Design of a pan-European underground infrastructure for very Large Apparatus for Grand Unification and Neutrino Astrophysics (LAGUNA)

André Rubbia (ETHZ)

ApPEC/ASPERA meeting, Paris, March 30th

A new infrastructure in Europe ?

- Advances in low energy neutrino astronomy and direct investigation of Grand Unification require the construction of very large underground observatories with total active volumes from O(10^5) m^3 up to O(10^6) m^3
- There is currently no such infrastructure in the world able to host underground instruments of this size, although in Europe many national underground laboratories with high technical expertise are currently operated with leading-edge smaller-scale underground experiments.
- A pan-European infrastructure able to host underground instruments of the required size volumes will provide new and unique scientific opportunities in low energy neutrino astronomy and Grand Unification physics.
- This field of research is at the forefront of particle and astro-particle physics and is the subject of intense investigation also in North America and Asia. Such an infrastructure in Europe would interest scientists from all over the world and ensure that Europe will continue to play a leading and innovative role in the field.

Six national underground science laboratories

IUS

Institute of Underground Science in Boulby mine, UK

CENTRE FOR UNDERGROUND PHYSICS IN PYHÄSALMI MINE

LSM

Laboratoire Souterrain de Modane, France

A pan-European Infrastructure for very large volume underground observatories ?

SUNLAB

Polkowice-Sieroszowice, Poland

LSC

Laboratorio Subterraneo de Canfranc, Spain

LNGS

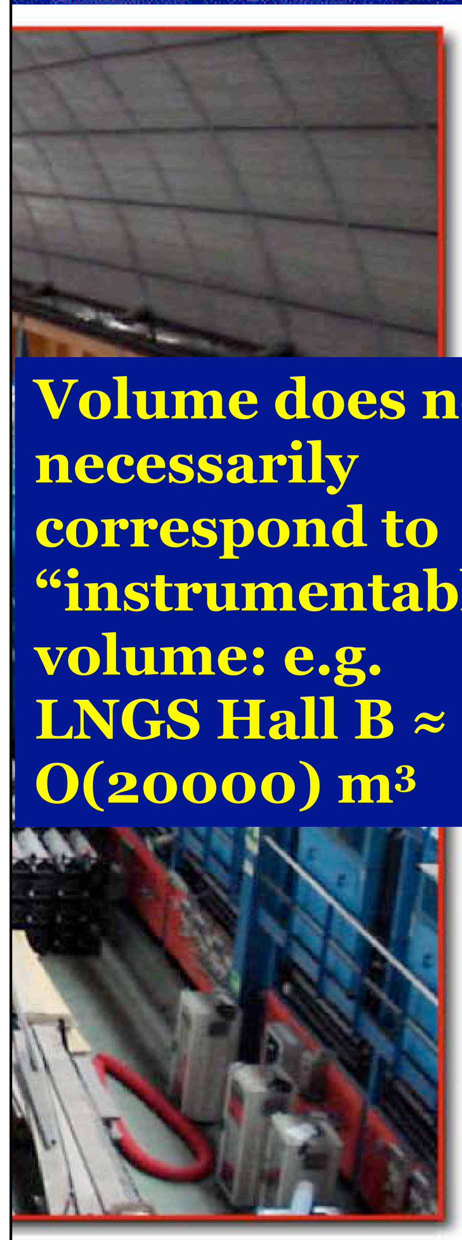
Laboratori Nazionali del Gran Sasso, Italy

None of these laboratories can host next generation very large volume observatories. Extension are needed.

- What depth?
- What other synergies? (beamline distance from artificial sources at accelerators)
- What is the distance from reactors?

Instrumenting underground cavities

Infrastructure ▸	LNGS Gran Sasso	LSM Fréjus	LSC Canfranc	IUS Boulby	BNO Baksan	CUPP Pyhäsalmi
Year of completion	1987	1982	1986, 2005	1989	1977, 1987	1993 (2001)
Area (m^2)	13000	500	150+600	500+1000	550, 600	500-1000
Volume (m^3)	180000	3500	8000	3000	6400, 6500	100-10000
Access	Horizontal	Horizontal	Horizontal	Vertical	Horizontal	Slanted truck road
Depth (m.w.e.)	3700	4800	2450	2800	850, 4800	1050, 1444 up to 4060
Surface profile	Mountain	Mountain	Mountain	Flat	Mountain	Flat
Muon flux (m^{-2} day^{-1})	24	4	406	34	4320, 2.6	8.6 @ 4060m
Neutron flux (>1 MeV) (10^{-6} cm^{-2} s^{-1})	O (1)	O (1)	O (1)	O (1)	- , O (1)	?
Radon content (Bq/m^3)	O (100)	O (10)	O (100)	O (10)	O (100)	O (100)
Main past and present scientific activities	- DM - ββ - solar ν - SN ν - atmos. ν - monopole - nuclear astrophysics - CRs (μ) - LBL ν's	Eighties: - Proton decay - atmos.ν Now: - DM (Edelweiss) - ββ (NEMO, TGV)	- DM (IGEX-DM, ROSEBUD, ANAIS) - ββ (IGEX)	- DM (Zeplin I,II, III, DRIFT)	*BUST:* - solar ν - SN ν - atmos. ν - CRs (μ) - monopo-les *SAGE:* - solar ν	- CRs (test set-up)
Number of visiting scientists	700	100	50	30	55	15



Volume does not necessarily correspond to "instrumentable" volume: e.g. LNGS Hall B ≈ O(20000) m³

Worldwide context: very large volumes

Europe enjoys today the most experience in underground science and sites, but lacks a coordinated plan for a possible future infrastructure of very large size

European context

- The prospects for large underground caverns in Europe are real
- The joint ILIAS-N2 & LAGUNA WG technical meeting held in Paris in December 2006 on the extension of the existing laboratories tentatively concluded that caverns of the contemplated sizes could be a real possibility in Europe
- The LAGUNA DS will have a real integrating influence on the community with similar physics goals, building on and strengthening of the fledgling integration, studying in more details and more coherently the issues of the cavity, but also the construction & operation of the large experiments.

