ATMOSPHERIC AND SOLAR NEUTRINO DETECTION WITH THE ICARUS T600 MODULE

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Abstract

A full test of the ICARUS T600 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 showed that the LAr TPC technology is mature for a large mass experimental programme. This paper deals with two of the physics subjects that will be addressed with the T600 module after its installation at the Gran Sasso Laboratory: solar and atmospheric neutrinos.

1 Introduction

The initial physics program with the T600 ICARUS module at Gran Sasso has been recently reviewed and reported in [1]. In this phase the detector mass will be rather limited, but the high efficiency and the detailed information which can be collected for each event will allow the study of some fundamental issues of the present underground physics: the study of interactions of solar, atmospheric and supernova neutrinos and nucleon decay.

The T600 detector and the recent test in Pavia will be briefly described. Subsequently, among the various physics topics envisaged for the T600 run at Gran Sasso, we focus on the solar and atmospheric neutrino issues reporting the main outcomes of dedicated studies [1, 4].

Figure 1: The T600 internal detector inside the first half-module.

2 The ICARUS T600 module

The ICARUS T600 module [2] is a large cryostat divided in two identical, adjacent half-modules (internal dimensions: $3.6 \times 3.9 \times 19.9$ m^3), each one containing more than 300 t of liquid Argon (LAr). Each half-module (Fig. 1) contains two symmetrical Time Projection Chambers (TPC), which share the same cathode, a stainless steel composite plate running longitudinally in the 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, 3 mm apart, and with a relative orientation of 120^0, 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) and is established in the LAr volume of each half-module by means of a high voltage system. In order to maintain the uniformity of the electric field even at the boundaries, the whole sensitive volume is surrounded by an array of tubular rings, the “race tracks” (35 mm diameter and 50 mm apart), kept at fixed voltages by a resistor chain. 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 during the cryostat filling by flowing through an Oxisorb filter. On-line recirculation through the same filter can be activated even when the detector is filled. 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. The e^- lifetime can be directly measured by an array of small, dedicated drift chambers (the "purity monitors" [3]) placed inside the liquid.

The construction of the internal detector was completed by the end of the year 2000. After the mounting of all ancillary equipments (insulation, cooling system, etc.) the T600 was ready for a complete test. The test foresaw the cooling and filling with LAr of one of the two half modules and cosmic-rays data taking. The other half-module, whose presence was needed as part of the cryogenic and insulating systems, was flushed with nitrogen gas. To allow the collection of specific classes of events, (e.g. muons crossing longitudinally the detector) an external trigger system of plastic scintillators was used.
The test took place during the period 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 (very long muon tracks, high multiplicity muon bundles, electromagetic and hadronic showers, low energy events) were recorded. Fig. 2 shows one impressive event, where an air shower core impinges on the detector. The upper view of the figure shows the 2D event image extended to the full length of the the detector (about 18 m) as recorded by both chambers of the active half-module. The bottom image shows a zoomed detail of the event. A feeling of the attainable spatial resolution can be obtained by images such as Fig. 3.
The analysis of the collected events is in progress and will allow us to refine the event reconstruction procedures (i.e. 3D imaging of tracks, dE/dx, particle identification etc.). As an example, a multiple muon bundle completely reconstructed is shown in Fig. 4 as it appears from a 3D analysis program.

