Measurements of Signals from Muons Crossing the Hamamatsu R5912 PMT Enclosure Vertically and Horizontally

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Abstract

Any photo multiplier tube (PMT) operated in the presence of background cosmic ray muons can show multi-photo electron signals due to the interaction of these high energy (around 2 GeV) muons with its glass envelope. The Cherenkov light produced in the glass is converted to photo-electrons (PE) at the photo cathode with high quantum efficiency since the light is predominantly in the UV-blue visible range.

This mechanism is common to all PMTs and the rate of these noise events increases with the PMT surface area. Knowledge of the PMT charge spectrum of this process will allow a subtraction of this background noise in the relevant situations or it can be used as the basis of a monitoring scheme to specifically monitor PMT gains uncoupled from the overall gain of the detector. We report on measurements of this effect for the Hamamatsu R5912 PMT. We have found that muons crossing the PMT vertically produce 40 PEs on average while muon crossing horizontally produce 29 PEs on average. In both cases the most probable values for the rise-times from 10% to 90% of these signals were around 12 ns.

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1 Introduction

Neutrino interactions in the Angra Experiment [1] will be detected by means of photo multiplier tubes surrounding the active volume of the detector. Cosmic ray muons crossing the active volume constitute the main background to the relatively rare neutrino interactions. In addition to interacting with the active volume, muons can also produce signals due to their interaction with the glass envelope of the PMTs through Cherenkov and possibly transition radiation processes. It is therefore important to have a good knowledge of the charge spectrum due to these effects. This knowledge will allow a possible subtraction of this background noise in the relevant situations or, at the same time, it can be used as the basis of a monitoring scheme of PMT gains. The PMT Hamamatsu R5912 [2] is among the candidate PMTs to be used for the Angra detector [1].

The background of single muons from the natural flux of secondary cosmic rays, arriving at a rate of $1min^{-1}cm^{-2}$ [3], was used to study the integrated charge and rise-time of the PMT signals produced by muons crossing the PMT near vertically and near horizontally. We use the result reported elsewhere [4] on the measurement of the gain of the Hamamatsu PMT by using an LED flasher to convert charge into number of PEs.

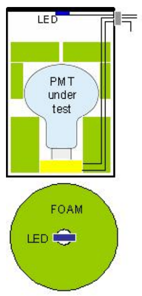

Figure 1: Schematic view of the Hamamatsu R5912 PMT placed inside the dark chamber (the LED was not used for the results reported in this note).

2 Experimental Setup

The experimental setup resembled closely that described in [4]. It consisted of a single R5912 PMT placed inside a sealed cylindrical chamber. The dark chamber consisted of a PVC tube with a thickness of 3mm, an internal diameter of 300mm and a height of 400 mm with PVC covers [5]. Figure 1 shows the way in which the Hamamatsu R5912 PMT was placed inside the chamber, except that the LED was not used in this case. The L-shaped bottom is glued to the cylindrical tube while the L-shaped top cover is movable. The tube and covers are internally painted with black seal and externally covered with aluminum foil, totally involving the borders to improve light-tightness and electromagnetic shielding. This tube is in turn placed inside another cylinder made out of a 2 mm thick aluminum sheet (400 mm by 900 mm with its borders tied together by an aluminum profile), with two aluminum covers also 2 mm thick, Three rods with hexagonal nuts were used to press the aluminum covers against the cylinder, this structure serves as a Faraday cage to provide electromagnetic shielding in addition to reinforcing light-tightness.

Figure 2: Photograph of the experimental setup showing the dark chamber in a horizontal position with the scintillation paddle on top of it (upper left corner), the HV power supply, the digital oscilloscope (Tektronix TDS1012B) and the PC monitor.

The background of single muons from the natural flux of secondary cosmic rays, arriving at a rate of $1min^{-1}cm^{-2}$ [3], was used to study the PMT signals produced by muons crossing the PMT near vertically and near horizontally. The trigger signal was obtained from a scintillation paddle (with active scintillation area of 10 cm by 15 cm) placed on top of the dark chamber. Two different positions of the chamber were used, one vertical and the other horizontal. Since muons are not vertical but have an angular distribution given approximately by $cos^2\theta$, the muon missed the R5912 PMT on many triggered events for which the PMT trace was simply black current. Figure 2 shows a photograph of the experimental setup for horizontal muons, it includes the dark chamber placed in horizontal position with the PMT inside and the scintillation paddle on top (upper left corner), the HV power supply, the digital oscilloscope and the PC. The oscilloscope used was a Tektronix TDS 1012B [6] connected to a PC through a USB port. The PMT traces of all triggered events were immediately transferred into the PC by means of a data acquisition program written in LabView [7].

