Signal over fiber and power over fiber transmission: a new concept for the PDS in DUNE VD

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on behalf of DUNE PhotonDetector Consortium

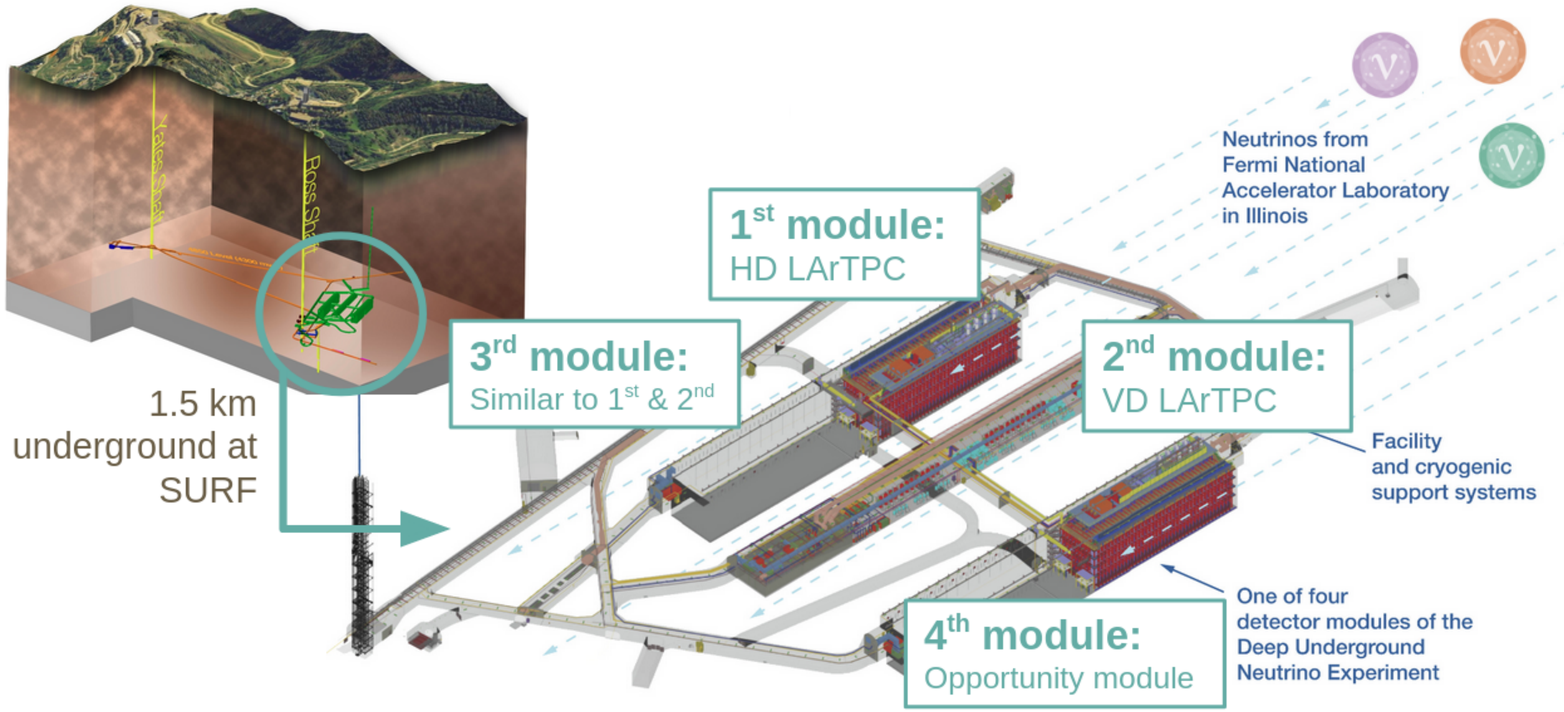
CPAD workshop at Stony Brook University
Nov. 29th - Dec 2nd, 2022

Outline:

- DUNE experiment
- Vertical Drift LArTPC for the 2^{nd} far detector module
- Photo Detection System for VD-FD2
- X-Arapuca and SiPM
- PoF and SoF to operate PDS on the HV cathode plane

DUNE

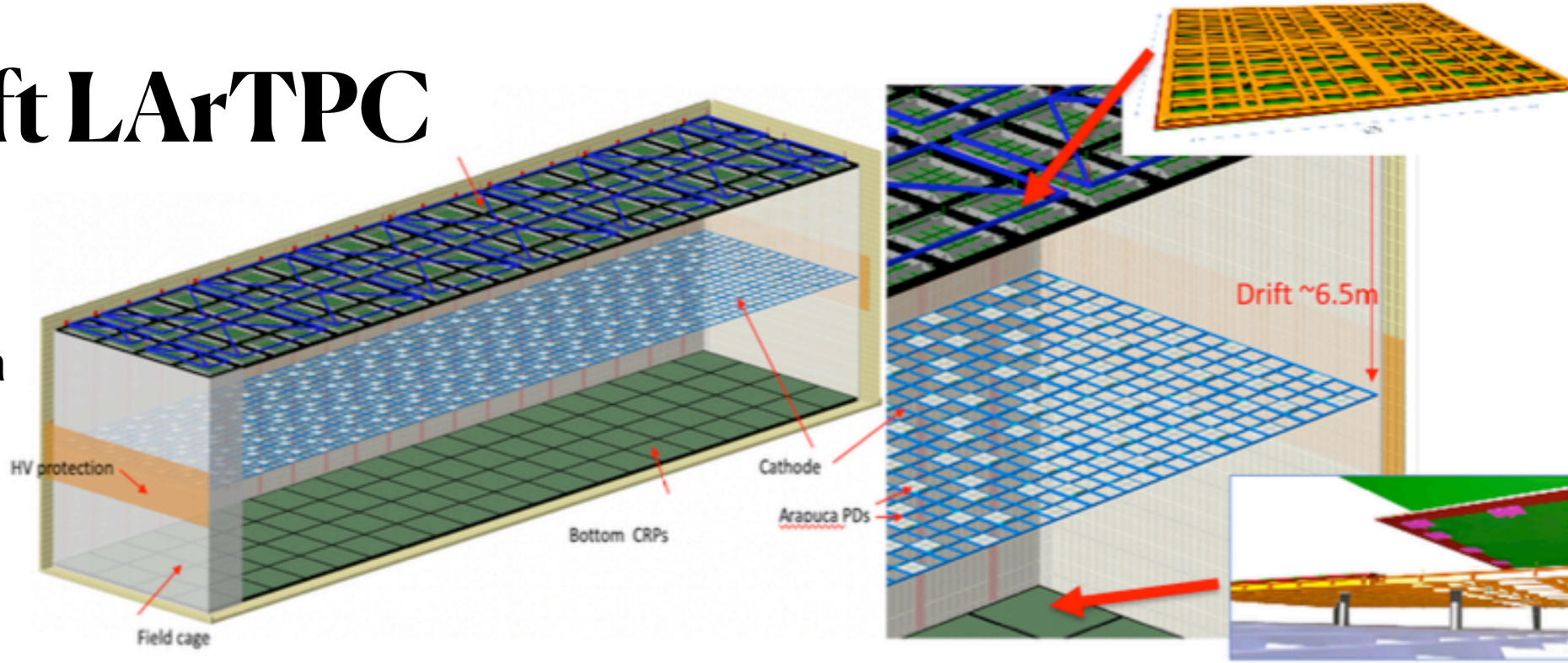
- **Deep Underground**
  - ➡ 1.5 *km* below surface
- **Neutrino Experiment**
  - ➡ Long Baseline ν Beam $\sim$ 1300 *km*
  - ➡ Atmospheric, Solar, Supernova ν
  - ➡ Proton Decay
- Super-Massive Liquid Argon detector
  - ➡ 4 modules
  - ➡ 17,000 tons of LAr per module
  - ➡ TPC + PDS



The Vertical Drift LArTPC concept is proposed for the second far detector module.

Vertical Drift LArTPC

- Single Phase LArTPC.
- Electron drift direction along the vertical axis.
- Two volumes of $13.5 \times 6.5 \times 60\, m^3$.