Primary physics focus

- Direct evidence for Grand Unification (Proton decay)
- Low energy neutrino astronomy
- Long baseline neutrino beam

But also...

- Large observatories for detection of dark matter (e.g. directional detection)
- Geophysics, rock science, ...
- Biology
- Extreme conditions underground civil engineering
- etc.

Grand Unification and Neutrino Astrophysics

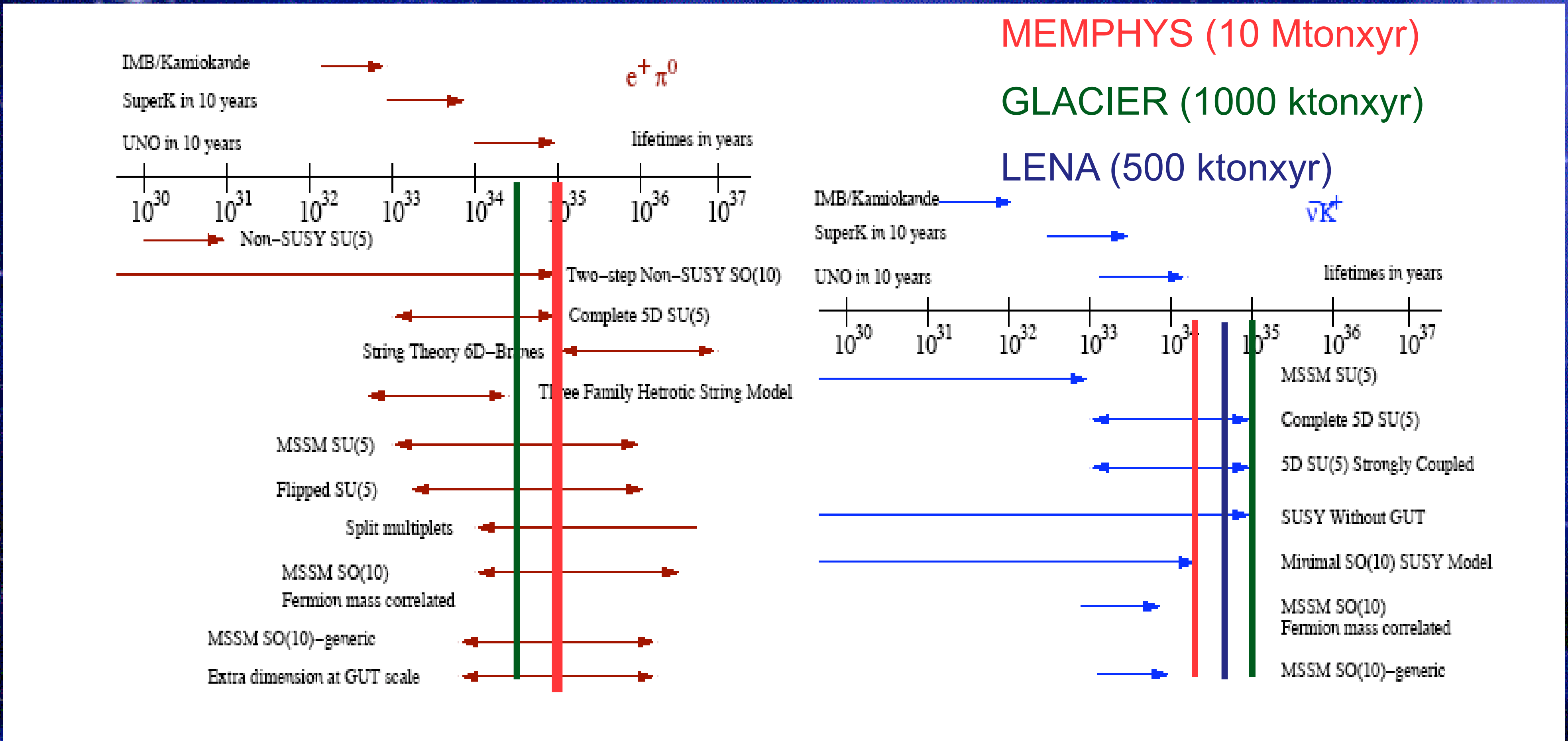
- **Rare event detection in very massive detectors will allow the search for proton decays with an unprecedented sensitivity. Proton decay is the most generic and directly verifiable consequence of Grand Unification (GU)**
  - Detecting proton decay implies de facto discovering GU
    - GU implies a 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
    - GU motivates see-saw (N_R) and consequently tiny neutrino masses

- **Very massive underground detectors will 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.

A very rich field !

