Commissioning of the Icarus detector

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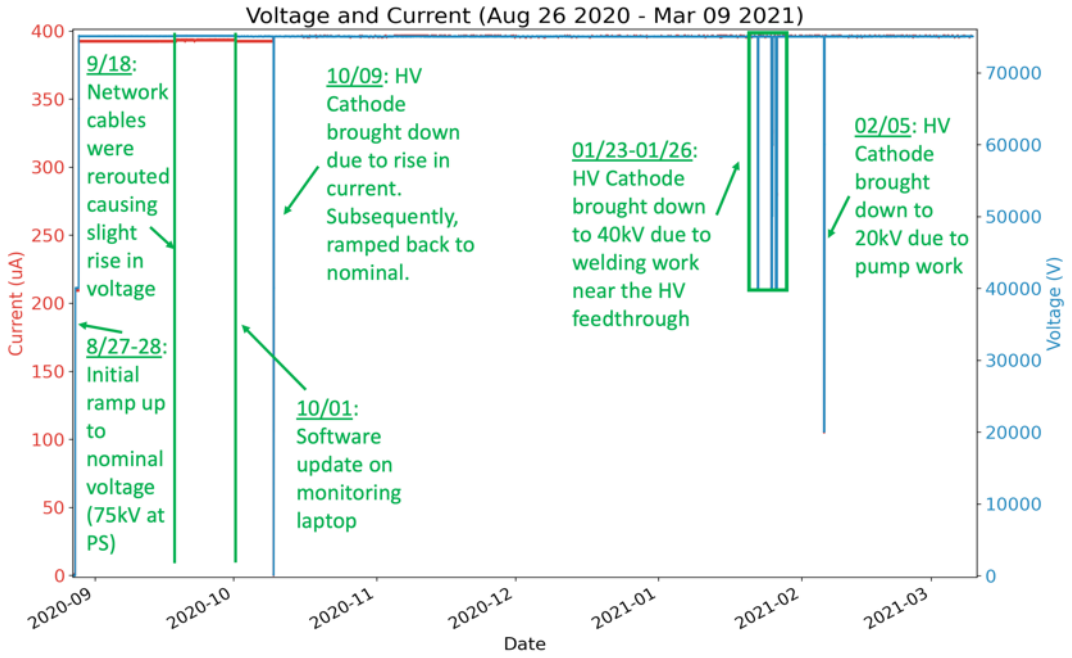
SBN Oversight Board meeting 03/12/2021

Detector commissioning status

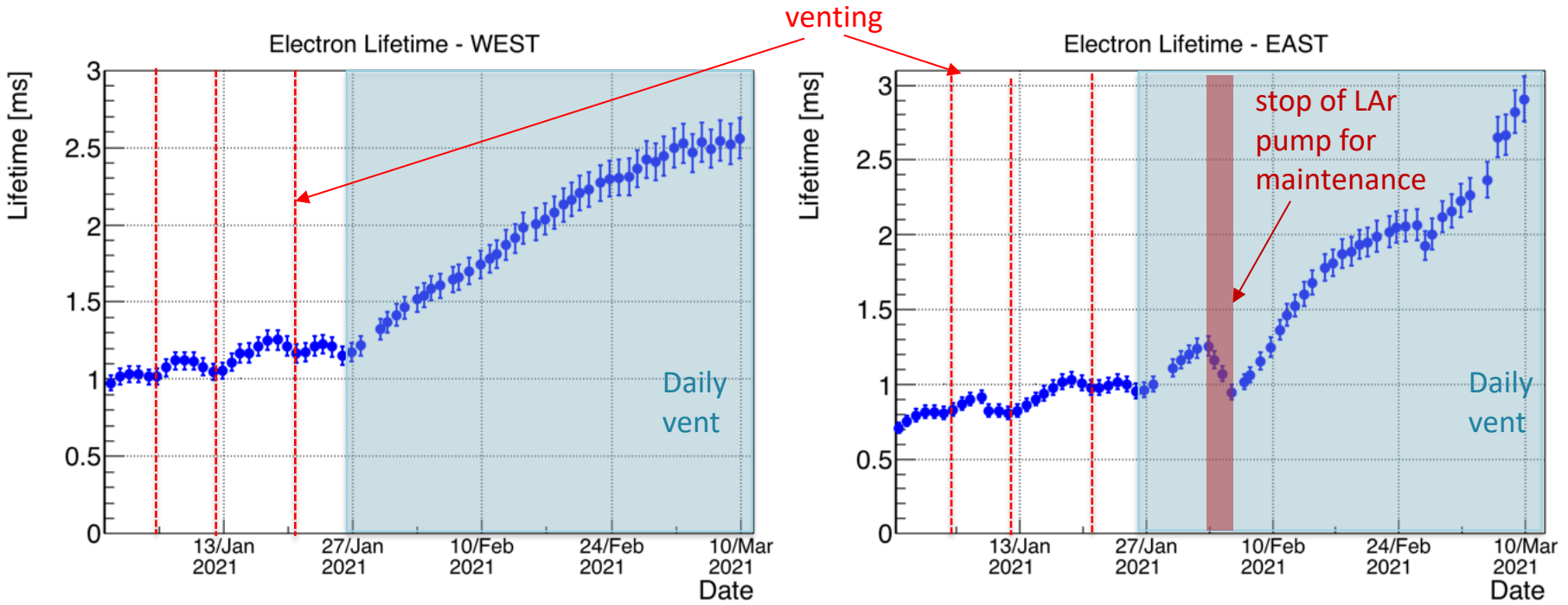
- Detector filled with liquid argon and in stable operations at nominal drift field 500 V/cm since Aug 27th. Remote-only shifts.
- Cosmic-ray interaction events initially collected with random 5 Hz trigger and data being analyzed for calibration purposes and measurements of electron lifetime.
- Additional runs taken for specific commissioning tasks. Initial trigger on Booster neutrino beamline which allowed to observe the first neutrino interactions.



