

High rate tests of the LHCb RICH Upgrade system

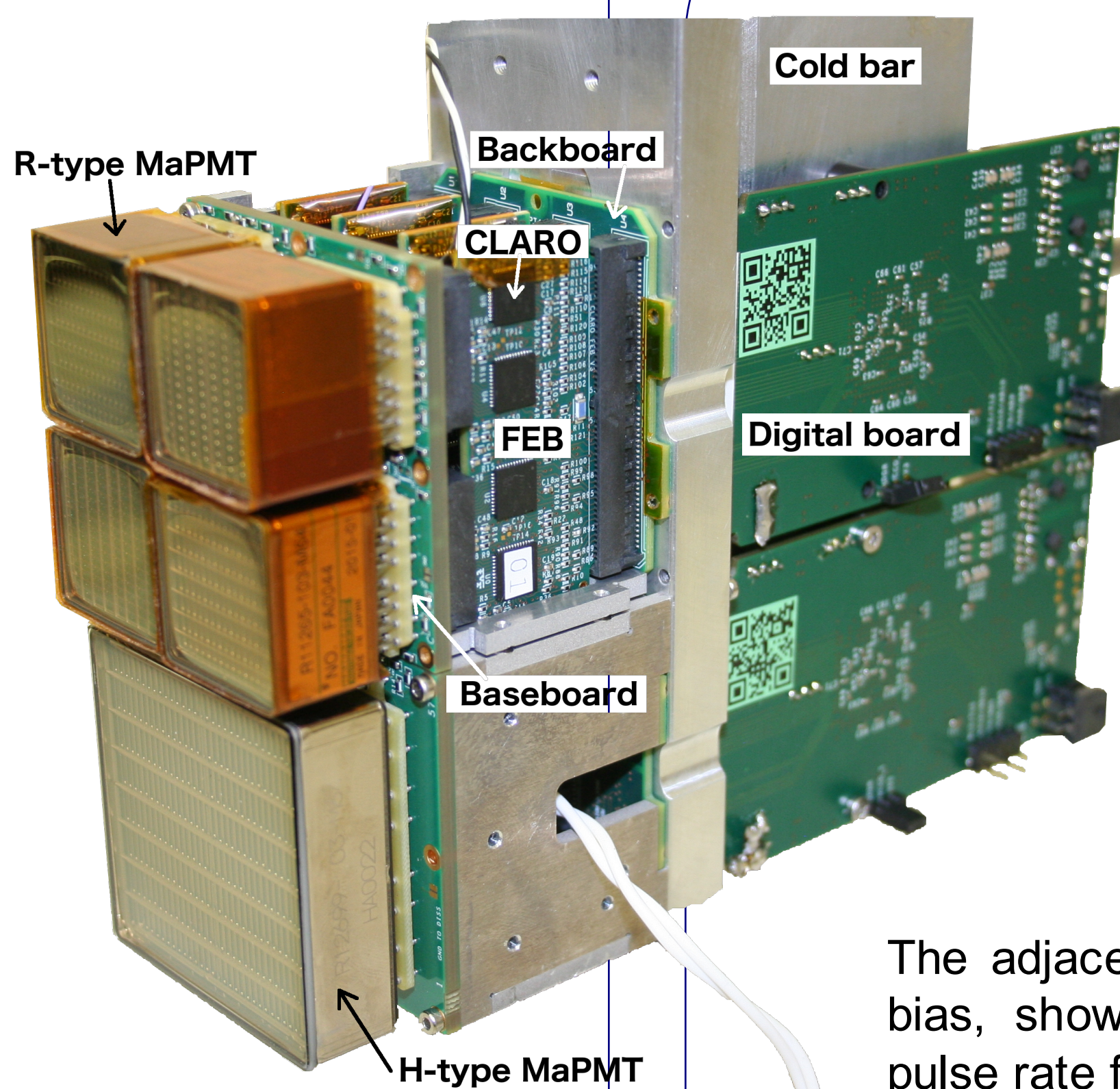
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on behalf of the LHCb RICH Collaboration

Upgrade overview

The LHCb detector upgrade aims to make more efficient use of the available luminosity during the CERN LHC Run III [1]. The photon detection system of the RICH detector will be upgraded to an array of multianode photomultiplier tubes (MaPMTs) with custom-built modular readout electronics. Key challenges for the system are single Cherenkov photon sensitivity, the 40 MHz readout rate of the LHC proton-proton collisions and regions with high photon occupancy.

