The LAGUNA project -
towards the giant liquid based detectors for proton decay searches and for low energy neutrino astrophysics.

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(on behalf of the LAGUNA project)

Scheme of presentation

- **The LAGUNA project – general information**
- **The detector techniques considered (liquid scintillator, water, liquid argon)**
- **Underground sites in Europe considered**
- **Selection from LAGUNA physics program:**
  - **- matter instability (proton decay),**
  - **- geo-neutrinos.**
- **Outlook**

LAGUNA – general information

- **LAGUNA: Large Apparatus for Grand Unification and Neutrino Astrophysics**

  Design Study in the framework FP7 (submitted 02.05.2007, 2 years duration from 01.08.2008, coordinating person: A.Rubbia, ETH Zürich, funding - 1.7 mln €) with main goal:

  - studies of possible localizations (in Europe) of a new underground laboratory able to host a very massive (10^5-10^6 tons) liquid based detector; all existing underground laboratories in Europe are too small.

LAGUNA – participating institutions

- 21 beneficiaries
  - 16 scientific partners
  - 5 industrial partners
- 9 affiliated scientific institutions
- about 100 participants from 11 countries

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

LAGUNA – working packages

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		

LAGUNA – project description

Large underground, liquid based detectors for astro-particle physics in Europe: scientific case and prospects

D Autiero [1], J Äystö [2], A Badertscher [3], L Bezrukov [4], J Bouchez [5], A Bueno [6], J Busto [7], J-E Campagne [8], Ch Cavata [9], L Chaussard [1], A de Bellefon [10], Y Déclais [1], J Dumarchez [11], J Ebert [12], T Enqvist [13], A Ereditato [14], F von Feilitzsch [15], P Fileviez Perez [16], M Göger-Neff [17], S Gninenko [4], W Gruber [3], C Hagner [12], M Hess [14], K A Hochmuth [17], J Kisiel [18], L Knecht [3], I Kreslo [14], V A Kudryavtsev [19], P Kuusiniemi [13], T Lachenmaier [15], M Laffranchi [3], B Lefievre [10], P K Lightfoot [19], M Lindner [20], J Maalampi [2], M Maltoni [21], A Marchionni [3], T Marrodán Undagoitia [15], J Marteau [1], A Meregaglia [3], M Messina [14], M Mezzetto [22], A Mirizzi [17,23], L Mosca [9], U Moser [14], A Müller [3], G Natterer [3], L Oberauer [15], P Otiougova [3], T Patzak [10], J Peltoniemi [13], W Potzel [15], C Pistillo [14], G G Raffelt [17], E Rondio [24], M Roos [25], B Rossi [14], A Rubbia [3], N Savvinov [14], T Schwetz [26], J Sobczyk [27], N J C Spooner [19], D Stefan [28], A Tonazzo [10], W Trzaska [2], J Ulbricht [3], C Volpe [29], J Winter [15], M Wurm [15], A Zalewska [28] and R Zimmermann [12]

