Cryogenic power over fiber: results from the Cryo-PoF project and tests on a remotely controlled DC-DC boost converter

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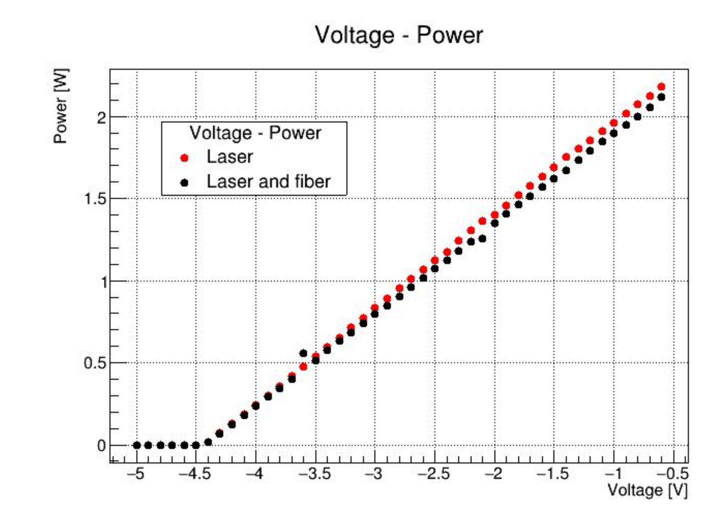
- **Cryo-PoF's main goal** is to power, at cryogenic temperature, both SiPM and cold amplifier, using a single Power over Fiber line and to tune SiPM bias with the laser power.
- R&D for the application of PoF for the DUNE Vertical Drift (VD) detector was initiated at Fermilab in 2020, motivated by the need to operate the Photon Detector System (PDS) on the high-voltage cathode surface [1].

- The **Power over Fiber** (PoF) technology delivers electrical power by sending laser light, through an optical fiber, to a photovoltaic power converter, in order to power sensors or electrical devices.
- PoF solution offers several **advantages**:
  - removal of noise induced by standard power lines,
  - robustness in a hostile environment,
  - spark free operation when electric fields are present,
  - no interference with electromagnetic fields.

GaAs laser source, 808 nm.

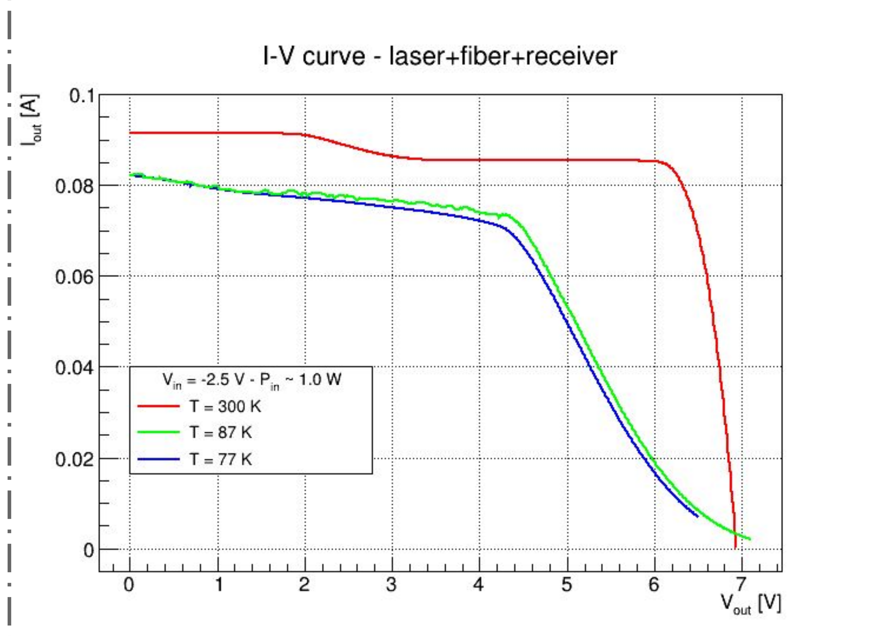
Output power tunable by means the input voltage.

