The design study for LAGUNA (Large Apparatus for Grand Unification and Neutrino Astrophysics)

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Open BENE SG meeting on the FP7 DS proposal
Feb 21st 2007

Grand Unification and Neutrino Astrophysics

- **Proton decay is the most generic and directly verifiable consequence of Grand Unification (GU)**
  - Detecting proton decay implies de facto discovering GU
    - GU implies a new fundamental symmetry between quarks & leptons (hence explains their identical number)
    - GU explains electric charges of elementary fermions
    - GU guides models of fermion masses and mixing
    - GU is one of the motivation for SUSY and SUSY predicts LSP as dark matter
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- **The so-called "megaton"-scale: Next generation very massive underground detectors are required to improve current experimental sensitivities by at least an order of magnitude**
- **Very massive underground detectors will also provide an extensive next generation neutrino physics programme**
  - They will detect neutrinos from a galactic Supernova, greatly advancing our understanding of stellar explosions and neutrino properties.
  - They could also further study the Sun's interior with real-time solar neutrino detection and detect geo-neutrinos, as well study of neutrinos produced in the Earth's upper atmosphere with high statistics.
  - Coupled to artificial neutrino beams, they will measure neutrino flavour oscillations with an unprecedented precision and offer new opportunities like the discovery of CP-violation in the leptonic sector.

Physics focus

- Proton decay
- Low energy neutrino astronomy
- Long baseline neutrino beam

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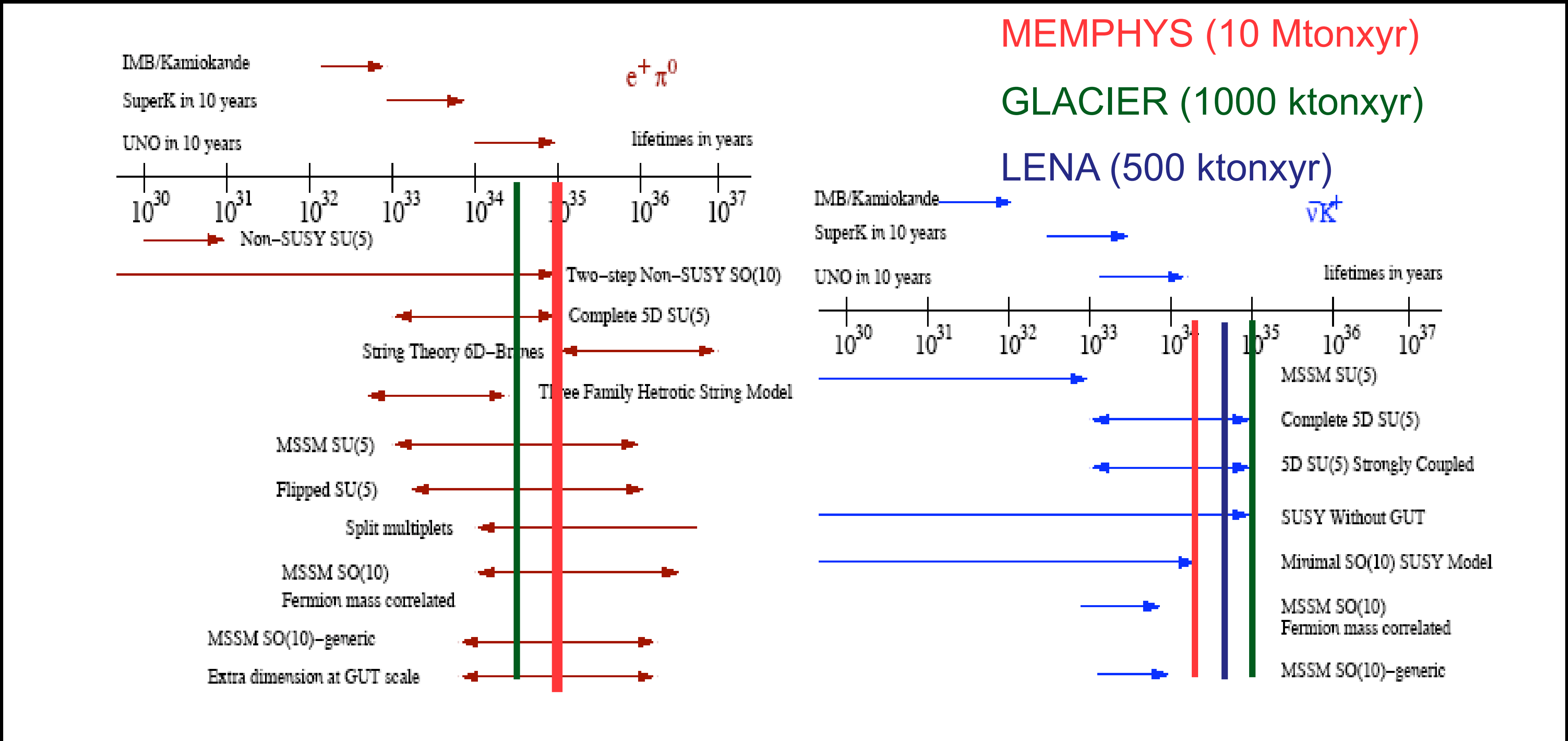
Sensitivity to proton decay: comparison with theory



