Results from Cryo-PoF project: power over fiber at cryogenic temperature for fundamental and applied physics

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Overview

- **Cryo-PoF:** Cryogenic Power over Fiber.
- It is funded by "Young Researcher Grant" from Istituto Nazionale di Fisica Nucleare (INFN, Italy) (INFN CSN5 Young Grant 2021) from February 2022 for 2 years; PI: M. Torti; Institutions: Univ. Milano-Bicocca and Univ. Milano Statale.
- **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.
- In this talk:
    - Cryo-PoF idea and setup;
    - results and comparison with the copper cable results in LN;
    - preliminary test at lower temperature (~ 10 K).

Power overe Fiber technology

- 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.
- Several producers of PoF systems are available on the market and this technology has been already employed in industry.
- No attempt has been done to port the technique at the cryogenic level. The reason is that electronic components are certified down to 233 K (-40° C) .

- 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.

- Ideal solution where the environmental conditions are prohibitive for a copper-based power line.

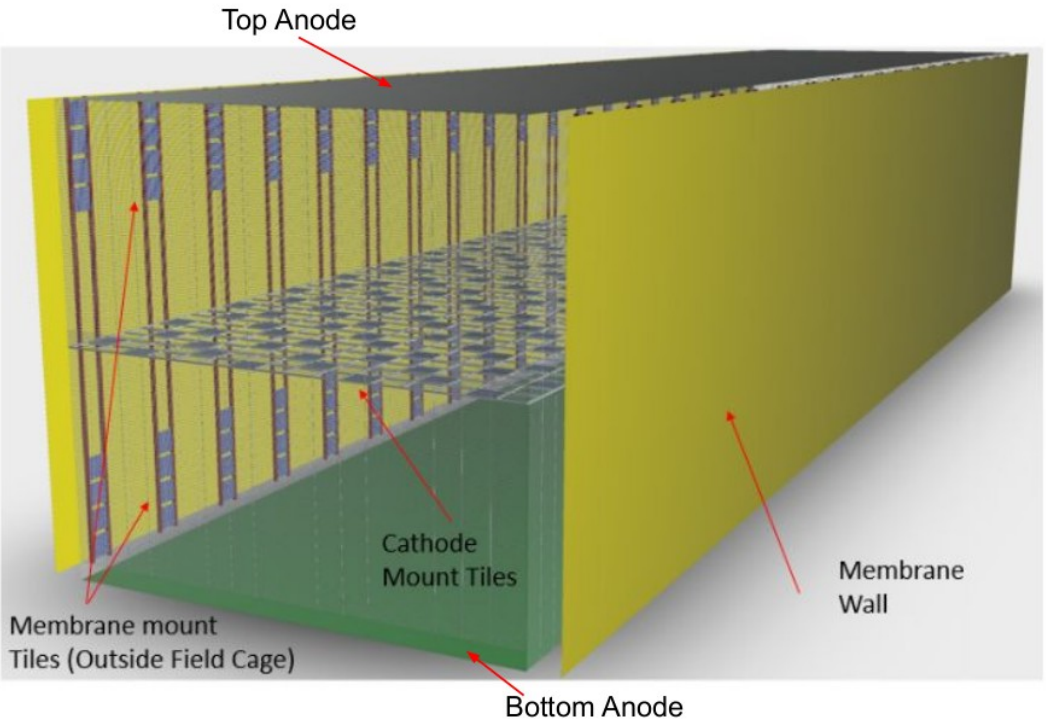
DUNE Vertical Drift

- **DUNE Vertical Drift** (VD) module: LAr TPC in which electrons drift toward the anodes placed on top and bottom of the detector. Anode planes will be made by PCBs, so light opaque.

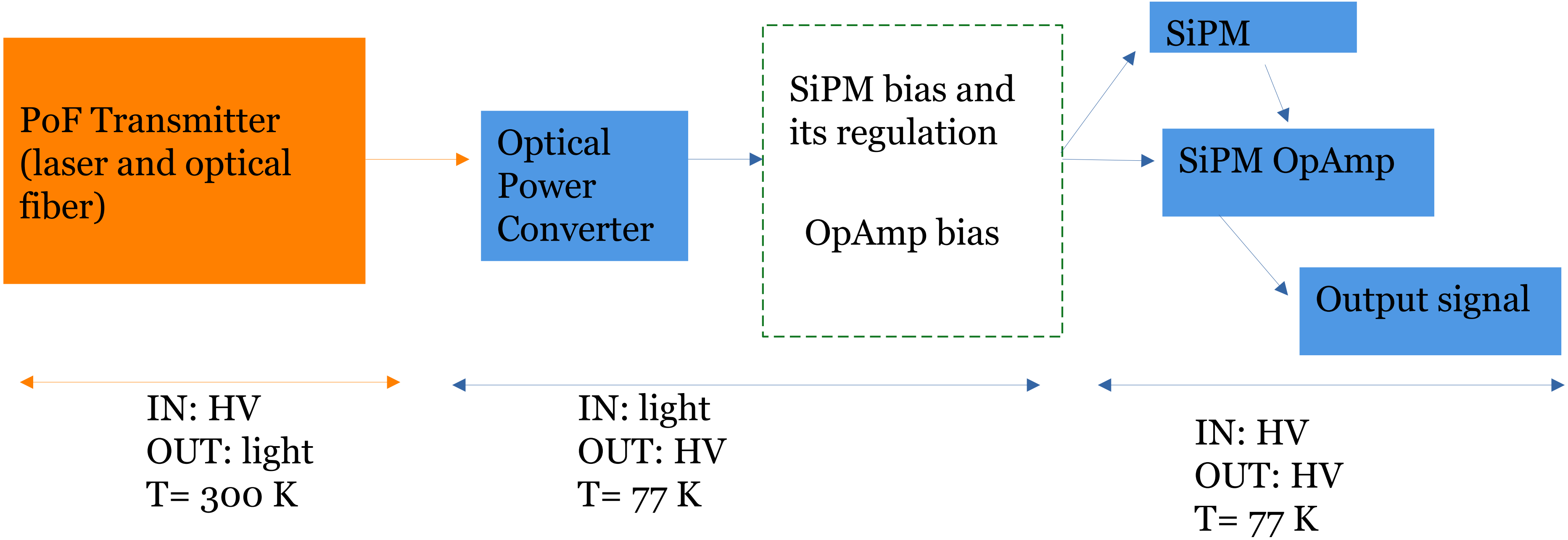
- The grid cathode is at half height and operated at 320 kV.

- **Photon Detection System** (PDS) can be placed or on the cathode or outside the field cage with much lower photon collection efficiency .

- PoF is the choosen technology to power the PDS (*W. Pellico's idea*: *"Power over fiber", talk at the DUNE FD-2 (VD) Photon Detector Workshop, Jul 26-27 2021, https://indico.fnal.gov/event/50157/*)



