# ICARUS. STATUS AND PROGRESS

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## ABSTRACT

We briefly report on the present status of the ICARUS R&D program. Results from the continuous running of a 3 ton LAr TPC by more than 18 months demonstrate that the ICARUS technique is reliable giving bubble chamber quality images of ionising particles. The analysis of the data taken in this period on atmospheric muons enabled us to determine various detector parameters (electrons lifetime in LAr, electrons diffusion parameter, spatial resolution, charge recombination). During the last months of the past year we successfully tested the possibility to purify the Argon directly in liquid phase. The high purification speed allowed by this method is an important tool to extend the ICARUS technique to very large mass detectors.

## 1. INTRODUCTION

A liquid argon time projection chamber (LAr-TPC) working as an electronic bubble-chamber, continually sensitive, self-triggering, able to provide 3-D imaging of any ionising event together with a good calorimetric response was first proposed by C. Rubbia in 1977 [1]. In order to verify the feasibility of such a detector, the ICARUS collaboration started in 1985 an intensive R&D program aiming to solve the main technological problems:

1) the liquid argon purity that has to be kept at the level of 0.1 ppb of electronegative molecules to allow the ionisation electrons for long drift distances;
2) the extreme cleanliness of the material employed in the construction of the detector and the complete reliability of the feed-throughs between pure argon and out-side world to avoid contamination due to degassing or leaks;
3) the realisation of wire chambers able to perform a non destructive read-out (in order to get a 3-D image of the event) made of several wire planes with few mm pitch; this requires high precision very reliable mechanics and good knowledge of the electric field in the detector;
4) the development of low noise preamplifiers to get a good signal to noise ratio.

The satisfactory results obtained on small scale tests [2, 3, 4] allowed us to start in 1989 the construction of a 3 ton prototype [5] which is presently working at CERN under stable conditions without interruptions since May 1991.

The step from small to large volumes has been made possible by:

a) the argon purification performed in gas phase with industrial methods with special care for the cleaning of the materials that come in contact with the purified argon [4];
b) the use of a recirculation system that purifies continually the gas due to the heat leakage of the dewar and liquefies it back into the detector. This inhibits the diffusion inside the liquid of electronegative impurities produced by degassing of materials in the high temperature region of the detector;
c) the use of signal feed-throughs made on vetronite support with the technique of the printed circuit board and welding each pin on it.

## 2. GENERAL FEATURES

The 3 ton detector configuration is well described in our proposal [5]. Here we want to remind the following aspects.

a) The LAr is contained in a stainless steel cryogenic vessel. The detector set is suspended from the top flange together with all the service elements (heat

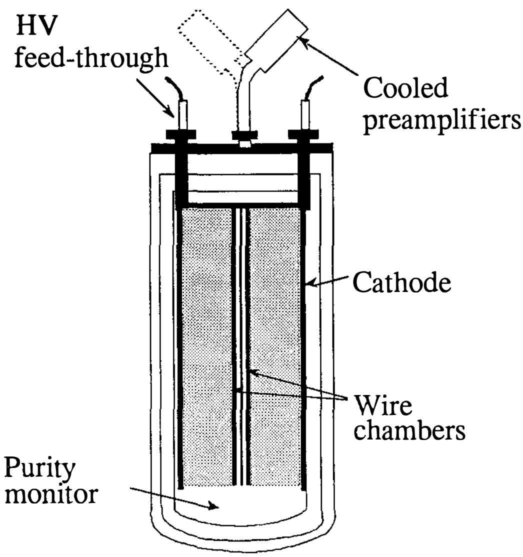



Fig. 1

exchanger, purity monitor, level and pressure indicators). The active volume, defined by the wire chamber and the field shaping electrodes, is split into two independent semi-cylindrical sections (fig. 1).

b) Each section is faced by a wire chamber that covers a surface of 2.4•0.9 $m^2$ and consists of three parallel grids. Drifting electrons go successively through the following wire planes:
   1. a plane with the function of screen transparent to the electrons;
   2. a sense wire plane where the electrons give an induction signal (again completely transparent);
   3. a plane with the wires perpendicular to the previous ones where the charge is collected.

   The pitch of each sense wire is 2 mm. The separation between planes is also 2 mm. The maximum drift path is 42 cm. The chambers are constituted of 3600 vertical wires (stainless steel, 100 μm diameter) 2.4 m long and 4800 horizontal wires 0.9 m long. The signal cables are kapton flat cables 3.5 m long inside the detector with low capacitance (40 pF/m). The 2100 signal feed-throughs are grouped in 8 flanges located on top of the dewar. Low noise pre-amplifiers are placed inside cooled boxes mounted directly on top of the signal feed-throughs flanges.

c) A purity monitor constituted by a double gridded ionisation chamber with a drift length of 6 cm is located at the bottom of the dewar separated from the active volume by a metal plate (fig. 1). The electron lifetime in LAr inside the detector is continually monitored by measuring the attenuation of an electron cloud produced by a laser UV pulse impinging on the photo-cathode [4].