Higher dimension models (eg. 6D SO(10)) not included

Definitively not exhaustive.

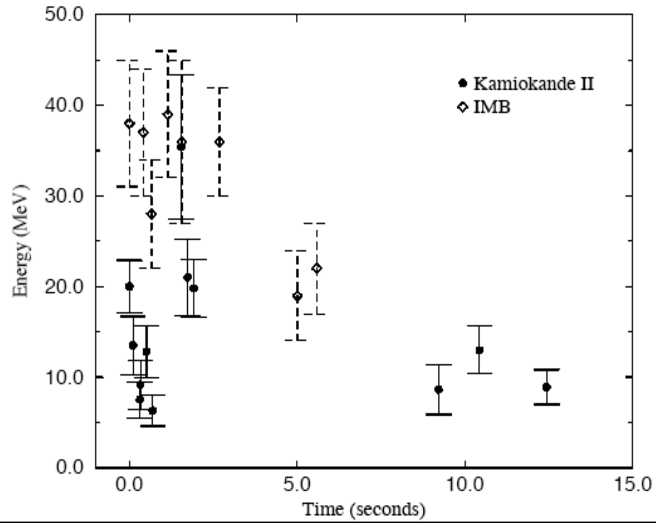
Supernova type-II neutrinos

⇒Access supernova and neutrino physics simultaneously

⇒Decouple supernova & neutrino properties via different detection channels

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

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

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

Proton decay and low energy neutrino astrophysics

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  - Solve common problems together.
  - Take into account the unique technological expertise in Europe and other existing or planned programs in the world.

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- **Mature designs and credible proposals should emerge around 2010.**
- This effort, although oriented towards a potential infrastructure in Europe, also allows Europeans to contribute in a coherent way and possibly with better impact, to the on-going discussions worldwide.

The step to 10^5-10^6 tons

- **Three detection techniques are currently investigated for such large underground infrastructures**

1. Water Cerenkov imaging
   - Ongoing R&D effort on photodetection in Europe: MEMPHYS
   - Synergy with HK (Japan) and UNO (USA)
2. Liquid scintillator
   - Ongoing R&D on scintillator characterization in Europe: LENA
   - Connected to BOREXINO R&D programme
3. Liquid argon time-projection chamber
   - Technology pioneered in Europe by the ICARUS R&D programme
   - Two new independent and on-going R&D efforts: GLACIER in Europe and LARTPC in USA

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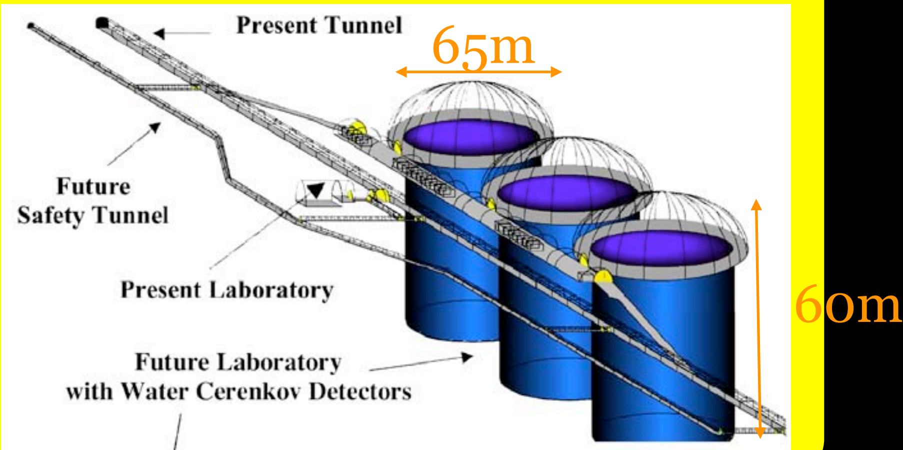
- **The construction of very large detectors of those technologies appears possible, but requires detailed design studies to optimize the underground implementation in very large scale and the most promising technology under well controlled cost estimates.**
- **In parallel, feasibility studies for site excavation are mandatory to build the required infrastructure to host these very large detectors, also under controlled cost boundaries.**

