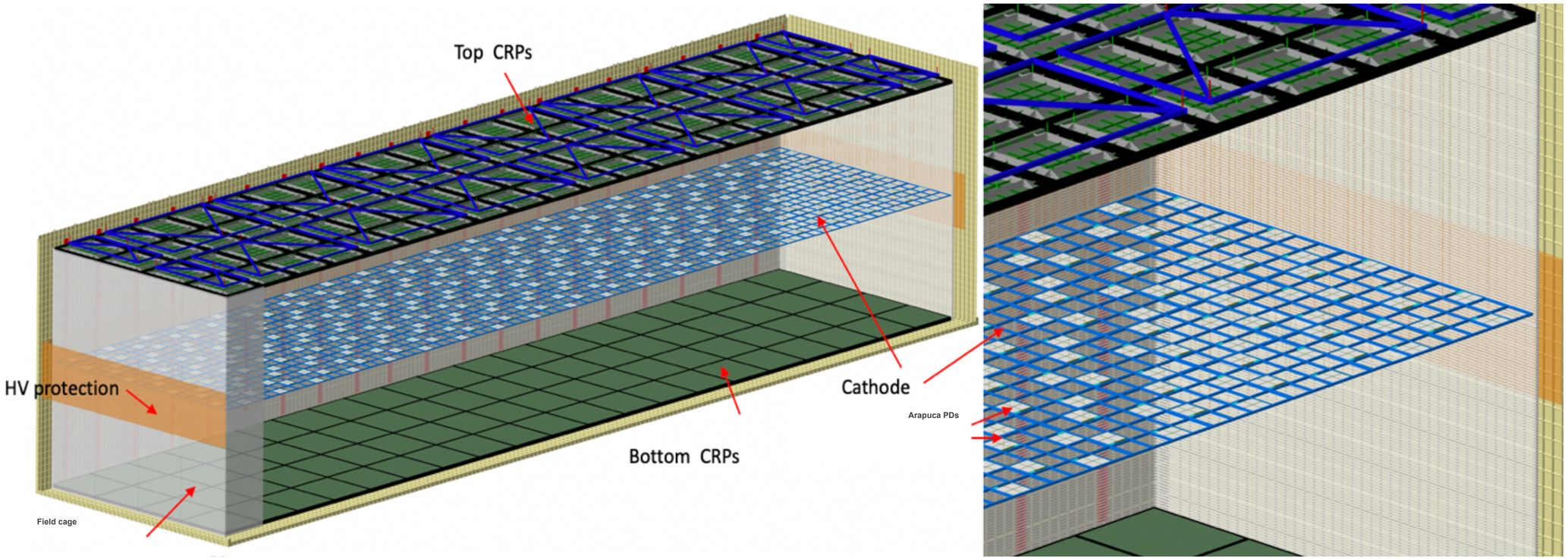
A Photon Detector for DUNE FD-2 (VD)



Flavio Cavanna (FERMILAB)

