Sirius Progress

October 2020

- Sirius project overview
- Commissioning results (partial)
- What still needs to be done

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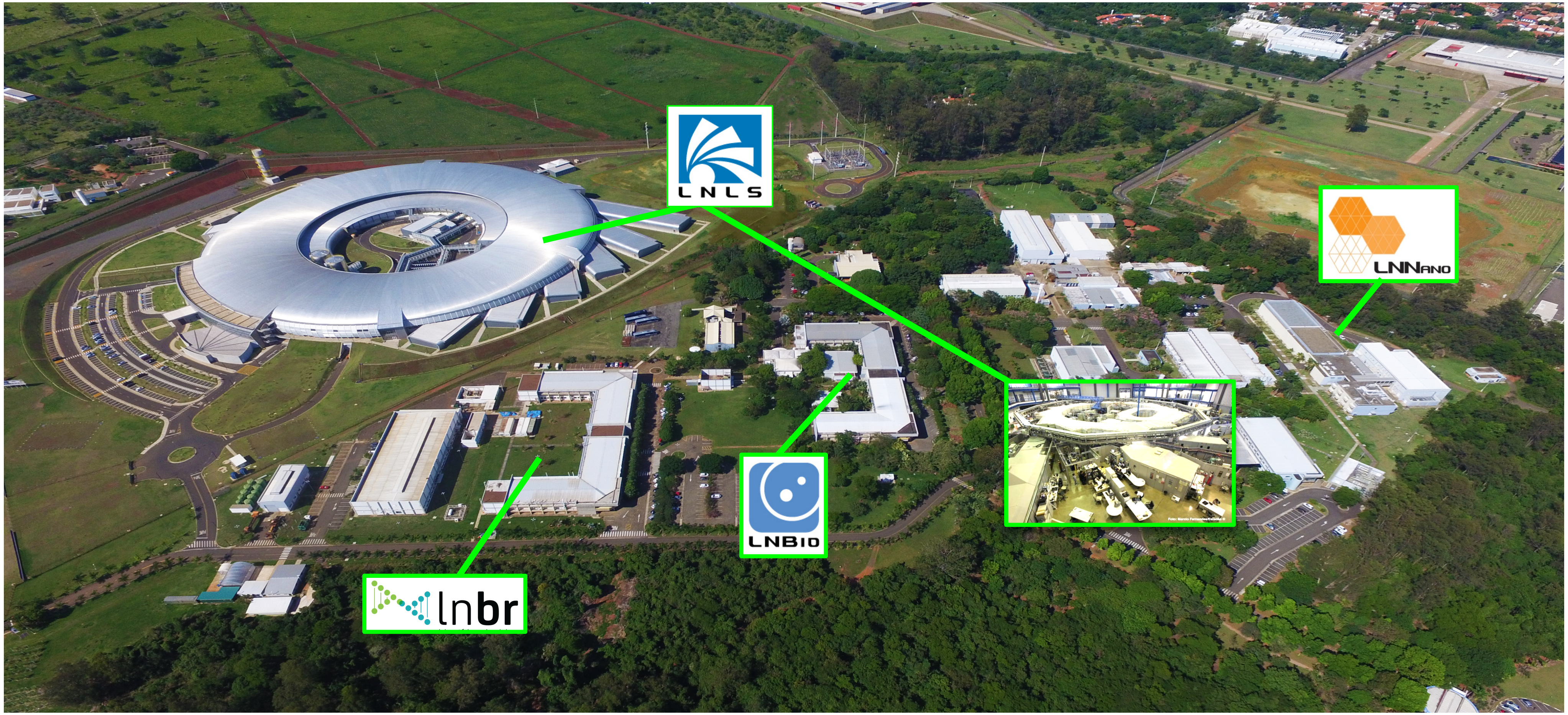
on behalf of the Sirius Team
Brazilian Synchrotron Light Laboratory - LNLS

Sirius is a 4th Generation 3 GeV synchrotron light source with natural emittance of 0.25 nm.rad.

It is presently under commissioning at CNPEM/LNLS campus, in Campinas, Brazil.



Brief History of LNLS

1982: Initial discussions on a synchrotron radiation lab in Brazil

1986: LNLS was created

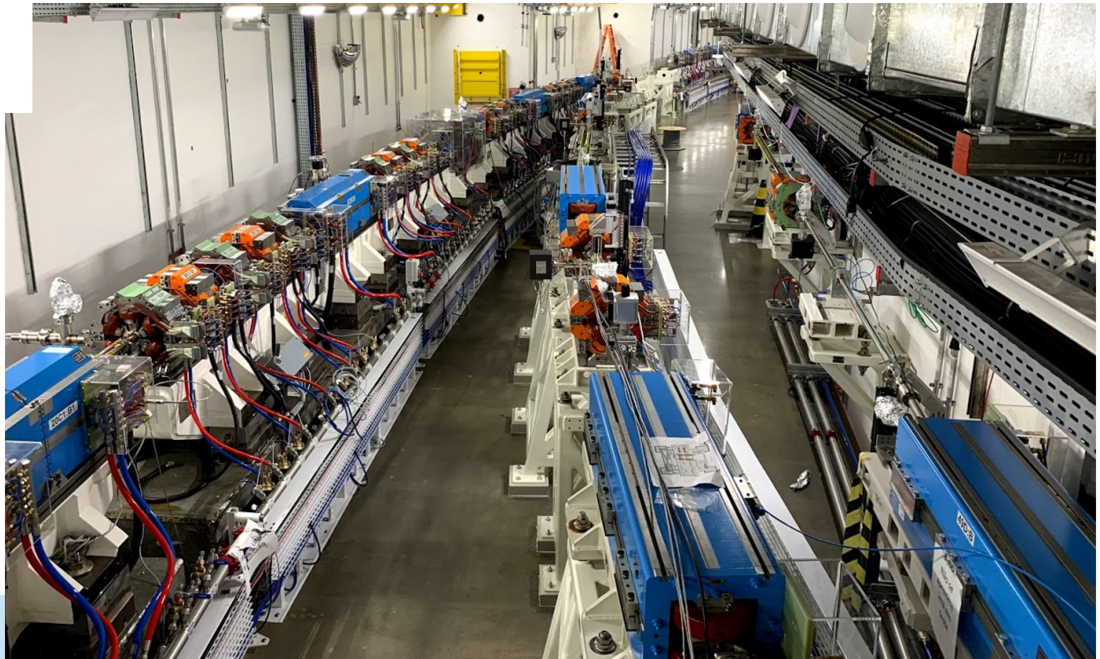
1987, January: LNLS starts hiring technical staff

1987 – 1996: Construction of UVX, a 1.4 GeV, 2nd generation source designed and mostly built from scratch in-house

1997 – 2019: 22 years of operation for users

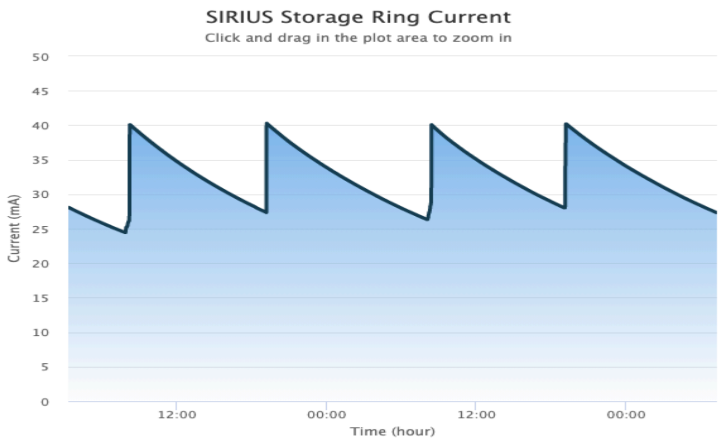
Sirius Timeline

2008: Preliminary proposal of a new light source submitted to Brazilian Government