Stability of the cathode voltage and current

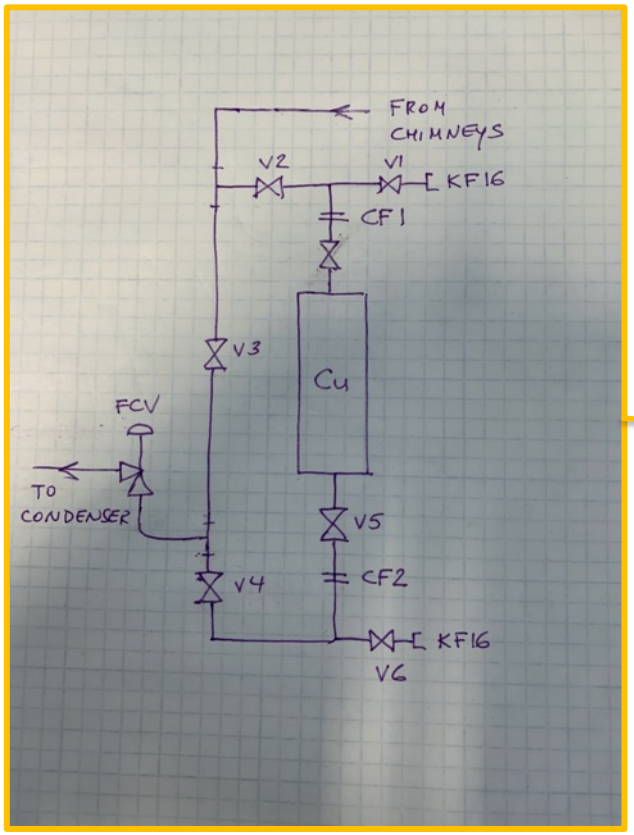
Cryogenics and electron lifetime

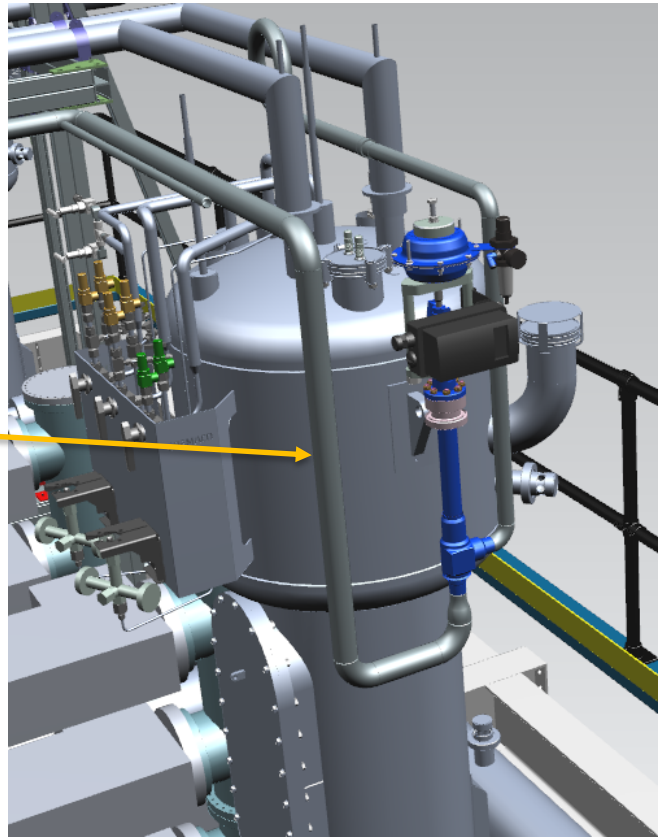
- Cryogenic system overall stable and fully operational!
  South-East condenser started on Feb 16th after modifications, and performing strong and steady. All GAr filters regenerated.
- Venting procedure continuing, now 10 minutes twice/day.
  LAr level to be re-topped this month.
- Electron lifetime improved up to almost 2.5/3 ms in West/East cryostat.



