The LAGUNA project (Large Apparatus studying Grand Unification and Neutrino Astrophysics)

Agnieszka Zalewska – IFJ PAN, Poland

Zakopane, 21.06.2007

What is LAGUNA

Detector concepts

Research program

Localization of the future large European laboratory

What happens outside Europe?

What is LAGUNA?

The European project „Large Apparatus studying Grand Unification and Neutrino Astrophysics" aiming at defining and realizing this research programme in Europe.

It includes the majority of European groups interested in the construction of the very massive detector (10^5 – 10^6 tons) realized in one of the three technologies using liquids: water, liquid argon and liquid scintillator.

No one of the existing European underground laboratories is able to host such a huge detector → a new large underground infrastructure is needed.

The group applied for the RI Design Study in the framework of FP7 (2.05.2007) with the main goal to study possible localizations of the future laboratory together with further R&D for the proposed detector technologies.

The ApPEC roadmap, January 2007

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

The ApPEC roadmap, January 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."

2.05.2007

COLLABORATIVE PROJECT

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**

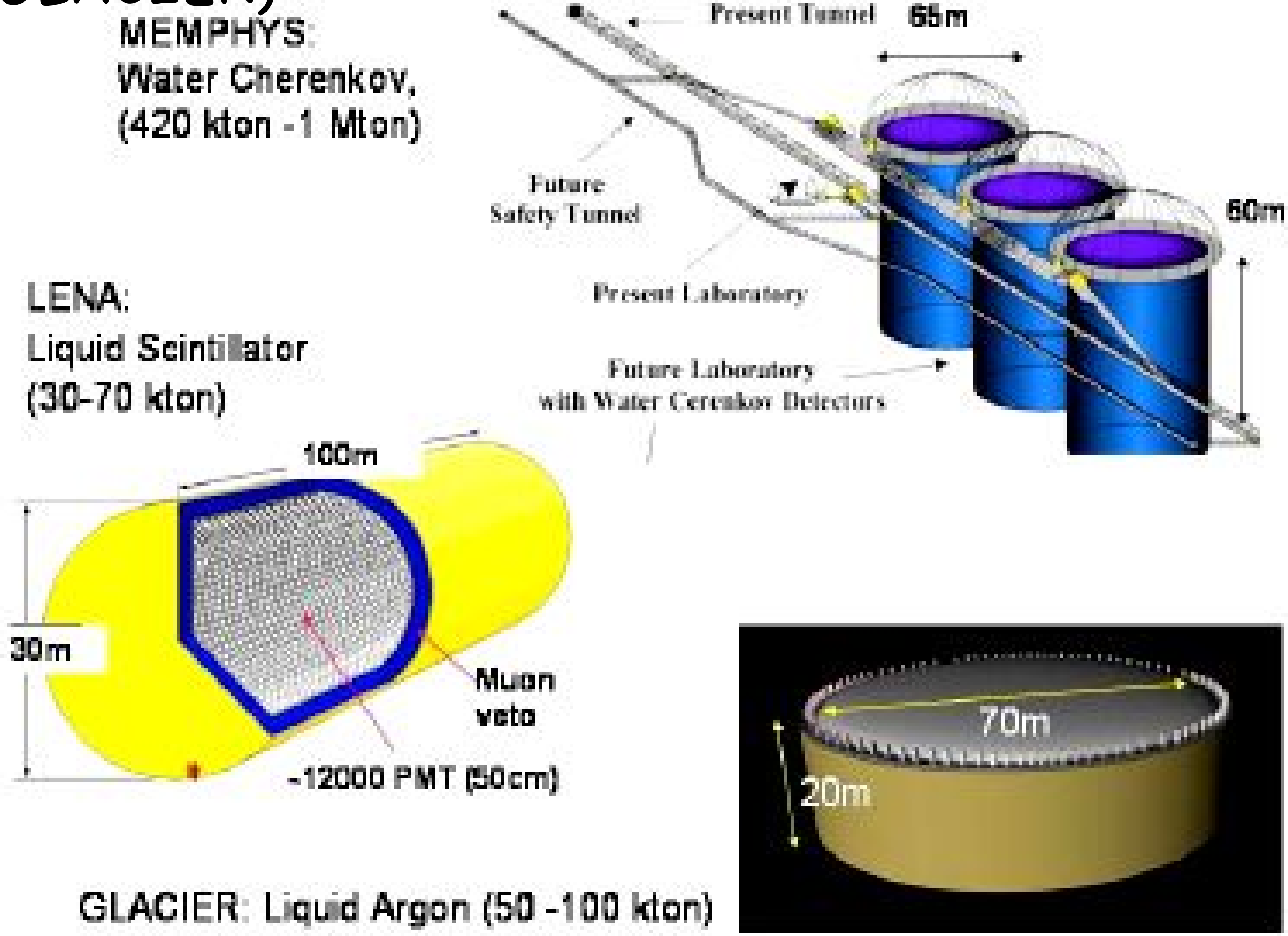
List of participants:

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.Soltan 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

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**		

Detector concepts

Three liquids: water (MEMPHYS), scintillator (LENA), liquid argon (GLACIER)



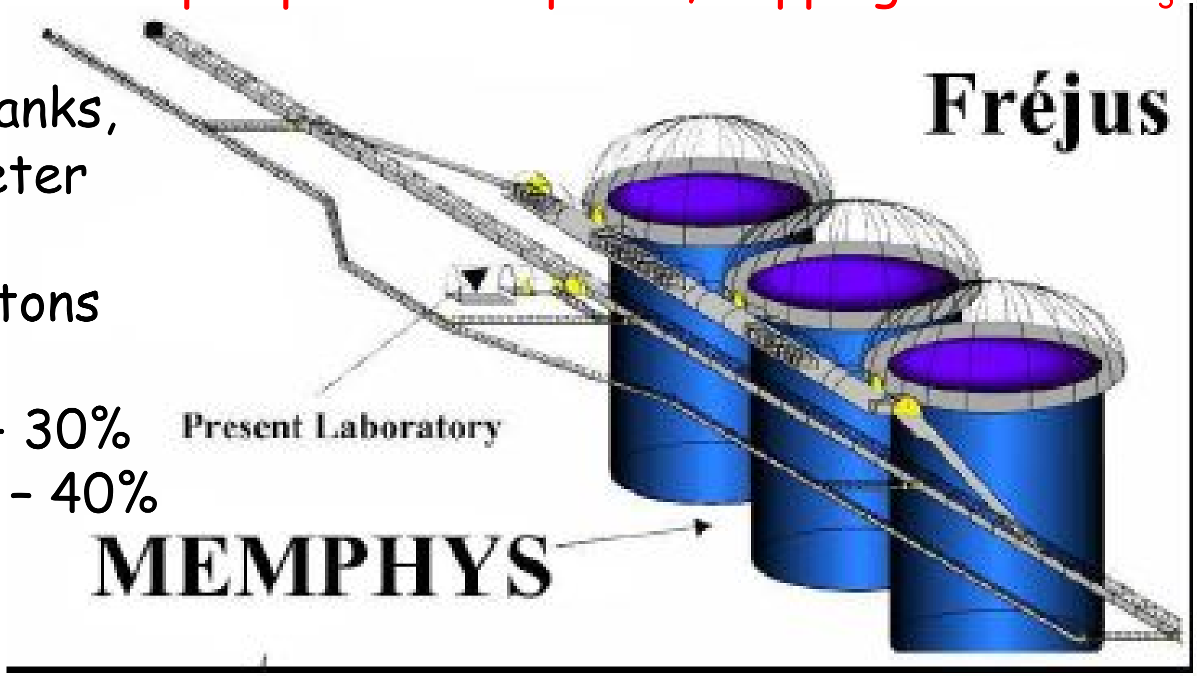
MEMPHYS – water Cherenkov detector

Concept: initial work for the Frejus laboratory, the SuperKamiokande detector as a prototype, rescaling by a factor up to 20

Advantages: the cheapest target material, mature technology, possible extrapolation to the 1 Mton mass

Challenges: better and cheaper photomultipliers, dopping with $GdCl_3$

Construction: 3-5 tanks, each one with a diameter and a height of 65 m, fiducial mass of 147 ktons read out by 81000 photomultipliers (12" – 30% surface coverage, 20" – 40% coverage)



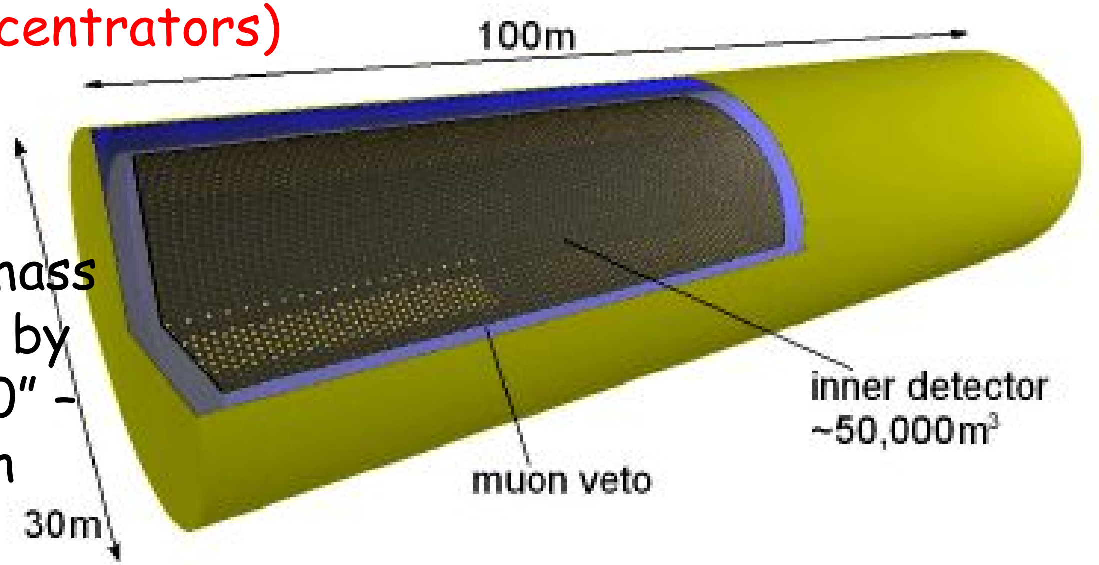
LENA – the liquid scintillator detector

Concept: initial work for the Pyhäsalmi mine in Finland (underwater placement near Pylos was also concidered), the Borexino, Chooz and KamLAND detectors as prototypes, rescaling by a factor 40-50

Advantages: very low energy threshold, good energy resolution, known technology

Challenges: scintillator cleaning, better and cheaper light detection (photomultipliers, light concentrators)

Construction: cylindrical tank 100m long and with a diameter of 30m, fiducial mass of about 50 ktons, readout by 12 000 photomultipliers (20" – 30% surface coverage, with added light concentrates - 50% coverage)



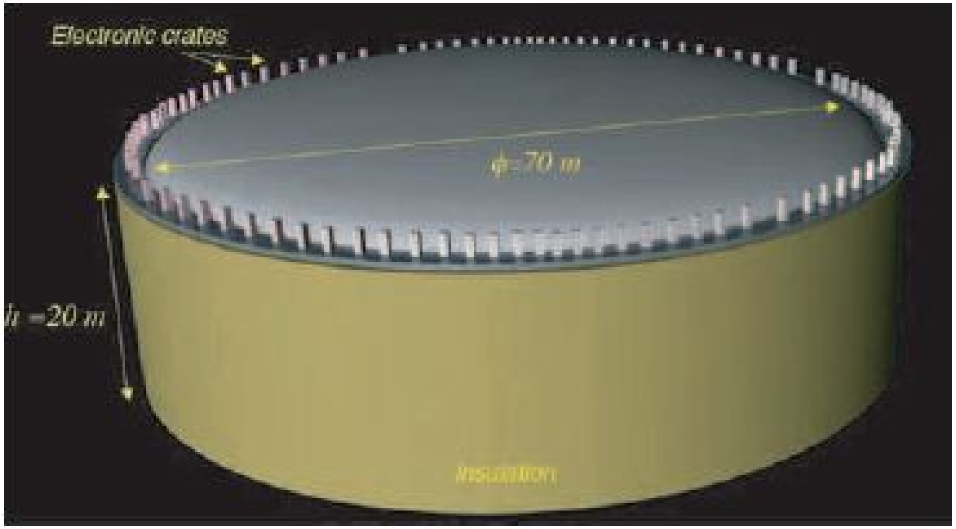
GLACIER – the Liquid Argon detector

Concept: initialy developed for Sieroszowice and Gran Sasso, prototype – the ICARUS detector, rescaling by a factor 150

Advantages: very good positional and energetic resolutions → imaging topologies, identification of low energy hadrons

Challanges: 20-m long drift of electrons, huge cryogenic installation, dewar thermal insulation

Construction: cylinder 70m in diameter and 20 m hight, total mass - 100 ktons of Liquid Argon, read out of the electron ionisation and light signals (scintillations – 1000 8" PMT, Cherenkov light – 27000 8" PMT)