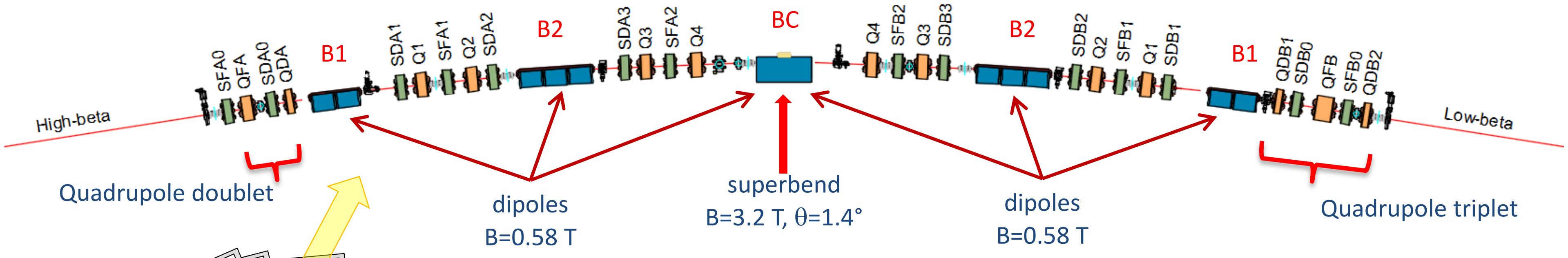


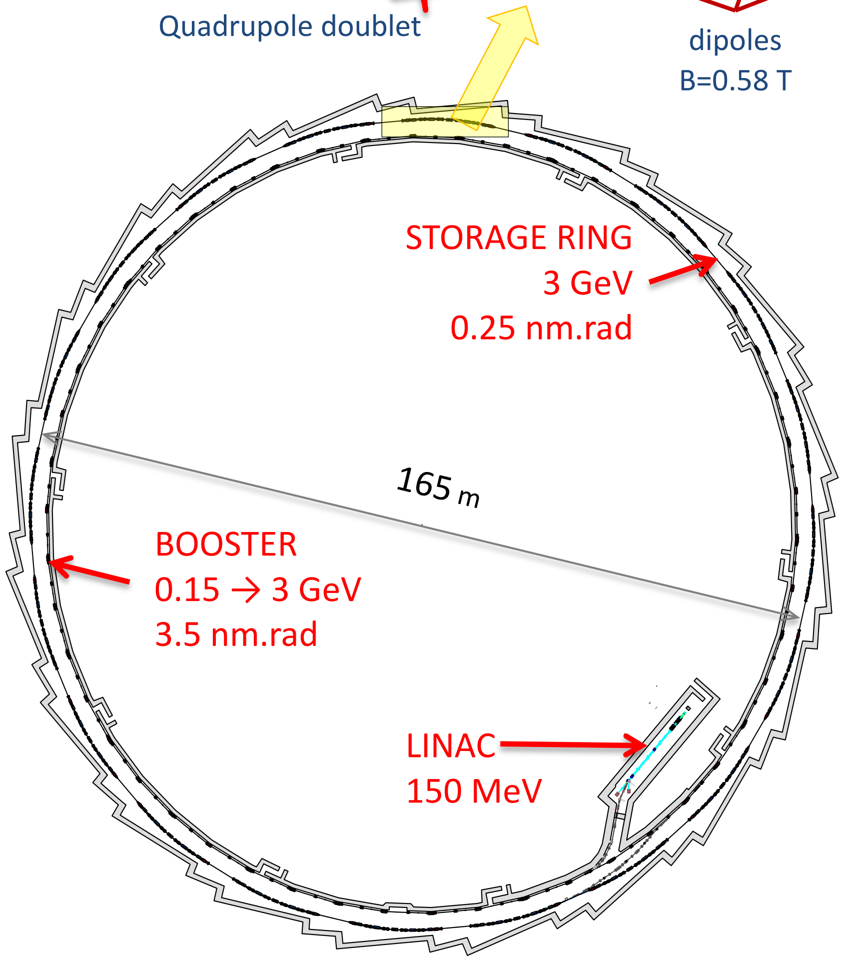
Sirius Timeline – 2020

January: Sirius project leader passed away



Sirius Main Parameters





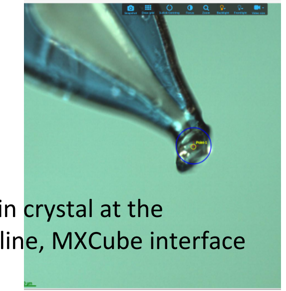
Storage Ring	
e⁻-Beam energy	**3.0 GeV**
Circumference	**518.4 m**
Lattice	20 x 5BA
Hor. emittance (bare lattice)	**0.25 nm.rad**
Hor. emittance (with undulators)	**0.15 nm.rad**
Betatron tunes (H/V)	49.11 / 14.17
Natural chrom. (H/V)	-119.0 / -81.2
Energy spread (rms)	0.85×10^{-3}
Energy loss/turn	473 keV
Damping times (H/V/L) [ms]	16.9 / 22.0 / 12.9
Beam current (top up)	**350 mA**

Booster	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Lattice	50 Bend
Cycling freq.	2 Hz

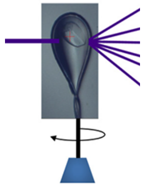
Linac	
Energy	150 MeV
Frequency	3 GHz
Repetition rate	2 Hz

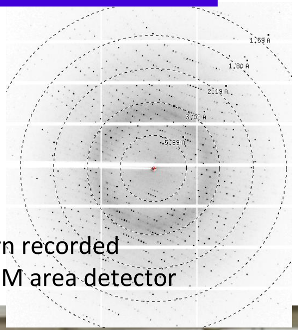
First experimental results from beamlines

MANACA – serial micro and nano protein crystallography

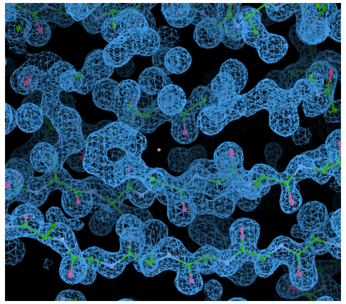


Protein crystal at the beamline, MXCube interface

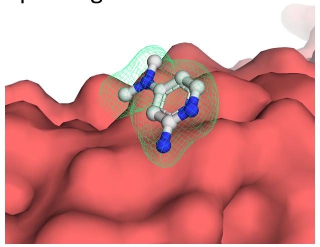




Diffraction pattern recorded with the Pilatus 2M area detector

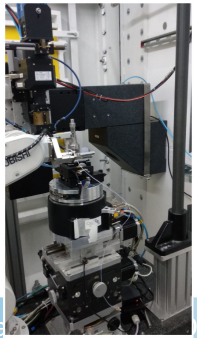


Electron density for a protein using Iodine SAD phasing at Manaca – 10/2020

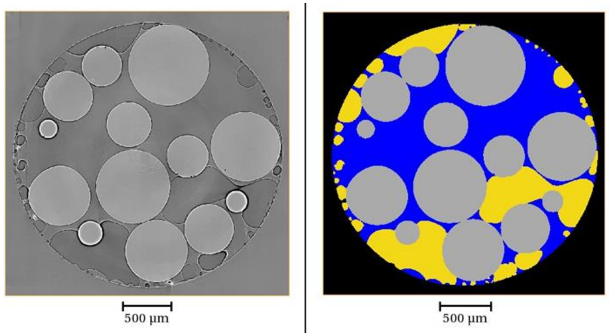


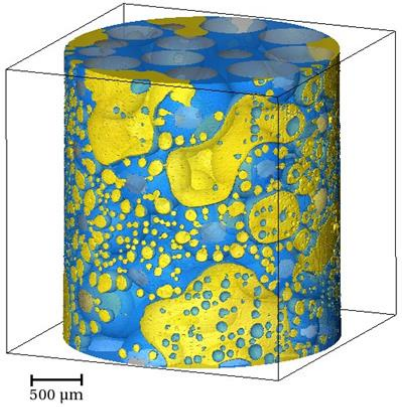
Fragment density (green) co-crystallized with SARS-COV2 Mpro protease (red) source: Andre Godoy PhD. Manaca 09/2020

MOGNO – micro and nanotomography



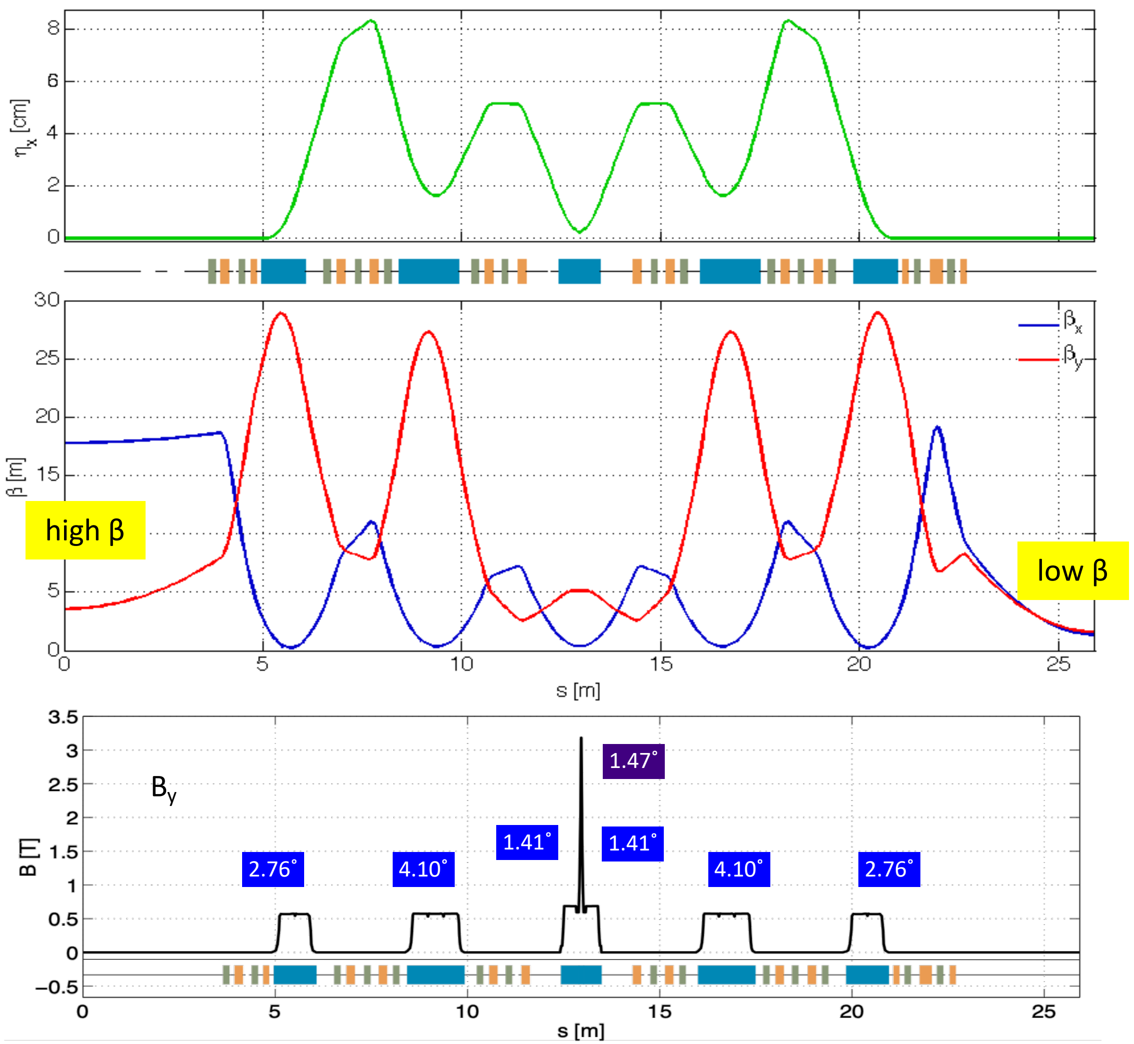
4D tomography





- Imbibition and drainage experiment with 3 mm glass beads sample
- 1 tomo/30 seconds

