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First data from the commissioned ICARUS side cosmic ray tagger

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The ICARUS detector will operate at shallow depth and therefore it will be exposed to the full surface flux of cosmic rays. This poses a problematic background to the electron neutrino appearance analysis. A direct way to suppress this background is to surround the cryostat with a detector capable of tagging incident cosmic muons with high efficiency (>95%). A Cosmic Ray Tagger (CRT) has been produced based on extruded organic scintillator, wavelength-shifting fibers, and silicon photomultipliers and multi-anode photomultiplier tubes. The installation of the ICARUS CRT side wall hardware is complete and commissioning of the system is underway. In this paper, we describe the status of the integration of the CRT readout and analysis of first data from the commissioned side CRT system.

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1. Introduction

The primary goal of the Short Baseline Neutrino (SBN) program [1] is to address observed anomalies that may originate from short baseline neutrino oscillations and to search for evidence of the existence of light sterile neutrinos with unprecedented sensitivity in eV^2 mass range. SBN has the near and far detectors, installation of the near detector is anticipated in about one year. An important background to the electron neutrino analysis arises from cosmogenic photons that generate electrons in the LAr detector via Compton scattering or pair production interactions that are misidentified as a single electron. Mitigation of such cosmic ray backgrounds is needed for each of the SBN detectors. We considered a two-fold strategy. Firstly, by installation of a 3-m of concrete overburden that will reduce lower energy particles in the flux of cosmic rays in both detectors. Secondly, instrumenting with a Cosmic Ray Tagger (CRT) system able to associate particle tracks observed in the Liquid Argon Time Projection Chambers (LArTPC) [2] with cosmic ray activity.

2. ICARUS Cosmic Ray Tagger (CRT) system

The ICARUS CRT consists of three subsystems namely top, side and bottom surrounding to the TPCs (Figure 1). The top part has all newly made plastic scintillator modules covering 400 m^2 above the cryostat and encounters about 80% of the cosmogenic muon flux that enters into the cryostat. Double Chooz modules originally build for the Double Chooz experiment are used for bottom portion of the CRT. These modules are placed below the cryostat. For the side CRT we recycled modules from the MINOS detector, which had been decommissioned. In total 173 modules were gifted to ICARUS for use in the CRT and these module were extracted from the Soudan Mine and shipped to Fermilab. Side CRT provide enough coverage, about 450 m^2, for the sides of the cryostat and reduces 20% of intercepted cosmic flux. However in the north side coverage is reduced due to space constraint in the building (Figure 2 (left)). Simulation study reveals that with this coverage a 97% geometric efficiency is achieved for intercepting muons that enter the cryostat. The relevant parameters for the different CRT subsystems are summarized in Table 1.

	Top	Side	Bottom
Scintillator	cast	extruded	extruded
Composition	polystyrene 2% pTP 0.05(0.03)% POPOP	polystyrene 1% pTP 0.03% POPOP	polystyrene 1% pTP 0.03% POPOP
Reflector	paint	coextruded TiO_2	coextruded TiO_2
LxWxH [cm]	184x23x1(1.5)	800x4x1	322x5x1
Strip Configuration	8 per layer, 2 layers X-Y	20 1 layer, Y	32 per layer, 2 layers X-X
Photodetector	S13360-1350CS (SiPM)	S14160-3050HS (SiPM)	H8804 (MAPMT)
No. of Optical fiber/Strip	2	1	1

Table 1: Various components are summarized for the different ICARUS CRT subsystems.

In the MINOS detector, PMTs were used as photosensor. These PMTs and front-end electronics

Figure 1: The installed top CRT, side CRT (east side) and bottom CRT surrounded by cryostat. Note: In the middle figure the large tank is a cryogenic pump.

could be used; however, the electronics were not designed to operate at the kHz rates associated with surface running ICARUS detector. Additionally the scintillator had aged enough to cause a meaningful drop in light yield that could impact their performance. Therefore a new SiPM-based photon readout system was developed. In side CRT, each module consists of 1 layer of 20 strips with dimension of 800 (L) x 4 (W) x 1 (H) in cm. Each strip contains a single WLS fiber read out at both ends. Two strips are optically ganged on a single SiPM on each end for a total of 20 channels per module. A single end of three modules is read out by a single CAEN front-end board.

3. Front end board electronics

The front-end boards (FEBs) used by the SBN program were designed by Igro Kreslo et al. and developed at the University of Bern (produced commercially by CAEN) [3]. The functionality of the Bern FEB design is summarized below. The FEB provides bias voltage in the range of 20-90 V individually adjustable for each of 32 SiPMs channels connected in one module. It provides amplification and shaping in the SiPM output pulse on each of 32 channels and discrimination of shaped signals at configurable level equivalent to 0 to 50 photoelectrons (PEs). The coincidence of signals is formed by each pair of adjacent channels (optional) and allows for triggering only on events that are validated by external signals, such as by a signal in a group of other FEBs. It also generates a trigger for digitization of all 32 signal amplitudes and a time stamp with respect to the input reference pulse with an accuracy of 1.3 ns RMS. It provides: the digitization of the signal amplitude of each of the 32 channels; on-board data buffering; efficient back-end communication based on the 100 Mbps Ethernet standard. It also allows for firmware upgrade via back end Ethernet link. Finally, it requires input power 5 V with the consumption ranging from 450 mA to 550 mA depending on channel configuration. The FEB was originally designed to readout a single CRT module consisting of 16 scintillator strips, each with two wavelength shifting (WLS) fibers. SiPMs are known to be noisy devices with typical dark rates in the range of kHz–MHz. To reduce the rate of false triggers due to dark noise, an approximate 30 ns coincidence gate is applied to channels x and x+1 with x = 0,2,4,...,30. Furthermore, the FEB can be configured to require an external validation signal in order to trigger a readout. The FEB is provided with a buffer of a capacity of 1024 hits and can work with triggers up to 37 kHz with a FEB delay time of 27 μs.

