Photon Detection System for ProtoDUNE-SP

Chris Macias, on behalf of the DUNE Collaboration
Indiana University

INDIANA UNIVERSITY

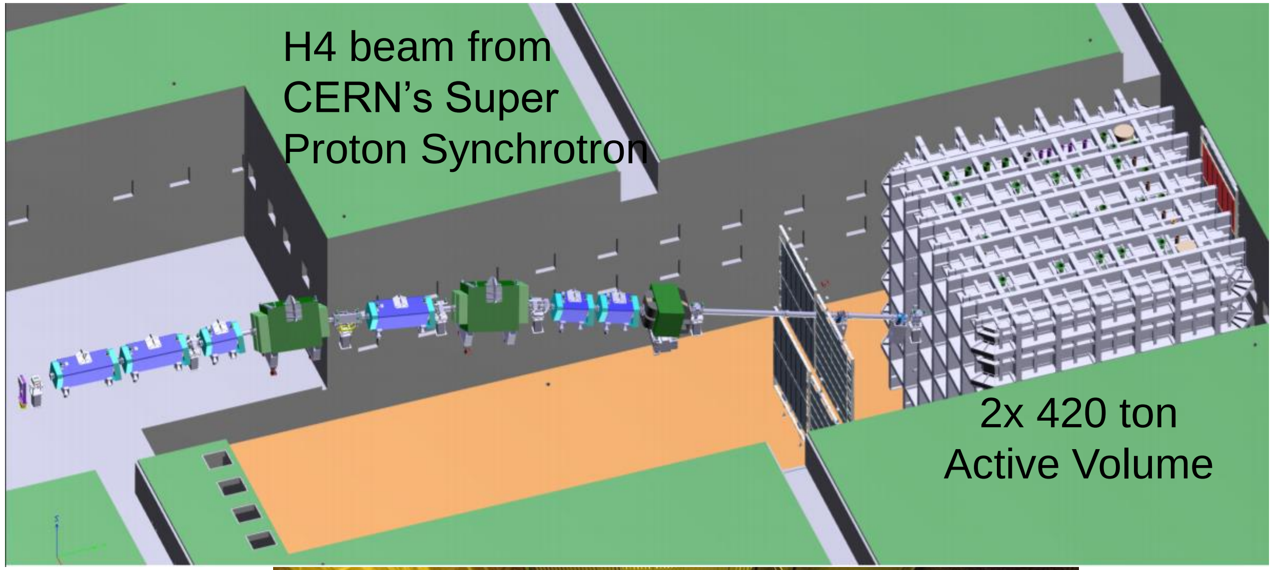
DUNE

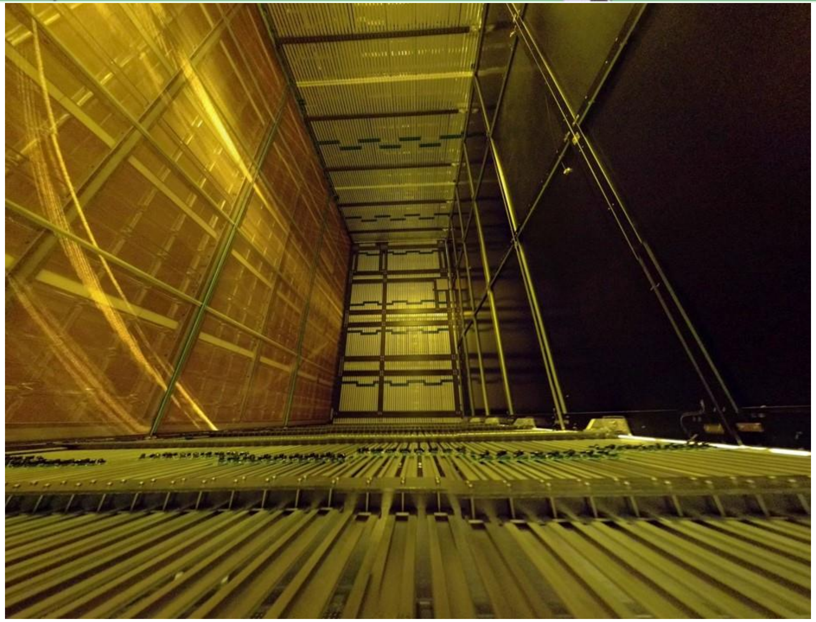
Outline

1. PDS Technologies
   - Double-Shift Light Guide
   - Dip-Coated Light Guide
   - ARAPUCA
2. PDS Commissioning
   - PD module Readout
   - Calibration System
   - Cosmic Telescope
3. Operations
   - SSP Control Panels
   - PDS Data Monitoring
4. PDS Data Available
5. Photosensor Calibration
   - SensL Calibration
   - MPPC Calibration
6. Stability & Rate Analysis (Ongoing)
   - Double-Shifted Modules
   - Dip-Coated Modules

ProtoDUNE-SP

- One of two prototype LArTPC detectors for DUNE
- Largest monolithic single-phase LArTPC detector to be built to date.
  - Located at CERN
- Test-beam data to understand/calibrate response of detector to different
  - Particle types: e±, μ±, π±, K±, p
  - Momentum range: 0.3 – 7 GeV/c
- Validation for a full-scale DUNE detector technology and engineering components
  - Demonstrating long term operational stability of the detector

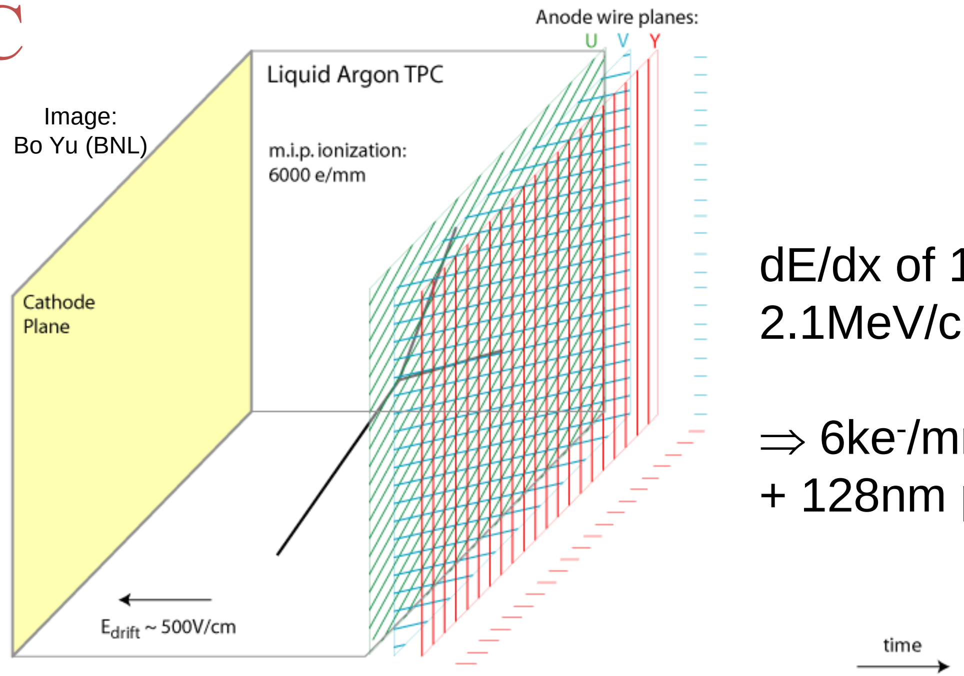




Scintillation Light in Liquid Argon TPC

- MIPs generate 40,000 photons/MeV as they traverse through LAr
  - 24,000 photons/MeV with E-field of 500 V/cm
- In LAr there are two important scintillation methods
  - Self trapped exciton luminescence
  - Recombination luminescence
- Photon Detection System (PDS) provides prompt signal, t0, for precise event time and to increase electron drift resolution.
- For DUNE, the PDS is needed for non-beam event timing
  - Atmospheric neutrinos, proton decay, and SN detection
- PDS goal in LArTPCs is to maximize spatial resolution without affecting functioning of TPC

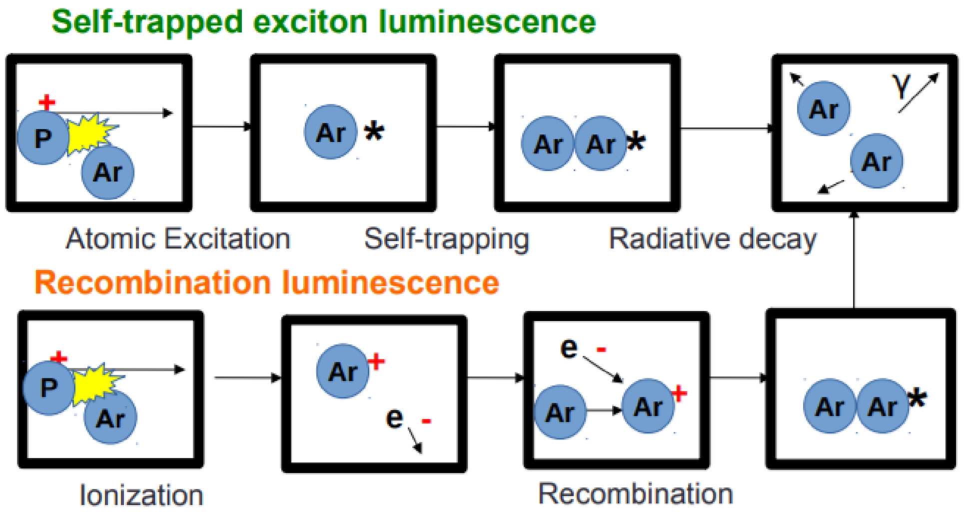
Image:
Bo Yu (BNL)



dE/dx of 1 MIP:
2.1MeV/cm

⇒ 6ke⁻/mm
+ 128nm photons

Image Credit: Ben Jones (MIT)



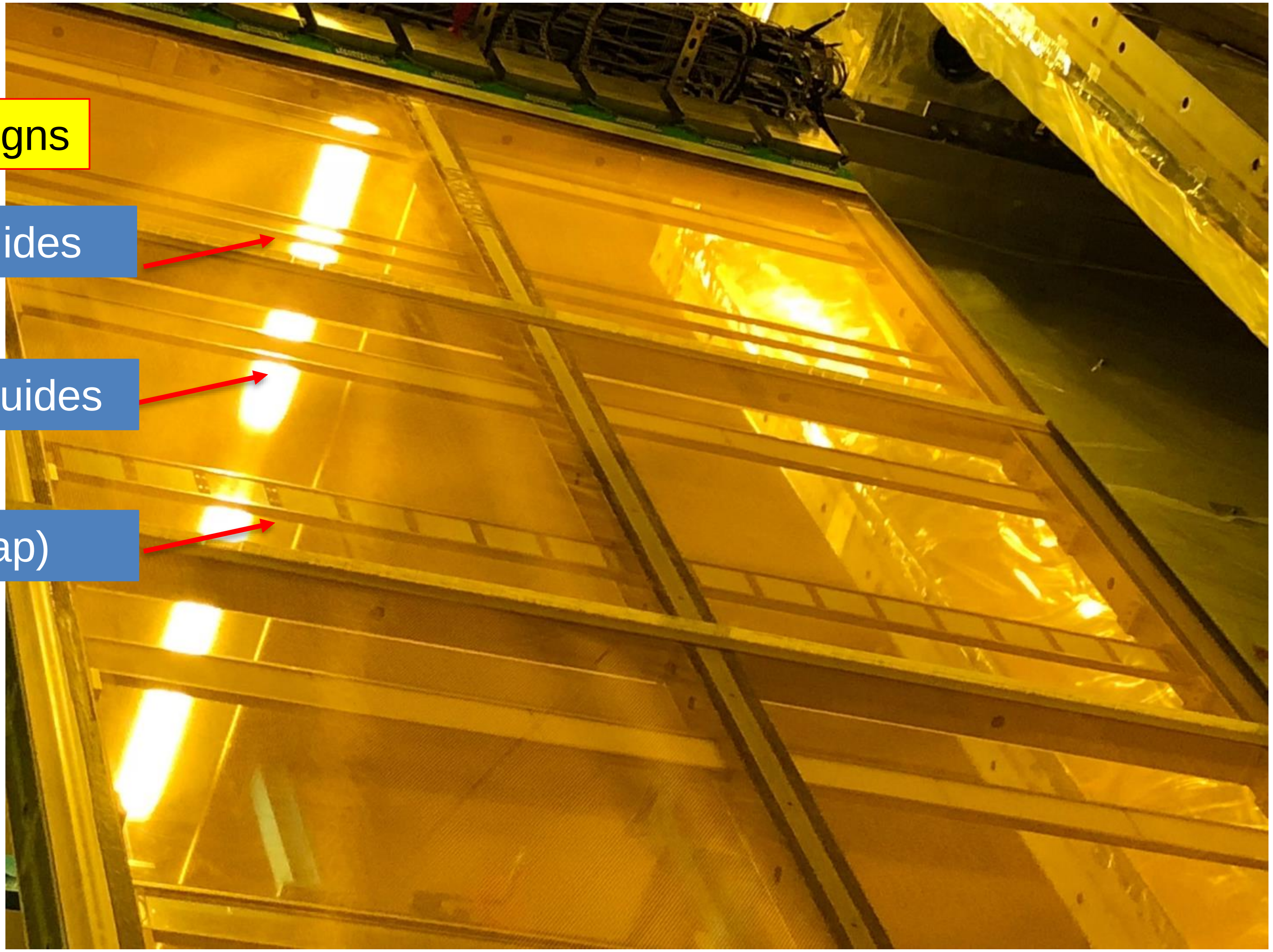
Photon Detector Module Technologies

PD Module Designs

Dip-Coated Light Guides

Double-Shift Light Guides

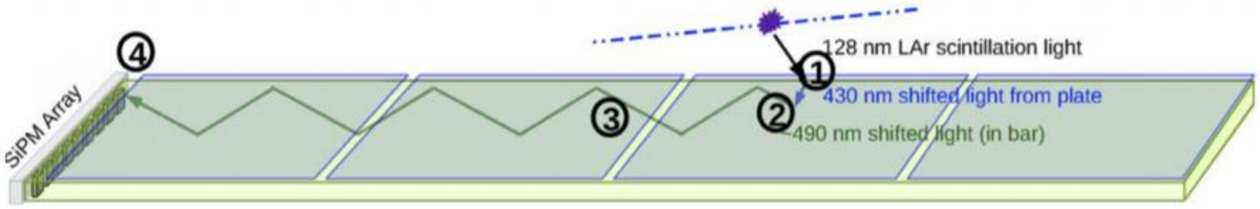
ARAPUCA (Light Trap)

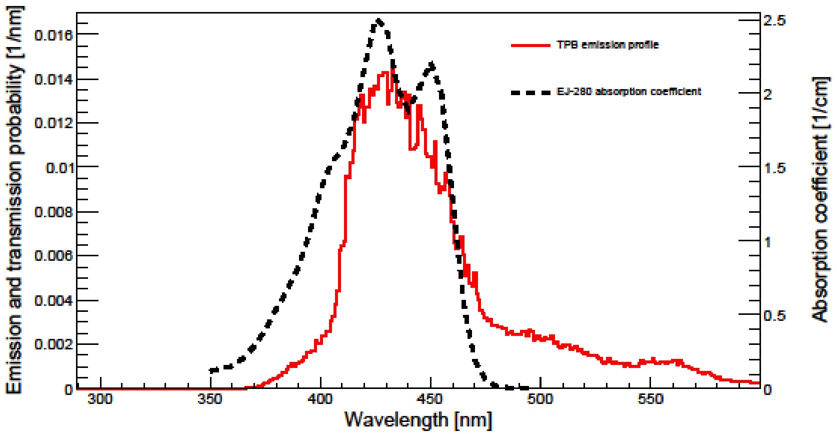


Double-Shift Light Guide

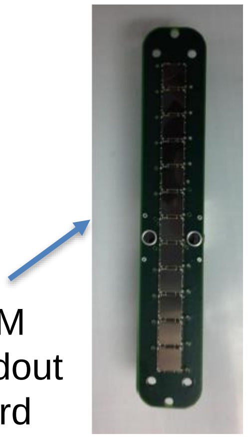
The way it works:

- Spray-coated Tetraphenyl-butadiene (TPB) wavelength shifting (WLS) acrylic plates
  - Scintillated VUV light -> Blue (430 nm)
- Commercial EJ-280 WLS light guides
  - Blue light -> Green (490 nm)
- Transports green light via total internal reflection to photosensors at the end of light guide
- Read out by SensL Silicon Photomultipliers (SiPM)
  - Well matched with light guides WLS emission
  - 3 SiPMs per channel
- 29 6mm x 86 mm x 2094 mm modules in ProtoDUNE

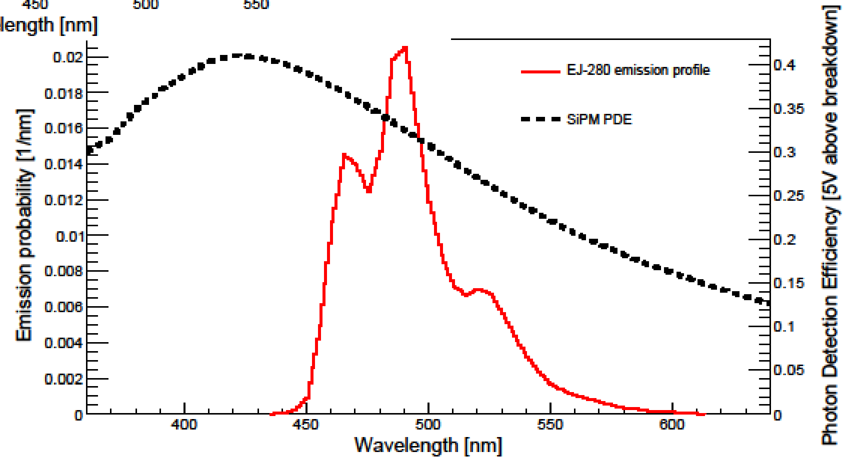




B. Howard et al.
10.1016/j.nima.2018.06.050



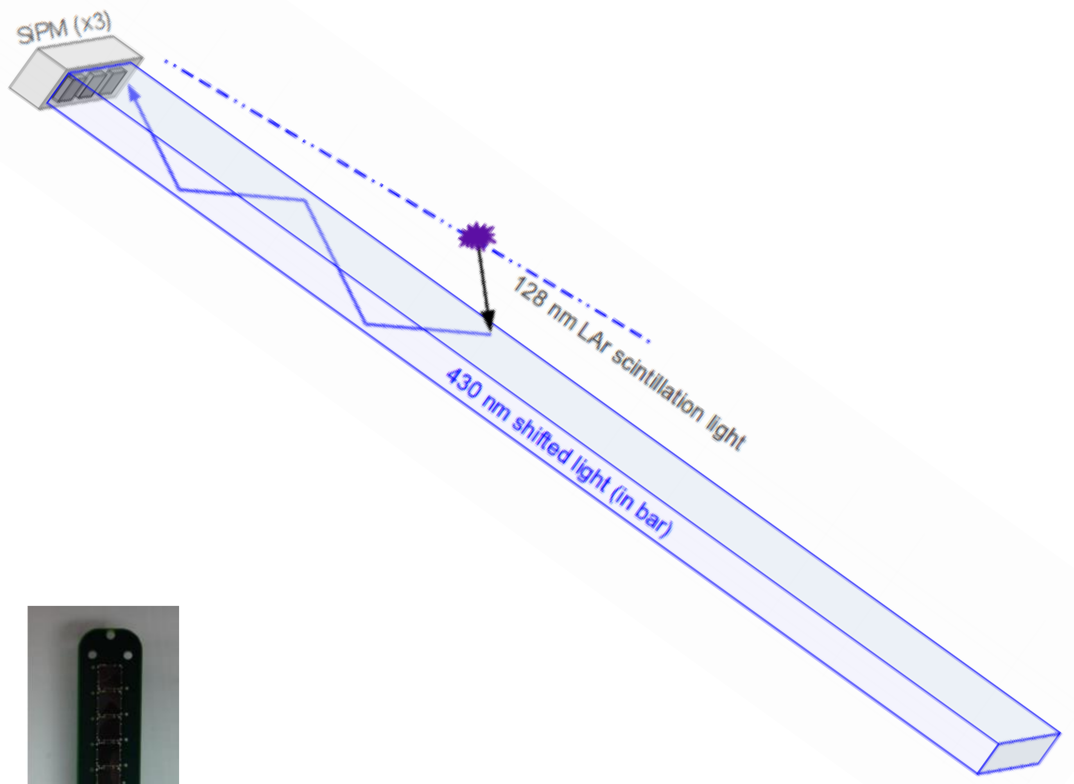
SiPM readout board

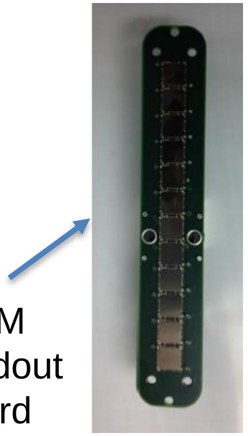


Dip-Coated Light Guide

The way it works:

- Cast, UV-Transmitting Acrylic Light Guide
- Annealed and vertically dip-coated in TPB WL solution
  - Scintillated VUV light -> Blue (430 nm)
- Transports blue light via total internal reflection to end of light guide
- Read out by SiPMs (SensL)
  - 3 SiPMs per channel
- 29 6mm x 86 mm x 2094 mm modules in ProtoDUNE





SiPM readout board

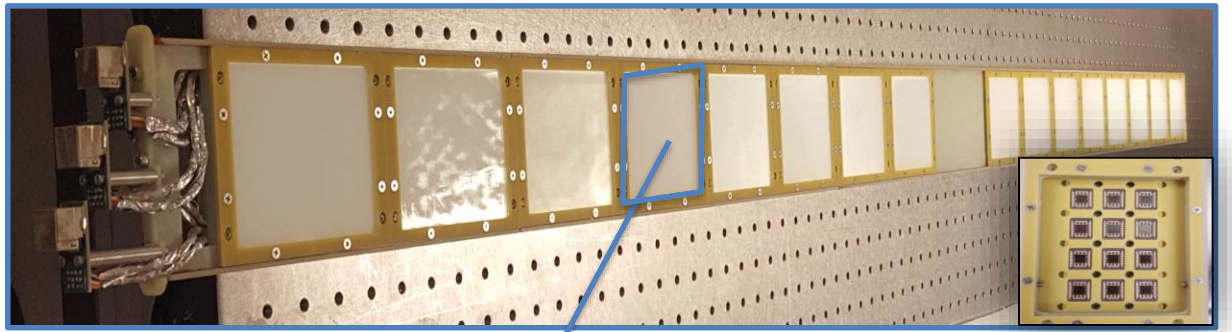
Matt Toups FNAL
Dune-DocDB 5930

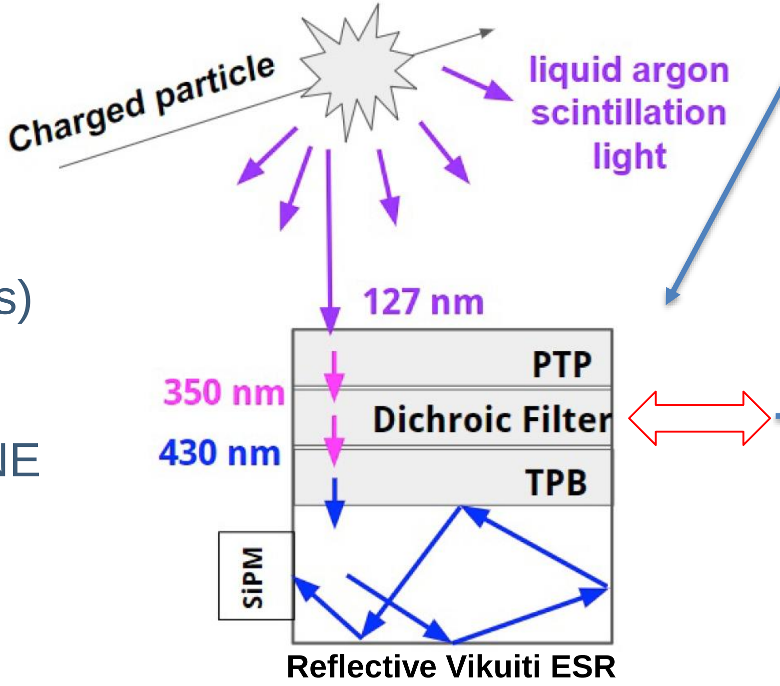
ARAPUCA

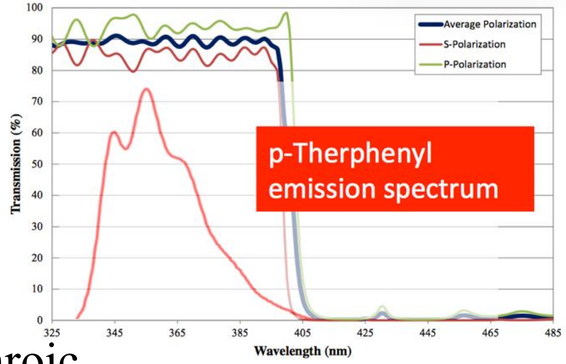
Brazil/FNAL Technology

The way it works:

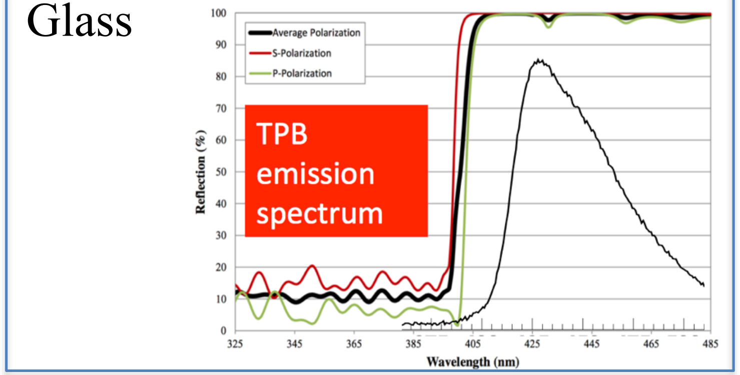
- Dichroic (short-pass) filter < 400 nm
  - P-TerPhenyl (PTP) on outer surface
    - Scintillated VUV light -> 350 nm
  - TPB on the inner surface
    - 350 nm -> Blue (430 nm)
- Highly reflective (trapped)
- Read out by SiPMs (Hamamatsu MPPCs)
  - 12 SiPMs per Channel
- 2 ARAPUCA module arrays in ProtoDUNE
  - 16 cells per module
    - Each cell 78 mm x 98 mm