Figure 3 shows a snapshot of the front panel of the LabView program used to measure off-line the charge, amplitude and rise-times of the PMT traces previously recorded onto the PC's hard disk, it displays a typical event corresponding to a muon crossing the PMT in a near vertical direction. The upper curve is the trace of the Hamamatsu R5912 PMT and the lower one its integrated charge. Likewise, Figure 4 displays the signal produced by a muon crossing the PMT in a near horizontal direction.

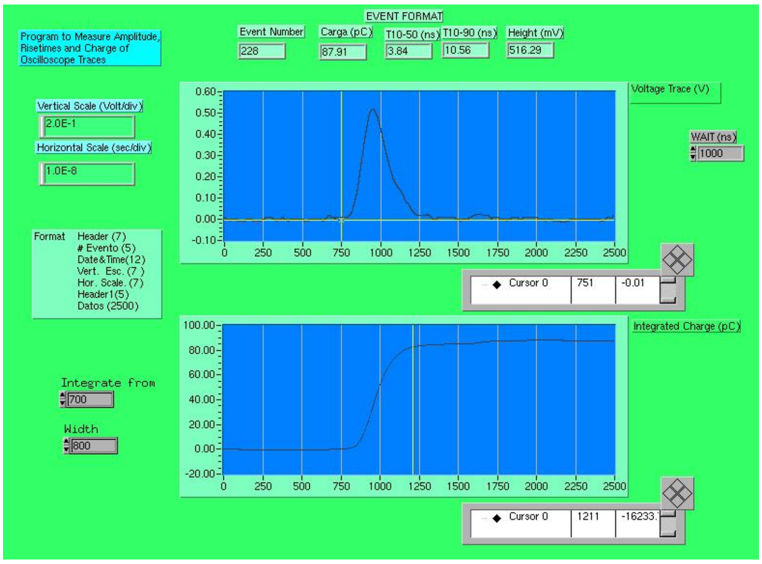

Figure 3: Typical event corresponding to a muon crossing the PMT in a near vertical direction. The upper curve is the trace of the Hamamatsu R5912 PMT and the lower one the integrated charge. The horizontal scale of the oscilloscope was 10 ns/div. The amplitude of the R5912 PMT trace was 516 mV for this particular event.

3 Results and Discussion

Although the maximum data acquisition rate obtained with the USB oscilloscope and the LabView-based DAQ system was around 5 Hz, in this case the acquisition rate was limited by the flux of muons (about 1 $min^{-1}cm^{-2}$ [3]) and the size of the scintillation paddle (about 10 cm by 15 cm). The pulse traces of thousands of events were recorded into the hard disk of a PC. The charge, amplitude and rise-time from 10% to 90% were subsequently measured off-line for every event by using another LabView program. These parameters were analyzed and plotted using the ROOT program [8]. The results we present in this note correspond to a high voltage of 1500 V for the R5912 PMT, however, since we convert the integrated charge to number of photoelectrons, these results are essentially independent of the HV (assuming we are in the linear region of the PMT).

Figure 5 shows the distribution of the integrated charge (expressed in number of photoelectrons) versus rise-time from 10% to 90% for the Hamamatsu R5912 PMT placed vertically below the scintillation paddle. The events clustered around zero charge correspond to the cases where the muons do not produce any signal either because they missed the PMT or because they crossed it through a passive region. Note that there is a clear gap between the region with zero charge and the region around the most probable value for the charge. Figure 6 shows the distribution of integrated PMT charge expressed in PEs. The cut $Q > 7pC$ was done to remove the peak at zero charge. From this plot we see that the charge distribution of Cherenkov radiation produced by muons crossing the PMT in a near vertical direction is asymmetrical, i.e., non Gaussian, with a mean value for the

