

LAGUNA DESIGN STUDY, Underground infrastructures and engineering

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Abstract. The European Commission has awarded the LAGUNA project a grant of 1.7 million euro for a Design Study from the seventh framework program of research and technology development (FP7-INFRASTRUCTURES – 2007-1) in 2008. The purpose of this two year work is to study the feasibility of the considered experiments and prepare a conceptual design of the required underground infrastructure. It is due to deliver a report that allows the funding agencies to decide on the realization of the experiment and to select the site and the technology. The result of this work is the first step towards fulfilling the goals of LAGUNA. The work will continue with EU funding to study the possibilities more thoroughly. The LAGUNA project is included in the future plans prepared by European funding organizations. (Astroparticle physics in Europe). It is recommended that a new large European infrastructure is put forward, as a future international multi-purpose facility for improved studies on proton decay and low-energy neutrinos from astrophysical origin. The three detection techniques being studied for such large detectors in Europe, Water-Cherenkov (like MEMPHYS), liquid scintillator (like LENA) and liquid argon (like GLACIER), are 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. The design study is also to take into account worldwide efforts and converge, on a time scale of 2010, to a common proposal.

1. Physics goals

Large underground neutrino detectors, for instance Super-Kamiokande (Japan), BOREXINO (Italy) or SNO (Canada), have achieved fundamental results in particle and astroparticle 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 (Grand Unification Theory) 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 θ_{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 [1]

2. General

The acronym LAGUNA stands for Design of a pan-European Infrastructure for Large Apparatus studying Grand Unification and Neutrino Astrophysics. The LAGUNA Project is coordinated by the Swiss Federal Institute of Technology Zurich, led by Prof. A. Rubbia, and there are 30 parties (Academic Partners, Industrial Partners and Affiliated Academic Partners) taking part in the project. The purpose is to design three very large underground laboratories in Europe and to find a suitable location for them. The coordination of the technical design considering underground infrastructures and engineering is led by Prof. F. von Feilitzsch. On behalf of Finland the universities of Oulu & Jyväskylä as well their industrial partner ROCKPLAN are taking part in the project [2].

2.1. Possible experiments

Three detection techniques being studied for such large detectors in Europe, Water-Cherenkov (like MEMPHYS), liquid scintillator (like LENA) and liquid argon (like GLACIER), are 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.

2.1.1. GLACIER

GLACIER stands for Giant Liquid Argon Charge Imaging ExpeRiment. The basic design features of the GLACIER detector can be summarized as follows:

Single 100 kton “boiling” cryogenic tanker at atmospheric pressure for a stable and safe equilibrium condition (temperature is constant while Argon is boiling). The evaporation rate is small (less than 10^{-3} of the total volume per day given by the very favorable area to volume ratio) and is compensated by corresponding refilling of the evaporated Argon volume.

Charge imaging, scintillation and Cherenkov light readout for a complete (redundant) event reconstruction. This represents a clear advantage over large mass, alternative detectors operating with only one of these readout modes. Scintillation and Cherenkov light can be readout essentially independently for improved physics performance.

Charge amplification to allow for very long drift paths. The detector is running in bi-phase mode. In order to allow for drift lengths as long as 20 m, which provides an economical way to increase the volume of the detector with a constant number of channels, charge attenuation will occur along the drift due to attachment to the remnant impurities present in the liquid argon. This effect can be compensated with charge amplification near the anodes located in the gas phase.

2.1.2. MEMPHYS

MEMPHYS stands for MEgaton Mass PHYSics. From a practical point of view, the most straightforward liquid is water, where the detection is based on the Cherenkov light emission by the final state particles. This faint light is detected by a very large number of photomultipliers positioned on the surface of the container. The technology was pioneered by the IMB and Kamiokande experiments (USA and Japan, respectively) and successfully extended to Super-Kamiokande during many years of operation. Super-Kamiokande is the largest Water Cherenkov detector ever built so far. The possibility of building a water Cherenkov detector with a fiducial mass of about 500 kton observed by about 200 000 photomultipliers is currently being investigated by different groups around

the world, and for different underground sites. While water is a cheap medium, the size of such detectors is limited by the cost of excavation and of the photomultipliers.

The MEMPHYS project is being discussed for deployment in an extended Frejus laboratory (South East France). In the US, the UNO detector is being proposed for a future underground facility in North America. In Japan Hyper-Kamiokande will provide an extension of Super-Kamiokande. All these investigations are based on Super-Kamiokande, where its size is increased by a factor 20, using 3 to 5 new caverns to be excavated.

2.1.3. LENA

LENA stands for Low Energy Neutrino Astronomy. Detecting a neutrino requires a very sensitive device in a low background environment. Due to a low interaction probability of a neutrino such a device must be very large, to get a reasonable amount of data in a reasonable time.

