LHC Status Report

(progress since 17\textsuperscript{th} February 2010)

Steve Myers
(on behalf of the LHC team)

CERN LHCC 5\textsuperscript{th} May 2010.
Topics

• LHC Status
  • Technical stop and Hardware Commissioning
  • Beam Commissioning and Operation March → now

• Strategy for Performance Evolution 2010-2011
Technical Stop

• nQPS connectors completed as schedule
• CMS repair of water cooling finished on time
• BUT! A few scares
  • CMS vacuum chamber
  • PS Motor generator set
• Hardware Commissioning finished a few days late.
  • 2 sectors late (S78 and S81): oil leak on a transformer:
    • 50 magnet quench (perverse set of conditions for nQPS)
    • 11 magnet quench
Hardware Commissioning

- New QPS fully deployed and tested
  - Massive job, limited resources, very tight schedule
- All magnet circuits qualified for 3.5 TeV
  - Main bends and quads to 6000 A
- Outstanding problem – discovered in final stages of HWC
  - Multiple induced quenches during power off - related to power converter switch off at same time as a fast discharge
  - **new QPS** – problem solved by a change of thresholds
  - **old QPS** – problem still there
    - Solution involves delaying one of the transients – requires modification of cards in tunnel
    - Solution will be fully tested and deployed after initial beam operation
  - Temporary fix: di/dt of MB limited to 2 A/s (normally 10A/s)
    - This fix has been used for all beam operation so far
Last LHCC was on 17 February

<table>
<thead>
<tr>
<th>Date</th>
<th>Event Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12th March</td>
<td>Ramp to 1.18 TeV</td>
</tr>
<tr>
<td>15th - 18th March</td>
<td>Technical stop – bends good for 6 kA</td>
</tr>
<tr>
<td>19th March</td>
<td>Ramp to 3.5 TeV</td>
</tr>
<tr>
<td>26th March</td>
<td>Set-up for 3.5 TeV collision under ‘stable’ beam conditions in progress</td>
</tr>
</tbody>
</table>
Overall Progress with Beam

• Successful ramps with beam to 1.18 TeV.
• Injection and capture of both beams & beam dump set up for safe beam.
• Machine tunes adjusted and controlled to nominal values routinely.
• Chromaticity measured and adjusted. Optics verified and corrected.
• Closed orbit adjusted to an rms of ~0.45 mm (about +/-2 mm peak to peak) ➔ factor 2 better than design orbit.
• Dispersion measured and verified (in vertical plane: 3 cm rms).
• Spectrometer and compensators set up and corrected with beam.
• Nominal separation bumps set up and included to corrected closed orbit.
• Golden reference orbit defined for collimation and machine protection.
• Collimation system (all ring collimators) set up. Efficiency: > 99.9%.
• Beam feedback commissioning partially completed, still ongoing.
• Luminosity separation knobs tested.
• Grazing events to ATLAS and CMS. Splash events to all experiments.
First Collisions at 7TeV cm
March 30, 2010
Separation bumps
ATLAS IP Separation
H = 4.173 mm : V = 0.035 mm

CMS IP Separation
H = 0.130 mm : V = 3.925 mm

ATLAS Coll Rate Evol

CMS Coll Rate Evol
30/3/2010

11:15 injected again
12:38 : At 3.5 TeV
Since the first Collisions
Easter Week-end; 21 hours colliding run at 7TeV cm

<table>
<thead>
<tr>
<th>Date</th>
<th>Fill #</th>
<th>Energy</th>
<th>I(B1)</th>
<th>I(B2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>05-Apr-2010 21:47:42</td>
<td>1022</td>
<td>0.0 GeV</td>
<td>1.54e+08</td>
<td>6.79e+07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Experiment Status</th>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Status</td>
<td>STANDBY</td>
<td>STANDBY</td>
<td>STANDBY</td>
<td>STANDBY</td>
</tr>
<tr>
<td>Instantaneous Luminosity</td>
<td>3.157e-05</td>
<td>0.000e+00</td>
<td>0.000e+00</td>
<td>0.000e+00</td>
</tr>
<tr>
<td>BRAN Count Rate</td>
<td>2.000e-323</td>
<td>1.402e-16</td>
<td>--</td>
<td>3.485e-06</td>
</tr>
<tr>
<td>BKGD 1</td>
<td>0.002</td>
<td>0.014</td>
<td>0.002</td>
<td>0.150</td>
</tr>
<tr>
<td>BKGD 2</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>BKGD 3</td>
<td>0.000</td>
<td>0.005</td>
<td>0.003</td>
<td>0.051</td>
</tr>
</tbody>
</table>