Plans to improve the electron lifetime

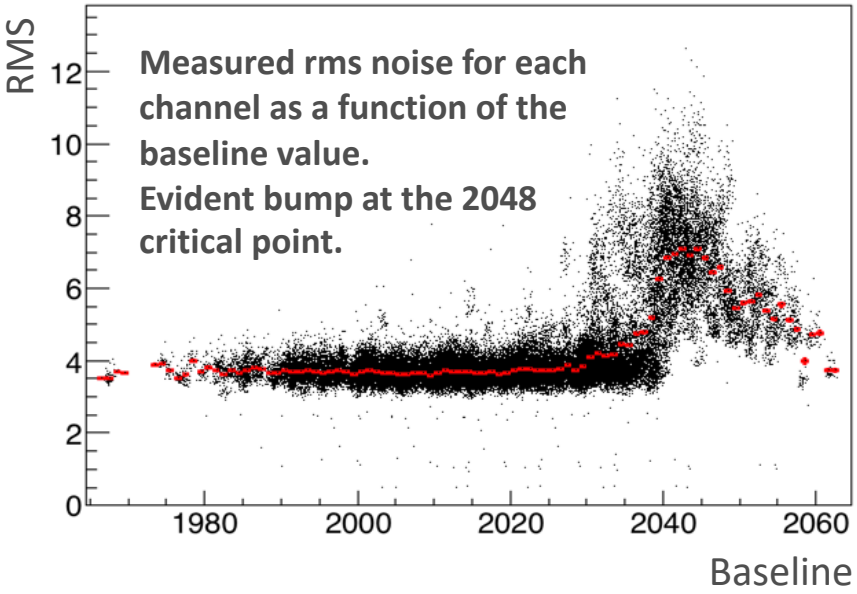
- Improvement in the purity after activation of SE condenser confirms that limited electron lifetime currently achieved possibly caused by insufficient GAr flow.
- 4 larger (up to 20L) external warm filters, 2 per cryostat, being constructed at CERN to be added to the gas collection system tentatively in late May.





Studies of TPC electronic noise in West cryostat

- The Dec '20 intervention mitigated the noise in the West cryostat with the addition of 2 x 100 Ohm resistors in the TPC readout boards and opened the window to better understand the TPC extra noise origin, disentangling the front-end electronics from external ancillary devices (cryo-boxes,...).



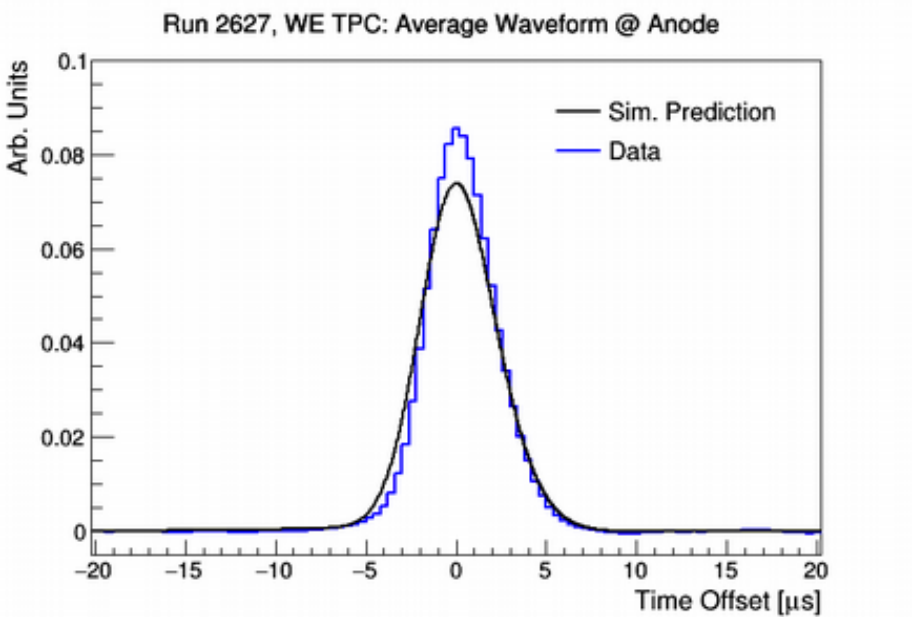
- Improvement NOT due to filtering but to baseline slight movement. The default value of the baseline (2048) corresponds to a conversion value of the ADC's where all bits are flipped, generating the observed noise.

