Cooled Silicon Photo-Multipliers for next generation of Ring Imaging Cherenkov detectors

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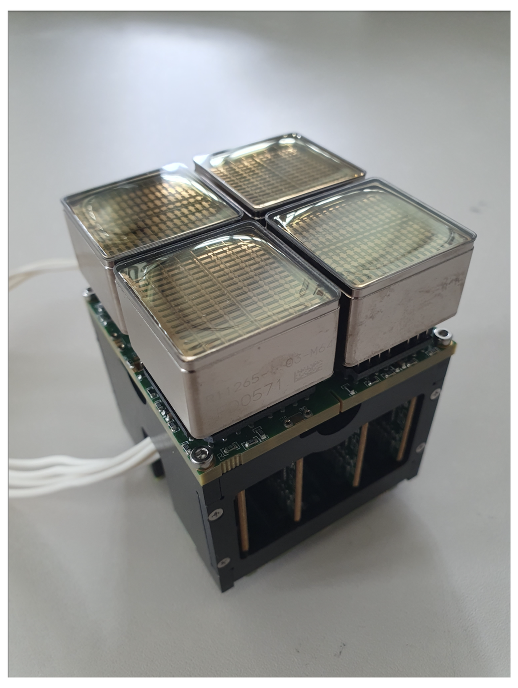
The integrated housing for SIPM for future RICH detectors

- The housing of photo-sensors for future RICH detectors is a complex task, regardless of the sensor choice, due the **many requirements**. In order to save on the required resources and simplify the design, **different functions should be possibly integrated all together**. Main requirements include:
  - structural stability to house and secure in place the sensor, the read-out boards as well as any other ancillary system;
  - **close-packing with large and uniform filling factor** on a large surface
  - **provide electrical connections** from/to the sensors, **thermal dissipation** functionalities for heat transfer to the cooling system
  - provide support for possible optical components (lenses and/or optical filter) and for components for calibration systems
  - ease of access for repair and maintenance.

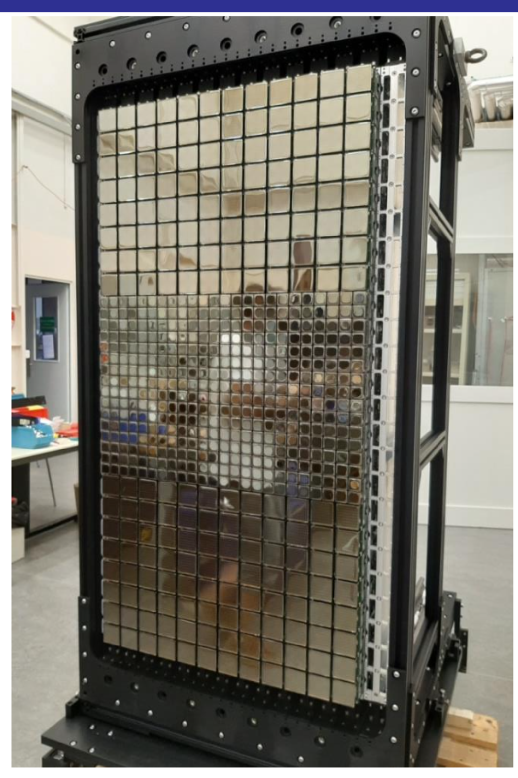
The housing of the LHCb RICH for the Upgrade I

The Elementary Cell (EC) is the housing module for the Hamamatsu R13742 and R13743 Multi-Anode Photomultiplier (MAPMT), currently used in the **Upgrade I LHCb-RICH** detector [1]. It consists of:

