LBNO-Prototype

Proposal for the participation of the neutrino groups from IN2P3 and IRFU to the construction, operation and data-analysis of a full scale demonstrator of the LBNO liquid argon detector.

The measurement in 2012 of a large value of the θ_{13} mixing angle [1] opened the way to a relatively easy accessibility of the next fundamental measurements in neutrino mixing, such as the determination of the mass hierarchy and the search for CP violation in the neutrino sector. These goals can be hence reached by exploiting conventional long-baseline neutrino beams coupled to large underground detectors, going from a few tens kton up to 1Mton masses.

The European programs LAGUNA (Large Apparatus studying Grand Unification and Neutrino Astrophysics, 2008-2011) and LAGUNA-LBNO (Long Baseline Neutrino Oscillations, 2011-2014) [2] have thoroughly investigated the feasibility and the complex technical issues related to the construction, in the eligible European underground sites, of giant neutrino detectors, as well as the study of their physics performance with neutrino beams. The LAGUNA/LAGUNA-LBNO studies benefited of important contributions of several French groups, which are also the proponents of this document (LBNO-Prototype). The outcome of the LAGUNA studies was to identify, as the best performance combination, the Pyhäsalmi underground site, hosting a liquid argon TPC with double-phase charge readout and a mass (for the first stage of the program) of 20 kton, coupled to a multi-GeV neutrino beam (CN2PY), produced by using protons extracted from the CERN SPS accelerator and travelling over a baseline of 2300 km. The liquid argon TPC represents a modern version of the bubble chamber. It allows to completely reconstructing the final state of neutrino interactions reconstruction. It also provides particle identifications by combining range and specific ionization measurements and it represents a uniform electromagnetic calorimeter. This setup (LBNO) allows for effectively measuring the oscillation patterns as a function of the energy over the first and second maxima, resulting in a complete experimental assessment of the neutrino oscillations phenomenology with an optimal sensitivity to the mass hierarchy determination, as well as world-level competitive CP search reach.

The LBNO far site installation, the liquid argon detector technology, the beam and the overall experimental program are described in details in the LBNO Expression of Interest. This was submitted in June 2012 to the CERN SPS committee [3] by the LAGUNA groups together with other European groups, gathering in total 51 institutions. This Expression of Interest was welcomed by the CERN SPSC, which carefully scrutinized it in the successive months. The SPSC concluded its review by supporting the LBNO physics case and by encouraging the successive steps in view of a proposal; in particular the construction of a full scale prototype of the liquid argon far detector (which is the target of our document): "*the SPSC supports the double-phase LAr TPC option as a promising technique to instrument very large LAr neutrino detectors in the future. The SPSC therefore encourages the LBNO consortium to proceed with the R&D necessary to validate the technology on a large scale.*" [4]. In parallel, the LBNO proposal was considered by the European Strategy Group (EGS) which acknowledged as well, among its recommended priorities in the document drafted at the end of January 2013, the physics case proposed by the LBNO EoI. The ESG consequently encouraged CERN to develop an experimental program in order to support the role of the European groups in the long-baseline neutrino physics [5] : "*Rapid progress in neutrino oscillation physics, with significant European involvement, has established a strong scientific case for a long-baseline neutrino programme exploring CP violation and the mass hierarchy in the neutrino sector. CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan.*" The physics considerations developed by the ESG which lead to this statement are discussed in details in the ESG Physics Briefbook document of January 2013 [6].

Neutrino oscillations are currently the only experimental evidence of physics beyond the Standard Model. The determination of the mass hierarchy and the search for CP violation are fundamental measurements which could bring to important discoveries. They will necessarily be the object of an intensive world-wide competition. In this respect the European neutrino groups are today in a very strong position:

a) They were the initiators of the liquid argon TPC technology, which is being considered also in the US and Japan neutrino long-baseline programs. They have been carrying on for about 10 years a strong R&D program on many aspects needed to extend this technology to large scale detectors, such as: the long drift, the double phase readout, the tank construction, the purification system, the cold front-end electronics and the DAQ readout
b) They are in a very advanced stage, thanks to the LAGUNA-LBNO program which has sorted out in full executive details and cost estimations the technical issues related to the implementation and operation of the detector underground, the tank construction, the LAr supply and purification system. All these aspects were thoroughly studied with the collaboration of the industrial partners and are among the deliverables which are being finalized by the LAGUNA-LBNO design study.
c) They have finalized the sensitivity studies and proposed in the EoI the LBNO experiment with a LAr detector at Pyhäsalmi and the CN2PY beam from CERN. We are convinced that this configuration is still the one with the best physics reach, with no equivalents in the world, while being at the same time the most affordable and achievable one in terms of costs, time schedule, construction efforts of the beam-line and technical aspects related to the far underground site.