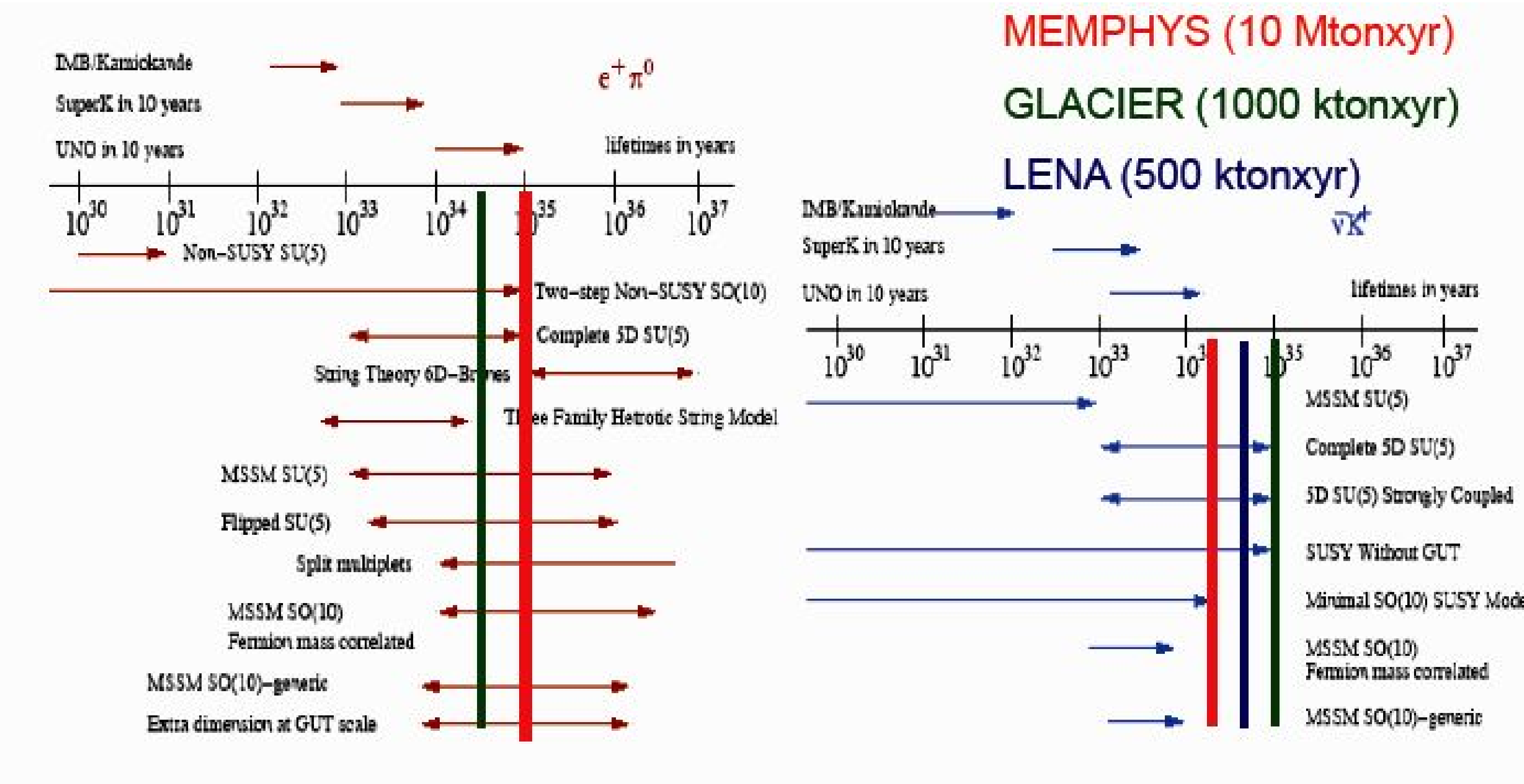
Research programme

1. Search for the proton decay

2. Studies of the low energy neutrinos from astrophysical sources (SN explosion, Sun, atmosheric neutrinos, relic SN neutrinos in our galaxy) and of the geo-neutrinos

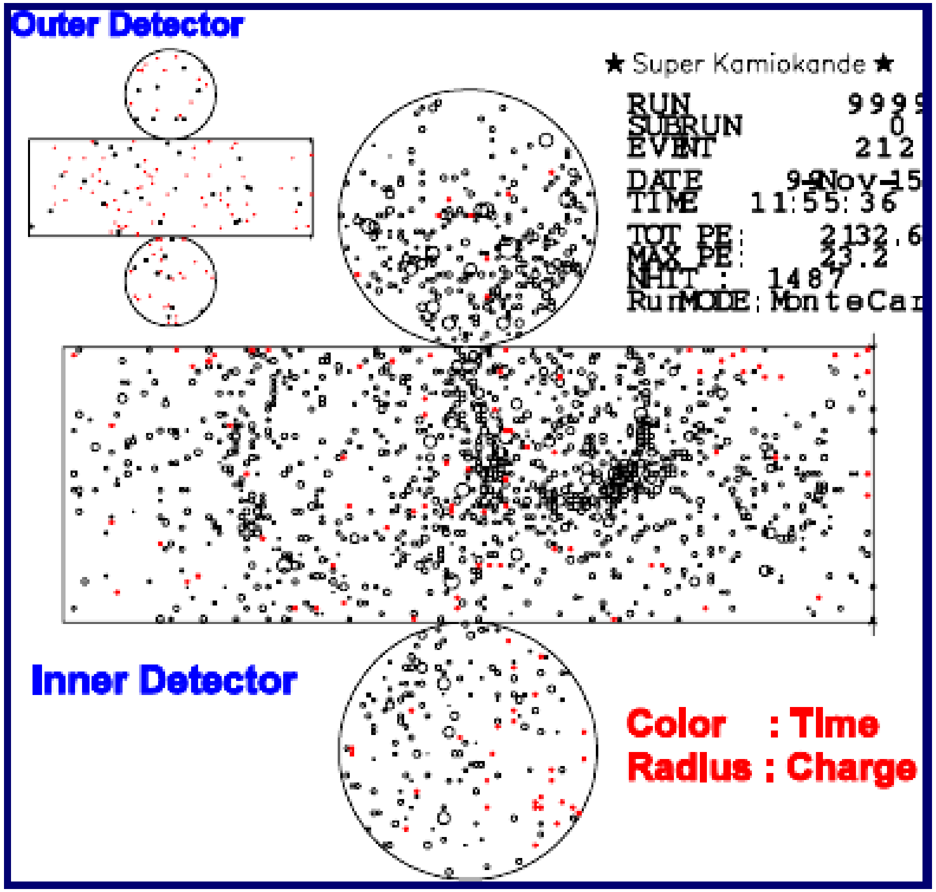
3. Studies of the neutrino properties based on accelarator neutrino beams

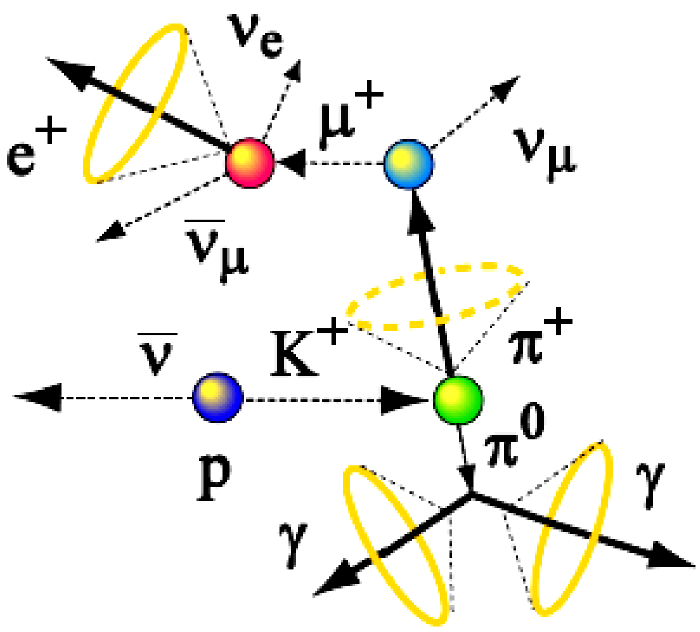
Proton decay



$p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ search (SK-I)

typical $p \to \nu K^+$, $K^+ \to \pi^+ \pi^0$ MC event



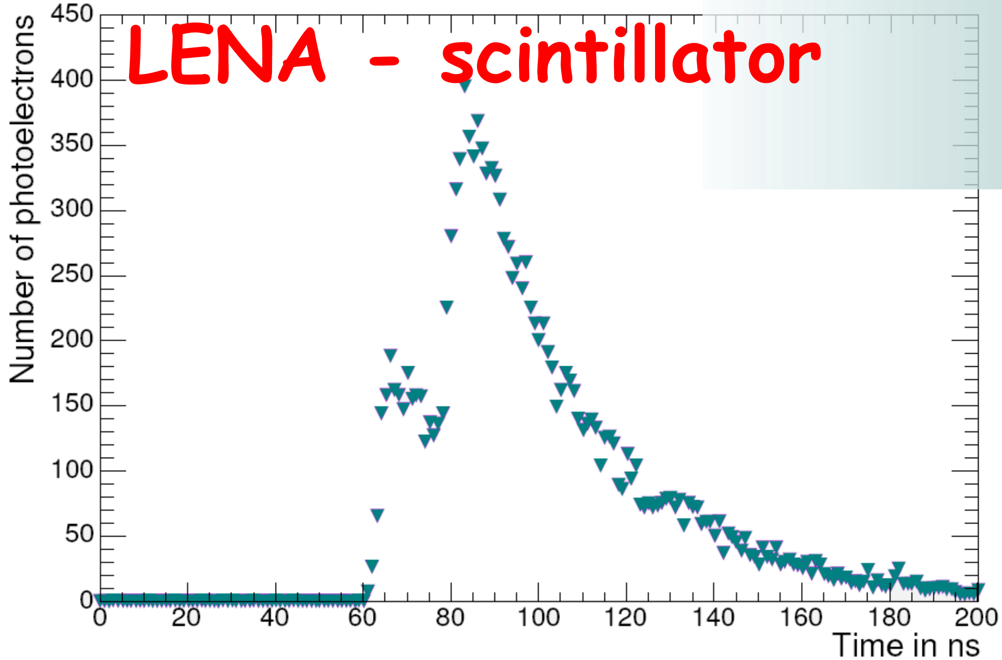


selection criteria

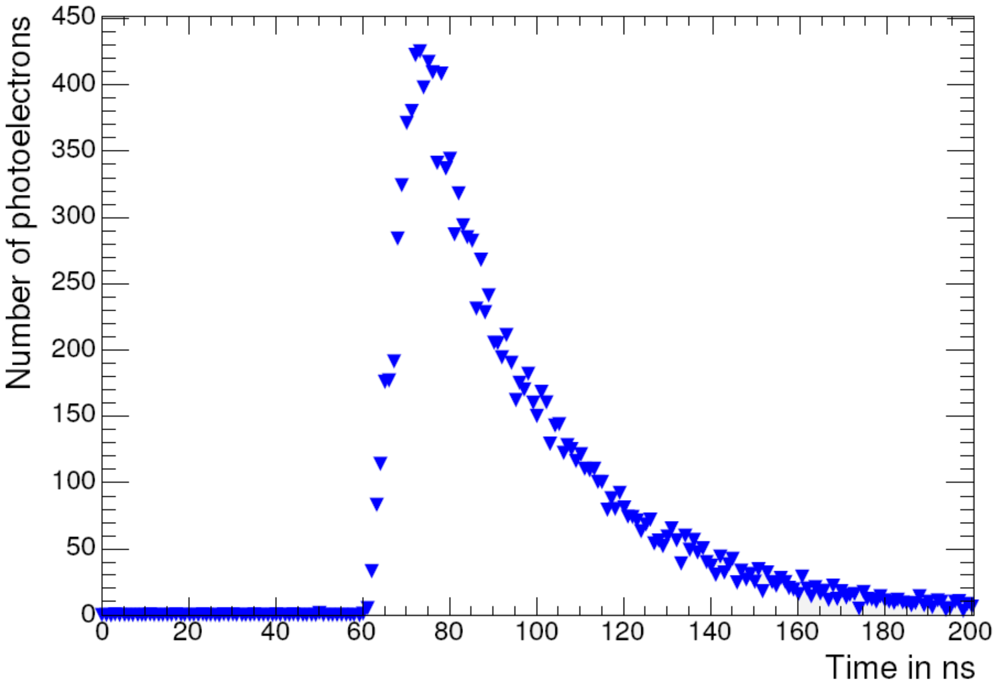
- 2 e-like ring
- 1 Michel electron
- $85 < m_{\pi^0} < 185$ MeV/c^2
- $175 < p_{\pi^0} < 250$ MeV/c
- $40 < Q_{\pi^+} < 100$PE, $Q_{res} < 70$PE

