Commissioning of the Icarus detector

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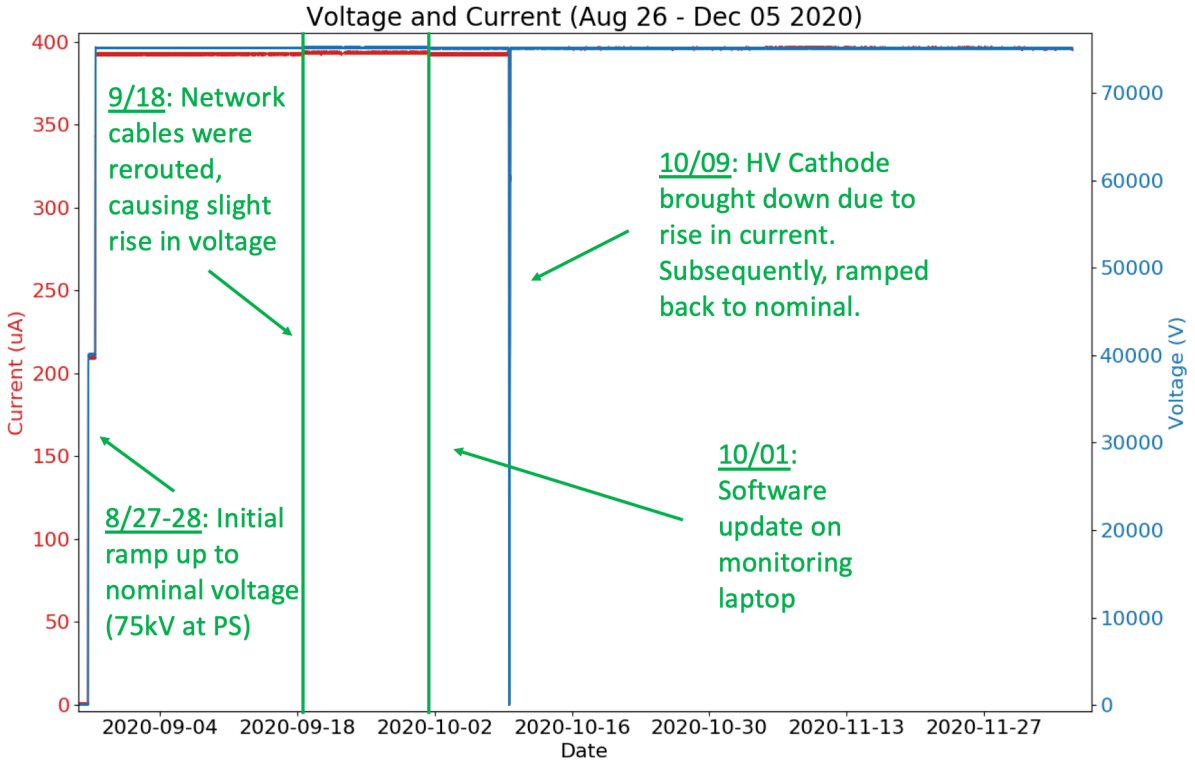
SBN Oversight Board meeting 12/11/2020

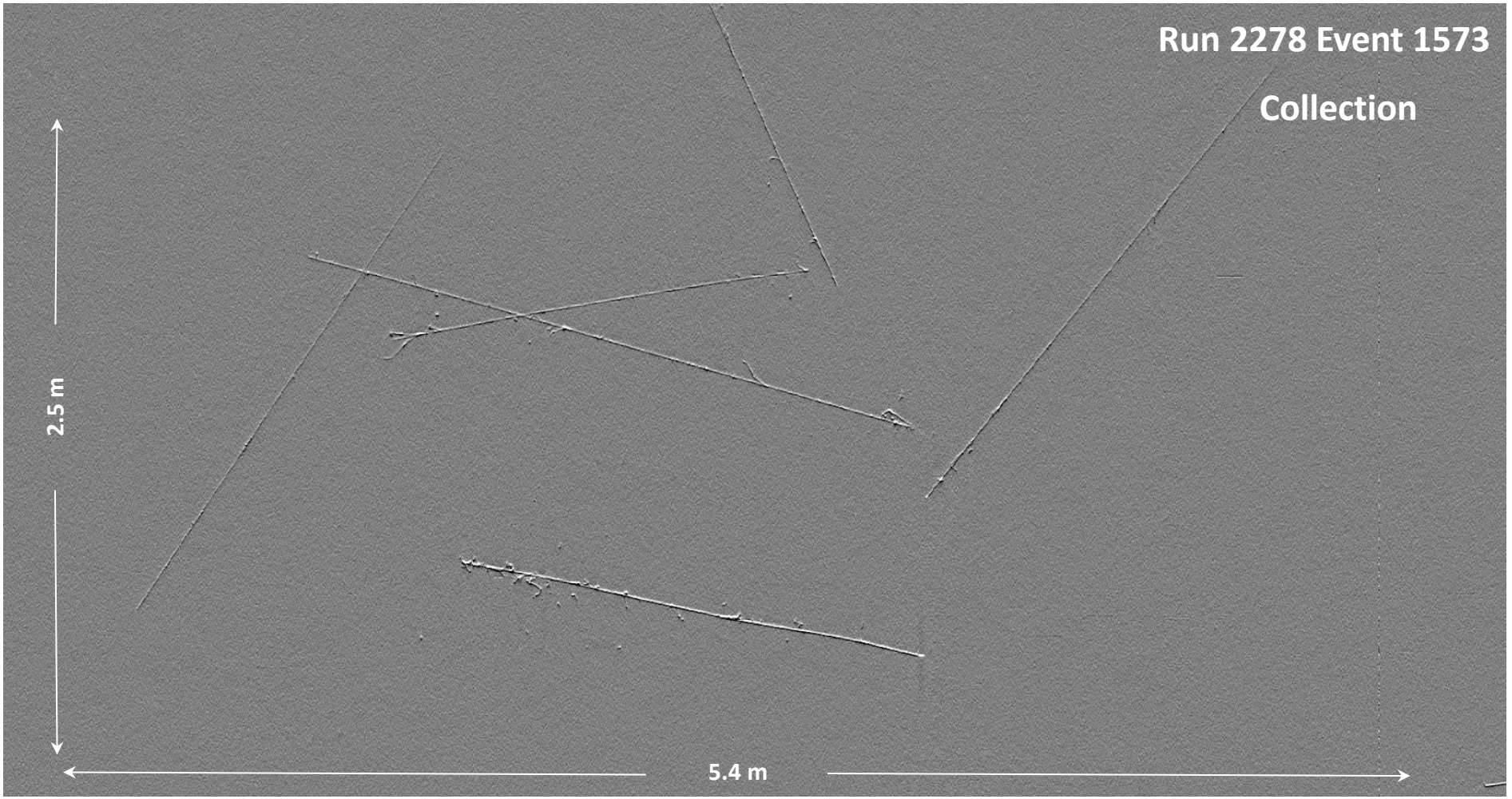
Detector commissioning status

- Stable operations in nominal conditions since Aug 27th. Remote only shifts.
- Cosmic-ray interaction events collected with random 5 Hz trigger and data being analyzed for calibration purposes.
  Dedicated runs also taken for specific commissioning tasks (ex: optimization of TPC noise conditions, PMT-LVDS commissioning, DAQ upgrades/longevity tests, etc).



