LHC Injectors Upgrade
LIU Beam Studies Day – setting the scene

Giovanni Rumolo
in LIU Beam Studies Day, CERN, 28 August 2012

- Milestones for future LHC beams
- Injector MD schedule: where we are now, how much is left
- Requests for LIU MDs this year and current status
  - PSB
  - PS
  - SPS
- Concluding remarks
Rough timeline 2012 – .. (as of now)

- **2012**
  - **28 August**
  - About 216h of MDs + 192h more until the end of 2012

- **Feb 2013**
  - LHC p-Pb operation (Jan-Feb 2013), possible MDs?

- **Sep 2014**
  - LHC operation with **25ns** beams!

**LS1 (LHC)**

- 
  - $N_b \approx 1.1-1.7 \times 10^{11}$ ppb
  - $\varepsilon_{x,y} \approx 2.5 - 3 \mu m$

**~ 2018**

**~ 2019**

- 
  - Brighter 25ns beams
  - Towards HL-LHC-type beams in the injectors

**LS2 (LIU)**
**O. Brüning, HL-LHC/LIU Day, 30 March 2012**

<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>2.2E+11</td>
<td>3.5E+11</td>
</tr>
<tr>
<td>n_b</td>
<td>2808</td>
<td>2808</td>
<td>1404</td>
</tr>
<tr>
<td>beam current [A]</td>
<td>0.58</td>
<td><strong>1.12</strong></td>
<td><strong>0.89</strong></td>
</tr>
<tr>
<td>x-ing angle [μrad]</td>
<td>300</td>
<td>480</td>
<td>550</td>
</tr>
<tr>
<td>beam separation [σ]</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>β* [m]</td>
<td>0.55</td>
<td><strong>0.15</strong></td>
<td><strong>0.15</strong></td>
</tr>
<tr>
<td>ε_n [μm]</td>
<td>3.75</td>
<td>2.5</td>
<td>3.0</td>
</tr>
<tr>
<td>ε_L [eVs]</td>
<td>2.51</td>
<td>2.5</td>
<td>2.5</td>
</tr>
<tr>
<td>energy spread</td>
<td>1.20E-04</td>
<td>1.20E-04</td>
<td>1.20E-04</td>
</tr>
<tr>
<td>bunch length [m]</td>
<td>7.50E-02</td>
<td>7.50E-02</td>
<td>7.50E-02</td>
</tr>
<tr>
<td>IBS horizontal [h]</td>
<td>80 -&gt; 106</td>
<td><strong>20.0</strong></td>
<td><strong>20.7</strong></td>
</tr>
<tr>
<td>IBS longitudinal [h]</td>
<td>61 -&gt; 60</td>
<td><strong>15.8</strong></td>
<td><strong>13.2</strong></td>
</tr>
<tr>
<td>Plwinski parameter</td>
<td>0.68</td>
<td>2.54</td>
<td>2.66</td>
</tr>
<tr>
<td>geom. reduction</td>
<td>0.83</td>
<td>0.37</td>
<td>0.35</td>
</tr>
<tr>
<td>beam-beam / IP</td>
<td>3.10E-03</td>
<td><strong>3.9E-03</strong></td>
<td><strong>5.0E-03</strong></td>
</tr>
<tr>
<td>Peak Luminosity</td>
<td>1.10³⁴</td>
<td><strong>9.0 10³⁴</strong></td>
<td><strong>9.0 10³⁴</strong></td>
</tr>
<tr>
<td>Events / crossing</td>
<td>19</td>
<td>171</td>
<td>340</td>
</tr>
</tbody>
</table>

---

- Rough timeline 2012 – .. (as of now)
- Towards HL-LHC-type beams in the injectors
- About 216h of MDs + 192h more until the end of 2012
- LHC p-Pb operation
- LS1 (LHC) Feb 2013
- LHC operation with 25ns beams!
- LS2 (LIU) 2012 – 2014
- O. Brüning, HL-LHC/LIU Day, 30 March 2012

---

- Rough timeline 2012 – .. (as of now)
- Towards HL-LHC-type beams in the injectors
- About 216h of MDs + 192h more until the end of 2012
- LHC p-Pb operation
- LS1 (LHC) Feb 2013
- LHC operation with 25ns beams!
- LS2 (LIU) 2012 – 2014
- O. Brüning, HL-LHC/LIU Day, 30 March 2012
B. Goddard, HL-LHC/LIU Day, 30 March 2012

