Tunable PoF for future modules and CACTUS VD first steps

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Alessandro Andreani[1,2], Marco Bassani[1,3], Paolo Cova[1,3], Nicola Delmonte[1,3], Massimo Lazzaroni[1,2], Danilo Santoro[1,3], Valeria Trabattoni[1,2], Andrea Zani[1]

[1] INFN Sezione di Milano
[2] Università degli Studi di Milano
[3] Università degli Studi di Parma

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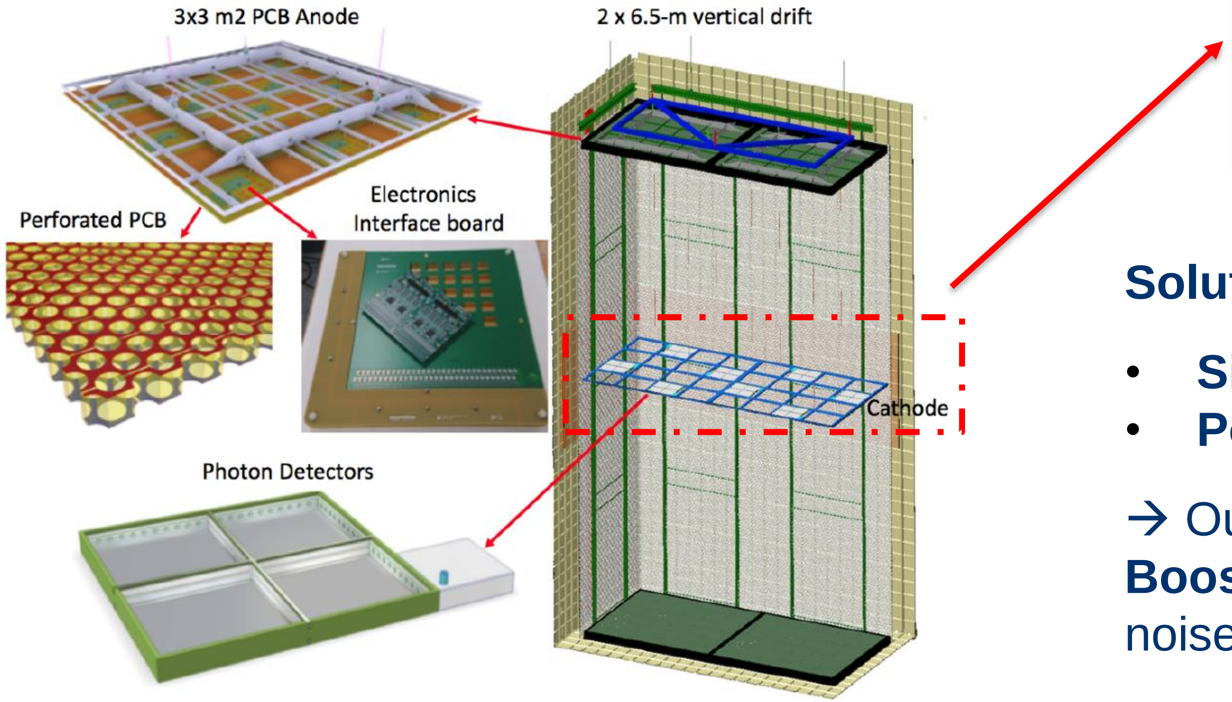
DUNE FD – Vertical Drift Technology (VD)

- Charge Readout Planes (**CRP**) are placed at top and bottom of the cryostat. CRP is composed by perforated PCBs and electrodes for charge collection
- Photon Detection System (**PDS**) modules installed on the cathode



High voltage (-300 kV) plane:
no conductive interconnections, but optical fiber technologies.

Solution:

- **Signal over Fiber (SoF)** to transmit output signals
- **Power over Fiber (PoF)** to supply the system

→ Output voltage of PoF is only of few volts: a **DC-DC Boost Converter** is used to obtain a stable and very low noise ~ 50 V output supply voltage for the PDS

