A cryogenic RICH detector demonstrator for SiPM operation with integrated flex-PCB electronics

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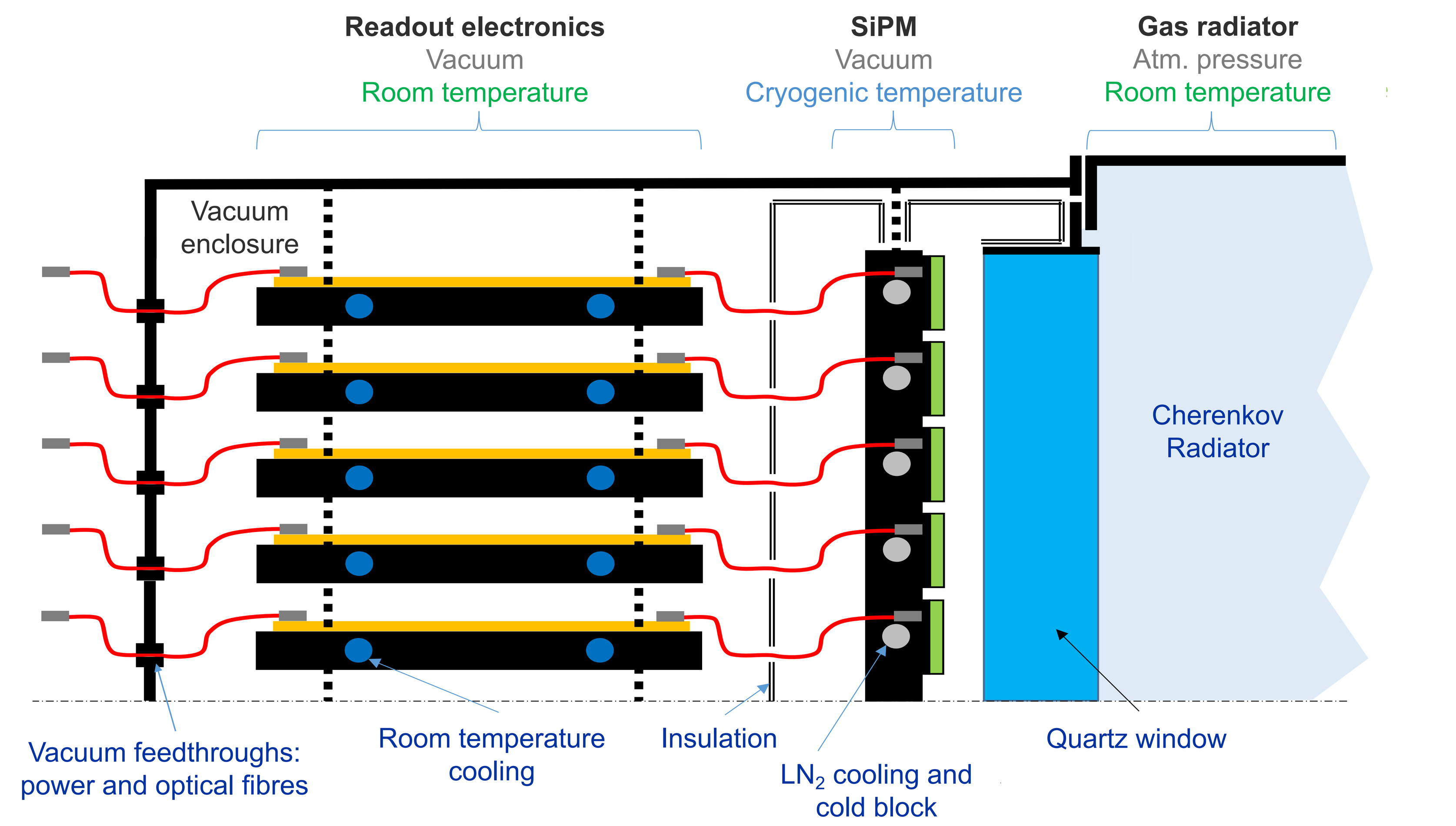
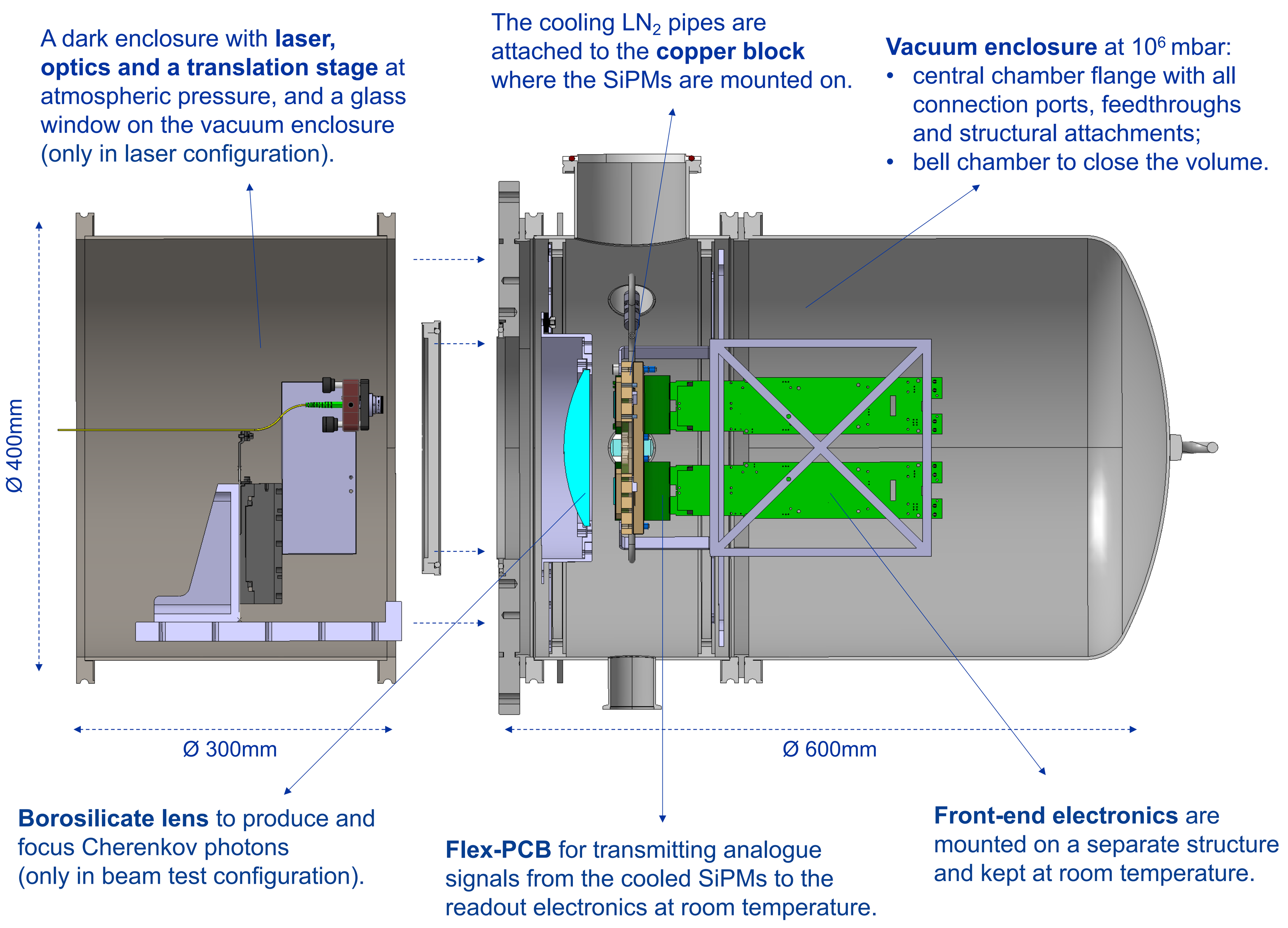
1. Introduction and motivation

