

# Online Tuning of Storage Ring Nonlinear Dynamics

and Fast ORM Measurement at SIRIUS

Optics Tuning and Corrections for Future Colliders Workshop  
CERN, June 27, 2023



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Brazilian Synchrotron Light Laboratory (LNLS/CNPEM)

## Introduction

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Fast Orbit Response Matrix Measruement

# SIRIUS storage ring

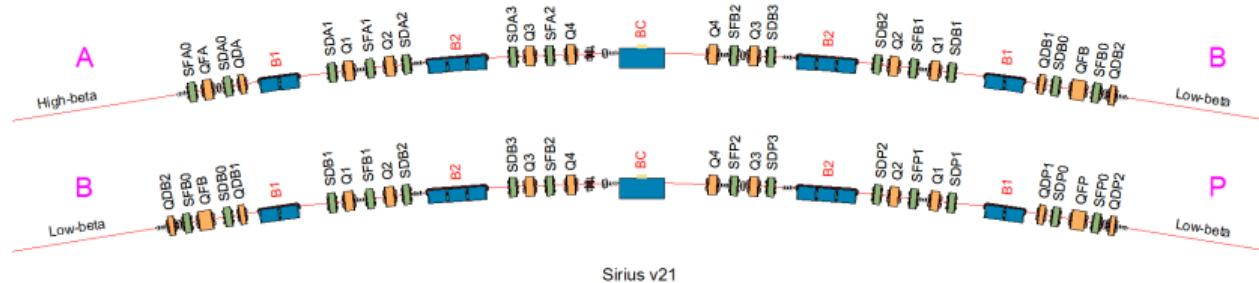


Designed, built and operated by the Brazilian Synchrotron Light Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM) campus, at Campinas, Brazil.

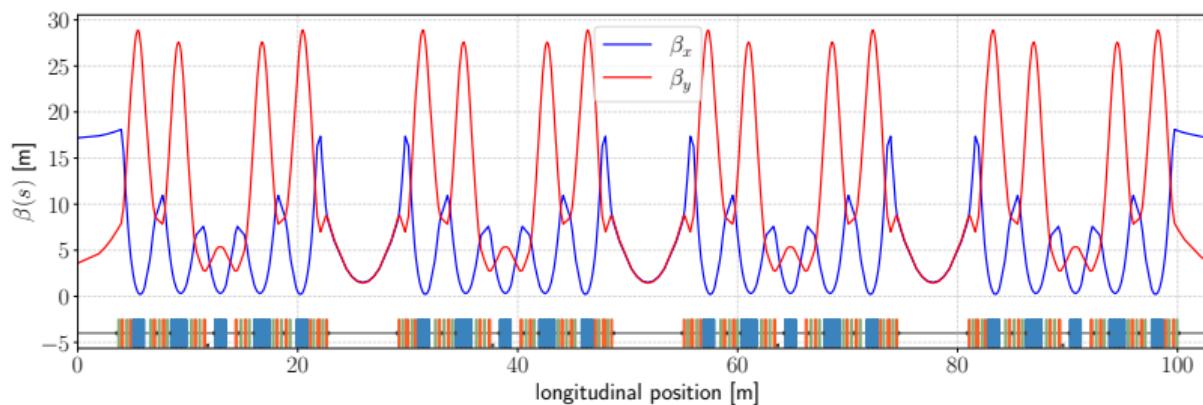
Parameter	Currently	Phase I
Energy	$E_0$	3 GeV
Current	$I_0$	100 mA
Operation mode		Top-up
RF Cavities		1 NC
RF Voltage	$\hat{V}_{\text{rf}}$	1.5 MV
RF Frequency	$f_{\text{rf}}$	499.667 MHz
Harmonic Number	$h$	864
Momentum compaction factor	$\alpha$	$1.6 \times 10^{-4}$
Energy Spread	$\sigma_\delta$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

