



Power over fibre for fundamental and applied physics at cryogenic temperature: final results of the Cryo-PoF project

Andrea Falcone

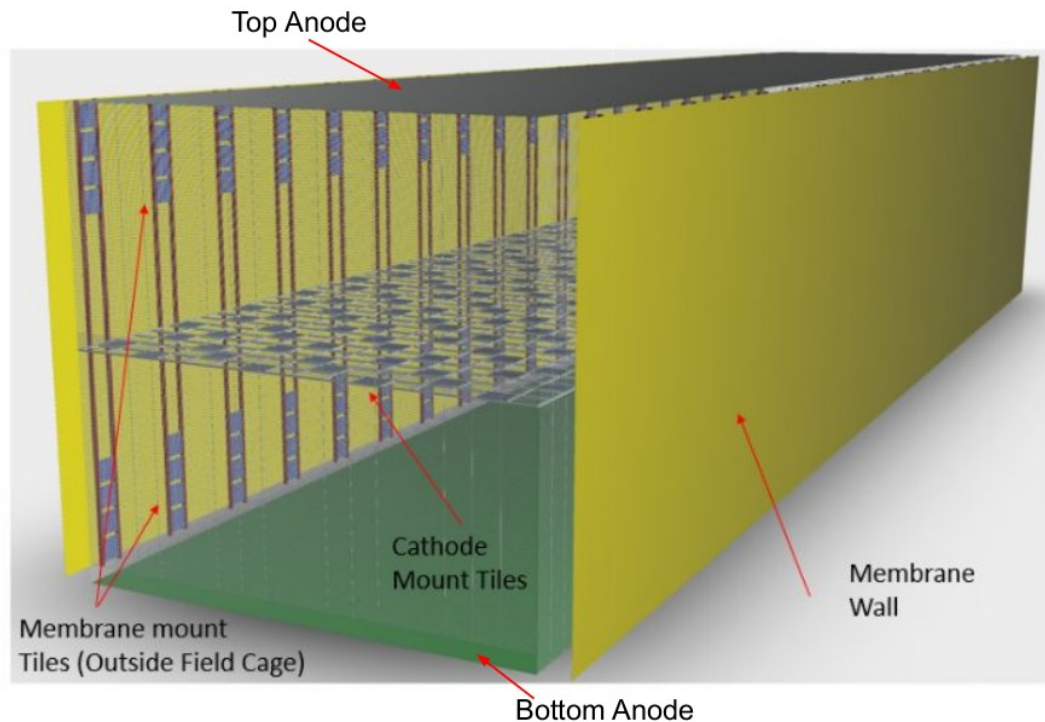
Istituto Nazionale di Fisica Nucleare – Sezione di Milano Bicocca

Cryo-PoF

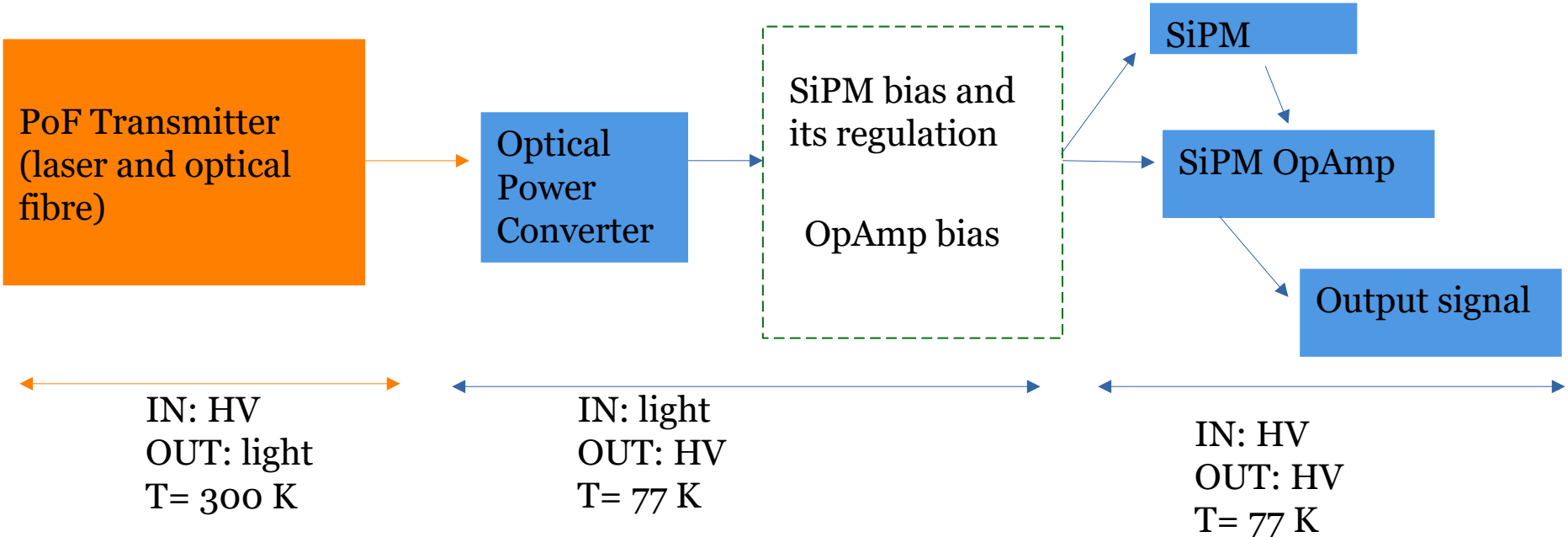
- **Cryo-PoF:** Cryogenic Power over fibre.
- **Cryo-PoF's main goal** is to power, at cryogenic temperature, both SiPM and cold amplifier, using a single Power over fibre line and to tune SiPM bias with the laser power.
- The **Power over fibre** (PoF) technology delivers electrical power by sending laser light, through an optical fibre, 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.

DUNE Vertical Drift

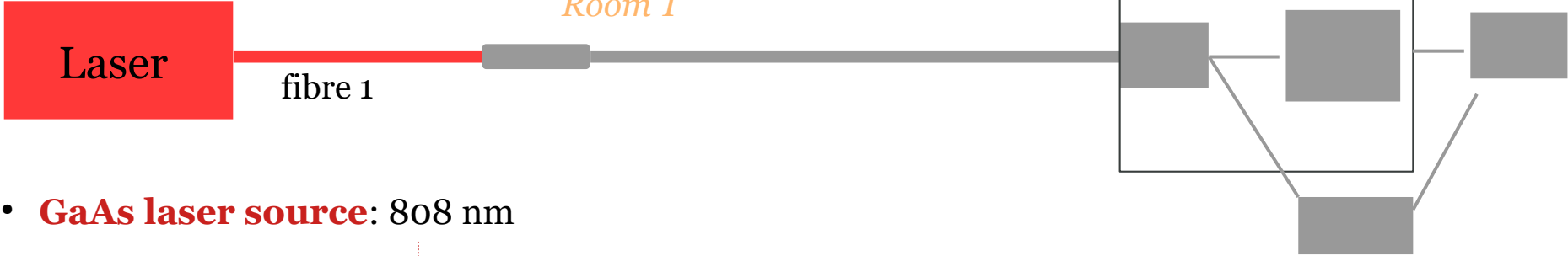
- **DUNE Vertical Drift (VD) module:** LAr TPC in which electrons drift toward the anodes placed on top and bottom of the detector. Anode planes will be made by PCBs, so light opaque.
- The grid cathode is at half height and operated at 320 kV.
- **Photon Detection System (PDS)** can be placed on the cathode or outside the field cage with much lower photon collection efficiency .
- PoF is the chosen technology to power the PDS (see [Dr. Biswaranjan Behera talk “Power-over-Fiber Development for DUNE Vertical Drift Photon Detection System”](#) on Thursday !)