The system employs two types of 8×8 channel MaPMTs. A 1×1 inch² 'R-type' to be used in high occupancy regions and a 2×2 inch² 'H-type' for low occupancy regions. An elementary cell (EC) is populated by four R-type MaPMTs or one H-type MaPMT. The baseboard contains the bleeder chain for the MaPMT bias, and routes the signals to the CLARO ASICs on the front-end boards (FEBs) for shaping and discrimination. Digital boards configure the CLAROs and capture and format the CLARO outputs into Ethernet packets sent to the data acquisition (DAQ) system.

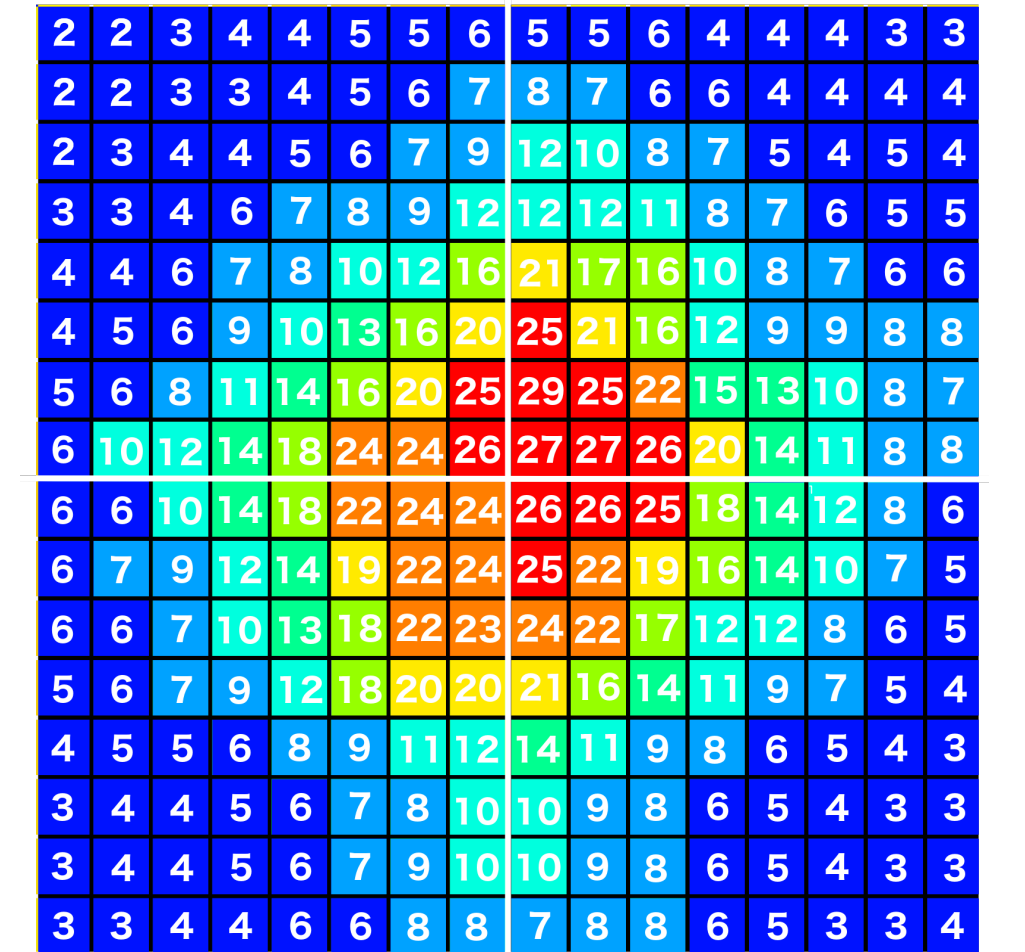
The system has been tested in a charged particle beam [2]. A test facility has been set up at CERN to further investigate the behaviour of the system at high event rates and different photon occupancies.