Sirius optics



- 5-fold symmetric optics:
  - 5 high β_x and 15 low β_x straight sections
- At low β_x sections
  - $\beta_x \approx \beta_y \approx 1.5$ m
  - Better matching of electron and photon beam phase-space for undulators → brightness optimization
  - Small H and V beam stay clear, allows for undulators with small H and V gaps
- At Permanent Magnet superbend
  - 20 beam sources
  - Beam size: $9.6 \times 3.6\ \mu m^2$
  - Photon ε_c: 19.2 keV

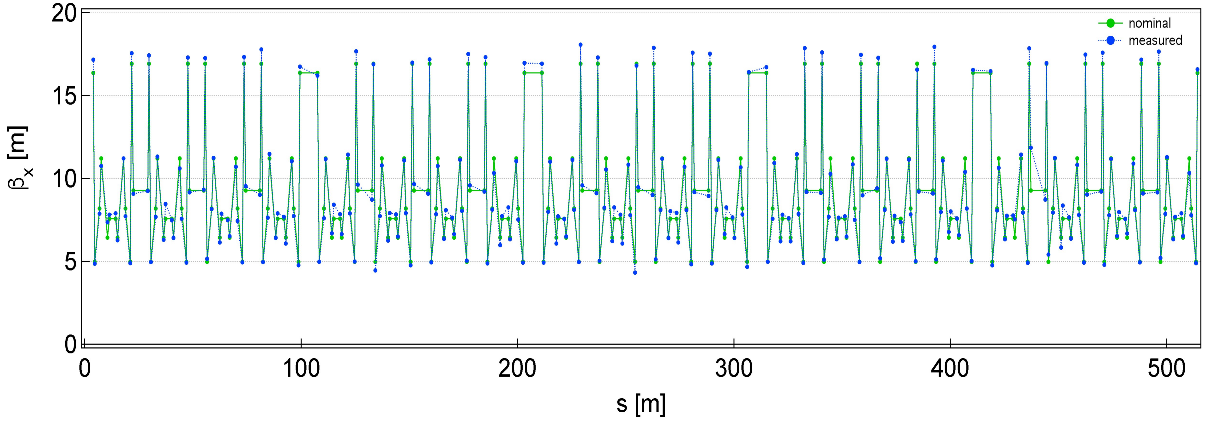
Initial Commissioning

- Injection
  - Off-axis injection in horizontal plane using Non-Linear Kicker (NLK) for beam accumulation @ 2 Hz
  - On-axis injection using Dipole Kicker for beam commissioning
- Large calibration error in low field EM dipole with respect to high field PM superbend. Initial calibration error of 2.3%
- Mismatch in Booster and Storage Ring circumference -> Booster operates off-energy.
- Stored beam from on-axis injection was used to perform initial optics measurements and corrections.
- After correction, accumulation with NLK was successful.
- Overall, the initial commissioning was a smooth process.

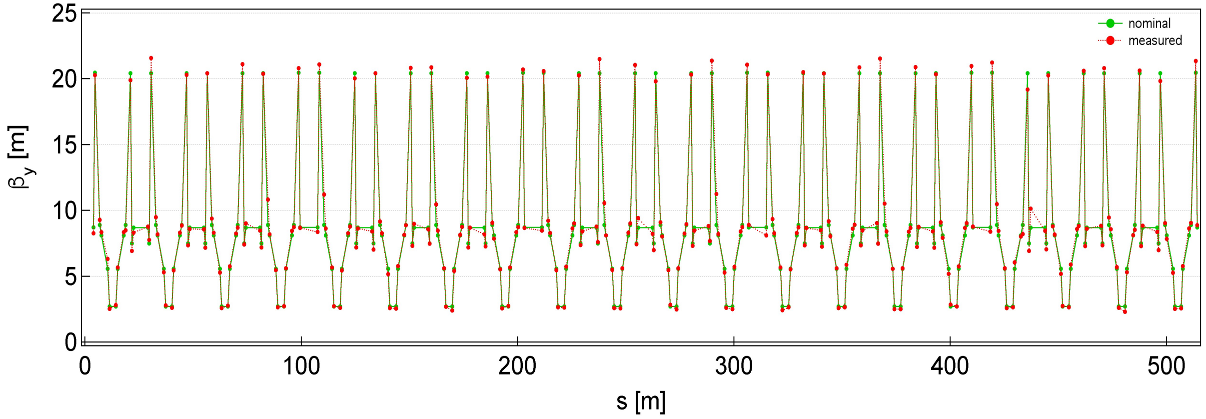
Optics measurement: beta and dispersion functions

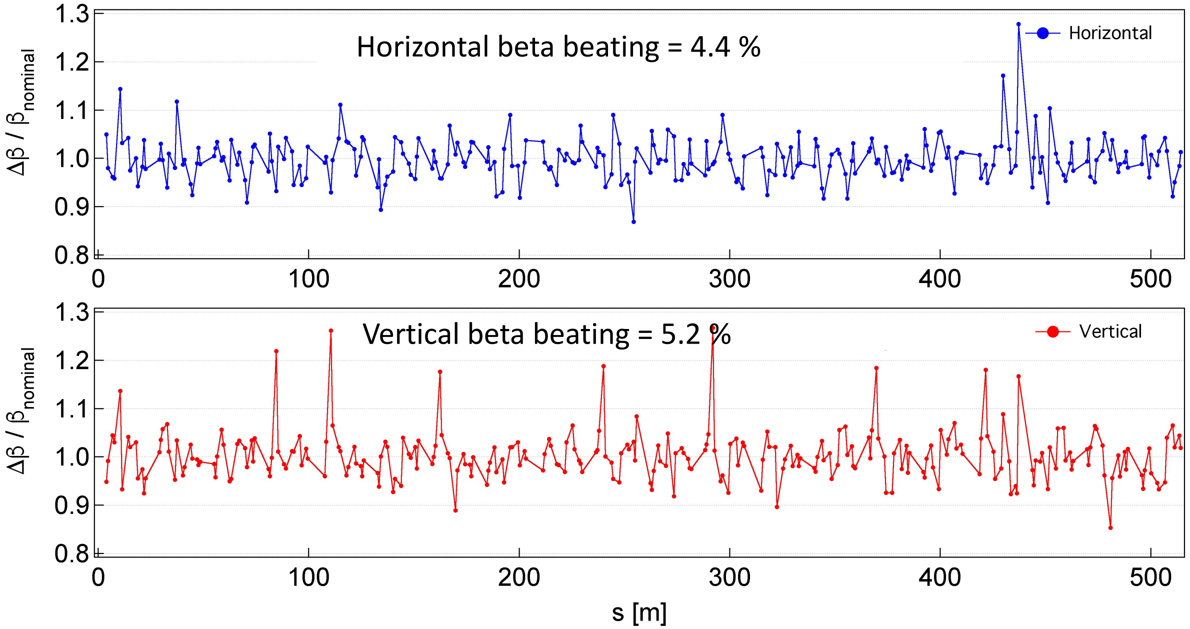
- Beta functions measured after LOCO optimization, by individual quadrupole variation method.