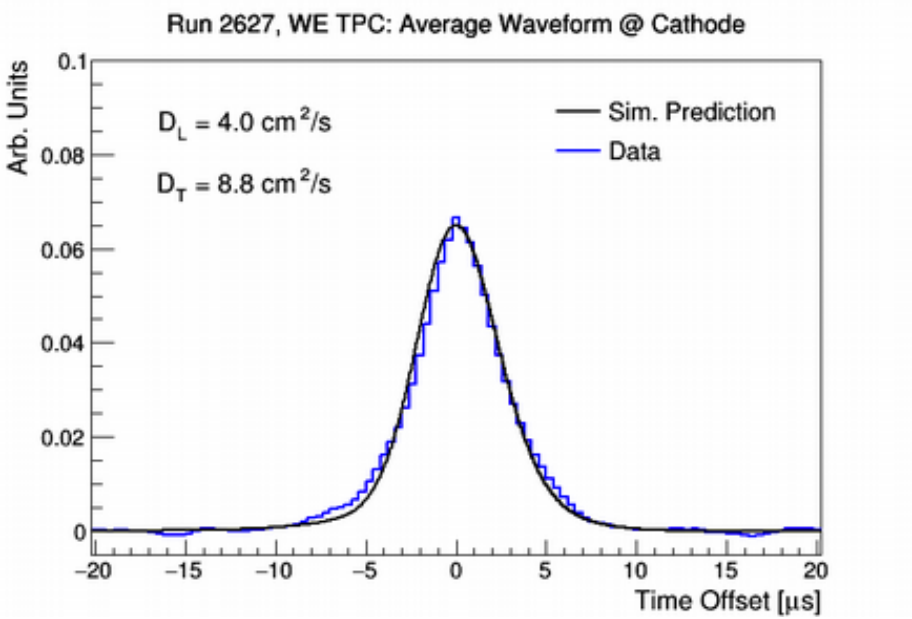
- Same effect observed but 10 times smaller on bench test setup. Suspect that current in excess at ADC critical point encounters ground loop, confirmed by increased noise observed when removing ground strap between mini-crate and feedthrough flange.

Additional TPC noise investigations and plans

- After Dec ‘20 intervention, large number of investigations performed at FNAL allowed to exclude potential noise sources, such as the TT-Link trigger/clock, cathode HV, wire bias and test-pulse distribution systems.
- Continuing the systematics survey of each flange would be needed to achieve S/N design figures BUT is extremely difficult with the present pandemic diffusion. For this reason, an effort has been initiated to reproduce the effects observed at FNAL on a bench test set-up in Padova.
- In occasion of the scheduled shutdown of many detector components in late March for re-topping the LAr level, a measurement campaign of the TPC noise will be carried out minimizing external noise sources:
  - ramping down cathode HV;
  - ramping down, disconnecting, and terminating (with 50 Ohms) wire bias;
  - terminating all unused connectors on the flanges (e.g. test pulse inputs);
  - performing a baseline scan with minimal online systems;
  - possibly powering down cryo boxes.

Modelling of TPC signals





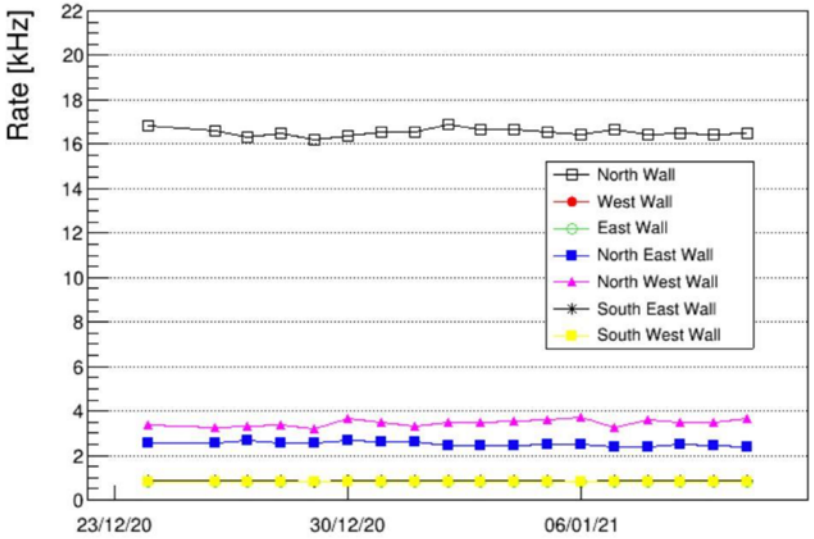
- Average waveform of TPC signals measured in tracks passing near the anode or the cathode useful respectively to tune electronics /wire field response simulation and to tune the simulation of electron diffusion along the drift.
- Anode waveform suggestive of minor response mismodeling.
- Reasonable agreement between data and simulation for the cathode waveform, though correction for field response bias using anode waveform still in progress. Extracted diffusion constants will be used to tune ICARUS simulation.