LHCf: STANDBY, Count(Hz): 0.000, LHCb VELO Position: OUT, Gap: 58.0 mm, TOTEM: STANDBY

Performance over the last 12 Hrs

Background 1

Background 2
Fill 1022

- Single beam lifetimes:
  - Beam 1: 990 hours
  - Beam 2: 730 hours
  - Very good beam-gas, negligible luminosity burn, negligible diffusion

- Luminosity lifetime
  - 40 – 50 hours
  - Mainly from gentle beam blow-up (tau ~ 40 hours for B2V)
  - Beam tune shift ~ 0.0015 (one plane, 2 real collision points, reduced emittances)
A very good 48 hour period!

<table>
<thead>
<tr>
<th>Experiment Status</th>
<th>ATLAS</th>
<th>ALICE</th>
<th>CMS</th>
<th>LHCb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instantaneous Luminosity</td>
<td>0.000e+00</td>
<td>0.000e+00</td>
<td>0.000e+00</td>
<td>8.989e-04</td>
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<tr>
<td>BRAN Count Rate</td>
<td>3.229e-07</td>
<td>4.059e-32</td>
<td>2.086e-11</td>
<td>1.635e-32</td>
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<tr>
<td>BKGD 1</td>
<td>0.002</td>
<td>0.014</td>
<td>0.002</td>
<td>0.131</td>
</tr>
<tr>
<td>BKGD 2</td>
<td>0.000</td>
<td>0.000</td>
<td>0.002</td>
<td>0.002</td>
</tr>
<tr>
<td>BKGD 3</td>
<td>0.000</td>
<td>0.005</td>
<td>0.003</td>
<td>0.037</td>
</tr>
</tbody>
</table>

Performance over the last 12 Hrs

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**Background 1**

- ATLAS
- ALICE
- CMS
- LHCb

**Background 2**

- ATLAS
- ALICE
- CMS
- LHCb
Magnet model

• The knowledge of the magnetic model of the LHC is remarkable and has been one of the key elements of a very smooth beam commissioning

• Tunes, energy matching, optics remarkably close to the model already

• Bodes very well for the future.
Tuesday 13.4.

- Q’ measurement during 800 GeV ramp: Beam2 Vertical
Tuesday 13.4.

- $\beta^*$ during squeeze to $\beta^* = 2\text{m}$ in IR8:
IP1&5 lumi vs squeeze

- Raw (online) lumi plots on 10 apr 2010, during the squeeze to 2m in IP1 and IP5
- Factor gained (raw numbers):
  - ~4.5 in Pt5 (after min scan)
  - ~4 in Pt1
- Not corrected for lumi decay over the ~5h of squeeze and mini scans
FMCM Beam Tests for D1 IR1/5

- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM masked.
- Beam dumped by BLMs in IR7.

- Trajectory over 1000 turns at a BPM.
- Position change of ~1.5 mm over last 250 turns.

Online PM!
FMCM beam tests

- Low intensity beam test.
- Trajectory evolution after OFF send to RD1.LR1, with FMCM active.
- Beam dumped by FMCM.

- Trajectory over 1000 turns at the same BPM.
- No position change visible within resolution.

>> The redundant protection is working
LHC Design Bunch Intensity:
Thursday 15.4.2010

• Higher intensity
  – Over-injection working well
  – Over-injected 1.1E11, with collimators at nominal 4.5 sigma settings.
  – Emittance at 1E11: 2.5 um H, 2,3 um V.
Qualification: Off-momentum collimation

Loss map for off-momentum error. All OK. See expected low leakage to experimental IR's. **OK for stable beams from coll.**
Setup Beam Flag: UNSAFE beam for the 1\textsuperscript{st} time
Squeeze to 2 m: Fast and Smooth

<table>
<thead>
<tr>
<th>Beta* IP1 [m]</th>
<th>Beta* IP2 [m]</th>
<th>Beta* IP5 [m]</th>
<th>Beta* IP8 [m]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.000</td>
<td>2.000</td>
<td>2.000</td>
<td>2.000</td>
</tr>
</tbody>
</table>

