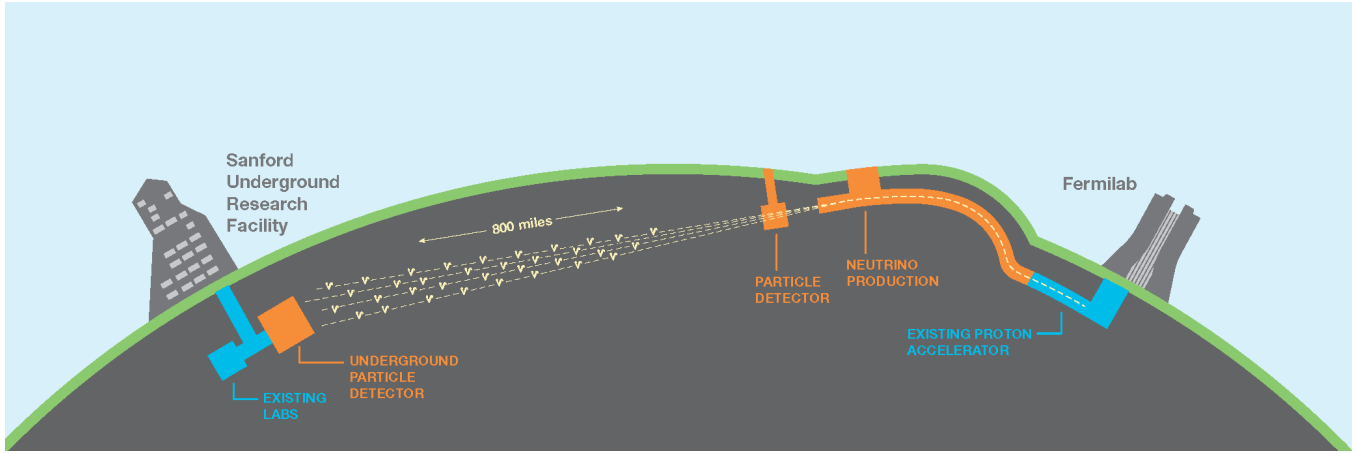


ProtoDUNE-SP Status

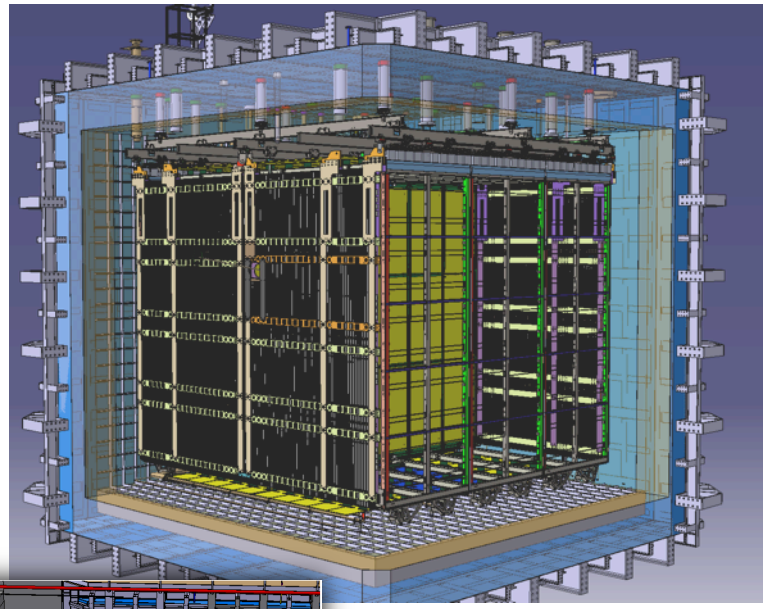
Gina Rameika

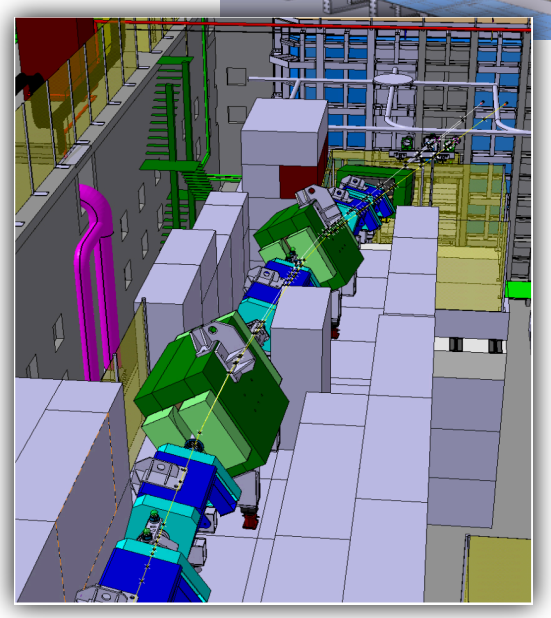
LBNC Meeting

December 7, 2018

Topics

- Reminder – Goals of ProtoDUNE-SP
- Final construction phase
- Operations
  - Instrumentation
  - Purity
  - High Voltage
- Beam data
- TPC performance
- Photon detection
- Reconstruction
- Post-beam studies
- Lessons learned





High Level Goals of ProtoDUNE-SP

- Engineering validation of the full-scale DUNE detector components
- Develop the construction and quality control process
- Validate the interfaces between the detector elements and identify any revisions needed in the final design
- Validate the detector operation using cosmic rays
- Study the detector response to known charged particles
- Improve event reconstruction and detector response models

High Level Goals of ProtoDUNE-SP

- Engineering validation of the full-scale DUNE detector components
- Develop the construction and quality control process
- Validate the interfaces between the detector elements and identify any revisions needed in the final design
- Validate the detector operation using cosmic rays

By the end of this talk I hope that I will have convinced you that we have achieved each of these goals

- Study the detector response to known charged particles
- Improve event reconstruction and detector response models

and this work is making good progress

Specifications and Goals for DUNE Far Detector

High Voltage : Spec = >250 V/cm; Goal = 500V/cm (180 kV)

- Spec met by PD-SP

Electron Lifetime : Spec > 3ms; Goal = 10 ms

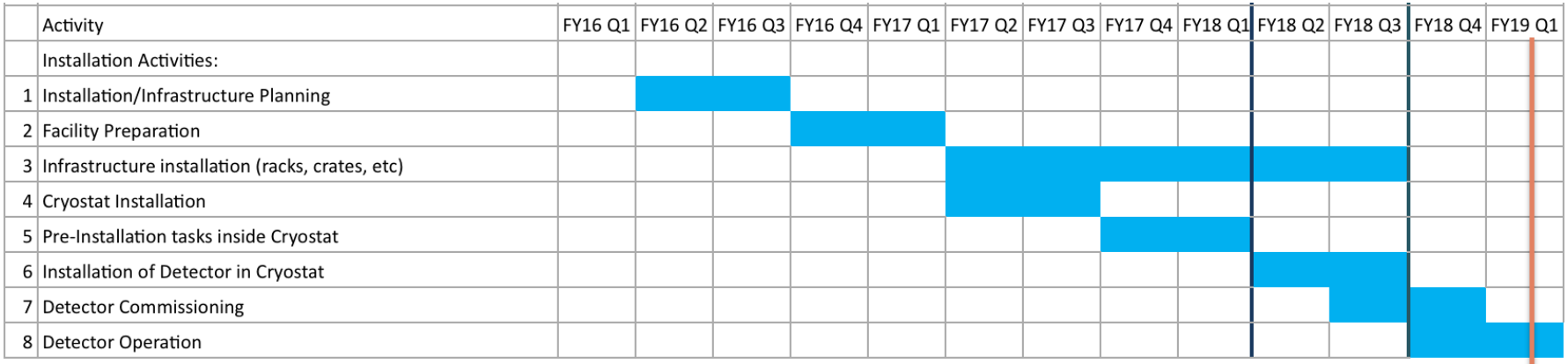
- Spec met by PD-SP

Electronic noise : Spec < 1000 enc; Goal = ALARA

- Spec met by PD-SP

- Long term studies being planned to understand limitations on meeting goals for long term operation of DUNE detector

Main challenge was schedule



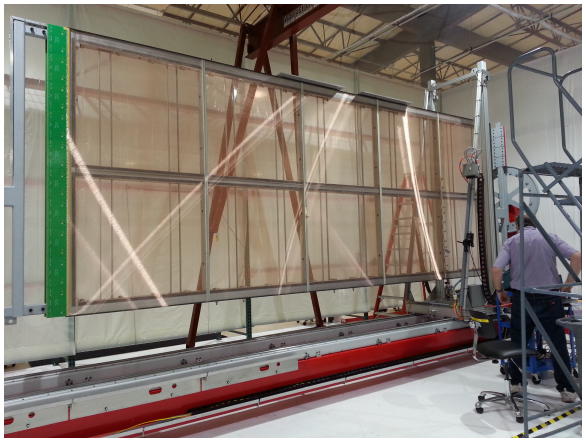
PD-SP was proposed to the SPSC in June 2015 (SPSC-P-351)
An MOU between CERN and FNAL, outlining responsibilities, was signed in December 2015.

The *original schedule* called for the detector to be ready for filling in Summer of 2018 and operation with test beam in Fall of 2018, test beam running to end with the start of the LS2.

Filling took place between August 8 and September 13, 2018
Last beam triggers were recorded on the morning of November 12.

CERN Accelerator Long Shutdown

APA Journey – build, ship, prep, test, install



July 2017

October 2017

January 2018

Work in Progress

		Winding		Transport			Cold Box Test Time		Could start TCO close	
		Start Winding X	Finish Winding G	Crate	Ship	Arrival at CERN	Start	Finish		
APA#1	PSL#1	2/1/17 A	6/30/17 A	7/7/17 A	7/11/17 A	7/14/2017 A	10/9/2017 A	11/26/17		Cold Box finish driven by arrival of APA#2
APA#2	PSL#2	8/9/17 A	10/23/17 A	11/10/17	11/14/17	11/17/17	11/29/17	1/8/18		Cold Box finish driven by arrival of APA#3
APA#3	UK#1	8/9/2017 A	12/19/17	1/2/18	1/8/18	1/10/18	1/22/18	1/28/18		Cold Box finish driven by installing Beam Right TPC elements
APA#4	PSL#3	11/10/17	1/30/18	2/9/18	2/13/18	2/16/18	2/26/18	3/5/18	3/15/18	Cold Box finish driven by TCO close date
APA#5	UK#2	1/5/18	3/20/18	4/1/18	4/2/18	4/5/2018*	4/10/18	4/17/18	4/27/18	Cold Box test driven by TCO close date
APA#6	PSL#4	2/6/18	4/13/17	4/20/18	4/27/18	5/1/18	5/7/18	5/14/18	5/21/18	Arrival at CERN likely too late to install
APA#7	UK#3	3/25/18	6/15/18	6/22/18	6/25/18	6/27/18				APA for Cold Box testing OR uninstrumented wires in 5 APA scenario

A Actual
Red Revised

* Need to accelerate delivery of this APA

Propose
1 Accelerate UK#2 to get it to CERN by mid-March
2 Ship UK#3 empty frame to CERN to go into Slot#6 (February)
3 PSL#3 goes into APA#5 slot (early March)
4 UK#2 goes into APA#4 slot (mid-March)
5 PSL#4 gets completed for test-stand use

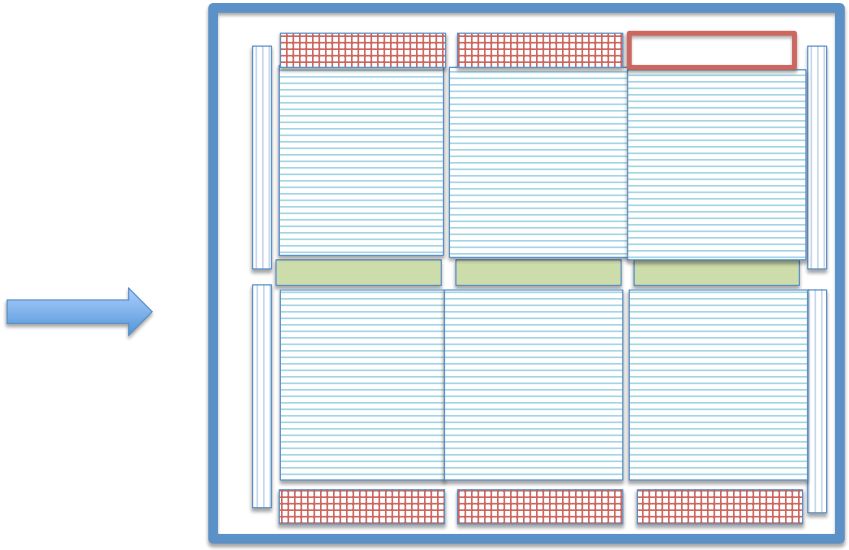
APA Progress Tracking Table developed for LBNC at October 2017 meeting at SURF

Slide from January 2018 collaboration meeting;

We knew we would have 4 APAs

But we thought we would be lucky to get 5 APAs installed

Installation Sequence



June 2018

Backup plan to install blank frames

29

Planning for APA 5 & 6

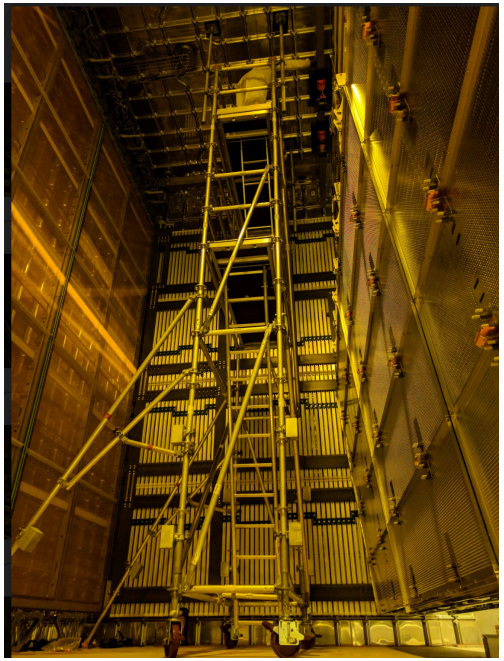
Week ending																							
30-Mar	6-Apr	13-Apr	20-Apr	27-Apr	4-May	11-May	18-May	25-May	1-Jun	8-Jun	15-Jun	22-Jun	29-Jun	6-Jul	13-Jul	20-Jul	27-Jul	3-Aug	10-Aug	17-Aug	24-Aug	31-Aug	7-Sep
♦	APA#5 (UK#2) Arrives																						
		Accept and test APA#5																					
		♦	APA#6 (US#4) Arrives																				
			Accept and test APA#6																				
					TPC assembly after last APA installed																		
					Close TCO																		
												Complete TPC assembly after TCO is closed											
											♦	Ready to start purge											
												Purge, Cooldown, Fill											
																				LAr Purification			
																				Ready for Beam Data			♦

APA's need to arrive early-mid April at the latest

They will get unpacked and inspected,
survey and tension measurements will be abbreviated;
photon detectors and CE will installed and tested locally
(no cold box)
They will then go into the cryostat.

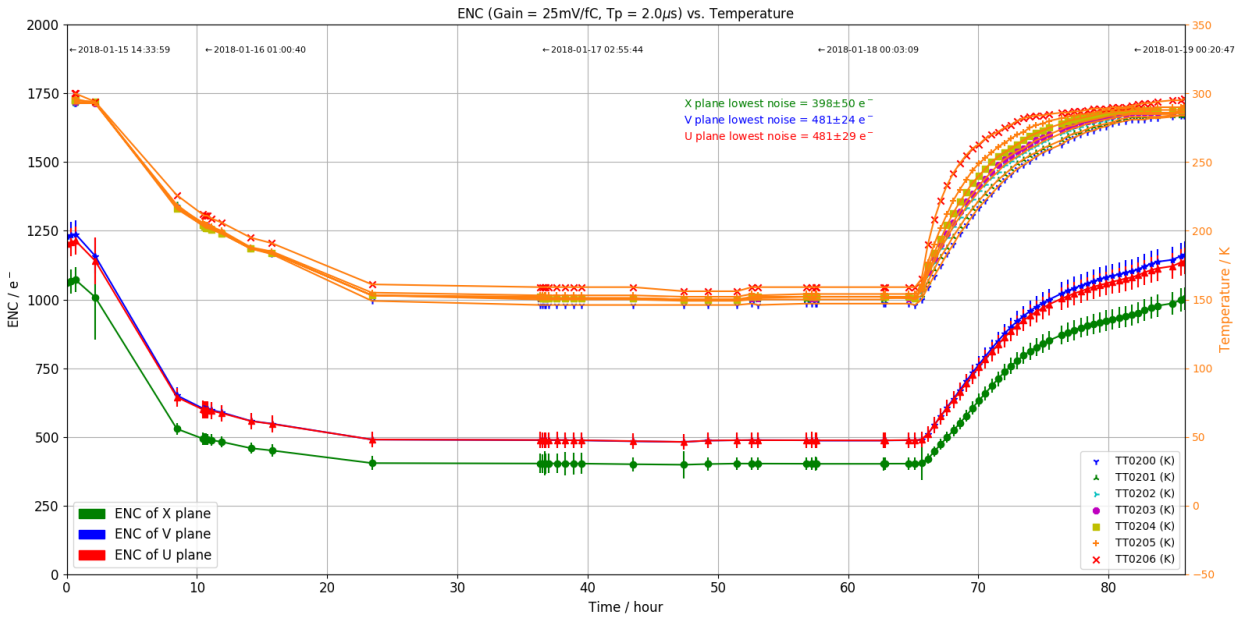
		Winding		Transport			Cold Box Test Time		In Cryostat	
		Start Winding X	Finish Winding G	Crate	Ship	Arrival at CERN	Start	Finish		
APA#1	PSL#1	2/1/17 A	6/30/17 A	7/7/17 A	7/11/17 A	7/14/2017 A	10/9/2017 A	11/26/2017 A	11/28/17 A	Cold Box finish driven by arrival of APA#2
APA#2	PSL#2	8/9/17 A	10/23/17 A	11/10/2017 A	11/14/2017 A	11/17/2017 A	11/29/2017 A	1/17/2018 A	1/26/18 A	Cold Box finish driven by arrival of APA#3
APA#3	UK#1	8/9/2017 A	12/01/2017 A	1/10/2018 A	1/12/2018 A	1/16/2018 A	1/31/2018 A	2/8/2018 A	2/9/2018 A	Cold Box finish driven by installing Beam Right TPC assembly
APA#4	PSL#3	11/20/2017 A	1/17/2018 A	2/9/2018 A	2/15/2018 A	2/20/2018 A	3/12/2018 A	3/23/2018 A	3/25/18 A	Cold Box finish driven by arrival of APA#5 and #6 and beam left installation
APA#5	UK#2	1/23/2018 A	2/28/18 A	3/9/2018 A	3/13/2018 A	3/16/2018 A	4/10/2018 A	4/24/2018 A	4/25/2018 A	4 week winding time; Working 12 hr days plus weekends
APA#6	PSL#4	2/8/2018 A	3/12/2018 A	3/23/2018 A	4/3/2018 A	4/6/2018 A			4/20/2018 A	*Did not Cold Box Test*

