

# The LAGUNA design study– towards giant liquid based underground detectors for neutrino physics and astrophysics and proton decay searches

**The LAGUNA consortium\*** : *D. Angus<sup>a</sup>, A. Ariga<sup>b</sup>, D. Autiero<sup>c</sup>, A. Apostu<sup>d</sup>, A. Badertscher<sup>e</sup>, T. Bennet<sup>f</sup>, G. Bertola<sup>g</sup>, P.F. Bertola<sup>g</sup>, O. Besida<sup>h</sup>, A. Bettini<sup>i</sup>, C. Booth<sup>f</sup>, J.L. Borne<sup>c</sup>, I. Brancus<sup>d</sup>, W. Bujakowsky<sup>j</sup>, J.E. Campagne<sup>c</sup>, G. Cata Danil<sup>d</sup>, F. Chipiesiu<sup>d</sup>, M. Chorowski<sup>k</sup>, J. Cripps<sup>f</sup>, A. Curioni<sup>e</sup>, S. Davidson<sup>c</sup>, Y. Declais<sup>c</sup>, U. Drost<sup>g</sup>, O. Dului<sup>l</sup>, J. Dumarchez<sup>c</sup>, T. Enqvist<sup>m</sup>, A. Ereditato<sup>b</sup>, F. von Feilitzsch<sup>n</sup>, H. Fynbo<sup>o</sup>, T. Gamble<sup>f</sup>, G. Galvanin<sup>p</sup>, A. Gendotti<sup>e</sup>, W. Gizicki<sup>k</sup>, M. Goger-Neff<sup>n</sup>, U. Grasslin<sup>g</sup>, D. Gurney<sup>q</sup>, M. Hakala<sup>r</sup>, S. Hannestad<sup>o</sup>, M. Haworth<sup>q</sup>, S. Horikawa<sup>e</sup>, A. Jipa<sup>l</sup>, F. Juget<sup>b</sup>, T. Kalliokoski<sup>s</sup>, S. Katsanevas<sup>c</sup>, M. Keen<sup>t</sup>, J. Kisiel<sup>u</sup>, I. Kreslob<sup>b</sup>, V. Kudryastev<sup>f</sup>, P. Kuusiniemi<sup>m</sup>, L. Labarga<sup>v</sup>, T. Lachenmaier<sup>n</sup>, J.C. Lanfranchi<sup>n</sup>, I. Lazanu<sup>l</sup>, T. Lewke<sup>n</sup>, K. Loo<sup>m</sup>, P. Lightfoot<sup>f</sup>, M. Lindner<sup>w</sup>, A. Longhin<sup>h</sup>, J. Maalampi<sup>s</sup>, M. Marafini<sup>c</sup>, A. Marchionni<sup>e</sup>, R.M. Margineanu<sup>d</sup>, A. Markiewicz<sup>y</sup>, T. Marrodan-Undagoitia<sup>n</sup>, J.E. Marteau<sup>c</sup>, R. Matikainen<sup>r</sup>, Q. Meindl<sup>n</sup>, M. Messina<sup>b</sup>, J.W. Mietelski<sup>y</sup>, B. Mitrica<sup>d</sup>, A. Mordasini<sup>g</sup>, L. Mosca<sup>h</sup>, U. Moser<sup>b</sup>, G. Nuijten<sup>r</sup>, L. Oberauer<sup>n</sup>, A. Oprina<sup>d</sup>, S. Paling<sup>f</sup>, S. Pascoli<sup>a</sup>, T.Patzak<sup>c</sup>, M. Pectu<sup>d</sup>, Z. Pileckij<sup>j</sup>, F. Piquemal<sup>c</sup>, W. Potzel<sup>m</sup>, W. Pytel<sup>x</sup>, M. Raczynski<sup>x</sup>, G. Rafflet<sup>z</sup>, G. Ristaino<sup>p</sup>, M. Robinson<sup>f</sup>, R. Rogers<sup>q</sup>, J. Roinisto<sup>r</sup>, M. Romana<sup>i</sup>, E. Rondio<sup>A</sup>, B. Rossi<sup>h</sup>, A. Rubbia<sup>e</sup>, Z. Sadecki<sup>x</sup>, C. Saenz<sup>i</sup>, A. Saftoiu<sup>d</sup>, J. Salmelainen<sup>r</sup>, O. Sima<sup>l</sup>, J. Slizowski<sup>j</sup>, K. Slizowski<sup>j</sup>, J.Sobczyk<sup>B</sup>, N. Spooner<sup>f</sup>, S. Stoica<sup>d</sup>, J. Suhonen<sup>s</sup>, R.Sulej<sup>A</sup>, M. Szarska<sup>y</sup>, T. Szegłowski<sup>B</sup>, M. Temussi<sup>p</sup>, J. Thompson<sup>q</sup>, L. Thompson<sup>f</sup>, W.H. Trzaska<sup>s</sup>, M. Tippmann<sup>n</sup>, A. Tonazzo<sup>c</sup>, K. Urbanczyk<sup>j</sup>, G. Vasseur<sup>h</sup>, A. Williams<sup>t</sup>, J. Winter<sup>n</sup>, K. Wojciszewska<sup>j</sup>, M. Wurm<sup>n</sup>, A. Zalewska<sup>y</sup>, M. Zampaolo<sup>c</sup>, M.Zito<sup>h</sup>*

