The 2011 Run: Availability Analysis

Alick Macpherson
LHC Performance Workshop
Chamonix
6 January 2012

Topics:
- Machine Performance
- Faults and Downtime
- Beam Dumps
Machine Performance
2011 Run: Luminosity Production

**2011 Run: Integrated Luminosity**

- ATLAS: 5.518 fb$^{-1}$
- ALICE: 4.813 pb$^{-1}$
- CMS: 5.601 fb$^{-1}$
- LHCb: 1.197 fb$^{-1}$

First fill: 1613  Last fill: 2261

Proton-Proton: $\sqrt{s} = 7$ TeV
All Experiments $L_{int} = 12.32$ fb$^{-1}$

**2011 Ions Run: Integrated Luminosity**

- ATLAS: 167.6 ub$^{-1}$
- ALICE: 143.6 ub$^{-1}$
- CMS: 149.7 ub$^{-1}$

First fill: 2290  Last fill: 2351

Lead - Lead: $\sqrt{s} = 7$ Z TeV
All Experiments $L_{int} = 460.9$ ub$^{-1}$

**2011 Run: Integrated Luminosity**

ALICE Experiment: 4.813 pb$^{-1}$
Proton-Proton: $\sqrt{s} = 7$ TeV
First fill: 1613  Last fill: 2261
2011 Run: Luminosity Production

- Well above Targets set in Evian 2010
- 2011 Proton Run: **156.6 days** [53.0 days of SB] => **123** \( \times \) (2010 Del Lumi)
- 2011 Ions Run: **28.9 days** [8.0 days of SB] => **16.6** \( \times \) (2010 Del Lumi)
- 1.38 TeV Proton Run: **3.15 days** \( L_{\text{Del}} = 345.1 \text{ mb}^{-1} \)
2011 Run Records

**Proton Run:** From Fill 1542 - 2267  [15th Feb - 30th Oct]
- Most Luminosity delivered in a single Fill: $L_{\text{DEL}} = 123.3 \text{ pb}^{-1}$ in Fill 2219
- Highest Peak Luminosity: $L_{\text{PEAK}} = 3693.88 \text{ (µb.s)}^{-1}$ in Fill 2208
- Longest Stable Beams period: 25 hrs 23 min
- Shortest Stable Beams period: 0 hrs 3 min 47 sec
- Fastest Turnaround [SB->SB]: 2 hrs 7 min
- Fastest Turnaround with 1380 bunches [SB->SB]: 2 hrs 7 min

**Ion Run:** From Fill 2289 - 2352 [11th Nov - 6th Dec]
- Most Luminosity delivered in a single Fill: $L_{\text{DEL}} = 6960.0 \text{ mb}^{-1}$ in Fill 2330
- Highest Peak Luminosity: $L_{\text{PEAK}} = 2010.0 \text{ (b.s)}^{-1}$ in Fill 2294
- Longest Stable Beams period: 8 hrs 4 min
- Shortest Stable Beams period: 0 hrs 20 min 48 sec
- Fastest Turnaround [SB->SB]: 2 hrs 37 min
Performance: Number of Bunches + Bunch Intensity

2011 p-p Run Evolution
Performance: Number of Bunches + Bunch Intensity

2011 p-p Run Evolution

1380 Bunches

Luminosity
Production Phase

Number of Bunches Per Beam

Avg Bunch Intensity [$10^{11}$]
Performance: Number of Bunches + Bunch Intensity

2011 p-p Run Evolution

1380 Bunches

~27%

Luminosity
Production Phase
2011 p-p Run: Luminosity Improvements - Emittance

Peak Luminosity Improvements

Reduced Emittance
2011 p-p Run: Luminosity Improvements - $\beta^*$
### LHC Availability and Performance in 2011