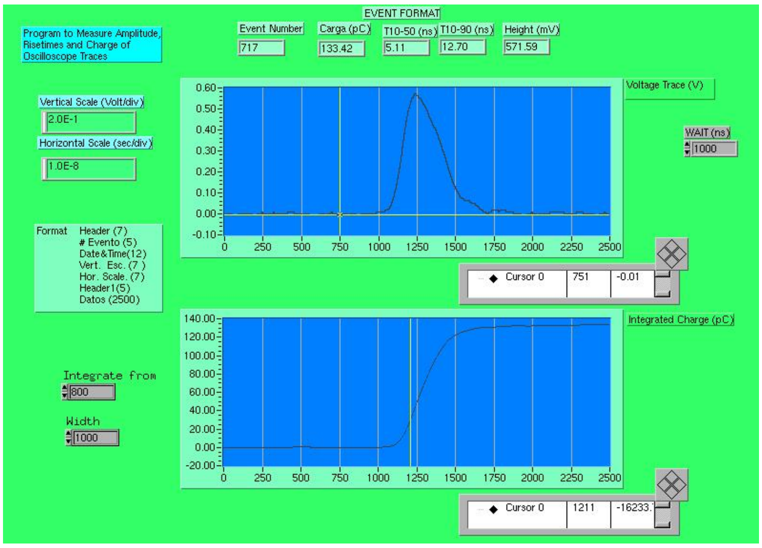

Figure 4: Typical event corresponding to a muon crossing the PMT in a near horizontal direction. The upper curve is the trace of the Hamamatsu R5912 PMT and the lower one the integrated charge. The amplitude of the PMT trace for this event was around 570 mV. The horizontal scale of the oscilloscope was 10 ns/div.

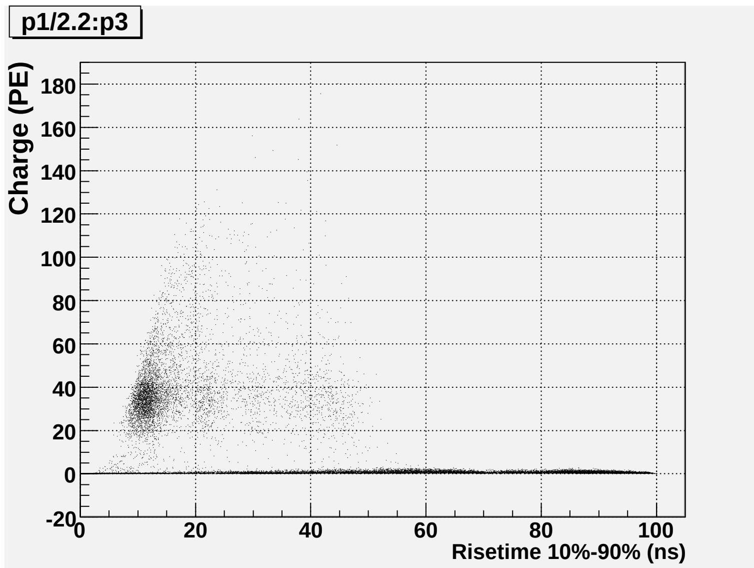

Figure 5: Charge vs rise-time from 10% to 90% for muons crossing the Hamamatsu PMT in a near vertical direction. The integrated PMT charge is given in number of photoelectrons. As described in [4] the PMT gain was 2.2 pC per PE at 1500 V.

number of PEs of 40 and the most probable value of 35 PEs.

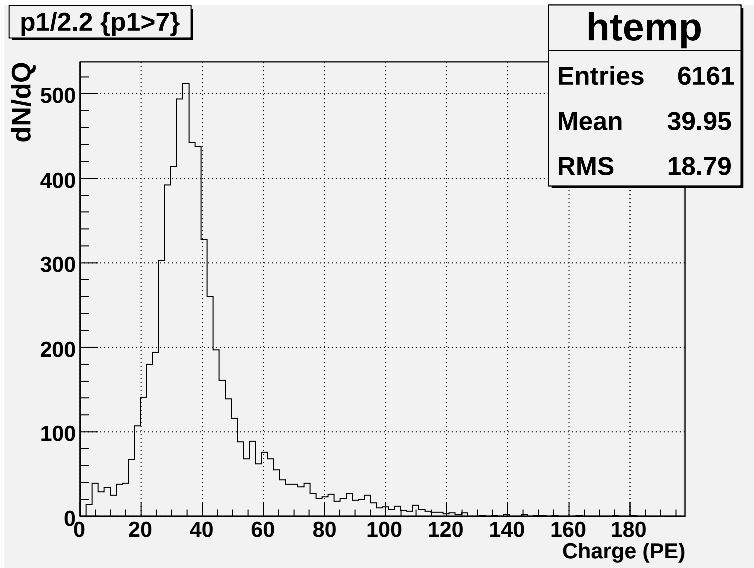

Figure 6: Charge distribution for muons crossing the Hamamatsu PMT in a near vertical direction. The integrated PMT charge is given in number of photoelectrons. The previously measured PMT gain was 2.2 pC per PE at 1500 V.