Horizontal beta function

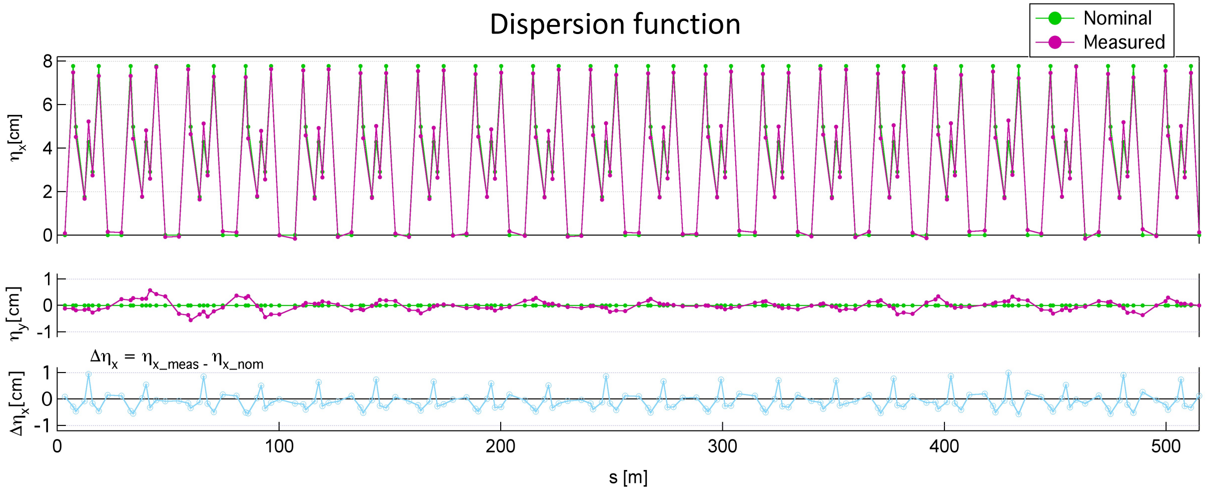


Vertical beta function





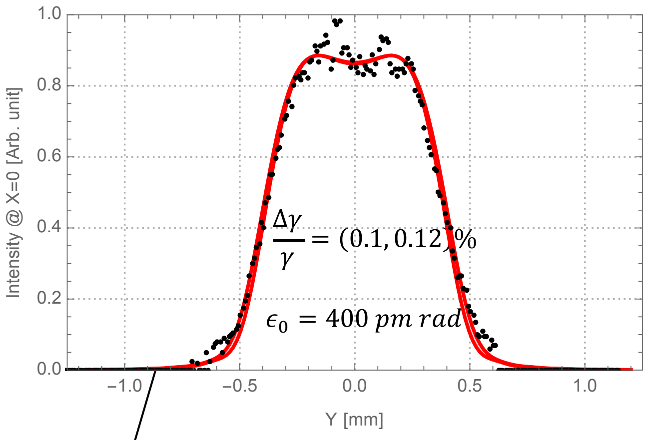
Dispersion function



Preliminary emittance measurement

- Preliminary emittance measurement using the undulator beam from MANACA beamline with no focusing optics.

Par	Exp. Value
$\beta_x \setminus \beta_y$	17.57 m \ 3.99 m
κ	0.18%
K (@7.13 mm)	0.755
E (-8 eV detune)	9.056 keV

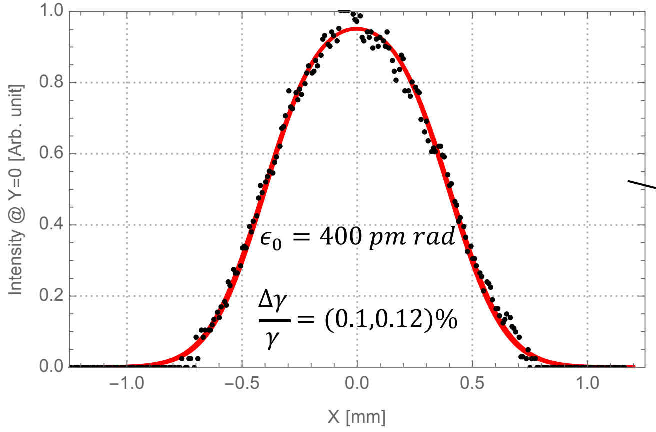


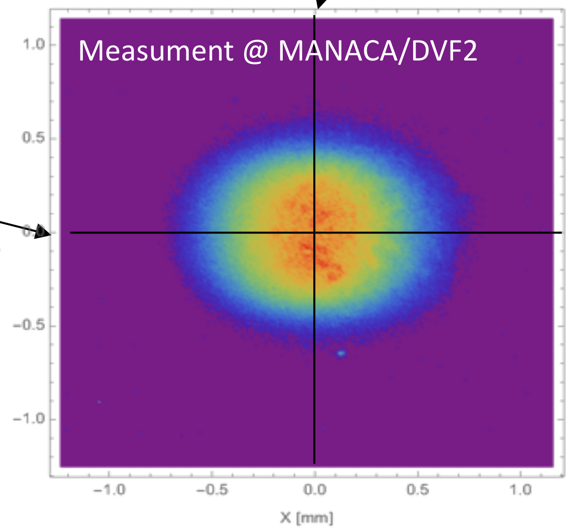
Courtesy Harry Westfhal Jr

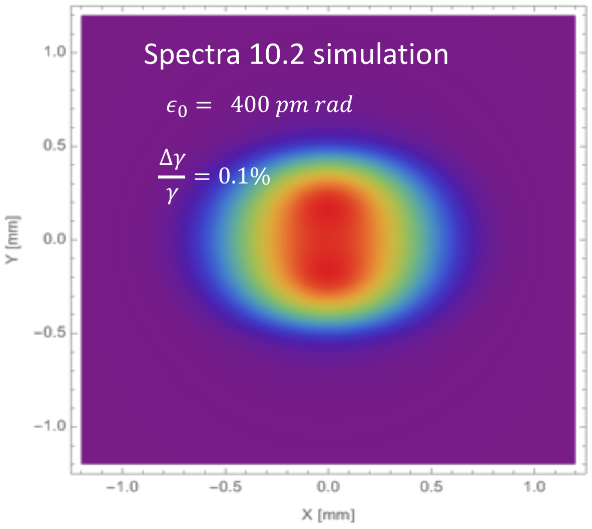
Estimative:

$$\epsilon_0 = 400\ pm\ rad$$

$$\frac{\Delta\gamma}{\gamma} = 0.11\%$$

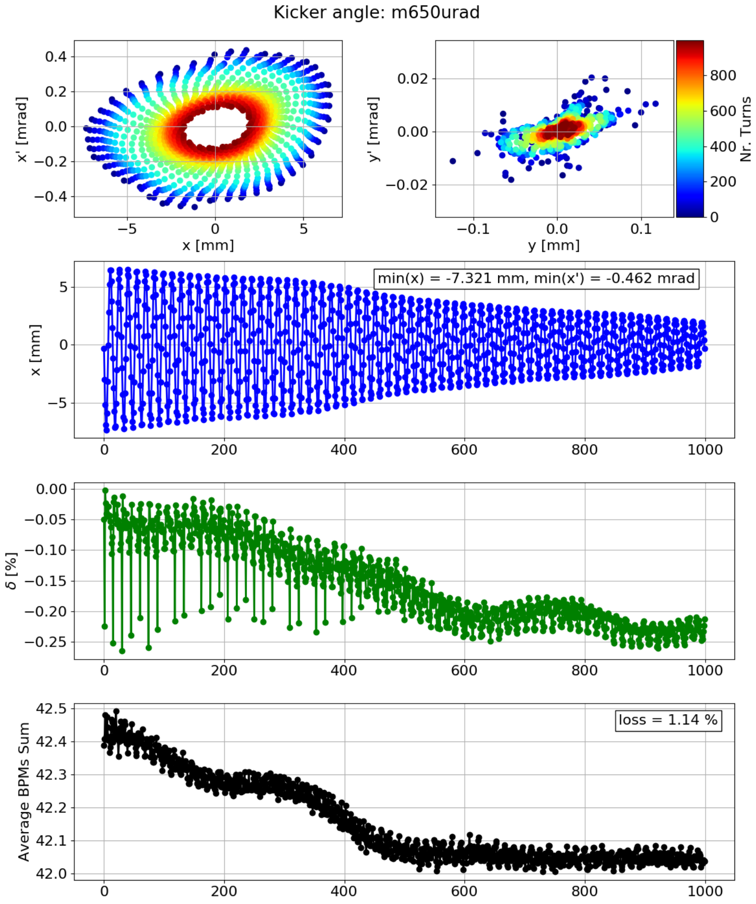


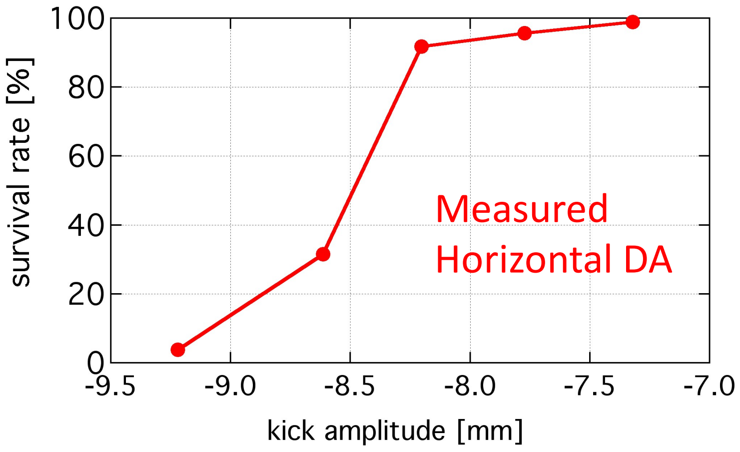


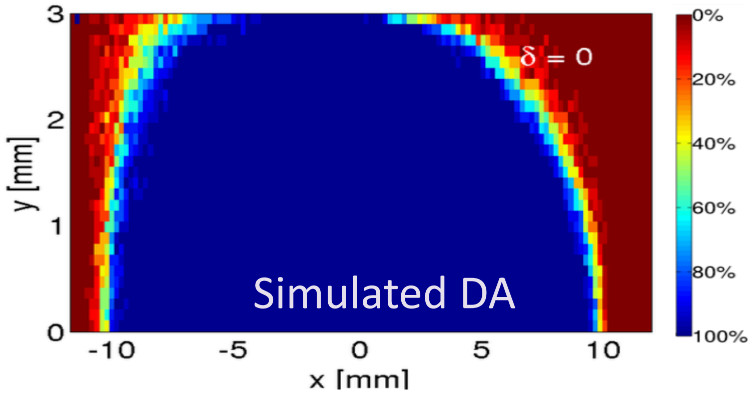


Dynamic aperture measurement

- DA in the horizontal plane was measured by kicking the stored beam and following its trajectory turn by turn.







