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

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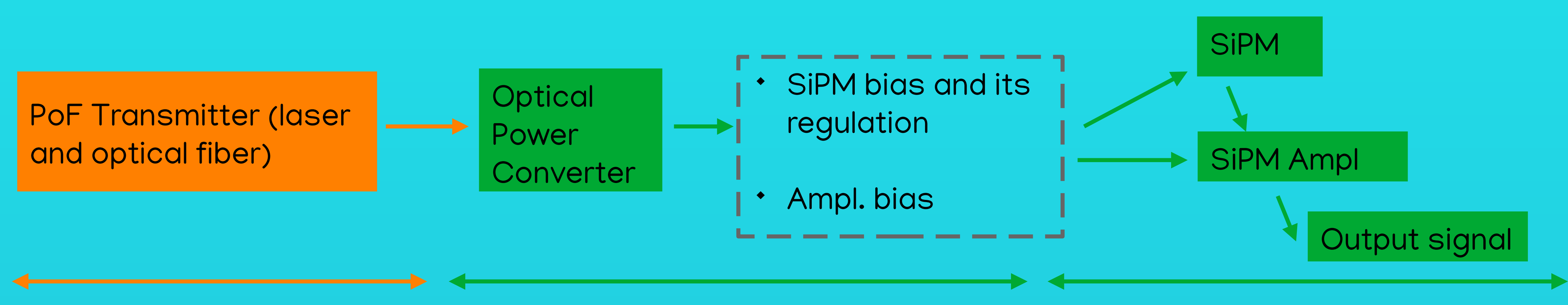
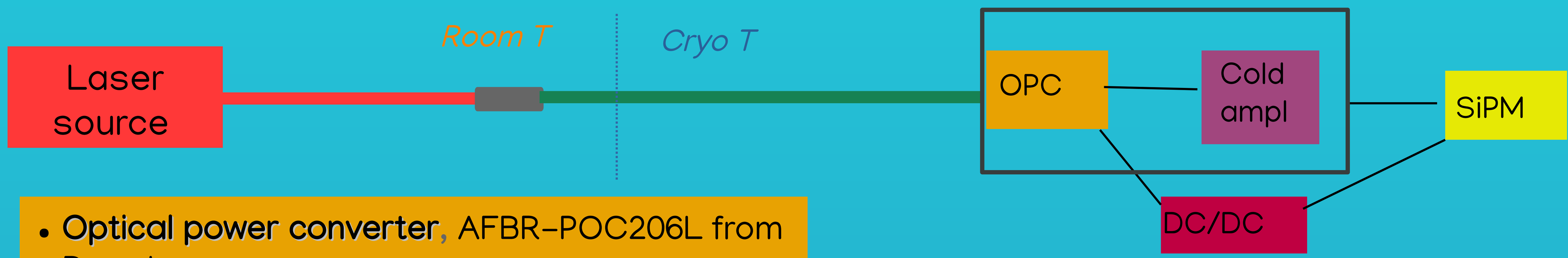
Project overview

- **Cryo-PoF:** Cryogenic Power over Fiber.
- It is funded by "CSN5 Young Researcher Grant" from INFN, from February 2022 for 2 years; PI: M. Torti; Institutions: INFN Milano-Bicocca and INFN Milano.
- **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.