Cryo-PoF : the concept



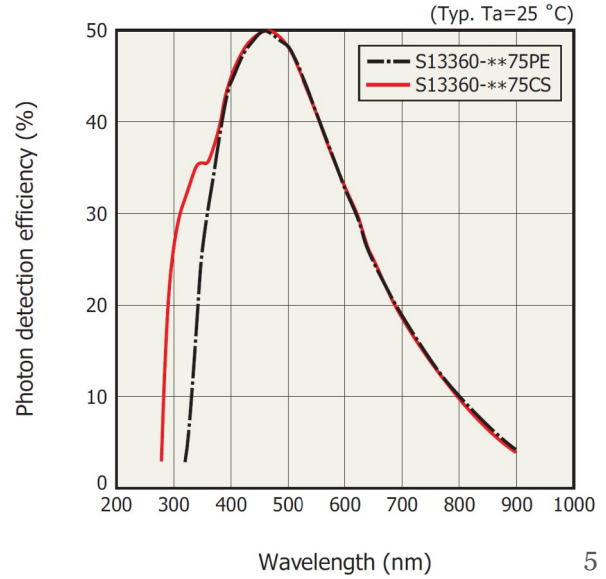
Laser source



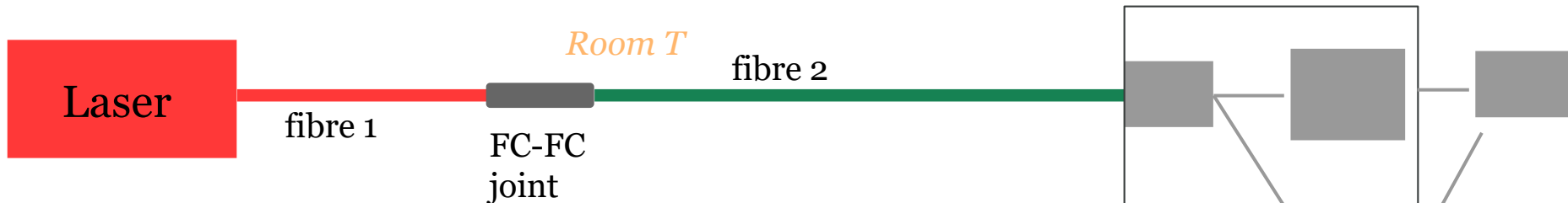
- **GaAs laser source:** 808 nm

Why?

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



Laser source

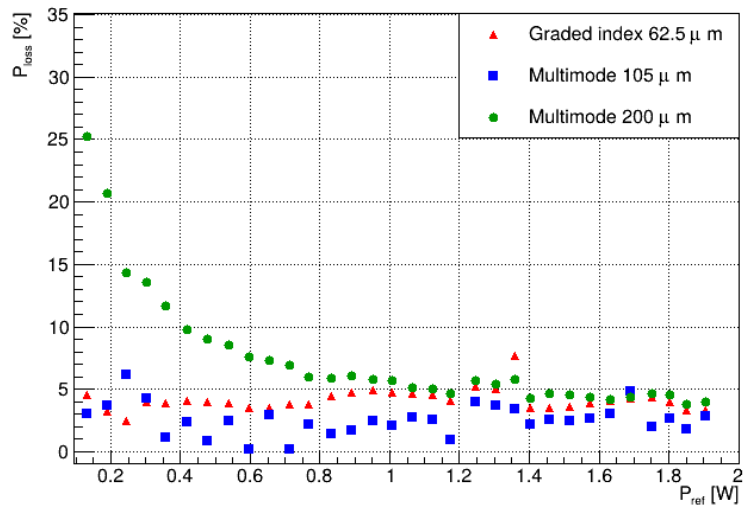
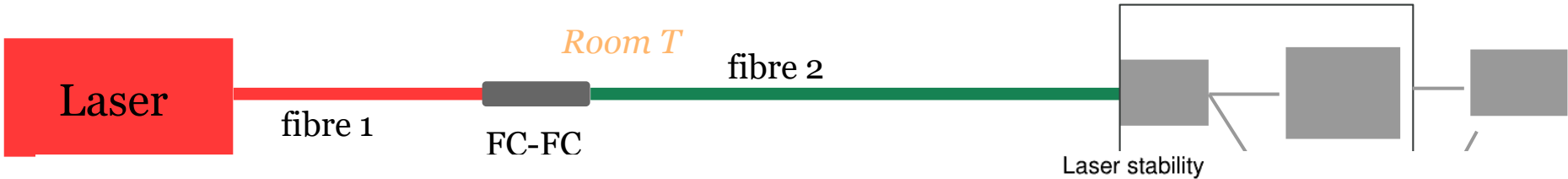


- **GaAs laser source**, 808 nm AFBR-POMEK2204 Broadcom, directly connected to a multimode optical fibre (62.5 μm core diameter).
- Characterization of the laser source in terms of:
 - linearity,
 - power loss connecting an **optical fibre**,
 - stability over time.

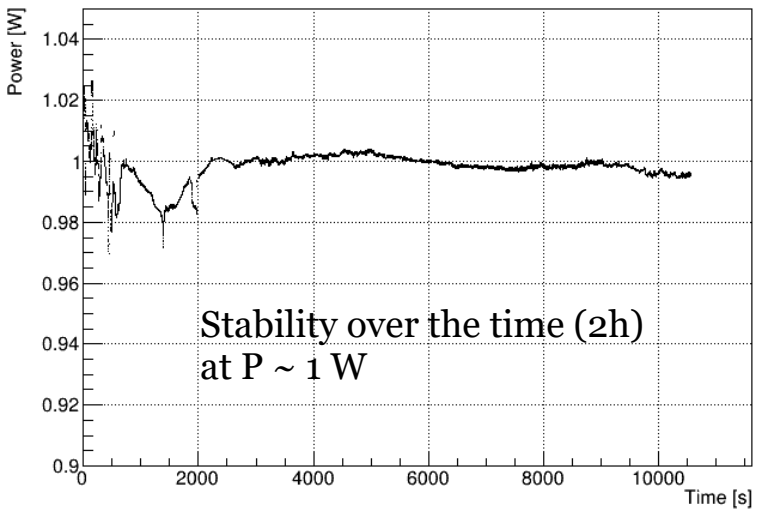
Graded index multi mode optical fibre, (core diameter 105 μm) with with black reinforced 3.8 mm tube. from Thorlabs



Laser source



Power loss adding a FC/FC joint and different optical fibres.

