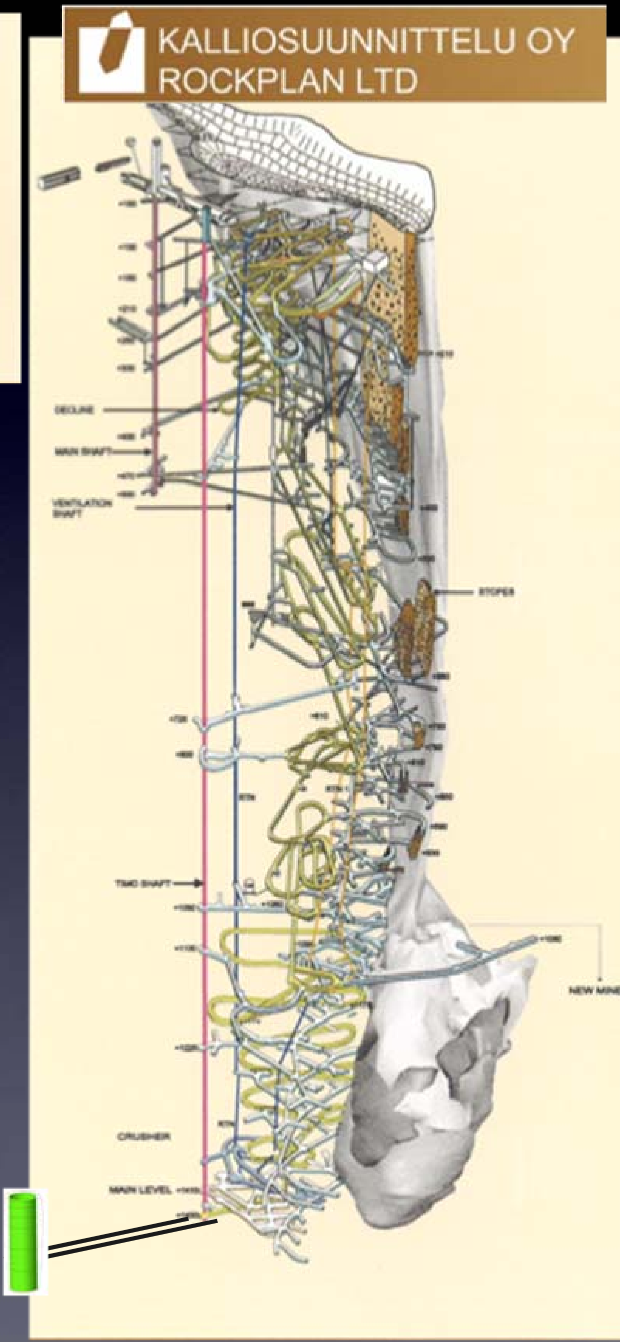


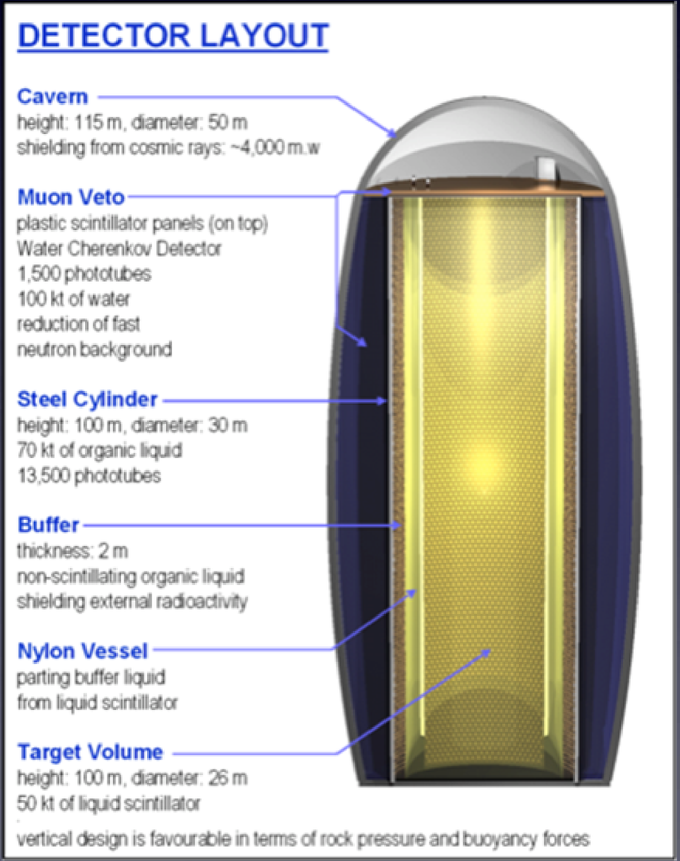


- LSM 300 kW
- LSM ext. 1.2 MW
- Safety tunnel 2 x 8.7 MW

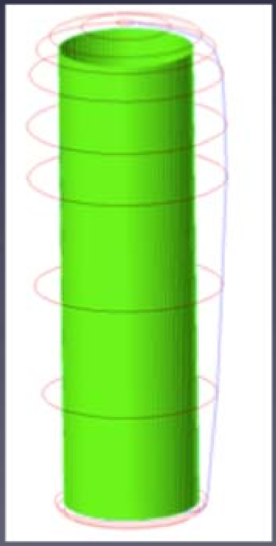
Site IIa Pyhäsalmi, Finland

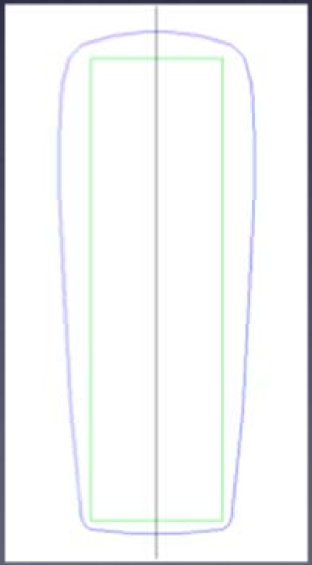
- Region of Pyhäjärvi, Finland
- Vertical tank for LENA at 4000 m.w.e
- Maximum height 114 m and width 44.5 m.



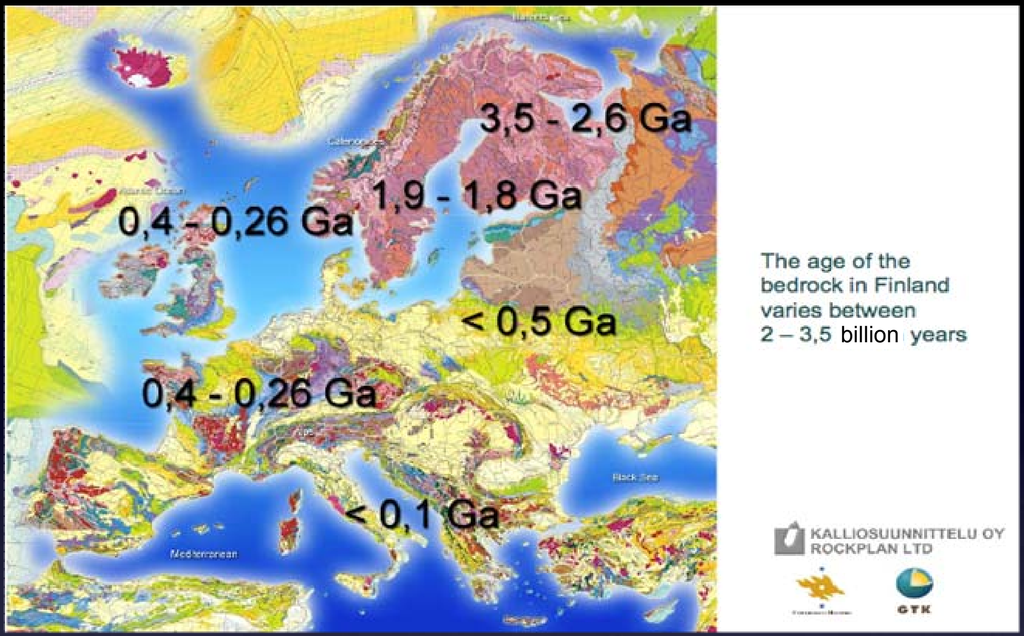


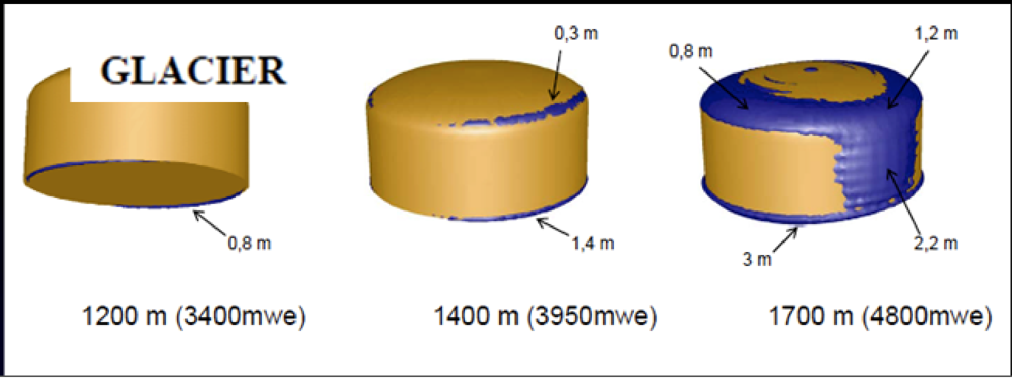
rock mechanical calculations performed:
vertical vs. horizontal
depths of -1400, -1700 & -2000
shapes cylindrical, elliptical, quasi rectangular

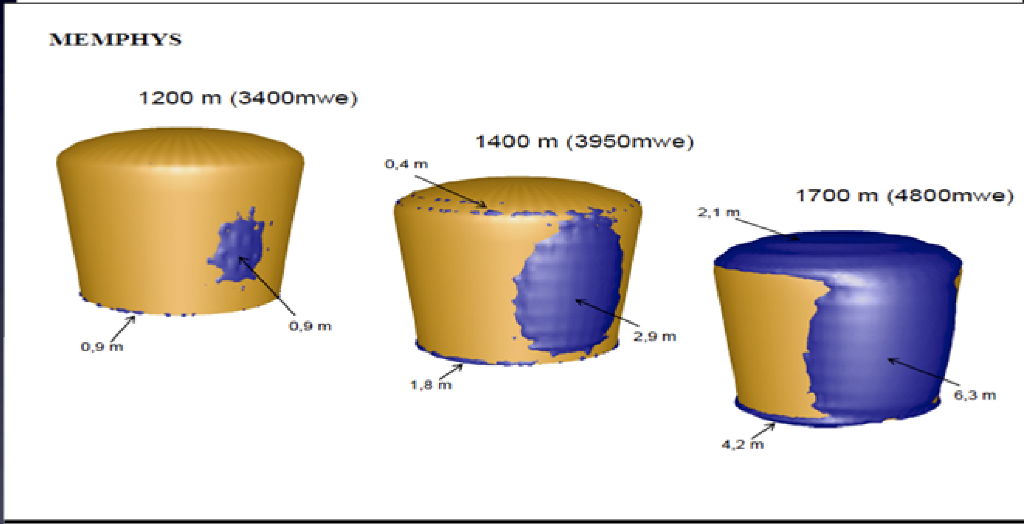




Site IIb Pyhäsalmi,Finland







- Based on current rock mechanical information and from the point of view of rock spalling GLACIER can be excavated 1200 m below ground surface level as such an to 1400 m by using elliptical shape. MEMPHYS can be excavated 1000 m below ground surface level as illustrated and to 1200 m if the shape is elliptical.

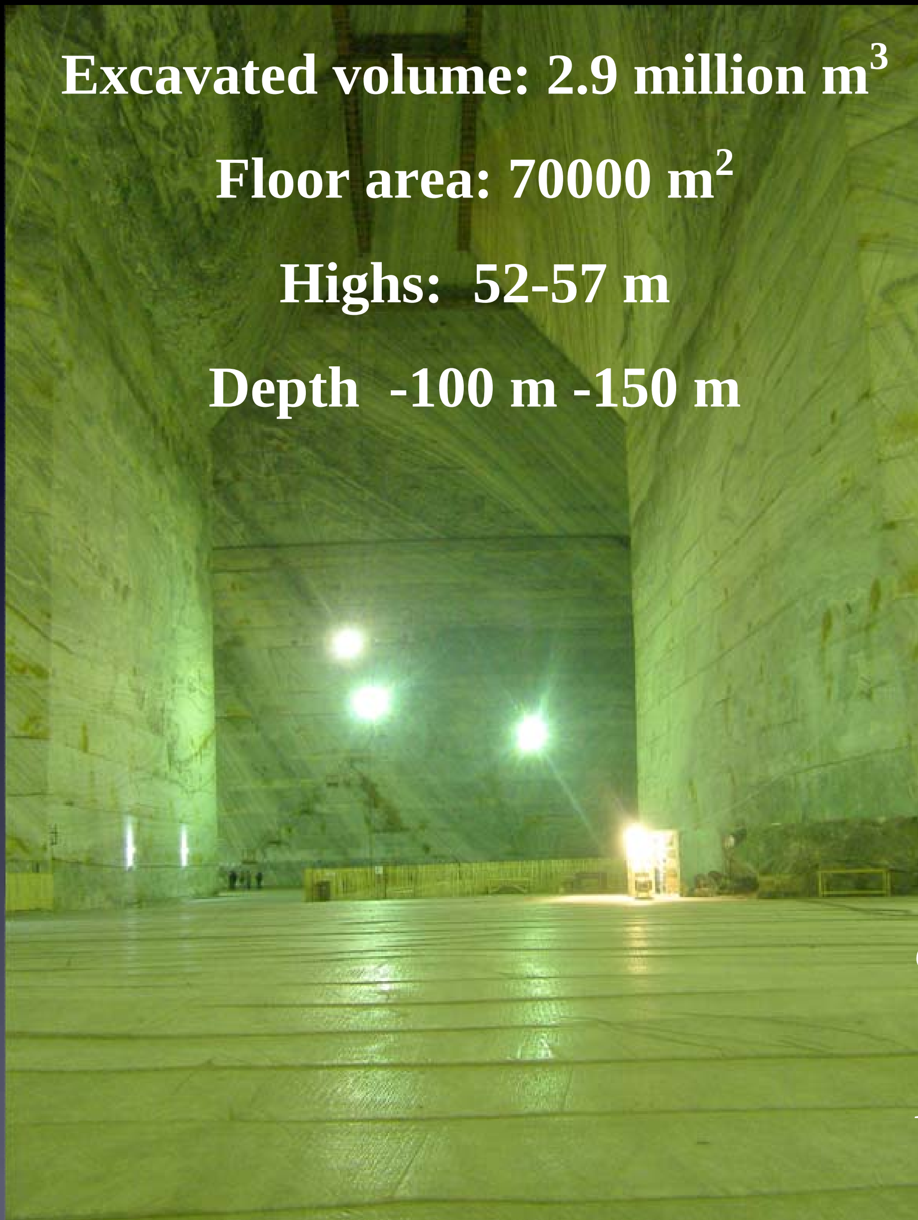
- The hard and very old bedrock (> 2 * 10^9 yr) of Finland provides one of the best locations in Europe to locate the LENA laboratory
- The depth of the laboratory is at -1400m (top) to -1500m (bottom level).
- The location of the cavern is about 0,5km west from the present mine.
- Construction of the access tunnels can be started directly at -1400m due to good infrastructure at that level.