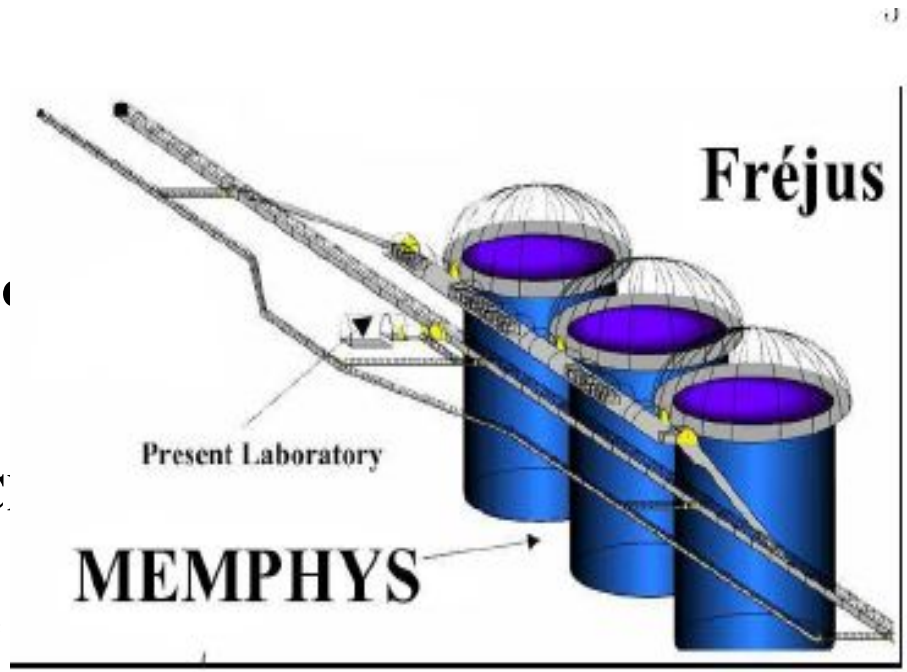
arXiv:hep-ph/0705.0116
J. Cosmol. Astropart. Phys. 11 (2007) 011

LAGUNA: three detector technologies

- **water Cherenkov: MEMPHYS, mass 420-1000 kton**
- **liquid scintillator: LENA, mass 30-70 kton**
- **liquid argon: GLACIER, mass 50-100 kton**

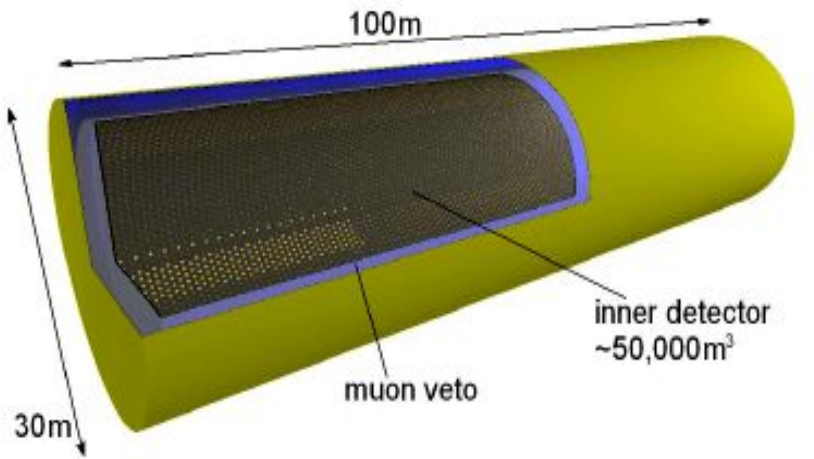
MEMPHYS (water Cherenkov)

- **extrapolation of Super-Kamiokande detector**
- **3-5 tanks in shafts 65m diameter and 65m height**
- **~81000 12'' PMTs (30% surfa coverage) or 20'' PMTs (40% coverage)**
- **possibility of introducing GdC (decrease of background by tagging neutrons from inverse beta decay)**



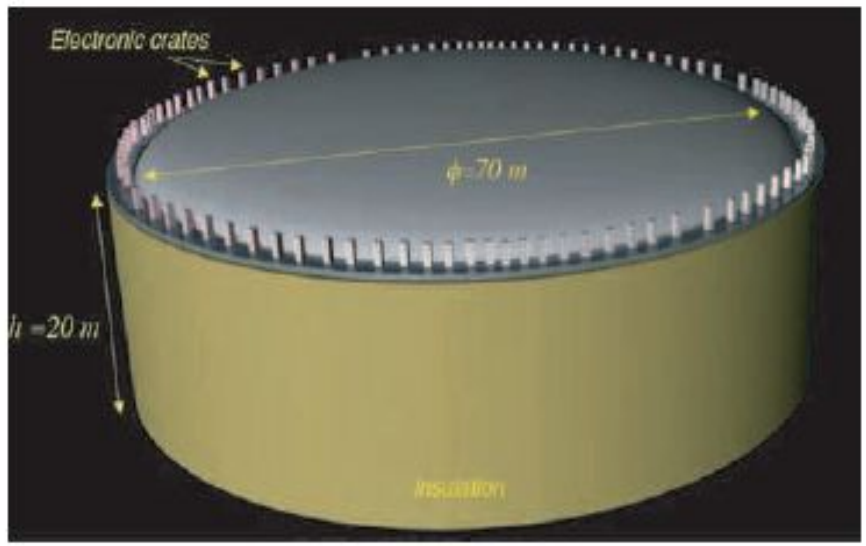
LENA (liquid scintillator)

