

# 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



Matheus M. S. Velloso

## Introduction

Online tuning of storage ring non-linear dynamics

Fast ("AC") Measurement of Orbit Response Matrix

# SIRIUS storage ring

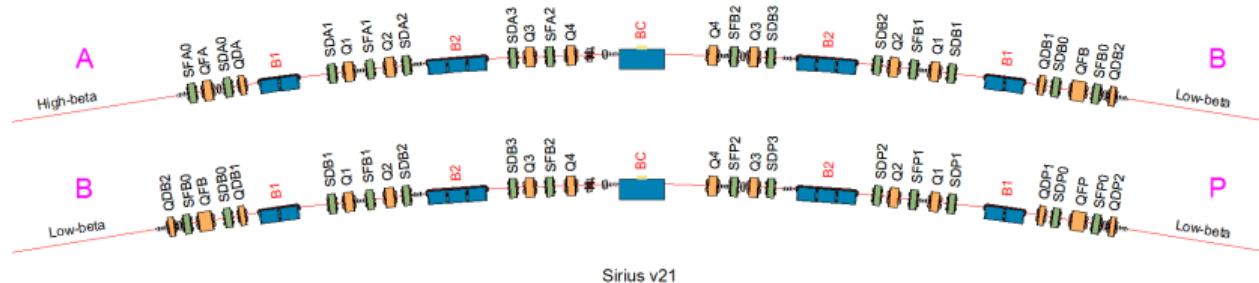


4th generation storage ring based Synchrotron Light Source with 250 pm rad emittance. Designed, built and operated by the Brazilian Synchrotron Light Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM), Campinas, Brazil.

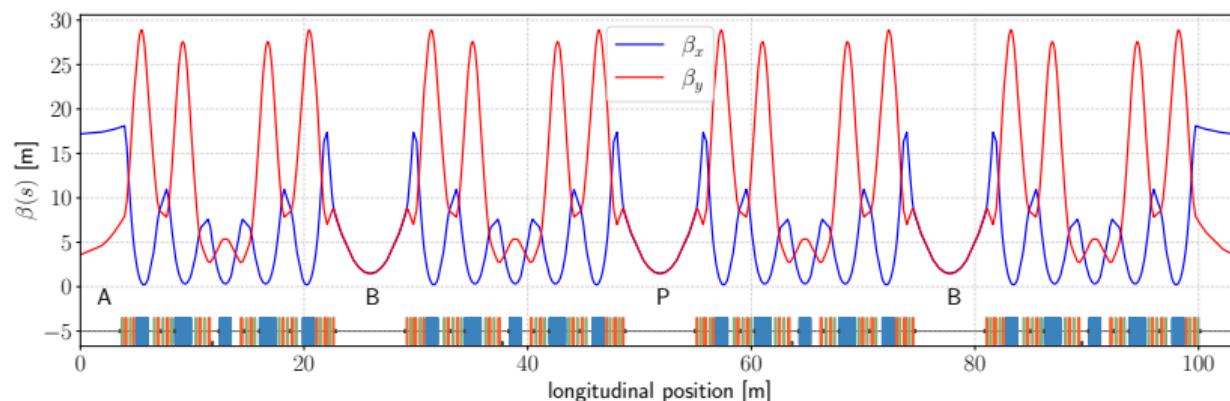
Parameter	Currently	Phase I
Energy	$E_0$	3 GeV
Current	$I_0$	100 mA
Operation mode		Top-up
Lifetime	$\tau$	15 h
RF Cavities		1 NC
RF Voltage	$\hat{V}_{\text{rf}}$	1.5 MV
RF Frequency	$f_{\text{rf}}$	499.667 MHz
Harmonic Number	$h$	864
Momentum compaction factor	$\alpha$	$1.6 \times 10^{-4}$
Energy Spread	$\sigma_\delta$	$8.5 \times 10^{-4}$
Bunch length	$\sigma_z$	2.5 mm
Energy loss p/ turn	$U_0$	470 keV
		12 mm
		870 keV

# SIRIUS Lattice and Optics

20×5BA lattice, with 5-fold symmetric high (A) and low (B, P) betatron functions sections: 1 Superperiod = A-B-P-B



