CDF/PUB/CALORIMETRY/CDFR/4420
Version 1.3
Jan. 19th, 1997

TEST ON 2,000 PHOTOMULTIPLIERS FOR THE CDF ENDPLUG CALORIMETER UPGRADE

I. FIORI [a]

Dipartimento di Fisica dell'Universitá and INFN Bologna
Viale Berti Pichat 6/2, I-40125 Bologna
E-mail: fiori@fnal.gov

for the CDF Plug Upgrade Group

Abstract

A systematic test of various characteristics, such as gain, dark current, maximum peak current, stability and relative quantum efficiency, has been made to evaluate about 2,000 photomultiplier tubes (PMTs) for the upgraded CDF Endplug calorimeters. The PMTs are Hamamatsu Mod. R4125, 19mm diameter with green-extended photocathode. In this report we discuss the distribution of the major characteristics measured and the failure modes. Comparisons between independent measurements made on some of the characteristics are used to evaluate the quality of the measurements themselves.

[a] Talk given at the VIIth Int. Conf. on Calorimetry in HEP, Tucson AZ, Nov.10-15 1997.

1 Introduction

The upgraded Endplug calorimeters for the CDF experiment [1] use as active elements scintillator tiles with embedded WLS fibers (Y11) spliced to clear optical fibers at the tile exit. The calorimeters are segmented into projecting towers pointing at polar angles ranging from $\theta = 37°$ to $3°$ (η from 1.1 to 3.6) measured from the beam line. The electromagnetic (EM) and Hadronic (HAD) sections have similar geometry and are read out separetely. One photomultiplier tube (PMT) is optically coupled (through a plexiglass light mixer) to the fiber bundle from each tower (EM or HAD), thus integrating the light signals ($\lambda_{peak} = 480nm$) from the 22 tiles in the tower. The phototubes are housed in some temperature-controlled boxes placed on the rear of the detectors. A total of 960 phototubes for the EM sections plus 846 for the HAD sections is needed.

2 Physics Requirements

The operating parameters of the CDF experiment for the next run ($\mathcal{L} = 2 \times 10^{32} cm^{-2} s^{-1}$, beam crossing time as low as $132ns$, $E_{cm} = 2TeV$, $\int \mathcal{L} \simeq 2fb^{-1}$) translate into physics requirements that constrain our phototube specifications. For the highest η towers we expect [b]:

- a maximum energy deposit from a single-particle-initiated shower of $770GeV$ for the EM and $600GeV$ for the HAD, which translates into maximum peak currents of $55mA$ and $35mA$ respectively when the phototubes are operated at the nominal gains of 2.5×10^4 (EM) and 2.5×10^5 (HAD);
- an energy flow due to the underlying event of $250MeV$/interaction in the HAD and $120MeV$/interaction in the EM, which produces a quasi-DC background current of about $1\mu A$ out of each PMT (almost the same for the EM and HAD);
- a total accumulated anode charge of about 10 C.

3 Phototube Choice

After comparative tests on small samples of several candidate phototubes, [2] we chose the *Hamamatsu R4125* as the one which best fulfilled our overall requirements. The R4125 is a 10-stages tube with a $19mm$ outer diameter. It has a $15mm$ diameter green-extended bialkali photocathode with a certified quantum efficiency of 12% at $\lambda = 480nm$. In the preliminary tests it showed

[b] Calculations are based on extrapolation of the tower energy deposits from the previous CDF run, the design values for the number of photoelectrons/GeV/tile, and the shape of the PMT signal. Recent test beam results yield slightly lower values for these parameters.

good photocatode uniformity (close to 20%) and behaved well in the lifetime test (the decrease of response for 100C of integrated charge being 12% on average). Bases of resistive chain type where designed at Fermilab and built by Thorn EMI Corporation.

4 Test Procedure

A total of 2,100 R4125 PMTs were purchased. For each one the vendor provided us with a measurement of the voltage and the dark current for a nominal gain of 500K and both the cathode blue and luminous sensitivity.
In our laboratories each PMT underwent a full test procedure consisting of two phases called the "initial test" and the "final test". The "initial test" phase was performed at Fermilab for all of the tubes, and the "final test" was performed at one of two test sites whit identical test setups: INFN lab. Bologna-Italy (820 tubes) and Fermilab (1280 tubes). For the "initial test" each tube/base combination had its Gain vs Voltage behaviour measured, then was conditioned for 48 hours by exposure to a steady-state LED light producing a $2\mu A$ anode current, after which a dark current measurement was made. For the "final test", a number of tests were performed on each tube/base combination: Gain vs Voltage, Dark Current, Linearity, Stability vs Time and Stability vs Background Current Change (in this time sequence). Relative Quantum Efficiency was measured at Fermilab on 10% of the PMTs.

