LHC: Machine Status and Prospects for the short, medium and long term.
Topics

• LHC progress in 2011
• Prospects in the Short term (2011—2012)
• Mid Term Prospects (2014-2021)
• Long Term Prospects (2022--....)
Topics

• LHC progress in first half of 2011

• Prospects in the Short term (2011—2012)

• Mid Term Prospects (2014-2021)

• Long Term Prospects (2022--....)
The 3 periods
1. Physics re-established with 75ns and increasing the number of bunches,
2. Intermediate energy run at 1.38 TeV/beam + Scrubbing Run
3. Start of going by steps towards 900b + TS + (MD)

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<th>Thu</th>
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**Technical stop**

**Hardware commissioning**

**Intermediate energy run**

**Scrubbing run**

**Start full non-LHC physics program**

**Apr**

<table>
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<tr>
<th>13</th>
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**Jun**

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July 26, 2011
S. Myers, HEP2011, Grenoble
Estimated Peak and Integrated Luminosity

- Baseline is 2E32 Peak and 1fb-1 (integrated)
- But following 2010, we are confident we will do better

\[ \beta^* = 1.5m \]

<table>
<thead>
<tr>
<th>days</th>
<th>H.F</th>
<th>Comm with</th>
<th>Fills with</th>
<th>kb</th>
<th>e_{\mu}</th>
<th>\xi/IP</th>
<th>L Hz/cm²</th>
<th>Stored energy MJ</th>
<th>L Int fb⁻¹ 4 TeV</th>
<th>L Int fb⁻¹ 3.5 TeV</th>
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<tr>
<td>160</td>
<td>0.3</td>
<td>150 ns</td>
<td>150 ns</td>
<td>368</td>
<td>1.2</td>
<td>2.5</td>
<td>0.006</td>
<td>~5.2e32</td>
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<td>~2.1</td>
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<td>135</td>
<td>0.2</td>
<td>75 ns</td>
<td>75 ns</td>
<td>936</td>
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<td>0.006</td>
<td>~1.3e33</td>
<td>~75</td>
<td>~3</td>
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<tr>
<td>125</td>
<td>0.15</td>
<td>50 ns</td>
<td>50 ns</td>
<td>1404</td>
<td>1.2</td>
<td>2.5</td>
<td>0.006</td>
<td>~2e33</td>
<td>~110</td>
<td>~3.2</td>
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July 26, 2011

Possible integrated Luminosity of 2-3 fb-1
First Record Fill of 2011 (on March 23)

Physics re-established with 75ns and increasing the number of bunches,

ATLAS Online Luminosity $\sqrt{s} = 7$ TeV * Z

- LHC All
- LHC Stable

8 days into the run
Summary of week 14 & part of 15

Scrubbing run

J. Uythoven, J. Wenninger, G. Arduini, B. Holzer, R. Assmann

Decision: Continue physics with 50ns
3rd Period: Goal to increase the number of bunches to 900

Issues encountered with Higher Intensities

• Requires much finer control of the beam parameters
  – Chromaticity, gain of feedback and use of Landau octupoles
  – Injection quality

• Many more UFOs: not yet serious
LHC precision front

- absolute luminosity normalization
- low, well understood backgrounds
- precision optics for ATLAS-ALFA and TOTEM

precise measurement of the luminous region + beam intensity --> absolute luminosity and cross section calibration

currently ~ 3.5% level precision
21 May: 912 bunches at 3.5TeV
Sunday morning May 22: $1.1 \times 10^{33} \text{ cm}^{-2} \text{s}^{-1}$
Introduced luminosity leveling for LHCb \(\rightarrow\) can run at optimal \(\mu\) and \(L_{\text{max}}\)

\[ L \sim 3 \cdot 10^{32} \text{ cm}^{-2} \text{s}^{-1} \text{ with } \mu \sim 1.5 \]
Continue to 1380 Bunches

- Reached 1380 (max possible with 50ns) on 28 June fill 1901
Topics

• LHC progress in 2011

• Prospects in the Short term (2\textsuperscript{nd} half 2011)

• Mid Term Prospects (2014-2021)

• Long Term Prospects (2022--....)
Schedule: 2\textsuperscript{nd} Half 2011

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<th>Sep</th>
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<td>Su</td>
<td>32</td>
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- **技术和停止**
- **Recommissioning with beam**
- **Machine development**
- **Ion run**
- **Ion setup**

- **Injectors - proton physics**

**Special runs (TOTEM etc.) to be scheduled**

**Ion Beam to SPS**

**Start ion physics**

**End non-LHC proton physics**

**End ion run**

**Xmas eve (comp)**

**Xmas Day**

July 26, 2011  
S. Myers, HEP2011, Grenoble
Mid Year performance Review
“mini-Chamonix”
(July 15)

The workshop will examine the possible performance improvement options available during the rest of the LHC's 2011 proton run. It will also consider the experiments' requirements and potential limitations from hardware and beam related phenomena. **The principle aim to arrive at a strategy for maximizing the delivered luminosity by the end of the year.** The results from, and plans for, machine development will be considered where the knowledge gained might impact the above goal.
Luminosity comparisons are wrt 1380 bunch operation with 1.1E11ppb, emittance 2.7um, beta* = 1.5, Lumi = 1.2E33

