DUNE vertical drift TPC

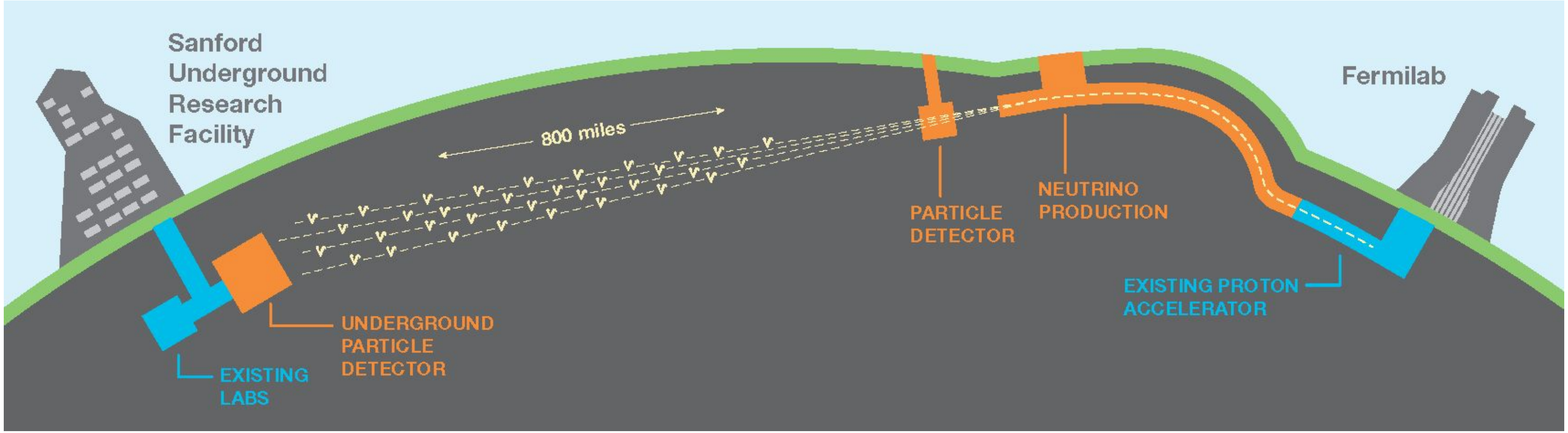
H. V. Souza for the DUNE Collaboration

11th international symposium on “Large TPCs for low-energy rare event detection”

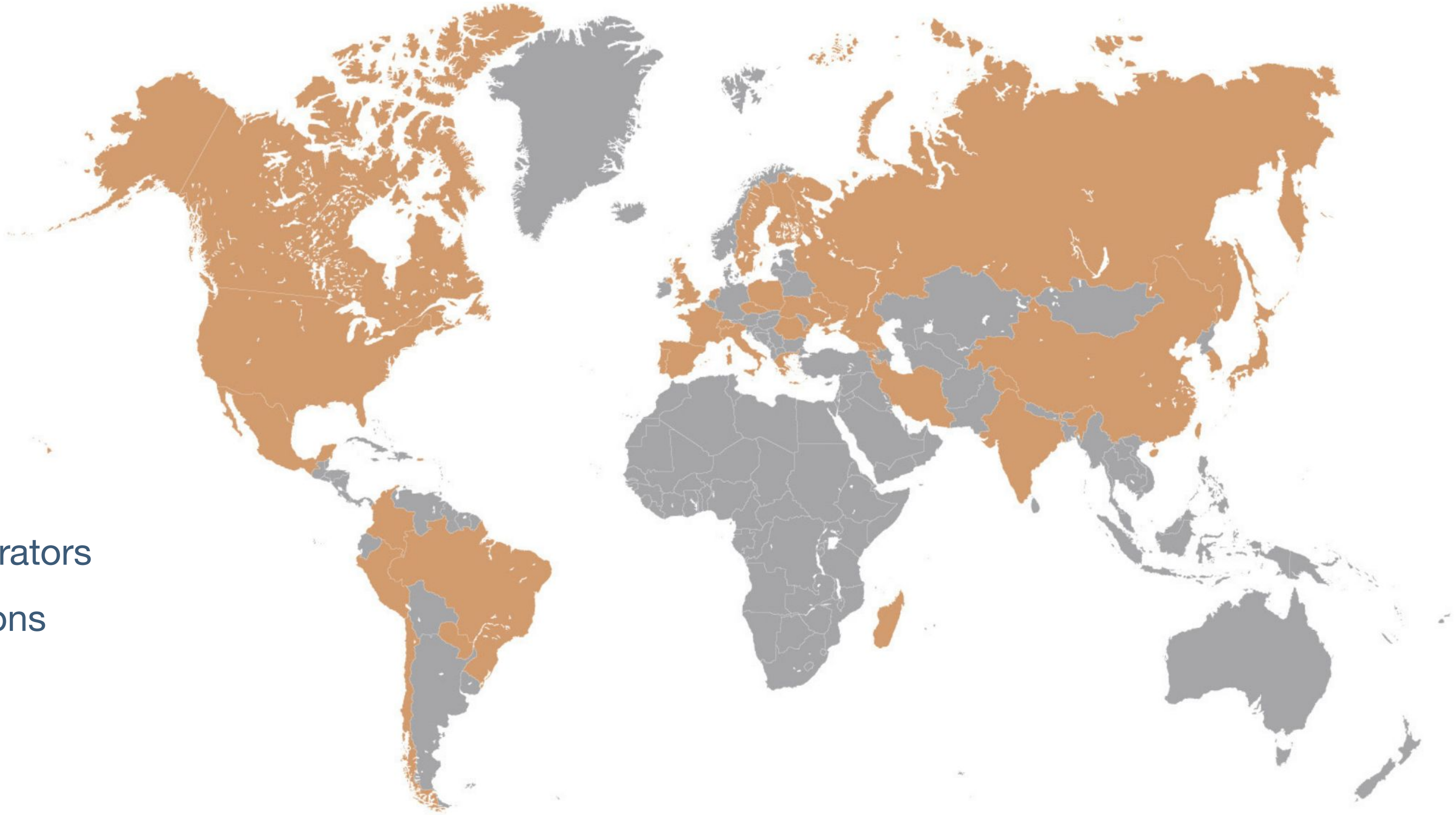
December 11, 2023

Deep Underground Neutrino Experiment (DUNE)

- Massive neutrino detector
- Four **Far Detector (FD) modules** of 17 kt each using Liquid Argon Time Projection Chambers (**LArTPC**)
- **Neutrino oscillations**, **supernova neutrinos**, **proton decay** and **solar and atmospheric neutrinos**
- The experiment search to answer open question in the field of particle physics, astronomy and cosmology (**CP violation phase** in the leptonic sector, octant of $\boldsymbol{\theta_{23}}$, **mass hierarchy**, etc.)
- Baseline of **1300** km and wide band beam, neutrinos energy from **0.1 to 10 GeV**



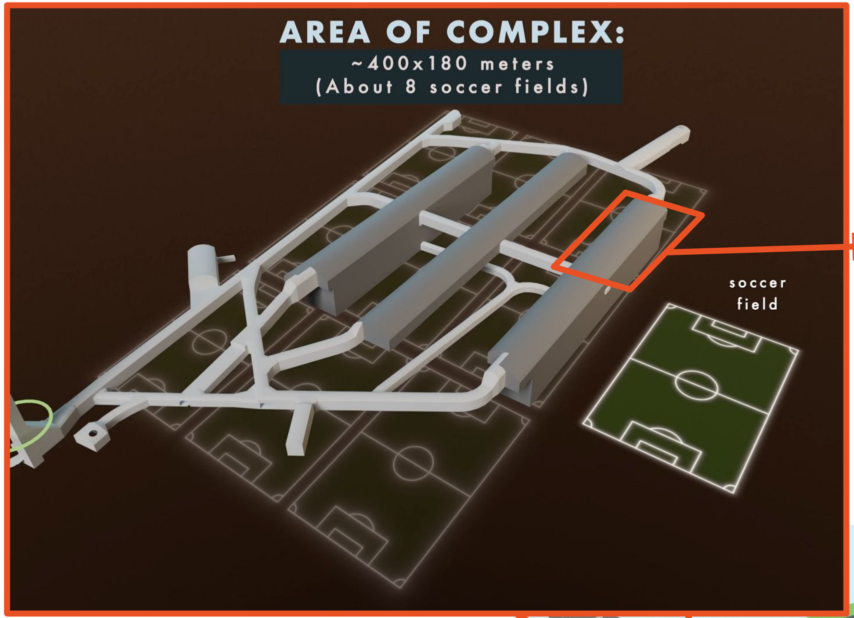
Deep Underground Neutrino Experiment (DUNE)

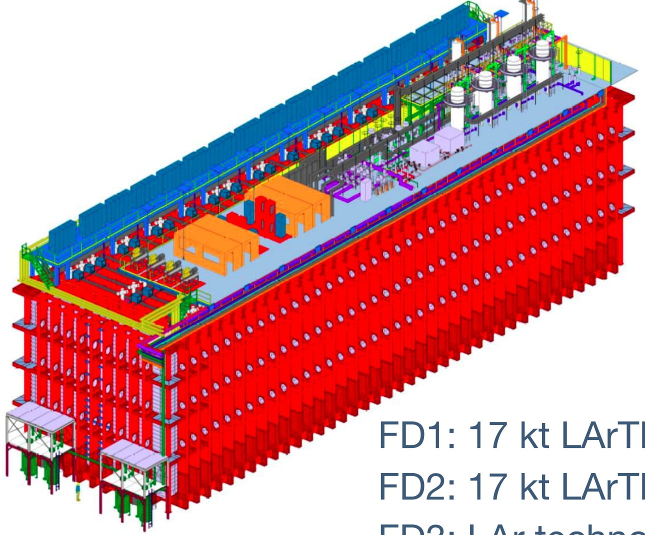


The collaboration:

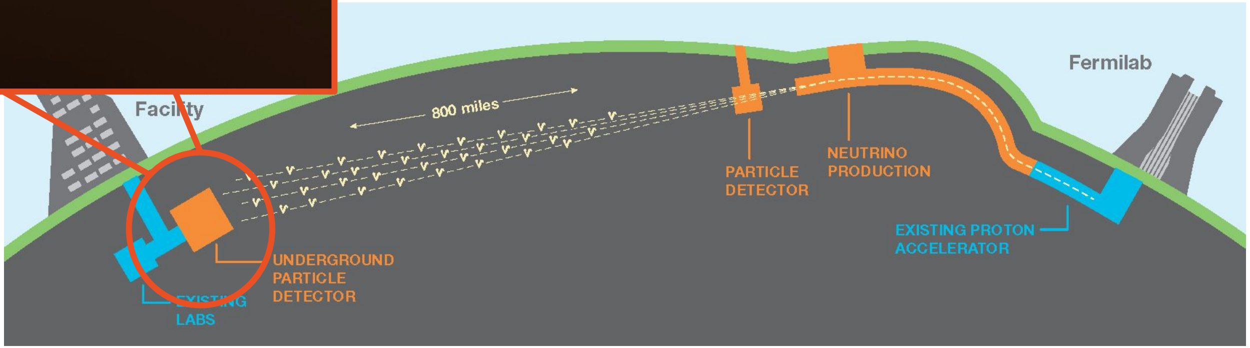
- 1400+ collaborators
- >200 institutions
- 35 countries

DUNE: Far Detector (FD)





FD1: 17 kt LArTPC Horizontal Drift*
FD2: 17 kt LArTPC Vertical Drift
FD3: LAr technology (solar ν)
FD4: Module of opportunity



*David Rivera's talk

Vertical Drift (VD) design

Ionization:

- Event reconstruction through ionization electrons.
- Requires an intense and uniform electric field
- Excellent 3D imagining with millimeter resolution

Scintillation:

- Electron recombination or self-excitation of LAr produce scintillation light (128 nm)
  - 25,000 photons per MeV
- Light measurements contribute to event reconstruction and calorimetric measurements
- Provides trigger for non-beam events, enable calorimetric for low energies

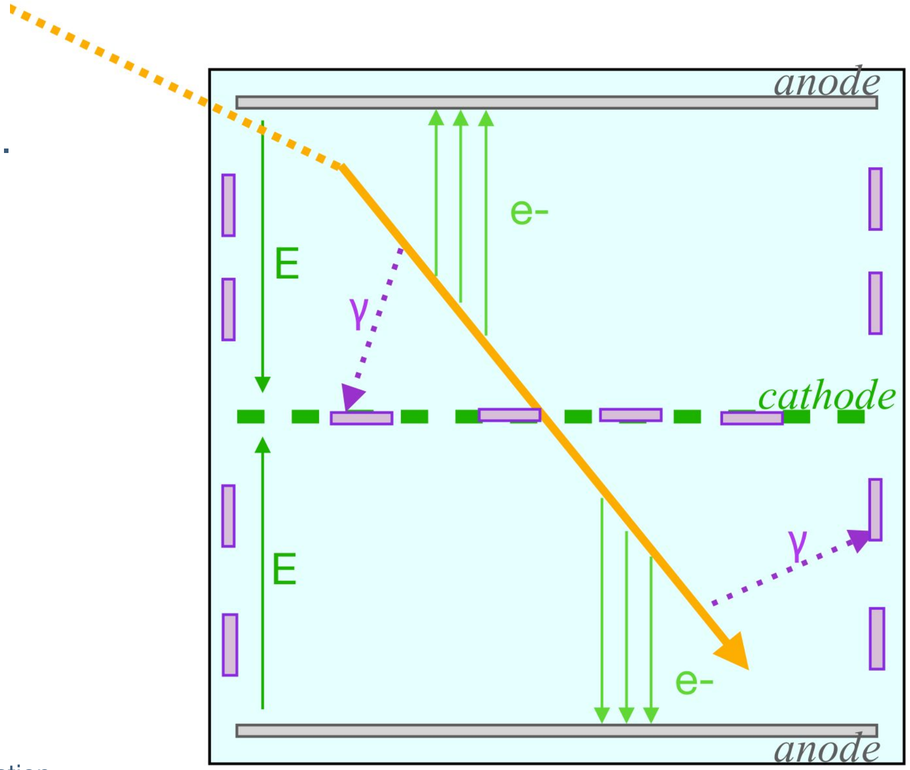
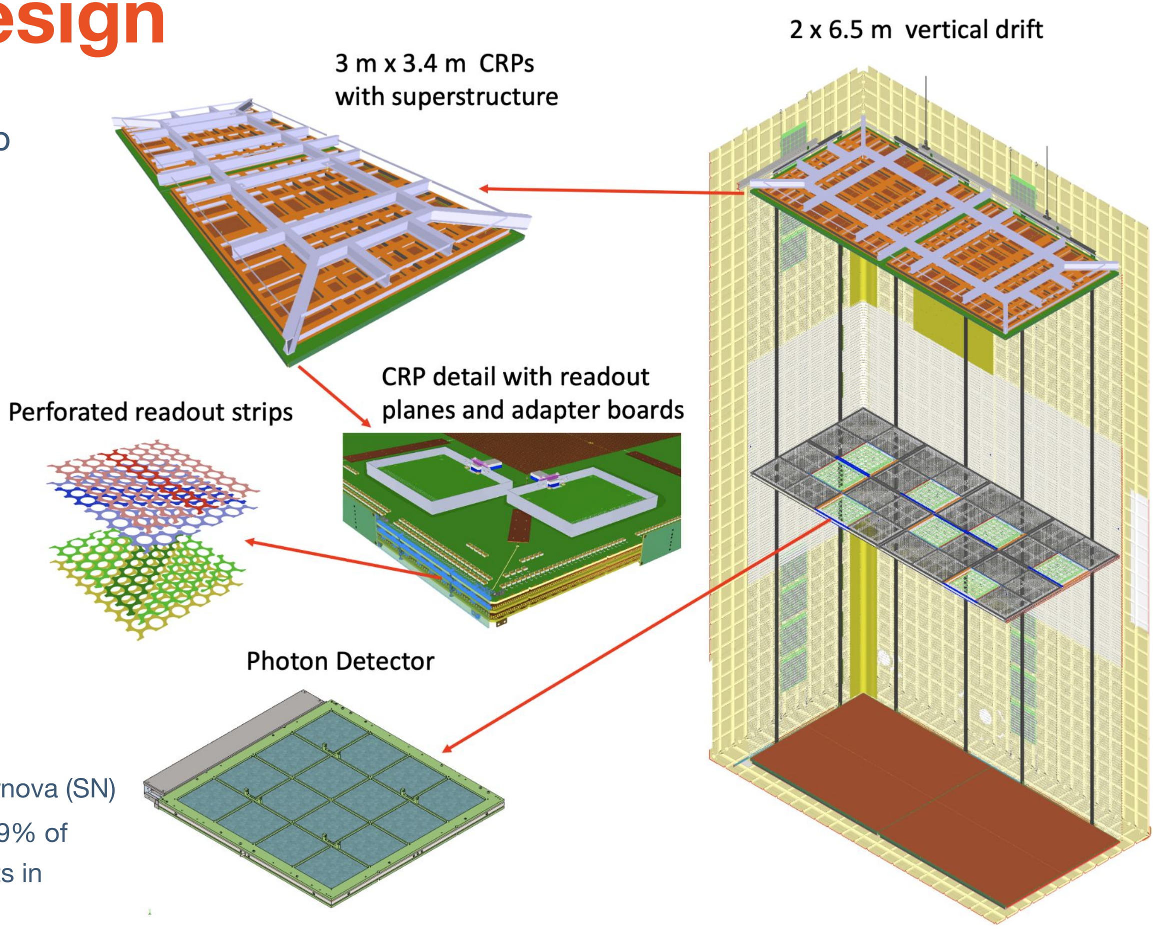


