Large Area Picosecond Photodetector
for the Upgrade II of the LHCb RICH

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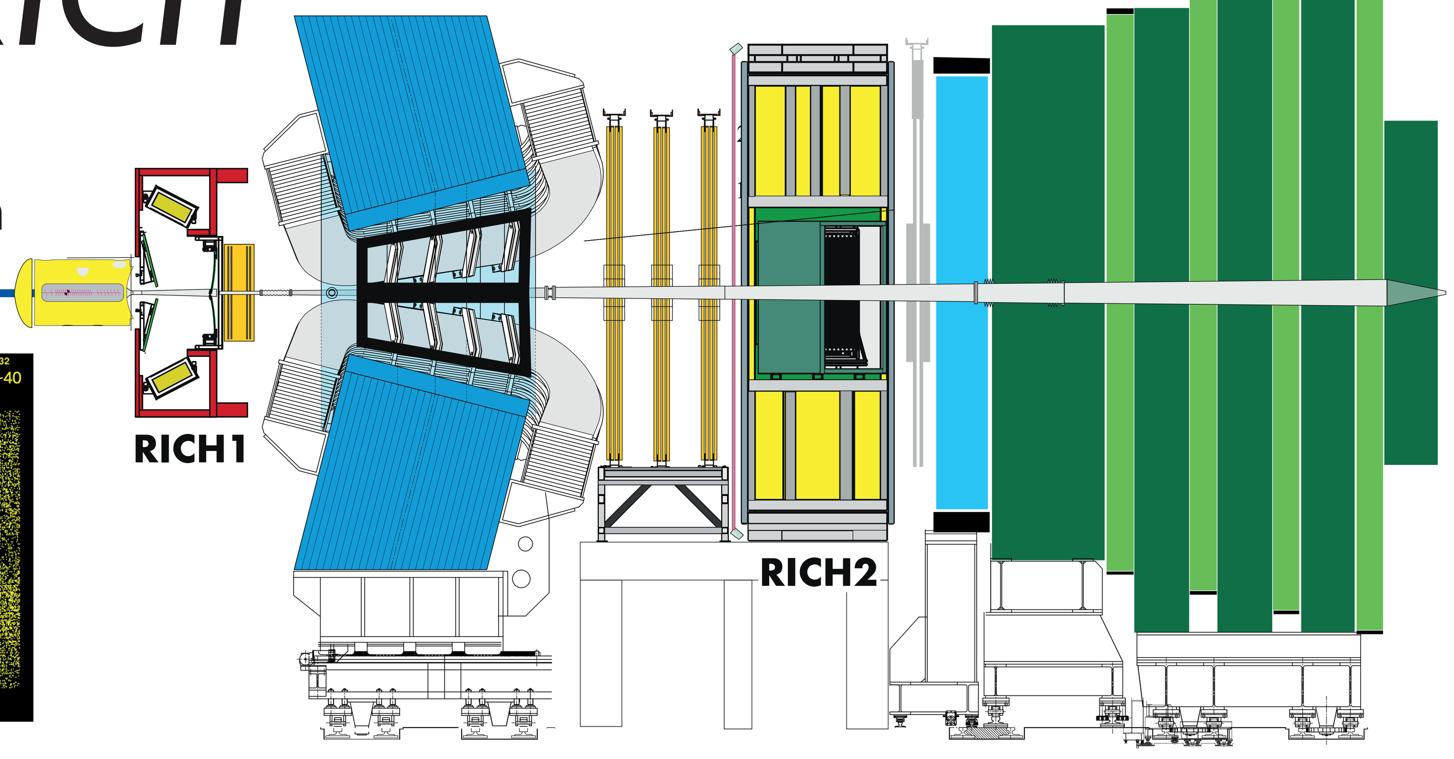
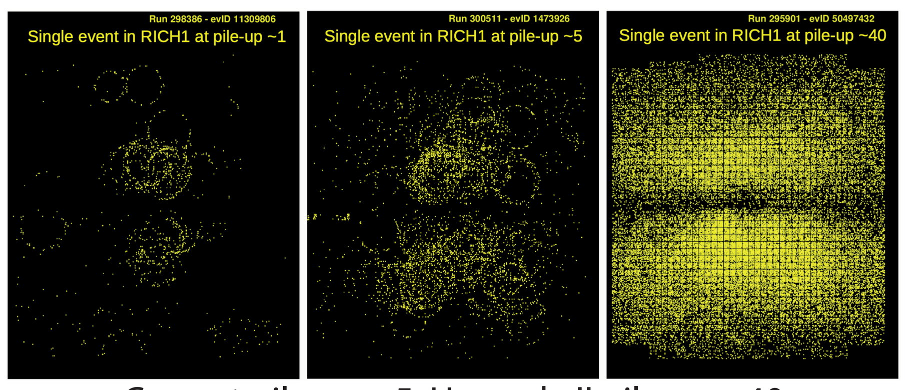
on behalf of the LHCb RICH collaboration
THE UNIVERSITY of EDINBURGH