All these reasons strongly motivate us to pursue this research line. We are in particular looking forward to the achievement of the next milestone, which was as well clearly identified by the ESG and the SPSC, namely: the construction and performance assessment of a full scale demonstrator prototype of the far detector. This prototype will rely on all the R&D efforts which have been focused during the last decade and on the related large-scale implementation studies performed in collaboration with the industrial partners of the LAGUNA-LBNO Design Study. The prototype will represent a mandatory milestone for the construction of the final detector. It is worth to stress that, even if the CERN to Pyhäsalmi experiment, which we still consider as the best option, should be abandoned in favor of another one agreed in order to establish a unique world-wide long-baseline neutrino collaboration, the construction and successful operation of the prototype will put the European groups in a very strong and effective position in view of this intercontinental collaboration. This point is indeed well taken in the ESG Physics

BriefBook document. The prototype project is currently seen as a very useful step also by the non-European groups, in order to strengthen and optimize the detector technology for the final experiment, wherever it will be built.

The French groups are involved since the beginning in the LAGUNA program. They are as well involved, since 2006, on the ongoing R&D efforts on the large scale LAr TPC. They contributed to aspects like the cold front-end amplifiers, the data acquisition electronics and the double-phase charge readout detectors. The physics case for LBNO, the liquid argon R&D and the prototype project have been naturally discussed in an extensive way in the framework of the GDR neutrino. The GDR neutrino, together with the IN2P3-IRFU Working Group 4, in the redaction of the IN2P3-IRFU perspective documents **[7]**, recommended LBNO in high priority among the future long-baseline projects. These recommendations on the French roadmap for neutrino physics were submitted in September 2012 to the Open Symposium of the European Strategy Preparatory Group in Krakov **[8].** They have been recently updated by the GDR in a new document, where, on top of recalling the interest for the LBNO experiment, the continuation of the LAr R&D and the participation to the construction of the LAr detector prototype at CERN are as well highly recommended **[9].** Two recent presentations, given at the GDR neutrino meeting held at LPNHE on May 21^{st}-22^{nd}, recall the physics case of LBNO **[10]** and discuss the proposal for the construction of the liquid argon detector prototype **[11]**.

As previously mentioned, the French groups have, since a few years, direct involvements in the R&D efforts on the liquid argon detector technology. The IRFU group in 2010 launched a R&D to test the feasibility of using bulk Micromegas to instrument double phase readout LAr TPC. The group has been working in collaboration with the ETH, Liverpool and IPNL groups. The large number of charge readout channels, needed for the few-10kton LAr detector sizes for LBNO, naturally called during the last years for R&D efforts in view of the development of large-scale readout solutions. These are characterized by high-integration levels, costs reductions and aims to performance improvement. An R&D on the charge readout electronics was started on this subject at IPNL in 2006. The R&D was performed in collaboration with the Swiss groups of Bern and ETHZ. It focused on two main axes:

a) The development of front-end electronics based on CMOS ASIC amplifiers working at cryogenic temperatures
b) The development of a modern, easily scalable to large detector dimensions, DAQ system. This is based on an evolution of the OPERA DAQ system "smart sensors", integrated in the micro-TCA telecommunication technology standard .The local processors of the OPERA smart sensors are now replaced by virtual processors emulated in low cost FPGAs.

The LABEX LIO program recently supported the installation at IPNL of a dedicated liquid argon laboratory with a TPC prototype (200 liters pure liquid argon mass and 600 liters total mass), designed on purpose as test bench for the R&D on the readout electronics and the double- phase detectors. This is in absolute the first installation liquid argon TPC installation in France. It represents an important step for the consolidation of the expertise in this detector technology and it will be exploited for common tests with the IRFU group and the other French groups.