10 m to 2 m

45 min
Beta Beat at 3.5 TeV – beam 1
Beta Beat: Beam 2
Orbit Feedback in Operation

Maximum orbit change during energy ramp: 0.08 mm

Ralph Steinhagen et al
Lifetime Drops with “Quiet” Beam

- Our friend the hump on the lifetime - ~ 7 minute period

**Hunting the Hump!**

The hump is a vertical excitation on the beam that has a fast frequency component (therefore visible as “hump” in the tune spectrum) and a slow moving frequency component (7 min).
Emittance Growth: Still a Problem

Time

Ramp start
Ramp finish
Bumps collapsed
VELO in
LHCb lumi-scan
CMS lumi-scan
ATLAS lumi-scan
LHCb 2nd lumi-scan

factor 3

Emittance

Time

LHC_BRANB_4L8

Mirko Pojer
23.4.2010
Transverse Damper: Damping Beam Excitations

Crucial device to keep emittance growth under control!

Wolfgang Hoefle et al

Transverse Damper will stabilize against the Hump
Ramp & Squeeze Start to Work Smoothly

Ramp & squeeze @ 3.5 TeV qualification:
...last 2 fills w/o problem, lost on purpose...
Transverse damper commissioning @ 450 GeV

~ 48 hours

Ramp & squeeze for physics @ 3.5 TeV with higher intensity

LHC UPS repair
SPS problem
Saturday 24/4/2010

PROTON PHYSICS: STABLE BEAMS

Energy: 3500 GeV  I(B1): 2.75e+10  I(B2): 3.22e+10

Comments 24-04-2010 03:04:01 :

- injection scheme 3x3 bunches:
  - B1 buckets: 1, 8941, 17851
  - B2 buckets: 1, 8911, 17851
- All IPs to 2m!!! Preparing stable beams

BIS status and SMP flags

- Link Status of Beam Permits
- Global Beam Permit
- Setup Beam
- Beam Presence
- Moveable Devices Allowed In
- Stable Beams

LHC Operation in CCC: 77600, 70480

PM Status B1: ENABLED  PM Status B2: ENABLED

by E.Malì
New Record Fill

Fill length: 30 h
First time: with unsafe beam.
Luminosity: > 1.1e28 Hz/cm^2
First time: 3 bunch scheme
First time: end of fill studies and dump.

One order of magnitude increase in luminosity

Just 4 more to go before the long shutdown!!!
## Performance 3.5 TeV

<table>
<thead>
<tr>
<th>IP</th>
<th>Beta* (x, beam 1)</th>
<th>Beta* (y, beam 1)</th>
<th>Beta* (x, beam 2)</th>
<th>Beta* (y, beam 2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2.28 m</td>
<td>2.02 m</td>
<td>1.92 m</td>
<td>2.10 m</td>
</tr>
<tr>
<td>2</td>
<td>2.07 m</td>
<td>1.85 m</td>
<td>2.09 m</td>
<td>2.12 m</td>
</tr>
<tr>
<td>5</td>
<td>2.05 m</td>
<td>2.02 m</td>
<td>1.92 m</td>
<td>2.58 m</td>
</tr>
<tr>
<td>8</td>
<td>2.07 m</td>
<td>1.86 m</td>
<td>2.24 m</td>
<td>1.72 m</td>
</tr>
</tbody>
</table>

All experiments:  \[ L > 1.1 \times 10^{28} \text{ cm}^{-2} \text{ s}^{-1} \]  
factor ~10 achieved, as predicted
Integrated lumi (delivered, in STABLE BEAMS)

(modulo some possible luminometers down time...)

PRELIMINARY
Sunday (02/05/2010)

• 9:05 : 1st fill for “test run” with injection of 2x2, \(1 \times 10^{11}/\)bunch
  – No lifetime problems during injection with separated beams
• 9:40 : Separation bump collapsed, all IPs at once, lifetime of about 5 h for both beams
• 13:44 : Filling again for Stable Beams, \(1 \times 10^{11}/\)bunch, 2x2
• 14:10: Collapsing bumps, all at once
• 14:34 : STABLE BEAMS
• Luminosity scans “manually” performed for all IPs
Sunday afternoon (02/05/2010)

PROTON PHYSICS: STABLE BEAMS

Energy: 450 GeV  I(B1): 1.80e+11  I(B2): 2.02e+11

Good life-time in collision!!

