The Sirius Project

Overview of the current status

Liu Lin – LNLS Accelerator Physics Group
on behalf of the Sirius Team

Diffraction Limited Storage Rings workshop – APS, Nov. 19th-21st, 2014.

Summary

- The Sirius project
- Buildings
- Accelerator Physics
- Magnets
- Girders
- Power Supplies
- Diagnostics
- RF
- Vacuum
- Beamlines

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LNLS – the Brazilian Synchrotron Light Laboratory

- UVX – the only synchrotron in Latin America
- Over 85% built in Brazil
- Operating for users since July 1997.

Sirius @ CNPEM campus (LNLS, LNBio, LNNano, CTBE)

Sirius @ CNPEM campus (LNLS, LNBio, LNNano, CTBE)

- Revised Budget (2014)
  - Accelerators R$ 228 M
  - 13 beamlines R$ 220 M
  - Building R$ 668 M
  - Human Resources R$ 88 M
  - Contingencies R$ 96 M
  - TOTAL R$ 1300 M

Sirius @ CNPEM campus (LNLS, LNBio, LNNano, CTBE)

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  - Contingencies R$ 96 M
  - TOTAL R$ 1300 M

- Revised Schedule (2014)
  - Nov. 2014 selection of construction company
  - Nov. 2017 start of machine installations
  - mid 2018 start of SR commissioning

Land ready to start construction

Picture taken 2014-Oct-14

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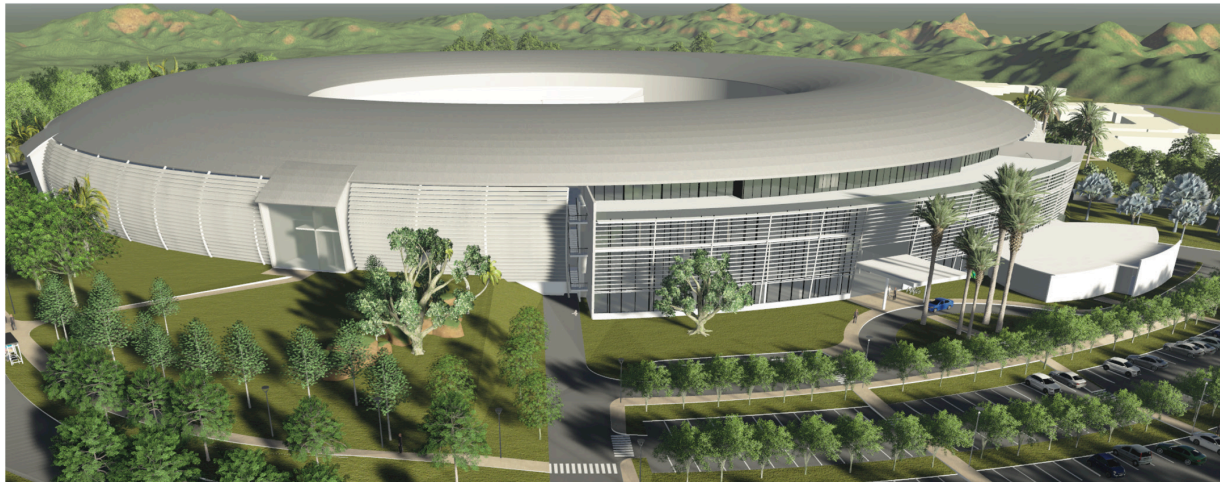
The Sirius Building

Detailed Engineering Design Concluded

- Definition of floor, facilities, etc. more complex than expected.
- Technical areas ended up larger than initially expected (from ~44.000 m^2 to ~68.000 m^2).
- Took longer than expected.



The Sirius Building

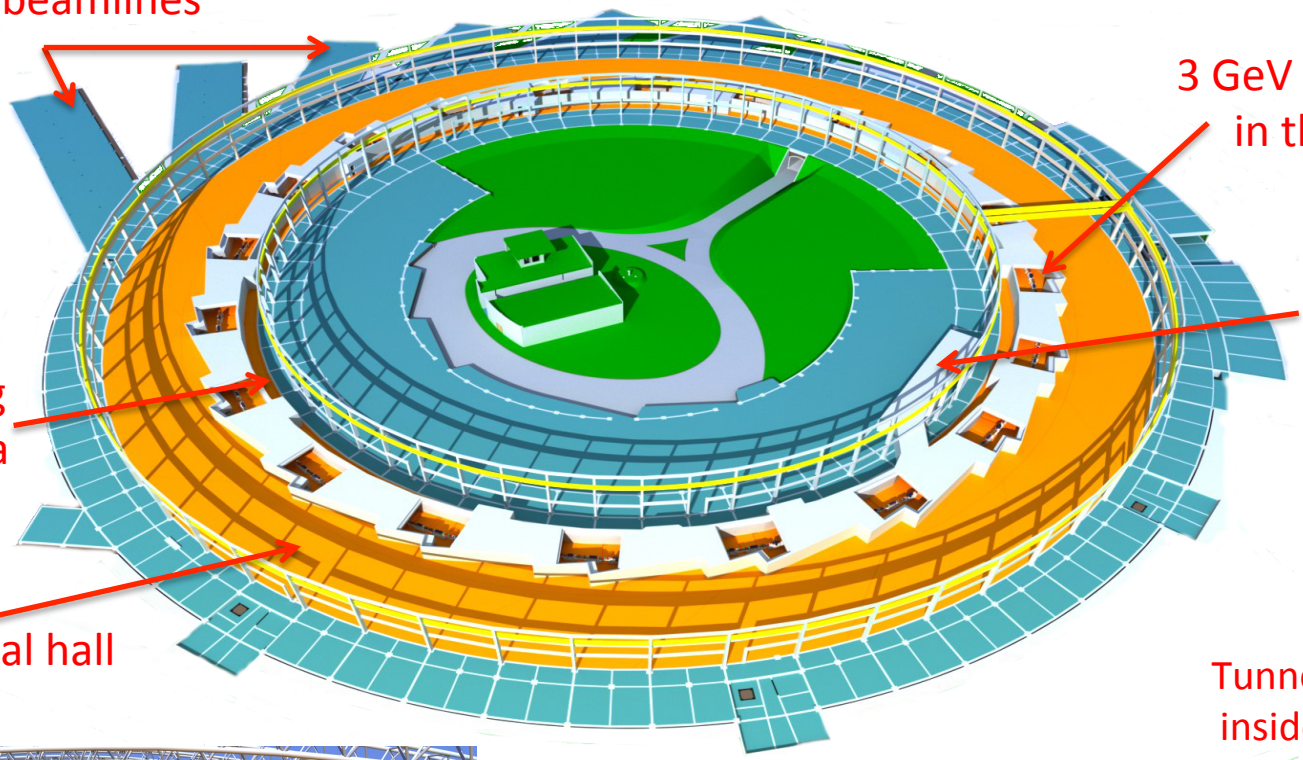
6 extra-long beamlines
(150-100 m)

