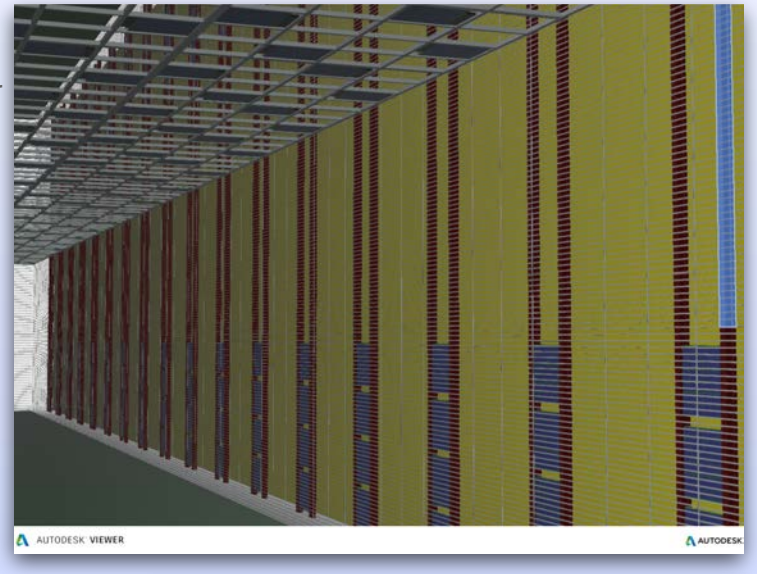
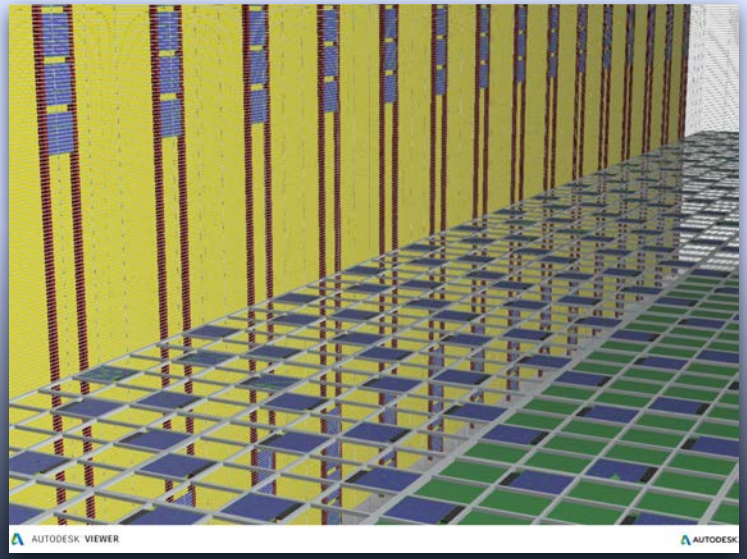
FD2 Photon Detector System Progress and Status

View from inside the Lower Volume with PD instrumented Cathode (above) and PD instrumented Membrane behind the FC

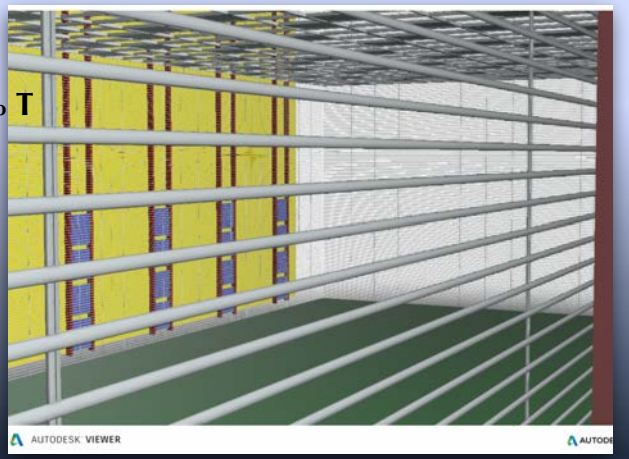


View from inside the Upper Volume with PD instrumented Cathode (below) and PD instrumented Membrane behind the FC



modified FC - 70% T

View of the Lower Volume from behind the FC, as seen by the Membrane PD modules



Operating PD on HV surface (Cathode) requires

electrically floating *Photo-sensors* and *r/o Electronics*

⇒ **Power (IN) and Signal (OUT) transmitted via non-conductive cables (e.g. optical Fibers)**

Existing PoF and SoF *(optolinks)* **technologies are commonly employed for voltage isolation between source/receiver and embedded electronics in high voltage or high noise environments.**

⇒ **however - none of the commercially available technologies are rated to operate in Cold (at LAr Temperature)**

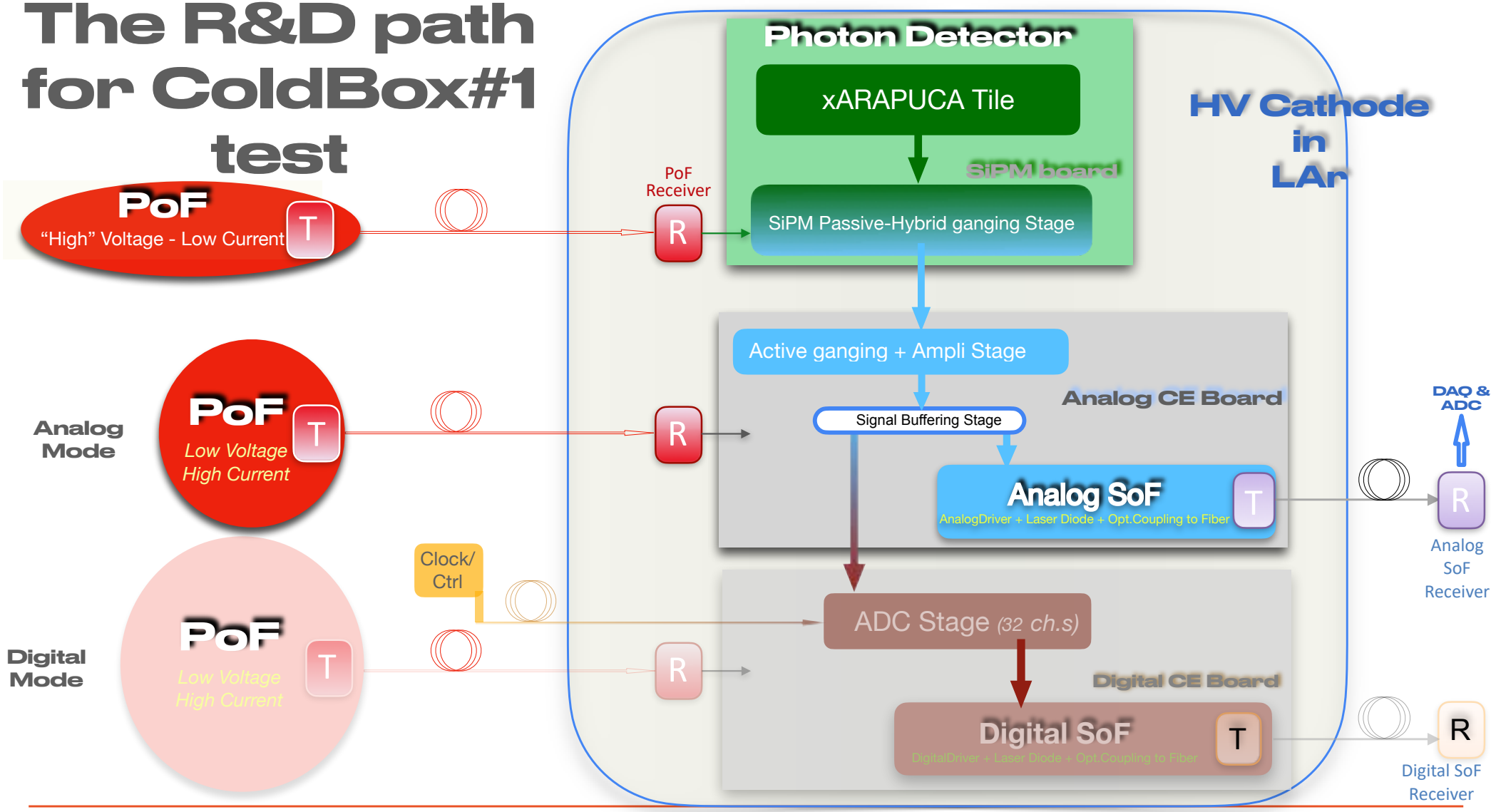
A highly specialized R&D has been launched (mid Mar '21)

to validate/customize COTS PoF and SoF technology for Cold applications

or

to thermally isolate from Cold environment and operate COTS technology in Warm

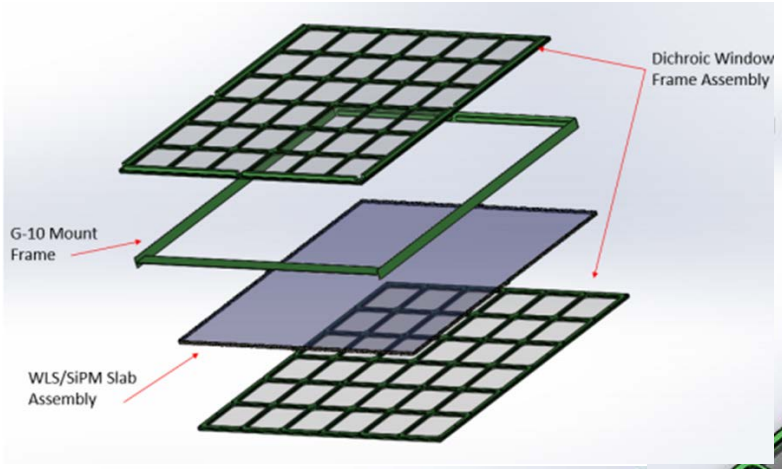
The R&D path for ColdBox#1 test

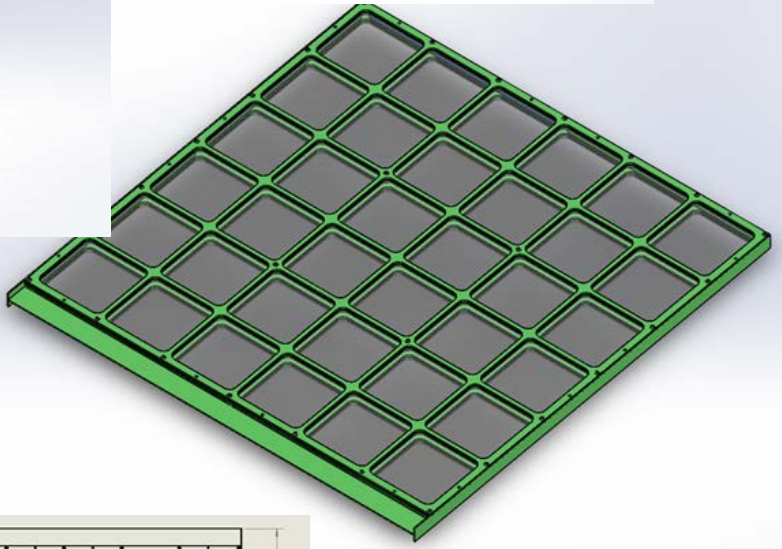


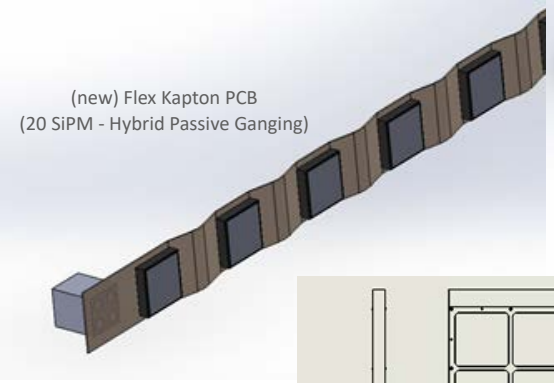
Photon Detector concept

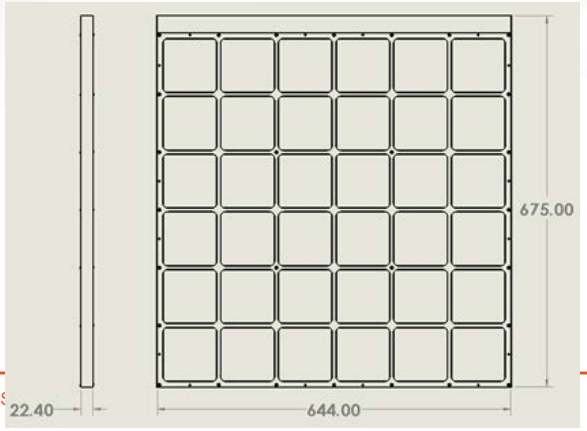
- Leveraged HD experience (xARAPUCA)
- New design (the “tile”):
  - WLS plate

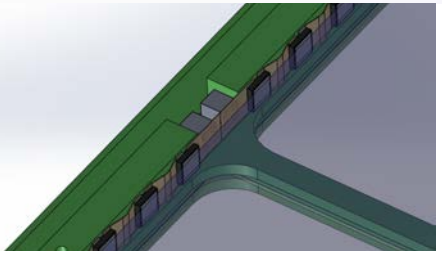
    600 x 600 x 3.8mm
  - Active area 3380 cm^2
  - Estimated mass 5.5 kg
  - SiPMs on flex circuits board (hybrid passive ganging) around perimeter glued or spring loaded to WLS plate
  - 160 SiPMs into 2-channels (80 SiPMs/ch = 20 Passively Ganged X 4 Actively Ganged)









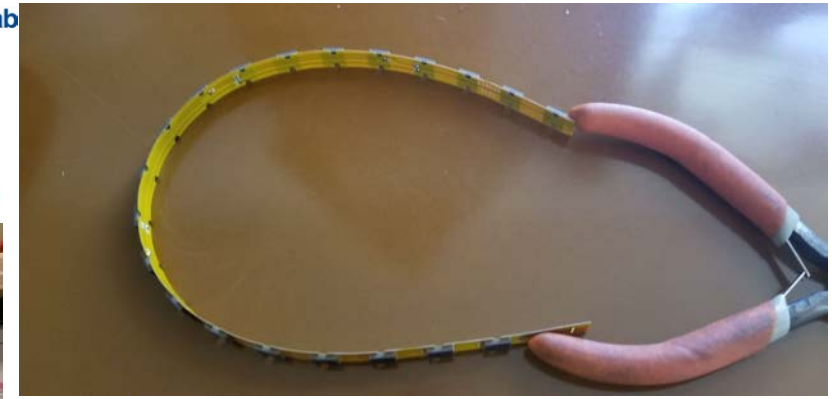


Ph Detector path

the first 60cm x 60cm xARAPUCA tile
as built

Sept 16: 160 SiPMs on 8 flex circuits (FNAL and UCSB) ready

Fermilab
UCSB

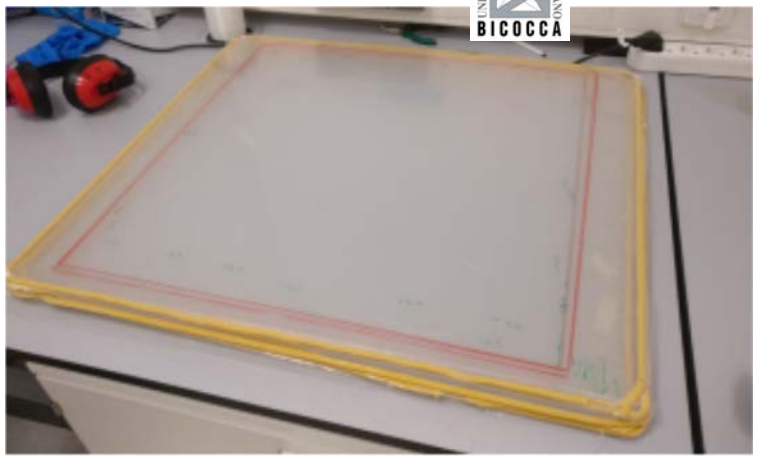


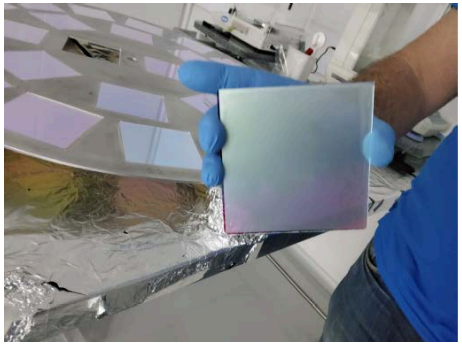
Oct 4, Design, SpringLoaded Contact and Frame production completed at CSU