Sirius v21

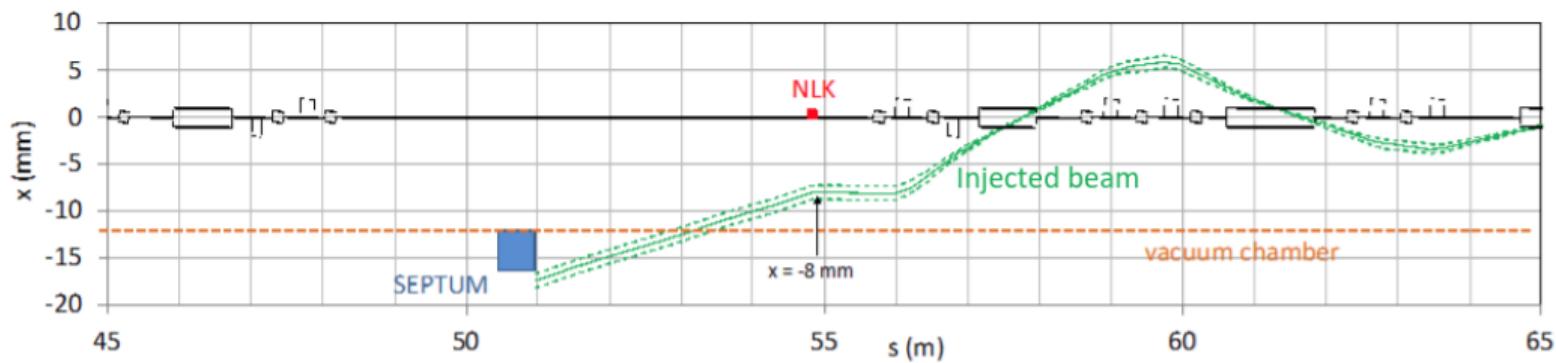


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# Off-axis injection scheme



100% efficiency with  $x = -9$  mm DA

88% efficiency observed

# RCDS Dynamic Aperture Optimization Setup

Robust conjugate direction search (RCDS) for DA optimization:

- ▶ objective function:
  - ▶ avg. injection efficiency of 5 pulses @ 2 Hz ( $\sigma \approx 1\%$ )
  - ▶ beam steered to the DA border to reduce efficiency
  - ▶ kick resilience optimization  $\not\Rightarrow$  injection efficiency optimization
- ▶ available knobs: 21 sextupole families
  - ▶ chromaticity response matrix nullspace singular-vectors (13, 17 knobs)
  - ▶ 13 free families + 6 compensation families
- ▶ Tuning in 3 machine working points: higher fractional tunes to reduce amplification factors and improve orbit stability

More details:

M. M. S. Velloso, M. B. Alves, L. Liu, X. R. Resende, F. H. de Sá, and X. Huang, in *Proc. IPAC'23 Venezia*, 05 2023, pp. 3222-3226. WEPL087 paper

About RCDS:

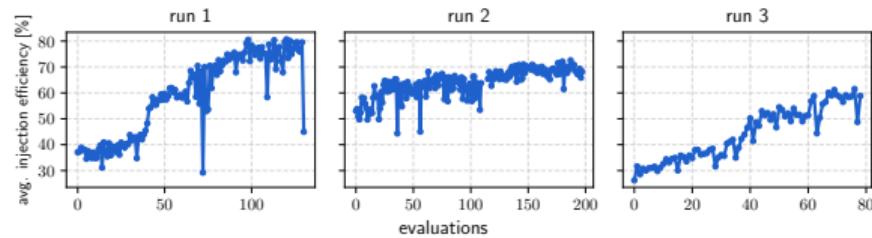
X. Huang, J. Corbett, J. Safranek, J. Wu, *Nucl. Instr. Meth.*, vol 726, pp.77-83, 2013.

