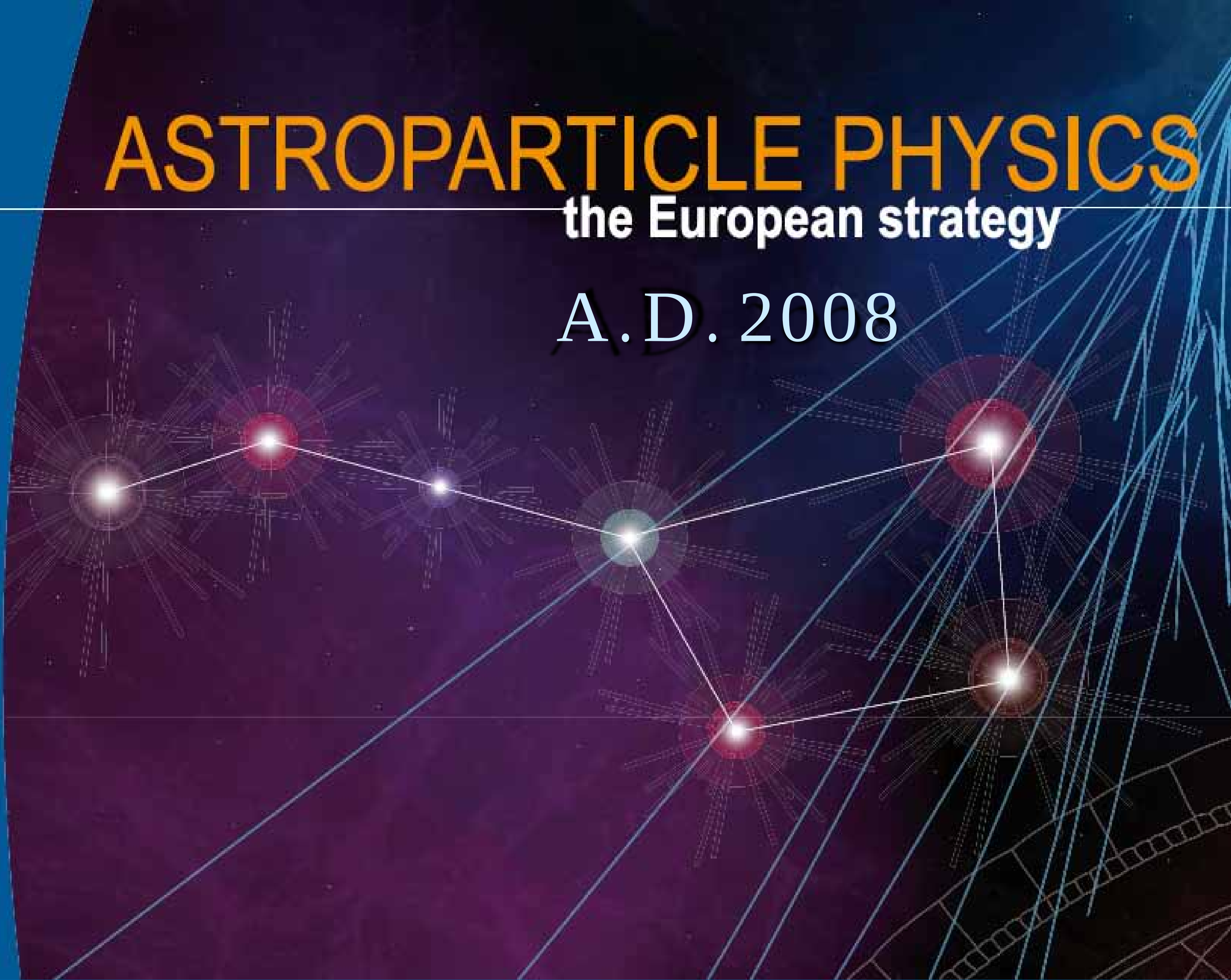
LAGUNA Project

W. H. Trzaska
Department of Physics, University of Jyväskylä, Finland
on behalf of LAGUNA collaboration

Erice, 16 – 24 September 2010



A.D. 2008

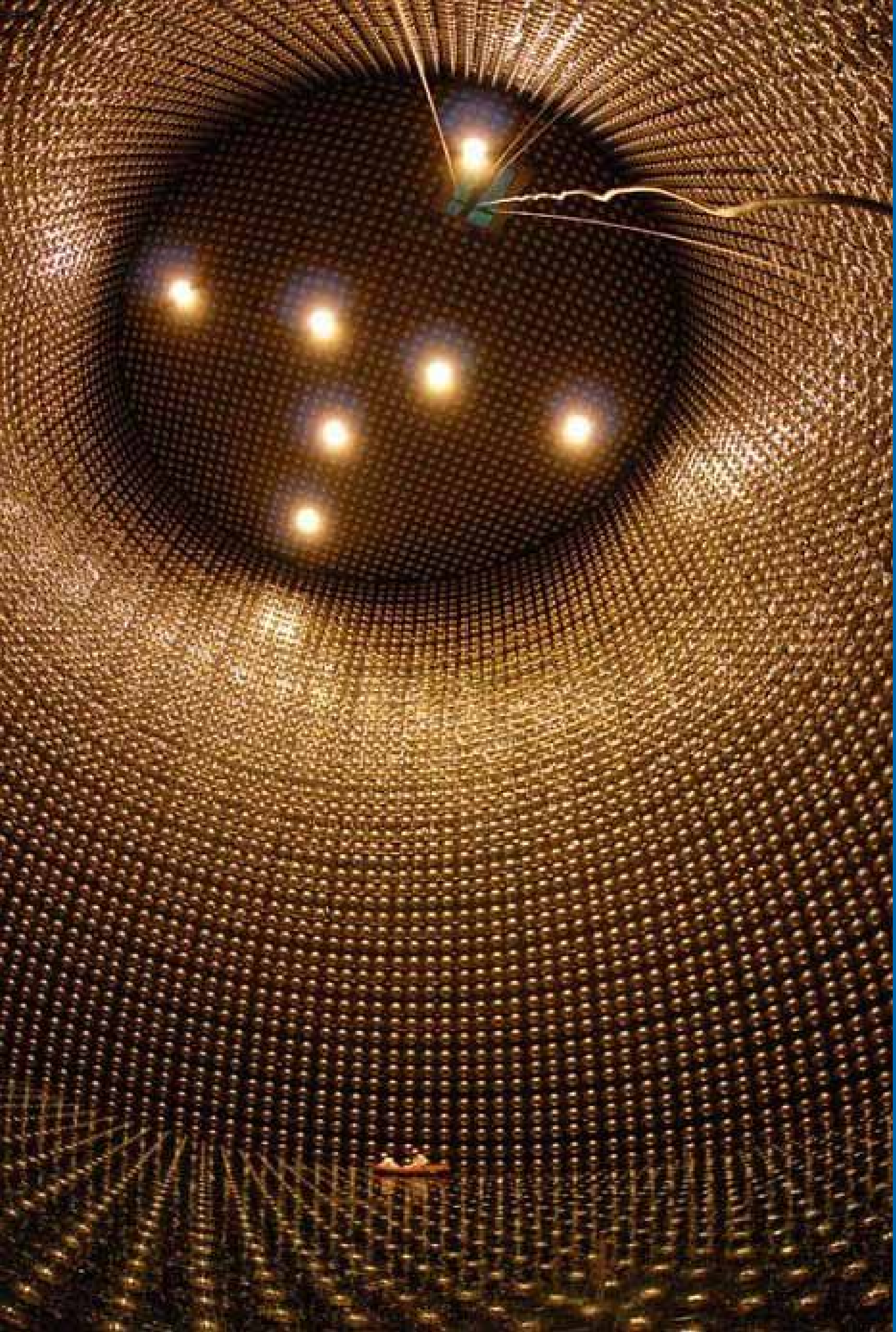
Roadmap recommends

projects that have strong potential for taking the experimental science above the threshold of new, exciting discoveries addressing questions like the nature of dark matter and dark energy; the stability of protons and the physics of the Big Bang; the properties of neutrinos and their role in cosmic evolution; the interior of the Sun or supernovae as seen with neutrinos; the origin of cosmic rays and the view of the sky at extreme energies; and violent cosmic processes as seen with gravitational waves.

On the top of the recommendation list

- Next-generation underground Megaton-scale detector for the search for
  - proton decay,
  - neutrino astrophysics
  - investigation of neutrino properties.

- This device is LAGUNA detector – Large Apparatus for Grand Unification and Neutrino Astrophysics.

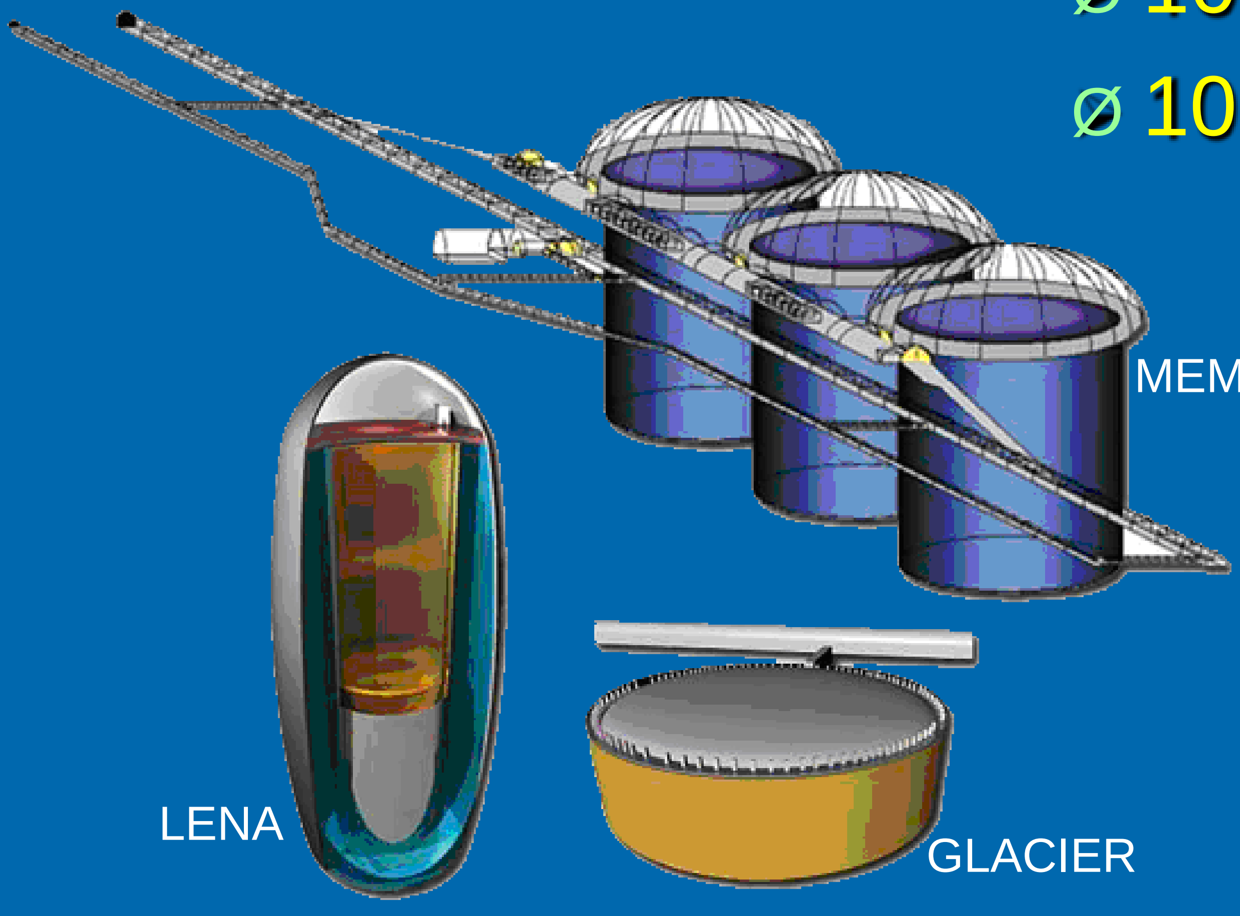


Super-K

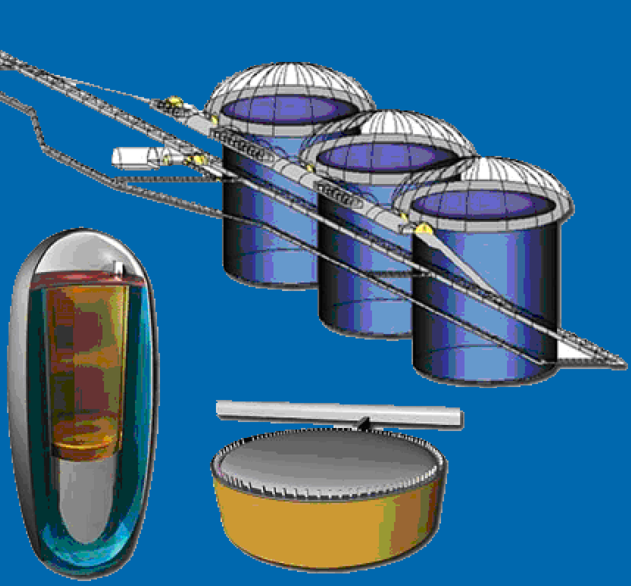
- One of the most successful devices in modern physics
  - Discovery of neutrino oscillations
  - Solar neutrino measurements
  - Best upper limits on proton lifetime
- The largest running underground experiment
  - 50 000 ton H_2O
  - 1 km underground

