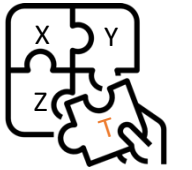
EP R&D Status of R&D on RICH detectors for future high energy experiments

Floris Keizer on behalf of EP R&D WP3.4/5

EP R&D days,

Monday 20 June 2022

Introduction (WP3.4)



Prompt Cherenkov radiation "+" focusing optics "=" photons from a track arrive **~ simultaneously**.

- Photon timestamp information is critical to **combinatoric backgrounds** in HL-LHC applications.

Initial R&D focus both at and outside* CERN has been on developing a **novel opto-electronic chain** with SiPMs and a fast-timing readout ASIC with ~ 25 ps bin size.

- **FastRICH** ASIC.
- Coupled to MAPMT (during Run 4) or **SiPM** (candidate Run 5) sensors.
- Next R&D phase aims to lower the **operating temperature**.

Test beam campaign at the CERN SPS facility.

- Testing of fast-timing readout **prototypes** (with **FastIC** ASIC and TDC).
- Studies with SiPM, MAPMT and (Oct 2022) LAPPD.
- New Cherenkov radiator studies.

LHCb note for Long Shutdown 3 (LS3) enhancements.

- DAQ considerations and compatibility with infrastructure incl. next-generation optical links (lpGBT/VL+).
- Model for bandwidth and power distribution.
- Software R&D for 4D reconstruction.

(*) Presentation includes activities with our collaborating institutes:
CERN, Barcelona, Bucharest, Cambridge, Edinburgh, Ferrara, Genova, Ljubljana and Perugia

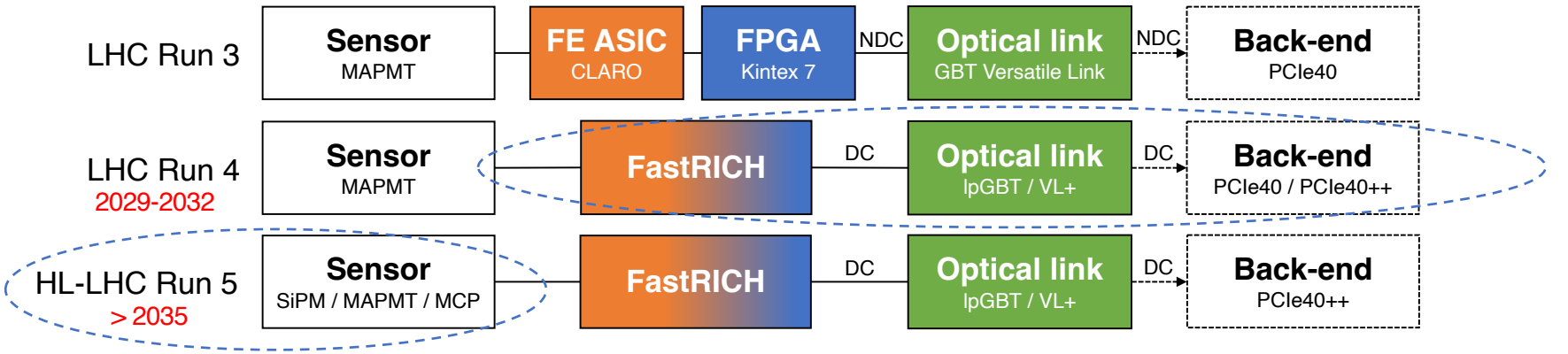
Novel fast-timing front-end readout electronics

Proposed LS3 enhancements:

- Introduce FastRICH ASIC (fewer and radiation-hard components in the chain).
- Change to Data Compressed (DC) format at front-end.
- Introduce lpGBT/VL+.

LS4 LHCb Upgrade II:

- Emphasis on system design and improved sensor technology.