- Historically a very rich field (SN1987A, solar & atmospheric neutrinos). The physics programme addressed by LAGUNA will span the next 30 years.
  - Testing proton lifetime up to 10^{35} years will provide a very stringent, perhaps ultimate, test of the Grand Unification hypothesis
  - After the optical observation of supernovae by mankind during the last centuries and the SN1987A neutrino detection, the next observable event with neutrinos will occur with high probability in the next decade and with certainty in the next 30 years. Neutrinos will shed more light on the SN explosion mechanisms than optical light!
  - Meanwhile the background flux of neutrinos from relic supernovae can be observed
  - The study of neutrinos properties have shown the first indication of physics beyond the Standard Model of Elementary Particles. New discoveries, like CP-violation in the leptonic sector, are expected in this field.
- High-energy accelerators like the LHC or the planned ILC cannot directly answer these fundamental questions about Nature. This was also recognized in the CERN European roadmap for particle physics: *"A range of very important non-accelerator experiments take place at the overlap between particle and astroparticle physics exploring otherwise inaccessible phenomena; Council will seek to work with ApPEC to develop a coordinated strategy in these areas of mutual interest."*

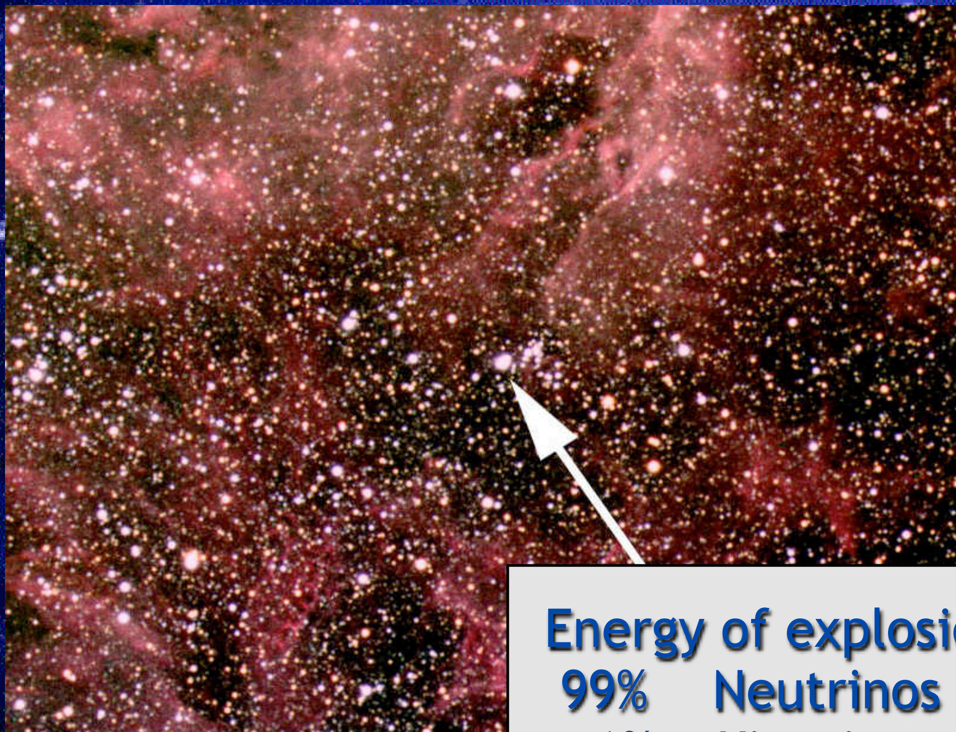
Sensitivity to proton decay: comparison with theory



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

Definitively not exhaustive.

Supernova explosion



Energy of explosion shows up as
99% Neutrinos
1% Kinetic energy of explosion
(1% of this into cosmic rays)
0.01% Photons, outshine host galaxy

Neutrino luminosity

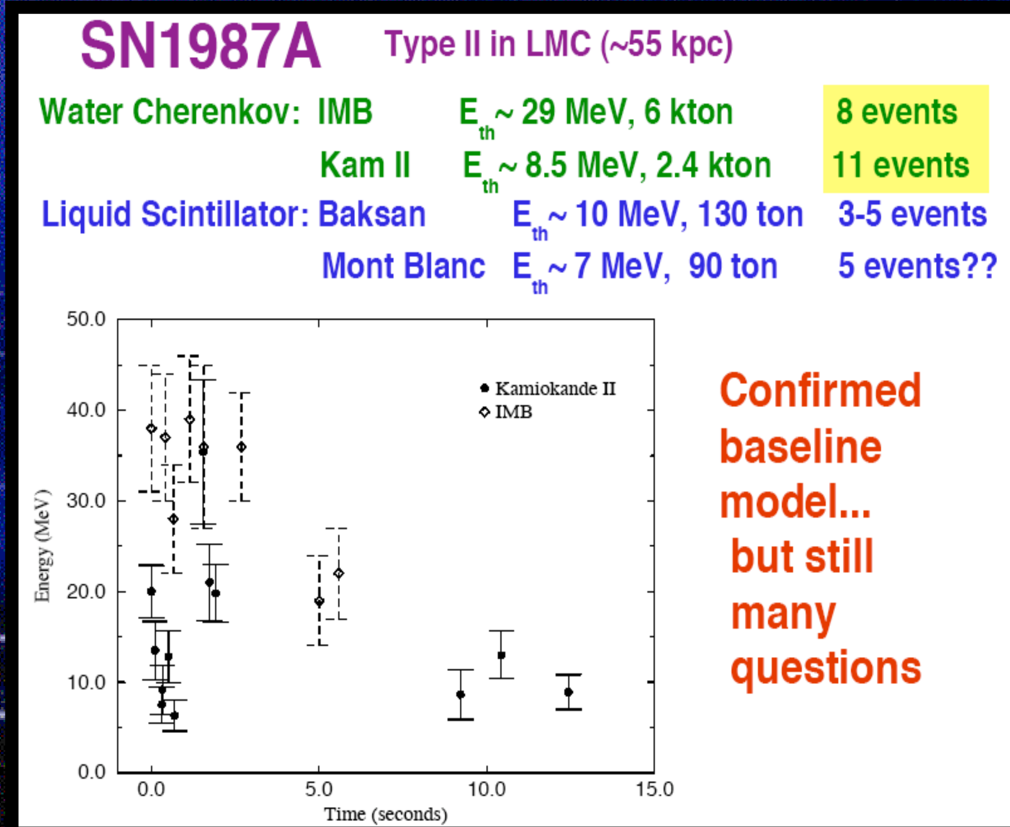
$$L_\nu \approx 3 \times 10^{53} \text{ erg} / 3 \text{ sec}$$
$$\approx 3 \times 10^{19} L_{SUN}$$

