Lessons Learnt from Beam Commissioning and Early Beam Operation of the Beam Loss Monitors (incl. outlook to 5 TeV)

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for the BLM team

Preconditions for operating at 5 TeV in 2010

Session 1 - 25th January 2010

Outline

- Introduction
- Operational Experience
  - Noise and Offset
  - Dependability (Reliability, Availability and Safety)
  - Accuracy of Thresholds
  - Known Limitations
- Threshold Levels Compared to Dynamic Range
- Extrapolation to Higher Intensities
  - Beam Cleaning
  - Injection Losses
- Summary
Introduction
Introduction

- Up to now very satisfying performance

- Machine protection functionalities are being **phased in**, in order not to compromise the availability during commissioning
  - Beam loss thresholds: from masked to unmasked in stages (end of 2009: running with most channels unmasked)
  - Acquisition system self tests – failure aborts beam – operational during 2009 run (see talk Ch. Zamantzas Evian 2010)
  - Sequencer driven regular system tests – failure or non-execution within 24 hours inhibits beam injection – to become operational before 2010 run
The important step for the BLM system is to go to unsafe beams ($10^{12}$ p at 450 GeV, see Jörg’s talk). This will happen in 2010!

To reach full protection level we need (mostly not covered in this talk):

- Technological tasks (see talk Ch. Zamantzas Evian 2010)
- Validate threshold settings (document for MPP approval in preparation)
- MPS tests (EDMS 896394)
- Apply all procedures for changes (EDMS 1027851)
Operational Experience

- Noise and Offset
- Dependability (Reliability, Availability and Safety)
- Accuracy of Threshold
- Known Limitations
Noise and Offset

- Important for availability (false dumps)
- Onset of problem detected early by about daily checks on offset and noise for each channel, cause can be identified (cable noise, card problem, ...)
- Cables had been exchanged (up to 800 m), noise reduction: factor 2
- Next shut-down: install single pair shielded cables, noise reduction: > factor 5
- Development of kGy radiation hard ASIC readout (PhD Giuseppe Venturini, ≈4 years): avoid long cables

Example mean offset level right of IP3
- Some bad channels in the DS have been repaired
- Long cables in LSS and DS lead to higher fluctuations
Noise single channel frequency distribution over 9 hours, low noise - short cable (left), high noise - long cable (right)

Max. noise frequency distribution, Ionization Chambers (IC) - left, Secondary Emission Monitors (SEM) - right

SEMs have a higher percentage of high noise

Max. noise above red line → channel will be repaired

≈3600 IC

≈300 SEM

A SEM is always installed next to an IC, it is less sensitive by factor of 70.000
Safety

- No safety related issues detected (hardware, firmware, software, parameters).

Availability, too early to give hardware failure and intervention rate. All hardware problems had been detected before the run. About one month of running: no newly developed problems.

- 3 hardware problems giving false dumps
  - 2 previously detected, but not considered urgent (optical fiber, tunnel card)
  - 1 detected intermittently during the summer (mezzanine surface card)
All quenches so far on MB (all injected beam). Most likely loss with circulation beam locations are the quadrupoles.

- 2 quenches in 2008 (injected beams): signals in BLMs could be reproduced by GEANT4 simulations to a factor of 1.5
  - thresholds raised by ≈50%

Analysis of second quench
LHC Project Note 422
The Four Quenches

analyzed (opposite beam equipped)

analyzed

highest IC saturation

MB not equipped
beam tests: provoke either a quench, or better, a ‘recovering quench’ on different magnets.

- Injected beam – detect with special version of nQPS
- Steady state (circulation beams) – detect with magnet temperature monitors
- Propose these tests for very beginning of 2010 run
Safety of ‘Recovering Quench’ Test

- Similar to 2009 beam dump test with reduced threshold levels and beam bump.
- nQPS Voltage difference detection level to be set at 50 mV (factor 4 below the QPS and factor 2 below nQPS limit).
- Conditions of the bump are well understood and very reproducible – nQPS test will (most likely) not cause a magnet quench and should be perfectly safe for the machine.