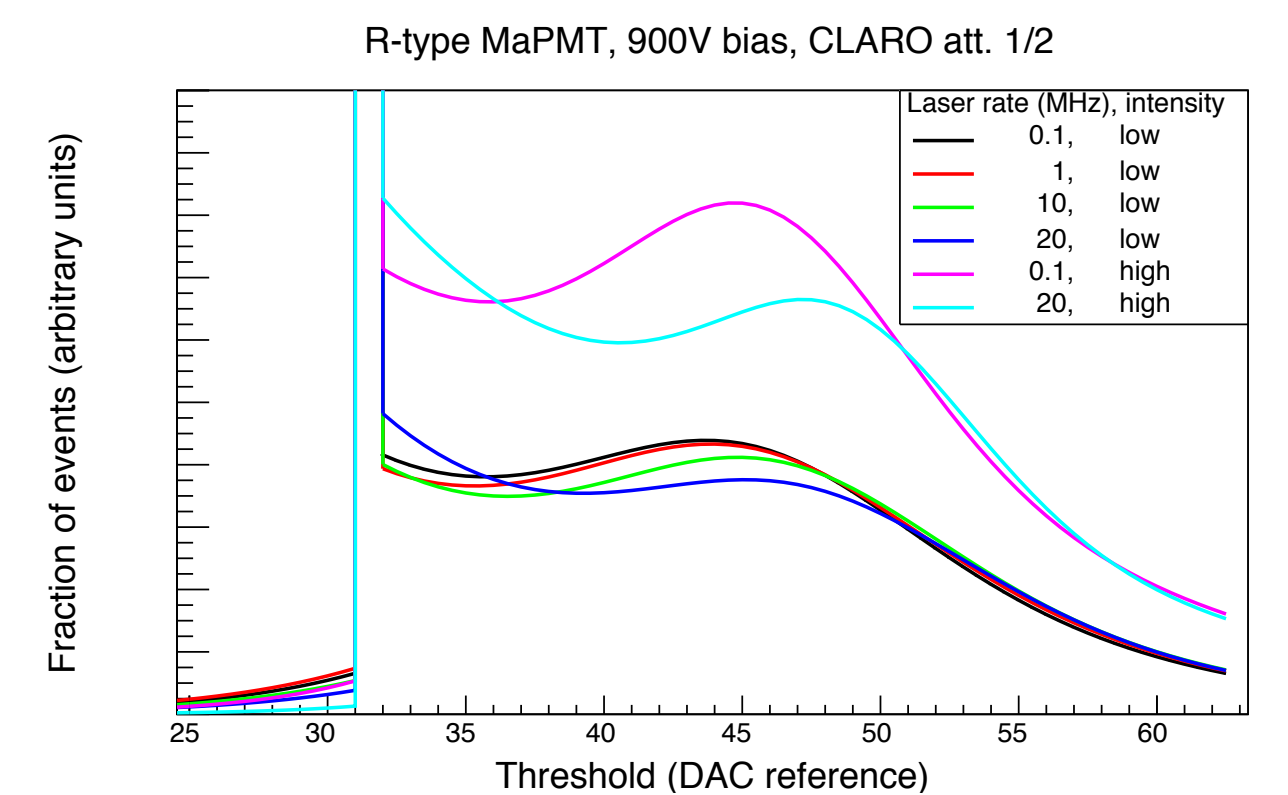
Results

R-type MaPMT

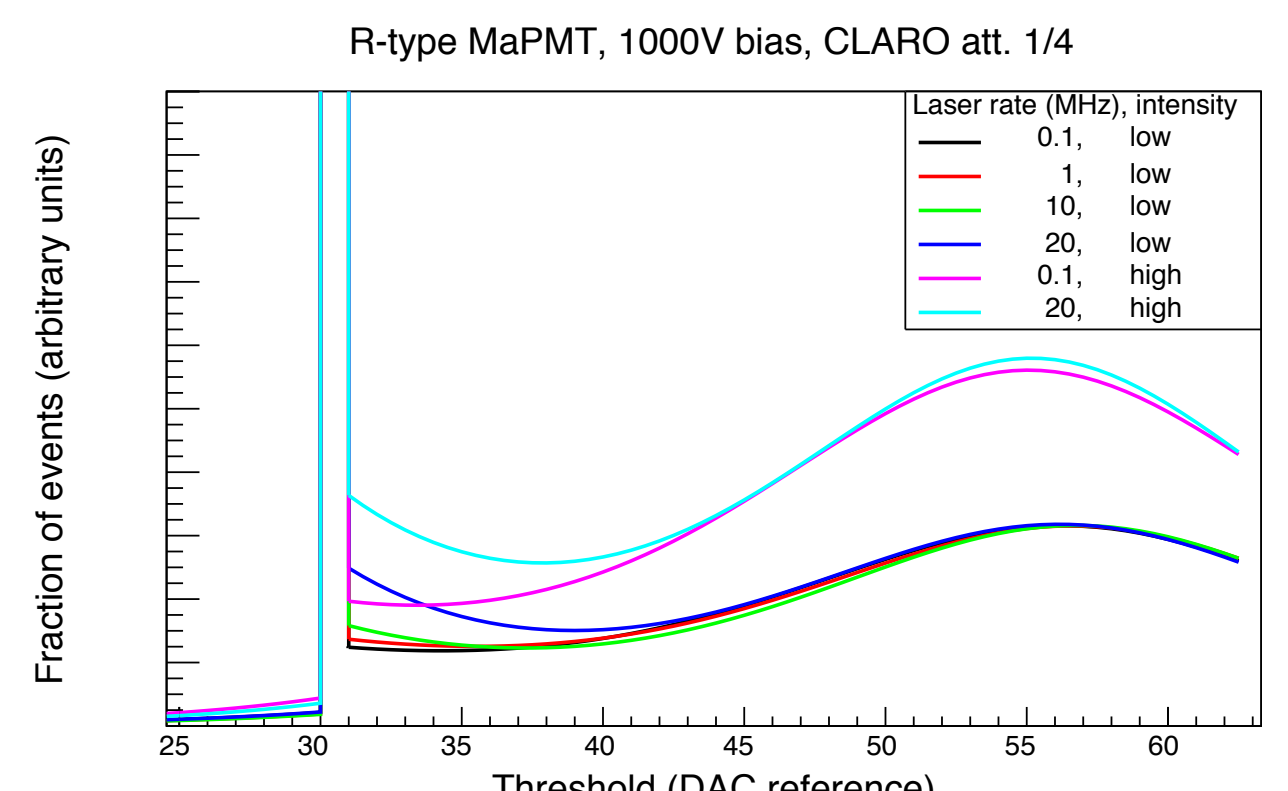
The adjacent image shows the percentage photon occupancy per channel of the R-type EC at 'low intensity'. The occupancy reaches nearly 30% at the centre of the laser spot. During high intensity tests, the central region has 45% occupancy.