#### 2011 Proton Run: Luminosity Production

<table>
<thead>
<tr>
<th>SB Time: 26.6 days</th>
<th>Total Time: 81.4 days</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>2011 Proton Run</th>
<th>Days</th>
<th>NB %</th>
<th>SET UP %</th>
<th>INJ %</th>
<th>RAMP %</th>
<th>FT+SQ +AD %</th>
<th>SB %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>299.3</td>
<td>25.7</td>
<td>30.5</td>
<td>17.4</td>
<td>1.7</td>
<td>4.3</td>
<td>20.5</td>
</tr>
<tr>
<td>2011-TS</td>
<td>277.9</td>
<td>23.3</td>
<td>29.5</td>
<td>18.7</td>
<td>1.9</td>
<td>4.7</td>
<td>22.0</td>
</tr>
<tr>
<td>p-p</td>
<td>156.6</td>
<td>22.0</td>
<td>20.4</td>
<td>19.2</td>
<td>2.2</td>
<td>3.8</td>
<td>33.8</td>
</tr>
<tr>
<td>p-p LP</td>
<td>81.4</td>
<td>23.6</td>
<td>19.3</td>
<td>18.9</td>
<td>2.0</td>
<td>3.5</td>
<td>32.6</td>
</tr>
<tr>
<td>Pb-Pb</td>
<td>24.1</td>
<td>25.0</td>
<td>20.8</td>
<td>13.6</td>
<td>2.2</td>
<td>5.5</td>
<td>32.9</td>
</tr>
<tr>
<td>MD</td>
<td>33.2</td>
<td>22.9</td>
<td>32.3</td>
<td>36.8</td>
<td>1.2</td>
<td>6.0</td>
<td>0.8</td>
</tr>
<tr>
<td>High β</td>
<td>4.2</td>
<td>6.2</td>
<td>43.7</td>
<td>10.3</td>
<td>3.2</td>
<td>35.4</td>
<td>1.1</td>
</tr>
</tbody>
</table>

*P-p, Pb-Pb runs do not include TS or MD time*
LHC Availability and Performance in 2011

2011 Proton Run: Luminosity Production

<table>
<thead>
<tr>
<th></th>
<th>Days</th>
<th>NB %</th>
<th>SET UP %</th>
<th>INJ %</th>
<th>RAMP %</th>
<th>FT+SQ +AD %</th>
<th>SB %</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>299.3</td>
<td>25.7</td>
<td>30.5</td>
<td>17.4</td>
<td>1.7</td>
<td>4.3</td>
<td>20.5</td>
</tr>
<tr>
<td>2011-TS</td>
<td>277.9</td>
<td>23.3</td>
<td>29.5</td>
<td>18.7</td>
<td>1.9</td>
<td>4.7</td>
<td>22.0</td>
</tr>
<tr>
<td>p-p</td>
<td>156.6</td>
<td>22.0</td>
<td>20.4</td>
<td>19.2</td>
<td>2.2</td>
<td>3.8</td>
<td>33.8</td>
</tr>
<tr>
<td>p-p LP</td>
<td>81.4</td>
<td>23.6</td>
<td>19.3</td>
<td>18.9</td>
<td>2.0</td>
<td>3.5</td>
<td>32.6</td>
</tr>
<tr>
<td>Pb-Pb</td>
<td>24.1</td>
<td>25.0</td>
<td>20.8</td>
<td>13.6</td>
<td>2.2</td>
<td>5.5</td>
<td>32.9</td>
</tr>
<tr>
<td>MD</td>
<td>33.2</td>
<td>22.9</td>
<td>32.3</td>
<td>36.8</td>
<td>1.2</td>
<td>6.0</td>
<td>0.8</td>
</tr>
<tr>
<td>High β</td>
<td>4.2</td>
<td>6.2</td>
<td>43.7</td>
<td>10.3</td>
<td>3.2</td>
<td>35.4</td>
<td>1.1</td>
</tr>
</tbody>
</table>

SB Time: 26.6 days  Total Time: 81.4 days

p-p, Pb-Pb runs do not include TS or MD time

Hubner factor: \( H = 11.57 \times \frac{L_{\text{Del}}}{(D \times L_{\text{Peak}})} \)  \( H_{\text{Expected}} = 0.2 \)

p-p (LP): 81.4 days  \( L_{\text{Peak}} = 2572 \ (\mu\text{b.s})^{-1} \)  \( L_{\text{Del}} = 4.01 \text{ fb}^{-1} \)  \( \Rightarrow H = 0.22 \)

