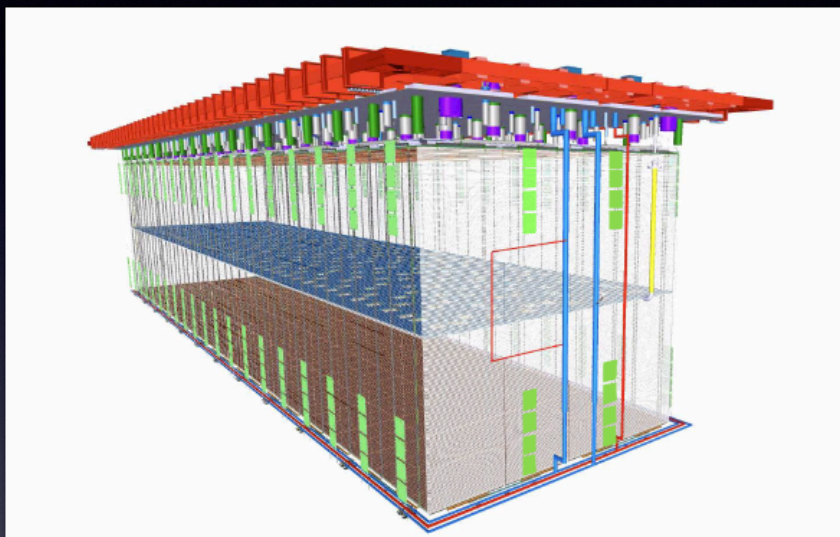


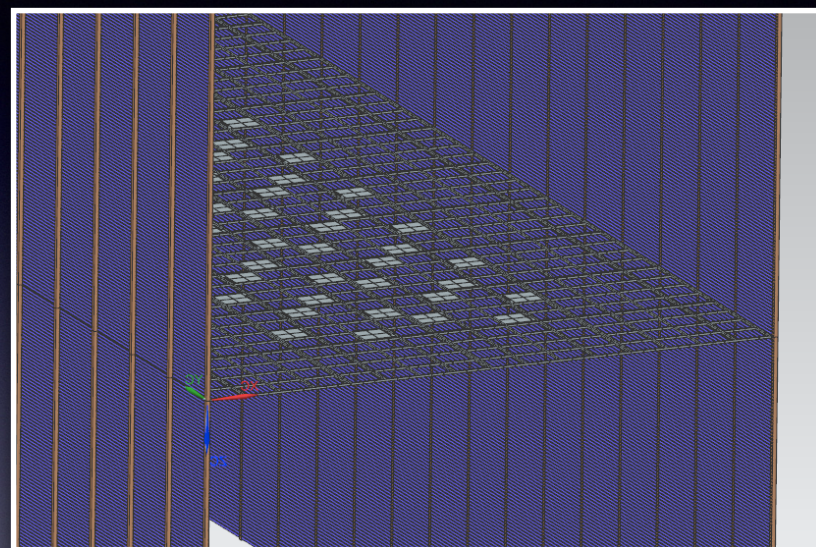
Jun 26 – 28, 2023
Stony Brook University Physics Building

DUNE FD3 Mini-Workshop Toward a Combined Photon Detection and Field Cage System

From this (FD2 - VD)



To this (FD3 - VD Optimized)



“VD Optimized FD3” w/ enhanced PDS Detector Design and Prototyping

June 26, 2023

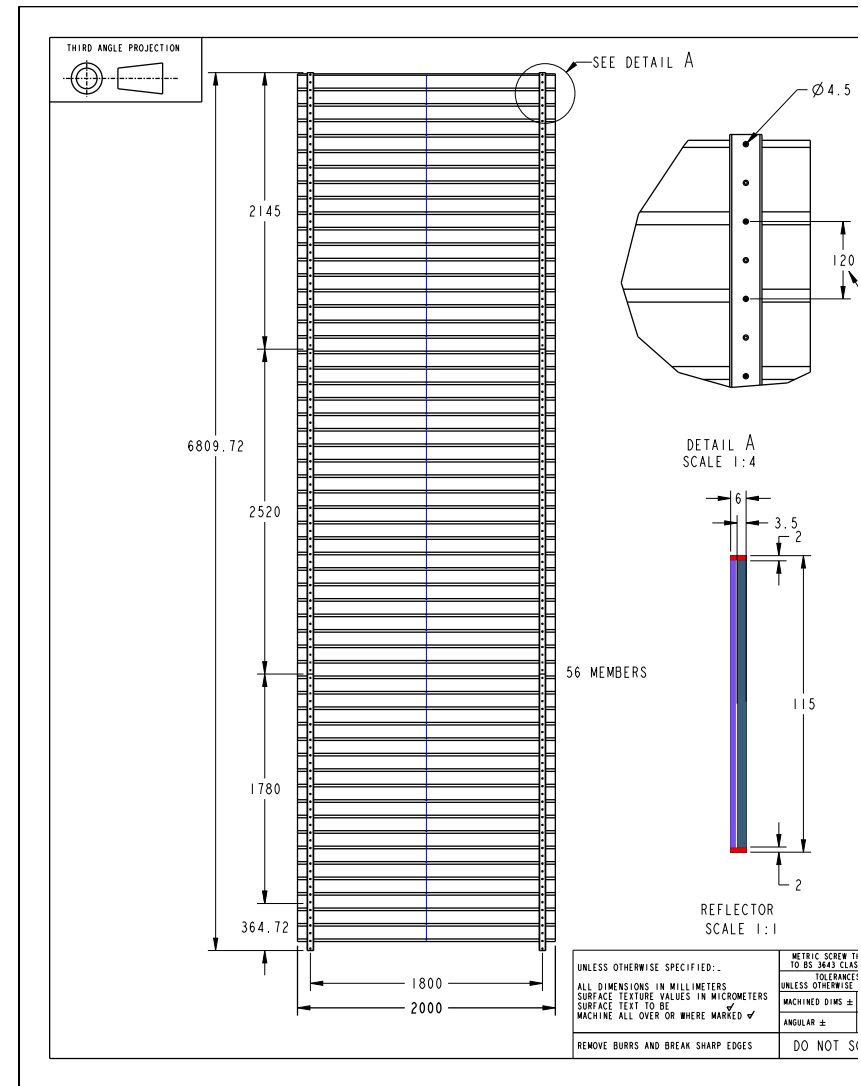
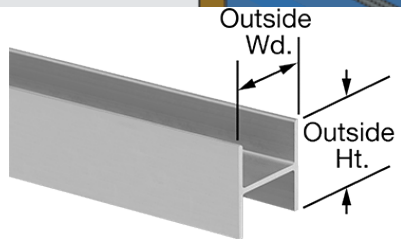
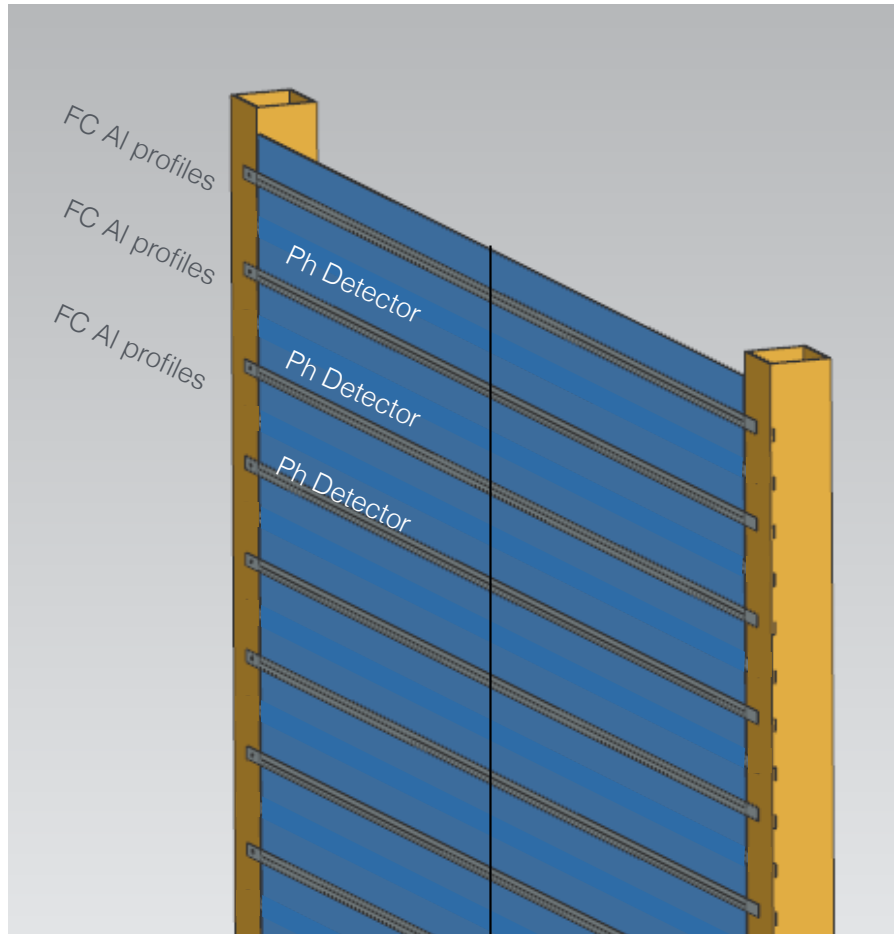
very large-area breakthrough **FC-PD system** for next generation LArTPC detectors

