PROCEEDINGS OF SCIENCE

ICARUS and the status of Liquid Argon technology

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ICARUS-T600 is the first example of an innovative detection technology, the liquid Argon Time Projection Chamber (*LAr-TPC*); A LAr-TPCs can be considered an "electronic bubble chamber"; its 3D reconstruction capability, excellent spatial granularity, tracking and particle identification performances, together with the calorimetric measurement of deposited energy, make it an ideal detector for the study of rare events such as neutrino interactions and nucleon decay. With a mass of 600 tons, ICARUS is the largest LAr-TPC ever built. It has been installed at the Gran Sasso underground laboratory and has been taking data since May 2010. ICARUS is performing a broad physics programme, mainly centered on the study of the neutrinos in the CNGS beam from CERN, but also including neutrinos from natural sources. Preliminary results from the 2010 run with CNGS neutrinos are presented here; they confirm the expected reconstruction capabilities of the detector, and prove that LAr-TPC is a mature technology for neutrino physics.

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1. The ICARUS-T600 detector

The ICARUS-T600 detector is the first large-scale LAr-TPC detector ever built and operated; it has been taking data in Hall B of Gran Sasso Laboratory since May 2010. It is composed by 2 identical modules for a total LAr active mass of 476 t. Each module hosts 2 TPCs with a common cathode; in each TPC the drift length is 1.5 m, and the anode is composed by three parallel wire planes, with wires running in different directions ($0^\circ, \pm 60^\circ$) on each plane. An electric field of $\approx$ 500 V/cm is applied to the LAr bulk. Any charged particle crossing the LAr active volume produces, along its path, ionization electrons which drift along the field. They produce a signal by induction on the first two planes, and are finally collected by the last plane, providing a signal proportional to energy deposition which can be used for calorimetry. The three planes produce a 3D stereoscopical image of any ionizing event occurring in the LAr volume, with a resolution given by the wire pitch (3 mm). A number of photomultipliers (74) are immersed in the LAr volume, in order to detect the scintillation light produced by charged particles, for triggering purposes.
LAr-TPCs are a very suitable detector for rare events studies, such as neutrino oscillation physics and searches for nucleon decay, since they combine large mass and good spatial granularity and calorimetric accuracy. The very good spatial resolution allows a LAr-TPC to fully reconstruct events with high track multiplicity and complex topologies; therefore an efficient signal/background separation can be obtained. In particular, the background given by neutral current interaction with production of π^0, which is critical for ν_e appearance searches, can be reduced by a factor $\approx$ 1000, while keeping more than 90% of ν_eCC events. The good calorimetric response ($\sigma_E/E \approx 11\%/\sqrt{\mathrm{E(GeV)}}$) allows a precise measurement of energy for contained events, while the momentum of non-contained particles (essentially muons) can be measured by multiple scattering.

2. The 2010 physics run with CNGS neutrinos

The ICARUS-T600 TPC was switched on at the end of May 2010 [1]. After some months of commissioning, it started taking physics data in stable conditions with the CNGS beam neutrinos from Oct.1, 2010. Before the CNGS beam stop of November 2010, it collected a statistics of $5.8 \cdot 10^{18}$ protons on target. The trigger used in this period was based on the sum of all PMT signals in a single chamber, discriminated with a fixed threshold of about 100 photoelectrons, in coincidence with a beam gate (width of 60 μs) driven by the early-warning signal sent from CERN at each CNGS beam extraction. The number of identified neutrino events is shown in table 1 and is consistent with expectations.

Event type	Collected	Expected
ν_μ CC	115	129
ν NC	46	42
ν XC (further analysis needed)	7	-
Total	168	171

Table 1: Number of observed CNGS neutrino interaction during the 2010 run. Most of the events flagged XC have vertex close to the detector border, needing a more detailed analysis to identify them as NC or CC.

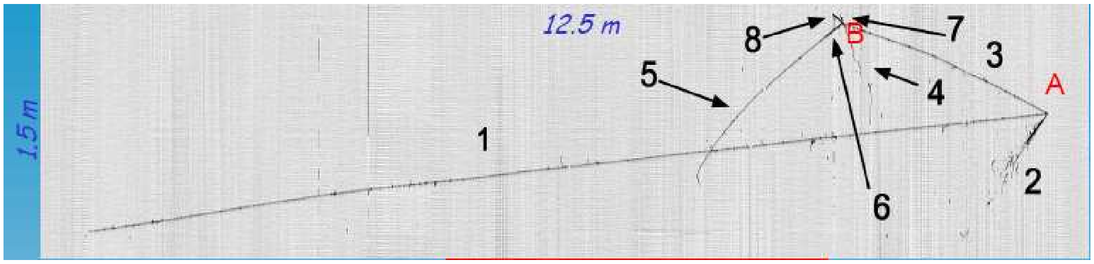

Figure 1: A typical ν_μCC event in ICARUS. The details of vertices and particles are discussed in the text.

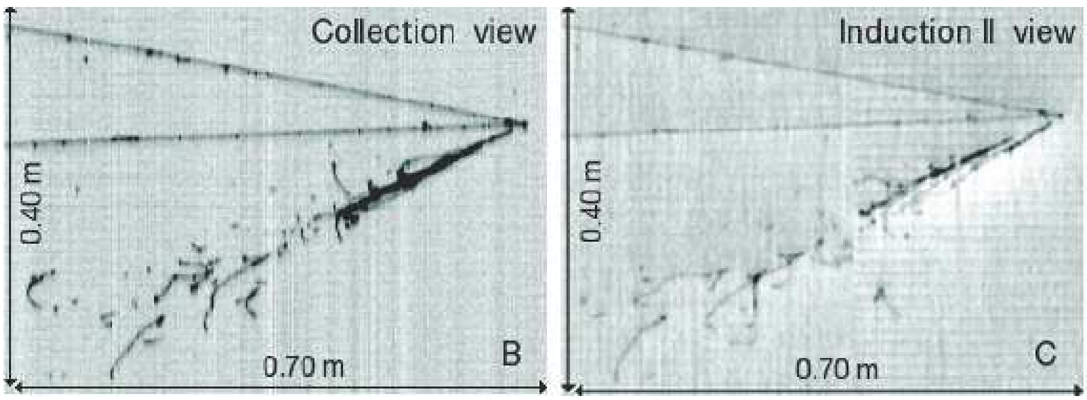

Figure 2: Zoom of the primary vertex region (marked as **A** in the previous figure)in Collection and Induction 2 views.

