

Online tuning of storage ring non-linear dynamics at SIRIUS and fast ORM measurement

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Optics Tuning and Corrections for Future Colliders Workshop
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Introduction

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Fast ORM Measurement

SIRIUS storage ring

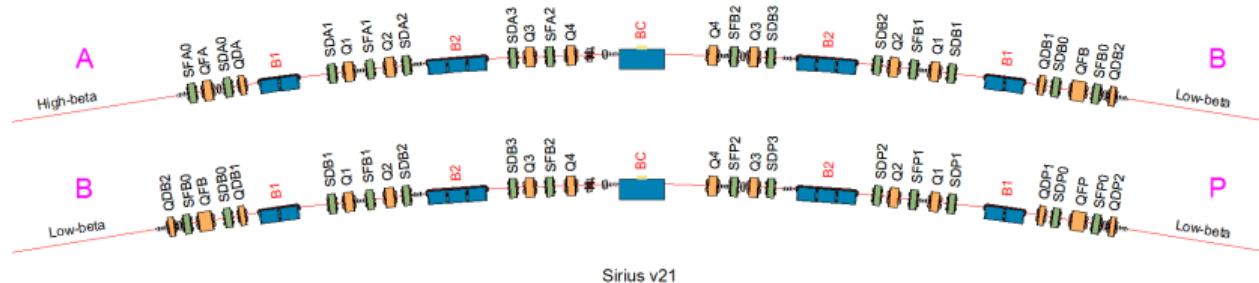


Designed, built and operated by the Brazilian Synchrotron Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM) campus, at Campinas, Brazil.

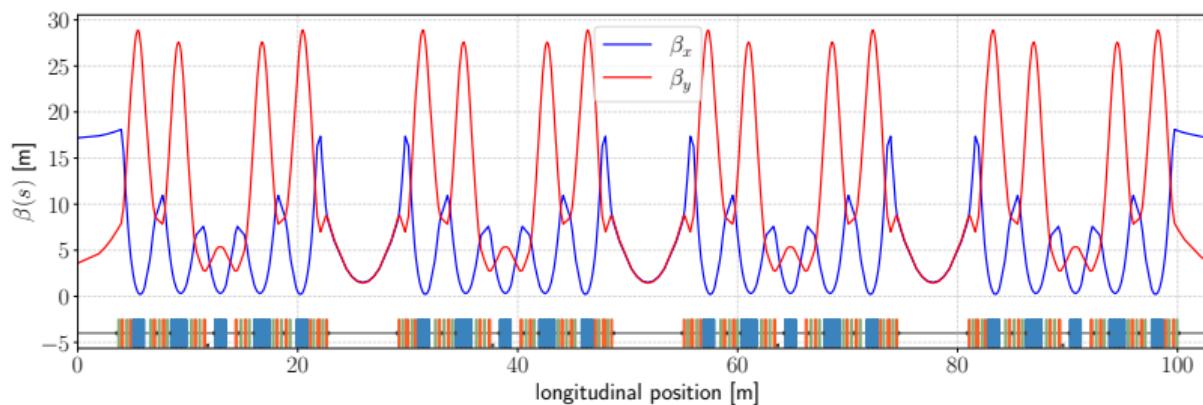
Parameter	Currently	Phase I
Energy	E_0	3 GeV
Current	I_0	100 mA
Operation mode		Top-up
RF Cavities		1 NC
RF Voltage	\hat{V}_{rf}	1.5 MV
RF Frequency	f_{rf}	499.667 MHz
Harmonic Number	h	864
Momentum compaction factor	α	1.6×10^{-4}
Energy Spread	σ_δ	8.5×10^{-4}
Bunch length	σ_z	2.5 mm
Energy loss p/ turn	U_0	470 keV
Lifetime	τ	> 10 h

SIRIUS Lattice and Optics

20-cell 5BA lattice with 5-fold symmetric high (A) and low (B, P) betatron functions sections. Superperiod = A-B-P-B



