IMTC 2004 - Instrumentation and Measurement
Technology Conference
Como, Italy, May 18–20, 2004

Selection and Testing of 2000 Photomultiplier Tubes for the CMS-HF Forward Calorimeter

E. Gülmez[1], U. Akgun[2], E.W.Anderson[4], A.S.Ayan[2], P.Bruecken[2], F.Duru[2], A.Mestvirishvili[2], M.Miller[2], J.Olson[2], Y.Onel[2], I.Schmidt[2], and D.Winn[3]

[1] Department of Physics, Bogazici University, Bebek, Istanbul 34342, Turkey
Phone: +90 212 3581540 ext:1630, Fax: +90 212 287 2466, E–mail: gulmez@boun.edu.tr.

[2] Department of Physics and Astronomy, The University of Iowa, Iowa City, IA 52242, USA

[3] Department of Physics, Fairfield University, Fairfield, CT 06430, USA

[4] Department of Physics, Iowa State University, Ames, IA 50011, USA

Abstract *– The CMS-HF Forward Calorimeter has specific requirements for the construction and the operation of the detector. The phototubes suggested by several manufacturers were tested and Hamamatsu R7525HA photomultiplier tube conformed best to these requirements. About 2000 PMTs were needed in the HF calorimeter. The timing, dark current, and relative gain values of these 2000 phototubes were measured and organized into a database. Single photoelectron spectrum resolution, absolute gain versus high voltage, and the lifetime were measured on a small sample. Except a few phototubes with unacceptably high dark currents, all the tubes were well within the specifications.*

Keywords *– photomultiplier, calorimetry, high energy physics experiment, Cherenkov light, PMT dark current, PMT absolute gain, relative gain.*

I. INTRODUCTION

The HF Forward Calorimeter is designed to be sensitive over a pseudorapidity region from three to five. This is very helpful for the detection and clear identification of heavy higgs and the SUSY searches in the CMS experiment at the new LHC facility at CERN.

There are two HF Forward Calorimeter units at each end of the CMS. Each unit has an active radius of 1.4 m and consists of iron absorbers, fibers, and phototubes. Very high energy particles passing through the iron absorber produce a shower of particles. Relativistic particles in these showers generate Cherenkov light when they traverse through the quartz fibers in the calorimeter. This Cherenkov light is then transmitted by the fiber onto the phototubes. The energy of the primary particle can be determined by collecting all the light generated in the fibers and converting it to an appropriate signal.

Phototubes that convert the Cherenkov light into electrical pulses will play an important role in the performance of the calorimeter. Selecting the optimum photomultiplier tubes that will perform best under the LHC conditions and obtaining the relevant information for all the tubes are crucial for the reliable operation of the calorimeter.

II. SELECTION PROCESS

The overall design of the CMS detector and the HF Forward Calorimeter defines the specifications of the phototubes that are needed in the HF Forward Calorimeter. LHC parameters put additional constraints on the phototubes. Overall requirements for the phototubes by the HF calorimeter concerning the physical specifications of the phototubes, such as having a borosilicate glass window, 22-28 mm head-on effective photocathode diameter, more than 15% quantum efficiency over 400 to 500 nm light wavelength range, a photocathode that can operate over an accumulated charge of 200mC, and an opaque and HV conductive coating, were met by the manufacturers when they made their suggestions.

There were additional requirements concerning the operational specifications of the phototubes. The CMS-HF Forward Calorimeter requires that the PMTs have spatial uniformity within 20%, 10^4 to 10^5 current gain at 75% of its maximum HV, 50% or better single photoelectron resolution defined as rms/mean, and less than 2nA dark current. They should be fast enough to provide less than 15ns FWHM pulse width, less than 25ns transit time with a maximum spread of 2 ns, and less than 5ns rise time. They should also operate up to an accumulated charge output of 1500 C within their specifications.

There were five PMT types suggested by the manufacturers. These candidate PMTs were R7525HA by Hamamatsu, XP3182 and XP2960 by Photonis, and D843WSB and D844WSB by Electron Tubes.