Two Anode planes:

- at the top and bottom of the detector volume
- perforated PCB
- opaque to the LAr scintillation light

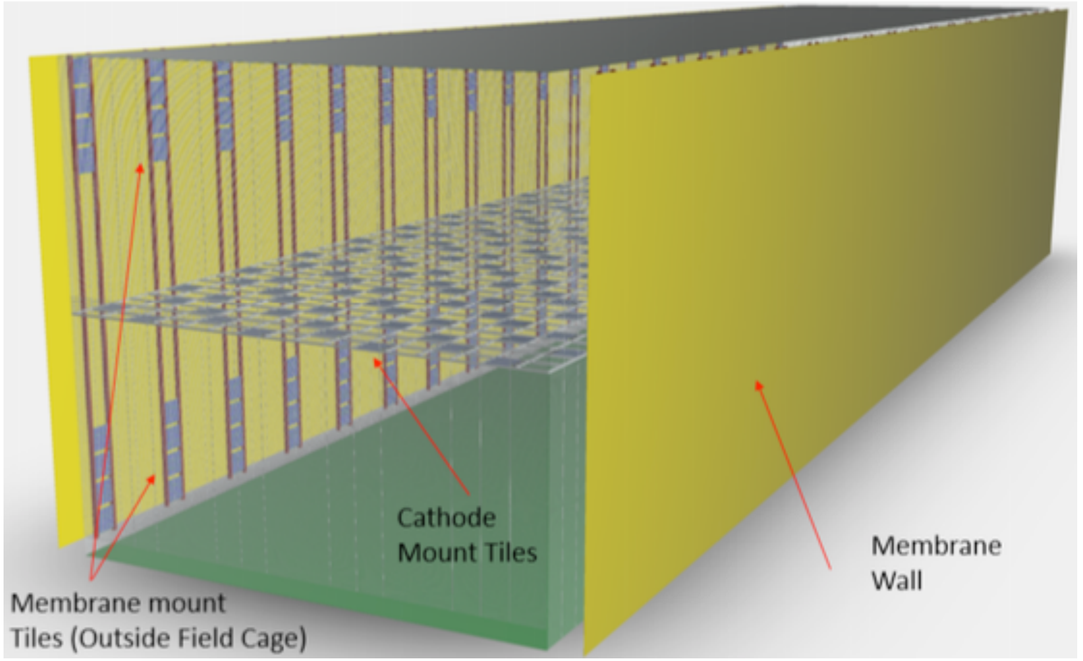
Cathode plane:

- at mid height of the detector volume
- restive mash with high transparency
- HV surface

Photo Detection System

Proposed $\sim 4\pi$ detector volume coverage:

- More uniform light yield
- Enhanced position reconstruction
- Improved energy reconstruction resolution
- Lower detection energy threshold



PDS modules distributed over the cathode plane and over the lateral planes (on the cryostat wall).

➡ NO PDS behind the anode plane.

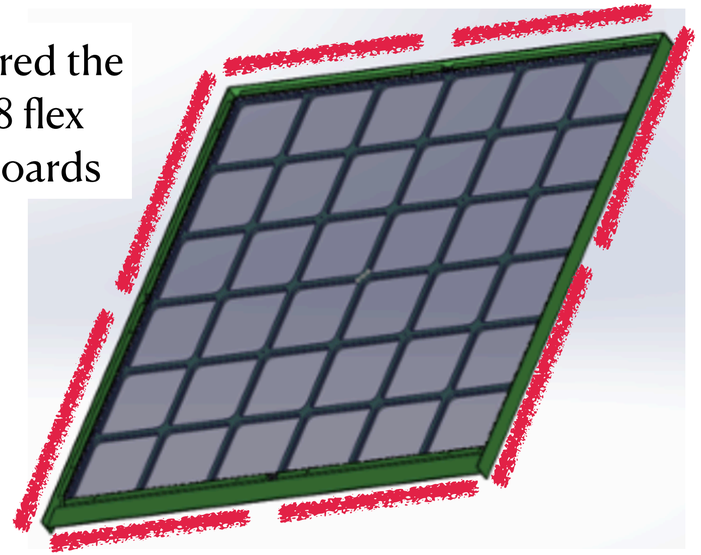
➡ PDS on the cathode needs to be electrical isolated.

New technologies are developed to provide the desired voltage isolation:

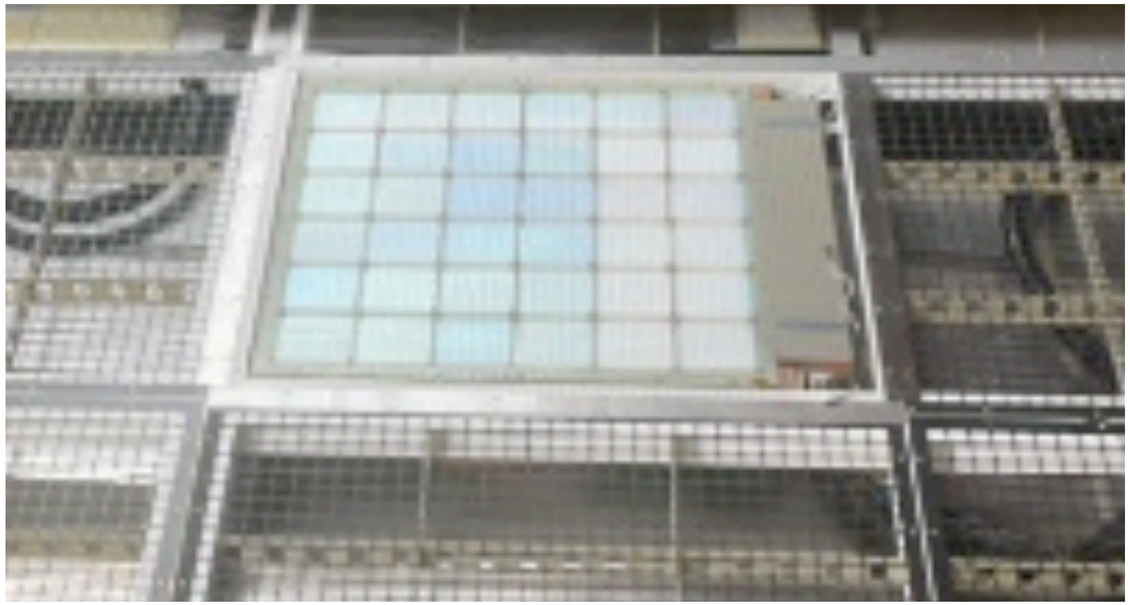
- **Power over Fiber (PoF)**
- **Signal over Fiber (SoF)**

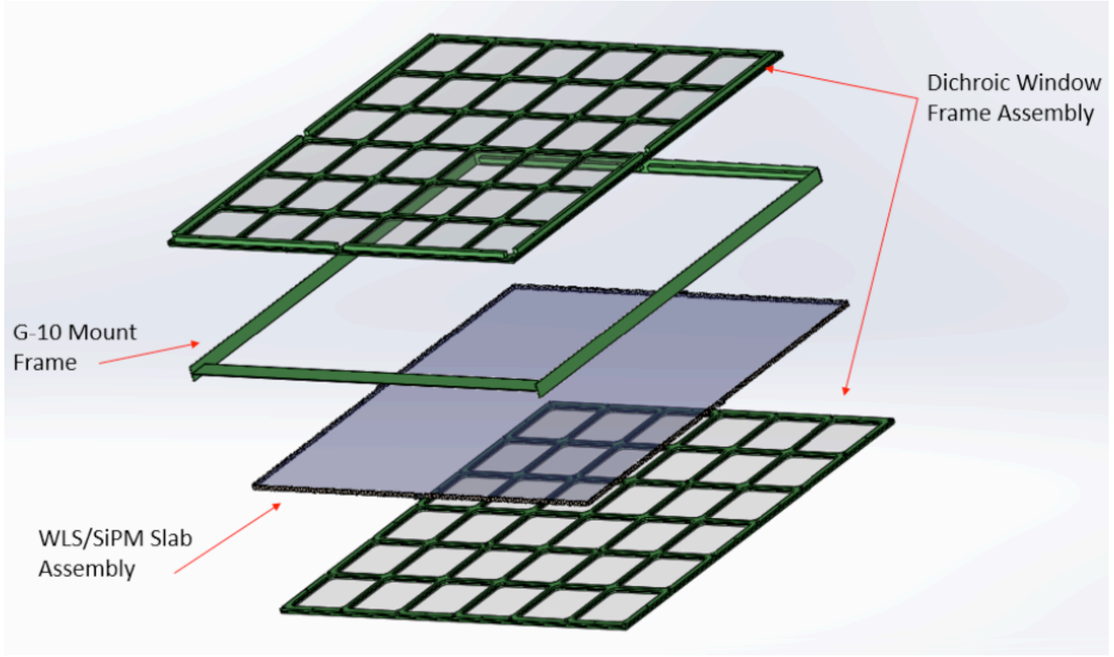
Photo Detectors: X-Arapuca

- $60 \times 60\, cm^2$ active surface, dichroic filter + WLS = light trap
- double sided (single sided for the field cage)
- 160 SiPM's ($6 \times 6\, mm^2$) distributed along the 4 edges
  - ➡ grouped in 8 flex boards each hosting 20 SiPM's