Fig.1: The cryostat of the liquid argon TPC at IPNL, more details are given in [11]

The coverage of large area with PMTs at a "low" cost implies a readout integrated electronic circuit (ASIC) for groups of PMT (matrix of 4x4). The development of such electronics is the aim of a dedicated French R&D program, called PMm2 [12] in which the APC and Annecy groups are involved. This R&D was motivated by the instrumentation of the giant water Cerenkov detectors, studied as well in LAGUNA, but it could be also applied to the readout of the photomultipliers in liquid argon. The circuit under development allows to integrate for each group of PMTs: a high-speed discriminator on the signal photoelectron (ph.e), the digitization of the charge (on 12 bits ADC) to provide numerical signals, the digitization of time (on 12 bits TDC) to provide time information, a channel-to- channel gain adjustment and a common high voltage. All the electronic and acquisition developed in the PMm2 program is going to be fully tested with the MEMPHYNO prototype installed at the APC laboratory.

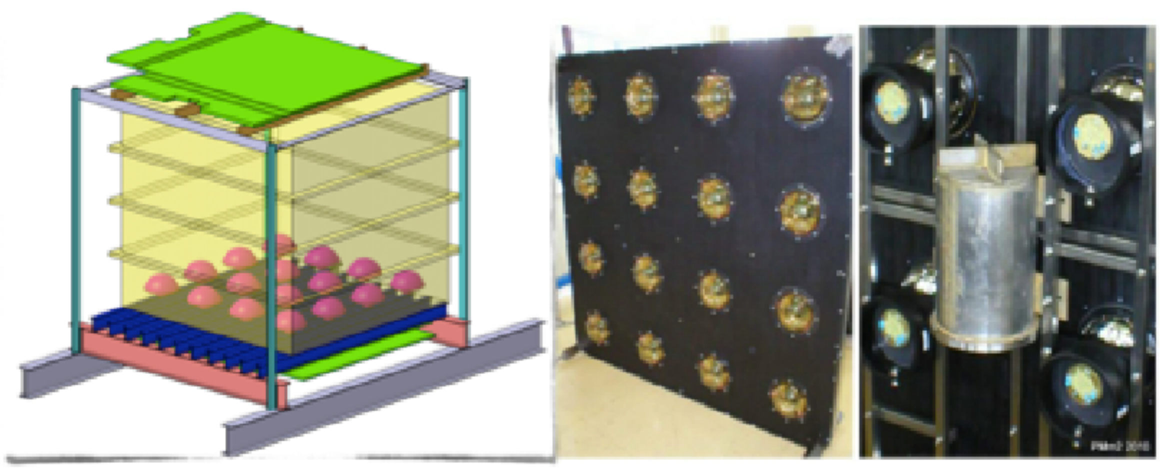

Fig 2. Left: Schematic view of the MEMPHYNO prototype. Middle: photograph of the PMm2 matrix of 16 8" Hamamatsu PMTs. Right: Backside of the matrix showing the watertight box for the electronics.

Since the fall of 2012, given the recommendations of the SPSC and the support provided by CERN management following the recommendations of the ESG, an intensive activity by the CERN technical divisions was started in order to study an extension of the North Area Hall EHN1. This extension will host the LBNO liquid argon detector prototype. It will allow benefiting of the support of the CERN ancillary infrastructures and exposing the prototype to a charged hadrons beam. The beam will be used for the calibration of the hadronic showers reconstruction and the assessment of the detector performance. CERN has recently foreseen in its Medium Term Plan funding support to neutrino physics. These funds can cover the extension and installation works in the North Area Hall EHN1.

In June 2013 the LBNO collaboration is in the process of submitting to the SPSC a detailed proposal for the prototype construction in the CERN North Area. A draft of the proposal can be found in attachment. In our document, we outline the IN2P3 participation to this project. A description of the prototype project is also provided in these slides **[11].**

The costs of the prototype construction will amount to 4 MCHF including contingency. The prototype should be eventually ready for data taking in the spring 2016. The collaboration which proposes this project has 3 main national components from UK, France and Switzerland together with other European groups which signed the LBNO EoI. The French groups, IRFU (M.Zito), IN2P3: APC (T.Patzak), IPNL (D.Autiero), LAPP (D.Duchesneau), LPNHE (J.Dumarchez), plan to provide a substantial contribution to the project, intervening on several aspects of the prototype: the double phase charge readout detectors, the cold front-end electronics and DAQ readout, the photomultipliers digitization system, the high voltage system, the field cage and the system for the alignment of the charge-readout plane. More details will be provided in the following.