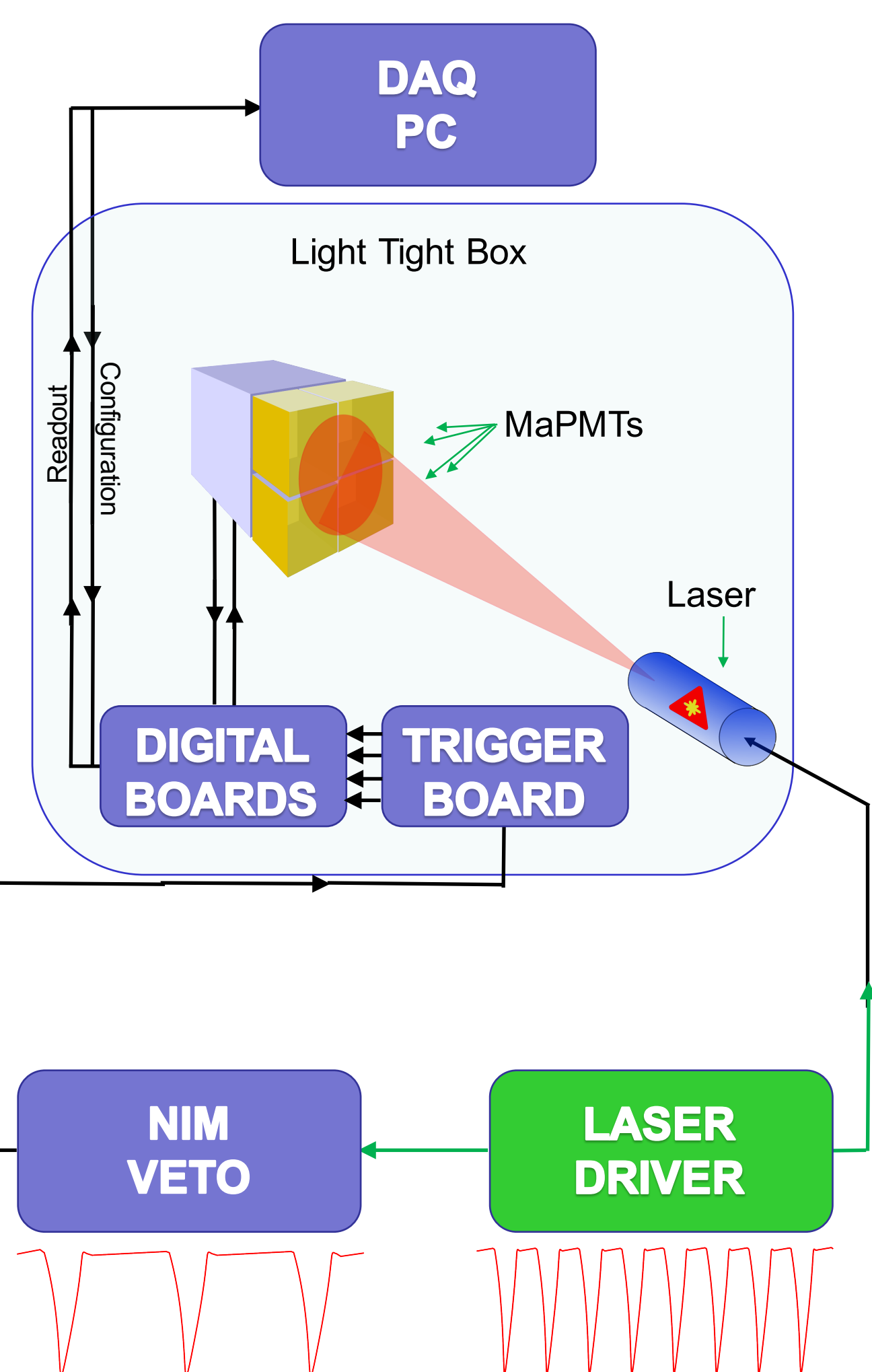
The adjacent plots, at 900V and 1000V bias, show four curves with increasing pulse rate from 100 kHz to 20 MHz at low intensity, as well as two curves at high intensity. The pedestal position is unchanged. The pedestal width increases with pulse rate as a result of the larger photocurrents flowing through the system.



