Pushing High Intensity and High Brightness Limits in the CERN PSB After the LIU Upgrades

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ABSTRACT

After the successful completion of the LHC Injectors Upgrade (LIU) project, the CERN Proton Synchrotron Booster (PSB) has produced beams with up to two times higher brightness. However, the efforts to continuously improve the beam quality for the CERN physics experiments are ongoing. In particular, the high brightness LHC beams show non-Gaussian tails in the transverse profiles that can cause losses in the downstream machines, and even at LHC injection. As a result, alternative production schemes based on triple harmonic capture are being investigated in order to preserve brightness and reduce transverse tails at the same time. In addition, in view of a possible upgrade to the ISOLDE facility that would require approximately twice the number of protons per ring, the ultimate intensity reach of the PSB is explored. In this context, injection schemes using painting both transversely and longitudinally in order to mitigate the strong space charge effects are developed.

Space charge mitigation techniques

Space charge induced tune shift:

$$\Delta Q_{x,y} = -\frac{r_0 \lambda}{2\pi e \beta^2 \gamma^3} \oint \frac{\beta_{x,y}(s)}{\sigma_{x,y}(s)(\sigma_x(s)+\sigma_y(s))} ds$$

LIU project upgrades in the PSB to reduce & control space charge:

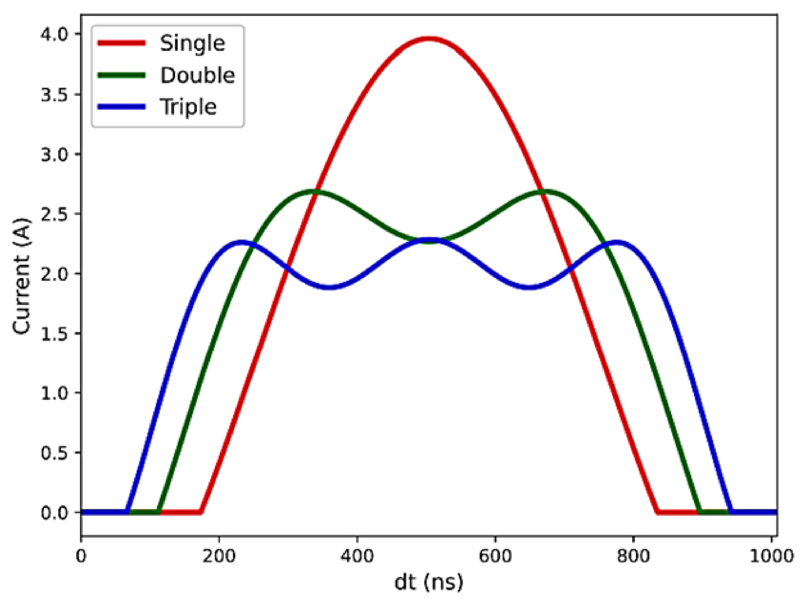
- ✓ **Injection energy upgrade** 160 MeV from 50 MeV ($\beta^2\gamma^3$)
- ✓ H^- **charge exchange injection** system allowing for transverse painting ($\sigma_{x,y}$)

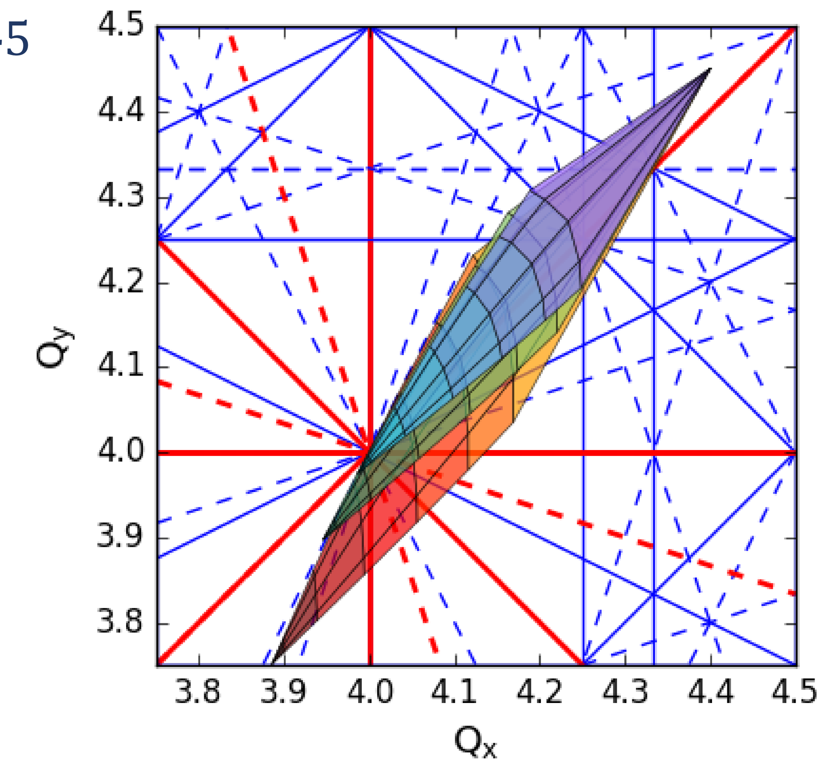
➢ Investigating the impact of the **longitudinal line density** (λ)

