Scintillation Light DAQ and trigger system for the ICARUS T600 experiment at Fermilab

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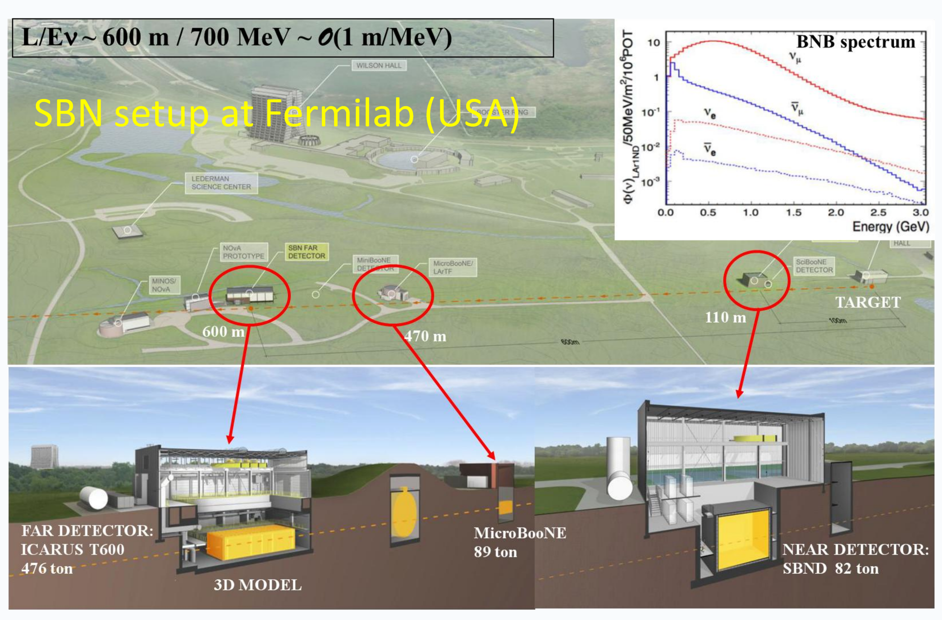
In experiments exploiting liquid argon time projection chambers (LAr-TPC), for the study of neutrinos and rare events, the light detection system plays a crucial role for the trigger and the determination of the absolute time of the event (t_0). The ICARUS T600 detector is a LAr-TPC with 474 t of LAr active mass being installed at Fermilab and will be exposed to the Booster (BNB) and NuMI neutrino beam in the framework of the SBN program for the ultimate search of sterile neutrinos.
Due to the operation on surface, a high cosmic background is expected, requiring the development of innovative trigger and DAQ systems. The trigger system of the ICARUS detector will exploit the coincidence of the prompt signals from the scintillation light in the LAr-TPC as detected by 360 PMTs with (the arrival time of neutrinos provided by the BNB (1.6 us @ 4Hz) and NuMI (8.6 us @ 0.7 Hz) beam. The DAQ system for the PMT signals is realized with 500 MS/s digitizers read-out by means of 1.25 Gb/s bandwidth optical links. This system allows to acquire the whole waveform of each PMT during the entire TPC drift time in order to associate the t_0 to each interaction occurring in the TPC volume. PMT digitized signals exceeding a defined threshold are processed by high performance FPGA modules in association with the beam gates to generate the whole ICARUS trigger.

1 - INTRODUCTION

ICARUS T600 will soon become the far detector of the Short Baseline Neutrino program at FNAL (USA), which foresees three liquid argon time projection chambers distributed along the Booster Neutrino Beam line. The apparatus underwent a major refurbishment at CERN in which a new light detection system was installed consisting of four arrays of photo-multiplier tubes (PMTs) with 90 units each.