July 26, 2021

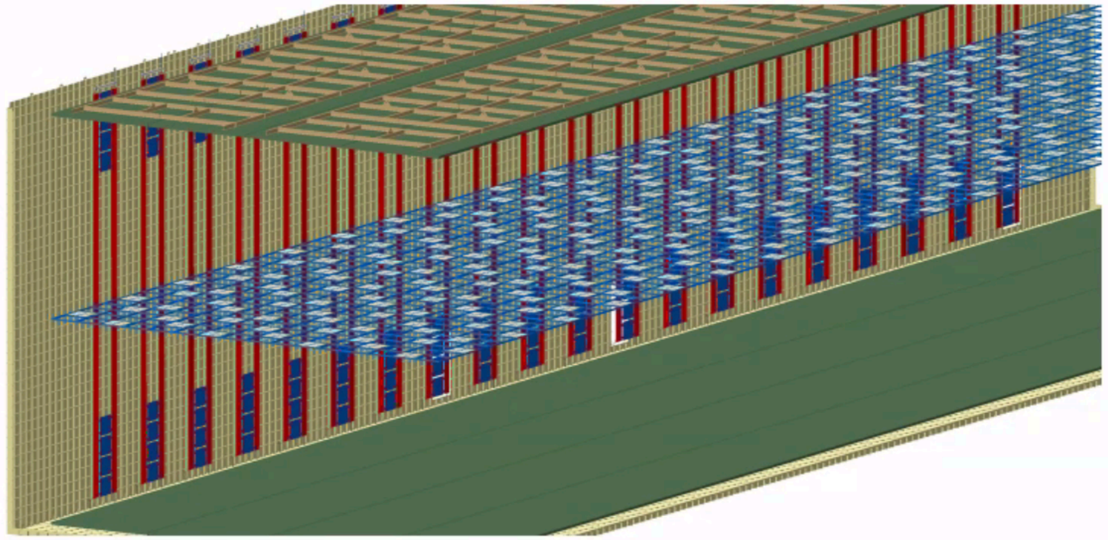
The (new) **VD Liquid Argon Detector concept** for DUNE FD-2 aims at exploiting in a more substantial way the abundant
LAr Scintillation Light - *complementary to Ionization Charge* -
produced by charged particles in LAr

Collection of the fast light signal can enhance/extend detection sensitivity
for ***UG Low-Energy rare events***.
The key point is to extend the PhDetector Optical Coverage as close to 4π as possible, as demonstrated by traditional large Volume Liq. Scintillator UG experiments.

However, it is a big technological challenge to embed a 4π-PDS into the LArTPC layout.

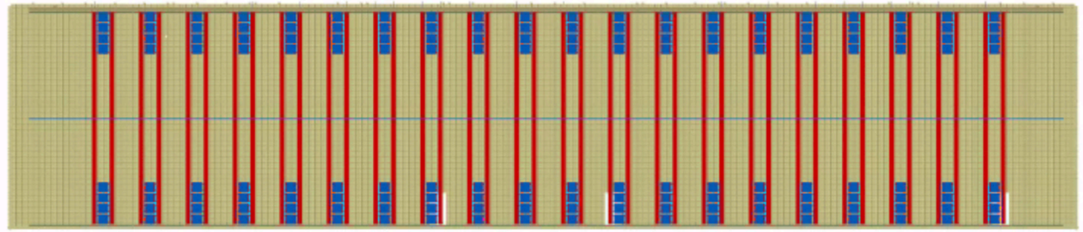
The VD PD Reference Design

Reference Design



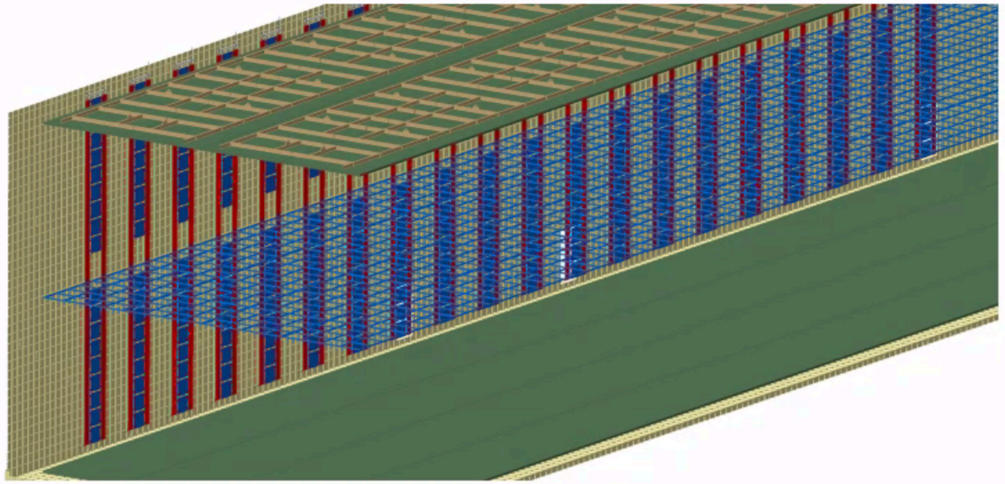
4 pi layout :

