ProtoDUNE-SP: Operations

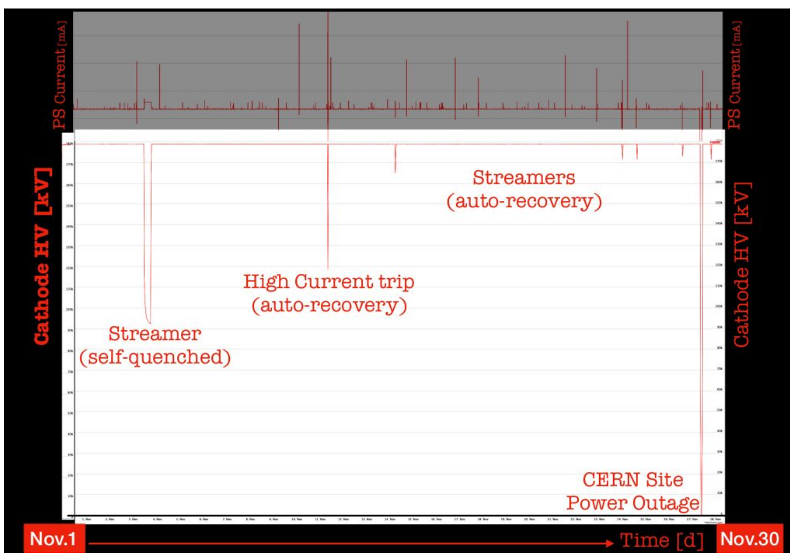
Roberto Acciarri on behalf of the "Operation Team"
(Fermilab)

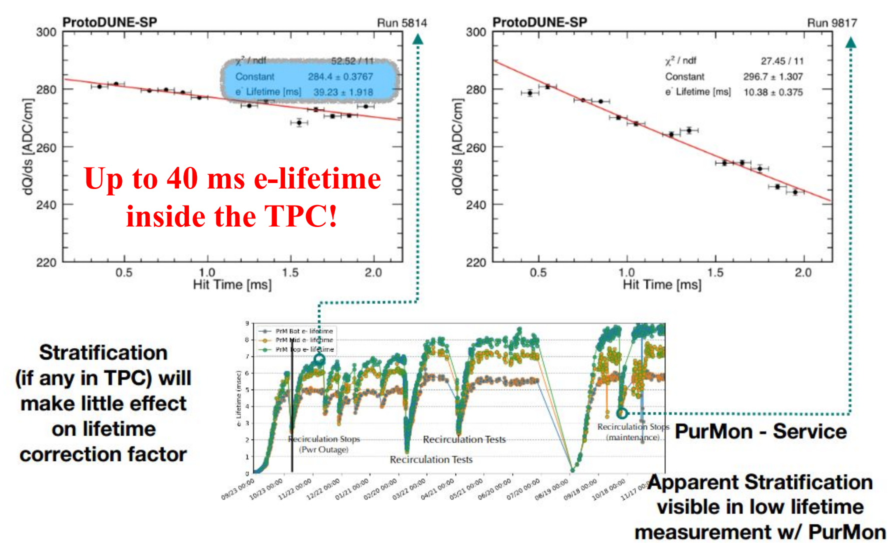
LBNC Review
March 4th - 6th, 2020

Status as of December 2019

After 500+ days of detector operation:

- ➢ Cryogenics parameters stable (P, T, heat load/LN2 consumption)
- ➢ HV stable at nominal setting (EF 500 V/cm) with **99.5% uptime**. Minimal current instabilities detected and attributed to charge up of some insulating material in a high field region. Design change in ProtoDUNE-SP Run II, removing insulating materials from high EF regions
- ➢ LAr Purity stable with a slight increase (e-lifetime vs time), except for occasional minor drops (cryo/recirculation tests) and an accidental major drop due to a hw failure in the GAr recirculation system. Purity fully recovered after the accident



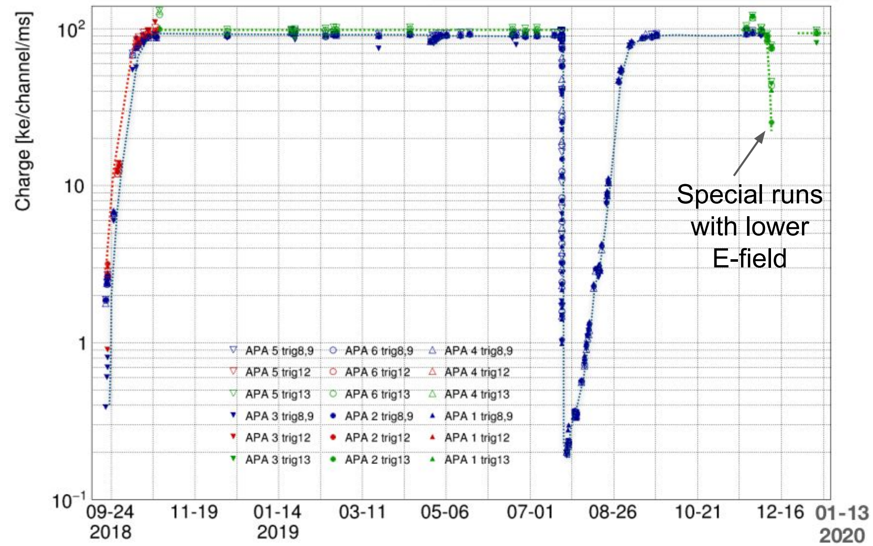


Status as of December 2019

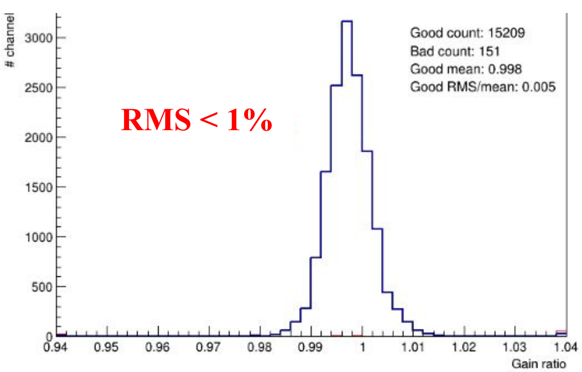
After 500+ days of detector operation:

- ➢ CE response stable
- ➢ PhotoSensors response stable
- ➢ TPC response stable (for stable LAr purity)
- ➢ PhotoDetector response stable (for stable LAr purity)

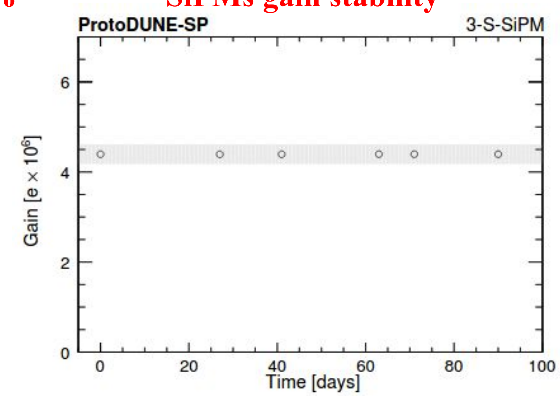
TPC Signal Strength (Average Charge per Channel per Event)



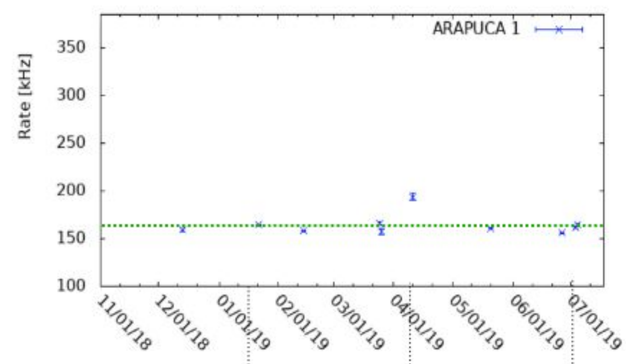
Dec. 19/Dec. 18 CE gain stable within < 1%



SiPMs gain stability

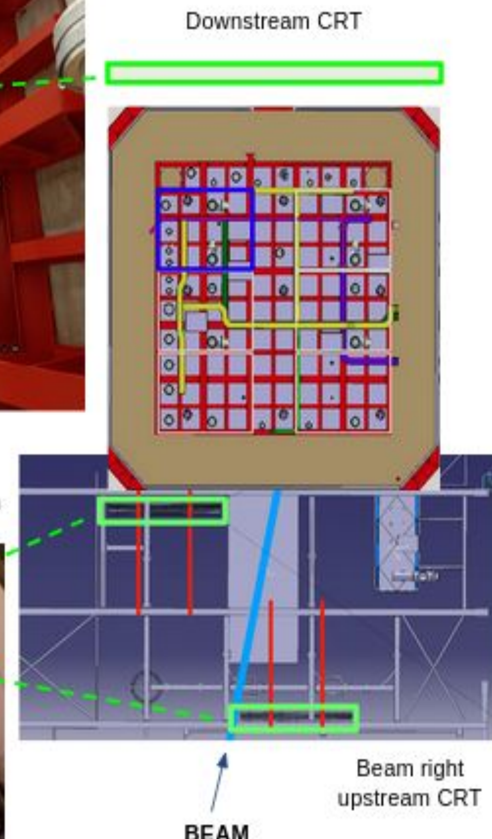


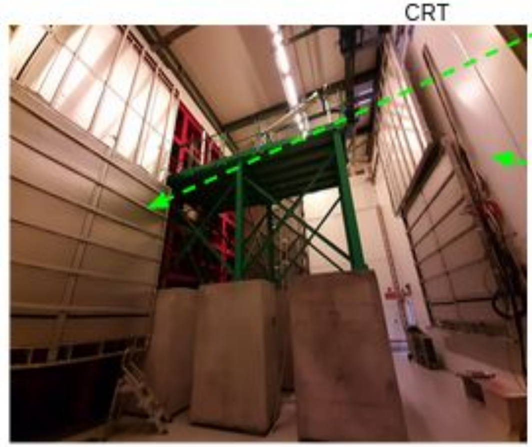
ARAPUCA Single Photon Rate



2019 CRT dedicated run

- CRT: 8 modules covering a ~6.8m x 6.8m area both upstream and downstream the cryostat
  - 2 layers of parallel scintillator strips
  - Upstream panels staggered
- Trigger TPC with passing muons (cosmics, beam halo)
  - Space charge and TPC performance
  - PDS attenuation studies
  - T0 tagging for Michel studies
- CRT was actively used during the beam runs for in-between beam spills cosmic data taking
- **Re-activated for a long cosmic run to characterize the detector response after 1 year of operation**





2019 CRT dedicated run

A series of actions have been taken in preparation for this run:

- ➢ CRT controls have been fully implemented into the slow controls
- ➢ CRT readout code was improved
  - ○ Cope with different trigger inhibiting scenarios
    - ■ Allowed stable and long CRT runs
  - ○ Reduced missing event rate
- ➢ Tuned the trigger timing between the various panel to allow a better beam right coverage

Thanks to CRT, trigger and DAQ groups!!

