Hybrid Photon Detectors and Ion Feedback

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Abstract

The long-term development of the Ion Feedback rate of Hybrid Photon Detectors in the LHCb Ring Imaging Cherenkov detectors was studied as a sensitive measure of the vacuum quality. From a phenomenological understanding of the development reliable predictions can be made for individual photon detectors. 80% of them will operate well for the lifetime of LHCb. In a 20% subsample a faster-than-expected degradation of the vacuum quality was found. A HPD repair and replacement programme guarantees a good performance of the LHCb RICH detector at all time during data taking.

Key words: Hybrid Photon Detector, Ion Feedback, Vacuum Quality, Ring Imaging Cherenkov (RICH) Counter
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The LHCb[1][2] Ring Imaging Cherenkov detectors (RICH) [3] have been commissioned with 484 Hybrid Photon Detectors (HPD) [4]. The HPD combines the best of two technologies: a vacuum photon detector with a pixelated silicon sensor read-out [5]. It is uniquely equipped to detect single Cherenkov photons with optimal efficiency and allows the detailed study of Ion Feedback. The HPDs have been comprehensively tested after production [6][7] and have regularly been monitored since October 2007 in RICH2 and since June 2008 in RICH1.

Ion Feedback (IFB) occurs when a photoelectron ionises a residual gas atom, as shown in Fig.1. The heavy ion drifts to the photocathode and produces on impact a cluster of secondary electrons. The cluster of electrons arrives at the sensor with a characteristic delay of typically 200-300ns due to the drift time of the ion. The hit multiplicity of such a cluster on the Silicon sensor typically is 10-40 pixels. As the IFB probability is proportional to the concentration of the residual gas in the volume it is a sensitive measure of the vacuum quality.

The measurement of IFB in HPDs relies on its two signatures: the cluster size (≥ 5 adjacent pixels) and the signal delay. Both signatures were used in dedicated bench tests, which typically were taken one month after the HPD production, cf. Fig.2. With a pulsed LED as light source the IFB was determined from the ratio of the peak samples of the delayed large clusters and the direct photoelectrons. For the whole production sample this yielded a very low average of $\langle \mathrm{IFB} \rangle = 0.04\%$, indicating an excellent vacuum. The in-situ IFB measurement in RICH uses a cw-laser as light source and the IFB rate can only be determined from the ratio of the rates of large and small cluster sizes. For IFB<0.3% the latter method yields $\mathrm{IFB}_{\mathrm{cw}}$ values which are larger by a factor 2.5 as all delays are integrated over. For IFB>0.3% the ratio rises exponentially as the secondary electrons become important.

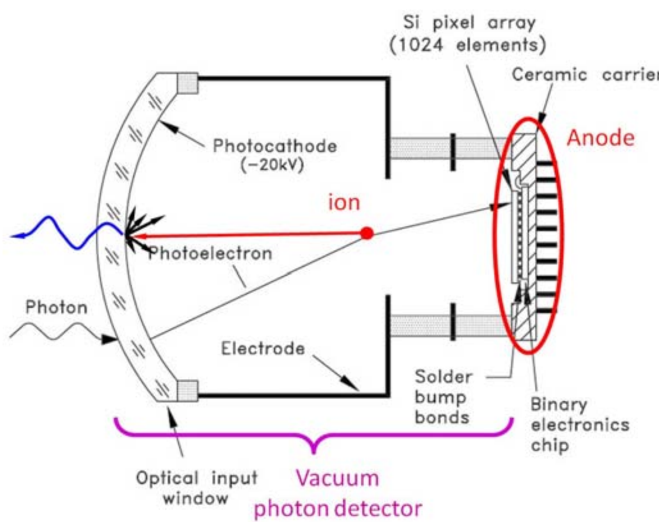

Figure 1: Schematic cut through a HPD showing the principle of Ion Feedback.

If the product of IFB probability and multiplicity of secondary electrons becomes larger than one, the IFB process turns into a self-sustaining cycle and the photon current rises exponentially. In this state a faint continuous blue light emission can be observed at the centre of the photocathode.

The IFB of the RICH HPDs was regularly monitored with cw-laser runs, example data are given in Fig.3. The IFB development for individual HPDs was fitted with a linear model. 80% of the HPD have $\mathrm{IFB}_{\mathrm{cw}} \ll 1\%$ and show $\Delta\mathrm{IFB}_{\mathrm{cw}} < 0.5\%$/year, Fig.4. These will operate well for the lifetime of the LHCb experiment. Negative $\Delta\mathrm{IFB}_{\mathrm{cw}}$

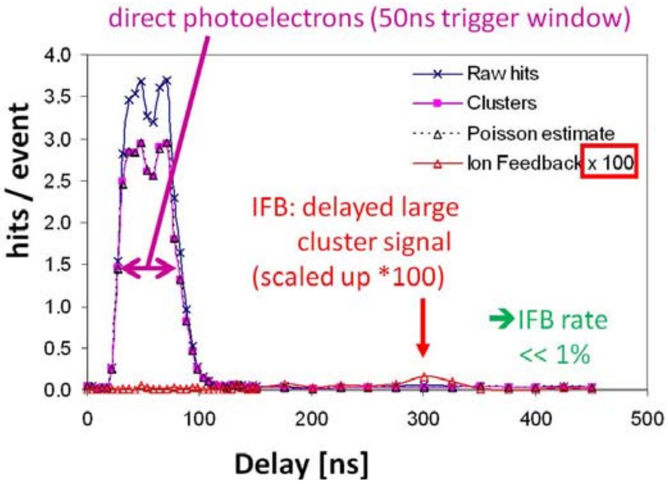

Figure 2: Photoelectron response of a HPD to a pulsed LED light source with varied delay.