At 900V bias, an increase of the pulse rate shifts the single photon peak position to a higher threshold value and reduces the peak height, indicating a lower photon detection efficiency. This effect could be caused by a reduction in the bias voltage of the last MaPMT dynode, leading to space charge effects that lower the charge collection efficiency at the anode. The effect is not present at 1000V bias.



High rate test setup



A pulsed laser with 405 nm wavelength was aligned with the centre of the EC, inside a light-tight box. The pulse rate was varied up to 20 MHz at the external laser driver.

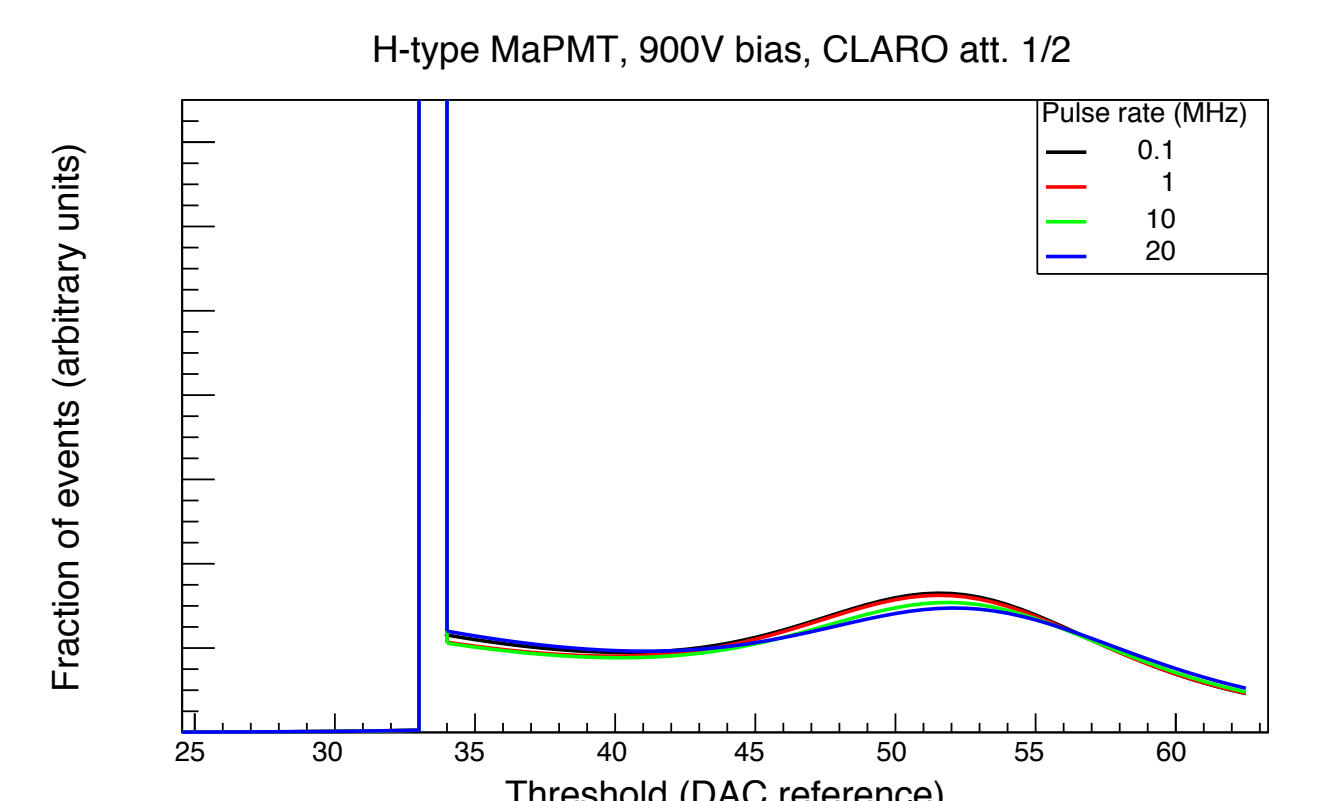
The digital boards were triggered from the laser driver with a veto applied to reduce the data rate to 20 kHz, which keeps the bandwidth within the limit of the Ethernet link. Recording only a subset of events does not affect the tests of the MaPMT and CLARO performance.