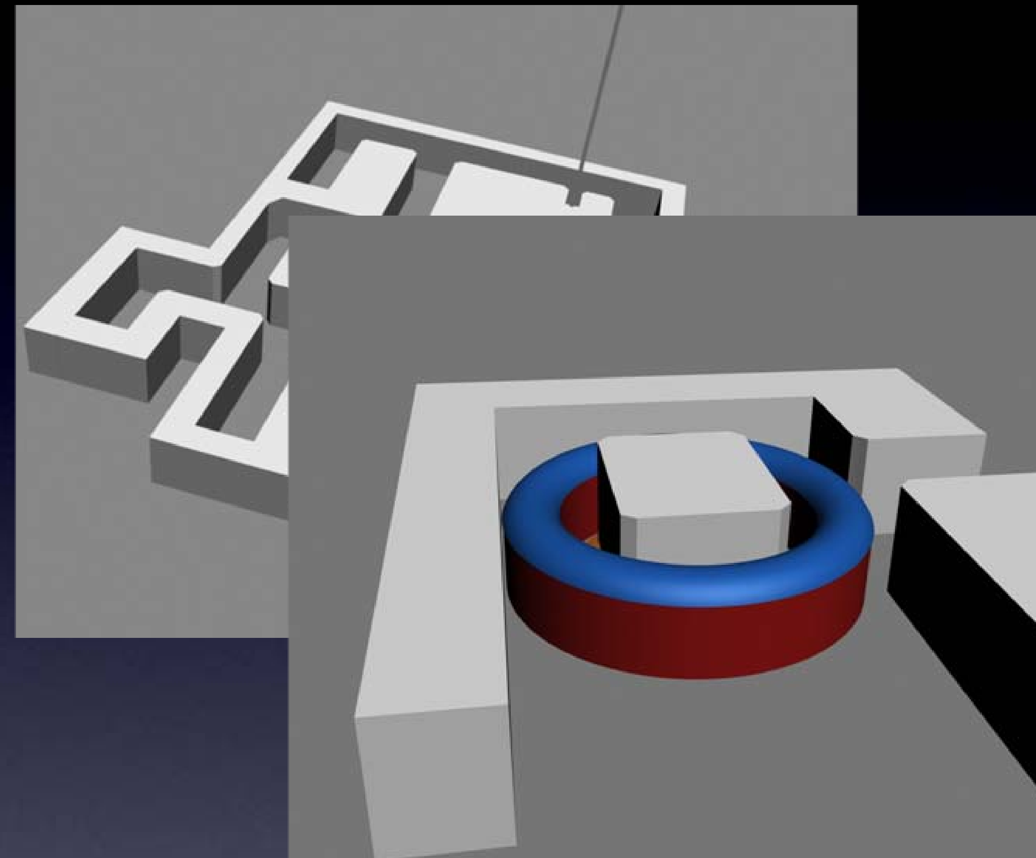
Sites III, **SUNLAB** at **Sieroszowice**

Polkowice-Sieroszowice is a **copper** and **salt** mine, situated at 70 km NW of Wroclaw, Legnica, **Poland**, owned by the Company KGHM Polska Miedz. (**70m thick** layer of **salt** at a **depth of 900-1000m**)

- **Large cavern excavation within Sieroszowice salt/anhydrite formation is possible and safe.**
- **Salt viscous behavior results in roof-floor convergence of about 3.0 m after 40 years.**
- **Hard anhydrite rocks keep the movement within very moderate, time-independent ranges.**
- **Possibility of plastic failure development within immediate roof/floor salt strata may be reduced by using lining and cable (composite) bolts.**
- **Further computational analyses will focus on better (more rafined) models for salt/anhydrite behavior as well as on the effect of high tectonic horizontal stress on large cavern stability.**
- ***Water cherenkov solutions disfavoured because of salt/anhydrite***

Sites IV, **Slanic-Prahova UNIREA Salt Mine**





GLACIER: *The request to have satisfied the ratio diameter to height at the value 3,5:1 is respected. But needs smaller tubes (2 modules?)*

LENA: *There is the possibility to dig up to the bottom of the salt lens increasing significantly the depth in m.e.w. BUT legal/formal problems, duration of the excavation, icreased costs*

MEMPHYS: *NOT ACCEPTED by the Saline management*

Sites V-VI, Boulby mine, Canfranc

Work in progress: tendering, subcontracting, discussions with author

- A working potash and salt mine (Cleveland - North East England)
- One of deepest in EU (850m-1.3km deep) (proposed 1.5-1.6 km)
- Unique environment for science (deep and low radioactivity)
- 940 mine staff + ~3000 local employment
- Durham - 75 mins; Sheffield - 105 mins; York - 60 mins

CLEVELAND POTASH

The way forward

(1) Palmer Laboratory

- Refurbish and extend into unused area
- Establish new small science experiments to meet short-term demand

requires small cash injection

(2) Salt Expansion (near-term option)

- Establish nearby new lab off south salt roadway
- Intallation for medium-scale experiments - ELENA, DM

requires feasibility study (part request from STFC)

(3) Polyhalite Laboratory (medium-term)

- Establish new medium scale lab in hard rock (30,000 m^3)
- Medium-scale, long-term experiments inc. geo, bio

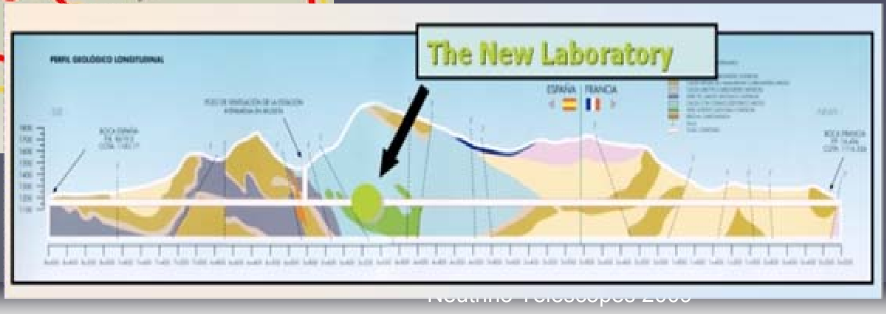
requires feasibility study (with regional assistance if possible)

(4) Laguna Laboratory (long-term)

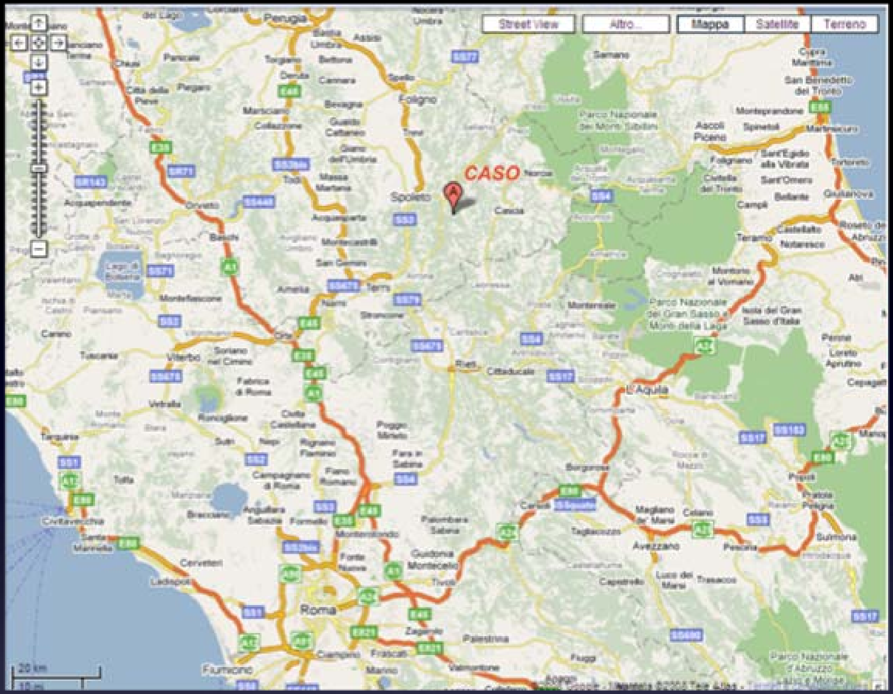
- Very large facility (>100,000 m^3)

requires feasibility study (part EU funded but not sufficient for full study)

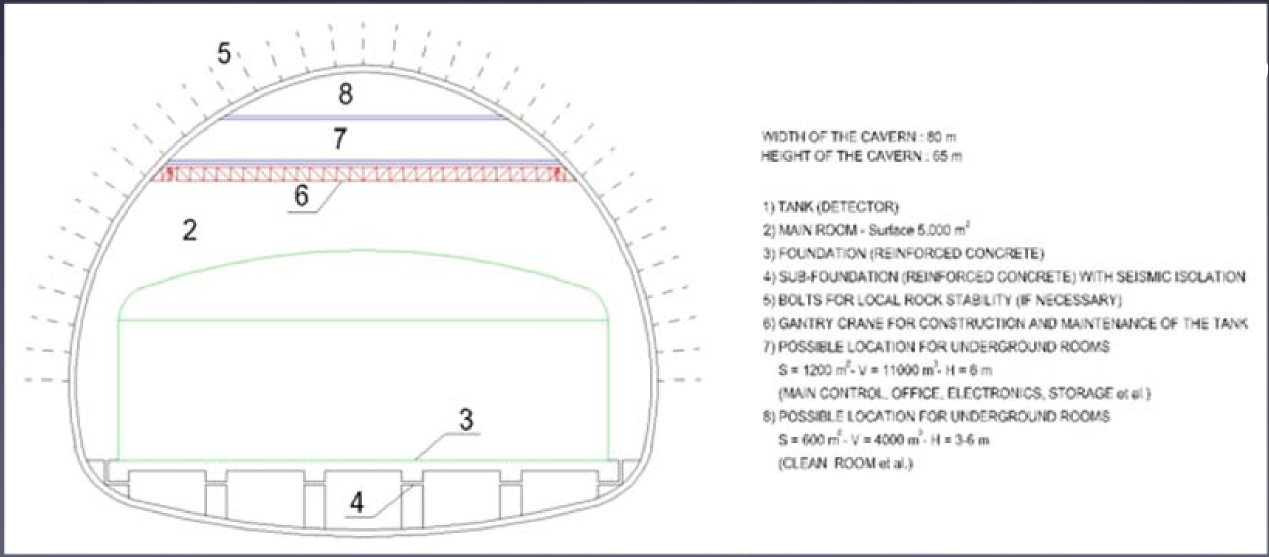
Canfranc: tendering with:
Different experienced companies,

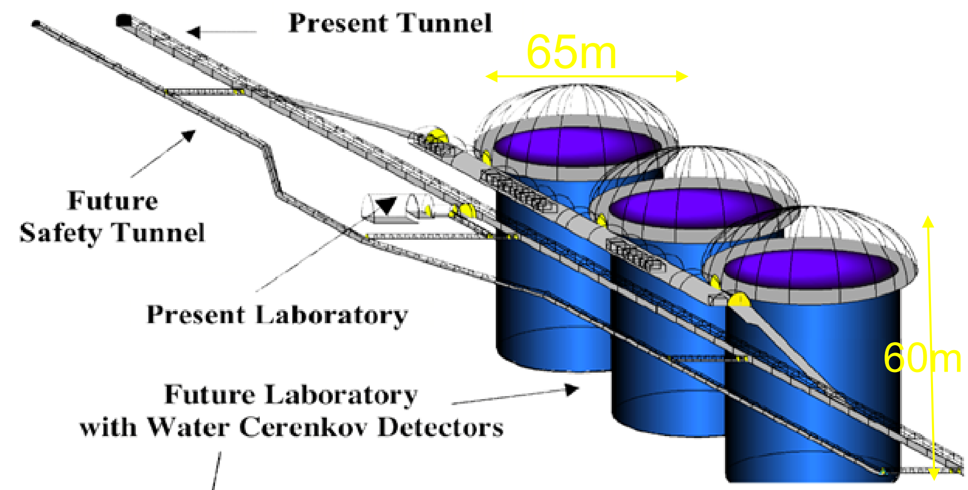


Sites VII, Caso : shallow site in Umbria, Italy



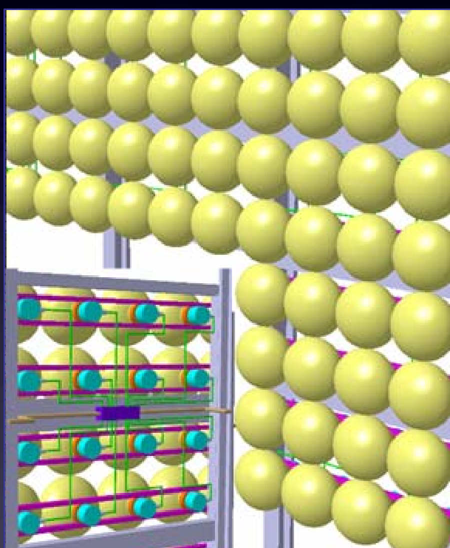
- Shallow site for GLACIER
- Small off-axis w.r.t CNGS
- Overburden ≈ 900 mwe
- Distance CERN ≈ 665 km
- Preliminary engineering study performed by AGT





WC R&D : MEMPHYS

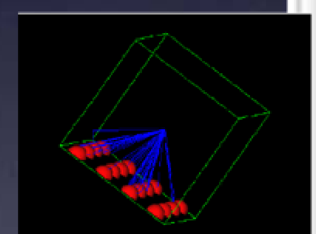
- Total fiducial mass: 440 kt :
- 3 Cylindrical modules 65x65 m
- Readout: 12” PMTs, 30% geom. cover
- (#PEs =40%cov. with 20” PMTs.

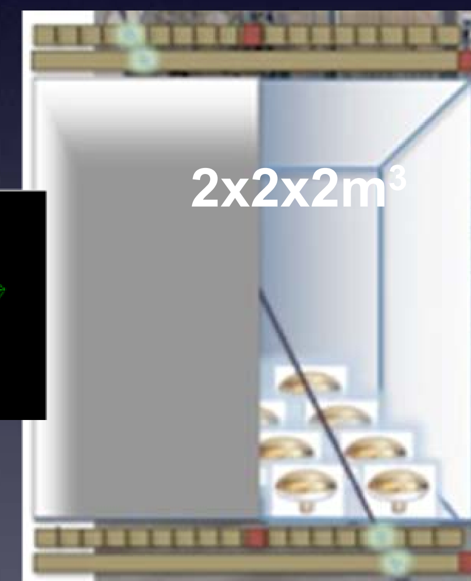


PMm2: Replace large PMTs (20”) by groups of 16 smaller ones (12”) with central ASIC : **arXiv: hep-ex/0607026**

- **Independent channels**
- **charge and time measurement**
- **water-tight, common High Voltage**
- **Only one wire out (DATA + VCC)**
- **Trigerless (OPERA)**

PHOTONIS repercussions?