current ideas under development:

simplify design (reduce costs and channel count)

and

retain collection & light trapping efficiency

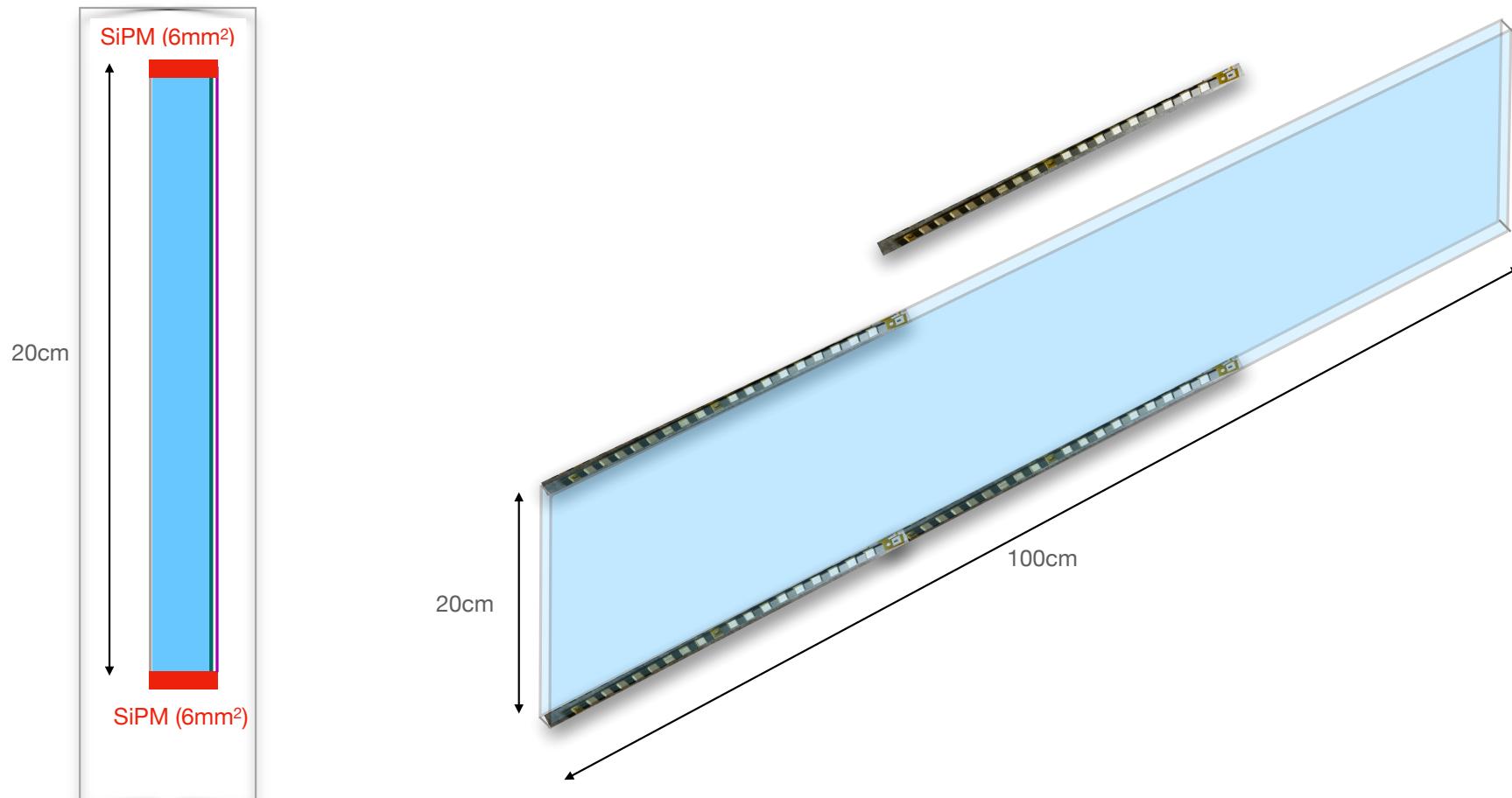


Courtesy - George Stavarakis [Liverpool, UK]

Simplified ARAPUCA* concept

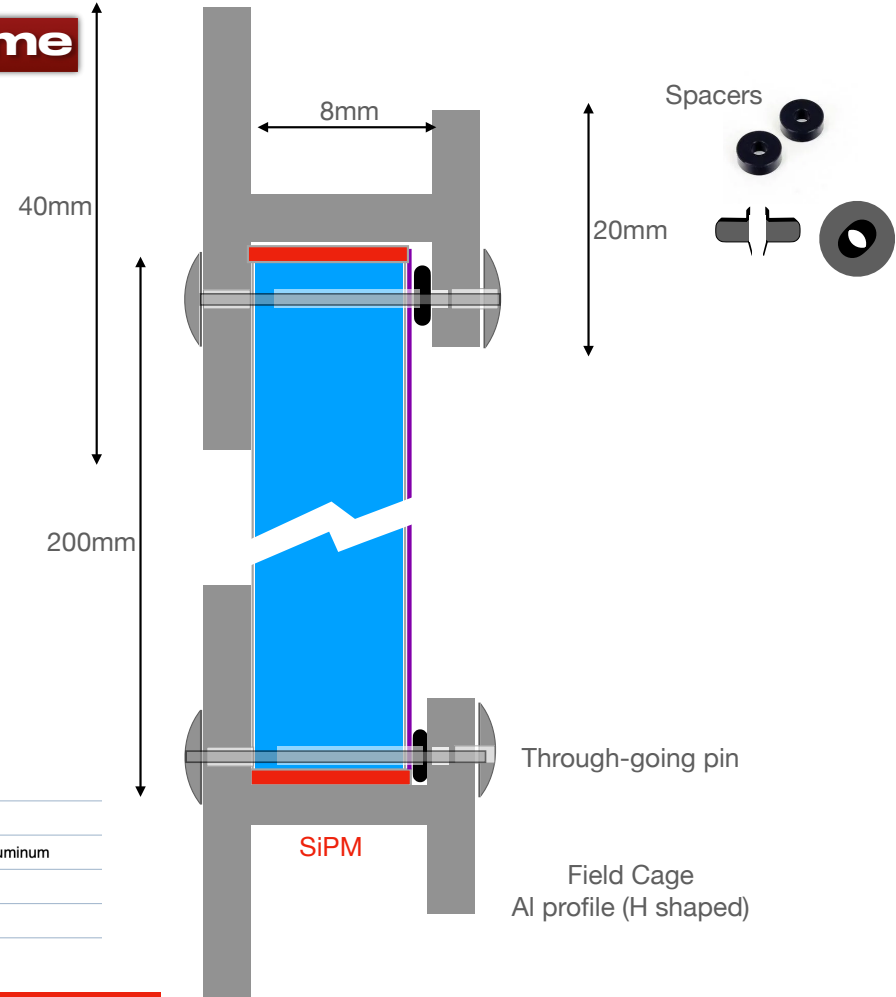
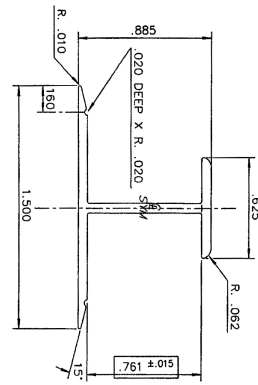
(One-sided)

[Reflector - WLS2 - Dichroic - WLS1]
VIKUITI foil - PMMA - VapDep orALD - pTer film



* from XARAPUCA (FD1-2), to original ARAPUCA concept (only if overall convenient)

FC Profile assembly ≡ PD Mechanical Frame



TECHNICAL SPECIFICATIONS

Product №	31311210
Width	1 1/2 in
Length	144 in
Interior Measurements	49/64 in
Finish	Satin