Diagram: Leïla Haegel

Three planes for disambiguation
External trigger or light: depth info
Max. e drift veloc.: 1.59 mm/μs

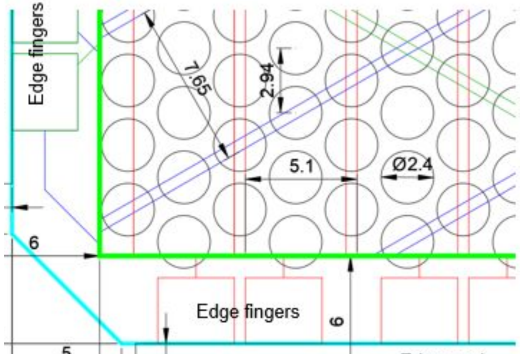
Vertical Drift (VD) design

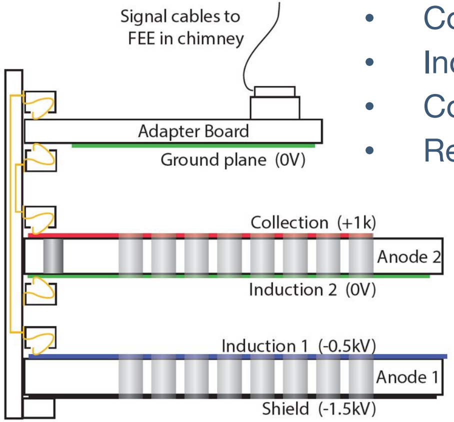
- Charge-readout planes (CRP) (anode) on top and bottom.
- Cathode in the middle at -300 kV
  - 6,5 m drift distance
- Photon detectors placed in the cathode
- Field cage transparency 70%
  - Photon detectors placed behind it, on the cryostat wall
- Requirement for photon detectors:
  - >20 PE/MeV (avg), gives PDS energy resolution comparable to that of the TPC for 5-7 MeV supernova (SN)
  - >0.5 PE/MeV (min) ν's, and allows tagging of > 99% of nucleon decay backgrounds with light at all points in detector.

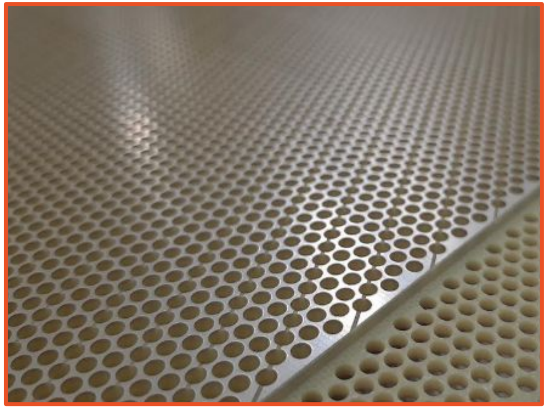


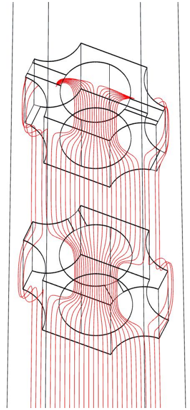
Charge Readout

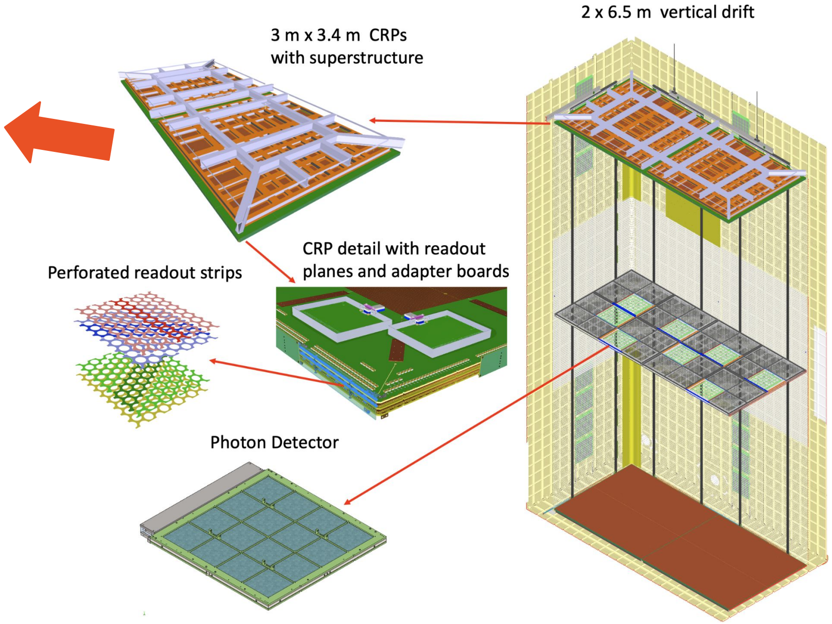
- Different bias in each Perforated Printed Circuit Boards (PCBs)
- Induced signal on the first two views
- Collection on the last view
- Induction view : 952 strips, pitch 7.65 mm, angle ±30°
- Collection view : 1168 strips, pitch 5.10 mm, angle 90°
- Readout channels per CRP: 3072





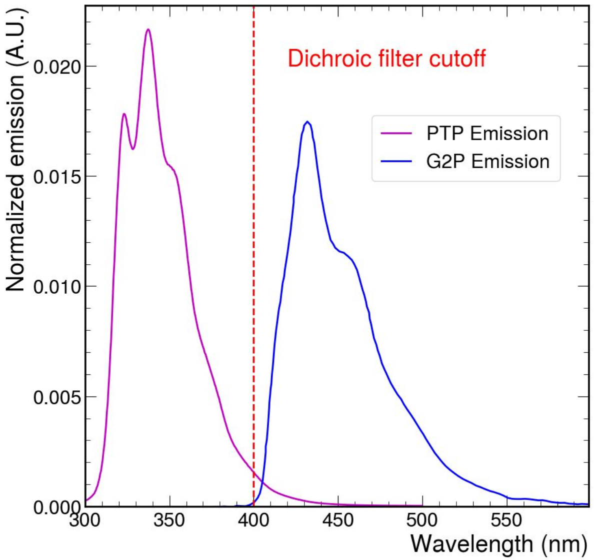


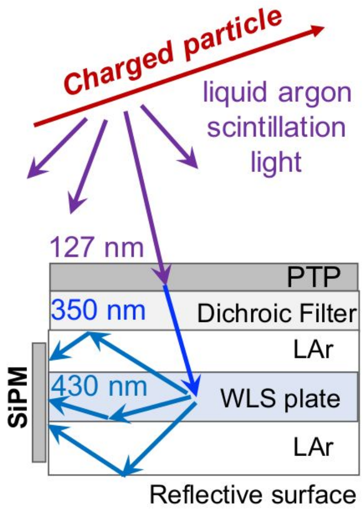


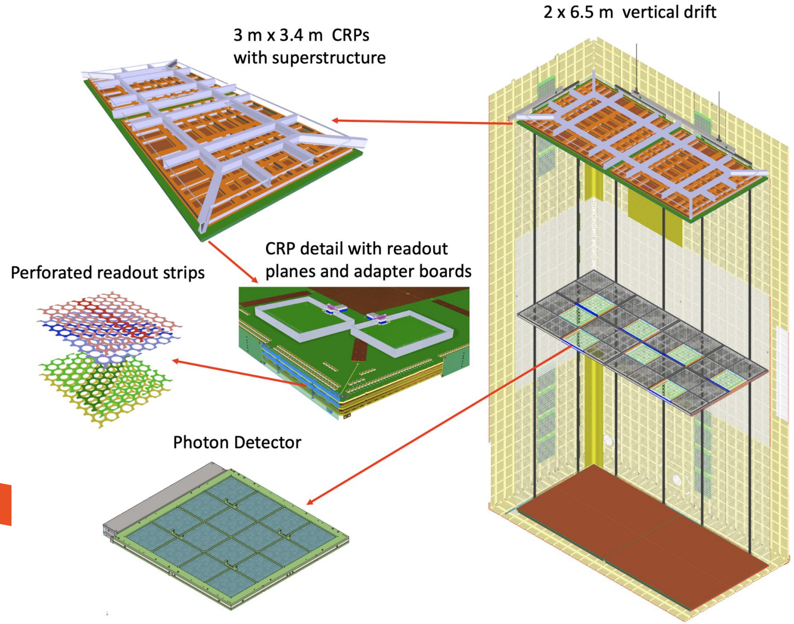


Photon detectors

- X-Arapucas, light trapping devices, are the photon detectors
- One module: 65x65 cm^2, 2x80 Silicon Photomultipliers (SiPMs), 1(2)x16 dichroic filters single-sided (double-sided)
- 4 modules per cathode unit

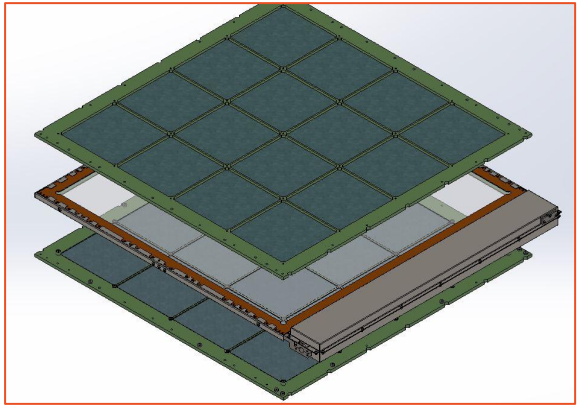


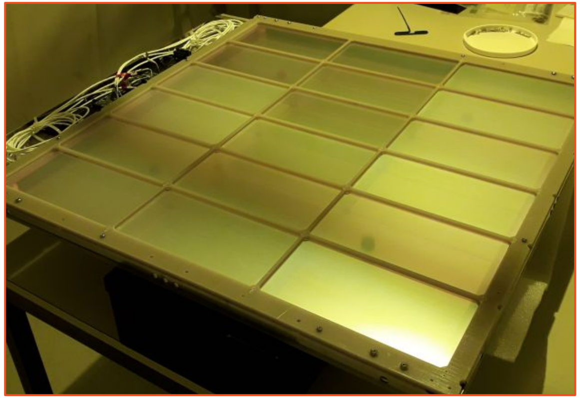


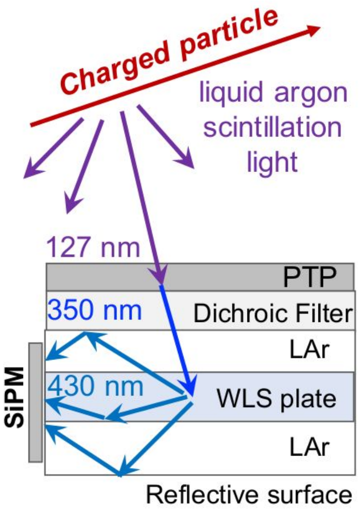


- Photons are "trapped" inside the X-Arapuca due to combination of two wavelength shifters and one dichroic filter