LHCb upgrade II

During the LHCb upgrade II, scheduled to take place during LS4 (2035), the two ring imaging Cherenkov (RICH) detectors will undergo an extensive photodetector upgrade [1]. The photodetector technology selected must have a intrinsic time resolution of <~100ps, and be able to operate under the high luminosity LHC conditions.



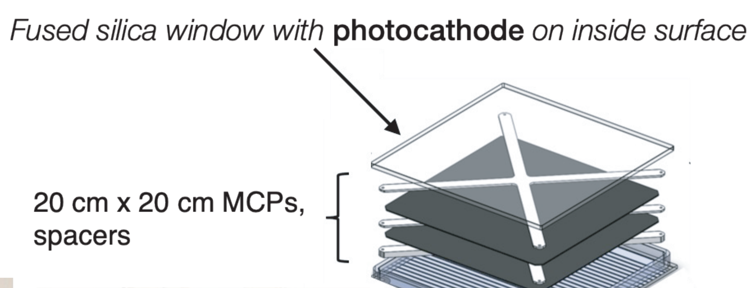
Current pile-up ~5, Upgrade II pile-up ~40

LAPPD

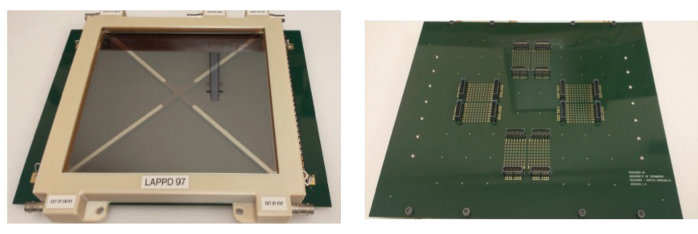
The Large Area Picosecond Photodetector (LAPPD) is a Micro Channel Plate (MCP) based photodetector developed by Incom (US) that, due to it's excellent time resolution [2], is a promising candidate photodetector technology for RICH Upgrade II.

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

LAPPD scheme



LAPPD 97:
- Gen II LAPPD, pixel readout, 20 µm pores
- Capacitively coupled readout
- Spectral response 160-650 nm
- Large area (20 x 20 cm^2)

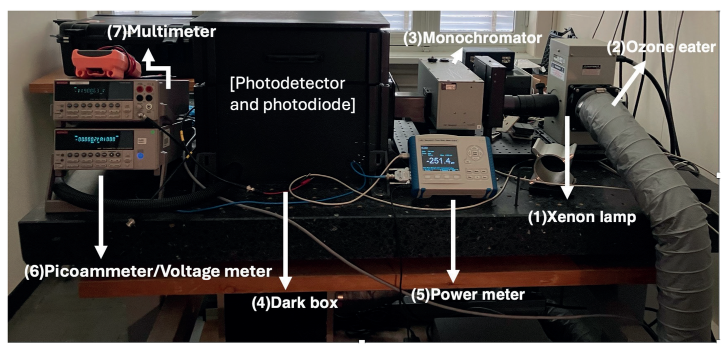


Edinburgh designed backboard:
- Custom readout board V0
- 512 pixels
- Pixel size: 3 mm pitch to pitch (2.9 x 2.9 mm^2 active area, 0.1 mm dead gap)
- Samtec connectors for use with RICH test beam readout chain