F. Pietropaolo, The Vertical Drift LAr-TPC for the DUNE Experiment

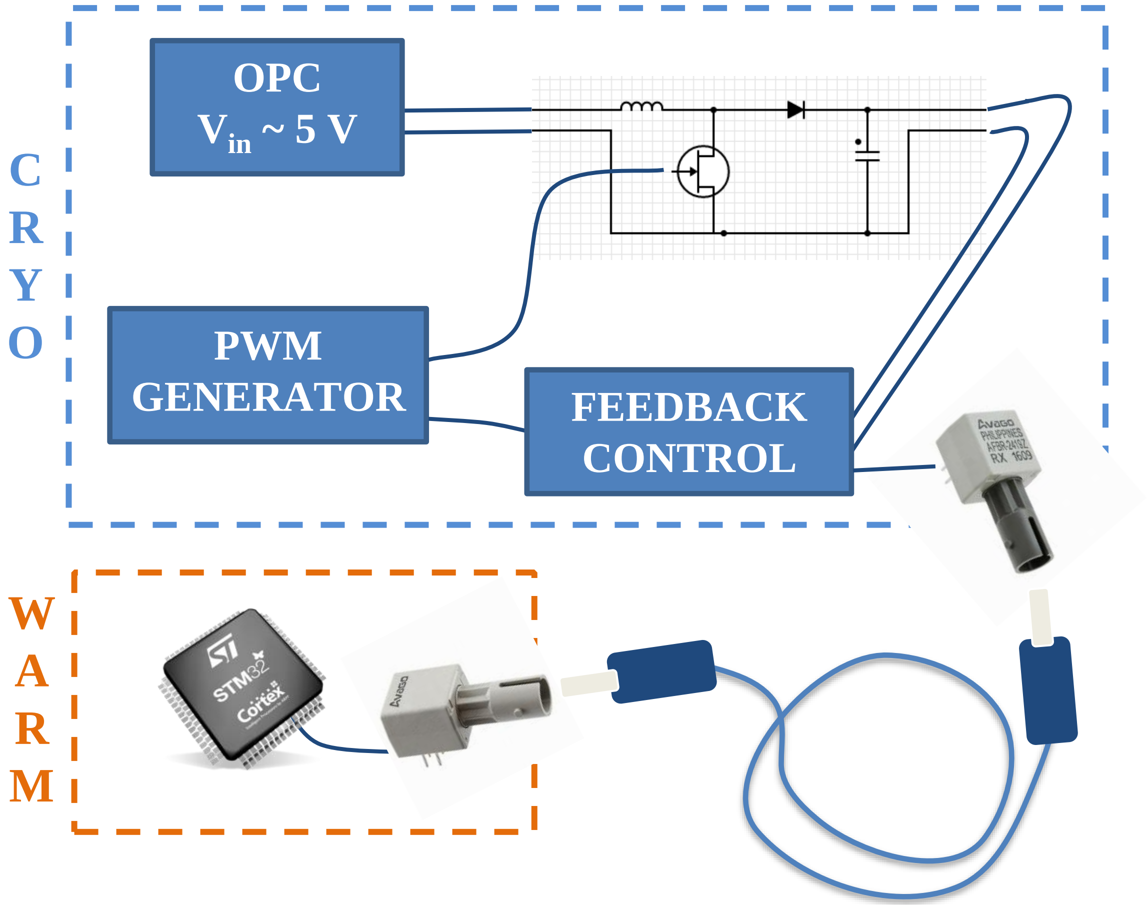
DC-DC Boost Converter – Overview

- **DC-DC Boost Converter**: high voltage to bias SiPMs at cryogenic temperature (77 K for LN_2)
- **Power supply** provided **by OPC** (Optical Power Converter): V_{in} = 5 V

DC-DC Boost Converter proposed by Milano Statale - Parma group

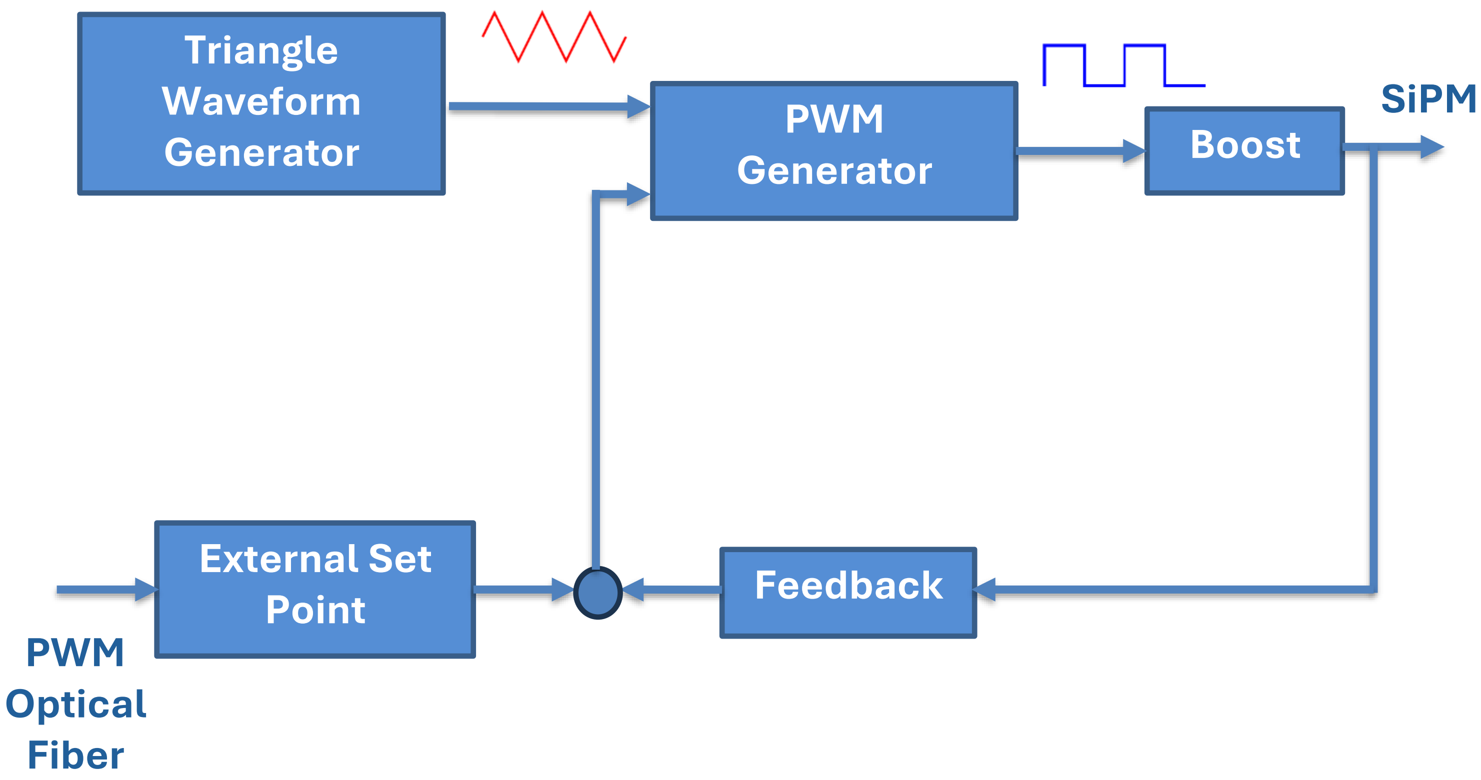
NEW!

