ICARUS T600 detector overhauling

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INTRODUCTION

The ICARUS T600 detector [1,2] has been successfully operated for three years at the Italian Gran Sasso Underground Laboratory (LNGS), collecting cosmic neutrinos and ν_μ from the CERN-Neutrino-to-Gran-Sasso (CNGS) beam. The ICARUS experiment was completed in 2013, and in December 2014 the detector was moved to CERN for a complete overhaul. The goal was to prepare the T600 for a new life, as part of the Short Baseline Neutrino program (SBN, [3]) at FNAL, dedicated to the definitive clarification of the sterile neutrino hypothesis.

The overhaul at CERN took two and a half years to implement, and it was meant to introduce technology developments, while maintaining the already achieved performance. Among affected components are: the light collection system, the TPC and PMT readout electronics, the cryogenic plant, the HV system. As well, new containers for the detectors were constructed. A Cosmic Ray Tagger is also being implemented, to identify cosmic backgrounds that will abundantly hit the detector in its new deployment station at shallow depth within the SBN program.

REFERNCES

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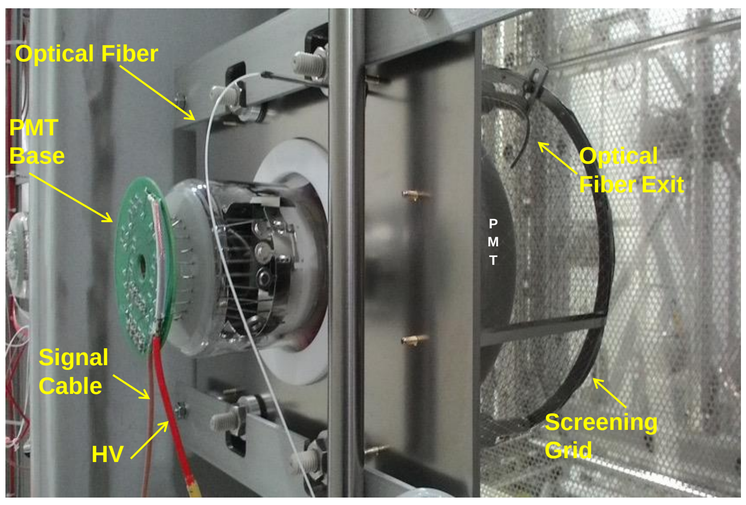
New Large-area PMT installation



New 8'' Hamamatsu PMTs were installed on the TPC frames (90 per TPC, 360 total), with a layout that maximizes the capability to perform elm shower/μ separation with the light signals. A 5% photocathodic coverage is achieved. PMTs were operated and characterized at room temperature (100% of the sample) and in LAr (10%), before installation [4].
They underwent an evaporation process that deposited a thin layer of wavelength-shifter (TPB) on their window, needed to collect UV LAr scintillation light emitted at 128 nm.

New electronics readout, with 1 ns precision, will allow exploiting the bunched structure of the Booster Neutrino Beam (BNB) at FNAL: this in turns helps selecting beam events among the cosmic background, which at shallow depth will fill the detector with multiple light and charge signals.

New Cold and Warm vessels

The new T600 cold vessels, designed and assembled at CERN, are made of double-walled extruded Aluminum profiles, welded together. Afterwards they underwent leak-tightness and mechanical vacuum testing, to certify their reliability. The vessels are surrounded by a passive insulation (polyurethane foam on plywood support) yielding maximal heat loss of 10-15 W/m^2, by design. The same foam is used, coupled to membrane cryostat technology (*www.gtt.fr*), in all the other cryostats built within the Neutrino platform: SBND within the SBN program, as well as the two ProtoDUNE and future DUNE detectors (*www.dunescience.org*)

The ICARUS Cold vessels and insulation are contained in a Warm structure that was designed at CERN and assembled directly at FNAL, in the new building dedicated to the detector.