The digital board reads out two R-type or one H-type MaPMTs. The trigger board distributes the trigger to up to four digital boards.

H-type MaPMT



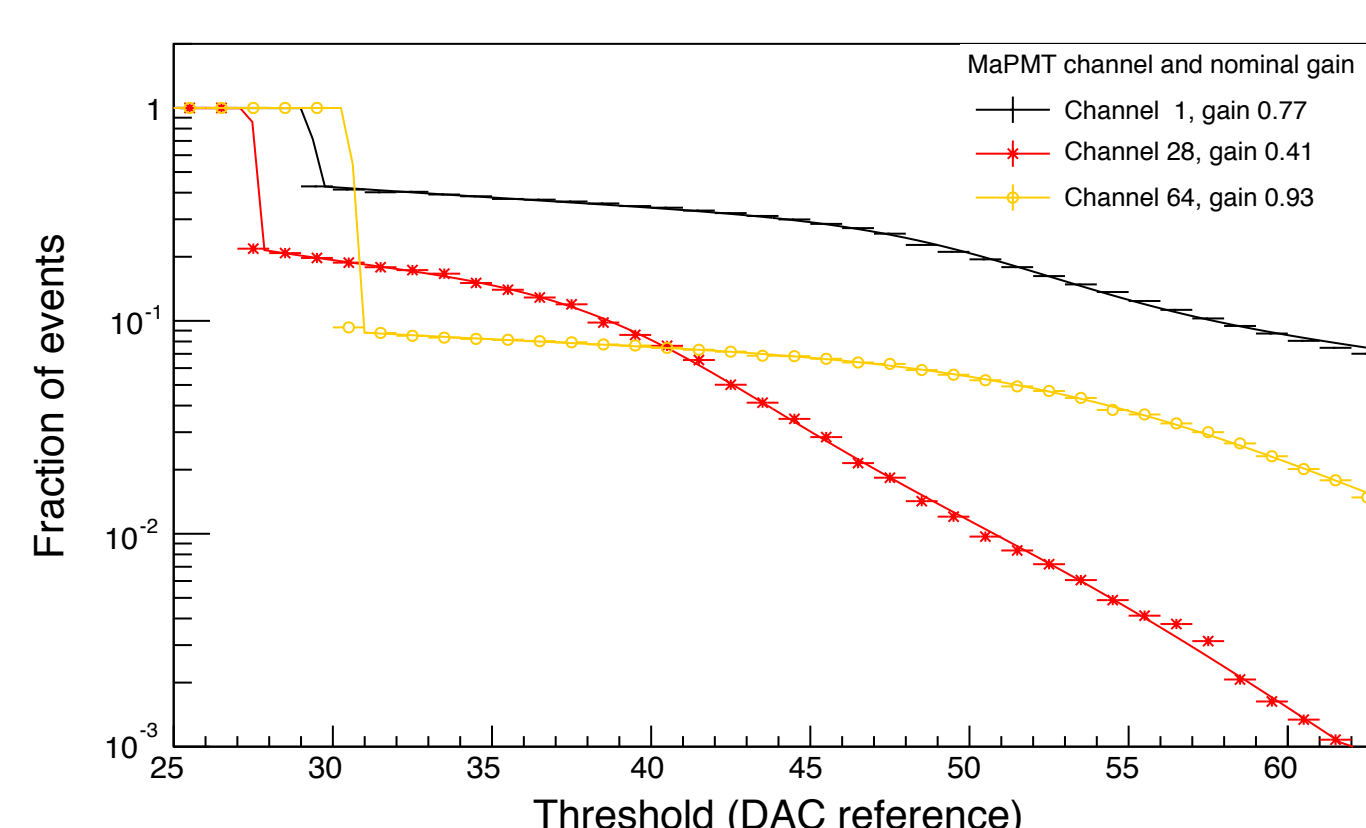
As for the R-type, the H-type MaPMTs show no significant change in photon detection efficiency or gain at high pulse rates at 1000V bias. As shown in the adjacent plot, the pedestal width increases less than for the R-type, and the first photon peak variation at 900V is typically small.



