Emittance Exchange at SIRIUS Booster for Storage Ring Injection Improvement

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Abstract

SIRIUS is the new 4th generation storage ring based synchrotron light source built and operated by the Brazilian Synchrotron Light Laboratory (LNLS) at the Brazilian Center for Research in Energy and Materials (CNPEM). Currently, the efficiency of the horizontal off-axis injection system of the storage ring is still not suitable for top-up operation due to a smaller than expected horizontal dynamic aperture. In this work, we report the simulations and experimental results of transverse emittance exchange (TEE) performed at SIRIUS booster by crossing a coupling difference resonance during energy ramp, with the goal of decreasing the injected horizontal beam size and improve the off-axis injection efficiency.

CROSSING SPEED AND TEE QUALITY

The TEE adiabaticity is described by the following scaling parameter:

$$S = \frac{\dot{\Delta}}{|C|^2} \tag{1}$$

while the exchange quality is computed by:

$$R = 1 - \frac{\epsilon_x - \epsilon_{y0}}{\epsilon_{x0} - \epsilon_{y0}}, \tag{2}$$

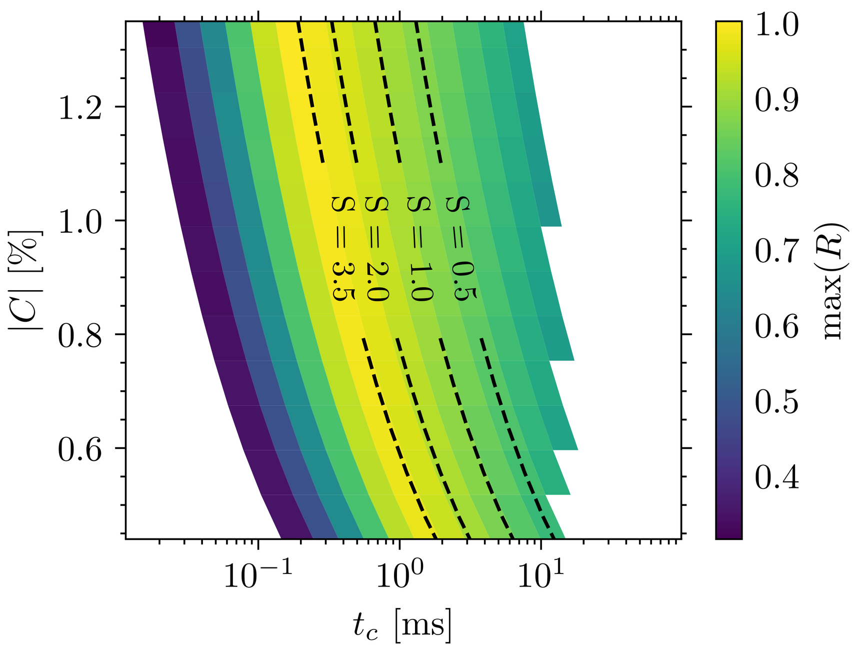

Figure 1: Emittance exchange quality as function of coupling coefficient $|C|$ and the time to cross the difference resonance t_c. The dashed lines indicate curves with constant S and emittance exchange quality higher than 80 %.