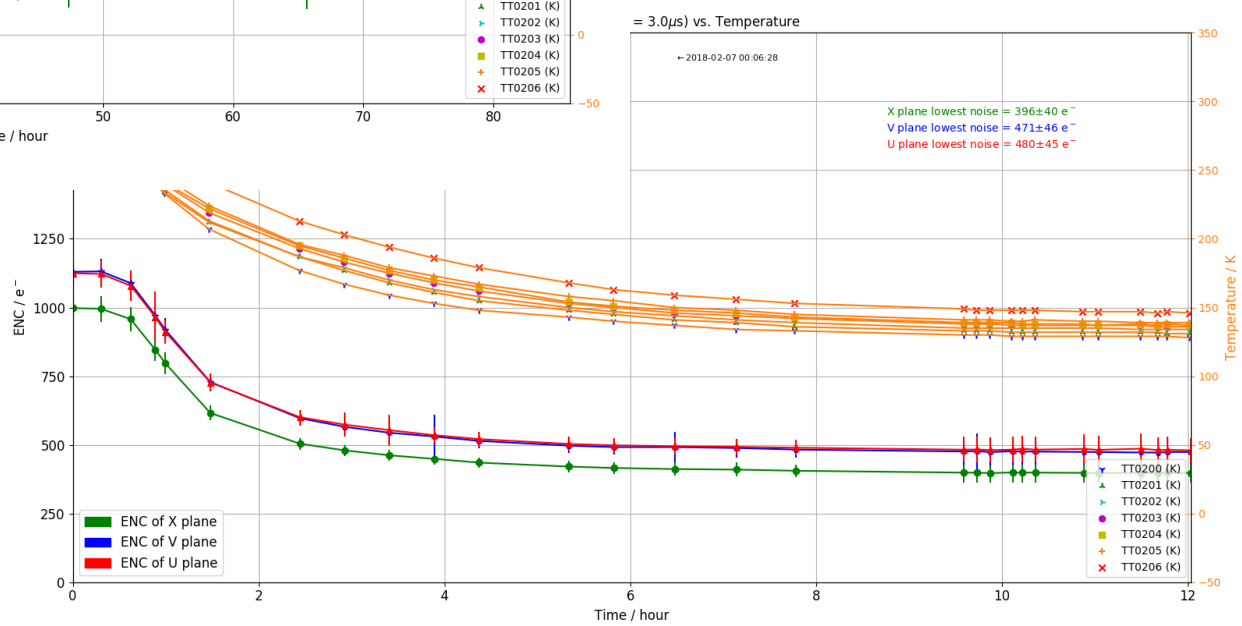
- APA#6 arrived at EHN1



Only one APA missed cold box testing

Cold Box testing of Front-end Electronics

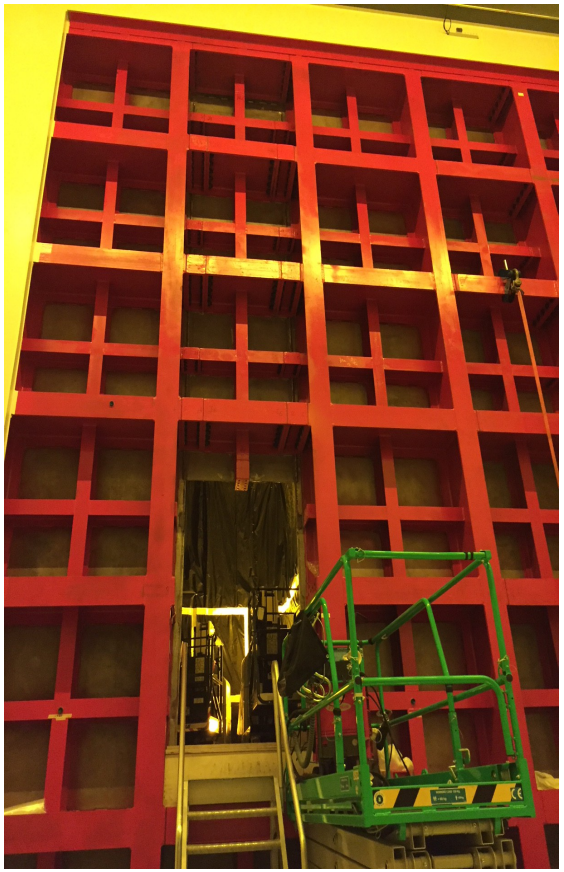


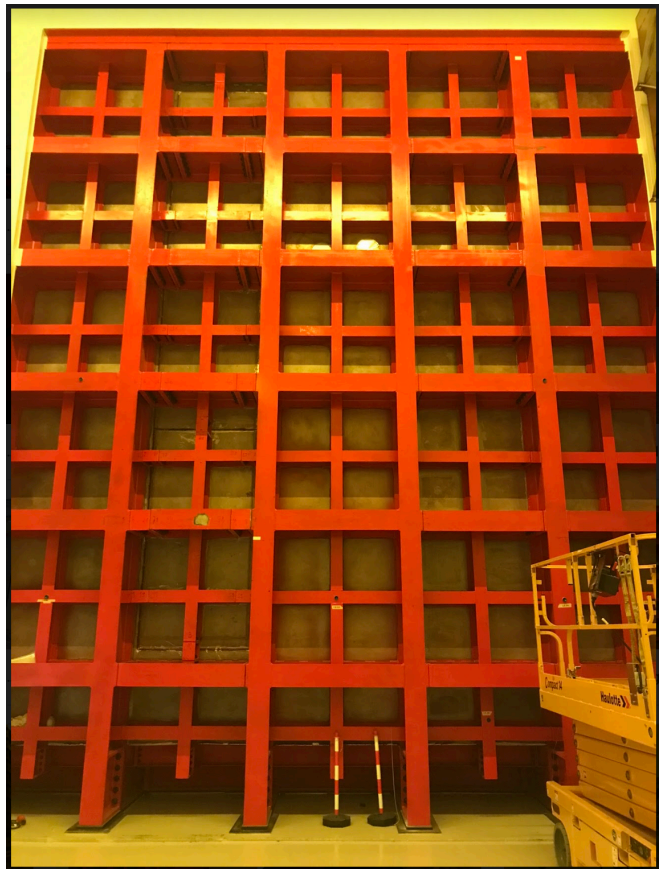


Cold Box testing insured QC on installation and validated the expected noise levels

Closing the Temporary Construction Opening

a hard deadline: **May 1 to June 13 - 2018**

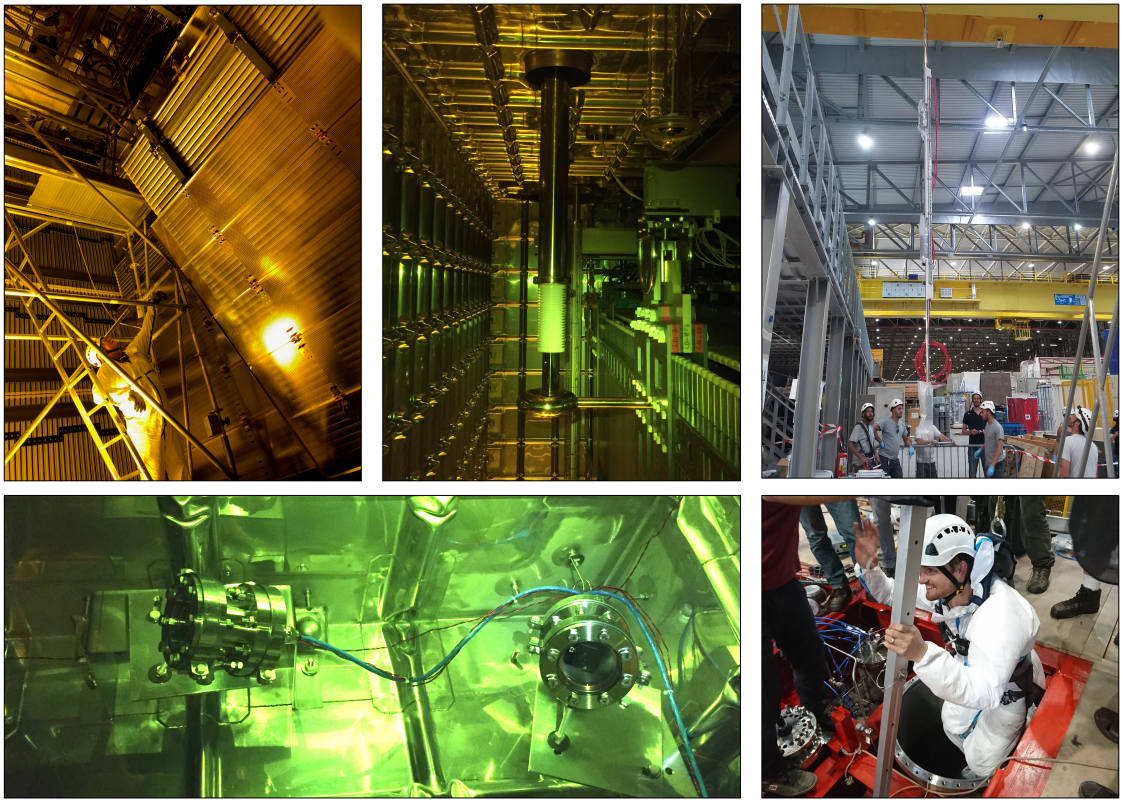




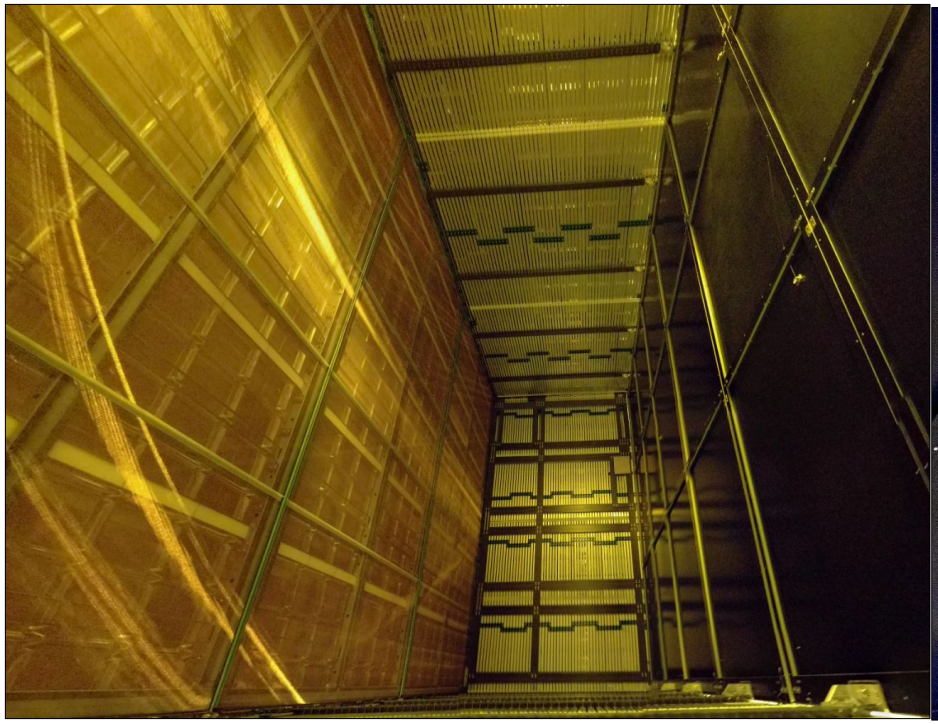
TPC mounting completed and LAr detector installation inside the Cryostat

one more step forward: June 14 to July 15 - 2018

- Regained access to the cryostat June 14th after the Temporary Construction Opening was sealed
- Completed the beam left drift
  - Fixed APAs and end walls into final position
  - Deployed top/bottom field cage units
  - Installed high voltage cup and feedthrough
- **Installed Cryo-Instrumentation**
  - Cameras
  - LEDs (visible and IR)
  - Temperature sensors/ profilers
  - Purity monitors

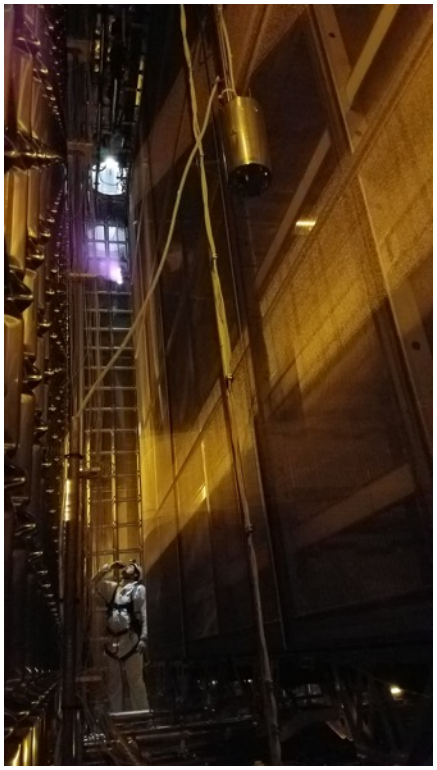


Final exit, June 28th

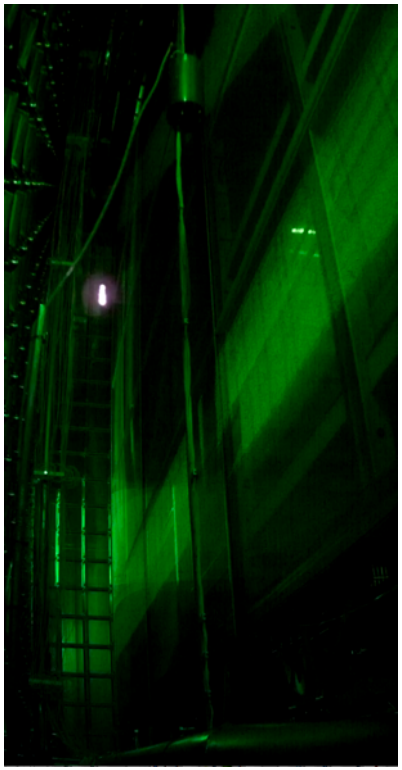


ProtoDUNE Instrumentation

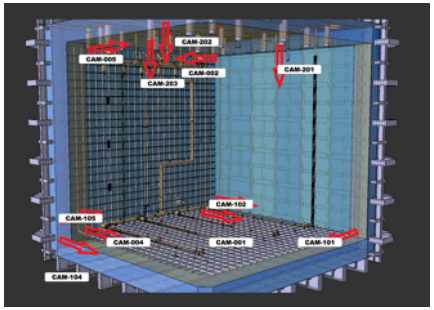
- 92 **high precision** temperature sensors for detailed temperature maps
- 12 cameras, to monitor the state of the apparatus and localize any sparking that may occur
- Purity monitors to measure the drift electron lifetime regularly, at 1.8m, 3.7m, 5.6m from floor

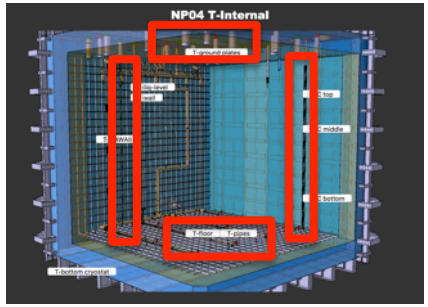


"Last days working in the cryostat"



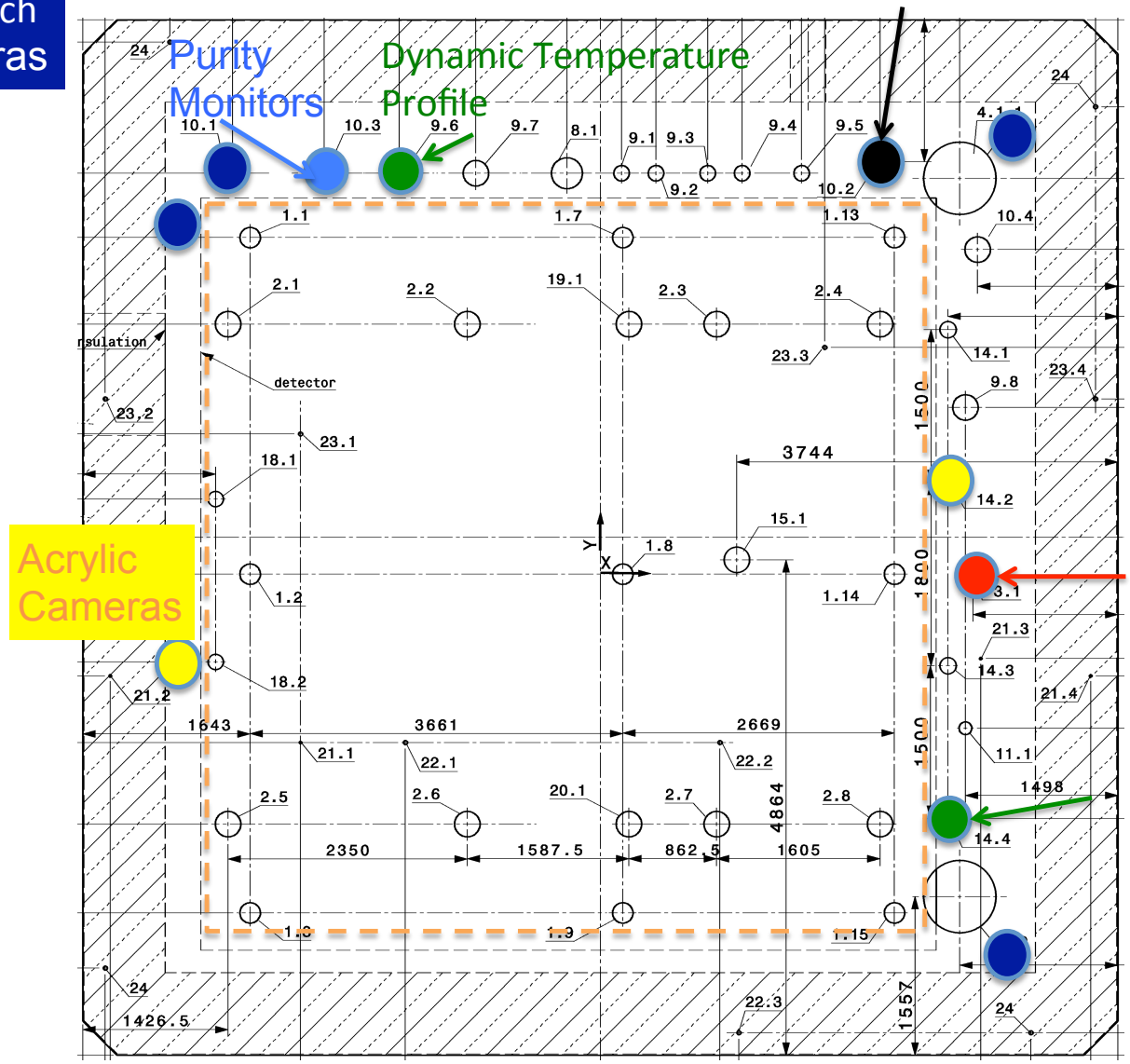
From cameras inside. TPC full of LAr





Level Monitor, Ground Plane Monitors & Cameras out

Revotech Cameras



1

Lessons Learned (Construction/Installation Phase)

- Integration Engineering and Engineering Coordination across sub-systems is essential and should receive high priority in resource planning
- Documentation of engineering analyses and calculations should be done in real time – not months after the fact
- Internal project engineering design and construction reviews should take place regularly throughout the lifetime of the construction phase
  - Early design reviews may not uncover the real issues or flaws in the design, particularly related to integration

We had a great team, but we could have done better

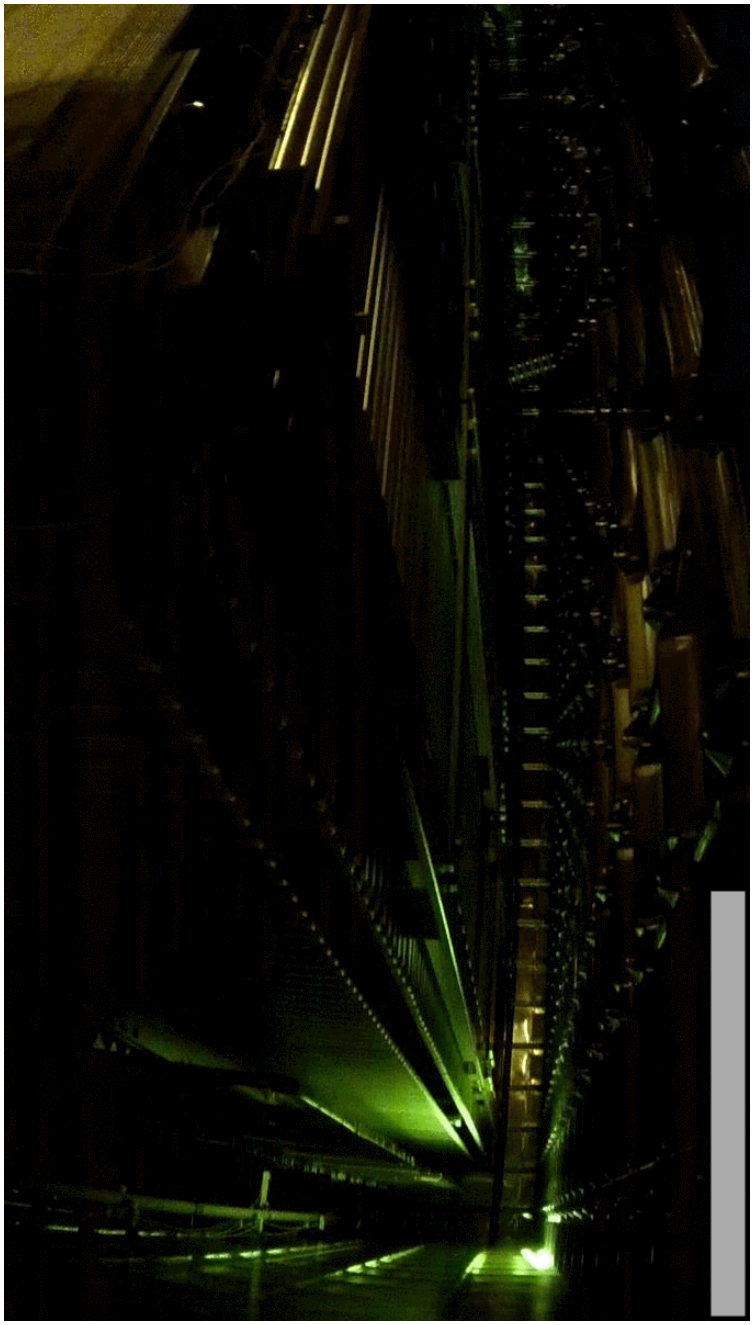
Full scale prototyping was essential

Final integration hardware (latches and hinges, etc) arrived late

Engineering resource limited (single point problem)

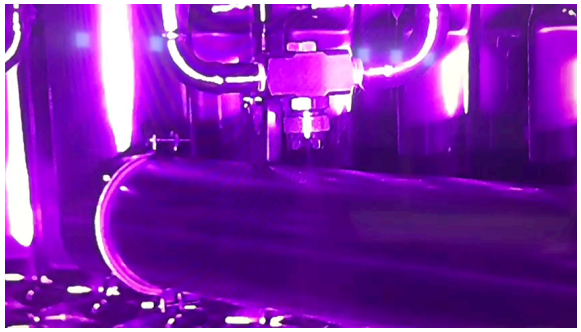
Cryogenic Commissioning
Purging, Cooling and LAr Filling

one last step: **July 15**
to Sept. 13 - 2018



LAr Filling:

LAr level going up as seen by a camera from Bottom of the Cryostat

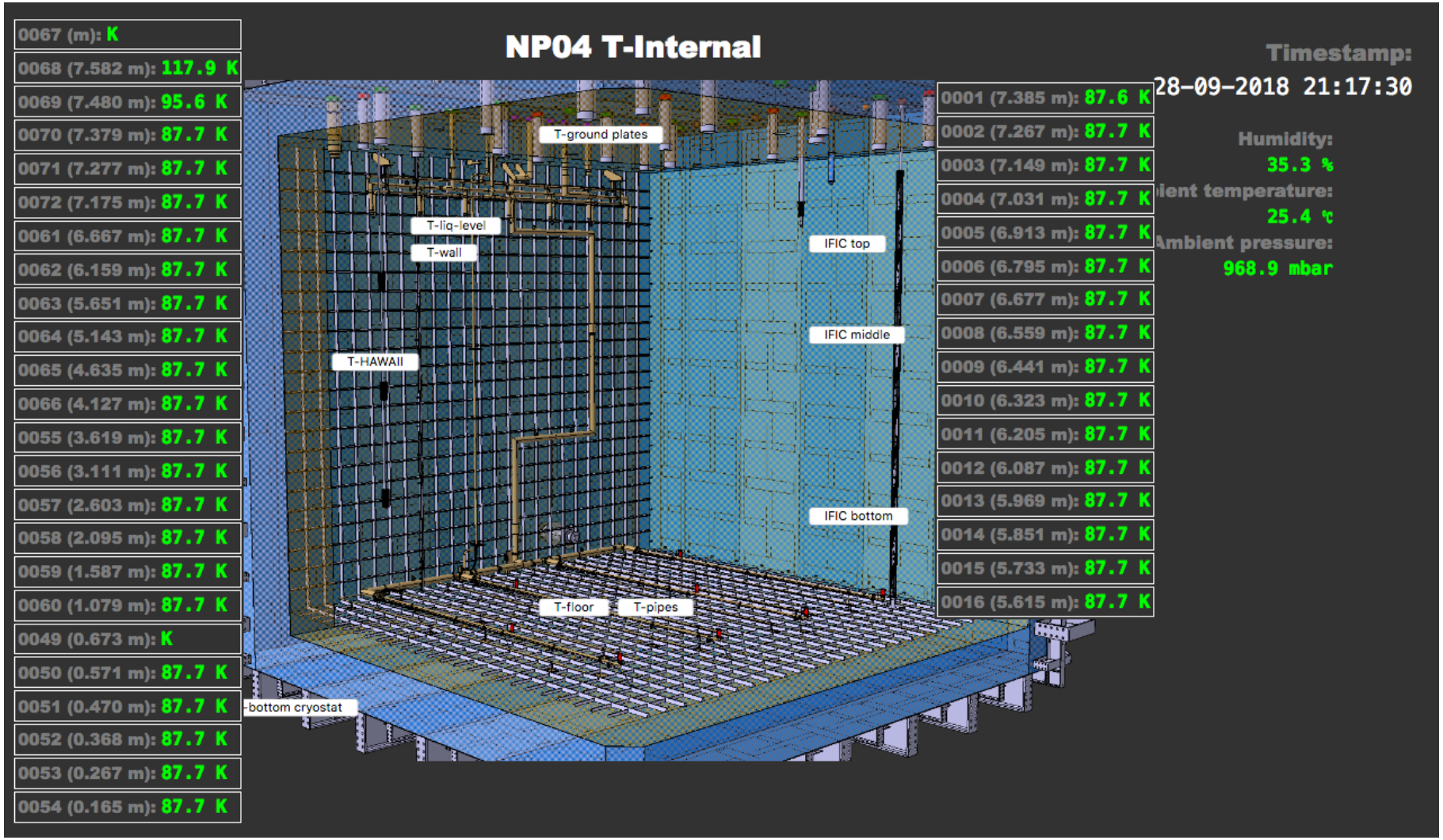


and Cooling: spraying cold Ar from top of the Cryostat for cooling

- Kept the LAr level below the APA until the temperature gradient across its height was no more than 50K

- August 13th, increased fill rate
- September 13th, reached nominal level

Internal temperature sensors monitored the liquid level



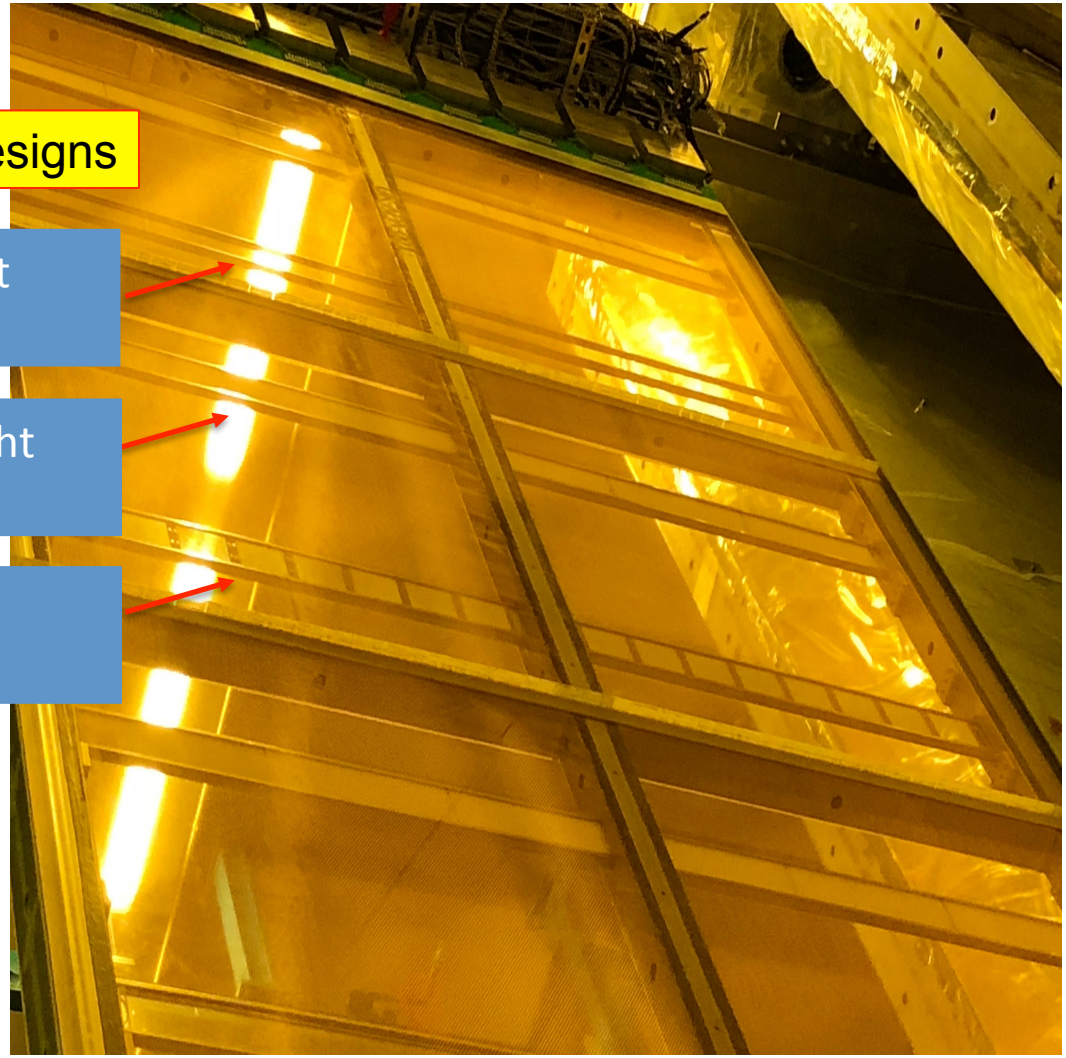
Photon Detector Module Layout

PD Module Designs

(29) Dip-Coated Light Guides

(29) Double-Shift Light Guides

(2) ARAPUCA (Light Trap)

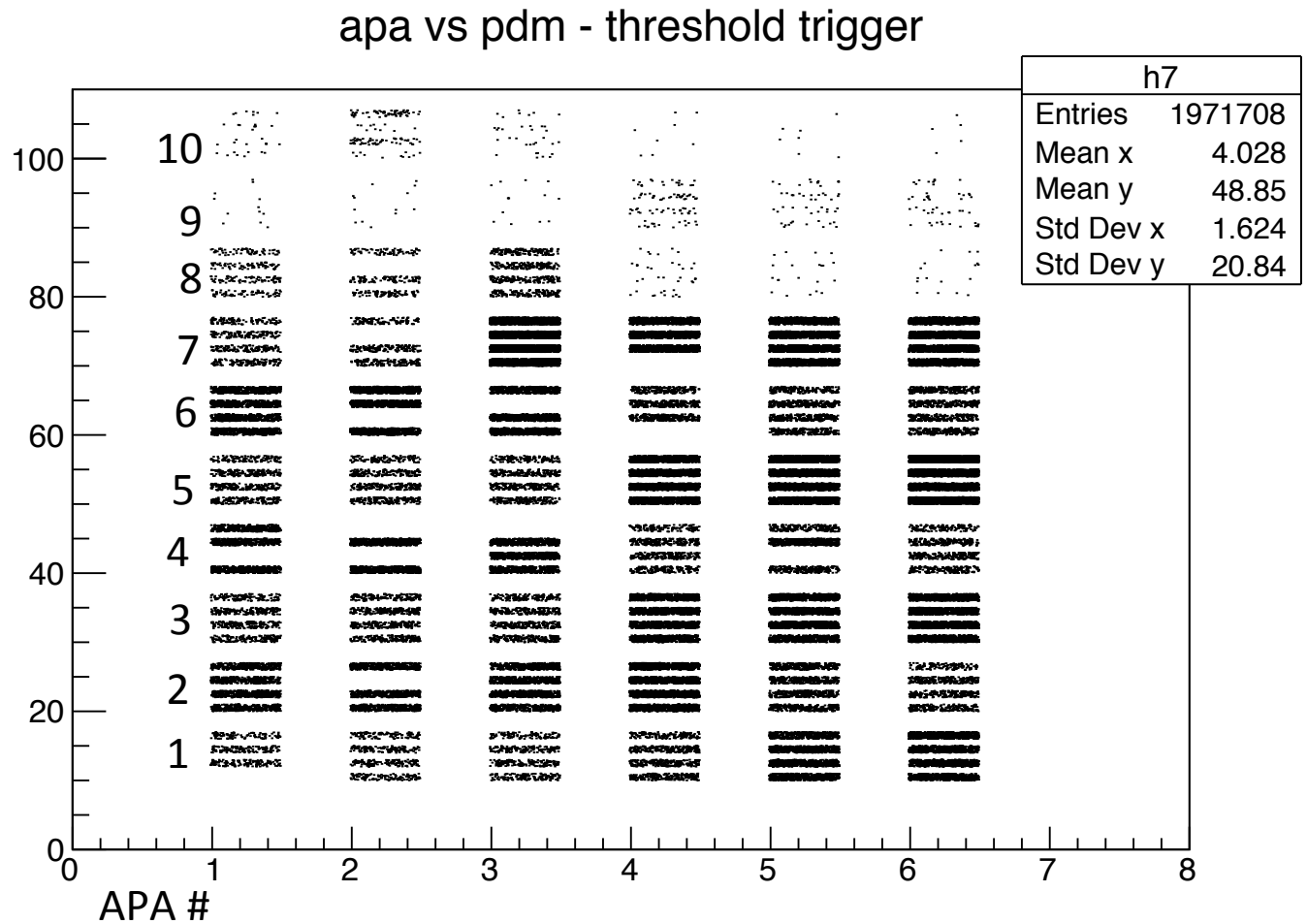


Photon detector trigger rate tracked the filling as well

10 modules per APA ; 4 readout channels per module

Bars in APA 1-3 have Sensel SiPMs

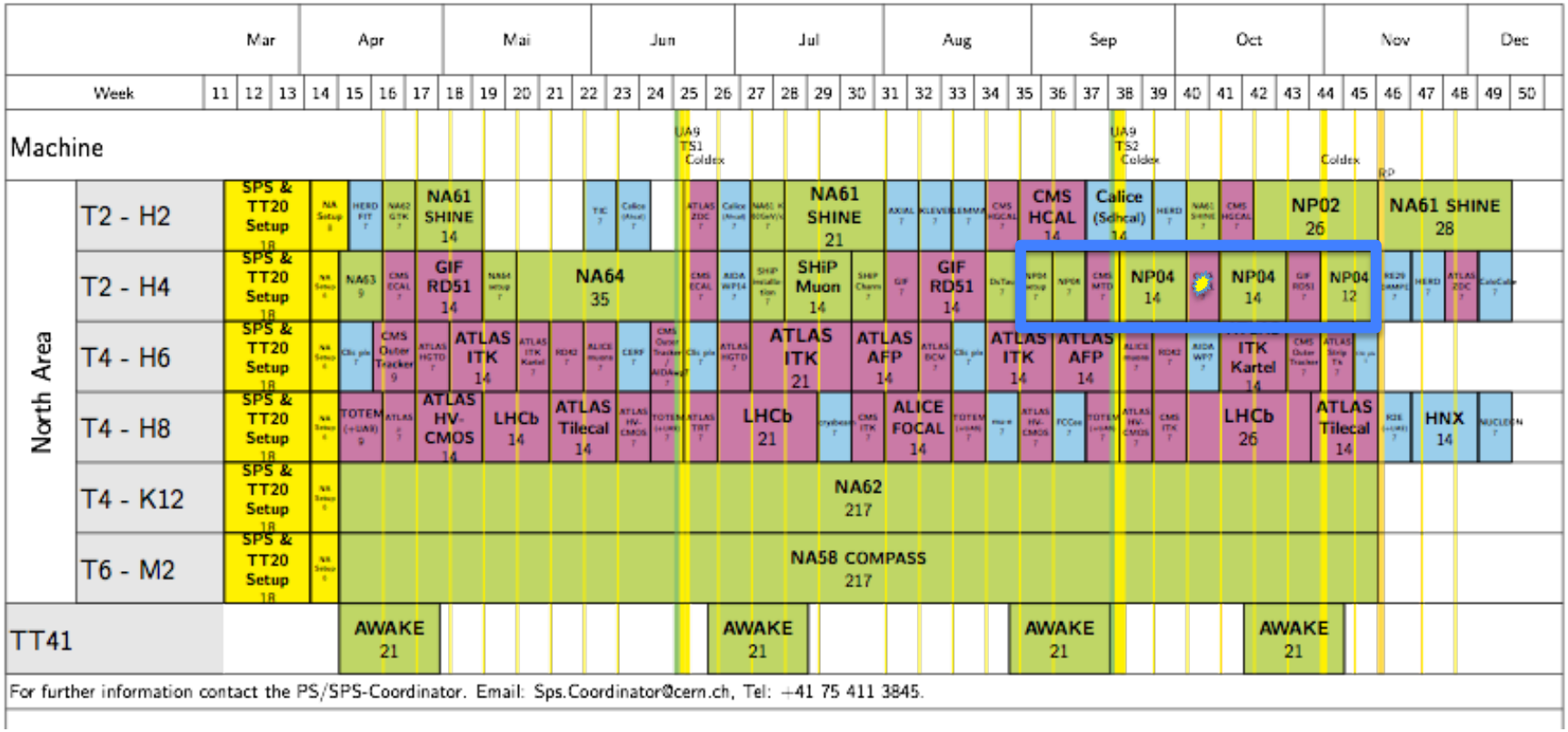
Bars in APA 4 – 6 plus Arapucas have Hamamatsu MPPCs



Beam operation started while we were still filling;
Beam was fully tuned by time we were ready for it.
Excellent support for beam operations through out the run.

SPS user schedule for 2018

schedule issue date: 26-Jan-2018 Version: 1.0 LHC Exp. PS/SPS Exp. Other Exp. INT Exp.

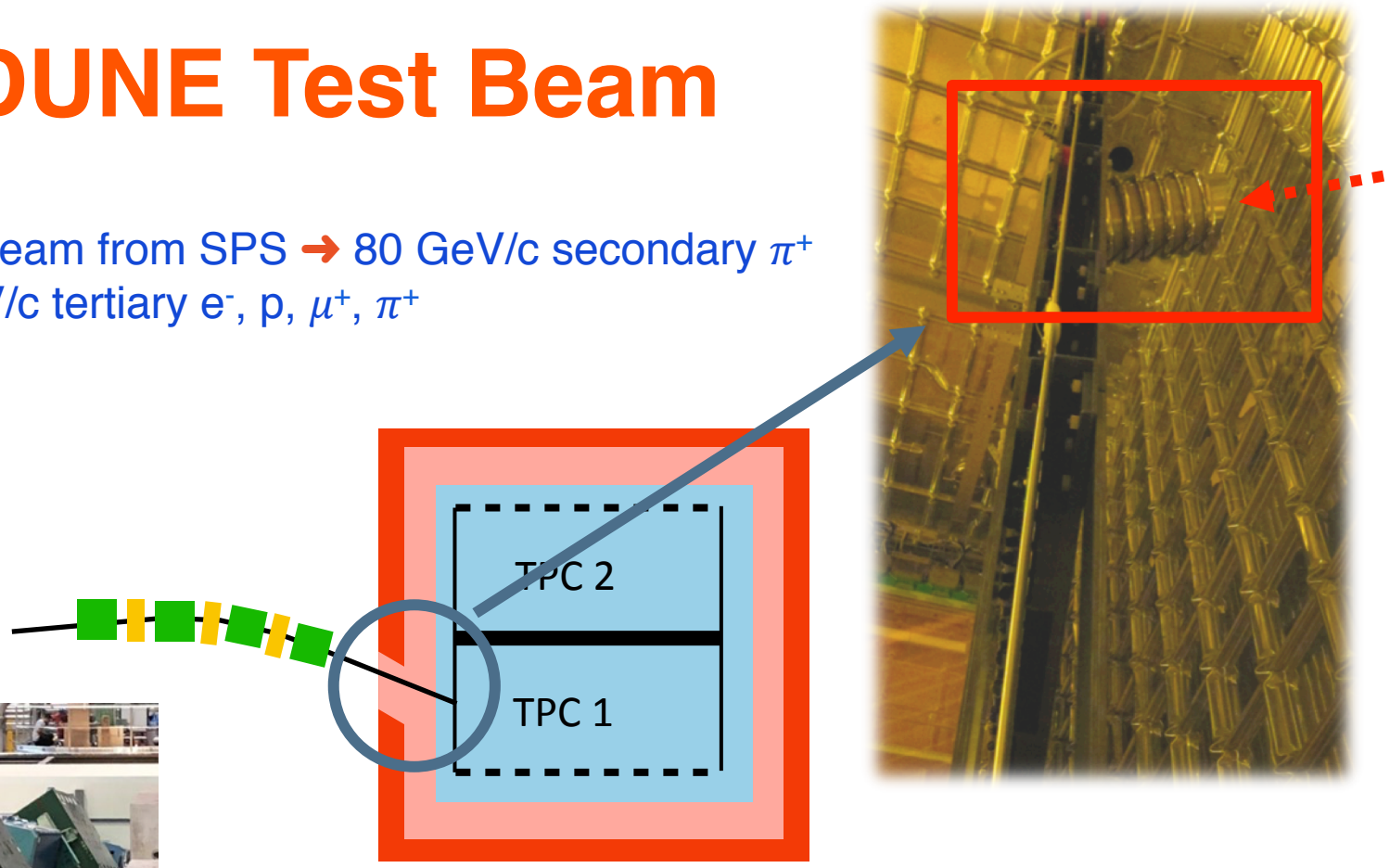


For further information contact the PS/SPS-Coordinator. Email: Sps.Coordinator@cern.ch, Tel: +41 75 411 3845.