To be a worthy successor, LAGUNA has to be:

- 10 x bigger or / and
- 10 x better



Considered technologies



- GLACIER – 100 kton of liquid argon
  - Excellent tracking (TPC)
  - Rapidly developing technology
  - Needs more R&D (a 1 kton prototype)
  - Requires 2500 m.w.e (900 m of rock)
- LENA – 50 kton liquid scintillator
  - Big astrophysics potential (Super Borexino)
  - Robust and proven technology
  - Requires 4000 m.w.e (1400 m of rock)
- MEMPHYS – 500 kton water Cherenkov
  - Competitor for Hyper - K
  - Requires 3000 m.w.e (1100 m of rock)

7 European sites are being considered

- **Pyhäsalmi** in Finland (mine),
- **Sieroszowice** in Poland (mine),
- **Boulby** in the UK (mine),
- **Slanic** in Romania (mine),

- **Fréjus** in France (road tunnel),
- **Canfranc** in Spain (road tunnel) and

- **Umbria** region in Italy (a virgin site).

Infrastructure Design Study

- The purpose: evaluate the proposed sites and to give realistic estimates of the cost and the time needed to prepare large-scale underground laboratories for LAGUNA detectors
- Supported with 1.7 M€ by the Framework Programme 7 of the EC (2008 – 2010)
- Involves over 100 physicists and engineers from 10 countries.

What is required of a LAGUNA site?

- Quality of the rock
- Seismic stability

Safety & construction cost

- Ready infrastructure & clear legal status
- Presence of scientific activity on site
- Experienced industrial partner
- Low background from nuclear power plants

What is required of a LAGUNA site?

- Quality of the rock
- Seismic stability
- Ready infrastructure & clear legal status
- Presence of scientific activity on site
- Experienced industrial partner
- Low background from nuclear power plants

Reduces construction time & cost

What is required of a LAGUNA site?

Cooperation between science & industry can not be taken for granted

- Quality of the rock
- Seismic stability
- Ready infrastructure & clear legal status
- Presence of scientific activity on site
- Experienced industrial partner
- Low background from nuclear power plants

What is required of a L A G U N A site?

Engineering & construction challenge!

- Quality of the rock
- Seismic stability
- Ready infrastructure & clear legal status
- Presence of scientific activity on site
- Experienced industrial partner
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What is required of a L A G U N A site?

- Quality of the ro
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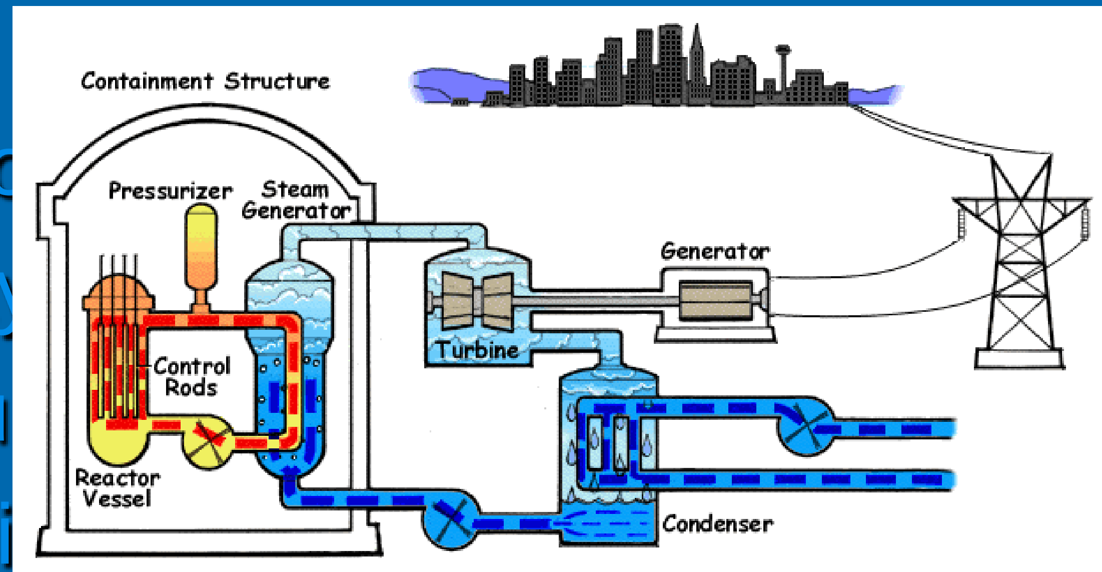


Essential for geo- and diffuse supernova neutrinos

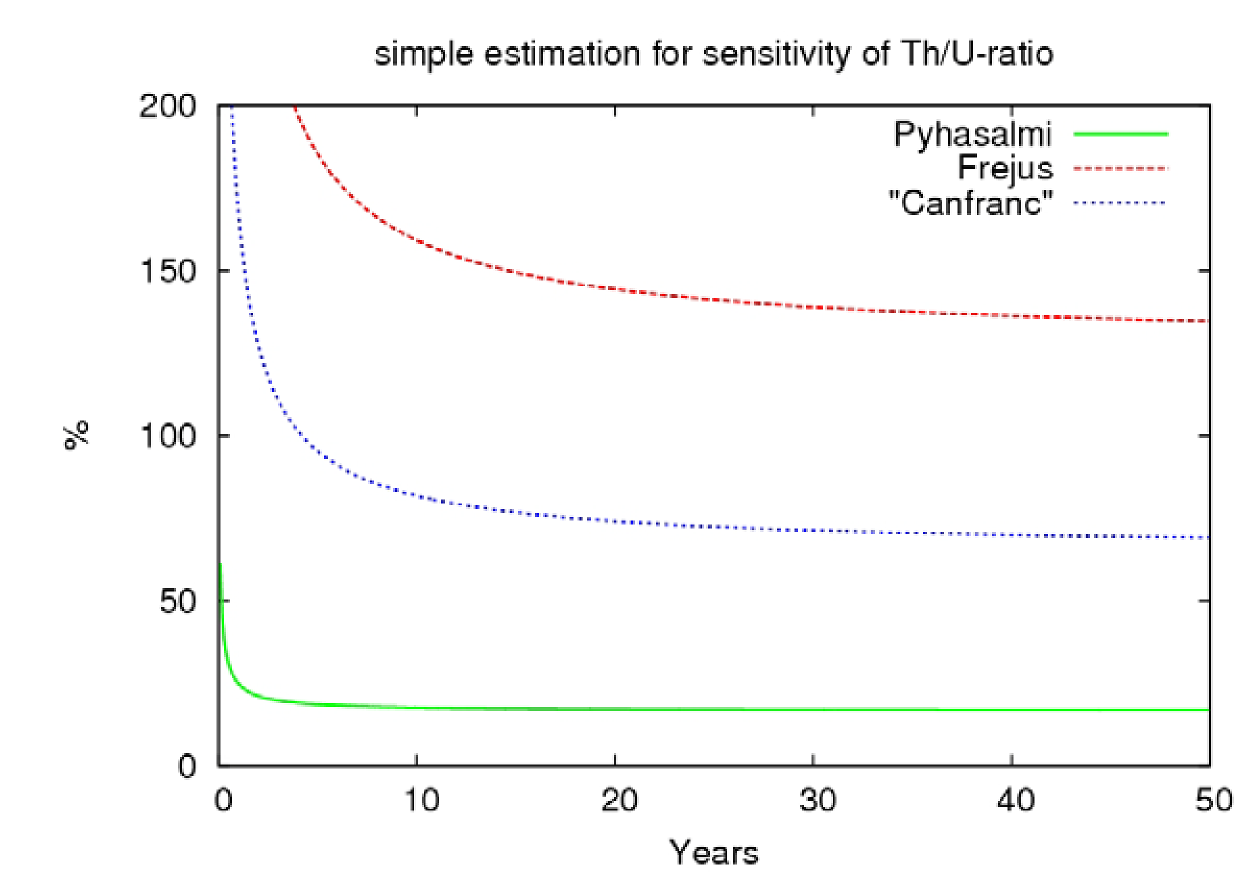
Nuclear power plants in Europe (2009)

Neutrino Background from Power Plants based on 2009 data (Kai Loo)

	Counts / kton / year
Pyhäsalmi (FIN)	~ 78
Pyhäsalmi after 2012	~ 86
Caso (ITA)	~ 110
Slanic (ROM)	~ 130
Sieroszowice (POL)	~ 200
Canfranc (ESP)	~ 300
Frejus (FRA)	~ 700
Boulby (GBR)	~ 1600
Boulby w/o Hartlepool	~ 280

Measured spectra of reactor neutrinos for U-235,Pu-239 and Pu-241 were used. For U-238 calculated spectra were used. Event rates were calculated for a KamLand-type scintillator det.

Influence of reactor neutrino background on determination of the Th/U ratio



Assumptions and methods as described by S. Dye in Earth Planet. Sci. Lett. (2010), doi:10.1016/j. epsl.2010.06.012:
crust contribution 30 – 38 TNU; Th/U = 4.3
mantle contribution 12 TNU; Th/U = 3.1
core contribution ignored; BGD only from reactors
X – axis: measurement time with LENA detector
Y – axis: error (%) of the measured Th/U ratio

What future experiments will have to measure

1. Leptonic CP violation
2. Mass Hierarchy
3. θ_{13}
4. $\pi/4 - \theta_{23}$ and the octant

- Plus new physics searches through non standard neutrino interactions (NSI) and/or the unitariety of the mixing matrix

The above order following the prescriptions of the CERN strategy group

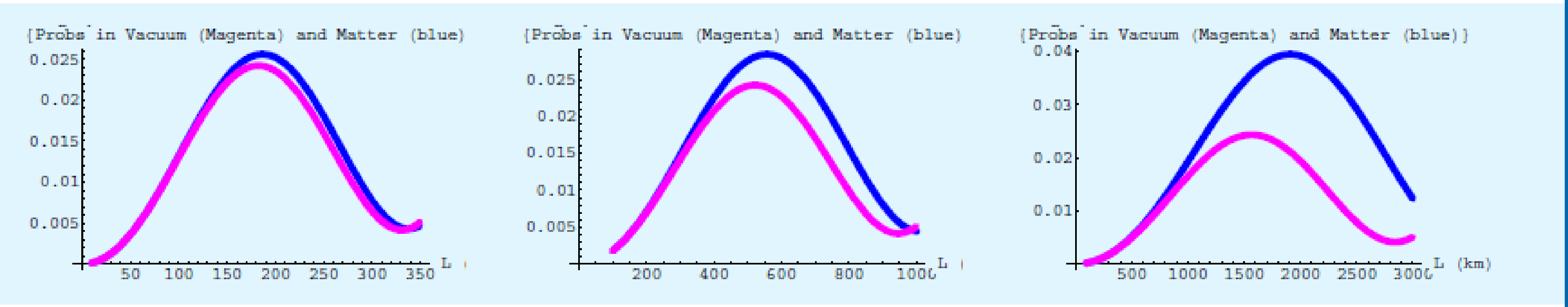
Neutrino mass model builders would probably order as 3,2,1,4