	Sensor	ASIC timewalk	FE time gate	TDC time bin
LHC Run 3	150 ps	< 4 ns	6.25 ns	None
LHC Run 4	150 ps	CFD correction	2 ns	25 ps
HL-LHC Run 5	~ 50 ps	CFD correction	2 ns	25 ps

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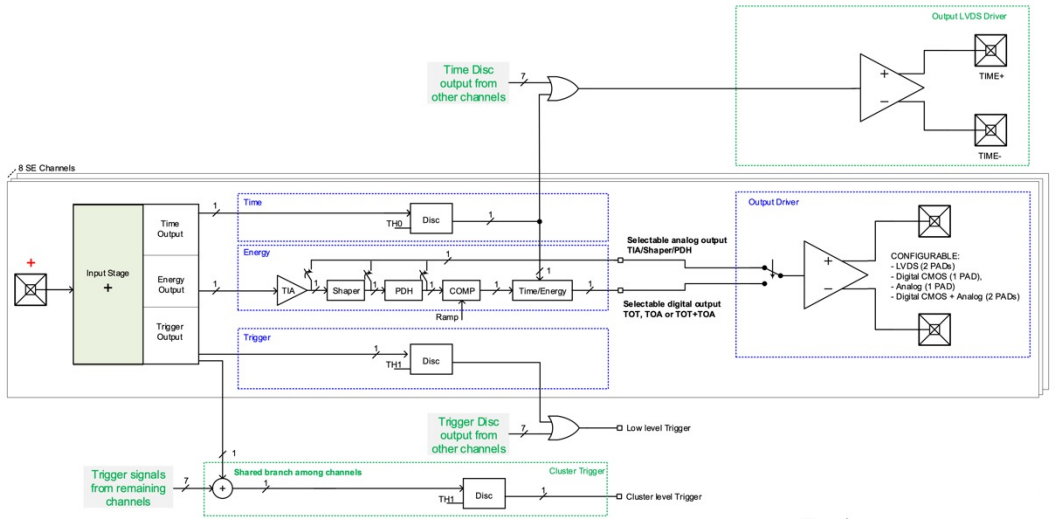
FastIC, FastIC+ and FastRICH ASICs

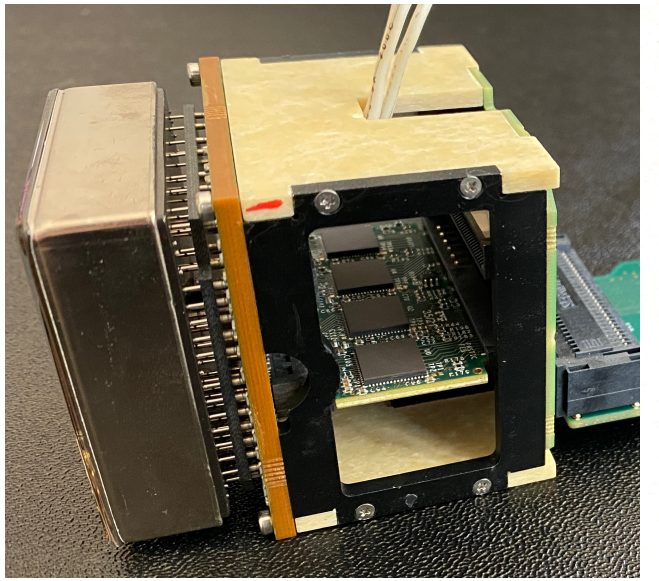
The Fast Integrated Circuit (FastIC) is an ASIC designed in 65 nm CMOS technology by the University of Barcelona (ICCUB) and CERN-EP-ESE.

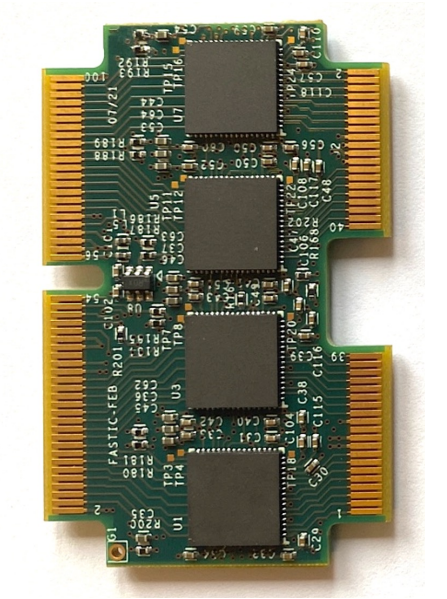
- 8-channel chip with **wide input dynamic range** of 5 uA to 25 mA for pos/neg signal polarities.
- **'Analog' ASIC** with fast discriminator (better than ~ 30 ps jitter).
- **Not** designed to be specifically **radiation hard**.

Used for the **beam test prototype** readout chain with fast timing.

- Output of fast-timing channel: ToA + **non-linear ToT**.
  Requires **external TDC** (in an FPGA, ~150 ps bins, for the RICH beam tests).





