Plans and developments for Cherenkov PID upgrades at LHCb and EP Strategic R&D

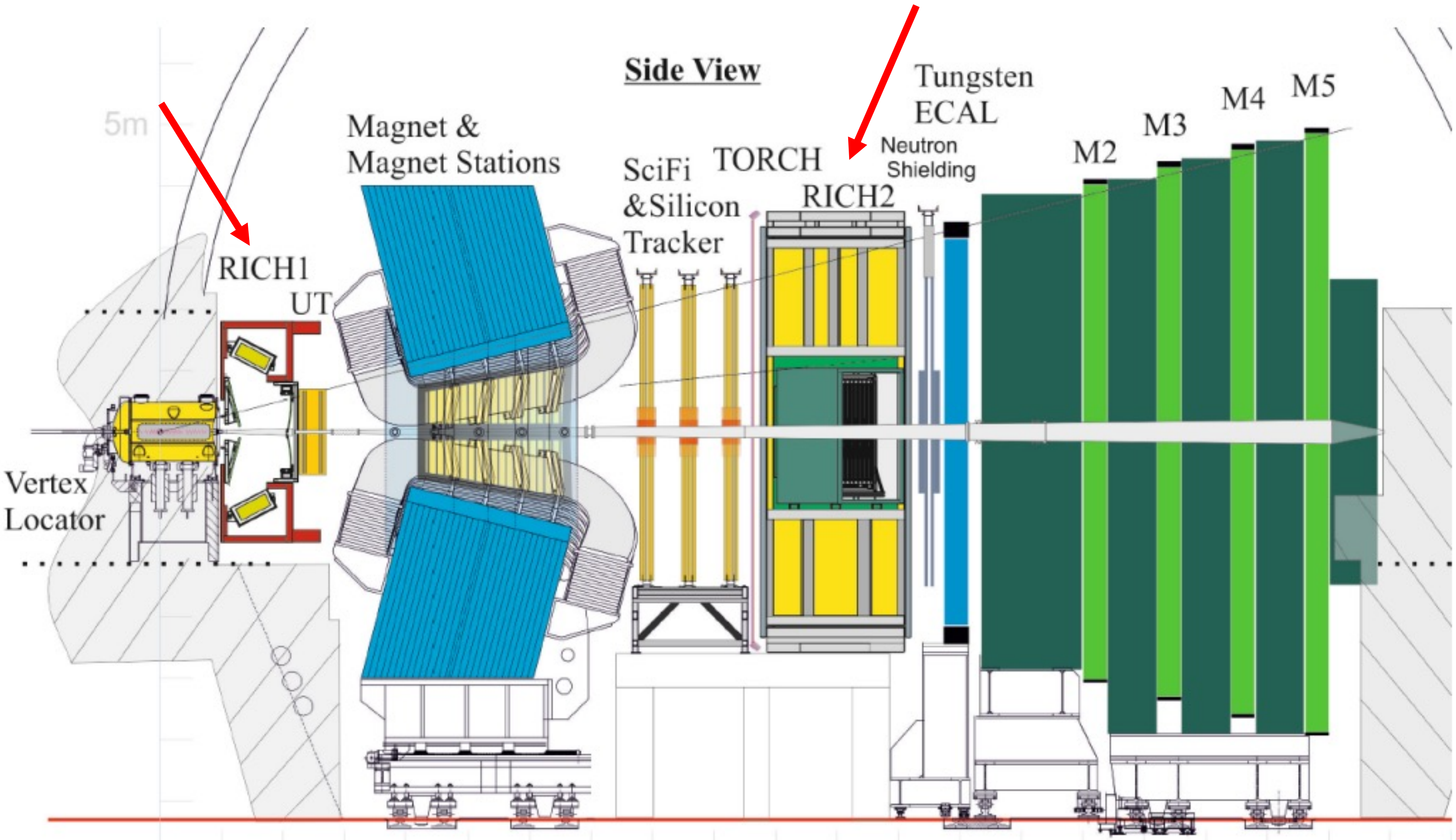
Floris Keizer on behalf of the LHCb RICH Collaboration

Meeting on PID and R&D at ALICE, ePIC and LHCb

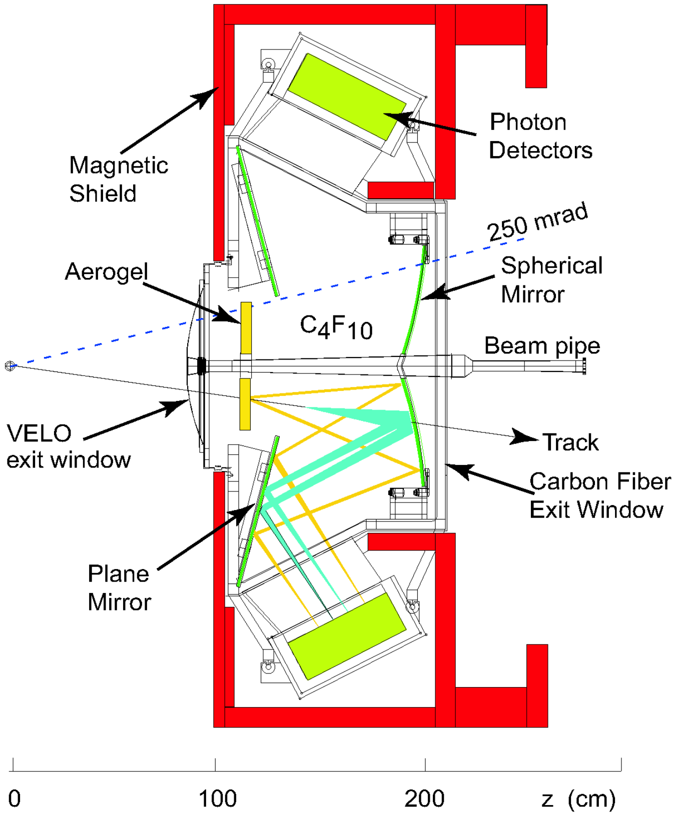
25 April 2023

- **LHCb RICH Upgrade II and LS3 enhancements.**
- Test beam campaign in 2021-2023.
- RICH institute R&D activities.

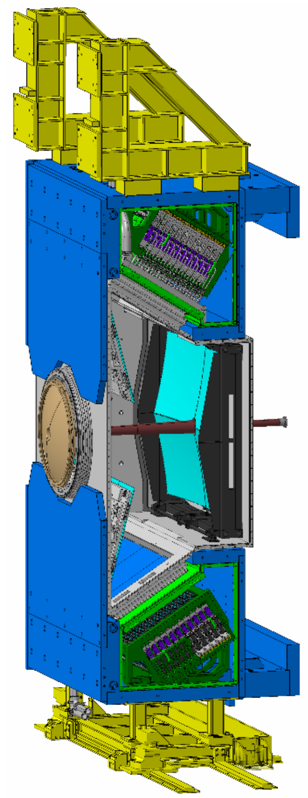
Introduction: the LHCb RICH detectors



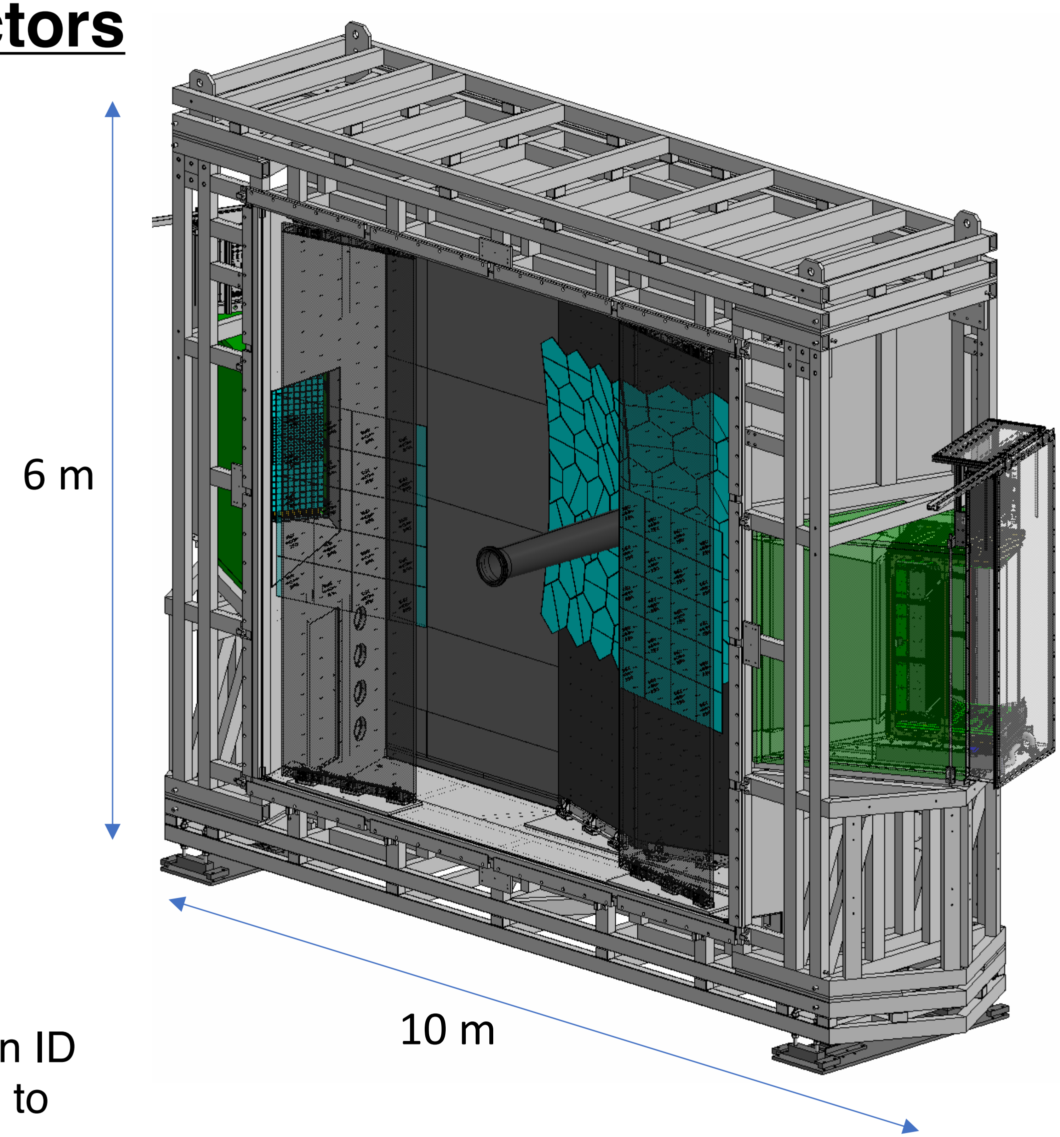
Introduction: the LHCb RICH detectors



The (old) RICH design including photon paths.

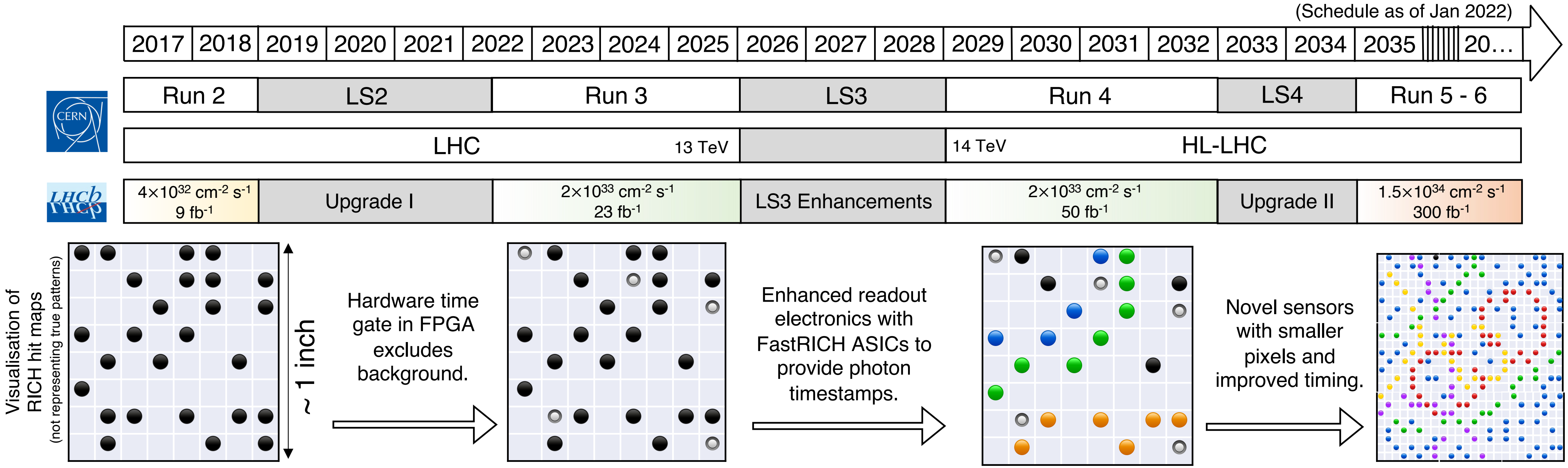


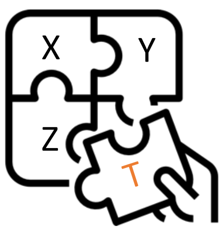
RICH 1 for charged hadron ID from 3 GeV/c (veto mode) to 65 GeV/c using C_4F_{10}.



RICH 2 covering 15-100 GeV/c using CF_4.

Introduction: LS3 enhancements and RICH evolution





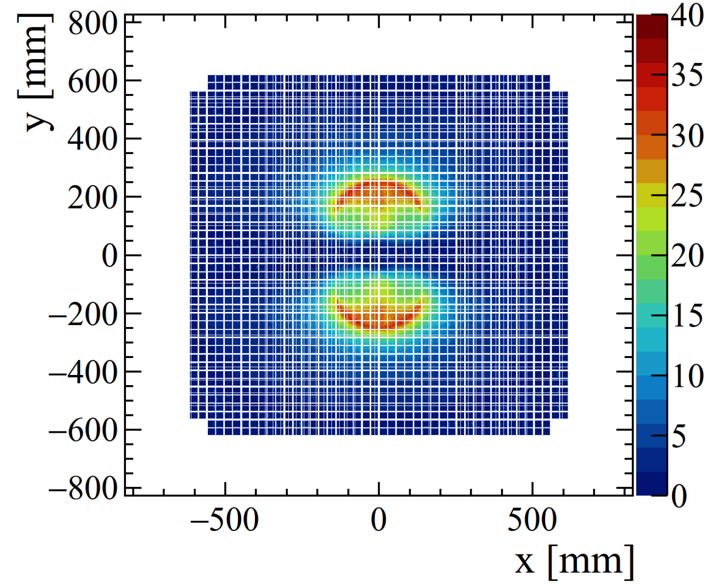
Addition of time:
4D ‘colour’ picture.