Height	57/64 in
Color	Aluminum
Material	Anodized Aluminum
Front Facing Height	5/8 in
Shape	H

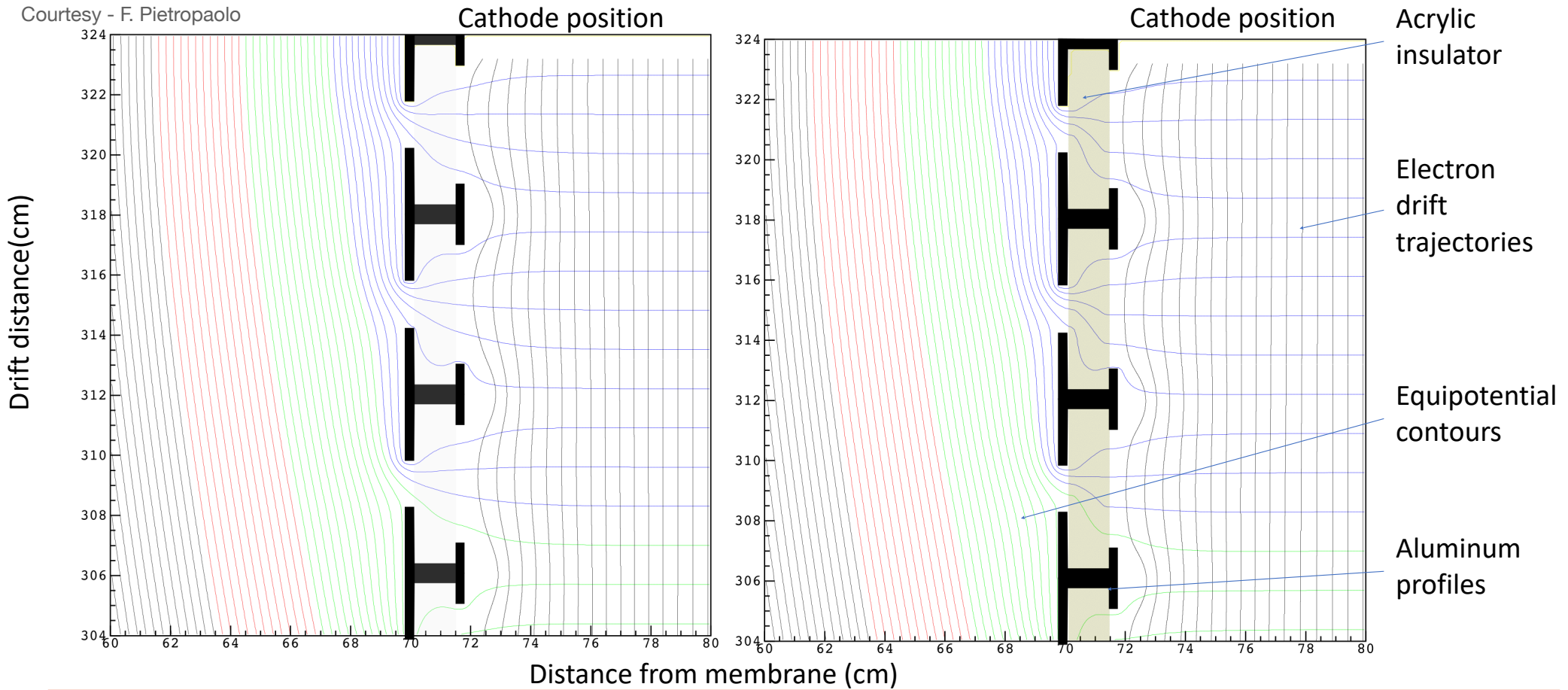
Detector main components: Al Profiles and PMMA plates radiopure, low emanation materials

FC-PDS Electrical performance

Bonus: improved EF uniformity at FC boundaries

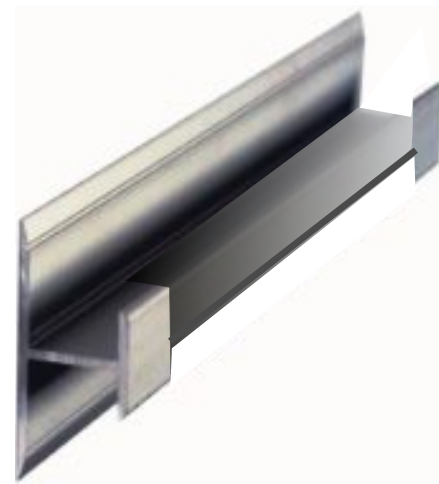
No insulating surfaces between profiles

With insulating surfaces between profiles

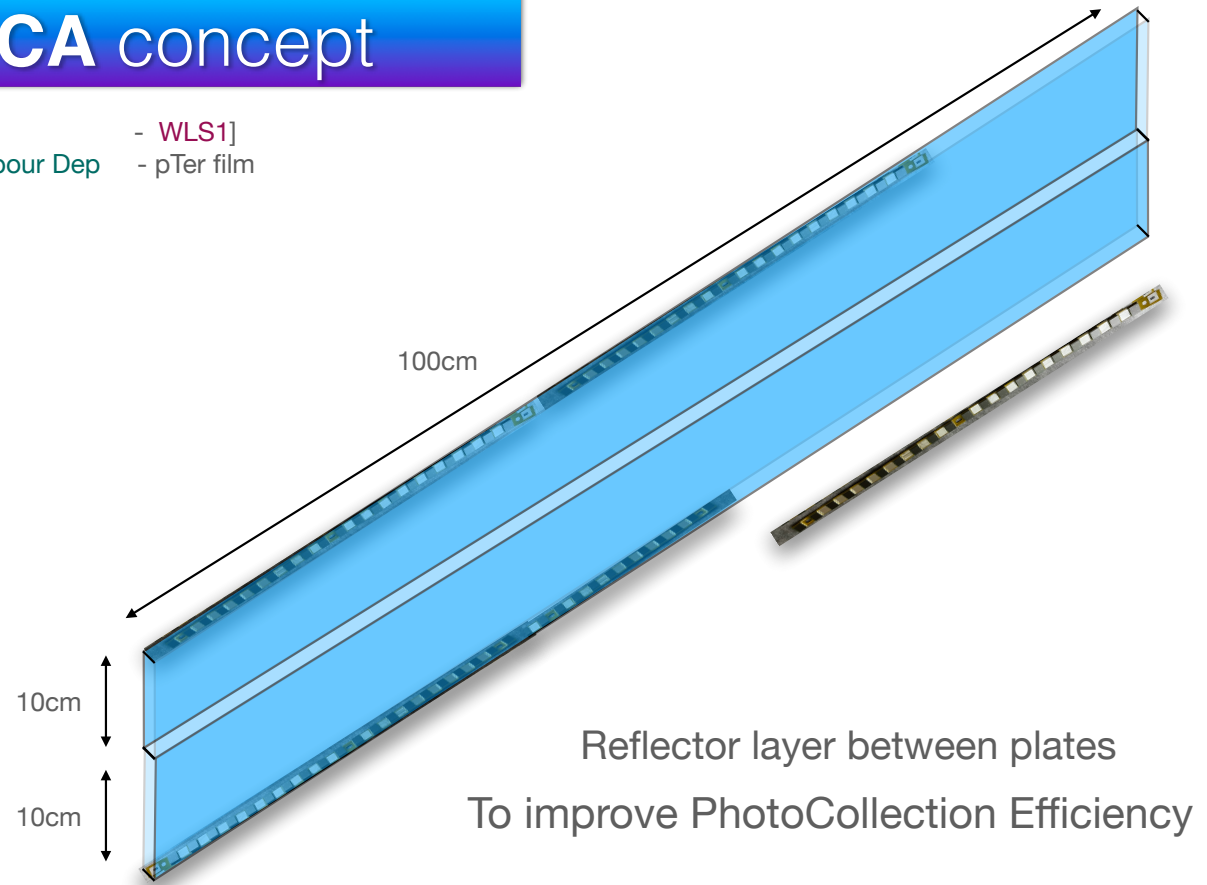
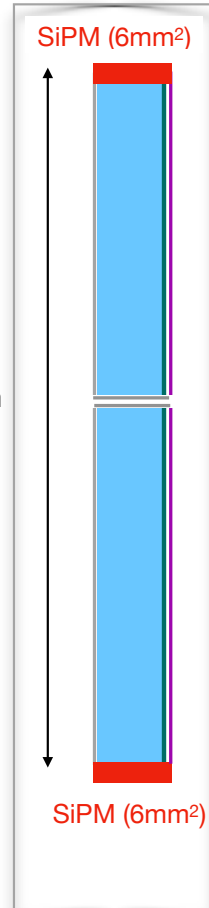


