# Europejski projekt LAGUNA – wielkie detektory w przyszłym podziemnym laboratorium

Agnieszka Zalewska
IFT UW, 29.05.2007

Co to jest LAGUNA?

Koncepcje detektorów

Program badawczy: rozpad protonu, fizyka/astrofizyka neutrin niskich energii

Lokalizacja podziemnego laboratorium

Co się dzieje poza Europą?

# Co to jest LAGUNA?

Akronim LAGUNA oznacza „Large Apparatus studying Grand Unification and Neutrino Astrophysics"

Projekt skupia większość europejskich grup zainteresowanych budową wielkiego detektora o masie rzędu $10^5$ – $10^6$ ton w technologiach wykorzystujących ciecze: wodę, ciekły argon i ciekły scyntylator

Żadne z istniejących podziemnych laboratoriów nie jest w stanie pomieścić tak wielkiego detektora → potrzebne jest nowe, wielkie laboratorium

Wystąpienie o europejski projekt typu studyjnego (design study) w ramach FP7 (2.05.2007), którego głównym celem jest wybór optymalnej lokalizacji nowego laboratorium.

# Mapa drogowa ApPEC, styczeń 2007

| Field/<br>Experiments | Cost scale<br>(M€) | Desirable<br>start of<br>construction | Remarks |
|---|---|---|---|
| **Dark Matter Search:**<br>Low background experiments with 1-ton mass | 60-100 M€ | 2011-2013 | 2 experiments (different nuclei, different techniques), e.g. 1 bolometric, 1 noble liquid; more than 2 worldwide. |
| **Proton decay and low energy neutrino astronomy:**<br>Large infrastructure for p-decay and ν astronomy on the 100kt-1Mton scale | 400-800 M€ | 2011-2013 | - multi-purpose<br>- 3 different techniques; large synergy between them.<br>- needs huge new excavation<br>- expenditures likely also after 2015<br>- worldwide sharing<br>- possibly also accelerator neutrinos in long baseline experiments |
| **The high energy universe:**<br>*Gamma rays:*<br>Cherenkov Telescope Array CTA | 100 M€ (South)<br>50 M€ (North) | first site in 2010 | Physics potential well defined by rich physics from present gamma experiments |
| *Charged Cosmic Rays:*<br>Auger North | 85 M€ | 2009 | Confirmation of physics potential from Auger South results expected in 2007 |
| *Neutrinos:*<br>KM3NeT | 300 M€ | 2011 | FP6 design study.<br>Confirmation of physics potential from IceCube and gamma ray telescopes expected in 2008-2010 |
| **Gravitational Waves:**<br>Third generation interferometer | 250-300 M€ | Civil engineering 2012 | Conceived as underground laboratory |

# Mapa drogowa ApPEC, styczeń 2007

*"We recommend that a new large European infrastructure is put forward, as a future international multi-purpose facility on the 100'000-1'000'000 tons 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. This design study should take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal."*

**COLLABORATIVE PROJECT** 2.05.2007

**Design Study**

FP7-INFRASTRUCTURES-2007-1

| | |
|---|---|
| Proposal title (max 200 characters) | **Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics** |
| Proposal acronym | **LAGUNA** |
| Type of funding scheme | RI design study implemented as Collaborative Project |
| Work programme topics addressed | Deep underground science, particle physics, astroparticle physics |
| Name of the coordinating person | Prof. André Rubbia |

**List of participants:**

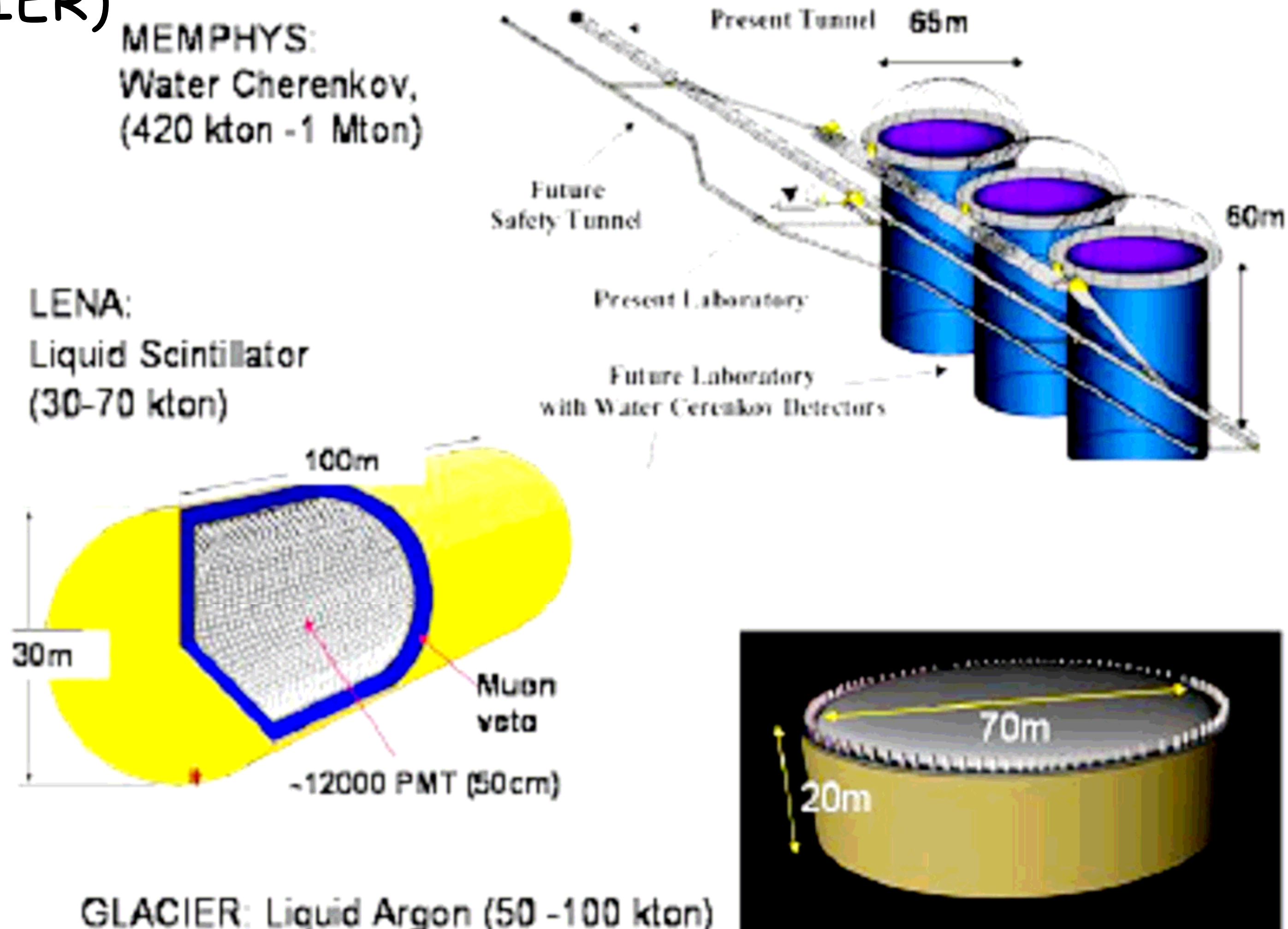
| Participant no. | Participant organisation name | Country |
|---|---|---|
| **1. ETH Zurich** | Swiss Federal Institute of Technology Zurich | Switzerland |
| **2. U-Bern** | University of Bern | Switzerland |
| **3. U-Jyväskylä** | University of Jyväskylä | Finland |
| **4. U-Oulu** | University of Oulu | Finland |
| **5. Rockplan** | Kalliosuunnittelu Oy Rockplan Ltd | Finland |
| **6. CEA/ DSM/ DAPNIA** | Commissariat à l'Energie Atomique /Direction des Sciences de la Matière | France |
| **7. IN2P3** | Institut National de Physique Nucléaire et de Physique des Particules (CNRS/IN2P3) | France |
| **8. MPG** | Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V. | Germany |
| **9. TUM** | Technische Universität München | Germany |
| **10. U-Hamburg** | Universität Hamburg | Germany |
| **11. IFJ PAN** | H.Niewodniczanski Institute of Nuclear Physics of the Polish Academy of Sciences, Krakow | Poland |
| **12. IPJ** | A.Sołtan Institute for Nuclear Studies | Poland |
| **13. US** | University of Silesia | Poland |
| **14. UWr** | Wroclaw University | Poland |
| **15. KGHM CUPRUM** | KGHM CUPRUM Ltd Research and Development Centre | Poland |
| **16. IGSMiE PAN** | Mineral and Energy Economy Research Institute of the Polish Academy of Sciences | Poland |
| **17. LSC** | Laboratorio Subterraneo de Canfranc | Spain |
| **18. UGR** | University of Granada | Spain |
| **19. UDUR** | University of Durham | United Kingdom |
| **20. U-Sheffield** | The University of Sheffield | United Kingdom |
| **21. Technodyne** | Technodyne International Ltd | United Kingdom |
| **22. ETL** | Electron Tubes | United Kingdom |
| **23. U-Aarhus** | University of Aarhus | Denmark |
| **24. AGT** | AGT Ingegneria Srl, Perugia | Italy |

## Table 1.3 a: Work package list

| Work package no. | Work package title | Type of activity | Lead participant no. | Person-months | Start month | End month |
|---|---|---|---|---|---|---|
| WP1 | Management, coordination and assessment | MGT | ETHZ | 52 | 1 | 36 |
| WP2 | Underground Infrastructures and Engineering | RTD | U-Oulu | 221 | 1 | 35 |
| WP3 | Tank Infrastructure and Liquid Handling | RTD | TUM | 249 | 1 | 35 |
| WP4 | Tank Instrumentation and Data Handling | RTD | IN2P3 | 439 | 1 | 35 |
| WP5 | Safety and environmental issues | RTD | U-Sheffield | 65 | 1 | 35 |
| WP6 | Science Impact and Outreach | RTD | IFJ PAN | 454 | 1 | 35 |
| | **TOTAL** | | | **1480** | | |

# Koncepcje detektorów

Wodny (MEMPHYS), scyntylacyjny (LENA), ciekło-argonowy (GLACIER)