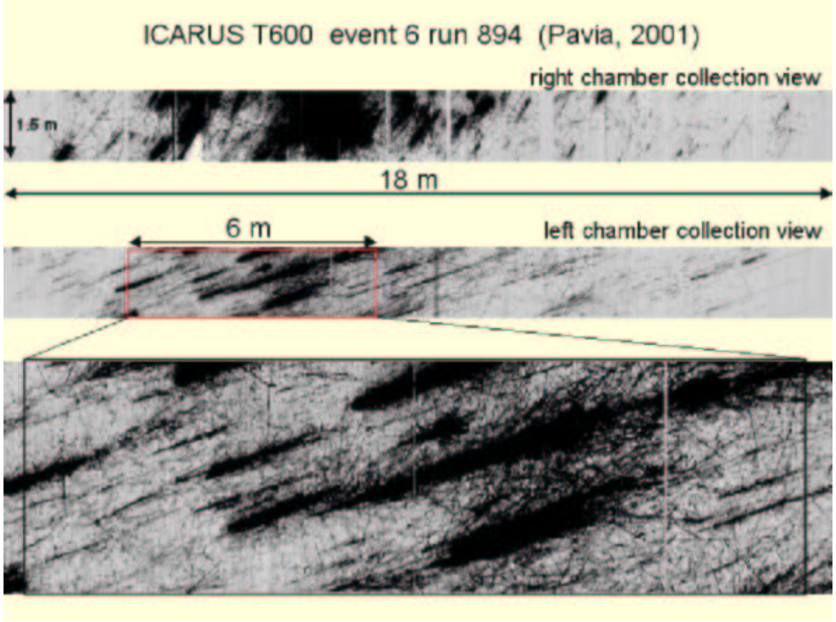

Figure 2: Example of a cosmic-ray event collected during the Pavia test.

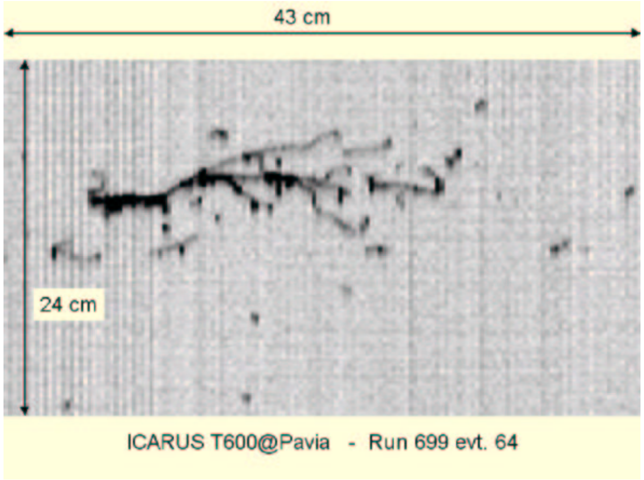

Figure 3: Detail of an event collected during the test in Pavia.

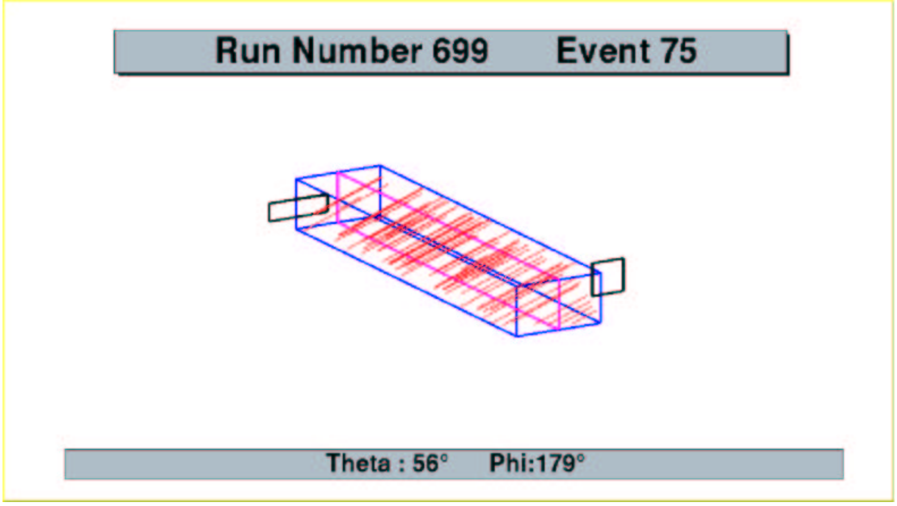

Figure 4: 3D reconstruction of a multi-muon cosmic-ray event.

3 Atmospheric neutrinos

The ICARUS T600 will provide the detection of atmospheric neutrinos with unique experimental features thanks to its performance in terms of resolution and precision. Even complicated final states with multi-hadron products will be thoroughly analysed and reconstructed with the T600 module. However, the capability to observe electron and muon neutrino charged current events and all neutral currents without detector biases down to kinematical threshold will provide a unique new approach to atmospheric neutrino studies. We recall the expected atmospheric neutrino rates obtained per year for an exposure of 2 ktons in Table 1, with and without $\nu_\mu \to \nu_\tau$ oscillation effect ($\sin^2 2\theta = 1$, $5 \times 10^{-4} \leq \Delta m^2 \leq 5 \times 10^{-3}$). It is worth noting that already after one year of the T600 run, about one hundred of high quality events will be collected.

