PMT System WG Report

Gian Luca Raselli

ICARUS Meeting, FNAL, 12-Sep-2019

OUTLINE

- Description of the PMT light detection system.
- Description of electronics and DAQ.
- Present status and some testing results.
- Use of scintillation light for triggering.
- Tests with the CERN facility.
- Conclusions.

PMT WG people list:

V. Bellini, A.B. Mohammadzadeh (Catania)

R. Benocci, M. Bonesini (MiB)

C. Vignoli (LNGS)

B. Behera, , T. Boone, M. Mooney, R. J. Wilson (CSU)

V. Paolone, A. Chatterjee, H. Su, A. Wickremasinghe (Pittsburg)

H. Carranza, B. Smithers, Z. Williams (UTA)

A. Falcone, G.L. Raselli, M. Rossella (Pavia)

M. Diwan, A. Zhang (BNL)

H. Budd (Rochester)

G. Petrillo (SLAC)

F. Garcia, C. James, M. Betancourt (FNAL)

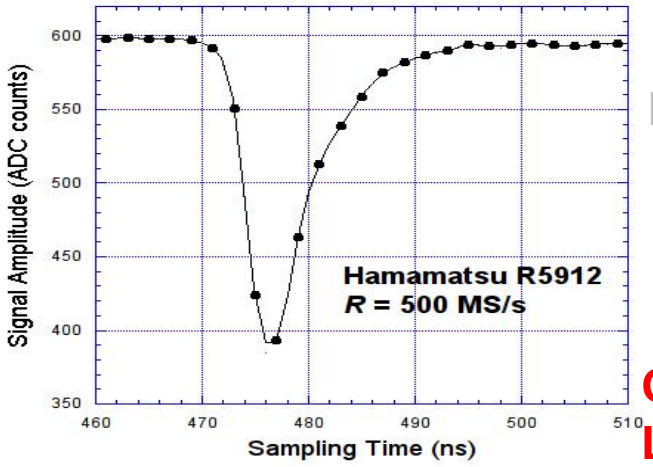
M. Babicz (CERN)

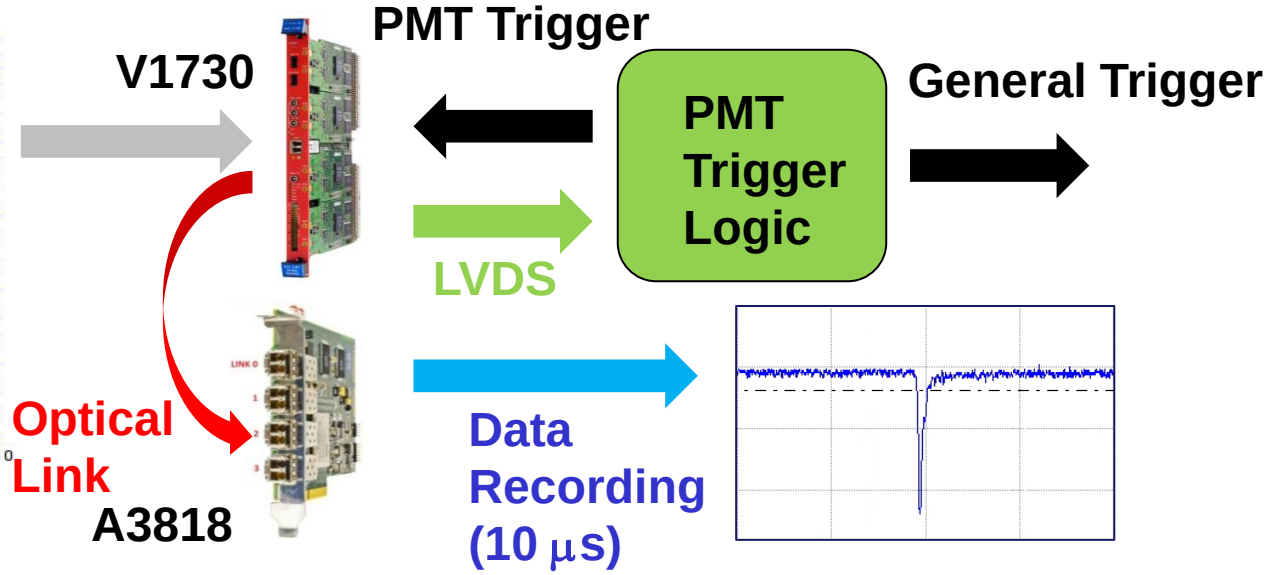
System Overview

- The T600 light collection system consists of 360 PMTs 8" HAMAMATSU R5912-MOD, each coated with ~200 $\mu g/cm^2$ of Tetra-Phenyl-Butadiene (TPB) to detect the λ=128 nm LAr scintillation.
- For each PMT, a 50 μm optical fiber allows the illumination of the photocathode by means of light pulses from an external Laser source (λ=405 nm, FWHM <100 ps).
- This configuration allows for a photo-cathode coverage of 5% of the wire plane area and a light collection of 15 phe/MeV;
- MC simulations demonstrate that this geometry 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).