- Characterization in terms of:
  - linearity,
  - power loss connecting an **optical fiber** (multi mode optical fiber, core diameter 105 μm, with 3.8 mm black plastic sheath) ~ 3.0 % power loss,
  - stability: max - min ~ 0.96%.



Optical Power Converter

- IV curvers using a semiconductor analyser.
- Tested at different P_{in}.
- Efficiency at cryogenic T ~ 30 %.



P_{in} ~ 1 W

T = 300 K : P_{max} = 0.52 W , I_{max} = 91.4 mA

T = 87 K : P_{max} = 0.32 W , I_{max} = 82.5 mA

T = 77 K : P_{max} = 0.30 W , I_{max} = 82.2 mA

Tests with SiPM in LN2 (T = 77 K)

SiPM, developed by Hamamatsu and FBK for DUNE [3,4]

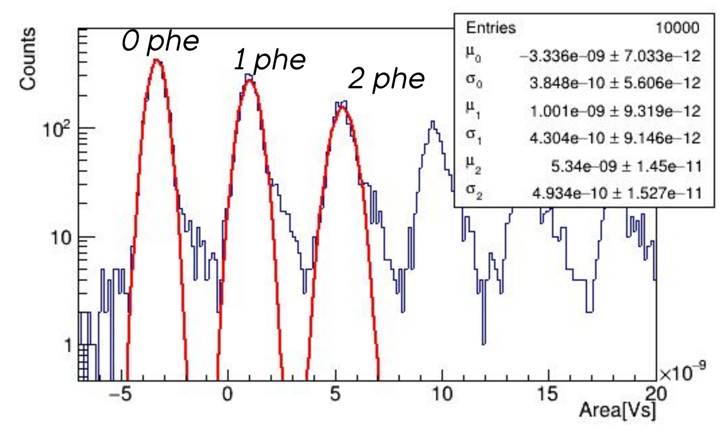
→ V_{bd} = 42.0 V at 77 K (Hamamatsu)

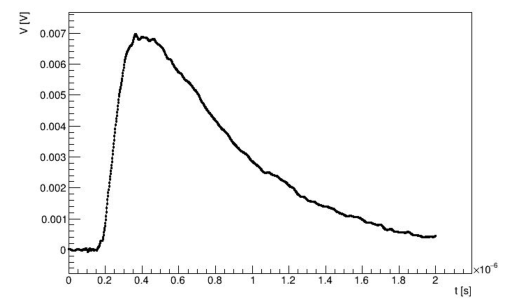
→ V_{bd} = 27.1 V at 77 K (FBK)

- Evaluation of the **Signal to Noise Ratio.**

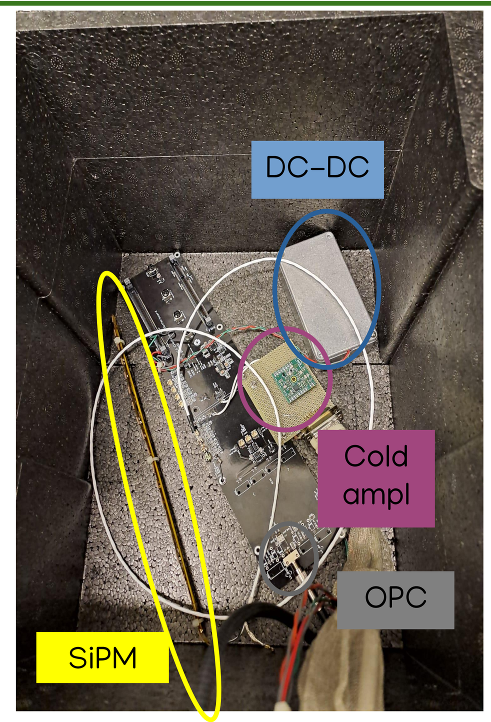
SiPM bias	SNR PoF
30.6 V	6.027
31.6 V	7.173
34.1 V	11.270