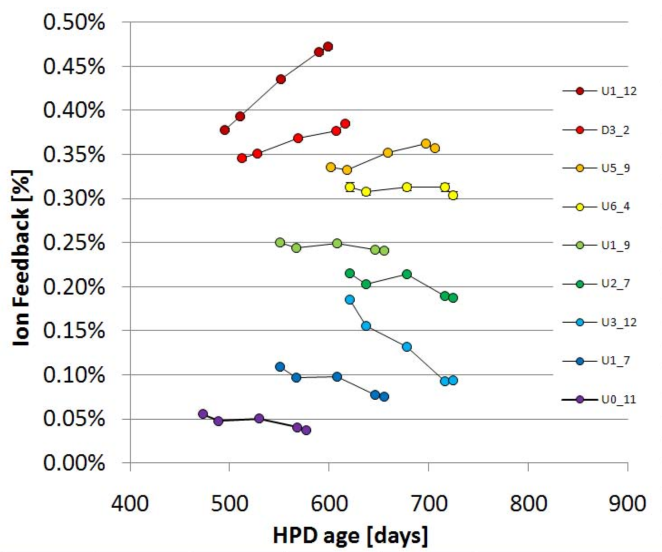

Figure 3: Examples of IFB development for individual HPDs.

occurs as ion-getting from constant illumination reduces the measured IFB proportional to the light level. This may dominate a low intrinsic IFB increase. 20% of the HPD show a faster-than-expected IFB increase. Self-sustaining IFB only turns on beyond $IFB_{cw} = 5\%$, cf. Fig.5. From the fitted ΔIFB_{cw} and the latest IFB measurement the month of passing this threshold can reliably be predicted. HPDs which approach this threshold are replaced in time to guarantee the performance of the RICH detectors at all time during data taking. The repair of these HPDs yields excellent photon detectors again, with low ΔIFB_{cw} values. These are used in subsequent replacements. So far 52 HPDs in the LHCb RICH detectors have been replaced by spare and repaired HPDs. We expect to replace about 55 more HPDs over the next five years.

Since May 2008 the LHCb RICH detectors are fully commissioned and operational. The timing to the beam has

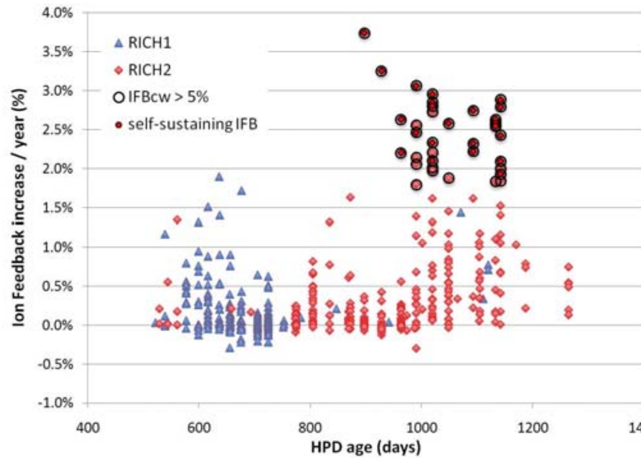

Figure 4: Fitted slopes of IFB development for all RICH HPDs, from 2007/08 data set.

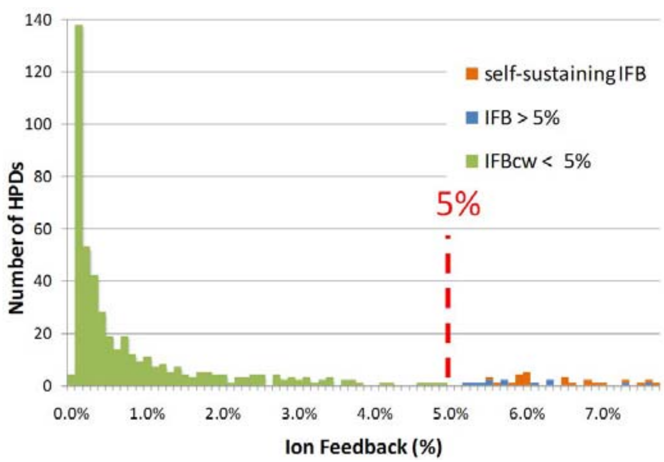

Figure 5: IFB_{cw} status of all HPD in the RICH detectors in 12/2008.

been achieved instantly on 10.09.2008, the first day of the LHC start-up. The photon yield is excellent due to the high Quantum Efficiency of the HPDs, on average 26% larger than expected from pre-production[7]. Overall the LHCb RICH detectors have proven a very good performance and robustness in the operation.

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