Megacell behind the cathode HV restive mash



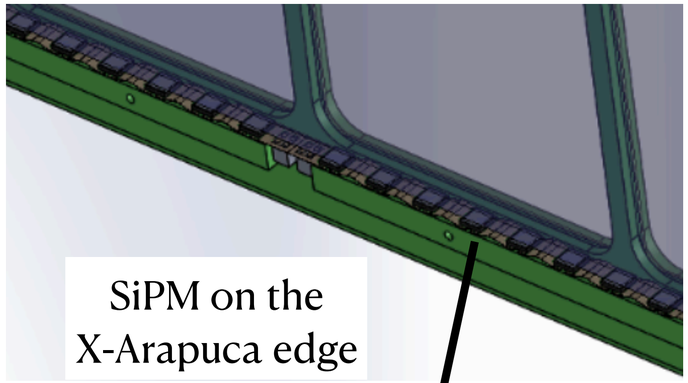


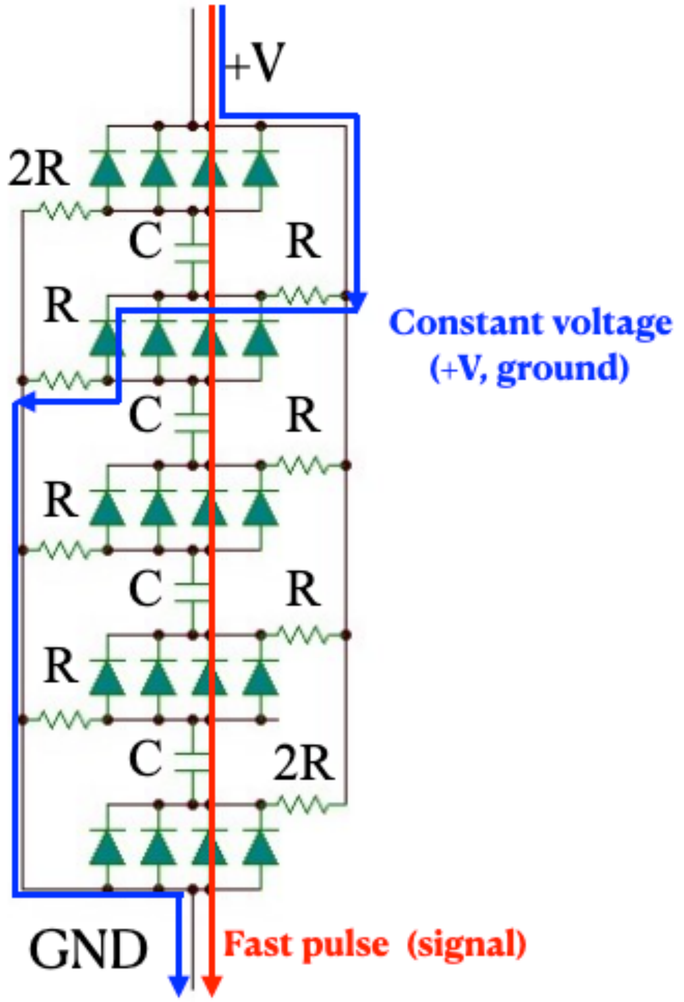
SiPM's hybrid ganging

160 SiPM's for each X-Arapuca are arranged in 8 subgroups (4 per channel) of 20 SiPM's passively connected in "hybrid mode".

The hybrid connection advantages:

- Same potential on the surface of SiPM's.
- Small capacitance → short recovery time
- Same bias voltage of a single SiPM

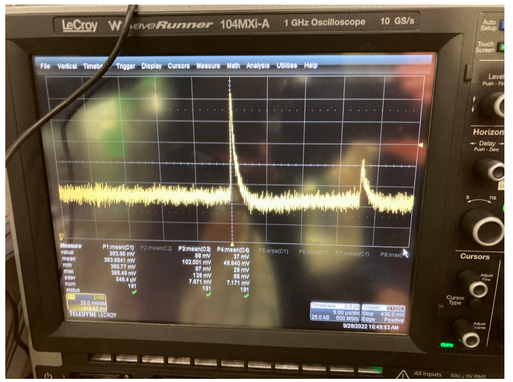




30cm long flex board with 20 SiPM in Hybrid ganging

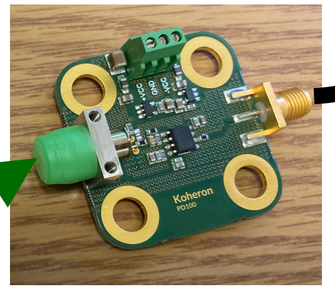
Operating on HV surface

- **Power Input through optical fibers (PoF)**
- **Signal Output through optical fibers (SoF)**