Cryo PoF : the concept

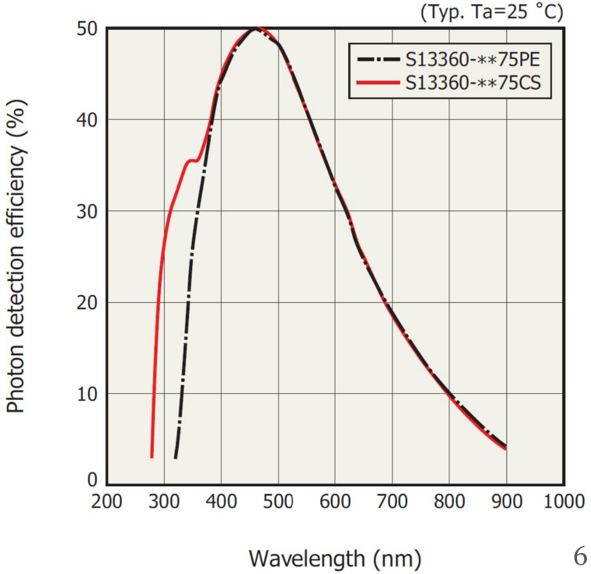


Laser source

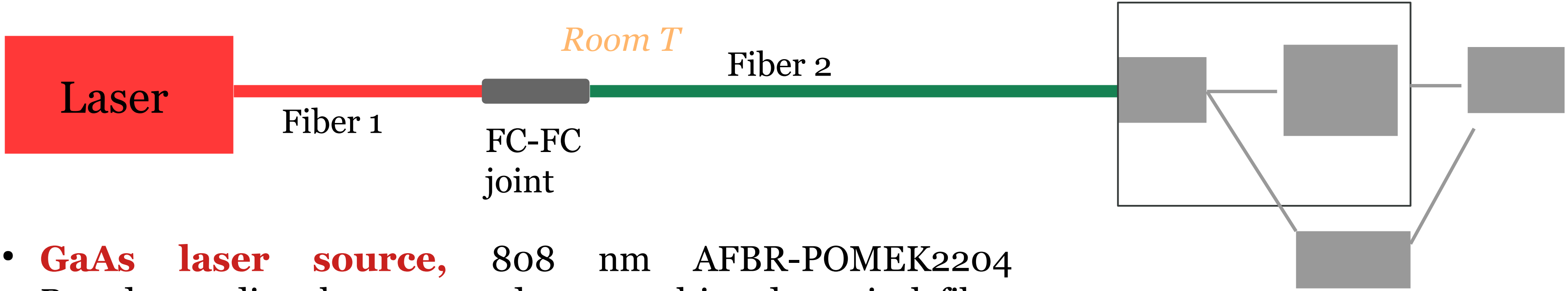
- **GaAs laser source**: 808 nm

Why?

SiPMs photon detection efficiency has a peak around 500 nm
→ laser light should better be far from it!



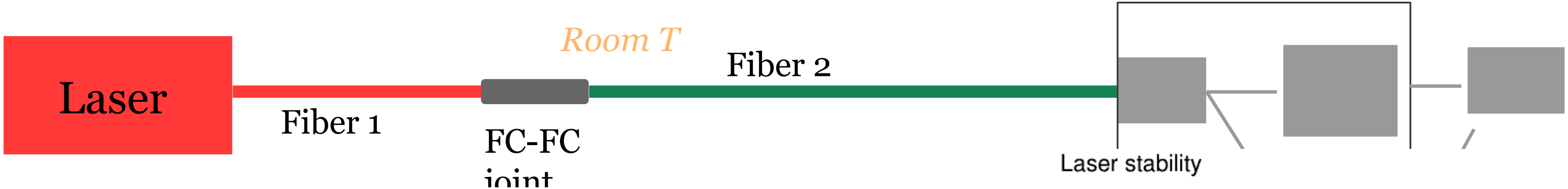
Laser source

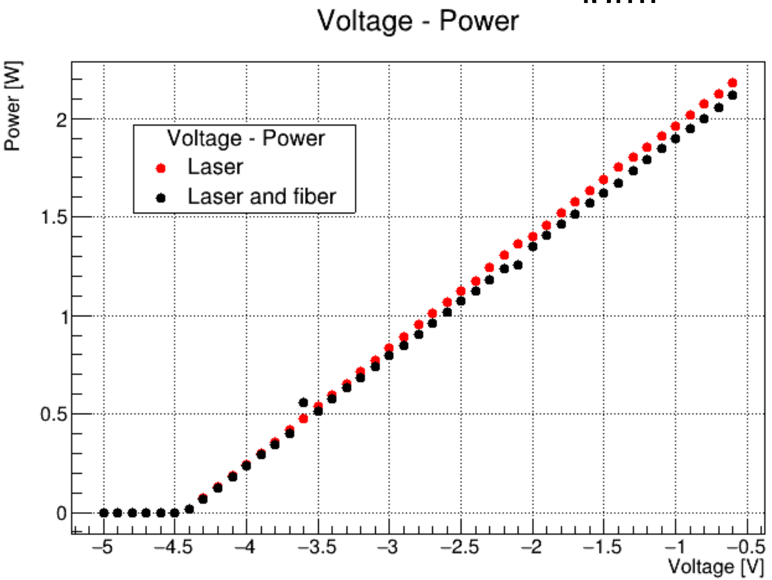


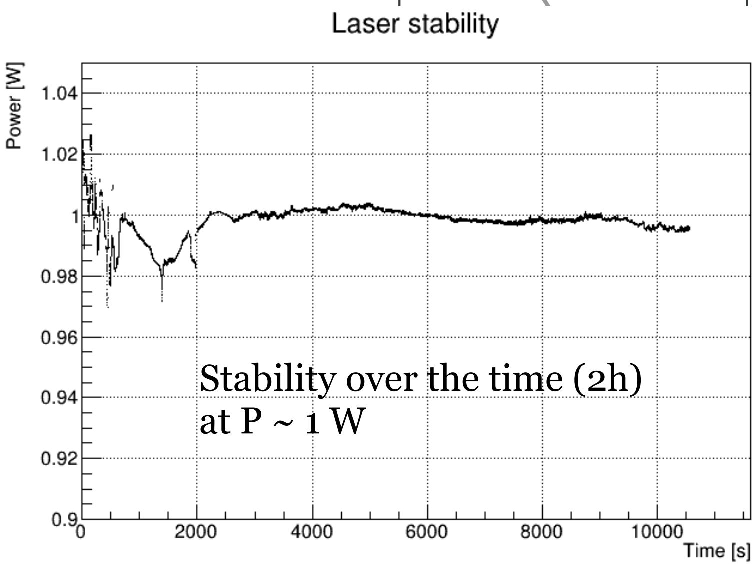
- **GaAs laser source,** 808 nm AFBR-POMEK2204 Broadcom, directly connected to a multimode optical fiber (62.5 µm core diameter).
- Characterization of the laser source in terms of:
  - linearity,
  - power loss connecting an **optical fiber**,
  - stability over time.

Graded index multi mode optical fiber, (core diameter 105 µm) with with black reinforced 3.8 mm tube. from Thorlabs

Laser source







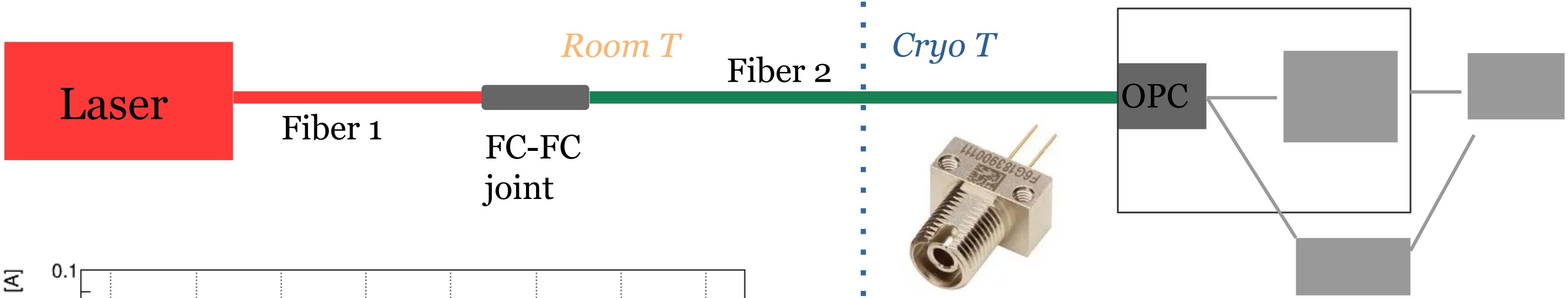
~ 4.5 % power loss adding a FC/FC joint and an optical fiber.