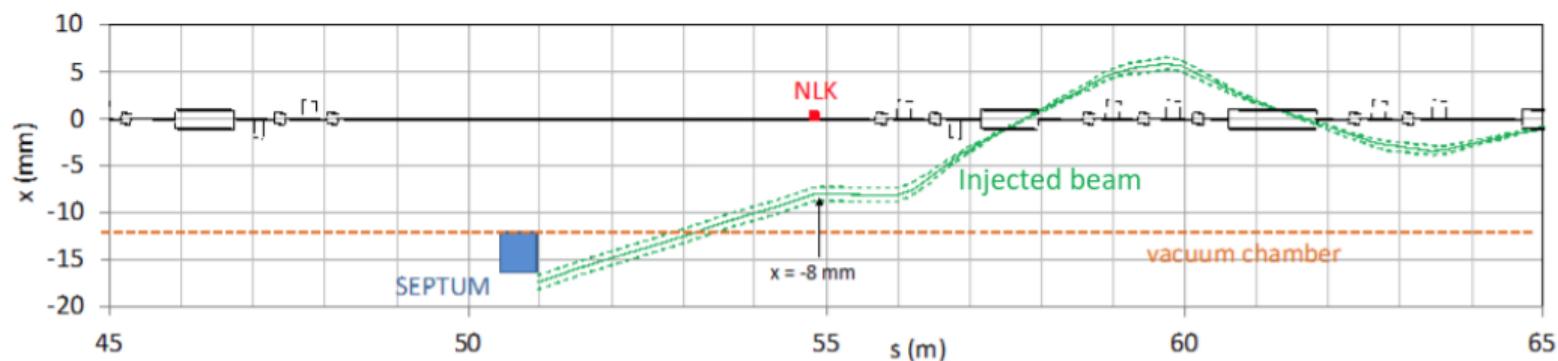


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# Off-axis injection scheme



# 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 ∈ chromaticity response matrix nullspace (13, 17 knobs)
  - ▶ 13 free knobs + 6 compensation knobs

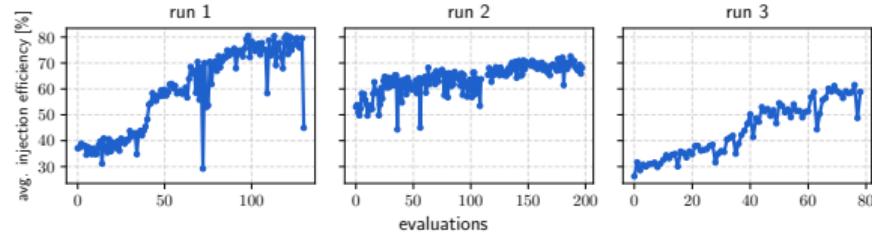
More details:

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

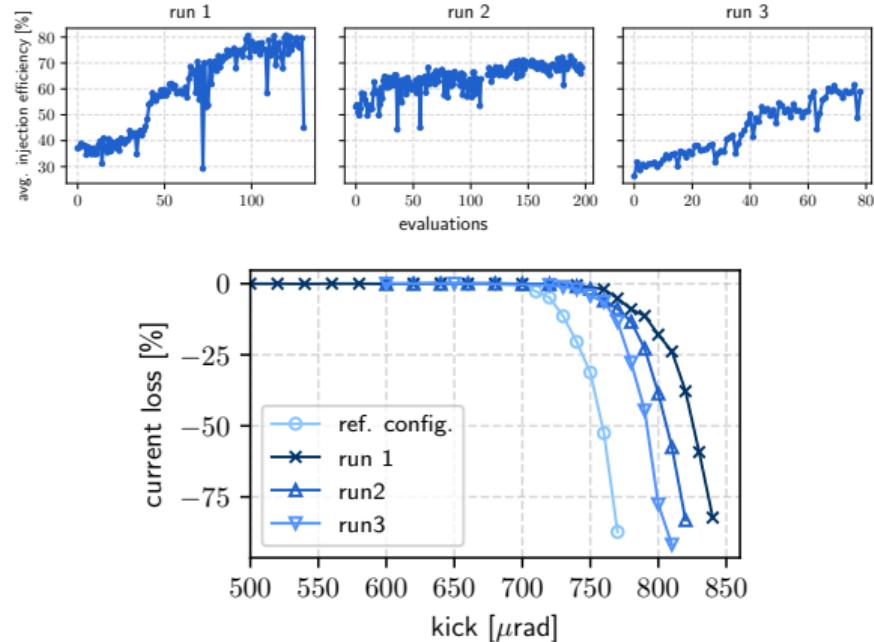
## SIRIUS sextupole families

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

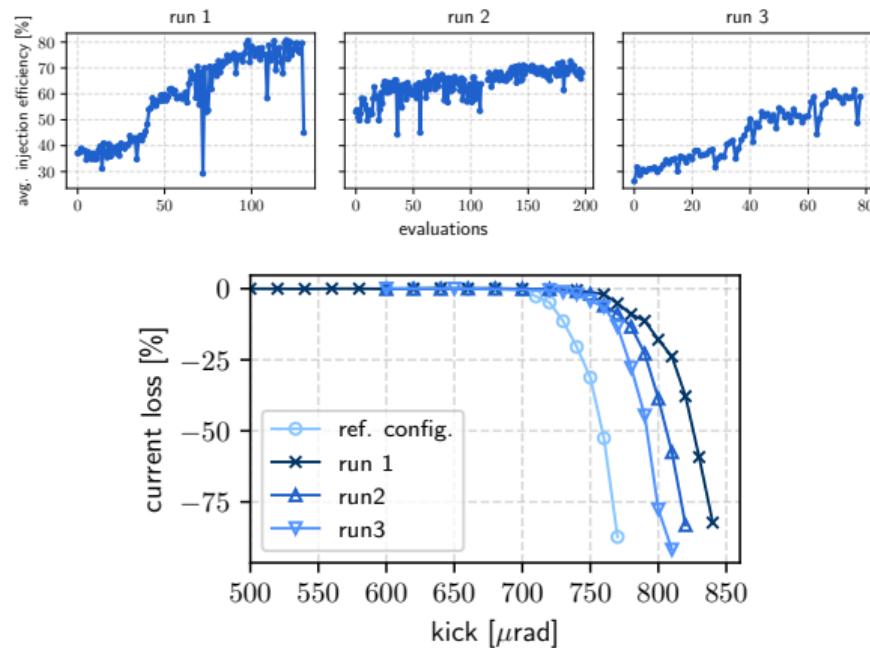
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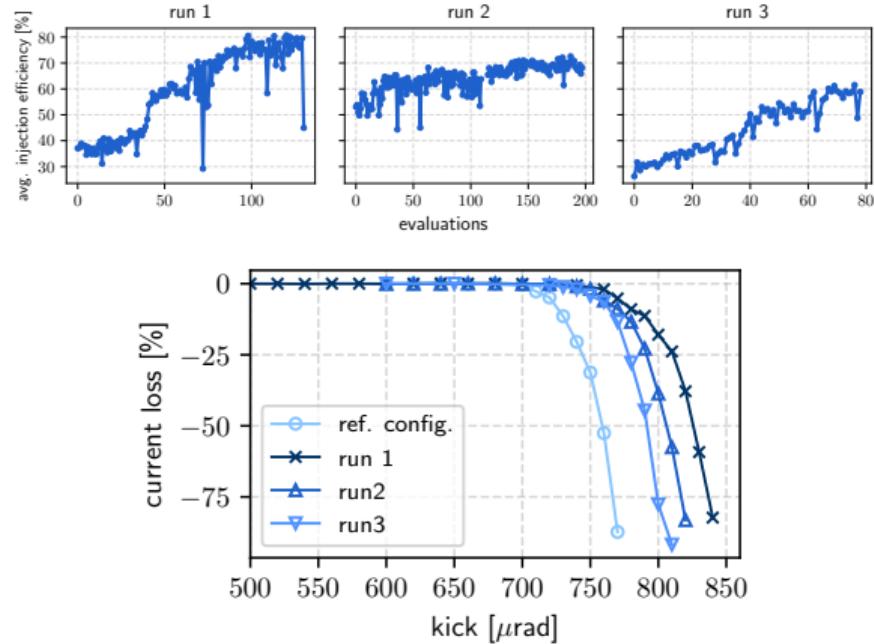


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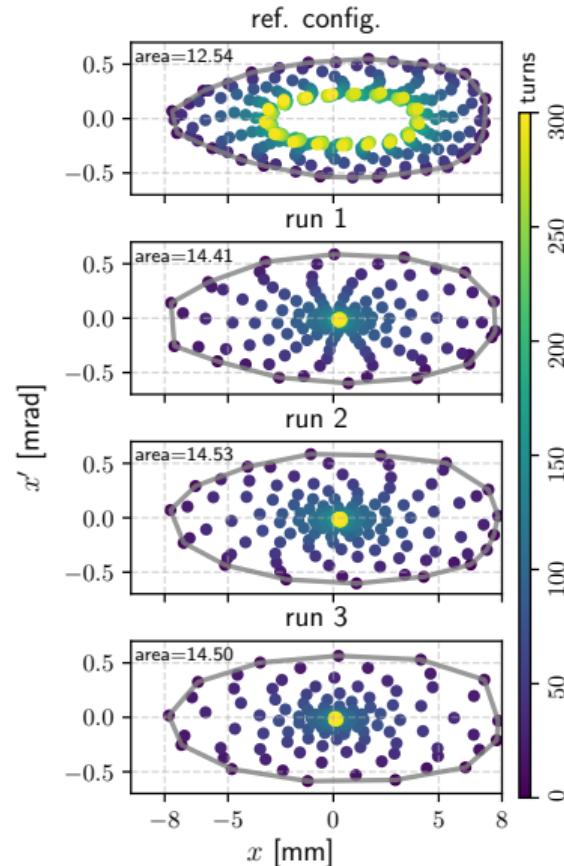


configuration	injection efficiency [%]	lifetime @ 60 mA
ref-config	$88 \pm 8$	21 hrs
run 1	$91 \pm 1$	
run 2	$98 \pm 1$	20 hrs
run 3	$87 \pm 3$	

