The electronic set-up for the scintillation light detection system of ICARUS-SBN at Fermilab

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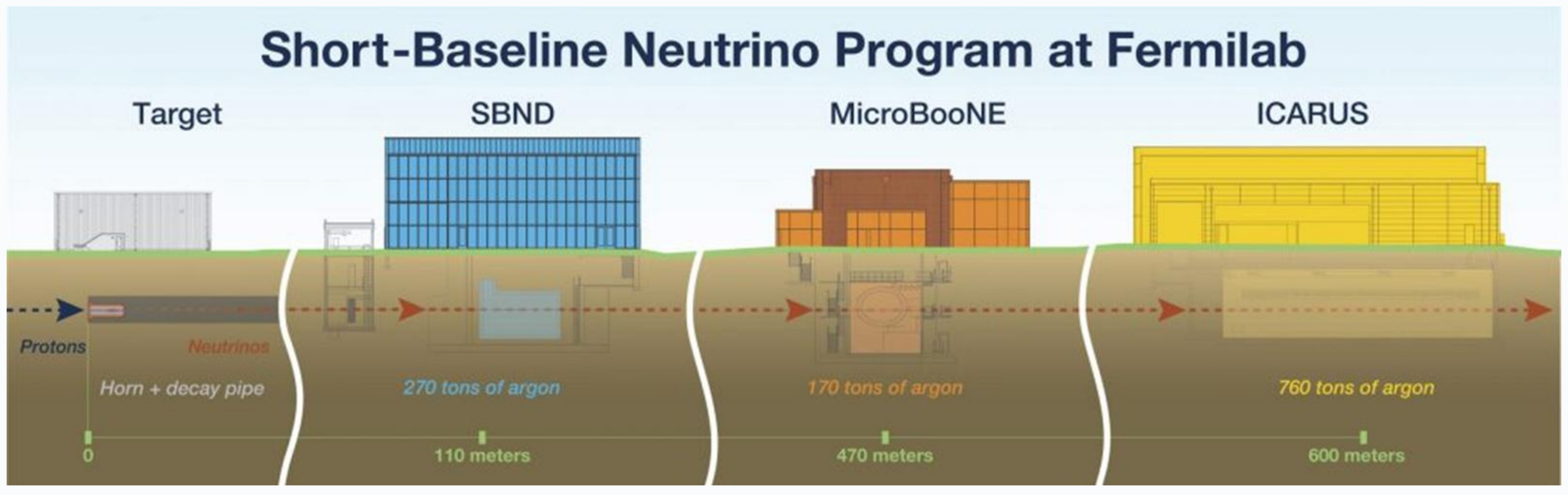
The ICARUS-T600 Liquid Argon (LAr) Time Projection Chamber (TPC) is presently used as a far detector of the Short Baseline Neutrino (SBN) program at Fermilab (USA) to search for a possible LSND-like sterile neutrino signal at $\Delta m^2 \sim o(eV^2)$ with the Booster Neutrino Beam (BNB).
A light detection system, based on large area Photo-Multiplier Tubes (PMTs), has been realized for ICARUS-T600 to detect VUV photons produced after the passage of ionizing particles in LAr. This system is fundamental for the TPC operation, providing an efficient trigger and contributing to the 3D reconstruction of events. Moreover, since the detector 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 BNB spill gate.
Based on 360 Hamamatsu R5912-MOD PMTs deployed behind the four TPC wire chambers, the system requires a high performance electronic set-up. The electronics consists of fast sampling digitizers (500 MSa/s, 14-bit) allowing for the recording and the discrimination of the signals directly extracted from the PMT anodes, and providing a fast identification of interactions and the exploitation of the scintillation light for trigger purposes.