Simplified ARAPUCA concept

[Reflector - WLS2 - Dichroic - WLS1]
 VIKUITI foil - PMMA - ALD or Vapour Dep - pTer film



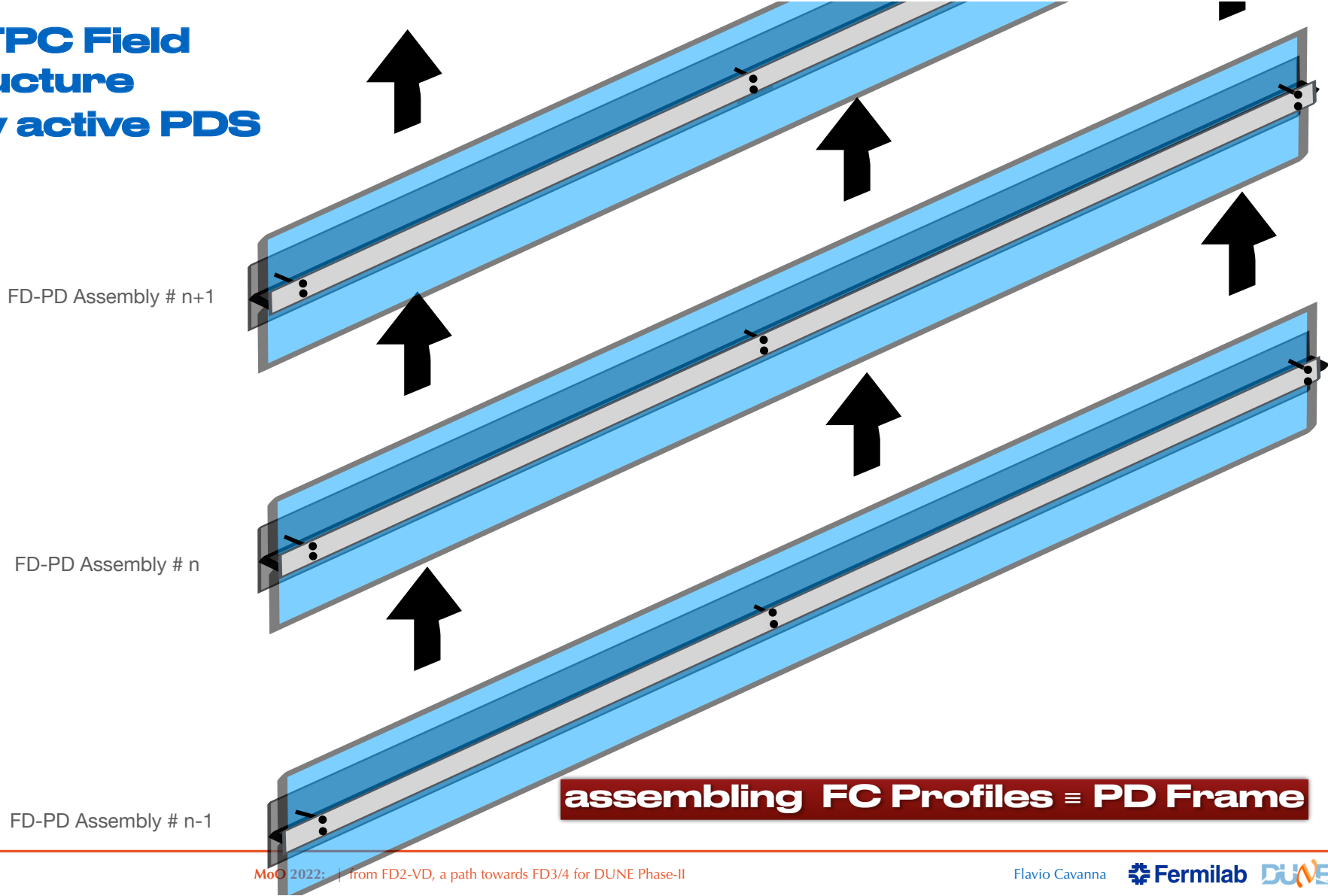
20cm

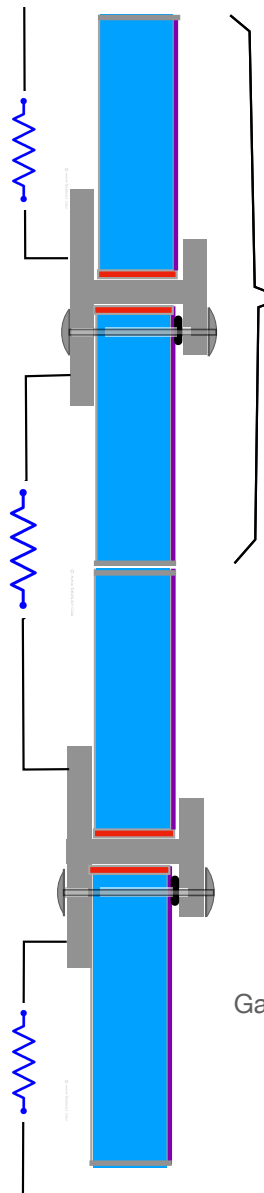


Reflector layer between plates
 To improve PhotoCollection Efficiency

Small gaps between WLS-PD plates may allow for
 LAr flow circulation inside cryostat volume
 (and continuous purification)

convert TPC Field Cage structure into a fully active PDS





Side View

One Optical and Electrical Channel

Gaps between adjacent WLS plates for fluid flow circulation

Arapuca Ph.Sensitive Area $A = 0.20 \text{ m}^2$

40 SiPM/plate(1m)

SiPM Area-to-Bar Area 1.4%

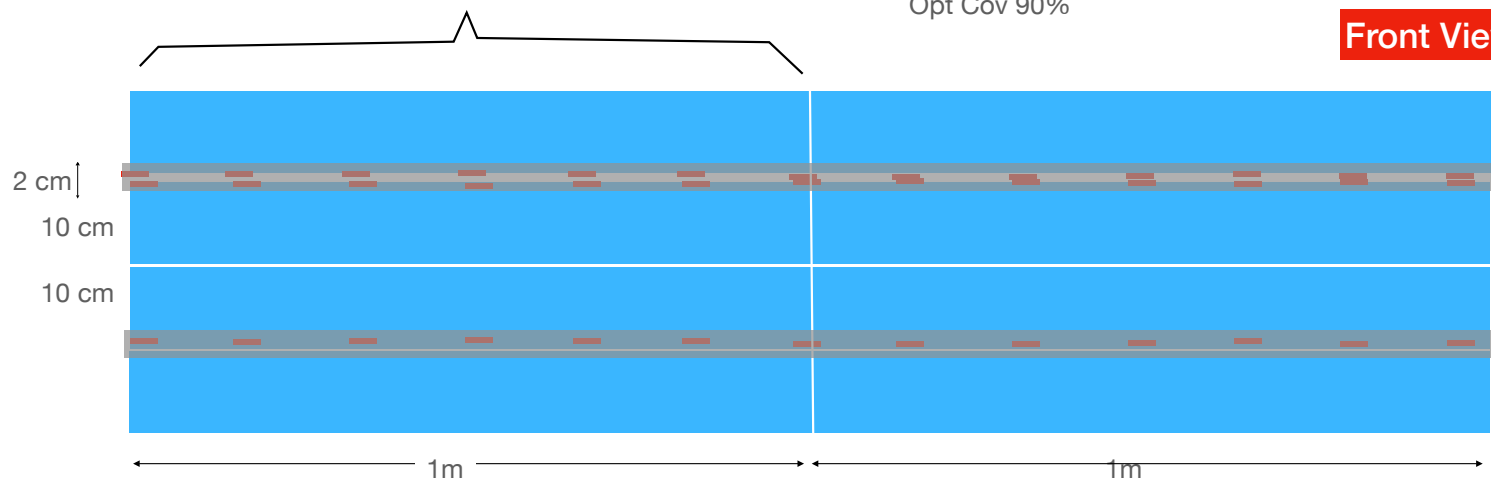
(vs FD2 Tile: 1.6%)