- LS3 / Run 4 : focus on **FastRICH** readout electronics with fast timing and wide input dynamic range.
- LS4 / Run 5 : focus on **sensor technology**. Fast-timing is essential for the luminosity challenge after Upgrade II.

RICH resolutions (Upgrade II)

The RICH detectors can benefit from a range of improvements to reduce the photon occupancy and improve the Cherenkov angle resolution in the high-multiplicity (x 7.5) environment during HL-LHC Run 5.

- Improved **granularity** to 1.0 x 1.0 mm^2 channels avoids the peak photon occupancy from exceeding 100 % and improves the pixel error.
- SiPM with **enhanced sensitivity in the green** wavelengths reduces the chromatic error.
  Additional studies ongoing on MCP-based detectors and next generation MAPMTs.
- **Redesign of the optics** with lightweight flat mirrors placed inside the acceptance reduces emission point error.

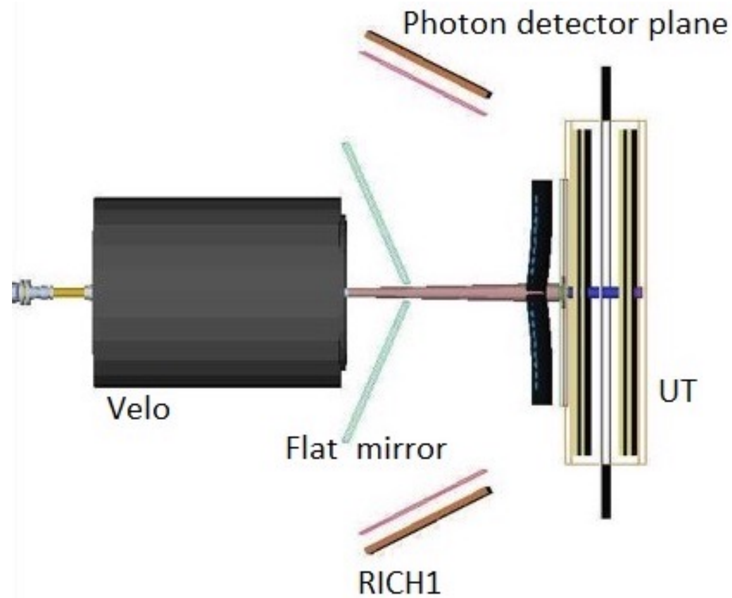


Configuration		Overall [mrad]	Chromatic [mrad]	Emission pt. [mrad]	Pixel [mrad]	Yield
RICH1	MaPMT	0.80	0.52	0.36	0.50	63
	SiPM	0.40	0.11	0.36	0.15	47
	SiPM & geometry	0.22	0.11	0.12	0.15	34
RICH2	MaPMT	0.50	0.34	0.32	0.22	34
	SiPM & geometry	0.13	0.1	0.05	0.07	20-30

Table 4.2: Examples of peak occupancies in RICH1 obtained using the LHCb simulation framework, assuming a pixel size of $2.8 \times 2.8\,mm^2$ for the MaPMT and $1 \times 1\,mm^2$ for the SiPM.

RICH1 peak occupancy	MaPMT	SiPM and geometry update
Upgrade I	35 %	3.9 %
Upgrade II	> 100 %	18 %

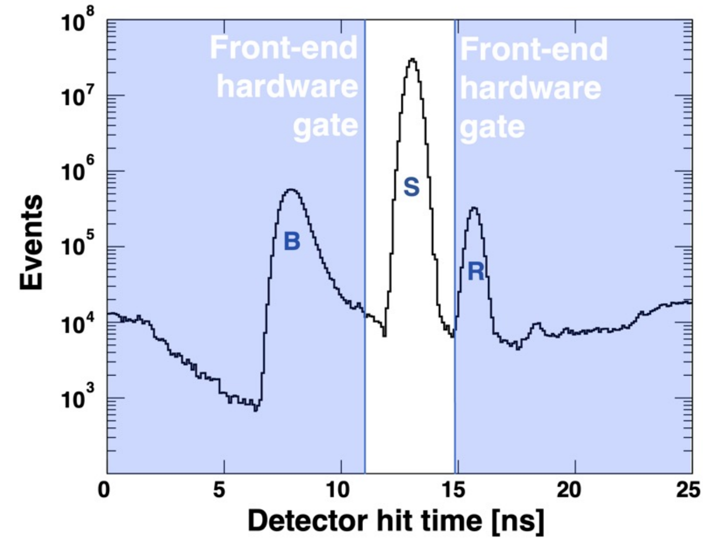
(Source: FTDR)



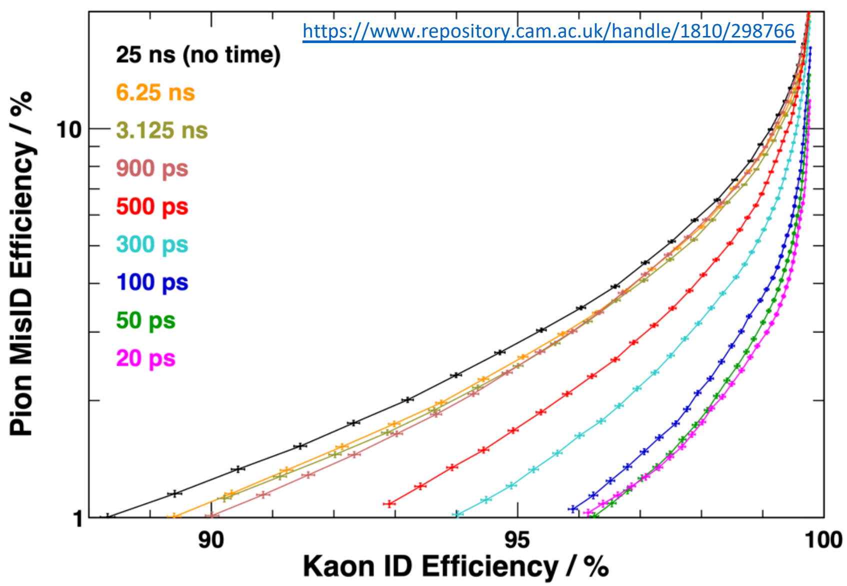
Fast timing in the RICH detectors

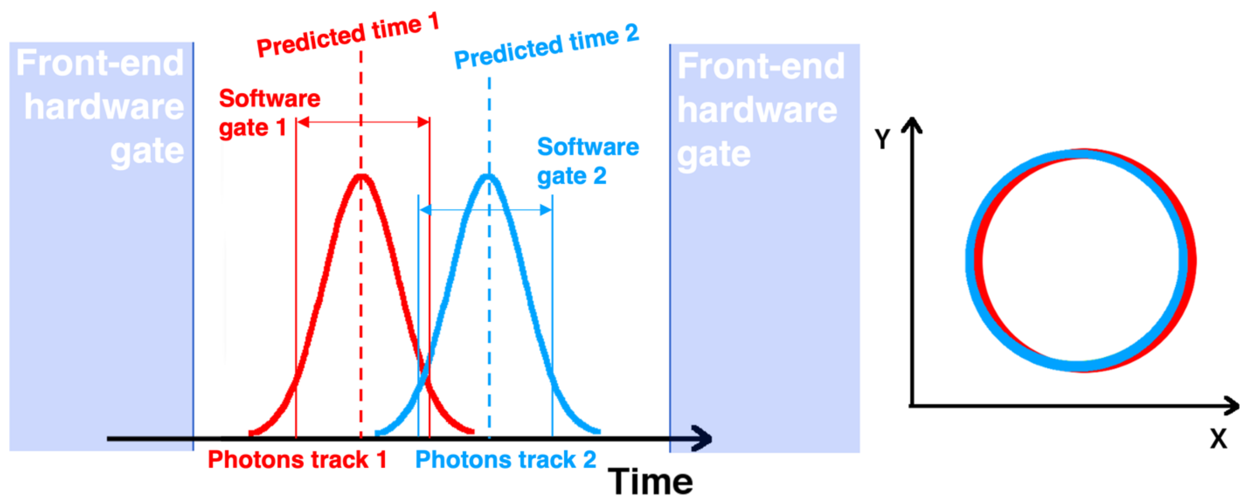
Two-fold use of fast-timing information in the RICHes:

- **Nanosecond front-end gate** to remove background hits and reduce data throughput.
- **Picosecond hit timestamps** to compare against expected time-of-arrival in reconstruction and reduce the combinatoric background.



PID curves with 'optimal' (zero time resolution) detectors show clear trend of improving performance: motivates R&D for sensors and readout electronics with excellent time resolution.

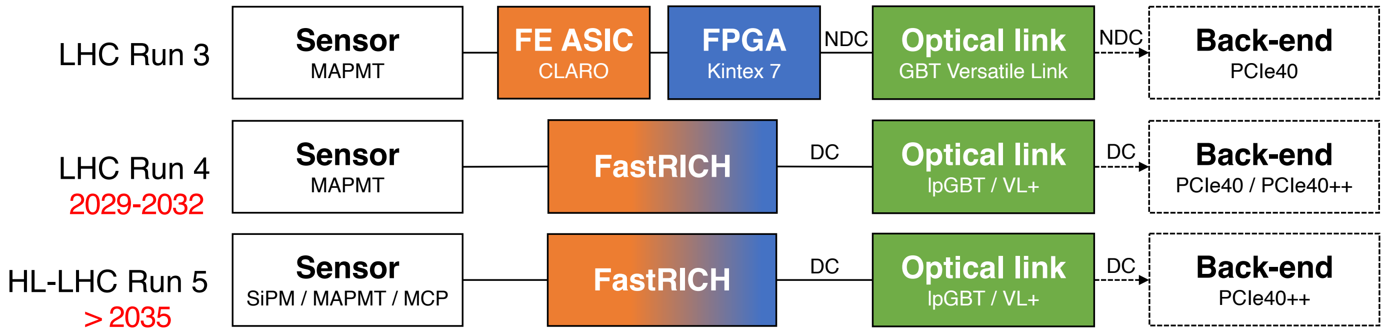




Fast-timing readout chain for LS3 and LS4

The LHCb RICH LS3 enhancements aim to equip the detector with new front-end readout electronics including the **FastRICH ASIC** capable of timestamping photon detector hits with ~ 25 ps time bins.

✓ Improve **PID performance during Run 4**.
✓ Introduce technologies for high-luminosity operation **ahead of Upgrade II**.
✓ Gather valuable experience with novel fast-timing and data compression techniques.

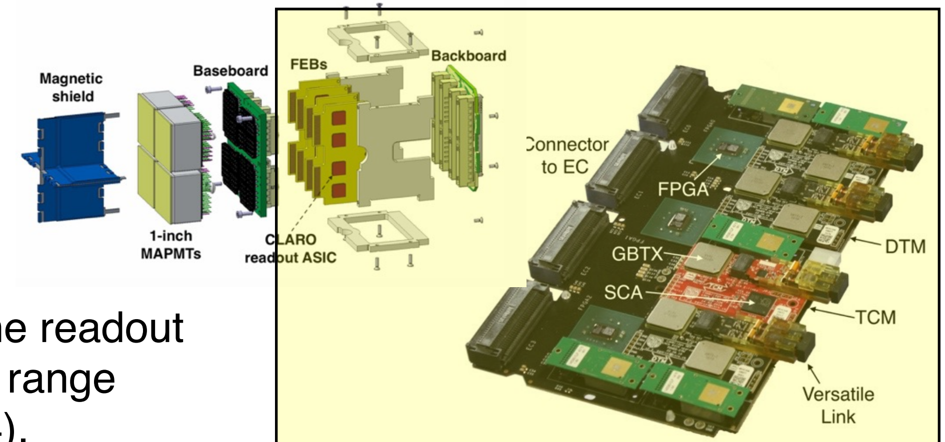


LS3 enhancements:

- Introduce FastRICH with 25 ps bins.
- Change to Data Compressed (DC) format.
- Introduce lpGBT/VL+.
- Small expansion at the back-end.

	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

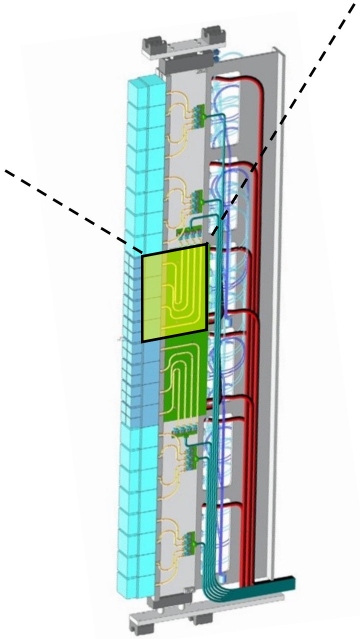
LS3 strategy for front-end with excellent photon time resolution



Run 3 readout electronics

Phased improvement of the detector, first consolidating the readout electronics with fast timing and wide input signal dynamic range (**LS3, FastRICH**), then improving sensor technology (LS4).

- **Leave untouched** the photodetectors (MaPMTs), optics and mechanics systems, LV, HV systems, modularity and services.



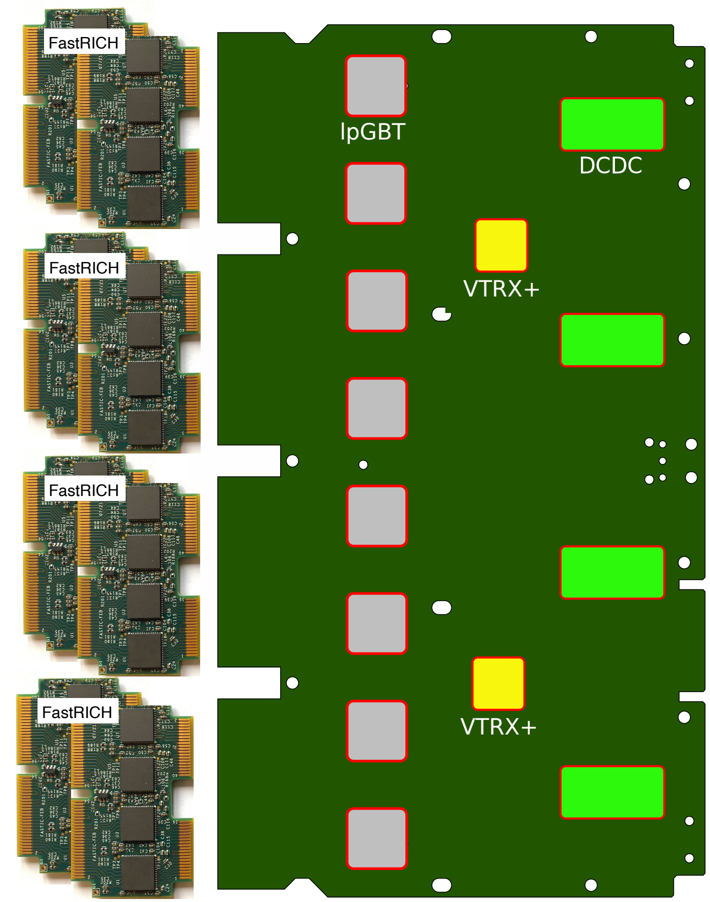
Advantages of this approach:

- Use effectively LS3 to consolidate/upgrade system and prepare for LS4;
- Picosecond-time-resolved RICH detector and a very interesting project to keep the important role of LHCb in this field;
- Give a new perspective to the whole LHCb experiment, by providing a good estimation of the t_0 for each primary vertex and the time stamp of each Cherenkov photon;
- Improve PID performance and physics throughput during Run 4 already;
- The improvements versus the costs are very favorable.

