Software Tools for the Analysis of the Photocathode Response of Photomultiplier Vacuum Tubes

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May 7, 2014

Abstract

The central institute of electronics (ZEA-2) in the Forschungszentrum Jülich (FZJ) has developed a system to scan the response of the photocathode of photomultiplier tubes (PMT). The PMT sits tight on a supporting structure, while a blue light emitting diode is moved along its surface by two stepper motors, spanning both the $x$ and $y$ coordinates. All the system is located in a light-tight box made by wood.

A graphical software was developed in-situ to perform the scan operations under different configurations (e.g., the step size of the scan and the number of measurements per point). During each point measurement the current output generated in the vacuum photomultiplier is processed in sequence by a pre-amplifier (mainly to convert the current signal into a voltage signal), an amplifier, and by an ADC module (typically a CAEN N957). The information of the measurement is saved in files at the end of the scan.

Recently, software based on the CERN ROOT and on the Qt libraries was developed to help the user analyzing deeper the data obtained by the scan. The new software, cross-platform due to its build performed inside the Qt-IDE, is described in this note.
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1 Introduction

This note describes how to use the programs designed to analyze the result of the scan of a PMT photocathode (or of a series of scans), which I developed for the Neutron and Gamma Detector Group (Arbeit Gruppe Neutron und Gamma Detektoren) at ZEA-2 in FZJ.

2 The Photocathode Scan Facility at ZEA-2

In the institute of electronics ZEA-2 at FZJ since many years a facility to analyze the performance of PMTs is present and available to external users upon request. In principle, photomultipliers of every size can be accommodated on the scan table inside the light-tight box, Fig. 1. The workshop of the institute can build the suitable support to keep sitting fest any PMT photocathode in front of the moving LED.

The scan is performed remotely by the program DetScan (designed and written by Uwe Clemens, ZEA-2 at FZJ), which drives the stepper motors, and takes care to show either online or offline the intensity (in ADC units) of the measurement in the scanned area of the photocathode, and to save the

![Diagram of the Photocathode Scan Facility](image)

Figure 1: Schematic of the facility available to scan the response of the photocathode surface of PMTs.
measurement data in files on disk. These files can be analyzed by the programs which I recently developed to investigate additional aspects of the photocathode response in a photomultiplier.

The pulse generator is typically set to generate a voltage pulse such to measure enough signal in all the investigated area, without saturating the photomultiplier. The current signal from the PMT is converted into a voltage signal by a pre-amplifier located inside the box, and can be eventually readout via a front panel provided with LEMO connectors with 50 Ohm impedance. The signal is additionally amplified and shaped by the ORTEC amplifier 571, and then sent to the CAEN ADC module N975. The date acquisition can run in auto mode continuously sampling the incoming signals (above a user-defined low-level threshold), and shipping the their peaking amplitude to the DetScan program. Or, a gate, synchronized with the pulse to the LED, can be set to the ADC module. In this latter case the measurement of the pedestal (to be subtracted from the data) is needed, because in some outer regions of the photocathode surface the efficiency of the photo-electron emission could be low enough to have statistically no signal at the device output.

It is clear that increasing the high voltage of the PMT can avoid this problem; on the other side, the region with more efficiency (also referred as gain, i.e., as the number of photo-electrons eventually produced per impinging photon) might generate a large signal to saturate the ADC module.

3 PMT Photocathode Scan:
Analysis of a single Scan Measurement

The PMT_PhotoCathodeScan program (written in C/C++ and based on the CERN ROOT libraries), shown in Fig. 2, processes the data generated during the scan of a PMT photo-cathode by the DetScan program.

To start a measurement the user should select the input data via the button `Browse FileSystem` in the bottom left side of the canvas; the selection allows only to choose one of the *.csv files generated by the DetScan, which saves in these files (in a 128x128 mask) the mean amplitude measured in each scan step. If an error in finding the input file is found, then that error will be prompted in a pop-up window. Instead, if no error appears (e.g. the selected file does exist) the button `Start` will get activated and the data can be analyzed by pressing it.

Note that to access all the information relative to that measurement all the corresponding files dumped by the DetScan program should be present in the same directory, as (among the other ones):
| Variable retrieved                                      | Start and stop time of the measurement          |
|--------------------------------------------------------|-----------------------------------------------|
| *_Info.txt                                             | Temperature (Celsius degree) internal          |
| *_TempIn.txt                                           | to the scan box measured during each scan step |
| *_TempOut.txt                                          | Temperature (Celsius degree) in the laboratory |
| *_PedSpk.txt                                           | measured during each scan step                |
| *_<date:YYYYMMDD>_<time:HHMM>.ph                       | Histogram of the pedestal measurement          |
|                                                       | Timestamp of the measurement                   |

After selecting the data file to process the user has the option to whether subtract the pedestal calculated by the DetScan (in the future it could be calculated directly from its saved spectrum) and to select a lower-level ADC cut. By clicking on the button **Start** the analysis is performed with the selected options. In case a different set of options is needed, then the analysis should be restarted.

