# Status of the ICARUS experiment

**F.Mauri**
INFN Sezione di Pavia, Via A.Bassi 6, 27100 PAVIA, Italy

(on behalf of the ICARUS Collaboration)

**Abstract.** In this paper we report on the current status of the ICARUS experiment. In particular, the main features of the liquid argon time projection chamber (TPC) technique are summarized and first results from tests of a full scale 600 ton module are described in some detail.

## 1. Introduction

The ICARUS Collaboration has developed in the past years a new type of particle detector [1]: the liquid argon TPC. Ionisation electrons produced in highly purified liquid Argon ($O_2$ eq. $\leq$ 0.1 ppb) by ionizing particles may drift over large distances (of the order of meters) under the action of an electric field. With an appropriate readout system (i.e. a set of fine pitch wire grids) it is possible to realize a massive, continuously sensitive ”bubble chamber-like” detector. One can perform multiple readout of the small charge that is produced (about 8000 e/mm), since no multiplication occurs at the wires.

During many years of an intense R&D activity the ICARUS Collaboration built and operated several liquid Argon imaging detectors: the 24 cm drift wire chamber (1987) [2], the 3 ton prototype (1991-1995) [3], the 50 litres prototype exposed to the CERN $\nu$ beam (1997-1999) [4], the 10 $m^3$ ”industrial” prototype (1999-2000) [5].

In the following, the main characteristics of the 600 ton module (T600) recently built and tested (Figure 1) will be described.

## 2. Detector features

The liquid argon TPC as developed by the ICARUS Collaboration is a new detector technology with very interesting features [6]:

- it is self-triggering;
- it is continuously sensitive;
- it has a high granularity (wire pitch $\approx 3mm$);
- it has a space resolution of $\sigma_{x,y} \approx 1mm$ and $\sigma_z \approx 0.15mm$ along the drift coordinate;
- it can provide highly accurate measurements of range, angles, multiplicity;
- from multiple scattering measurement one can derive the muon momentum with a typical resolution of $\pm 20\%$ at 10 GeV;
- from the measurement of local energy deposition it is possible to separate electrons and gammas and identify particles by means of dE/dx vs range measurement;

