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THE ICARUS T600 EXPERIMENT IN THE GRAN SASSO UNDERGROUND LABORATORY* **

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With a mass of about 600 tons of Liquid Argon (LAr), the ICARUS T600 detector is the biggest, up to now, LAr Time Projection Chamber (TPC). Following its successful test run, on the Earth surface, in Pavia (Italy) in 2001, the detector is now very close to start data taking in the Gran Sasso underground laboratory. The main features of the LAr TPC technique, together with a short discussion of some of the ICARUS T600 test run results, are presented in this paper.

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1. Introduction

The idea of a LAr TPC, proposed in 1977 by Rubbia [1], can be summarized in the following way:

— the electrons, released during LAr ionization, can drift in an electric field, many meters distances, if LAr is pure enough,

— both, the calorimetric measurement of particle energy, and three dimensional particle track reconstruction are provided by non-destructive ionization electron readout by several anode wire planes.

Many years of ICARUS Collaboration R&D studies, with bigger and bigger in mass prototypes, resulted in construction of a LAr TPC cryostat of mass of 600 tons of LAr. More than three months of continuous successful tests on the Earth surface in Pavia (Italy) in 2001 proved that the LAr technique should be considered as an option for a very massive, next generation "rare phenomena", detectors. Presently, the installation of the ICARUS T600 detector in the underground Gran Sasso laboratory is nearly completed. Although, due to the too small mass of the ICARUS T600 detector, fundamental discoveries cannot be expected either in the neutrino physics or in the proton decay searches, the experience gained during its long term underground operation, will be invaluable for the next generation LAr TPCs. In this paper, the ICARUS T600 experimental setup, and some results from the test run, namely the reconstruction of electromagnetic showers, are presented.

2. The T600 ICARUS detector

Four identical TPCs, in two identical T300 half-modules, form the T600 ICARUS LAr detector. The external dimensions of each T300 half-module are the following: 19.9 m (length), 3.9 m (height), and 3.6 m (width). The cathode, placed in the middle of the T300 half-module, is common for each two TPCs. Each TPC has three parallel planes (two induction planes and one Collection plane) of anode wires, parallel to the cathode, placed along the longest walls of the T300 half-module. The anode wires are oriented at 60 degrees with respect to each other, 3 mm apart, with a wire pitch of 3 mm. The total number of wires in one TPC is 13312, *i.e.* 53248 in the T600 detector. To keep LAr in a stable and uniform temperature both, a Liquid Nitrogen circuit and an external thermal insulation are applied. In order to allow the ionization electrons to drift safety towards the anode wires a LAr purification system [2], with purity monitors is used. The "zero" time t_0 of an event is defined by prompt detection of scintillation and Cerenkov light in LAr [3]. The nominal voltage of 75 kV produces a uniform electric field of 500 V/cm, perpendicular to the cathode, over the maximum electron drift length of about 1.5 m. The electrons induce signals on two induction wire planes, whereas the electrons ionization charge is finally collected in the collection wire plane. Such non-destructive signal read-out allows for three-dimensional reconstruction of an event. The detailed description of the T600 ICARUS detector design, construction and test can be found in [4].

3. Electromagnetic shower reconstruction in the T600 ICARUS LAr TPC

In this section, a brief summary of a recently completed analysis of electromagnetic showers is presented. The detailed discussion can be found in [5]. The main motivation for this study is twofold:

— to show the detector capability to distinguish electrons from pions, *i.e.* distinguish ν_e charge current (CC) interactions ($\nu_e + n \to e^- + p$) from ν_μ neutral current (NC) interactions ($\nu_\mu + n \to \nu_\mu + \pi^0 +$hadrons). Because both, e^- from CC interactions and photons from π^0 decays (π^0 decays into 2 γ with a branching ratio of 99%) may develop electromagnetic showers in LAr, this distinction is not straightforward;

— to obtain the electromagnetic shower energy resolution $\Delta(E)/E$ as a function of photon energy E. The reconstruction of π^0 ($\pi^0 \to \gamma\gamma$) well known mass (134.9764 ± 0.0006 MeV, [6]) can be used for energy calibration.