PROTON DECAY
EVENT SIGNATURE

LENA - scintillator



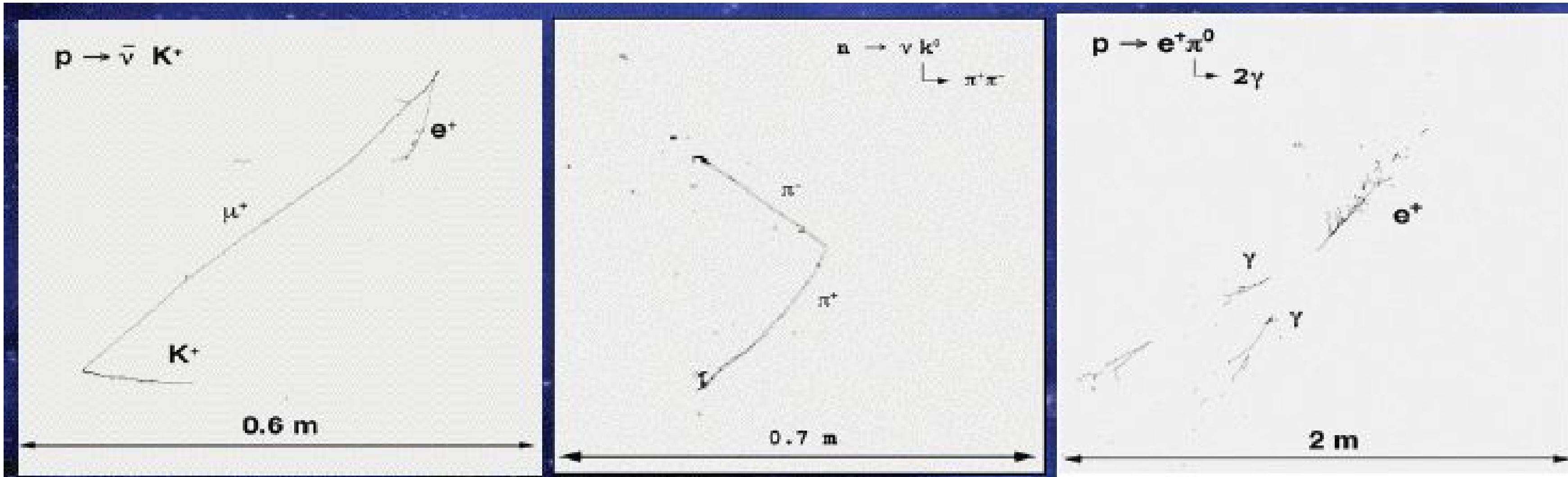
Kaon decay after 18ns



Kaon decay after 5ns

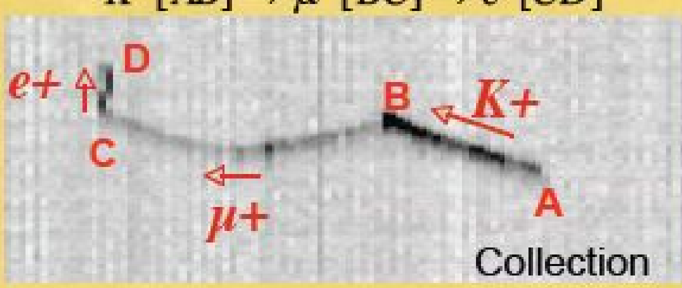
Challenge:
short decay time of the Kaon (12.8ns)

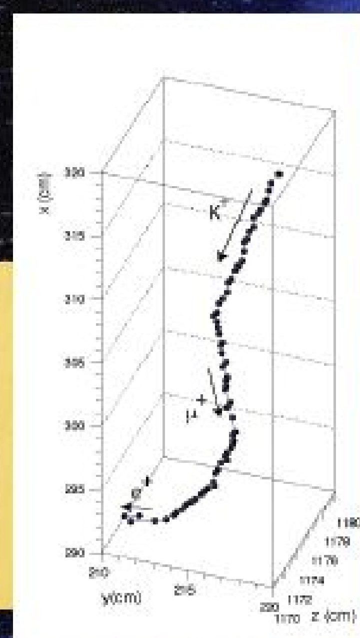
Proton decay in Liquid Argon

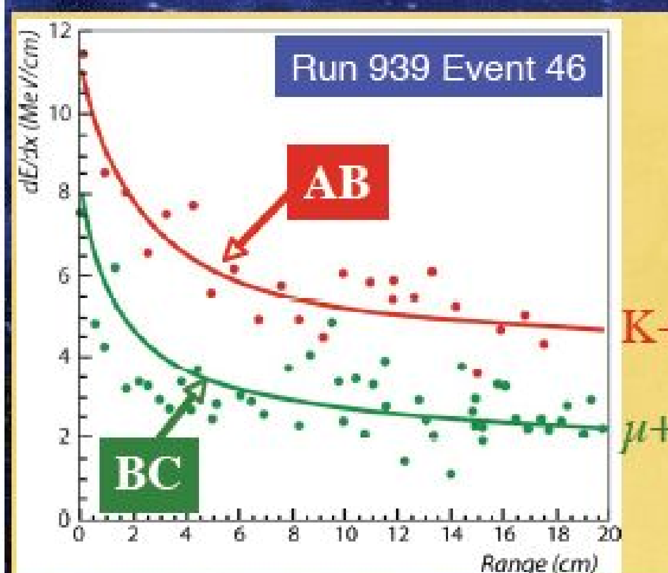


An example of real event:

$K^+[AB] \rightarrow \mu^+[BC] \rightarrow e^+[CD]$







Neutrinos from Supernova explosions

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

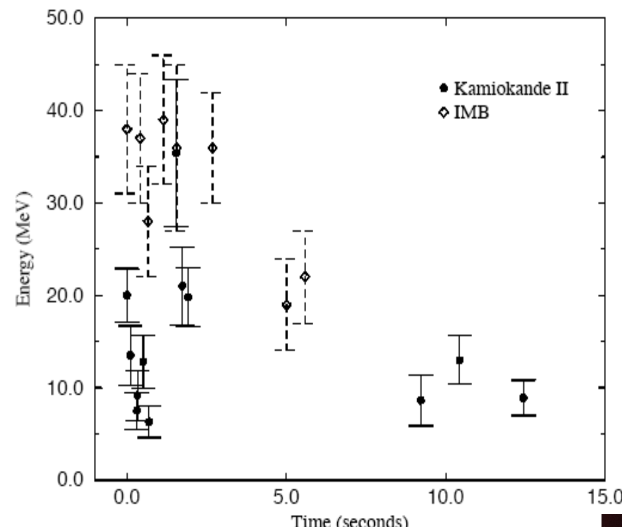
- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and θ_{13} mixing angle

3. Early alert for astronomers

- Pointing to the supernova

SN1987A Type II in LMC (~55 kpc)

Water Cherenkov:	IMB	E_{th} ~ 29 MeV, 6 kton	8 events
	Kam II	E_{th} ~ 8.5 MeV, 2.4 kton	11 events
Liquid Scintillator:	Baksan	E_{th} ~ 10 MeV, 130 ton	3-5 events
	Mont Blanc	E_{th} ~ 7 MeV, 90 ton	5 events??



Confirmed baseline model... but still many questions

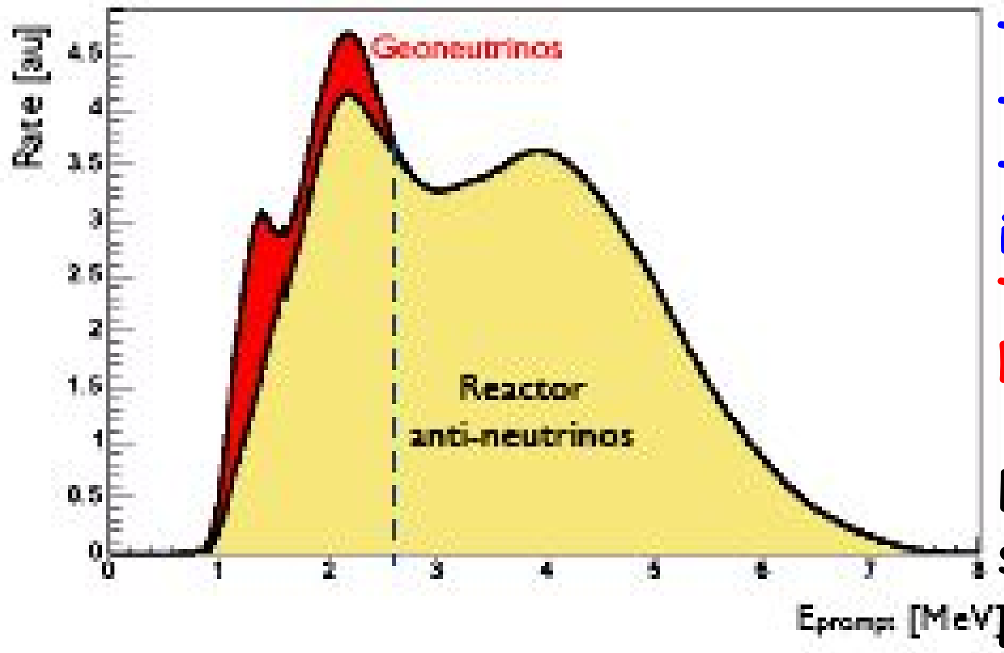
The Crab Nebula in Taurus (VLT KUEYEN + FORS2)

A.Rubbia

Geo-neutrinos

• Antineutrinos from ^{238}U, ^{232}Th i ^{40}K decays inside Earth allow the estimation of the heat generation due to these decays.

• KamLAND experiment provided the first measurement of the flux of geo-neutrinos from the U and Th decays (geo-neutrinos from K decays have energies below the detection threshold in scintillator)



The KamLAND limit for the heat production due to the radioactive decays inside earth < 60 TW

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

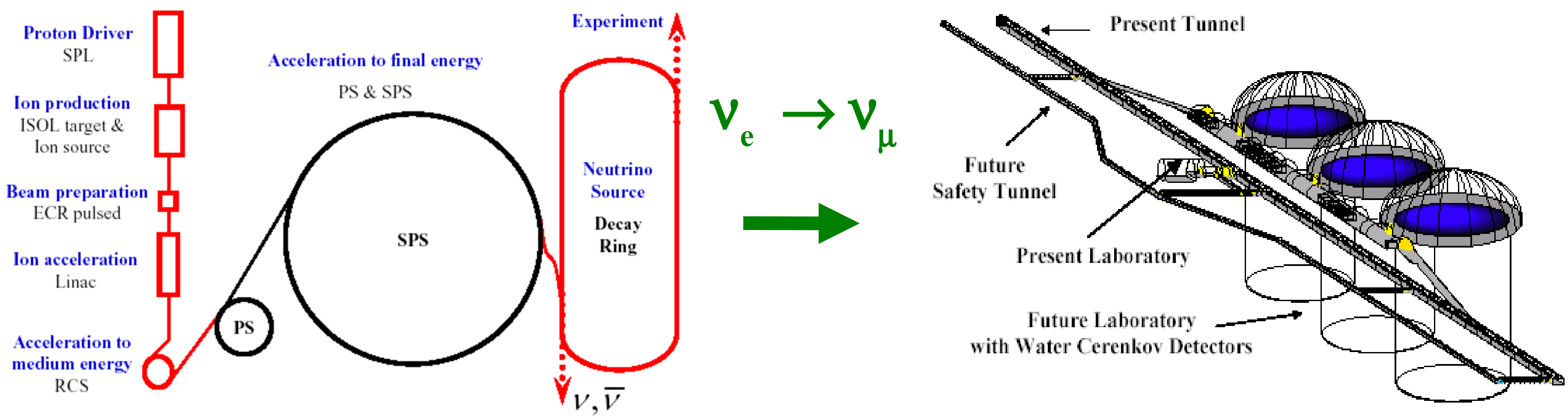
KamLAND:
signal 25^{+19}_{-18}, background 127±13

LENA:
expected signal 1000, background 240(events/year)

Neutrinos from β beam – MEMPHYS

- Acceleration of ^{6}He nuclei (source of antineutrinos) and of ^{18}Ne nuclei (source of neutrinos), R&D in the framework of EURISOL DS. (FP6)

- ...But a small obstacle (worth ~1 billion CHF) – the programme requires a serious intervention into the CERN accelerator chain, also problems with poor knowledge of low energy neutrino cross-sections



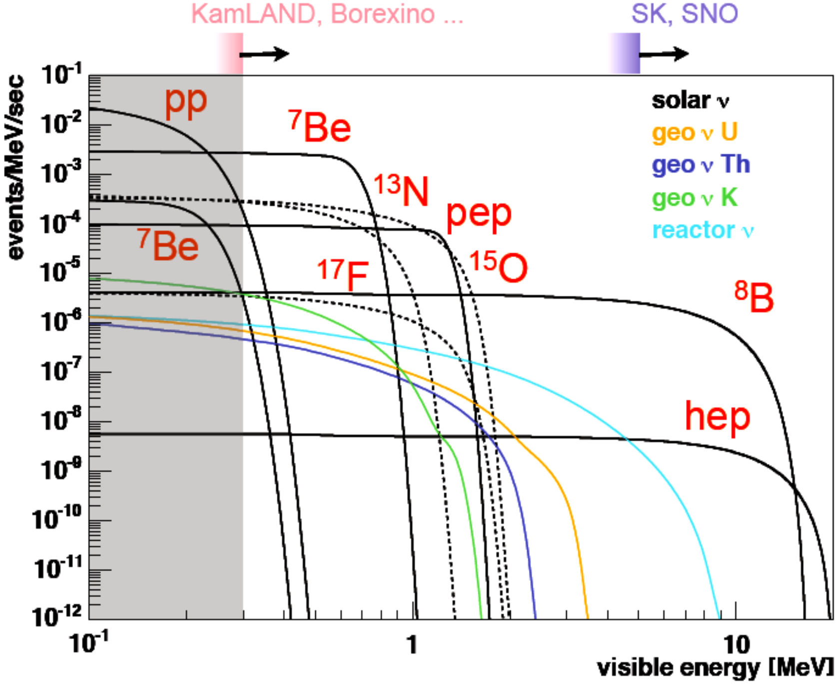
Low energy neutrinos – cont.