The core of LENA consists of a huge tank filled with a special organic liquid. The liquid may be composed of three components: solvent, scintillator and wavelength shifter. The solvent might be an aromatic hydrocarbon coded PXE (phenyl-o-xylylethane). It has a high light yield and large attenuation length. Particularly, it is considered a non-hazardous liquid (flash-point of 145°C, HMIS ratings <1). Laboratory experiments have shown that attenuation lengths of ~10 m (@ 430 nm) and a good photoelectron yield can be achieved in both pure PXE and a mixture containing 80% of dodecane. Another alternative may be LAB, mixed with small amounts of other chemicals. Its optical properties are probably better but need to be studied more.

The liquid target will have a very large volume, to minimize the presence of any radioactivity. The maximum width is given by the optical properties of the liquid. For PXE the maximum, and also optimal diameter is about 13 m, for LAB probably 15 m.

A neutrino hitting the scintillator target may induce a reaction resulting in a light pulse. The light pulses will be observed by light sensors at the outer walls of the tank. There will be about 12 000 light sensors, probably 50 cm photo multiplying tubes, and respective amount of wires to data acquisition system. The phototubes require also a high-voltage (> kV) line.

2.2. Possible sites

Seven different sites being studied for such large detectors in Europe are 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.

2.2.1. Pyhäsalmi, Finland

Pyhäsalmi Mine Oy is owned by Inmet Mining Corporation. Pyhäsalmi is an underground copper and zinc mine located in central Finland. The mine is at present the deepest mine in Europe, reaching a depth of 1440 meter below surface. The Mine produces three types of concentrates: copper, zinc and pyrite.

In 1962 the Mine began as an open pit operation. This phase lasted until 1967, the year when Mine operations commenced underground. In 1975 the open pit was completely worked out. As mining progressed the Mine was gradually deepened. The latest phase of deepening with a view to exploiting the ore lens below 1050 level was carried out between 1998 and 2001. The resulting new Mine started operation in 2001 and mining is carried out via the new 1440 meter deep Timo Shaft.

The Pyhäsalmi Mine is a very modern and safe operation and one of the best performing Mines worldwide with an annual production of 1.4 million tones. To secure extend mining into the future the Mine invests significantly in exploration both in the Mine site and regionally. Pyhäsalmi's safety and health management system was certified under the Occupational Health and Safety Assessment System (OHSAS) 18001 standard.

Present at location are all main needed infrastructure facilities as 110 kV power supply, railway connections and a good road infrastructure. The railway station in Pyhäsalmi is the second biggest freight station of Finland as provides a very good connection with the harbor in Kokkola, about 160

km distance. The harbor of Kokkola is situated on the west coast. The town also has an airfield. The main corridor from Helsinki to Oulu passes at only 6 km from the site. [2]

2.2.2. *Fréjus, France*

The Fréjus site of LAGUNA is located near to the Italian-French border next to the Fréjus Highway tunnel connecting the villages of Modane in France and Bardonecchia in Italy. The distance from Fréjus to CERN is only 135 km.

Regarding to transport services the Fréjus tunnel is one of the main connections through the French Alps between the main cities of Lyon and Torino. The connection consists both the road tunnel as the railway tunnel. Connected to the road tunnel Fréjus is known for its present laboratory, LSM, standing for Laboratoire Souterrain de Modane, created in 1982. [3]

2.2.3. *Boulby, United Kingdom*

Boulby mine is located on the coast of North East England, 15km North of the town of Whitby in Yorkshire. The site is rather exceptional in the UK being within a major national park of outstanding beauty (the North York Moors National Park) yet close to one of the largest industrial zones in Europe, Middlesbrough and Tees valley (30 km away), with excellent transport links.

There are thus outstanding recreational facilities for the visitor, with an excellent living environment and some of the most spectacular coasts and beaches in England, but also easy access to all the industry and materials needed for LAGUNA, including liquid argon and mineral oils manufactured in the huge petro-chemical plants of the Tees valley, connected directly to the mine by a dedicated rail link. [4]

2.2.4. *Umbria, Italy*

The Italian site, unlike other sites analyzed in this feasibility study, is not corresponding to any existing infrastructure, such as a mine or a tunnel. It has been located referring to a hypothesis of an off-axis experiment, using existing neutrino beam from CERN in Geneva to LNGS, the Gran Sasso National Laboratory.

After research a site has been located in the region of Umbria, that answers to all scientific and technical requests. The location is in the mountains in the area of Valnerina. The location is about 650 km from CERN. Valneria is a narrow and tortuous valley, sparsely populated with a rural and high environmental value. [5]

2.2.5. *Polkowice-Sieroszowice, Poland*

The Polkowice-Zieroszowice mine has been under continuous operation for almost 30 years. Including the holding of KGHM there are 4000 employees in the mine and 18000 in the holding. The mine operates in three mining regions, covering a total surface area of about 175 km². In 2008 about 11 millions tons of ore were extracted.

