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SiPM R&D for LHCb

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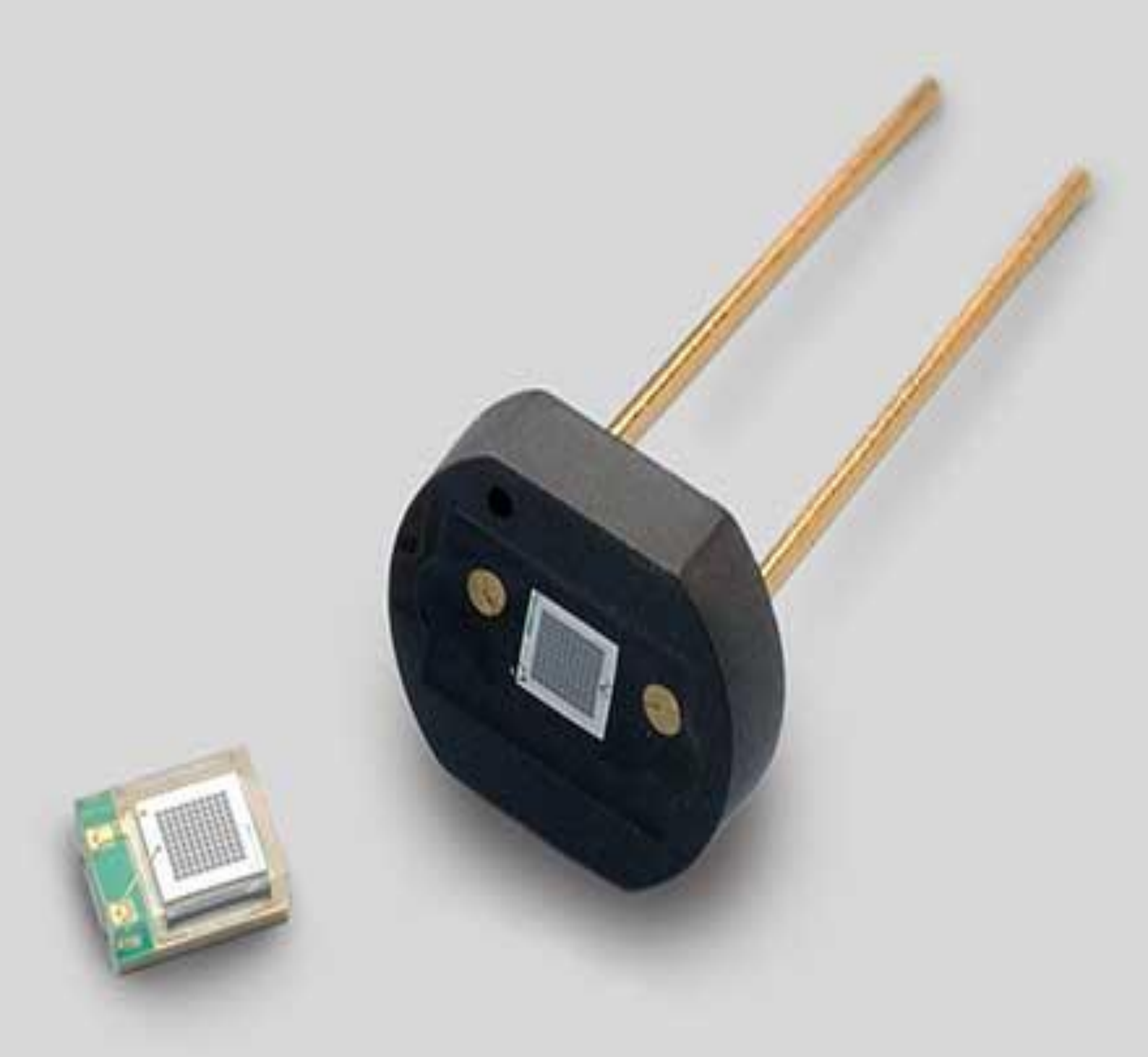
PPD R&D showcase
27 July 2022