<table>
<thead>
<tr>
<th>Energy GeV</th>
<th>PSB inj</th>
<th>PSB extr/PS inj</th>
<th>PS extr/SPS inj</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Ib [e11 p+]</td>
<td>35.2</td>
<td>33.5</td>
<td></td>
</tr>
<tr>
<td>Ib in LHC [e11 p+]</td>
<td>2.9</td>
<td>2.8</td>
<td>2.7</td>
</tr>
<tr>
<td>Exyn [mm.mrad]</td>
<td>1.9</td>
<td>2.0</td>
<td>2.1</td>
</tr>
</tbody>
</table>

- Space charge in the PSB ($\Delta Q > 0.36$) ?
- Space charge in the PS ($\Delta Q > 0.28$) ?

<table>
<thead>
<tr>
<th>Energy GeV</th>
<th>PSB inj</th>
<th>PSB extr/PS inj</th>
<th>PS extr/SPS inj</th>
<th>SPS extr/LHC inj</th>
<th>LHC top</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>1</td>
<td>1</td>
<td>36</td>
<td>144</td>
<td>1404</td>
</tr>
<tr>
<td>Ib [e11 p+]</td>
<td></td>
<td></td>
<td>4.2</td>
<td>3.9</td>
<td>3.5</td>
</tr>
<tr>
<td>Ib in LHC [e11 p+]</td>
<td></td>
<td>4.2</td>
<td>3.9</td>
<td>3.5</td>
<td></td>
</tr>
<tr>
<td>Exyn [mm.mrad]</td>
<td></td>
<td>2.5</td>
<td>2.7</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

- Longitudinal instabilities in the PS?
- Space charge in the SPS ($\Delta Q > 0.15$) ?

<table>
<thead>
<tr>
<th>loss %</th>
<th>PSB</th>
<th>PS</th>
<th>SPS</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>blowup %</th>
<th>PSB</th>
<th>PS</th>
<th>SPS</th>
<th>LHC</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>5</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>
• **Space charge in the PSB, PS, SPS (acceptable ΔQ)**
  → Do we fully understand the effects and do we have simulation tools (benchmarked with our machines) for predictions?

• **Longitudinal instabilities in the PS**

• **Longitudinal instability and TMCI in the SPS**
  → Is Q20 optics enough to raise these thresholds above the requested values?

• **Electron cloud effects with larger intensity (PS & SPS)**
  → Can we rely on scrubbing or do we need coating?
  → High bandwidth transverse feedback system?
**2012 MDs**

<table>
<thead>
<tr>
<th>Wk</th>
<th>Jan</th>
<th>Feb</th>
<th>Mar</th>
<th>April</th>
<th>May</th>
<th>June</th>
<th>July</th>
<th>Aug</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mo</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>14</td>
<td>18</td>
<td>22</td>
<td>27</td>
<td>31</td>
</tr>
<tr>
<td>Tu</td>
<td>2</td>
<td>9</td>
<td>16</td>
<td>15</td>
<td>19</td>
<td>23</td>
<td>28</td>
<td>32</td>
</tr>
<tr>
<td>We</td>
<td>3</td>
<td>16</td>
<td>23</td>
<td>16</td>
<td>20</td>
<td>24</td>
<td>29</td>
<td>33</td>
</tr>
<tr>
<td>Th</td>
<td>4</td>
<td>23</td>
<td>30</td>
<td>17</td>
<td>21</td>
<td>25</td>
<td>30</td>
<td>34</td>
</tr>
<tr>
<td>Fr</td>
<td>5</td>
<td>30</td>
<td>6</td>
<td>18</td>
<td>22</td>
<td>26</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sa</td>
<td>6</td>
<td>1</td>
<td>13</td>
<td>19</td>
<td>23</td>
<td>27</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Su</td>
<td>7</td>
<td>16</td>
<td>20</td>
<td>20</td>
<td>24</td>
<td>28</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- More than half-way through the 2012 run
  - 5-days scrubbing run
  - 3 blocks of fully dedicated MDs
  - 8 blocks of floating MDs (sometimes split into 12h blocks)
• How much time is left
  ✓ 3 blocks of floating MDs
  ✓ 96h (4 blocks) of floating MDs to be rearranged (LHC TS will not take place)
  ✓ Restore the weekly 12h MDs on Wednesdays to optimize use of time for users
  ✓ Can we still use some MD time in 2013 during the p-Pb LHC run?
  ✓ Parallel MDs will continue in all injectors
PSB intensity limitations