Colorado State University

Jul 26, INFN-MiB: G2P completed production of WLS plates

UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA





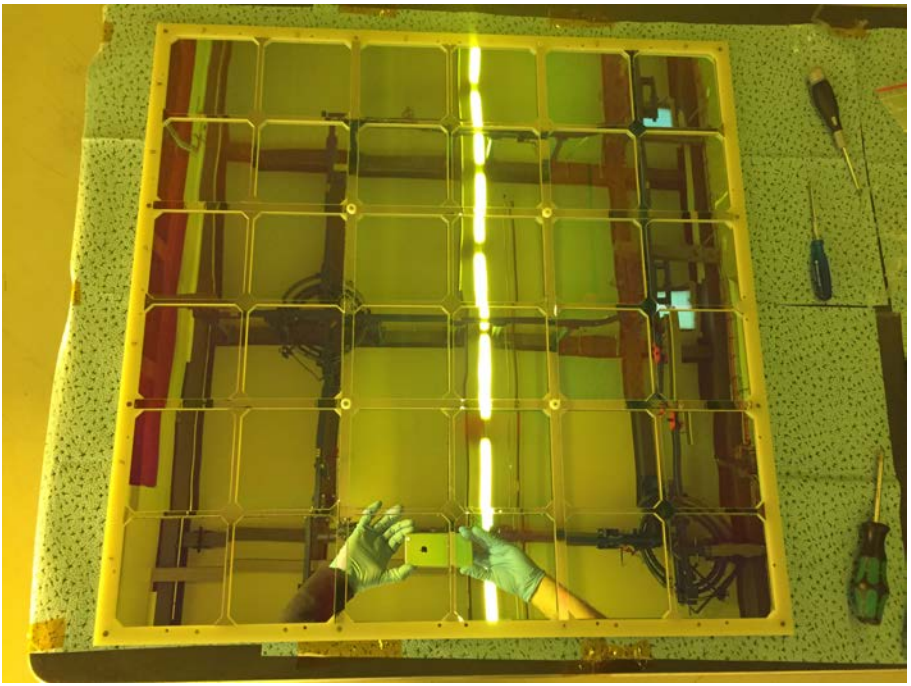
Dichroic Filters w/ pTer WLS film

UNICAMP

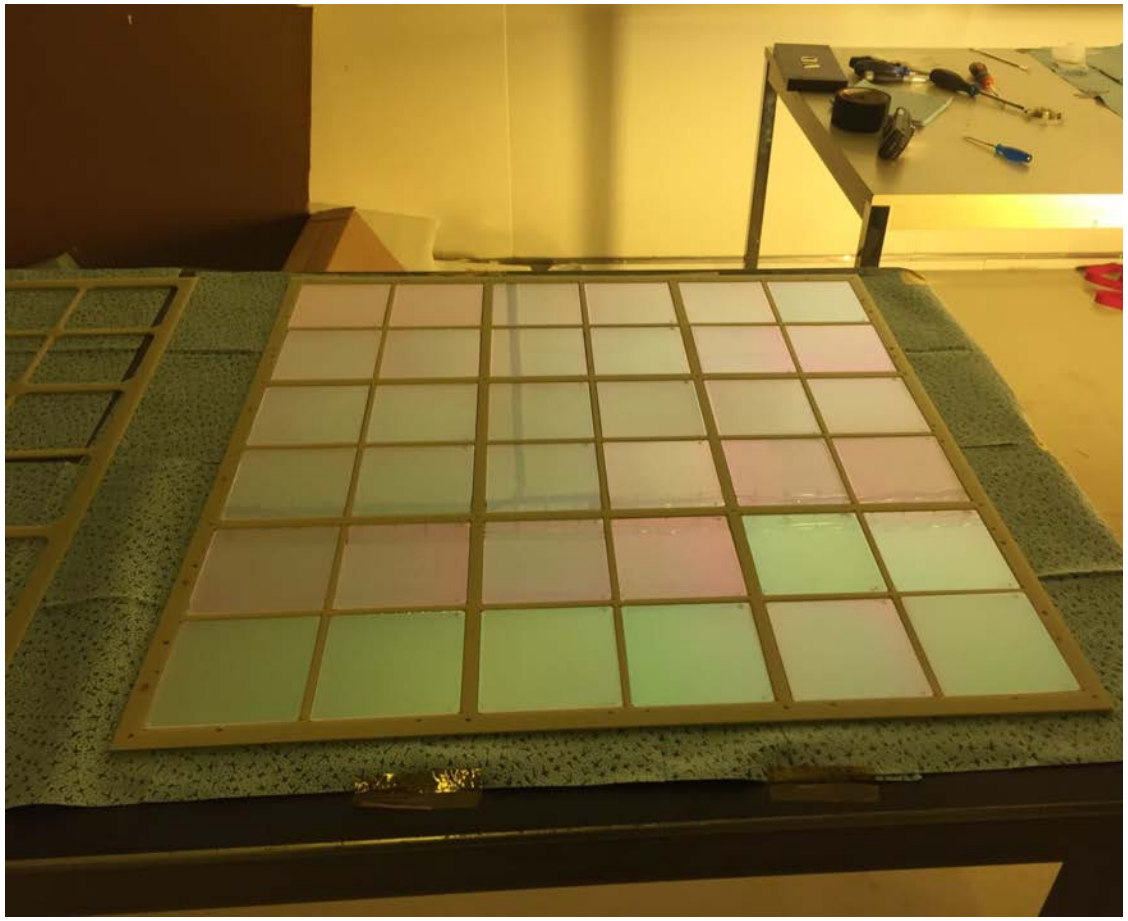
29/09/2021

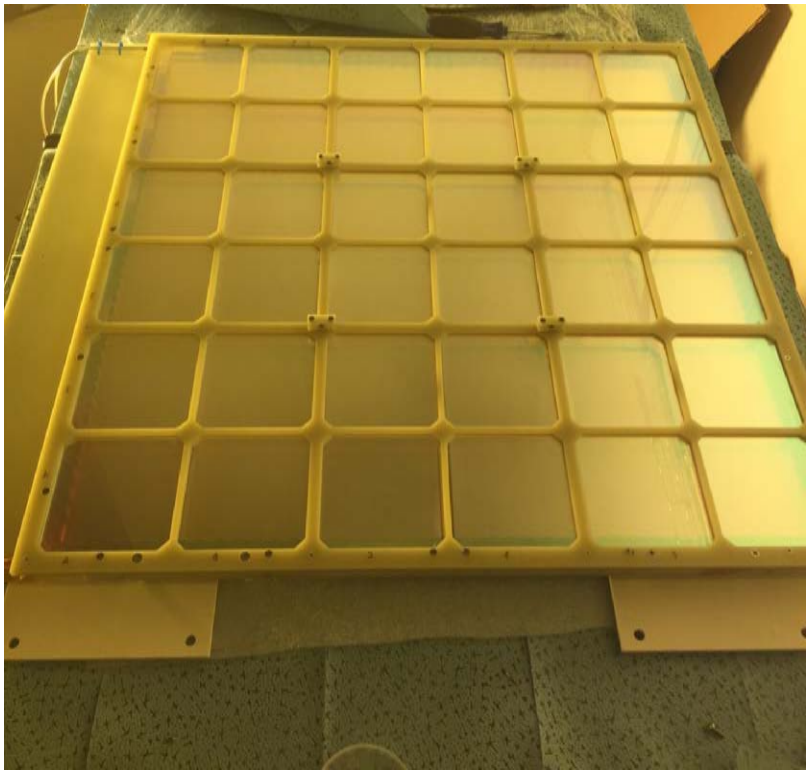
as built

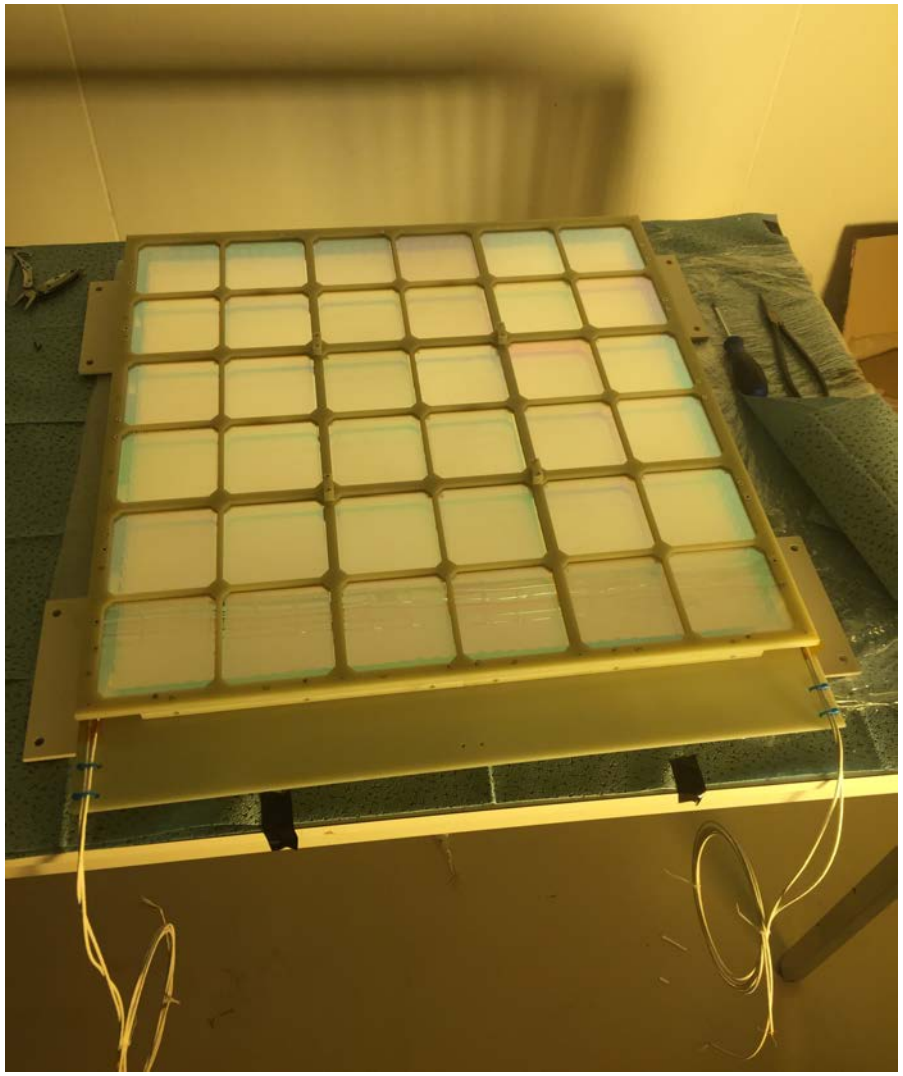
Oct 13: Parts received at CERN



xARAPUCA during assembly in Clean Area (NP04)



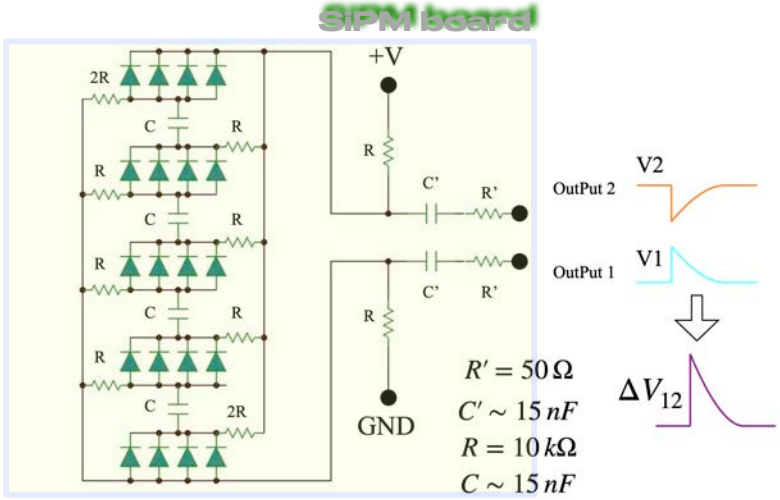


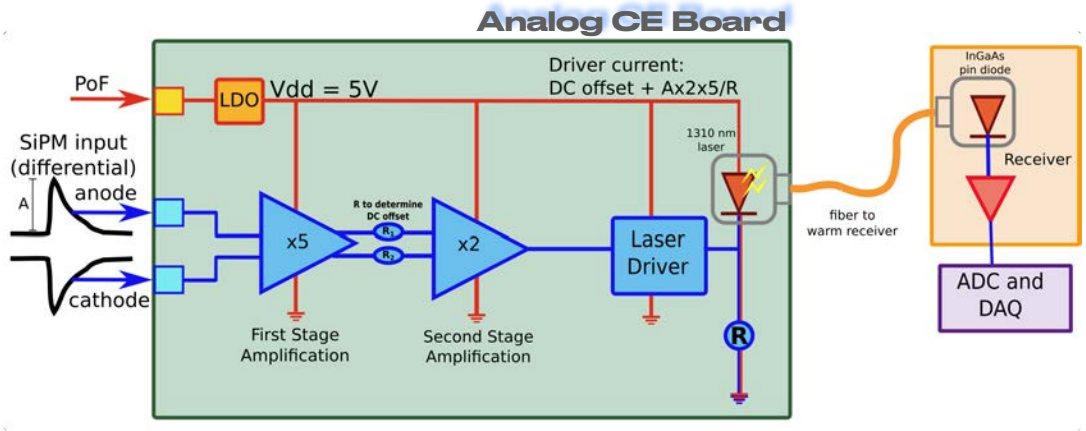


xARAPUCA tile assembled and cabled

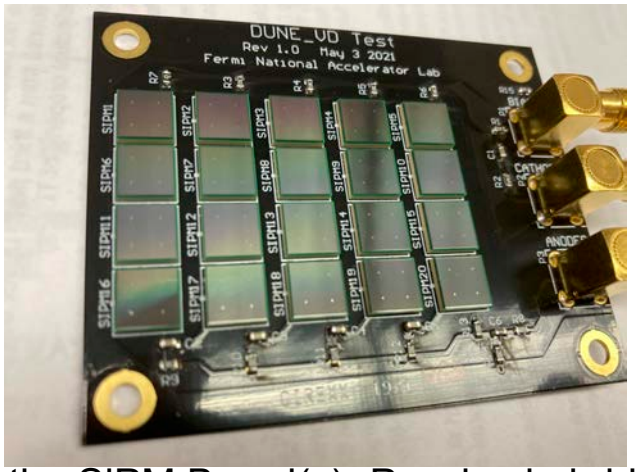
ready for installation into cathode frame

