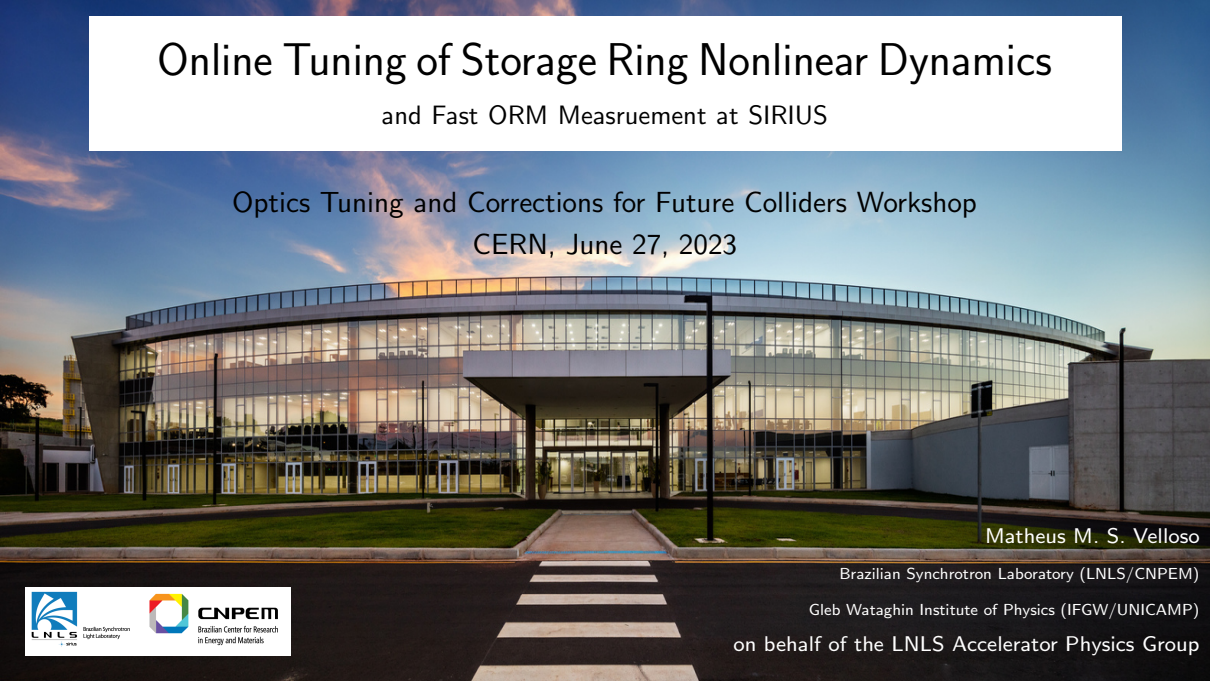
Online Tuning of Storage Ring Nonlinear Dynamics

and Fast ORM Measruement at SIRIUS

Optics Tuning and Corrections for Future Colliders Workshop

CERN, June 27, 2023



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LNLS Brazilian Synchrotron Light Laboratory

CNPEM Brazilian Center for Research in Energy and Materials

Introduction

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Fast ORM Measruement

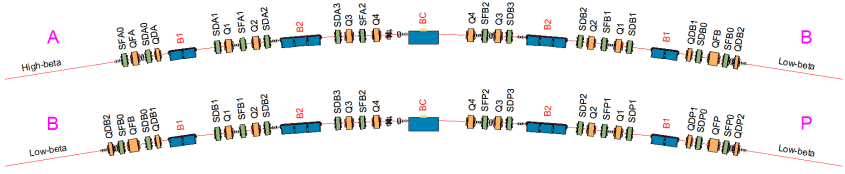
SIRIUS storage ring

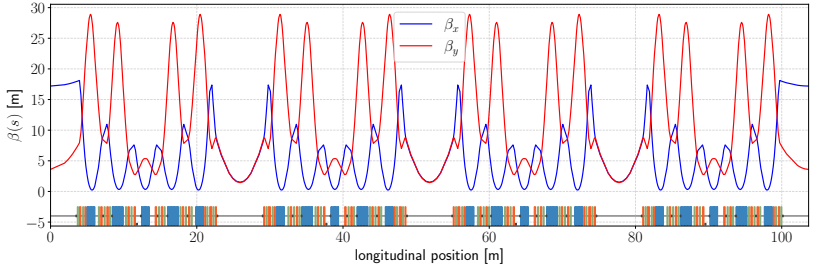
Designed, built and operated by the Brazilian Synchrotron Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM) campus, at Campinas, Brazil.