The detector that we propose to build in the CERN North Area will represent a full scale proof prototype of all the technologies needed for the 20 kton far detector foreseen in Finland. It will be completely based on the LNG tank industry technology investigated in LAGUNA. This technology foresees a stainless steel cryogenic liner made with a corrugate membrane with around a thermal insulation of 1.2 m of GRPF polyurethane foam layers, interspersed by pressure distributing layers of plywood. The liquid argon active volume contained in the detector will amount to 6x6x6 cubic meters for a mass of about 300 ton. The inner dimensions of the tank will be 8.3x8.3x8.3 cubic meters, corresponding to a total liquid argon mass of 700 ton. One free meter of liquid argon, in between the active detector region and any wall of the tank, will allow keeping a very large safety factor with respect to the risk of discharges from the high voltage system needed for the generation of the long drift electric field.

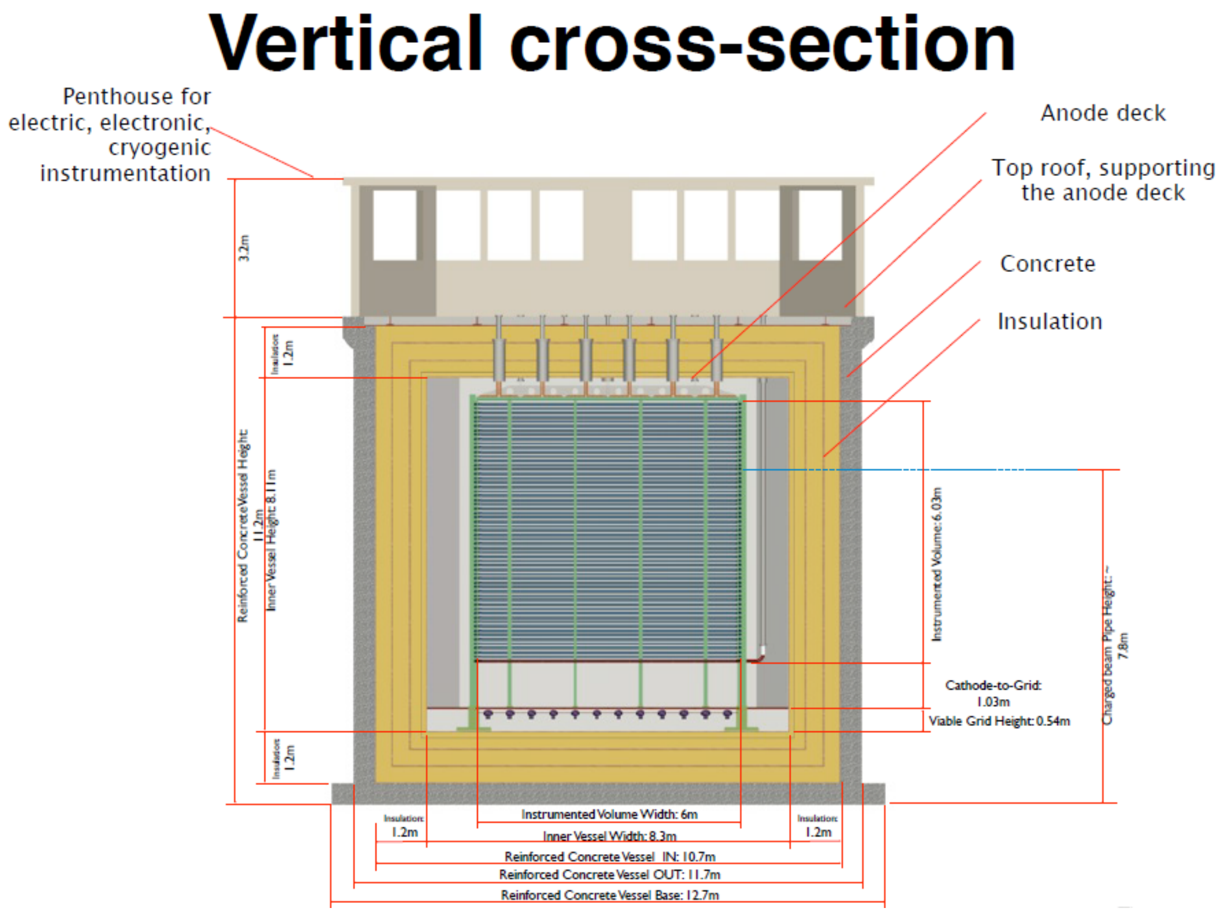

Fig.3: Cross section of the LBNO prototype proposed for the CERN North Area

Electrons from charged tracks ionization, drifting in the liquid phase up to 6 m length towards the anode, will be then extracted to the gas phase by a local electric field at the boundary in between the two phases. The charges will be then amplified, with a gain of about 20 obtained in pure Ar vapors, in absence of any quenching component, by micro-pattern detector such as Large Electron Multipliers (LEM) or Micromegas. The charges, after amplification, are finally collected in two views on a PCB anode. The basic units of the charge-readout plane will consist in 144 modules of 0.5x0.5 square meters. Correspondingly, there will be the same number of photomultipliers (144) installed at the bottom of the tank below the cathode plane. The 0.5x0.5 square meters charge readout units will be connected in series in order to assemble 3 m long strips in each view, with a pitch of 3 mm. The total number of charge readout channels will be 7680. These channels will be cabled in groups of 64 up to feedthroughs located at the bottom chimneys crossing the insulation layers at the top of the detector. The chimneys will host at their bottom the front-end cold electronics based on CMOS ASIC chips, which will be at a temperature of 110K. This solution provides the best noise performance, while still preserving the accessibility of the electronics from outside without needing to open the pure liquid argon volume of the cryostat.

