Radiation damage and GSO luminosity monitor at the LHC

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- Introduction and motivation
- Projects and Status
  - Radiation measurements at the LHC
  - Testing GSO scintillators
  - GSO luminosity monitor
- Conclusions

New Hadron workshop
RIKEN, Mar. 1st, 2011
Forward region

- Zero degree instrumentation slot at 140m away from IP1 (ATLAS).
- Luminosity monitor and ZDC are located as well as the LHCf detectors.
- Pseudo-rapidity covers above ~8.
- Only neutral particles achieve TAN through a dipole magnet.

**Zero degree instrumentation slot**
- Located 140m away from IP1 (ATLAS).
- Includes Luminosity monitor and ZDC.
- Pseudo-rapidity covers above ~8.
- Only neutral particles achieve TAN through a dipole magnet.

**Forward region**
- Arm1: BRAN, ZDC
- Arm2: LHCf detectors
- Pseudo-rapidity covers above ~8
Energy flow at forward region

Absorbed dose

\[ \text{Dose (Gy)} \equiv \frac{J}{kg} \propto \text{Energy} \times L \]

Significant at high luminosity operation and especially in forward region where luminosity monitor is placed.

Estimated dose at the LHCf location (MC simulation)

<table>
<thead>
<tr>
<th>( \sqrt{s} )</th>
<th>Gy/hr@L=10^{29}</th>
<th>100Gy@L=10^{29}</th>
<th>Gy/hr@L=10^{31}</th>
<th>100Gy@L=10^{31}</th>
</tr>
</thead>
<tbody>
<tr>
<td>900GeV</td>
<td>( 4.1 \times 10^{-4} \text{Gy} )</td>
<td>( 1.0 \times 10^4 \text{ days} )</td>
<td>( 4.1 \times 10^{-2} \text{Gy} )</td>
<td>100 days</td>
</tr>
<tr>
<td>7TeV</td>
<td>( 1.9 \times 10^{-1} \text{Gy} )</td>
<td>22 days</td>
<td>( 1.9 \times 10^1 \text{Gy} )</td>
<td>( 2.2 \times 10^{-1} \text{ days} )</td>
</tr>
<tr>
<td>14TeV</td>
<td>1.5Gy</td>
<td>2.7 days</td>
<td>( 1.5 \times 10^2 \text{Gy} )</td>
<td>( 2.7 \times 10^{-2} \text{ days} )</td>
</tr>
</tbody>
</table>

(K. Kawade)

Good opportunity to understand a radiation in forward region.
Projects

- Measurements of radiation at the forward region.
  - LHCf data sets at $\sqrt{s}=7$ & 14TeV
  - dosimeter in TAN

- Testing GSO($\text{Gd}_2\text{SiO}_5$) radiation hardness
  - @HIMAC, Chiba
  - will be tested by LHCf in 2014

- Luminosity monitor with GSO scintillator
Measurements of radiation at the LHC
Radiation at the forward region

- Integrated Luminosity
- Time variation of $\pi^0$ mass (LHCf-Arm2)
- Dosimeter (located inside IPI-TAN)

Preliminary
Comparisons

For example IPI-TAN at $\sqrt{s}=14\text{TeV}$,

- Calculation by Mokov (based on MARS) indicates
  - $1.8 \times 10^8 \text{Gy/y@L}=10^{34}$
  - $5.0 \text{Gy/d}(0.2 \text{Gy/h})@L=10^{29}$
- while our calculation based on the Epics MC library shows different estimation
  - $1.4 \text{Gy/h}@L=10^{29}$
- but configuration (material etc.) has a slight difference between each calculation and it affects a few of factor.

Detailed analysis is ongoing.

(Mokov et al, LHC Project Report 633, (2003))
Performance test of GSO scintillator
What and why is GSO?

- Plastic scintillator (e.g. EJ-260) highly suffers from radiation damage.
  - 10% down at 10^2 Gy (~45 min @ 14 TeV & L = 10^{31}).

- GSO is strong to radiation damage. Degradation of light yield less than 10% even at 10^4 Gy.

- GSO is the best solution considering other similar properties to plastic scintillator.

**Properties of scintillators**

<table>
<thead>
<tr>
<th>Property</th>
<th>GSO</th>
<th>EJ-260</th>
<th>BGO</th>
<th>PWO</th>
<th>CeF3</th>
</tr>
</thead>
<tbody>
<tr>
<td>density (g/cm³)</td>
<td>6.71</td>
<td>1.023</td>
<td>7.13</td>
<td>8.28</td>
<td>6.16</td>
</tr>
<tr>
<td>r.l. (cm)</td>
<td>1.38</td>
<td>14.2</td>
<td>1.12</td>
<td>0.92</td>
<td>1.68</td>
</tr>
<tr>
<td>decay time (ns)</td>
<td>30-60</td>
<td>9.6</td>
<td>300</td>
<td>2.7,26</td>
<td>5,15</td>
</tr>
<tr>
<td>Fluorescence (NaI=100)</td>
<td>20</td>
<td>19.6</td>
<td>12</td>
<td>0.26</td>
<td>7</td>
</tr>
<tr>
<td>λem (nm)</td>
<td>430</td>
<td>490</td>
<td>480</td>
<td>430</td>
<td>305</td>
</tr>
<tr>
<td>Refractive (λem)</td>
<td>1.85</td>
<td>—</td>
<td>2.15</td>
<td>2.16</td>
<td>1.68</td>
</tr>
<tr>
<td>tolerance (Gy)</td>
<td>10^6</td>
<td>100</td>
<td>10^4</td>
<td>10^4</td>
<td>10^4</td>
</tr>
<tr>
<td>melting point (℃)</td>
<td>1950</td>
<td>—</td>
<td>1050</td>
<td>930</td>
<td>1460</td>
</tr>
</tbody>
</table>

