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

Agnieszka Zalewska – IFJ PAN, Poland

CERN, 15.09.2008

What is LAGUNA

Detector concepts

Research program

Localization of the future large European laboratory

What is LAGUNA?

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

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

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

4. 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 recommendation, 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."

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	100 M€ (South) 50 M€ (North)	first site in 2010	Physics potential well defined by rich physics from present gamma experiments
Charged Cosmic Rays: Auger North	85 M€	2009	Confirmation of physics potential from Auger South results expected in 2007
Neutrinos: KM3NeT	300 M€	2011	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

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**

LAGUNA – after negociations with the EC

Approved by the European Commission but with the recommendation to concentrate on the underground laboratory site studies

Funding – 1.7 mln Euro (out of 5 mln in the application)
– detector R&D should be funded with different money

Two years study with a start up on the 1st of July 2008, kick-off meeting at ETH Zurich, 3-4 July 2008

Results of the study should be ready for the ESFRI recommendations in 2010

The LAGUNA Collaboration

21 beneficiaries (16 scientific partners, 5 industrial partners) plus 6 affiliated scientific institutions

~100 participants from 11 countries

CERN, 15.09.2008

Beneficiary no.	Beneficiary name	Beneficiary short name	Country	Date enter project	Date exit project
1. (coordinator)	Swiss Federal Institute of Technology Zurich	ETH Zurich	Switzerland	1	24
2.	University of Bern	U-Bern	Switzerland	1	24
3.	University of Jyväskylä	U-Jyväskylä	Finland	1	24
4.	University of Oulu	U-Oulu	Finland	1	24
5.	Kalliosuunnittelu Oy Rockplan Ltd	Rockplan	Finland	1	24
6.	Commissariat à l'Energie Atomique / Direction des Sciences de la Matière	CEA	France	1	24
7.	Institut National de Physique Nucléaire et de Physique des Particules (CNRS/IN2P3)	IN2P3	France	1	24
8.	Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V.	MPG	Germany	1	24
9.	Technische Universität München	TUM	Germany	1	24
10.	H.Niewodniczanski Institute of Nuclear Physics of the Polish Academy of Sciences, Krakow	IFJ PAN	Poland	1	24
11.	KGHM CUPRUM Ltd Research and Development Centre	KGHM CUPRUM	Poland	1	24
12.	Mineral and Energy Economy Research Institute of the Polish Academy of Sciences	IGSMiE PAN	Poland	1	24
13.	Laboratorio Subterraneo de Canfranc	LSC	Spain	1	24
14.	Universidad Autonoma, Madrid	UAM	Spain	1	24
15.	University of Granada	UGR	Spain	1	24
16.	University of Durham	UDUR	United Kingdom	1	24
17.	The University of Sheffield	U-Sheffield	United Kingdom	1	24
18.	Technodyne International Ltd	Technodyne	United Kingdom	1	24
19.	University of Aarhus	U-Aarhus	Denmark	1	24
20.	AGT Ingegneria Srl, Perugia	AGT	Italy	1	24
21.	Institute of Physics and Nuclear Engineering, Bucharest	IFIN-HH	Romania	1	24

Work packages

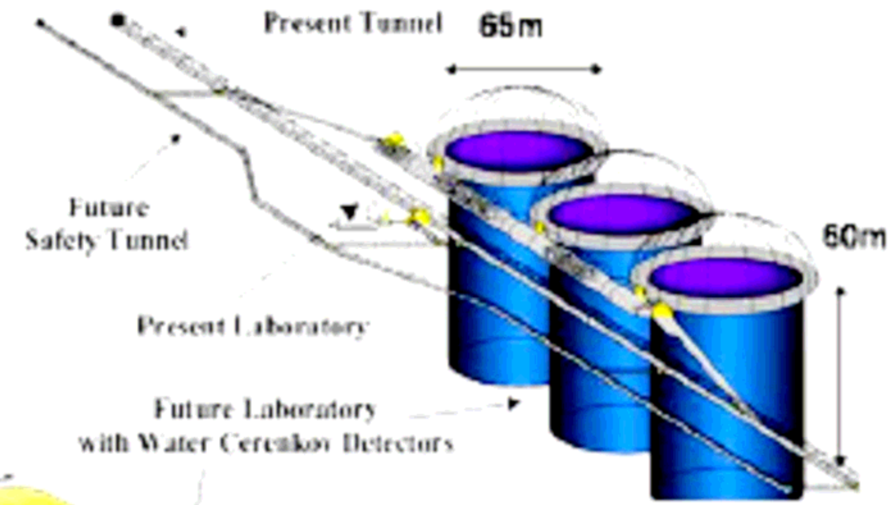
B.1.3.3. Work package list / overview

Work package no.	Work package title	Type of activity	Lead beneficiary no.	Person-months	Start month	End month
WP1	Management, coordination and assessment	MGT	ETHZ	26.5	1	24
WP2	Underground Infrastructures and Engineering	RTD	TUM	157.5	1	24
WP3	Safety, environmental and socio-economic issues	RTD	U-Sheffield	46	1	24
WP4	Science Impact and Outreach	RTD	IFJ PAN	49.9	1	24
	TOTAL			**279.9**		

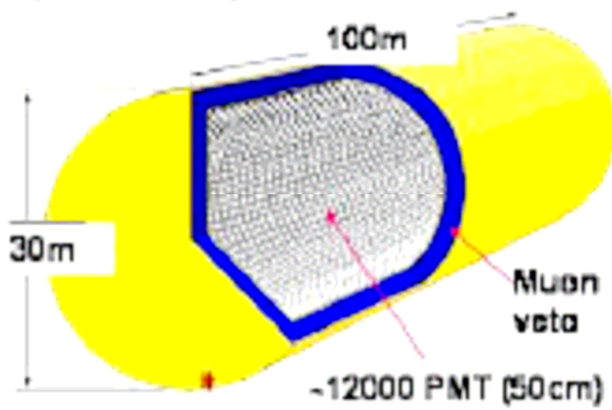
Detector concepts

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

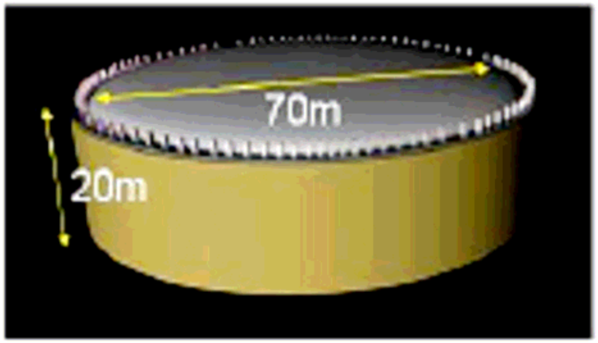
MEMPHYS:
Water Cherenkov,
(420 kton -1 Mton)



LENA:
Liquid Scintillator
(30-70 kton)



GLACIER: Liquid Argon (50 -100 kton)