2019 CRT dedicated run

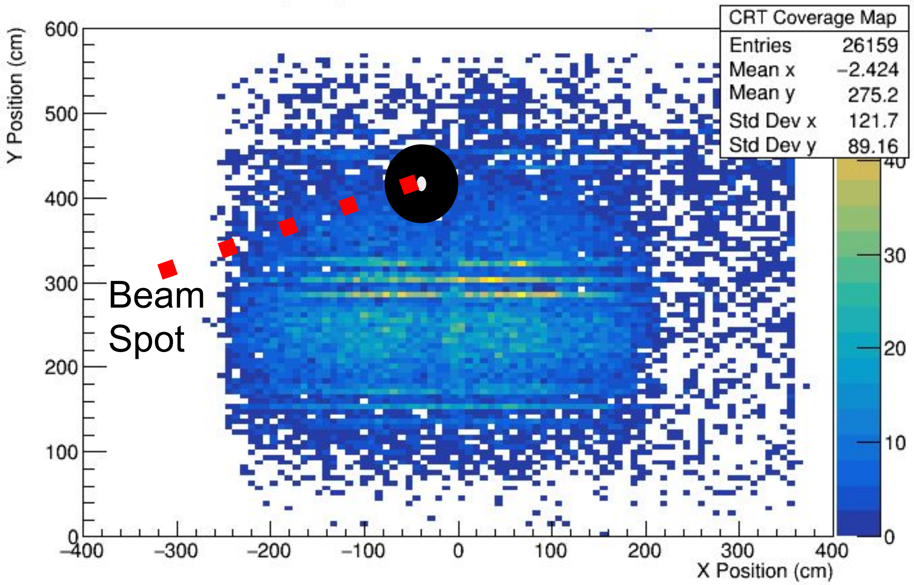
- Three weeks (Nov 18 - Dec 6) of dedicated data taking with CRT triggers:
  - Cover as much as possible the beam right side for CRT studies on tracking and space charge effect
  - Run varying the electric field for better understandings of the electron lifetime
  - Trigger on location-specific CRT hits for attenuation studies for PDS
  - Calibration runs for PDS and TPC ADCs
- Data taking and DAQ shifts:
  - Collaborators from US, Brasil, Italy and CERN contributed to the data taking
  - DAQ support with extended on-call hours and active monitoring on the data taking quality
- More than 100h of cosmic data collected with ~15Hz CRT trigger!

Thanks to all shifters, detector experts, DUNE DAQ and computing groups !

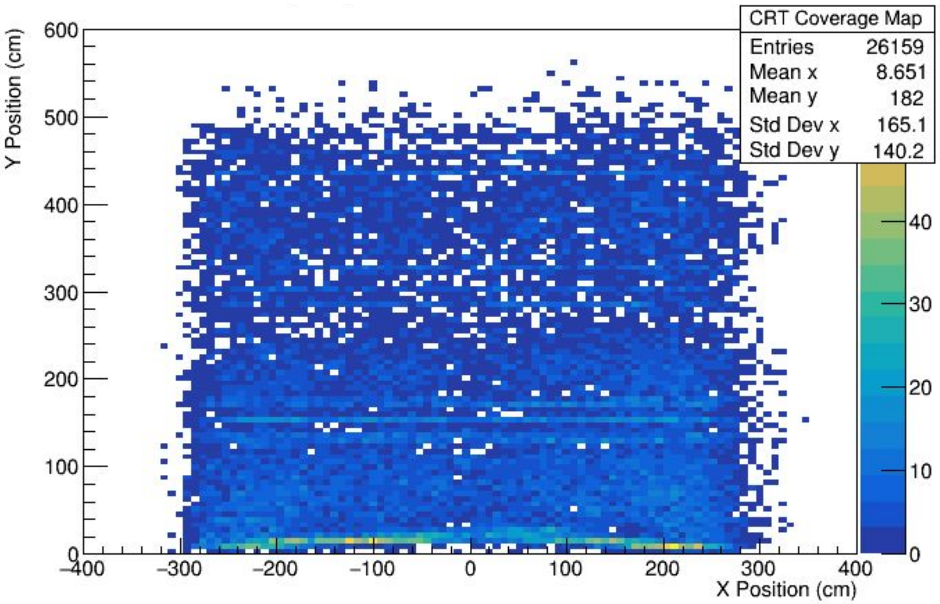
2019 CRT dedicated run

Thanks to both the improvement in the performance and readout of the CRTs and the amount of data collected, we reached a very good coverage of the TPC volume, which allowed the determination of the TPC and PDS performances shown before

Upstream TPC face



Downstream TPC face



2019 CRT dedicated run

The improved coverage of the area around the beam entrance has been particularly useful for addressing the impact of space charge effects in our beam data

Through going tracks

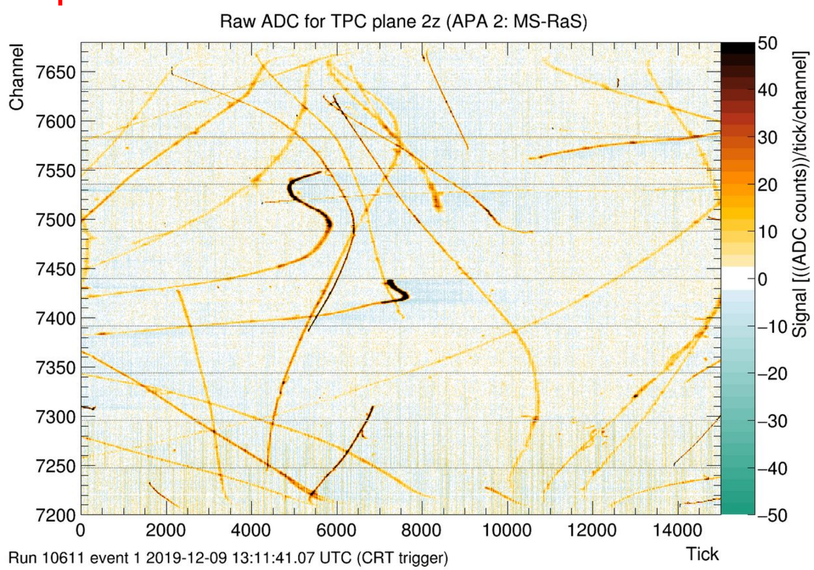
Run-10431:

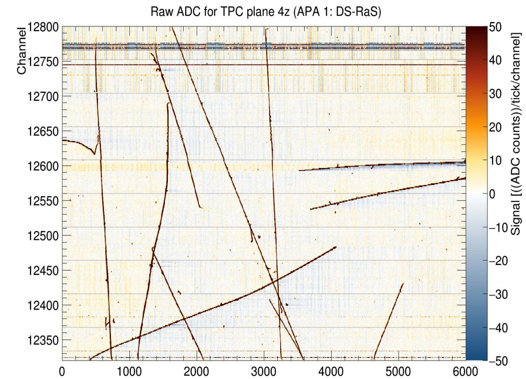
- CRT triggered run
- 500V/cm
- 3ms readout

HV scan runs

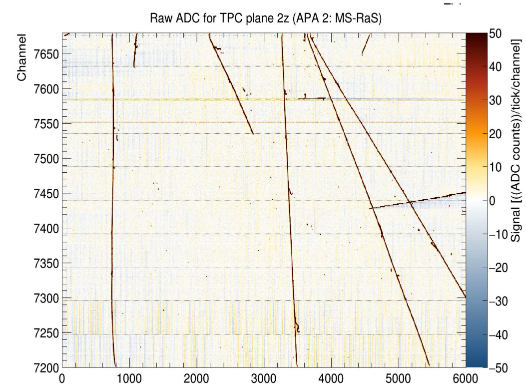
Run-10611:

- **100V/cm field**
- APA-2, coll plane
- 7.5ms readout window

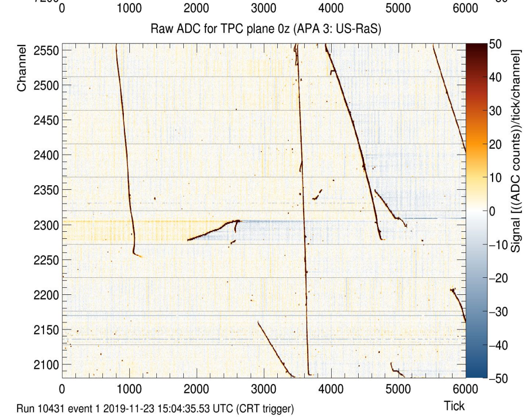




APA-1



APA-2



APA-3

Plans for 2020

January 2020

W	S	M	T	W	T	F	S
1				1	2	3	4
2	5	6	7	8	9	10	11
3	12	13	14	15	16	17	18
4	19	20	21	22	23	24	25
5	26	27	28	29	30	31	

February 2020

W	S	M	T	W	T	F	S
5							1
6	2	3	4	5	6	7	8
7	9	10	11	12	13	14	15
8	16	17	18	19	20	21	22
9	23	24	25	26	27	28	29

March 2020

W	S	M	T	W	T	F	S
10	1	2	3	4	5	6	7
11	8	9	10	11	12	13	14
12	15	16	17	18	19	20	21
13	22	23	24	25	26	27	28
14	29	30	31				

April 2020

W	S	M	T	W	T	F	S
14				1	2	3	4
15	5	6	7	8	9	10	11
16	12	13	14	15	16	17	18
17	19	20	21	22	23	24	25
18	26	27	28	29	30		

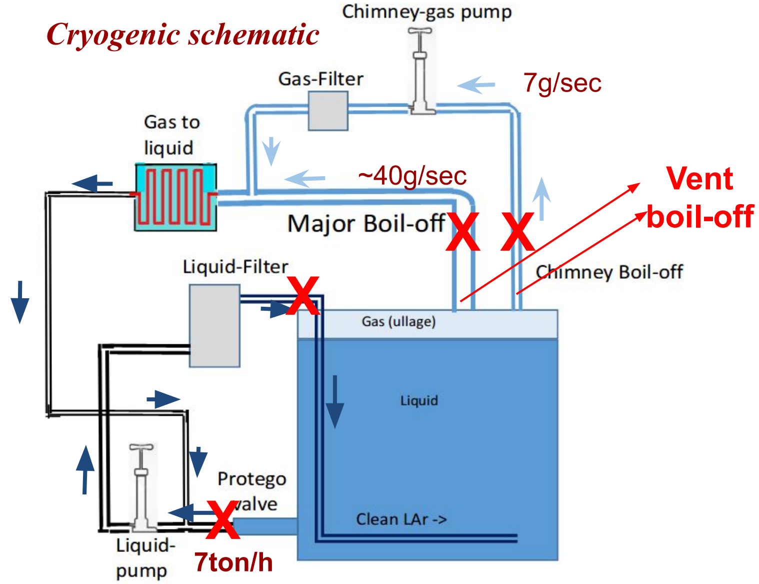
- Preparations for Xe-doping, cryogenic tests
- Xe runs
- (Neutron generator tests)?
- Data taking with CRT trigger at different LAr purity levels
- HV tests with voltages above 180kV