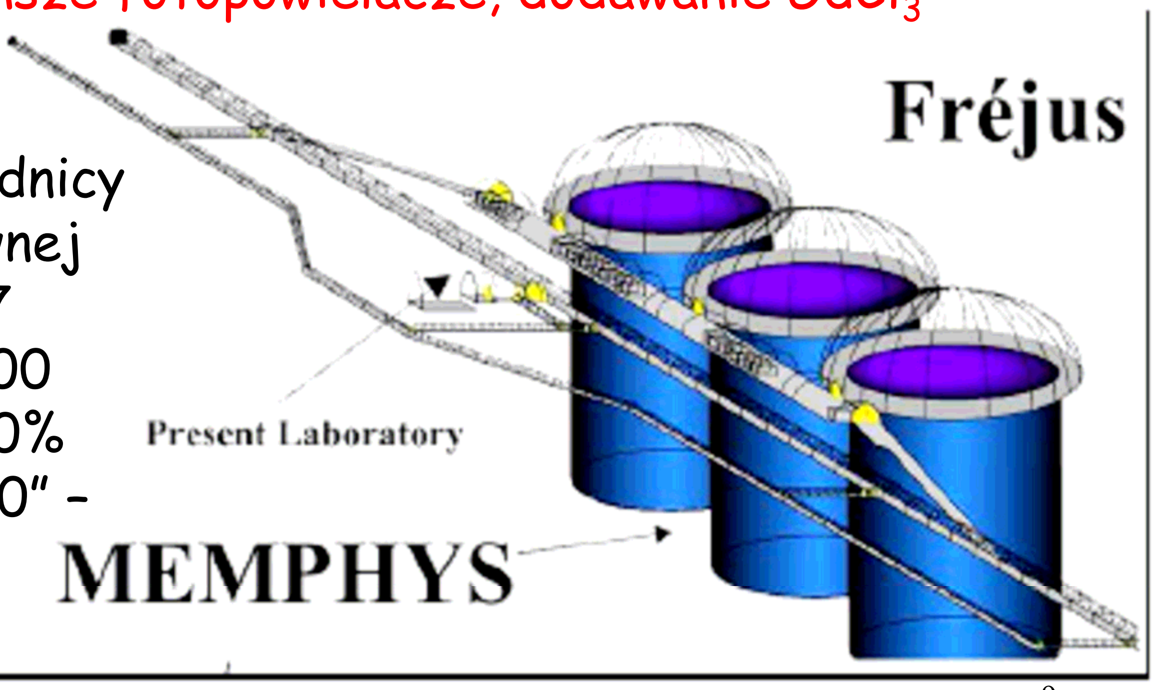
# Wodny detektor MEMPHYS

Koncepcja: pierwotnie rozwijana dla laboratorium Frejus, pierwowzór detektor SuperKamiokande

Zalety: najtańszy materiał tarczy, dobrze opanowana technologia, możliwa ekstrapolacja do masy rzędu 1 Mtony

Wyzwania: lepsze i tańsze fotopowielacze, dodawanie $GdCl_3$

Konstrukcja: 3-5 zbiorników, każdy o średnicy i wysokości 65 m, aktywnej masie detektora ok. 147 kton, odczyt przez 81000 fotopowielaczy (12" – 30% pokrycia powierzchni, 20" – 40% pokrycia)



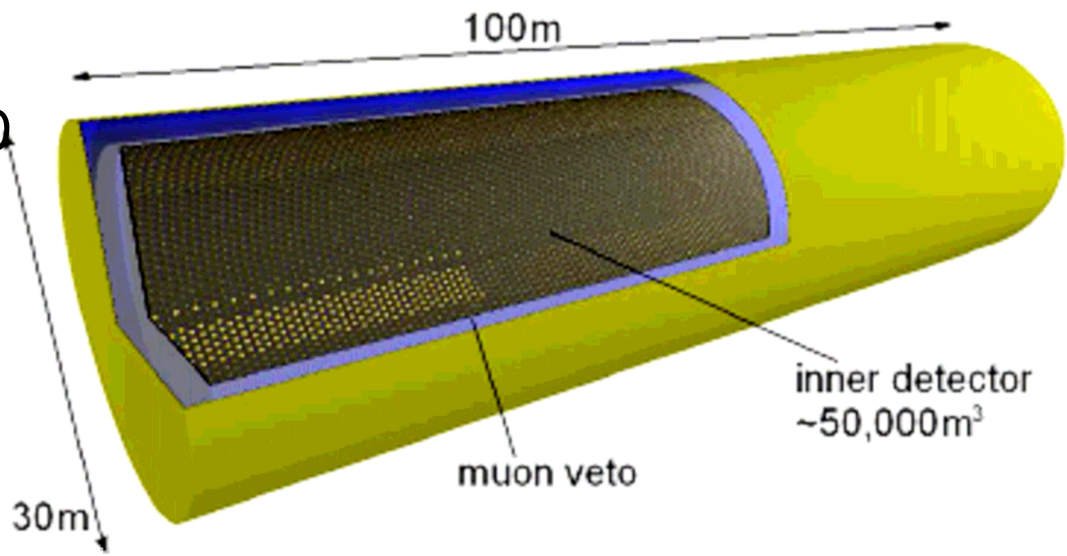
# Scyntylacyjny detektor LENA

Koncepcja: pierwotnie rozwijana dla laboratorium Pyhäsalmi (Finlandia), pierwowzór – detektory Borexino i KamLAND

Zalety: niski próg energetyczny, dobra energetyczna zdolność rozdzielcza, znana technologia

Wyzwania: lepszy i tańszy odczyt światła (fotopowielacze, koncentratory światła

Konstrukcja: cylinder o średnicy 30 m i długości 100 m, pomiarowej masie detektora ok. 50 kton, odczyt przez 12 000 fotopowielaczy (20" – 30% pokrycia powierzchni, z koncentratorami światła - 50% pokrycia)



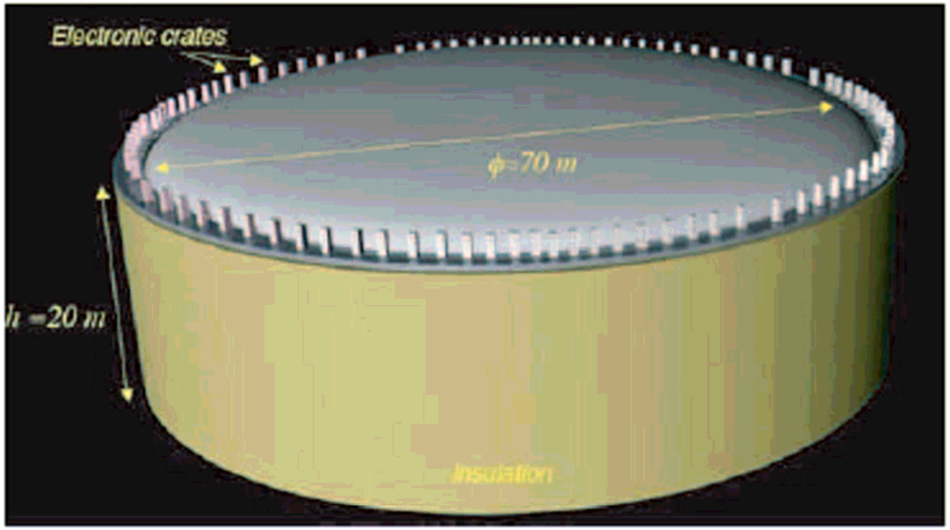
# Ciekło-argonowy detektor GLACIER

Koncepcja: pierwotnie rozwijana dla Sieroszowic i Gran Sasso
pierwowzór – detektor ICARUS

Zalety: bardzo dobra przestrzenna i energetyczna zdolność rozdzielcza → obrazowanie topologii, identyfikacja cząstek

Wyzwania: 20-metrowy dryf elektronów, wielka instalacja kriogeniczna, termiczna izolacja zbiornika

Konstrukcja: cylinder o średnicy 70 m i wysokości 100 m, masa detektora ok. 100 kton, odczyt elektronów jonizacji oraz światła (scyntylacje – 1000 8″ PMT, promieniowanie Czerenkowa – 27000 8″ PMT)



# Program fizyczny

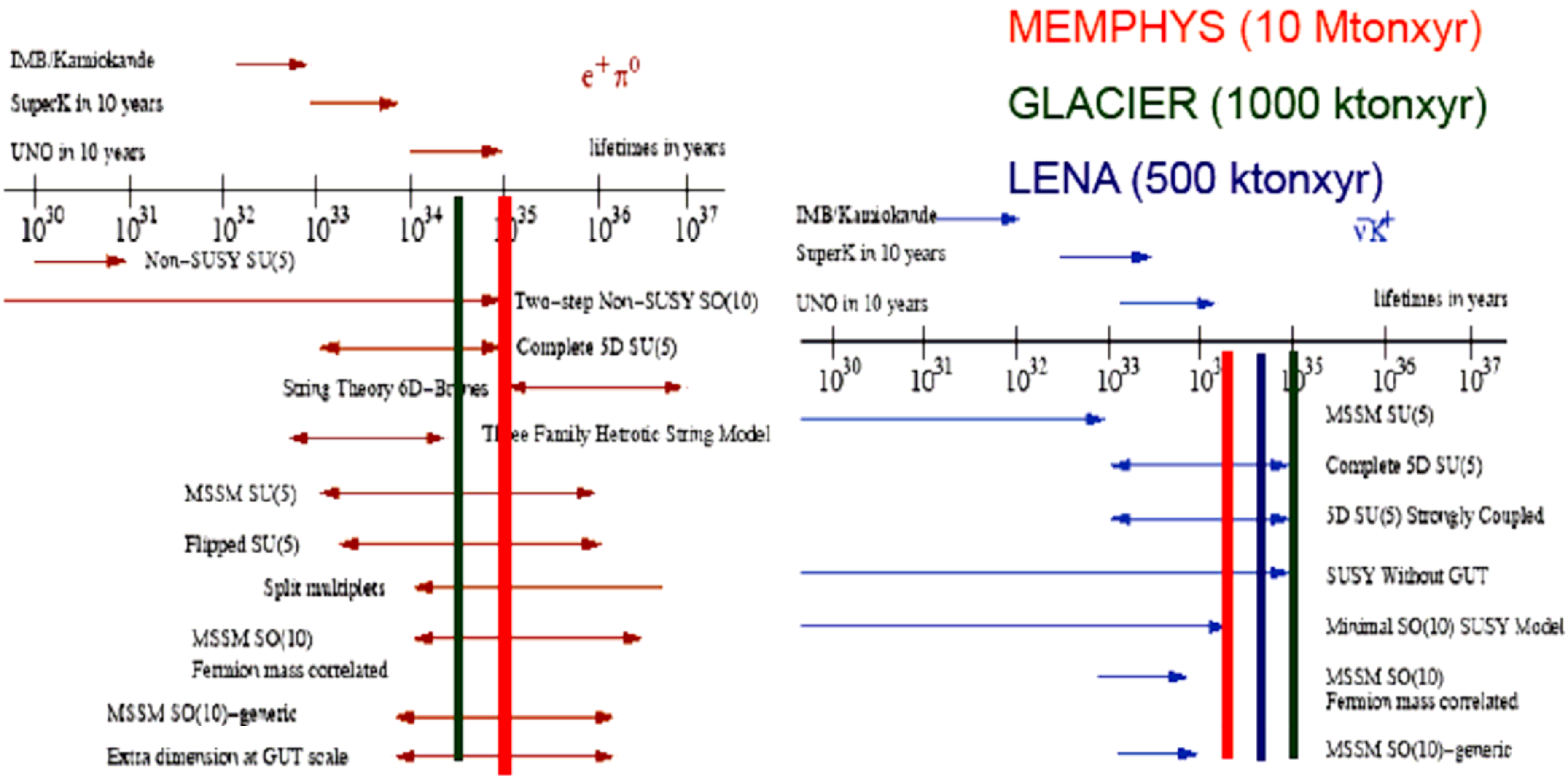
1. Poszukiwania rozpadu protonu
2. Badania nisko-energetycznych neutrin/antyneutrin pochodzenia astrofizycznego (z wybuchu SN, słoneczne, atmosferyczne, z tła od starych wybuchów SN w obrębie naszej galaktyki) oraz geo-neutrin
3. Badania własności neutrin w oparciu o wiązki akceleratorowe