- **one cylindrical tank (vertical or horizontal)**
- **inner volume contains about 50000m^3 of liquid scintillator**
- **scintillation light detected by 12000 20'' PMTs (30% surface coverage)**
- **outer part (muon veto) filled with water**
- **technology used in KamLAND and Borexino detectors**



GLACIER (liquid argon)

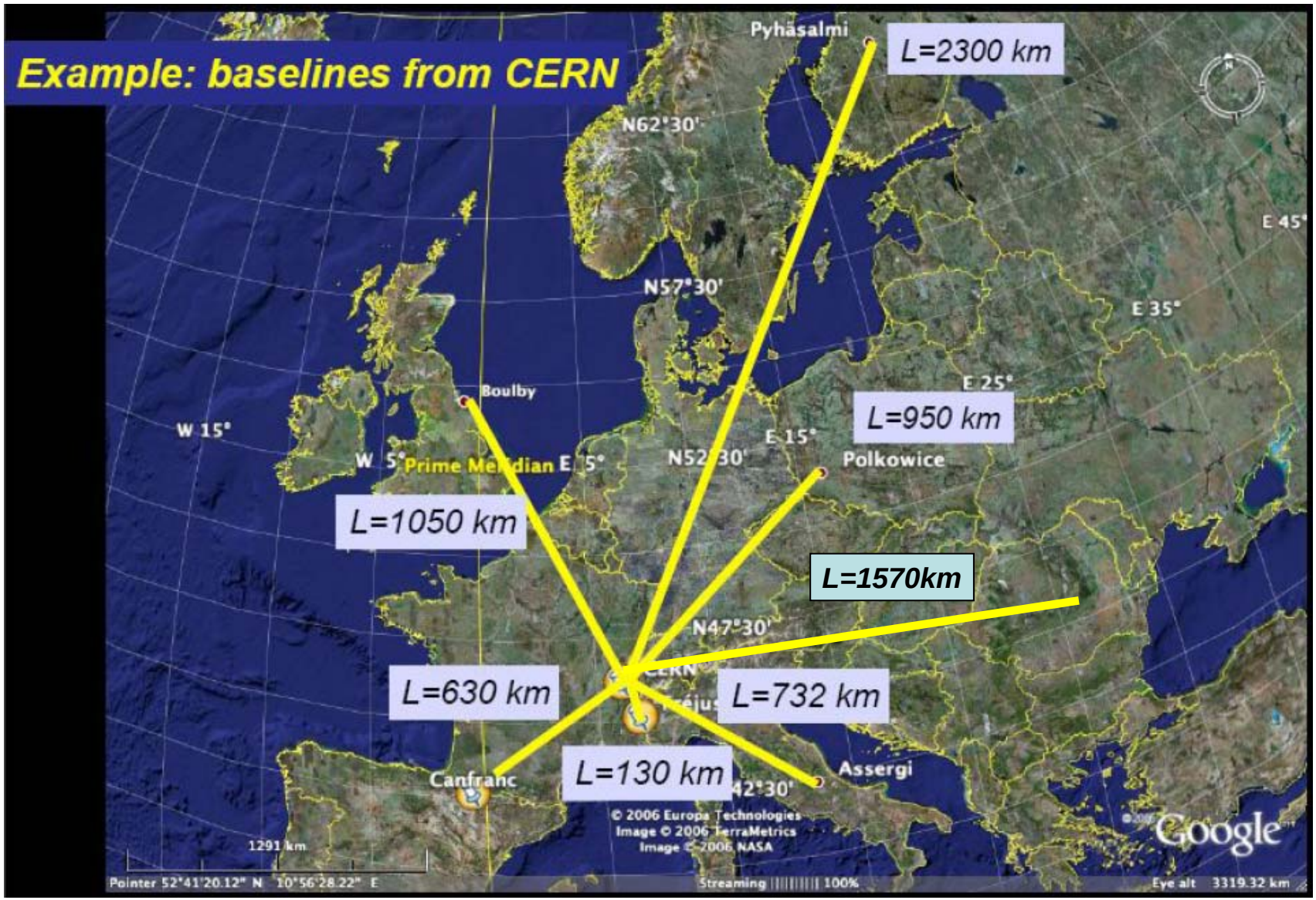
- **liquid argon (LAr) Time Projection Chamber (TPC)**
- **3D reconstruction of events using information provided by ionization in LAr and light (scintillation and Cherenkov) readout by PTMs**
- **bi-phase mode (drifting electrons from liquid phase are extracted into gas phase and amplified)**
- **LAr TPC pioneered by the ICARUS experiment**