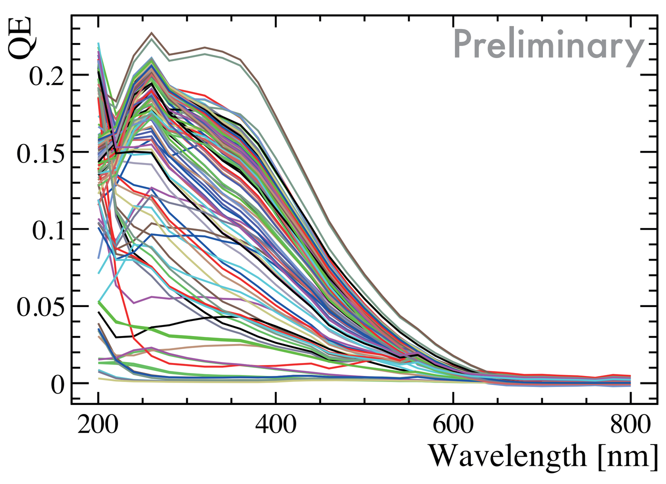
Quantum Efficiency

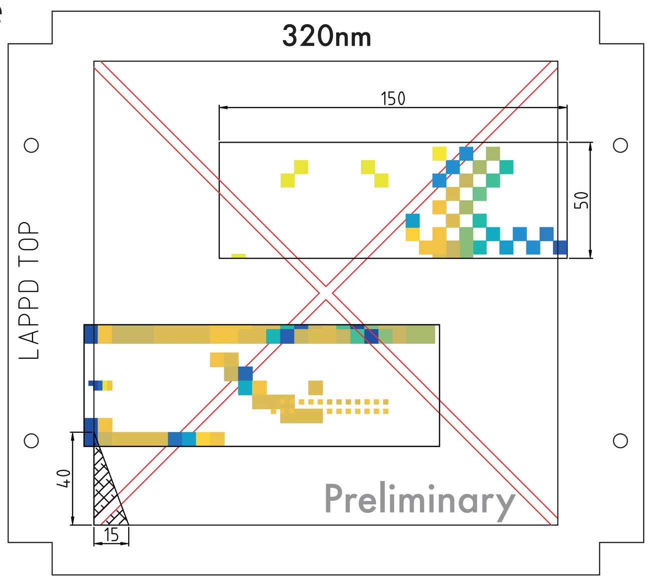
The quantum efficiency (QE) of a detector is an important characteristic for both simulation and analysis.

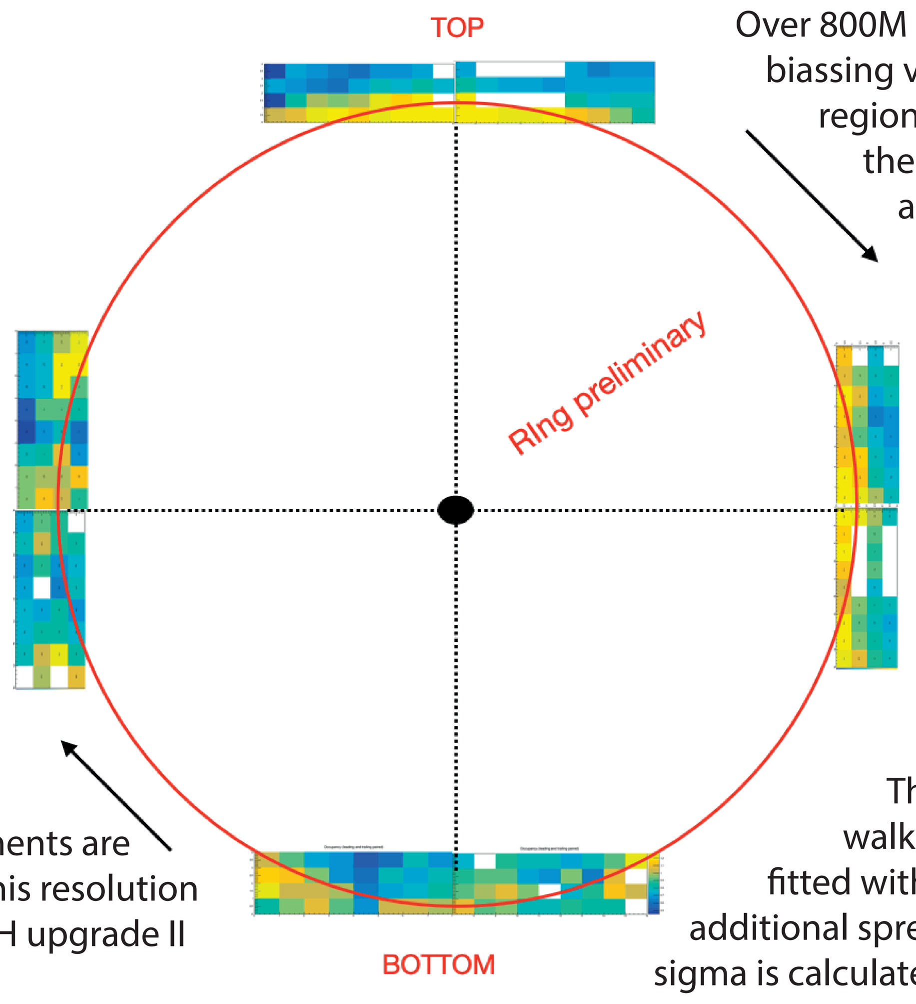
$$QE = QE_{Reference} * \frac{LAPPD\ photocurrent}{Reference\ photocurrent}$$