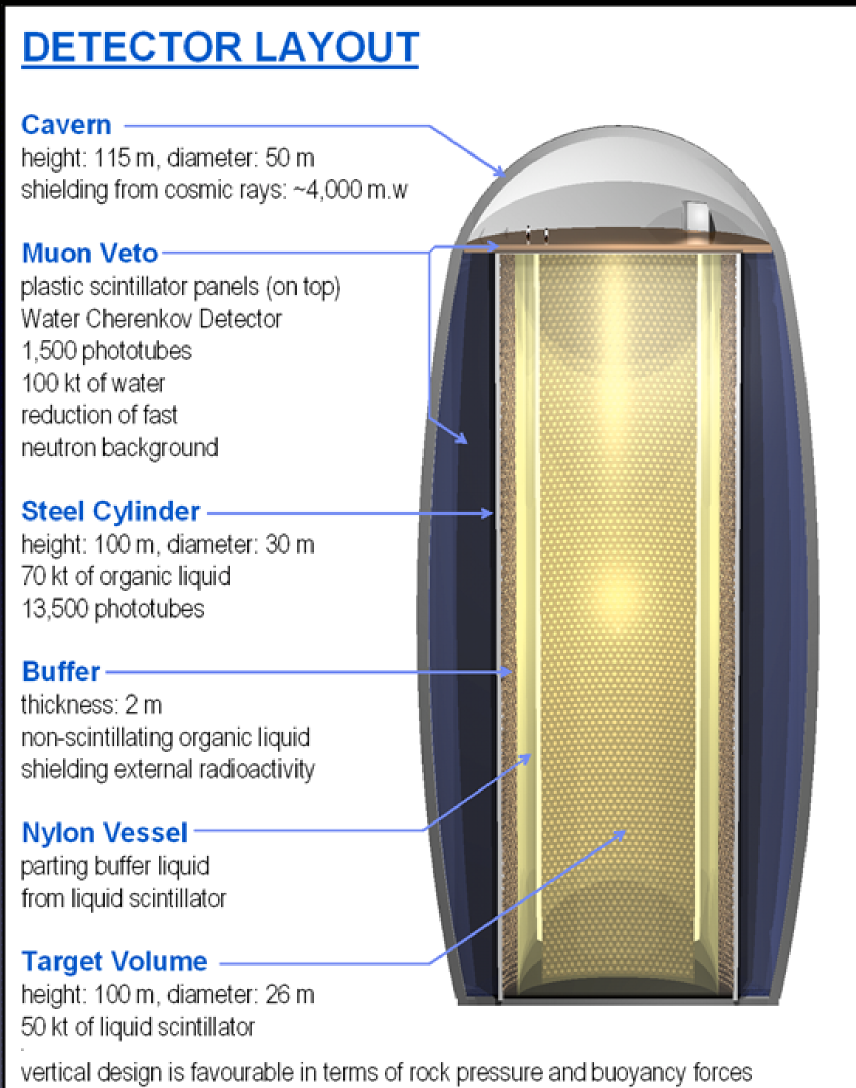
I. studies on 12" PMTs design
- parameter correlation
- potting
- pressure resistance

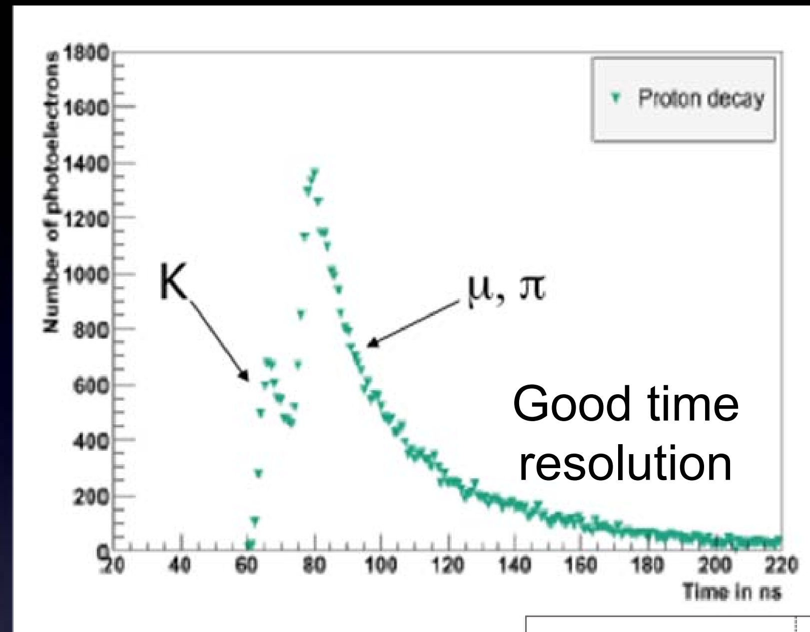
(collaboration with BNL since NNN07)

II. PARISROC readout chip
- complete front-end chip with 16 channels
- testboard now in layout, soon available

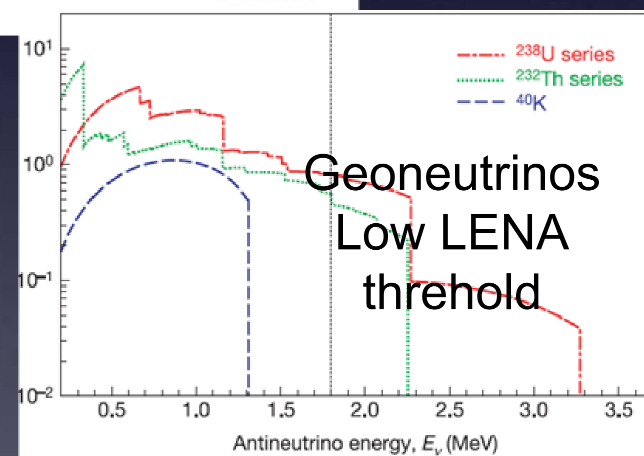
MEMPHYNO to test these ideas

Liquid scintillator R&D : LENA





Good time resolution



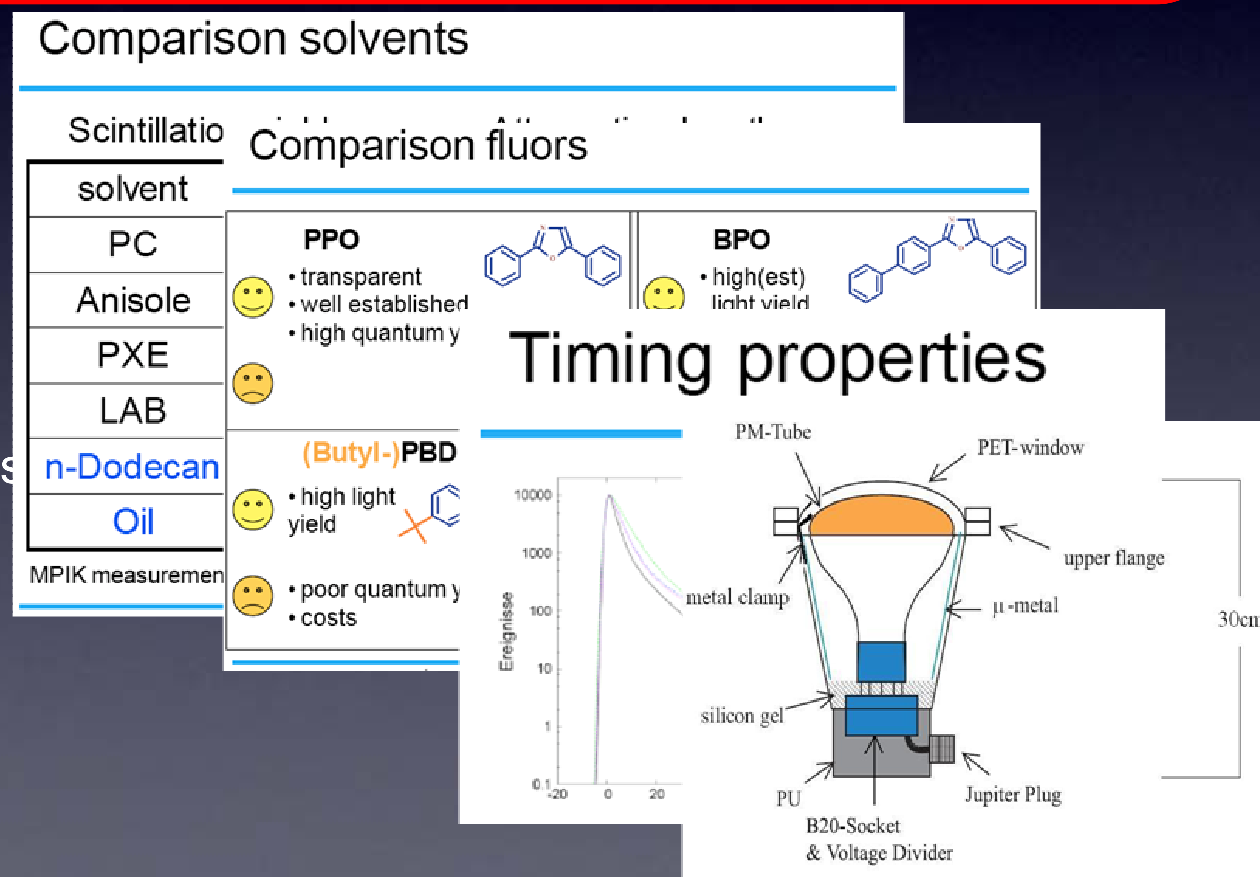
Geoneutrinos Low LENA threhold

Physics potential: proton decay, supernova, solar neutrinos, geoneutrinos, Gev neutrinos and beam?

Liquid scintillator R&D

Requirements for scintillator:

- High energy resolution
- Low energy detection threshold
- high purity (Borexino)
- fast signals (timing)
- moderate cost
- Improved stability of metal loaded scintillators



- ☐ detailed study of many candidates for individual components
- ☐ comparison of purification methods
- ☐ timing measurements
- ☐ detailed light-yield model for simulations

Other Liquid scintillator R&D

Metal loaded scintillators

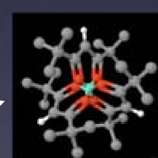
- **Solar neutrinos (LENS, SIREN)**
  - **Yb, In, Gd**
  - **challenge: high loading**

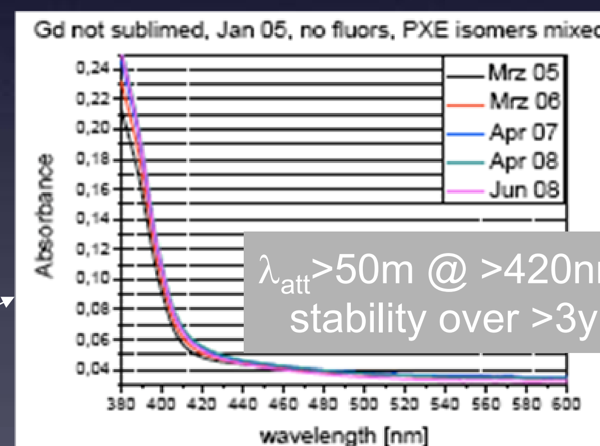
Indium-loaded scintillators at LLBF > 1 year
- MPIK: $In(acac)_3$ (F.X.Hartmann et al.)
- INR/LNGS: Carboxylic acid version

> 50 g/l Indium

- **Reactor (Double Chooz (LENA))**
  - **Gadolinium**
  - **Challenge: stability**

carboxylates (LNGS)
beta-dikitonates (MPIK)





100 kg produced
(for both DC detectors)

λ_{att}>50m @ >420nm
stability over >3y

- **bb decay (SNO+)**
  - **Neodymium**
  - **Challenge: transparency, purity**

tests done on BDK and carvboxylates
@ MPIK / LNGS

R&D towards very large LAr detectors

Starting from ICARUS, several proposals aiming at increasing volume by another ×100÷200 compared to T600

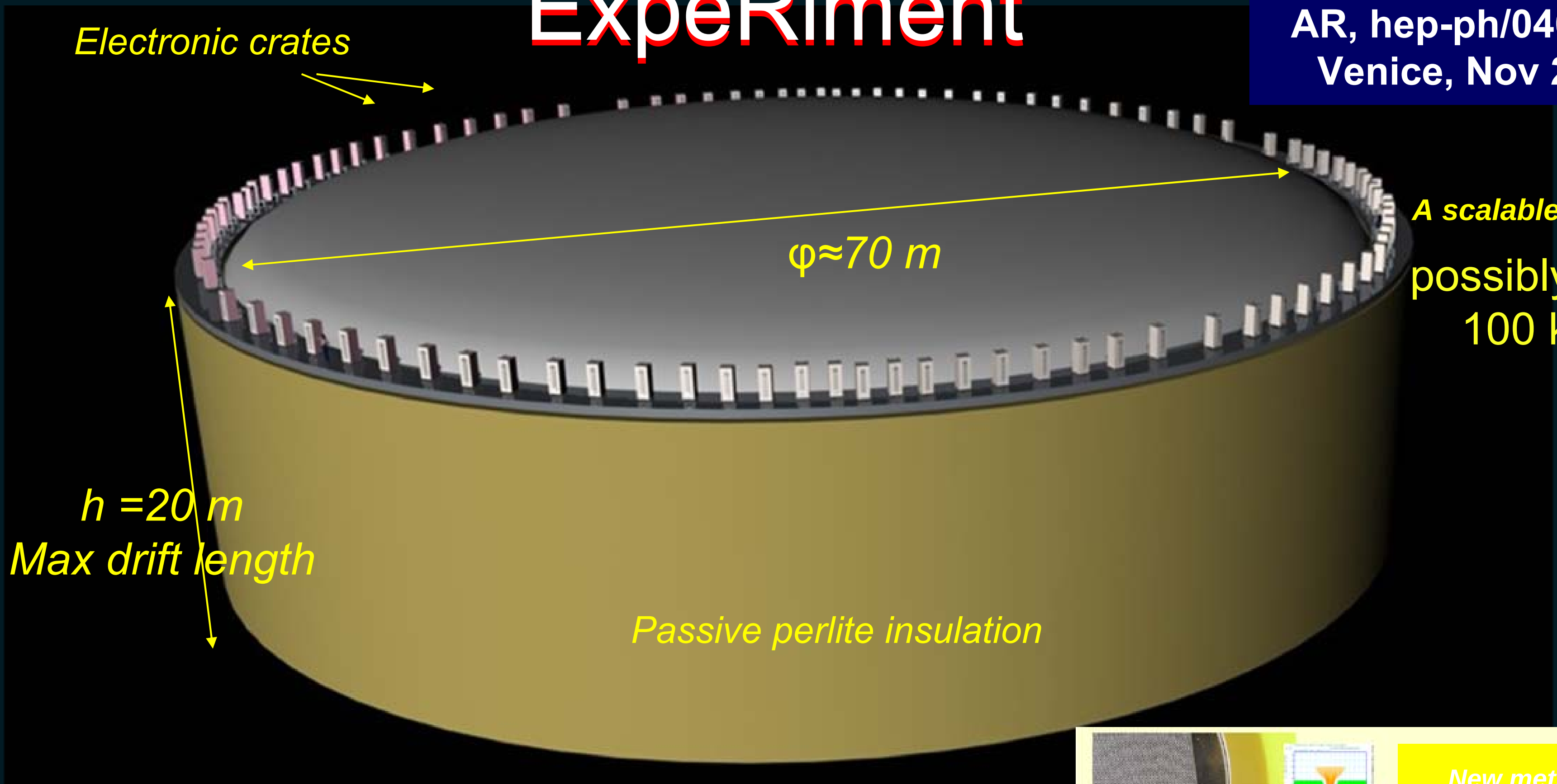
- ✦ LANNDD 2001
- ✦ GLACIER 2003
- ✦ FLARE 2004
- ✦ MODULAR 2007 (treated later)

