PROCEEDINGS OF SCIENCE

The Cosmic Ray Tagger system of the ICARUS detector at Fermilab

Francesco Poppi (on behalf of the ICARUS Collaboration)[a,b,*]

[a] *Dipartimento di Fisica e Astronomia, Università di Bologna, 40127 Bologna, Italy*
[b] *Istituto Nazionale di Fisica Nucleare, INFN Sezione di Bologna, 40127, Italy*

E-mail: francesco.poppi@bo.infn.it

The goal of the Short Baseline Neutrino program at Fermilab is to confirm, or definitely rule out, the existence of sterile neutrinos at the eV mass scale. The program searches for ν_e appearance and ν_μ disappearance signals from the $\nu_\mu \rightarrow \nu_e$ oscillation in the Booster Neutrino Beamline. Neutrino interactions will be observed by two Liquid Argon Time Projection Chamber detectors at near (100 m) and far (600 m) positions from the neutrino source. The Far Detector (ICARUS T600) is a high granularity uniform self-triggering detector with 3D imaging and calorimetric capabilities allowing to reconstruct ionizing events with complex topology. ICARUS T600 is located on surface. A 4π Cosmic Ray Tagger system was installed in order to mitigate the background induced by cosmic muons. The Cosmic Ray Tagger will identify muons crossing the detector with a resolution of few ns during the 1 ms drift time window of the Time Projection Chamber. In this paper an overview of the Cosmic Ray Tagger system, its role and performances as a tagger system are presented.

41st International Conference on High Energy physics - ICHEP2022
6-13 July, 2022
Bologna, Italy

*Speaker

PoS(ICHEP2022)580

1. SBN and ICARUS-T600 at Fermilab

The Short Baseline Neutrino program (SBN) at Fermilab consists of three Liquid Argon Time Projection Chamber (LArTPC) detectors located along the Booster Neutrino Beamline (BNB) [1]. This program aims to perform the most sensitive search for sterile neutrinos at eV mass-scale through the analysis of both the ν_e appearance and ν_μ disappearance oscillation channels. SBN will be the first short-baseline neutrino program exploiting a near and far detector structure with similar technologies (LArTPC). The near detector, SBND, is located 110 m from the BNB target; with a total active mass of 112 t of LAr it will characterize the muon-neutrino beam before the oscillation. MicroBooNE, with an active mass of 87 t of LAr, is located 470 m from the BNB target. It began data acquisition in October 2015 and recently published its results on the MiniBooNE Low Energy Excess (LEE) [2][3]. The Far Detector, ICARUS-T600, is situated 600 m from the BNB target and has an active target mass of 476 t of LAr.

The ICARUS T600 detector is composed of two identical modules 19.6 (L)$\times$ 3.6 (W) $\times$ 3.9 (H) m^3 each. Each module is divided in two TPCs sharing a common central cathode at 75 kV, generating an electric field of 500 V/cm along the 1.5 m drift length [4]. The anode planes in each TPC are three parallel wire planes oriented at 0° and ± 60° with respect to the horizontal direction. Behind the anodic planes, each TPC is instrumented with 90 PhotoMultiplier Tubes (PMTs), for a total of 360 PMTs, to detect the scintillation light and generate the event trigger.

2. The cosmic background

The SBN Far Detector building is located at ground level. The ICARUS detector is thus exposed to a rate of ~11 kHz of cosmic particles. Cosmic particles entering the detector during the 1.6 μs BNB neutrino beam-spill interact in the liquid argon generating scintillation light and an event trigger, the so-called in time activity. The out of time cosmic activity corresponds to cosmic muons crossing the detector during the ~ 1 ms TPC drift time. On average ~ 11 cosmic tracks are expected over the full T600 volume during the drift window, generating a background that has to be disentangled from the neutrino event tracks.

In order to mitigate the cosmic background, ICARUS is instrumented with a Cosmic Ray Tagging (CRT) system ensuring a 4π coverage of the detector. Additionally, 3 m of concrete overburden (OB) is placed above the CRT. The overburden is composed of three layers of concrete blocks of 1 m height each. The reduction of the cosmic activity in ICARUS provided by the overburden is reported in Table 1. In Figure 1 (left) a picture of the roof of the detector after the

Particle	without OB	with OB
$\mu^\pm$	15.5	11.5
p	<0.045	$\ll$0.001
γ	<0.01	0
n	<0.45	$\ll$0.01

Table 1: Expected number of cosmic particles crossing the active liquid argon volume of ICARUS during the 1 ms drift time.