- ➢ **Single RF system** – $\Delta Q_y < -0.6$

Additional RF system in:

- ➢ **Double harmonic** – $\Delta Q_y \cong -0.5$
- ➢ **Triple harmonic** – $\Delta Q_y \cong -0.45$





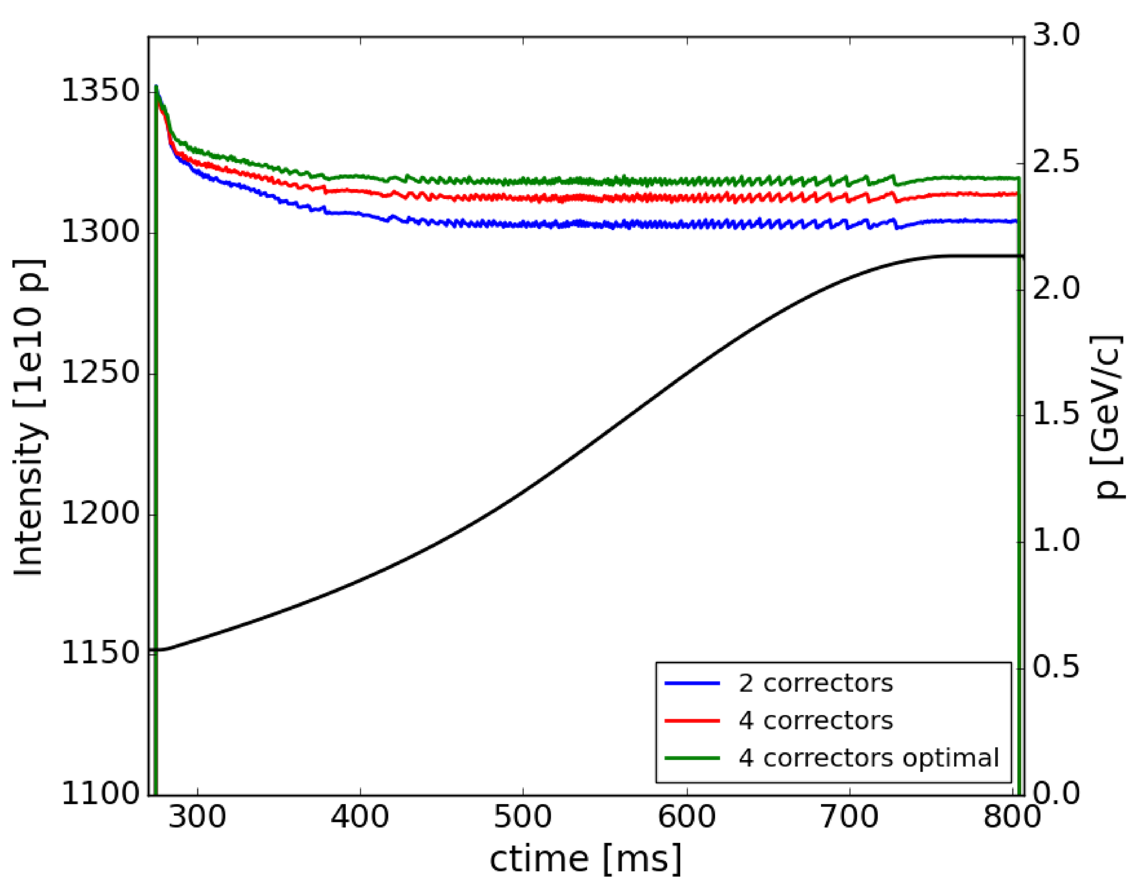
High Intensity beams

Taking advantage of the additional margin provided by

- **triple harmonic capture**
- **transverse painting** adjustments
- **resonance compensation of 4th order resonances** in the regime of operations