...with different approaches:

- a **modular** or a **scalable** detector for a total LAr mass of 50-100 kton
- **evacuable** or **non-evacuable** dewar
- detect ionization charge in LAr **without amplification** or with **amplification**

GLACIER: Giant Liquid Ar Charge Imaging ExpeRiment

AR, hep-ph/0402110
Venice, Nov 2003



A scalable design

possibly up to 100 kton

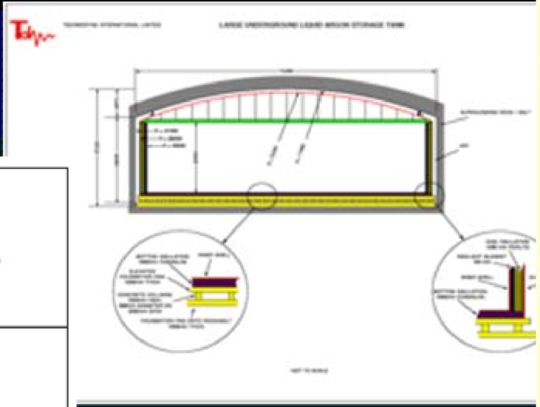
Single module cryo-tanker based on industrial LNG technology

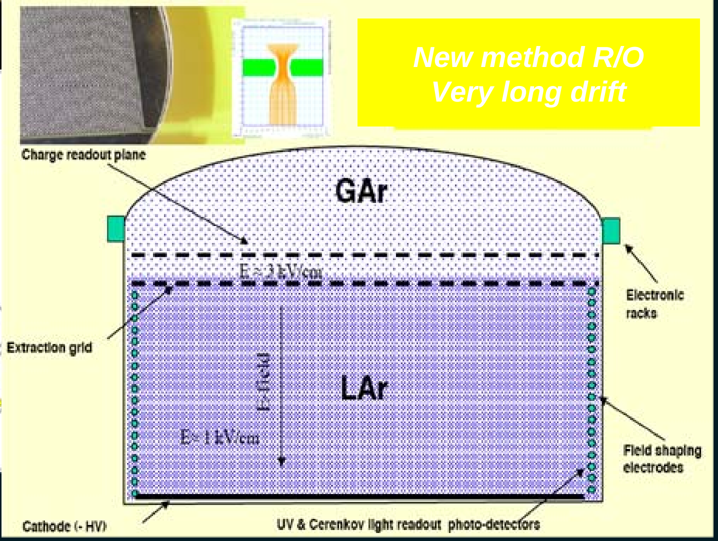
Project: Large Underground Argon Storage Tank

Issued By: JMH

Document Title: Study report

A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004





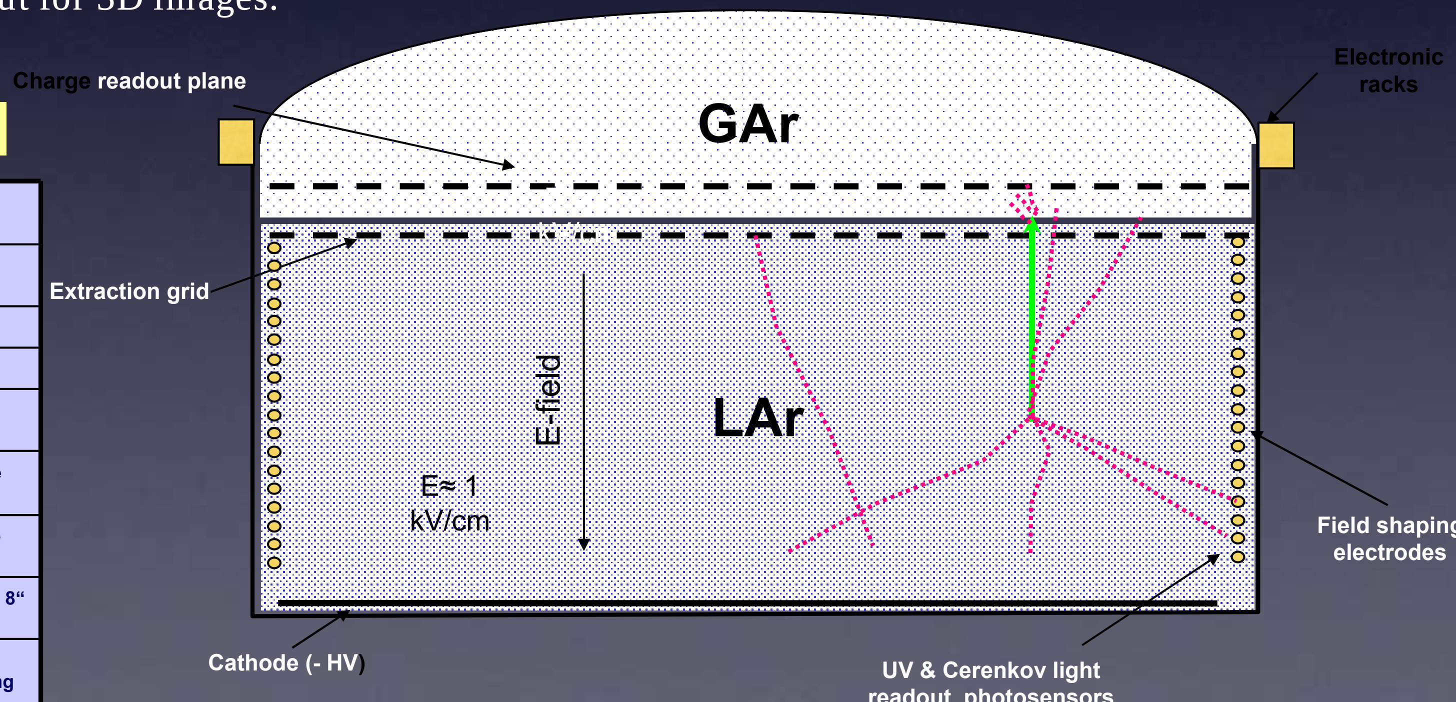
GLACIER novel concepts

- ✓ Safe LNG tank, as developed for many years by petrochemical industry
  - Certified LNG tank with standard aspect ratio
  - Smaller than largest existing tanks for methane, but underground
  - Vertical electron drift for full active volume
- ✓ A very large area LAr LEM-TPC
  - to allow for very long drift paths and cheaper electronics
  - to allow for low detection threshold (≈50 keV)
  - to avoid use of readout wires
  - Maybe pixelized readout for 3D images.

- ✓ Immersed DUV sensitive light readout on surface of tank for T_0
- ✓ Possibly immersed visible light readout for Cerenkov imaging
- ✓ Possibly immersed (high Tc) superconducting solenoid to obtain magnetized detector

Scalable up to 100 kton LAr

Dewar	⌀ ≈ 70 m, height ≈ 20 m, perlite insulated, heat input ≈ 5 W/m²
Argon storage	Boiling Argon, low pressure (<100 mbar overpressure)
Argon total volume	73000 m³, ratio area/volume ≈ 15%
Argon total mass	102000 tons
Hydrostatic pressure at bottom	3 atmospheres
Inner detector dimensions	Disc φ ≈70 m located in gas phase above liquid phase
Charge readout electronics	100000 channels, 100 racks on top of the dewar
Scintillation light readout	Yes (also for triggering), 1000 immersed 8" PMTs with WLS
Visible light readout	Yes (Cerenkov light), 27000 immersed 8" PMTs of 20% coverage, single γ counting capability



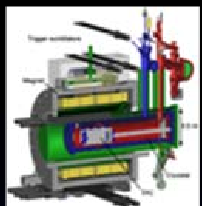
Glacier R&D

Since 2004, several critical issues are subject to intense R&D efforts

- LAr tank → design with Technodyne in LAGUNA DS
- Readout system → novel techniques, other than wires, with charge multiplications (double phase) developed in the context of the ArDM effort. Proof of principle is achieved.
- HV system → small scale tests successful
- Readout electronics → new modern solution developed in collaboration with industry, in addition R&D on warm/cold solutions, ASIC preamplifier working in cold, ethernet based readout chain + network time distribution
- LAr purification systems → in Collab. with industry
- Safety → dedicated Workpackage in LAGUNA DS
- Test beams → under consideration
- Detector prototyping

Steps towards GLACIER

- Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?



B-field test

➠

LEM test

proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m^2 scale

➠

LEM readout on 1x1 m^2 scale
UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)

ArDM ton-scale

➠

direct proof of long drift path up to 5 m

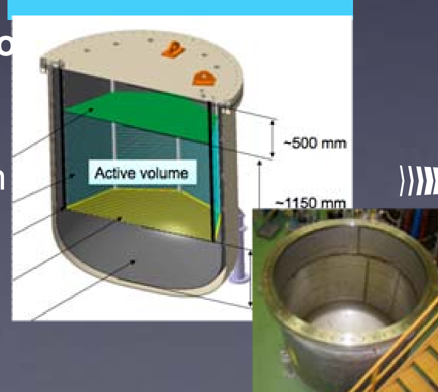
ArgonTube: long drift, ton-scale

We are here

➠

Application of LAr LEM TPC to neutrino physics: particle reconstruction & identification (e.g. 1 GeV e/μ/π), optimization of readout and electronics, possibility of neutrino beam exposure

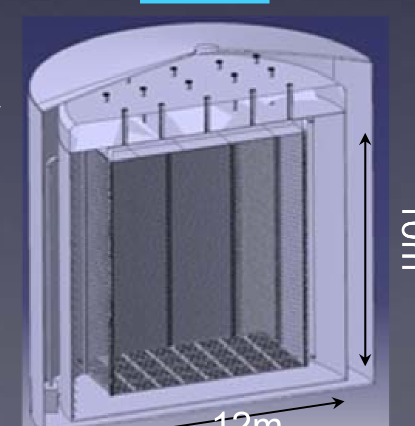
Test beam
1 to 10 ton-scale



➠

full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, …

1 kton



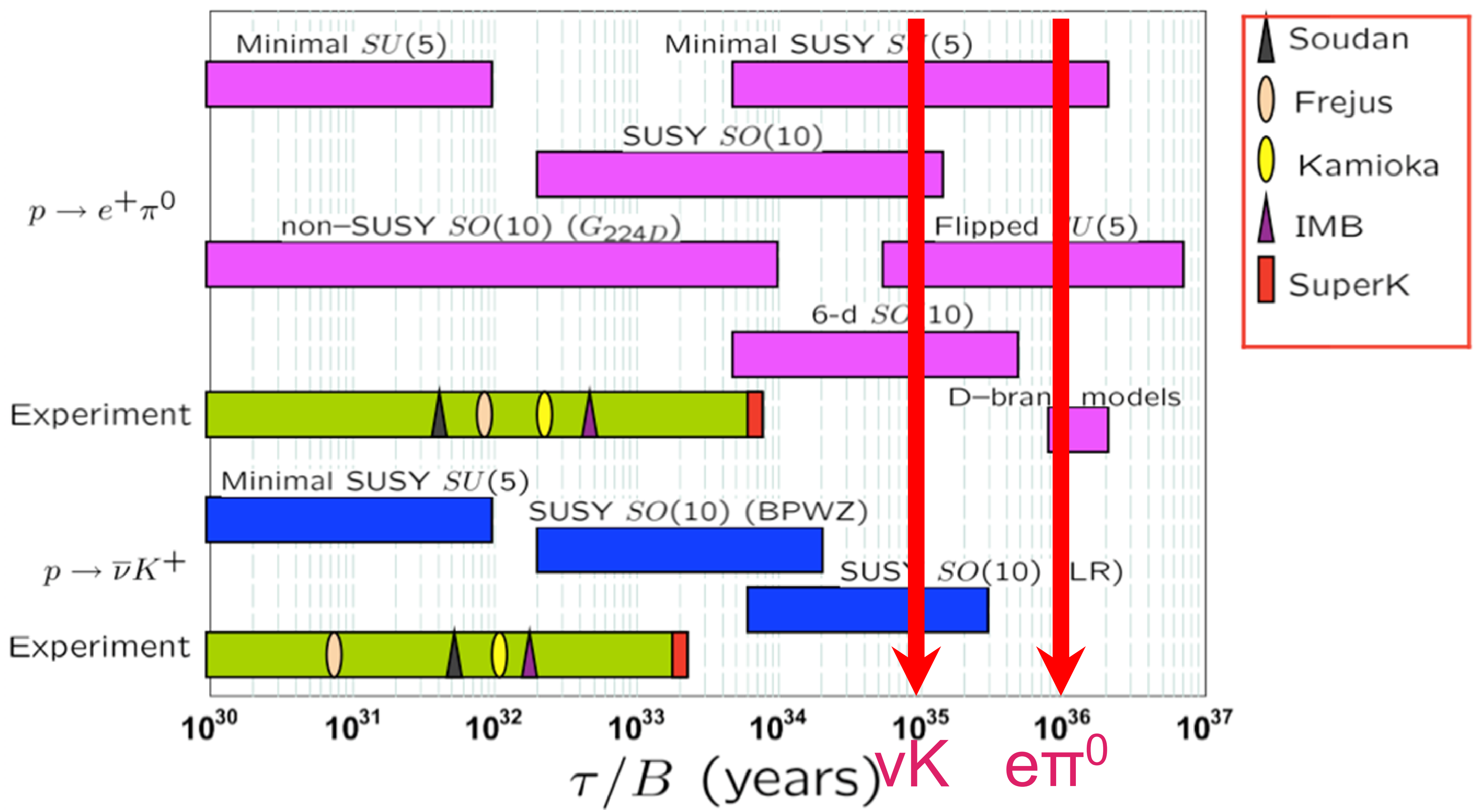
Physics scope

JCAP 0711:011,2007
(ArXiv 0705.0116)

	Water Cerenkov	Liquid Argon TPC	Liquid Scintillator
Total mass	500 kton	100 kton	50 kton
$p \rightarrow e\ \pi^0$ in 10 years	$1.2\text{x}10^{35}$ years ε = 17%, ≈ 1 BG event	$0.5\text{x}10^{35}$ years ε = 45%, <1 BG event	~10^{32} years in 1year ε = 12%, BG under study
$p \rightarrow \nu\ K$ in 10 years	$0.15\text{x}10^{35}$ years ε = 8.6%, ≈ 30 BG events	$1.1\text{x}10^{35}$ years ε = 97%, <1 BG event	$0.4\text{x}10^{35}$ years ε = 65%, <1 BG event
SN cool off @ 10 kpc	194000 (mostly $\nu_e p \rightarrow e^+ n$)	38500 (all flavors) (64000 if NH-L mixing)	20000 (all flavors)
SN in Andromeda	40 events	7 (12 if NH-L mixing)	4 events
SN burst @ 10 kpc	≈250 ν-e elastic scattering	380 ν_e CC (flavor sensitive)	≈30 events
SN relic	250(2500 when Gd-loaded)	50	20-40
Atmospheric neutrinos	56000 events/year	≈11000 events/year	5600/year
Solar neutrinos	91250000/year	324000 events/year	[illegible]
Geoneutrinos	0	0	≈3000 events/year