Atmospheric neutrinos – a very big range of E/L,

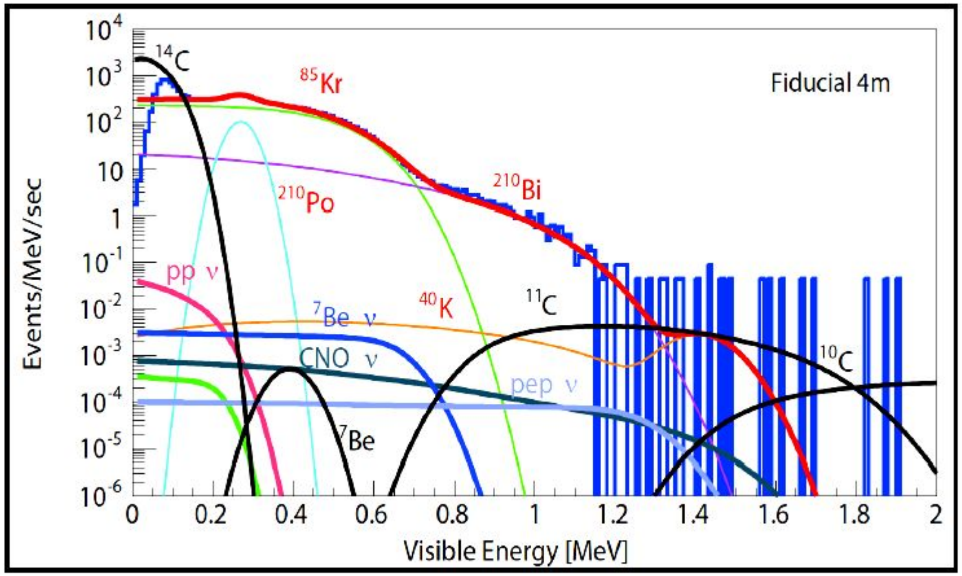
Search for WIMPS in the SUN and Earth cores

Neutrino astronomy of the Sun

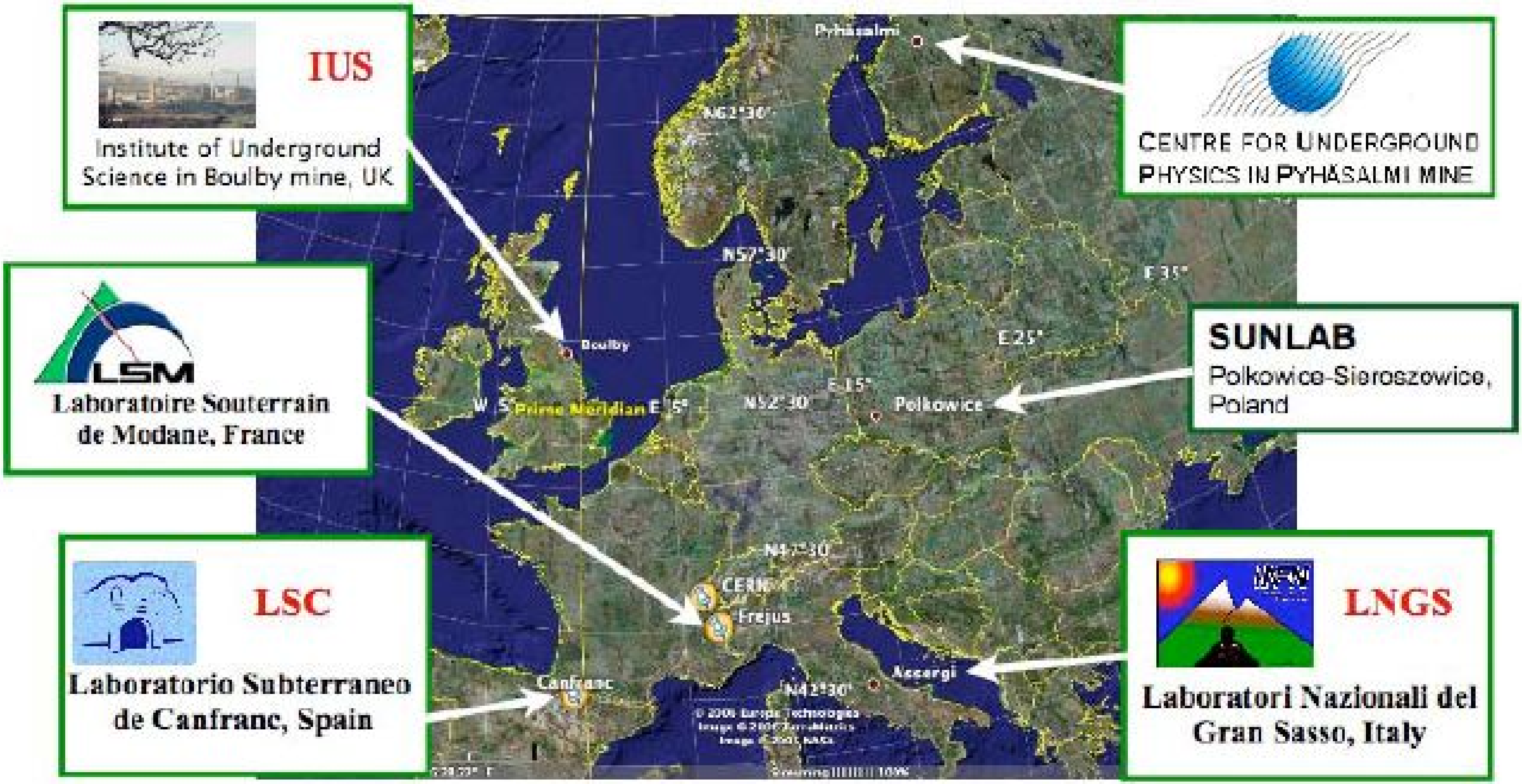
Energy spectrum for the $\nu_e e$ elastic scattering