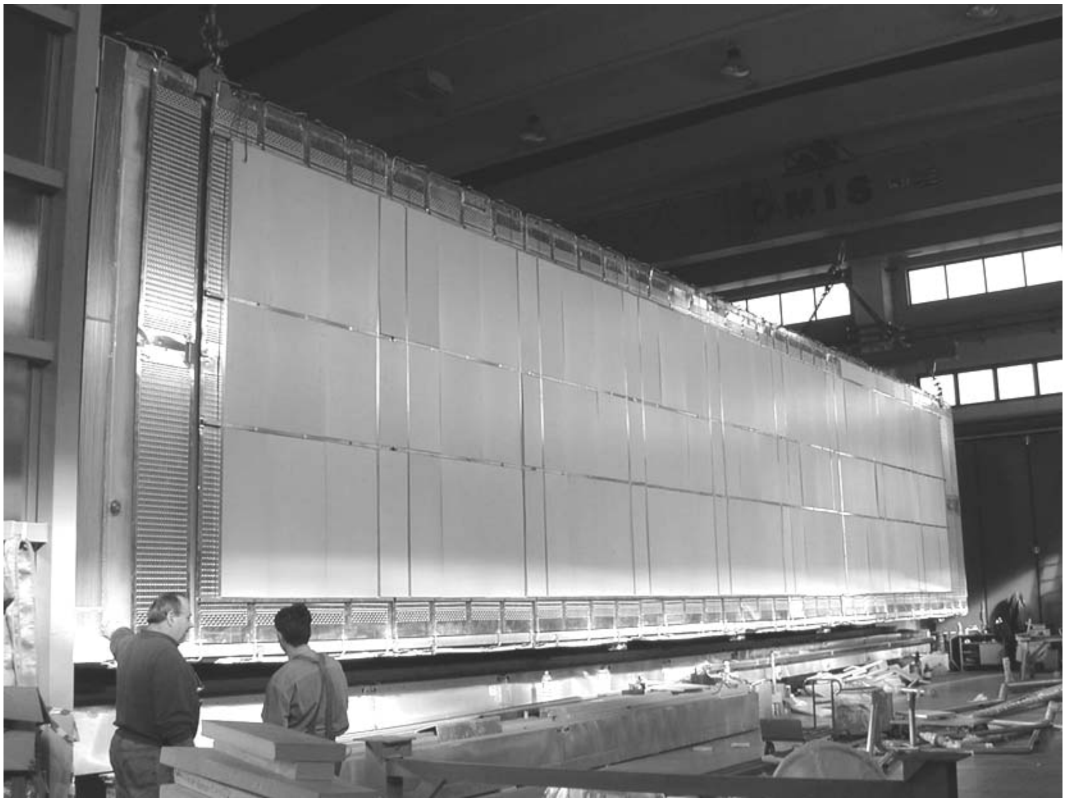

**Figure 1.** One of the two containers of the T600 in the Pavia laboratory.

- the liquid argon is an excellent calorimeter with high resolution for contained events of the order of:
  $\sigma(E)/E = 7\%/\sqrt{E(MeV)}$ for low energy electrons;
  $\sigma(E)/E = 3\%/\sqrt{E(GeV)}$ for electromagnetic showers;
  $\sigma(E)/E = 16\%/\sqrt{E(GeV)} + 1\%$ for hadronic showers.

## 3. T600 Module

The T600 module was proposed in 1995 [7] as an intermediate step towards the realization of a multi-kton detector. Above all, it was intended as an industrialization of the technologies developed in the laboratory.

The detector is composed by two liquid argon (Lar) containers (semi-modules) surrounded by a common thermal insulation layer. The two containers, realised with Aluminum honeycomb panels, surrounded by a thermal insulation made with Aramid fiber honeycomb, are independent from the point of view of the readout and LAr handling (filling, purification and recirculation), while the cooling system is quasi-independent (separate circuits with common engine). In Table 1 the main design features of the T600 are summarized.

Inside each container one has the internal detector shown in Figure 2. It consists of the stainless steel sustaining structure, the wire chambers system and the HV system. In Table 2 and 3, respectively, the wire chambers and the HV system main characteristics are summarized.

The frame of the wire chamber system is elastic in order to greatly reduce the thermal

**Figure 2.** The stainless steel sustaining structure of the internal detector of the T600.

**Table 1.** T600 features.

| | |
|---|---|
| Overall Dimensions | $9.3 \times 5.4 \times 20.6 m^3$ |
| Single container internal dimensions | $3.6 \times 3.9 \times 19.3 m^3 = 270 m^3 (368 ton)$ |
| Sensitive volume/container | $3.0 \times 3.16 \times 17.95 m^3 = 170 m^3 (238 ton)$ |
| Wires chambers/container | 2 |
| Maximum drift length | 1.5 m |
| Maximum drift time at 500 v/cm | 1 ms (HV = 75 kV) |
| Thermal insulation thickness | 450 mm |
| LAr filling/purification speed/container | $2 m^3/hr$ |
| Liquid recirculation speed/container | $2.7 m^3/hr$ (liquid) |
| Gas recirculation speed/container | $60 m^3/hr$ (gas) |

stress on the wires during the cooling phase and to cope with the wide dimensions of the structure.

The high voltage system, that keeps a stable and uniform field over the 1.5 m maximum drift length in each drift volume, is made by a cathode and by the electric field shaping electrodes (race tracks).

## 4. T600 test in the Pavia laboratory

The test of the first semi-module of the T600 conducted in Pavia during MayAugust 2001 was mainly dedicated to the verification of the detector functionalities (technical run) with regards

**Table 2.** Wire chambers main characteristics.

| | |
|---|---|
| Number of read-out chambers | 4 |
| Number of wire planes per chamber | 3 |
| Wires orientation respect to horizontal | $0, \pm 60^\circ$ |
| Wires pitch | 3 mm |
| Wires length: | |
| horizontal wires | 9.40 m |
| wires at $\pm 60^\circ$ | 3.77 m |
| wires at $\pm 60^\circ$ (triangles) | 0.49 - 3.81 m |
| Wires diameter | 0.15 mm |
| Wires nominal tension | 12 N |
| Number of wires per chamber: | |
| horizontal wires | 2,112 |
| wires at $\pm 60^\circ$ | 9,280 |
| wires at $\pm 60^\circ$ (triangles) | 1,920 |
| total | 13,312 |
| Total number of wires | 53,248 |
| Total sensitive LAr mass | 476 ton |

