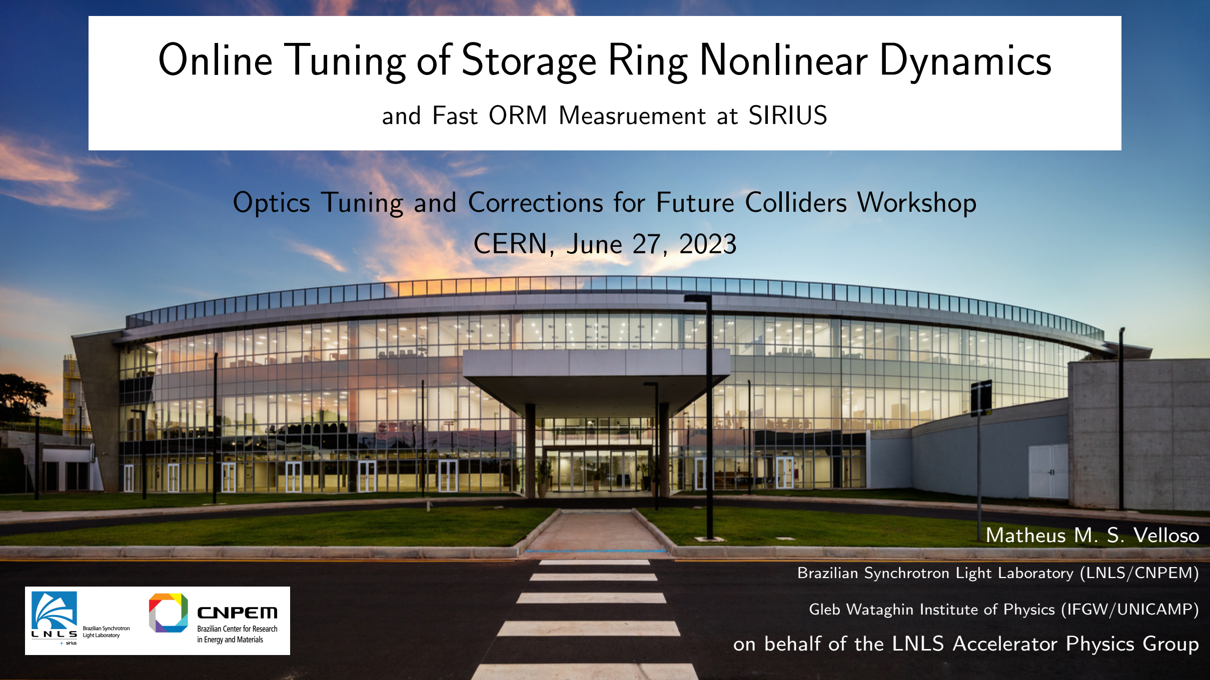
Online Tuning of Storage Ring Nonlinear Dynamics

and Fast ORM Measruement at SIRIUS



Optics Tuning and Corrections for Future Colliders Workshop

CERN, June 27, 2023

Matheus M. S. Velloso

Brazilian Synchrotron Light Laboratory (LNLS/CNPEM)

Gleb Wataghin Institute of Physics (IFGW/UNICAMP)