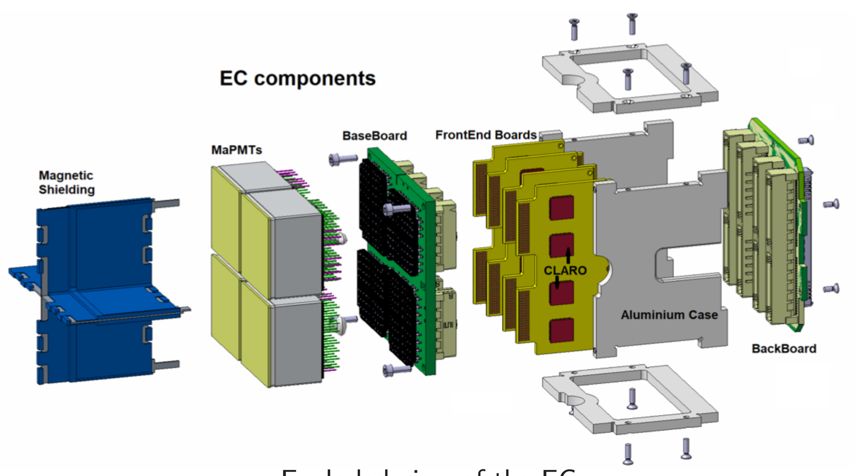
- A **Base-Board (BB)** with custom sockets to house the MaPMTs. It provides High Voltage (HV) to the MaPMTs, and a resistor divider chain(s) which supply potential(s) to the dynodes and connect the MaPMT anodes to the Front-End Boards. It has been designed to efficiently transfer the heat from the voltage-divider power by means of an internal structure made of several thick copper layers buried inside the PCB.
- **Front-End Boards (FEBs)**, each equipped with eight CLARO chips [2].
- A **BackBoard**, which interfaces the FEBs to the Digital Board for configuration and read out.
- An **aluminium case** which secures all the EC components and provides the thermal path from the BB to the back-end cooling structure, the column, which has ducts for coolant circulation.



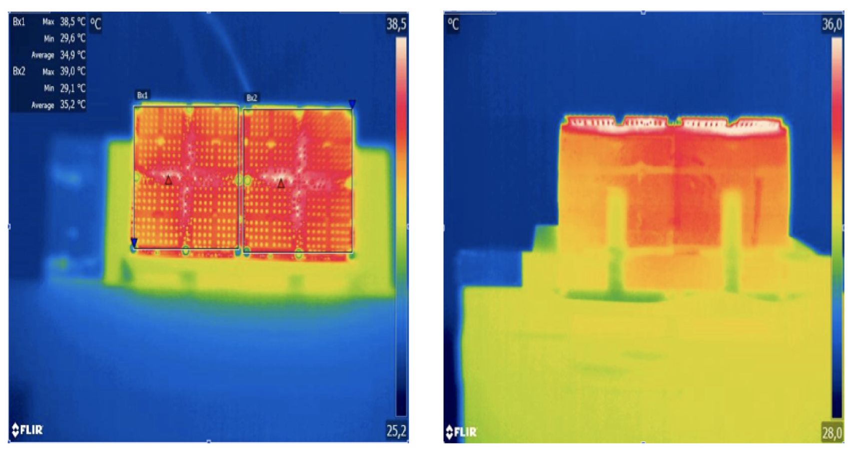
The EC for high-occupancy regions.



PhotoDetector plane assembly with high and low-occupancy regions ECs.