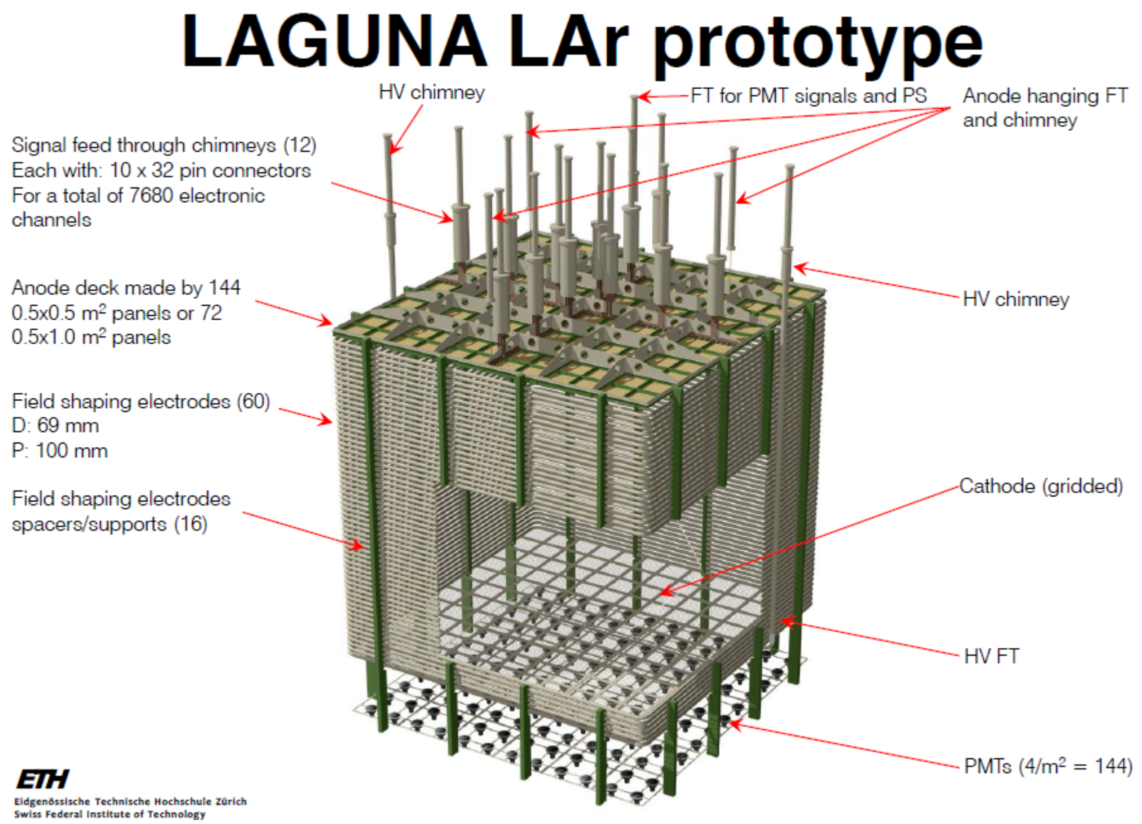

Fig.4: Details of the instrumentation of the active LAr region

The ASIC amplifiers allow for high integration level at low production costs. The DAQ system will also have the 640 channels modularity corresponding to the chimneys segmentation. It will be based on a network backbone implemented in the micro-TCA standard used in modern telecommunication systems. The local DAQ processors will be virtually emulated in the FPGAs of the micro-TCA cards. All these solutions are aimed to large scale implementation and costs savings. It is worth stressing that the technology envisaged for LBNO is much cheaper with respect to the traditional liquid argon TPC technology as used in ICARUS. This applies to the construction of the detector and its tank as well as to the cost of the electronics normalized per readout channel. This one will be less than one third than in ICARUS. On top of that, while keeping the same granularity as the ICARUS T600, the LBNO prototype has only 7680 channels instead of 27000 for 300 ton of target mass. This difference, which also helps in reducing the costs, is due to the long drift and the 2D anode collection readout scheme. The detector will be exposed to a charged hadron beam of momenta in the range 1-20 GeV channeled with a beam pipe down to the liquid argon volume. The size of the prototype is well suited for a full containment of hadronic showers.

The LBNO prototype will allow assessing with a full scale proof detector all the technical issues which have been the object of the R&D efforts and of the collaboration with the industrial partners during the last decade:

a) The LNG tank construction technique

b) The LAr supply, purification and recirculation systems.
c) The long drift up to 6 m. Purity better than 0.1 ppb in terms of oxygen contamination is required to achieve the electron lifetimes needed for such a long drift. The drift occurs in an electric field going from 0.5 to 1 kV/cm. with velocities of 1.6-2 mm/s
d) The High Voltage system operating in two different stages from 300 KV up to 600 KV
e) The double-phase readout implemented on very large detection surfaces