The location of the mine is in the south west corner of Poland. The biggest nearby city is Wrocław, about 90 km from the mine, with over 600000 inhabitants. Wrocław offers a railway station, an international airport, universities, research institutions and a rich cultural life. The road infrastructure also offers good connections to Germany. [6]

2.2.6. *Canfranc, Spain*

The Canfranc site of LAGUNA is located near to the Spanish-French border next to the Somport Highway tunnel. The Canfranc Underground Laboratory (LSC) is a new facility for Underground Science. It is conceived as a Consortium of the Spanish Ministry of Science and Innovation, the Aragon Regional Government and the University of Zaragoza.

Canfranc is a small village located in Northern Spain. The Somport international mountain pass connects Spain and France in this region, and has provided communication since ancient times in the Pyrenees. The tunnel links the Jaca area in Spain with the city Pau. [7]

2.2.7. *Slanic, Romania*

Slanic town is situated in the sub Carpathian hills about 100 km north from Bucharest. Slanic hosts a salt mine, Unirea, which is administrated by SALROM, SA. The salt exploitation ended in 1971. For the time being the mine is used for tourism and medical purposes. The access into the mine is assured by elevator able to carry up 15 tons. The network of galleries in the Unirea salt mine are very large. The current area is 70000 m² and 2.9 million m³ were excavated.

The temperature in the mine is very modest, around 12°C. The Unirea salt mine is connected to electricity, rads, railway, phone, internet and GSM networks[8]

3. General and scientific considerations for Finland

Within Finland the Pyhäsalmi Mine offers the best location for this purpose, as it is the deepest present location in Finland 1400 meters below surface.

Pyhäsalmi Mine has expressed its interest to be chosen as one of the locations for the underground laboratory as stated in the memorandum of understanding between the Mine and LAGUNA parties in Finland.

Pyhäsalmi is located in the municipality of Pyhäjärvi in the middle of Finland, 450 km north of Helsinki and 150 km south of Oulu.

LAGUNA has received a very positive support from the municipality of Pyhäjärvi as well from the local region Northern Ostrobothnia. A part from the scientific involvement by the Universities of Jyväskylä and Oulu, also the University of Helsinki, the Helsinki Institute of Physics and the Finnish Academy have shown to be interested in the LAGUNA project. The national government of Finland and members of the House of Parliament have been informed and their response, although unofficial, is genuinely positive.

The clearance from nuclear plants to avoid reactor neutrino events is good as there are no nuclear reactors nearby. The nearest nuclear plant is located in Olkiluoto, about 425 km from Pyhäsalmi.

The high level of the existing infrastructure as well as the excellent rock conditions offers the possibility to host all Laguna alternatives simultaneously.

For all options Pyhäsalmi offers the required depth to reduce sufficiently the muon flux at the laboratory level.

Concerning CERN's possible future long distance neutrino beam experiment Pyhäsalmi offers the ideal distance required, i.e. 2300 km from CERN. This offers a very interesting possibility to connect LAGUNA in Finland with experiments in CERN.

4. Technical considerations for Finland

Finland is known for its Precambrian tectonically stable hard bedrock. Earthquake zones are absent at the vicinity, therefore earthquakes occur extremely rarely and their magnitude may be neglected. The hard and very old bedrock of Finland provides by far one of the best locations in Europe to locate any of the LAGUNA laboratories deep under the ground.

Finland has high expertise and good experience in designing and construction of large, complex underground excavations and constructions.

Pyhäsalmi Mine has a suitable low temperature of surrounding rock. The temperature is only a moderate 16°C at 900m and about 23°C at 1400m depth. Pyhäsalmi Mine has very suitable hydrological conditions. The deep rock is nearly completely dry and there are no rock formations, that show time related deformations (like creep of salt or anhydrite).

The Mine has one decline, one main transport hoist shaft and one ventilation shaft. The present underground infrastructure only needs to be enlarged with a ventilation shaft and it provides a perfect layout to conduct excavation as well construction and filling of the tank.

On surface there is an excellent rail yard and with good rail and road connections to the harbor in Kokkola. Construction of the tunnels can be started directly at the depth desired due to excellent existing infrastructure as well on surface as below surface.

Pyhäsalmi has no challenges how to dispose excavated rock as all excavated rock can be handed over to the Mine and will be disposed underground.

5. Estimated costs and realisation time for Finland

Construction costs of the laboratory and observatory infrastructure can be divided in two parts: underground infrastructure and the observatory including detector, sensors and liquids. In the Design Study the main focus is towards the costs for the underground infrastructure. These costs content of preparation costs of the site and all design and legal questions, of excavation costs of the main detector cavern including all auxiliary rooms and needed access routes to the underground site and finally these costs content also all reinforcement works needed for the safety and stability of the cavern. Operation and maintenance costs are not included in this study. The total costs are estimated to range from 45M€ to 125M€.

The preparation time (design, decision taking etc.) is assumed to be finished at the end of 2012. Technically it can be started at any time. External factors may influence the possible date of starting of the project. The construction time, starting directly after the preparation phase, of the underground infrastructure is estimated to range from 3 to 7 years, depending on the size of the detector.

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