FastRICH front-end ASIC specifications

Specifications are tailored to ensure backwards-compatibility with the Run 3 mechanics whilst equipping the detector for Upgrade II.

- Time resolution: TDC with ~ 25 ps time bins.
- Power consumption: ~ 8 mW per channel (analogue + digital).
- Radiation hardness: ASIC solution for ~ 10^{13} n_{eq}/cm^2 and ~ 5 kGy.
- Dynamic range: 5 μA to few mA for coupling to MAPMT / SiPM / MCP.
- LHCb compatibility: direct compatibility with lpGBT / VTRX+ chipset.
- Readout rate: 40 MHz (LHC).
- Number of channels: 16.
- Hardware shutter time (configurable) to limit timestamp range to ~ 1 ns.
- Constant-fraction discrimination (CFD).
- Zero-suppressed output, aiming for ~ 12 bits per hit or less.



Note: Sketch for illustrative purposes. The numbers and placement of components will be subject to R&D and optimisation.

The FastRICH design is progressing well by the CERN-EP-ESE group and the University of Barcelona. The analogue part of the design is near completion and the digital design ongoing.

Sensor considerations

Generally, RICH detectors require **highly efficient single-photon sensors**.
There is no 'perfect' sensor that satisfies all the future RICH requirements.

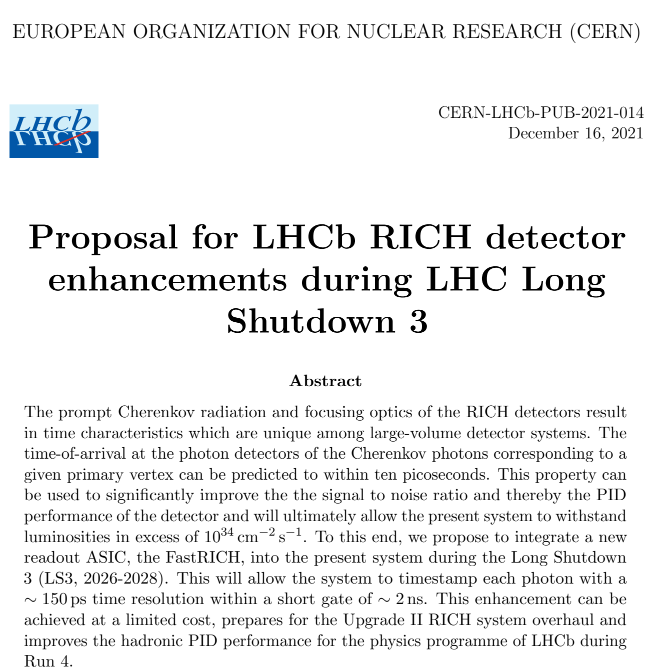
- **R&D is ongoing** into several candidates.
- **Silicon photomultipliers (SiPMs)** are a highly attractive 'off the shelf' technology but suffer from a high DCR especially after irradiation.
- **Micro-channel plate (MCP)**-based detectors have excellent time resolution but relatively poor anode current capability and gain ageing.

	SiPM / Solid-state	MAPMT	HPD	MCP-based family
Time res. sigma [ps]	60	150	~ 100	~ 30
Channel size [mm]	≥ 1	≥ 2.8	Custom (R&D)	Custom (R&D)
Peak quantum efficiency	> 45 % at 460 nm	> 35 % at 350 nm	30 % at 400 nm	20-30 % at 350 nm
Dark-count rate [Hz/mm^2]	$\mathcal{O}(10^5 - 10^7)$ at room T	1	1	1
Radiation tolerance	Lattice defects	UV glass window	Si ASIC	UV glass window
Gain ageing (50%) [C/cm^2]	SPAD	~ 10^3	Si ASIC	$\mathcal{O}(10)$ ALD
Bias voltage [V]	10-100	$\mathcal{O}(10^3)$	$\mathcal{O}(10^4)$	$\mathcal{O}(10^3)$
Robustness in B-field	Not affected	RICH 1 shielding (< 5 mT)	Orientation dependent	Micro-channel (< 2 T)

Further reading on the LHCb RICH Upgrades

More details on the **RICH LS3 proposal**:
- ➢ https://cds.cern.ch/record/2798273/files/LHCb-PUB-2021-014.pdf
- ➢ Progress on multiple fronts since then and now entered the Technical Design Report (TDR) phase.

The Upgrade II activities are summarised in the **FTDR**:
- ➢ https://cds.cern.ch/record/2776420


EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH (CERN)

CERN-LHCb-PUB-2021-014
December 16, 2021

Proposal for LHCb RICH detector enhancements during LHC Long Shutdown 3

Abstract

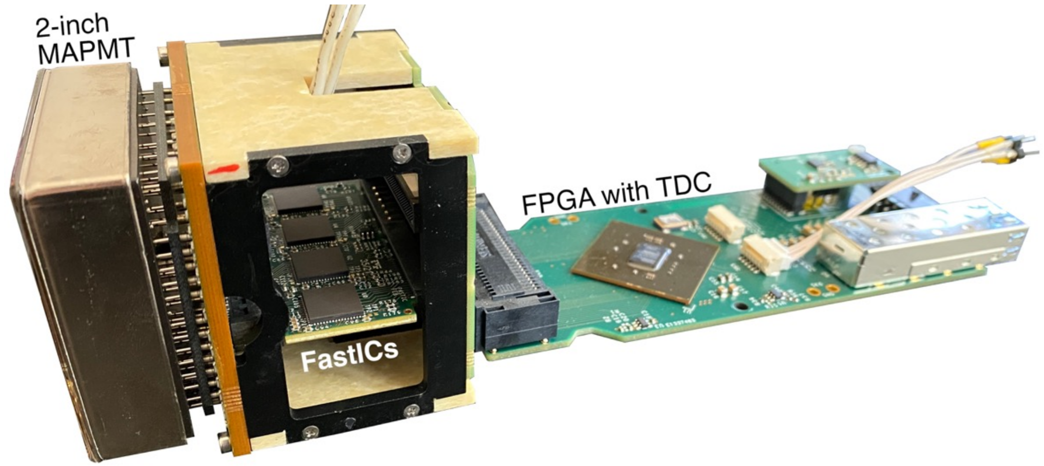
The prompt Cherenkov radiation and focusing optics of the RICH detectors result in time characteristics which are unique among large-volume detector systems. The time-of-arrival at the photon detectors of the Cherenkov photons corresponding to a given primary vertex can be predicted to within ten picoseconds. This property can be used to significantly improve the the signal to noise ratio and thereby the PID performance of the detector and will ultimately allow the present system to withstand luminosities in excess of $10^{34}\,cm^{-2}\,s^{-1}$. To this end, we propose to integrate a new readout ASIC, the FastRICH, into the present system during the Long Shutdown 3 (LS3, 2026-2028). This will allow the system to timestamp each photon with a $\sim 150\,ps$ time resolution within a short gate of $\sim 2\,ns$. This enhancement can be achieved at a limited cost, prepares for the Upgrade II RICH system overhaul and improves the hadronic PID performance for the physics programme of LHCb during Run 4.

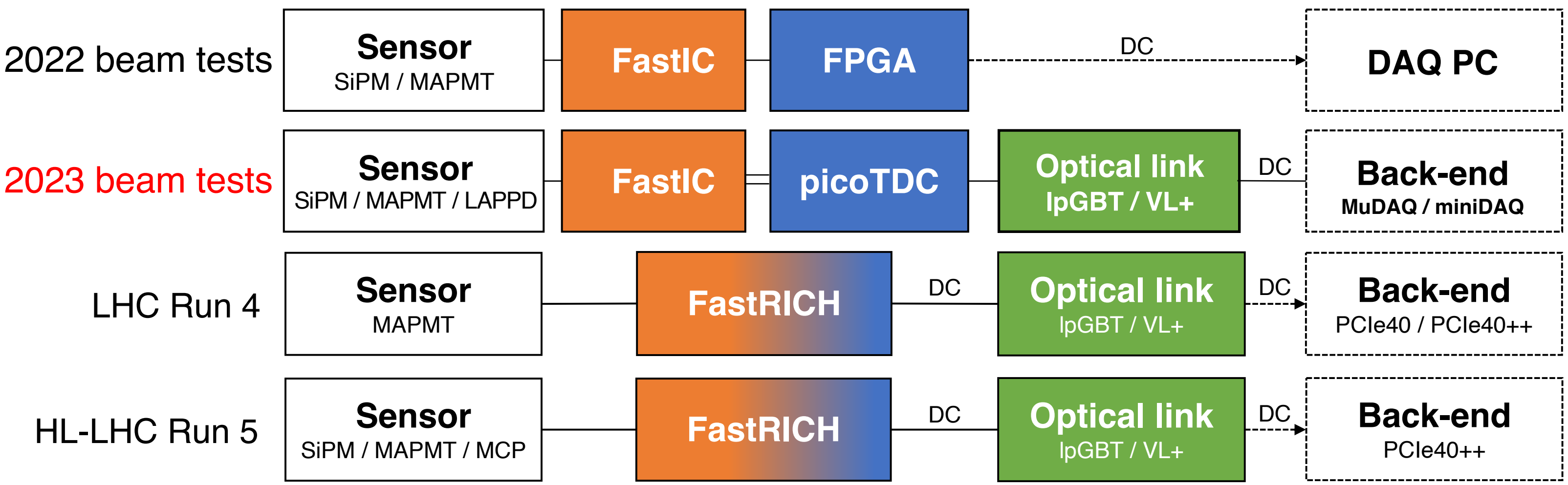
- ➢ LHCb RICH Upgrade II and LS3 enhancements.
- ➢ **Test beam campaign in 2021-2023.**
- ➢ RICH institute R&D activities.

SPS beam tests of prototype fast-timing chain

Studies of a prototype opto-electronic chain with $\mathcal{O}$(100 ps) timing for LS3 / LS4.
- ‘Proof-of-principle’ demonstration to detect 4D **Cherenkov rings / arcs**.

The FastIC under study will be the predecessor of the FastRICH for LS3.
- FastIC was coupled to SiPMs and MAPMTs.
- Read out by TDC-in-FPGA with 150 ps bins.
- Valuable information was collected on fast-timing techniques, FastIC operation, sensor coupling, clock and signal distribution etc.





Box with RICH timing setup

TimePix4 tracker

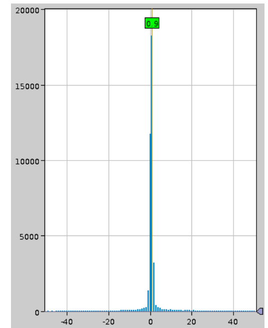
Particle beam

Box with RICH radiator setup

Box with RICH timing setup

SPS test beam studies of a prototype opto-electronics chain

- CERN SPS test beam facility.
- 180 GeV/c pions and protons.
- Pencil beam with $\sigma < 5$ mm.
- Few hundred kHz average particle rate.
- RICH MCP-PMT for track time reference.
- TimePix4 telescope for tracking information.

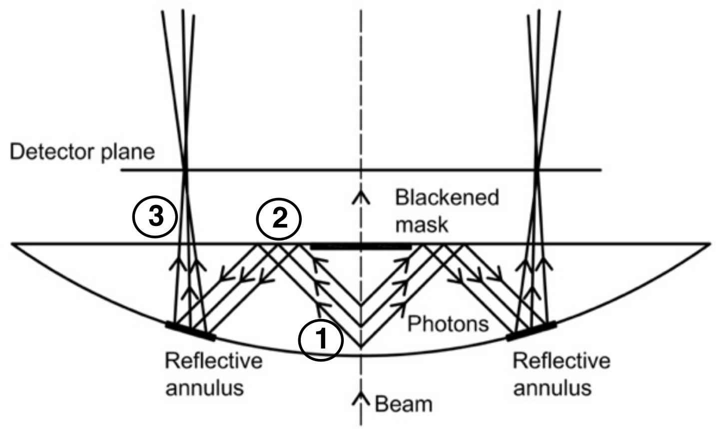


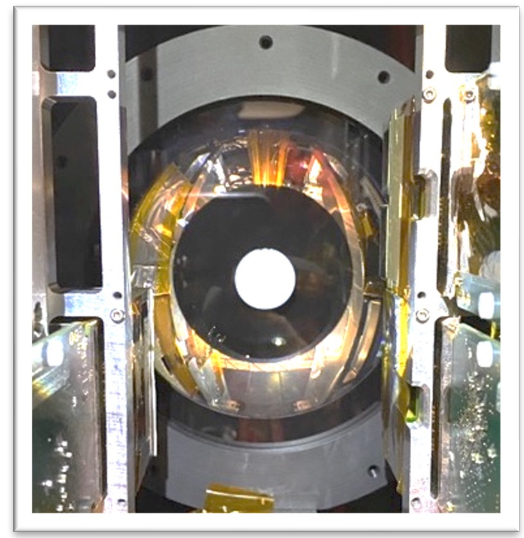
Beam profile horizontal [mm]

Coated borosilicate **lens** in the beam to:

1. generate the Cherenkov photons,
2. reflect them and
3. focus the Cherenkov ring onto the detector plane.