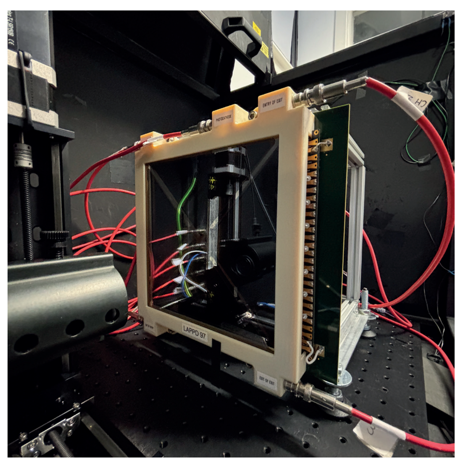
- Monochromator uses a diffraction grating to provide light with a tuneable wavelength.
- LAPPD mounted on an X-Y translation stage.
- Reference photodiode used to calibrate QE measurement.





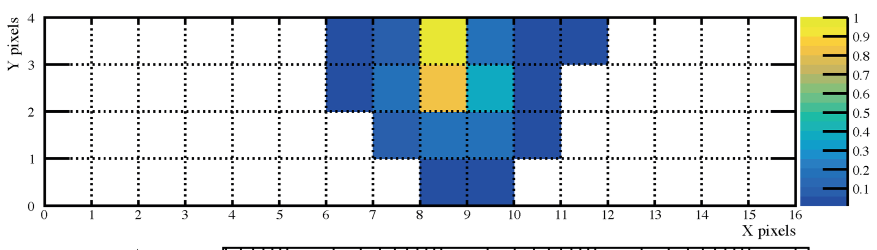


Lab results



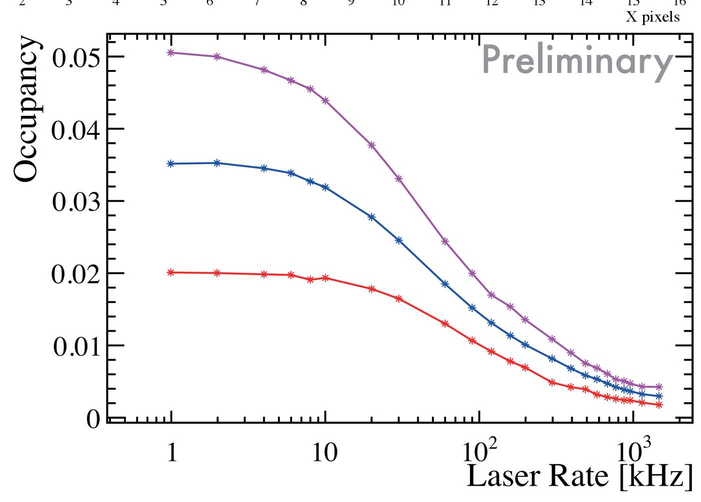
Lab measurements of the LAPPD with the RICH test beam readout chain were conducted using a custom picosecond 405 nm Pilas laser (timing jitter < 2ps).