- **Pulse Width Modulated (PWM) generation** with **two** possible controls:
  - **Inner feedback** setting output voltage at nominal point: V_{out} = 48 V
  - Optical input to **change the setting voltage** within few volts



DC-DC Boost Converter – Control design

- **Triangle-Waveform Generator:** it produces a triangle-like signal used for comparison, serving as a reference signal to control the Boost
- **PWM Generator:** it provides the MOSFET control signal, comparing an analog value with a triangle waveform
- **Boost Section:** responsible for storing the energy required to supply the SiPMs
- **Feedback:** it adjusts the analog level to counterbalance output variations and fix the operating point
- **External Set Point:** it can vary the output voltage using an external PWM



DC-DC Boost Converter – External control

NEW!

The DC-DC converter includes a **remote control** able to determinate different output voltages operating through a **connection at room temperature**, while power supply units remain unreachable inside the cryogenic set-up.

Internal feedback

Output voltage control at desired set point with two configuration:

- **Nominal:** set at design stage and fixed throughout the entire run (e.g. 48 V for Hamamatsu SiPMs)
- **External:** set point modified through external communication (nominal set point in case of failure or no external control)

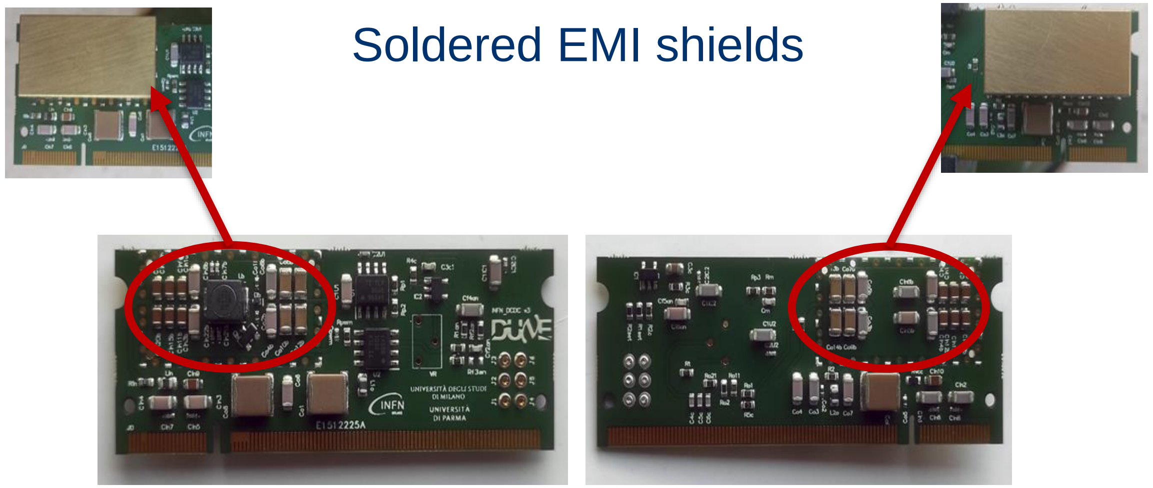
→

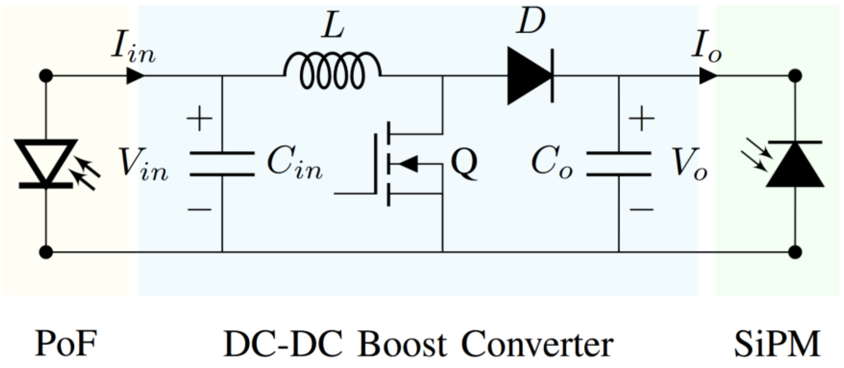
An external signal can be provided by an **optical fiber**, using an optical-to-electrical converter.