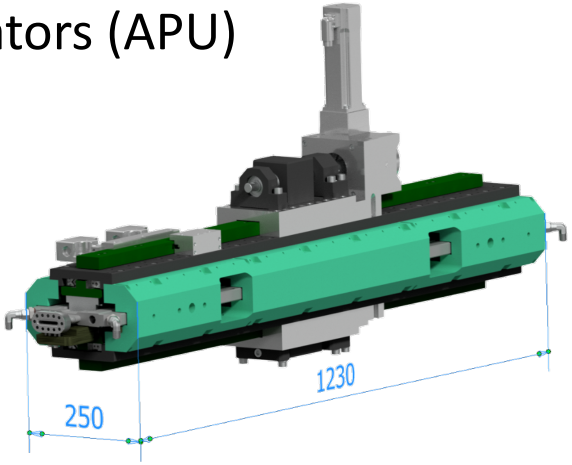
Random truncated Gaussian errors

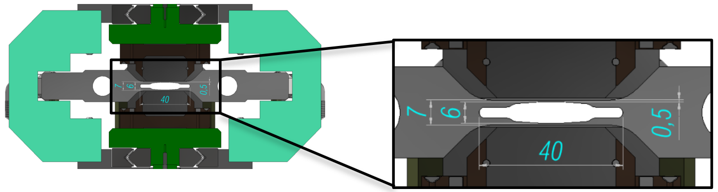
- Alignment, magnets: 40 µm
- Alignment, girders: 80 µm
- Roll: 0.3 mrad
- Excitation: 0.05 %
- Multipole: $\Delta B/B_{x=12\ mm} = 1\text{x}10^{-4}$

Commissioning with undulators

- 4 undulators for commissioning have been installed in the machine, 1 high beta, 3 low beta straights
- Commissioning undulators: fixed gap, adjustable phase planar undulators (APU)

	APU22	
Period	22	mm
Total length	1.2	m
Kmax	1.43	
Full gap	8	mm
Gap for beam	6	mm

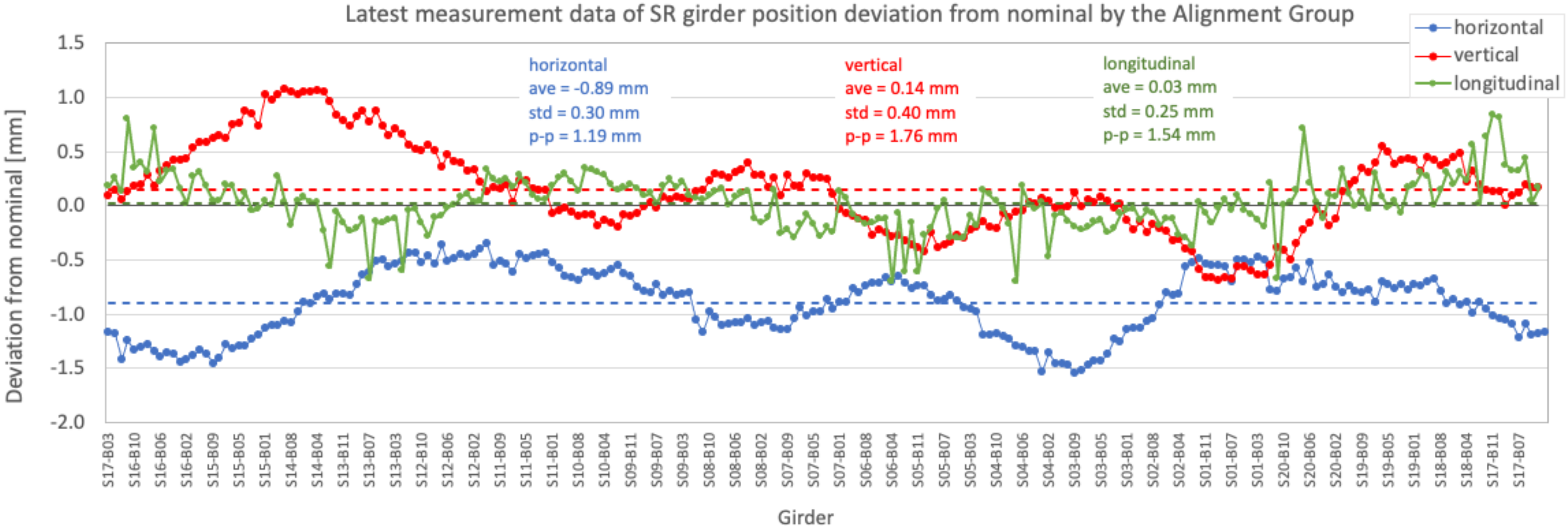




- APU22 undulator commissioning was straightforward. Only APU22 in high beta straight required local quadrupole adjustment. APU22 in low beta straights had no detectable effect on optics.
- For Adjustable Phase Undulators, focusing strength does not depend on phase.
- Final undulators are being developed in-house.

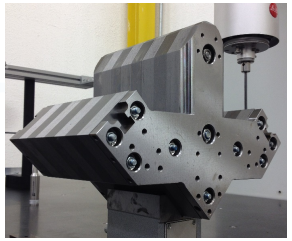
Girder alignment: preliminary measurements

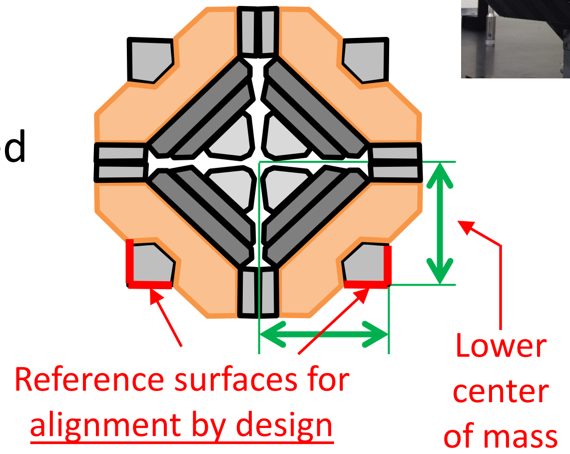
- All magnets have been aligned on the girders in the transverse direction by construction, using precise reference surfaces.
- Since initial alignment (without temperature stabilization), the building has deformed, as expected for a new construction.
- Latest survey shows large transverse and longitudinal girder alignment errors.

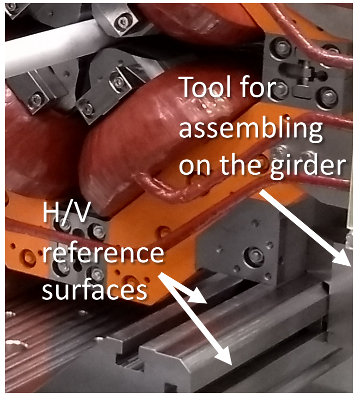


Magnet transverse alignment in the girder

- Magnets assembled and aligned on girders “by design” (no adjustable supports).
- Stacked laminations for each pole. Low mechanical tolerances achieved by the Brazilian company WEG.
- BPMs are also aligned on girders by design.
- There is evidence of good intra-girder transverse magnet alignment.

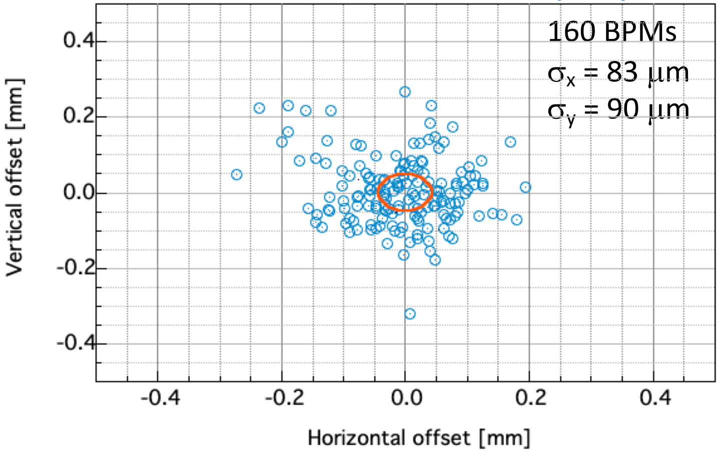




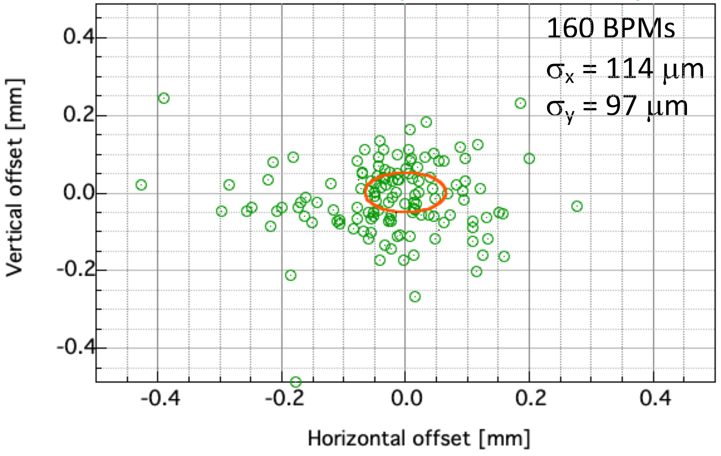


Beam-Based BPM Offset Calibration

Electrical offsets (EO)



