SIRIUS
Lessons Learned

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LEL 2022 – 3rd Workshop on Low Emittance Lattice Design
Jun 26-29, 2022 - ALBA

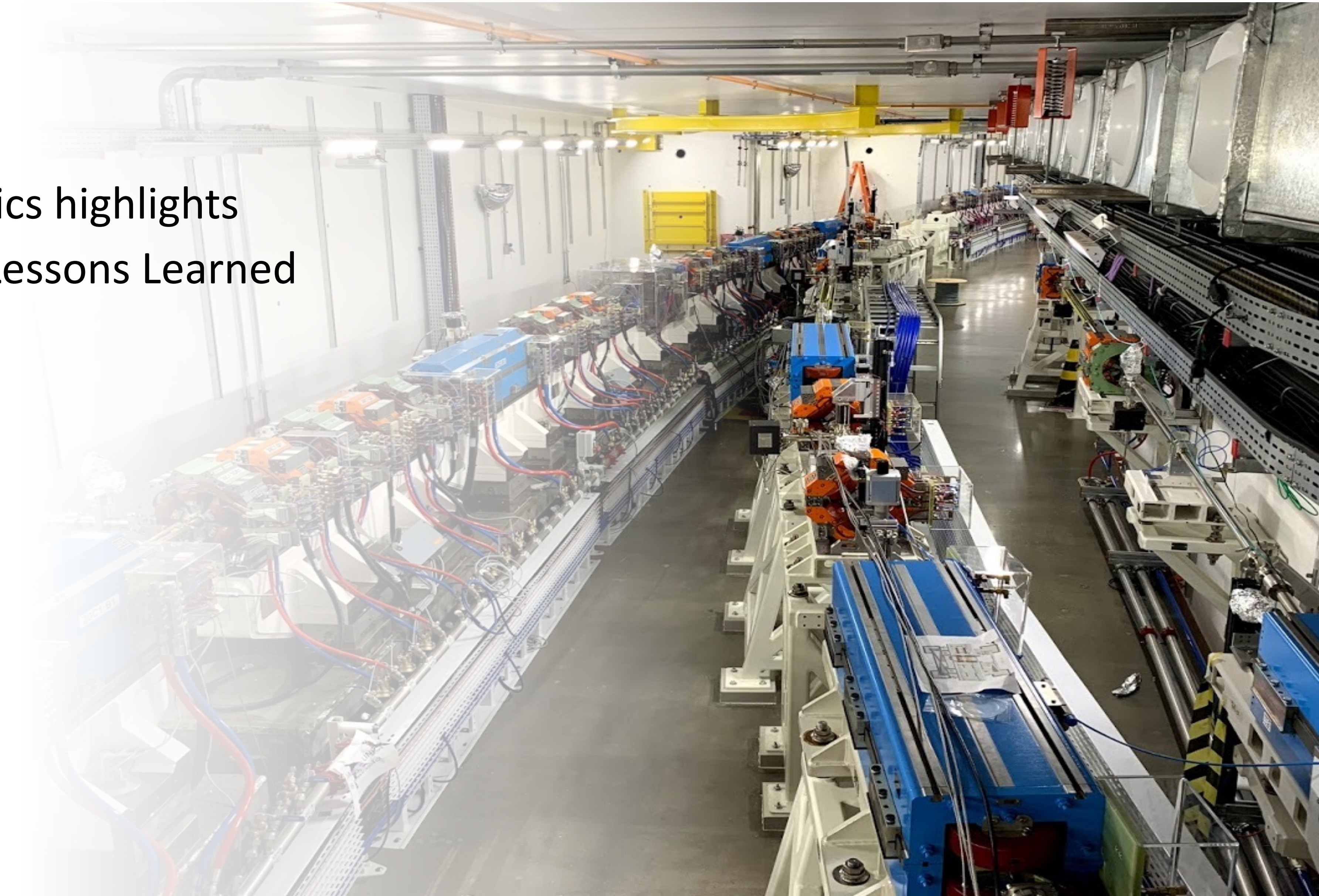
CNPEM
Centro Nacional de Pesquisa em Energia e Materiais