- Full trigger capabilities down to 10 MeV
- Energy, Position, Timing and T0
- xArapucas 60x60 on the cathode, 115 mq, analog readout
- xArapucas 60x60 on the cryo membrane, ~3m from anode



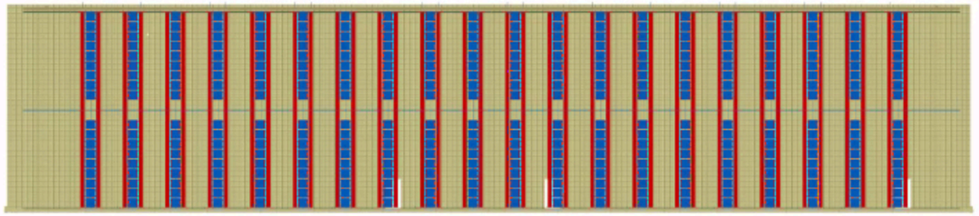
the Backup Design Option

Backup Design (All-Membrane mounted PDS ⊕ Xe doping)



Minimal layout:

- Trigger via charge TPC readout down to 10 MeV
- T0, (Energy)
- xArapucas 60x60 on the cryo membrane, 20 columns, each column 18 xArapucas, SPHD readout



Reference design for the VD PD System

PD Active Optical Coverage distributed onto 3 sides of the LAr Volume

(Cathode side and 2 Long Membrane Cryostat sides, w/ modified FC - 70% T)

+

PD Passive Optical Coverage (reflector) on the Anode side

+

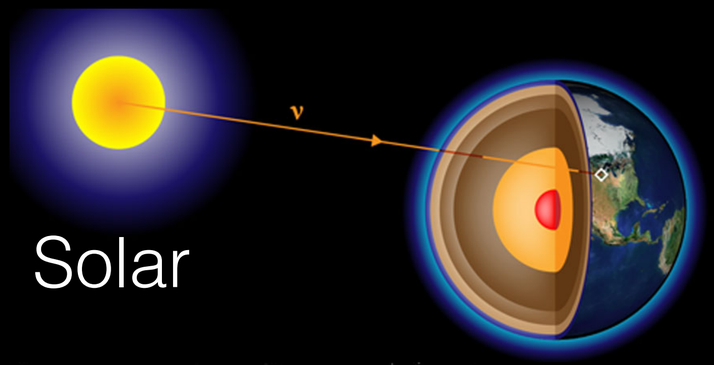
Xe doping (minimize Rayleigh scatter for light at far distance)

The Reference design endorses the ***~4π coverage concept (originally suggested in the VD proposal)****:*

⇒ *good uniformity of response, very low detection&trigger threshold, energy resolution, position resolution and time resolution capabilities*

- ***Potential high impact on LowEn UG Physics*** *(PD standalone trigger and reconstruction)*
- *Further enhancement of response when combined with TPC*
- *Highest Live Time (PD active also when LArTPC may be OFF for purity drop/maintenance, HV issues/ maintenance,..) very relevant for UG Physics*