Pb-Pb: 24.1 days  \( L_{\text{Peak}} = 512 \ (\text{b.s})^{-1} \)  \( L_{\text{Del}} = 167.6 \mu\text{b}^{-1} \)  \( \Rightarrow H = 0.24 \)
Luminous Region Evolution over the Run
Luminous Regions: ATLAS and CMS
2011 Performance: Emittance vs Intensity

Emittance vs Bunch Intensity

Transverse Emittance determined from luminosity at start of Stable beams
2011 Performance: Emittance vs Intensity

Fill 2030: emit= 1.89    Bunch Intensity = 1.20e11p    Bunch length = 1.22ns
Fill 2032: emit= 1.96    Bunch Intensity = 1.28e11p    Bunch length = 1.18ns

Transverse Emittance determined from luminosity at start of Stable beams
Evolution of Emittance Variation over a Fill

Both beams show some gentle blowup with fill duration. Outliers may not be just BSRT measurement artifacts.
Performance: Stable Beams Duration

Average SB Duration: 5.76 hrs

Consistency Check

Av Turn around (SB->SB) = 12.62 hrs
Time in Stable Beams = 33.8%
Mean SB Time = 12.6 hrs x 33.8/66.2
= 6.44 hrs
Performance: Stable Beams Duration

Average SB Duration: **5.76 hrs**

Consistency Check

Av Turn around (SB->SB) = **12.62 hrs**

Time in Stable Beams = **33.8%**

**Mean SB Time** = \(12.6 \text{ hrs} \times \frac{33.8}{66.2} = 6.44 \text{ hrs}\)
Performance: Stable Beams Duration

Average SB Duration: 5.76 hrs
Consistency Check
Av Turn around (SB->SB) = 12.62 hrs
Time in Stable Beams = 33.8%
Mean SB Time = 12.6 hrs * 33.8/66.2 = 6.44 hrs

50:50 Point: ~4 hrs
50% of SB time was produced with fills of 4 hrs or less of SB
=> Optimization of turnaround time can only be beneficial
Performance: Turnaround

**Turnaround Time after Stable Beams**

- **Protons**

**Average Turn Around Times**
- SB -> INJ = 6.46 hrs
- SB -> SB = 12.62 hrs
- Lumi Production: SB -> SB = 13.81 hrs
- Most Probable: SB -> SB = 5.23 hrs
Performance: Turnaround

Turnaround Time after Stable Beams

Protons

Average Turn Around Times

- SB -> INJ = 6.46 hrs
- SB -> SB = 12.62 hrs
- Lumi Production: SB -> SB = 13.81 hrs
- Most Probable: SB -> SB = 5.23 hrs

SB->SB Speed records

Top 5 Turnaround times

1st  2h07
2nd  2h13
3rd  2h28
4th  2h29
5th  2h29
Performance: Turnaround

Average Turn Around Times

- SB -> INJ = 5.53 hrs
- SB -> SB = 9.08 hrs

Most Probable: SB -> SB = 4.59 hrs

Fastest Turnaround [SB->SB]: 2hrs 37min
Performance: Time at Injection

Time at Injection - Protons

Mean time for injection = 1 hr 24 min

Time at Injection - Ions

Mean time for injection = 1 hr 33 min
In 2011 filling for protons and filling for ions took about the same time! (Ions just felt slower ... ) Dedicated LHC filling (protons) could improved turnaround time.
Turnaround improvements: Injection

SPS supercycle: \(41 \text{ BP} \Rightarrow 49.2 \text{ sec}\)
Could be reduced to \(28 \text{ BP}\)

Dedicated LHC filling (SPS): \(28 \text{ BP} \Rightarrow 33.6 \text{ sec}\)

Recoverable Time \(= 38.5 \times 800 \times 15.6 \text{ sec} = 5.6 \text{ days}\)

Dedicated LHC filling:
Not just a technical issue: **Sharing beam time with other CPS and SPS Users**
Faults and Downtime
2011 Faults tracking: As seen by the e-logbook

2011 Run: Faults

Total Fault Duration = 27.5 %
Total Fault Duration = 73.4 days
Access - no fault recorded = 4.1 days

