# Sirius Accelerators Overview

- Sirius project overview
- Optics design highlights
- Engineering highlights

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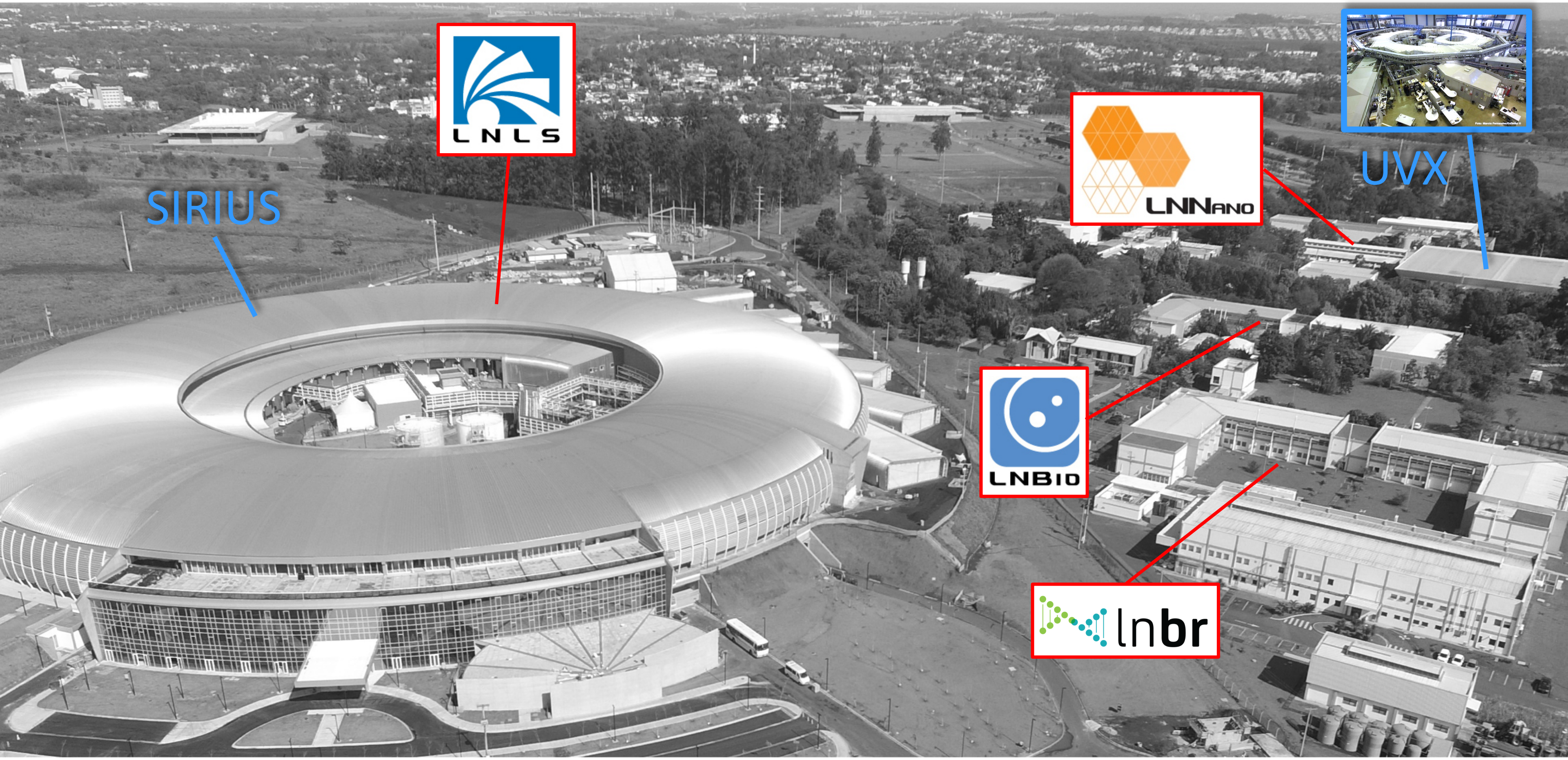
on behalf of the Sirius Team
LNLS Accelerator Division

Sirius is a 4th Generation, 3 GeV synchrotron light source presently under commissioning (accelerator and beamlines) at CNPEM/LNLS, in Campinas, Brazil. It is the second synchrotron light source designed and built at LNLS.



# Brief History of LNLS

1982: Initial discussions on a synchrotron radiation lab in Brazil

1986: LNLS was created

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

1997 – 2019: UVX operated for users for 22 years
user community consolidated

2008: Discussions for a new synchrotron light source start

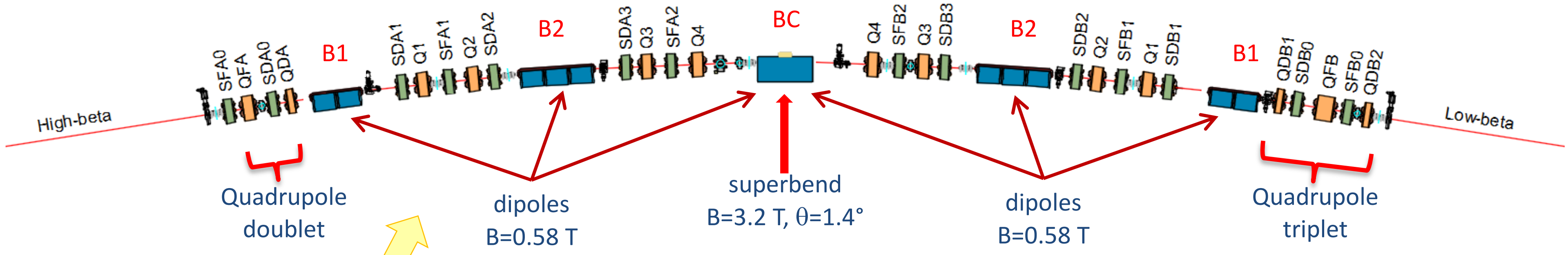
2009 – 2011: Design of a 3rd generation source
Improving the in-house engineering technical infrastructure and measurement labs.

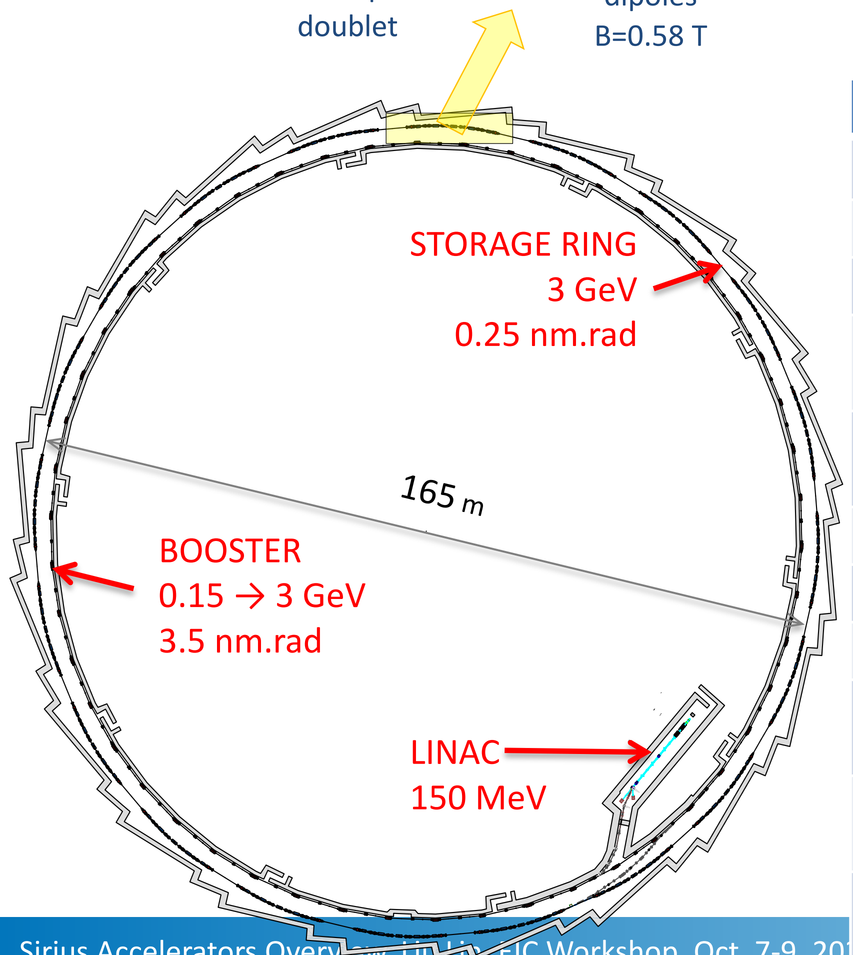
2012: Design of a 4th generation source starts