Underground sites: localization criteria

- **Bedrock (type and rock quality for large cavern excavation)**
- **Reactor neutrino background (relevant to geo-neutrinos searches by LENA)**
- **Natural radioactivity background**
- **Depth (protection against cosmic-rays background)**
- **Baseline (distance from existing/future accelerator neutrino sources - CERN?)**

LAGUNA: considered underground sites



LAGUNA – physics program

- **proton decay searches (matter instability)**
- **studies of low energy neutrinos:**
  - neutrinos from supernova explosion,
  - solar neutrinos,
  - atmospheric neutrinos,
  - diffuse supernova neutrino background (relic neutrinos),
  - geo-neutrinos,
- **studies of neutrinos from neutrino beams (neutrino factory, neutrino beta beam, neutrino superbeam)**

arXiv:hep-ph/0705.0116
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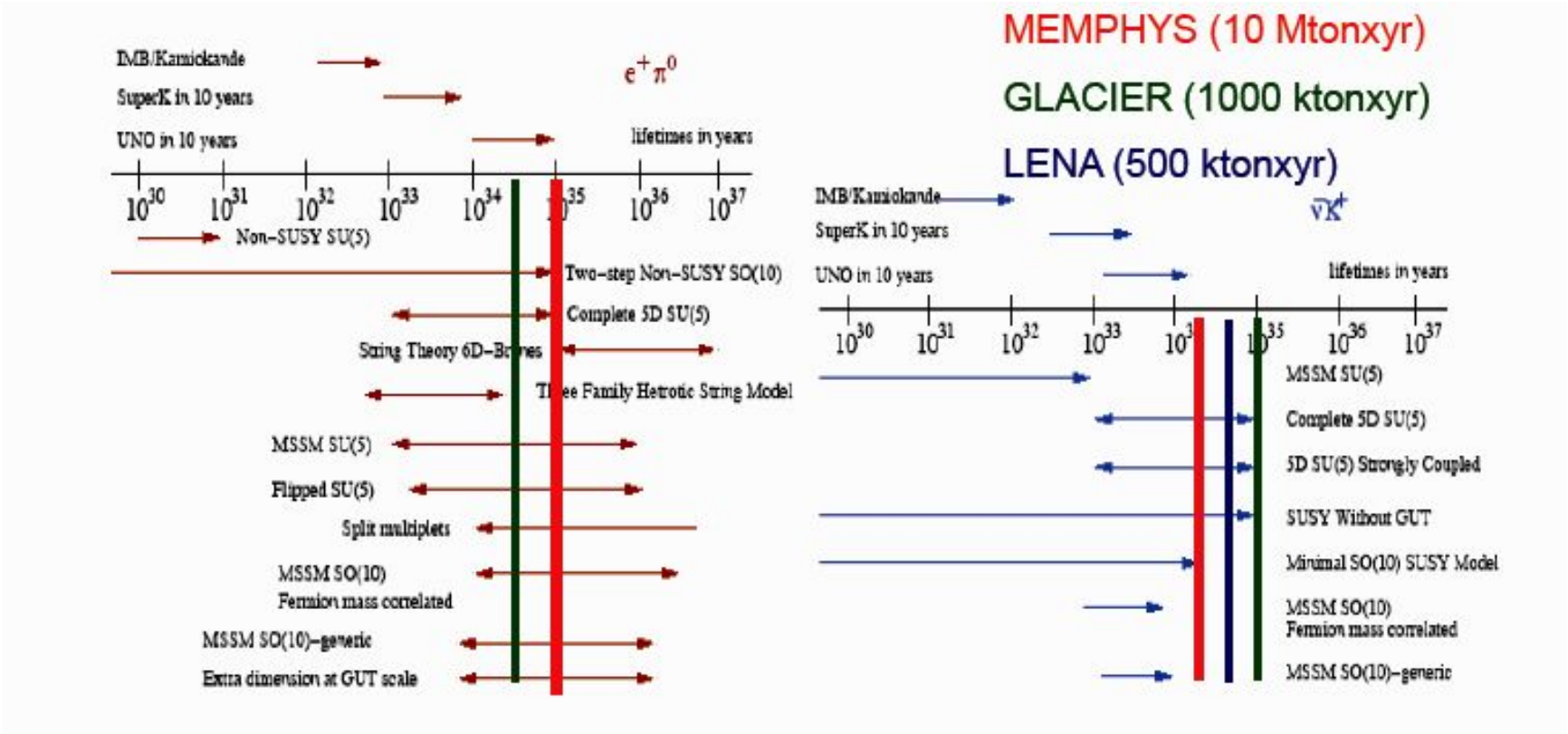
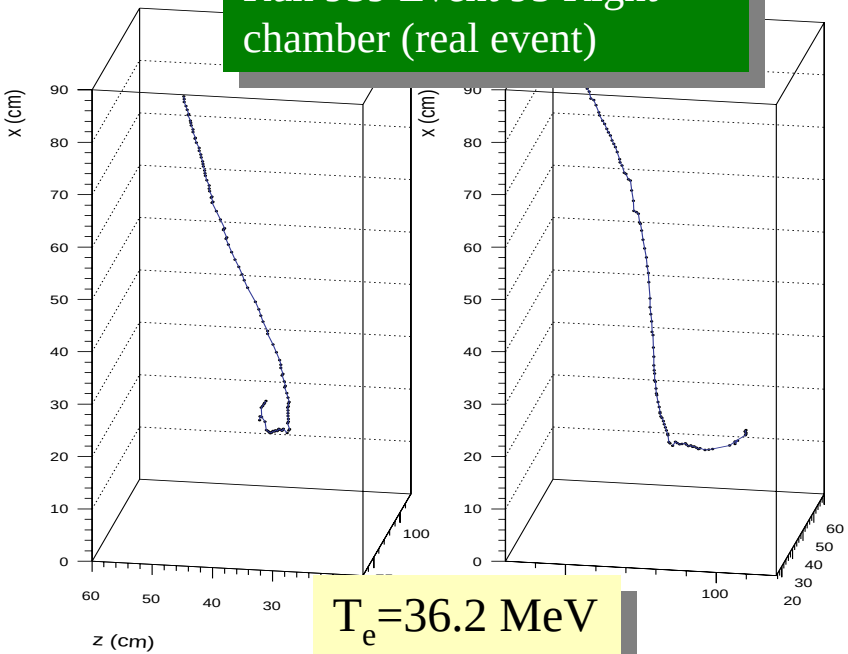
Proton decay sensitivity