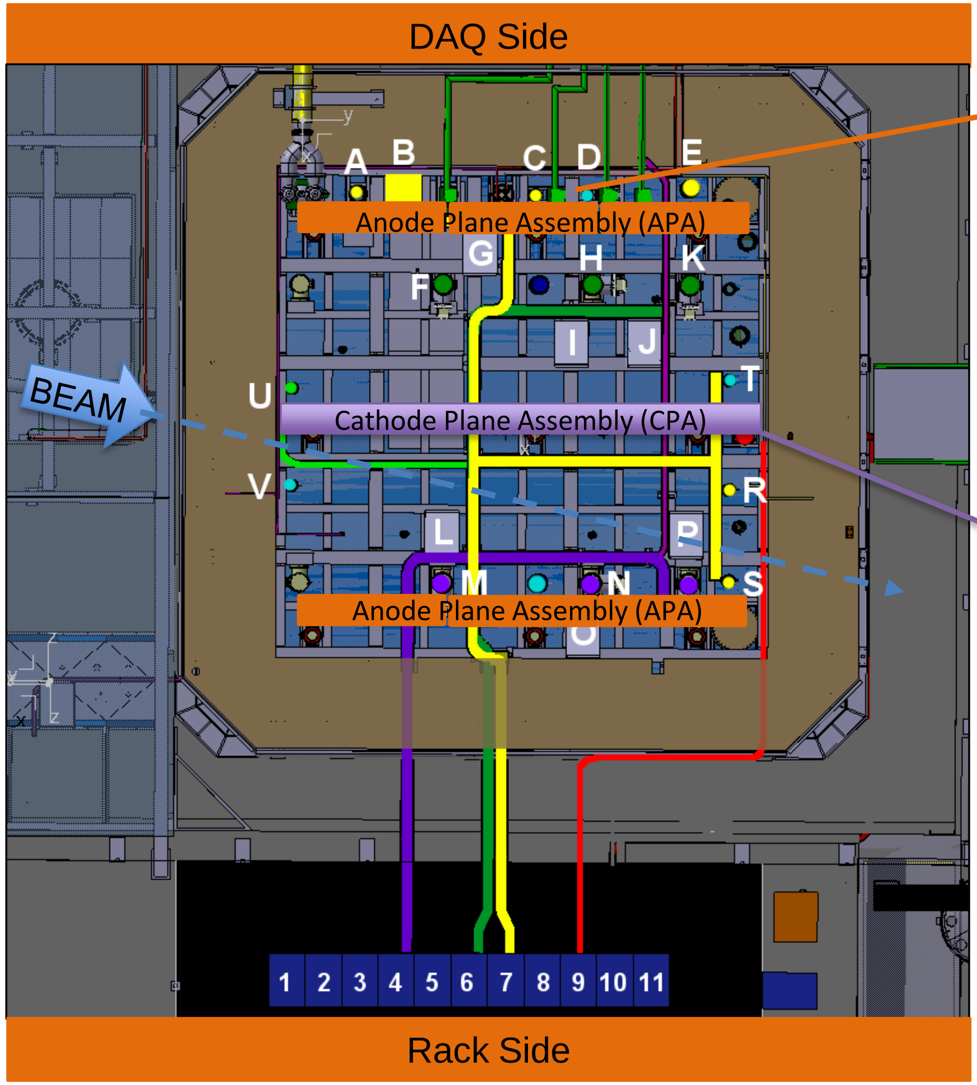


Dichroic Glass



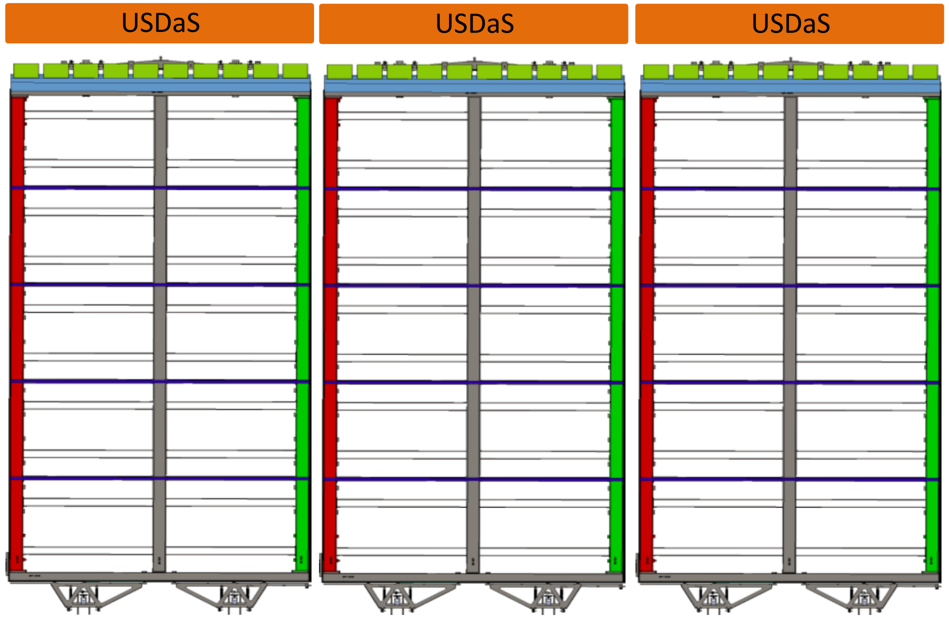
PDS Commissioning @ProtoDUNE

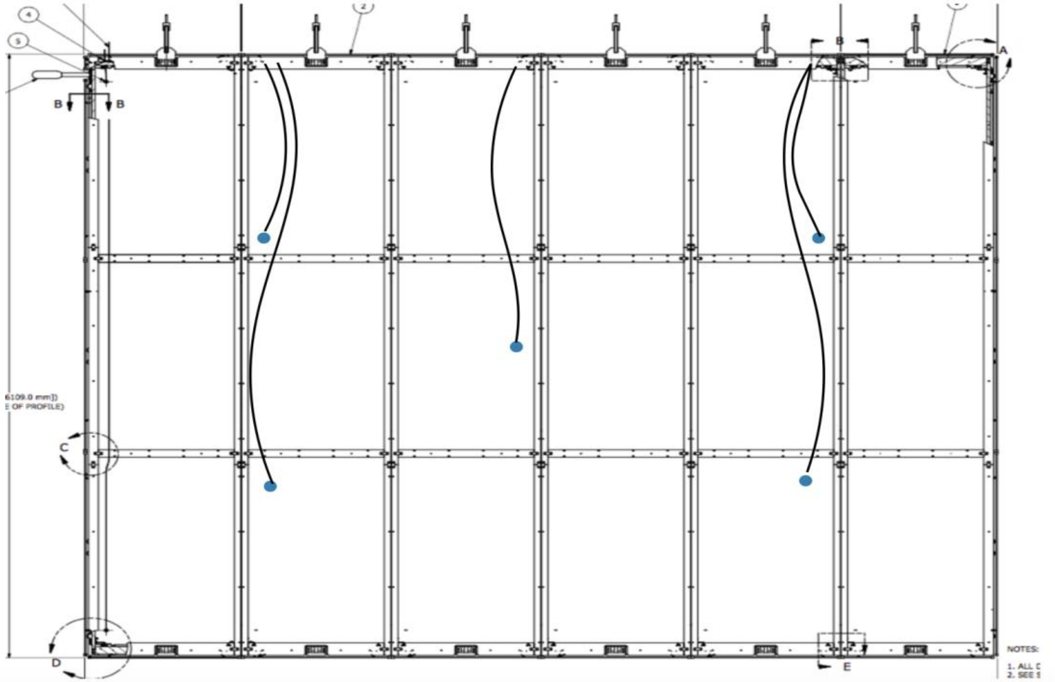
ProtoDUNE Plane Assembly Layout



3 APAs

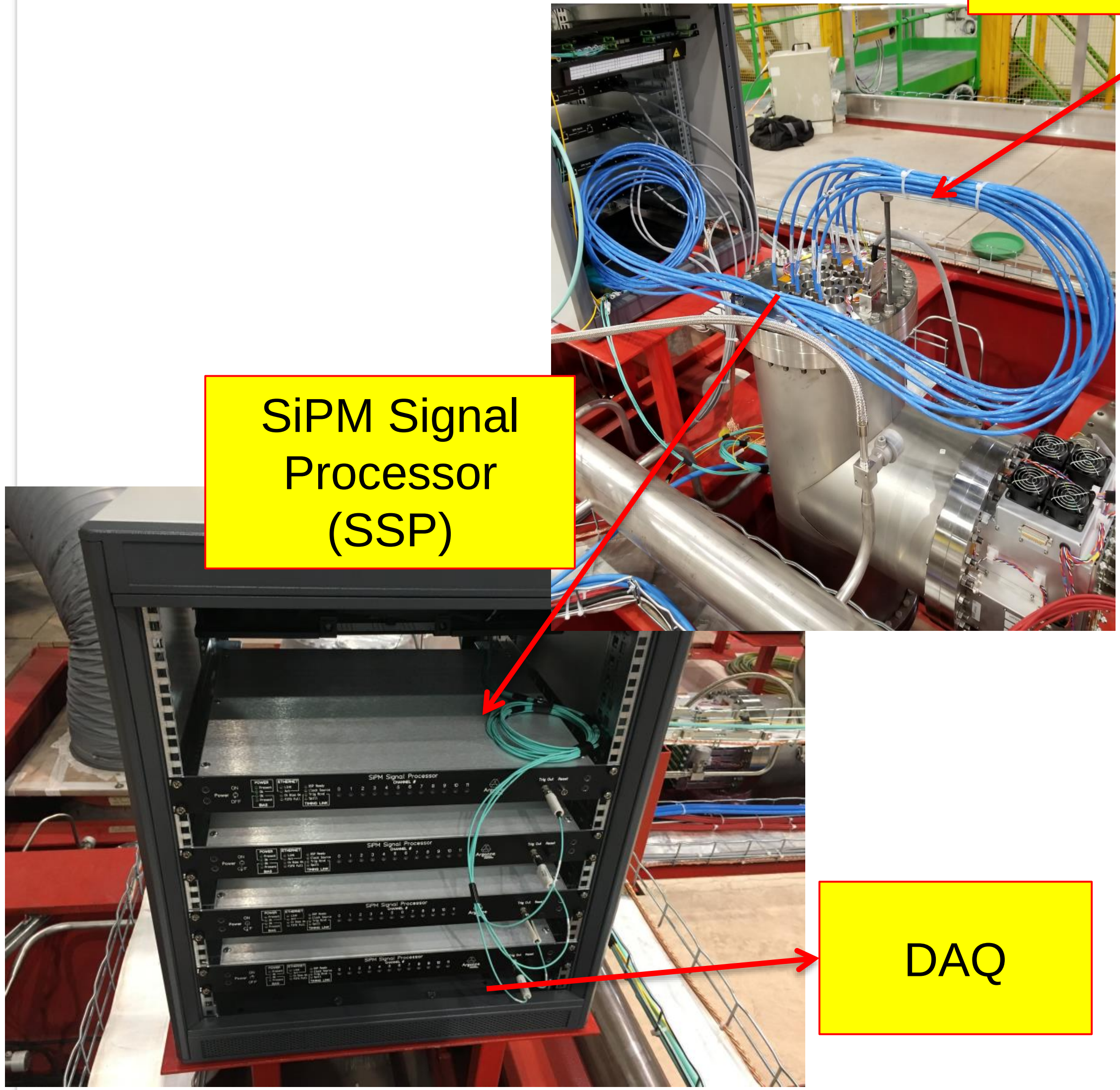
CPA

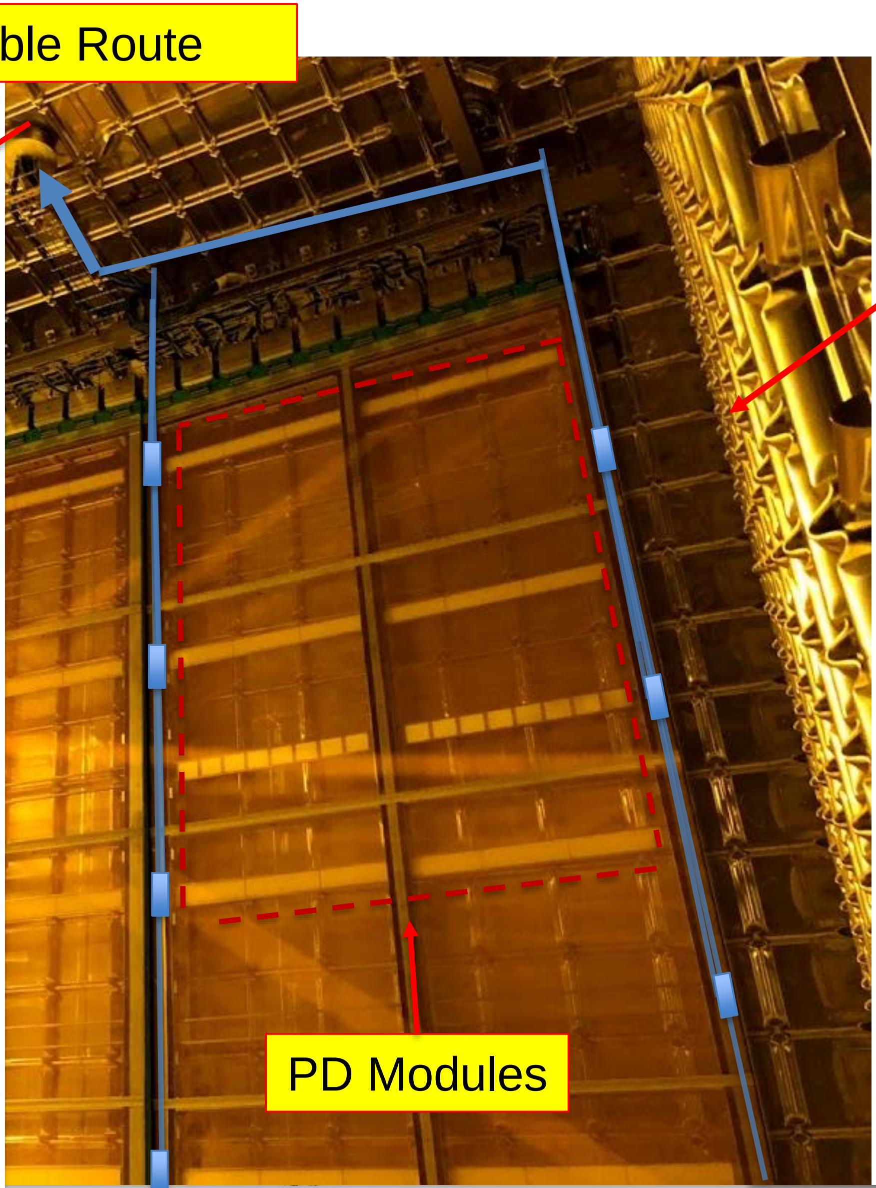


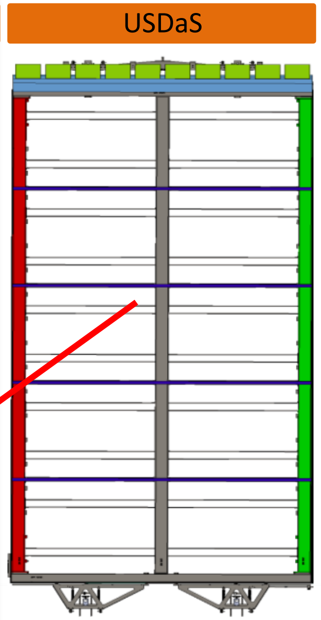


3 APAs

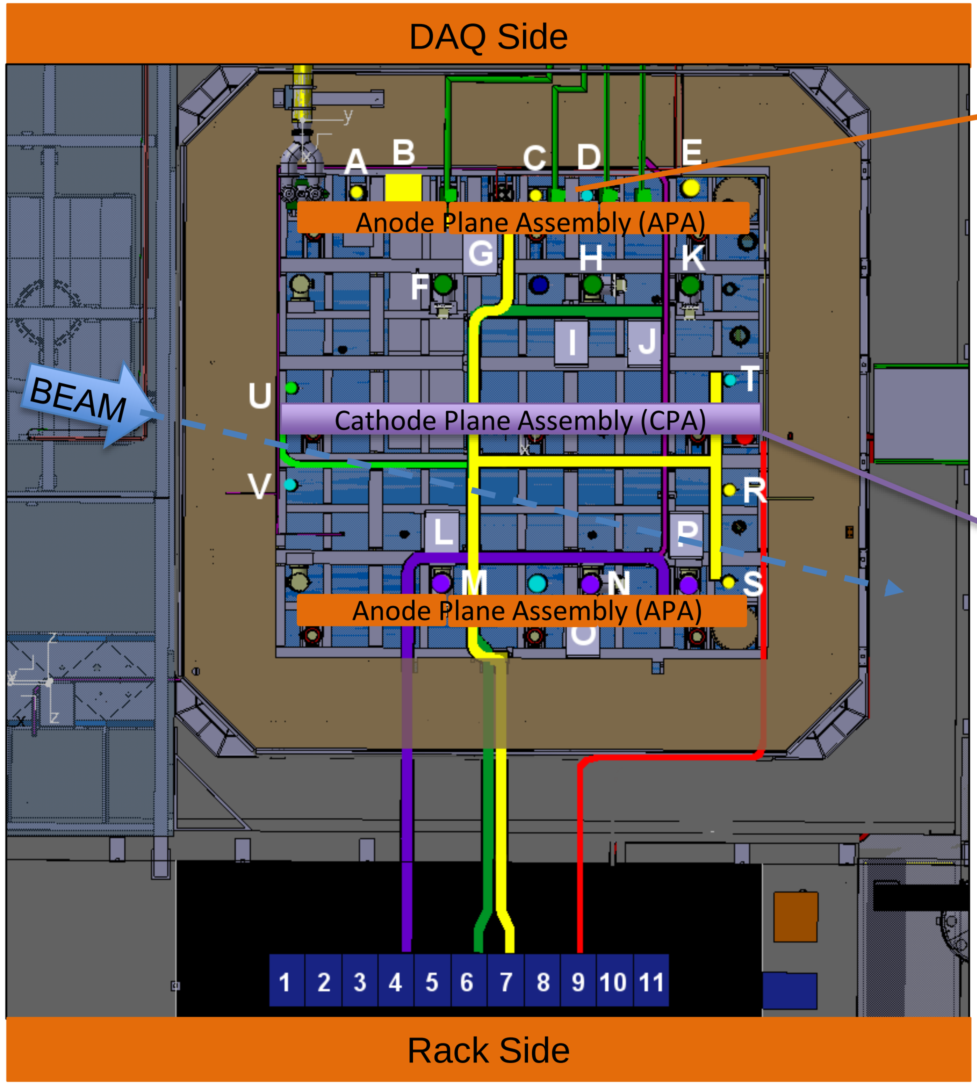
Photon Detector Module Readout





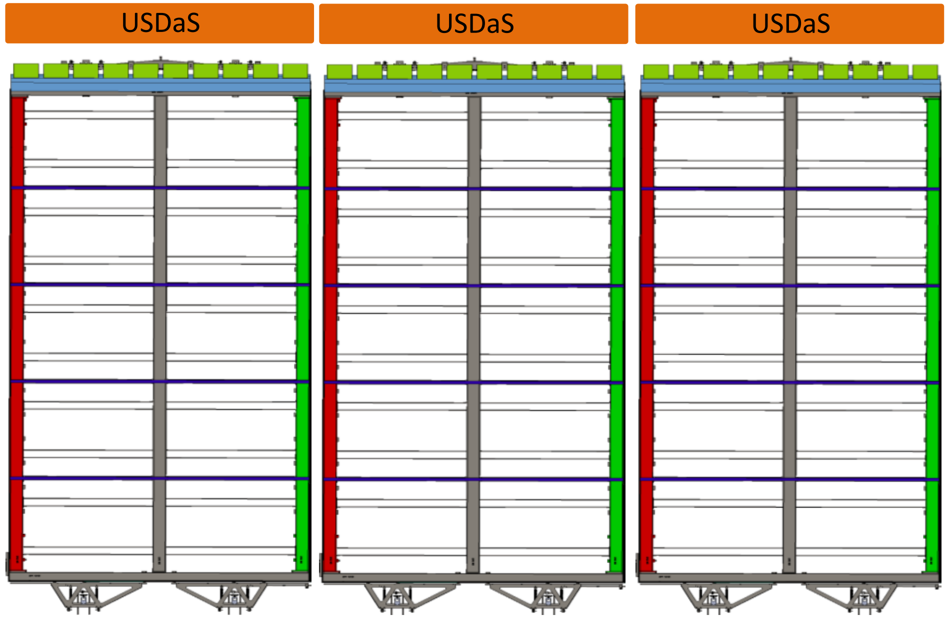


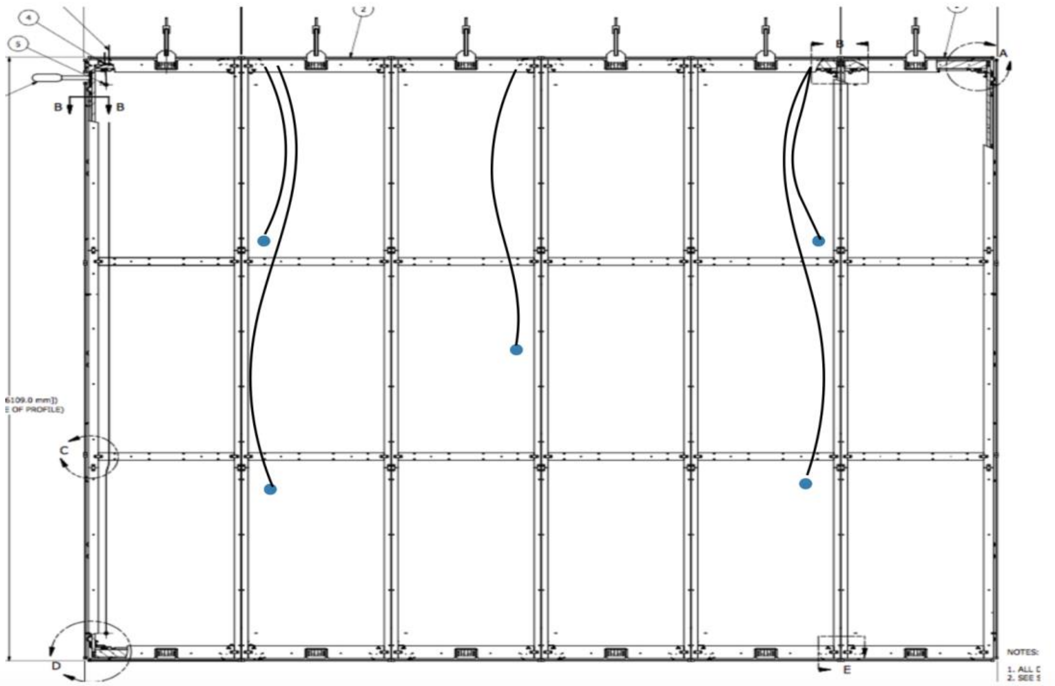
ProtoDUNE Plane Assembly Layout



3 APAs

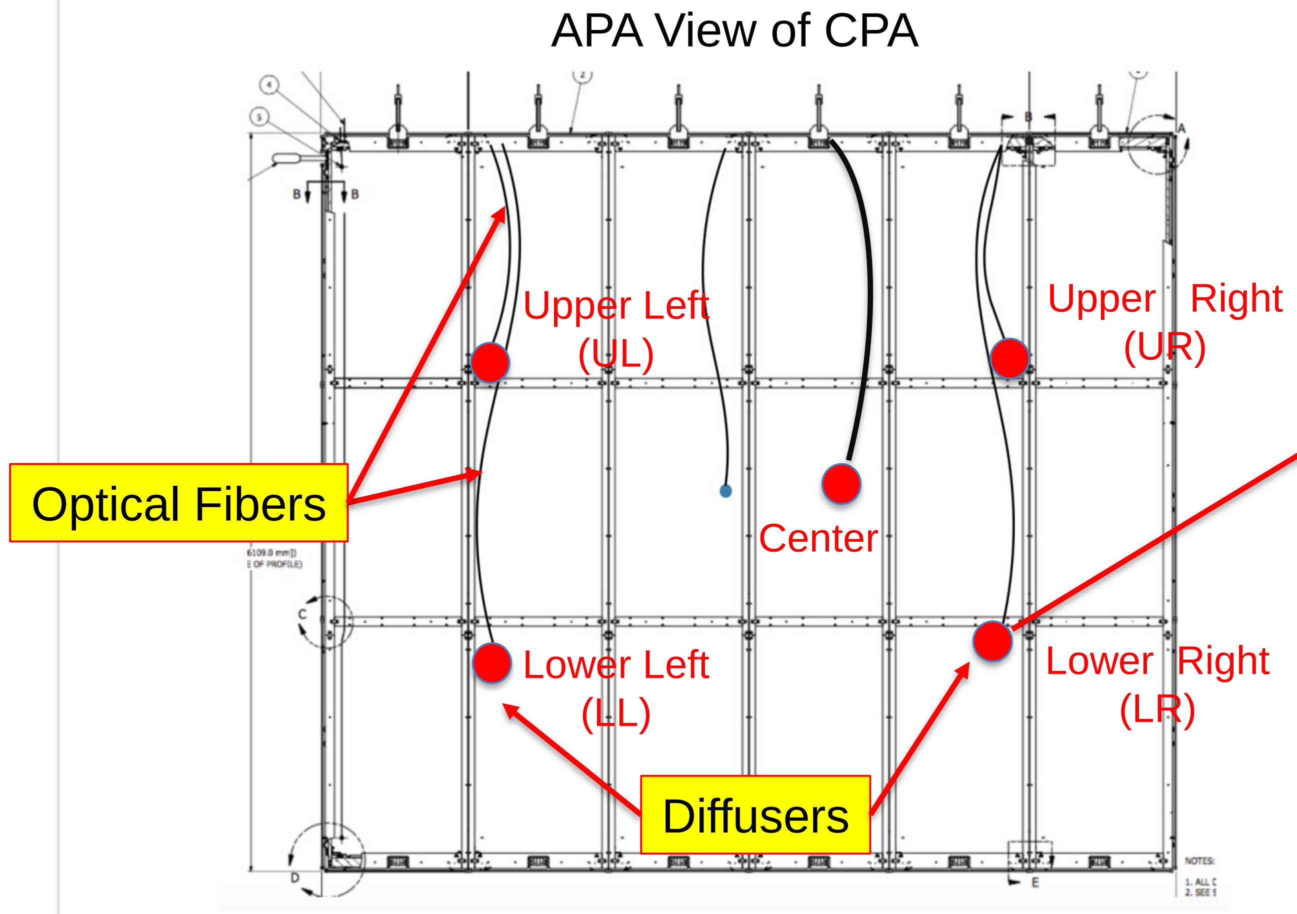
CPA

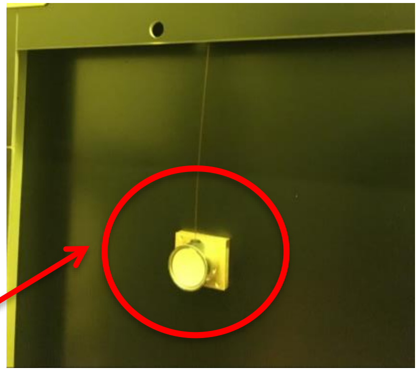


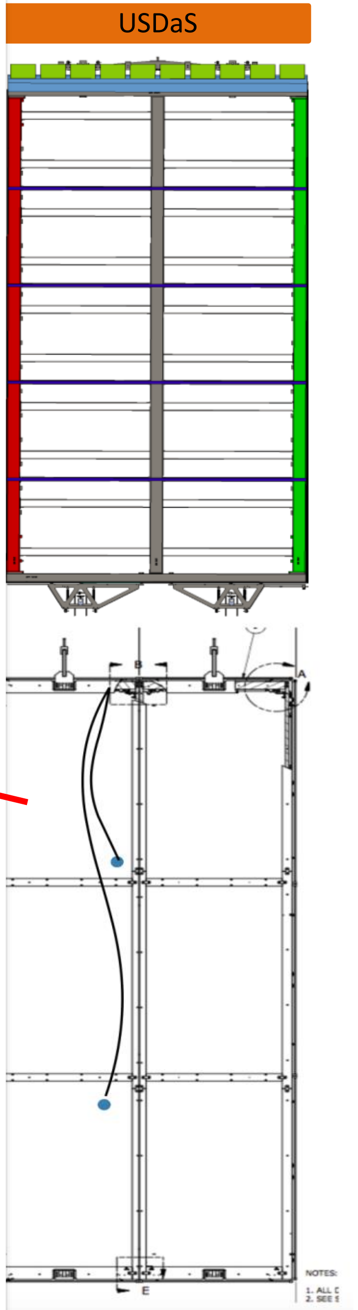


3 APAs

PDS Calibration System





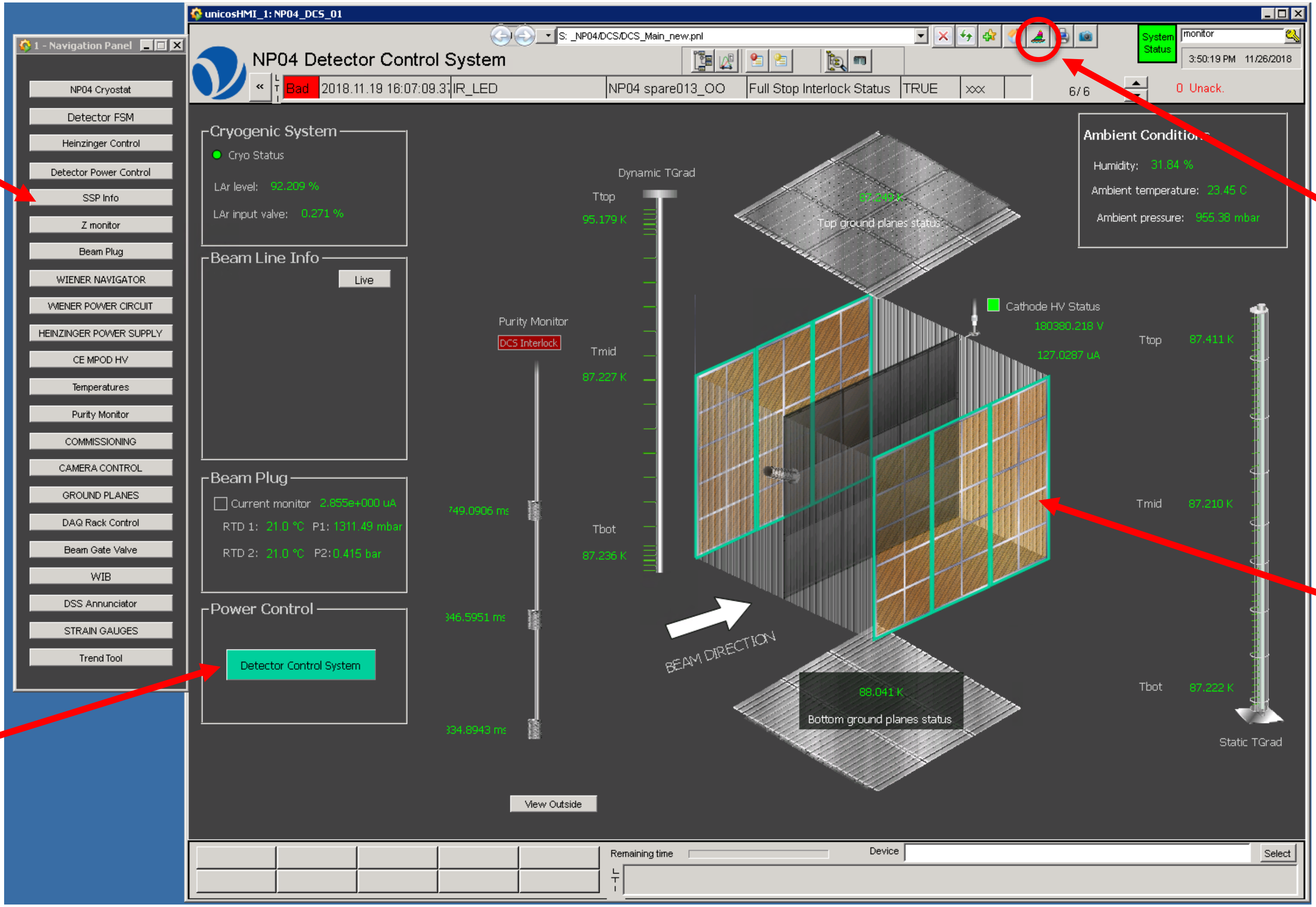


- UV (245 nm to 280 nm) LED
- Quartz fiber-optic cables
- Diffusers
- 5 LEDS per side
- Distributes uniform light to photon detectors