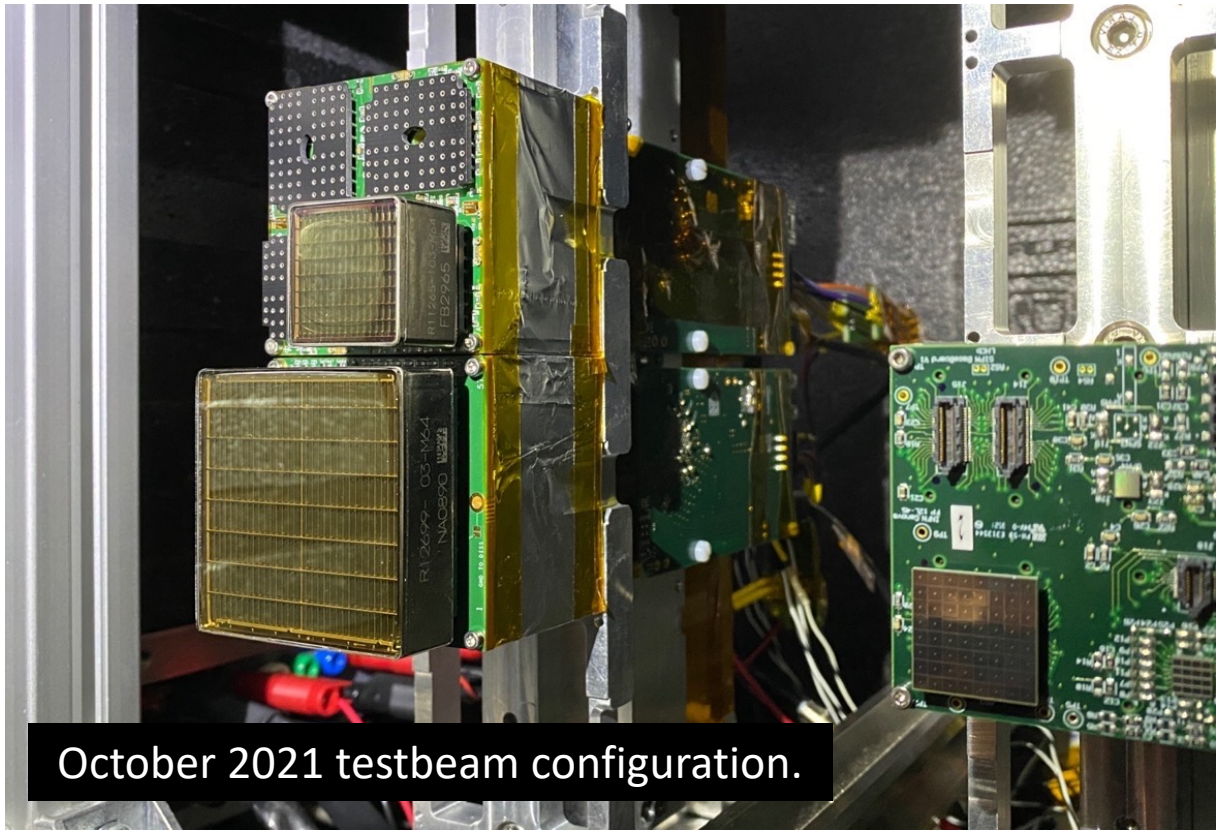


RICH elementary cell with FastIC ASICs.

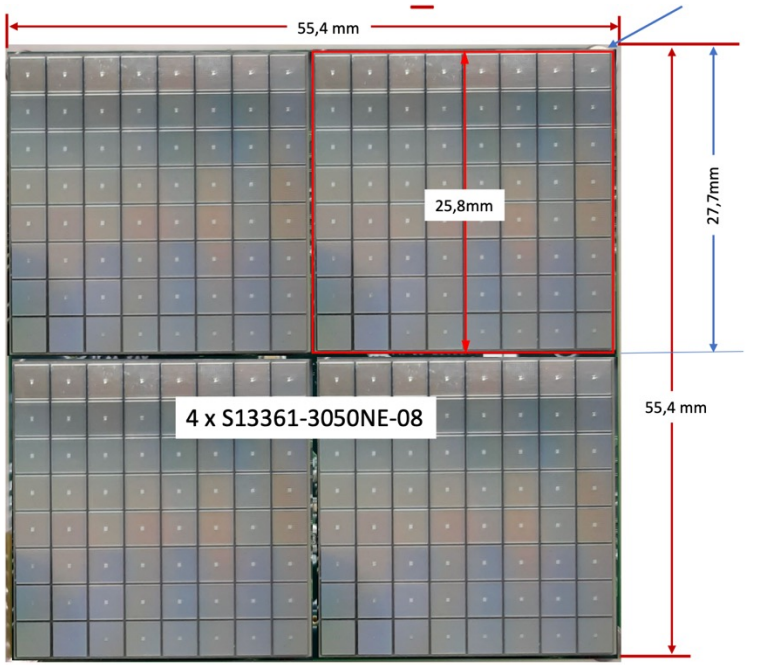
RICH test beam campaign: fast-timing readout chain