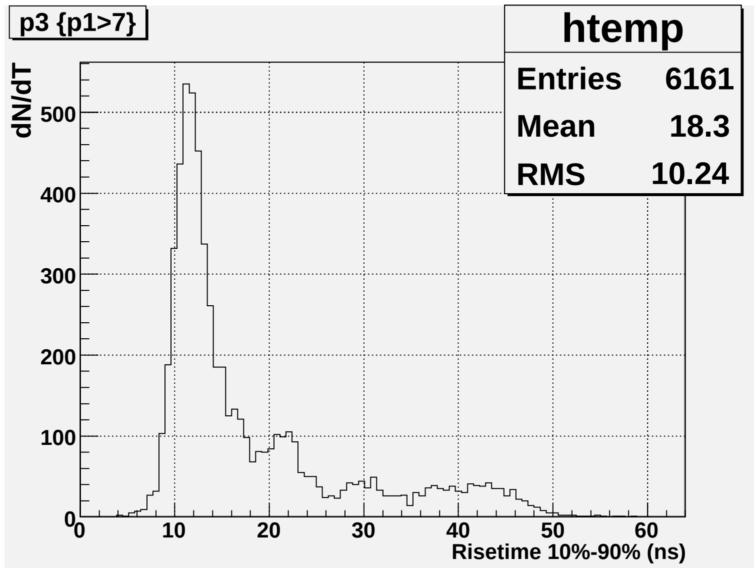

Figure 7: Rise-time from 10% to 90% for muons crossing the Hamamatsu PMT in a near vertical direction.

Figure 7 shows the distribution of rise-time from 10% to 90% for muons crossing the Hamamatsu PMT in a near vertical direction. As in Figure 6, the cut $Q > 7pC$ was merely done to remove the events where the muon missed the PMT or it did not produce any significant signal. The rise-time distribution is very asymmetrical with a mean value of 18 ns and a most probable value of 12 ns.

Figure 8 shows the integrated charge distribution expressed in number of photoelectrons versus the rise-time from 10% to 90% for the Hamamatsu R5912 PMT placed horizontally below the scintillation paddle. The events clustered around zero charge correspond to the cases where the muons that do not produce any signal either because they missed the PMT or because they crossed it through a passive region. Unlike the case where the muons cross the PMT vertically, in this case there is no gap between the the line of zero charge and the region with significant values for the integrated

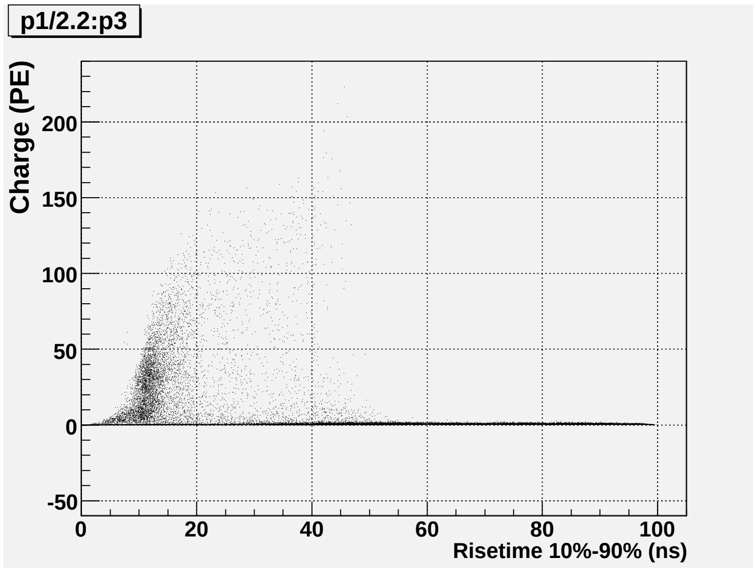

Figure 8: Distribution of integrated charge vs rise-time from 10% to 90% for muons crossing the Hamamatsu PMT in a near horizontal direction. Charge is given in number of photoelectrons. As described in [4] the PMT gain is 2.2 pC per PE at 1500 V.