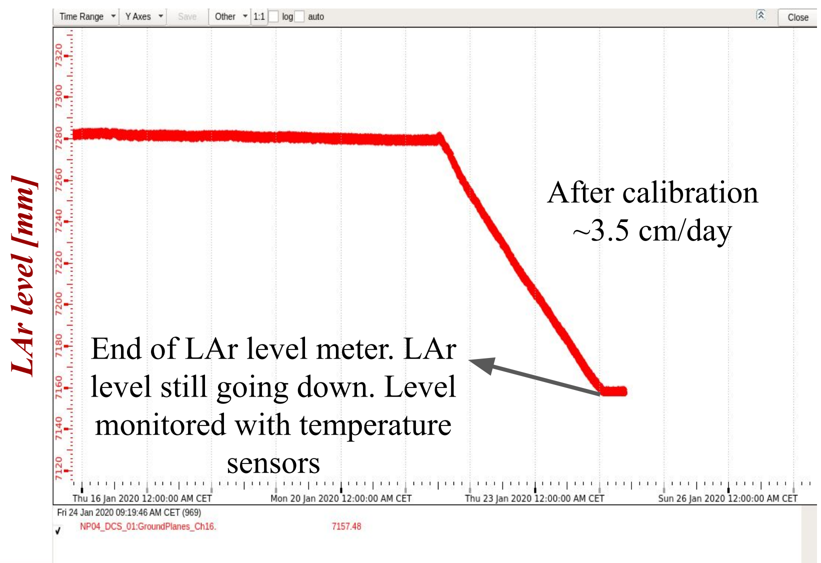
➢ DAQ dedicated weeks, DAQ Mondays and open model for tests
  - DAQ dedicated testing time in April/post April
  - Additional testing time for DAQ and system tests:
    - Each Monday is dedicated to DAQ testing/improvement
    - During the preparation for Xe, Neutron, HV... tests
    - CERN night time, US ~day time

➢ Cold-box tests with APA-7
  - Install/test SBND FEMBs
  - Install/test FEMBs with ColdADC+FPGA
  - Install/test FEMBs with ColdADC+COLDATA

Cryogenic tests and electron lifetime

- How electron lifetime would change when cryostat cooling and re-circulation is turned off?
- Cryogenic tests from Jan 21st to Jan 27th
  - Stopped cooling and LAr recirculation. All boil-off is vent into the atmosphere
  - LAr level inside the cryostat decreased ~3.5 cm/day
  - Tested running at DUNE ullage conditions
  - Cathode HV turned off on January 25th evening as a precaution !!
- Collected CRT and random triggered cosmic data continuously during the test





Cryogenic tests and electron lifetime

No degradation observed in the electron lifetime! Impurities are coming from the chimney boil-off

Xe doping in ProtoDUNE-SP

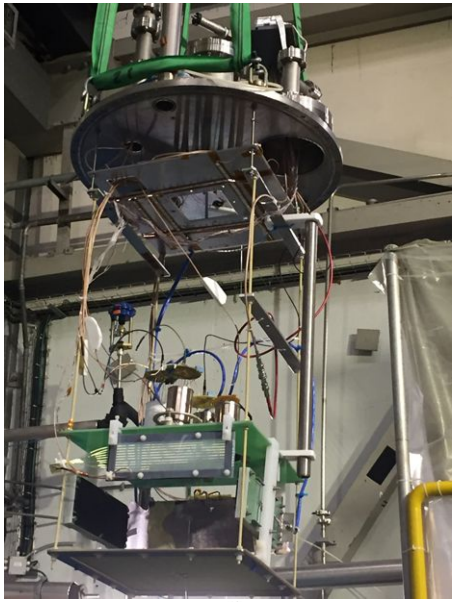
➢ Doping ProtoDUNE-SP with Xe first proposed in 2019
  - Study potential to increase light yield and efficiency
  - Study long term stability and uniformity of Xe in LAr

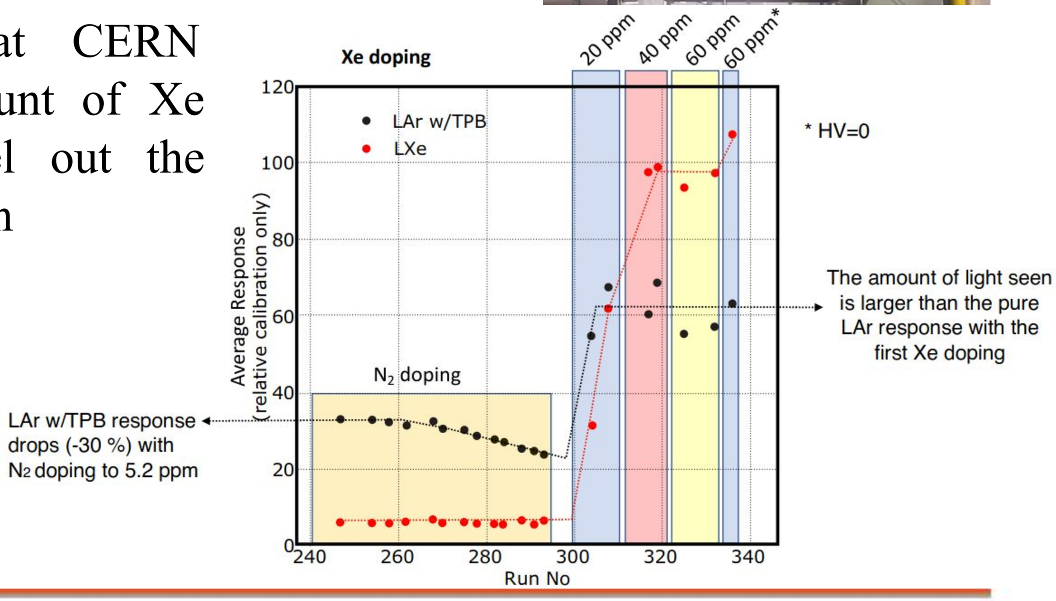
➢ However, after the pump failure last summer, ~5.7ppm of nitrogen were injected into the system and the test was postponed

➢ Tests with a 50L setup at CERN demonstrated even small amount of Xe (~5ppm) is enough to cancel out the effects of nitrogen contamination

➢ Preparation for Xe doping started in January, tests started in February with a Xe concentration target of 20ppm

50 L test setup @ CERN

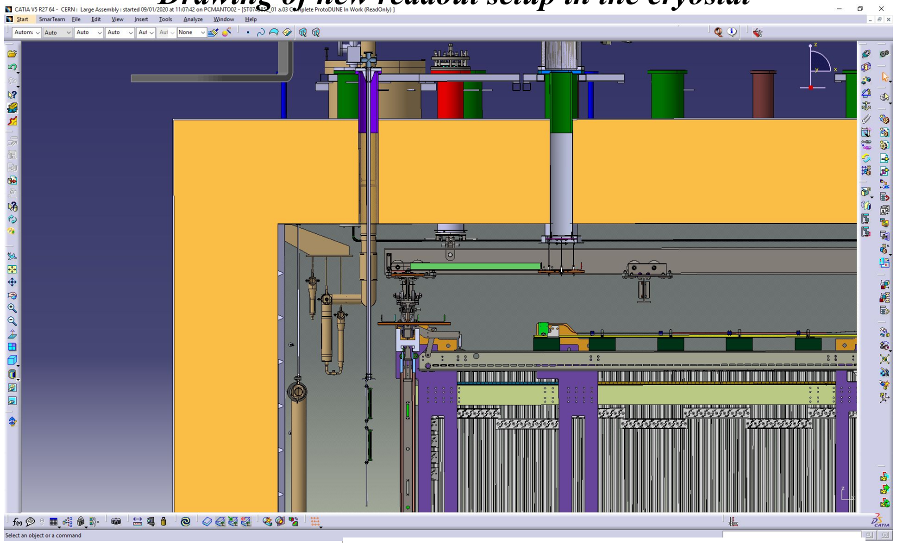




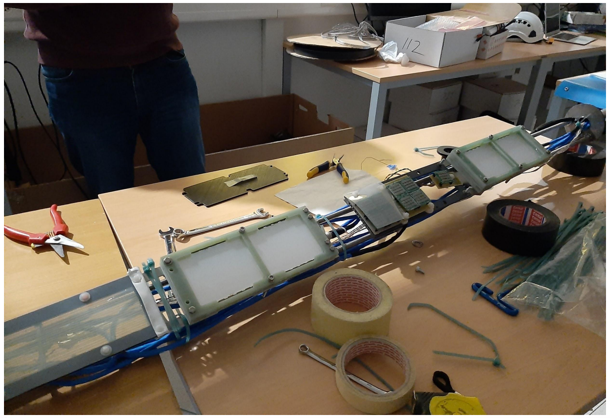
Xe doping preparation

- Prepare and install new Xe light sensitive PDS system into the cryostat:
  - 1 X-Arapuca sensitive to Xe light
  - 1 X-Arapuca sensitive to Ar light
  - Fiber pen module
  - SIPM array
- Remove one of the cryogenic cameras sitting inside the cryostat
- Insert the mechanical structure holding the new detectors

