LHC machine status

LHCC 3rd June 2015
Mike Lamont for the LHC team
In parallel with sector by sector cool-down

The LHC powering tests overview

Since September 15th 2014:

1566 superconducting circuits commissioned through execution and analysis of more than 10,000 test steps (~13,800 test steps including re-execution)
Dipole training 1/2

- 154 dipoles per sector, powered in series
- Ramp the current until single magnet quenches - “training quench”
- Usually quench 3 – 4 other dipoles at the same time
- Cryogenics recovery time: 6 – 8 hours
Dipole training 2/2

Training: frictional energy released during conductor motion

Campaign summary

<table>
<thead>
<tr>
<th>Circuit</th>
<th>Status</th>
<th>#M Firm 1</th>
<th>#M Firm 2</th>
<th>#M Firm 3</th>
<th>#MQ Firm 1</th>
<th>#MQ Firm 2</th>
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<th>#CQ total</th>
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<td>3</td>
<td>26</td>
<td>29</td>
<td>26</td>
</tr>
</tbody>
</table>

#M: Number of magnets in a sector.

#MQ: Number of magnet training quenches in a sector.

#CQ: Number of circuit quenches in a sector.

- All magnets have been trained to well over 7 TeV in SM18 before installation
- Extensive re-training in situ was not expected
LHC - 2015

- Target energy: 6.5 TeV
  - looking good
- Bunch spacing: 25 ns
  - strongly favored by experiments (pile-up limit around 50)
- Beta* in ATLAS and CMS: 80 to 40 cm

**Energy**

- Lower quench margins
- Lower tolerance to beam loss
- Hardware closer to maximum (beam dumps, power converters etc.)

**25 ns**

- Electron-cloud
- UFOs
- More long range collisions
- Larger crossing angle, higher beta*
- Higher total beam current
- Higher intensity per injection
LHC bunch structure - 2015

- 25 ns bunch spacing
- ~2800 bunches
- Nominal bunch intensity $1.15 \times 10^{11}$ protons per bunch

1 PS batch
(72 bunches)

1 SPS batch
(288 bunches)

26.7 km 2800 bunches

New limits of ~2 PS batches per injection from the injection protection absorbers – will reduce the maximum number of bunches to around 2500
2015: beta* in IPs 1 and 5

• Many things have changed. Start carefully and push performance later.

• Start-up: $\beta^* = 80 \text{ cm} – \text{(very) relaxed}$
  – 2012 collimator settings
  – 11 sigma long range separation
  – Aperture, orbit stability... checks ongoing

• Ultimate in 2015: $\beta^* = 40 \text{ cm}$
  – Possible reduction later in the year

$L \propto \frac{1}{\beta^*}$
2015 commissioning strategy

• **Low intensity commissioning of full cycle – 8 weeks**
• Pilot physics – low number of bunches
• Special physics run: LHCf and luminosity calibration
• Scrubbing for 50 ns
• **Intensity ramp-up with 50 ns**
  – Characterize vacuum, heat load, electron cloud, losses, instabilities, UFOs, impedance
• Scrubbing for 25 ns
• **Ramp-up 25 ns operation with relaxed beta**
• Possibly commission lower beta
• 25 ns operation
### 2015 Q2

- **FIRST BEAM**: 5th April
- **FIRST STABLE BEAM**: 3rd June
- **SCRUBBING FOR 50 ns**
- **PILOT PHYSICS**

- **8 weeks beam commissioning**
- **Pilot physics** – up to at least 40 bunches per beam
- **5 days special physics at beta* = 19 m (VdM, LHCf, TOTEM & ALFA)**
- **Start technical stop** – 15th June

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<th>June</th>
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</table>

**Start LHC commissioning with beam**

- **Easter Mon**
- **Recommissioning with beam**
- **Injector TS**
- **1st May**
- **Ascension**
- **Special physic run**
- **TS1**
### 2015 – latest schedule

