LHC Machine Status Report
134th LHCC Meeting

Rende STEERENBERG
With valuable input from: LHC Machine Coordinators, LHC Operations Team and many specialists
Topics

- Hardware and Beam Re-commissioning
- LHC Machine Status & Performance
- Outlook for the remainder of 2018
Hardware and Beam Re-commissioning
# 2018 LHC Schedule – Q1

<table>
<thead>
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<th>Wk</th>
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**Version 1.2**

**Version 1.3**

- **LHCC Meeting #134**
- **30 May 2018**
- **Rende Steerenberg BE/OP**
Successful & Efficient HW re-commissioning

1561 circuits tested in 2 weeks
9390 successful tests
7076 powering tests (excluding signatures)
10533 tests done (repetitions included)
2018 LHC Schedule – Q2

### Version 1.2

<table>
<thead>
<tr>
<th>Week</th>
<th>April</th>
<th>May</th>
<th>June</th>
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<td>Mo</td>
<td>14</td>
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<td>Tu</td>
<td>9</td>
<td>30</td>
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<td>We</td>
<td>16</td>
<td>Scrubbing</td>
<td>1st May</td>
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<td>Th</td>
<td>Recommissioning with beam</td>
<td>Interleaved commissioning &amp; intensity ramp up</td>
<td>7</td>
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<tr>
<td>Fr</td>
<td>CMS testbed work</td>
<td>Ascension</td>
<td>14 Whitsun</td>
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<td>Su</td>
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</tbody>
</table>

- **Start Beam Commissioning**
- **Collisions with 3 bunches**
- **Collisions with 1200 bunches**

Full machine 13 days ahead of schedule

### Version 1.3

<table>
<thead>
<tr>
<th>Week</th>
<th>April</th>
<th>May</th>
<th>June</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo</td>
<td>Easter</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Tu</td>
<td>Machine checkout</td>
<td>Scrubbing</td>
<td>1st May</td>
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<tr>
<td>We</td>
<td>Recommissioning with beam</td>
<td>Interleaved commissioning &amp; intensity ramp up</td>
<td>7</td>
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<tr>
<td>Th</td>
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<td>Ascension</td>
<td>14 Whitsun</td>
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<td>23</td>
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</tbody>
</table>

- **First Stable beams**
- **Collisions with 1200 bunches**

Reached 1200 bunches

Scheduled to be at 1200 but reached 2556

**LHCC**
Smooth & Fast Intensity Ramp-up

Intensity ramp up plan: 3 - 12 - 72 - 300 - 600 - 900 - 1200 - 1800 - 2400 – 2550

- With interleaved beam commissioning and intensity ramp up **1227 bunches in only 10 days** (excl. scrubbing)
  - In 2017 it took 15 days
- **2556 bunches** reached after **17 days**
  - In 2017 it took 24 days.

- **This is thanks to excellent machine availability and dedicated teams, signing off checklists for every step at any moment**
LHC Machine Status & Performance
LHC Statistics Since First Collisions

### Availability
- 82.8%
- 49.7%

### Fault vs Operation Time Distribution
- Stable Beams: 49.7%
- Operations: 31.8%
- Fault: 17.2%
- Pre-cycle: 1.3%

### LHC Activity
- Energy
- Beam 1 intensity
- Beam 2 intensity

### Accelerator Mode Activity
- Prophylaxis
- Maintenance
- Operations (SB: 49.7%)
- Turnaround periods
- Beam dump
- Fill number

### Faults in Selected Window
- Accelerator Controls
- Access Management
- Access System
- Beam Injection
- Beam Instrumentation
- Beam Losses
- Cooling and Ventilation
- Electrical Services
- High Voltage
- Injection Systems
- Machine Interlock System
- Magnet Circuits
- Operations
- Power Converters
- Radiation Detectors
- Transverse Pumps

17.04.2018 – 28.05.2018

LHCC Meeting #134
30 May 2018
Rende Steerenberg BE/OP
2018 LHC Performance up to now