Neutrino Oscillations in Matter

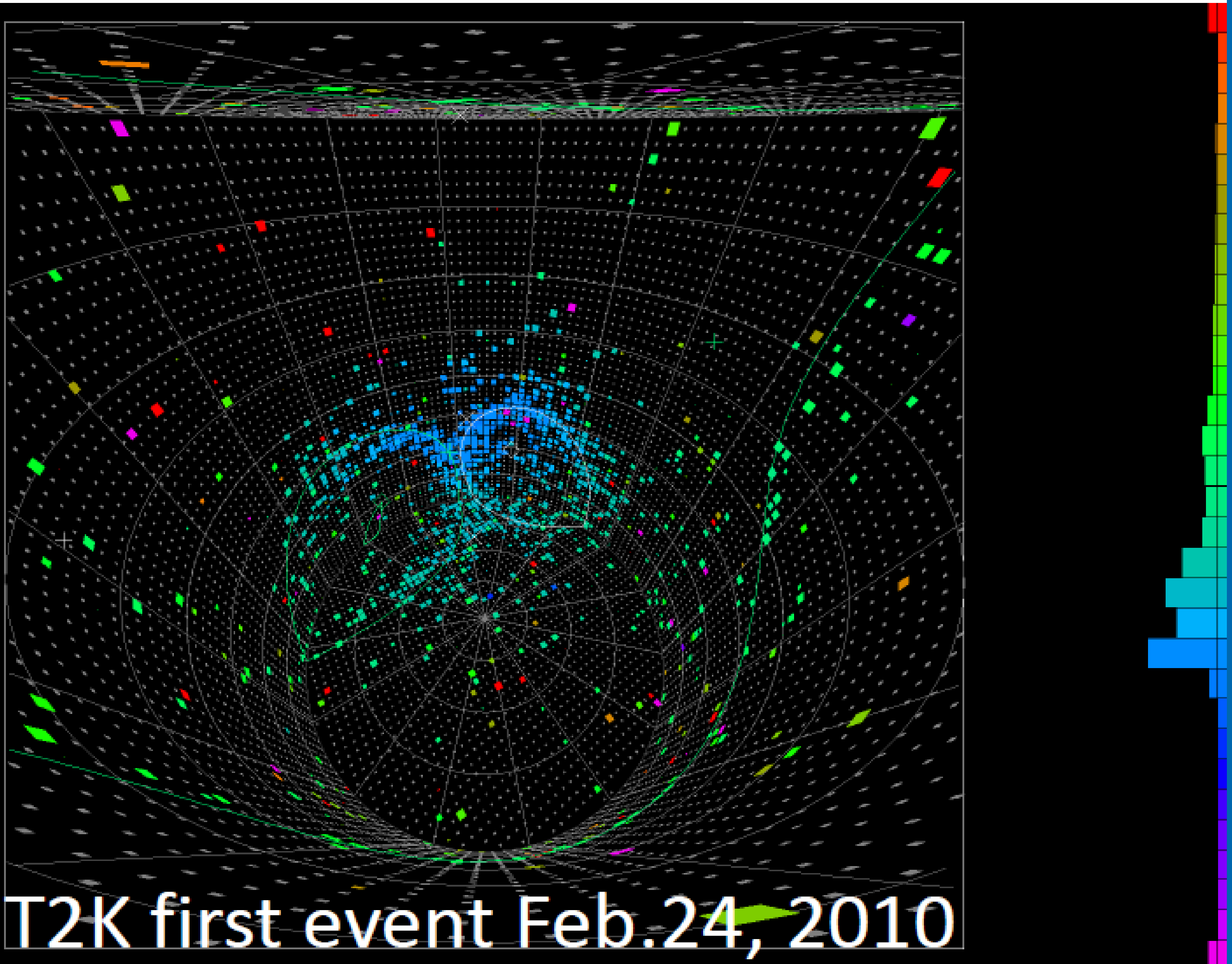
The longer the baseline the stronger matter effects in the oscillations.
This implies an increased sensitivity to the type of neutrino mass spectrum
and a better resolution of the degeneracies.

Matter effects require long "long baselines"

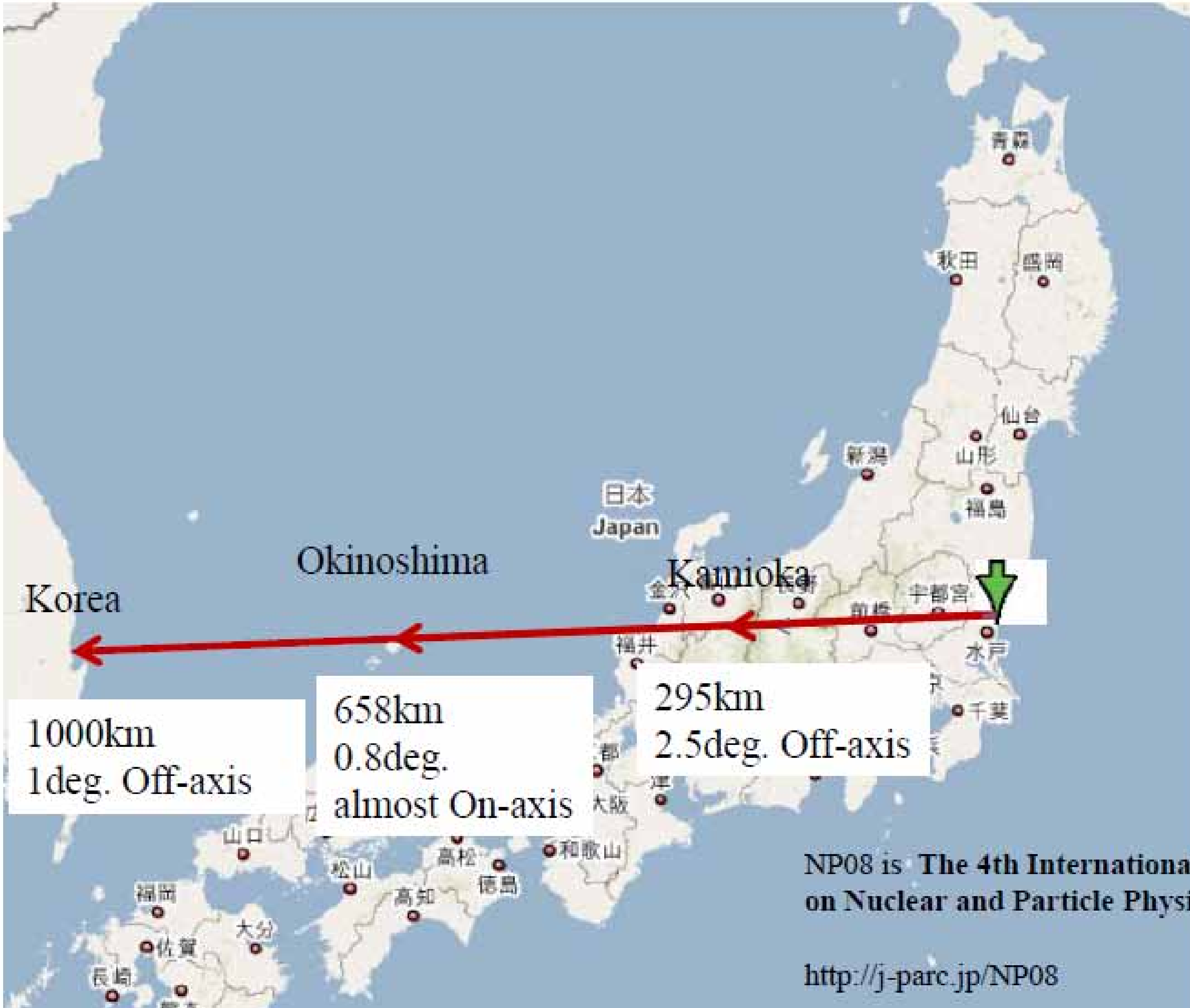
$E_\nu = 0.35\text{GeV}$ $L \simeq 130$ km $E_\nu = 1\text{GeV}$ $L \simeq 500$ km $E_\nu = 3\text{GeV}$ $L \simeq 1500$ km



T2K has started January 2010



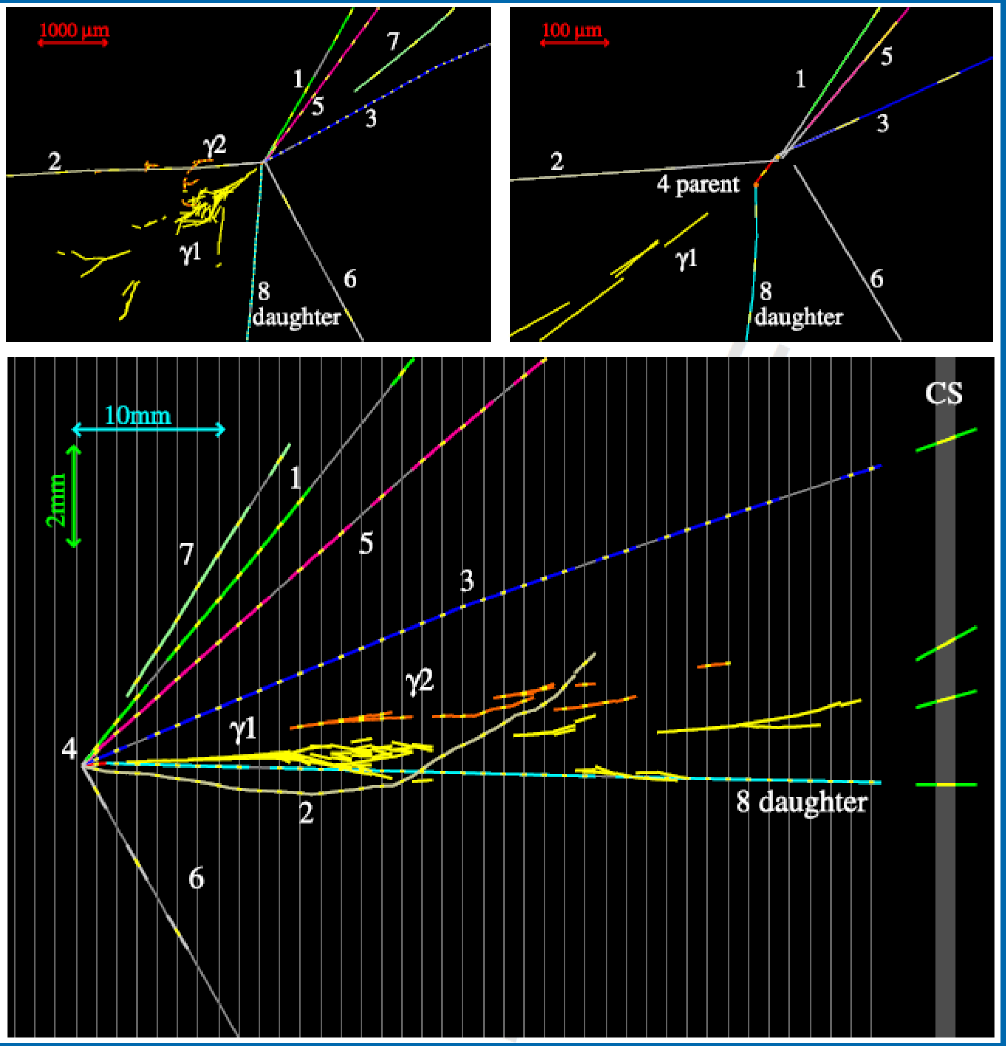
Three possible scenario studied at NP08 workshop