# Sirius Timeline

| | | |
|---|---|---|
| 2012 | | - start of MBA lattice design after first MAC meeting |
| 2015 | | - start of building construction |
| 2016 | | - start of components production by Brazilian industry |
| 2018 | April<br>May<br>June | - 150 MeV Linac from SINAP commissioned<br>* start of booster installation<br>* start of storage ring installation |
| 2019 | Mar 08<br>Nov 22<br>Dec 14<br>Dec 16<br>Dec 16 | - first turn in the booster @ 150 MeV<br>* first turn in storage ring with on-axis injection<br>* first stored beam with on-axis injection, 30 uA<br>* first light from superbend BC at Mogno beamline<br>- first X-ray microtomography experimental result from Mogno |
| 2020 | Feb 20<br>Mar 23<br>Apr 23<br>May 25<br>October | * first beam accumulation with NLK, 10 mA<br>- Activities in campus interrupted due to covid-19 pandemic<br>- controlled restart of beam tests in accelerators with few in-person staff<br>- installation of first ID for MANACA beamline (planar adjustable phase)<br>- 2 beamlines operating with internal/friendly users (1 undulator + 1 superbend)<br>- 2 undulator beamlines in final and 1 in initial installation phase. 1 planned for Nov.<br>- 40 mA in decay mode for beamlines. Accelerators commissioning is underway. |

# Sirius Main Parameters



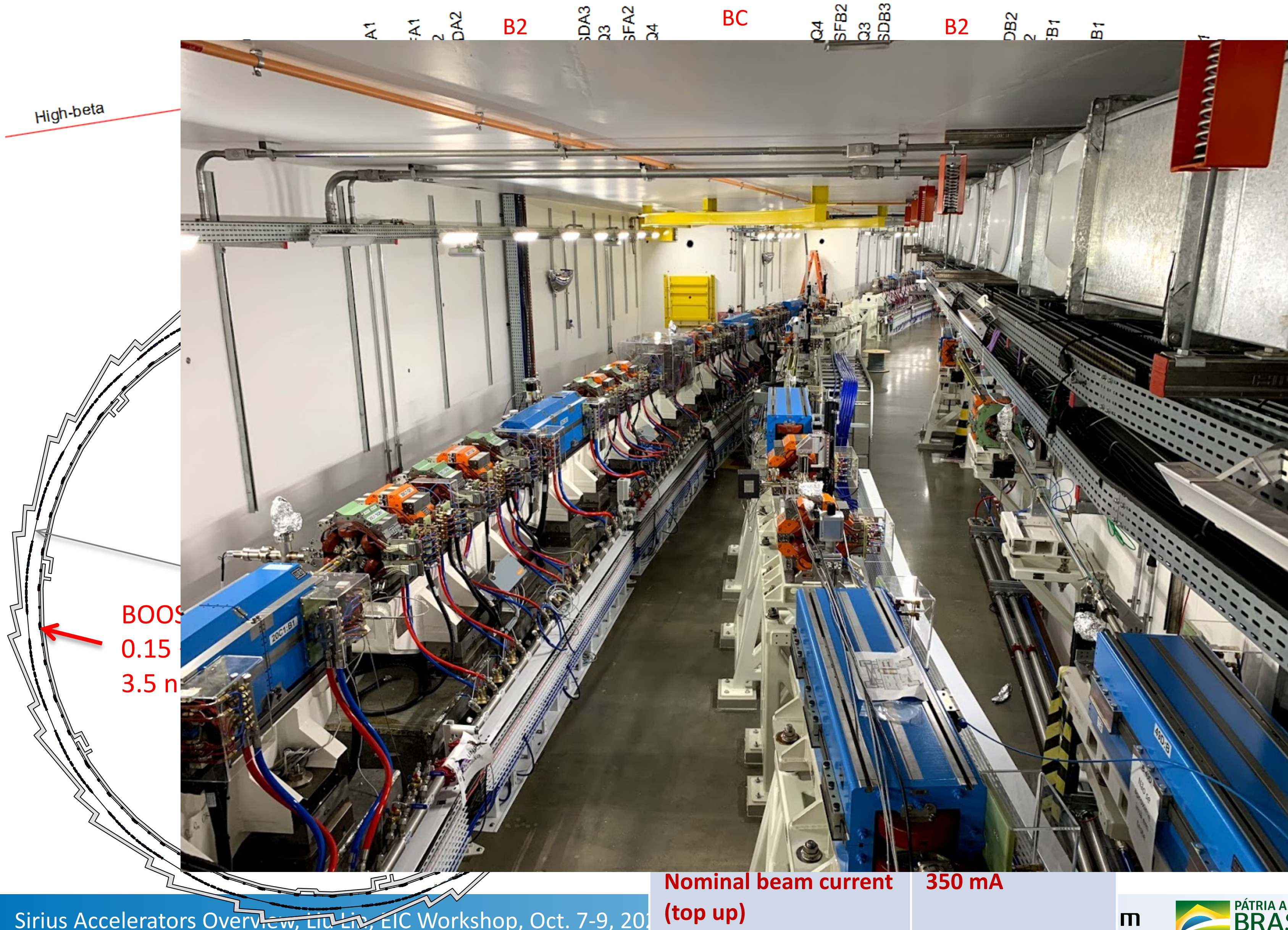




| Storage Ring | |
|---|---|
| **$e^-$-Beam energy** | **3.0 GeV** |
| **Circumference** | **518.4 m** |
| Lattice | 20 x 5BA |
| **Hor. emittance (bare lattice)** | **0.25 nm.rad** |
| **Hor. emittance (with undulators)** | **0.15 nm.rad** |
| Betatron tunes (H/V) | 49.11 / 14.17 |
| Natural chrom.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

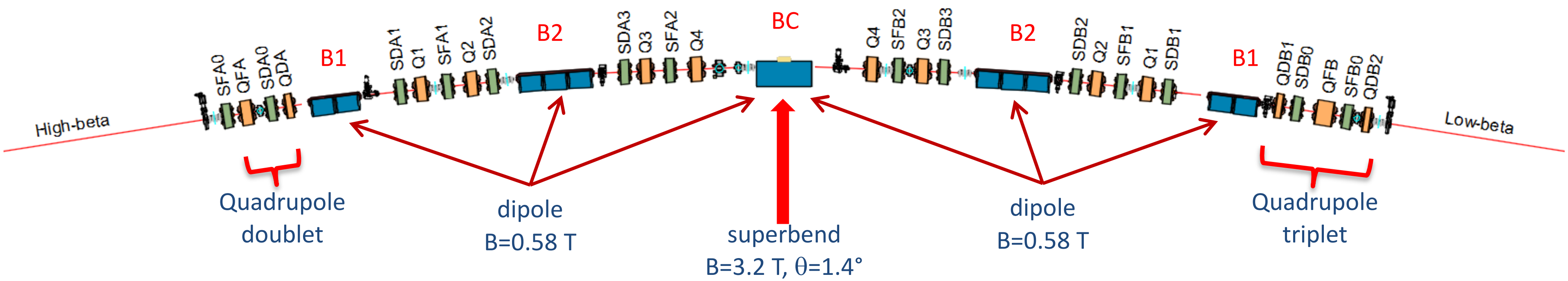
| Element | # in SR |
|---|---|
| Dipoles | 100 |
| Quadrupoles | 270 |
| Sextupoles | 280 |
| Hor. Correctors | 120 |
| Ver. Correctors | 160 |
| Skew Correctors | 100 |
| Fast correctors | 80 + 80 |
| BPMs | 160 |