Photon detectors







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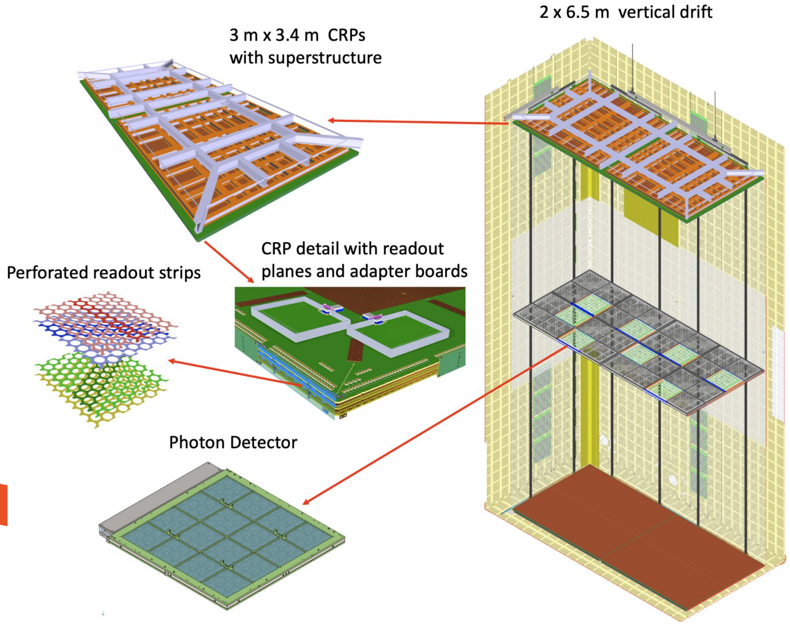
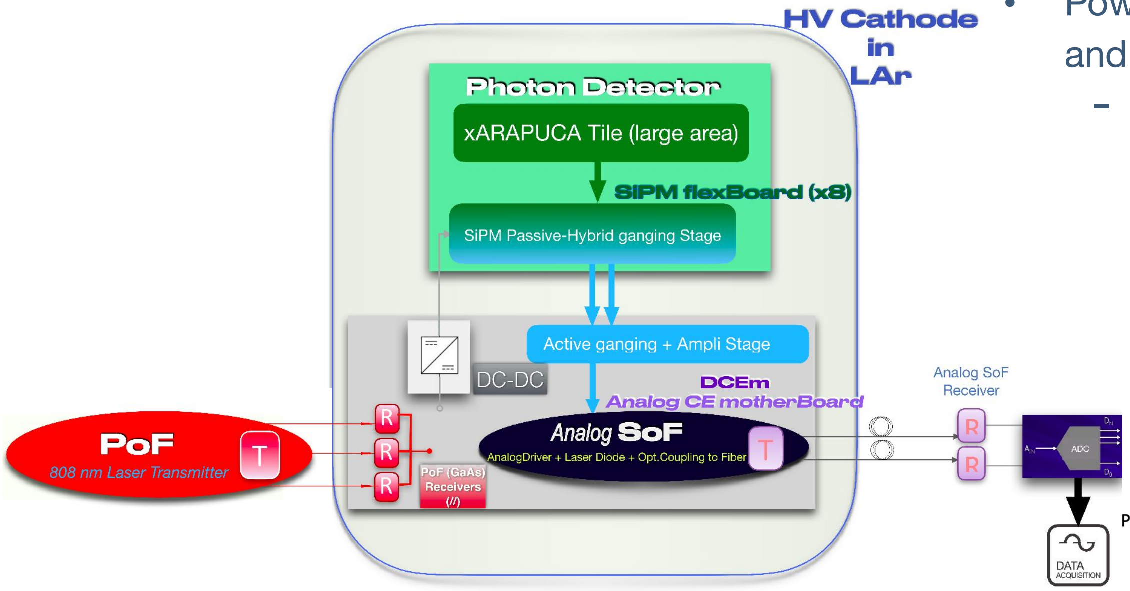
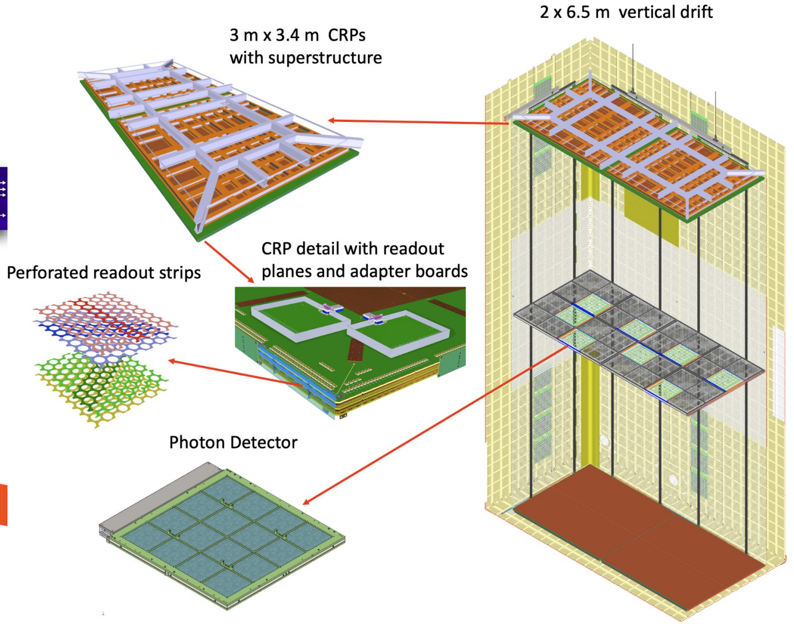
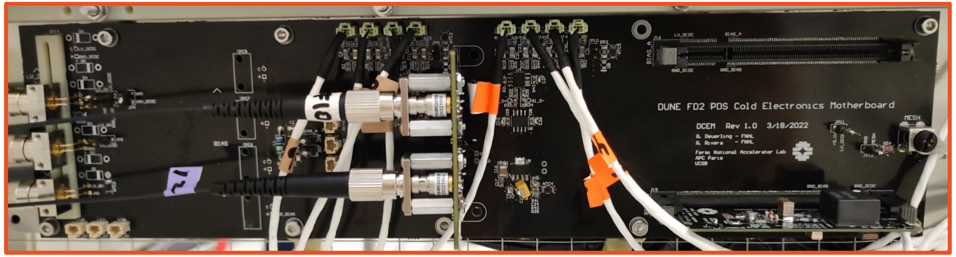


Photon detector readout



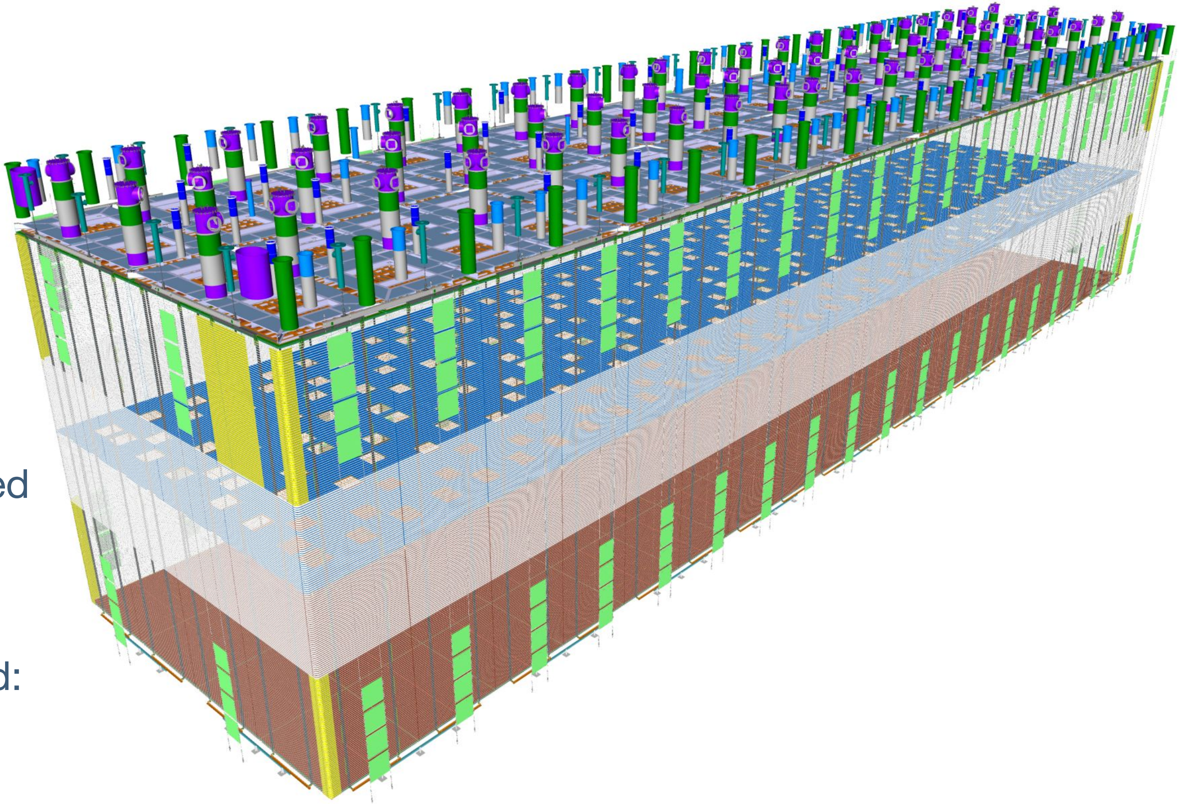
- Power and Signal over fiber are used for powering and analog readout of the PDS in the cathode
  - **Allows the operation of the PDS in a high voltage surface with non-conductive materials**



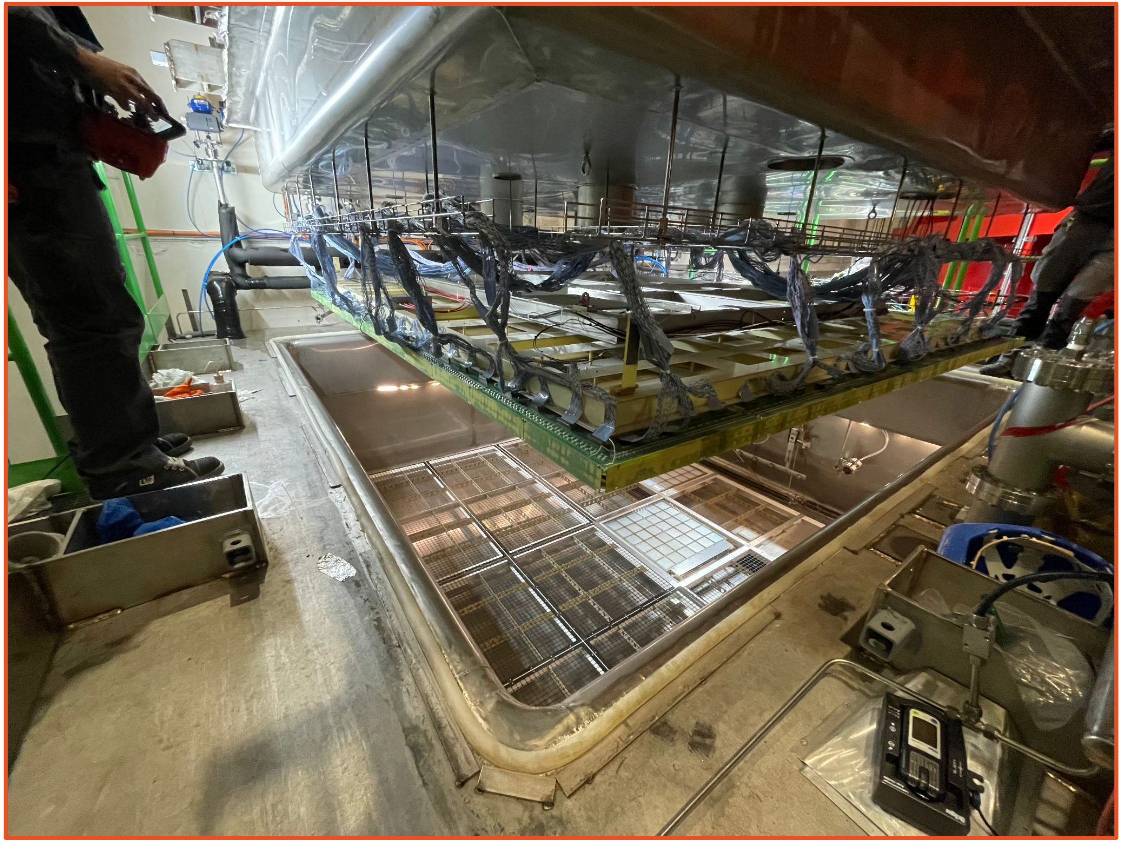


Vertical Drift (VD) overview

- Detector dimension:
  62 m x 15 m x 14 m
- Total of 160 CRPs (3 x 3.4 m^2):
  - 80 suspended at the top
  - 80 at the bottom
- Total 80 cathode units (3 x 3.4 m^2)
- Total of 320 X-Arapucas double sided
  - Integrated in the cathode
  - 13% optical coverage
- Total of 352 X-Arapucas single sided:
  - Behind the field cage onto the cryostat wall
  - 6.8% + 3% optical coverage



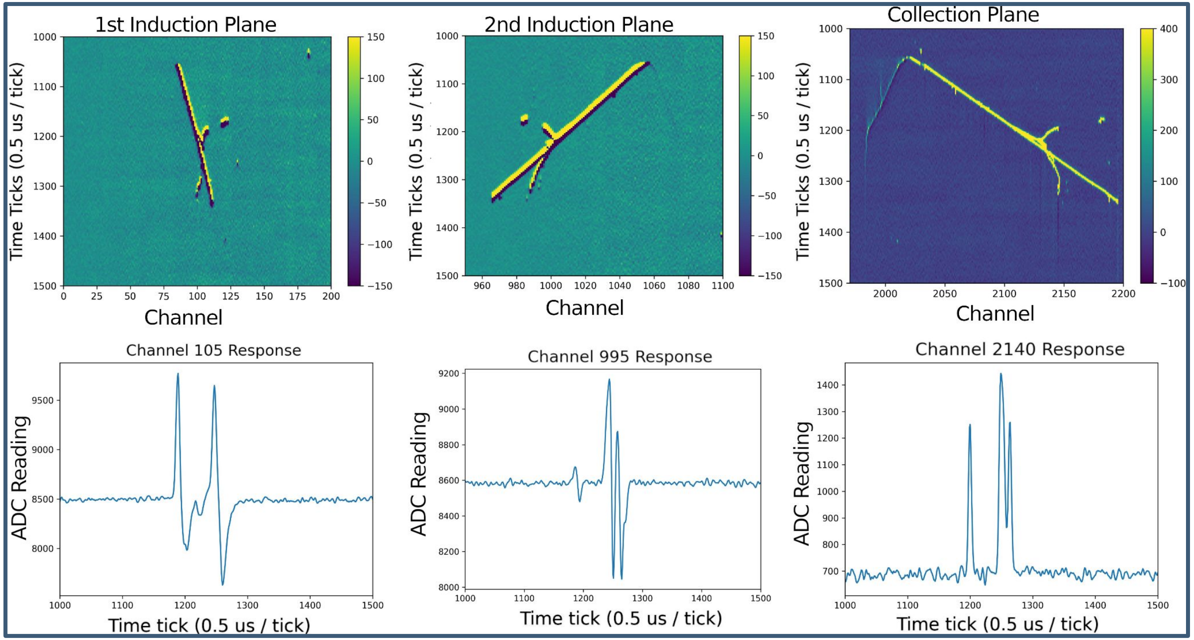
Tests in the VD-Coldbox



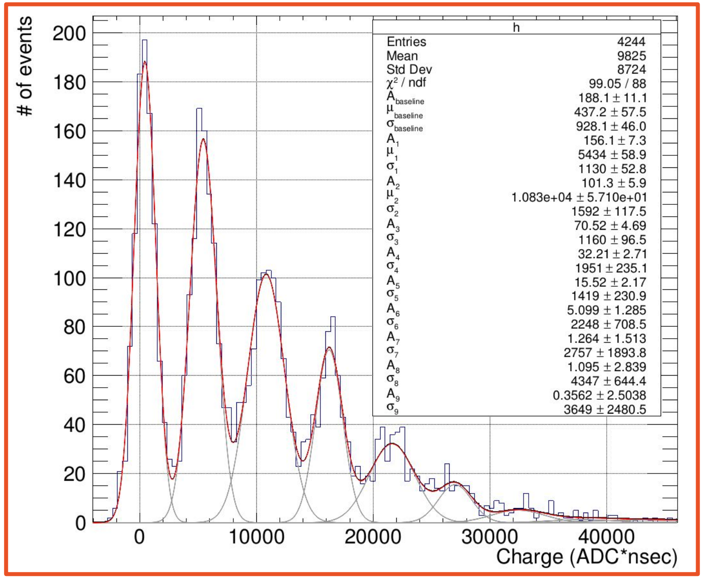
- Coldbox is a 3×3×1 m^3 cryostat for LAr tests conducted at CERN Neutrino Platform
- Drift distance of 23 cm, with cathode placed on the bottom and CRP on the top
- Tests from November 2021 to May 2023 (over >10 different runs)
- Goal of testing and validation of different systems

Tests in the VD-Coldbox

CRP



- Five different CRPs tested.
  - Operation at 11 kV (~480 V/cm) shows expected behaviour of charge signals.
  - Less than 1% of channels failure