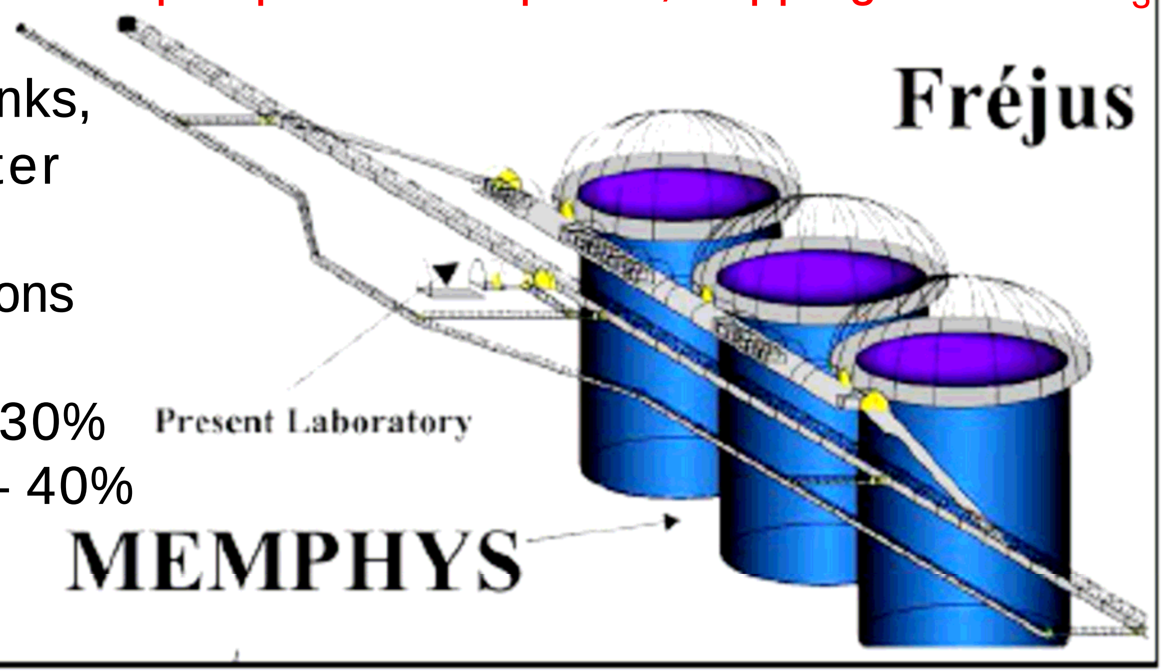
MEMPHYS – water Cherenkov detector

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)



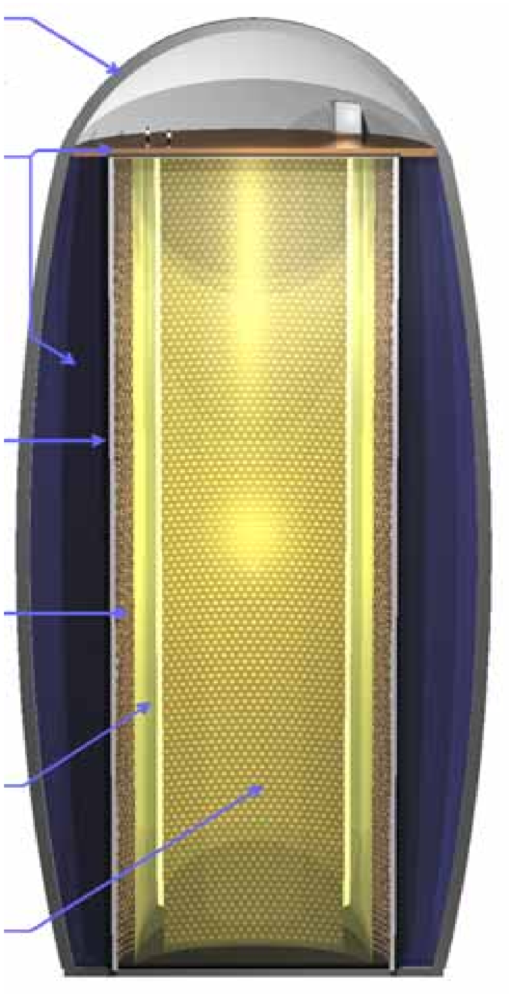
LENA – the liquid scintillator detector

Concept: initial work for the Pyhäsalmi mine in Finland, 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 high and with a diameter of 30m, fiducial mass of about 50 ktons, readout by 12 000 photomultipliers (20" – 30% surface coverage, with added light concentrators - 50% coverage)



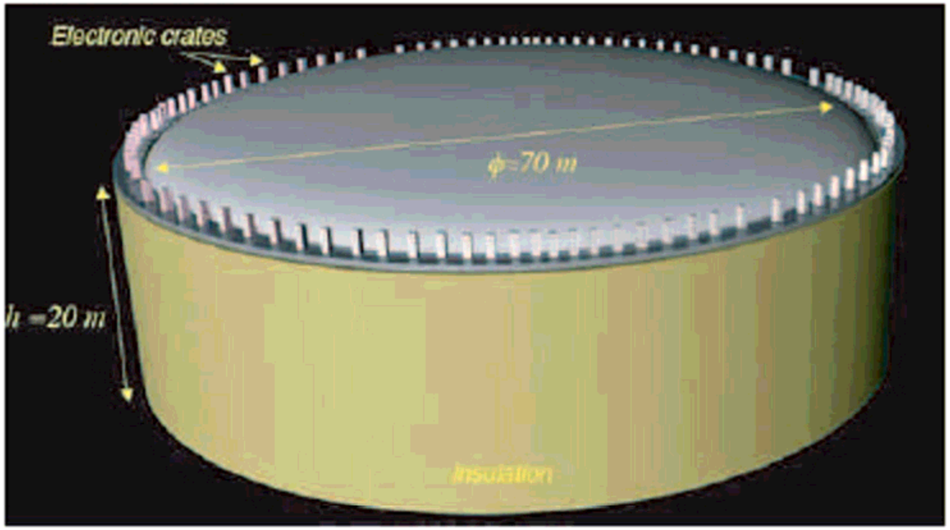
GLACIER – the Liquid Argon detector

Concept: initial work 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

Construction: cylinder 70m in diameter and 20 m hight, total mass - 100 ktons of Liquid Argon, read out of the ionisation signal and two types of light signals (scintillations and Cherenkov light)