FastIC coupled to MAPMT (1 and 2-inch devices, Run 4) and an SiPM array (Run 5 candidate) first tested with detected Cherenkov arcs at the CERN SPS facility in October 2021.

- Further measurements and improved timing characterisation / TDC in July and October 2022.
- R&D is evolving to **larger sensor areas in a temperature-controlled (cryogenic) prototype**.
- LAPPD planned to be coupled to the electronics.
- Studies currently in parallel to ongoing FastRICH design.



October 2021 testbeam configuration.



Foreseen elementary cell with SiPM arrays for October 2022 beam tests.

- SiPM / MPPC arrays purchased.

FastIC, FastIC+ and FastRICH ASICs

Next-generation **FastRICH** is based on the FastIC and specific requirements of the RICH detector.
ASIC design is ongoing (CERN-ICCUB) with the analog parts far advanced.

- **16-channel** chip with **analog and digital** signal processing.
- **Compatibility** with lpGBT and the architecture of the Run 4 and Run 5 DAQ.
- **Radiation hard** by design.
- **TDC** with ~ 25 ps time bins.
- **40 MHz** readout rate.

The FastRICH will also include data-compression techniques:

- **Hardware shutter time** (configurable) to limit the timestamp range to ~ 1 to 2 ns.
- **Constant-fraction discrimination** (CFD).
- **Zero-suppressed** output over configurable number of output links to lpGBT.

… Resulting in **7 bits timing** (ToA only) plus **4 bits channel ID** per hit.

The FastIC+ is another development to include a TDC with 25 ps bins into the FastIC chip, targeting medical applications without radiation hardness.

- Synergy in terms of digital design and TDC with the custom FastRICH.

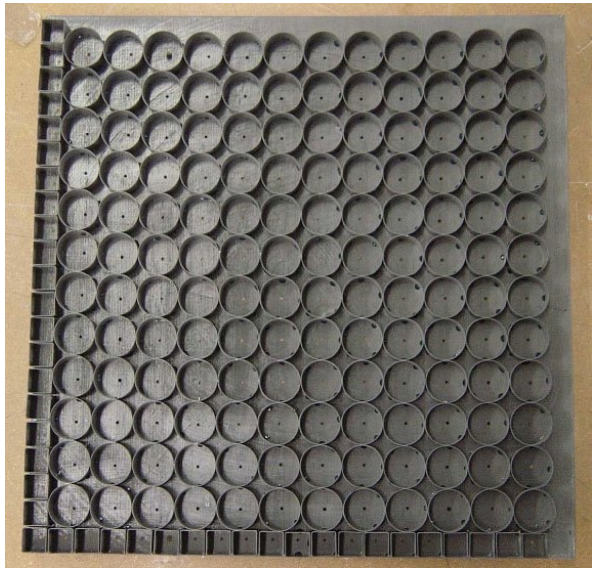
R&D efforts to specify the RICH requirements, integrate the ASIC in scalable designs and study the prototype chain in beam tests.

Light-weight composite mirrors and supports

In current RICH 1, carbon fibre-based spherical mirrors (~ 1% X_0) and support structures are already developed and produced by CMA (AZ, USA).

R&D is still needed to:

- Develop flat mirrors.
- Improve quality and radiation length.
- Reduce cost.
- Look into new developments such as Si-Carbide mirrors (up to 1.5 m and ~ 5 kg/m^2).