Commissioning activities of the PMT system

- The main PMT commissioning activity is presently the gain equalization:
  - data is being recorded with laser light pulses, to determine operation voltages for all PMTs to ensure a gain of 10^7 in LAr;
  - a procedure to monitor and improve the PMT equalization using single photoelectrons from background is being developed;
  - tests to certify the adopted equalization method and the obtained result (~6% resolution) are in progress.
- PMT counting rates for several configurations of discrimination thresholds and multiplicities are under study in order to determine the optimal values to be used for triggering purposes.
- Analysis procedures are being defined to improve the timing calibration of the PMTs using laser data.

CRT updates

- Commissioning of the side CRT in progress.
  - Seven wall sections integrated in DAQ readout
  - CRT data taking integrated in standard shifter runs
  - Last CRT wall (south end) installed in Feb 2021. Electronic installation and cabling in progress.
  - High rates in some CRT components (generally near the cryo devices) observed: investigations ongoing.



CRT South wall complete

- Top CRT.
  - Installation of vertical support structures planned to start in April
  - Modules already at FNAL, will be installed soon after (Summer).

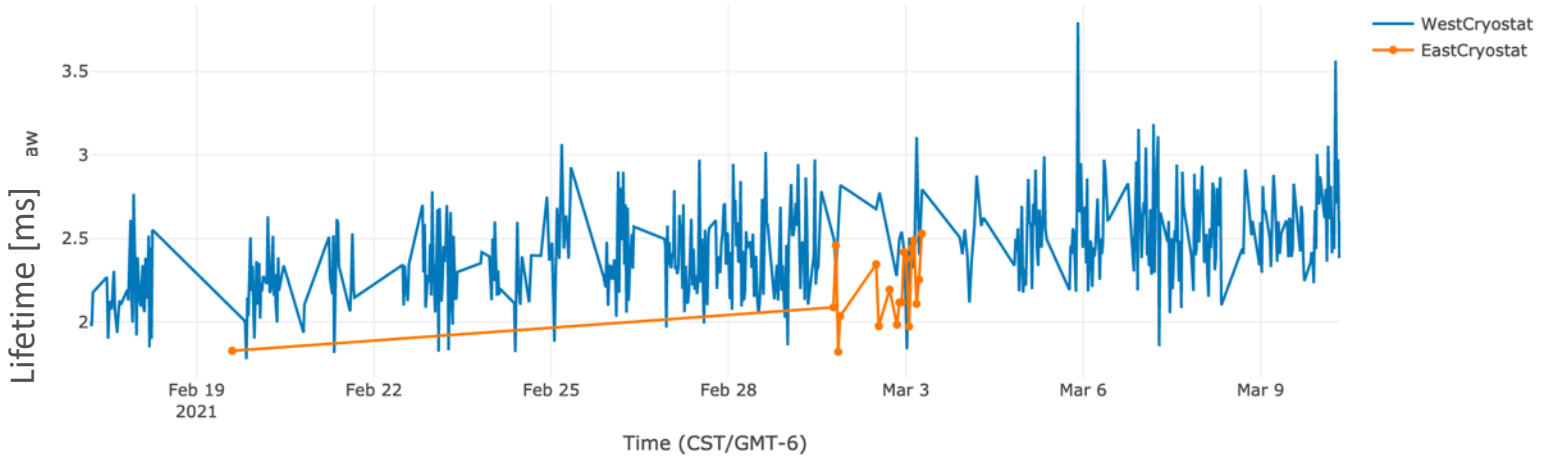
DAQ updates

- Thanks to help from SLAM (Scientific Linux and Architecture Management), SIS (Scientifics Server Infrastructure), Networking and artdaq (DAQ framework) team, fixed a major issue in system configuration that was making non-optimal use of networking. As a result, DAQ and online systems are performing much better.
- Icarus DAQ now fully uses the artdaq configuration database and an upgraded online software suite (more robust for handling larger CRT rates and exploiting time synchronization with the trigger for event building).
- Configuration software developed for baseline/threshold setting of PMTs.
- Substantial support to commissioning the trigger system allowed to fix some event synchronization issues and will help finalize commissioning of DAQ.
- WhiteRabbit BoardReader (responsible for interfacing DAQ with readout hardware) has been developed and is undergoing integration testing.
- Updated online monitoring suite includes live measurements of the LAr electron lifetime in the detector. Initial studies show stable operation, processing ~100 tracks in the detector every 15-20 minutes.

Icarus online LAr purity monitoring

ICARUS Monitoring | TPC | PMT | Side CRT | ICARUS EPICS | Archiver Status | Ground Monitor | CRYO | CathodeHV | TPC Power Supplies | PMT High Voltage | Data Browser

TPC Purity



An online measurement of the purity is obtained calculating the attenuation of the charge signal as a function of the drift time along each selected cosmic muon track and then averaging the obtained attenuation on 100 tracks crossing the detector. The measurement is then repeated every 15-20 minutes.