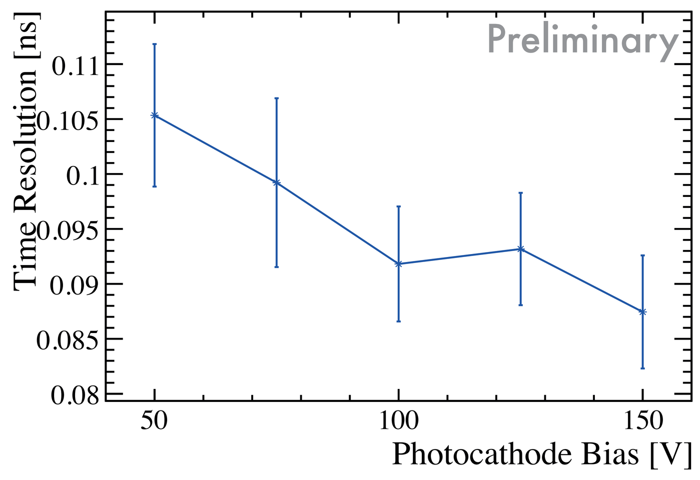
The single photon time resolution (SPTR) measurements are compatible with those acquired in the test beam. This resolution meets the timing requirements required for the RICH upgrade II (<~100 ps).



However, a known limitation of MCP based photodetectors is their sensitivity to high rates. As the photon rate increases, gain decreases. This may limit their suitability for operation in the high-rate enviroment of the LHCb upgrade II.

Plots prepared by Z. Haenggi, summer student on "Advanced Detector Development" (University of Edinburgh)

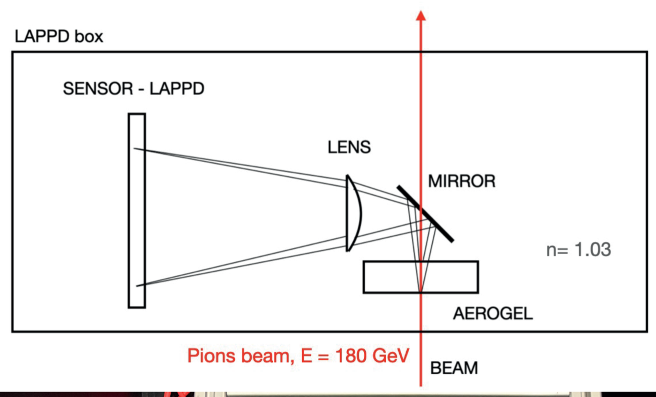




RICH test beam

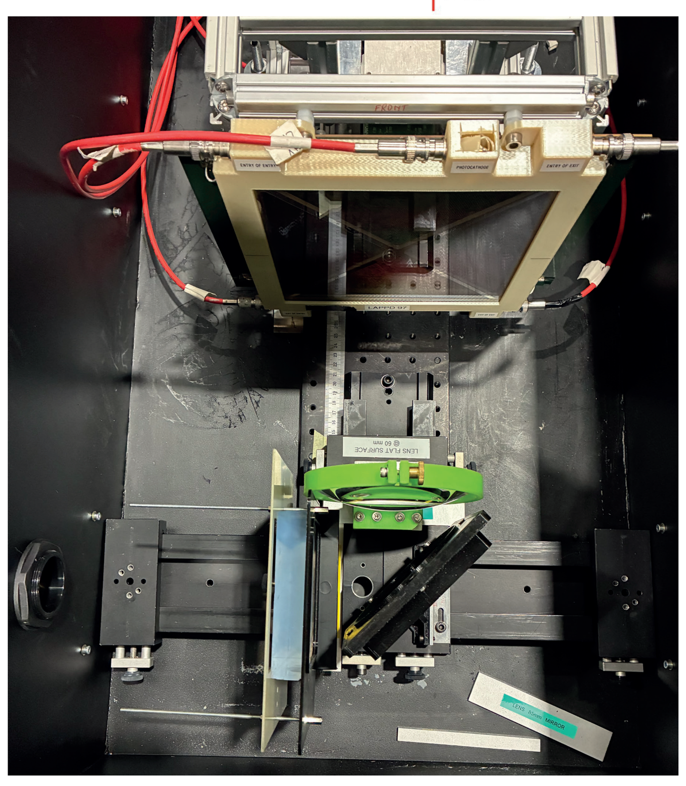
The RICH test beam took place in the CERN SPS beam facility from the 21st of May to the 4th of June 2025.

