Single Phase Far Detector

Gina Rameika

LBNF/DUNE DOE IPR

30 October – 1 November 2019

Who am I?

- Scientist at Fermilab since 1982
- Worked on :
  - Fixed Target : Hyperons, Neutrinos (DONUT)
  - Deputy Head of Research Division
  - NuMI/MINOS Project management
  - Soudan Laboratory Operations Manager for Fermilab
  - LBNE Project Scientist
  - MicroBooNE Project Manager (2011 – 2014)
  - Neutrino Division Head (2014 – 2016)
  - ProtoDUNE-SP Construction Coordinator (2016 – 2018)
  - DUNE Resource Coordinator (2019 -)

Content - I

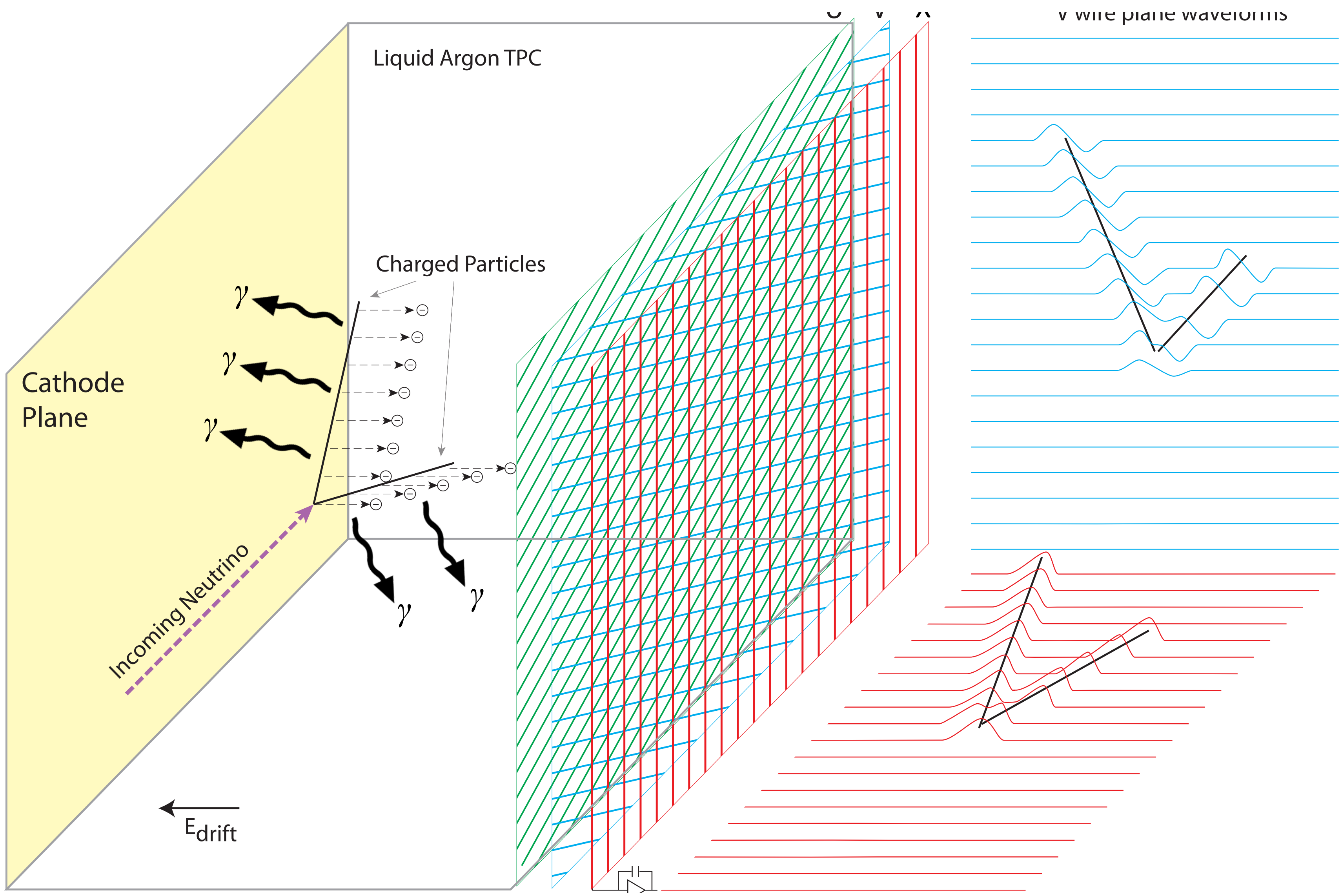
- Single Phase Liquid Argon Time Projection Chamber
  - Basic Concept
  - Components
- The DUNE 10 kT fiducial volume module
  - High Voltage : Cathode Planes and Field Cages
  - Anode Plane Assemblies
  - TPC Electronics (cold and warm)
  - Photon Detectors
  - Data Acquisition
  - Instrumentation and Calibration

Content - II

- Learnings from ProtoDUNE I
  - Purity/electron lifetime
  - High Voltage behaviour
- On-going and Up-coming Studies
  - In ProtoDUNE I
  - Prototyping at Ash River
  - APA7 @ CERN
- ProtoDUNE II

I will go through Content–I quickly so that we have time for these topics

Single Phase LAr TPC



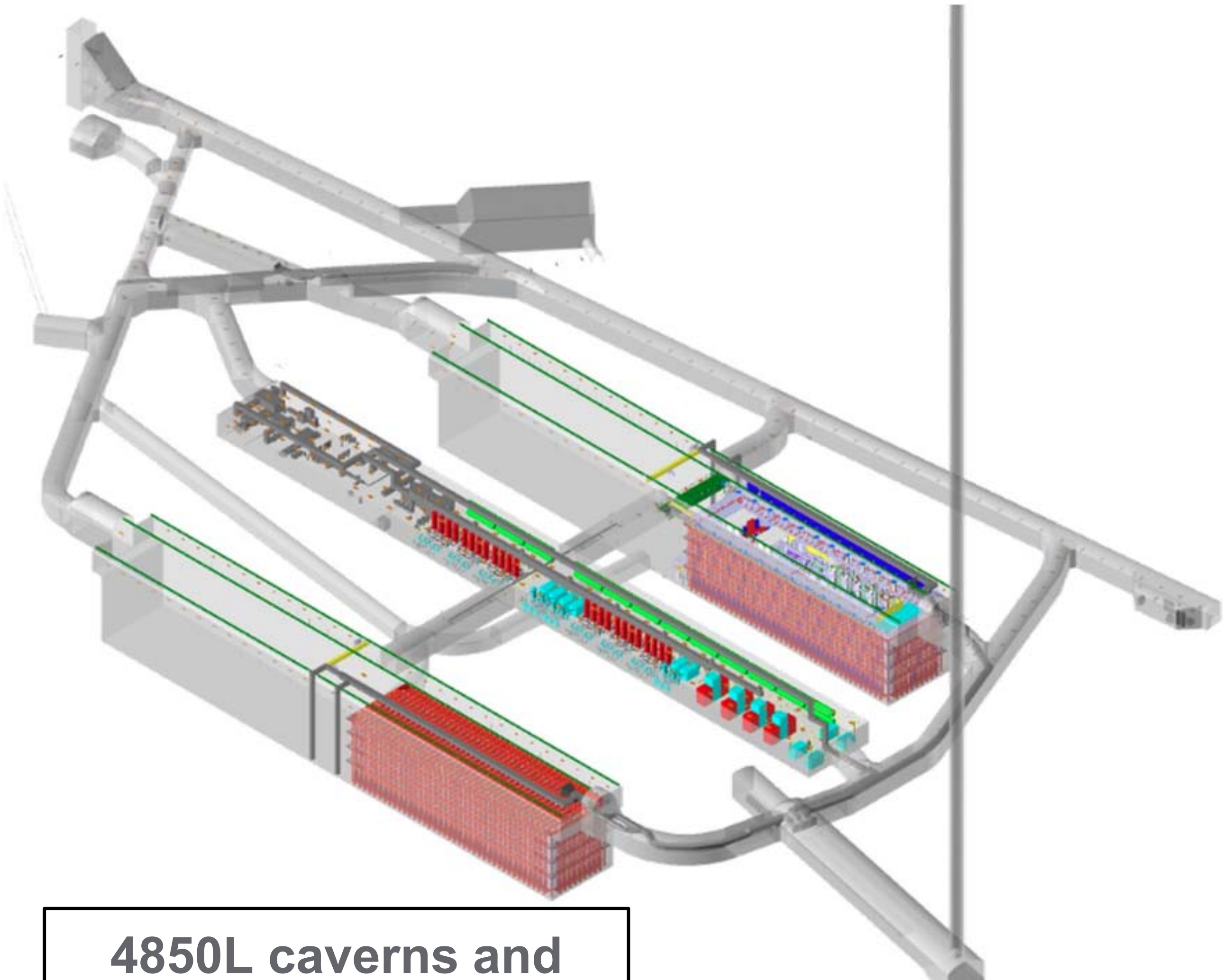
Components

- Drift ionization charge : High Voltage
  - HV power supply and feed-through
  - Cathode Plane
  - Field Cages
    - Resistive dividers
- Collect ionization charge : Sense wires, electronics
  - Anode Planes
  - Front-end amplification, digitization, readout
- Collect scintillation light : wavelength shifters, light guides, light collection electronics
  - Photon detector modules with SiPM readout
- Data Acquisition
- Instrumentation and Calibration systems

Other factors that matter

- Ionization
  - Electron lifetime – argon purity
  - Diffusion
  - Recombination
- Scintillation light
  - Nitrogen content in the argon