PID in LHCb upgrade 2 (Run5 and Run6)

Main challenge: operate RICH at luminosity x7 that of Run3-4, up to 1.5×10^{34} $cm^{-2}s^{-1}$

Requirements for photon detectors to keep PID capabilities at current level:

- Improvement in space (<1mm) and time resolution (<100ps)
- High radiation tolerance
- High efficiency and high readout rate capabilities

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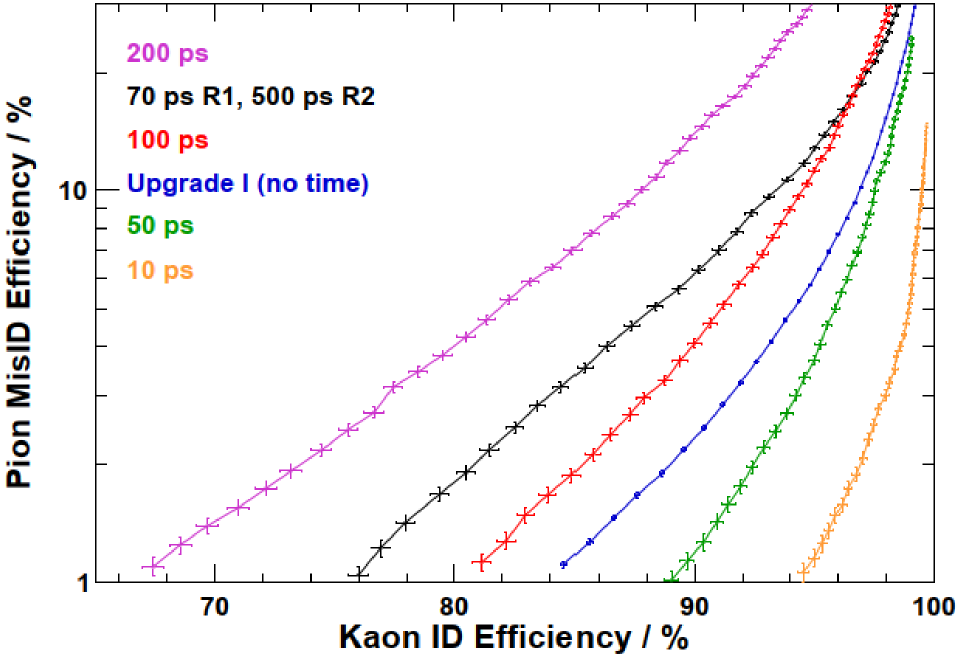
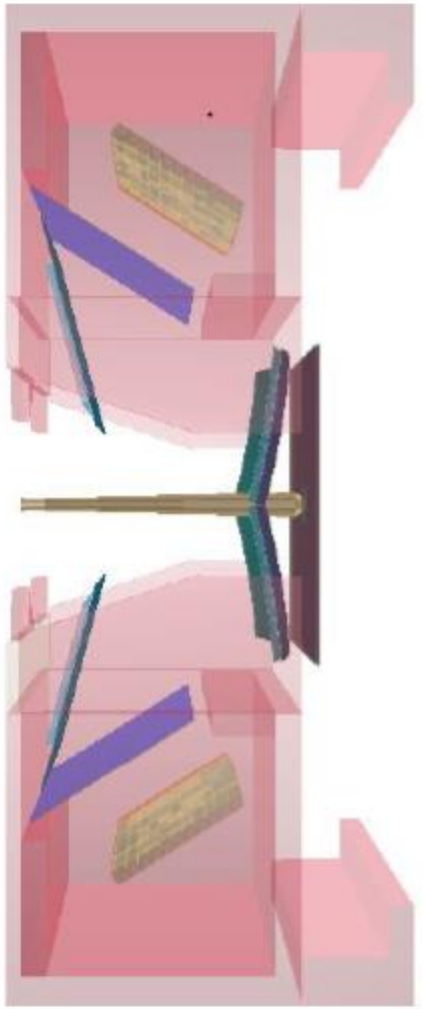
PID performance vs time resolution in Run 5

