ICARUS AND STATUS OF THE LIQUID ARGON TECHNOLOGY

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The ICARUS T600 is the largest Liquid Argon (LAr) Time Projection Chamber (TPC) ever realized. It represents the state of the art of this technique and it marks a major milestone in the practical realization of large-scale LAr detectors. The apparatus, assembled in the Hall B of the Gran Sasso underground National Laboratory (LNGS) of Istituto Nazionale di Fisica Nucleare (INFN), is collecting neutrino events from the CERN CNGS beam since May 2010. It also acts as an underground observatory for atmospheric, solar and supernovae neutrinos and it is able to search for nucleon decay into exotic channels. Furthermore, it represents a major milestone towards the realization of future LAr detectors for rare events physics, such as the idea to use a LAr-TPC at CERN-PS to solve the sterile neutrino puzzle.

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 drift length 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 ≈ 54000 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.

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.

The electronics for data acquisition allows 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 $\approx$ 15000 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 since 1999 in Pavia (Italy), where one of its two 300-tons half-modules was brought to operation in 2001 and tested with cosmic rays at the Earth surface. A number of ancillary works to build the cryogenic plant and other technical infrastructures inside the LNGS Hall B were accomplished after the transfer in 2004. 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 LAr-TPC performance

The high resolution and granularity of the LAr-TPC imaging allow precise reconstruction of events topology: particle identification is obtained through dE/dx versus range analysis and the decay/interaction topology. Electrons are identified by the characteristic electromagnetic showering; they can be well separated from π^0 via γ reconstruction, dE/dx signal comparison and π^0 invariant mass measurement at the level of permil [2]: this feature guarantees a 90% efficiency identification of the leading electron in ν_e charged-current (CC) interactions, while rejecting neutral-current (NC) interactions to a negligible level.

Estimated energy resolutions are: $\sigma(\mathrm{E})/\mathrm{E} = 0.03/\sqrt{(\mathrm{E(GeV)})} + 0.01$ for electromagnetic showers; $\sigma(\mathrm{E})/\mathrm{E} = 0.30/\sqrt{(\mathrm{E(GeV)})}$ for hadronic showers; $\sigma(\mathrm{E})/\mathrm{E} = 0.11/\sqrt{(\mathrm{E(MeV)})} + 0.02$ for low energy electrons [3].

For long muon tracks escaping the detector, momentum is determined exploiting their multiple scattering by a Kalman filter algorithm with a resolution Δp/p up to 10% [4].

3 Operation at LNGS in 2010

In May 2010 the detector was filled with ultra-pure LAr and immediately activated [5]. 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 by the CNGS proton extraction time.

In Figure 1 some remarkable events are shown: a) a charged-current ν_μ interaction with the production of two π^0; b) a neutral-current ν_μ interaction; c) a muon from a ν_μ interaction in the rock surrounding the detector.

LAr purity was continuously monitored measuring the charge attenuation along ionizing cosmic muon tracks crossing the full drift path. With the liquid recirculation turned on, the LAr purity steadily increased, reaching, after few months of operation, values of free electron lifetime exceeding 6 ms in both half-modules, well above the needs for a drift path of 1.5 m (1 ms of drift time).

During the 2010 CNGS run, the T600 acquired neutrino interaction events with steadily increasing efficiency, up to 90% live time, and with increasing quality. In the last 2010 period, about 100 neutrino CC events were collected and classified, in agreement with expectations.

As an example of the detector capabilities, a CNGS ν_μ CC event with a 13 meters long muon track is shown in Figure 2 together with zoomed projections for two different views; this allows

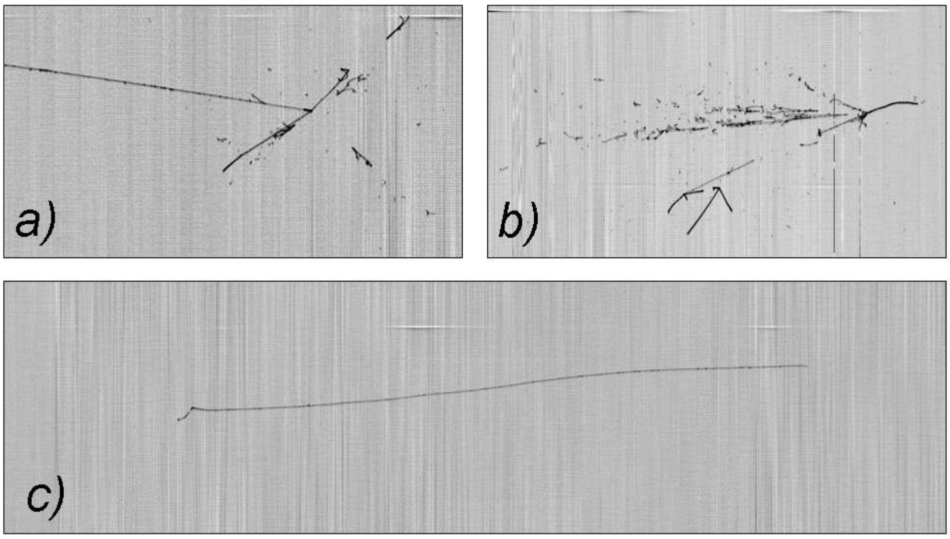

Figure 1: Example of collected events: *a*) a CC ν_μ interaction with two π^0 production; *b*) a NC ν interaction; *c*) a muon, from a neutrino interaction in the rock surrounding the detector, stopping and decaying.