80 FBK SiPM
V_{bias} = 34.1 V





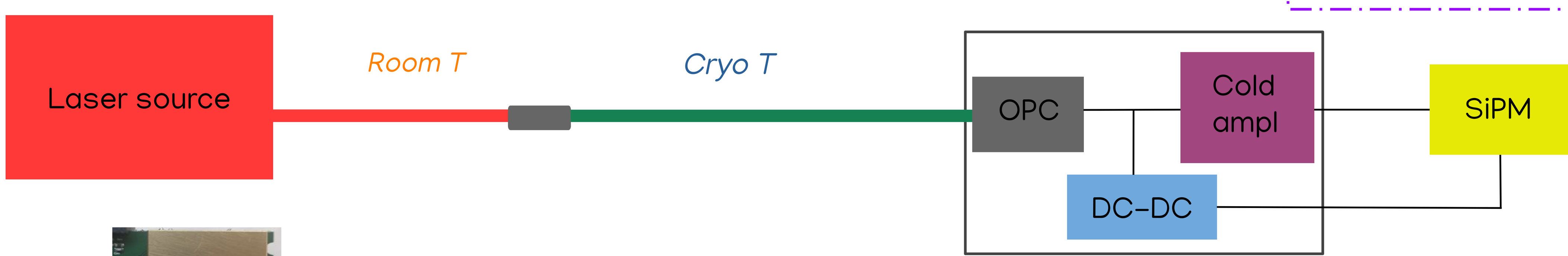
1 phe mean waveform



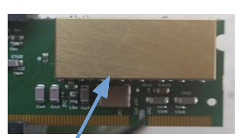
20 Hamamatsu SiPM

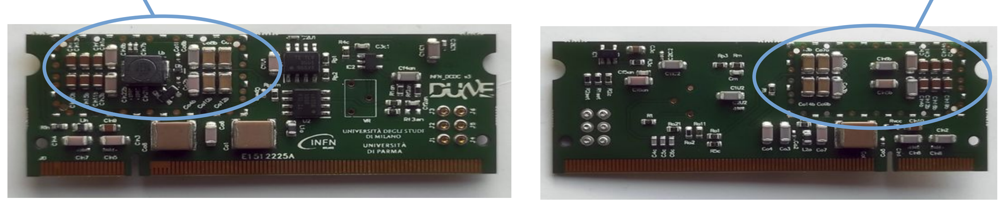
SiPM bias	SNR Copper cable	SNR PoF
45 V	7.830	7.520
46 V	10.665	9.409
47 V	13.004	11.070

Cold amplifier developed by MiB group for DUNE [2] → V_{in} = 3.3 V



Soldered Electromagnetic Interference (EMI) shield over the boost for noise measurements

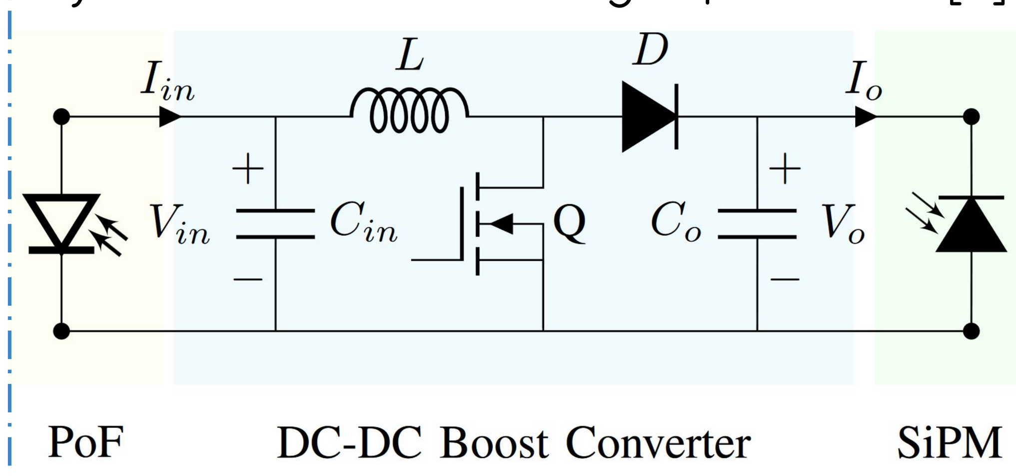




DC-DC prototype top layer (left) and bottom layer (right).