Sirius v21

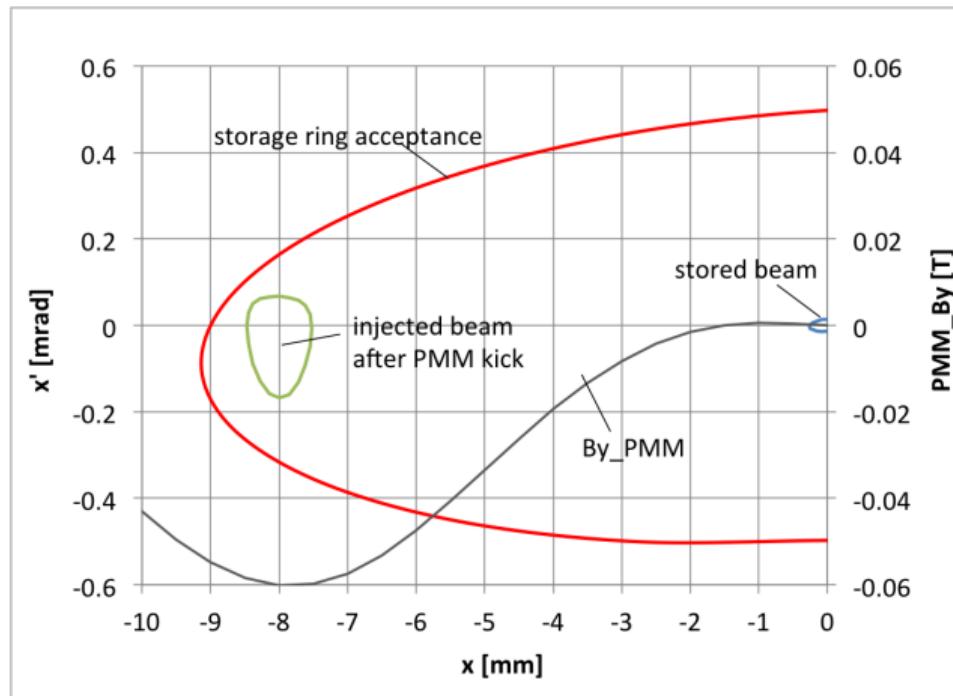
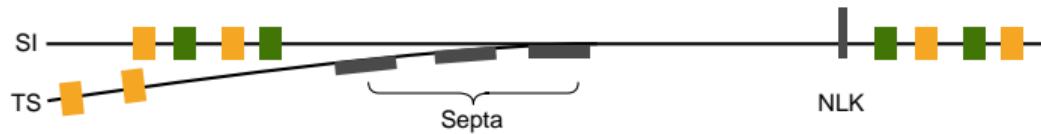


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Off-axis injection scheme



The optimization setup

21 sextupole families

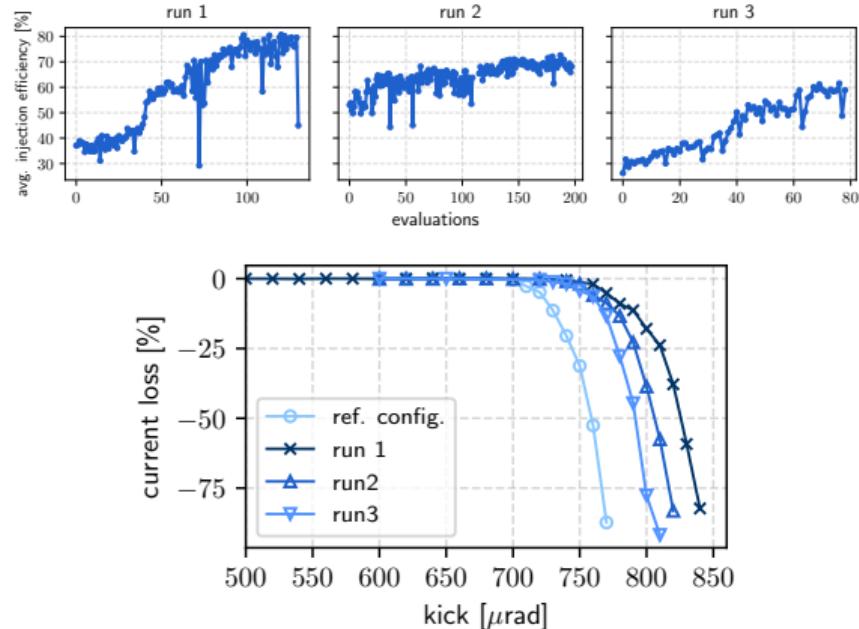
	SFA0, SDA0,
achromatic	SFB0, SDB0, SDP0, SFP0
	SDA1, SFA1, SDA2, SFA2, SDA3, SDB1,
chromatic	SDB2, SFB2, SDB3, SFP1, SDP1, SFP2, SDP2, SDP3