MINISTÉRIO DA CIÊNCIA, TECNOLOGIA, INOVAÇÕES E COMUNICAÇÕES

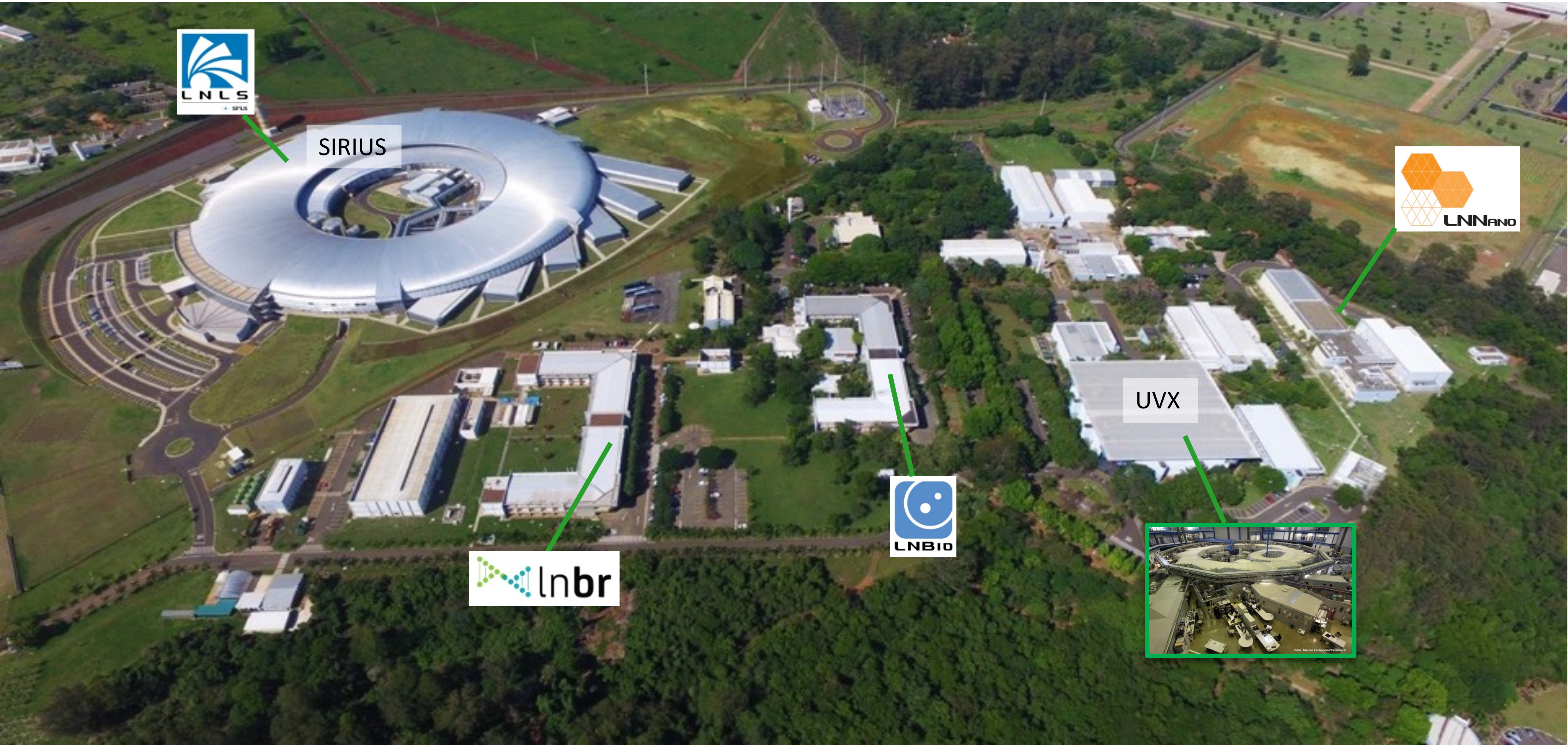
PÁTRIA AMADA BRASIL
GOVERNO FEDERAL

Outline

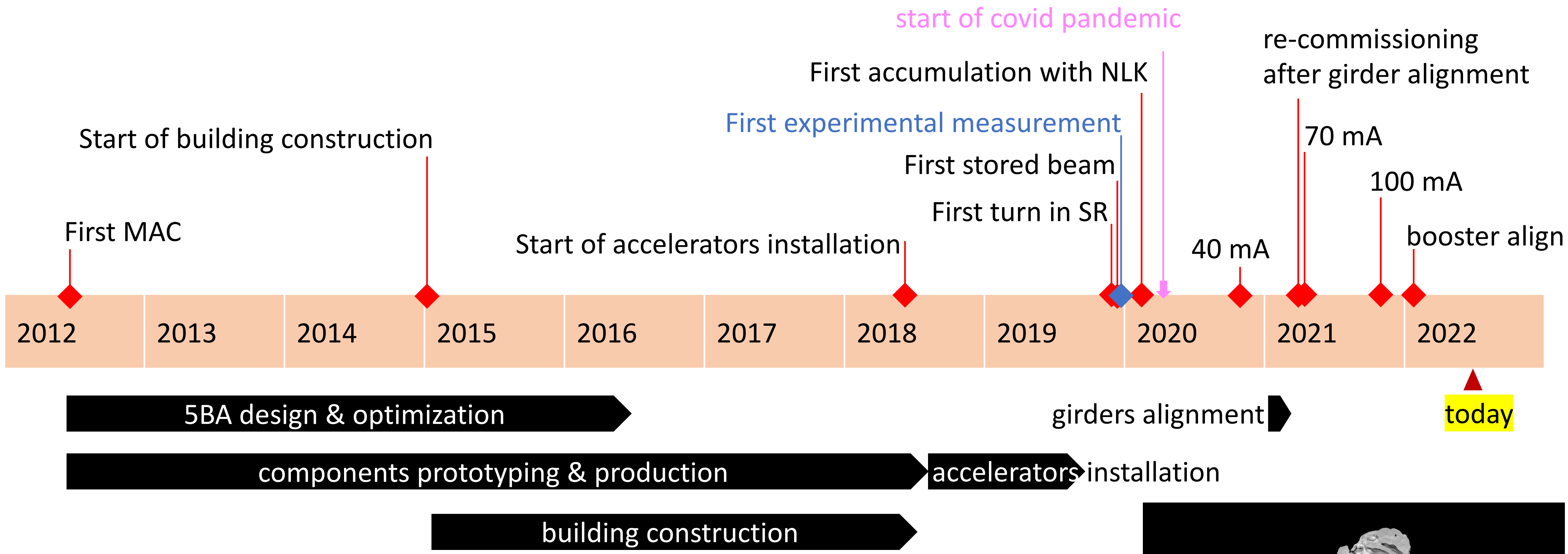
- Introduction
- Magnet lattice and optics highlights
- Project highlights and Lessons Learned
  - Magnets and supports
  - Beam stability
  - Injector
  - SR Injection
  - Vacuum system
  - General comments
- Conclusion

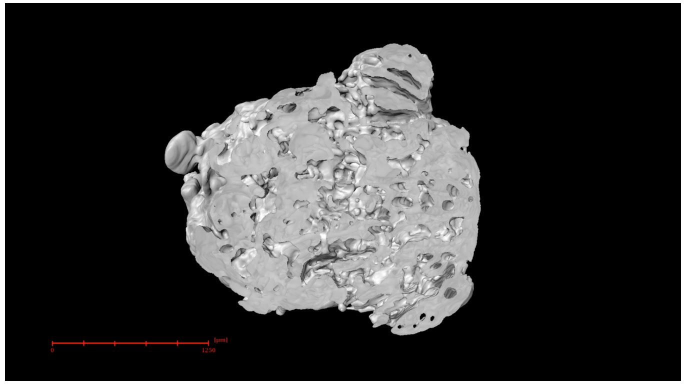


CNPEM Campus



Brief timeline overview



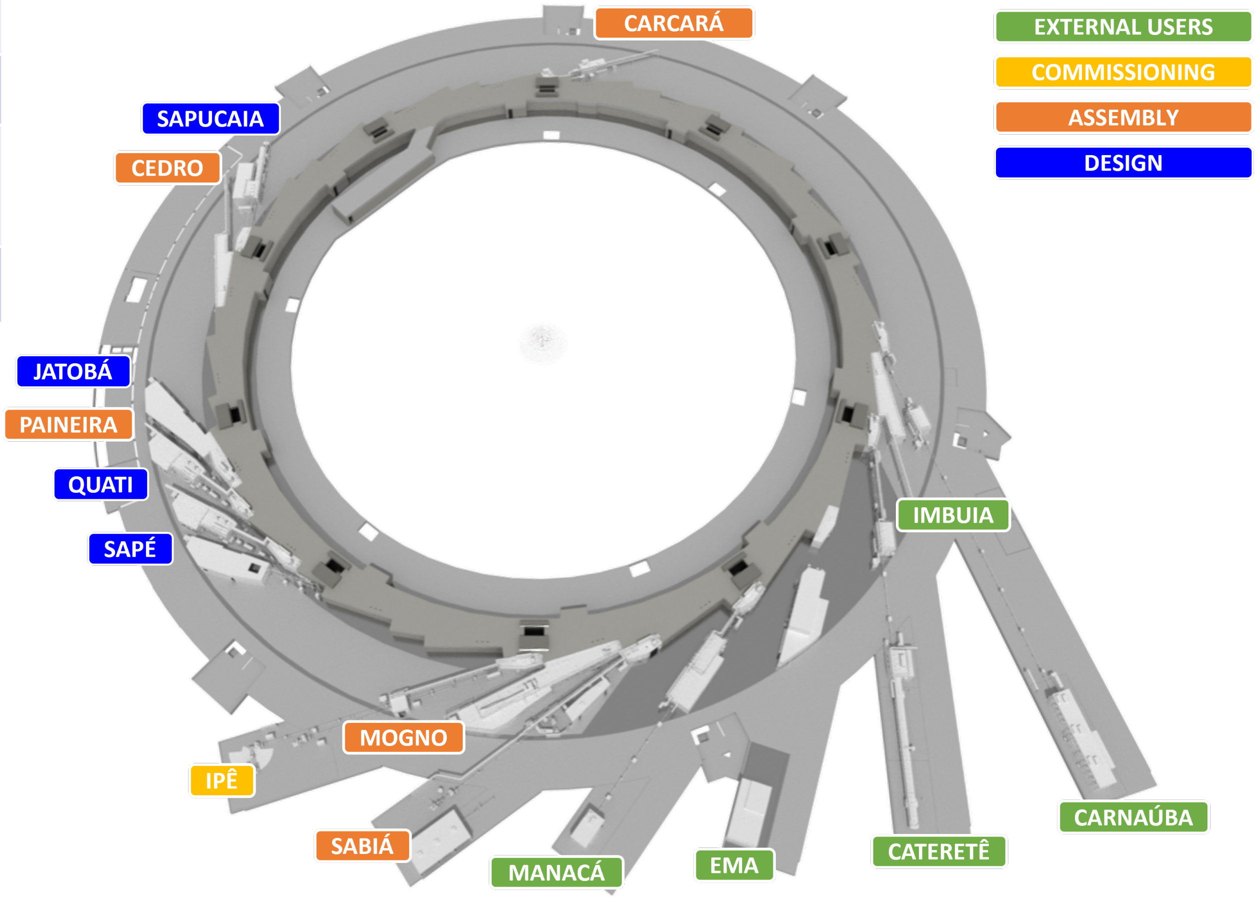


Key Performance Parameters

Parameter	Today (Phase 0)	Phase 1
Beam energy	3.0 GeV	3.0 GeV
Current	100 mA	350 mA
Injection mode	decay	top-up
Beam stability	$\gtrsim$ 10% σ_x $\gtrsim$ 40% σ_y	< 10% σ
Beamlines (in oper.)	6	14