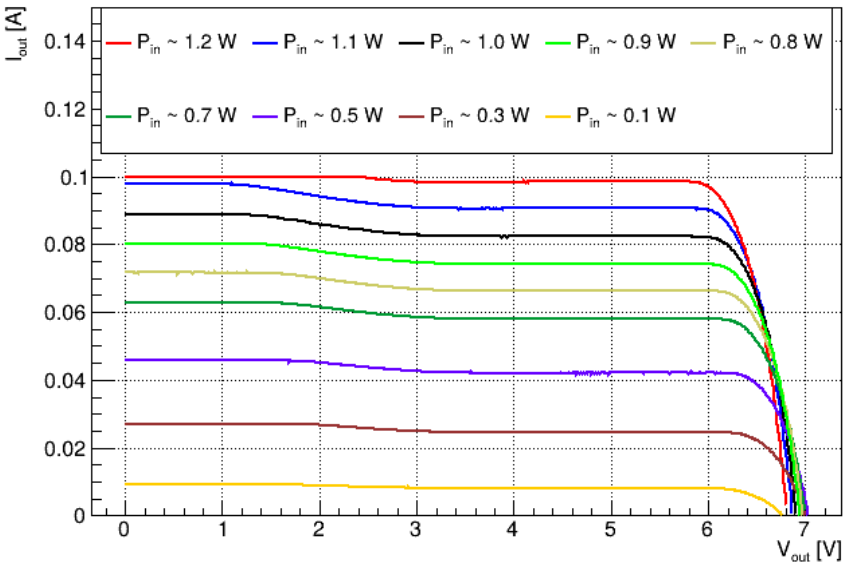
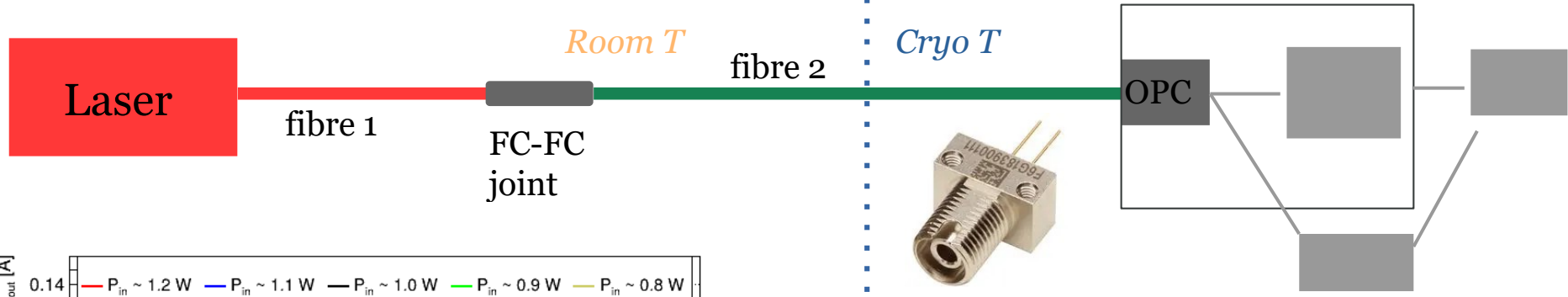


Max – Min ~ 5.7% - Mean($P_o - P_i$) = 17.1 mW

Without the first 30 min:

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

Optical Power Converter

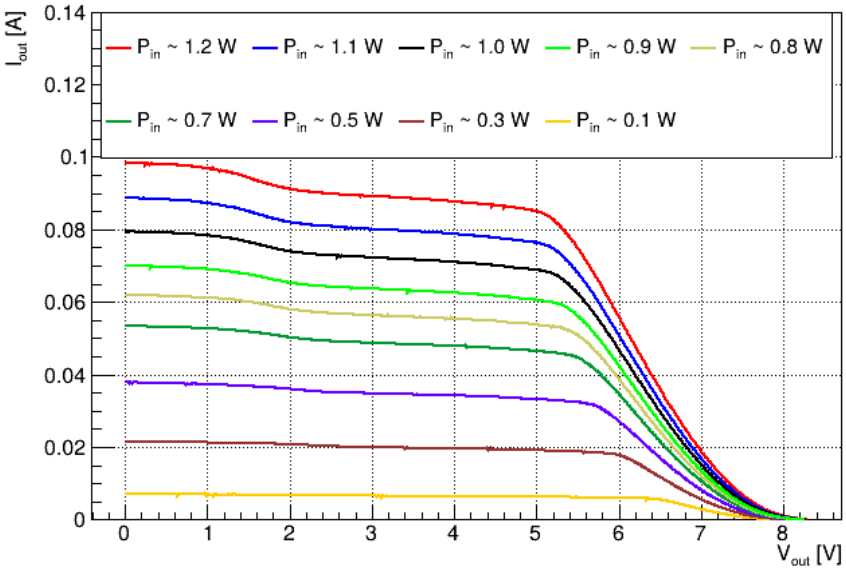
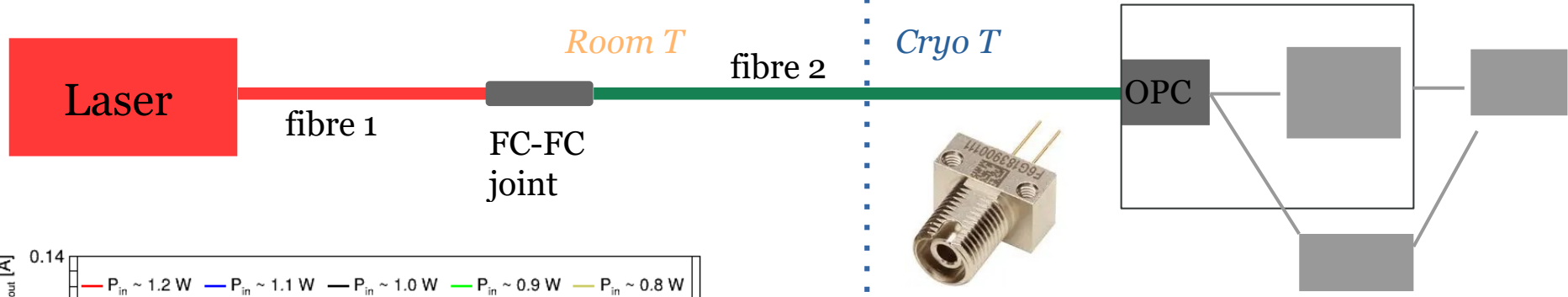