NP08 is The 4th International Workshop on Nuclear and Particle Physics at J-PARC

http://j-parc.jp/NP08

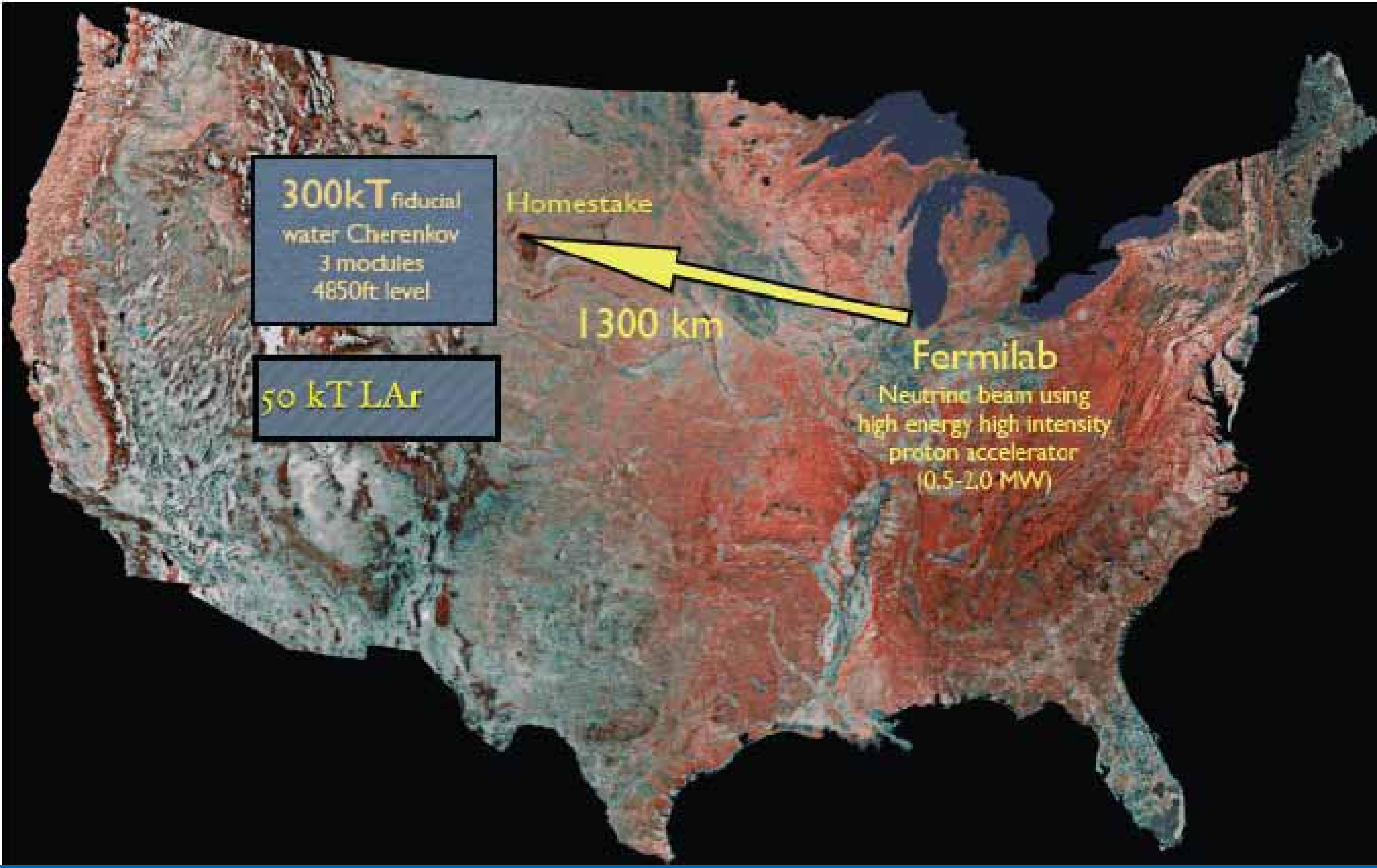
CERN à Gran Sasso (OPERA)
730 km



Observation of a first ν_τ candidate event in the OPERA experiment
in the CNGS beam

Physics Letters B (2010), doi:10.1016/j.physletb.2010.06.022

Long-Baseline Neutrino Experiment



Preferred long baselines

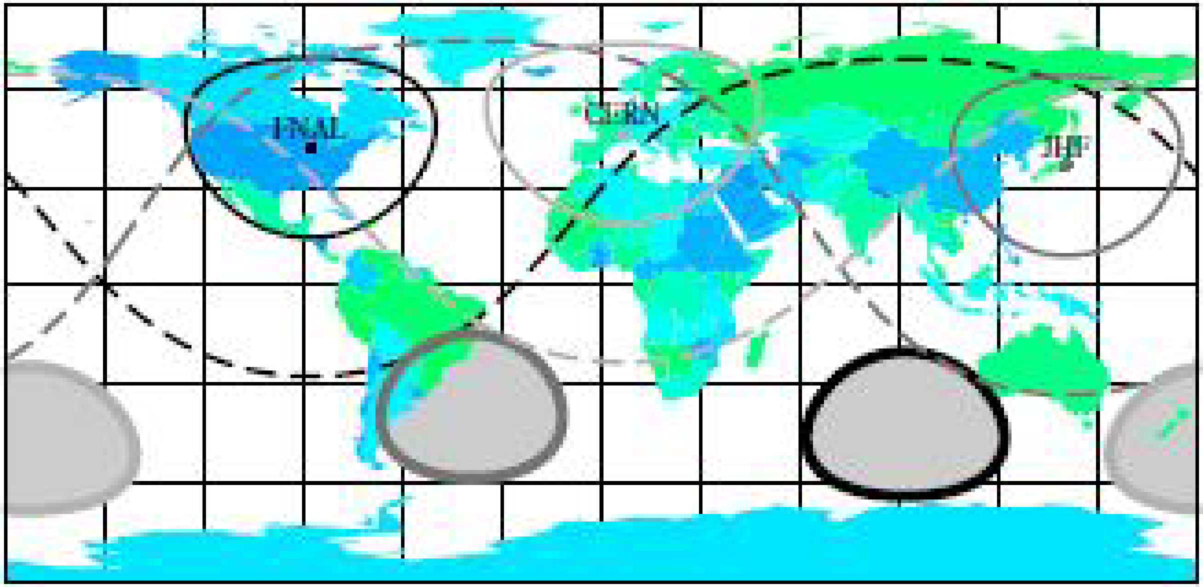


Figure 2. Three of the major potential NF laboratories and possible detector locations at $L = 3\,000\,\mathrm{km}$ (thin solid curves), $L = 7\,250\,\mathrm{km}$ (dashed curves), and inner core crossing baselines (shaded regions) in the corresponding lab colors.

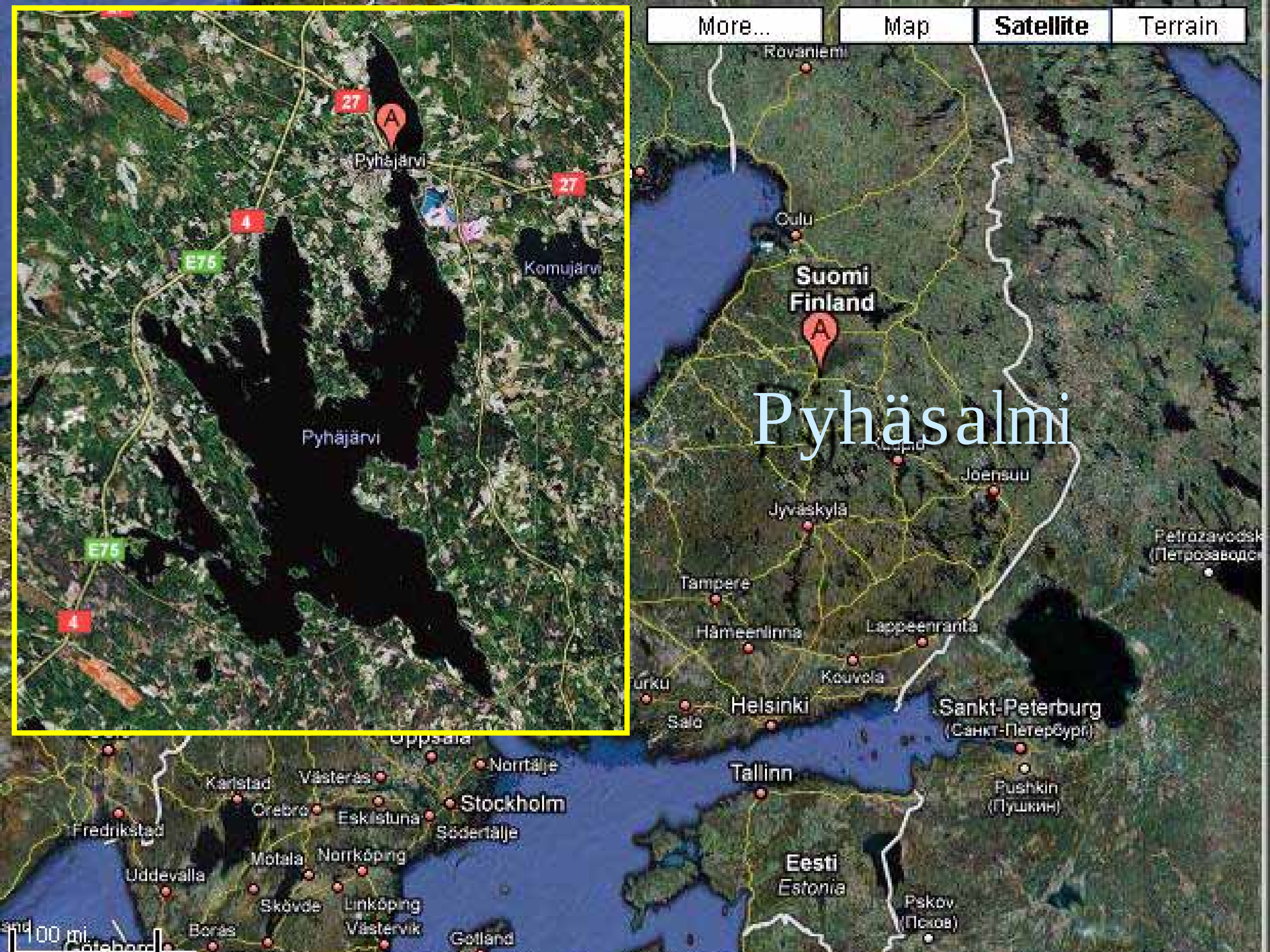
W. Winter / Nuclear Physics B (Proc. Suppl.) 155 (2006) 197–198

Long baseline distances to the proposed LAGUNA sites

Location Baseline (km)	CERN 3000	J-PARC 7250	FNAL 7250
Pyhäsalmi	2290 (76%)	7090 (98%)	6630 (91%)
Boulby	1050 (35%)	8480 (117%)	5980 (82%)
Canfranc	650 (22%)	9280 (128%)	6550 (90%)
Frejus	130 (4%)	8900 (123%)	6840 (94%)
Sieroszowice	940 (31%)	8180 (113%)	6960 (96%)
Slanic	1540 (51%)	8150 (112%)	7780 (107%)
Umbria	670 (22%)	8850 (122%)	7300 (101%)