2 – introduction

- Neutrino oscillation is a quantum mechanical phenomenon in which a neutrino created with a specific "lepton flavor" (electron, muon, tau) can later be measured with different lepton flavor.
- Despite the well established 3-flavour mixing picture within the Standard Model, anomalies at $\Delta m^2 \sim o(eV^2)$ have been observed in the last 20 years, all suggesting a possible existence of at least a fourth neutrino flavor, named "Sterile Neutrino".
- The SBN program at Fermilab has been proposed to provide a definitive clarification: Three detectors, all based on the Liquid Argon TPC technique and placed along the Booster Neutrino Beam (BNB) line, will investigate the possible presence of Sterile Neutrino States.

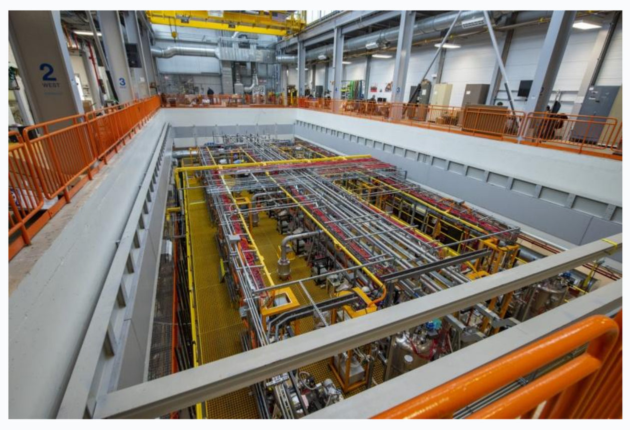


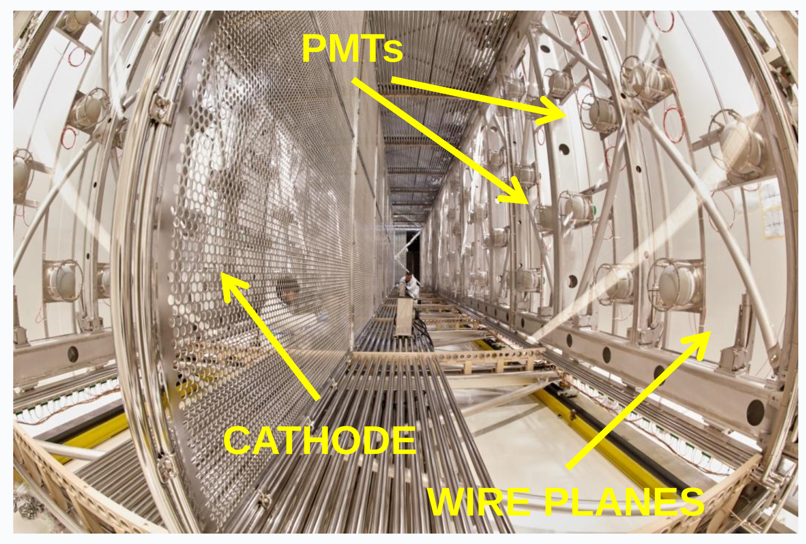
Thanks to the simultaneous study at different baseline of electron neutrino appearance and of muon neutrino disappearance channels, SBN will cover much of the oscillation parameters allowed by past anomalies, contributiong to the resolution of the "neutrino sterile puzzle"

See poster Short-Baseline neutrino oscillation searches with the ICARUS detector

2 – The ICARUS T600 detector

ICARUS T600 detector is made of two identical cryostats, filled with about 760 t of ultra-pure liquid argon. Each cryostat houses two TPCs with 1.5 m maximum drift path, sharing a common central cathode made of punched stainless-steel panels. Charged particles interacting in liquid argon produce both scintillation light and ionization electrons. Electrons are drifted by a 500 V/cm electric field to the anode, made of three parallel wire planes. The electronics is designed to allow continuous read-out, digitization and independent waveform recording of signals from each wire allowing a full 3D reconstruction of tracks, with a spatial resolution of about 1 mm³. Scintillation light is detected by photomultiplier tubes (PMTs) directly immersed in the liquid argon.