Research programme

1. Searches for proton decay

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

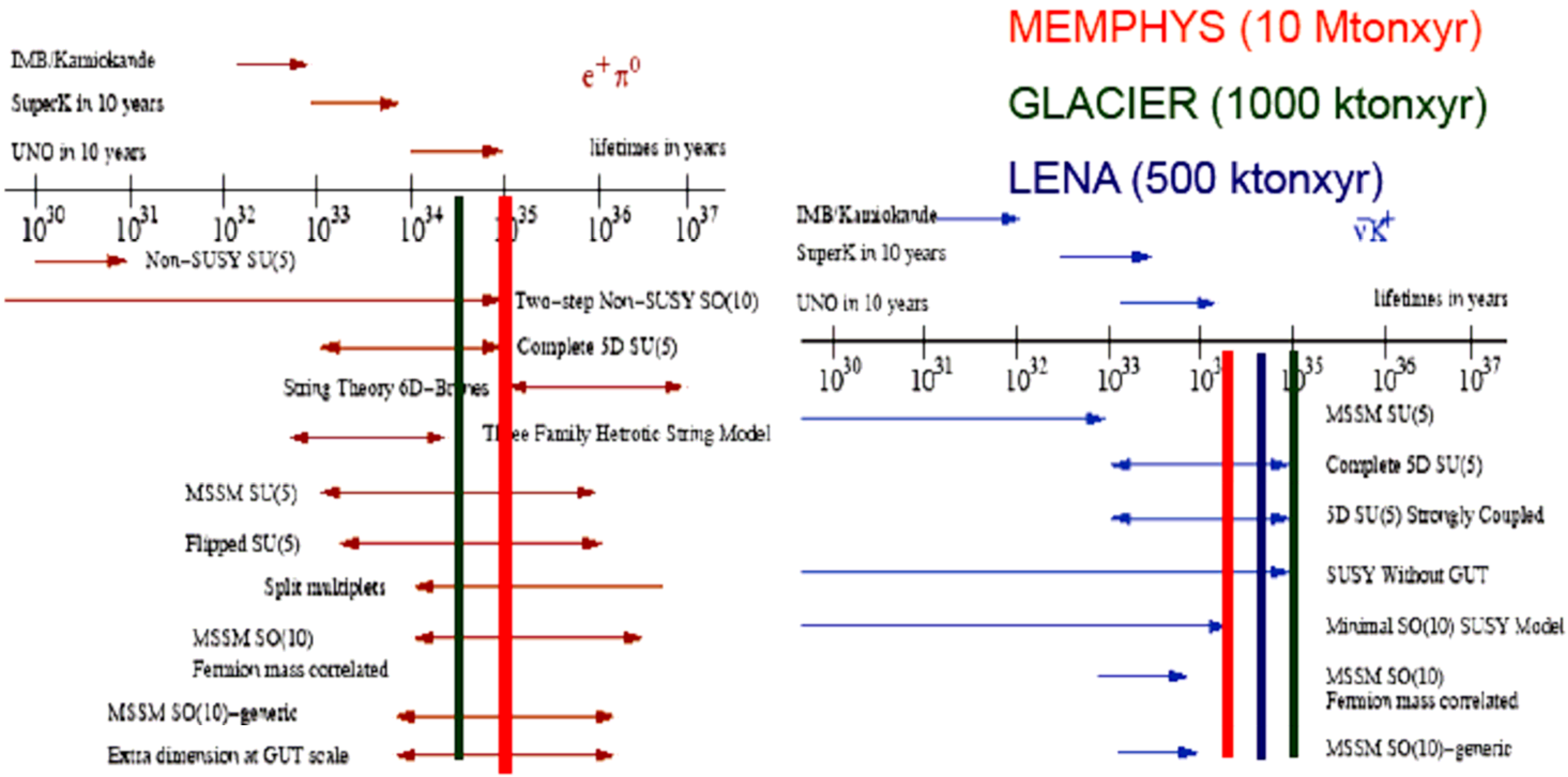
3. Studies of neutrino properties based on accelarator neutrino beams

J.Aysto et al.., hep-ph/07050116;
J. Cosmol. Astropart. Phys. 11 (2007) 011;

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

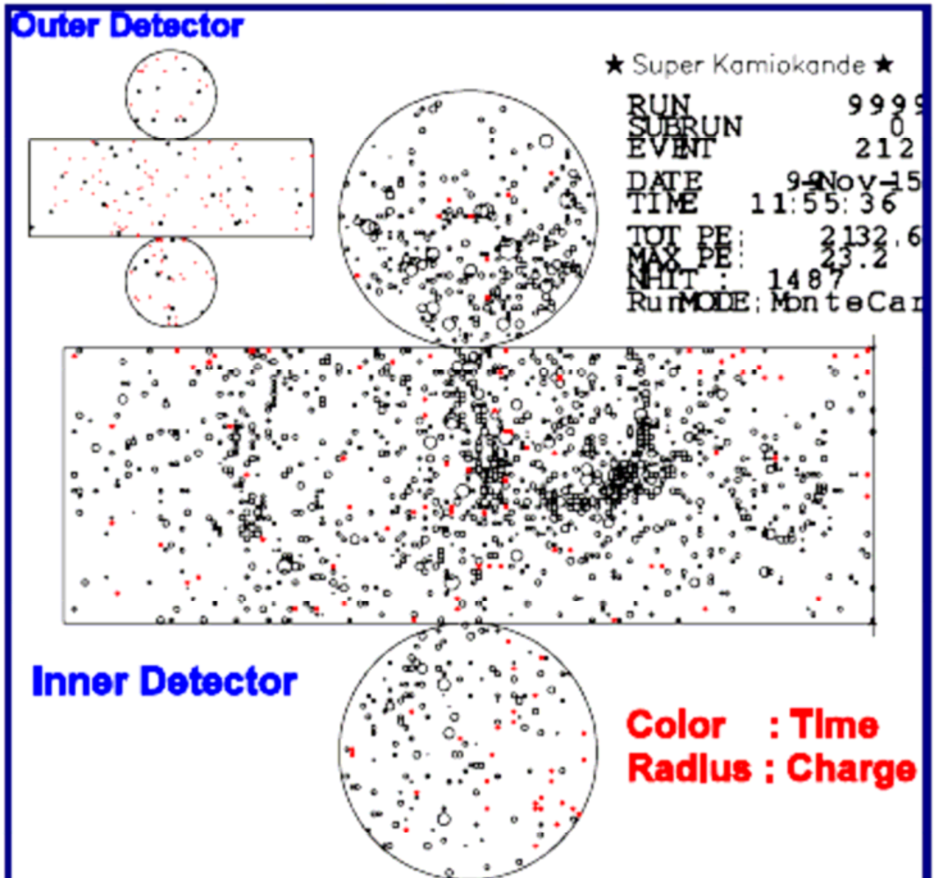
Topics	GLACIER (100 kt)	LENA (50 kt)	MEMPHYS (400 kt)
proton decay, sensitivity (years) decay mode $e^+ \pi^0$ decay mode anti-ν K^+	 $0.5 \cdot 10^{35}$ $1.1 \cdot 10^{35}$	 TBD $0.4 \cdot 10^{35}$	 $1.0 \cdot 10^{35}$ $0.2 \cdot 10^{35}$
SN at 10 kpc, # events CC NC ES	 $2.5 \cdot 10^4$ (ν_e) $3.0 \cdot 10^4$ $1.0 \cdot 10^3$ (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