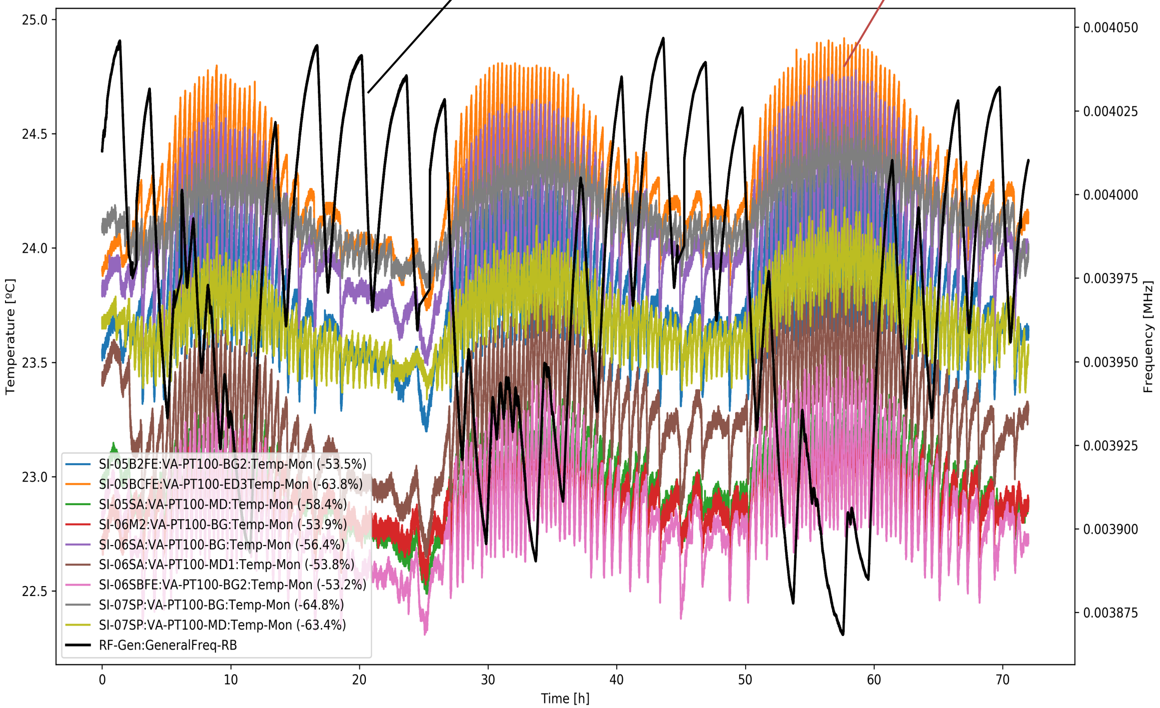
BBA offsets (includes EO)



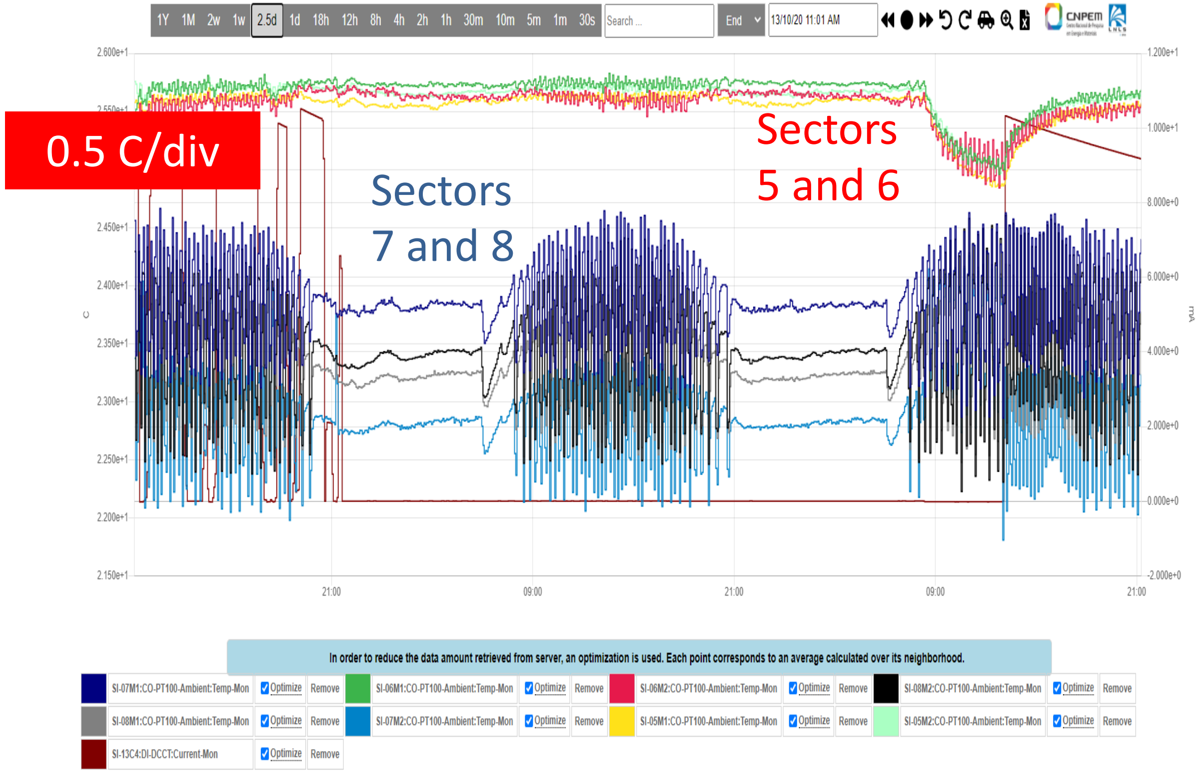
Tunel temperature and RF frequency

- RF frequency and temperature variation.
- Correlation is not perfect but temperatures are local measurements while RF frequency depends on ring circumference variation, a global effect.