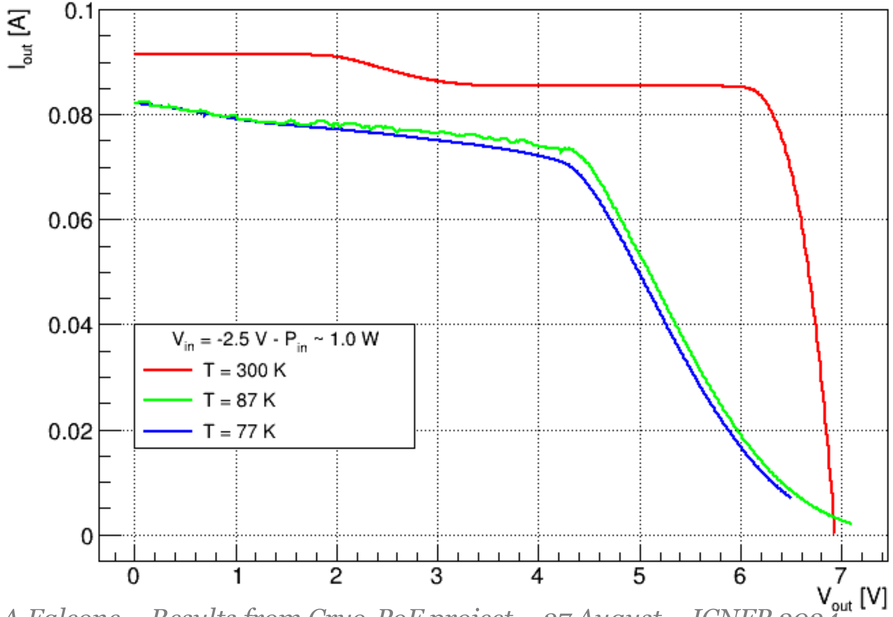
Max – Min ~ 5.7% - Mean(P_o – P_i) = 17.1 mW

Without the first 30 min:

Max – Min ~ 0.96% - Mean(P_o – P_i) = 15.9 mW

Optical Power Converter





- **Optical power converter,** AFBR-POC206L from Broadcom
- IV curvers using a semiconductor analyser
- Tested at different P_{in}

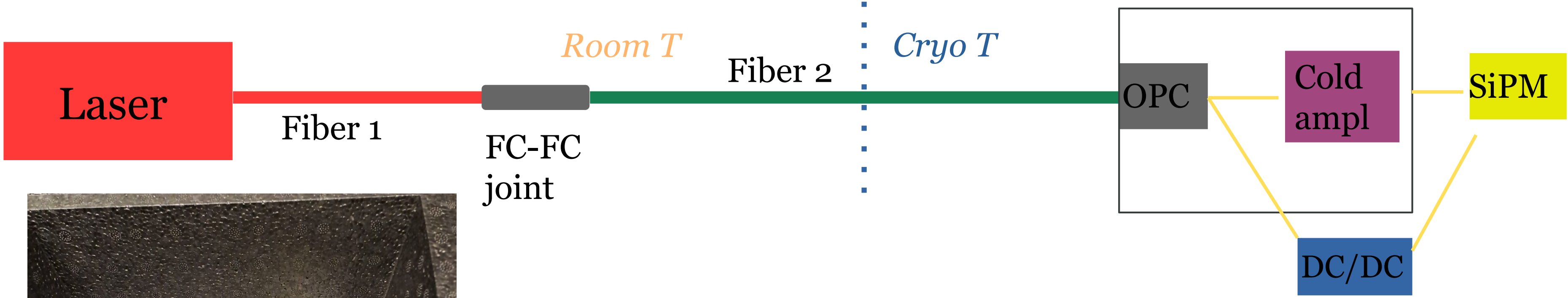
P_{in} ~ 1 W

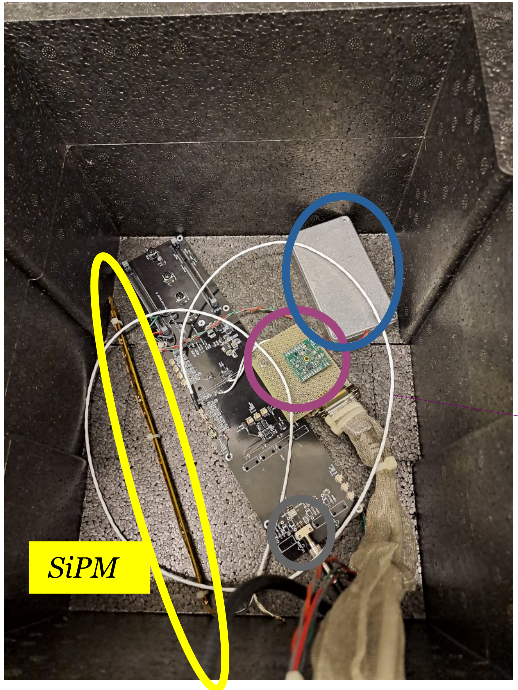
T = 300 K : P_{max} = 0.52 W , I_{max} = 91.4 mA

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

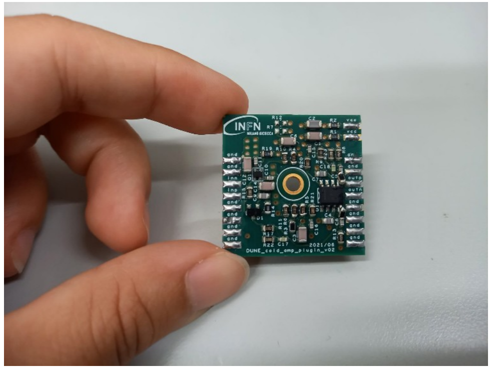
T = 77 K : P_{max} = 0.30 W , I_{max} = 82.2 mA

From laser to SiPM





- **Cold amplifier** developed by Milano Biccoca group for DUNE,
  → V_{in} = 3.3 V



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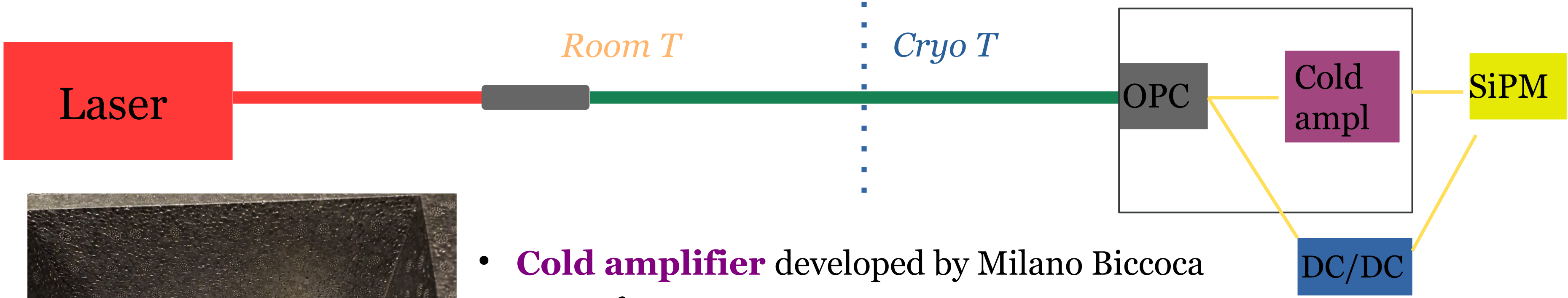
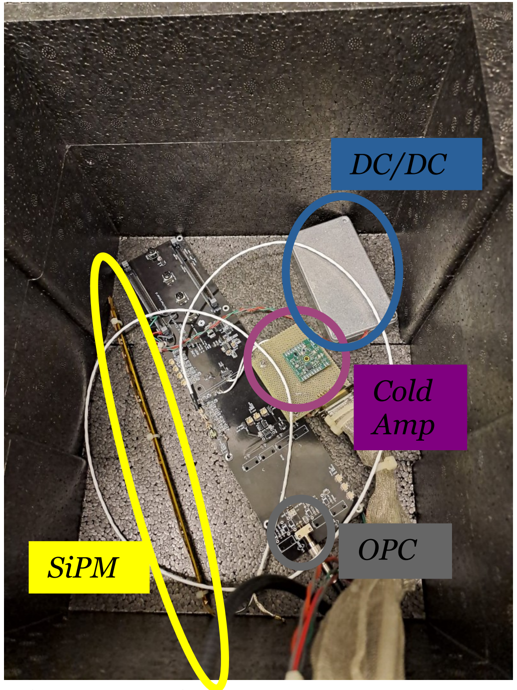
From laser to SiPM