5 Test Setup

Our test setups consist of a light-tight temperature-controlled box that can house up to 30 PMTs for testing. Three kinds of light sources are used to independently excite the PMTs through clear optical fibers: an array of pulsed red LEDs (for the gain measurements), an array of steady-state green LEDs (to provide the background current) and a pulsed UV laser (for the linearity and stability measurements). The laser light, monitored by a PIN diode, is carried to a *cow distributor system* [3] where it is wavelength shifted into green and distributed to the phototubes. In this way the PMTs are tested with light pulses that closely match the real calorimeter signals. Tests are carried on in a quasi-automated way by a PC-controlled CAMAC/NIM DAQ system.

6 Measurements and Results

6.1 Gain vs Voltage

For each PMT the gain was measured with the statistical method [2] at various voltages (from 700V to 1800V in 100V steps). Data points were fitted with a power-law dependence in voltage ($\log G = K + P \times \log V$); the parameters of

the fit allow us to calculate the PMT voltage for any gain.
In fig.1 the voltages for four different gains are plotted for all PMTs. A comparison is made between the two re-measurements done in the initial (all measurement done with the Fermilab setup) and final test (measurements done at Fermilab or Bologna). The distribution of the ratios shows that the overall quality of our measurements is satisfactory having a spread (FWHM/mean) arount unity of about 7%. Our measurements also do correlate well with the voltage values provided by Hamamatsu, the 8% offset being due to a difference in the gain measuring methods used.

6.2 Dark Current

In fig.2 a comparison is made between our initial and final measurements and the vendor measurement of the PMT dark current at a gain of 500K. A decrease in the dark currents of about a factor of two is found between Hamamatsu and our initial measurement probably due to the conditioning and the exercising of the tubes during the tests. Very few tubes fail the specified limit of $5nA$. The final average value for the dark current at a gain of 500K is 0.43 nA.

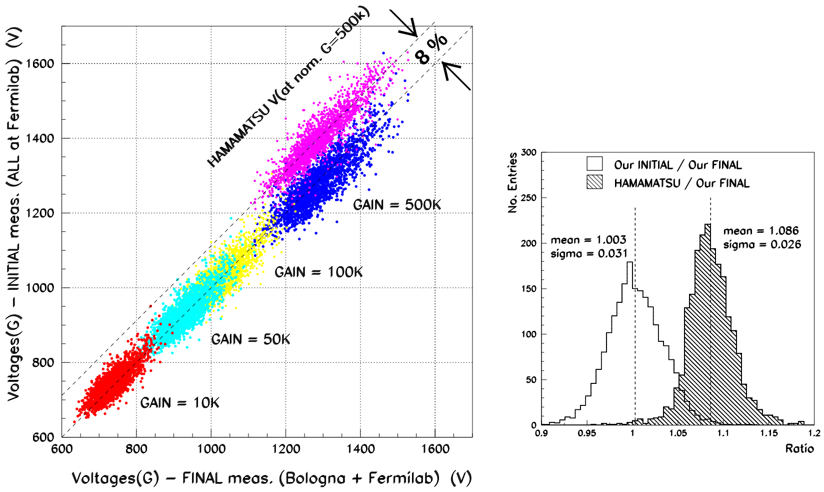

Figure 1: Comparison between independent measurements of all PMT voltages at four different gains.