**Table 1 Overview of the physics potential of the three types of instruments considered**

| Topics | GLACIER (100 kt) | LENA (50 kt) | MEMPHYS (400 kt) |
|---|---|---|---|
| **proton decay**, sensitivity (years)<br>decay mode $e^+ \pi^0$<br>decay mode anti-ν $K^+$ | <br>$0.5 \cdot 10^{35}$<br>$1.1 \cdot 10^{35}$ | <br>TBD<br>$0.4 \cdot 10^{35}$ | <br>$1.0 \cdot 10^{35}$<br>$0.2 \cdot 10^{35}$ |
| **SN at 10 kpc**, # events<br>CC<br>NC<br>ES | <br>$2.5 \cdot 10^4$ ($\nu_e$)<br>$3.0 \cdot 10^4$<br>$1.0 \cdot 10^3$ (e) | $9.0 \cdot 10^3$ (anti-$\nu_e$)<br>$3.0 \cdot 10^3$<br>$5.0 \cdot 10^3$ (p)<br>$6.0 \cdot 10^2$ (p) | <br>$2.0 \cdot 10^5$ (anti-$\nu_e$)<br>-<br>$1.0 \cdot 10^3$ (e) |
| **Diffuse SN**<br># Signal/Background events<br>(after 5 years) | <br>60/30 | <br>(10-115)/4 | <br>(40-110)/50<br>(with Gadolinium) |
| **Solar neutrinos**<br># events, 1 year | $^8$B ES : $4.5 \cdot 10^4$<br>Abs: $1.6 \cdot 10^5$ | $^7$Be: $2.0 \cdot 10^6$<br>pep: $7.7 \cdot 10^4$<br>CNO: $7.6 \cdot 10^4$<br>$^8$B(CC): $3.6 \cdot 10^2$<br>$^8$B(NC): $5 \cdot 10^3$ | $^8$B ES: $1.1 \cdot 10^5$ |
| **Atmospheric ν**<br># events, 1 year | $1.1 \cdot 10^4$ | TBD | $4.0 \cdot 10^4$ |
| **Geo-neutrinos** # events, 1 year | Below threshold | $1.5 \cdot 10^3$ | Below threshold |

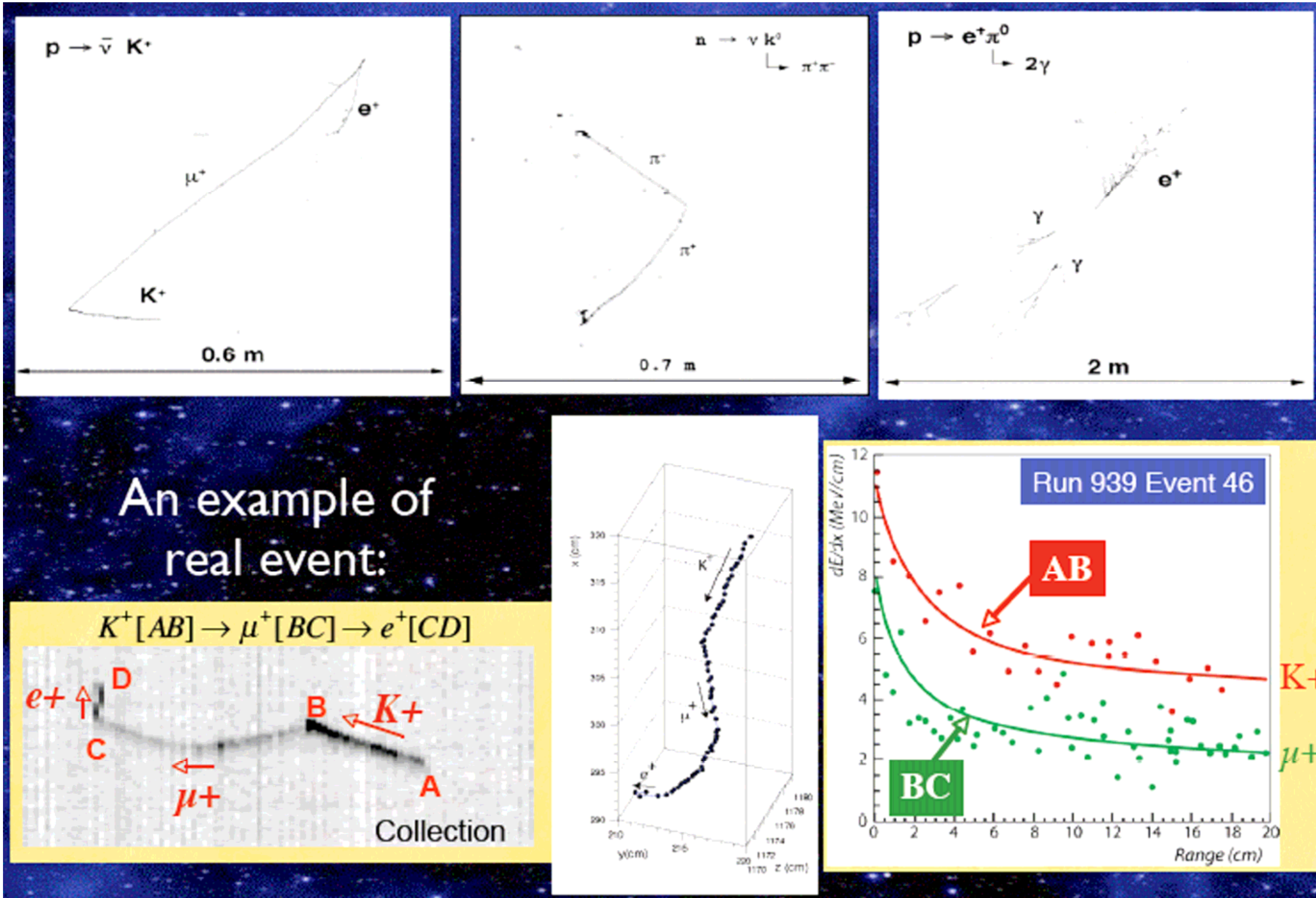
# Przewidywania przy założeniu 10 lat zbierania danych

# Rozpad protonu – pomiary, porównanie z teorią




Lista zawiera tylko wybrane, najprostsze modele

# Rozpad protonu w ciekło-argonowej TPC



# Neutrina z Supernowych

## 1. Supernova physics:

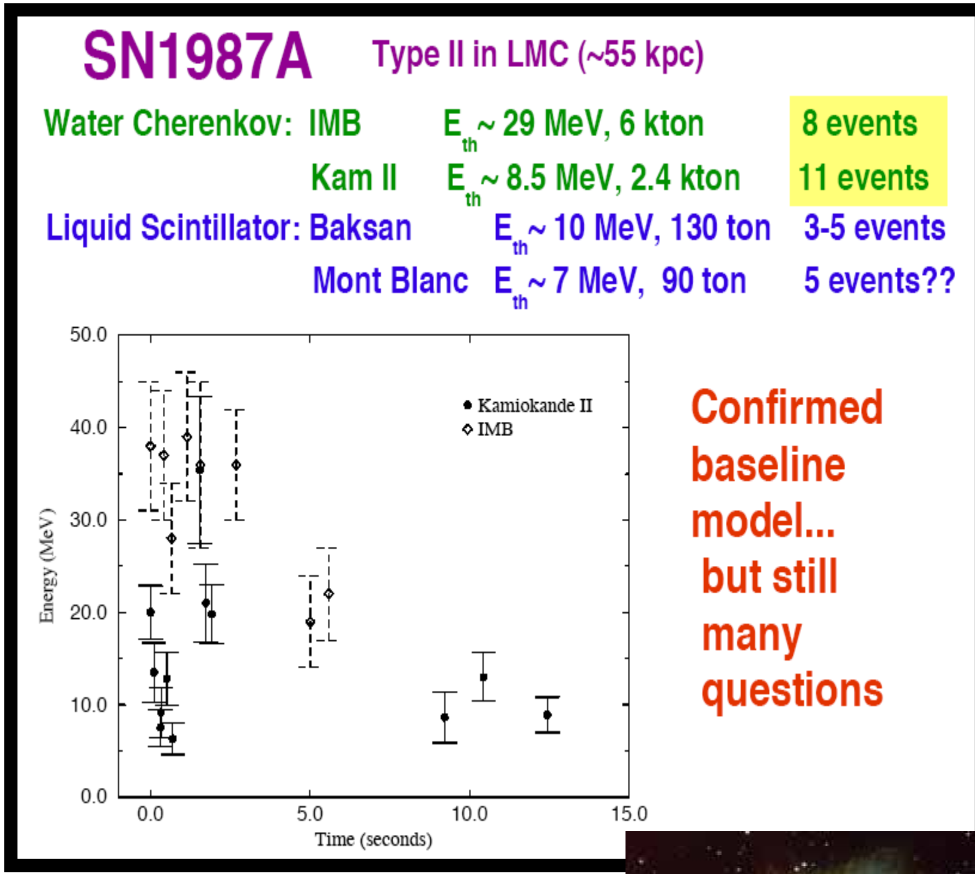
- Gravitational collapse mechanism
- Supernova evolution in time
- Burst detection
- Cooling of the proto-neutron star
- Shock wave propagation
- Black hole formation?