Accesses with No Fault Recorded

- BCT
- Operation
- Controls/WorldFIP
- BPM
- TS-Services
- Feedback
- BIS
- TS-CV
- Vacuum
- Controls
- BLM
- PSB No Beam
- RF
- Injection
- Access
- Beam Dump
- Collimation
- PS No Beam
- Power Converters
- Miscellaneous
- QPS
- TS-Electrical Services
- SPS No Beam
- Cryo

Duration of access (hrs)

Time (days)

48 accesses with no fault registered: Typically for QPS
2011 Faults tracking: As seen by the e-logbook

2011 Run: Faults

Total Fault Duration = 27.5 
Total Fault Duration = 73.4 days

Access - no fault recorded = 4.1 days

BCT Operation Controls/WorldFIP BPM TS-Services Feedback BIS TS-CV Vacuum Controls BLM PSB No Beam RF Injection Access Beam Dump Collimation PS No Beam Power Converters Miscellaneous QPS TS-Electrical Services SPS No Beam Cryo

Accesses with No Fault Recorded

Cryo downtime due to Electrical glitch

48 accesses with no fault registered: Typically for QPS
2011 Faults tracking: As seen by the e-logbook

2011 Run: Faults

**Total Fault Duration = 27.5 %**

**Total Fault Duration = 73.4 days**

Access - no fault recorded = 4.1 days

Cryo downtime due to Electrical glitch

48 accesses with no fault registered: Typically for QPS

Fault tracking Issues
- Not all faults registered: some hidden in shadow of others.
- Fault tracking mechanism to be revised/upgraded
Downtime: Recovery of Cryo Conditions

Not Included 69 occurrences when Cryo Maintain was lost for 30 minutes or less
Cryo Global Availability

Legend:
- PLC P8_QSCB
- : Single Event (SEU)

- Between TS 2010
- Scheduled Stops
- Daily 2011
- Weekly 2011
- Between TS 2011
Cryo Global Availability

**Global Availability:** 89.7%

**Global downtime:** 10.3%

Detailed Cryo Analysis: 2011

- **Supply:**
- **Cryo:**
- **Cryo SEU:**
- **Users:**
- **Global availability:**

**Legend:**
- : PLC P8_QSCB
- : Single Event (SEU)
Global Cryo Downtime: Online Monitoring

2011: Cryo Down Time

- **downtime: 47.8 days (16.3%)**
- **25.9 days (9.7%)**

Cryo availability taken from Global Cryo Maintain signals in Timber
Based on fill-by fill analysis
Global Cryo Downtime: Online Monitoring

5th August Intervention to improve PLC Redundancy against SEUs
Intervention appears to have been beneficial!

2011: Cryo Down Time

Cryo availability taken from Global Cryo Maintain signals in Timber
Based on fill-by fill analysis

5th August Intervention to improve PLC Redundancy against SEUs
Intervention appears to have been beneficial!

Downtime: 47.8 days (16.3%)
25.9 days (9.7%)

All fills:
TS subtracted
... Unaccounted Faults: Examples

Fill 1999

Electrical Glitch
~ 2 hrs down
Unaccounted Faults: Examples

Fill 1999
Electrical Glitch
~ 2 hrs down

Fill 1968
Electrical Glitch
~ 2.5 hrs down
... Unaccounted Faults: Examples

Fill 1999
Electrical Glitch
~ 2 hrs down

Fill 1968
Electrical Glitch
~ 2.5 hrs down

Fill 2110
nQPS Fault
~ 4 hrs down
... Unaccounted Faults: Examples

**Fill 1999**
- Electrical Glitch
  - ~ 2 hrs down

**Fill 1968**
- Electrical Glitch
  - ~ 2.5 hrs down

**Fill 2110**
- nQPS Fault
  - ~ 4 hrs down

**Example: some electrical glitches**
- Beam dumped + no loss of Cryo + no Access
- TI Major Event created => TIOC followup
- **No fault recorded**

**Example: Some QPS faults:**
- Beam dumped + No Access
- **No fault recorded**

**Proposal:**
- **Structure and standardize** fault recording + tracking
  - Requires new database tool set across OP
- **Re-model interface/procedure** for entering faults
- **Regular review** of LHC-OP faults
  - with feedback from equipment teams
Beam Dumps
Beam Dumps in 2011 Proton Run