Exploded view of the EC



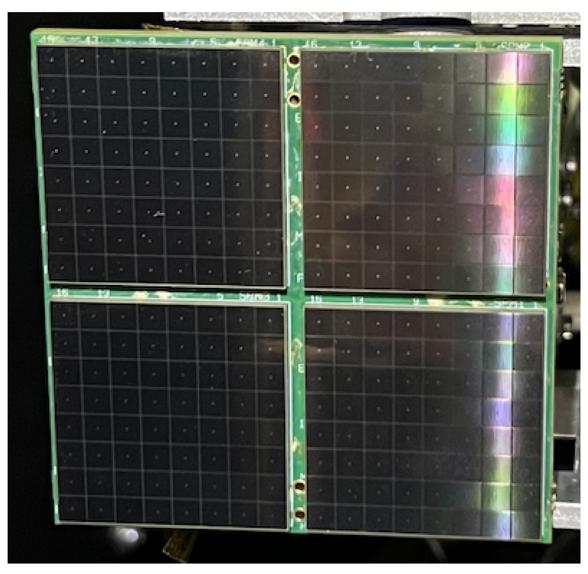
EC Thermal measurements

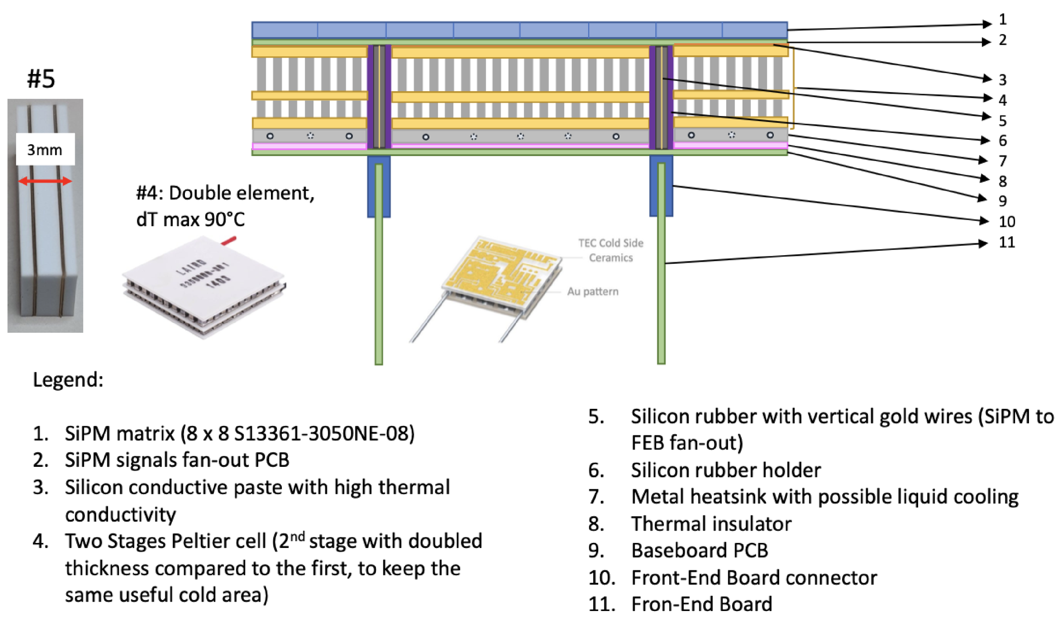
Upgrade with SiPM

- **SiPMs Advantages**: smaller pixel size compared to the current $3\,\mathrm{mm}$ size, excellent timing resolution and enhanced photo-detection efficiency.
- **High Dark Count Rate (DCR) and limited Radiation Hardness**: SiPMs face significant challenges with high DCR at room temperature and limited radiation hardness. **Cooling** can reduce DCR, as it is temperature-dependent, and annealing can help repair radiation damage.
- **Measurement of Photon Arrival Times**: introducing time bins, in addition to pixel spatial bins, significantly aids in suppressing DCR.
- **Neutron Shielding**: investigating the use of neutron shielding around the photodetector plane to reduce radiation level.
- **Micro-Lensing**: using micro-lensing can reduce the physical area of the SiPMs. This approach reduces the number of channels and sensor capacitance, mitigating DCR adverse effects.