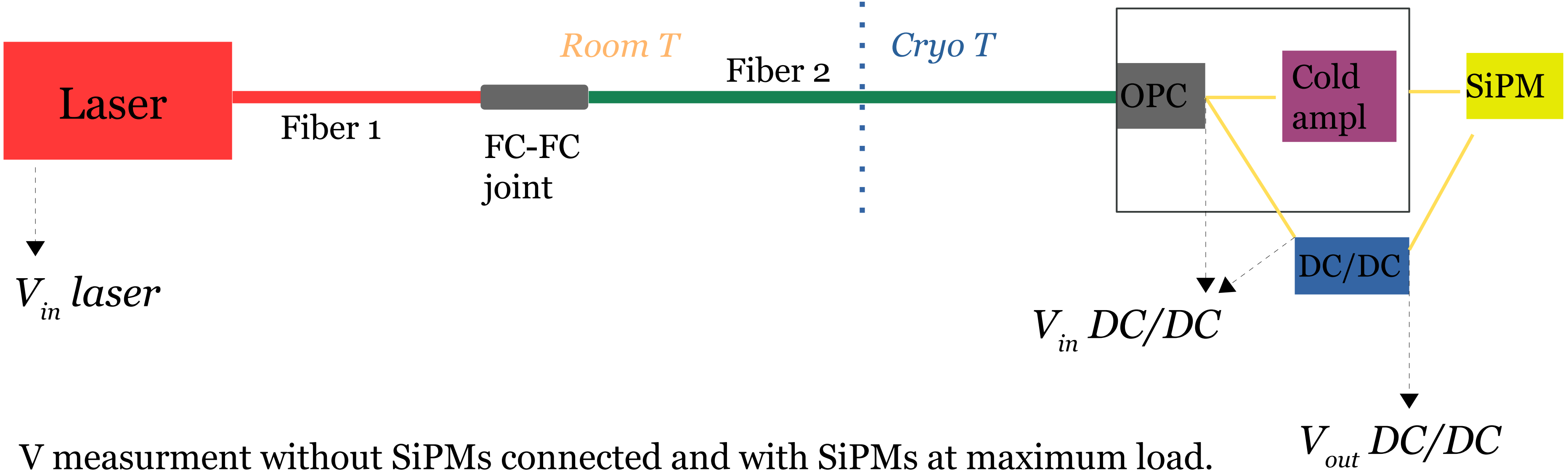




- **Cold amplifier** developed by Milano Biccoca group for DUNE → V_{in} = 3.3 V
- **DC-DC** boost converter developed by INFN Milano Statale group, → give bias to SiPMs;
  → V_{in} ~ 5 V; V_{out} ~ [40, 50] V for Hamamatsu SiPM
  → V_{in} ~ 5 V; V_{out} ~ [25, 35] V for FBK SiPM
  → placed in a metallic box to reduce noise.

N. Gallice et al., 2022 IEEE I2MTC.

DC/DC boost converter



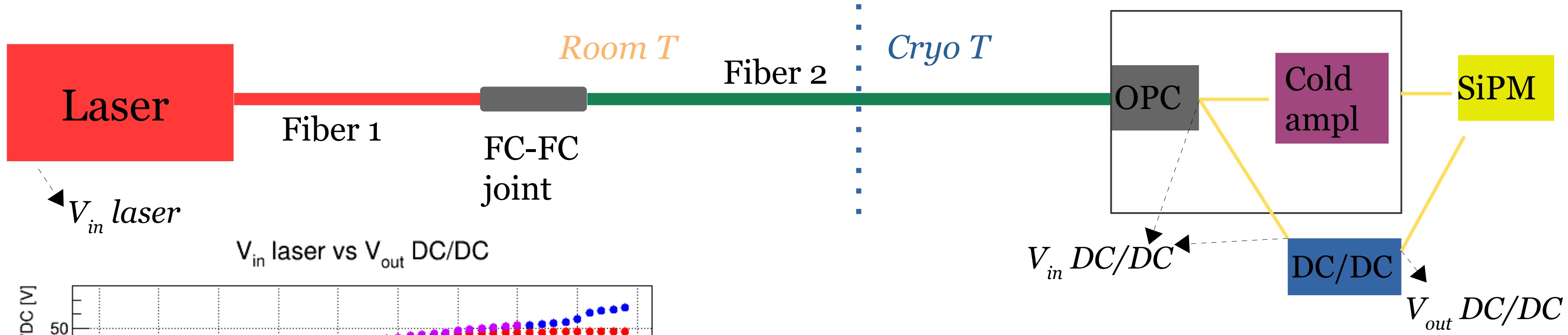
V measurment without SiPMs connected and with SiPMs at maximum load.

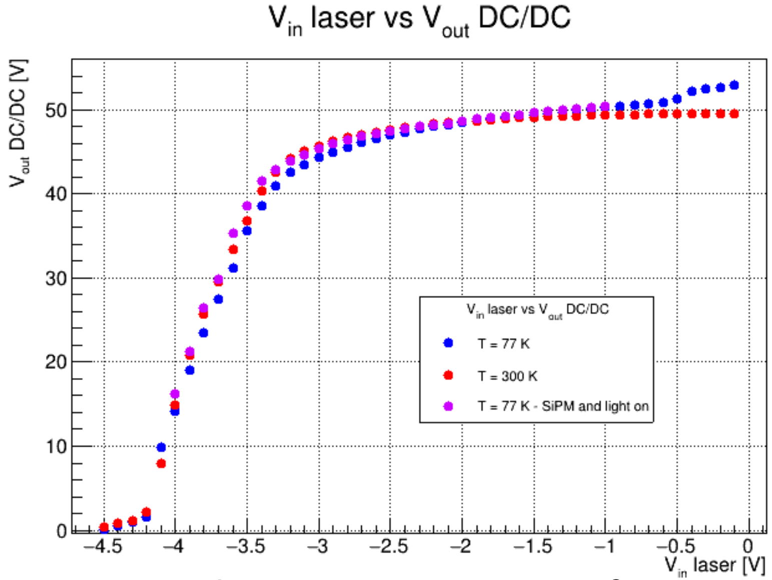
V_{in} laser → V laser source input, proportional to the laser power;

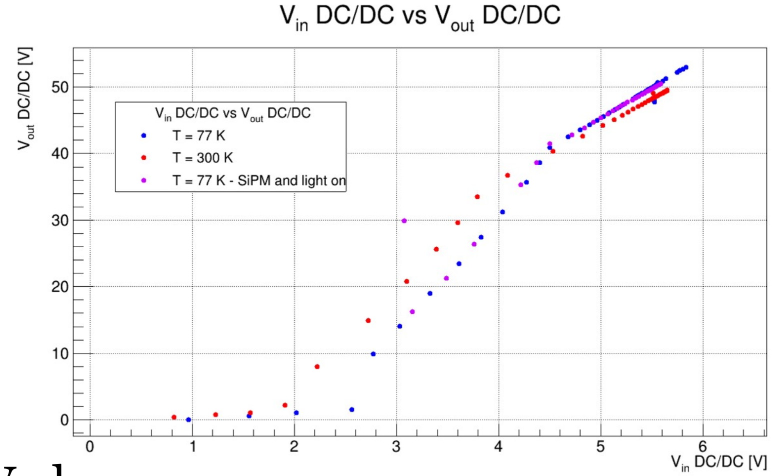
V_{in} DC/DC → V output from the OPC, that is the DC/DC input ;

V_{out} DC/DC → V output from the DC/DC, that is the SiPMs bias voltage.