DUNE Single Phase Far Detectors at SURF

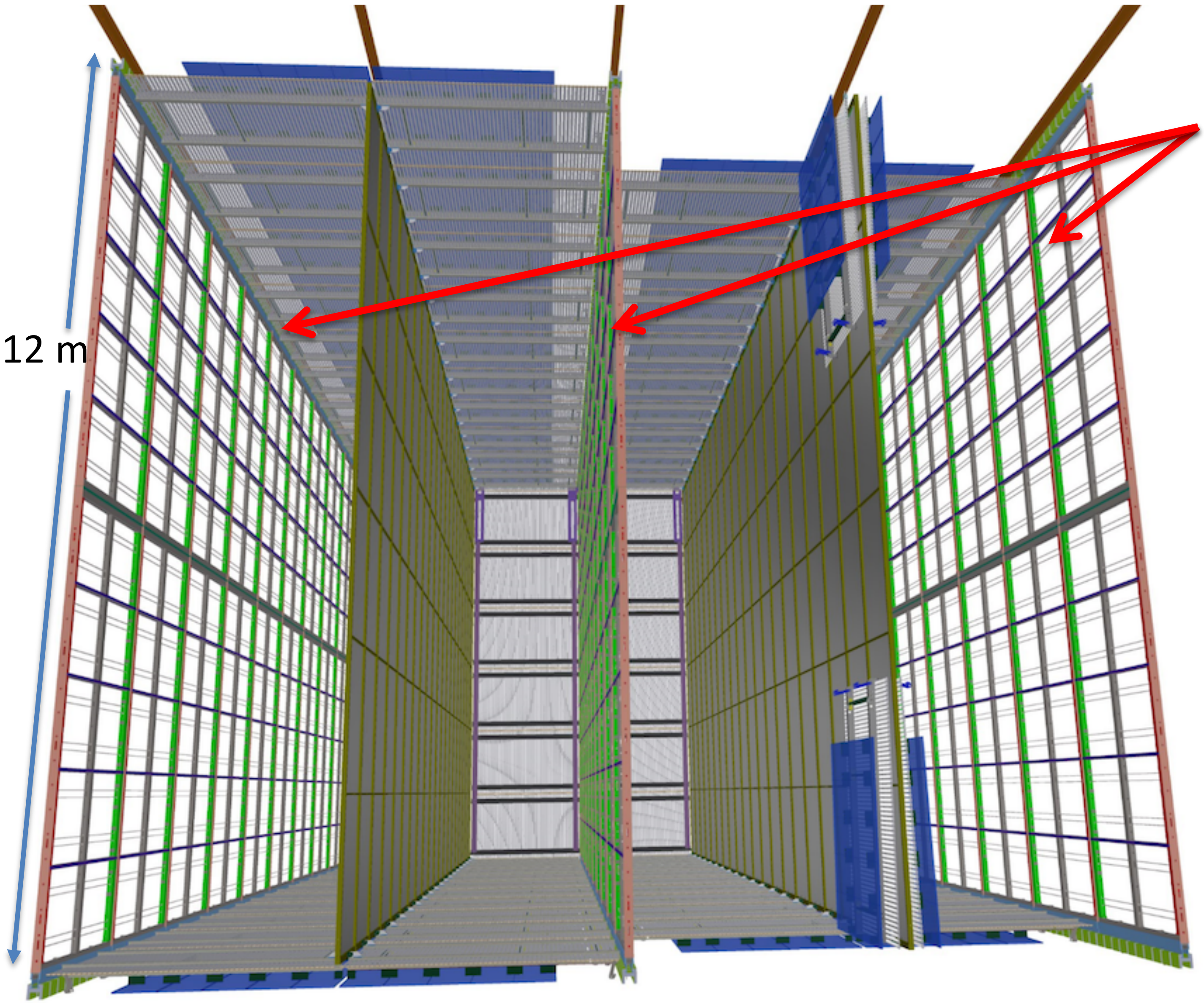


4850L caverns and drift layout

Introduction

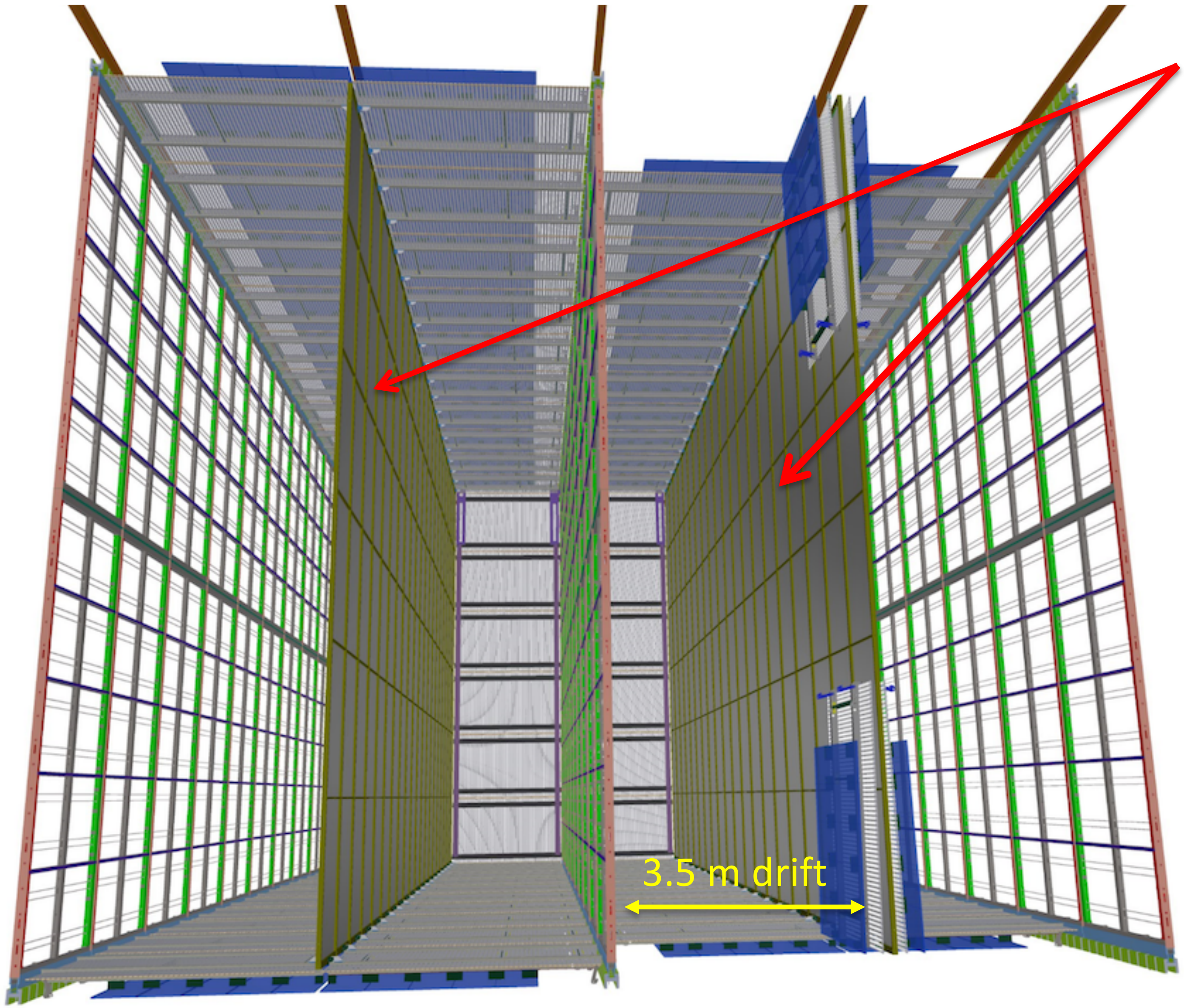
- Construction of the DUNE detectors is the responsibility of the international DUNE collaboration through the organization of the Consortia
- The Single Phase Far Detector is at a very high level of design maturity as demonstrated in the successful operation of the ProtoDUNE SP-I
- Many lessons learned from ProtoDUNE have been incorporated into DUNE final designs
- ProtoDUNE-SP-II will provide the opportunity to construct, install and operate DUNE Module 0 components
- Full scale prototyping of components and tooling for installation are on-going at Ash River
- We have a working model that assigns **almost all** major components for two SP far detector modules to either DOE, NSF or international partners; presented to the international Resources Review Board in September
- Opportunity for further partner contributions exist, in particular, in the areas of instrumentation and calibration

The DUNE Single Phase Module



150 APAs arranged in three planes, double high APAs in 25 rows

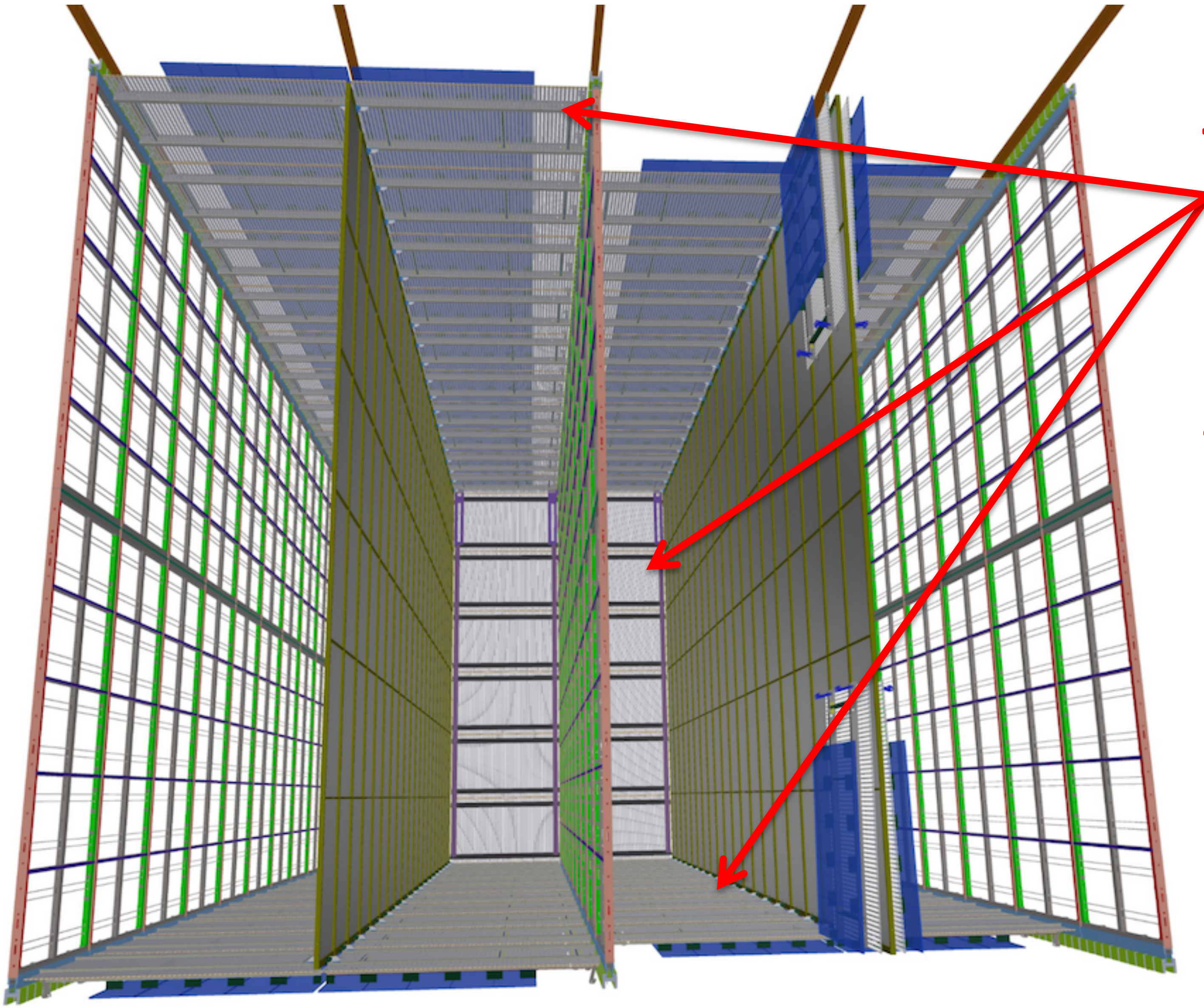
The DUNE Single Phase Module



High Voltage Cathode Planes

2 cathode planes each composed of 150 1.2m w x 4m h CPA modules

The DUNE Single Phase Module



Field Cages :