No other improvements of the RICH taken into account





LHCb RICH 1

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Position sensitive photon detectors

	MaPMT	SiPM	MCP-based solutions
Spatial resolution	✗	✓	✓ ✓
Time resolution	✓	✓	✓ ✓
Radiation hardness	✓	✗ ✗	✓
Low dark counts	✓	✗	✓
Magnetic field immunity	✗	✓	✓
Low cost	✗	✗	✗
Gain ageing	✗	✓	✗ ✗
Saturation current	✗	✓	✗ ✗
Low voltage operation	✗	✓	✗

from https://rich2018.org/indico/event/1/contributions/10/

no obvious solution available off the shelf: R&D in collaboration with industrial partners for custom solutions needed

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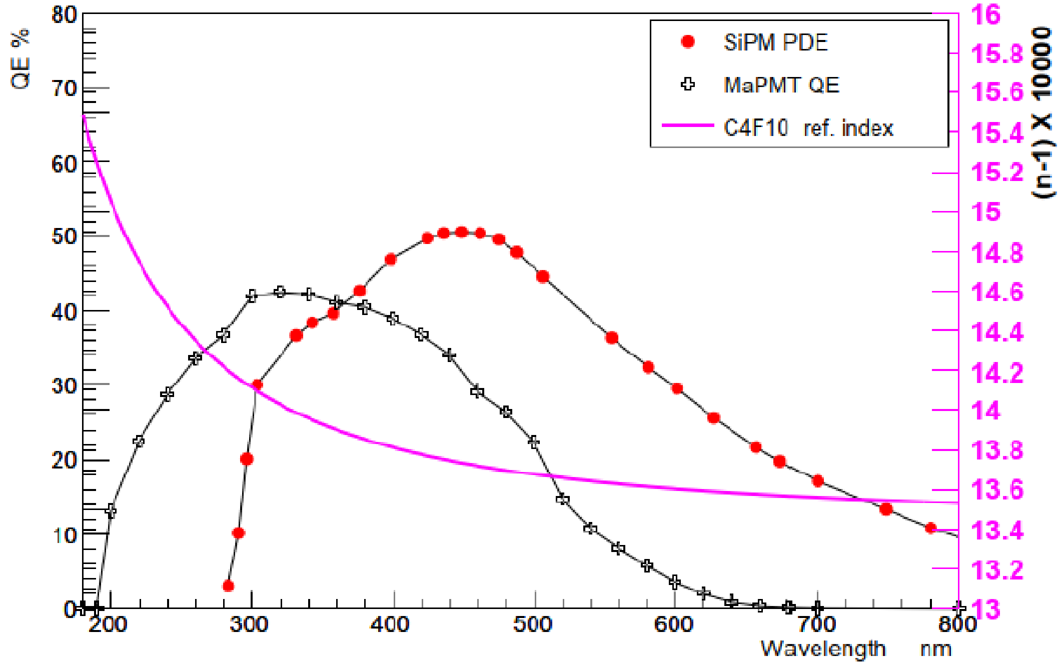
SiPMs for RICH in LHCb Upgrade 2

Promising technology:

- ➢**High PDE** shifted to red to reduce chromatic dispersion (thus improving angular resolution)
- ➢**Small pixel size** (1x1mm) will provide high granularity and reduce photon occupancy/pixel
- ➢**Good time-resolution** of ~100 ps/photon further reduces effective occupancy and mitigates combinatorial background
- ➢**Insensitive to magnetic fields** (removal of magnetic shield frees up space for neutron shield and cooling)



Main challenge:

➢**High DCR at room temperature**. DCR must be kept to a few 100kHz/mm^2 to be readout at 40 MHz. Challenging after irradiation. Necessity of cooling, shielding during data-taking and annihilation during shutdown periods