DAQ

Photovoltaic receiver for Signal

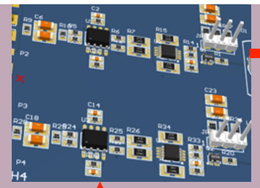


Signal over Copper

Cryostat

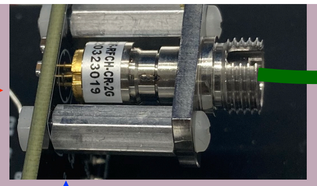
Cathode

Front-end cold electronics



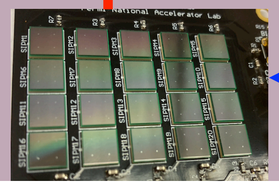
Signal over Copper

Laser Emitter for Signal



Signal over Fiber

Power over Copper



Photosensors

Photovoltaic receiver for Power

Power over Fiber

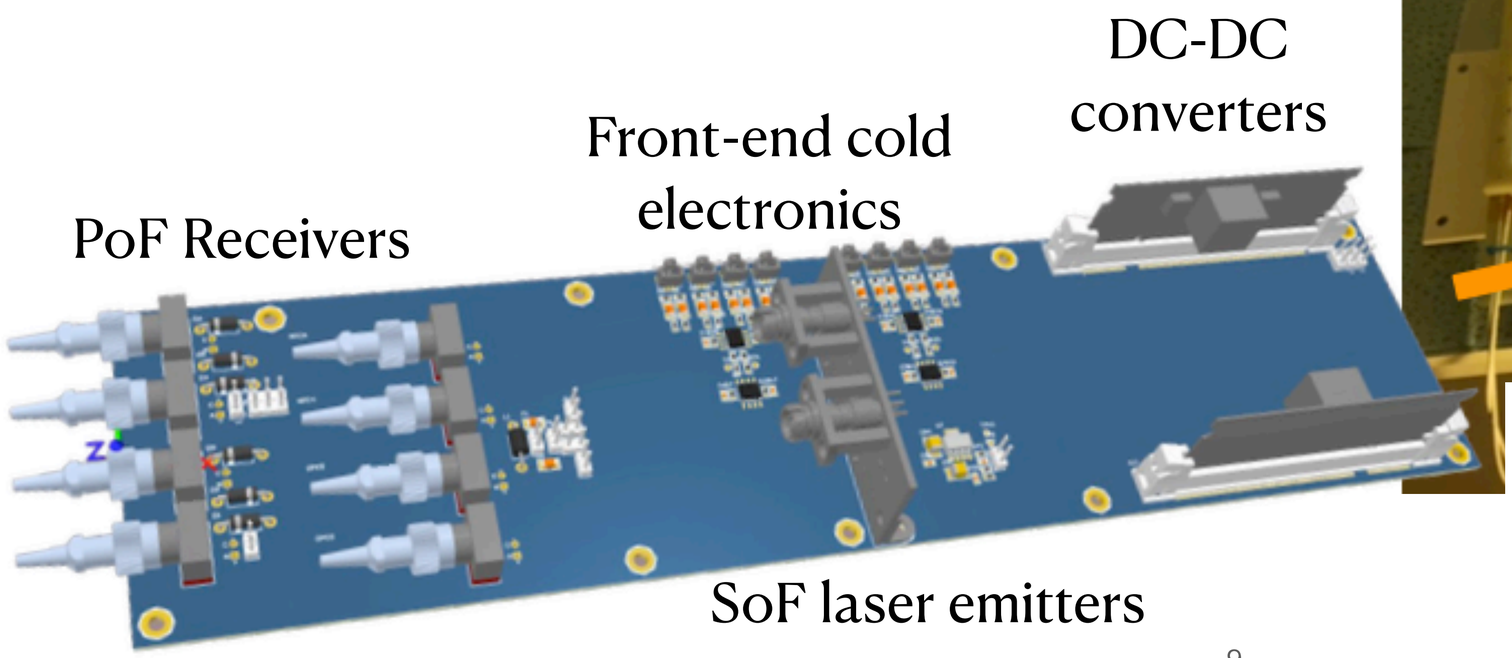
Laser Emitter for Power

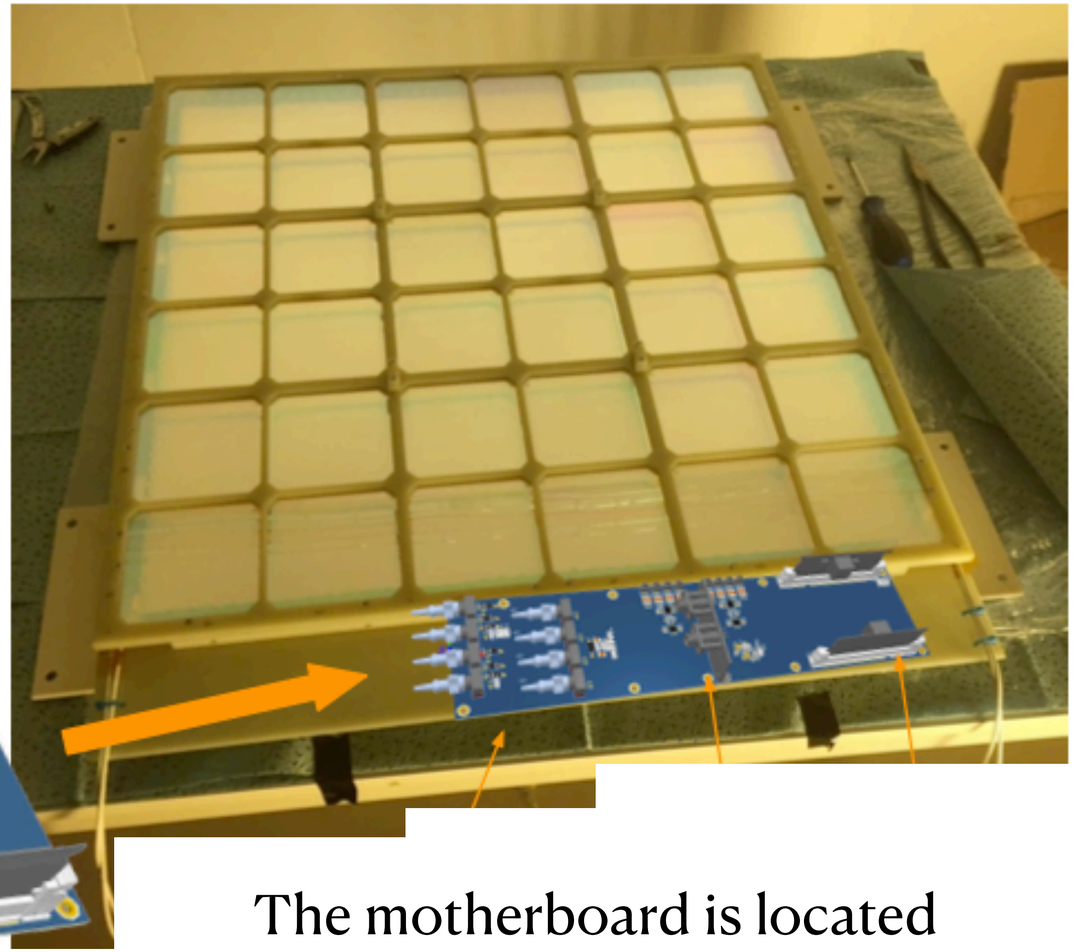
External

Integrated motherboard

- PoF receivers
- DC-DC converter
- frond-end cold electronics
- SoF laser emitters

are integrated in a unique motherboard.





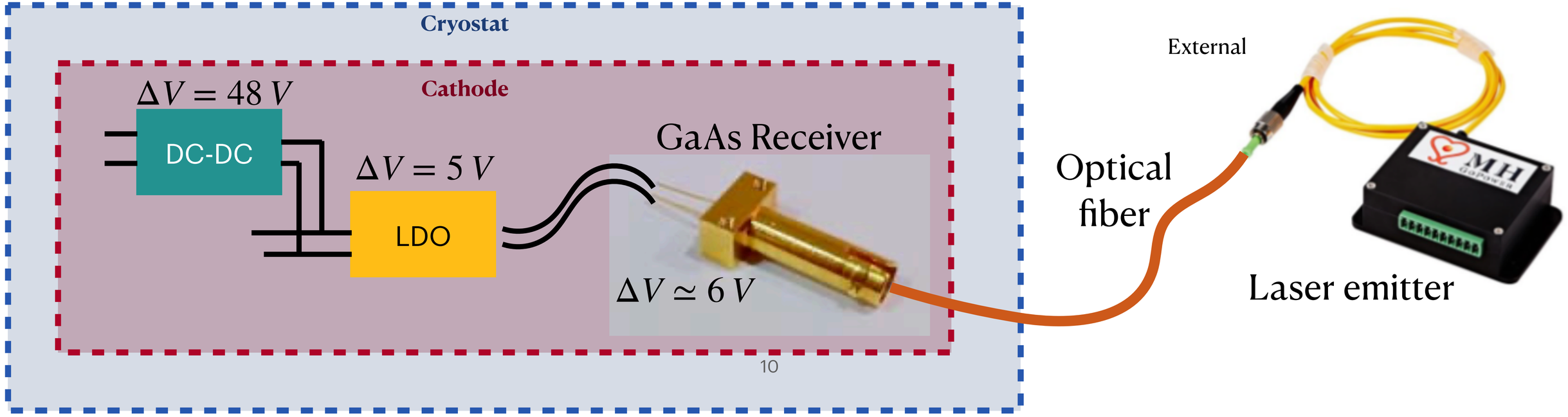
The motherboard is located on the X-Arapuca edge, hosted by a shielded box.

Power over Fiber

- 3 Gallium Arsenide receivers in parallel, convert $\sim 1.5\ W$ of optical power in I-V power.
- A LDO provides stable voltage for front-end electronics bias ($5\ V$).

  ➡ **front-end electronics: "Low Voltage - High Current"**
- A DC-DC provides higher voltage for the SiPM's bias. ($5\ V \rightarrow 48\ V$).

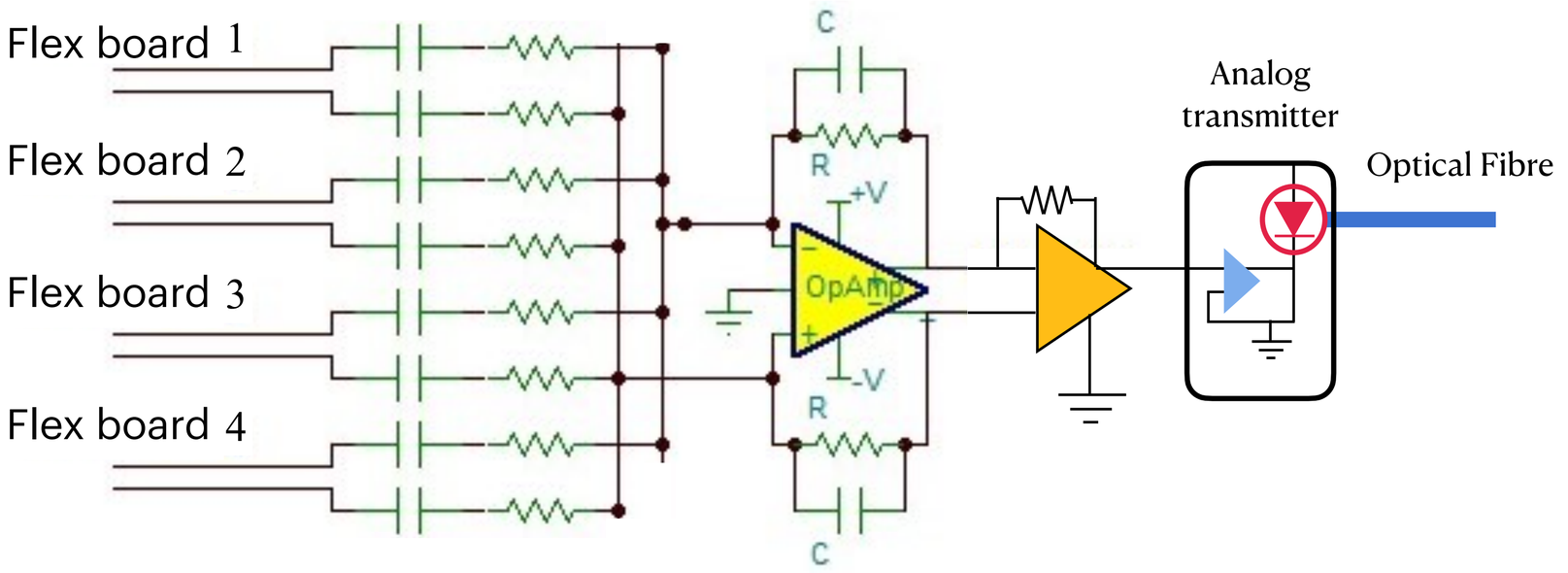
  ➡ **SiPM's : "High Voltage - Low Current"**



Front-end cold electronics

Two readout channels per

X-Arapuca, (4 flexes per channel)



1^{st} Stage:
- **Active Ganging** → Summing multiple channels preserving signal shape
- **Amplification** → Tuning signal amplitude to match SPE amplitude, SNR, full range.

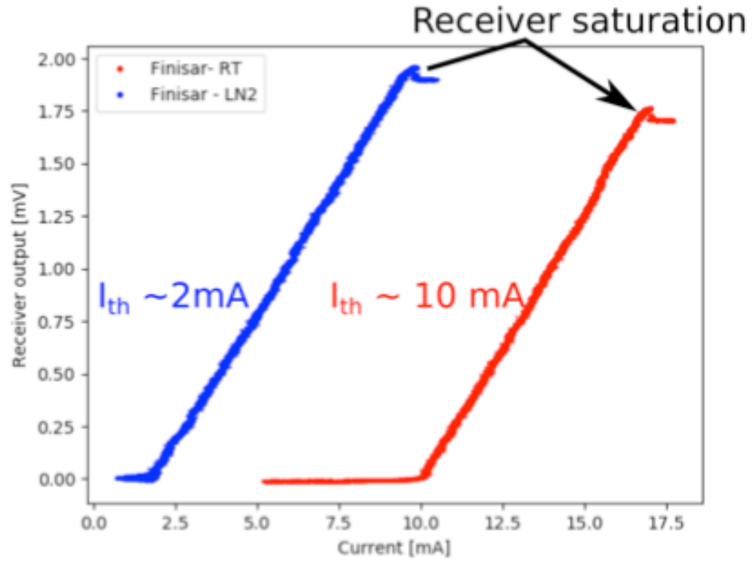
2^{nd} Stage:
- **Full-Differential to Single Ended** → To match analog transmitter.

3^{rd} Stage:
- **Laser Diode Driver** → Current source to drive the laser emitter.