(a) University of Durham (UDUR), University Office, Old Elvet, Durham DH1 3HP, United Kingdom (b) University of Bern, 4 Hochschulstrasse, CH-3012, Bern (c) Centre National de la Recherche Scientifique, Institut National de Physique Nucléaire et de Physique des Particules (CNRS/IN2P3), 3 rue Michel-Ange, Paris 75794, France (d) Horia Hulubei National Institute of RD for Physics and Nuclear Engineering, IFIN-HH, 407 Atomistilor Street, R-077125, Magurele, jud. ILFOV, PO Box MG-6, postal code RO-077125, Romania (e) ETH Zurich, 101 Raemistrasse, CH-8092 Zurich (f) The University of Sheffield (USFD), New Spring House 231, Glossop Road, Sheffield S102GW, United Kingdom (g) Lombardi Engineering Limited, via R.Simen, CH-6648, Minusio (h) Commissariat à l’Energie Atomique (CEA)/ Direction des Sciences de la Matière, 25 rue Leblanc, Paris 75015, France (i) Laboratorio Subterráneo de Canfranc (LSC), Plaza del Ayuntamiento no. 1, 22880 Canfranc (Huesca), Spain (j) Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (IGSMIE-PAN), Wybickiego 7, 30-950 Krakow, Poland (k) Wrocław University of Technology (PWr Wrocław), ul. Wybrzeże Wyspińskiego 27, 50-370 Wrocław, Poland (l) University of Bucharest (UoB), Faculty of Physics Bld.Atomistilor nr.405, Physics Platform, Magurele, Ilfov County, RO-077125, MG-11 Bucharest-Magurele, Romania (m) University of Oulu (U-OULU), 1 Pentti Kaiteran Katu, Oulu 90014, Finland (n) Technische Universität München (TUM), 21 Arcisstrasse, München 80333, Germany (o) University of Aarhus (AU), 1 Norde Ringgade, Aarhus C 8000, Denmark (p) AGT Ingegneria Srl, Perugia, 10 A via della Pallotta, Perugia 06126, Italy (q) Technodyne International Ltd., Unit16, Shakespeare Business Centre Hathaway Close, Eastleigh UK SO 50 4SR, United Kingdom (r) Kalliosuunnittelu Oy Rockplan Ltd., 2 Asemamiehenkatu, Helsinki 00520, Finland (s) University of Jyväskylä (JyU), 9 Survontie, Jyväskylä 40014, Finland (t) Cleveland Potash Limited (CPL), Boulby Mine, Loftus, Saltburn Cleveland, TS13 4UZ, UK (u) Institute of Physics, University of Silesia Uniwersytecka 4, 40-007 Katowice, Poland (v) Universidad Autonoma de Madrid (UAM), C/Einstein no. 1; Rectorado, Ciudad Universitaria de Cantoblanco, 28049 Madrid, Spain (w) Max-Planck-Institute for Nuclear Physics, Heidelberg (x) KGHM CUPRUM Ltd Research and Development Centre, Pl. 1 Maja, 50-136 Wrocław, Poland (y) IFJ Pan, H.Niewodniczanski Institute of Nuclear Physics PAN, Radzikowskiego 152, 31-342 Krakow, Poland (z) Max-Planck-Institute for Physics, Munich (A) High Energy Physics Department - A. Soltan Institute for Nuclear Studies (SINS) Hoza 69 00-681 Warsaw, Poland (B) Faculty of Physics and Astronomy, Wrocław University, pl M. Borna 9, 50-204 Wrocław, Poland.

\*LAGUNA Coordinator : andre.rubbia@cern.ch

## Abstract

The feasibility of a next generation neutrino observatory in Europe is being considered within the LAGUNA design study. To accommodate giant neutrino detectors and shield them from cosmic rays, a new very large underground infrastructure is required. Seven potential candidate sites in different parts of Europe and at several distances from CERN are being studied: Boulby (UK), Canfranc (Spain), Fréjus (France/Italy), Pyhäsalmi (Finland), Polkowice-Sieroszowice (Poland), Slanic (Romania) and Umbria (Italy). The design study aims at the comprehensive and coordinated technical assessment of each site, at a coherent cost estimation, and at a prioritization of the sites within the summer 2010.