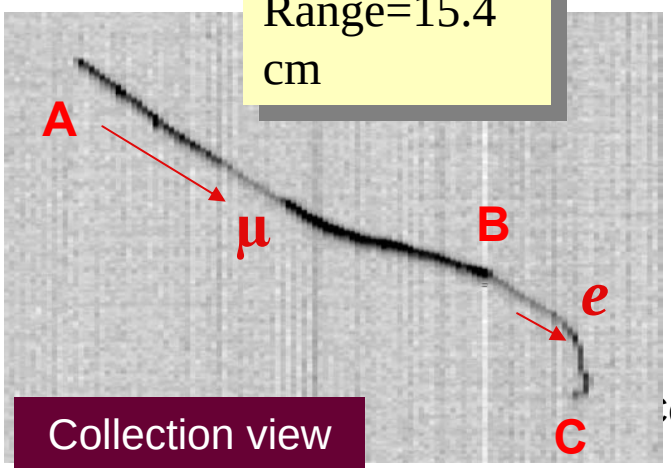


Proton decay (in LAr, ICARUS)

Run 939 Event 95 Right chamber (real event)

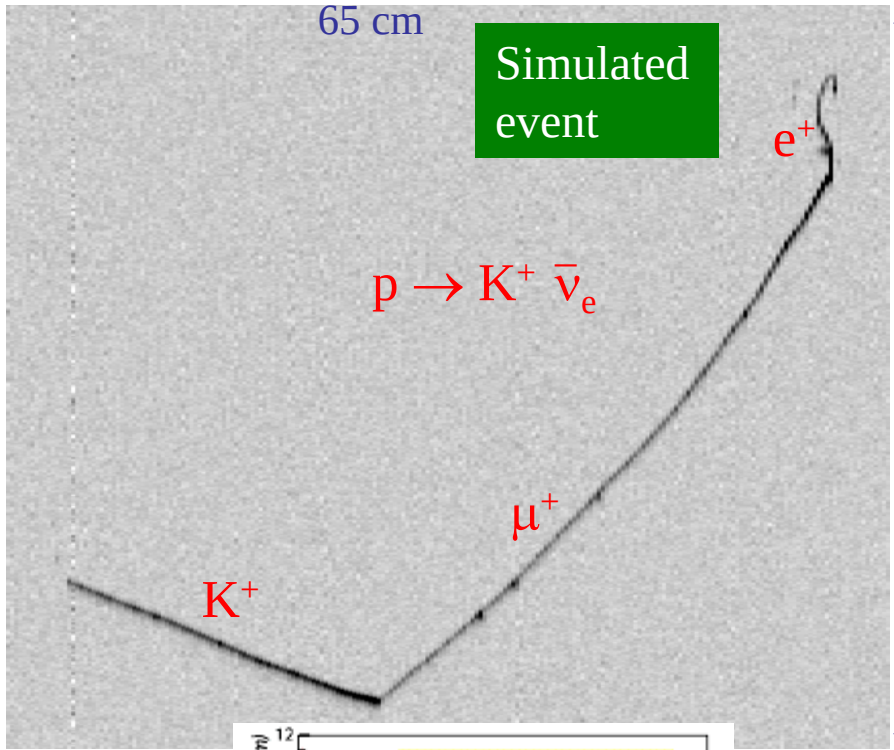


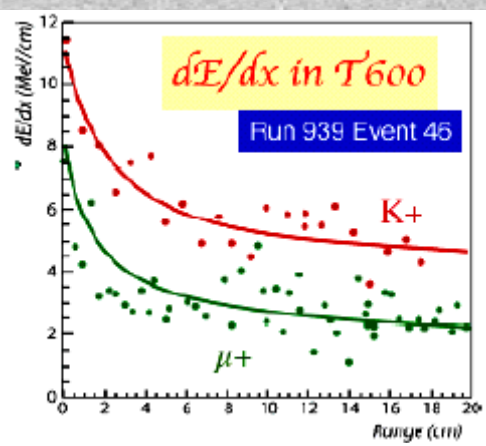
T_e=36.2 MeV
Range=15.4 cm



65 cm

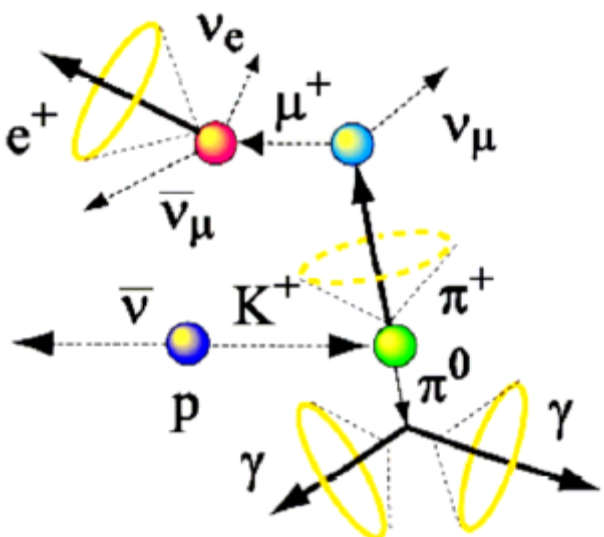
Simulated event





Proton decay (in water, Super-Kamiokande)

