SPS experience for LHC ion run


SPS & PS operators

LIU beam performance meeting, 13 December 2018
SPS cycles and beams used

• First half of the 2018 run with 4 bunch (100 ns) scheme
  • Cycle prepared for 12 injections – LHC took only 9 injections due to abort gap settings
  • Similar transmission in Q26 (2018) as in Q20 (2016)

• Second half with 3 bunch (75 ns) scheme
  • Cycle with up to 14 injections
  • Scraping had been requested by LHC
Intensity evolution LHC Pb-Pb run 2018

- 648 bunches in LHC
- 733 bunches in LHC
- 4 bunch scheme
- 3 bunch scheme

Average bunch intensity [Pb82+] vs. time from 07-11-2018 to 02-12-2018.
Performance target reach: risk & mitigation

• **Slip-stacking represents main performance risk**
  • Without slip stacking only 58% of target for same beam production scheme (losses in SPS remain the main bottleneck)

• **Progress on alternative beam production scenarios**
  • Option of 3 bunches spaced by 75 ns demonstrated with Xe-ions in LEIR & PS → 67% of target expected (to be tested with Pb)
  • Further gain from reduced batch spacing in SPS → feasibility of 125 ns to be tested with beam in 2018

<table>
<thead>
<tr>
<th></th>
<th>Pb82+/b @SPS inj.</th>
<th>PS bunch spacing (ns)</th>
<th>bunches (from PS)</th>
<th>MKP gap (ns)</th>
<th>SPS slip stacking</th>
<th>LHC total bunches</th>
<th>expected SPS transmission</th>
<th>expected total Pb82+</th>
<th>total intensity relative to target</th>
</tr>
</thead>
<tbody>
<tr>
<td>baseline</td>
<td>3.6e8</td>
<td>100</td>
<td>4</td>
<td>150</td>
<td>YES</td>
<td>1256</td>
<td>56%</td>
<td>2.35e11*</td>
<td>104%</td>
</tr>
<tr>
<td>4 bunches</td>
<td>3.6e8</td>
<td>100</td>
<td>4</td>
<td>150</td>
<td>NO</td>
<td>696</td>
<td>56%</td>
<td>1.40e11</td>
<td>58%</td>
</tr>
<tr>
<td>3 bunches</td>
<td>4.8e8</td>
<td>75</td>
<td>3</td>
<td>150</td>
<td>NO</td>
<td>750</td>
<td>45%</td>
<td>1.62e11</td>
<td>67%</td>
</tr>
<tr>
<td>3 bunches</td>
<td>4.8e8</td>
<td>75</td>
<td>3</td>
<td>125</td>
<td>NO</td>
<td>798</td>
<td>45%</td>
<td>1.72e11</td>
<td>71%</td>
</tr>
</tbody>
</table>

* including 5% losses for slip stacking
Integrated luminosity in LHC

Delivered Luminosity 2018

Preliminary
- ATLAS: 1.797 nb⁻¹
- CMS: 1.802 nb⁻¹
- LHCb: 0.235 nb⁻¹
- ALICE: 0.905 nb⁻¹

HL-LHC goal: 2.85 nb⁻¹ (in ALICE, ATLAS, CMS)
Pb-ion performance over the last years

LIU goal (2.35e11)

- 100 ns spacing
- 75 ns spacing

2015 (Pb-Pb) 2 bunches from PS
2016 (p-Pb) 4 bunches from PS
2018 (Pb-Pb) 3 bunches from PS

slip stacking
Issues with longitudinal stability

- Significant reduction of intensity and bunch length along the SPS batch at end of flat bottom
  - leads to instability of the shortest (and less intense) bunches

- Transition crossing
  - Adjustments are done using many knobs (2 main: transition timing and radial beam displacement)
  - Instability and emittance blow-up during transition crossing lead to better beam stability later on
  - Will be improved after LS2 due to LLRF (phase discriminator) upgrade

- But … bunches crossing transition without significant blow-up become unstable later

- Had to run with relaxed BQM settings
  - bunch length tolerance 2.2 ns, …
  - No particular issue from LHC side!
Observations during slip-stacking MD

- Radial displacement at intermediate flat portion (20 mm) didn’t lead to BCT losses
  - maybe we can displace only one beam and simplify slip-stacking?

- Instability is often starting at the plateau
  - reduction in the synchrotron frequency spread?

- Slip-stacking of unstable beam will be difficult and not reproducible
  - Need to find mitigation measures for beam stabilisation before and during slip-stacking

Beam becoming unstable on flat portion

Beam stable after blow-up at transition
Possible stabilisation of the ion beam

- **800 MHz RF system was finally applied during one MD after deployment for ions**
  - relative phase was not specifically calibrated for ion operation
  - no effect on beam was observed
  - can be used only after transition crossing (too late?)
  - if used during slip-stacking – need separate control of each cavity (as 200 MHz) – not available

- **Controlled emittance blow-up**
  - very difficult in a single RF system due to small frequency spread
  - In double RF can be done only after transition crossing (too late?)
  - large bunch-by-bunch variation in bunch length (> 50%) and then in synchrotron frequency shift

- **Feasibility of controlled blow-up needs to be studied during LS2 in simulations for realistic bunch-by-bunch particle distribution and SPS impedance model**
  - before transition crossing in a single RF
  - after transition in double RF with phase noise or phase modulation of 800 MHz
Summary & Outlook

• Very successful ion run for the SPS and all injectors
  • High intensity beam delivered by Linac3/LEIR and PS
  • No particular issue related to 75 ns beam
  • Q26 re-deployed with no big difference wrt. Q20 (Q26 required to avoid bunch rotation after slip stacking in the future!)
  • Reached expected total intensity in LHC (67% of LIU intensity) with 3 bunch 75 ns scheme
  • Longitudinal instabilities encountered after transition crossing (as with Q20)
  • MDs devoted to tune scans and tests in view of slip stacking (data analysis ongoing)
  • Test of 6 bunch scheme successful – option for slip stacking commissioning (low bunch intensity)

• Outlook: slip stacking
  • Reaching LIU goal requires slip stacking (in first run after LS2)
  • Achieving longitudinal stability of ion bunches is big challenge, but pre-requisite to slip stacking
  • Simulation studies during LS2 for achieving longitudinal stability and optimizing slip stacking manipulations
  • Will need commitment of all people involved to make it operational in first year after LS2