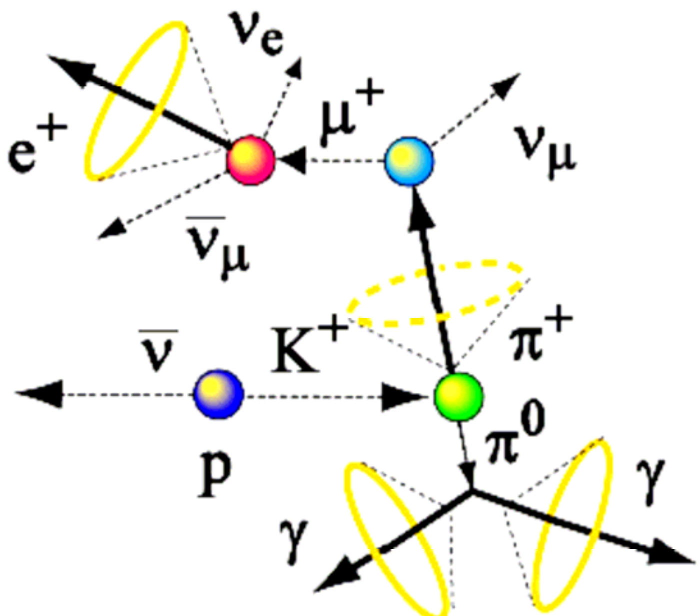
Proton decay



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

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



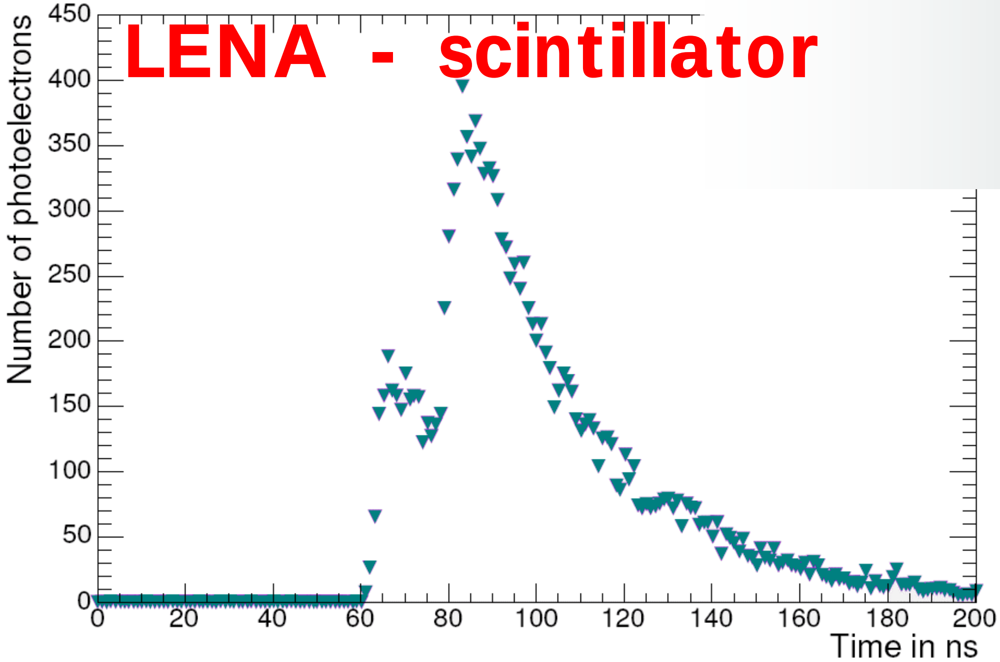


selection criteria

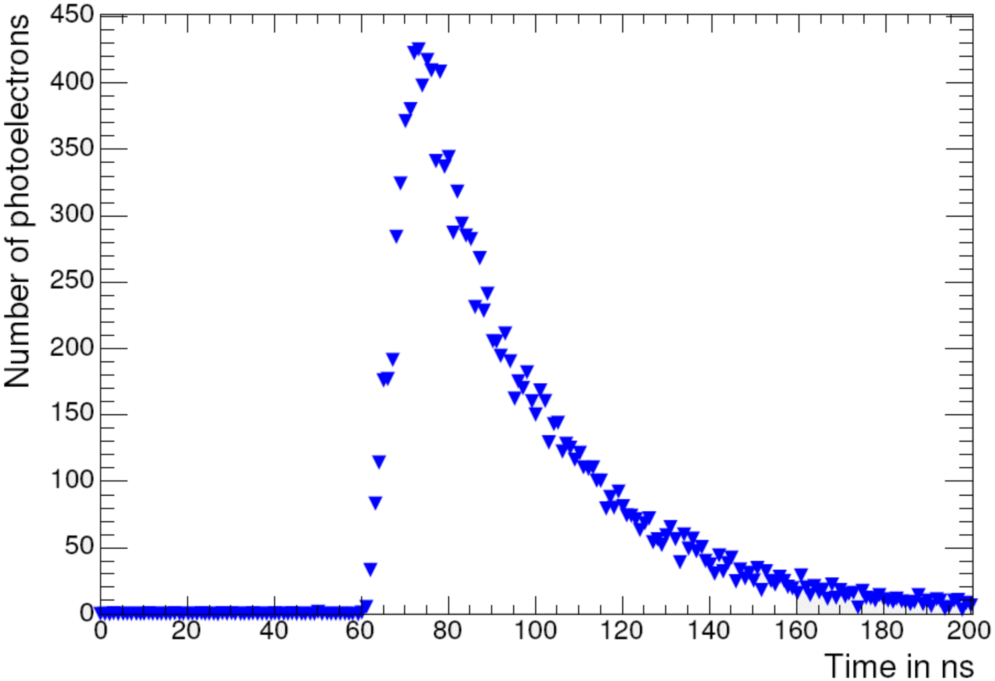
- 2 e-like ring
- 1 Michel electron
- $85 < m_{\pi^0} < 185$ MeV/c^2
- $175 < p_{\pi^0} < 250$MeV/c
- $40 < Q_{\pi^+} < 100$PE, $Q_{res} < 70$PE

PROTON DECAY
EVENT SIGNATURE

LENA - scintillator



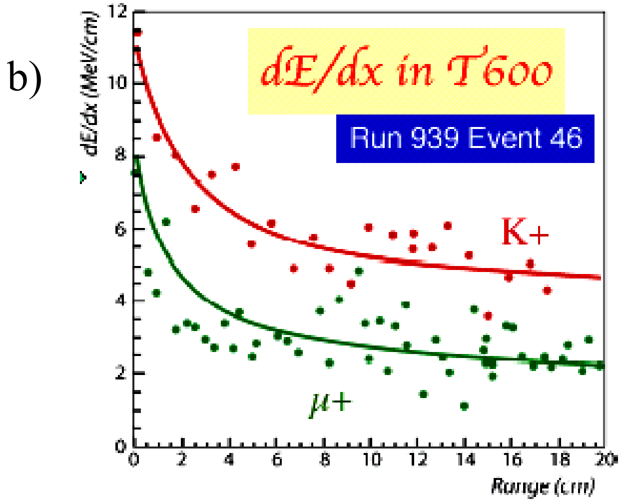
Kaon decay after 18ns

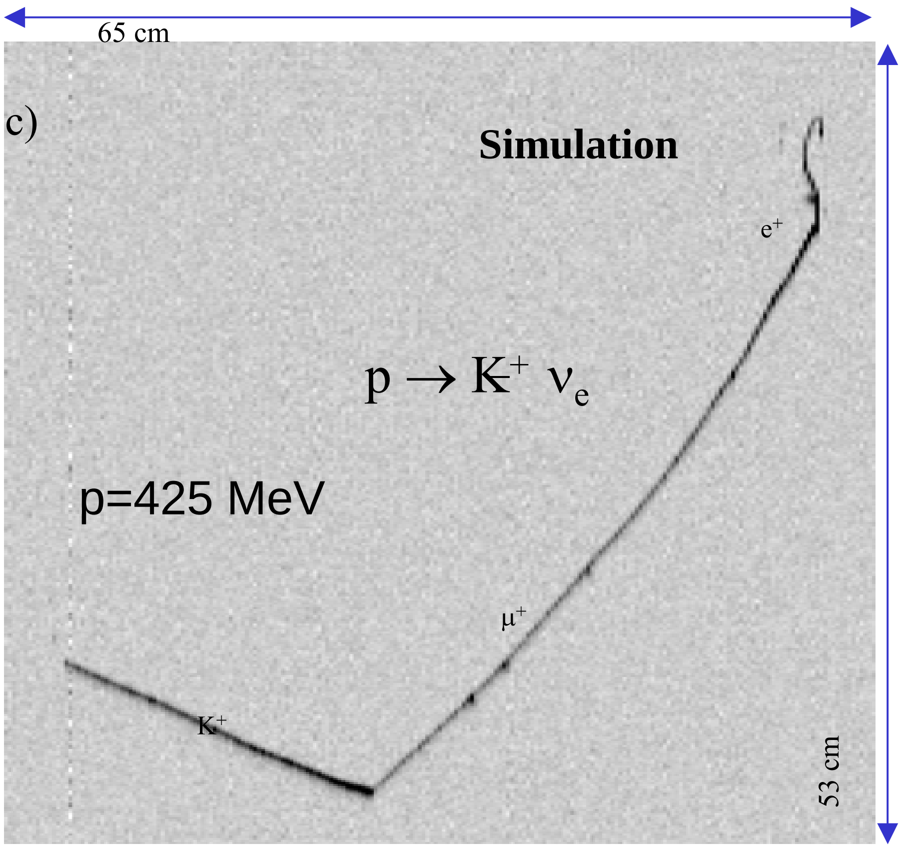


Kaon decay after 5ns

Challenge:
short decay time of Kaon (12.8ns)