on behalf of the LNLS Accelerator Physics Group

LNLS Brazilian Synchrotron Light Laboratory sirius

CNPEM Brazilian Center for Research in Energy and Materials

Introduction

Online tuning of storage ring non-linear dynamics

Fast Orbit Response Matrix Measruement

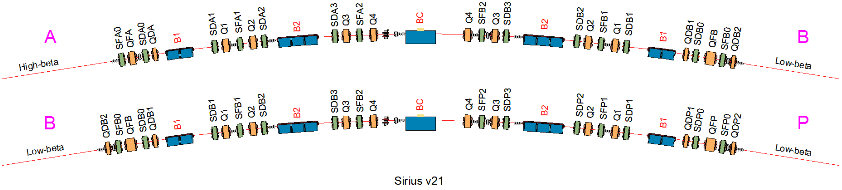
SIRIUS storage ring

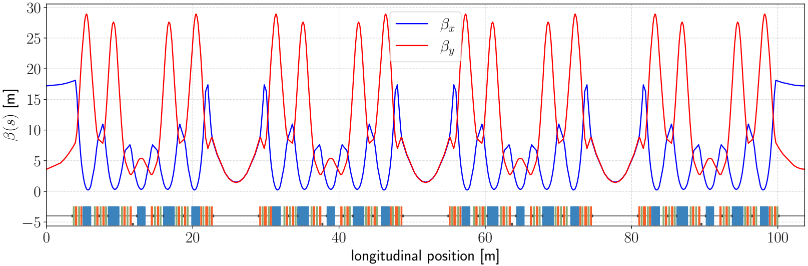
Designed, built and operated by the Brazilian Synchrotron Light Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM) campus, at Campinas, Brazil.

Parameter		Currently	Phase I
Energy	E_0	3 GeV	
Current	I_0	100 mA	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

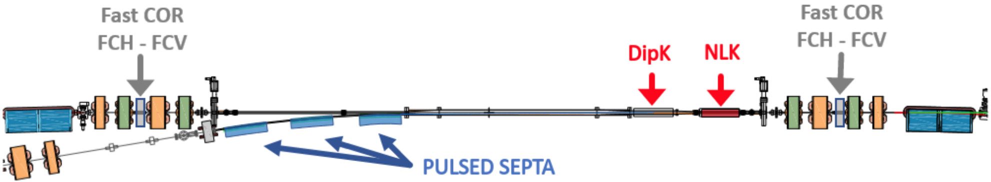
SIRIUS Lattice and Optics

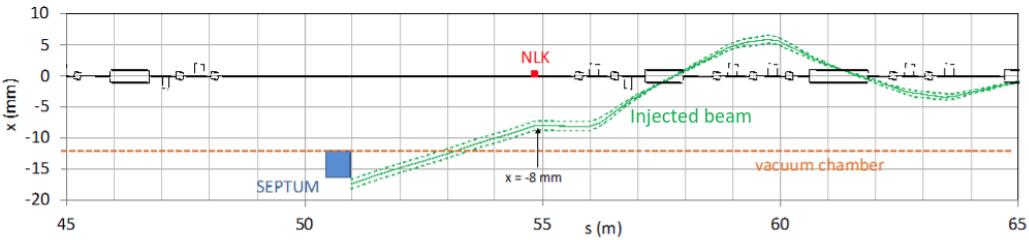
20-cell 5BA lattice with 5-fold symmetric high (A) and low (B, P) betatron functions sections. Superperiod = A-B-P-B





Off-axis injection scheme





RCDS Dynamic Aperture Optimization Setup

Robust conjugate direction search (RCDS) for DA optimization:

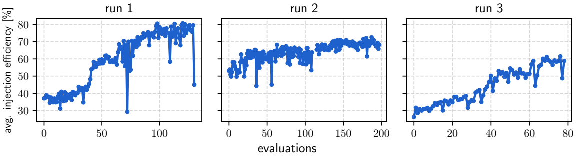
- objective function: avg. injection efficiency of 5 pulses @ 2 Hz ($\sigma \approx 1\%$)
  - beam at the DA border to reduce efficiency
- available knobs: 21 sextupole families
  - knobs $\in$ chromaticity response matrix nullspace (13, 17 knobs)
  - 13 free knobs + 6 compensation knobs
- Tuning in 3 machine working points: higher fractional tunes for improved 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
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

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)



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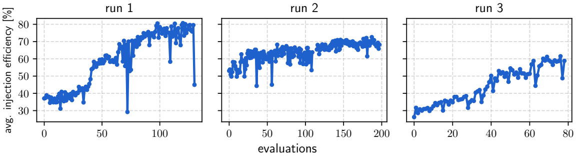

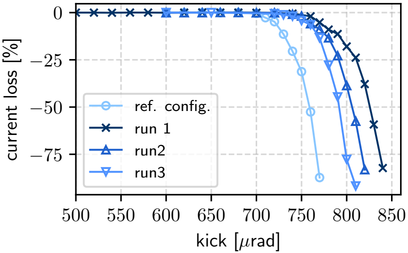

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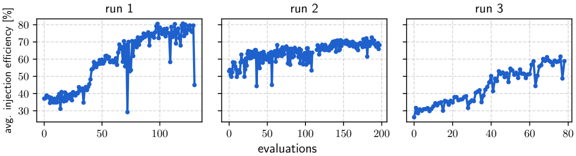