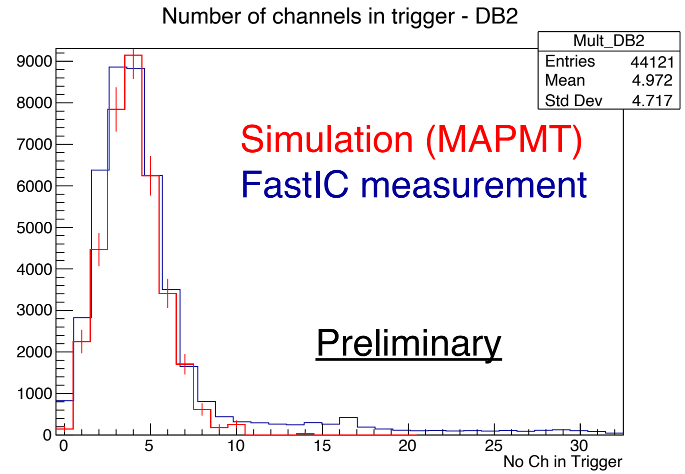
DOI:10.1088/1748-0221/12/01/P01012



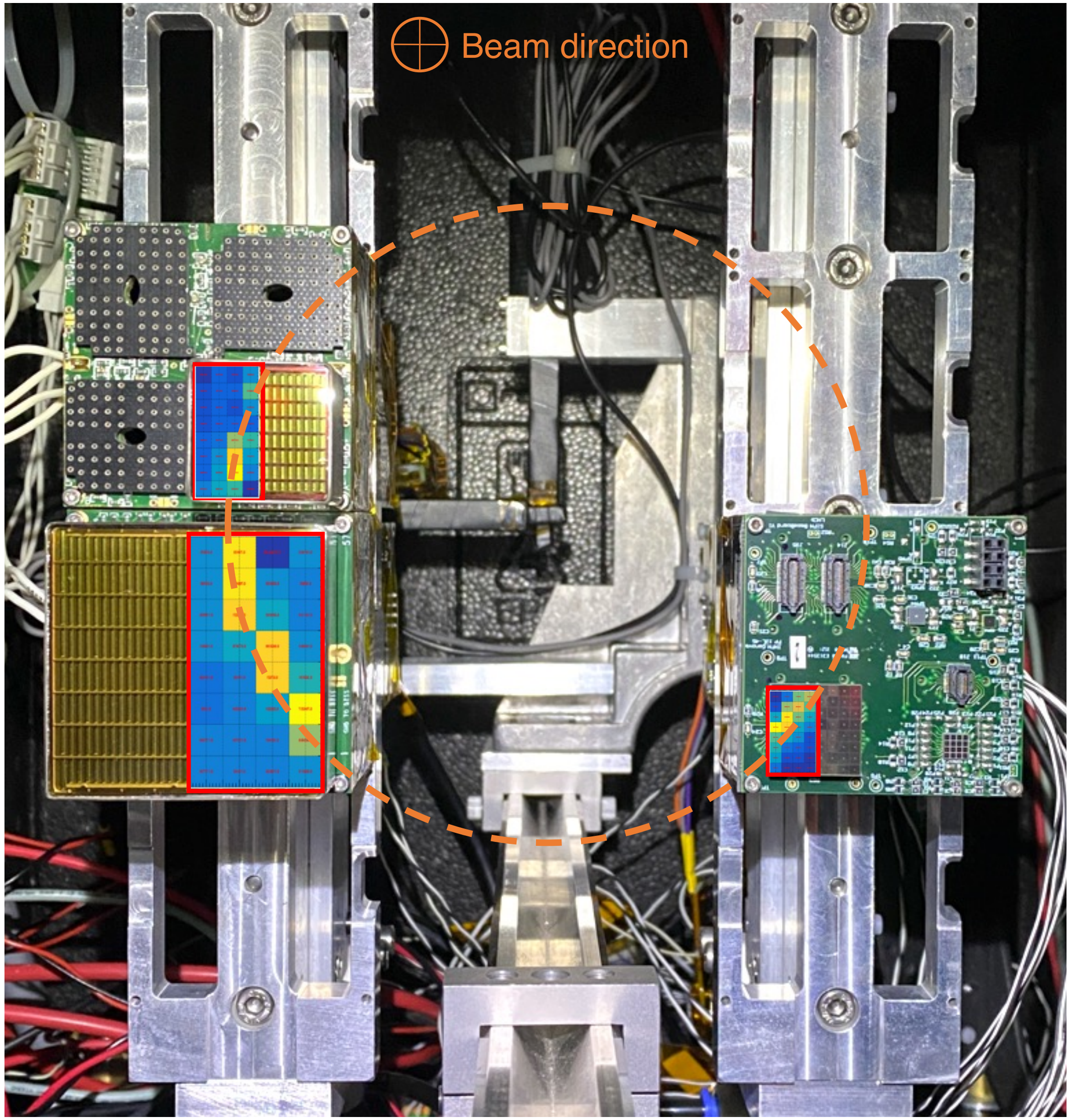


SPS test beam studies of a prototype opto-electronics chain

Superimposed hit maps show detected arcs from the Cherenkov ring (orange-dotted line) during beam tests. Good agreement in photon yield between MAPMT simulation and measurements with the FastIC.



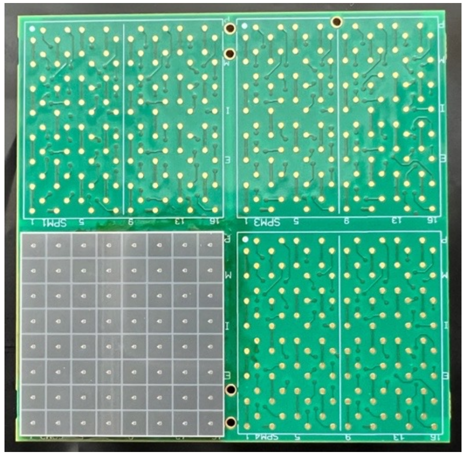
FastIC FEBs for partial readout of sensor area.



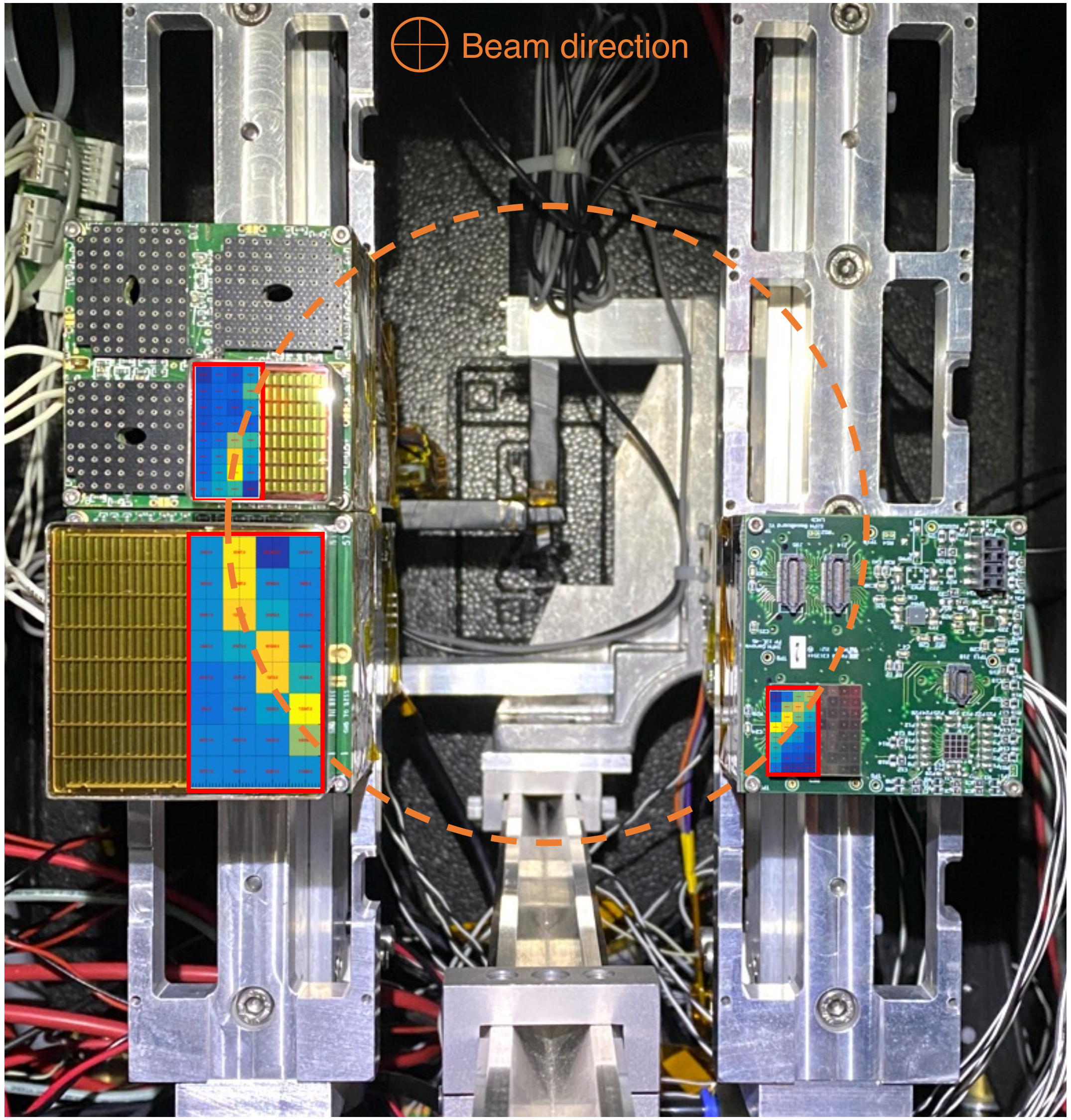
SPS beam tests of prototype fast-timing chain

Studied MAPMTs as well as SiPMs arrays with 8x8 channels.

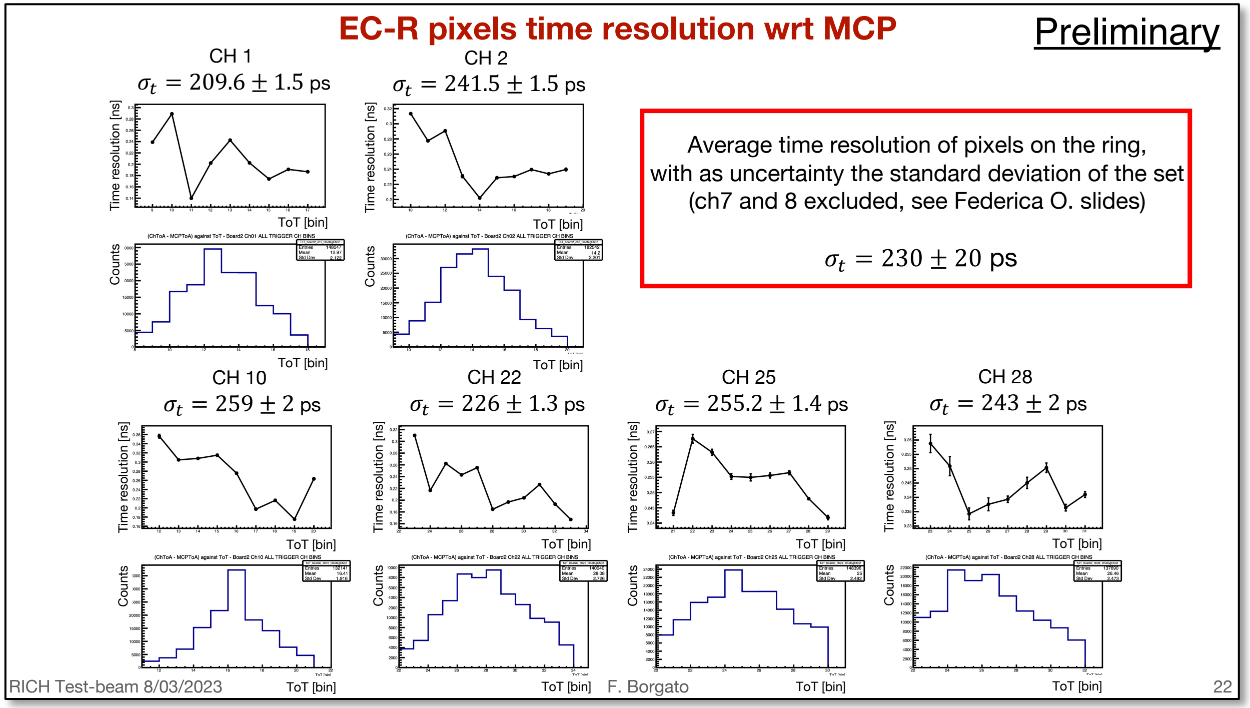
- Hamamatsu S13361 series using 2.0 mm channels and 3.0 mm channels with both LGA and connector on the readout side.
- Additionally, an LAPPD is foreseen to be studied during the 2023 campaign.
- R&D will evolve to larger sensor areas in a temperature-controlled / cooled prototype.

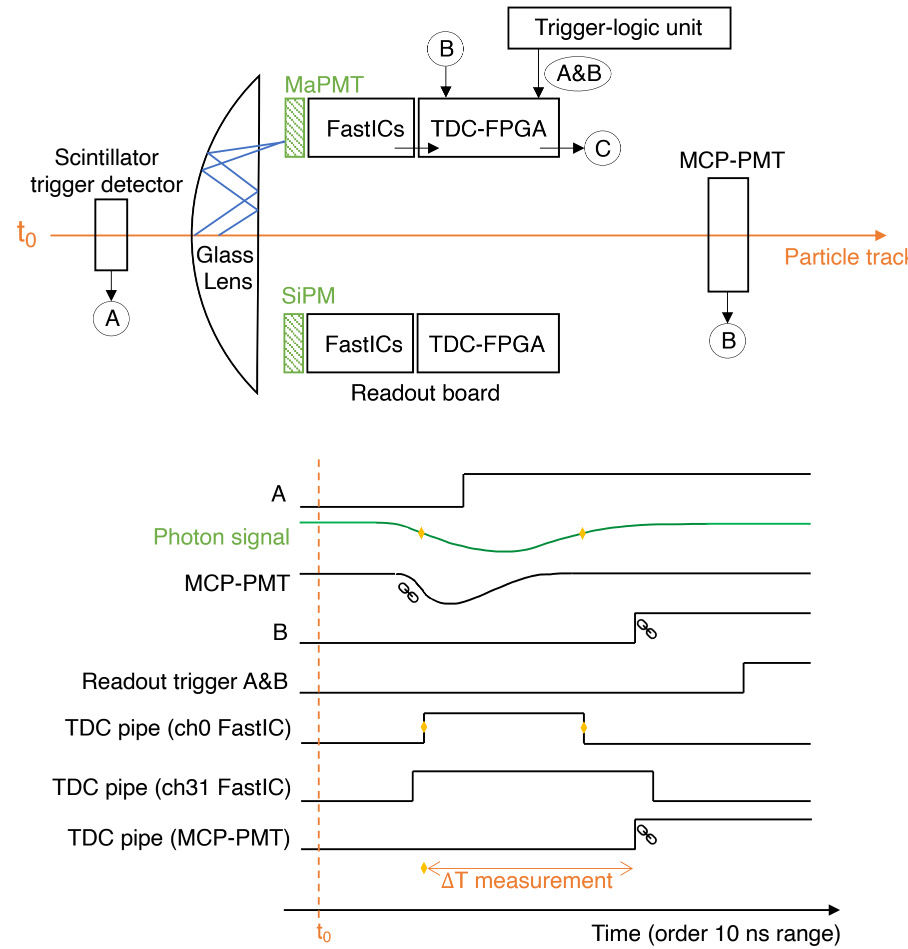


Baseboard can hold up to 4 SiPM arrays with LGA (solder grid) for high fill factor EC.