RF frequency various temperatures



Tunnel temperature

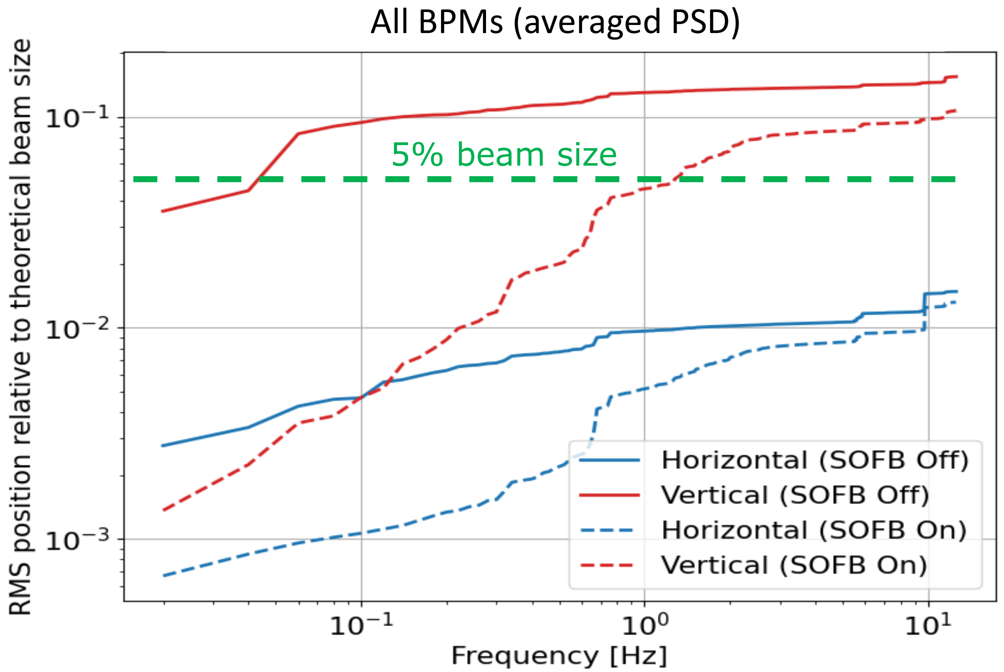


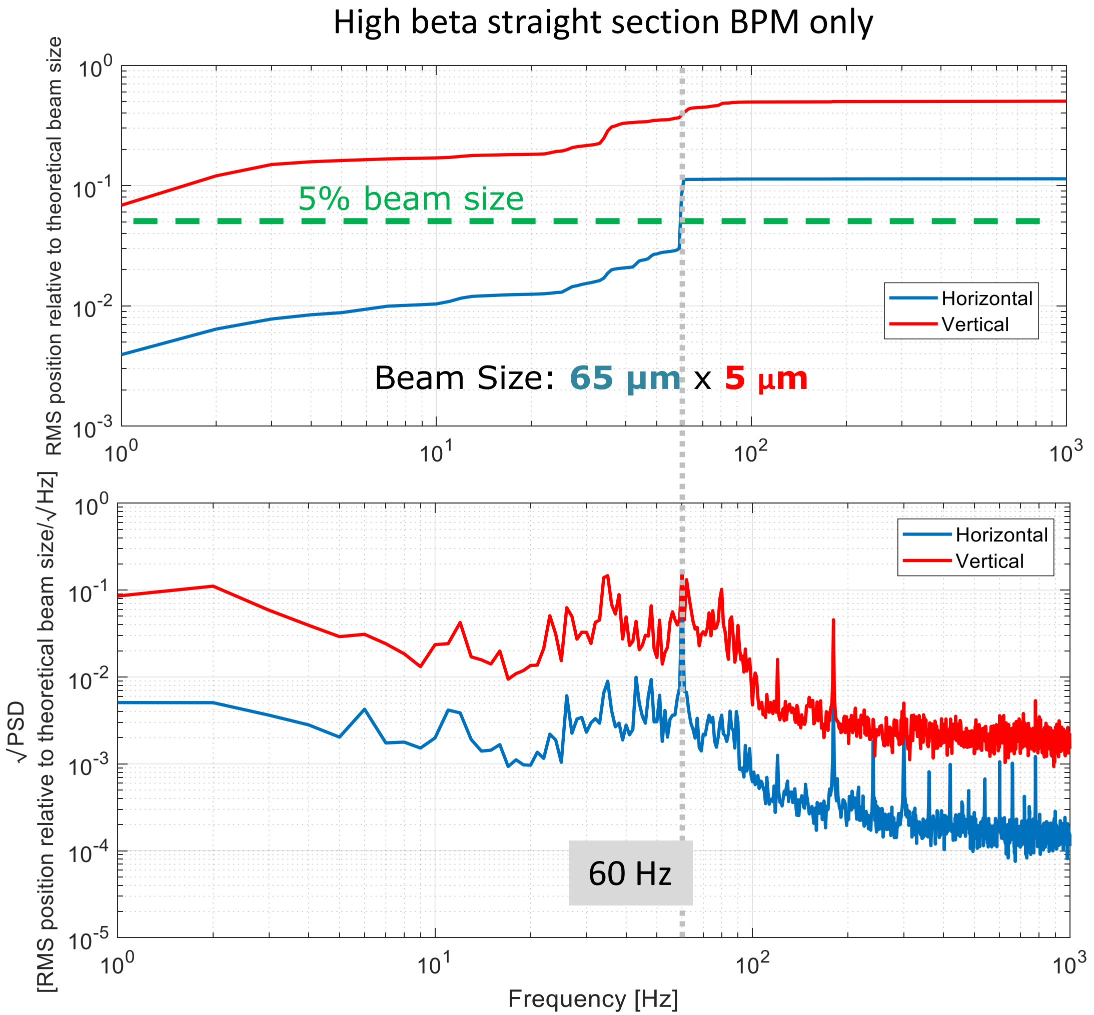
Orbit stability

Courtesy Diagnostics Group

- Slow Orbit Feedback System (SOFB) is operating @ 10 Hz
- FOFB scheduled for July 2021

Effect of SOFB in orbit stabilization @ low frequency

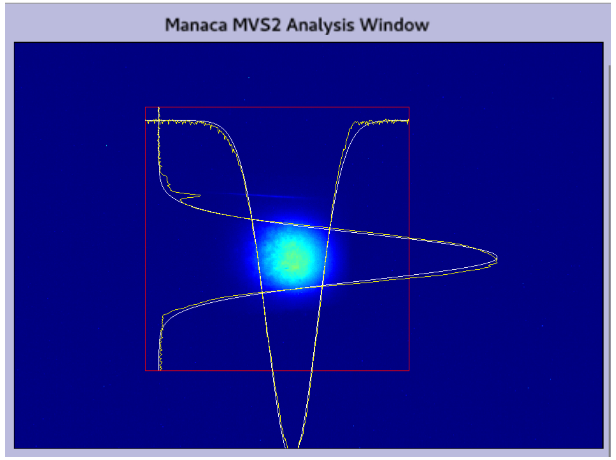




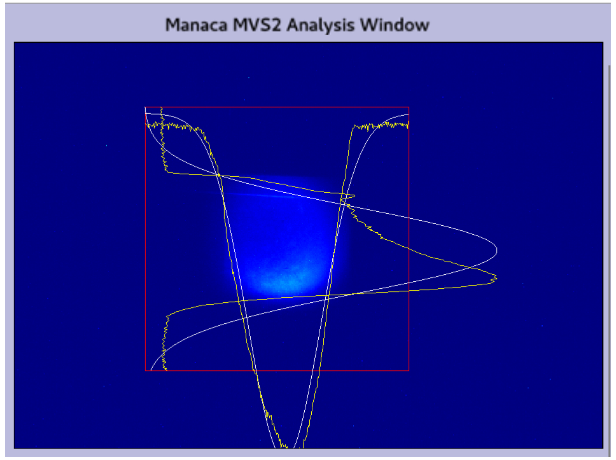
Operation current

- Present operation: 40 mA in decay mode, beam stabilized with bunch-by-bunch feedback (BBB)
- Limited by longitudinal instabilitty driven by NC Petra-7 cell RF cavity Higher Order Modes
  - Instability threshold ~ 22 mA
  - Maximum injected current in test run: **90 mA**
  - **BbB is being optimized/upgraded to be effective up to higher currents**

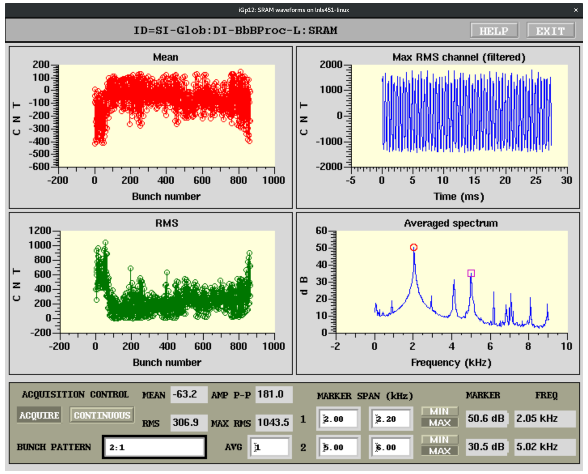
22 mA, stable



25 mA, unstable



Stabilization with BbB, up to 45 mA



RF System

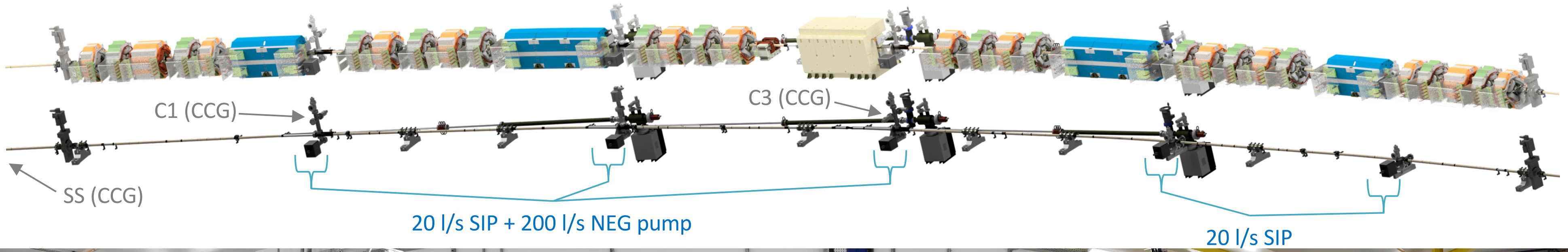
- Solid state amplifiers @ 500 MHz
  - Developed in collaboration with Soleil, fabricated in China
- LLRF developed by ALBA
- Commissioning with a reduced RF system, with a Normal Conducting Petra 7-cell 500 MHz cavity
- The final system consists of 2 Super Conducting cavities expected to be installed by the end of 2021.

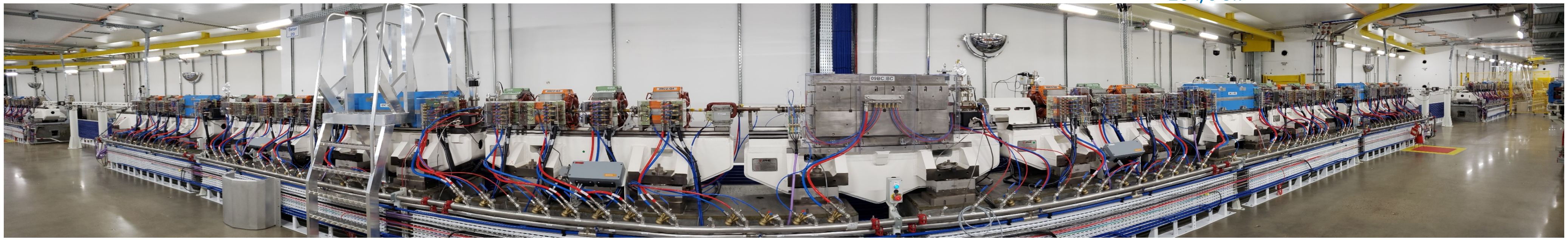
	Phase 1	Phase 2	Phase 3
RF Cavity	1 x NC (Petra-7)	2 x SC CESR	2 x SC CESR
SS Amplifiers	2 x 60 kW	4 x 60 kW	8 x 60 kW
Gap voltage	1.8 MV	3 MV	3 MV
Current	50 mA	300 mA	350 mA
Installation	2019	End 2021	2023