The plots showed in the tabs can be saved in external files. This possibility is displayed in the menu option **File**. The default graphic format is png but it

Figure 2: Screenshot at start-up of the GUI to analyze the data provided by the DetScan program. The program is started along with LOG file canvas at its side.
can be changed via the menu option **Options/Config Format for Pictures**. In the same menu item **Options** one can choose whether to show the legends in the plots, and to show the LOG file. At the end of the menu bar the option **Help**
gives the possibility to see the version history of the program and the reference to its author.

The program allows to show several data property in a 2D and 3D visualization with different plotting options, as displayed in the radio-buttons widgets
in the top side of the tabs. In this case there is no need to restart the analysis, but it is sufficient to redraw the histogram with the button **Redraw Histo**. The available options are taken by the ROOT library. For clarification of the way all the ROOT objects used in this program behave please refer to the ROOT documentation [1].

The Tab **2D Histo** shows the x-y gain response of the photo-cathode surface. For every point scanned by the blue-light LED of the scanning system the mean amplitude (as calculated by the DetScan) is shown (eventually with the pedestal subtraction in case this option was required). It is clear, that using the functions of the ROOT classes, specific slides of the surface can be investigated directly from the 2-dimensional histogram of the photocathode response. An example of this measurement is shown in Fig. 3 using the multi-anode 8x8 photomultiplier H8500 from Hamamatsu [3]. Clearly visible is the large non-homogeneous

![Figure 3: Intensity response of the photocathode surface for the H8500 PMT.](image)

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response on the scanned surface. This is a typical behavior observed in PMTs.

The Tab 1D Histo shows the one-dimensional histogram which contains the amplitudes for all x and y bins.

The Tab Relative Deviation shows the entries of the relative deviation with respect to the measured maximum amplitude. Note that, by construction, the relative deviation can vary between null and unity.

The Tab Integrated Counts shows the integrated sum of entries (pixels) with respect to the relative deviation. As an example, this histogram can tell the user what is the fraction of pixels within a relative deviation of value $D$. It is clear that considering that $D$ can range between 0 and 1, then the fractional integral can be at most unity, as shown in Fig. 4 obtained again using the H8500 photomultiplier. Please note that here the term pixel is interpreted not as a real physical pixel in the photocathode surface (as for example in multi-anode PMTs), but as the investigated region during one scan-step.

![Figure 4: Integration of the relative deviation with respect to the maximum amplitude measured in a scanned bin for the H8500 PMT.](image)

In this specific example, within a specific PMT and experimental setup, it appears that 80% of the scanned points have a response lower at least than 30% of the measured maximum.

The Tab Pixel Structure, upper panel of Fig. is very useful to compare the response of different area (of equal size) of the photocathode surface.

The scrollbars in x and y allow to select the area of interest, which can be then divided in sub-pads using the corresponding Number of Pixels in X (Y) entry widgets. When the selection is done, then clicking on the button Analyse...
Figure 5: Top panel: The response of the H8500 multi-anode photomultiplier with a plexi-glass mask on its surface (which results in the observed circular shapes) shows the strong non-homogeneous response of the device. Bottom panel: The scrollbars select the area to be divided in several pixels whose intensity is shown in the corresponding histogram.
"Sub-structures" pops up a new canvas displaying all the selected pads; each pad shows a one-dimensional histogram containing the amplitude value of all scanned points in the corresponding region, bottom panel of Fig. 5.

The variation of the mean value of the displayed histograms shows the gain mismatch in different area of the photocathode surface. In case of a multi-anode PMT, as the H8500, this tool can quantify within few percent of systematical uncertainty the gain mismatch between the independent amplifying channels (properly selecting the area under investigation, and the number of equal-size pixels in $x$ and $y$), thus allowing for its correction by introducing, e.g., adequate resistors in the channels with higher gain.

Moving downward the scrollbar the two buttons Hide Canvas and Dump Results at the bottom of the canvas become visible. They allow, respectively, to iconize the frame, and to dump the results into an ascii file whose path is dumped in the LOG panel. The result file can be eventually used for an offline analysis on the gain-matching. To perform this analysis it is crucial to correctly select the area to investigate by setting the area borders as close as possible to the transition regions between the physical pixels.

4 PMT Scan Systematics:

Stability of the Experimental Apparatus

The stability of the scan measurement is a crucial aspect to monitor, in order to reliably provide the results of a photocathode scan. On this regard, a GUI was developed to analyze a set of measurements performed in the same hardware configuration. This allows to monitor how stable is the measurement (e.g., the mean intensity of the PMT), and in case of any observed instability, to possibly spot a dependence of the measurement on some variables of the system. Please note that the measurements to compare should be performed while keeping the system as much as possible untouched, to avoid introducing a bias in the measurement.

The program PMT_SYSTEMATICS is a GUI with a layout similar to the PMT_PhotoCathodeScan program, above described, and at startup shows up as in Fig. 6 with an additional small canvas dedicated to monitor the LOG activities. To help the user in easily distinguish the two analysis programs (when both are running), a different color (violet) was chosen for the GUI dedicated to systematic studies.