Critical systems	Today (Phase 0)	Phase 1
RF cavities	Petra7 (1)	SRF (2) + 3HC (1)
RF power	120 kW	480 kW
Orbit feedback	SOFB	SOFB, FOFB, FF
BbB feedback	H, V, L	H, V, L
Undulators	Commis. APUs	IVU, hybrid, Apple-II

- Phase0: completed by end of 2021
- Phase1: Funding approved → mid 2024



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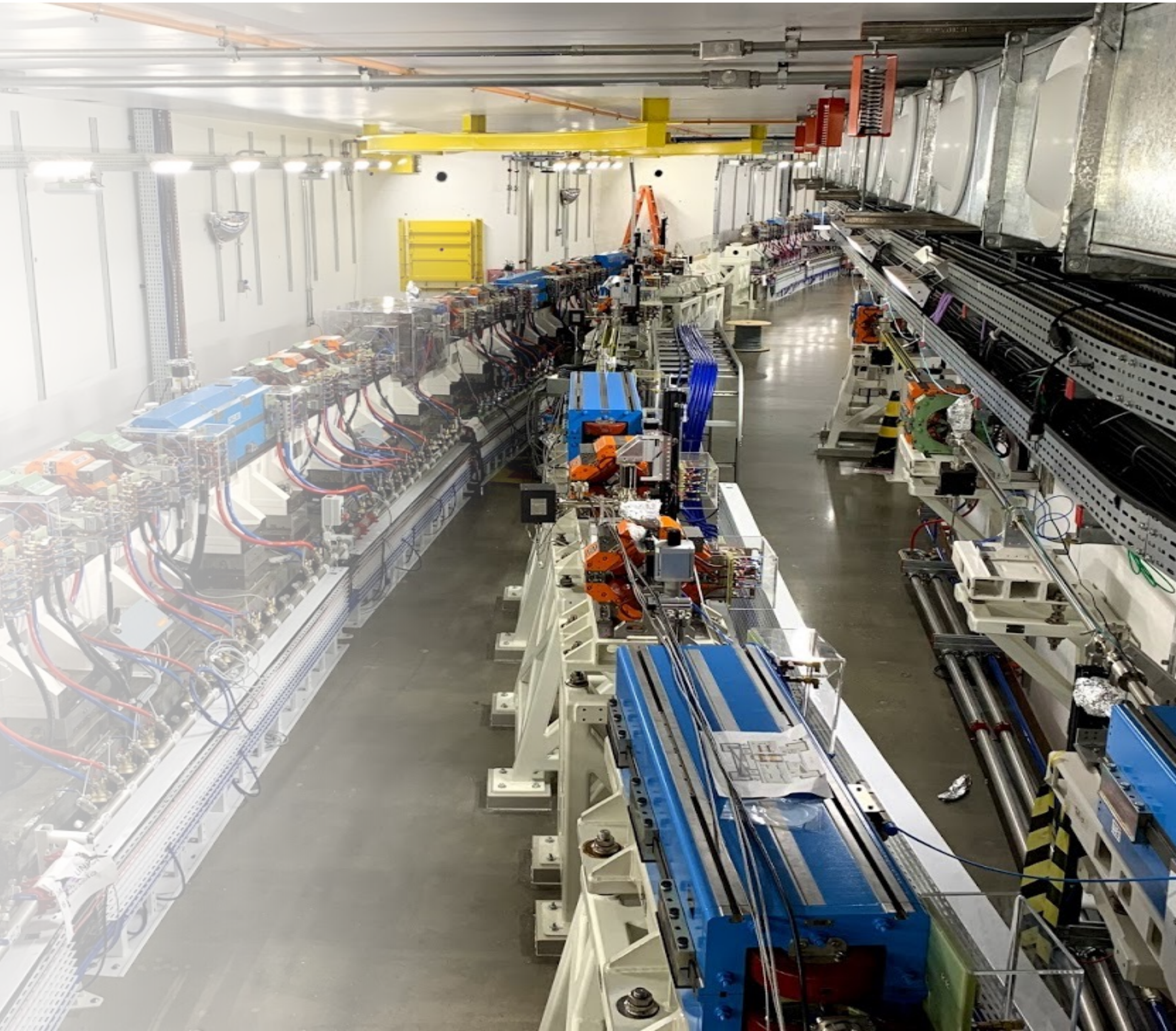
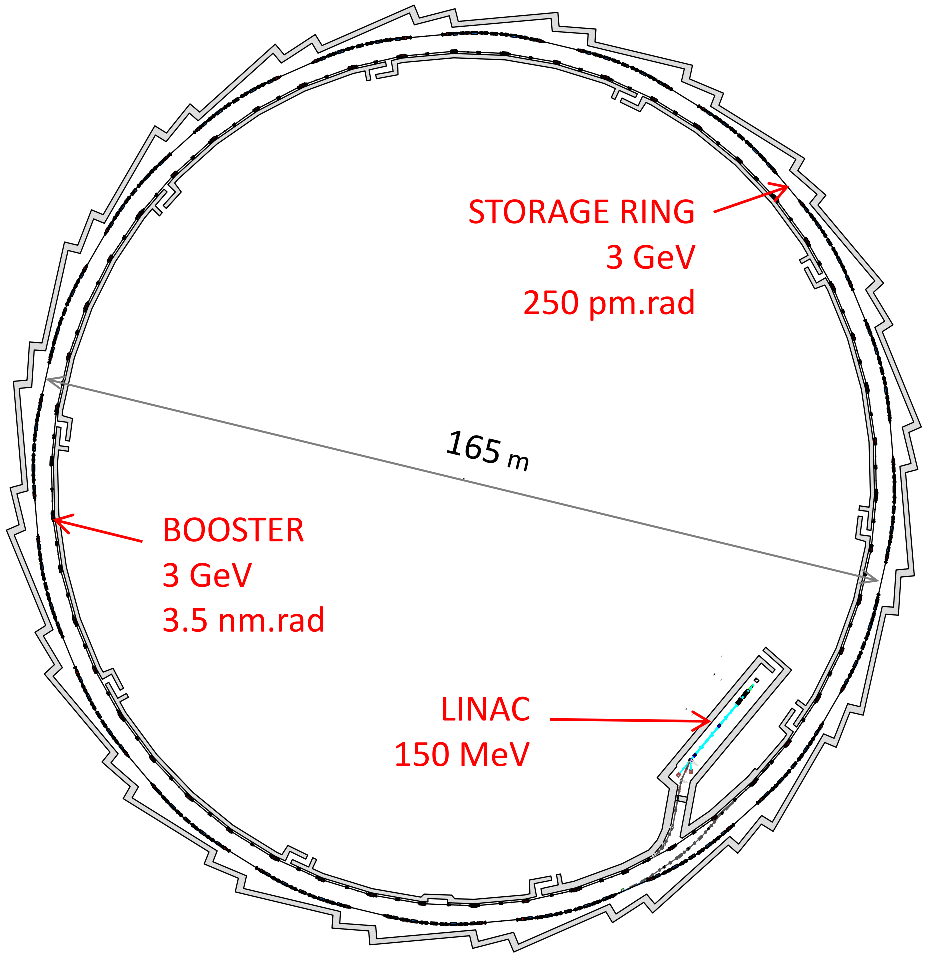