SIMULATION OF INJECTION WITH TEE

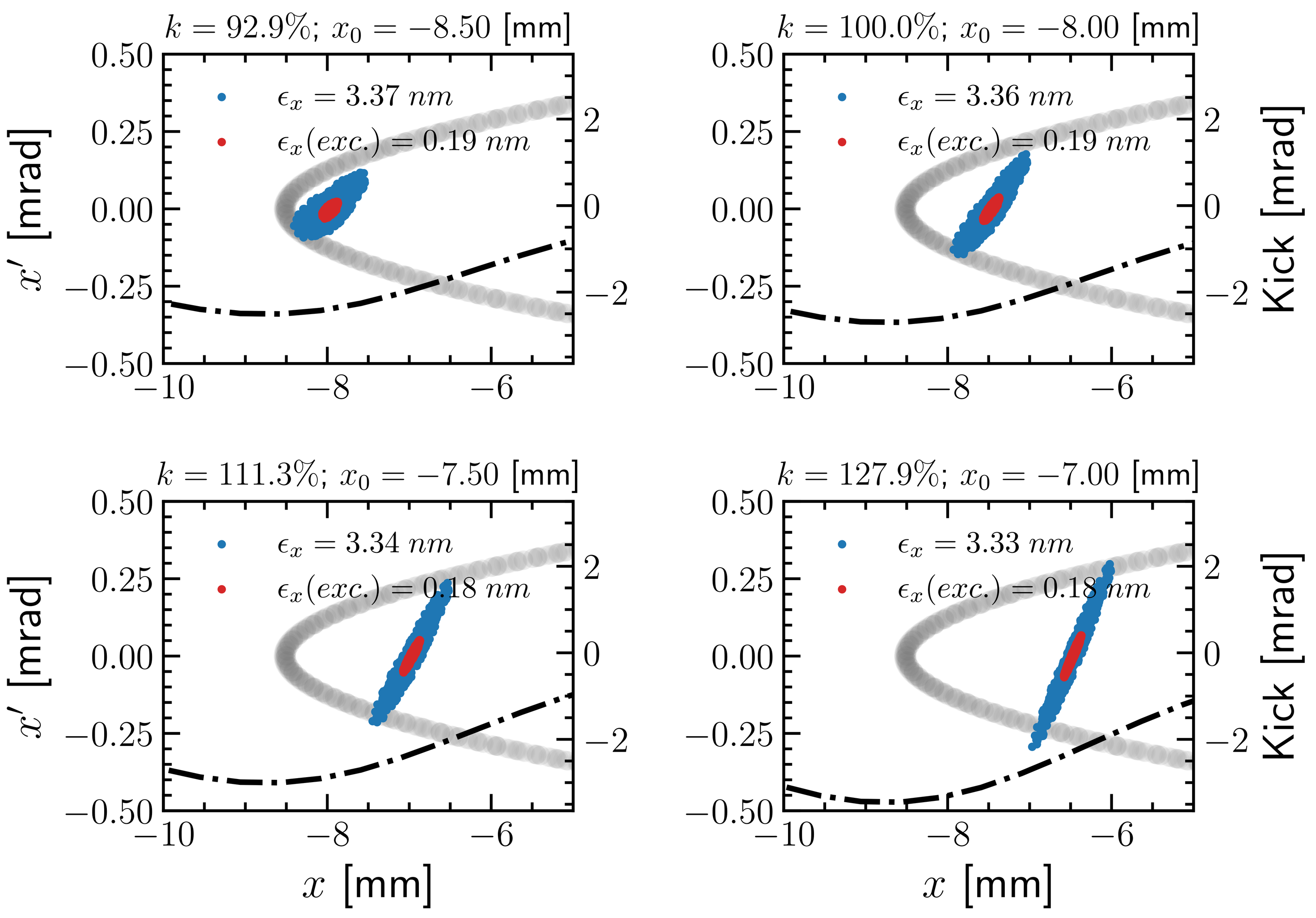

Figure 2: Phase-space diagrams of the bunch after the NLK for different initial horizontal positions x_0 at the NLK entrance. The dash-dotted lines represent the NLK pulse in units of angular kick. At each initial position, the NLK kick was optimized to deliver the bunch with $\langle x' \rangle \approx 0$, the parameter k express the pulse intensity relative to the pulse used to align the bunch with $x_0 = -8.00$ mm.

BOOSTER COUPLING MEASUREMENT

Table 1: SIRIUS booster nominal parameters at extraction energy.