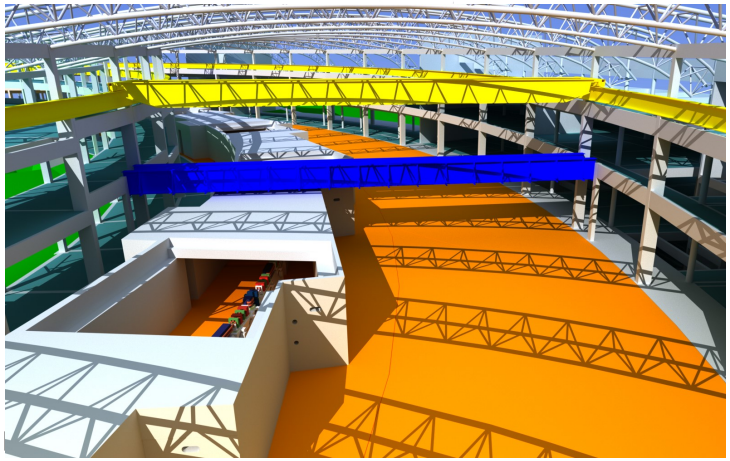
3 GeV booster and SR
in the same tunnel

150 MeV Linac

Engineering
service area

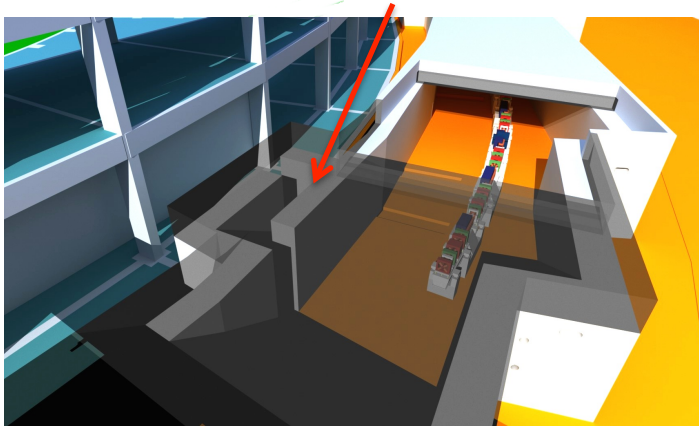
Experimental hall



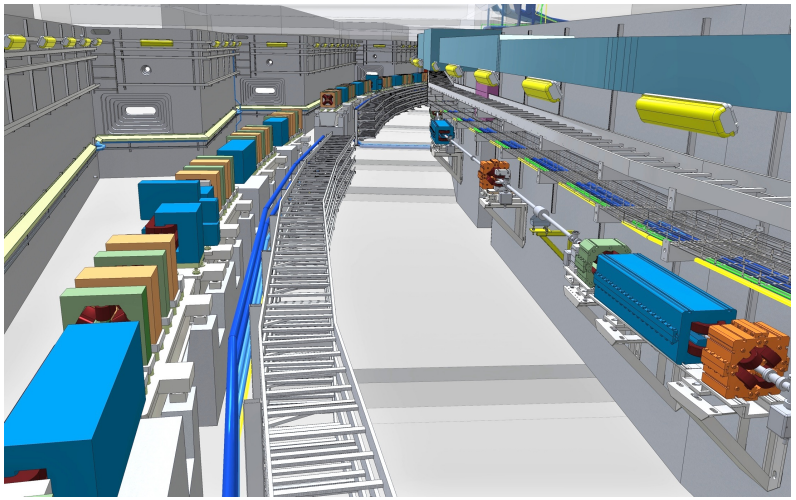


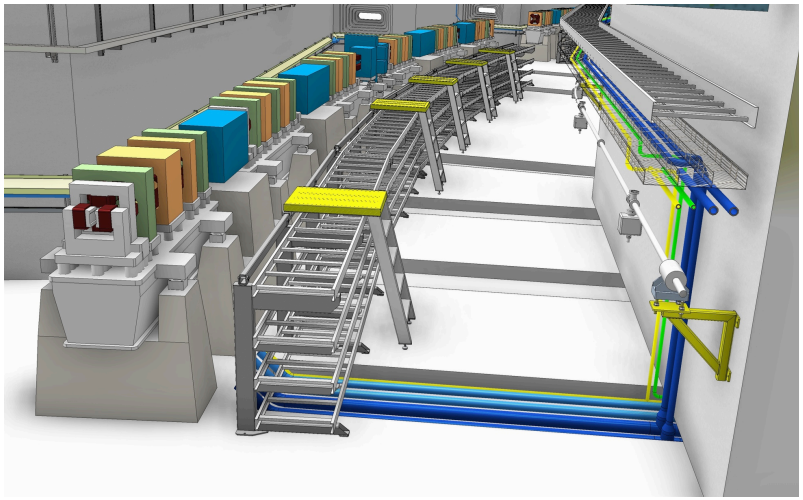
Tunnel access from top:
20 openings
(up to 3x20 ton cranes)

Tunnel access from
inside: 10 chicanes



Inside the accelerators tunnel





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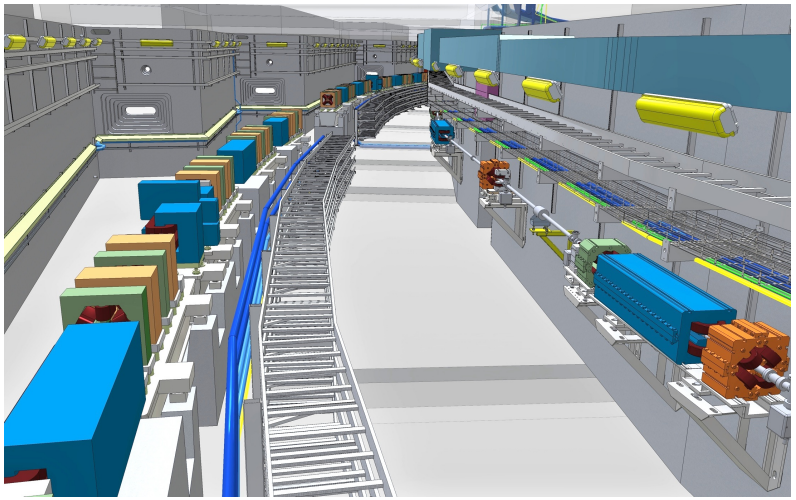
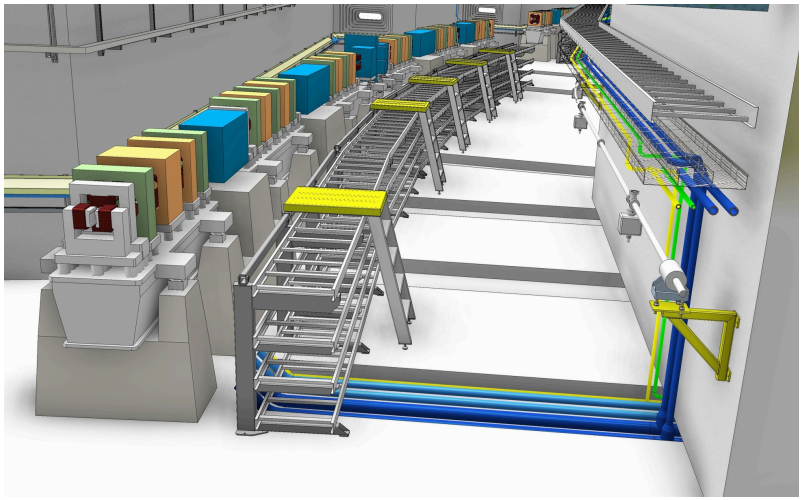
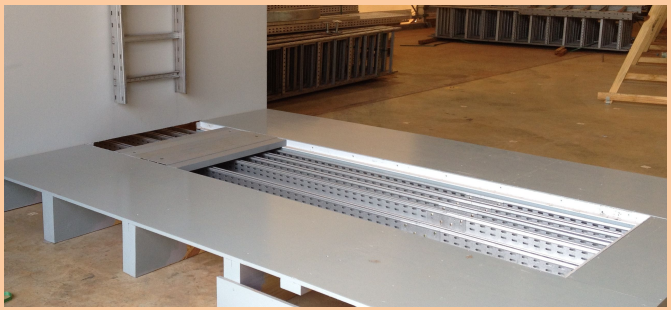