Main Parameters

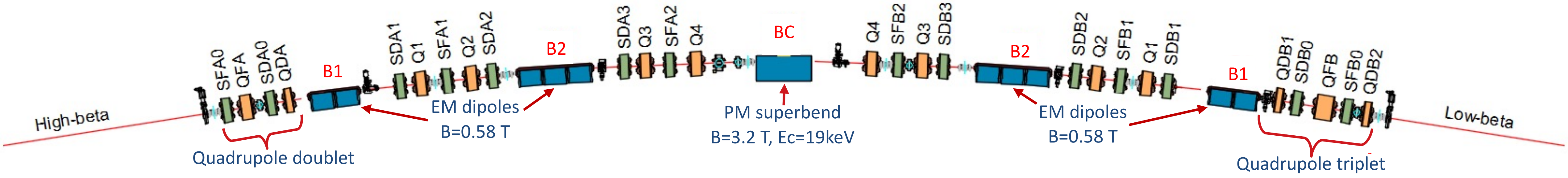


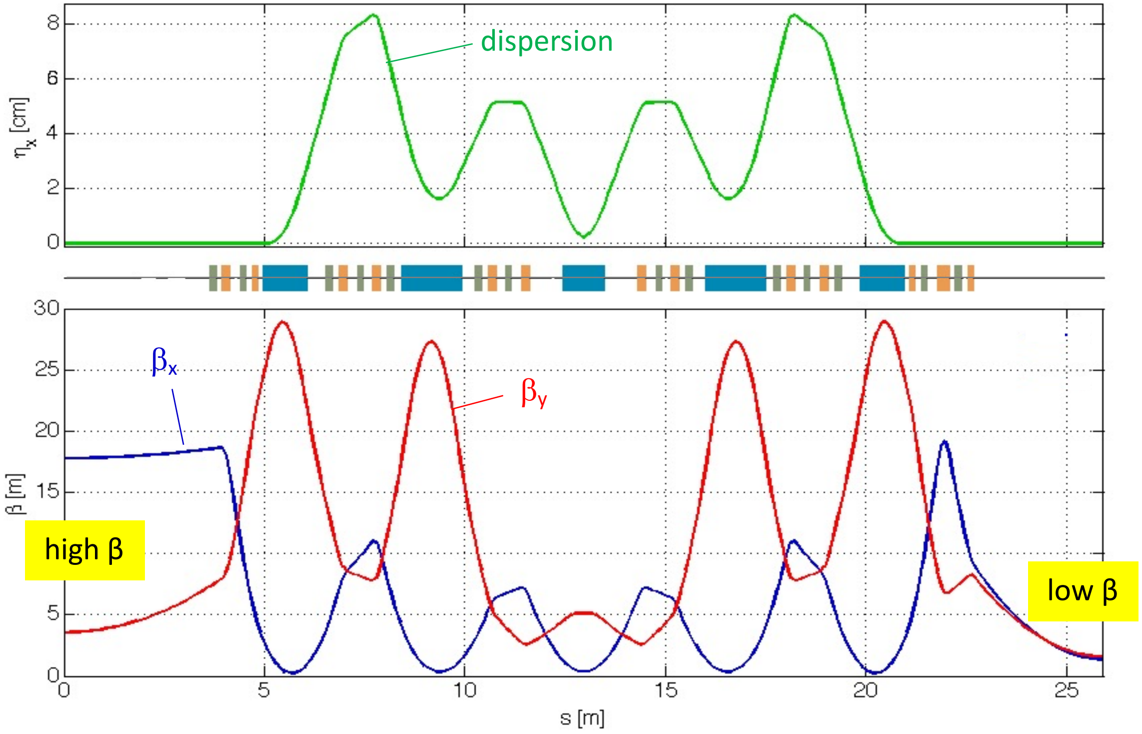
Storage Ring parameters	
Beam energy	3.0 GeV
Circumference	518.4 m
Lattice	**20 x 5BA**
Current, top up	350 mA
Hor. emittance (bare ⇢ w/ids)	**250 ⇢ 150 pm.rad**
Emittance ratio	3 %
Lifetime	**10 h**
Betatron tunes (H/V)	49.107 / 14.13
Natural chrom. (H/V)	-119.0 / -81.2
Energy spread (rms)	0.85×10^{-3}
RF frequency	500 MHz
Harmonic number	864
Straight section free length, low β / high β	5.8 m / 6.5 m

Booster parameters	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Momentum compaction	7.2×10^{-4}
Lattice	50 FODO
Cycling frequency	2 Hz

SR Elements	**# in SR**	Max. strength
Dipoles	80	0.56 T
Superbend	20	3.2 T
Quadrupoles	270	45 T/m
Sextupoles	280	2400 T/m^2
Hor. Corrs (slow/fast)	120/80	350/30 μrad
Ver. Corrs (slow/fast)	160/80	350/30 μrad
Skew Corrs	90	0.1 T
BPMs	160	-

Magnet Lattice and Optics





- 20 – 5BA arcs
  - 5 high β_x straight sections – matching with quad doublets.
  - 15 low β_x straight sections – matching with quad triplets.
- At low β_x sections ($\beta_x \approx \beta_y \approx 1.5$ m):
  - Matching of e^- and photon beam phase spaces for undulators
  - Small H and V beam stay clear
  - Small ID perturbation on optics
- 20 permanent magnet superbends
  - optical functions matched to reduce emittance
  - sharp peak field of 3.2 T in the center → ε_c: 19.2 keV
  - Beam size: 9.6 x 3.6 μm^2