Comments 02-05-2010 14:35:16 :

********** Stable beams **********

BIS status and SMP flags

- Link Status of Beam Permits: true, true
- Global Beam Permit: true, true
- Setup Beam: true, true
- Beam Presence: true, true
- Moveable Devices Allowed In Stable Beams: true, true

LHC Operation in CCC: 77600, 70480

PM Status B1: ENABLED  PM Status B2: ENABLED
Losses during the dump higher by factor 2.5 for beam 1 as compared to beam 2.
Second fill with better lifetime conditions for B1 after RF phase loop adjustment.
Topics

• LHC Status
  • Technical stop and Hardware Commissioning
  • Beam Commissioning and Operation March → now

• Strategy for Performance Evolution 2010-2011
# Time lines (Very Preliminary)

<table>
<thead>
<tr>
<th>Activity</th>
<th>Year</th>
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<tbody>
<tr>
<td>LHC Operation</td>
<td>Yes</td>
</tr>
<tr>
<td>Injector Chain Operation</td>
<td>Yes</td>
</tr>
<tr>
<td>LEIR/Linac3/Ions</td>
<td>Yes</td>
</tr>
<tr>
<td>Linac4 Project</td>
<td>Yes</td>
</tr>
<tr>
<td>Inner Triplet (Phase I Upgrade)</td>
<td>Yes</td>
</tr>
<tr>
<td>LHC Upgrade &quot;cryo&quot; Collimation</td>
<td>Yes</td>
</tr>
<tr>
<td>Consolidation LHC</td>
<td>Yes</td>
</tr>
<tr>
<td>Consolidation Injectors</td>
<td>Yes</td>
</tr>
<tr>
<td>SPS Upgrade</td>
<td>Yes</td>
</tr>
<tr>
<td>PS Booster energy increase</td>
<td>Yes</td>
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<table>
<thead>
<tr>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
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<tbody>
<tr>
<td>J</td>
<td>F</td>
<td>M</td>
<td>J</td>
<td>J</td>
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</tr>
<tr>
<td>F</td>
<td>M</td>
<td>A</td>
<td>M</td>
<td>J</td>
<td>J</td>
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<td>J</td>
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<td>A</td>
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<td>O</td>
<td>N</td>
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<td>F</td>
<td>M</td>
<td>A</td>
<td>M</td>
<td>J</td>
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</tbody>
</table>

**Start of 2 year cycle**

**3.5 TeV per beam**

**High Energy Possible**

**Higher Intensity from injectors?**
Beam commissioning strategy 2010

Global machine checkout

450 GeV re-commissioning

Machine protection commissioning

Ramp commissioning

Establish stable safe beams at 3.5 TeV

Collisions at 3.5 TeV

System/beam commissioning continued
Squeeze

Collisions at 3.5 TeV squeezed

Full machine Protection qualification

Finish This!!
**Instantaneous Luminosity**

\[
L = \frac{N^2 k_b f}{4\pi\sigma x \sigma y} F = \frac{N^2 k_b f\gamma}{4\pi\varepsilon \beta^*} F
\]

- Nearly all the parameters are variable (and not independent)
  - Number of particles per bunch \( N \)
  - Number of bunches per beam \( k_b \)
  - Relativistic factor \( (E/m_0) \) \( \gamma \)
  - Normalised emittance \( \varepsilon_n \)
  - Beta function at the IP \( \beta^* \)
  - Crossing angle factor \( F \)
    - Full crossing angle \( \theta_c \)
    - Bunch length \( \sigma_z \)
    - Transverse beam size at the IP \( \sigma^* \)

\[
F = 1 / \sqrt{1 + \left( \frac{\theta_c \sigma_z}{2\sigma^*} \right)^2}
\]

**Intensity**
\( N k_b \)

**Energy**
\( \gamma \varepsilon_n \)

**Interaction Region**
\( \theta_c \sigma_z \sigma^* \)
LHC performance drivers/limiters

Machine Protection is super critical

Interaction region ($\beta^*, F$)

Optics
Aperture
Machine protection

Collimation
Injector chain
Electron cloud effect
Machine protection

Interconnects
Training
Machine protection

Presently we are here!!
Beam Energy; Chamonix

Decision from Management following Chamonix

• Run at 3.5 TeV/beam (or slightly higher e.g. 4TeV) up to a predefined integrated luminosity (1fb$^{-1}$) with a date limit (end 2011).

