Injection Chicane Beta-Beating Correction for Enhancing the Brightness of the CERN PSB Beams

T. Prebibaj*[1], S. Albright, F. Antoniou, F. Asvesta, H. Bartosik, C. Bracco,
G.P. Di Giovanni, E. H. Maclean, B. Mikulec, E. Renner[(2)],
CERN, Geneva Switzerland
[(1)]also at Goethe University, Frankfurt, Germany
[(2)]also at TU Wienn, Vienna, Austria

ICFA HB2021

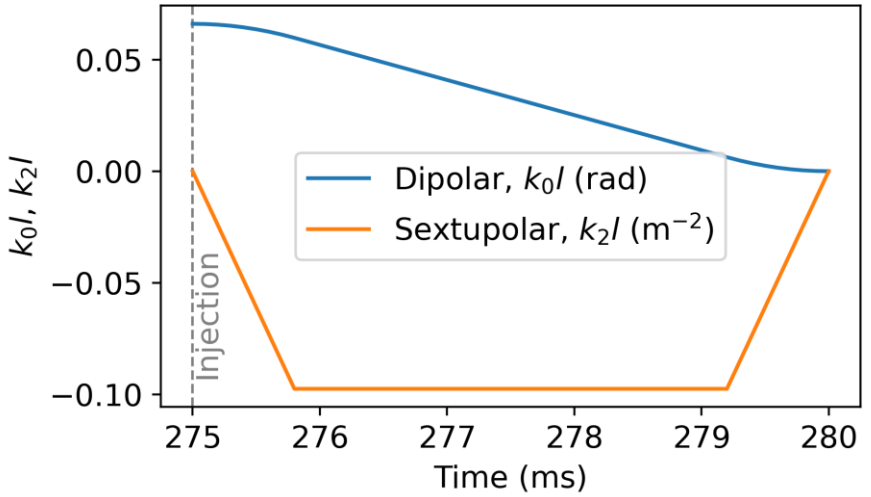
65th ICFA Advanced Beam Dynamics Workshop
on High-Intensity and High-Brightness Hadron Beams
4-8 October 2021, Fermi National Accelerator Laboratory, Batavia, USA

*tirsi.prebibaj@cern.ch

Introduction

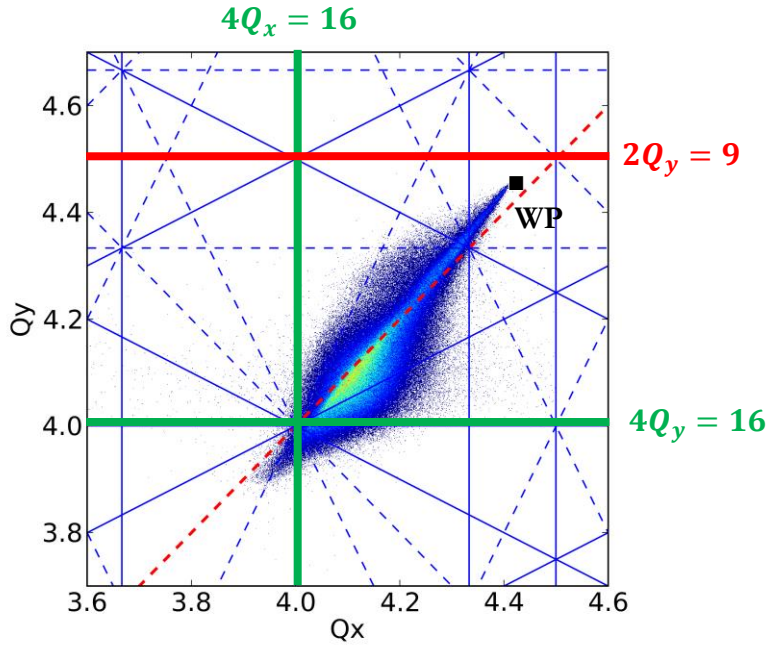
- A new ***H*⁻ charge exchange injection system** [1] was developed for the CERN PS Booster (PSB) in the context of the LHC Injectors Upgrade Project (LIU) [2].