PMT Electronic System Overview

- The designed data acquisition is equivalent to an oscilloscope channel for each PMT: it allows the recording of the full shape development of the light signal with a ns time resolution as requested for the timing event reconstruction.
- Moreover, using a time window of 10 μs, it allows also the recording of the slow component of the scintillation light for the deposited energy measurement.
- 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.

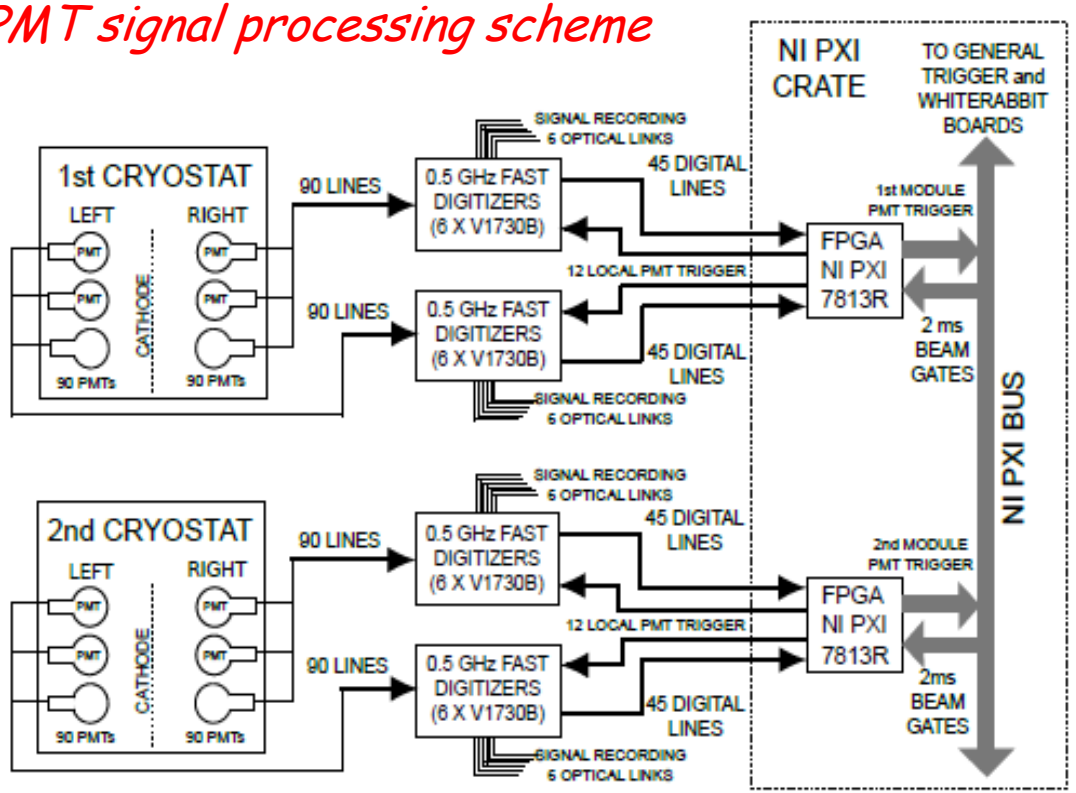


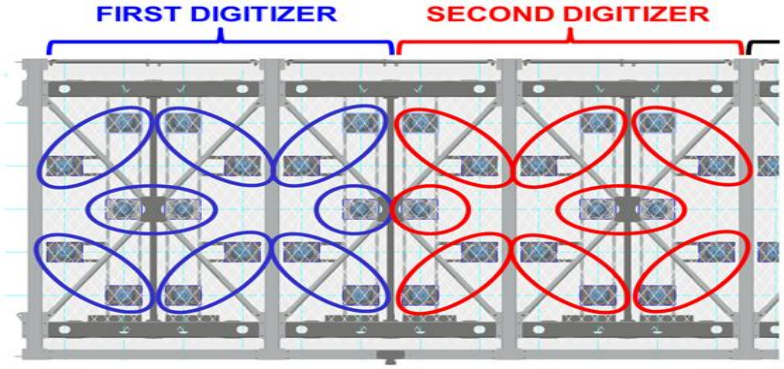


ICARUS PMT DAQ Layout

- For each T600 chamber, 90 PMTs are directly connected to 6 CAEN V1730B boards, 16 channels each.
- The boards will provide the sampling and recording of PMT signals (500 MS/s, 14 bit res.) inside a ±1 ms window around the beam extraction.
- V1730B will also generate a set of discriminated output LVDS signals in term of OR/AND of pairs of adjacent channels for prompt light triggering purposes. The timing precision (8 ns) guarantees the recognition of an interaction inside the spill.
- Thresholds (~ 10 phe) will be set to guarantee the full detection efficiency of interactions with deposited energy <100 MeV in the full T600 LAr active volume.

PMT signal processing scheme