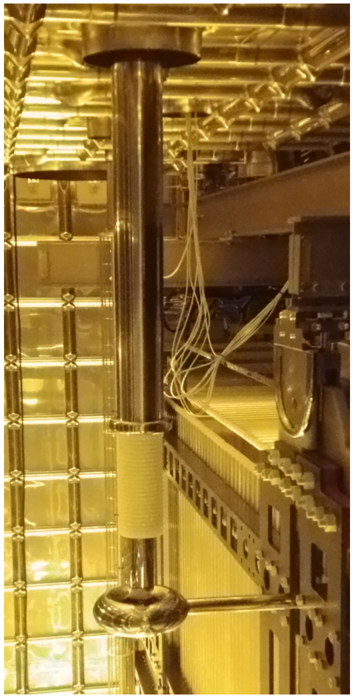
Top, Bottom and Endwalls

100 T and B modules
48 Endwall modules

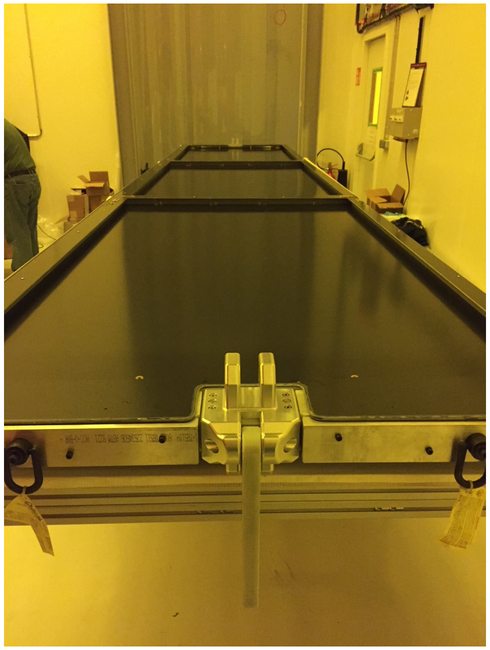
High Voltage System Components

US-DOE, CERN, INFN

Power Supply



Feed-through



CPA Panel (from PD)
DUNE will be
2X longer

Top/bottom Field
Cage module
with Ground plane

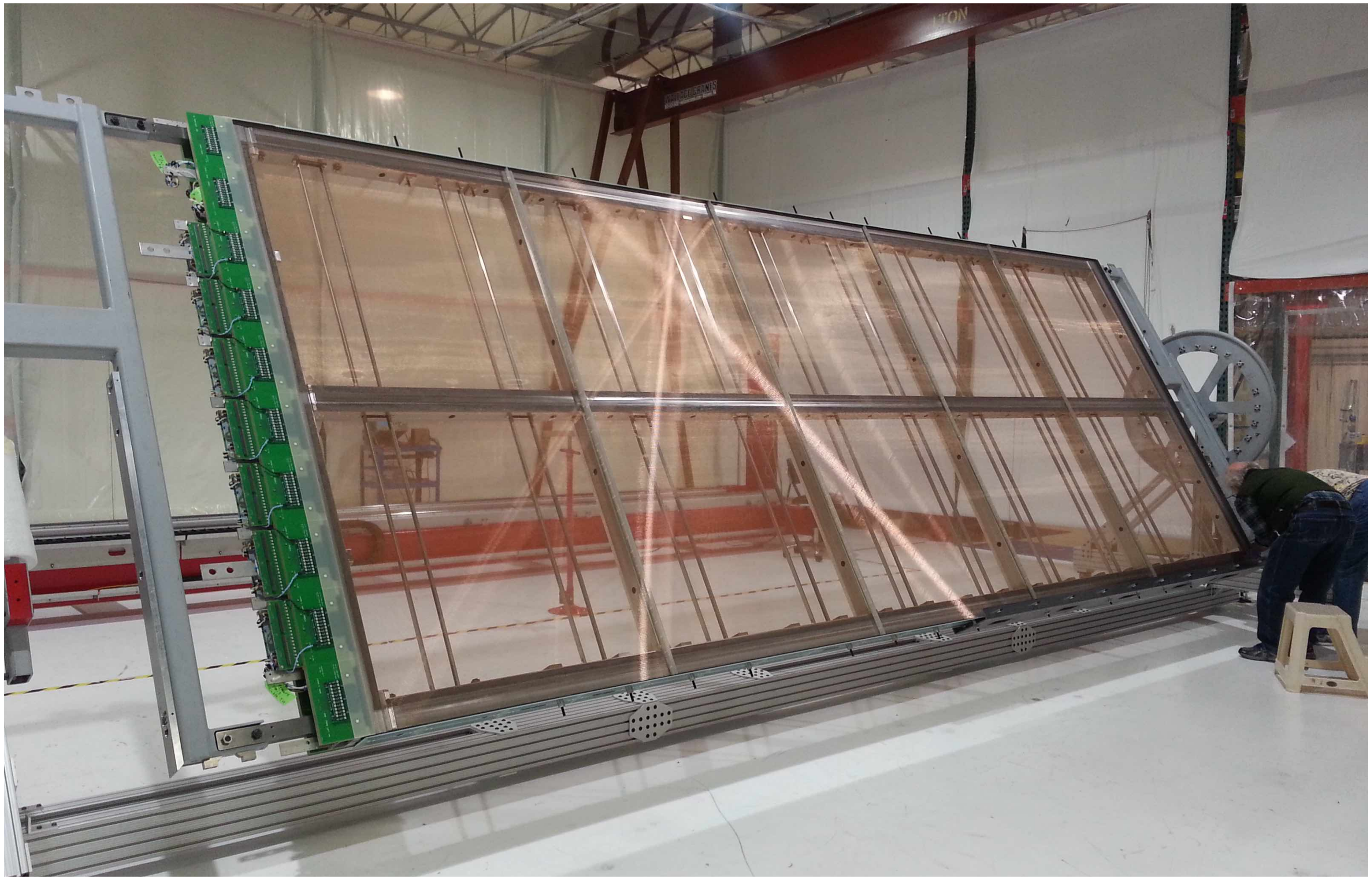
Resistor Dividers

End-wall

High voltage drift volume in PD

Anode Plane Assemblies

UK - 150
US-NSF - 150



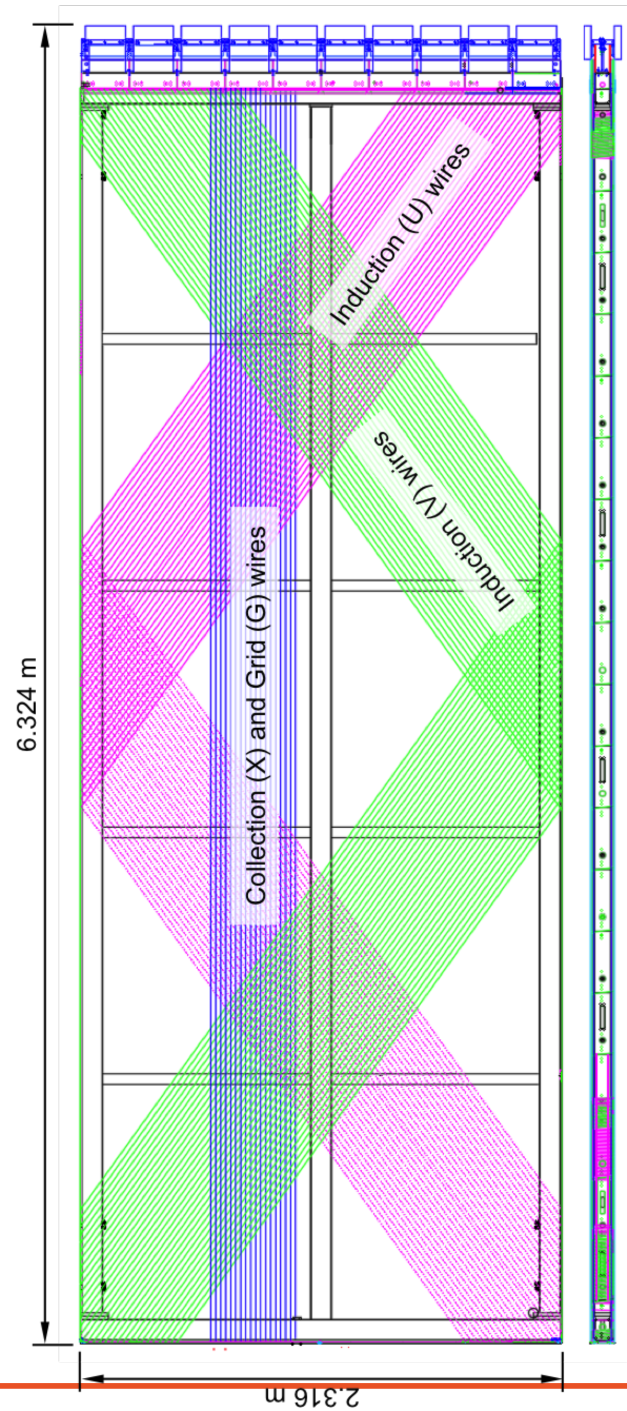
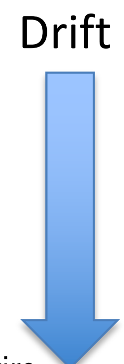


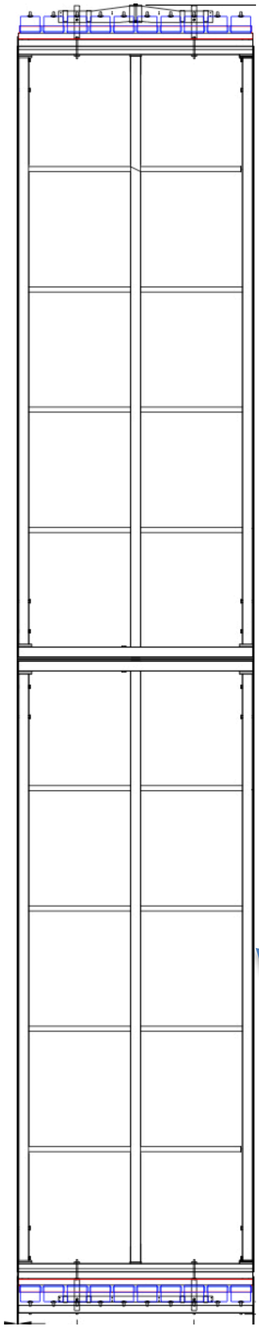
Table 1.3: APA design parameters

Parameter	Value
Active height	5.984 m
Active width	2.300 m
Wire pitch (U, V)	4.669 mm
Wire pitch (X, G)	4.790 mm
Wire pitch tolerance	$\pm$0.5 mm
Wire plane spacing	4.75 mm
Wire plane spacing tolerance	$\pm$0.5 mm
Wire Angle (w.r.t. vertical) (U, V)	$\pm 35.7^\circ$
Wire Angle (w.r.t. vertical) (X, G)	0°
Number of wires / APA	960 (X), 960 (G), 800 (U), 800 (V)
Number of electronic channels / APA	2560
Wire material	beryllium copper
Wire diameter	150 μm

Anode Plane	**Bias Voltage**
G - Grid	-665 V
U - Induction	-370 V
V - Induction	0 V
X - Collection	820 V
Grounding Mesh	0 V

Table 1.2: Baseline bias voltages for APA wire layers.

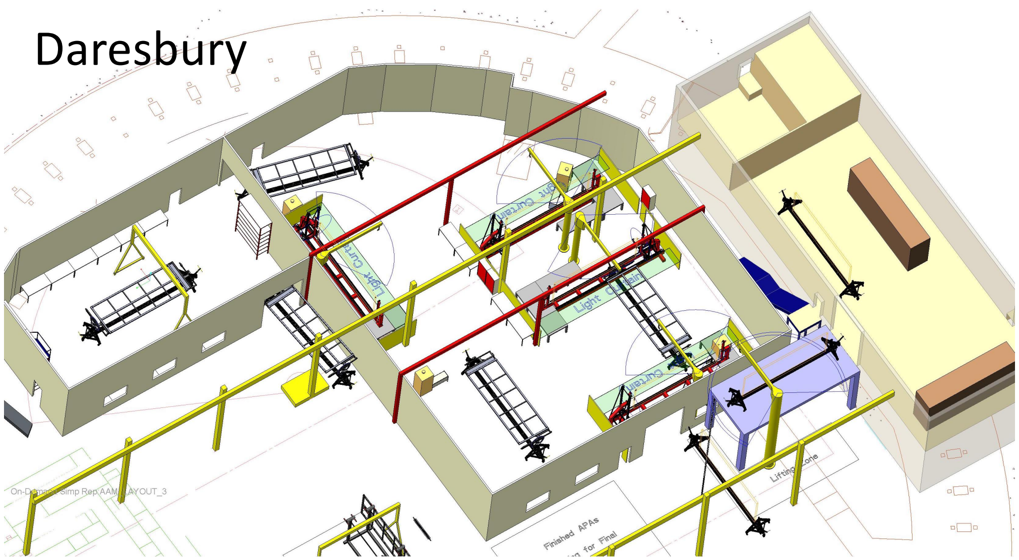


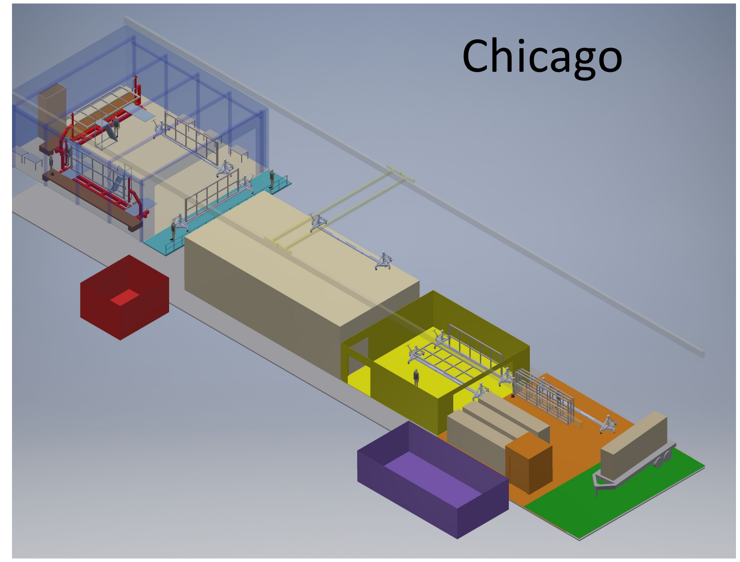


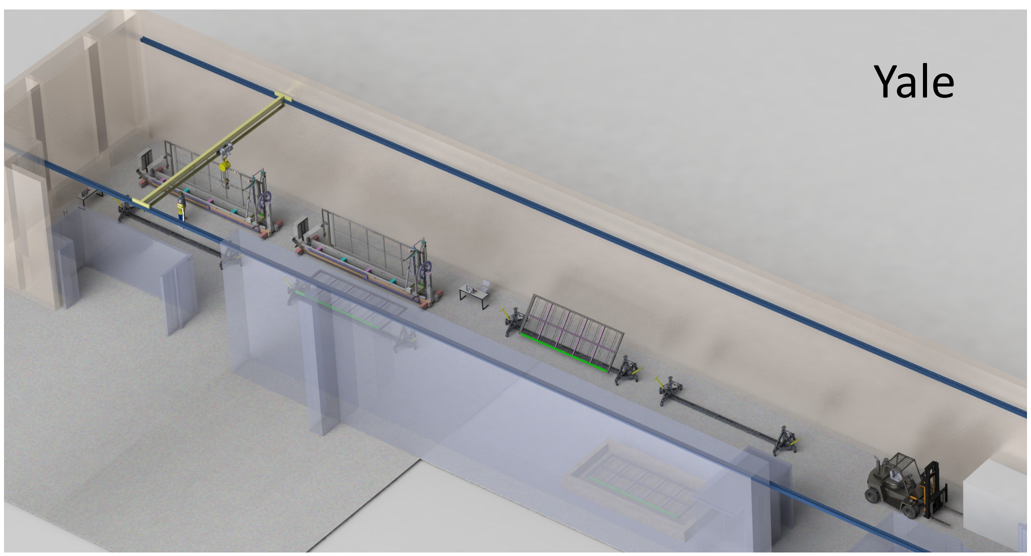
- Two APA's are stacked vertically, joined at the "feet"
- Production
  - 150 produced in UK, 150 in US
  - UK Factory at Daresbury Lab
    - 4 winding machines
  - US Production Sites : Chicago, Yale and PSL(Wisc)
    - 2 winding machines each at Chicago, Yale, PSL

