Large Water Cerenkov detectors

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Abstract

A brief Status Report on the present projects of Water Cerenkov Megaton scale detectors in the world.

Contribution to the International Scoping Studies on future Neutrino Factories and Super Beam Facilities

1 Introduction

Since the pioneering age of Kamiokande and IMB detectors, and after the success of the Super-Kamiokande detector (extension by a factor 20 with respect to the previous detectors), the physicist community involved in this area is continuously growing in the three geographical regions namely Japan, USA and Europe.

To strengthen the know how and R&D exchanges, a series of International Workshops have been set up since 1999, the so-called NNN Workshop standing for "Next Nucleon Decay and Neutrino Detectors". The last meeting was organized at Aussois (France) in 2005, and for the two next years, the workshop will held at Seattle (USA 06) and at Hamamatsu (Japan 07). As, it is clearly stated in the title of this Workshop, detection techniques other than Water Cerenkov are also considered as for instance Liquid Scintillator, Liquid Argon as well as Iron detectors.

Also, if the pioneer Water Cerenkov detectors were built to look for Nucleon Decay, a prediction of Grand Unified Theories, the Neutrino physics has been the bread and butter since the beginning. Just to remind the glorious past: first detection of a Super Novae neutrino burst, Solar and Atmospheric anomalies discovery that was explained as mass & mixing of the neutrinos, the latter being confirmed by the first long base line neutrino beam.

Nucleon decay and neutrino physics are so closely theoretically linked (ie. most if not all of the GUT theories predict nucleon to decay and neutrinos to have non zero masses & mixings) that are for sure area of equally strong interest to motivate the R&D program extension of the next generation Water Cerenkov mass to megaton scale (about a factor 20 more than SuperKamiokande). So, one should keep in mind that the ISS[1] framework tends to reduce the physics potential of such detector: nucleon decay, supernovae neutrinos from burst and from relic explosion, solar & atmospheric neutrinos, long base line low energy neutrinos (beta beam, super beam and combined with atmospheric neutrinos) and other astrophysical aspects.

The scalability and robustness of Water Cerenkov detector are well established and the R&D efforts are concentrated in two engineering aspects: the excavation of large cavities, and the cost reduction of the photodetectors. The addition of Gadolinium salt once it will be safely used in 1kT prototype and after in SuperKamiokande, then it could be a decisive ingredient for the new detectors, especially for neutrinos from Supernovae.

2 The present detector design

Up to now the three geographical regions comes with three detector design with a fiducial mass around 500kt. Some characteristics are presented in table 1.

[1]International Scoping Study of a future Neutrino Factory and Super Beam facility (http://www.hep.ph.ic.ac.uk/iss/)

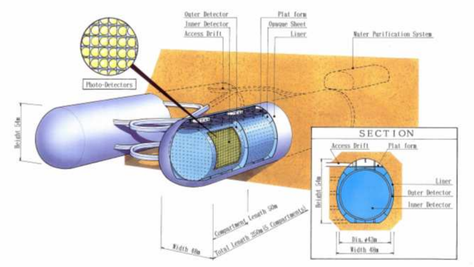

Figure 1: Sketch of the Hyper-K detector (Japan).

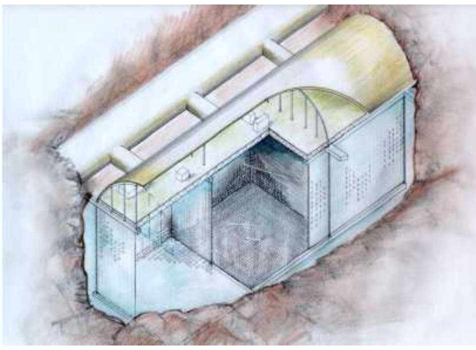

Figure 2: Sketch of the UNO detector (USA).

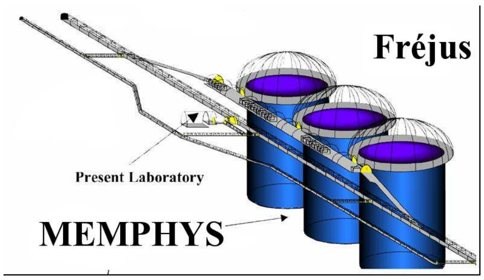

Figure 3: Sketch of the MEMPHYS detector under the Fréjus mountain (Europe).

The Japanese design (Fig.1) [1], HyperK, is based on two twin tunnels with 5 optically independent cylindrical compartments, each 43 m in diameter and 50 m long each covered by about 20,000 photodetectors to realize a 40% surface coverage. An alternate project under study but not discussed hereafter, would be to install half of Hyper-K in Japan and half in South Korea [2]. The US design (Fig.2) [3], UNO, is composed by 3 cubic optically independent compartments ($60 \times 60 \times 60$ m^3). The inner detector regions are viewed by about 57,000 20" PMTs, with a photocathode coverage of 40% for the central compartment and 10% for the two side compartments. A outer detector serves as a veto shield of 2.5 m depth and is instrumented with about 15,000 outward-facing 8" PMTs. The European design (Fig.3) [4], MEMPHYS, is based on up to 5 shafts (3 are enough for 500kt fiducial mass), each 65 m in diameter and 65 m height for the total water container dimensions. The PMT surface defined as 2 m inside the water container is covered by about 81,000 12" PMTs to reach a 30% surface coverage equivalent to a 40% coverage with 20" PMTs (see sec. 4). The fiducial volume is defined by an additional conservative guard of 2 m. The outer volume between the PMT surface and the water vessel is instrumented with 8" PMTs.