Enlarging the DUNE Physics Scope



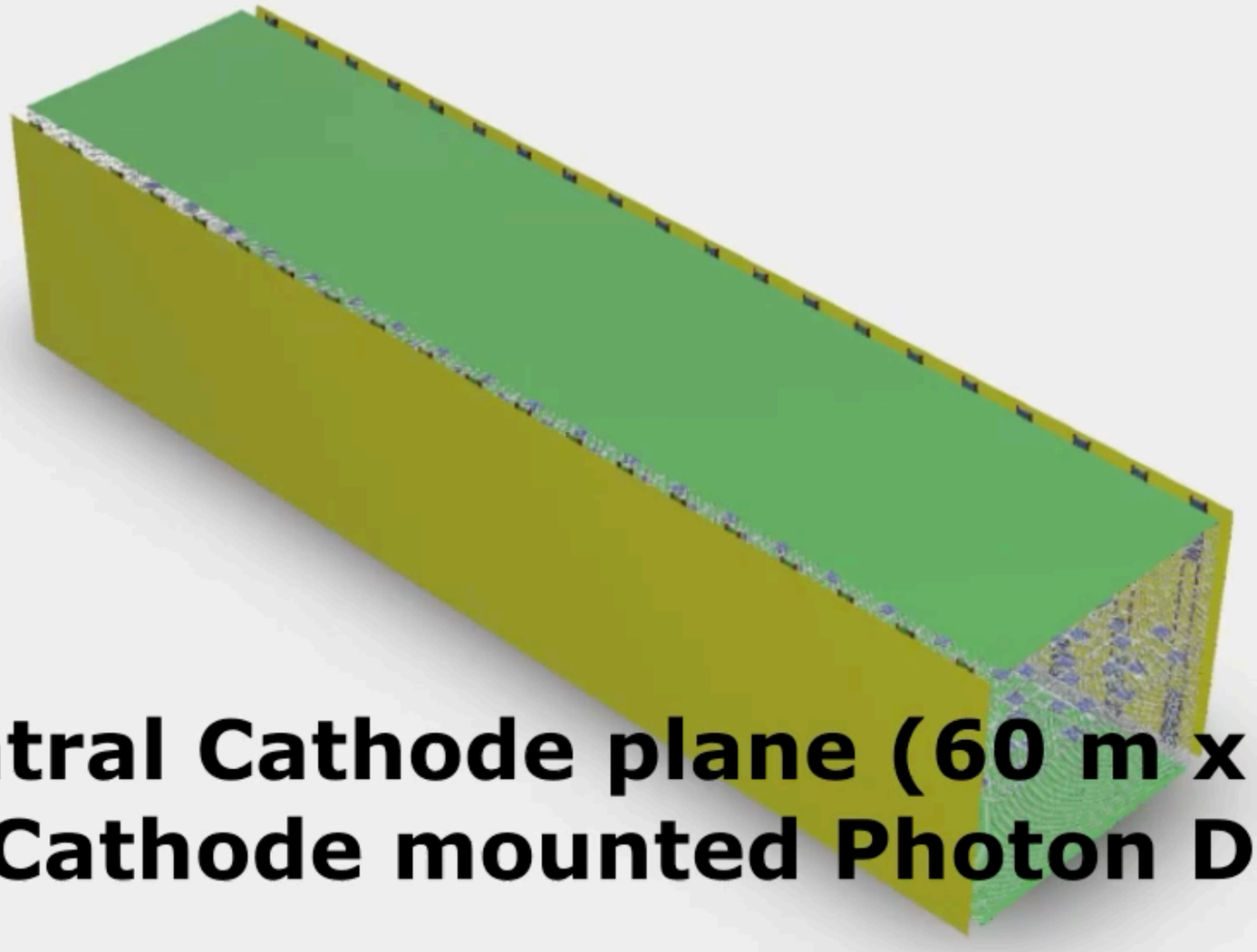
Solar

SuperNova

- CoreCollapse SN is the most spectacular phenomenon in Nature and is imprinted in neutrino signal
- Low energy UG neutrinos opened discovery space in particle and astro-particle physics