# Sirius Main Parameters



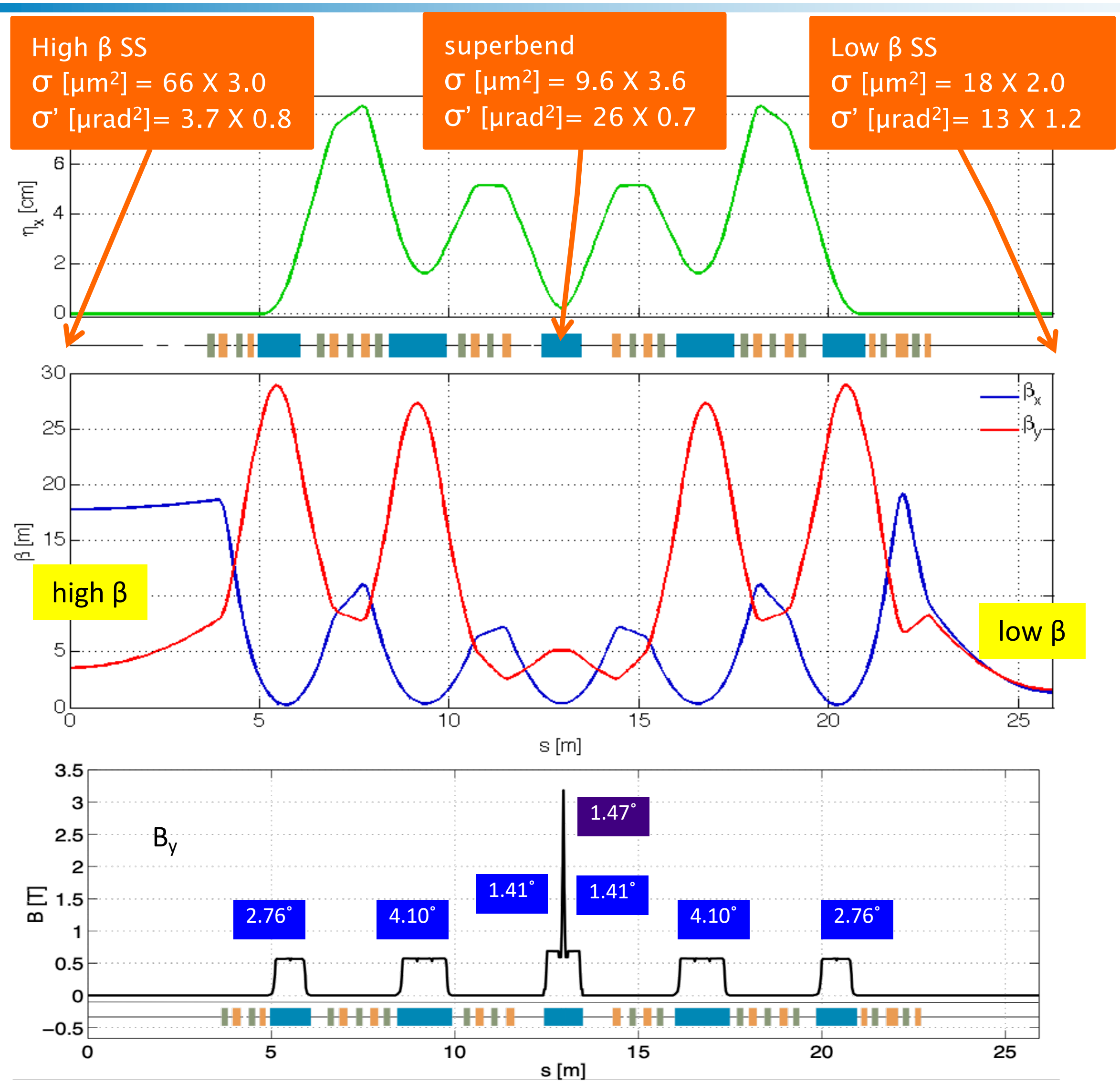

| | |
|---|---|
| | 496.8 m |
| | 3.5 nm.rad |
| | 50 Bend |
| | 2 Hz |
| Nominal beam current (top up) | 350 mA |

# The Sirius 5BA magnet lattice and emittance optimization




- 20 - 5BA arcs and 2 types of straight sections for insertion devices:
  - 5 **high $\beta_x$** straight sections of **7.0 m** – matching with quad **doublets**.
  - 15 **low $\beta_x$** straight sections of **6.0 m** – matching with quad **triplets**.
- 20 PM longitudinal gradient superbends
  - sharp peak field of $B_p$= 3.2 T in the center → critical photon energy of $e_c$ = 19.2 keV
- Low field (0.58 T) EM and PM dipoles with transverse field gradient (7.8 T/m) to increase $J_x$
- 13 quadrupoles/cell, 14 sextupoles/cell, no octupoles
- Different lengths for B1 and B2 (but same unit block)
- Achromatic cells ⇨ IDs help to reduce the emittance

# Sirius optics

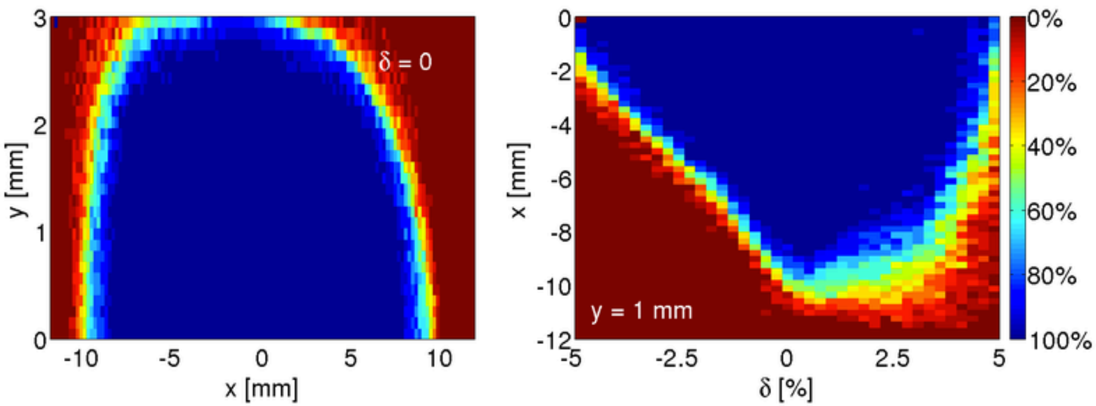



- 5-fold symmetric optics:
  - 5 high $\beta_x$ and 15 low $\beta_x$ straight sections
- At low $\beta_x$ sections
  - $\beta_x \approx \beta_y \approx 1.5$ m
  - Better matching of electron and photon beam phase-space for undulators → brightness optimization
  - Small H and V beam stay clear, allows for undulators with small H and V gaps
- At superbend
  - 20 beam sources
  - Beam size: 9.6 x 3.6 μm²
  - Photon $\varepsilon_c$: 19.2 keV

# Non-linear dynamics performance

– 6D tracking with alignment and multipole errors, physical limitations (including small gap IDs), orbit, tune and coupling corrections.

**Model Optimized Dynamic Aperture**



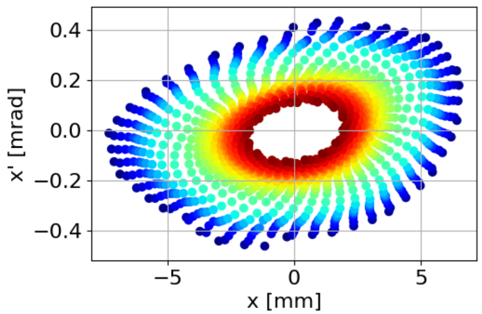

Random Gaussian errors

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

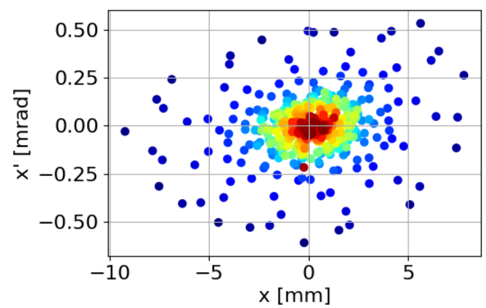
Physical limitations

- straight sections: Ø = 24 mm
- dipoles: Ø = 24 mm
- IDs: full gap = 4.5 mm, L=2m