ProtoDUNE Test Beam

Beamline

400 GeV/c p beam from SPS ➜ 80 GeV/c secondary π^+
➜ 0.5 – 7 GeV/c tertiary e^-, p, μ^+, π^+

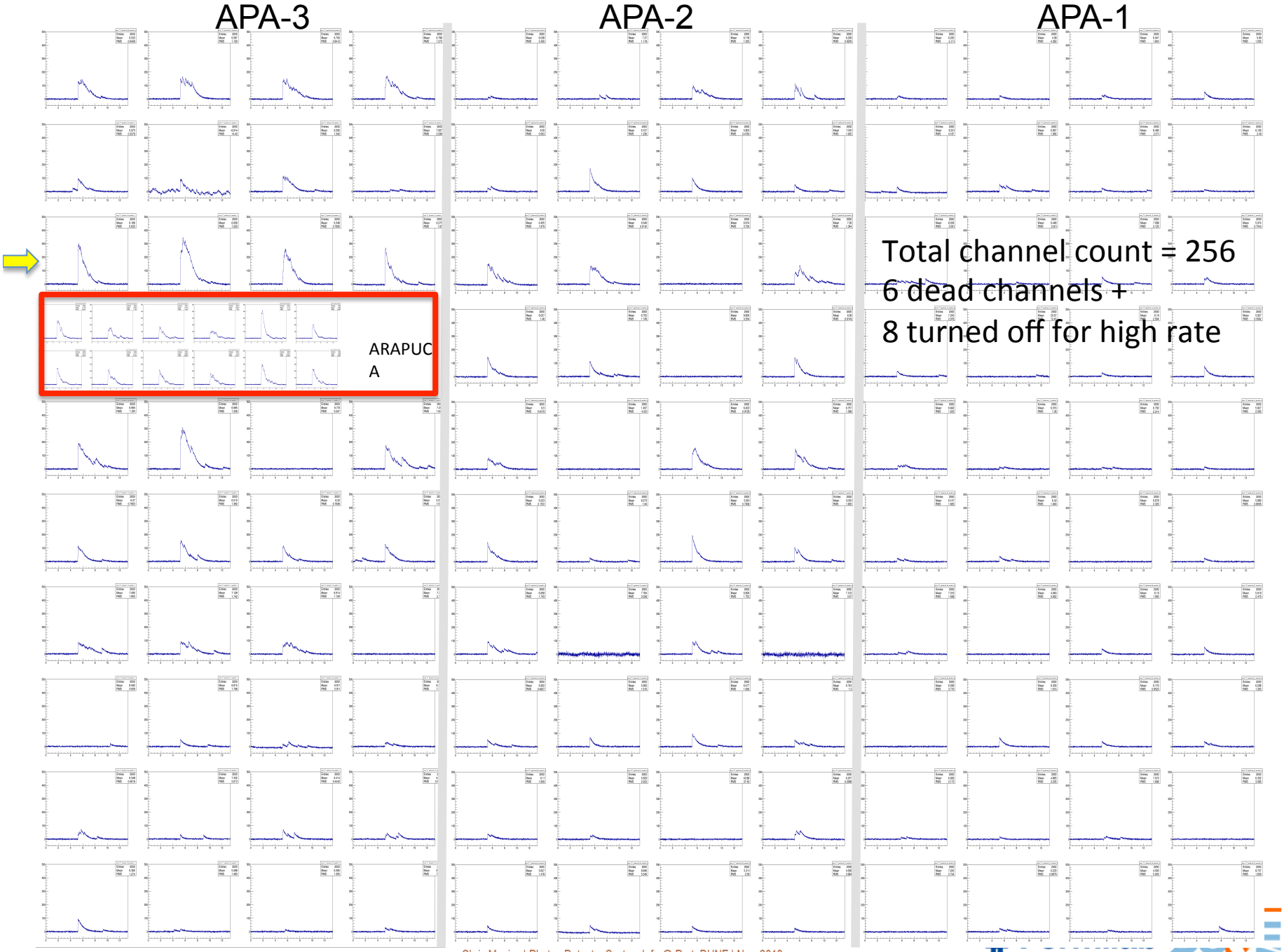


EHN1 extension, H4 beamline

Beam plug = END of beamline to get electron showers inside TPC, filled with N2

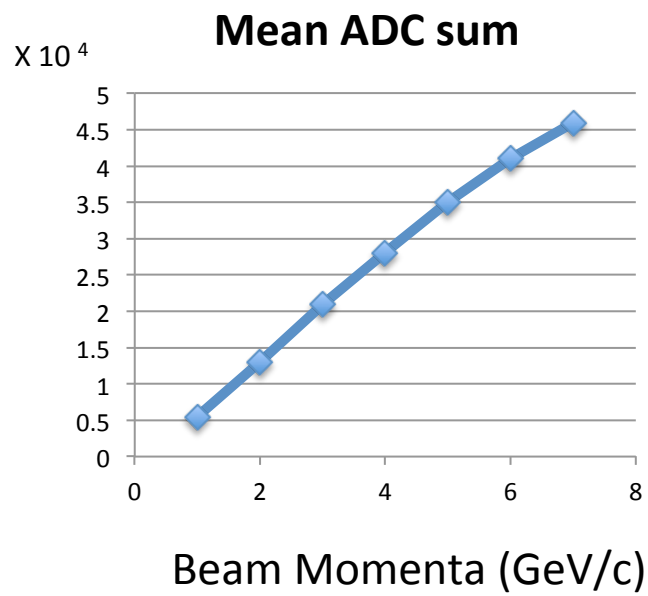
*PHYS. REV. ACCEL. BEAMS **20**, 111001 (2017)*

Run_5770_Event_777 – 6GeV

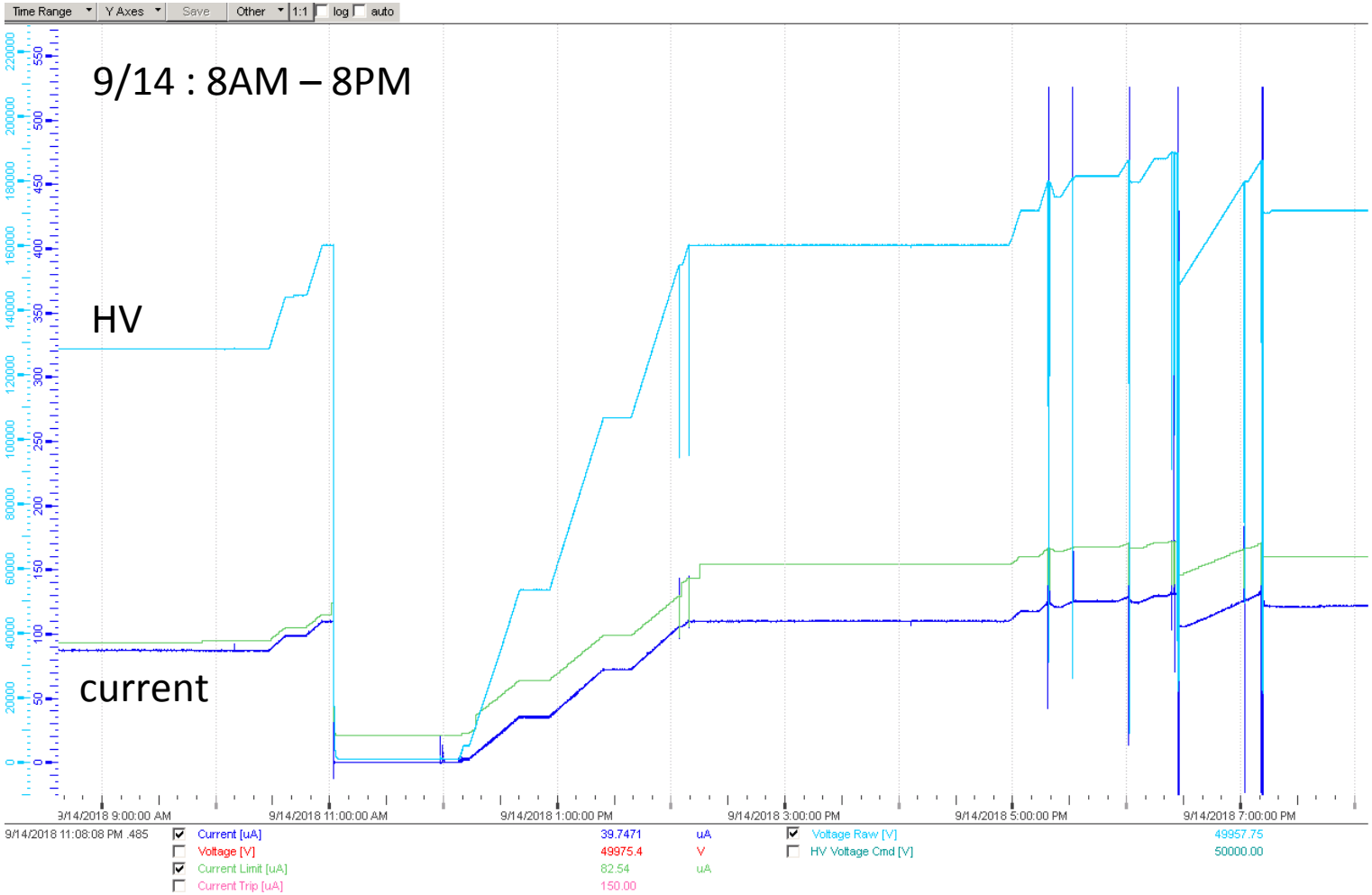


Beam Data

- Looked at Beam Energy Scan : 1 – 7 GeV
- See sensible response from the Photon Detectors on Beam Right :
  - Timing
  - Upstream to downstream; beam right to left, etc.
  - Used the Beam right Arapuca module to look at light collected

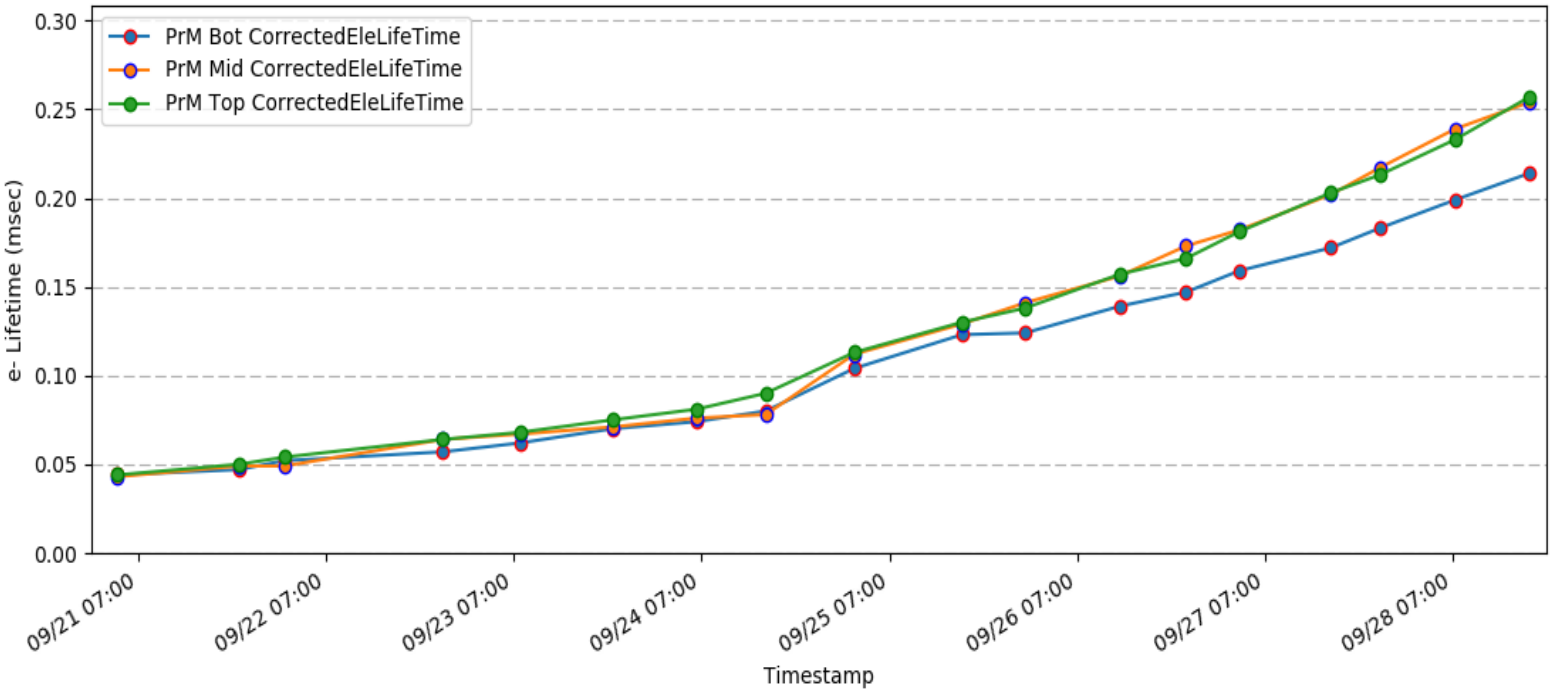


High Voltage Startup (September 13 – 20)

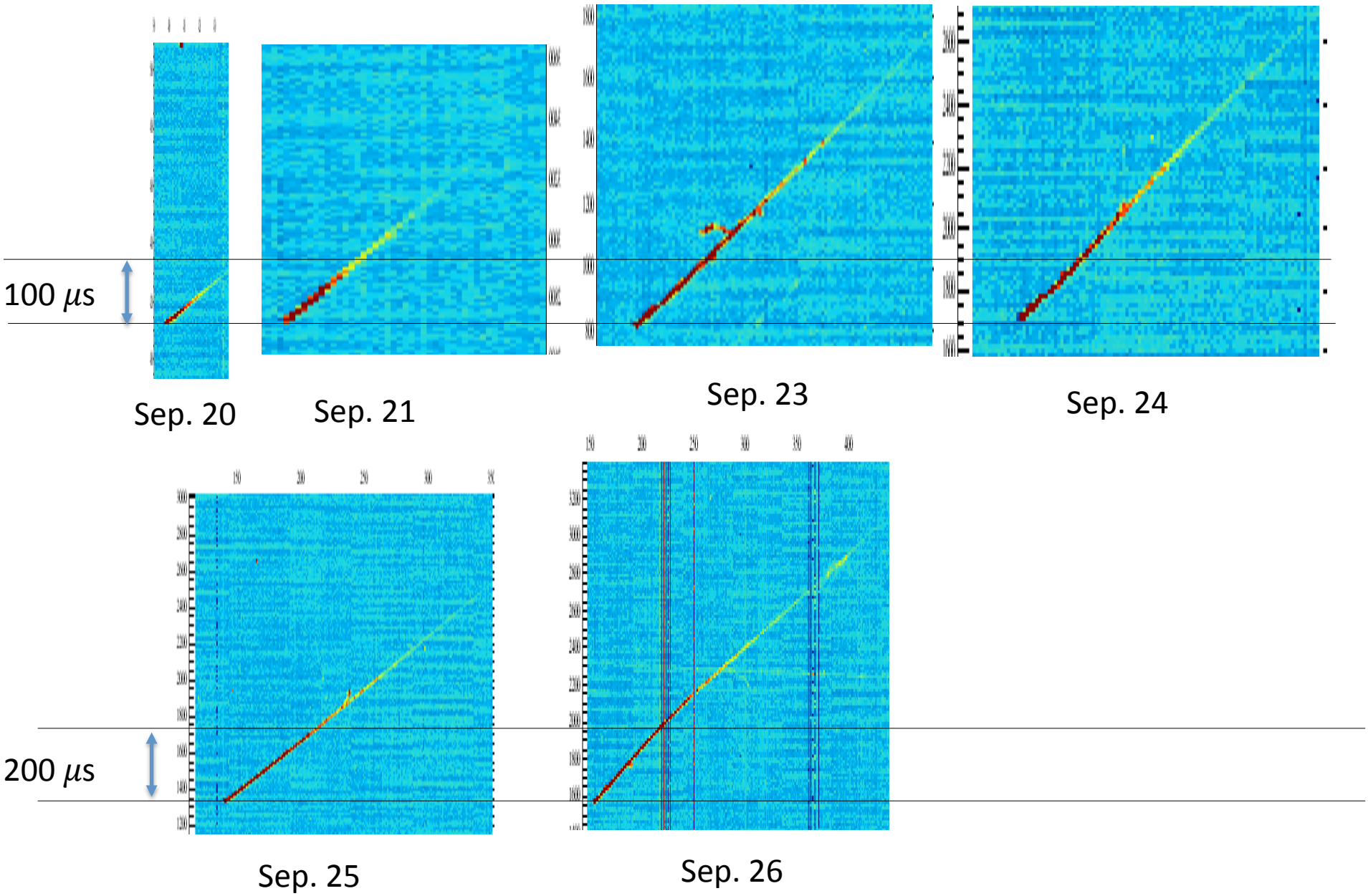


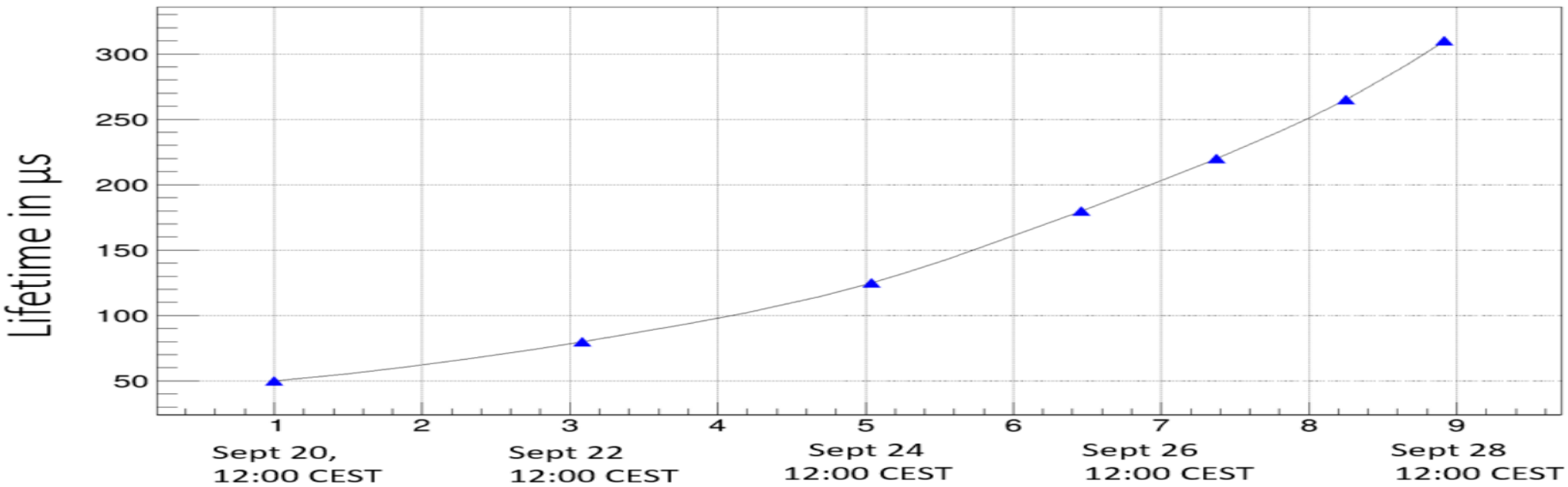
Some hardware challenges (Power supply, filters, cables…)/learning curve....