The design target is that of providing PWM waveform and to be able **to adjust the output voltage of a few volts.**

DC-DC Boost Converter – Version 3

Soldered EMI shields





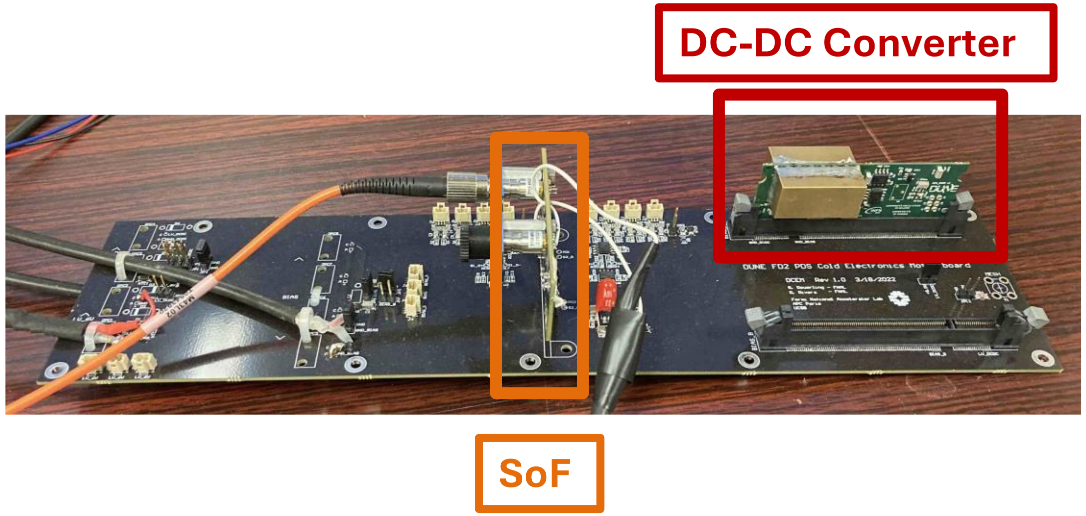
Picture of one the prototypes tested with and without shields (top) and schematic of the DC-DC Boost Converter (bottom).

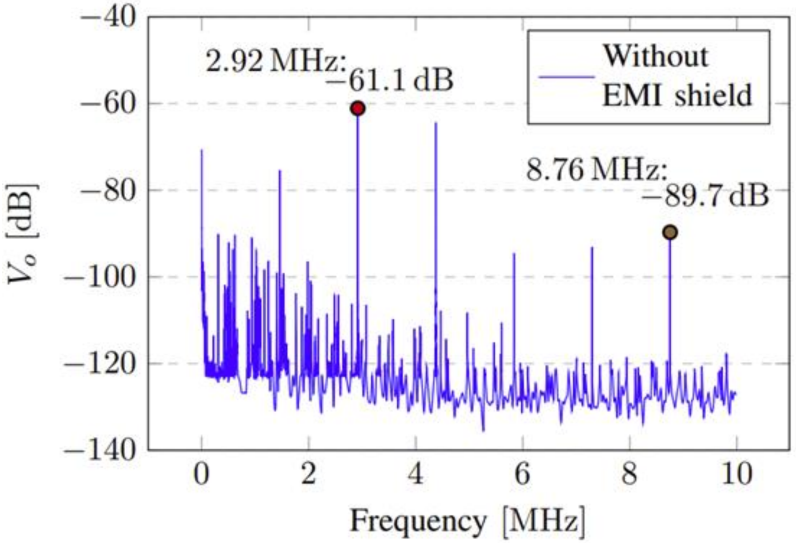
- **Discrete components** independently characterized at 77 K in the last two years
- **Working version** demonstrated in a test set-up at CERN
- Version 2 and Version 3 used in test set-up to bias SiPMs (Cryo-PoF by Marta Torti)
- Soldered an **Electromagnetic Interference (EMI) shield** over the boost to reduce noise
- Characterization of the **advanced DC-DC prototype (DC-DC v3)** with improved input and output filters, and optimized analog feedback control circuitry tested