Proton decay in Liquid Argon





<u>Detection efficiency of almost 100%</u>

<u>with practically no background</u>

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

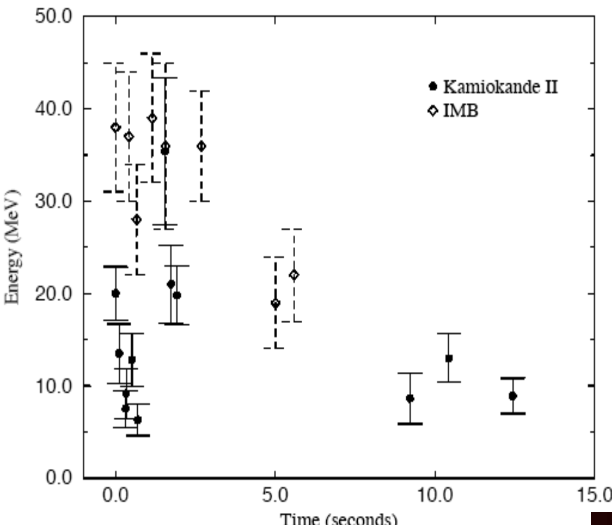
- Neutrino mass (time of flight delay)
- Oscillation parameters (flavor transformation in SN core and/or in Earth): Type of mass hierarchy and θ_{13} mixing angle

3. Early alert for astronomers

- Pointing to the supernova

SN1987A Type II in LMC (~55 kpc)

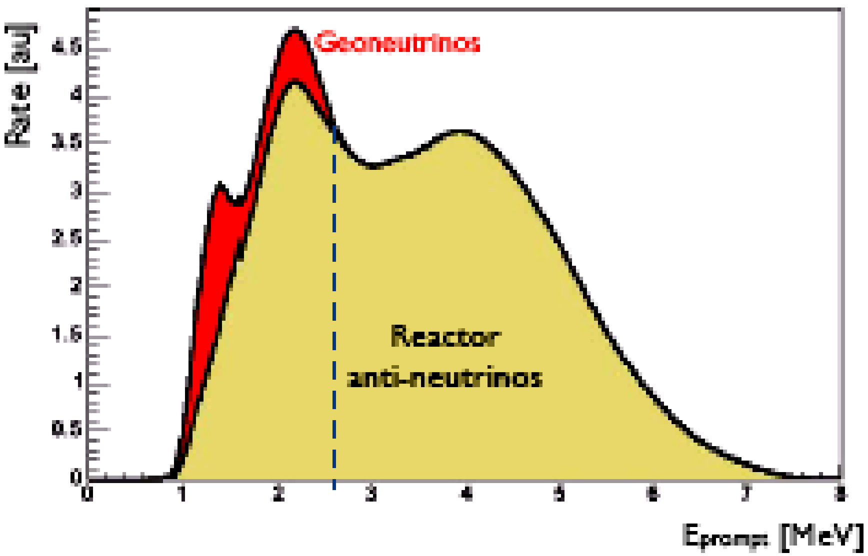
Water Cherenkov:	IMB	E_{th} ~ 29 MeV, 6 kton	8 events
	Kam II	E_{th} ~ 8.5 MeV, 2.4 kton	11 events
Liquid Scintillator:	Baksan	E_{th} ~ 10 MeV, 130 ton	3-5 events
	Mont Blanc	E_{th} ~ 7 MeV, 90 ton	5 events??



Confirmed baseline model... but still many questions

A.Rubbia

Geo-neutrinos



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)

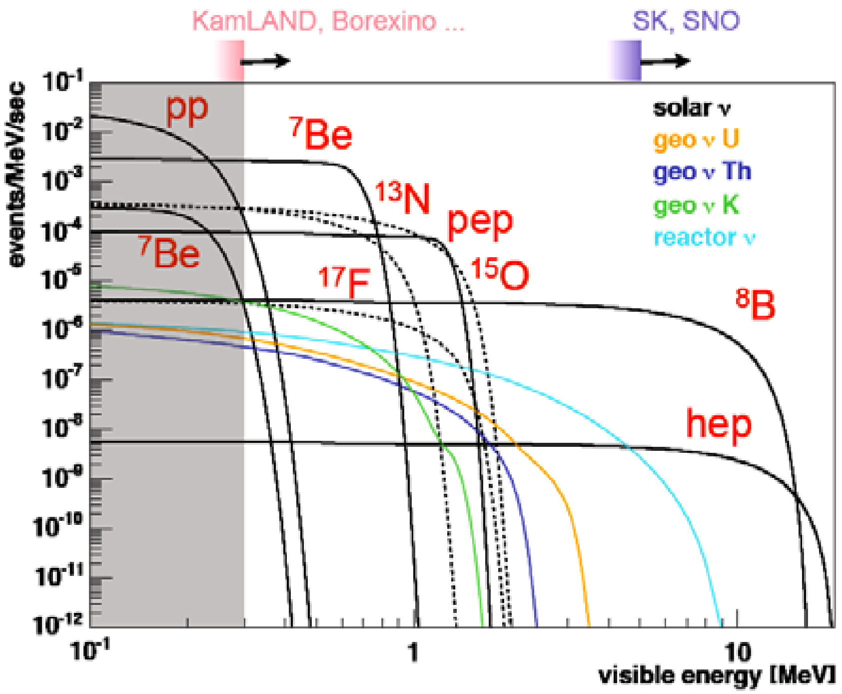
Low energy neutrinos – cont.

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

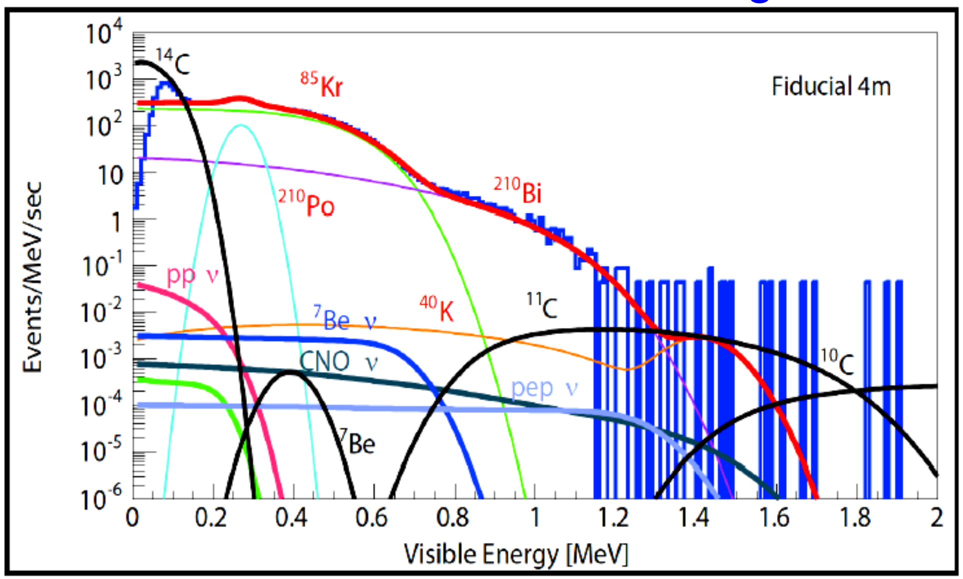
Search for WIMPS in the SUN and Earth cores