Parameter		Currently	Phase I
Energy	E_0	3 GeV	
Current	I_0	100 mA	350 mA
Operation mode		Top-up	
RF Cavities		1 NC	2 SC + HC
RF Voltage	$\hat{V}_{\mathrm{rf}}$	1.5 MV	3.0 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	12 mm
Energy loss p/ turn	U_0	470 keV	870 keV
Lifetime	τ	15 h	> 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





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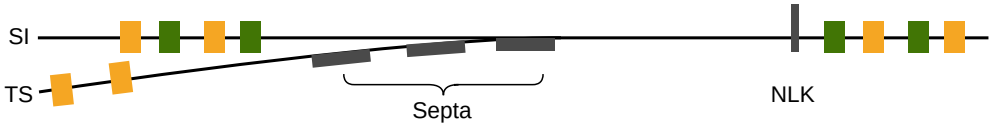
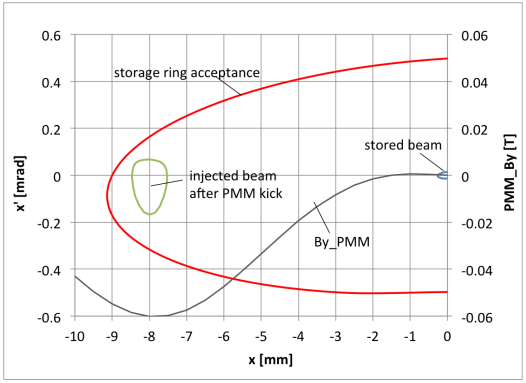
Off-axis injection scheme





- 100% efficiency with a $x = -9$ mm DA
- $88 \pm 8\%$ efficiency is observed

RCDS optimization setup

- objective function: avg. injection efficiency of 5 pulses @ 2 Hz
  - beam at the DA border to reduce efficiency
- available knobs: 21 sextupole families
  - knobs $\in$ chromaticity response matrix nullspace (13, 17 knobs)
  - 13 free knobs + 6 compensation knobs

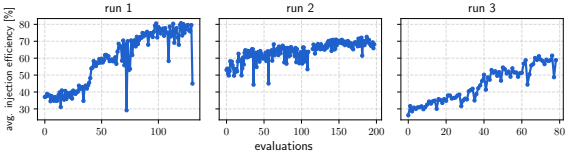
More details:

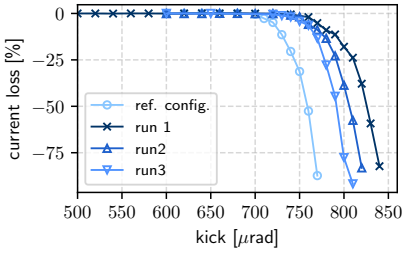
M. M. S. Velloso, L. Liu, F. de Sá, M. Alves, X. Resende, and X. Huang, "Online optimization of SIRIUS nonlinear optics", *presented at IPAC'23*, Venice, Italy, May 2023,

SIRIUS sextupole families

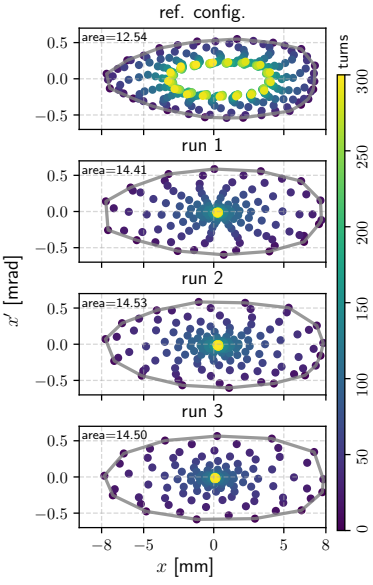
achromatic	SFA0, SDA0, SFB0, SDB0, SDP0, SFP0
chromatic	SDA1, SFA1, SDA2, SFA2, SDA3, SDB1, SDB2, SFB2, SDB3, SFP1, SDP1, SFP2, SDP2, SDP3

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

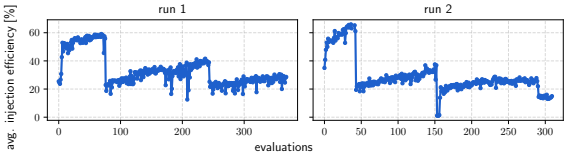


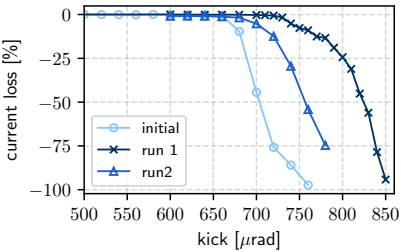


configuration	injection efficiency [%]
ref-config	88 ± 8
run 1	91 ± 1
run 2	98 ± 1
run 3	87 ± 3