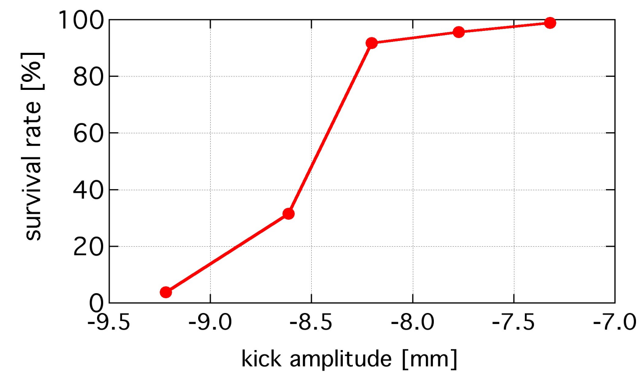
**Measured Horizontal Dynamic Aperture:** using H pinger and turn-by-turn data




$\theta$ = 0.65 mrad; survival rate = 99 %

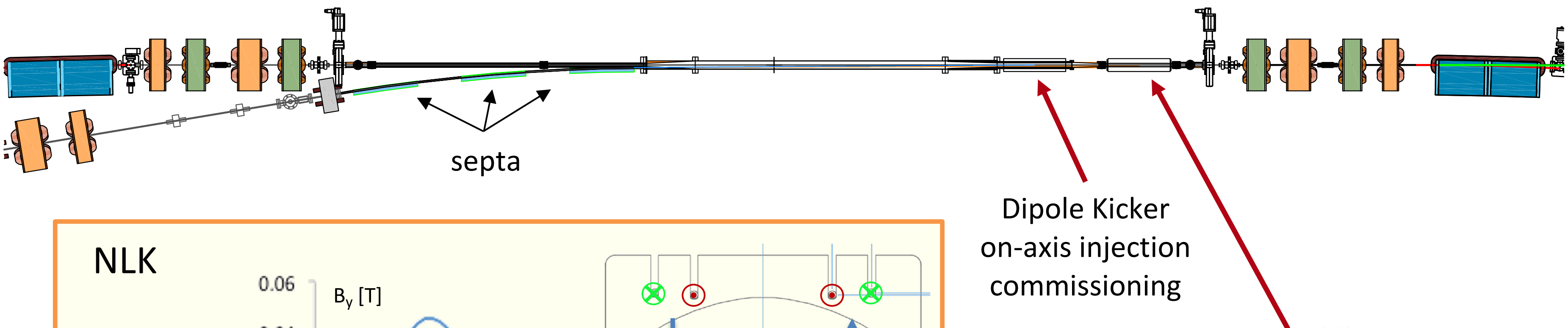



$\theta$ = 0.85 mrad; survival rate = 4 %

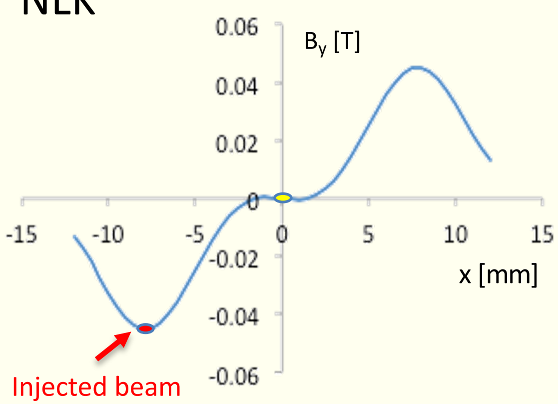


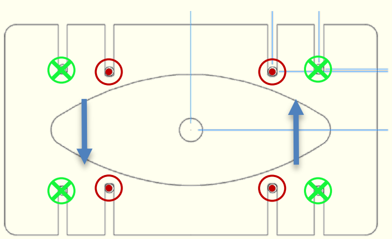
# Injection

- 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
  - Dipole kicker is being used as horizontal pinger for machine studies




NLK



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

# Sirius Design and Fabrication of Components

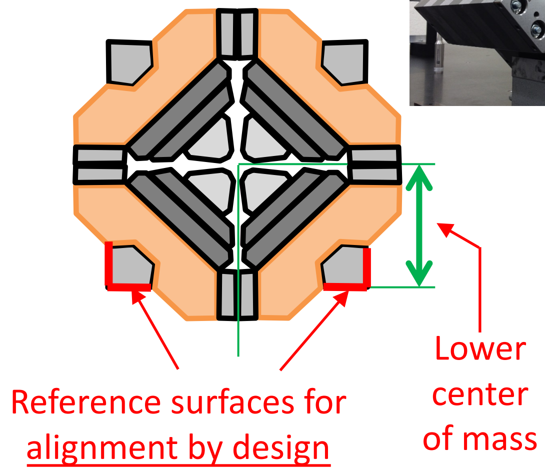
150 MeV LINAC: acquired turn-key from SINAP.

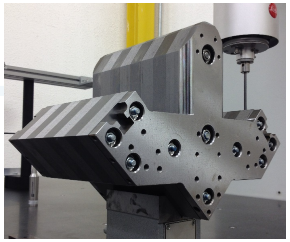
Booster, Transport-lines and Storage Ring: complete in-house design and parts fabricated by local companies:

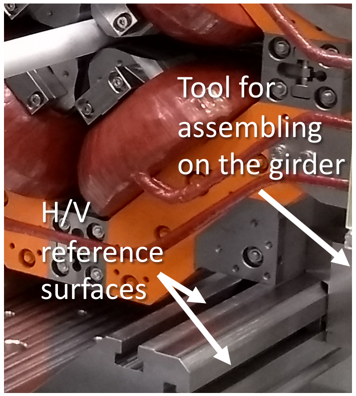
- $e^-$-Beam optics design (storage ring, booster and transport lines)
- Magnets and its power supplies
- Supports for critical components
- Vacuum system (mostly fabricated in-house)
- Control and timing systems
- $e^-$-Beam -position monitors and its electronics (0.1µm resolution)
- RF transmitters (440kW / 500MHz)
- Pulsed magnets and their power supplies
- Interlock system
- Radiation shielding design