- **Optical power converter, AFBR-POC206L** from Broadcom
- IV curvers using a semiconductor analyser
- Tested at different P_{in}

$$P_{in} \sim 1 W$$

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

Optical Power Converter



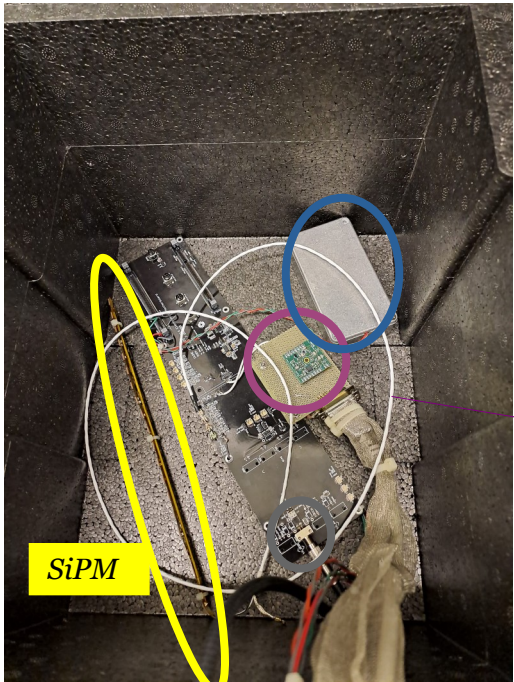
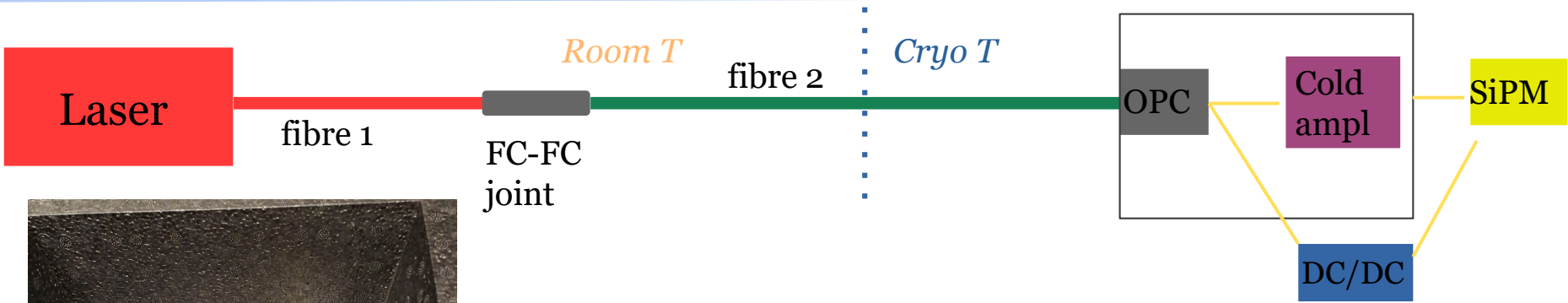
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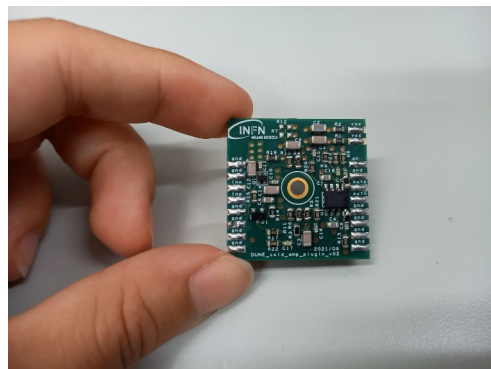
$T = 300 K : P_{max} = 0.52 W, I_{max} = 91.4 mA$

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

From laser to SiPM

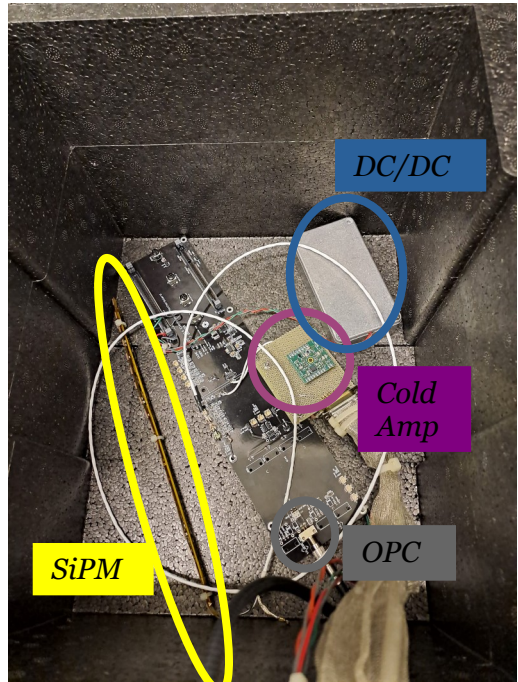


- **Cold amplifier** developed by Milano Bicocca group for DUNE,
 $\rightarrow V_{in} = 3.3 V$



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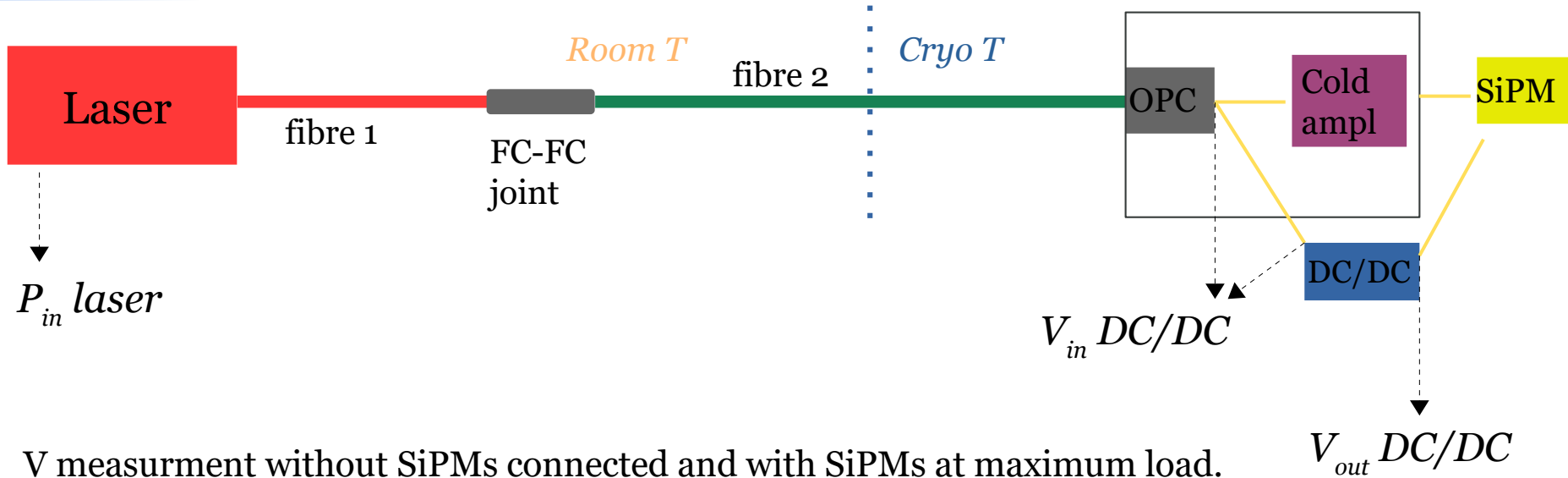
From laser to SiPM



