Commissioning of the Icarus detector

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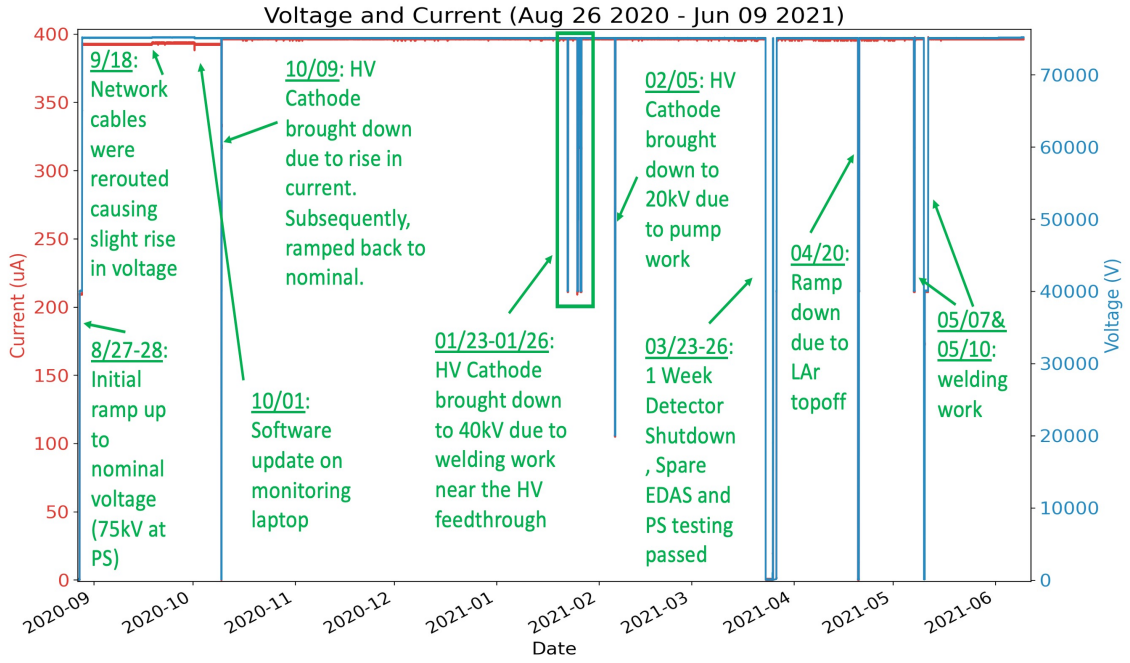
SBN Oversight Board meeting 06/11/2021

Detector status and stability

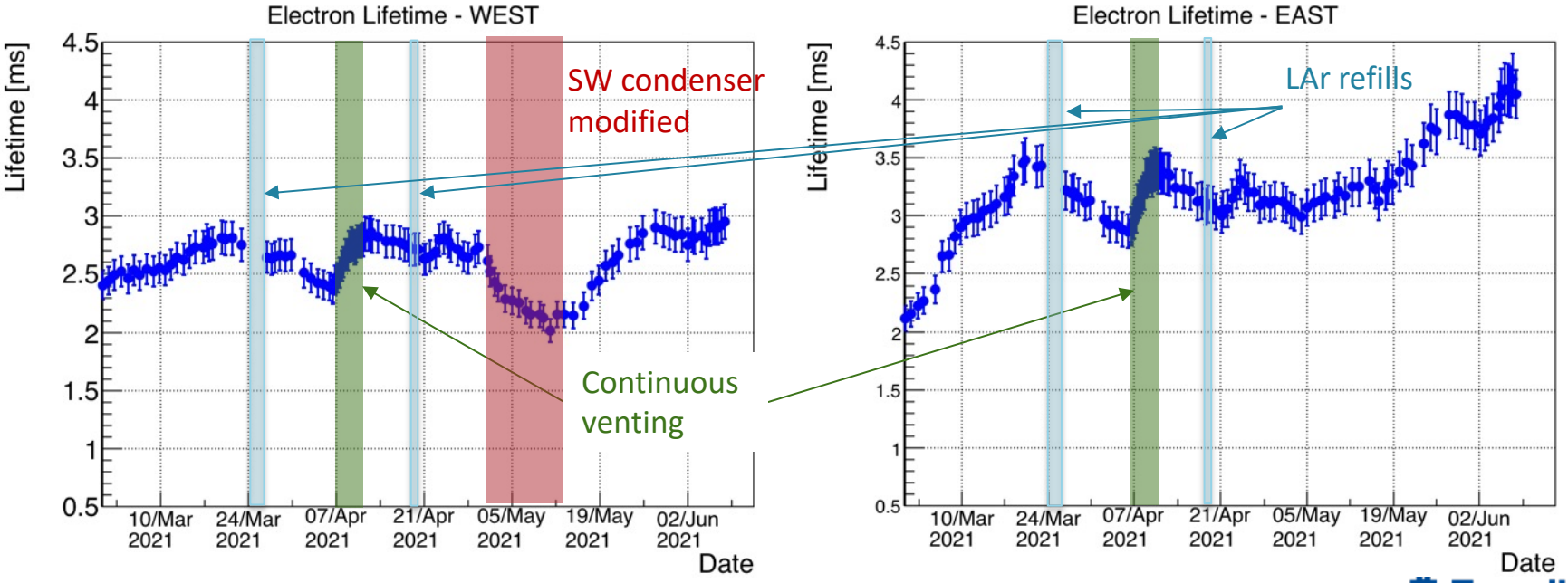
- Stable detector operations for both TPC and PMTs since Aug 27th.
- Networking upgraded to the final configuration with redundancy.
- Slow controls performing steadily and continuously upgraded to add more components. Remote-only shifts.
- Steady data taking with neutrino beams overnight and during weekends since mid March, in parallel with continuing commissioning activities during working hours. Full time (24/7) neutrino beam run since May 30th.