VD PDS

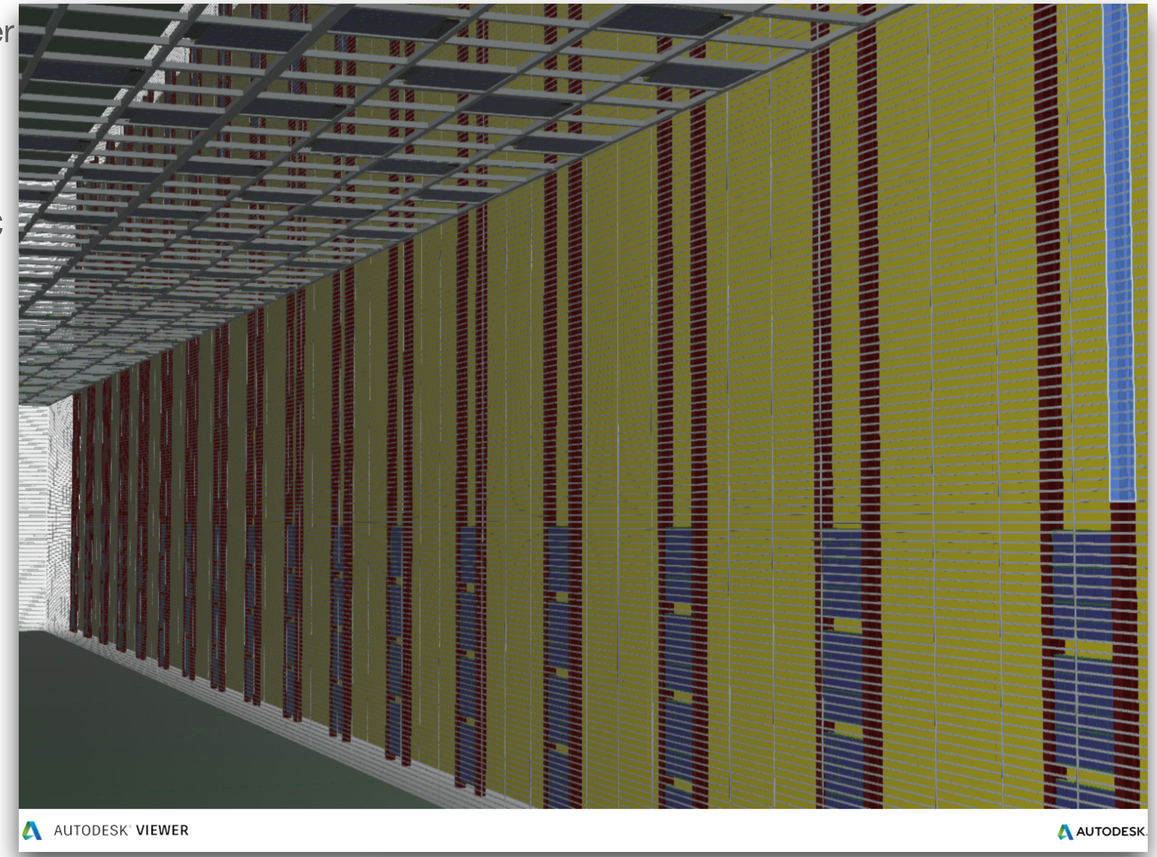
- *It is critical to DUNE Science Program to succeed at measuring low energies rare UG neutrinos*
- *It is is critical to lower Trigger E-threshold to extend range of SN detection (toward and beyond Galaxy edge).*
- *It is critical to guarantee good Time resolution and improve Energy resolution for SN-signatures in time & energy spectra*