Analog SoF concept





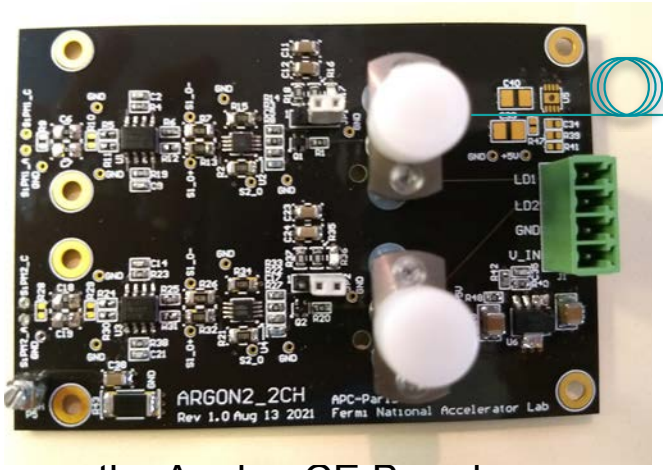
Analog SoF path



UCSB

Fermilab

the SiPM Board(s)- Passive hybrid ganging



cnrs

Fermilab

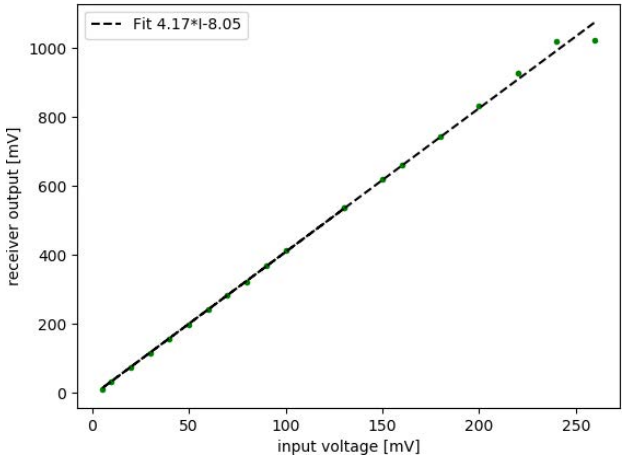
the Analog CE Board
Active ganging/Ampli & SoF

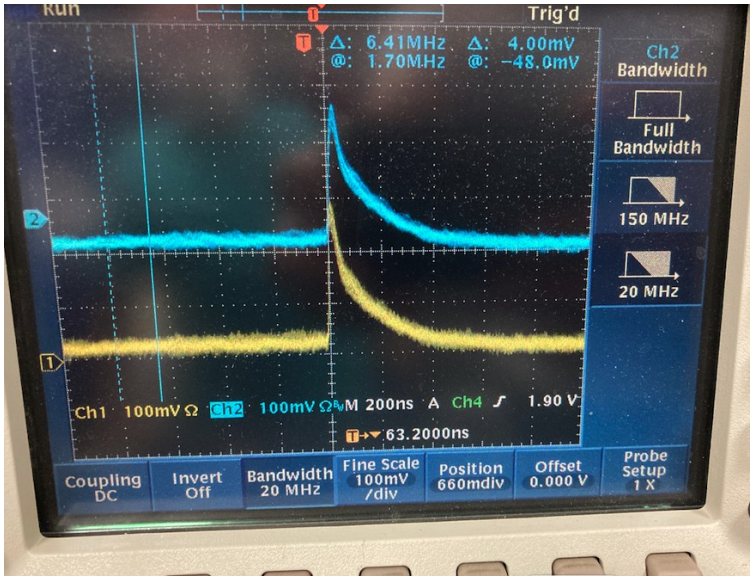
Exposed Cold electronics (PoF & SoF)

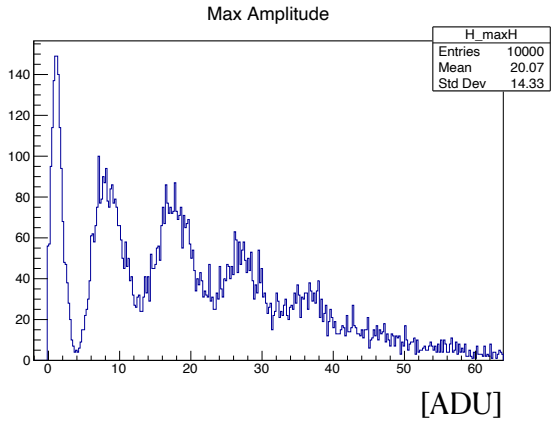
Status of SoF

Presented at LIDINE Conference

- Performance studies on-going: board+laser linearity, noise spectrum, small signal transmission







- Latest achievement: test of full chain in **LN_2**
  PoF + 20xSiPM + transmitter + receiver

Power Path

Power-over-Fiber Concept

Fermilab

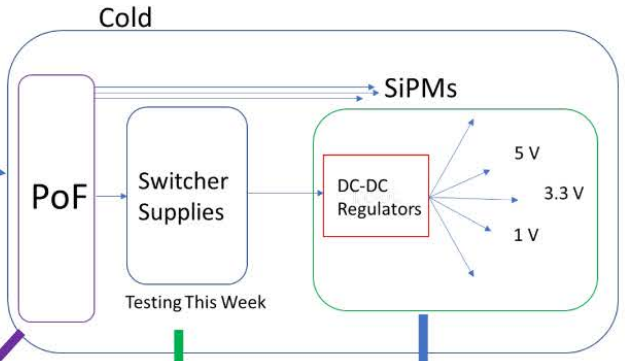
Lasers Transmitter+ Fiber

+ *Low Volt/High Current* Receiver (CE)

+ *High Volt/Low Current* Receiver (SiPMs)

Fermilab
AD/SCD/PPD/ND

Lasers – Deliver Power



2 Systems:

SiPM: 48 Volts @ <1 ma

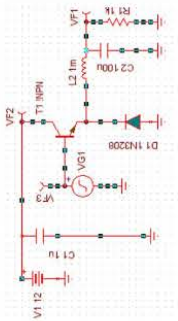
Electronics:
Communication Systems:
5, 3.3, 1 Volt @ Amps

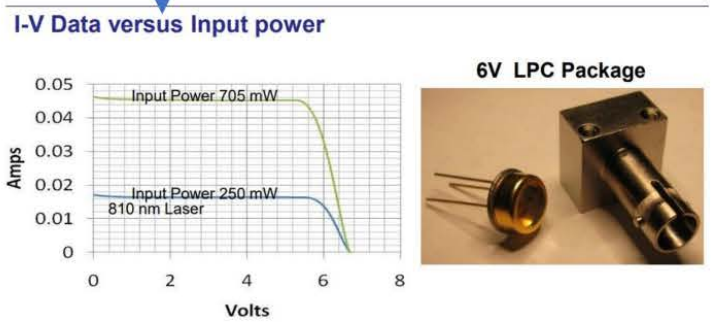
(3) (2)

(1)

Fibers Testing

Light Receiver

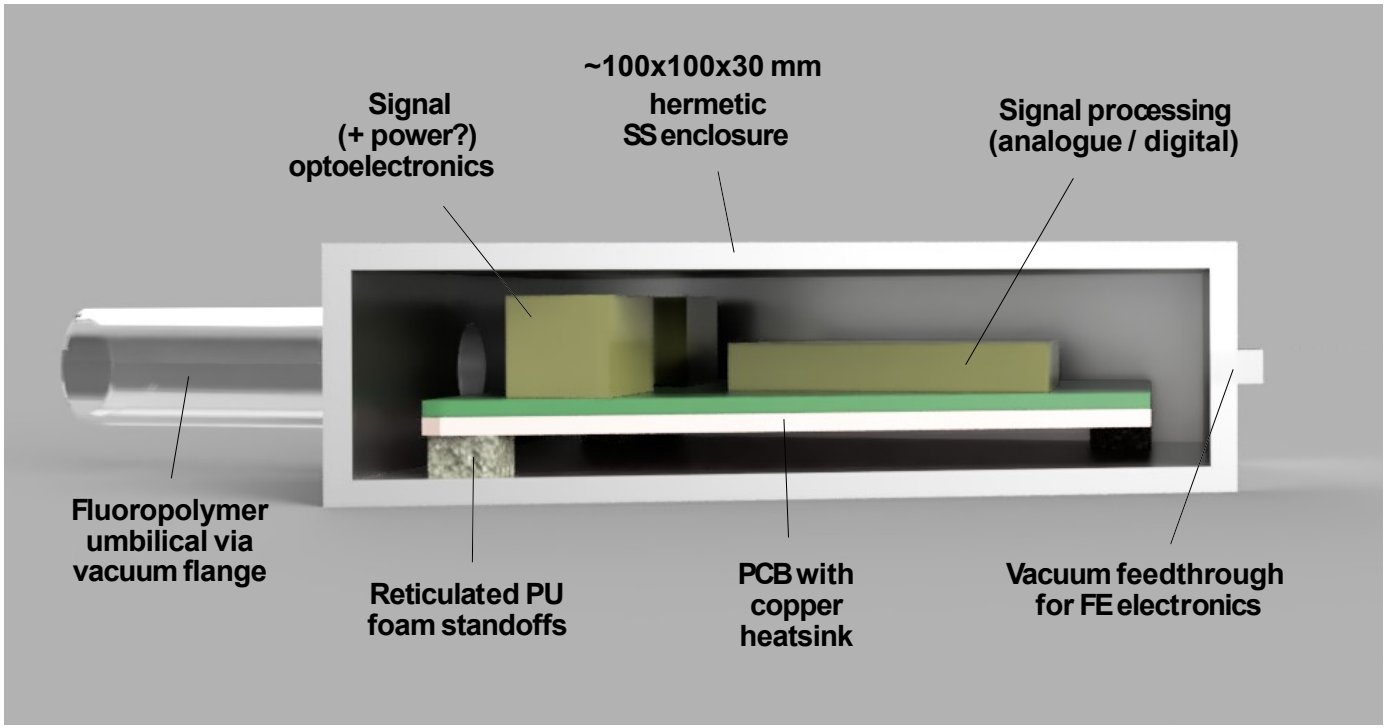




High Voltage/vLow Current Light Receiver

Low Voltage/High Current Light Receiver

Insulated Warm electronics: CryoSub concept



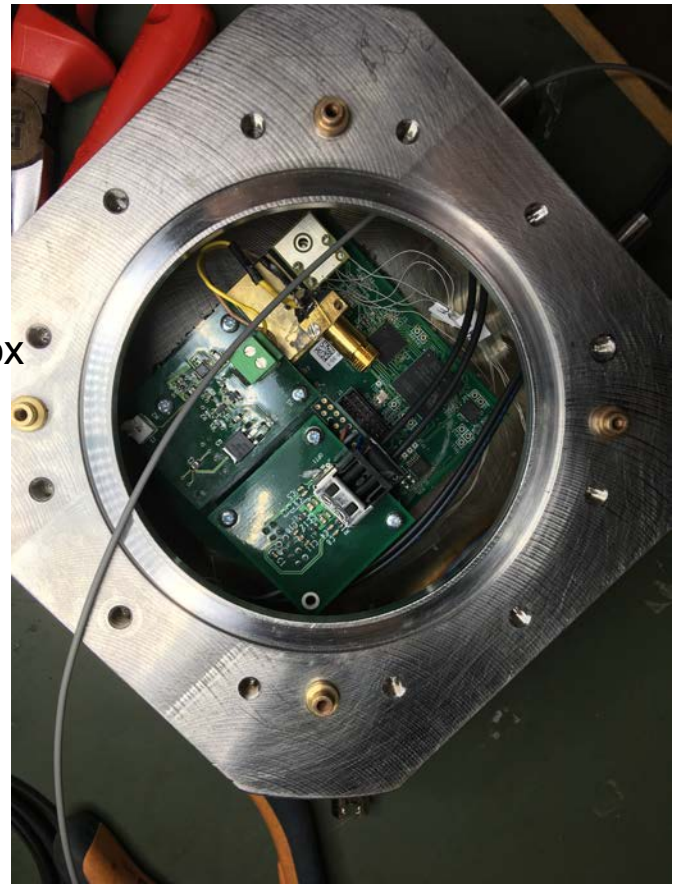
Science & Technology Facilities Council
Rutherford Appleton Laboratory