- Space charge (losses, emittance blow up)
- Instabilities along the cycle (efficiency of the transverse feedback system)
- LHC beams presently not limited by these effects
PSB in 2012

LIU-PSB activities in 2012 (RF, hardware)

① Continue deployment of the digital RF control
① Test the newly installed Finemet prototype cavity hardware

LIU/Beam dynamics/performance MDs

- Parametric dependence of the transverse instabilities and identification of the impedance source, importance of the damper
- Determine resonance diagram with tune scans at 160 MeV to optimize placement of working point at injection with Linac4
- Optics model based on turn-by-turn data from the available BPMs
- Study the efficiency of the resonance compensation schemes
- Space charge induced emittance blow up
- Capture and acceleration in h=2
- Equalization of transverse emittances across rings
- Bunch lengthening at top energy for PSB-PS transfer (in view of 2GeV)
PSB in 2012

From MSWG meeting, 17 February 2012

LIU-PSB activities in 2012 (RF, hardware)

1. Continue deployment of the digital RF control
2. Test the newly installed Finemet prototype cavity hardware

LIU/Beam dynamics/performance MDs

- Parametric dependence of the transverse instabilities and identification of the impedance source, importance of the damper
- Determine resonance diagram with tune scans at 160 MeV to optimize placement of working point at injection with Linac4
- Optics model based on turn-by-turn data from the available BPMs
- Study the efficiency of the resonance compensation schemes
- Space charge induced emittance blow up (effect of working point)
- Capture and acceleration in h=2
- Equalization and optimization of transverse emittances across rings
- Bunch lengthening at top energy for PSB-PS transfer (in view of 2GeV)
PS intensity limitations

Acceleration/Bunch splittings
Longitudinal CBI
Transient beam loading
Transition crossing

Injection flat bottom:
Space charge
Headtail instability

Flat top:
Longitudinal CBI
Electron cloud
Transverse instabilities

Time [ms]

Intensity
Magnetic Field [T]

1st Injection
2nd Injection
h=7
h=21
h=42
h=84

Av. intensity = 1.33*10^{11} ppb

Pick-up signal [a.u.]
e-cloud signal [a.u.]

Av. intensity = 1.33*10^{11} ppb

PS MDs in 2012

LIU PS machine studies requested in 2012

- Space charge studies: is 0.26 the limit for the PS?
- Additional feedback against longitudinal CBI (should extend the intensity reach for 50 and 25ns beams!)
- Batch compression $h=9 \rightarrow 10 \rightarrow 20 \rightarrow 21$, acceleration, transfer to SPS
- Batch compression + bunch merging scheme
- One-turn feedback against transient beam-loading
- Electron cloud measurements in presence of B field and with double step bunch rotation
- PS-SPS transfer studies (SPS capture loss maps as a function of PS bunch rotation timings)
- Commissioning of transverse feedback system
- Head-tail instabilities on the flat bottom
- Transverse instabilities of short intense bunches at flat top
- Impedance identification for modeling
- Miscellaneous injection studies and optics model at different energies
  - Tuning of working point from injection in 5 CM
  - Tests of low energy elements
  - Acceleration-deceleration for double batch transfer

From MSWG meeting, 17 February 2012
PS MDs in 2012

LIU PS machine studies requested in 2012

- Space charge studies: is 0.26 the limit for the PS? **Integer crossing**
- Additional feedback against longitudinal CBI (should extend the intensity reach for 50 and 25ns beams!)
- Batch compression $h=9 \rightarrow 10 \rightarrow 20 \rightarrow 21$, acceleration, transfer to SPS/LHC
- Batch compression + bunch merging scheme
- One-turn feedback against transient beam-loading
- Electron cloud measurements in presence of B field and with double step bunch rotation
- PS-SPS transfer studies (SPS capture loss maps as a function of PS bunch rotation timings)
- Commissioning of transverse feedback system @injection
- Head-tail instabilities on the flat bottom
- Transverse instabilities of short intense bunches at flat top
- Impedance identification for modeling (**transverse & longitudinal**)
- Miscellaneous injection studies and optics model at different energies
  - Tuning of working point from injection in 5 CM
  - Tests of low energy elements
  - Acceleration-deceleration for double batch transfer