2006 - spectrum in KamLAND

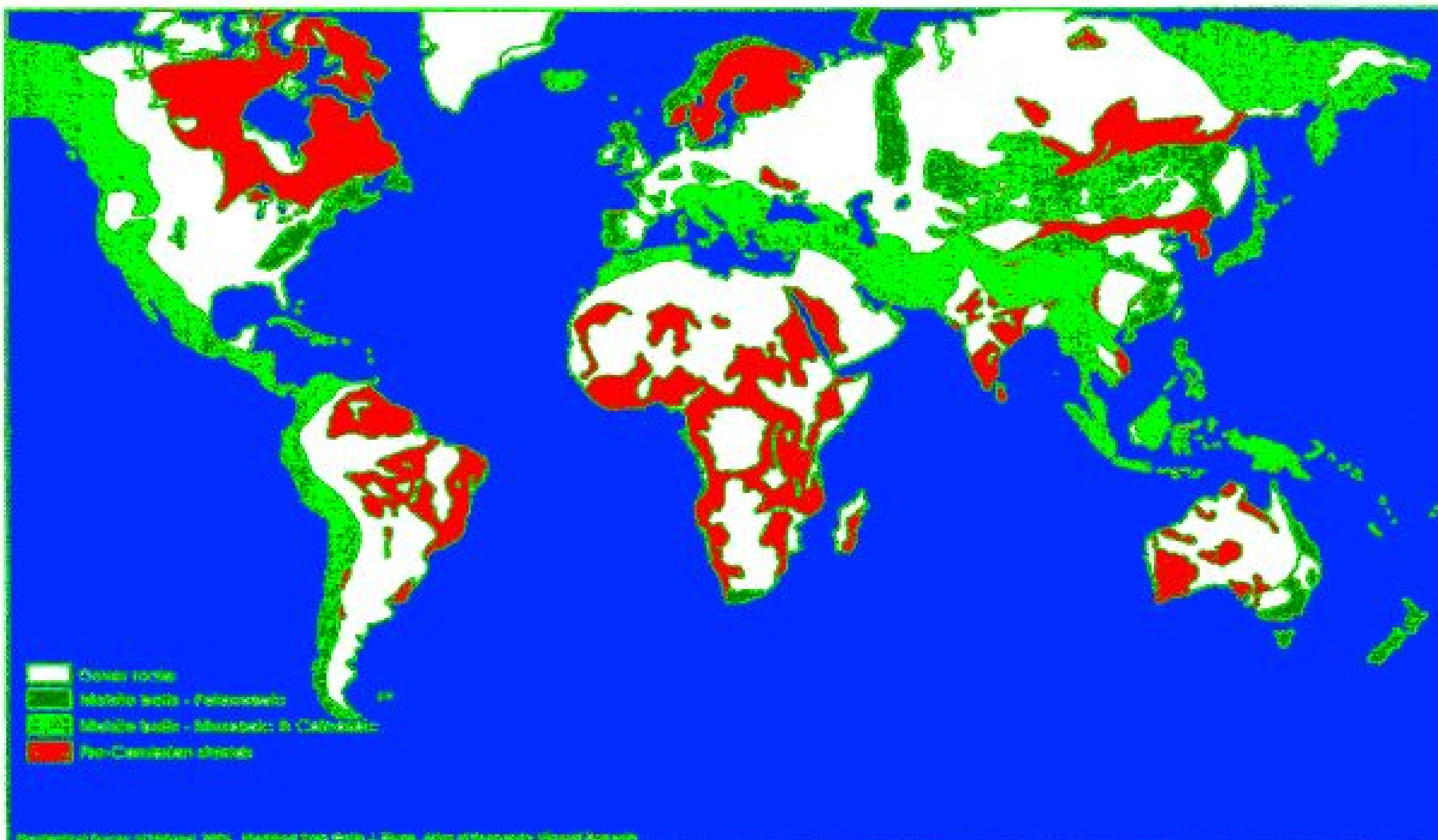


Possible localizations of the future large underground laboratory



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



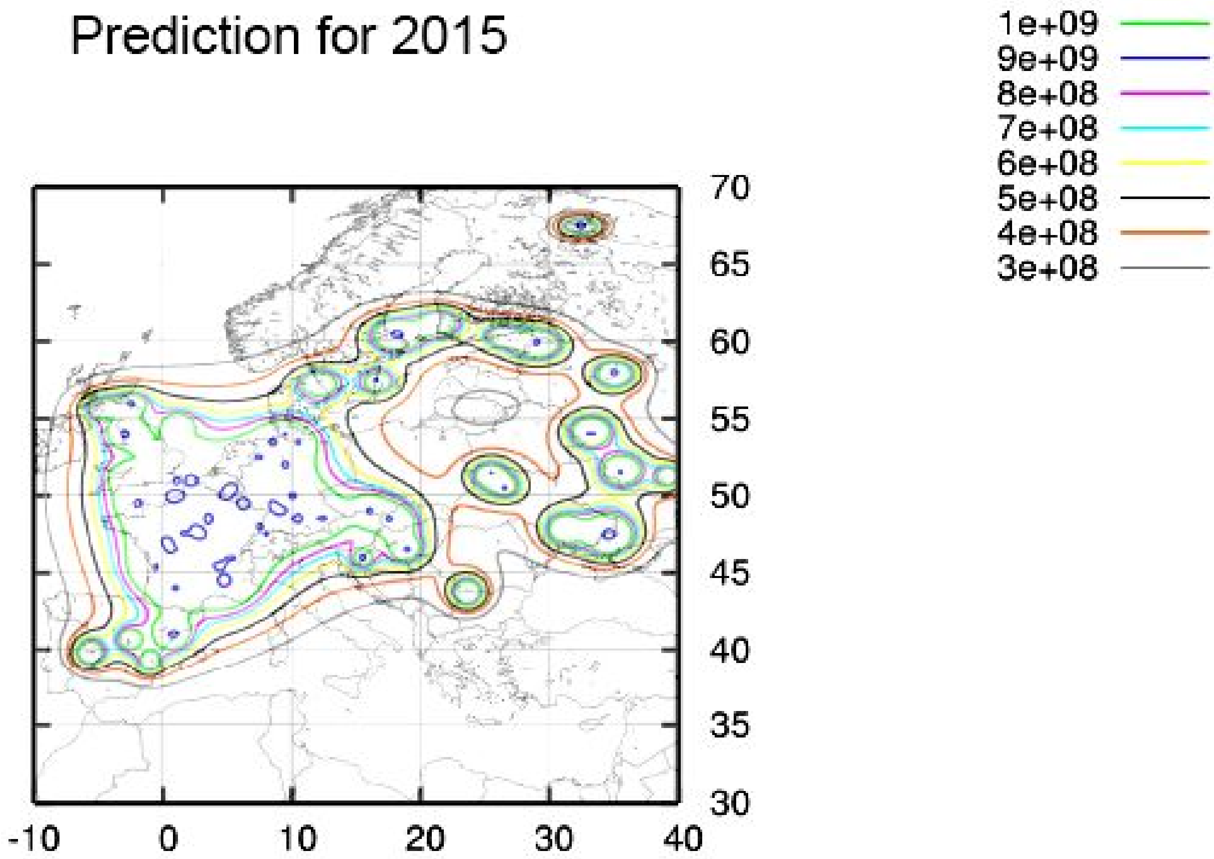
Nuclear reactor background

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

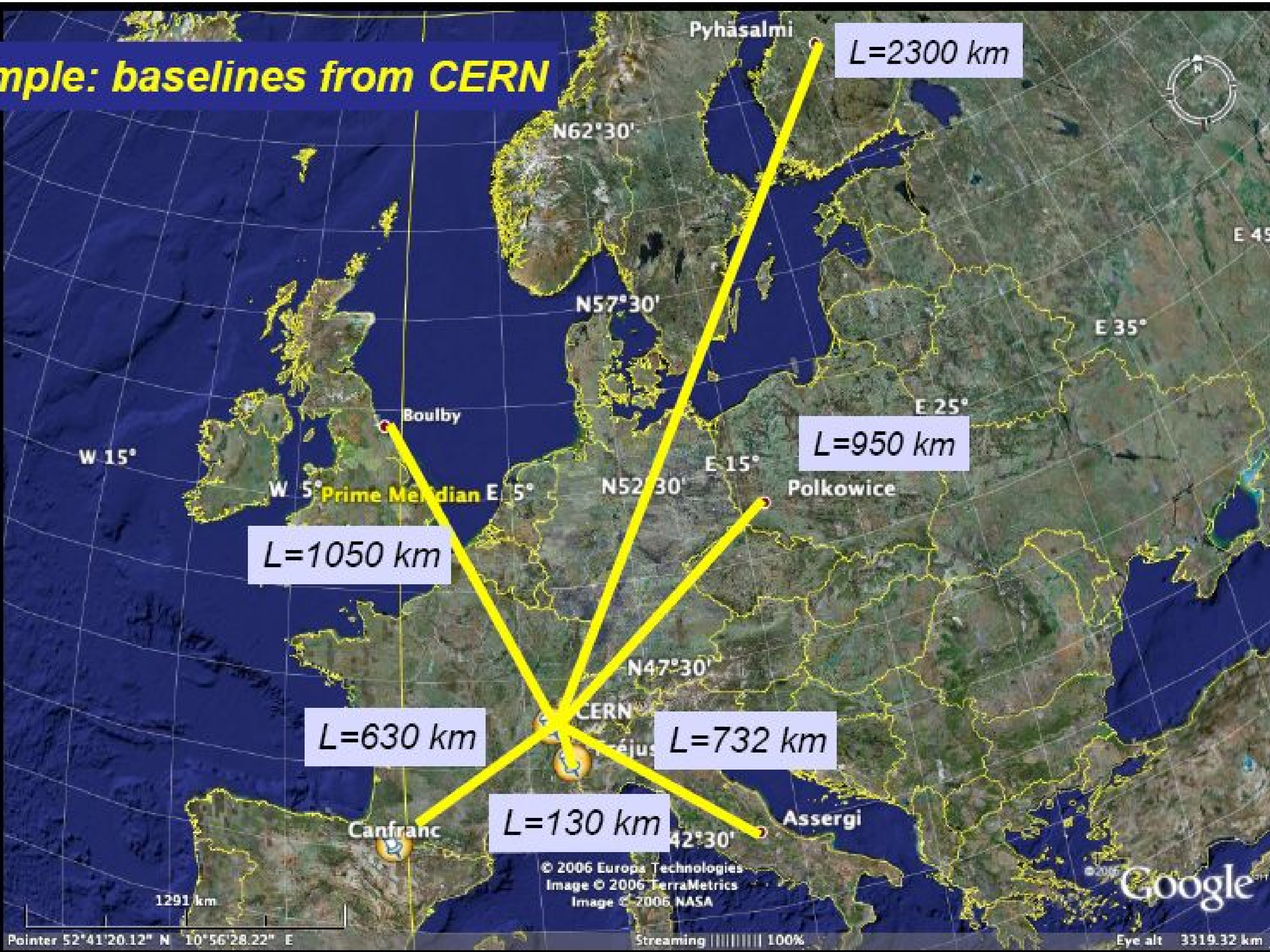
Location	ν (10^8 1/m^2 s)
Pyhäsalmi	40
Gran Sasso	54
Frejus	175
Canfranc	196
Boulby	190
Kamioka	408
Sudbury	100
Soudan	33
Pylos	12

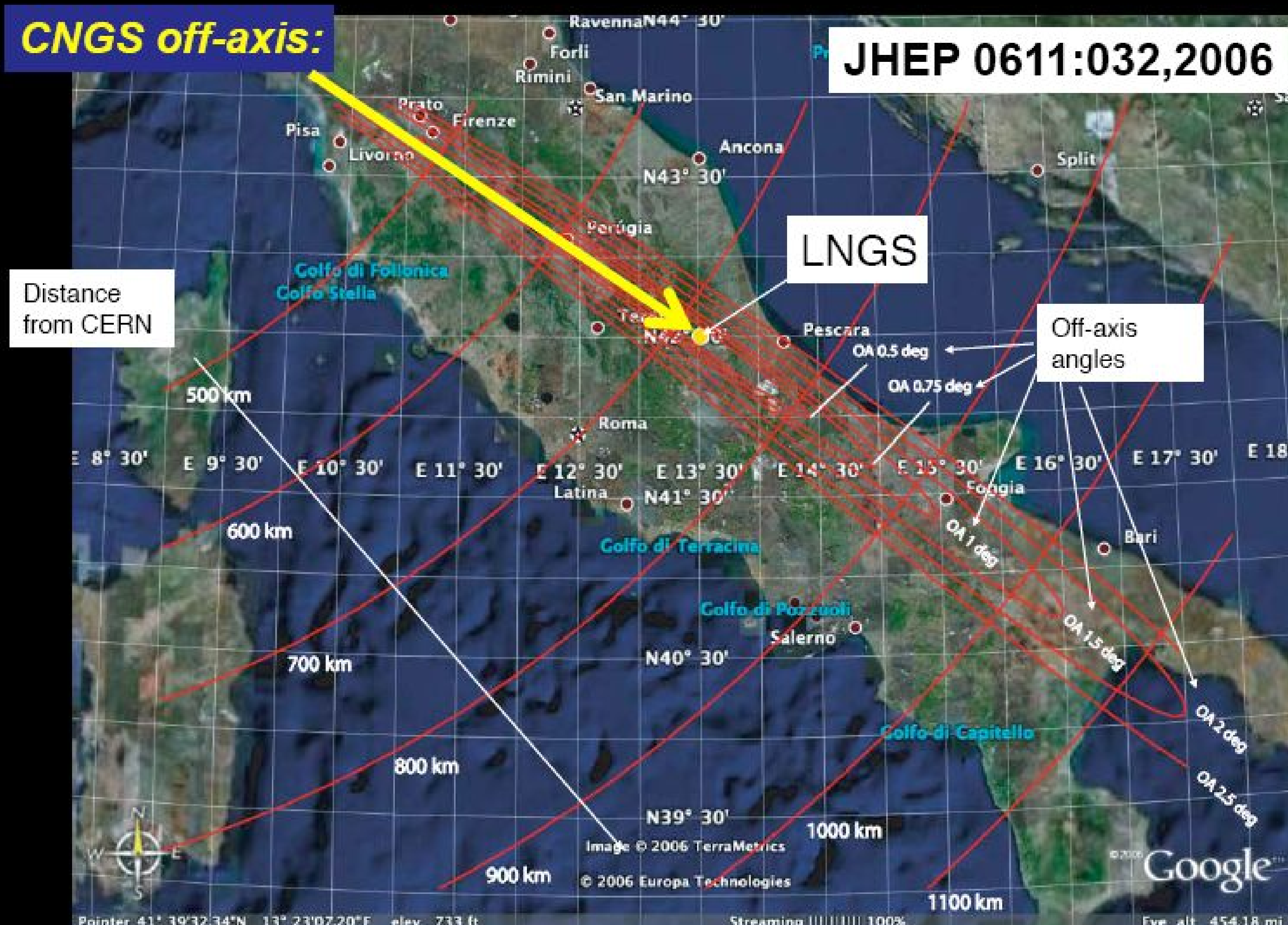
2005

Reactor electron anti-neutrino flux density



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
Forlì
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
N44° 30'
N43° 30'
N41° 30'
N40° 30'
N39° 30'
E 8° 30'
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E 16° 30'
E 17° 30'
E 18°
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

A.Rubbia, Fermilab, 16-17.09.2006

Background due to natural radioactivity

W.Mietelski et al

Salt:

U-238: 0.0165+-0.0030 Bq/kg

U-234: 0.0225+-0.0030 Bq/kg

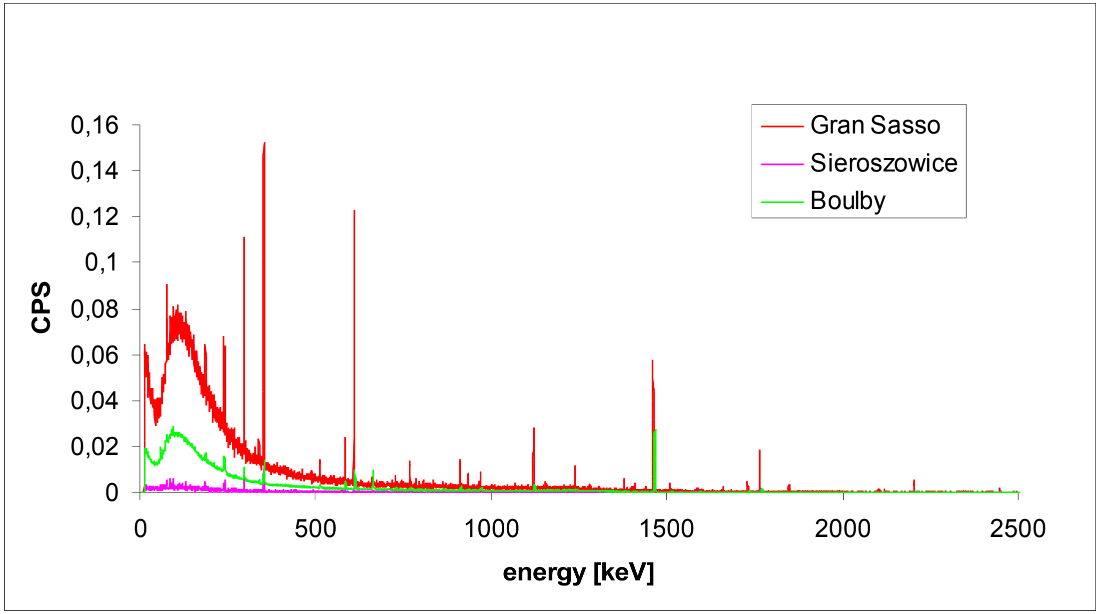
Th-232: 0.008+-0.001 Bq/kg

K-40: 4.0 +-0.9 Bq/kg

Anhidrite:

U-238: 0.82+-0.10 Bq/kg

Natural radioactivity - in-situ measurements



J.Kisiel et al..

In situ measurements: GS, Boulby, Sieroszowice
Integral background counting rates

Energy [keV]	Gran Sasso	Boulby	Sieroszowice
50-2700	57.68 (0.05)	17.00 (0.01)	2.30 (0.02)

Localization of the future laboratory

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

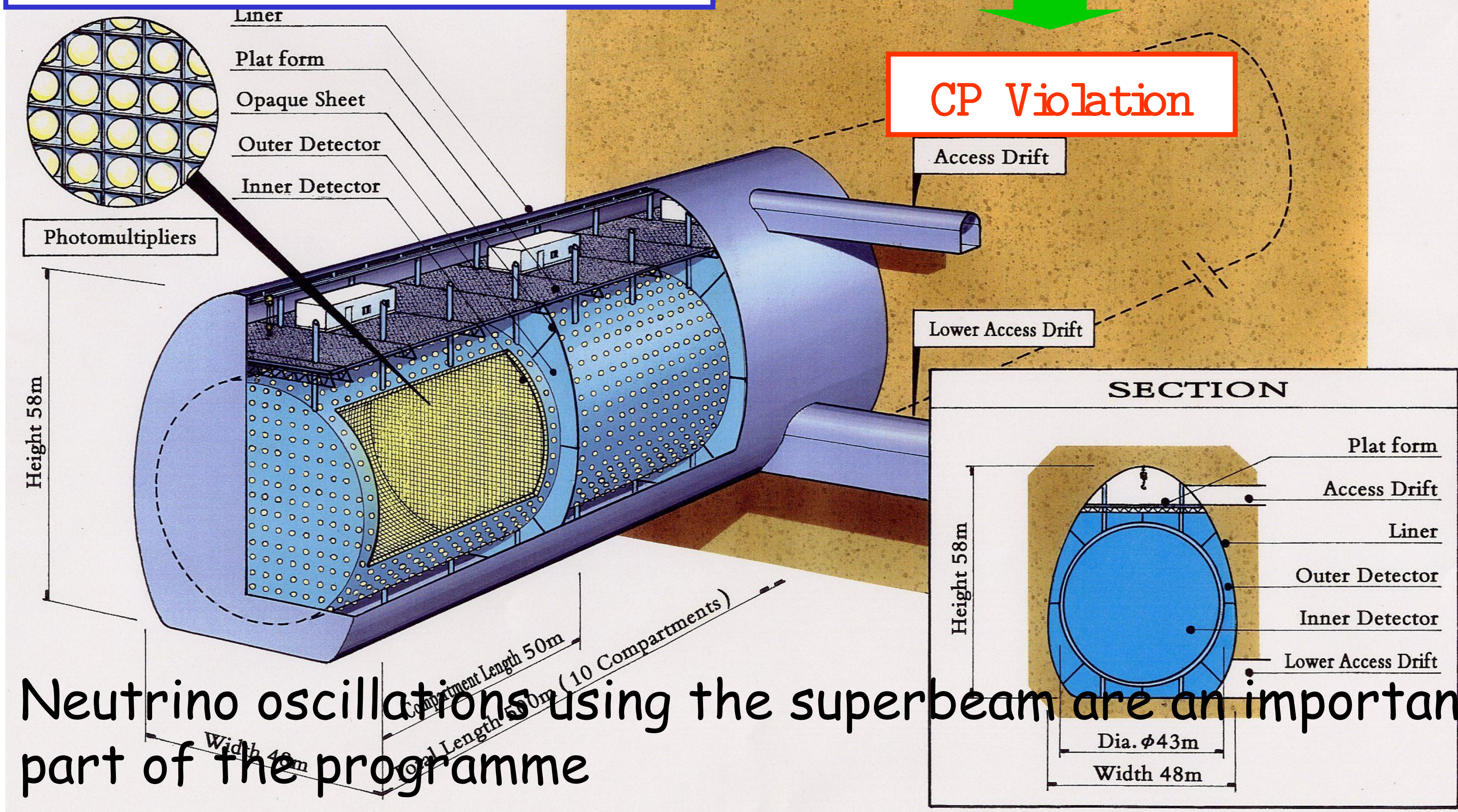
Outside Europe: Japan – T2K phase II (?)