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



DC/DC boost converter



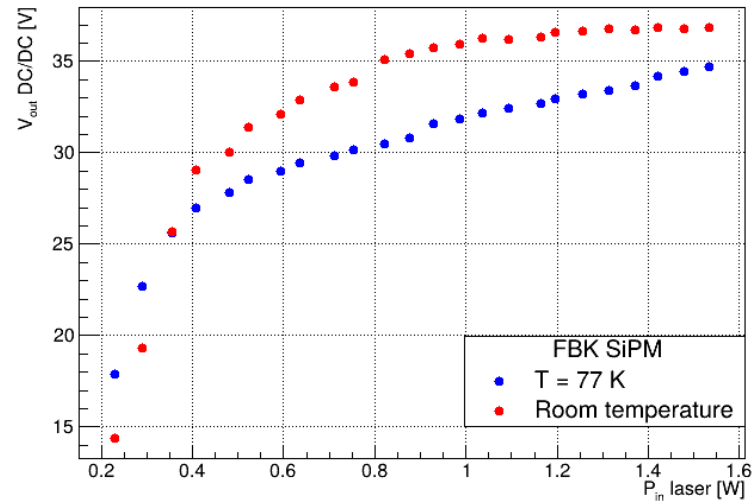
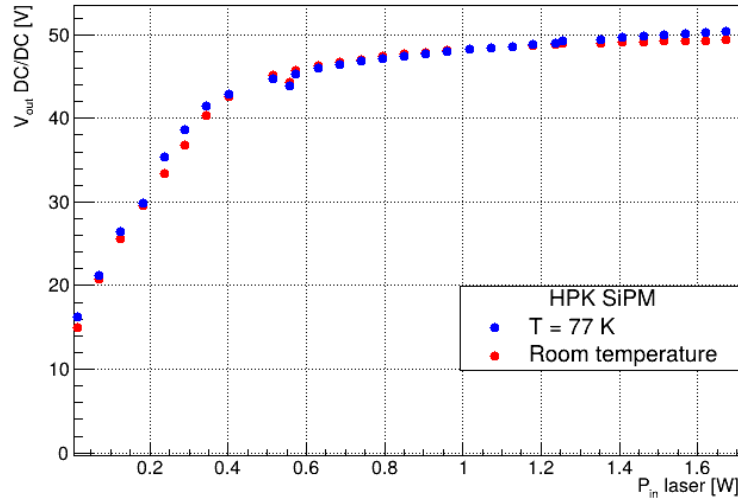
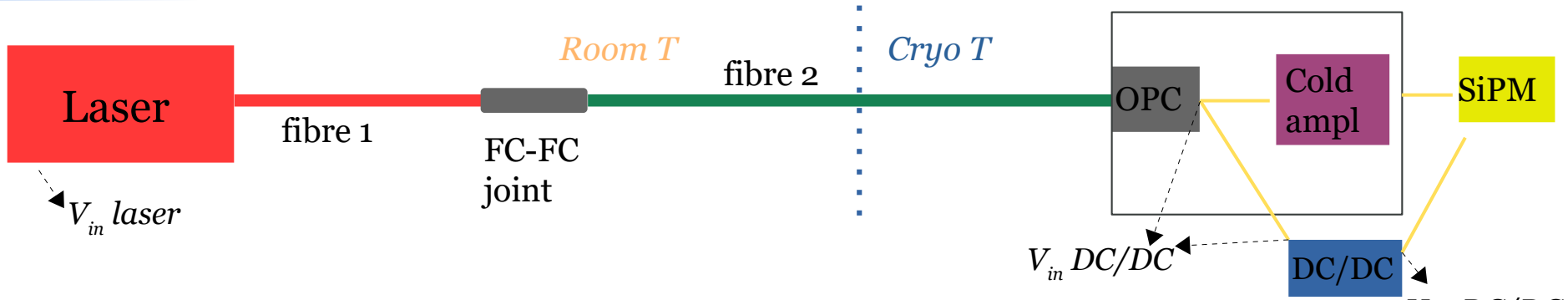
V measurment without SiPMs connected and with SiPMs at maximum load.

$P_{in \text{ laser}}$ → laser source input, proportional to the input voltage;

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

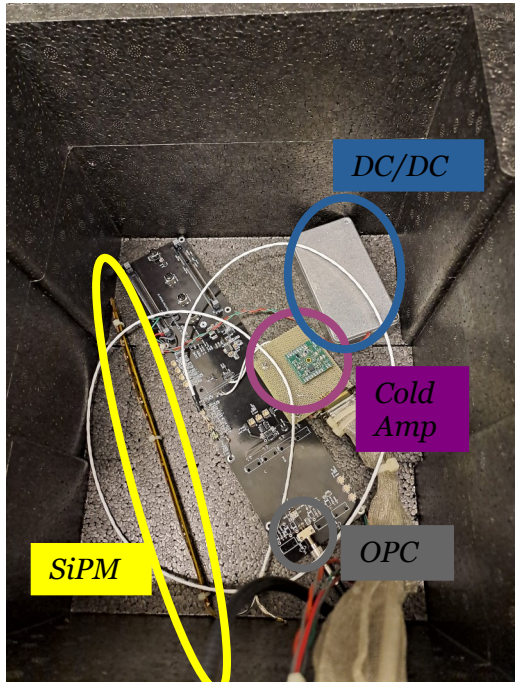
$V_{out \text{ DC/DC}}$ → V output from the DC/DC, that is the SiPMs bias voltage.