Site example:
Pyhäsalmi mine in Finland

Skip

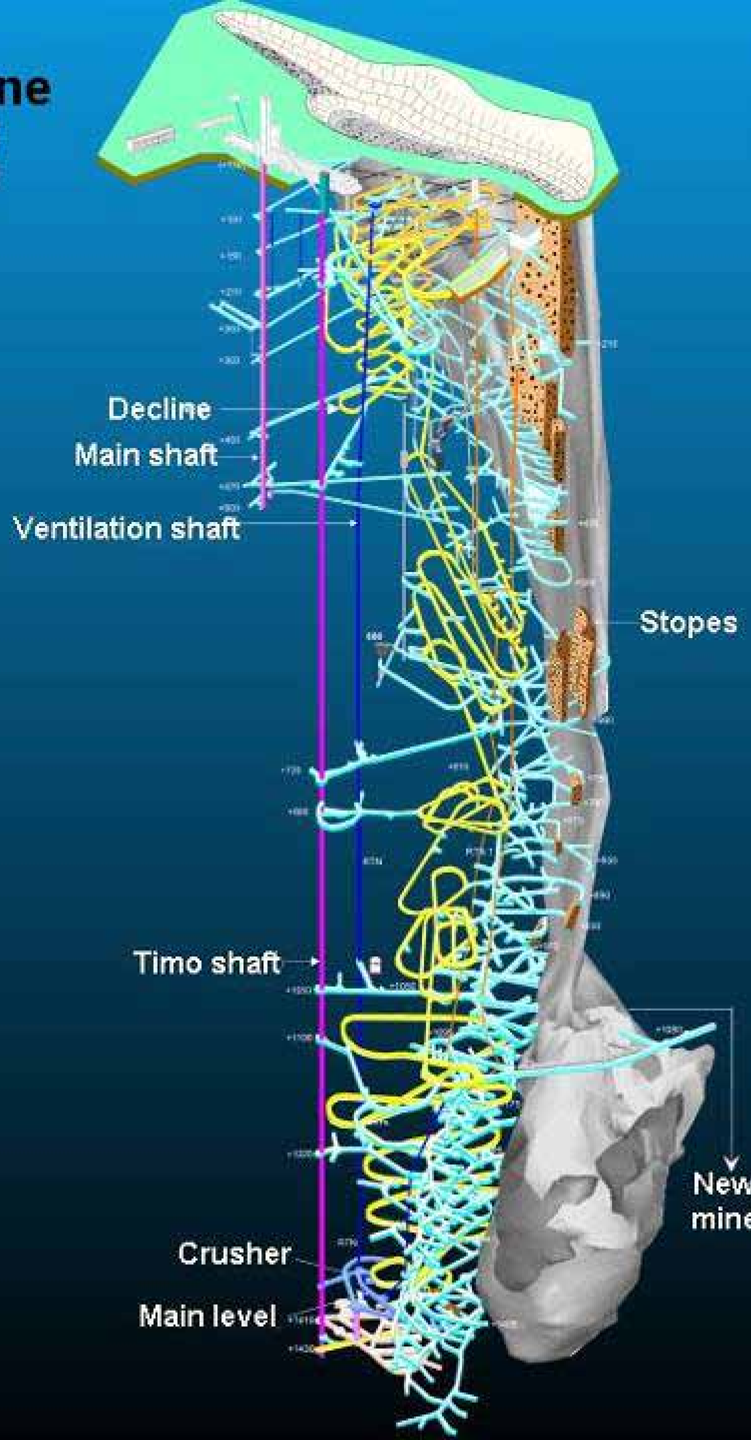


Pyhäsalmi
More...
Map
Satellite
Terrain
Pyhäjärvi
27
27
4
E75
Komujärvi
Pyhäjärvi
E75
4
Rovaniemi
Oulu
Suomi
Finland
Joensuu
Jyväskylä
Petrozavodsk
(Петрозаводск
Tampere
Hämeenlinna
Lappeenranta
Kouvola
Salo
Helsinki
Sankt-Peterburg
(Санкт-Петербург)
Pushkin
(Пушкин)
Tallinn
Eesti
Estonia
Pskov
(Псков)
Uppsala
Norrtälje
Karlstad
Västerås
Stockholm
Örebro
Eskilstuna
Södertälje
Fredrikstad
Motala
Norrköping
Uddevalla
Skövde
Linköping
Borås
Västervik
Gotland
100 mi

Pyhäsalmi mine

3D model, 2004

www.inmetmining.com

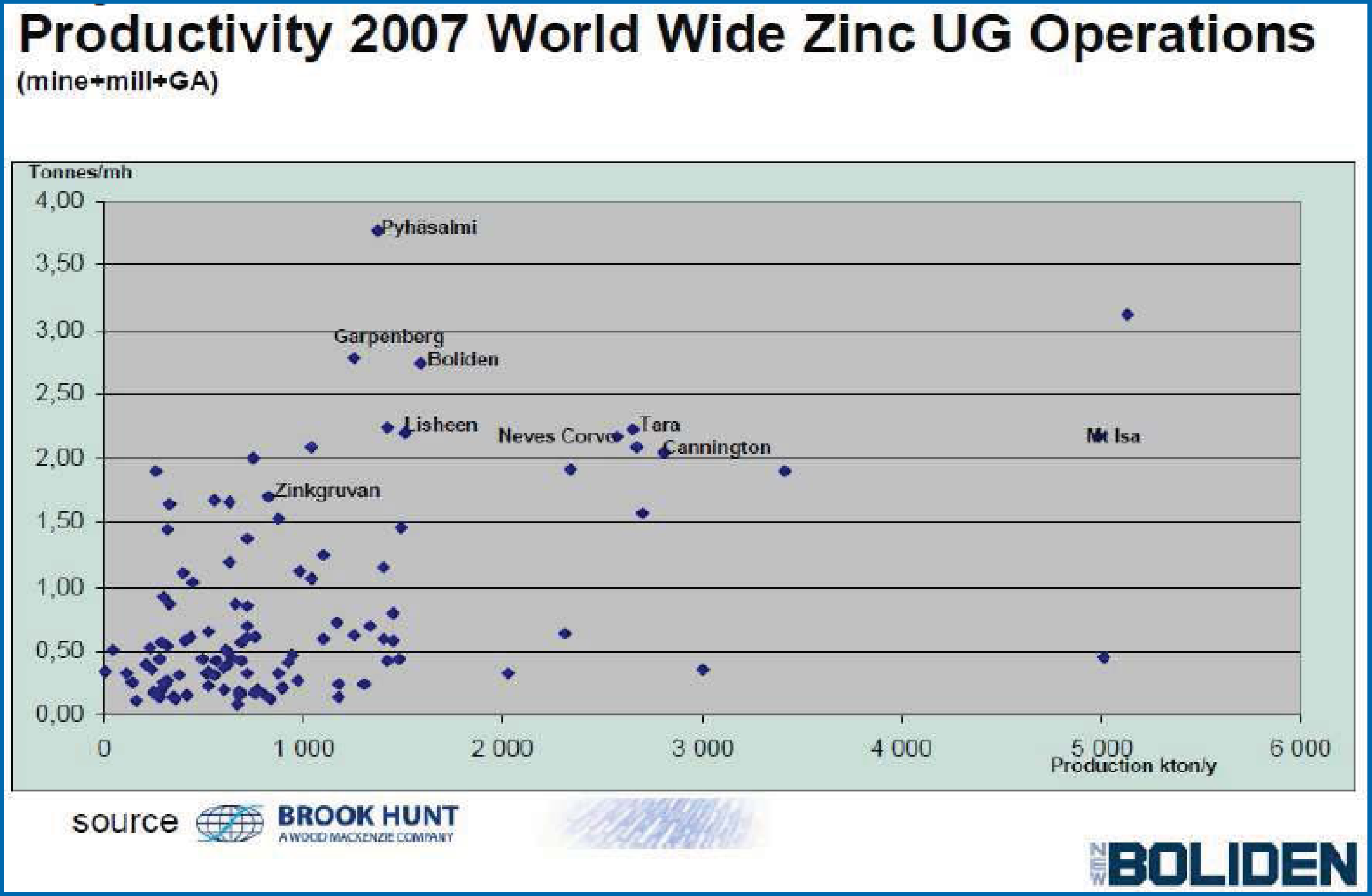



T o reach the bottom by car:
11 km serpentine
… or in 3 minutes with the elevator

