Test on 2,000 Photomultipliers for the CDF Endplug Calorimeter Upgrade

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for

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OUTLINE

- PHYSICS REQUIREMENTS
- TEST PROCEDURE
- TEST SETUP
- RESULTS
- CONCLUSIONS
Physics Requirements

- $E_{cm} = 2 \text{ TeV}$
- $\mathcal{L} = 2 \times 10^{32} \text{ s}^{-1} \text{cm}^{-2}$
- Integrated ($\mathcal{L}$) = 2 $fb^{-1}$

1. Maximum Energy deposited into a single tower:

<table>
<thead>
<tr>
<th></th>
<th>Max Energy per tower (GeV)</th>
<th>Peak Current (mA)</th>
<th>Nom. Gain</th>
</tr>
</thead>
<tbody>
<tr>
<td>EM</td>
<td>770</td>
<td>55</td>
<td>25K</td>
</tr>
<tr>
<td>HAD</td>
<td>600</td>
<td>35</td>
<td>250K</td>
</tr>
</tbody>
</table>

2. **Maximum** Energy flow per tower (~DC background): $\sim 1 \mu\text{A}$

3. **Maximum** Total integrated energy deposit per tower: $10\mu\text{C}$
Phototube Specifications

- Good Quantum Efficiency at $4.80 \text{nm} (>12\%)$ \( \text{(Y11)} \)
- Photocathode Uniformity $>80\%$
- Gain range: $10^4$ to $10^6$
- spread of Voltages ($G = 10^6$) $< 20\%$
- Linear Response up to 70 mA Peak Current at $G = 500K$
- low Dark Current ($< 5 \text{nA at } G = 500K$)
- Drift of response with time $< 6\%$ in 48 hr
- Shift of response with $\Delta I_{BG} = 1\mu\text{A}$ less than 5\%
- low Temperature dependence
- low Spontaneous Pulse Rate
- Small size
HAMAMATSU mod. R4125

- 10 stages
- green - extended Bialkali photocathode
- 19 mm outer diameter
- 15 mm diameter photocathode
- Base by Thorn EMI
Data from HAMAMATSU

- Voltage for a $G = 500K$
- Dark Current at $G = 500K$
- Cathode Blue (Lum.) Sensitivity

Test Procedure:

"Initial Test" (at FNAL)

- "Conditioning" (2\$\mu\text{A}$ for 48hr at $G=500K$)
- Gain - Voltage curve
- Dark Current

"Full Test" (FNAL or Bologna)

- Gain - Voltage curve
- Dark Current
- Linearity (at 4 Gains)
- Stability in Time
- Stability with BackGround Current
- Relative Q. E. (10% of tubes)
Gain vs. Voltage Test

\[ \log(G) = K + P \log(V) \]

\[ \chi^2 / \text{ndf} = 18.07 / 13 \]

\[ P = -15.86 \pm 0.1204 \]

\[ \Phi_2 = 6.921 \pm 0.3915 \times 10^{-1} \]

S.N. = CX3001
Gain - Voltage: Quality of Production

G = 25K (EM)  
Voltage for G = 25K (Volts)

G = 250K (HAD)  
Voltage for G = 250K (Volts)

No. pmt

11.0 %

11.5 %

For G = 500K (Volts)

Serial. Number

14 MONTHS

Feb. '94

Apr. '95
Dark Current: Quality of Production

HAMAMATSU

OUR Final meas.
Linearity Test

Reject Band $\sigma = 100$

slope = 0.724022
intercept = -12.7426

% Deviation

$-2\%$ dev.
## Linearity Test Results

<table>
<thead>
<tr>
<th>Gain</th>
<th>Peak Current measured range</th>
<th>Specified Lower Limit</th>
<th>Peak Current Mean Value *</th>
<th>No. of Rejected pmts</th>
<th>% Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 K</td>
<td>up to 40 mA</td>
<td>10 mA</td>
<td>16.5 mA</td>
<td>3</td>
<td>0.1 %</td>
</tr>
<tr>
<td>50 K</td>
<td>up to 90 mA</td>
<td>20 mA</td>
<td>44.0 mA</td>
<td>2</td>
<td>0.1 %</td>
</tr>
<tr>
<td>100 K</td>
<td>up to 100 mA</td>
<td>35 mA</td>
<td>74.3 mA</td>
<td>3</td>
<td>0.1 %</td>
</tr>
<tr>
<td>500 K</td>
<td>up to 160 mA</td>
<td>70 mA</td>
<td>93.5 mA</td>
<td>35</td>
<td>1.7 %</td>
</tr>
</tbody>
</table>