X. Huang, J. Safranek, *Phys. Rev. ST Accel. Beams*, vol 18, p.18

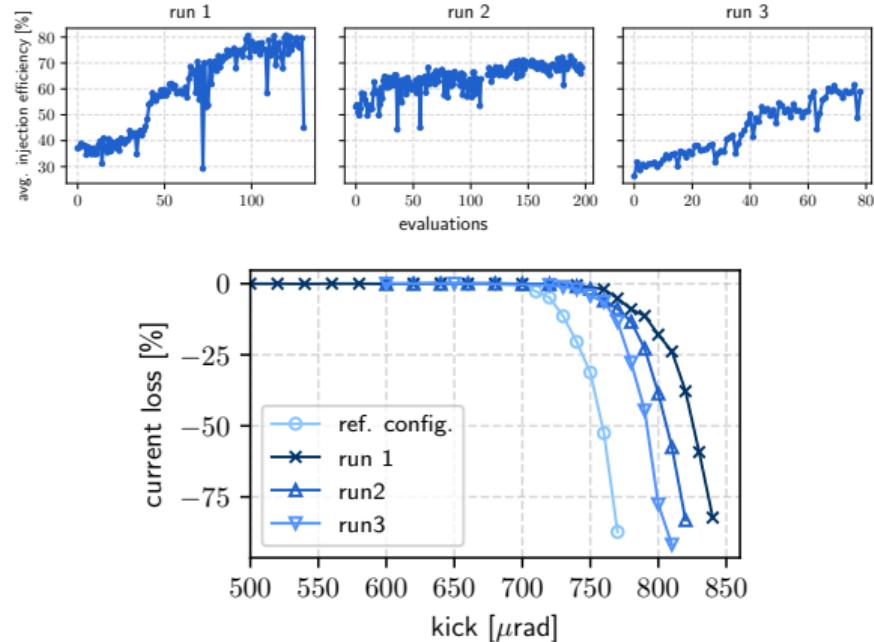
## SIRIUS sextupole families

	SFA0, SDA0,
achromatic	SFB0, SDB0, SDP0, SFP0
	SDA1, SFA1, SDA2, SFA2, SDA3,
	SDB1, <b>SFB1</b>
chromatic	SDB2, SFB2, SDB3, <b>SFP1</b> , SDP1, SDP2, SFP2 SDP3

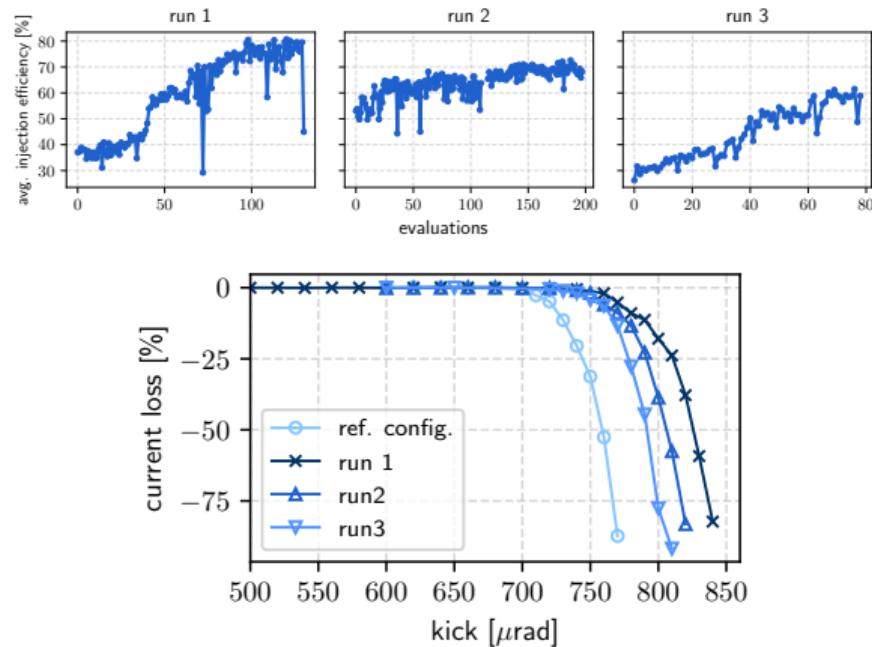
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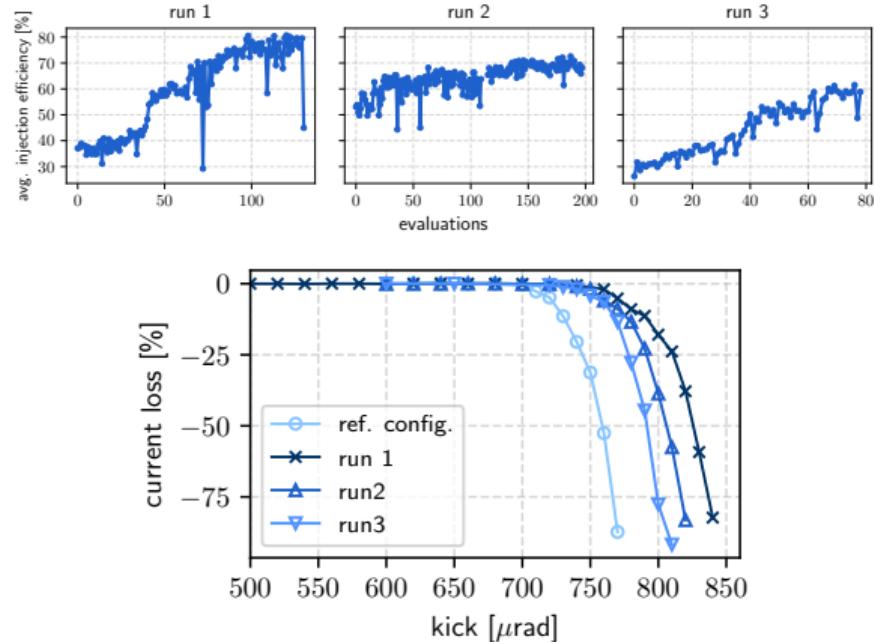