- Full machine (2556 bunches) reached on May 5th
- Peak lumi in stable beams of $2.1 \times 10^{34}$ cm$^{-2}$s$^{-1}$ reached during intensity ramp up
- Might be a new record, pending luminosity measurement calibration
- After that small step back in bunch intensity
- Two “16L2 storms” encountered with successful recovery
Run 1 + Run 2 Lumi Production

- Peak Luminosity
  - 2018 shows steepest increase in peak luminosity of all years
  - Possibly new record of $2.1 \times 10^{34}$ cm$^{-2}$s$^{-1}$

<table>
<thead>
<tr>
<th>Period</th>
<th>Int. Luminosity [fb$^{-1}$]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Run 1</td>
<td>29.2</td>
</tr>
<tr>
<td>Run 2: 2015</td>
<td>4.2</td>
</tr>
<tr>
<td>Run 2: 2016</td>
<td>39.7</td>
</tr>
<tr>
<td>Run 2: 2017</td>
<td>50.2</td>
</tr>
<tr>
<td>Run 2: 2018</td>
<td>16</td>
</tr>
<tr>
<td>Total Run 1+ 2</td>
<td>139.3</td>
</tr>
</tbody>
</table>

28.05.2018
The recent “16L2 Storms”

- Steady state losses partly suppressed by solenoid
- Loss peaks can trigger beam dump
Time Structure of Losses

- Looks very similar to 2017:
  - Events starts with a spike at 16L2
  - This is followed by a “loss runaway” at 16L2
  - After about 10 ms a transverse instability is triggered, which causes fast losses at the collimators dumping the beams
“16L2 Storm” Recovery

- 1st storm a recovery à la 2017 was used
- 2nd storm was recovered with a single fill with 900 bunches, losing little time...
Luminosity Levelling

- In certain conditions and depending on the experiments request, it is desirable to adapt the luminosity dynamically with beams in collision – levelling.
  - *Each levelling technique has its advantages and drawbacks.*

Levelling by beam offset / separation

Levelling by crossing angle

Levelling by $\beta^*$ (= beam size at IP)

Complexity
Luminosity (Anti-)Levelling

• In 2017 the step-wise crossing angle anti-levelling was introduced
  • 3 steps depending on the luminosity burn-off

• In 2018:
  • The crossing angle anti-levelling is done continuously, down to 130 $\mu$rad
  • A step-wise $\beta^*$ anti-levelling has been added
    • $\beta^*$=30 cm $\rightarrow$ 27.5 cm $\rightarrow$ 25 cm

• This allows minor gain in integrated luminosity, but is a vital exercise for future (HL-LHC) levelling
Special Runs

- Van de Meer run scheduled for week 26 and under preparation

- Seven day long $\beta^* = 90$ cm run scheduled for week 26 & 27
  Setting up well advanced

- Special runs week 41 are a place holder for Low energy high $\beta$ run
  - Tests in 2017 and recently at 900 GeV were unsuccessful due to background noise growth, which is not (yet) fully understood
  - Not sure if doubling the energy would solve the background issue
Multi-annual Integrated Performance

![Graph showing integrated luminosity from 2012 to 2018 with key dates and luminosity values.]

- **28.05.2018**: End of proton run
- **28.10.2018**:
Outlook for the remainder of 2018
## 2018 Machine/Beam Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Design</th>
<th>2018</th>
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<tbody>
<tr>
<td>Bunch population $N_b$ [$10^{11}$ p]</td>
<td>1.15</td>
<td>~1.2 ($\rightarrow$ 1.4)</td>
</tr>
<tr>
<td>No. bunches per train</td>
<td>288</td>
<td>144</td>
</tr>
<tr>
<td>No. bunches</td>
<td>2780</td>
<td>2556</td>
</tr>
<tr>
<td>Emittance $\varepsilon$ [mm mrad]</td>
<td>3.5</td>
<td>~2.2</td>
</tr>
<tr>
<td>Full crossing angle [$\mu$rad]</td>
<td>285</td>
<td>300 $\rightarrow$ 260</td>
</tr>
<tr>
<td>$\beta^*$ [cm]</td>
<td>55</td>
<td>30 $\rightarrow$ 27.5 $\rightarrow$ 25</td>
</tr>
<tr>
<td>Peak luminosity [$10^{34}$ cm$^{-2}$s$^{-1}$]</td>
<td>1.0</td>
<td>~2</td>
</tr>
<tr>
<td>Integrated luminosity [fb$^{-1}$]</td>
<td></td>
<td>~60</td>
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</tbody>
</table>