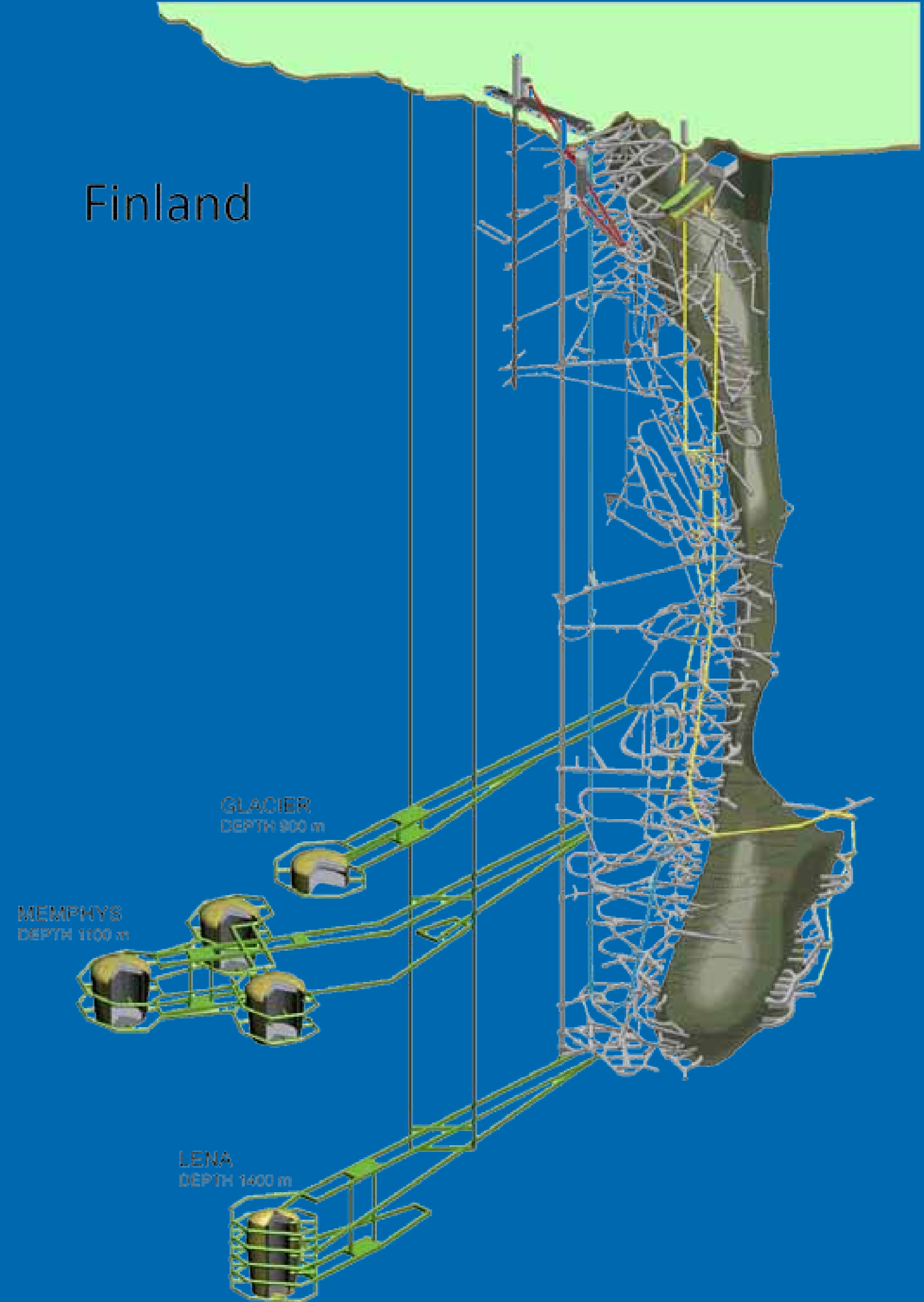
At 1.4 km below the surface


1

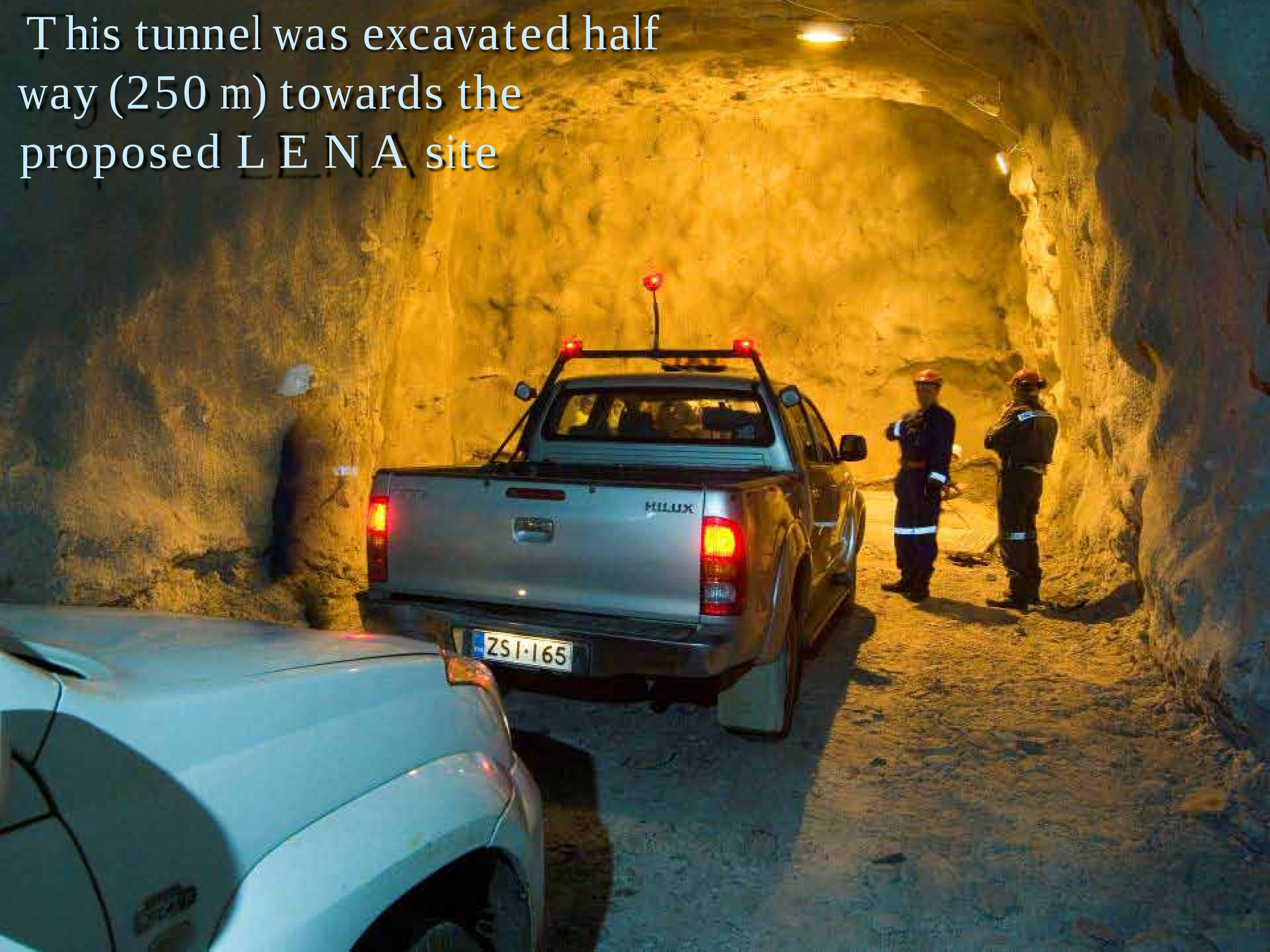
Productivity of the Pyhäsalmi mine

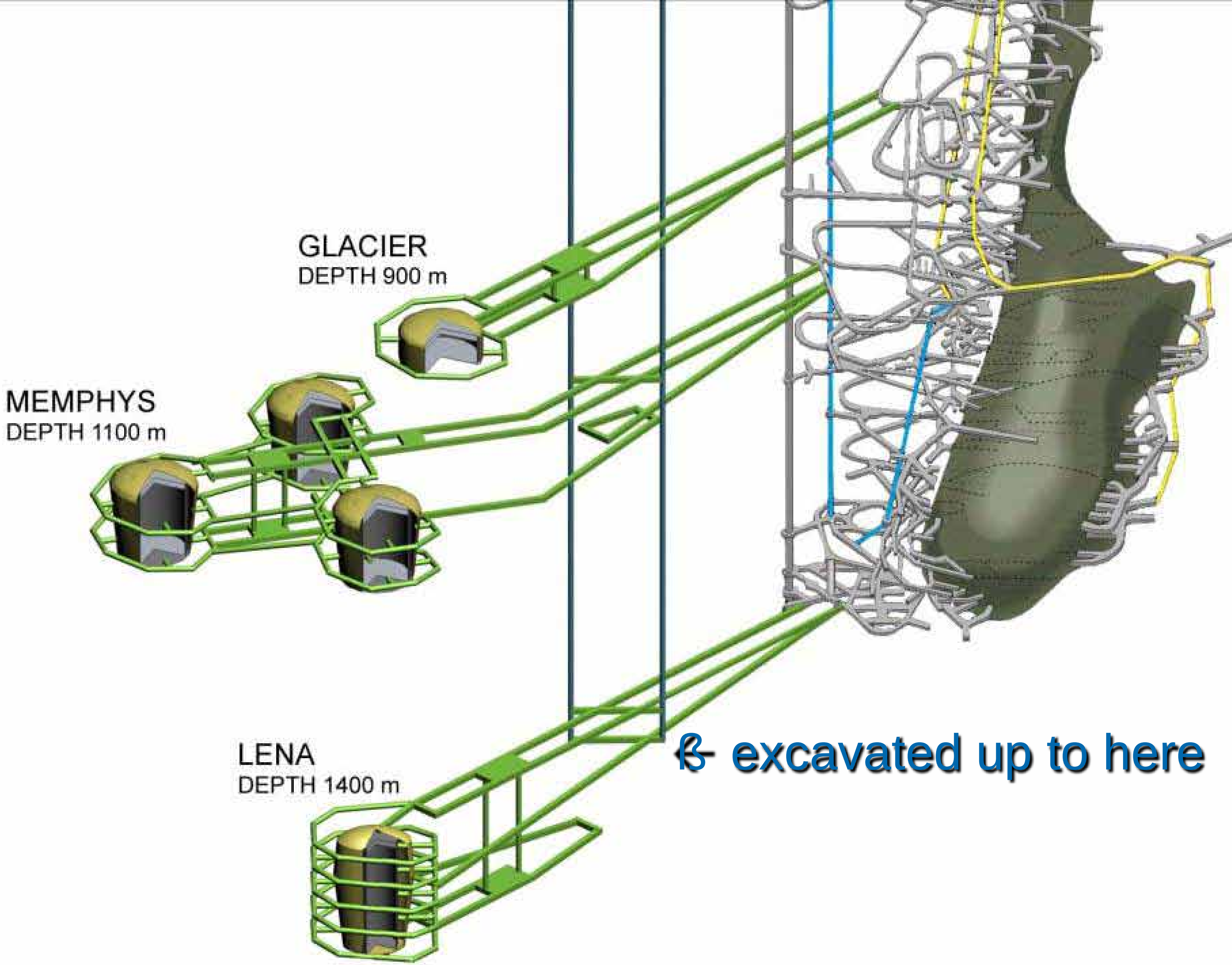


All 3 proposed LAGUNA detectors can be safely & <u>cost-effectively</u> located in Pyhäsalmi!



This tunnel was excavated half way (250 m) towards the proposed L E N A site




GLACIER
DEPTH 900 m
MEMPHYS
DEPTH 1100 m
LENA
DEPTH 1400 m
← excavated up to here

Dry, room temperature conditions at the 1430m level (below the ground)

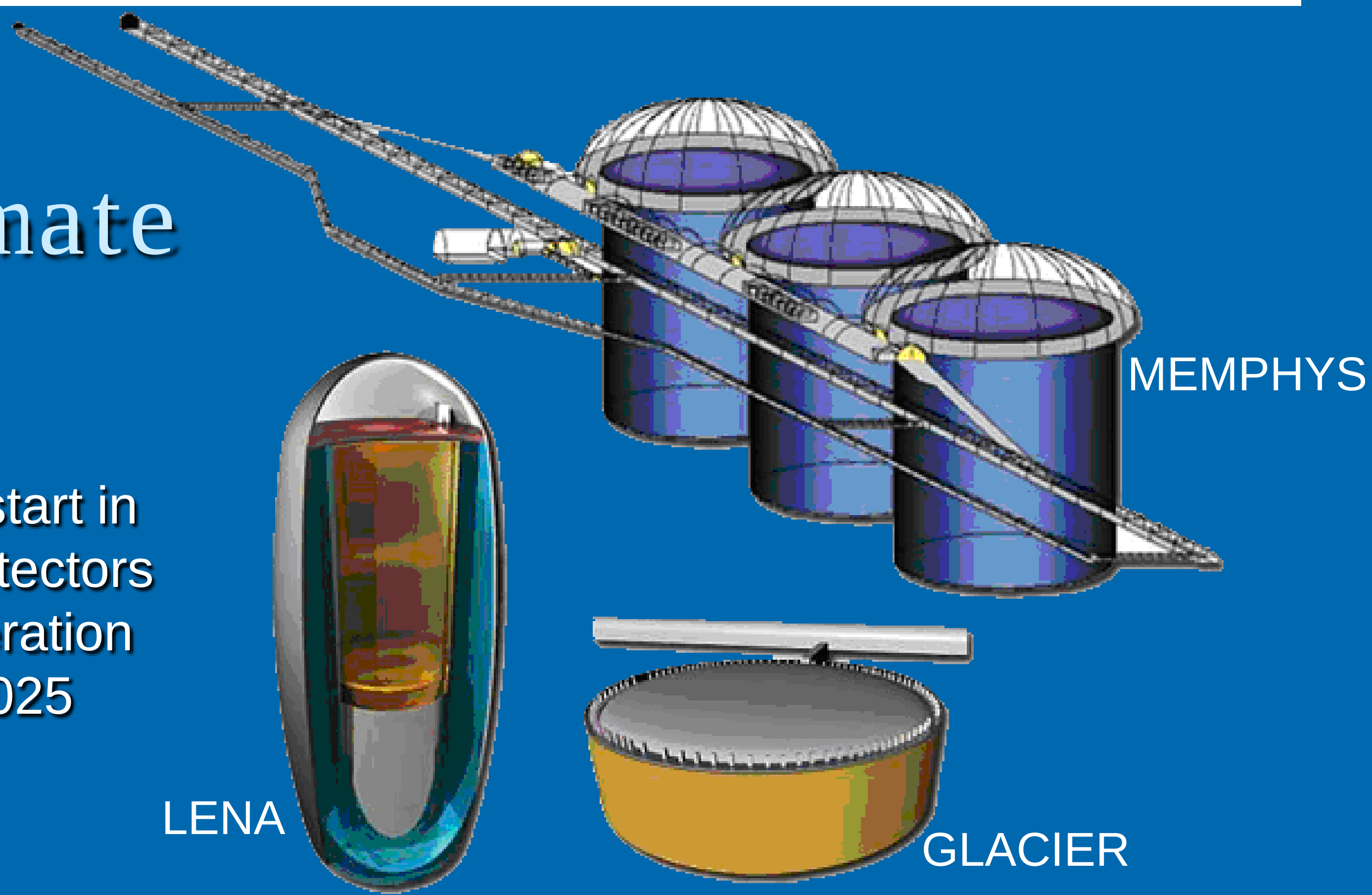
Summary

- LAGUNA Design Study (FP7 funded) is a very successful project and is well underway
- Feasibility of 3 detector types at 7 sites was evaluated
- We are now finalizing deliverables, adding comparison among sites, and prioritizing the sites
- "LAGUNA NEXT" will be submitted in November 2010
  - long baseline neutrino beam from CERN
- If the project can start in 2013, LAGUNA detectors will come into operation around 2020-2025.