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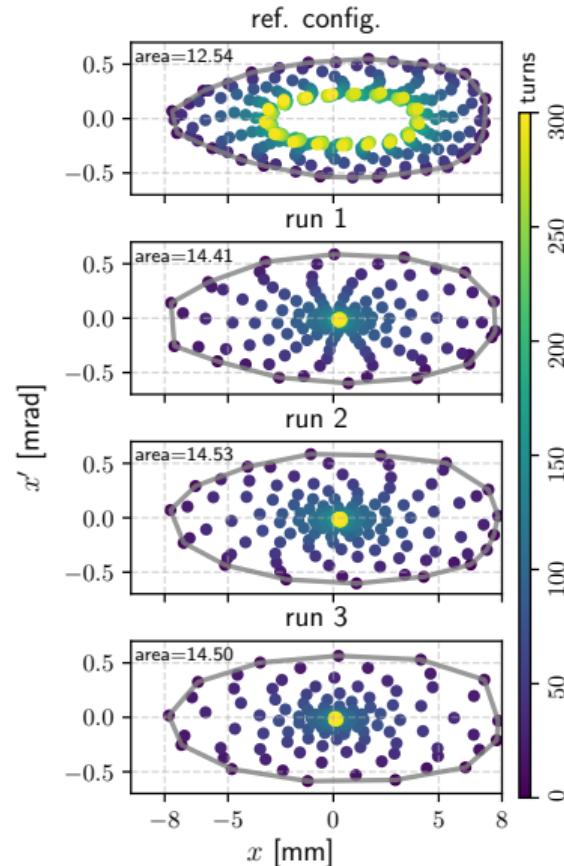


configuration	injection efficiency [%]	lifetime @ 60 mA
ref-config	$88 \pm 8$	21 hrs
run 1	$91 \pm 1$	
run 2	$98 \pm 1$	20 hrs
run 3	$87 \pm 3$	