The only known source of heavy elements from Iron to Uranium in the Universe

Supernova type-II neutrinos

⇒Access supernova and neutrino physics simultaneously

⇒Decouple supernova & neutrino properties via different detection channels



1. Supernova physics:

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

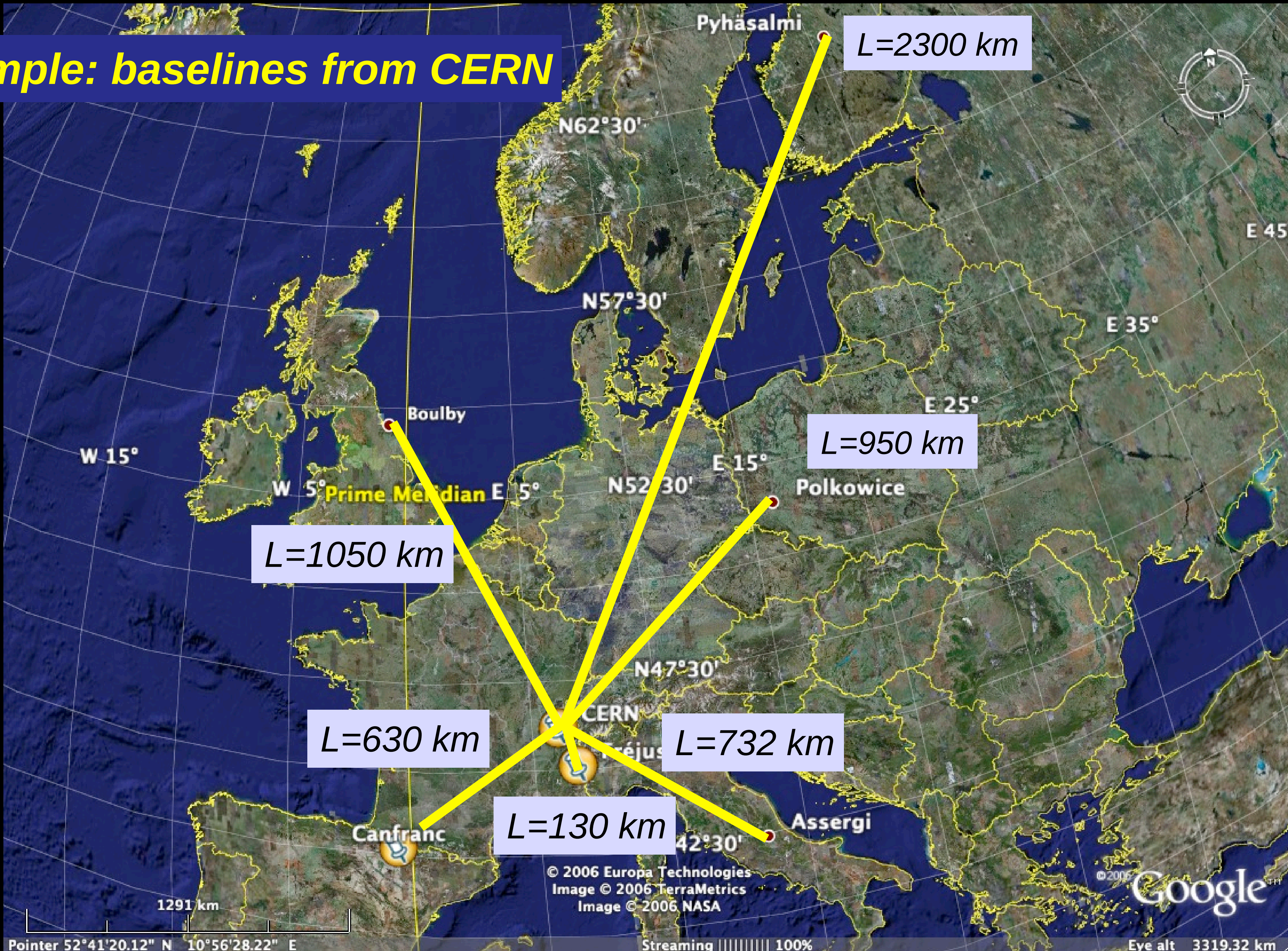
2. Neutrino properties

- 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

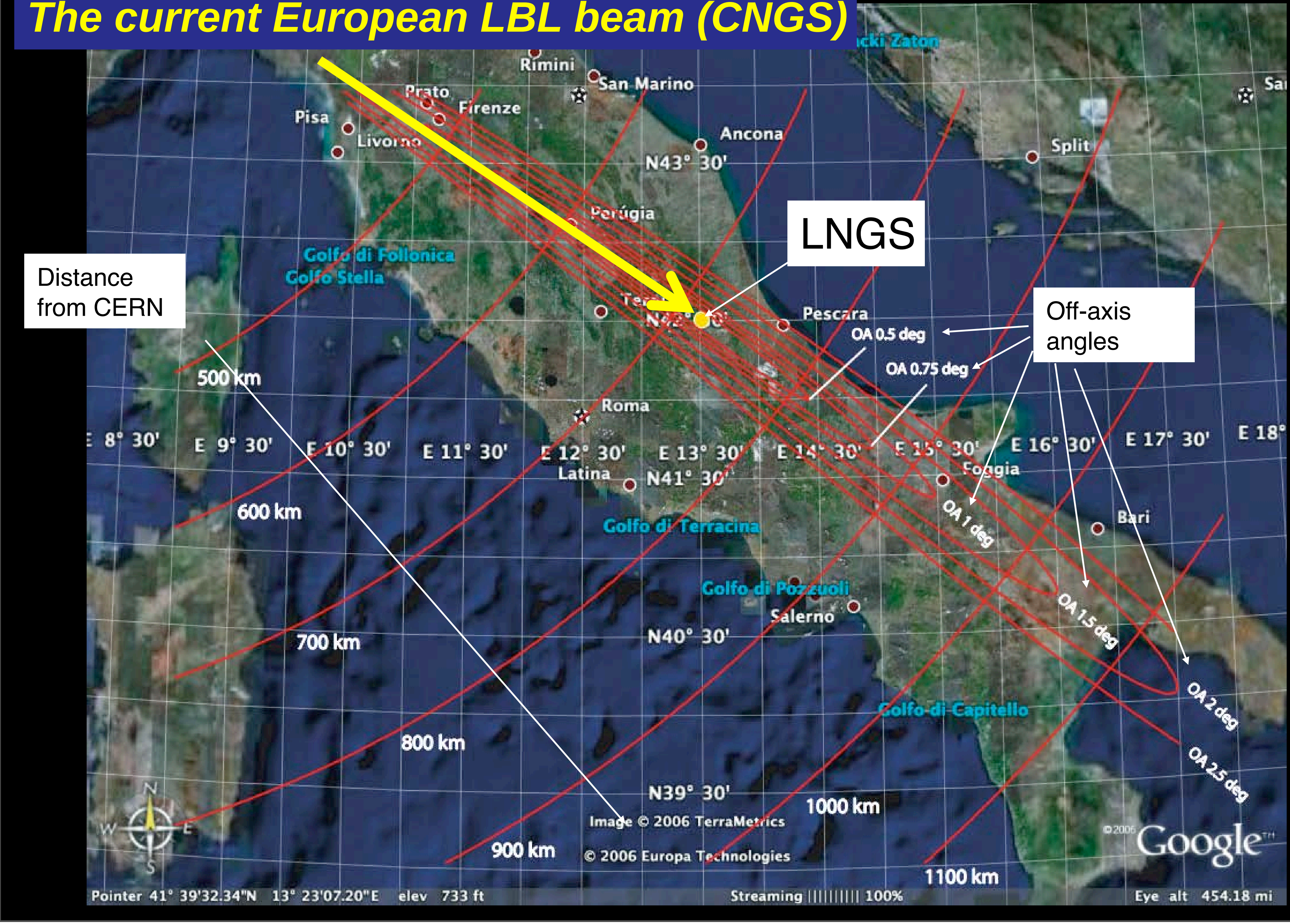
3. Early alert for astronomers

- Pointing to the supernova

Example: baselines from CERN



The current European LBL beam (CNGS)



ApPEC Roadmap, January 2007

Proton decay and low energy neutrino astrophysics

