Cross Talk Study to the Single Photon Response of a Flat Panel PMT for the RICH Upgrade at LHCb


Abstract—The Ring Imaging Cherenkov (RICH) detector at LHCb is now readout by Hybrid Photon Detectors. In view of its upgrade a possible option is the adoption of the flat panel Photon Multipliers Tubes (PMT). An important issue for the reconstruction of the Cherenkov rings is a negligible level of cross-talk. We have experimentally studied the cross-talk from the 16x16 pixels of the Hamamatsu H9500 PMT. Results have shown that for the single photon response, as expected at LHCb, the statistics tied to the small number of electrons generated at the first dynode of the PMT chain (a few units) leads to a number of cross-talk signals that are a small fraction of the fired pixel. Due to the discrete nature of the electron charge, those few cross-talk signals have amplitude that is a significant fraction of the fired pixel, which is in consequence depelated.

I. INTRODUCTION

The Ring Imaging Cherenkov detector (RICH) at LHCb [1], [2], [3] is now readout by Hybrid Photon Detectors developed in close collaboration with industry. In view of its upgrade a possible option is the adoption of the flat panel Photon Multipliers Tubes (PMT) [4]. An important issue for the reconstruction of the photons produced in the radiator is a negligible level of cross-talk. We have experimentally studied the cross-talk from commercial 16x16 pixels Hamamatsu H9500 PMT.

The Cherenkov signal from the RICH contains about 20 photons, on average, distributed along a ring. Each photon hits a single pixel whose signal gives the signature of the event. The characteristics of the PMT need therefore to be tested for the single photon response. We did such a characterization with a dedicated set-up that will be described in the following, and preliminary results will be also presented.

II. MEASUREMENT SET-UP

The acquisition system adopted for this study was designed and tested for the BTeV experiment. It consists in a monolithic 64 channels [5], [6] front-end chip, VA64MaPMT, developed by Ideas [7].

All the 64 analogue channels are composed by a charge sensitive preamplifier followed by a CR-RC like shaping filter having about 70 ns peaking time. A comparator is AC coupled to this filter. The triggering threshold voltage for the comparator is common to each other comparator of the chip and can be set at an input pin. A fine tuning of the threshold to each channel is possible by means of few bits DAC, one per channel embedded in chip, that is able to add/subtract a current to a resistor, one per channel, in series in the chip to the above pin.

This version of the front-end chip used does not have analog outputs. Only the outputs from the comparators are read as a serial string at a pin.

The digital output from the chip is processed by a FPGA and sent to a PCI board developed at FERMILAB. The set-up dumps, when full, a memory present on the FPGA board filled with the trigger hits from each channel. The memory is written at every given reading-strobe that we set from a few Hz up to tens of KHz. Acquired data had enough tagging information that allowed to perform an accurate off-line analysis.

We studied both the cross-talk and noise. Evaluation of these two parameters was extracted by measuring the rate as a function of the trigger threshold voltage, as will be explained in the next section.

A calibration was done injecting at the preamplifier input a known charge through a test capacitance. In this way the response to a single photon event was available for the study. Fig. 1 shows the threshold voltage, $V_{th}$, as a function of the injected charge. $V_{th}$ was the level for which the frequency of the acquired signals dropped to half maximum. As can be seen the saturation of the input preamplifier is just above 4 MeV (el=electron).

The PMT is a square matrix composed by 16x16 pixels having each one an area of 3x3 mm². To study the cross-talk we selected clusters of 9 pixels: a central pixel and its 8 lateral neighbours, those of which marked with a black dot in Fig. 2 result the most probable to be fired by the fake fraction of the signal. A black plastic mask, 1 cm in thickness, with 256 holes patterned like the pixel matrix, was put in front and in contact with the PMT. We covered all the holes with a black tape except the central pixel of the selected cluster. A commercial 1 mm diameter optical fibre was fitted in the hole in one side and tiny coupled to a blue diode, that simulates the Cherenkov light, on the other side. The diode was biased just above threshold to generate a very small amount of light. The arrangement allowed lighting only the central pixel of the cluster with single-photons signals at a rate of few Hz.

The PMT was put inside a light-tight metallic box. For further precaution a thick black-cloth covered completely the box. Very short shielded connections were used from the PMT to the external of the box where a short high-density flat cable,
having a pitch of 0.64 mm, was connected to the front-end. A fed through 25-pins connector was used on the box. The whole set-up was put inside a Faraday cage.

