Maintenance and Operation for ECAL Monitoring (WBS4.3)

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Status of Monitoring Laser System

WBS4.3 construction is on schedule and cost

- Completed monitoring test bench in 1999, determined the monitoring wavelength at 440 nm.

- 1st laser system installed/commissioned at CERN in August, 2001, and has been used in beam test since.

- 2nd and 3rd lasers and switches are installed/commissioned at CERN in July, 2003, and have been used in beam test.

- M&O starts FY03.
PWO Radiation Damage by $\gamma$–rays

- No damage in scintillation mechanism;
- Damage is caused by radiation induced color center formation and is dose rate dependent.
- Variations of PWO crystal light output may be estimated by monitoring the variations of crystal’s transmittance.
- Monitoring light pulses are sent to crystals in 3 us gaps in every 89 us \textit{in situ} at LHC.
- The design precision of CMS PWO ECAL is expected to be maintained by using the monitoring system.
PWO Radiation Damage (I)

No damage in scintillation mechanism

No damage in resolution if light attenuation length > 1 m
PWO Radiation Damage (II)

Damage and recovery: color center formation
Dose rate dependent: cc creation and annihilation
Monitoring PWO Crystals

Radiation induces color centers
  → reduces transmittance in the blue and green
  → monitoring the relative loss of transmittance with pulsed laser light

Little damage in the red
  → monitor with red and IR laser pulse to separate out possible variations in the other components of the readout chain
Light Monitoring System

Initial calibration on test beam (as much crystals as possible)

Physics calibration *in situ*: $e^+e^-$ pair (resonance) and $e$ ($E/p$)

Monitoring crystal evolution by light injection system

Four wavelengths from laser to be distributed to 80 super-modules, then to 77k PWO.

- 440 nm
- 495 nm
- 709 nm
- 796 nm
Monitoring Wavelength Determination


Δ(T) versus Δ(LY)

Sensitivity and Linearity

→ 440 nm is chosen for the best linearity
Lasers at CERN for PWO Monitoring

The 1st laser system was installed in 2001, and used in 2002 beam test.

The 1st Laser System at Caltech
Tunable Ti:Sapphire & YLF Pumping Lasers
Provide two wavelengths: 440/495 or 709/796 nm
Laser System Control & DAQ

Control: Two Lasers and Monitoring Run Mode

Laser Settings

Laser Waveform Display
History: Laser Pulse Energy & r.m.s.

- Short term r.m.s 1.7%, or 15 uJ.
- Peak to peak variation 15%, corresponding to overall r.m.s. 3.7%.
- Specification: r.m.s. <10%.
- Drifting caused by power supply, temperature.
**History: Laser Pulse FWHM & r.m.s**

- **Short term r.m.s**: 0.38 ns, or 1.6%.
- **Overall r.m.s.**: 0.5 ns, or 2%.
- **Specification**: FWHM < 40 ns.
- **Drifting**: roughly anti-correlated to the pulse energy.
Laser Temperature Dependence

Ti:S Pulse FWHM versus T

No good correlation
→ multiple factors
→ 4%/°C

Ti:S Pulse Energy versus T

Slope = -3.86 ± 0.01 %/°C

Slope = 1.34 ± 0.002 ns/°C

→ 1.3 ns/°C
1st Laser Installed at H4, 2001
Issues: space and environment
New Laser Barracks Design

Double door & air conditioning: safety, environment & non-interrupted operation
New Laser Barracks at H4, 2003

Front View

Back View

Inside View

Chilled Water

Transformers

December 18, 2003
Safety

6 Class 4 Lasers

- Interlocks: 3 inner doors, 3 laser covers, level 2 and calorimeter.
- Maintenance interlock: bypassing inner door and laser cover, adding outer door.
- Emergency stop.
Experiences in Laser M&O

• Four major services at CERN by Quantronix:
  - October 15--16, 2002: a visit for the 1st YLF laser;
  - December 2--6, 2002: a visit/training for the 1st Ti:S laser, replaced a HTIHR mirror and the golden reflector of the puma chamber in YLF;
  - August, 2003, for the 1st laser: phone call to Quantronix, replaced the Q-switch HV generator in Ti:S and the logical unit in YLF power supply.
  - December, 2003, for the 1st laser power supply and transformer: phone call to Quantronix, transformer mailed to CERN. May still need a visit.