Intensity *of the higher intensity beams pushed from* ***1000×10¹⁰ ppr to > 1300×10¹⁰ ppr***

- *Losses: 3.6% (partial correction at 160MeV)*
- *Losses reduced to 2.7%: additional correctors (full correction at 160MeV)*
- *Losses reduced to 2.4% optimizing current share (full correction along the ramp)*



High Brightness beams

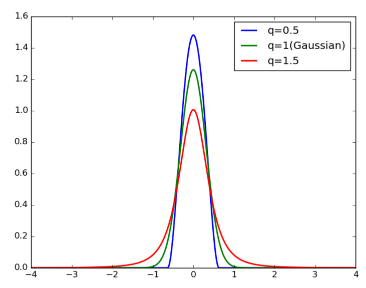
Taking advantage of the additional margin provided by the **triple harmonic capture**

- **Working point** manipulations along the cycle
- **Resonance compensation** improved (less resonances overlapped allow better control)

✓ **Brightness improved** *(showcased by emittance)*

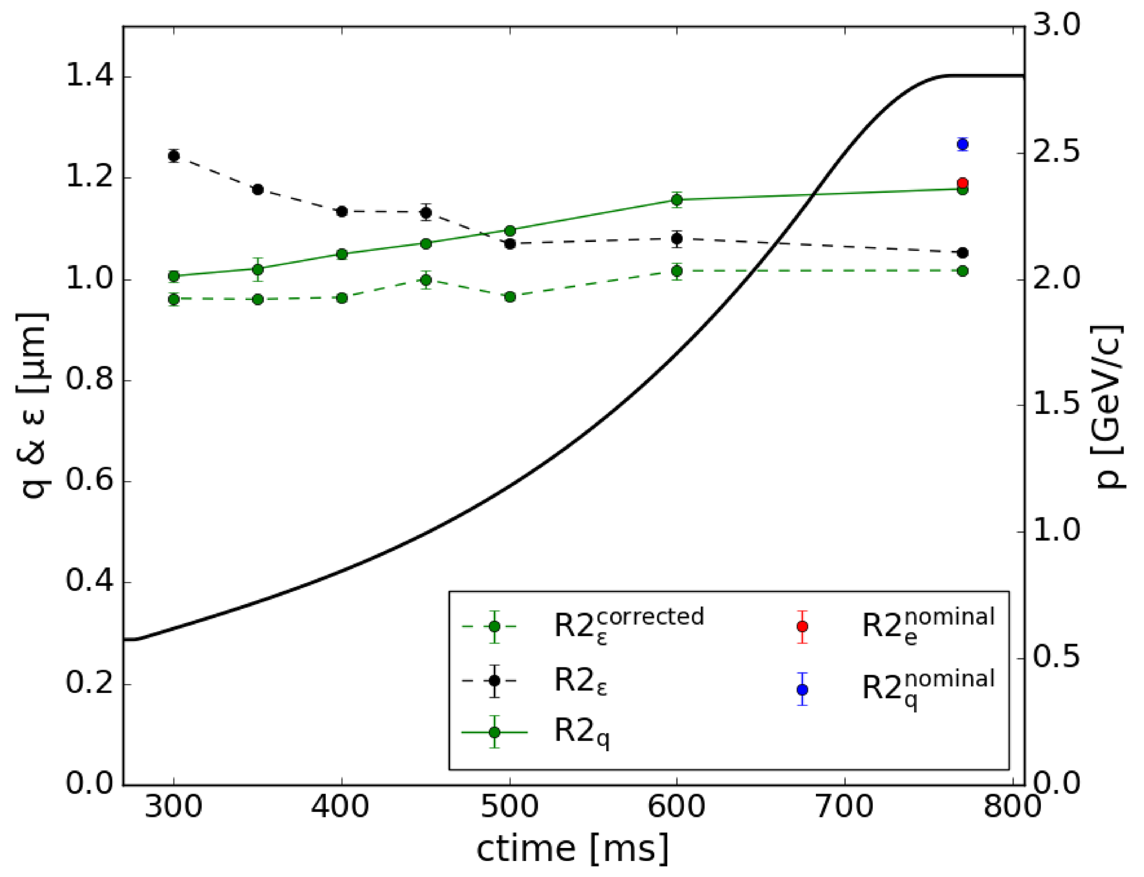
✓ **Profile quality improved** *(showcased by q-factor)*

