γ-ray Induced Light Loss in PWO Crystals

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Observations *in situ* at LHC

Yong Yang, Talk in CMS ECAL PFG, November 11, 2010

http://indico.cern.ch/getFile.py/access?contribld=4&resId=1&materialId=slides&confId=113597

Reconstructed $\pi^0$ mass, indicating significant light loss

**Barrel:**
Mean loss at the end of pp running:
-1.3%

**Endcap $|\eta| < 2$:**
Mean loss at the end of pp running:
-3.4%
Is this Degradation Understood?

Recalling earlier observations from Lenny and Sasha we have no doubt observed light loss in PWO crystals. Since we are at $10^{32}$ or two orders of magnitude away from the designed luminosity it is important that we understand the level of light loss in PWO as a function of luminosity.

The following slides are based upon two sets of data measured at the Caltech Crystal lab in the last decade for two batches of PWO crystals produced at BTCP and SIC (two main producers for CMS). Some were presented in a CMS ECAL SLHC Workshop at Fermilab on 11/20/2008. The summary slides were sent this Summer to ECAL colleagues when the ECAL upgrade was in discussion.
Light Loss versus Transmittance

Data measured for 5 CMS endcap size samples (BTCP & SIC) @ 100 and 400 rad/h & recovery


**BTCP-2531**
- Dose rate: 100 rad/h

**SIC-572**
- Dose rate: 100 rad/h

Transmittance @ 440 nm (%)

- LT, irradiation
- LT, recovery
- LO, irradiation
- LO, recovery

Light Output (p.e./MeV)

- LT, irradiation
- LT, recovery
- LO, irradiation
- LO, recovery

Time (hours)
L.O. Loss versus RIAC ($\mu$)

RIAC: radiation induced absorption coefficient

Two exponentials are needed to fit the data

Measured with Cs Source

Cosmic Ray Data
Summary of Light Loss vs. RIAC

<table>
<thead>
<tr>
<th>μ (m&lt;sup&gt;-1&lt;/sup&gt;)</th>
<th>0.2</th>
<th>0.5</th>
<th>1.0</th>
<th>2.0</th>
<th>5.0</th>
<th>10.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTCP-2482</td>
<td>23.7%</td>
<td>43.3%</td>
<td>65.4%</td>
<td>87.2%</td>
<td>99.3%</td>
<td>100.0%</td>
</tr>
<tr>
<td>BTCP-2531</td>
<td>25.0%</td>
<td>46.6%</td>
<td>69.6%</td>
<td>90.2%</td>
<td>96.7%</td>
<td>100.0%</td>
</tr>
<tr>
<td>BTCP-2376</td>
<td>22.4%</td>
<td>44.8%</td>
<td>66.3%</td>
<td>85.9%</td>
<td>98.8%</td>
<td>100.0%</td>
</tr>
<tr>
<td>SIC-570</td>
<td>13.8%</td>
<td>31.1%</td>
<td>52.5%</td>
<td>77.4%</td>
<td>97.6%</td>
<td>99.9%</td>
</tr>
<tr>
<td>SIC-572</td>
<td>17.1%</td>
<td>31.8%</td>
<td>47.7%</td>
<td>68.6%</td>
<td>93.2%</td>
<td>99.5%</td>
</tr>
</tbody>
</table>

BTCP & SIC crystals are self-consistent.
Two groups, however, behave differently.

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Average RIAC fits to 2nd order polynomials of log dose rate.
Large spread of RIAC under high dose rate is noticed.

EM Dose Rate Used in Estimation

Data from CMS ECAL TDR (1996) for LHC of 14 TeV

<table>
<thead>
<tr>
<th>Pseudo rapidity ($\eta$)</th>
<th>0.1</th>
<th>0.8</th>
<th>1.4</th>
<th>1.7</th>
<th>2.1</th>
<th>2.5</th>
<th>2.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>LHC (rad/h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td>6</td>
<td>7</td>
<td>10</td>
<td>17</td>
<td>70</td>
<td>234</td>
<td>826</td>
</tr>
<tr>
<td>Peak</td>
<td>17</td>
<td>19</td>
<td>25</td>
<td>41</td>
<td>160</td>
<td>478</td>
<td>1193</td>
</tr>
<tr>
<td>SLHC (rad/h)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ave</td>
<td>60</td>
<td>70</td>
<td>100</td>
<td>170</td>
<td>700</td>
<td>2340</td>
<td>8260</td>
</tr>
<tr>
<td>Peak</td>
<td>170</td>
<td>190</td>
<td>250</td>
<td>410</td>
<td>1600</td>
<td>4780</td>
<td>11930</td>
</tr>
</tbody>
</table>
Expected LO Loss by EM Dose

Using two parametrizations extracted from data: about 10 and 5% light loss is expected at $10^{33}$ in the barrel because of the EM dose for BTCP and SIC crystals respectively.

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**BTCP PWOs**

**Gamma Induced Light Output Loss**

- 7 TeV, Luminosity $10^{33}$ cm$^{-2}$ s$^{-1}$
- 7 TeV, Luminosity $10^{34}$ cm$^{-2}$ s$^{-1}$
- 7 TeV, Luminosity $10^{35}$ cm$^{-2}$ s$^{-1}$

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**SIC PWOs**

**Gamma Induced Light Output Loss**

- 7 TeV, Luminosity $10^{33}$ cm$^{-2}$ s$^{-1}$
- 7 TeV, Luminosity $10^{34}$ cm$^{-2}$ s$^{-1}$
- 7 TeV, Luminosity $10^{35}$ cm$^{-2}$ s$^{-1}$
Light Loss Expected for BTCP PWO

A few percents are expected in the barrel at a few $10^{32}$, consistent with $\pi^0$ mass data shown on slide 2. More than 10% is expected at $10^{34}$. 
Light Loss Expected for SIC PWO

Should also see a few percents at high eta of endcaps at a few $10^{32}$. 
Effect of Light Loss to Resolution

\[ \sigma_E / E = a / \sqrt{E} \oplus b \oplus c/E, \ E \text{ in GeV} \]

The net effect of light loss to resolution is not dramatic, indicating that we have a working detector before SLHC. Note, the hadron damage induced loss is not included.

Barrel
2.7, 0.55. 16%

Endcaps
5.7, 0.55. 77%

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CMS ECAL SLHC Workshop at Fermilab, Ren-yuan Zhu, Caltech
Summary

- Lead tungstate crystals suffer from radiation damage originated from photons/electrons and hadrons. Data obtained at LHC showed that significant light loss is observed at both the barrel and endcaps.

- Data measured at the Caltech crystal lab are used to parametrizing the expected light loss, which is consistent with the $\gamma$-ray induced light loss.

- Extrapolate to the designed LHC luminosities at $10^{34} 10$ to 60% light loss in average is expected. It is a serious challenge to our monitoring system.

- Next two years will see significant light loss in PWO. Adding the loss due to hadrons will make the whole picture more clear.