Accelerator: 4 MW

Detector HiperKamiokande
(1Mton water Cherenkov)

10^6 events (ν_μ i anti-ν_μ together)

CP Violation



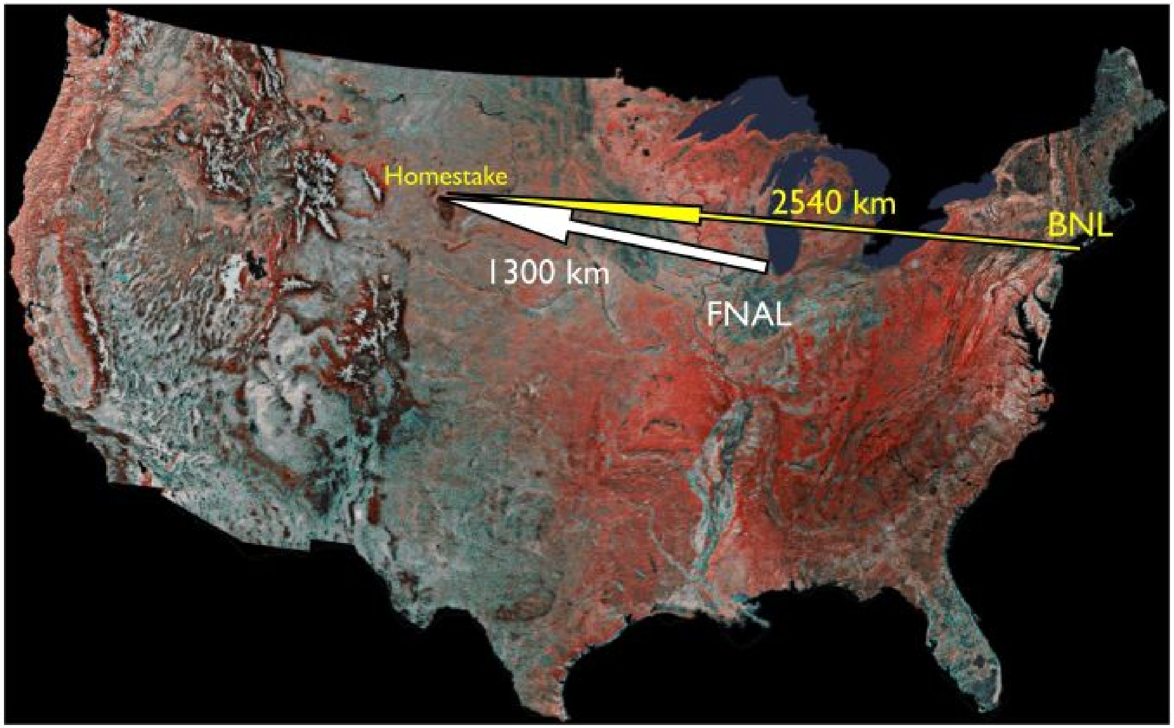
Neutrino oscillations using the superbeam are an important part of the programme

Outside Europe: USA - DUSEL

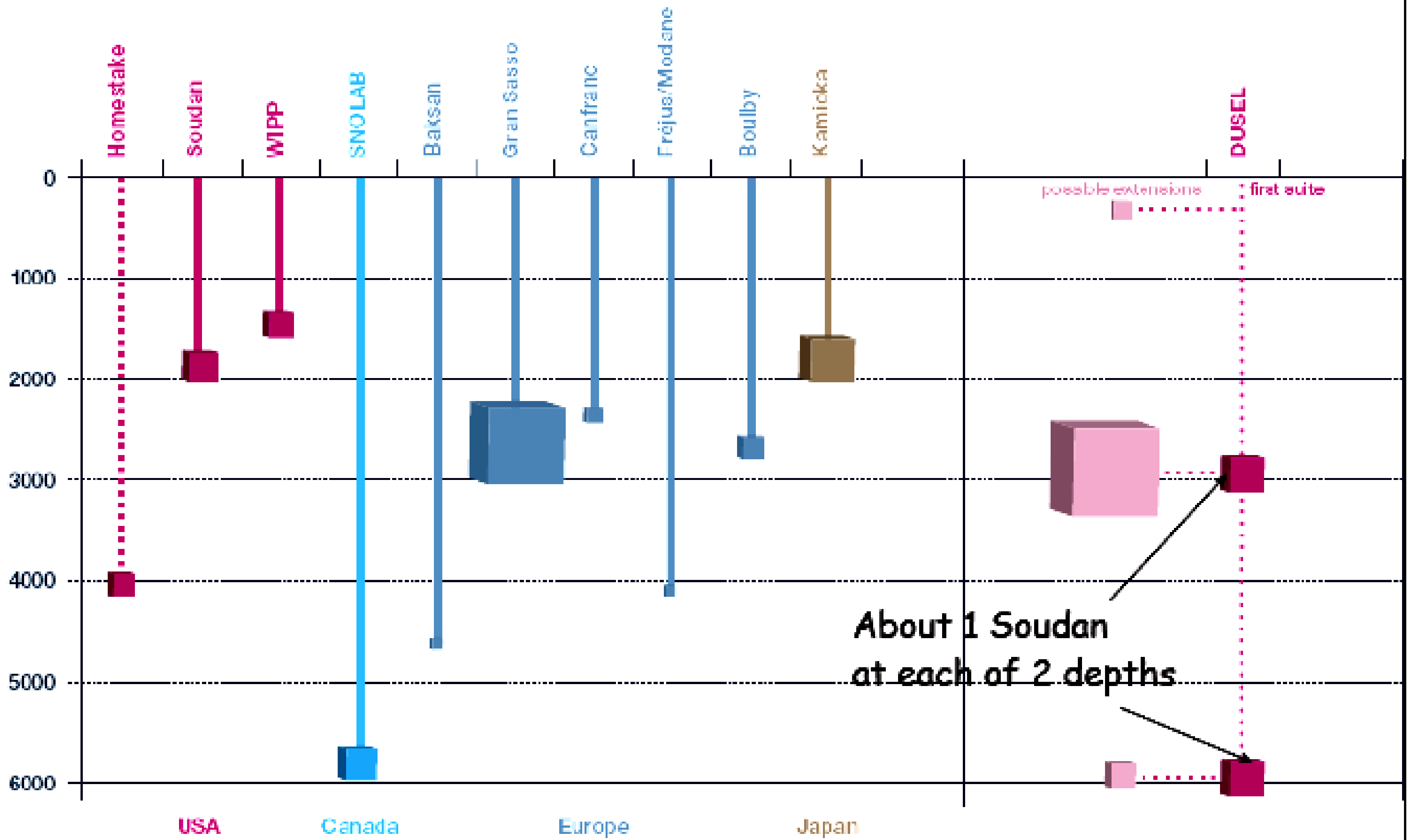
DUSEL – Deep Underground Science and Engineering Laboratory

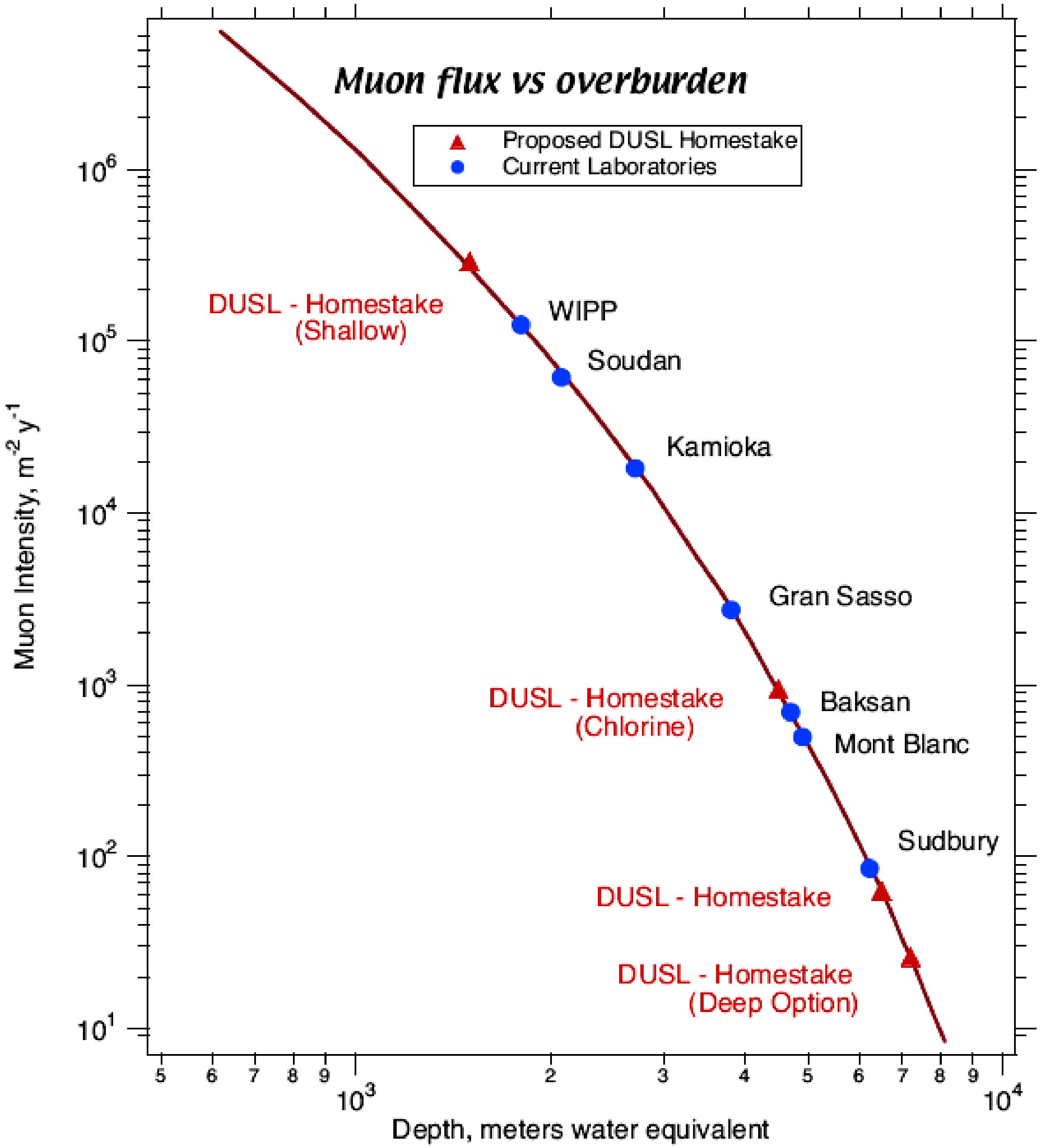
Very rich interdisciplinary programme – from fundamental physics, through biology and egineering studies to the education and outreach.

Four proposed localizations (Homestake, Henderson mine, Pioneer Tunnel, Soudan), decision soon, startup in 2010 according to the most optimistic scenario.