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SiPM radiation hardness

At room temperature DCR makes single photon detection impossible already at 10^{11} cm^{-2} 1-MeV-equivalent neutron fluence [LHCb U2 RICH range up to 10^{13} 1-MeV n_{eq} cm^{-2}]

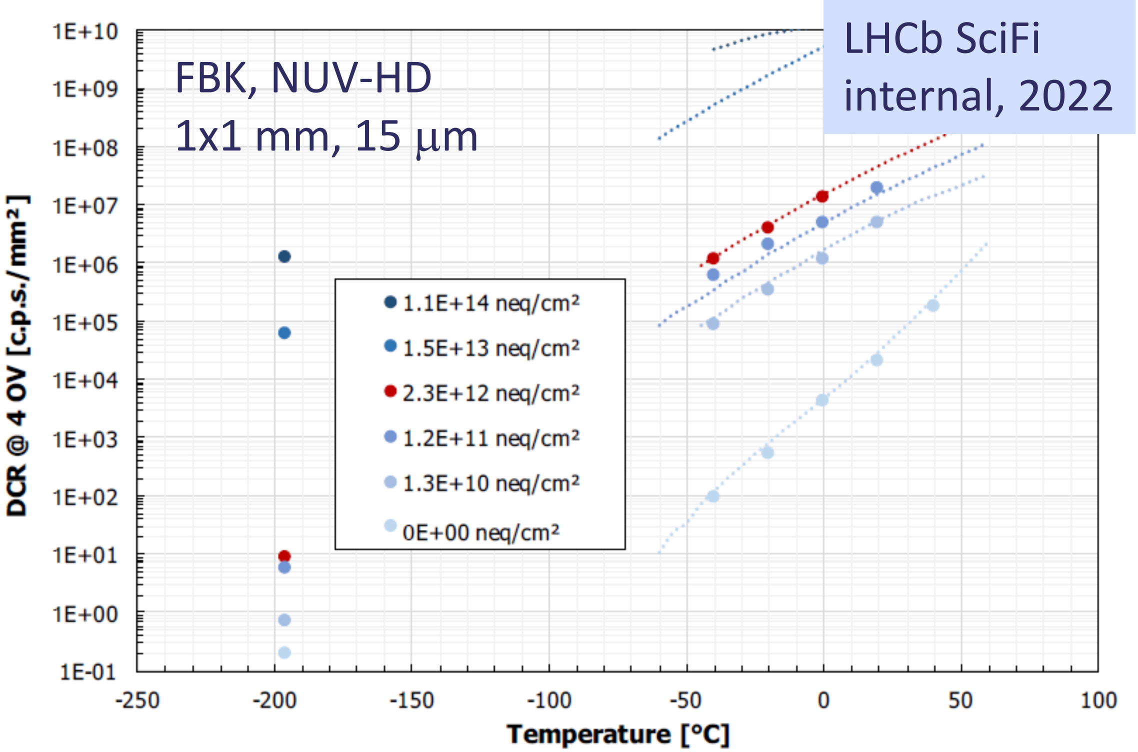
- Previous studies for various SenSL and Hamamatsu SiPMs (M. Calvi et al., NIM A, 922 (2019) 243)
- Irradiation damage induce strong dependence of DCR on T : DCR below 1 kHz/mm was achieved with SiPM irradiated up to 10^{14} n/cm^2, annealed for days to 175^{o}C and cooled to LN2 temperatures

Using improved annealing techniques and cooling at -40^{o}C, it may be possible to operate RICh detector beyond a fluence of 10^{12} 1-MeV n_{eq}/cm^2 (Korpar and Krizan, NIM, 970, 163804, 2020)

Key questions:

Which temperature could we keep the SiPMs at?

How long will we be able to operate the RICH before replacing them?