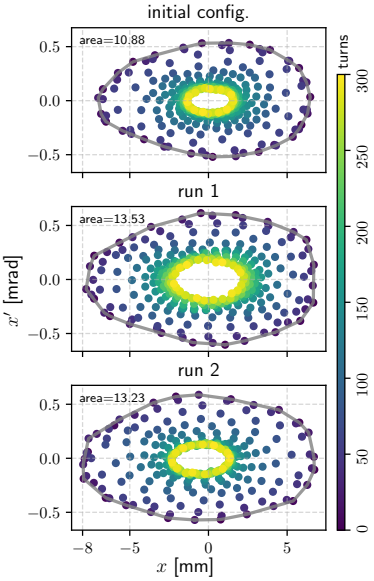


Tuning at $\nu_x = 49.20, \nu_y = 14.25$ (Working Point 2)

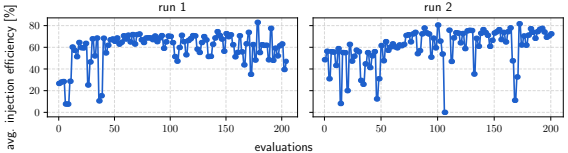


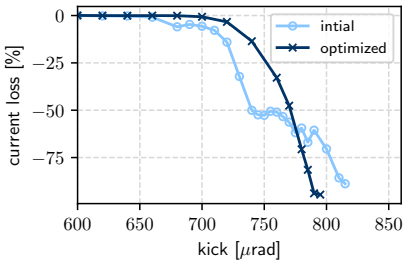


configuration	injection efficiency [%]
non-optimized	51 ± 1
run 1	79 ± 3
run 2	65 ± 1

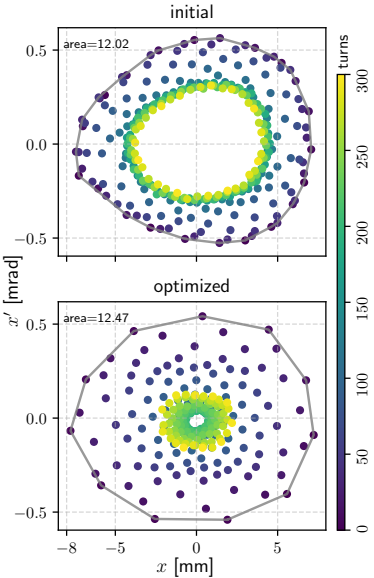


Tuning at $\nu_x = 49.16, \nu_y = 14.22$ (Working Point 3)





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



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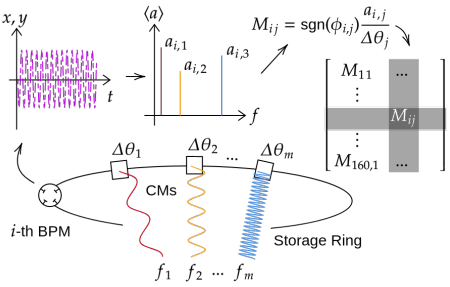
Fast ORM Measruement

Fast ORM Measurement



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.

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

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

- Expected beam motion

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

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

- ORM elements:

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

Measurements at SIRIUS storage ring and LOCO performance

SIRIUS BPMs-CMs circuit

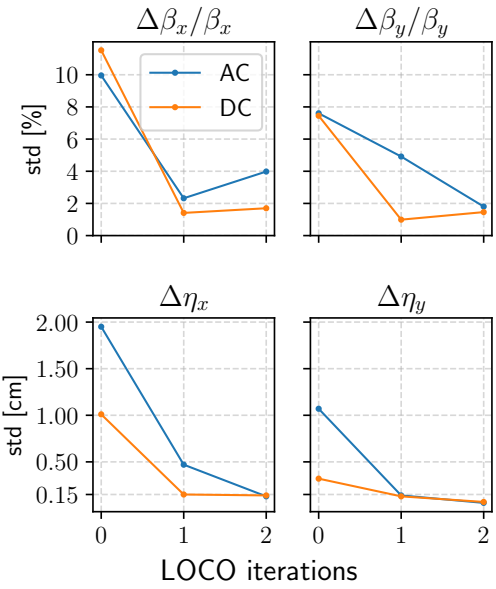
- 160 BPM buttons
- $n_x = 120$ CHs, $n_y = 160$ CVs, $n = n_x + n_y = 280$ CMs

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 µrad strength, during 4 seconds.
- The complete measurement took around $2.5 - 3$ min.

AC- and DC-ORM signature correlation

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



Thank you!

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