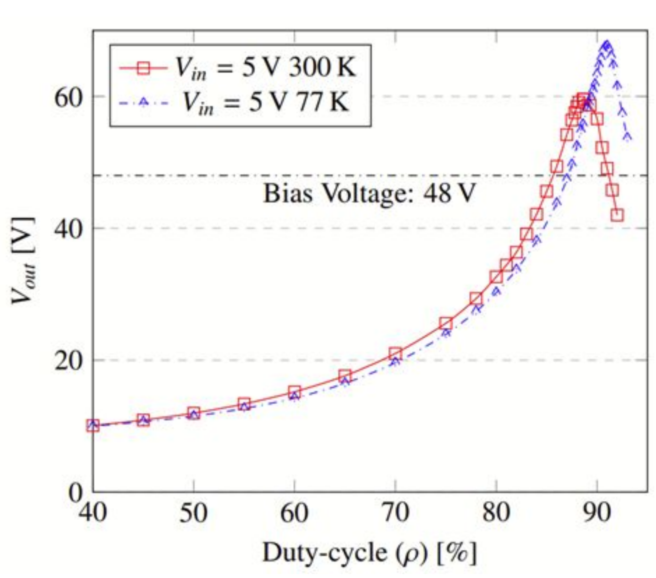
- **Discrete components** independently characterized at 77 K in the last two years [5].
- **Working version** has been demonstrated in test set-ups at CERN.
- **Advanced DC-DC prototype** with improved input and output filters, and optimized analog feedback control circuitry tested.

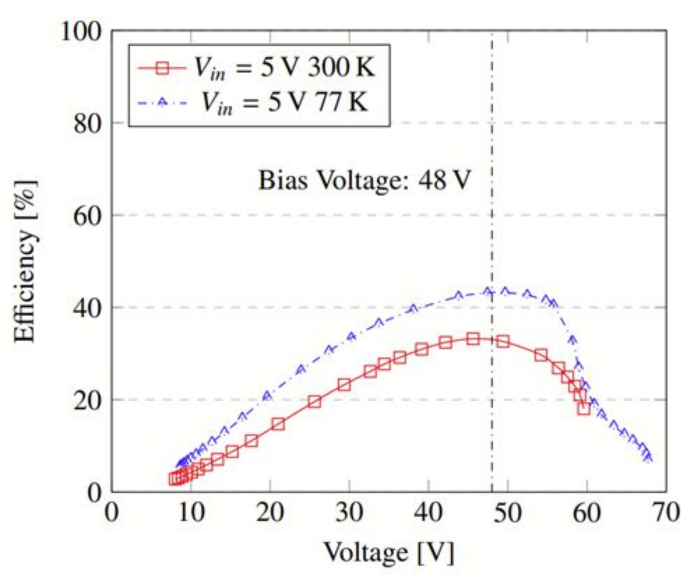
DC-DC Boost Converter prototype proposed by Milano Statale - Parma group for DUNE [5]



System overview

- **Power supply** by Optical Power Converter → V_{in} = 5 V
- **Pulse Width Modulated (PWM) generation** with inner feedback setting output voltage at nominal point → V_{out} = 48 V
- **Analog feedback** control loop circuit