- The injection chicane magnets induce strong **focusing errors** in the vertical plane [3]:
  i. through **edge focusing**,
  ii. and eddy currents in the vacuum chamber → generate a sextupolar component → beam enters with an offset → **feed-down effects**.



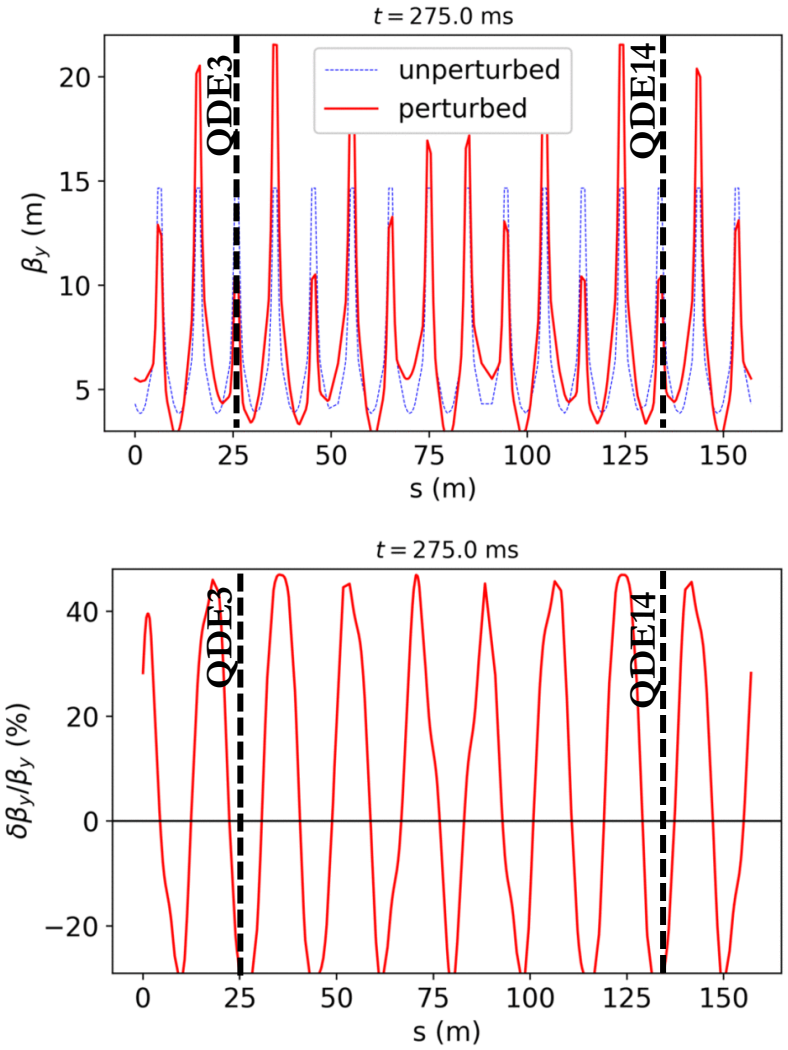
- The achievable beam brightness in the PSB is limited by the space charge effects at injection [4]:
  - tune spread can exceed values $\Delta Q_{x,y} = -0.5$ [5]
  - to avoid beam degradation due to the **integer resonances**, the machine is operated with working points (**WP**) very close to the **half-integer resonance**.

- The focusing errors induce optics perturbations (**β-beating and tune distortions**) in the vertical plane which are **strongly enhanced** in the proximity of the half-integer resonance and can lead to **beam losses**.

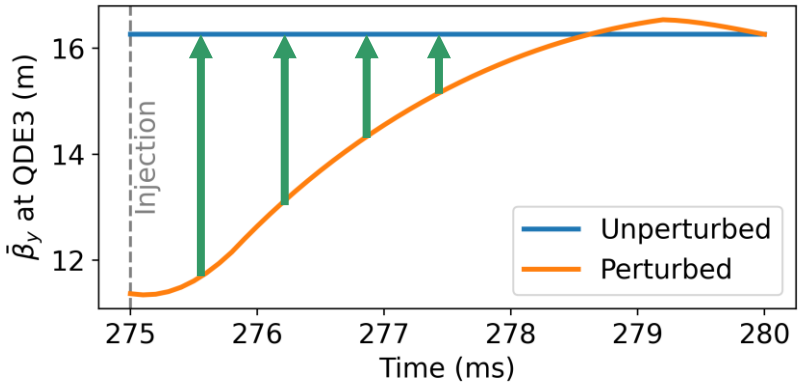


tirsi.prebibaj@cern.ch

Simulations of the PSB Injection Chicane Optics Perturbations



- The β-beating **dynamically changes** during this collapse of the injection chicane.
- β-beating is dynamically **compensated by correcting the local β distortions** at the position of two individually powered quadrupoles (**QDE3 and QDE14**) [6].



