

# Online Tuning of Storage Ring Nonlinear Dynamics

and Fast ORM Measurement at SIRIUS

Optics Tuning and Corrections for Future Colliders Workshop  
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Matheus M. S. Velloso

## Introduction

Online tuning of storage ring non-linear dynamics

Fast ORM Measurement

# SIRIUS storage ring

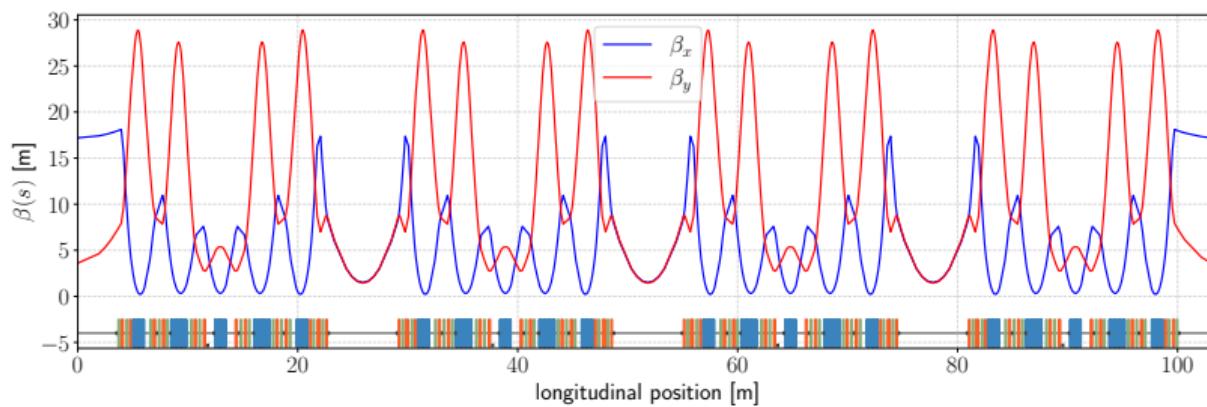
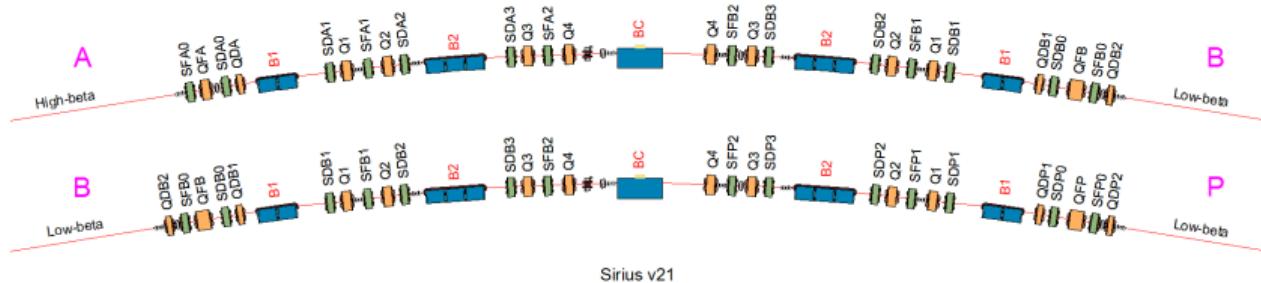


Designed, built and operated by the Brazilian Synchrotron Laboratory (LNLS), at the Brazilian Center for Research in Energy and Materials (CNPEM) campus, at Campinas, Brazil.

Parameter	Currently	Phase I
Energy	$E_0$	3 GeV
Current	$I_0$	100 mA
Operation mode		Top-up
RF Cavities		1 NC
RF Voltage	$\hat{V}_{\text{rf}}$	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