Proton lifetime expectations (GUT)

K.S. Babu, NNN08



Complementarity among techniques

Normalized to d=10kpc (Galactic center)

Detection in H2O

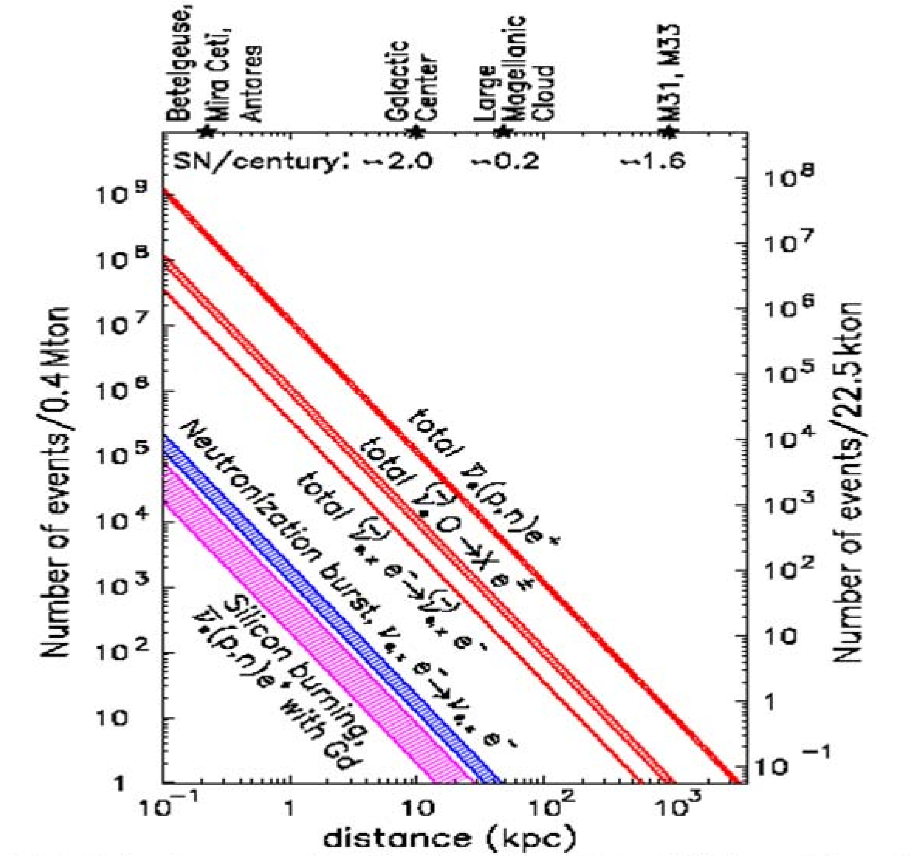
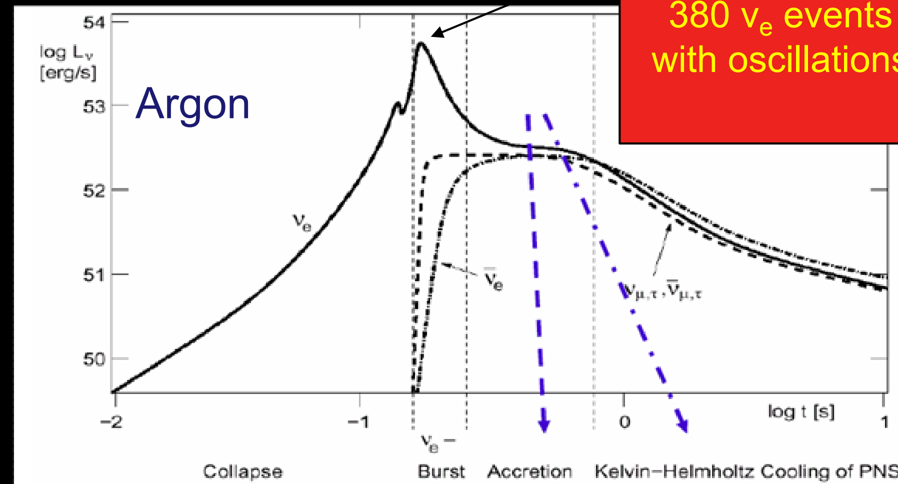


FIG. 6: Number of events expected in 0.4 Mton detector (left y-axis) or in a SK-like detector (right y-axis)

380 ν_e events with oscillations



$\nu_e + {}^{40}Ar \to {}^{40}K^* + e^-$ Q=1.5 MeV

$\bar{\nu}_e + {}^{40}Ar \to {}^{40}Cl^* + e^+$ Q=7.48 MeV

$\overset{(-)}{\nu}_x + {}^{40}Ar \to {}^{40}Ar^* + \overset{(-)}{\nu}_x$ Q=1.46 MeV

← Detection on Ar

- $\bar{\nu}_e + p \to n + e^+$ (Q=1.8 MeV)
  $n + p \to d + \gamma$; $E_\gamma = 2.2$ MeV ~8700 events
- $\bar{\nu}_e + {}^{12}C \to {}^{12}B + e^- +$ (Q=17.3 MeV)
  ${}^{12}B \to {}^{12}C + e^+ + \bar{\nu}_e$; $\tau_{1/2} = 20.20$ ms ~494 events
- $\nu_e + {}^{12}C \to e^- + {}^{12}N$ (Q=13.4 MeV)
  ${}^{12}N \to {}^{12}C + e^+ + \nu_e$; $\tau_{1/2} = 11.00$ ms ~85 events
- $\nu_x + {}^{12}C \to {}^{12}C^* + \nu_x$
  with ${}^{12}C^* \to {}^{12}C + \gamma$; $E_\gamma = 15.11$ MeV ~2925 events
- $\nu_x + e^- \to \nu_x + e^-$ (elastic scattering) ~610 events
- $\nu_x + p \to \nu_x + p$ (elastic scattering)
  Detector energy threshold: $E_{th} = 0.2$ MeV ~7370 events

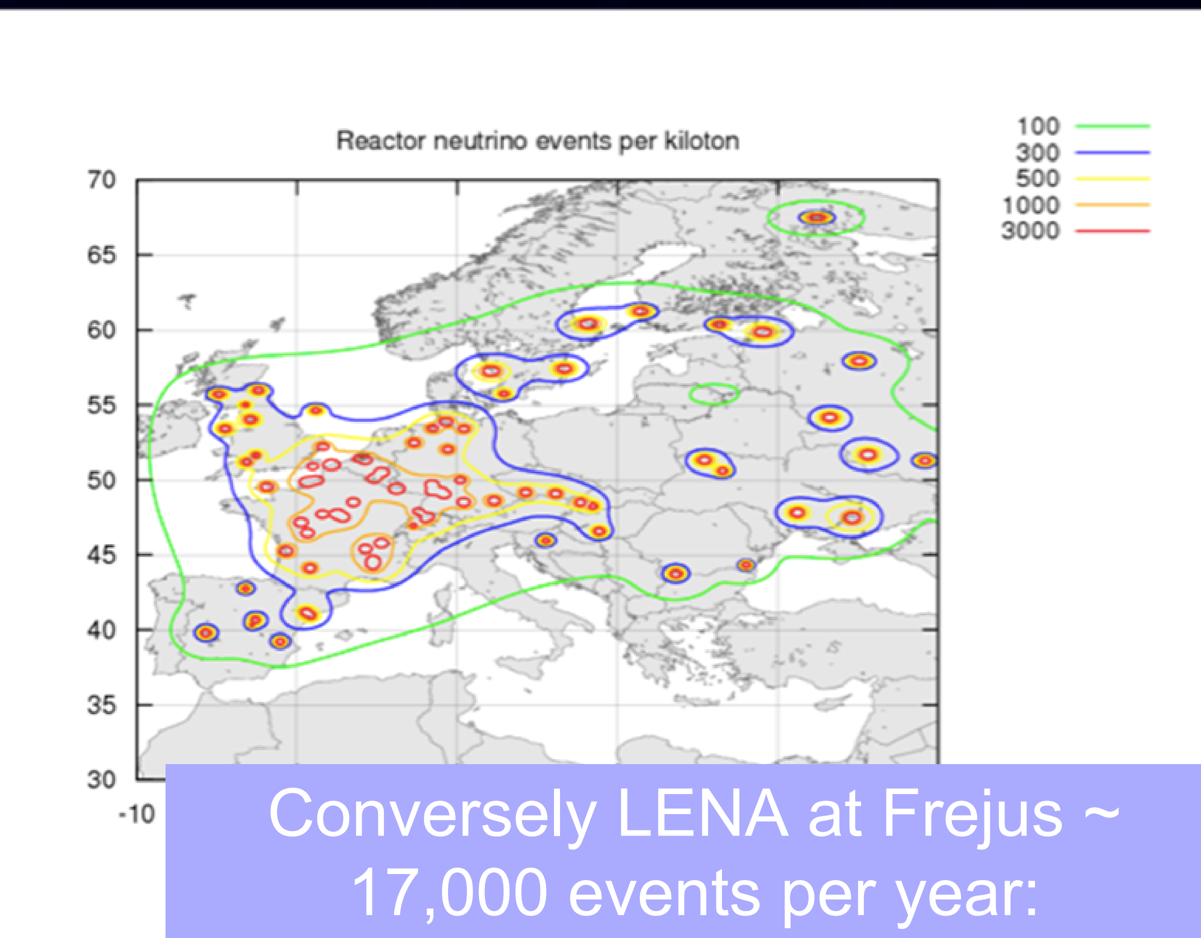
Hierarchy	$\sin^2\theta_{13}$	ν_e neutronization peak	Shock wave	Earth effect
Normal	⊠ 10^{-3}	absent	ν_e	$\bar{\nu}_e$ ν_e (delayed)
Inverted	⊠ 10^{-3}	present	$\bar{\nu}_e$	ν_e $\bar{\nu}_e$ (delayed)
Any	$\lesssim 10^{-5}$	present	—	ν_e, $\bar{\nu}_e$

Exploiting these complementary signatures one could extract useful information on the neutrino mass hierarchy and on θ_{13}

←Detection in scintillator

Geoneutrinos: distance from reactors

- Mostly relevant for MeV energy events (LENA)
- Marine reactors neglected



Conversely LENA at Frejus ~ 17,000 events per year: $\Delta m^2_{12} \sim 1\%$, $\Theta_{12} \sim 10\%$

	$\times 10^8$ /m^2/s
Pyhäsalmi	40
LNGS	54
Fréjus	175
Canfranc	196
Boulby	190
Kamioka	408
Sudbury	100
Soudan	33
Pylos	12

Neutrino beam related physics: 3-flavor neutrino oscillations

$$\begin{array}{cccc} & \Delta m^2_{31} & & \Delta m^2_{21} \\ U = & \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} & \begin{pmatrix} c_{13} & 0 & e^{-i\delta} s_{13} \\ 0 & 1 & 0 \\ -e^{i\delta} s_{13} & 0 & c_{13} \end{pmatrix} & \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \\ & \text{atmospheric+LBL} & \text{Chooz} & \text{solar+KamLAND} \end{array}$$

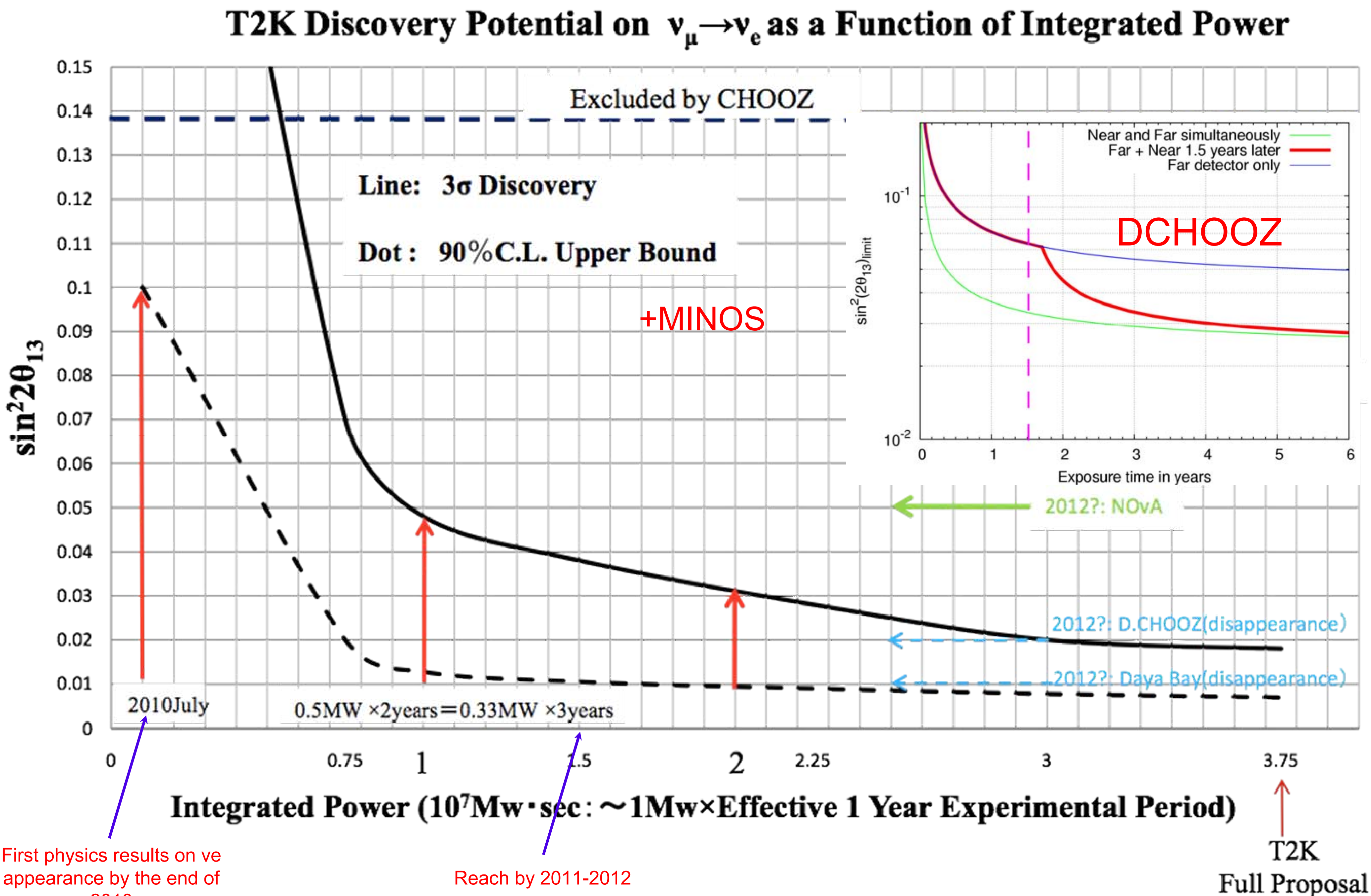
Δm^2_{21}	$(7.65^{+0.23}_{-0.20})\ 10^{-5}\ \mathrm{eV}^2$
$\sin^2\theta_{12}$	$0.304^{+0.022}_{-0.016}$
$\lvert\Delta m^2_{31}\rvert$	$(2.40^{+0.12}_{-0.11})\ 10^{-3}\ \mathrm{eV}^2$
$\sin^2\theta_{23}$	$0.50^{+0.07}_{-0.06}$
$\sin^2\theta_{13} < 0.056$ @ 3σ	

Schwetz, Tortola, Valle, arXiv:0808.2016

Remaining task:

1. Discover the unknown angles: θ_{13} & δ
2. Determine the sign of: Δm^2_{31}

Current program: DCHOOZ/T2K/DayaBay



First physics results on ve appearance by the end of 2010

Reach by 2011-2012

An important milestone...