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SiPM R&D programme at RAL

- **Goal:** radiation hardness evaluation of different SiPMs types
- **Main measurements:**
  - breakdown voltage with I_V curves vs T
  - dark current rate and correlated noise vs T
  - PDE, gain vs T
  - time-resolution vs T

  Useful reference: Klanner, 2019
- **Milestones**
  1. Characterisation of Ketek 3x3mm SiPM at room temperature
  2. SiPM single-cell cooling system ready and tested
  3. SiPMs readout ready
  4. Measurements of different kind of SiPMs (Hamamatsu, FBK) at room temperature
  5. Measurements of cooled devices (down to -40^{o}C)
  6. Presentation of results before irradiation
  7. Irradiation campaign (various fluences)
  8. Tests after irradiation
  9. Publication of results
- **Deliverables**
  - Assessment of suitability and optimal operational temperature of various SiPMs for LHCb Upgrade 2
  - Collaboration with industries (investigate changes to SiPMs internal design to improve radiation hardness)

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Preliminary schedule

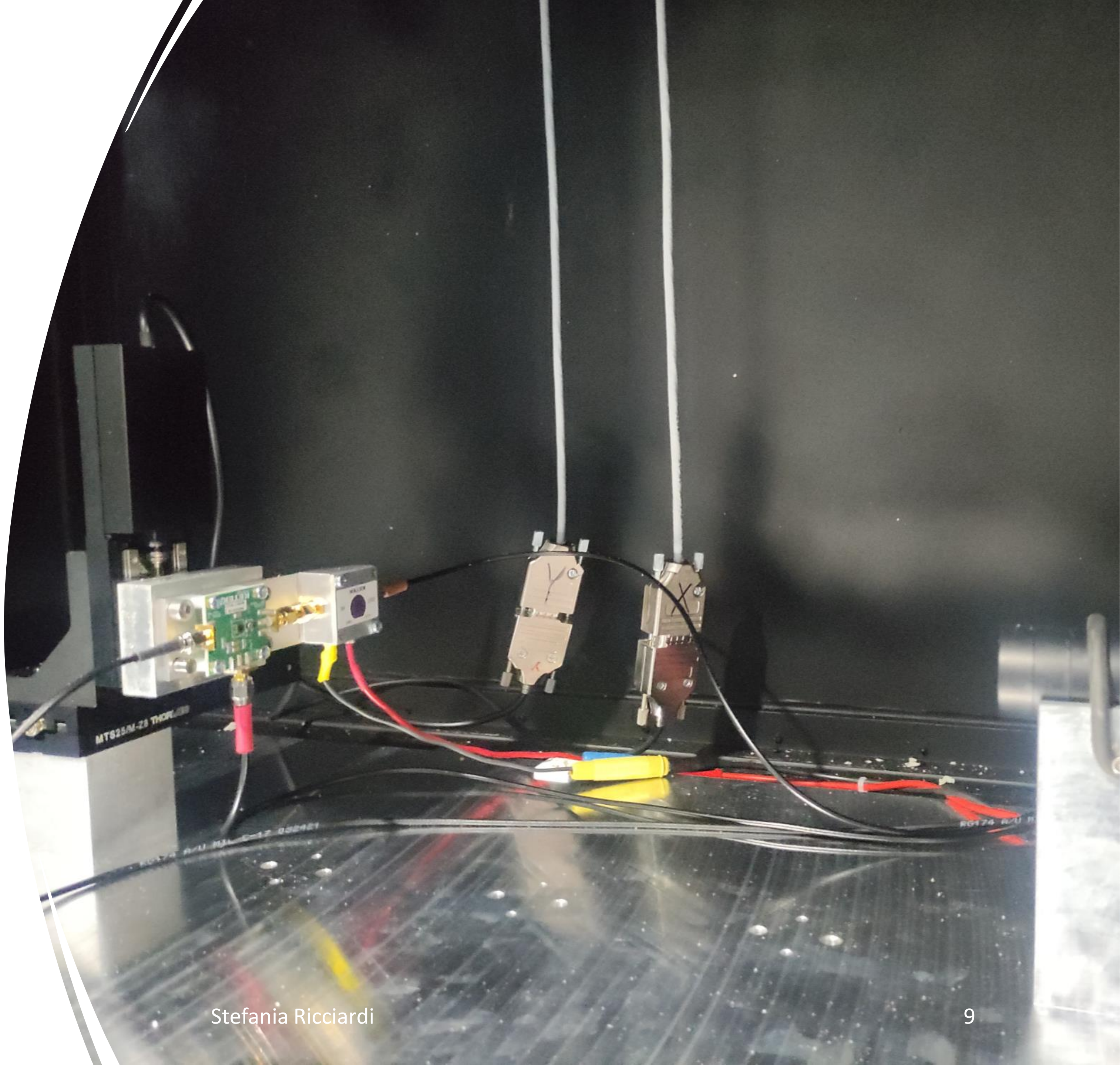
	Jul-Sept 2022	Oct-Dec 2022	Jan-March 2023	Apr-Jun 2023	July-Sept 2023
1. Test Ketek SiPM at room T					
2. Develop single-cell SiPM cooling system					
3. Develop SiPM readout					
4. Test Hamamatsu SiPMs at room temperature					
5. Test of SiPMs vs T					
6. Presentation of results before irradiation		December			
7. Irradiation			January	Provision for second irradiation campaign	
8. Tests after irradiation					
9. Publication					