Silicon photomultiplier (SiPM) arrays are strong photodetector candidates for future RICH detectors [1][2] owing to their excellent single-photon detection efficiency, time resolution and fine granularity. The main challenge in operating SiPM arrays is the **dark-count rate** (DCR), especially after irradiation damage [3]. Operation at **cryogenic temperatures** effectively mitigates the DCR [4]. The design and integration of a cryostat in a RICH detector pose technical challenges, particularly when gas is used as Cherenkov radiator.

A **modular cryostat demonstrator** is being developed at CERN to characterise SiPM arrays at liquid-nitrogen (LN_2) temperatures (~80–120 K), under different experimental conditions [5]. This demonstrator will provide valuable insights into the scalability of the system to large photodetector areas.





2. Cryostat demonstrator

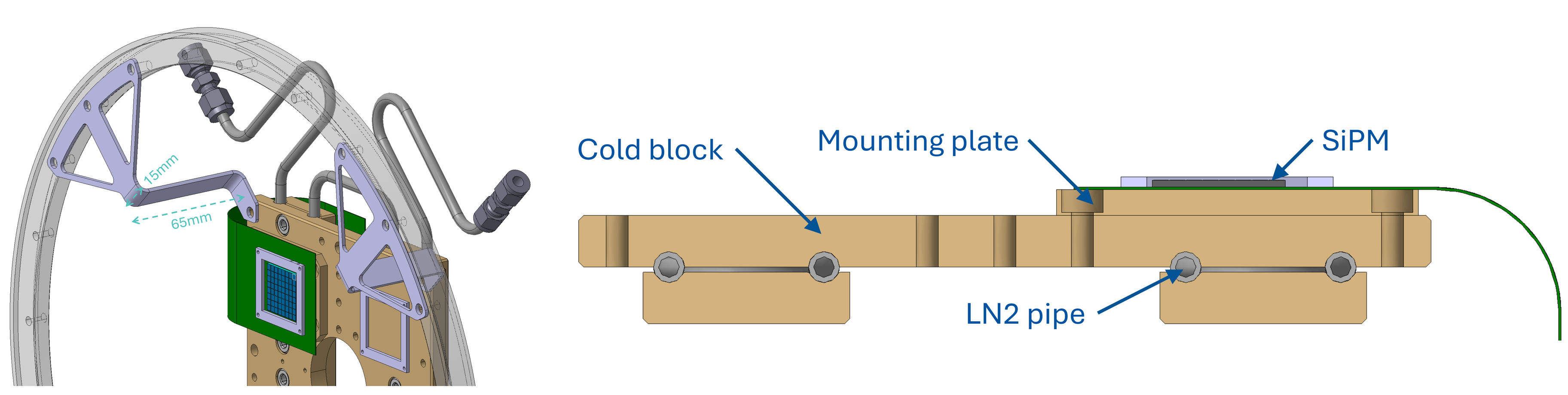
The modular cryostat demonstrator has a vacuum enclosure that houses a copper cold block for mounting the SiPM arrays and mechanical structures to support the readout electronics.

The cold block is coupled to the **LN_2 cooling circuit,** while the readout electronics are attached to an independent room-temperature cooling system. A **flexible PCB (flex-PCB)** solution has been adopted to carry analogue signals from the SiPM array to the readout electronics and to limit the heat transfer to the cold part.

The vacuum enclosure hosts all **interfaces and ports** for LN_2 cooling, vacuum pumping, sensor and readout electronics powering, and optical data transmission.

The demonstrator supports two test configurations:

- **Laser tests** using a glass window and an external picosecond pulsed laser mounted on translation stages.
- **Beam tests** using an aluminium sheet (2 mm central thickness) and a borosilicate lens inside the vacuum to produce and focus Cherenkov photons.