Position and detection reproducibility of 4 beam tests
Known Limitations

- **TDI at over-injection**: IC signal short integration times over electronic measurement limit – installation of capacitor

- **Triplet magnets at over-injection**: BLM over threshold. Measurements and beam tests suggest that radiation from TDI reaches monitors at triplet magnets from the outside (through the tunnel)
  - Long term solution: shielding
  - Short term solution: increasing the short integration time threshold or the monitor factor or installing an additional capacitor.
Triplet at Over-Injection

IP8 + mirrored signals from IP2

BLM signal RS01 [Gy/s]

BLMs on beam 1
BLMs on beam 2
thresholds

signals in BLMs on beam 1
signals in BLMs on beam 2
superimposed injection in IP2, beam 2
superimposed injection in IP2, beam 1

Chamonix 2010
Session 1 - Preconditions for operating at 5 TeV in 2010
Known Limitations

- **Triplet magnets at collision**: debris from interaction same magnitude signal as a critical loss
  - Long term solution: new monitors placed close to the coil of new triplet. *BLMs on Triplets preliminary studies*, Mariusz Sapinski et al., IR upgrade WG meeting 2009.02.12, EDMS 1049072
  - Short term: no problem up to luminosity of $10^{33}$ cm$^{-2}$ s$^{-1}$
**Losses at Injection**

- **TCDI set up:**
  - Losses in the ring already close to BLM interlock limit for pilot bunch...scraping in the SPS
  - Ratio of one pilot bunch to one nominal SPS batch: 6.4e3

<table>
<thead>
<tr>
<th>TCDIs at..</th>
<th>BLM: threshold/losses B1/B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>4.5 σ hor/vert</td>
<td>5e9 (B1/B2)</td>
</tr>
<tr>
<td>6.0 σ hor / 4.5 σ vert</td>
<td>10/20</td>
</tr>
<tr>
<td>6.0 σ hor / 4.5 σ vert + SPS scraping</td>
<td>30/60</td>
</tr>
</tbody>
</table>

→ **Superconducting machine demands a very clean injection**

- Scrape tails in SPS
- Improve beam 1 to the quality of beam 2
- **Unfortunately we did not reproduce the above results → last chapter of this talk**
Known Limitations – Dynamic Range

- SEM noise
  - Spurious signal: insulation problem - being corrected now
  - High noise (≈2000 Gy/s for short integration time)
    - Ambiguity for short losses in the gap between IC and SEM dynamic range
  - Thresholds cannot be set in SEM

- Partial activation of beam abort functionality was not foreseen in electronics (thresholds partially in SEM and partially in IC)
  - Installation of additional capacitors to spread the signal over longer time
  - Depending on requirement: new monitor type, small IC, 30 times less sensitive than IC (installation during 2010), ≈56 monitors.
Threshold Levels Compared to Dynamic Range
Are the thresholds at higher energies still safely above the noise levels? → yes (analyzed IC 40 µs, 1.3 s and 84 s integration time window up to now)

Threshold levels compared to dynamic range

Highest threshold cold magnets: OK (as defined in functional spec)

- Problem reduces with higher energies
- TCP: worst case
  TCSG and TCLI: 10 times lower thresholds
  → capacitor (up to factor 100)
- Similar for warm magnets
  → most locations should need no changes
- possible limitation? → see next slides
Extrapolation to Higher Intensities

- Beam Cleaning
- Injection Losses
Extrapolation to Higher Intensities

- Preliminary results
- Assuming intensity increases, all other conditions unchanged
- 6 data sets analyzed (same data sets as presented in Evian by Ch. Bracco and W. Bartmann)
- At what intensity do we reach the loss threshold? Which are the most-critical elements?
- Collimation cleaning 450 GeV (1.3 s loss data compared to 84 s thresholds), scaled to nominal intensity
  - B1 and B1 longitudinal cleaning
  - B1 vertical and B2 horizontal cleaning
- Injection (40 μs loss data compared to 40 μs thresholds)
  - B1 and B2, cleanest injections: SPS scraping, TCDI 6 σ hor. / 4.5 σ vert.
Cleaning - Beam 2 Horizontal

Preliminary

20091210-230305_RS09_LHC

Signal [Gy/s]

10^2

10

10^{-1}

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

10^{-7}

10^{-8}

19800
19900
20000
20100
20200
DCUM [m]

signal ICs B2
thresholds ICs B2
thresholds ICs B1
signal ICs B1

IP7
### Cleaning - Transversal

**Most-Critical Elements at nominal intensity 3E14**

<table>
<thead>
<tr>
<th>Beam 2 horizontal cleaning</th>
<th>Beam lifetime at threshold [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLMQI.04L6.B2I10_MQY</td>
<td>18 – 24</td>
</tr>
</tbody>
</table>