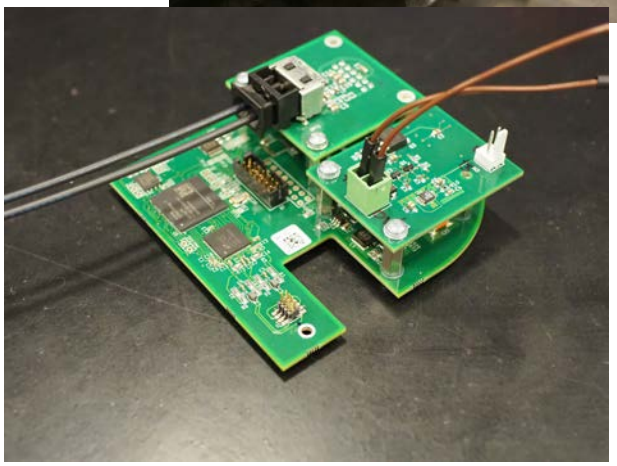
- Proposed June 2021 – 'crash' project

The CryoSub path

as built

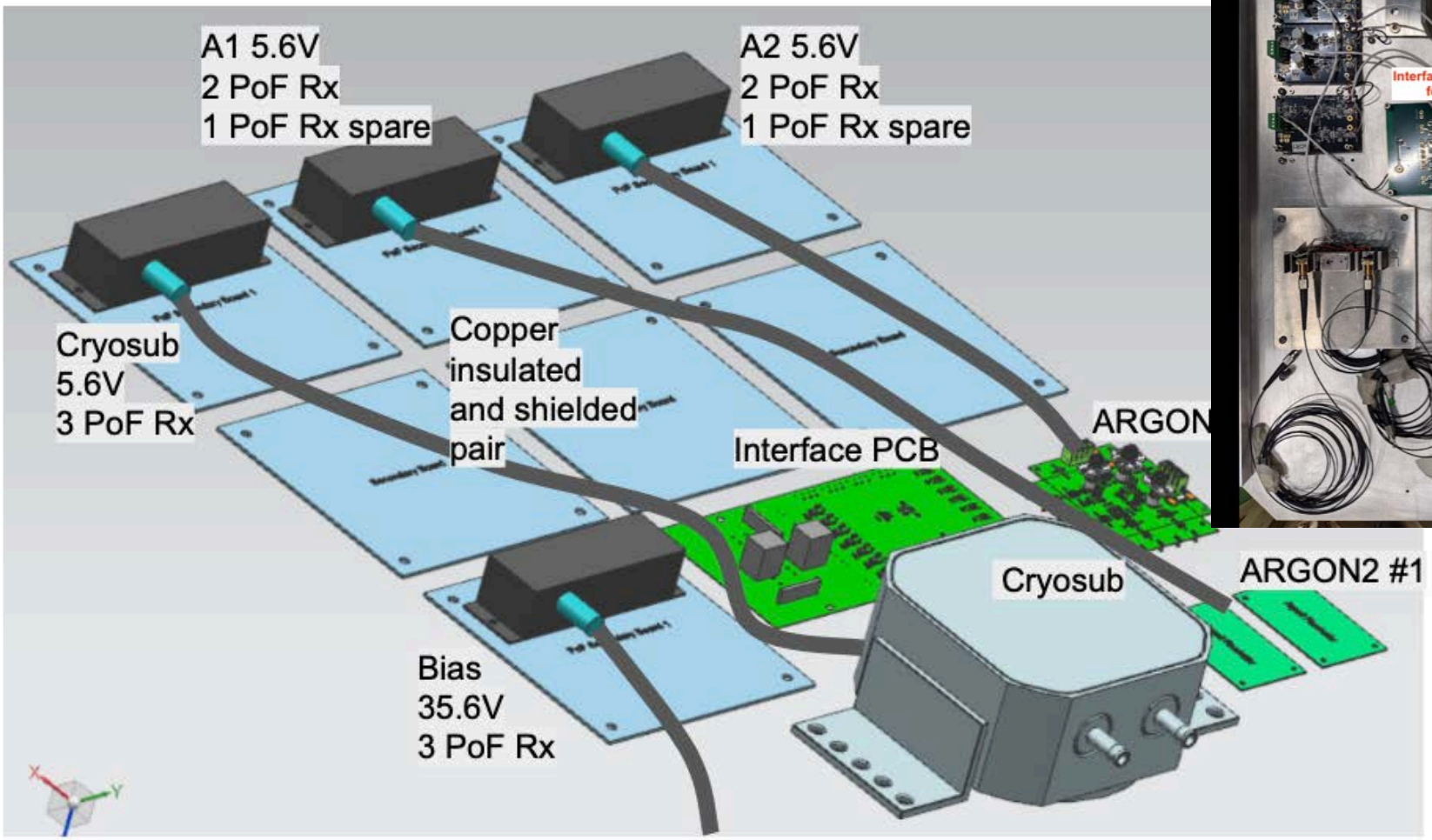
The insulation box

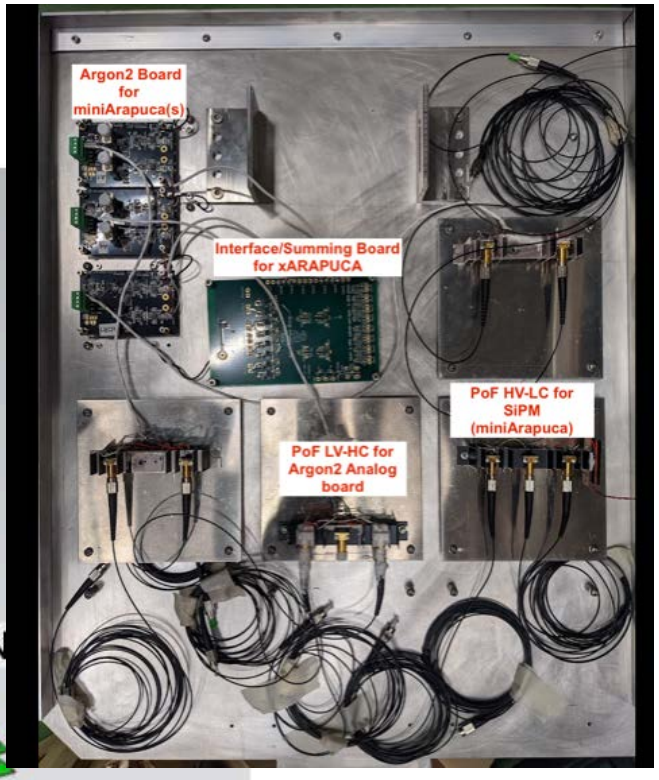




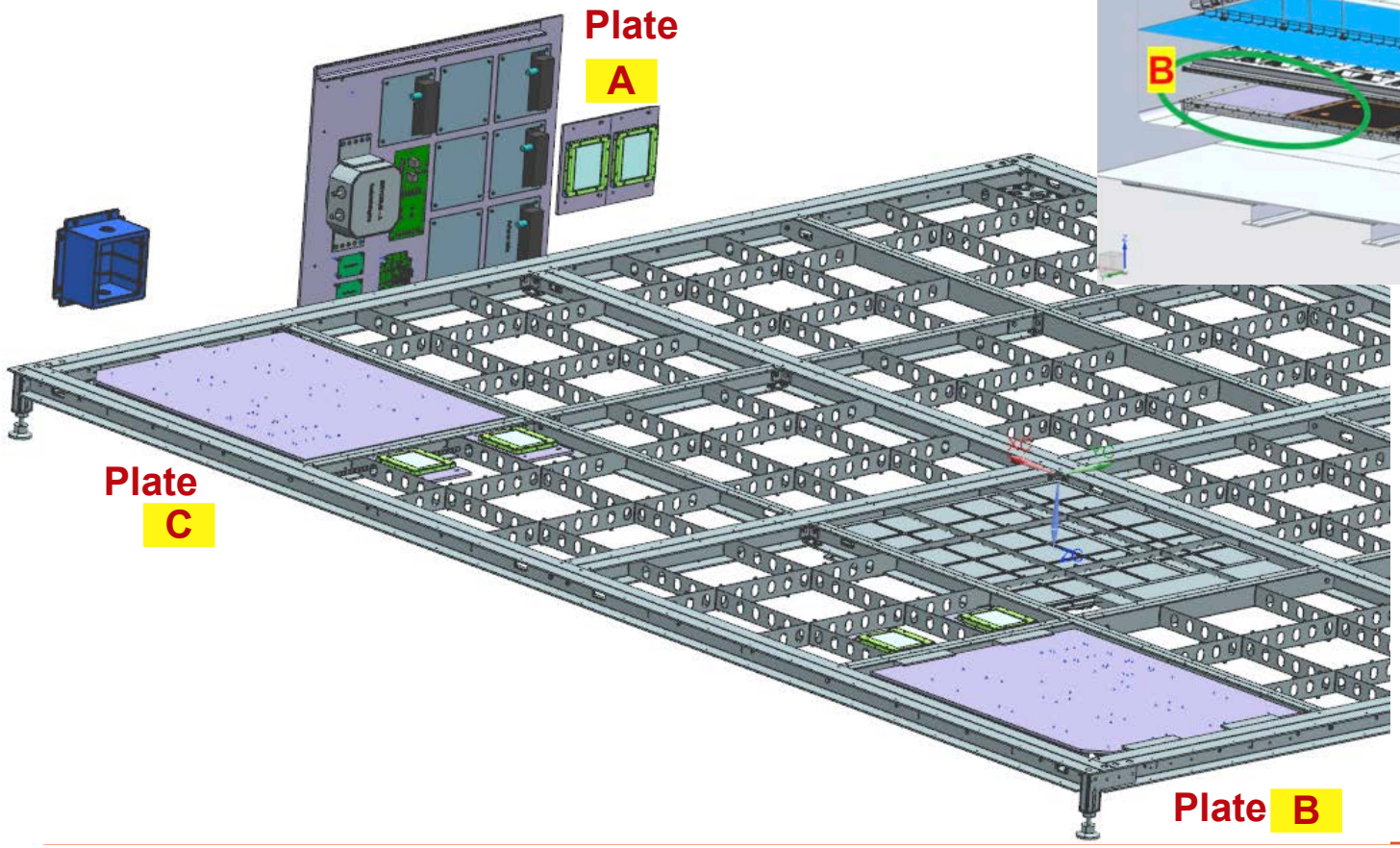
Insulated
Warm Electronics

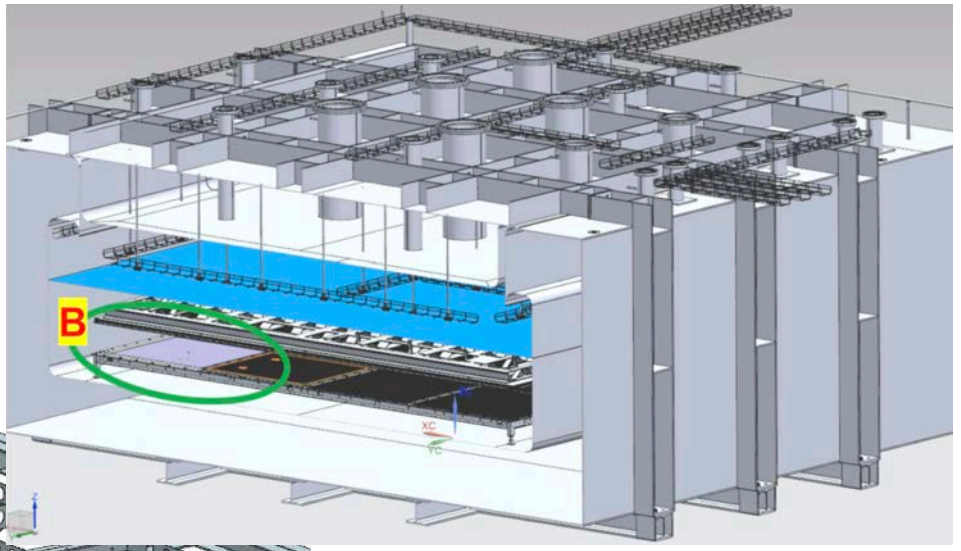
PoF Locations for C





Cold Box #1 Topology





- 3 Positions
  - 2 w/PoF on cathode
  - 1 w/copper on wall
- 6 mini-ARAPUCA
- 1 xARAPUCA

View from below the cathode plane

Plate
B

Plate
C

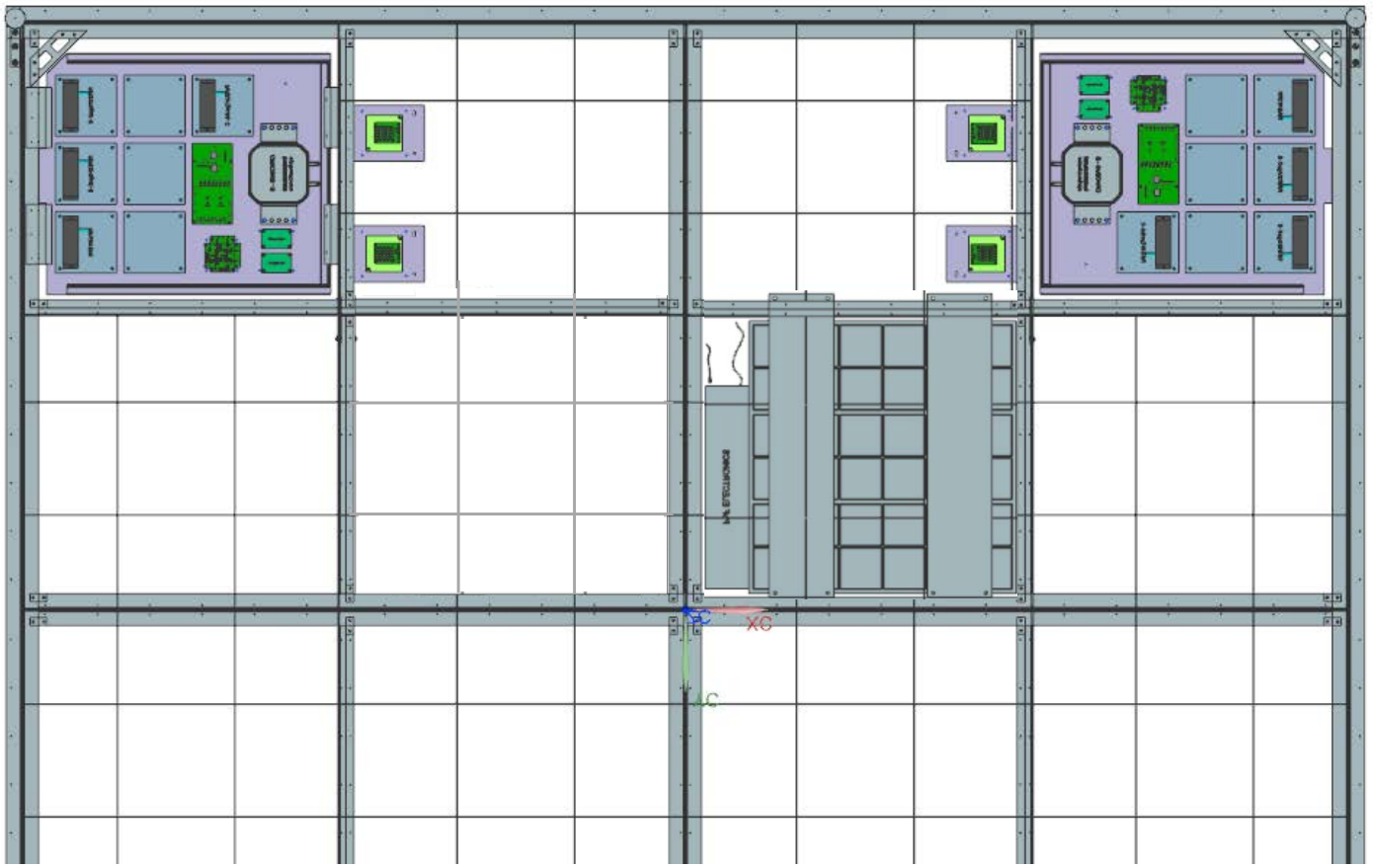


Plate
A

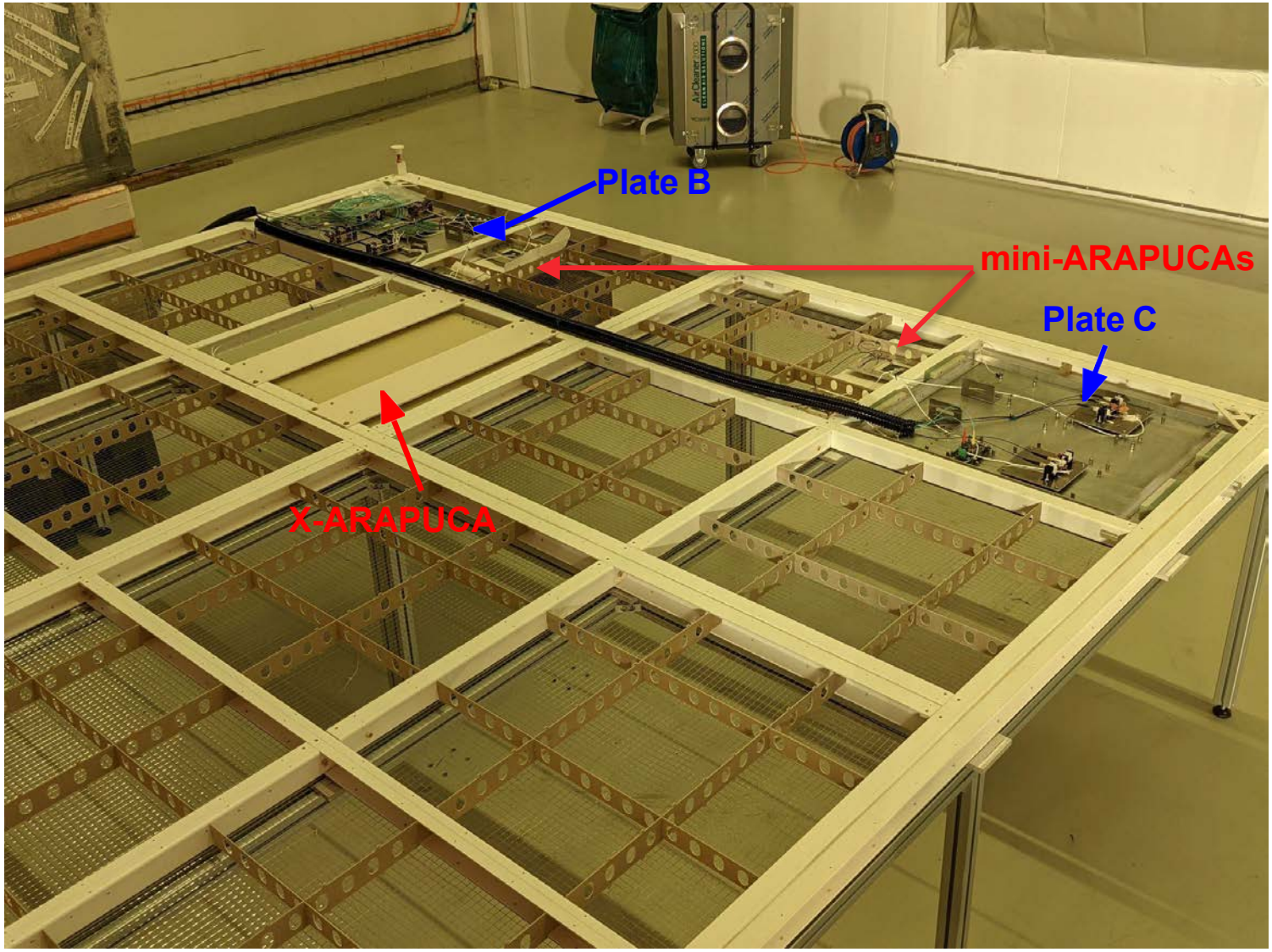
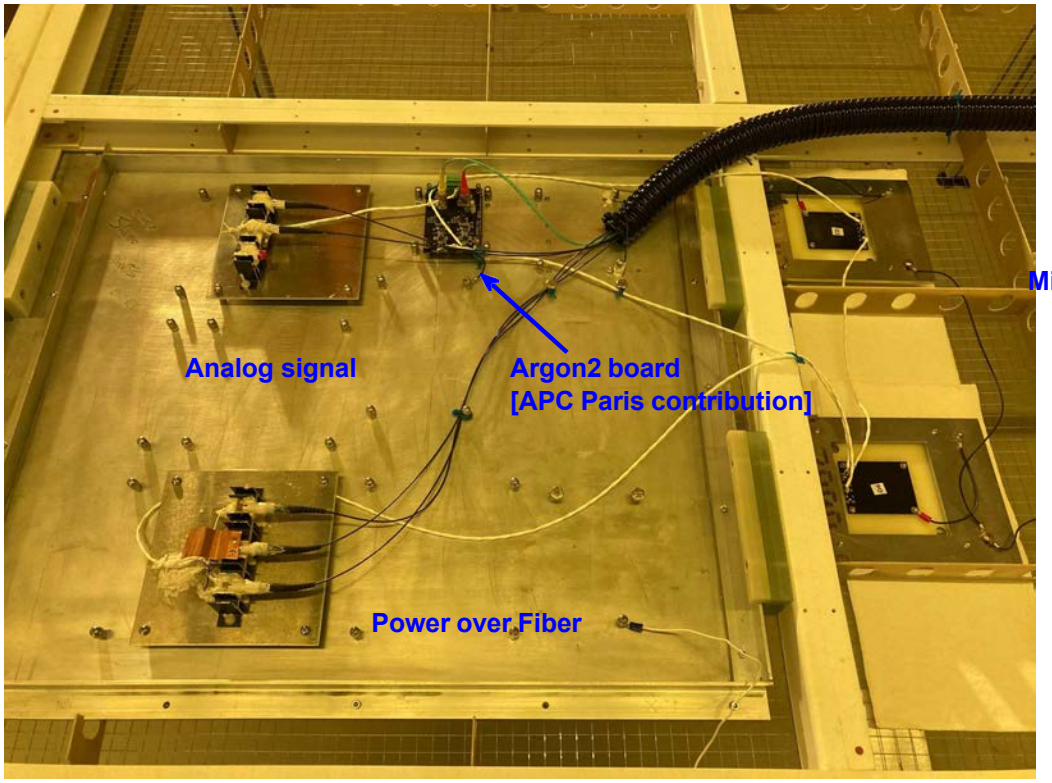
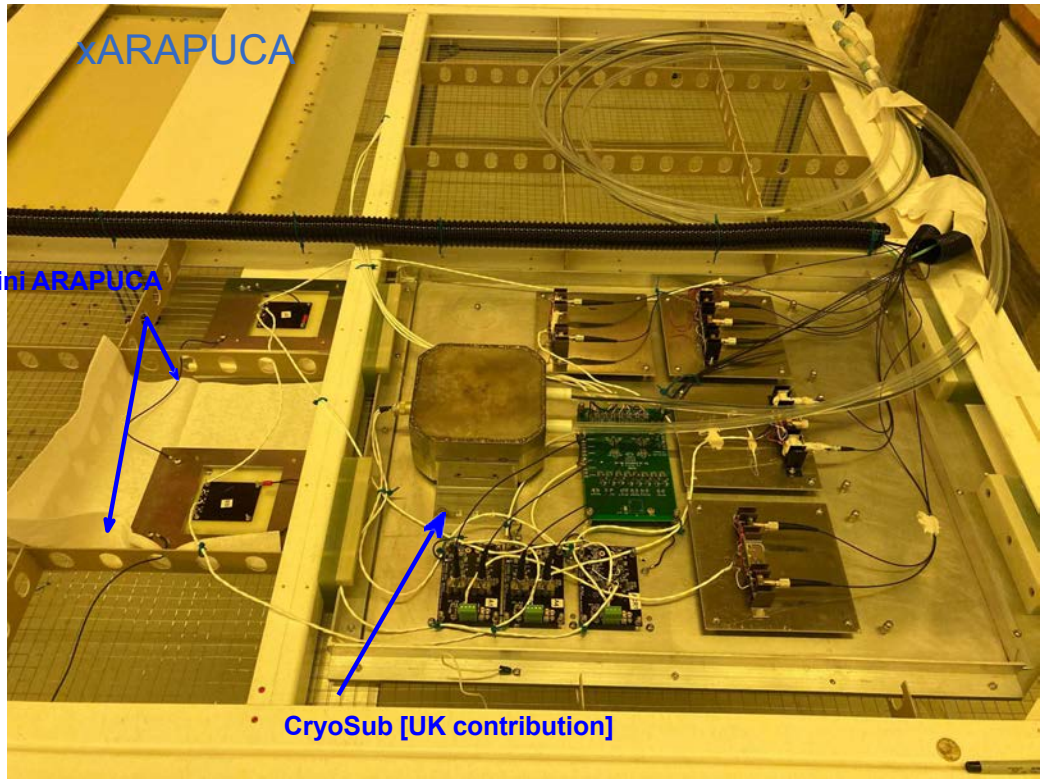


