ICARUS: A SECOND GENERATION PROTON DECAY AND NEUTRINO DETECTOR AT THE LNGS

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ABSTRACT

The ICARUS physics programme is unique in that it addresses several of the most fundamental issues of modern high-energy physics: proton decay, atmospheric neutrino, long baseline neutrino (with a neutrino beam from CERN) and solar neutrino studies. These will involve the construction and operation of a very large argon TPC (several thousand tons) in the underground Gran Sasso Laboratory. We have developed the detector technique to the point that we now feel ready to start the construction.

We report on the mechanical and cryogenic aspects of the dewar, the argon purification techniques and results, the characteristics of the multiplane internal detector, the analog front-end and the digital readout electronics.

A recent important development concerns the possibility of doping the liquid argon with TMG to reach a better energy resolution.

Presented by F. Mauri

1. Introduction

The aim of the ICARUS project[1] is to build a multi-kton liquid argon TPC to be put in the Gran Sasso underground laboratory (LNGS) to perform a rich physics programme. The detector is homogeneous, fully sensitive with no dead time and provides high quality images of ionizing particles (like an electronic bubble chamber) as well as good energy and dE/dx measurements.

The priorities of the ICARUS programme are the following two fundamental issues:

(a) The stability of the nucleon, which is the only way to access phenomena at the energy scale of Grand Unification. From LEP measurements we know that the electromagnetic, weak and strong running coupling constants do not cross in a single point, unless we invoke some intermediate symmetry breaking scale[2]. If minimal SUSY provides such a breaking, then the favourite proton decay channel will be $p \rightarrow \nu + K^+$. Thanks to its large sensitive mass and to its spatial and energy resolution capabilities, ICARUS is an ideal device for nucleon decay detection, in particular for those channels which are not accessible to Cherenkov detectors, like $p \rightarrow \nu + K^+$. In a five year running time we can reach a limit of 10^{33} years for most of the decay channels.

(b) The nature of neutrinos, in particular the question of the neutrino mass. This is being investigated in ICARUS both through the study of atmospheric neutrinos and through long baseline studies with a CERN neutrino beam (three orders of magnitude improvement in the length of baseline with respect to the present accelerator experiments).

Even though ICARUS is not optimized to study solar neutrinos, the issue remains extremely interesting and therefore solar neutrinos are also an important part of our programme.

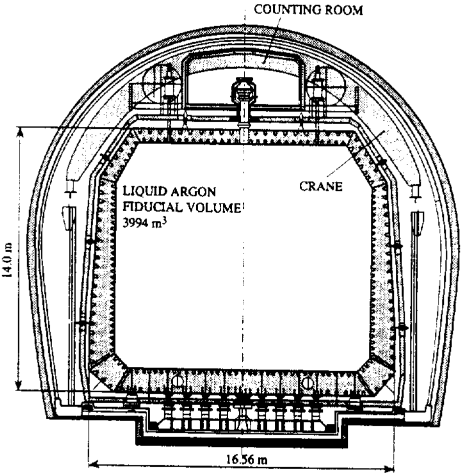

Fig. 1: Frontal view of the ICARUS detector dewar.

Finally astrophysical and cosmological neutrinos from supernova or any unexpected event which might occur during the lifetime (≈10 years) of the experiment will merit all our attention.

2. Detector dewar

In planning the feasibility study of the ICARUS cryostat, we have paid special attention to the choice of the dewar geometry in order to maximize the useful liquid argon volume. A parallelepiped efficiently matches the geometry of the readout chambers and fits the LNGS Hall C geometry and the facility structures. The frontal view of the detector dewar is shown in fig. 1 and the main design parameters are summarized in Tab. 1.

External dimensions	29.18 x 18.5 x 15.22 m^3
Internal dimensions	26.45 x 13.8 x 11.8 m^3
Outer vessel weight	≈ 530 ton
Inner vessel weight	≈ 1100 ton
Internal volume	4205 m^3
Volume occupied by LAr	3995 m^3
Total LAr mass	5591 ton
Active volume	3500 m^3
Active LAr mass	4800 ton
Project pressure	1.5 bar abs
Hydrostatic pressure	1.6 bar
Working temperature	90.5 K
Maximum drift length	2.1 m
Maximum drift time	1.4 ms
Drifting electric field	500 V/cm
Maximum high voltage	105 kV

Tab 1: ICARUS main design parameters.

The cryostat is composed of two vessels, the inner and the outer one, structurally independent and connected by support devices and spacers. The volume occupied by liquid argon (LAr) is about 4000 m^3, while the active LAr mass, i.e. the mass seen by the readout chambers, is about 4800 ton.

3. Argon purification

The free electrons produced by ionization in liquid argon must be able to drift over distances of the order of metres (2.1 m of maximum drift length), without substantial capture by electronegative impurities. This implies that the contamination of electronegative impurities must be kept below 0.1 ppb.

One of the first results obtained by the ICARUS R&D programme[3] was that of being able to successfully obtain liquid argon at this level of purity using simple and reliable purifiers.