<table>
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<th>Phase</th>
<th>Days</th>
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<tr>
<td>Initial Commissioning</td>
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<tr>
<td>Scrubbing</td>
<td>23</td>
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<tr>
<td>Special physics run 1 (LHCf/VdM)</td>
<td>5</td>
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<tr>
<td><strong>Proton physics 50 ns</strong></td>
<td>9 + 21</td>
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<tr>
<td><strong>Proton physics 25 ns</strong></td>
<td>70</td>
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<td>Special physics run 2 (TOTEM/VdM)</td>
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<td>Machine development (MD)</td>
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<td>Technical stops</td>
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<tr>
<td>Technical stop recovery</td>
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<tr>
<td>Ion setup/Ion run</td>
<td>4 + 24</td>
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<tr>
<td><strong>Total</strong></td>
<td>253 (36 weeks)</td>
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</table>
Schedule - comments

• Picked up some 4 weeks delay from:
  – Powering tests/quench training overrun
  – Earth fault resolution

• Proton-proton physics down to 70 days
  – Decrease in beta* to be reviewed after gaining some experience (although considerable progress made during commissioning)

• Ion program unaffected
  – Proton-proton reference data will be difficult to squeeze in
Commissioning

- **System commissioning with beam**
  - Collimation
  - Beam dump
  - Feedbacks
  - Beam instrumentation
  - Machine protection
  - RF
  - Transverse damper
  - Injection

- **Machine characterization**
  - Optics measurement and correction
  - Magnetic machine

- **Operations**
  - High intensity injection
  - Ramp to 6.5 TeV
  - Squeeze

- Complete
- Ongoing
- Collide & validation
# Milestones

<table>
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<th>Milestone</th>
<th>Date</th>
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<td>Circulating beam</td>
<td>Sunday 5(^{th}) April</td>
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<tr>
<td>Ramp to 6.5 TeV</td>
<td>Friday 10(^{th}) April</td>
</tr>
<tr>
<td>First 13 TeV collisions</td>
<td>Wednesday 20(^{th}) May</td>
</tr>
<tr>
<td>First Stable beams</td>
<td>Wednesday 3(^{rd}) June</td>
</tr>
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</table>

**Working throughout with:**
- probes (5e9 protons per bunch) or
- 1 or 2 nominals (1.2e11 protons per bunch)

**THIS IS NOT BAD!**
Threading – Easter Sunday

- Threading of B2 started at 10:12, ended 10:41.
  - Followed by 1 hour of work to establish a closed orbit and circulate more than 25 turns.
- Threading of B1 started at 11:54, ended 12:26.
  - Almost immediately obtained a closed orbit and more than 25 turns.

Horizontal

Vertical
6.5 TeV for the first time
First images of collisions at 13 TeV

by Cian O’Luanaigh

21st May

2 nominal bunches per beam
De-squeezed to 19 m
First Stable Beams

This morning

• 07:00 Injection delayed
  – Issue with interlocked BPM
  – SPS beam dump kicker fault
• 08:25 Start ramp
• 08:38 Beams dump at 4.1 TeV
  – Software interlock related to interlock BPM fix!
• 09:46 Start ramp
• 10:15 Start squeeze
• 10:40 Stable beams
PROTON PHYSICS: STABLE BEAMS

Energy: 6500 GeV  I(B1): 2.93e+11  I(B2): 2.96e+11

FBCT Intensity and Beam Energy

Instantaneous Luminosity

Comments (03-Jun-2015 10:40:01)
collapsed separation bumps in IP1 and 5
collapsed separation bumps in IP2 and 8
preparing for stable beams

BIS status and SMP flags

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<tr>
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<th>B1</th>
<th>B2</th>
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<tbody>
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<td>Beam Presence</td>
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<td>Moveable Devices Allowed In</td>
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<td>Stable Beams</td>
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</table>

AFS: Single 3b 2 2 2 with nc probes

PM Status B1: ENABLED  PM Status B2: ENABLED
Of note 1/2

• A lot of lessons learnt from Run 1
• Excellent and improved system performance:
  – Beam Instrumentation
  – Transverse feedback
  – RF
  – Collimation
  – Injection and beam dump systems
  – Vacuum
  – Machine protection
• Improved software & analysis tools
• Experience!
• Magnetically reproducible as ever
• Optically good, corrected to excellent
• Aperture
  – measurements at top energy, 80cm, before and after collision indicate that the aperture is ok and compatible with the present collimation hierarchy. This is a very good result.
• Behaving well at 6.5 TeV
  – One additional training quench so far
• Operationally well under control
  – Injection, ramp, squeeze, de-squeeze