## 1 Physics goals

Large underground neutrino detectors, for instance SuperKamiokande or SNO, have achieved fundamental results in particle and astro-particle physics. A next-generation very large multipurpose neutrino observatory of a total mass in the range of 100'000 to 1'000'000 tons will provide new and unique scientific opportunities in this field, very likely leading to fundamental discoveries. It will aim at a significant improvement in the sensitivity to search for proton decays, pursuing the only possible path to directly test physics at the GUT scale, extending the proton lifetime sensitivities up to  $10^{35}$  years, a range compatible with several theoretical models; it will measure with unprecedented sensitivity the last unknown mixing angle  $\theta_{13}$  and unveil the existence of CP violation in the leptonic sector, which in turn could provide an explanation of the matter-antimatter asymmetry in the Universe; moreover it will detect neutrinos as messengers from astrophysical objects as well as from the Early Universe to give us information on processes happening in the Universe, which cannot be studied otherwise. In particular, it will sense a large number of neutrinos emitted by exploding galactic and extragalactic type-II supernovae, allowing an accurate study of the mechanisms driving the explosion. The neutrino observatory will also allow precision studies of other astrophysical or terrestrial sources of neutrinos like solar and atmospheric ones, and search for new sources of astrophysical neutrinos, like for example the diffuse neutrino background from relic supernovae or those produced in Dark Matter (WIMP) annihilation in the centre of the Sun or the Earth.

## 2 The LAGUNA design study

The construction of a large scale neutrino detector in Europe devoted to particle and astroparticle physics was discussed several years ago (see e.g. [1]) and is currently one of the priorities of the ASPERA roadmap, defined in 2008 [2]. Four national underground laboratories located resp. in Boulby (UK), Canfranc (Spain), Gran Sasso (Italy), and Modane (France), are today in operation, hosting detectors looking for Dark Matter or neutrino-less double beta decays, or performing long-baseline experiments. However, none of these existing laboratory is large enough for the next-generation neutrino experiments.

The FP7 Design Study LAGUNA [3] (Large Apparatus studying Grand Unification and Neutrino Astrophysics) is an EC-funded project carrying on underground sites studies and developments in view of such detectors observatories. Three detector options are currently being studied: GLACIER [4], LENA [5], and MEMPHYS [6]. The study is evaluating possible extensions of the existing deep underground laboratories, and on top of it, the creation of new laboratories in the following regions: Umbria Region (Italy), Pyhäsalmi (Finland), Sieroszowice (Poland) and Slanic (Romania). Table 1 summarizes some basic characteristics of the sites under consideration, including the distance from CERN, which is relevant in case a neutrino beam is sent from CERN to the selected underground site.

**Table 1:** Potential sites being studied with the LAGUNA design study.

Location	Type	Envisaged depth m.w.e.	Distance from CERN [km]	Energy 1 <sup>st</sup> Osc. Max. [GeV]
Fréjus (F)	Road tunnel	$\simeq 4800$	130	0.26
Canfranc (ES)	Road tunnel	$\simeq 2100$	630	1.27
Umbria(IT) <sup>a</sup>	Green field	$\simeq 1500$	665	1.34
Sieroszowice(PL)	Mine	$\simeq 2400$	950	1.92
Boulby (UK)	Mine	$\simeq 2800$	1050	2.12
Slanic(RO)	Salt Mine	$\simeq 600$	1570	3.18
Pyhäsalmi (FI)	Mine	up to $\simeq 4000$	2300	4.65

<sup>a</sup>  $\simeq 1.0^\circ$  off axis.

### 3 Site selection

Site selection is a complex process involving the optimization and assessment of several parameters, encompassing physics performance, technical feasibility, safety and legal aspects, socio-economic and environmental impact, costs, etc. As a result, LAGUNA is interdisciplinary, involving most European physicists interested in realizing massive neutrino detectors, as well as geo-technical experts, geophysicists, structural engineers, mining engineers and also large storage tank engineers. It regroups 21 beneficiaries, composed of academic institutions from Denmark, Finland, France, Germany, Poland, Spain, Switzerland, United Kingdom, as well as industrial partners specialized in civil and mechanical engineering and rock mechanics, commonly assessing the feasibility of a this Research Infrastructure in Europe. Some of the typical issues addressed by LAGUNA are illustrated below:

1. assessment of strengths and weaknesses of each site;
2. rock mechanics and excavation of the required caverns;
3. overburden vs. detector options;
4. design and construction of tanks in relation to sites;
5. transport, access, delivery of detector liquids;
6. safety issues, in road tunnels and in operating mines;
7. environmental impact, e.g. rock removal;
8. relative costs;
9. etc.