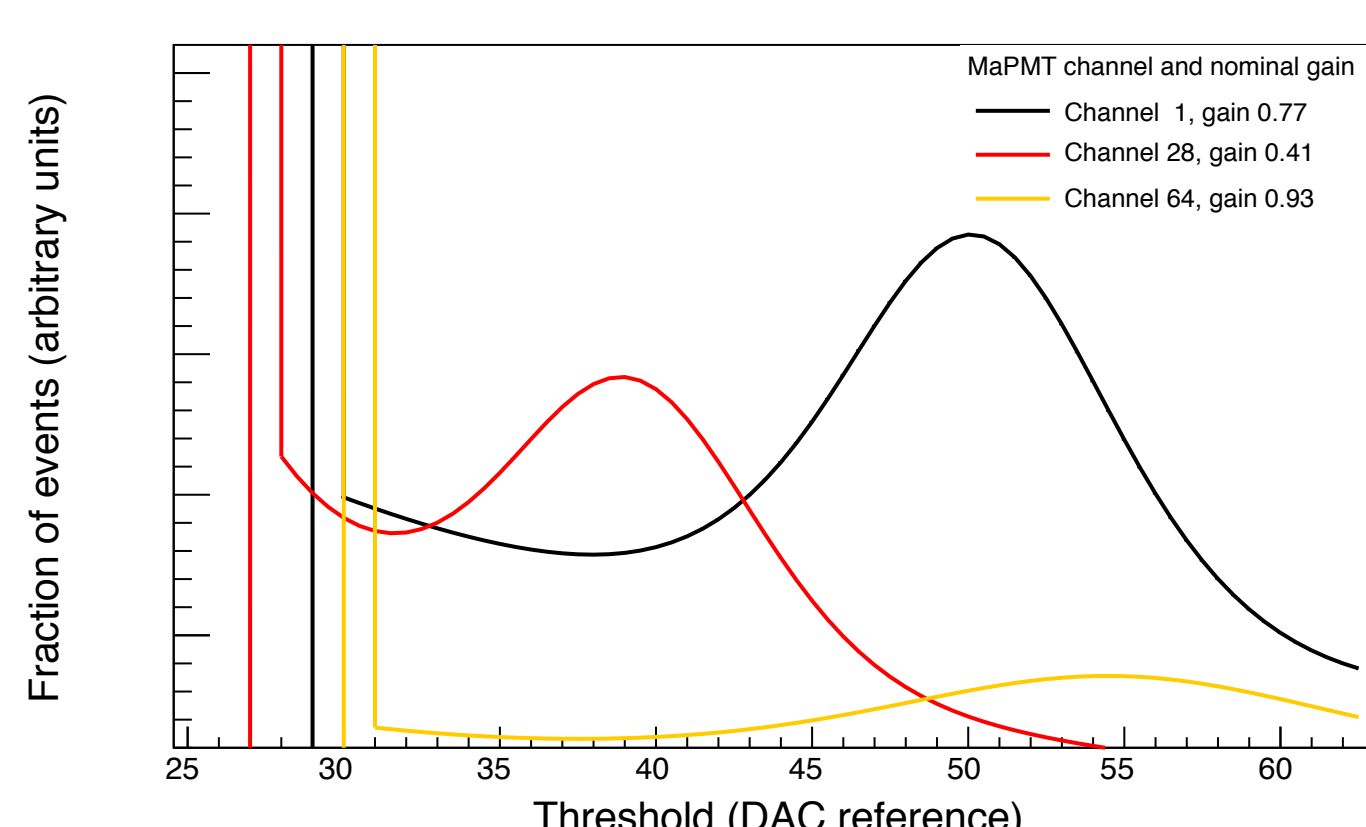
Threshold scans

A threshold scan increments the threshold at the CLARO discriminator, recording 250,000 events at each step. A threshold unit corresponds to approximately 35,000 electrons. The CLARO functionality to offset the thresholds by 32 units was used to determine the pedestal characteristics, in addition to the photon signals.

At low threshold, the CLARO outputs are always high. The pedestal position is marked by a sharp drop in the fraction of events above threshold. At thresholds above the pedestal, the fraction of events is dominated by the integrated photon signal and was therefore used to estimate the photon occupancy of the channel.