Reasonable assumption

$\epsilon_D \approx 2 \%$

Opt Cov 90%

Front View



60 A-plates/FC panel x 30 FC panels (long side) x 2 sides=3600 plates

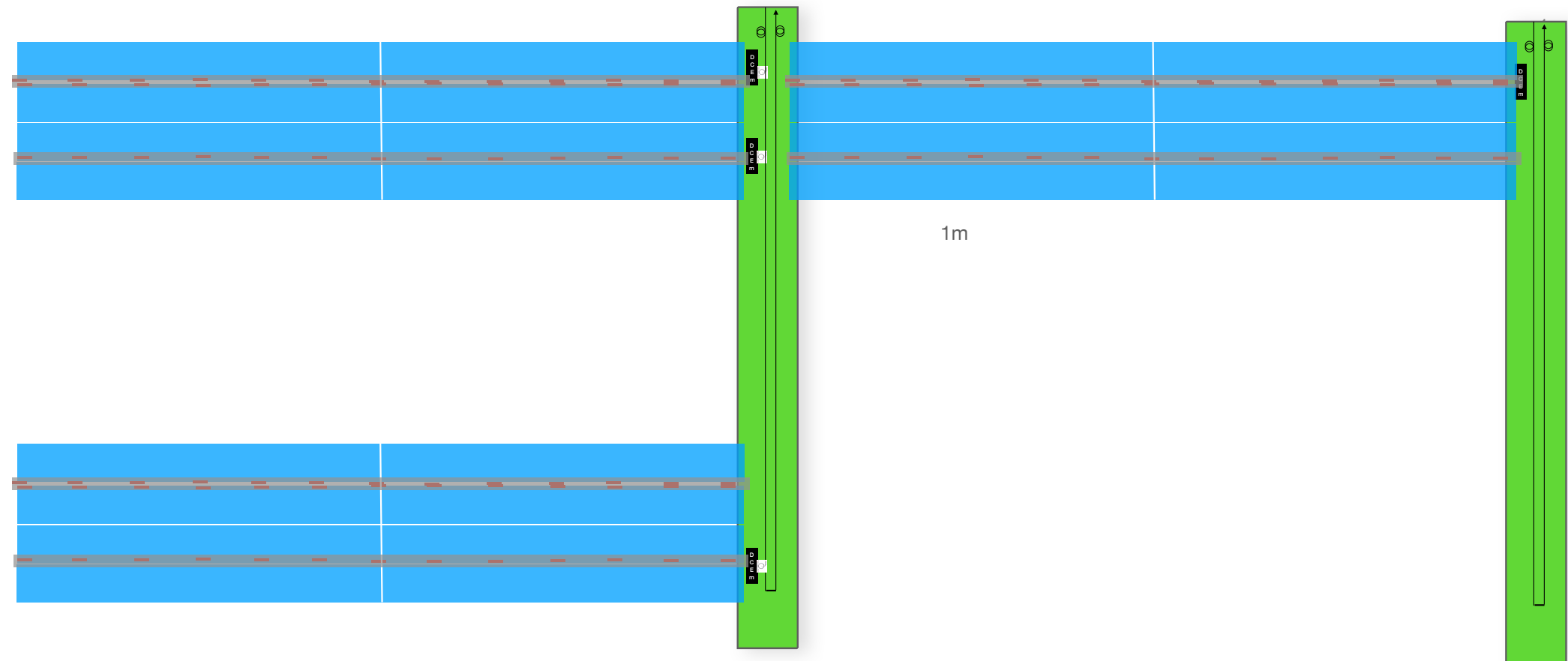
40 SiPM/A-plate → 144,000 SiPM

60 A-plate/FC panel x 6 modules (short side) x 2 sides = 720 plates

40 SiPM/A-plate → 28,800 SiPM

Half Module - Tot:

4320 A-plates, 172,800 SiPMs



Incremental R&D path on mature technologies
two enhanced LArPDS
for
Optimized VD FD3

- ➔ New design PD module framed in FC electrodes
- ➔ high efficiency, low power PoF system
- ➔ CE (F/E & ADC) + large transmission bandwidth SoF

and a staged Prototyping program

Three elements of novelty in the *FC-PD System* are identified:

- ➔ **the PD module framed in the FC electrodes.** The PD module, based on the X-ARAPUCA technology concept, and the FC electrodes, based on standard Al profile, to be developed into a new design. Simplified solutions (SiPM-WLS, ALD dichroic, ..) to be developed (with specialized industry partnership) and demonstrated at prototype level at Lab's
- ➔ **The high efficiency PoF system.** The PoF solution developed for DUNE FD2 cathode-mount PDS will require a new technological advancement to cope with the higher power demand of the PD system. High efficiency, low power OPCs (Optical Power Converter - core element of the PoF) must be designed in sync with the PD, developed in collaboration with specialized Industry and validated by lab tests.
- ➔ **The large bandwidth SoF.** Signal digitization in cold and transmission through fiber is a novelty item. Some development already carried out at FERMILAB, with encouraging results.

Signal over Fiber

new state-of-art silicon photonics solution

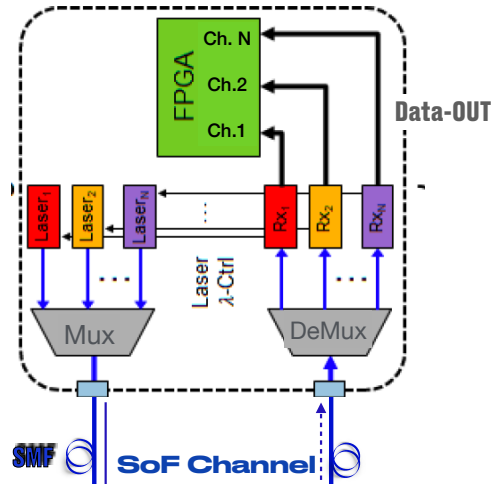
MultiChannel Electro-Optical Interconnection



developed for advanced telecommunication
(Next-Generation 100G Interconnects)

to be
customized for cryogenic

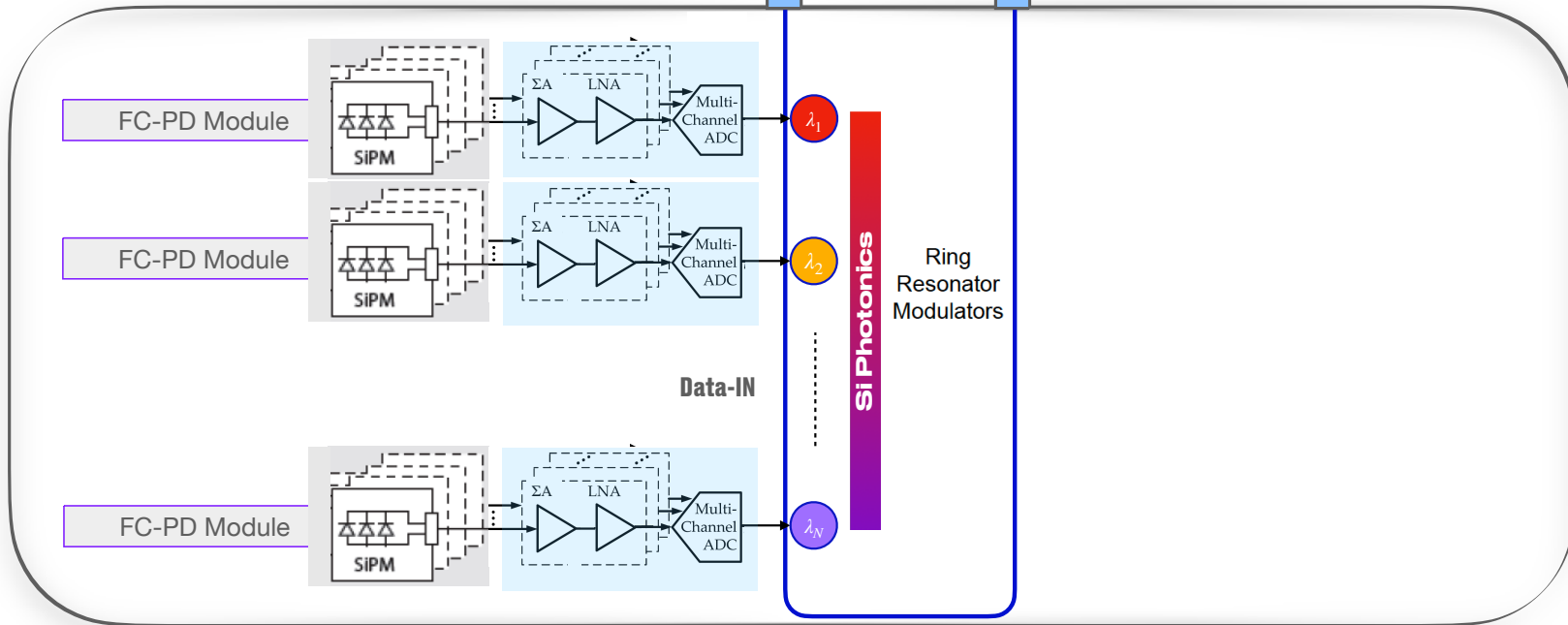
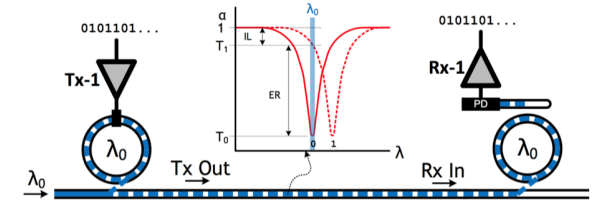
Resonator driver
Thermal wl management