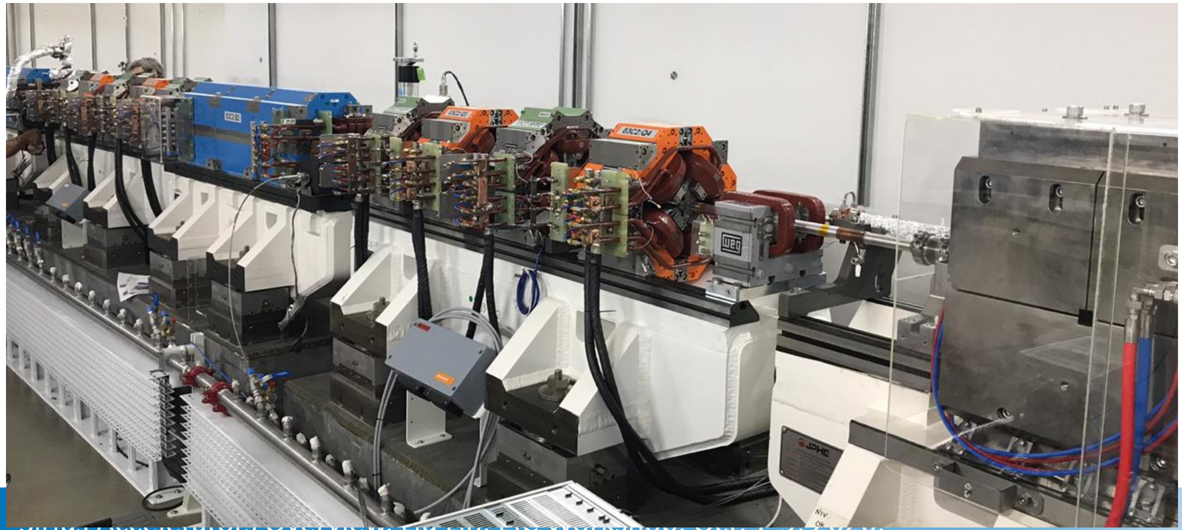
# Storage Ring Magnets

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

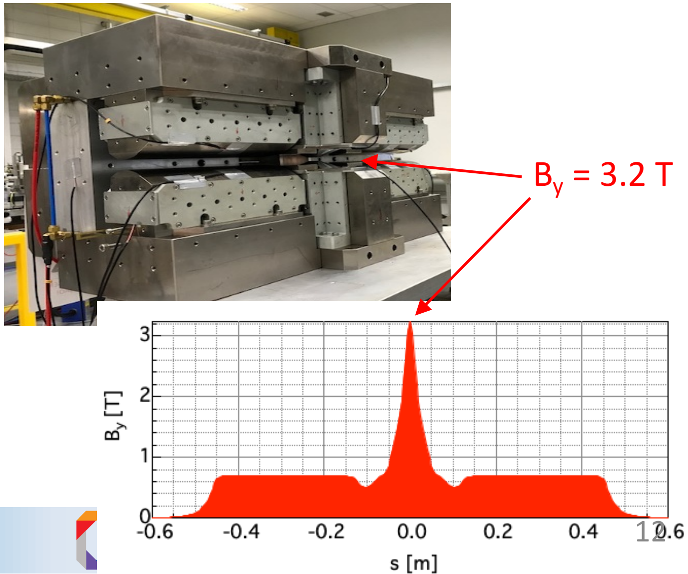




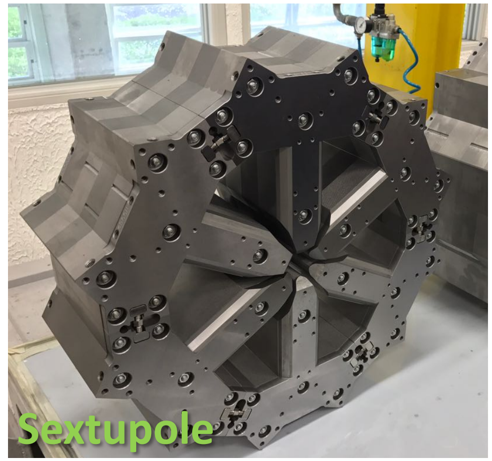



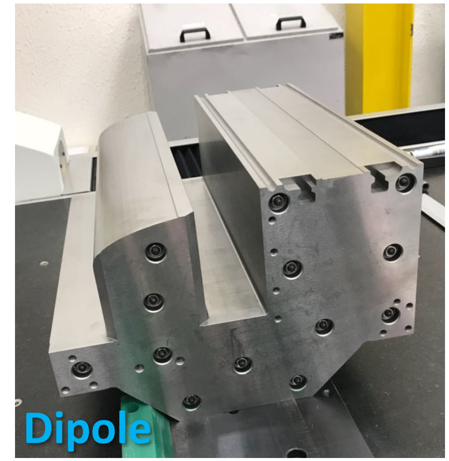
PM superbend



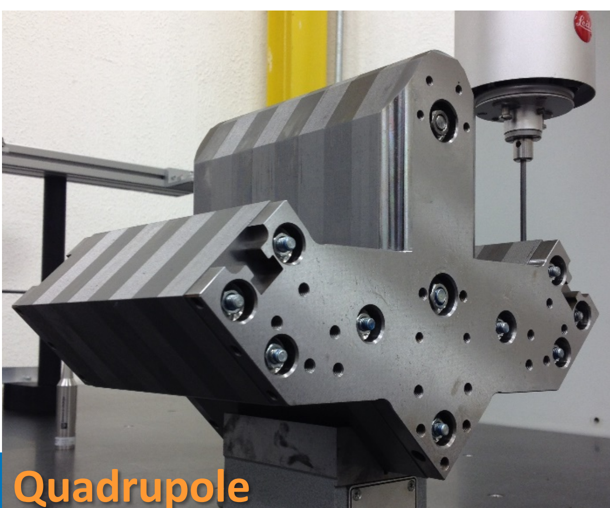
# Storage ring magnets Fabrication

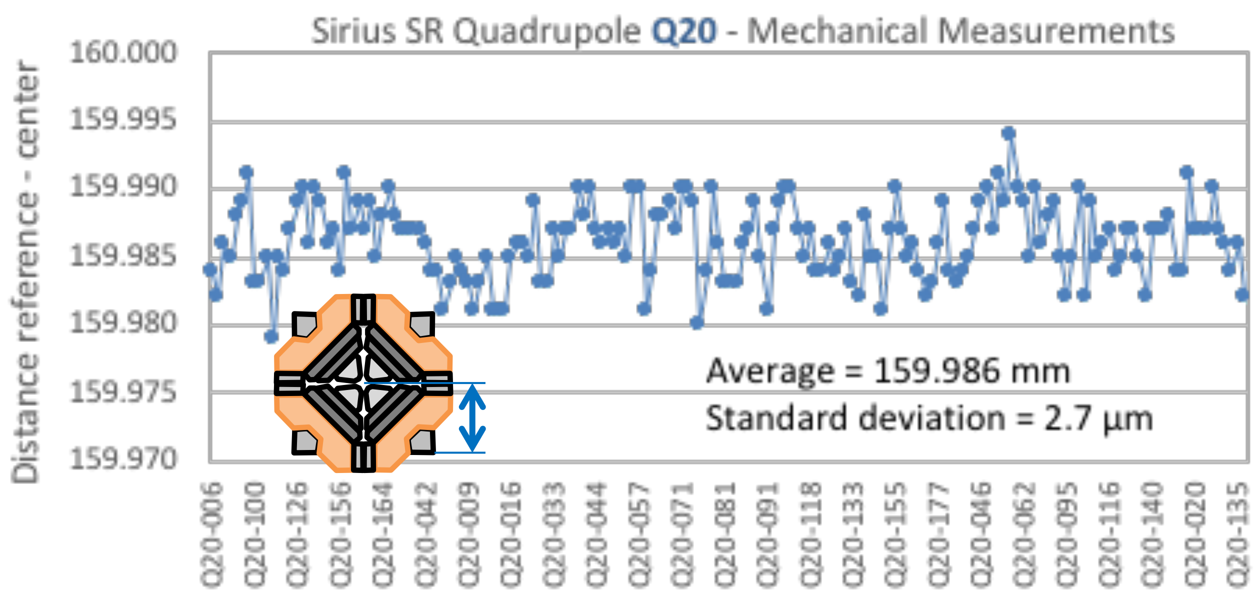
- Use of Si-Fe steel for all magnets (lower remanence)
- Stacked laminations for each pole
- Assemble poles in specially designed equipment




Desired low mechanical tolerances achieved by WEG Motores S.A.



# Magnet alignment and support system

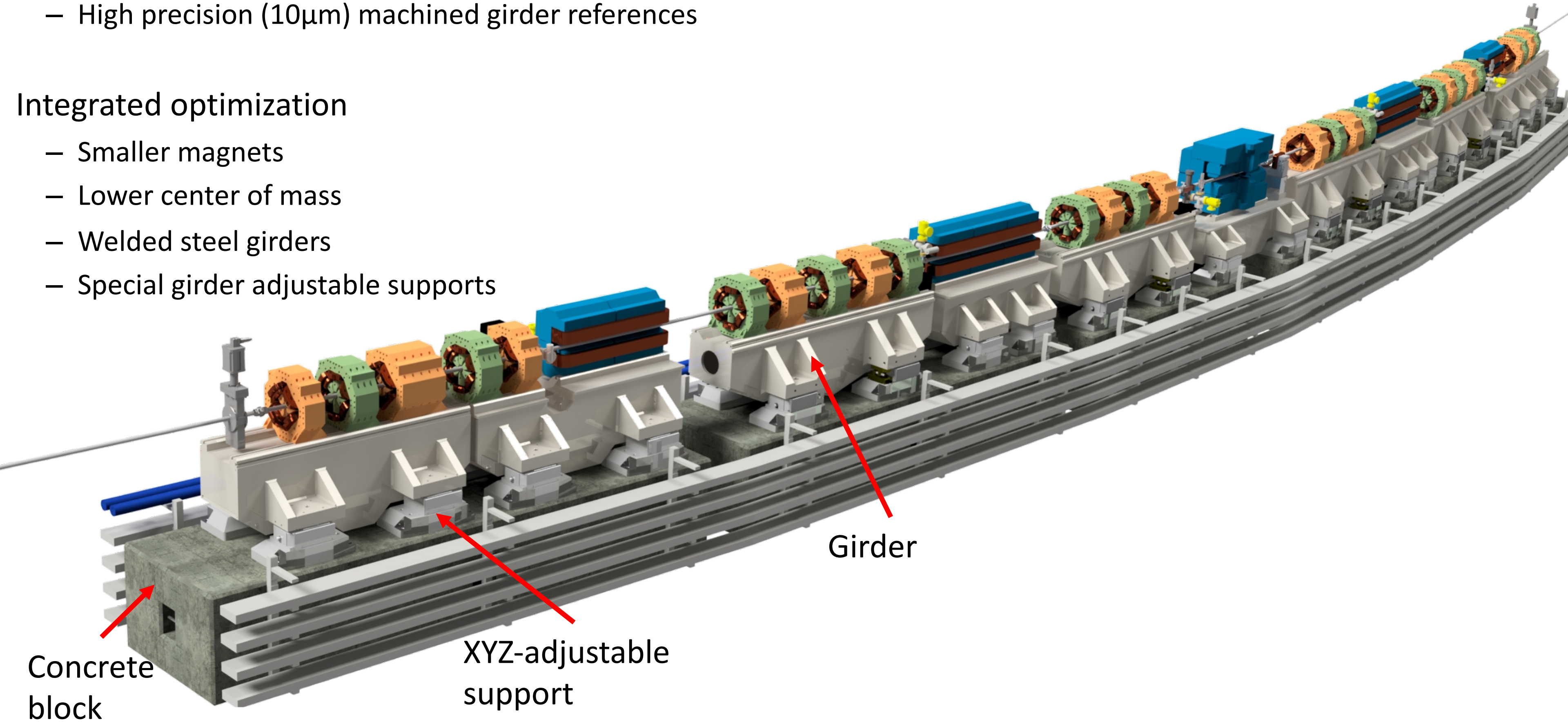
Target: high rigidity from magnets to floor (increases resonant frequencies)