Below, we very shortly present the π^0 invariant mass reconstruction's results. About 30000 cosmic ray events have been collected during more than 3 months of data taking, on the Earth surface, in Pavia (Italy) in 2001. Each of about 7500 images, from 2001 on surface data, has been visually scanned, independently by two laboratories. There are the following scanning criteria:

(1) two or more electromagnetic (EM) showers originating from the same vertex,

(2) no other interactions in the region of EM showers energy deposition,

(3) determination of the t_0 time possible,

(4) both EM showers are fully contained in the detector within at least 3 radiation lengths $X_\gamma = 17.4 \pm 0.8$ cm, and

(5) relative difference $(E_1 - E_2)/[(E_1 + E_2)/2]$ between reconstructed shower energies in two laboratories smaller than 50%, resulted in selection of 97 π^0 candidates.

The reconstruction of the π^0 invariant mass $m_{\gamma\gamma}$

$$m_{\gamma\gamma} = \sqrt{2E_1E_2(1-\cos\theta_{12})} \tag{1}$$

requires measurements of three quantities: EM showers' energies E_1, and E_2 and the angle θ_{12} between two photons originating from the common vertex. The reconstruction procedure consists of the following steps: hit finding (particle tracks consist of hits), hit energy reconstruction, summing up all hit energies belonging to the EM shower, θ_{12} measurement by knowledge of the three starting points (the main interaction vertex, and the two starting points of both EM showers).

The $m_{\gamma\gamma}$ distribution with a mean value of 139.9 ± 2.8 MeV and a $\sigma = 22.6 \pm 2.8$ MeV for the total sample of 97 π^0 candidates, obtained after crowded environment suppression, is shown in Fig. 1. The obtained electromagnetic shower energy resolution $\Delta(E)/E = 33\%/\sqrt{E[\text{MeV}]} \oplus 1\%$.

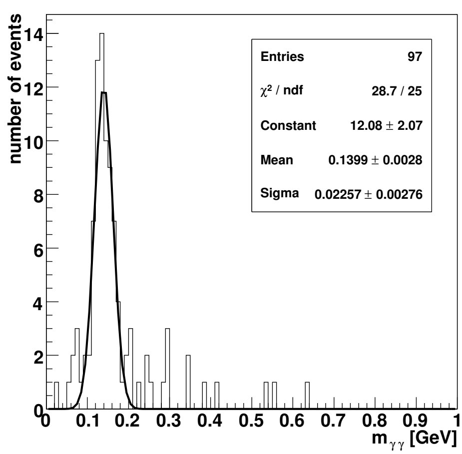

Fig. 1. The $m_{\gamma\gamma}$ invariant mass distribution.

4. Conclusions

The successful operation of the ICARUS T600 detector on the Earth surface proved that the LAr TPC technique can be scaled up to an "industrial" size. The detector installation in the Hall B of the Gran Sasso underground laboratory (LNGS) required two new components of the detection system (see [7]), namely: (1) a closed circuit for liquid nitrogen cooling, and (2) a LAr plant. Both have been built (see Fig. 2) and tested allowing for the detector commissioning.

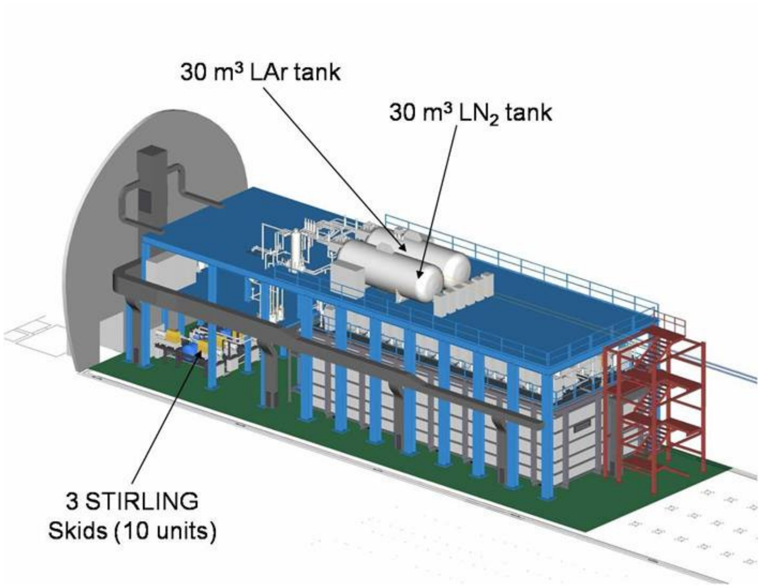

Fig. 2. The ICARUS plant in LNGS Hall B.

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