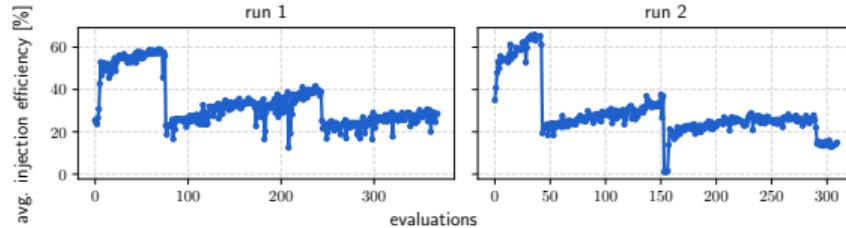
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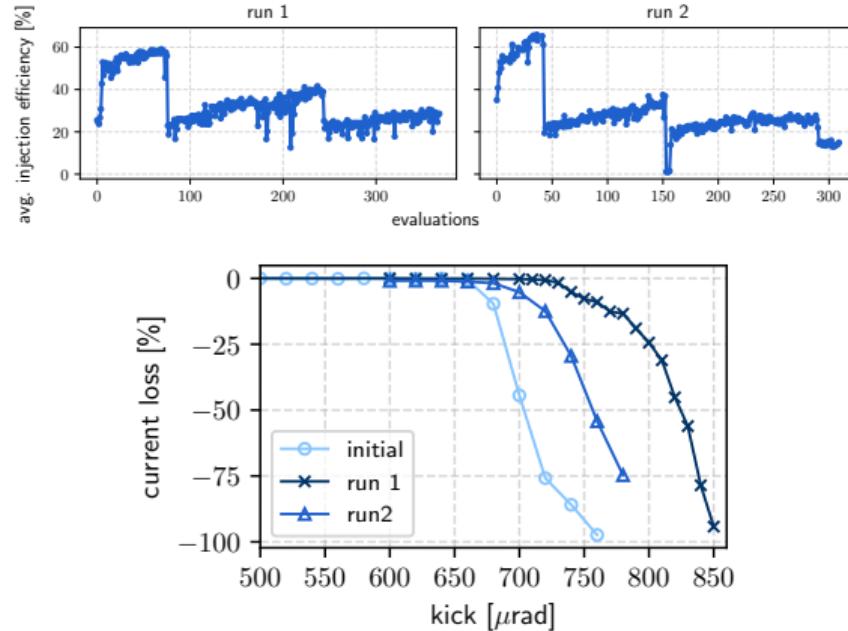
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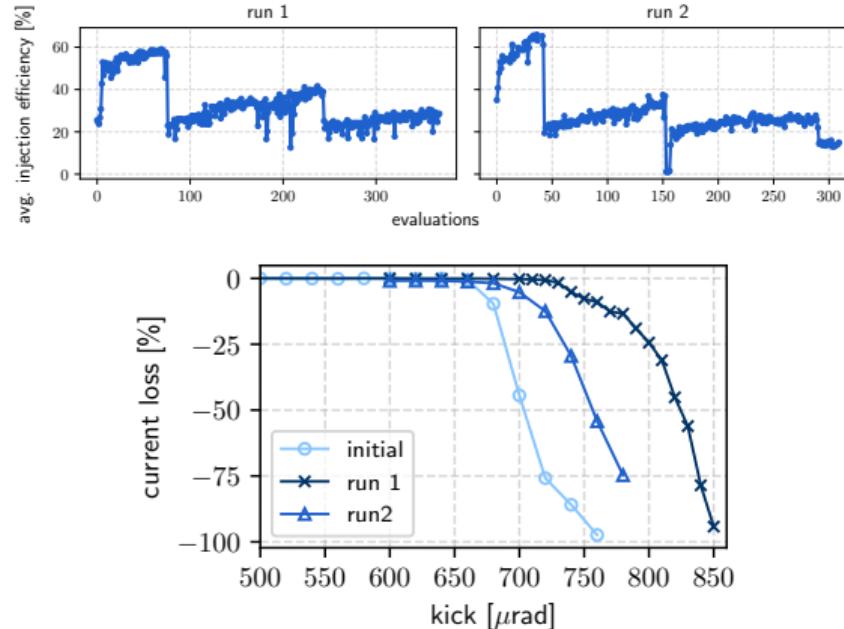
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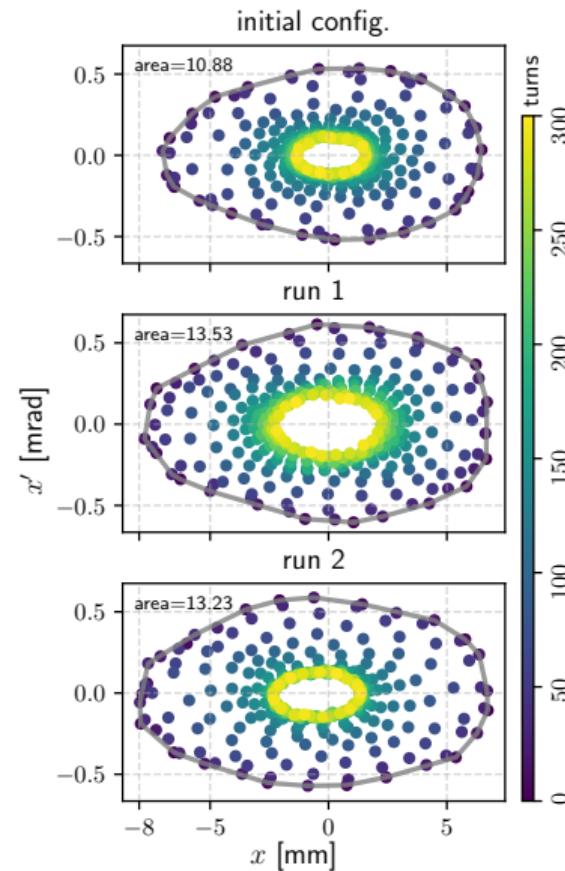
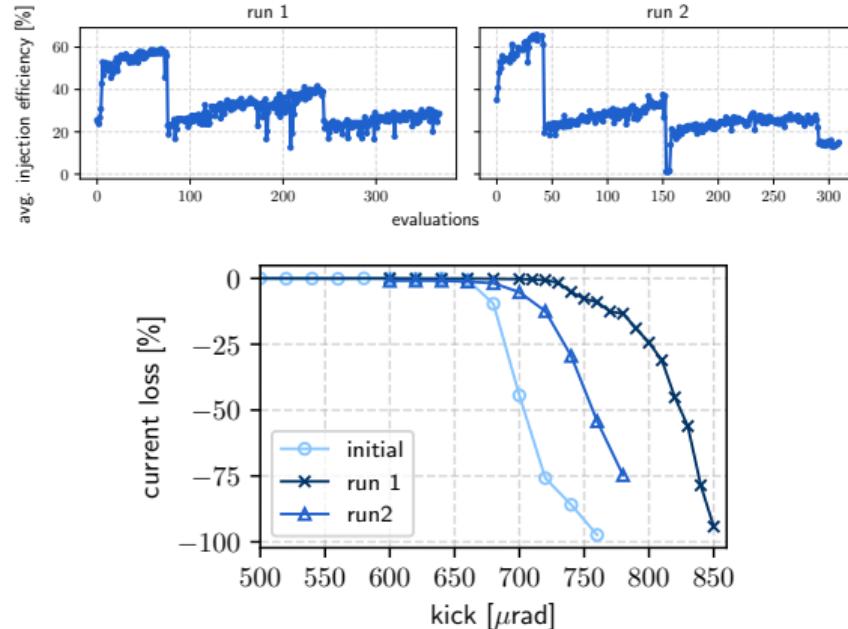