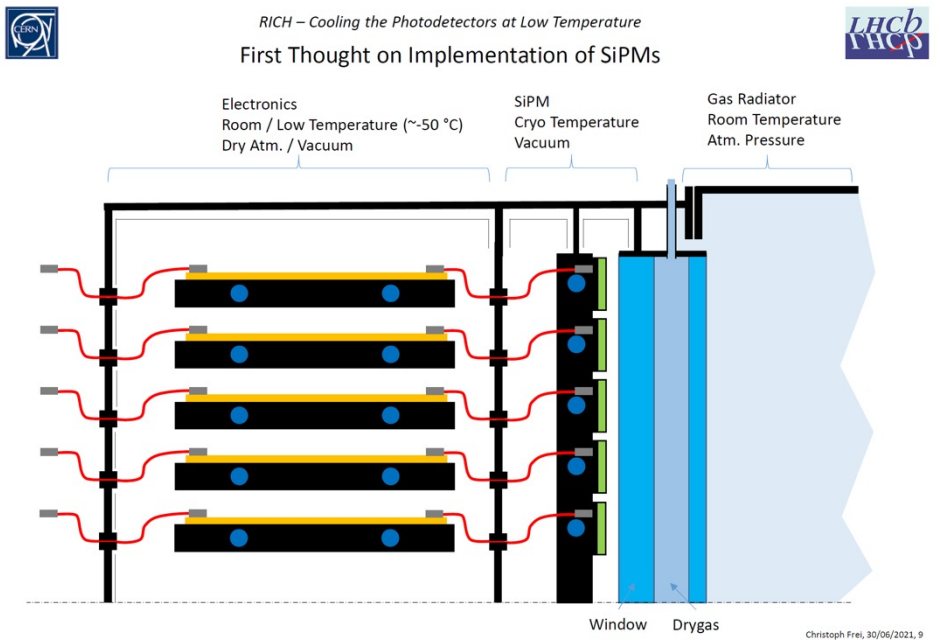
First flat carbon-fibre mirror prototype produced for RICH 1.

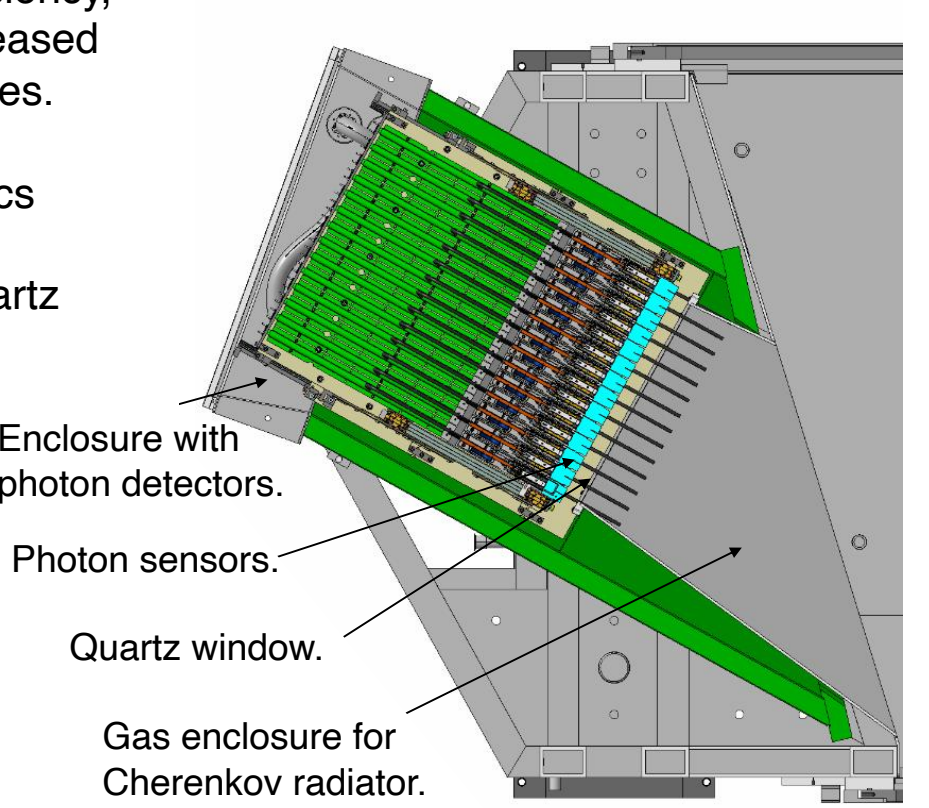
Low temperature / cryogenic cooling of photon detectors

Silicon photomultipliers (SiPMs) are an attractive technology for future RICH detectors (time resolution, photon detection efficiency, insensitivity to magnetic field, etc). The dark count rate (increased after radiation damage) requires operation at low temperatures.