The visible fluctuations are related to the fast measurement based on a reduced statistics.

This online monitor can provide in real time a signature for possible change of the LAr purity status in the two module

Common SBN monitoring infrastructure

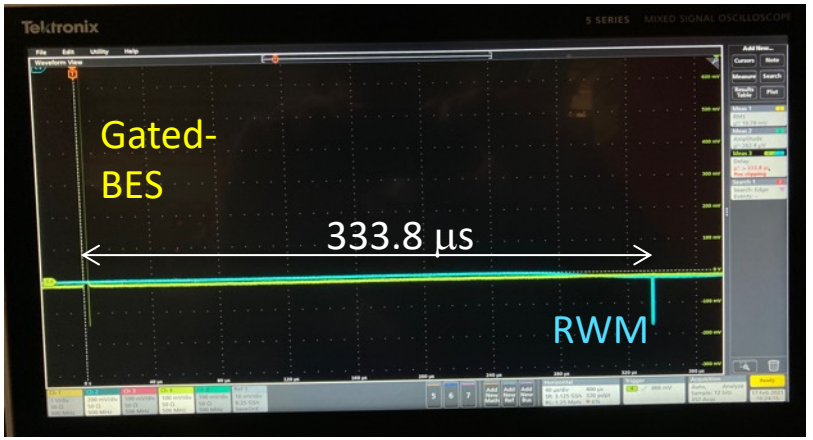
- Integration of purity monitoring into online monitoring system is a significant milestone for the common SBN online, to provide in real time a signature for possible change of the LAr purity status.
- Demonstrates convergence of many efforts across the SBN:
  - DAQ and dataflow development (SBND, ICARUS, FNAL ND and SCD)
  - online monitoring processing and display infrastructure (heroic efforts from Gray Putnam, SBND)
  - data archiving (Justin Mueller, ICARUS)
  - channel mapping effort (Bishu Bisweranjan, ICARUS)
  - processing chain using LArSoft (LArSoft team from FNAL, SBN and ICARUS software developers)
  - algorithm development and verification (ICARUS efforts from Christian Farnese and former FNAL Intern Olivia Bitter)
- Shared efforts in SBN are essential to developing these DAQ tools. Need to continue to foster these and invest in support from each detector collaboration.

Initial activation of the trigger system

- Setup of an initial simplified trigger system aimed at verifying the correctness of the trigger chain and its functioning, as well as exercising the synchronization of the DAQ components.
  In parallel with development/commissioning of full trigger.

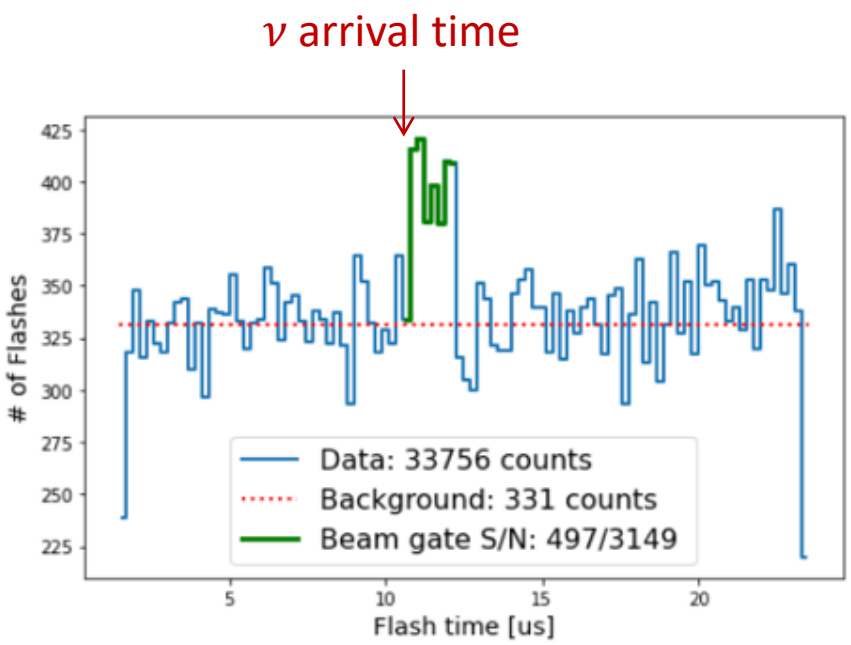
- Two steps:
  1) “spill-only”, based on the BNB extraction signal (gated-BES) distributed via White Rabbit network (guaranteeing synchronization of nodes to better than 1 ns), to read-out both TPC and PMTs signals in the East cryostat;
  2) addition of scintillation light info by requesting ~10 PMT pairs in either PMT wall in the EAST cryostat inside a 1.6 μs BNB gate.