3 Underground large cavities

All the detector projects are located in underground laboratories. The water equivalent depth of the different detectors sites are: ≈ 1500 m.w.e for the Tochibora mine in Japan, and around 4200 m.w.e for the Homestake or Henderson mines (the two remaining sites after NSF decision for DUSEL possible site candidates) in the USA, and ≈ 4800 m.w.e for the Fréjus road tunnel in Europe. A deeper site, so fewer cosmic ray induced background, is especially important in the case of relic supernovae and solar neutrinos, but in case of nucleon decay the detector segmentation may help also.

The main difficulty is the non existence of yet man made large cavities (see Tab. 1) at depth envisaged. But on an other hand, there are no a priori indications that one could not built such large cavities and engineering studies are undertaken in the three geographical regions. In Japan, a preliminary survey of the candidate place for Hyper-K is already done, and the rock properties at the Tochibora mine have been checked. The cavity model has been analyzed in the real environment. The egg transversal shape and the twin tunnels scenario is envisaged as baseline for Hyper-K. In the US, various engineering models have been used by different consultants. It turns out that with the present knowledge UNO cavity seems feasible, although a more refined work with experimental inputs from rock quality measurements and geological faults knowledge in situ is needed to go further in the project design. In Europe, a pre-study have been performed too by the Italian and French companies involved in the building of the existing road tunnel. These companies have taken advantage of the numerous measurements made during the excavation of the present road tunnel and (relatively small) LSM Laboratory to establish a valid estimation of the rock quality as input for simulations. The main outcome of this pre-study is that very large cavities with a "shaft" shape is feasible, while a "tunnel" shape looks disfavored. The next step that can be undertaken in an European Founding framework, is to validate the rock quality at the exact detector location and to finalize the cavities detailed shape and access tunnels in close conjunction with the detector design optimization.

Beyond the cavity shape and excavation scenario optimization, there is the need of an extensive R&D on water container (vessels versus multi-liners). This is an important aspect for radioactivity background suppression and also in detector mechanical design with its associate impacts on detector cost.

4 Photodetector R&D

The surface coverage by photodetector is not yet optimized as more feedback are needed from SuperKamiokande I-II and III phases analysis and from MC studies of the foreseen detectors. Nevertheless, one may already state that the very low energy neutrino events (Super Novae neutrinos, ^{8}B Solar Neutrinos) as well as the search of π^0 in Nucleon Decay or the π^0/e separation in ν_e appearance experiment are all demanding on good coverage.

In all the detector design there are at least one order of magnitude more photodetectors than SuperKamiokande I (or III). The R&D is largely shared among the three regions and in very close contact with the two manufacturers, namely Hamamatsu in Japan and Photonis in Europe and USA (since July 05, Photonis had inquired DEP and Burle companies).

The research axis on large HPDs in Japan has been mainly driven by the need to get a lower price for a new photodetector than the presently available Hamamatsu 20" PMTs, especially to get ride of the dynode amplifier system which is introduced manually in such a tube. Their measured characteristics are encouraging: single photo-electron sensitivity, wide dynamic range limited only by the readout, good timing and good uniformity over the large photo-cathod. But these HPD needs to be operated at 20kV High Voltage and a low noise fast electronics. So, the cost per channel is a real challenge.

In Europe, Photonis is very competitive on 12" PMTs and argue that the main parameter to optimize is the $cost/(cm^2 \times QE \times CE)$ electronic included. Some French laboratories are involved with Photonis in a joined R&D concerning the 12" characteristics measurements and improvements and also concerning the integrated electronic Front-end. The main idea is to adopt smart-photodetectors which provide directly digitized data. The front-end requirements are: a High speed discriminator for autotrigger on single photo-electron, a coincidence logic to reduce dark current counting rate (to be defined by MC studies), a digitization of charge over 12 bits with a dynamical range up to 200p.e, a digitization of time of arrival over 12 bits to provide nano-second accuracy, a variable gain to equalize photomultiplier response and operate with a common high voltage (cost reduction). This electronic R&D takes advantage from the past years R&D and concrete realizations for OPERA, LHCb, WSi calorimeter for ILC...

References

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Parameters	**UNO** (USA)	**HyperK** (Japan)	**MEMPHYS** (Europe)
Underground laboratory			
location	Henderson / Homestake	Tochibora	Fréjus
depth (m.e.w$\pm$5%)	4500/4800	1500	4800
Long Base Line (km)	$1480 \div 2760$ / $1280 \div 2530$	290	130
	FermiLab$\div$BNL	JAERI	CERN
Detector dimensions			
type	3 cubic compartments	2 twin tunnels 5 compartments	$3 \div 5$ shafts
dimensions	$3 \times (60 \times 60 \times 60)\mathrm{m}^3$	$2 \times 5 \times (\phi = 43\mathrm{m} \times L = 50\mathrm{m})$	$(3 \div 5) \times (\phi = 65\mathrm{m} \times H = 65\mathrm{m})$
fiducial mass (kt)	440	550	$440 \div 730$
Photodetectors†			
type	20" PMT	20" H(A)PD	12" PMT
number	38,000 (central) & 2×9500 (sides)	20,000 per compartment	81,000 per shaft
surface coverage	40% (central) & 10% (sides)	40%	30%
Cost & Schedule			
estimated cost	500M$	500 Oku Yen?*	161M€ per shaft (50% cavity) + 100M€-infrastructure
tentative schedule	~ 10 yrs construction	~ 10 yrs construction	$t_0^{**} + 8$ yrs cavities digging $t_0 + 9$ yrs PMTs production $t_0 + 10$ yrs detectors installation Start of Non Accelerator Prog. as soon as a shaft is commissioned

Table 1: Some basic parameters of the three Water Cerenkov detector baseline designs. †: Only inner detector photodetectors are mentioned in this table. *:Target cost, no realistic estimate yet.**: The t_0 date envisaged is 2010.