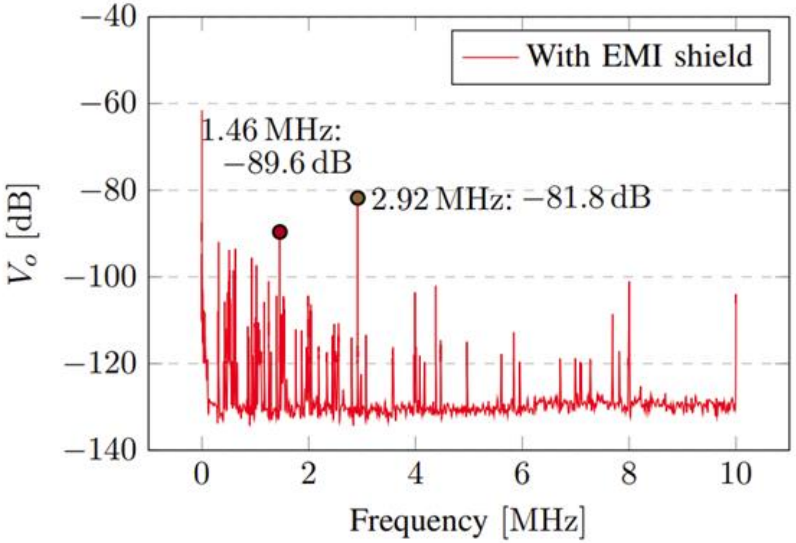
DC-DC Boost Converter – Noise results

Motherboard (from ProtoDUNE at CERN) with the DC-DC board mounted for the noise measurements.

Employing a Koheron optical-electric converter board, the **output signal from the DC-DC** Boost Converter was monitored.







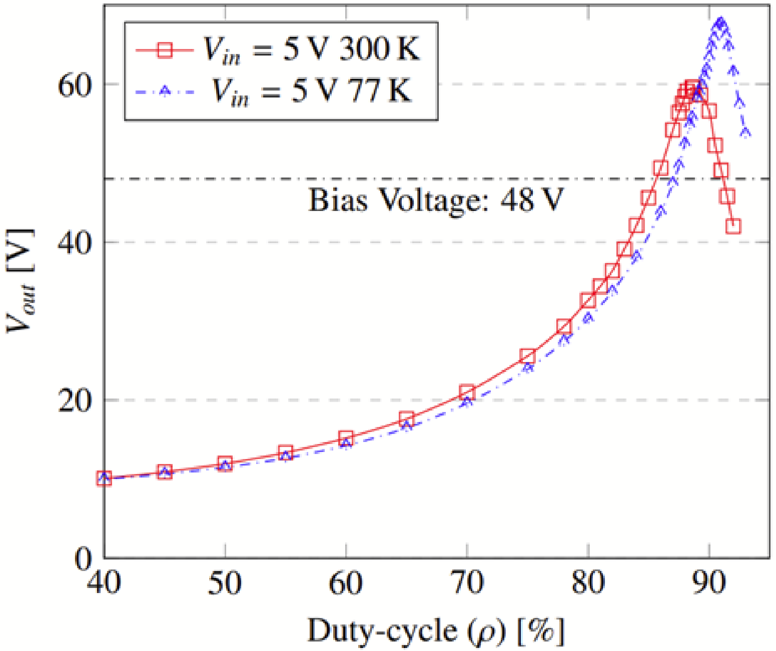
Noise Results in LN_2:

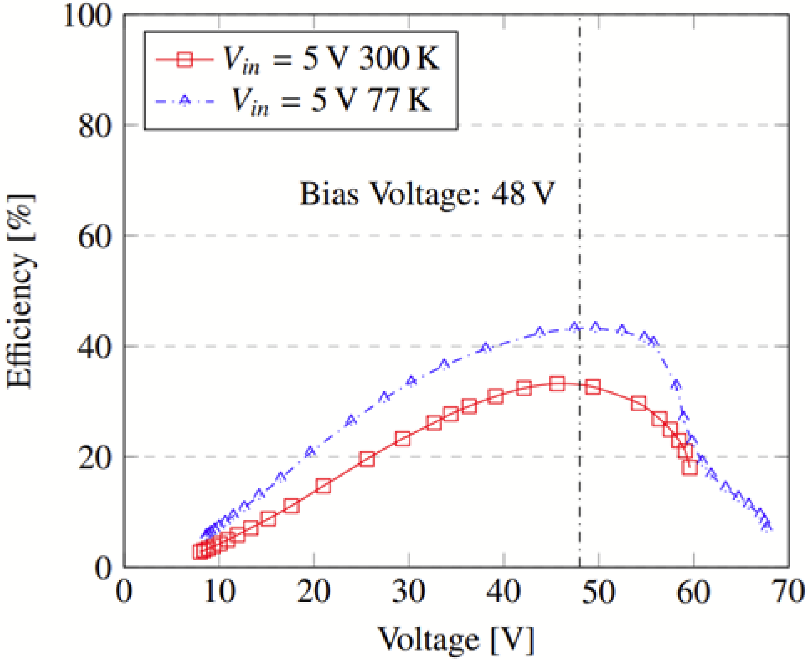
- Output voltage **FFT measurements** confirmed a **noise reduction** achieved with the EMI shield

DC-DC Boost Converter – Test results

Measurements Results:

- T = 300 K: V_{out} is limited by the inductor series resistor
- T = 77 K: V_{out} = 68 V at 91% of duty-cycle
- T = 77 K at V_{out} = 48 V: efficiency is greater than 40%