Stability of the cathode voltage and current

Sample events @ 500 V/cm



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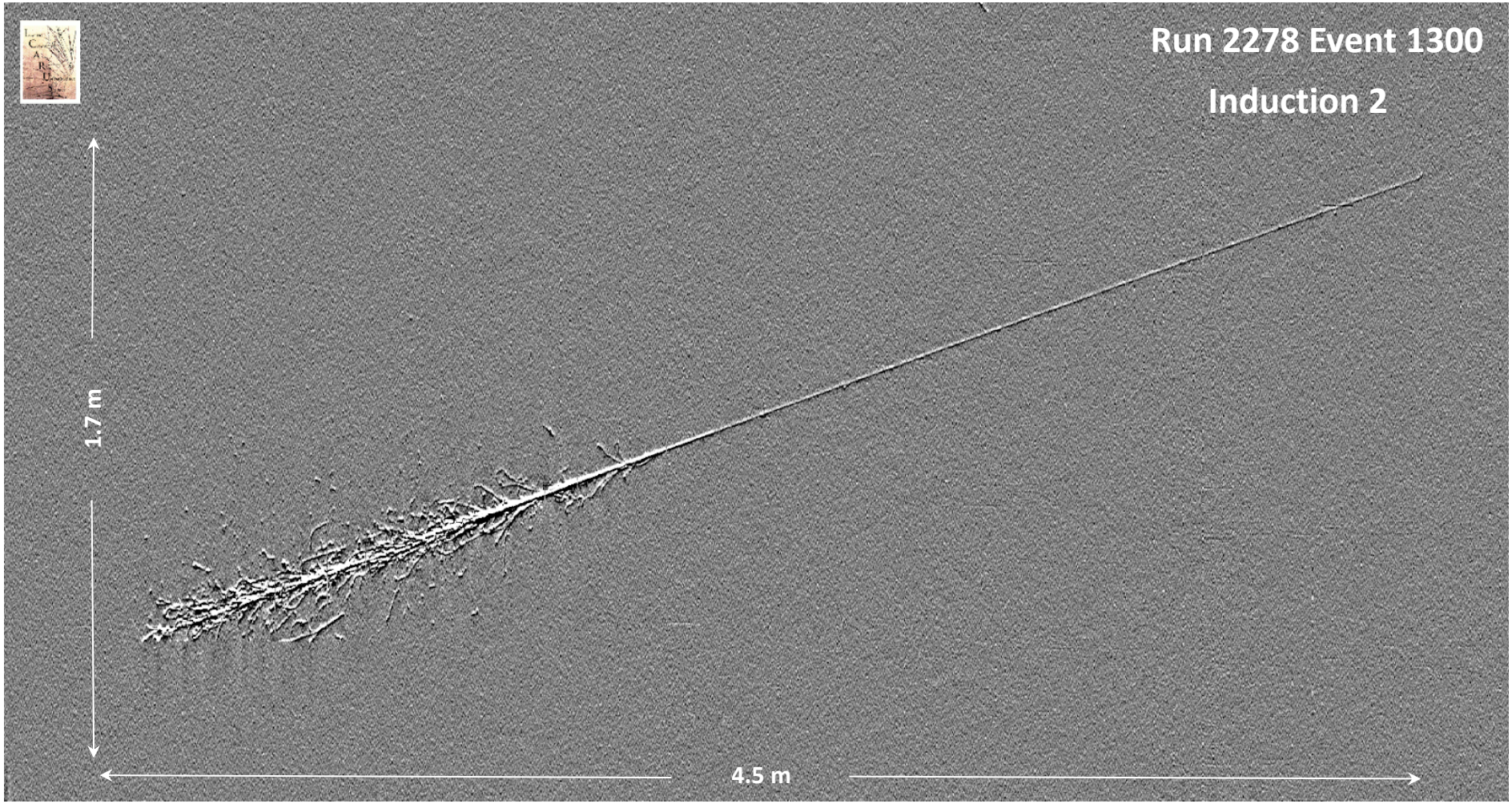
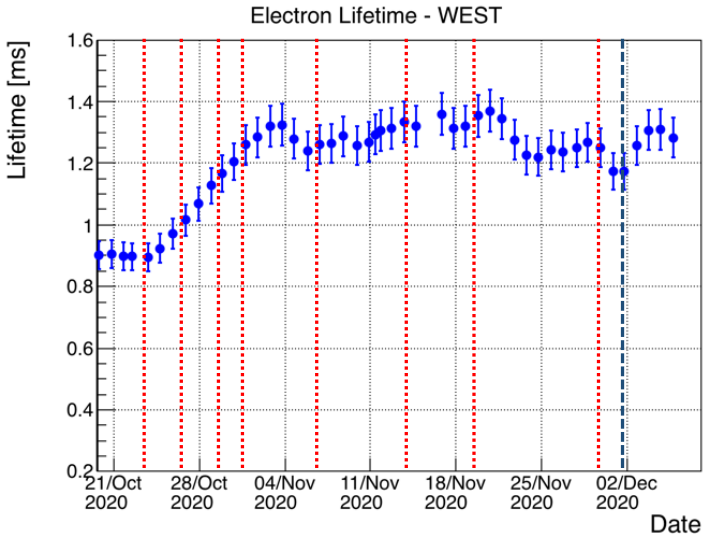
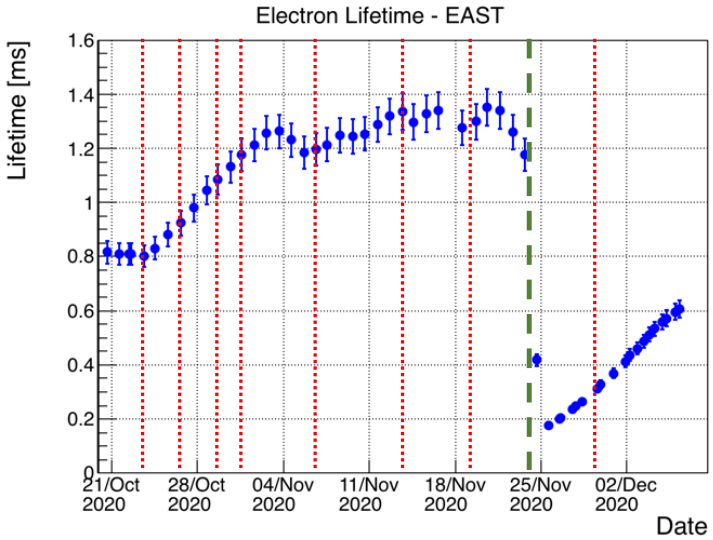