	GLACIER	LENA	MEMPYS
CAVERN	50 – 75	40 – 85	130 - 200
DETECTOR	380	280	580
TOTAL	455	365	780

Cost estimate (M€)

If the project can start in 2013, LAGUNA detectors will come into operation around 2020-2025

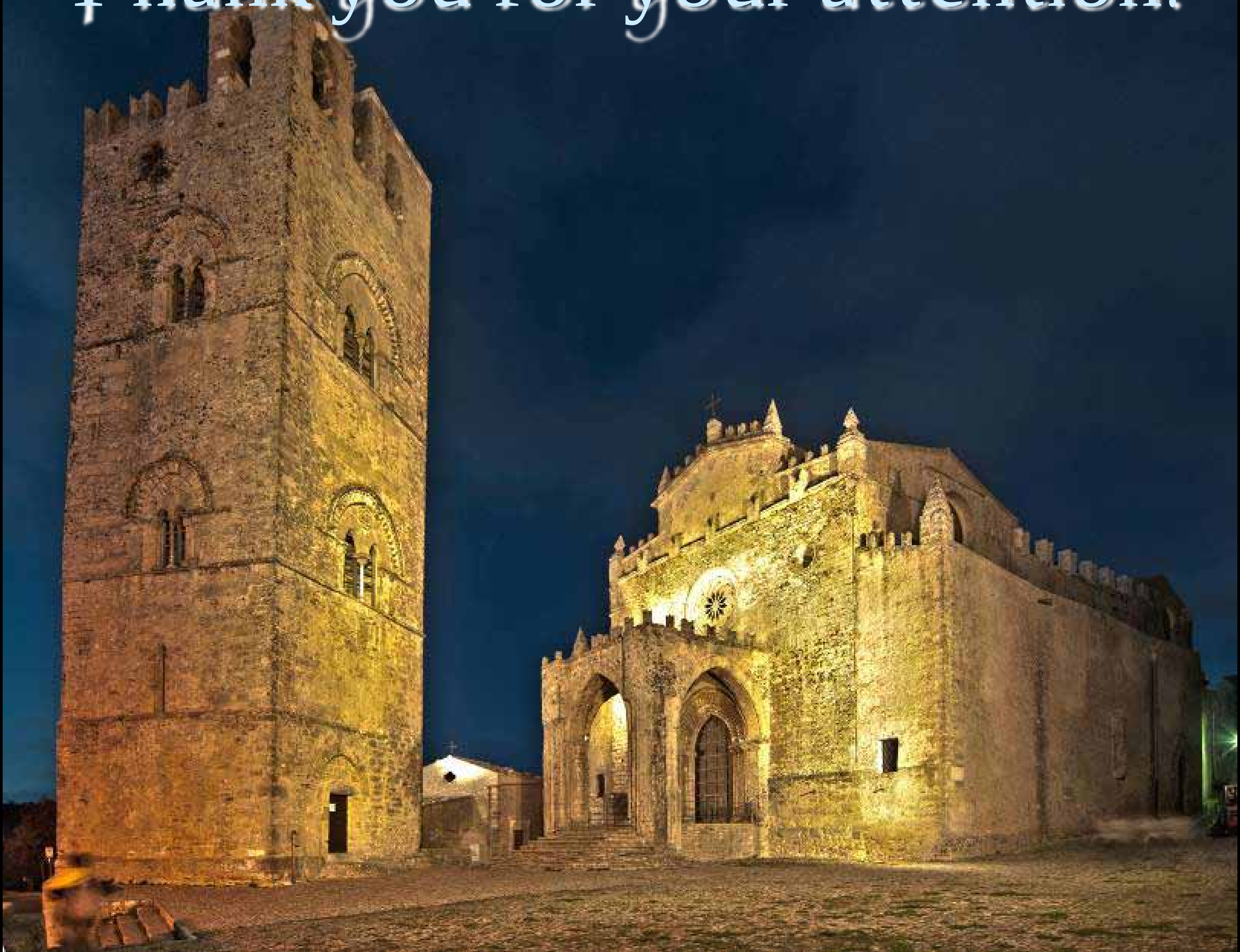


Latest developments

- According to our preliminary simulations, LENA should have relatively good tracking capabilities in the 0.5 – 5 GeV range!
- Oscillometry should provide an attractive option/alternative to long baseline measurements with neutrino superbeams

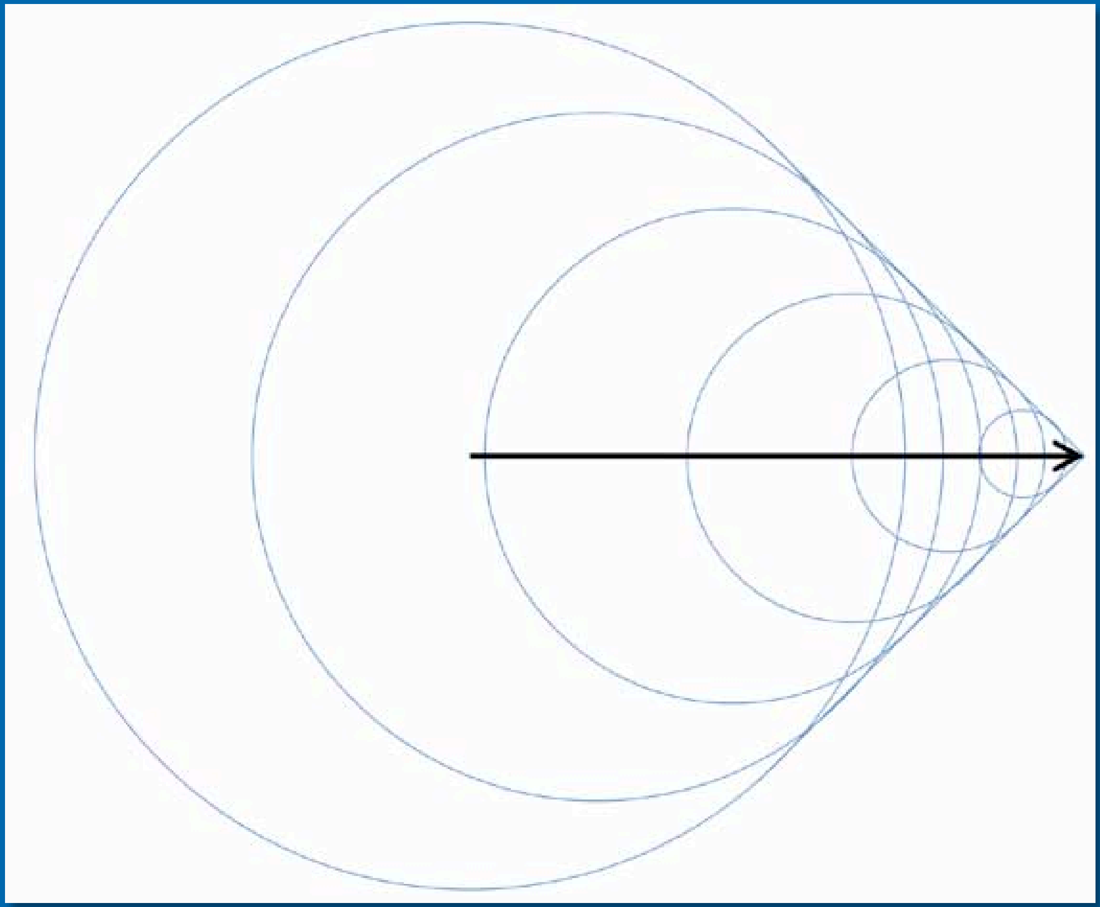
- If the above claims are confirmed, **LENA in Pyhäsalmi** would be the best choice for the first phase of LAGUNA

Thank you for your attention!



Tracking with LENA

Scintillation Light Front



HE particles create along their track a light front very similar to a Cherenkov cone.

But: 50x more light!

Tracking Performance

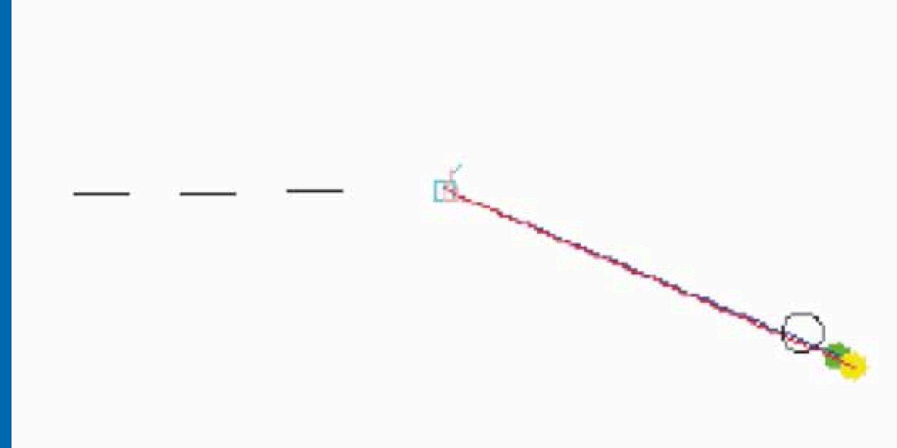
Single Tracks/Single Pion Prod.:

- Flavor recognition almost absolute
- Position resolution: few cms
- Angular resolution: few degrees
- Energy resolution: ca. 1% for 2-5 GeV range, depends on particle, read-out information

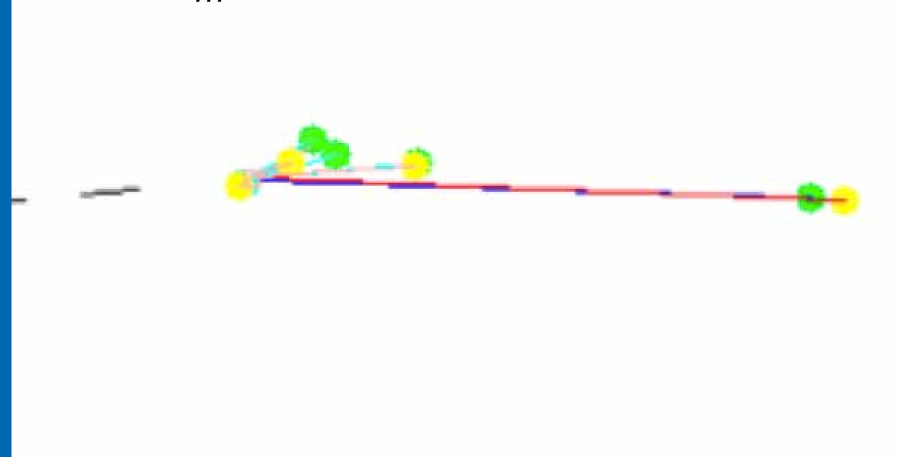
Multiparticle Events:

- 3 tracks are found if separated
- more tracks very demanding
- muon tracks always discernible
- overall energy resolution: few %
- track reconstruction less accurate

2GeV n_m quasielastic scattering



4GeV n_m deep-inelastic scattering



Oscillometry

“Global” values for the neutrino oscillation parameters

$\Delta m_{21}^2 \equiv m_2^2 - m_1^2 \approx \mathbf{7.9 \cdot 10^{-5}\ eV^2}$

$\Delta m_{31}^2 \approx \Delta m_{32}^2 \equiv m_3^2 - m_2^2 \approx \mathbf{2.4 \cdot 10^{-3}\ eV^2}$

$\sin^2\theta_{12} \approx \mathbf{0.31}$

$\sin^2\theta_{23} < \mathbf{0.9}$

$\sin^2\theta_{13} < \mathbf{0.4}$

Still unknown *(!!!)*:

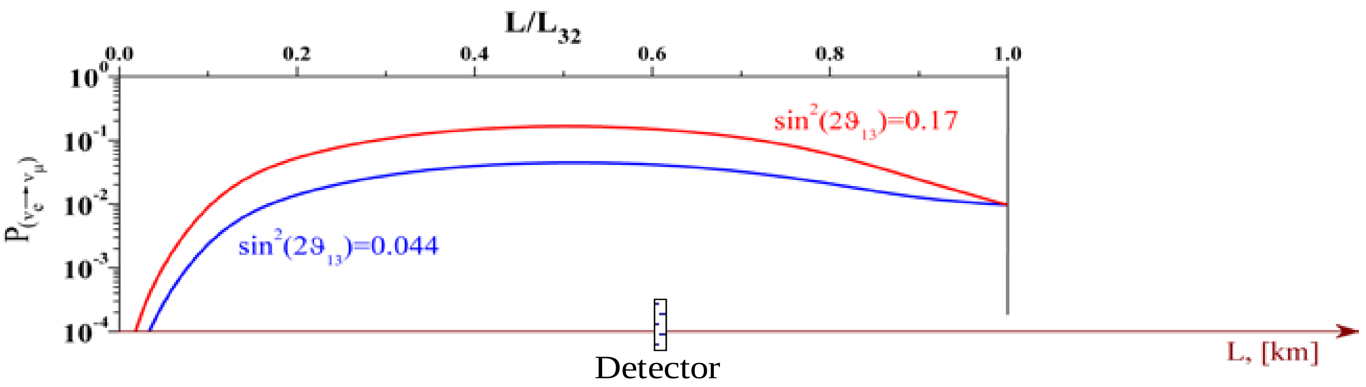
- **Neutrino/antineutrino mass values,**
- **Type of neutrino (D. or M.)**
- $\boldsymbol{\theta_{13}}$, $\boldsymbol{\theta_{23}}$ and $\mathbf{L_{32}}$

$L_{32}\,[m] = 2.5\ E_\upsilon / \Delta m_{32}^2 \quad [m \cdot MeV/eV^2]$

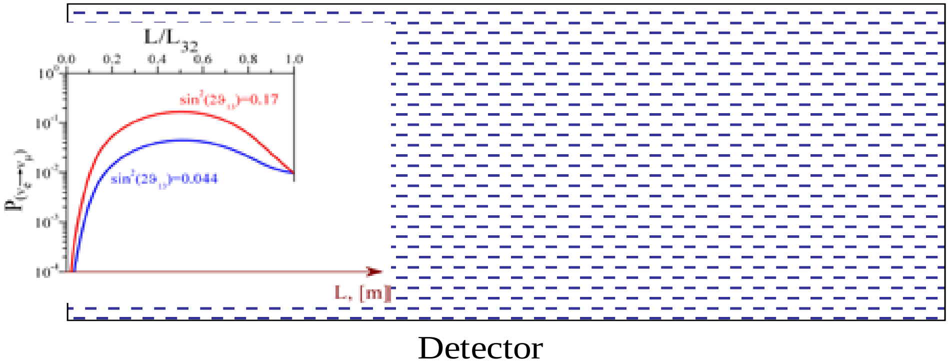
$\mathbf{L_{32}\,[m] \approx E_\upsilon\,[keV]}$

Sketch for comparison of "one-point" oscillation identification in long base-line experiments with continuous oscillometry measurement within the sizes of detector with the low energy monoenergetic neutrinos

Long baseline ($E_\nu >> 1$ MeV)→ L in [km]



Short baseline ($E_\nu << 1$ MeV)→ L in [m] - **oscillometry**



Courtesy of Yu. Novikov

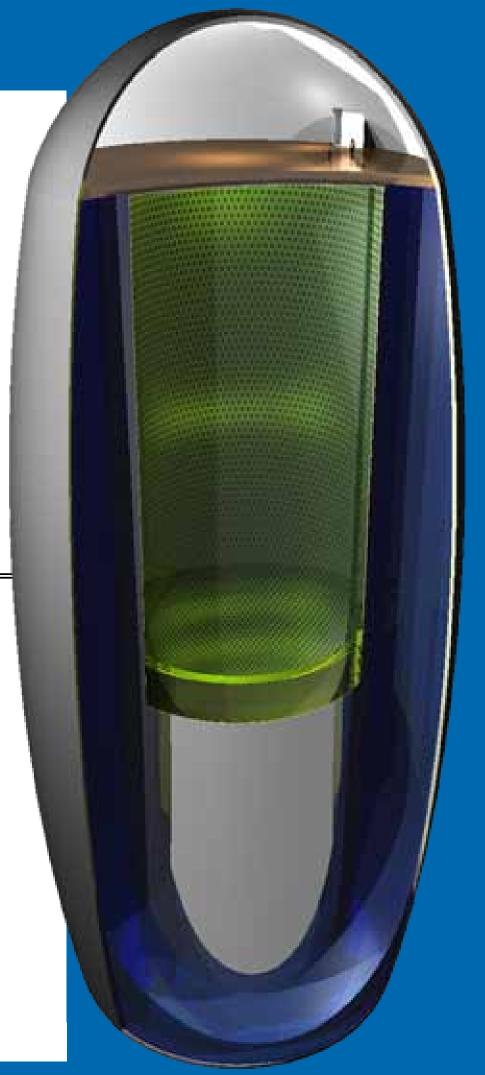


Table of candidates for the low energy monoenergetic neutrino oscillometry.

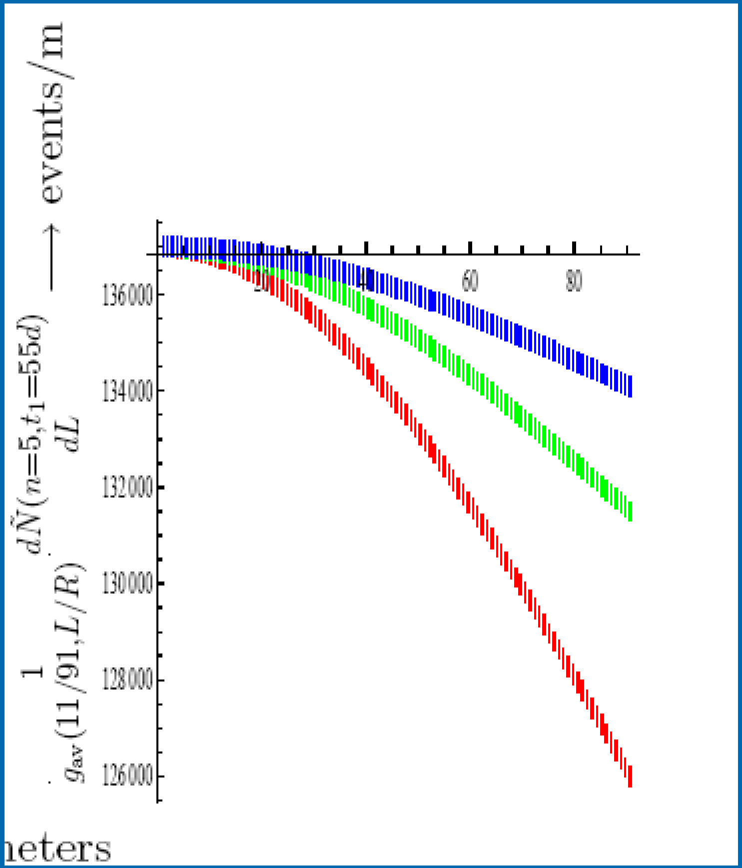
The intensity of 20 MCi for ^{51}Cr and ^{75}Se can be produced with the appropriate time irradiation in the neutron reactor

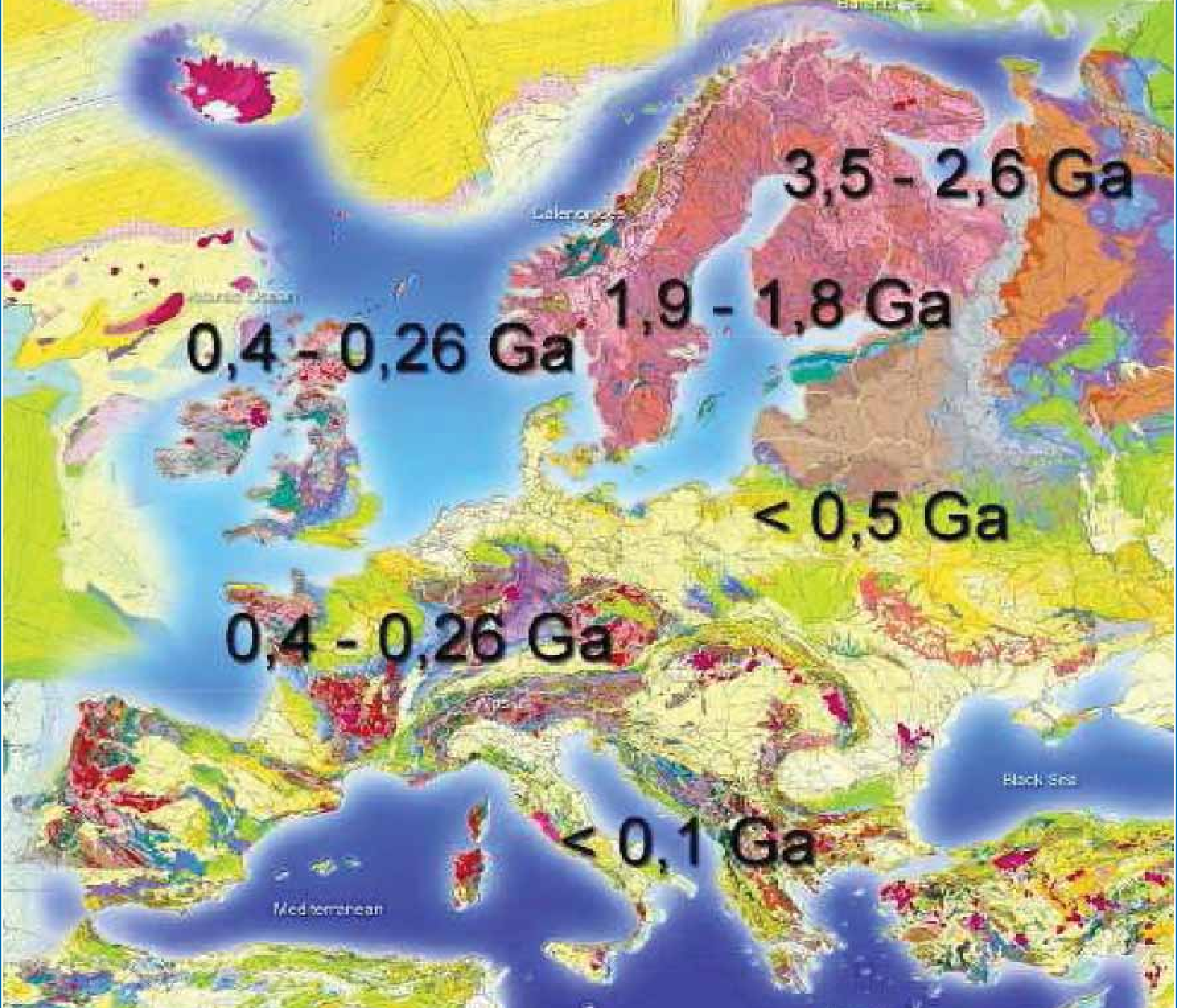
Nuclide	$T_{1/2}$	Q_ε (keV)	$E_\upsilon = Q_\varepsilon - B_i - E_\gamma$ (keV)	$L_{23}/2$ (m)	$E_{e,max}$(keV)	Irradiated target during 10 days	υ-intensity (per 1 kg of target, per s)
^{37}Ar	35 d	814	811 (100%)	406	617	Ar	$8.3x10^{15}$
^{51}Cr	28 d	753	747 (90%)	373	560	^{50}Cr	$2.3x10^{16}$
^{75}Se	120 d	863	450 (96%)	225	287	Se	$1.1x10^{14}$
^{113}Sn	116 d	1037	617 (98%)	308	436	Sn	$8x10^{11}$
^{145}Sm	340 d	616	510 (91%)	255	340	Sm	$2x10^{12}$
^{169}Yb	32 d	910	470 (83%)	235	304	Yb	$1.1x10^{15}$

Courtesy of Yu. Novikov

Number of expected ν-e events from ^{51}Cr –source installed at the top of the LS-detector LENA in dependence on the length L.

Geometrical factor of cylinder g is taken into account. Red, green and blue with the error bands correspond to the $\sin^2 2\theta_{13}$= 0.17, 0.085 and 0.045, respectively. Differences of curves are very well seen.




3,5 - 2,6 Ga
1,9 - 1,8 Ga
0,4 - 0,26 Ga
< 0,5 Ga
0,4 - 0,26 Ga
Black Sea
< 0,1 Ga
Mediterranean

Seismic levels