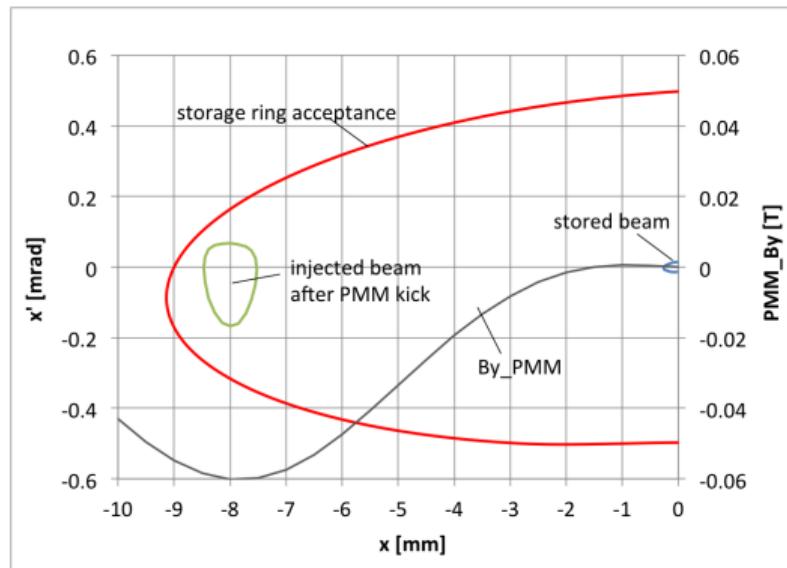
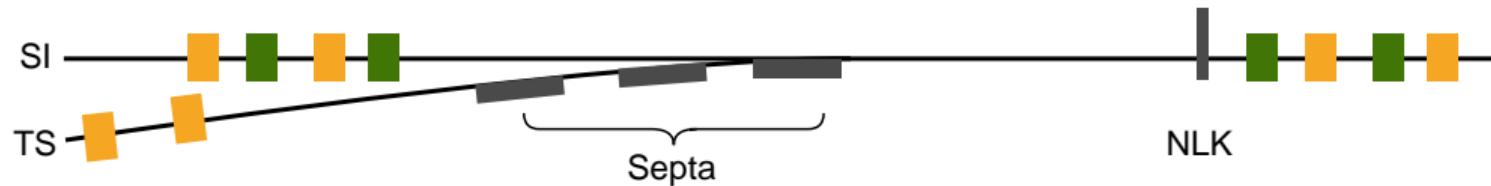


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# Off-axis injection scheme



- ▶ 100% efficiency with a  $x = -9 \text{ mm}$  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 ∈ chromaticity response matrix nullspace (13, 17 knobs)
  - ▶ 13 free knobs + 6 compensation knobs

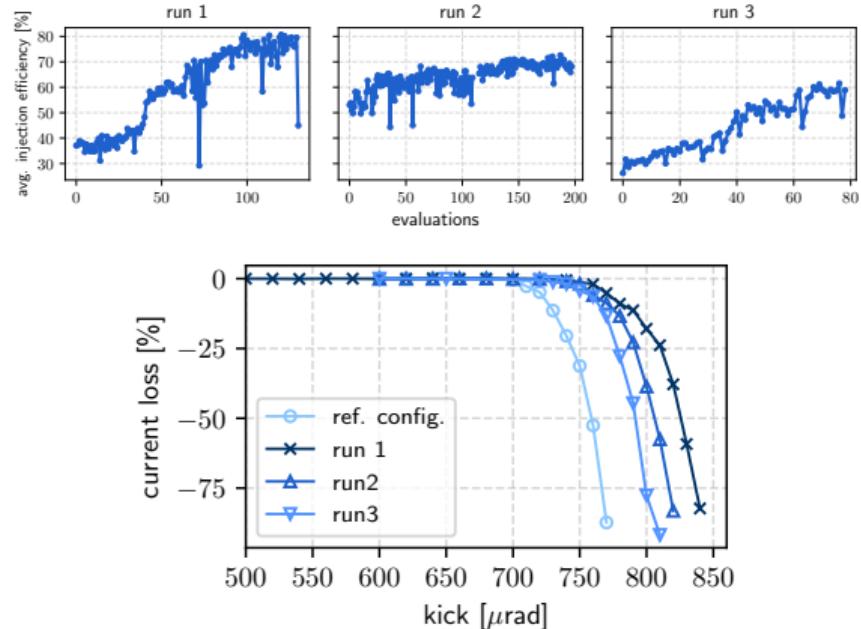
More details:

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,

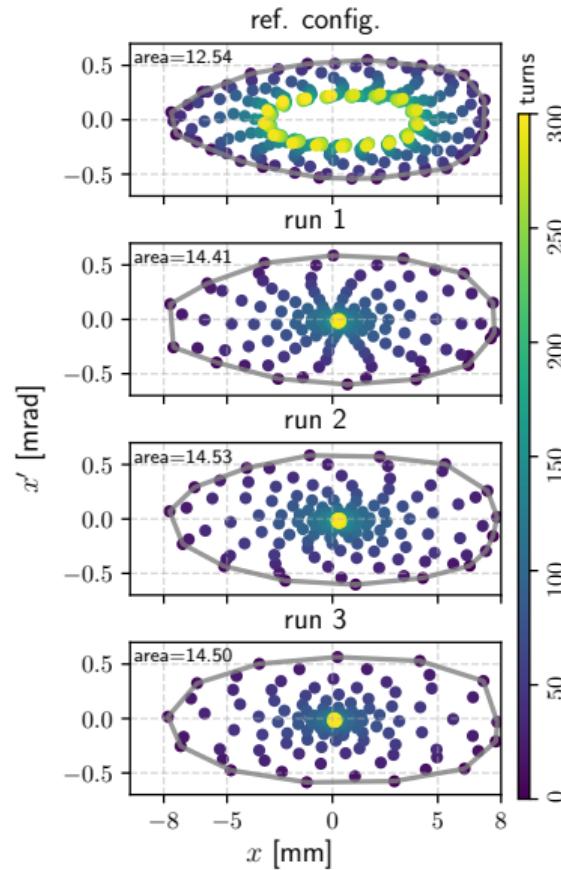
## SIRIUS sextupole families

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

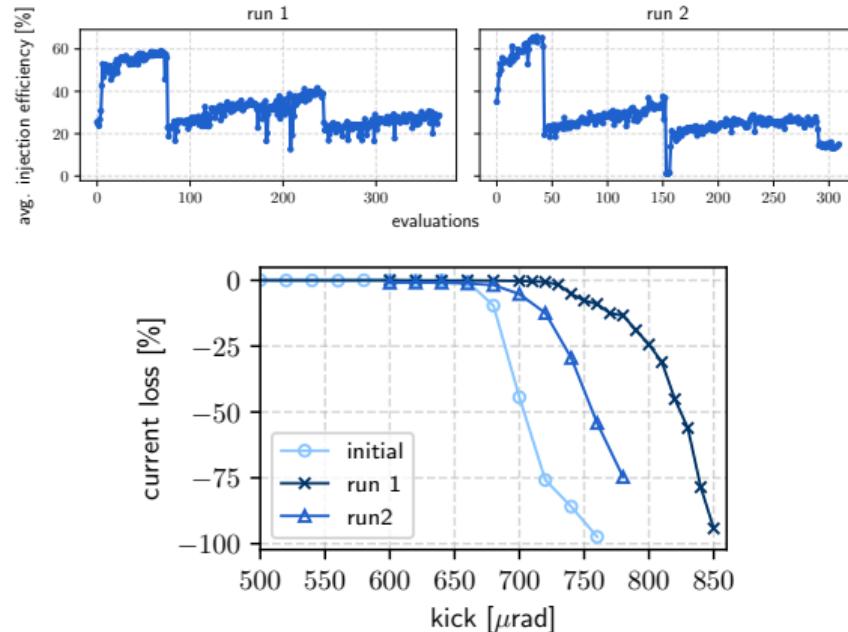
# Tuning at $\nu_x = 49.08, \nu_y = 14.14$ (Working Point 1)