This one hangs upside down

APA Factory layouts



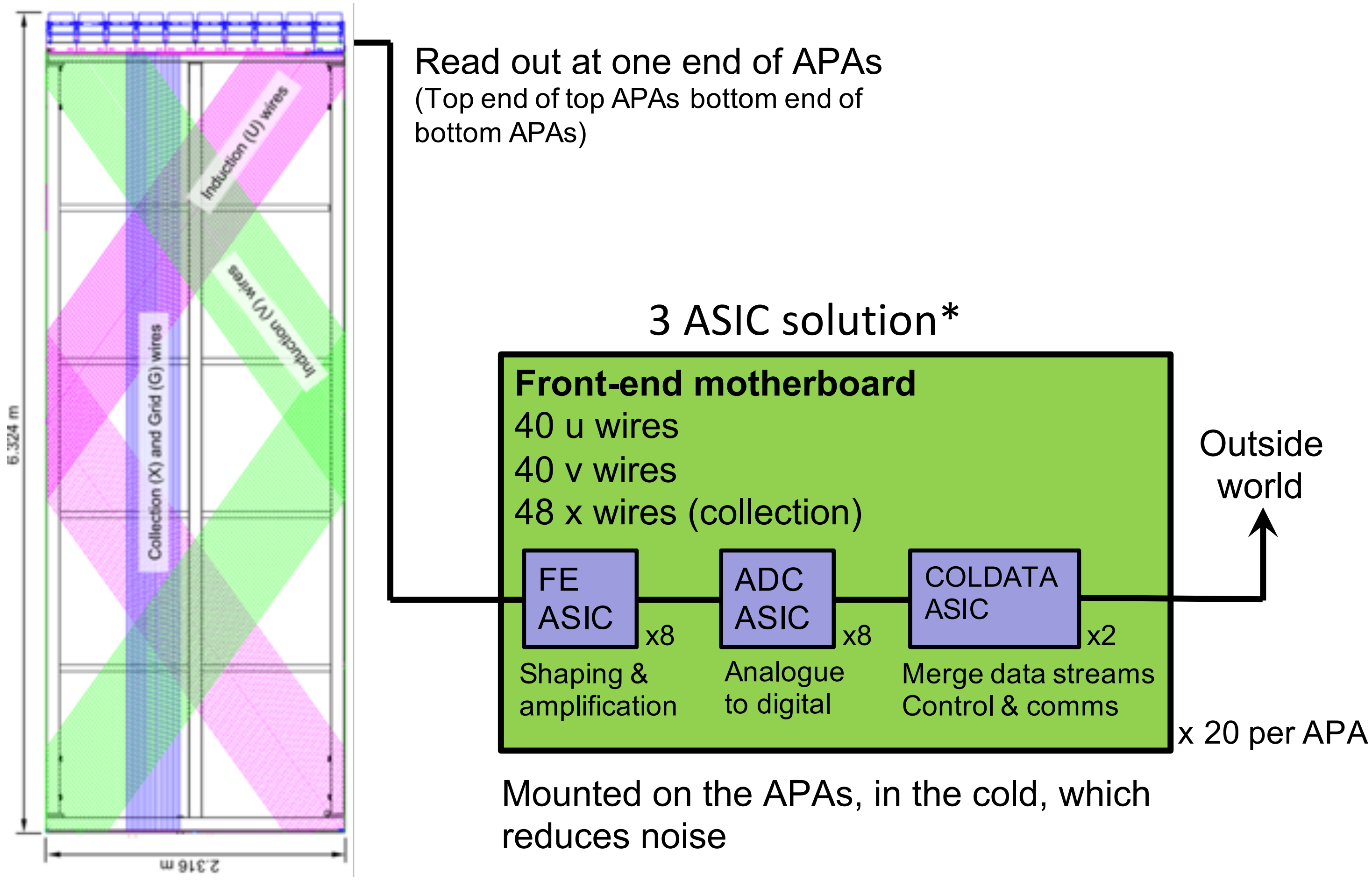




TPC Electronics

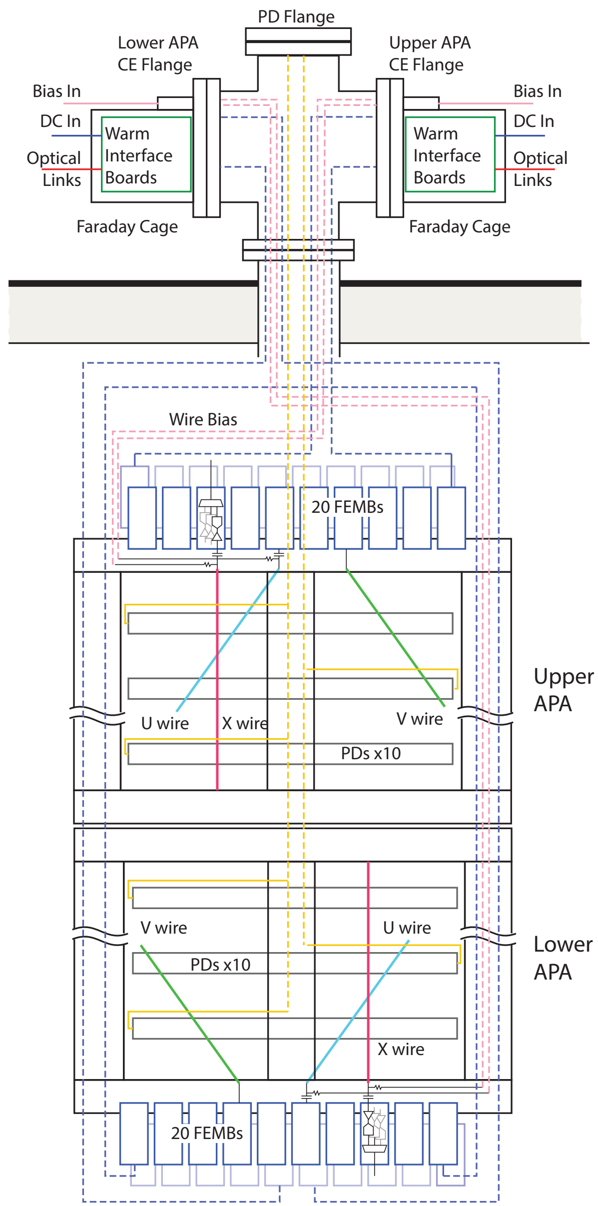
100% DOE Scope

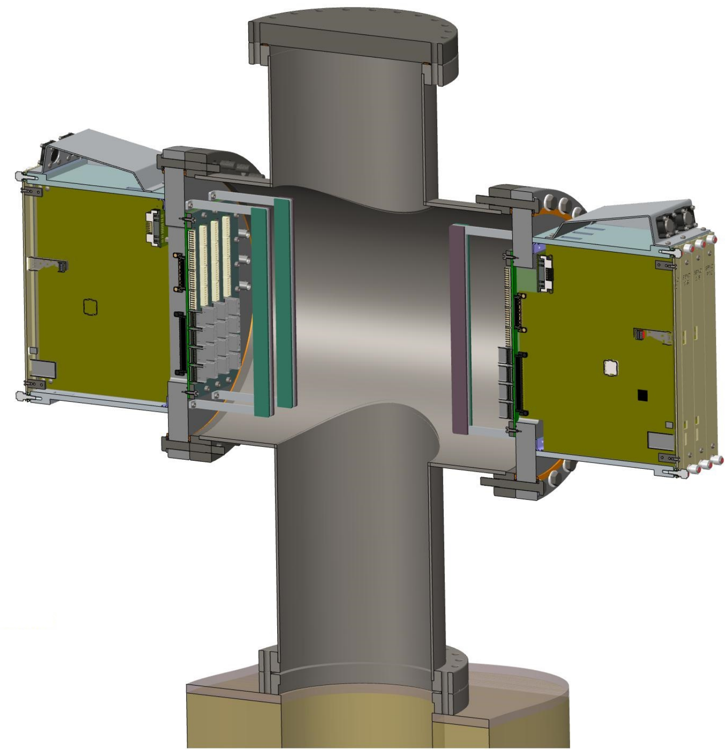
- 2560 electronics channels (wires) per APA
- 128 channels per FE ASIC -> 20 COLD mother boards per APA
- 3000 mother boards per Single Phase module



*alternative : single ASIC CRYO chip under development

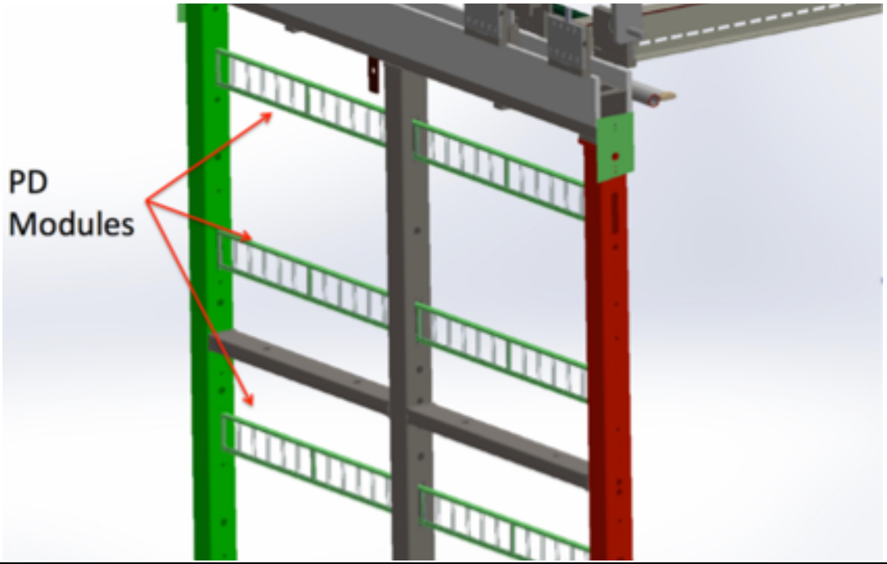
Cold cables to warm electronics





1 Feed-through per APA pair
5 WIBs per APA

Photon Detector System



ARAPUCA Modules : Brazil
SiPMs & Summing : Italy, Spain
Readout : Peru, Columbia
Calibration : US DOE

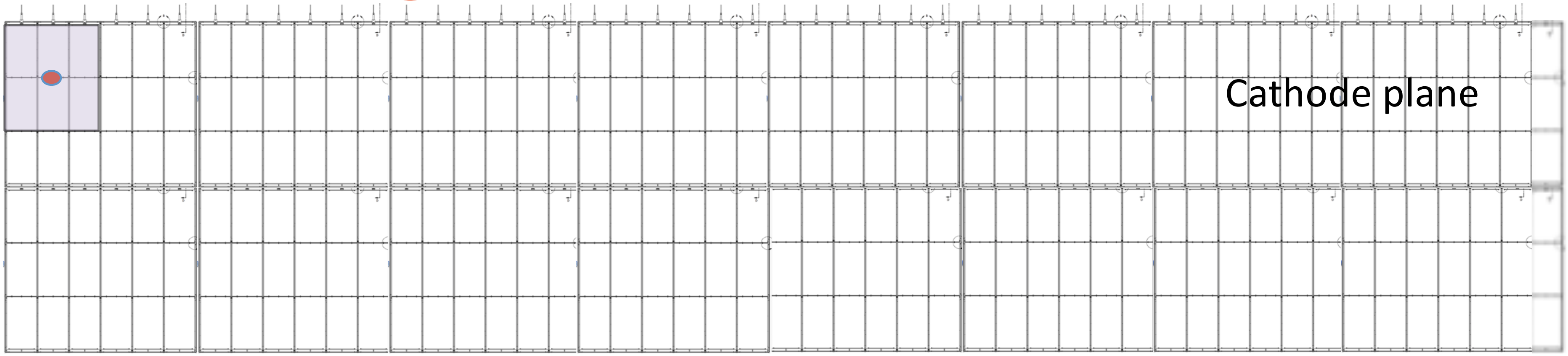
Component	Description	Quantity
Light collector	X-ARAPUCA	10 modules per APA; 1500 total (1000 single-sided; 500 double-sided)
Photosensor	Hamamatsu MPPC 6 mm×6 mm *	192 SiPM per module; 288,000 total
SiPM signal summing	6 passive × 8 active	4 circuits per module; 6000 total
Readout electronics	Based on commercial ultrasound chip	4 channels/module; 6000 total
Calibration and monitoring	Pulsed UV via cathode-mounted diffusers	45 diffusers/CPA side; 180 total

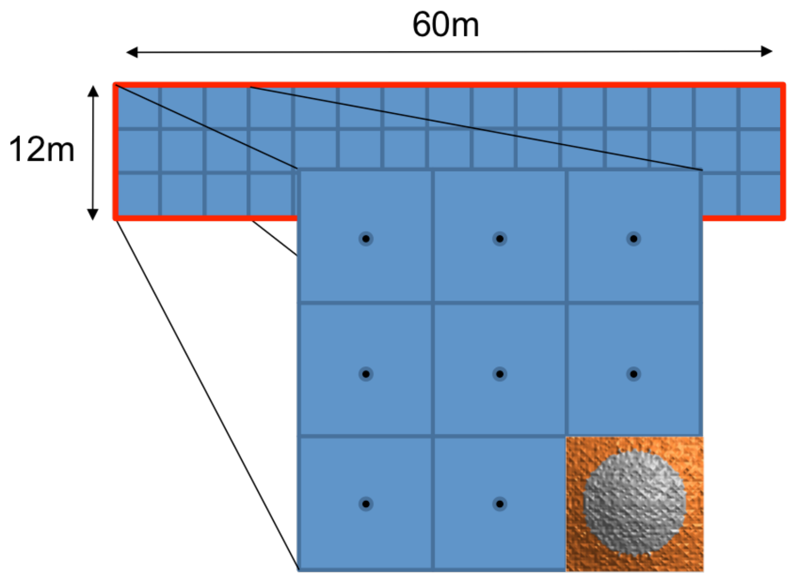
* FBK/Italy also being studied; both to be evaluated in PD-SP II

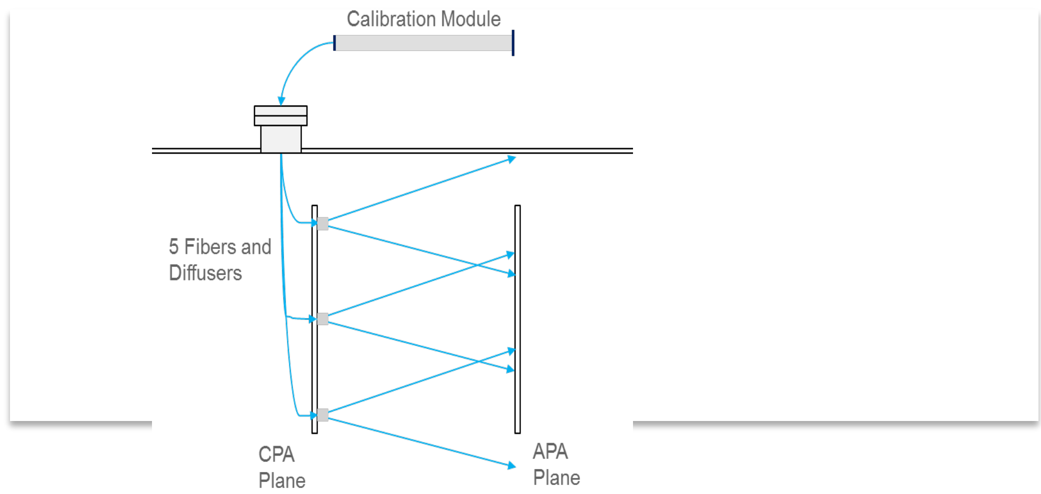
X-ARAPUCA developments

- X-ARAPUCA Double-sided (with dichroic filters on both sides) tested
- The detection efficiency results to be comparable with the Single-sided version (around 3%, which exceeds the 2.5% requirement)
- New tests were performed with Single-sided and confirmed previous measurements
- First batch of dichroic filters produced in Brazil delivered at UNICAMP. Evaporation of wavelength shifter being studied.
- X-ARAPUCAs prototypes are being assembled at UNICAMP. Will be used at CERN for the Xenon doping test. Other prototypes sent to Milan, South Dakota and Spain for testing.