III. PMT CHARACTERIZATION WITH SINGLE PHOTON

The set-up described in the previous section was exploited not only for cross-talk study but also for evaluating signal response.

The output from the VA64MaPMT is a digital signal that indicates only if the output of the corresponding channel had exceeded the trigger threshold. If we suppose the single photon response having a Gaussian distribution, by fixing the threshold, \( V_{th} \), we count all the signals in the distribution above it, if the frequency of the reading-strobe is greater than the frequency of the events, as was our case. This is equivalent to evaluate the following integral:

\[
F(V_{th}) = \int_{V_{th}}^{\infty} N(V)dv = \int_{0}^{V_{th}} N(V)dv - \int_{V_{th}}^{\infty} N(V)dv
\]

where \( N(V)dv \) is the part of signal that can be found with amplitude between \( V \) and \( V+dV \). Fig. 3 shows the number of counts, or frequency if normalized to the measurement time, as a function of the trigger threshold, expressed in electrons. The curves have been taken at different values of the PMT biasing voltage, which ranged from 750 V to 950 V. The smaller bias level was that having the lower acceptable signal to noise ratio, while at the larger bias we found the limit of the dynamic of our set-up.

![Fig. 3: Frequency of the triggered events from one pixel as a function of the trigger threshold, expressed in Mel, taken at different biasing voltages of the H9500. Fitting was made with (1).](image)

The fitting curve \( F(V_{th}) \) of (1) is superimposed to the data of Fig. 3. In Fig. 4 the Gaussian distributions \( N(V) \) of (1) that fit the corresponding data of Fig. 3 are shown. In the measurements the smaller trigger threshold considered was that just above noise. Table 1 is a summary of the characteristics of the curves of Fig. 4.

![Fig. 4: Example of cluster of pixels readout for cross-talk study.](image)

![Fig. 2: Example of cluster of pixels readout for cross-talk study.](image)

![Fig. 1: Calibration of a typical channel of the VA64MaPMT: the threshold is calibrated vs the input charge expressed in mega-electrons (Me) at the bottom, and in femto-Coulomb (fC) at the top.](image)

### Table 1: Single photon peak position (SP Peak) and resolution (Sigma) of the fitting single photon responses of Fig. 4 vs the PMT Bias voltages.

<table>
<thead>
<tr>
<th>Bias (V)</th>
<th>750</th>
<th>800</th>
<th>850</th>
<th>900</th>
<th>950</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP Peak (Mel)</td>
<td>0.399</td>
<td>0.826</td>
<td>1.500</td>
<td>2.061</td>
<td>2.982</td>
</tr>
<tr>
<td>Sigma (Mel)</td>
<td>0.429</td>
<td>0.638</td>
<td>0.886</td>
<td>1.283</td>
<td>1.735</td>
</tr>
</tbody>
</table>
The output signal has a strong dependence on the PMT bias voltage. This is visible from Table 1 and Fig. 4. In Fig. 5 the response to the single photon is shown as a function of the PMT bias voltage. The fitting curve is:

\[ \text{Charge}_{el} = a + b e^{cV} \]  

(2)

where parameters \(a\), \(b\) and \(c\) are listed in the inset of Fig. 5.

The response curves of Fig. 4 have the mean values consistent with the gain measured for continuous light. The rate of the signals from the LED, biased with a fixed voltage value, remains constant while varying the reading-strobe from a few Hz up to a few tens of KHz, an indication of the absence of pile-up. These considerations prove that the set-up was able to generate and read single photon excitations.

IV. CROSS-TALK STUDY

The statistics that regulates the cross-talk from a single photon response in a PMT must consider the mechanism of generation of the electrons at each dynode.

When a photon enters the quartz window of the PMT a photo-electron is generated at most. This photo-electron is accelerated by an applied field to hit the first dynode. There a few electrons, Poisson distributed with mean at about 3.5 el, are generated. Each of such a new generation of electrons are driven toward a second dynode by the electric field. Each electron will rise a new generation at this second stage. The process continues at each stage of the dynodes chain. 12 stages are present in the H9500 before the final anode collects all the charge. The final gain is in the order of few MeV/photon.