Experimental setup

- SiPM and light sources confined in a light-tight thermally-insulated enclosure (green box)
- External power supply for pre-amp, Agilent E3648A (0-20V, 2.5A)
- External power supplies for pulsed diode PicoQuant PDL200-B and laser
- Oscilloscope, LeCroy WavePro725zi, 2.5GHz, 40Gs/s
- Desktop (Windows with LabView installed)

Experimental setup/2

- Evaluation kit including:
  - Ketek 3x3mm SiPM, preamplifier, connection to external bias power supply
- Stepper motors control SiPM x-y position with 2μm accuracy
  - new Thorlab x-y stage
- Light sources:
  - Pulsed diode
  - Laser (420nm, 44-70 ps pulse width, PicoQuant LDH-D-C-420)



Experimental setup/3

In addition:

- SiPMs to be tested
  - 5 Hamamatsu S13360-1350PE (surface mount, 1.3x1.3mm) – Delivered July 5
  - FBK off-shell and not (collaboration with FBK established by LHCb)
  - Other types/sizes?
- CAEN wide-band preamplifier A1423B – Delivered June 20
- Keithley SMU 2450 – Ordered in May, long lead time but a demo unit on loan delivered on July 6
- SiPM cooling box components:
  - Peltier cooler (double-stage)
  - Heat sink
  - Fan
  - Insulating material, optical acrylic window, pipes and connectors
- Dry-air/dry-ice
- Humidity and temperature sensors

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Cooling system initial design