Ring Resonator Modulation

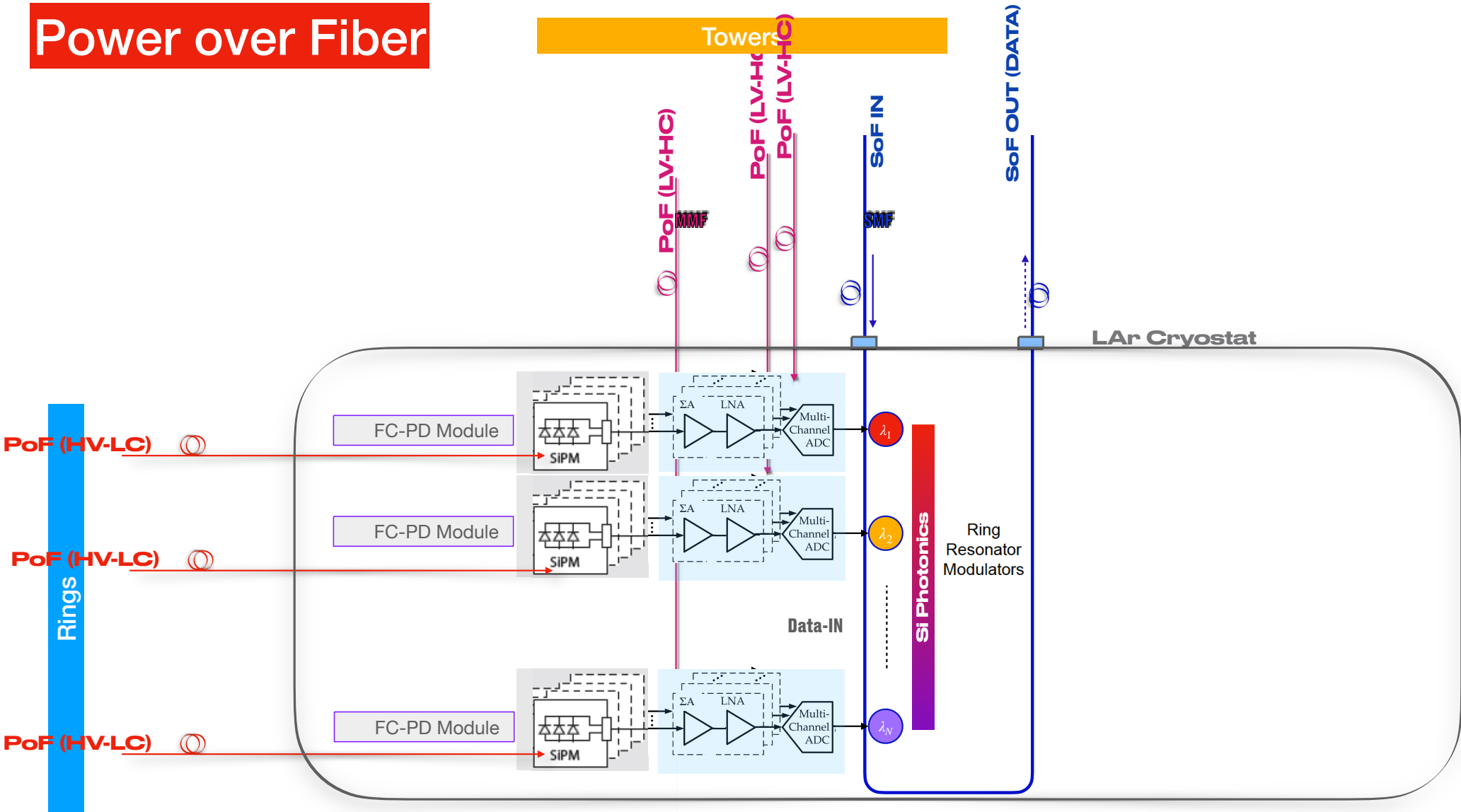
for Digital Data encoding
and
very large bandwidth transfer

[14(ADC-bits) x 67 Mbit/s] x 100 ch.s = 100 Gbit/sec



LAr Cryostat

Power over Fiber



FD3 FC-PD Names and Numbers:

FC-PD Module (L 200 x H 20 cm2)

[1 H Al profile (L 200 cm x H 2 cm) + 2 Acrylic bars (WLS) (L 100 x H 10) + 4 Flex PCB (L100 cm) + 160 SiPMs + pTer film (L 200 x H 10 cm x 2) + VIKUITI foil (L 200 x H 10 cm

FC-PD Panel (L 2 x H 6 m2)

FD3 LongWall (L 60 x H 6 m2) x 2 x 2

- 2=R,L wall, 2=Top,Bot wrt Cathode Plane

FD3 ShortWall(L12 x H 6 m2) x 2 x 2

- 2=Upstream/Downstream, 2=Top,Bot wrt Cathode Plane

1 Opt Channel = 4 Flex Board (assume 1m long flex board - w/ channel read-out at one end)

N. Opt Channels/Module: 2

N. FlexBoards/Module: 4

N. SiPMs/FlexBoard: 40

N. SiPMs/Channel: 160

N. Modules/Panel: 60

N. Opt Channels/Panel: 120

N. SiPMS/Panel: 2400

N. Opt Channels/Electronic Channel: 4

N.Panels/LongWall: 30 x 2 x 2 = 120

N.Panels/ShortWall: 6 x 2 x 2 = 24

N. Tot Panels: 144

N. Tot Modules: 60 x 144 = 8640

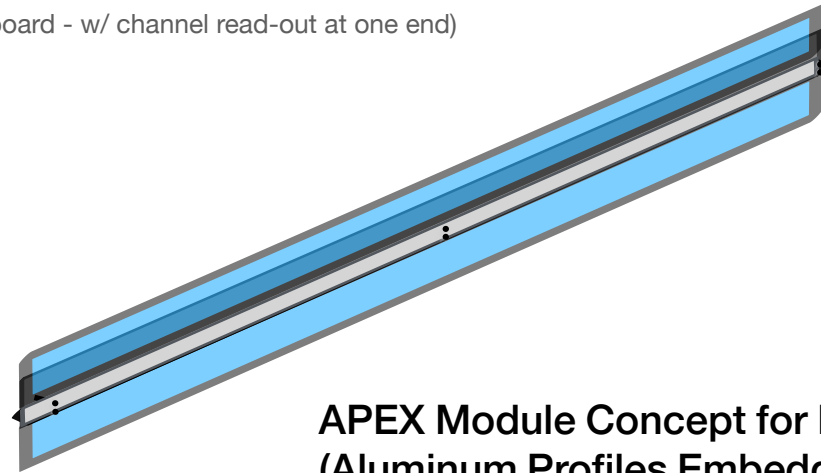
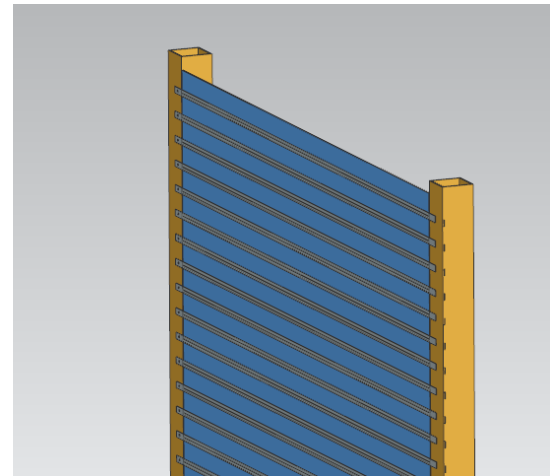
N. Tot Opt Channels: 2 x 8640 = 17280