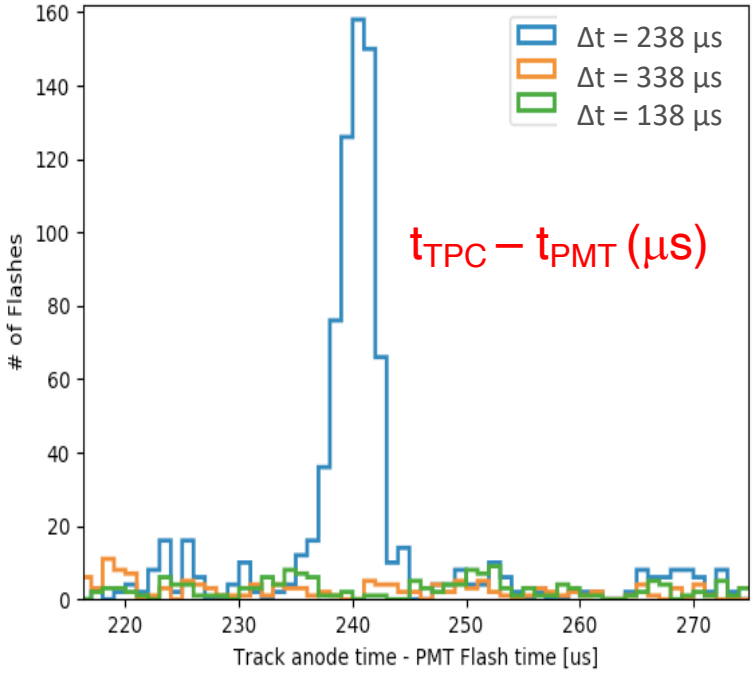
- Offset added to the gated-BES for the PMT trigger generation ~ 335 μs: time difference between gated-BES and neutrino extraction (RWM) signals + ν time of flight from MI-12 (beam target hall) to ICARUS.



Measurements with “spill-only” trigger

- Time of PMT light flashes (>5 fired PMTs within 150 ns window in coincidence in both left and right TPCs) in PMT readout window shows excess over the cosmic background rate at the expected ν arrival time.
- Anode-to-cathode cosmic μ tracks with unambiguously measured crossing time in the TPC image t_{TPC} found to match the corresponding time of PMT light signal t_{PMT}. Clear ~2 μs peak in $t_{TPC} - t_{PMT}$ confirming the correct relative TPC - PMT timing.