ICARUS at Fermilab is facing a more Challenging experimental condition (surface) than underground condition at LNGS: Large (~10 kHz) of cosmic ray events will be occurring continuously during the readout time window of T600 at SBN. To overcome the new experimental challenge, T600 underwent an intensive overhauling at CERN. One of the significant upgrade is on light detection system (PMTs)

3 – The ICARUS T600 Ligh Detection System

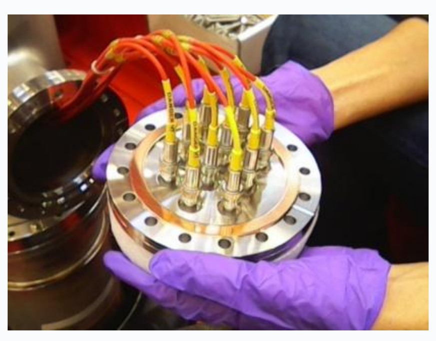
Scintillation light emission in LAr is due to the radiative decay of excimer molecules Ar^{+2} produced by ionizing particles, releasing monochromatic VUV photons ($\lambda \approx 128$ nm) in transitions from the lowest excited molecular state to the dissociative ground state. The emitted light is characterized by a fast ($\tau \approx 6$ ns) and a slow ($\tau \approx 1.5$ µs) decay components. Their relative intensity depends on dE/dx, ranging from 1:3 for minimum ionizing particles, up to 3:1 for alpha particles. This isotropic light signal propagates with negligible attenuation throughout each TPC volume.

The realized light detection system features 360 total Hamamatsu R5912-MOD PMTs deployed in groups of 90 devices behind each wire chambers. Since the PMT glass windows is not transparent to the scintillation light produced in liquid argon, each unit was coated with a proper wavelength shifter re-emitting in the visible. The PMTs were installed using dedicated mechanical supports.

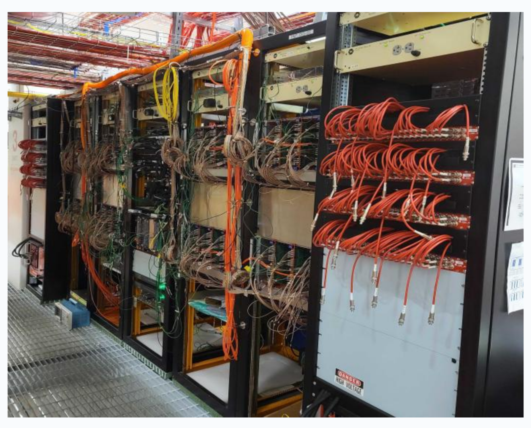
The electrical connection between PMT and electronics is performed by 7 m (internal) + 37 m (external) cables interconnected by special designed flanges.

The light detection system is completed by a laser calibration system which permits the timing calibration of the single units (See poster *Calibration of the ICARUS cryogenic photo-detection system at FNAL*).