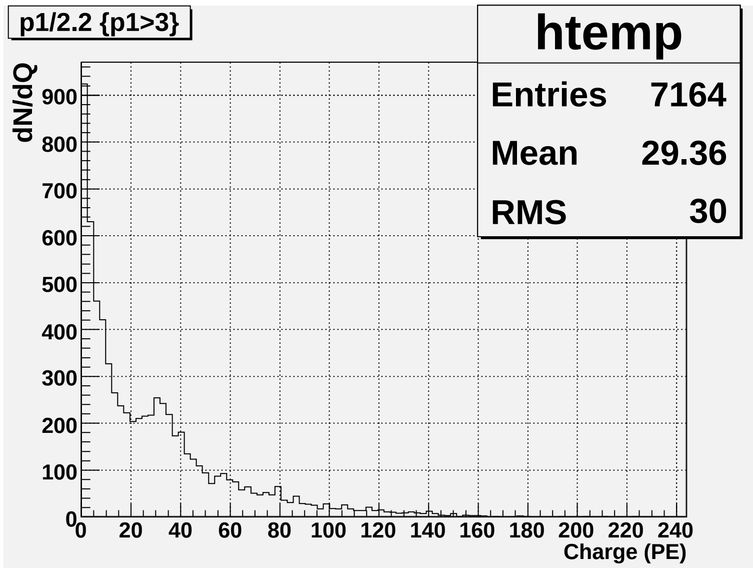

Figure 9: Distribution of the integrated charge for muons crossing the Hamamatsu PMT in a near horizontal direction. Charge is converted to number of photoelectrons.

PMT charge. Figure 9 shows the distribution of integrated PMT charge expressed in PEs. The cut $Q > 3pC$ was merely done to cut out part of the peak at zero charge in order to make more visible the structure of the charge distribution. From this plot we see that the spectrum of Cherenkov radiation signal produced by muons crossing the PMT in a near horizontal direction is clearly different from the case where the muons cross the PMT near vertically. In the horizontal case the most probable value for the integrated charge deposited by muons is near zero, with a second peak at 30 PEs and a mean value of 29 PEs.

Figure 10 shows the distribution of rise-time from 10% to 90% for muons crossing the Hamamatsu PMT in a near horizontal direction. As in Figure 9, the cut $Q > 3pC$ was merely done to remove part of the peak at zero charge. The rise-time distribution is very asymmetrical with a mean value of 21 ns and a most probable value of 16 ns.

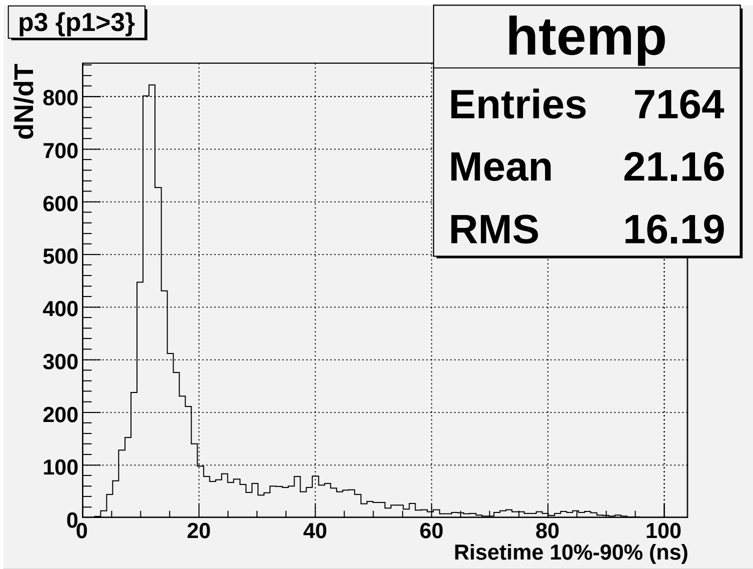

Figure 10: Rise-time from 10 to 90% for muons crossing the Hamamatsu PMT in a near horizontal direction.

At this point it is convenient to point out that the most probable value for the rise-time from 10% to 90% for single photoelectrons for the same Hamamatsu R5912 PMT operated at the same 1500 V were measured, see [4], and presented a most probable value of around 10 ns.

4 Conclusions

We have reported on measurements of the charge spectrum due to the interaction of cosmic ray muons with the glass envelope of the Hamamatsu R5912 PMT. The quantitative knowledge of this effect is important for at least two reasons: it allows a subtraction of this background noise in the relevant situations, and it can be used as the basis of a monitoring scheme to specifically monitor PMT gains. The mean number of PEs produced by vertically crossing muons was 40. The charge distribution obtained was Gaussian-like with long tails (more similar to a Landau distribution). The non-Gaussian distribution measured for the rise-time from 10% to 90% showed a mean value of 18 ns, a most probable value of 12 ns and a long tail for higher values.

In the case of horizontal muons, the charge distribution consisted on two different distributions superimposed: a Gaussian-like centered around 33 PEs and an exponential-like one as shown in Figure 9. These different charge distributions might indicate two main physical processes to produce the signals. The mean number of PEs produced by horizontally crossing muons was 29, i.e., in contrast with 40 for vertical muons. The non-Gaussian distribution measured for the rise-time from 10% to 90% showed a mean value of 21 ns with a most probable value of 12 ns.

References

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