Energy ramp	150 MeV to 3 GeV
Tunes	19.204, 7.314
Energy spread	0.087 %
Natural emittance	3.5 nm rad
Damping times	11.3 ms, 13.7 ms
Ramp up duration	≈ 300 ms
Repetition rate	2 Hz

Measured **coupling**:

$$|C| = 0.6(3)\ \%$$

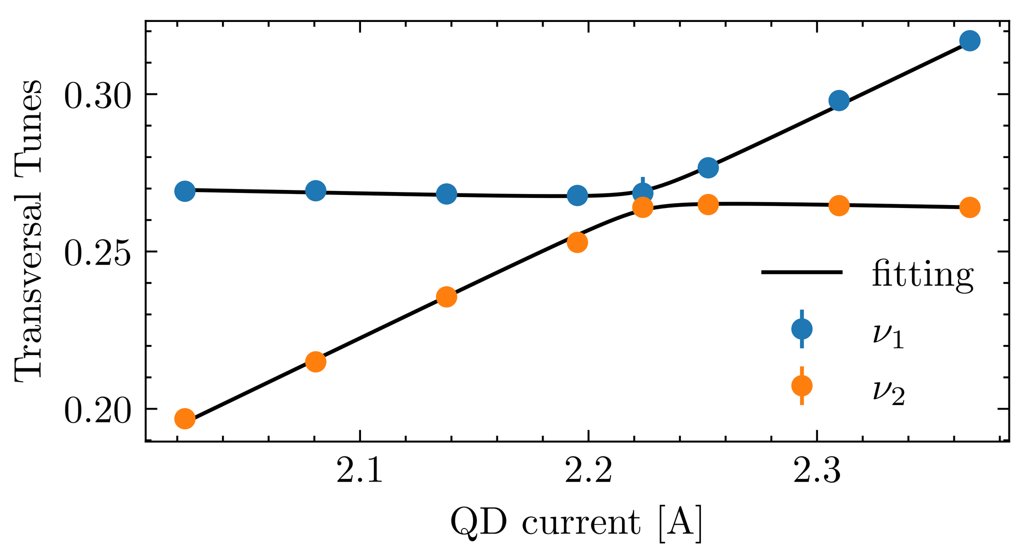

Figure 3: Closest tune approach method for measurement of natural betatron coupling close to extraction energy.