360 HAMAMATSU R5912-MOD (8" diameter) mounted behind the 4 TPC wire planes.



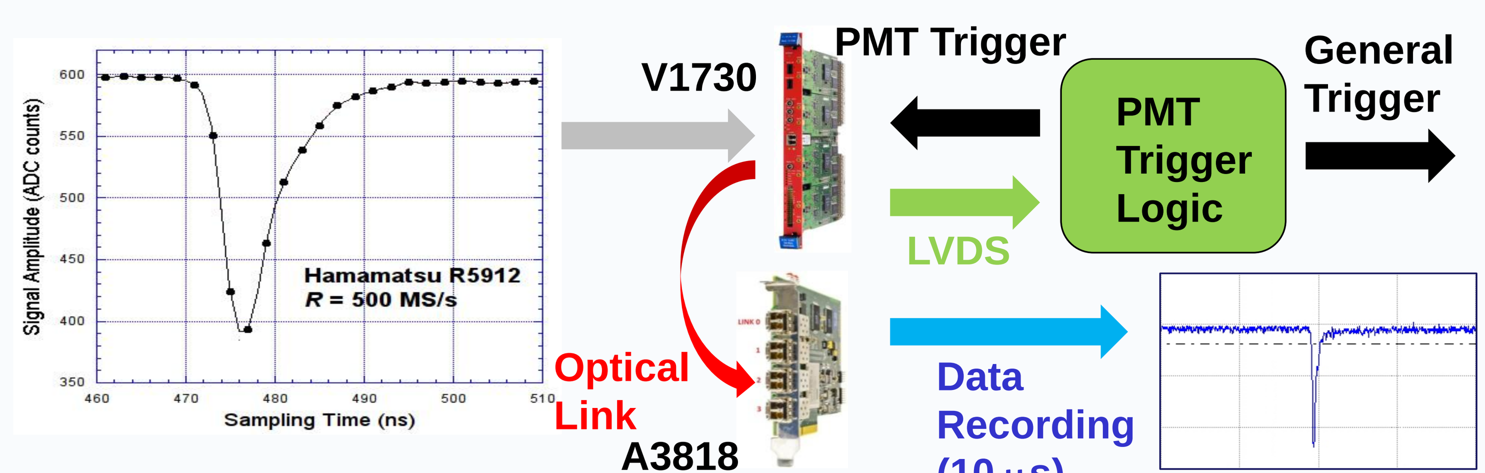
36 Signal + 36 High Voltage special designed flanges permit the cabling internal/external interconnection for PMT signal and power supply.



PMT electronics fully installed in a lateral alcove of the ICARUS building.

4 – Description of PMT Electronics

PMT electronics is designed to allow continuous read-out, digitization and independent waveform recording of signals coming from the 360 PMTs of the light detection system. This operation is performed by 24 V1730B digitizers. Each module consists of a 16-channel 14-bit 500-MSa/s FLASH ADC with 2 Vpp input dynamic range. In each board 15 channels are used for the acquisition of PMT signals, while a channel is left for the acquisition of ancillary signals. During the acquisition, data stream of each channel is continuously written every 2 ns in a circular memory buffer of 5kSa, corresponding to 10 µs, allowing the recording of both components of the LAr scintillation light, i.e. photons from fast and slow decays of exited excimers to ground state. When a boards receives an external trigger request (STOP), the active buffers are frozen, writing operations are moved to the next available buffers and stored data are available for download via optical link. Trigger pulses are generated by the ICARUS Trigger System every time a ionizing interaction is recognized in the detector on the base of information coming from neutrino beams and other apparatus subsystems (See poster *Implementation of the trigger system of the ICARUS-T600 detector at Fermilab*). To this aim, V1730B boards generate trigger-request logical patterns through LVDS (Low Voltage Differential Signal) outputs showing the presence of signals with amplitude overcoming digitally programmed thresholds.



