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ICARUS and status of liquid argon technology

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Abstract. ICARUS T600 is the largest liquid Argon Time Projection Chamber (LAr TPC) detector ever realized. It operates underground at the LNGS laboratory in Gran Sasso. It has been smoothly running since summer 2010, collecting data with the CNGS (Cern to Gran Sasso) beam and with cosmic particles. Liquid Argon TPCs are indeed ”electronic bubble chambers”, providing a completely uniform imaging calorimetry with unprecedented accuracy on such massive volumes. ICARUS T600 is internationally considered as a milestone towards the realization of the next generation of massive detectors (tens of ktons) for neutrino and rare event physics. Results will be presented on the data collected so far with the detector.

1. The ICARUS T600 detector

The ICARUS T600 [1] detector consists of a large cryostat split into two identical, adjacent half-modules with internal dimensions $3.6 \times 3.9 \times 19.6$ m^3 and filled with a total of 760 tons of ultra-pure LAr. Each half-module houses two TPCs separated by a common cathode, with a maximum drift of 1.5 m.

Ionization electrons, produced by charged particles along their path, are drifted under uniform electric field ($E_D = 500$ V/cm) towards the TPC anode made of three parallel wire planes, facing the drift volume. A total of ≈ 53000 wires are deployed, with a 3 mm pitch, oriented on each plane at different angles ($0°, +60°, -60°$) with respect to the horizontal direction. The drift time of each ionization charge signal, combined with the electron drift velocity information ($v_D = 1.55$ mm/μs), provides the position of the track along the drift coordinate. Combining the wire coordinate on each plane at a given drift time, a three-dimensional image of the ionizing event can be reconstructed with a remarkable resolution of about 1 mm^3 on an overall active volume of 340 m^3.

The absolute time of the ionizing event is provided by the prompt ultra-violet scintillation light emitted in LAr and detected through an array of 74 Photo-Multiplier Tubes (PMTs), installed in LAr behind the wire planes [2].

The electronics for data acquisition allows for a continuous read-out, digitization and independent waveform recording of signals from each wire of the TPCs. The electronic noise is 1500 electrons r.m.s. to be compared with ≈ 17000 free electrons produced by a minimum ionizing particle in a 3 mm path.

In order to allow electrons produced by ionizing particles to drift unperturbed from the point of production to the wire planes, electronegative impurities (mainly O_2, H_2O and CO_2) in LAr must be kept at a very low concentration level (less than 0.1 ppb). Therefore, both gaseous and liquid Argon are continuously purified by recirculation through standard Hydrosorb/Oxysorb^{TM} filters.

The ICARUS T600 detector was pre-assembled in Pavia (Italy), where one of its two 300 tons half-modules was brought to operation and tested with cosmic rays at the Earth surface [3] [4] [5]. A number of ancillary works to build the cryogenic plant and other technical infrastructures inside the LNGS Hall B were accomplished after the transfer of the T600 in 2004 [6]. The final assembling of the detector was achieved in the first months of 2010 and ICARUS T600 was finally brought into operation with its commissioning.

2. First results from 2010 runs

In May 2010 the detector was filled with ultra-pure LAr and immediately activated [8]. Events from the CNGS neutrino beam and cosmic rays were observed with a trigger system relying on both the scintillation light signals provided by the internal PMTs and the CNGS proton extraction time: in Fig. 1 few CNGS-induced events are shown.

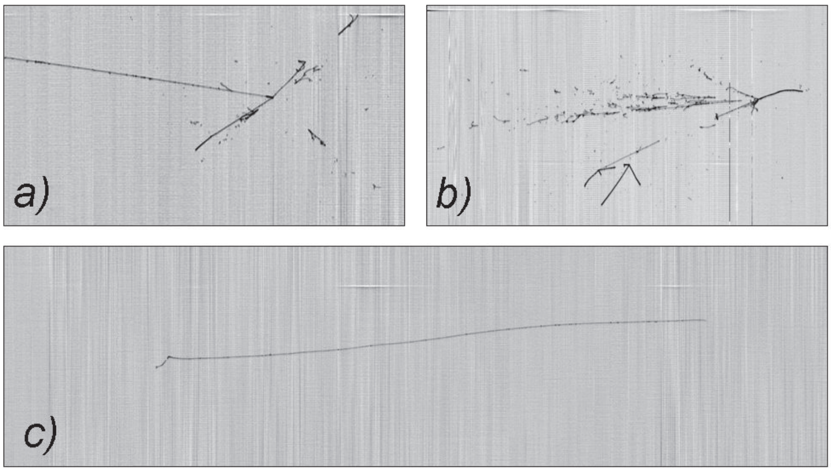

Figure 1. Example of collected events: *a*) a charged current (CC) ν_μ interaction with two π^0 production; *b*) a NC ν interaction; *c*) a muon, from a neutrino interaction in the rock surrounding the detector, stopping and decaying.

In the time interval from October 1^{st} to November 22^{nd}, 2010, CNGS delivered $8 \cdot 10^{18}$ protons on target (pot). The detector live time in the same period was up to 90%, allowing the collection of about $5.9 \cdot 10^{18}$ pot. All collected neutrino events have been classified by means of a visual scan. The target mass taken into account after a fiducial volume cut is 447 tons. The number of charged over neutral current (CC/NC) interactions foreseen per pot is $2.6 \cdot 10^{-17}/0.86 \cdot 10^{-17}$, in the energy range up to 100 GeV. As shown in Tab. 1, the expected number of interactions is in good agreement with expectations after correcting for dead time.