f) The cold electronics and the large scale DAQ readout electronics

The exposure of the prototype to a charged hadron beam will allow assessing and keeping under control the detector performance. We will study in details the response to hadronic showers, which is the most demanding task in the reconstruction of neutrino interactions. The experimental program includes:

a) Measurements in hadronic and electromagnetic calorimetry and particle identification performance
b) Full-scale software development, validation and improvement of the events reconstruction and simulation

The time scale for the construction of the prototype foresees that the extension of the EHN1 hall should be completed by the spring 2014. The tank construction will take one year from the spring 2014 to the spring 2015. The construction of the detector will last till the spring 2016 when the data-taking will start.

Some preliminary details of the contributions foreseen by the French groups for the detector constructions are given in the table below. Costs are mentioned just for the four IN2P3 groups. They include the hardware costs needed for the completion of each one of the mentioned detector items. We made also a preliminary evaluation of the missions and functioning budgets of the groups are. They will be detailed in the presentation given to the IN2P3 CS on June 27th. The time profile of these construction contributions spans over 3 years.

Group	Contribution	Hardware cost
APC	Photomultipliers digitization system	48 keur
IPNL	Cryogenic ASICs and DAQ system	265 keur
IRFU	Charge readout detectors	
LAPP	Photomultipliers digitization system Field cage construction and readout plane alignment system under discussion	12 keur
LPNHE	High voltage system and feedthroughs	150 keur
Total		475 keur / 3250 keur (total detector cost)

Table 1: Contributions to the prototype hardware costs by the French groups

The LAPP group foresees to contribute to the PMTs signal digitization, additional contributions to the field cage mechanics and the alignment system of the charge readout plane are under evaluation. A detailed spending profile of the 4 groups including the hardware contributions, missions and functioning is presented in the table below.