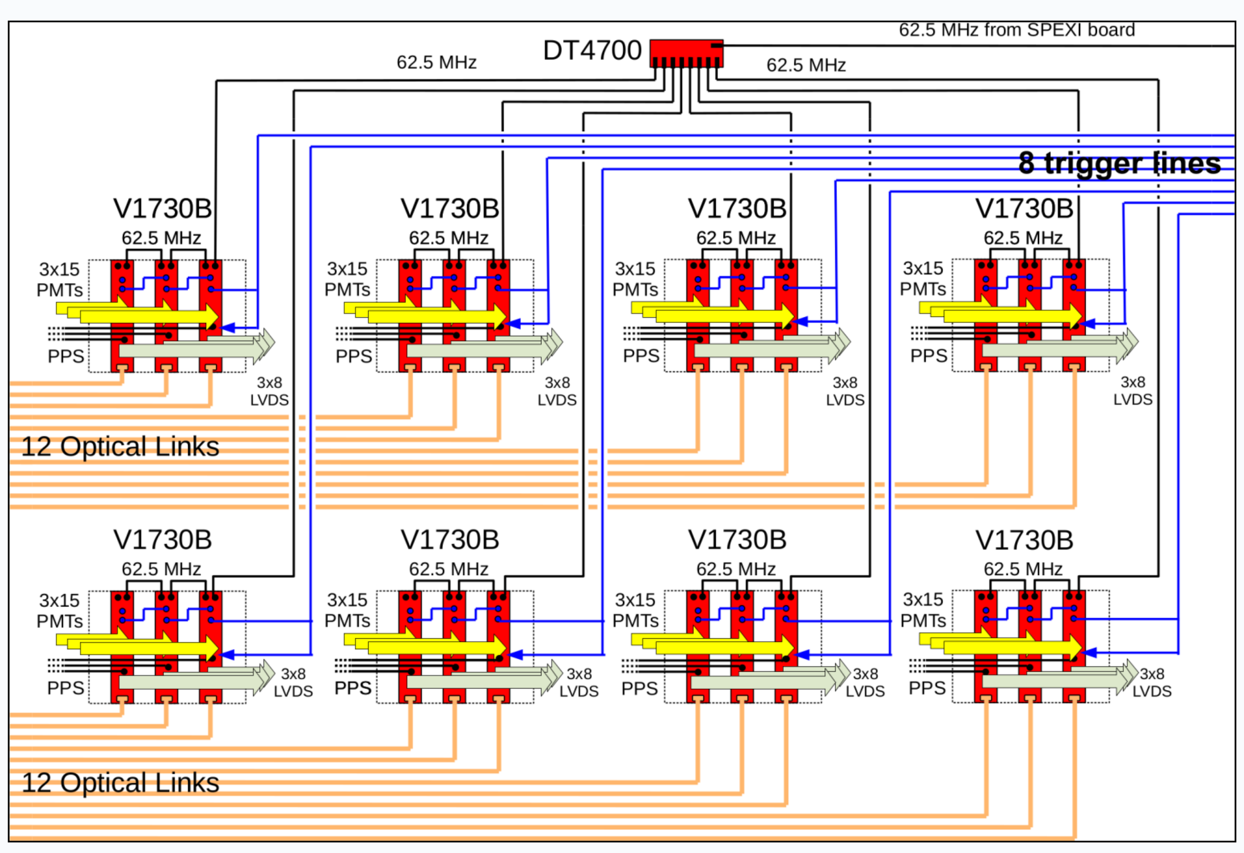
CAEN V1730B Digitizer:

- **16 Channels, 2Vpp dynamic range, 14-bit resolution and 500 MSa/s sampling rate**
- **Discriminated pulses in 8 programmable outputs (combining 2 ch.) LVDS standard**
- **Data readout is performed by an optical link according to the CAENET protocol**

5 – Electronic Set-up

The 24 V1730B digitizers are deployed in 8 VME crates (3 units each).

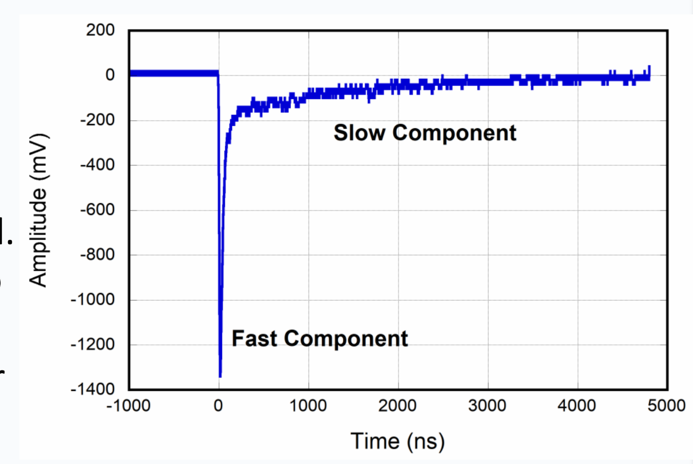
- Each V1730 board receive the signal of 15 PMTs which are recorded inside 15 ms time windows every time a trigger (STOP) pulse is received by the Trigger Electronics.
- For each crate a Master Unit permits the Desy-Chain distribution of the trigger pulses and of the 62.5 Mhz clock frequency, both generated by the Trigger Electronics.
- The 8 Master Units allow the acquisition of trigger pulses together with the PMTs, for timing purposes.
- A PPS (Pulse Per Second) is sent to each board by the trigger electronics to perform a synchronized reset of the Timestamp.
- Each board is read by a single optical link, in order to maximize the data read-out throughput.
- For each board, 8 discriminated LVDS output, in terms of copuple (OR) of adjacent PMTs, are generated and sent to the Trigger logic for trigger generation.