<table>
<thead>
<tr>
<th>Parameter and Criteria</th>
<th>adiabatic?</th>
<th>Estimated Max Lumi Improvement Factor</th>
<th>Lost Time for physics (days)</th>
<th>Risk/Reversibility</th>
<th>Pile-up</th>
<th>Cumulative Improvement factor (50ns)</th>
<th>Cumulative Improvement factor (25ns)</th>
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<td>beta*</td>
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<td>1.5</td>
<td>3</td>
<td>&gt;0</td>
<td>higher</td>
<td>Yes</td>
<td>Yes</td>
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<tr>
<td>25ns</td>
<td>No</td>
<td>1.9</td>
<td>10</td>
<td>&gt;0</td>
<td>same</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

\[ L = \frac{n_b \cdot N_{bunch1} \cdot N_{bunch2} \cdot f_{rev} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)}{4\pi \cdot \beta \cdot \varepsilon_n} \]

Luminosity Factor 4.1 2.9
Pile Up 28 10
Estimated Relative Integrated Luminosity 307 185

Relative Integrated Luminosity if we do nothing 90
Conclusion

• Continue with 50ns
  – Operate with minimum emittance (2um)
  – Adiabatically increase the bunch intensity (max $1.55 \times 10^{11}$)
  – ? Reduce beta* to 1m (LATER after next Technical Stop)
Luminosity comparisons are wrt 1380 bunch operation with 1.1E11ppb, emittance 2.7um, beta* = 1.5, Lumi = 1.2E33

<table>
<thead>
<tr>
<th>Parameter and Criteria</th>
<th>adiabatic?</th>
<th>Estimated Max Lumi Improvement Factor</th>
<th>Lost Time for physics (days)</th>
<th>Risk/Reversibility</th>
<th>Pile-up</th>
<th>Available Improvement factor (50ns)</th>
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<td>0</td>
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<td>emittance</td>
<td>yes</td>
<td>1.35</td>
<td>0</td>
<td>0</td>
<td>higher</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>beta*</td>
<td>No</td>
<td>1</td>
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<td>Yes</td>
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<tr>
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<td>1.9</td>
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<td>same</td>
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<td>Yes</td>
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\[ L = \frac{n_b \cdot N_{bunch1} \cdot N_{bunch2} \cdot f_{rev} \cdot R(\phi, \beta^*, \epsilon_n, \sigma_s)}{4\pi \cdot \beta^* \cdot \epsilon_n} \]

- **Luminosity Factor**: 2.7, 1.9
- **Pile Up**: 19, 7
- **Estimated Relative Integrated Luminosity**: 209, 124
- **Relative Integrated Luminosity if we do nothing**: 90
Emittances – start of fill

Goal: minimum achievable from injectors

Since mini Chamonix
Since mini Chamonix
Since mini Chamonix
Up-to-Date Performance Plots
Peak Luminosity

ATLAS Online Luminosity \( \sqrt{s} = 7 \text{ TeV} \)

- LHC All
- LHC Stable

Many fills above 10\(^{33}\) cm\(^{-2}\) s\(^{-1}\)
Best Fill

![Graph showing ATLAS Online Luminosity over time.](image)

- **ATLAS Online Luminosity**
  - LHC Delivered All
  - LHC Delivered Stable
  - ATLAS Ready Recorded

**S. Myers, HEP2011, Grenoble**
Daily Integrated Luminosity (22/7)

- Average 26pb^{-1} per physics day

ATLAS Online Luminosity \( \sqrt{s} = 7 \text{ TeV} \)

- LHC Delivered All
- LHC Delivered Stable
- ATLAS Ready Recorded

Day in 2011: 26/02, 27/03, 25/04, 25/05, 23/06, 23/07
Weekly Integrated Luminosity

ATLAS Online Luminosity

- LHC Delivered All
- LHC Delivered Stable
- ATLAS Ready Recorded

$\sqrt{s} = 7$ TeV

Day in 2011
# Evolution of Peak Performances to date

25th July 2011

<table>
<thead>
<tr>
<th>Fill Number</th>
<th>Date</th>
<th>Bunch Spacing</th>
<th>Number of Bunches</th>
<th>Peak Luminosity ((10^{33}\text{ cm}^{-2}\text{s}^{-1}))</th>
<th>Total Number of protons per beam ((10^{14}))</th>
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<tr>
<td>1635</td>
<td>18 March 2011</td>
<td>75</td>
<td>32</td>
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<td>0.04</td>
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<td>1637</td>
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<td>75</td>
<td>64</td>
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<td>1644</td>
<td>22 March 2011</td>
<td>75</td>
<td>136</td>
<td>0.17</td>
<td>0.16</td>
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<td>1645</td>
<td>22 March 2011</td>
<td>75</td>
<td>200</td>
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<td>1712</td>
<td>15 April 2011</td>
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<td>228</td>
<td>0.24</td>
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<td>1716</td>
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<td>50</td>
<td>336</td>
<td>0.35</td>
<td>0.42</td>
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<td>26 April 2011</td>
<td>50</td>
<td>480</td>
<td>0.51</td>
<td>0.58</td>
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<td>1749</td>
<td>30 April 2011</td>
<td>50</td>
<td>624</td>
<td>0.72</td>
<td>0.76</td>
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<td>1755</td>
<td>02 May 2011</td>
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<td>768</td>
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<td>0.93</td>
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<td>912</td>
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<td>1.15</td>
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<td>1092</td>
<td>1.27</td>
<td>1.33</td>
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<td>50</td>
<td>1236</td>
<td>1.25</td>
<td>1.64</td>
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<td>1970</td>
<td>23 July 2011</td>
<td>50</td>
<td>1380</td>
<td>1.75</td>
<td>1.65</td>
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### Records as of July 25