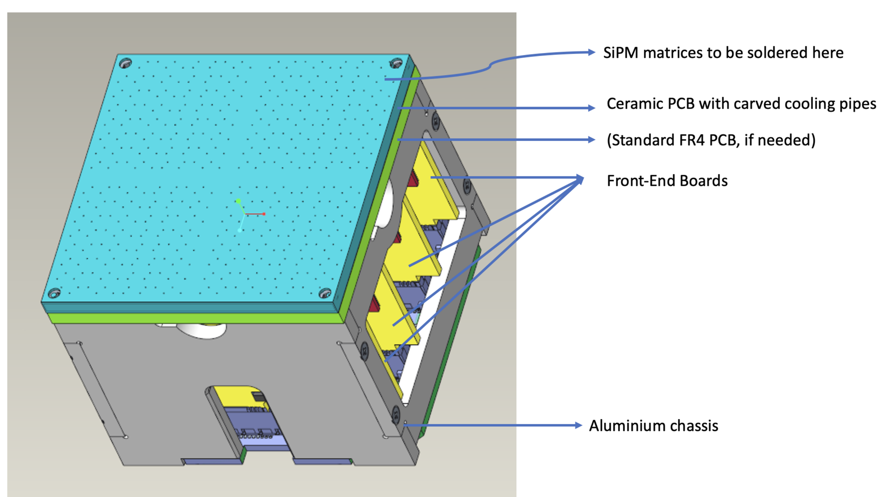
Local Cooling Strategy

- Cool down only a small region around the sensor to $-60\,^{\circ}\mathrm{C}/-80\,^{\circ}\mathrm{C}$
- Possible technologies include: miniaturised active Peltier coolers, fluid micro-channel cooling technologies, miniature cryo-coolers, ...
- The BB has been already adapted to host SiPM with very high geometrical acceptance, and used successfully in particle-beam at CERN
- First design of the BB with active cooling using a Peltier cell
- Radiation hardness campaign of the Peltier cell has been performed to verify any possible performance degradation: activation of the Peltier cell which pose issues with handling during any required maintenance of the detector
- Design on-going of a new BB with active cooling using a ceramic PCB with fluid coolant and SiPM directly soldered to pads on the metalized layer of the ceramic PCB

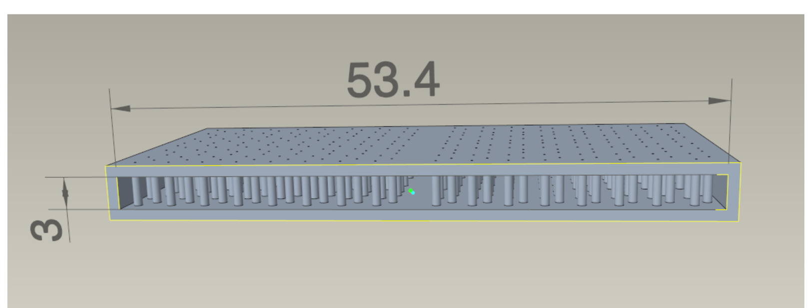




Design of the BB with active cooling using Peltier



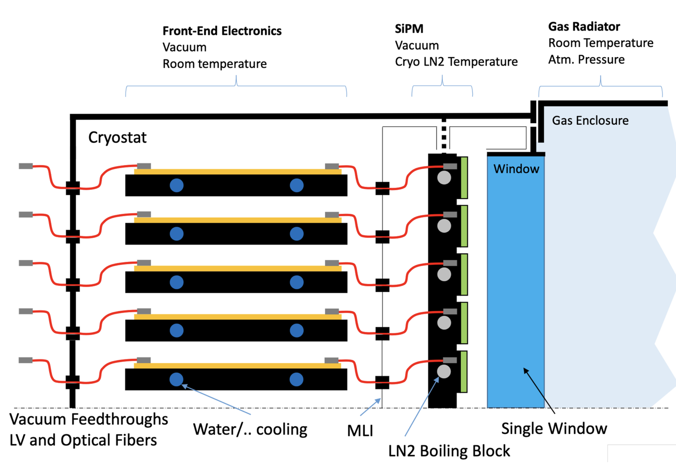
Design of the new ceramic PCB housing SiPMs.