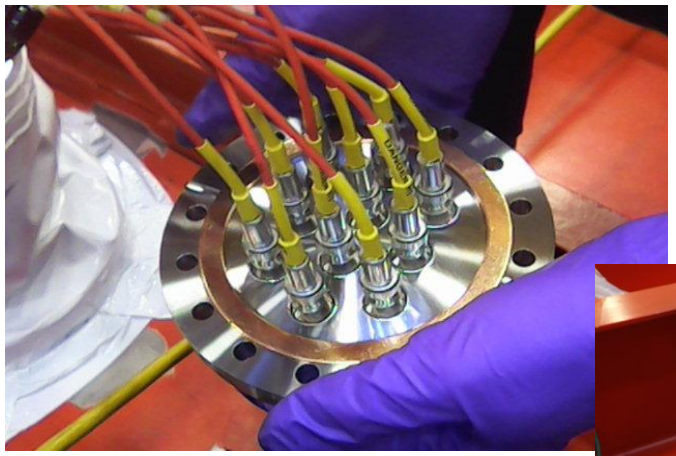




Coupling scheme of adjacent PMTs

Status of light detection installation – flages/cables

- The PMT/Laser flanges installation involved 72 chimneys/crosses, installed with all the necessary flanges from Dec. 2018 to Feb. 2019.
- Installation of PMT cables (HV and signal) started on Sep. 2019: presently 90 PMTs cabled.
  Cables for other 270 PMTs in shipment to FNAL.
- Optical fibers installation started on Sep. 2019.

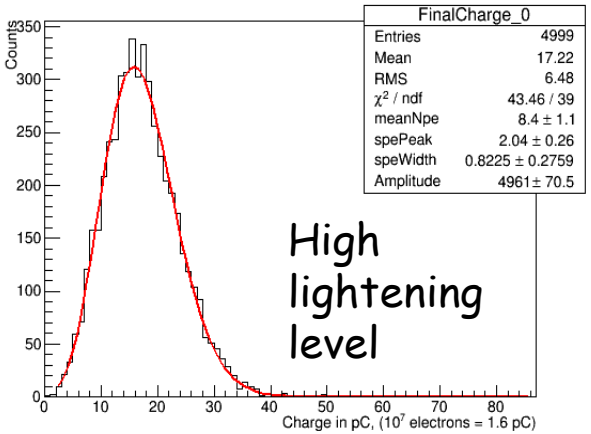


Calibration Campaign

- A PMT calibration campaign was started at warm temperature in order to:
  - Check that all PMTs are working after the detector transfer to FNAL. Found 358/360 working PMTs.
  - Optical fiber effectiveness (some issue fixed during installation).
  - Evaluate the PMTs' performance before the cooling down.
  - Gain knowledge on how to do calibration at commissioning stage.
- In the analysis, we focused on:
  - Gain calibration - results are consistent within 10% with the calibration carried out at CERN.
  - Dark rate measurement at SER level - resulting an overall average rate of 1.6 kHz, consistent with earlier ICARUS measurements.
  - Understanding the presence PMT after pulses.
- A summary of the results are collected at https://www.phy.bnl.gov/icarus/test/database/