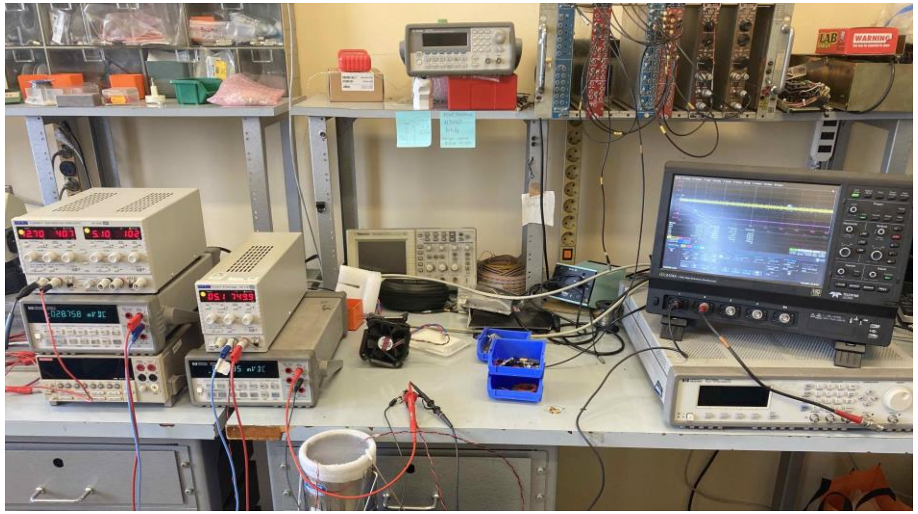


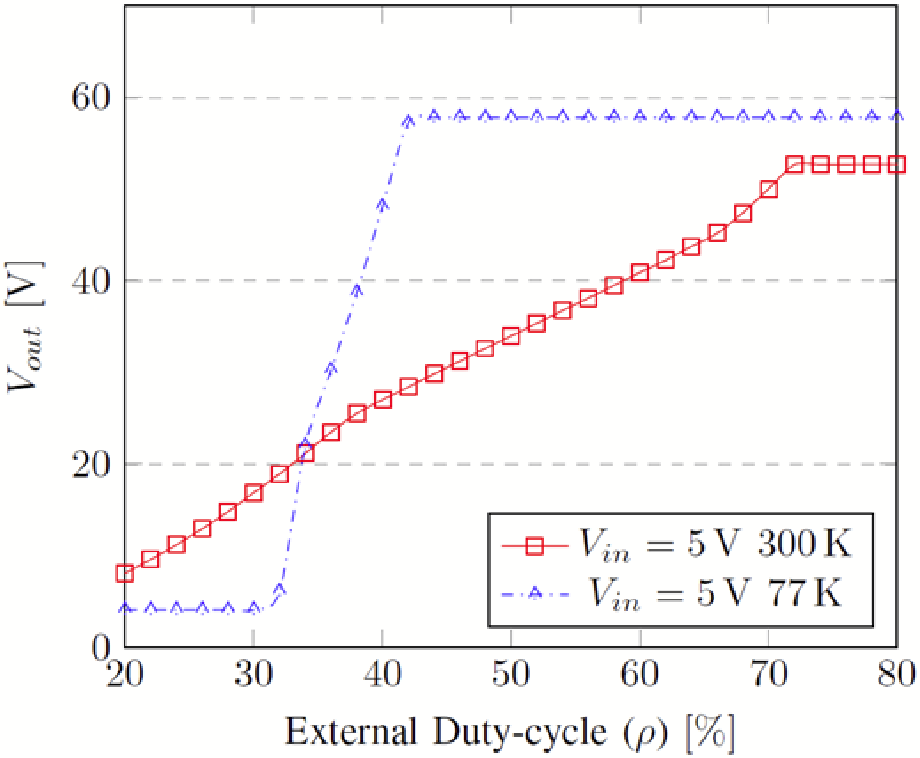
- ➢ Ascending at low duty-cycles: low current consumption
- ➢ Descending at high duty-cycles: high current consumption

DC-DC Converter – Remote control results

Test Results:

- **Linear trend** in the output voltage with the external duty-cycle
- **Steeper slope** at 77 K: saturation of the curve before 50% duty-cycle of the external signal