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<thead>
<tr>
<th>Category</th>
<th>Value</th>
<th>Fill/Date</th>
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<tbody>
<tr>
<td>Peak Stable Luminosity Delivered</td>
<td>$1.75 \times 10^{33}$</td>
<td>11/07/23, 20:31</td>
</tr>
<tr>
<td>Maximum Luminosity Delivered in one fill</td>
<td>62.85 pb$^{-1}$</td>
<td>Fill 1970</td>
</tr>
<tr>
<td>Maximum Luminosity Delivered in one day</td>
<td>62.85 pb$^{-1}$</td>
<td>Monday 27 June, 2011</td>
</tr>
<tr>
<td>Maximum Luminosity Delivered in 7 days</td>
<td>242.32 pb$^{-1}$</td>
<td>Wednesday 08 June, 2011 - Tuesday 14 June, 2011</td>
</tr>
<tr>
<td>Maximum Colliding Bunches</td>
<td>1331</td>
<td>Fill 1956</td>
</tr>
<tr>
<td>Maximum Peak Events per Bunch Crossing</td>
<td>14.01</td>
<td>Fill 1732</td>
</tr>
<tr>
<td>Maximum Average Events per Bunch Crossing</td>
<td>8.93</td>
<td>Fill 1644</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for one fill</td>
<td>19.2 hours</td>
<td>Fill 1900</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for one day</td>
<td>19.9 hours (82.9%)</td>
<td>Monday 27 June, 2011</td>
</tr>
<tr>
<td>Longest Time in Stable Beams for 7 days</td>
<td>93.0 hours (55.4%)</td>
<td>Thursday 21 April, 2011 - Wednesday 27 April, 2011</td>
</tr>
<tr>
<td>Fastest Turnaround to Stable Beams</td>
<td>2.4 hours</td>
<td>Fill 1718</td>
</tr>
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</table>

July 26, 2011

S. Myers, HEP2011, Grenoble
Integrated Luminosity (25/7)

2011 Luminosity Production

Delivered Luminosity for All Experiments = 3611.0 pb⁻¹

- ATLAS: 1552 pb⁻¹
- ALICE: 2.7 pb⁻¹
- CMS: 1545 pb⁻¹
- LHCb: 510 pb⁻¹

Integrated Luminosity (pb⁻¹)
Some Concerns with High Intensity
<table>
<thead>
<tr>
<th>Date</th>
<th>Mode</th>
<th>Fill</th>
<th>SB</th>
<th>pb⁻¹</th>
<th>Cause of dump</th>
</tr>
</thead>
<tbody>
<tr>
<td>MON 18</td>
<td>STABLE BEAMS</td>
<td>1955</td>
<td>6h8m</td>
<td>18.3</td>
<td>QPS trigger, trip of RQTL7.L7B1</td>
</tr>
<tr>
<td>MON 18</td>
<td>STABLE BEAMS</td>
<td>1956</td>
<td>17m</td>
<td>.4</td>
<td>Cryo lost S56, SEU on a thermometer at a current lead</td>
</tr>
<tr>
<td>MON 18</td>
<td>ADJUST</td>
<td>1957</td>
<td>0</td>
<td>0</td>
<td>Dumped by SW interlock on BLM HV channel (1.3e11/bunch)</td>
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<tr>
<td>MON 18</td>
<td>STABLE BEAMS</td>
<td>1958</td>
<td>21m</td>
<td>1.1</td>
<td>Loss of cryogenic conditions in Sector 34 – PLC crash</td>
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<td>WEDS 20</td>
<td>STABLE BEAMS</td>
<td>1960</td>
<td>1h9m</td>
<td>5.2</td>
<td>Problem on valve on DFB in arc 8.1 Possible SEU</td>
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<td>WEDS 20</td>
<td>STABLE BEAMS</td>
<td>1961</td>
<td>2h7m</td>
<td>8.2</td>
<td>QPS - blown fuse in WorldFIP repeater</td>
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<td>THURS 21</td>
<td>STABLE BEAMS</td>
<td>1962</td>
<td>15h26</td>
<td>46.3</td>
<td>CMS BCM2</td>
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<tr>
<td>FRI 22</td>
<td>SQUEEZE</td>
<td>1963</td>
<td>0</td>
<td>0</td>
<td>QTF trip: QFB versus QPS</td>
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<tr>
<td>FRI 22</td>
<td>RAMP</td>
<td>1964</td>
<td>0</td>
<td>0</td>
<td>RCBXH.R1 tripped, PC changed</td>
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<tr>
<td>FRI 22</td>
<td>STABLE BEAMS</td>
<td>1966</td>
<td>8.56</td>
<td>34.6</td>
<td>CMS BCM2</td>
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<td>SAT 23</td>
<td>STABLE BEAMS</td>
<td>1967</td>
<td>11.4</td>
<td>41.7</td>
<td>Valve controller IT.R1 – possible SEU</td>
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## The Last Week 2/2

<table>
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<tr>
<th>Date</th>
<th>Mode</th>
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<th>SB</th>
<th>pb⁻¹</th>
<th>Cause of dump</th>
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<tr>
<td>Sat 23</td>
<td>STABLE BEAMS</td>
<td>1968</td>
<td>46m</td>
<td>4.0</td>
<td>Electrical network glitch</td>
</tr>
<tr>
<td>Sat 23</td>
<td>ADJUST</td>
<td>1969</td>
<td>0</td>
<td>1.8e33!</td>
<td>Vacuum spike 4L8</td>
</tr>
<tr>
<td>Sun 24</td>
<td>STABLE BEAMS</td>
<td>1970</td>
<td>1h37m</td>
<td>9.5</td>
<td>Vacuum spike 4L8</td>
</tr>
<tr>
<td>Sun 24</td>
<td>STABLE BEAMS</td>
<td>1971</td>
<td>1h8m</td>
<td>6.2</td>
<td>Controller IT5, Possible SEU</td>
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<td>Sun 24</td>
<td>STABLE BEAMS</td>
<td>1972</td>
<td>46m</td>
<td>4.4</td>
<td>Cryo – R1 24V supply, Possible SEU</td>
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<tr>
<td>Sun 24</td>
<td>FLAT TOP</td>
<td>1973</td>
<td>-</td>
<td>-</td>
<td>QPS communication problem</td>
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<td>Sun 24</td>
<td>STABLE BEAMS</td>
<td>1974</td>
<td>5h15</td>
<td>25.5</td>
<td>Electrical network glitch</td>
</tr>
</tbody>
</table>