PDS Operations @ProtoDUNE

PDS Control via Slow Control

Navigation to SSP Info Panel

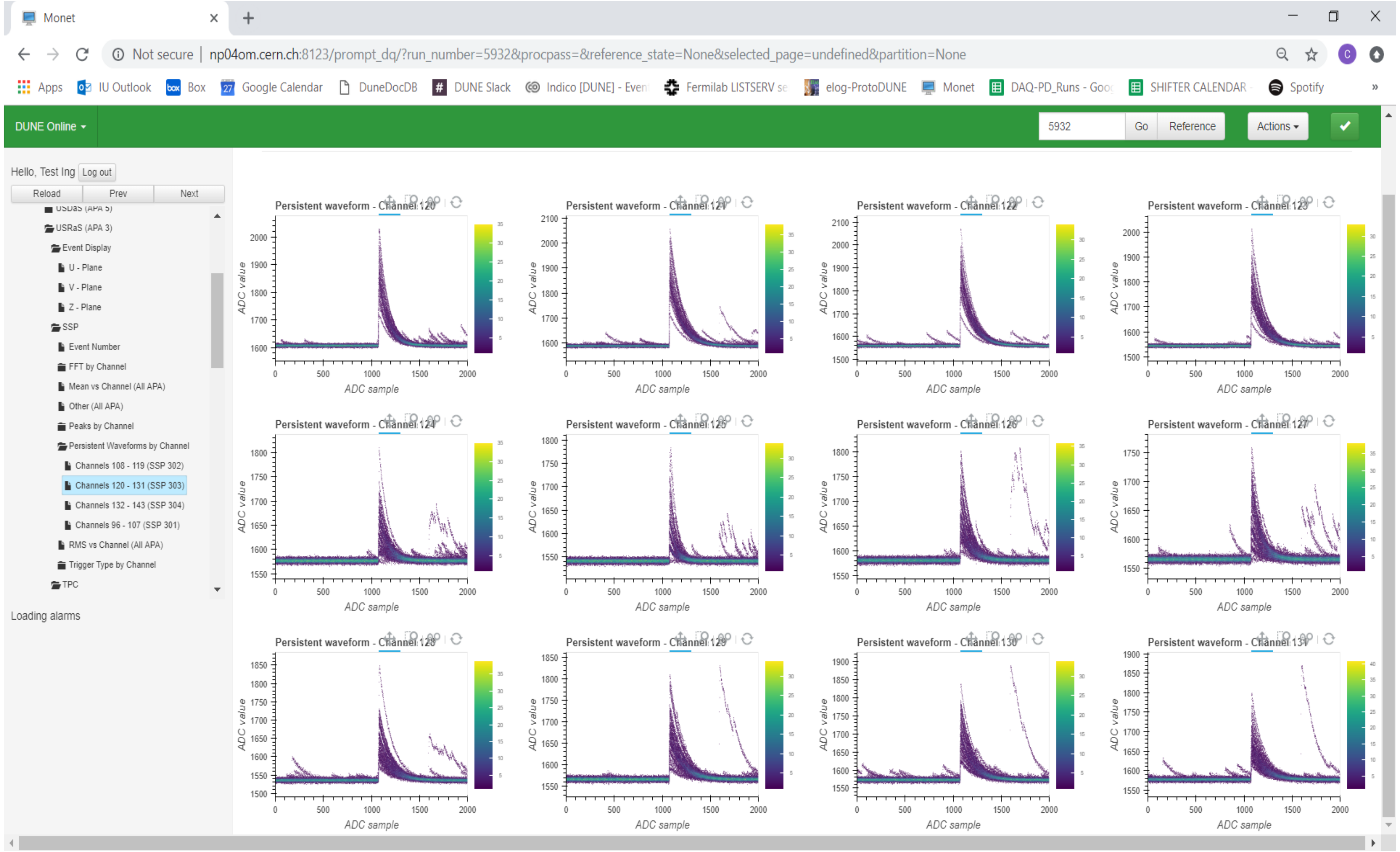


Access to Navigation panel

SSP Control per APA

For Easy Detector Control

Check Live via Online Monitor



Data Available

DAQ-PD_Runs- ProtoDUNE

File Edit View Insert Format Data Tools Add-ons Help Last edit was on June 12

This is a first pass UNFILTERED list of all "good" beam runs. A little more detail of what you're looking at:
<beam momentum from Rob's googlesheet)>, <run #>, <labeled good/bad by shifter>, <labeled physics/cosmic/noise/etc. by shifter>, <config used>, <#of raw data files per run>, <Total Evnts in root file (via meta-data, i.e. not all true beam events)>, <list of SSP thresholds set, per DA
NOTE: File locations for each run has been made, located on a dunegpvm here: "**/dune/app/users/cmacias/Public/pDUNE**"
ex:<momentum>GeV_loc_info contains a txt file for each run, each with a list of file locations

Momentum	Run_Num	Content_Status	Data_Stream	Config_Used	Num_Raw_files	Tot_Evnts	ch0-Thresh	ch1-Thresh	ch2-Thresh	ch3-Thresh	ch4-Thresh	ch5-Thresh	ch6-Thresh	ch7-Thresh	ch8-Thresh
OneGeV	5216	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00001	84	8382	100	100	100	100	100	100	100	100	100
OneGeV	5219	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00001	109	11475	100	100	100	100	100	100	100	100	100
OneGeV	5225	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00002	132	13541	100	100	100						
OneGeV	5235	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00003	227	24135	100	100	100						
OneGeV	5240	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00004	97	10509	100	100	100						
OneGeV	5244	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00005	132	13567	100	100	100						
OneGeV	5249	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	117	12056	100	100	100						
OneGeV	5250	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	126	13156	100	100	100						
OneGeV	5254	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	27	2286	100	100	100						
OneGeV	5257	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	153	16297	100	100	100						
OneGeV	5258	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	279	30113	100	100	100						
OneGeV	5259	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	144	15749	100	100	100						
OneGeV	5260	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	378	40259	100	100	100						
OneGeV	5261	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	108	11447	100	100	100						
OneGeV	5267	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	252	27049	100	100	100						
OneGeV	5276	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	547	58801	100	100	100						
OneGeV	5282	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	234	24591	100	100	100						
OneGeV	5283	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	567	60824	100	100	100						
OneGeV	5284	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	1005	108305	100	100	100						
OneGeV	5287	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	693	73965	100	100	100						
OneGeV	5290	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	1260	135988	100	100	100						
OneGeV	5293	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	144	16716	100	100	100						
OneGeV	5298	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	24	[illegible]	100	100	100						
OneGeV	5301	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	8	122	100	100	100						
OneGeV	5303	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	[illegible]	17820	100	100	100						
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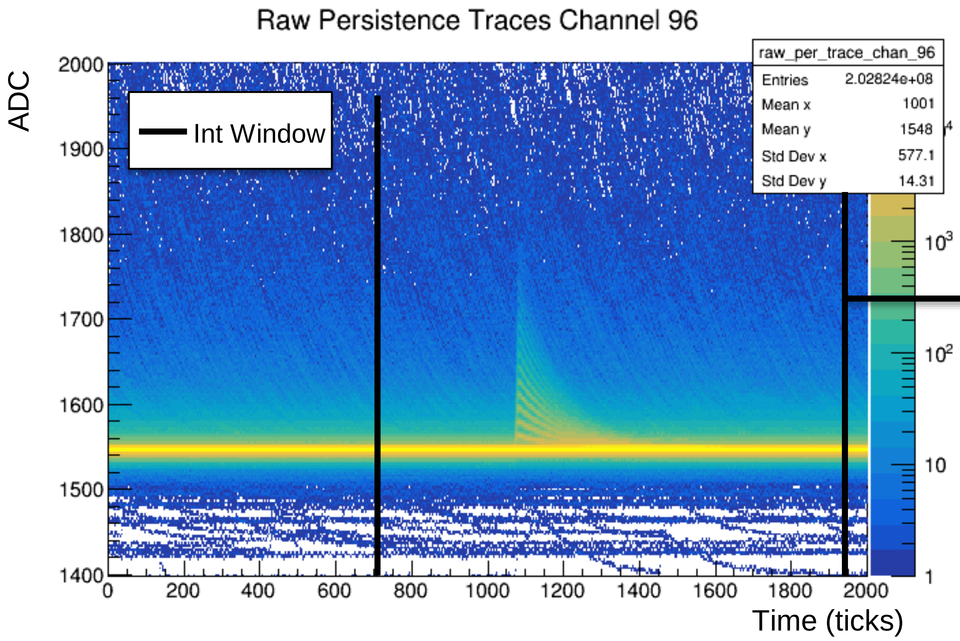
OneGeV	5311	good	physics	np04_WibsReal_Ssps_BeamTrig1GeV_00008	475	50893	100	100	100	100	100	100	100	100	100

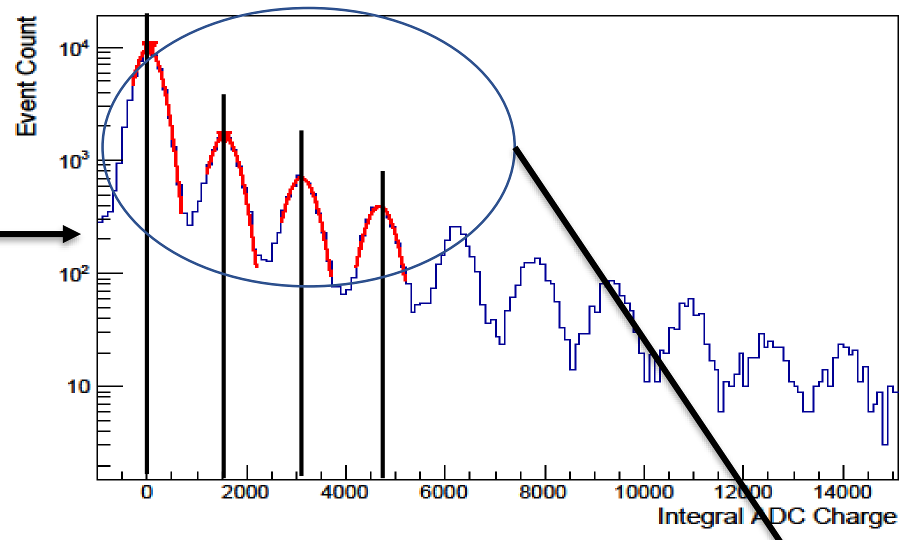
Beam Runs | PD Bias scan | DCM runs | CRT runs | Cryostat Fill Tests | Bad CH | APA5-USDaS Cold Tests | APA5-USDaS Warm Tests | APA4-DSDaS Cold Tests

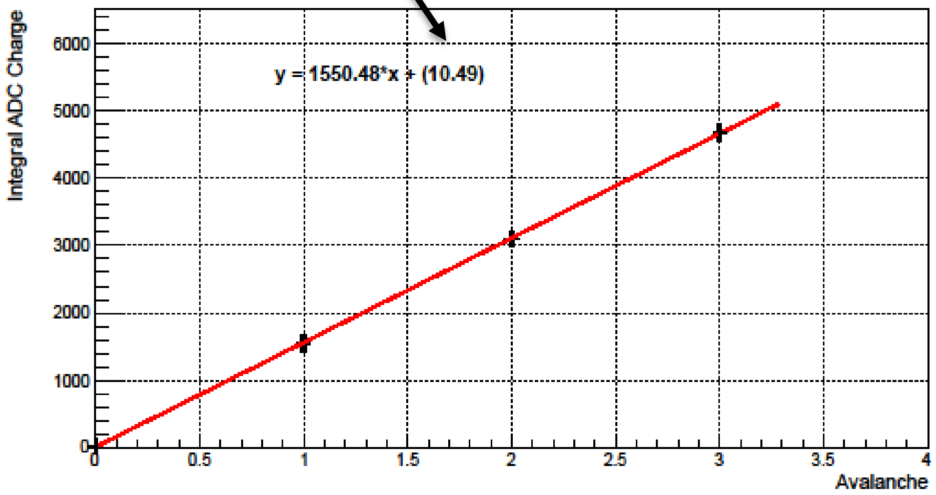
- Beam Data
- Cosmic Data
- Calibration Data
  - LED Triggers
  - Random Triggers

Photosensor Calibration @ProtoDUNE

Calibrations- ADC/Avalanche



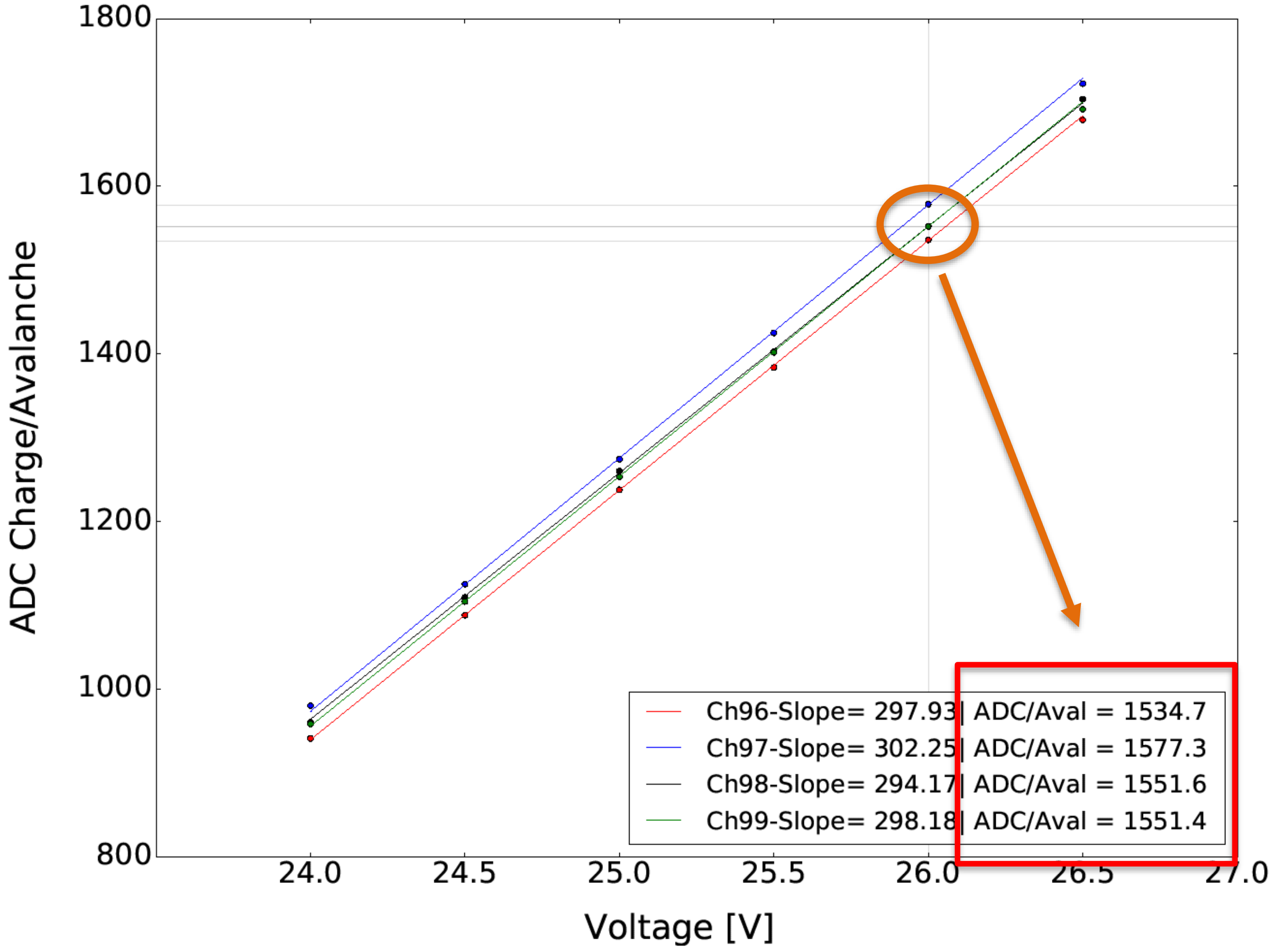




- Integration intervals - [700,1975] x 6.67ns samples
- Fit the first 4 Avalanche peaks with a gaussian
  - Fit range - [Peak-500, Peak+500]
- Linear Fit, via TF1 fit, using
  - mean of each peak
  - sigma as error

ADC/Avalanche vs. SiPM Bias Voltage

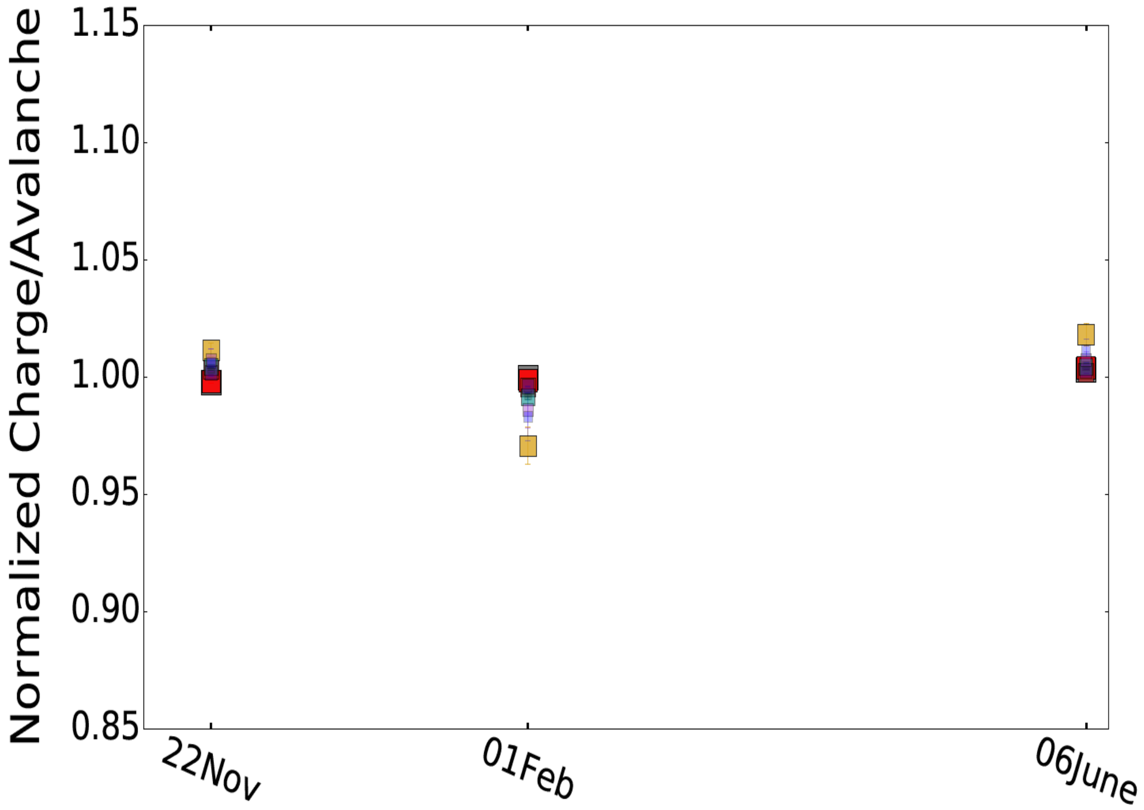
Consistent Gains!



Determination of ADC/Avalanche Constant @ Nominal Voltage

Gain Stability

- Mean Charge/Avalanche per Module
  - Double-Shift & Dip-Coated Modules
    - SensL Devices
- Over 7-month time span
- Normalization
  - Mean(module gain) over time



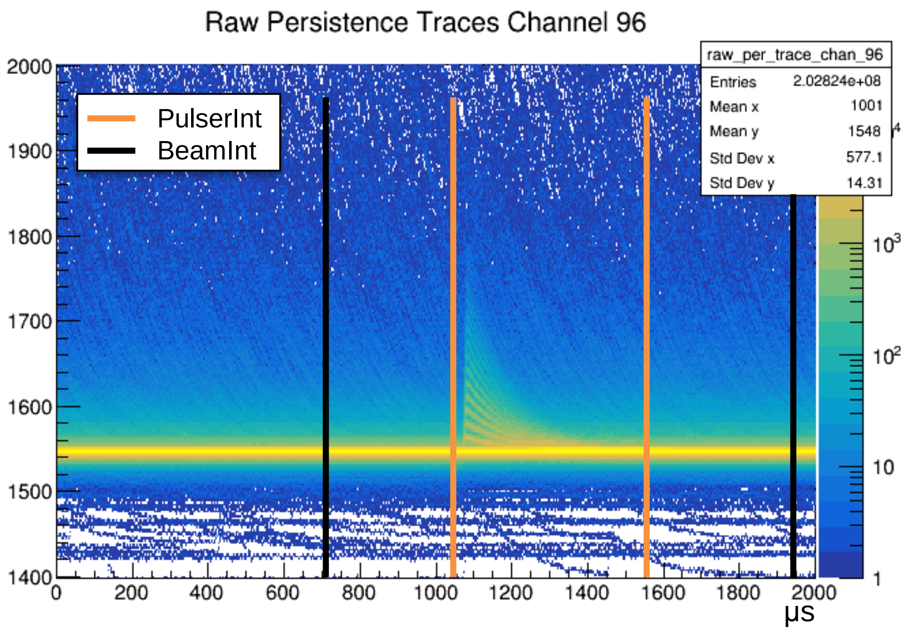
ADC/Photon

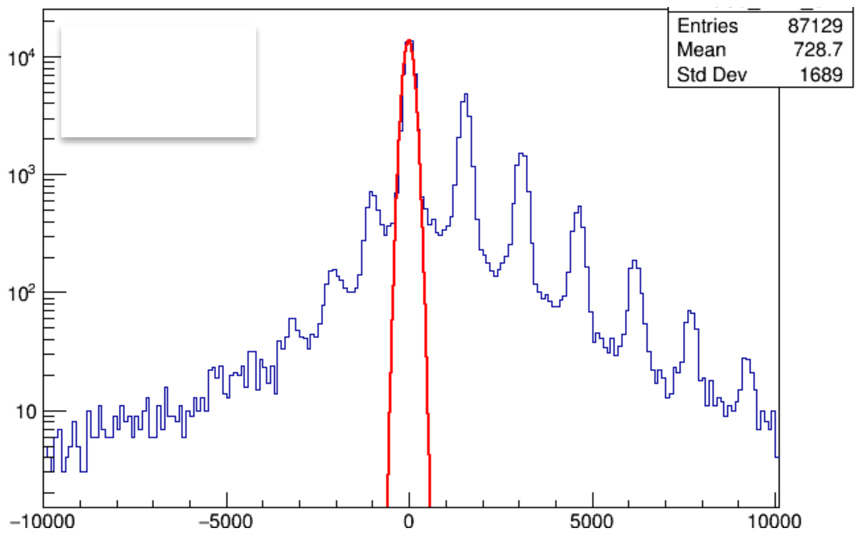
- Use our PDS Calibration System
  - Illumination detectors with constant intensity
- Poisson statistics to determine the mean number of photons per window, λ, using the zero photon events.

$$P(x) = \frac{\lambda^x e^{-\lambda}}{x!} \Rightarrow P(0) = \frac{\lambda^0 e^{-\lambda}}{0!} = e^{-\lambda}$$

$$P(0) = \frac{N(0)}{\sum_x N(x)} \Rightarrow \boxed{\boldsymbol{\lambda = -ln\left(\frac{N(0)}{\sum_x N(x)}\right)}}$$

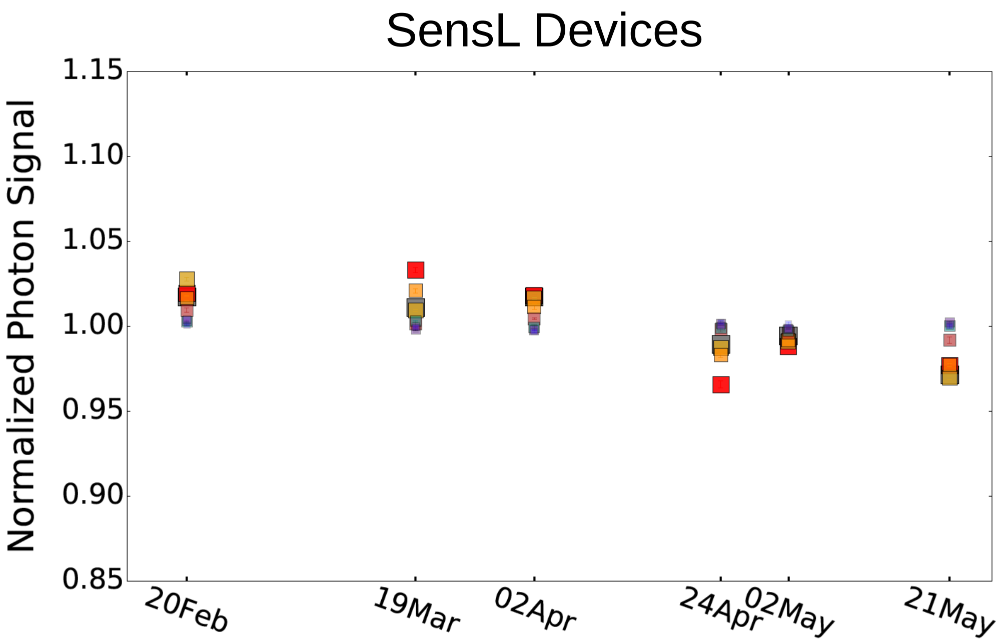
  - Use Gaussian Fit to count how many zeros, N(0).

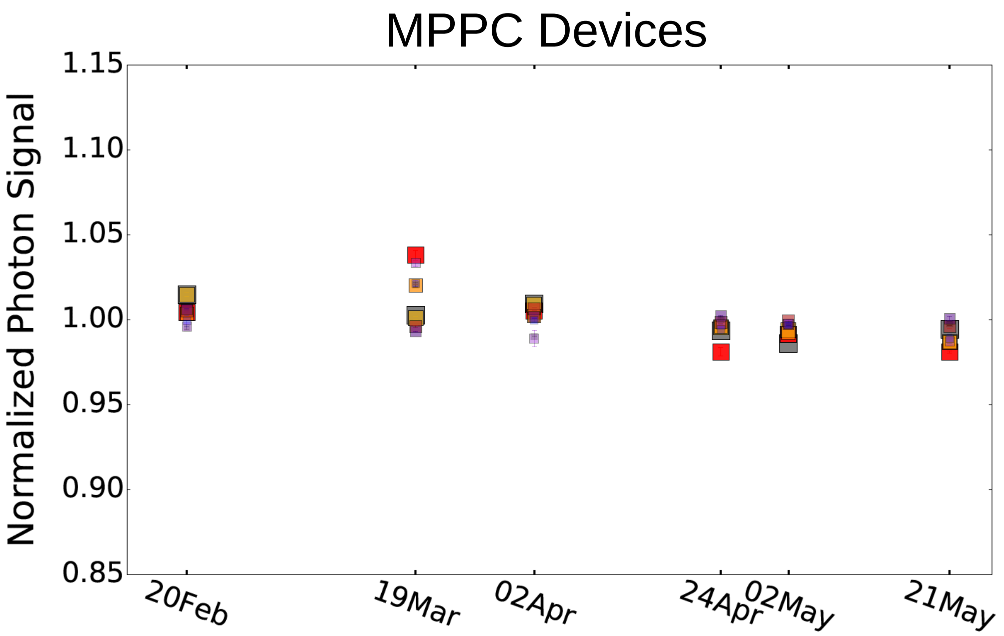




Signal Stability

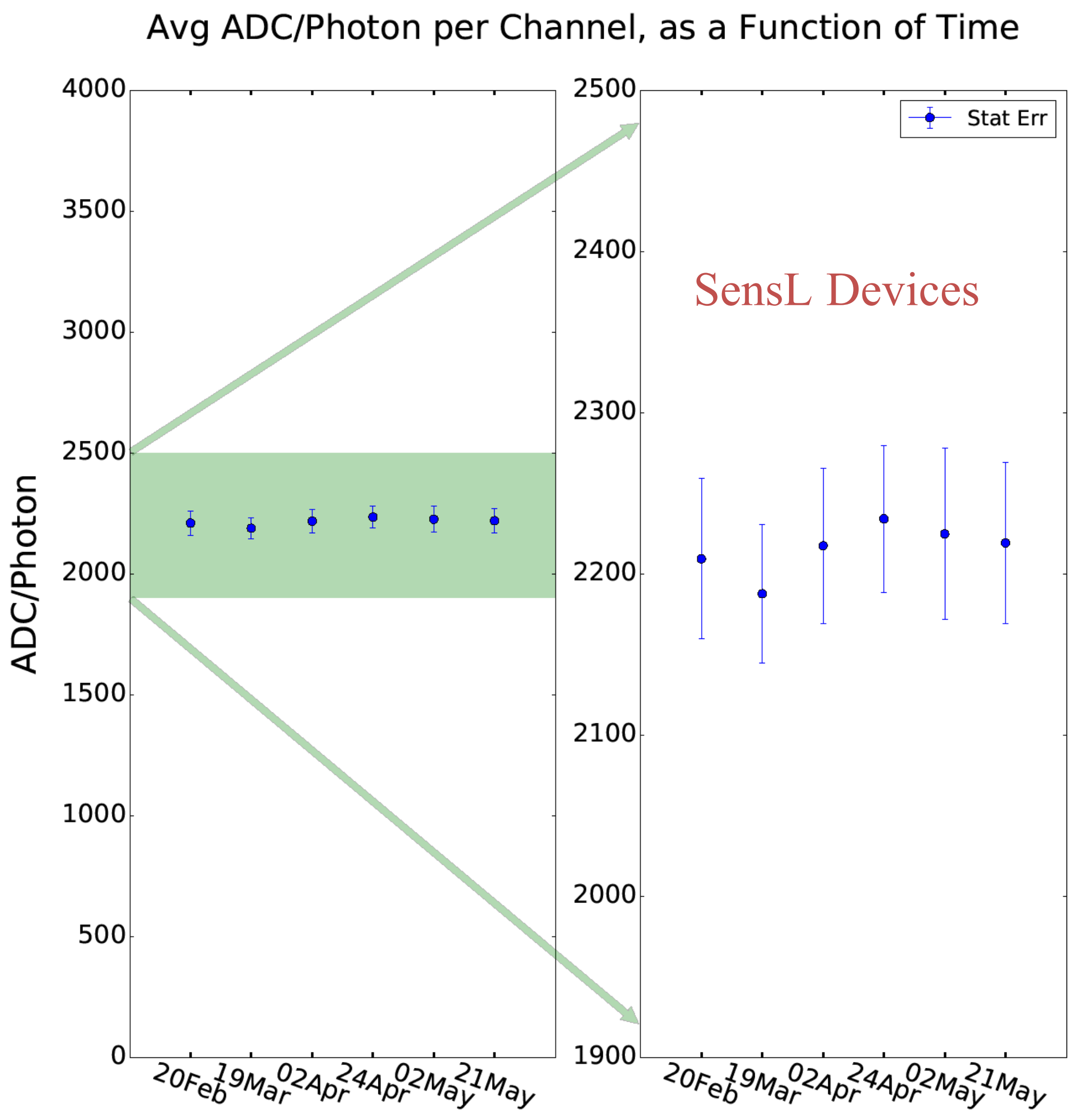
- Mean Photon Signal per Module
  - Double-Shift & Dip-Coated Modules
    - SensL Devices
    - Hammamatsu (MPPC) Devices
- Normalization
  - Mean(module signal) over time
- Very Stable over time!