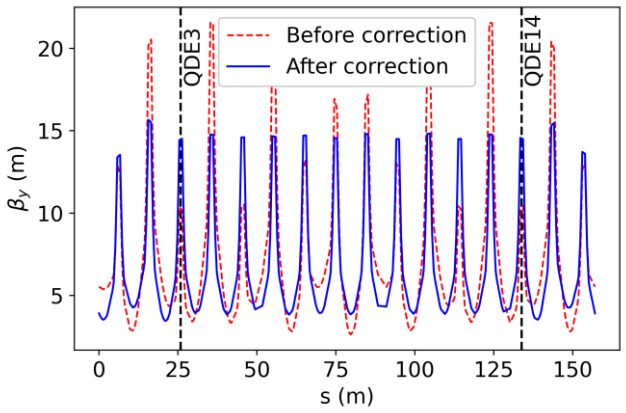
tirsi.prebibaj@cern.ch

Simulations of the PSB Injection Chicane Optics Perturbations

K-modulation measurement at QDE3 and QDE14

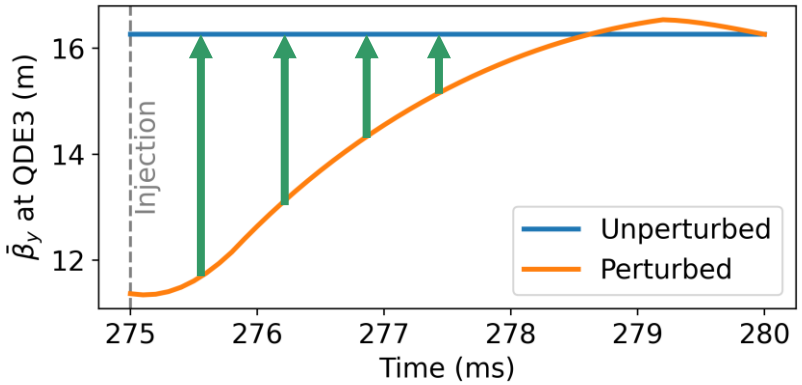
Interpolation of local distortions to a response matrix.

Time dependent correction applied to QDE3 and QDE14



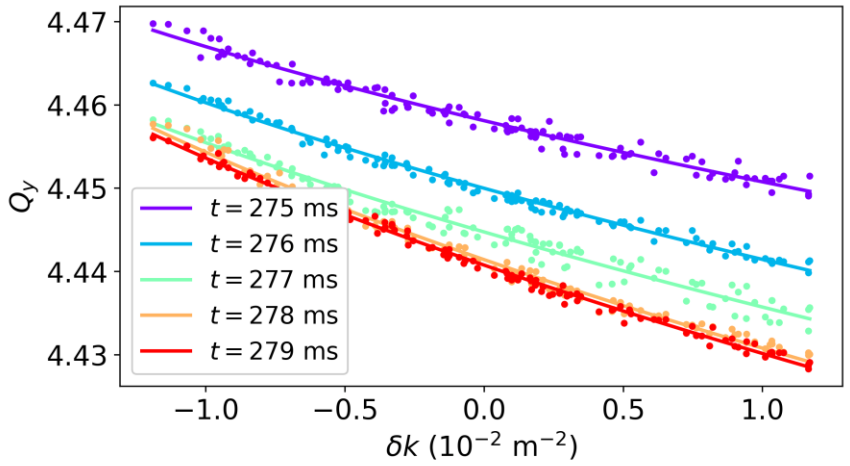
Extensive simulation studies [7,8]