Photon Detector Monitoring







Data Acquisition

UK | CERN

Data Selection scope (trigger) in NSF proposal

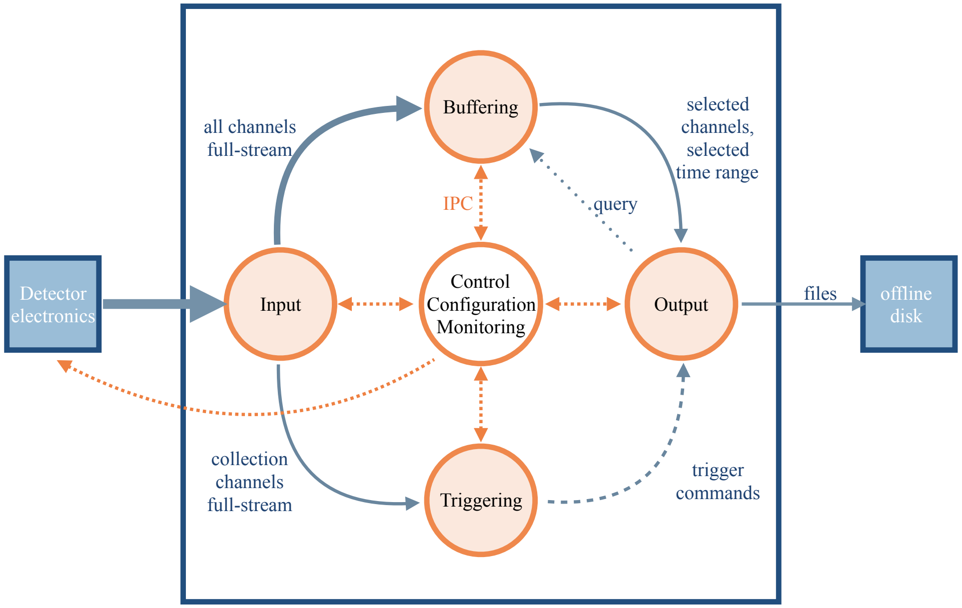
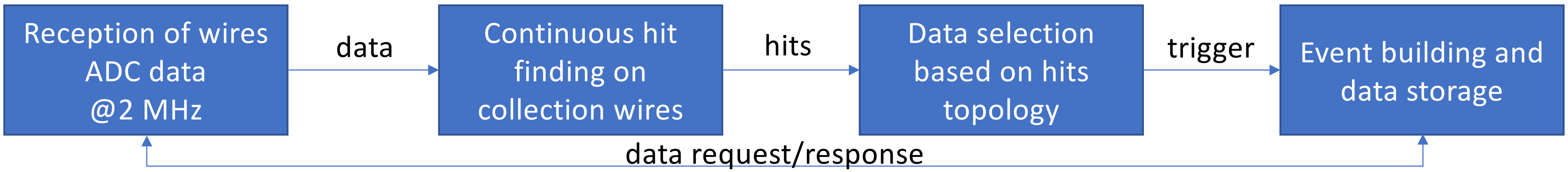


Figure 1.3: Conceptual Overview of DAQ System Functionality for a single 10 kt module

Each set of APA WIBs connects to one FELIX FPGA PCIe 3.0 board

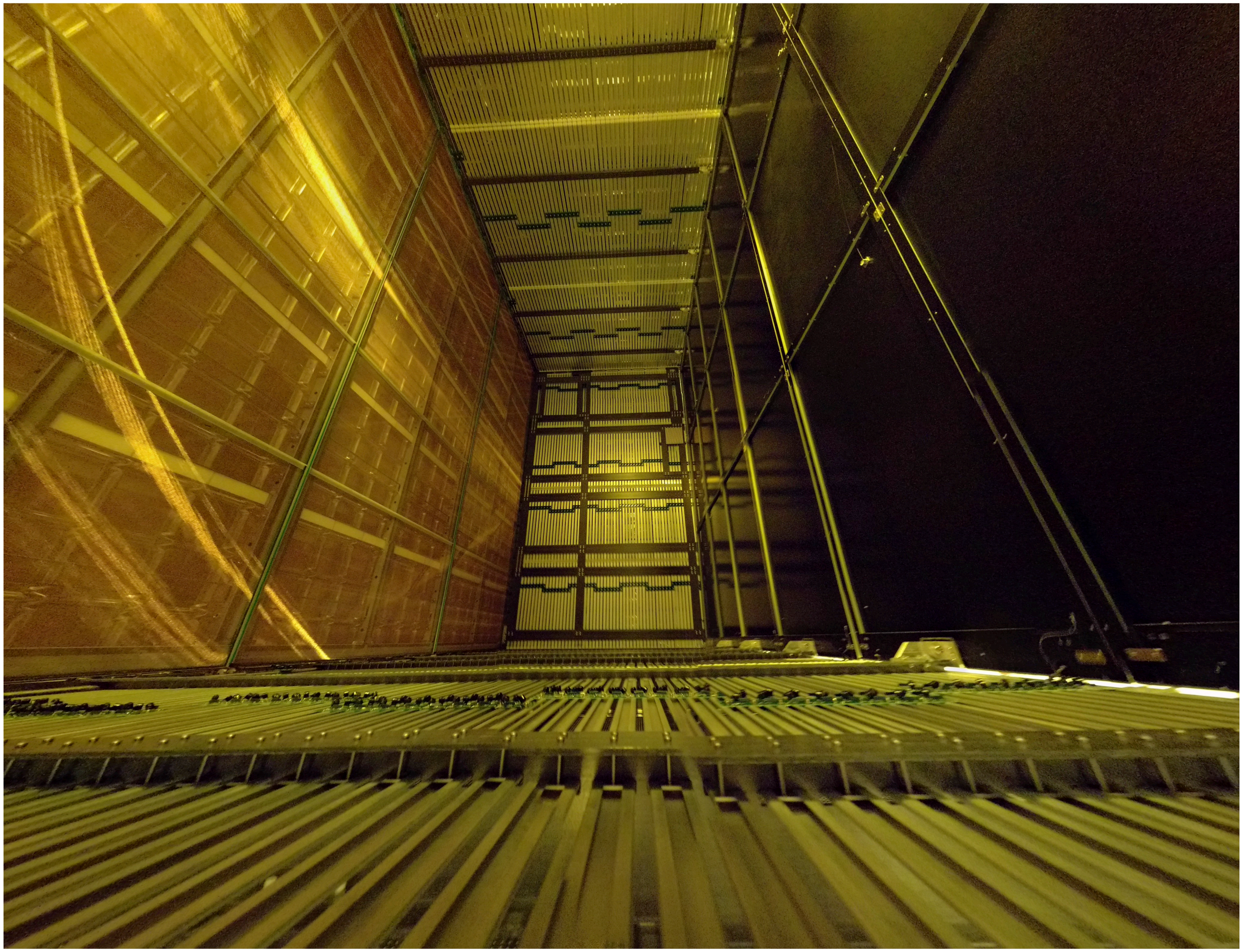
- System requirements driven by need for
  - High uptime
  - Configurable and controllable from remote locations
  - Operational during installation and commissioning via separate partitions
  - Large buffering capability and low fake triggers for Supernova
  - Reduce data volume prior top off-line storage
- Five sub-systems
  - Upstream DAQ
  - Data selection
  - Back-end subsystem
  - Control, Configuration and Monitoring
  - Timing and synchronization

Data driven triggering



- DAQ receives a continuous stream of TPC data
- In ProtoDUNE external signals (cosmic rays tagger, beam instrumentation, random) determine when data shall be collected
- In DUNE the content of the TPC data (and PD data) will be used to trigger the event building and data storage
- In 2019 NP04 was used to demonstrate the capability of data driven triggering for DUNE
- In PD-II we plan to exercise data driven triggering from the Photon System

The Single Phase TPC



- APA's + electronics, along with Photon Detectors, the High Voltage and Data Acquisition Systems comprise the essential elements of the Single Phase Detector.

Instrumentation and Calibration

- Instrumentation includes :
  - Temperature probes
  - Level meters
  - Gas analyzers
  - Purity Monitors
  - Cameras

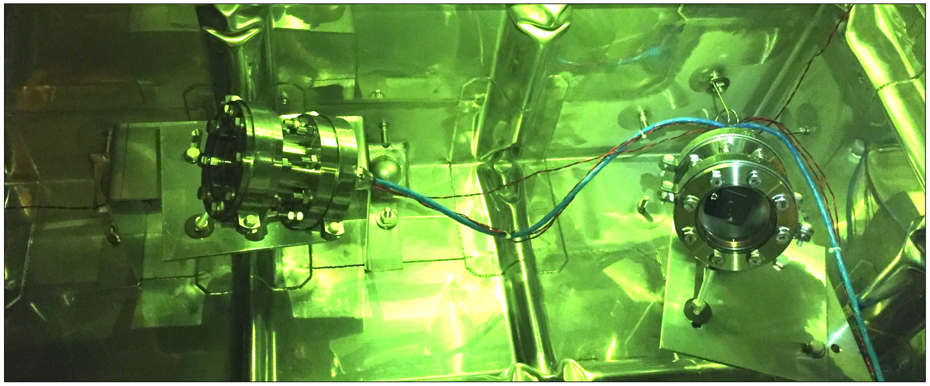
Static Temperature Probes to be provided by IFIC, Valencia

Currently no significant LBNF/DUNE Scope for Instrumentation or Calibration

Potential contributions to calibration from US funds (i.e. Gollipini ECA)

- Systems proposed :
  - Laser *
  - Pulsed Neutron Source
  - Radioactive source

These systems had Scope reviews in June 2019;
ProtoDUNE-II plans being developed;
Follow-up reviews planned for early 2020

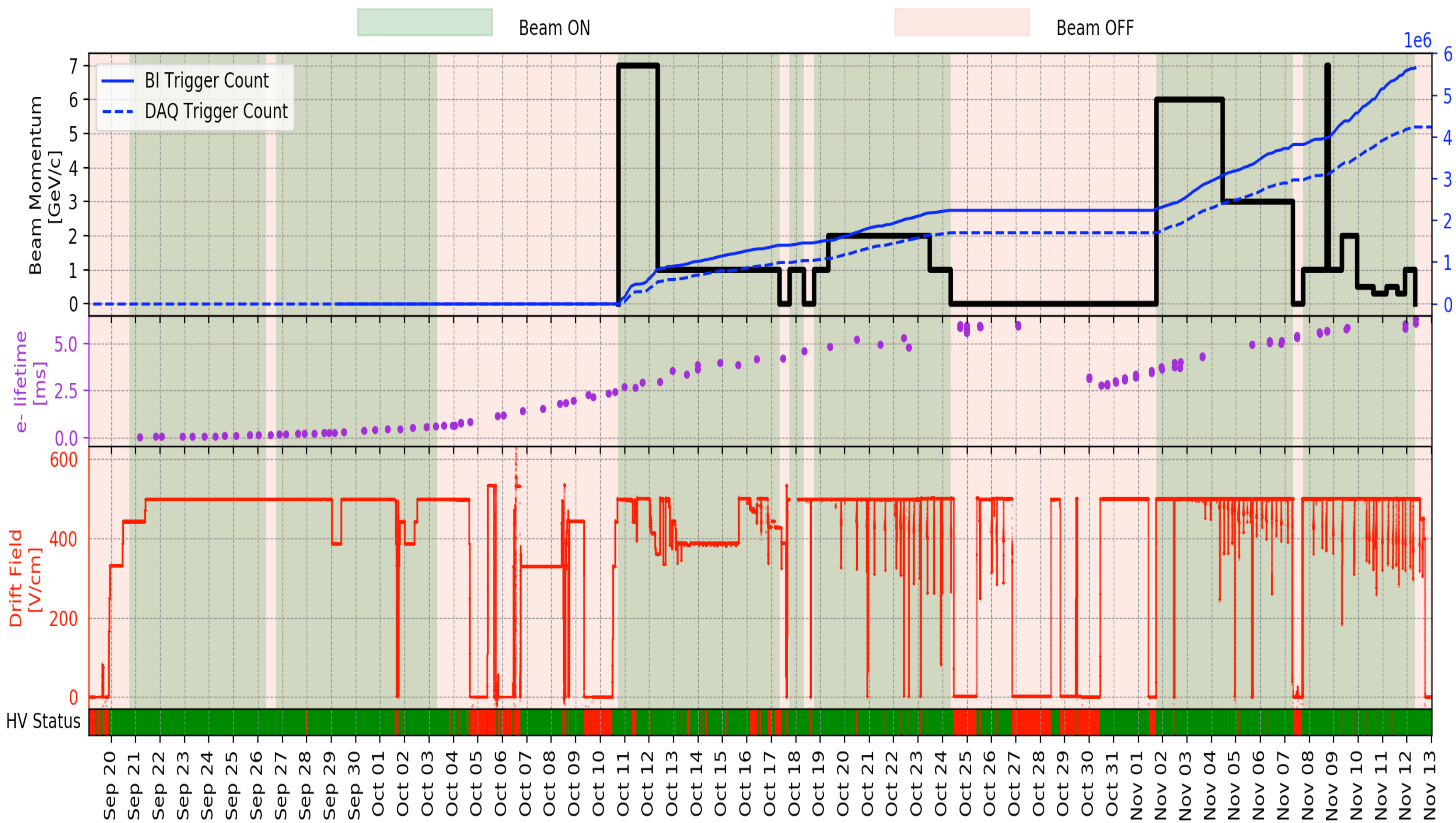


*Lasers are the most significant cost impact of these two areas

ProtoDUNE SP-I

- **Developed Model for Organization** of Construction, Component Delivery, Integration & Installation
  - Detector components were constructed at distributed sites and delivered to CERN
  - Integration in clean room (APA, Photon Detectors, Cold Electronics)
  - Cold box testing
  - Installation through Temporary Construction Opening
  - Installation on top of cryostat
- Demonstrated **design maturity** for APAs, High Voltage, Front-end electronics, Data Acquisition, Instrumentation
- **Operational experience** with cryogenics, purity, high voltage, instrumentation and data taking
- Data processing and analysis