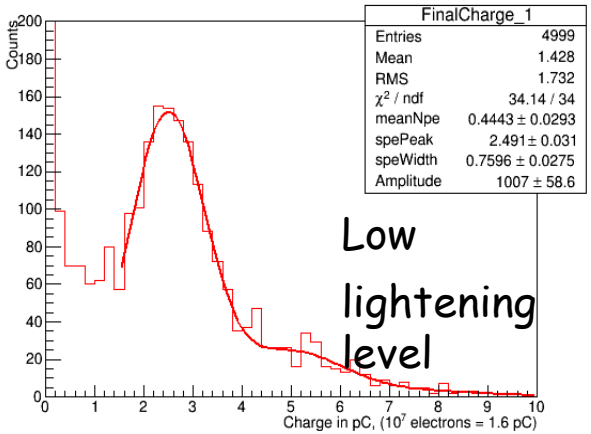
Some Tests Results

Gain results: extracted from fitting charge distributions



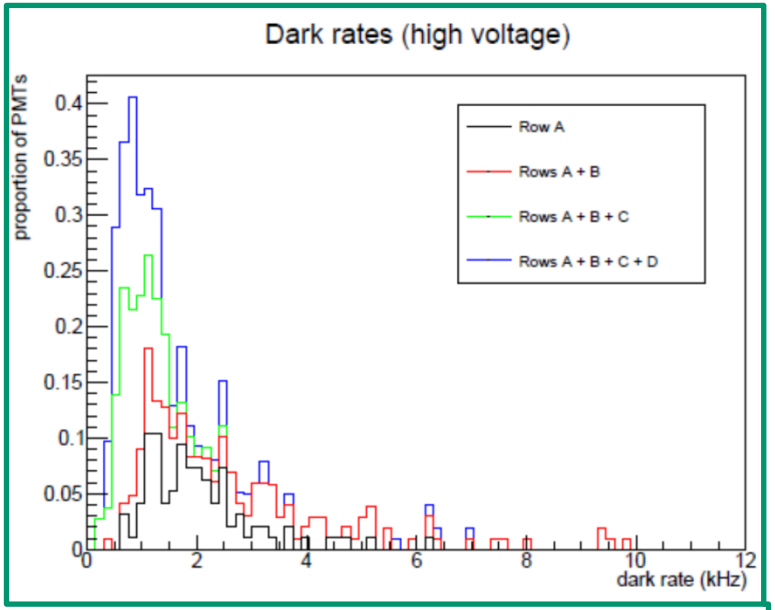
High lightening level

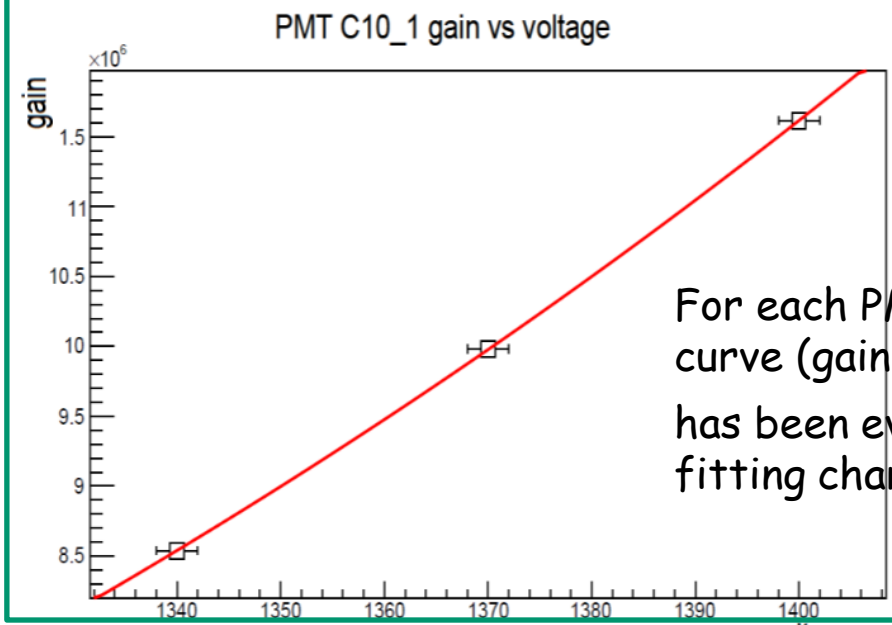
PMT A18C1, 1460V
Gain: 1.28×10^7. (mean p.e.: 8)