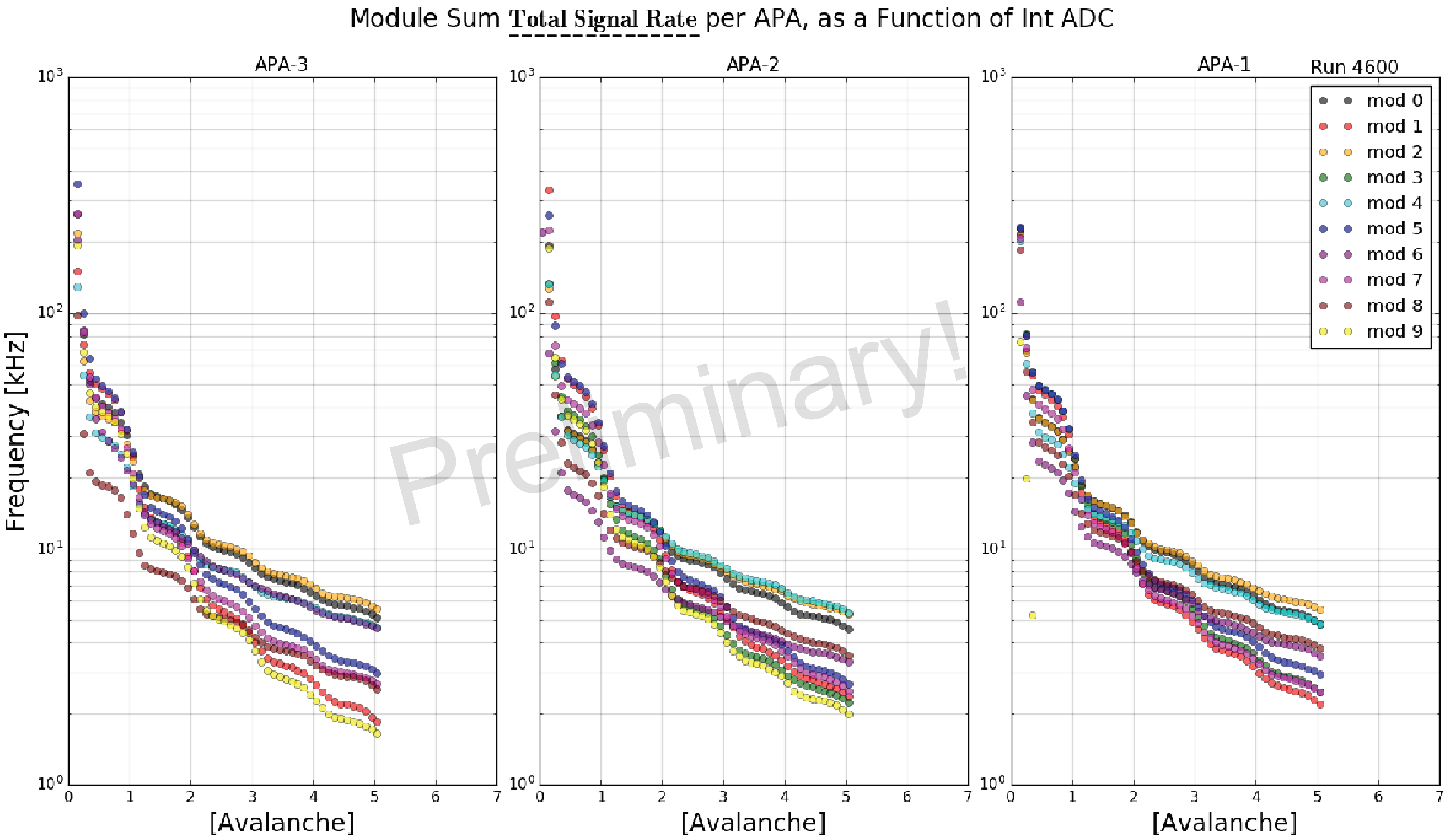
Cross Talk & After Pulse

- SensL -3x per channel
  - $\langle \langle ADC/\gamma \rangle_{Ch} \rangle_{LED}$ = 2084.2 +- 27.7
  - $\langle \langle PE/\gamma \rangle_{Ch} \rangle_{LED}$ = 1.29 +- .01
- MPPC- 3x per channel
  - $\langle \langle ADC/\gamma \rangle_{Ch} \rangle_{LED}$ = need
  - $\langle \langle PE/\gamma \rangle_{Ch} \rangle_{LED}$ = need
- MPPC- 12x per channel
  - $\langle \langle ADC/\gamma \rangle_{Ch} \rangle_{LED}$ = need
  - $\langle \langle PE/\gamma \rangle_{Ch} \rangle_{LED}$ = need



Double-Shift & Dip-Coated Module Rates

- Measure rates of events due to:
  - Cosmic Rays
  - Argon-39
  - etc…



Summary

- Lots of ProtoDUNE PDS Data Available!
- Calibration Done ✓
- Stability & Rates Analysis (Ongoing)
  - Double-Shifted Modules
  - Dip-Coated Modules
- Please see Talks from Bryan and Dante for more ProtoDUNE PDS Analysis!

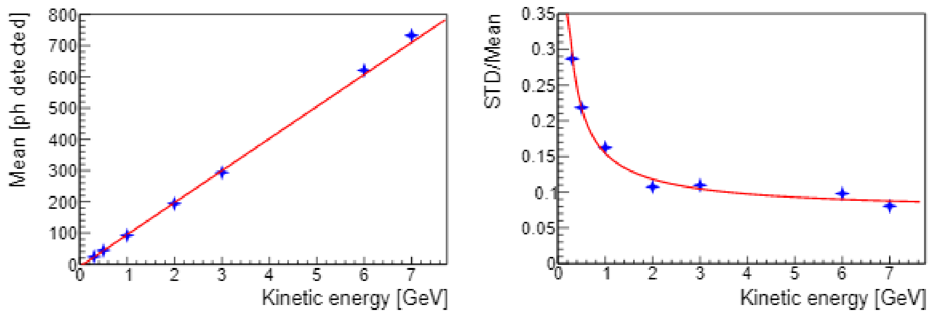


Figure 28: Mean number of collected photons as a function of incident electron kinetic energy (left); photon counting resolution of the S-ARAPUCA array as response to test-beam electrons (right).

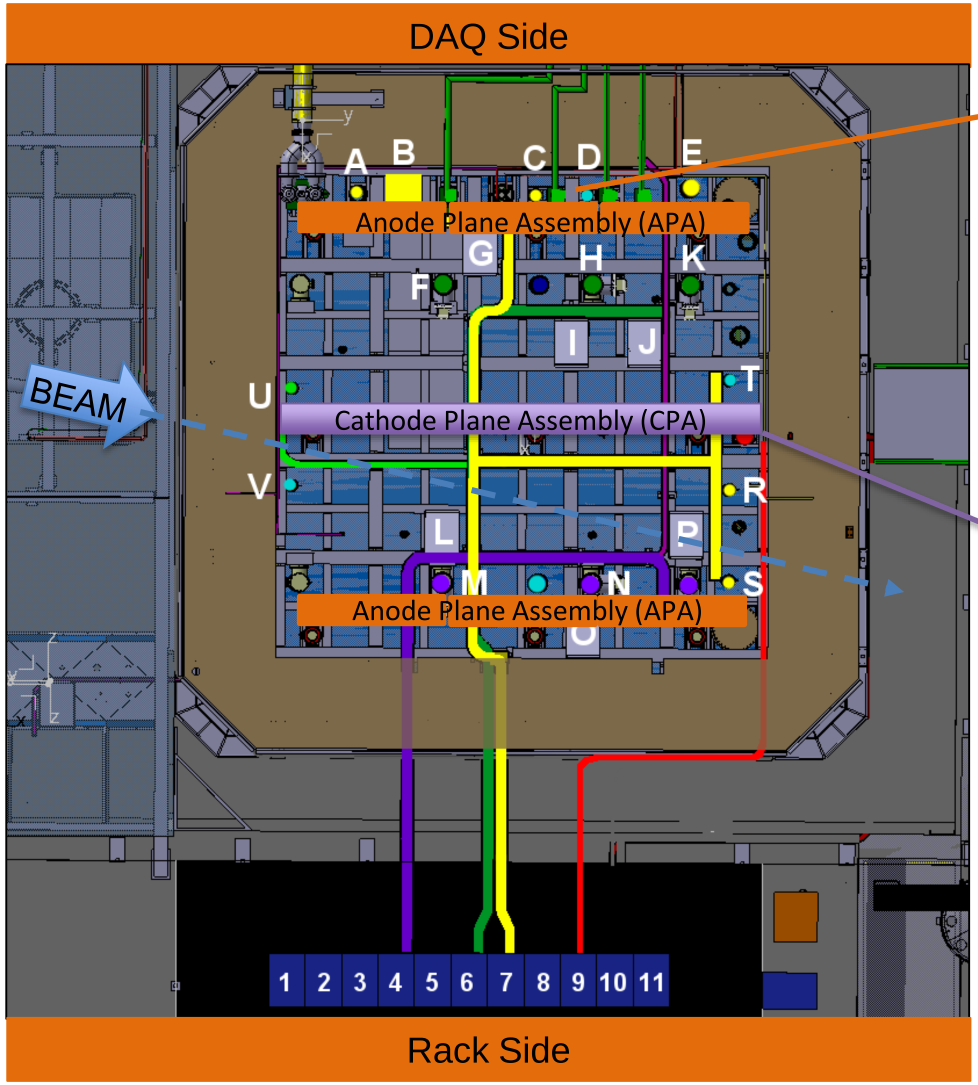
Dr. Bryan Ramson, August 30th, 2019, 09:45
Optical Properties of Liquid Argon measured by the PDS in ProtoDUNE-SP

Dante Totani, August 29th, 2019, 09:15
Single photon rate observation and first calorimetric energy reconstruction of beam events from LAr scintillation light in ProtoDUNE-SP

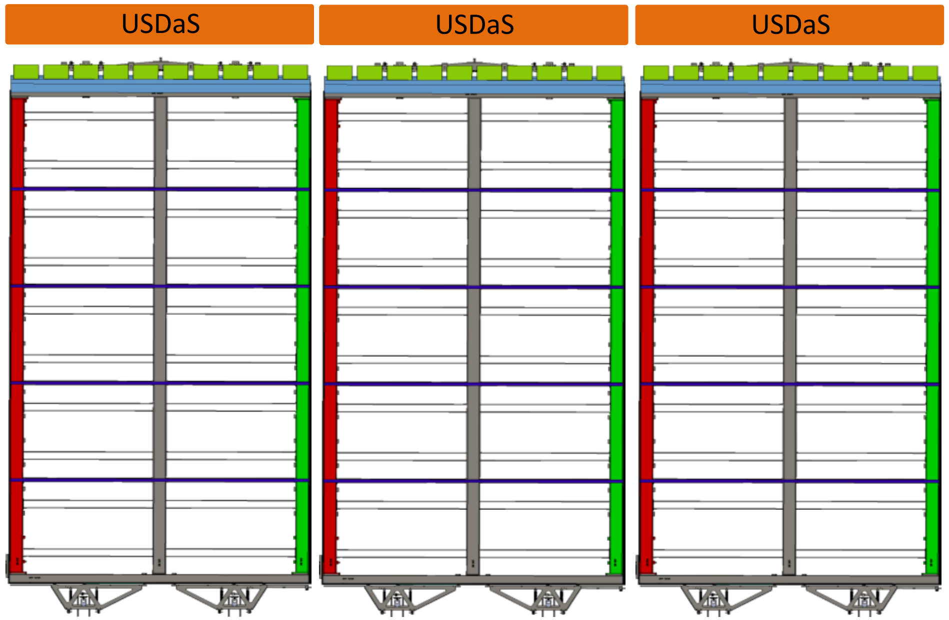
Backup

4. PD Channel Mapping

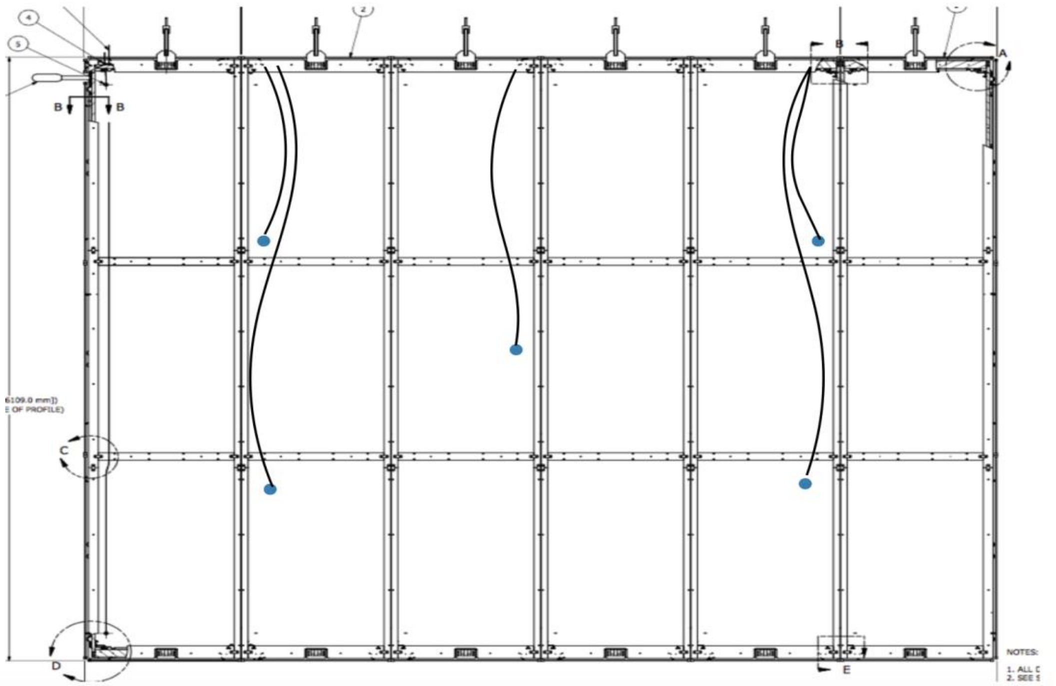
ProtoDUNE Plane Assembly Layout



3 APAs



CPA



3 APAs

PDS Channel Mapping

⊙ APA- Face A

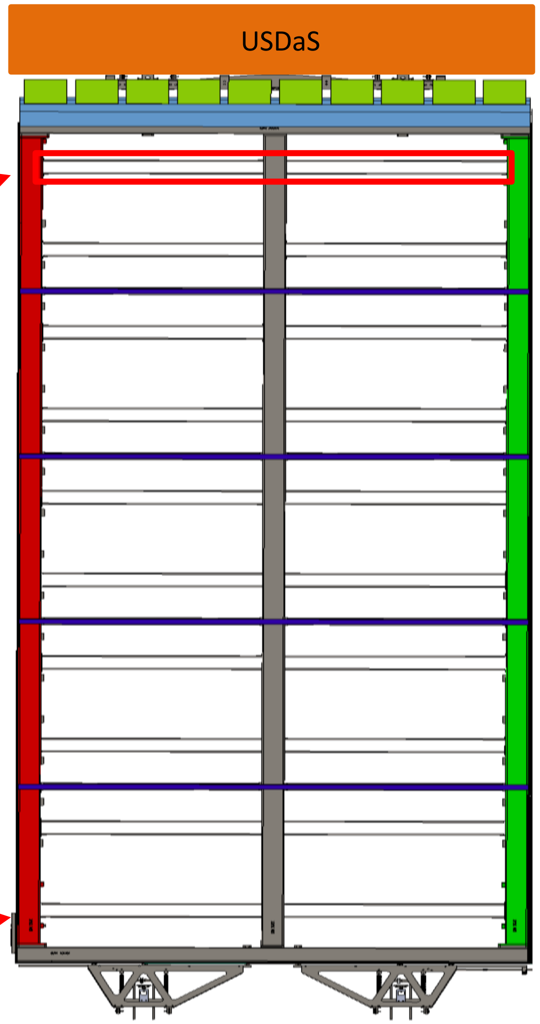
X APA- Face B

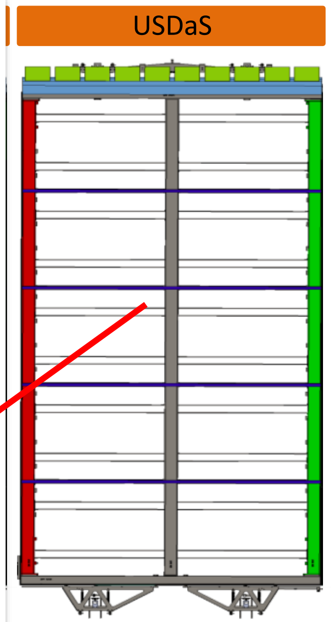
= Readout end

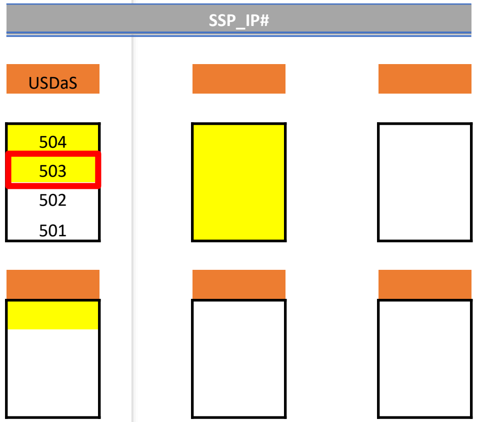
TOP of Cryo #0

USDaS					
PD Module	HB	SSP	SSPch	OpChannel	OptDet
002-0047-FL34	Hamamatsu	SSP503	0-3	216-219	41
002-0008-IU54	Hamamatsu	SSP503	4-7	220-223	43
002-0058-FL24	Hamamatsu	SSP503	8-11	224-227	45
002-0063-IU19	Hamamatsu	SSP504	0-3	228-231	47
003-0026-FL07*	SensL-C1	SSP501	0-3	192-195	49
002-0014-IU26	Hamamatsu	SSP504	4-7	232-235	51
003-0024-FL33	SensL-C1	SSP501	4-7	196-199	53
003-0004-IU48	SensL-C1	SSP501	8-11	200-203	55
002-0041-FL36	Hamamatsu	SSP504	8-11	236-239	57
002-0036-IU47	SensL-C1	SSP502	0-3	204-207	59

#9 **Bottom of Cryo**







ProtoDUNE PDS Channel Map

APA- Face A

APA- Face B

= Readout end

*Modified SSP

BEAM

USDaS

PD Module	HB	SSP	SSPch	OpChannel	OptDet
002-0047-FL34	Hamamatsu	SSP503	0-3	216-219	41
002-0008-IU54	Hamamatsu	SSP503	4-7	220-223	43
002-0058-FL24	Hamamatsu	SSP503	8-11	224-227	45
002-0063-IU19	Hamamatsu	SSP504	0-3	228-231	47
003-0026-FL07*	SensL-C1	SSP501	0-3	192-195	49
002-0014-IU26	Hamamatsu	SSP504	4-7	232-235	51
003-0024-FL33	SensL-C1	SSP501	4-7	196-199	53
003-0004-IU48	SensL-C1	SSP501	8-11	200-203	55
002-0041-FL36	Hamamatsu	SSP504	8-11	236-239	57
002-0036-IU47	SensL-C1	SSP502	0-3	204-207	59

MSDaS

PD Module	HB		SSPch	OpChannel	OptDet
002-0002-FL22	Hamamatsu	SSP601	0-3	240-243	21
002-0054-IU22	Hamamatsu	SSP601	4-7	244-247	23
002-0059-FL08	Hamamatsu	SSP601	8-11	248-251	25
002-0020-IU09	Hamamatsu	SSP602	0-3	252-255	27
002-0060-FL39	Hamamatsu	SSP602	4-7	256-259	29
ARAPUCA-2	Hamamatsu	SSP603	0-3	264-267	31
		SSP603	4-7	268-271	
		SSP603	8-11	272-275	
002-0055-FL40	Hamamatsu	SSP602	8-11	260-263	33
002-0013-IU01	Hamamatsu	SSP604	0-3	276-279	35
002-0011-FL15	Hamamatsu	SSP604	4-7	280-283	37
002-0031-IU02	Hamamatsu	SSP604	8-11	284-287	39

DSDaS

PD Module	HB	SSP	SSPch	OpChannel	OptDet
001-0003-FL01	SensL-C1	SSP401	0-3	144-147	1
002-0044-IU50	SensL-C1	SSP401	4-7	148-151	3
002-0039-FL29	SensL-A1	SSP401	8-11	152-155	5
003-0002-IU27	SensL-C1	SSP402	0-3	156-159	7
002-0025-FL25	SensL-C1	SSP402	4-7	160-163	9
003-0011-IU37	SensL-C1	SSP402	8-11	164-167	11
003-0048-FL42	SensL-C1	SSP403	0-3	168-171	13
002-0023-IU53	SensL-C1	SSP403	4-7	172-175	15
002-0038-IU35	SensL-C1	SSP403	8-11	176-179	17
002-0040-FLP06*	SensL-C1	SSP404	0-3	180-183	19

USRaS

PD Module	HB	SSP	SSPch	OpChannel	OptDet
003-0031-IU20	SensL-A1	SSP301	0-3	96-99	40
002-0055-FL03	SensL-A1	SSP301	4-7	100-103	42
002-0020-IU31	SensL-A1	SSP301	8-11	104-107	44
ARAPUCA-1	Hamamatsu	SSP304	0-3	132-135	46
		SSP304	4-7	136-139	
		SSP304	8-11	140-143.	
002-0042-IU52	SensL-A1	SSP302	0-3	108-111	48
002-0056-FL30	SensL-A1	SSP302	4-7	112-115	50
002-0047-IU17	SensL-A1	SSP302	8-11	116-119	52
002-0054-FL38	SensL-A1	SSP303	0-3	120-123	54
001-0039-IU51	SensL-A1	SSP303	4-7	124-127	56
003-0015-FL04	SensL-C1	SSP303	8-11	128-131	58

MSRaS

PD Module	HB	SSP	SSPch	OpChannel	OptDet
002-0049-IU16	SensL-A1	SSP201	0-3	48-51	20
001-0054-FL18	SensL-A1	SSP201	4-7	52-55	22
002-0035-IU13	SensL-A1	SSP201	8-11	56-59	24
002-0006-FL14	SensL-A1	SSP202	0-3	60-63	26
001-0044-IU18	SensL-A1	SSP202	4-7	64-67	28
002-0012-FL19	SensL-A1	SSP202	8-11	68-71	30
002-0027-IU12	SensL-A1	SSP203	0-3	72-75	32
002-0015-FL21	SensL-A1	SSP203	4-7	76-79	34
001-0052-IU14	SensL-A1	SSP203	8-11	80-83	36
003-0025-FL06	SensL-A1	SSP204	0-3	84-87	38

DSRaS

PD Module	HB	SSP	SSPch	OpChannel	OptDet
403-003-0063-IU28	SensL-A1	SSP101	0-3	0-3	0
403-003-0041-FL9	SensL-A1	SSP101	4-7	4-7	2
403-002-0001-IU15	SensL-A1	SSP101	8-11	8-11	4
403-003-0054-FLP12	SensL-A1	SSP102	0-3	12-15	6
403-001-0006-IU49	SensL-A1	SSP102	4-7	16-19	8
403-003-0064-FLP13	SensL-A1	SSP102	8-11	20-23	10
403-001-0061-IU04	SensL-A1	SSP103	0-3	24-27	12
403-001-0042-FLP4	SensL-A1	SSP103	4-7	28-31	14
403-001-0025-IU21	SensL-A1	SSP103	8-11	32-35	16
403-003-0020-FL5	SensL-A1	SSP104	0-3	36-39	18

SSP_Serial#

USDaS	MSDaS	DSDaS
127	131	120
125	130	119
132	129	118
121	128	117

USRaS	MSRaS	DSRaS
123	113	109
116	112	108
115	111	107
114	102	106

SSP_IP#

USDaS	MSDaS	DSDaS
504	604	404
503	603	403
502	602	402
501	601	401

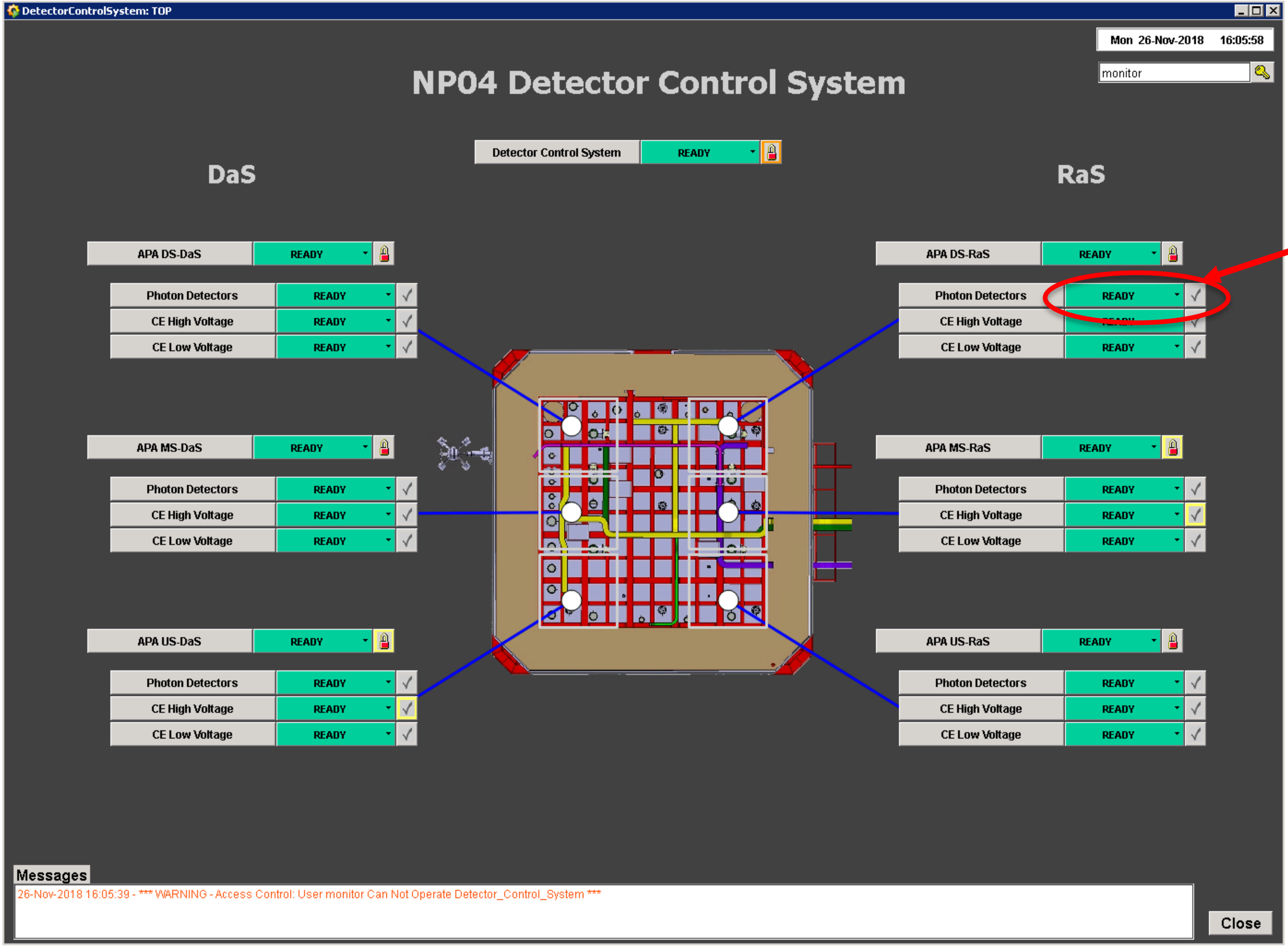
USRaS	MSRaS	DSRaS
304	204	104
303	203	103
302	202	102
301	201	101

PD Channel Summary

- Module Count
  - (29) Double-Shift Light Guides
    - 4 channels/module
  - (29) Dip-Coated Light Guides
    - 4 channels/module
  - (2) ARAPUCAs
    - 12 channels/module
- Total Channels
  - (256) channels
    - 288 available channels (24 SSPs, 12 chs/SSP)
  - Known dead channels
    - DAQ ch: 49, 51 , 73, 75, 101, 156
  - Known *high trigger rate* channels
    - DAQ ch: 25, 36, 58, 62, 65, 82, 110*,119

