Beta-beating measurement and correction during the fall of the PSB injection chicane

Update on R3 measurements of LHC2A

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Space Charge WG Meeting – 23/06/2021
Overview

• LHC25: current status
• Improving the machine performance
• Measurement and correction of the beta-beating with k-modulation
• Impact on intensity
• Impact on emittance
• Summary and Next Steps
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• **Measurement and correction of the beta-beating with k-modulation**

• **Impact on intensity**

• **Impact on emittance**

• **Summary and Next Steps**
LHC25: current status

- Tune control:
  - **until C300:** tune perturbations as a result from both injection chicane optics distortion and regulation (which was improved considerably)
  - **after C300:** systematic +0.01 shift in $Q_V$ between set (4.43) and measured (4.44) values

Constant set tune at 4.38/4.43
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• Tune evolution along the cycle: 4.38/4.4 at $C277$ to 4.17/23 at $C475$
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- **Resonance correctors (Foteini):**
  - QNOs (half-integer) are not operationally used because in the current configuration they seem to enhance the vertical tails
  - Sextupoles (XNO, XSK) and octupoles (ONO) are ramped up and down based on the resonance crossing
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- Brightness curve (measurements performed by **Hannes and Foteini**)
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- **MD user (LHC2A) 1.5 eVs instead of 2 eVs (operational user)**
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• Increasing the vertical tune would in principle allow a smaller emittance blow-up with the same intensity.
Operation close to the half-integer

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- Beam core interacts with the integer resonance causing emittance blow-up. The space charge tune spread decreases until equilibrium.
- Increasing the vertical tune would in principle allow a smaller emittance blow-up with the same intensity.

- Operation close to the half-integer induces losses because:
  - beta-beating is enhanced
  - chromaticity drives the particles to the resonance
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The improvement of POPS-B and the tune control allowed the measurement and correction of the optics perturbations.

A dynamically changing beta-beating is expected in the first ms after injection.

These optics perturbations are measured at the positions of the individually powered quadrupoles BR.QDE3/14 using k-modulation.
Very good **agreement** between the expected and the measured perturbation: good modelling of the error sources and the machine lattice.

*Tune is evaluated over 1000 turns (~1 ms): optics perturbations are changing over this interval.*
K-modulation measurement and correction (logbook)

Dynamic beta-beating correction (q-strips of QDE 3/14)
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The correction will induce perturbations on the tune: needs to be corrected back (q-strips of all QDEs and QFOs)
K-modulation measurement and correction (logbook)

Before correction

After correction
Additional correction on the tune

Additional correction functions to the q-strips to flatten the tune:
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\[ Q_v = 4.43 \]
Impact on intensity

\[ Q_v = 4.45 \]
Impact on intensity

\[ Q_v = 4.46 \]
Impact on intensity

$Q_v = 4.47$
Impact on intensity

Set tune is 4.47; **actual tune** is even larger (4.48-4.49)!

- Clear improvement on the beta-beating: beam intensity is stable much closer to the half-integer resonance
- Similar situation for larger intensities

Investigations ongoing to check if the vertical chromaticity correction is overall beneficial
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Impact on emittance (Run 2 intensities)

Only vertical emittance measured
Impact on emittance (Run 2 intensities)

Only vertical emittance measured

Run 2 intensities (~150E10)

Emittance at C770 (μm)

without beta-beat correction
with beta-beat correction

Qν (set)

amplitude (a.u.)

Qν = 4.44

position (mm)
Impact on emittance (Run 2 intensities)

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![Emittance Comparison](image-url)
Impact on emittance (LIU intensities)

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- For the LIU intensities there seems to be a clear emittance decrease with the increase of the vertical tune
- Emittance blow-up at 4.47 could come from the interaction with the half-integer (remember: QNOs are OFF)

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• Injection chicane induced beta-beating measured with k-modulation at expected levels.
• Correction calculated and applied on R3.
• Intensity restored when correction applied for vertical tunes close to the half-integer (reduced beta-beating).
• Brightness gain when increasing the vertical tune only visible for the LIU intensities.
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Next:
• Evaluate impact of chromaticity correction and half-integer correction (QNOs)
• Repeat measurements on clone of operational LHC25 user for different tune evolutions (larger tune plateau at injection); optimize horizontal emittance.
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Ultimately:
• Define correction functions for QDE3/14 for all rings and apply them to all operational beams depending on the working point.
• Study the half-integer resonance and investigate if injection above it would be feasible

Thank you for your attention!
Backup
K-modulation after the fall of the chicane

Half-integer correction is ON

Half-integer correction is OFF
Impact on the tails

At 4.40/4.45 where beta-beating non-negligible but not so strong to cause losses; very low intensity beam (~30E10) and profile measured at C290

Slight improvement?
Impact on emittance (Run 2 intensities)

Same measurements as before but with QNOs ON