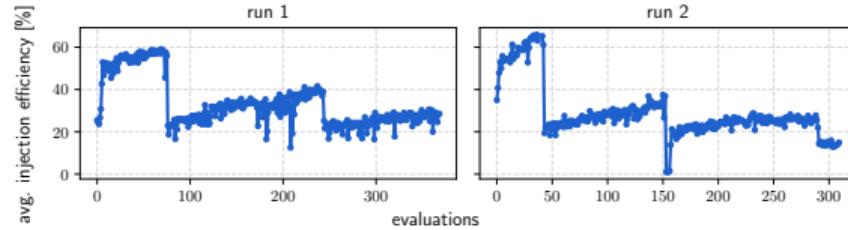
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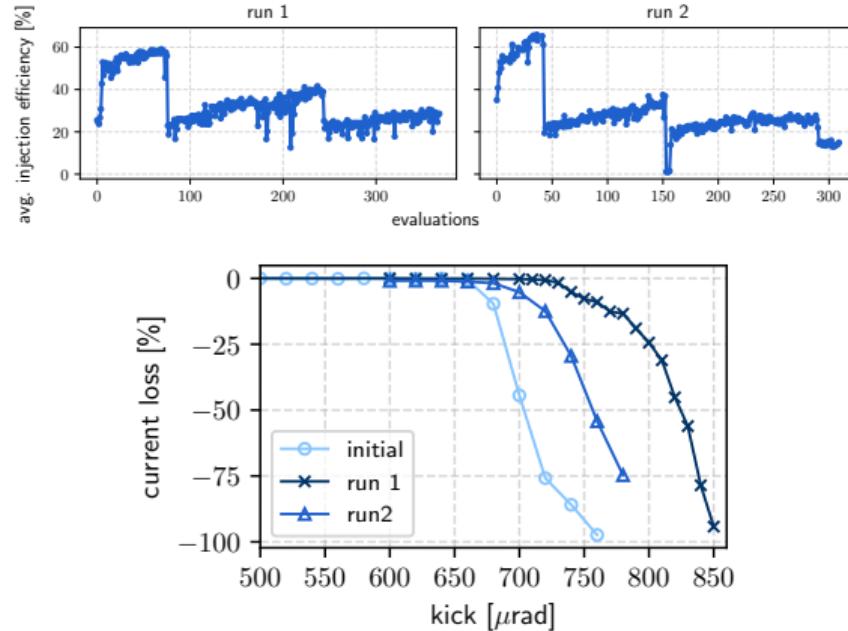
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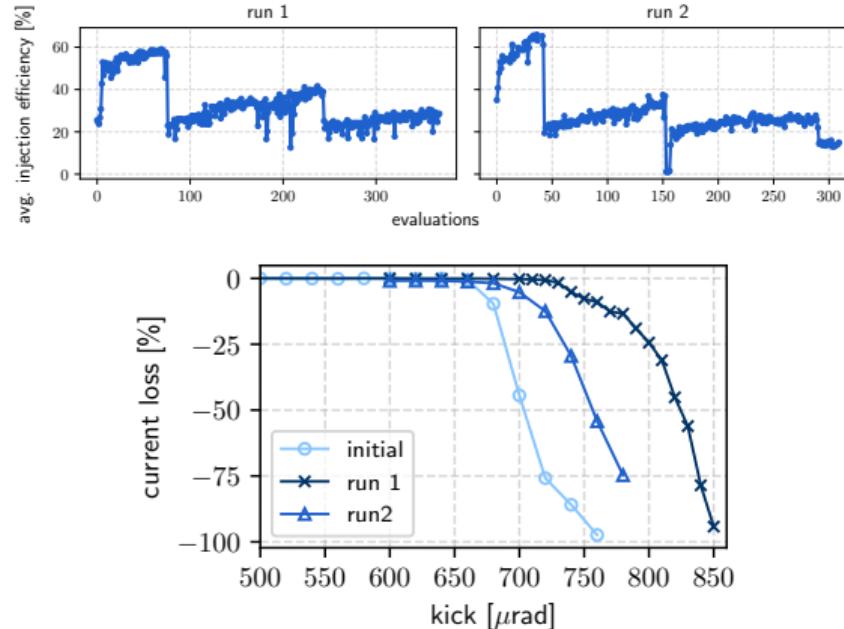
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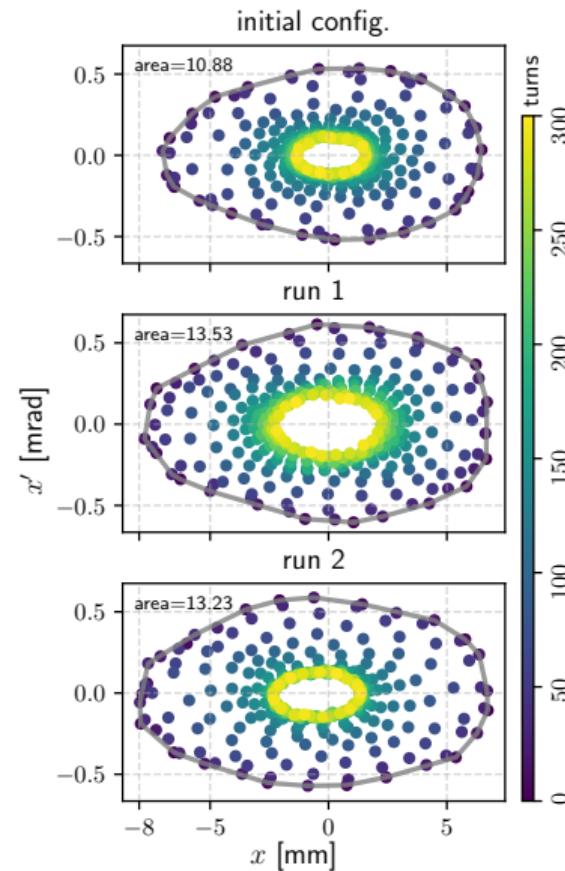
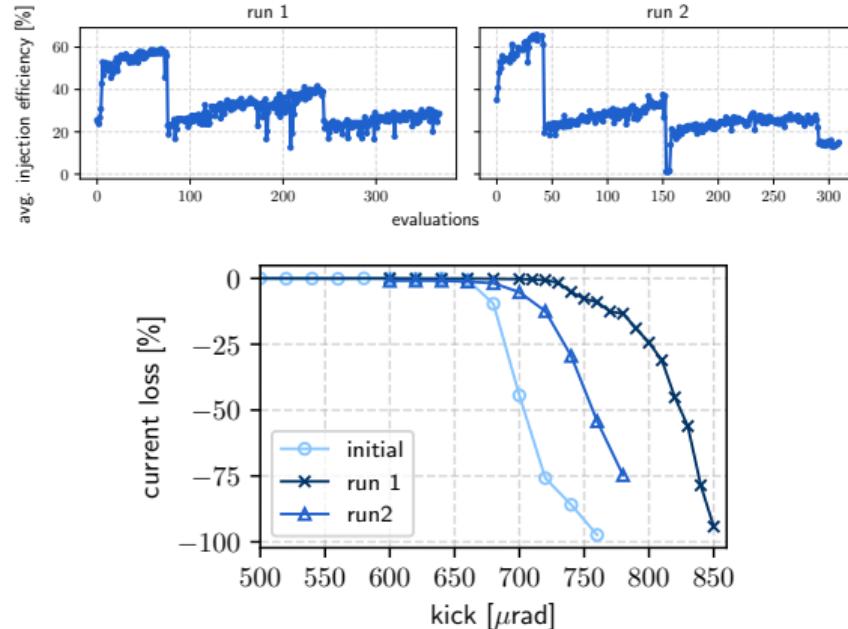