LAr purity: trend and plans for improvement





Venting (exhaust argon gas)

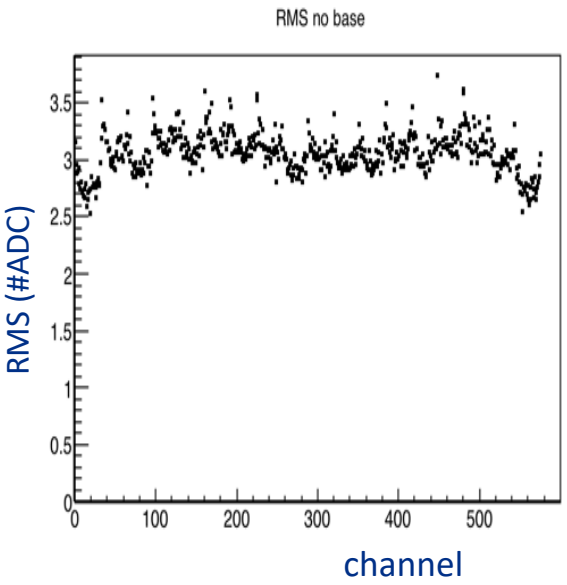
Gas recirculation filters regenerated and online

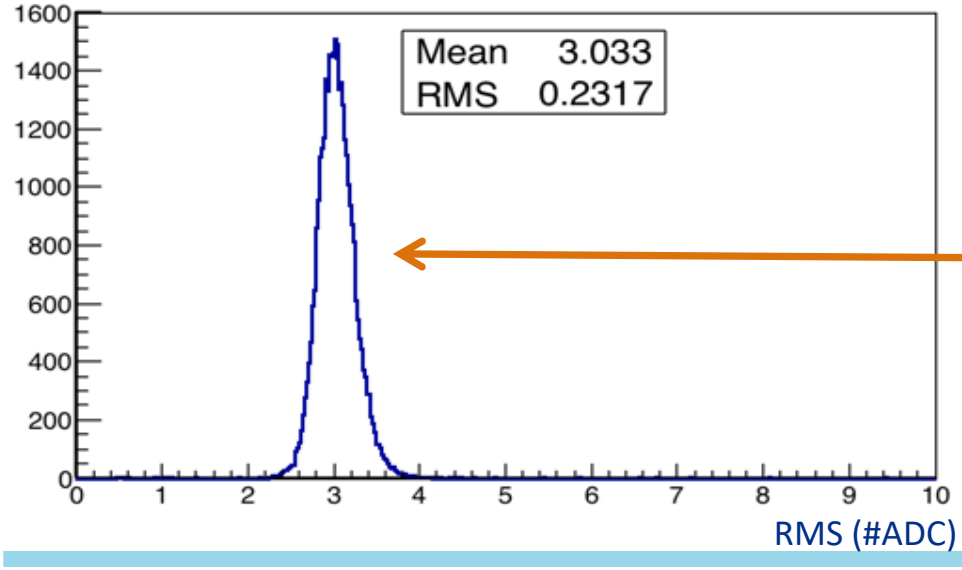
Accidental pollution of the EAST module

- Relatively short lifetime (≈ 1 ms) measured in both cryostats.
  Maximum drift time 1 ms (0.3 ppb O_2 eq.), goal lifetime > 3 ms (0.1 ppb O_2 eq.).
- Most likely due to the saturation of the gas recirculation filters.
- Regeneration of existing filters, 2 per cryostat, started on Nov. 2nd, halfway through.
- New larger warm filters, 2 per cryostat, to be constructed and installed on the gas collector lines to significantly increase filtering capacity.
- Need for an order of Ar delivery for refilling in case of loss of argon.

TPC electronic noise before LAr filling

- For the 45824 Collection/Induction2 channels connected to standard and bottom corner flanges, 2.2 – 2.7 m flat cables corresponding to 102- 127 pF are used for signal extraction;
- 3 ADC counts (~1650 e-) average noise level for the 36864 channels associated to wires with ~3.8 m standard length.
  Expected signal for m.i.p. ≈ 15000 e- / 3 mm, corresponding to a 20 ACD counts pulse height in Coll.





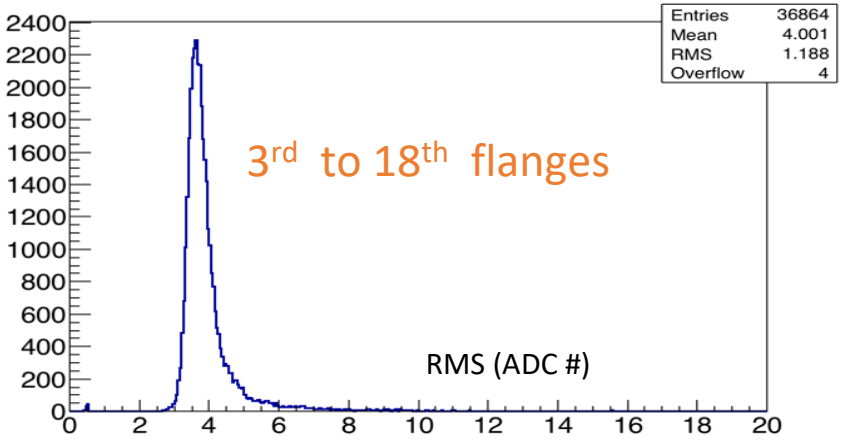
90% of the standard Collection/Induction2 channels are below 3.3 ADC counts ~ 1820 e-.