• Laser system operates flawlessly in 2003:
  - **Crucial**: daily Communication between CERN technician and Caltech engineers and the spare laser system;
  - Problem in power supply forced to switch the Blue/Green laser on November 9, 2003;
  - Laser aging: replacement optics are needed;
  - Quick switch: 3rd diagnostics and 3 x 1 switch are needed.
2002 Beam Test Data

1st laser system is used
2003 Beam Test Data
All four wavelengths are used

\[
\ln(S) \text{ vs } \ln(R/R_0), \text{ cry 1097}
\]

\[
\begin{array}{c|c|c|c}
\chi^2 / \text{ndf} & 28 / 28 \\
\text{Prob} & 0.4644 \\
p_0 & 8.758 \pm 0.0007701 \\
p_1 & 10.54 \pm 0.3162
\end{array}
\]

0.05%
PWO Resolution With Light Monitoring


Before/after beam irradiation: 10% variation in light output
After seven years R&D and construction, all three laser systems have been installed and commissioned at CERN, and was successfully used in beam test. The entire US CMS WBS 4.3 monitoring construction project is on schedule and cost.

To be constructed: 3rd diagnostics and 3 x 1 switch are crucial for fast laser switching.
Complete Three Laser System
Budget for Laser System M&O

$79.5 k per year, in addition to David Bailleux

- **Quantronix service contract for three lasers:**
  - Originally budgeted $15k/laser/year: a total of $45k/year
  - Quantronix 2003 quotation: $100k for the 1st year and $75k for the 2nd year on, which consists with industrial practice (15% of laser cost/year).
  - Additional cost for equipment not made by Quantronix.
  - **SOLUTION:** use ¼ FTE Caltech engineer for entire system.

- **Manpower:** $34.5k plus cost for David Bailleux.
  - David Bailleux at CERN: shared with other ECAL activities at CERN;
  - Adolf Bornheim at CERN: supported by Caltech base program;
  - Liyuan Zhang and Kejun Zhu at Caltech: a total of ¼ FTE: $34.5k.

- **M&S:** $45k.
  - Optics and consumables: $30k ($10k/laser/year);
  - Caltech/Quantronix services: $9k;
  - Other electronics: $6k.
People Involved in this Effort

No full time person on project, starting 11/03

- Liyuan Zhang: 3/98 – 12/01, 8/02 – 10/03, starting 11/03: 1/4 FTE, share with LIGO;
- Kejun Zhu: 7/99 – 10/01, 3/03 – 8/03;
- Qing Wei: 8/01 – 8/02;
- John Hanson and Larry Mossbarger;
- Duncan Liu of JPL;
- David Bailleux at CERN, starting 8/01, shared with other ECAL activities;
- Adi Bornheim at CERN, starting Fall, 2002, supported by Caltech HEP base program.
PWO Crystal R&D for SLHC

• PWO crystal radiation damage by $\gamma$-rays is well understood (see page 3--5).

• Three main issues for PWO crystal R&D:
  - Current mass-produced crystals are radiation hard enough for an environment of up to a few hundreds rad/h. Further improvement is needed if thousands rad/h is expected at e.g. SLHC.
  - About 5% crystals delivered are type III, which may cause problem for monitoring, so should be eliminated by manufacture.
  - Recent data on PWO crystals irradiated by protons needs to be clarified by doing a low dose hadron irradiation test.

• Budget for PWO R&D: $70k
  - ½ FTE technician: $43k;
  - Use of irradiation facility: $10k;
  - Radiochemical analysis: $10k;
  - M&S: $7k.
Randomly Selected PWO Samples

20 Each from BTCP, Russia, and SIC, China

BTCP: $28.5^2 \times 220 \times 30.0^2$ mm

SIC: $22^2 \times 230 \times 22^2$ mm
L.T. and L.O.: 20 Sample Comparison

BTCP: higher L.T., partly due to birefringence

SIC: 58% more light, the reason is unclear!
Comparison of Transmittance Loss

SIC samples less diverse: Bridgman technology
Type III: 1 in 20 found in BTCP, confirmed by 8 in 150 by Rebecchi
EWRIAC (1/m) and Normalized r.m.s

\[
EWRIAC = \frac{\int Riac(\lambda) Em(\lambda) d\lambda}{\int Em(\lambda) d\lambda}
\]

<1 m\(^{-1}\) : no damage in uniformity

<table>
<thead>
<tr>
<th>Vendor</th>
<th>15 rad/h</th>
<th>400 rad/h</th>
<th>9,000 rad/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>BTCP</td>
<td>0.16 (45%)</td>
<td>0.69 (37%)</td>
<td>1.43 (50%)</td>
</tr>
<tr>
<td>SIC</td>
<td>0.10 (33%)</td>
<td>0.51 (32%)</td>
<td>1.16 (48%)</td>
</tr>
</tbody>
</table>

BTCP Samples

SIC Samples
Type III (BTCP-2465): LT & LO

This anomalous behavior may cause confusion for monitoring with 440 nm light
Three samples cut to 5 pieces: 4.3 cm each:
Type I: 2467, Type II: 2436, Type III: 2465
Investigation on BTCP Samples (II)

A good type I sample

A typical type II sample

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Transmittance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300</td>
<td>0</td>
</tr>
<tr>
<td>400</td>
<td>0</td>
</tr>
<tr>
<td>500</td>
<td>0</td>
</tr>
<tr>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>0</td>
</tr>
<tr>
<td>800</td>
<td>0</td>
</tr>
</tbody>
</table>