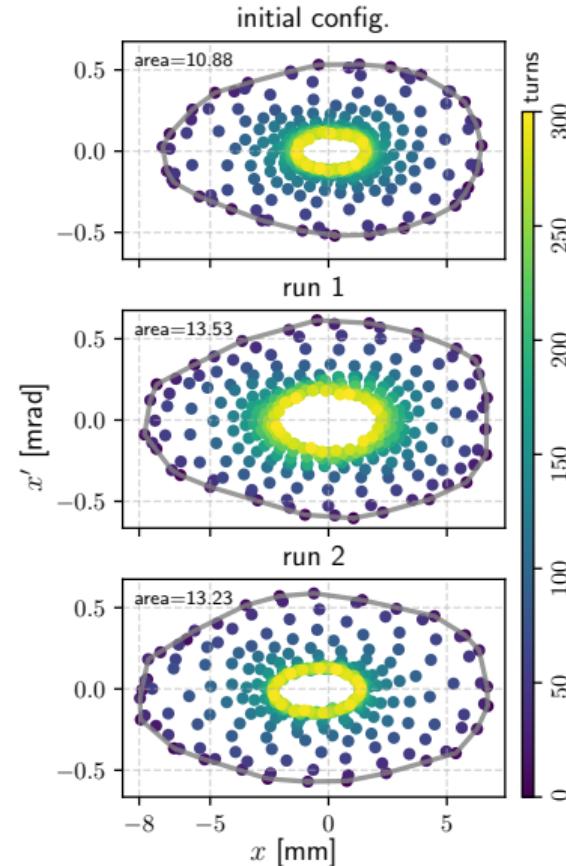
configuration	injection efficiency [%]
ref-config	$88 \pm 8$
run 1	$91 \pm 1$
run 2	$98 \pm 1$
run 3	$87 \pm 3$



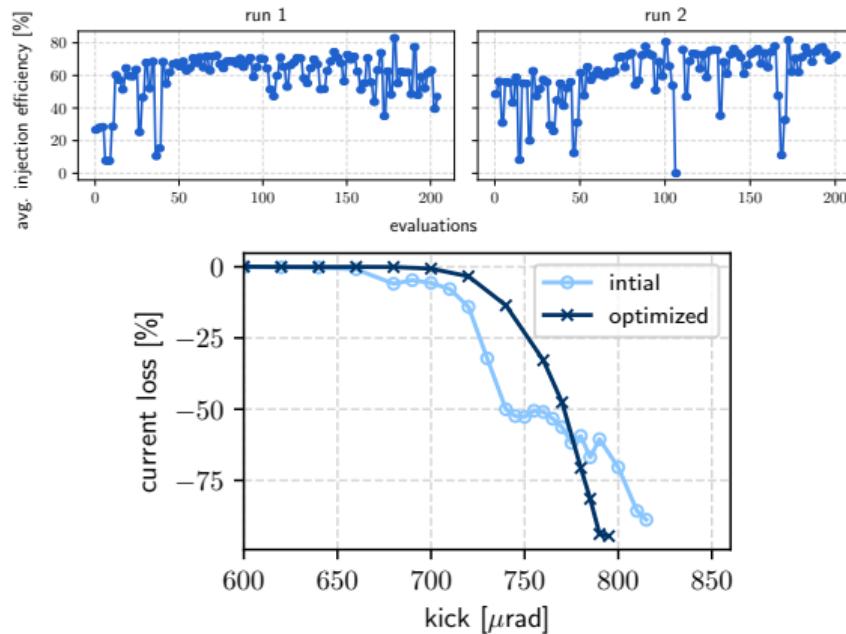
# Tuning at $\nu_x = 49.20, \nu_y = 14.25$ (Working Point 2)



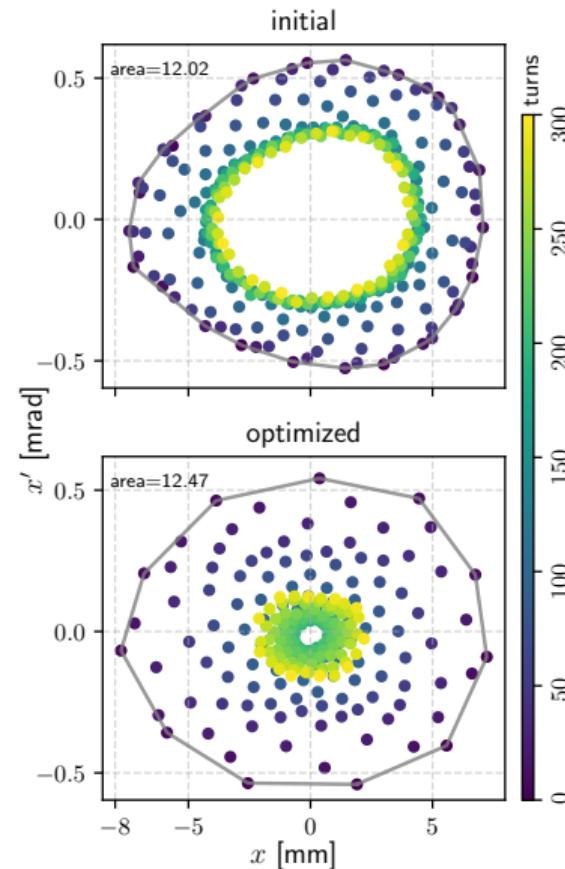
configuration	injection efficiency [%]
non-optimized	$51 \pm 1$
run 1	$79 \pm 3$
run 2	$65 \pm 1$