TPC electronic noise after LAr filling

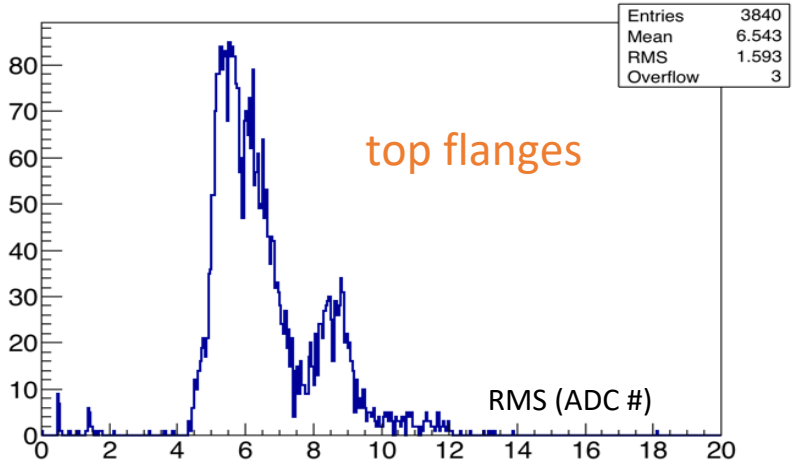
After LAr filling largely increased noise.

- Collection/Induction-2 wires (3684 wires): average RMS noise 2200 e- (4 ADC #); 90 % of wires < 2680 e- (4.7 ADC #).
- Induction-1 wires 90 % of wires < 4800 e- (8.7 ADC #)
  Top flanges: average RMS noise 3550 e- (6.5 ADC #), but 2-peaks distribution;
  Middle flanges: average RMS noise 3850 e- (7 ADC #) with tail up to 15 ADC #;

± 60° wires (≈3.8 m wires + ≈ 2.5 m cables)



Horizontal Wires (9 m wires + ≈ 5 m cables)



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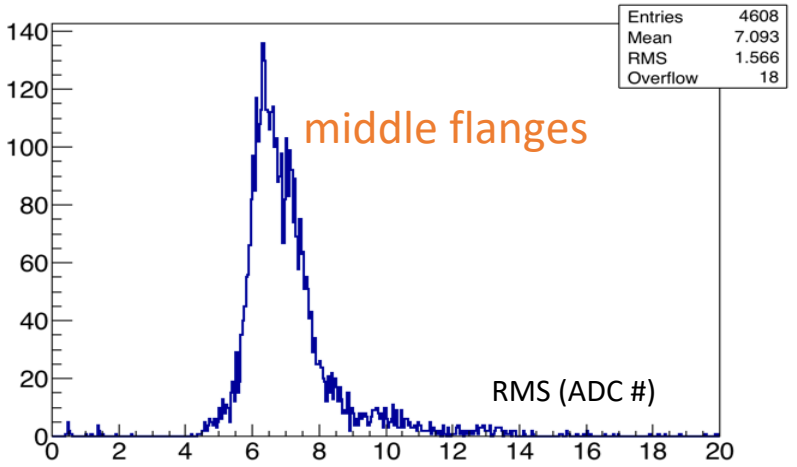
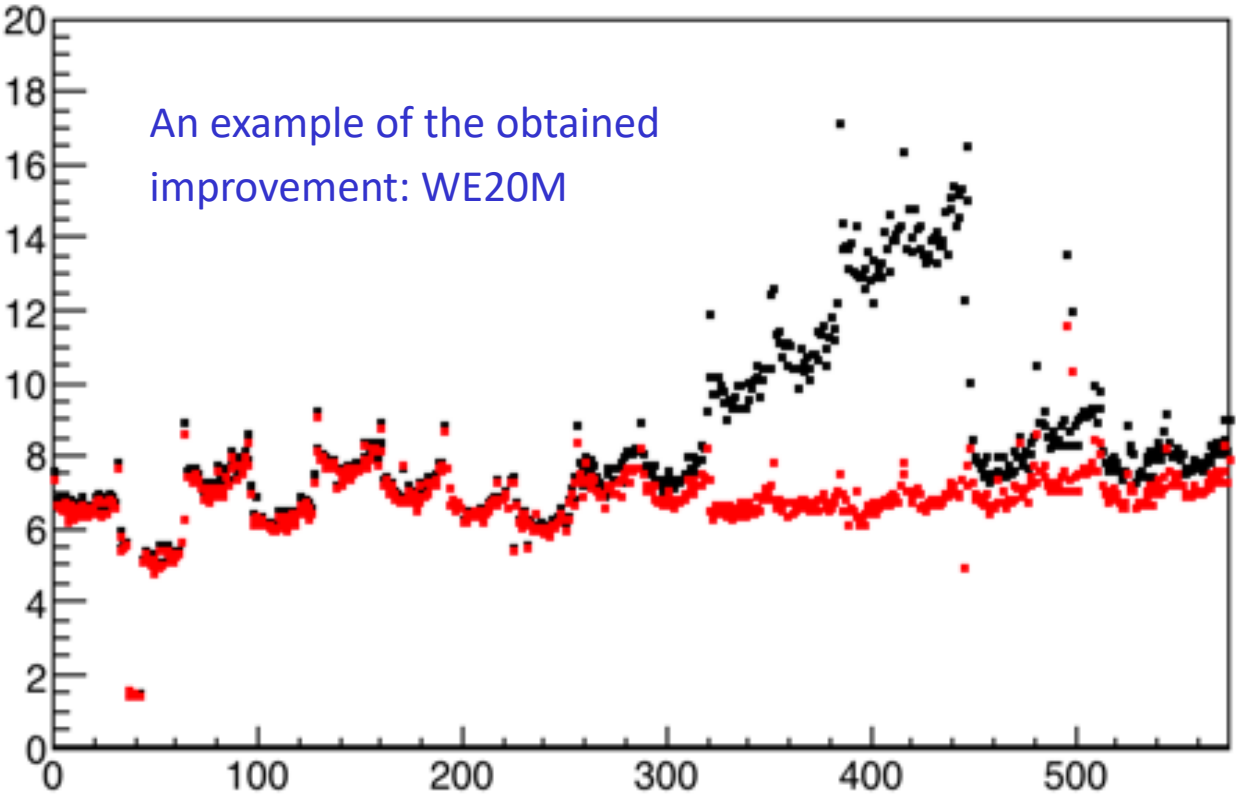


TPC electronic noise at FNAL mitigation

- After LAr filling the noise increased in all the TPCs, at least in part due to the increased capacitance due to the presence of the LAr ($\varepsilon_r = 1.4$).
- In Induction 1 need to understand the origin of the higher noise in some channels.
- WEST detector performs differently (better) compared to EAST. There are extremely noisy wires in both detectors, mainly at the corners.
- Need to investigate the relevant coherent noise and chase the origin.
- Noise could be caused by microphonic (likely the coherent noise), inappropriate ground connections (loops), AC distribution, interference with external apparatus (sensors, pumps, etc.), few bad electronics modules etc.
- Systematic survey of each flange for achieving S/N design figures started on Nov 30th. Optimization seems possible although difficult circumstances posed by pandemic virus diffusion.