Low lightening level

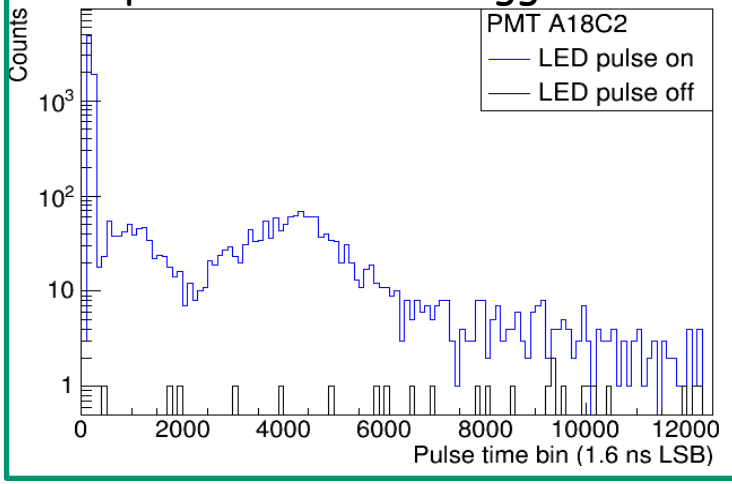
PMT A18C2, 1420V
Gain: 1.56×10^7 (SER spectrum)





For each PMT a calibration curve (gain vs voltage) has been evaluated from fitting charge distributions

Presence of afterpulses of two types, ~1.6μs and ~7μs after the main pulse from LED trigger.



Installation of PMT Electronics

- PMT HV and Digital racks are being instrumented with electronics;
- Operation Readiness Clearance is in approval by FNAL authorities;
- A Vertical Slice Test (PMT-VST) is in operation in order to record PMT signal for some units with the final electronic set-up (long PMT cables and V1730 digitizers)

Two PMT HV racks have been assembled with:

- ✓ One Primary Bertan power supply.
- ✓ One CAEN SY1527 with 4 A1932AN HV distributors.
- ✓ 4 R648 SHV adapters.
- ✓ One AC switch.
- ✓ Slow control system.

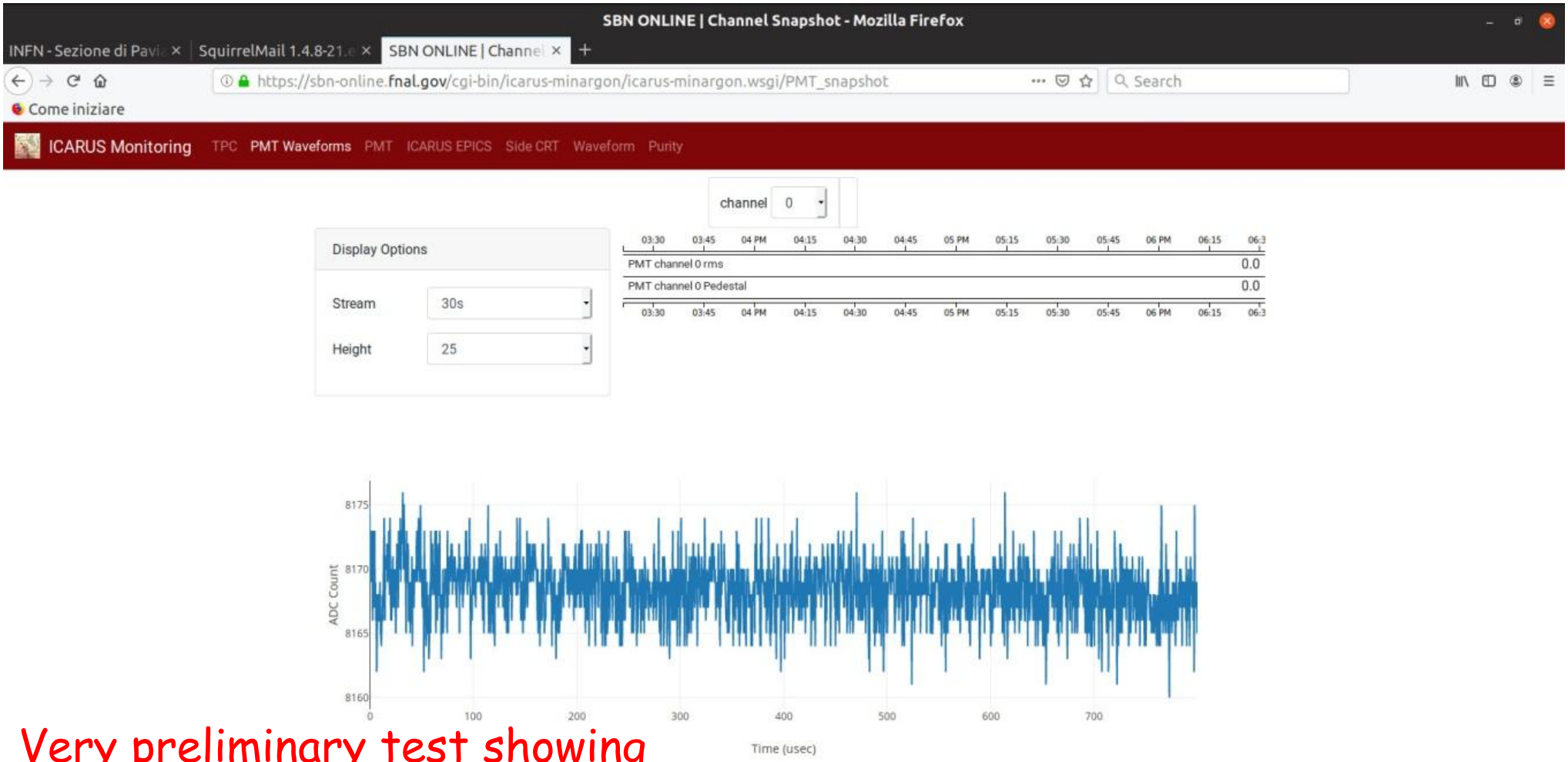
4 PMT DIG racks have been assembled with:

- ✓ Two VME Crates.
- ✓ 6 CAEN V1730B digitizer.
- ✓ External clock distribution system.
- ✓ One AC switch.

One digitizer completed with optical readout link for Vertical Slice Test VST.

PMT Electronics Online Monitoring

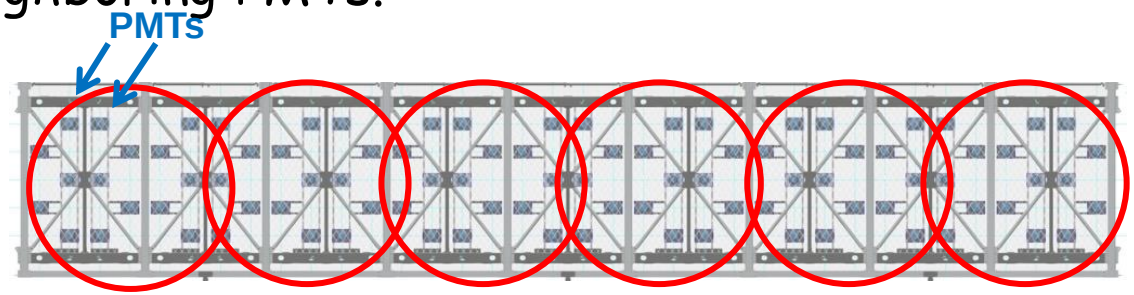
- PMT electronics can be monitored by the ICARUS Online Monitoring System



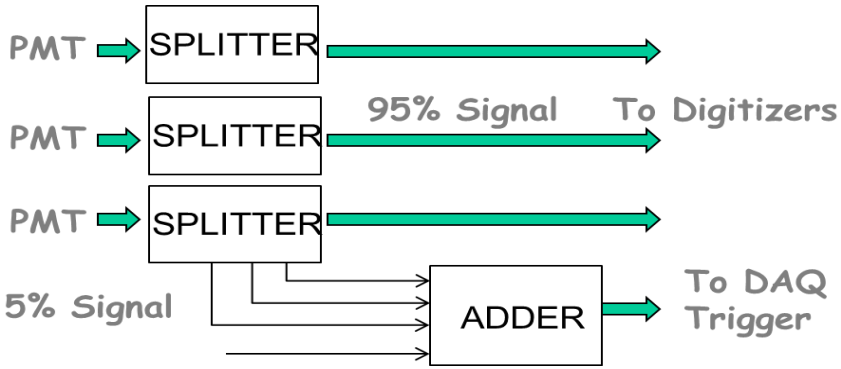
Very preliminary test showing electronic noise on VST digitizer.

Trigger recognition capabilities

- According to the low energy of BNB/NuMI beams, ν interactions as well as crossing cosmic μ's are expected mainly spatially confined in a small ~ 3 m long section of T600, involving ~ 15 neighboring PMTs.