• Then consolidate/repair the whole machine for 7TeV/beam.
Interaction Regions $\beta^*$ and F in 2010

- Lower energy means bigger beams:
  - Less aperture margin
  - Higher $\beta^*$ (lower $\beta_{\text{peak}}$)

- $> 150$ bunches requires crossing angle (beam-beam):
  - Requires more aperture
  - Higher $\beta^*$

- Targets for 3.5TeV
  - 2m without/with crossing angle in 2010
  - 2m with crossing angle in 2011
With > 150 bunches per beam, need a crossing angle to avoid parasitic collisions
Machine Protection Strategy for intensity increase

Presentation (Jorg Wenninger) to LMC on 17 February

or Why are we so diligent about increasing the LHC intensity?
At less than 1% of nominal intensity LHC enters new territory. Collimators must survive expected beam loss...
In terms of damage potential, LHC advances the state of the art by 3 orders of magnitude!
Uncontrolled beam loss in the SPS at 400-450 GeV leads to severe damage for stored energies $\geq 1$ MJ. (SBF limit = 70 kJ)

The danger at $\geq 2$ MJ beam stored energy:

- Holes
- Punctured
Strategy for Increasing the Beam Intensity

• The magic number for 2010/11 is 1 fb\(^{-1}\). To achieve this, the LHC must run flat out at 1-2\(\times10^{32}\) cm\(^{-2}\)s\(^{-1}\) in 2011,

  • Correspond to 8\(\times10^{10}\) ppb, 700 bunches, with a stored energy of 35 MJ (with \(\beta^*=2\) m and nominal emittance).
Maximum intensity increase versus stored energy:

- Up to 0.25 MJ: typical factor ~2, max 4
- Up to 1-2 MJ: max. factor ~2
- Above 1-2 MJ: ≤ ~2 MJ per step
“Old Predictions” 2010

<table>
<thead>
<tr>
<th>Step</th>
<th>E [TeV]</th>
<th>Fill scheme</th>
<th>N</th>
<th>β* [m] IP1 / 2 / 5 / 8</th>
<th>Run time (indicative)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.45</td>
<td>2x2</td>
<td>$5 \times 10^{10}$</td>
<td>11 / 10 / 11 / 10</td>
<td>Weeks</td>
</tr>
<tr>
<td>2</td>
<td>3.5</td>
<td>2x2</td>
<td>$2 \cdot 5 \times 10^{10}$</td>
<td>11 / 10 / 11 / 10</td>
<td>Weeks</td>
</tr>
<tr>
<td>3</td>
<td>3.5</td>
<td>2x2*</td>
<td>$2 \cdot 5 \times 10^{10}$</td>
<td>2 / 10 / 2 / 2</td>
<td>Weeks/Months</td>
</tr>
<tr>
<td>4</td>
<td>3.5</td>
<td>43x43</td>
<td>$5 \times 10^{10}$</td>
<td>2 / 10 / 2 / 2</td>
<td>Weeks/Months</td>
</tr>
<tr>
<td>5</td>
<td>3.5</td>
<td>156x156</td>
<td>$5 \times 10^{10}$</td>
<td>2 / 10 / 2 / 2</td>
<td>Weeks/Months</td>
</tr>
<tr>
<td>6</td>
<td>3.5</td>
<td>156x156</td>
<td>$9 \times 10^{10}$</td>
<td>2 / 10 / 2 / 2</td>
<td>Weeks/Months</td>
</tr>
<tr>
<td>7</td>
<td>3.5</td>
<td>50 ns-144**</td>
<td>$7 \times 10^{10}$</td>
<td>2.5 / 3 / 2.5 / 3</td>
<td>Months</td>
</tr>
<tr>
<td>8</td>
<td>3.5</td>
<td>50 ns - 288</td>
<td>$7 \times 10^{10}$</td>
<td>2.5 / 3 / 2.5 / 3</td>
<td>Months</td>
</tr>
<tr>
<td>9</td>
<td>3.5</td>
<td>50 ns - 720</td>
<td>$7 \times 10^{10}$</td>
<td>2.5 / 3 / 2.5 / 3</td>
<td>Months</td>
</tr>
</tbody>
</table>

* Turn on crossing angle at IP1.
** Turn on crossing angle at all IPs.