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

LAGUNA WG is a coordinated European effort

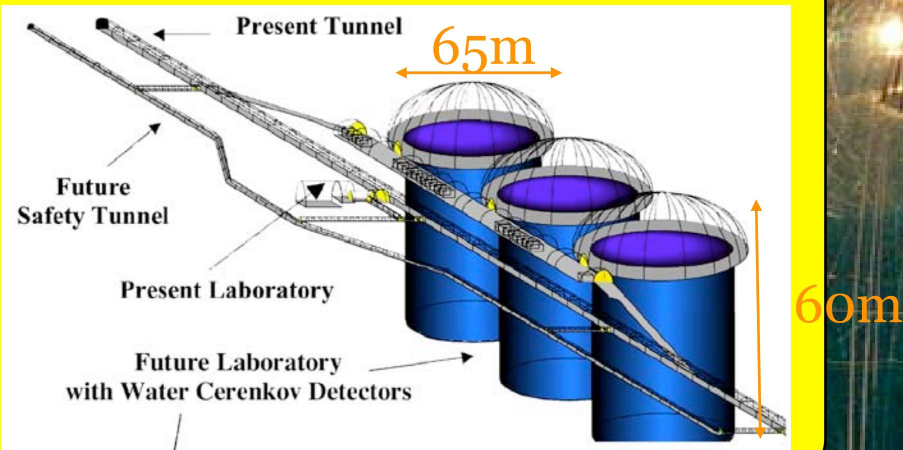
- **Originally a working group aimed towards common physics goals**
  - Proposed and accepted at the ApPEC "Munich meeting" on November 2005
- **Develop conceptual designs for European large underground detectors**
  - Investigate physics complementarities and common R&D needs.
  - Provide a coherent and well-coordinated EU wide efforts. Work in synergy.
  - Solve common problems together.
  - Take into account the unique technological expertise in Europe and other existing or planned programs in the world.
- **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 very large volume liquid detectors