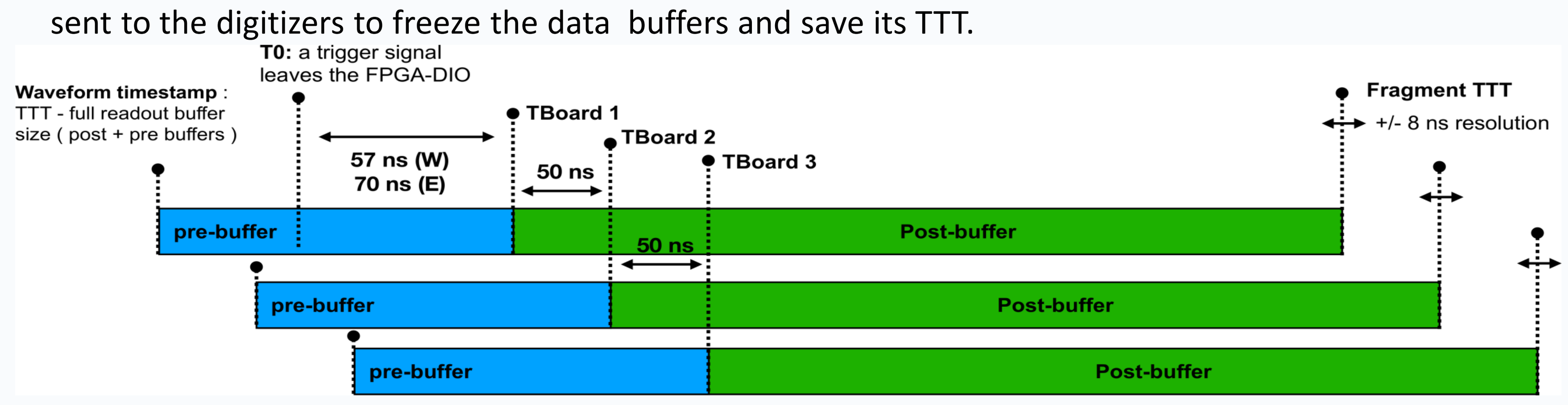


6 – Timing, Synchronization and Calibration

PMT gains are set to G= 5 10^6, corresponding to 4 mV (50 ADC counts) per photoelectron.
PMT signals are recorded in "fragments" of 10 µs. In order to correctly acquire both components of the LAr scintillation light, a correct timing and synchronization of DAQ electronics is requested.

- Each fragment is divided in 3 µs pre-buffer + 7 µs post-buffer to correctly acquire the scintillation light waveform.
- The header of each fragment contains a 8 ns resolution counter called Trigger Time Tag (TTT);
- When a trigger is generated inside the trigger crate a signal is sent to the digitizers to freeze the data buffers and save its TTT.





To precisely evaluate off-line the actual time of occurrence of each PMT waveform, the time of the trigger pulse Ttrig (fully synchronized to beam radio-frequency) is also measured by one digitizer channel together with the PMT signals. The actual time of the PMT signals is determined as $T_{PMT} = T_{trig} + \Delta T$, where ΔT is the time difference between the recorded trigger pulse and the PMT signal. We measured ~1 ns resolution on ΔT, allowing to perfectly determine the absolute timing of collected events.