2022 RICH setup: MAPMTs and SiPMs, MCP-PMT for reference





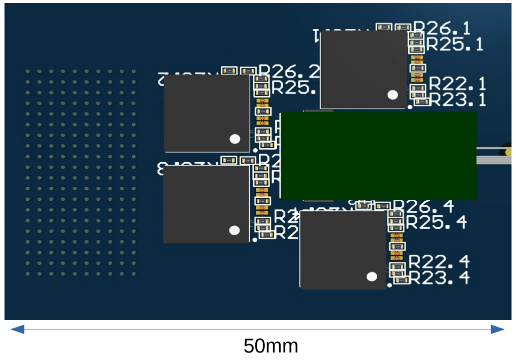
Analyses of timing performance are ongoing with preliminary best estimate of ~ 230 ps SPTR for MAPMTs (approaching the 150 ps TTS limit), including errors from MCP-reference and TDC bins.

- ➢ Analysis continues to compare this result to laser data and to perform Cherenkov ring timing.

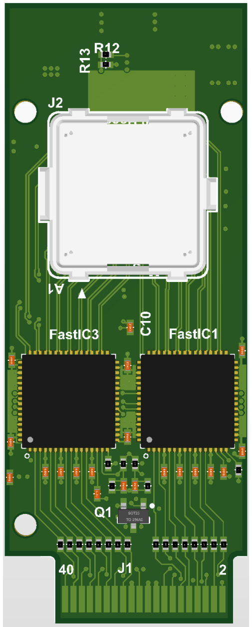
2023 SPS beam test campaign

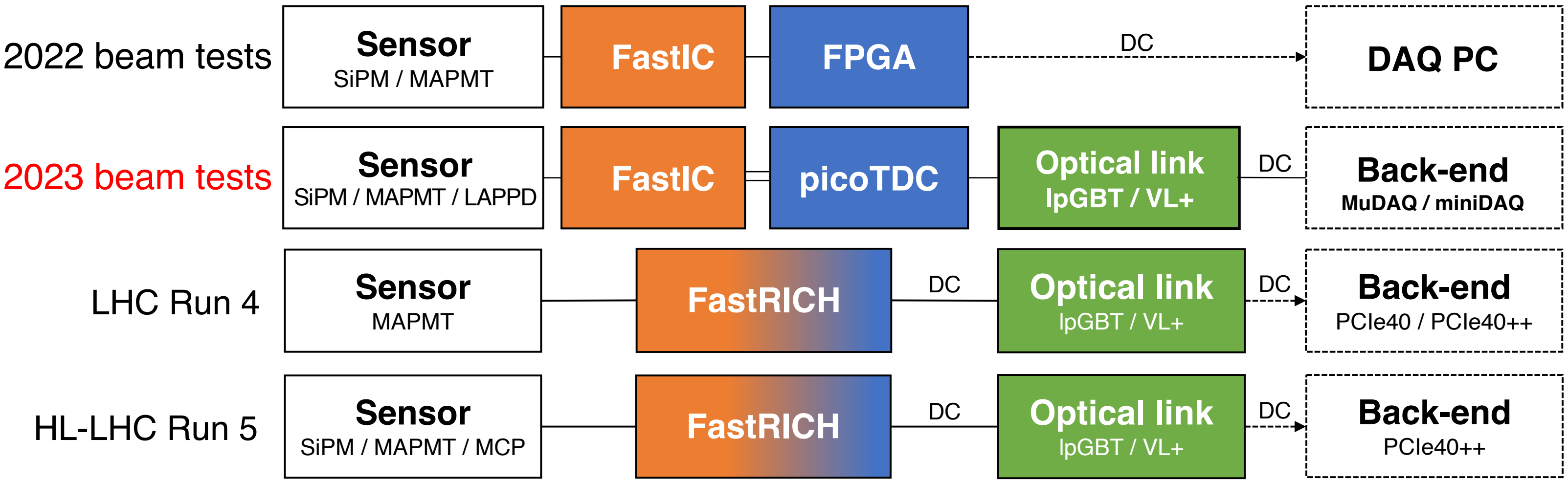
For the 2023 campaign, **the fast-timing readout chain is evolving**:
- Plug-in design for optimal flexibility.
- Differential readout mode of the FastIC (better for ASIC operation).
- Improved timing performance with **picoTDC** readout.
- Introduce **lpGBT/VTRX+** readout, for prototype studies and as first step towards testing of the FastRICH ASIC from 2024 onwards.

(preliminary) lpGBT plug-in.

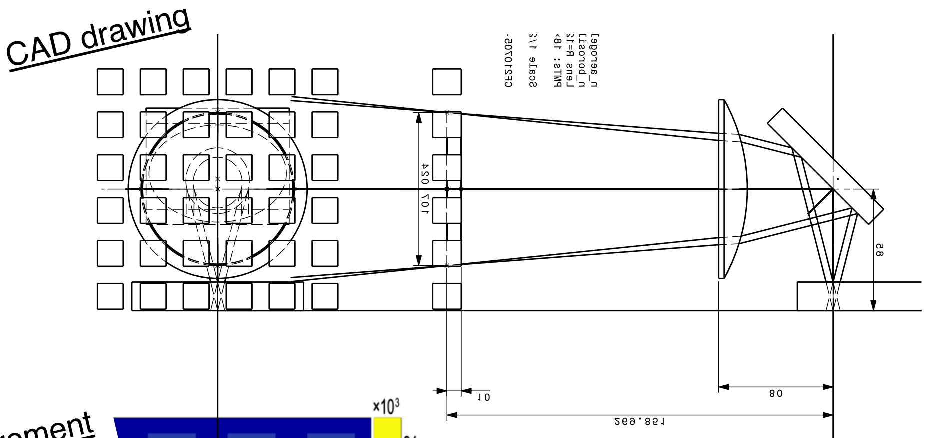


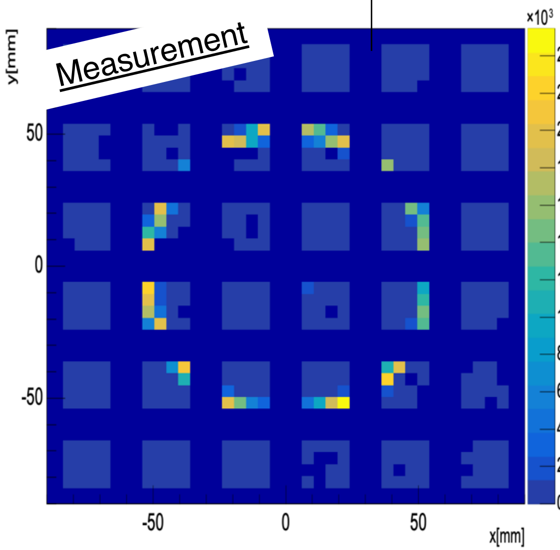
(preliminary) FastIC plug-in.

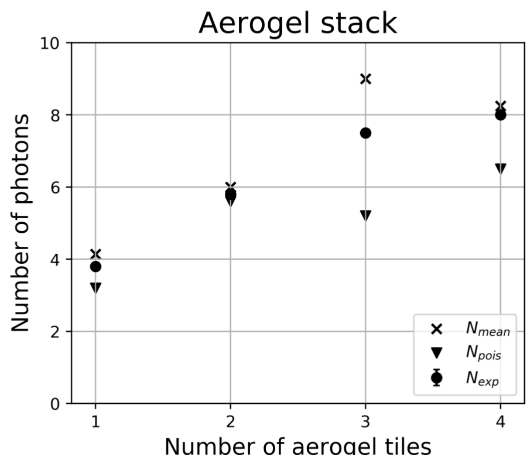


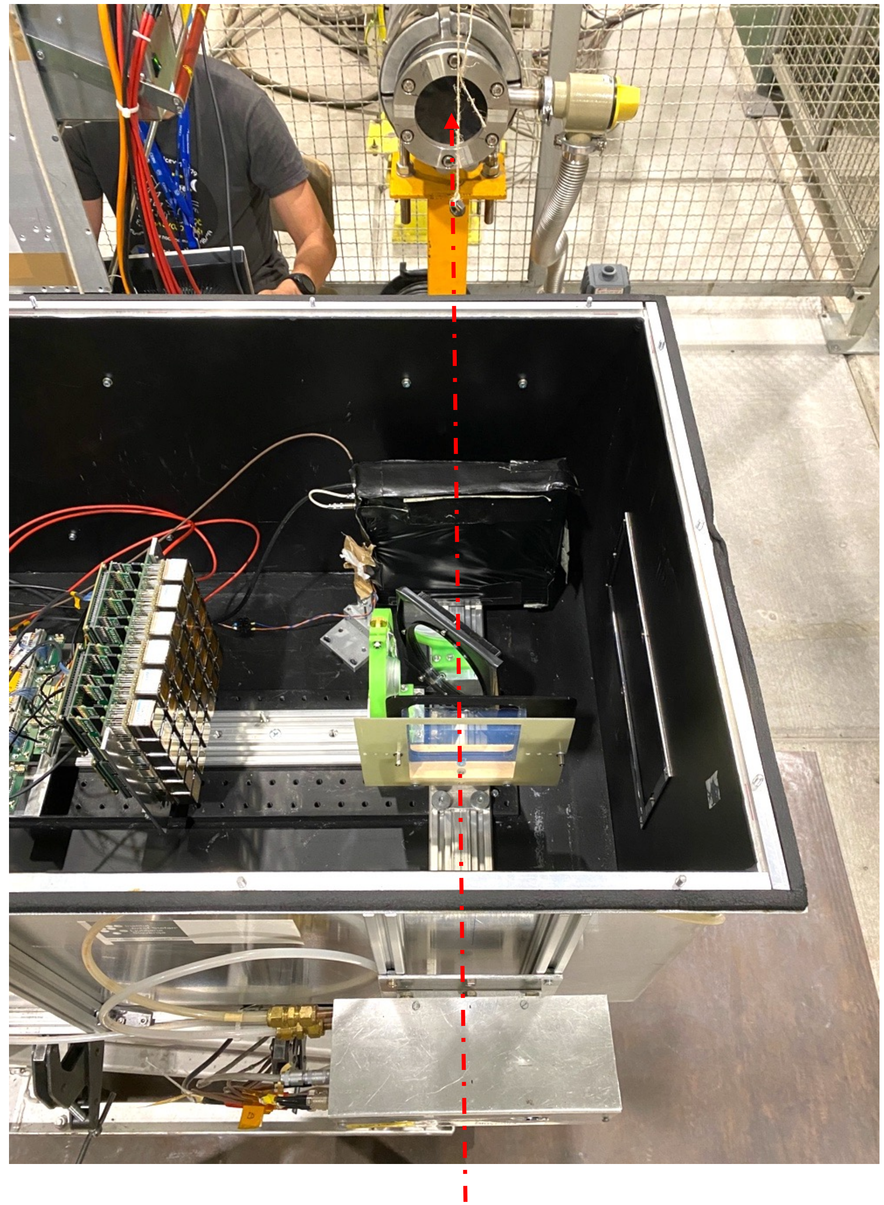


Novel radiator R&D on aerogel









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.

More information in poster: https://indico.cern.ch/event/1094055/contributions/4932293/

- LHCb RICH Upgrade II and LS3 enhancements.
- Test beam campaign in 2021-2023.
- **RICH institute R&D activities.**

RICH institute R&D activities

The following set of slides highlights the great interest, motivation and professionalism of our RICH collaborators.
It's only a selection of material and not an exhaustive list.

Thank you to the institutes for providing the material and to Carmelo D'Ambrosio for putting it together
for the LHCb Upgrade II workshop: https://indico.icc.ub.edu/event/163/timetable/#20230330.detailed
For details of the most recent studies and activities, please visit https://indico.cern.ch/event/1271273/

As a general note,

- Almost all labs are getting instrumentation and custom set-ups for testing photon sensors.
- Every laboratory is designing and producing new test set-ups for components and system characterization and Quality Control

Cooled SiPMs Characterisation

Conclusions

In Ferrara

- We can peform SiPM characterization down to LN2 temperature in LN2 vapour through a dedicated custom system;
- We tested so far 4 different HPK models:

	13360-3025CS	13360-3025PE	14160-3015PS	13081-050CS
Pitch(um)	25	25	15	50
Area(mm^2)	3x3	3x3	3x3	1x1
DCR @-120, +5OV (Hz/mm^2)	0.77	0.15	0.47	2

- DCR behaviour with burst effect (random train of pulses at kHz);
- DCR decreses from MHz at room temperature down to Hz at -120°;
- We are currently testing other SiPM models.

For the near future:

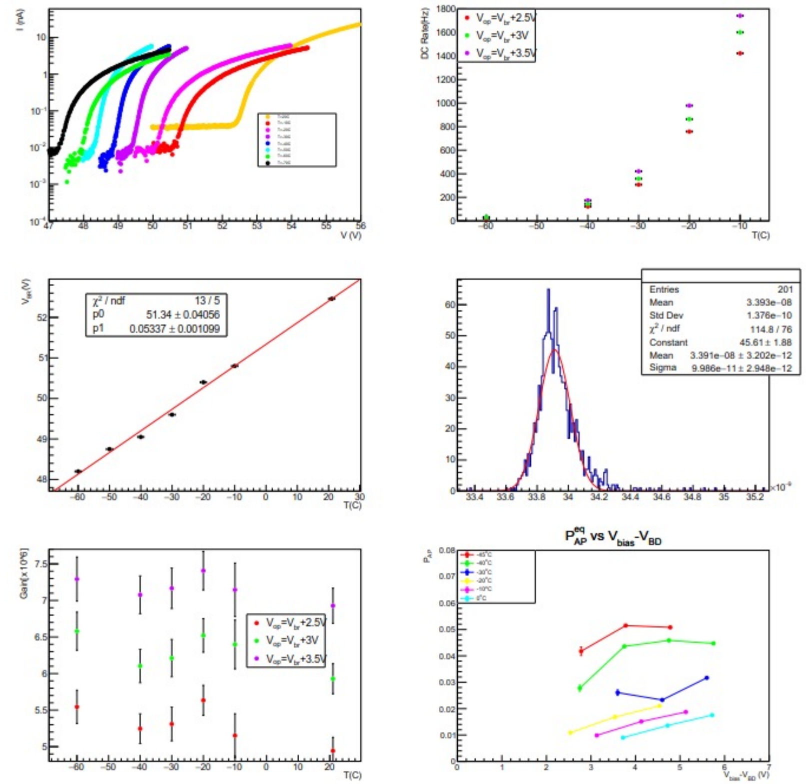
- We plan to test these sensors after different dose irradiation;
- We plan to test the irradiated sensors after different annealing procedure;
- We are setting-up a setup for temporal measurements with UV laser pulses.