7 SEUs in one week, is becoming a serious issue. Mostly luminosity dependant.
Beam intensity and vacuum (4L8)
Present “Issues”

• SEUs (dependent on total intensity and luminosity)
• UFOs (not intensity dependent)
  – Not serious for the moment (at 3.5TeV/beam but...)
• HOM heating of Injection kickers, cryo, collimators.. (total intensity and bunch length dependence)
• Vacuum instabilities at very high bunch intensities (adiabatic) ? Proton losses causing heating and desorption
• Steering beams into collision (LHCb) often provoked serious reductions in beam lifetime (beam dumps)
Topics

• LHC progress in 2011

• Prospects in the Short term (2012)
  • Protons and ions

• Mid Term Prospects (2014-2021)

• Long Term Prospects (2022--....)
Physics data-taking until end of 2012

- 50ns or 25 ns
  - For peak luminosity, 50ns is still higher due to the better performance beams from the injectors. But... event pile-up?
  - Very high intensity operation at 50ns may need beam scrubbibng with 25ns
- beam energy
  - Following measurements of the copper stabilizers resistances during the Christmas stop, we will re-evaluate the maximum energy for 2012 (Chamonix 2012)
Short term (ions)

Lead-lead for 4-5 weeks at end of 2011 with increased number of bunches and luminosity

Feasibility Test end 2011 for protons-lead (possibly 2012)

If feasible protons-lead in 2012 otherwise continue with lead-lead. Can profit from any energy increase for the protons
Topics

• LHC progress in 2011

• Prospects in the Short term (2011—2012)

• Mid Term Prospects (2014-2021)

• Long Term Prospects (2022--....)
LS1 then operation around 7TeV/beam

LS1

- Repair defectuous interconnects
- Consolidate all interconnects with new design
- Finish off pressure release valves (DN200)
- Bring all necessary equipment up to the level needed for 7TeV/beam
- Not necessary to install the DS collimators in IR3
- Experiments consolidation/upgrades
LHC MB circuit splice consolidation proposal

Phase I
Surfacing of bus bar and installation of redundant shunts by soldering

Phase II
Application of clamp and reinforcement of nearby bus bar insulation

Phase III
Insulation between bus bar and to ground, Lorentz force clamping

July 26, 2011
S. Myers, HEP2011, Grenoble
Not yet approved!

New rough draft 10 year plan

--- | --- | --- | --- | --- | --- | ---

**LHC**
- LS1
  - Machine: Splice Consolidation & Collimation in IR3
  - ALICE - detector completion
  - ATLAS - Consolidation and new forward beam pipes
  - CMS - FWD muons upgrade + Consolidation & Infrastructure
  - LHCb - consolidations
  - Cryo-collimation point

**Injectors**
- SPS upgrade
- ? SPS - LINAC4 connection & ? PSB energy upgrade

---

--- | --- | --- | --- | --- | ---

**LHC**
- LS2
  - Machine: Collimation & prepare for Crab cavities & RF cryo system
  - ATLAS: new pixel detector - detect for ultimate luminosity.
  - ALICE - Inner vertex system
  - CMS - New Pixel, New HCAL Photodetectors. Completion of FWD-muons upgrade
  - LHCb - full trigger upgrade, new vertex detector etc.

**Injectors**

---

2022

**LS3**
- Installation of the HL-LHC hardware.
- Installation of LHeC
- Preparation for HE-LHC

---

July 26, 2011

S. Myers, HEP2011, Grenoble
Possible Luminosity Evolution: optimistic to 2012, then prudent

Shown by Lucio Rossi last Saturday
Not yet validated by LMC or Directorate
Topics

• LHC progress in 2011

• Prospects in the Short term (2011—2012)

• Mid Term Prospects (2014-2021)

• Long Term Prospects (2022--....)
### New rough draft 10 year plan

**Not yet approved!**

#### LHC

<table>
<thead>
<tr>
<th></th>
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- **LS1**
  - Machine: Splice Consolidation & Collimation in IR3
  - ALICE: detector completion
  - ATLAS: Consolidation and new forward beam pipes
  - CMS: FWD muons upgrade + Consolidation & Infrastructure
  - LHCb: consolidations
  - Cryo-collimation point

- **X Maxwell maintenance**

#### Injectors

- **SPS upgrade**

- **? SPS - LINAC4 connection & ? PSB energy upgrade**

---

#### LHC

<table>
<thead>
<tr>
<th>Year</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
<th>2022</th>
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<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **LS2**
  - Machine: Collimation & prepare for crab cavities & RF cryo system
  - ATLAS: new pixel detector - detect for ultimate luminosity
  - ALICE: Inner vertex system
  - LHCb: full trigger upgrade, new vertex detector etc.