Drawing of new readout setup in the cryostat



Readout modues



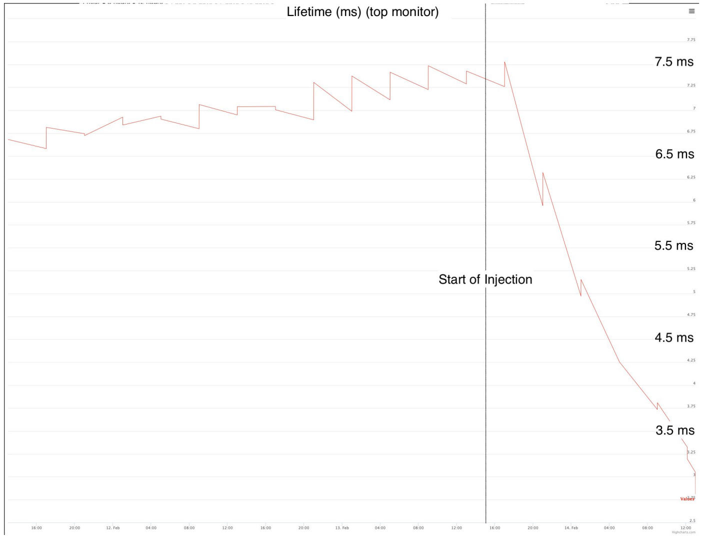
Readout setup assembly

Readout setup insertion

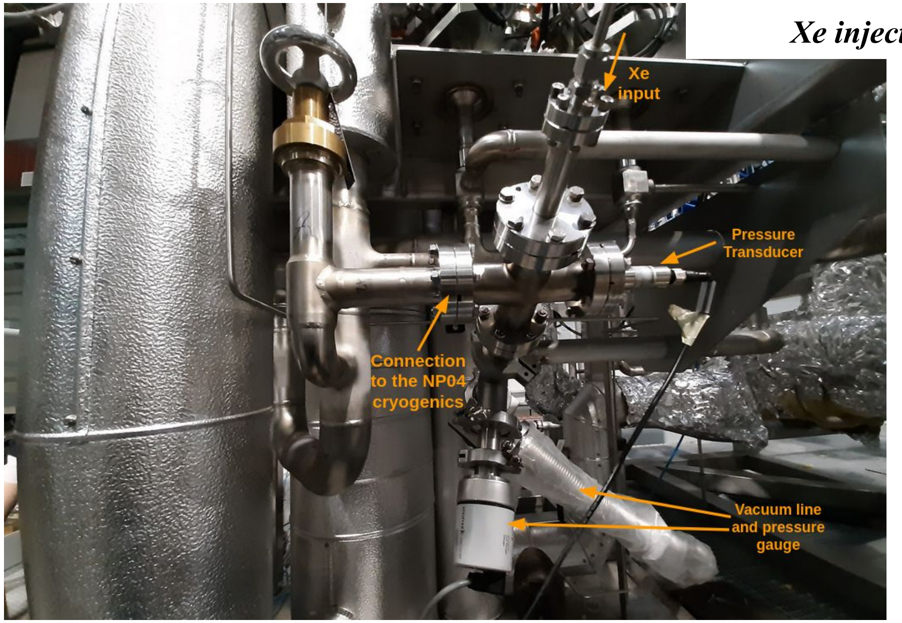
First Xe doping

- Dope with only 1 ppm of Xe (0.7 kg)
  - Wait for LAr level to be at its nominal and continue doping once TPC is back online
  - Verify if Xe goes effectively in the LAr bulk
  - Observe how long it takes to have Xe in the system
  - Inject Xe with ~30gr/h rate → ~1day to reach 1ppm level
  - Started injection on Thursday, Feb 13th
    - **Stopped on Friday, Feb 14th at noon due to reduction in purity**

LAr electron lifetime



Xe injection system



Investigation of the problem

- Impurities inside the Xe bottle?
  - Bottle analyzed by CERN chemistry and gas lab for impurities
    - ***Found O2 at least at the level 100ppm and C2F6***
- Analysis of the Xe bottle used in 182 tests
  - No O2 and C2F6 contamination
- New Xe bottle from the ATLAS experiment
  - Analyzed prior to use, no sign of any contamination

THE LINDE GROUP

Linde

XENON

Description: Xenon gas is odorless, colorless, tasteless, nontoxic, monatomic and chemically inert. The concentration of Xenon gas in the atmosphere, by volume percent, is 8.7×10^{-6}. Xenon gas is principally shipped and used in gaseous form for excimer lasers, light bulbs, window insulation, ion propulsion, medical applications and Research and Development laboratory research. Linde Material Safety Data Sheets (MSDS) are available for Xenon and should be used as guidelines in regard to first aid, methods of storage, handling and general use of Xenon gas.

Purity Specifications

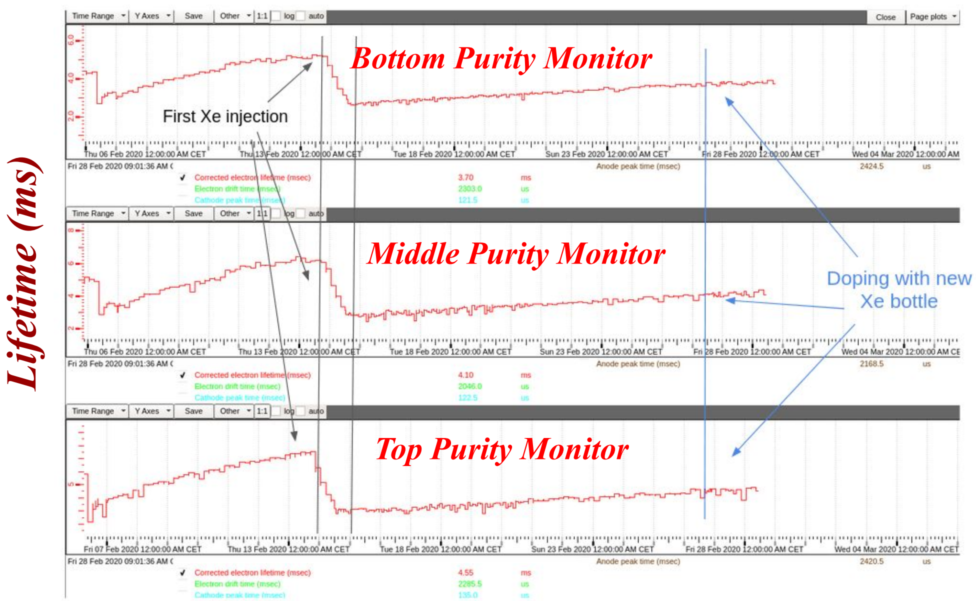
Contaminant	Research Grade 99.999%*	UHP Grade 99.995%*
Argon (Ar)	1.0 ppm	10.0 ppm
Carbon Dioxide (CO_2)	1.0 ppm	2.0 ppm
Carbon Tetrafluoride (CF_4)	0.5 ppm	1.0 ppm
Hydrogen (H_2)	2.0 ppm	5.0 ppm
Krypton (Kr)	5.0 ppm	25.0 ppm
Nitrogen (N_2)	2.0 ppm	5.0 ppm
Oxygen (O_2)	0.5 ppm	1.0 ppm
Total Hydrocarbons (THC)	0.5 ppm	1.0 ppm
Water (H_2O)	0.5 ppm	1.0 ppm

* Maximum Impurity Levels
Note: Higher purities are available upon request.

Second Xe doping

- ➢ Restart doping with Xe obtained from ATLAS
- ➢ Applied slight modifications on the system
  - ○ New cold getter as an additional safety, rebuilding piping
- ➢ Started 2nd stage of doping with ~33gr/h of injection rate
- ➢ Doping continued for 49h and stopped on Friday, Feb 28th, 5pm CERN time

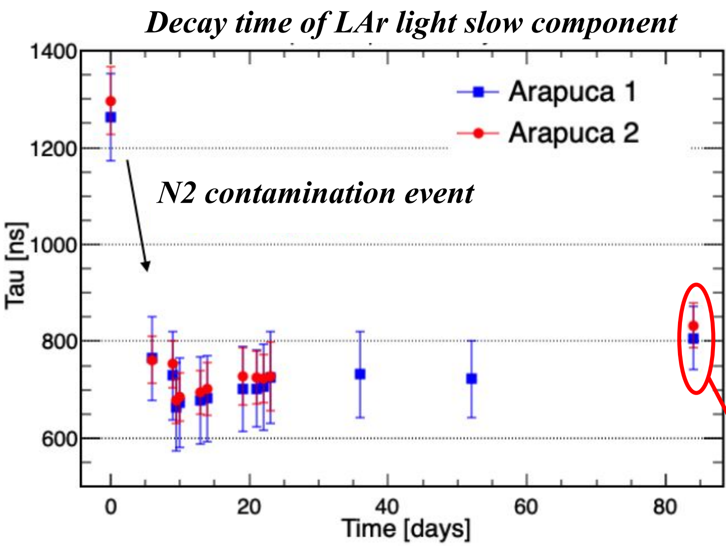
Modified Xe injection system



- ➢ After the first and second Xe dopings:
  - ○ ~3ppm of Xe by mass injected into the system (1ppm by atoms)
  - ○ Collected continuous PDS data with both DAQ (triggering on CRT tracks and telescope) and standalone system using X-arapucas

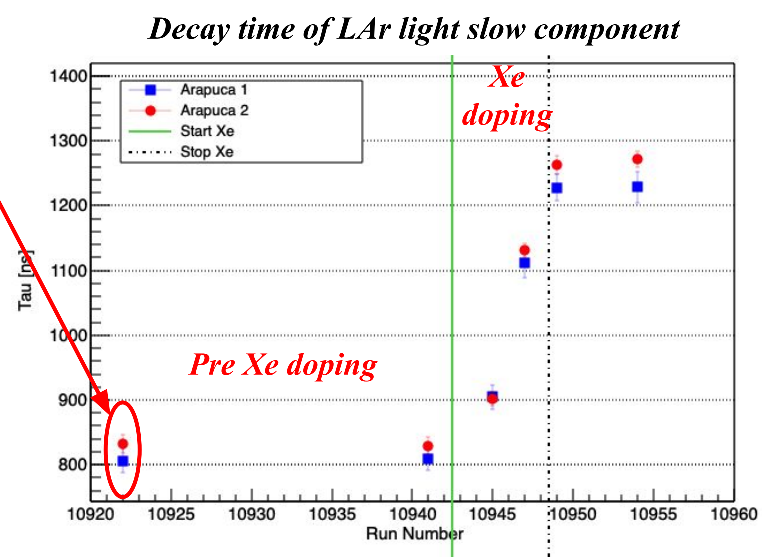
- ➢ Doping will continue up to 20 ppm goal once the LAr is at nominal level and TPC is turned on

Preliminary analysis of light data



Detector's ARAPUCA light signals

- Exponential fit of the light signal slow component provides information about N2-induced light quenching and Xe-induced light recovery
- Decay constant of the slow component dropped from ~1300 ns to ~700 ns as a result of air contamination last summer



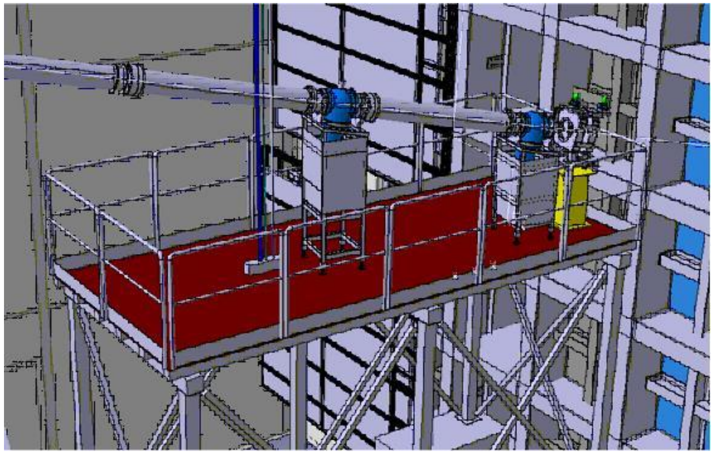
- Decay constant of the slow component raised from ~800 ns to ~1250 ns as a result of first LAr doping with 1ppm of Xe