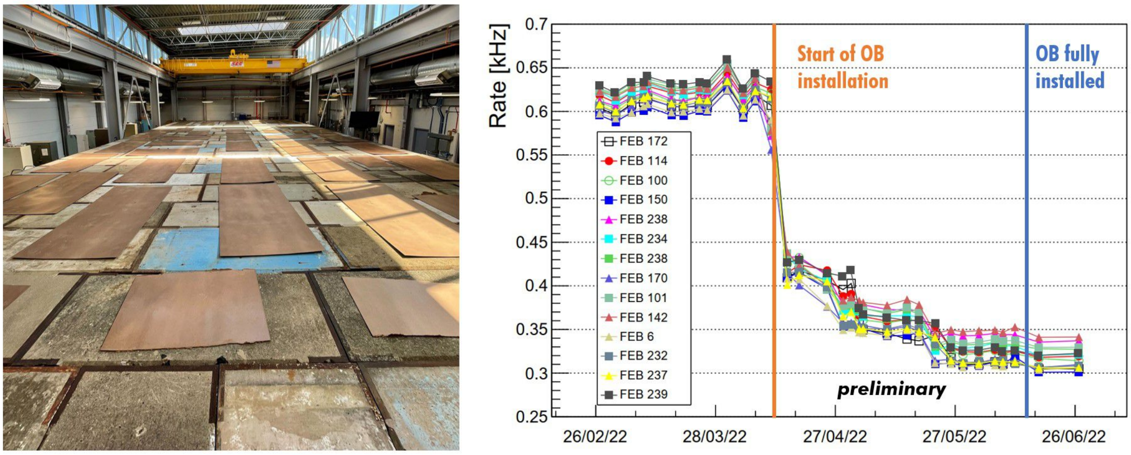

Figure 1: Left: picture of ICARUS after the full installation of the 3 overburden concrete layers. Right: average trigger rate as a function of time for a sample of Top CRT harizontal modules; the rate decrease follows the progress of the overburden installation.

completion of the overburden is shown. The average rate for each Top CRT module of the horizontal plane decreased from ~ 620 Hz to ~ 330 Hz after full overburden deployment. The average rate versus time for a sample of horizontal Top CRT modules is presented in Figure 1 (right).

3. Cosmic Ray Tagging System

The CRT system is a sub-detector external to the LArTPC aiming at identifying charged particles entering the active volume of the detector. The CRT system provides spatial and timing coordinates of the tagged particles, in order to match them with the tracks reconstructed in the TPC. It is divided into three different sub-systems, each deployed over different regions of the TPC: Top CRT, Side CRT and Bottom CRT.

The Bottom CRT consists of 14 modules situated under the detector warm vessel. Each module is composed of two layers of parallel scintillator strips readout by PMTs. The Bottom CRT is currently under maintenance and work is ongoing for its integration in the data acquisition system. In Figure 2 (right) a picture of the Bottom CRT modules on the ground pit of the ICARUS building before the installation of the cryostat is shown.

The Side CRT provides coverage of the four sides of the detector: north, east, west and south sides. Each Side CRT module is composed of 20 scintillator strips readout on both ends by Silicon PhotoMultipliers (SiPMs). On the east, west and north sides the CRT panels are installed in two parallel layers, while on the upstream wall (south) they are arranged orthogonally. A picture of the fully installed and commissioned Side CRT is presented in Figure 2 (right).

The Top CRT intercepts ~ 80% of the entering cosmic muons. It consists of 123 modules: 84 horizontal modules cover the top of the cryostat and 39 modules are installed vertically along the rims of the horizontal plane. Each module consists of two orthogonal layers of scintillators of different thicknesses: 15 mm for the bottom layer and 10 mm for the top one. Each layer is composed of 8 scintillators 23 cm wide and 184 cm long, readout at one end by two SiPMs. A