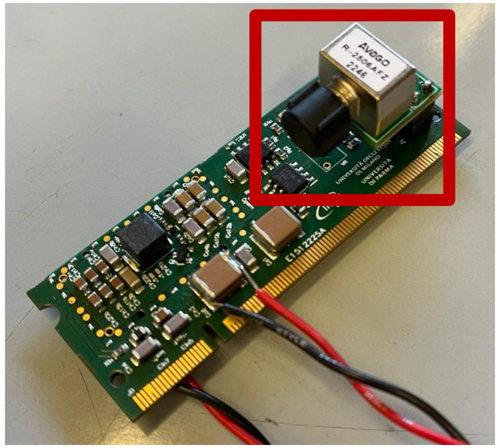




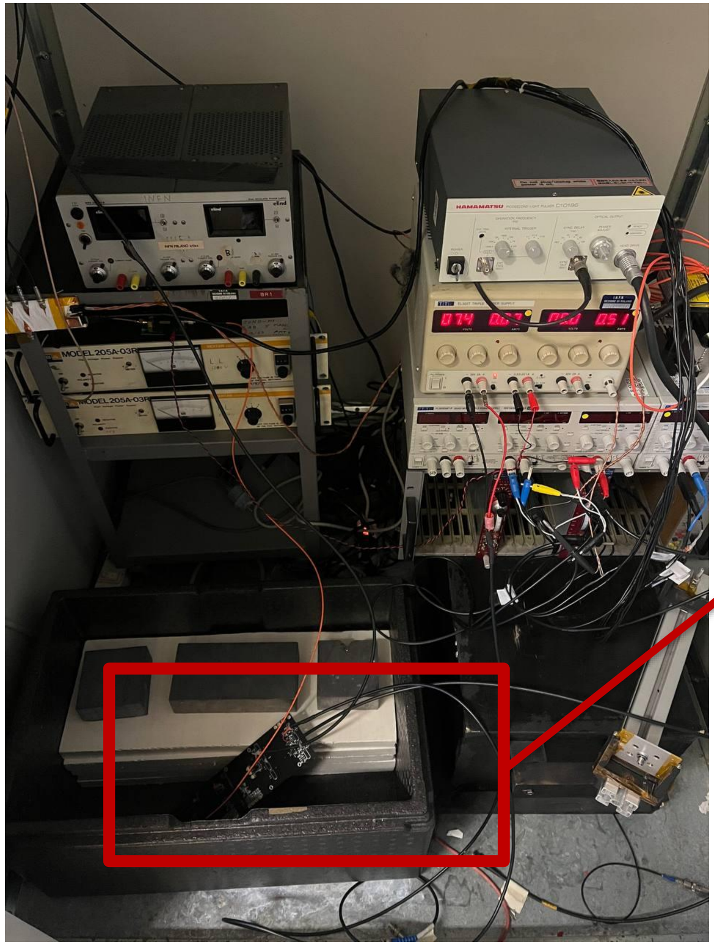
* **Waveform generator** for the external signal

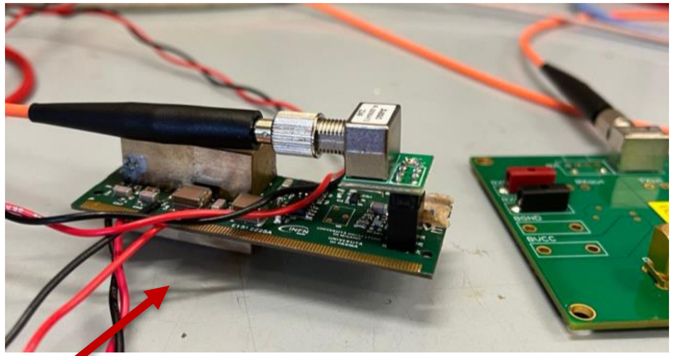
Optical link for remote control – Tests

Study of the DC-DC Boost Converter with **remote control via optical link.**



Preliminary tests performed at room temperature and 77 K.

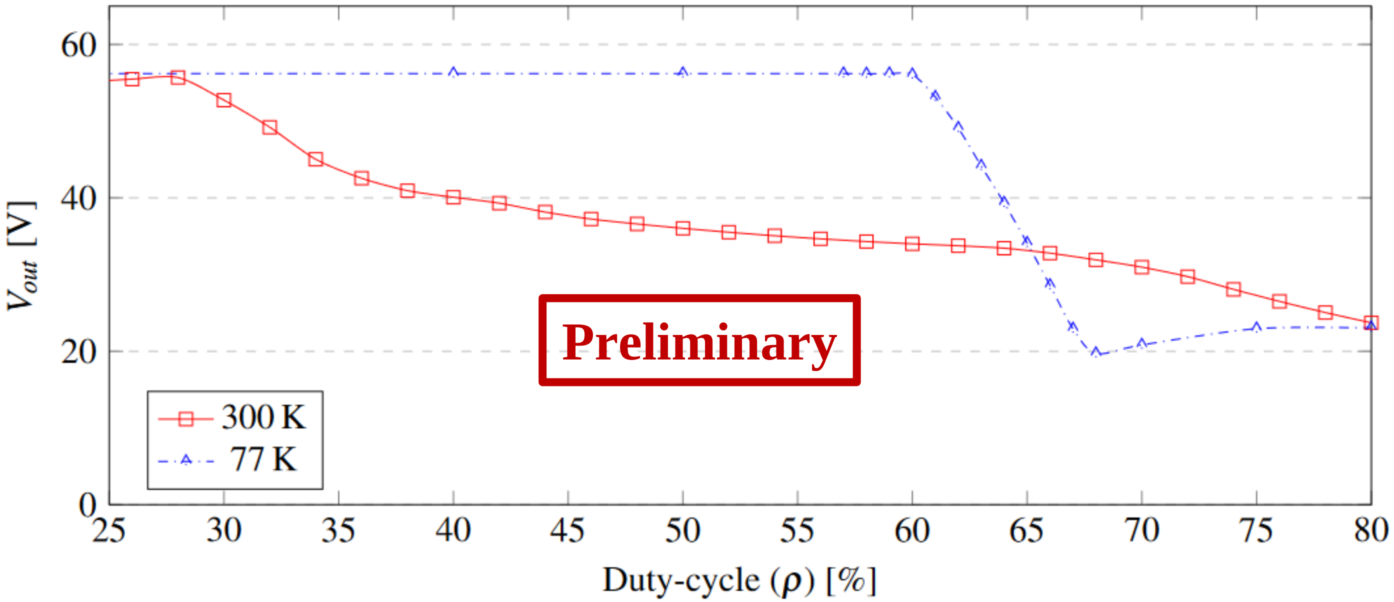




Interfaced board mounted on the DC-DC Converter.