DC/DC boost converter

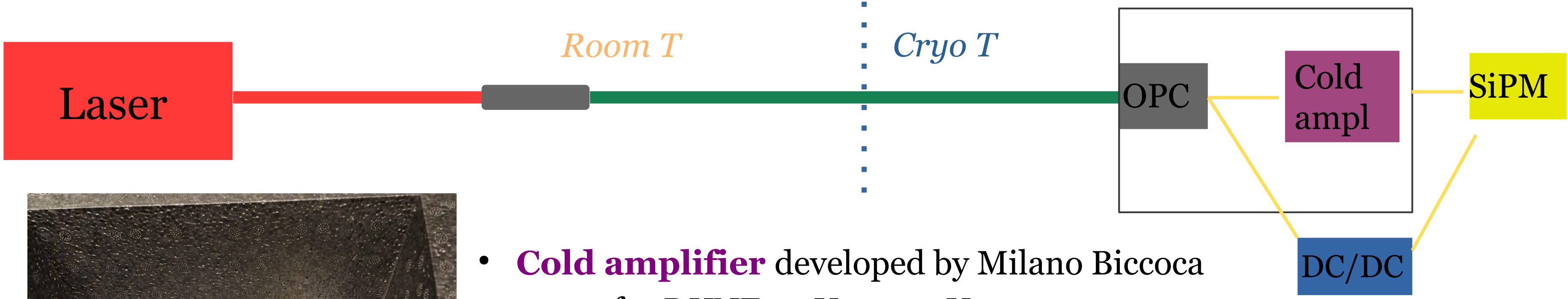


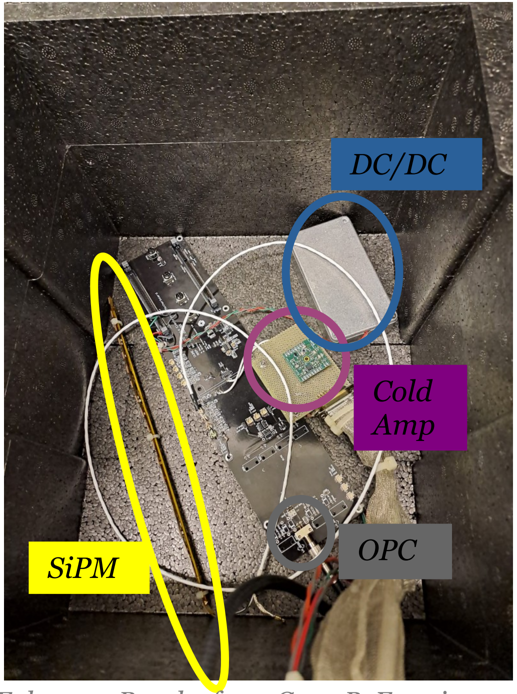




V_{out} DC/DC increases as a function of V_{in} laser.

From laser to SiPM





- **Cold amplifier** developed by Milano Biccoca group for DUNE → V_{in} = 3.3 V
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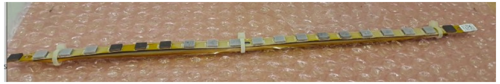
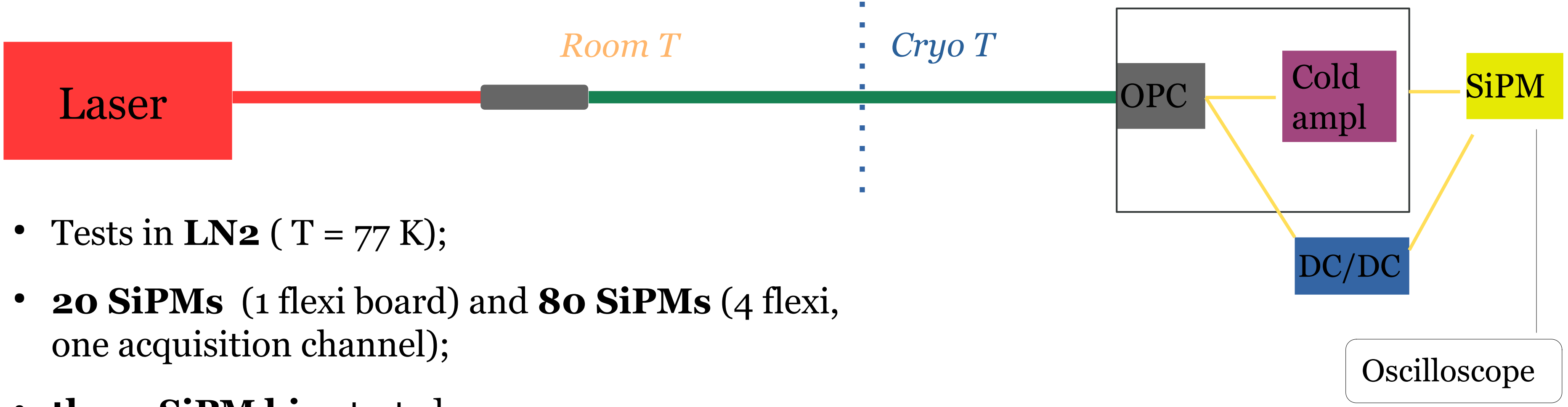
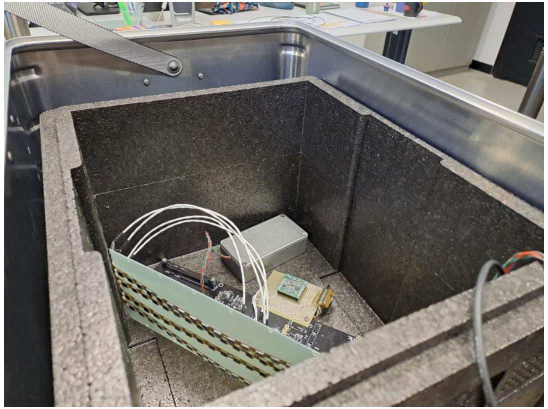
  → V_{in} ~ 5 V; V_{out} ~ [40, 50] V for Hamamatsu SiPM
  → V_{in} ~ 5 V; V_{out} ~ [25, 35] V for FBK SiPM
  → placed in a metallic box to reduce noise.
- **SiPM**, developed by Hamamatsu and FBK for DUNE,
  → flexi board with **20 SiPMs**,
  → V_{bd} = 42.0 V at 77 K for Hamamatsu
  → V_{bd} = 27.1 V at 77 K for FBK



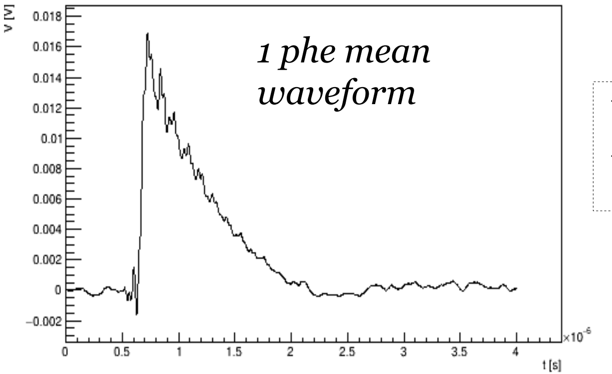
Results



- Tests in **LN2** (T = 77 K);
- **20 SiPMs** (1 flexi board) and **80 SiPMs** (4 flexi, one acquisition channel);
- **three SiPM bias** tested :
  → 45 V, 46 V, 47 V for HPK;
  → 30.6 V, 31.6 V, 34.1 V for FBK;
- trigger with an external by LED source;
- evaluation of the **Signal to Noise Ratio** $SNR = \frac{\mu_1 - \mu_0}{\sigma_0}$
- comparison of the results: PoF vs copper line.