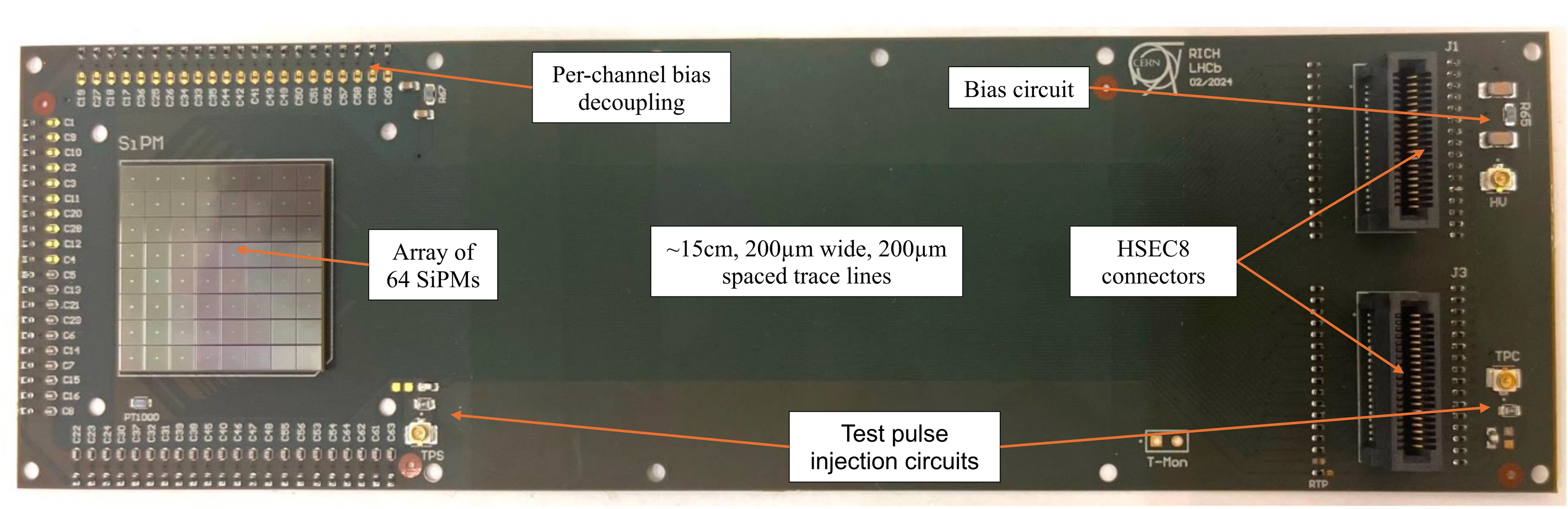


3. Flex-PCB

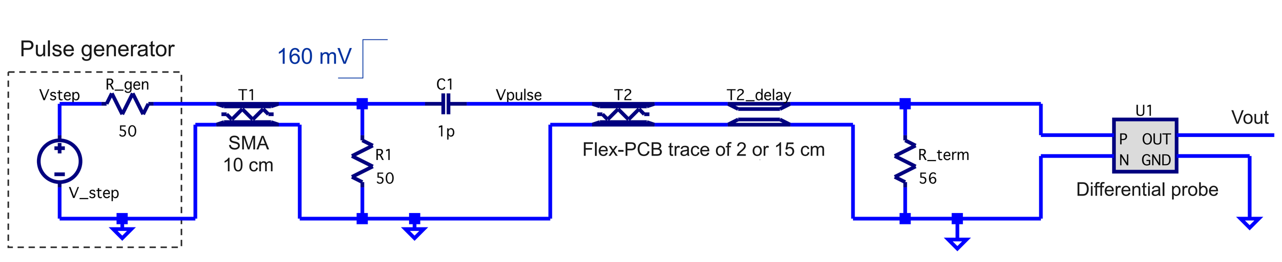
The purpose of the **flex-PCB** is to transmit analogue signals from the **cryogenically cooled SiPM array** to the **readout electronics at room temperature**. Its thin and flexible design improves thermal contact between the SiPM array and the cold block.

The flex-PCB consists of a **3-layer board** for the readout of a Hamamatsu S13361-3050NE-08 SiPM array (64 channels). It features **analogue traces spaced by 200 µm and approximately 15 cm in length** from the SiPM array to the connectors for the readout electronics.

The stack-up and layout are designed for a **signal trace impedance of ~50 Ω** and to guarantee a minimum **banding radius of 20 mm**. The SiPM array negative bias circuit includes 64 RC filters for per-channel bias decoupling. **Two test-pulse injection circuits** are included: one with a 15 cm trace and one with a 2 cm trace. A **PT1000 sensor** is placed close to the SiPM array for temperature monitoring.