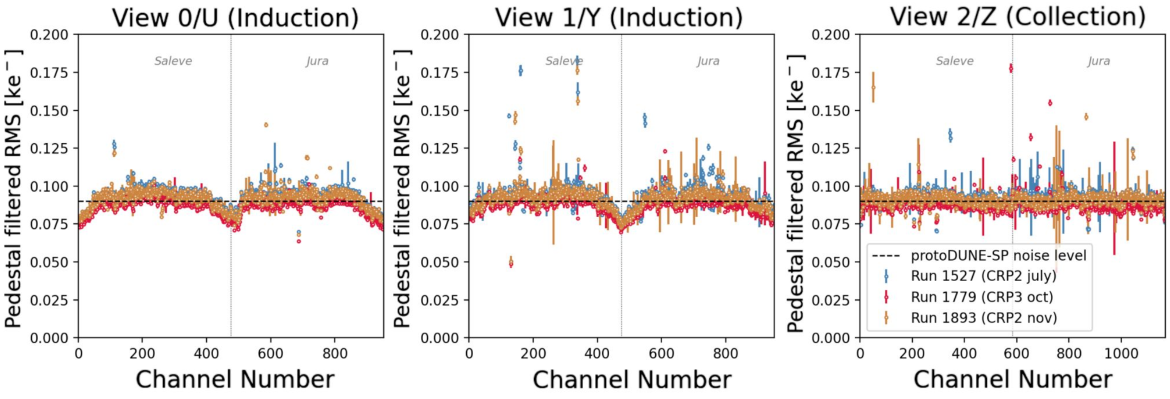


- Stable operation of PDS in a high voltage surface
- Signal-to-noise > 4 reached

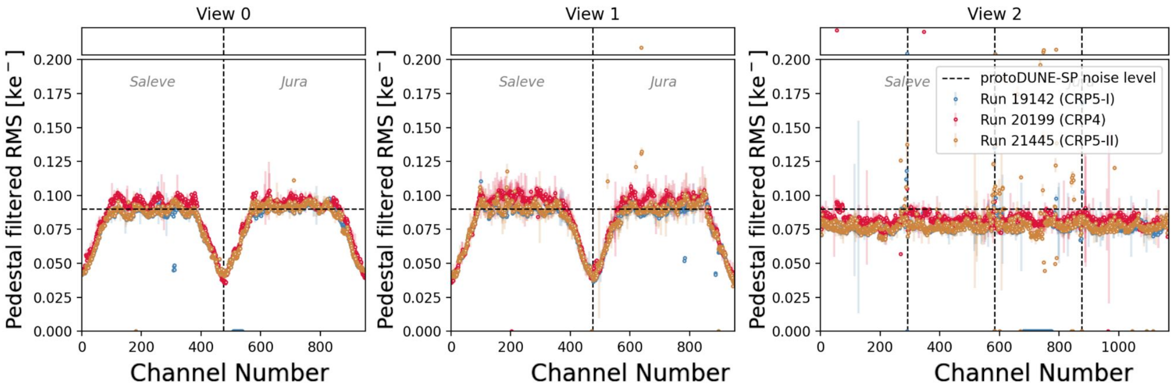
PDS

Tests in the VD-Coldbox

Top CRP



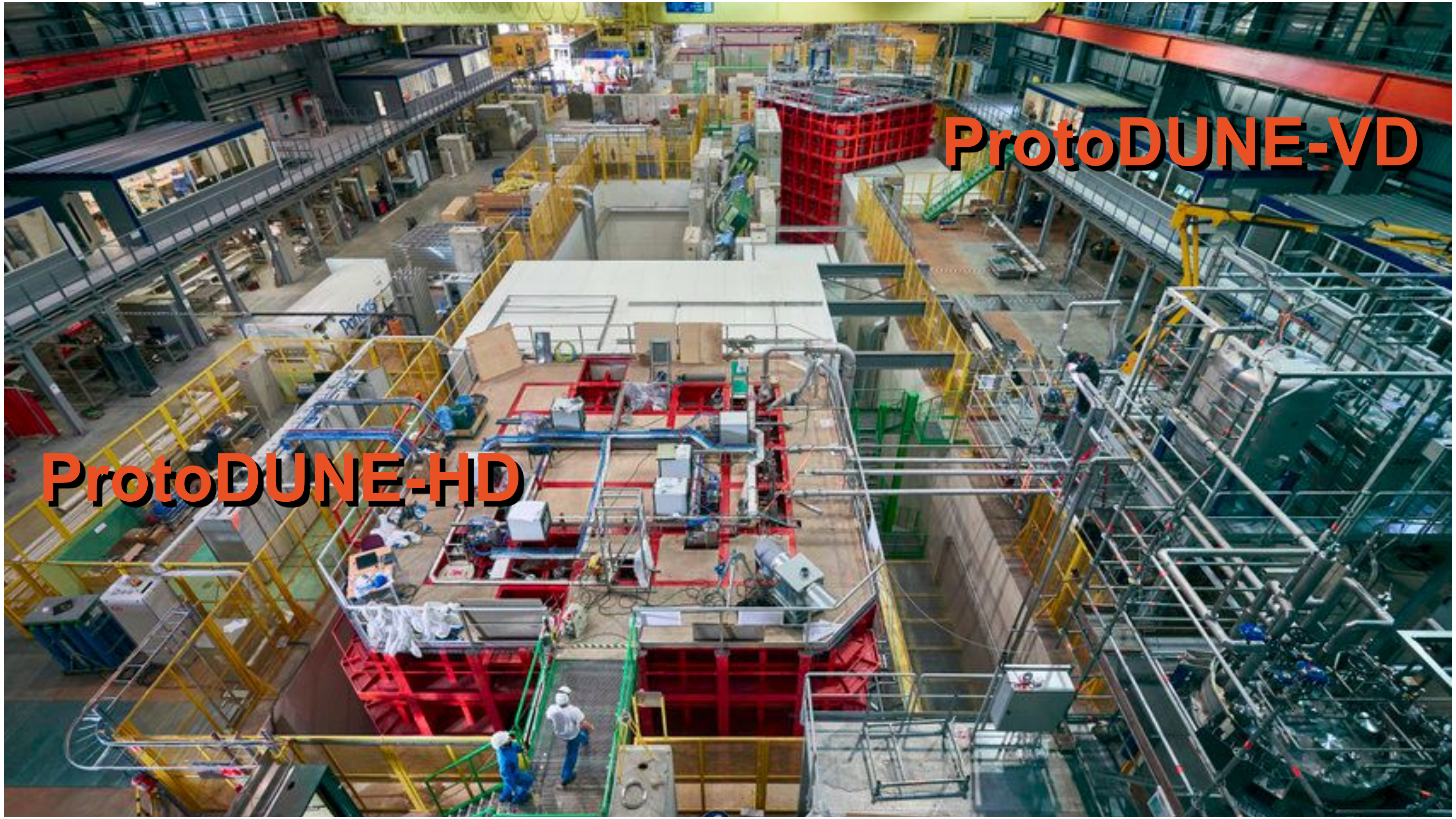
Bottom CRP



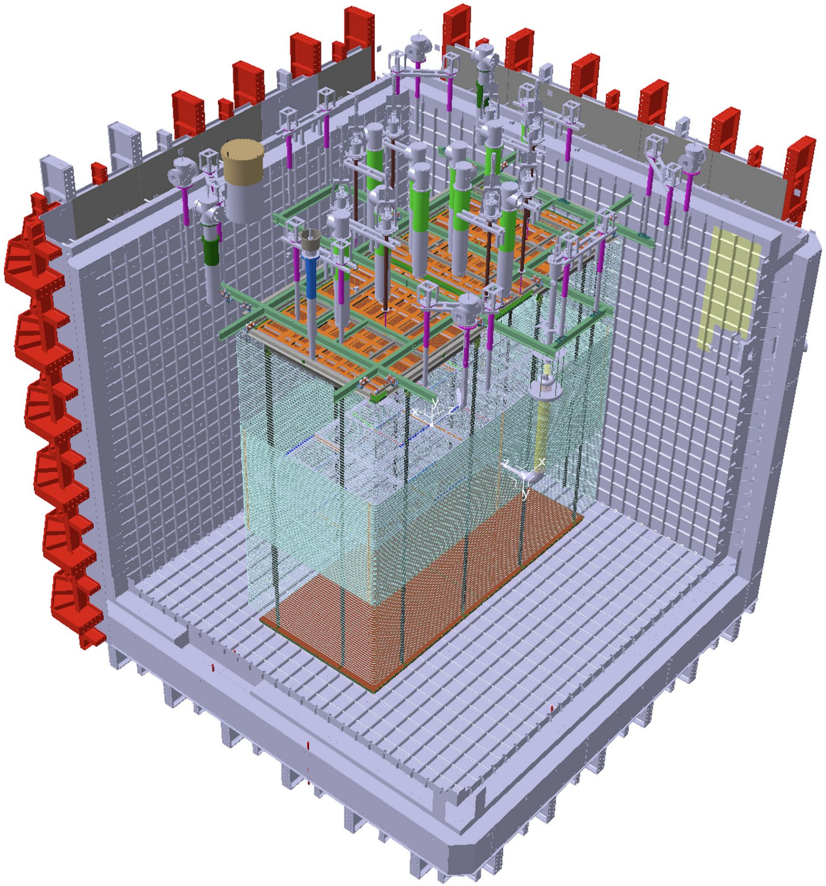
- Bridge-shape due to the noise being proportional to the strip length
- Equivalent amount of noise for Top and Bottom CRP, at the same level of protoDUNE-SP

From: Laura Zambell, NuFACT2023

ProtoDUNE VD



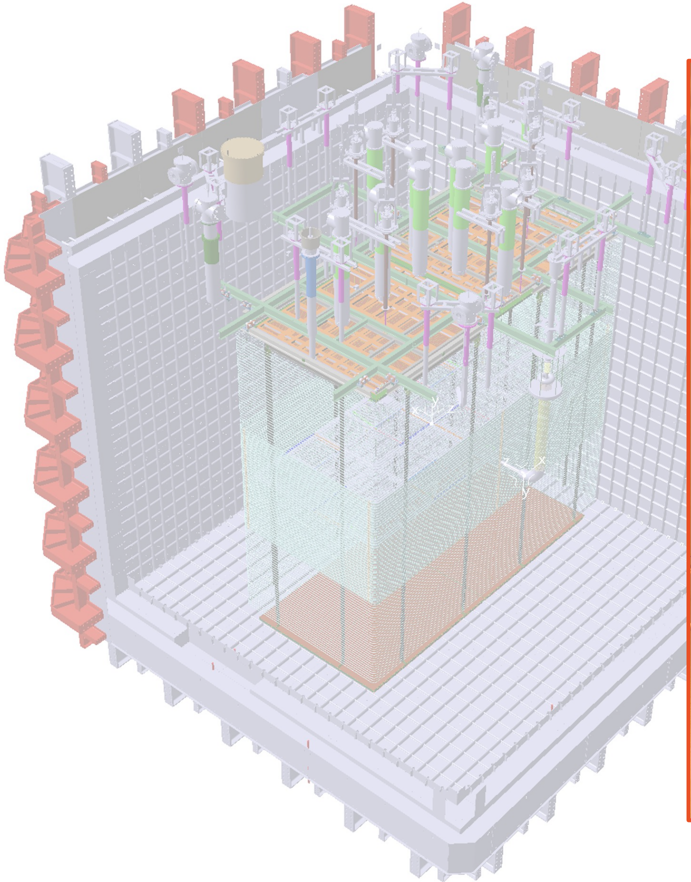
ProtoDUNE VD



- Large-scale test of the Vertical Drift design in the NP02 cryostat in the Neutrino Platform at CERN
- Active volume: 3 × 6.8 × 7 m^2
  - 2 CRPs top
  - 2 CRPs bottom
  - 2 Cathode modules
    - Operated at -175 kV
  - 8 X-Arapucas double-sided
  - 8 X-Arapucas single-sided
- Goals:
  - Demonstrate the high-level complete functional system integration of all FD2-VD components
  - Acquisition with Cosmic muons and Beam

ProtoDUNE VD

Installation completed, operation planned for 2024



Top volume

Bottom volume

Conclusions

- Vertical Drift technology has evolved rapidly since the 2020, huge development for
  - Field cage, cathode, anodes, cryogenic instrumentations, etc…
  - DAQ and event reconstructions

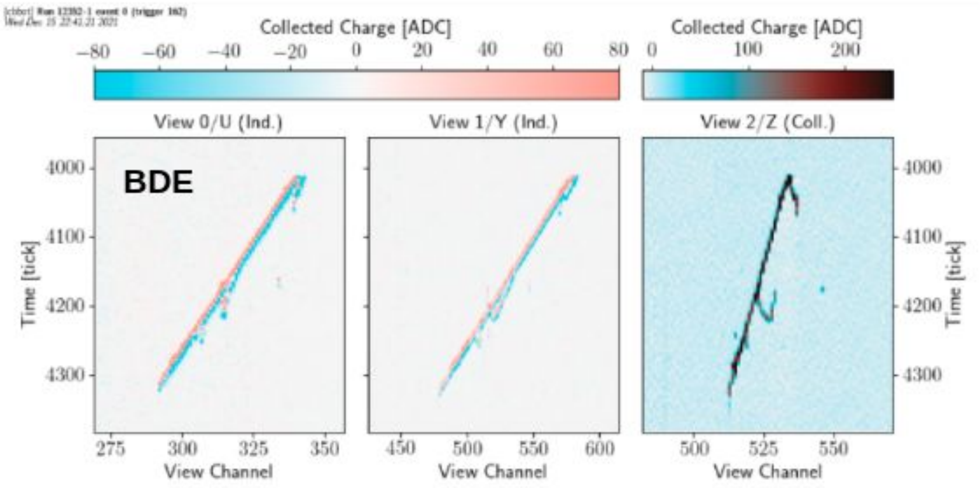
- Successful and promising results from charge and light readout when tested in the ColdBox

- The Vertical Drift LArTPC design will be tested at large scale in ProtoDUNE-VD with cosmics and beam data

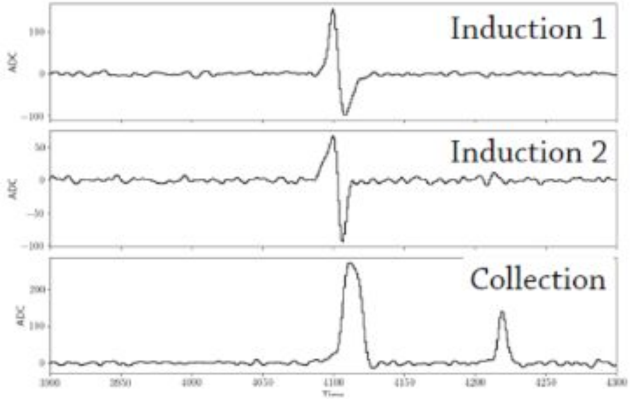
- Liquid Argon filling will occur during 2024

Thanks :)

