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Study of cosmic rays in the ICARUS-T600 detectors

Magda Cicerchia[a,*] **on behalf of the ICARUS collaboration**

[a] *University of Padova and INFN Sezione di Padova, via Marzolo 8, 35131 Padova, Italy*

E-mail: magda.cicerchia@unipd.it

The ICARUS liquid argon TPC was moved to Fermilab after a successful three-year long run at INFN-LNGS. Currently, ICARUS-T600 is collecting data exposed to Booster Neutrino beam and NuMI off-axis beam to clarify within SBN program the existence of sterile neutrinos. A light detection system, based on PMTs deployed behind the TPC wire chambers, is in place to detect vacuum ultraviolet photons produced by ionizing particles in liquid argon. This system is fundamental for the detector operation, providing an efficient trigger and contributing to the 3D reconstruction of events. Moreover, since the TPC is exposed to a huge flux of cosmic rays due to its shallow depths operations, the light detection system allows for the time reconstruction of events, contributing to the identification and to the selection of neutrino interactions within the beam spill gates. In this contribution preliminary comparison of MC simulation with DATA are presented for the light signal of cosmic muon.

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*Speaker

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1. Short Baseline Neutrino program at Fermilab

The primary goal of the Short-Baseline Neutrino (SBN) program at Fermilab is to investigate the possible existence of 1 eV mass-scale sterile neutrinos motivated by a set of anomalies seen in the past collected neutrino data, mainly driven by the result of Liquid Scintillator Neutrino Detector (LSND) experiment [1]. The SBN detection system is based on three Liquid Argon Time Projection Chamber (LAr-TPC) detectors exposed at shallow depth to the $\sim 0.8 GeV$ Booster Neutrino Beam (BNB) at different distances from the target: ICARUS-T600, SBND and Micro-BooNE [2].

The LAr-TPCs (proposed by C. Rubbia in 1977 [3]) are high granularity, continuously sensitive and self triggering detectors with excellent 3D imaging and calorimetric reconstruction of ionizing particle(s). This detection technique will provide an highly efficient identification of neutrino interactions, measurement of their energy (from a few MeV to several hundreds of GeV) and a strong mitigation of possible sources of background, as demonstrated by the first large-scale experiment performed by the ICARUS Collaboration at the LNGS underground laboratory [4]. Performing this study with almost identical detectors at various distances from the neutrino source allows identification of any variation of the spectra, which should be a clear signature of neutrino oscillations.

2. The SBN Far Detector: ICARUS

The ICARUS-T600 is the first large-scale operating LAr-TPC containing 760 tons of ultra-pure LAr, placed at 600m from the target [5]. It consists of two large and identical adjacent modules, housing two LAr-TPC separated by a common central cathode with a maximum drift distance of 1.5 m (drift time $\sim$ 0.96 ms at the nominal 500 V/cm electric drift field). The anode of each TPC is made of three parallel wire planes placed 3 mm apart from each other and oriented at 0^o and $\pm 60^o$ with respect to the horizontal direction. Behind the anode planes, 360 photomultiplier tubes (PMT) are placed. Each unit is provided with a coating to convert the 128-nm wavelength scintillation light produced in liquid argon to the VUV photons to visible light. It is complemented by a laser calibration system allowing for gain equalization, timing and monitoring of all the PMTs. The PMT electronics are designed to allow continuous read-out, digitization and independent waveform recording of signals coming from the 360 PMTs. Each module consists of a 16-channels pattern; for each channel, an internal trigger-request logic signal is generated every time the sampled PMT pulse passes through a programmable threshold. For each pair of adjacent channels, trigger-requests are logically combined and the result is presented in a low-voltage differential signaling (LVDS) logic output with configurable duration in term of OR logic between neighboring PMTs.

The shallow depth at which ICARUS functions at FNAL, exposes the detector to an abundant flux of cosmic rays which would overwhelm the detector, as these can induce several additional and uncorrelated triggers during the 1 ms drift time. On average $\sim$ 11 cosmic tracks are expected to cross the entire detector volume during each drift window, which need to be identified and suppressed. In order to reduce the cosmic ray flux, the detector setup includes a $\sim$ 3m concrete overburden complemented by a cosmic ray tagger (CRT) system surrounding the TPC to tag the remaining incoming charged particles. Besides that, the coincidence of CRT signal with the light and charge signals of the chamber are also exploited to further suppress the backgrounds.

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3. Reconstruction of the light signal

The ICARUS light detection system is used to detect the prompt LAr scintillation light for the purpose of event triggering and absolute timestamp of the recorded events, reconstructing the interaction position along the drift coordinate, and is a fundamental feature for the T600 operation at shallow depth.