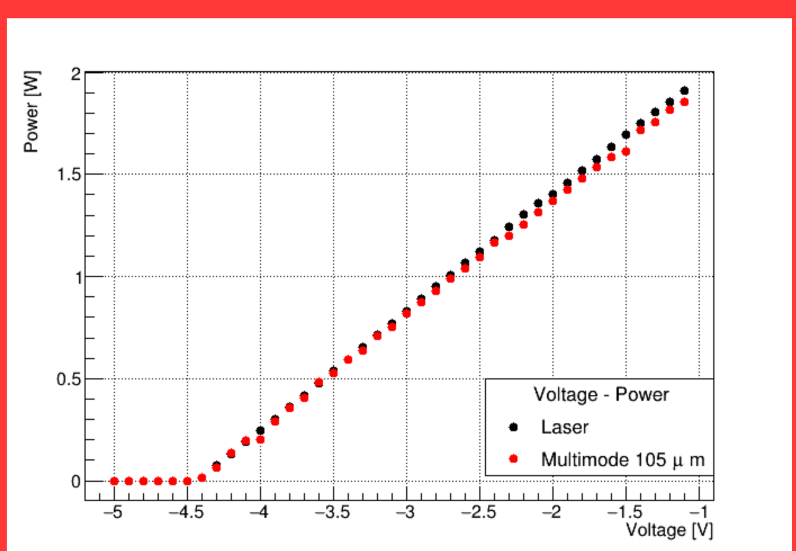


- The **Power over Fiber** (PoF) technology delivers electrical power by sending laser light, through an optical fiber, to a photovoltaic power converter, in order to power sensors or electrical devices. PoF solution offers several **advantages:** removal of noise induced by standard power lines, robustness in a hostile environment, spark free operation when electric fields are present, no interference with electromagnetic fields.
- 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 on the high-voltage cathode surface (see talk by William Pellico) [1]. Here additional studies on characterizing PoF performance are presented with a focus on tunability and low T operation.

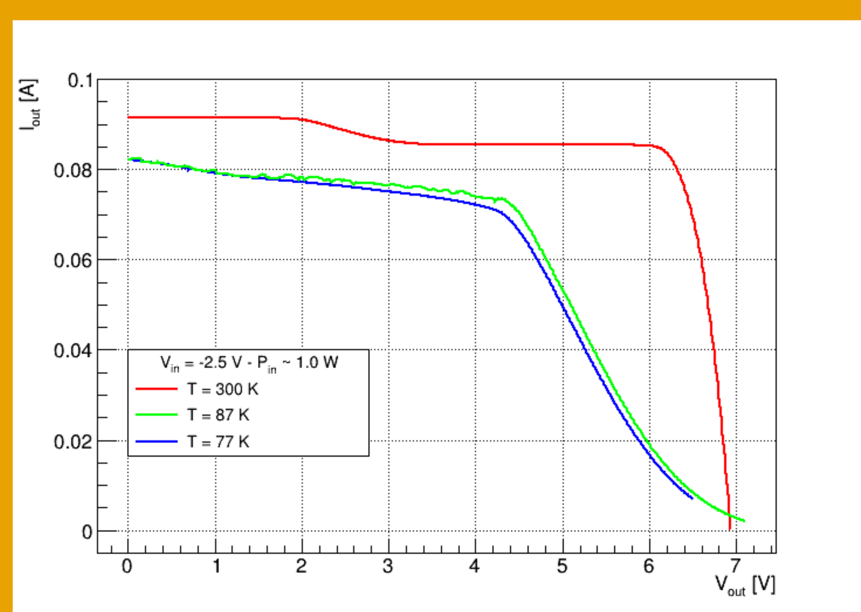
Setup



- **GaAs laser source**, 808 nm AFBR-POMEK2204 from Broadcom company. Output power tunable by means the input voltage.
- Characterization of the laser source 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 adding a FC/FC joint and an optical fiber.
  - Stability: max – min ~ 0.96%.



- **Optical power converter**, AFBR-POC206L from Broadcom company.
- IV curvers using a semiconductor analyser.
- Efficiency at cryogenic temperatures ~ 30%.