Performance through beam run

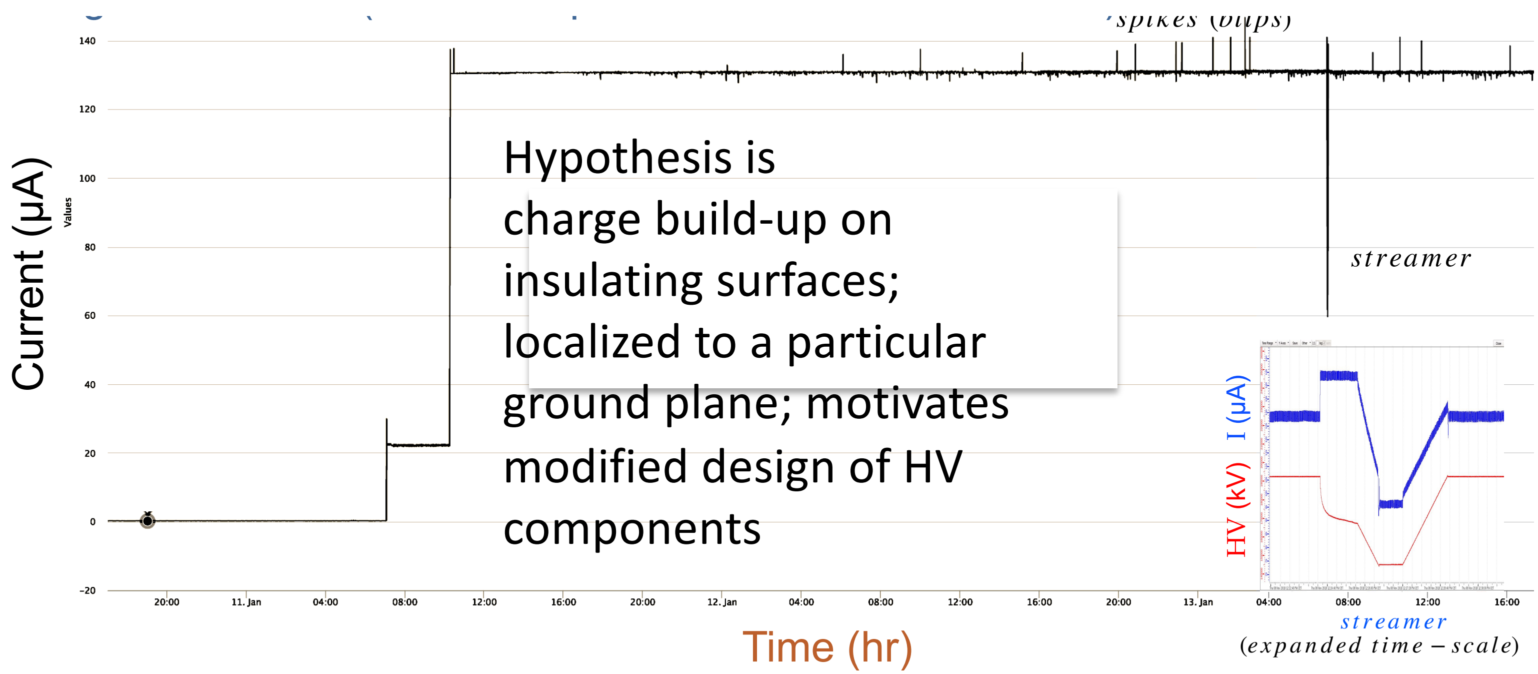


PD-SP TPC Performance Summary

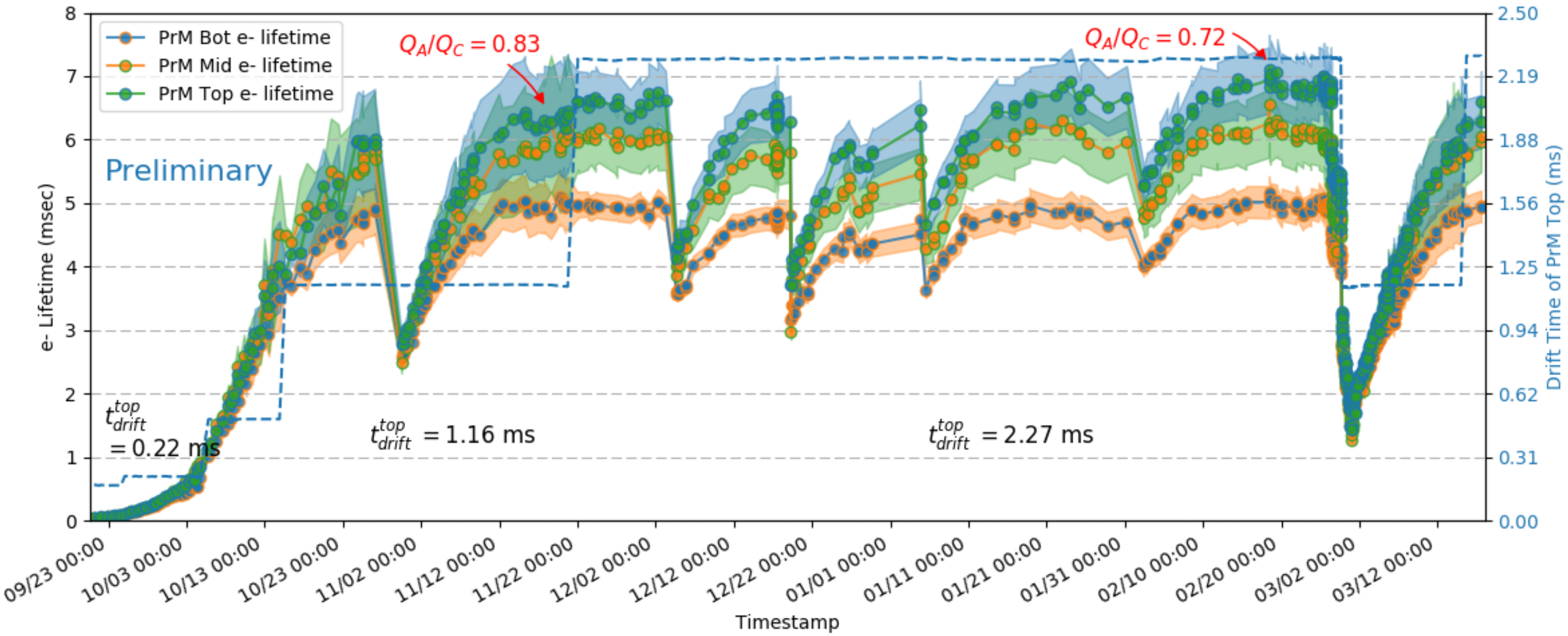
Detector Parameter	Specification	Goal	ProtoDUNE Performance
Electric Drift Field	> 250 V/cm	500 V/cm	500 V/cm
Electron Lifetime	> 3 ms	10 ms	> 15 ms (TPC)
Electronics Noise	< 1000 enc	ALARA	550-630 enc (raw)

High Voltage Performance

- Design voltage = 180 kV to give a drift field of 500V/cm over the 3.6 m drift length
- Steady operation at 180kV was achieved with two types of instabilities
  - Spikes or “blips” of ~10ms duration (self-quenching) and current draw of ~10μa
  - Streamers : sustained excessive current draw, a few per day; mitigated during data taking by auto reset; 98% live-time during beam operation



Purity ⟶ Electron life-time



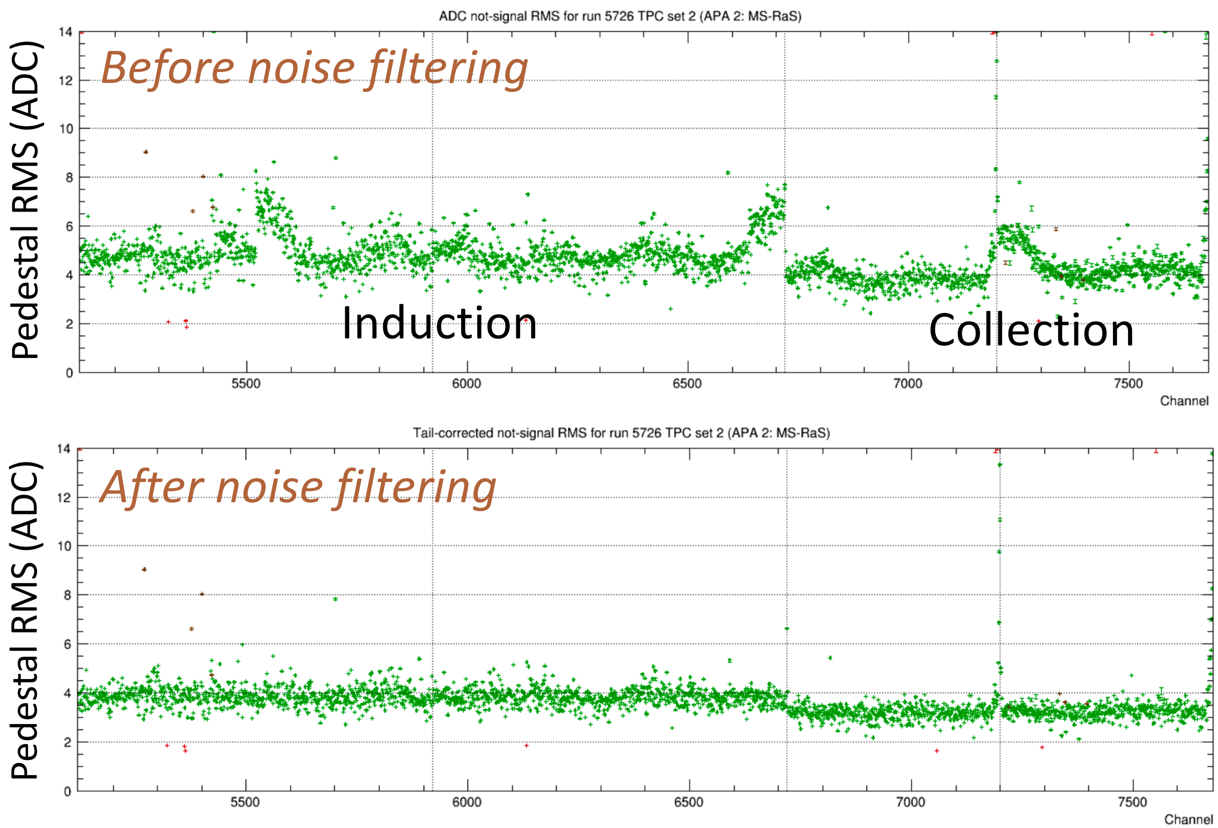
Liquid Argon purity routinely measured by three Purity Monitors at 1.8 m, 3.7 m, and 5.6 m from the bottom of the cryostat.

Purity monitors operated very stably since Sep 2018 and measured e-lifetime from 45**μ**s to 7ms (sensitivity up to ~10 ms).

Lifetime determined with purity monitor measurements outside TPC are not equivalent to the l