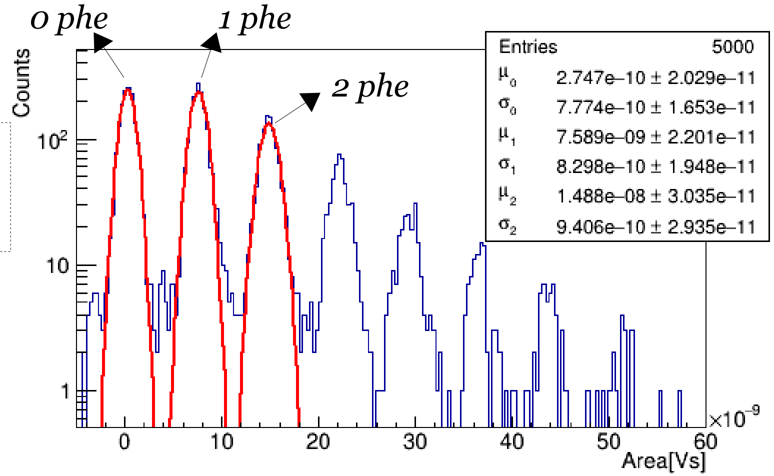
20 HPK SiPM test



PoF

V_{in} laser = -2.61 V (~ 1 W)
V_{bias} = 47 V – 5 V ov

SNR = 11.070



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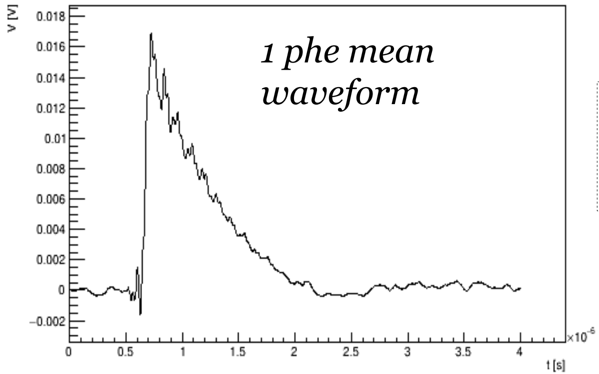

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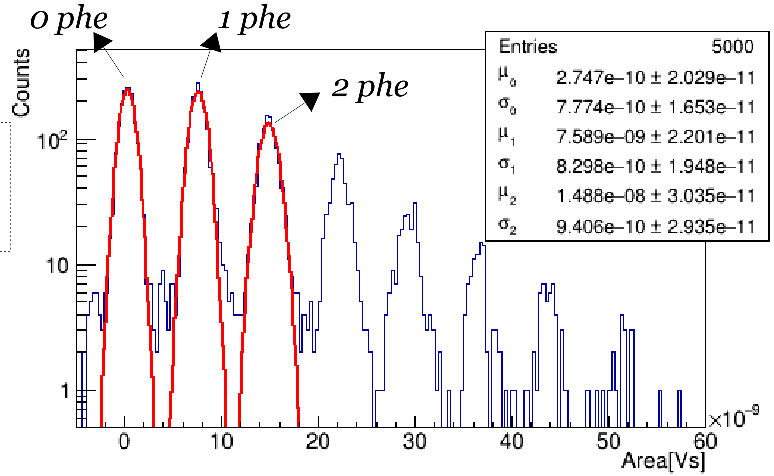
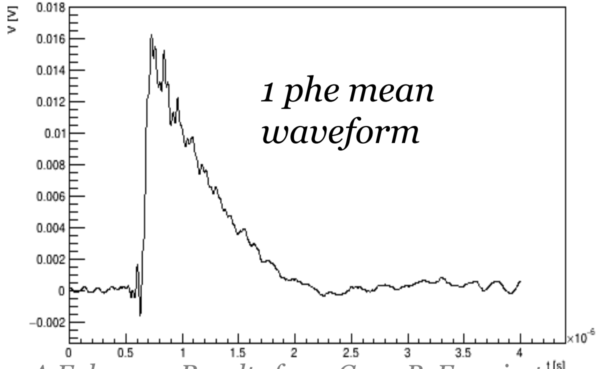
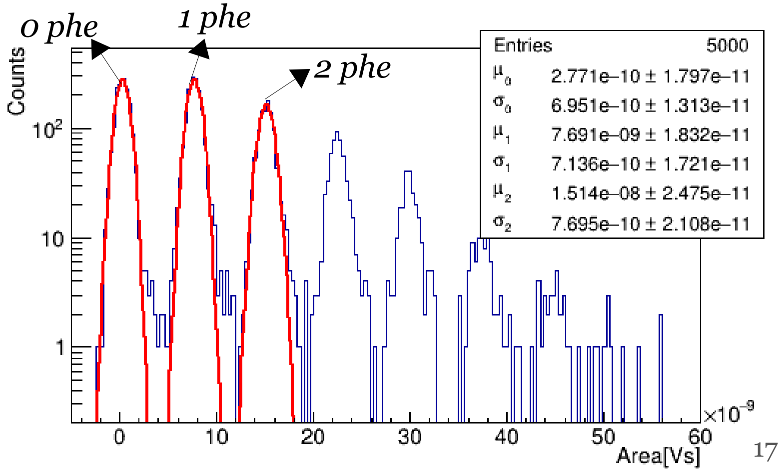