* for pmts that show > 2% deviation (about 50% of total)
ENDPLUG E.M.
PMT ALLOCATION

Maximum Reacheable
within 2% from Linearity

$E_{\text{max}}, P_t$

$E_{\text{max}} = \frac{\text{Peak Current (}\mu\text{A)}}{44 \ \mu\text{A on 50 } \Omega / \text{GeV}}$

$P_T_{\text{max}} = E_{\text{max}} \cdot \sin \theta$

$\eta$
Stability in Time

AVG $B_G(nA) = 660.12$
RMS $B_G(nA) = 4.76$

Channel No. = 10
Base No. = 15262

% Max Deviation in 48 hr within 90 hr measurement

- Mean = 2.238
- 6% limit
- 1602
- 43 pmts
- 2.7% failures
Stability vs. B.G. current change

**S.N. = 3269**
- $I_{BG} = 0.0 \ \text{nA}$
- $I_{BG} = 1 \ \mu\text{A}$

**S.N. = 696**
- $I_{BG} = 0.1 \pm 0.01 \ \text{nA}$
- $I_{BG} = 248.4 \pm 42.59 \ \text{nA}$
- $I_{BG} = 1040.9 \pm 178.44 \ \text{nA}$
Stability with B.G.: Quality of Production

54 %
mean = -1.3 %

46 %
mean = 1.9 %

ABS (% Shift)

2028 pmt
5 % limit
2.3 % failures

48 pmt
Relative Q.E.

\[ P(n) = e^{\mu} \cdot \frac{\mu^n}{n!} \]

\[ \mu = N pe \]

\[ \mu = \ln P(0) \]

\[ P(0) = e^{\mu} \]
Relative Q.E. : Quality of Production

23% spread

No. pmt

1.5  2  2.5  3  3.5
(arbitrary units)

C. Lum S. and (C. BLUE S. x 11.34) (μA/lum)

Cathode Lum. Sens. (μA/lum)

Serial Number.
## Summary Table

<table>
<thead>
<tr>
<th>TEST</th>
<th>Selection Criteria</th>
<th>Specified Limit</th>
<th>Mean Value</th>
<th>No. of Rejected</th>
<th>% of Rejected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gain Voltage</td>
<td>V. spread at $G = 500$ K</td>
<td>$&lt; 20%$</td>
<td>$\sim 11 %$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dark Current</td>
<td>D.C. at $G = 500$ K</td>
<td>$&lt; 5$ nA</td>
<td>0.43 nA</td>
<td>10</td>
<td>0.5 %</td>
</tr>
<tr>
<td>Linearity at $G = 10$ K</td>
<td>Peak Anode Current that gives a 2% dev</td>
<td>$&gt; 10$ mA</td>
<td>16.5 mA</td>
<td>3</td>
<td>0.1 %</td>
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<td>Linearity at $G = 50$ K</td>
<td></td>
<td>$&gt; 20$ mA</td>
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</tr>
<tr>
<td>Stability with Time</td>
<td>% Deviation in 48 hours</td>
<td>$&lt; 6 %$</td>
<td>2.2 %</td>
<td>55</td>
<td>2.7 %</td>
</tr>
<tr>
<td>Stability with bkgr. Current</td>
<td>% Shift for $\Delta I_{BG} = 1 \mu A$</td>
<td>$&lt; 5 %$</td>
<td>1.7 %</td>
<td>48</td>
<td>2.3 %</td>
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</tbody>
</table>

Total of Rejected $= 156$ / out of $2085$ $= 7.5 \%$
Conclusions

- We have made extensive measurements on 2085 (Hamamatsu R4125) phototubes for the CDF Endplug Calorimeter: 960 (EM), 846 (HAD)
- We have measured the following properties:
  - Gain vs Voltage
  - Dark Current
  - Linearity
  - Stability vs Time
  - Stability vs background Current
- Some of the properties were measured twice for each phototube
- Measurements taken at three test sites (Hamamatsu, Bologna, Fermilab) are well correlated
- The phototubes show little variation in major properties with manufacturing date
- The Dark Current tends to decrease over time
- 7.5% (156) 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