EMITTANCE EXCHANGE IMPLEMENTATION

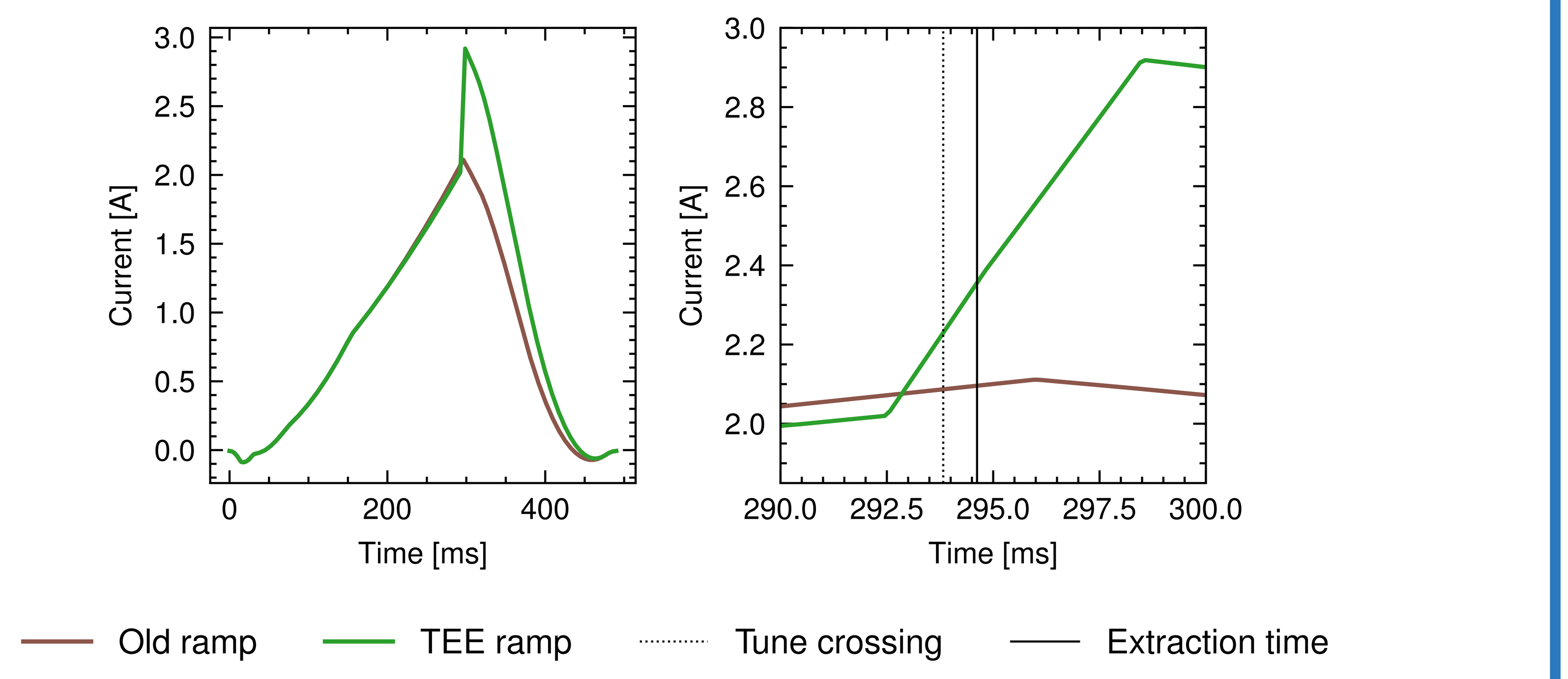

Figure 4: Modification made in QD quadrupoles current ramp to implement the TEE. On the left, the full ramp is shown and a zoom with the details around the extraction point is on the right plot.

