

# The ICARUS T600 Liquid Argon Time Projection Chamber

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## Abstract

A full test of the ICARUS T600 liquid Argon detector has been carried out in the year 2001 in Pavia, Italy. The test, extended over about 100 days of continuous operation, has been successful, and has shown that the LAr TPC technology is mature for a large mass experimental programme. A large number of cosmic rays events have been recorded during that test. In this paper we show some results of that test, from the point of view of the imaging capabilities of the technique.

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## 1 The ICARUS T600 module

The ICARUS project foresees the installation of a multi-kton liquid Argon detector in the Gran Sasso underground laboratory, for neutrino and rare events physics. The structure of the detector is modular, and the first building block, already existing, is the “T600” module [1,2]. It is a large cryostat divided in two identical, adjacent half-modules (internal dimensions:  $3.6 \times 3.9 \times 19.9$  m<sup>3</sup>), each one containing more than 300 t of liquid Argon (LAr). Each half-module hosts two symmetrical Time Projection Chambers (TPC), which share the same cathode, a stainless steel composite plate placed longitudinally in the center of the half-module. The readout wire chambers are placed, parallel to the cathode, along the walls of the container. Each chamber consists of three parallel planes of wires (called *induction-1*, *induction-2*, *collection*), 3 mm apart, and with a relative orientation of 120<sup>0</sup>, with 3 mm of pitch between adjacent wires. A uniform electric field, perpendicular to the wire planes, allows the drift of the ionisation tracks (the maximum drift path is 1.5 m). An array of stainless steel tubular frames, the “race tracks” (35 mm diameter and 50 mm apart) kept at fixed voltages by a resistor chain guarantees the uniformity of the field. Each wire is connected, by cables, connectors, and a feed-through flange to the external electronics, which is structured as a multi-channel waveform recorder. It continuously samples the signal (after the shaping and amplification stages) generated by each sense wire during the drift of the electrons. The detector equipment is completed by an array of photomultipliers placed behind the wires and looking at the sensitive

volume. The photomultipliers detect the scintillation light of liquid Argon ( $\lambda = 128nm$ ). They have a bi-alkali photo-cathode, with a Platinum internal coating (to maintain the correct resistivity at LAr temperature) and a Tetra-Phenyl-Butadiene (TPB) external coating to shift the 128 nm line to visible light. Also present in the LAr volume are several “slow control” sensors to measure LAr level, walls deformations, temperatures etc.. One of the most important parameters to be kept under control is the level of electro-negative contaminants (mainly Oxygen) in the liquid. Even in quantities of less than a ppb they can impair the detector capabilities by limiting the maximum free electron path in the LAr. To this purpose the LAr is purified by flowing through an Oxisorb filter. The electron lifetime in LAr (with an operating field strength of 500 V/cm) must be in excess of 1 ms to reach a maximum drift length of 1.5 m without significant charge losses. The  $e^-$  lifetime is directly measured by an array of small, dedicated drift chambers (the “purity monitors”) placed inside the liquid, but outside the imaging volume boundaries. The test of the T600 took place in Pavia, Italy in April-July 2001. All technical aspects of the system, cryogenics, LAr purification, read-out chambers, detection of LAr scintillation light, electronics and DAQ were tested and found to be satisfactorily in agreement with expectations. A large statistics of cosmic ray events has been recorded.

## 2 Imaging capabilities

By gray coding each wire waveform and putting them together one obtains images such as Fig. 1. Thanks to such kind of images ICARUS is often referred as “electronic bubble chamber”. With respect to a traditional bubble chamber, however, it is continuously sensitive, self triggerable, and it has the quantitative information of the released charge (the waveforms), opening the possibility of performing accurate calorimetry and particle ID studies.

The reconstruction procedure [3] is composed by the following steps, performed on each waveform:

- (1) Filtering procedure to reduce the noise components.
- (2) Regions of Interest (ROI’s), i.e. those containing the signal peak above the baseline, are then identified in the waveforms
- (3) By extraction of the physical parameters of the signal inside the ROI(peak amplitude, time and rise time), a “hit” is defined.
- (4) Combining the informations from drift time and amplitude of the hits separately from (at least) two of the wire planes, two 2D views are obtained for each event.
- (5) A clustering algorithm is performed, searching for a set of subsequent points (“clusters”) among the hits found by the signal processing.

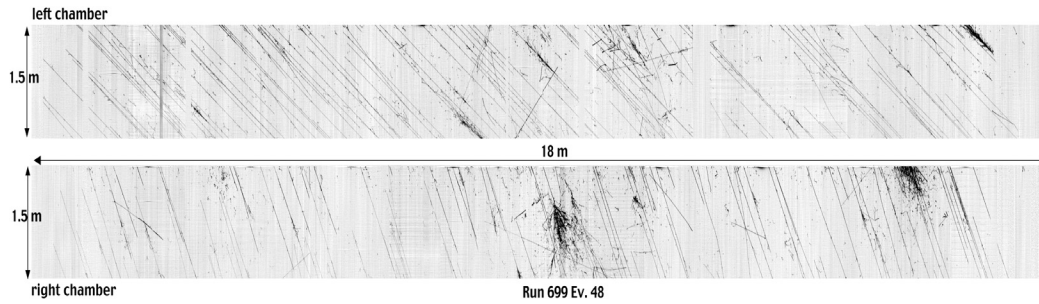


Fig. 1. A cosmic rays muon bundle seen by the T600 detector with the left (up) and right(down) wire chambers.