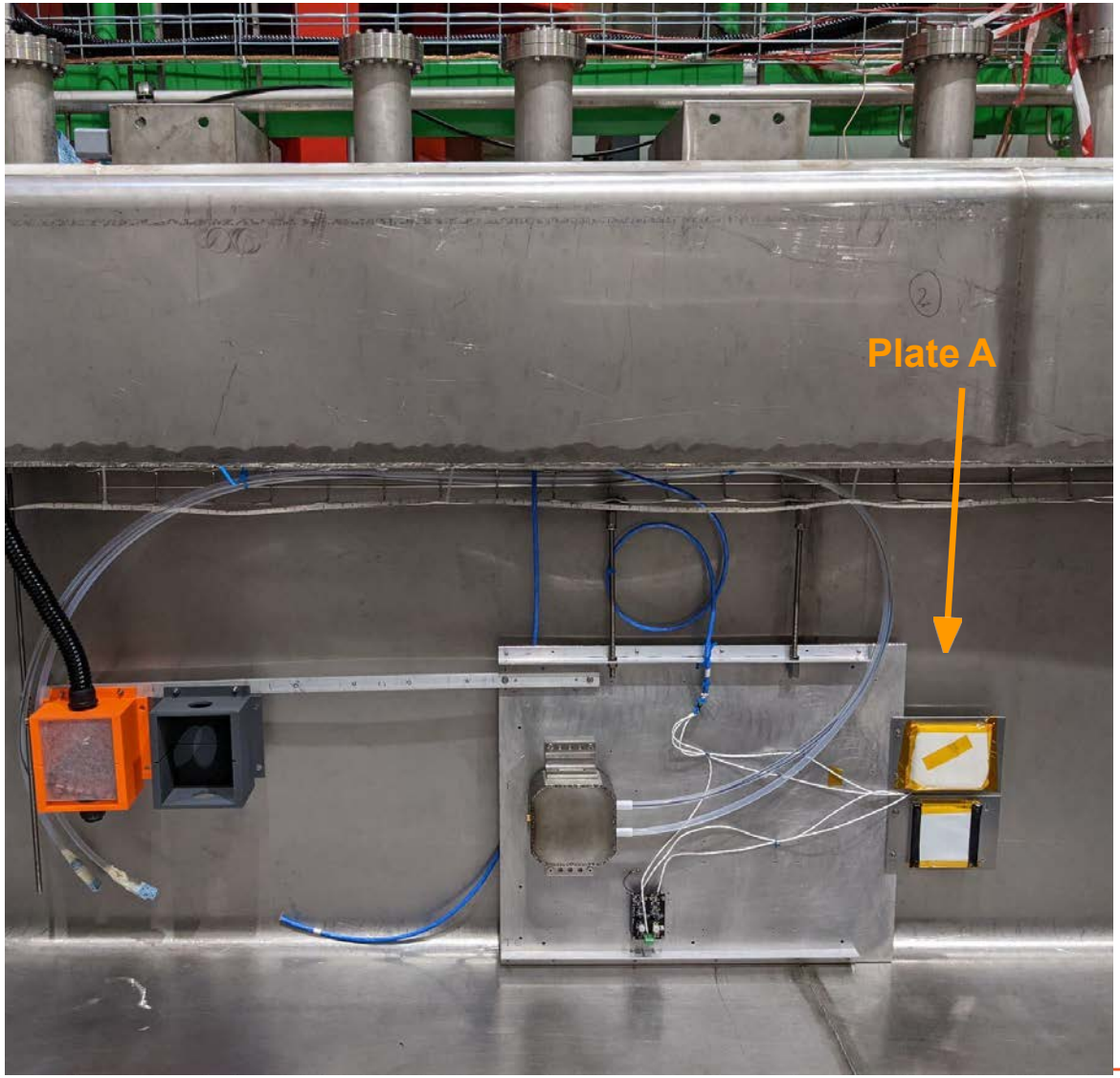
Plate B
mini-ARAPUCAs
Plate C
X-ARAPUCA

PLATE C

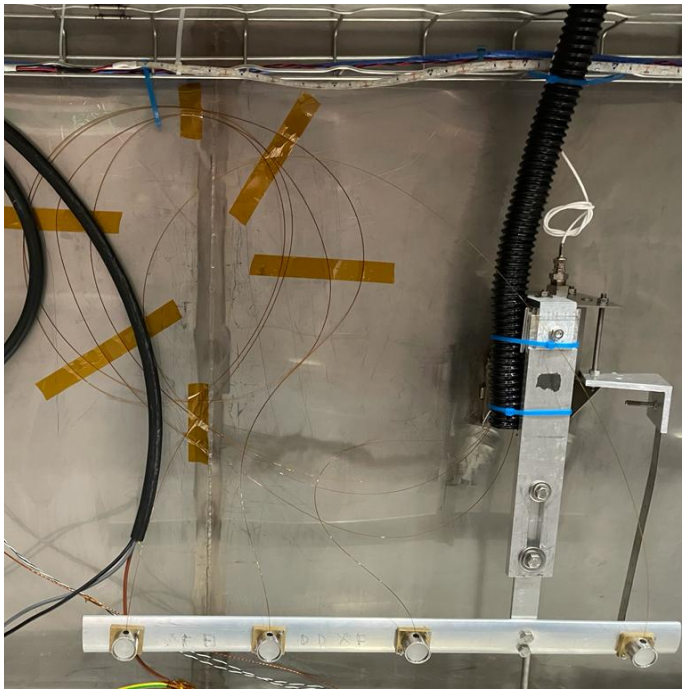
PLATE B

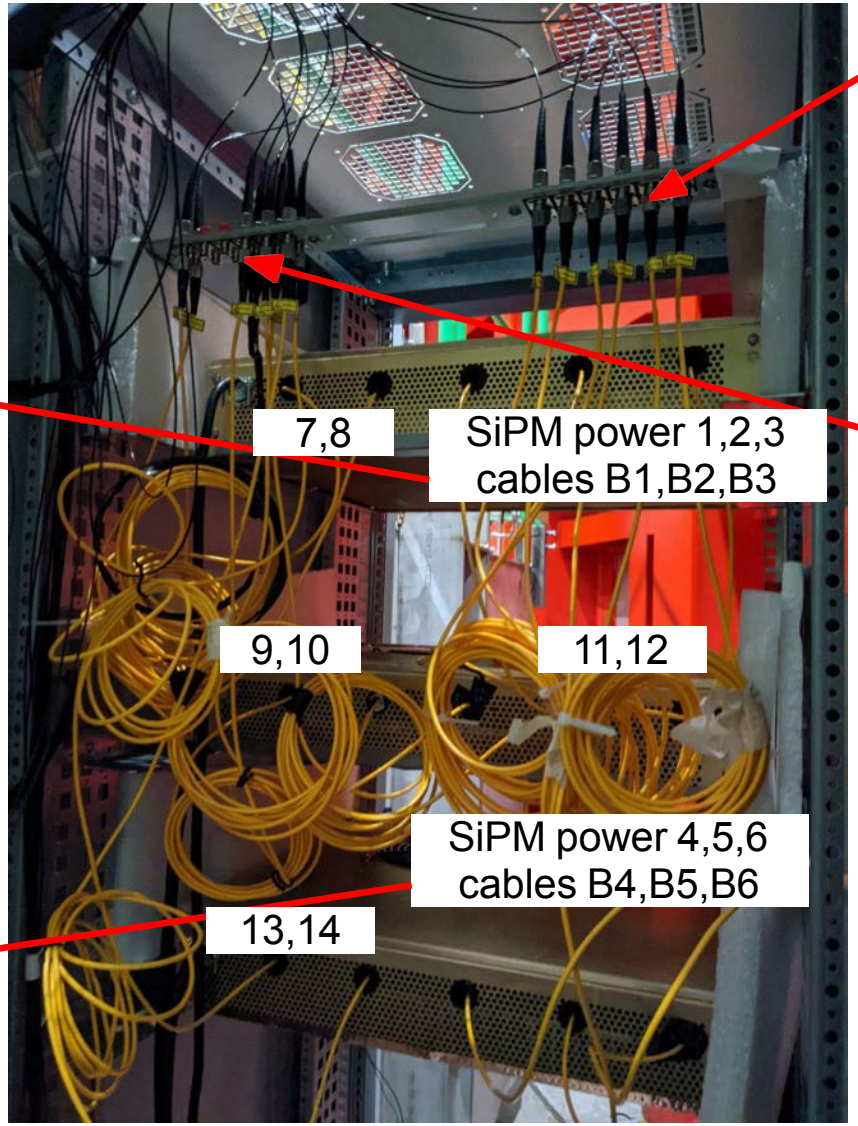






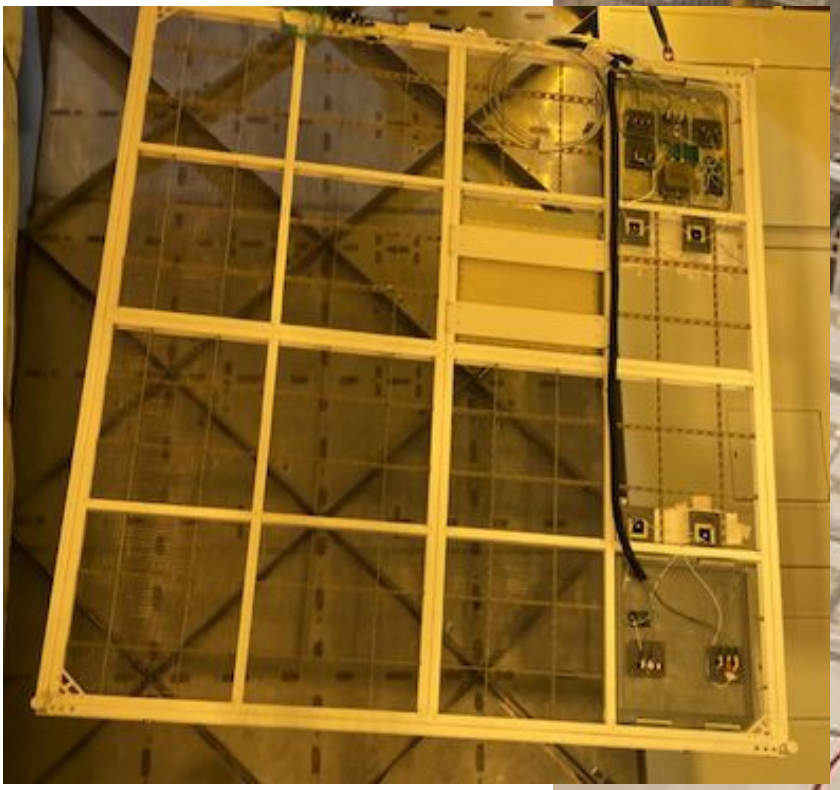
LED diffusers and fibers for Calibration