EVALUATING THE EXCHANGE QUALITY

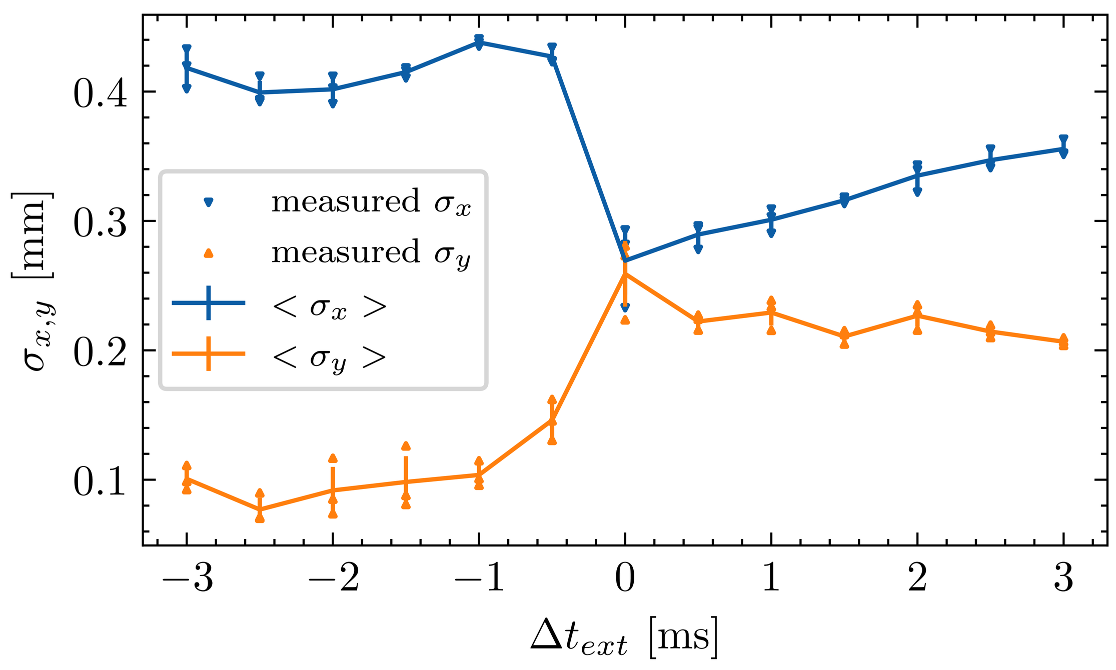

Figure 5: Beam sizes during emittance exchange.

The emittances can be estimated using the following equation with nominal values for energy spread and optical functions:

$$\epsilon_{x,y} = \frac{\sigma_{x,y}^2 - (\sigma_\delta \eta_{x,y})^2}{\beta_{x,y}}$$

Table 2: Nominal optical functions at the YAG screen in the booster-to-storage ring transport line.

$\beta_x,\ \beta_y$	17.11 m, 6.60 m
$\eta_x,\ \eta_y$	−13 cm, 0 cm

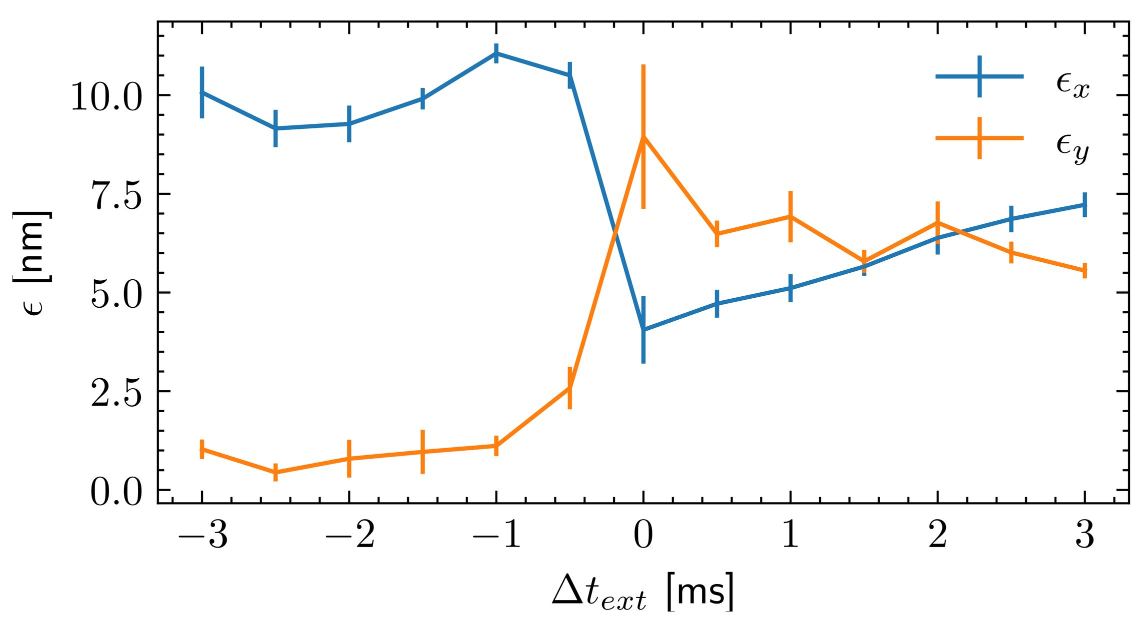

Figure 6: Estimate of emittances behavior using nominal optical functions.

Based on this estimation, the **exchange quality** at the extraction energy is:

$$R = 70(10)\ \%$$

INJECTION EFFICIENCY

Table 3: Injection efficiency comparison

	Before TEE	After TEE
Optimized Inj. System	86 %	96 %
User shifts	75 %	82 %

In addition, we also observed a lower correlation between injection efficiency and pulsed magnets temperatures after the TEE implementation.