Backup

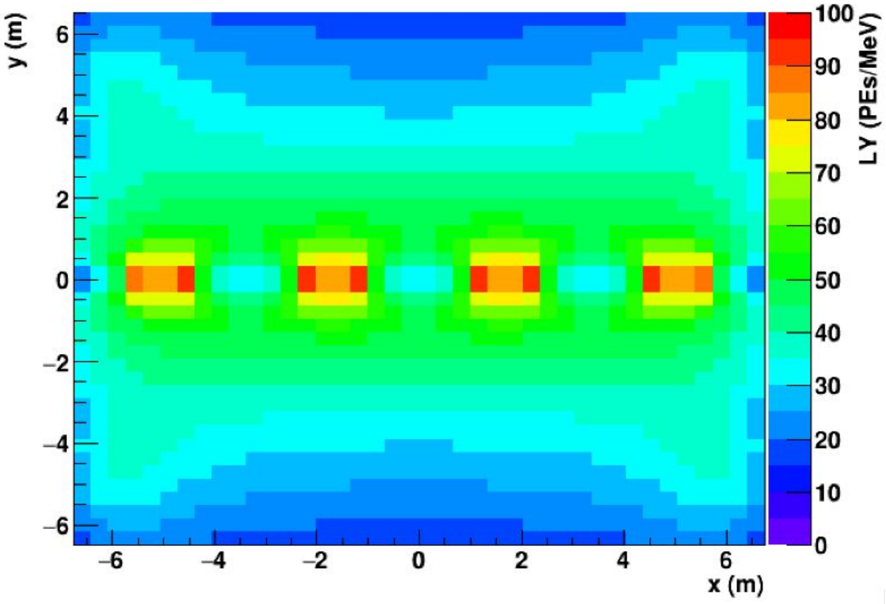


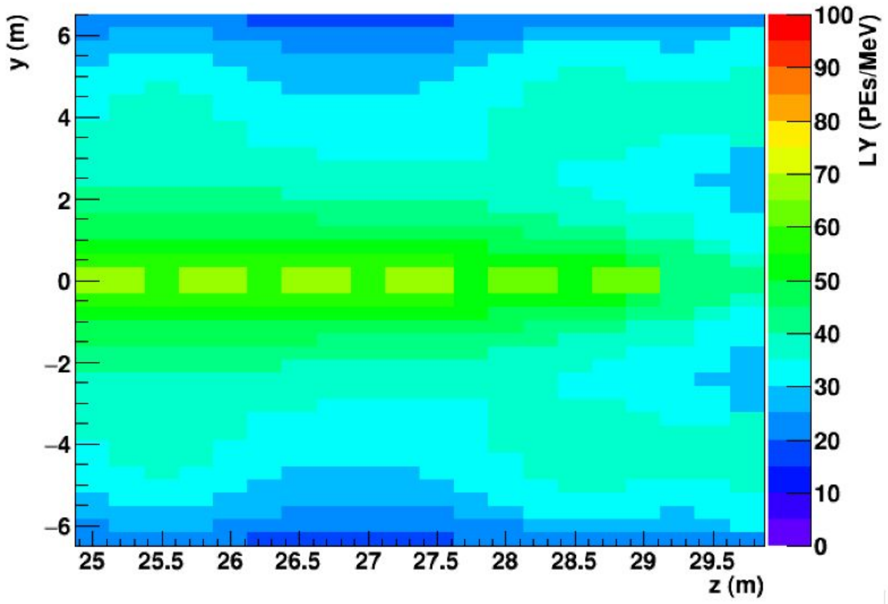
Collected Charge [ADC]
−80 −60 −40 −20 0 20 40 60 80
Collected Charge [ADC]
0 100 200
View 0/U (Ind.)
View 1/Y (Ind.)
View 2/Z (Coll.)
BDE
4000
4100
4200
4300
Time [tick]
275 300 325 350
450 500 550 600
500 525 550
View Channel



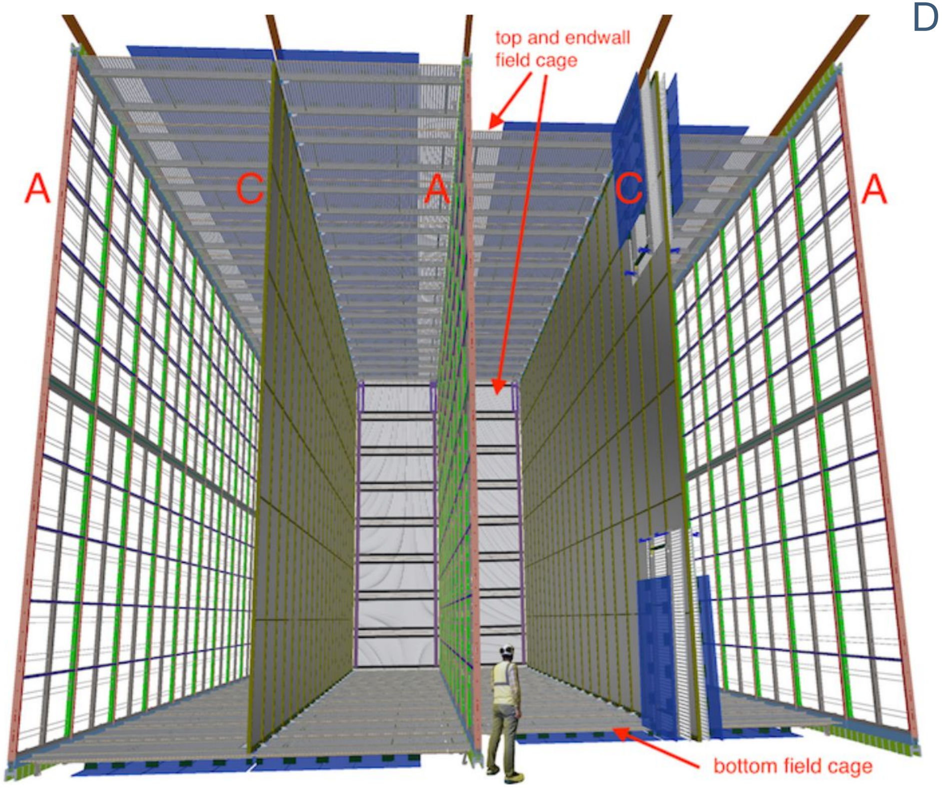
Induction 1
Induction 2
Collection

Backup


y (m)
6
4
2
0
−2
−4
−6
−6
−4
−2
0
2
4
6
x (m)
100
90
80
70
60
50
40
30
20
10
0
LY (PEs/MeV)

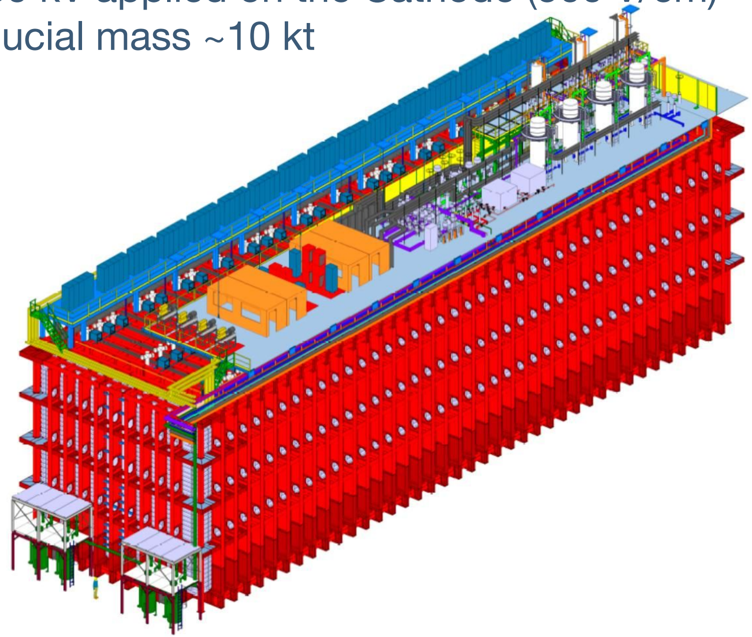

y (m)
6
4
2
0
−2
−4
−6
25
25.5
26
26.5
27
27.5
28
28.5
29
29.5
z (m)
100
90
80
70
60
50
40
30
20
10
0
LY (PEs/MeV)

LArTPC: Horizontal Drift (HD) module



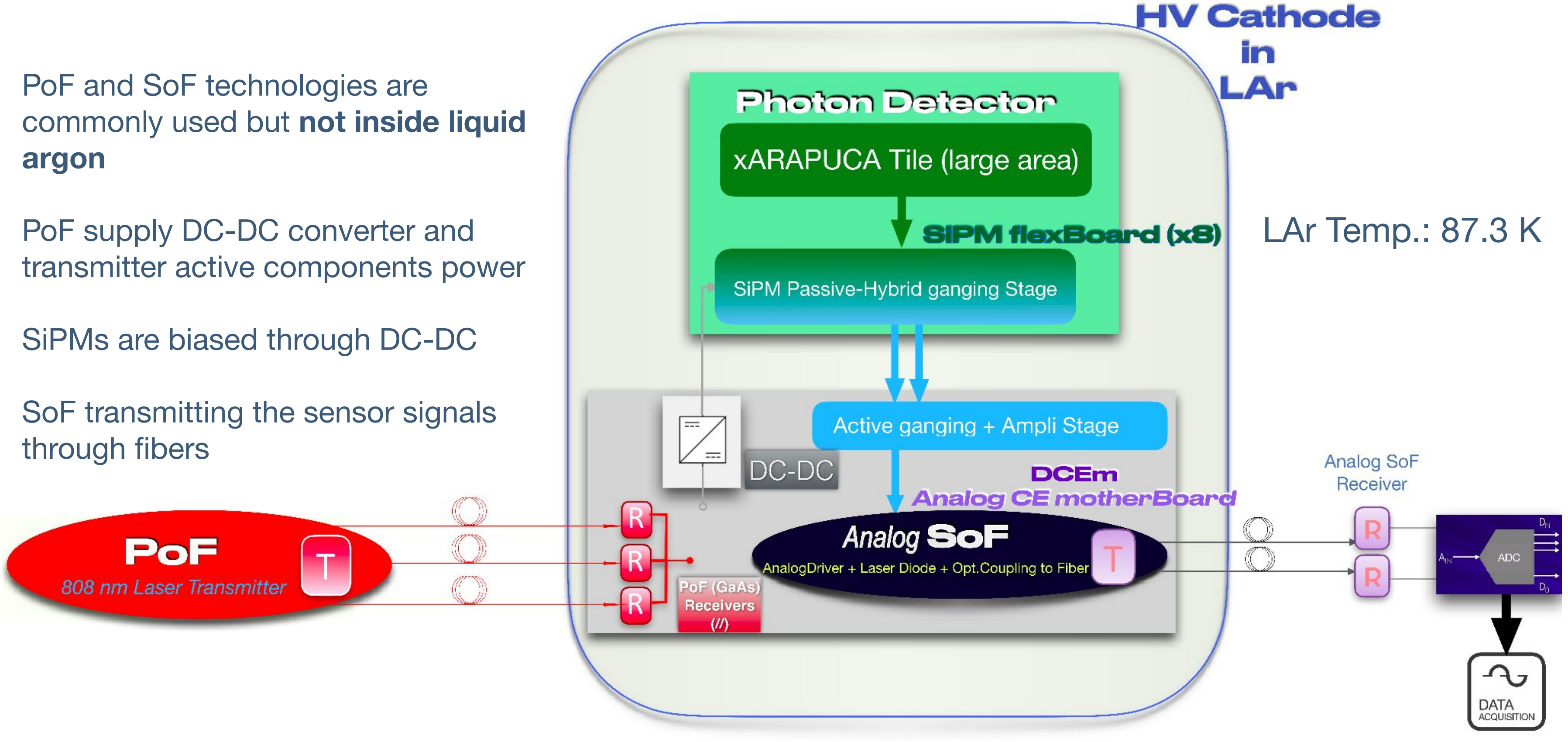
DUNE HD FD module:

- 12.0 m ×14.0 m × 58.2 m
- 3.5 m drift distance
- -180 kV applied on the Cathode (500 V/cm)
- Fiducial mass ~10 kt



PDS: Power and Signal over Fiber

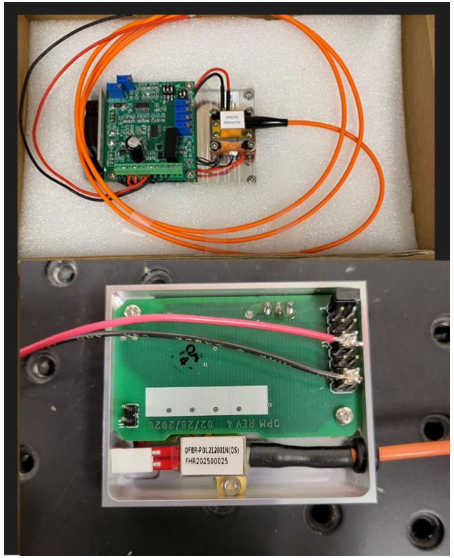
- PoF and SoF technologies are commonly used but **not inside liquid argon**
- PoF supply DC-DC converter and transmitter active components power
- SiPMs are biased through DC-DC
- SoF transmitting the sensor signals through fibers



Power over fiber

Low voltage (5 V) and high current PoF for DC-DC converter, OpAmps and other active analog electronics components.

Three receivers in parallel with efficiency >65%



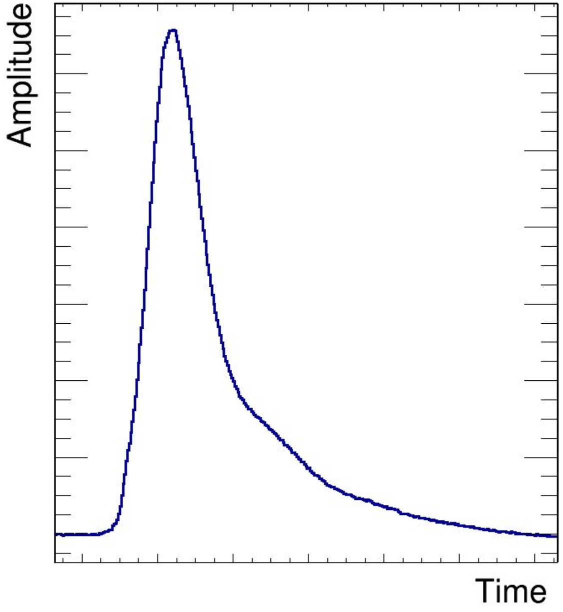
Multimode fiber with FC connector

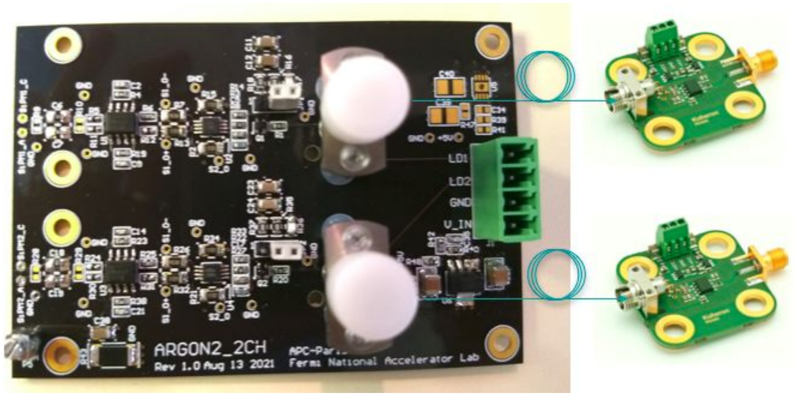
PoF transmitter
806 nm 3 W laser

PoF Receiver
Gallium arsenide (GaAs)
Photovoltaic Power Converter (PPC) on heatsink

Signal over fiber

- **Board requirements**
  Efficiently transmit **single photo-electron** signals (also the signals from LAr scintillation, but this is mostly limited by the dynamic range)