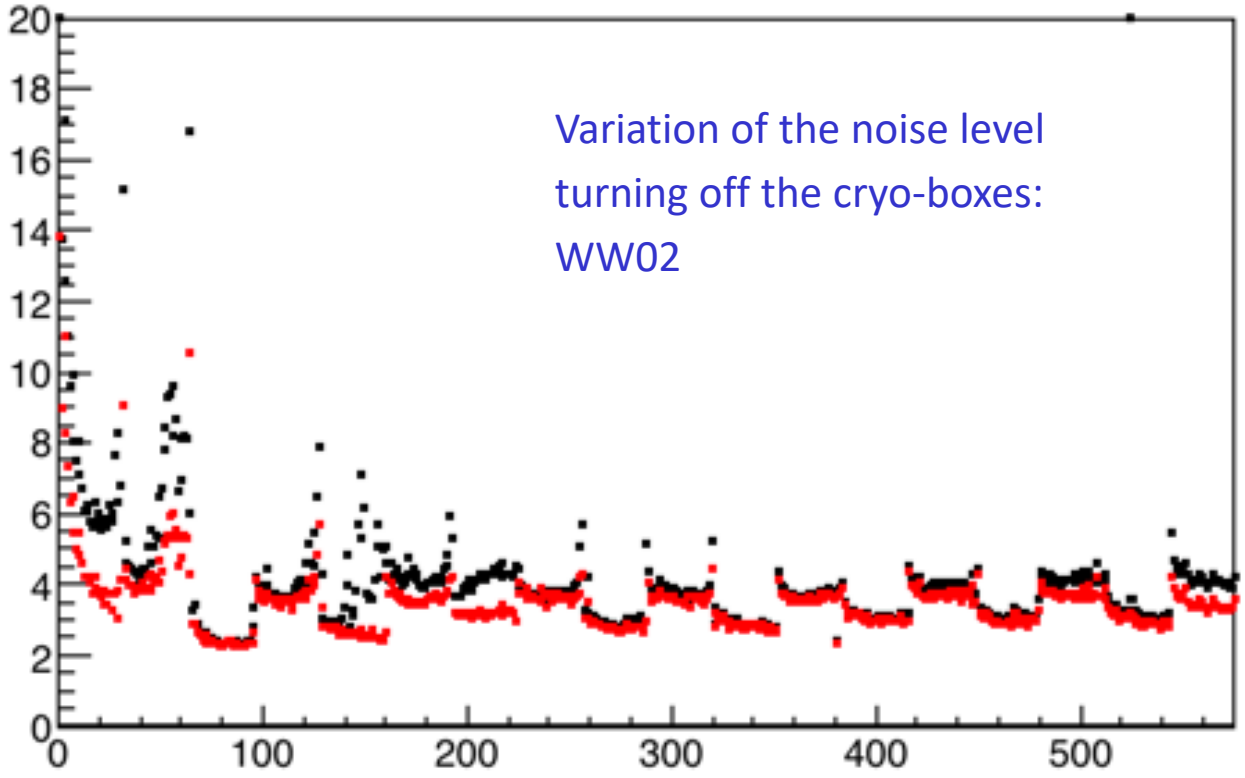
Improvement of TPC noise in West cryostat

- Higher-than-average noise in West mini-crates reduced installing on the digitizer boards 2 100 Ohm resistors (or substituting the board with a new board from CAEN with such resistors already installed)
  - Improvement in 10 mini-crates.

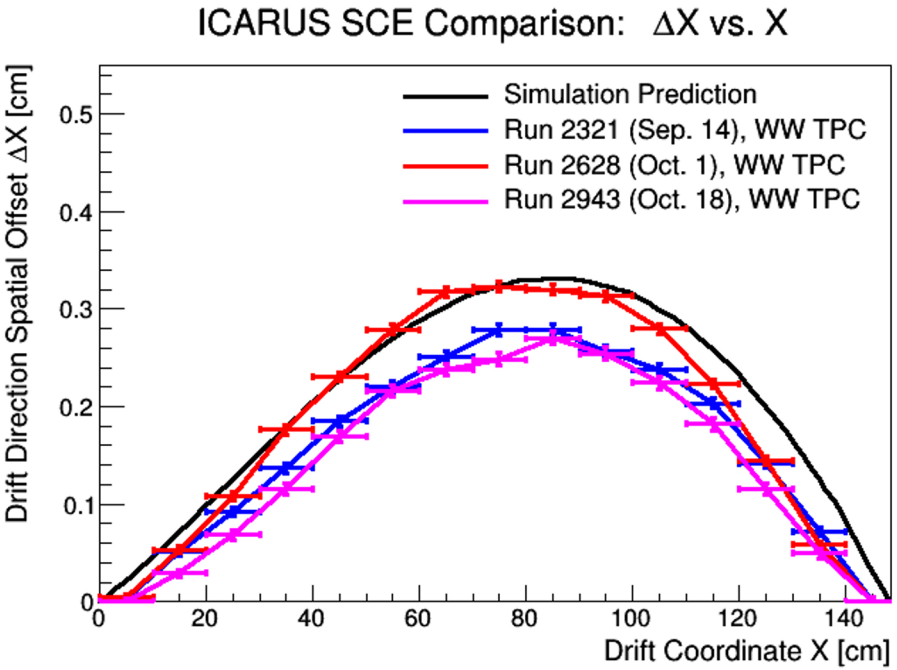


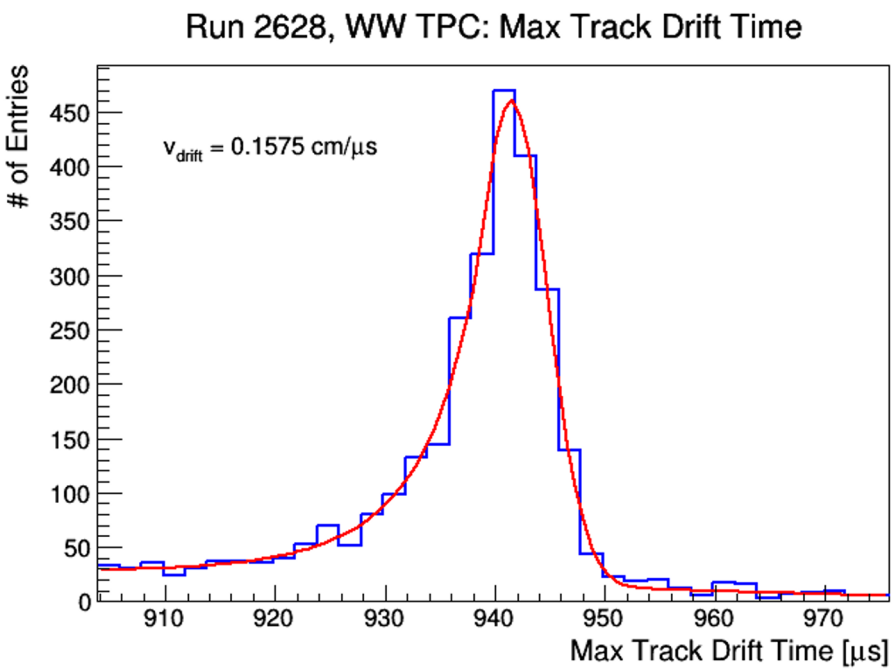
Studies of TPC noise on the WEST cryostat

- Possible sources of noise (cryo-boxes and strain gauges) switched off to verify the impact on the RMS on 12 mini-crates in the West cryostat.
- Relatively small changes observed, in particular when turning off the cryo-boxes.