4. Test pulse measurements for signal integrity

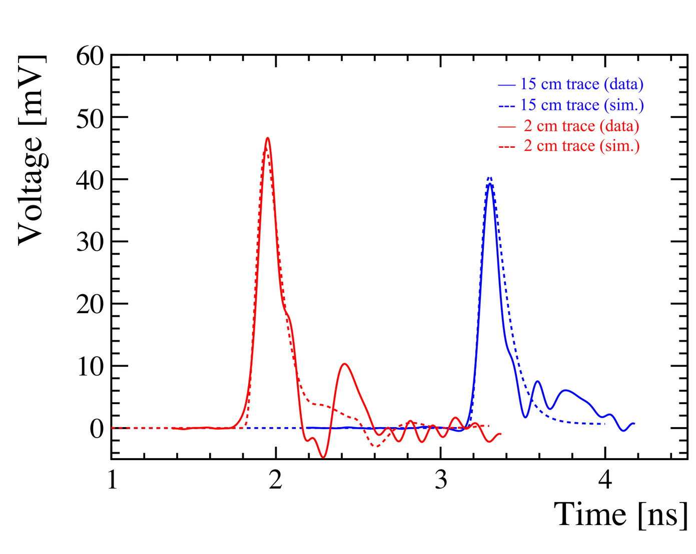


The main concern for the flex-PCB is the **impact of high-density, centimetre-long traces on signal integrity and time resolution**. The two test-pulse injection circuits were used to address this.

A step pulse of 160 mV with a rise time of 70 ps and 4 ps jitter is injected into a 1 pF capacitance to produce a SiPM-like pulse of 1 Me. The output pulse is recorded with a 5.3 GHz differential probe across a resistive termination chosen to match the trace impedance.

A **rise time comparable to the injected one** and a **jitter of approximately 10 ps** are measured, showing that signal integrity is preserved. The data agree with simulation. Ripples in the tails are due to second-order effects not included in the simulations.

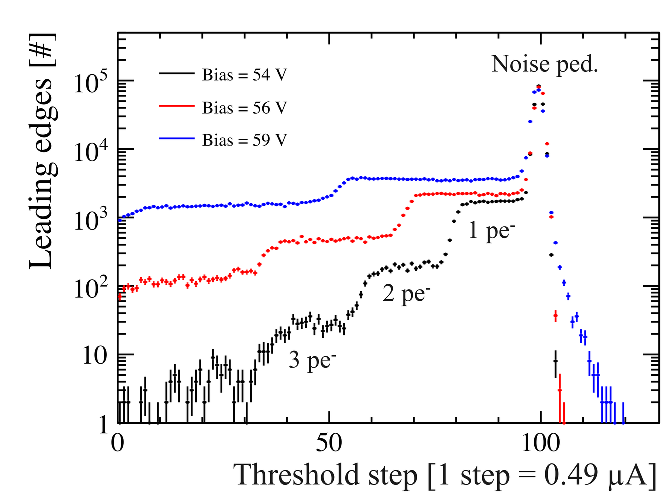
\	Rise time	Jitter
2 cm trace	71 ± 10 ps	10.8 ± 0.5 ps
15 cm trace	69 ± 10 ps	10.7 ± 0.5 ps