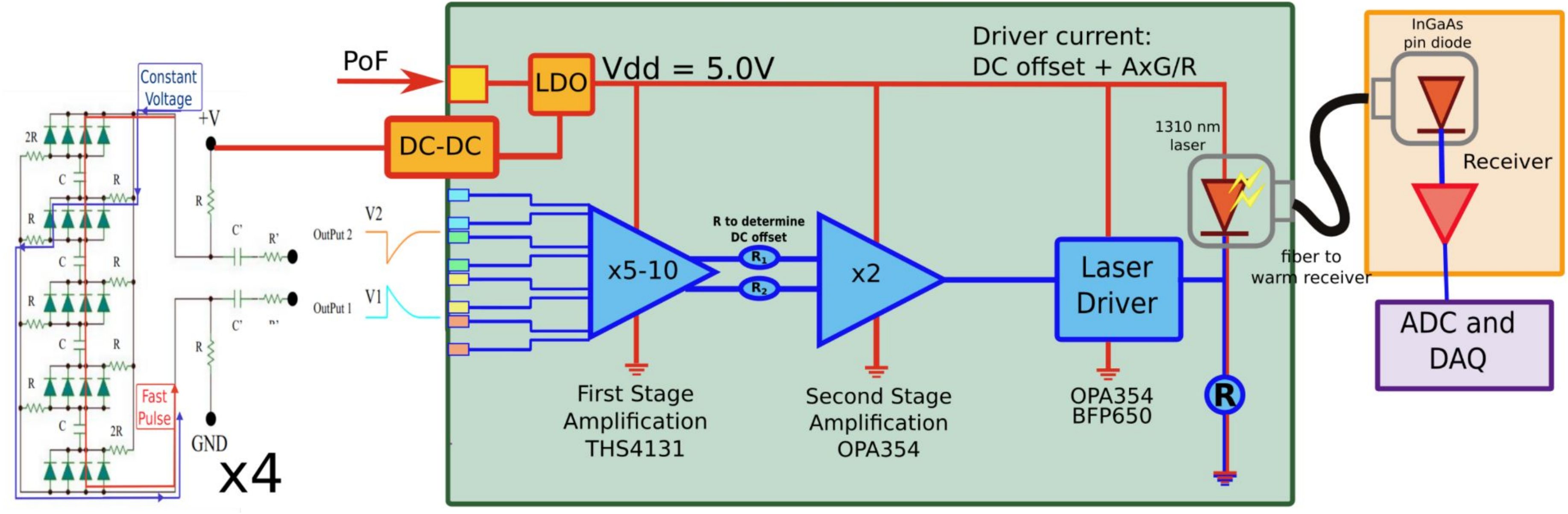
First prototype

Amplitude ~ 50 - 100 μV
Rise time ~ 20 to 80 ns
Discharge time constant ~ 100 to 300 ns

Bandwidth ~ 30 MHz
Signal-to-noise ratio > 4
Dynamic range ~ 1000 photo-electrons

Signal over fiber

- DCem board (2 channels/board)
  - Fabry Perot 1310 nm lasers FC connector
  - Voltage gain ~x20 to x40
  - Laser optical power output ≲ 2 mW
  - Integrated Photovoltaic Power Converter (PPC)
  - Integrated DC-DC converter
  - NTC resistor to enable warm and cold operation
  - Low-Drop Out Voltage Regulator (LDO)



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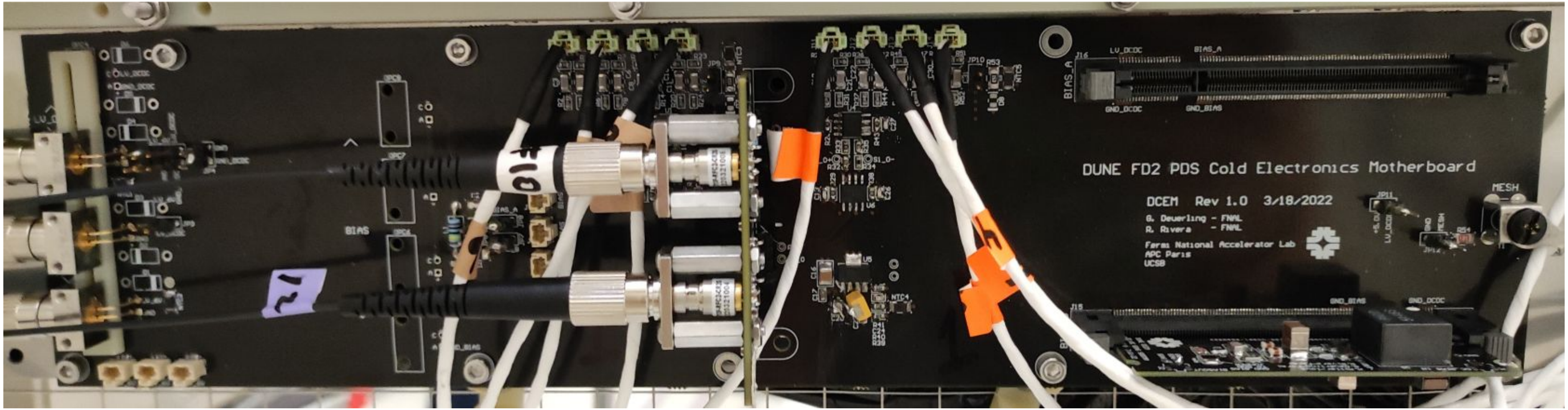
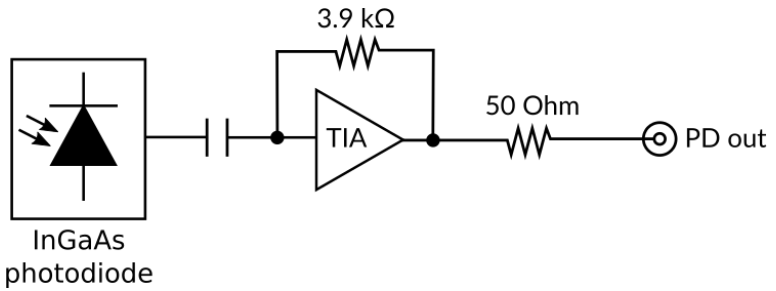
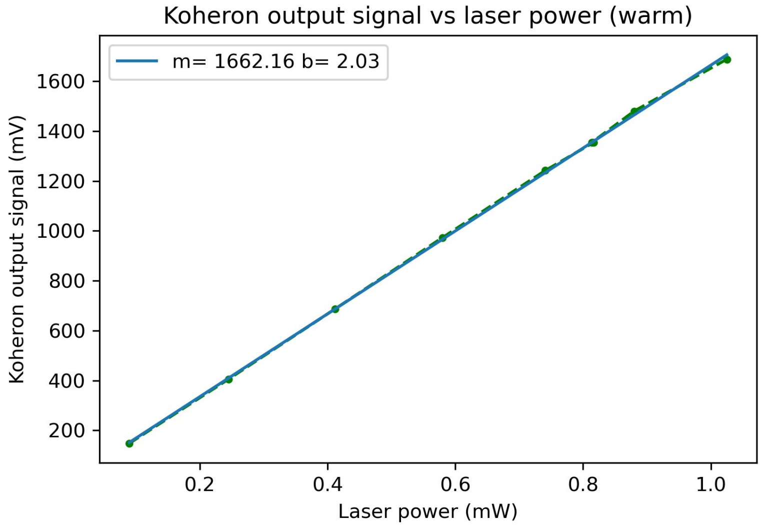


Signal over fiber

Koheron PD100 low noise photodiode

- single channel commercial solution - found early 2021
- Indium gallium arsenide (InGaAs) photodiode
- DC-coupled
- 0.9 A/W - 3.9 kV/A amplification
- 600 μW maximum input at 100 MHz
- ± 6V bias, ~40mA





PoF and SoF operation

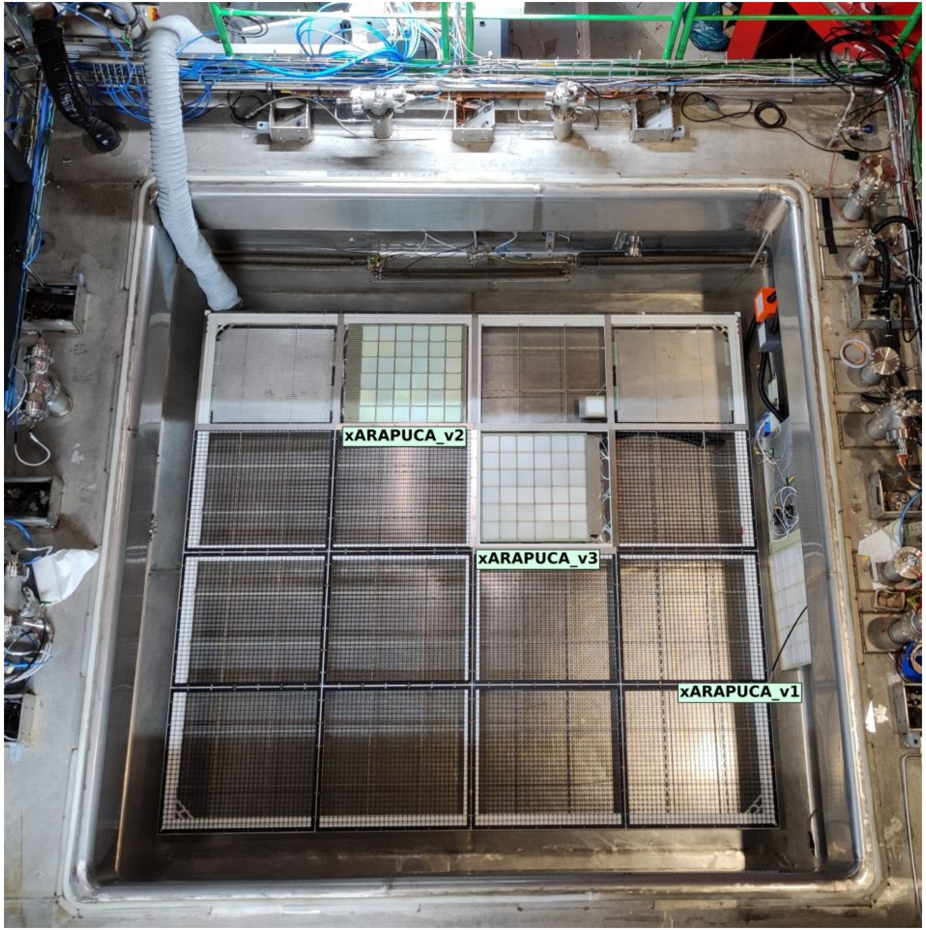
CERN Neutrino Platform **coldbox**:

3×3×1 m^3 cryostat for LAr tests

Cathode placed on feet, TPC is mounted on the coldbox cover (23 cm drift distance)

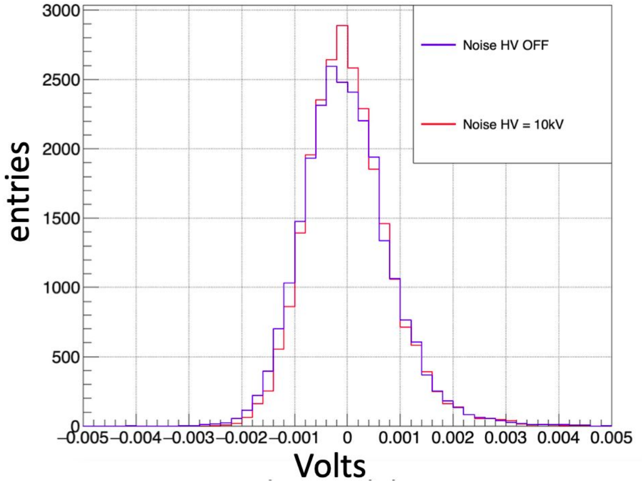
Target: operation of PDS system in LAr

PD with signal and power transmission through fiber, operating on an HV surface



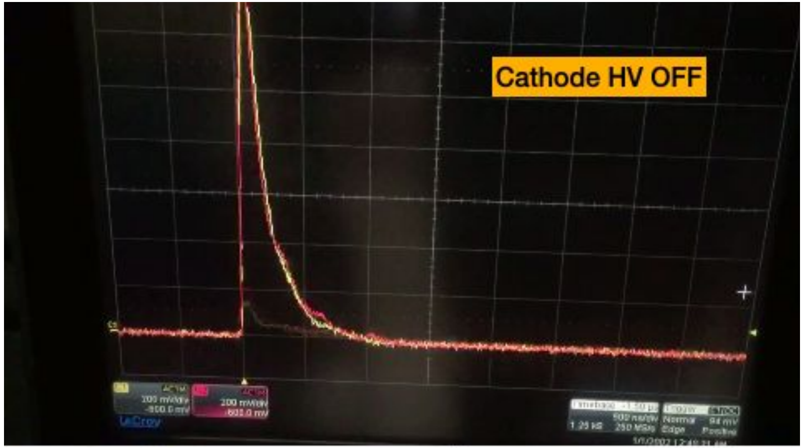
PoF and SoF operation

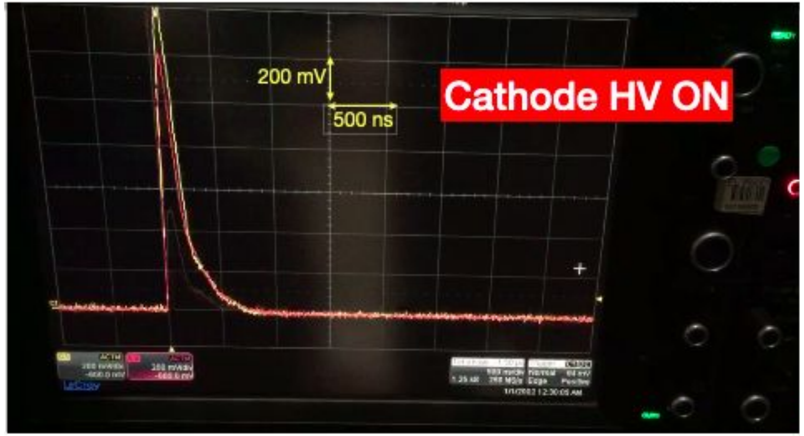
- Photon Detection System principle successfully demonstrated
  - Power and readout done through fiber only at liquid argon
  - Operation stable with High Voltage on and off
  - No interference in the TPC performance