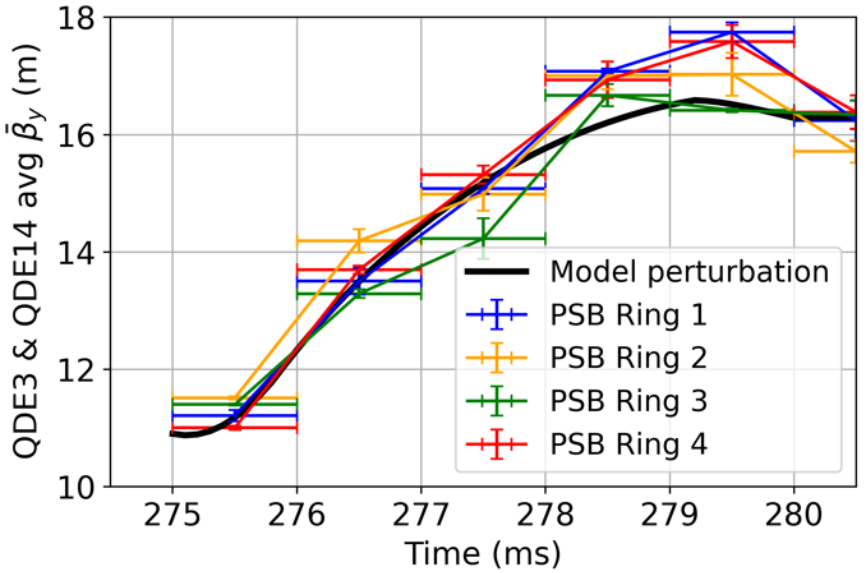
- The β-beating **dynamically changes** during this collapse of the injection chicane.
- β-beating is dynamically **compensated by correcting the local β distortions** at the position of two individually powered quadrupoles (**QDE3 and QDE14**) [6].

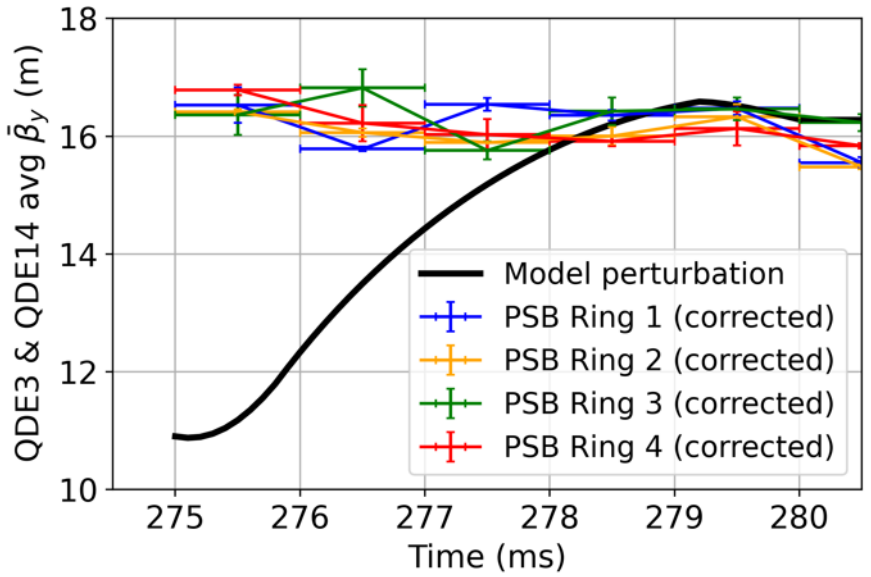


- Local β distortions at QDE3 and QDE14 measured with **K-modulation**.
- The dynamic β-beating **correction strengths** are calculated by interpolating the local distortions to a **response matrix** and then applied to QDE3 and QDE14.