DC/DC boost converter



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

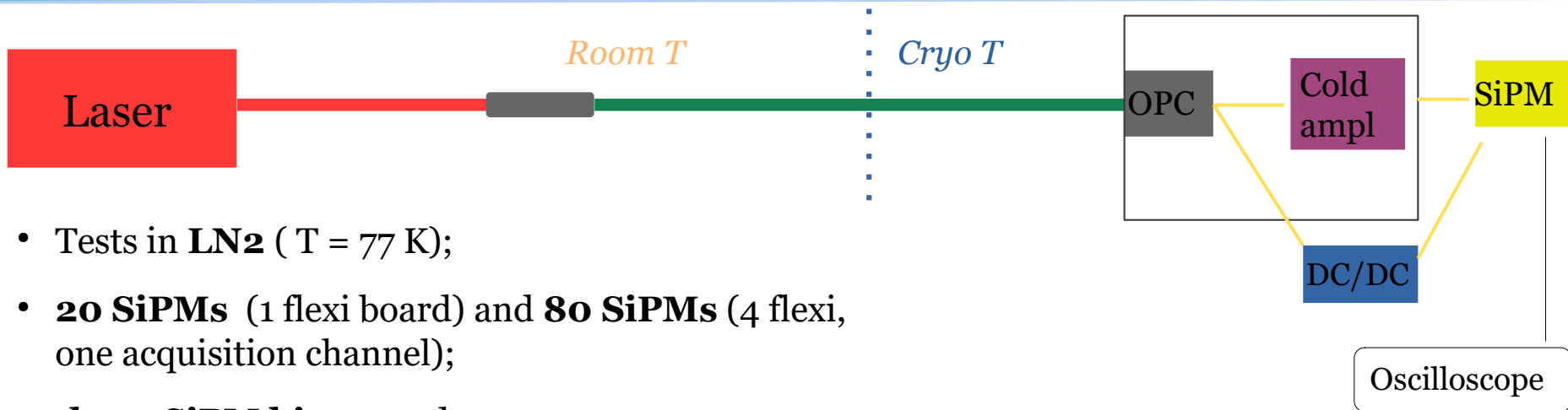
From laser to SiPM



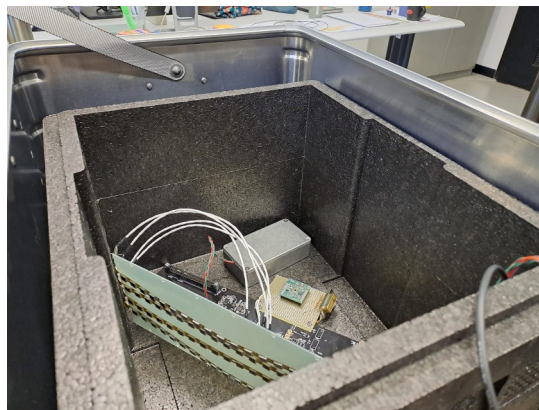
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 - $V_{in} \sim 5 \text{ V}$; $V_{out} \sim [25, 35] \text{ V}$ for FBK SiPM
 - placed in a metallic box to reduce noise.
- **SiPM**, developed by Hamamatsu and FBK for DUNE,
 - flexi board with **20 SiPMs**,
 - $V_{bd} = 42.0 \text{ V}$ at 77 K for Hamamatsu
 - $V_{bd} = 27.1 \text{ V}$ at 77 K for FBK

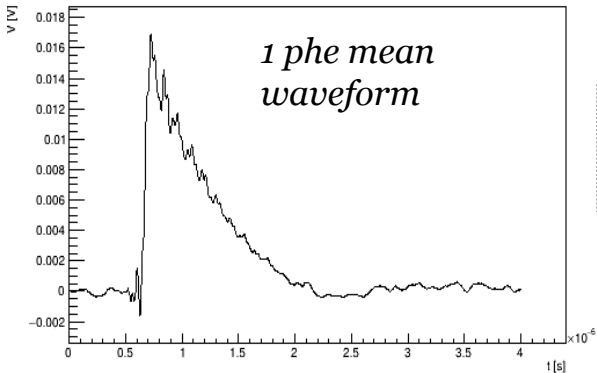


Results



- 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.

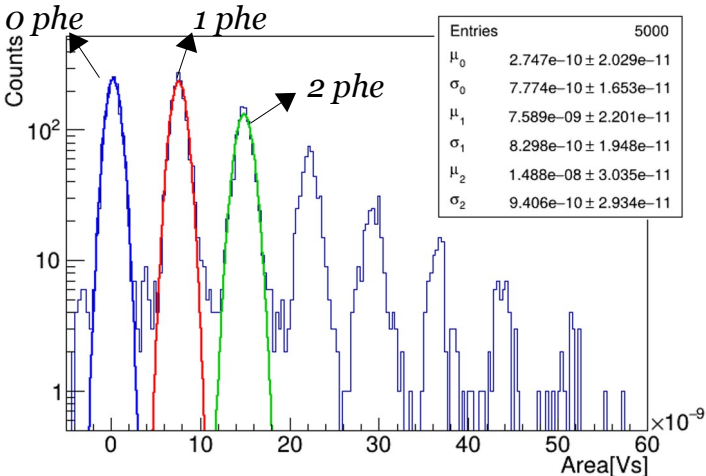




PoF

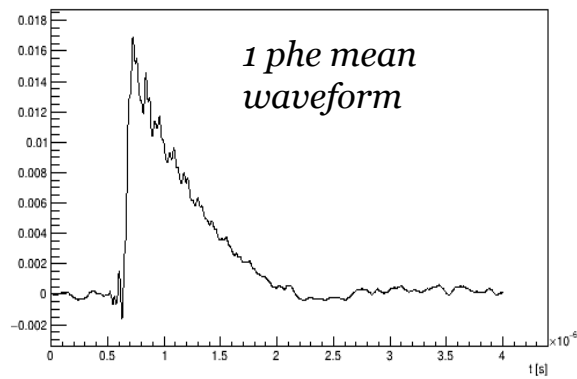
$P_{in} \text{ laser} = 1 \text{ W}$
 $V_{bias} = 47 \text{ V} - 5 \text{ V ov}$

SNR = 11.070



PoF

1 phe mean waveform

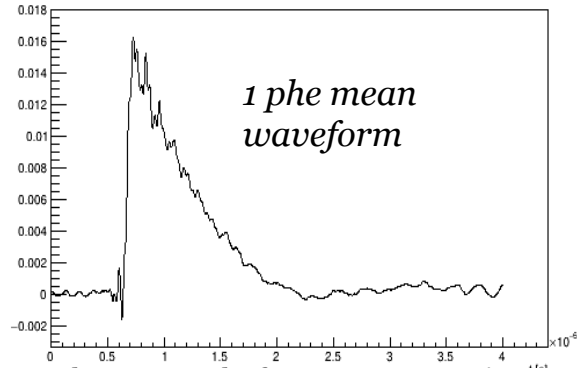


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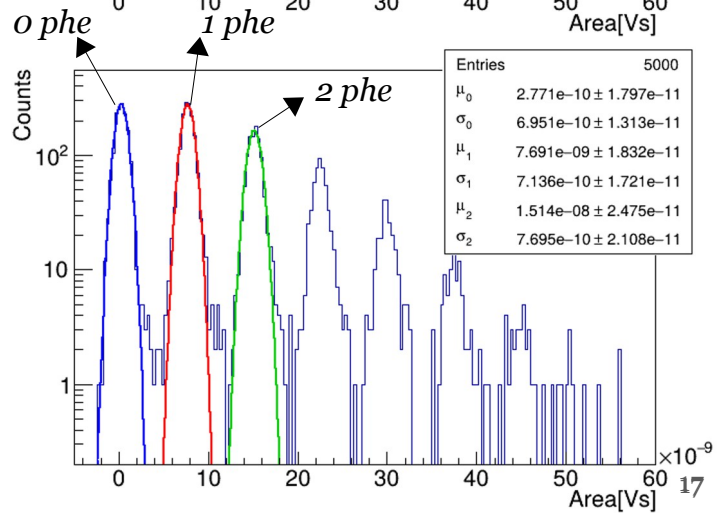
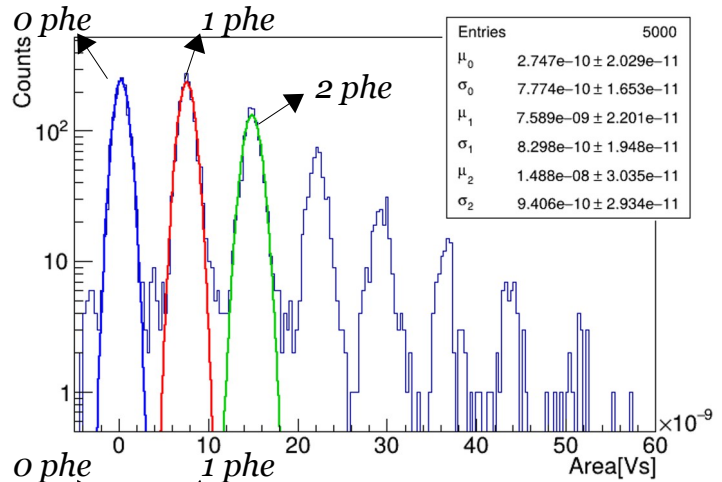
Copper cable

