SPS-LHC transfer losses
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BE-RF-FB

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Thanks to: A. Lasheen, M. Schwarz, D. Amorim
Introduction

- Voltage reduction campaign in the LHC due to beam-loading
- SPS-LHC injection losses and at flat-bottom (FB)
Procedure

1. Benchmark with SPS model
2. Bunch generation in the SPS: present and future
3. Injection into the LHC: results with and without energy offsets and discussion
Benchmark

- Benchmark of the bunch generation in the SPS with model that reproduces measurements
- Feedback and feedforward
- Agreement of the bunch position offset w.r.t. bucket centre (full range of $\sim 180$ ps)

$1.15 \times 10^{11}$ ppb, 72b, $V_{200}/V_{800} = 7$ MV/0.65 MV
Bunch length $\tau_{4\sigma}^{\text{FWHM}} = 1.65$ ns Q26 optics ($\gamma_t = 17.95$)
Bunch generation in the SPS: present and future

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Present</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunch intensity</td>
<td>$10^{11}$ ppb</td>
<td>1.15</td>
<td>2.30</td>
</tr>
<tr>
<td>No. bunches per train</td>
<td>1</td>
<td>48b (BCMS)</td>
<td>72b (STD)</td>
</tr>
<tr>
<td>RF voltage $V_{200}/V_{800}$</td>
<td>MV</td>
<td>7/1.24</td>
<td>10/1.50</td>
</tr>
<tr>
<td>Ave. bunch length $\tau_{4\sigma}^{\text{FWHM}}$</td>
<td>ns</td>
<td>1.55, 1.65, 1.75</td>
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</tr>
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- Bunch generation matched to the RF bucket with intensity effects
  - Binominal with $\mu = 2$
  - Two cases with shorter/longer bunches lengths w.r.t. to the nominal $\tau_{4\sigma}^{\text{FWHM}} = 1.65$ ns @ extraction are studied to get error bars
- Present and future SPS impedance models (latest GitLab version)
- $10^5$ macroparticles per bunch are tracked for $5 \times 10^3$ turns ($\sim 115$ ms)
  - To check that the distribution is matched
  - Convergence studies (e.g. on the no. of macroparticles) are needed
- Q20 optics ($\gamma_t = 22.80$)
LHC and HL-LHC

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<th>HL-LHC</th>
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<td>RF voltage $V_{400}$</td>
<td>MV</td>
<td>3, 4, 6</td>
<td>5, 6, 8</td>
</tr>
</tbody>
</table>

- Tracked bunches in the SPS are injected into the LHC:
  - Without injection offset: the average bunch position corresponds to the centre of the LHC bucket
  - With a 50MeV-injection offset
- Present and future LHC impedance models (ABP database)
- Quantify losses (based on the separatrix w/o intensity effects in both cases):
  - At injection: first turn
  - At flat bottom: after $5 \times 10^3$ turns ($\sim 445$ ms)
LHC and future (no injection offset)

- HL-LHC performs better than expected (why?)
SPS beam-loading patterns

Present

Future
SPS beam-loading patterns

Present

Future
Injection into the LHC (4 MV)

Present (4 MV)
Injection into the HL-LHC (5 MV)

Future (5 MV)
### 50MeV injection offset

<table>
<thead>
<tr>
<th>Voltage [MV]</th>
<th>LHC, 0MeV</th>
<th>LHC, 50MeV</th>
</tr>
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<tr>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>6</td>
<td>7</td>
</tr>
<tr>
<td>5</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td></td>
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</tbody>
</table>

- **Number of macroparticles [10⁵]**
  - LHC, 0MeV: 48, 49, 50
  - LHC, 50MeV: 70, 71, 72

- **Injection transmission [%]**
  - LHC, 0MeV: 94, 95, 96
  - LHC, 50MeV: 97, 98, 99

- **Injection losses [%]**
  - LHC, 0MeV: 0, 0, 0
  - LHC, 50MeV: 1, 1, 1

**HL-LHC, 0MeV**

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<tr>
<th>Voltage [MV]</th>
<th>HL-LHC, 0MeV</th>
</tr>
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<tbody>
<tr>
<td>5</td>
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</tr>
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- **Number of macroparticles [10⁵]**
  - HL-LHC, 0MeV: 70, 71, 72

- **Injection transmission [%]**
  - HL-LHC, 0MeV: 97, 98, 99

- **Injection losses [%]**
  - HL-LHC, 0MeV: 1, 1, 1
Injection vs flat-bottom (no injection offset)
Conclusions and discussion

• Dominated by capture losses (first impression)
• Convergence studies: number of macroparticles
• HL-LHC scenario performs better than expected (why? – if it is confirmed)
  • More uniform beam-loading pattern?
• Study dependence on the distribution profile
• Does the SPS model need improvement?
LHC and HL-LHC impedance models
Injection vs flat-bottom (50MeV injection offset)

LHC, inj  LHC, FB

Number of macroparticles [$10^5$]

Injection transmission [%]

Injection losses [%]

Voltage [MV]

HL-LHC, inj  HL-LHC, FB

Number of macroparticles [$10^5$]

Injection transmission [%]

Injection losses [%]

Voltage [MV]