β-beating Measurement and Correction at the Injection of the PSB





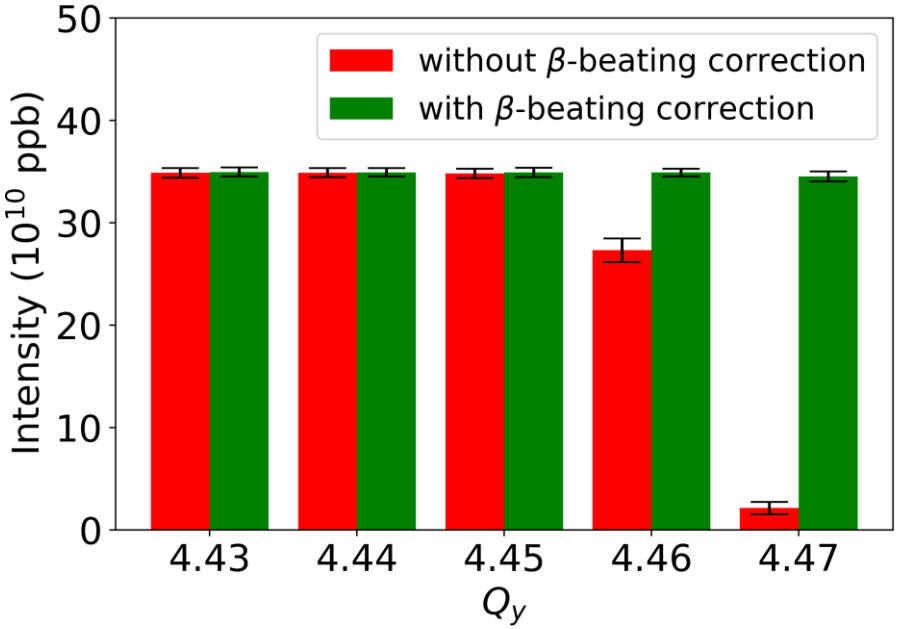


- Measurement of the **$\bar{\beta}_y$ at QDE3 with k-modulation**. Similar results for QDE14 and also for the other rings of the PSB.

- Average QDE3 & QDE14 local β distortions for all rings: **excellent agreement between the expected and the measured perturbation** → good modelling of the injection chicane error sources and the machine lattice.

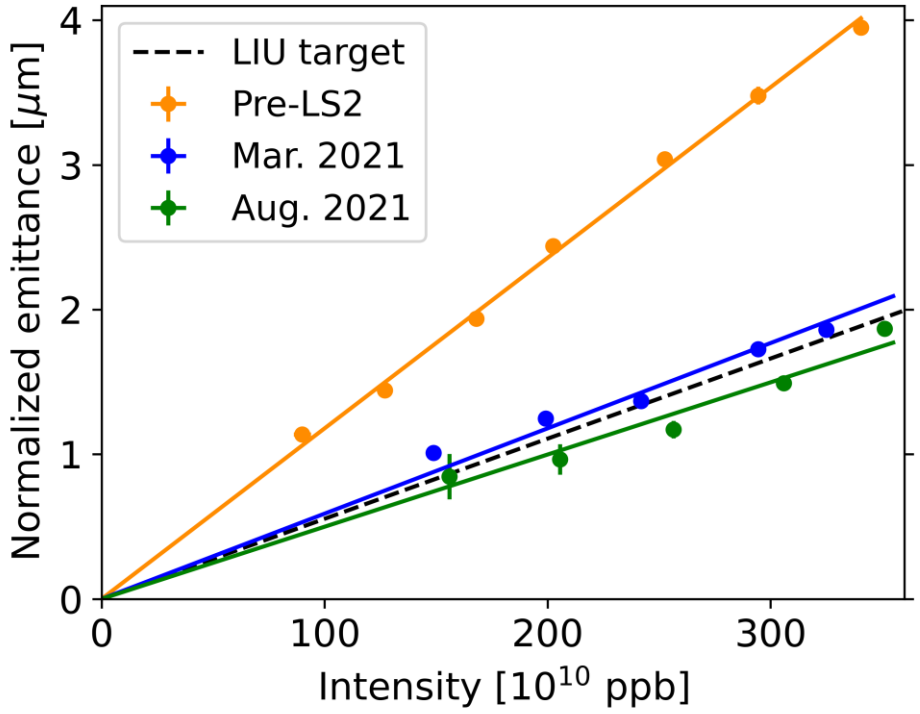
- After correction applied: β-function remains constant and close to the unperturbed value → **dynamic correction of the β-beating** throughout the fall of the chicane.