Stability of the cathode voltage and current, at nominal drift field 500 V/cm

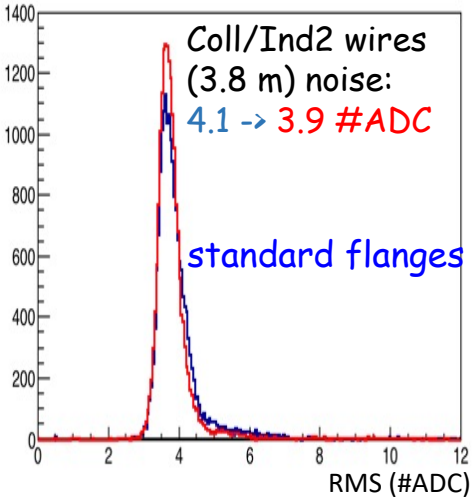
Cryogenics and electron lifetime

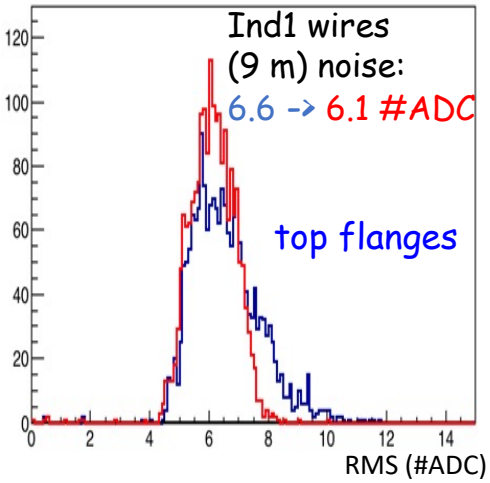
- Cryogenic system overall stable and fully operational! All GAr filters regenerated and LN_2 and LAr pumps maintained.
- The two South GAr recirculation units modified, to increase performance. All 4 units performing well and steadily. LAr refills on March 24th (≈ 5000 l) and April 19th (≈ 2500 l) to bring the level 1.5 cm above the nominal level: smooth operations.
- April 7th to April 9th: 1 day of continuous venting at 20 g/s/module and 2 days at 15 g/s/module to check the effect on the purity.

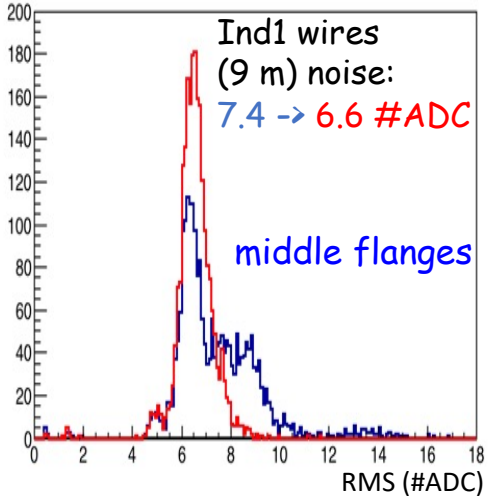


TPC electronic noise mitigation

- Increase of TPC electronic noise by ~30% after LAr filling, well above expectations from dielectric effect. However not preventing neutrino events collection.
- Intervention in Dec '20 allowed to mitigate in the West cryostat a 120 kHz noise detected in several boards, disentangling contributions of front-end electronics from external ancillary devices and restoring some ground connections.