Mockup for one superperiod

October 31, 2014



Building Floor

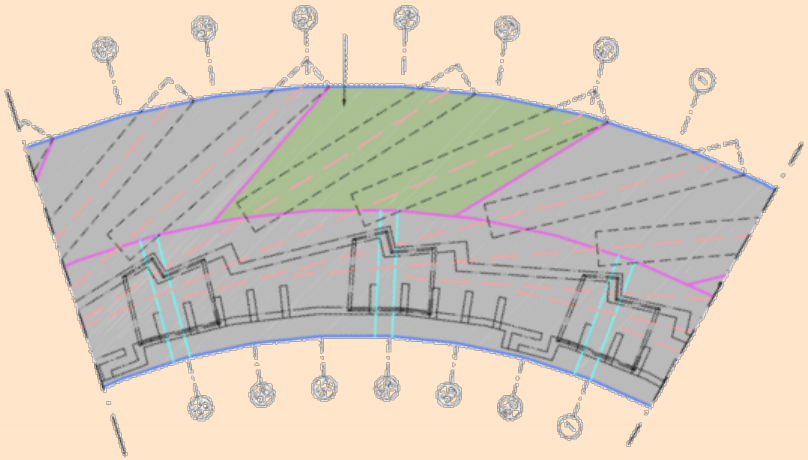
Two Sirius slab prototypes studied

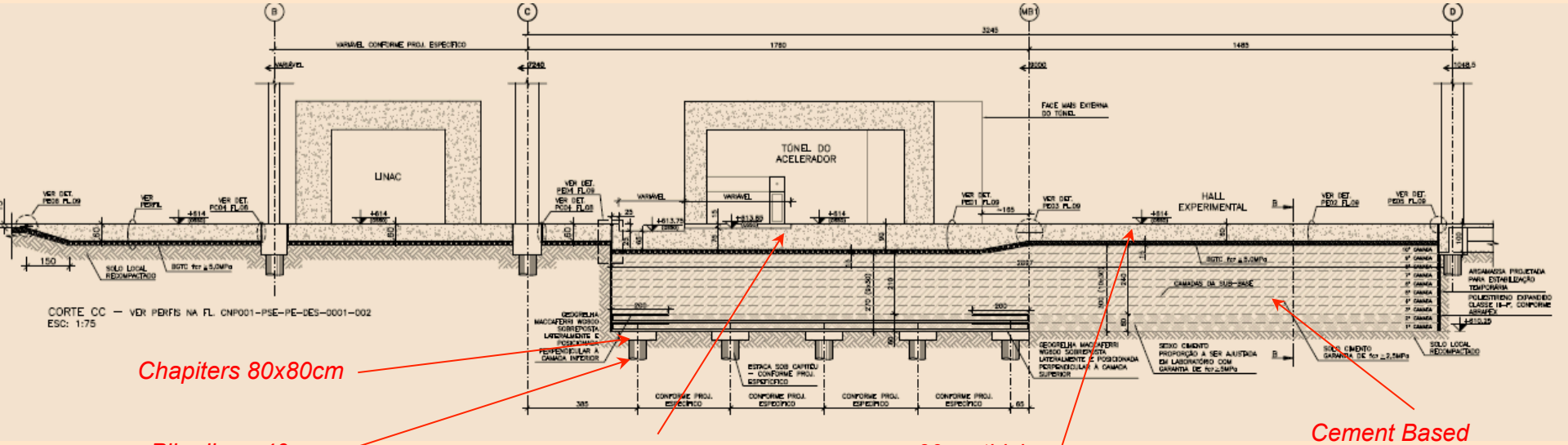
Pile response measurement

Building Floor

Two Sirius slab prototypes studied

Final design





Chapiters 80x80cm

Pile diam; 40cm
Only under SR Floor

90cm thick concrete reinforced floor

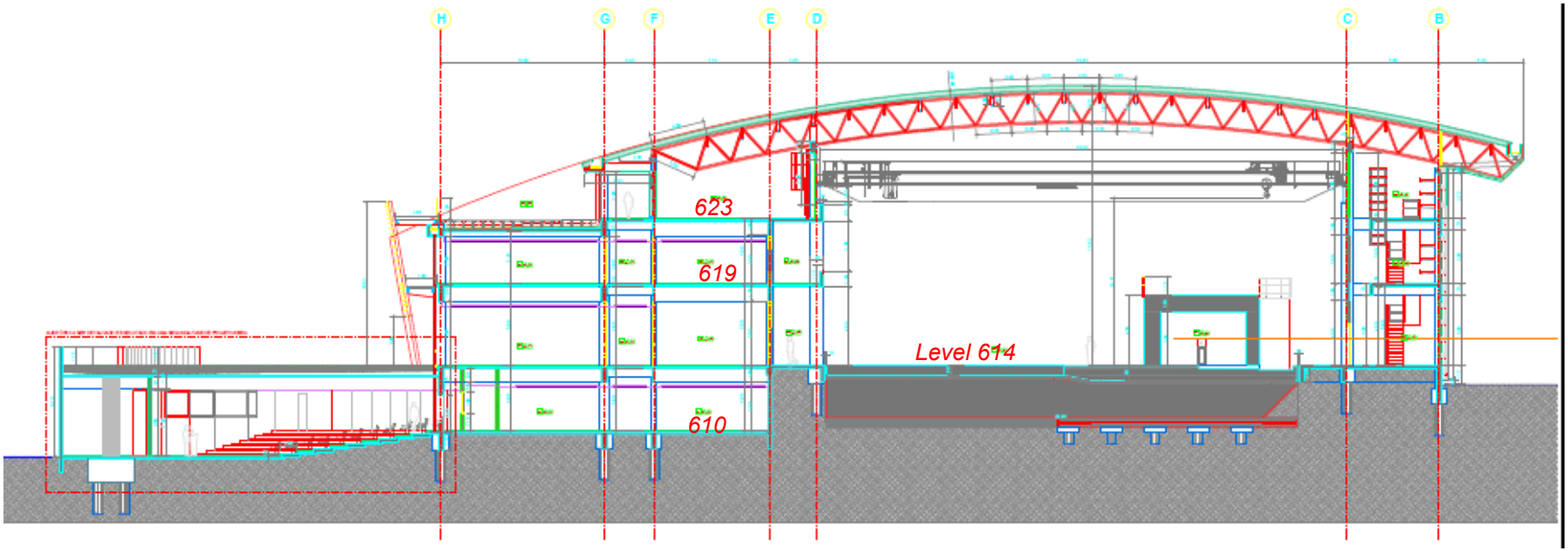
60cm thick concrete reinforced floor

Cement Based Engineered Soil

Final design: typical section

4 FLOORS:

LEVEL 610 - MAIN ENTRANCE AND LOBBY
LEVEL 614 - EXPERIMENTAL HALL, ACCELERATORS, ENGINEERING AND LABS
LEVEL 619 - OFFICES .
LEVEL 623 - TECHNICAL AREA