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Initial design

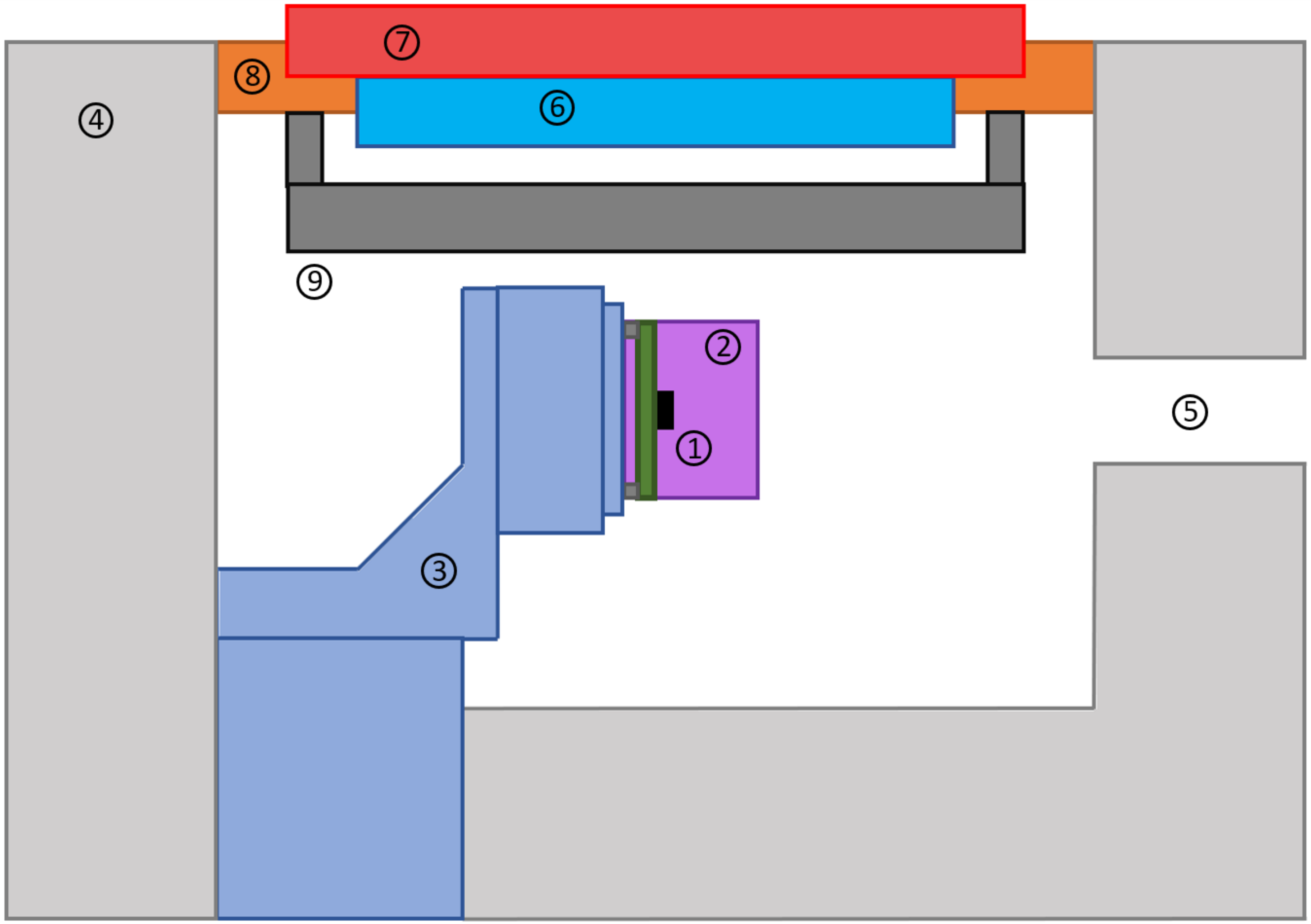
- Low cost and simple
- Conductive cooling not compatible with Ketek testing kit ⟶ convective cooling
- Most components can be reused for a conductive cooling design if necessary

Apparatus under test

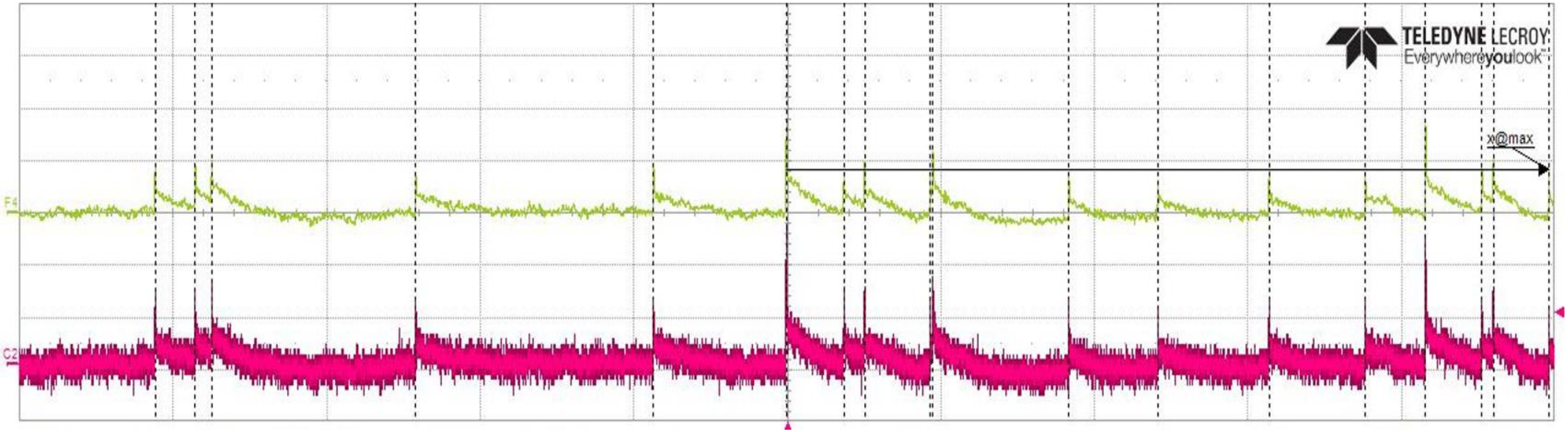
- SiPM (1) is mounted on a PCB providing connections to bias voltage and to preamp. (2)
- (1), (2) are secured to testing mount (3)