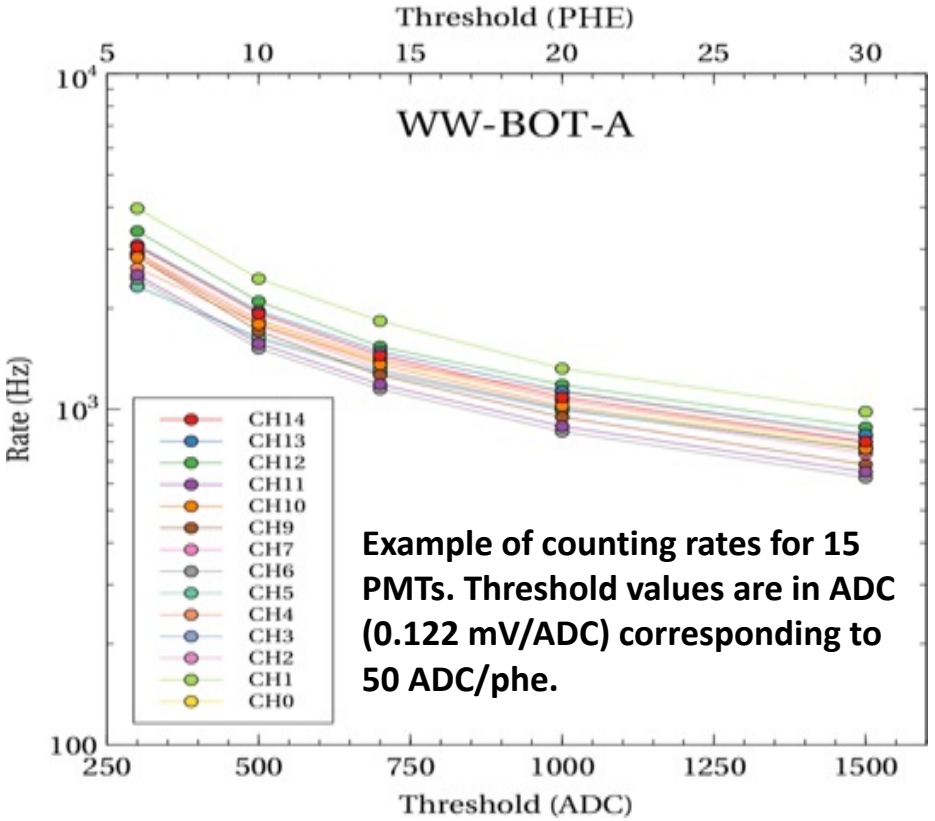


Before intervention
After intervention

- Several potential external noise sources (TT-Link trigger/clock, cathode HV, wire bias and test-pulse distribution systems) excluded through investigations in situ. Deep investigation of coherent noise on all signal flanges needed but extremely difficult within the pandemic; test-bench in Padova studying the issue.

Status of the scintillation light system

- Excellent stability of the light detection system (PMTs) since activation. PMT HV system remotely controlled during regular shifts by means of a GUI interface allowing PMT voltages monitoring/setting.
- The PMT system has been extensively employed for calibration purposes and now being integrated in the trigger system.
- Ongoing PMT calibration activity to equalize the gain to G = 10^7 using both laser light pulses and single photoelectron (phe) from background (~50 kHz per PMT).
  PMT timing calibration under study.
- PMT rates measured as a function of signal discrimination threshold :
  - uniform behavior across PMTs;
  - being compared with expectation from MC simulation.



Example of counting rates for 15 PMTs. Threshold values are in ADC (0.122 mV/ADC) corresponding to 50 ADC/phe.

CRT status

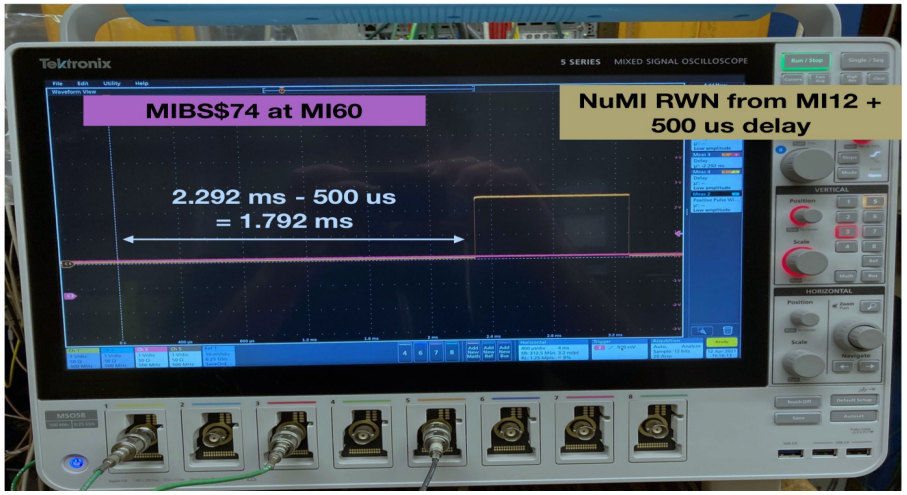
- Installation of the last wall of the side CRT completed, including readout and cabling.

