The ICARUS T600 experiment in the Laboratori Nazionali del Gran Sasso (LNGS) underground laboratory

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Abstract. The ICARUS T600 detector is installed in the underground Gran Sasso National Laboratory (LNGS) in Italy. This detector is the biggest Liquid Argon (LAr) Time Projection Chamber (TPC) ever built. Since May 2010 it is collecting data, both CERN CNGS neutrino beam and atmospheric neutrino interactions. A short description of the ICARUS T600 experiment and its first *underground* results are presented.

1. The ICARUS T600 detector description and its performance

The idea of the LAr TPC comes from C.Rubbia [1]. A charge particle traversing clean LAr produces ionization charge (electrons) which can drift in an electric field, practically undistorted, over distances of meters. The readout of the electron signal is performed by the use of anode wire planes. This, together with the measurement of the electron drift time allows for the three dimensional imaging of tracks. Particle identification is obtained by exploiting the *dE/dx* versus range measurement. This completes the event reconstruction. The ICARUS T600 detector is composed of two identical half-modules. Each of them has internal dimensions of 3.6m (width) x 3.9m (height) x 19.6m (length). It is filled with a total amount of 760 tons of LAr. Each half-module houses two TPC's with centrally placed cathode, the electric field shaping system and 74 photomultipliers for the LAr scintillation light detection. Three parallel planes of anode wires – 2 *induction* and 1 *collection*, oriented at 60 degrees with respect to each other, are mounted along the longest walls of the half-module. The total number of wires is 53248. The maximum electron drift length is 1.5 m, with the maximum drift time of about 1ms, when the nominal voltage of 75 kV is used. The drifting electrons induce a signal in the first two *induction* planes, whereas the charge is collected in the last *collection* plane. The detailed description of the detector can be found in [2]. The detector has first been tested on the Earth surface in 2001 in Pavia (Italy). Then the ICARUS T600 detector has been equiped with dedicated technical infrastructure [3] to fulfill safety and reliability requirements for underground operation at LNGS. Since May 2010 it is taking data underground in the Gran Sasso National Laboratory (LNGS) in Italy. The detector performance has been studied by using data from the test run on the Earth surface. The estimated energy resolutions are the following: $\sigma(E)/E = 0.03/\sqrt{(E(GeV))} \oplus 0.01$ for electromagnetic showers, in the sub-GeV range, obtained from the π^0 mass reconstruction [4]; $\sigma(E)/E = 0.30/\sqrt{(E(GeV)}$ for hadronic showers; $\sigma(E)/E = 0.11/\sqrt{(E(MeV))} \oplus 0.02$ for low energy electrons obtained from the measurement of the Michel electron spectrum from muon decays [5]. By applying the Kalman filter technique to the multiple scattering, the momentum of long muon tracks, escaping the detector volume, can be estimated with a precision up to 10% [6]. Thanks to the detector granularity (anode wires pitch of 3mm) a resolution of about 1 mm^3 in the three-dimesional reconstruction of ionizing event has been achieved. In figure 1, a schematic view of the ICARUS T600 working priciple is presented.