varying sextupoles w/o changing chromaticity

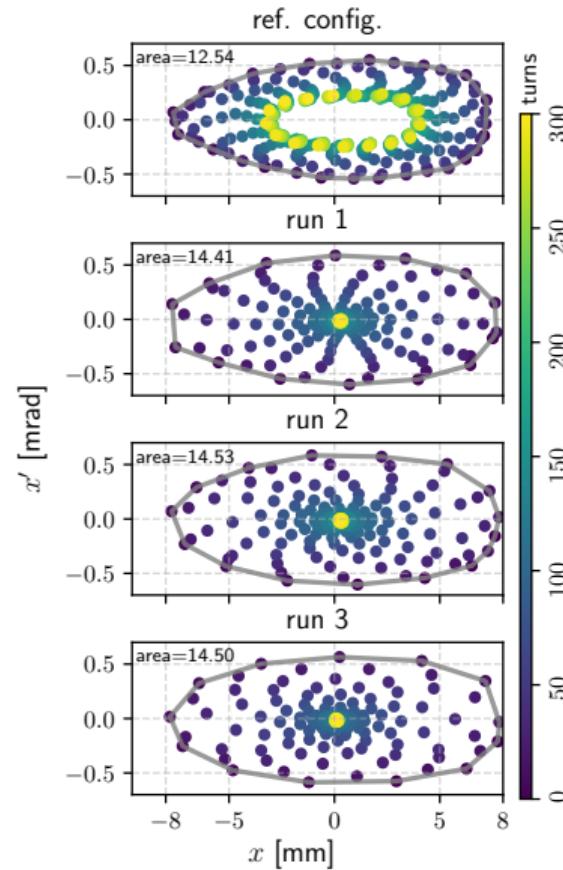
- ▶ knobs \in chromaticity response matrix nullspace
- ▶ free knobs + compensation knobs

M. M. S. Velloso, L. Liu, F. de Sá, M. Alves, X. Resende, and X. Huang, “Online optimization of SIRIUS nonlinear optics”, *presented at IPAC'23*, Venice, Italy, May 2023,

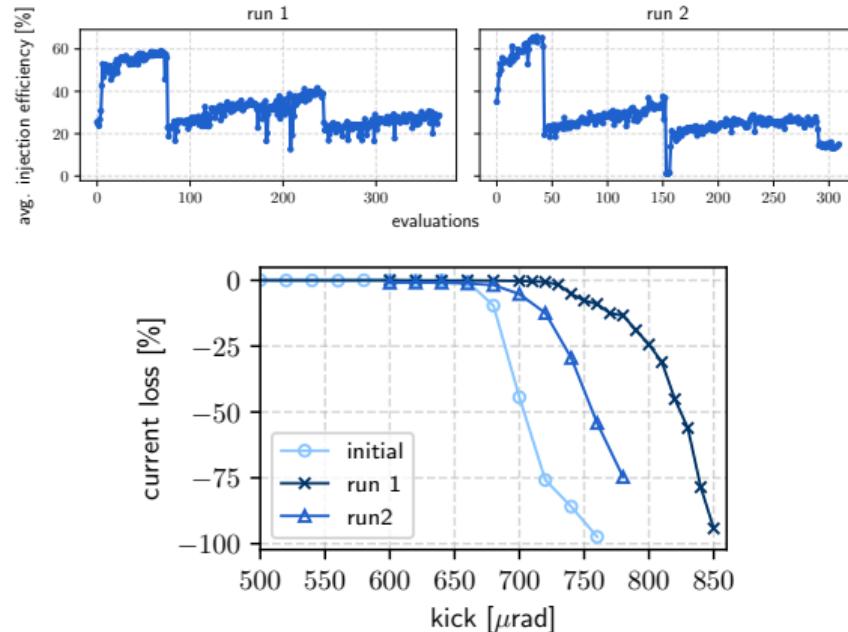
Tuning at $\nu_x = 49.08, \nu_y = 14.14$ (Working Point 1)



