Transverse beam dynamics issues in the PS

on behalf of PS-LIU team
Outline

I. Transverse challenges
II. Space Charge at injection
III. Injection oscillations
IV. Transverse damper and feedback
V. Flat-top challenges
VI. Transition instabilities
VII. Summary and Conclusions
Transverse Challenges in the PS

**Acceleration:**
- Transition crossing

**Flat top:**
- Electron cloud
- Transverse instabilities

**Injection flat bottom:**
- Injection oscillations
- Space charge
- Headtail instability

Graphs with timelines, magnetic field, intensity, and other parameters are shown, along with annotations for specific time intervals and intensity values.
Space Charge at injection

- Current injection energy: 1.4 GeV

- Typical tune-spread of current operational beam $\sim$ (-0.2 ; -0.28)

- LHC double batch injection:
  Long flat bottom: 1.2s

- LIU Budgets: 5% beam loss,
  5% emittance growth

- Requests @2GeV:
  LIU $\Rightarrow$ $\Delta Q \sim$ (-0.19 ; -0.31)
  HL-LHC $\Rightarrow$ $\Delta Q \sim$ (-0.18 ; -0.30)
• The beam tune-spread is trapped between the $4q_y=1$ and the integer resonances.
  ➔ The choice of the working point is a compromise between losses and emittance blow-up

• To respect the LIU budgets of beam loss and emittance growth, $\Delta Q_{\text{max}} \approx -0.31$
Space Charge at injection

Vertical tune scan

-> Successful implementation of a resonance compensation scheme

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The resonance compensation would empty larger area for the working area, but the $4Q_y=25$ resonance is still limiting this area.

- Solutions under investigation for $4Q_y$ resonance (to be studied in 2014):
  - Simulation study with the change of the integer for the vertical tune shows promising results to avoid the $4Q_y$ resonance
  - Changing the optics: larger horizontal dispersion & larger vertical dispersion
  - Longitudinally hollow bunches
Injection Oscillations

- At injection of high intensity beams, intra-bunch oscillations were observed.

- No unstable behavior observed associated to losses.

- A study revealed that the cause of these oscillations is indirect space charge.


- The effect of these oscillations on the emittance of future beams (HL-LHC: 32.5 $10^{11}$ ppb, LIU :28 $10^{11}$ ppb) has to be studied.

- TFB damp it effectively. Effect on the emittance to be studied.
Transverse Damper and Feedback

- The TFB was designed to damp injection orbit errors of 3mm (peak to peak) within 50 µs, to limit the caused emittance growth:

\[
n = r \frac{x^2 + \left( \frac{x'}{2} \right)^2}{r} + \left( \frac{a}{b} \right)^2
\]

- It also has been used as feedback to dump Headtail instabilities at injection. (Chromaticity should be controlled at 2GeV)

Injection oscillation

\[
\text{Oasis Viewer}
\]

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Transverse Damper and Feedback

- Upgrade of the TFB (2015): new amplifiers to dump injection oscillations at 2GeV

<table>
<thead>
<tr>
<th></th>
<th>Current Amplifier</th>
<th>New Amplifier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Power [kW]</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>CW Power [kW]</td>
<td>0.8</td>
<td>5</td>
</tr>
<tr>
<td>-3dB Bandwidth [MHz]</td>
<td>23</td>
<td>100</td>
</tr>
</tbody>
</table>

- We will probably need to control the chromaticity at 2 GeV to avoid high order headtail mode not accessible by the damper depending if no linear coupling will be used.
Flat-top challenges

- **Up to now e-cloud in the PS has never been a limitation** for the production of the 25 ns LHC type beams but **transverse instabilities** are observed when “storing” 25 ns beams at 26 GeV (new transverse feedback proved to help)

- **40 MHz RF Voltage program** can be tailored to mitigate e-cloud effects without affecting beam quality at extraction (tested in MD)

- To predict the e-cloud behavior at higher intensities **PyECLoud modules** have been developed for the simulation of combined function magnets

- Extensive simulation studies have been performed for the main chamber profiles installed in the main magnets and in the straight sections

*Pycloud simulations for combined function magnets established to predict future operation*
Flat-top challenges

- **TFB** able to delay the observed instability by ~10ms

- A main magnet has been equipped for e-cloud detection during LS1 (shielded pickup and optical window)

- Measurement campaign planned after LS1 to characterize the e-cloud formation in the PS main magnets (for different beam conditions, possibly up to LIU bunch intensity)

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Instabilities at Transition

- Instabilities at transition are not a limitation for the LHC beams and they are not expected to be for future beams. Study ongoing to confirm this assumption based on non-LHC high-intensity beams studies.

- The PS impedance model is being improved to have a better understanding of the source of these instabilities.

- About 70% of the measured impedance has been explained.

- A measurement campaign is planned at the restart of the machine.
Summary and conclusions

• Injection flat-bottom:
  1. Injection oscillations: \( \rightarrow \) TFB, effect on the emittance?
  2. Space charge: \( \rightarrow \) 2GeV injection upgrade, Resonance compensation, studies on going (change of vertical integer, new optics, hollow bunches… etc)
  3. Headtail instability: \( \rightarrow \) TFB

• Transition instabilities: No limitation expected

• Flat-top:
  1. Electron Cloud / Transverse instabilities: \( \rightarrow \) TFB
THANK YOU FOR YOUR ATTENTION!

LHC Injectors Upgrade
Backup slides
BCMS scheme (48 bunches / PS batch)

LIU upgrades
- SPS 200 MHz upgrade
- SPS e-cloud mitigation
- PSB-PS transfer at 2 GeV

Limitations BCMS scheme
- SPS: longitudinal instabilities + beam loading
- PS: space charge
- SPS: space charge

Performance reach
- $2.0 \times 10^{11} \text{ p/b in } 1.37 \mu \text{m (@ 450GeV)}$
- $1.9 \times 10^{11} \text{ p/b in } 1.65 \mu \text{m (in collision)}$
max. tune shift in this simulation is approx. 0.01 larger than in the measurement

→ effect very sensitive to the longitudinal distribution
The 4th order resonance seems to be excited by space charge

Horizontal tune fixed at 6.23
Vertical tune: 6.24->6.3->6.24

Maximum detuning due to space charge:
Beam 1 : (-.22 ; -.4)
Beam 2 : (-.18 ; -.37)
Beam 3 : (-.08 ; -.07)
Beam 4 : (-.01 ; .01)
Resonance compensation

2Qx+Qy compensation

3Qy compensation

Horizontal tune scan

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