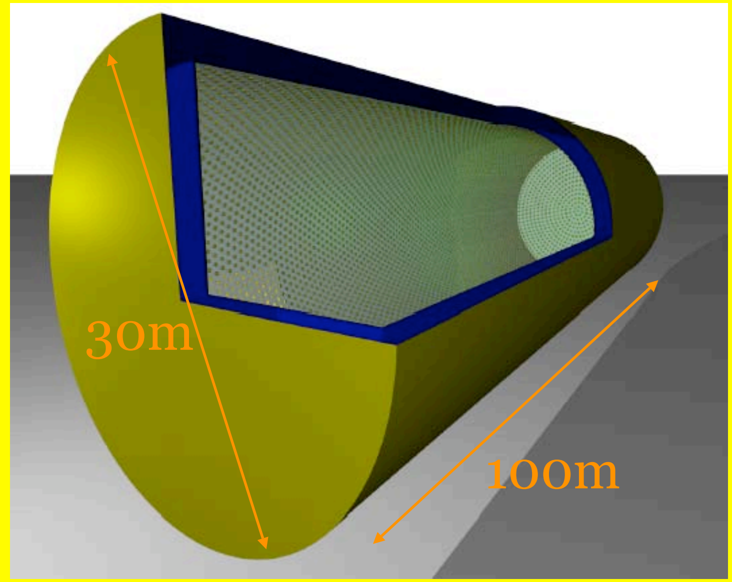
Large Underground detectors considered in LAGUNA

MEMPHYS



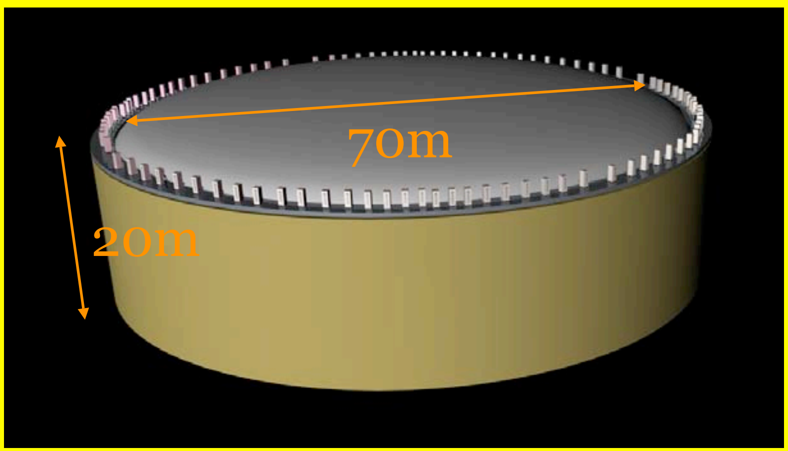
Water Cherenkov (≈0.5 → 1 Mton)

LENA



Liquid Scintillator (→ 50 kton)

GLACIER



Liquid Argon (≈10→100 kton)

LAGUNA WG constituency

- ≈60 members
- 22 institutes from CH, DE, ESP, FR, FIN, I, POL, UK
- University of Bern, CPPM, CUPP, University of Helsinki, University of Katowice, University of Krakow, IN2P3/CNRS-LAL, IN2P3/CNRS-LPNHE, University of Granada, University of Hamburg, Max-Planck-Institut für Kernphysik Heidelberg, University of Jyväskyla, Max-Planck-Institut für Physik München, Technische Universität München, University of Oulu, Institut de Physique Nucléaire Orsay, INFN/University of Padova, APC-Paris, DAPNIA/CEA-Saclay, University of Sheffield, ETH-Zürich
- New interest was raised at Valencia meeting

From LAGUNA WG to DS

- During the last months, an effort has been made to consolidate these ideas into a format compatible with a potential "design study".
- A series of working meeting were held
  - ☑ Munich, April 24th, 2006
  - ☑ Munich, June 2nd, 2006
  - ☑ Paris, July 21st ,2006
  - ☑ Zurich, October 12th, 2006
  - ☑ Paris, December 18th, 2006
  - ☐ <u>Next</u>: Chambery, March 2nd, 2007
- A scientific case document (≈30 pages) has been drafted.
- A list of Working Packages, in a suitable form for the FP7 DS, has been prepared.
- The list of milestones & deliverables with detailed tables of tasks has still to be elaborated.
- The potential FP7 DS document is being drafted (preliminary version) to be finalized until May 2007.