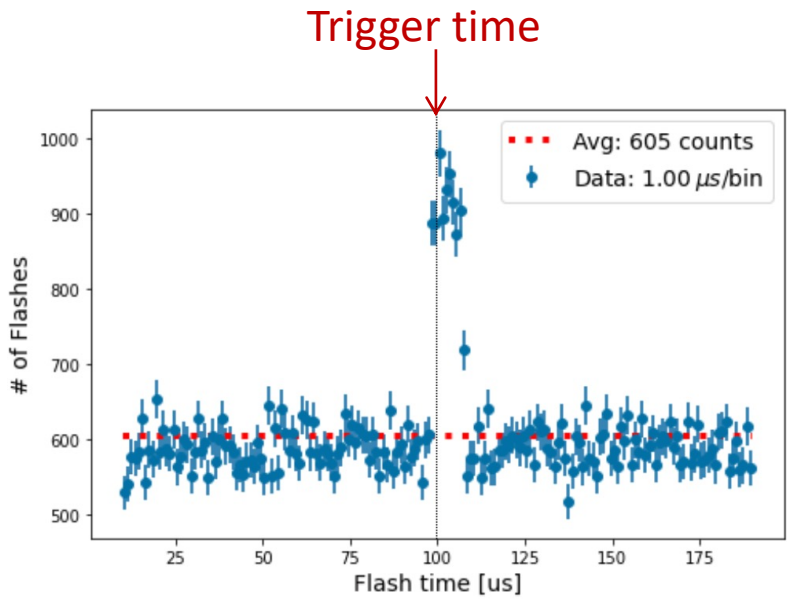
- Several ongoing activities:
  - chasing the origin of noise sources;
  - side CRT data/MC comparison;
  - optimization of thresholds for CRT hits identification;
  - deep investigation of relative timing between PMT and CRT systems;
  - work on CRT hits reconstruction.

CRT South wall complete

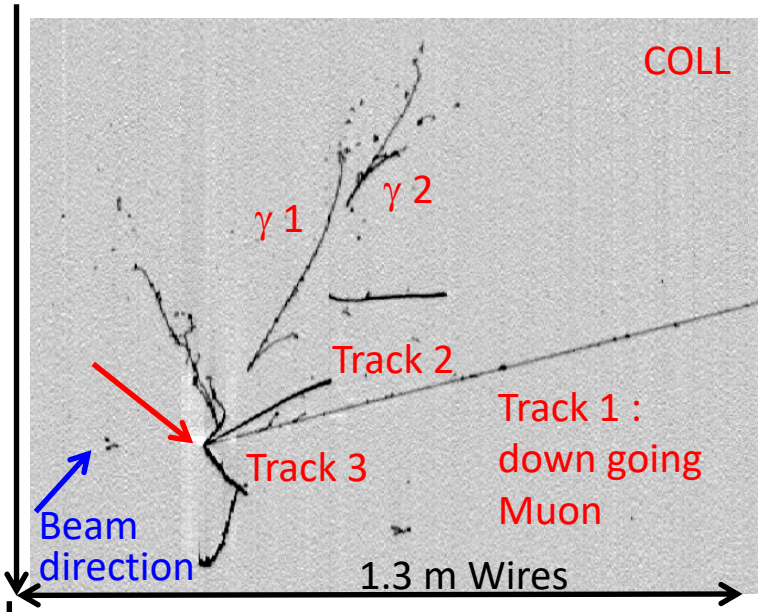
Activation of the NuMI beam trigger

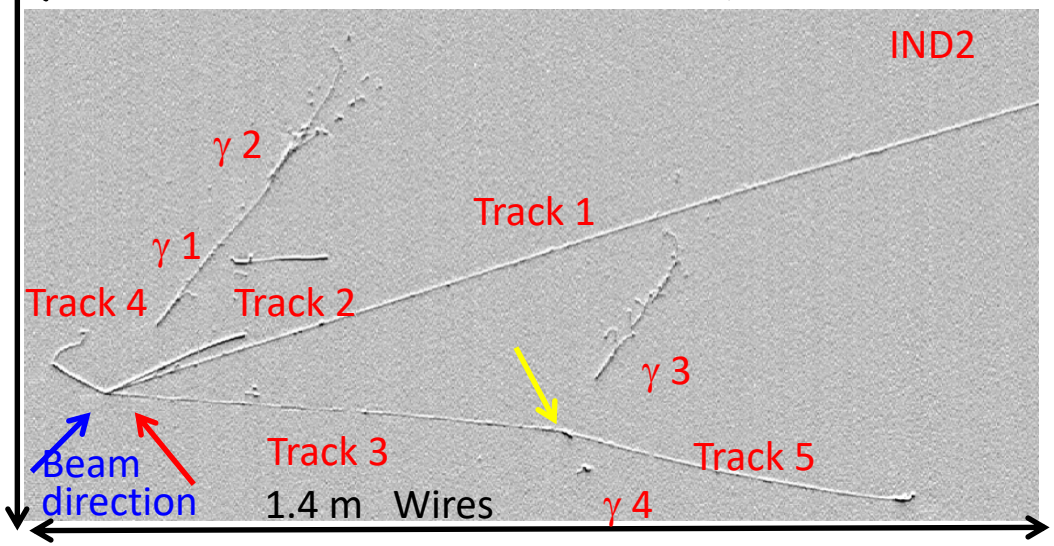
- After verifying correct timing of BNB signals, similar procedure adopted for NuMI:
  1) time interval between Early warning signal (MIBS$74) and proton extraction signal (RWM counters at target) measured at oscilloscope;
  2) excess of PMT light flashes (>5 fired PMTs within 200 ns window in coincidence in both left and right TPCs) over the cosmic background rate at the expected time verified in dedicated test run recording only PMT components;
  3) setup of minimum-bias NuMI trigger to record all components (PMT, TPC and CRT) at each beam extraction.