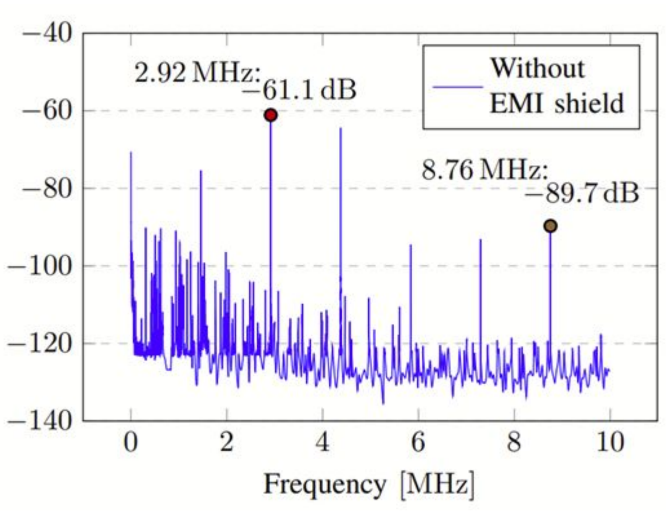


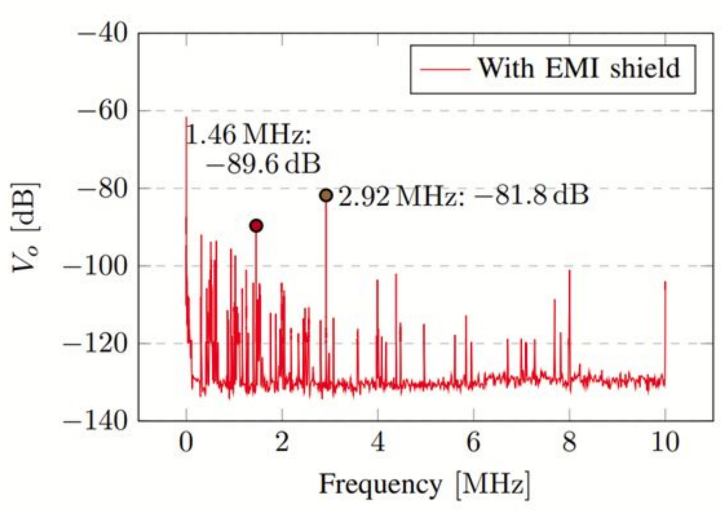
Test Results

T = 300 K : V_{out} is limited by the inductor series resistor

T = 77 K : V_{out} = 68 V at 91% of Duty Cycle

Efficiency at T = 77 K at V_{out} = 48 V is greater than 40%





Noise Results in LN2

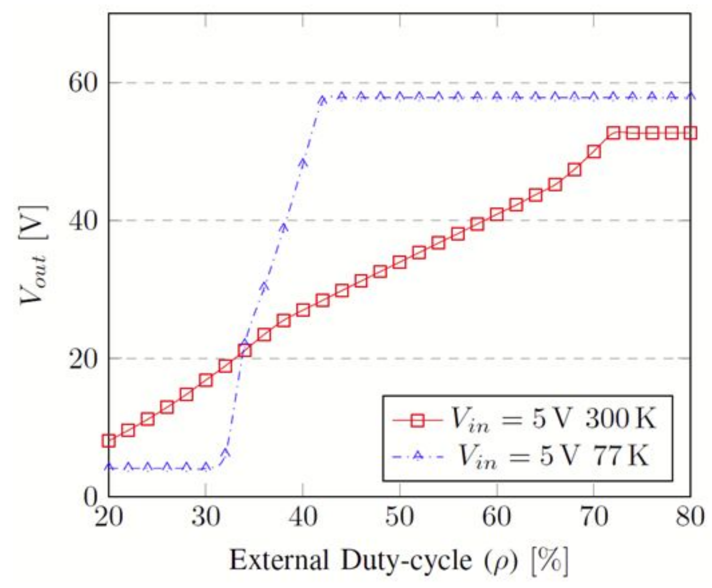
Output voltage **FFT measurements:** confirmation of noise reduction achieved through the EMI shield.

Control design

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
- **External:** set point modified through external communication (nominal set point in case of failure or no external control)



*Test performed with electrical connection (waveform generator)

Test Results

- External PWM signal through optical fiber: **external set point.**
- The reference level changes.
- AC-coupling in case of external PWM, otherwise reference set by voltage divider.

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[1] W. Pellico, "Power over fiber", talk at the DUNE FD-2 (VD) Photon Detector Workshop, Jul 26-27 2021, https://indico.fnal.gov/event/50157/
[2] C. Brizzolari et al.,"Cryogenic front-end amplifier design for large SiPM arrays in the DUNE FD1-HD photon detection system", 2022 JINST 17 P11017
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