Year	APC				IPNL				LAPP				LPNHE				Total	Year
	FTE	Detector	Missions	Function.	FTE	Detector	Missions	Function.	FTE	Detector	Missions	Function.	FTE	Detector	Missions	Function.		
2014	3,8	15	10	10	6,7	40	20	10	0,8	2	4	0,5	2,5	30	10	5	156,5	2014
2015	3,9	25	15	10	6,7	200	30	10	0,8	8	4	0,5	2,5	100	10	5	417,5	2015
2016	4,9	8	15	10	6,7	25	25	10	0,8	2	4	0,5	2,5	20	10	5	134,5	2016
2017	4	0	10	5	6,7	0	25	10	0,8	0	4	0,5	2,5	0	10	5	69,5	2017
	16,6	48	50	35	26,8	265	100	40	3,2	12	16	2	10	150	40	20	778	Grand total (hardware+Miss.+Fu
																	475	Hardware total
			85	5,120482			140	5,223881			18	5,625			60	6		
			Mis+Fun	Mis+Fun/FTE			Mis+Fun	Mis+Fun/FTE			Mis+Fun	Mis+Fun/FTE			Mis+Fun	Mis+Fun/FTE		

Table 2: Spending profile of the hardware contributions, missions and functioning budgets

On top of the construction contributions, the French groups are willing to engage in a coherent effort on the assessment of the LAr detector technology. They will jointly contribute to the understanding of the related technological issues and their effect on the performance. The will work on the data analysis of the large samples of hadronic interactions and on the optimization of the reconstruction and the comparison of the data with the simulations. This project will provide a unique opportunity for strengthening the expertise on this detector technique and prepare for the long-baseline experiment.

Additional documents:

[1] Observation of electron-antineutrino disappearance at Daya Bay 7 March 2012 (e-link)

[2] LAGUNA: Large Apparatus studying Grand Unification and Neutrino Astrophysics (e-link)

[3] Expression of Interest for a very long baseline neutrino oscillation experiment (LBNO), June 28 2012, CERN-SPSC-2012-021; SPSC-EOI-007 (e-link); slides presented at the 106th meeting of the SPSC (e-link)

[4] Minutes of the 106th Meeting of the SPSC 26-27 June 2012 (e-link); Minutes of the 107th Meeting of the SPSC 23-24 October 2012 (e-link); Minutes of the 108th Meeting of the SPSC 15-16 January 2013 (e-link)

[5] European Strategy group "Proposed Update of the European Strategy for Particle Physics" Erice 25 January 2013 (e-link)

[6] European Strategy group "Physics Briefbook" CERN-ESG-005 13 January 2013 (e-link)

[7] Groupe de travaille de prospective IN2P3-IRFU : « Neutrino : masses , oscillations. Désintégration du proton » 16/2/2013 (e-link). Synthése du Groupe de travaille 17/2/2013 (e-link).

[8] Open Symposium - European Strategy Preparatory Group 10-12 September 2012, **"**Neutrinos: masses, oscillations; proton decay. A roadmap proposal by the French physicists"**.** (e-link)

[9] Update of the proposed French roadmap for Neutrino Physics, May 26th 2013. (e-link)

[10] GDR Neutrino Paris 2013, T. Patzak "LBNO strategy and LAGUNA" (e-link)

[11] GDR Neutrino Paris 2013, D. Autiero "LAr Prototyping at CERN" (e-link)

[12] B. Genolini, P. Barrillon, S. Blin et al., "PMm∗∗2: large photo- multipliers and innovative electronics for the next-generation neutrino experiments," *Nuclear Instruments and Methods in Physics A,* vol. 610, pp. 249–252, 2009. J. E. Campagne, S. Conforti Di Lorenzo, S. Drouet et al., "PMm∗∗2: R&D on trigger less acquisition for the next generation neutrino experiments," *JINST,* vol. 6, 2011.