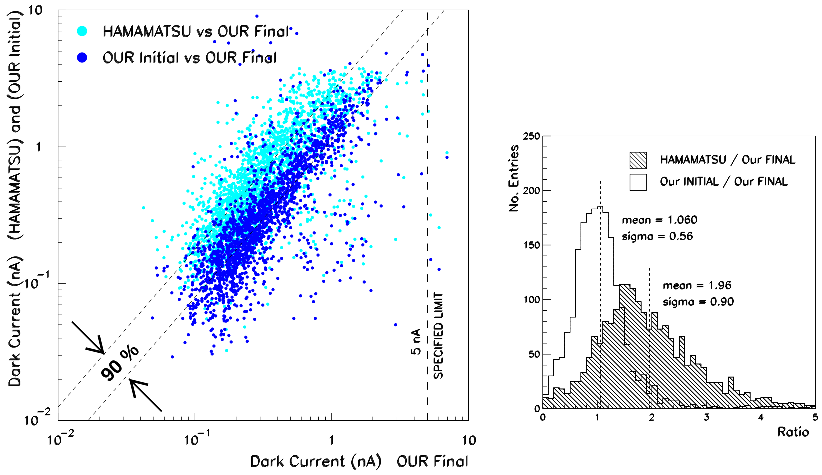

Figure 2: Comparison between independent measurements of all PMT dark currents. The log-log scale emphasizes the small values region where most of the data gather.

6.3 Linearity

The linearity of PMT response with the intensity of the input light signal was measured at four gain values. The figure of merit is the peak anode current that can be reached without causing a 2% deviation from linearity. Results and specified limits for the peak currents are summarized in table 1. At the highest tested gain of 500K, 1.7% of the PMTs failed the test.

Table 1: Linearity test results.

Gain	Peak Curr. Measured Range	for 2% deviation		No. of tubes Rejected	% of tubes Rejected
		Specified Lower Limit	Peak Curr. Mean Value*		
10 K	up to 40 mA	10 mA	16.5 mA	3	0.1
50 K	up to 90 mA	20 mA	44.0 mA	2	0.1
100 K	up to 100 mA	35 mA	74.3 mA	3	0.1
500 K	up to 160 mA	70 mA	93.5 mA	35	1.7

* for tubes that showed > 2% deviation within the measured range (about 50% of total)

Based on these measurements higher linearity PMTs are selected for assignement to higher η calorimeter towers. In fig.3 the maximum peak anode current is converted into energy deposit per tower (for one EM section) using the conversion factor measured at the test beam.

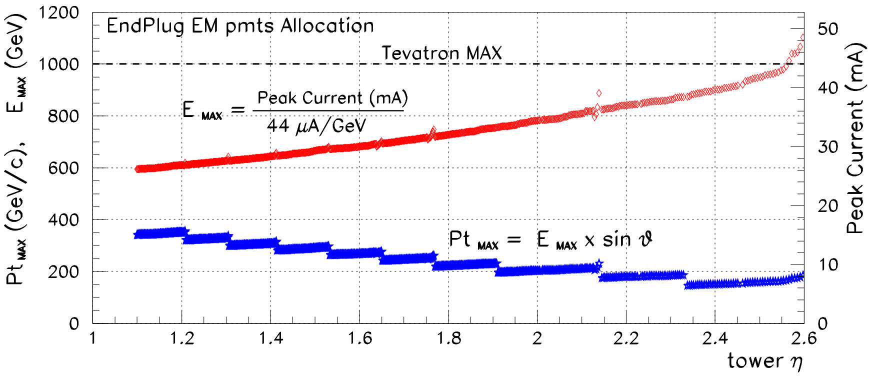

Figure 3: Maximum energy and transverse momentum that can be deposited in each η EM calorimeter tower within 2% from linearity.

6.4 Stability with Time

The variation in the response to pulsed light was measured over a 72-hour period during which the PMTs were also exposed to a steady-state green light to mimic the quasi-DC background current from a minimum bias events. The figure of merit is the maximum percent variation in 48 hours which must be less than 6% (48 hours is the expected maximum duration of a Tevatron store for the next run). On average, the response of the tubes decreases by about 2% over 48 hours. A 2.7% subset of the PMTs failed this test.

6.5 Stability with Background Current Change

We measured the percent shift of the PMT response to pulsed light when the DC background current was changed from zero to about $1\mu A$. This mimics the situation the higher η phototubes will experience at the beginning of a store. About half of the PMT About half of the PMTs showed a positive shift in response (+1.9% on average), and the other half showed a negative shift (-1.3% on average). For 2.3% of the PMTs, the absolute value of the shift was greater than 5%, our specified limit for this test.

6.6 Relative Quantum Efficiency

This measurement was done, for monitoring purposes, on the 3 tubes out of every 30 that had the lowest rated value for the blue cathode sensitivity. We measured the number of photoelectrons produced at the photocathode by electrons from a radioactive source exciting a standard tile/fiber combination, to which the tube was optically coupled in a very reproducible way [2].
In fig.4 we compare our measurements of relative Q.E. with the cathode sensitivity values from Hamamatsu. A good correlation is found (a,c). The cath-

ode blue sensitivity shows little fluctuation with manufacturing date (c). The shapes of the distribution for our measurements and the chatode blue sensitivity (rescaled) are also in good agreement (b). Even though ours is a relative measurement of Q.E., we have actually measured the 23% spread of Q.E. values around the mean.