Neutrino astronomy of the Sun

Energy spectrum for the $\nu_e e$ elastic scattering



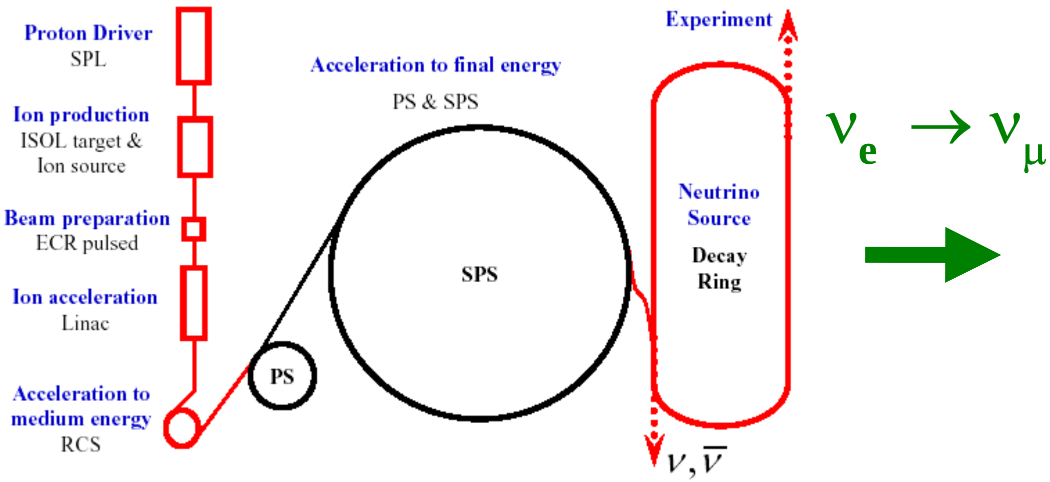
2006 - spectrum in KamLAND before scintillator cleaning

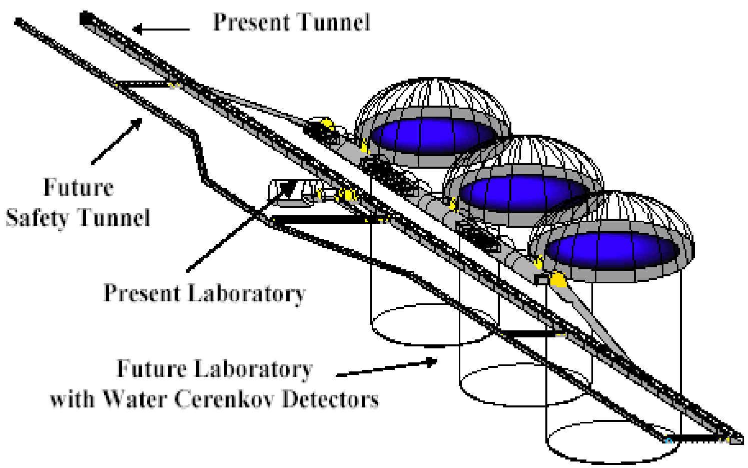


Neutrinos from β beam – oscillations in MEMPHYS

• 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





Possible localizations of the future large underground laboratory

SITE STUDY

Candidate Sites

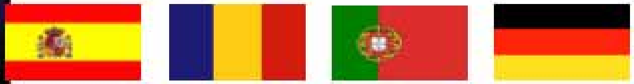
- Boulby, UK
- Canfránc, Spain
- Fréjus, France
- Pyhäsalmi, Finland
- Sieroszowice, Poland
- Slanic, Romania
- Italy

LAGUNA Collaboration

100 scientists

more than 20 institutes

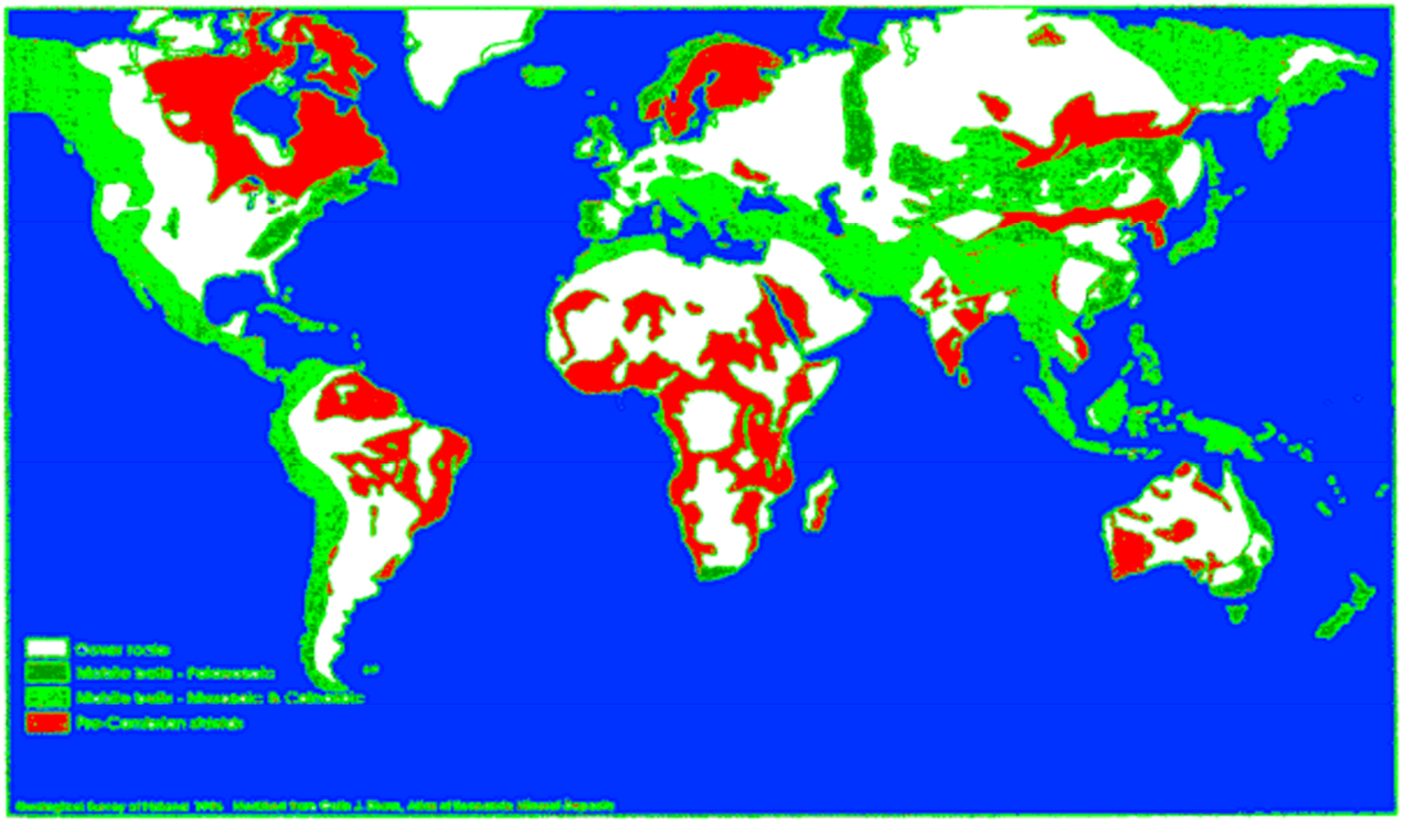
11 European countries



Localization criteria – 1.

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



Localization criteria – 2.