Science Underground





Muon flux vs overburden
Proposed DUSL Homestake
Current Laboratories
DUSL - Homestake (Shallow)
WIPP
Soudan
Kamioka
Gran Sasso
DUSL - Homestake (Chlorine)
Baksan
Mont Blanc
Sudbury
DUSL - Homestake
DUSL - Homestake (Deep Option)
Muon Intensity, m-2 y-1
Depth, meters water equivalent

Spare transparencies

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) decay mode $e^+ \pi^0$ decay mode anti-ν K^+	 $0.5 \cdot 10^{35}$ $1.1 \cdot 10^{35}$	TBD $0.4 \cdot 10^{35}$	$1.0 \cdot 10^{35}$ $0.2 \cdot 10^{35}$
SN at 10 kpc, # events CC NC ES	$2.5 \cdot 10^4$ (ν_e) $3.0 \cdot 10^4$ $1.0 \cdot 10^3$ (e)	$9.0 \cdot 10^3$ (anti-ν_e) $3.0 \cdot 10^3$ $5.0 \cdot 10^3$ (p) $6.0 \cdot 10^2$ (p)	$2.0 \cdot 10^5$ (anti-ν_e) - $1.0 \cdot 10^3$ (e)
Diffuse SN # Signal/Background events (after 5 years)	60/30	(10-115)/4	(40-110)/50 (with Gadolinium)
Solar neutrinos # events, 1 year	^{8}B ES : $4.5 \cdot 10^4$ Abs: $1.6 \cdot 10^5$	^{7}Be: $2.0 \cdot 10^6$ pep: $7.7 \cdot 10^4$ CNO: $7.6 \cdot 10^4$ ^{8}B(CC): $3.6 \cdot 10^2$ ^{8}B(NC): $5 \cdot 10^3$	^{8}B ES: $1.1 \cdot 10^5$
Atmospheric ν # 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

Deconstructing the Earth

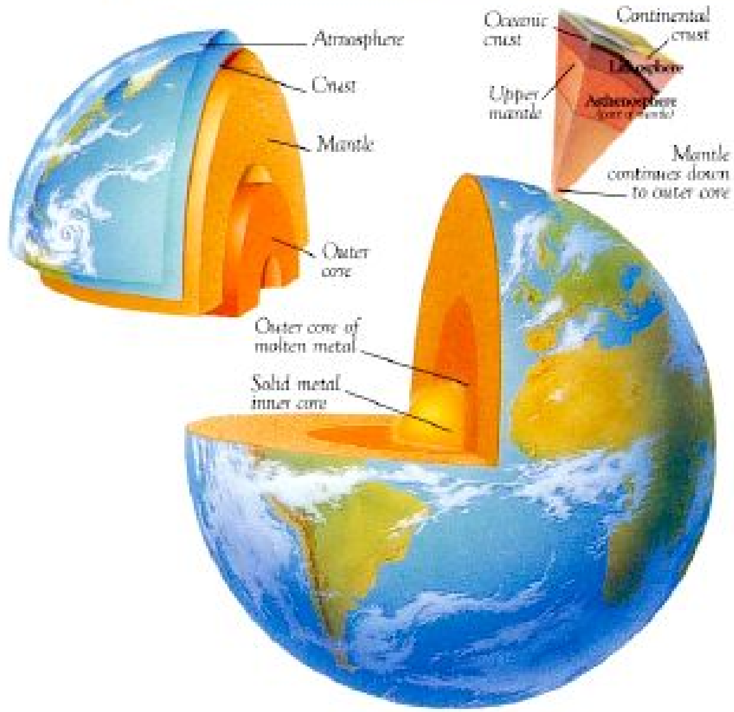
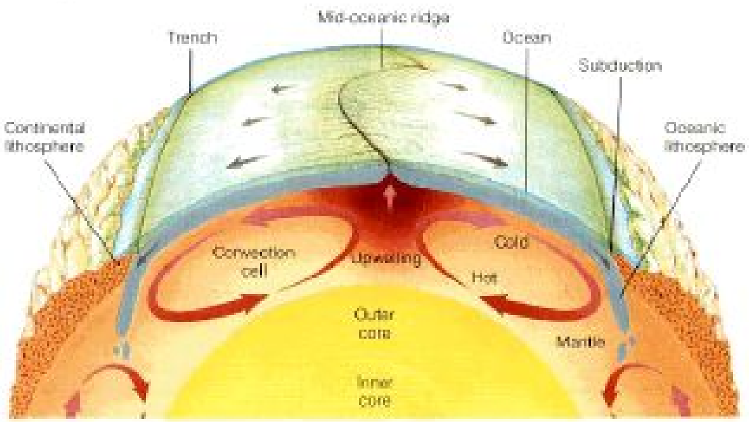


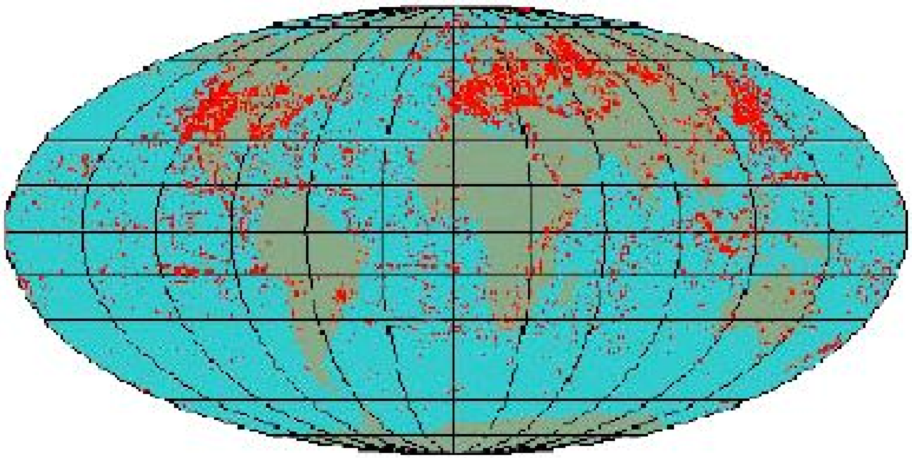
Image by Colin Rose and Dorling Kindersley



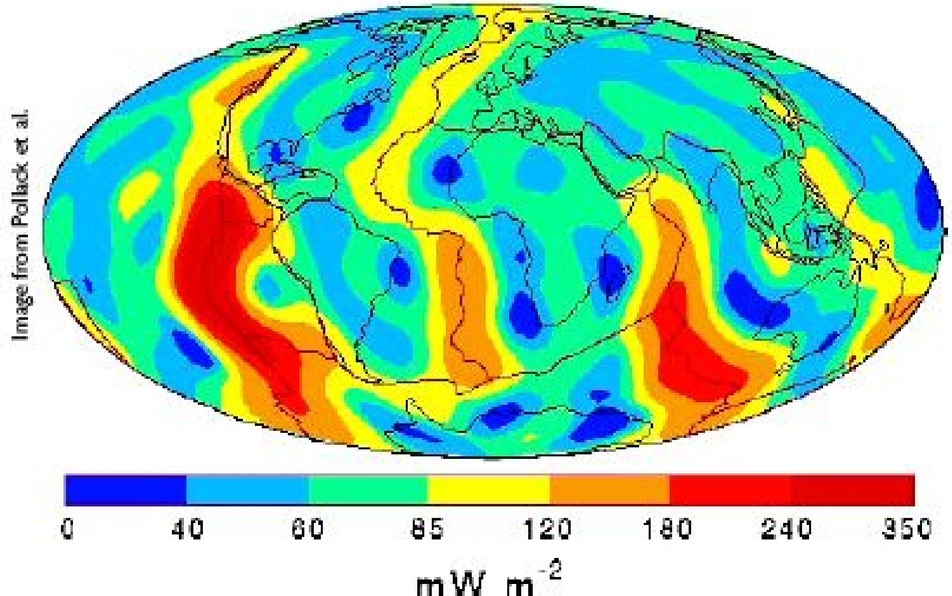
- Seismologists subdivide the Earth into five basic regions:
  - Core
  - Mantle
  - Oceanic crust
  - Continental crust
  - Sediment
- These regions are solid except for the outer core
- Oceanic crust is made at mid-oceanic ridge and recycled at continental trenches

Earth Heat Flow

Bore hole locations



Heat Flow



- Based on bore holes measuring conductive heat flow (need temp gradient and conductivity):
  - Total heat flow of 44±1TW
  - 40 times larger than total world reactor power
  - Average heat flux: 87 mW/m^2
  - (a more recent calculation estimates it to be 31±1TW)
- Where does this heat come from?

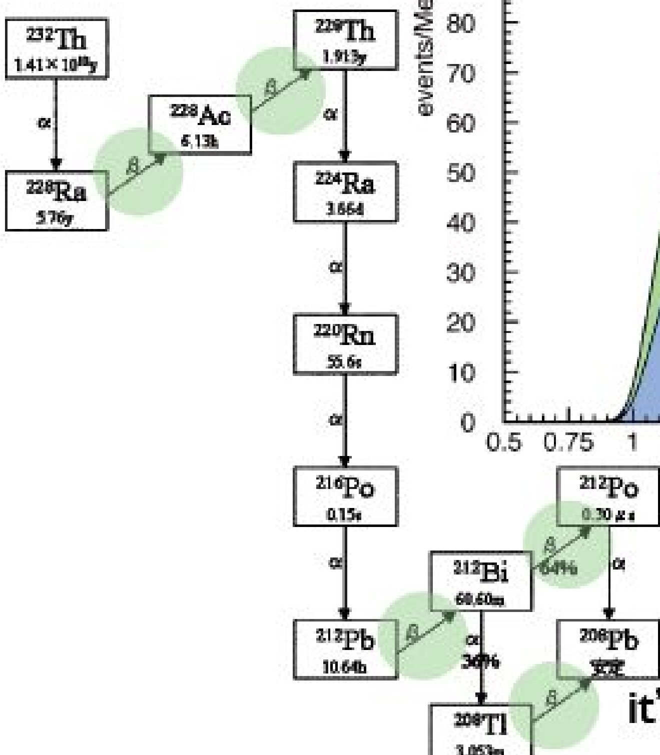
Radiogenic Heat

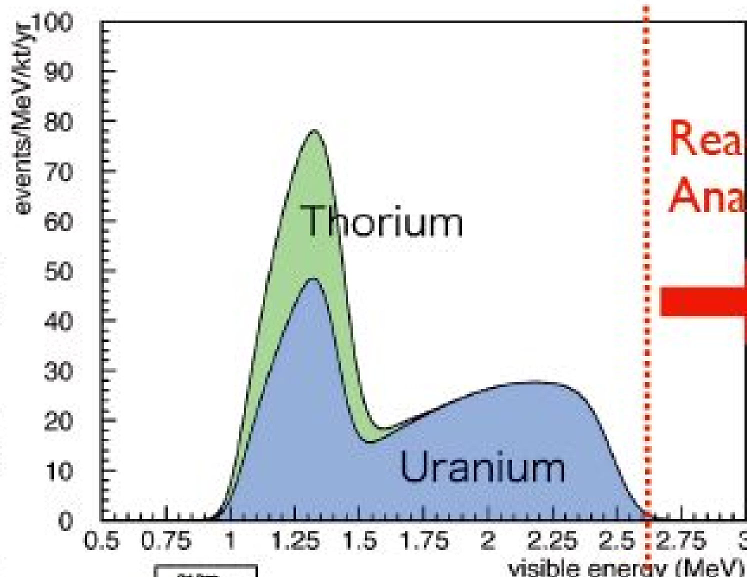
- U, Th and K concentrations in the Earth are based on chondritic meteorites
- Chondritic meteorites consists of elements similar to those in the solar photosphere
- From these meteorites, we know the Th/U ratio to be ~3.9
- In one popular model:
  - Uranium and Thorium account for 8TW each
  - Potassium is 3TW
  - Total radioactive power: 19TW
  - Rest is 'old' heat
- U, Th and K concentrations highest in continental crust, also some in mantle, but none in core