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



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

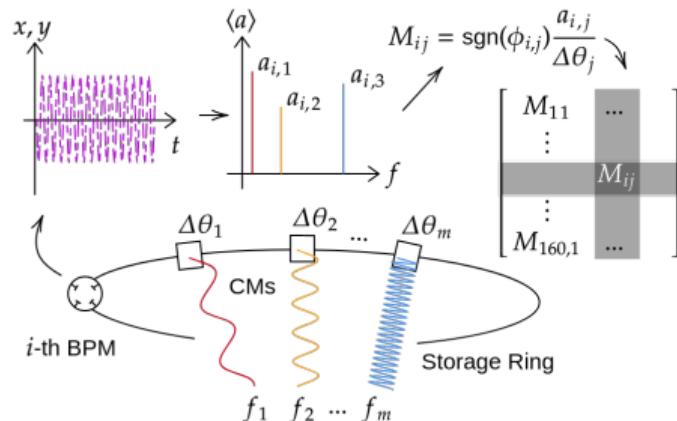


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# Fast ORM Measurement



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  $u_i(t_j)$ :

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

- ▶ 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:

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

# Measurements at SIRIUS storage ring and LOCO performance

## SIRIUS BPMs-CMs circuit

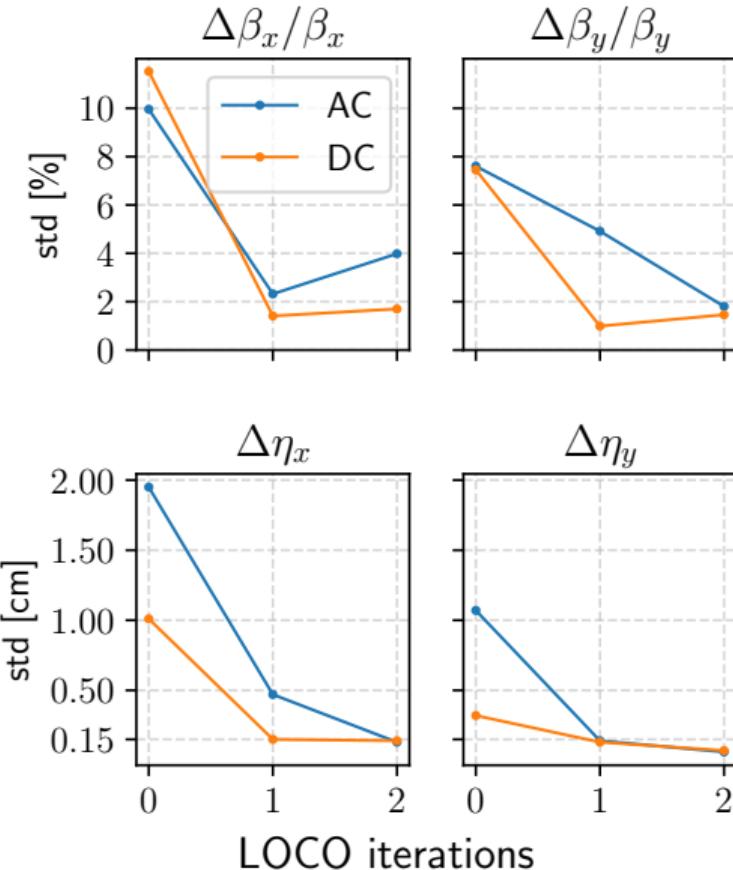
- ▶ 160 BPM buttons
- ▶  $n_x = 120$  CHs,  $n_y = 160$  CVs,  
 $n = n_x + n_y = 280$  CMs

## 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  $\mu$ 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



Thank you!

[matheus.veloso@lnls.br](mailto:matheus.veloso@lnls.br)

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