UNIVERSITY of OULU

Nuclear reactor background

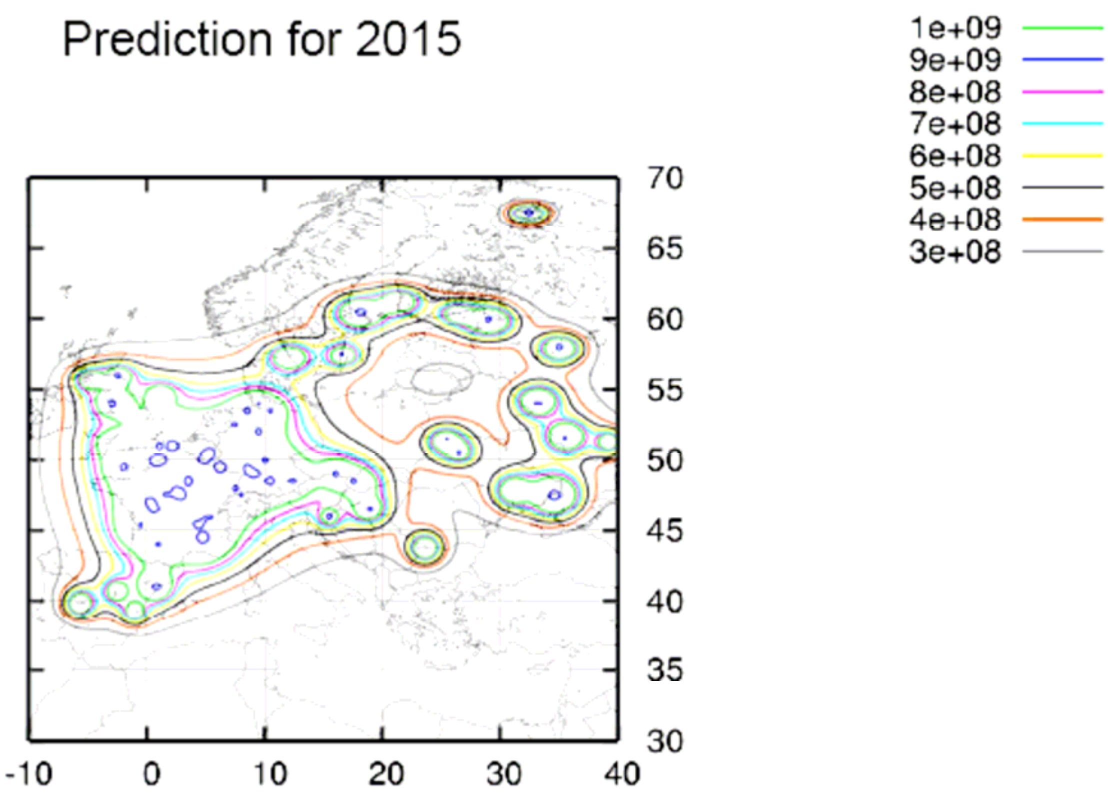
- Relevant mostly for LENA
- Reactor fluxes estimated globally
- Marine reactors irrelevant?

Location	ν (10^8 1/m² s)
Pyhäsalmi	40
Gran Sasso	54
Frejus	175
Canfranc	196
Boulby	190
Kamioka	408
Sudbury	100
Soudan	33
Pylos	12