September 18 started LAr circulation pumps

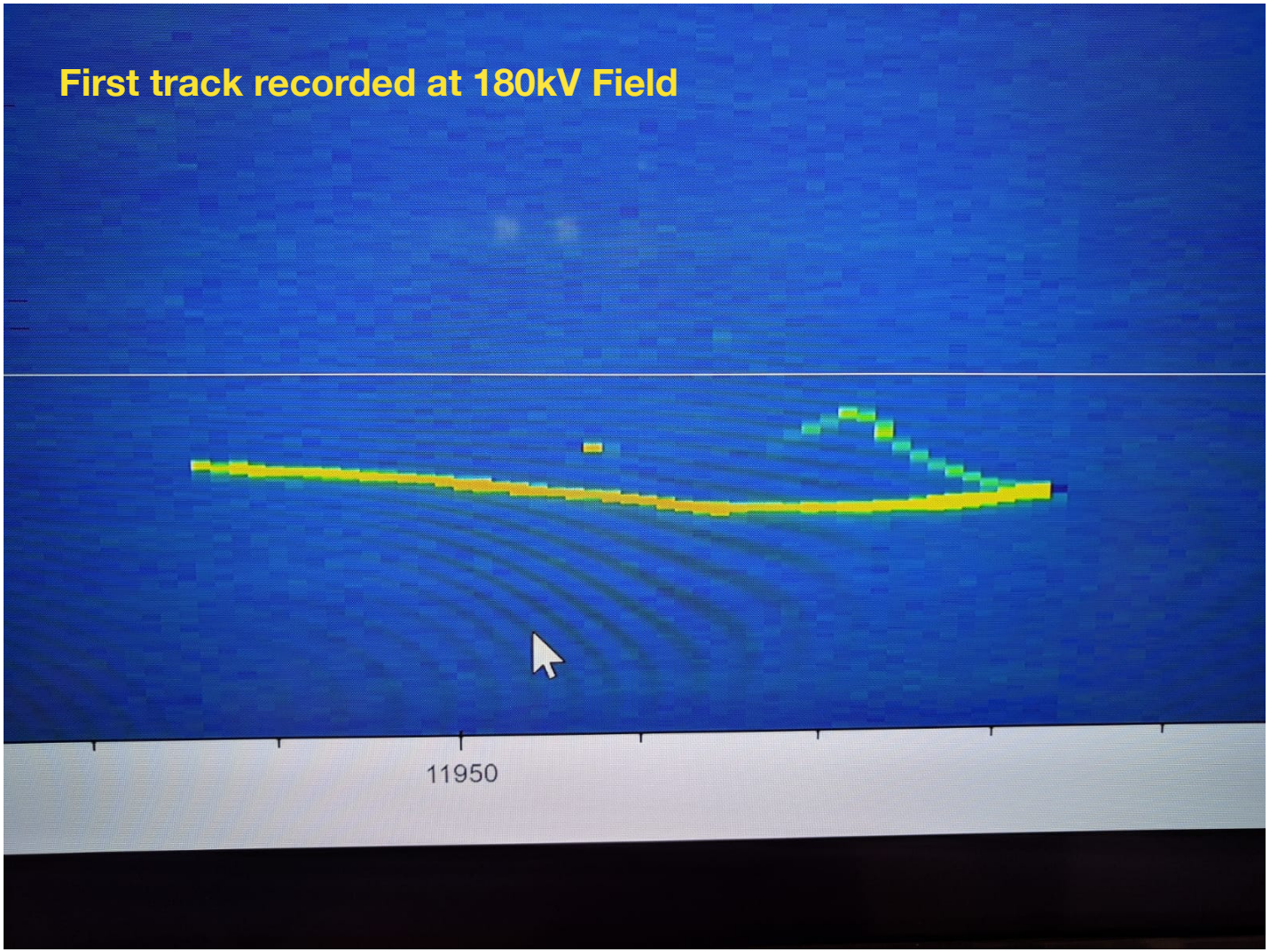


LAr purity from (3)PurMon


100 μs
Sep. 20
Sep. 21
Sep. 23
Sep. 24
200 μs
Sep. 25
Sep. 26

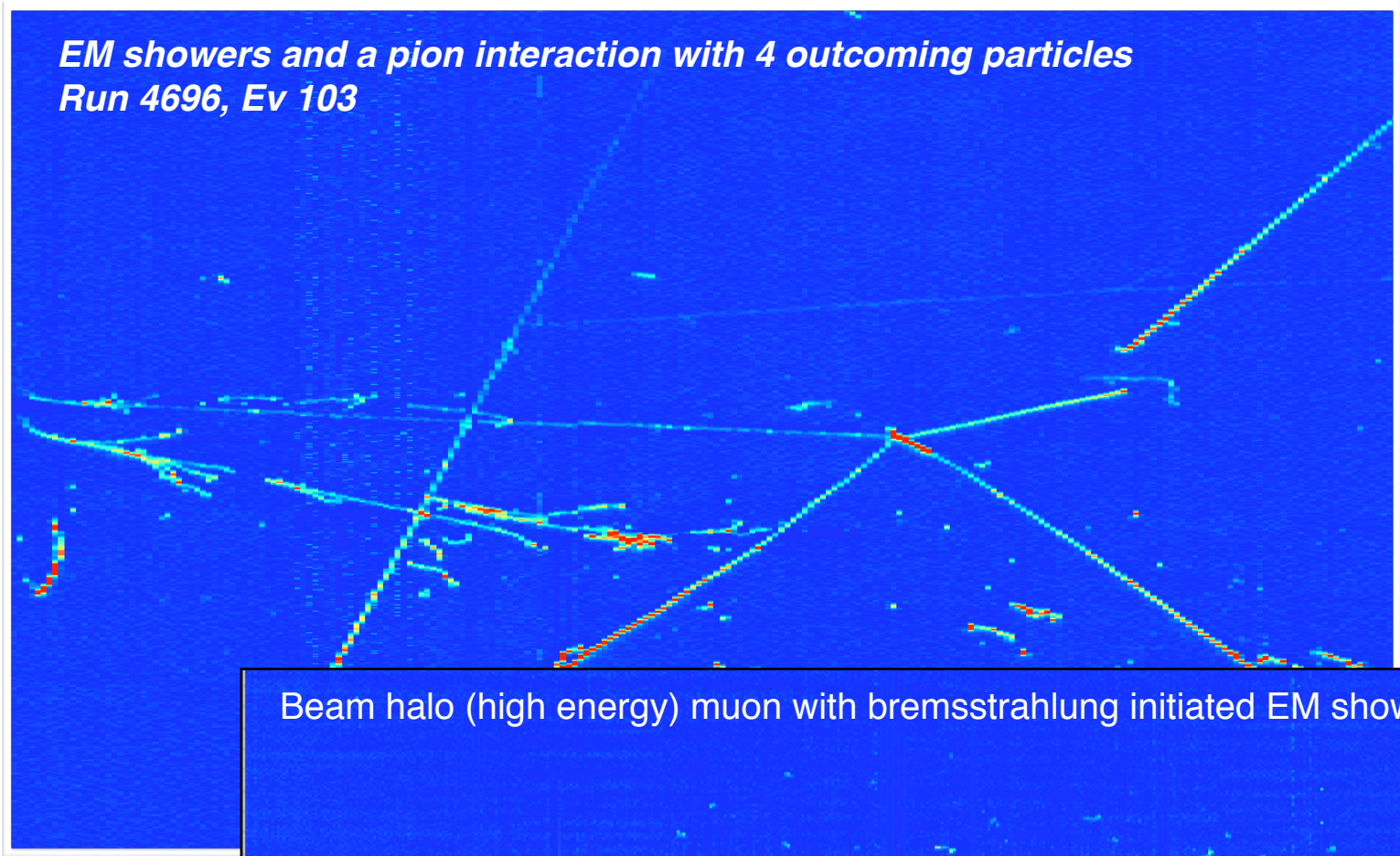


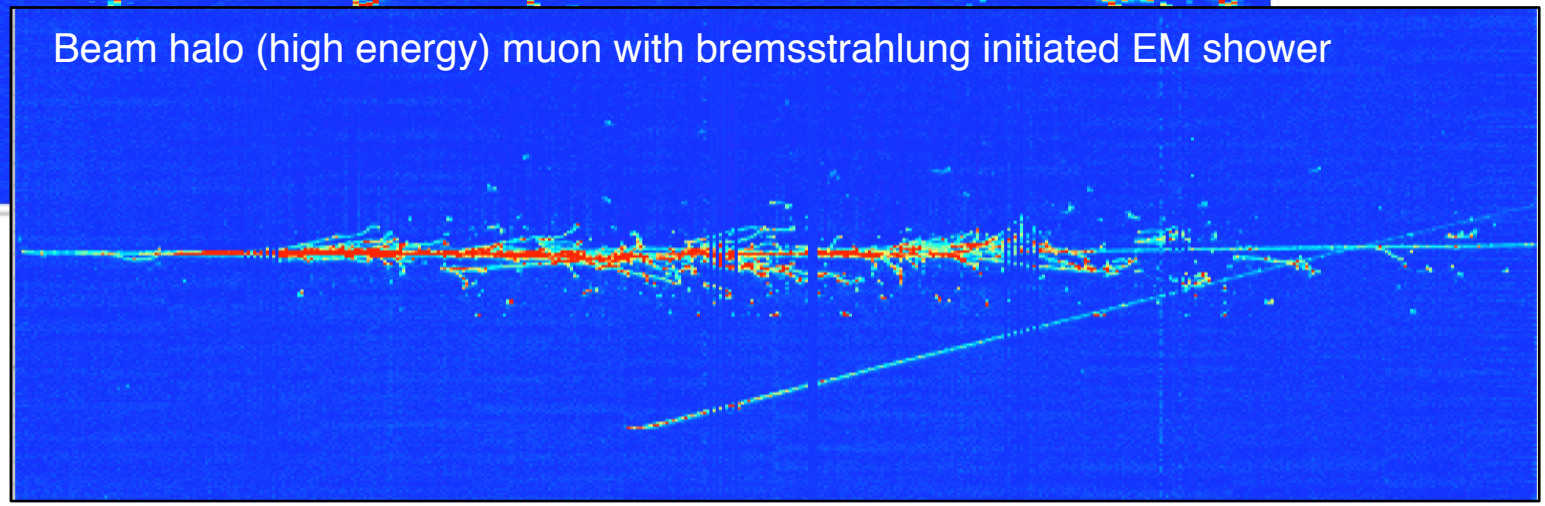
LAr purity from automatic TPC Tracks reconstruction



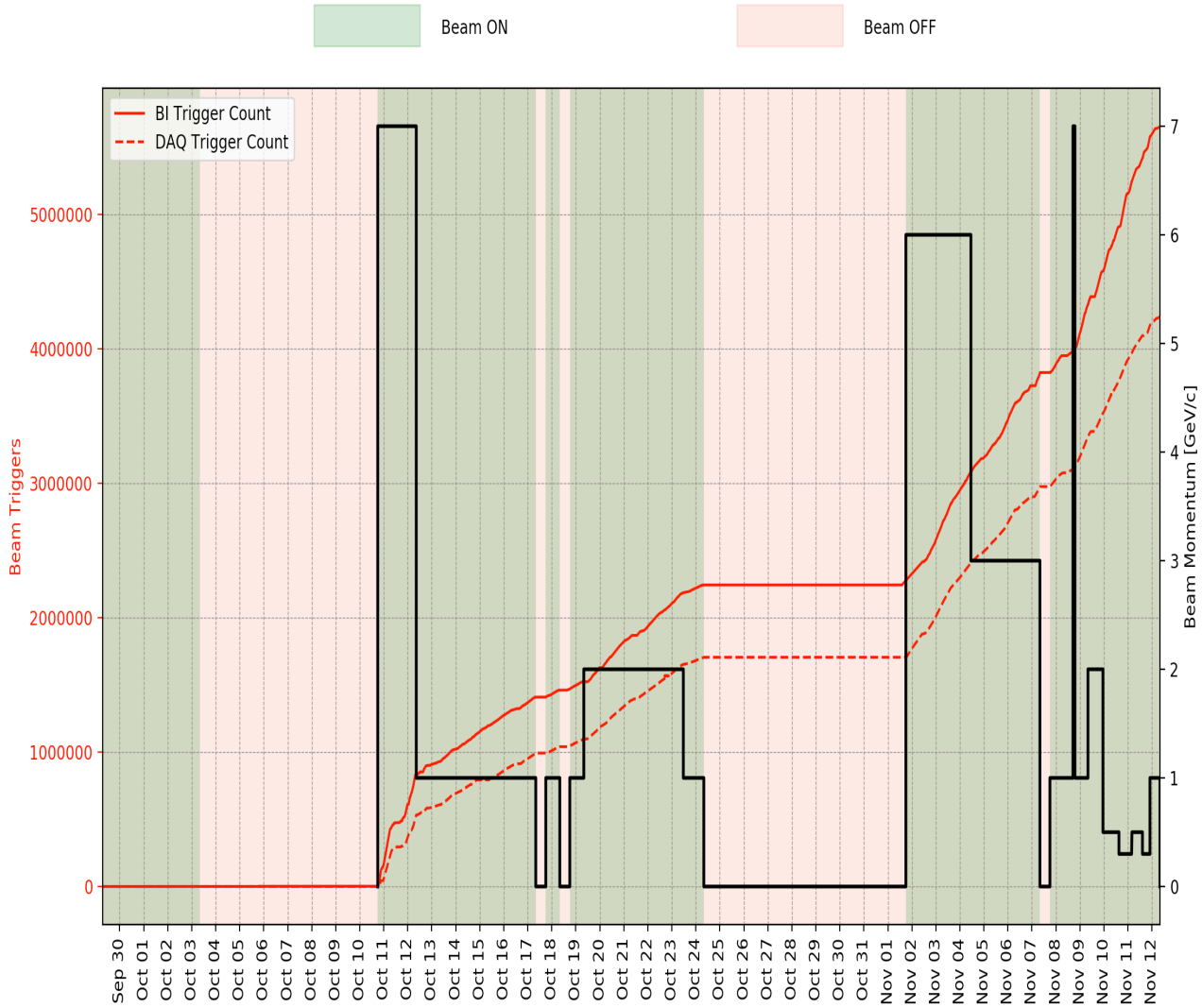
Field + purity = operational TPC

Some Events


EM showers and a pion interaction with 4 outcoming particles
Run 4696, Ev 103


Beam halo (high energy) muon with bremsstrahlung initiated EM shower

Beam Data with operational TPC



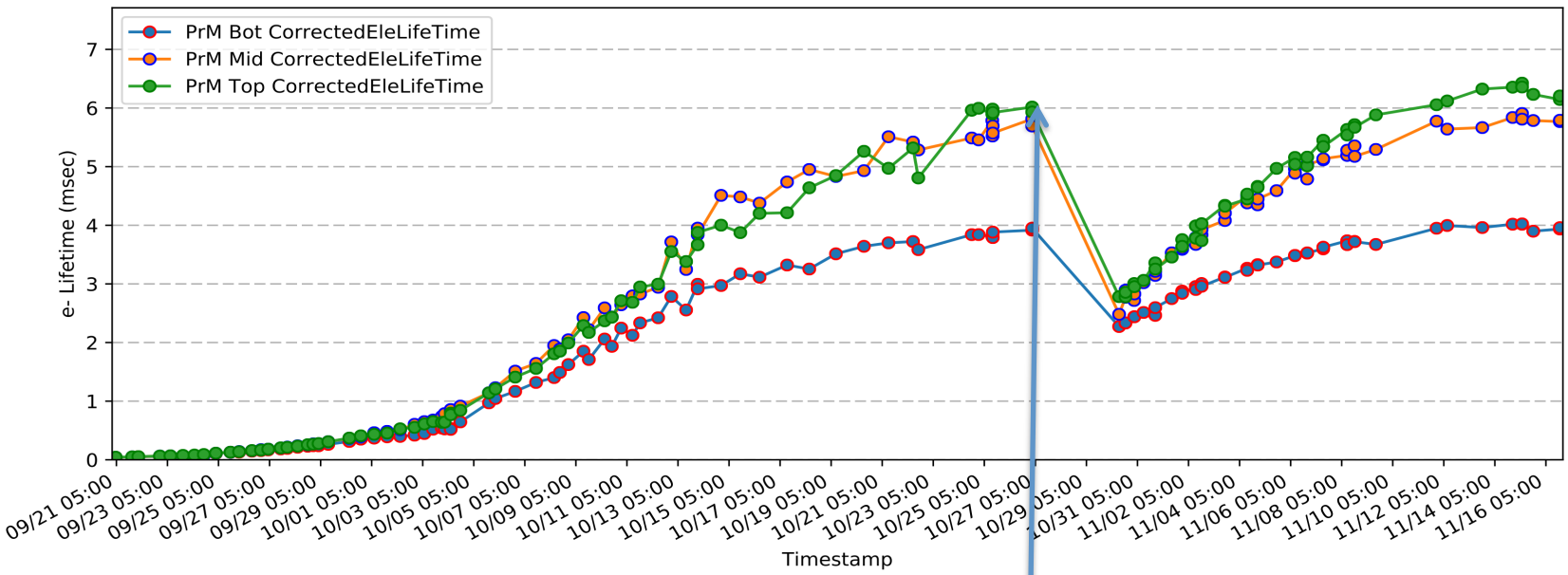
Beam Data Accumulation

Momentum (GeV/c)	Total Triggers Recorded (K)	Total Triggers Expected (K)	Expected Pi trig. (K)	Expected Proton Trig. (K)	Expected Electron Trig. (K)	Expected Kaon Trig. (K)
0.3	269	242	0	0	242	0
0.5	340	299	1.5	1.5	296	0
1	1089	1064	382	420	262	0
2	728	639	333	128	173	5
3	568	519	284	107	113	15
6	702	689	394	70	197	28
7	477	472	299	51	98	24
All momenta	4173	3924	1693.5	777.5	1381	72

Particle content is based on the expected rates from the Geant simulation of the beamline

Compiled by Roberto Acciarri

Purity monitors



Purity monitors undergoing some Development work right about here;

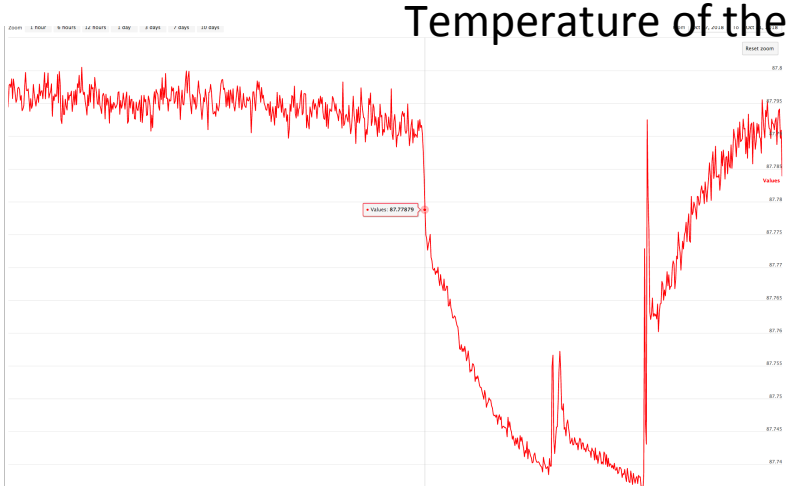
Beam (and hence HV) off, so no one looking in real time at the lifetime from cosmics

After the fact detective work by S. Pordes

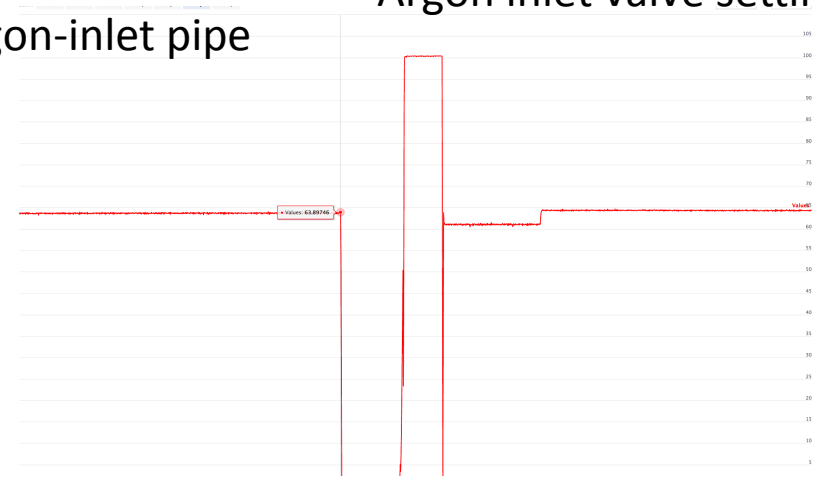
Argon circulation pumps went off…

There were indications in the cryo-instrumentation that something had happened, but was not picked up In real time by either active (human) or passive (automated) monitoring

Temperature of the argon-inlet pipe



Argon inlet valve setting



High Voltage

-2 classes of HV instability:

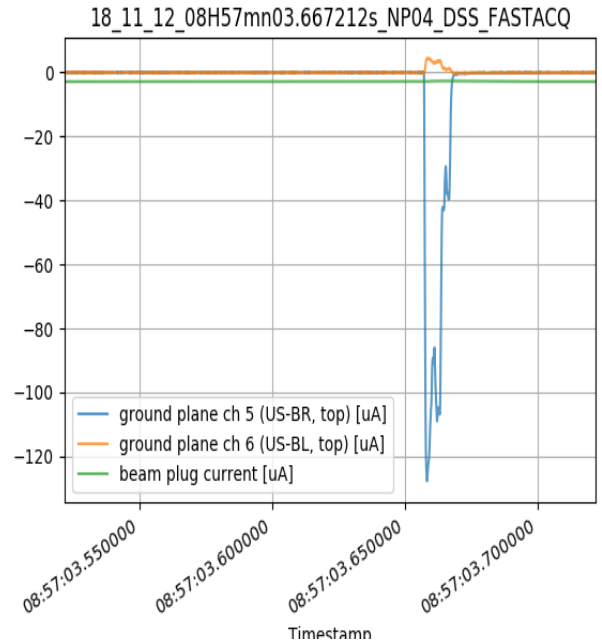
1) Fast discharges:

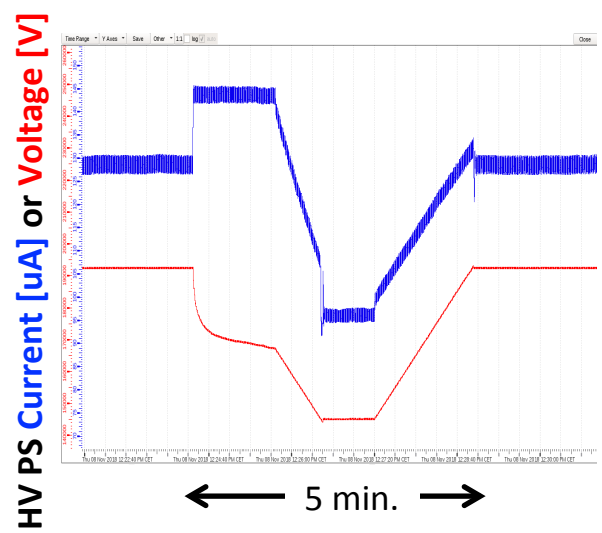
- O(10/day) recorded by the DCS fast acquisition
- All of them report a current signal on at least one ground plane
- Total charge from PS correspond to total charge on planes

2) Sustained excessive current streams:

- Few per day (rate builds up over time)
- Typically current limiting
- Only a fraction of the PS current visible on US-BL-Top ground plane & beam plug

-NOTE: The BL-US end wall's termination point was not properly connected during installation. Therefore, we are unable to tune the voltage here. It sits at it's 'natural' ~ -1kV instead of -1.665kV.