## 2. Neutrino properties

- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and $\theta_{13}$ mixing angle

## 3. Early alert for astronomers

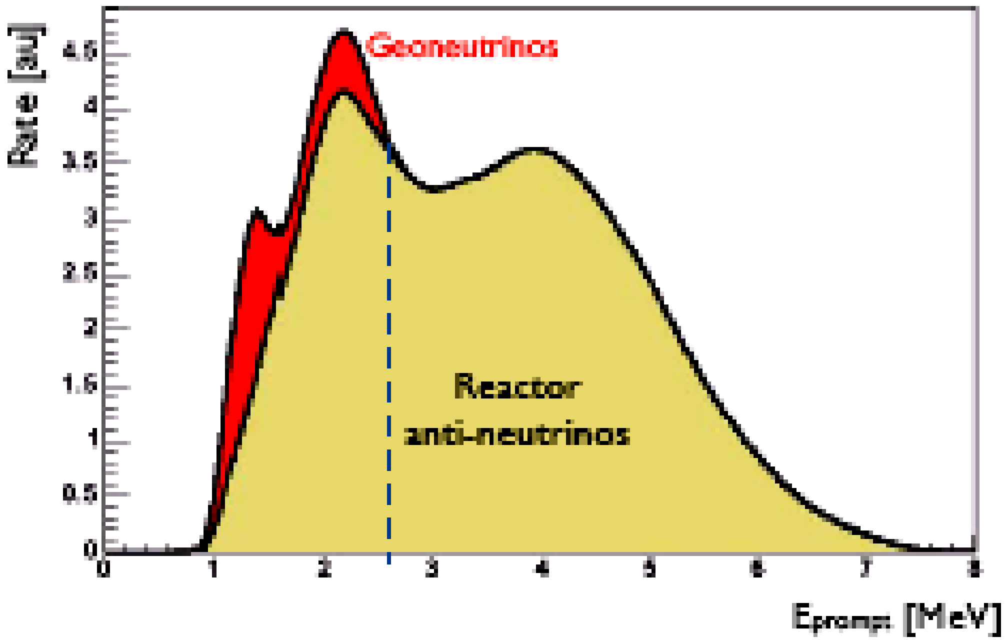
- Pointing to the supernova




# Geo-neutrina

• Antineutrina z $^{238}U$, $^{232}Th$ i $^{40}K$ dają możliwość zajrzenia do wnętrza Ziemi i zbadania mechanizmu generacji energii

• KamLAND był pierwszym detektorem dostatecznie czułym, aby zmierzyć geoneutrina z rozpadów U i Th (neutrina z K poniżej progu detekcji w scyntylatorze)




**Ograniczenie z KamLAND-u na ciepło z rozpadów radioaktywnych < 60 TW**

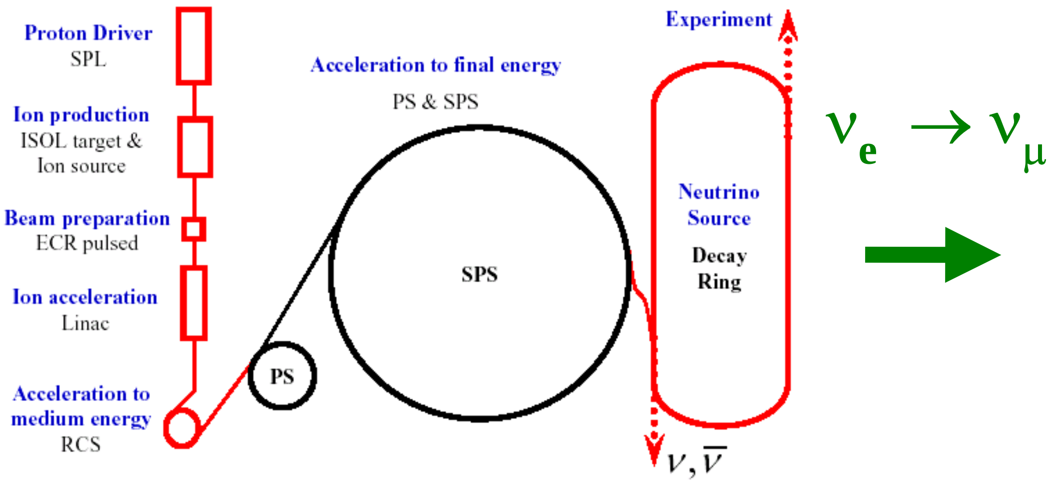
**T.Araki et al., Nature 436 (2005) 467**

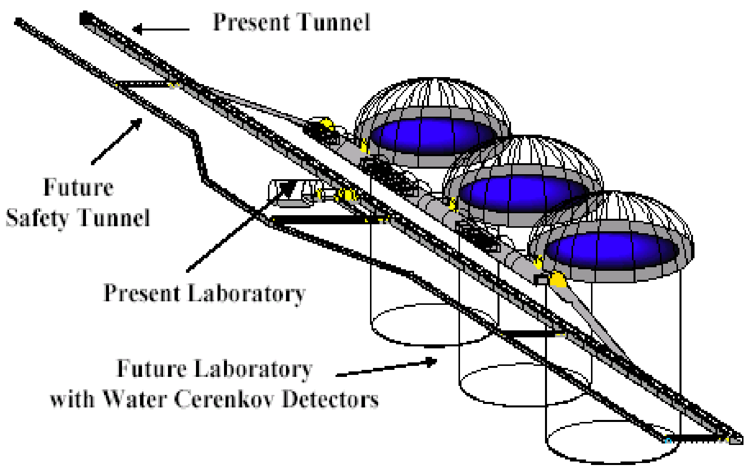
**KamLAND:**
**sygnał $25^{+19}_{-18}$, tło 127±13**
**LENA:**
**sygnał 1000, tło 240(/rok)**

# Neutrina z wiązki $\beta$ – MEMPHYS

• Przyspieszanie jąder $^{6}He$ (źródło antyneutrin) i $^{18}Ne$ (źródło neutrin), R&D w ramach programu EURISOL DS. (FP6)

• Synergia z programem rozbudowy CERN-owskich akceleratorów, potrzebny ogromny detektor o niskiej gęstości i krótka baza pomiarowa → MEMPHYS, wady: małe, źle zmierzone i źle rozumiane przekroje czynne, badania oscylacji bez czułości na znak $\Delta m^2_{23}$



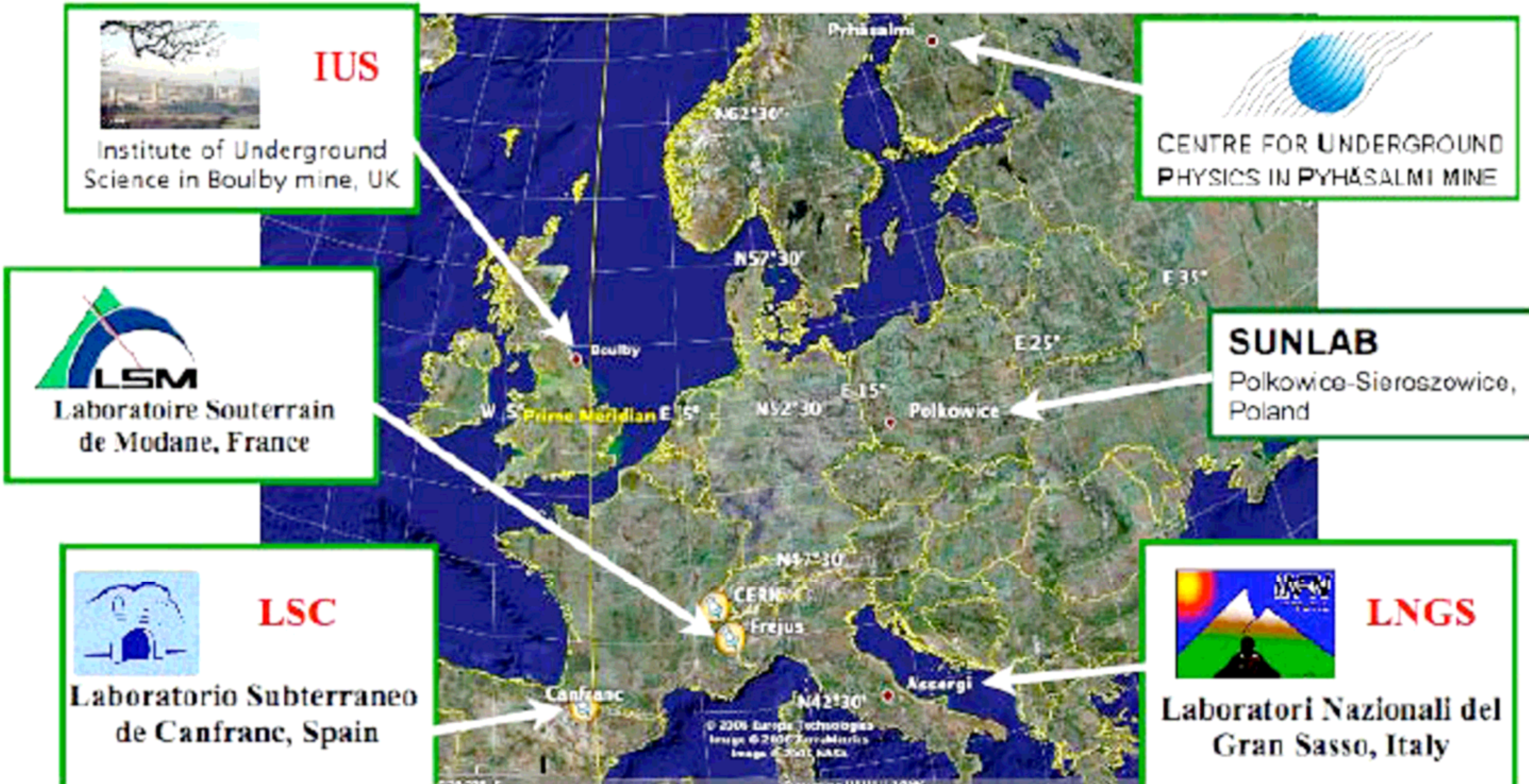
# Neutrina niskoenergetyczne – c.d.