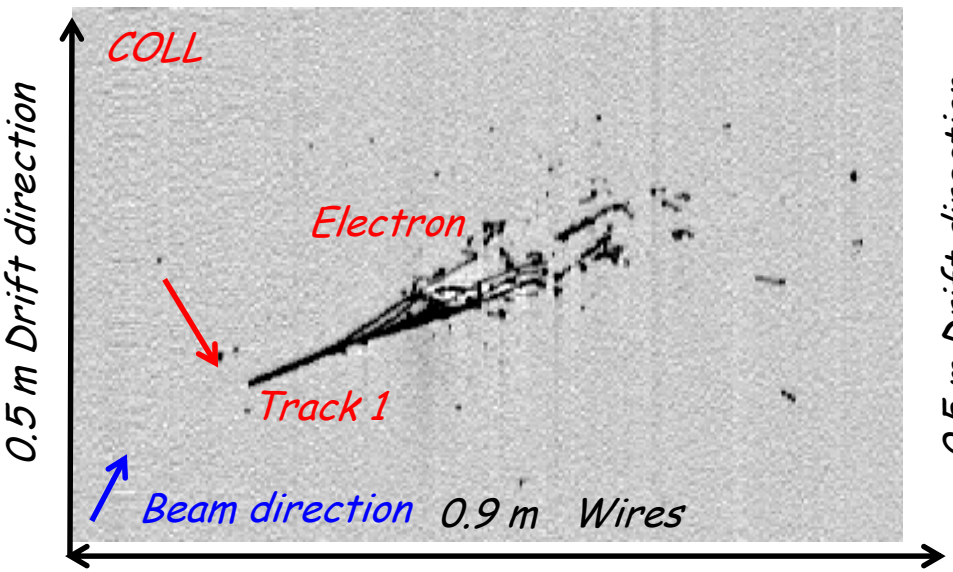
Example of NuMI ν_μCC candidate

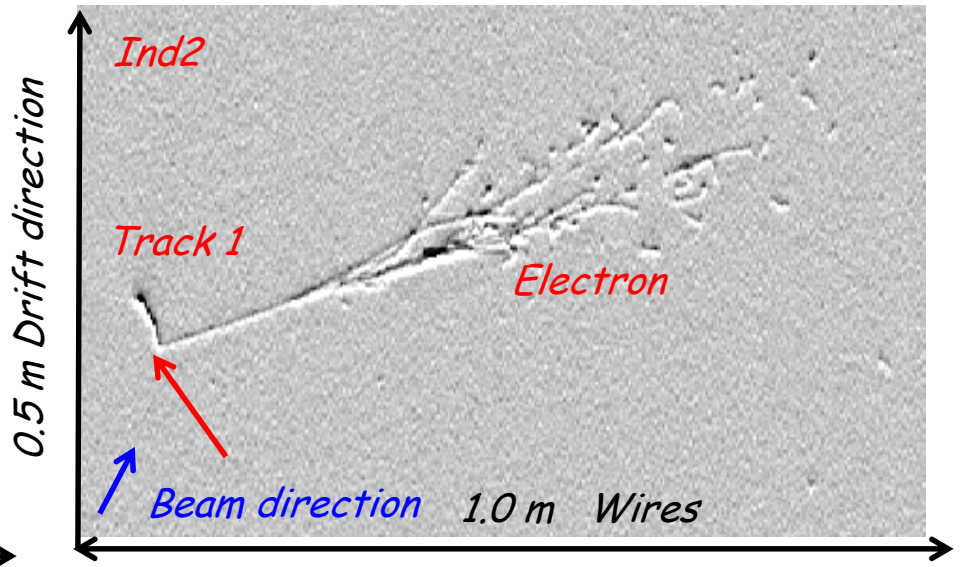




- Five particles produced at vertex (red arrows), E_{DEP} ~ 2.5 GeV:
  - Track 1: downward going μ, crossing the cathode and exiting downstream, L= 4.2 m, p~ 1.3 GeV/c by MCS;
  - Track 2: upward going p candidate, L=31 cm;
  - Two photons $\gamma 1$, $\gamma 2$ pointing to the primary vertex, E_1 ~ 200 MeV, E_2~ 240 MeV, converting at 18 cm, 58 cm distance;
  - Track 3: hadron that produces a secondary vertex (yellow arrow) where a short proton, another hadron (Track 5) and two photons $\gamma 3$, $\gamma 4$ are also clearly visible;
  - Track 4: charged pion with visible Michel electron produced in the π -> μ -> e decay chain.

