S01 – Lessons from 2011
Machine Protection

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• Machine Protection System - reminder
• MPS response in 2011
• Dependability of MPS backbone
• Issues and areas of upcoming improvements
• MPP/rMPP and ramping intensity in 2012
LHC Machine Protection System

Interlock conditions

- 24
- ~ 20,000
- ~ 1,800
- ~ 3,500
- ~ few 100
- ~ few 100

- MPS ‘backbone’ consists of magnet and beam interlock system, LBDS, active detection systems (BLM, BCM, QPS, SIS,…), injection protection, collimation,…
- Additional inputs from many equipment systems to preventively dump beams
- In total many 10,000 interlock conditions
• MPS architecture is constantly evolving
• In addition every year some 100 major changes to operational systems that require tracking and follow-up (threshold changes, maintenance/replacement of components, R2E, operational tools, procedures,...)
• Special physics/MD runs require particular attention

Courtesy of B.Todd
1200 beam dumps were cleanly executed during 2011 (-10% wrt to 2010)

40% more successful ramps to 3.5TeV

~ Factor of 3 less dumps caused by beam losses, orbit changes,... -> confirm 2010/11 improvements

No beam induced quench with >100MJ beams @ 3.5TeV in 2011 (including all ‘quench’ tests)

No equipment damage observed (apart from kicker erratic causing damage in SDD calibration of ALICE)

MPS response of all dumps from 3.5TeV meticulously analyzed and validated – Initiating system always identified, but sometimes not fully clear why it triggered (‘spurious’ triggers, SEUs,...)

Nota bene: All statistics only counting fills with E > injection
Complexity and high level of safety in MPS systems comes at certain cost, i.e. false positives

False triggers of most MPS backbone systems remained (surprisingly) constant with time

95% of false dumps in 2011 above injection energy (< thresholds, ...)

Increase of false positives from QPS + interlock to large extend due to R2E -> See talk of R.Denz

2010: 8% of fills dumped due to MPS

2011: 12.6% of fills dumped due to MPS

7.7% not accounting for SEUs
Occurrence of false dumps of some systems clearly related to increasing beam intensities

Clear effect of intensity/integrated luminosity on QPS/PIC/...!

HW faults in Q10.L2 with ions
High local activation
Some 40 dumps in 2011 by beam monitoring indicate possible improvements of redundant active detection

Mostly slow losses, caused by Vacuum activities, Feedback issues and beam instabilities

Very well protected by BLMs (and QPS), but $E>\beta^*$ means tight collimator settings, lower BLM threshold

Maintain current good level of orbit stability -> additional interlocks for orbit corrector current and DIDT

<table>
<thead>
<tr>
<th>EVENT_TIMESTAMP</th>
<th>ENERGY</th>
<th>MPS_DUMP_CAUSE</th>
<th>MPS_DETECTION</th>
<th>COMMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>21-NOV-11 08.53.39</td>
<td>3499920</td>
<td>Orbit Feedback</td>
<td>BLM</td>
<td>Unstable OFB in squeeze with gain increase by a factor of 10</td>
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<tr>
<td>04-NOV-11 10.00.29</td>
<td>726600</td>
<td>Orbit Feedback</td>
<td>OP dump</td>
<td>Wrong OFB Parameter ORBIT_REF CHANGING_TIME (1s instead of 680s)</td>
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<tr>
<td>03-NOV-11 02.57.45</td>
<td>3500040</td>
<td>Beam Loss</td>
<td>BLM</td>
<td>Beam Loss during aperture measurements</td>
</tr>
<tr>
<td>17-OCT-11 06.58.51</td>
<td>3500040</td>
<td>Transv. beam instability</td>
<td>SIS</td>
<td>High Losses due to bad tune signal (end of ramp and squeeze without QFB)</td>
</tr>
<tr>
<td>28-SEP-11 08.56.30</td>
<td>1773720</td>
<td>Transv. beam instability</td>
<td>SIS</td>
<td>OFB problems during ramp</td>
</tr>
<tr>
<td>28-SEP-11 08.52.30</td>
<td>629280</td>
<td>Transv. beam instability</td>
<td>SIS</td>
<td>OFB not sending correct trims</td>
</tr>
<tr>
<td>20-SEP-11 07.44.34</td>
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<td>Beam Loss</td>
<td>BLM</td>
<td>QFB dragged tune of B2H on resonance</td>
</tr>
<tr>
<td>11-SEP-11 04.50.52</td>
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<td>Beam Loss</td>
<td>BLM</td>
<td>Vacuum spike</td>
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<td>11-SEP-11 02.56.59</td>
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<td>Beam Loss</td>
<td>BLM</td>
<td>Vacuum spike</td>
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<tr>
<td>25-JUL-11 02.32.30</td>
<td>3500040</td>
<td>Beam Loss</td>
<td>BLM</td>
<td>Orbit oscillations and consequent losses during optimisation</td>
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<tr>
<td>24-JUL-11 03.12.35</td>
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<td>Beam Loss</td>
<td>BLM</td>
<td>Vacuum spike</td>
</tr>
<tr>
<td>09-MAY-11 01.07.45</td>
<td>3500040</td>
<td>Transv. beam instability</td>
<td>BLM</td>
<td>Beam instability after quench test (ADT picking up wrong tune)</td>
</tr>
<tr>
<td>08-MAY-11 06.22.17</td>
<td>3500160</td>
<td>Beam Loss</td>
<td>BLM</td>
<td>Beam instability in B2V at end of coupled bunch instability MD</td>
</tr>
<tr>
<td>28-APR-11 09.20.22</td>
<td>3500160</td>
<td>Beam Loss</td>
<td>BLM</td>
<td>Vacuum spike</td>
</tr>
<tr>
<td>25-APR-11 08.40.04</td>
<td>3500040</td>
<td>Beam Loss</td>
<td>BLM</td>
<td>Vacuum spike</td>
</tr>
<tr>
<td>20-APR-11 02.26.26</td>
<td>2930880</td>
<td>Transv. beam instability</td>
<td>BLM</td>
<td>Horizontal beam instability with 2-3 s risetime</td>
</tr>
<tr>
<td>16-APR-11 11.58.41</td>
<td>3500040</td>
<td>FB 2</td>
<td>SIS</td>
<td>Orbit reference change applied in 1s instead of 385s, excursion in B2H</td>
</tr>
<tr>
<td>14-APR-11 05.37.30</td>
<td>3500160</td>
<td>Transv. beam instability</td>
<td>BPM6</td>
<td>Beam instability during IP scan</td>
</tr>
</tbody>
</table>