**Table 3.** Features of the HV system.

| | |
|---|---|
| Number of cathode panels | 9 |
| Dimensions of a cathode panel | $2.0 \times 3.2 m^2$ |
| Cathode panel thickness | 1.5 mm |
| Cathode panel pierced surface | $58\%$ |
| Race tracks dimensions | $18.1 m \times 3.2 m$ |
| Number of elements/race track | 20 |
| Race track diameter | 34 mm |
| Race track thickness | 0.8 mm |
| Race track pitch | 50 mm |

to:

- cryogenics;
- wire chamber mechanics;
- liquid Argon purification;
- electronic noises;
- HV for the drift volume;
- readout & DAQ;
- slow control.

The most important run phases can be summarized as follows:

- clean up (vacuum): 10 days (7 days to find and recover the leaks and 3 days to reach $10^{-4} mbar$) (Figure 3);
- cooling: 15 days (11 days for pre-cooling (down to $-50^\circ C$) and 4 days to reach $-178^\circ C$);

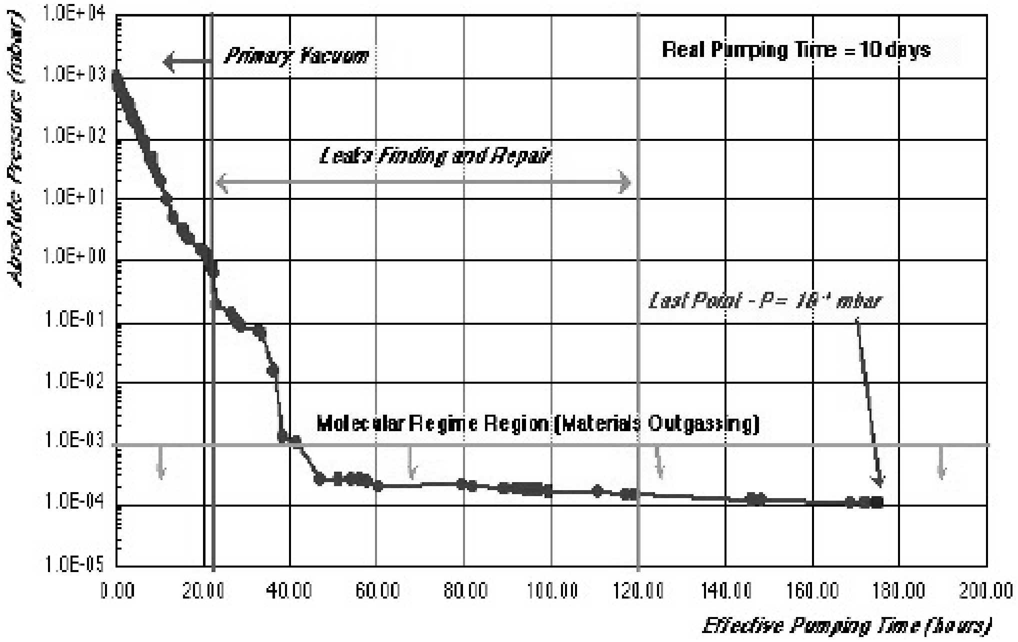

**Figure 3.** The residual pressure inside the container during the cleanup procedure.

- LAr filling: 10 days;
- data taking: 68 days.

The cooling of the container (see Figure 4) was obtained in two steps:

- precooling: a temperature-controlled gas-liquid nitrogen mixture circulating in closed loop in the cooling circuit was used as a smooth preconditioning of the cooling circuit in order to avoid large thermal stresses. When reached the equilibrium with the heat coming from outside, precooling was stopped;
- fast cooling, by using pressurised $LN_2$ in the cooling circuit. It was designed to provide cooling of the cryostat and of the auxiliary cryogenic systems (purifiers, transfer lines, etc.). There was a large cooling power (nominal $LN_2$ flow rate = $36m^3/hr$) with a cooling speed $\approx 2.5°/hr$. Due to the slow temperature variation no movements were seen on the wire tensioning devices ($\leq 300mm$) or on the reciprocal position of the structure elements.

The liquid Argon filling started when the pre-filling requirements were fulfilled:

- temperature in the cryostat close to the final value;
- gas contamination $\leq 0.1ppm\ O_2$ equiv.