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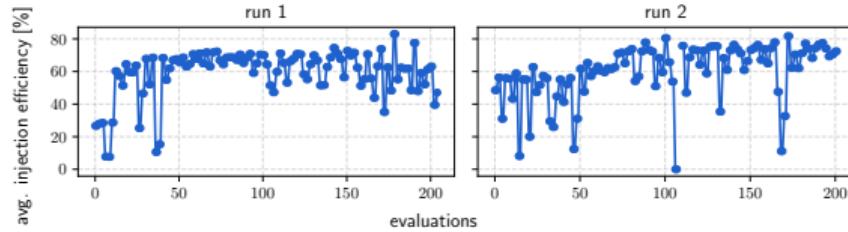
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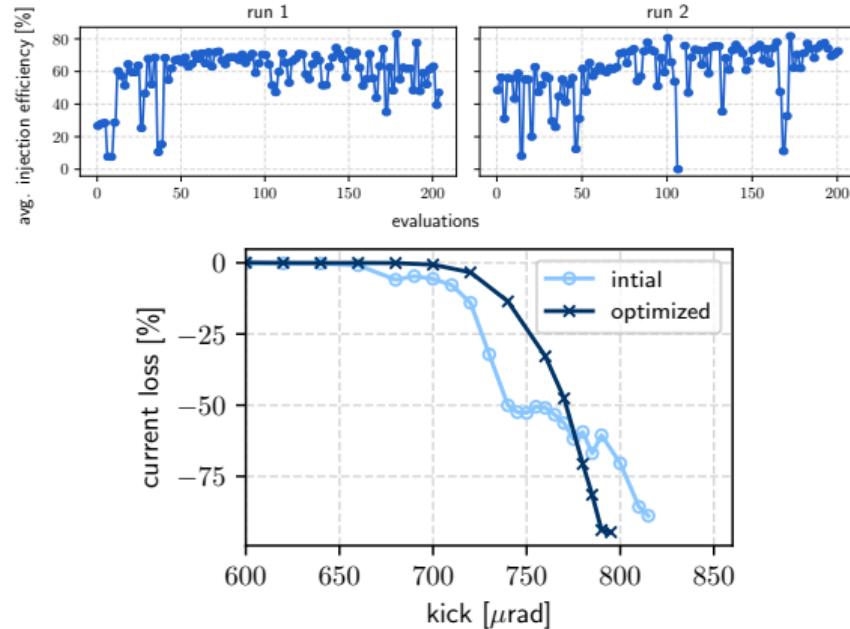