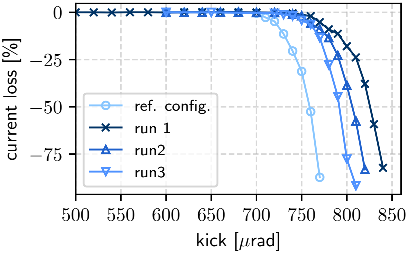

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ref-config	88 ± 8	21 hrs
run 1	91 ± 1	
run 2	98 ± 1	20 hrs
run 3	87 ± 3	

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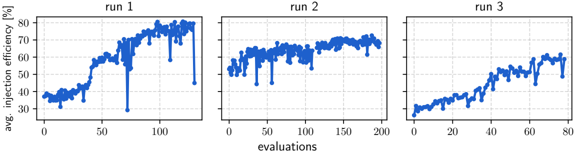

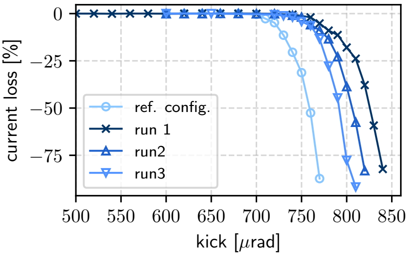

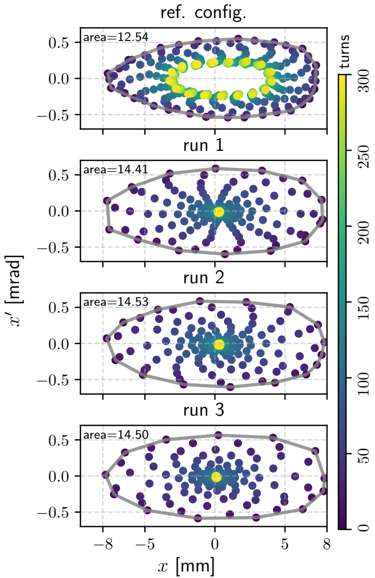

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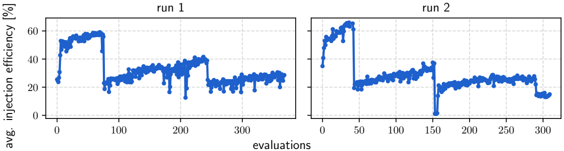

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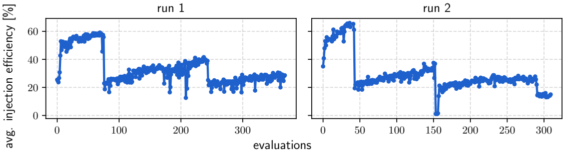

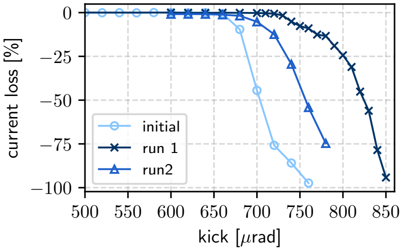

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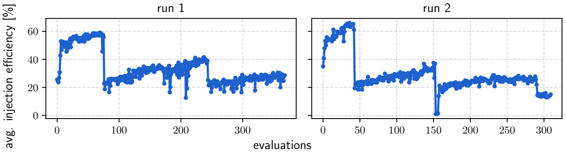

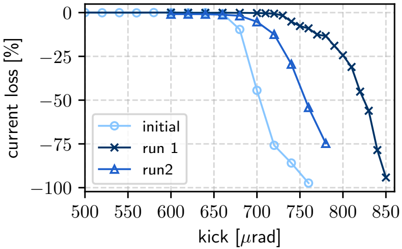

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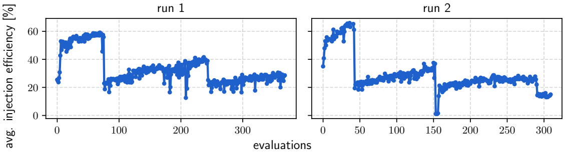