Nota bene: Not showing dumps of BPM in IR6 following too low bunch intensity (x4) & UFO dumps (x17 - see T.Baer)
Beam Current Change Monitor was vital part of MPS systems for e.g. HERA

Proposed for use in LHC MPS in 2005 (EDMS Doc. 359172)

With HERA like system, changes of < 0.1% of total beam current could be captured in 10 turns

Bl started development (with DESY consultancy) mid 2010, for deployment end 2011 + 2012 run

First system installed and data recorded, but showing not understood effects of bunch length,…?

Important to validate and finish soon, as such system adds layer of protection when probing quench/UFO limits with > BLM thresholds

First system now installed in IR4

First measurements during proton runs

Courtesy of M.Pfauwel, D.Belohrad
Work ongoing: Novel PC Interlock System

In addition to existing SIS interlocks at injection, ramp, squeeze and SB, new SW interlock system monitoring PC currents to protect against operations- and feedback- failures

Redundant to SIS for arcs, adds protection for LSS 1/2/5/8 due to capability of tracking bump shape amplitude/variations

Key interest for all other (non-COD) converters where currently no current tracking is done

Currently under commissioning and testing, after initial experience connection to BIS

Distribution of RT max kick difference to BP reference during ramp

Fill 1717: Bump >2mm during ramp in IR7

Courtesy of K. Fuchsberger
Other improvements for 2012 - ADT

- Considerable work went into finalization and commissioning of transverse damper
- MDs demonstrated selective and very deterministic bunch blow-up
- Allows for abort gap cleaning and increased efficiency when performing loss-maps, quench MDs,...
- System fully operational for both beams, should become default procedure as of start-up 2012 onwards

Blow up of selected bunches during MD (left) and unaffected bunches (right)

Loss-maps performed with ADT and 3rd order resonance method
Other improvements for 2012 - Abort Gap cleaning

- New procedure to be applied to proton running, from start-up 2012 onwards
- Cleaning ideally left on all the time, but currently costs of a few percent in luminosity
- If AGC switched on with too large abort gap population (~1e12), losses on the TCP risk to dump the beam at worst moment
- Cleaning always to be applied simultaneously to both beams
- Towards fully automated cleaning after LS1:
  -> Need Improved ADT HW + improved reliability of BSRA

- $I_{ag} > 1e10\ p+$: LHC announcer to ask for abort gap cleaning to be activated, first at 50% then 100%
- $I_{ag} < 4e9\ p+$: Switch cleaning off
- $I_{ag} > 1e11\ p+$ AND $I_{ag} < 1e12\ p+$: Manually dump the beams
- $I_{ag} > 1e12\ p+$: Logically one should never arrive here
  Don’t touch. Wait for decay below 1e12 p+ and dump the beams

Cleaning at 3.5TeV

Courtesy of J.Uythoven
Other improvements for 2012 - RP review

- Following discussion in Evian/Chamonix 2011, procedure for ‘non-working dump trigger’ has been prepared and will be implemented and commissioned for 2012 start-up
  - Sequence of actions to be taken by operations to force beam dump at different levels in case of equipment/controls malfunctioning