From top to bottom:
- 200°C annealing
- 15 rad/h (65 h)
- 100 rad/h (63 h)
- 400 rad/h (62 h)
- 9000 rad/h (10 h)

<table>
<thead>
<tr>
<th>Wavelength (nm)</th>
<th>Transmittance (%)</th>
</tr>
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<tr>
<td>300</td>
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<tr>
<td>600</td>
<td>0</td>
</tr>
<tr>
<td>700</td>
<td>0</td>
</tr>
<tr>
<td>800</td>
<td>0</td>
</tr>
</tbody>
</table>

From top to bottom:
- 200°C annealing
- 15 rad/h (67.5 h)
- 100 rad/h (65 h)
- 400 rad/h (66 h)
- 35 k rad/h (20 h)
Investigation on BTCP Samples (III)

Light Output Degradation

Type I Sample

Type II Sample

BTCP-2467

Normalized Light output
under certain dose rate in equilibrium
for 4.2 cm long small pieces.

From top to bottom
2467E
2467D
2467C
2467B
2467A

BTCP-2436

Normalized Light output
under certain dose rate in equilibrium
for 4.2 cm long small pieces.

From top to bottom
2436E
2436D
2436C
2436B
2436A
Investigation on BTCP Samples (IV)

Anomaly is shown also at the Tail end (E and D)

**BTCP-2465**

Normalized Light output under certain dose rate in equilibrium for 4.2 cm long small pieces.

From top to bottom:
- 2465E
- 2465D
- 2465C
- 2465B
- 2465A

**BTCP-2465**

Normalized L.O. versus irradiation time under 15 rad/h for 4.2 cm long small pieces.

From top to bottom:
- 2465E
- 2465D
- 2465C
- 2465B
- 2465A

December 18, 2003
Investigation on BTCP Samples (V)

GDMS on BTCP PWO(Y/Nb/La) Samples (ppmw)
by Shiva Technology (November, 2003)

<table>
<thead>
<tr>
<th>Element</th>
<th>2467 Seed/Tail</th>
<th>2436 Seed/Tail</th>
<th>2465 Seed/Middle/Tail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na</td>
<td>0.95/0.98</td>
<td>2.5/5.2</td>
<td>3.8/3.4/5.2</td>
</tr>
<tr>
<td>Si</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>K</td>
<td>0.36/0.58</td>
<td>0.45/0.90</td>
<td>0.71/0.56/1.6</td>
</tr>
<tr>
<td>Ca</td>
<td>2.4/1.8</td>
<td>1.3/0.9</td>
<td>1.7/1.3/1.2</td>
</tr>
<tr>
<td>Cu</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>As</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Y</td>
<td>71/74</td>
<td>94/120</td>
<td>98/83/100</td>
</tr>
<tr>
<td>Nb</td>
<td>0.06/0.11</td>
<td>0.07/&lt;0.05</td>
<td>&lt;0.05/0.27/0.26</td>
</tr>
<tr>
<td>Mo</td>
<td>0.2/0.23</td>
<td>0.33/0.38</td>
<td>0.37/0.37/0.41</td>
</tr>
<tr>
<td>Sb</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
<td>&lt;0.05</td>
</tr>
<tr>
<td>Ba</td>
<td>1.7/1.5</td>
<td>1.5/1.2</td>
<td>5.3/1.7/2.5</td>
</tr>
<tr>
<td>La</td>
<td>250/140</td>
<td>200/130</td>
<td>280/160/150</td>
</tr>
<tr>
<td>Eu</td>
<td>0.6/0.5</td>
<td>0.8/1.4</td>
<td>1.1/0.53/0.3</td>
</tr>
<tr>
<td>TC†</td>
<td>6.4/5.7</td>
<td>7.0/10</td>
<td>13/7.9/11</td>
</tr>
</tbody>
</table>

†: Total contamination, excluding Y, Nb and La.

Impurity segregation:

- Na, K, Nb, Mo: <1;
- Ca, Ba, La: >1;
- Y: slightly less, but close to 1.

BTCP PWO is triple doped with Y/Nb/La!!!
Fast recovery??
Damage by 20 GeV Protons at T7
M. Huhtinen et al., 8th ICATPP Conference, Como, October 2003

High rate no dose rate dependence?  High T annealing: permanent damage?

Light Transmission Results

Crystal 410-8 – high-T annealing

A 2 cm long crystal “410-8” was irradiated at \( \sim 2 \times 10^{13} \text{ p/cm}^2/\text{h} \) for 5 hours
About half a year after irradiation is was annealed in successive temperature cycles

!! Band-edge shifts !!

Low fluence: Some dose-rate dependence
High fluence: No dose-rate dependence seen