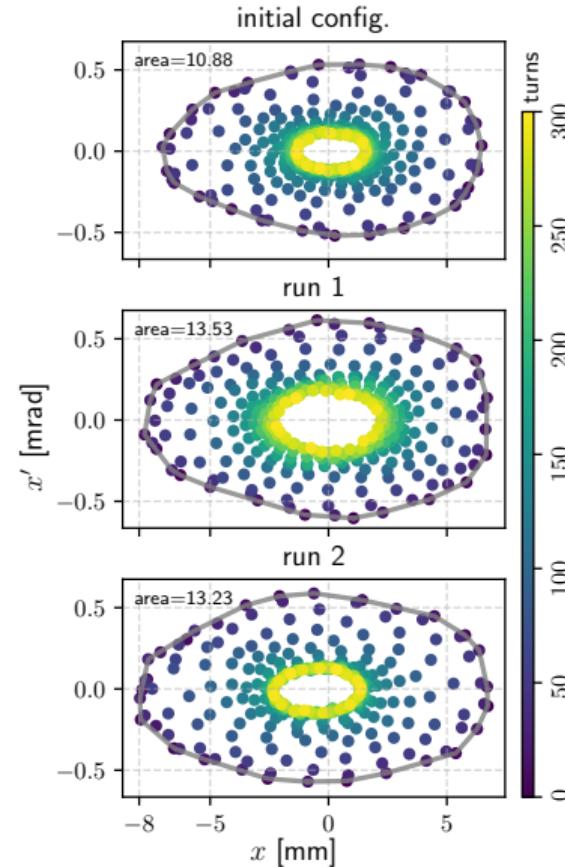
configuration	injection efficiency [%]
ref-config	88 ± 8
run 1	91 ± 1
run 2	98 ± 1
run 3	87 ± 3



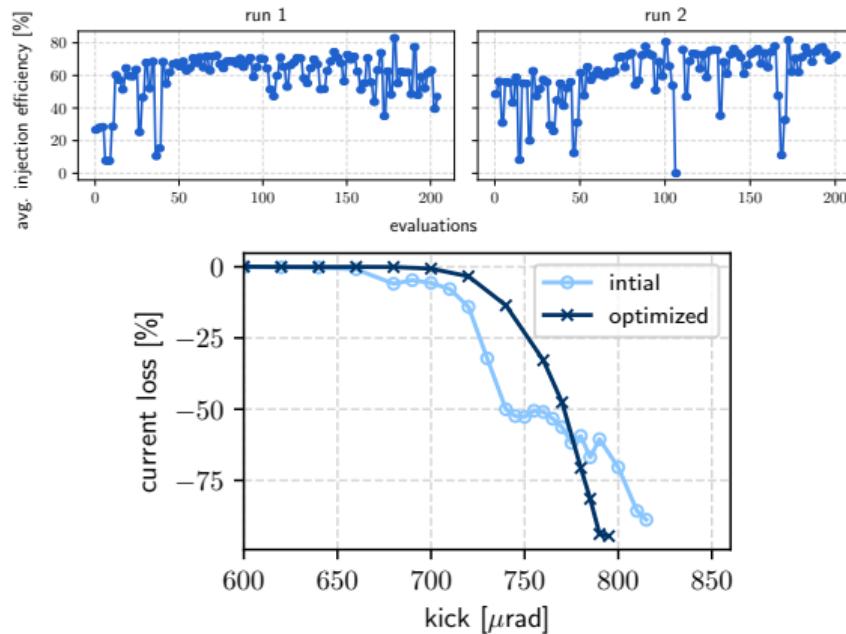
Tuning at $\nu_x = 49.20, \nu_y = 14.25$ (Working Point 2)



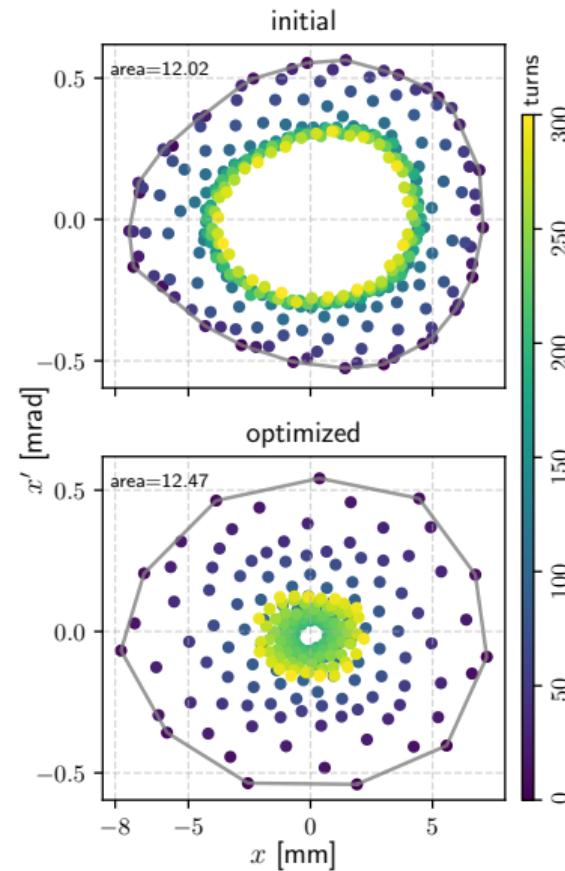
configuration	injection efficiency [%]
non-optimized	51 ± 1
run 1	79 ± 3
run 2	65 ± 1