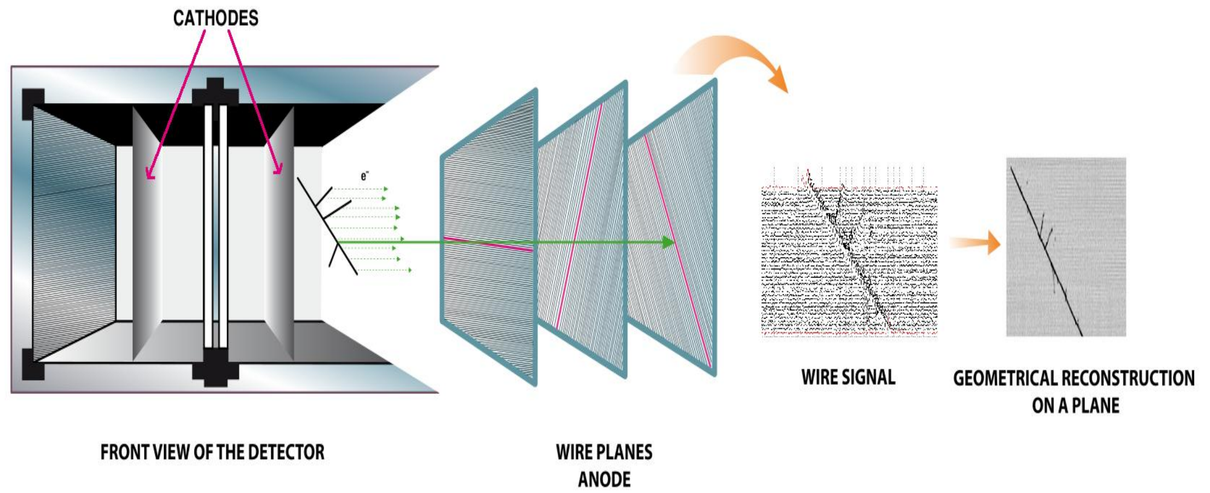

Figure 1. Illustration of the ICARUS T600 working principle: from a charged particle ionization path in LAr to its geometrical reconstruction [3].

2. The LAr purity

LAr purity is the key issue for the ICARUS T600 detector performance. Electrons, produced by ionizing particles, can "safely" travel over meters and reach anode wires planes only if electronegative impurities (mainly O_2, H_2O and CO_2) in LAr are kept at a very low concentration level (less than 0.1 ppb). Therefore, each half-module of the detector is equipped with two gas-phase and one liquid-phase recirculation/purification systems. LAr is recirculated by immersed cryogenic pump (full volume recirculation in 6 days) and purified through Hydrosorb/Oxysorb™ filters before being re-injected into the cryostats. Argon gas is continuously drown, re-condensed, purified and put back to the cryostat. The LAr purity is continuously monitored (see figure 2).

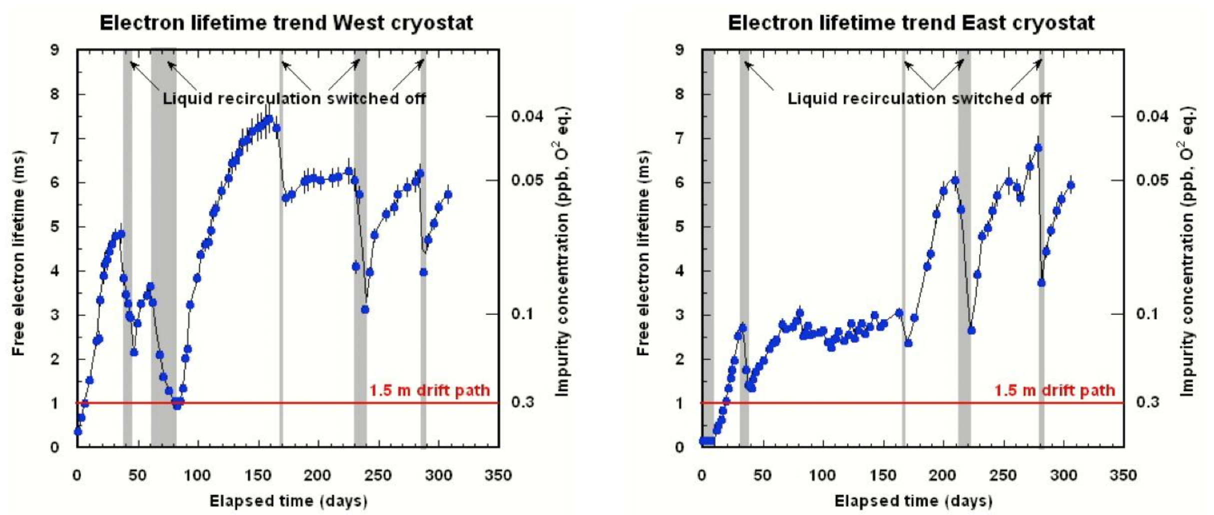

Figure 2. Free electron lifetime evolution in time (days) in both ICARUS T600 cryostats.

It is done by measuring the free electron lifetime, exploiting charge attenuation along sufficiently long (i.e. traversing the full drift path) cosmic muon tracks without evident associated δ-rays and γ's. The precision of 3% in the charge attenuation measurement can be obtained with about 50 muon tracks. The LAr purity steadily increases in time and after few months reaches 6 ms of free electron lifetime in both half-modules. As can be seen in figure 2, any stops of the LAr recirculation for the pumps maintenance causes purity degradation. However, it should be noticed that the purity is quickly recovered and the value of the free electron lifetime is always bigger than 1 ms, which corresponds to the maximum drift distance of 1.5 m.