2 x 60 kW SSA combination

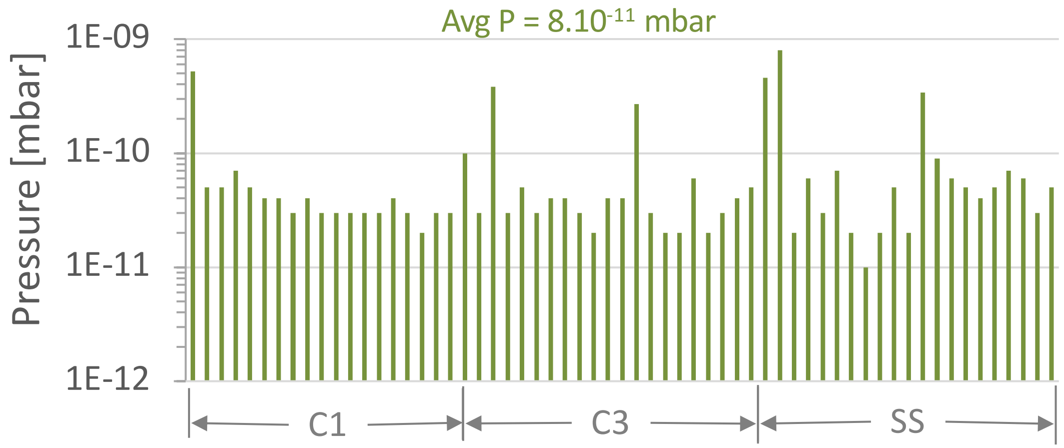
The SR 7-cell cavity in the tunel

Vacuum System (fully in-house NEG-coated chambers)

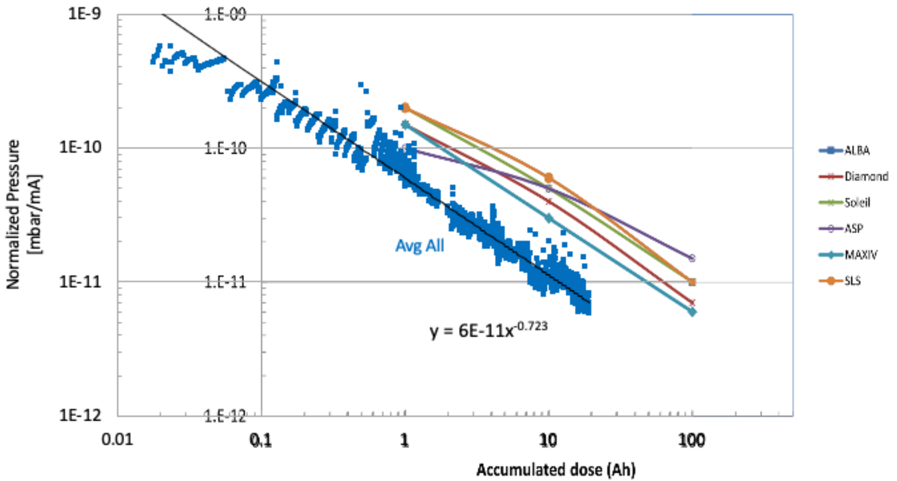




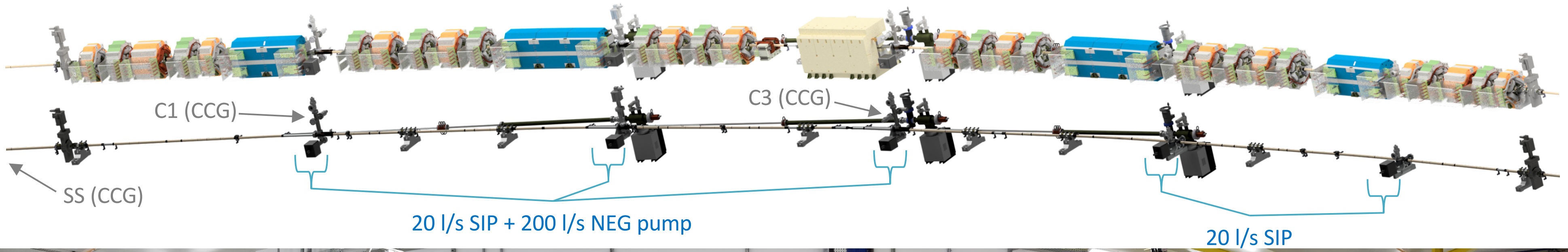
Storage Ring Static Pressures

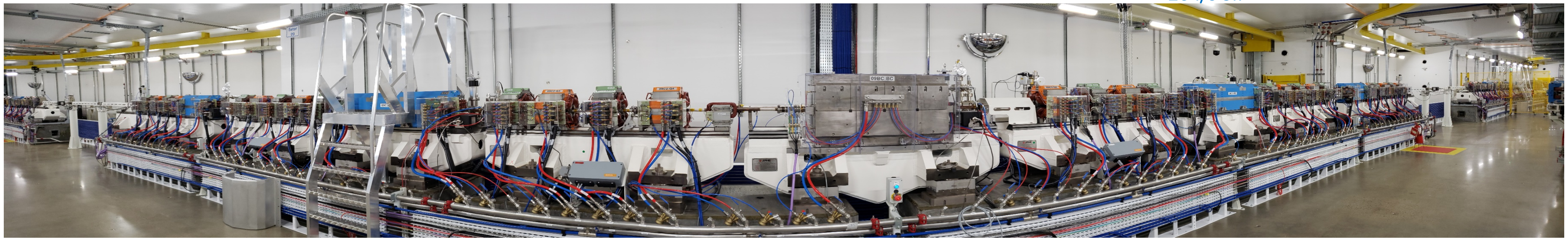


Storage Ring Dynamic Pressure

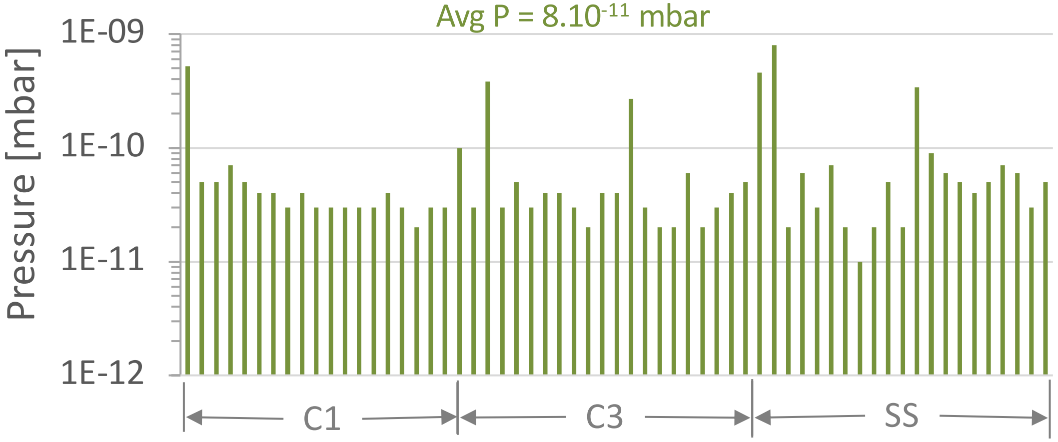


Vacuum System (fully in-house NEG-coated chambers)



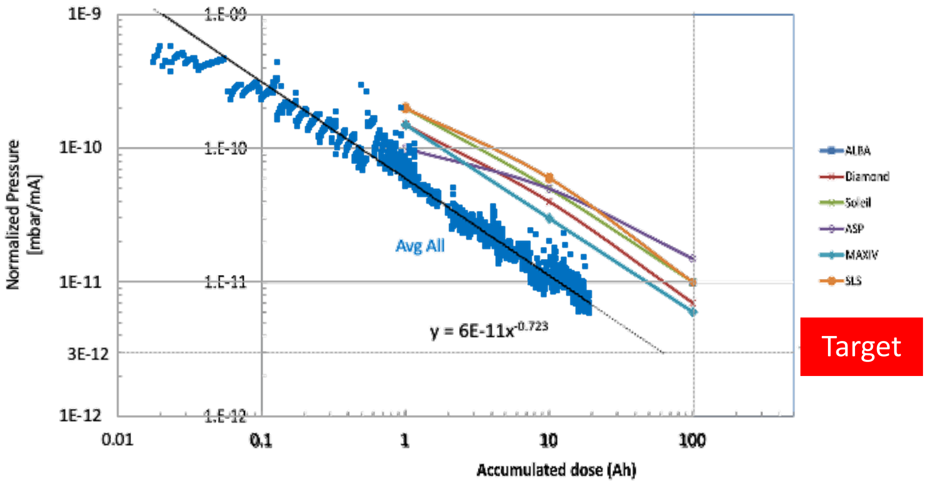


Storage Ring Static Pressures



Target will be reached before expected

Storage Ring Dynamic Pressure



Summary and Outlook

- Sirius commissioning has started by the end of 2019 and is progressing slowly, partly due to the pandemic, but steadily.
- There is still a lot of work ahead to reach design parameters.
- Nevertheless, 5 beamlines are already in different commissioning phases and the integration of practically all subsystems, from the storage ring operation to data processing in the beamlines, are being tested.
- We see no show stoppers up to now.
- We defined a prioritized list of subsystem developments aiming at reaching the phase 1 design parameters by the end of 2021.

Thank you!

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