In two sentences...

- The DS should provide the means to elaborate the <u>scientific and objective information</u> to make an optimized choice for site(s) for an European Underground Infrastructure capable of hosting megaton-class detector(s).

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- The deliverables contain the elaboration of "decision factors" like

(i) technical feasibility (cavern, access, safety, liquid procurement, ...)
(ii) cost optimization of infrastructure (digging, safety, ...)
(iii) physics performance (e.g. depth, baseline, ...)
(iv)...

LAGUNA FP7 – DRAFT DRAFT DRAFT

Proposal full title	**A Design Study for Large Apparati for Grand Unification and Neutrino Astrophysics**
Proposal acronym	**LAGUNA**

DRAFT

EU contribution, Timescale:
5 M€ over 2-3 years (estimate)

Table of contents

LAGUNA working packages

- **WP1: Underground infrastructures (site engineering)**
  - Feasibility of large excavations, access, local conditions, site preselection
- **WP2: Underground tanks**
  - Design, geometry, support structure, materials, insulation, underground assembly
- **WP3: Tank instrumentation**
  - Charge & light readout large scale schemes, HV, calibration, mechanical aspects
- **WP4: Liquid procurement and handling systems**
  - Production, handling, purification, filling, long-term stability, gases
- **WP5: Safety & Environment**
  - Additional infrastructure, interface between installation and host site (tunnel or mine)
- **WP6: Underground scientific programme assessment and optimization**
  - Physics potential of the facility, multidisciplinarity, other sciences
- **WP7: Management and coordination**

WP resources subdivision

DRAFT

WP1	Underground infrastructure	2.3+0.7 M€
WP2	Underground tanks	0.8+0.5 M€
WP3	Tank instrumentation	0.5+2.0 M€
WP4	Pure liquid procurement	0.5+0.5 M€
WP5	Safety and environment	0.25+0.25 M€
WP6	Underground science optimization and outreach	0.5+1.0 M€
WP7	Management and coordination	0.15+0.15 M€
TOTAL		5.0+5.1 M€

Where?

IUS

Institute of Underground Science in Boulby mine, UK

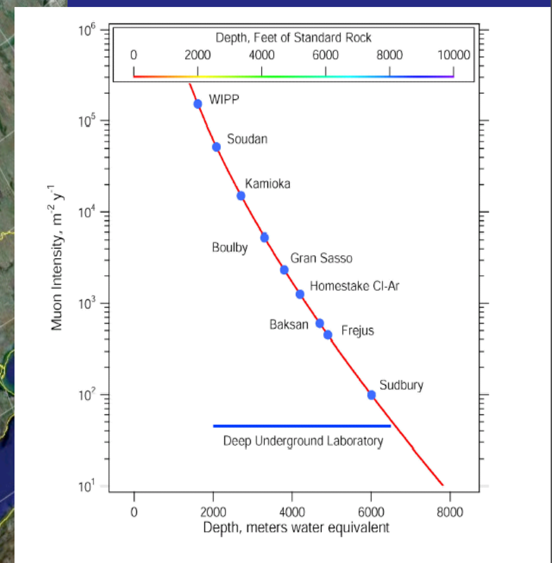
Laboratoire Souterrain de Modane, France

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

Currently there is no available sight to host very large scale detectors in Europe!

- New facilities will have to be excavated or old one extended
- What depth?
- What other synergies? (beamline distance)
- What is the distance from reactors?