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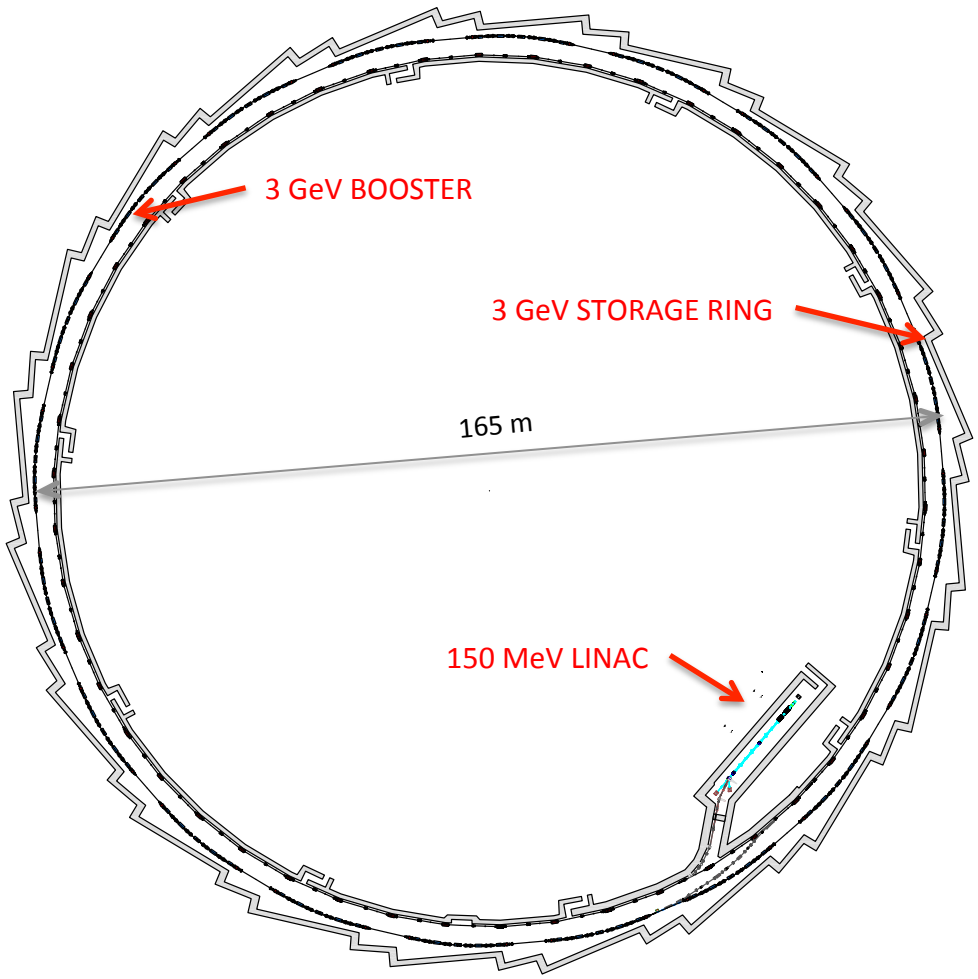
Sirius main parameters

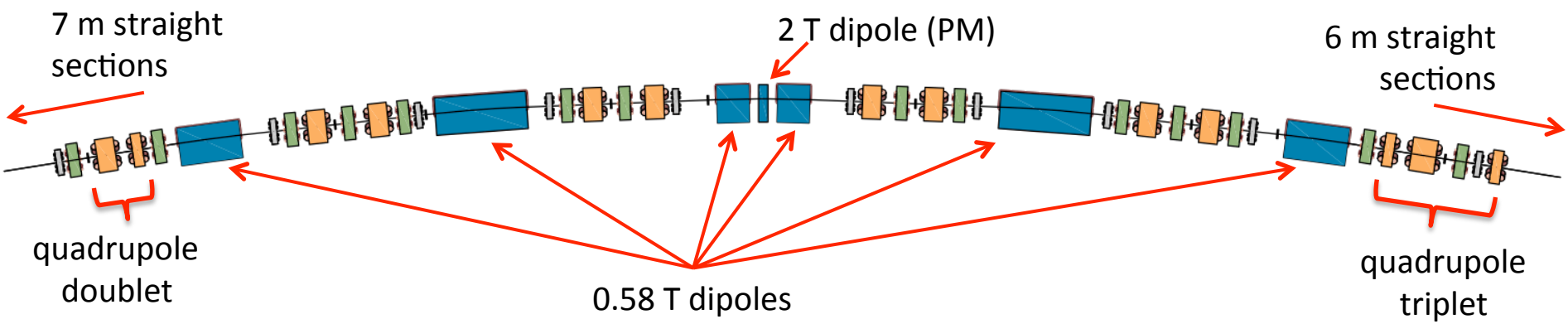


Storage Ring	
Beam energy	3.0 GeV
Circumference	518.4 m
Lattice	20 x 5BA
Straight sections	10 x 7m, 10 x 6m
Current, top up	350 mA
Betatron tunes (H / V)	48.25 / 13.15
Hor. Emittance	190 - 270 pm.rad
Vert. emittance (k=1%)	2.7 pm.rad
Number of bunches	864
Bunch length	10 ps
Energy spread	0.083 %
RF frequency	500 MHz

Booster	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Cycling frequency	2 Hz

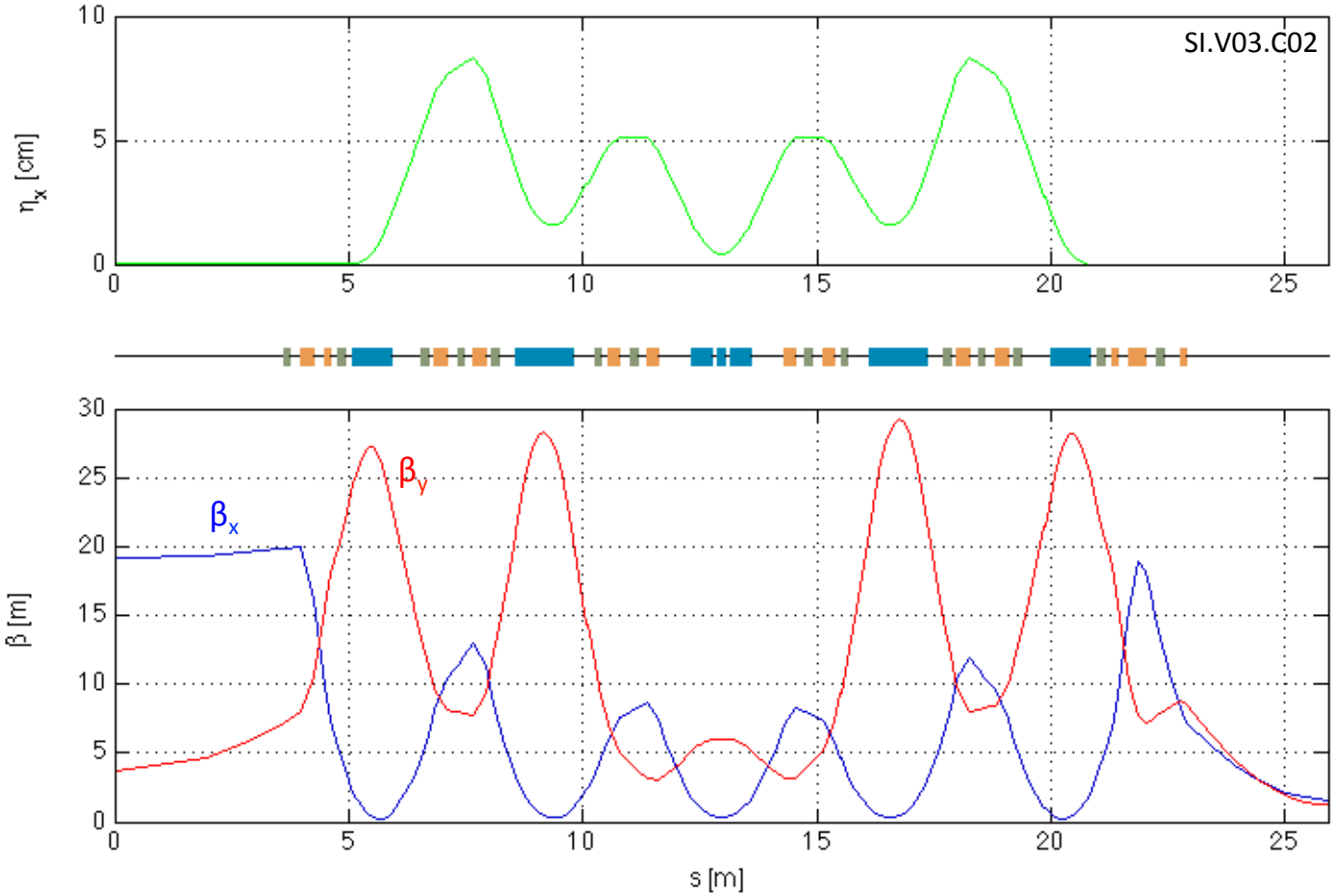
The storage ring lattice and emittance optimization