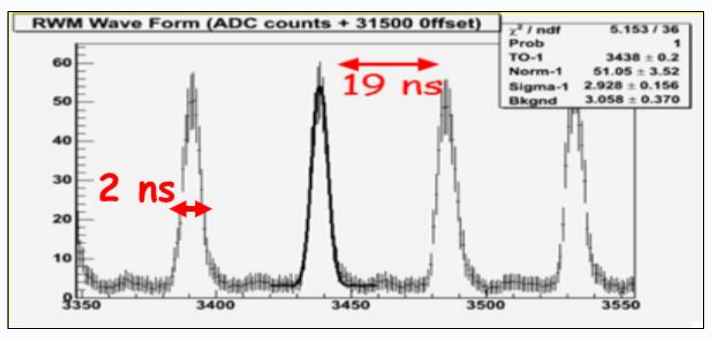
See also at this conference:
A. Zani *ICARUS T600 Detector Overhauling*
M. Bonesini *The development of the Icarus T600 laser diode calibration system*



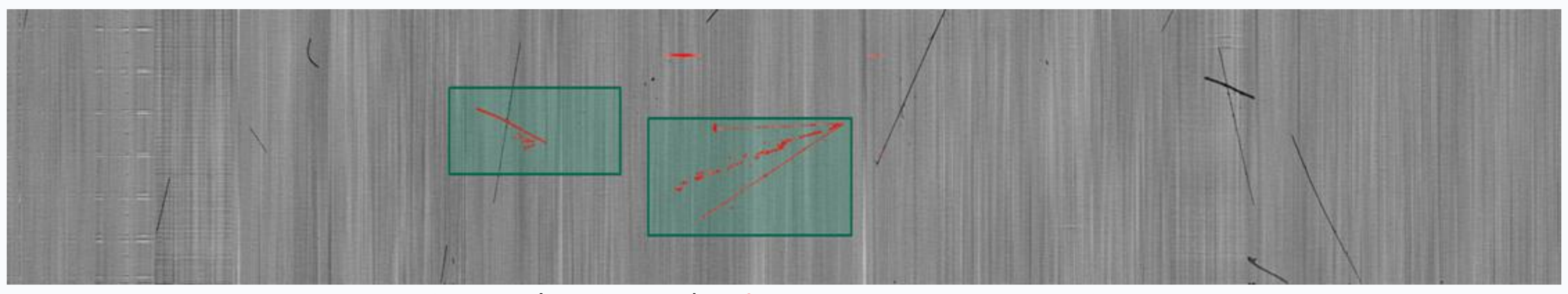
A Proposal for a Three Detector Short-Baseline Neutrino Oscillation Program in the Fermilab Booster Neutrino Beam arXiv:1503.01520 (2015)

2 - EVENT FINDING AT SHALLOW DEPTHS

- ICARUS at FNAL will take data at shallow depth, facing more challenging experimental conditions than at LNGS, requiring a cosmic ray background mitigation.
- A 3 m concrete overburden will remove contribution from cosmic hadrons and gamma rays. Moreover about 11 μ tracks will occur per triggering event in 1 ms drift readout.
- The gamma rays associated with cosmic-ray muons represent a serious background for ν_e search since *electrons* produced via Compton scattering/pair production can mimic a genuine ν_e CC.
- To reconstruct the triggering event associated to the beam ν extraction, it is necessary to precisely determine the timing of each track in the TPC image, exploiting a much improved light detection system, ~1 ns PMT 's time resolution.



~1 ns precision is advisable to exploit BNB bunched beam structure.