R&D into compact vessel structures, meetings with cryogenics experts at CERN EP-DT-EF.

- One of the ideas could be to use two specially-coated quartz windows separated by a vacuum.



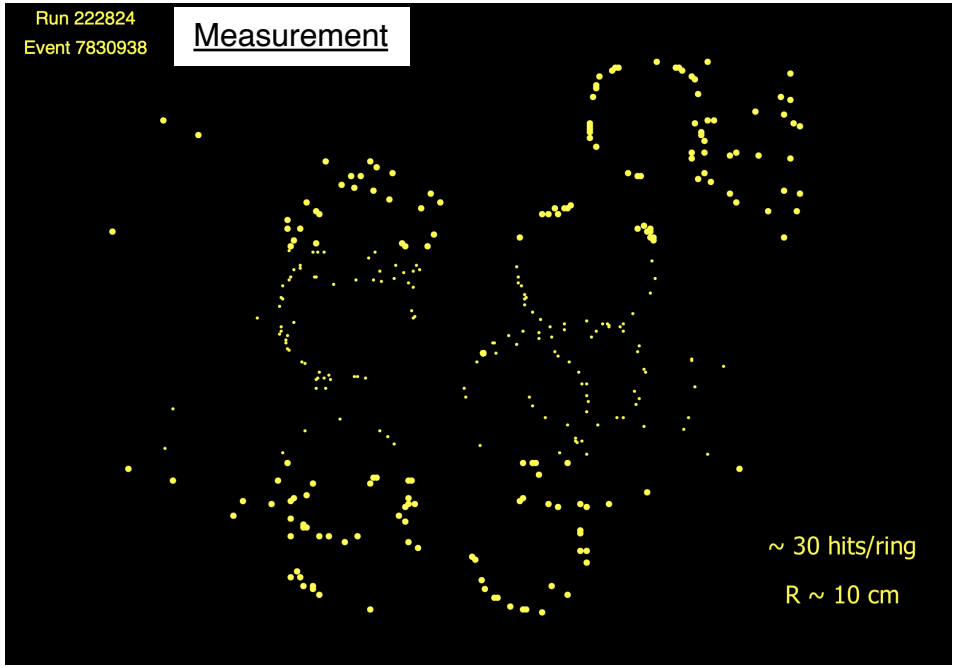


https://indico.cern.ch/event/1050470

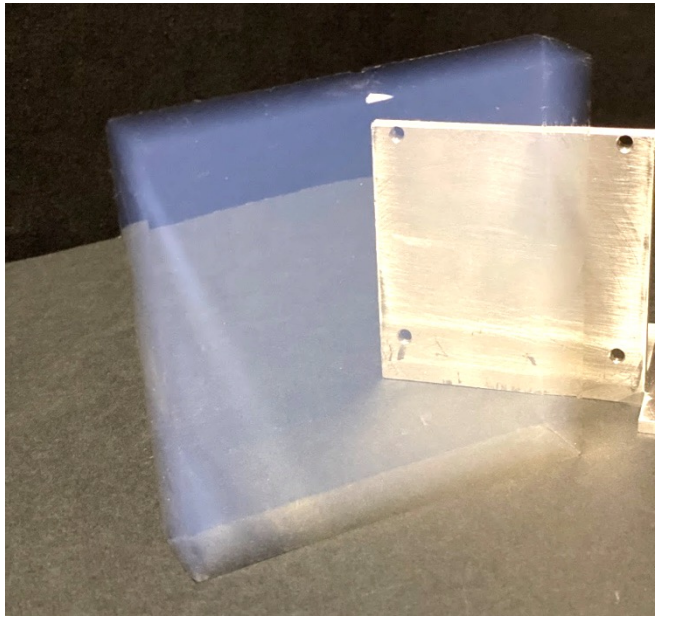
Novel radiator R&D [1/2]

R&D to provide the RICH detectors with '**green gases**' and R&D of novel radiators including **aerogel**.

- Similar ref. index but lower global warming potential (GWP) where possible.
- Sensors with wavelength range shifted towards the green spectrum provide new opportunities.
- Alternative R&D into leak-less gas system.