The magnets are positioned on the girder by reference surfaces

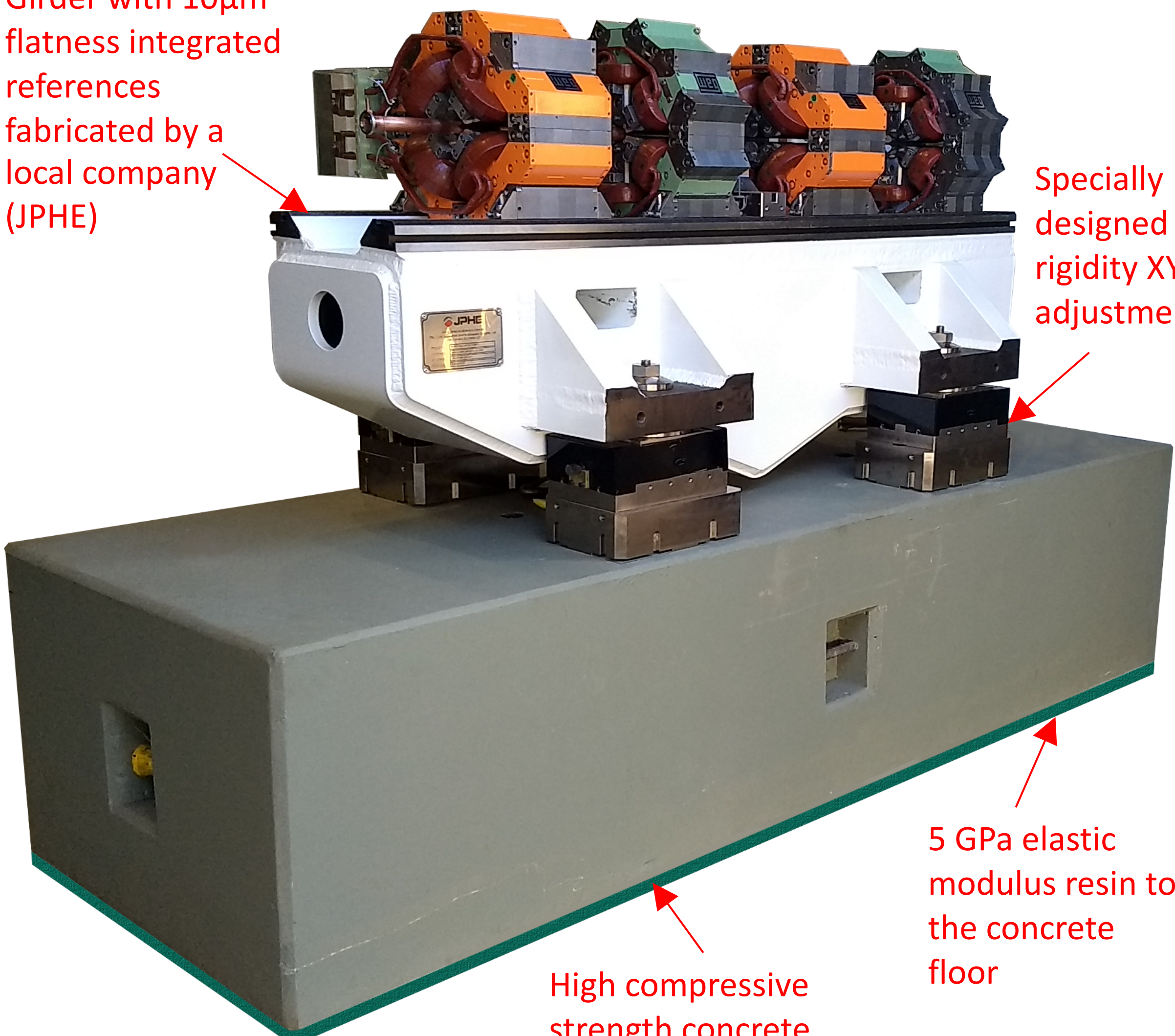
- High precision (10µm) external magnet references
- High precision (10µm) machined girder references

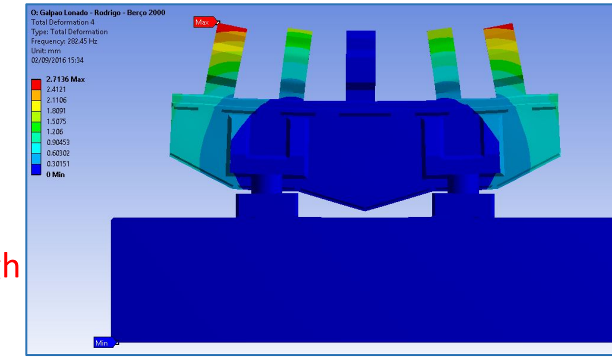
Integrated optimization

- Smaller magnets
- Lower center of mass
- Welded steel girders
- Special girder adjustable supports