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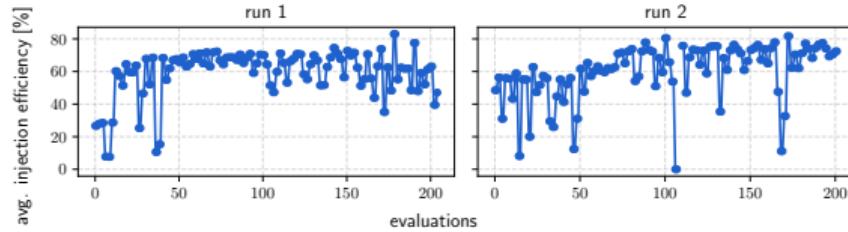
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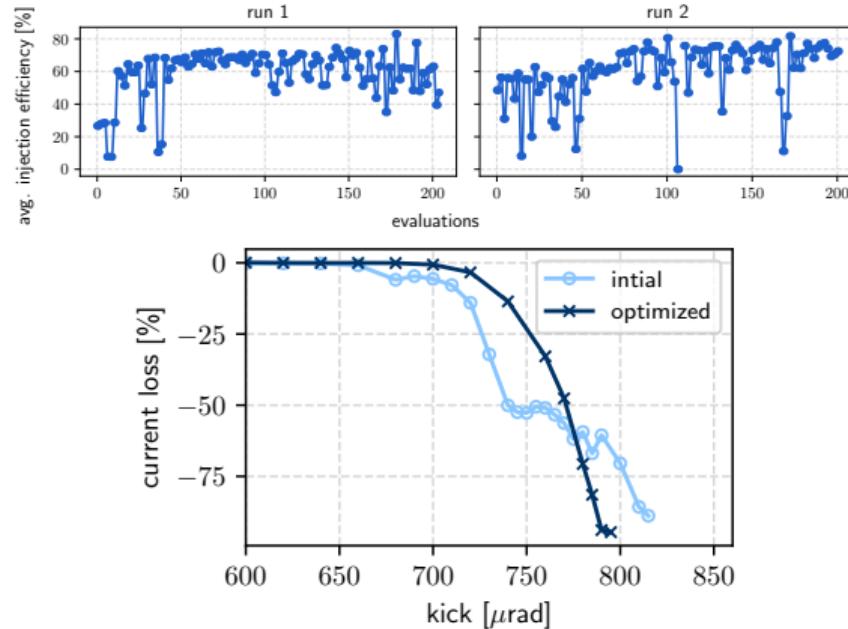