These candidate tubes were tested under the same conditions for their performances. All the measurements were done at the University of Iowa PMT test station developed for the eventual measurement and quality check of all the tubes prior to the installation in the calorimeter. The measurements were especially designed to compare the candidate tubes for their

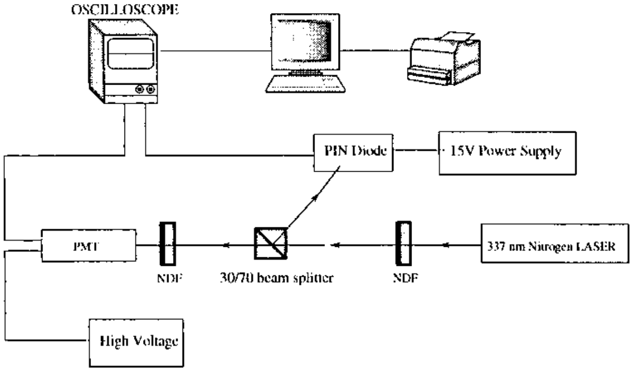

Fig. 1. Test setup for timing measurements.

compliance with the HF Forward Calorimeter requirements related to the operational specifications.

The University of Iowa PMT Test Station comprised of three setups: timing measurements, gain and dark current measurements, and lifetime measurements. All the measurements were carried out in light-tight dark boxes.

We used a 337nm pulsed laser to measure the timing characteristics[1], [2] of the PMTs. The light pulses from the laser were first directed onto a beam-splitter. Then the reflected light went onto a PIN diode to provide the trigger for the measuring system. PIN diode signal also provided the reference time for some of the measurements. The transmitted light continued onto the phototube. A digital oscilloscope was used to acquire the data (Fig.1). Single photoelectron spectra were also taken with this setup with some modifications. (A preamplifier and a CAMAC ADC system were added.)

Timing properties of all the candidate tubes were comparable with some minor differences (Fig.2). However, their single photo electron responses showed a big difference. Photonis candidates did not produce a single photo electron spectrum as the other candidates under the same conditions (Fig.3). The Hamamatsu candidate, which conformed best to the HF requirements, was selected by the HF Forward Calorimeter selection committee[3].

III. TESTING OF 2300 PMTS

In the testing phase, all 2000 PMTs to be used in the HF Forward Calorimeter including the spares were tested for quality control. These tests included initial visual inspection of the tubes, measuring their pulse widths, transit times, transit time spreads, rise times, anode dark currents, and relative gains. The results of these measurements were organized into a database for future reference.

Transit time, transit time spread, pulse width, rise time, and dark current measurements yield very narrow distributions. Average transit time is 15.5ns with a standard deviation of 0.2ns. Average transit time spread is 0.15±0.04ns. Similar to

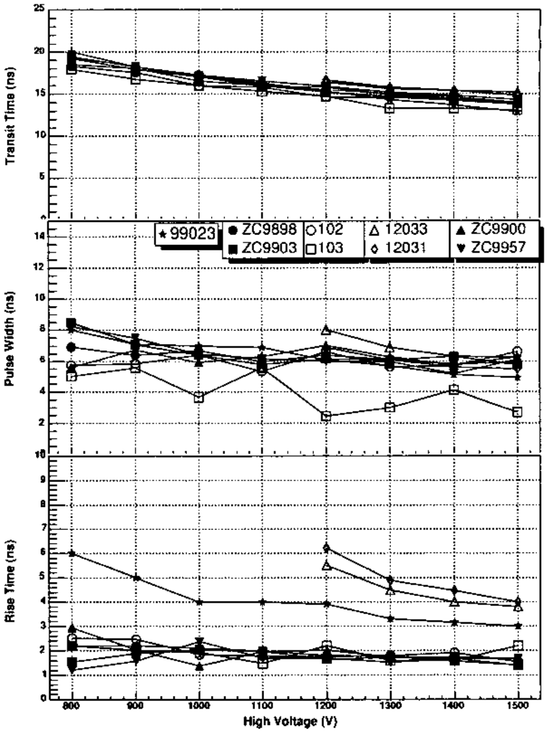

Fig. 2. Timing characteristics of the candidate PMTs as a function of high voltage.

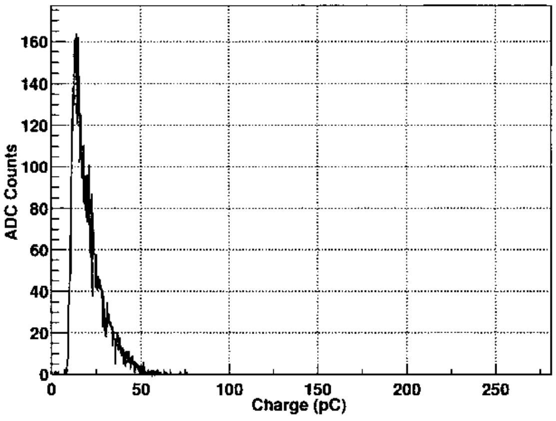

Fig. 3. Single photoelectron spectrum measurement of Photonis XP3182/D1 at 10^6 gain did not produce a standard spectrum as the others.