From MSWG meeting, 17 February 2012
SPS intensity limitations

Injection flat bottom:
Capture losses
Longitudinal instability
Space charge
TMCI

Along the whole cycle:
Longitudinal instability
Electron cloud

Time (s)

26 GeV

450 GeV

Energy (p)

3.5 \times 10^{13}
SPS MDs in 2012

- **2012 electron cloud studies**
  - Scrubbing in W13 and e-cloud MD sessions
  - Qualification of 25ns beams
  - Interpretation of the pressure data
  - Testing efficiency of scrubbing with uncaptured beam
  - Monitor and qualify beam induced scrubbing under different beam/chamber conditions (beam observables, direct electron cloud observables)
  - Validate simulation models on scrubbing times (like for LHC)
  - New setups for validation of a-C coating

- **Other LIU SPS machine studies in 2012**
  - Q20 optimization
    - Longitudinal stability and quality at extraction
    - Injection tests into LHC
    - Transverse emittance preservation and single bunch limits
    - Nonlinear optics model
    - Instabilities (TMCI, ECI)
    - Extension of Q20 to fixed target physics cycles
  - ZS studies
  - Tests with increased peak RF power
  - High bandwidth feedback studies (close feedback loop and prove damping of head-tail modes)
  - Impedance identification

From MSWG meeting, 17 February 2012
SPS MDs in 2012

- **2012 electron cloud studies**
  - Scrubbing in W13 and e-cloud MD sessions
  - Qualification of 25ns beams
  - Interpretation of the pressure data
  - Testing efficiency of scrubbing with uncaptured beam
  - Monitor and qualify beam induced scrubbing under different beam/chamber conditions (beam observables, direct electron cloud observables)
  - Validate simulation models on scrubbing times (like for LHC)
  - New setups for validation of a-C coating

- **Other LIU SPS machine studies in 2012**
  - Q20 optimization (single and multi-bunch!)
    - Longitudinal stability and quality at extraction (also for Q26 high intensity)
    - Injection tests into LHC
    - Transverse emittance preservation and single bunch limits
    - Nonlinear optics model
    - Instabilities (TMCI, ECI)
    - Extension of Q20 to fixed target physics cycles
  - ZS studies
    - Tests with increased peak RF power
    - High bandwidth feedback studies (close feedback loop and prove damping of head-tail modes)
    - Impedance identification

From MSWG meeting, 17 February 2012
In conclusion

Most of the requested LIU MDs in PSB/PS/SPS have progressed significantly in 2012 and status will be reviewed in the next talks

- **PSB**
  - LHC beams performance and optimization (B. Mikulec)
  - RF and transverse feedback aspects (A. Findlay)
  - Space charge effects (A. Molodozhentsev)

- **PS**
  - Space charge limit at injection (R. Wasef)
  - Transverse studies (S. Gilardoni)
  - Longitudinal studies, alternative schemes (H. Damerau)

- **SPS**
  - Q20 single and multi-bunch operation (H. Bartosik)
  - Electron cloud studies: coating vs. scrubbing (G. Iadarola)
  - Longitudinal beam stability & quality (T. Argyropoulos)
  - High bandwidth transverse feedback system (W. Höfle)
Some key questions (that will be addressed today)

- Are we on the right path to provide LHC with the required beams at the different stages (post-LS1, post-LS2)?
- Which studies will still require more information and significant MD time before LS1?
- Is any study presently limited by instrumentation or diagnostics? Any improvement possible before LS1?
- Is any study strongly relying on the installation and test of new hardware before LS1?
- How can we optimize the use of the remaining available MD time? Do we need to request for more?
- Which are the main motivations why we could benefit from the extension of the MD run into 2013?
- ...
THANK YOU FOR YOUR ATTENTION!