Cooling box

- Apparatus is enclosed in a box made of insulating material (4) with an acrylic window opening along the SiPM axis (5)
- Cooling provided by a double-stage peltier (6) connected to a heat exchanger (7) , embedded in the upper panel (8)
- A fan (9) directs cold dry air on the SiPM
- Electric wires are passed through openings in the panel



Side view



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Dark counts of Ketek SiPM

- Oscilloscope screenshot: Time scale at 500 ns, Voltage scale at 5 mV
- Noise reduction (green) applied to analogue signal from preamp (red)
- Peaks found by detecting rising edge of signal, 3 mV threshold
- Good detection accuracy, number of peaks counted in 50x5 μs regions
- Measured DCR at room temperature: 2.9 ± 0.8 MHz (preliminary!)
- Offline analysis will be performed to improve measurement accuracy and reproducibility

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Funding

- LHCb upgrade 2 R&D funded for 3 years by STFC until September 2023
- Total WG1 (charged hadrons PID) £381k, shared among all participating institutes (Bristol, Cambridge, Edinburgh, ICL, Oxford, RAL, Warwick)
  - about £10k consumables to RAL, already spent
  - RAL only institute involved in SiPM R&D in the UK currently
- £4.8M rewarded to LHCb from UKRI Infrastructure Fund for next 3 years starting FY 2024/25

https://www.ukri.org/what-we-offer/creating-world-class-research-and-innovation-infrastructure/funded-infrastructure-projects/

Large Hadron Collider beauty (LHCb) 2030+

Funding

£1.1 million over the next three years. £49.4 million from the Infrastructure Fund in total including future funding years.

Project start date: financial year 2024 to 2025.

About the project

The Large Hadron Collider (LHC) at CERN is the world's largest and highest-energy particle collider, used to increase our understanding of matter and of the origins of the universe.

The Large Hadron Collider beauty (LHCb) experiment is set up to explore what happened after the Big Bang that allowed matter to survive and build the universe we inhabit today.

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SiPM R&D starting in earnest now!

Many thanks to all PPD people who have helped/advised us:
Atanu, Gary, Giulio, John, Matt, Tai-Hua, IT group and others

SiPM R&D outlook

- Radiation-hard internal designs of the sensor will continue in close collaboration with industrial partners, and other LHCb groups (CERN, Italy, Slovenia groups also involved).
- Micro-lensing: A light collection system which demagnifies the effective optical pixel into the real pixel area can reduce the overall dark-count rate, the surface for radiation damage and sensor capacitance.
- Timing: time gate in the front-end electronics can reduce the contribution of dark counts to the bandwidth and event reconstruction.
- Cryogenic temperature: studies could be extended for operation of SiPMs at cryogenic temperatures
- Cooling system for the photo-detector planes in the RICH will have to be designed