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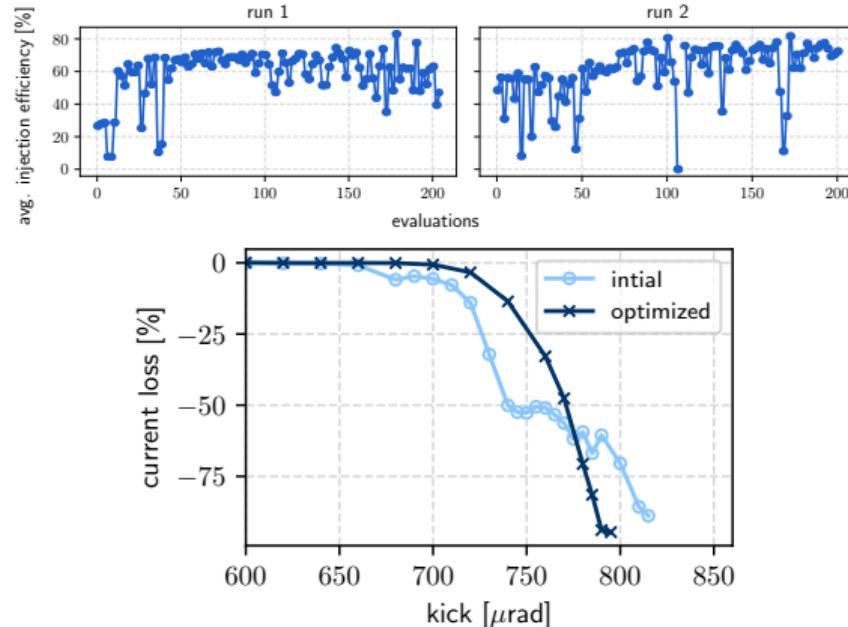
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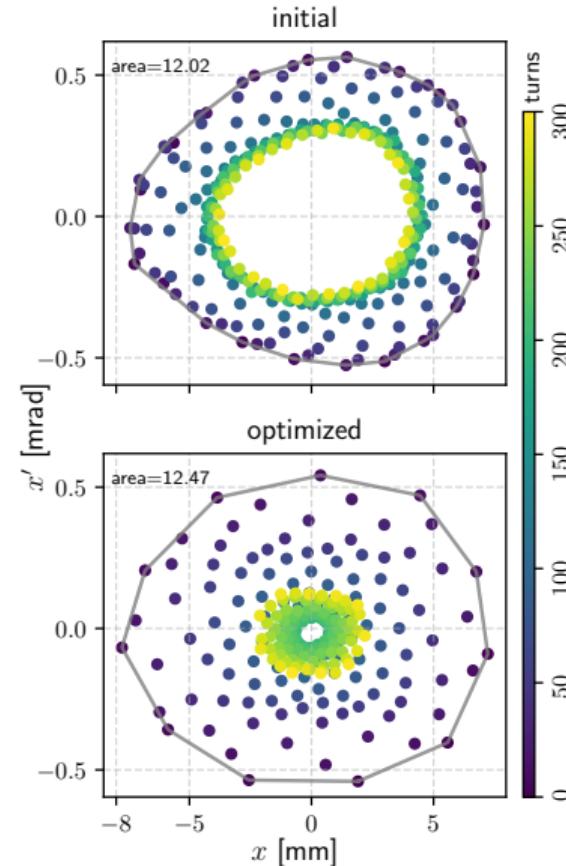
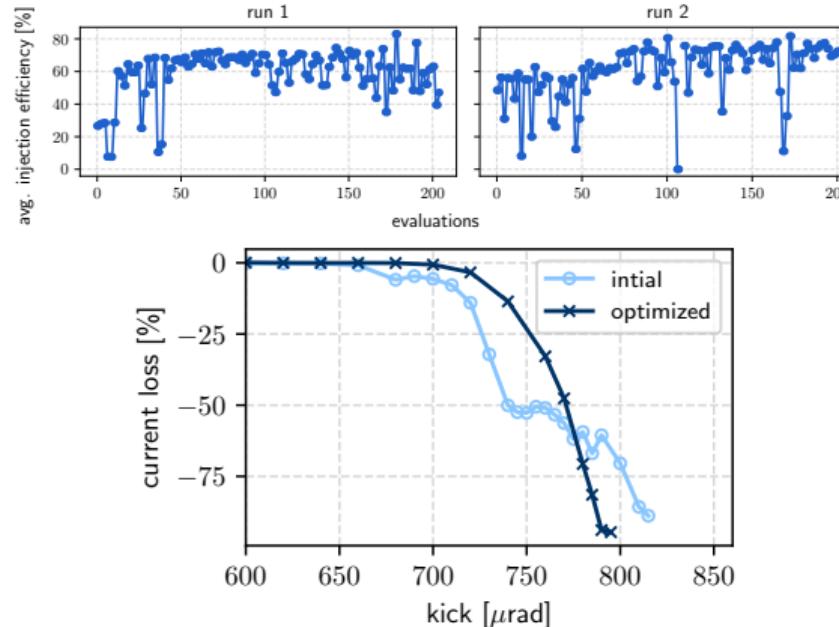