Copper cable



V_{bias} = 47 V – 5 V ov

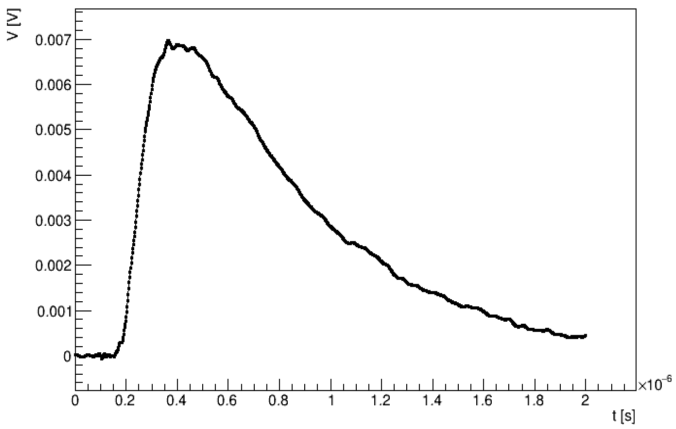
SNR = 13.004

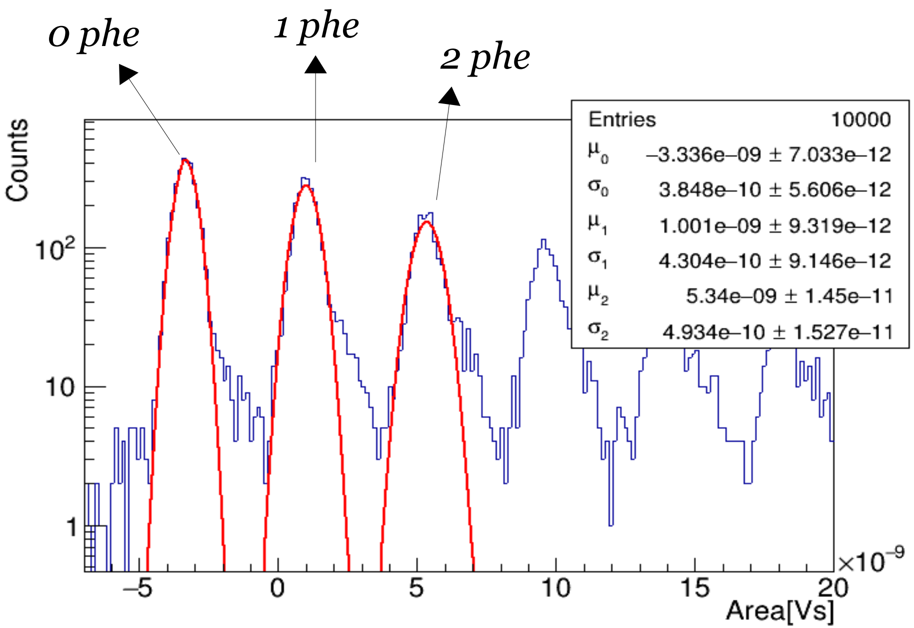


80 FBK SiPM test

V_{in} laser = -1.94 V (~ 1.3 W)
V_{bias} = 34.1 V – 7 V ov

1 phe mean waveform

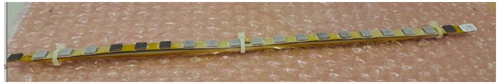




SNR = 11.270

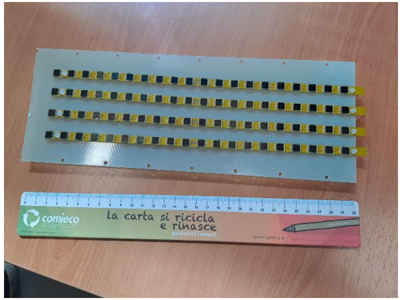
Summary of the SNR

HPK – 20 SiPMs



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

FBK – 80 SiPMs

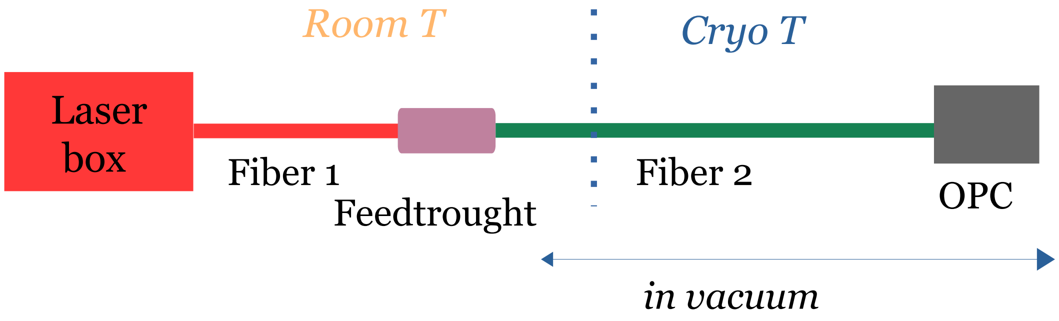


SiPM bias	***SNR PoF***
30.6 V	6.027
31.6 V	7.173
34.1 V	11.270

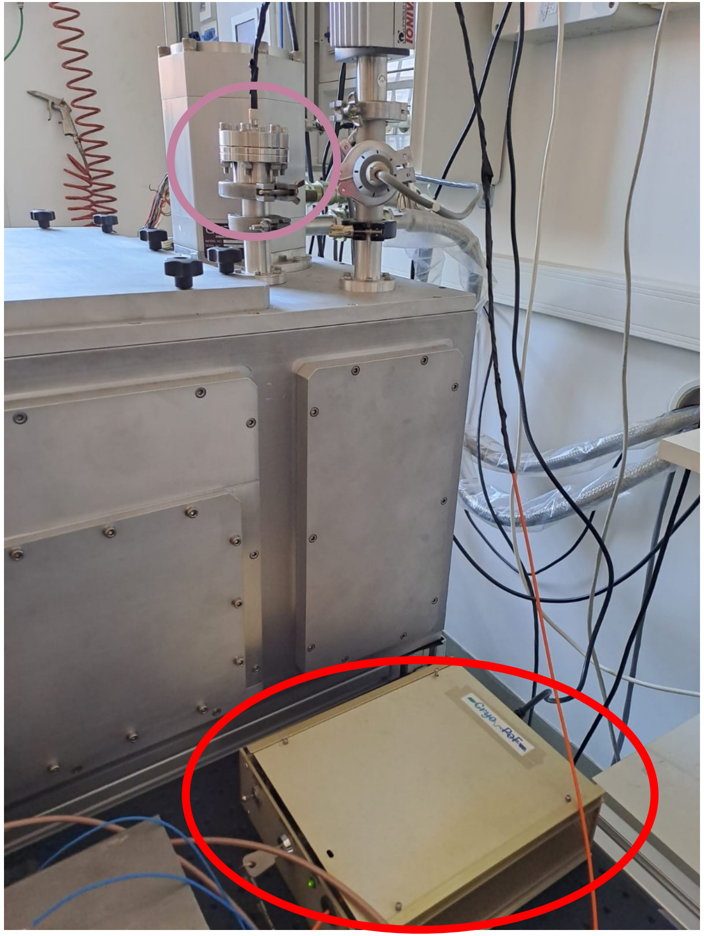
Test at lower temperatures then LN (< 77 K)

- Test Power over Fiber technology at temperature lower then 77 K.
- We tested our setup (from laser to OPC) in a cryostat **till 7 K** and characterized the OPC output registering the I-V curves with the semiconductor analyzer.
- The system was in vacuum; the temperature was fixed and controlled by means of an heater and a termometer.
- There was a large power loss in the feedtrough (its core diameter smaller than the fiber core).
- The laser power at the OPC was ~ 5 mW.

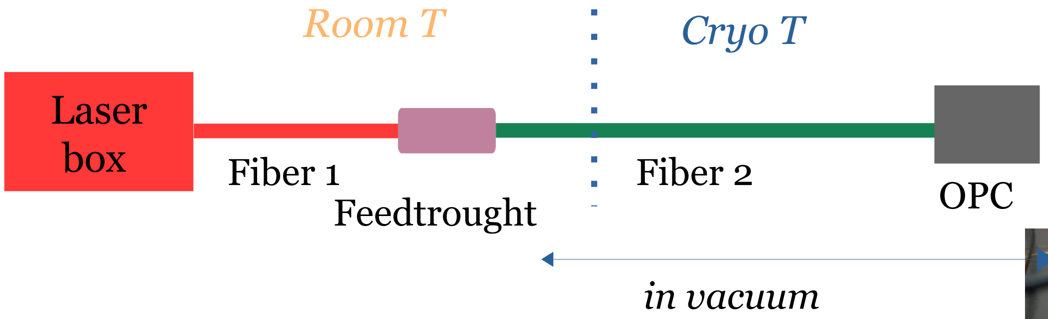
Test at lower temperatures then LN (< 77 K) - Setup



- **Laser Box** with the GaAs laser source, 808 nm;
- **optical feedtrought** (50 um core diameter);
- **graded index multi mode optical fiber** with 62.5 um core diameter;
- **optical power converter** AFBR-POC206L from Broadcom,
- temperature sensors,
- heater.