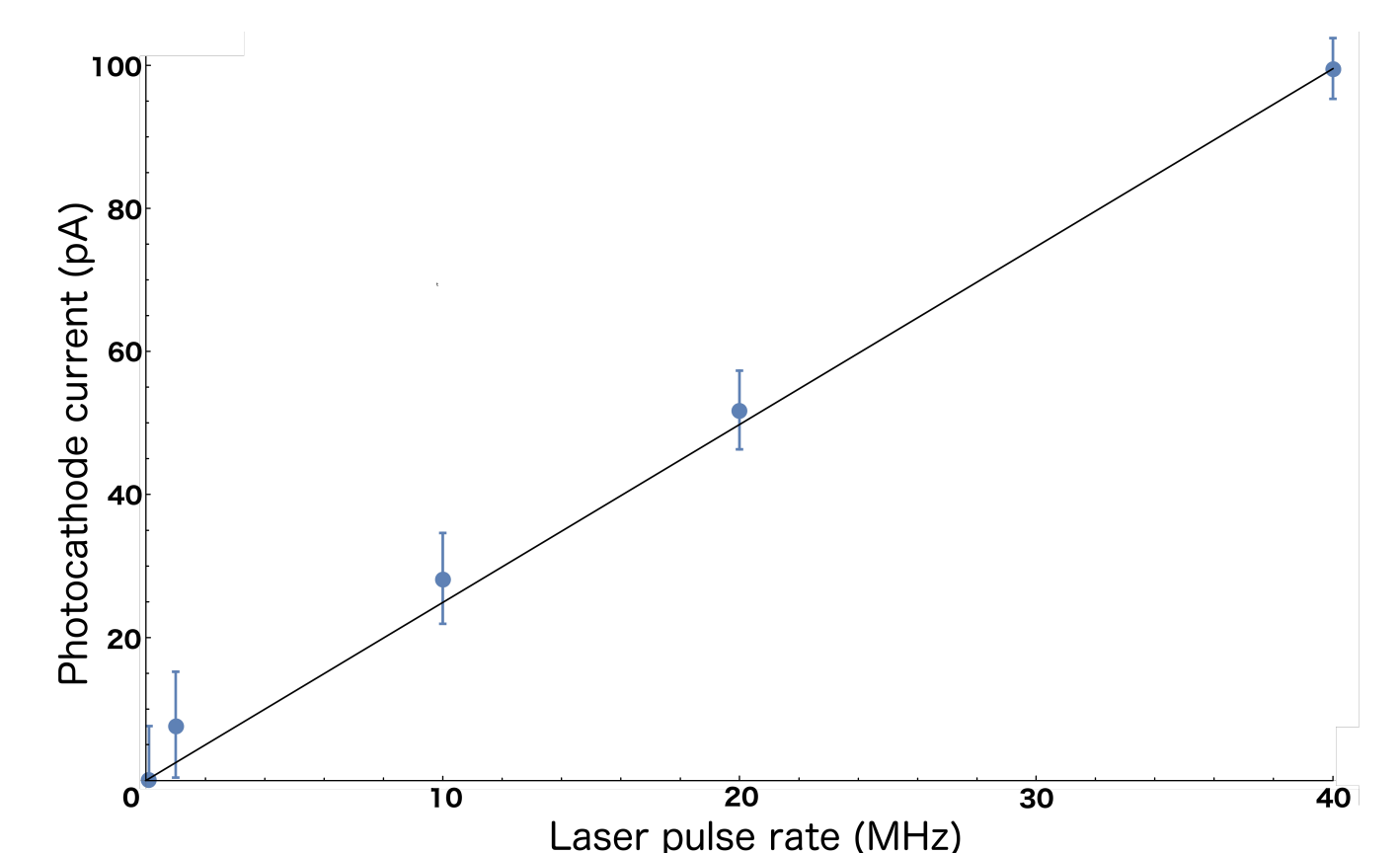
A function based on three Fermi probability distribution functions, representing the pedestal and first and second photon peak, was fitted to the threshold curve. The function was differentiated to recover the analogue distribution.



The current drawn by the MaPMTs from the power supply was monitored as a function of the pulse rate, and converted into a photocathode current using a SPICE simulation of the baseboard bleeder chain. From 100 kHz to 40 MHz pulse rate, all measurements agree within error with a linear increase of the photocathode current with pulse rate.

In contrast to the threshold scans, where the sampling of the CLARO digital outputs was limited to 20 MHz, the measurements of the photocathode current include the 40 MHz rate.

Photocathode current



Conclusion and further tests

The LHCb RICH Upgrade photon detection system has been tested at pulse rates up to 20 MHz and photon occupancy up to 45%. A reduction in photon detection efficiency was observed at high pulse rate at 900V bias, which will be further investigated with the last MaPMT dynode powered separately. Future tests also involve the implementation of customised firmware for the digital boards, which allows the MaPMTs and readout electronics to be tested at 40 MHz rate.

References

- [1] LHCb collaboration. *LHCb PID Upgrade Technical Design Report*, CERN-LHCC-2013-022, LHCb-TDR-014
- [2] LHCb RICH Upgrade collaboration. *Test of the photon detection system for the LHCb RICH Upgrade in a charged particle beam*, CERN-LHCb-PUB-2016-019.