- Dipoles with transverse gradient to increase J_x.
- Achromatic cells ⇨ IDs help to reduce the emittance.
- 2 T superbend ⇨ longitudinal field gradient ⇨ strong focusing of the H-function at superbend.
- Dipoles with different lengths. Center dipoles are longer: here the dispersion function is optimized for emittance reduction.
- Low field dipoles ⇨ smaller energy spread.



Upgraded optics to match with IDs

- New optics with lower β at the 6 m straight sections to match the electron beam phase-space to the photon beam phase-space from IDs.



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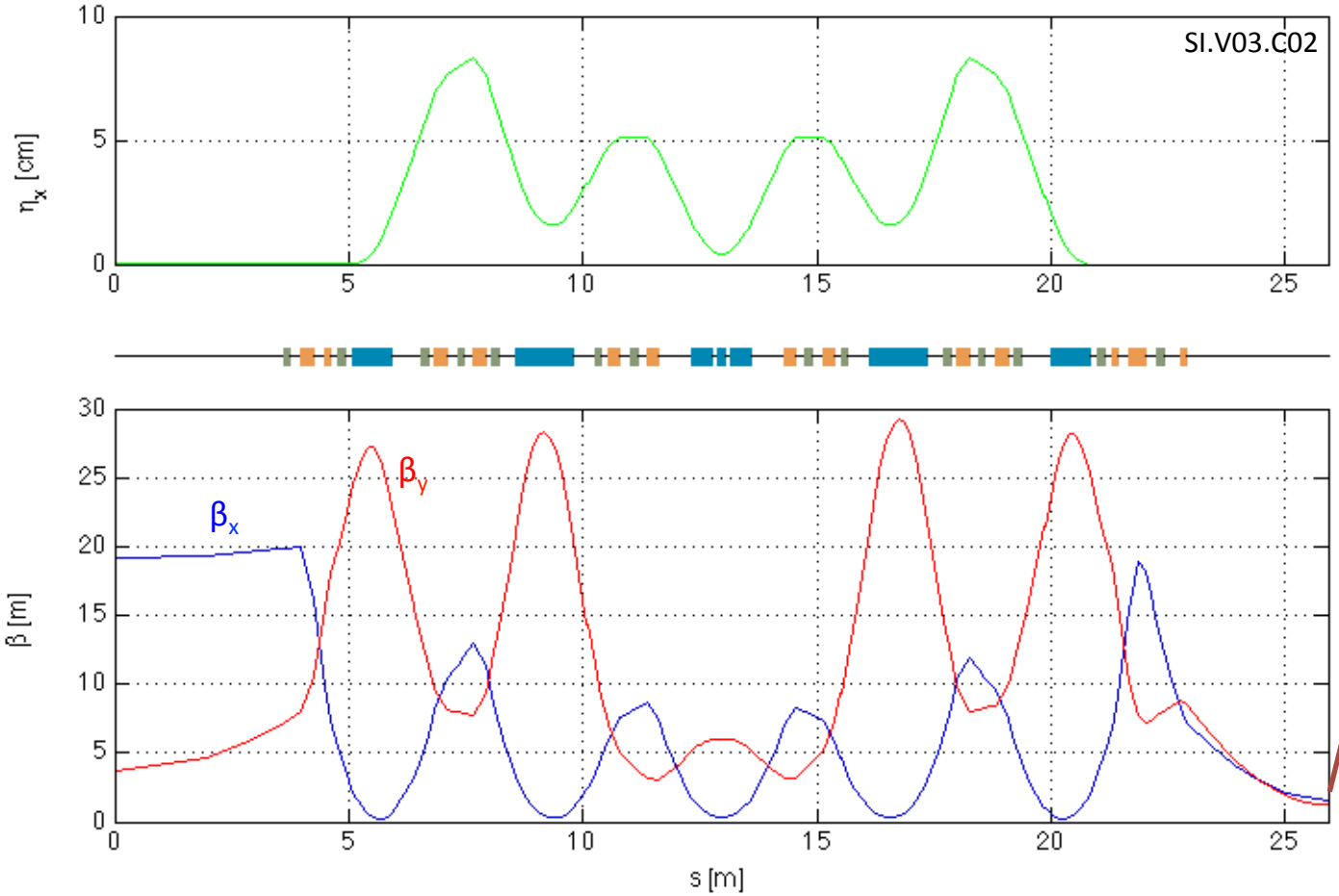