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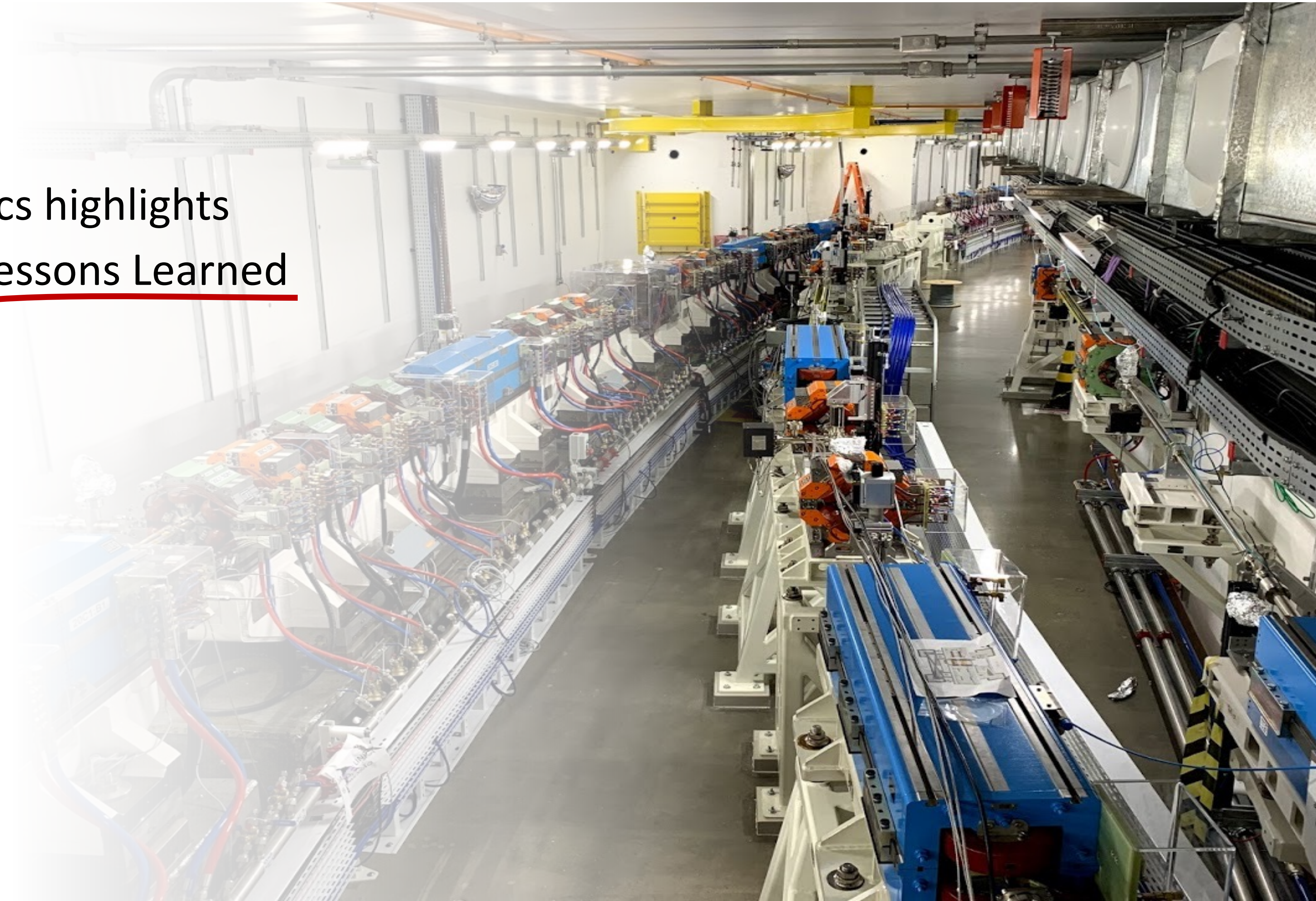
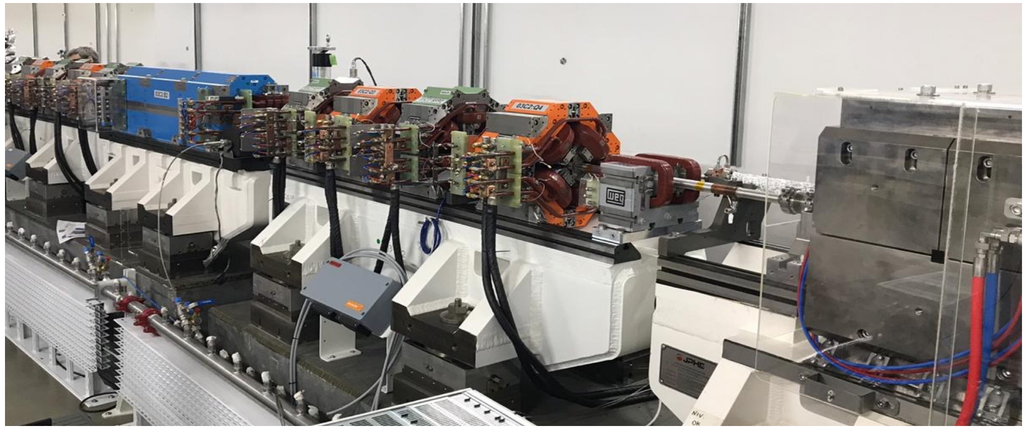
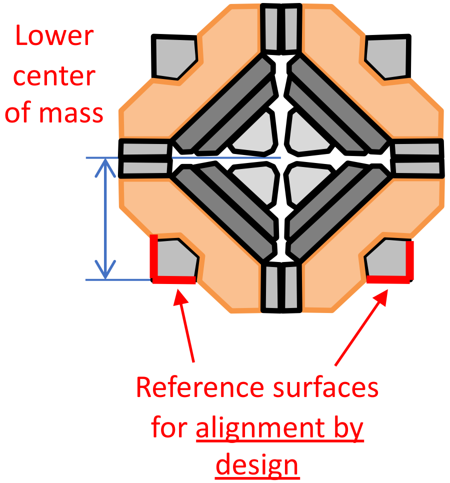
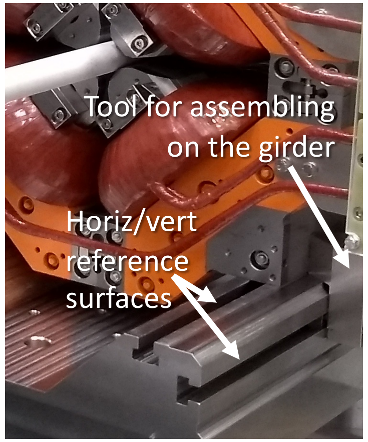


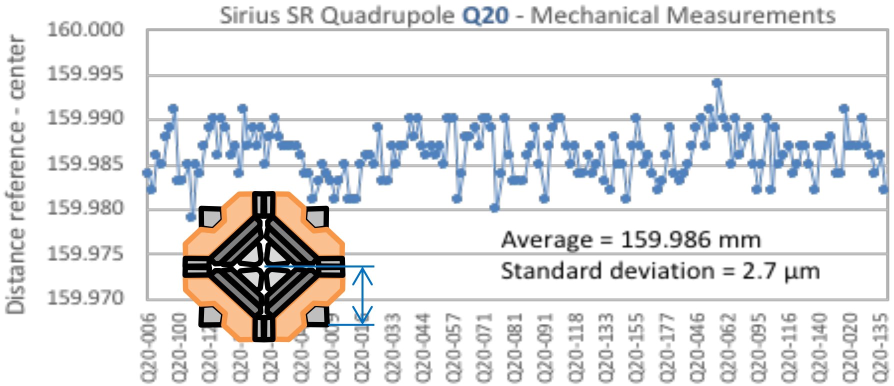
Storage Ring Magnets

- Magnets assembled and aligned on girders “by design” (no adjustable supports)
- Quadrupoles with trim coils and sextupoles with CH, CV and QS coils
- In-house produced permanent magnet dipole with thin superbend (3.2 T) in the center