3. DETECTOR RESPONSE

A large amount of data have been collected with the 3 ton prototype using atmospheric muons. An event that illustrates very well the peculiar characteristics of the detector is shown in fig. 2: a cosmic muon stopping with electron decay. The event is seen by the detector in two orthogonal views: the induction plane (non-destructive read-out) and the collection plane (destructive read-out) with the sense wire direction at 90° in one plane with respect to the other and with the drift time (third orthogonal coordinate) in common to both of them; the last feature together with the charge deposited along the tracks allows a 3-D reconstruction. The electric field in the drift volume is 350 V/cm corresponding to an electron drift velocity of 1.24 mm/μs. The sampling time is 200 ns. The charge deposited over one wire is about 10000 electrons for minimum ionising particles. The signal to noise ratio is ≈6 for the induction wires and ≈10 for the collection ones. This event proves, with the many others we are collecting, that the LAr-TPC works as an electromagnetic calorimeter with high granularity (2•2•2 $mm^3$ cell) and low electronic noise (equivalent to 25 KeV). In fact the measure of dE/dx along the muon track allows the determination of the total energy deposited, the incoming direction (by the increase of ionisation near the stopping point), the particle identification (by dE/dx vs range near the stopping point), the exact point of the decay

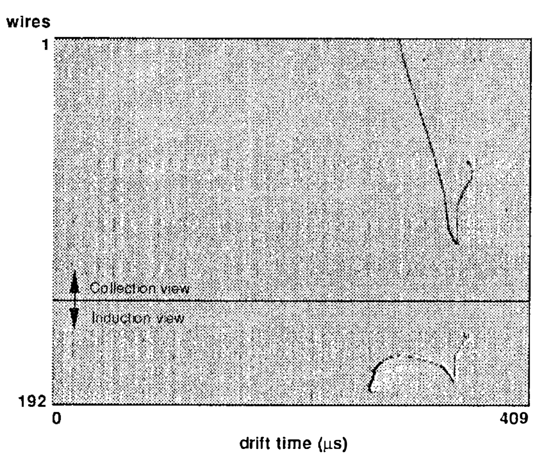
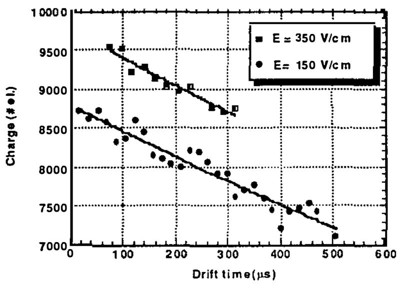



Fig. 2

Furthermore the energy of the electron from muon decay track is also measurable both by energy loss and range: in particular, for the event in fig. 2, the measured electron energy is 18 MeV.

From the analysis of through-going cosmic muons it has been possible to extract several parameters characterising the detector: electron lifetime, electron recombination, electron diffusion,




| E.F. (V/cm) | Lifetime (μs) | Free charge (# el.) |
|---|---|---|
| 350 | 2584 | 9775 |
| 150 | 2540 | 8800 |

Fig. 3

energy resolution, space resolutions.

The electron lifetime value given by the purity monitor has been checked by means of cosmic ray muons crossing vertically the drift volume. The trigger was constituted three scintillators placed two on top and one on the bottom of the dewar in coincidence with the signal on the wires planes. The events have been selected requiring that there was no evidence of large multiple scattering and delta rays ensuring thus that they were minimum ionising particles. The distribution of the charge deposited along the tracks is measured for each drift time slice with a binning of 17 μs, the most probable value is extracted and plotted as a function of the drift time; an exponential fit to this plot gives directly the free electron yield and the electron lifetime (fig. 3). This measure has been repeatedly performed giving a stable value of lifetime of about 2.5 ms, in agreement with the data from the purity monitor.

The dependence of the electron-ion recombination on the ionisation density have been obtained analysing data from muons stopping inside the detector. The charge yield as a function of the dE/dx is well described by the formula (Birk's law) dQ/dx = A dE/dx/(1+K dE/dx) with A = 35 el/keV and K = 0.13 cm/MeV for a