By 2013-2014 (if we are lucky earlier) we will know whether $\sin^2 2\theta_{13} > 0.01$

Then,

a)the measurement of the leptonic δ_{CP} phase with upgraded conventional neutrino beams and far detectors is possible

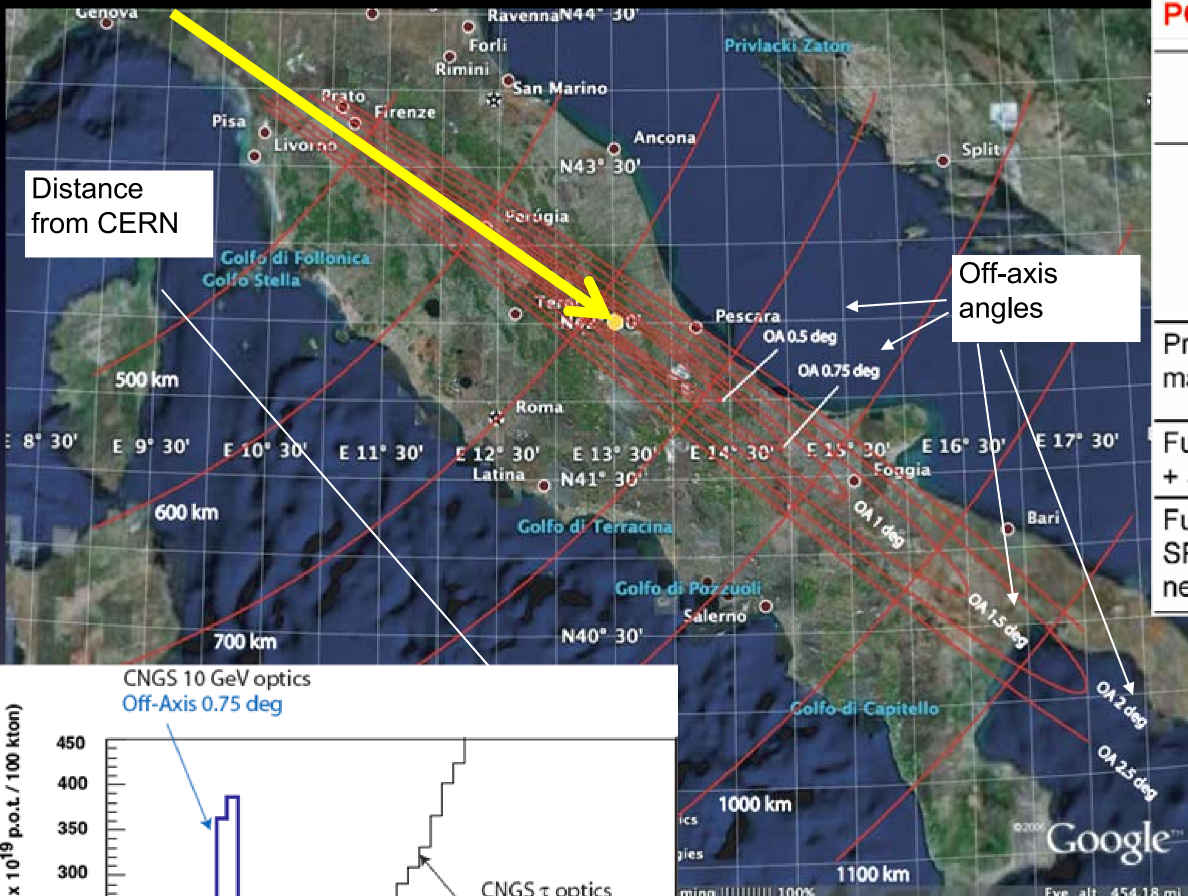
b)the mass hierarchy also can be tackled by a combination of beam/atmospheric or different distances

A strategy needs to be defined:

CERN European Strategy plan and EURONu

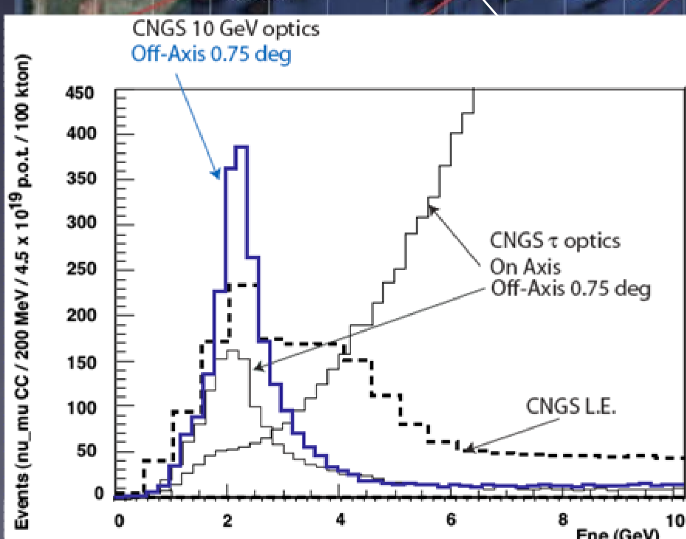
Strategies I: Upgrade CNGS ?

- The physics potential of an intensity upgraded CNGS beam coupled to a new off-axis detector has been first addressed in JHEP 0611:032, 2006

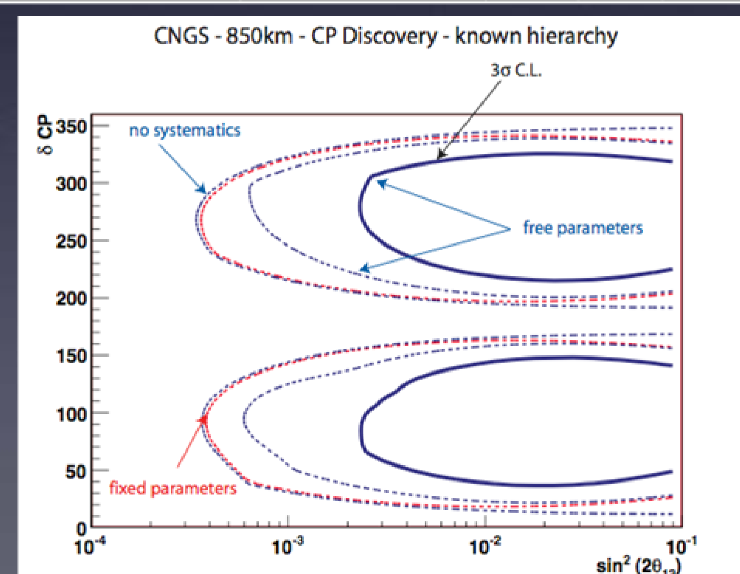


POT/year [10^{19}] for 200 days of operation with 80% machine efficiency

	SPS cycle length	6 s		4.8 s	
	Injection Energy	14 GeV		26 GeV	
	Beam sharing / Max SPS intensity @ 400GeV [$\times 10^{13}$]	0.45	0.85	0.45	0.85
Present injectors + machines' improvement	4.8	5	9.4		
	5.7	5.9	11.1		
Future injectors (>2016) + SPS RF upgrade	7			9	17.1
Future injectors + new SPS RF system + CNGS new equipment design	10			12.9	24.5



100 kton
7 yrs ν + 7 yrs $\bar{\nu}$
2.4 x 10^{20} pots/yr

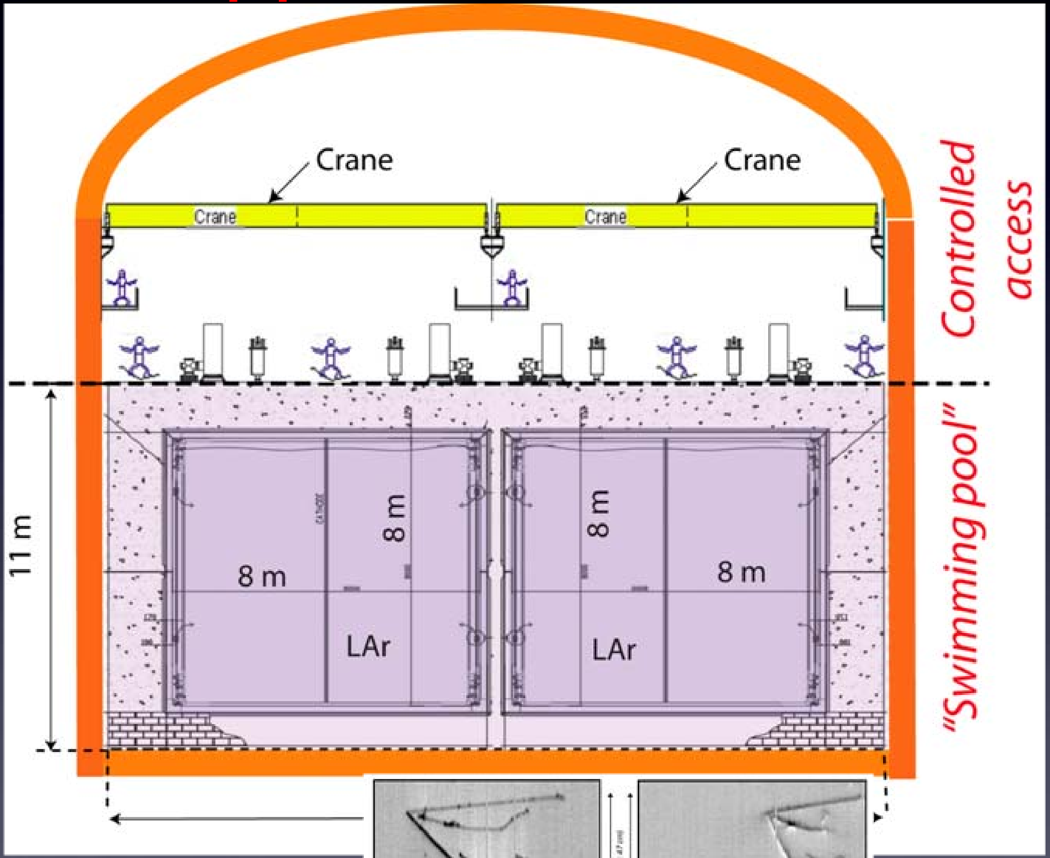


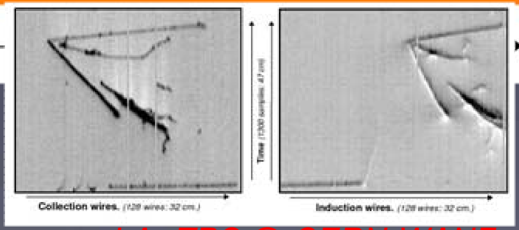
Liquid Argon: MODULAr

From ICARUS-T600 to a multi-kton LAr-TPC with a modular approach

- MODULAr will be initially composed by four identical module located in the new shallow-depth cavern
- Each module is a scaled-up version of the T600 (x 2.66^3):
  - 8 x 8 m^2 cross section and about 60 m length
  - LAr active mass: 5370 ton
  - 4 m electron drift
  - 3-D imaging similar to T600 but 6 mm pitch

    (three wire planes, ~50000 channels)



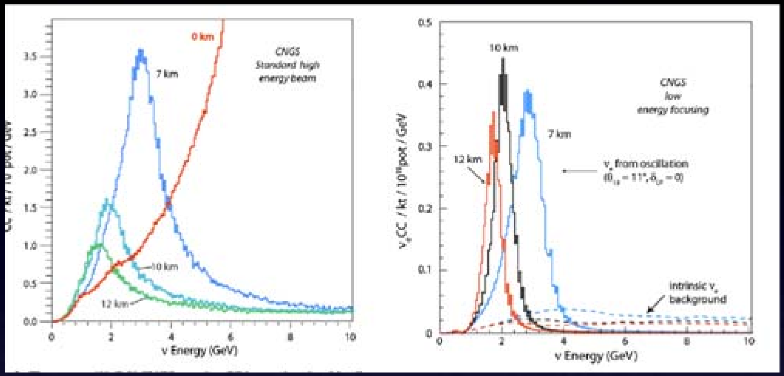


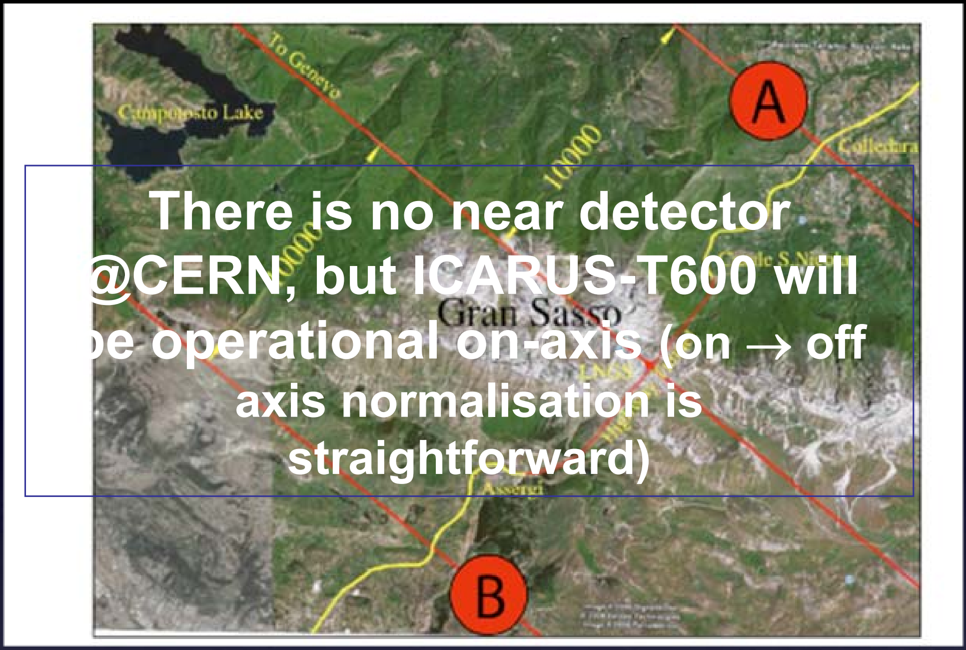
LAr-TPC @ CERN-WANF
Phys. Rev. D 74, 112001 (2006)