Polkowice-Sieroszowice



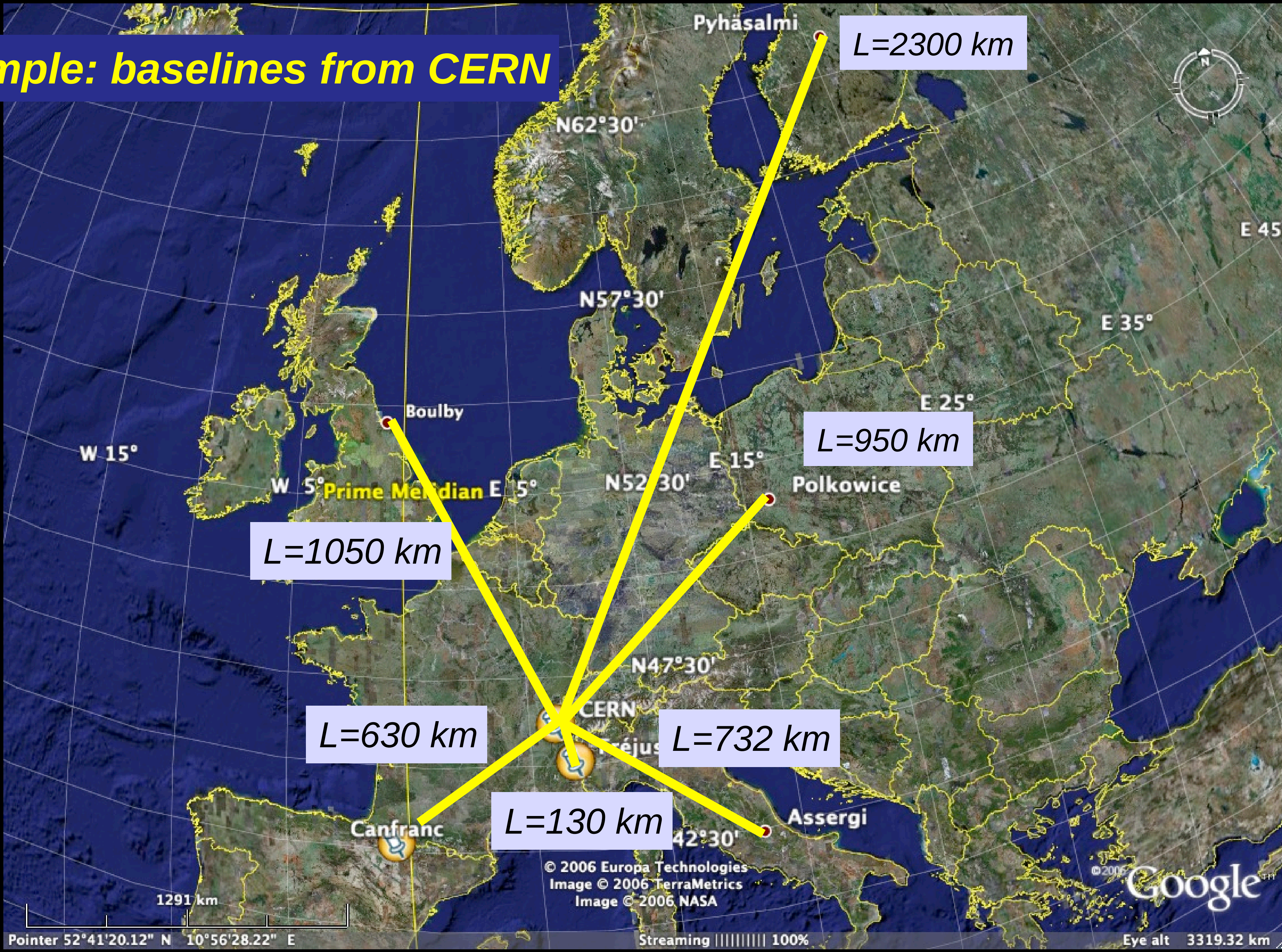
LSC

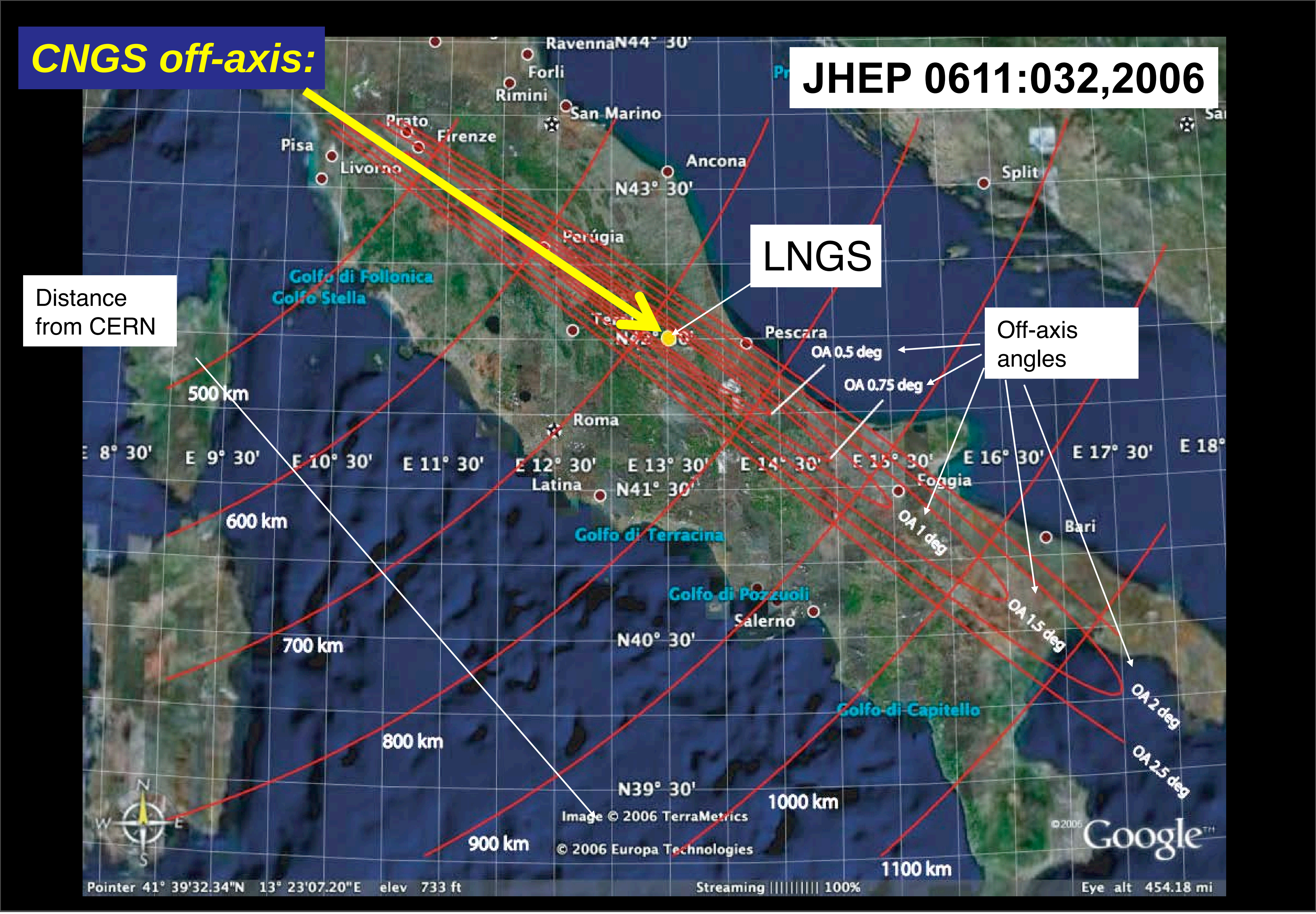
Laboratorio Subterraneo de Canfranc, Spain

LNGS

Laboratori Nazionali del Gran Sasso, Italy

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
Perúgia
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 9° 30'
E 10° 30'
E 11° 30'
E 12° 30'
E 13° 30'
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

Outlook

- The discovery of proton decay would be one of the most fundamental discoveries in particle physics. This requires new generation very massive detectors.
- These detectors also provide an extensive neutrino physics programme detecting supernova, atmospheric, possibly solar and geo-neutrinos, as well as artificial neutrinos from accelerators. These latter measurements could lead to the discovery of CP-violation in the leptonic sector.
- The LAGUNA design study will provide the means to perform site feasibility studies and to develop mature conceptual design for large underground detectors including their infrastructures, with a credible cost estimate. The DS will provide the means to elaborate the scientific and objective information needed to make an optimized choice for site(s) for the European Underground Infrastructure capable of hosting megaton-class detector(s).
- It should address all techniques and optimize performance and choice of technologies for the best physics output, taking also into account the worldwide stage.
- It should mature around 2010 and lead to possible construction decision soon after, when a few years of running of LHC and T2K&NovA&DOUBLE CHOOZ will have drawn the new landscape concerning supersymmetry, unification, and hopefully the last unknown neutrino mixing angle θ_{13}.