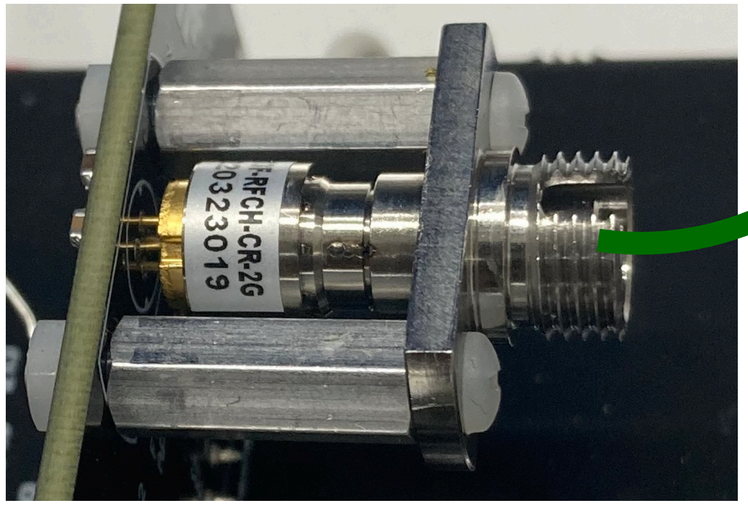
Signal over Fiber

- FP 1310 nm laser have been shown to work well in cryogenic temperatures.
- Current offset is provided to work in the linear regime.
- Receiver convert SoF to electrical signal in warm.

Laser to Fiber coupling is a critical point in Liquid Argon.