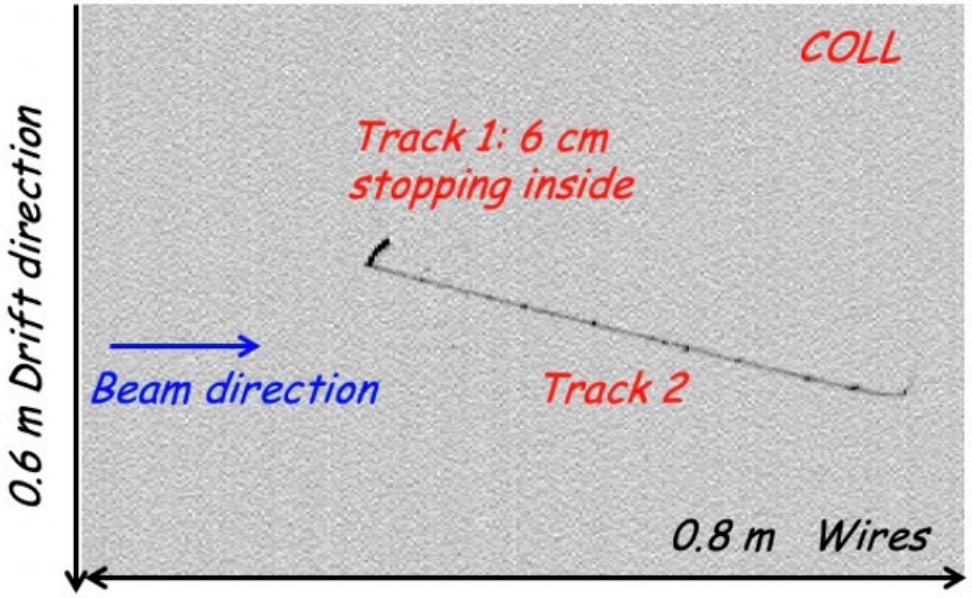


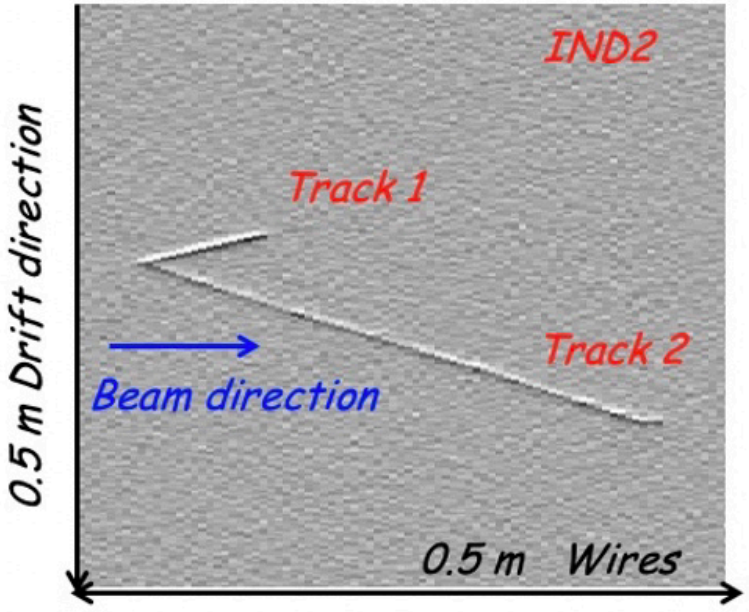
Initial search for neutrino interaction candidates

- 5207 BNB spills (2.8 E12 ppp, 3 Hz repetition rate, Run # 4575) collected with ”spill-only” trigger, recording both TPCs and PMTs. LAr purity ~1 ms.
  113 events selected by requiring >5 fired PMTs (PMT threshold corresponding to 50 phes) within 150 ns window in both left and right TPCs, within 3 μs around the expected beam spill time.
- Similarly ~10 k BNB spills collected in Run # 4626 in the same conditions.
  220 events selected according to the same criteria.
- Selected event samples visually studied to search for ν candidates identified by a clear vertex compatible with the incoming ν beam direction and a possible μ track:
  - vertex position at least 5 cm from top and bottom TPC sides, 50 cm from the upstream and downstream TPC walls, 5 cm from the anode, 1.5 cm from the cathode. TPC signals searched in 1 ms time window starting at beam spill time;
  - a procedure to reduce the TPC electronic noise was applied for sake of a better tracks visualization

First ν_{CC} candidates identified!

Example of ν_μCC candidate

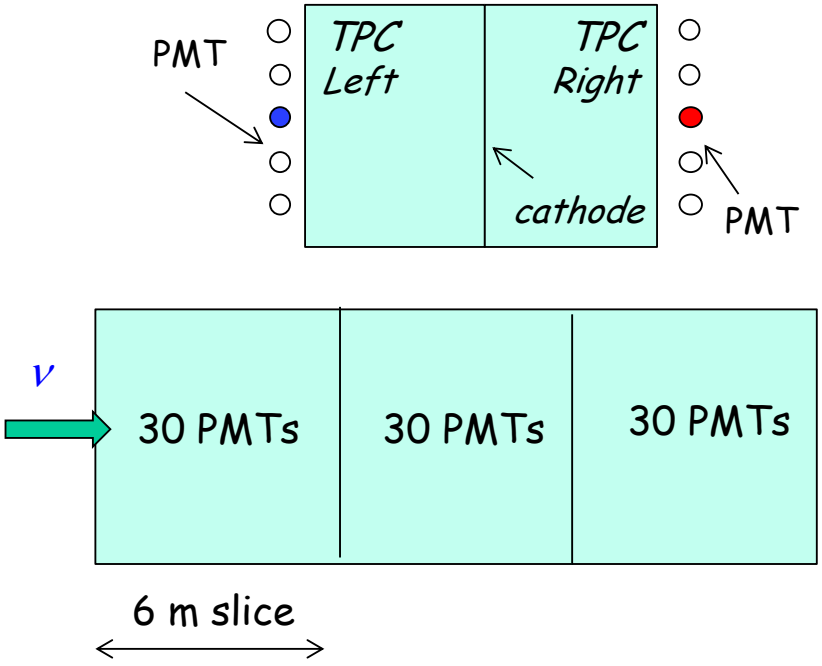




- QE ν_μCC candidate (run #4626, ev #227) in COLL and IND2 views.
- Vertex at 29 cm from the bottom wall. Two tracks produced, $E_{DEP} \sim 170$ MeV
  - Track 1 is the proton candidate with $E_K \sim 70$ MeV, stopping after L = 6 cm
  - Track 2 is likely the μ exiting on bottom wall after L = 51 cm.

Present trigger system status and next steps

- Full trigger logic foreseen for data taking with the beam, based on a fired PMT majority in coincidence with the BNB extraction, being implemented step-by-step:
  1. Measurement of multiplicity/rate for 30 PMTs in 6 m detector slice in one TPC wall as a function of PMT threshold. **Ongoing.**
  2. Production of a trigger signal by PMT majority inside one 6 m slice in coincidence with BNB beam spill. **Ongoing.**
  3. Extension of the PMT majority logic to 2 others 6 m detector slices of East cryostat and then similarly for the WEST cryostat. **To follow**.



Backup