Proposal: Astroparticle Physics 29 (2008) 174–187

MODULAr at LNGS off-axis

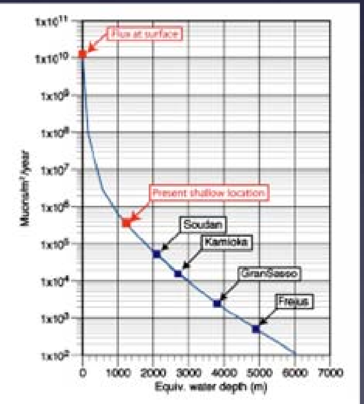
732km CERN-LNGS, 10km off-axis





There is no near detector @CERN, but ICARUS-T600 will be operational on-axis (on → off axis normalisation is straightforward)

New idea surface detector at 5 km
Same sensitivity (proposal)

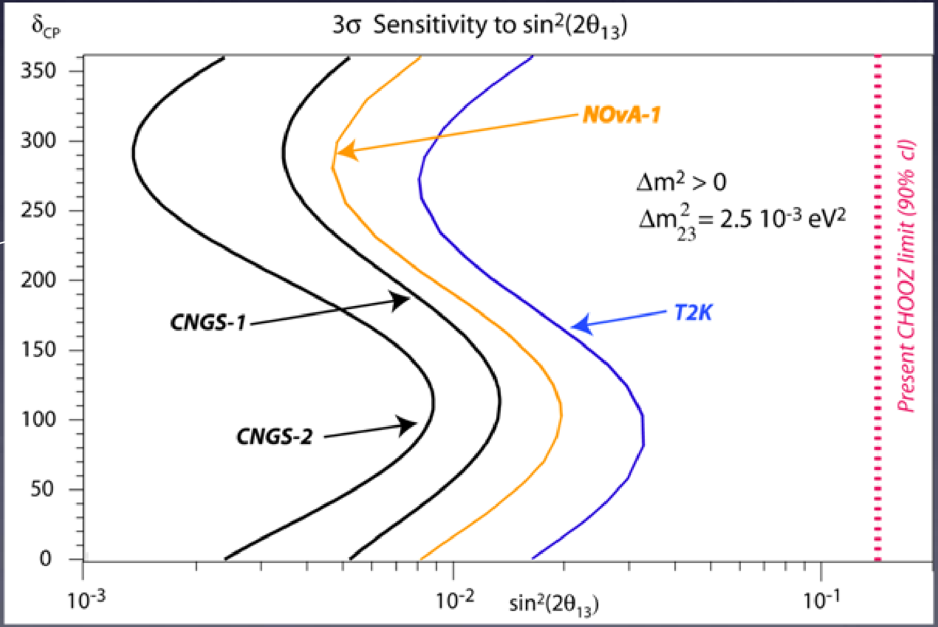


Sensitivity to θ_{13} and δ_{CP}

CNGS-1(-2): 1.2 (4.3) 10^{20} pot/y

Exposure: 20 kt x 5 years

GLoBES: 5% beam syst., $\Delta E/E$ = 15%



MODULAr (20 kt) + CNGS (400 GeV , 1.2 10^{20} pot/y)
~ NOvA + NUMI (120 GeV 6.5$10^{20}$ pot/y)

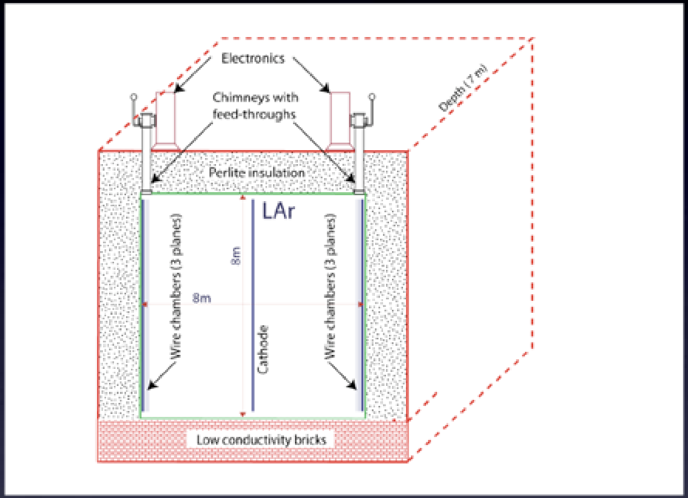
MODULAr R&D

Scaling by only 1 order of magnitude w.r.t. ICARUS600 requires only some "not very substantial" R&D items:

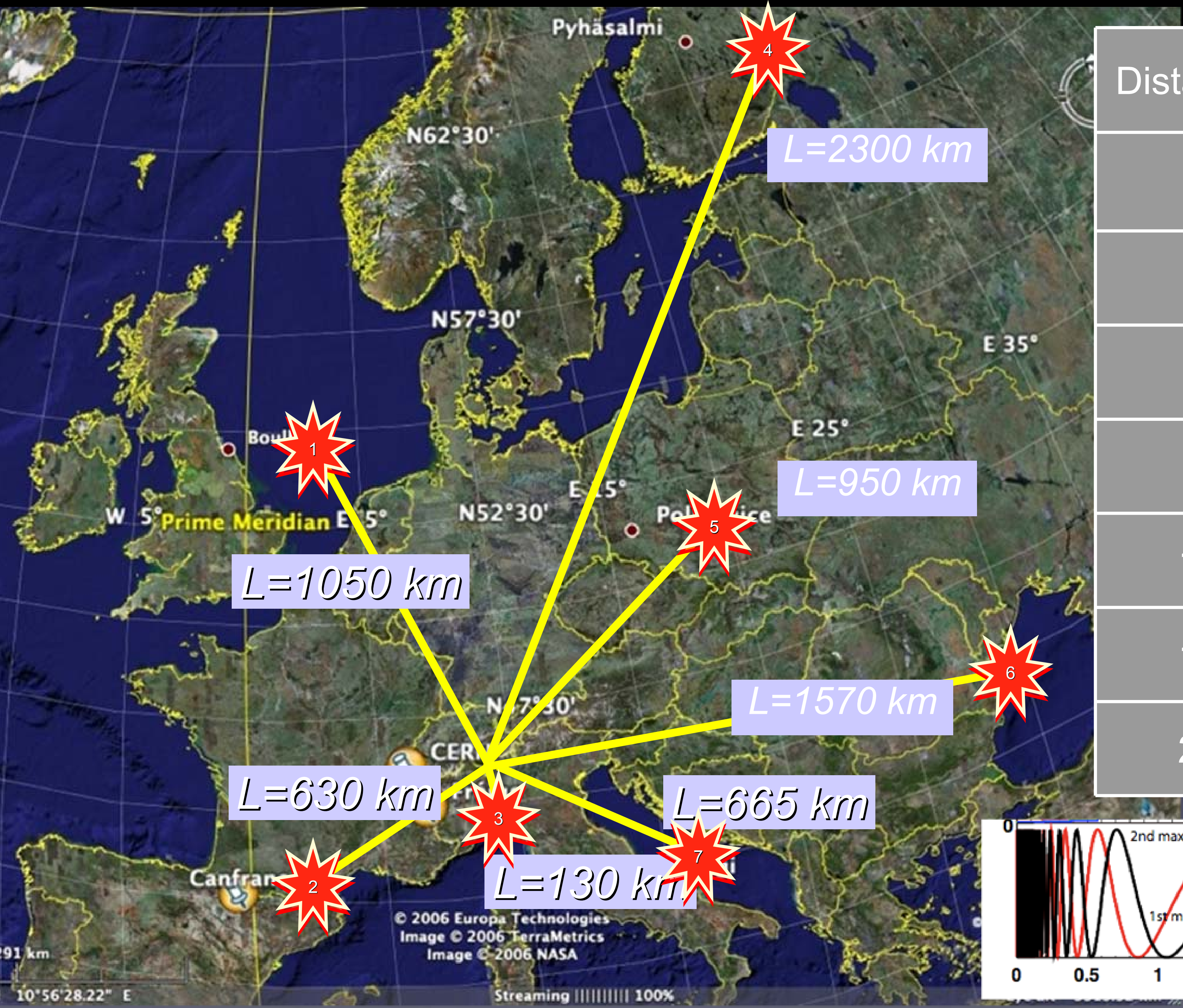
- the filling process starting from air to pure LAr, taking into account the motion of the gas, optimizing the inlet and outlet geometries and minimizing the number of cycles;
- the thermal convection of the LAr, in order to optimize the temperature gradients and to ensure circulation in all regions of the dewar, both in the cool down and stationary phases;
- the out-gassing rate and the re-circulation processes necessary to achieve the required electron lifetime;
- the geometry of the compact re-circulators both in the liquid and in the gaseous phases.
- finally, also the electronics and DAQ may require some specific developments to improve the layout of the analogue front-end and the DAQ architecture.

SLICE prototype

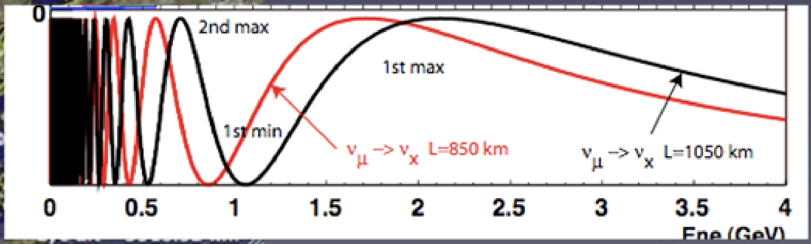
sensitive area 8x8m2, depth 4m



Strategy II: other neutrino beams from CERN



Distance/km	1st oscillation max (GeV)
130	0.26
630	1.27
665	1.34
950	1.92
1050	2.12
1570	3.18
2300	4.65



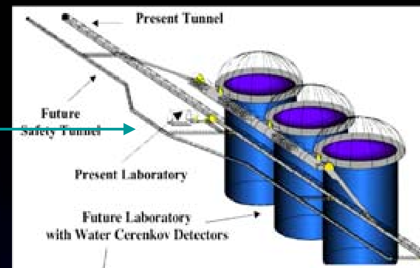
EUROnu

- "A High Intensity Neutrino Oscillation Facility in Europe"
  4.5 M€, 15 beneficiaries in 9 countries
- Timescale for realization of facility: >2016

	WP title
WP2	**Superbeam**: design of a 4 MW proton beam (SPL), target and collection system for a conventional neutrino beam
WP3	**Neutrino factory**: define design of muon front-end, acceleration scheme, proton beam handling and component integration in an end-to-end neutrino factory simulation
WP4	**Beta-beam**: following from EURISOL, study production, collection and decay ring of beta beam for high Q isotopes
WP5	**Neutrino detectors:** study Magnetized Neutrino Iron Detector (MIND) performance for golden measurement at neutrino factory, water Cerenkov detector for beta and super beams and near detectors for all facilities
WP6	**Physics**: comparison of physics performance, systematic errors and optimization for all facilities

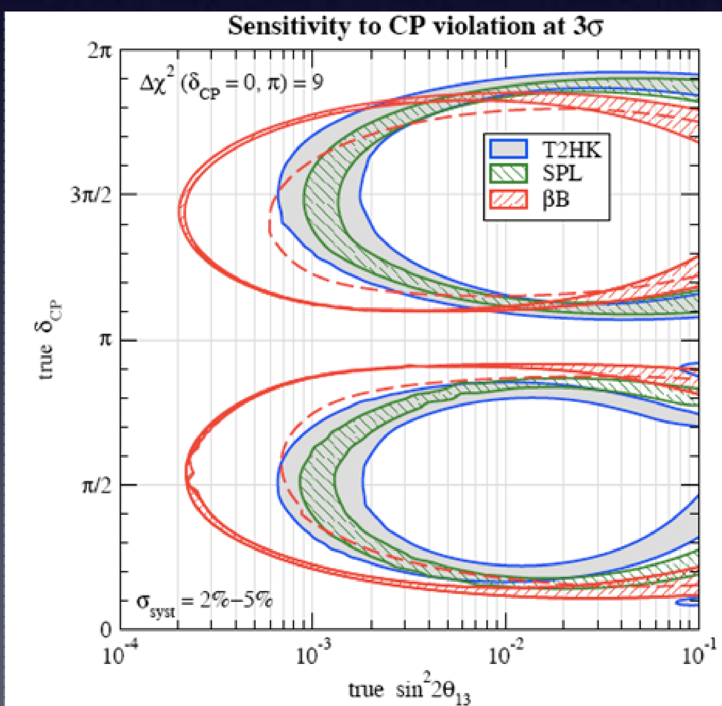
Neutrino oscillation with Megaton detectors, example: Fréjus

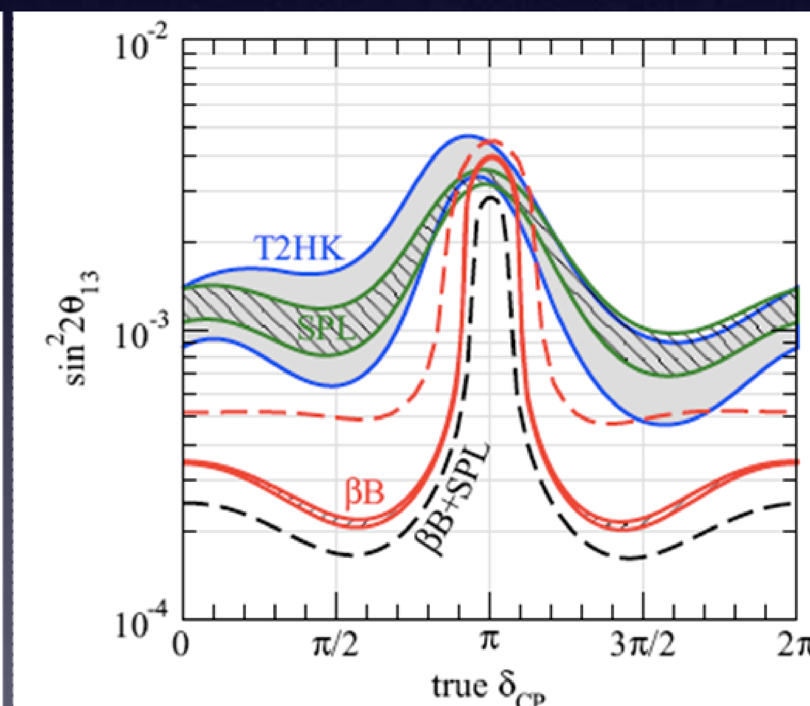
130 km



good baseline for oscillations of Super-Beam / Beta-Beam neutrinos

- good sensitivity to θ_{13} and δ_{CP} with Beta-Beam ($\nu_e \rightarrow \nu_\mu$) or Super-Beam ($\nu_\mu \rightarrow \nu_e$)
- improved sensitivity with synergy of the two beams