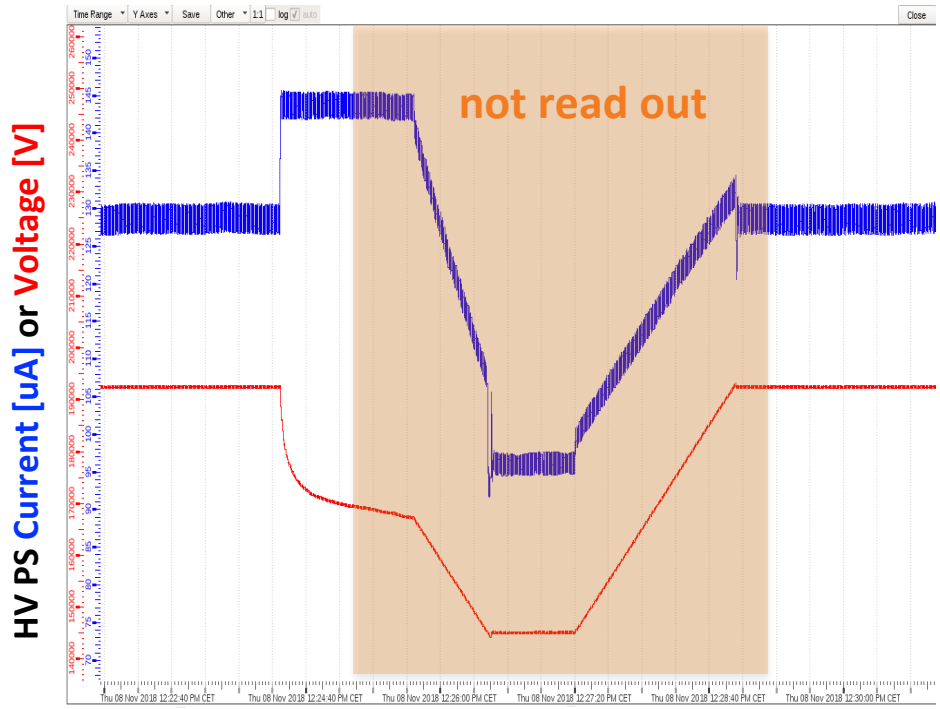


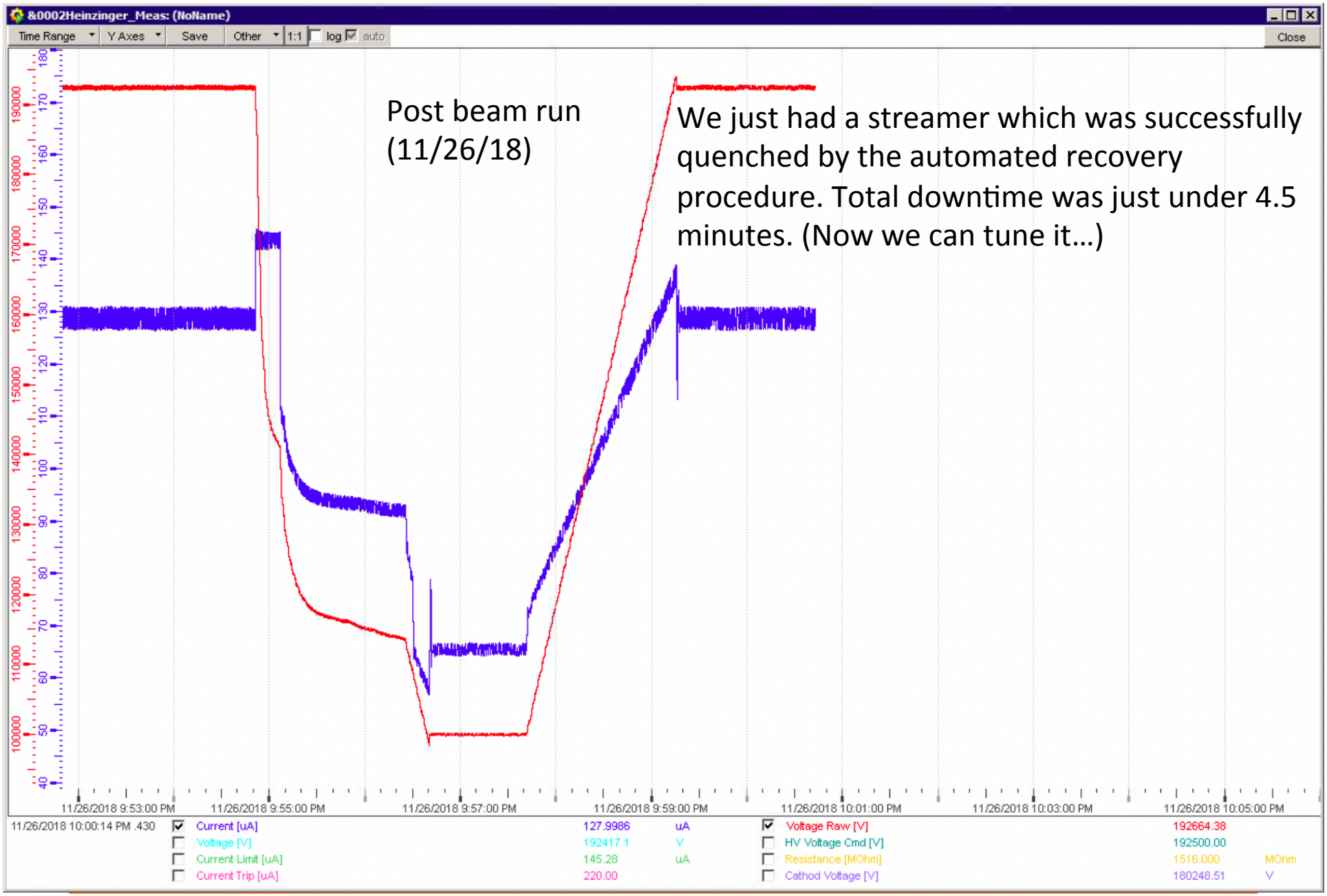
High Voltage

On October 17, we changed to a replacement high voltage power supply
We also changed our philosophy for dealing with “streamers” at this time

- Before: continue running when streamers open up, operate at lower voltages to try and mitigate
- After: inhibit triggers, lower the voltage until current draw returns to nominal, raise voltage to nominal, allow triggers

- Typically takes ~10 minutes when a human needs to perform the recovery procedure
  - At its worst, streamers open up once every 4 hours or so
  - Conservatively, >95% uptime achievable
- An automated recovery mode is being implemented into the PS controls soon
  - Should increase uptime




&0002Heinzinger_Meas: (NoName)
Time Range
Y Axes
Save
Other
1:1
log
auto
Close
Post beam run
(11/26/18)
We just had a streamer which was successfully quenched by the automated recovery procedure. Total downtime was just under 4.5 minutes. (Now we can tune it…)
11/26/2018 9:53:00 PM
11/26/2018 9:55:00 PM
11/26/2018 9:57:00 PM
11/26/2018 9:59:00 PM
11/26/2018 10:01:00 PM
11/26/2018 10:03:00 PM
11/26/2018 10:05:00 PM
11/26/2018 10:00:14 PM .430
Current [uA] 127.9986 uA
Voltage [V] 192417.1 V
Current Limit [uA] 145.28 uA
Current Trip [uA] 220.00
Voltage Raw [V] 192664.38
HV Voltage Cmd [V] 192500.00
Resistance [MOhm] 1516.000 MOhm
Cathod Voltage [V] 180248.51 V

Operations Phase Observations

Considering the severe schedule pressure, the run went very smoothly!

Credit goes to the on-site team lead by Roberto and Fillipo.

Excellent support from CERN for Beam and Cryo.

The team of on-site experts (DAQ, CE, HV, TPC, PDS, Slow controls, Beam,..) were excellent and always available.

The shifters were dependable and learned quickly.

Control room tools reflect the generation of scientists doing most of the work (SLACK channels used more than e-log…)

Developed an efficient way to deal with the “features” of the drift HV so as to minimize the affect on data taking.

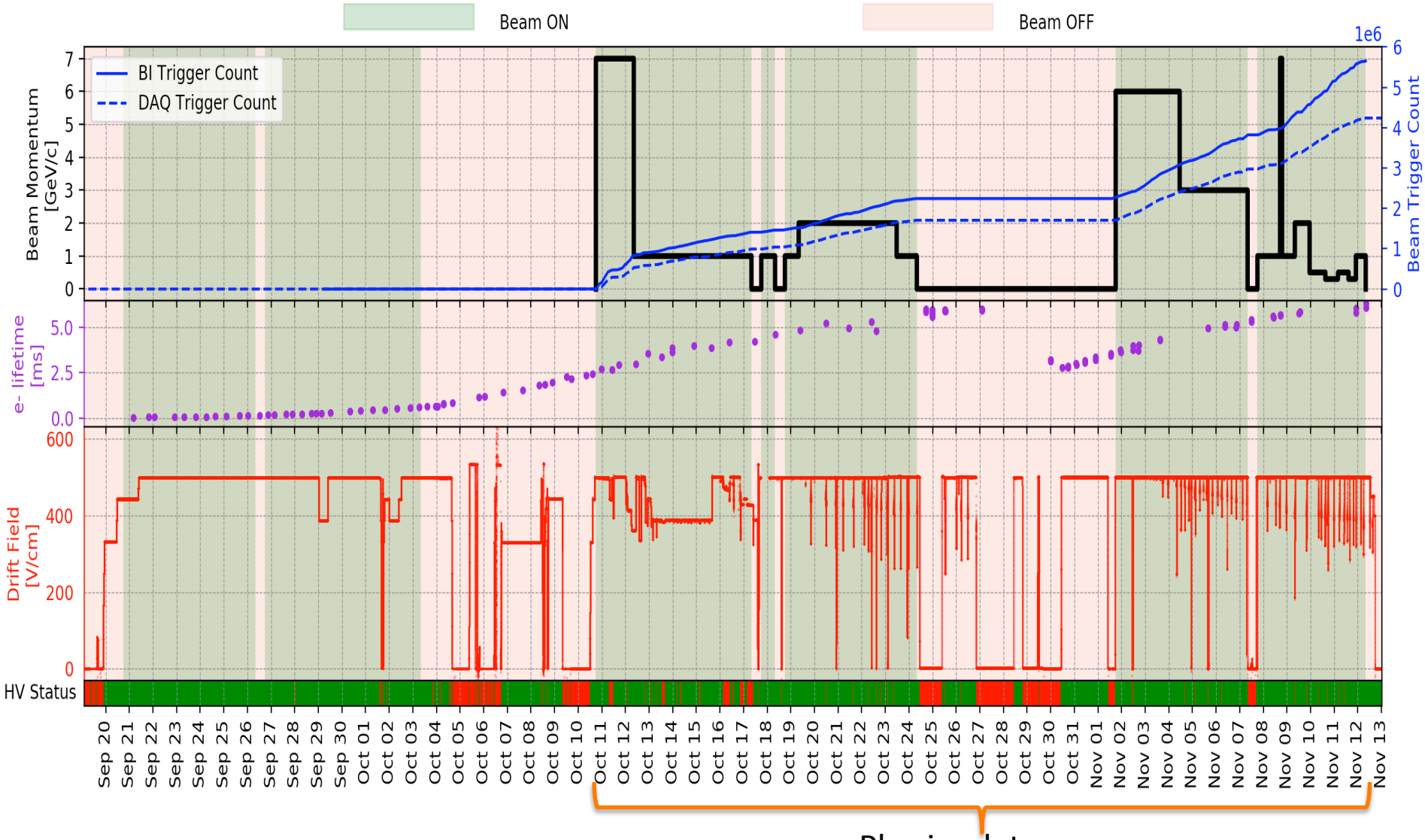
DQM team (on and off-site) worked round the clock to keep results current.

Data processing at both FNAL and CERN made for fast turnaround

Note the DAQ lessons learned posted for this meeting

For DUNE : On-line monitoring and controls (alarms and limits) need top priority;
Did not have the time to develop these properly for PD-SP

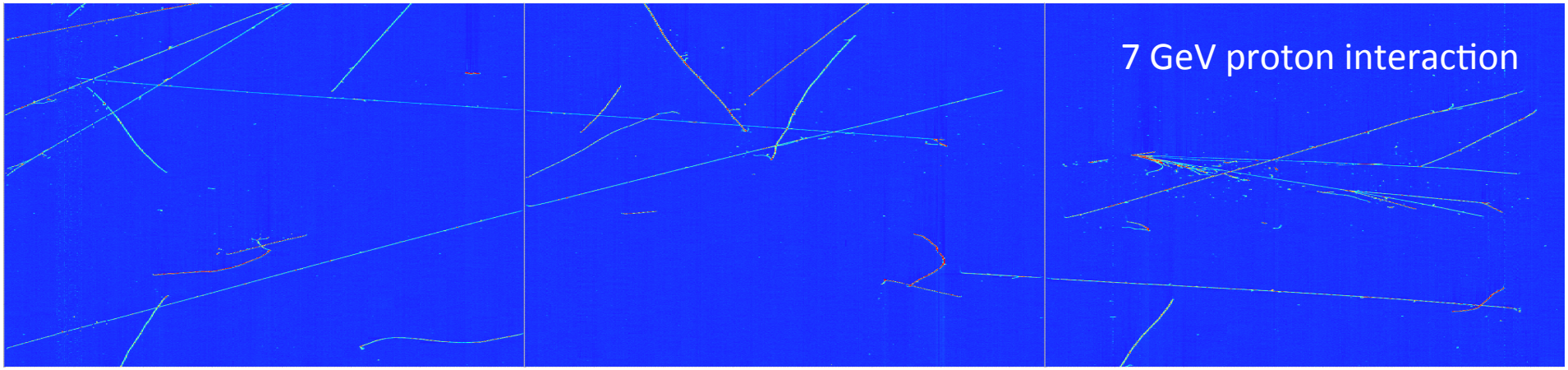
One Page Run Summary



Compiled by Kevin Wood

We have lots of data!
The good, the bad and the ugly…

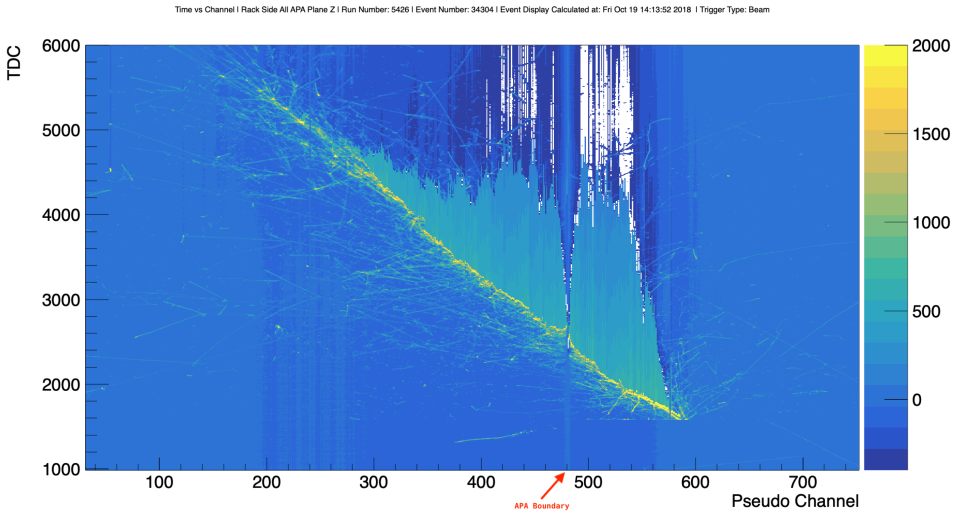
99.7% of 15,360 channels working

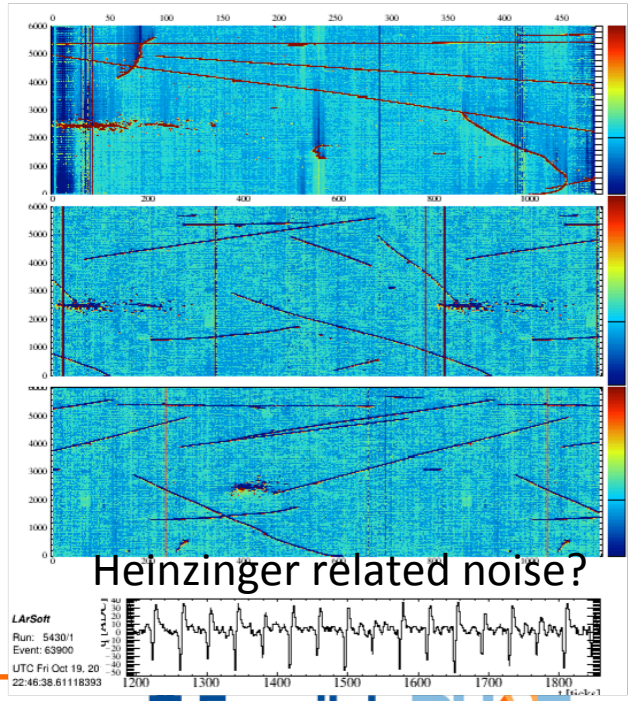


Effect on Showers

Noticed by Aidan Reynolds and James Pillow

"flatlands" saturation.





The ProtoDUNE SP DRA Organization

Tingjun Yang presentation to LBNC physics group

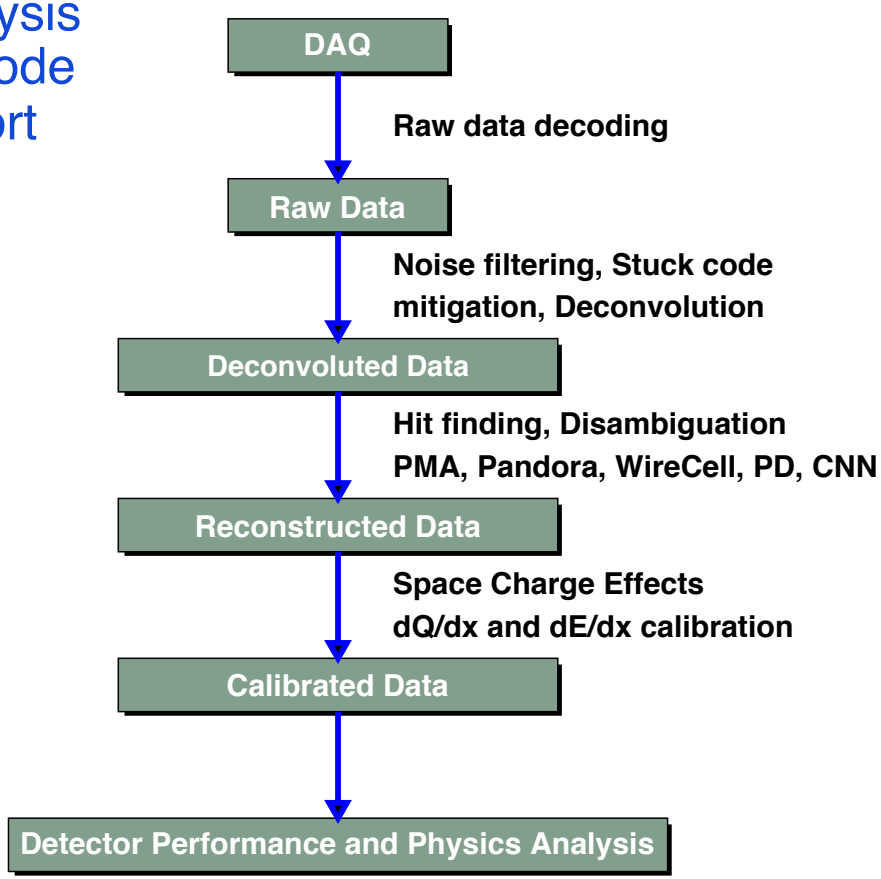
DRA – Detector Reconstruction and Analysis
DRA Level 1 – overall responsibility on code development and organizing analysis effort

- T. Yang (FNAL)
- G. Christodoulou (CERN)

DRA Level 2

- Reconstruction – L. Whitehead (CERN)
- DQM – M. Potekhin (BNL)
- Calibration – M. Mooney (CSU)
- Analysis – S. Bordoni (CERN)

Weekly meeting on Wednesday 9:30 am Fermilab time, 4:30 pm CERN time
Mailing list: dune-proto-sp-dra@fnal.gov



https://web.fnal.gov/collaboration/DUNE/SitePages/ProtoDUNEs%20simulation%20and%20reconstruction%20activities.aspx

ProtoDUNE Analysis Goals

Short-term goals – detector performance

- Dead channels, noisy channels
- Noise level, signal to noise ratio
- Electron lifetime

Medium-term goals – detector response

- dE/dx of pions, protons, kaons, electrons
- Energy and momentum resolutions

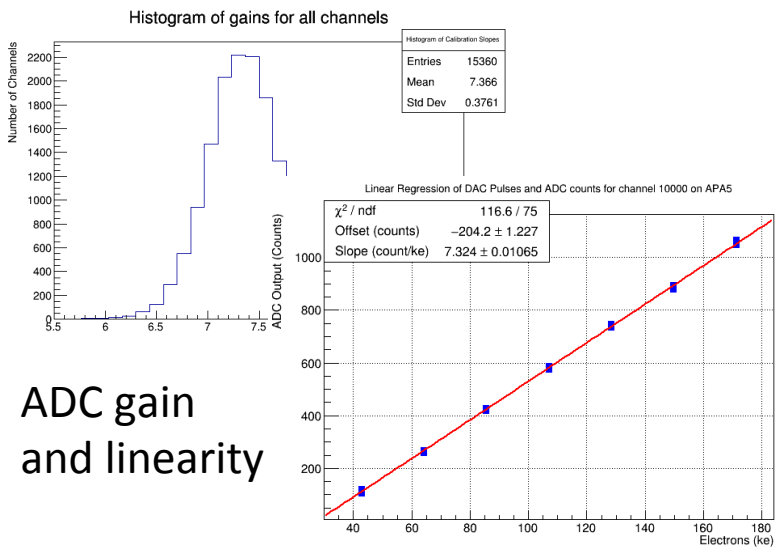
Long-term goals – cross sections

- Inclusive pion cross section
- Exclusive channels – charge exchange, etc.