1 phe mean waveform



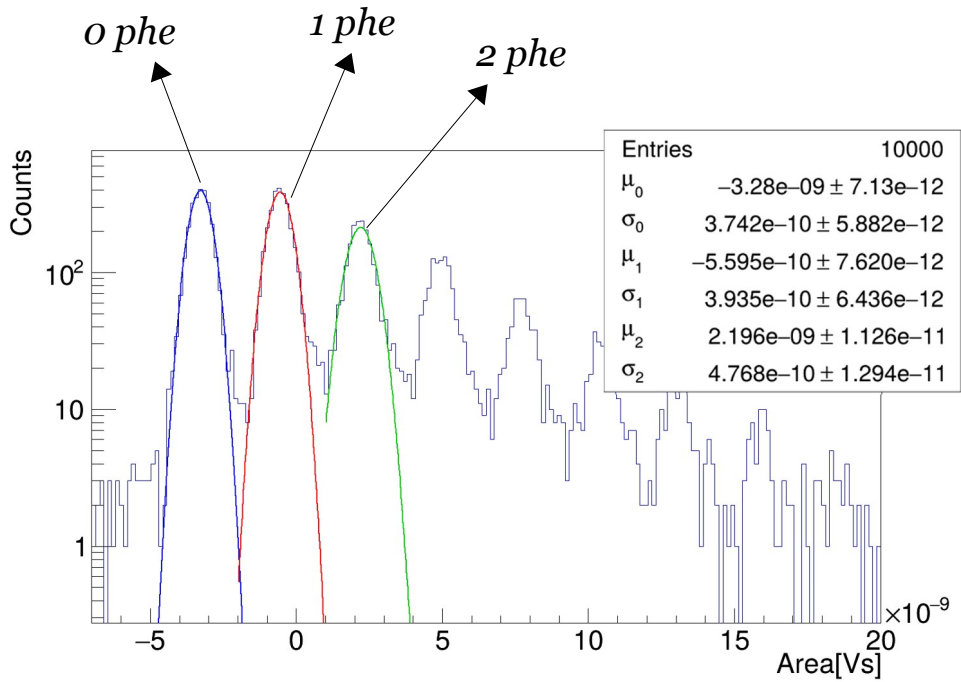
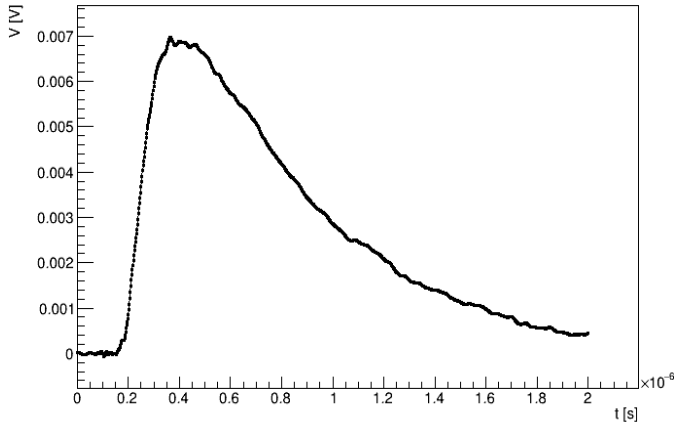
$V_{bias} = 47 \text{ V} - 5 \text{ V ov}$

SNR = 13.004



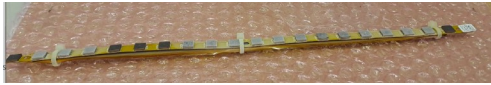
$V_{in} \text{ laser} = -1.94 \text{ V} (\sim 1.3 \text{ W})$
 $V_{bias} = 34.1 \text{ V} - 7 \text{ V ov}$

1 phe mean waveform



SNR = 11.270

HPK – 20 SiPMs



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

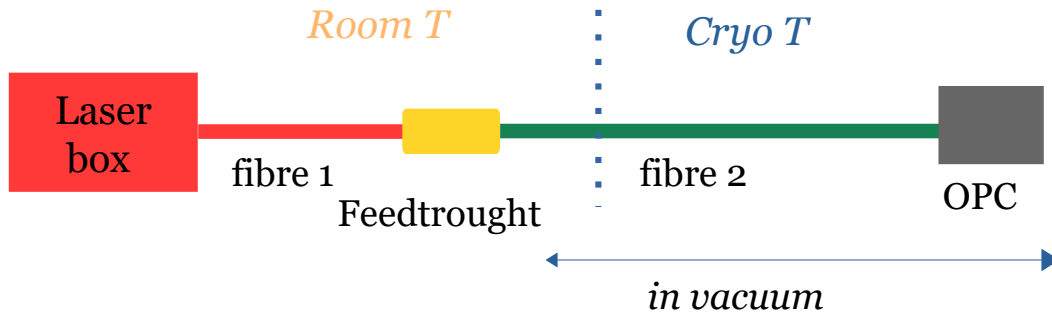
FBK – 80 SiPMs



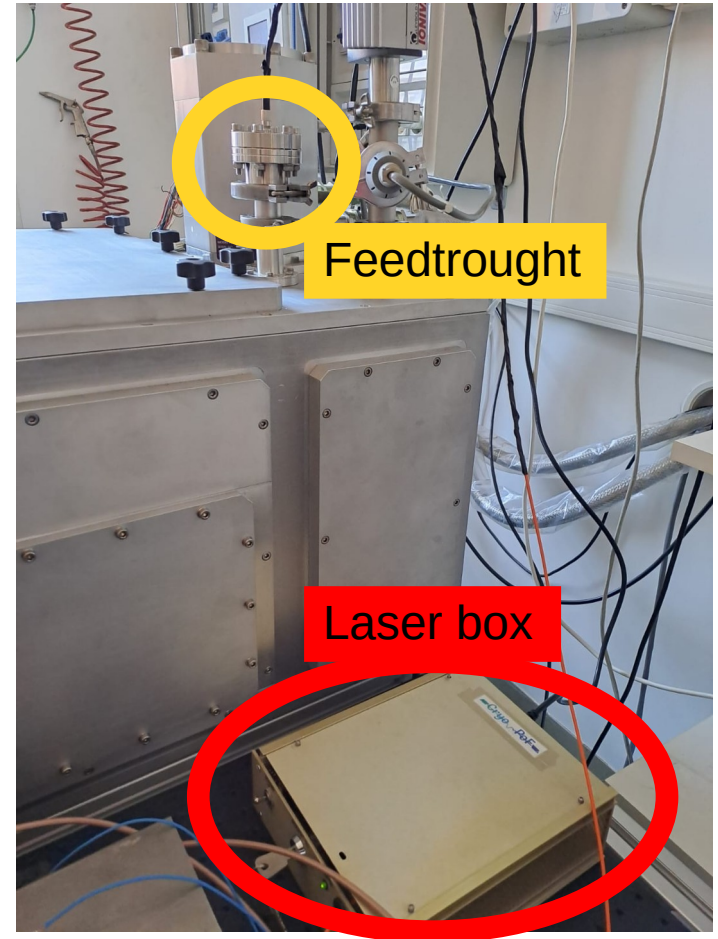
SiPM bias	<i>SNR PoF</i>
30.6 V	6.027
31.6 V	7.173
34.1 V	11.270

- Test Power over fibre technology at temperature lower than 77 K, in view of application in rare events physics and quantum technology.
- We tested our setup (from laser to OPC) in a cryostat **till 4.6 K** and characterized the OPC output registering the I-V curves with the semiconductor analyzer.
- The system was in vacuum; the temperature was controlled by means of a thermometer.
- The laser power at the OPC was ~ 100 mW.