To start the analysis the user should select the input data list via the button Select Input Data List in the bottom left side of the canvas; the selection allows only to choose one *.list file, which contains a list of the *.cvs files generated by the DetScan program. This list should be prepared in advance by the analyzer, and should contain in each line the correct path of a *.cvs file. That location (directory) should also contain all the files generated by the DetScan needed, as for PMT_PhotoCathodeScan program, to retrieve all necessary information for the analysis.
Figure 6: Startup of the PMT_SYSTEMATICS GUI, along with its LOG panel.

If an error in finding the list file or one of the files in the list is encountered, then that error will be dumped in the LOG panel. Instead, if no error appears the button Start will get activated and the data can be analyzed by pressing it.

Also here, after selecting the data file to process the user has the option whether to subtract the pedestal calculated by the DetScan (in the future it could be calculated directly from its spectrum) and to select a lower-level ADC cut. The analysis is performed with the selected options. In case, a different set of options is needed, then the analysis should be restarted.

The plots showed in the tabs can be saved in external files. This possibility is displayed in the menu option File. The default graphic format is png but it can be changed via the menu option Options/Config Format for Pictures. In the same menu item Options one can choose to show the legends in the plots, and to show the LOG file. At the end of the menu bar the option Help gives the possibility to see the version history of the program and the reference to its
Figure 7: Behavior of the mean values of the temperature measured inside and outside the scan box during the series of photocathode scans. for the Hamamatsu R580 (serial number CE3049).

The Tab \( <ADC> \ vs \ Time \) shows the mean amplitude of a scan for the series of measurements inserted in the selected list. The program allows to change the visualization using different plotting options, as displayed in the radio-buttons widgets in the top side of the tabs. In this case there is no need to restart the analysis, but it is sufficient to redraw the histogram with the button \textit{ReDraw Histo}. An example of a series of measurements covering one entire day (on March 2013) is shown in Fig. 7.

The measurements presented here and in the following were performed with
Figure 8: One-dimensional distribution of the mean values of the intensity measured during the series of the photocathode scans.

the photomultiplier Hamamatsu R580 (serial number CE3049). A small trend during the investigated day of approximately 4% is visible, although in most of the measurements the system appears quite stable. The statistical uncertainty of the mean is calculated out of each one-dimensional histogram containing the measured intensity for all scan-points as $\text{RMS/} \sqrt{N_{\text{points of scan}} - 1}$.

The Tab $1D \text{ Histo}$ shows the distribution of all mean values shown in the Tab $(<\text{ADC}> \text{ vs Time})$. For the above mentioned series of measurements the one-dimensional histogram is presented in Fig. 8.

The Tab $<T> \text{ vs Time}$ shows the mean temperature for the same photocathode scans. The temperature is measured inside the scan light-tight box,
Figure 9: Behavior of the mean values of the temperature measured inside and outside the scan box during the series of photocathode scans.

and in the room containing the scanning device. The room is typically kept at a relatively stable temperature by a cooling system. For every scan, during each step of the LED on the photocathode surface the temperature is measured, and the statistical mean of all these measurements characterizes here the presented mean value.

For the considered series of measurements the behavior of the "inner" and "outer" temperature is shown in Fig. 9. A small change of the temperature, in the order of fraction of one degree Celsius, is observed. This tiny change can hardly be considered the source of the observed relative 4% maximum deviation found in the response means.
At the beginning of each photocathode scan the LED is moved by the stepper motors far away from the PMT front-surface. This way, the pedestal of the system is obtained, measuring the signal in the PMT, and can be thus subtracted to the raw data in the offline analysis. Due to the system noise the distribution of the pedestal values (typically 1000 LED pulses are sent) is not a delta function but should typically follow a Gaussian distribution, and a mean value is thus calculated. The Tab $<\text{Ped}>$ vs Time shows the behavior the mean pedestal during the measurements. For the series of measurements here considered as example, Fig. 10 shows a very good stability of the pedestal.
5 Conclusions and Outlook

We have presented in this note new software tools for the analysis of the photocathode response of vacuum photomultipliers (using the data accumulated by the DetScan program already available at ZEA-2). These programs perform a deeper investigation of the PMT data quantifying the level of homogeneity response, with and without the application of a lower level cut and of the pedestal subtraction (when the pedestal has been measured). In addition, in case of multi-anode PMTs the gain mismatch of the individual channels can be investigated, allowing to bring the non-homogeneity within few percents.

This code was already used to investigate the relative gain of several Hamamatsu vacuum photomultipliers R580 during the commissioning of the JUDIDT electronics for an Anger Camera prototype [4].

The program to monitor the stability of the measurement showed a systematical uncertainty of some percents, whose source has not been spotted yet. The blue-light LED system could be a possible source of the observed "long-term" instability.

In principle, the long-term behavior of additional variables, e.g., the system noise, and two-dimensional correlation plots could be added in dedicated tabs, enlarging the control of the measuring system.

A natural extention of this software suite (not possible here due to time constraints) would be the inclusion of an extra GUI dedicated to compare the measurements of different PMTs to investigate the relative gain.

Acknowledgments

The author gratefully acknowledges U. Clemens, R. Engels and C. Wesolek for their valuable technical contribution and suggestions to the work here presented.

References

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