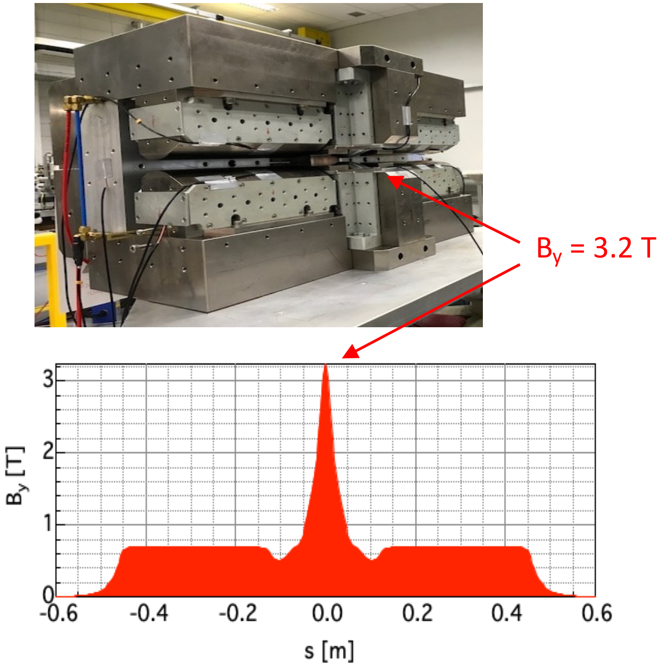






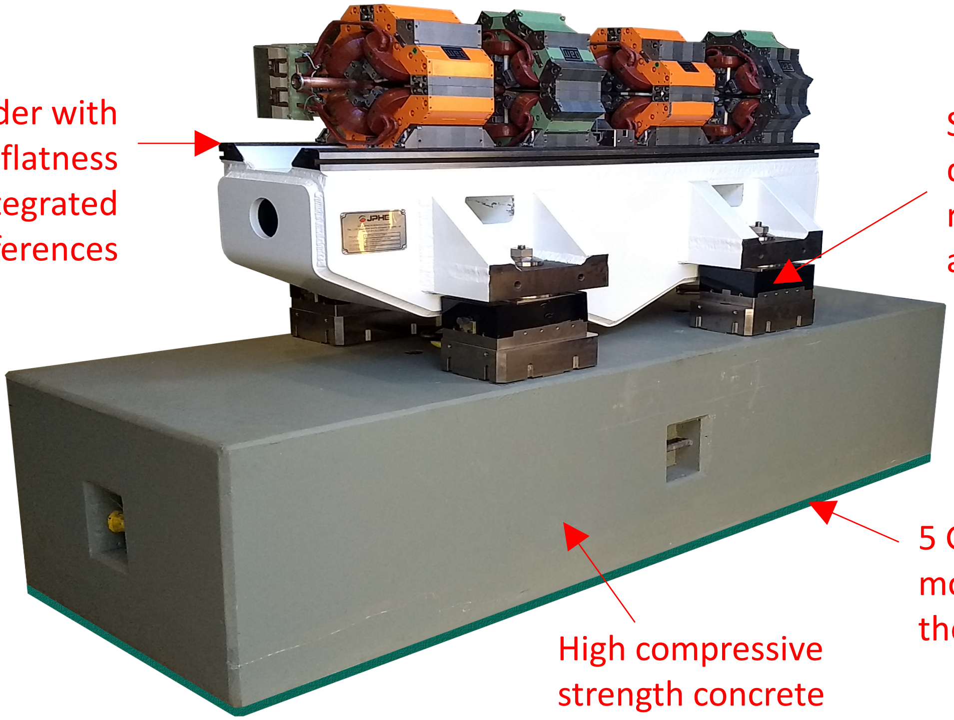


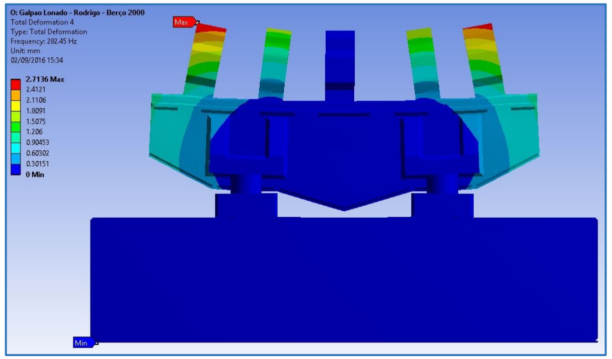
PM superbend



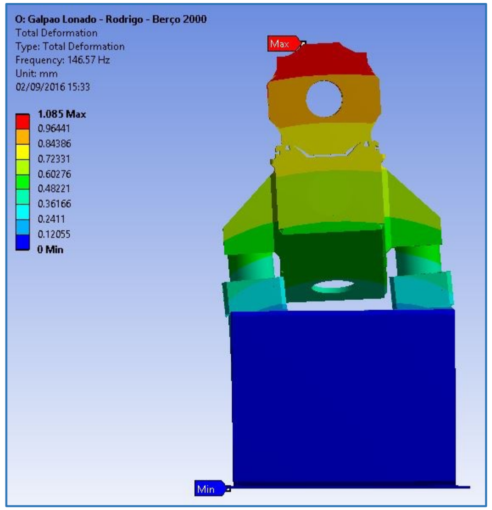
Supports

- Integrated optimization of the whole system: magnets, girders, position adjustment pads, concrete base
- Very rigid girder, all machine components aligned by construction
- Very high first mode vibration frequencies



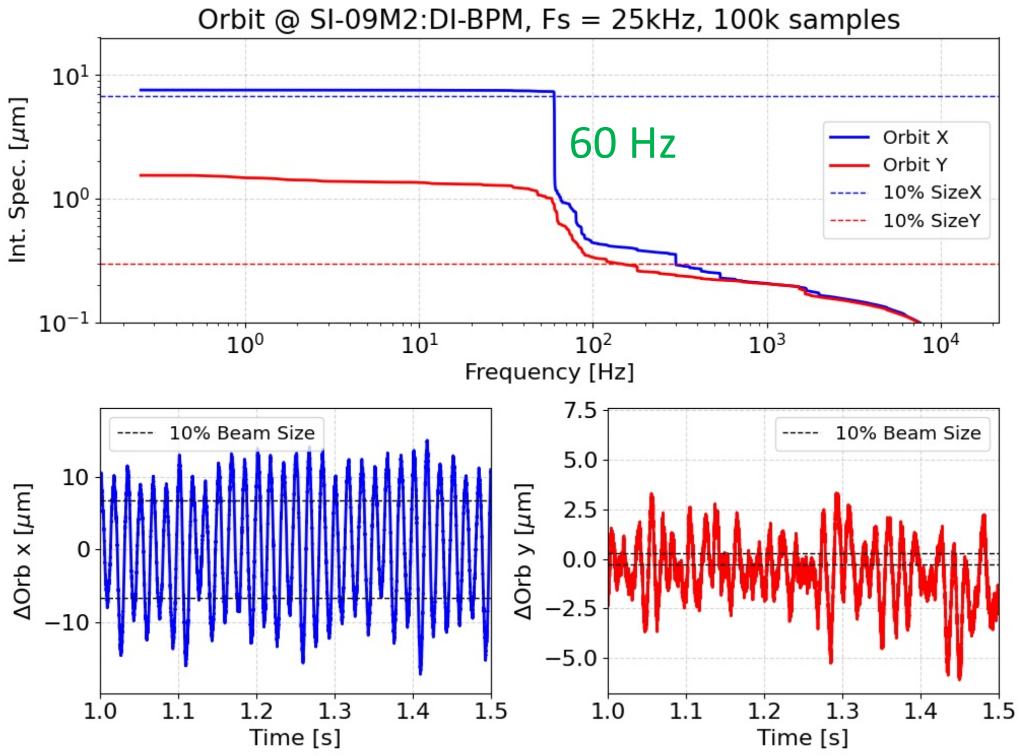


1st Vert. mode: 268 Hz



1st Horiz. mode: 152 Hz

Orbit Stability



- Integrated optimization efforts to minimize mechanical vibrations resulted in good orbit stability
- Main orbit perturbation at mains frequency of 60 Hz
  - Sources under investigation
  - Within FOFB attenuation range (FOFB not operational yet)
- Horizontal plane → orbit stability slightly larger than target of 10% σ_x
- Vertical plane → orbit stability about 40% σ_y