Information for DUNE physics TDR

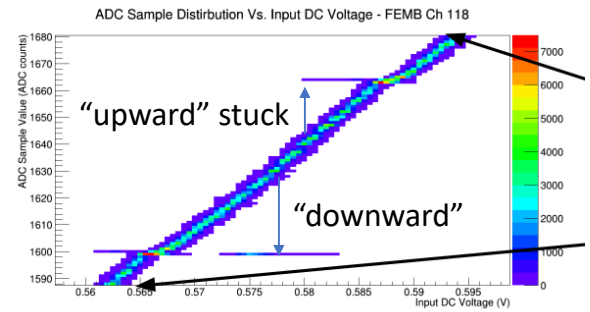
Physics publications

Weekly progress reported at DRA meeting



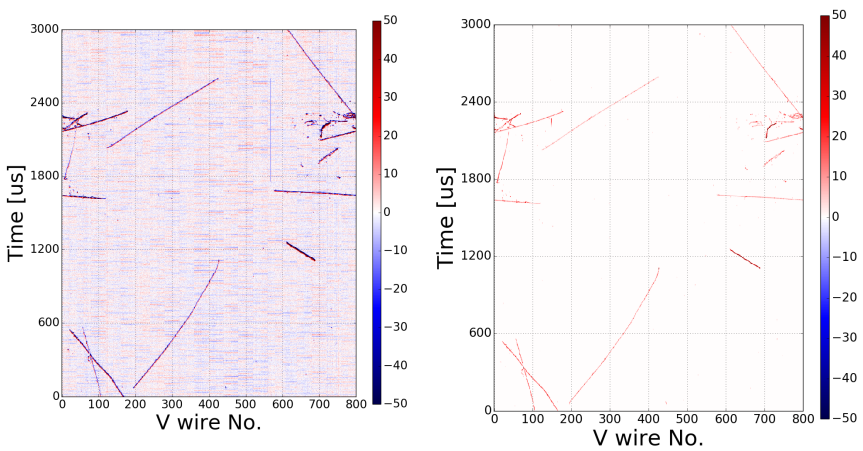
ADC gain
and linearity

Digital Out



Sticky codes **Analog In**

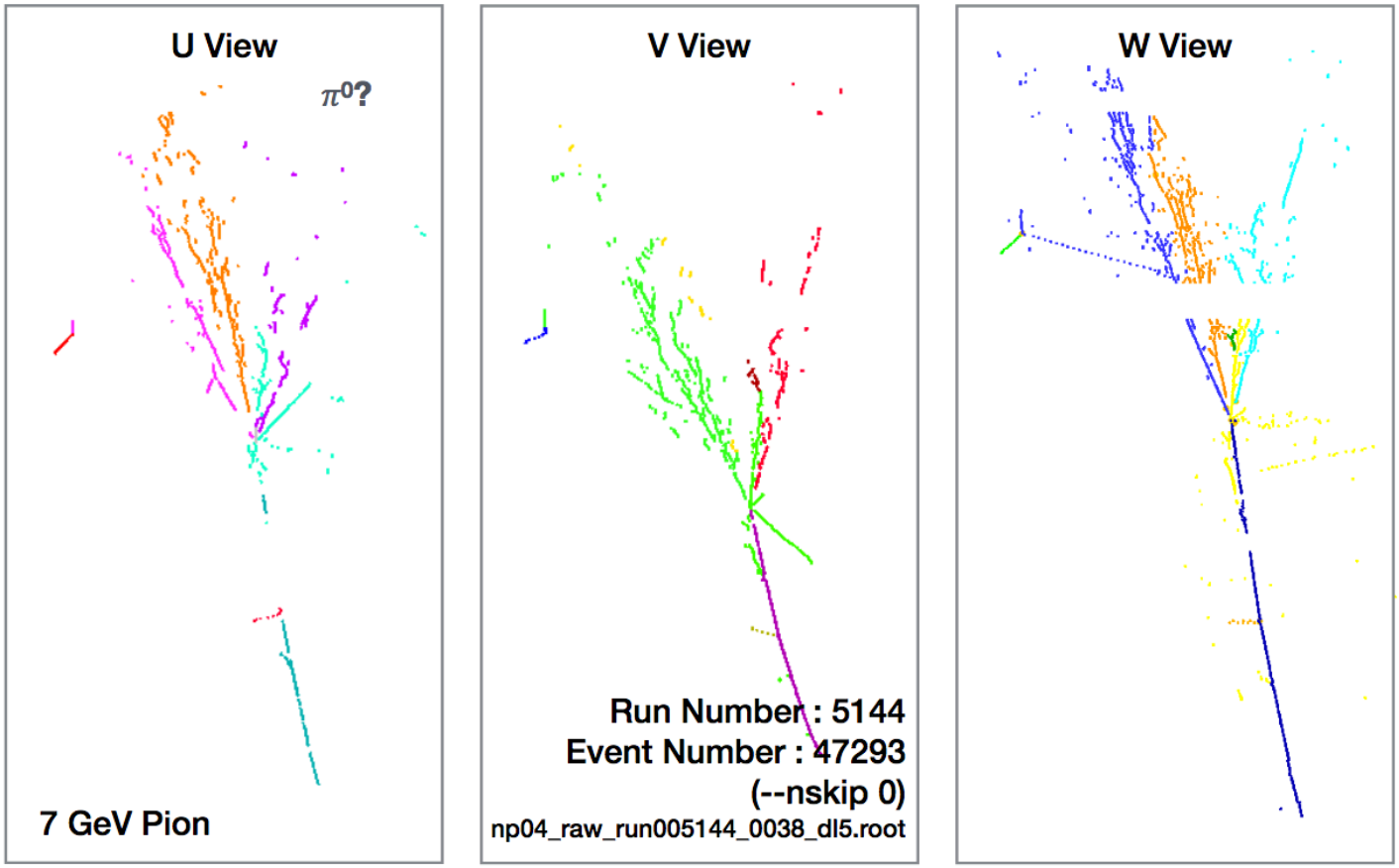
Signal processing



On-going studies :

- dQ/dx, dE/dx
- Pandora reconstruction
- Track stiching across CPA and APA
- Sticky code mitigation
- Signal to noise ratio
- Beam particle id
- Saturation and ledge effects
- Signal processing
- .....

Pandora Reconstruction



Pandora pattern recognition algorithms are being optimized for data. Preliminary results look good.

PD-SP 2019

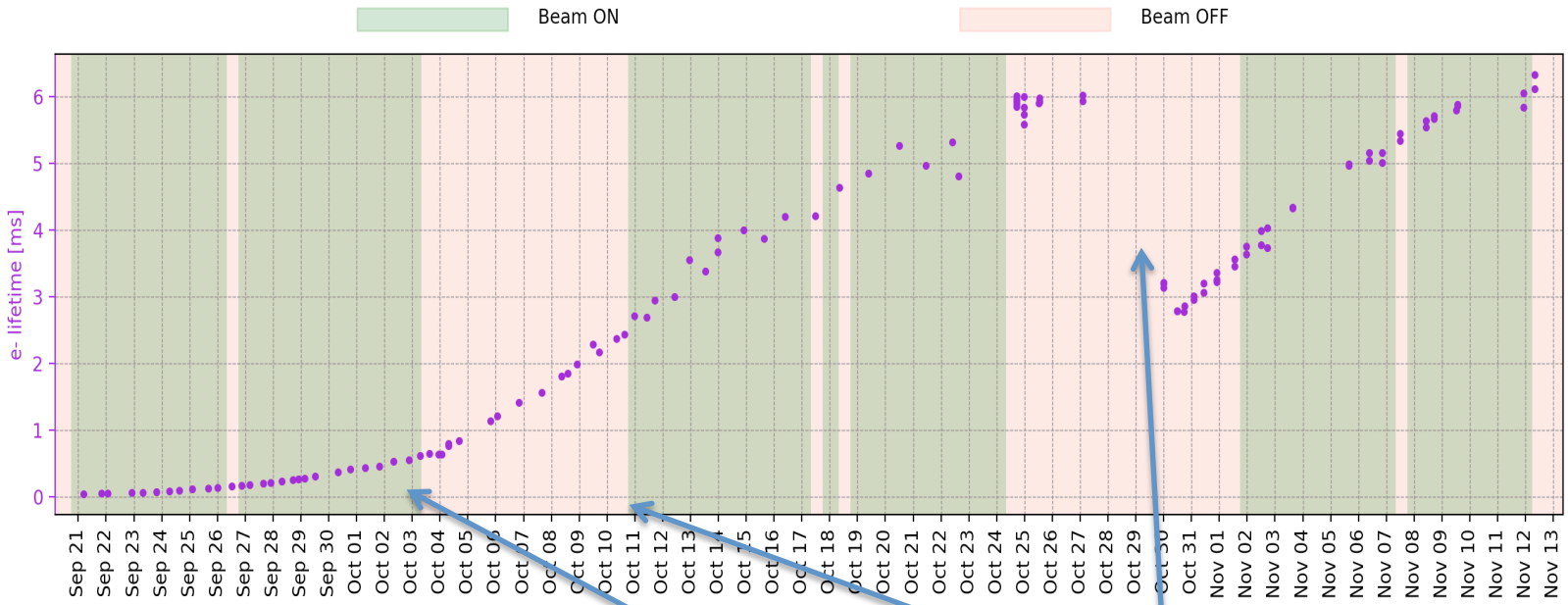
- Organization being formulated : on on-site team + Consortia based teams
- Procedure for requesting directed studies being developed [Development in progress]
  - Several meetings to discuss specific tasks plus procedures have taken place
- Task force(s) for High Voltage and Purity
  - Longer term studies to address questions of HV “features”, monitoring, control
  - Studies to address purity plateau, purity measurements (monitors and tracks), affects of space charge

Conclusions

- The **complete PD-SP detector** was installed and operated, including **test beam exposure** with data taken at 0.3, 0.5, 1, 2, 3, 6 and 7 GeV/c beam momentum.
- **Electron lifetime** is > 6 ms.
- The majority of data was recorded with Drift High Voltage, operating in a current limiting mode, at the **goal voltage of 180kV.**
- DAQ operated reliably at typical triggered **data rates of 10 – 20 hz.**
- Electronics noise levels are at a level of **500 – 600 enc**, within design goals.
- Cosmic and beam events have been **reconstructed**.
- Plans for operation in 2019 are under development.

Backup slides

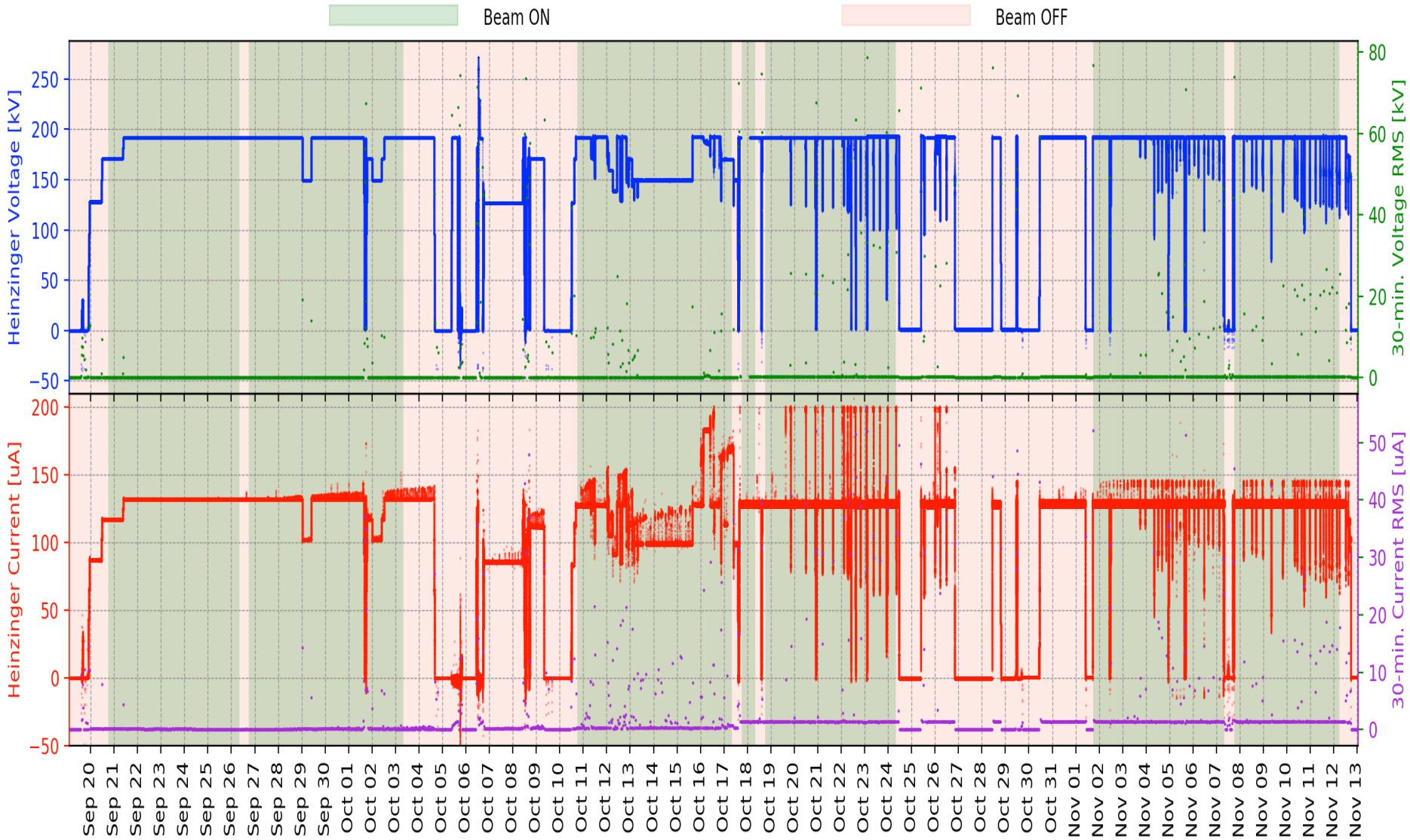
Purity



Started to see the beam faintly on Oct. 3. The beam run started in earnest on Oct 11, around the time we achieved 3ms argon

Recirculation pumps turned off for ~22 hours on October 29th at 13:30 due to a drastic change in atmospheric pressure that affected the controls in an unforeseen way

- Purity monitor software also went offline for a few days around this time


Beam ON
Beam OFF
Heinzinger Voltage [kV]
30-min. Voltage RMS [kV]
Heinzinger Current [uA]
30-min. Current RMS [uA]
Sep 20
Sep 21
Sep 22
Sep 23
Sep 24
Sep 25
Sep 26
Sep 27
Sep 28
Sep 29
Sep 30
Oct 01
Oct 02
Oct 03
Oct 04
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Nov 01
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Nov 03
Nov 04
Nov 05
Nov 06
Nov 07
Nov 08
Nov 09
Nov 10
Nov 11
Nov 12
Nov 13

Performance : TPC Electronics

1) front-end saturation
2) font-end ledge effect (different from saturation)
3) AC-coupling -> undershoot on the pedestal
4) sticky codes out of the ADCs
5) FEMB 302's loss of timing signals and mitigation
6) FEMB 110's ASIC with delayed signals

dead, disconnected, noisy, and otherwise problematic channels

Some noises we've seen:
1) HV-related on beam-left APA's
2) very low-frequency noise in the induction planes

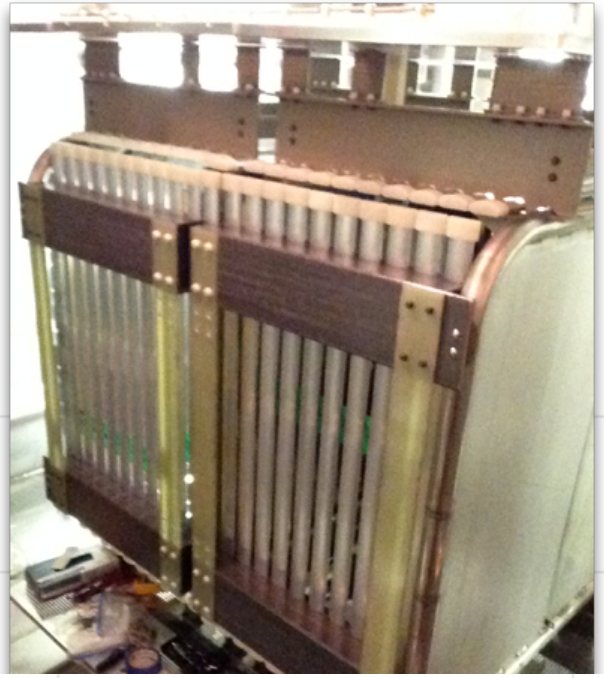
And distortions seen in the data:

electron diverters grounded via a resistance instead of energized
space charge
field cage nonuniformities

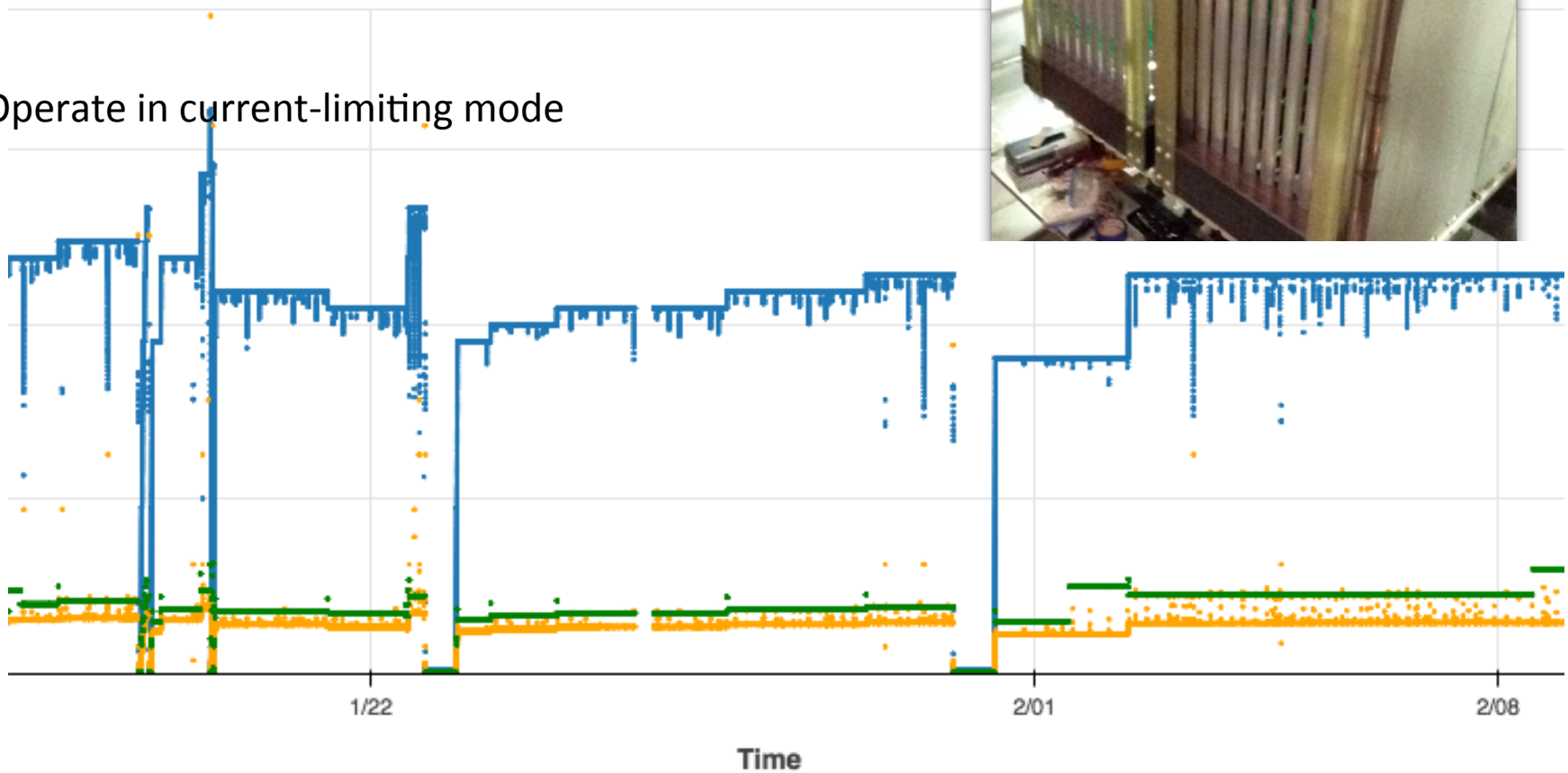
Tentative Plan - to be revised	**Hadron Beam** *Cu Target*		
Beam Setting (Mom, Sign)	**Accumul. Stat. (goal)**	**Trig. Rate/Beam Rate**	**Beam Time**
2 GeV/c - Positive	750 k [500 k π]	25 Hz / 38 Hz	**1 week**
3 GeV/c - Positive	750 k [500 k π]	25 Hz / 56 Hz	
no beam	-	-	1 week
1 GeV/c - Positive	1 M [500 k π]	25 Hz / 27 Hz	**2 week**
no beam	-	-	1 week
4 GeV/c - Positive	600 k [500 k π]	25 Hz / 196 Hz	
5 GeV/c - Positive	600 k [500 k π]	25 Hz / 200 Hz	**2 week**
6 GeV/c - Positive	600 k [500 k π]	25 Hz / 226 Hz	
7 GeV/c - Positive	600 k [500 k π]	25 Hz / 252 Hz	
no beam	-	-	1 week
	Electron Beam *Pb Target*		
Energy Ramp: **0.5, 0.6, 0.7, 0.8, 0.9,** **1., 2., 3., 4., 5., 6., 7. GeV**	75 k per En. setting 900 k Tot.	25 Hz / 60 Hz	**1.5 week**