$\beta_x \approx \beta_y \approx 1\ m \approx L/\pi$

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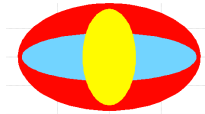
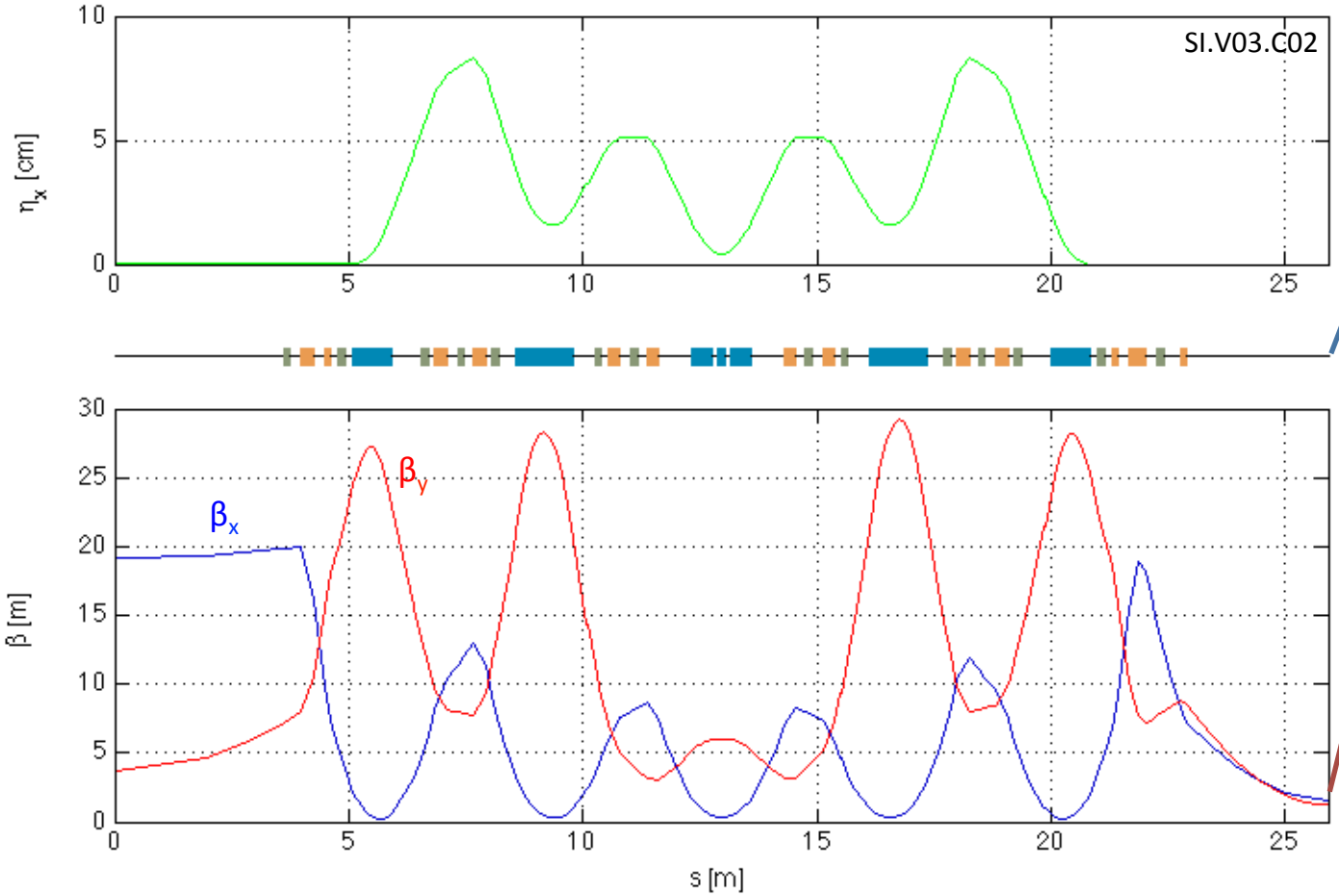
κ = 1%

ε_y = 2.7 pm.rad





Low β SS
σ [μm²] = 20 X 1.8
σ' [μrad²]= 13 X 1.5

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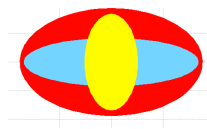

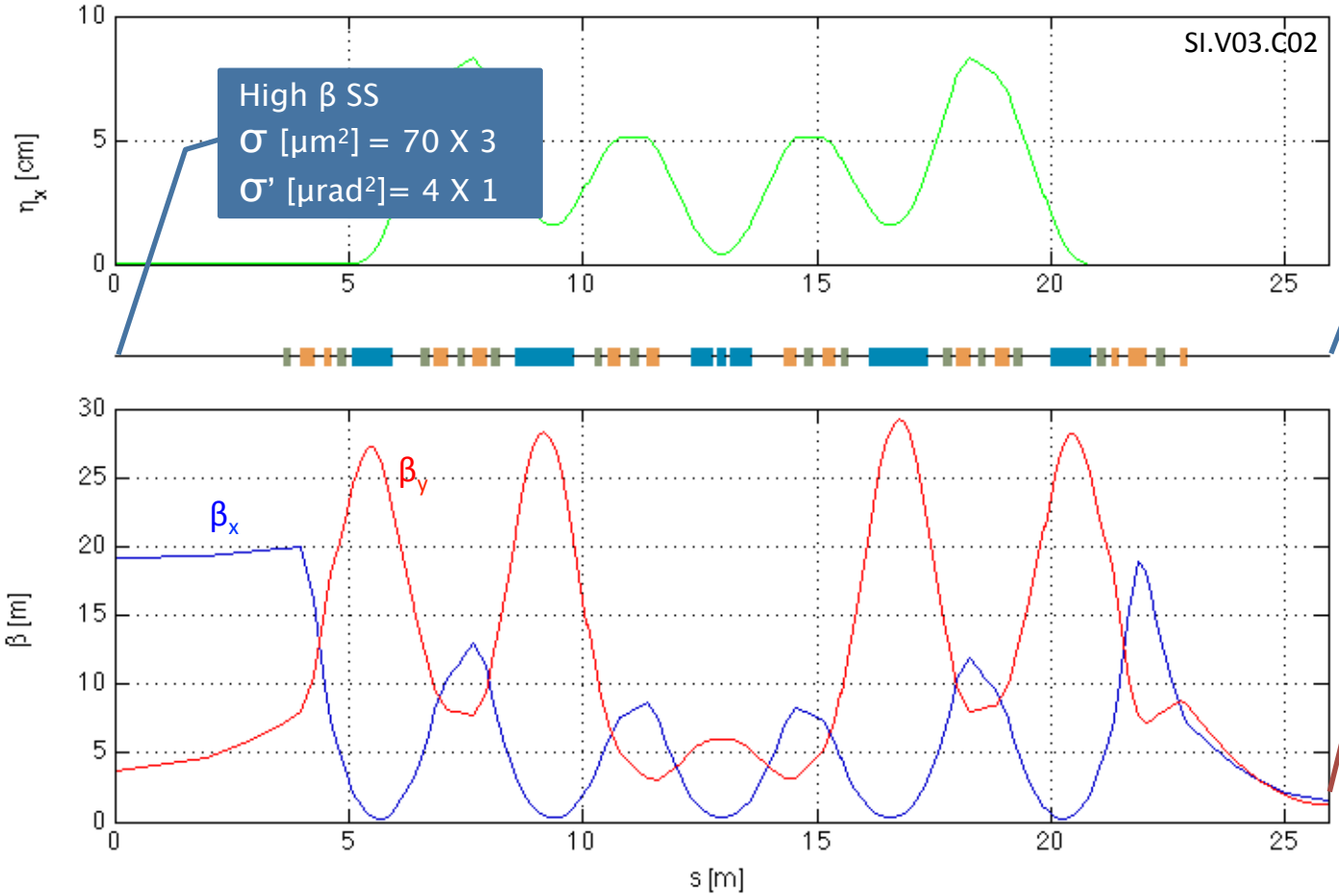

High β SS
σ [μm²] = 70 X 3
σ' [μrad²]= 4 X 1

Low β SS
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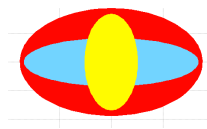