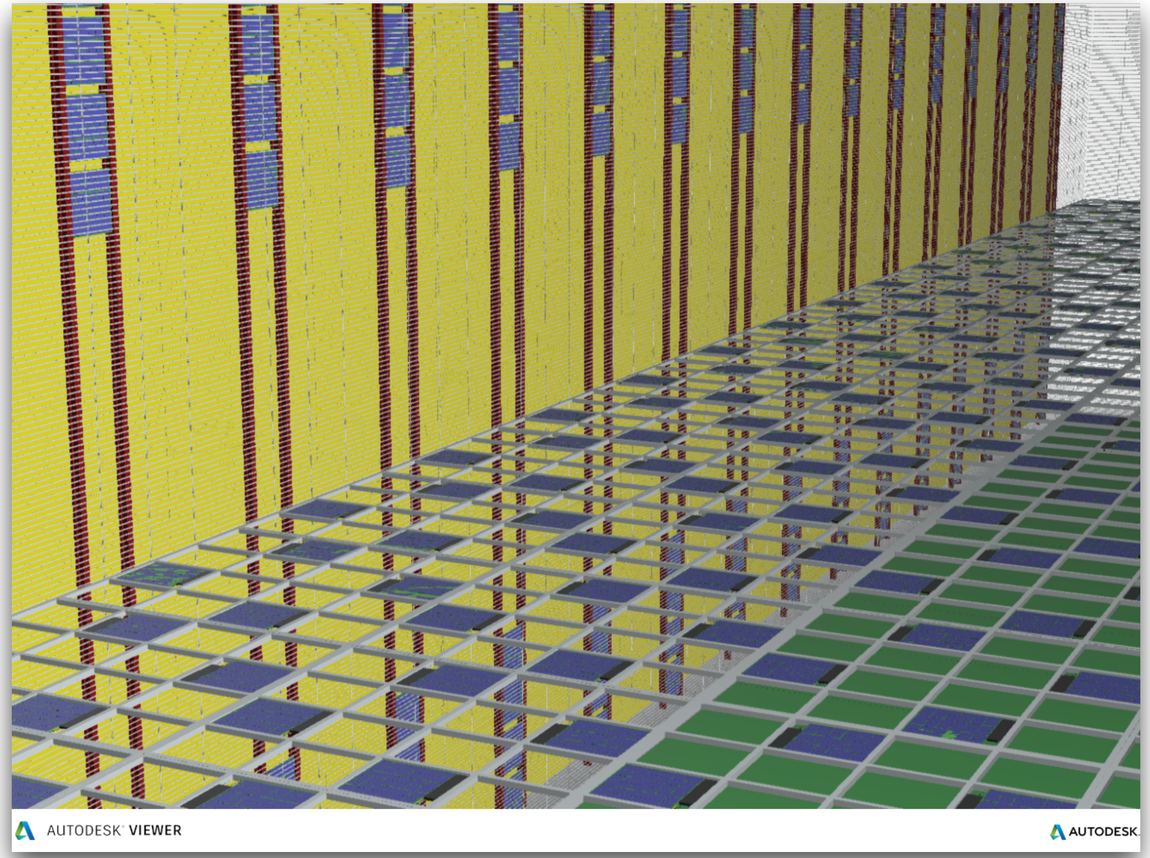
Central Cathode plane (60 m x 13 m)
with Cathode mounted Photon Detectors

The technological Challenge for the Reference PD design

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

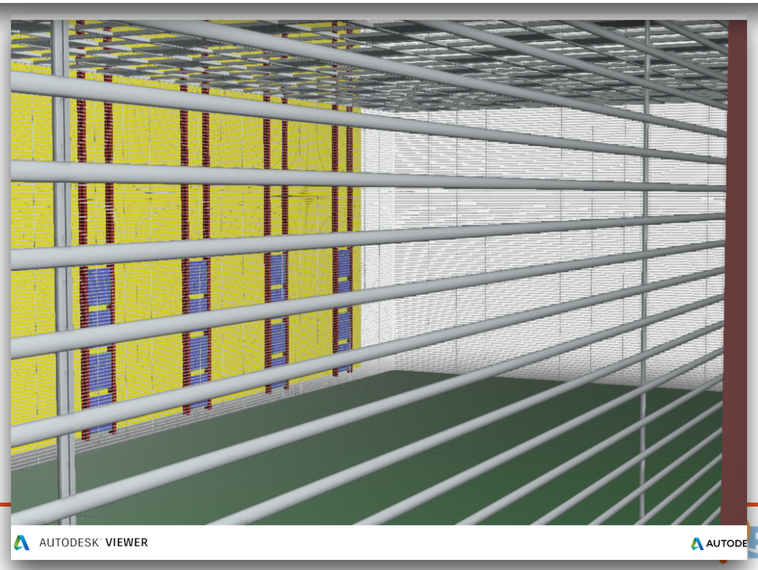


View from inside the Upper Volume with PD instrumented Cathode (below) and PD instrumented Membrane behind the FC



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)

⇒ none of the commercially available technologies (PoF and optolinks) is rated to operate in Cold (at LAr Temperature)