Neutrina słoneczne – powrót do astronomii Słońca

Neutrina atmosferyczne – duży zakres E/L, więc przy wielkich detektorach wspomaganie pomiarów akceleratorowych możliwe

Poszukiwanie Ciemnej Materii z anihilacji WIMO-ów w środku Słońca

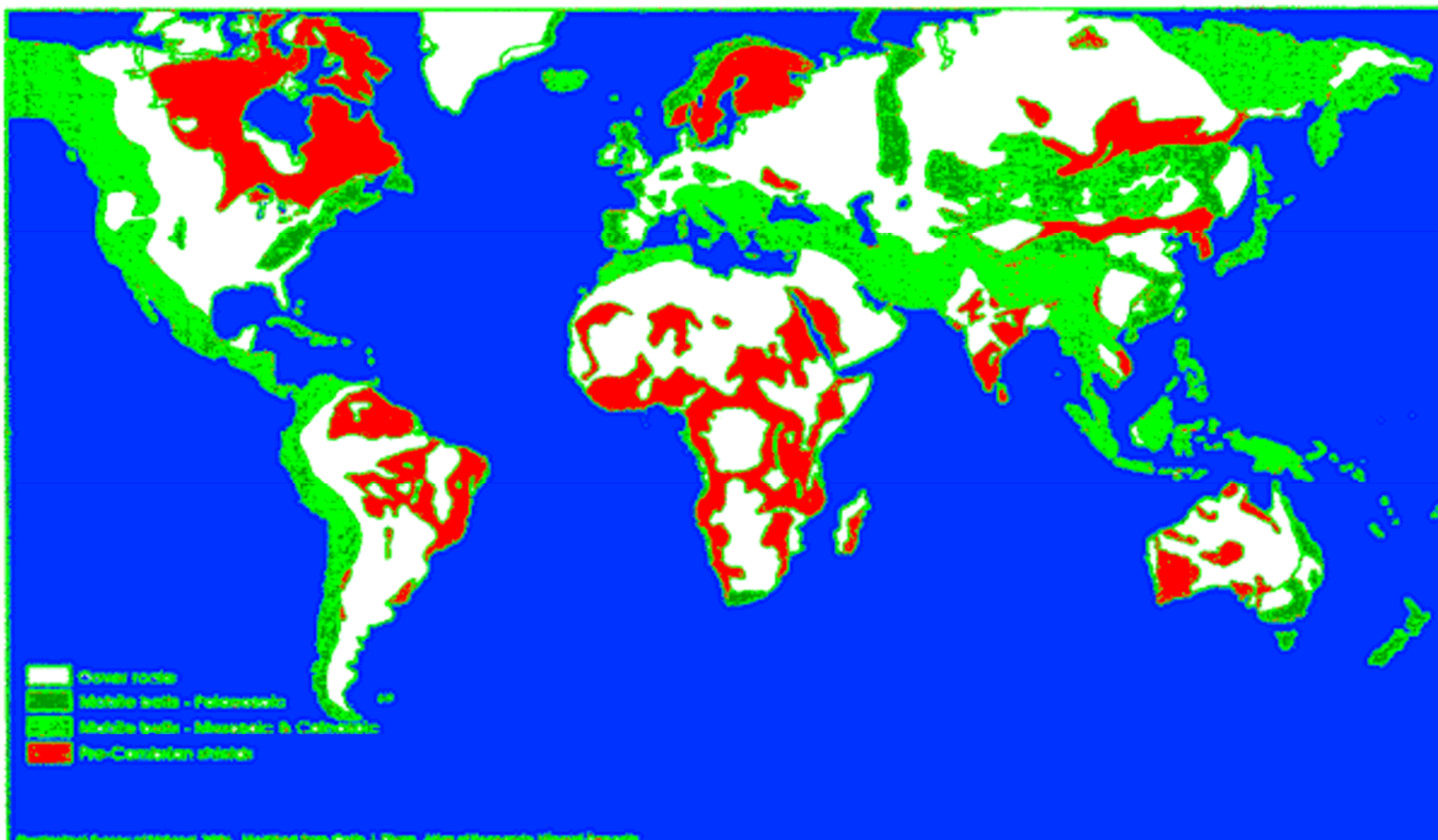
# Lokalizacja podziemnego laboratorium




Istniejące i powstające podziemne laboratoria europejskie

# Bedrock zones in the Earth

- Red: very old bedrock, hard crystalline rock: usually very good
- Green: mobile belts (mountains etc), hard rock: fair/variable
- White: sedimentary covers (soft rock): often bad
- Local variations within each zone



# Nuclear reactor background

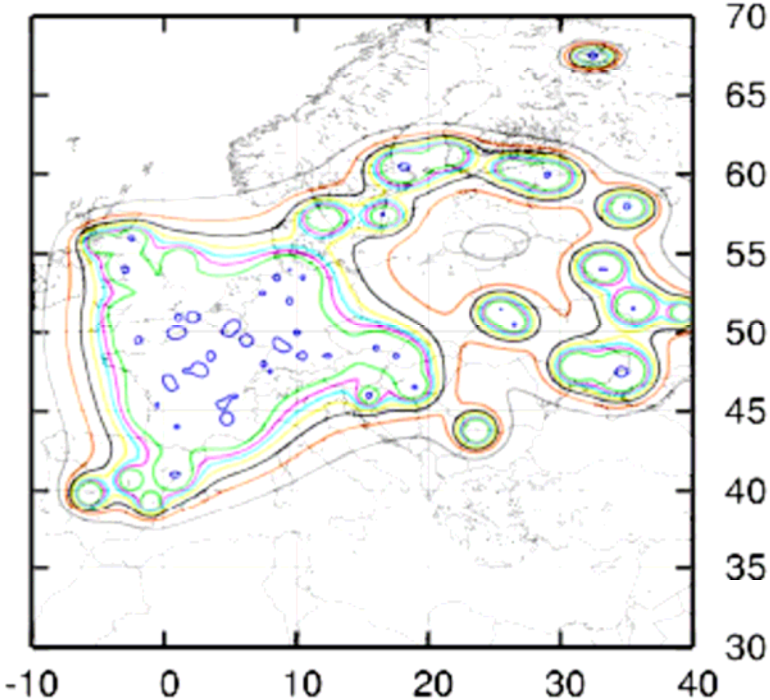
- Relevant mostly for LENA
- Reactor fluxes estimated globally
- Marine reactors irrelevant?

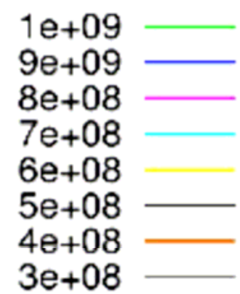
| Location | $\nu$ ($10^8$ $1/m^2$ s) |
|---|---|
| Pyhäsalmi | 40 |
| Gran Sasso | 54 |
| Frejus | 175 |
| Canfranc | 196 |
| Boulby | 190 |
| Kamioka | 408 |
| Sudbury | 100 |
| Soudan | 33 |
| Pylos | 12 |

2005

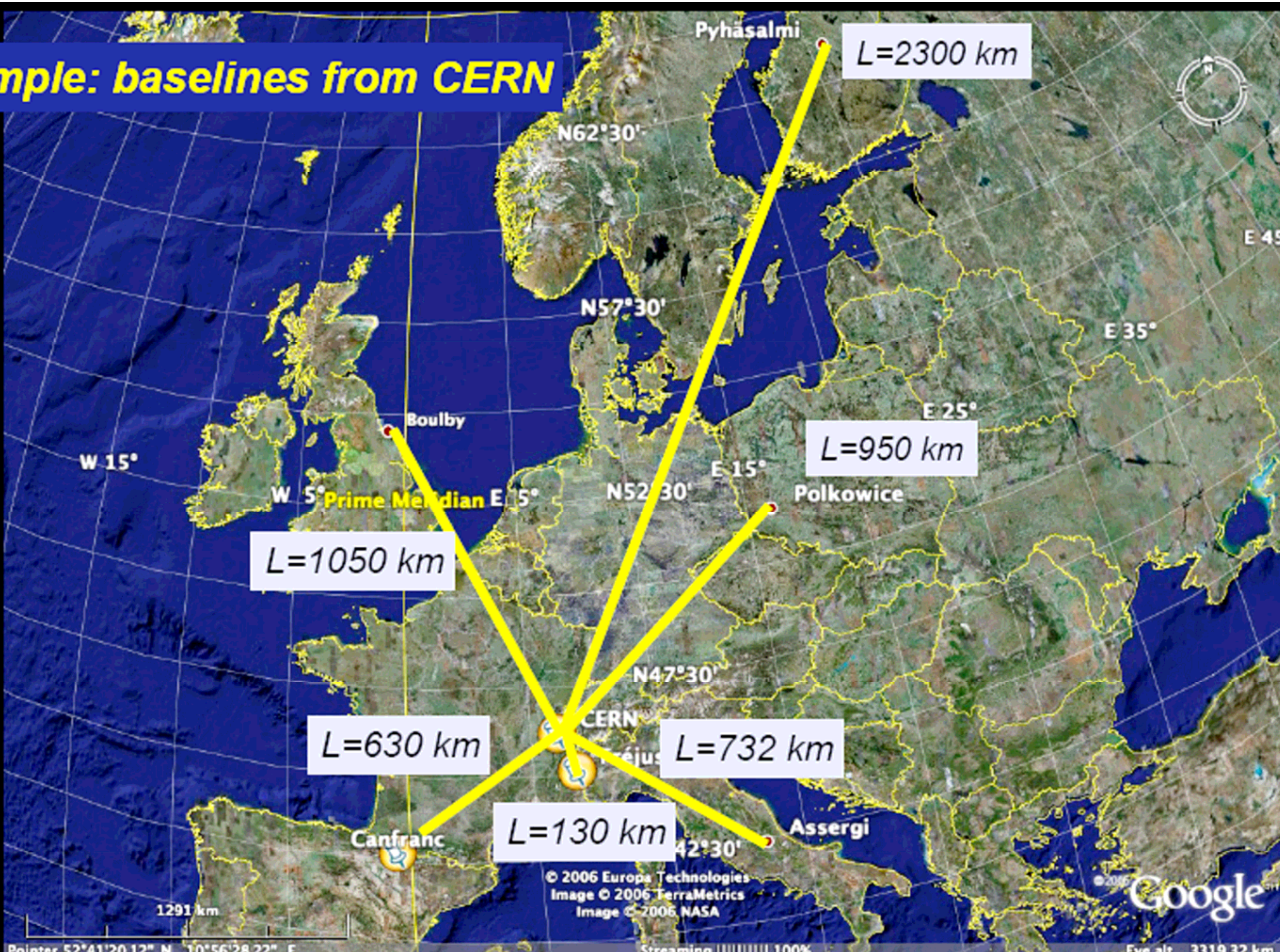
Reactor electron anti-neutrino flux density