"Muon-like" events contain an identified muon and correspond to $\nu_\mu/\bar{\nu}_\mu$ CC interactions. "Electron-like" are events with an identified electron and are due to $\nu_e/\bar{\nu}_e$ CC interactions. Given the clean event reconstruction the ratio R of muon-like to electron-like events can be determined free of large experimental systematic errors. The expected purity of the samples is above 99% and the contamination from π^0 in the electron-like sample is expected to be completely negligible.

One can further split the muon and electron-like events into "fully-contained" and "partially-contained" samples. The first are those for which the visible products of the neutrino interaction are completely contained within the detector volume. The second are events for which the leading lepton exits the detector volume.

In Table 1 we list the expected event rates classified according to their final state multiplicity. Approximately 60% of CC events contain an identified proton with kinetic energy above 50 MeV in the final state. The detection of a single recoil proton or a multi-prongs (accompanying the leading lepton from CC interaction) final state will provide a precise determination of the incoming neutrino energy and direction thanks to the precise reconstruction of all particles.

Finally, we point out that atmospheric neutrino events in ICARUS can be analysed down to production threshold. We illustrate this by classifying the events according to the energy of the leading lepton (electron or muon). We subdivide the samples into P_{lepton} < 400 MeV and P_{lepton} > 400 MeV. Almost 50% of the expected rate lies in the first sample. Hence ICARUS could really contribute to the understanding of the low energy part of the atmospheric neutrino spectrum.

The presence of neutrino oscillations leads to differences in the predicted rates of upward and downward going neutrino events. For a 2 kton × year exposure, one can measure a clear deficit of upward going muon-like events [1] for the range of oscillation parameters presently allowed by the Super-Kamiokande results.

4 Solar neutrinos

The unique capabilities of the LAr-TPC are suitable to the real-time detection of the neutrinos produced in the Sun. Two independent neutrino reactions contribute to the total expected rate: elastic scattering by electrons (CC+NC reaction) ($\nu_{e,\mu,\tau} + e^- \rightarrow \nu_{e,\mu,\tau} + e^-$) and absorption on Argon nuclei (CC reaction) ($\nu_e + {}^{40}\mathrm{Ar} \rightarrow {}^{40}\mathrm{K}^* + e^-$). The absorption interactions usually result in the production of a primary electron track possibly accompanied by secondary electron tracks of lower energy. The background is mostly due to natural radioactivity. The requirement to establish the electron direction in elastic scattering events imposes a threshold for the detection of primary electrons. This threshold should be of the order of 5 MeV for elastic and absorption events. This implies the detection of the higher energy portion of the solar neutrino ^{8}B spectrum.

Signal to background separation and absorption to elastic scattering signature recognition are based on topological cuts. Elastic scattering events are defined by isolated electron tracks with direction pointing to the Sun. Absorption events are identified by one energetic electron track surrounded by low energy secondary electrons, from gamma conversion following $^{40}\mathrm{K}^*$ de-excitation. These electrons appear as spots of deposited charge in a limited volume around the main track. The

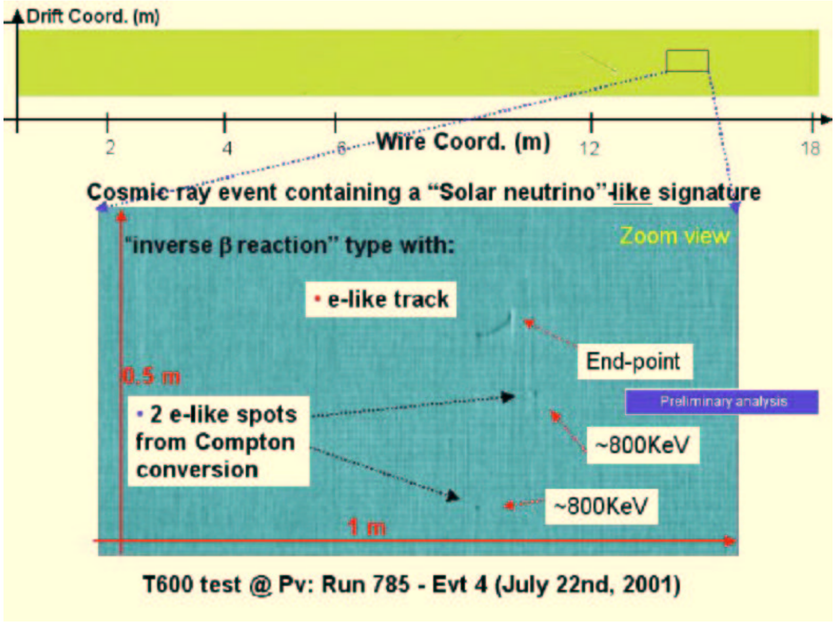

Figure 5: A T600 event showing a solar neutrino like topology (detail).