Test at lower temperatures then LN (< 77 K) - Setup



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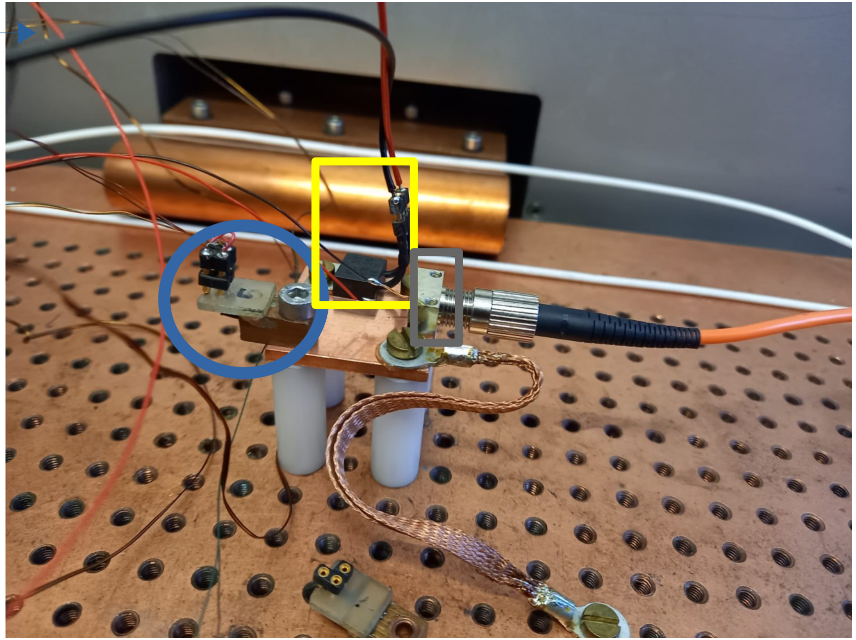
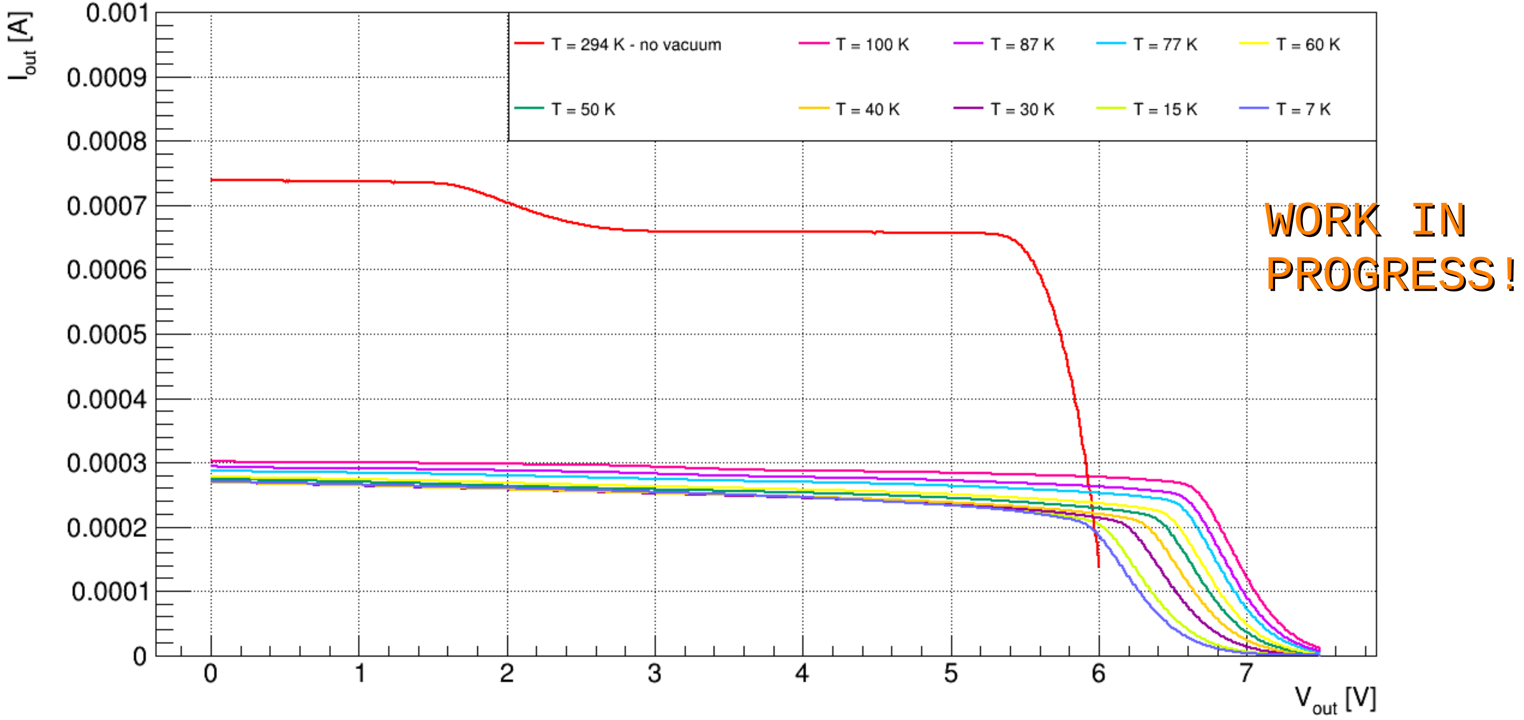


Test at lower temperatures then LN (< 77 K) - Results



The device works till 7 K with P_{max} ~ 15 % P_{in} .

Conclusion

- The main goal of Cryo-PoF is to power both SiPM and cold amplifier, using a single Power over Fiber line.
- We reach the goal and we are able to change the SiPM bias, modifying the laser power.
- Comparing the SNR of SiPMs at different overvoltages with and without PoF, we obtain good results.
- We test the PoF line at very low temperature (till 7 K) with promising results.
- We are working to improve!

We are grateful to the Fermilab and BNL DUNE groups, the Univ. of Milano Statale and the Univ. of Parma for support and suggestions!

Thanks!

Back up

OPC radio purity measurements

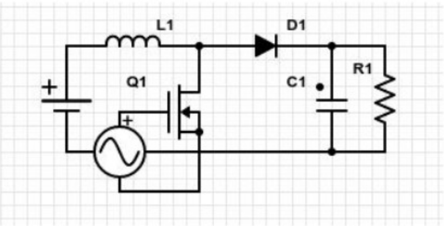
- We performed a **gamma spectroscopy** in order to measure the radio purity of the Broadcom Optical Power Converter (AFBR-POC206L).
- A Ge detector was used.
- The live time of the measurements was 1038 h, while background measurement was taken for 321 h.
- Before this test, the device was **already soldered** to an electronic board. It has to be removed from the support and cleaned.
- The measured activities are calculated with a confidence level of 90%.
- We did not observe contaminations, with the exception of potassium, for which an excess was found.

	Activity [Bq/Kg]
^{232}Th	
^{228}Ac	<0.2
^{208}Tl	<0.3
^{238}U	
^{226}Ra	<2
^{214}Bi	<0.2
^{235}U	<0.1
^{40}K	15±2
^{60}Co	<0.07
^{137}Cs	<0.06

From N. Gallice talks at F D2-VD Photon Detector Cold Electronics Workshop at BNL

DC-DC boost prototype test bench

- A matrix board is equipped with L1, D1, R1, C1:
  - **Load** is a **10 kΩ** resistor
- The Q1 (**NTF**) **transistor** can be changed to test all models
- **DC input** provided by a **linear supply** (AimTTi PL303QMD-P)
- The input current is monitored with a multimeter (HP 971A)
- The **control signal** is produced by a **Pattern Generator** (HP HP 81104A), High-level = 5 V, Low-Level = 0 V and rise/fall time = 3 ns with **100 kHz of period**.



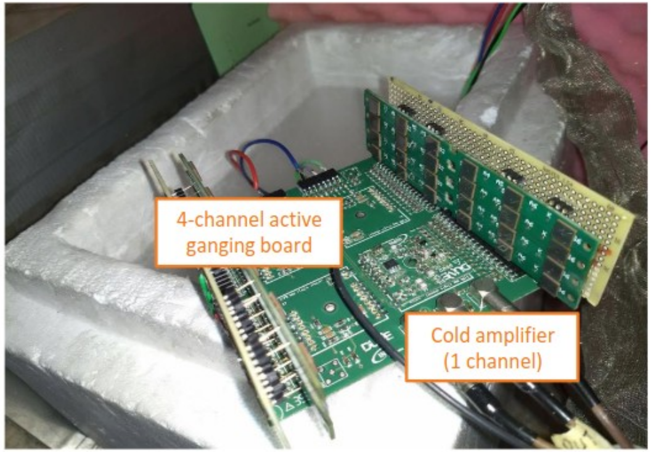
L1	10 mH
D1	BAV16W
C1	C0G 100 nF
R1	10 kΩ
Q1	NTF3055L108T1G

The system is tested at room and LN2 temperature, with different inputs (4V, 5V) and different duty cycle [0.1, 0.93].

- Output readout with a Lecroy HDO6104A oscilloscope.

PDS - Cold electronics

- Used to collect the signals of 48 SiPMs of a supercell into a single readout channel.
- Each channel reads out 48 6x6 mm2 SiPMs → 60 nF total input capacitance.
- 1 channel per SuperCell, 4 channels per module, 6000 channels in DUNE (1st module).
- Two-stage amplifier - SiGe bipolar transistor + fully differential op-amp.
- Low series noise is required → SiGe input transistor gives 0.37 nV/√Hz at cryo temperature.
- Low power consumption (2 mW/channel) to prevent boiling of LAr.



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