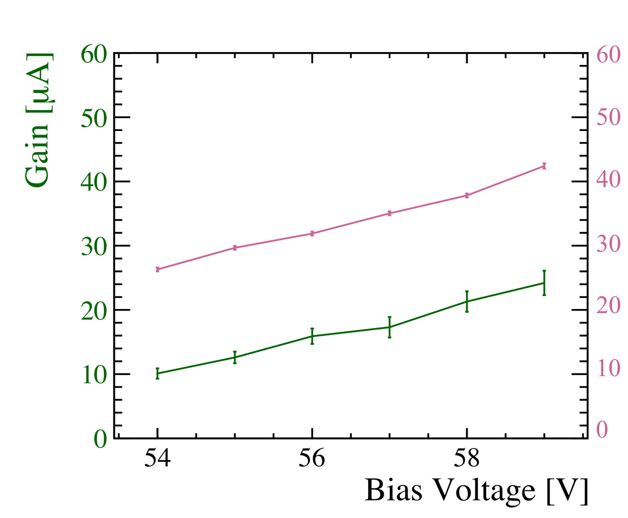


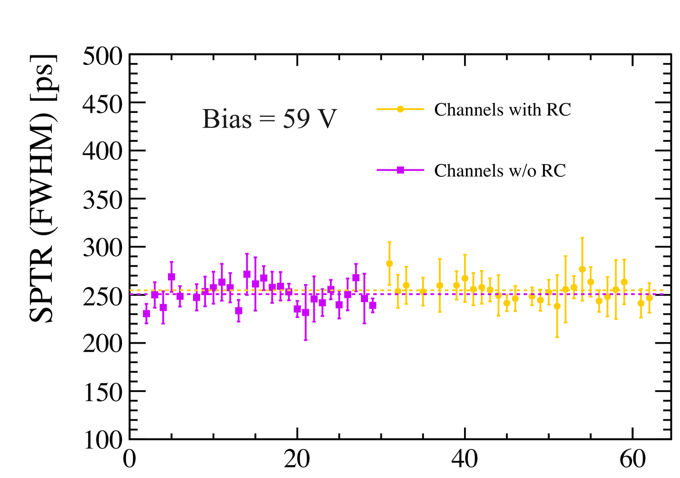
5. SiPM array characterisation

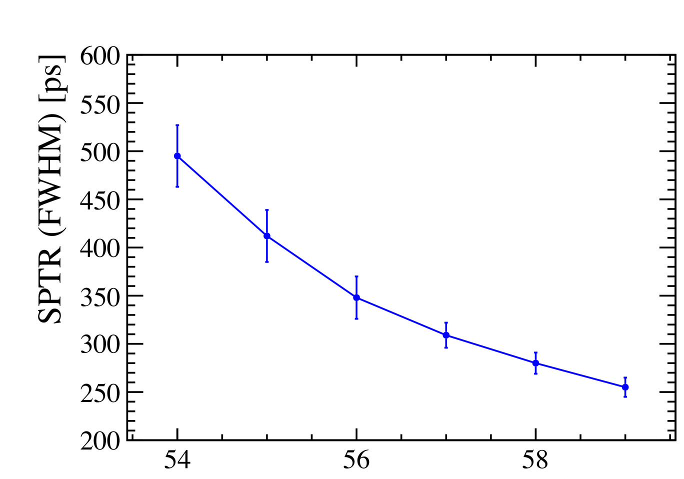
The flex-PCB has been coupled to a **FastIC-based readout chain** developed for the LHCb RICH beam test campaigns [6]. Threshold scans were performed at different bias voltages. **Gain and DCR show a linear increase** with applied bias as expected from the datasheet.

Single-photon time resolution (SPTR) of the SiPM array was also measured using a picosecond-pulsed laser. The SPTR improves with increasing SiPM bias voltage, reaching an average of **103 ± 5 ps (σ) at 59 V** at room temperature.









6. Outlook and conclusion

Assembly and commissioning of the cryostat demonstrator are ongoing. Each component is being validated in the lab, with particular focus on vacuum insulation, thermal exchange and mechanical stability. First operation is expected by the end of 2025.

Room-temperature measurements on the flex-PCB have demonstrated the reliable transmission of single-photon signals from the SiPM array to the readout electronics. These measurements have also provided key input for scaling the design to closely packed SiPM arrays.

These developments represent a **concrete step toward the deployment of scalable cryogenic photodetector systems for future RICH detectors**.

KEY REFERENCES

[1] LHCb Technical Design Report 26, CERN/LHCC 2024-010.
[2] *The Belle II Detector Upgrades Framework Conceptual Design Report*, H. Ahiara et al. (2024) DOI: 10.48550/arXiv.2406.19421.
[3] *Radiation damage of SiPMs*, E. Garutti et al. (2018) DOI:10.1016/j.nima.2018.10.191.
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[5] EP R&D Annual Report 2024, CERN-EP-RDET-2025-004.
[6] *LHCb RICH Fast-timing photon detection at the SPS charged particle beam.* M. Bartolini et al. (2025), DOI:10.1088/1748-0221/20/03/P03034.

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