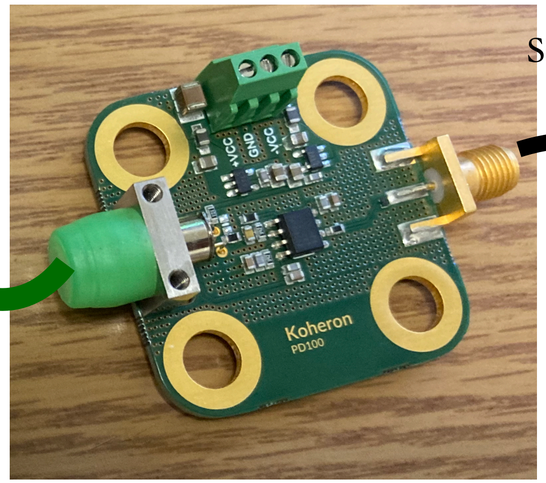


Laser Emitter for Signal



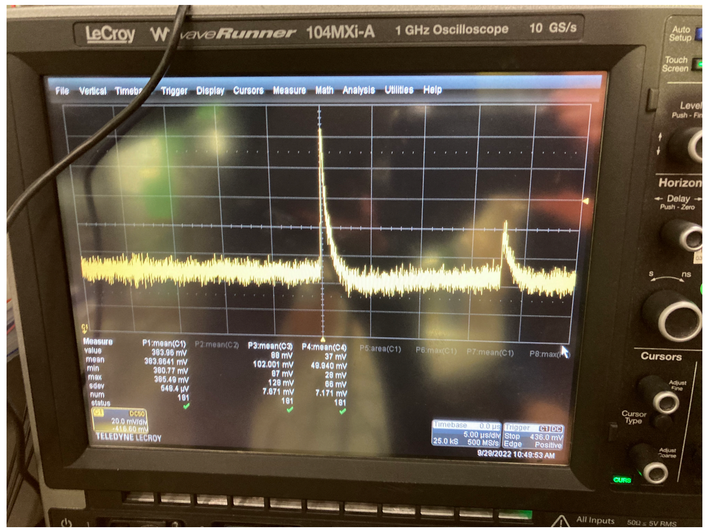
Signal over Fiber

Photovoltaic receiver for Signal



Signal over Copper

DAQ

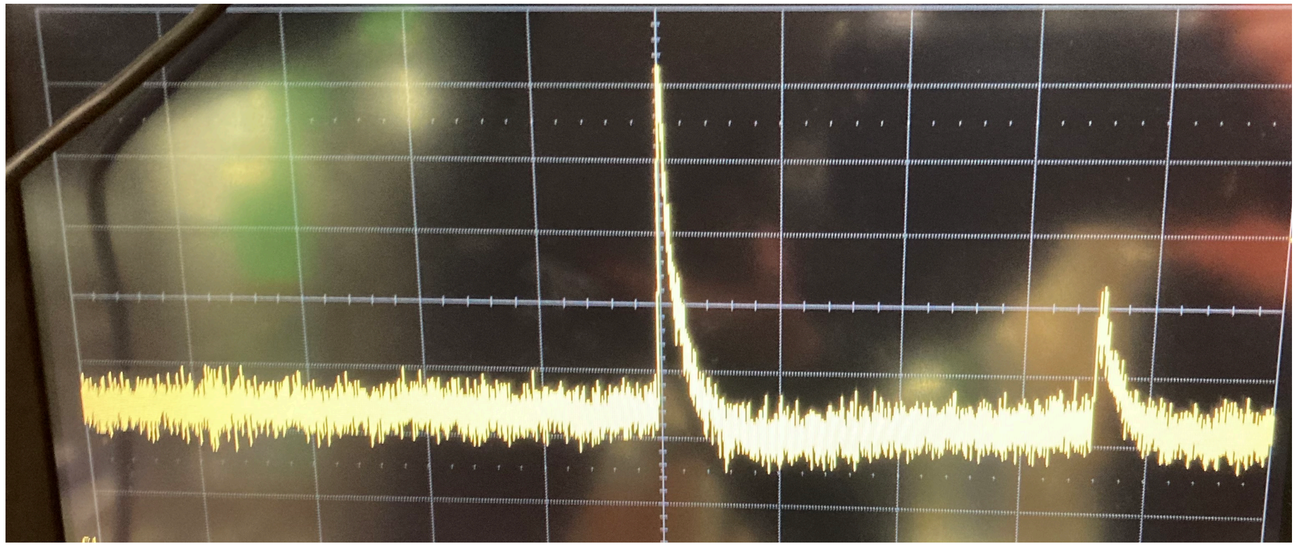


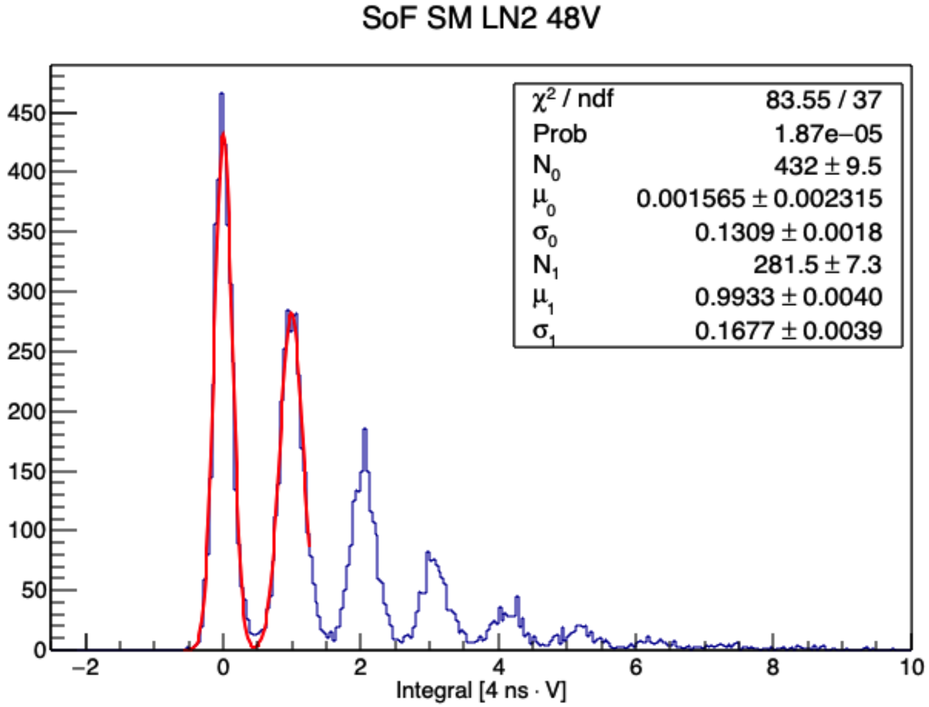
Stand alone test at UCSB

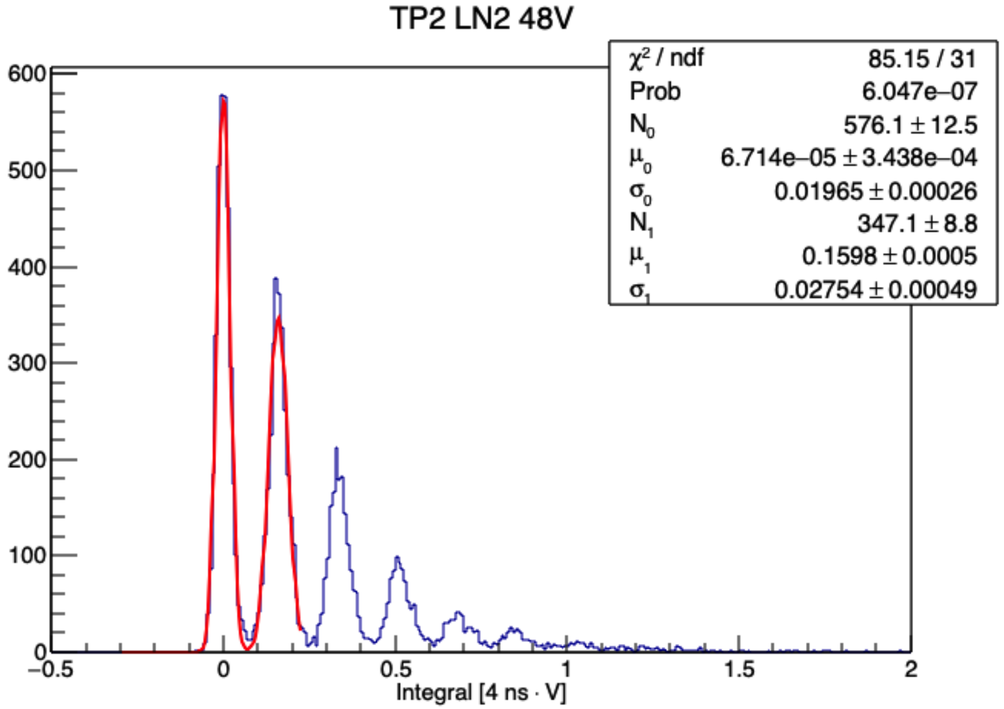
SPE resolution: SoF vs. signal over copper

- SoC SNR $= 6.8$
- SoF SNR $= 6.6$

DUNE requirement: SNR > 4





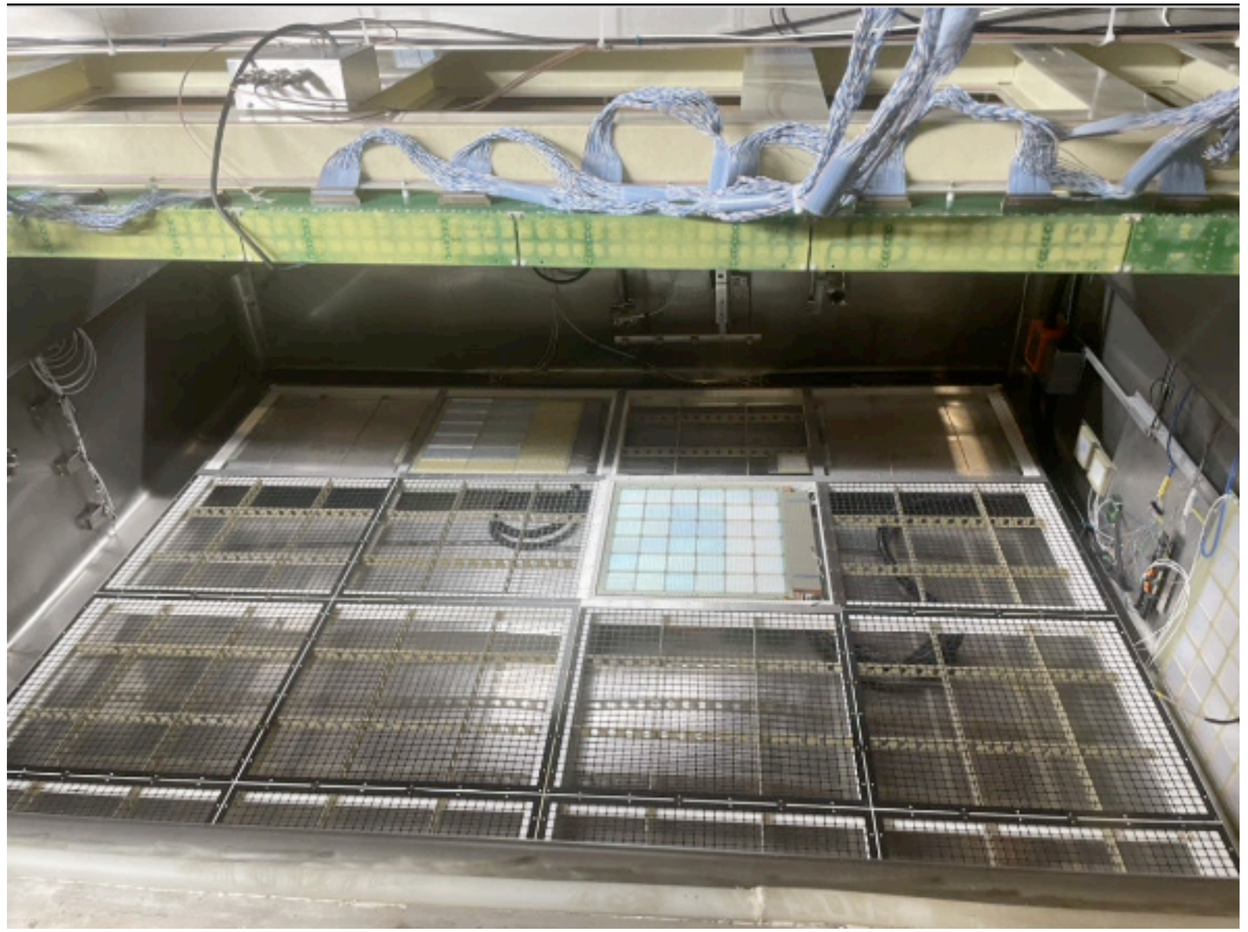


ProtoDUNE -VD and Cold Box Test at CERN

The VD concept will be validate in a large scale prototype at CERN:

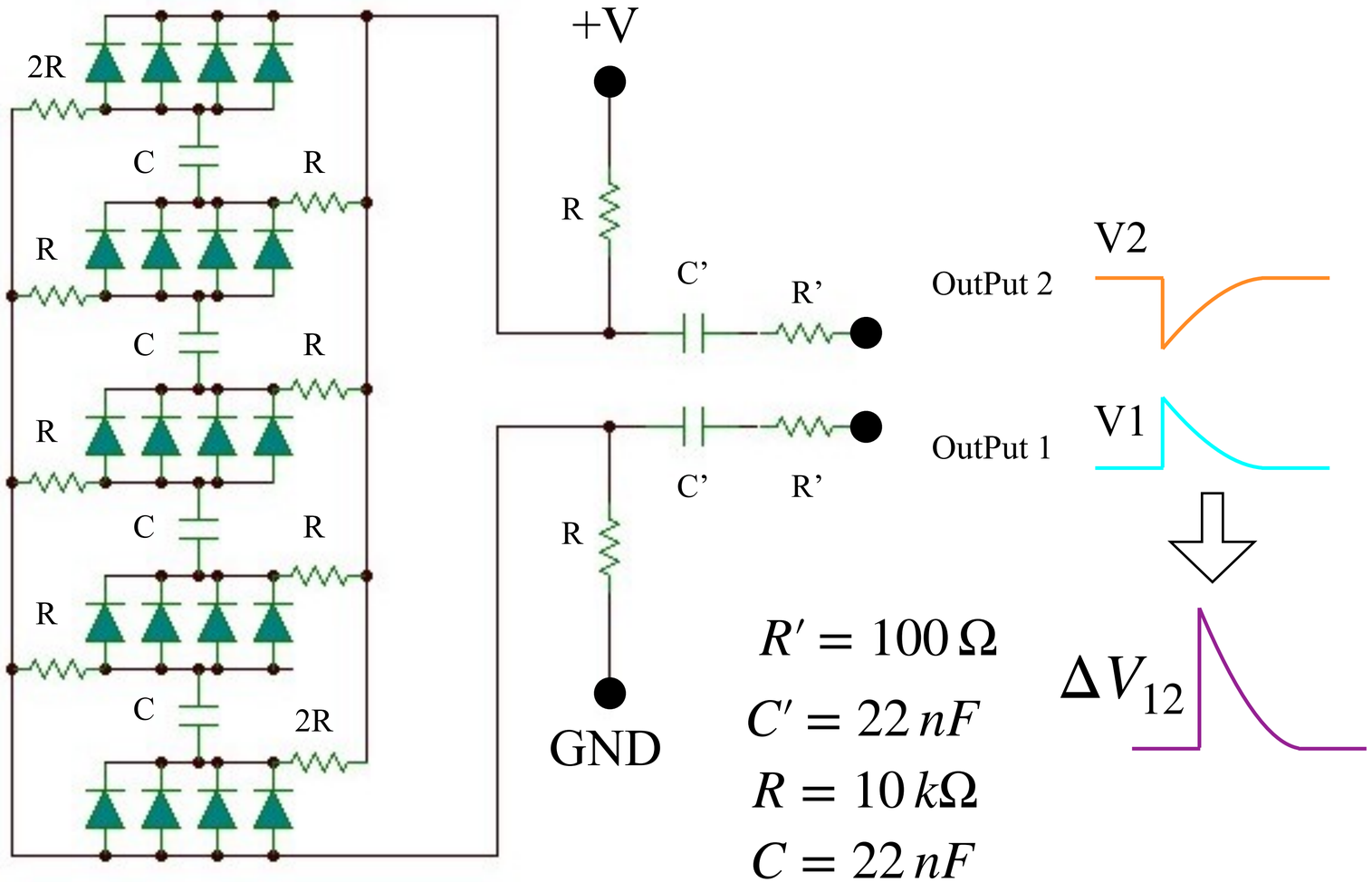
- TPC and PDS joint tests are ongoing in a Cold Box at CERN since the end of 2021.