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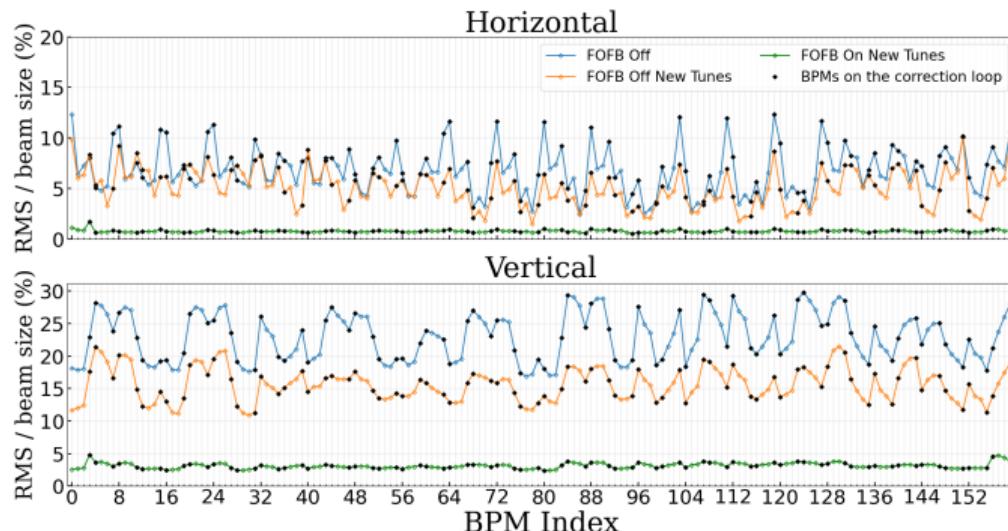
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## Summary

- ▶ Oline tuning with RCDS is effective at optimizing injection efficiency
- ▶ Some mysteries
  - ▶ Larger kick resiliency  $\not\Rightarrow$  larger phase portrait areas  $\not\Rightarrow$  injection efficiency

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- ▶ Online tuning with RCDS is effective at optimizing injection efficiency
- ▶ Some mysteries
  - ▶ Larger kick resiliency  $\Rightarrow$  larger phase portrait areas  $\Rightarrow$  injection efficiency
- ▶ WP 3 contributed for SIRIUS recent milestone of reaching  $< 1\% \sigma_x$  and  $< 4\% \sigma_y$  orbit rms variations in the horizontal and vertical planes, respectively.