  - The analogue sum signal of these 15 PMT signals in ~ 3 m detector slice can be used to identify ν events.
  - Each PMT line can be split to feed both digitizers and a 15 signal adder where waveforms are summed up and then discriminated /digitized.

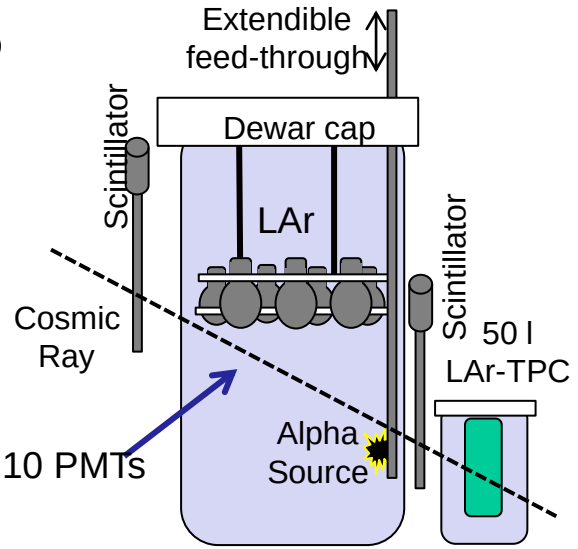


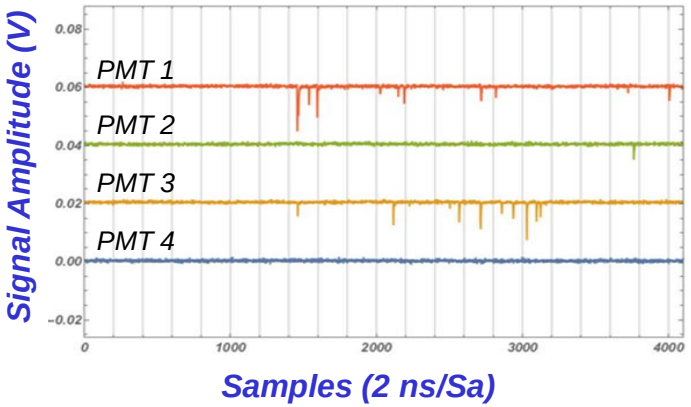
  - According to ICARUS experiment at LNGS this would increase the trigger recognition capability rejecting at same time detector noise, and possibly identifying the interested detector region.

- First prototype with 10 chs realized and tested at CERN. Defined the final electronic layout with 15 chs. The first 6 boards for 90 PMTs are in production. Final production expected after the test.

LAr Test Facility at CERN

- A small scale LAr test facility is ongoing at CERN to test PMT efficiencies, rates as well DAQ software (ArtDAQ) and synchronization (trig./wire/PMT).
- 10 R5912 Hamamatsu PMTs (6 with TPB and 4 without) equipped with laser calibration system are arranged into ~1600 liters LAr cryostat exposed to c-rays .
- The set-up is complemented with ICARUS 50 l x-y LAr-TPC to perform synchronous DAQ for PMTs and TPC signals. Cosmic μs crossing both TPC/PMT cryostat are selected by external plastic scintillators.
- Test bench for components of trigger system. Used to test the first prototype of analog adder with 10 chs., LVDS level shifters and laser system components.





^{39}Ar event as seen by 4 PMTs in the Lar test facility

- High detection efficiency (100%) of the system for c-rays triggered by scintillators.
- Intrinsic PMT dark rate (5 kHz) is increased in LAr by ~10 kHz additional backgr. induced by ^{39}Ar, generating sparse single-γ in few μs.

Thresholds of few phe reduce the rate of each PMT to < 1 kHz, almost cancelling stochastic coincidence rate among different PMTs.

Light detection system: online, software & slow control tasks

- Other important activities concern:
  - Development of software for the PMT signal recording and integration on the detector DAQ system (see presentations on DAQ and Trigger);
  - Development of software for PMT signal analysis;
  - Development of the light detection system calibration and monitoring (procedure, signal reconstruction algorithm…).
  - Deployment of the light detection system slow control (see presentation on slow control).
- In addition a number of tests are being performed to improve the performance of the light detection system and to get familiar with the different subsystems before operating at FNAL:
  - Study of the synchronization between different boards;
  - Study of the Laser calibration protocol finalized to a precise PMT signal synchronization.