**Beam 1 vertical cleaning**


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**Beam 2 horizontal:**
- TCLA losses seem to be caused by “crosstalk” particle showers from B2
- Most critical cold element in IP6
- No limits from BLM dynamic range (all long integration time thresholds are within the dynamic range of the BLM system)

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**Diagram:**

- signal ICs B2
- thresholds ICs B2
- thresholds ICs B1
- signal ICs B1

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**PRELIMINARY**
B2: most critical element is a cold dipole

Losses localized: most-critical elements in IP3

Most-critical TCSG and TCLA correspond for B1 and B2, MBs are next to each other

No limits from BLM dynamic range (all long integration time thresholds are within the dynamic range of the BLM system)

### Cleaning - Longitudinal

<table>
<thead>
<tr>
<th>Most-Critical Elements at nominal intensity 3E14</th>
<th>Beam lifetime at threshold [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Beam 1 longitudinal cleaning</strong></td>
<td></td>
</tr>
<tr>
<td>BLMEI.08R3.B1I23_MBB</td>
<td>7 – 10</td>
</tr>
<tr>
<td><strong>Beam 2 longitudinal cleaning</strong></td>
<td></td>
</tr>
</tbody>
</table>
SPS scraping, TCDI 6 σ hor. / 4.5 σ vert., Beam 2, 2e10 p
# Injection with SPS scraping

**Nominal:** 3E13  
**2010:** 4E12

<table>
<thead>
<tr>
<th>Most critical</th>
<th>Beam 1</th>
<th>Number of injected protons at threshold</th>
</tr>
</thead>
<tbody>
<tr>
<td>16% of 38 most critical elements are cold magnets</td>
<td>Collimator: BLMEI.06L7.B1E10_TCP.A6L7.B1</td>
<td>1.5E+11</td>
</tr>
<tr>
<td>Warm magnet: BLMEI.06L7.B1E10_MBW.B6L7</td>
<td>5.5E+11</td>
<td></td>
</tr>
<tr>
<td>Cold magnet: BLMQI.08L2.B1E30_MQML</td>
<td>6.7E+11</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Beam 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>50% of 30 most critical elements are cold magnets</td>
</tr>
<tr>
<td>Cold magnet: BLMEI.04R8.B2E10_MBXB</td>
</tr>
</tbody>
</table>

- Numerous elements (collimators, cold and warm magnets) yield similar limits for injected protons
- IC thresholds in warm elements limited by BLM dynamic range. But, losses at cold magnets about equally close to threshold (≈3 times below quench limit).
- → injection losses need to be reduced further, scraping in the SPS seems crucial
- → possible to increase thresholds on primary and secondary collimators and warm magnets (additional capacitors, small IC) but not on cold elements
Summary

- Crucial to reach full protection level
  - Beam test to determine safe setting of threshold levels, full application of procedures

- Known BLM system limitations and upgrades look compatible with LHC schedule
  - Typically, warm elements should have higher thresholds
  - Certain locations need higher thresholds (add capacitor or install new small IC, choose different monitor location, install shielding, etc.)

- No additional limitation found for energies up to 5 TeV

- Collimation cleaning looks very promising

- Injection losses have to be substantially reduced (even for 2010)
  - Various cold magnets are affected
  - BLM system seems not to be the limiting factor
Some more slides
MP Footprint

Setup Beam Flag limit versus beam energy

A pilot bunch is the only beam that can be used for commissioning (and for most MD) activities at ≥ 3.5 TeV!

1/18/2010

JW - BC Workshop - Evian - Jan. 2010
# Noise and Offset

## Preconditions for operating at 5 TeV in 2010

<table>
<thead>
<tr>
<th>Range [bits]</th>
<th>~ Range [Gy/s] 40µs monit. in %</th>
<th>Nr. of monitors</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-30</td>
<td>0 - 0.003</td>
<td>20.1</td>
<td>690 very good</td>
</tr>
<tr>
<td>30-100</td>
<td>0.003 - 0.01</td>
<td>71.2</td>
<td>2445 good</td>
</tr>
<tr>
<td>100-200</td>
<td>0.01 - 0.02</td>
<td>7.7</td>
<td>264 ok</td>
</tr>
<tr>
<td>200-300</td>
<td>0.02 - 0.03</td>
<td>0.7</td>
<td>23 candidates for problematic channels</td>
</tr>
<tr>
<td>&gt; 300</td>
<td>&gt; 0.03</td>
<td>0.0</td>
<td>0 critical noise</td>
</tr>
<tr>
<td>= 0</td>
<td>no data</td>
<td>0.3</td>
<td>10 no data</td>
</tr>
</tbody>
</table>