- Issue with RP movements on 6/11/2011 stopped RP operation in 2011 and triggered review between TOTEM/ALFA, Collimator and MPS experts

- Identified actions include
  - additional FLUKA studies for worst case failure scenarios
  - Implementation and commissioning of new state machine
  - New key panel to allow bypassing of position readings only when RP are in home position and motor power disabled (https://edms.cern.ch/document/1183242/1)
  - Improvements to mitigate cross-talk between stopper signals
  - Improved diagnostic and monitoring of all thresholds and limits

- All changes will be fully re-commissioned before operation of RPs will be allowed in 2012
Machine Developments

- Machine Developments per definition explore new machine and machine protection territory!
- MD requestors demonstrated responsibility in proactively providing the required MP documents
- More than 20 documents approved through EDMS for MD periods in 2011
- Preparation phase has proven very useful for MD and Machine Protection teams and often increased the efficiency of the MDs

To be made better for 2012:
- rMPP classification of requests + preparations of documents tbd more timely before the MD
- Certain flexibility wrt to agreed procedure was useful to increase efficiency (BFPP test, ion quench tests,...) but must not become the default
- **Scientific work on MP issues done by MPP, preparing the arguments for decision**
- **rMPP gathers main players in operation and protection to agree on the way to proceed and operational envelope**
- **Final decision by LMC**
- **Propose to continue with this structure for 2012 run, re-discuss after LS1**

### Improvements for 2012
- **Formalise ‘standard’ ramp-up after TS**
- **Checklists: after the steps with 624b, 840b and 1092b @ 1380b once every 14 days**

### Role of MPP and rMPP

<table>
<thead>
<tr>
<th>Item</th>
<th>Status</th>
<th>Who</th>
</tr>
</thead>
<tbody>
<tr>
<td>Internal test (safety checks) results must be true</td>
<td>OK</td>
<td>BD</td>
</tr>
<tr>
<td>Rise time (10 to 90%) of fast losses must be larger than 200 us</td>
<td>OK</td>
<td>BD</td>
</tr>
</tbody>
</table>

**Checklist**

- Non-conformity: points to the unresolved issue.

<table>
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<tr>
<th>Item</th>
<th>OK</th>
<th>BD</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLM monitors in the E2 dump line have been replaced, BLM procedure. This will be changed on Tuesday when the BLM connects to the B0 system, but used by the HPC for checks a cold soldering of the high voltage supply. Recording and the threshold change. The monitors have factors of 0.6. Threshold window</td>
<td>OK</td>
<td>BD</td>
</tr>
<tr>
<td>Threshold change: BLM: 0.462 0.930 0.20</td>
<td>OK</td>
<td>BD</td>
</tr>
<tr>
<td>BLM: 0.462 0.930 0.20 factors are set to 0.5 pushing the both in the threshold change</td>
<td>OK</td>
<td>BD</td>
</tr>
</tbody>
</table>

### Improvements

- **Formalise ‘standard’ ramp-up after TS**
- **Checklists: after the steps with 624b, 840b and 1092b @ 1380b once every 14 days**

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**Checklist**

- No-unexpected step changes in BLM system configuration.
- No unexpected step changes in ramp-up after TS.
- Checklists after the steps with 624b, 840b and 1092b @ 1380b once every 14 days.
Intensity ramp-up in 2011 and 2012

- Majority of Machine protection tests done with SBF <= 3 nom bunches, requiring relatively little time during ramp-up

- Main driving factor was machine availability up to 768b, initial steps to 912 b and 1092 b set off UFOs, vacuum activities and SEU

- Risk with faster intensity ramp up is not risk with machine protection, but effect of decreasing the efficiency

- Balanced approach to intensity increase allows for probing and resolving of upcoming issues while maintaining certain integrated luminosity (<$\beta^*$, new collimator settings, < orbit tolerances will need time to master)

- Reduce to 7 steps in 2012
  - 3b for MPS
  - 2-3 fills and 4-6 hours with 48b, 84b, 264b and 624b (cycle validation)
  - 3 fills and 20 hours with 840b, 1092b, 1380b (lumi related problems)
LHC Machine Protection Systems have been working well during 2011 run thanks to a lot of loving care and rigor of operation crews and MPS experts.

Ever more failures are captured before effects on beam are seen (no losses or orbit movements).

Still no quenches with circulating beam (with ~ 100MJ per beam and 10mJ for quenching a magnet).

Additional active protection will provide further essential redundancy for next years of running (DIDT, PC interlock...).

Maintaining present good level of orbit stability is a primary importance when moving to $\langle \beta^* \rangle$ + tight collimator settings.

Still we have to remain vigilant to maintain current level of safety of MPS systems while increasing efforts on increasing MPS availability.
Thanks a lot for your attention