Cosmic rays (Pavia test) + low energy CNGS neutrino events

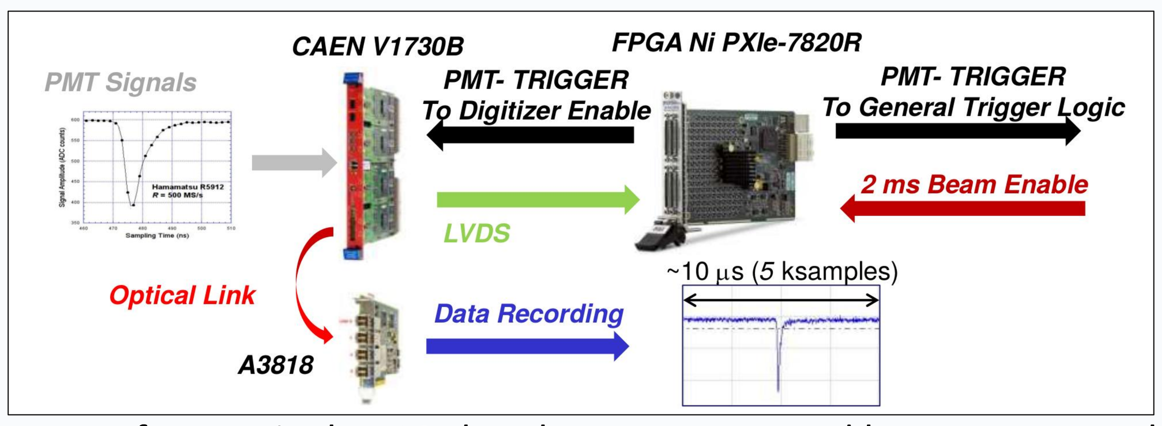
3 - THE NEW ICARUS T600 PMT SYSTEM

- The new ICARUS light collection system consists of four sets of 90 8'' HAMAMATSU R5912-MOD PMTs, one set behind each of the 4 wire planes of the T600 (360 PMTs in total); this configuration gives a photo-cathode coverage of 5% of the wire plane area and a light collection of 15 phe/MeV;
- Monte Carlo simulations demonstrate that this PMT deployment permits to trigger low energy events (<100 MeV) with fairly high threshold/multiplicity. It offers an event longitudinal localization better than 0.5 m and allows an initial classification of different interaction topologies (μ-tracks vs e.m. showers).
- A total of 400 PMTs, delivered by Hamamatsu at CERN, were equipped with a customized cryogenic base.
- All PMTs were tested at room temperature; 60 units were tested in a LAr bath to evaluate the change at cryo temperature of gain, linearity & dark counts.
- 360 PMTs were uniformly coated by evaporation with 200 μg/cm² of Tetra-Phenyl-Butadiene (TPB) to detect the λ = 128 nm LAr scintillation light.
- The PMTs have been installed in new mechanical supports and each device is set inside a wire screen cage to prevent signals being induced on the adjacent TPC Collection wire planes by pulses in the PMTs.
- The PMT timing/gain equalization is performed by using light pulses from a Laser source (Hamamatsu PLP10, λ=405 nm, FWHM <100 ps, peak power ~400 mW). For each PMT, a 50 μm optical fiber allows the illumination of the photocathode.

4 - PMT TRIGGER AND DAQ ELECTRONICS

The scintillation light data acquisition and recording can be thought of as if there was an oscilloscope channel for each PMT. This is performed by means of CAEN V1730B (500MS/s, 14-bit). Recorded signals will be available through optical links (A3818 board).

Moreover the V1730B boards will generate a set of discriminated output signals (LVDS) which will be available for triggering purposes.

