80 bunch scheme in the LHC

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March 12, 2015
## Turn-around time

Since Chamonix 2014 HL-LHC beams need a **7.2s longer SPS ramp** (E. Shaposhnikova):

<table>
<thead>
<tr>
<th>Phase</th>
<th>Time [minutes]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ramp down/precycle</td>
<td>60</td>
</tr>
<tr>
<td>Pre-injection checks and preparation</td>
<td>15</td>
</tr>
<tr>
<td>Checks with set-up beam</td>
<td>15</td>
</tr>
<tr>
<td>Nominal injection sequence</td>
<td>20</td>
</tr>
<tr>
<td>Ramp preparation</td>
<td>5</td>
</tr>
<tr>
<td>Ramp</td>
<td>25</td>
</tr>
<tr>
<td>Squeeze</td>
<td>30</td>
</tr>
<tr>
<td>Adjust/collisions</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>180</strong></td>
</tr>
</tbody>
</table>

Maybe 80 bunch scheme helps with turn-around-time
80 bunch scheme and 4 PS batch trains

- 8 non-colliding bunches (min?)
- Train gap 950ns (min 900ns)

First train in the LHC

Full LHC

Abort gap 110 slots

\[ 9 \times 4 \times 80 = 2880 \]

if 3 nc bunches

\[ 120 \times 10^4 \]
Comparing to nominal (colliding bunches)

<table>
<thead>
<tr>
<th>#</th>
<th>IP1&amp;5</th>
<th>IP2</th>
<th>IP8</th>
<th>Abort gap</th>
<th>Non-Coll.</th>
<th># SPS inj</th>
</tr>
</thead>
<tbody>
<tr>
<td>72</td>
<td>2736</td>
<td>2452</td>
<td>2524</td>
<td>120</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>72+</td>
<td>2808</td>
<td>2276</td>
<td>2232</td>
<td>120</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>80</td>
<td>2800</td>
<td>2727</td>
<td>2694</td>
<td>110</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>80+</td>
<td>2880</td>
<td>2380</td>
<td>2366</td>
<td>110</td>
<td>8</td>
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</tbody>
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If 3 non-colliding bunches OK, abort gap = 120 OK. Else train gap can be shorter by 2 slots (950 → 900ns). Saving 2 SPS injections shortens turn-around-time (183’ → 178’) and decreases IBS emittance growth by ≈ 1% in first trains.
Comparing to nominal (luminosity)

<table>
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<td>12</td>
</tr>
<tr>
<td>72$^+$</td>
<td>+2.6%</td>
<td>-7.2%</td>
<td>-11%</td>
<td>120</td>
<td>12</td>
<td>11</td>
</tr>
<tr>
<td>80</td>
<td>+2.3%</td>
<td>+11%</td>
<td>+6.7%</td>
<td>110</td>
<td>8</td>
<td>12</td>
</tr>
<tr>
<td>80$^+$</td>
<td>+5.2%</td>
<td>-3%</td>
<td>-6.2%</td>
<td>110</td>
<td>8</td>
<td>10→</td>
</tr>
</tbody>
</table>

With 80 everybody wins

Does IP2 want it?

80$^+$ is optimized for IP1&5

Is 80$^+$ OK for LHCB? → Need input

extra $\approx 0.5\%$ from TAT not included
How to find the optimum?

3 PS batch types: 72, 80, 81
SPS trains made of 1,2,3 or 4 PS batches
(120 different SPS trains)
with ≈10 possible train gaps (900-1150ns)
and between 10 and 15 SPS injections

This gives about $10^{40}$ possible LHC filling schemes
(symmetries are used to find good combinations)
Long ranges in Nominal

Non-colliding bunches
Long ranges in $80^+$

No differences other than fewer non-colliding bunches is better
80 bunches/4 trains merits and issues

Merits:
- ★ 5.2% more luminosity in IP1&5 (same pile-up)
- ★ with room for compromises with other IPs
- ★ Possibly faster turn-around
- ★ Potential to be a scrubbing beam

Issues:
- ★ SPS to LHC transfer with $4 \times 80 = 320$ bunches instead of $4 \times 72 = 288$
- ★ Injection protection devices (TDI, TCDI, etc) need to “survive” the extra charge
- ★ ≈10% larger heat load due to e-cloud
Pushed 8b+4e

Merits:

★ 7 PSB bunches can provide $56 \times 4 \times 9 = 2016$ bunches in the LHC

★ Considerably lower e-cloud than 25 ns baseline

★ Larger lumi than 50 ns or plain 8b+4e

★ Smaller $\beta^*$ and smaller crossing angle thanks to fewer long ranges.

Issues:

★ Lower luminosity than baseline

★ with 10% more peak pile-up
Lower number of long range encounters allows for smaller crossing angle and smaller $\beta^*$ ($\beta^* = 10\text{cm}$, $\theta = 530\mu\text{m} \ (9\sigma)$ with crab cavities in the following)
Pushed 8b+4e: Performance I (preliminary)

- More IBS
- Lower $\beta^*$
Pushed 8b+4e: Performance II (preliminary)

- Lower leveled lumi
- Same pile-up
- More peak pile-up

- Lower performance
- -22% C C CW

- Larger tuneshift

Graphs showing trends over time for various parameters.
Conclusions

★ 80 bunch scheme is promising for performance and flexibility: up to 5.2% in lumi, turn-around-time, scrubbing beam, 80bunch/3batches, etc

★ Experimentally not yet demonstrated

★ and full LHC potential not yet explored

★ Need to know: minimum number of non-colliding bunches, figure of merit for luminosities in the IPs and abort gap margin.

★ Risk of protection devices to be assessed.