HV OFF:
Mean = -0.05 mV
Sigma =0.77 mV

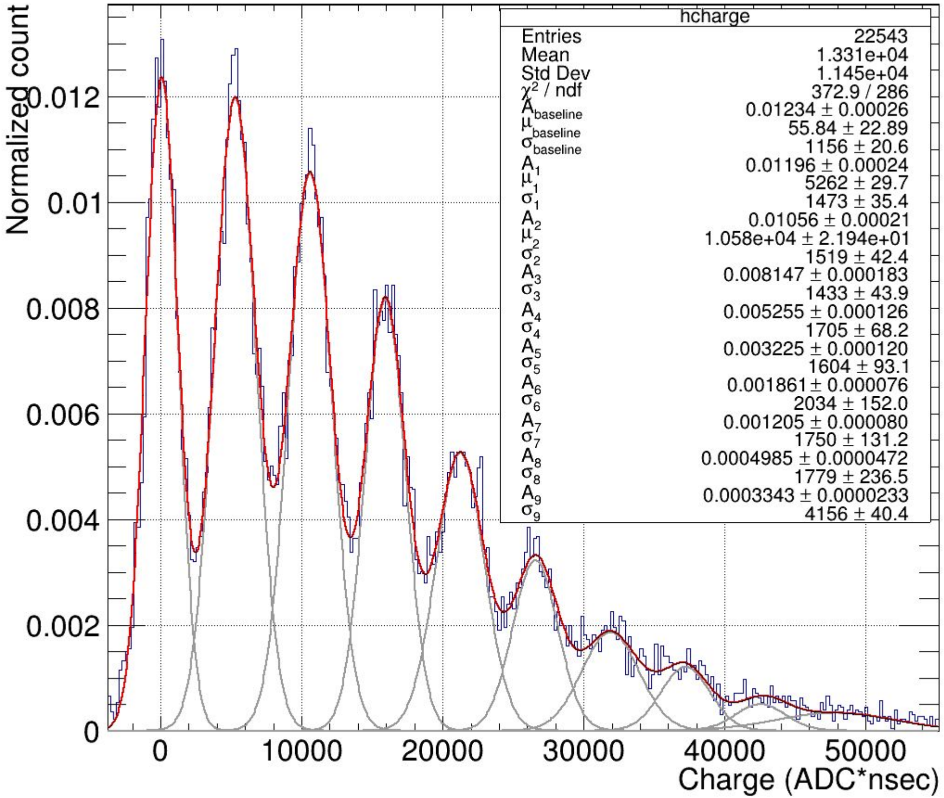
HV = 10 kV
Mean =-0.02 mV
Sigma=0.71 mV





SoF operation

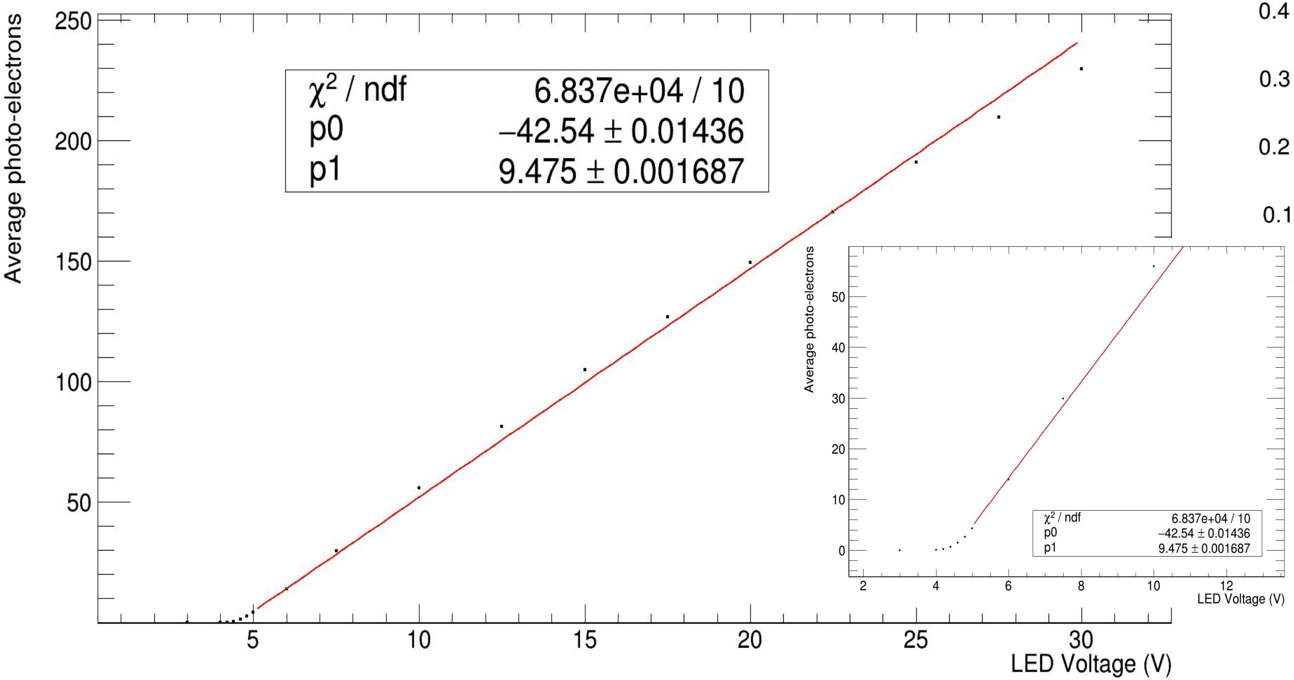
- LED flashes also made possible for single photo-electron calibration

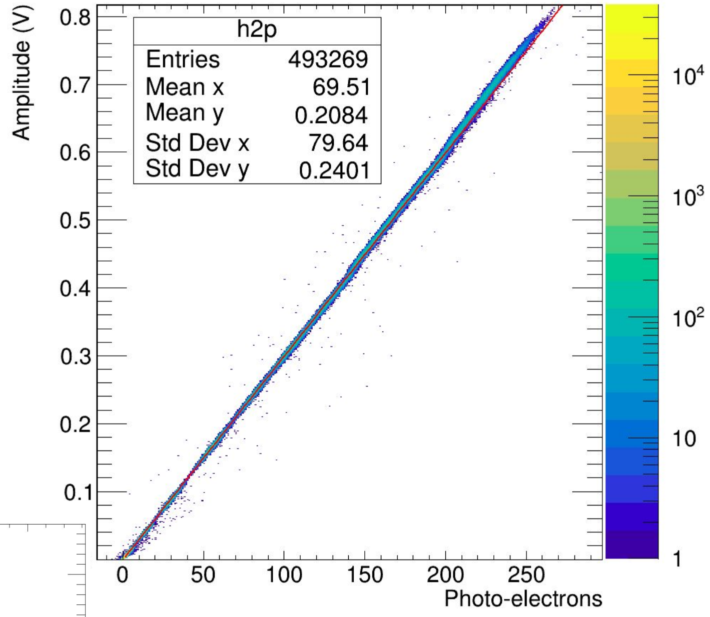


- Arapuca detector in the LArTPC membrane
- 20 SiPMs hybrid ganged
- Bias through copper (37V)
- Argon2x2 board (namely A1)
- Signal-to-noise ratio ~ 4.9

PoF and SoF operation

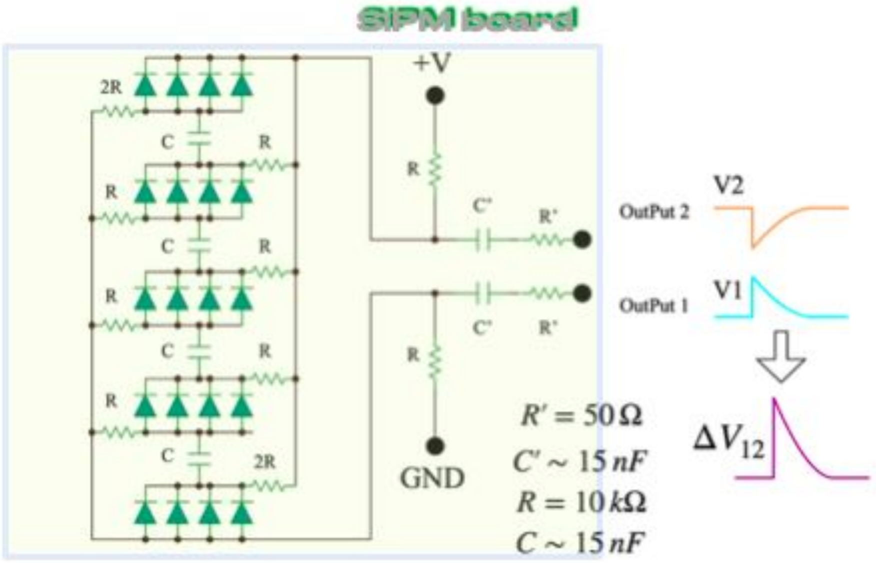
- Full chain linearity up to ~ 250 – 300 PE using LED calibration light

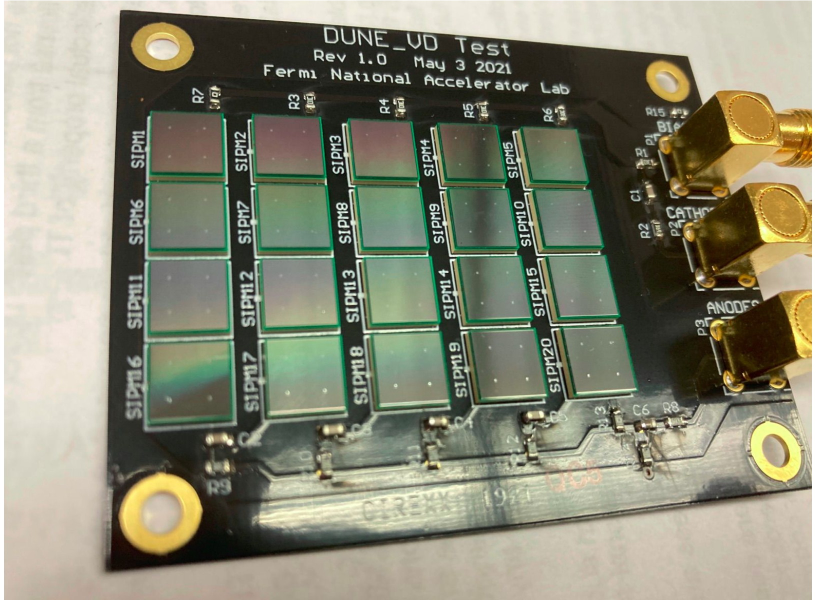




- Light output regulated through voltage (up to 30V) or pulse width
- SPE charge 0.3 Vns (measured)

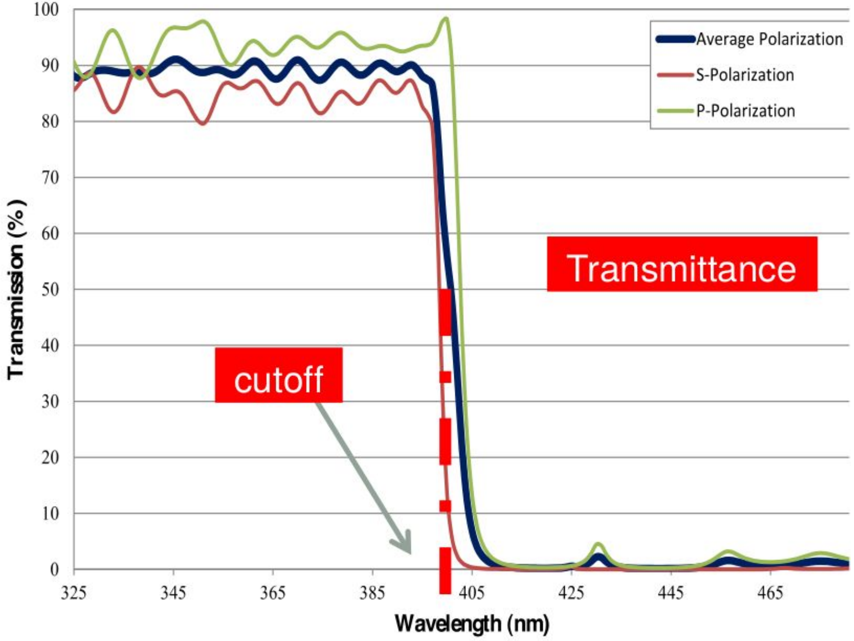
Backup slides

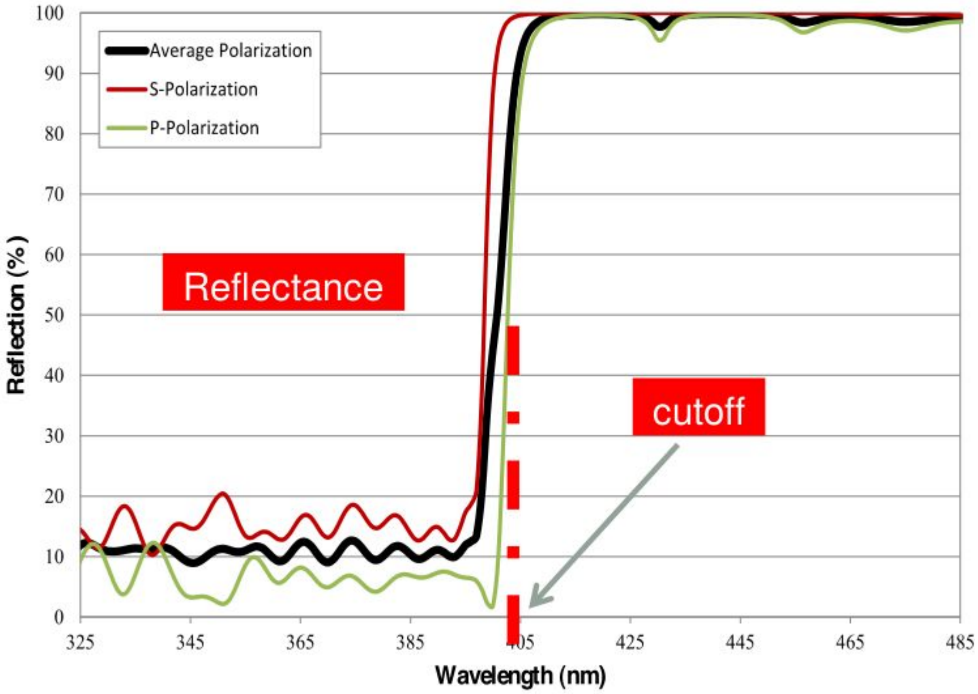




Backup slides

X-Arapuca



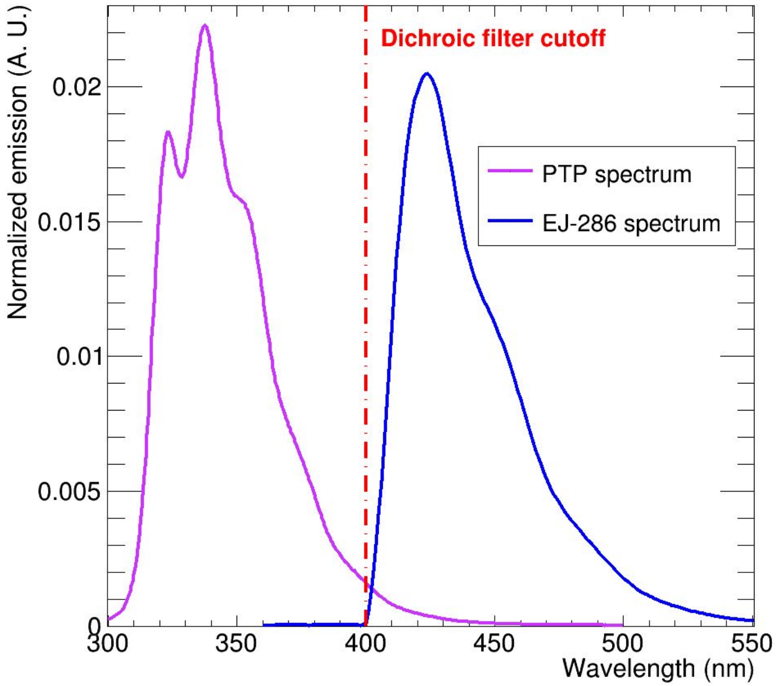


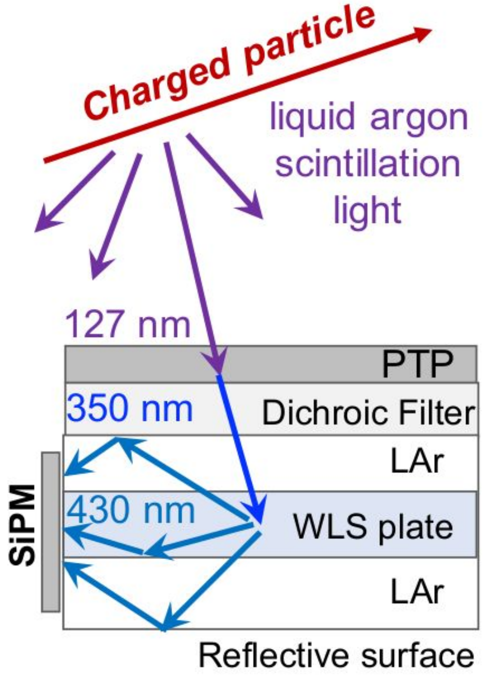
The device makes use of a dichroic filter in combination with two wavelength shifters (WLS)