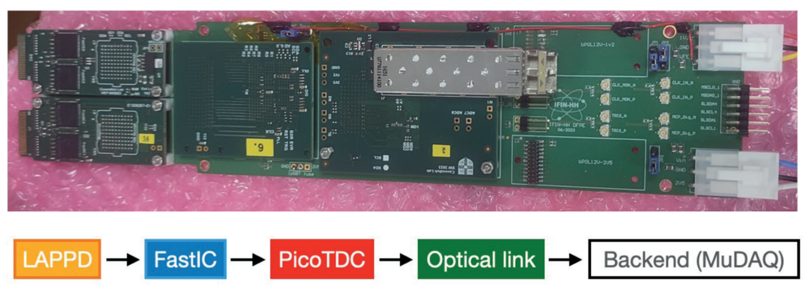
A 180 GeV pion beam is delivered to a dark box containing the LAPPD apparatus. Cherenkov radiation is produced in an Aerogel block placed in the beam. The Cherenkov photons are reflected by a mirror and focused by a lens onto the LAPPD surface positioned off beam.



The detector is read out by the RICH test beam readout chain [3]. A time reference is provided by two downstream MCPs triggering on beam particles.

Test beam readout chain:
- FastIC - descriminator
- PicoTDC - time to digital convertor
- MuDAQ - backend control
- Ethernet link to PC

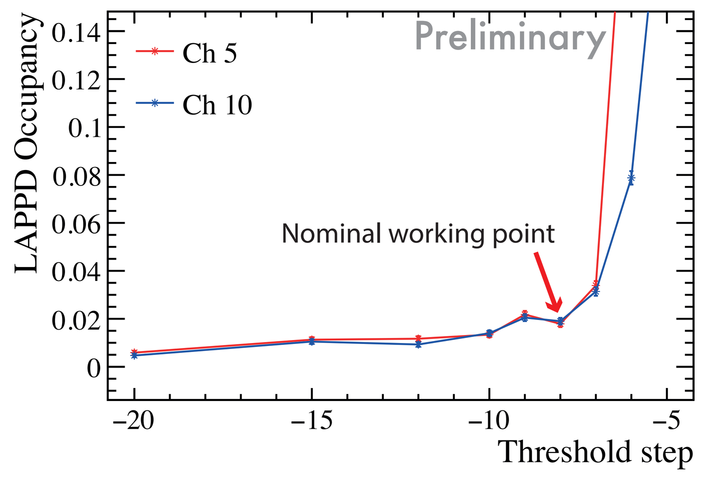




Test beam results

Over 800M triggers were taken throughout the test beam. Data was taken with various biassing voltages and discriminator thresholds. Two readout boards instrumented regions of the LAPPD active area. These were moved during the testbeam to capture the full Cherenkov ring. Nominal operation of LAPPD applied an 850V MCP bias and 100V photocathode bias.

The nominal FastIC descriminator threshold is 8 (* 0.5 uA) steps below the electronic noise pedestal.