Our goal is to fill the 5 kton detector in about 3 months, corresponding to about 50 ton of ultrapure liquid argon per day; this can be obtained using the liquid phase purification system[4] made of several small units, similar to those used in our R&D tests, running in parallel. The ultrapure liquid argon in the dewar, even in absence of any leak, can be contaminated by outgassing of the walls and of the various materials in contact with the gaseous argon at the top of the dewar. To keep the liquid argon at the necessary purity, we have designed and successfully tested at CERN for our 3 ton prototype a vapour recirculation/purification system, that can be scaled up to the 5 kton detector.

4. Readout chambers and electronics

The performance of the multiplane wire chambers readout have been well tested in our 3 ton prototype[5] at CERN. Nevertheless their use presents some weak points due mainly to the mechanical structure. Our present design for the 5 kton detector foresees the use of large-size 3D image chambers, based on the multi-layer printed-board circuit technology, which present an intrinsically simpler and safer structure and with performance comparable to that of the wire technique[6].

In total there are 3 double readout chambers with 5 mm electrode pitch and a number of readout channels of the order of 56,000 (30,000 in collection mode and 26,000 in induction mode).

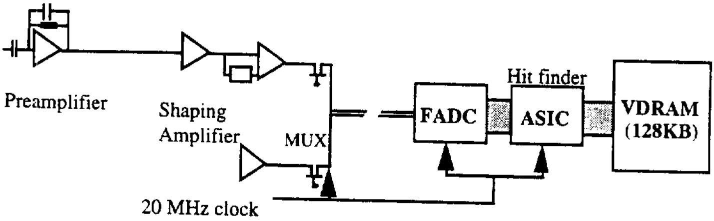

Fig. 2: Front-end block diagram.

The electronic design has to face the following criteria:

- a signal-to-noise ratio of 10 is necessary for dE/dx measurements (collection plane), while a $S/N \geq 6$ is enough for tracking (induction plane);

- to distinguish a minimum-ionizing particle, while ensuring no overflow when a shower is detected, 10-bit FADCs are needed;
- given a drift velocity of 1.5 mm/µs, corresponding to a maximum drift time of 1.4 ms, a sampling time of 400 ns is required to efficiently reproduce the signal shape.

The block diagram of one front-end electronic channel is shown in fig. 2.

5. The liquid argon doping test

In pure liquid argon, only a small part of the deposited energy results in free electrons, especially at high dE/dx and low electric fields. Part of the deposited energy ends up in the form of scintillation light, coming from direct excitation of the Ar discrete levels or due to the electron-ion recombination, and so is lost in our measurement. This effect implies a non-linear response of charge collection with respect to the dE/dx.

Recently we successfully tried to convert the scintillation light to free electrons by doping the liquid argon with photosensitive molecules. We have chosen TMG (Tetramethylgermanium) as dopant because of its high photo-absorption cross-section and its good solubility in liquid argon.

The main results of the test are[7]:

- we observe no degradation of the electron lifetime:
- the spatial resolution remains unchanged, provided that the dopant concentration exceeds 3.5 ppm. At lower concentrations, the electrons emitted by TMG molecules are sensibly far from the original track, which implies a worse spatial resolution;
- there is a considerable linearization of the charge yield for heavy ionizing particles, as measured by muons and protons near their stopping points (fig. 3);

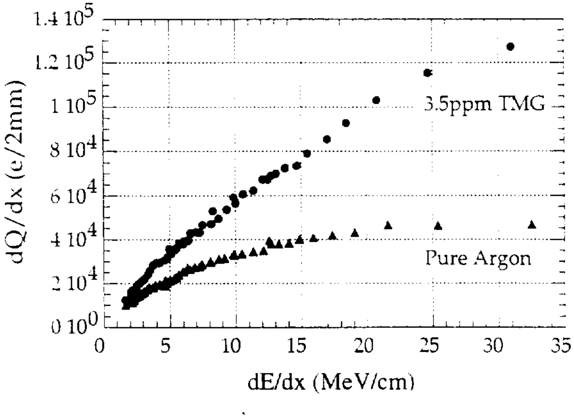

Fig. 3: Charge yield vs. energy density in pure LAr and with a TMG concentration of 3.5 ppm (electric field of 350 V/cm).

- there is a noticeable increase (≈30%) of the free charge also for minimum ionizing particles (fig. 4).

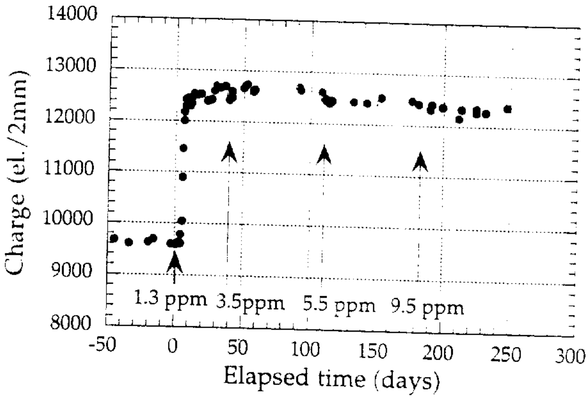

Fig. 4: Collected charge in different doping concentrations for m.i.p. (electric field of 350 V/cm).

6. Conclusion

A scientific and technical proposal has been completed in May 1994: the LNGS scientific committee has approved the lines of research and has recommended the continuation of the engineering designs.

The future programme foresees:

- the detailed engineering of the 5 kton detector;
- the realization of an intermediate mass prototype to optimize the main parameters of the final detector.

7. References

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