*finicky

Turning On/Off Entire APA SSP Power Supplies



Control LV &HV
for ALL SSPs/APA

SSP Panel

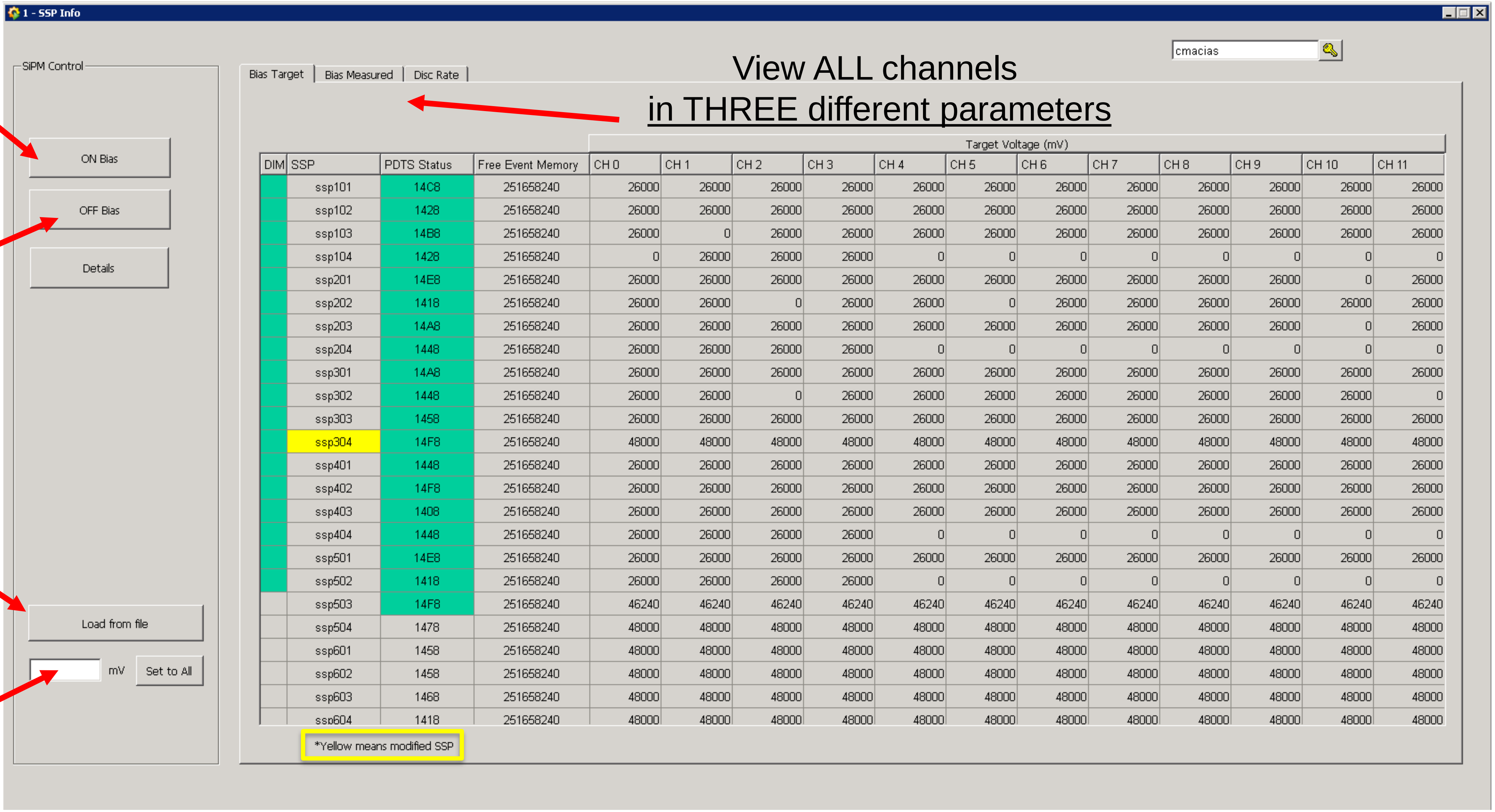
Turn all channels to nominal bias

Turn all channels to ~1/2 nominal bias

Load a different config file

Set ALL channels to specified voltage

View ALL channels
in THREE different parameters



DIM	SSP	PDTS Status	Free Event Memory	CH 0	CH 1	CH 2	CH 3	CH 4	CH 5	CH 6	CH 7	CH 8	CH 9	CH 10	CH 11
	ssp101	14C8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp102	1428	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp103	14B8	251658240	26000	0	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp104	1428	251658240	0	26000	26000	26000	0	0	0	0	0	0	0	0
	ssp201	14E8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	0	26000
	ssp202	1418	251658240	26000	26000	0	26000	26000	0	26000	26000	26000	26000	26000	26000
	ssp203	14A8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	0	26000
	ssp204	1448	251658240	26000	26000	26000	26000	0	0	0	0	0	0	0	0
	ssp301	14A8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp302	1448	251658240	26000	26000	0	26000	26000	26000	26000	26000	26000	26000	26000	0
	ssp303	1458	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp304	14F8	251658240	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000
	ssp401	1448	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp402	14F8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp403	1408	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp404	1448	251658240	26000	26000	26000	26000	0	0	0	0	0	0	0	0
	ssp501	14E8	251658240	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000	26000
	ssp502	1418	251658240	26000	26000	26000	26000	0	0	0	0	0	0	0	0
	ssp503	14F8	251658240	46240	46240	46240	46240	46240	46240	46240	46240	46240	46240	46240	46240
	ssp504	1478	251658240	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000
	ssp601	1458	251658240	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000
	ssp602	1458	251658240	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000
	ssp603	1468	251658240	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000	48000
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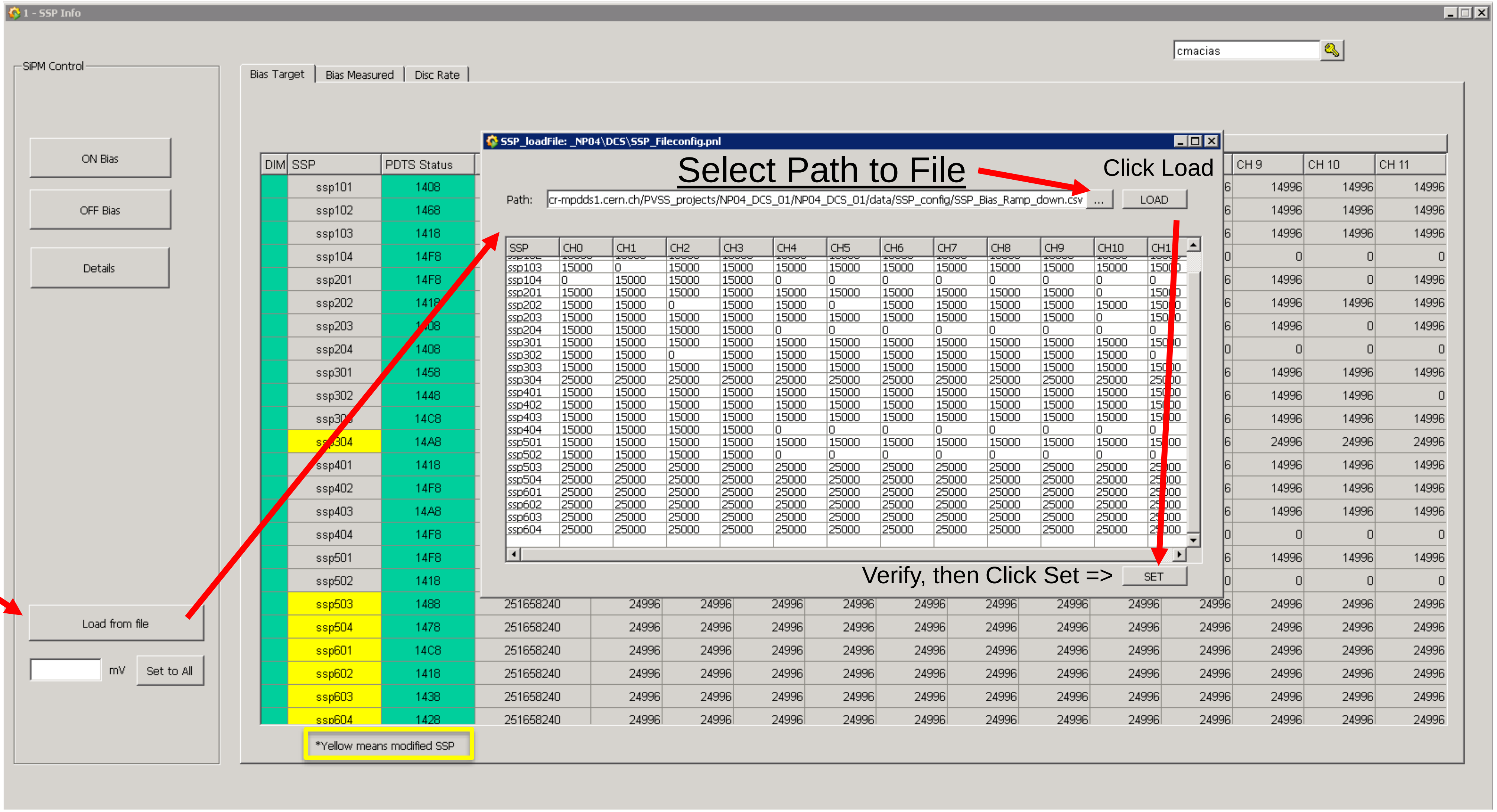
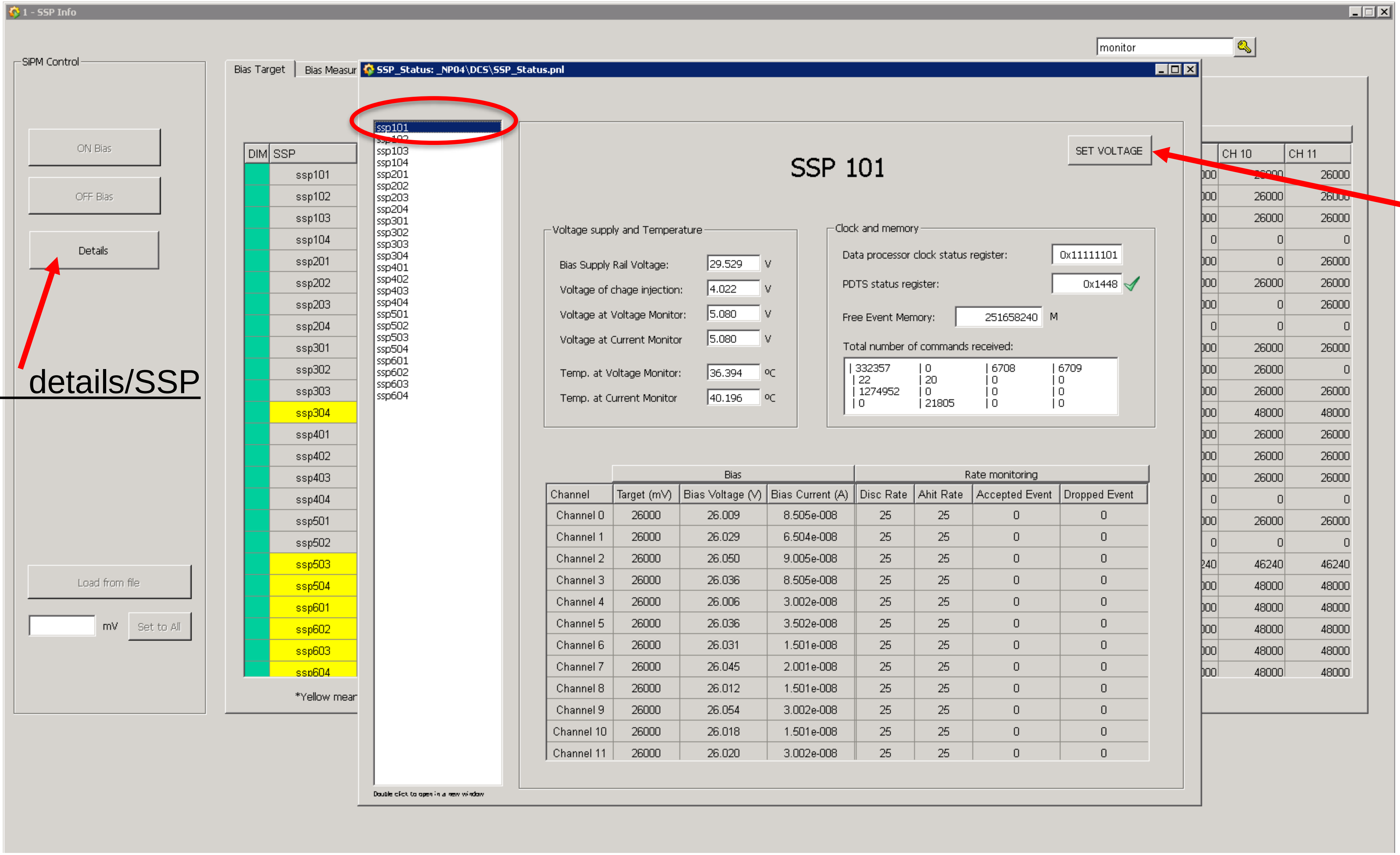
Loading SSP Bias Configuration File



Load a different config file

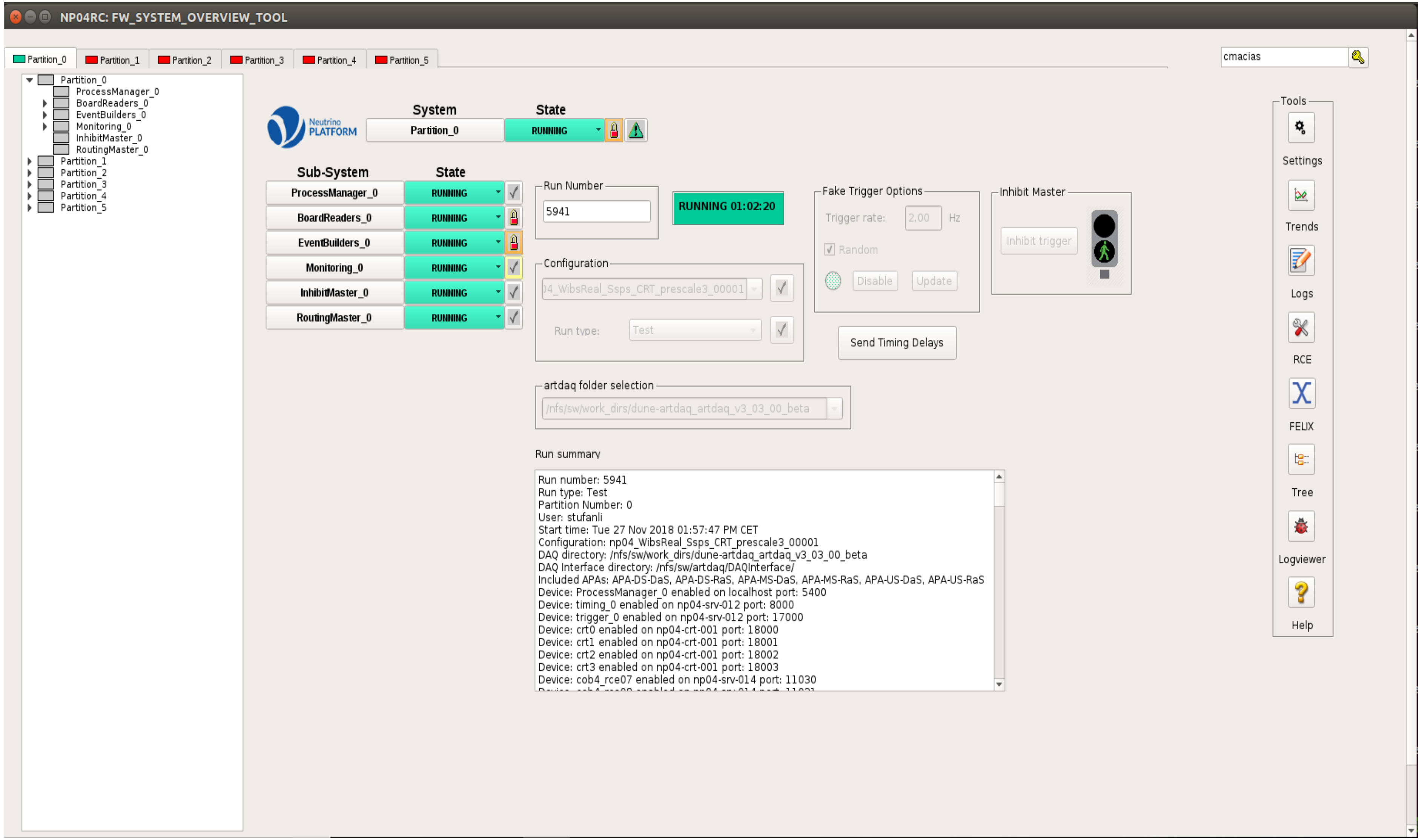
SSP Detailed Panel



View more details/SSP

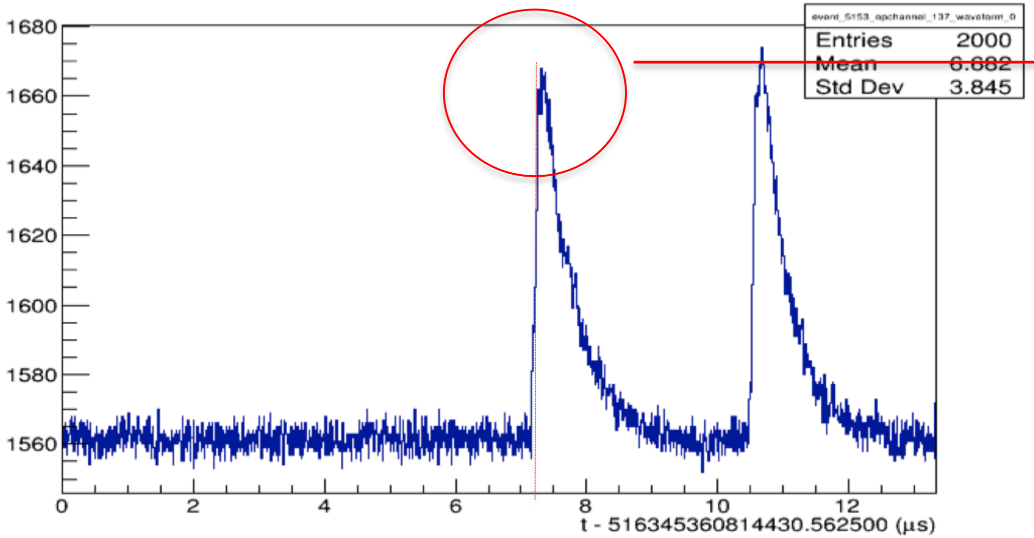
Set bias to individual channels

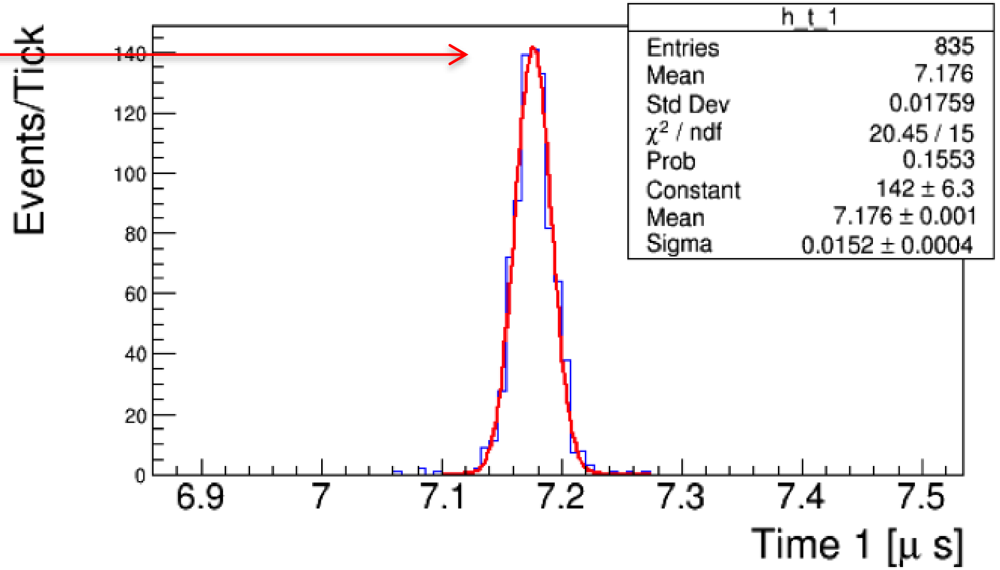
Run Control

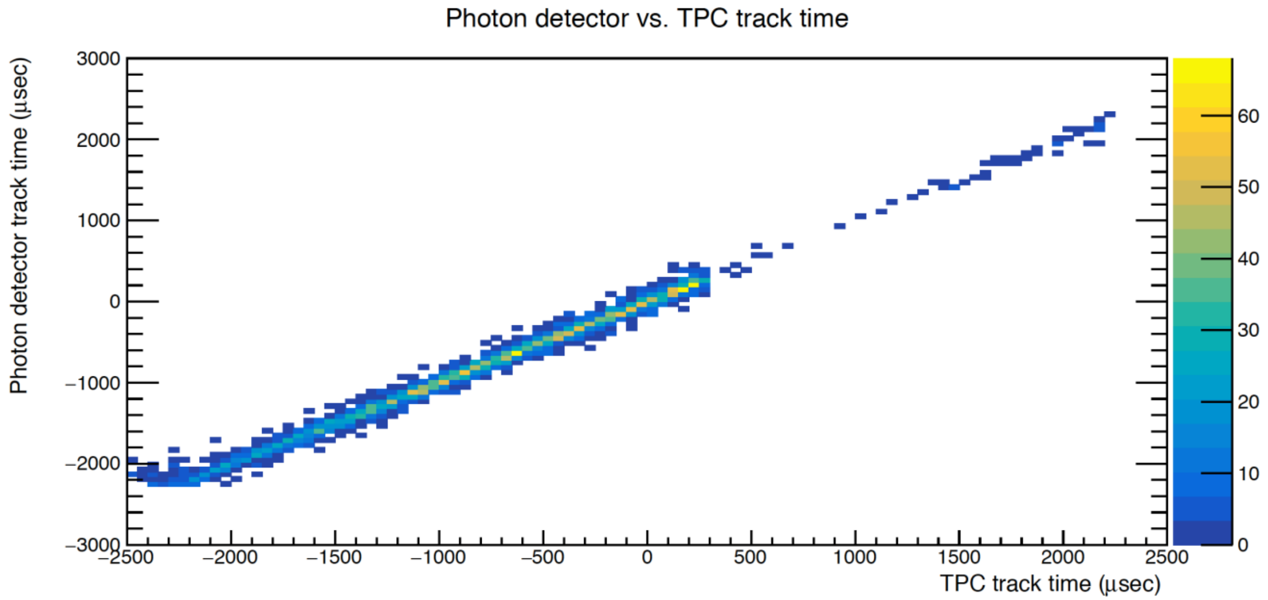


NP04RC: FW_SYSTEM_OVERVIEW_TOOL
Partition_0
Partition_1
Partition_2
Partition_3
Partition_4
Partition_5
cmacias
ProcessManager_0
BoardReaders_0
EventBuilders_0
Monitoring_0
InhibitMaster_0
RoutingMaster_0
Neutrino PLATFORM
System
State
RUNNING
Sub-System
Run Number
5941
RUNNING 01:02:20
Fake Trigger Options
Trigger rate:
2.00
Hz
Random
Disable
Update
Inhibit Master
Inhibit trigger
Configuration
Run type:
Test
Send Timing Delays
artdaq folder selection
/nfs/sw/work_dirs/dune-artdaq_artdaq_v3_03_00_beta
Run summary
Run number: 5941
Run type: Test
Partition Number: 0
User: stufanli
Start time: Tue 27 Nov 2018 01:57:47 PM CET
Configuration: np04_WibsReal_Ssps_CRT_prescale3_00001
DAQ directory: /nfs/sw/work_dirs/dune-artdaq_artdaq_v3_03_00_beta
DAQ Interface directory: /nfs/sw/artdaq/DAQInterface/
Included APAs: APA-DS-DaS, APA-DS-RaS, APA-MS-DaS, APA-MS-RaS, APA-US-DaS, APA-US-RaS
Device: ProcessManager_0 enabled on localhost port: 5400
Device: timing_0 enabled on np04-srv-012 port: 8000
Device: trigger_0 enabled on np04-srv-012 port: 17000
Device: crt0 enabled on np04-crt-001 port: 18000
Device: crt1 enabled on np04-crt-001 port: 18001
Device: crt2 enabled on np04-crt-001 port: 18002
Device: crt3 enabled on np04-crt-001 port: 18003
Device: cob4_rce07 enabled on np04-srv-014 port: 11030
Tools
Settings
Trends
Logs
RCE
FELIX
Tree
Logviewer
Help