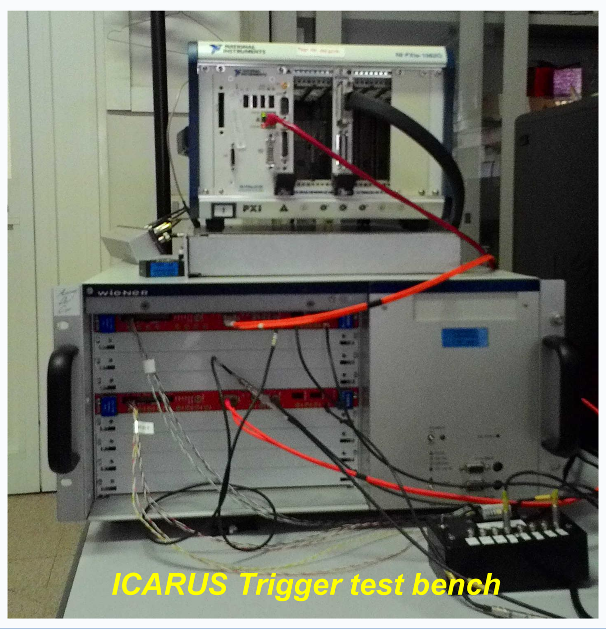


- The 45 signal outputs from a single TPC chamber, are processed by a programmable logic unit FPGA (NI-PXIe 7820R, one for each T300).
- A PMT-TRIGGER signal defined by majority/coincidence patterns, will enable fast PMT digitizers if this occurs inside a 2 ms wide BNB/NuMI beam gate to record all the PMT activity during the TPC time drift window.
- This signal will be also used to generate the GENERAL TRIGGER signal in coincidence with the BNB/NuMI beam spill to enable the event read-out.
- Each PMT pulse is recorded by considering a 10 μs sampling size.

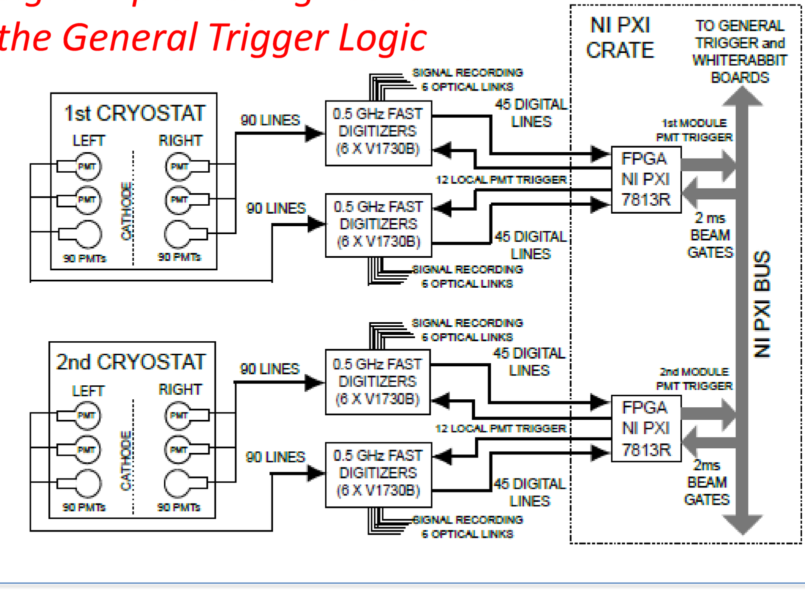
5 - ICARUS T600 PMT trigger system

The General Trigger layout is based on NI PXIe instrumentation in a single NI crate. NI boards previously employed at LNGS are being replaced: new CPU (PXIe-8135), Real Time (RT) controller, SPEXI board by Incaa Computers and 3 NI boards (PXIe-7820R), one for the General Trigger and two for PMT Trigger:

- RT controller implements all features for communication with DAQ, monitoring of available buffer/veto generation;
- SPEXI synchronizes timing of whole detector, handles beam extraction messages, and generates signals for TPC readout, Clock & Reset for PMT;
- PMT trigger boards: generate PMT Trigger & start to the fast PMT pulse digitizers of PMT activity recording;
- General Trigger board combines inputs from PMT Trigger boards with SPEXI signals to generate Global Trigger.