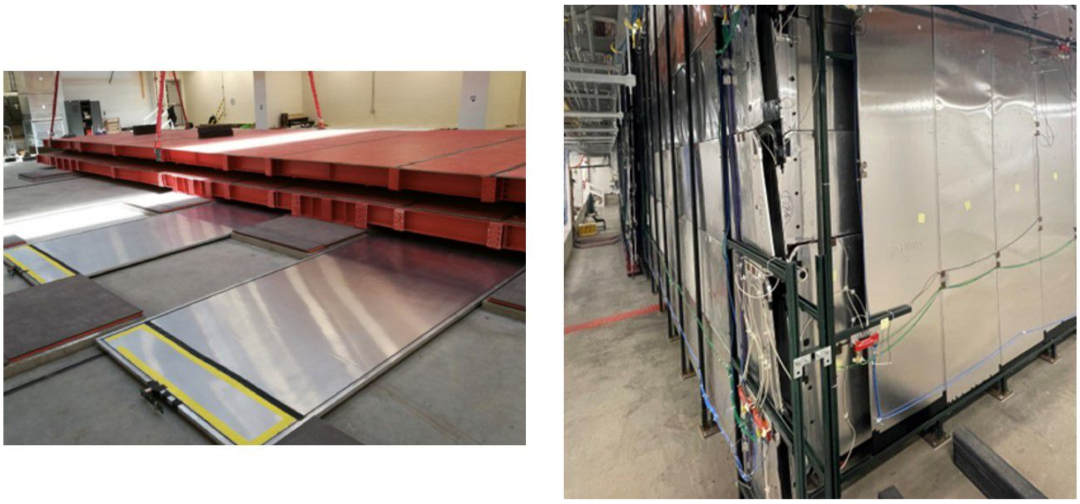

Figure 2: Left: picture of the Bottom CRT on the ground pit of the ICARUS cryostat. Right: picture of the south-west corner of ICARUS fully covered by the Side CRT modules.

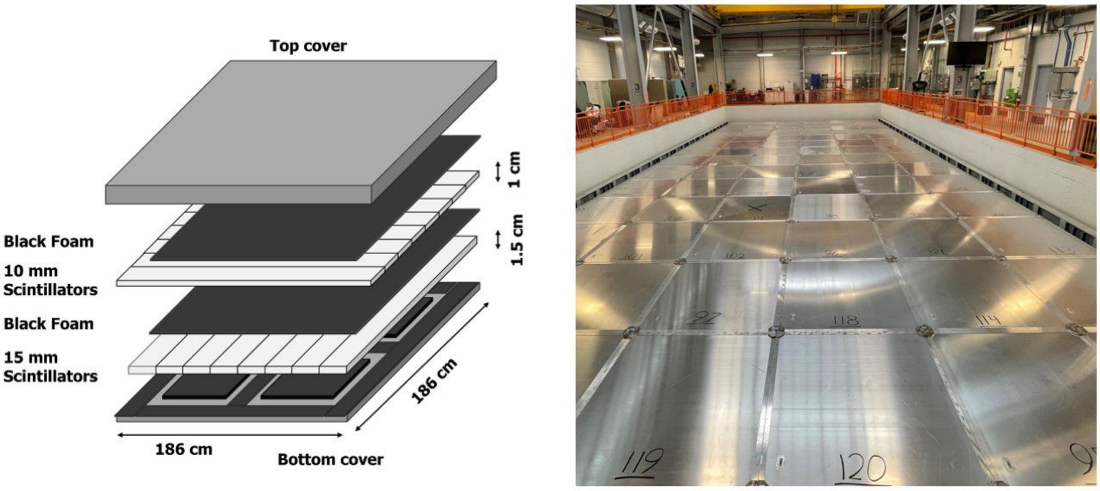

Figure 3: Left: illustration of the Top CRT module and its different components. Right: picture of the horizontal plane of the Top CRT system fully installed on top of the ICARUS detector.

sketch of the Top CRT module and its components is shown in Figure 3 (left), while in Figure 3 (right) a picture of the horizontal planes of the Top CRT system after its full installation is presented.

4. CRT calibration and performances

Both the Side and Top CRT systems exploit a common Front End Board (FEB) for the biasing and readout of 32 SiPMs per module. Each FEB allows a precise (~ns) timing of the cosmic tagged particle (CRT hit) thanks to an internal counter reset every second by a Pulse-Per-Second (PPS) commonly distributed to the whole detector. The timing of the CRT system has been verified by