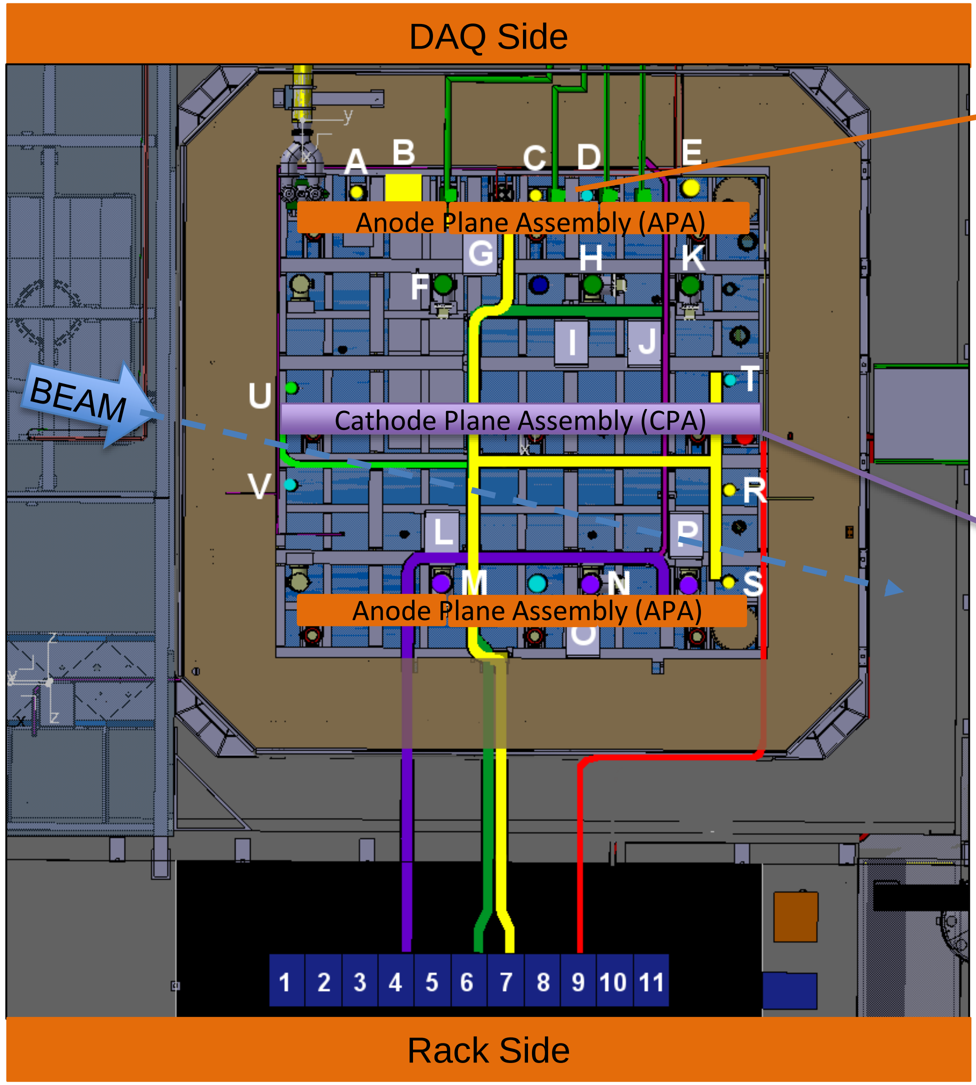
PDS Calibration System (DCM) Response





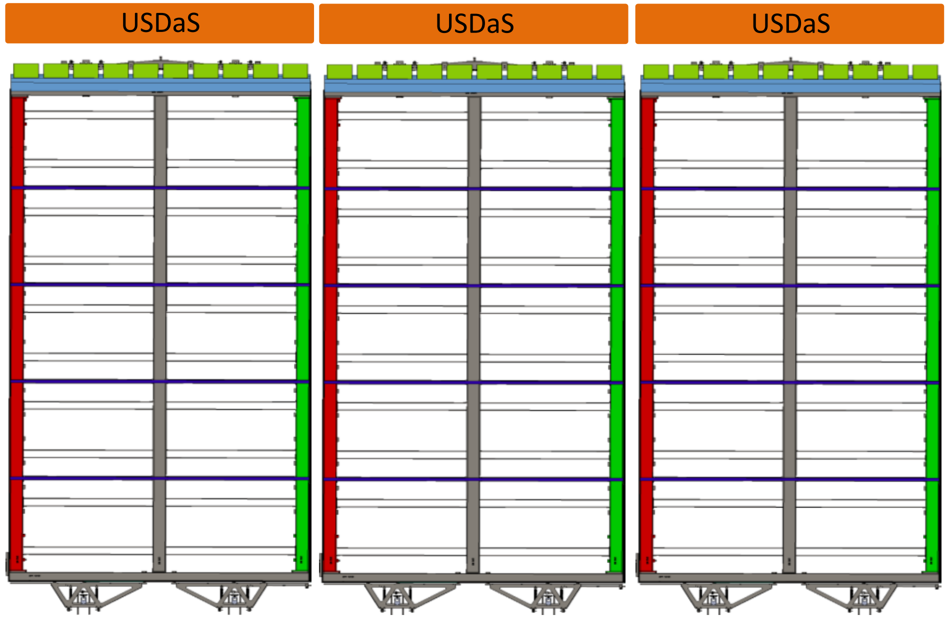


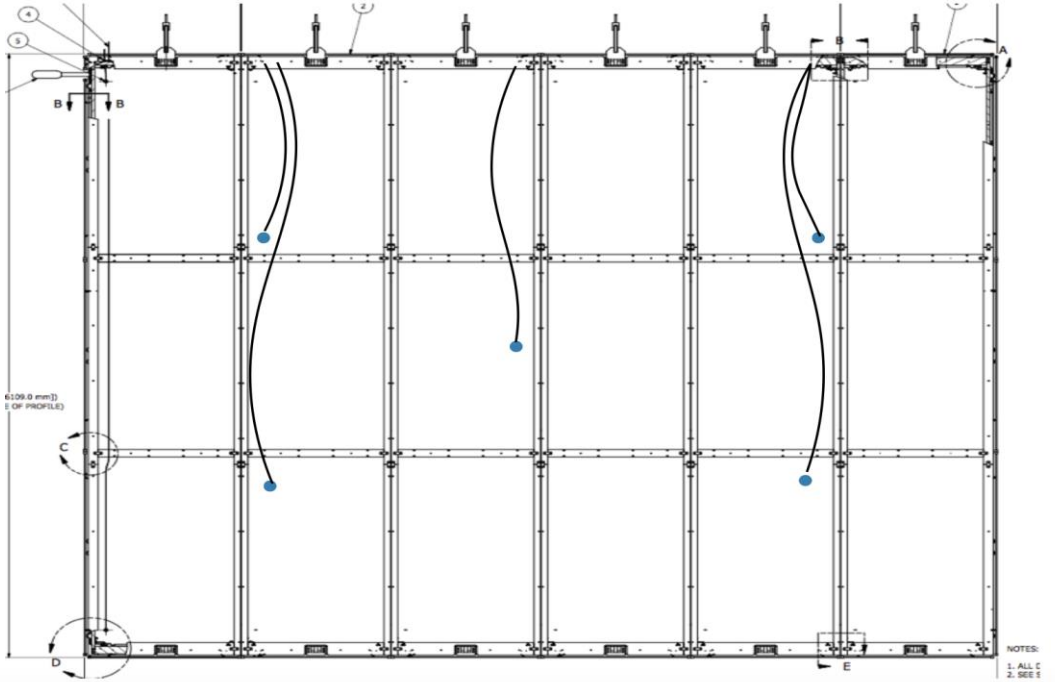
ProtoDUNE Plane Assembly Layout



3 APAs

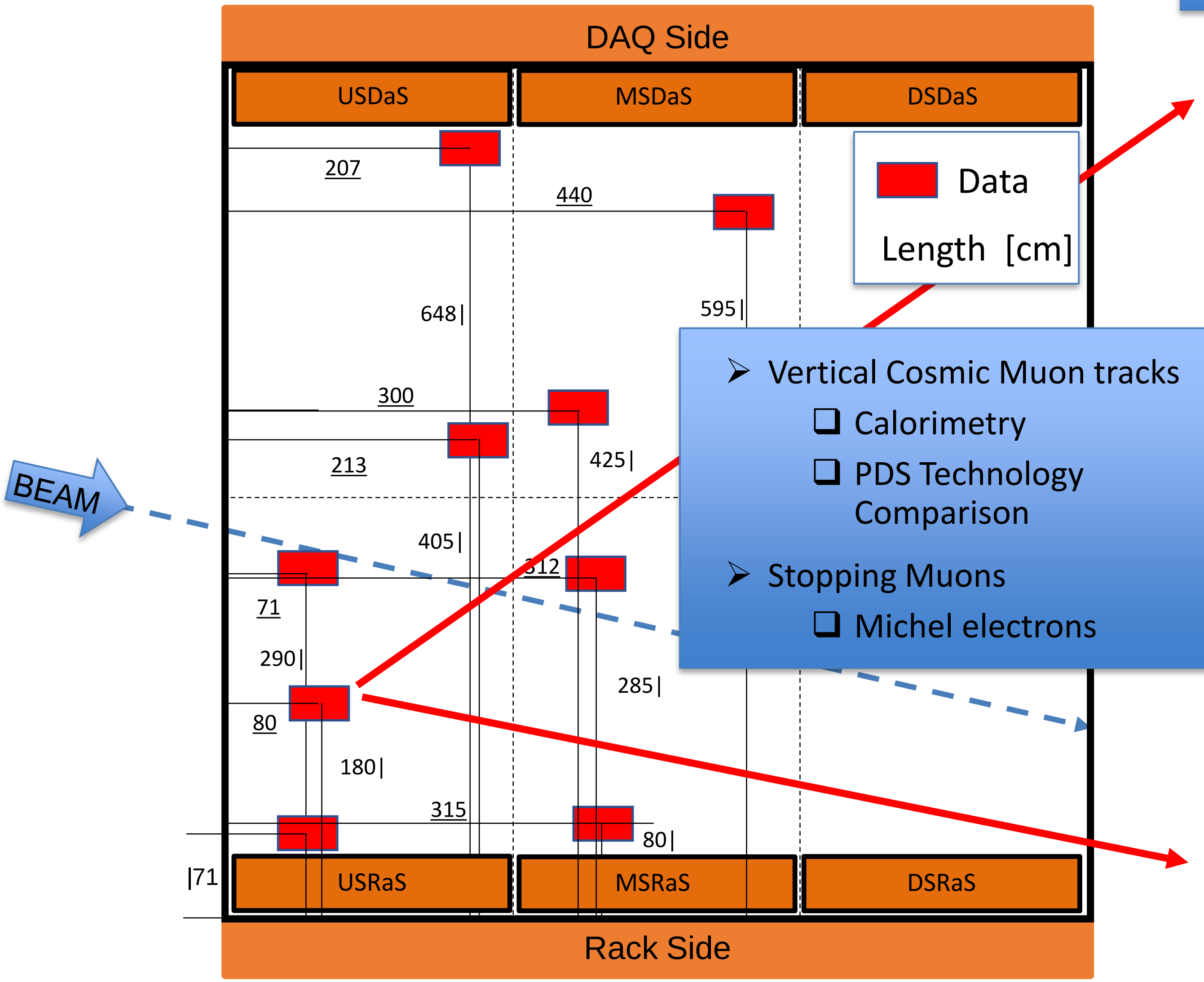
CPA



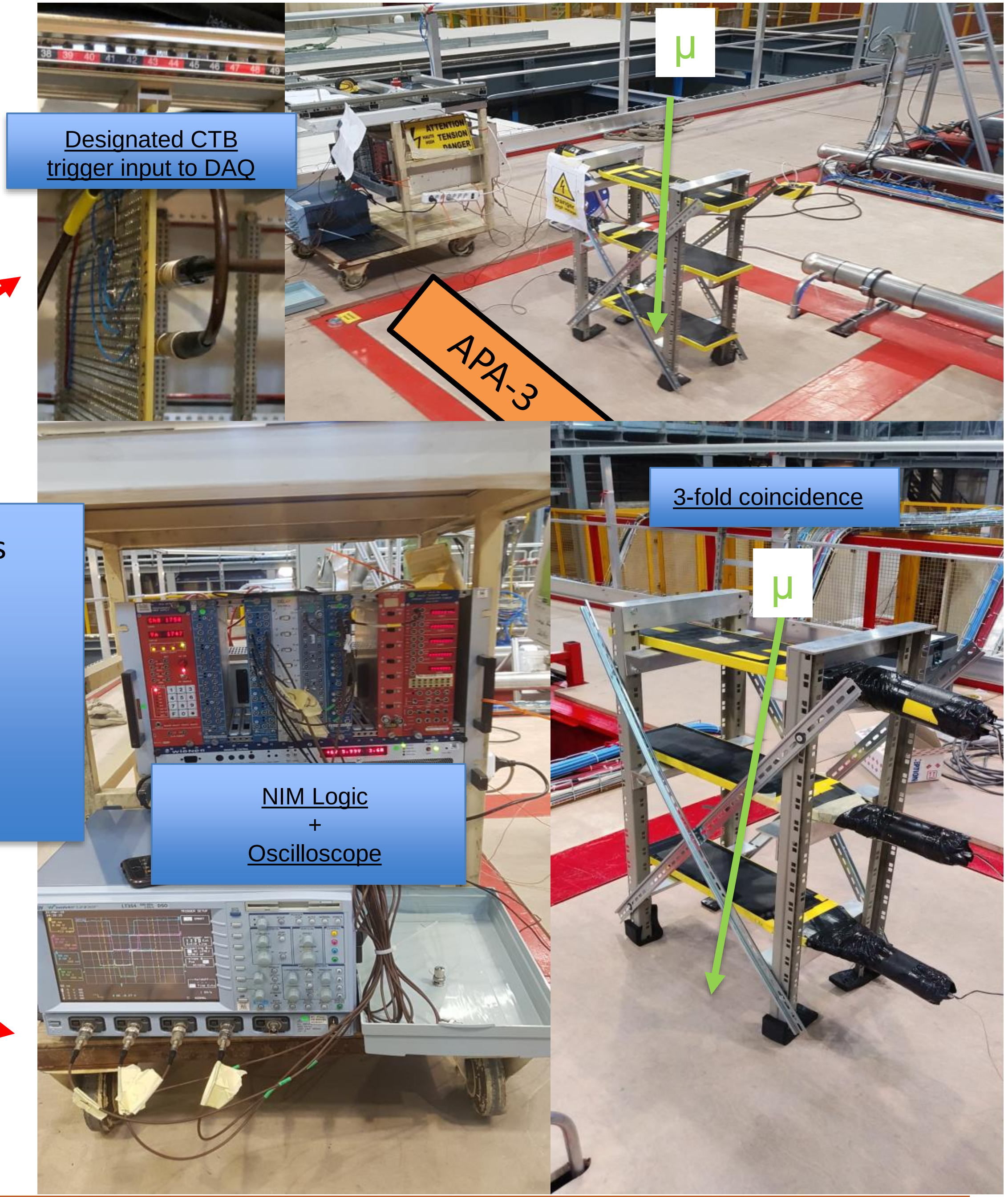


3 APAs

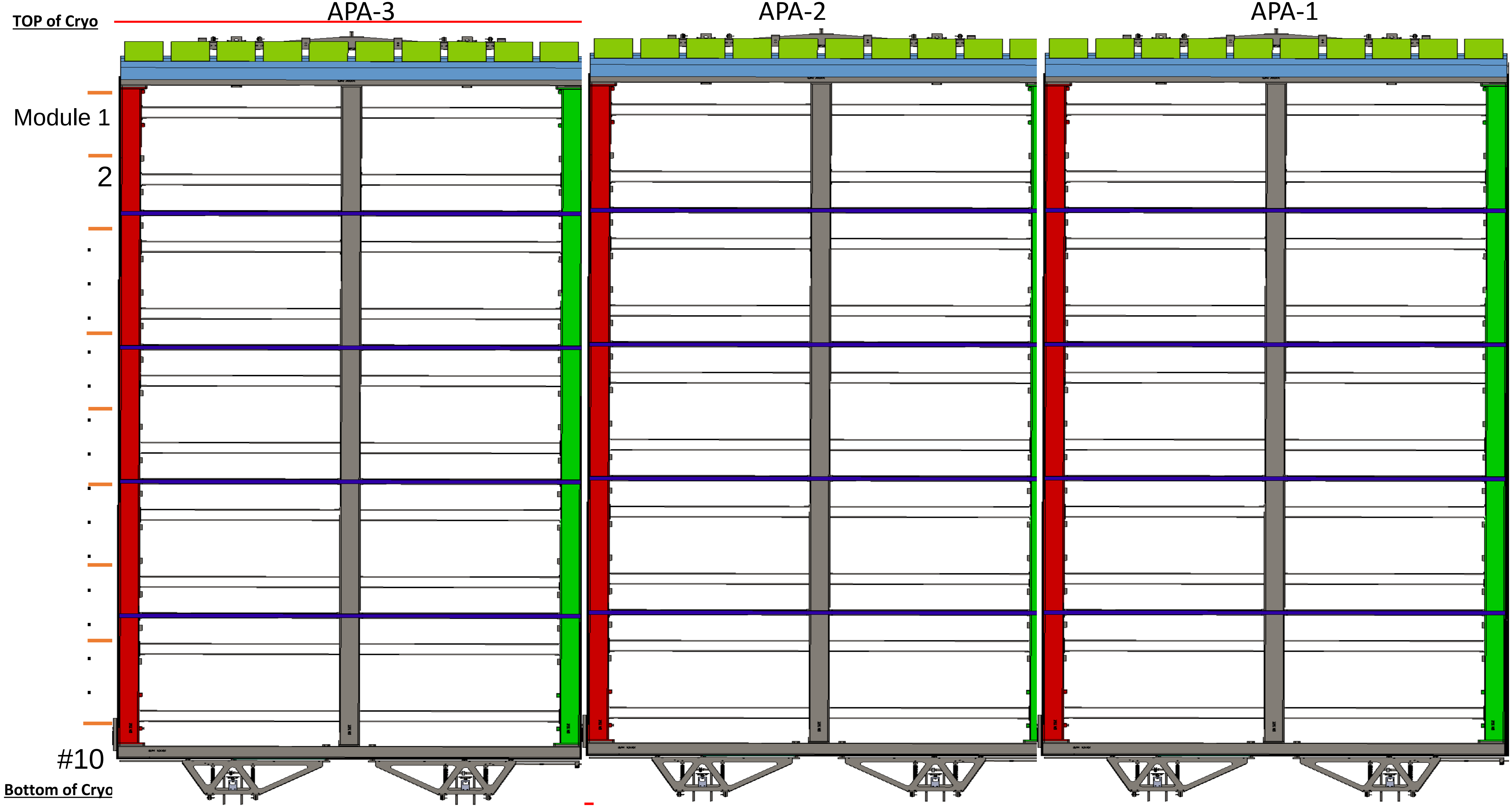
Cosmic Telescope



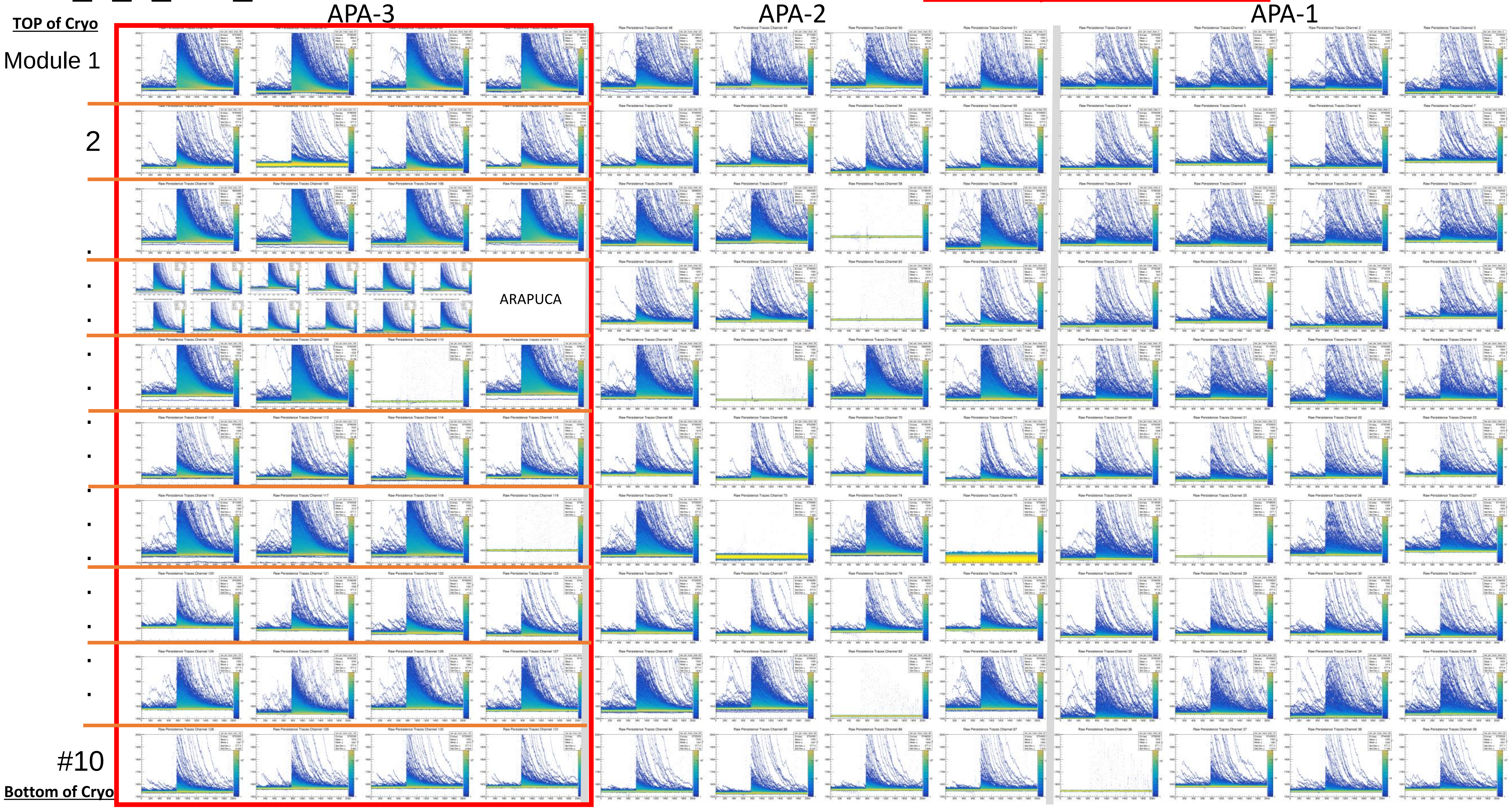
- Vertical Cosmic Muon tracks
  - Calorimetry
  - PDS Technology Comparison
- Stopping Muons
  - Michel electrons



APA_1_3_Run_Run7278 RAW DATA- Persistence Traces – Telescope Above APA3

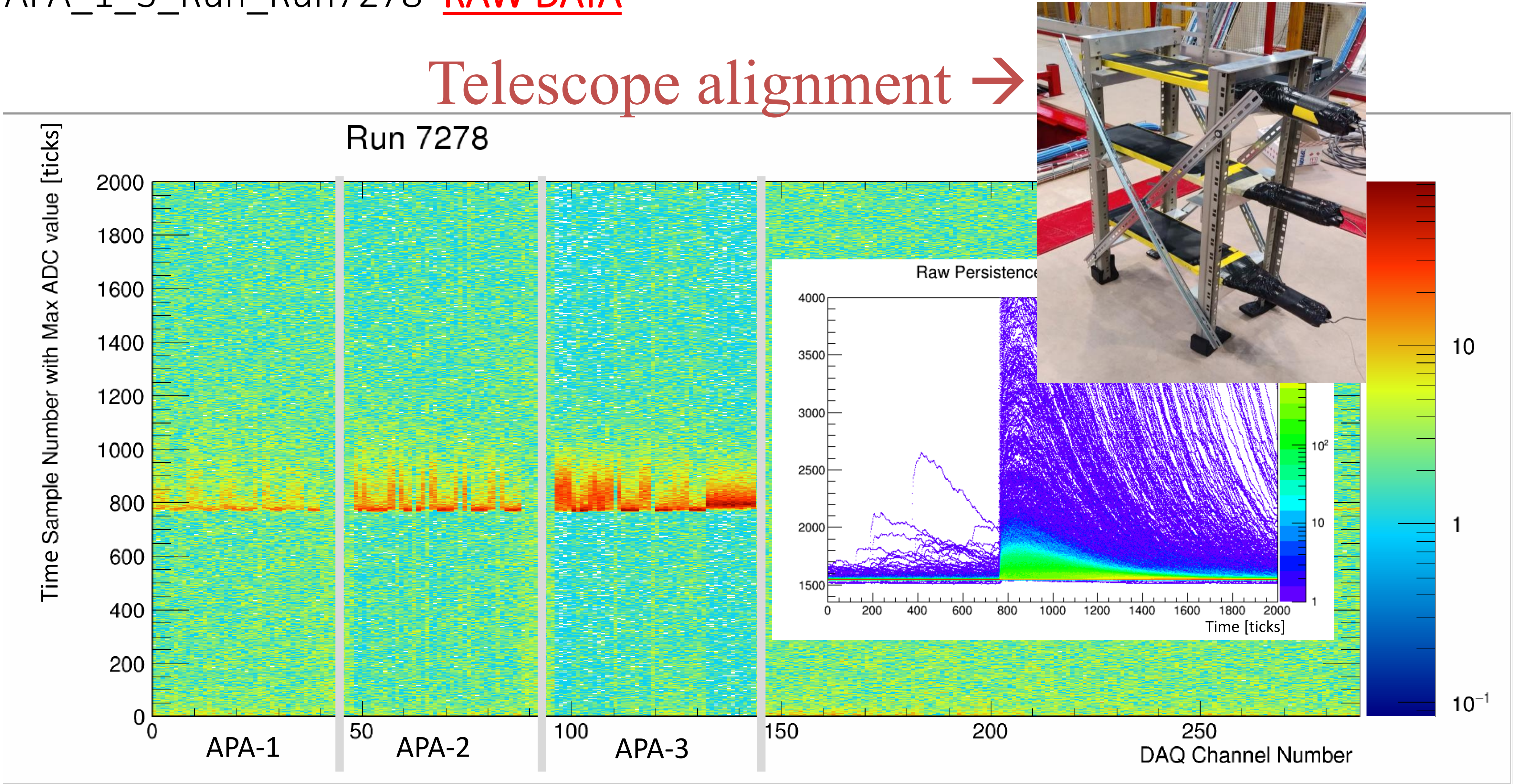


APA_1_3_Run_Run7278 RAW DATA- Persistence Traces – Telescope Above APA3



APA_1_3_Run_Run7278 RAW DATA

Telescope alignment →



Thanks, Leon!

ProtoDUNE PDS Channel Map

⊙ APA- Face A

ⓧ APA- Face B

▮ = Readout end

2/3 PD Channels are SensL

BEAM

USDaS

PD Module	HB	SSP	SSPch	DAQch		OptDet
002-0047-FL34	Hamamatsu	SSP503	0-3	216	219	41
002-0008-IU54	Hamamatsu	SSP503	4-7	220	223	43
002-0058-FL24	Hamamatsu	SSP503	8-11	224	227	45
002-0063-IU19	Hamamatsu	SSP504	0-3	228	231	47
003-0026-FL07*	SensL-C1	SSP501	0-3	192	195	49
002-0014-IU26	Hamamatsu	SSP504	4-7	232	235	51
003-0024-FL33	SensL-C1	SSP501	4-7	196	199	53
003-0004-IU48	SensL-C1	SSP501	8-11	200	203	55
002-0041-FL36	Hamamatsu	SSP504	8-11	236	239	57
002-0036-IU47	SensL-C1	SSP502	0-3	204	207	59

MSDaS

PD Module	HB		SSPch	DAQch		OptDet
002-0002-FL22	Hamamatsu	SSP601	0-3	240	243	21
002-0054-IU22	Hamamatsu	SSP601	4-7	244	247	23
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
002-0013-IU01	Hamamatsu	SSP604	0-3	276	279	35
002-0011-FL15	Hamamatsu	SSP604	4-7	280	283	37
002-0031-IU02	Hamamatsu	SSP604	8-11	284	287	39

…DaS

PD Module	HB	SSP	SSPch	DAQch		OptDet
001-0003-FL01	SensL-C1	SP401	0-3	144	147	1
002-0044-IU50	SensL-C1	SP401	4-7	148	151	3
002-0039-FL29	SensL-A1	SP401	8-11	152	155	5
003-0002-IU27	SensL-C1	SP402	0-3	156	159	7
[illegible]	SensL-C1	SP402	4-7	160	163	9
003-0011-IU37	SensL-C1	SP402	8-11	164	167	11
003-0048-FL42	SensL-C1	SP403	0-3	168	171	13
002-0023-IU53	SensL-C1	SP403	4-7	172	175	15
002-0038-IU35	SensL-C1	SP403	8-11	176	179	17
002-0040-FLP06*	SensL-C1	SP404	0-3	180	183	19

USRaS

PD Module	HB	SSP	SSPch	DAQch		OptDet
003-0031-IU20	SensL-A1	SSP301	0-3	96	99	40
002-0055-FL03	SensL-A1	SSP301	4-7	100	103	42
002-0020-IU31	SensL-A1	SSP301	8-11	104	107	44
ARAPUCA-1	Hamamatsu	SSP304	0-3	132	135	46
		SSP304	4-7	136	139	
		SSP304	8-11	140	143	
002-0042-IU52	SensL-A1	SSP302	0-3	108	111	48
002-0056-FL30	SensL-A1	SSP302	4-7	112	115	50
002-0047-IU17	SensL-A1	SSP302	8-11	116	119	52
002-0054-FL38	SensL-A1	SSP303	0-3	120	123	54
001-0039-IU51	SensL-A1	SSP303	4-7	124	127	56
003-0015-FL04	SensL-C1	SSP303	8-11	128	131	58

MSRaS

PD Module	HB	SSP	SSPch	DAQch		OptDet
002-0049-IU16	SensL-A1	SSP201	0-3	48	51	20
001-0054-FL18	SensL-A1	SSP201	4-7	52	55	22
002-0035-IU13	SensL-A1	SSP201	8-11	56	59	24
002-0006-FL14	SensL-A1	SSP202	0-3	60	63	26
001-0044-IU18	SensL-A1	SSP202	4-7	64	67	28
002-0012-FL19	SensL-A1	SSP202	8-11	68	71	30
002-0027-IU12	SensL-A1	SSP203	0-3	72	75	32
002-0015-FL21	SensL-A1	SSP203	4-7	76	79	34
001-0052-IU14	SensL-A1	SSP203	8-11	80	83	36
003-0025-FL06	SensL-A1	SSP204	0-3	84	87	38

DSRaS

PD Module	HB	SSP	SSPch	DAQch		OptDet
403-003-0063-IU28	SensL-A1	SSP101	0-3	0	3	0
403-003-0041-FL9	SensL-A1	SSP101	4-7	4	7	2
403-002-0001-IU15	SensL-A1	SSP101	8-11	8	11	4
403-003-0054-FLP12	SensL-A1	SSP102	0-3	12	15	6
403-001-0006-IU49	SensL-A1	SSP102	4-7	16	19	8
403-003-0064-FLP13	SensL-A1	SSP102	8-11	20	23	10
403-001-0061-IU04	SensL-A1	SSP103	0-3	24	27	12
403-001-0042-FLP4	SensL-A1	SSP103	4-7	28	31	14
403-001-0025-IU21	SensL-A1	SSP103	8-11	32	35	16
403-003-0020-FL5	SensL-A1	SSP104	0-3	36	39	18

*Modified SSP

SSP_Serial#

USDaS	MSDaS	DSDaS
127	131	120
125	130	119
132	129	118
121	128	117

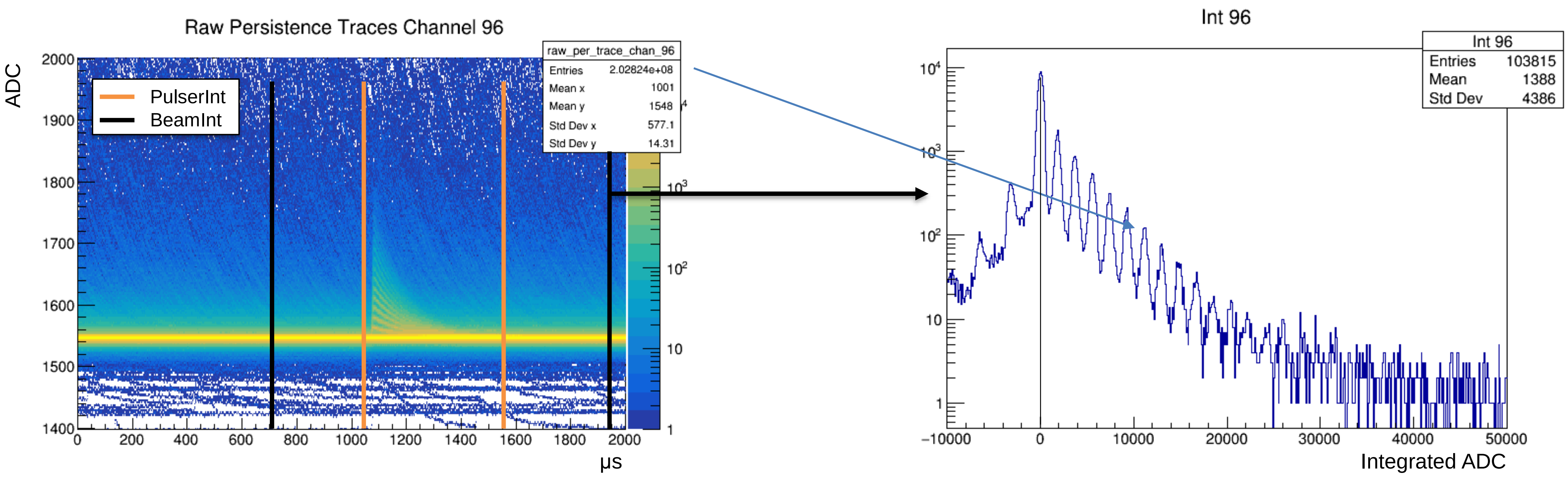
USRaS	MSRaS	DSRaS
123	113	109
116	112	108
115	111	107
114	102	106

SSP_IP#

USDaS	MSDaS	DSDaS
504	604	404
503	603	403
502	602	402
501	601	401

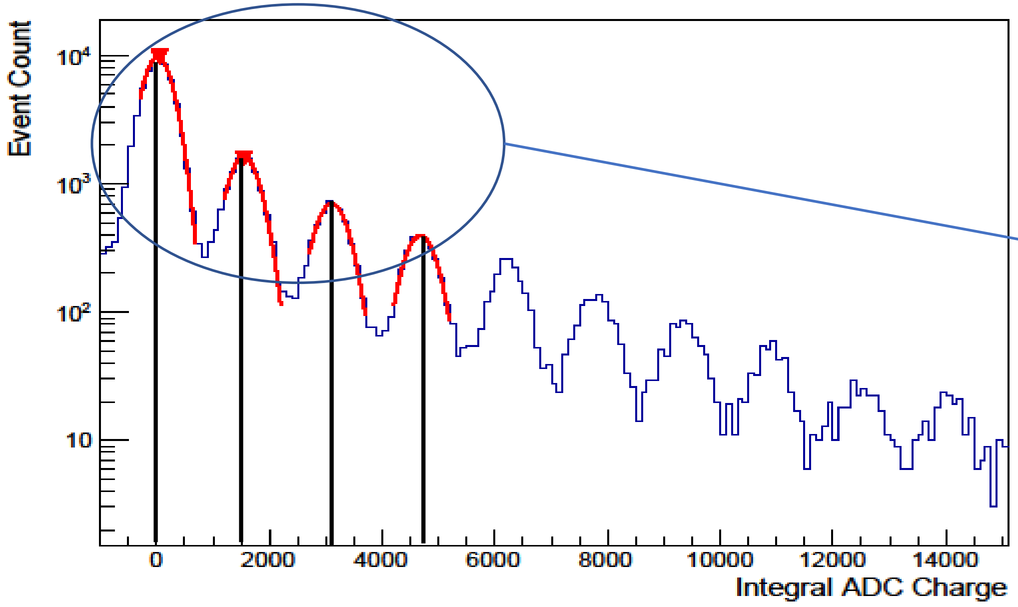
USRaS	MSRaS	DSRaS
304	204	104
303	203	103
302	202	102
301	201	101

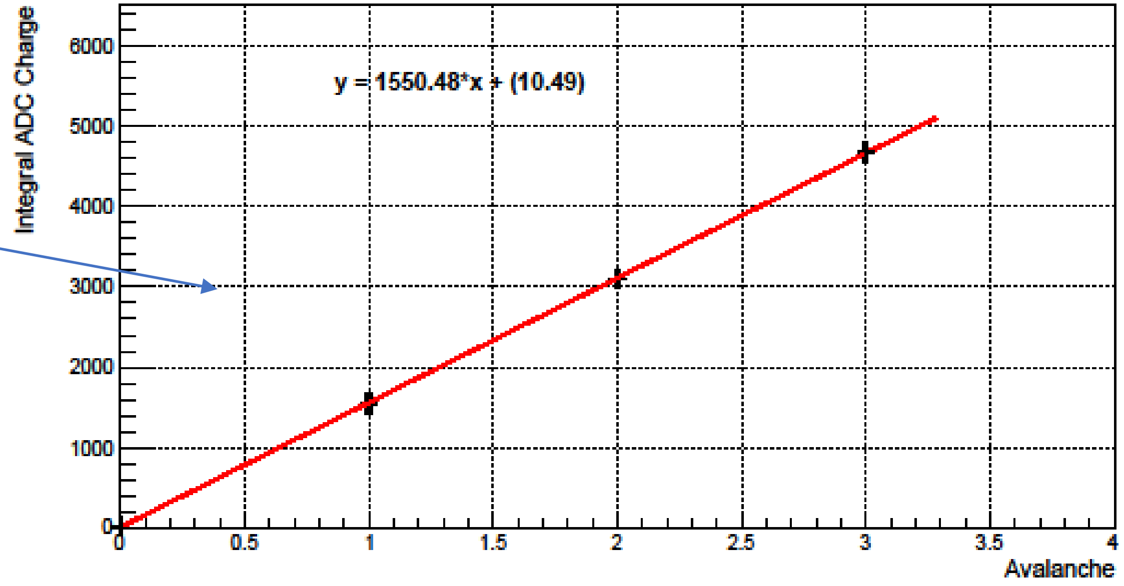
Calibrations- ADC/Avalanche



- Processed Runs
  - Pedestal calculation (using 725 samples)
  - Integration, using fixed intervals
    - BeamInt - [700,1975] samples