Università degli Studi di Ferrara

INFN FERRARA

SiPM characterization/validation with focus on the local cooling design [Upgrade II]

Genova



LAPPD and MCPs characterisation (timing)

The Large Area Picosecond PhotoDetector

LAPPD (INCOM US)

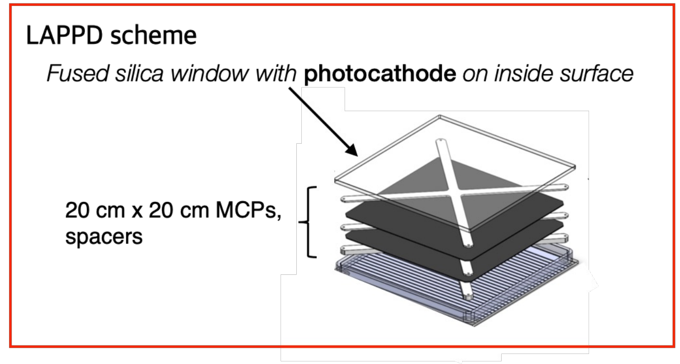
Micro Channel Plate photomultiplier,
Dimension 20 x 20 cm^2

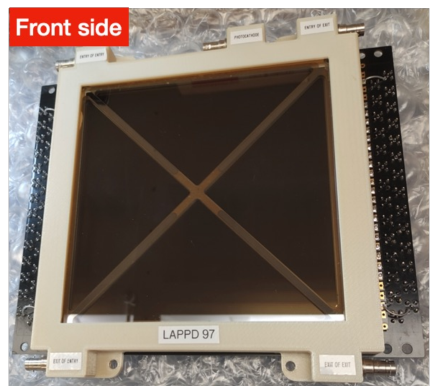
Advantages:

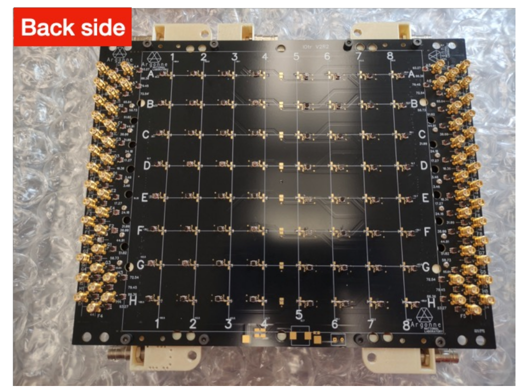
- Time resolution lower than 60 ps
- High gain (~ 10^7)
- capable of imaging single photons

Gen II LAPPD 97 @ Edinburgh

- Gen II LAPPD, pixel readout
- Spectral response 160-650 nm
- 5 taps for independent voltage control of the photocathode and entry/exit of each MCP
- readout board used for testing so far as directly provided from INCOM, pixel Pitch to pitch distance 25 mm, effective dimension 24 x 24 mm^2



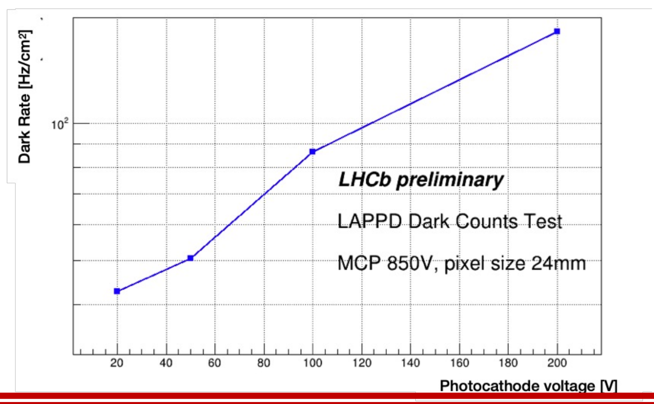




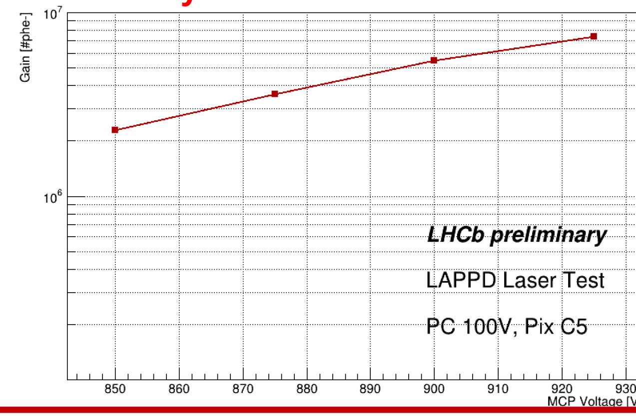
LAPPD and MCPs characterisation (timing)

Overview of the measurements in Edinburgh

Dark counts



Gain study

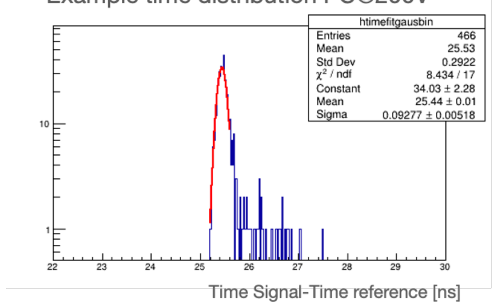


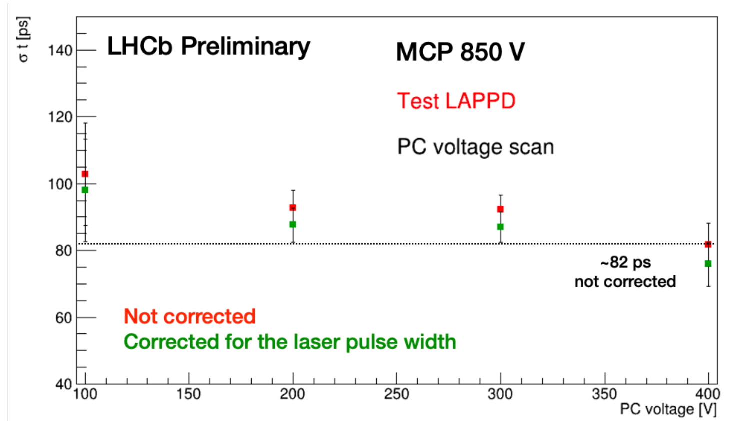
- Single photoelectron condition
- Laser frequency 5kHz

Time resolution

Extracted from Gaussian fit
to the time difference Signal-Laser trigger

Example time distribution PC@200V





- Single photoelectron condition
- Laser frequency 5kHz

MCP studies

Milano-Bicocca

- Comparison between MaPMT (R13742) and MCP-PMT (R10754)
- from Hamamatsu
- R10754 has 4x4 pixels in 1’’x1’’ (≈5 mm pixel side)
- MCP saturates above ≈100 kHz/mm2

https://doi.org/10.1088/1748-0221/15/10/P10031

Single photon time resolution of photodetectors at high rate: Hamamatsu R13742 MaPMT and R10754 MCP-PMT

M. Calvi[1,2], S. Capelli[1,2], P. Carniti[1,2], C. Gotti[2] and G. Pessina[2]

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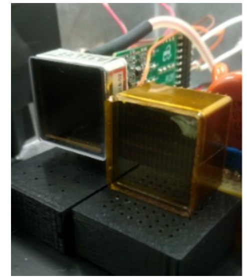
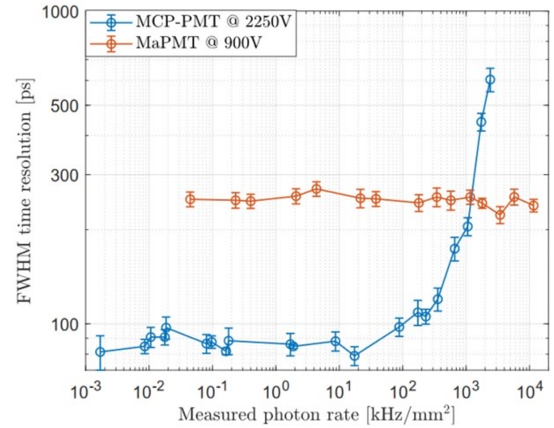
Journal of Instrumentation, Volume 15, October 2020

Citation M. Calvi *et al* 2020 *JINST* 15 P10031

DOI 10.1088/1748-0221/15/10/P10031





- Study of the Photek Auratek-Square MCP-PMT (15um pores)
- Pixel size down to ≈1x1 mm2, but significant charge sharing
- MCP saturates above ≈100 kHz/mm2

https://doi.org/10.1088/1748-0221/17/11/P11009

Single photon counting performance of the Auratek-Square MCP-PMT

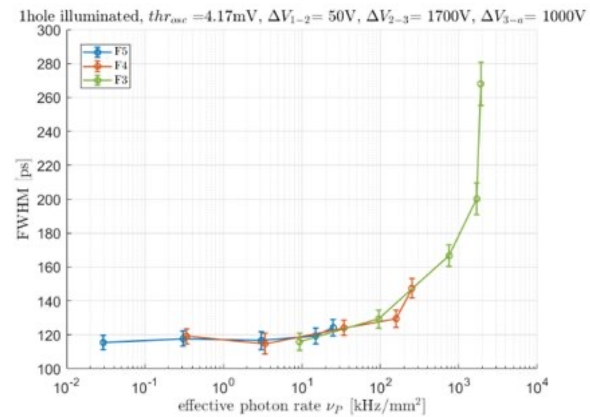
M. Calvi[1,2], S. Capelli[1,2], P. Carniti[1,2], C. Gotti[2] and G. Pessina[2]

Published 10 November 2022 • © 2022 IOP Publishing Ltd and Sissa Medialab

Journal of Instrumentation, Volume 17, November 2022

Citation M. Calvi *et al* 2022 *JINST* 17 P11009

DOI 10.1088/1748-0221/17/11/P11009

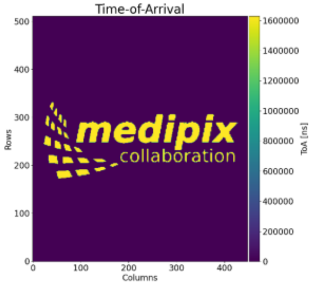


Next steps

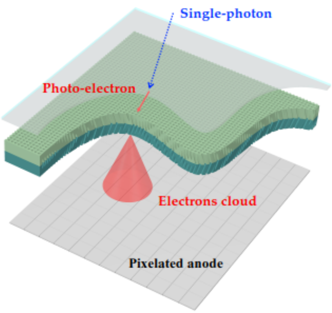
focused on development of low gain, high rate MCP-PMTs and development of readout electronics for a low gain MCP.

Hybrid MCP development

- Hybrid vacuum photo-detector development (INFN, UniFE, CERN)
  - Photocathode + MCP multiplication + Timepix4 anode in vacuum tube
- Timepix4 prod.: v0 (Q1-2020), v1 (Q4-2020), v2 (Q4-2021), v3 (Q1-2023)
  - v2 bare ASIC extensively tested; first tests with Si sensor in summer 2022
- Activities
  - C++ software development for ASIC configuration, DAQ and analysis
  - Development of FPGA-based control board
  - Development of ceramic carrier (signal integrity simulation)
  - Power measurements and cooling system development
  - Calibrations with laser, radioactive sources, test pulses



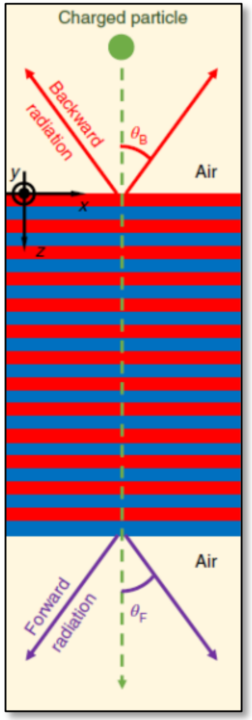
- Issues
  - Extremely long procurement times or production delays for many critical components
- Prototype detectors expected early 2024
  - Beam tests with Cherenkov radiator
  - Measurements in life science applications

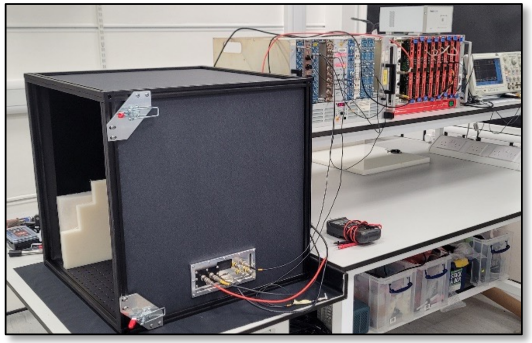


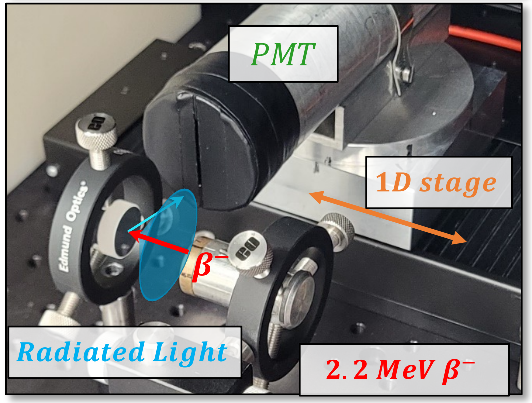
JINST 13 C12005 2018

Using Metamaterials for PID

- Goals: exploit backward **T**ransition **R**adiation (TR) from **metamaterials** for PID.
  - $\theta_{TR} \propto \vec{v}_{particle}$
  - Replace RICH gas radiators with metamaterials
  - Re-imagine RICH geometry in upgraded LHCb
- Lab setup to search for TR:
  - Sr^{90} source: 2.2MeV electrons
  - Sample: Thorlabs BB03-E02 dielectric mirror
- Provide design inputs for custom metamaterials sample, fabricated at Imperial College
  - Can specify refractive index tailored to our use cases
  - Computational support also from collaboration with Prof. Ortwin Hess & postdoc (Trinity & Imperial)