<table>
<thead>
<tr>
<th>Range [bits]</th>
<th>Range [Gy/s] 40µs</th>
<th>Monitors in %</th>
<th>Nr. of monitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-30.0</td>
<td>0.0-190.0</td>
<td>2.65</td>
<td>8</td>
</tr>
<tr>
<td>30.0-100.0</td>
<td>190.0-633.0</td>
<td>15.89</td>
<td>48</td>
</tr>
<tr>
<td>100.0-200.0</td>
<td>633.0-1265.0</td>
<td>52.32</td>
<td>158</td>
</tr>
<tr>
<td>200.0-300.0</td>
<td>1265.0-1898.0</td>
<td>12.25</td>
<td>37</td>
</tr>
<tr>
<td>&gt;300.0</td>
<td>&gt;1898.0</td>
<td>16.56</td>
<td>50</td>
</tr>
<tr>
<td>0</td>
<td>No data</td>
<td>0.3</td>
<td>1</td>
</tr>
</tbody>
</table>

### IC Offset (3592 monitors) 18.12.2009 (1 hour) RS09

<table>
<thead>
<tr>
<th>Range [bits/1310.72ms]</th>
<th>Range [Gy/s x10^7] in 1310.72ms</th>
<th>Monitors in %</th>
<th>Nr. of monitors</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0-30.0</td>
<td>0.19-1.85</td>
<td>6.91</td>
<td>249</td>
<td>Too low</td>
</tr>
<tr>
<td>33.0-134.0</td>
<td>1.85-3.7</td>
<td>77.71</td>
<td>2799</td>
<td>Very good</td>
</tr>
<tr>
<td>134.0-201.0</td>
<td>3.75-5.56</td>
<td>6.83</td>
<td>246</td>
<td>good</td>
</tr>
<tr>
<td>201.0-537.0</td>
<td>5.56-14.8</td>
<td>3.28</td>
<td>118</td>
<td>Reset needed</td>
</tr>
<tr>
<td>537.0-1340.0</td>
<td>14.8-37.0</td>
<td>5</td>
<td>180</td>
<td>problematic</td>
</tr>
<tr>
<td>&gt;1340</td>
<td>&gt;37.0</td>
<td>0</td>
<td>0</td>
<td>Serious card problem</td>
</tr>
</tbody>
</table>

### SEM Offset (302 monitors) 18.12.2009 (1 hour) RS09

<table>
<thead>
<tr>
<th>Range [bits/1310.72ms]</th>
<th>Range [Gy/s] in 1310.72ms</th>
<th>Monitors in %</th>
<th>Nr. of monitors</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.0-104.0</td>
<td>0.0-0.02</td>
<td>2</td>
<td>6</td>
<td>Too low</td>
</tr>
<tr>
<td>104.0-208.0</td>
<td>0.02-0.04</td>
<td>88</td>
<td>256</td>
<td>Very good</td>
</tr>
<tr>
<td>208.0-312.0</td>
<td>0.04-0.05</td>
<td>7.8</td>
<td>24</td>
<td>good</td>
</tr>
<tr>
<td>312.0-832.0</td>
<td>0.06-0.16</td>
<td>0</td>
<td>0</td>
<td>Reset needed</td>
</tr>
<tr>
<td>832.0-2080.0</td>
<td>0.16-0.4</td>
<td>1.1</td>
<td>3</td>
<td>Problematic</td>
</tr>
<tr>
<td>&gt;2080.0</td>
<td>&gt;0.4</td>
<td>1.1</td>
<td>3</td>
<td>Serious card problem</td>
</tr>
</tbody>
</table>
- Factor between noise level and lowest threshold:
  - RS01: 450GeV: $\approx 150$  
  - 3.5TeV: $\approx 25$  
  - 5.0TeV: $\approx 11$
  - RS09: 450GeV: $\approx 81$  
  - 3.5TeV: $\approx 37$  
  - 5.0TeV: $\approx 20$
Session 1 - Preconditions for operating at 5 TeV in 2010
Session 1 - Preconditions for operating at 5 TeV in 2010
- Beam 2 longitudinal (right)
- Beam 1 longitudinal (bottom right)
- Beam 2 horizontal (bottom left)