- *q<1 → less than Gaussian tails*
- *q=1 → Gaussian*
- *q>1 → heavier than Gaussian tails*



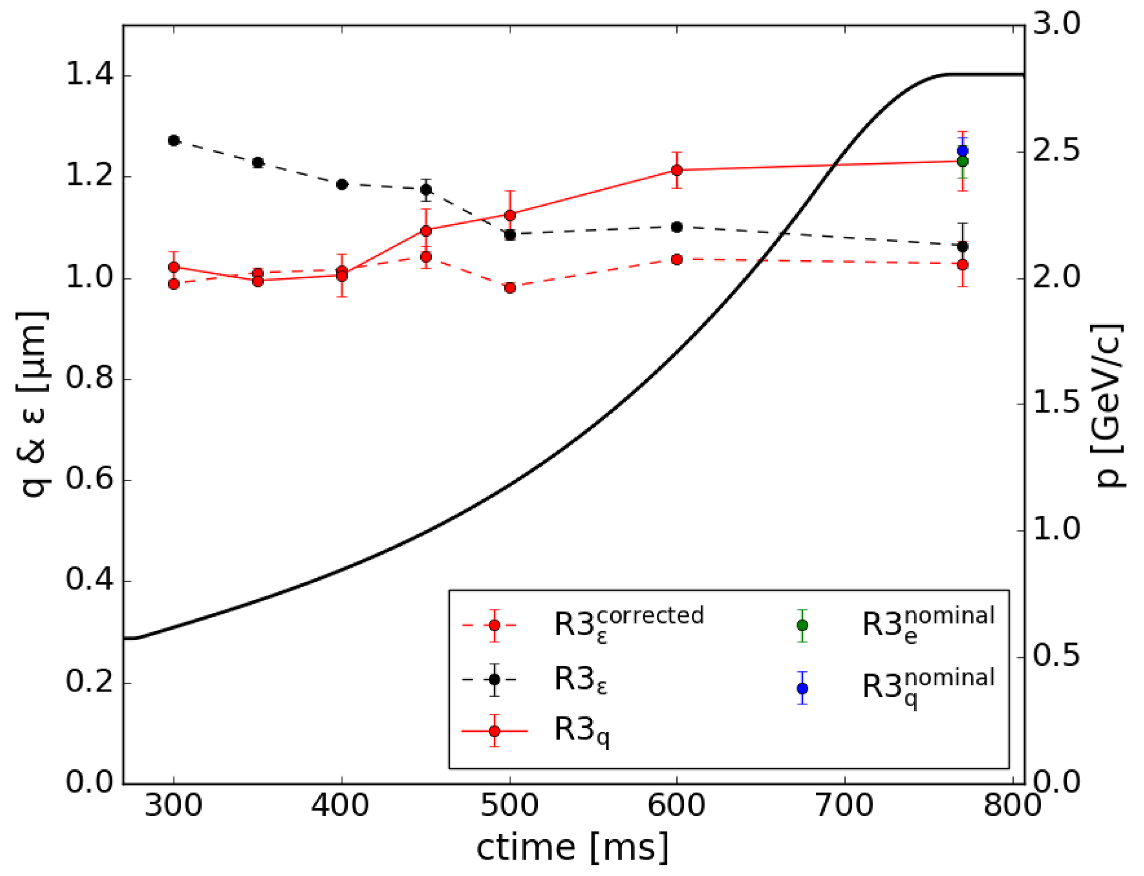
Ring 2

- ***Emittance reduced by: 11.55%***
- ***Tails (q-factor) reduced by: 7%***



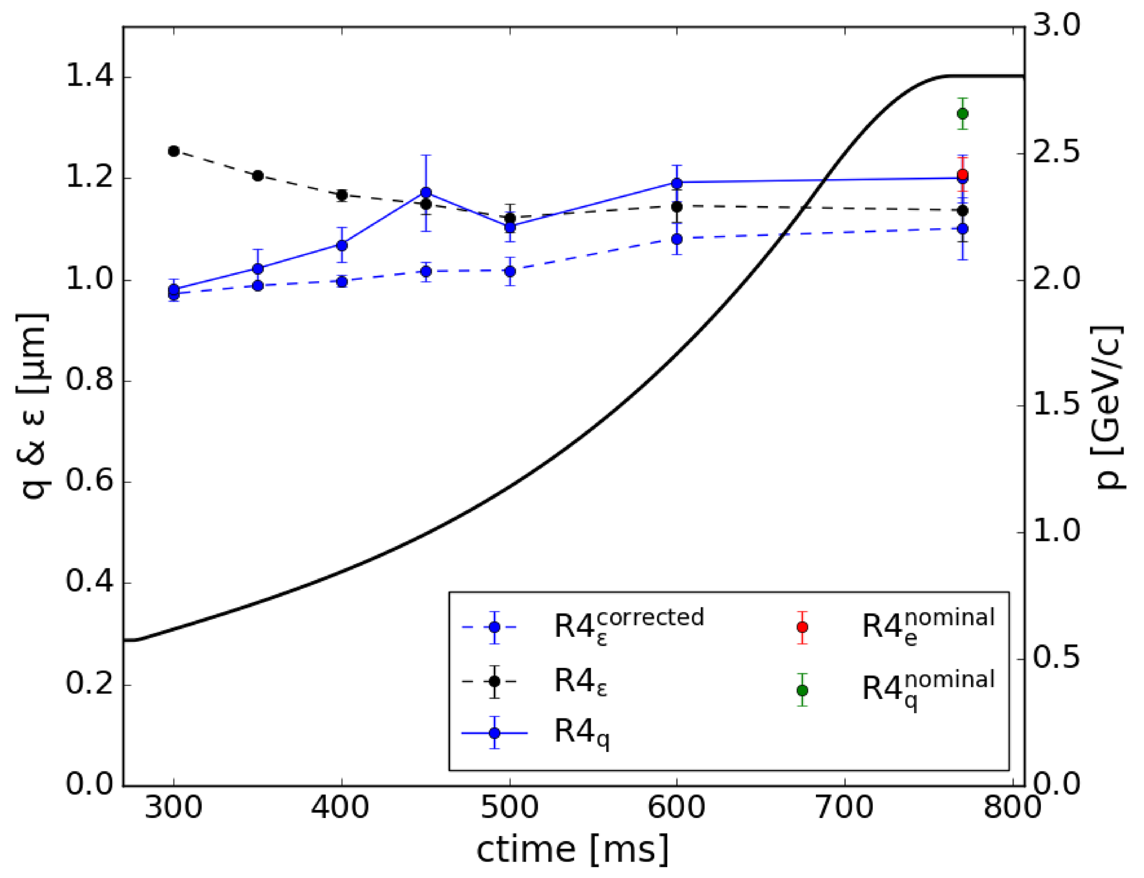
Ring 3

- ***Emittance reduced by: 13.5%***
- ***Tails (q-factor) reduced by: 1.7%***



Ring 4

- ***Emittance reduced by: 6%***
- ***Tails (q-factor) reduced by: 9.6%***



CONCLUSION

The PSB has managed to push the limits for both high intensity and high brightness beams at CERN. In particular, the target for the brightness has been exceeded using a triple harmonic capture to minimize space charge at injection. In addition, the margin provided by this longitudinal manipulation has been used to optimize beam quality and keep the beam profiles closer to the Gaussian distribution. Furthermore, high intensities have been achieved combining transverse painting, careful resonance compensation and the triple harmonic capture. The losses can be kept below the 3% level due to new resonance compensation schemes that optimize not only the resonances crossed and the number of correctors used but also the sharing of the current among the various magnets.

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