- **X Maxwell maintenance**

#### Injectors

- **? SPS - LINAC4 connection & ? PSB energy upgrade**

---

**July 26, 2011**

S. Myers, HEP2011, Grenoble
Longer Term

HL-LHC

LHeC

HE-LHC
HL-LHC
Luminosity Upgrade Scenario

- For LHC high luminosities, the luminosity lifetime becomes comparable with the turn round time ⇒ Low efficiency
- Preliminary estimates show that the useful integrated luminosity is greater with
  - a peak luminosity of $5 \times 10^{34}$ cm$^{-2}$ s$^{-1}$ and a longer luminosity lifetime (by luminosity levelling)
  - than with $10^{35}$ and a luminosity lifetime of a few hours
- Luminosity Levelling by
  - Beta*, crossing angle, crab cavities, and bunch length
  - ??? Off steering
- Goal 200-300fb$^{-1}$ per year
Hardware for the Upgrade

- New high field insertion quadrupoles
- Upgraded cryo system for IP1 and IP5
- Upgrade of the intensity in the Injector Chain (LIU)
- Crab Cavities to take advantage of the small beta*
- Single Event Upsets
  - SC links to allow power converters to be moved to surface
- Misc
  - Upgrade some correctors
  - Re-commissioning DS quads at higher gradient
  - Change of New Q5/Q4 (larger aperture), with new stronger corrector orbit, displacements of few magnets
  - Larger aperture D2
## Draft Parameters HL-LHC

### Results from Injectors Upgrades

<table>
<thead>
<tr>
<th>Parameter</th>
<th>nominal</th>
<th>25ns</th>
<th>50ns</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>1.15E+11</td>
<td>2.0E+11</td>
<td>3.6E+11</td>
</tr>
<tr>
<td>( n_b )</td>
<td>2808</td>
<td>2808</td>
<td>2808</td>
</tr>
<tr>
<td>beam current [A]</td>
<td>0.58</td>
<td>1.02</td>
<td>1.34</td>
</tr>
<tr>
<td>x-ing angle [( \mu \text{rad} )]</td>
<td>300</td>
<td>475</td>
<td>580</td>
</tr>
<tr>
<td>beam separation [( \sigma )]</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>( \beta^* ) [m]</td>
<td>0.55</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>( \varepsilon_n ) [( \mu \text{m} )]</td>
<td>3.75</td>
<td>2</td>
<td>3.75</td>
</tr>
<tr>
<td>( \varepsilon_L ) [eVs]</td>
<td>2.51</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>energy spread</td>
<td>1.00E-04</td>
<td></td>
<td>1.00E-04</td>
</tr>
<tr>
<td>bunch length [m]</td>
<td>7.50E-02</td>
<td>0.7</td>
<td>7.50E-02</td>
</tr>
<tr>
<td>IBS horizontal [h]</td>
<td>80 -&gt; 106</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>IBS longitudinal [h]</td>
<td>61 -&gt; 60</td>
<td></td>
<td>21</td>
</tr>
<tr>
<td>Piwinski parameter</td>
<td>0.68</td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>geom. reduction</td>
<td>0.83</td>
<td></td>
<td>0.37</td>
</tr>
<tr>
<td>beam-beam / IP</td>
<td>3.10E-03</td>
<td></td>
<td>3.9E-03</td>
</tr>
<tr>
<td>Peak Luminosity</td>
<td>1 ( 10^{34} )</td>
<td>7.4 ( 10^{34} )</td>
<td>6.8 ( 10^{34} )</td>
</tr>
</tbody>
</table>

### Events / crossing

|           | 19 | 141 | 257 | 95 | 190 |

5.6 \( 10^{14} \) and 4.6 \( 10^{14} \) p/beam

OK for HL goals, if CRAB cavities are a viable option

(Leveled to \( 5 \times 10^{34} \) cm\(^{-2}\) s\(^{-1}\))
LHeC options: RR and LR

RR LHeC:
- new ring in LHC tunnel, with bypasses around experiments
- e-/e+ injector
- 10 GeV
- 10 min. filling time

LR LHeC:
- recirculating linac with energy recovery, or straight linac

July 23, 2011
S. Myers
ECFA-EPS, Grenoble
### Design Parameters

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>LR</th>
<th>LR*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>electron beam</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>e- energy at IP [GeV]</td>
<td>60</td>
<td>60</td>
<td>140</td>
</tr>
<tr>
<td>luminosity [10^{32} cm^{-2}s^{-1}]</td>
<td>17</td>
<td>10</td>
<td>0.44</td>
</tr>
<tr>
<td>polarization [%]</td>
<td>40</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>bunch population [10^{9}]</td>
<td>26</td>
<td>2.0</td>
<td>1.6</td>
</tr>
<tr>
<td>e- bunch length [mm]</td>
<td>10</td>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>bunch interval [ns]</td>
<td>25</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>transv. emit. γ_{x,y} [mm]</td>
<td>0.58, 0.29</td>
<td>0.05</td>
<td>0.1</td>
</tr>
<tr>
<td>rms IP beam size σ_{x,y} [μm]</td>
<td>30, 16</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>e- IP beta funct. β^*_ {x,y} [m]</td>
<td>0.18, 0.10</td>
<td>0.12</td>
<td>0.14</td>
</tr>
<tr>
<td>full crossing angle [mrad]</td>
<td>0.93</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>geometric reduction H_{hg}</td>
<td>0.77</td>
<td>0.91</td>
<td>0.94</td>
</tr>
<tr>
<td>repetition rate [Hz]</td>
<td>N/A</td>
<td>N/A</td>
<td>10</td>
</tr>
<tr>
<td>beam pulse length [ms]</td>
<td>N/A</td>
<td>N/A</td>
<td>5</td>
</tr>
<tr>
<td>ER efficiency</td>
<td>N/A</td>
<td>94%</td>
<td>N/A</td>
</tr>
<tr>
<td>average current [mA]</td>
<td>131</td>
<td>6.6</td>
<td>5.4</td>
</tr>
<tr>
<td>tot. wall plug power [MW]</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>RR</th>
<th>LR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>proton beam</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bunch pop. [10^{11}]</td>
<td>1.7</td>
<td>1.7</td>
</tr>
<tr>
<td>tr.emit. γ_{x,y} [μm]</td>
<td>3.75</td>
<td>3.75</td>
</tr>
<tr>
<td>spot size σ_{x,y} [μm]</td>
<td>30, 16</td>
<td>7</td>
</tr>
<tr>
<td>β^*_ {x,y} [m]</td>
<td>1.8, 0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>bunch spacing [ns]</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