- The Module-0 assembling is starting in these days.



Backup slides

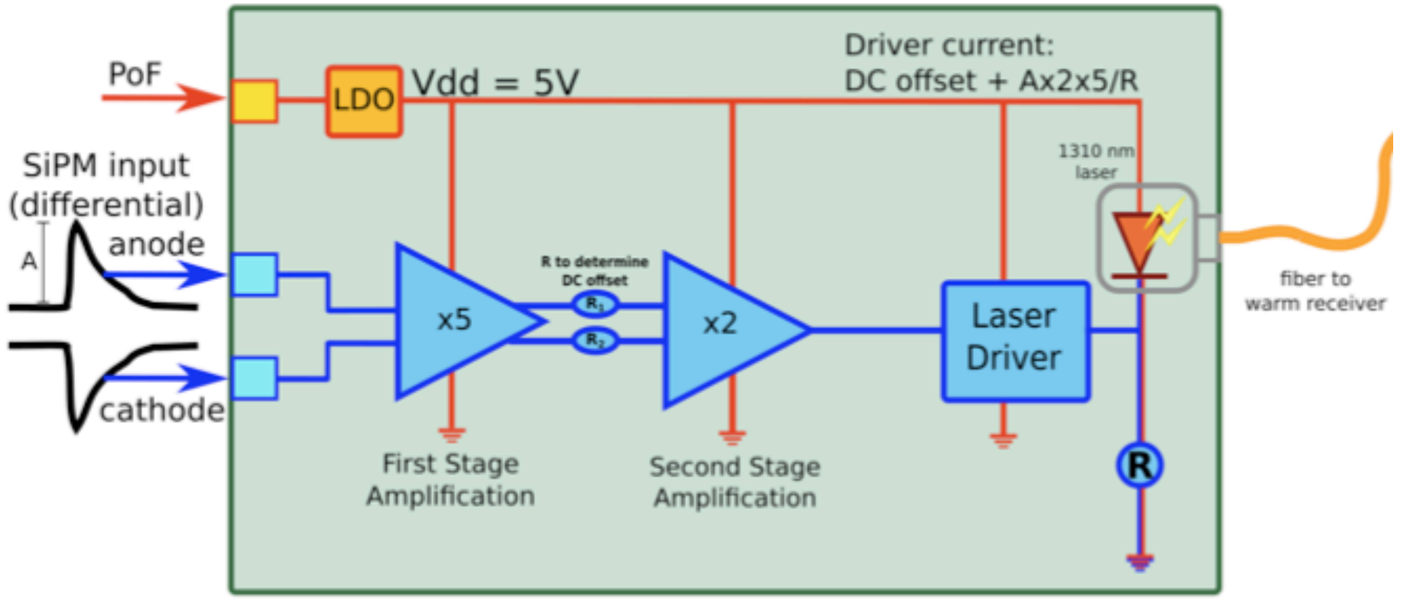
SiPM's hybrid ganging



RC stage before +V / GND provide the AC output. Signal can be read by both output.

The two outputs are specular, reading the signal in "differential" mode increases the signal-noise ratio.

Readout cold electronics



Two readout channels per

X-Arapuca, organized in 3 stages:

1^{st} Active Ganging + Amplification

2^{nd} Full-Differential to Single Ended

3^{rd} Laser Diode Driver

1- Active Ganging Stage

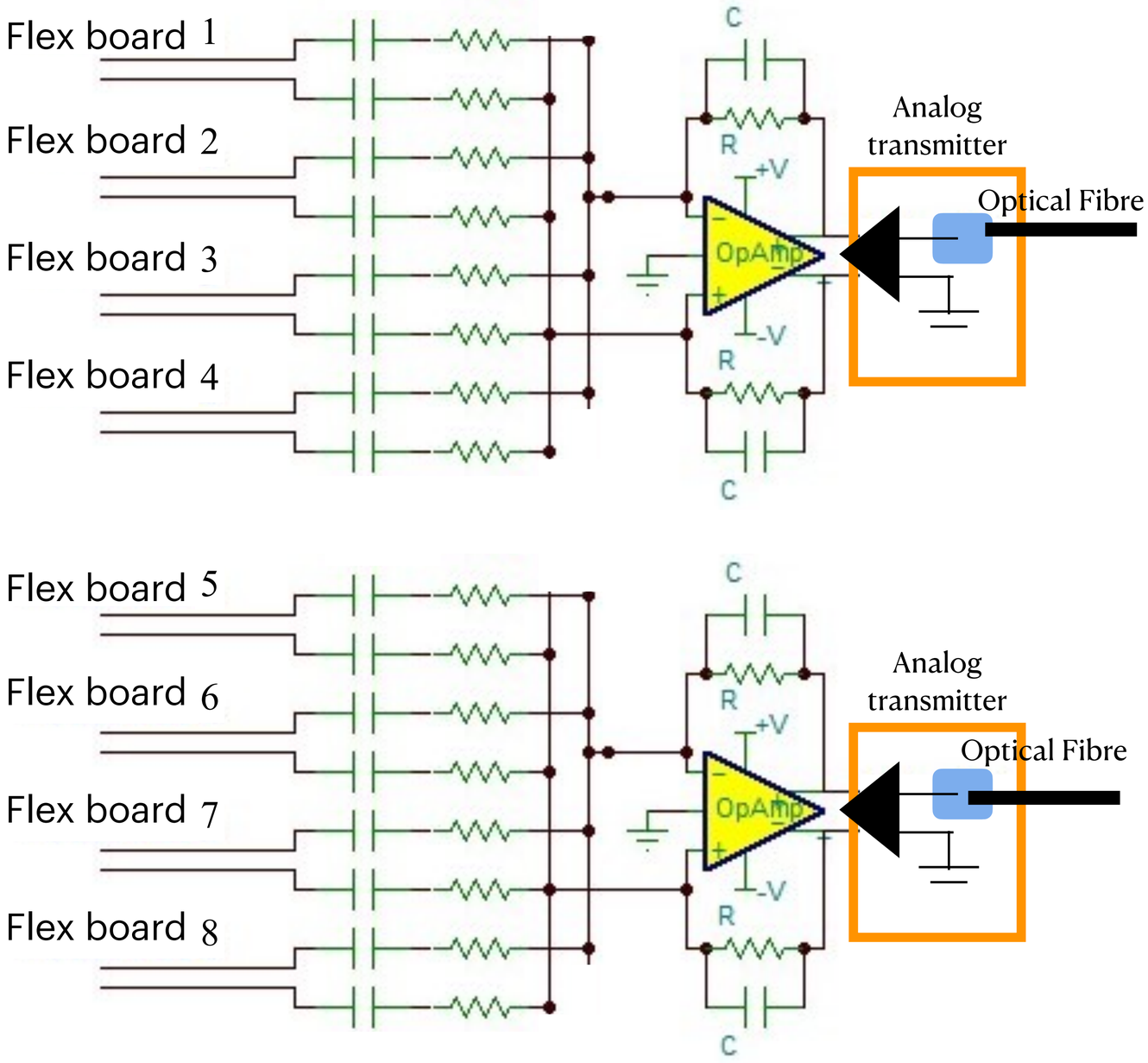
8 flex boards form the X-Arapuca are arranged in two channels.

The 1st OpAmp (Active Ganging) allows to sum multiple channels decoupling the capacitance.

At the same time it can provide a signal amplification (Gain).

Increasing/tuning the signal in order to match:

- Transmitter full range
- SPE noise ratio
- Maximum number of photons amplitude

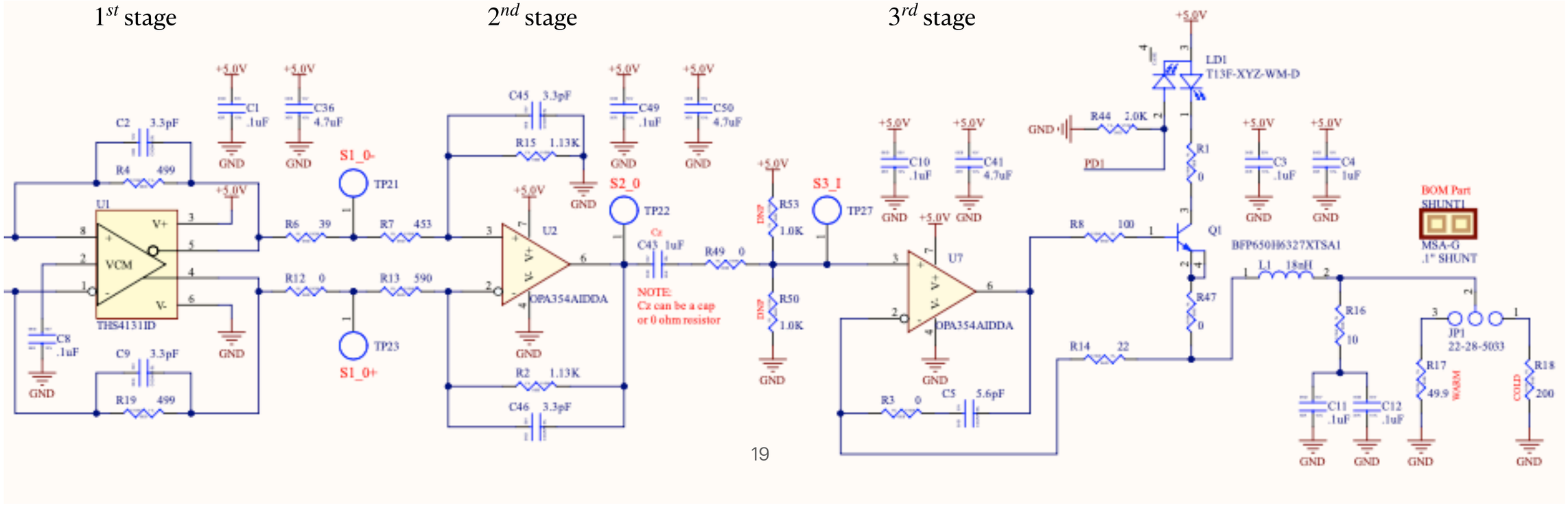


2- Full-Differential to Single Ended

A 2nd OpAmp stage is used to convert the full differential signal in single eded signal, needed to drive the last stage.