A highly specialized R&D has been launched (mid Feb.'21) and is currently ongoing to validate COTS technology in Cold

or

develop Cold custom technology for this application

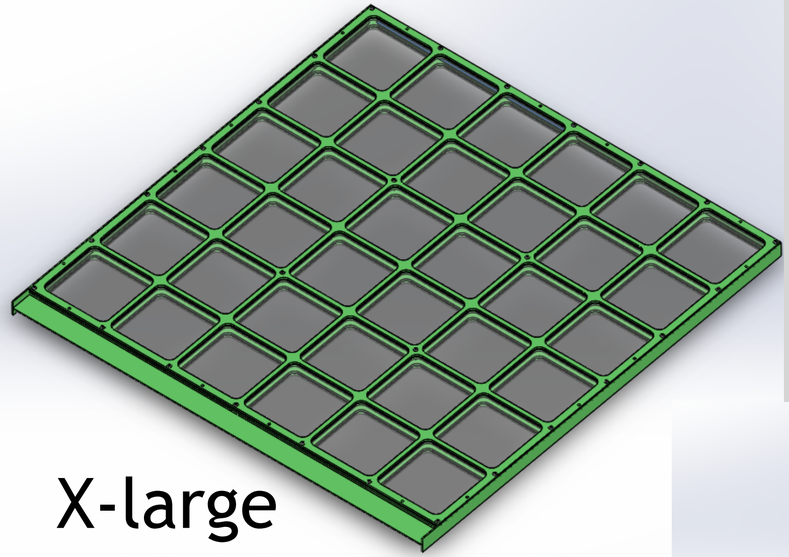
Boundary conditions for VD PD on HV surface

⇒ **Power budget and limitation for power dissipation in LAr**

⇒ **Cost envelop for VD PD**

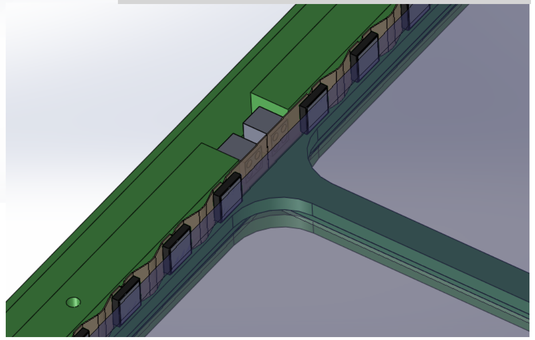
[with baseline plan of substantial part of the “cathode” mounting scheme in DUNE-US Project]

⇒ **Creation of a new PD community from US, EU and International, within the existing DUNE PD Consortium**



- 160 SiPMs (40 per side)
  - Glued to WLS Bar for improved optical contact
- SiPMs mounted on Kapton flexi-PCB
  - Addresses relative thermal contraction of elements
- Glass-to-Power (G2P) FB-118 HQE WLS plate (Milano)

X-large xARAPUCA Tile (new generation)



PoF - Power over Fiber

Relatively new technology rapidly developing

- **Proprietary and patented silicon based Vertical Multi-Junction (VMJ)**

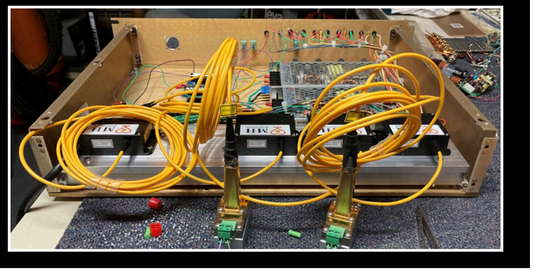
used for systems requiring isolation – eg. PhotoVoltaic Cell Towers, and Low Noise Experimental Systems

FD2-VD PhDet:

Lasers Transmitter+Fiber → *Low Volt/High Current* Receiver (CE)

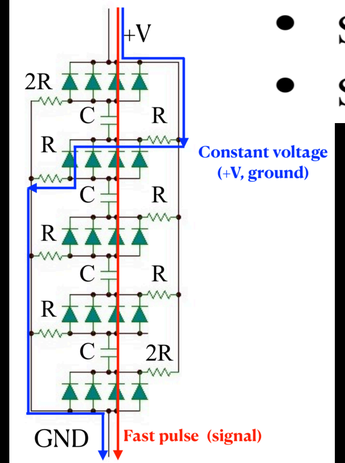
Lasers Transmitter+Fiber → *High Volt/Low Current* Receiver (SiPM)