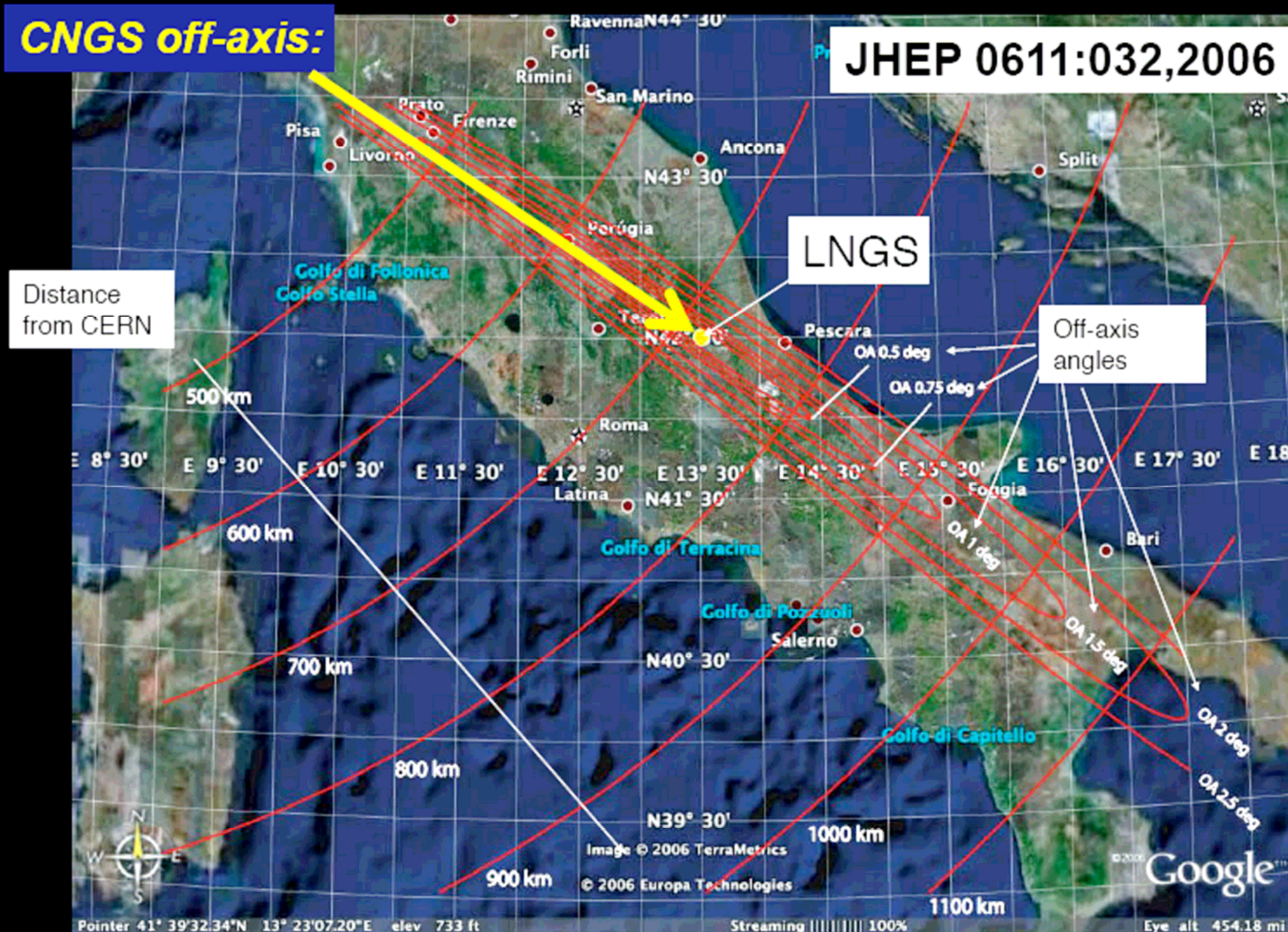
Prediction for 2015



# Example: baselines from CERN




CNGS off-axis:
JHEP 0611:032,2006
LNGS
Distance from CERN
Off-axis angles
OA 0.5 deg
OA 0.75 deg
OA 1 deg
OA 1.5 deg
OA 2 deg
OA 2.5 deg
500 km
600 km
700 km
800 km
900 km
1000 km
1100 km
Ravenna
Forli
Rimini
San Marino
Prato
Firenze
Pisa
Livorno
Ancona
Split
Perugia
Golfo di Follonica
Golfo Stella
Pescara
Roma
Latina
Foggia
Bari
Golfo di Terracina
Golfo di Pozzuoli
Salerno
Golfo di Capitello
N43° 30'
N41° 30'
N40° 30'
N39° 30'
E 8° 30'
E 9° 30'
E 10° 30'
E 11° 30'
E 12° 30'
E 13° 30'
E 14° 30'
E 16° 30'
E 17° 30'
Image © 2006 TerraMetrics
© 2006 Europa Technologies
Google
Pointer 41° 39'32.34"N 13° 23'07.20"E elev 733 ft
Streaming 100%
Eye alt 454.18 mi

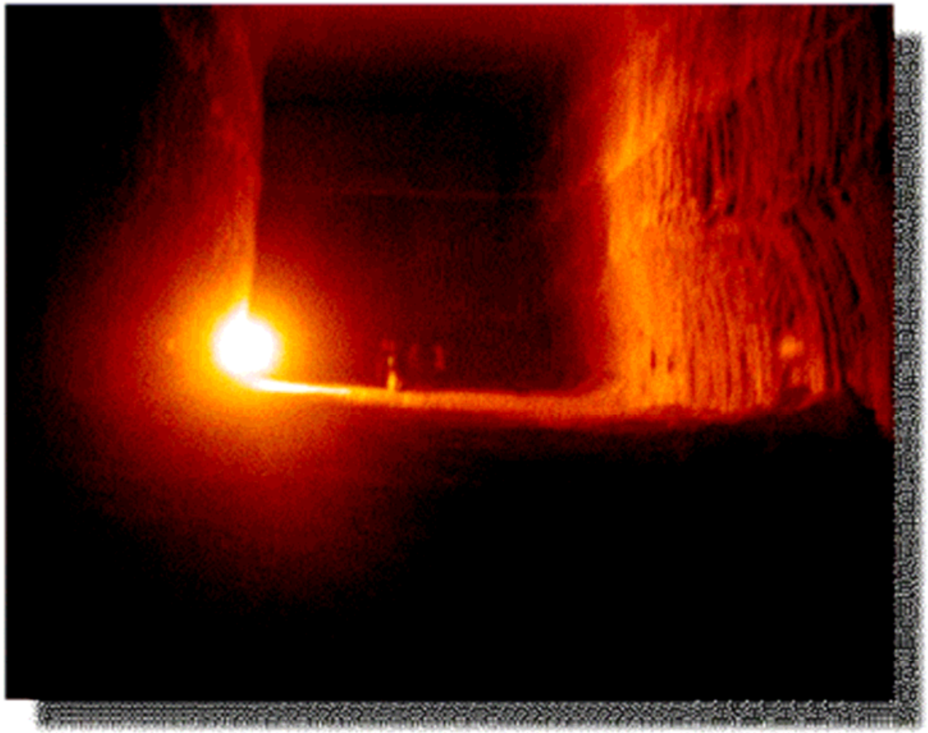
# Sieroszowice mine (Poland) - big salt cavern

Copper - 6th position in the world's exploitation ranking

Silver - 2nd position

But also Salt

A. Zalewska



Volume (100x15x20) $m^3$

Depth ~950 m from a surface

Salt layer ~70 m thick

Temperature ~35$^0$C

Very good radioactive background conditions

# Lokalizacja podziemnego laboratorium

## *Very preliminary sites vs experiments*

| | | Mt Water Cerenkov | 50 kt Liquid Scintillator | 100 kt Liquid Argon |
|---|---|---|---|---|
| Fréjus | Tunnel / hard rock | √√√ | √√ | √√ |
| Gran Sasso | Tunnel / soft rock | √ | √√ | √ |
| Canfranc | Tunnel | ? | ? | ? |
| Pyhäsalmi | Mine / hard rock | √ | √√√ | √√ |
| Boulby | Mine / salt (potash) | ? | ? | ? |
| Polkowice - Sieroszowice | Mine / salt & rock | √ | √√ | √√√ |
| Green fields | Own shaft / Hard rock | √ | √ | √√√ |

√√√ primary interest; √√ probably; √ unlikely; ? unknown

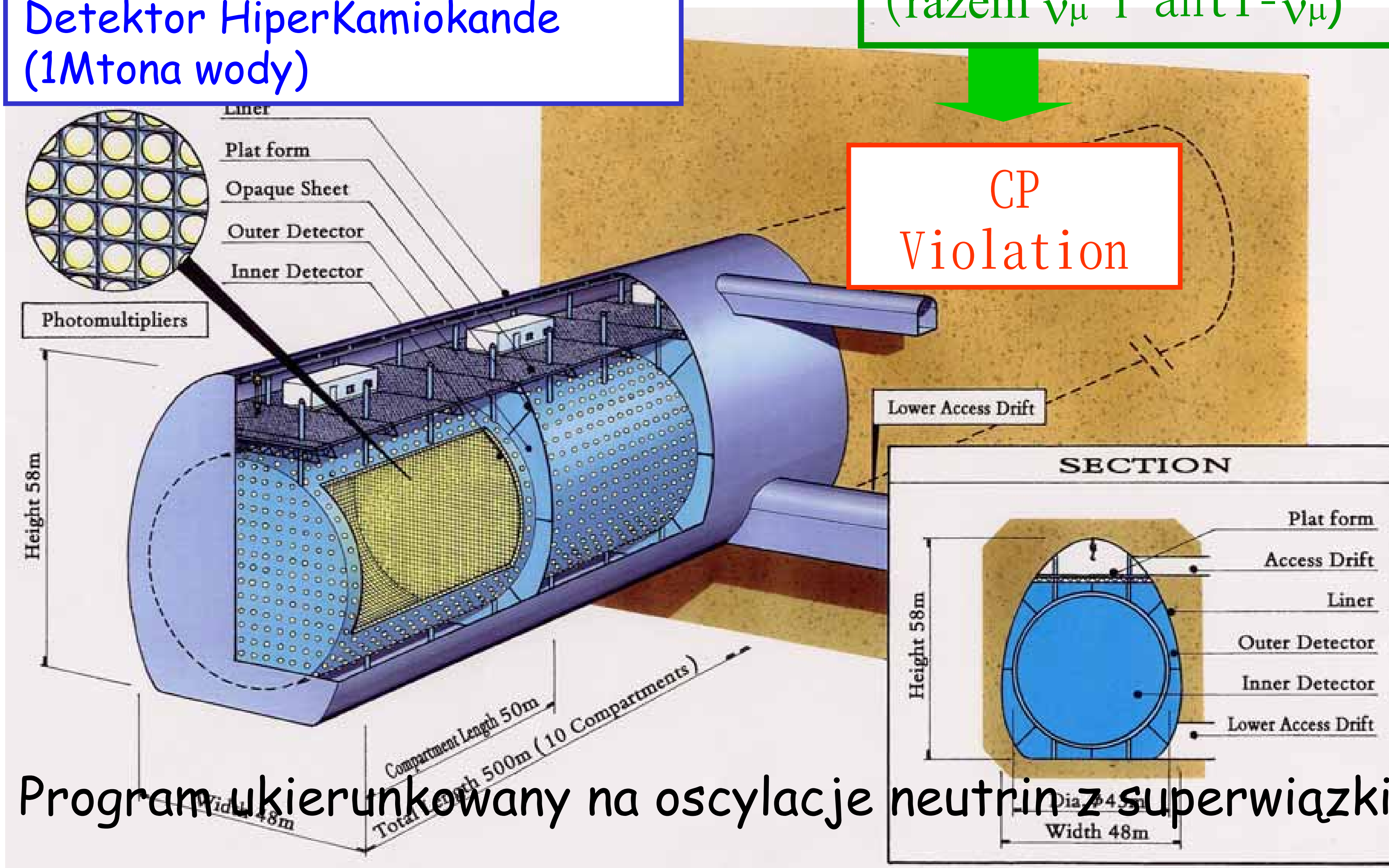
# Co się dzieje poza Europą? Japonia - faza2 T2K