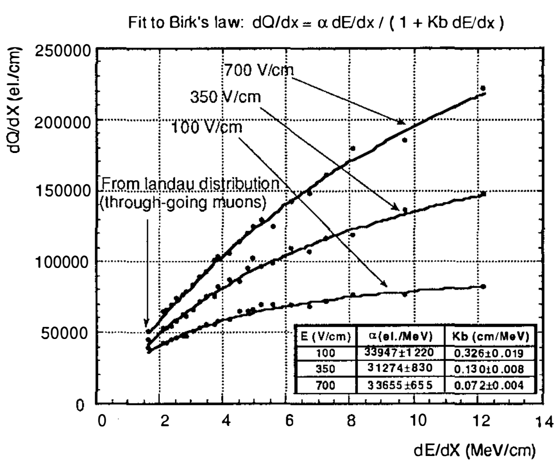



Fig. 4

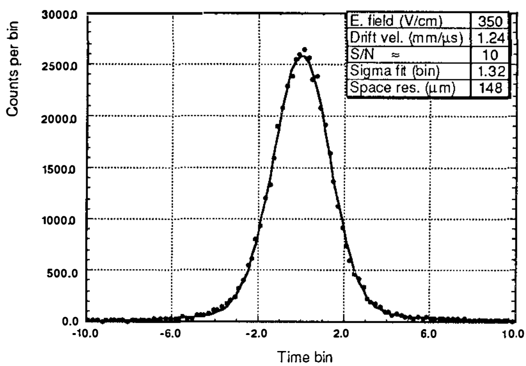



Fig. 5

drifting field of 350 V/cm (fig. 4). The increase in recombination at the end of the range shows that the detector energy response at low fields is non-linear.

A big effort is now in course to fully understand the effects of the recombination on the energy response of the detector. At present we are analysing crossing muons data of  in order to extract the recombination dependence on the electric field strength and on the angle between the track and the electric field. As part of our next program we plan to dope the LAr in order to lower the recombination and thus avoid the related problems.

The space resolution along the drift direction has been measured from the distribution of the residuals to a linear fit of the tracks of high energy crossing muons. An r.m.s. resolution of 150 μm has been found roughly independent from the electric field (fig. 5) and the drift distance. In a dedicated test on a small scale with the preamplifiers immersed in LAr and a low input capacitance we got a signal to noise ratio of ≈ 20 and a spatial resolution of 58 μm [6].

The analysis of the signal rise time allows the determination of the longitudinal diffusion as a function of the drift time. The rise time (RT) is proportional to the spread (s) of the signal due to diffusion and $s^2 = 2Dt$ (where D is the longitudinal diffusion coefficient and t is the drift time), hence a linear fit of $RT^2$ versus drift time gives directly D. The data taken 350 V/cm and at 250 V/cm give a value of $D = 4.8 \pm 0.2$ $cm^2/s$ in agreement with the measurement of other authors [7] and the value expected from brownian motion and electrostatic repulsion between the electrons.

From the results presented above turns out that a certain amount of technical work has to be done in order to improve the S/N ratio. This can be accomplished by connecting the preamplifiers directly to the wires inside the LAr thus reducing the input capacitance due to the cables and the intrinsic thermal noise.

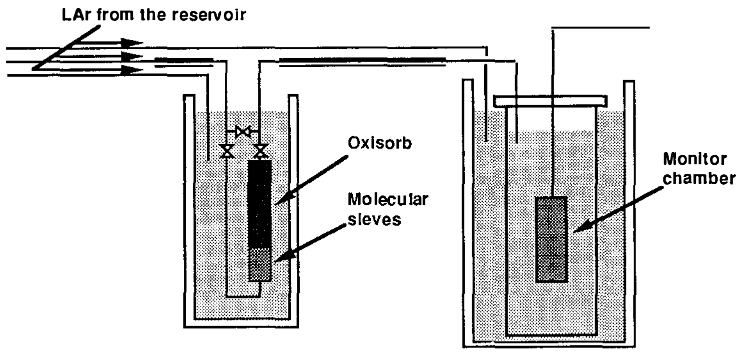



Fig. 6

5. LIQUID PHASE PURIFICATION

During the last months of the past year we made a test in order to verify the possibility to purify the Argon directly in liquid phase. A schematic view of the apparatus we used is shown in fig. 6. Industrial LAr (1ppm $O_2$ equivalent) from a storage dewar passes, through vacuum lines, into a filter immersed in LAr and then fills a second dewar (130lt volume) where is contained a monitor chamber similar to the one used into the 3 ton prototype. The filter is constituted of 2lt of molecular sieves (5A type) that mainly remove $H_2O$ and 4lt of Oxisorb [9] that remove $O_2$ and can purify up to 75000lt of industrial LAr.

The flow rate was controlled by setting the appropriate pressure drop into the circuit.

We performed a series of purifications/fillings of the detector dewar at different fluxes up to a maximum rate of 800lt/h and always found an electron lifetime above 3-4ms, that is the limit of our experimental sensitivity. The maximum rate was determined by the impedance of the Oxisorb cartridge and has not to be taken as the limit of this technique; two or more filters in parallel can be used to increase the flux.

4. CONCLUSIONS

We reported on the latest results from the R&D program of the ICARUS project. The continuous running by more than 18 months of the 3 ton prototype demonstrates that the ICARUS technique is reliable. The detector provides electronic bubble-chamber quality images with millimetre size "bubbles". It is continually sensitive and self-triggering. Spatial resolution is in the range of 150 μm. Ionisation and range measurements provide particle identification.

Extension of this technique to very large volume detectors is now possible thanks to the Argon purification in liquid phase nevertheless for the full completion of our R&D activity we still need to investigate some point:

a) LAr doping, in order to reduce the recombination rate.

b) Development of low noise low temperature pre-amplifiers to increase the signal to noise ratio.

c) Design of very large wire chambers mechanically reliable.

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