- HV/LC - PoF: COTS Si-based Receivers fully validated in cold
- LV/HC PoF: high efficiency GaAs-based Receivers better suited for low temperatures
  - Custom units with building voltage specification under development

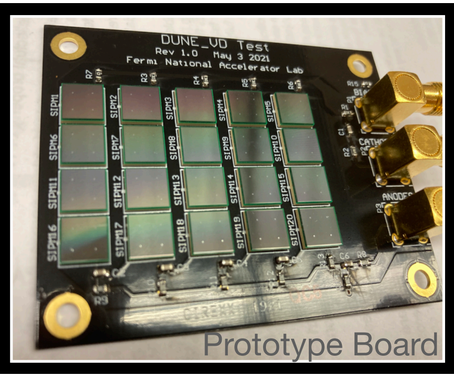


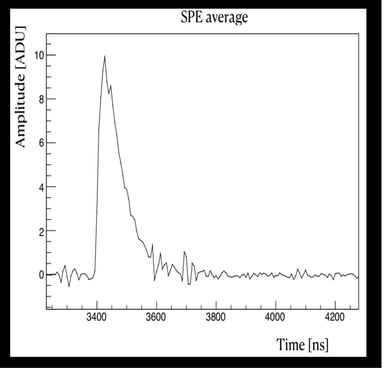
Largest SiPM array → One Channel (new solution):

20 ***hybrid*** Passive ganging X 8 ***OpAmp*** Active ganging



- Small capacitance → short recovery time
- Same bias voltage of a single SiPM



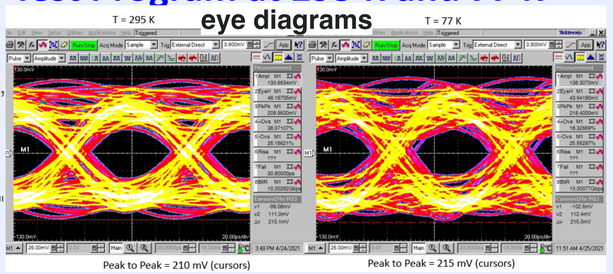


SoF - Signal over Fiber

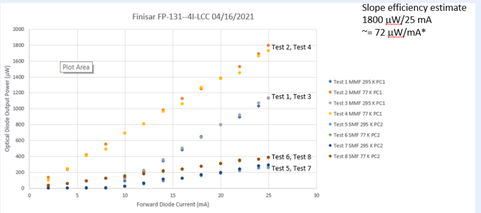
Test Program at 295 K and 77 K

Validation in Cold

Selection → Binary "1" → Laser Driver → ***Driver Testing*** → Binary "0"



Laser Diode → ***Diode Testing***



COTS Transceivers

FD2-VD PhDet:

Bring Together Custom Gbps Transmitter

SUMMARY

Achievements from R&D in Progress

⇒PoF for SiPM demonstrated (optimization in progress), PoF for CE in progress (easier for Analog CE option)

⇒ **xARAPUCA tile** (new design) ⊕ **ANALOG CE/Transmission: prototype#1 under assembly** in time for ColdBox test (Fall 2021)

⇒ **Digital CE/Transmission (prototype#2) - validation in Cold in progress: prototype#2 for ColdBox in the plan**

Boundary Conditions are met

⇒ PoF for PD CE and SiPMs: estimated Power budget is within limits for power dissipation in LAr

⇒ Cost envelop for PD Reference (and Backup) solution within FD-2 VD current boundaries.

Resources from International are important (negotiations w/ funding agencies)

⇒ VD PD core-group from US, EU and International created and included within the existing DUNE PD Consortium.

Existing Groups are growing with new highly qualified expertise, and new Groups are showing interest to join