Neutron Run

- Deuterium-Deuterium (DD) neutron generator at ProtoDUNE-SP detector to collect liquid argon TPC data of neutron captures
  - 2.5 MeV neutrons produced by a portable DD neutron generator
  - Injected through the beam plug
- R&D efforts for the development of the Pulsed Neutron Source (PNS) calibration system for the DUNE far detector
  - collect neutron capture data to verify our neutron transport model in simulation and help develop analysis algorithms
- DD neutron generator, *Thermo Scientific MP 320*, from LANL
- Safety documentation and ODH about to be finalized - currently working on the radiation simulation and finalization of the shielding accordingly
- Run foreseen at the end of March/beginning of April

Neutron Generator

Neutron generator positioning



Test with voltages above 180 kV on cathode

- ➢ As last test in ProtoDUNE-SP, we would like to increase the high voltage on the cathode up to values above 180 kV
    - ○ Collect data with fields higher than 500 V/cm
- ➢ Hardware status:
    - ○ High voltage feedthrough has been tested up to 300kV
    - ○ 300kV PS has been refurbished and delivered to CERN
    - ○ HV cable connections are ready
    - ○ HV noise filter needs to be tested

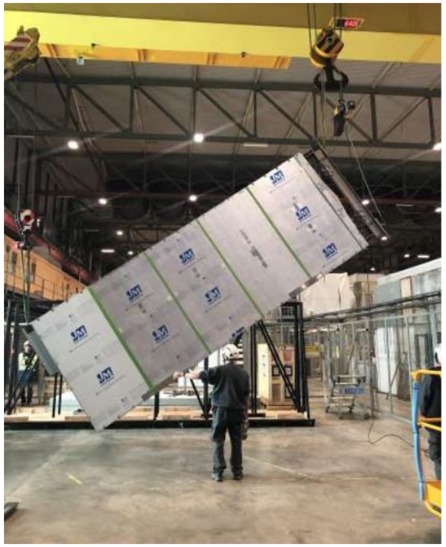
300 kV PS

Cable and connector

Cold Box CE tests with APA7: preparation

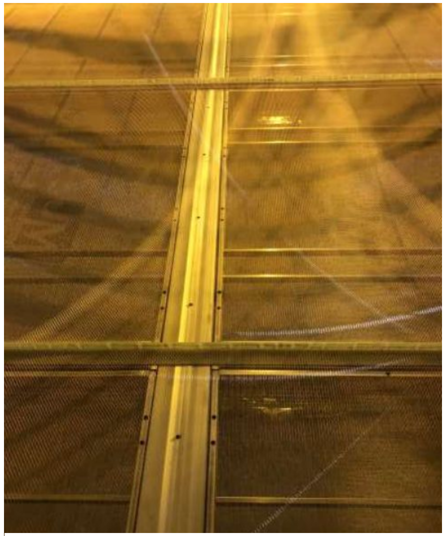
➢ Un-boxing, inspection and preparation of APA-7 for the cold-box tests done the week of Sept 30th - Oct 7th 2019:
  - Yoke load tested and box opened
  - APA moved into the clean room
  - Visual inspection and wire tension measurements
  - Installed cable trays
  - Test fit/rolled into the cold-box
  - Parked in front of the cold box for the CE installation

APA7 unboxing



APA7 test fit

Cable tray installed

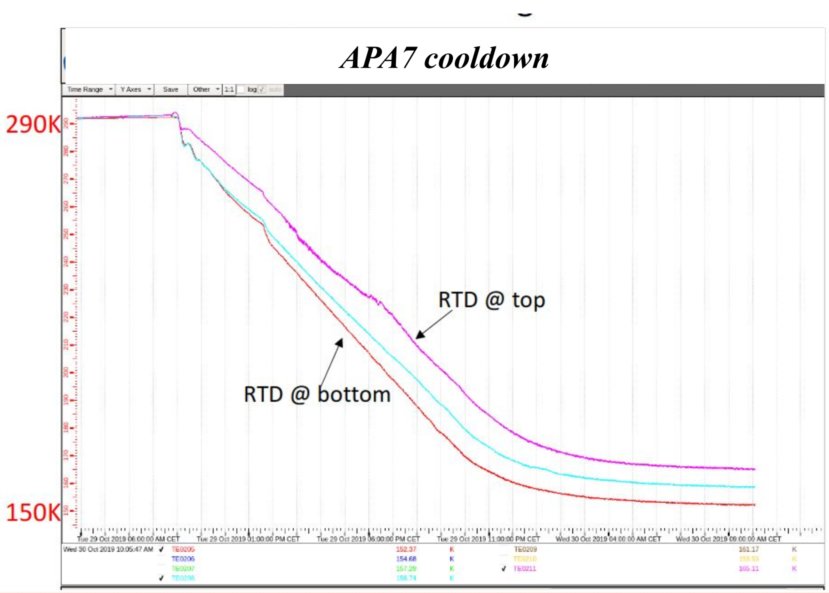


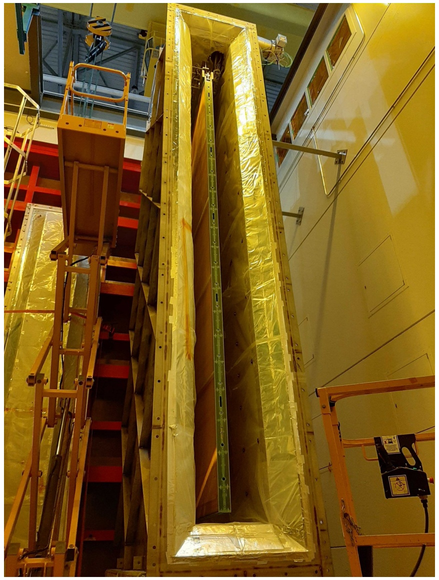
Visual inspection

Cold Box CE tests with APA7: pre-tests

- ➢ Initial tests and preparations:
  - ○ 20 CE boxes (ProtoDUNE-FEMBs) were tested in warm and installed on APA-7: all 2560 channels responding to the calibration pulser
  - ○ CE flange + WIEC were installed
  - ○ All necessary cabling and strain relief was done
  - ○ APA-7 was pushed into the cold-box
- ➢ Purging and cooling down: 10K/hour rate for a total of ~12h

APA7 insertion into the cold box



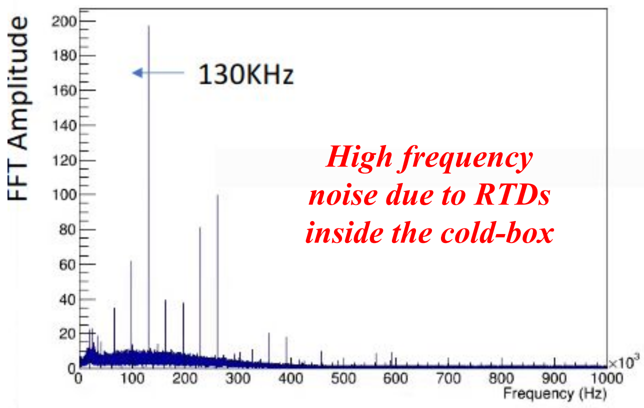


Cold Box CE tests with APA7: pre-tests

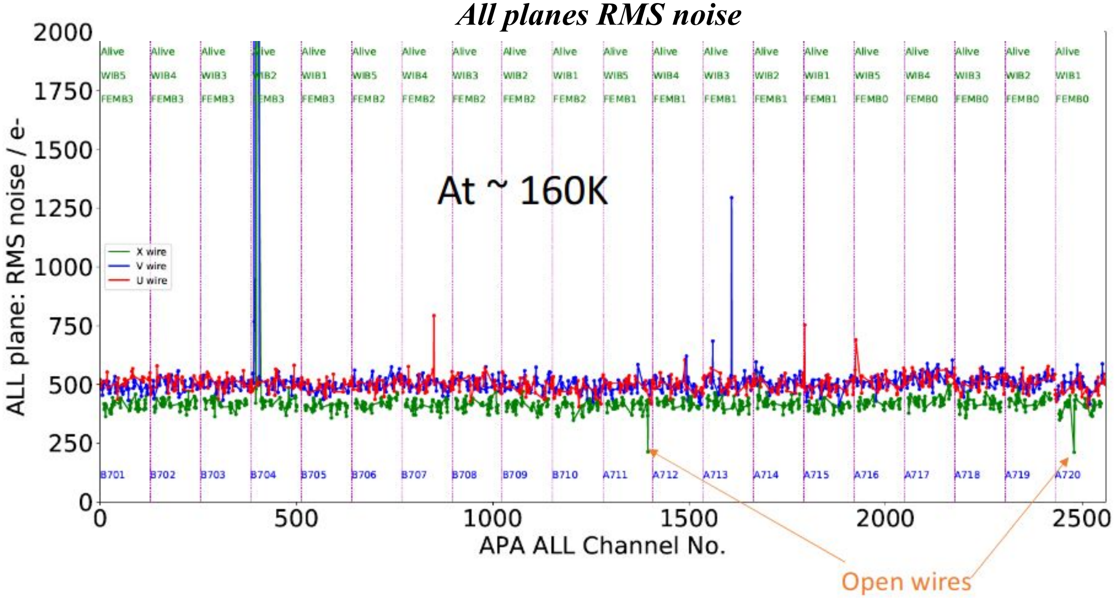
Warm, cold runs and summary of data set:

- ➢ Long noise runs during cool down and warm up
- ➢ Noise data for various CE gains and shaping time configurations at both warm and cold
- ➢ External pulser data for various CE gains and shaping time configurations at both warm and cold
- ➢ Special 15 msec and 100 msec readout window runs to study low frequency noise