Backup slides

PTP → p-Terphenyl
SiPM → Silicon photomultiplier

X-Arapuca

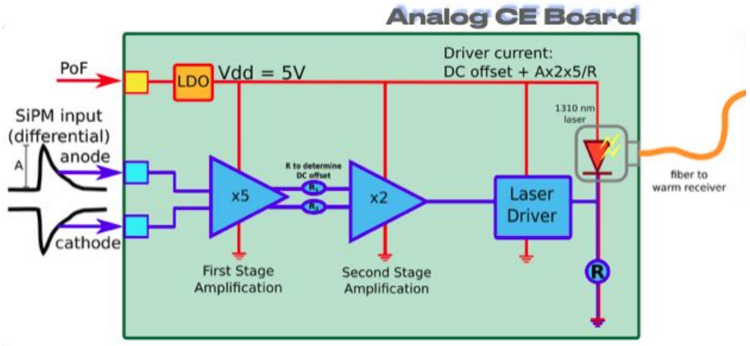


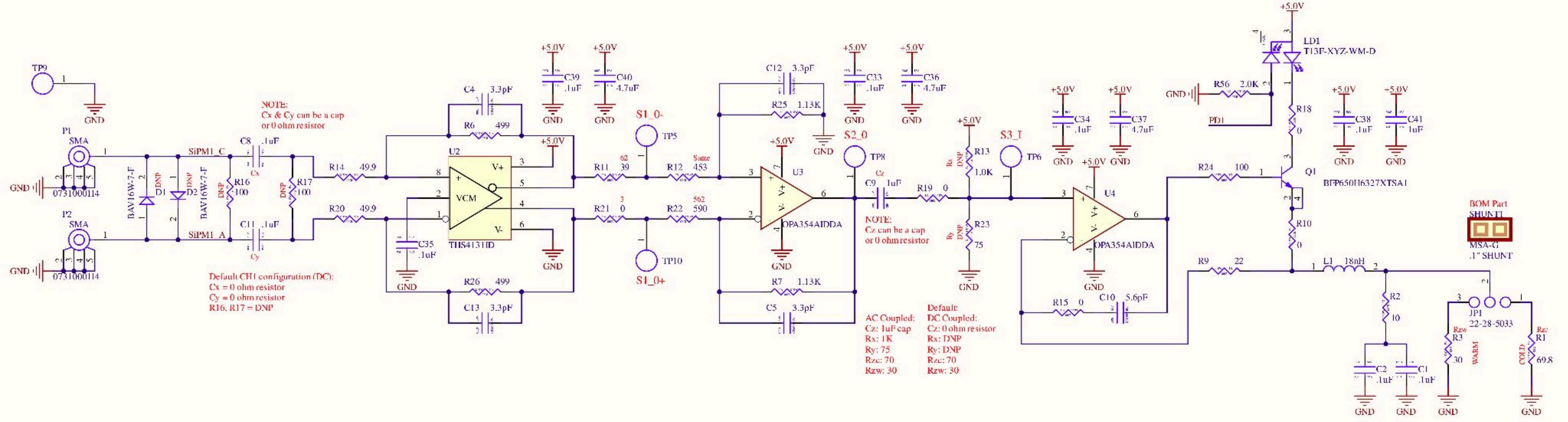


The device makes use of a dichroic filter in combination with two wavelength shifters (WLS)

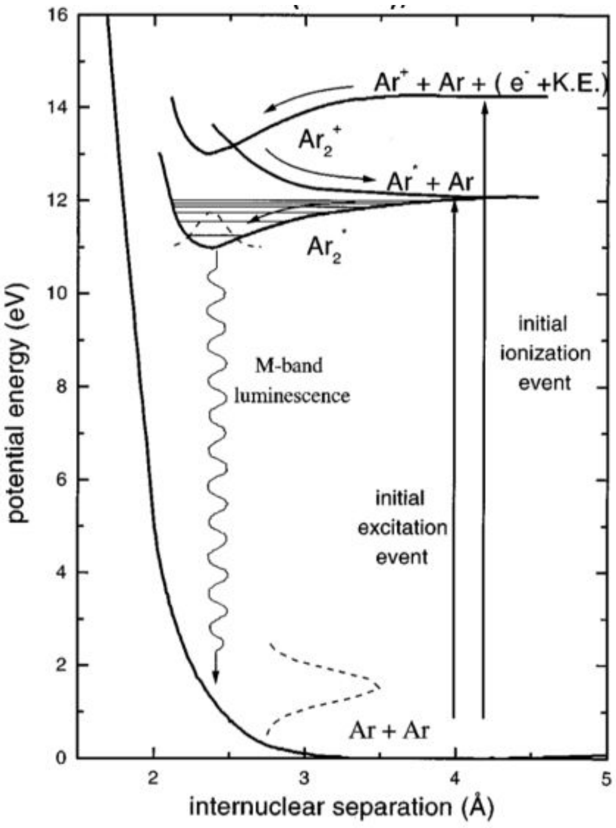
Backup slides

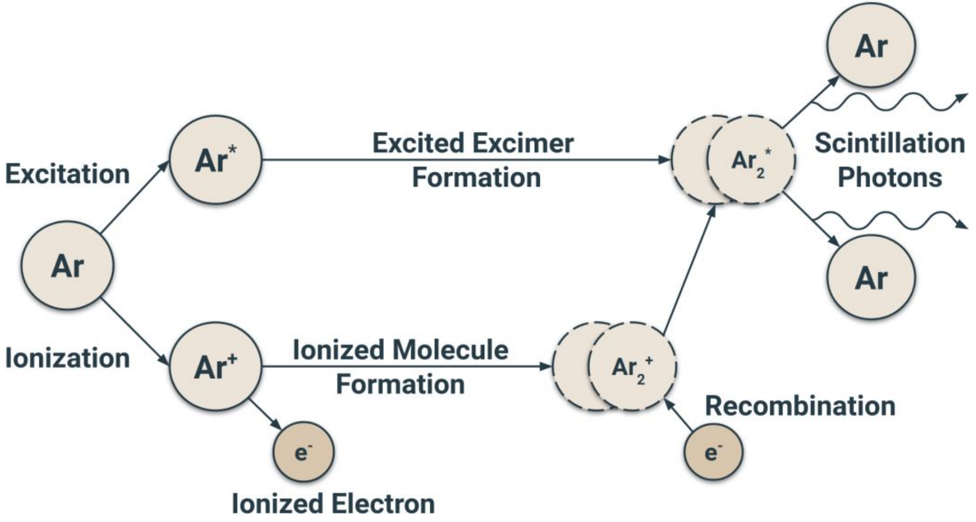
- ARGON2x2 (2 channels/board)
  - V = 5.1V, I < 35 mA (< 100 mW/ch)
  - FP 1310 nm lasers FC connector
  - Voltage gain ~20
  - Optical power ≲ 0.1 mW at receiver

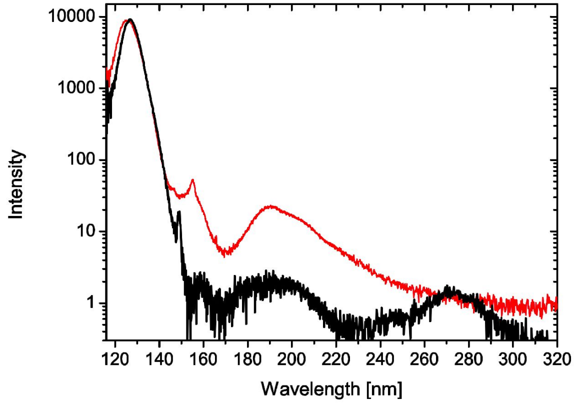




Backup slides

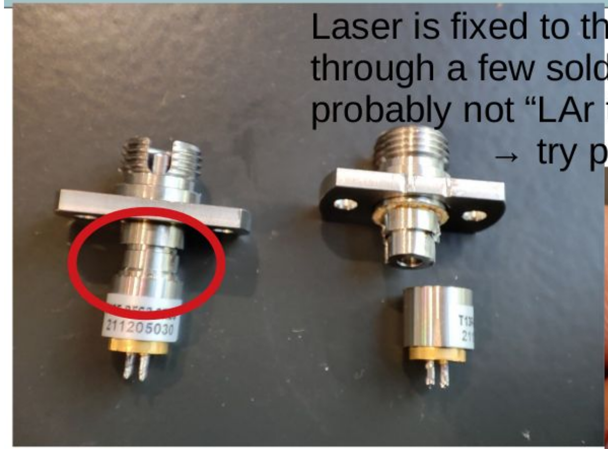




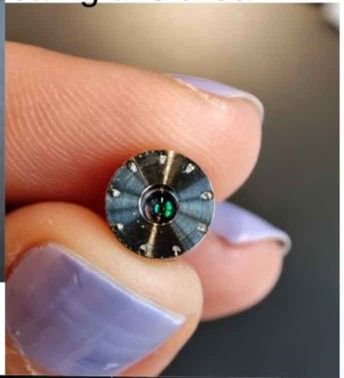


Backup slides

Lasermate FC connector

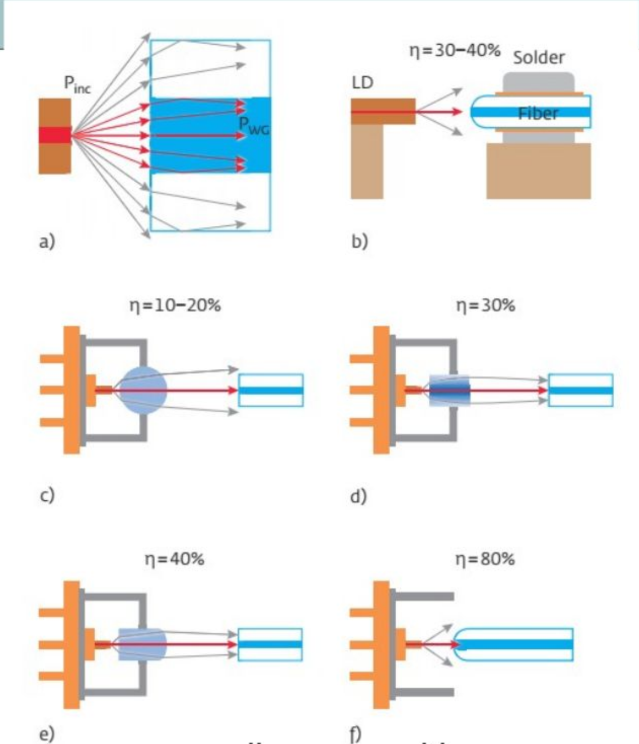


Laser is fixed to the FC connector through a few solder points: probably not “LAr tight”
→ try potting this area?



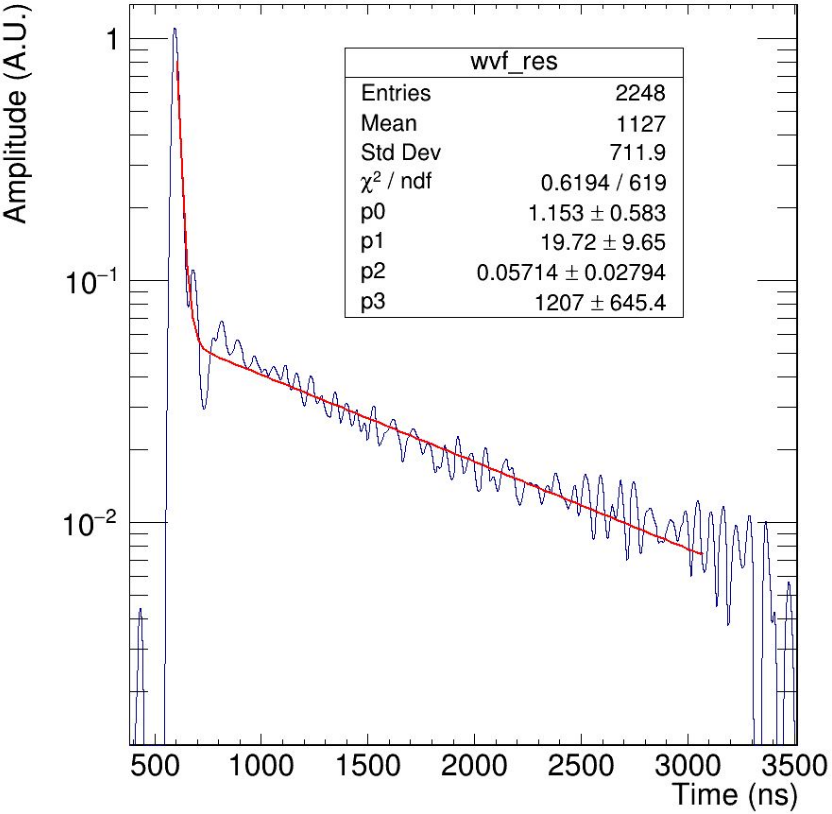
* There seems to be a lens inside → usually the laser beam has a focus point ~few mm from lens

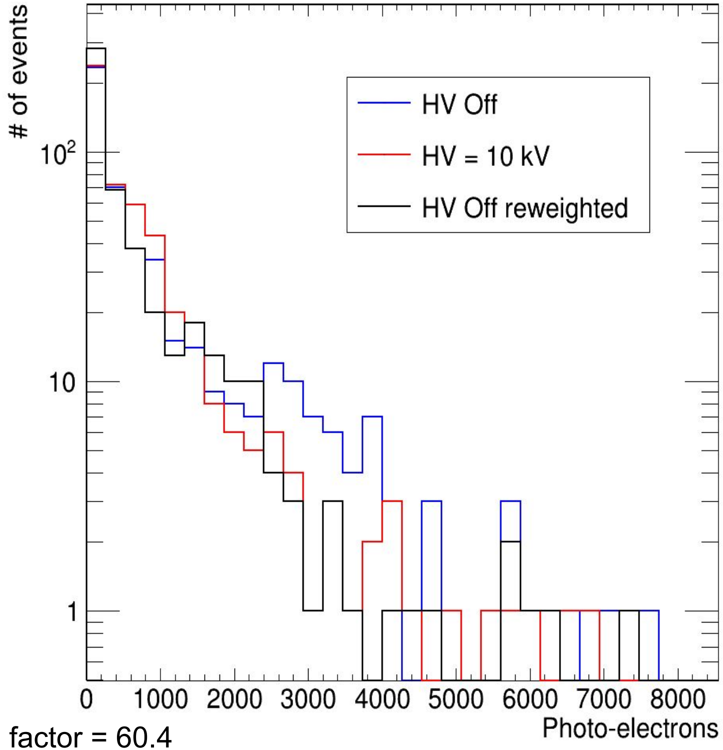
* By fully potting a pigtailed laser we did not see the power output drop
* potting is not trivial



Lasers usually come with some kind of lens → not clear how LAr affects the focus

Backup slides





Scaling factor = 60.4
This would mean 60% of light
with 10 kV (430 V/cm)