The LAr was provided by Air Liquide Italia new extraction plant with certified quality: $O_2$ contamination $\leq 0.5ppm$, $H_2O$ contamination $\leq 2.5ppm$, $N_2$ contamination $\leq 0.5ppm$ and checked online with a dedicated gas chromatograph.

A double purification system (in series) to the input line (Oxygen and water removal) dimensioned for filling 8 times the cryostat volume was used. Its functionality was periodically tested before and during the filling by an external purity monitor on the input line. A good purification rate was achieved:

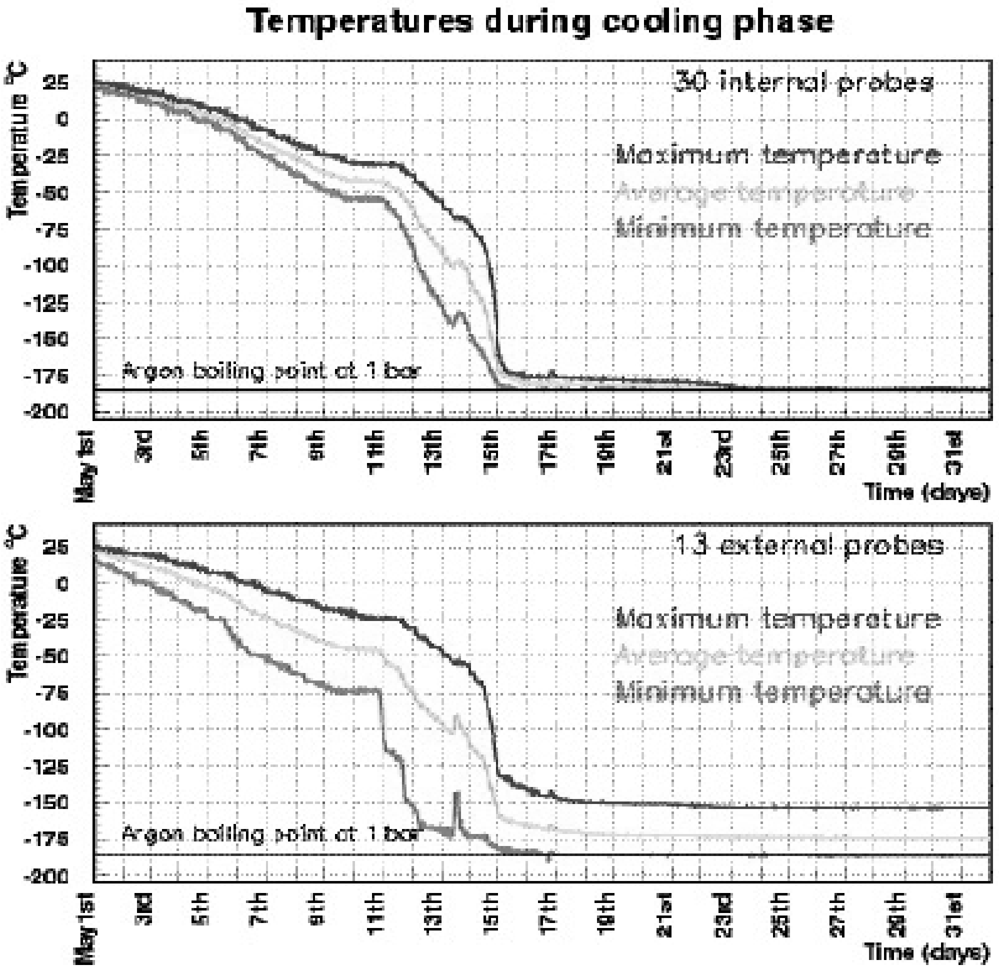

**Figure 4.** The temperature variation with time for the inner (top) and outer (bottom) walls of the container.

- Volume flow rate $\geq 50lt/s$;
- Filling speed $\approx 2m^3/hr$ (design value of 2 LAr $m^3/hr$).