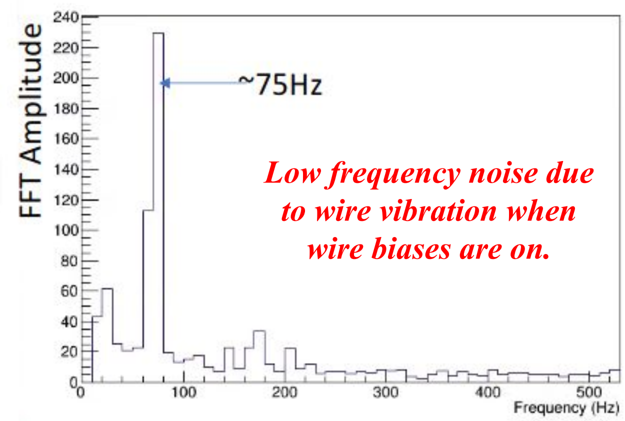
Noise spectrum: high frequency range



All planes RMS noise



Noise spectrum: low frequency range



Cold Box CE tests with APA7: pre-tests

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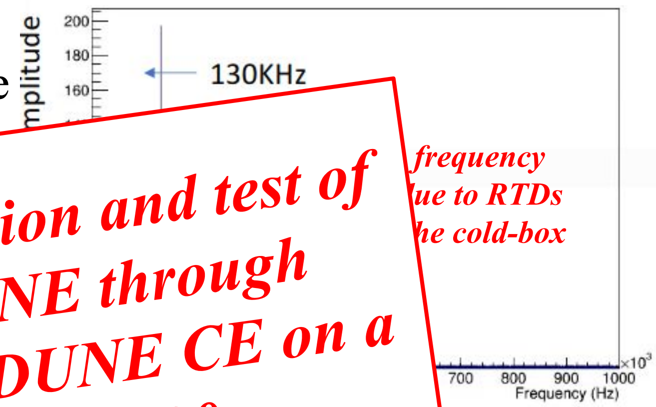
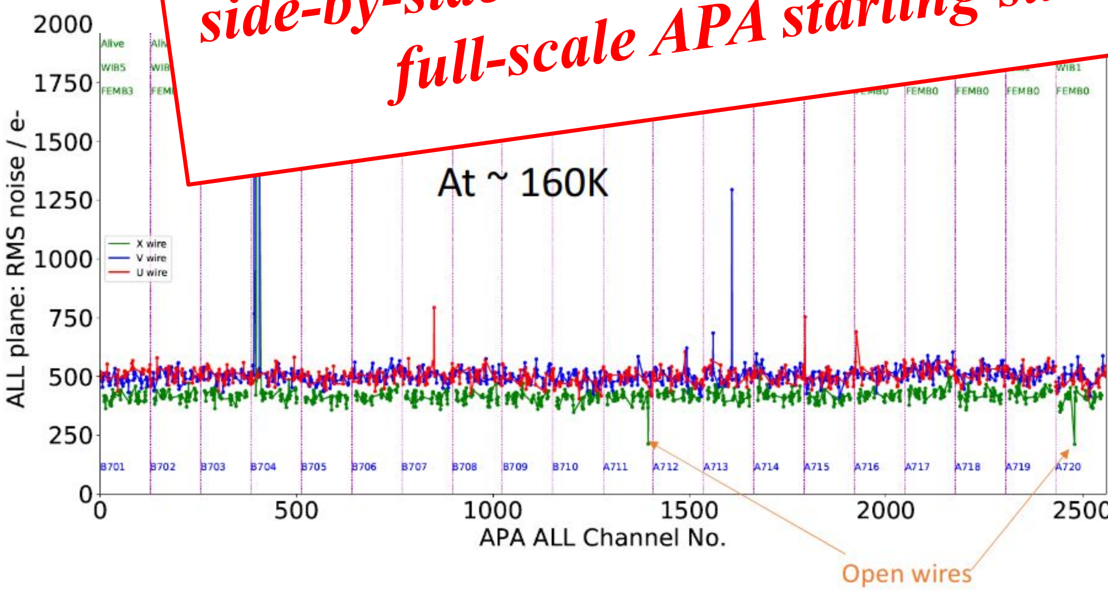
- ➢ External pulser data fo[...] tim[...]
- ➢ Spe[...] stud[...]

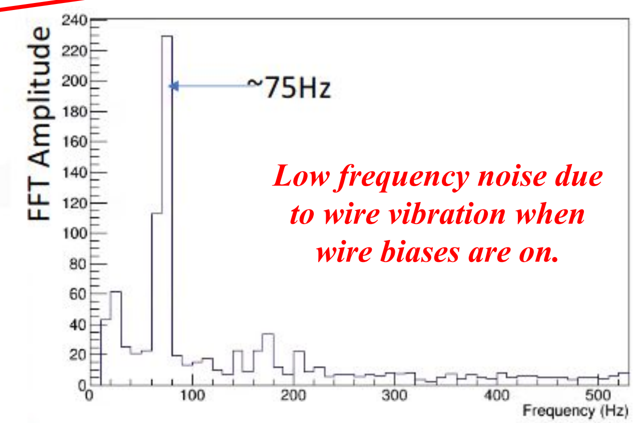
Noise spectrum: high frequency range



System ready for noise characterization and test of the proposed CE solution for DUNE through side-by-side comparison with ProtoDUNE CE on a full-scale APA starting summer 2020



[...]e spectrum: low frequency range

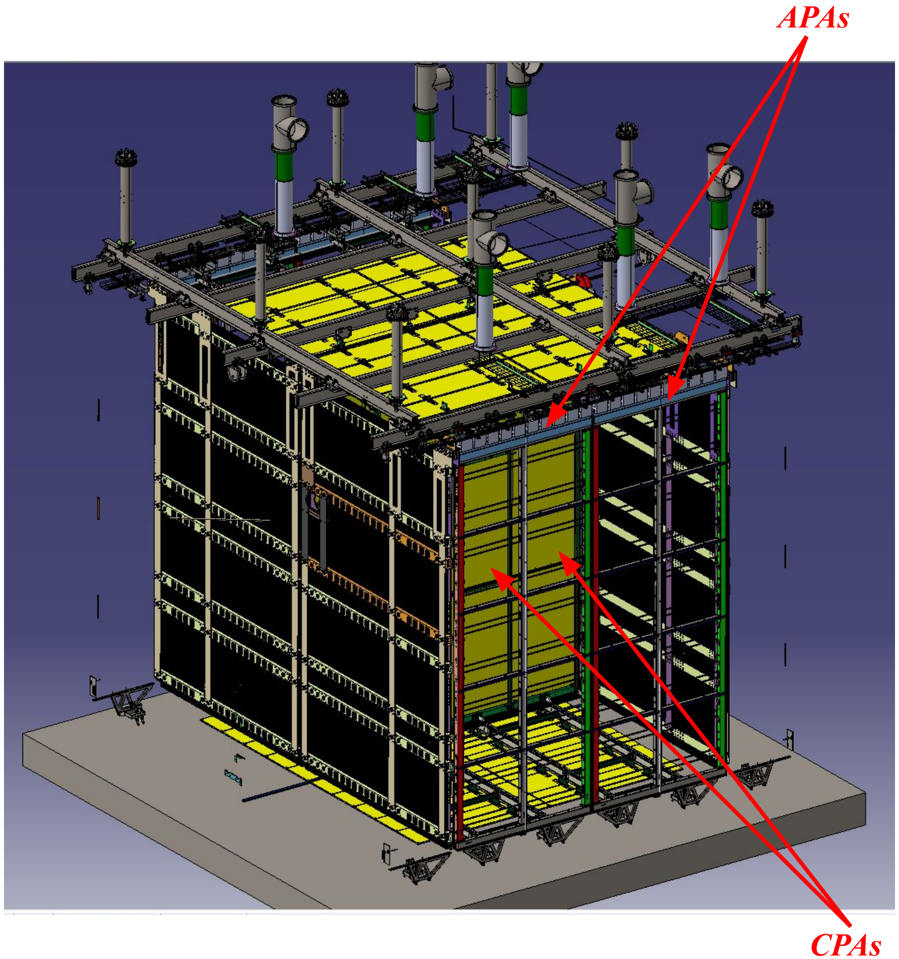


ProtoDUNE-SP Run II: Goals

- Full characterization of ”Module 0”s for DUNE Far Detector: improved APAs, CRPs, cold electronics, photon detectors etc.
- Increase beam data statistics for cross section measurements, particle identification, calibration, and reconstruction
- Complete data sets with different polarities for electrons, muons, pions, kaons, and protons in momentum range 0.3-7 GeV
- Develop, implement, and demonstrate new calibration techniques including a laser calibration system and a pulsed neutron source

ProtoDUNE-SP Run II: Configuration

- 4 APAs instead of 6
- Flipped APAs on one-side (electronics on bottom)
- DUNE-like distances between Cryostat and End Wall Field Cages
- Improved cryogenics systems, based on experience from ProtoDUNE-SP I and ProtoDUNE-DP
- New calibration and cryogenic instrumentation (laser, neutron source, temperature sensors on APAs, etc.)
- As much as possible, final Far Detector components



ProtoDUNE-SP Run II: Timeline

- April 2020: end of Run I operations. Starting cryostat emptying procedures
- Spring 2020: construction of first pre-production APA, to be tested in the Cold Box at CERN as soon as completed
- Summer 2020: final APA design review. Production of ProtoDUNE Run II APAs to be started immediately after
- Late 2020: final design reviews for other sub-systems, with production starting in early 2021
- January 2021: open TCO, remove the detector
- Summer 2021: cryostat modifications. All detector components at CERN by the end of summer
- Fall 2021: Detector installation
- January 2022: close TCO, begin operations

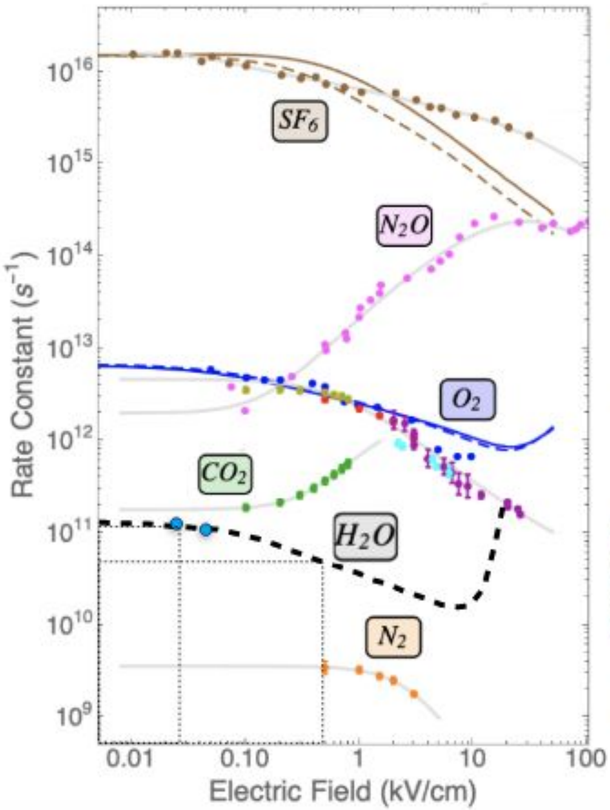
Summary

- ProtoDUNE-SP had a busy and successful 2019
  - Detector performance and stability proven with 1+ years of operations
  - CRT reactivated and used for cosmic data taking campaign
  - First set of cold-electronics tests were finalized using APA-7 and cold-box
- 2020 schedule appears no less busy
  - Cryogenics tests showed electron lifetime not affected by LAr recirculation
  - Xe doping and dedicated data taking ongoing
  - Continuous DAQ development and testing
  - Planned set of cold-electronics test with APA-7 in the cold-box
  - Planned set of test with CRTs at different LAr purity levels to validate the track method for lifetime estimation
  - Planned set of tests with higher drift field
- Plans for ProtoDUNE-SP Run-II are in place, with installation of a new detector expected for Fall 2021 and operations starting early 2022

Backup Slides

e-Lifetime vs Purity

$$\tau_e = \frac{1}{k_A\,[X]} \qquad Q_{corr} = \frac{Q_{det}}{exp[-t_d/\tau_e]}$$