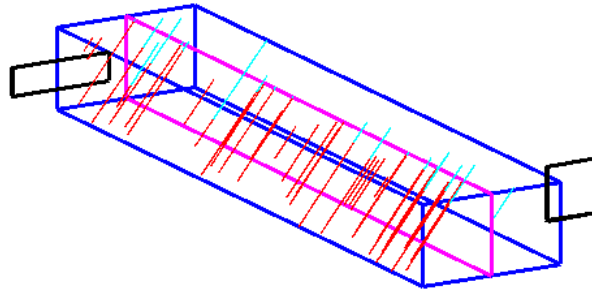


Fig. 2. 3D reconstruction of the event of Fig. 1

Then, in case of a straight muon track, with characteristics typical of m.i.p.-like event, a linear fit through the hits belonging to the “cluster” is performed separately on each view. This fit gives the parameters (slope and intercept) of each of the two 2D track projections. For each track we accomplish a geometrical 3D reconstruction employing an analytical approach: the “geometrical 3D track” is derived combining the parameters of the 2D track projections to obtain the track direction in space (zenith angle  $\theta$ , azimuth angle  $\phi$ ) and the three coordinates  $(x_0, y_0, z_0)$  of a point belonging to the track. In Fig. 1 a muon bundle is shown as seen by the *collection* wire planes of both chambers, and in Fig. 2 the same event is shown with a complete 3D reconstruction.

A geometrical reconstruction is no more applicable in case of non straight tracks, such as the event of Fig. 3 (left and center). In this case the key step is the association of the space coordinates in the cartesian frame to each energy deposition segment produced by the ionizing particle passing through the detector. We start from hits belonging to the *collection* view and we look for corresponding hits from another complementary wire plane (*induction-1* or *induction-2*). The correspondence is based on the common drift coordinate and on the geometrical compatibility. A simple calculation, then, brings to the cartesian coordinates. The result is visible in Fig. 3 (right).

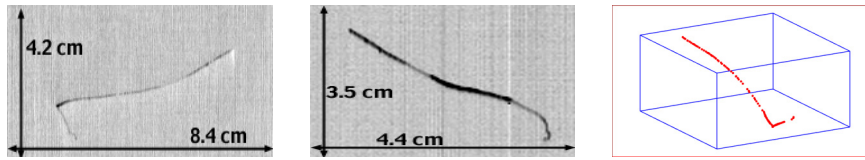


Fig. 3. A muon decay, seen (from left to right) by the *induction-2*, *collection* wire planes, and by the 3D reconstruction.

Multi-tracks events, such as the shower of Fig. 4 (left) are at a higher level of complexity. The hit-finding algorithms, developed on single-track events, do fairly well even on such kinds of images (Fig. 4 right). Dedicated 3D reconstruction algorithms are under development.

### 3 Conclusions

The ICARUS Liquid Argon TPC has proven to be a powerful imaging technique for particle physics. The T600 detector is ready to be installed in the Gran Sasso Laboratory to perform a large physics programme. Thanks to the large information contained in the data, the 3D reconstruction of the events is a complex task. The existing algorithms can handle single-track events. The 3D reconstruction of more complicated event topologies is under development.

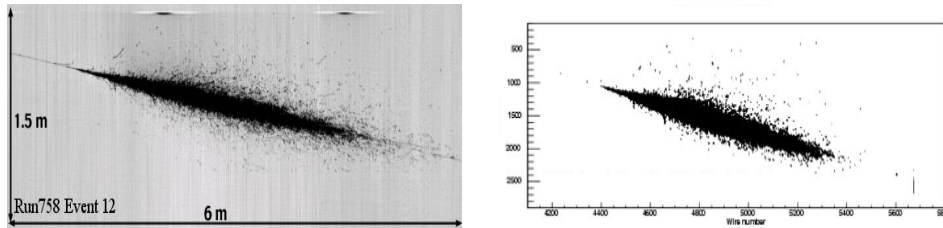


Fig. 4. An electromagnetic shower, seen by the *collection* wire plane (left) and reconstructed in 2D (right) by the hit-finding algorithm.

### References

- [1] ICARUS Collaboration, "A first 600 ton ICARUS detector installed at the Gran Sasso Laboratory", Addendum to Proposal by the ICARUS Collaboration, LNGS - 95/10, (1995).
- [2] F. Arneodo et al., "Cloning of T600 modules to reach the design sensitive mass", LNGS-EXP 13/89 add.2/01, CERN/SPSC 2002-027 (SPSC-P-323)
- [3] F. Arneodo et al., "Performance of the 10m<sup>3</sup> ICARUS liquid argon prototype", Nucl. Inst. Meth., A498 (2002) 292-311