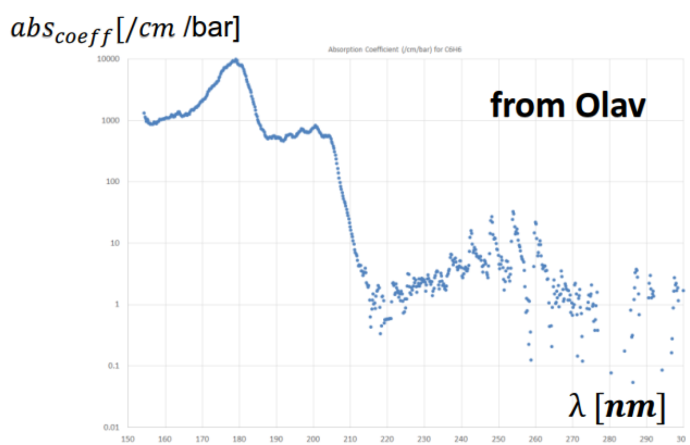


Nature Phys **14**, 816–821 (2018)

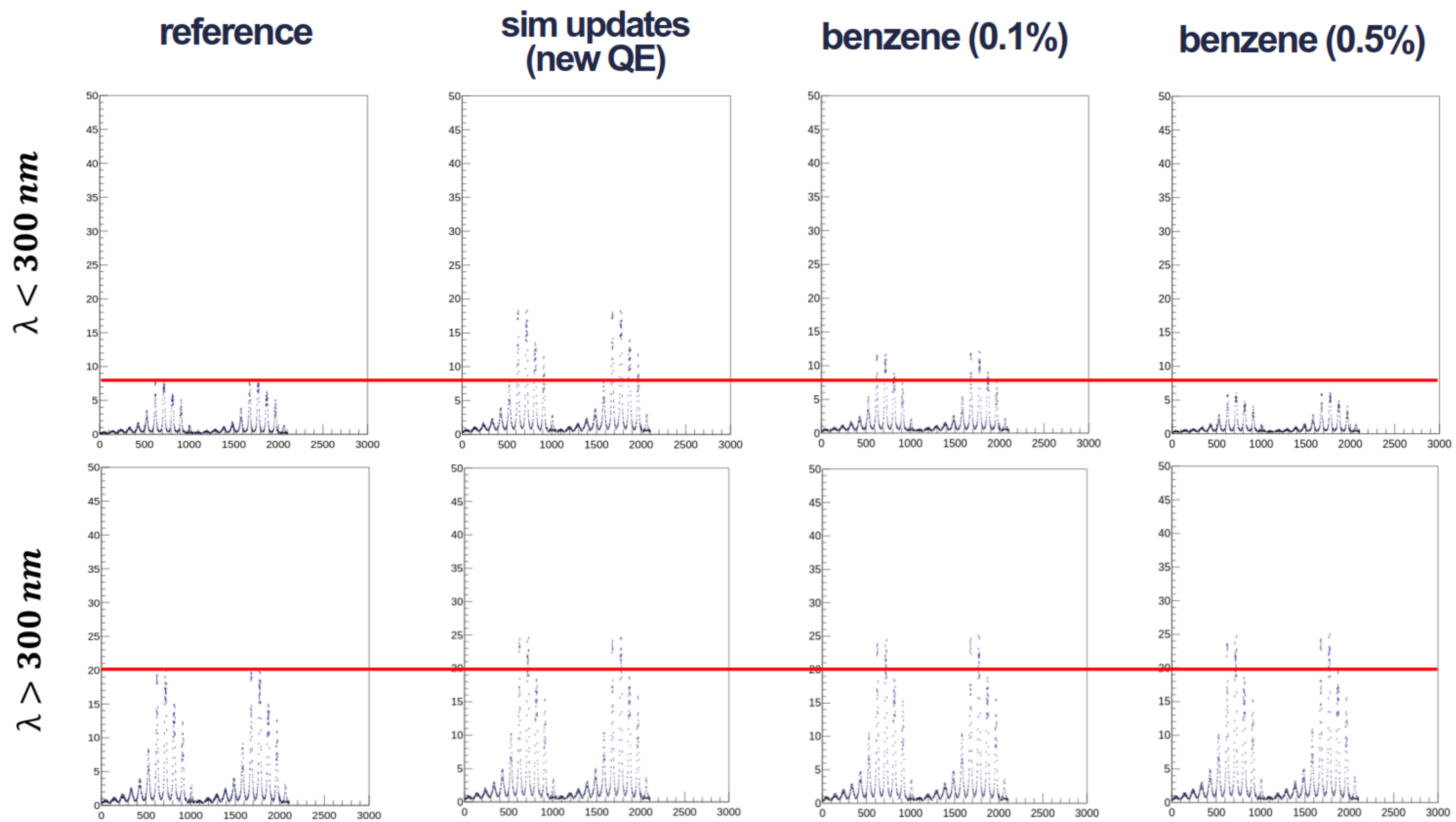
Benzene – introduction

- **Benzene** can be used to **filter the low-wavelength photons away**.
  - Assign the benzene absorption properties to the existing gas radiator in the simulation, in the range < 300 nm (no absorption above this value).
  - Can it help to mitigate the occupancy increase? ⟶ **CHECKED**
  - How will it affect the PID? ⟶ **CHECKED**

- **Benzene fractions for R2** given in the plot labels should be interpreted as e.g. **`equivalent to 0.1% in R1`**.
  - The actual fractions for R2 are divided by a factor of 3 (due to the different optical paths in both R1/R2).

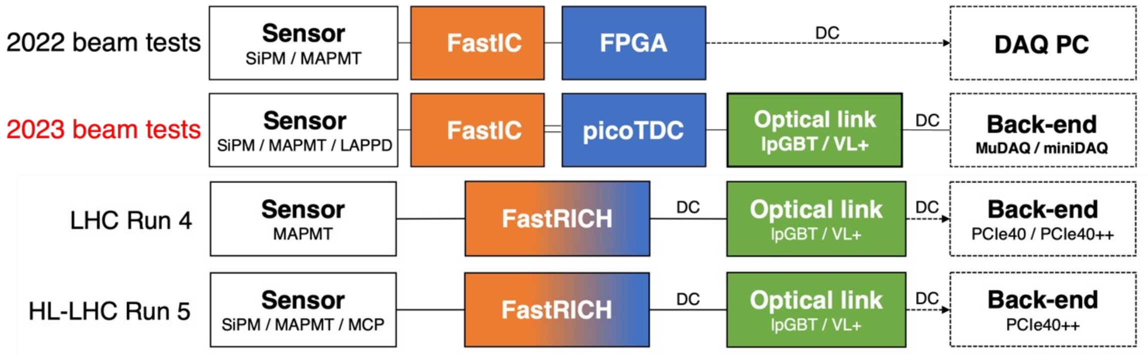


Benzene (occupancy, Gauss) (WL regions, R1)



Adding between **0.1-0.5%** of benzene in R1 **reduces the occupancy in the low-WL region to a level comparable to the `reference`**. The high-WL region is not affected by adding benzene (as expected).

Upgrade II RICH FE roadmap



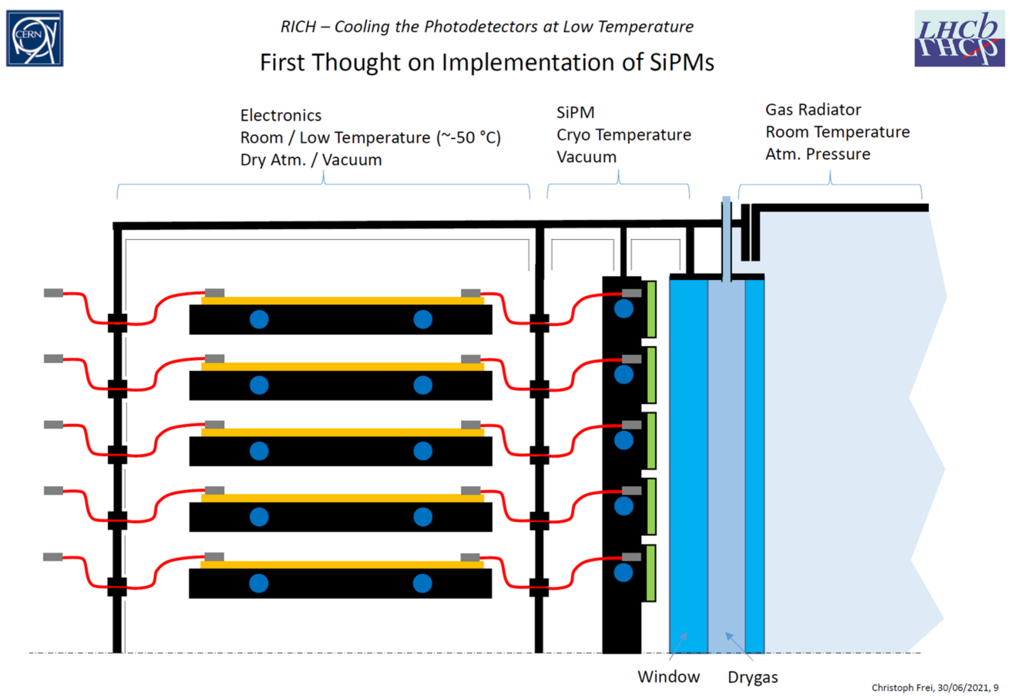
Cambridge Upgrade 2 interests

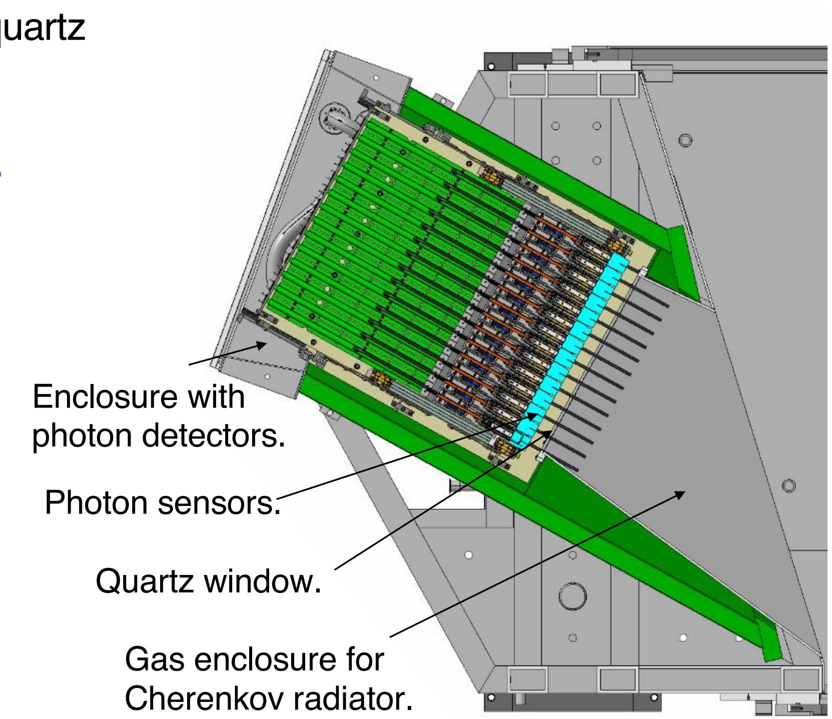
- Electronics
  - Specification, development, prototyping, production, testing and commissioning of FE electronics and read-out architectures for Run 4.
  - Further refinement of electronics adapted to new sensors for Run 5 (higher granularity, better time-resolution)
  - Specification, development, proyotyping, production, testing and commissioning of FE electronics and read-out architectures for Run 5.
  - Testing and characterisation of timing performance of front-end electronics in the laboratory and beam facilities.
  - Read-out system support for laboratory, beam test, and irradiation campaigns.
- Software
  - Detector optimisation and design through simulation and integration with LHCb simulation
  - Development of new reconstruction algorithms and with new architectures
  - Integration with RTA
  - Optimisation of algorithms for resource usage
  - Monitoring alignment and calibration

Low temperature / cryogenic cooling of photon detectors

R&D into compact vessel structures has started and several meetings held with the cryogenics experts at CERN (TE-CRG-CI).

- One of the ideas could be to use two specially-coated quartz windows separated by a vacuum.
- Exploring synergies with other LHCb sub-detectors.
- Design of a lab/testbeam demonstrator is far advanced.



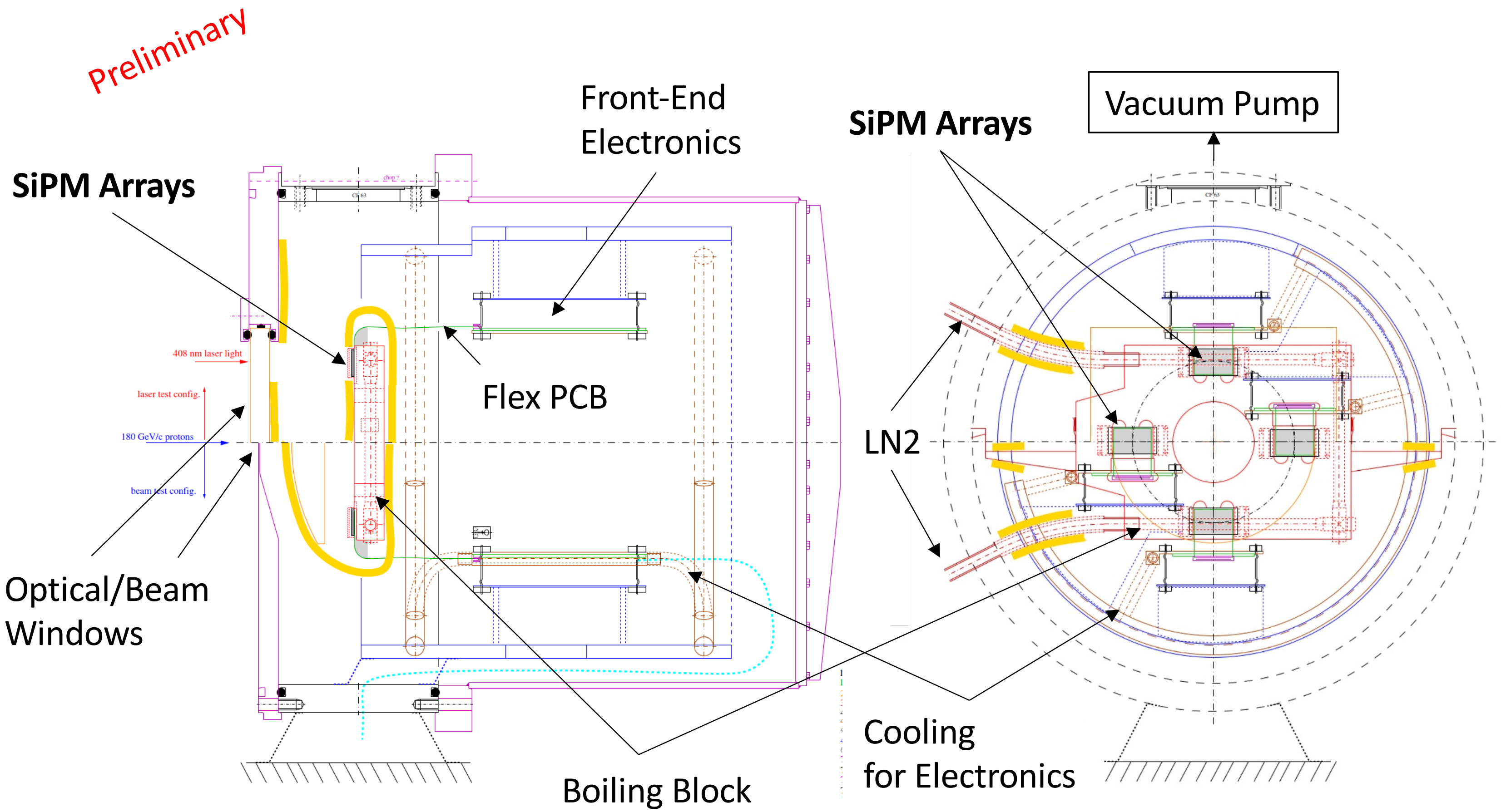


https://indico.cern.ch/event/1175130/

CERN

RICH – SiPM – Cryostat Testbench

Cryostat for Characterizing SiPMs Arrays in Testbeam Facility and Lab

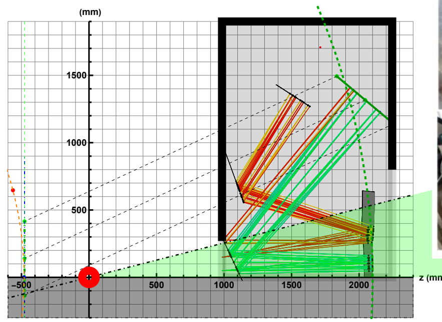


[Piet Wertelaers]