Now under revision since we collided 1e11

One month: 720 bunches of 7 e10 at beta* = 2.5 m. gives a peak luminosity of 1.3 e32 cm\(^{-2}\)s\(^{-1}\) and an integrated of about 85 pb\(^{-1}\) per month
“Old Predictions” 2011

3.5 TeV: run flat out at ~100 pb\(^{-1}\) per month

<table>
<thead>
<tr>
<th></th>
<th>No. bunches</th>
<th>ppb</th>
<th>Total Intensity</th>
<th>Beam Stored Energy (MJ)</th>
<th>beta*</th>
<th>Peak Lumi</th>
<th>Int Lumi per month [pb(^{-1})]</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 ns</td>
<td>432</td>
<td>7 e10</td>
<td>3 e13</td>
<td>17</td>
<td>2</td>
<td>1.3 e32</td>
<td>~85</td>
</tr>
<tr>
<td>Pushing intensity limit</td>
<td>720</td>
<td>7 e10</td>
<td>5.1 e13</td>
<td>28.2</td>
<td>2</td>
<td>2.2 e32</td>
<td>~140</td>
</tr>
<tr>
<td>Pushing bunch current limit</td>
<td>432</td>
<td>11 e10</td>
<td>4.8 e13</td>
<td>26.6</td>
<td>2</td>
<td>3.3 e32</td>
<td>~209</td>
</tr>
</tbody>
</table>

With these parameters we should be able to deliver 1 fb\(^{-1}\)
Thank You
Electromagnetic transient along the dipole magnet string

**Problem A (50 magnet quench problem):** when switching off the power converter for the main dipole magnets at full voltage and later opening the energy extraction switches, an electromagnetic transient along the magnet string triggers detectors of the new quench detection system. The voltage difference for adjacent magnets exceeds the threshold of 200mV and fires heaters. This led to the quench of 50 magnets on 24/2/2010.

**Problem B (11 magnet quench problem):** when switching off the power converter at full voltage and at the same time opening the energy extraction switches during a ramp down, an electromagnetic transient along the magnet string triggers detectors of the existing quench detection system. The voltage difference for the two apertures in one magnet exceeds the threshold of 100mV and fires the heaters. This led to the quench of 11 magnets on 4/3/2010.
Impact of EM Transients from Power Converters and Energy Extraction on Quench Detection

The adaptive filter was implemented in new QPS to cope with transient signals during Fast Power Abort, preventing spurious firing of quench heaters

- Elevate threshold for 1300ms after fast power abort to ignore the spike
- Rearm condition: all voltages of the detector > 0V i.e. during next powering cycle
Oscillations along the magnet string due to Power Converter switch-off during ramping

- The new QPS acquisition allowed for the first time to record and measure the waves created by a power converter during its emergency switch-off.
- Amplitudes of the oscillations are particularly high if power converter is switched-off during ramping up or ramping down the current.
- Oscillations influence the proper functionality of the new QPS symmetric quench detection adaptive filter.
- Power Converter oscillations superposed with Fast Power Abort perturbations can trigger the old QPS as well.
Event of Feb-24 at 3.5kA
Quench heaters of 50 dipoles fired after FPA

Simulated Powering failure at ~3500A
Simulated Fast Power Abort at ~3300A

Oscillation in Umag triggers nQPS adaptive filter

- Power converter switch-off during ramping causes oscillation seen by nQPS
- Adaptive filter was activated for nQPS SymQ of 50 dipoles
- Filter switched back to std. threshold after 1.3s and was blocked

Adaptive filter was disabled

- At Fast Power Abort filter was not available (threshold stayed low)

→ nQPS SymQ triggered heaters in 50 dipoles

Std Threshold, filter armed

Std. Threshold, filter blocked

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Mitigation

• Both, power converter and energy extraction EM transients are now well investigated and understood

• Two “side effects” of the EM transients were observed:
  – Symmetric quench detector can fire heaters on multiple transients
  – Old QPS can fire heaters due to superposition of transients

• Symmetric quench detector vulnerability can be treated by raising the threshold (at 6 kA still well within the protection margins)
  – 436 controllers storing the device parameters need to be re-programmed

• Old QPS triggering can be mitigated by delaying the energy extraction switches