Impact on Beam Parameters



- Correction of the β-beating: allowed the **stable beam operation much closer to the half-integer resonance.**
- Working points closer to the half-integer resonance, i.e. further away from the integer resonance: **smaller emittance blow-up** for the same intensity and space charge tune spread.

- β-beating correction, resonance correction scheme improvements [9], working point and tune evolution optimization: **beam brightness gain at extraction of the PSB (green points)**



tirsi.prebibaj@cern.ch

Conclusions and Outlook

- Strong vertical **β-beating is induced by the magnets of the H− injection chicane** after the LIU upgrades in the PSB.

- The injection chicane β-beating was **measured using k-modulation at the expected levels** and then **dynamically corrected** using the defocusing quadrupoles QDE3 and QDE14.

- The correction allowed a stable operation of the beam with working points closer to the half-integer resonance **which mitigated the interaction of the beam with the integer resonance**, contributing to an **increased beam brightness**.

➢ Work to inject above the half-integer resonance without considerable beam degradation to further increase the brightness is ongoing.

Thank you for your attention!

References

[1]: W. J. M. Weterings, C. Bracco, L. O. Jorat, M. Meddahi, R.Noulibos, and P. Van Trappen, “The New Injection Region of the CERN PS Booster”, in *Proc. 10th Int. Particle Accelerator Conf. (IPAC’19)*, Melbourne, Australia, May 2019, pp. 2414–2417. doi:10.18429/JACoW-IPAC2019-WEPMP039

[2]: J. Coupard (ed.) *et al.*, “LHC Injectors Upgrade, Technical Design Report, Vol. I: Protons”, *CERN-ACC-2014-0337* CERN, Geneva, 2014.

[3]: E. Benedetto, B. Balhan, J. Borburgh, C. Carli, V. Forte, and M. Martini, “Detailed Magnetic Model Simulations of the H- Injection Chicane Magnets for the CERN PS Booster Upgrade, Including Eddy Currents, and Influence on Beam Dynamics”, in *Proc. 5th Int. Particle Accelerator Conf. (IPAC’14)*, Dresden, Germany, Jun. 2014, pp. 1618-1620. doi:10.18429/JACoW-IPAC2014-TUPRI027

[4]: E. Benedetto, M. Cieslak-Kowalska, V. Forte and F. Schmidt, “Space Charge Effects and Mitigation in the CERN PS Booster, in View of the Upgrade”, in *Proc. 57th ICFA Advanced Beam Dynamics Workshop on HighIntensity and High-Brightness Hadron Beams (HB’16)*, Malmö, Sweden, Jul. 2016, pp. 517-522. doi:10.18429/JACoW-HB2016-THPM9X01

[5]: B. Mikulec, A. Findlay, V. Raginel, G. Rumolo, and G. Sterbini, “Tune Spread Studies at Injection Energies for the CERN Proton Synchrotron Booster”, in *Proc. HB2012*, Beijing, China, Sep. 2012, paper MOP249, pp. 17-21.

[6]: M. Aiba, C. Carli, M. Chanel, B. Goddard, M. Martini, W. Weterings, “Lattice Issues of the CERN PSB with H- Charge Exchange Injection Hardware”, in *Proc. PAC’09*, Vancouver, BC, Canada, May 2009, paper TH6PFP036, pp. 3781-3783

[7]: T. Prebibaj *et al.*, “Beta-beat correction in the PSB during injection bump decay”, Presentation at ABP Injectors Working Group Meeting, CERN, Geneva, Switzerland, Apr. 2020 [Online]. Available: https://indico.cern.ch/event/910642/contributions/3830849.

[8]: T. Prebibaj *et al.*, “Status of the k-modulation application”, Presentation at Injectors Performance Panel Meeting, CERN, Geneva, Switzerland, Nov. 2020 [Online]. Available: https://indico.cern.ch/event/975301/contributions/4107125

[9]: F. Asvesta *et al.*, “Resonance Compensation for High Intensity and High Brightness Beams in the CERN PSB”, in *Proc. 65th ICFA Advanced Beam Dynamics Workshop (HB2021)*, Fermilab, Batavia, Illinois, USA, Oct. 2021, this conference.