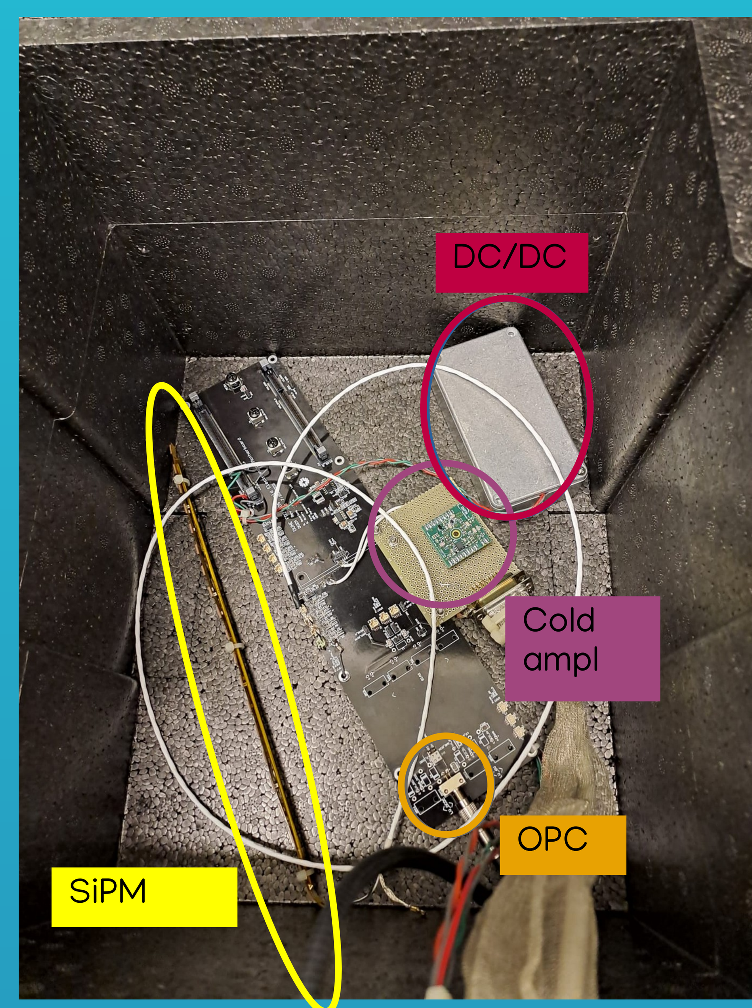


P_{in} ~ 1 W

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

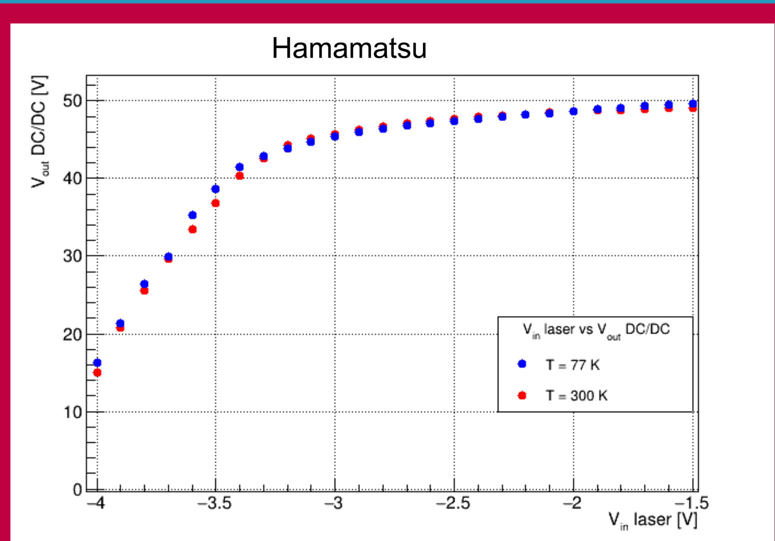
T = 87 K : P_{max} = 0.32 W , I_{max} = 82.5 mA

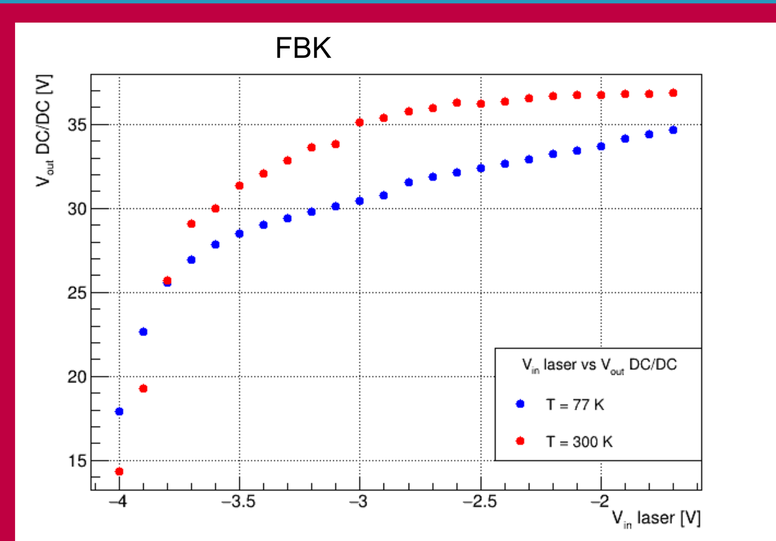
T = 77 K : P_{max} = 0.30 W , I_{max} = 82.2 mA