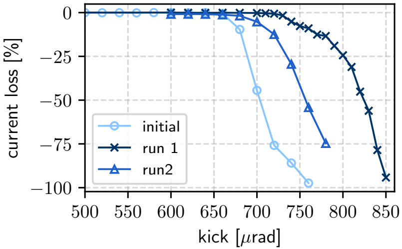

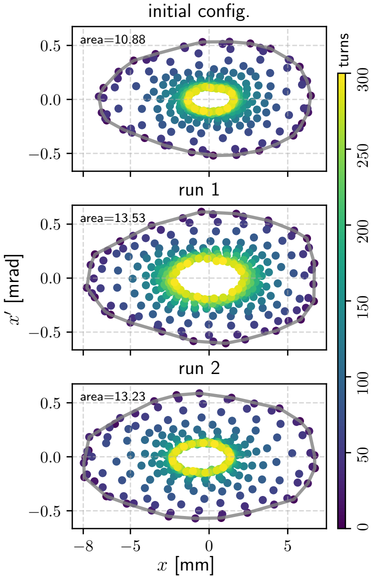

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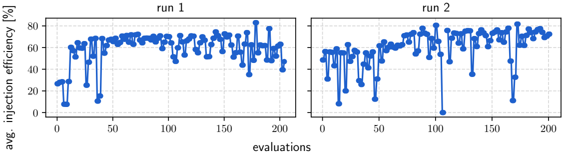

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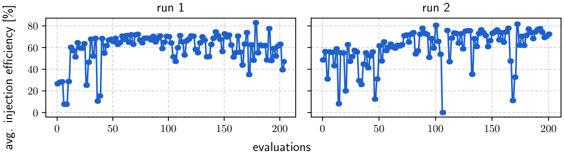

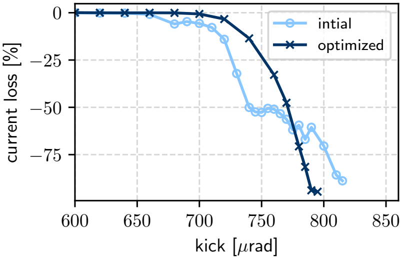

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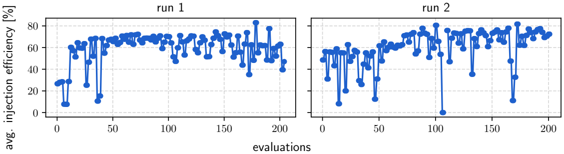

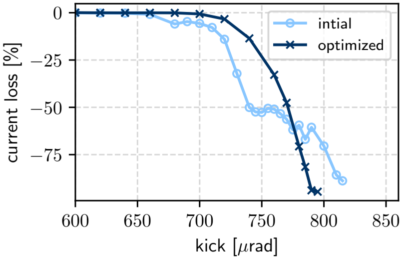

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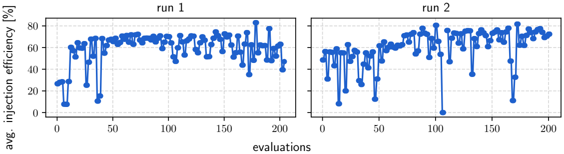