“ultimate p beam”
1.7 probably conservative

Design also for deuterons (new) and lead (exists)

RR = Ring – Ring
LR = Linac – Ring

Ring uses 1° as baseline : L/2
Linac: clearing gap: L*2/3

*) pulsed, but high energy ERL not impossible
LHeC Tentative Time Schedule

We base our estimates for the project timeline on the experience of other projects, such as (LEP, LHC and LINAC4 at CERN and the European XFEL at DESY and the PSI XFEL)
HE-LHC

First Thoughts on an Energy Upgrade
HE-LHC – LHC modifications

HE-LHC 2030-33

SPS+, 1.3 TeV, 2030-33

2-GeV Booster

Linac4
## Very Long Term Objectives: Higher Energy LHC

### Preliminary HE-LHC - parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Normal LHC</th>
<th>HE-LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>beam energy [TeV]</td>
<td></td>
<td>16.5</td>
</tr>
<tr>
<td>dipole field [T]</td>
<td></td>
<td>20</td>
</tr>
<tr>
<td>dipole coil aperture [mm]</td>
<td></td>
<td>40-45</td>
</tr>
<tr>
<td>#bunches / beam</td>
<td></td>
<td>1404</td>
</tr>
<tr>
<td>bunch population [10^{11}]</td>
<td></td>
<td>1.29</td>
</tr>
<tr>
<td>initial transverse normalized emittance [μm]</td>
<td></td>
<td>3.75 (x), 1.84 (y)</td>
</tr>
<tr>
<td>number of IPs contributing to crossings</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>maximum total beam momentum</td>
<td>0.01</td>
<td>0.01</td>
</tr>
<tr>
<td>IP beta function [m]</td>
<td>0.55</td>
<td>1.0 (x), 0.43 (y)</td>
</tr>
<tr>
<td>full crossing angle</td>
<td>285 (9.5 σ_{x,y})</td>
<td>175 (12 σ_{x,0})</td>
</tr>
<tr>
<td>stored beam momentum</td>
<td>362</td>
<td>479</td>
</tr>
<tr>
<td>SR power</td>
<td>3.6</td>
<td>62.3</td>
</tr>
<tr>
<td>longitudinal damping time [h]</td>
<td>12.9</td>
<td>0.98</td>
</tr>
<tr>
<td>events per crossing</td>
<td>19</td>
<td>76</td>
</tr>
<tr>
<td>peak luminosity [10^{33} cm^{-2}s^{-1}]</td>
<td>1.0</td>
<td>2.0</td>
</tr>
<tr>
<td>beam lifetime [μs]</td>
<td>46</td>
<td>13</td>
</tr>
<tr>
<td>integrated luminosity over 10 h [fb^{-1}]</td>
<td>0.3</td>
<td>0.5</td>
</tr>
</tbody>
</table>

*Very preliminary with large error bars*
HE-LHC – main issues and R&D

- high-field 20-T dipole magnets based on Nb$_3$Sn, Nb$_3$Al, and HTS
- high-gradient quadrupole magnets for arc and IR
  - fast cycling SC magnets for 1-TeV injector
- emittance control in regime of strong SR damping and IBS
- cryogenic handling of SR heat load (first analysis; looks manageable)
  - dynamic vacuum
Summary on Future Prospects

- LHC Upgrades: 3 very interesting projects
  1. HL-LHC (approved) and needs LIU (approved)
  2. LHeC (CDR published, and will be reviewed by ECFA and CERN in October 2011)
  3. HE-LHC (project pre-study under way)
- Linear Colliders ILC/CLIC
- Proposal for next energy frontier project will be dependant on the physics output from the LHC until end 2012
LHC present status Summary

- Beam Intensity, peak and Integrated luminosity still going up very (quite) rapidly
- Successfully implemented luminosity leveling for LHCb and luminosity calibration (vdM scans)
- We reached our 2011 target integrated luminosity, with ~16 weeks still to go, and will certainly produce more barring accidents
- However, progress from here on will be slower due to many simultaneous issues limiting the total intensity
- Conclusions. We are way ahead of the game, and the future is bright. But Euphoria is dangerous
- We must remain extremely vigilant with protection of the machine (100MJ of stored energy) and hope that there are no more old unexploded bombs in the hardware!!
Thanks to the dedication of the CERN staff and the many excellent collaborators from around the world who pulled together to make this performance possible.