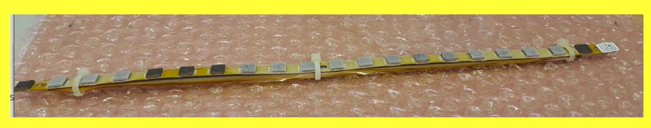
- **Cold amplifier** developed by Milano Biccoca group for DUNE [4], → V_{in} = 3.3 V.

- **DC/DC** boost converter developed by INFN Milano Statale group [5], give bias to SiPMs
  → V_{in} ~ 5 V; V_{out} ~ [40, 50] V (Hamamatsu)
  → V_{in} ~ 5 V; V_{out} ~ [25, 35] V (FBK)
  → placed in a metallic box to reduce noise.





- **SiPM**, developed by Hamamatsu and FBK for DUNE [2,3],
  → 1 flexi board with **20 SiPMs** in parallel,
  → V_{bd} = 42.0 V at 77 K (Hamamatsu)
  → V_{bd} = 27.1 V at 77 K (FBK)



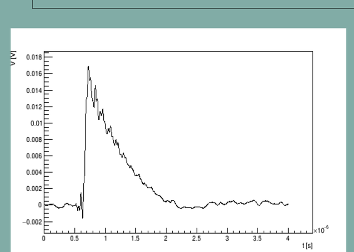
Results

Tests in LN (T = 77 K)

- Both Hamamatsu and FBK SiPMs tested at different bias;
- SNR from the charge integral Gaussian fit = $\frac{\mu_1 - \mu_0}{\sigma_0}$
- The performances of the PoF are comparable with the copper cable ones.

20 Hamamatsu SiPMs in parallel

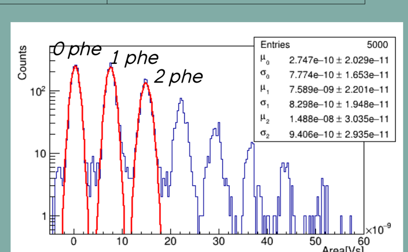
SiPM bias	*SNR Copper cable*	*SNR PoF*
45 V (40%PDE)	7.830	7.520
46 V (45%PDE)	10.665	9.409
47 V (50%PDE)	13.004	11.070