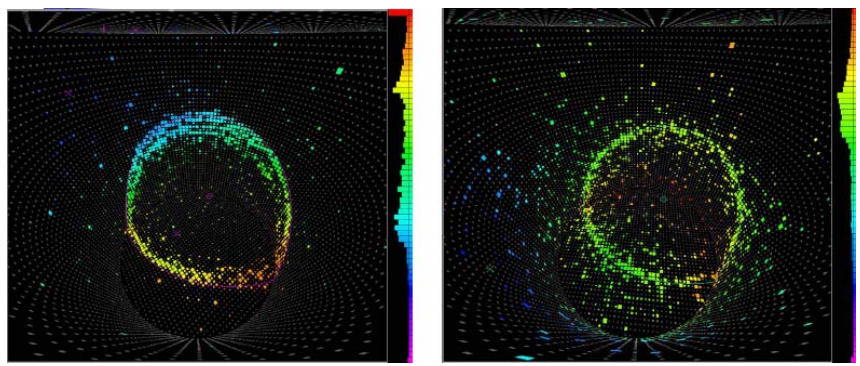
$p \rightarrow \nu K^+,\ K^+ \rightarrow \pi^+ \pi^0$



(K.Kobayashi, UNO meeting, 2005)

- **K^+ momentum below the water Cherenkov threshold → detection of its decay products**
- **signature:**
  - **two e-like Cherenkov rings**
  - **one Michel electron**
  - **kinematical cuts**