Example of NuMI ν_eCC candidate

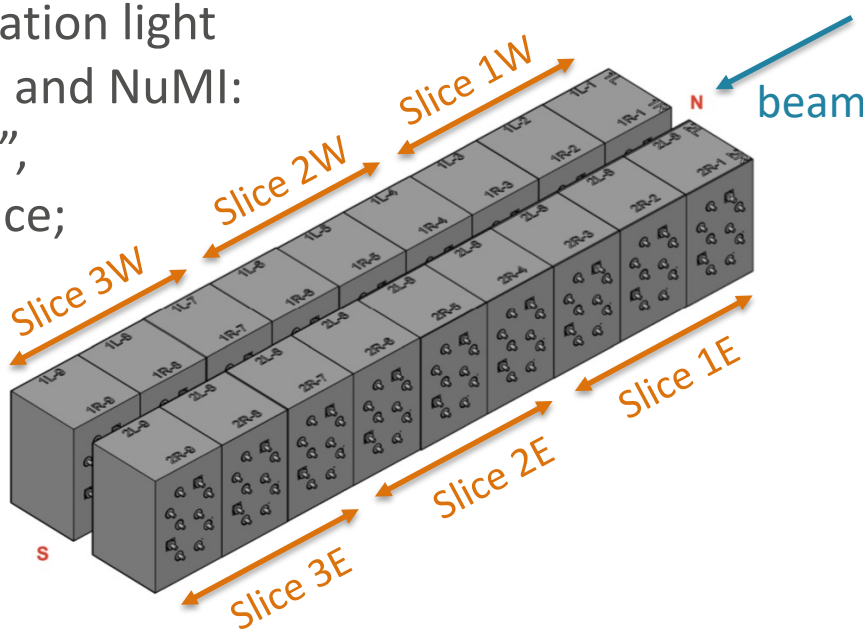




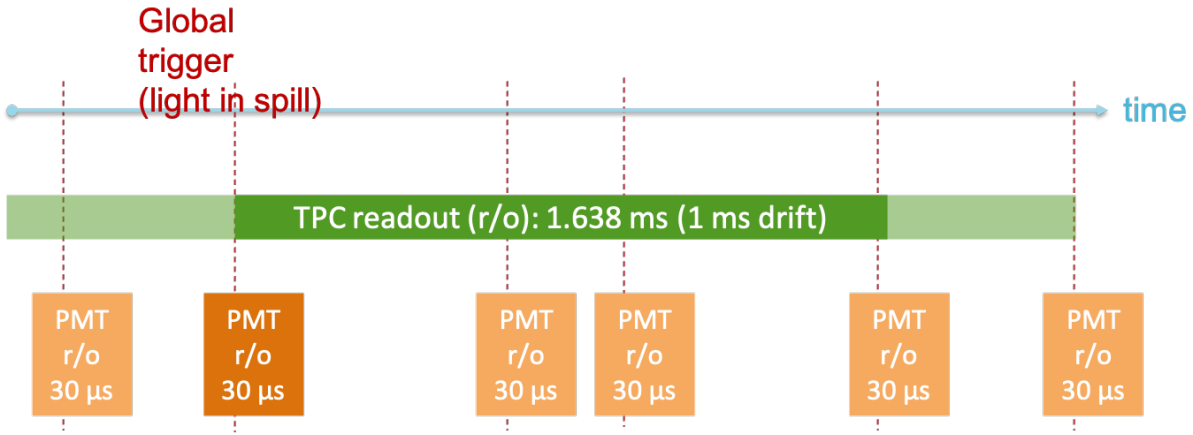
- QE electron neutrino candidate with two particles at the primary vertex (indicated by red arrows):
  - Track 1 is the upward going proton candidate stopping inside L= 13 cm
  - The electron shower is downward going: the beginning of the shower is clearly visible in particular in Induction 2 view (in Collection the e^- and track 1 are overlapped).

First beam trigger based on scintillation light

- Activation of beam trigger requesting scintillation light in coincidence with beam gate, for both BNB and NuMI:
  - PMTs in each cryostat grouped in 3 ”slices”, 6m size along beam direction, 60 PMTs/slice;
  - request of signal $\gtrsim$ 10 phe in at least 10 pairs of adjacent PMTs in at least one slice.



- PMT waveforms readout at any scintillation light activity in 2 ms around the beam gates. Allows recording of information on cosmics during TPC drift time for offline matching of light and charge.