BRAVO!
 Beam parameters at LHC injection [50 ns] 

<table>
<thead>
<tr>
<th>Beam Parameters at 7 TeV</th>
<th>LIU baseline goal</th>
<th>LIU stretched* goal</th>
</tr>
</thead>
<tbody>
<tr>
<td>H/V transverse emittances [mm.mrad]</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Bunch intensity within constant longitudinal emittance [x10^{11} p/b]</td>
<td>2.8</td>
<td>3.3</td>
</tr>
<tr>
<td>PSB</td>
<td>2.9</td>
<td>3.2</td>
</tr>
</tbody>
</table>

* Feasible for the SPS injectors…

LIU baseline goal
LIU stretched* goal

Beam Parameters at 7 TeV

Sterbini (LHC CC10)
Fartoukh (Chamonix11)
Bruning (Chamonix11)
Zimmermann (Chamonix11)
Beam parameters at LHC injection [50 ns]

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<tr>
<td>SPS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PS</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PSB</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MD: single bunch with low $\gamma_t$

* Feasible for the SPS injectors...
Beam parameters at LHC injection [25 ns]

<table>
<thead>
<tr>
<th>Intensity/bunch [x 1E11]</th>
<th>Transverse emittances [mm.mrad rms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>1.8</td>
</tr>
<tr>
<td>PS 3.5</td>
<td>2.0</td>
</tr>
<tr>
<td>PSB</td>
<td>2.1</td>
</tr>
</tbody>
</table>

LIU baseline goal
LIU stretched* goal

* Feasible for the SPS injectors…

Beam Parameters at 7 TeV
Beam parameters at LHC injection [25 ns]

<table>
<thead>
<tr>
<th></th>
<th>Intensity/bunch [x 1E11]</th>
<th>Transverse emittances [mm.mrad rms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>SPS</td>
<td>1.8</td>
<td>2.5</td>
</tr>
<tr>
<td>PS 3.5</td>
<td>2.0</td>
<td>2.4</td>
</tr>
<tr>
<td>PSB</td>
<td>2.1</td>
<td>2.3</td>
</tr>
</tbody>
</table>

LIU baseline goal
LIU stretched* goal
Beam Parameters at 7 TeV
MD: double PSB batch (?)
MD: single bunch with low $\gamma_t$

* Feasible for the SPS injectors...
Luminosity (round beams):

\[
L = \frac{n_b \cdot N_{bunch,1} \cdot N_{bunch,2} \cdot f_{rev}}{4\pi \cdot \beta^* \cdot \varepsilon_n} \cdot R(\phi, \beta^*, \varepsilon_n, \sigma_s)
\]

1) maximize bunch brightness \([N_{bunch}/\varepsilon_n]\) 
   beam-beam limit and injector complex performance
2) minimize beam size \([\beta^*]\) (constant beam power)
3) maximize number of bunches (beam power limit)
4) compensate for ‘R’
LHC Challenges: R

geometric luminosity reduction factor:

\[ R_\theta = \frac{1}{\sqrt{1 + \Theta^2}} \; ; \; \Theta \equiv \frac{\theta_c \sigma_z}{2\sigma_x} \]

large crossing angle:

- reduction of long range beam-beam interactions
- reduction of head-on beam-beam parameter
- reduction of the mechanical aperture
- synchro-betatron resonances
- reduction of instantaneous luminosity
  - inefficient use of beam current
  - option for L leveling!
On average 8 UFOs/hour.
Is there a conditioning effect?

2301 candidate UFOs (excluding MKI UFOs) during stable beams in fills with at least 1 hour stable beams.
all UFOs: Signal RS05 > 2·10^{-4} Gy/s.
Data scaled with 1.85 (detection efficiency from reference data)
• **Ufo amplitude:** Linear dependency of BLM signal on beam energy observed (from wire scans).

  \[(\text{cf. M. Sapinski at Chamonix 2011})\]

• **BLM Thresholds:** Arc Thresholds at 7 TeV are about a factor 5 smaller than at 3.5 TeV.

• **UFO rate:**
  - At 450 GeV: extremely rare.
  - During 1.38 TeV run: 3 UFOs in 36.5 h.
  - At 3.5 TeV: 8 UFOs/h.
The number of MKI UFOs is much higher in Pt. 2 for the last few fills.
In the last physics fills many MKI UFOs with large amplitudes occurred with a high rate. No obvious change found to explain this.
Most MKI UFOs occur shortly after the last injections.
• For 2010: 113 UFOs below threshold found in logging database.
  (E. Nebot)

• For 2011: Online UFO detection by **UFO Buster**.

  *Detects UFOs in BLM concentrator data (1Hz).*

• **5000 UFOs** below threshold found so far.

  *Most events are much below threshold.*

“threshold” = lowest threshold in standard arc cell.
The UFOs are distributed all around the machine. About 7% of all UFOs are around the MKIs.

**53 candidate UFOs at MKI for Beam 2.**

gray areas around IRs are excluded from UFO detection.

Mainly UFOs around MKIs
On average: **10 UFOs/hour**

1510 candidate UFOs during stable beams. Signal $RS05 > 2 \cdot 10^{-4}$ Gy/s. Data scaled with 1.76 (detection efficiency from reference data)
• **679 UFOs** around the MKIs caused **9 beam dumps**.

Most of the UFOs around the MKIs occur before going to stable beams.
Event of 7\textsuperscript{th} April

- Thursday afternoon (7\textsuperscript{th} April) all powering was stopped in the LHC following the discovery of a worrying cabling problem affecting the QPS system protecting the HTS current leads.
- Followed by an extensive verification campaign.
- Lost about 2 days.
HTS quench (sc link)- what happened

- QPS tripped the RB circuit in sector 45 on Thursday around 07:00.
  *First time ever quench of HTS current lead*

- The HTS quenched due to a lack of cooling in the DFB
  - Faulty electronics board corrupted the temperature feedback loop

- Protection by the QPS monitoring the current leads.
  - Logging of the two HTS signals showed that only one of the two measurements was correct, the other was measuring a short circuit

- An identical fault on the redundant signal would have left the system unprotected and could lead to beyond repair damage to the DFB. No spares

- Decided to stop powering magnets
  - To validate other circuits
QPS signals monitoring the HTS

One of the signals is not correct!