The free electron mean lifetime (a very important parameter for this detector) was checked periodically after the filling and a steady increase was recorded, until the Lar recirculation was turned off. The maximum drift electron lifetime achieved was about 1.8 ms which corresponds to an attenuation length of more than 2.5 meters. A 2 months run of data taking then started. A total of 27,770 triggers were recorded, with different trigger requirements (long quasi-horizontal tracks, vertical tracks, photomultipliers driven, stopping muons, etc.). Each event had a size of the order of 110 Mbytes/chamber and a total of 5 Tbytes of data were stored in 100 DLTs. A typical cosmic ray induced event is shown in Figure 5, proving the high quality and granularity of the events.

## 5. Outlook

The completion of the T600 assembly (second semi-module) is foreseen for the end of 2002 and the transportation and installation at LNGS for the second half of 2003.

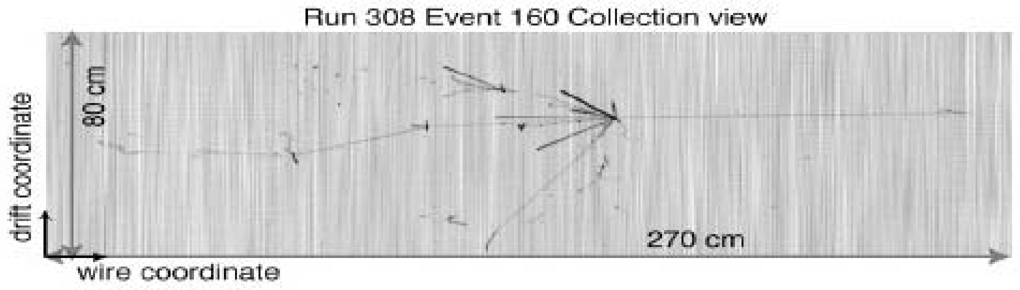

**Figure 5.** View of an hadronic interaction recorded in the T600 test run in Pavia.

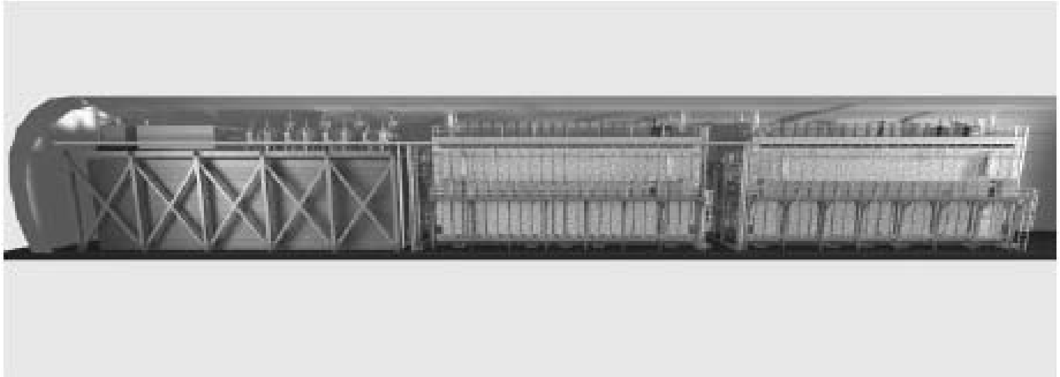

**Figure 6.** Artistic view of the T3000 in the LNGS underground laboratory.

The ICARUS Collaboration is now preparing the multi-kton final design which envisages the cloning of the basic T600 module. The existing T600 plus four additional T600 modules assembled into two T1200 units will constitute the final T3000 detector [8] (Figure 6). With this detector the Collaboration will conduct a complete astroparticle underground physics program that includes the study of solar, atmospheric, supernovae and accelerator neutrinos, as well as the search for rare phenomena such as nucleon decay.

## References

[1] ICARUS Proposal - INFN/AE-85/7 (1987)
[2] S.Bonetti et al. - Nucl. Inst. and Meth. A286, 135 (1990)
[3] P.Benetti et al. - Nucl. Inst. and Meth. A332, 395 (1993)
[4] F.Arneodo et al. - $36^{th}$ Workshop on New Detectors - World Scientific, 3 (1999)
[5] F.Arneodo et al. - Nucl. Inst. and Meth. A461, 286 (2001)
[6] P.Cennini et al. - Nucl. Inst. and Meth. A345, 230 (1994)
[7] P.Cennini et al. - LNGS 95/10 (1995)
[8] F.arneodo et al. - LNGS-EXP 13/89 add 2/01 (2001)