Still have to face the intensity ramp-up
• UFOs, e-cloud, vacuum, beam induced heating, instabilities
Optics - 40 cm

LHCb1 6.5 TeV, $\beta^* = 0.4$ m

$\Delta\beta/\beta_y$

$\Delta\beta/\beta_x$

Longitudinal location [km]

OMC team
# Flat top collimator gaps

<table>
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<th>L(mm) MDC</th>
<th>PRS R(mm)</th>
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<th>Gap (mm)</th>
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S. Redaelli, LHC meeting, 26-05-2015
Off momentum loss map 6.5 TeV

Novel features of collimation system – BPM equipped tertiary collimators, automatic beam based set-up
Aperture
MUFOs in 15R8

- Multiple loss events after a short time at 6.5 TeV compatible with particles falling into the beam
  - loss patterns point to a specific position in the middle of a dipole magnet
  - Quenched twice, numerous BLM triggered dumps...
Aperture restriction in 15R8

ULO (Unidentified Lying Object)

• Aperture restriction measured at injection and 6.5 TeV
• Presently running with orbit bumps
  – -3 mm in H, +1 in V, to optimize available aperture
  – aperture probably not limiting for operation
• Behaviour with higher intensities and bunch trains still unknown
• MUFOs went away but last week
UFO in 15R8 are back

Dump 1: 5.1 TeV with 2 bunches
Dump 2: 4.3 TeV with 1 bunch

This following a 15R8 aperture scan. A worry.
2015: ATLAS and CMS performance

- Conservative beta* to start
- Nominal bunch population
- Reasonable emittance into collisions
- Assume same machine availability as 2012

<table>
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<th></th>
<th>Nc</th>
<th>Beta*</th>
<th>ppb</th>
<th>EmitN</th>
<th>Lumi [cm⁻²s⁻¹]</th>
<th>Days (approx)</th>
<th>Int lumi</th>
<th>Pileup</th>
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<td>1300</td>
<td>80</td>
<td>1.2e11</td>
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<td>21</td>
<td>~1 fb⁻¹</td>
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<td>1.2e34</td>
<td>30</td>
<td>~5 fb⁻¹</td>
<td>35</td>
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</table>

Official GPD luminosity target for the year was 10 fb⁻¹
Now on the challenging side – let’s say 5 to 10 fb⁻¹
Special physics runs

• First run 5 day run scheduled for next week
  – LHCf and luminosity calibration with VdM scans. TOTEM and ALFA to piggy-back.
  – De-squeeze to 19-19-19-24 m commissioned (and test collision delivered)
  – Roman Pot set-up and validation still to do
  – Pilot physics and ~10 pb$^{-1}$ to be delivered before but in good shape

• Second 7 day run for later in year
  – VdM and 90 m run for TOTEM and ALFA
  – Procedures and tools for set-up in good shape – should allow effective exploitation of scheduled time
“Doublet” scrubbing beam: PyE CLOUD simulation results

Buildup simulations show a substantial enhancement of the e-cloud with the “doublet” bunch pattern

PyE CLOUD simulations for the LHC arc dipoles

Cryogenics limit

50 ns beam
~1400 bunches
$1.7 \times 10^{11}$ p/b

25 ns beam
~2800 bunches
$1.15 \times 10^{11}$ p/b

Doublet beam
~900 doublets
$0.7 \times 10^{11}$ p/b

Giovanni Iadarola and Giovanni Rumolo
Conclusions

• Looking good at 6.5 TeV
  – Great job done in LS1 and during powering tests
  – Impressive progress so far, lot of lessons learnt in Run 1 and fed-forward

• Fundamentals look sound, no show stoppers for the moment
  – Some irritants – resolution cost time

• Next challenge - higher intensity and e-cloud

• 2015 will be a short year for proton physics but lay foundations for production for the rest of Run 2