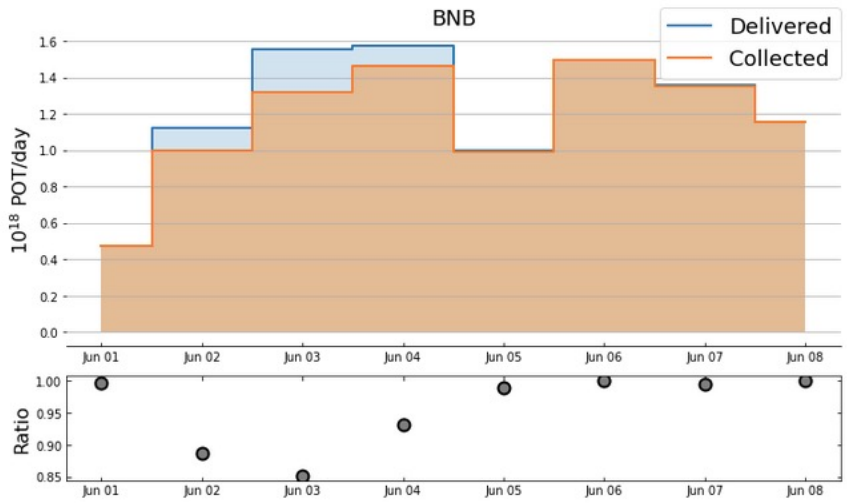


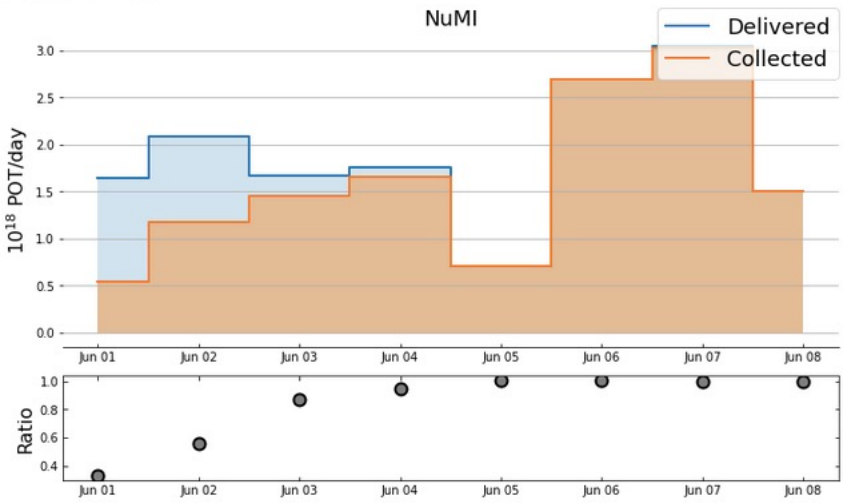
Initial neutrino data taking

- Advancement in the detector commissioning process, nominal free electrons lifetime and detector operational stability recognized at the last ICARUS Collaboration meeting (March 16-17, 2021) allowing to initiate data taking collecting steadily neutrino beam events with the full PMTs + TPCs.
- Since end of March BNB neutrinos collected overnight with minimum bias trigger (data collected for every spill), while commissioning activities (trigger development, PMTs calibration, CRT, ...) continued during the day. NuMI minimum bias beam trigger added in the second half of April.
  - Very stable running conditions. Average run duration > 9 h.
  - Raw data written to tape. Simple light filter used to down-select events that contain light activity in coincidence with the beams spill gate for higher level processing (e.g TPC reconstruction): reduction factor in the data load ~1/30.
  - Collected events used to setup the software infrastructure for data processing/storage and workflow management.

Test of physics run

- Since May 30th full-time beam run to emulate the physics run that will start in the next Fall:
  - trigger based on scintillation for both BNB and NuMI;
  - run coordination structure with A. Scarpelli Run Coordinator, A. Fava Deputy;
  - ICARUS is now the primary BNB user.
- All episodes of unplanned interruption of data taking investigated and lessons learned informing improvement of the operation procedures.