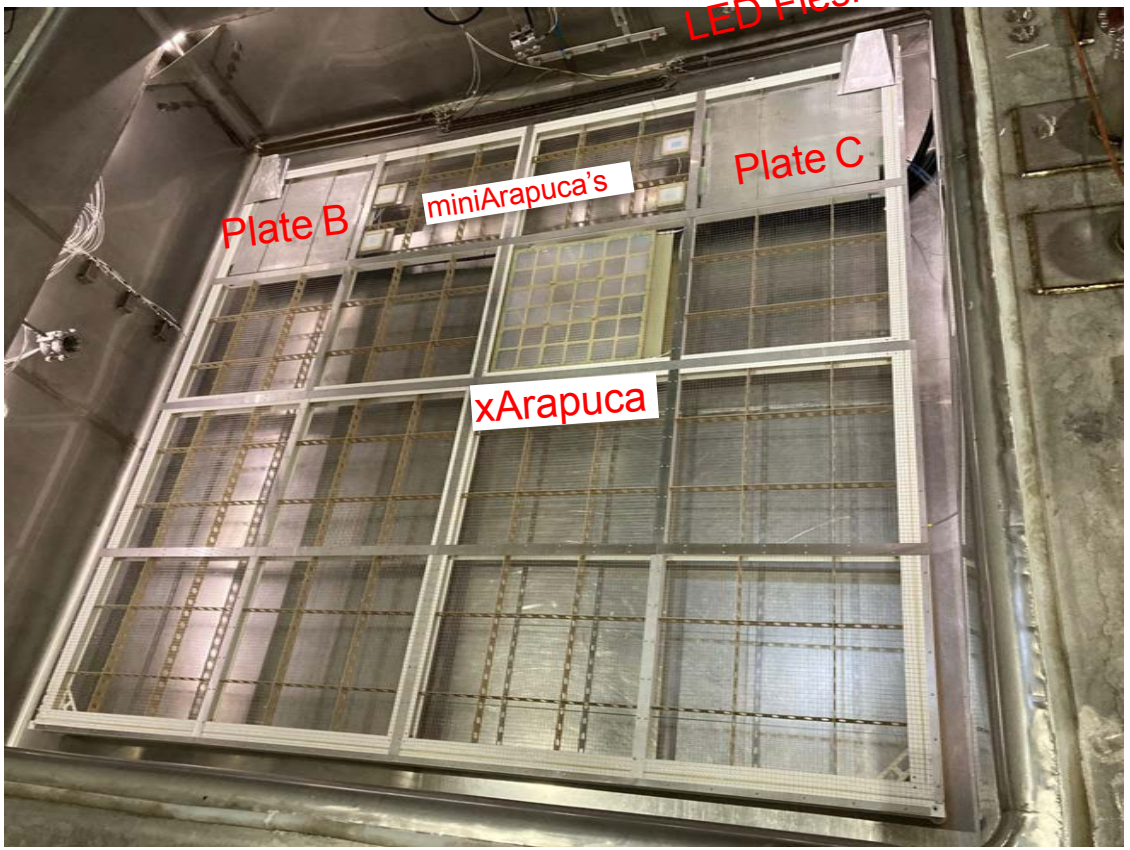


Back L --- R
8,10,12,14

Front L --- R
7,9,11,13



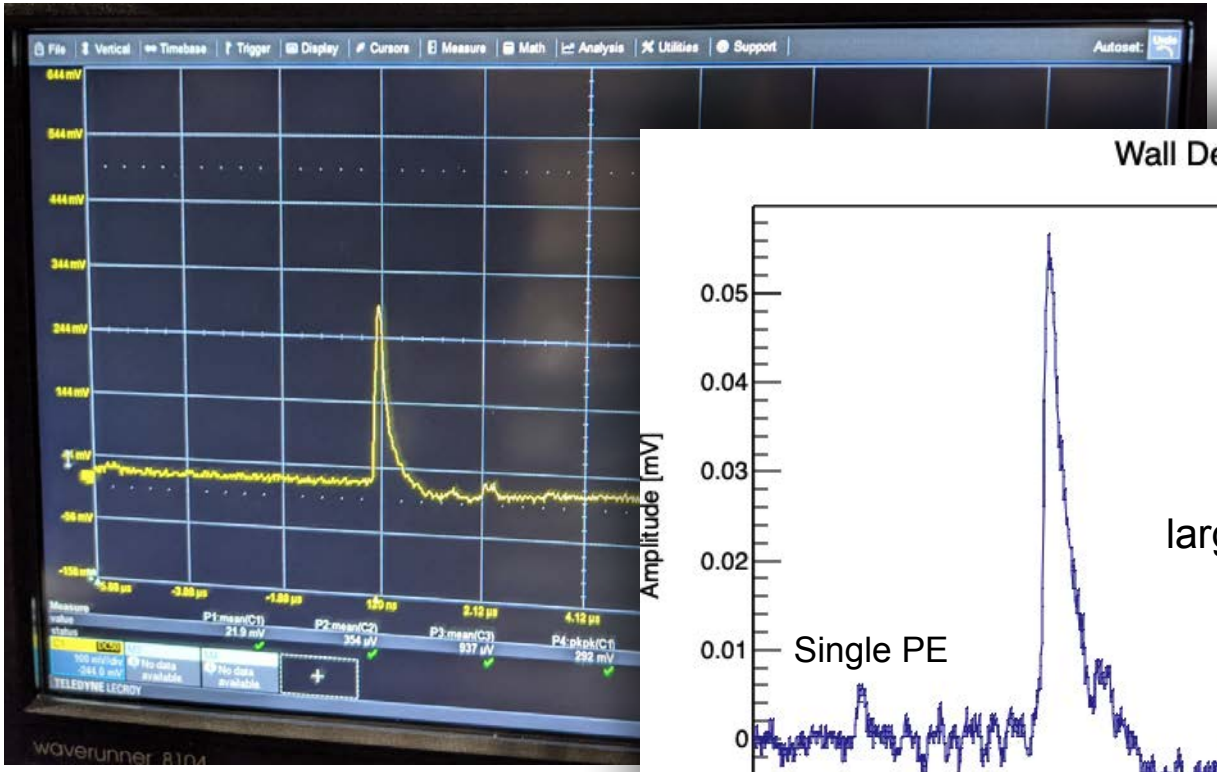
Cold box is closed.



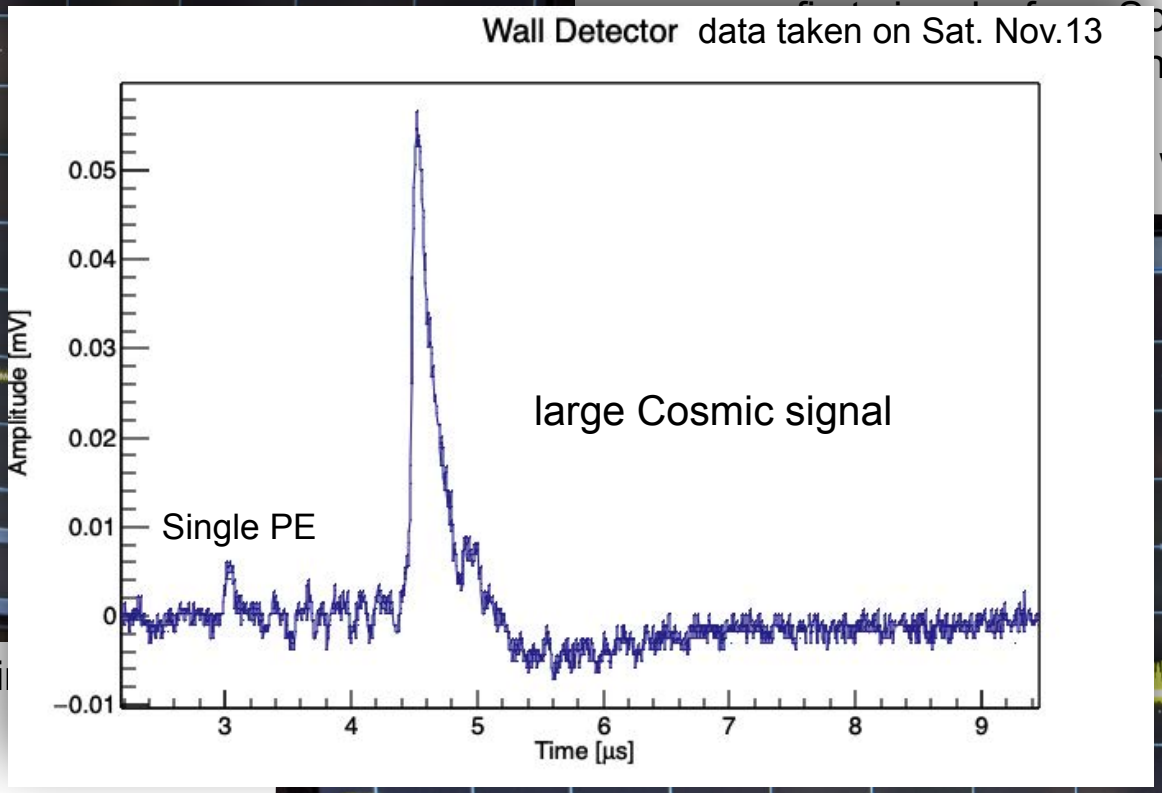
Oct. 30 - (end of first LAr filling)

oF
niARAPUCA)

window



Large light signal from through-goi



Detector activation and commissioning expected to start this week

Summary

- PoF and SoF technology is well suited for the electrically isolated Cathode-mount PDS in FD#2 VD
- Development in 2021 provided successful validation of PoF and SoF in Cold environment
- Design of large sized xARAPUCA module (tile) and a new hybrid solution for SiPM passive ganging were also developed for the FD#2 VD PDS.
- A full scale xARAPUCA 60x60 cm^2 tile prototype equipped with PoF and SoF technology was built and integrated in the Cathode module by end of October as scheduled, in time for ColdBox#1
- 6 additional mini-ARAPUCA modules with exposed or insulated PoF and SoF r/o were also installed in ColdBox#1
- detected very first signals from SoF with miniARAPUCA
- xARAPUCA activation and commissioning expected to start this week

BackUp

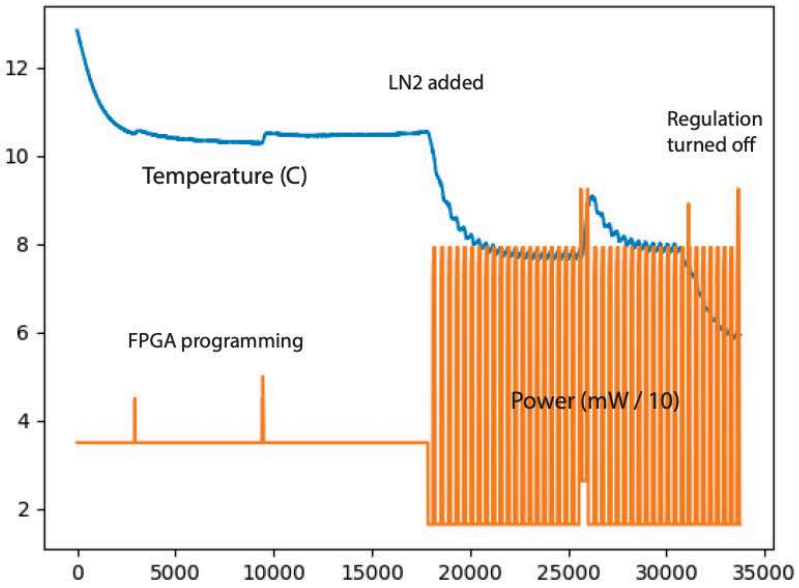
Dynamic range question:

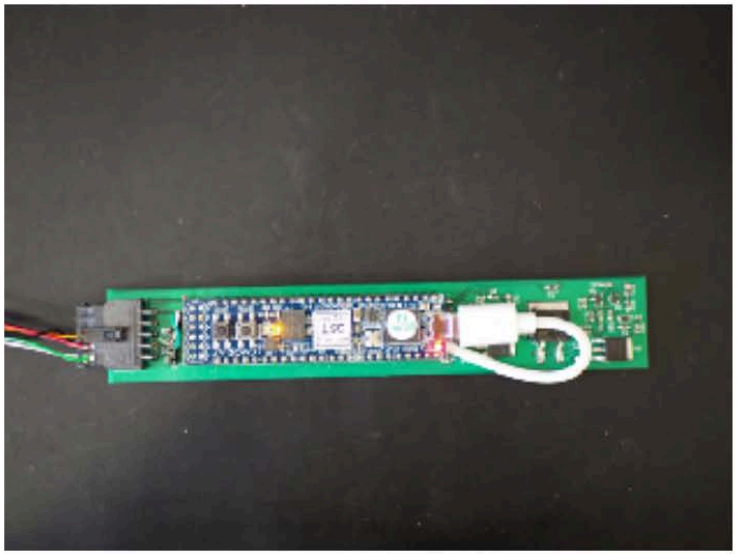
we assume to have noise sigma of <= 2 ADC and S/N ~ 5

⇒ Single PE at ~10 ADC (Min signal), Max signal ~ 1000 PEs (amplitude of 1000 PE piled up in the same time bin)
this corresponds to a many more PE signal, with PE's distributed over ~ 1mus as expected for Xe doped LAr signals. (note: Tests in cold with a hybrid passive ganging board showed S/N and SPE where expected, eg see slide 9).

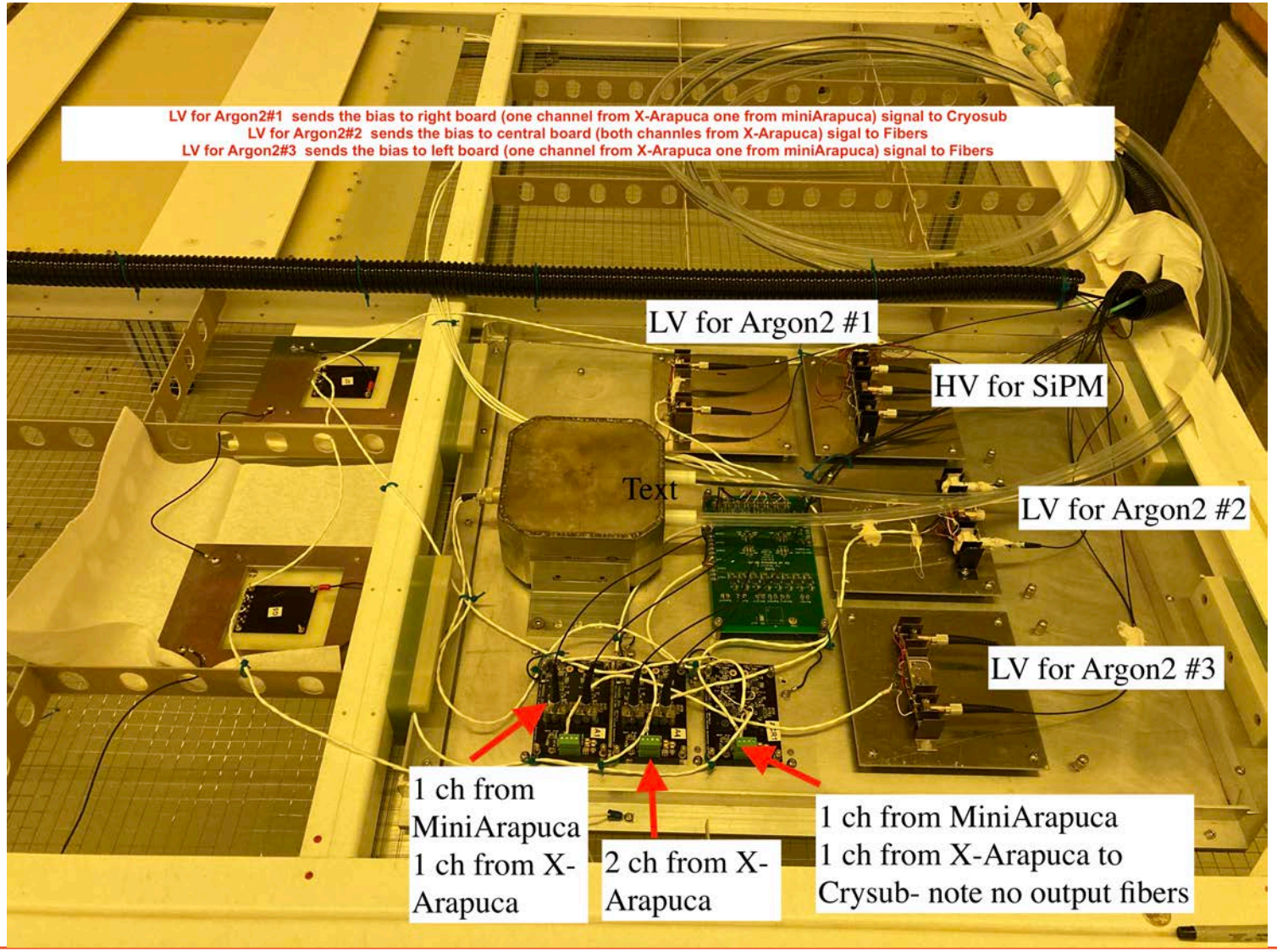
If we adopt a 14 bit ADC (70 MSPS) should be OK to collect 1000 PE max amplitude signal before reaching saturation (16384 ADU).