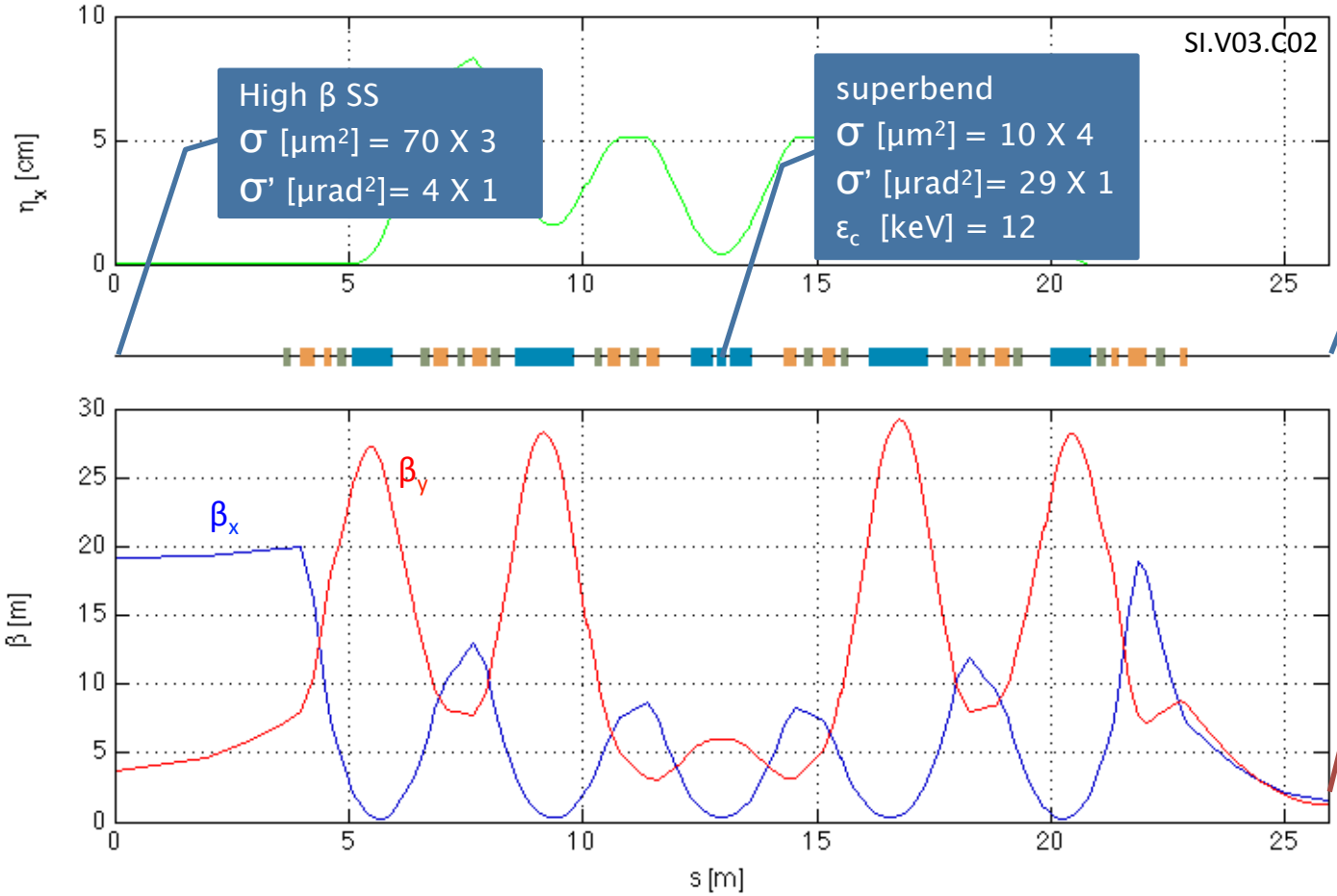

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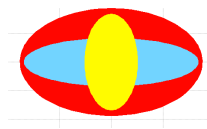
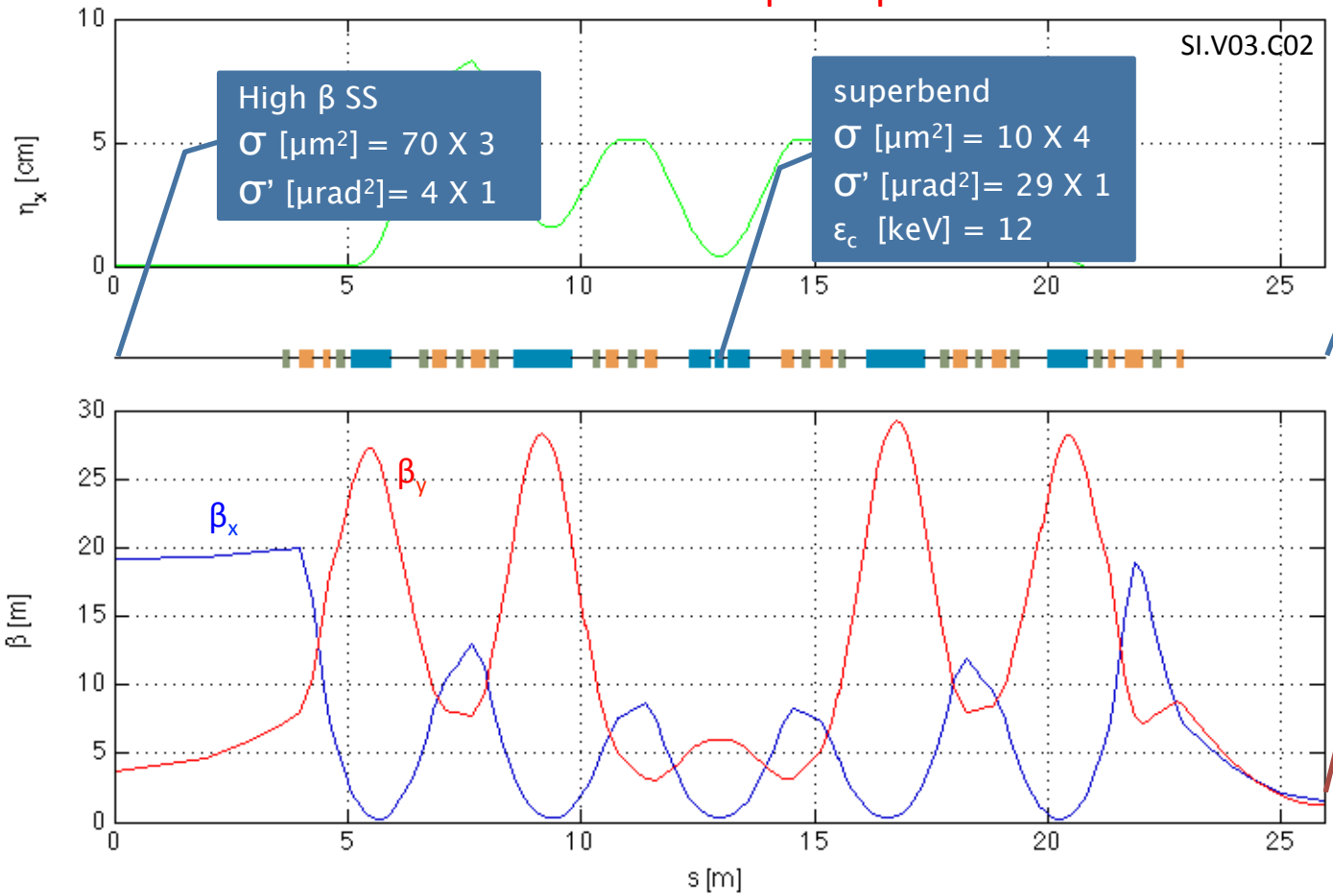