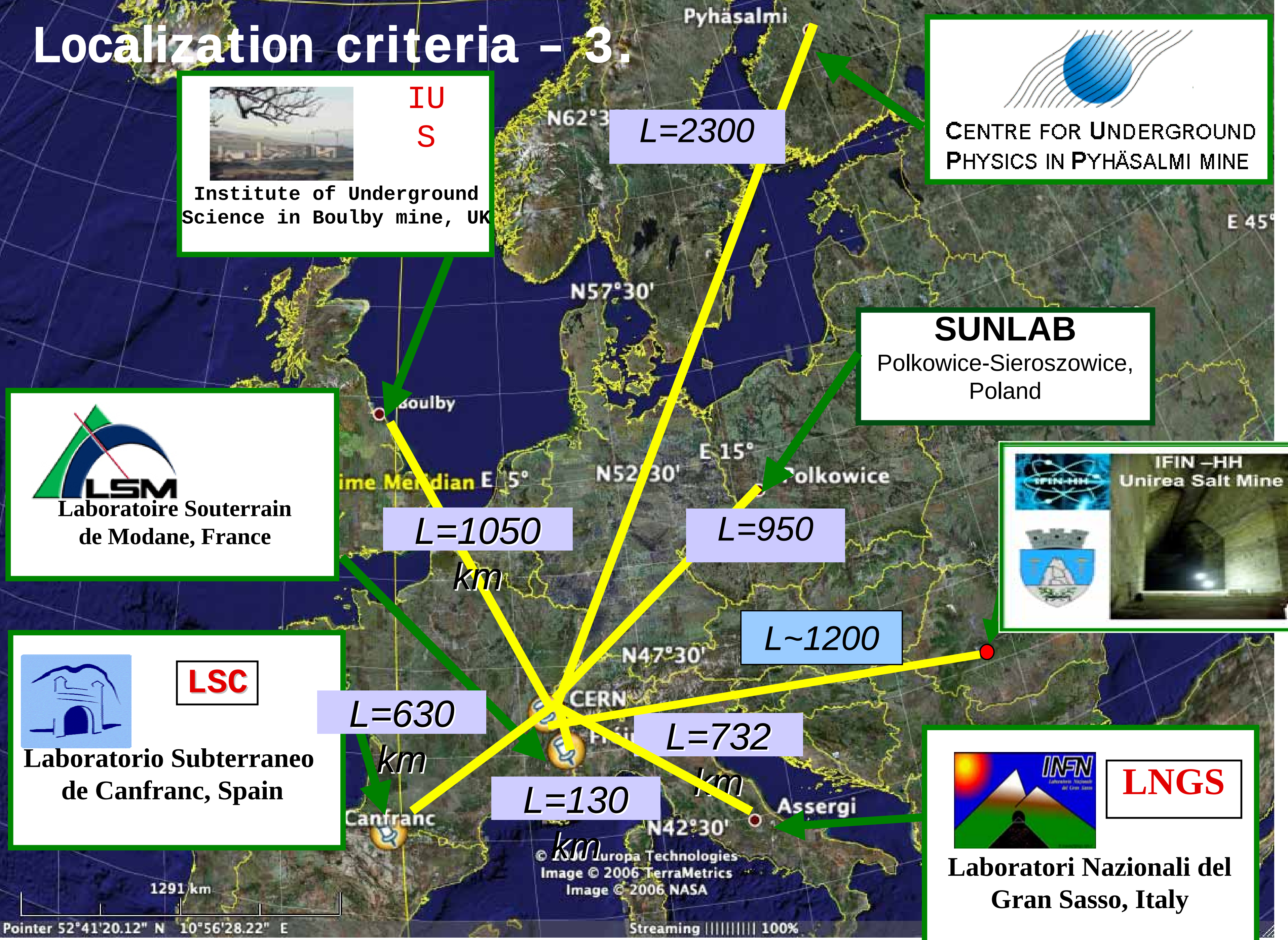
2005

Reactor electron anti-neutrino flux density

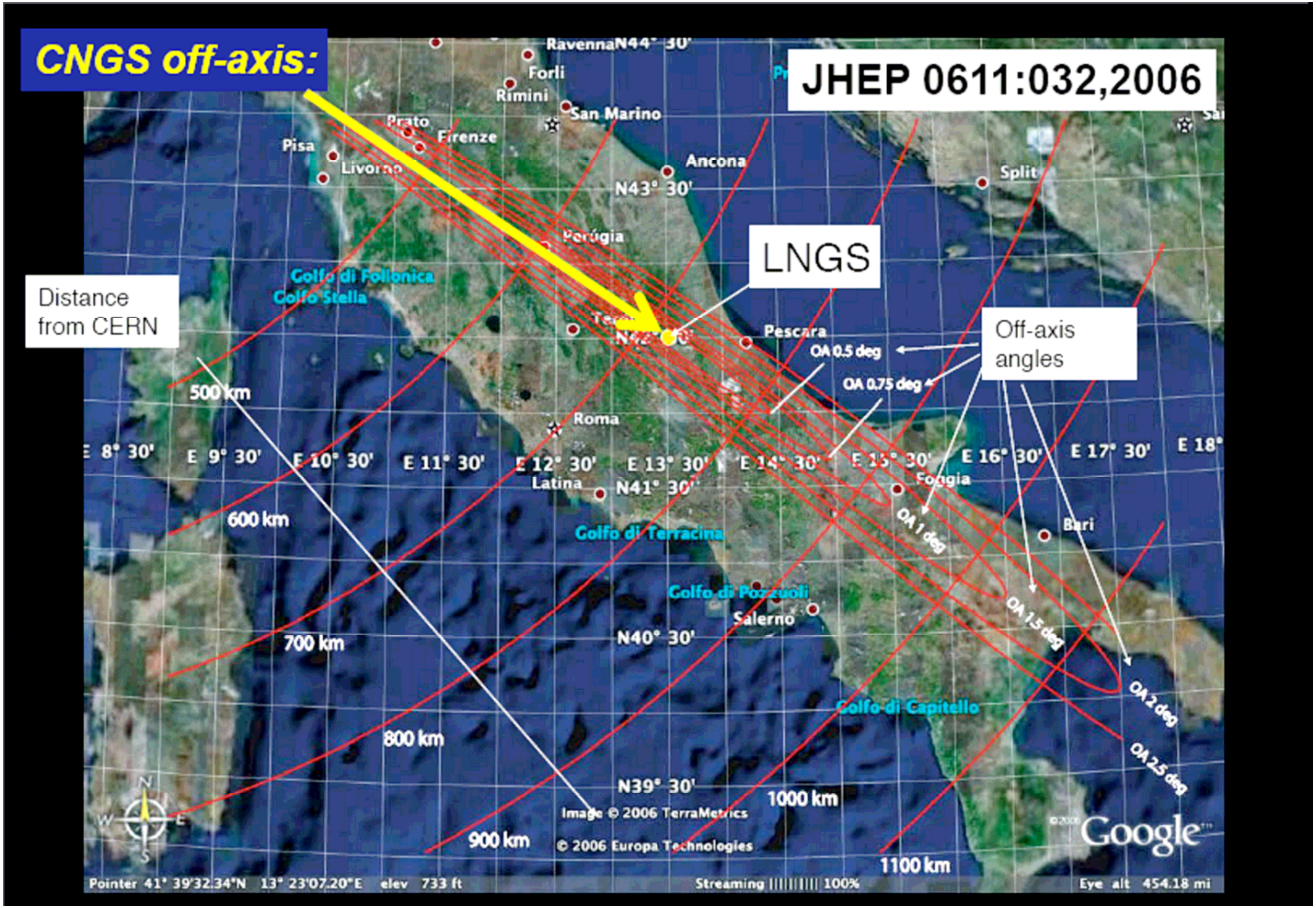
Prediction for 2015



Localization criteria – 3.



Localization criteria – 4.

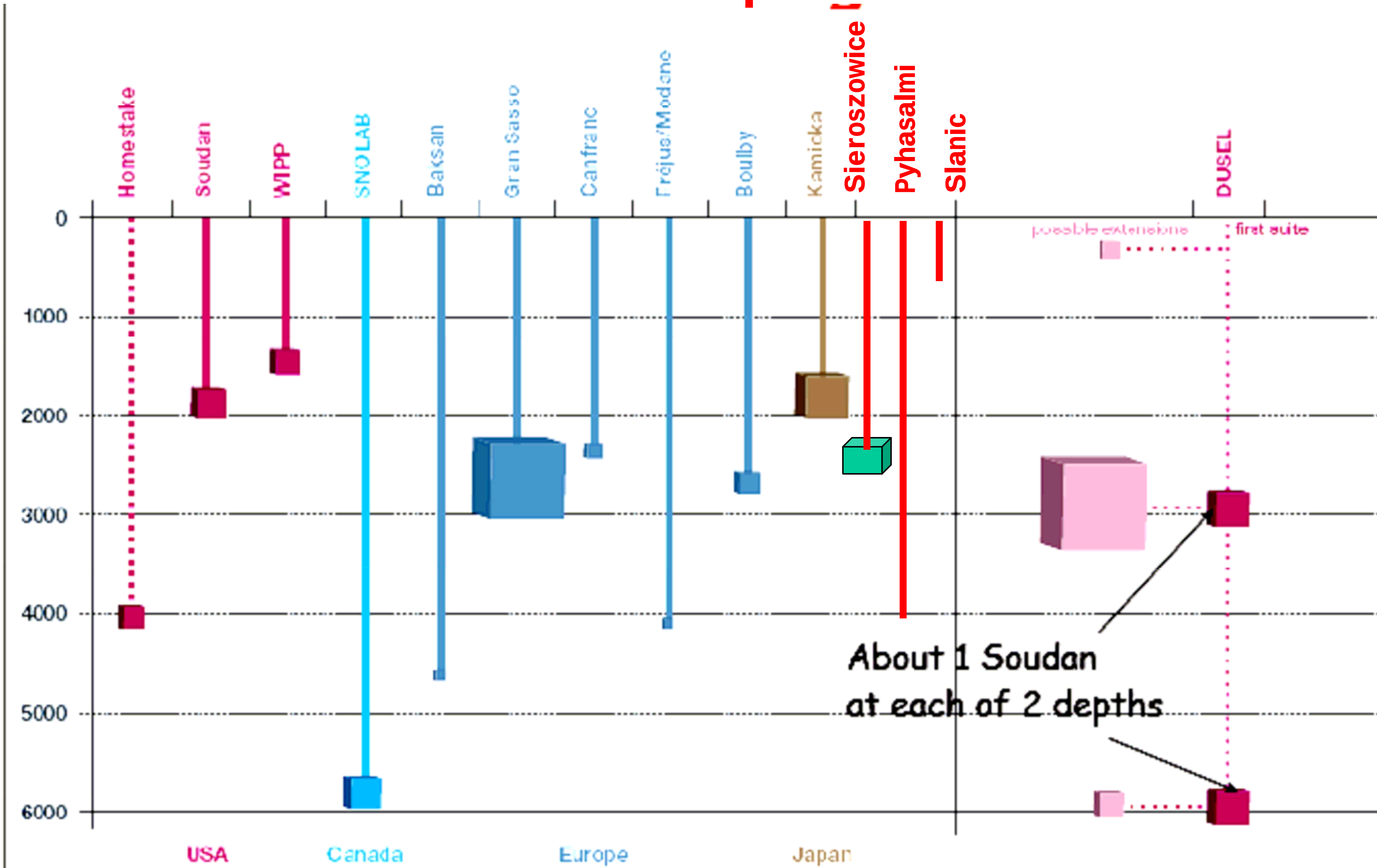


5. Natural radioactivity of rocks

Integral background counting rates 50 – 2700 keV [CPS/keV*kg]	
Sieroszowice	2.30 (0.02)
Gran Sasso	57.68 (0.02)
Modane	66.06 (0.03)
Boulby	23.83 (0.05)

J. Kisiel et al., University of Silesia, Katowice

6. Depth



Homestake
Soudan
WIPP
SNOLAB
Baksan
Gran Sasso
Canfranc
Fréjus/Modane
Boulby
Kamioka
Sieroszowice
Pyhasalmi
Slanic
DUSEL
0
1000
2000
3000
4000
5000
6000
possible extensions
first suite
About 1 Soudan
at each of 2 depths
USA
Canada
Europe
Japan

Conclusions

Very interesting and challenging project

Short time scale – results in two years to fit the ESFRI recommendation process