Early assessment of TPC performance

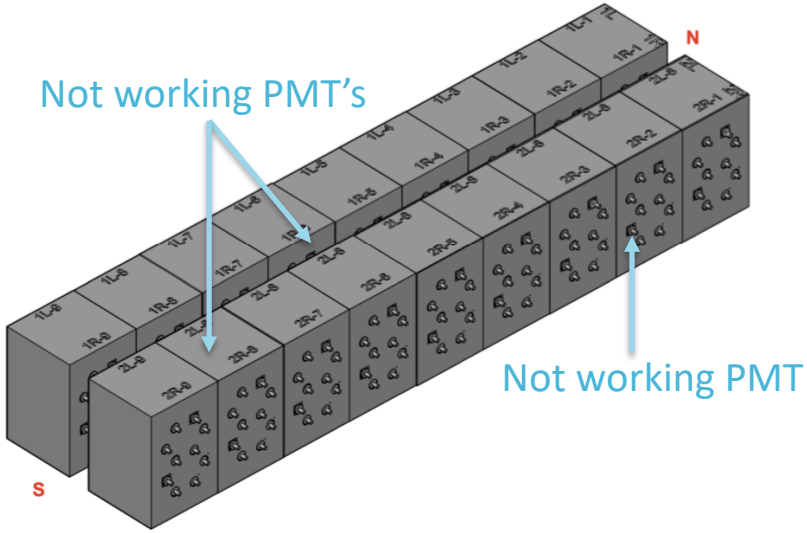


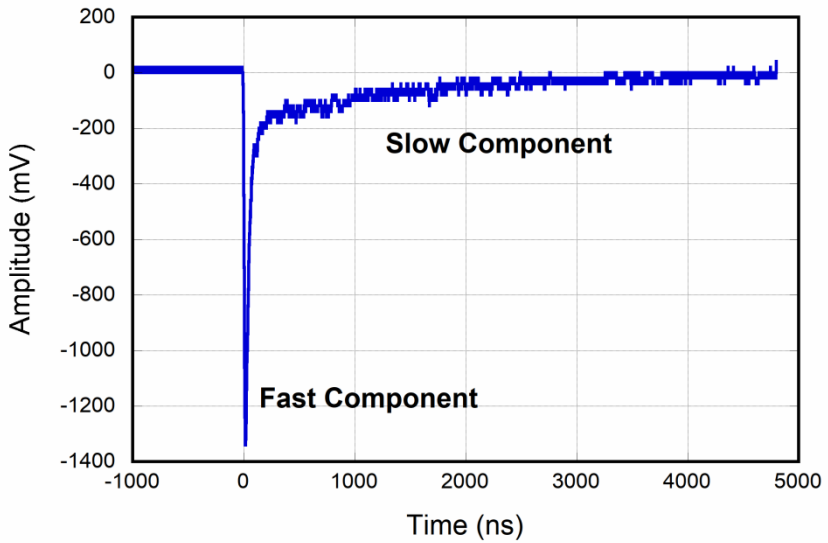


- Space charge effects (SCE) measured using anode-cathode-crossing cosmic muon tracks, looking at spatial distortions in drift direction. Rough agreement with previous measurement (ICARUS Coll., JINST 15 (2020) 07, P07001) and simulation aside from small time dependence.
- Same track sample used to measure drift velocity by maximum drift time of charge associated with tracks - results in line with previous ICARUS measurements to 1-2%; small discrepancies being investigated.

PMT activation

- After LAr filling, all the 360 PMTs were activated:
  - 357 PMTs are working fine;
  - the 3 not working ones, in 3 different chambers, were already marked as “not working” from warm testing.





- Preliminary tests using the nominal voltages to attain 10^7 gain at room temperature.
  - This permitted to carry out checks on the HV distribution system, on PMT signal recording, on PMT cabling and mapping.
  - It also allowed to develop software tools for remote control of the system.

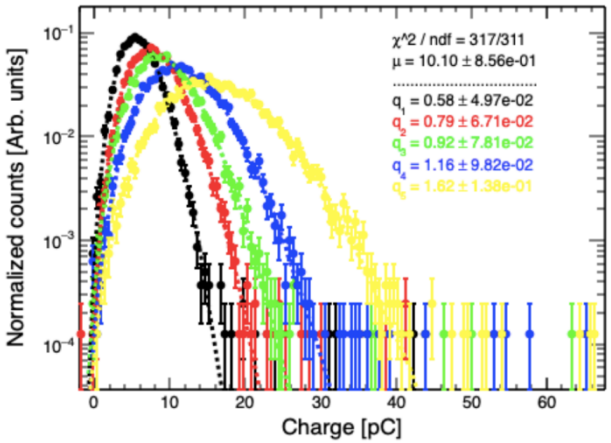
PMT calibration

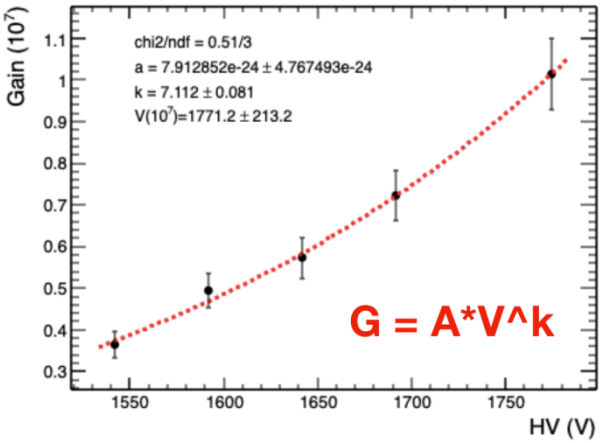
- Calibration with laser system performed to find the nominal voltage for each PMT for getting a 10^7 gain in cryogenic environment.
- Signals recorded for 5 different voltages under the same illumination condition and data fitted with an analytical function to measure the released charge q.