Full Scale Trial Assembly at Ash River

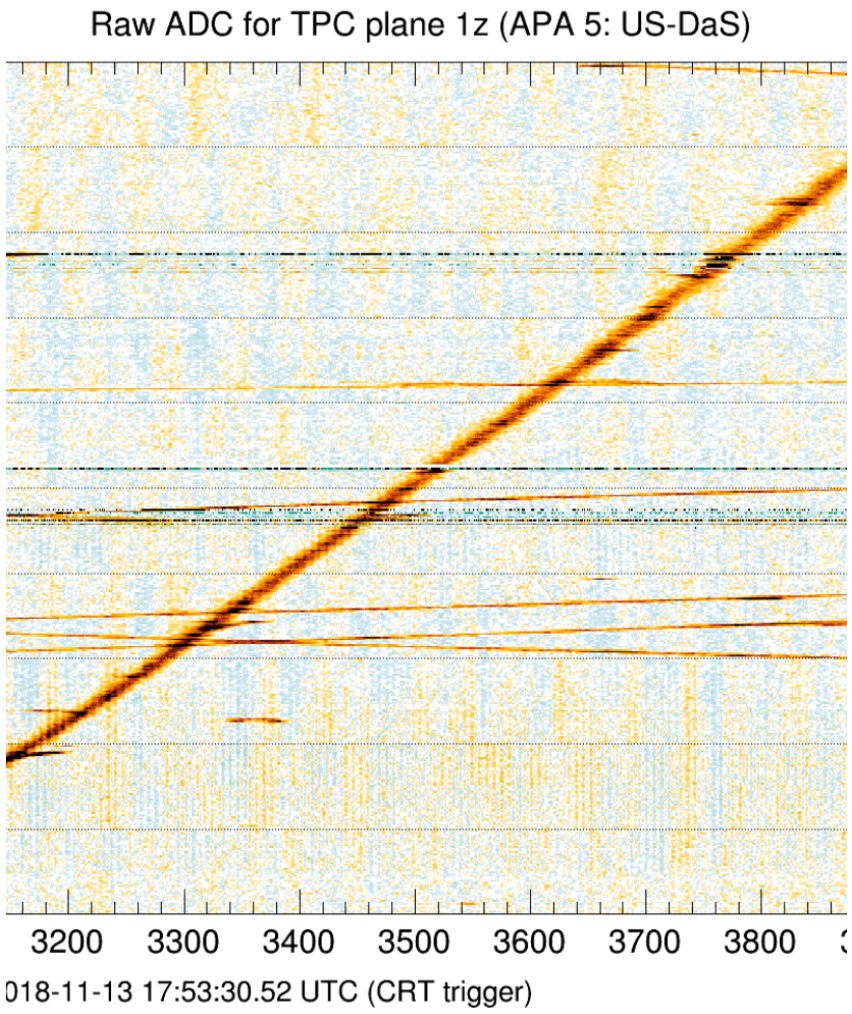
35ton HV test

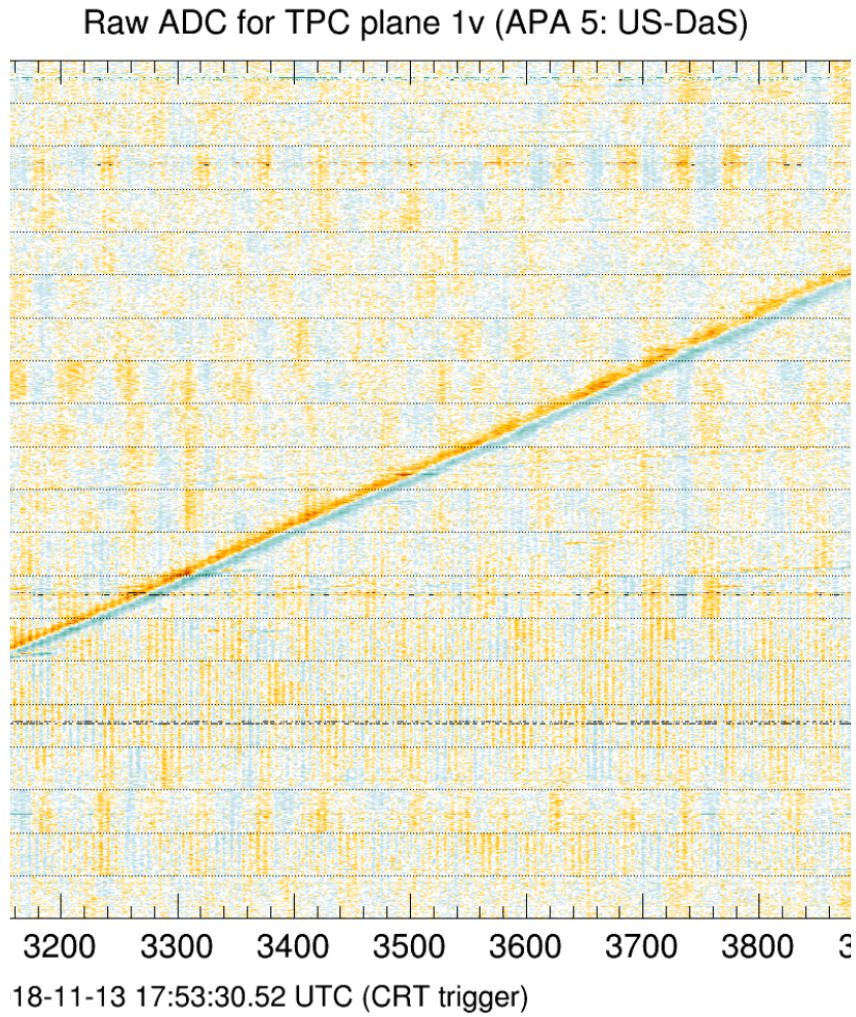


Operate in current-limiting mode



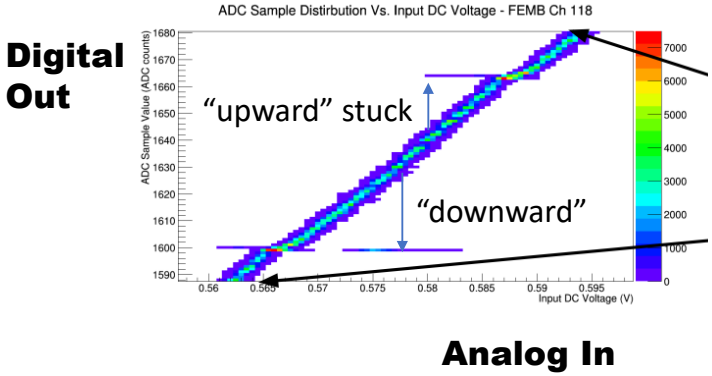
Drift field @ 100V/cm



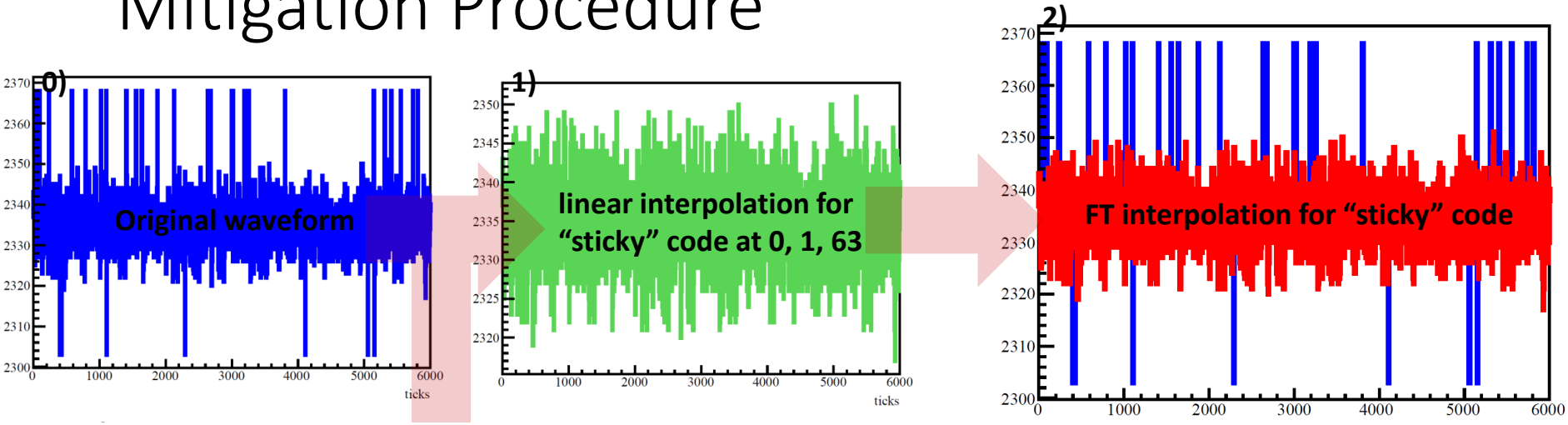


Sticky Code Mitigation

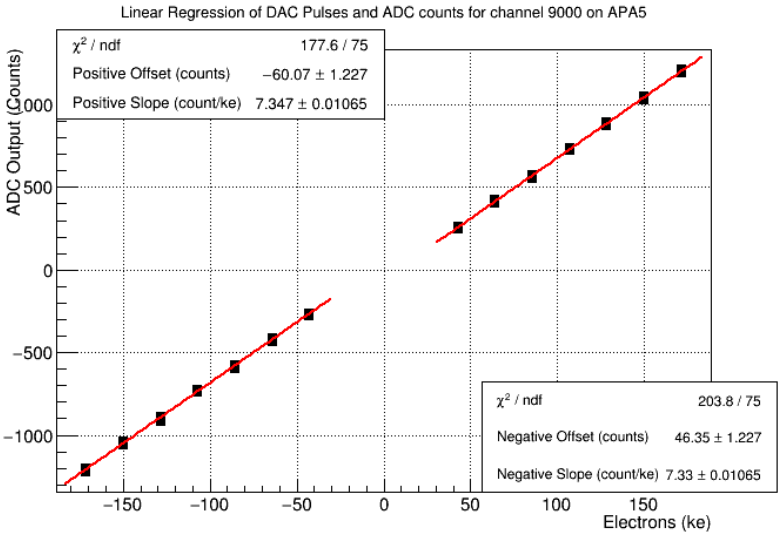
Sticky code - the 6 LSBs in ADC ASIC was found to be "sticky" around 000000 (0x00) or 111111 (0x3F).
Can be mitigated through linear interpolation.
A new method is developed to interpolate through FT.
The current focus is on noise mitigation and deconvolution.

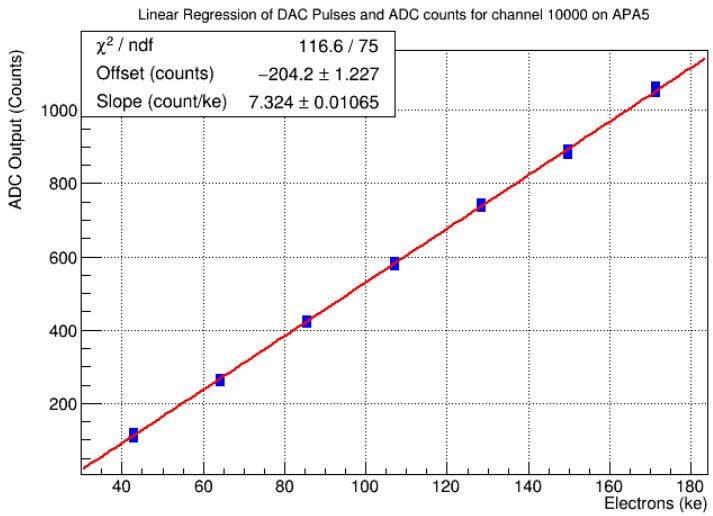


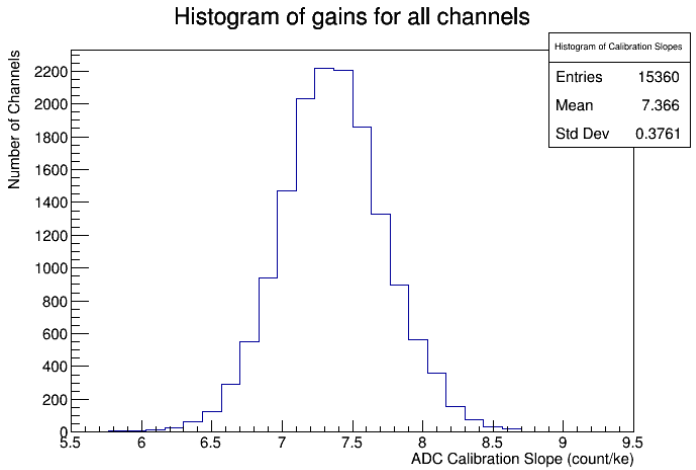
Mitigation Procedure



ADC gain and linearity







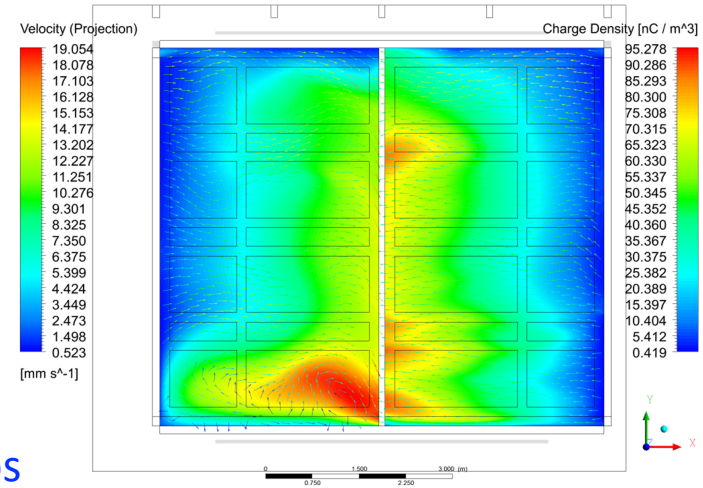
Using pulser data to measure ADC gain and linearity.
Analysis of a recent pulser run 4565.
Gain variation is ~5% over all channels.

Space Charge Simulation with LAr Flow

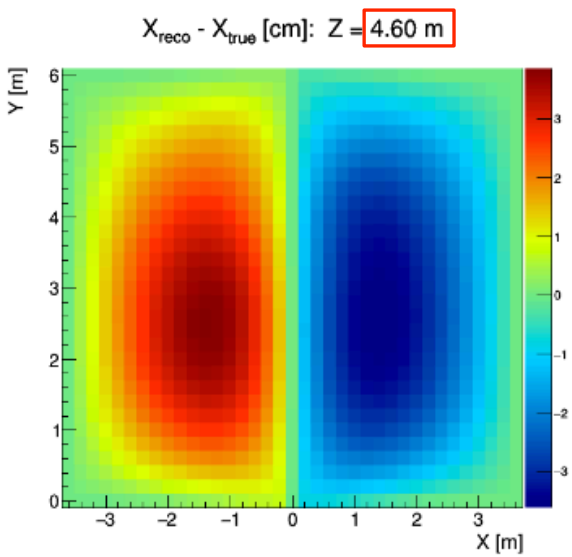
We now simulate SCE using the space charge density map with LAr flow - **first study of LAr flow on SCE**

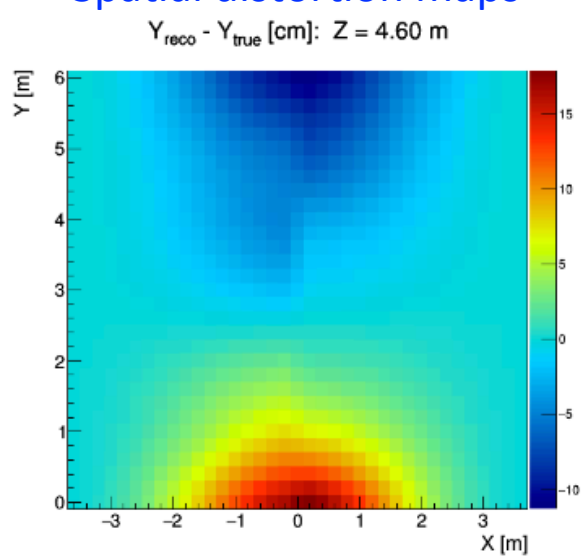
Very different distributions in the two drift volumes

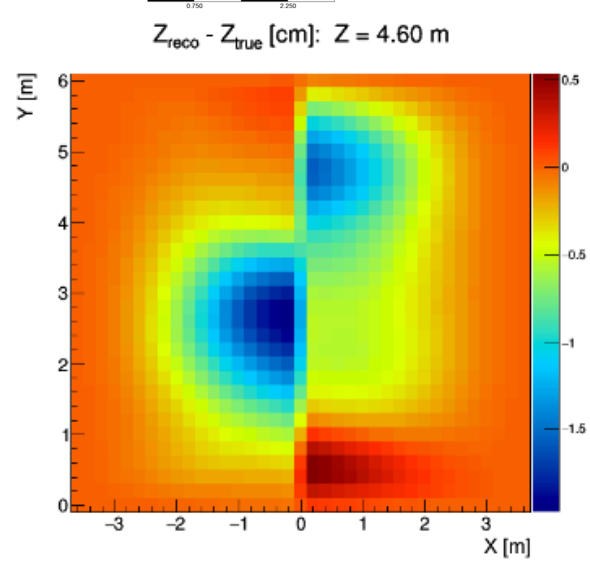
Essential to have **data-driven calibration**



Spatial distortion maps







Detector Calibration with Muons

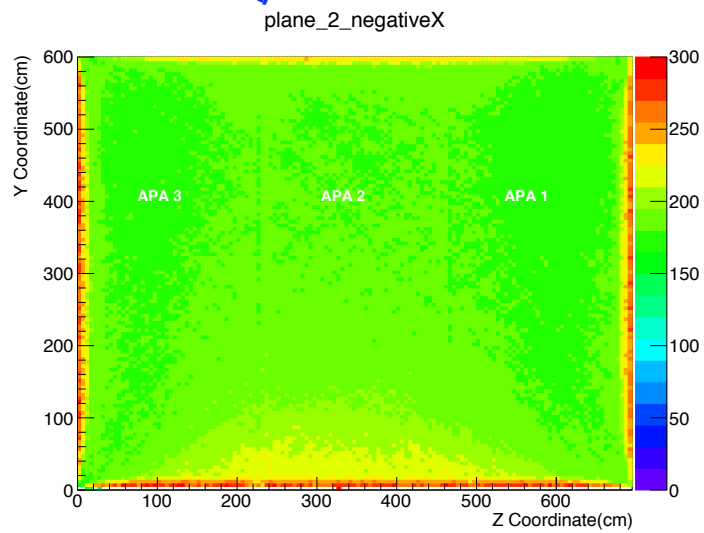
Similar procedure developed by MicroBooNE: MicroBooNE-NOTE-1048-PUB (2018).
Tools are developed using MC.
dQ/dx calibration using through-going muons

- Remove **spatial** and **temporal** variations in detector response
- Calibration constants are being uploaded to database by Jon Paley

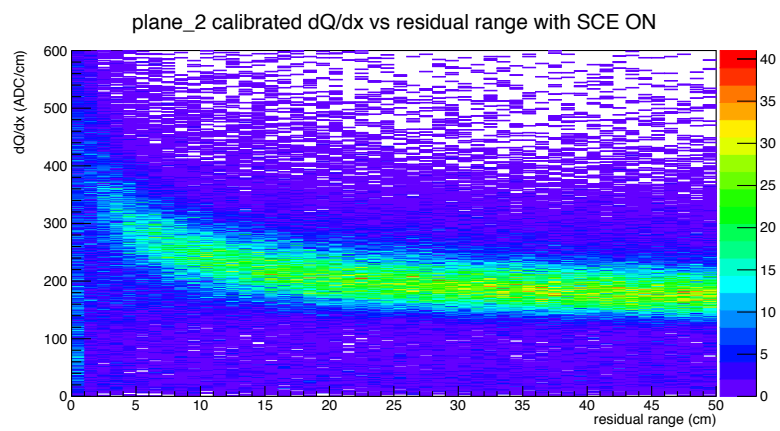
dE/dx calibration using stopping muons

- Determine absolute energy scale using muon stopping power
- More details in DRA meeting next week

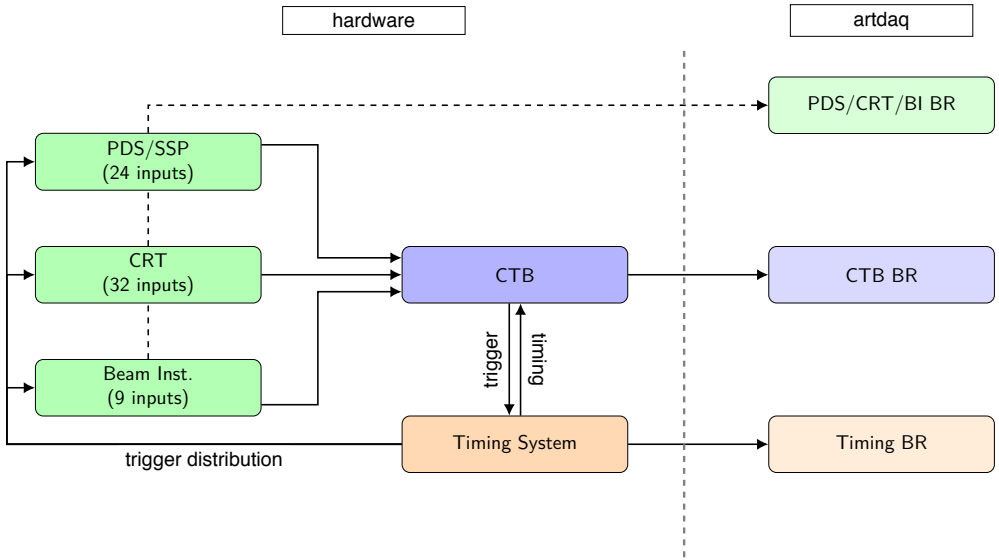
dQ/dx calibration



dE/dx calibration



Trigger

The Central Trigger Board (CTB) drives the ProtoDUNE-SP detector readout by issuing global triggers

- The trigger decision is derived from logical combinations of the following inputs:
  - **Beam Instrumentation** (e.g. Cherenkov counters for PID, scintillator planes for position and momentum measurement)
  - **Cosmic Ray Tagger** (Upstream and Downstream planes to detect crossing muons/beam halo particles)
  - Photon Detection System (Light bars and ARAPUCAs for light readout inside the cryostat)
- The trigger logic is configurable at run time and can be used to:
  - Veto/Select e^+/e^-
  - Trigger on proton/π-like events
  - Trigger on crossing muons outside of the beam spill
- In the absence of beam, the trigger is typically driven by the CRT