The neutrino events recorded in 2010 have been used as a training and control sample for the reconstruction and analysis software tools: the momentum of muons generated in ν_μ CC interactions is measured exploiting the multiple scattering along the track. The implemented algorithm is based on the Kalman filter technique [7]. The expected momentum resolution Δp/p depends mainly on track length: on muons from CNGS neutrinos, Δp/p $\approx$ 16% on average. The average reconstructed momentum for 2010 CNGS data is 11.0±1.8 GeV/c, in agreement with the expected value of 10.7 GeV/c. Charged particle tracks are reconstructed in three dimensions thanks to a polygonal line algorithm. Particle identification is performed both with topological

Table 1. Number of collected neutrino interactions compared with predictions. In ν XC interaction type additional analysis is needed for the classification CC vs NC.

Event type	Collected	Expected
ν_μ CC	115	129
ν NC	46	42
ν XC	7	
Total	168	171

considerations (for example decay products) and with the reconstruction of dE/dx versus range. Corrections to recover the ionization quenching are applied to the reconstructed energy loss.

As an example of the capability of the analysis tools on reconstructing neutrino events, a fully reconstructed ν_μ CC event is shown in Fig. 2.

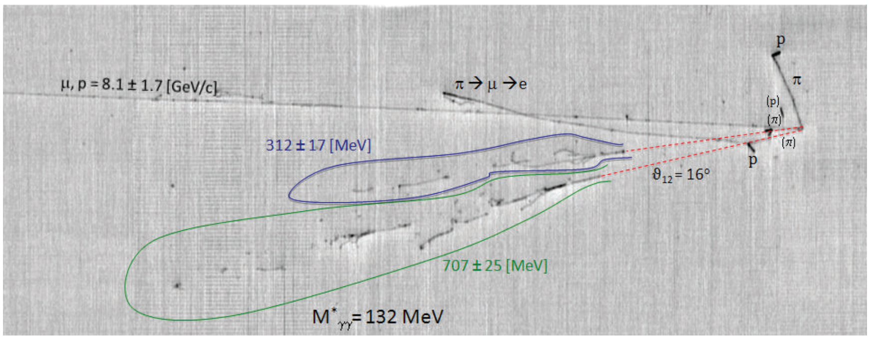

Figure 2. Example of a fully reconstructed CNGS ν_μ CC interaction event inside the ICARUS T600 detector.

The calorimetric reconstruction of the energy deposited in the detector by ν_μ CC events shows a nice agreement with expectations. The deposited energy in each event is corrected for quenching on average, and a further correction for non-containment and non-compensation is applied. This correction has been computed from Monte Carlo simulations and depends on the vertex position in the detector. For CC events, the energy deposited by the muon is subtracted from the total, and muon momentum is reconstructed by multiple scattering: the reconstructed neutrino spectrum, obtained from the combination of muon momentum and calorimetric energy is shown in Fig. 3. The agreement with the predicted spectrum ν_μ is satisfactory. The analysis tools are being refined and tuned with real data with the aim to address in particular the main items of physics with CNGS beam, namely tau neutrino and ν_e CC identification/measurement and NC rejection performance.

3. Perspectives for 2011 and 2012 run

The CNGS beam restarted on March 19^{th}, 2011: the smooth data taking operations allowed to collect an event statistics corresponding to $3.7 \cdot 10^{19}$ pot over the $3.9 \cdot 10^{19}$ pot delivered by CERN up to September 12^{th}, with detector live-time of 93% for CNGS exploitation. The CNGS events triggered by the PMTs inside the neutrino beam gate are processed off-line to separate genuine CNGS events from fake empty events. In addition, all events in time with beam spills, even if not triggered by PMTs, are collected and immediately filtered, to identify also the few

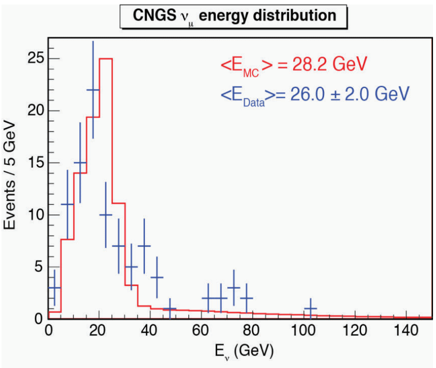

Figure 3. Neutrino energy spectrum from 93 ν_μ CC events reconstructed with the calorimetric method (blue points), compared with expectations (red histogram).

neutrino interactions/rock muons that may escape the PMT based trigger. As a result, about 10 neutrino interactions and 30 rock muons per day are globally selected.

CNGS runs are expected to integrate in 2011-2012 as much as 10^{20} pot also thanks to the dedicated SPS period at high intensity. About 3000 beam related ν CC events are expected in the T600, including also 24 ν_e CC intrinsic beam associated events. About 80 atmospheric neutrino events per year will also be collected and analyzed.

4. Conclusions

The ICARUS-T600 detector, installed underground at the LNGS laboratory, is taking data since May 2010. The successful assembly and operation of this LAr-TPC is the experimental proof that this technique is mature, allowing a better reconstruction and identification of events than any other monolithic neutrino detector (currently in operation).

The main physics goal is to collect events from the CNGS neutrinos to search for the $\nu_\mu \rightarrow \nu_\tau$ oscillation and possible LSND-like ν_e excess [9], but also to study solar and atmospheric neutrino and explore in a new way the nucleon stability, in particular channels beyond the present limits.

Furthermore, ICARUS-T600 is a major milestone towards the realization of future massive LAr detectors [10]. Recently, the employment of this technique at a refurbished CERN-PS neutrino beam has been proposed after the ICARUS-T600 exploitation at LNGS to definitely solve the sterile neutrino puzzle [11].

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