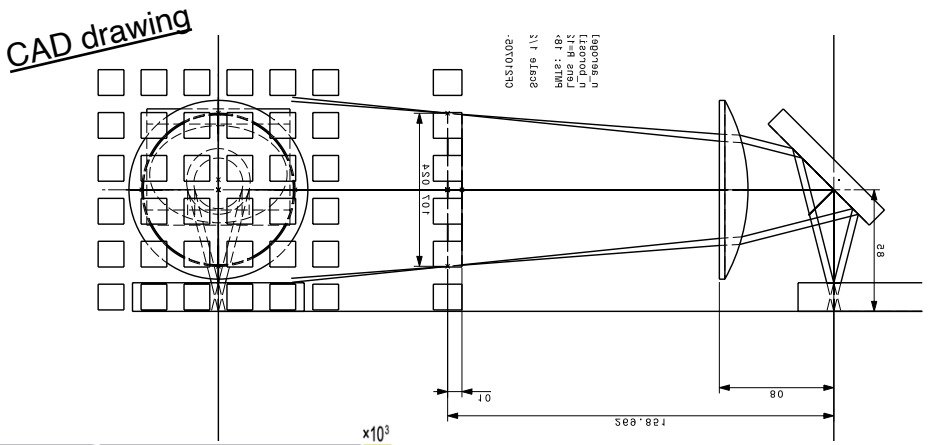
Example: during the LHC pilot beam tests (in October) RICH 2 was running on CO_2 (GWP=1) instead of CF_4 (GWP=4880).
Image of a collision event provided by Giovanni Cavallero, Silvia Gambetta and Antonino Sergi (https://indico.cern.ch/event/1093474/).

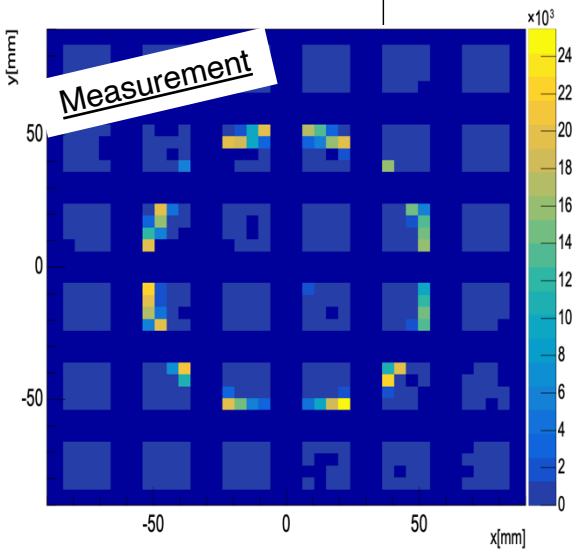


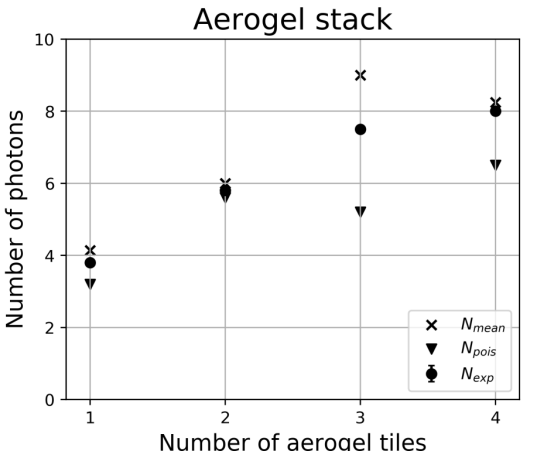
Novel silica aerogel tiles produced in Japan (https://arxiv.org/abs/1112.3121). Hydrophobic and with improved transparency.