4. CRT simulation

Cosmic ray fluxes have been simulated with the CORSIKA code [4] as implemented in the LarSoft framework [5]. Cosmic primaries are sampled from a data library generated by CORSIKA uniformly distributed across top of the cryostats, in a surface extending by 10 m on each side. Each particle with kinetic energy $E_K \geq 50$ MeV is then extrapolated back to a surface placed 18.5 m above the center of the TPCs and fed as input to the MC simulation. These particles are then propagated with GEANT4 [6] through the experimental setup, together with all their secondaries, down to 1 MeV threshold. Next step is the CRT detector simulation, the task involved in it is to convert energy deposited in the scintillator strips into an analog SiPM signal. The analog signal is then fed into the detector readout simulation, simulating the front-end electronics, including gain, charge resolution, threshold, time stamp generation, and trigger logic. Therefore, the detector simulation [7] is reproducing the data obtained from measurement.

5. CRT hit reconstruction

The first step in the reconstruction chain is to construct CRT hits defined as points in space and time corresponding to a muon track crossing the CRT volume. At first, CRT data coming from FEB readouts in a given event are ordered in time and grouped by CRT region. In the side CRT we perform coincidence between FEBs residing in adjacent layers (additionally, there can be multiple FEB readouts within the same layer). However, in the Top or Bottom CRT as each module is a self-contained coincidence unit. In order to identify a coincident grouping of CRT data objects, we perform a software based coincidence gate. The hardware based coincidence gate width is 150 ns and same value is considered as the minimum for the software gate. The reason for not making the coincidence window too large is to avoid introducing fake coincidences from low energy events. After creation of coincident groupings of CRT data, the spatial information is extracted to reconstruct the position of the crossing track. The channel with the largest amplitude is the channel that generated the FEB trigger signal by considering all channels and all FEB in a coincidence grouping of CRT data. The channel position is identified and extracted from the geometry based on the global coordinates of the ICARUS building. The hit position is taken as the mean strip position where a track crosses multiple strips in each layer.

The time stamp is generated when the charge amplitude exceeds the discriminator threshold and several correction factors have been applied to obtain the most accurate time stamp: first, the time walk correction, due to the fact the larger the amplitude is, the shorter is the rise time of the signal. This relationship is established by measurement and can be corrected using a charge dependent correction factor. Second, there is jitter on the front-end board clock. This is corrected by a simple scale factor determined by taking the ratio of the measured to the assumed PPS period. Third, the propagation time experienced by the scintillation light propagating from the point of interaction to the photodetector. Furthermore, we correct all the timing cable delays, different from FEB to FEB.

We validated the hit reconstruction algorithm and compared the data with MC. The Figure 2 (middle) shows the hit positions in x-direction in the east-south wall. The larger peak in the middle refers the mean position of two layer of side CRT and two smaller peaks corresponds to

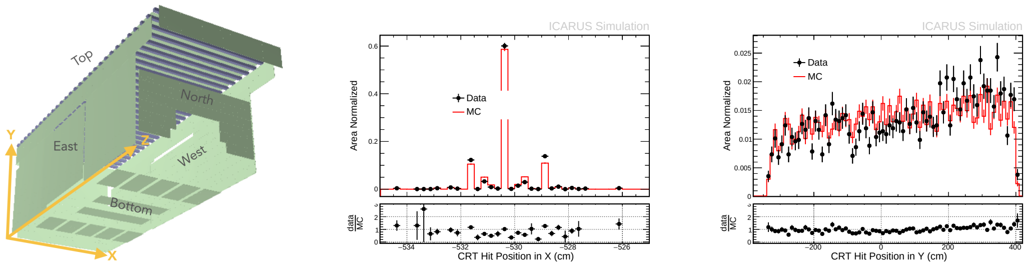

Figure 2: A sketch of the CRT geometry with coordinates (left). Side CRT reconstructed hit position in x-direction (middle) and y-direction (right) for the east-south wall.

inner and outer layer. In the right figure we are observing more data compared to MC in the higher y-direction (vertical) mostly due to low energy particles. The achieved level of performances on hit reconstruction is satisfactory for the further use in the high level of reconstruction such as CRT tracks and matching between CRT hit and light signal as well as CRT hit associating to TPC tracks; nevertheless, based on current known limitations, plans for further improvements underway.

6. Conclusion

ICARUS is currently collecting and analyzing neutrino data. In parallel we have commissioned and collected data with the side CRT. The Top CRT has been fully installed and commissioning is in progress.

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References

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

[2] C. Rubbia, *Searching for short baseline anomalies with the LArTPC detector at shallow depths.*, [`arXiv:1408.6431 (2014)`].

[3] M. Auger et al., *Multi-channel front-end board for SiPM readout*, JINST 11 (2016), no.10, P10005

[4] `https://www.iap.kit.edu/corsika/`

[5] `https://larsoft.org/`

[6] S. Agostinelli et al., *Geant4 - a simulation toolkit*. Nuclear Instruments and Methods in Physics Research A 506 (2003) 250-303.

[7] Christopher M. Hilgenberg, *Cosmogenic Background Rejection for the sterile neutrino search with the short baseline neutrino program far detector*, `SBN-docdb:19166-v1`.