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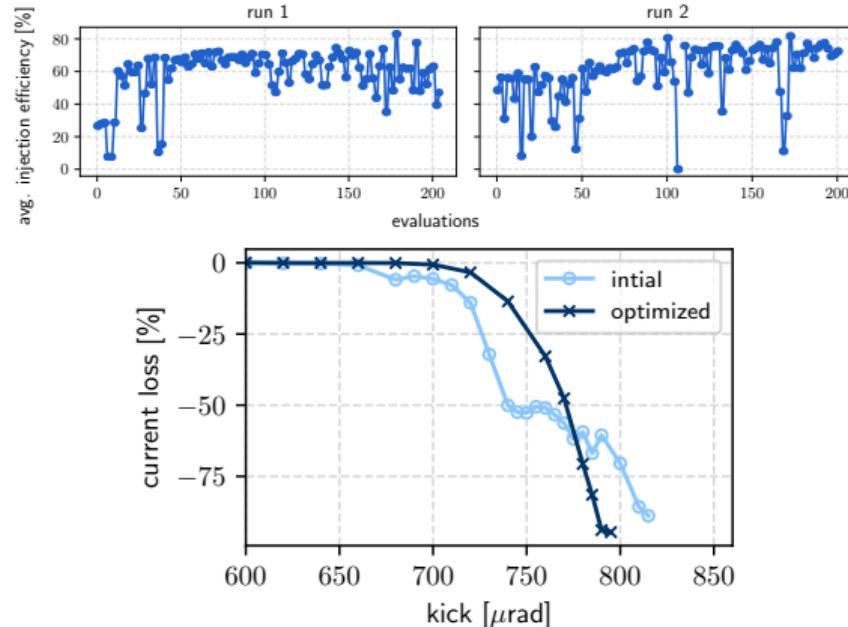
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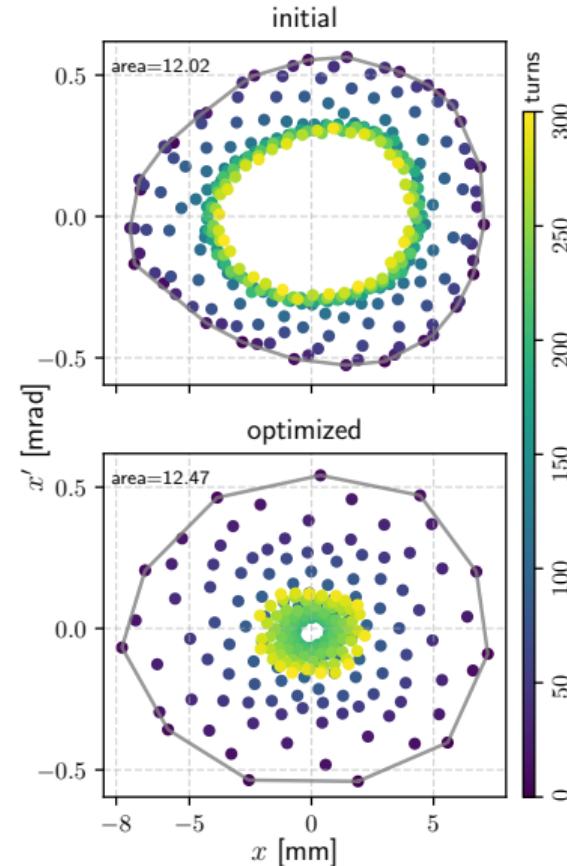
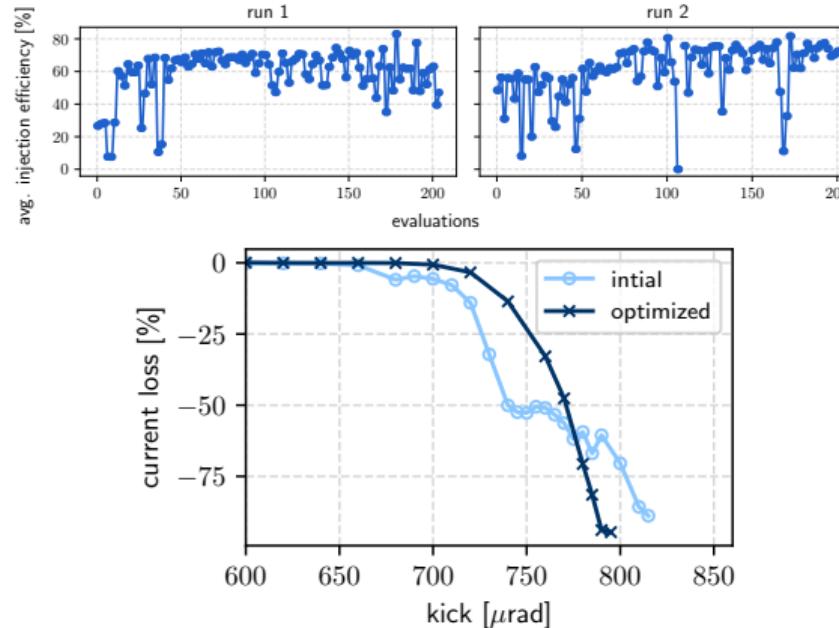