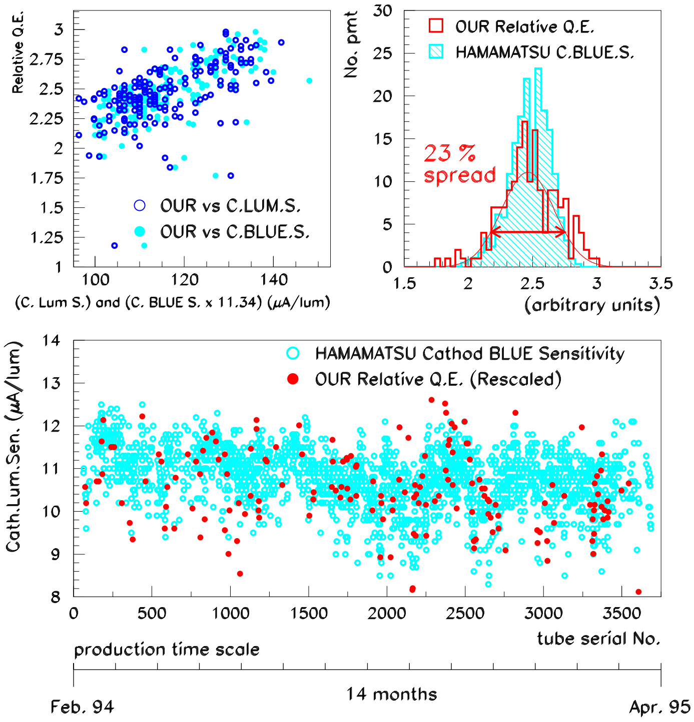

Figure 4: (a) Scatterplot of our relative Q.E. measurements vs Hamamatsu values for Cathode Blue and Lum. Sens. (b) Our Relative Q.E. measurements and Hamamatsu C. Blue S. rescaled with the ratio of the mean values of the two. (c) Hamamatsu C. Blue S. vs manufacturing time with our rescaled Relative Q.E. superimposed.

7 Summary and Conclusions

We have made extensive measurements on 2,100 Hamamatsu R4125 phototubes for the CDF Endplug calorimeters. We have measured the following properties: Gain vs Voltage, Dark Current, Linearity, Stability vs Time and vs Background Current. Some properties were measured twice for each phototube. Results are summarized in tables 1 and 2.

Table 2: Results of Tests other than Linearity.

TEST	Selection Criteria	Specified Limit	Mean Value	N. Rej.	% Rej.
Gain vs Voltage	Voltage spread at G=500K	$< 20\%$	11.5%		
Dark Current	Value at G=500K	< 5nA	.43nA	5	0.2
Stability with Time	% Deviation in 48 hours	$< 6\%$	2.2%	55	2.7
Stab. with Bkg Current	% Shift for $\Delta I_{bkg} = 1\mu A$	$< 5\%$	1.7%	48	2.3

- Those characteristics that were measured twice show good reproducibility.
- Measurements taken at three test sites (Hamamatsu, Bologna, and Fermilab) are well correlated.
- The phototubes show little variation in major properties with manufacturing date.
- A fraction of 7.5% of the phototubes failed at least one of our selection criteria.
- The phototubes that pass all tests have properties that typically are well within our specified limits.

Acknowledgments

I would like to acknowledge the many physicists and technicians both from Fermilab and INFN-Bologna who dedicated their efforts to this work (which lasted approximately four years). M. Mishina, S. Delchamps and S. Zucchelli also deserve thanks for their help in producing this summary report.

References

1. G. Apollinari et al., *CDF Calorimeter Upgrade Project*, Proc. of the IVth Int. Conf. on Calorimetry in HEP (1994), World Scientific 200-225.
2. W. Koska et al., *Evaluation of Candidate Photom. Tubes for the Upgrade of the CDF End Plug Cal.*, FERMILAB-PUB-97/092, Subm. to NIM A.
3. D. Cauz et al., Proc. of the VIth Int. Conf. on Calorimetry in HEP, June 1996, Frascati (Italy).