Tuning at $\nu_x = 49.16, \nu_y = 14.22$ (Working Point 3)



configuration	injection efficiency [%]
non-optimized	$- \pm 1$
optimized	93 ± 3

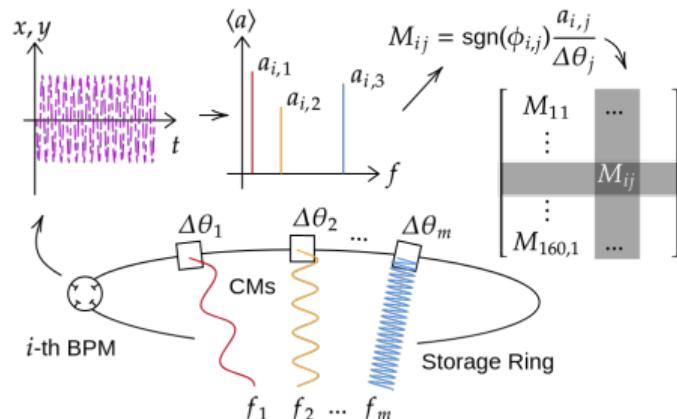


Introduction

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Fast ORM Measruement

Fast ORM Measurement



- ▶ Fitting to i -th BPM data $u_i(t_j)$:

$$\begin{bmatrix} \cos(2\pi f_1 t_1) & \sin(2\pi f_1 t_1) & \dots \\ \cos(2\pi f_1 t_2) & \sin(2\pi f_1 t_2) & \dots \\ \vdots & \vdots & \vdots \\ \cos(2\pi f_1 t_n) & \sin(2\pi f_1 t_n) & \dots \\ \vdots & \vdots & \vdots \\ M_{11} & \dots & M_{ij} \\ \vdots & \vdots & \vdots \\ M_{160,1} & \dots & \dots \end{bmatrix} \begin{bmatrix} b_{i1} \\ c_{i1} \\ \vdots \\ b_{im} \\ c_{im} \end{bmatrix} = \begin{bmatrix} u_i(t_1) \\ u_i(t_2) \\ \vdots \\ u_i(t_n) \end{bmatrix}$$

- ▶ Expected beam motion

$$\Delta u_i(t)_n = \sum_j a_{i,j} \sin(2\pi f_j t_n + \phi_{i,j})$$

$$a_{i,j} = \sqrt{b_{i,j}^2 + c_{i,j}^2}, \quad \phi_{i,j} = \text{atan2}(b_{i,j}, c_{i,j}) \in (-\pi, \pi]$$

- ▶ ORM elements:

$$M_{ij} = \text{sgn}(\phi_{i,j}) \frac{a_{i,j}}{\Delta\theta_j},$$

M.M.S. Velloso, M.B. Alves, and F.H. de Sá, "Fast Orbit Response Matrix Measurement via Sine-Wave Excitation of Correctors at SIRIUS", in Proc. IPAC'22, Bangkok, Thailand, Jun. 2022, pp. 425–428.

Measurements at SIRIUS storage ring and LOCO performance

SIRIUS BPMs-CMs circuit

- ▶ 160 BPM buttons
- ▶ $n_x = 120$ CHs, $n_y = 160$ CVs,
 $n = n_x + n_y = 280$ CMs

Measurment Procedure

- ▶ At each one of the **20 sectors**,
 - ▶ **6 CHs** $f_x = 3, 7, 13, 19, 29, 37$ Hz
 - ▶ **8 CVs** $f_y = 5, 11, 17, 23, 31, 41, 47, 59$ Hz
 - ▶ 5 μ rad strength, during 4 seconds.
- ▶ The complete measurement took around 2.5 – 3 min.

AC- and DC-ORM signature correlation

- ▶ $\cos \theta_j = \mathbf{v}_{AC,j} \cdot \mathbf{v}_{DC,j} / \| \mathbf{v}_{AC,j} \| \| \mathbf{v}_{DC,j} \|$
- ▶ avg $|1 - \cos \theta_j| \sim 0.03\%$ for diagonal blocks and
 $\sim 3\%$ for off-diagonal blocks