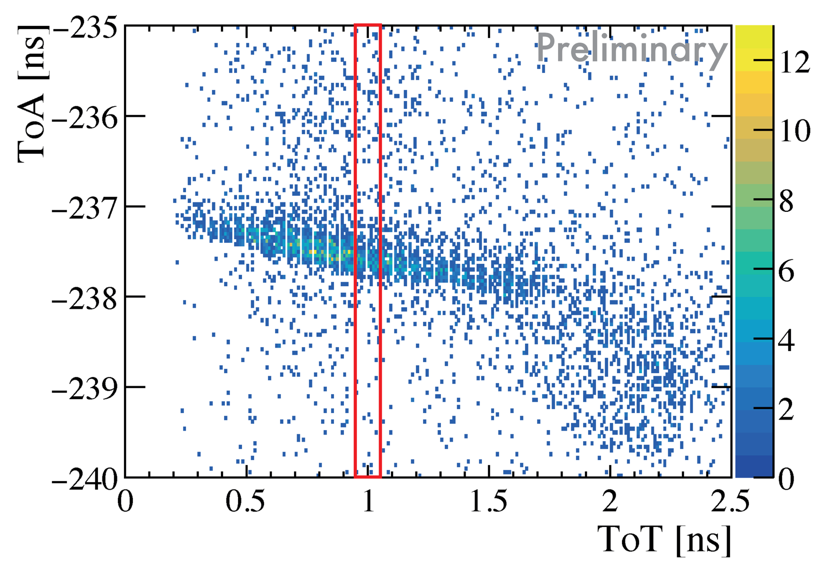


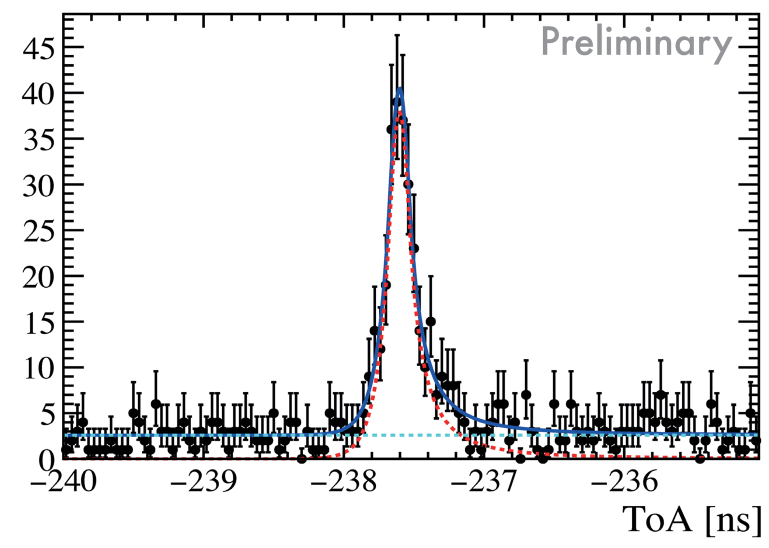
To mitigate the effect of time walk, a cut on time over threshold (ToT) is applied, selecting only signals with ToTs from 0.95 ns to 1.05 ns.

The resulting time of arrival (ToA) distribution has very little smearing due to time walk effects. The ToA distribution (measured with respect to the time reference) is fitted with a double Crystal Ball and a uniform dark count background. To account for any additional spread from the tails, the FWHM is extracted from the fit, and the equivalent Gaussian sigma is calculated.

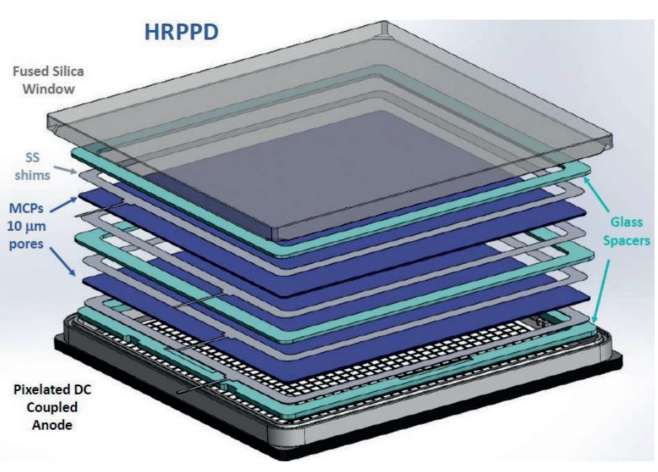
Equivalent Gaussian sigma = FWHM / 2.355
FWHM = 198.6 ± 26 ps
Fit equivalent Gaussian sigma = 84 ± 11 ps

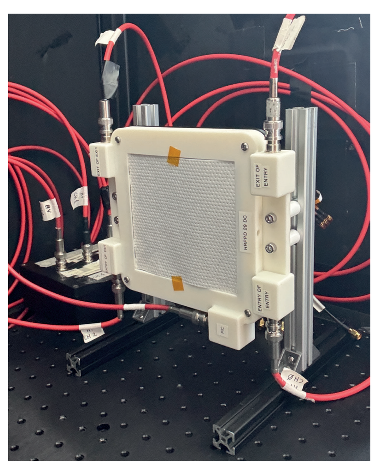
After correcting for the sources of timing jitter:
SPTR (Ch 50 LAPPD bottom) = **76 ± 10 ps**