to recognize the presence of two distinct electromagnetic showers pointing to, but detached from, the primary vertex. The associated invariant mass $m^*_{\gamma\gamma} = 125 \pm 15$ MeV/c^2, compatible with the π^0 mass, is determined. The closer photon initial ionization amounts to 2.2 m.i.p. (minimum ionizing particle): this is a clear signature of a pair conversion confirming the expected e/π^0 identification capabilities of the detector.

4 Operation and expectations in 2011-2012

ICARUS T600 detector smoothly started data taking on March 18th 2011 receiving the CNGS neutrino beam operating in high intensity dedicated mode. In the time interval from March 18th to May 23th CNGS delivered 1.7×10^{19} pot. The detector live time in the same period was about 93%, allowing the collection of about 1.5×10^{19} pot. The analysis tools to fully reconstruct the event topology and kinematics are under deployment with the real data, addressing in particular the main items of physics with the CNGS beam, i.e. ν_τ search, ν_e CC identification/measurement and NC rejection capability. A consistent analysis framework unifying all the available tools and allowing to store and share analysis results together with successive refinements by different groups is also being finalized.

It is expected to integrate as much as 10^{20} pot with the CNGS run in 2011-2012. For 1.1×10^{20} pot (including the data taken in 2010) about 3000 beam related muon neutrino CC events are expected in the ICARUS-T600. About 7 ν_e CC intrinsic beam associated events are also expected. Taking into account the $\nu_\mu - \nu_\tau$ oscillation probability and the τ decay branching ratio into $\nu\nu e$, a sufficiently clean separation from intrinsic ν_e CC events will result in 1-2 ν_τ CNGS events expected in ICARUS T600 in next 2 years. On the same beam, the search for sterile neutrinos in LNSD parameter space can be also performed, looking at an excess of ν_e CC events.

ICARUS-T600 is studying also neutrinos from natural sources (atmospheric, solar, supernovae) and it can play a role in the long sought for nucleon decay search, in particular in interesting exotic channels not accessible to Čerenkov detectors. With an exposure of a few years, its sensitivity on some super-symmetric favored nucleon decay channels will exceed the present known limits.

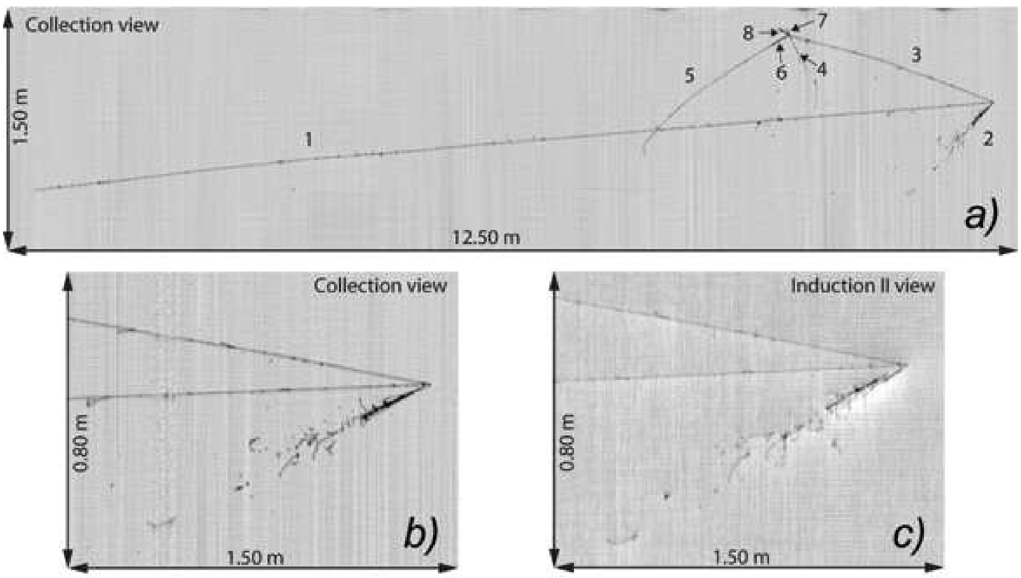

Figure 2: An example of ν_μ CC interaction from the CNGS beam in Collection view *a*); a close-up view of the primary vertex for the Collection *b*) and Induction-2 *c*) projections allow solving completely the event topology.

5 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. It demonstrates to have unique imaging capability, spatial and calorimetric resolutions and the possibility to efficiently distinguish electron from π^0 signals, thus allowing to better reconstruct and identify events with respect to the other neutrino experiments.

This experiment address a wide physics programme. The main goal is to collect events from the CNGS neutrinos beam from CERN-SPS to search for the $\nu_\mu \rightarrow \nu_\tau$ oscillation and LSND-like ν_e excess, 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 detector. 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 [6].

References

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