David Adams

TPC Noise Levels

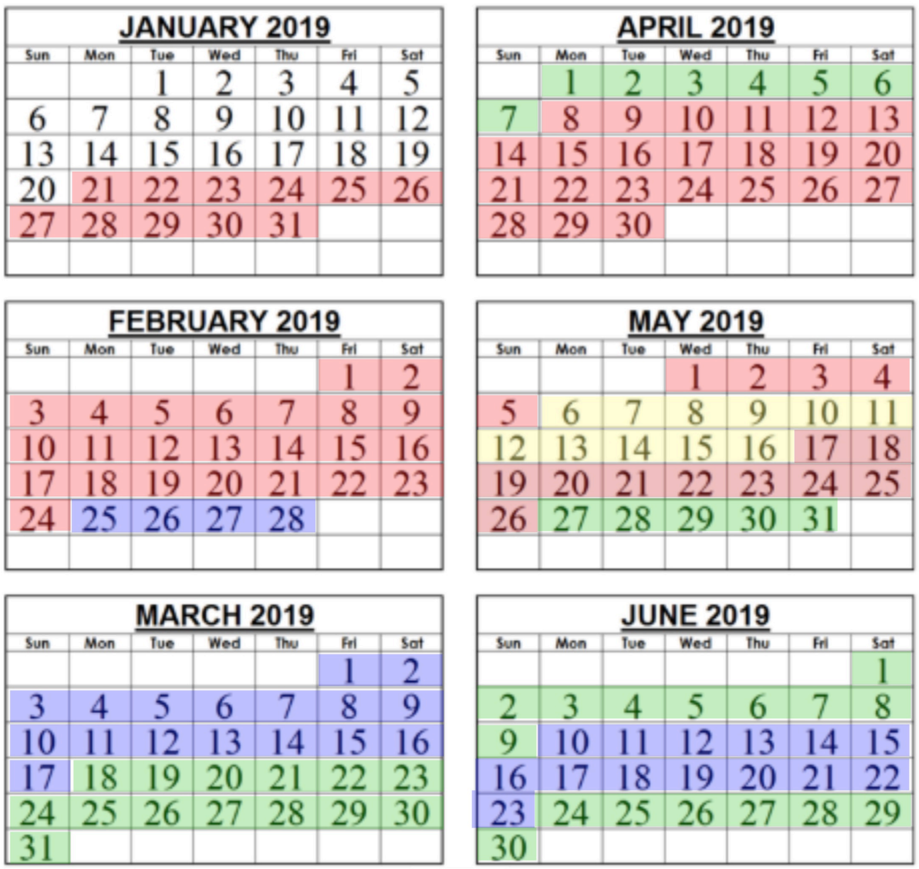


ENC = Equivalent Noise Charge

	Induction	Collection
Raw	630 e^-	550 e^-
After noise filter	500 e^-	450 e^-

Post-beam studies

2019 Calendar



HV+Purity+SCE+T test time

DAQ test time

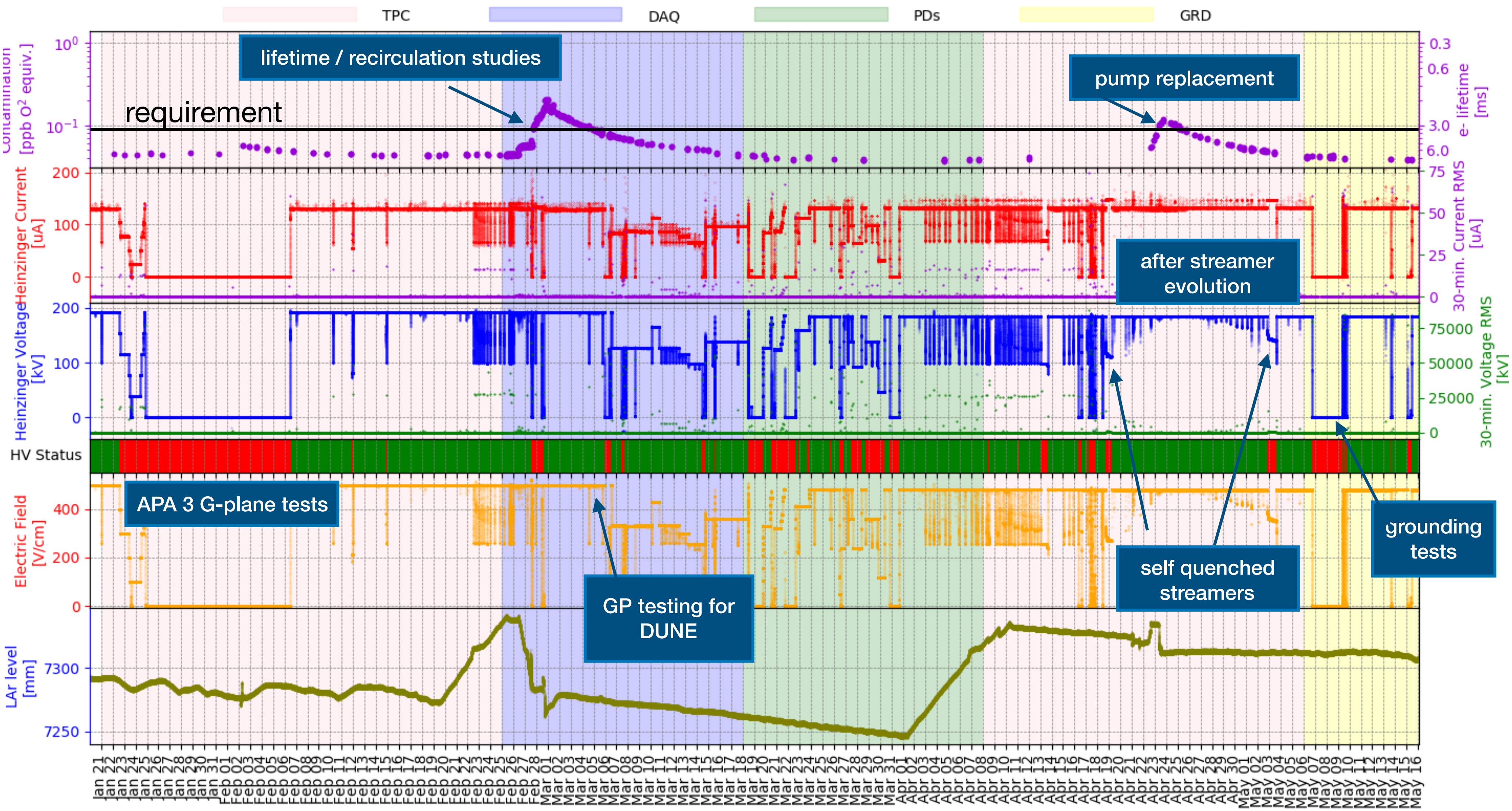
PD test time

Grounding and noise

**CE tests will proceed in parallel to the other tests*

**CE pulser runs and grounding/noise studies will be accommodates in the schedule upon request*

Summary of the protoDUNE-SP activities



2019 Calendar

JULY 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

OCTOBER 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

AUGUST 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

NOVEMBER 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	25	26	27	28	29	30

SEPTEMBER 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

DAQ Tests

DECEMBER 2019

Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

HV+Purity+SCE+T test time

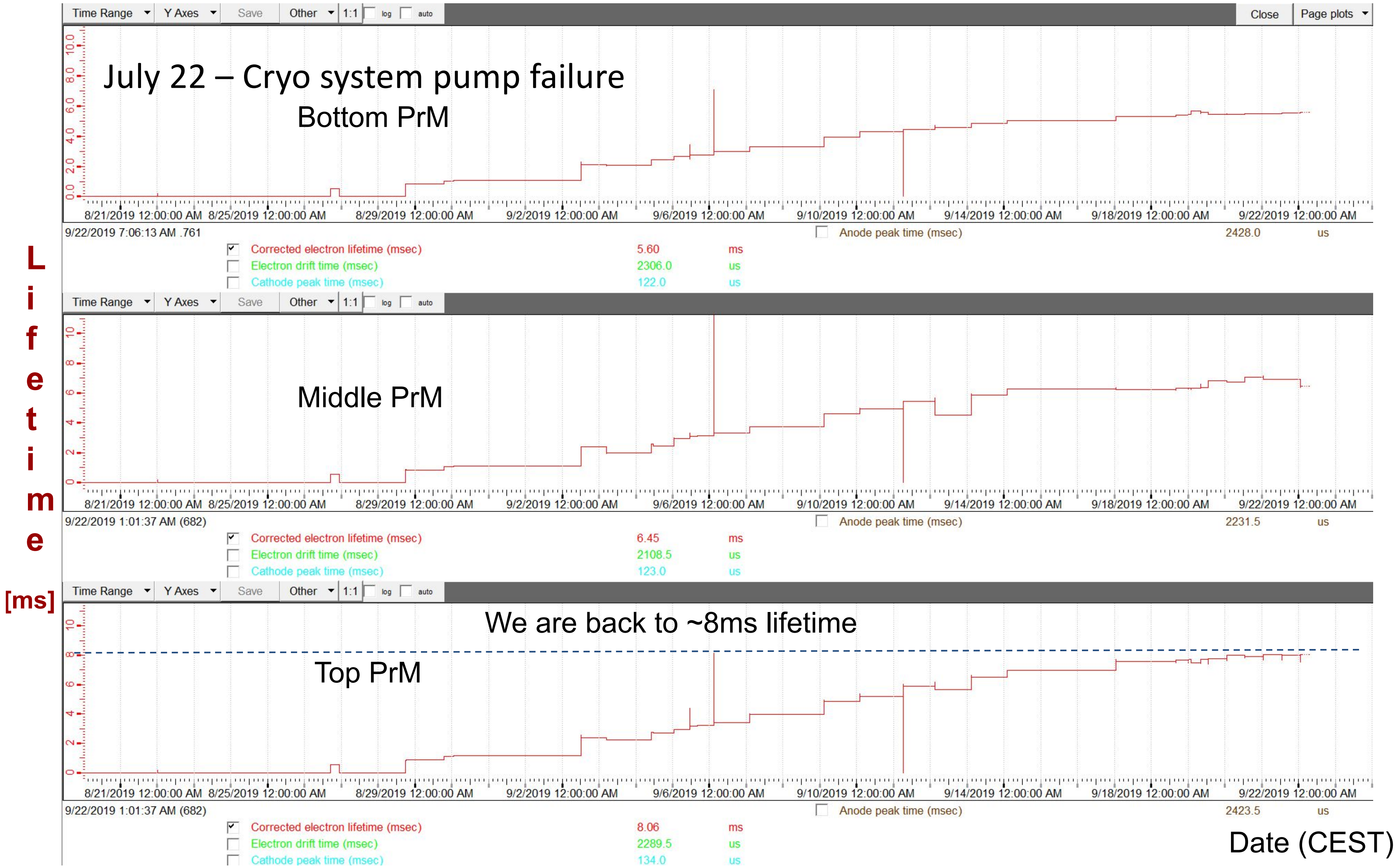
DAQ test time

PD test time

**CE tests will proceed in parallel to the other tests*

**CE pulser runs and grounding/noise studies will be accommodates in the schedule upon request*

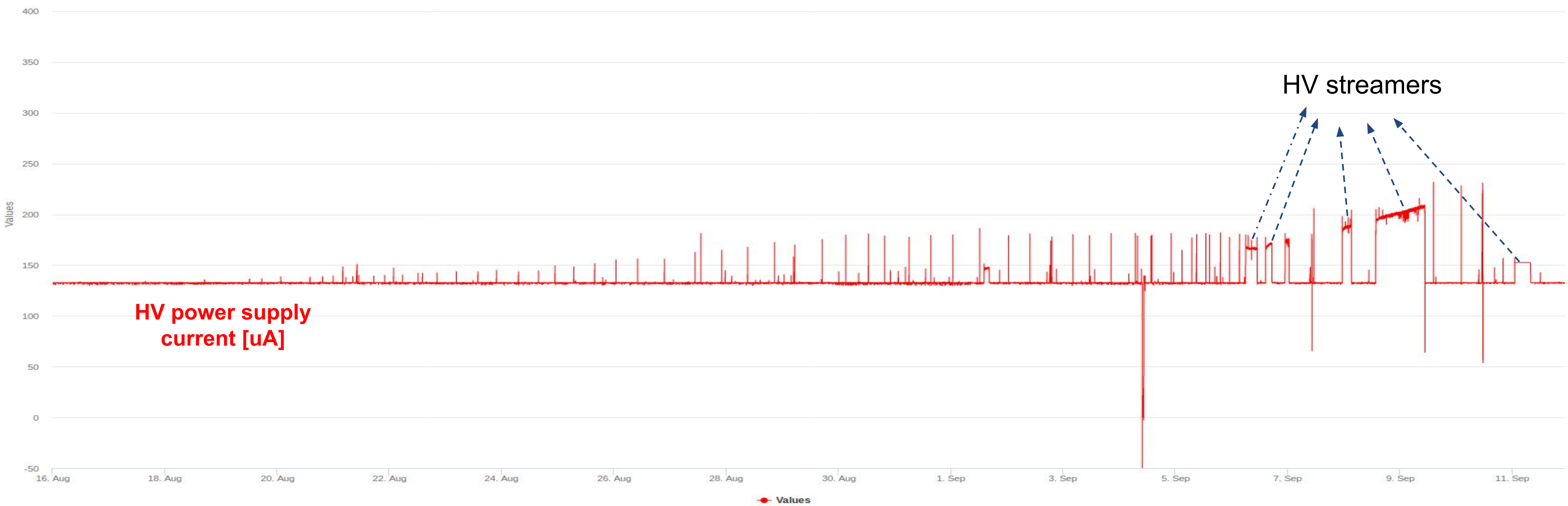
Current status of the lifetime (from purity monitors)



9 **DUNE collaboration meeting - September 2019**

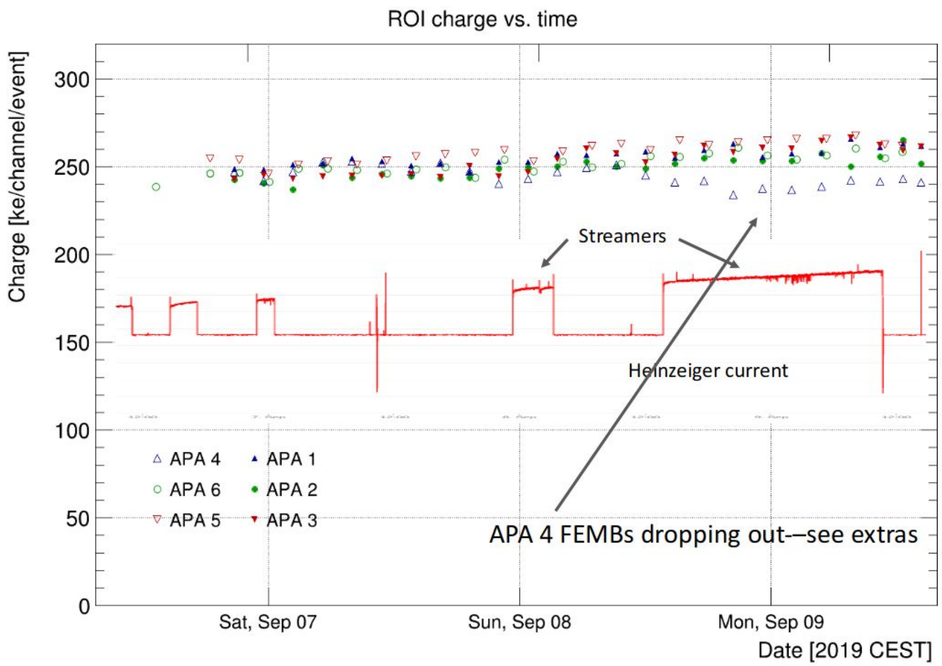
HV activities

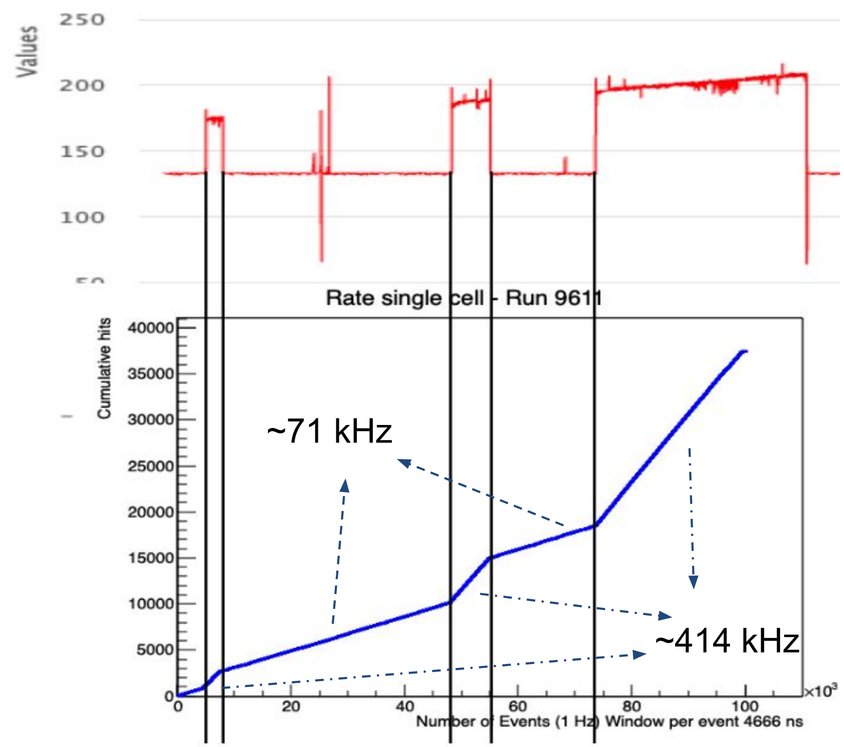
- Running stably @ 180 kV
- HV streamer situation
  - Before the cryo pump failure, we observed a decrease in their frequency from one every ~6 hr to one every ~20 hr
  - With the loss of lifetime, they disappeared, but they are now back again



Consequence of streamers

- Charge collection : no visible effects
- Light collection : increased rate of single p.e.