- Number of Beam Dumps in 2011 p-p Run: **482**
- Number of Non-Programmed Beam Dumps: **375 (78%)**
- Number of Non-Programmed Beam Dumps in Stable Beams: **168 (35%)**
Beam Dumps in 2011 Proton Run

- Number of Beam Dumps in 2011 p-p Run: **482**
- Number of Non-Programmed Beam Dumps: **375 (78%)**
- Number of Non-Programmed Beam Dumps in Stable Beams: **168 (35%)**

Non-programmed dumps in 2011 p-p Run
2011 Proton Run: Beam Dump Causes

- **Beam Monitoring Related**: Orbit, BPM, Beam Loss, Collimator adjustments, BCM, Feedbacks
- **Machine Protection System**: LBDS, PIC, BLM, BIC, SIS
- **Programmed Beam Dump**: LBDS, PIC, BLM, BIC, SIS
- **Equipment**: Equipment faults, external conditions, etc.

- **E = 3.5 TeV**
- **I > 10^{12} protons**

- **168** STABLE BEAMS
- **263** MDs excluded
- **272** All beam dumps

- **42%**
- **71%**
- **10%**
- **79%**
PIC is the dominant protection mechanism, even though the FMCM is the fastest MPS system.

FMCM trips are typical of electrical network glitches.
2011 Proton Run: Beam Dumps By Cause

E = 3.5 TeV
I > 10^{12} protons

"Top 5 List": 77% of dumps in SB
1st QPS
2nd Cryogenics
3rd Power Converters
4th RF
5th Electrical Network
2011 Run: Machine Protection Expert Analysis

2011 Run: Dumps at 3.5 TeV by MPS Cause

Dumps analyzed by MPS team = 240
Non-programmed dumps = 172
Dumps confirmed as result of SEU = 42
Dumps suspected as result of SEU = 16

Note: Blue and yellow histogram bars are stacked. Red and green bars are not
2011 Run: Machine Protection Expert Analysis

2011 Run: Dumps at 3.5 TeV by MPS Cause

Dumps analyzed by MPS team = \(240\)
Non-programmed dumps = \(172\)
Dumps confirmed as result of SEU = \(42\)
Dumps suspected as result of SEU = \(16\)

Low Statistics, but no abnormalities in SEU distribution

Note: Blue and yellow histogram bars are stacked. Red and green bars are not

Stable beams duration by MPS Type

All Beam Dumps evaluated by MPS
All Non-programmed Dumps evaluated by MPS
Dumps where SEU Confirmed
Dumps where Possible SEU

Number of Beam Dump Events

Duration of Stable Beams (hrs)
Summary and Comments

• **Performance:**
  - **Machine Availability:** 76.7 % (213.2 out of 277.9 days)
  - **Time with beam in the LHC:** 47.2 % (131.2 out of 277.9 days)
  - Percentage of allocated **Physics time in Stable Beams:** 33%

• Stable Beams Duration
  - **Most probable** = 6.44 hrs
  - **Average** = 5.56 hrs
  - **50:50 Point** = ~ 4hrs

• Turnaround Time
  - **Most probable (SB->SB)** = 4.59 hrs
  - **Average (SB->SB)** = 13.81 hrs
Summary and Comments

- **Downtime and Turn Around**
  - **Cryogenics recovery time** still the biggest factor
    - **25.9 days** or **9.7 %**
  - Cryogenics SEU Mitigations show benefits
  - Faults need proper recording/tracking.
    - Proposal to upgrade tools/procedures
  - Injection has potential for improvement of turnaround time

- **Beam Dumps**
  - **Non programmed dumps:** 375 (78%)
    - **During Stable Beams (p-p Run):** 168 (35%)
  - Equipment failures still dominant MPS dump cause
    - QPS still at the top of the MPS dump cause list
  - **2011 Run: Stable beams fills dumped by SEUs:** 24%
    - SEU mitigation should improve 2012 performance (eg Cryo, QPS)
Spare Slides
Evolution of Emittance Variation over a Fill

Emittance variations more prevalent for Beam 2.

Both beams show increased variations in luminosity production phase.

Caution: further analysis of BSRT dat is needed.