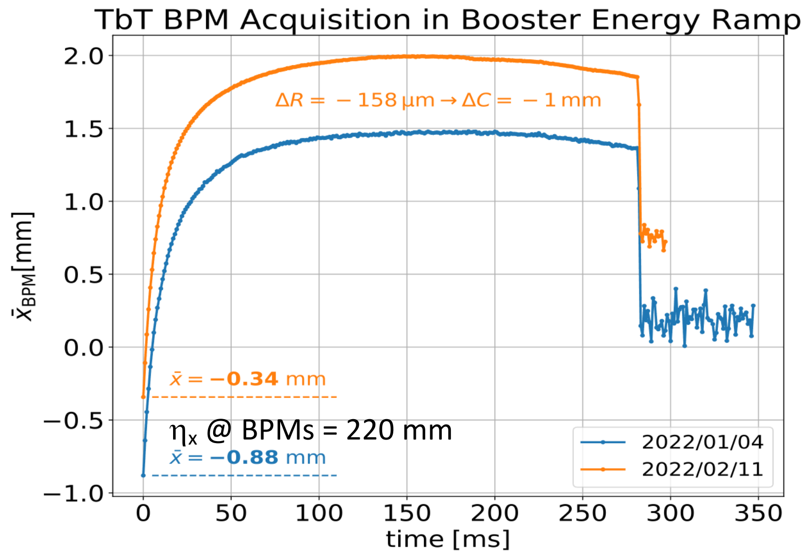
Injector

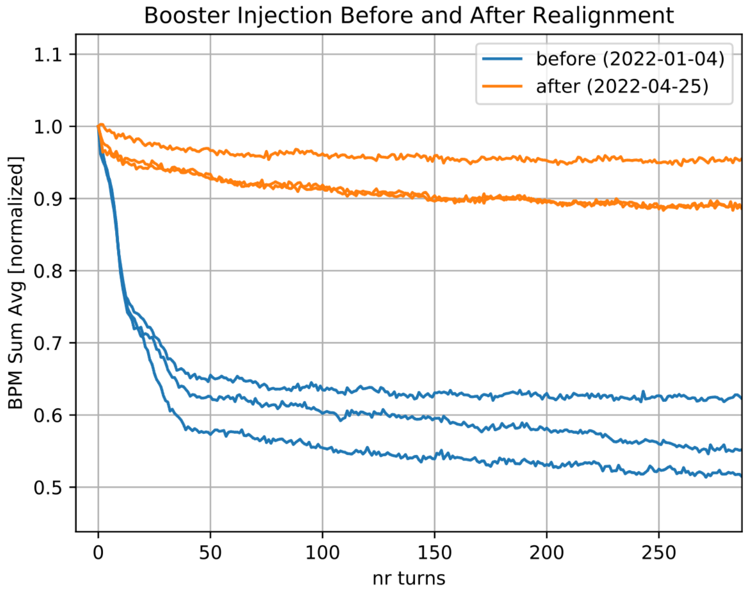
- The effect of revolution frequency (f_0) change during acceleration is generally negligible in electron synchrotrons with large α_c.
- For small α_c, since the booster RF frequency (f_{RF}) is fixed (locked to the SR), the mismatch between f_{RF} and f_0 along the ramp results in a non-negligible energy deviation δ
- On-energy operation either at low energy **or** high energy
- For SIRIUS booster,

  E_{inj} = 150 MeV
  E_{final} = 3 GeV
  $\alpha_c = 7.2 \times 10^{-4}$

  } δ = 0.8%
  $\langle \Delta x_{BPM} \rangle \approx$ 2 mm

- Booster realignment was necessary to match the circumference at injection energy, where most losses occurred during the energy ramp

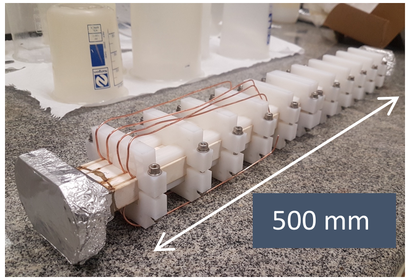


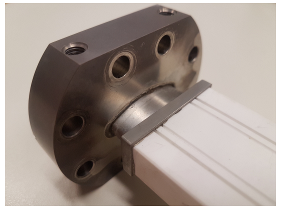


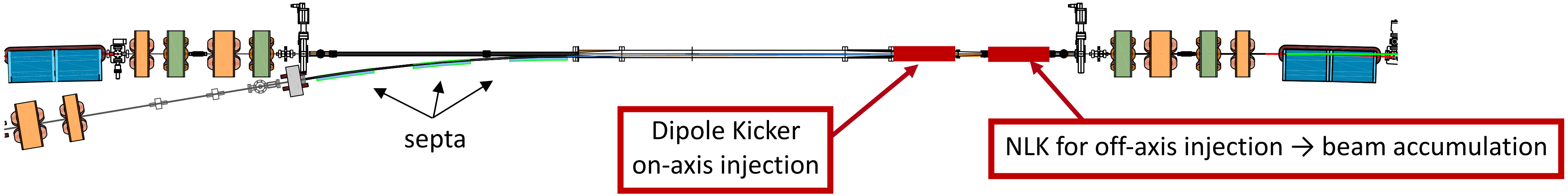
Storage Ring Injection

- On-axis injection for commissioning using a dipole kicker, DipK
- Off-axis injection for beam accumulation using NLK

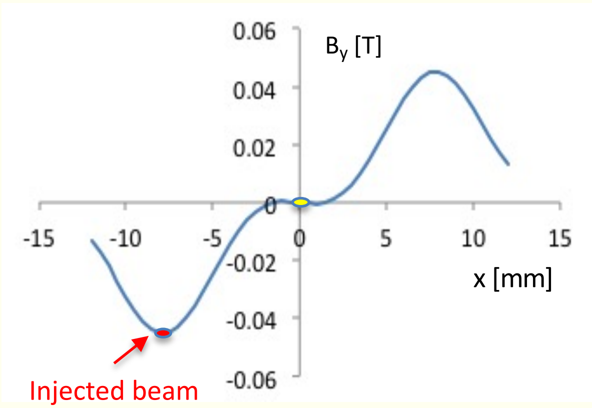
- Bessy-type NLK
  - Single piece ceramic chamber
  - Machined grooves for wire positioning
  - Future test: residual field compensation using current shunts

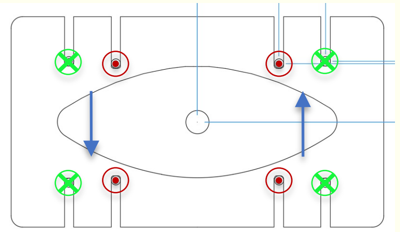






- Initial plans were to modify DipK into a horizontal pinger after commissioning → weaker and shorter pulse width
- It turns out that on-axis injection has proved to be very useful after maintenance periods
- Having the on-axis injection scheme as an option is very useful to speed up machine recovery

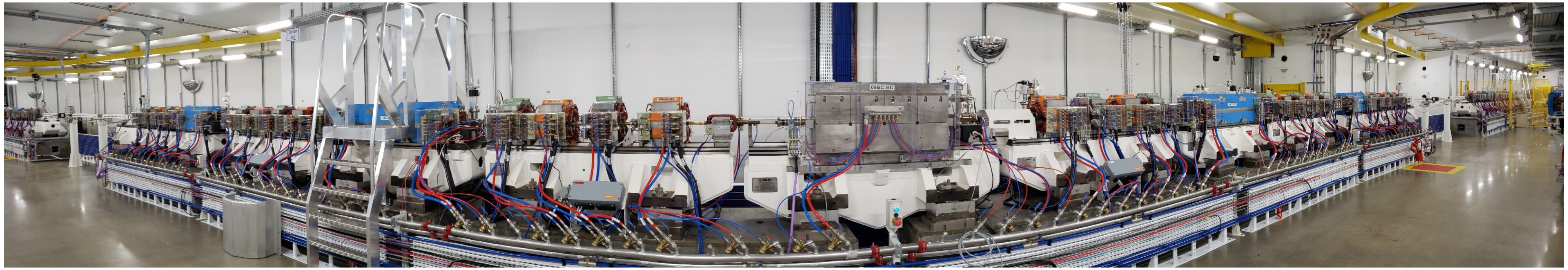


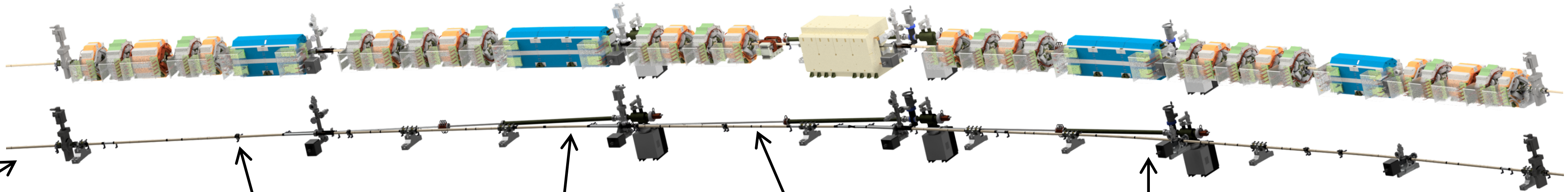


Field @ peak	800	Gauss
Peak position	-8.0	mm
Current	0.8	kA
Voltage	4.8	kV
Pulse width	2.7	µs