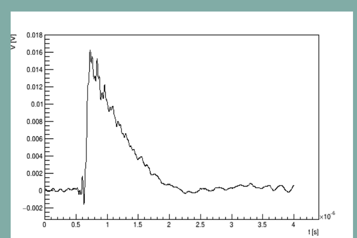
1 phe mean waveform

PoF

V_{in} laser = −2.61 V
V_{bias} = 47 V

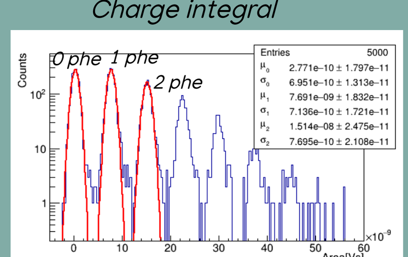


Charge integral



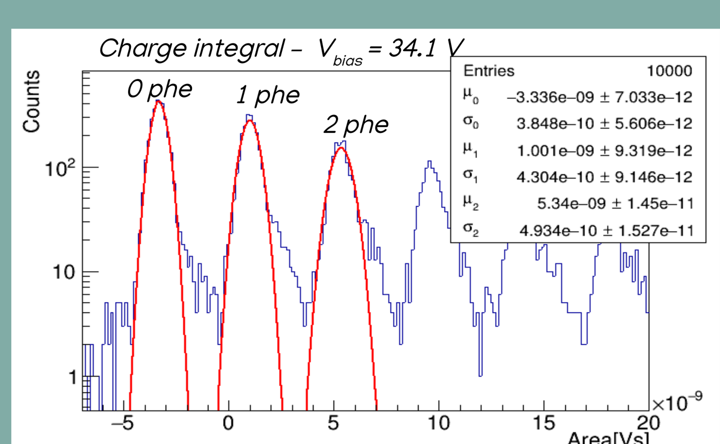
Copper cable

V_{bias} = 47 V



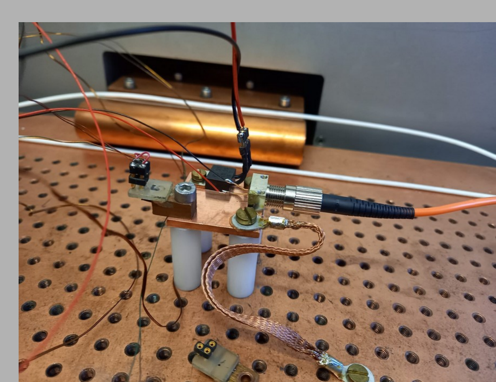
80 FBK SiPMs in parallel

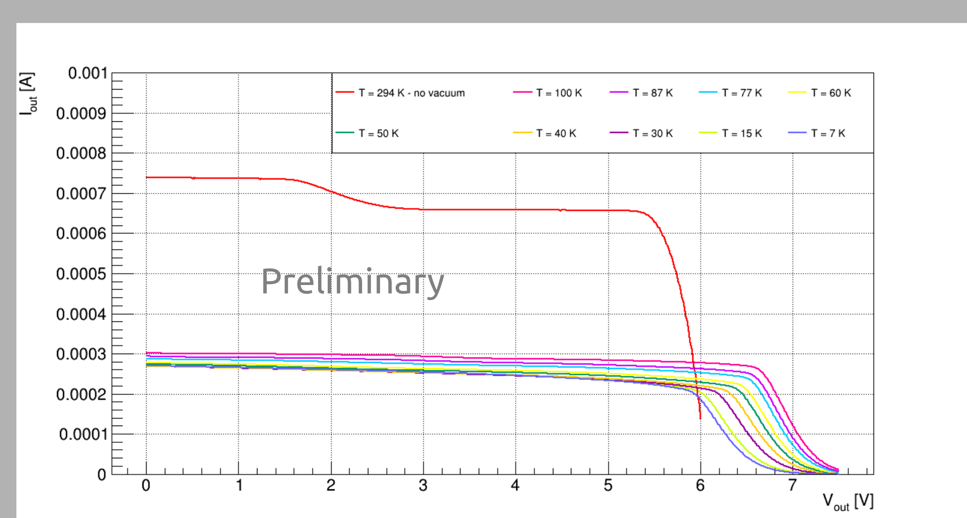
SiPM bias	SNR PoF
30.6 V (40%PDE)	6.027
31.6 V (45%PDE)	7.173
34.1 V (50%PDE)	11.270



Test at lower temperatures then LN (< 77 K)

- We tested our setup (from laser to OPC) in a cryostat **till 7 K.**
- IV curves using 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.
- The device works till 7 K with P_{max} ~15 % P_{in}.

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Acknowledgement

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References

[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] M. Andreaotti et al., "Cryogenic characterization of Hamamatsu HWB MPPCs for the DUNE photon detection system" 2024 JINST 19 T01007
[3] A. Falcone, "Cryogenic SiPM arrays for the DUNE photon detection system" Nucl. Instr. and Meth. A (2021) 985, 164648
[4] 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
[5] N. Gallice et al., "Development of a cryogenic DC-DC Boost Converter: devices characterization and first prototype measurements," 2022 IEEE I2MTC.