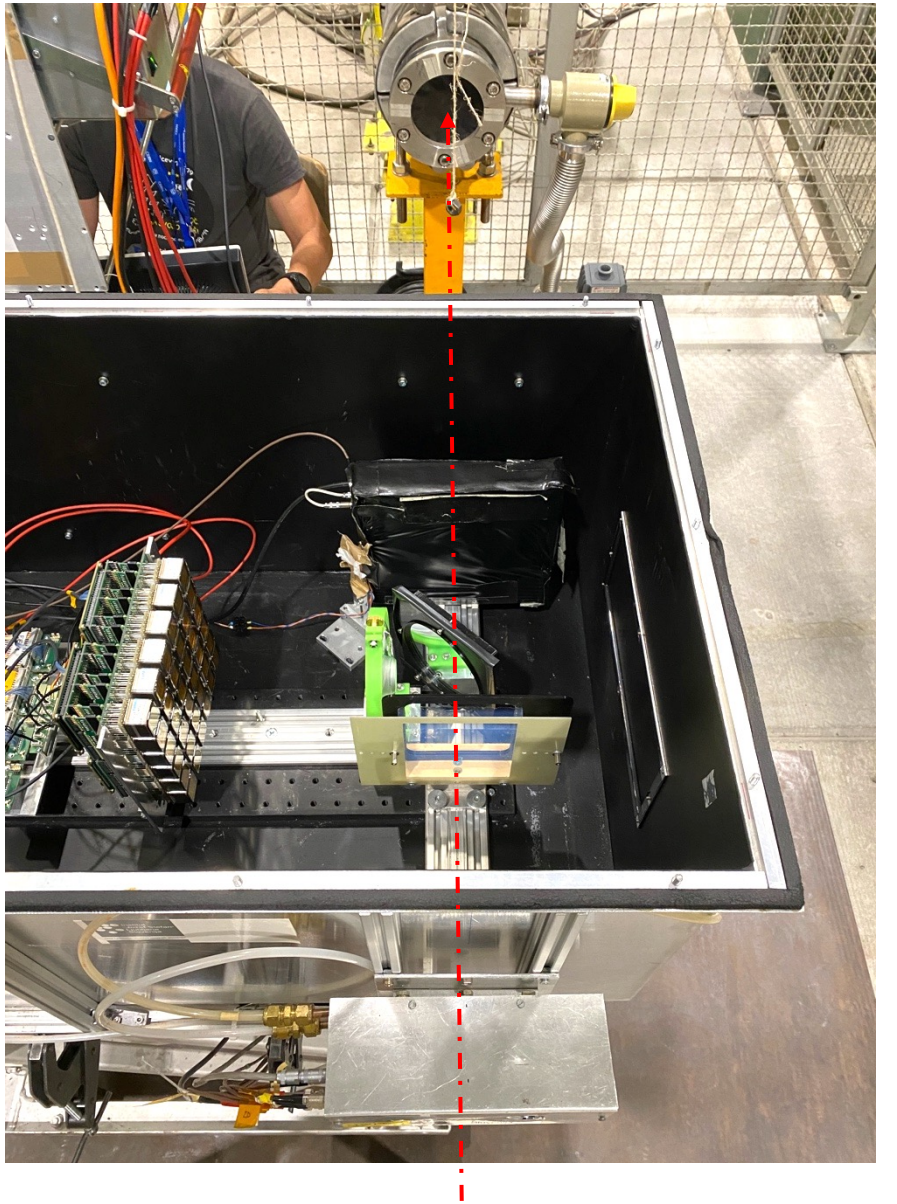
- Studied at SPS beam tests, see next slide.

Novel radiator R&D [2/2]









Tentative/preliminary results show high transparency (nearly linear for thicknesses up to 8 cm) and, taking into account various corrections, a yield of $\mathcal{O}(50)$ photons / cm of aerogel.

SciFi detectors for future HEP experiments (WP3.5)

Sune Jakobsen et al

R&D on novel scintillating plastic fibres:

- Geant4 simulations of 2 fibre variants.
- Simulation upgraded (v10.7) to allow mixtures of wavelength shifters.
- Studies demonstrated **gain in light output of up to 85%**.
- **Improved radiation tolerance** in new fibre concept.

Following these promising simulation results, collaboration with producer Kuraray:

- Currently procuring dyes with the desired properties.
- Next R&D stage: prototype fibre will be fabricated and characterised at CERN.

Conclusion

Fast-timing information is key for the operation of our RICH detectors in **high-luminosity** conditions.

Therefore, initial R&D focus on the development of a **fast-timing opto-electronic chain** through the implementation of the **FastRICH** ASIC **with key features:**

- 25 ps time bins.
- Wide input dynamic range (coupling to MAPMT / MCP as well as SiPM).
- Data compression techniques: CFD, 2 ns FE gate and zero-suppressed readout.
- Direct compatibility optical links (lpGBT): rad-hard chain with fewer components.

Further progress on R&D for **SiPM arrays with cryogenic cooling**, lightweight **composite mirrors** and supports and new **Cherenkov radiators** (gaseous and aerogel) with test beams at the SPS facility.

Simulation results on **novel scintillating plastic fibres** for the SciFi show light output gain of up to 85% with improved radiation hardness. In collaboration with manufacturer for prototype fibre production.