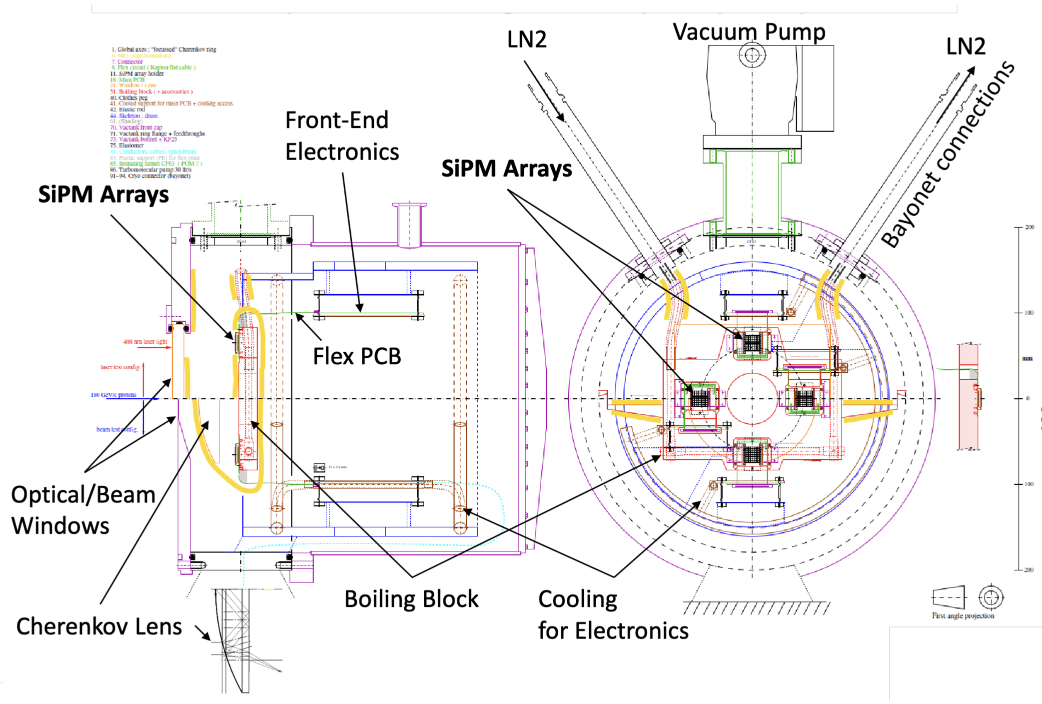
Section view of a possible design for the ceramic SiPM PCB.

Global Cooling Strategy

- **Cryostat** enclosing (part of) the RICH detector, for a global cooling of the RICH detector at the liquid nitrogen temperature ($\approx -200\,^{\circ}\mathrm{C}$) [3].
- Quartz windows separate the SiPM region from gas radiator regions: possible thermal interference among the ambient temperature gas radiator. In order to avoid gas condensation due to the nearby cooled sensors:
  - Vacuum between SiPM and quartz window
  - Use Air Pocket Insulator
- Small-scale test bench design on-going to be tested in the lab and in particle-beam tests



Sketch of the Cryostat



Small-scale test bench design

Conclusions

- SiPMs are highly promising photodetectors for RICH systems in next-generation collider experiments
- Active cooling at temperatures well below zero is especially necessary in highly irradiated environments.
- A series of tests foreseen in the coming months in the lab and on test beams to evaluate the cooling effectiveness and guide the design process.

References

[1] Roel Aaij et al. The LHCb upgrade I. 5 2023.
[2] M. et al Baszczyk. CLARO: an ASIC for high rate single photon counting with multi-anode photomultipliers. *JINST*, 12(08):P08019, 2017. doi: 10.1088/1748-0221/12/08/P08019.
[3] CERN EP Group. Annual Report 2023 and Phase-I Closeout, CERN-EP-RDET-2024-001. https://cds.cern.ch/record/2891650/.