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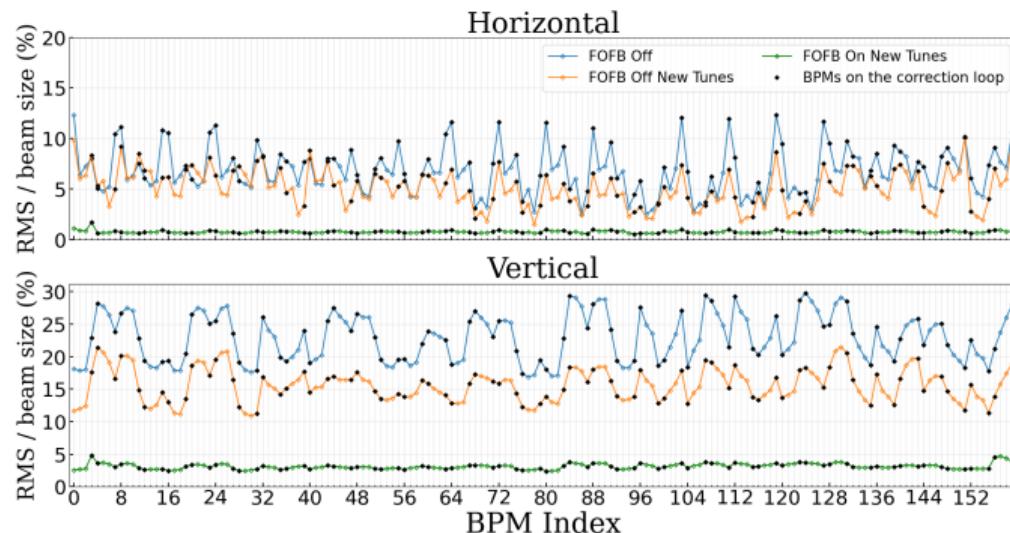
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# Orbit stability improvements

WP 3 contributed for SIRIUS recent achievement 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.

Courtesy of Daniel Tavares

## Summary

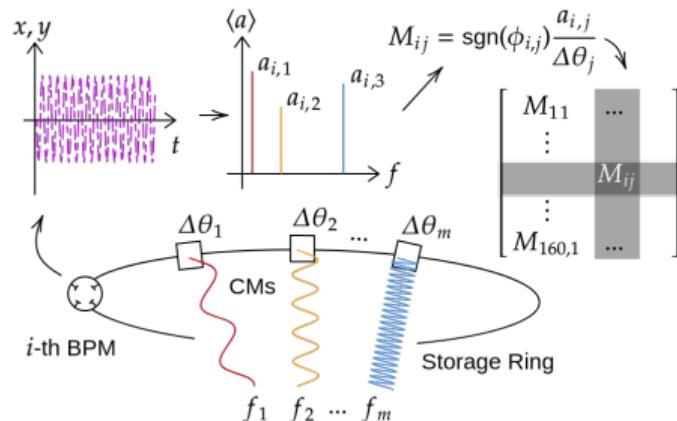
- ▶ Online tuning with RCDS was effective at optimizing injection efficiency
- ▶ Optimizing injection efficiency  $\Rightarrow$  larger kick resiliency/larger phase portrait areas

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# AC ORM Measurement



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

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

► 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

## 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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## Measurement 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
  - ▶ 30 mins for DC method
  - ▶ 2.5 – 3 mins AC method

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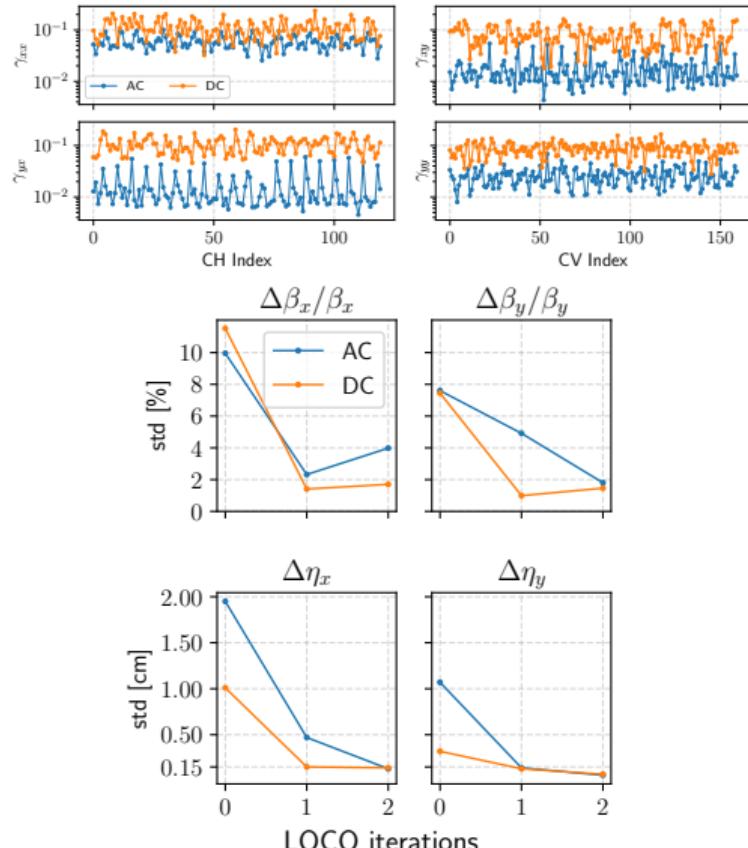
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Thank you!

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Light Laboratory



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