Temperature setting in CryoSub Question

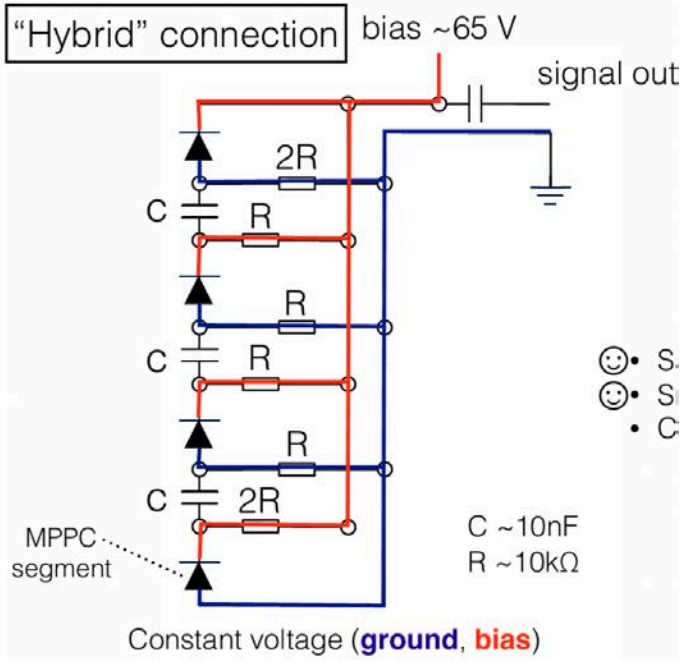


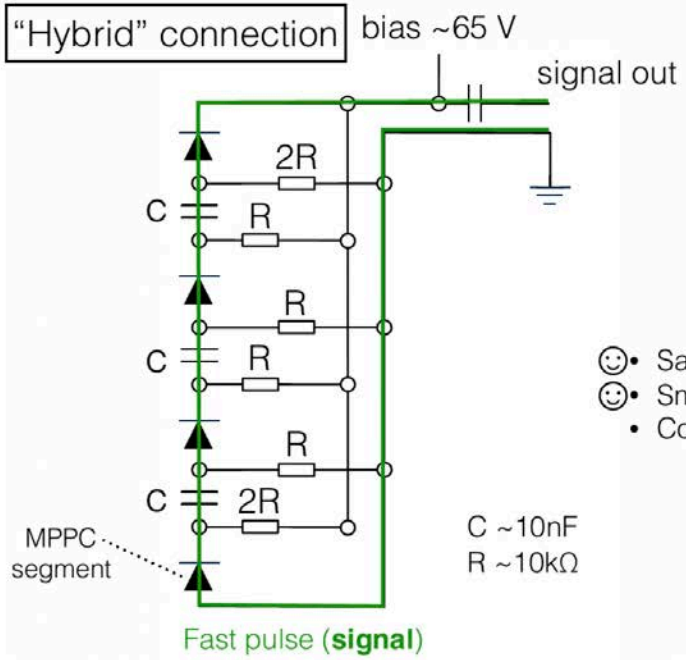


- System operates at ~8C with ~50mW input power

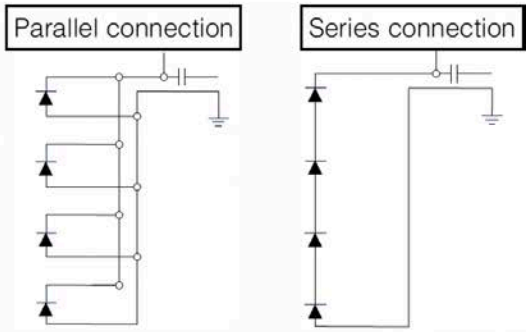

LV for Argon2#1 sends the bias to right board (one channel from X-Arapuca one from miniArapuca) signal to Cryosub
LV for Argon2#2 sends the bias to central board (both channles from X-Arapuca) sigal to Fibers
LV for Argon2#3 sends the bias to left board (one channel from X-Arapuca one from miniArapuca) signal to Fibers
LV for Argon2 #1
HV for SiPM
Text
LV for Argon2 #2
LV for Argon2 #3
1 ch from MiniArapuca
1 ch from X-Arapuca
2 ch from X-Arapuca
1 ch from MiniArapuca
1 ch from X-Arapuca to Crysub- note no output fibers

Hybrid connection





Standard (usual)



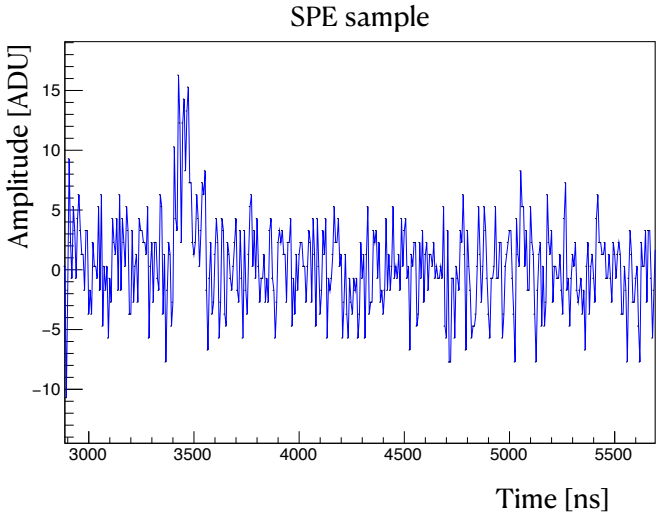
- ☺ Same potential on the surface of MPPCs
- ☺ Small capacitance →Short waveform
- Common bias voltage (~65 V)

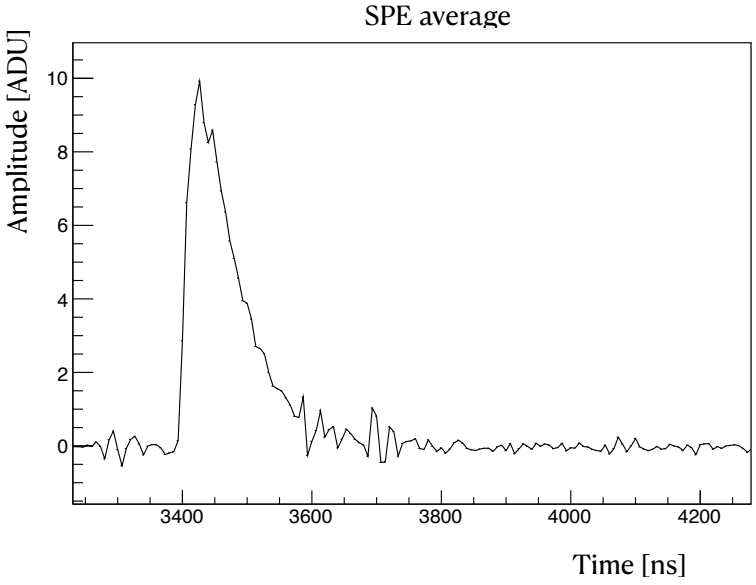
SPE response

Liquid Nitrogen Bias = 45V

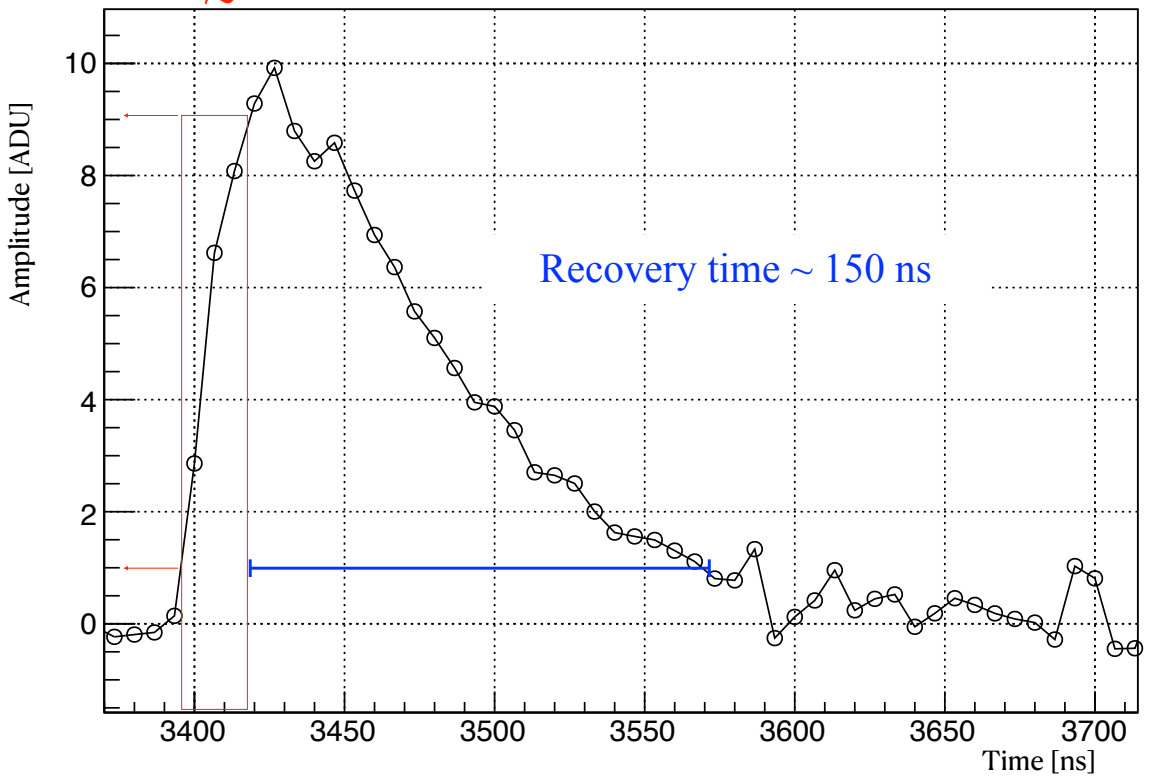
SSP: 150 MHz, 122 μV/ADU,

Full Diff (G=18.5), 100nF/50Ω per single input



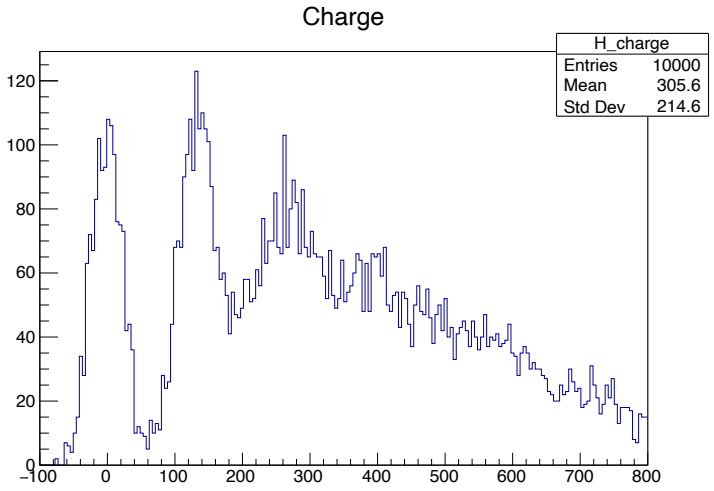


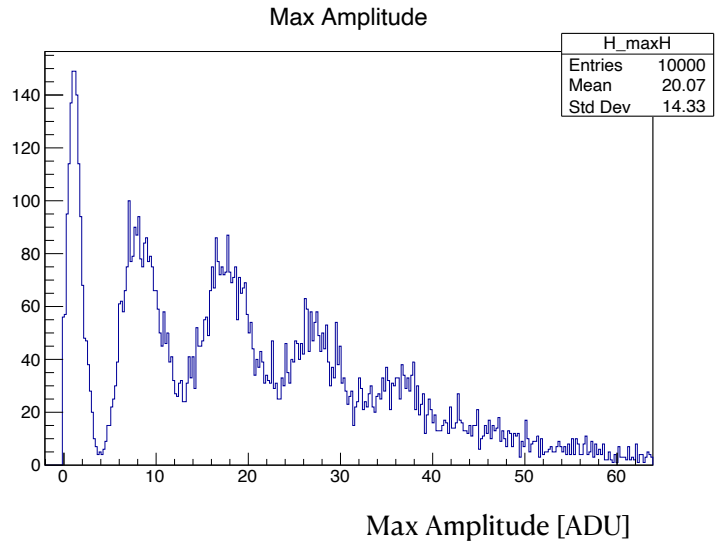
Rise time $\lesssim$ 20 ns



@ Bias = 45V in Liquid Nitrogen

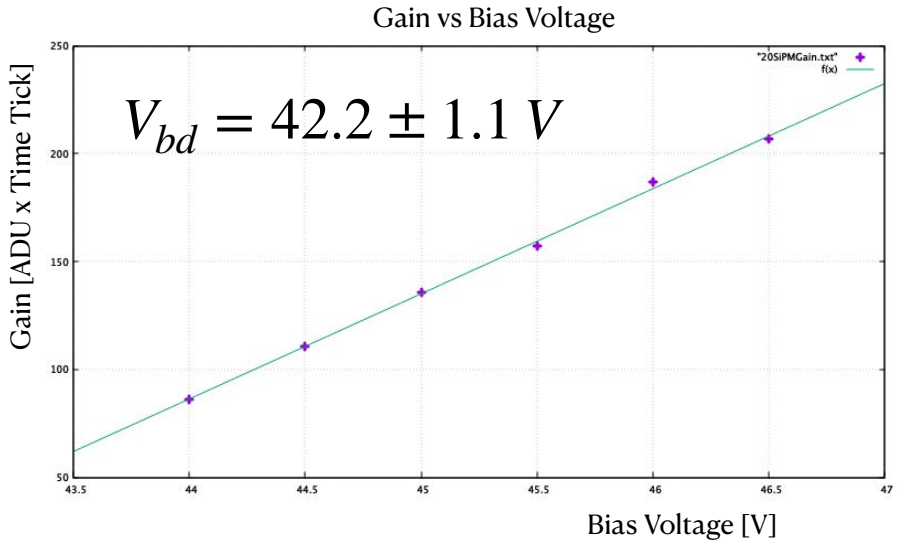
SiPM used here are Hamamatsu old version.