The “CMS bump” to compensate ground movement was increased from **-1.5 mm** to **-1.8 mm**
2018 LHC Schedule, version 1.3

- Approved by the Research Board on 6 December 2017
  - Some minor modification after that, mainly adaptation to “as executed”
  - TS1 shortened by 1 day in favor of physics
  - Perhaps still some additional MD time to be allocated

- Specials runs
  - VdM programme is planned
  - $\beta^*$ = 90 meter run scheduled
  - Low energy run to be re-discussed following tests
  - 4-week Pb-Pb ions run

- End of 2018 run 3 December 2018

- Magnet tests in view of 7 TeV operation after LS2 during week 49
# Summary Table 2018 - 2017 - 2016

<table>
<thead>
<tr>
<th>Phase</th>
<th>2018 Days</th>
<th>Ratio [%]</th>
<th>2017 Days</th>
<th>Ratio [%]</th>
<th>2016 Days</th>
<th>Ratio [%]</th>
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</thead>
<tbody>
<tr>
<td>Comm. &amp; Intensity ramp up</td>
<td>33**</td>
<td>13.4</td>
<td>35</td>
<td>16.1</td>
<td>28*</td>
<td>11.3</td>
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<tr>
<td>Scrubbing</td>
<td>1</td>
<td>0.4</td>
<td>7</td>
<td>3.3</td>
<td>2</td>
<td>0.8</td>
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<td><strong>25 ns Proton Physics</strong></td>
<td>131</td>
<td>53.3</td>
<td>127</td>
<td>58.5</td>
<td>139</td>
<td>56.3</td>
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<td>Special Physics Runs</td>
<td>17</td>
<td>6.9</td>
<td>18</td>
<td>8.3</td>
<td>10</td>
<td>4</td>
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<td>Setting up Pb-Pb ion run</td>
<td>4</td>
<td>1.6</td>
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<td>6</td>
<td>2.4</td>
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<td>Pb-Pb ion run</td>
<td>24</td>
<td>9.8</td>
<td>-</td>
<td>-</td>
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<td>9.3</td>
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<td>Machine Developments (MD)</td>
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<td>8.3</td>
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<td>8.5</td>
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<td>Technical Stops (3x)</td>
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<td>4.9</td>
<td>8</td>
<td>3.7</td>
<td>12</td>
<td>5</td>
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<tr>
<td>Technical Stop Recovery (3x)</td>
<td>4</td>
<td>1.6</td>
<td>4</td>
<td>1.8</td>
<td>6</td>
<td>2.4</td>
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<tr>
<td><strong>Total</strong></td>
<td>246</td>
<td>100</td>
<td>217</td>
<td>100</td>
<td>247</td>
<td>100</td>
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<tr>
<td>Integrated luminosity [fb⁻¹]</td>
<td>~ 60</td>
<td></td>
<td>50.2</td>
<td></td>
<td>39.7</td>
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* Did not fully include intensity ramp up – interleaved commissioning and interleaved intensity ramp up was as of 2017

** With 1200 bunches per beam, previously with 3 bunches
2018 is the final production year before Long Shutdown 2. Important to reach a stable beam time ratio of 50%.

60 fb⁻¹ is the goal for 2018 for ATLAS & CMS.
2 fb⁻¹ is the 2018 goal for LHCb.