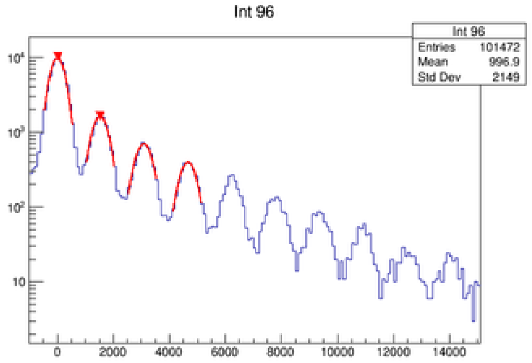
SensL Calibrations- ADC/Avalanche

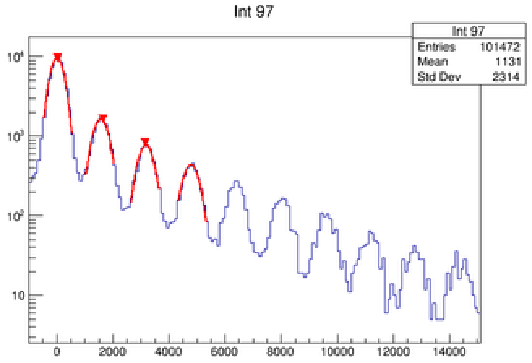


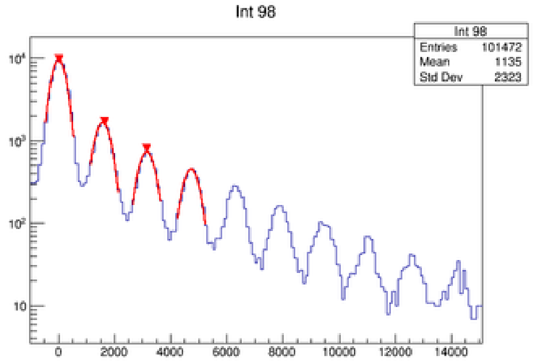


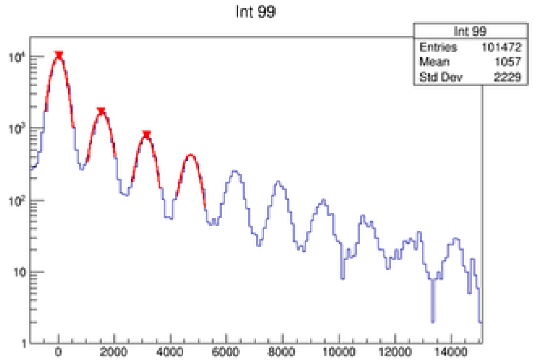
- Fit the first 4 Avalanche peaks with a gaussian, using TF1 fit.
  - Fit range - [Peak-500, Peak+500]
- Linear Fit, via TF1 fit, using
  - mean of each peak
  - sigma as error

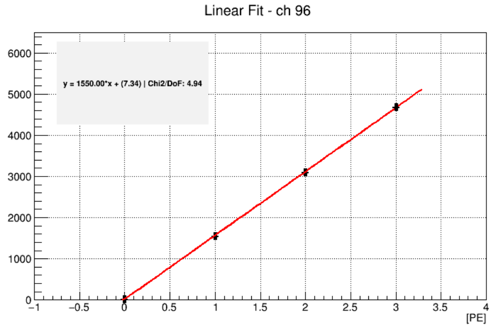
SensL’s- ADC/Avalanche @ 26.0

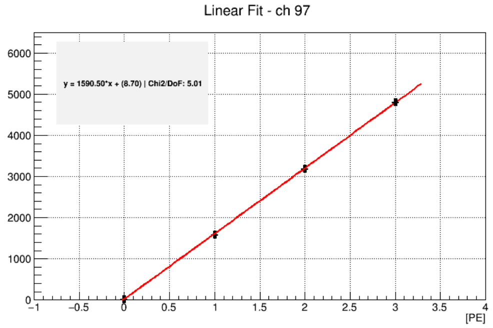


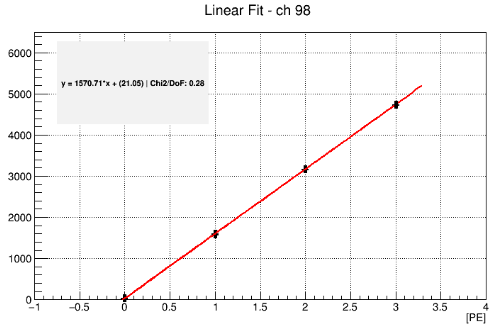


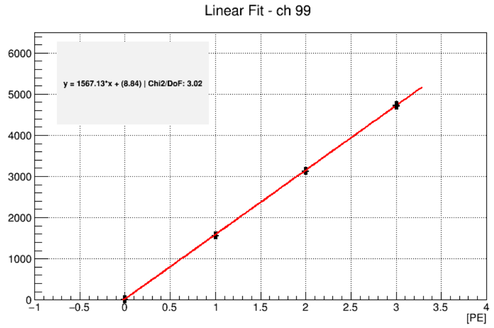




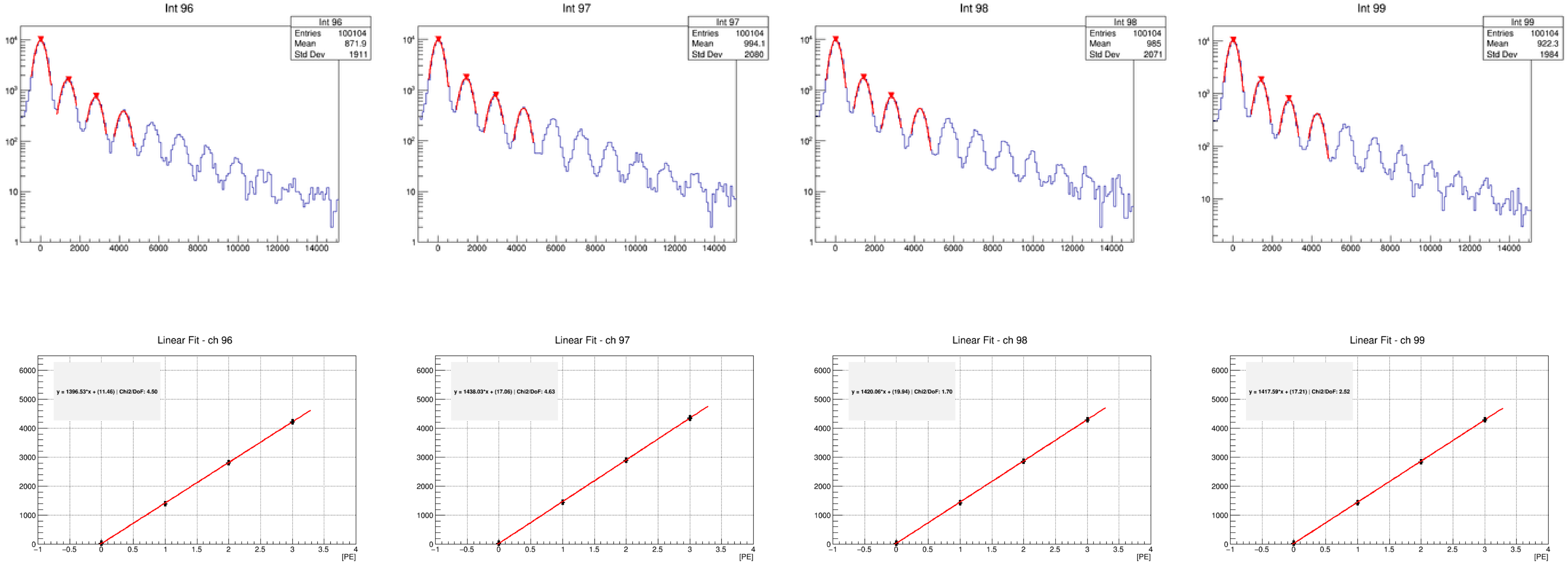




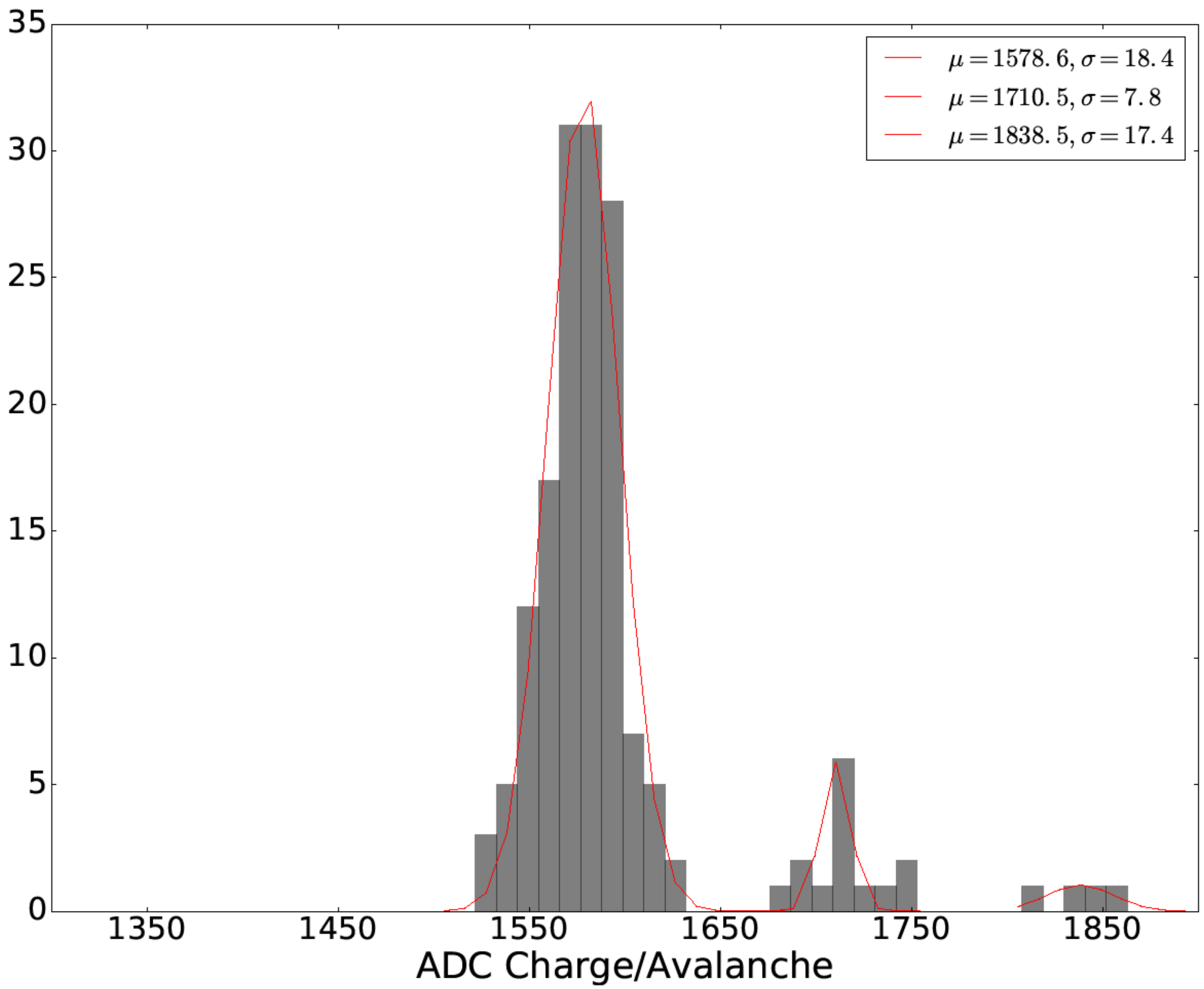




SensL’s- ADC/Avalanche @ 25.5



SensL's- ADC/Avalanche via Gain Fit



Correcting for Under/Over Counting Events - Using a Random Trigger

- Determine “Pedestal”

$$\boldsymbol{Ped} = \frac{\sum(\boldsymbol{baseline\ value})}{\sum_x \boldsymbol{N}(\boldsymbol{x})}$$

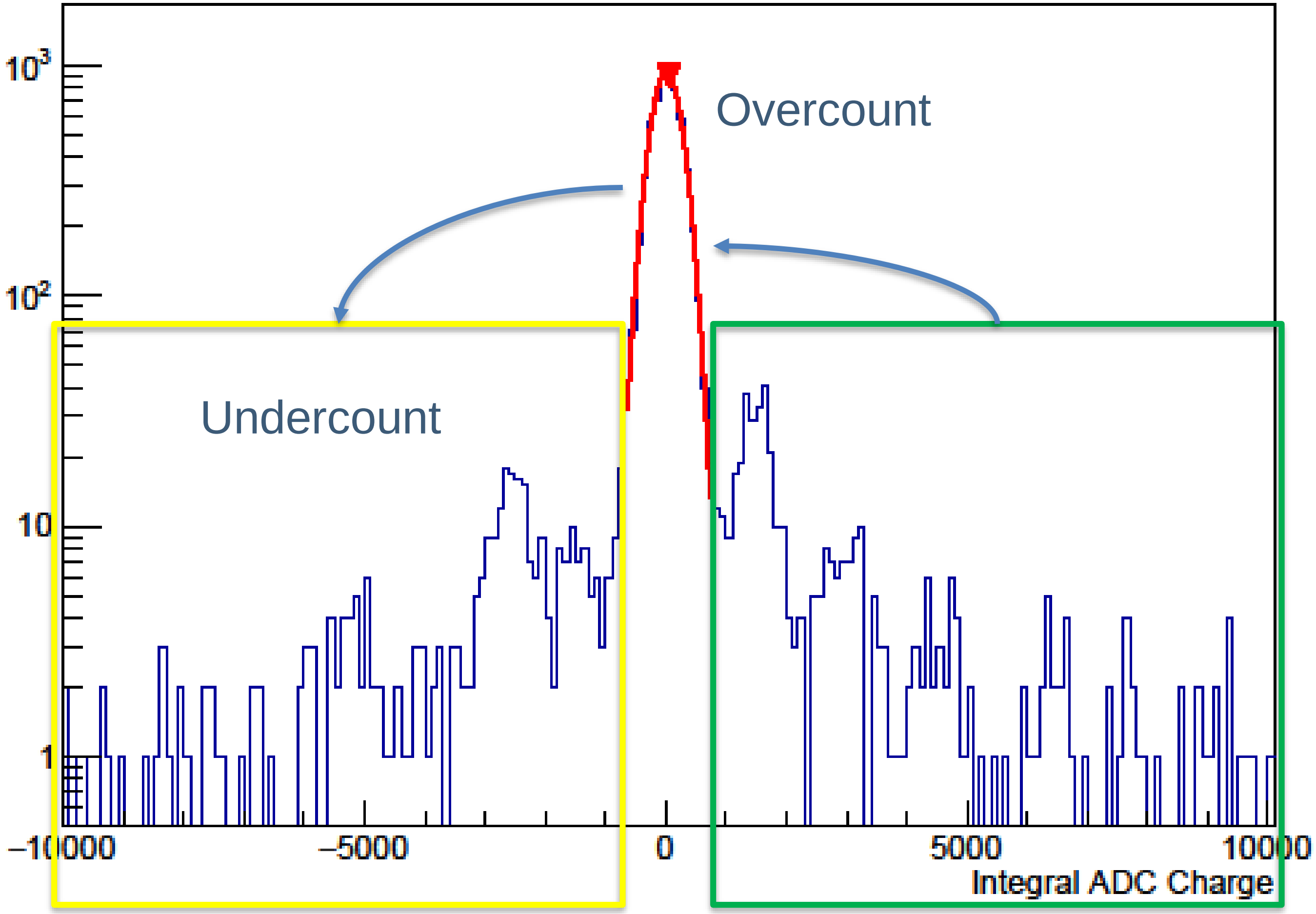
- Determine “Integral ADC Charge”

$$\boldsymbol{Integral} = \sum(\boldsymbol{ADC}) - \boldsymbol{Ped} \times (\boldsymbol{Integration\ \ Window})$$

- IF a signal is caught in baseline, then the average Ped value is perturbed
  - Under counting the integral value!

$$\boldsymbol{Offset} \times (\boldsymbol{Integration\ \ Window})$$

- Under count ≡ values fall from “zero bin” into the yellow region
- Over count ≡ values falling out from green region into “zero bin”



* accounting for the same window (i.e. Pedestal & Beam window)

Correcting for Under/Over Counting Events

- Determine "Undercount Probability"

$$\text{fracUnder} = \frac{\sum(\boldsymbol{yellow\ box})}{\sum_x \boldsymbol{N(x)}}$$

- Determine "Overcount Probability"

$$\text{fracOver} = \frac{\sum(\boldsymbol{green\ box})}{\sum_x \boldsymbol{N(x)}} \times \ \mathbf{fracUnder}^*$$

- Correct the fraction of Zero-Avalanche Events

$$\text{fracZero}_\text{T} = \frac{\sum(\boldsymbol{Gaussian})}{\sum_x \boldsymbol{N(x)}} + \mathbf{fracUnder} \ - \mathbf{fracOver}$$

- Corrected λ for under/over counting

$$\boldsymbol{\lambda_{RT}} \ = -\boldsymbol{ln(fracZero_T)}$$

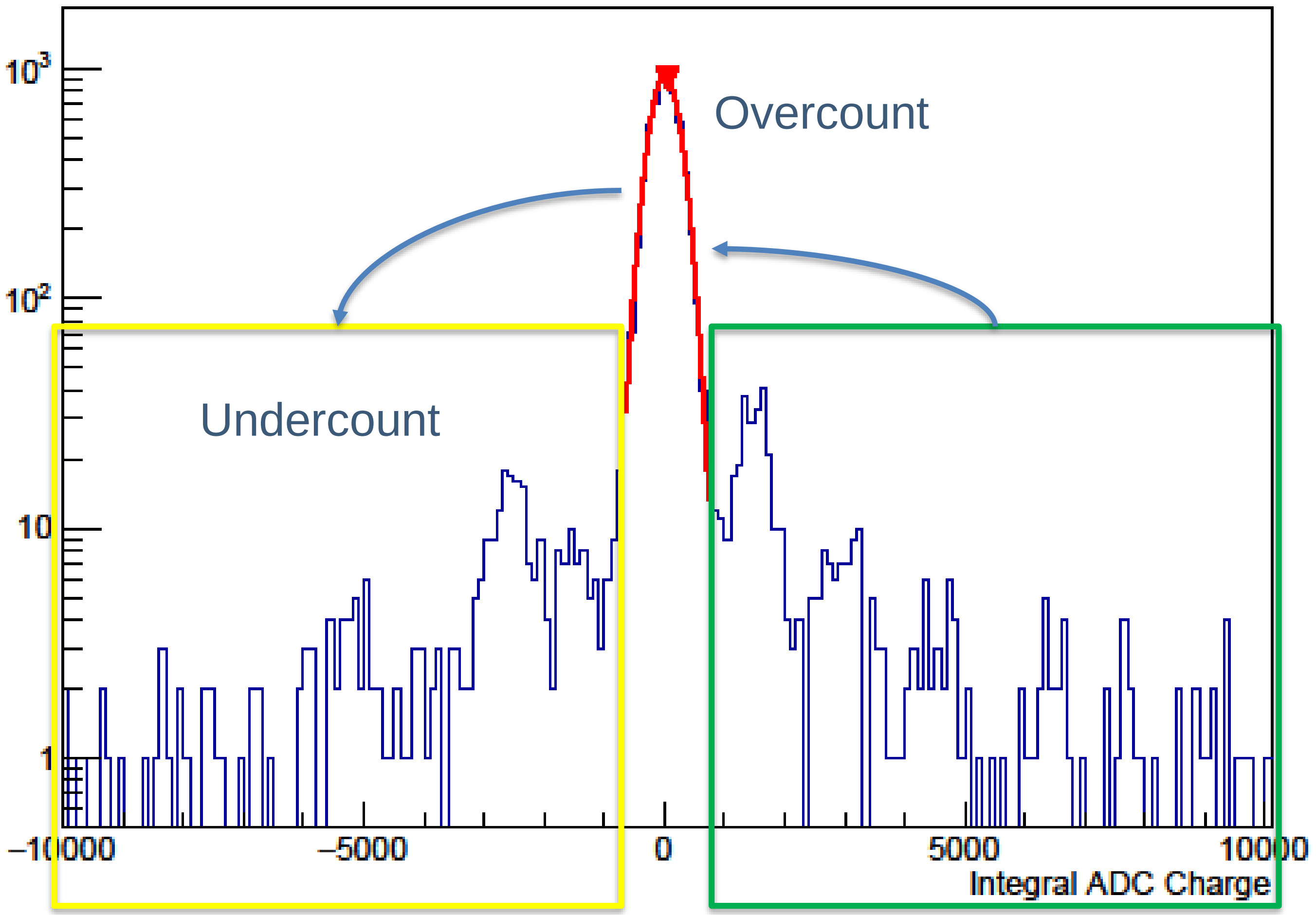
Where λ_{RT} is the number of photons expected given a random distribution

- Finally, accounting for dark charge background ($\boldsymbol{\lambda_{RT}}$)

$$\boldsymbol{\lambda_{LED}} \ = -\boldsymbol{ln[fracZero_T} \times (\mathbf{1} + \boldsymbol{\lambda_{RT}})]$$

- Correct the Mean ADC value

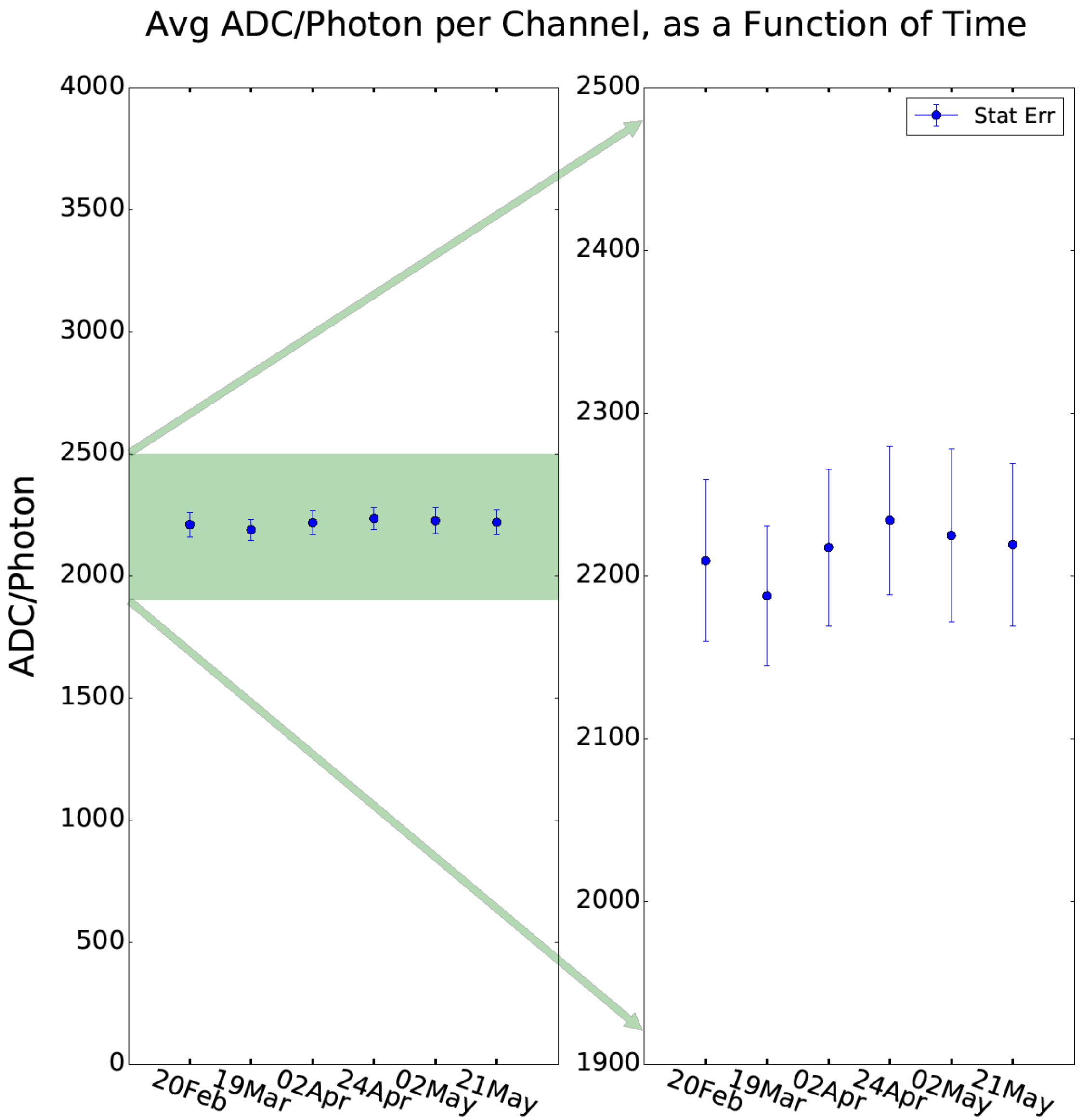
$$< \text{ADC} >_\text{T} = \frac{\sum \boldsymbol{ADC(green\ box)}\ (\mathbf{1} + \mathbf{fracOver})}{\sum_x \boldsymbol{N(x)}}$$



* accounting for the same window (i.e. Pedestal & Beam window)

SensL ADC/Photon Stability

- <ADC/Photon> per Channel APA 3
  - IU + FNAL modules
- Runs 6848, 7224, 7447, 7461, 7475, 7651, 7726, 7944
  - Stability Run
  - Pulse Peak Height = ‘0x577’
  - All viable LEDs on
- ADC/Photon value
  - Mean(channels)
- Statistical error
  - RMS(channels)/sqrt(N)

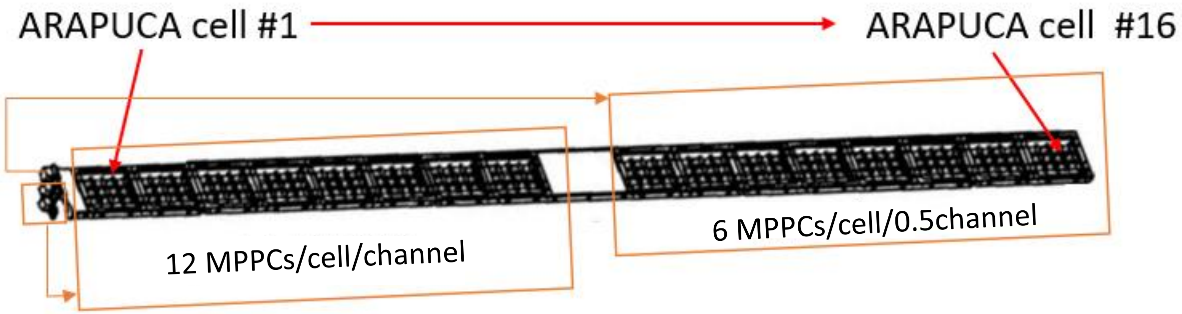


Run Summary Root file

Produced root TTree in same root file of all EXTERNAL triggers (beam/DCM/CRT)

- Contains:
  - Run – Run number from DAQ
  - Event – Event number from DAQ
  - TS – TimeStamp (double in ns, generally ~unix time)
  - Chan – DAQ Channel number
  - PH – Amplitude as: Peak – Pedestal
  - Amp – Peak ADC value
  - Ped – Pedestal calculated as average of 40 samples and beginning [5-45]
  - Tmax – Sample time of Peak ADC value [0-1999]
  - BeamInt – Sum(ADC(i)-Ped) {i=700-1975}
  - PulserInt – Sum(ADC(i)-Ped) {i=1050-1550}
  - AllInt - Sum(ADC(i)-Ped) {i=0-1999} (or AllWindow)
  - AllWindow – Number of samples in the AllInt (in case it ever changes)
  - BeamWindow – Number of samples in the BeamInt (in case it ever changes)
  - PulserWindow – Number of samples in the PulserInt (in case it ever changes)
- Many variables are redundant or hardly change, but Tree compression will handle that nicely.
- MANY examples of what to do with these in the root macros that produce the summary pictures

ARAPUCA ProtoDUNE Mapping



ARAPUCA Module

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16

Readout end

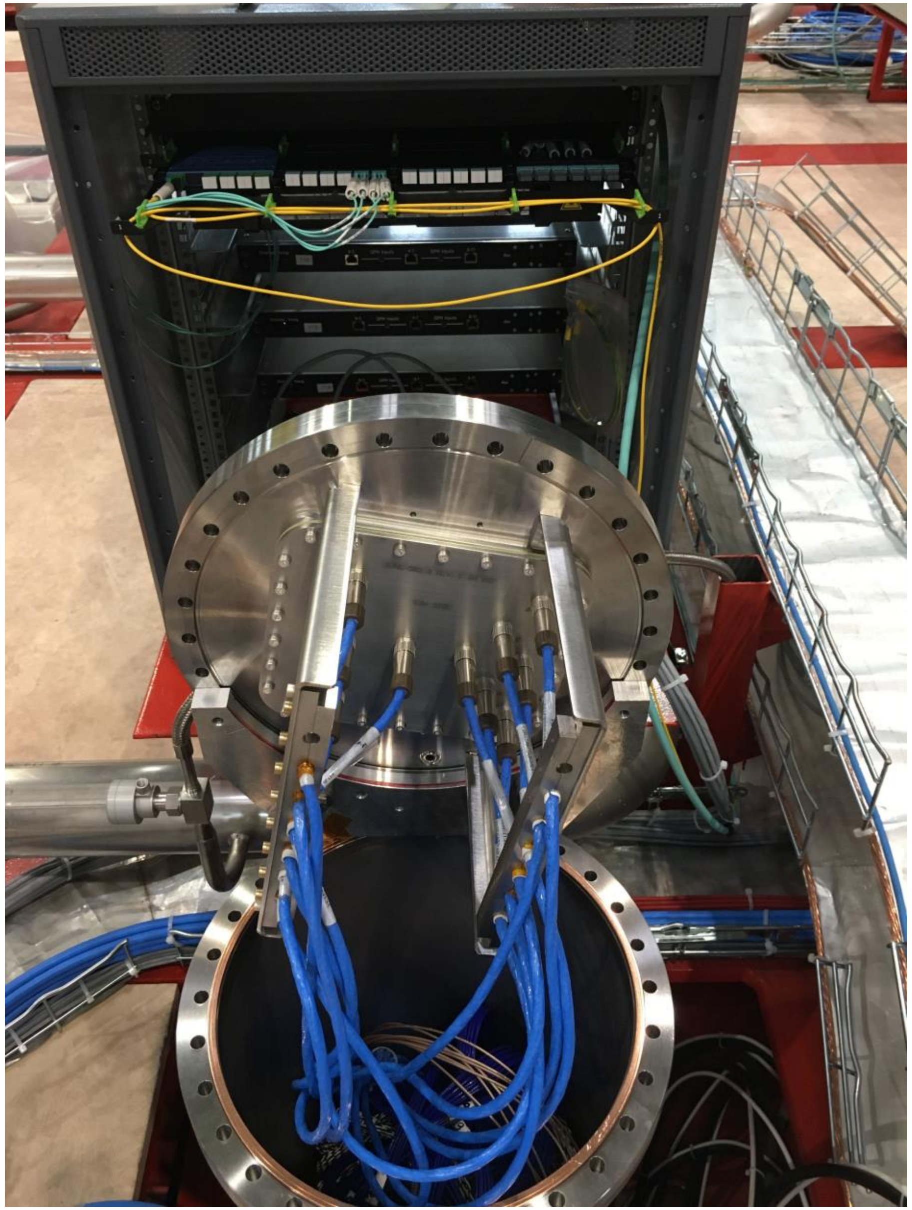
ARAPUCA-1 DAQ ch#

Still figuring out ARAPUCA cell to RJ-45 connector scheme.