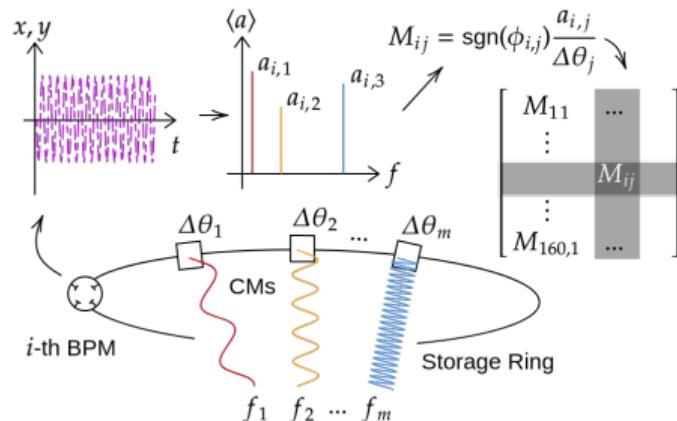
L. Liu *et al.*, "Status of SIRIUS operation with users", presented at the IPAC'23, Venice, Italy, May 2023, paper WEOGA2.

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# 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  $u_i(t_j)$ :

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

- ▶ 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:

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

# Measurements at SIRIUS storage ring and LOCO performance

## SIRIUS BPMs-CMs circuit

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

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## 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
  - ▶ prime frequencies to easily distinguish nonlinear harmonics
  - ▶  $5 \mu\text{rad}$  strength, during 4 seconds.
  - ▶ integer number of oscillations, orthogonal harmonics
- ▶ The complete measurement took around 2.5 – 3 min.

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

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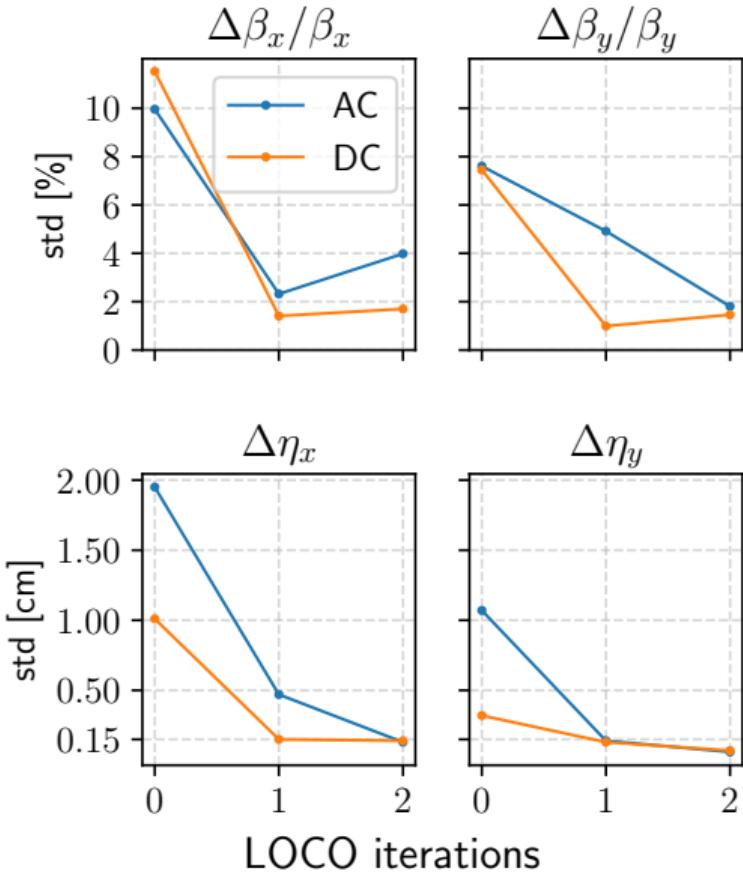
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Thank you!

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M. M. S. Velloso is supported by the São Paulo Research Foundation via Grant #2022/04162-4