background is mainly due to neutrons coming from the Gran Sasso rock, according to the results of a measurement performed in Hall C [5]. A measurement of ^{8}B solar neutrinos will be performed in a reasonable data-taking time. Direct proof of the oscillation mechanism in a solar model-independent way will be possible for a vast fraction of the presently allowed parameter region through the comparison of the elastic and absorption event rates, differently affected by oscillation patterns.

The event shown in Fig. 5 collected in the cosmic ray test in Pavia can give a reasonable idea of how a solar neutrino event looks like. The figure represents the whole left TPC, with the wire coordinates on the x axis and the drift time on the y axis. The picture appears almost empty, since no large charge deposition can be observed. However, in the shown zoomed section a small electron track, accompanied by other energy depositions well mimics a solar ν absorption event.

5 Conclusions

The ICARUS T600 module was successfully tested in a surface site. The test opened the way for the installation of the module at the Gran

Sasso Laboratory expected by mid 2003.
The measurements of solar and atmospheric neutrino events with the LAr TPC technique, in which both high visual resolution and accurate calorimetry are combined, will provide additional hints to clarify the scenario of neutrino oscillation.

References

[1] ICARUS Collaboration, "A second-Generation Proton Decay Experiment and Neutrino Observatory at the Gran Sasso Laboratory", LNGS-P28/2001.

[2] 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).

[3] G. Carugno,et al., "Electron Lifetime Detector for Liquid Argon", Nucl. Instr. and Meth. A292, (1990), 580.

[4] ICARUS Collaboration, Nucl. Instr. and Method A 455 (2000) 42.

[5] F. Arneodo et al., "Neutron background measurements in the ICARUS area at the underground Gran Sasso Laboratory", Nuovo Cimento, A8 (1999), 819.

Table 1: Expected atmospheric neutrino rates in case no oscillations occur and assuming $\nu_\mu \to \nu_\tau$ oscillations take place with maximal mixing. Four different Δm^2 values have been considered. Only statistical errors are quoted.

	2 kton×year				
		Δm^2_{23} (eV^2)			
	No osci	5×10^{-4}	1×10^{-3}	3.5×10^{-3}	5×10^{-3}
Muon-like	270 ± 16	206 ± 14	198 ± 14	188 ± 14	182 ± 13
Contained	134 ± 12	100 ± 10	96 ± 10	88 ± 9	86 ± 9
Partially-Contained	136 ± 12	106 ± 10	102 ± 10	100 ± 10	96 ± 10
No proton	104 ± 10	76 ± 9	74 ± 9	68 ± 8	66 ± 8
One proton	82 ± 9	64 ± 8	60 ± 8	58 ± 8	56 ± 7
Multi-prong	84 ± 9	66 ± 8	64 ± 8	62 ± 8	60 ± 8
$P_{lepton} < 400$ MeV	114 ± 11	82 ± 9	80 ± 9	74 ± 9	70 ± 8
$P_{lepton} \geq 400$ MeV	156 ± 12	124 ± 11	118 ± 11	114 ± 11	112 ± 11
Electron-like	152 ± 12	152 ± 12	152 ± 12	152 ± 12	152 ± 12
Contained	100 ± 10	100 ± 10	100 ± 10	100 ± 10	100 ± 10
Partially-Contained	52 ± 7	52 ± 7	52 ± 7	52 ± 7	52 ± 7
No proton	64 ± 8	64 ± 8	64 ± 8	64 ± 8	64 ± 8
One proton	48 ± 7	48 ± 7	48 ± 7	48 ± 7	48 ± 7
Multi-prong	40 ± 6	40 ± 6	40 ± 6	40 ± 6	40 ± 6
$P_{lepton} < 400$ MeV	74 ± 9	74 ± 9	74 ± 9	74 ± 9	74 ± 9
$P_{lepton} \geq 400$ MeV	78 ± 9	78 ± 9	78 ± 9	78 ± 9	78 ± 9
NC-like	192 ± 14	192 ± 14	192 ± 14	192 ± 14	192 ± 14
TOTAL	614 ± 25				