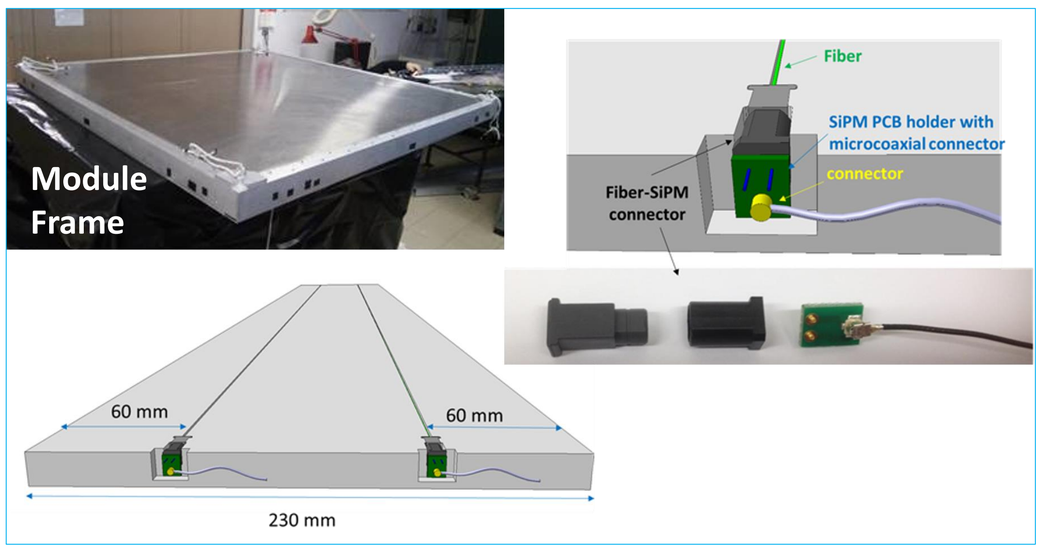
Other activities

- ***Planarization of TPC cathode panels***: these panels presented deviations from planarity of the order of 25 mm (max). Precision physics measurements carried out during the CNGS campaign could reveal the non-planarization of the panels, therefore at CERN they were removed completely and flattened with a thermal treatment. This has reduced the deformation by a factor 10, ensuring higher-precision physics at FNAL, as demonstrated in the analysis of LNGS data on muon momentum measurement with Multiple scattering [5].

- ***New cryogenic plant***: a refurbishment of the system was carried out, while maintaining the same architecture used at LNGS. A *new cold shield*, circulating dual-phase N_2 around the detector vessels has been designed and it has been installed in the warm vessel in the past few weeks. The shield is aimed at intercepting residual heat losses though the insulation.
Purification of Argon will be performed with new copper filters developed at FNAL for O_2 adsorption. Such new solution, which substitutes the well performing Oxysorb/Hydrosorb commercial filters used at LNGS, has been heavily tested at CERN on a small TPC called *FLIC – 50 Liters Icarus Chamber*.
A 30x30 cm^2 wide, 50 cm drift-path, complete LAr-TPC setup, FLIC was very useful during the full overhauling period, to test many new components/solutions, such as the mentioned filters, the TPC readout electronics, the new Hamamatsu PMTs.

- ***Laser Calibration***: each PMT features an optical fibre pointing towards its window centre. At FNAL, a laser system will be installed, to feed light to all the fibre. This will serve for PMT gain calibration before and during the operations.

Cosmic Ray Tagger (top section)