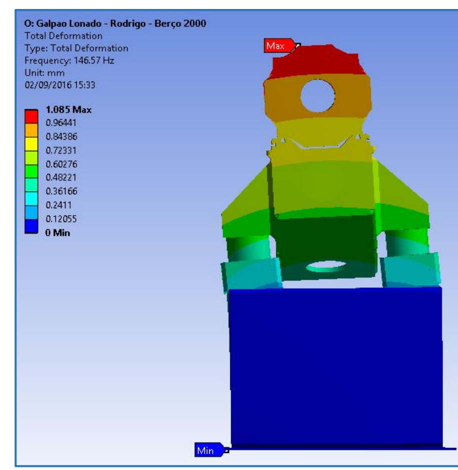


# Girder optimization



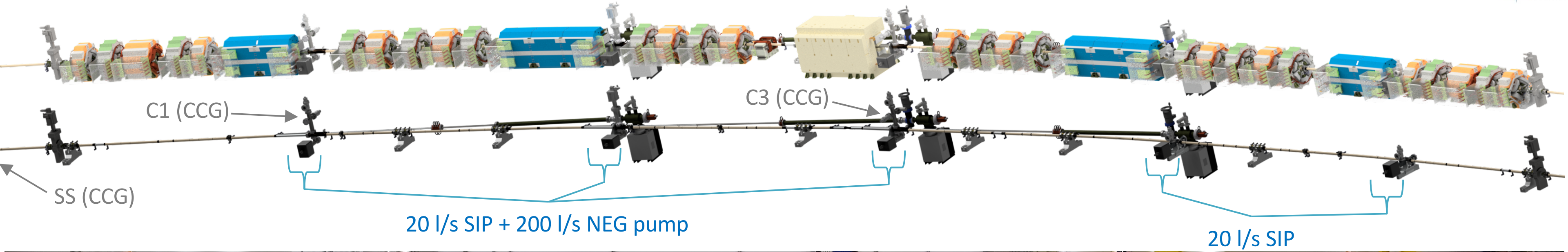

1st Vert. mode: 268 Hz*

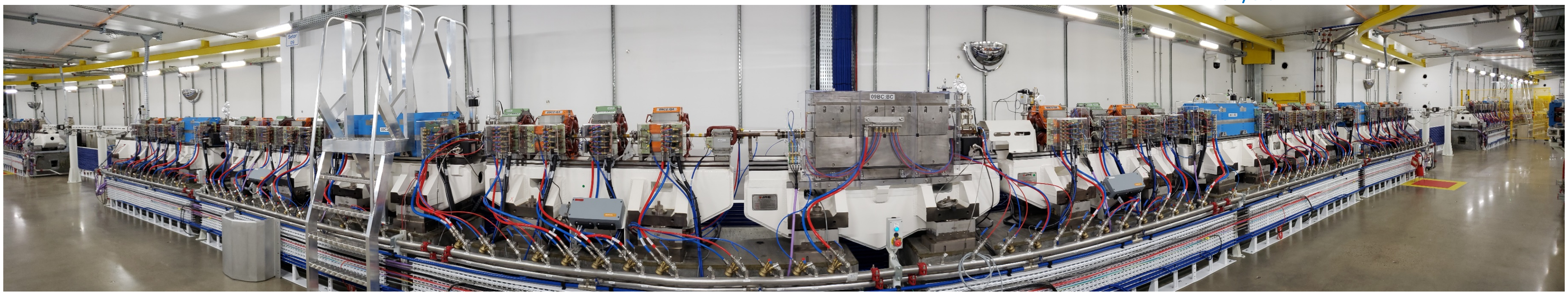



1st Horiz. mode: 152 Hz*

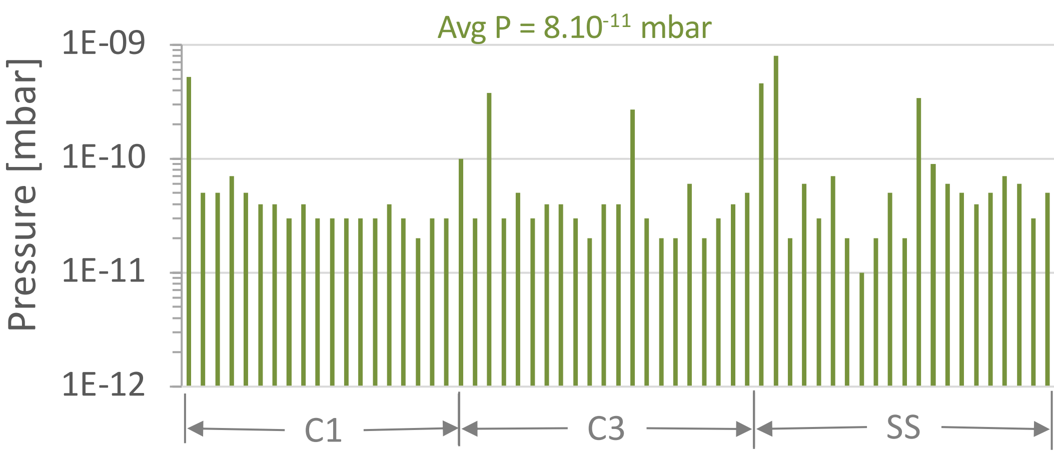
*Confirmed by measurement

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

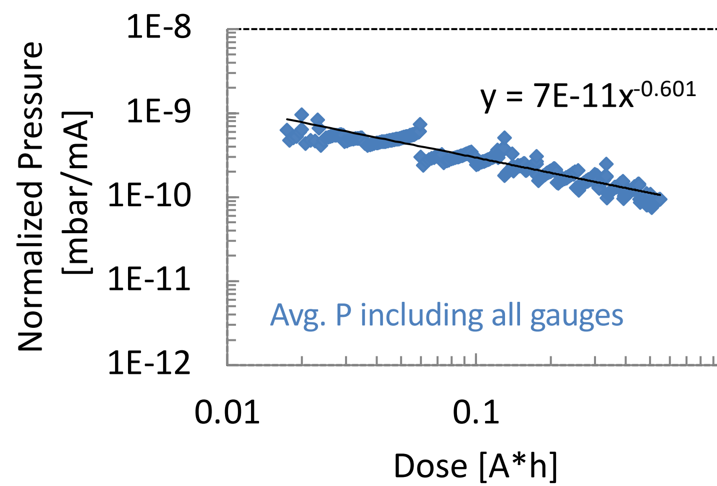


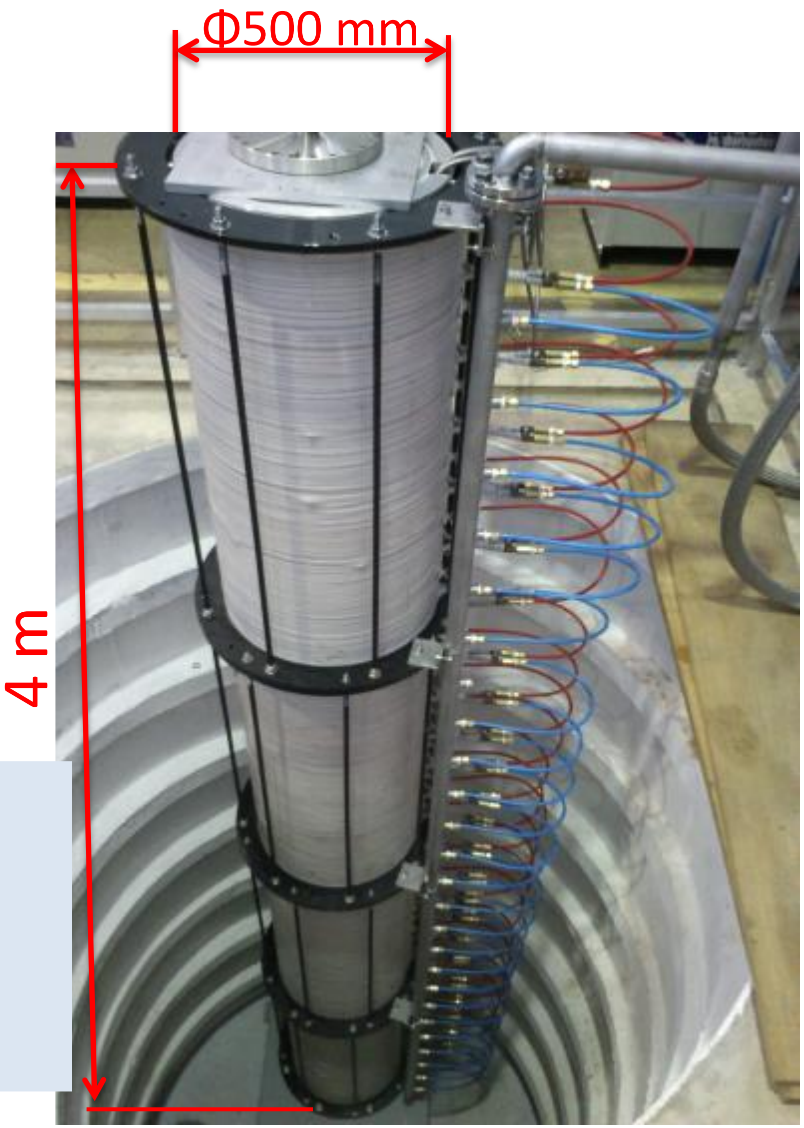
## Storage Ring Static Pressures




## Storage Ring Dynamic Pressure



# In-house NEG* coating facility

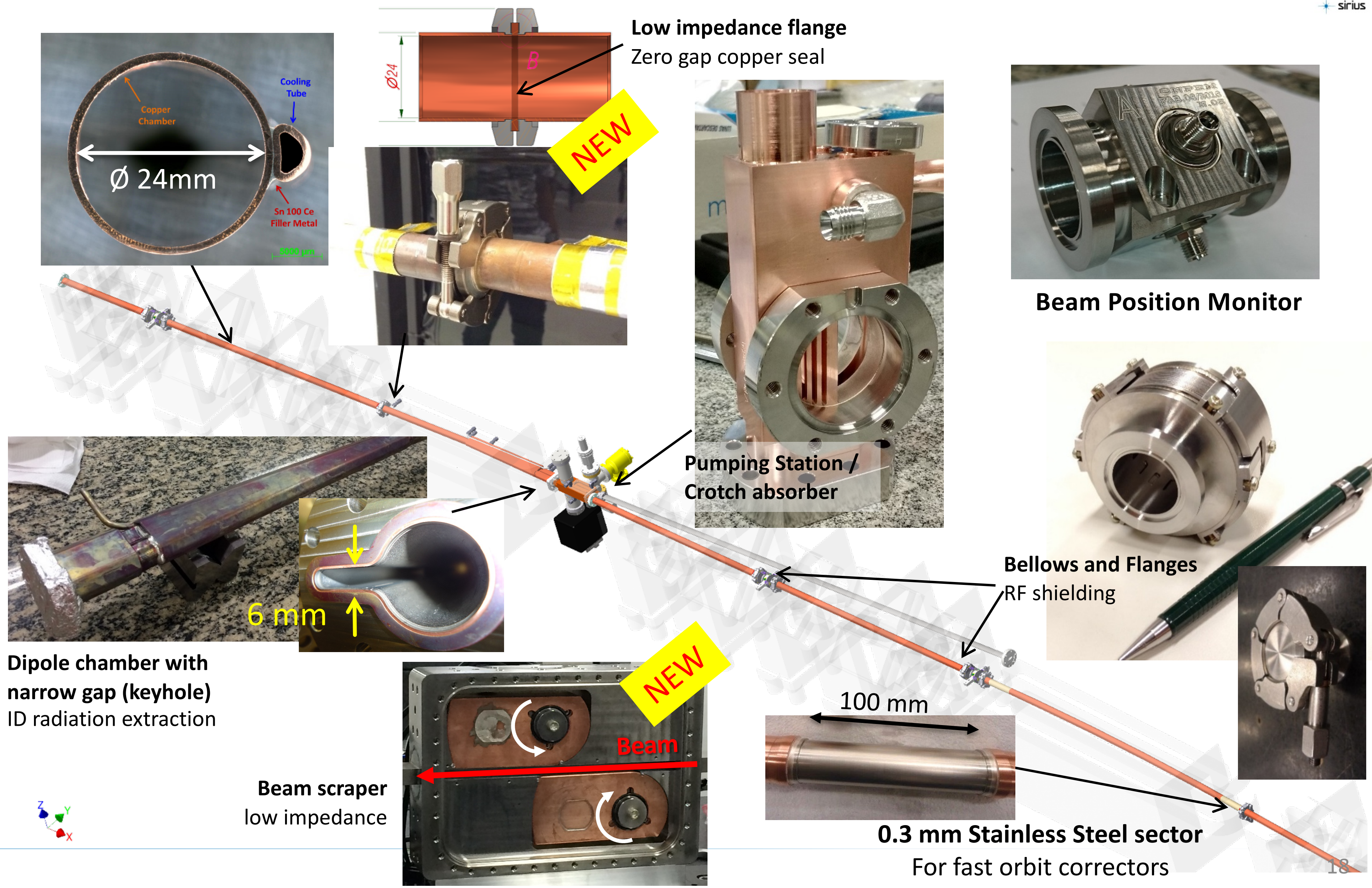



**Main characteristics**

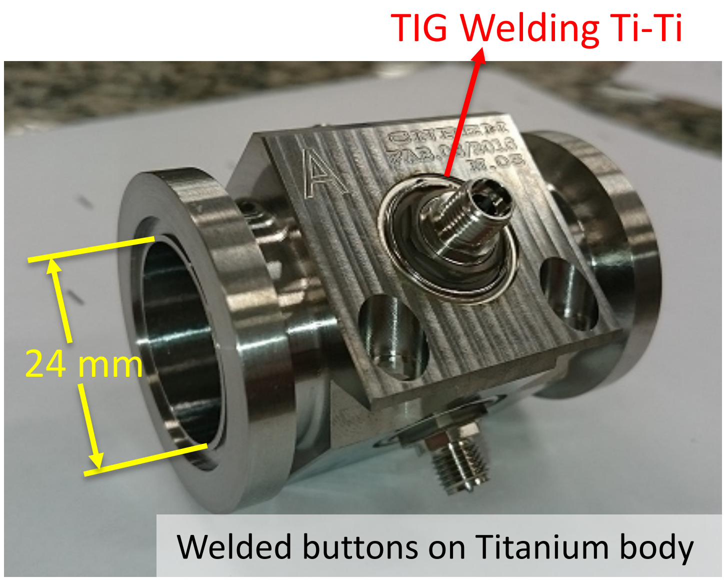
- Up to 6 x 3.2m straight chambers simultaneously
- Individual control of each chamber
- Magnetic field up to 600 Gauss
- Bake-out system integrated to the solenoids
- Automatic control of the deposition

**"Non-Evaporable-Getter"; License agreement with CERN in 2012*

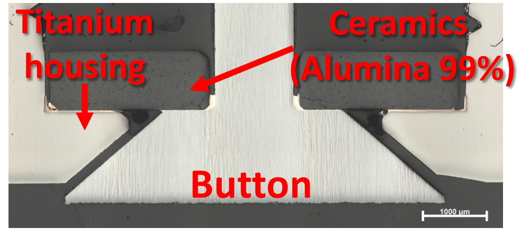