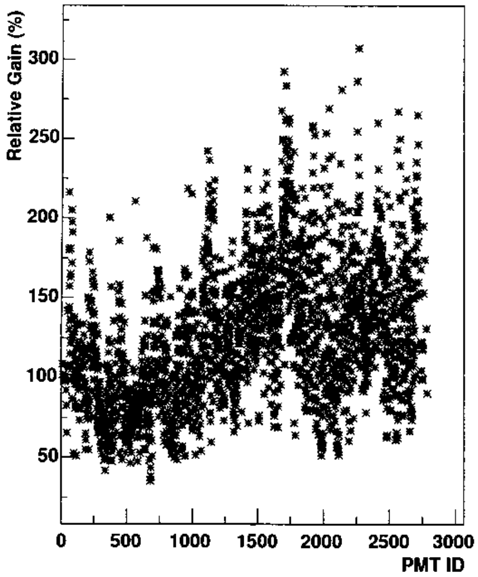

Fig. 4. Relative gain as a function of production time. (PMT ID is correlated to the production time.)

transit time, rise time and pulse width values are also well below the requirements. The average for the FWHM pulse width is 4.0 ± 0.4ns and the rise time is 2.1 ± 0.2ns. Since the time between two successive pulses is 25ns, having a shorter transit time and pulse width combination reduces the pile-up. Also, comparatively small standard deviations show that the values for all the tubes are almost the same.

Almost all the phototubes have dark current values below 0.2nA which is well below the 2-nA limit in the HF requirements.

In the case of dark current, absolute current gain, and relative gain measurements, a simple tungsten light bulb was used and anode currents were measured with a picoammeter. A constant voltage was applied to the light bulb and to change the intensity of the light falling onto the photomultiplier tube, neutral density filters were used. The setup was placed in the second dark box.

Current gains were determined by measuring the cathode and anode currents for the same light intensity and calculating the ratio as a function of the high voltage applied on the PMT. On the other hand, relative gains were determined by placing a reference PMT and seven other PMTs next to each other in the second dark box with a light intensity uniform to 2%. Relative gain of a PMT was defined as the percentage ratio between its anode current and the anode current of the reference tube.

Relative gain values vary from 50 to 200 percent (Fig.4). Such a wide distribution is partly due to the slow shift during the production. Another reason is the fact that the relative gain measurements that we have done actually measure a combination of relative gain and relative quantum efficiency of the photocathode.

In addition to these timing, relative gain, and dark current measurements, single photoelectron resolution, absolute gains, and lifetime of the tubes were determined for a small number of PMTs. Average single phoelectron resolution was about 40% in terms of rms/mean for the single photoelectron peak.

Lifetime of a tube was defined as the amount of accumulated charge passing through the anode until the current gain reduces by half. A few PMTs were burned in the third dark box to estimate how long they would be able to sustain their nominal characteristics, especially their gain. The lifetime value varies as a function of the high voltage applied on the tube. At our operating HV of 1100V, the PMTs selected for this test resulted in more than 3200C which is more than twice the amount required by the HF calorimeter.

IV. CONCLUSION

Hamamatsu R7525HA PMT was chosen for the CMS-HF Forward Calorimeter and all 2000 tubes purchased went through complete timing, dark current, and relative gain tests. Relative gain values are especially important for the energy calibration of the Calorimeter, since all the PMTs will be divided into groups with similar relative gains and the high voltage for all the PMTs in a group will be the same. Only 20 tubes were rejected due to high dark currents (over 2nA).

ACKNOWLEDGEMENT

We would like to thank our colleagues from CMS, in particular Peter Bruecken, John Elias, Jim Freeman, Dan Green, Mithat Kaya, Claudio Rivetta, and Andris Skuja for their encouragement and support. We have appreciated the efforts of the manufacturer Hamamatsu, for producing such high quality PMTs. This work was supported by the US Department of Energy (DE-FG02-91ER-40664), NSF (NSF-INT-98-20258), and the Scientific and Technical Research Council of Turkey (TÜBITAK). We also thank the University of Iowa, Office of Vice-President of research for their support. One of us (E. Gülmez) would like to thank the Bogazici University Foundation and the Bogazici University Research Fund for their support for attending the conference.

REFERENCES

[1] Philips Photonics, *Photomultiplier Tubes, Principles and Applications*, Philips France, 1994.

[2] Hamamatsu Photonics K.K. Editorial Committee, *Photomultiplier Tubes, Basics and Applications*, Hamamatsu Photonics K.K., 1999.

[3] U.Akgun, et al., *Comparison of PMTs from three different manufacturers for the CMS-HF Forward Calorimeter*, CMS Note-2003/029, 2003.