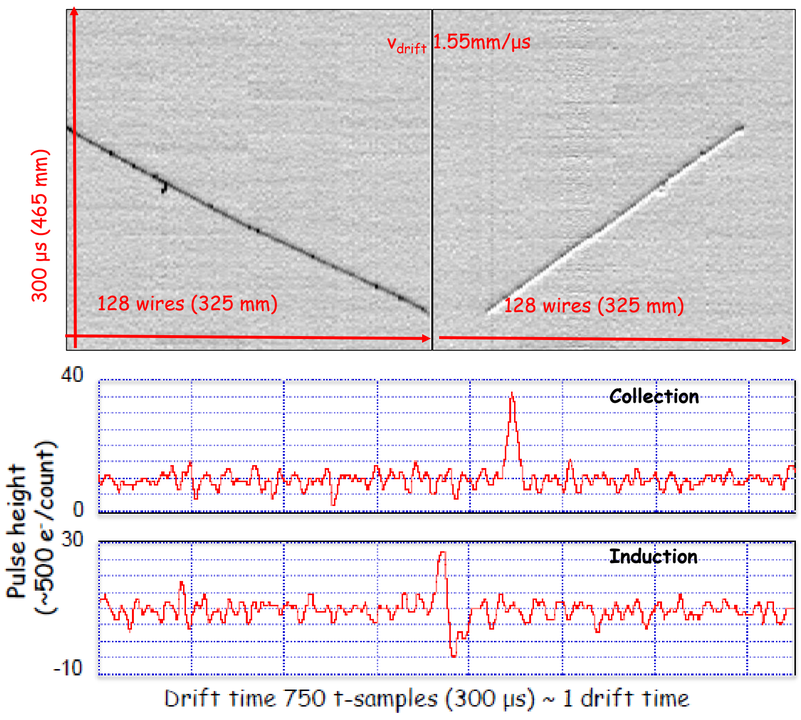


Cosmic rays will represent a significant background for SBN where, at shallow depth, they will hit in large numbers the detector: from simulations and the Pavia test experience [1], on average 12 muons are expected per drift per T300.

The identification of the real triggering event, and then the reconstruction of its true 3D position, requires therefore to correctly associate timing and charge-induced signal of each track in every TPC image. This can be achieved with two main levers, namely: *(i)* the exploitation of the mentioned PMT ~1 ns time resolution, to reject hits out-of-time, w.r.t. the beam spill; *(ii)* the identification of incoming cosmic particles by means of an external system, called a *Cosmic Ray Tagger*, CRT.

The general design of the system foresees a layer of scintillating bars surrounding the T600, providing 98% detector coverage. The bars will be equipped with optical fibers, driving light to SiPM arrays for the readout. The bottom and sides are taken care of by FNAL, who has recovered modules previously installed on Double Chooz and Minos detectors, respectively. The Top section is under CERN/INFN responsibility, and it will feature 122 modules made of two layers of bars (around 2000 bars in total), for precise 2D localization. At CERN, scintillating bars with different characteristics and materials were tested, as well as the interconnection between the fibers and the bars. Two wavelength-shifting fibers per bar will collect the light and bring it to SiPM's with an active area of 1.3 x 1.3 cm^2. Modules production is now underway. The estimated tagging efficiency of the Top-CRT alone is of 80%.

Renovated warm electronics chain – tests at CERN



TPC wire readout will feature a new warm electronic chain, mainly developed by INFN-Padova, exploiting the same architecture of the previous one, while profiting of newer, higher-performing components and technologies developed during the last twenty years. Each single read-out board hosts 64 front-end low-noise charge sensitive pre-amplifiers, 64 serial 12 bit ADC (2.5 MHz), FPGA, memory, and optical link interface. Specially designed minicrates house 9 Boards (576 wires), and connect directly to custom feedthrough flanges of the cold vessel (see above figure, Left). Achieved miniaturization allows minimizing the occupancy of the detector roof, as in LNGS.

Multiple test campaigns at CERN helped finalize the architecture. Last results shown above are obtained by collecting cosmic muon tracks with the FLIC setup (see above). FLIC represents the perfect low-noise environment to test the new electronics, as it can accommodate readout cables with the similar length as the ones to be used for the T600. The analyzed data show rms noise of ~2 ADC counts, i.e. ~1000 e-, on both planes. The unipolar Collection signal is around ~25 ADCc high, while the bipolar Induction signal structure is symmetric and almost un-distorted even in the case of heavily-populated showers. This leads to clear track separation even for crowded events, and to the possibility of charge measurement, even in the Induction views.

In the same way, a new set of Decoupling and Biasing Boards, to decouple HV bias and signal on TPC wires, has been developed by INFN-PD and CERN jointly. These DBBs will be installed at FNAL on the inner face of each custom feedthrough flange during the phase of electronics deployment.

STATUS OF THE PROJECT

The main part of the overhauling program has been completed in March 2017, when both modules of the T600 had been equipped with the new components, and their vessels were ready. Once inserted in their vessels [6], the detector modules were shipped to FNAL in June-July 2017. A very delicate operation in itself, developed over more than an year, the shipment saw the T600 navigate the Rhein river in Europe, the Atlantic Ocean and the Great Lakes, before getting to FNAL [7]. Before insertion into their new building, the modules are undergoing final preparatory activities.

T600-related activities do continue at CERN, within the framework of the Neutrino Platform: among these, procurement and production of the Top Cosmic Ray Tagger, tests on PMT-based triggering, validation of the TPC electronics series-production. At the same time, activities and personnel started to move at FNAL, where the installation of the detector and its commissioning is about to begin.