Damaged by ^12C beam @ HIMAC, where data has been taken with different beam intensities (DATE_1-3).
Testing GSO w/ $^{12}$C beam

- Artificially damaged by $^{12}$C beam@HIMAC
  - monitoring light yield until $10^6$ Gy
  - 2 GSOs are prepared for test and reference

### Estimation of absorbed dose

$$\text{Dose (Gy)} = \frac{\text{Energy deposit (J)}}{\text{Mass (kg)}}$$

- Energy deposit = $N \times <E>$.  
  - $N$ is counted by IC  
  - $<E>$ is estimated by Bethe-Bloch
- Mass is calculated by beam size which has been controlled by collimator.

(1.5% Ce is doped to GSOs)
Testing GSO w/ $^{12}$C beam

Somewhat increasing >20%?

Relative Light Output

(Two PMTs are used for redundancy)
Discussions

- No decrease of light-yield until $\sim 7 \times 10^5$ Gy, rather it is increased about 20%.

- This mechanism can be understood as follows,

  Originally an energy transfer from GSO-excited to Ce-excited state emits photon.

  No photon can be emitted when de-excited to band gap which restricts scintillation efficiency.

  If band gap is occupied by irradiation, all of electrons must be transferred to Ce excited state which is able to emit photon.

  Thus irradiated GSO cause increase of light yield.

(M. Tanaka et al, NIM A404, 1998, 283)
Comparison

Increase of light yield is significant in 0.5%Ce doped GSO.

Light yield increases as depending on “Gy/hour” and independent of radiation source.
GSO luminosity monitor
LHC luminosity monitor

Cross section of the IPI-TAN

- **BRAN-IC** (High-L)
  - Strong to radiation, but small sensitivity to low energy
- **BRAN-Sci** (Low-L)
  - Sensitive from low energy, but weak to radiation

LHC Lumi monitor
GSO luminosity monitor

- Substituted for the “old” scintillators.
- Design and product by Nagoya–U.
- Four 40mmx40mm GSO scintillators cover 80mmx80mm aperture.
- Left/right, Bottom/top separation is able to monitor a position of beam axis, especially in nonzero crossing-angle run.
- GSO scintillator is connected to PMT using quartz guides and optical fibers.

- Assembly and test is ongoing by CERN lumi-team(Enrico Bravis et al.).
- BRAN-Sci will be upgraded soon.
We proposed three subjects can be proceeded together with the LHC operation.
- Measurement of radiation at the LHC
- Testing GSO scintillator
- GSO luminosity monitor for the LHC

They are going well as considering slight delay of the LHC machine.

New insight to GSO scintillator was obtained.
Backup
Testing GSO : Part I

$N_2$ laser (300ps, 337.1 nm) firing to each scintillator and measured by Hamamatsu R7400 (same as LHCf).

**EJ260 (Plastic)**

- FWHM ~ 12 ns

**GSO**

- FWHM ~ 30 ns

GSO output is decreased to less than 0.1% after 2 µs, thus no problem to the LHCf DAQ.
LHC operation (+LHCf)

Run in 2009
- From End of October 2009 LHC restarted operation.
  - 450 GeV + 450 GeV → 1.18 TeV + 1.18 TeV
- Stable operation at $\sqrt{s}=900$ GeV, while no stable beam declared to $\sqrt{s}=2.36$ TeV

Run in 2010
- LHCf data taking at 7 TeV since March to July.
- High intensity short run at 900 GeV.
- Crossing angle run started on June 25th.
- Uninstallation of the LHCf detectors on July.

Planing run in 2011-2012
- LHCf detector upgrade on summer and SPS beam test on November.
- $\sqrt{s}=7$ TeV run will be continued until half of 2012.
- p-Pb run is planed in 2012 for studying nuclear effects.
- $\sqrt{s}=14$ TeV run will start at 2014(?) after long shut down in 2013.
Two IC’s should be put here for measurement of total dose. The thickness of the IC is about 2.5mm.

Diodes for measurement of low energy neutrons

These are lumps to warm the circuit. Because the dosimeters is sensitive to humidity. If it is really dry in the slot, we can remove them.
He agree to modify the dosimeter and gave me some suggestions of modification.

- We can remove the connector and bond cables to the circuit. To avoid noise, he recommend to use the special cable with shield. It is not flat cable, but we can remove the cover of the cable and flatten the wires.
- If it is dry in the TAN slot, we can remove the lambs.
- We can bond IC’s directly on the circuit like surface mounting.

=> In case without lambs, the thickness expect to be 4.1mm. (This is less than 7mm gap between BRAN and LHCf)
Read-out box for the dosimeter have 2 versions of 4 and 5. (Dosimeter is same for both).

Read-out boxes has been already installed in the bottom of TAN. But it is v.4. We have some possibility.

- Replace all read-out boxes of v.4 to v.5.
- Additionally install the boxes of v.5.

It is completely depend to cost, time and we will have a discussion again together with Daniela or Anne-Laure for this point.
Purchase

- Dosimeter – 600 euros we can buy at CERN store.
- Readout box (including dosimeter and cables) – 2000 CHFs
  To get it, Agreement of Radiation Project Leader is needed.
増光に関して

伝導帯

エネルギーギャップ

価電子帯

不純物の励起状態

不純物の基底状態