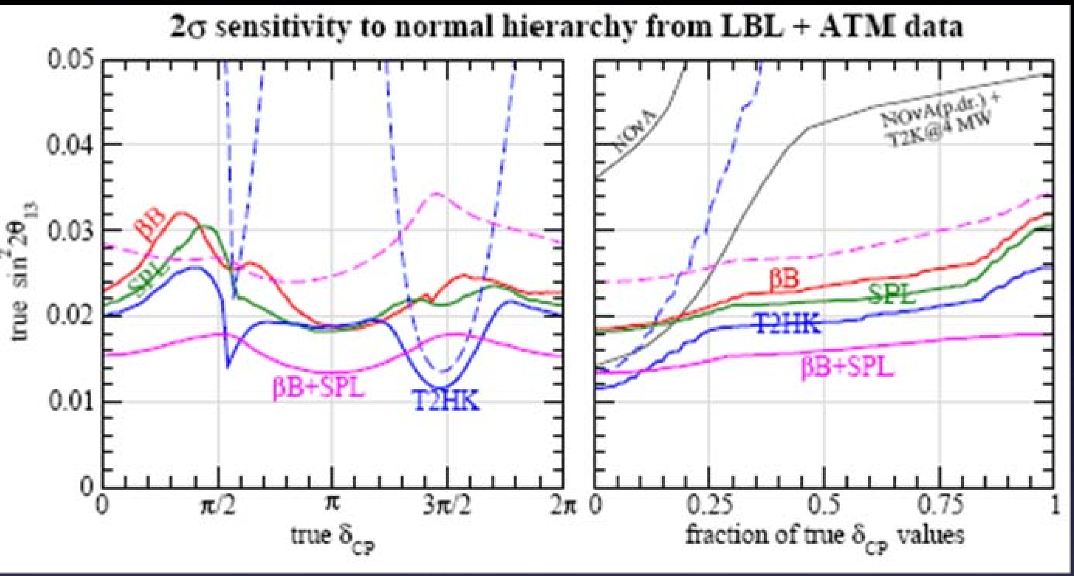


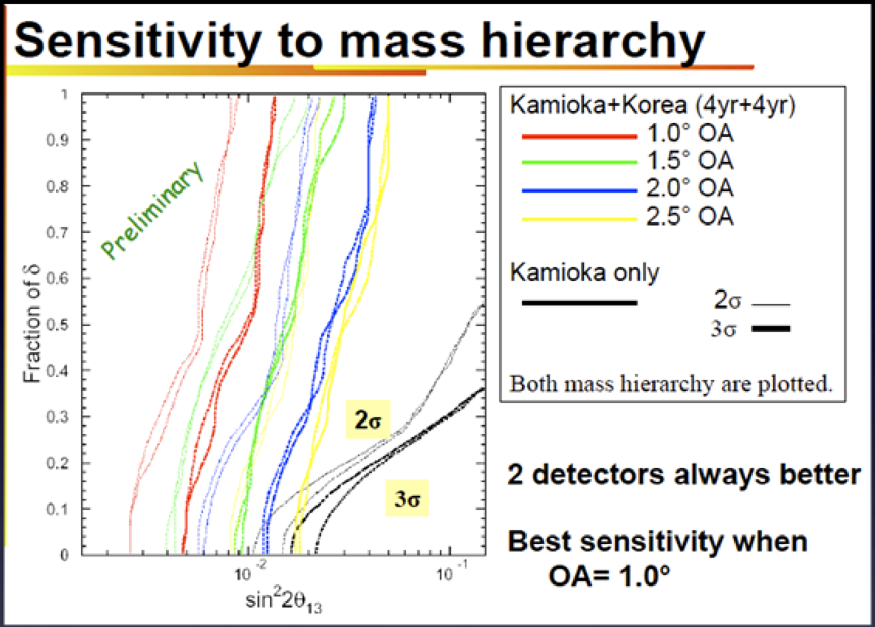
in addition, combination with atmospheric ν's allows to measure sign(Δm_{23}) and θ_{23} octant

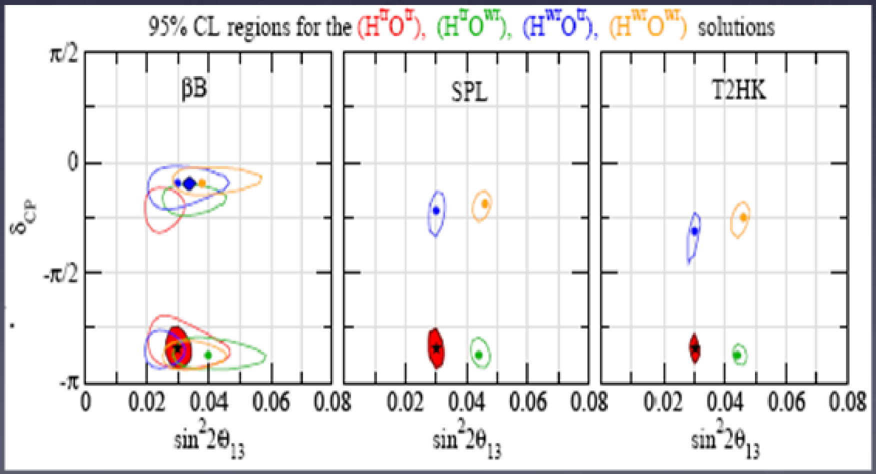
Campagne et al., hep-ph/0603172

mass hierarchy and degeneracies

Campagne, Mezzetto, Maltoni, Schwetz , 2007, Kajita et al. 2006.

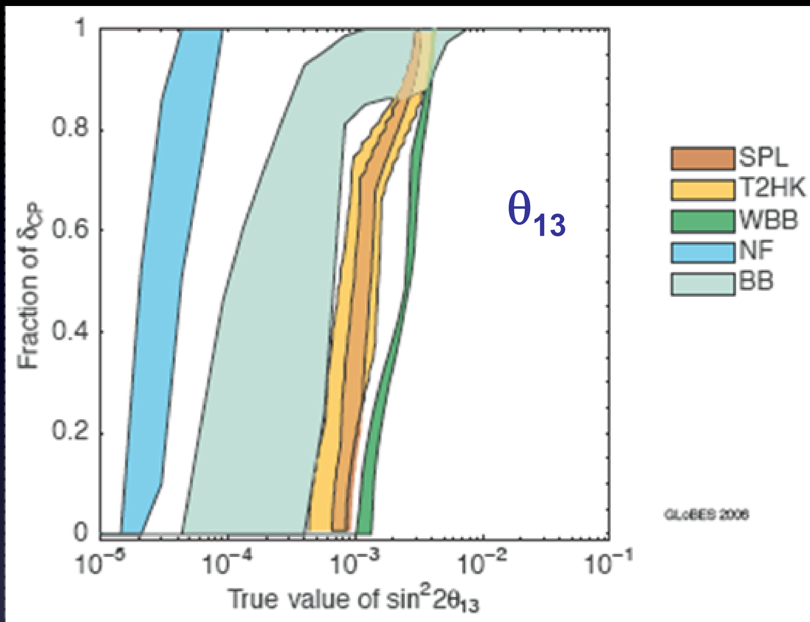


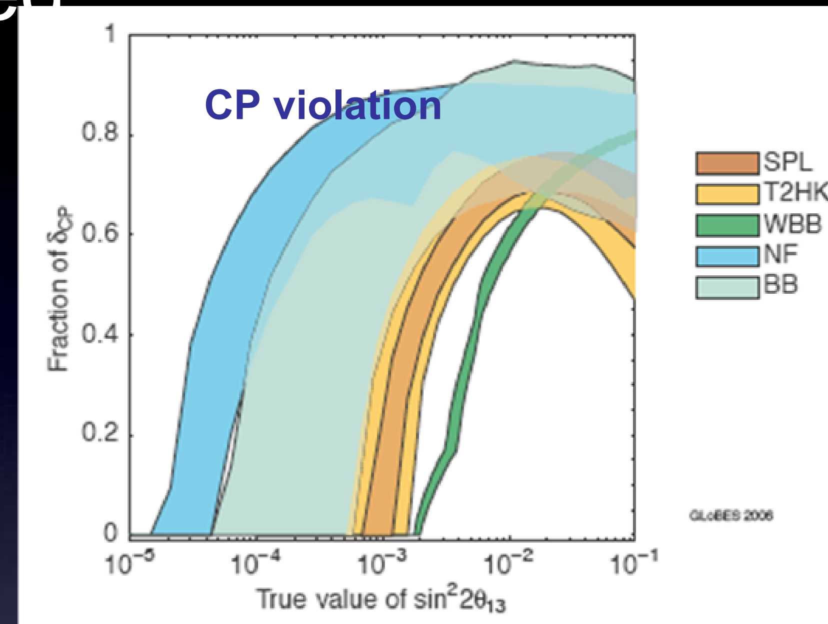




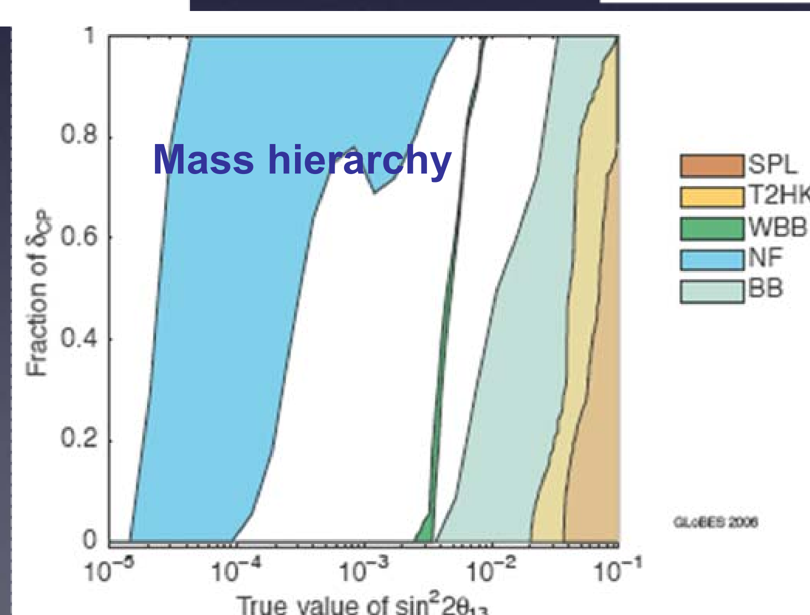
- For large enough θ_{13} masse hierarchy and resolve degeneracies by combining with atmospherics
- For larger angles, one would have to combine beamlines in different continents or in the same continent (Kamioka/Korea)
- A lot of work yet to be done….

If one constrains $\sin^2 2\theta_{13} < 0.01$ without evidence for a signal, new neutrino beam technologies will be most likely required



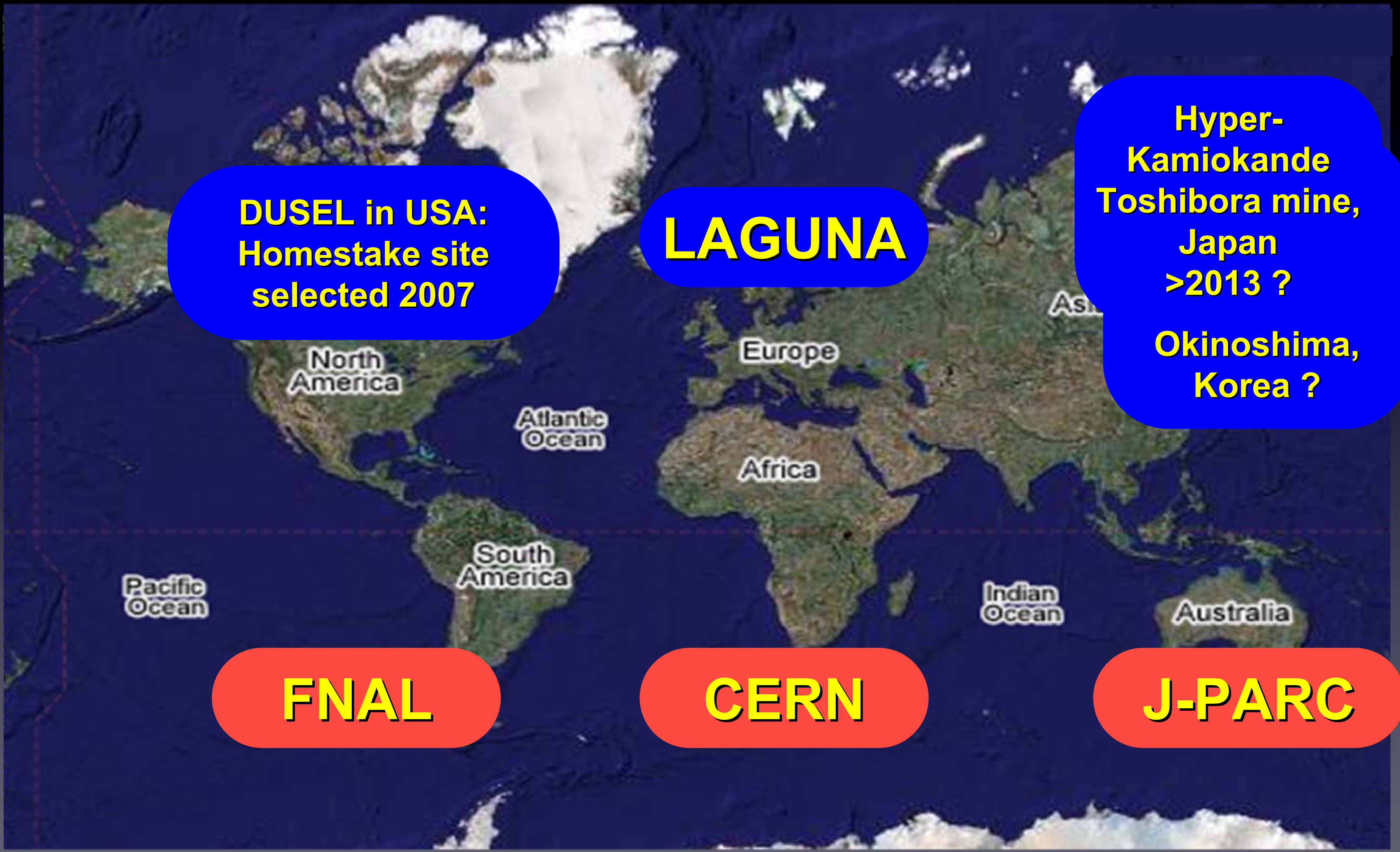


Neutrino Factories, Magnetised detectors etc..



Task of EURONu

Megaton scale are Billion€ scale programs, need to have global coordination (OECD, FALC,…?)



Conclusions

- Key questions in particle/astroparticle physics can be answered only by construction of new giant underground observatories to search for proton decay and study sources of terrestrial and extra-terrestrial neutrinos.
- European megaton detector community (3 liquids) in collaboration with its industrial partners is currently addressing common issues (sites, safety, infrastructures, non-accelerator physics pontential) in the context of LAGUNA (EU FP7). A CDR accompanied with cost estimates will be ready by July 2010.
- In parallel, R&D for the different technologies is performed with national funds.
- A program concentrating on the neutrino beam R&D and evaluation of the neutrino oscillation physics potential, has just started (kickoff 23rd March 2009 at CERN). A milestone for decisions for the next steps is the output of the current generation experiments (DCHOOZ, T2K, Dayabay) expected around 2012-2013.
- There is a clear understanding , at the researchers and the agency level, that these are global scale projects and that they have to be conceived and executed with world level coordination (OECD, FALC).