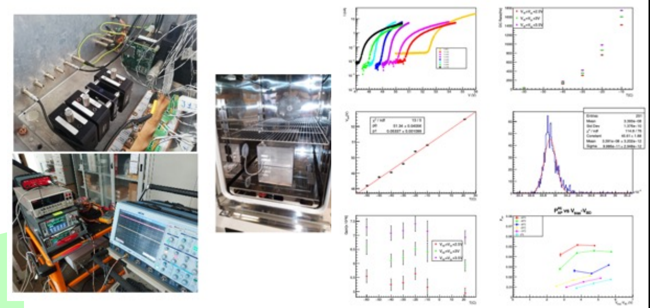
LS4 (Upgrade 2) – Genova's activities and interests

- Design of the new optical layout
- Optics technologies studies (lightweight mirrors in acceptance).
- SiPM characterization/validation with focus on the local cooling design.
- Design, development and production of the new BaseBoard and EC++ housing for sensors with integrated local cooling.
- DAQ firmware development
- Detector Control System (TBC).
- Calibration/Alignment/Monitoring
- Detector Simulation.
- Reconstruction, pattern recognition and analysis.
- Physics performance of the RICH detector.

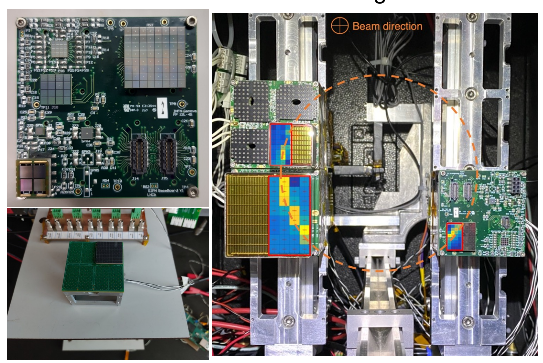
New optical layout to minimize the aberrations, reduce the occupancy by longer focal length, split to deal with large occupancy dynamic range



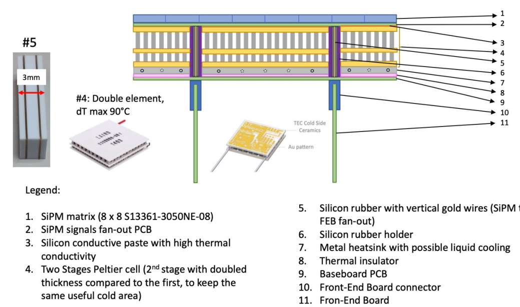
SiPM characterization/validation setup and measurements

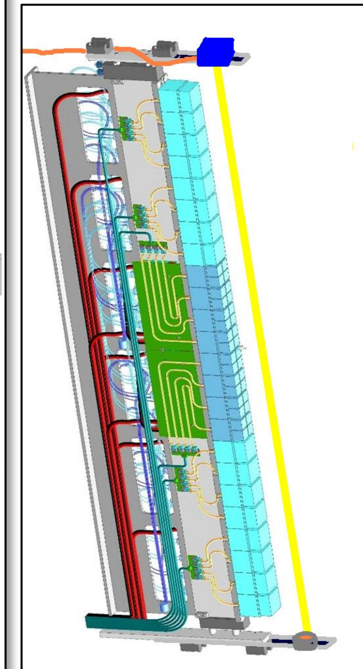


SiPM housing BaseBoards already produced and tested both in lab and during testbeams



Development of new SiPM housing BaseBoards with integrated local cooling





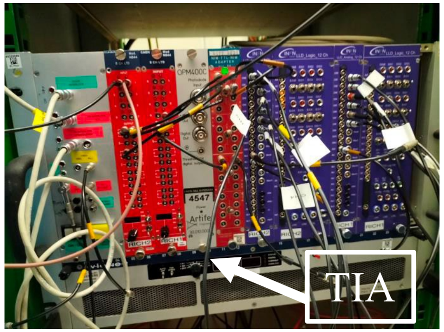
Calibration and alignment system using a Rayleigh scattered laser beam technique.

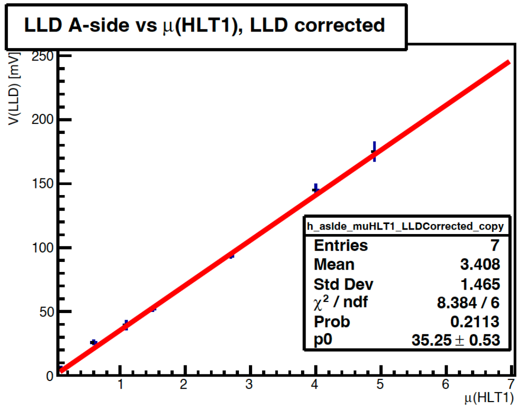
Calibration and monitoring

Perugia

- **Calibration:**
  Ready to work together with Genova group on their idea to develop a calibration system based on Rayleigh scattering (see previous slide for the setup)

- **Monitoring:**
  For the 2024 data taking we will install two TIA (Trans Impedance Amplifier) in the readout chain of as many LLDs.
  We usually use such device to characterize and calibrate the LLDs, this will allow to further improve the sensitivity of LLD as **luminosity monitor,** without compromising the LLD main functionality.





LHCb-Romanian team and activities in LHCb RICH Upgrade II

- Bucharest Team in LHCb Upgrade program – envisioned R&D activities and tasks, for 2024 - 2034:

1. Design, produce, and test Digital Boards, more explicitly their Motherboards – for both LS3 and LS4;
2. Characterization of FastRICH chips when operating with new Photon Counter arrays with higher granularity;
3. Irradiation campaign of FastRICH, Photon Counters (e.g., SiPMs), EC prototypes – both for LS3 and LS4;
4. Precise measurement of radiation effects and annealing for SiPM and Photon Counters in general:
   - Investigate the feasibility to operate commercial Photon Counters in hard radiation environments,
   - E.g., implement mitigation procedures to reduce the dark counts in SiPMs besides reducing the operating temperature;
5. Contribute to the mass testing of: FEB, Digital Board plugins, ECs.
6. Contribute to the construction and commissioning of new RICH detectors.

Irradiation possibilities @ TRIGA nuclear reactor

Institut "Jožef Stefan", Ljubljana, Slovenija

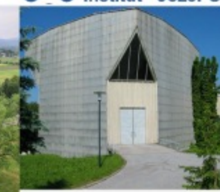
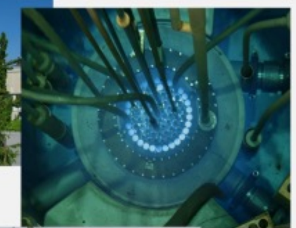
JSI TRIGA nuclear reactor:
- max. power 250kW
- Neutron fluxes up to 3.57x 10^{12} n/cm2/s

https://ric.ijs.si/en/info-za-uporabnike/

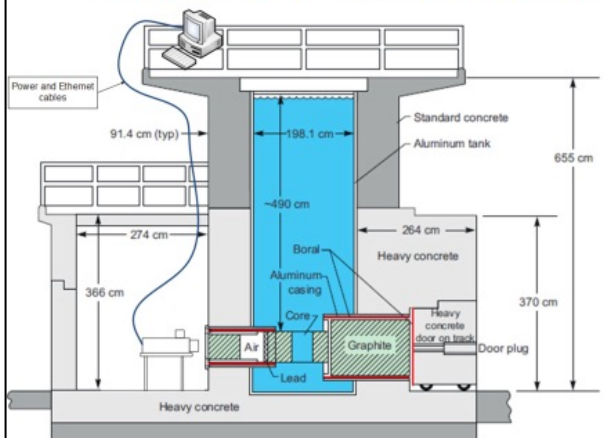
Irradiation of samples
- Directly in the reactor core
- Side channels - approx 20x20 cm2 (trolley)

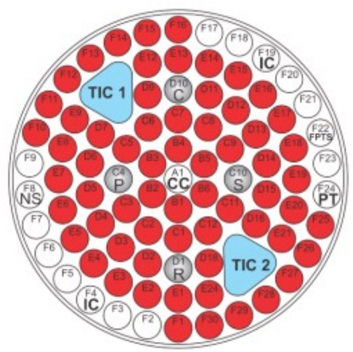
Ljubljana

2000 samples/year
for LHC experiments

- 1st criticality: 31st May, 1966
- P_{max}
  - 250 kW (steady state)
  - 1 GW (pulse)
- Fuel
  - UZrH (12 wt. % U)
  - E= 20 %





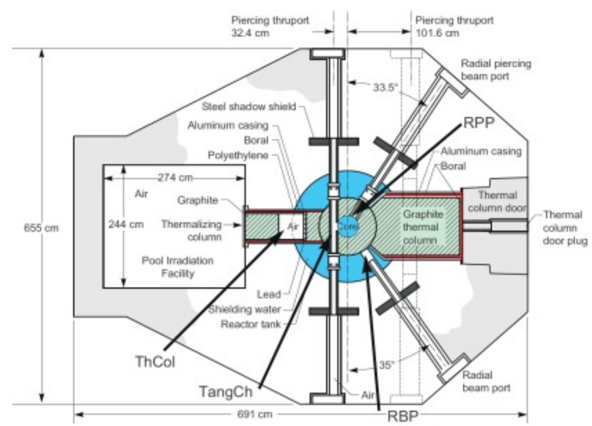


Fig. 2. TRIGA reactor at JSI, top view (Jeraj and Ravnik, 1999).

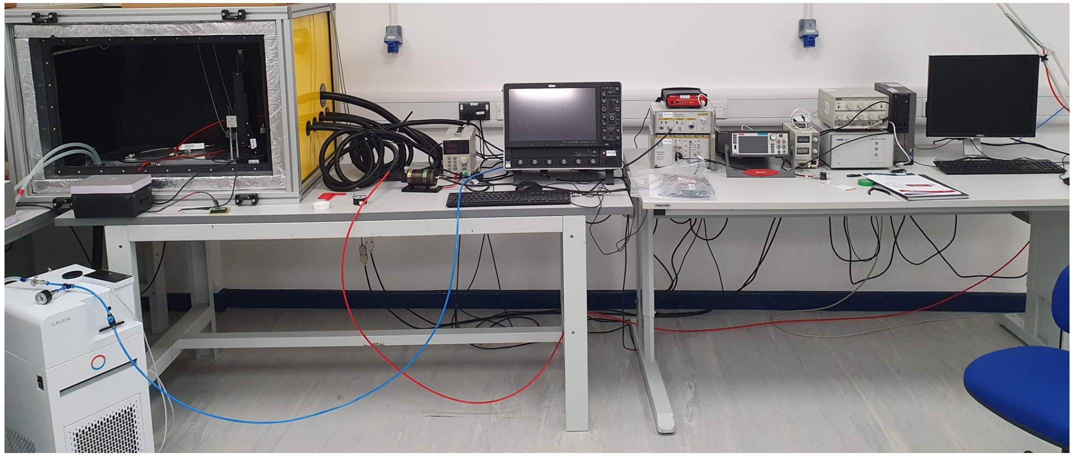
Radiation damage studies plans

- Electronics for Upg Ib
  - Study SEE with ions from TANDEM and TANDEM+ALPI
  - Collaboration with Lubjana group
  - TANDEM allows irradiation scanning ionic species with LET in the range 1-40MeV/(mg/cm2)
  - TANDEM+ALPI irradiation allows a single specie of ions (Xe) with high energy (O(1GeV))
- Sensors for Upg II
  - Irradiated SiPM (Hamamatsu) avalable from Belle II group flux=10^{11} 1MeV neq/cm2
  - Investigating a neutron source @ Legnaro (^{7}Li)should reach higher doses, to be checked allowed limits from radioprotection

Padova

STFC – RAL

- Simulation:
  - Extensive activity on simulation for Run 3, 4 & 5
  - Simulation of testbeams
- Testing of SiPMs:
  - New lab setup for testing SiPMs
  - Plans for irradiation and evaluation
  - Could extend to other photon detectors
- Testing of boards for testbeams and prototypes for LS3 enhancements
  - Some experience with lpGBT
  - Activity to start soon
- Planning work on cryogenic cooling



Science and Technology Facilities Council

Antonis Papanestis

Conclusion

- The LHCb RICH **Upgrade II will be a complete overhaul of the detector** to prepare it for **High-Luminosity** operation. This will include fast-timing readout information, revised optics and novel photon sensors with smaller channel dimensions and improved time resolution.

- **RICH LS3 enhancements** aim to equip the detector with **new front-end readout electronics** including the **FastRICH** ASIC capable of timestamping photon detector hits with ~25 ps time bins, **improving PID during Run 4 and preparing for Upgrade II**.

- An active **SPS test beam campaign** is ongoing to test a prototype **fast-timing** readout chain coupled to novel **sensors** and Cherenkov **radiators**.

- The RICH collaboration is performing a **well-coordinated and thorough programme of R&D** on topics including the photon sensor, radiators, electronics, mechanics, (cryogenic-)cooling, optical schemes, detector calibration, irradiation and software and pattern recognition.