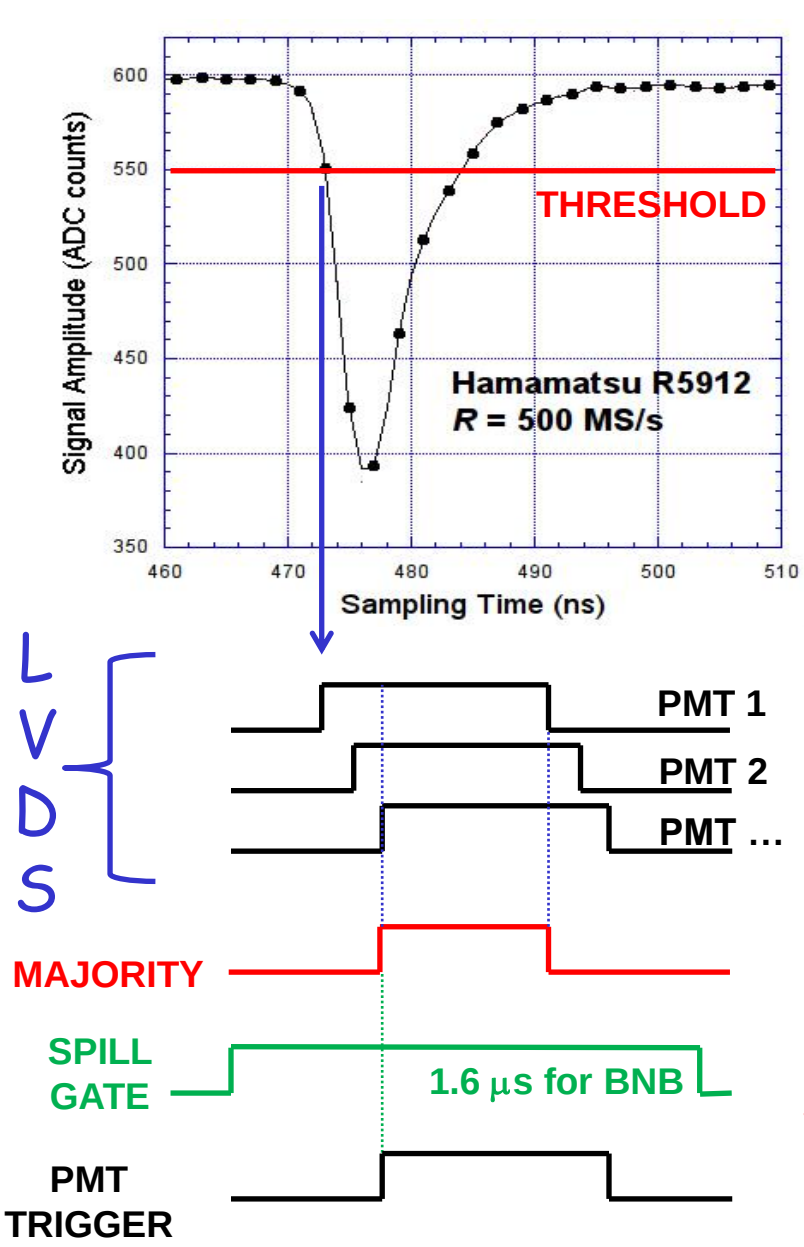
CONCLUSIONS

- The T600 light detection system is devoted to:
  - Identify precisely the time of occurrence (t_0) of each interaction;
  - Identify the event topology for fast selection purposes;
  - Generate a trigger signal to enable the event read-out by combining the PMT signal pattern to the BNB/NuMI beam spills
  - (≈1 ns precision) and the veto from the external Cosmic Ray Tagger (CRT).
- A great effort is being devoted at CERN and at FNAL to the implementation of the light detection system.
- A lot of work has been done, but more effort has to be devoted to complete the mounting and make operative the system.

… any volunteer is welcome!!!

Backup Slides

Promt scintillation light signal for triggering



- Each PMT signal is internally discriminated by the V1730B board;
- When an input signal > threshold (few phes) a LVDS (Low Voltage Differential Signaling) digital output pulse is generated with 8 ns precision;
- These LVDS are processed by logical units (FPGA Ni-PXIe 7820R) to generate a PMT majority or PMT coincidence signal;
- An event occurring inside the proton beam spill gates (1.6 μs Booster, 10 μs NuMI) generates a PMT trigger signal to start the data acquisition;
- All PMT signals are recorded inside a ±1 ms window around the beam extraction;

The timing precision (8 ns) guarantees the recognition of an interaction inside the spill.