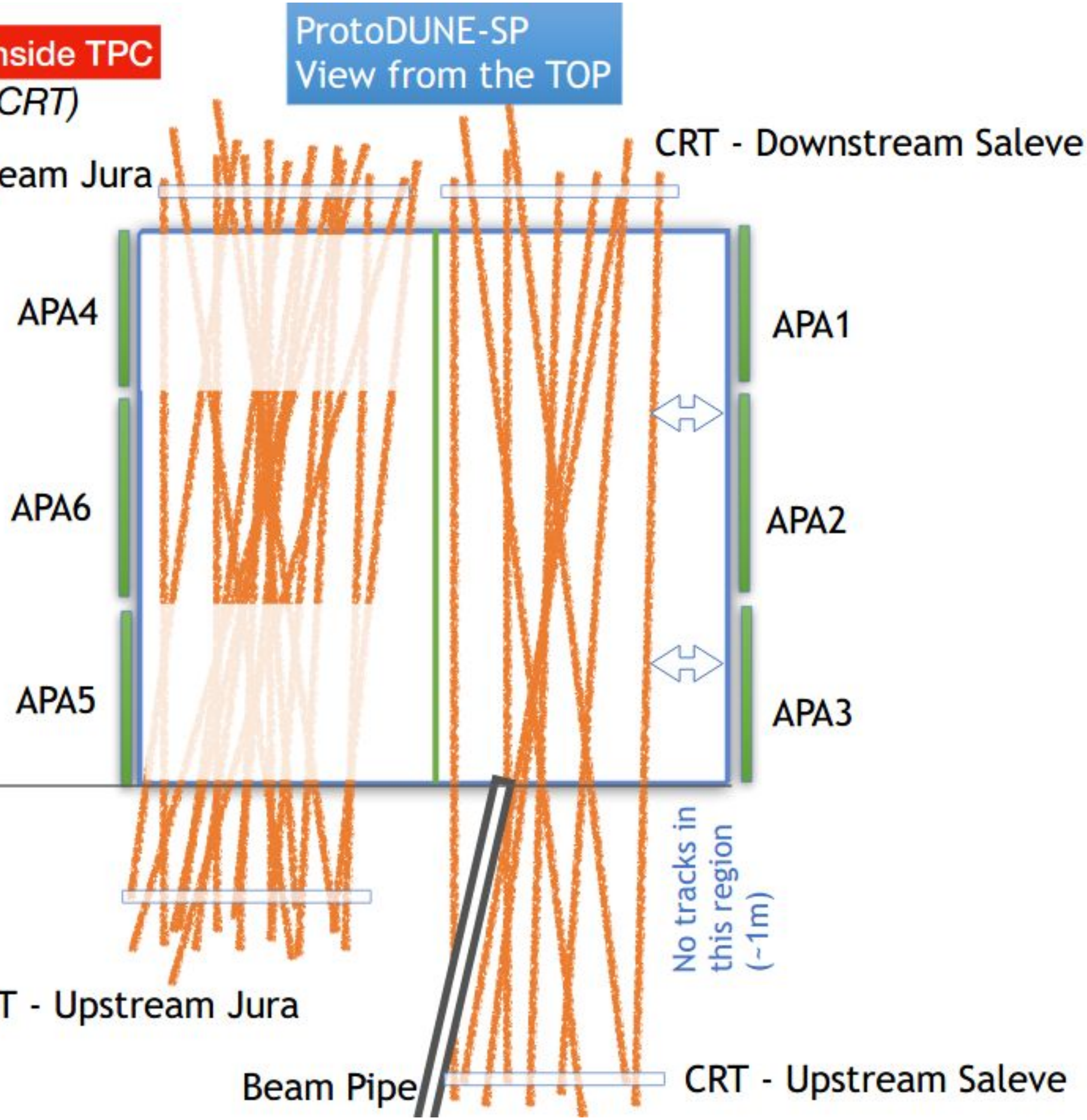
- **Purity of LAr depends on** $[X]$ (ppt) **-** ***concentration of el.neg. impurity*** X **- with** $X = H_2O, O_2$
- $k_A = k_A(EF)$ **-** ***Attachment Rate constant*** **(for** X**) depends on EF in the drift volume**
- τ_e **measures the LAr Purity, but its value depends on the EF where is measured**
- **TPC vs PurMon:** $\tau_e(500\ V/cm) > \ \tau_e(20\ V/cm)$
- **Lifetime measurement in TPC with tracks** (dQ/ds vs t_d) **difficult on surface due to SpCh track distortion**

How to measure e-Lifetime inside TPC

(the importance of the CRT)

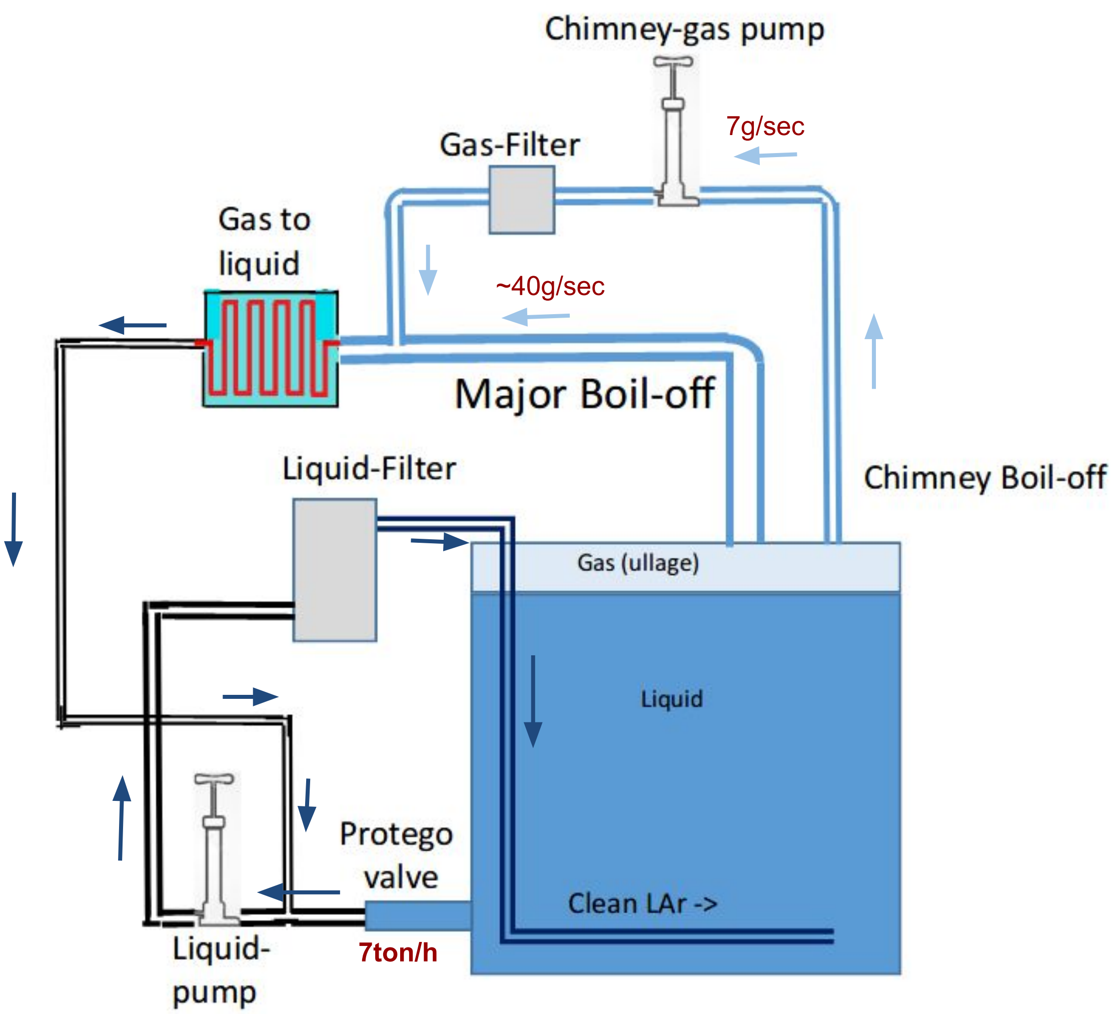
CRT Triggered ~Hor. Muons parallel to APA & Tracks in TPC central region:

No/minimal Space Charge Spacial Distortion *[in drift x-coord Correction for EF distortion on recombination*



Schematics of the ProtoDUNE-SP cryogenic system

S. Pordes



Loss of drift-lifetime in ProtoDUNE-SP

July 21 — **Gas pump injects air into the system and GAs filter exhausts**

GAr filter starts to saturate and exhaust around midnight

July 22 — **LAr filter exhausts and the problem appears**

LAr filter saturates ~7am and electron lifetime starts to drop. Around the lunch time, all lifetime is lost. LAr re-circulation stopped.

July 23 — **Checks for possible leaks**

Inspect the system and perform regular purity monitor measurements to monitor the system.

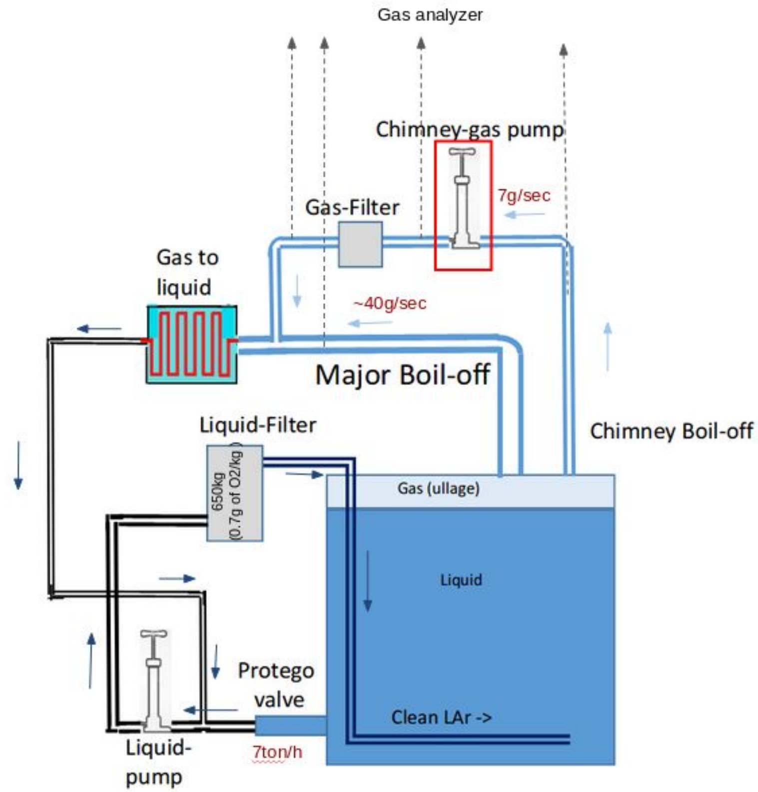
July 24 — **LAr filter regeneration**

July 25 — **GAr filter regeneration and smoking gun**

With LAr and GAr filters re-generated, impurities are trapped.