3. Preliminary reconstruction results

The statistics collected in 2010 is too small to allow physically significant analysis; this sample is therefore used to tune reconstruction and analysis procedures and to characterize the detector performances. A typical ν_μ CC event is shown in figure 1; the event has been fully reconstructed, identifying all particles and evaluating their energy and direction in three-dimensional space. The neutrino interacts in vertex **A**, producing a very long muon (1), a charged pion (3) and an e.m. shower (2). At a closer look, as shown in figure 2, the shower can be identified as generated by a neutral pion; two electron/positron pairs can be resolved, especially in Induction 2 view, and the invariant mass of the two-photon system is measured as $M^*_{\gamma\gamma} = 125 \pm 15$ MeV, consistent with the π^0 mass. The muon escapes the detector volume; its momentum, measured by multiple scattering, is 10.5$\pm$1.8 GeV. In the secondary vertex **B**, the π interaction produces several hadrons; a K decaying into a muon, which in turn decays into an electron, can be seen (5). The total transverse momentum of the event is 250 MeV, consistent with the nucleon Fermi momentum.

The preliminary momentum spectrum of muons from ν_μCC interactions is in agreement with simulations (figure 3 left); the distribution of the total energy deposited in the detector in the same class of events, as measured by calorimetry, also agrees with expectations (fig. 3 right). In general, preliminary results of analysis of 2010 data show that the main ingredients of the event reconstruction procedure (calorimetry, muon momentum measurement via multiple scattering and spatial

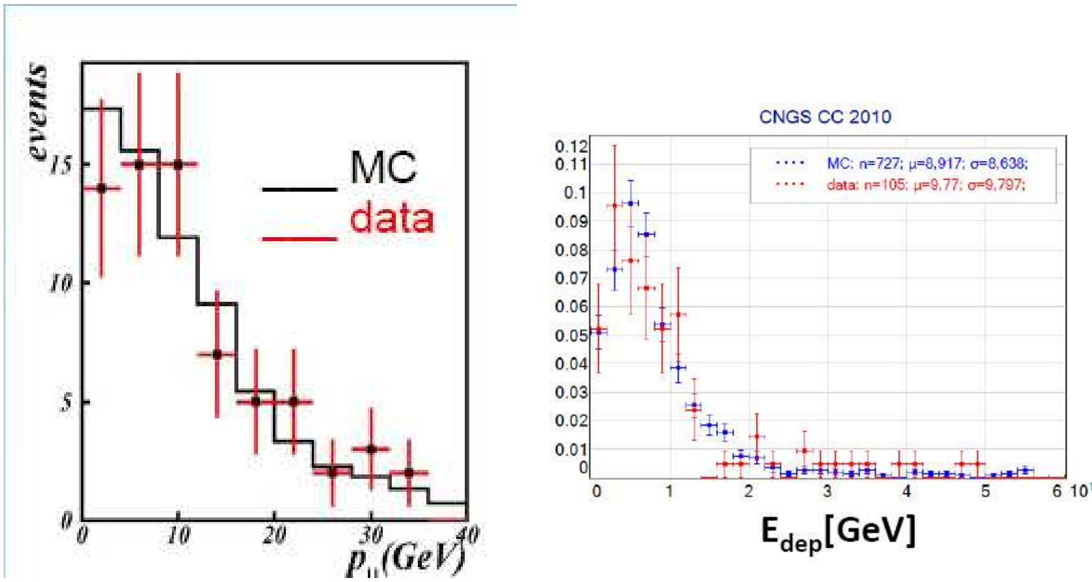

Figure 3: Left: momentum spectrum of muons from ν_μCC interaction reconstructed by multiple scattering, compared with MonteCarlo. Right: distribution of the total deposited energy in ν_μCC interaction events, compared with MonteCarlo.

reconstruction) of the event reconstruction/analysis are well under control.

4. Perspectives and conclusions

ICARUS-T600 is expected to keep taking data in Gran Sasso until the end of 2012, for a total exposure of about $1.1 \cdot 10^{20}$ pot. About $3 \cdot 10^{19}$ pot have already been collected during the 2011 run. The physics programme will be mainly focussed on CNGS beam neutrinos; ICARUS will be able to detect $\nu_\mu \to \nu_\tau$ oscillation by observing 1-2 ν_τ interactions, with a background much lower than one event. It will also investigate the existence of sterile neutrinos by searching for a ν_e excess in the 10-30 GeV region, partially covering the parameter space identified by the LSND signal.
ICARUS will also be able to perform searches of proton and neutron decay, improving the existing limits in some channels, and to detect neutrinos from natural sources such as the Sun, cosmic rays and supernovae. Moreover, it will represent a fundamental milestone in the development of LAr-TPC technology, in view of future larger detectors.

References

[1] C Rubbia et al., *Underground operation of the ICARUS T600 LAr-TPC: first results*, 2011 JINST 6 P07011 doi:10.1088/1748-0221/6/07/P07011