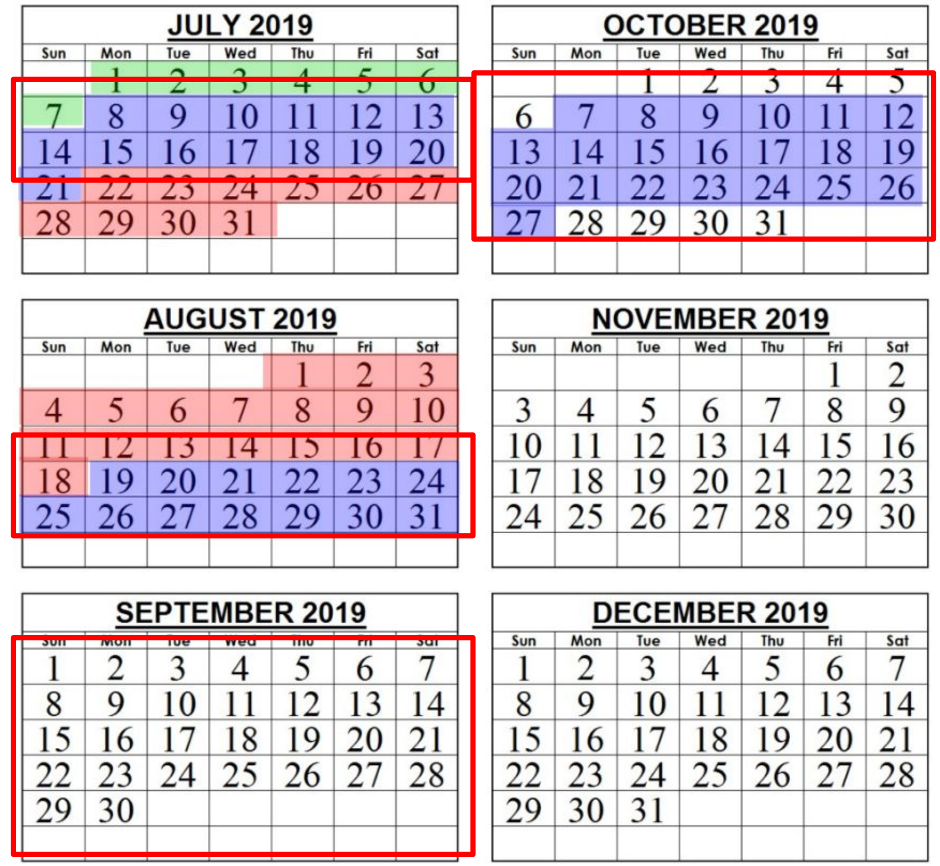


ProtoDUNE SP-II will have modified HV components and enhanced light collection to allow much more study

Fermilab DUNE

Plans for rest of 2019

- Due to lack of lifetime, much DAQ work completed in September
- October is also dedicated to DAQ
- Proposal has been made to study the effect of Xe doping for light collection
- Studies on-going in Building 182 to determine remaining program of studies



APA 7

Test next round of FE Electronics

Ready to go!

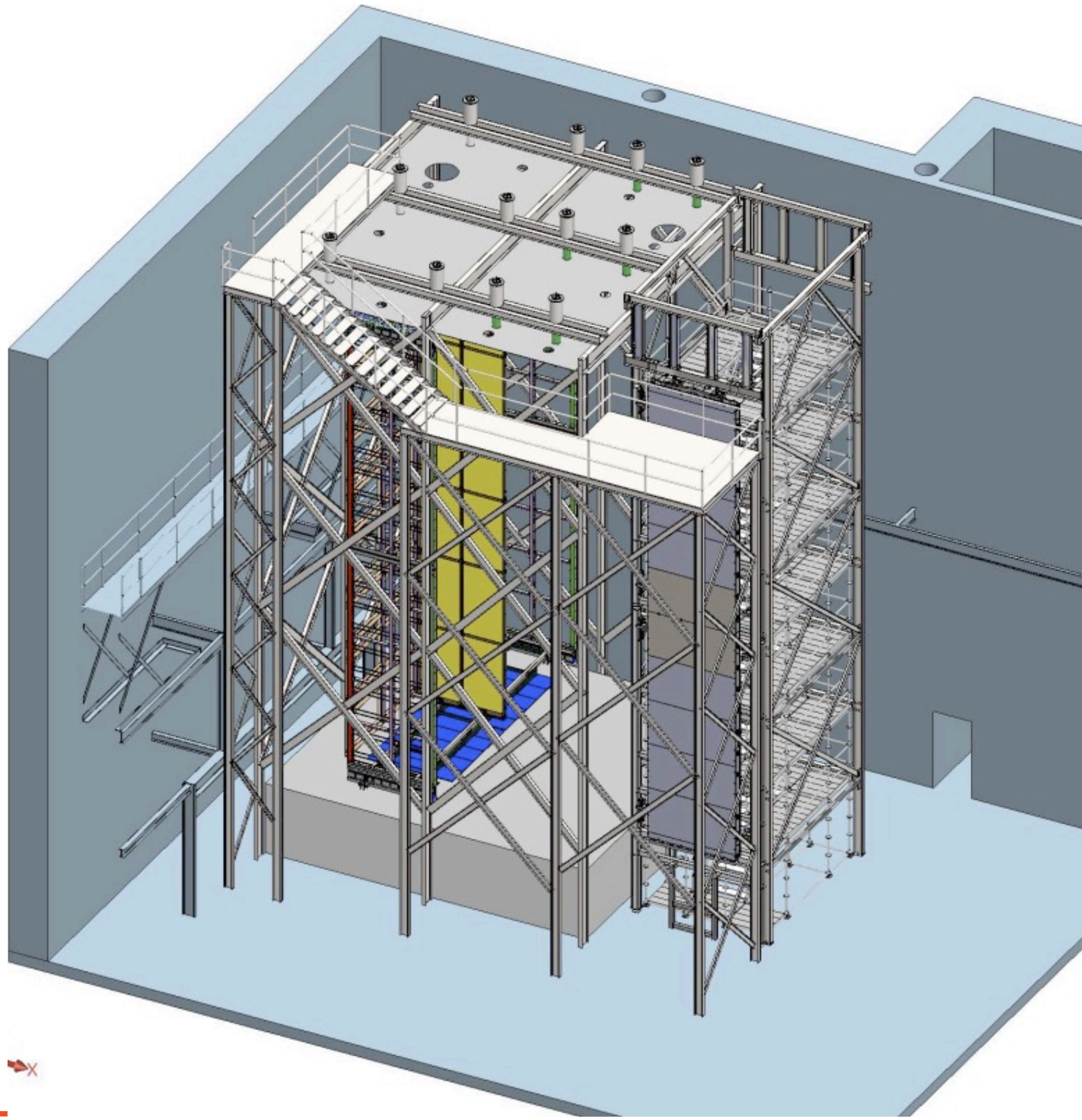
ProtoDUNE → DUNE

Full scale prototyping at Ash River

Installation Workshop
Week of September 30

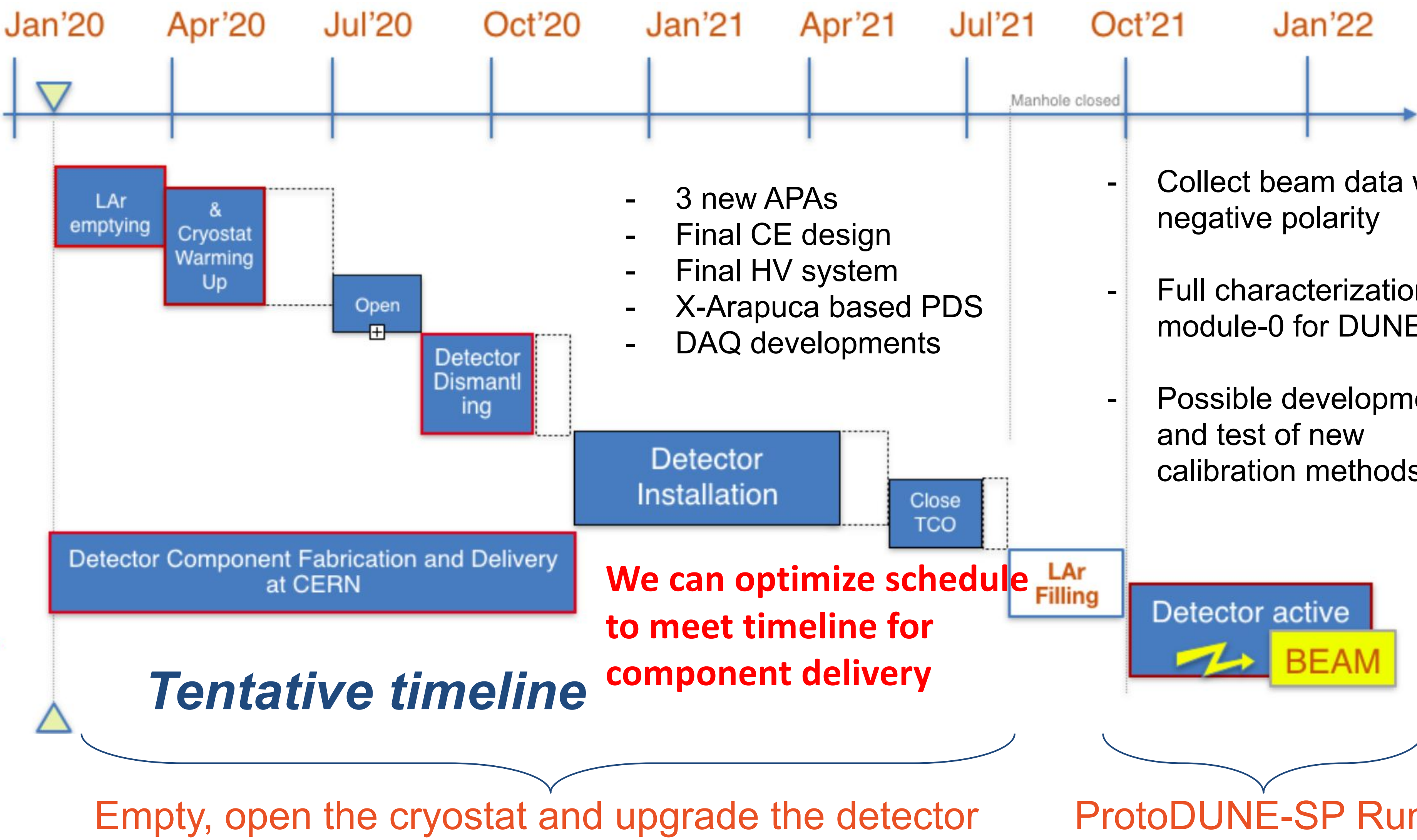
Concentrating on Tooling and Cabling

Ash River Phase 2 : mid-2020



Planning for ProtoDUNE-SP II

Not driven by an immanent beam shutdown, as was case in PD I



- 3 new APAs
- Final CE design
- Final HV system
- X-Arapuca based PDS
- DAQ developments

We can optimize schedule to meet timeline for component delivery

- Collect beam data with negative polarity
- Full characterization of module-0 for DUNE
- Possible development and test of new calibration methods

Matrix today and looking forward

2 Single Phase Modules Responsibility Matrix	US DOE	US NSF	UK	Brazil	Italy	CERN	Canada	Spain	Portugal	Opportunity
SP TPC Electronics System (SP-CE)	**100%**									
SP APA System (SP-APA)		**50%**	**50%**							
SP Photon Detection System (SP-PD)	**10%**									
SP HV System (SP-HV)	**40%**									
SP DAQ System (SP-DAQ)		**18%**	**32%**							
SP Cryo Inst and Slow Control (SP-CISC)										
SP Calibration Systems (SP-CAL)										

	Color code	Detectors
Agreements in place or funding secured		49%
Proposals under review		16%
Proposals in preparation		15%
Aspirational/beginning discussions		2%
Opportunity or Scope Reduction		18%
		100%

- Expect Brazil and Spain to turn from blue to light green in the very near future
- Italy will be more firm once costs for the Near Detector contribution is better understood
- Firming up commitments is tied to development of the Multi-institutional MOU

Summary

- Construction of the DUNE detectors is the responsibility of the international DUNE collaboration through the organization of the Consortia
- The Single Phase Far Detector is at a very high level of design maturity as demonstrated in the successful operation of the ProtoDUNE SP-I
- Many lessons learned from ProtoDUNE have been incorporated into DUNE final designs
- ProtoDUNE-SP-II will provide the opportunity to construct, install and operate DUNE Module 0 components
- Full scale prototyping of components and tooling for installation are on-going at Ash River
- We have a working model that assigns almost all major components for two SP far detector modules to either DOE, NSF or international partners; presented to the international Resources Review Board in September; Progress on MOU to be reported to RRB in April
- Opportunity for further partner contributions exist, in particular, in the areas of instrumentation and calibration