DC-DC Boost Converter plugged into the ProtoDUNE motherboard.

Optical link for remote control – Results



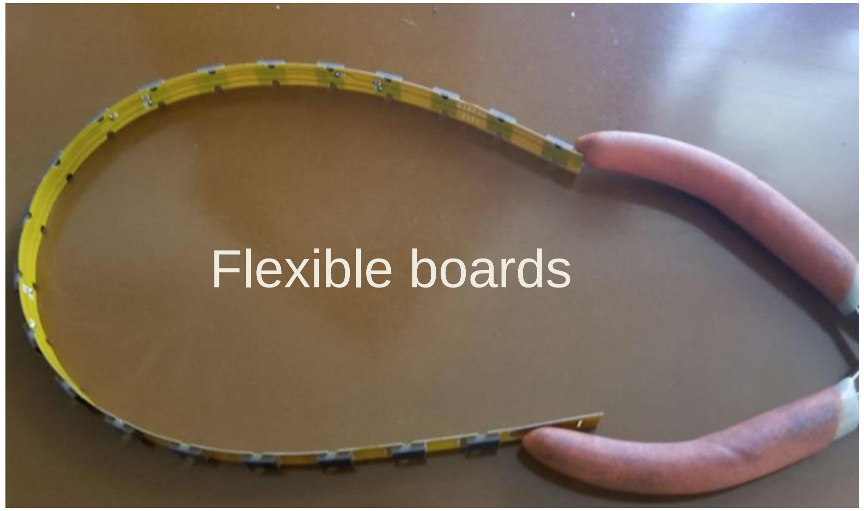
Test Results:

- **Linear trend** in the output voltage with the external duty-cycle
- **Steeper slope** at 77 K: saturation of the curve before room temperature case
- **Limit** for output voltage at 77 K: V_{out} = 56 V
- Tests have to be further performed to investigate the performance

New activity – CACTUS VD

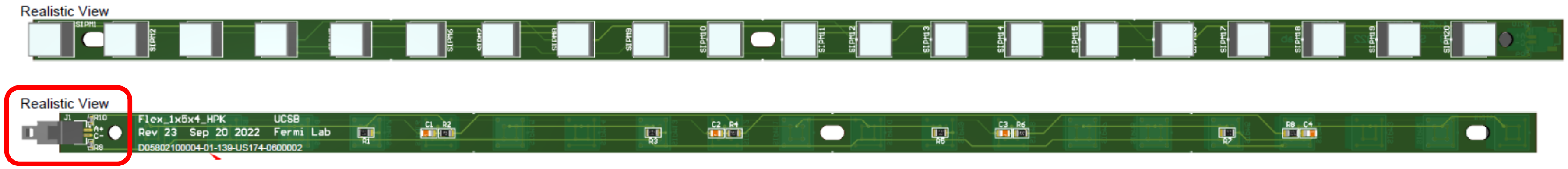
CACTUS (Cryogenic Apparatus for Control Tests Upon SiPMs) for automatic **SiPMs characterization** at room and liquid nitrogen temperature.

Each SiPM has dimensions of 6 × 6 mm^2 and each of them is passively ganged on one flexible Kapton PCB strip → **Flexi PCB** (i.e., one 30 cm flexible board has 20 SiPMs)



It is reasonable to think of a number close to <u>5800 Flexi boards</u> to be tested.

Connections



Design of CACTUS VD

Recyclable and/or reusable parts with modifications from CACTUS HD (to be further investigate):

- Warm Boards for signals read out (with modifications)
- LabVIEW program must be implemented starting from actual version

Ex novo parts for CACTUS VD (to be further investigated):

- Design Cold Boards (where the Flexi are installed during the test)
- Manufacturing of Cold Boards
- Mechanical structure

Schedule:

We estimated about 130 days to complete the tests but considering the rounding done (tests to be redone, spare parts, preliminary tests, etc.), we arrive at an **estimate of 150 days**: 2 measurements cycles per day (morning and afternoon)

→ We are evaluating a semi-manual or automatic testing procedure to verify if the individual SiPM is functioning properly or not (to be discussed)

Conclusions and future developments

DC-DC Boost Converter version 3:

- **Improved performance** at cryogenic temperature compared to room temperature
- **Noise reduction** achieved through the EMI shields
- Control studies provided an understanding of how the output varies in relation to the duty cycle of the **external signal**
- More tests to **investigate the performances** of the circuit in more complete configuration

Next steps for CACTUS VD:

- Ongoing tests aimed at defining the **design** of CACTUS VD
- More **preliminary tests** are mandatory (Flexi boards in the future)
- Some activities are on going; funds have been required and available from 2025

We will keep the Collaboration updated