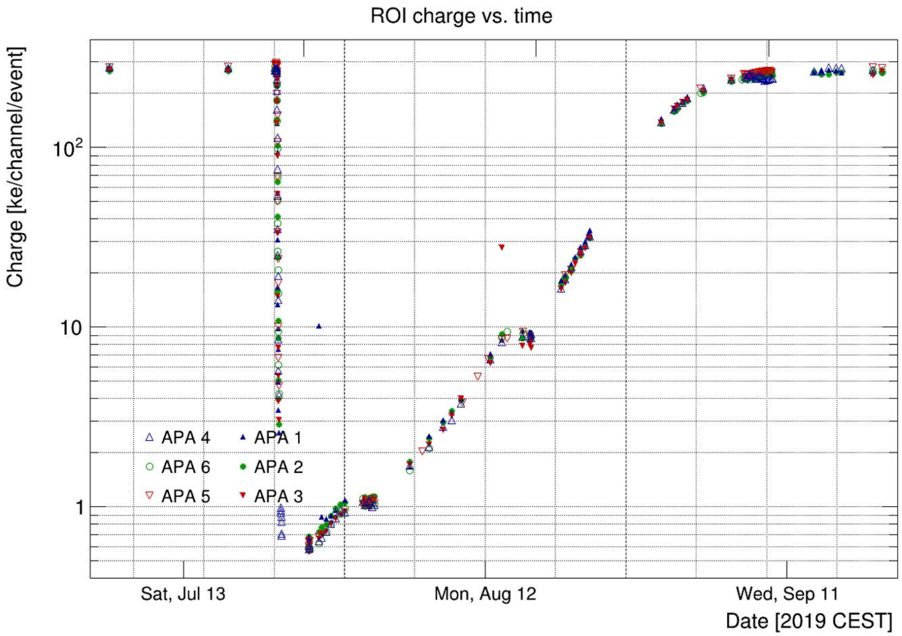
July 26 — **GAr filter saturated. Source of problem understood**

Gas analyzer overflowed at the pump output. Gas circulation pump stopped and excluded from the cryogenic circuit.

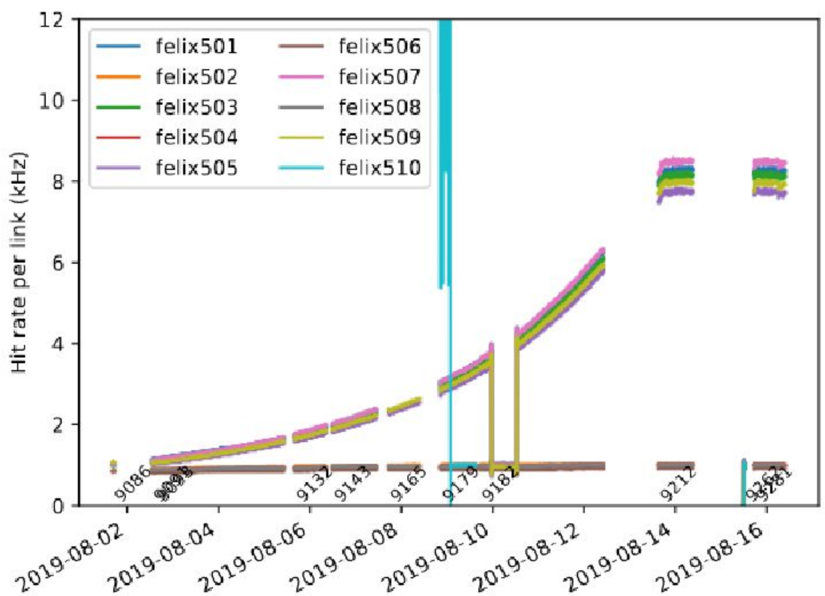


Filtering, re-circulation and recovering the lifetime

- Right after the problem was resolved, LAr and GAr filters were regenerated and LAr circulation has been started
- Regular purity monitors runs to monitor the system
  - Many thanks to S. Pordes, I. Seong, J. Bian and N. Nayak
- Developed indirect monitoring tools using the collected charge and hit rate



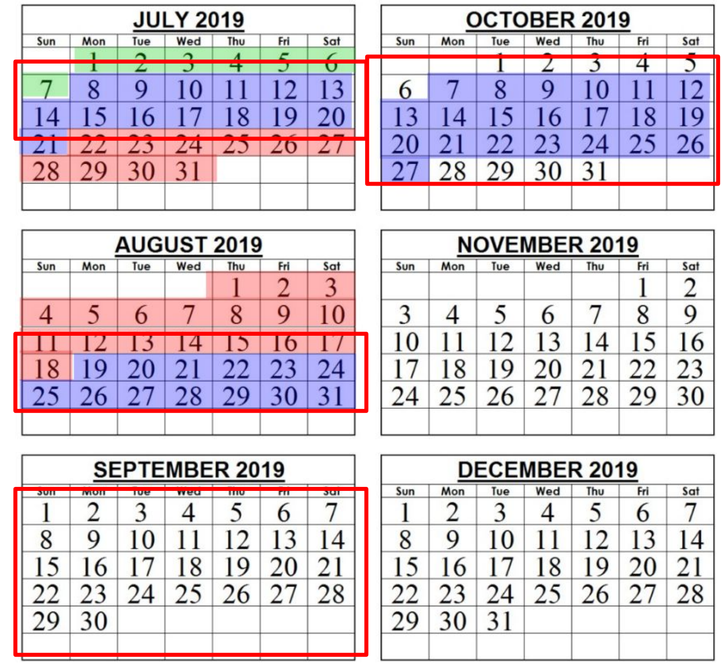
D. Adams
see the talk on the ProtoDUNE-SP:
Operation session on Wednesday



P. Rodrigues
see the talk on the ProtoDUNE-SP:
Operation session on Wednesday

DAQ development and testing

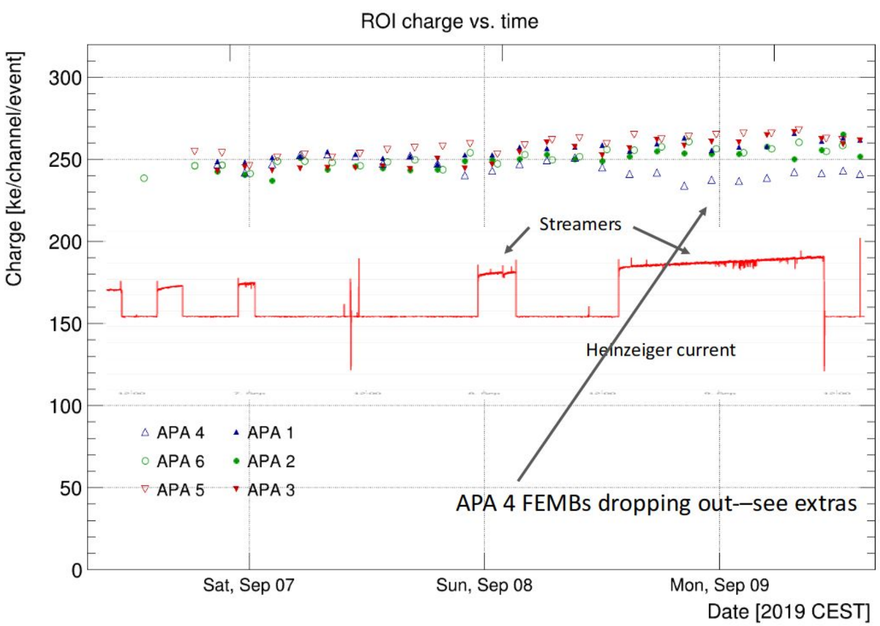
- Dedicated DAQ weeks and DAQ-Mondays for development and tests
- Highlights from the developments and ongoing work
  - Extension of Felix readout
    - APA4 moved to FELIX (Moving more in October)
    - On-host mode (Single server for card, data processing and selection)
  - Dataflow
    - Improvements and new features (e.g.: DUNE DAQ dataflow orchestration, event integrity monitoring, etc.)
    - New and better way of development procedure
  - Data selection
    - Software HitFinding on FELIX APAs
    - Self-triggering chain is complete
  - System administration
    - Remote management of DAQ computers deployed
    - Cold start and automation procedures improved
- Huge support for the ProtoDUNE-SP operations!
  - Thanks a lot to all DAQ team

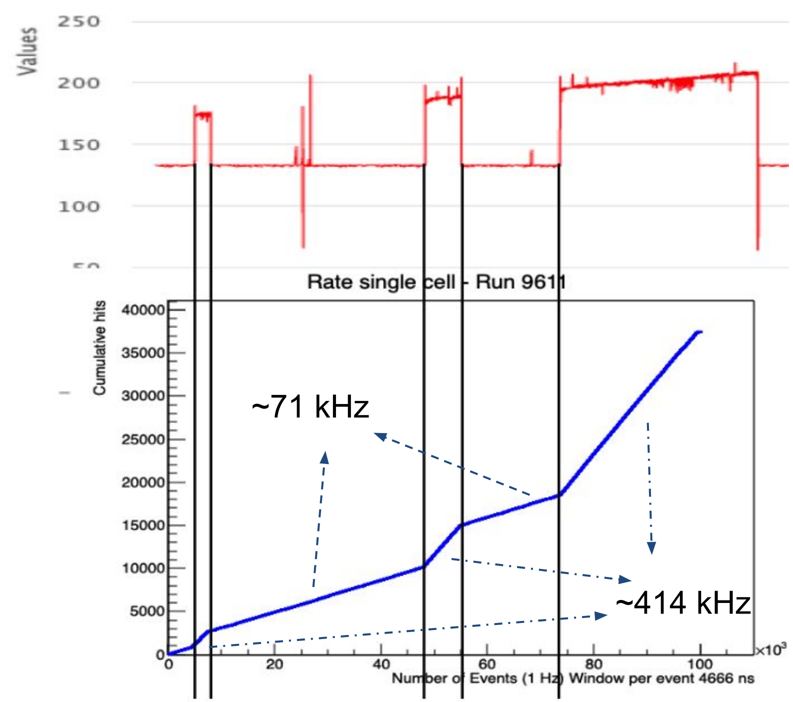


See R. Sipos' talk for the details on the ProtoDUNE-SP: Operation session on Wednesday for the details

HV activities

- HV Streamers: Do they have any negative effects on the collected data?
  - Charge collections: No visible effects
  - Light collection: Increase in the rate of single photo-electrons





Details in the “ProtoDUNE-SP: Operations” session on Wednesday

ProtoDUNE-SP Run II

- An effort has been initiated to understand how the ProtoDUNE II TPC will be assembled

- Need engineering design for how APAs will be hung upside-down from the Detector Support Structure rails

- Based on this design, need to converge on an integrated model that defines the position of TPC within cryostat

- Allocation of cryostat penetrations based on TPC location

- Workshop is being planned for May 7-8 at CERN to settle on calibration systems and cryogenic instrumentation for ProtoDUNE II (and DUNE)