Space-charge studies at PS injection

E. Benedetto
NTU-A and CERN

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Motivations (1)

- Can we reduce PS inj. energy to 2 GeV (kinetic, proton-equivalent)?
- 3.5 GeV was chosen (*) for max. Space-Charge Laselett $|\Delta Q| = 0.22$
  - Maybe too pessimistic!
- Challenging to inject at 3.5 GeV:
  - Space available: PS long straight section are not so long!
  - Technology of the septum
  - Strength of the kickers + high rep.rate (10 Hz)


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Motivations (2)

• Integration in the CERN LHC Upgrade scenario:
  • 2 GeV energy for the LHC Injectors Upgrade Project
  • Maybe they will also have an RCS upstream
    – we could profit of the same injection equipment
• Motivation for LHC Injectors:
  Deliver high intensities required by HL-LHC & preserve transverse emittance
  – Space-Charge at present inj. (1.4 GeV) induces blow-up:
    • If Laslett $|\Delta Q| > 0.3$
    • If 1.2s long flat bottom (double-batch inj.) $\rightarrow$ it is 2s for $\beta$Beams
  – Mitigation: Go to 2 GeV & further optimize Working Point (WP)
Space-Charge & Working Point

- Space-charge induces tune spread (‘neck-tie’)

- Particles can cross betatron resonance lines and
  - either lost
  - either emittance blow-up

- Today’s Working point (WP) is around 6.22 (both planes)
  - if $|\Delta Q_{\text{Laselett}}| > 0.2$ the SC neck-tie extends down to the integer line $\rightarrow$ TO AVOID !!!

1) Determine the best WP to avoid dangerous lines & accommodate the largest SC neck-tie

Courtesy S. Aumon
Space-Charge & Emittance growth

Test end 2010:

190 \cdot 10^{10} \text{ ppb (at PS ejection)}
90 \text{ ns}
Increase total emittance ($\varepsilon_x + \varepsilon_y$) $\sim 40\%$

\[
\begin{align*}
\Delta Q^{\text{LHC25MD}}_x @\text{PS FT} &= -0.34 \\
\Delta Q^{\text{LHC25MD}}_y @\text{PS FT} &= -0.56
\end{align*}
\]

- Compare with measurements by *R. Cappi et al., PAC’93*: different growth rate, why?
- Repeat @ 2 GeV and once optimized WP

2) Identify max allowed SC blow-up

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Working Point scan

- **GOAL:** Identify dangerous resonance lines in tune diagram
- **Losses measurements** for different WPs:
  - Low intensity beam (not SC-dominated) → $130 \times 10^{10}$
  - Large emittance (to fill the chamber & provoke immediate losses)
  - Long flat bottom @ 1.4 GeV
  - Tune program:
    - Scan between (0.1 - 0.4)
    - Vertical tune constant
    - Sweep of the horizontal tune
  - Slope in the intensity signal indicates importance of the crossed resonance line
Sweep:

\[ Q_h = 0.4 \rightarrow 0.1 \]

✓ OK! The method is validated

A. Huschauer
WP scan @ 1.4 GeV - debunched

A. Huschauer

Sweep $Q_h = 0.4 \rightarrow 0.1$
✓ OK!
✓ Differences with previous case understood

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WP scan @ 2 GeV- bunched

- Couldn’t do the debunched case (instability?)
- Same lines (*) as before (@1.4 GeV)
  ✓ OK! As expected
- Still need to:
  - Correct chromaticity
  - Check in the lower left corner

(*) Apart form the 3Qv=1...need vertical sweep to see it! CAREFUL!!!)
PS magnets and WP control
PS magnets and WP control

• **Combined function magnets:**
  – Dipol+Quad component

• **Low-energy Quadrupoles**
  – Change the tune (Qh,Qv) @ injection
  – Only linear component
  – BUT no control of Chromaticity

• **Pole Face Windings (PFW)**
  – Additional coils around main magnets
  – Control tune AND chromaticity
  – BUT non-linearities & resonances
WP scan @ 2 GeV- with PFW

- New resonance line appeared!!!

- First attempt:
  - Chromaticity is corrected
  - BUT can’t access lower left corner

- Need to find another PFW configuration:
  → PS-OP colleagues are working on it
Conclusions

• WP scan to identify dangerous resonances
  – Losses measurements @ 1.4 GeV done (by Alex)
  – Method (tune sweep) is validated
  – Losses measurements @ 2 GeV w/o PFW done & no surprises!
  – Measurements with PFW ongoing

• Using PFW can introduce new resonance lines
  – Where? Are they dangerous?
  – We need to measure them
  – Find a config. which is not perturbing too much
Next steps

- Find a PFW configuration to access lower tunes
  - AND to correct chromaticity
  - AND not to create too many resonances lines
  - OP colleagues are working
- Repeat measurements with this config.
- Identify optimum WP @ 2 GeV, with large SC neck-tie
- Emittance blow-up measurements
  - Extract growth time & check profiles
  - Identify driving mechanism (and find cures)
  - (Simulation campaign with PTC-ORB/IT code → Simone (planning))
- Repeat loss measur. with ion beam (should be the same)

Define max tolerable SC tune shift and check whether compatible with BetaBeam injection @ 2 GeV
Back-up material
Space Charge

- $E_x^* = 10.3 \text{ mm mrad} \rightarrow E_{x\_He}: 6.7, E_{x\_Ne}: 4$
- $E_y^* = 5.5 \text{ mm mrad} \rightarrow E_{y\_He}: 3.6, E_{y\_Ne}: 2.1$

- $I_{\_He} = 1.7 \times 10^{13} \text{ /20 bunches} = 8.5 \times 10^{11}\text{ ppb}$
- $I_{\_Ne} = 5.2 \times 10^{12} \text{ /20 bunches} = 2.6 \times 10^{11}\text{ ppb}$

- $DQ = -0.22$
WP scan

Qv=0.25

Intensity (1e10)

Time (ms)

Qh=0.4  Qh=0.1

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Pole Face Windings