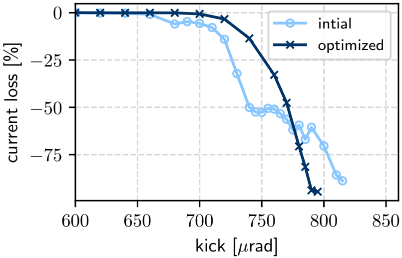

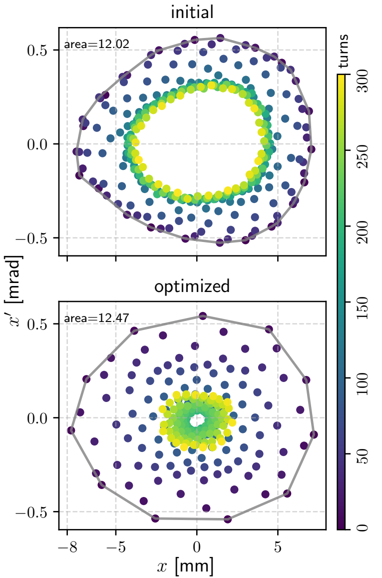

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- Some mysteries
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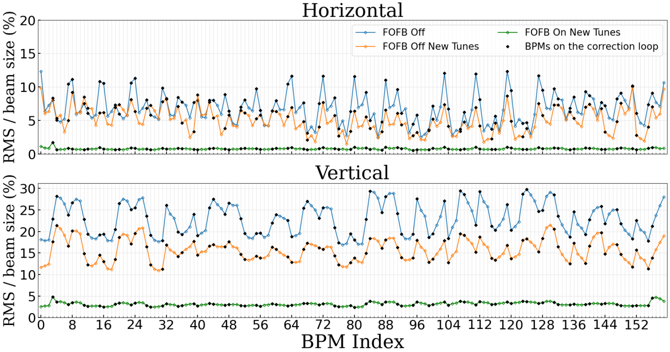
- Oline tuning with RCDS is effective at optimizing injection efficiency
- Some mysteries
  - Larger kick resiliency $\not\Longrightarrow$ larger phase portrait areas $\not\Longrightarrow$ injection efficiency
- WP 3 contributed for SIRIUS recent milestone of reaching $< 1\%\ \sigma_x$ and $< 4\%\ \sigma_y$ 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.

Introduction

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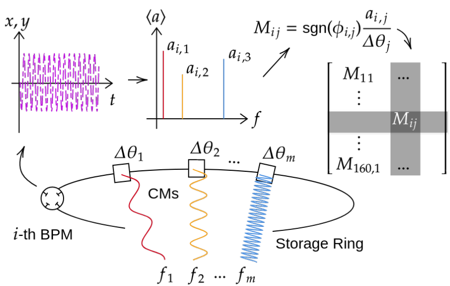
Fast Orbit Response Matrix Measruement

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 $u_i(t_j)$:

$$\begin{bmatrix} \cos(2\pi f_1 t_1) & \sin(2\pi f_1 t_1) & \dots & \\ \cos(2\pi f_1 t_2) & \sin(2\pi f_1 t_2) & \dots & \\ \vdots & \vdots & & \\ \cos(2\pi f_1 t_n) & \sin(2\pi f_1 t_n) & \dots & \end{bmatrix} \begin{bmatrix} b_{i\,1} \\ c_{i\,1} \\ \vdots \\ b_{i\,m} \\ c_{i\,m} \end{bmatrix} = \begin{bmatrix} u_i(t_1) \\ u_i(t_2) \\ \vdots \\ u_i(t_n) \end{bmatrix}$$

- 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,
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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 µrad strength, during 4 seconds.
  - integer number of oscillations, orthogonal harmonics
- The complete measurement took around $2.5 - 3$ min.

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

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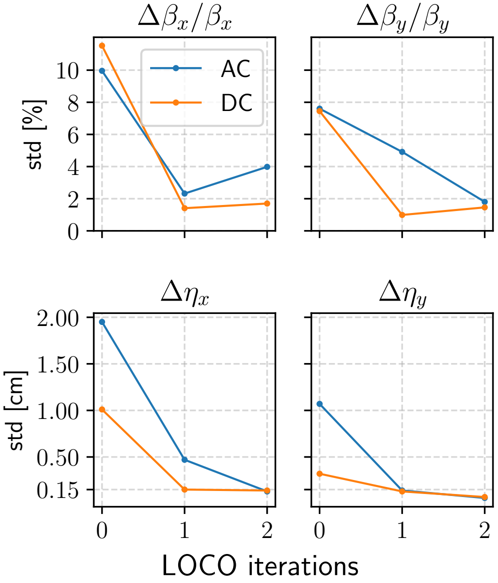

Thank you!

`matheus.velloso@lnls.br`

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FAPESP

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CNPEM Brazilian Center for Research in Energy and Materials

MINISTRY OF SCIENCE TECHNOLOGY AND INNOVATION

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