Geoneutrinos

Neutrinos from radioactivity provide direct information on the Earth's interior

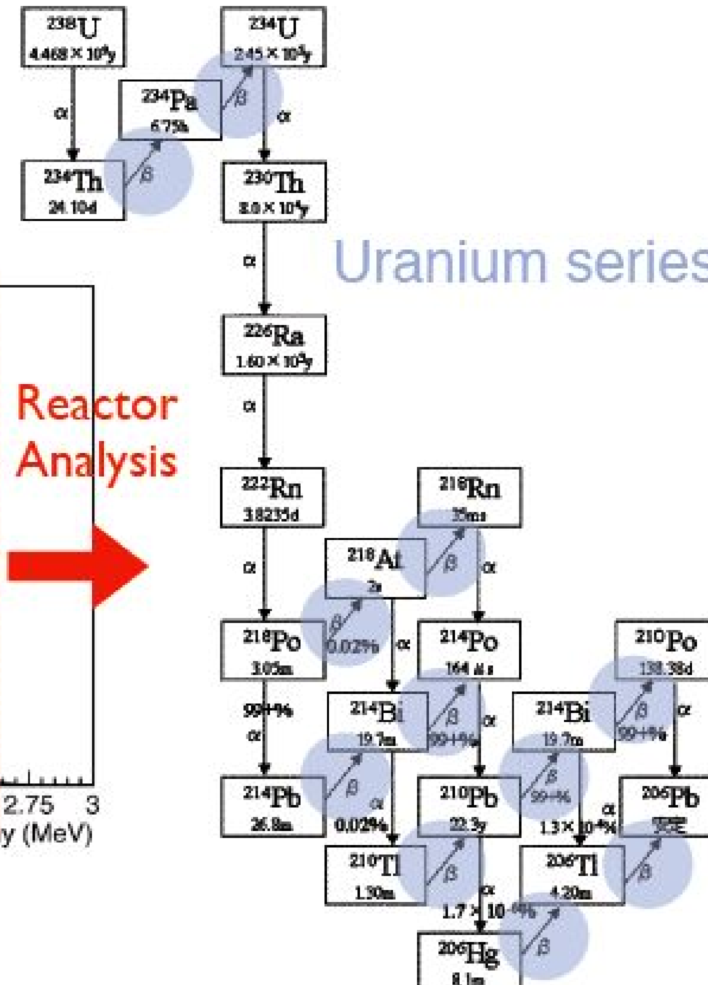
Thorium series





Reactor Analysis

Uranium series



Potassium not visible, because it's below inverse beta-decay threshold of 1.8MeV

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

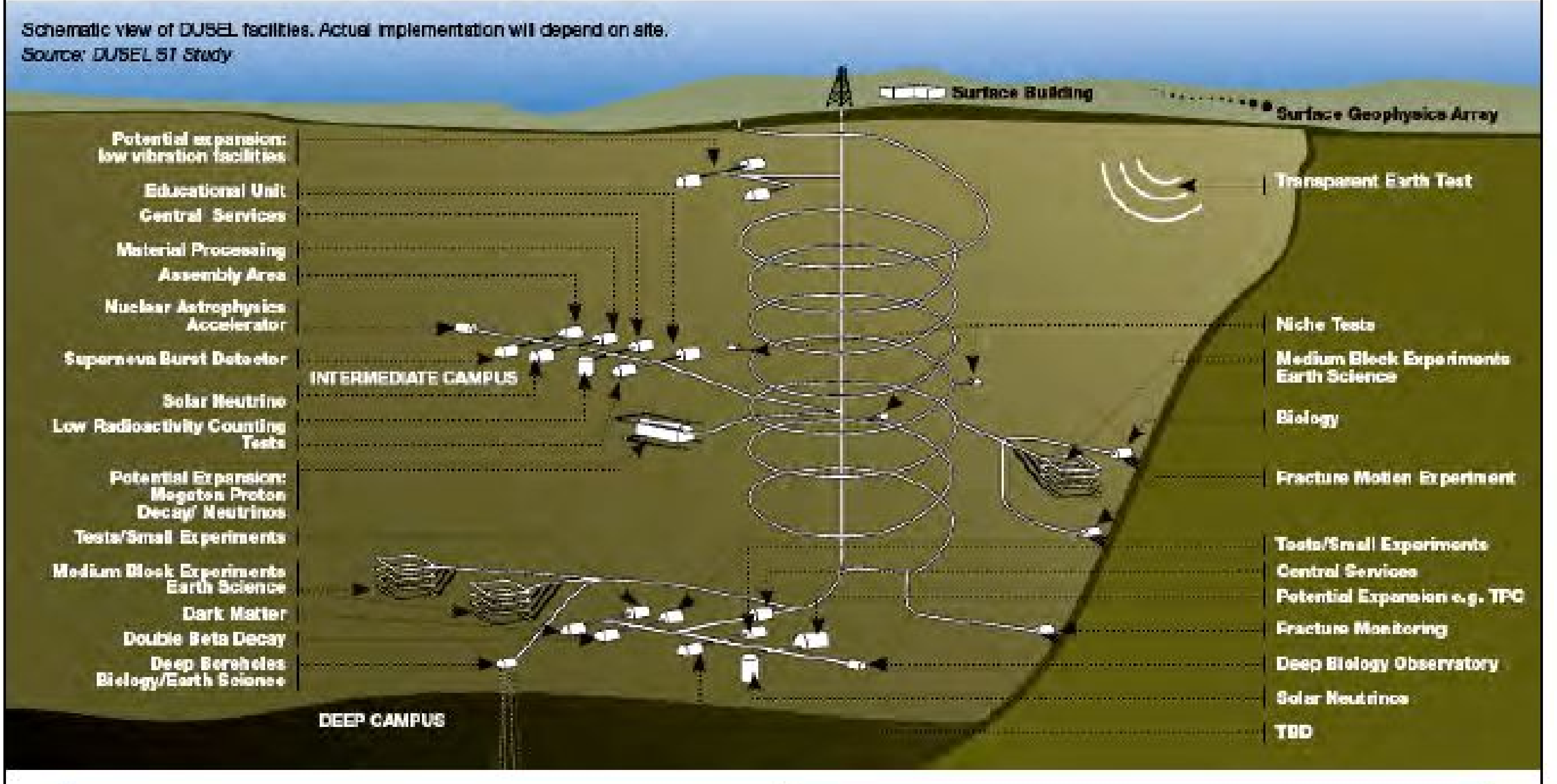
- **Underground construction**: the new frontier (urban, mining, fuel storage)
- **Resource extraction**: Critical need for recovery efficiency improvement
- Water resources:
- **Environmental stewardship**
  - Remediation (e.g. with micro-organisms)
  - Waste isolation and carbon dioxide sequestration.
- **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

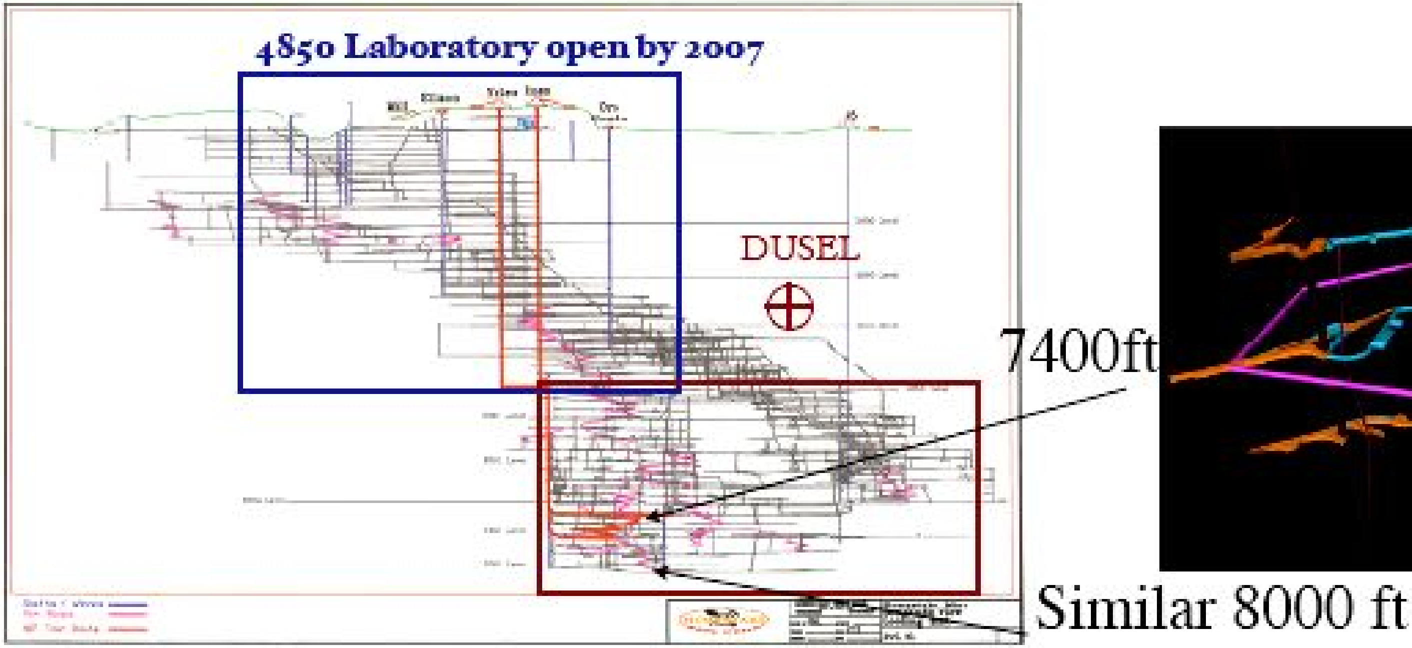
+ public outreach: better understanding of science

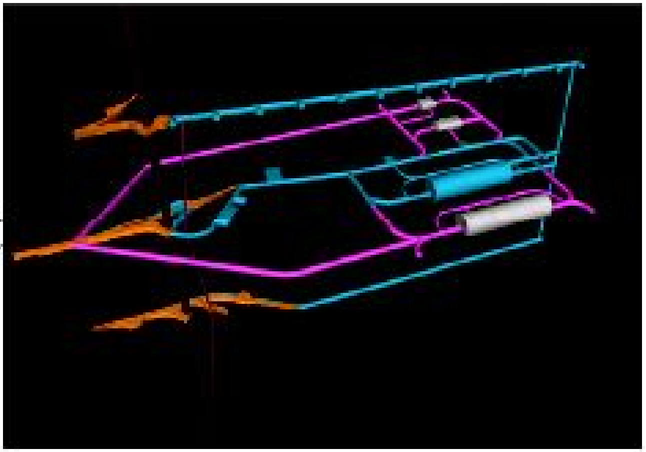
First Suite of Experiments+ Extension

Note science before and during the excavation



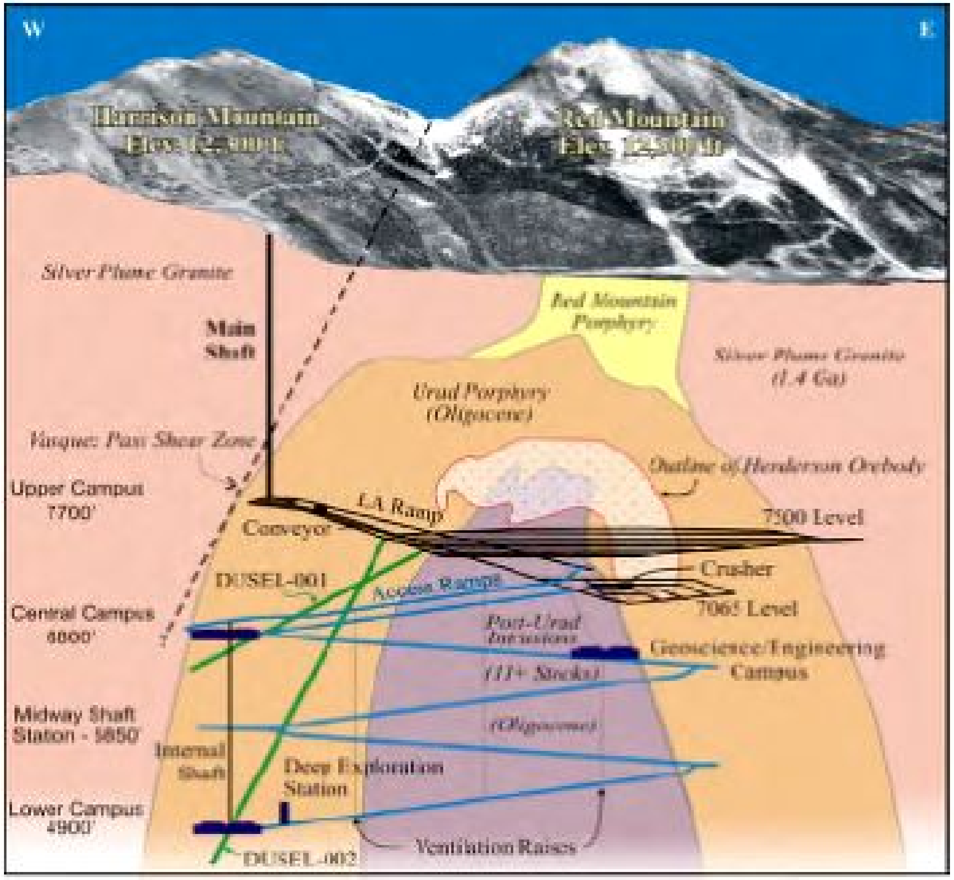
Homestake





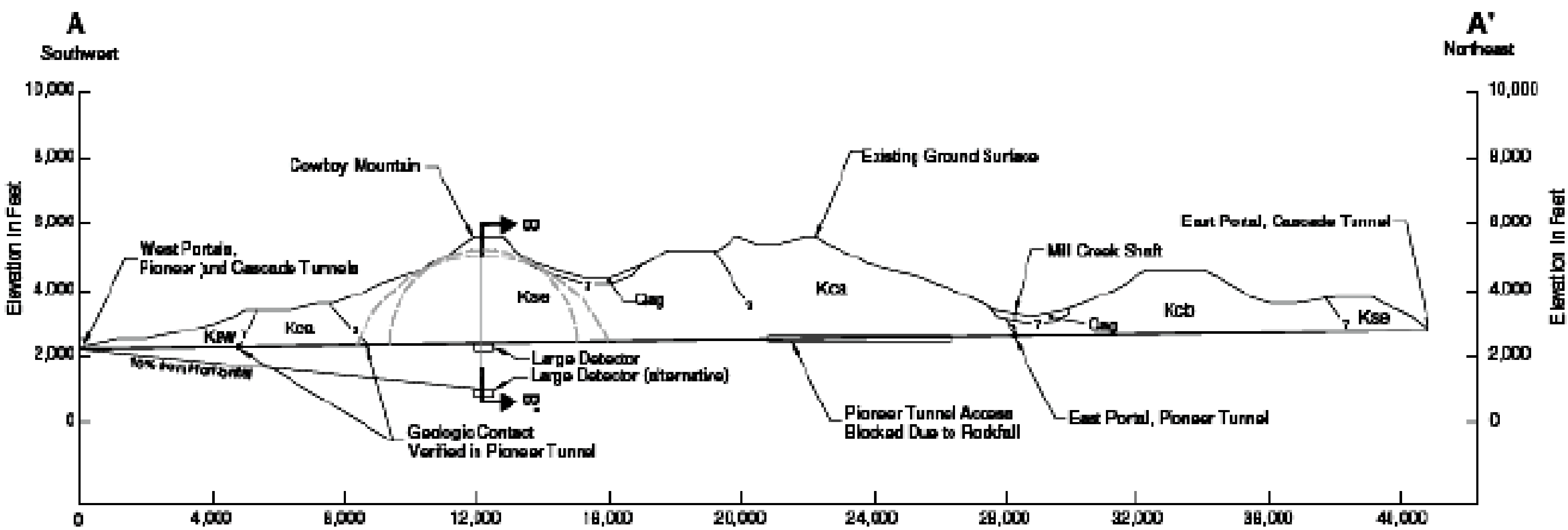
- Well-Characterized Site with miles of tunnels
  - Varied, Interesting, and Suitable Geology
  - Extensive Experience to > 8000 feet below ground. Low risk
- Phased Approach to Developing the Facility
  - Ability to host near-term R&D and Experimental Opportunities: interim lab
  - Phased entry into 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!