Let’s suppose now that, for reasons tied to very small non-uniformity in the geometry of the dynode-structure and/or electric field applied, while travelling to a dynode an electron had a small probability to change direction toward a lateral dynode. At the end of the chain a cross-talk signal is therefore generated. As first approximation any dynode and any electron have the same probability to undergo this process. Nevertheless, due to the multiplication mechanism described, the first and the second dynode of the chain are those where the largest cross-talk signals are generated. Two situations are possible. In the first case many photons, at the same time, hit the input quartz window at the same pixel position. The model is illustrated in Fig. 7. A similar number of photo-electrons is created, at the first dynode, and generate many secondary electrons, \(K\). If \(p\), \(p<<1\), is the probability that an electron changes its direction while travelling to the following stage of the chain, on the average \(pK\) electrons, with \(pK>1\), travel to lateral pixels generating, at the end of the chain, a cross-talk signal that is \(p\) times smaller than that of the central pixel. This signal is present every time a large number of photons hit the pixel, or every time \(pK>1\).

The situation is different if only one photon hits the pixel, Fig. 8. In this case only \(J\) electrons are generated, with \(J\) a few units, and \(pJ<1\). This means that not all the signals generate...
cross-talk. On average, a cross-talk signal is generated every 1/pJ single-photon events from which, due to the corpuscular nature of the process, for most of the times only one electron fakes generating a cross-talk signal that is a significant fraction of the inducing signal, in a ratio 1/(J-1), that can be 20% to 30% in amplitude. A simulation has been done to validate the model of Fig. 8. In the simulation we oversimplified the system by modelling the electron generations from any hitting electron as an independent random variable with Poisson distribution. We can see in Fig. 10 the distribution of the amplitudes of the cross-talk signals and the inducing signals. As expected, the cross-talk extends in amplitude to a significant fraction of the signals from the central pixel.

We have experimentally verified the statistical model with our set-up. As described in the previous section, we generate single photon signals and collect both the inducing signals and the cross-talk signals. In our study we refer only to those cross-talk events in coincidence with those coming from, or induced from, the central pixel of the cluster, to suppress as much as possible the contribution from noise and dark current.

The probability p of Fig. 7 and Fig. 8 can be appreciated from Fig. 9, where the histogram of the central pixel and the 4 lateral pixels marked with a dot in the cluster example of Fig. 2, are shown when the trigger threshold is set just above noise. From the measurement we can extrapolate for p a value of about 2.9% (the total probability from the 4 lateral pixels is 11.5%).

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under test when biased at 900 V. In Fig. 13 measurements are shown where the percentage of missing signals is in respect of the percentage of cross-talk signals. Results obtained so far do not tell us if advantages are present to work at small or large PMT bias.

The observed statistical effect allows saying that although the cross-talk level for the single photon in the H9500 PMT is not negligible, its probability to occur is small. As an example in the RICH at LHCb a ring contains about 20 photons for which we expect the presence of a cross-talk signal for only a pair of pixels on the average.

![Fig. 11: Cross-talk signals in coincidence with the central single photon signal. Curves superimposed to measured data are only to guide the eyes.](image1)

![Fig. 12: Comparison between measured cross-talk signals and inducing signals.](image2)

### V CONCLUSIONS

Cross-talk from Photon Multipliers Tubes (PMT) has been studied for the single photon response. Results has shown that due to the statistics that regulates the process and the discrete nature of the electron charge cross-talk from a single photon event is present any several hits, having a significant fraction of the signal. This is the consequence of the small number of electrons (a few units) generated at the first dynode of the multiplication chain. We have modelled and verified experimentally this with the commercial Hamamatsu H9500, a 16x16 pixels PMT. For this device we found a fractional rate of cross-talk signals all around the fired pixel that can be 11% under very worst conditions, with fractional amplitude between 20% and 30%.

![Fig. 13: The percentage of missing signals is shown as a function of the maximum percentage of cross-talk signals obtained by modifying the trigger threshold.](image3)

<table>
<thead>
<tr>
<th>Threshold (Mel)</th>
<th># of Cross-talk signals (%)</th>
<th># of missing signals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.474</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>0.805</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>1.217</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td>1.467</td>
<td>0</td>
<td>26</td>
</tr>
</tbody>
</table>

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### REFERENCES