The study also gives the opportunity to the members of the consortium to visit all the potential sites and hold several meetings to exchange ideas and work together on common areas, solving common issues, in a collaborative spirit, although a sense of healthy competition is implied among the sites.

The results will be summarized in 16 reports (“deliverables”) to be submitted to the EC within the fall 2010. A first report on the health, safety and environmental impact has been prepared during the summer 2009. Seven “interim” reports, one for each site, are currently under preparation and should be available during the winter 2009/2010. They demonstrate that the site studies are well underway with definitions of the infrastructure in advanced stages, providing well-defined conceptual designs and reliable excavation cost-estimates.

### 4 The future of long baseline neutrino physics in Europe

The next generation deep underground neutrino detector should be coupled to advanced neutrino beams from CERN to complete the understanding of the leptonic mixing matrix, in particular to study matter-antimatter asymmetry in neutrino oscillations (CP-violation), thereby addressing the outstanding puzzle

of the origin of the excess of matter over antimatter created in the very early stages of evolution of the Universe. The outcome of the current international program to measure the (small) mixing angle  $\theta_{13}$  (T2K in Japan, DoubleChooz in Europe, Daya Bay in China and NOvA in the US) will define the strategy to measure CP-violation in the neutrino sector, whether using conventional superbeams or more exotic beta-beams or neutrino factories. In the case that  $\theta_{13}$  is below the sensitivity of T2K/DoubleChooz/Daya Bay/NOvA, a new far detector designed to measure CP-violation coupled to an intensity upgraded conventional superbeam, is the most natural next step to continue exploring neutrino oscillations, since the increased statistics yields an order of magnitude better sensitivity in  $\theta_{13}$ .

Similar plans are emerging worldwide, for instance in North America with the Deep Underground Science and Engineering Laboratory (DUSEL) at Homestake (South Dakota), envisioning a deep underground facility coupled to US accelerator laboratories located at appropriate distances, for long baseline neutrino oscillation experiments [7]. In Asia, the Japanese High Energy Research Accelerator Research Organization (KEK) roadmap foresees extensions of the JPARC neutrino programme beyond the current T2K experiment by increasing the neutrino beam intensity and by constructing a new far detector in addition to SuperKamiokande [8].

This international landscape underlines the "global" nature of the project, with potential options being considered in several continents, jointly debated by the international scientific community, making all the more likely that only one such facility will be built worldwide.

## 5 Conclusions and Outlook

The LAGUNA consortium is studying the feasibility of a new large underground infrastructure in Europe able to host next generation neutrino physics and astrophysics and proton decay experiments. Seven sites are presently being considered. The study aims at the comprehensive and coordinated technical assessment of each site, at a coherent cost estimation, and at a priority list for site selection, by Summer 2010. After that, a more focused design study, aiming also at detector option selection, should be envisaged. Future long baseline in Europe should consider a new beam line from CERN towards the chosen LAGUNA site. The new large underground infrastructure could in the future be operated in connection with other, more advanced neutrino beams like beta-beams or neutrino factories.

## Acknowledgements

The LAGUNA design study is financed by FP7 Research Infrastructure "Design Studies", Grant Agreement No. 212343 FP7-INFRA-2007-1.

## References

- [1] D. Autiero *et al.*, "Large underground, liquid based detectors for astro-particle physics in Europe: scientific case and prospects," JCAP **0711** (2007) 011 [arXiv:0705.0116 [hep-ph]].
- [2] ASPERA is a network of national government agencies responsible for coordinating and funding national research efforts in Astroparticle Physics. See <http://www.aspera-eu.org>
- [3] For up-to-date information see <http://laguna.ethz.ch>
- [4] A. Rubbia, "Experiments for CP-violation: A giant liquid argon scintillation, Cerenkov and charge imaging experiment?," arXiv:hep-ph/0402110.
- [5] L. Oberauer, F. von Feilitzsch and W. Potzel, "A large liquid scintillator detector for low-energy neutrino astronomy," Nucl. Phys. Proc. Suppl. **138** (2005) 108.
- [6] A. de Bellefon *et al.*, "MEMPHYS: A large scale water Cerenkov detector at Frejus," arXiv:hep-ex/0607026.
- [7] Y.K. Kim, "Plans for super-beams in US", this report.
- [8] T. Hasegawa, "Plans for super-beams in Japan", this report.