# Storage Ring vacuum components

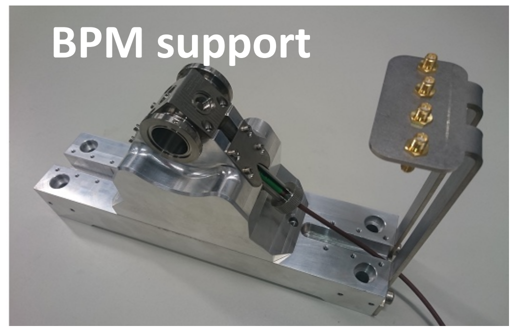


# Beam Position Monitors

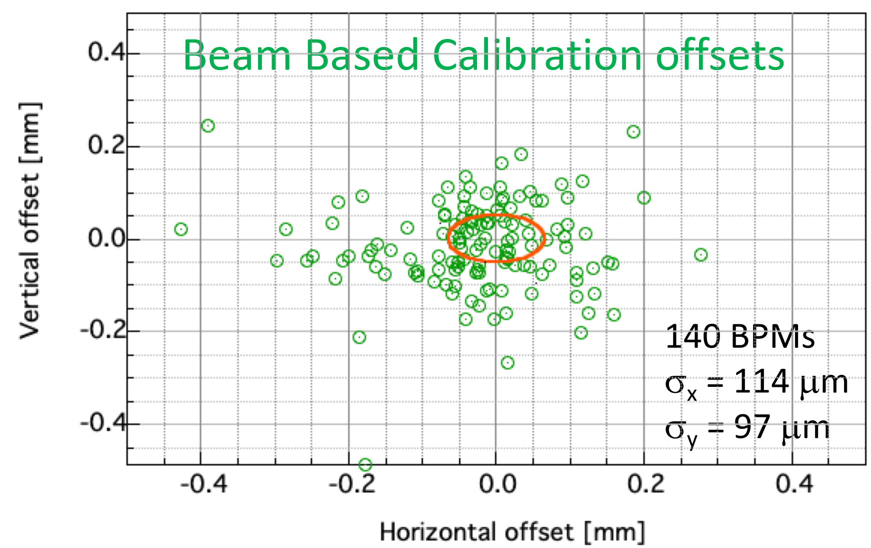


Welded buttons on Titanium body




- 160 BPMs
  - All BPM parts contracted to Brazilian industry
  - In-house button assembly and brazing
  - In-house welding of buttons to the BPM body
  - All BPMs have bellows on both sides and are referenced to the girders by design
- BPM electronics
  - In-house development
  - Local company production (WEG)



# Outlook

- > 80% in-house developments and transfer to local industries
- The Particle Accelerator community is going through a very exciting time, with many new developments under way both in machine and Science case sides.
- International collaboration is one of the most important sources for learning and advancing in our field.

# Thank you!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