q_i : mean amplified charge at each dynode (depends on voltage)

$$S_i(x) = a_0 E_N(x, q_0, \sigma_0, \tau_0) + a_i \sum_{n=1}^{100} \frac{1}{\sqrt{2\pi n}\sigma_i} \frac{\mu^n e^{-\mu}}{n!} \exp\left(\frac{-(x - q_i n)^2)}{2n\sigma_i^2}\right)$$

μ: Mean number of PE at Photocathode (Identical on same PMT)





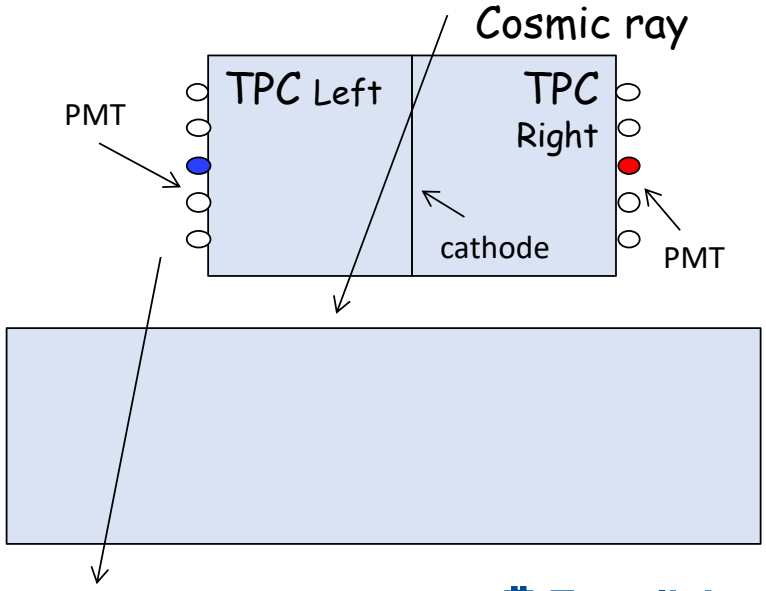
- Results fitted with power law to get PMT gain vs. voltage curve.
- Nominal voltage at cryogenic temperature evaluated and set.

Present activities on PMTs and plan

- Fine gain equalization and check of gain stability using both laser and random trigger ongoing.
- Measurement of PMT rates for different discrimination thresholds being performed using the trigger system instrumentation.
- Additional PMT activities in preparation for trigger foreseen:
  - measurement of rates as a function of different PMT logic combinations;
  - installation of PMT signal adders to get the analog sum of groups of 15 PMTs to implement an additional trigger signal;
  - set up a preliminary data acquisition with both TPC and PMT systems.

Commissioning of the trigger system

- Functionality of single ingredients of the Trigger system already assessed:
  - phase locking of clocks generated by SPEXI with common time (D<1 ns);
  - correctness of decoding of beam extraction signals and gate opening.
- Trigger functionalities (Majority signal recognition, General Trigger signal generation, cosmic trigger rate inside a few ms gate, out-of-time cosmics rate) being checked with unbiased random triggers.
- A first trigger based on PMT-majority in a 6 m slice of one TPC will be used to study PMTs to TPC matches on cosmics.
- In parallel, timing of the gate opening will be optimized searching for the maximum event rate induced by the extra ν in spill interactions.
- Trigger efficiency will be evaluated looking at PMT majority signal in one slice of the opposite TPC as a function of the PMT discrimination threshold, majority level and distance of crossing cosmics from PMTs.



DAQ: status of essential items

- Essential functionalities of DAQ system are almost entirely developed
- Completed functionality includes:
  - Readout of detector electronics from TPC, PMT, and CRT detector subsystems at >5 Hz average rate
  - Interface to trigger and timing detector subsystems
  - Software for online event-building, data compression, local storage of data, and monitoring of data quality
  - Configuration and control of DAQ system
  - Transfer of data to permanent storage
- A few essential components depend on ongoing trigger development and are in process of being commissioned
  - Inclusion trigger and timing information in data stream
  - Finalization of PMT configuration

DAQ: final integration & commissioning

- Once trigger integration is complete, fully integrated readout of the detector is possible and can be fully validated
  - Main task: final validation of event and timing synchronization across all detector components, and with beam spill information
  - Full commissioning of dataflow from both modules of detector with beam-based trigger
  - Further improvements on monitoring tools to better ensure high-quality data from all subsystems
- Further, non-critical, developments are being finalized/integrated and will also be commissioned when ready
  - Firmware compression of TPC data
  - Software-based trigger inhibiting mechanism

Slow controls development and commissioning

ICARUS specific:

- Inside cryostat
  - Liquid argon temperatures/levels
- TPC
  - Wire bias power supply
  - Readout crate power supply
- PMT
  - HV power supply
  - HV distribution
  - VME crate power supply
  - Calibration system
- Drift (cathode) HV
- CRT
  - Readout power supplies
  - HV power supplies

SBN Common:

- GPS
- Impedance monitor
- Cryogenics
- Beam
- Computer status
- DAQ status
- Environment