- **Three complementary techniques are currently being investigated for next generation large volume underground rare event observatories**
  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 and DOUBLE-CHOOZ
  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.
- **The underground construction of very large volume instruments of those technologies appears possible, but requires detailed design studies to optimize the required site(s) under controlled cost boundaries.**
- **In parallel, the most promising technologies under controlled cost boundaries and their underground implementation in very large scale must be further assessed.**

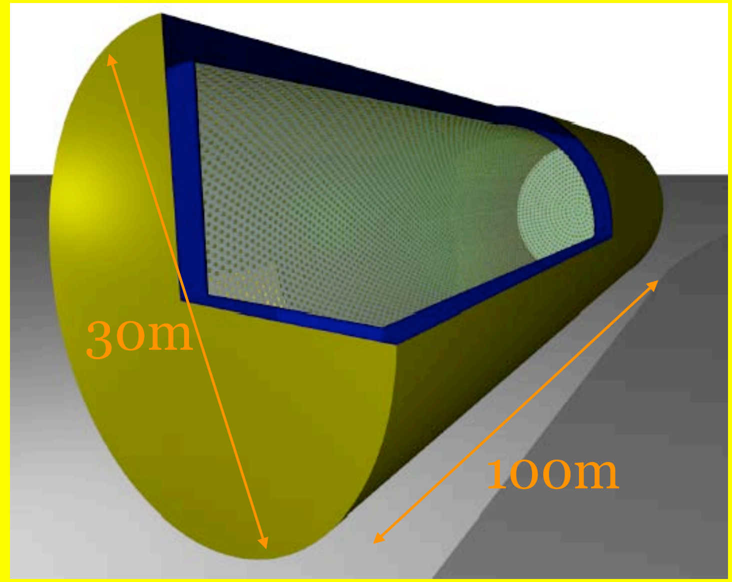
Large Underground detectors considered in LAGUNA

MEMPHYS-like



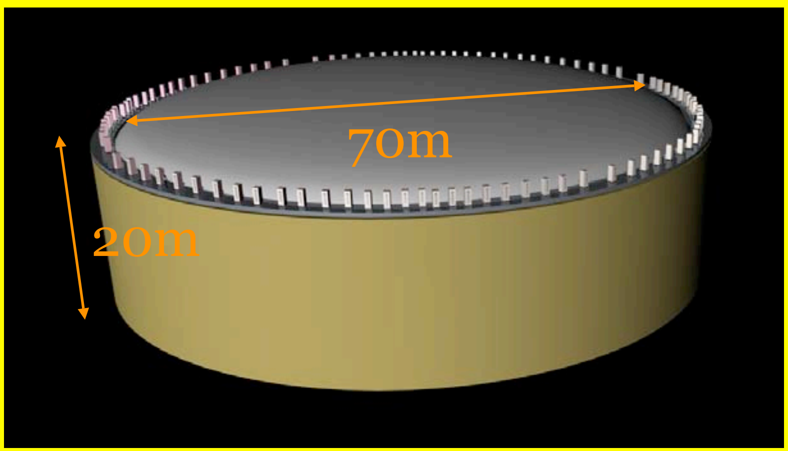
Water Cherenkov (≈0.5 → 1 Mton)

LENA-like



Liquid Scintillator (→ 50 kton)

GLACIER-like



Liquid Argon (≈10→100 kton)

photo: BOREXINO calibration

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
  - ✓ Chambery, March 2nd, 2007
  - ✓ Paris, March 29th, 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 been prepared.
- Strong links with specialized industry (subcontractors) have been defined.
- The potential FP7 DS document is being drafted (preliminary version) to be finalized by May 2007.

LAGUNA DS participation

- ≈60 members
- >20 institutes from CH, DE, ESP, FR, FIN, I, POL, UK
- New interest was raised at Valencia meeting

- List of "participants" for LAGUNA DS in the process of being finalized. So far includes:
  - All underground laboratories (CUPP, LNGS, LSC, LSM, IUS, SUNLAB)
  - All involved scientific partners
  - Industrial partners (excavation, tanks, ...)
  - Potential subcontractors (underground storage, ...)