3- Laser Driver

The 3rd OpAmp stage combined with a transistor is used to drive the Laser Diode emitter.



Laser Emitter: Signal over Fiber

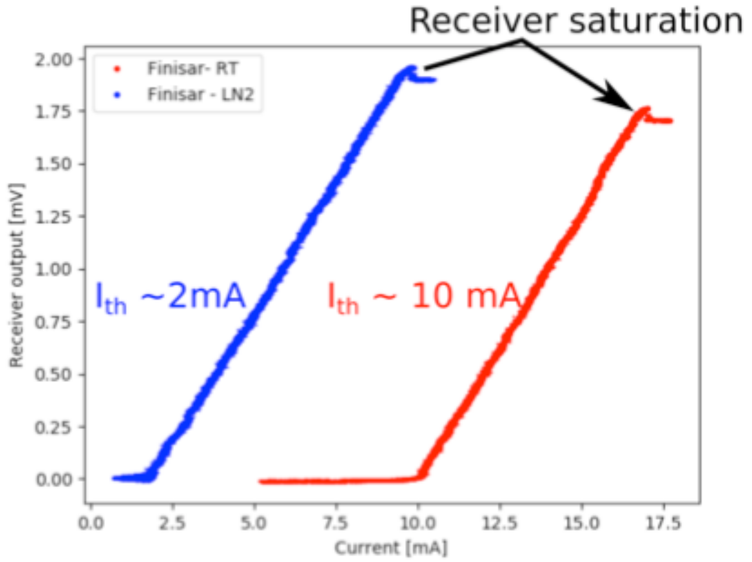
FP 1310 nm laser have been shown to work well in cryogenic temperatures.

Current offset is provided to work in the linear regime.

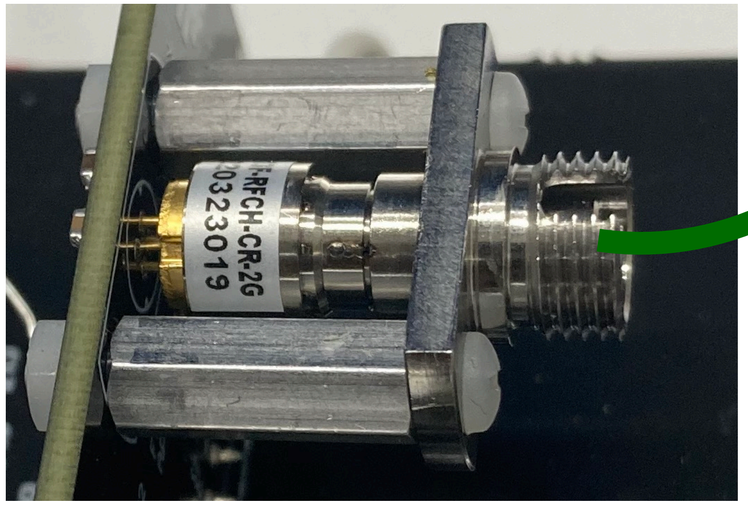
Laser to Fiber coupling is a critical point in Liquid Argon:

Liquid Argon flood the laser → Refraction index change →

The original focal distance is not working well → Reduced transmission efficiency

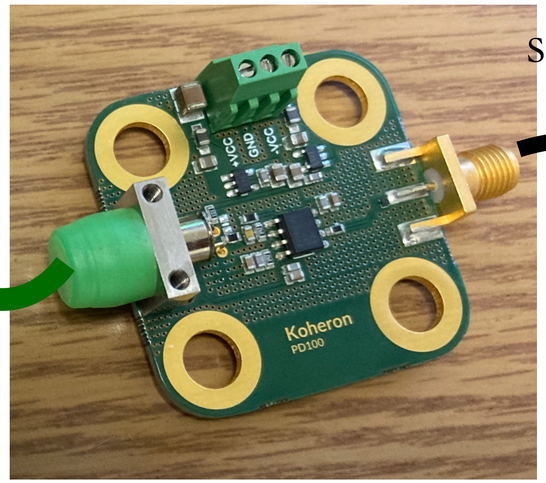


Laser Emitter for Signal



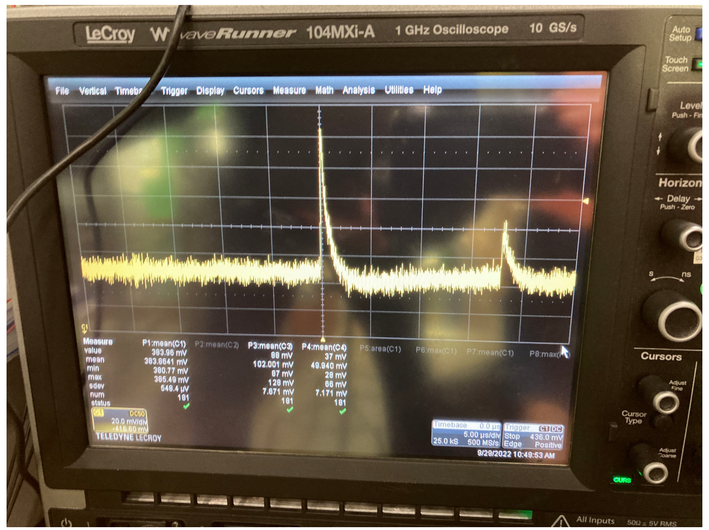
Signal over Fiber

Photovoltaic receiver for Signal



Signal over Copper

DAQ



SiPM and Cold Electronics bias: Power over Fiber

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- The LDO helps to set a stable voltage value for the front-end electronics ($5\ V$).

  ➡ front-end electronics: "Low Voltage - High Current"
- The DC-DC provides the desired voltage for the SiPM's ($5\ V \rightarrow 48\ V$).

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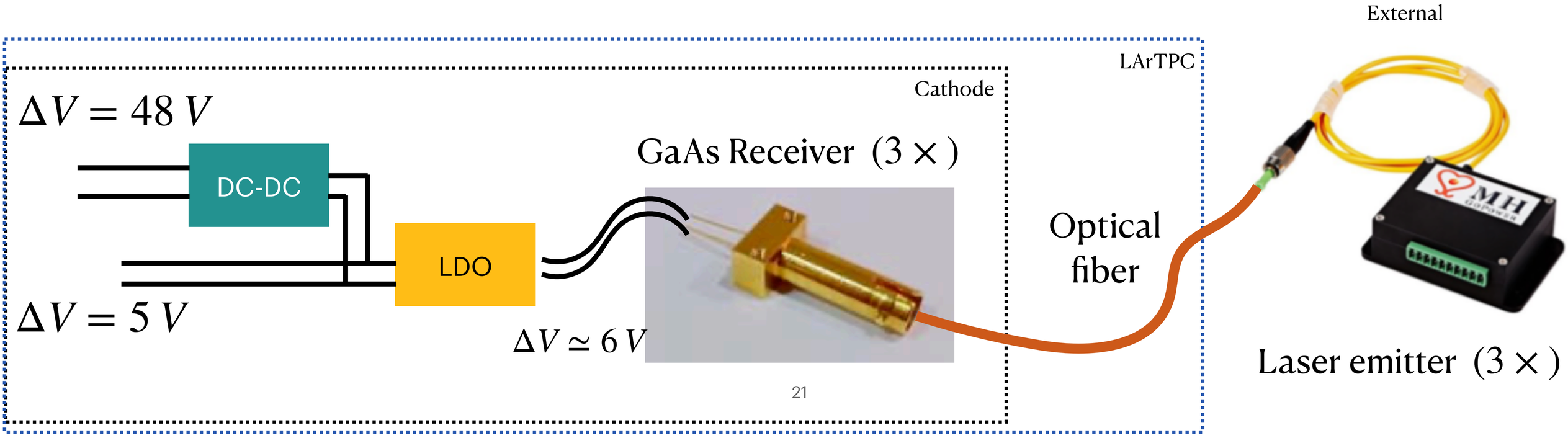

Test at UCSB