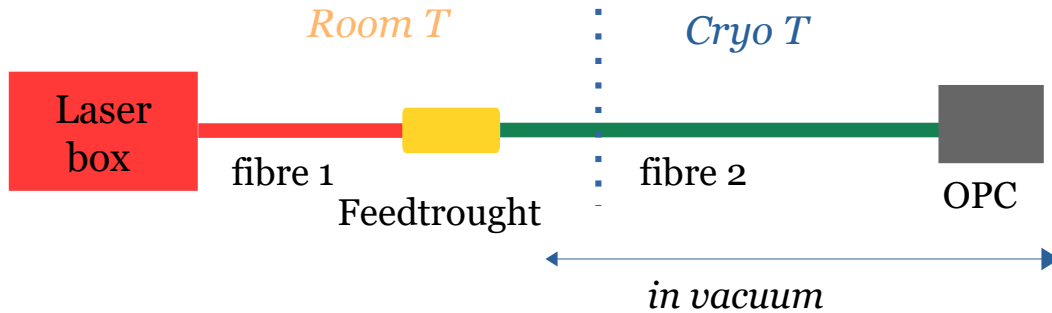
Test at lower temperatures than LN (< 77 K) - Setup



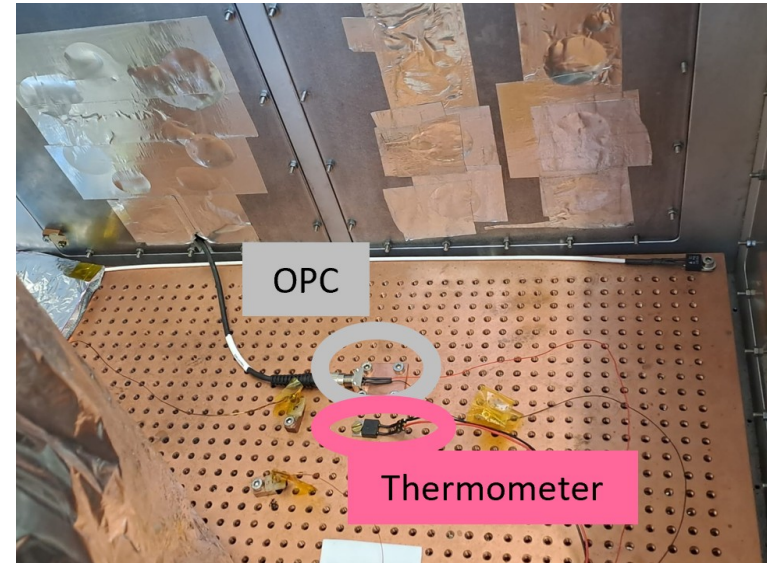
- **Laser Box** with the GaAs laser source, 808 nm;
- **optical feedtrought** (100 μm core diameter);
- **graded index multi mode optical fibre** with 105 μm core diameter;
- **optical power converter** AFBR-POC206L from Broadcom;
- **thermometer**.

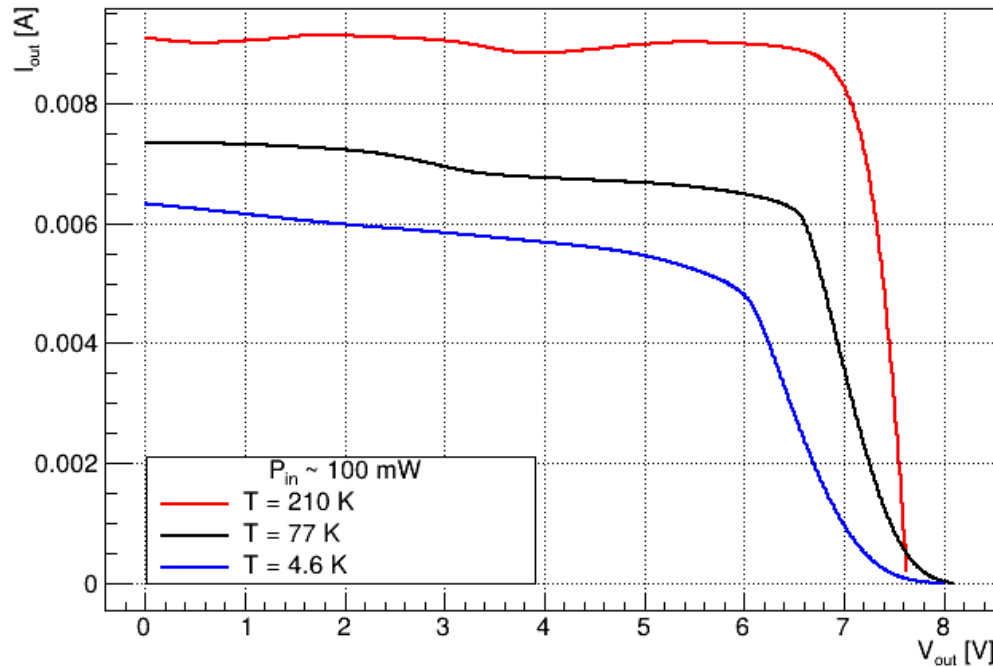


Test at lower temperatures than LN (< 77 K) - Setup



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- **thermometer**.





The OPC reliably operates down to 4.6 K, with an efficiency of 29%.

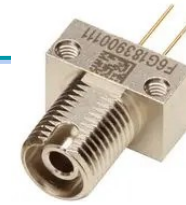
- The main goal of Cryo-PoF is to power both SiPM and cold amplifier, using a single Power over fibre line.
- We reach the goal and we are able to change the SiPM bias, modifying the laser power.
- Comparing the SNR of SiPMs at different overvoltages with and without PoF, we obtain good results.
- We test the PoF line at very low temperature (till 4.6 K) with promising results.
- CryoPoF on arXiv: <https://arxiv.org/abs/2512.21207>

Thanks to the Fermilab and BNL DUNE groups, the Univ. of Milano and the Univ. of Parma for support and suggestions!

Thanks!

Back up

OPC radio purity measurements

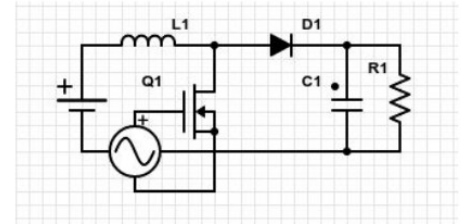


- We performed a **gamma spectroscopy** in order to measure the radio purity of the Broadcom Optical Power Converter (AFBR-POC206L).
- A Ge detector was used.
- The live time of the measurements was 1038 h, while background measurement was taken for 321 h.
- Before this test, the device was **already 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
^4K	15 ± 2
^{60}Co	<0.07
^{137}Cs	<0.06

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.