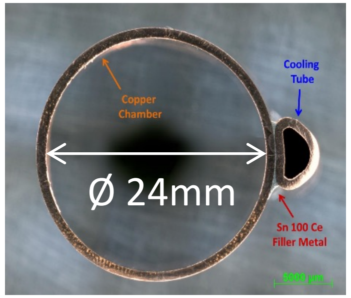
Vacuum System

Fully in-house NEG-coated chambers with in-situ baking

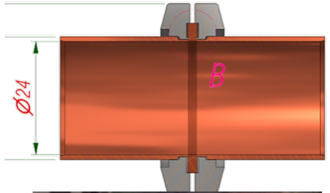


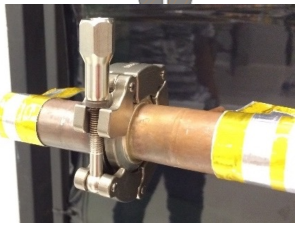


Straight sector copper chamber

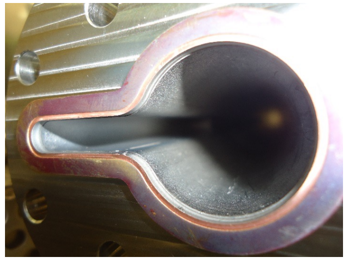


Low impedance flange
Zero gap copper seal





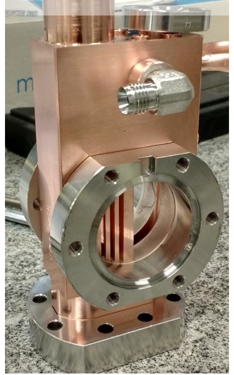
Dipole chamber w/ narrow gap for ph extraction



0.3 mm Stainless Steel sector
For fast orbit correctors

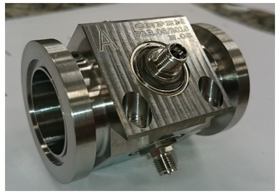
100 mm

Pumping Station Crotch absorber



Bellows
RF shielding

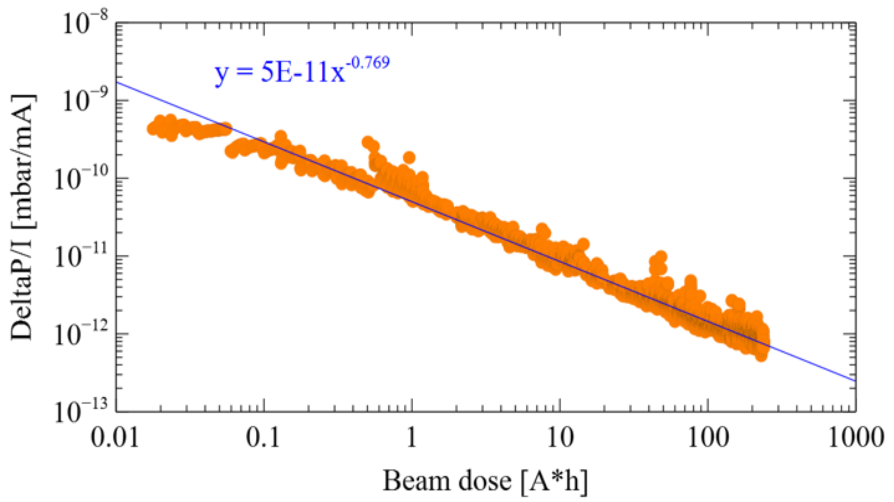
BPM
bellows on both sides



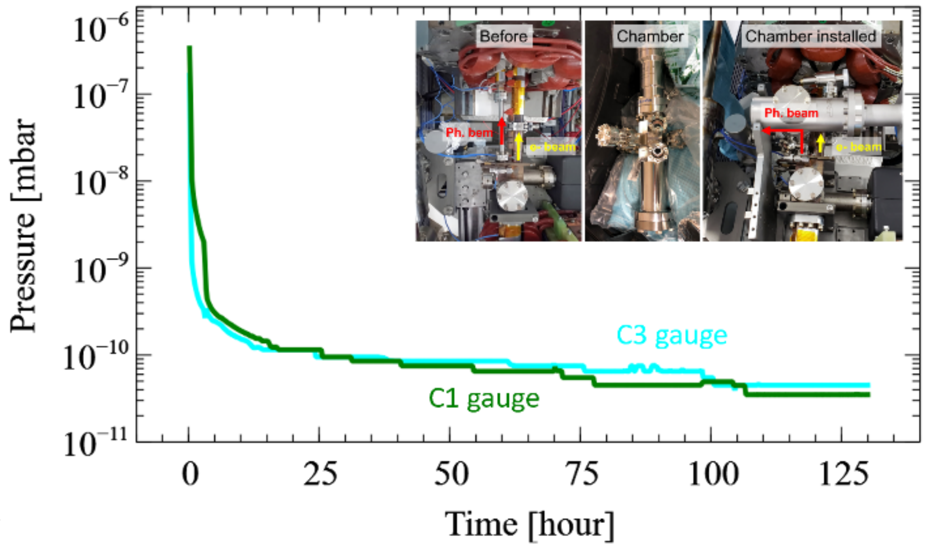
Vacuum System

- SIRIUS is based on fully NEG-coated vacuum chambers
  - Fast conditioning. For SIRIUS, the design dynamic pressure of 3×10^{-12} mbar/mA was achieved with a beam dose of 60 A.h
  - Foresee additional pumping close to large areas without NEG (such as cavities and diagnostics components). Degassing from such areas can saturate the nearby NEG coating
- Neon venting for vacuum interventions
  - Until now, no NEG-coated vacuum chamber of SIRIUS arcs had to be reactivated
  - For machines based on NEG coating, it is important to foresee ports and flanges for Neon venting during design phase

Normalized average dynamic pressure rise vs beam dose



Pump down curve after vacuum intervention with Ne venting



General Comments

- Cabling: dedicated team instead of sharing responsibility between different groups
- Accelerators and beamlines development standardization → cost reduction and easier maintenance. E.g.: motors, cameras, interlock systems, data acquisition systems, archiving systems, etc
- Development of equipment testing protocols (BPM electronics, power supplies, etc) to help debugging
- Foresee equipment production completion well ahead installation to allow for burn-in and long-term tests. Important for BPMs, power supplies, in-vacuum motion systems (e.g. scrapers)
- Implement automatic testing of commercial equipment IOCs with a network setup similar to the final one → continuous variable monitoring to improve debugging
- SIRIUS accelerator interlock system required many unmapped expansions → system already near full capacity
- Infrastructure related to control system software (software management, e.g. docker, ansible, standardization of servers structure, database, etc) took longer than expected → dedicated team could speed-up subsystem integration

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Lessons Learned - Conclusion

- Integration between machine and beamline teams.
- Integration between all subsystems teams.
- Documentation and accessibility to latest project parameters.
  - Good experience with collaborative documentation of latest project parameters in the web-based wiki platform. wiki-sirius.lnls.br
- Thorough testing of critical equipment.
- Be prepared to solve unexpected problems, fix equipment and make modifications quickly.
- State-of-the-art diagnostics and flexible tools to test accelerator physics models are available today → personal experience in commissioning UVX and SIRIUS → commissioning of SIRIUS was smoother!
- Celebrate milestones reached!

Thank you for your attention!