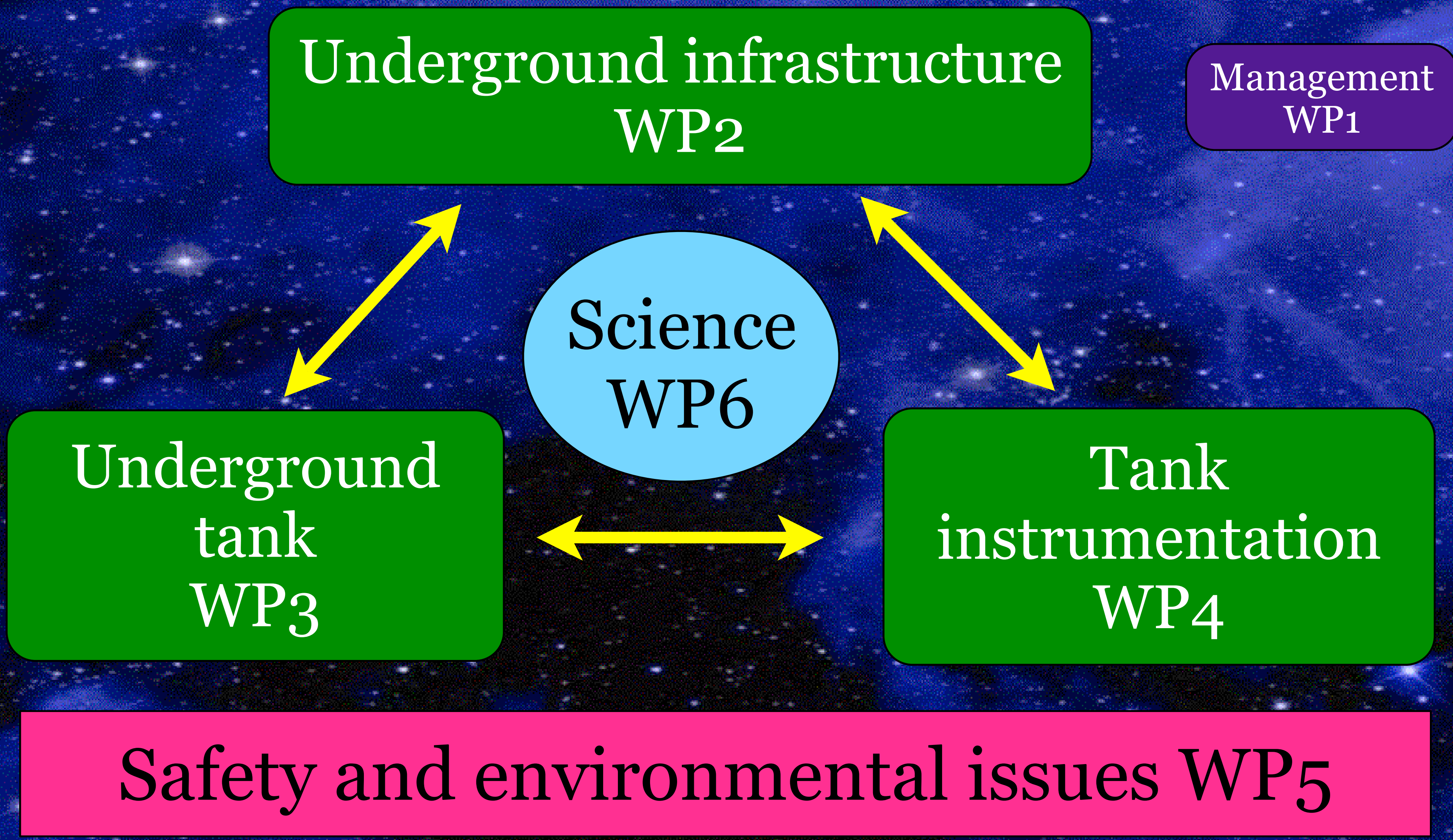
LAGUNA working packages

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

For example...

- **WP2 Underground infrastructure:**
  - ✦Focuses on the technical issues of underground large-scale civil engineering needed to host large volume instruments considered in the DS, including general geological studies for the site, preliminary designs for the cavities, simulations of rock mechanics, analyses of local rocks, planning of the cavity construction and cost optimisation.
  - ✦The studies will be performed coherently for each cavity and site. The project will be started with several alternatives, but during the project the scope will be narrowed down to fewer cases as we gain sufficient information to select the most promising candidates. The selection processes form the major milestones of the work. The cases passing the selections will be subject to more thorough studies, including rock sampling (drilling by subcontractors) to preliminary fix the location of the cavity within the site.
  - ✦Industrial partners: STONE (I), Rockplan (FIN), SETEC (F), KGHM CUPRUM (Pol), IGSMiE (Pol), Lombardi (CH), IMPREGILO (I)

WP interconnection



The main "deliverable"

- The DS will lead to a "conceptual design report" for a new infrastructure, to allow policy makers and their advisors to prepare the relevant strategic decisions for the development of a new research infrastructure in Europe.
- 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) ...