Plan for the summer shutdown

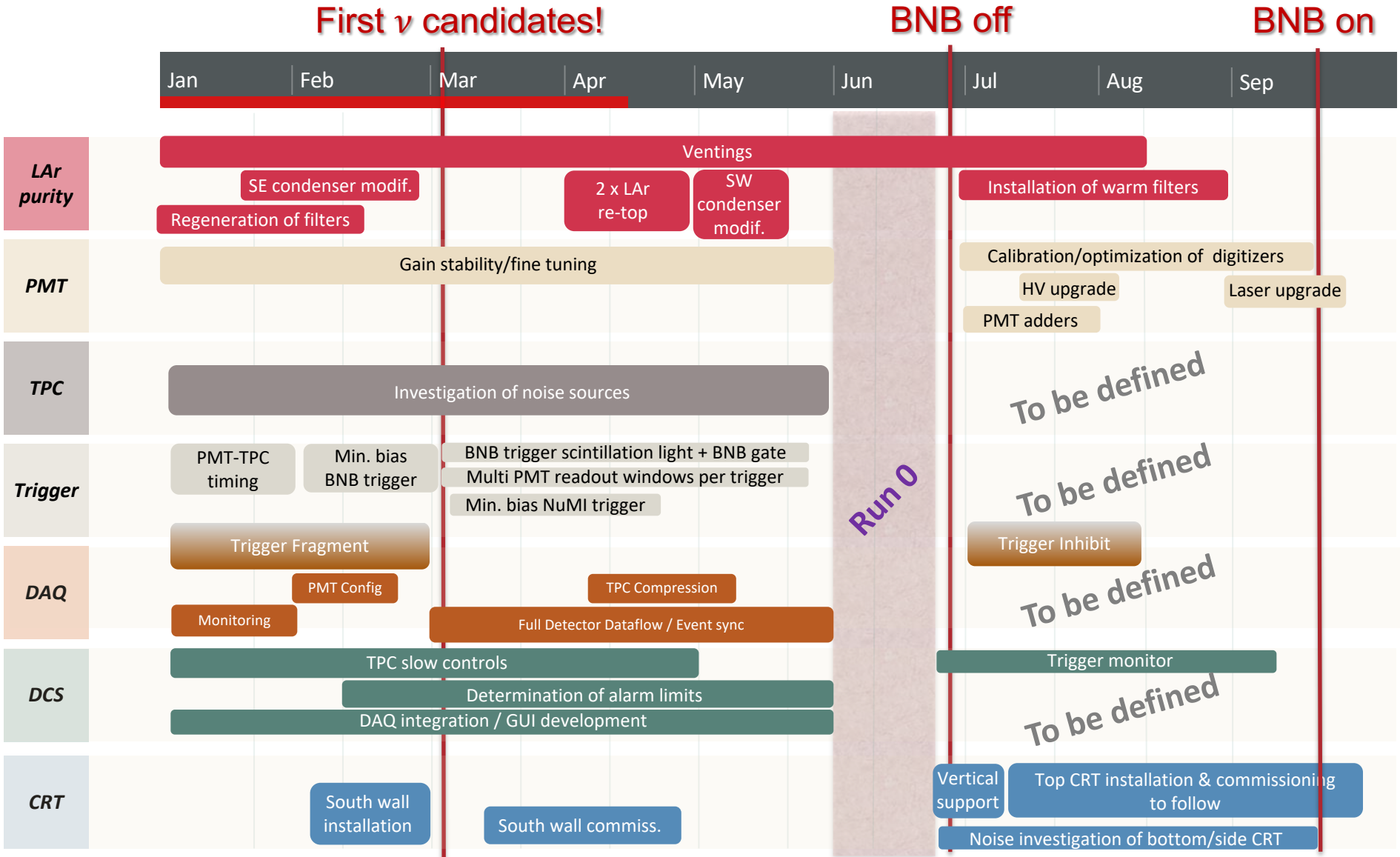
- Collected data being analyzed and used for tuning of event reconstruction software tools. First results will be presented at summer conferences.
- Commissioning activities (calibrations, trigger development, ...) will be restarted with cosmic ray data.
- Upgrades of the PMTs HV system and interventions on the TPC readout electronics (noise reduction) are planned.
- Upgrade of the GAr recirculation system (insertion of warm filters with H_2O removal) will be implemented.
- Main installation activity will be the installation and commissioning of the Top CRT to be followed by the installation of the overburden.
- Deploy a stable data processing, storage and related workflow.
- Complete the automatic data transfer by RUCIO system from FNAL to CNAF (Italy), at present in preparation with FNAL and CNAF Computing Centers support.
  A suitable book-keeping database exploiting run metadata will be also prepared.

Top CRT installation

- CRT modules delivered from CERN and stored in the warehouse.
- Mounts for vertical modules:
  - mount design modified for more rigidity and easier CRT module installation;
  - grinding/welding above the detector;
  - installation to start after beam run.
- Module installation planning:
  - 18 INFN collaborators identified to come to Fermilab in teams over a period of ~ 4 months;
  - support from PPD and ND technicians;
  - preparing for first team of four in July.

- Module installation schedule:
  - May-early July: modify and install vertical mounts
  - July: vertical modules
  - July-Aug: support beams, fire protection, and lighting
  - Aug-Oct: horizontal modules
  - Oct-Nov: commissioning

High-level planning of commissioning activities



Summary

- Both detector and cryogenic systems running steadily since several months.
- Free electrons lifetime now at the level of 3 ms and stable.
- ICARUS data taking collecting steadily BNB neutrino beam events with the full PMTs + TPCs since mid-March. NuMI beam added in mid-April.
- Since end of May full-time neutrino beam run ongoing with trigger based on scintillation light information. ICARUS primary BNB user.
- Installation of the Top CRT and of the overburden needed in order to fulfil the requirements for sterile neutrino search:
  - side CRT completely installed and commissioned;
  - top CRT modules at Fermilab, to be installed during the summer shutdown;
  - installation of the overburden to follow at the beginning of the next neutrino run.

Backup