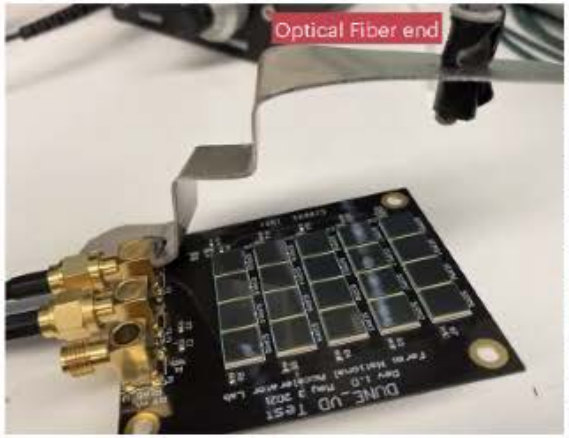
20 SiPM Hybrid Ganging

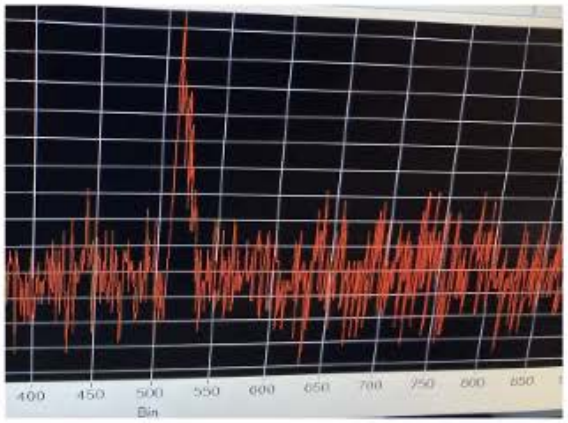
V Bias (V)	Gain	SNR	ApCt (%)
44.0	86.2	3.4	16.7
44.5	110.7	4.6	21.8
45.0	135.8	6.2	34.6
45.5	157.0	6.8	49.2
46.0	186.7	8.1	71.1
46.5	207.0	9.0	112



Readout test stand development

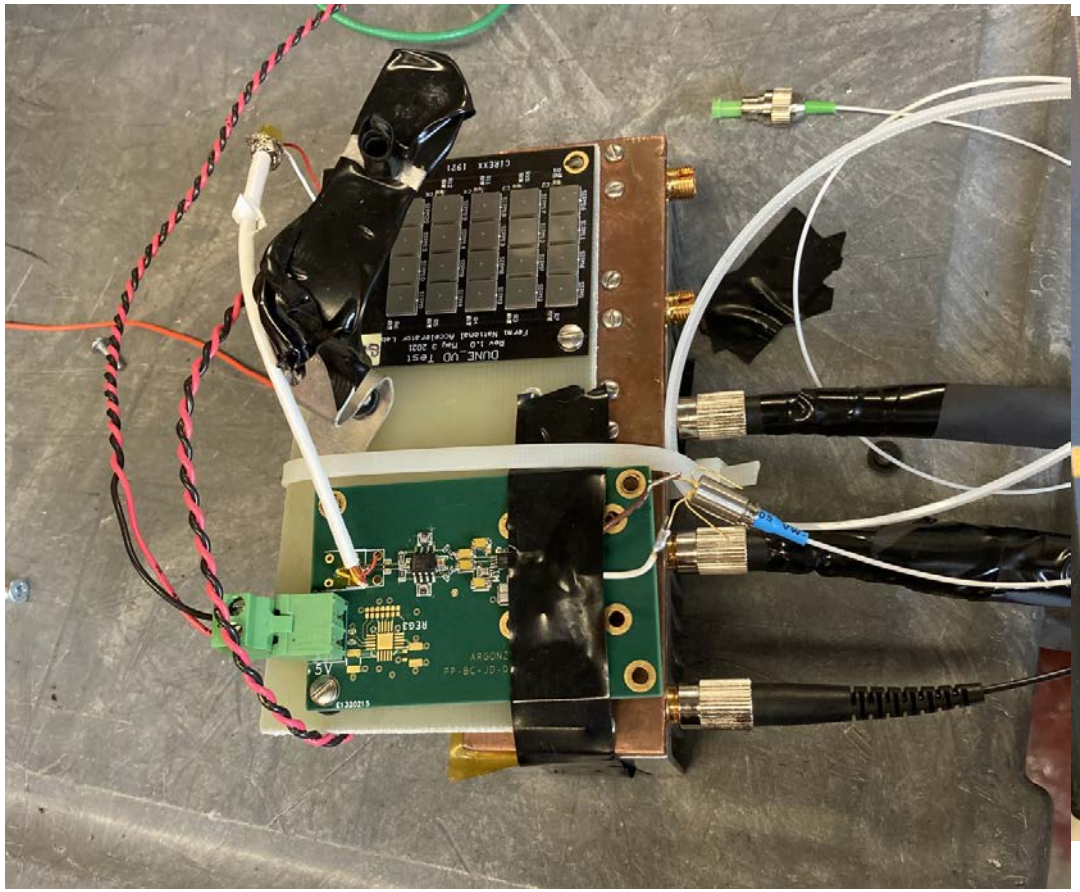
- Test bench work done with a standard PCB passively ganging 4 rows of 5 SiPMs.
  - Test card becoming mini-ARAPUCA for Cold Box 1
  - Same 20-SiPM ganging topology employed for xARAPUCA
  - Signal injection with optical fiber at test stand

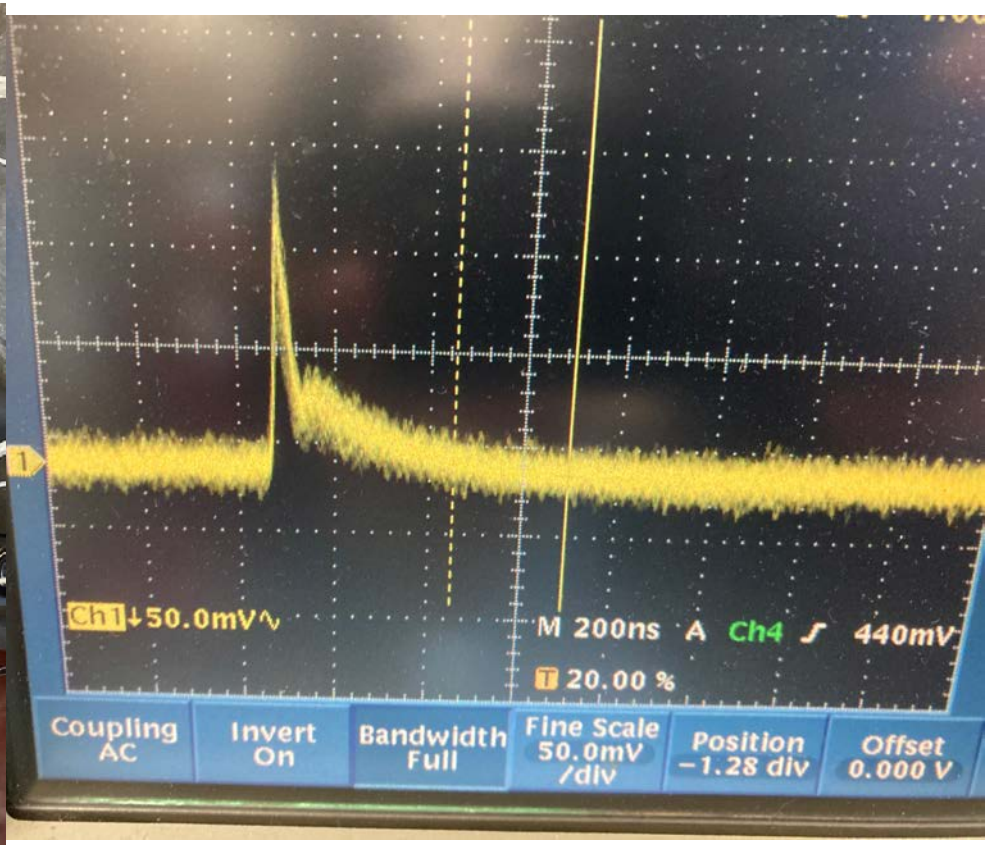




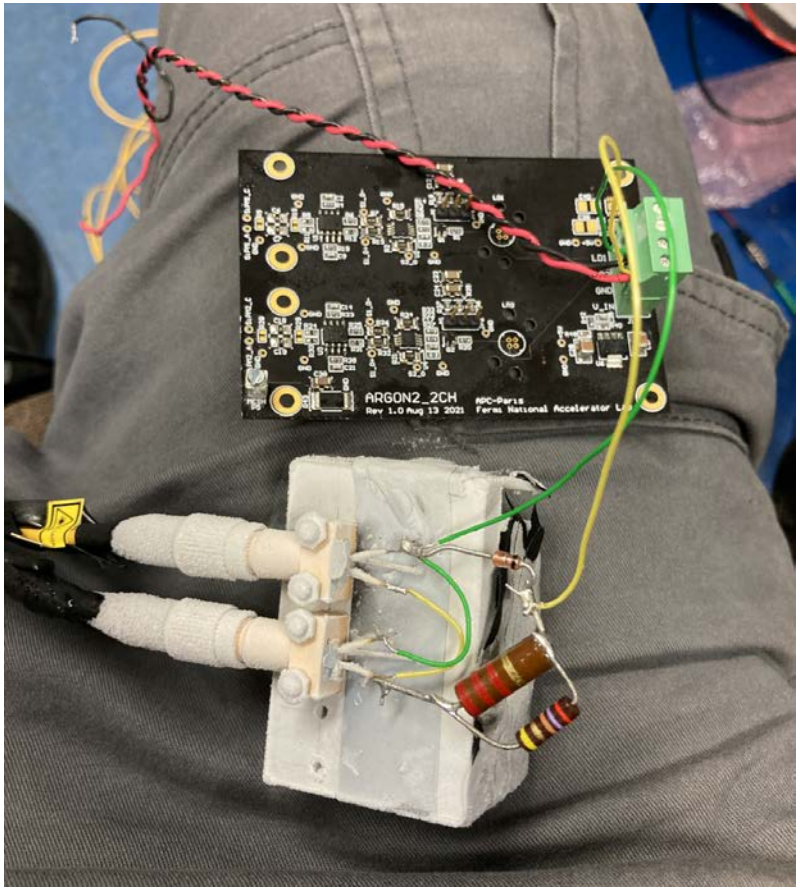
Aug 11, 2021: first demonstration of full chain in cold w/PoF!

- Exposed bias PoF and insulated readout PoF

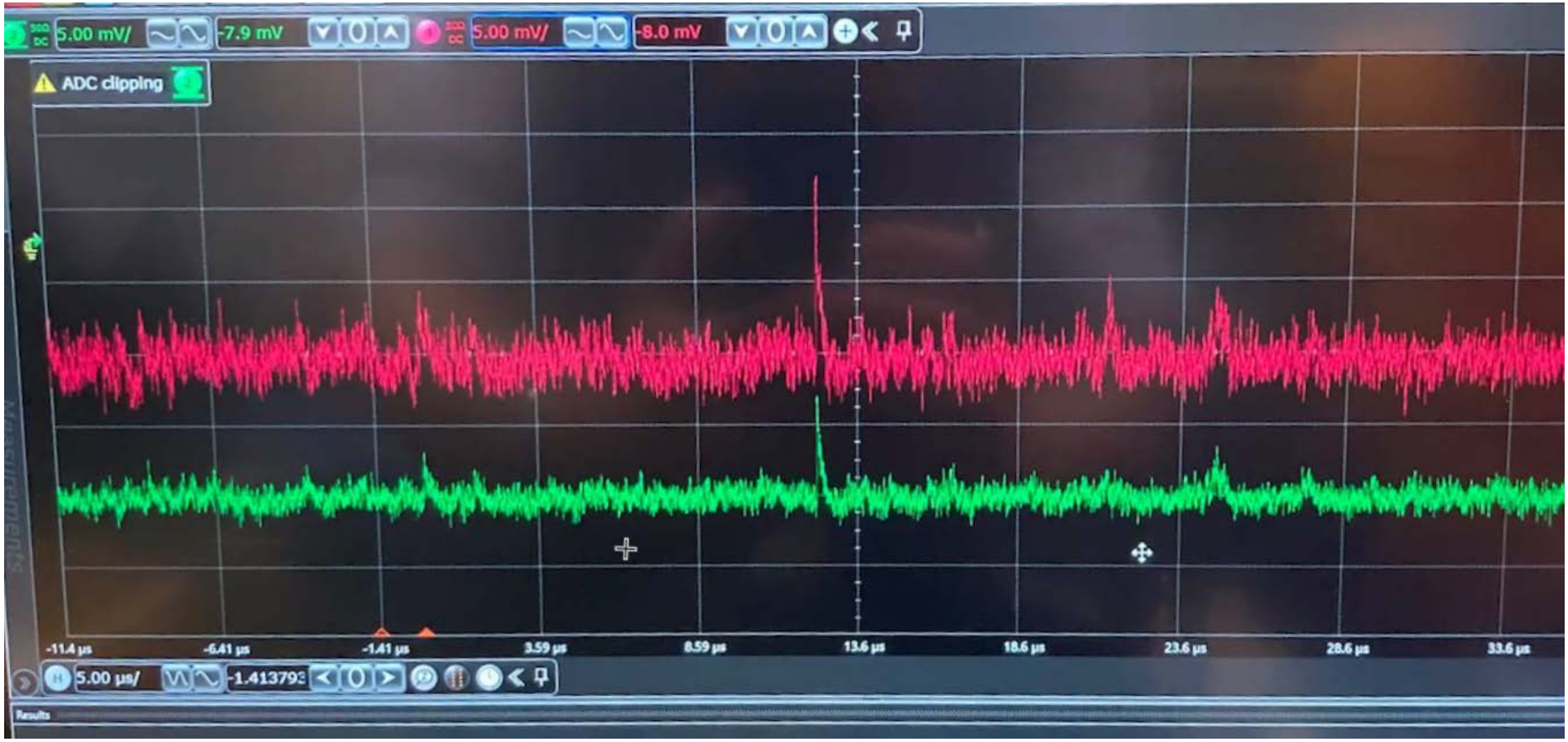




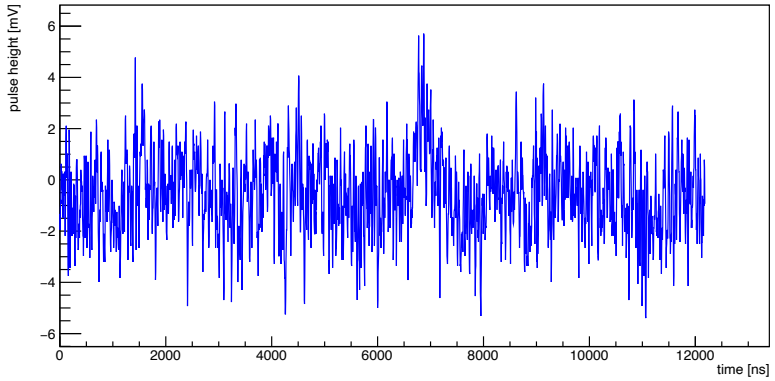
Aug 27, 2021: first demonstration of cold exposed readout PoF



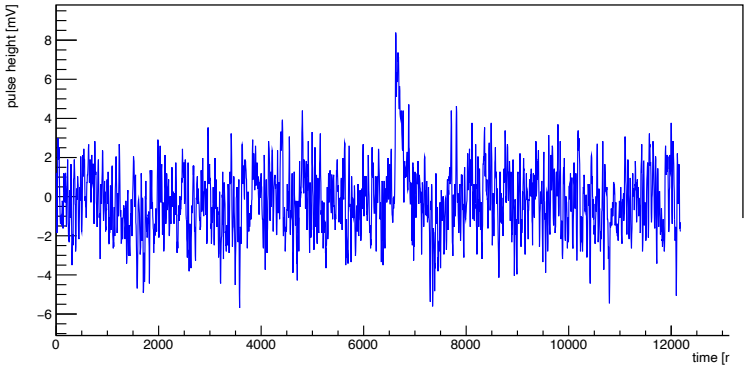
Sept 9 - improved signal-to-noise

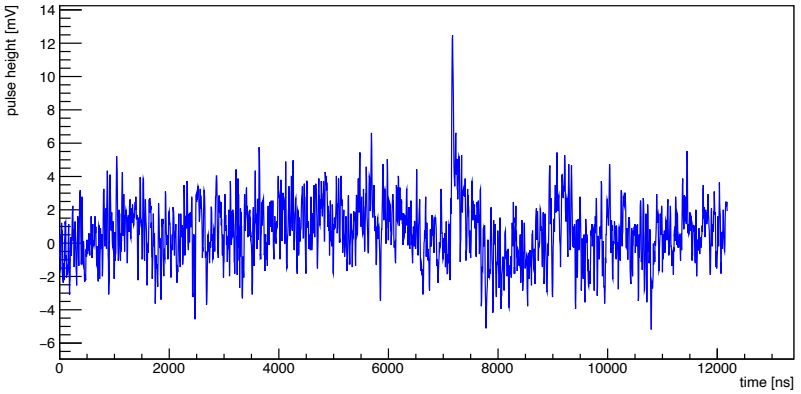


Sept. 17 - last test in cold before shipping to CERN



collected signals (in the few PE's range)
- no noise filter applied





NP02 - ARAPUCA behind Field Cage

Random Triggers