WP resources subdivision

DRAFT

WP		Total	EU funds
WP1	Management and coordination	0.3 M€	0.15 M€
WP2	Underground infrastructure and engineering	3.0 M€	2.3 M€
WP3	Underground tanks and liquid handling	1.8 M€	1.05 M€
WP4	Instrumentation and data handling	2.5 M€	0.5 M€
WP5	Safety and environment	0.5 M€	0.25 M€
WP6	Underground science optimization and outreach	1.5 M€	0.5 M€
TOTAL		9.6 M€	4.75 M€

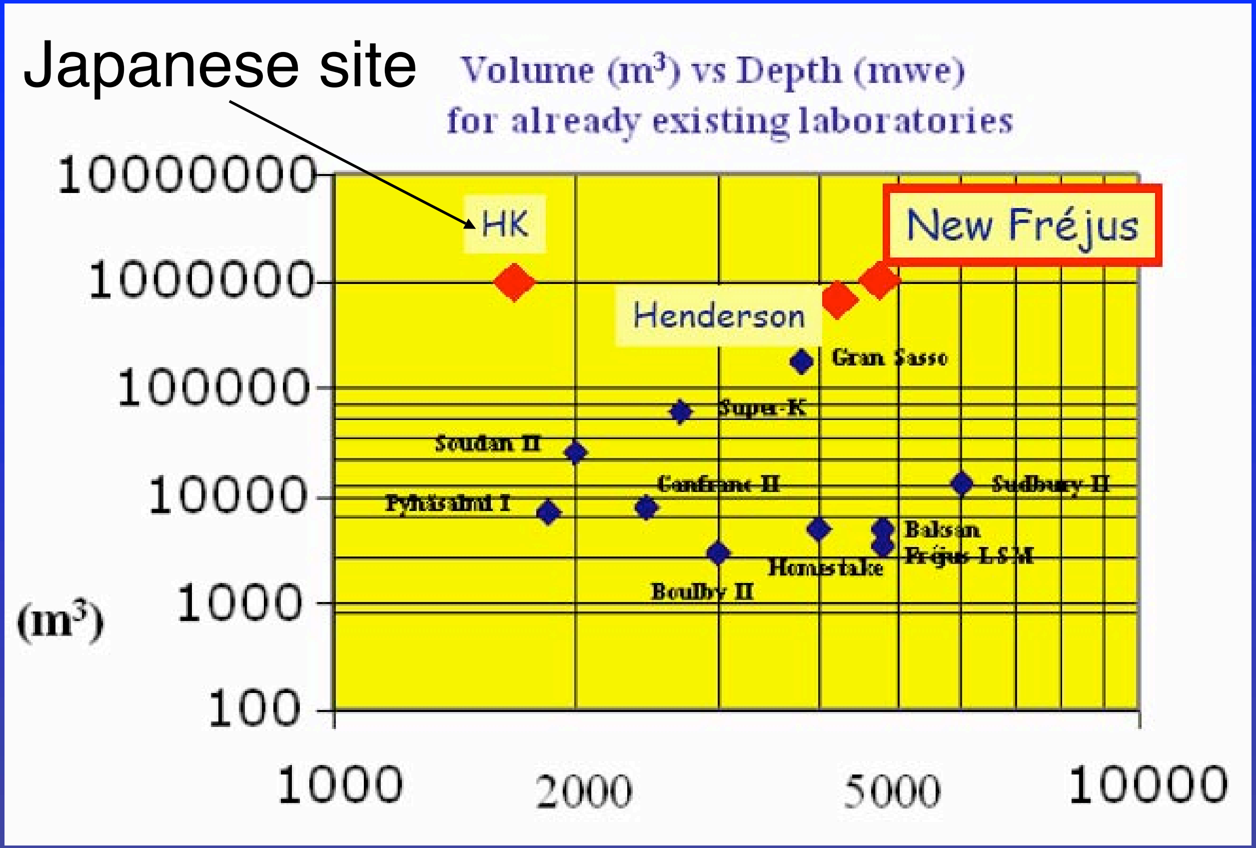
Over 36 months

Outlook

- Advances in low energy neutrino astronomy and direct investigation of Grand Unification require the construction of very large volume underground observatories.
- The direct evidence for Grand Unification would be one of the most fundamental discoveries in particle physics. This requires new generation very massive detectors.
- An extensive neutrino physics and astronomy programme will be accessible with these new rare event detection instruments, 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 volume underground instruments 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 pan-European Underground Infrastructure.
- 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}.

The end

Risks at large deep underground laboratories

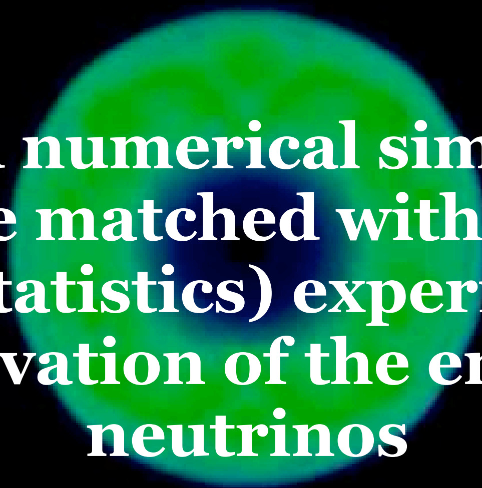


- **Rock type / rock chemistry**
  - Creep & solubility are the principal issues
- **Rock quality / In situ stress**
  - Commonly influences costs by a factor of 2 to 4, could make a site unfeasible
- **Access / rock removal**
  - Can influence costs significantly, but is very site dependent

Two dimensional numerical simulation

97.6ms

The central region of a massive, dying star, just after the core has collapsed into a neutron star. Yet it does not explode!



Detailed numerical simulations must be matched with precise (high statistics) experimental observation of the emitted neutrinos

Simulations courtesy of R. Buras, M. Rampp, H.-Th. Janka, Max Planck Institute for Astrophysics