3. ICARUS T600 results in 2010 and the first half of 2011

In this section a brief summary of the ICARUS T600 experiment results is presented. The first events from both, CNGS muon neutrino beam and cosmic rays have been recorded after filling the detector with LAr in May 2010. The beam events trigger system uses the CNGS proton extraction time, whereas the cosmic events trigger exploits the coincidence of the PMT’s sum signals of the two adjacent chambers in the same half-module. The trigger rates are 1 mHz and 30 mHz for beam and cosmic rays events, respectively. An example of a CNGS ν_μ charge current (CC) event with about 13 meters long muon track (track 1) is shown in figure 3. The muon of momentum of 10.5±1.1 GeV/c (from multiple scattering) deposits by ionization in the LAr volume a total energy of 2.7 GeV. The other particles, tracks 2 and 3, originating in the primary vertex are π^0 and a charge pion, respectively. The invariant mass of the two overlapping electromagnetic showers was measured (from calorimetric measurement) to be 125±15 MeV/c^2, i.e. compatible with the π^0 mass. The secondary vertex results from the charge pion (track 3) interaction. The leading track from the secondary vertex is a kaon (track 6) decaying in flight into a muon (track 5). The initial kaon momentum of 672±44 MeV/c is calculated from the kaon energy deposited before decay, muon energy and the decay angle. Two anothers short tracks (7 and 8) are also visible. The total hadronic energy in the event is measured to be 2.3±0.5 GeV, however it should be noted that it is underestimated due to the not measured energy of track 8 (it escapes the detector) and not measured neutrons, which could be produced (but are not visible). This example shows the capability of LAr TPC detection technique to reconstruct even complicated event topologies.

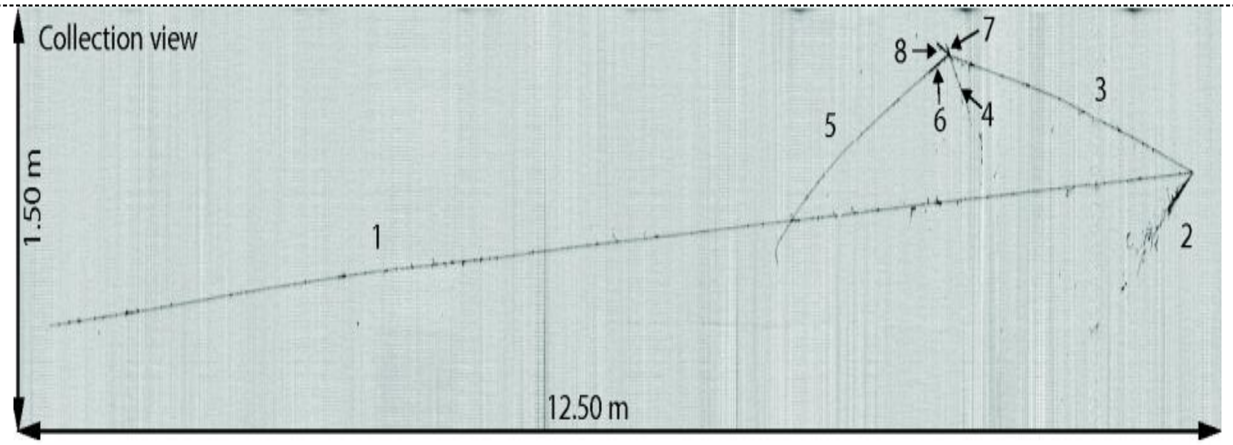

Figure 3. Muon neutrino CC CNGS beam interaction in the ICARUS T600 detector. For particle identification details see text.

During the 2010 CNGS run, the ICARUS T600 detector collected, with increasing efficiency up to 90%, about 100 CC events in agreement with expectations. In 2011 the detector started data taking from CNGS beam on March 18th. Up to May 23rd 1.7 x 10^{19} pot have been delivered, whereas 1.5 x 10^{19} pot have been collected, resulting in the detector lifetime of 93%. The events are continuously reconstructed.

4. Summary and perspectives

The ICARUS T600 detector has been successfully installed underground at LNGS. It is so far the biggest LAr TPC ever built and demonstrates that the technology is mature and can be extended to larger masses for the next generation of detectors for rare events investigation, like neutrino physics or proton decay. In 2011-2012 it is expected to integrate about 10^{20} pot with the CNGS beam resulting in 1.1×10^{20} pot in total (including the 2010 run). This will allow the ICARUS T600 collaboration to collect about 3000 beam related muon neutrino CC events, about 7 electron neutrino CC intrinsic beam events, and 1-2 reconstructed tau neutrino events.

The support of the Ministry of Science and Higher education in Poland (grant No N N202 064936) is acknowledged.

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