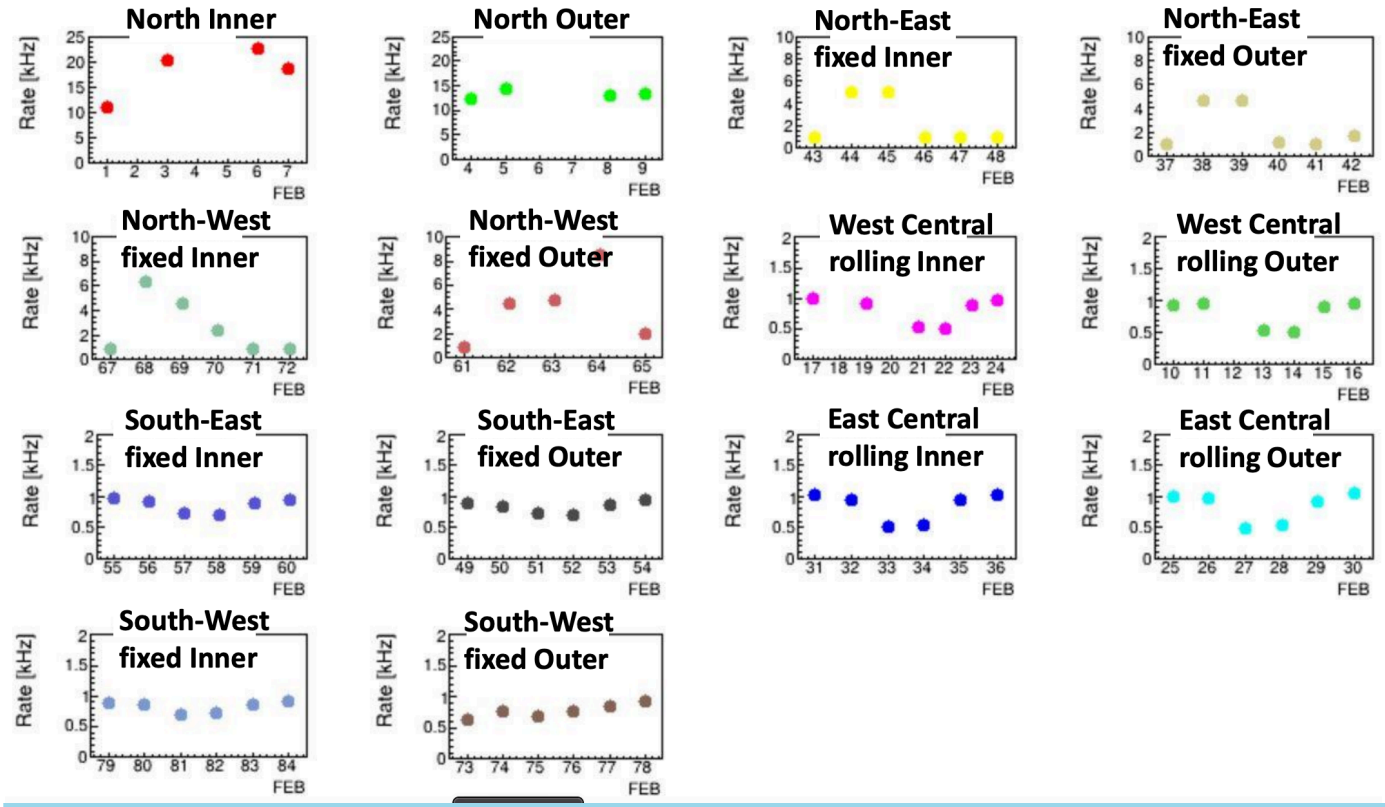
Integration:

- Update CSS gui
- Implement alarm handler in one gui
- Monitoring of core slow controls applications
- Move all code into repository
- Set alarm limits for all readback values
- Displays in online monitoring web interface

Underscore indicates tested with a user interface. All other items are in progress.

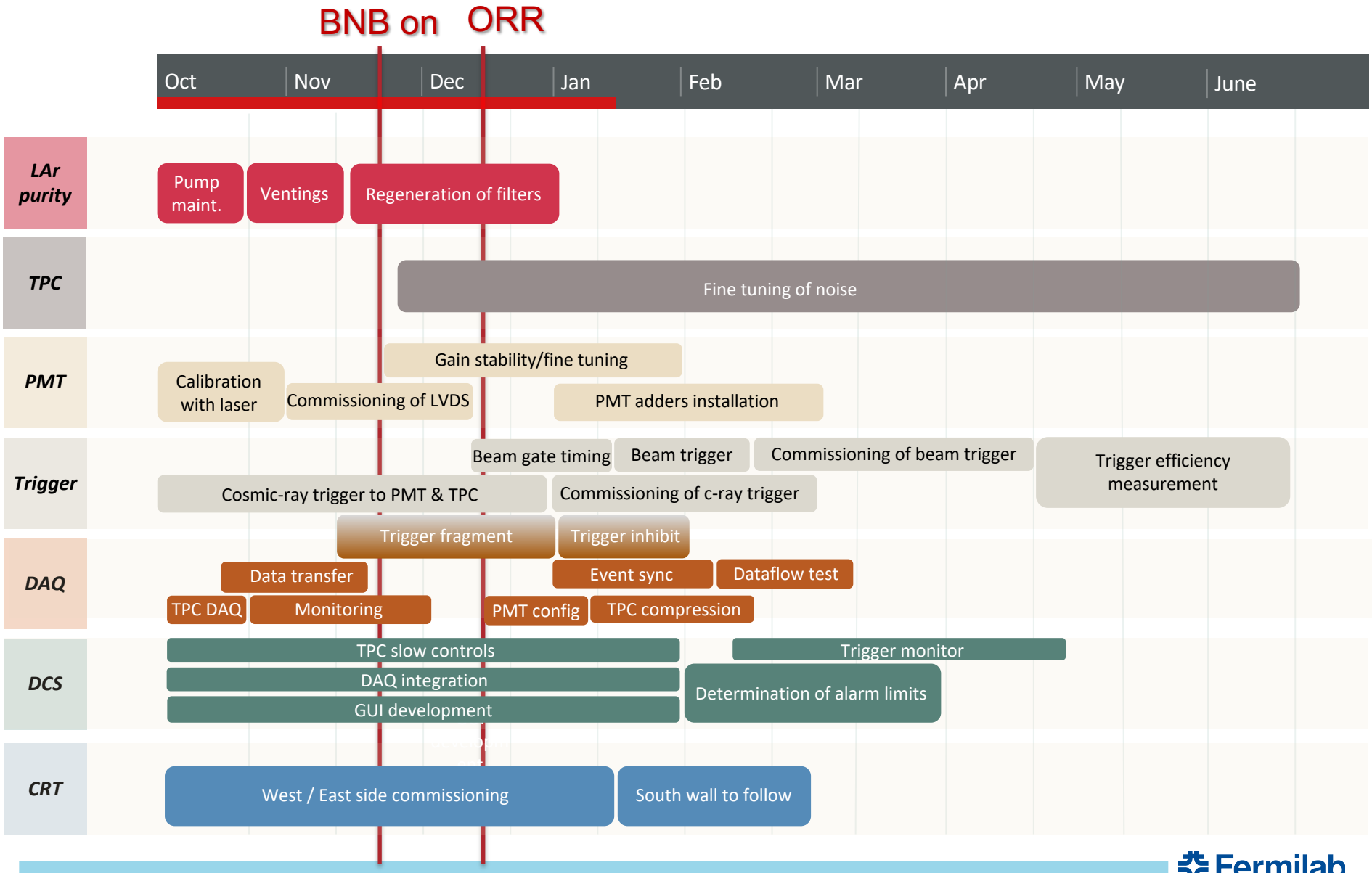
Early CRT commissioning

- **7** side CRT wall sections (5 installed even during the pandemic) being integrated in the readout.
  - Implemented into standard DAQ for some shifter-piloted runs, in a noise study configuration.
  - Moving toward more standard inclusion.



High rates in some CRT components (generally near the cryo). Investigations ongoing.

High-level planning of commissioning activities



Backup