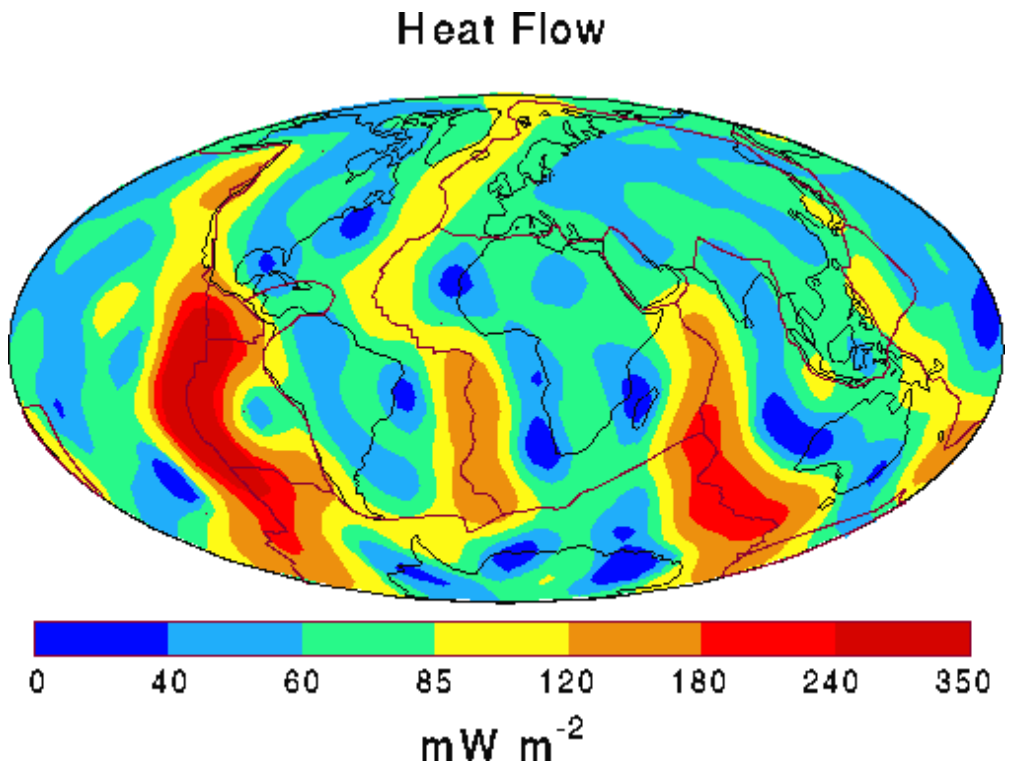
Super-Kamiokande



μ – like ring **e – like ring**

Geo-neutrinos

- **the total power dissipated from the Earth is 44.2±1.0 TW (31±1 TW, recent evaluation of the same data), in average about 90 mW/m^2**
- **about 16 TW is from ^{238}U and ^{232}Th decay which produce electron antineutrinos (geo-neutrinos) by β decay**
- **the measurement of geo-neutrinos flux is important for geophysics**



http://geophysics.ou.edu/geomechanics/notes/heatflow/global_heat_flow.htm

Geo-neutrinos (cont.)

- **the first observation of geo-neutrinos: KamLAND (*Nature 436 (2005) 499)***

  - 1kton liquid scintillator

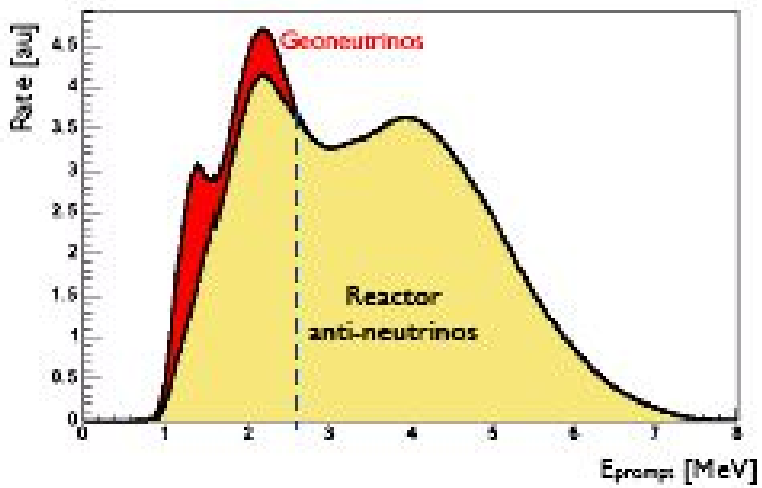
  - measured rate: 25±19 for total background 127±13 ev

  - background: 2/3 nuclear reactors, 1/3 natural radioactivity

  - upper limit (<60 TW) for radiogenic heat production

- **for LENA at Pyhäsalmi:**

  1000 events / year with 240 events of background



Physics potential (overview)

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

Outlook

- **All three different detection techniques (liquid scintillator, water and liquid argon) offer very rich (in some extent complementary) physics program**
- **The LAGUNA should give a recommendation for the localization of new European underground laboratory**
- **The first deliverable of the LAGUNA project (Health, Safety, Environment and Socio-Economic Overview Report) has been submitted.**