Akcelerator: 0.77 MW → 4 MW

Detektor HiperKamiokande (1Mtona wody)

$10^6$ przypadków (razem $\nu_\mu$ i anti-$\nu_\mu$)

CP Violation




Program ukierunkowany na oscylacje neutrin z superwiązki

# Co się dzieje poza Europą? USA - DUSEL

DUSEL – Deep Underground Science and Engineering Laboratory

Bardzo bogaty interdyscyplinarny program – od fizyki, poprzez biologię i nauki inżynierskie do kształcenia młodzieży i popularyzacji nauki

Cztery możliwe lokalizacje (Homestake, Henderson, Pioneer Tunnel, Soudan), wybór wkrótce, w najkorzystniejszym przypadku start w 2010 roku

# Scientific Motivation

Extraordinary increase of interest in underground science and engineering

## 3 Fundamental Questions that uniquely require a deep laboratory

- What is the universe made of? What is the nature of dark matter? What is dark energy? What happened to the antimatter? What are neutrinos telling us?
  Particle/Nuclear Physics: Neutrinos, proton decay
  Astrophysics: Dark Matter, Solar/Supernovae neutrinos

- How deeply in the earth does life extend? What makes life successful at extreme depth and temperature? What can life underground teach us about how life evolved on earth and about life on other planets?
  Unprecedented opportunity for long term in situ observations

- How rock mass strength depends on length and time scales? Can we understand slippage mechanisms in high stress environment, in conditions as close as possible to tectonic faults/earthquakes?
  Earth Sciences: Mechanisms behind the constant earth evolution
  Engineering: rock mechanics at large scales, interplay with hydrology/chemistry/biology

# Other Motivations

## Exciting potential for cross disciplinary synergies

Pushing the rock mechanics envelope <-> physicists needs for large span cavities at great depth

"Transparent earth" Improvement of standard methods + new technologies

Neutrino tomography of the earth?

Sensors, low radioactivity, education etc...

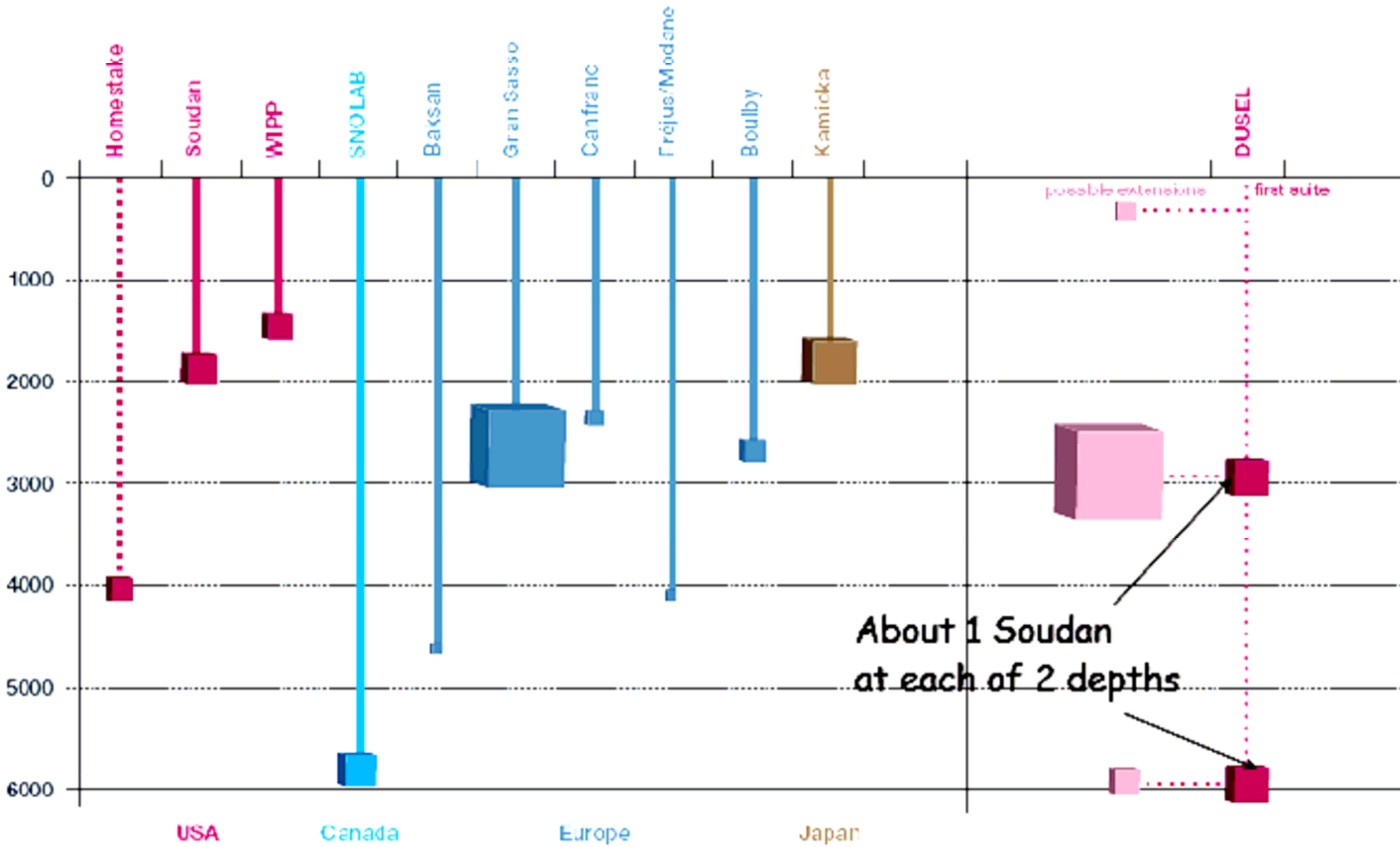
## Relevance to Society

- **Underground construction**: the new frontier (urban, mining, fuel storage)
- **Resource extraction**: Critical need for recovery efficiency improvement
- Water resources:
- **Environmental stewardship**
  - Remediation (e.g. with micro-organisms)
  - Waste isolation and carbon dioxide sequestration.
- **Risk prevention and safety**
  - Making progress in understanding rock failure in structures and earthquakes
- **National security**
  - Ultra sensitive detection methods based on radioactivity

## Training next generation of scientists and engineers

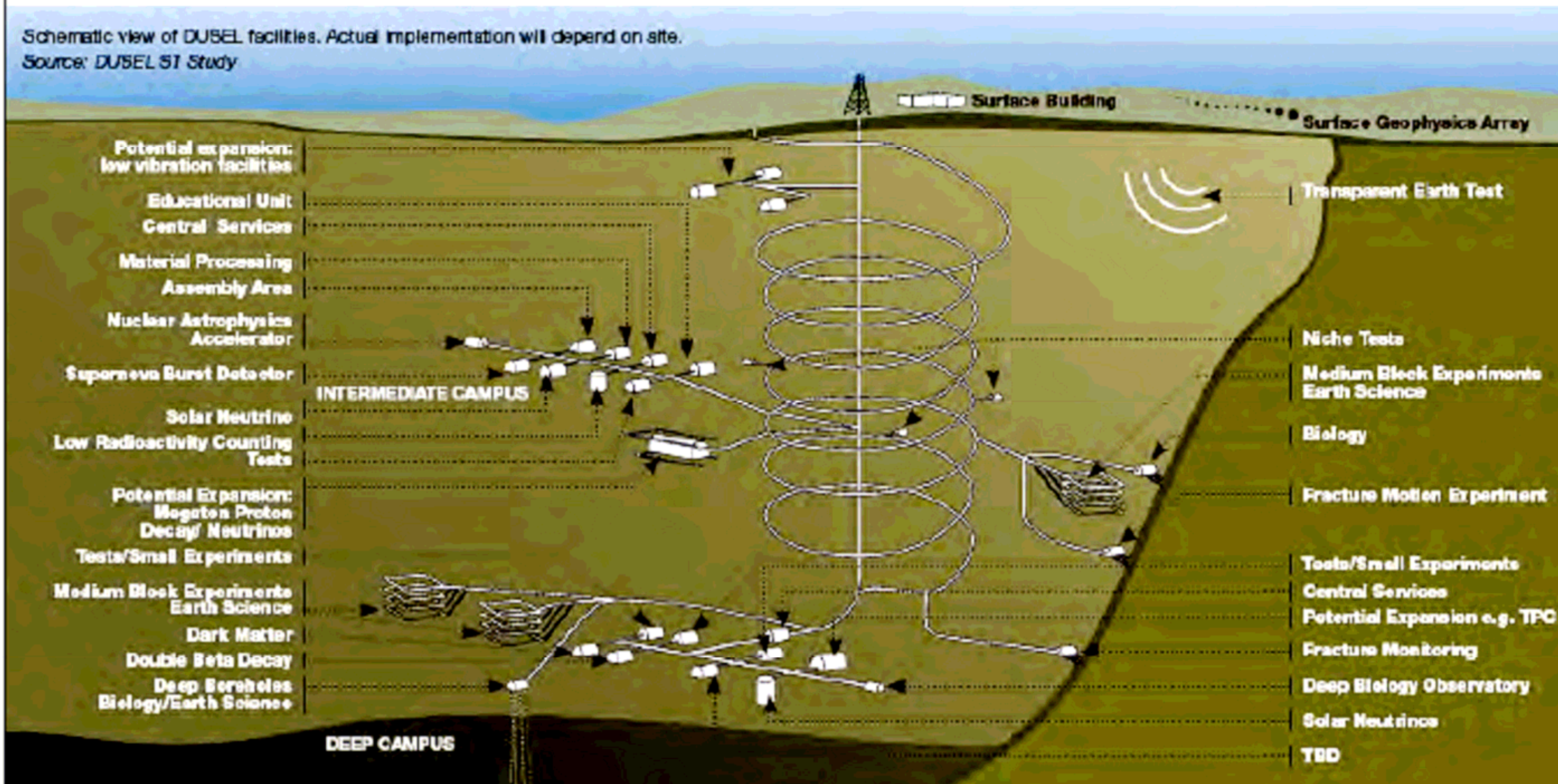
+ public outreach: better understanding of science