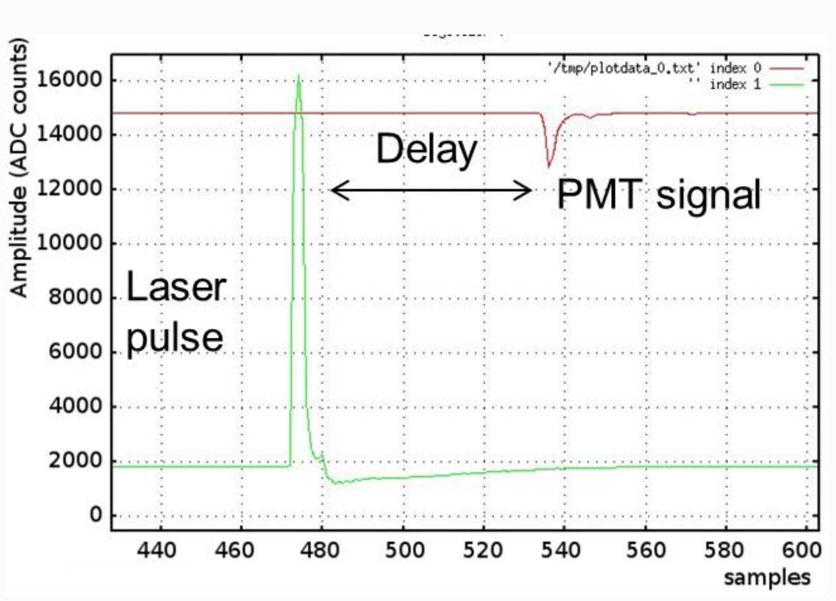


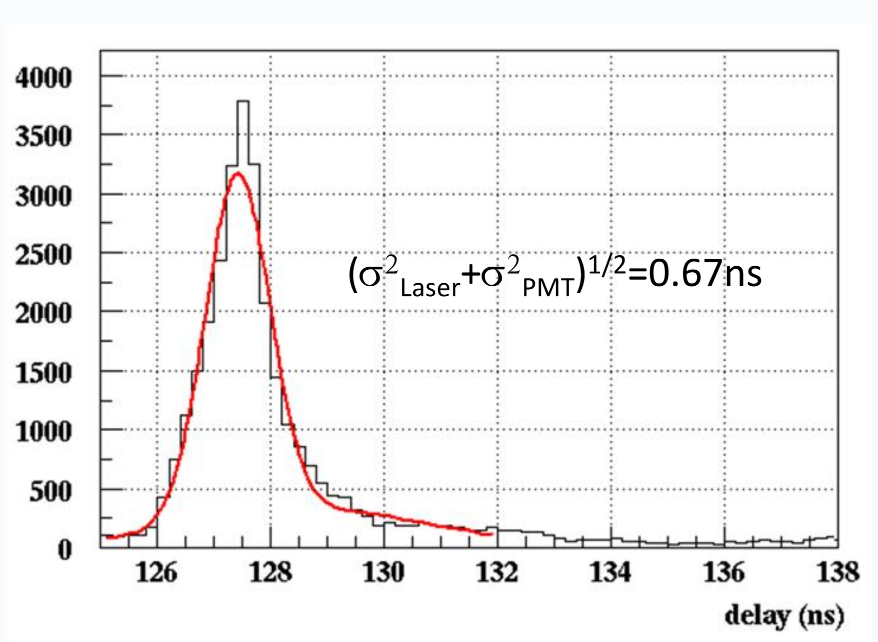
PMT signal processing scheme inside the General Trigger Logic



6 - FIRST PMT DAQ TESTS

On going tests on PMT DAQ electronics are mainly focused on the timing characteristics of the system.





Example of measured time delay distribution between the PMT response to laser illumination and the Laser pulse, simulating a laser calibration procedure. Thanks to the multiple sampling of the input pulses, it is possible to reconstruct the leading edge of the signals and evaluate the time response at 50% of their amplitude. The resolution resulting from a Gaussian fit $(\sigma^2_{Laser}+\sigma^2_{PMT})^{1/2}$=0.67ns is better than digitizer sampling time (2 ns). This work is in progress to better reconstruct the signal time response and refine the attainable resolution.

ACKNOWLEDGMENTS

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