N. Tot Elec Channels: 17280/4 = 4320

N. Tot SiPMs: 17280 x 20 = 345600

N. Tot Modules: 8640 ⇒

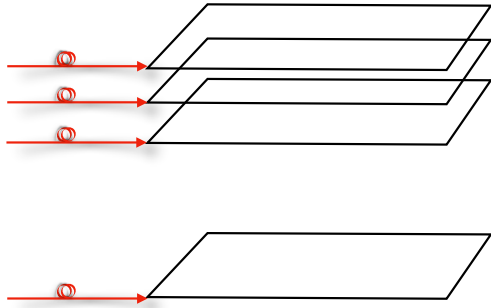
- N. Tot H-Al Profile: 8640
- N. Tot Acrylic WLS Bars: 2 x 8640 = 17280
- N. Tot Flex Boards: 2 x 8640 = 17280



APEX Module Concept for DUNE FD3 (Aluminum Profiles Embedding X-Arapucas)

N. WLS Bars/WLS Plate (100x100 cm2) = 10
N. Tot WLS Plates: 1728

Ring



PoF & PoF Fibres

FC-PD ring ($L = 60 + 12 + 60 + 12 = 144$ m)

N. Tot Rings: $60 \times 2 = 120$

N. Modules/Ring: $144/2 = 72$

N. FlexBoards/Ring: $72 \times 2 = 144$

N. SiPM/Ring: $144 \times 20 = 2880$

PoF for SiPM:

N. OPCs/Ring: 2 (II) - (1 redundant) 400mW EIPwr

N. Fibre/Ring: 2 - (1 redundant)

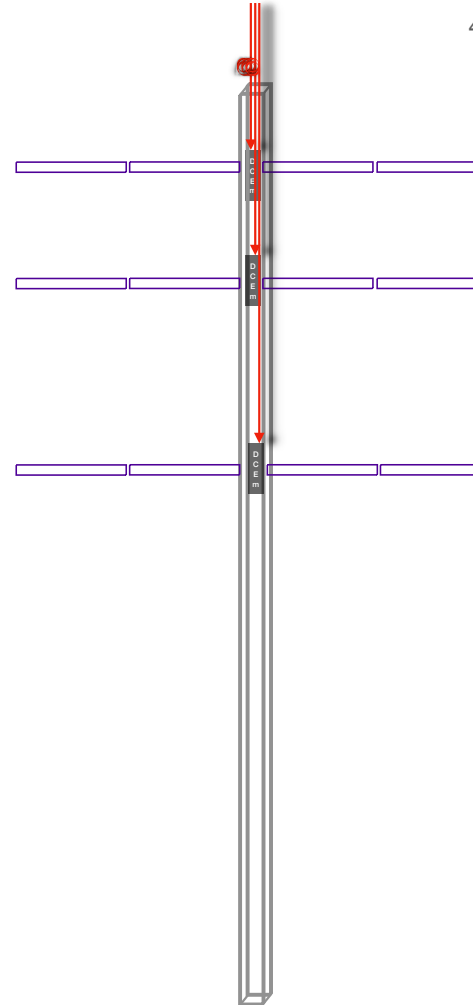
N. DC-DCs/Ring: 1

N. Tot Fibre: 240

N. Tot OPCs: 240

N. DC-DC: 120

Post & Crosses (Xs)



4 Opt Channels \rightarrow 1 Electronic Board (4-Ch ADC)
[Mini-DCEM (Digital)]

PoF & PoF Fibres

FC-PD Post

1 Post/2 Panels

N. Posts/LongWall: $1/2 \times 30 \times 2 \times 2 = 60$

N. Posts/ShortWall: $1/2 \times 6 \times 2 \times 2 = 12$

N. Tot Posts: 72

FC-PD X

N. Xs/Post: 60

N. Tot Xs: $60 \times 72 = 4320$

N. Boards/X: 1

N. Boards/Post: 60

N. Tot. Boards: 4320

PoF for Elec Board:

N. OPCs/Board: 2 (Σ) - stacked- (1 redundant) 400mW EIPwr

N. Fiber/Board: 1

N. Fiber/Post: 60

N. Tot Fibre: 4320

N. Tot OPCs: 8640 (including x2 for redundancy)

Prototyping FC-PDS

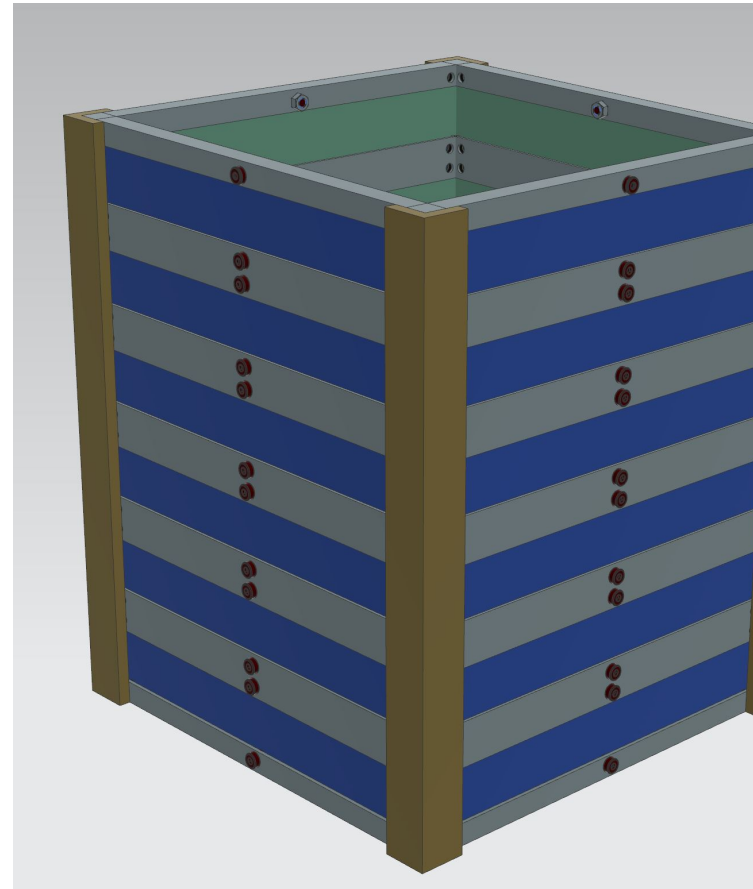
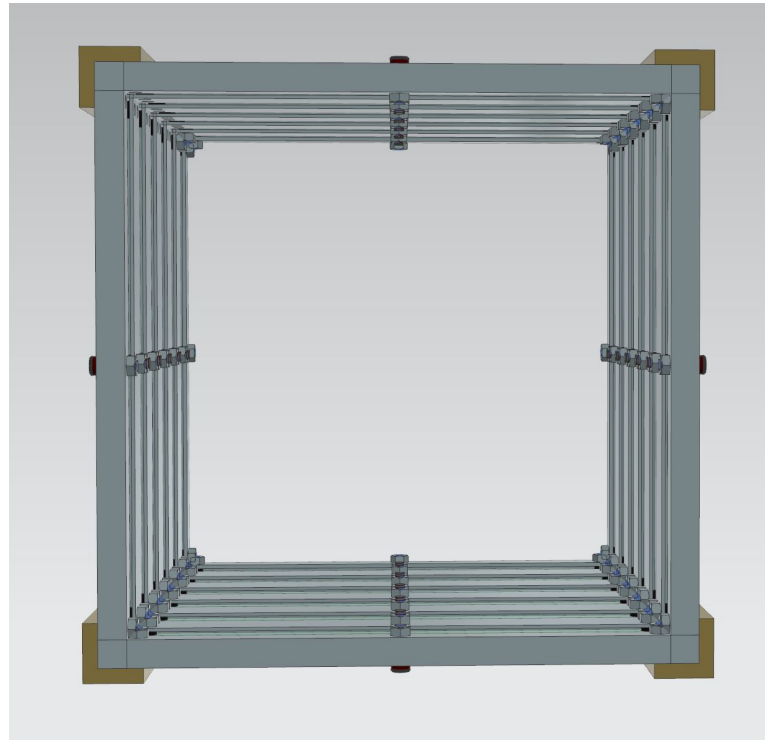
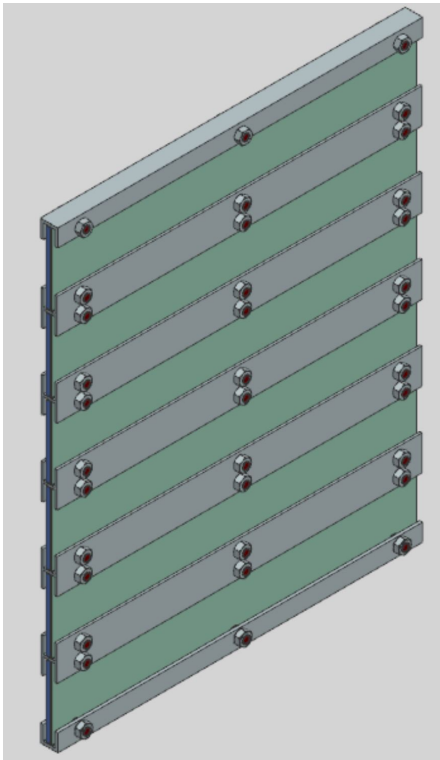
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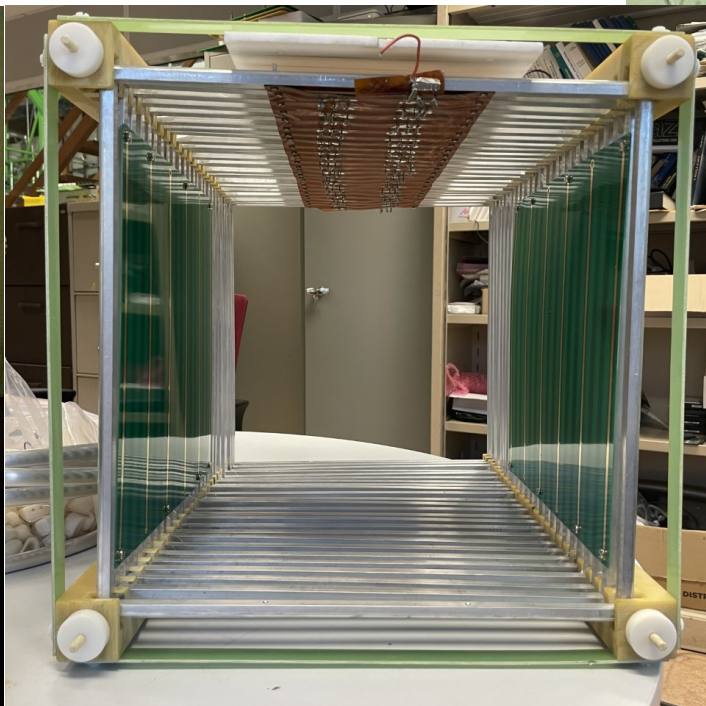
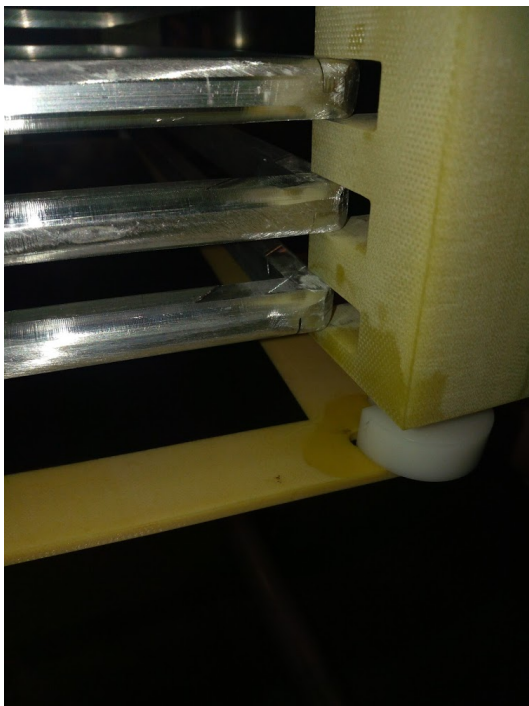
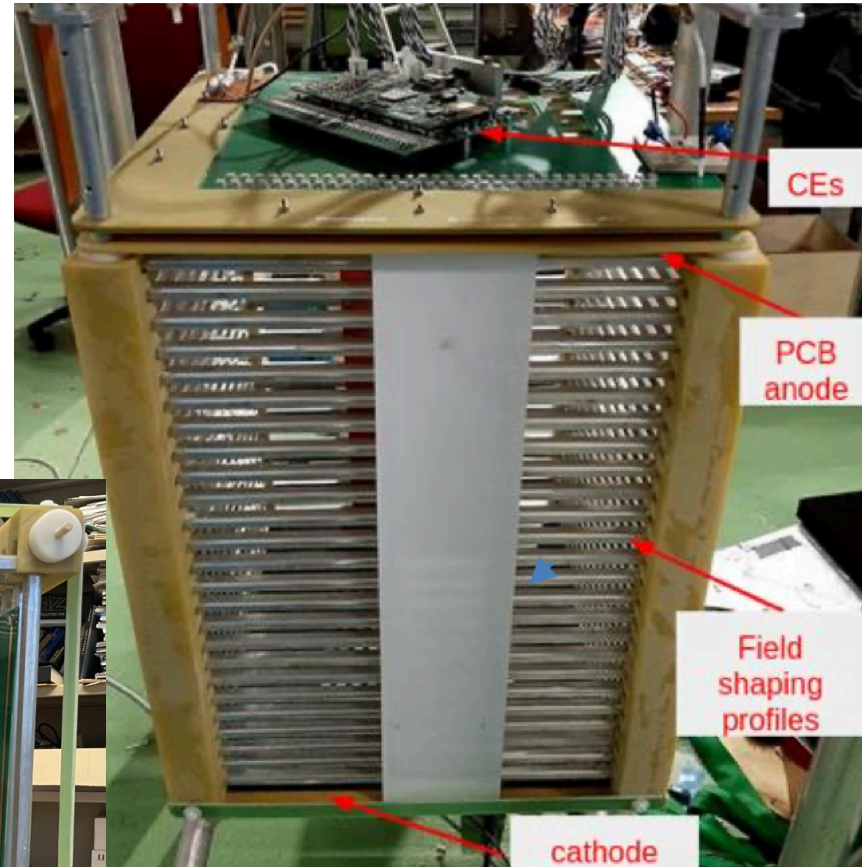
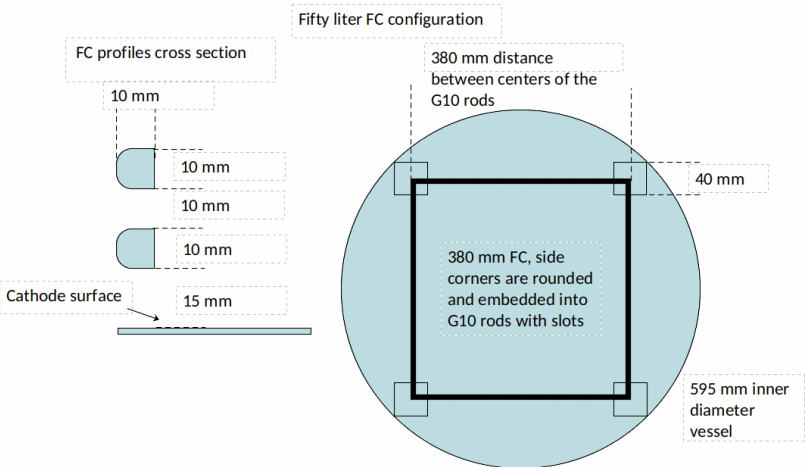
Optimized VD FD3

Demonstrator R&D: a staged prototyping path

- **table-top size:** FC-PD module assemblies and electronic boards with PoF-OPC and digital SoF solution - 1yr (mid '23-mid'24) - test @ *CERN 50lt facility*
- **larger sized (m³ of LAr)** - order of 100-channels SoF read-out and PoF (2024-25) - test @ LAr lab - IERC-EEwards building - in the large 2mx2mx3m FNAL "*ColdBox*" facility
- deployment of a **full-sized, fully PD-instrumented FC** of a Vertical Drift LArTPC in the *protoDUNE* cryostat at CERN (2025-26), for a 1-kT scale validation in view of DUNE Phase-2 Far Detector (FD3)
—> opportunity for combining into ARIADNE proposal to SPSC for a protoDUNE run

Table top prototype for 50lt @ CERN - start in 2023, build and operate in 2024





test @ CERN 50lt facility

The large sized demonstrator in a few m³ LAr cryostat with O(100-channel) SoF read-out and PoF and the first O(10 m²) active surface PD-instrumented FC will be the goal for 2024-25 (application for funds at FNAL, and other US institutions).

The LAr lab at the FNAL IERC-Ellen Edwards building, where a large 2mx2mx3m “ColdBox” facility for LAr technology development is currently being built, will be ideal and necessary for this step. Availability of a 2