Ures Uhts redundant signals, logging swaps every 30 s from board A to board B
What was swapped…?

What was found swapped in RB.A45, Lead#2 on DFBAI (L5)?
EE22 (pin 15) and EE42 (pin 16) of cable between PE and QPS controller.

This connection had been like this since 2005.

Are all connections like this?

Stop operation until all connections are verified.

S. Myers, HEP2011, Grenoble

July 26, 2011
Analysis of the logging data from old ramps allowed the QPS team to verify the correctness of the signals for other 13 kA circuits.

- Verification of U_RES & U_HTS on all IPQs, IPDs, ITs using dedicated powering cycles by the QPS team
- Verification of boards A & B

Example of a healthy channel: both boards move in unison during a ramp.
In the late afternoon all high current circuits except the 600 A circuits had been checked.
- Acceptable risk for 600 A circuits.
- All tests showed the presence of the expected signals.
- Green light for powering from TE/MPE in the evening.

Among all the high current circuits we happen to quench exactly the one circuit with a cabling problem!!
Event of 18th April

- Flashover (high voltage breakdown) on B2 MKI magnet D (first one seen by the beam) while injecting 72b

- Extensive beam losses through P8 and arc 78: result
  - Kicker interlocked off
  - Quench heaters fired on 11 magnets
  - Vacuum valves closed

- Several very anxious hours....
<table>
<thead>
<tr>
<th>Date</th>
<th>Time</th>
<th>State</th>
<th>Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>30/05</td>
<td>11h08</td>
<td>Stable beams</td>
<td>QPS trigger circuit detector of RCBXH2.L1. SEU?</td>
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<tr>
<td></td>
<td>15h43</td>
<td>Adjust</td>
<td>New RF interlock not masked</td>
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<td>20h20</td>
<td>Adjust</td>
<td>FMCM. Electrical glitch</td>
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<td>31/05</td>
<td>06h22</td>
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<td>UFO IR2L</td>
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<td>10h38</td>
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<td>22h20</td>
<td>Squeeze</td>
<td>UFO IR2L</td>
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<tr>
<td>01/06</td>
<td>02h10</td>
<td>Squeeze</td>
<td>QPS trigger (Quench of Q9R5 ?)</td>
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<td>06h53</td>
<td>Adjust</td>
<td>RF trip (radiation-induced arc detector signal?)</td>
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<td></td>
<td>09h17</td>
<td>Ramp</td>
<td>Collimator temperature</td>
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<td>20h37</td>
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<td>Collimation crate IR5R failure (PRS)</td>
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<td>02/06</td>
<td>16h58</td>
<td>Beam dump</td>
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<td>21h50</td>
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<td>00h28</td>
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<td>13h30</td>
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<td>Loss of I_meas reading</td>
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<td>18h24</td>
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<td>UFO in IR8R</td>
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<td>21h17</td>
<td>Stable beams</td>
<td>Trip undulator IR4.</td>
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<td>07:56</td>
<td>Stable beams</td>
<td>QPS FIP communication lost, close to IR1. S12 tripped.</td>
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<td>16:19</td>
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<td>Power converter fault.</td>
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<td>Bad current reading on RTQX2.R1</td>
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<td>08/06</td>
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<td>Stable beams</td>
<td>Alice dipole trip</td>
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26 beam dumps at > 450 GeV, only one dumped by OP.

Increase of BLM dump threshold for Q4 (MQY) at MKI’s by factor 2
Bunch length

- Important parameter for
  - Cryogenics stability
  - Collimator heating
  - Injection kicker heating
  - ...

- Work ongoing to improve blow-up control during the ramp by the RF-team
  - Better reproducible results -> test operation with longer bunches
  - Disadvantage is possibly more debunched beam when a cavity trips, but not an issue at the moment
UFO’s: 90 in 90 minutes

Presently 10 per hour on average
Issues with Machine Protection

1. Collimation loss of hierarchy at 450 GeV
   – Due to order in which the loss maps were performed

2. 72 (108/144) bunches
   – Last bunch of previous injection got kicked; low intensity and higher emittance
   – BPMs position calibration is sensitive to bunch intensity
   – Dump interlock measures local position of all bunches

3. HTS quench (7th April) quench of 11 sc magnets

4. Injection Kicker Flashover (18th April)
MD1
Some highlight ...

• MDs prove excellent performance potential of LHC:
  – No head-on beam-beam limit encountered with 3 times nominal brightness. Total tune shift: 0.03 with ATLAS/CMS collisions.
  – New ATS injection optics with different integer tunes tested to 3.5 TeV. Next MD test squeeze
  – Collimation system reached tighter settings with better cleaning efficiency. (results crucial for decision on “cryo collimator system)

• Operational improvements:
  – 90m optics for ALFA and TOTEM works fine.
Beam-beam limit

• Collided high intensity beams (1.7 E11) and small emittances (smaller than 1.5 um) in IP1 and IP5.

• In final attempt reduced vertical tune to end up below 10th order after putting beams in collision. No more blowup observed, tune shifts per IP in excess of 0.015 (with initial emittance below 1.2 um).

• No limit found for head-on beam-beam effects for the intensities investigated so far (no long range yet).
Integrated Luminosity

• Assumptions
  – 90 days left
  – 50ns: 3 days of machine studies followed by 30 days linear increase from present luminosity to max luminosity
  – 25ns: 10 (3+7) days of machine studies followed by 30 days linear increase from zero to max luminosity