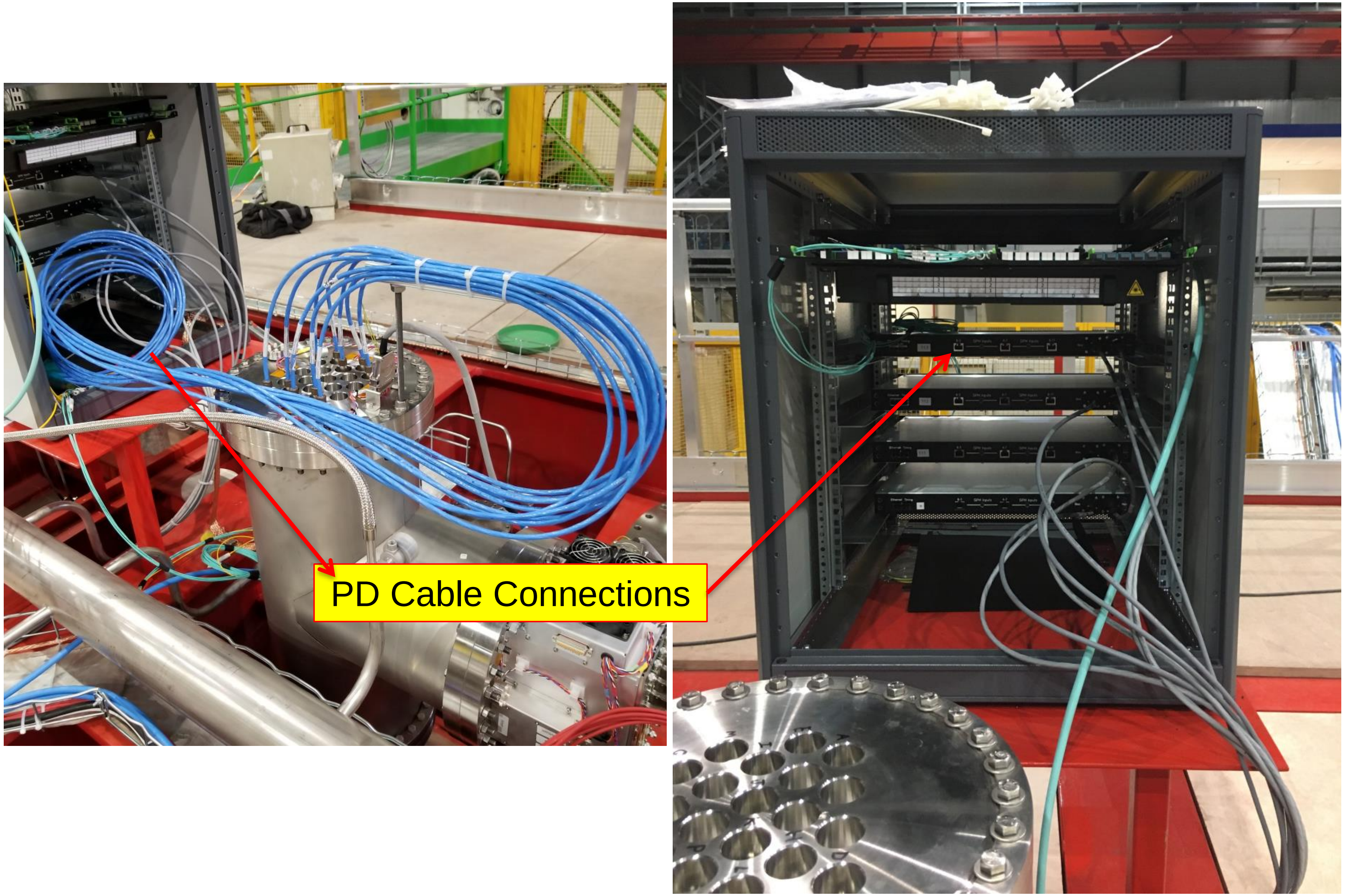
ARAPUCA-2 DAQ ch#

271	270	269	268	275	274	273	272	267	267	266	266	265	265	264	264

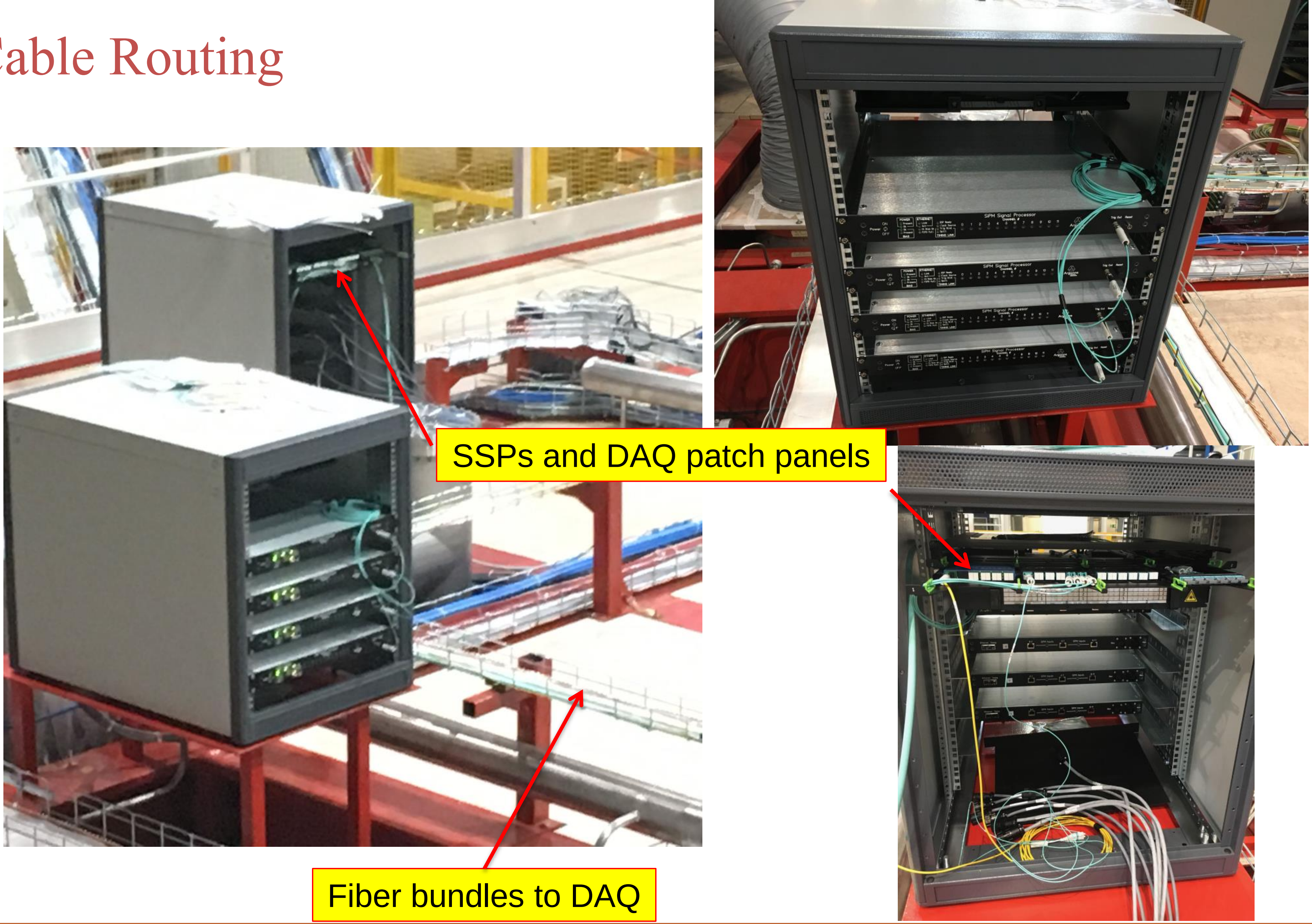
PD Cable Routing



PD Cable Routing

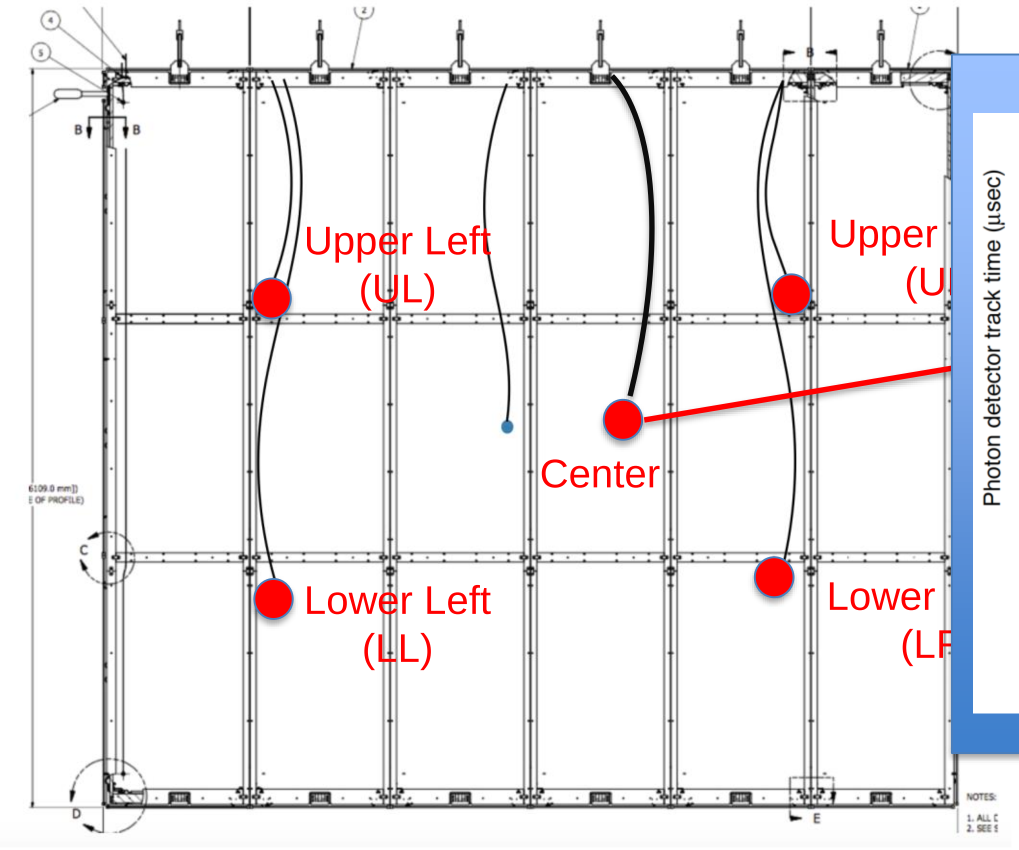


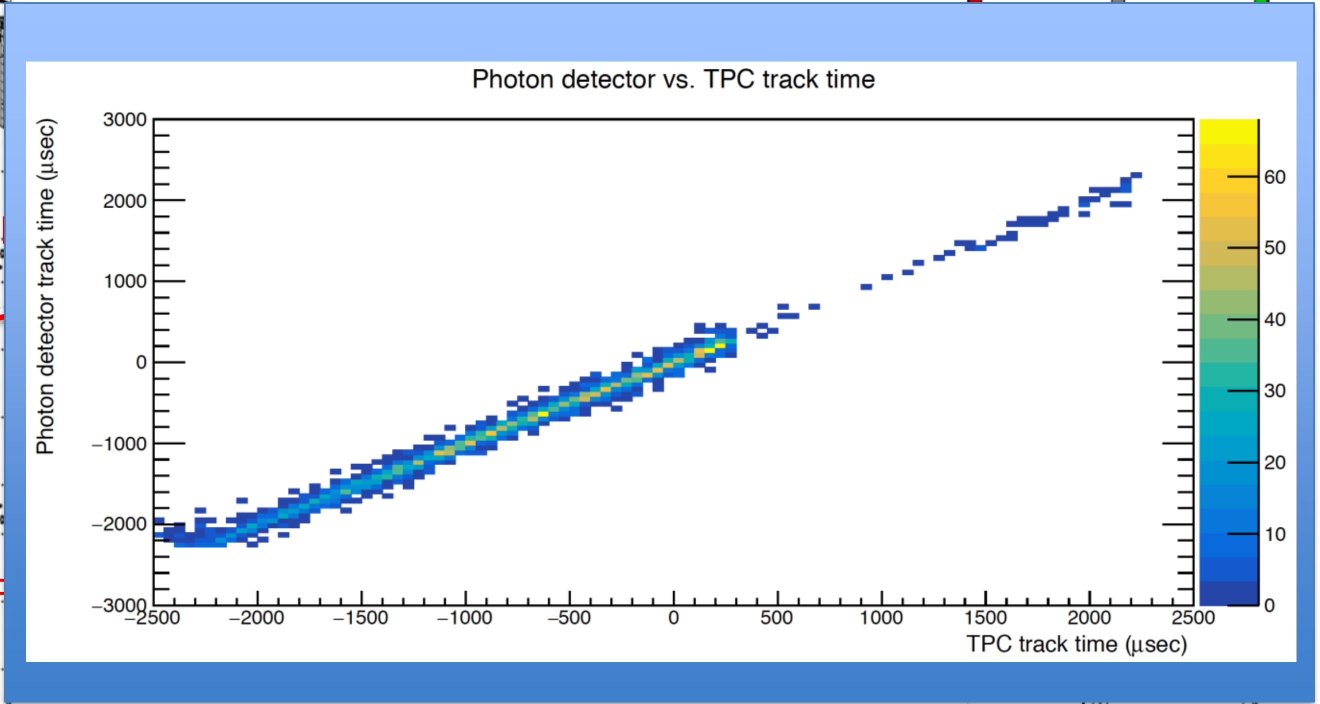
PD Cable Routing

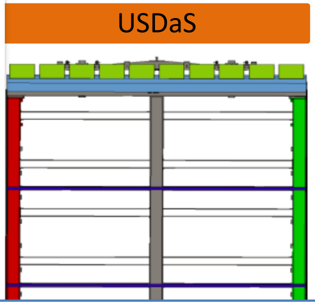


PDS Calibration System (DCM) Layout

APA View of CPA

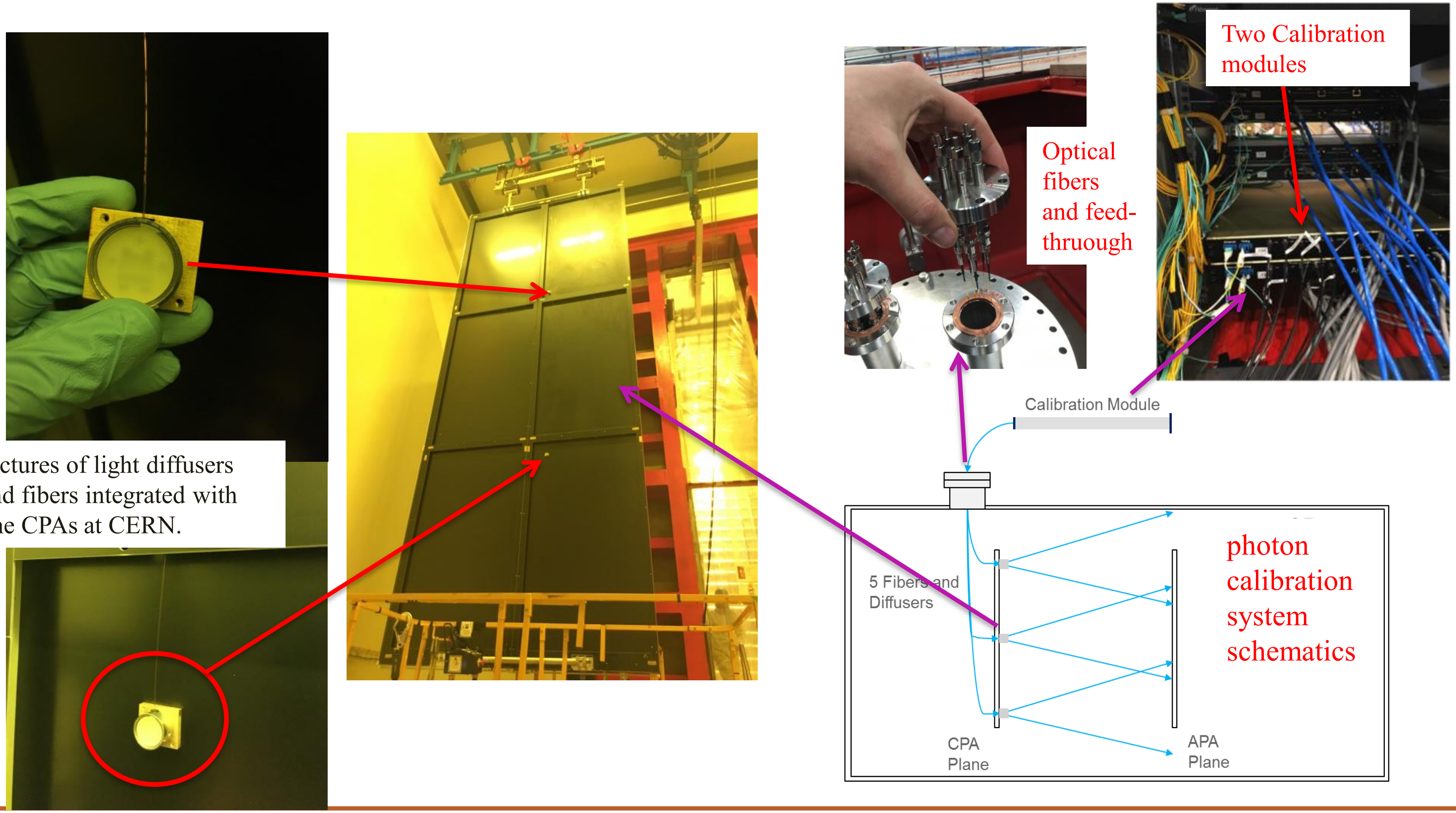






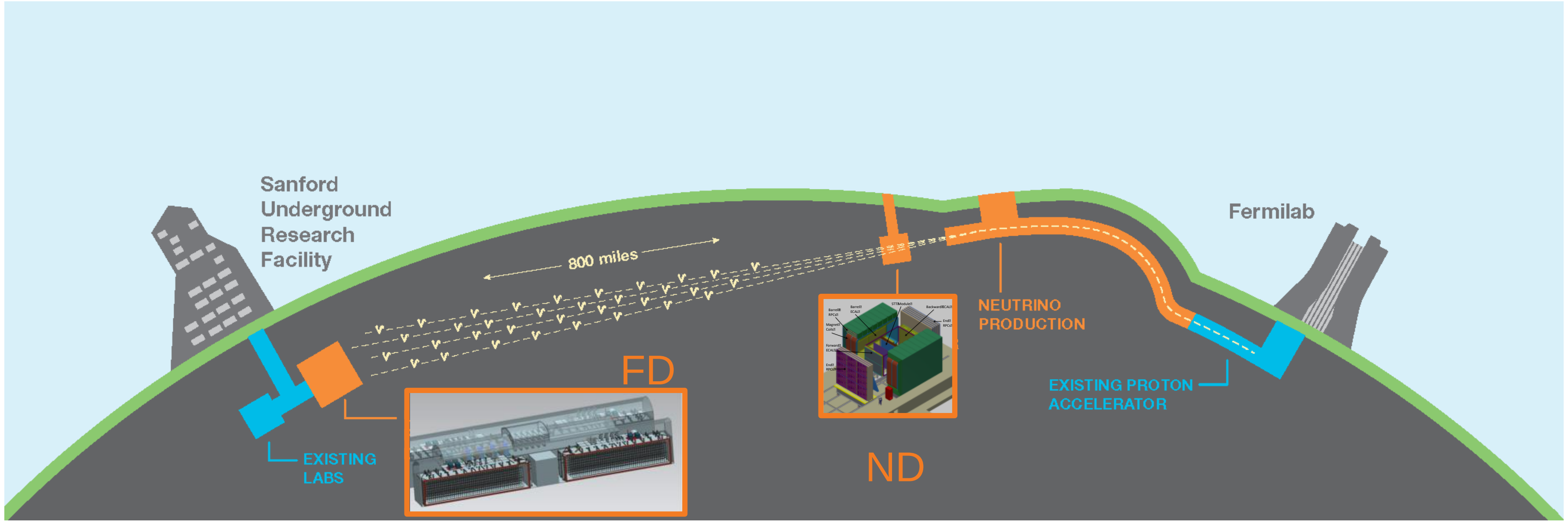
One Slide Illustration to summarize the design

- Prototype of the system completed (designed, fabricated, installed) for ProtoDUNE
  - ➢ ProtoDUNE system components illustrated here in the single page
- This all worked (see next slides)



Pictures of light diffusers and fibers integrated with one CPAs at CERN.

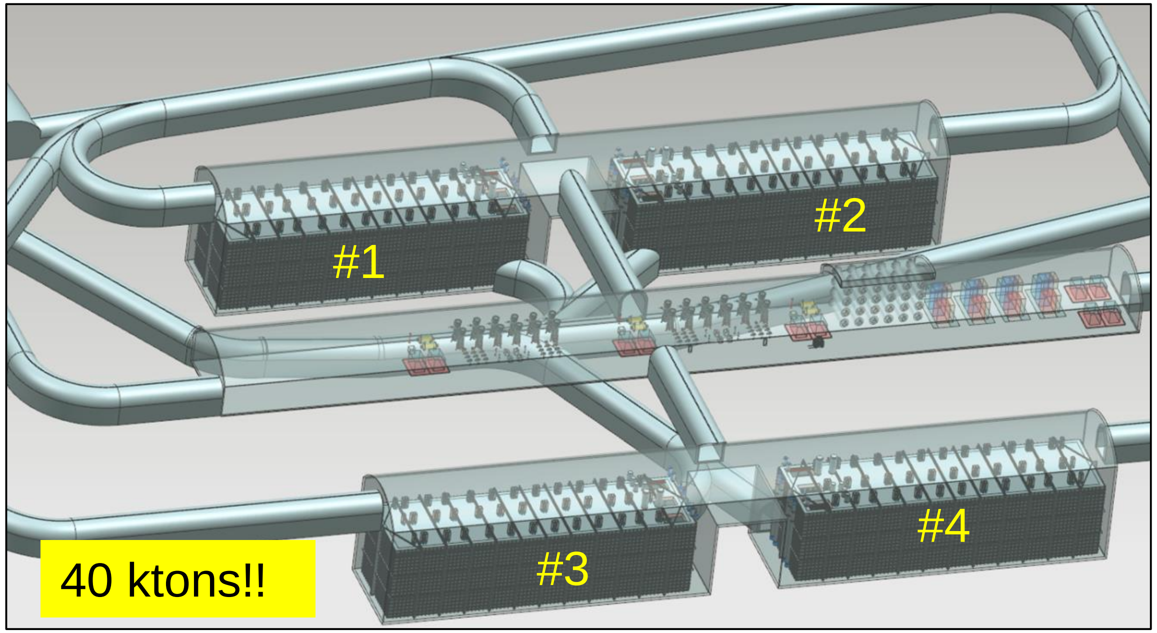
What is DUNE?

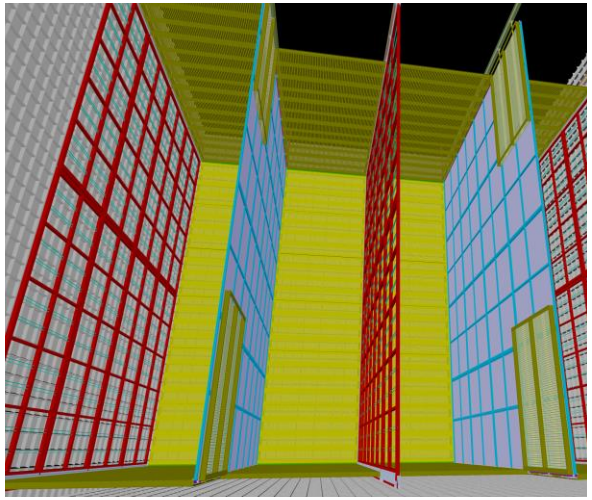


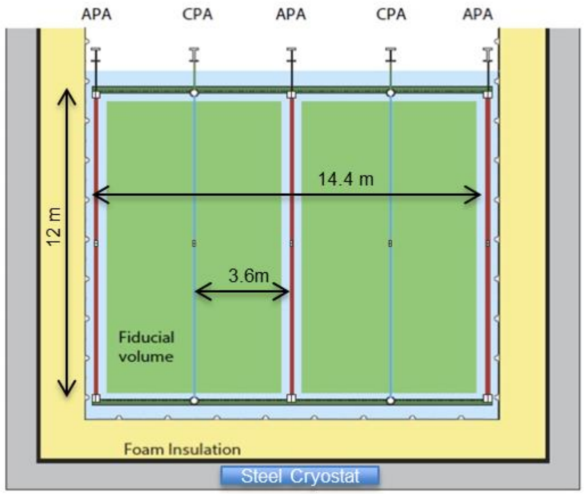
- Deep Underground Neutrino Experiment (DUNE)
- Liquid Argon (LAr) based neutrino experiment
  - 40 kiloton fiducial mass liquid argon Far Detector (FD) ← will focus on
  - Near Detector located at Fermilab (FNAL)
- Beamline from FNAL to FD at Sanford Underground Research Facility (SURF) in Lead, SD
  - 1300 km (800 mile) baseline
  - high-intensity MW neutrino beam originating at FNAL
- Data collecting starts in 2024

DUNE Far Detector Conceptual Design

- 4 x 10kiloton (fiducial) LAr vessels
- Two detector technologies:
  - Single phase (SP), with multi-layer projective wire readout
    - Segmented drift volumes within the liquid
    - Excellent (~mm scale) spatial resolution
    - Excellent energy resolution & particle ID, via dE/dx
    - Calorimetry for EM and hadronic showers
    - Scintillation light detected for drift time
    - Detector Parameters (One 10-kton SP Module)
      - 58 m x 12 m x 14.4 m
      - Alternating Anode and Cathode Plane Assemblies resulting in four 3.6 m drift volumes
      - 150 Anode Plane Assemblies, 384k readout channels
      - Modular design to facilitate underground transport and installation
  - Dual phase, drift in liquid -> amplification in gas with 2D projective strip readout





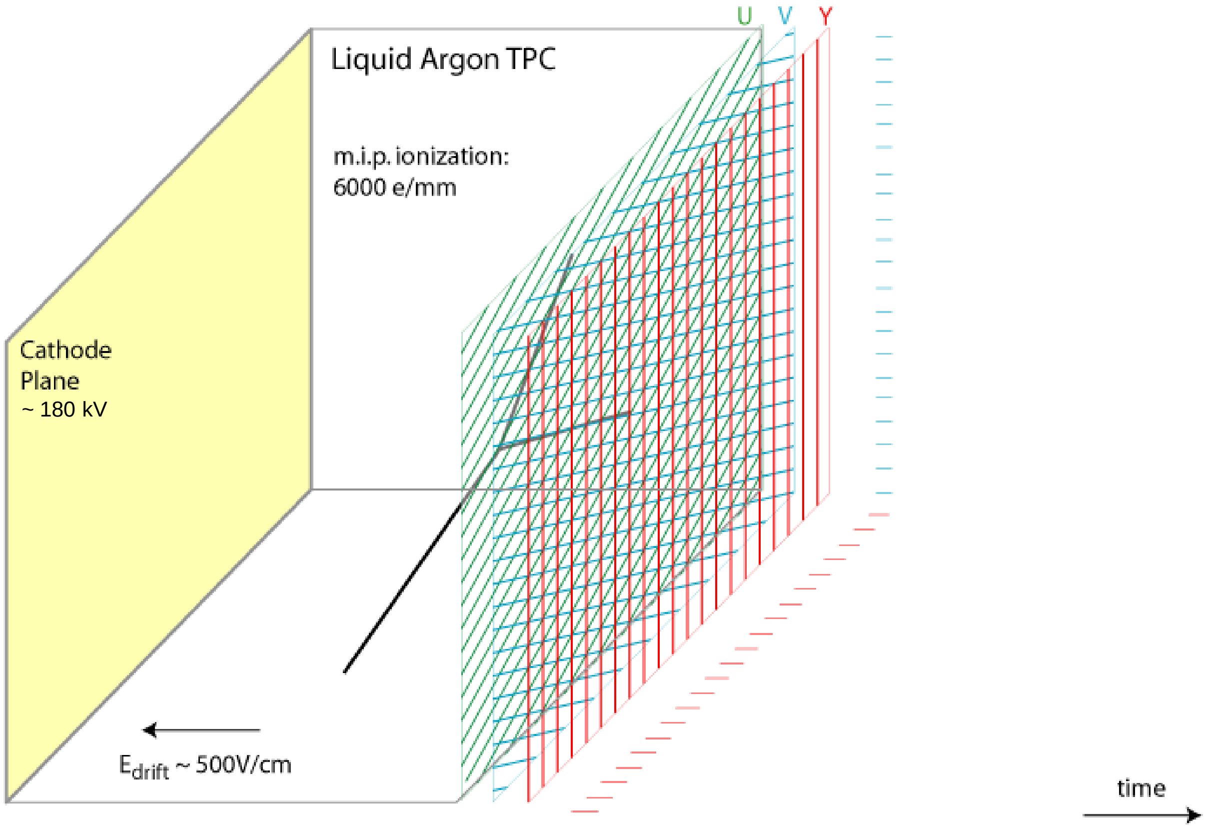


Single Phase

Liquid Argon Time Projection Chamber (LArTPC)

- LAr is used in neutrino detectors because they have many attractive properties:
  - Ionization charge that won't recombine easily
  - LAr is transparent to Scintillation light
  - Good dielectric properties (doesn't breakdown easily at high voltage)
- Horizontal drift field
  - Cathode Plane Assembly (CPA)
  - Anode Plane Assembly (APA)
    - Four planes of wires
      - 2 induction planes (+/- 35.7^{0} from vertical)
      - Vertical collection plane disambiguates signal volume
      - Grid plane shields wires behind from charge elsewhere in TPC volume
    - Sensitive to charge coming from both sides of anode
    - 2560 readout channels
- Provides 3D reconstruction
  - High resolution tracking, calorimetry, and particle identification via dE/dx

Bo Yu (BNL)



dE/dx of 1 MIP: 2.1MeV/cm

$\Rightarrow$ 6ke^{-}/mm + 128nm photons