# Science Underground

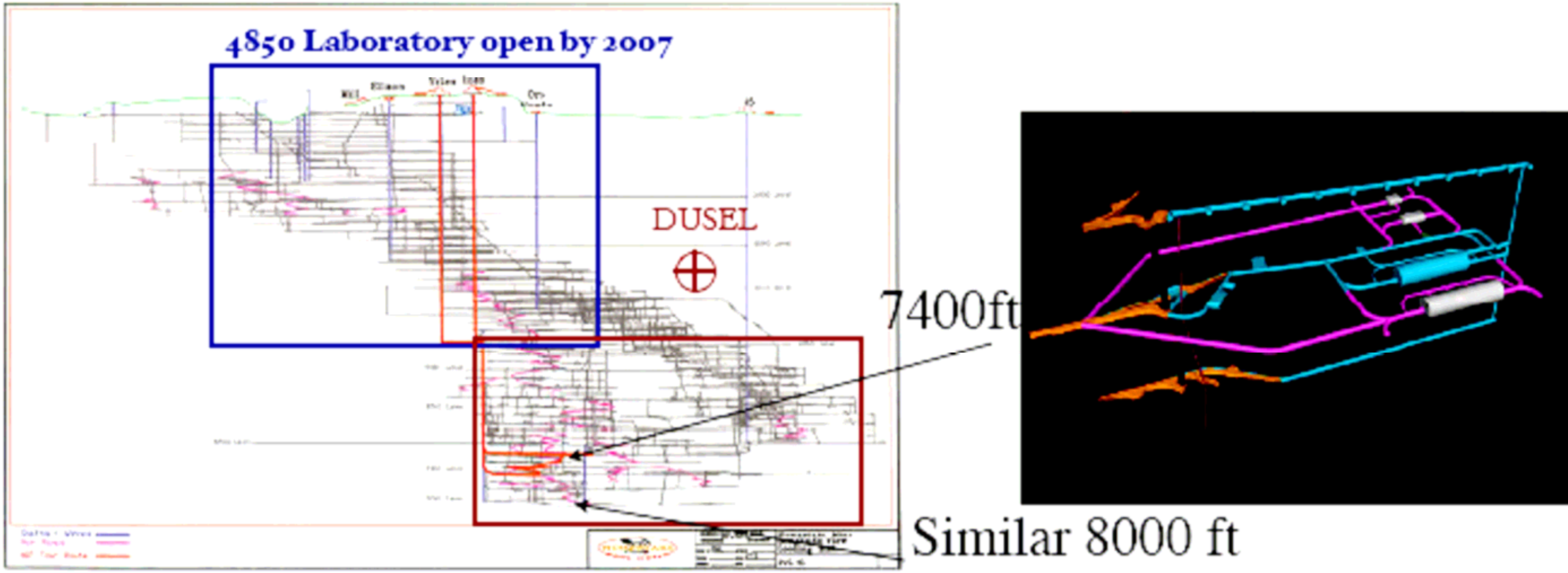


# First Suite of Experiments+ Extension

## Note science before and during the excavation

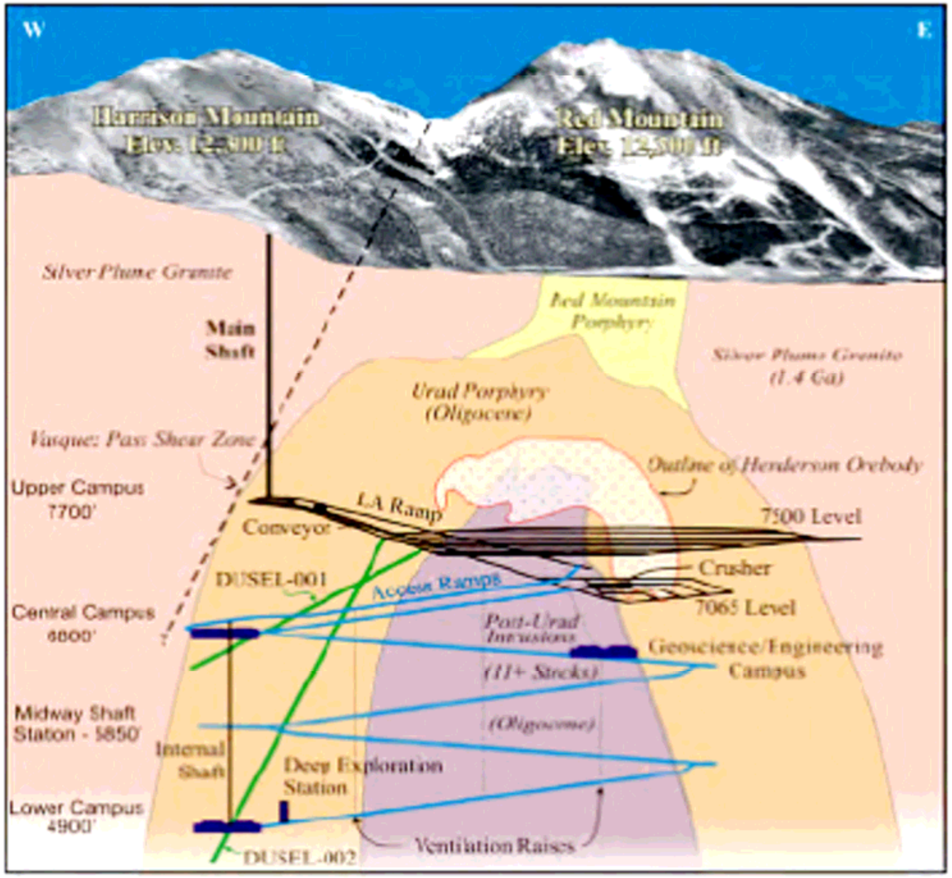


# Homestake



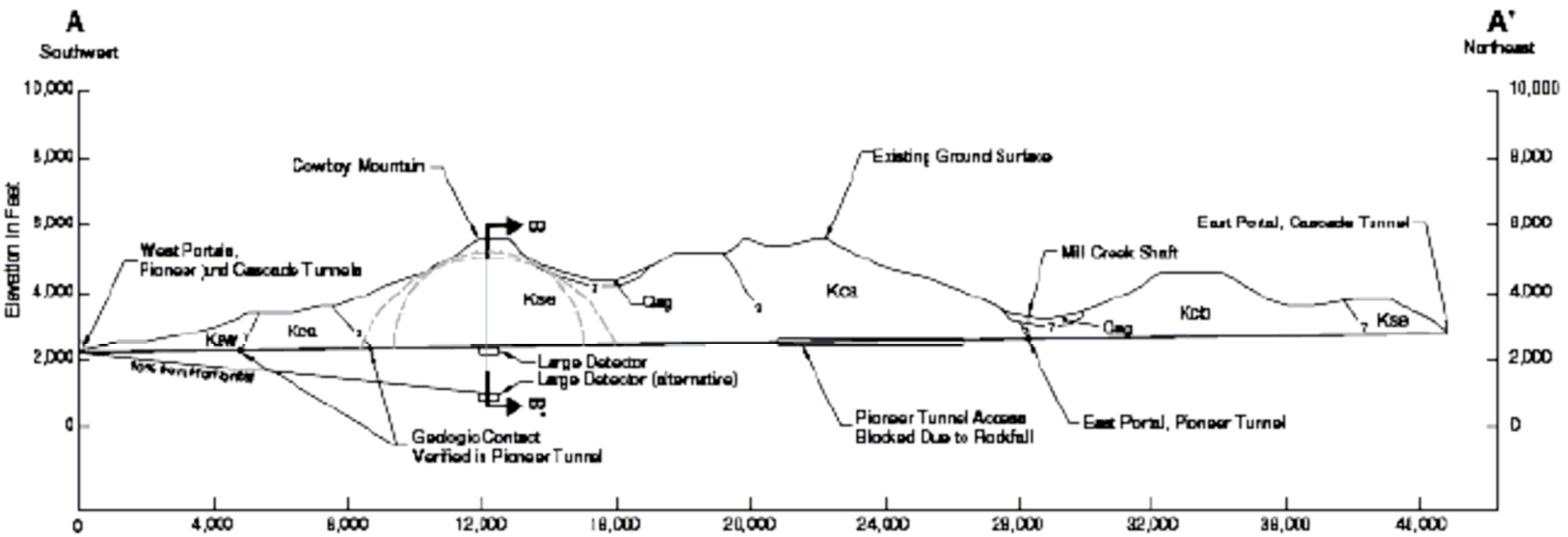

- Well-Characterized Site with miles of tunnels
  - Varied, Interesting, and Suitable Geology
  - Extensive Experience to > 8000 feet below ground. Low risk
- Phased Approach to Developing the Facility
  - Ability to host near-term R&D and Experimental Opportunities: interim lab
  - Phased entry into the Initial Suite of Experiments
- Success in Securing Independent Funding for Interim Lab
  - Exceptional Local and Regional Support for DUSEL Goals
- Dedicated Facility without Competition for Access,Resources, or Priorities

# Henderson




- Modern mine
- Large shaft down to 7500 ft level
- Ramp to be built down to 2 science campuses
- Very large rock handling capability (+ permit 340Mt)
- Large water+sewage treatment, 2x24MW

# Pioneer Tunnel




## Unused existing tunnel

parallel to *Grand Cascade* tunnel: *Cooperation of railway company*

Horizontal access down to 2120 mwe at low cost

## Arguments

all that is needed in the short run (Use SNOLAB for really deep needs)

put money in detectors

go down later when needs appears

# Soudan


## Multi-site => multidisciplinary, non traditional users

- Science => sites—not vice versa
- A neutrino beam towards Soudan. Cost of replacing or upgrading the NuMI beam.
- Geoscience (including geohydrology, geochemistry, geomicrobiology, etc.) is best served by multiple sites. Expensive instruments shared among multiple locations.
- There is a need **now** for low background counting. Soudan is available and can expand capacity quickly.
- No clear need for a new ultradeep facility for at least a decade. Investing a huge amount in a new facility will divert funds critically needed to initiate and develop new experiments. Decision when clear!