The reconstruction of the scintillation light associated with the event of interest (neutrino interaction or cosmic rays) is based on the recorded PMTs signals in the event, sampled at 500 MHz. For any event triggered in coincidence with the beam spill, the digitized signals of all 360 PMTs are recorded in 30 μs long time intervals. In addition, for cosmic rays crossing the detector in ± 1 ms around the beam gate and identified by the trigger logic, all 180 PMTs belonging to the ICARUS module containing the event are recorded in 10 μs long time intervals. A threshold-based algorithm is applied to each recorded signal, to identify fired PMTs and to reconstruct the characteristics of the detected light to be used in the event analysis.

Whenever a PMT signal exceeds the baseline by 0.5 photo-electron, a new *OpHit* object is created, characterized by a start time, a time interval for the signal to return back to baseline, a maximal amplitude, and an integral of the signal over the baseline. As a second stage, all *OpHits* in coincidence within 100 ns are clustered together into an *OpFlash* object. The *Opflash* is then expanded to include also *OpHits* within 1μs after the first *OpHit* time. Nominally, an *OpFlash* should correspond to the total detected light associated to each interaction, either due to cosmic rays or to a neutrino interaction. The distribution of the PMT signals in an *OpFlash* (time, amplitudes, integrals and geometrical positions) is clearly determined by the associated interaction in the TPC.

4. Preliminary comparison data vs. MC of the cosmic muon light signals

To compare the MC predictions to the data, strict selections are applied to both samples[1]: firstly, the *tracks* of the ionizing particle have to pass through the cathode, have to be fully detected in the TPC, and longer than 50 cm; then, *OpFlash* in coincidence with *tracks* are selected requiring that the difference between *track*'s and *OpFlash*'s times[2] have to be lower than 4 ms and the difference between *track*'s and *OpFlash*'s barycenters lower than 30 cm. For each *OpFlash*, the barycenter and its spatial extension (i.e. root mean square or RMS) along the beam axis z are determined taking into account the number of collected photo-electron on each fired PMT. Comparison between MC and data of the light signal extension along the beam direction shows a good agreement (Fig.1(a)).

Currently, several factors that can affect the comparison of peculiar variables are still under study: quantum efficiency at LAr temperature, effects of the refraction index of LAr, possible reconstruction artifacts etc. In the meantime, the MC light yield is re-scaled to the average value evaluated in data light yield curve (in terms of number of photoelectrons). In Fig.1(b) a comparison of photo-electron number in MC re-scaled and in data is presented.

[1]In the present analysis the samples used are: (i) for data, the run 9435 of the RUN2; (ii) for MC, 50000 events of cosmic rays in and out of time.

[2]The *track* time correspond to the moment when the *track* passes through the cathode. While, the first fired PMT provides the *OpFlash*.

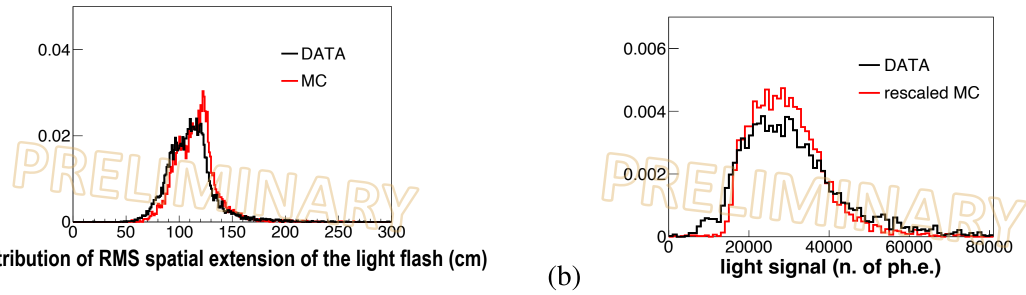

Figure 1: (a) Distribution of RMS spatial extension of the light flash along the beam (z) direction (cm). (b) Light yields in term of number of reconstructed photo-electron.

5. Summary and conclusions

A preliminary study of light signal related to cosmics muon in the LArTPC is presented. The MC simulation of the light signal extension along the beam direction for cosmic muon is well describing the collected data. Relevant parameters in the optical simulation of the scintillation light, which affect the signal detected by PMTs are still under study. A re-scaling of light simulated by MC to the collected data is applied to study the features of events associate with light in order to develop event selection criteria and analysis.

A deeper analysis is ongoing to better determine possible reconstruction artifact (selecting specific detector regions, or specific tracks inclination and length). In meanwhile, in order to improve the MC simulation, test and measurement of the relevant parameters of scintillation light production and collection by PMTs are ongoing.

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