HRPPD

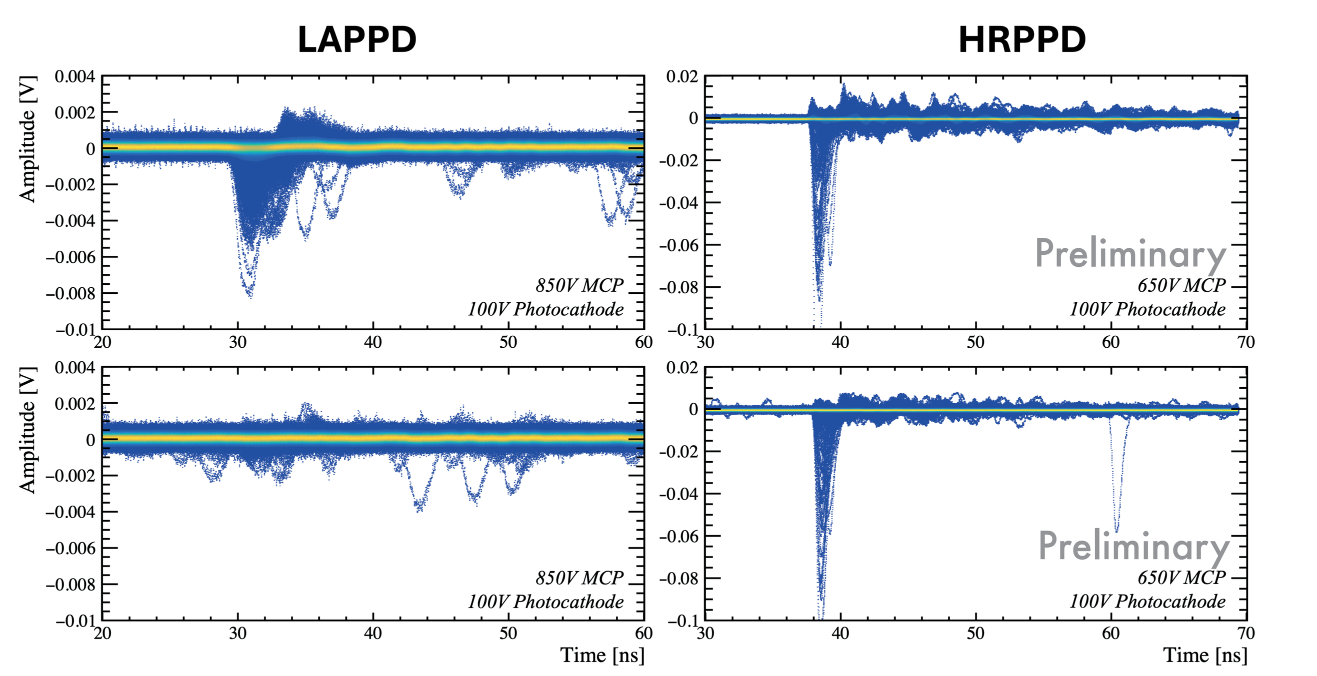




High Rate Picosecond Photodetector (HRPPD) is a development on the LAPPD technology also produced by Incom (US) [4]. Arrived in Edinburgh on the 29th of July.

- Dimensions: 120 x 120 mm^2
- Active area: 103.92 mm x 103.92 mm (75%)
- 10 µm pores
- Directly coupled device
- Anode: 1024 pixels, 3x3 mm^2 area

The HRPPD is expected to have reduced charge sharing, a better time resolution, and higher rate capabilities. This makes for a promising potential detector technology for RICH upgrade II. Characterisation of the detector is ongoing.



References

[1] - LHCb, Framework TDR for the LHCb Upgrade II , CERN-LHCC-2021-012, LHCB-TDR-023, CERN, 2021.
[2] - A.V. Lyashenko et al., Performance of Large Area Picosecond Photo-Detectors (LAPPD™), Nucl. Instrum. Meth. A 958 (**2020**), 162834.
[3] - F. Keizer, The FastRICH ASIC for the LHCb RICH enhancements, Nucl. Instrum. Meth. A 1067 (**2024**), 169664.
[4] - A.V. Lyashenko et al., HRPPD photosensors for RICH detectors with a high resolution timing capability, Nucl. Instrum. Meth. A 1082 (**2026**), 170964.

RICH 2025, Mainz, Germany 15-19 September 2025