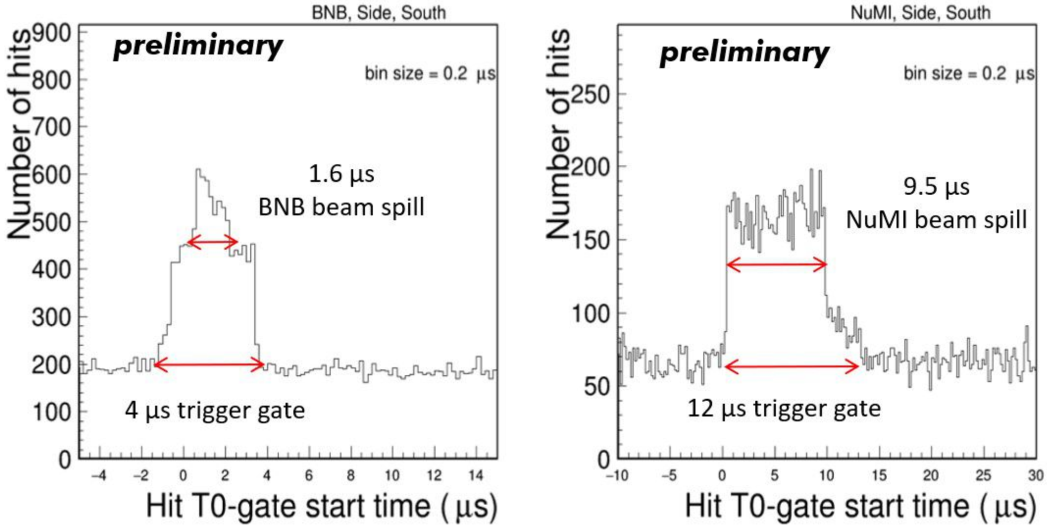

Figure 4: Excess of CRT Hits observed in the Side CRT (south wall) for the BNB (left) and for the NuMI (right) beamlines.

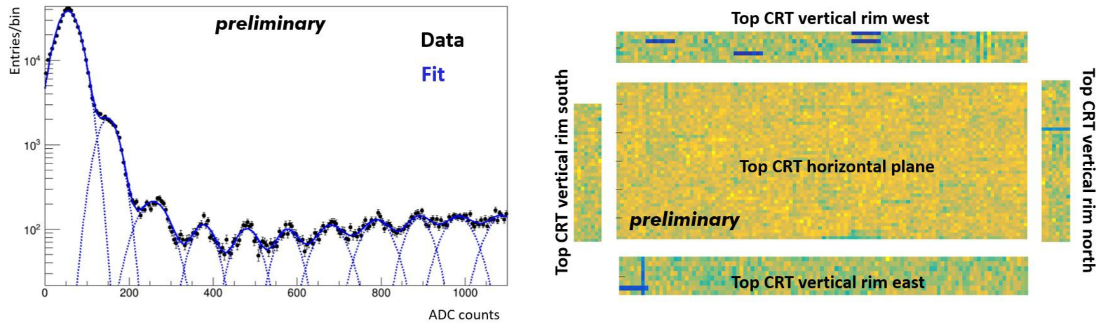

Figure 5: Left: plot of the ADC spectrum of one channel of the Top CRT with overlayed the fit of the pedestal and the consecutive PE peaks. Right: distribution of the CRT hits reconstructed in the different regions of the Top CRT. Blue regions correspond to mulfunctioning channels.

observing in Side CRTs the excess of hits within the spill gates of the BNB and NuMI beams (see Figure 4). The CRT hit excess is due to muons generated from the neutrino interactions in the rock.

A channel-to-channel calibration has been performed for all the Top and Side CRT modules. The calibration was obtained by fitting the ADC spectra of each channel to extract pedestal values and the SiPM gain, evaluated as the distance of consecutive single Photo-Electron (PE) peaks. An example of a channel ADC spectrum for the Top CRT is presented in Figure 5 (left) with overlayed the fit of each single PE peak. The calibration results are used to confirm stability of the CRT system and to perform the conversion between ADC and PEs.

The CRT hit timing is provided by the associated timestamp generated by the Front End Board. The spatial information is obtained by first reconstructing the hit position within the module local coordinate system and then re-mapping it to the global coordinates of the detector. The distribution of reconstructed CRT Hits on the Top CRT sytem is shown in Figure 5 (right).

5. Conclusions and perspectives

The Top and Side Cosmic Ray Tagger systems of the ICARUS detector have been fully commissioned and are actively taking data with the other detector components. A full channel-to-channel calibration has been performed and is progressively updated along with the data acquisition. The ongoing effort of measuring the precise timing of the system with an accurate evaluation of systematics is carried on in order to achieve a synhcronization with the other detector components, thus allowing to identify background events generated by cosmics.

References

[1] M. Antonello *et al.* [MicroBooNE, LAr1-ND and ICARUS-WA104], 'A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam', [arXiv:1503.01520].

[2] P. Abratenko *et al.* [MicroBooNE Collaboration], 'Search for Neutrino-Induced Neutral-Current Δ Radiative Decay in MicroBooNE and a First Test of the MiniBooNE Low Energy Excess under a Single-Photon Hypothesis', Phys. Rev. Lett., Volume 128, Issue 11, 2022, [10.1103/PhysRevLett.128.111801].

[3] P. Abratenko *et al.* [MicroBooNE Collaboration], 'Search for an Excess of Electron Neutrino Interactions in MicroBooNE Using Multiple Final-State Topologies', Phys. Rev. Lett., Volume 128, Issue 24, 2022, [10.1103/PhysRevLett.128.241801].

[4] C. Rubbia *et al.* [ICARUS Collaboration], 'Design, construction and tests of the ICARUS T600 detector', Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 527, Issue 3, 2004, [https://doi.org/10.1016/j.nima.2004.02.044.].