To match in dipoles β = 0.4 mm



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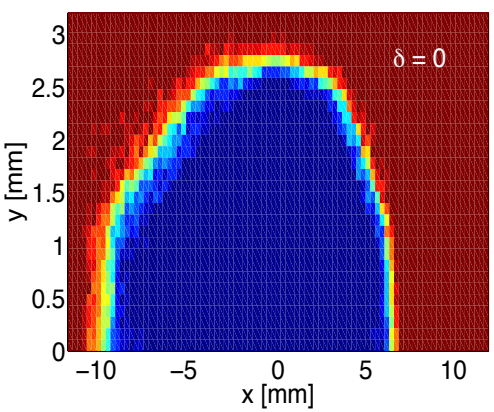
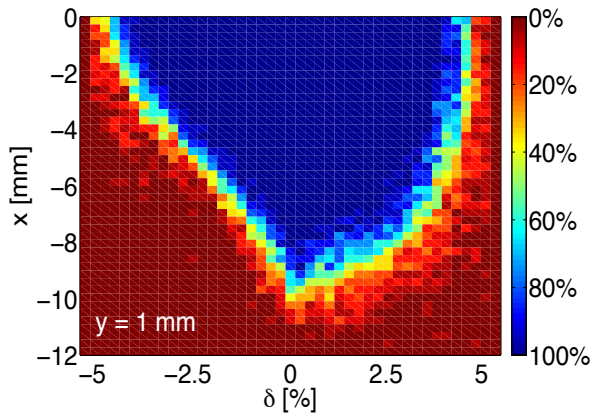
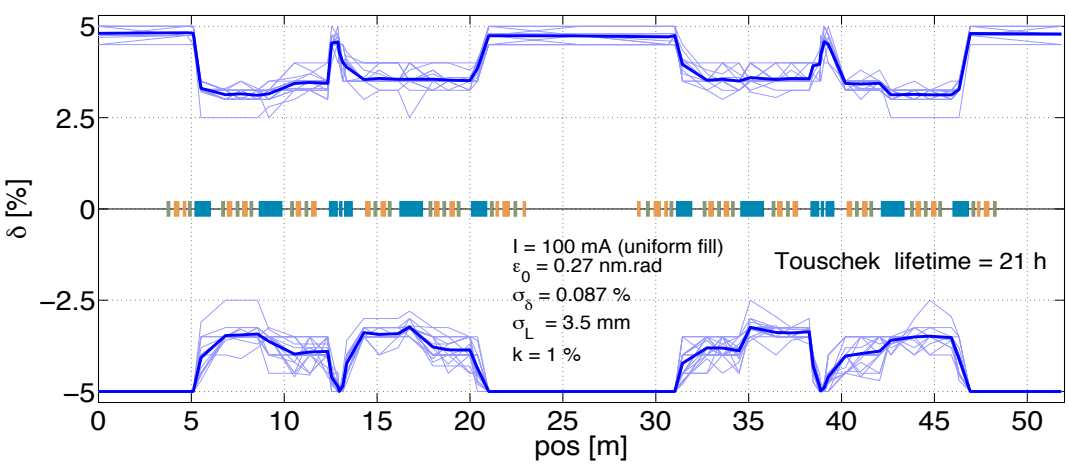
Non-linear dynamics

- Dynamic and momentum apertures optimized with 14 sextupole families. No octupoles.
- Optimization in progress using genetic algorithms.
- 6D tracking with alignment and multipole errors, and physical limitations (including IDs).







Random gaussian errors

- Alignment, Q, S: 40 µm
- Alignment, dip: 100 µm
- Roll: 0.2 mrad
- Excitation: 0.05 %
- Multipole: $\Delta B/B_{x=12\ mm} = 1\times10^{-4}$

Orbit correction

- BPMs close to strong sextupoles and quadrupoles (BBA).
- Slow and fast cors in same yoke.
- BPMs: 180 (9/cell)
- HCMs: 160 (slow) / 80 (fast)
- VCMs: 120 (slow) / 80 (fast)

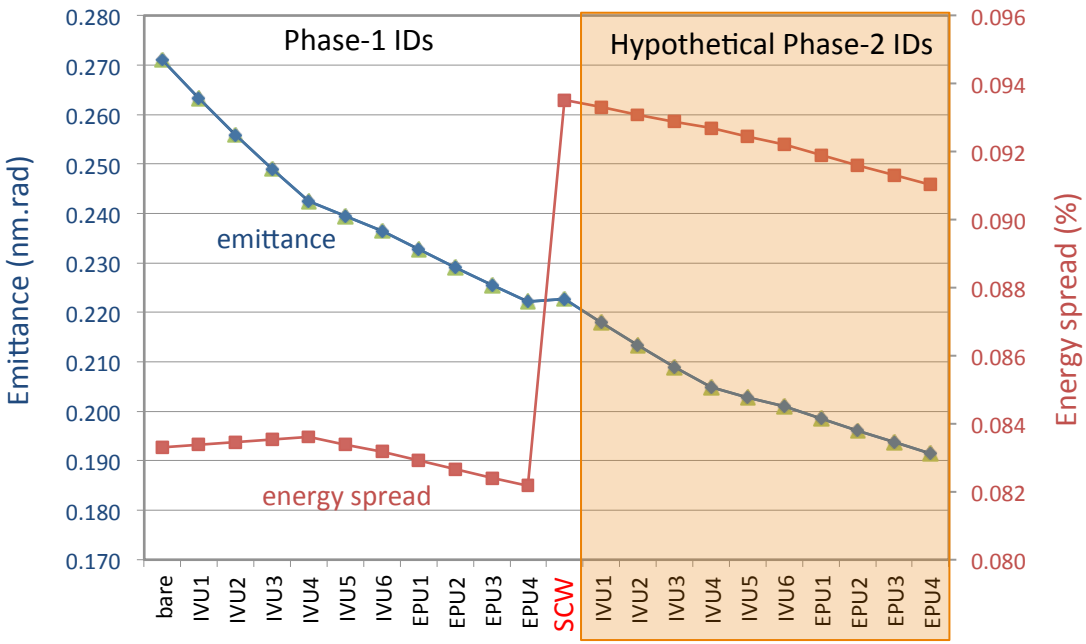
Physical limitations

- straight sections: ∅ = 24 mm
- dipoles: ∅ = 24 mm
- IVUs: full gap = 4.5 mm, L=2m

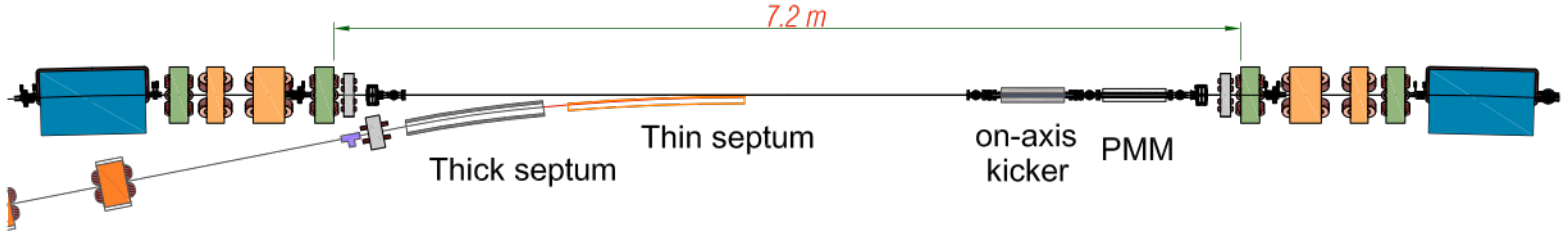
Emittance and Insertion Devices

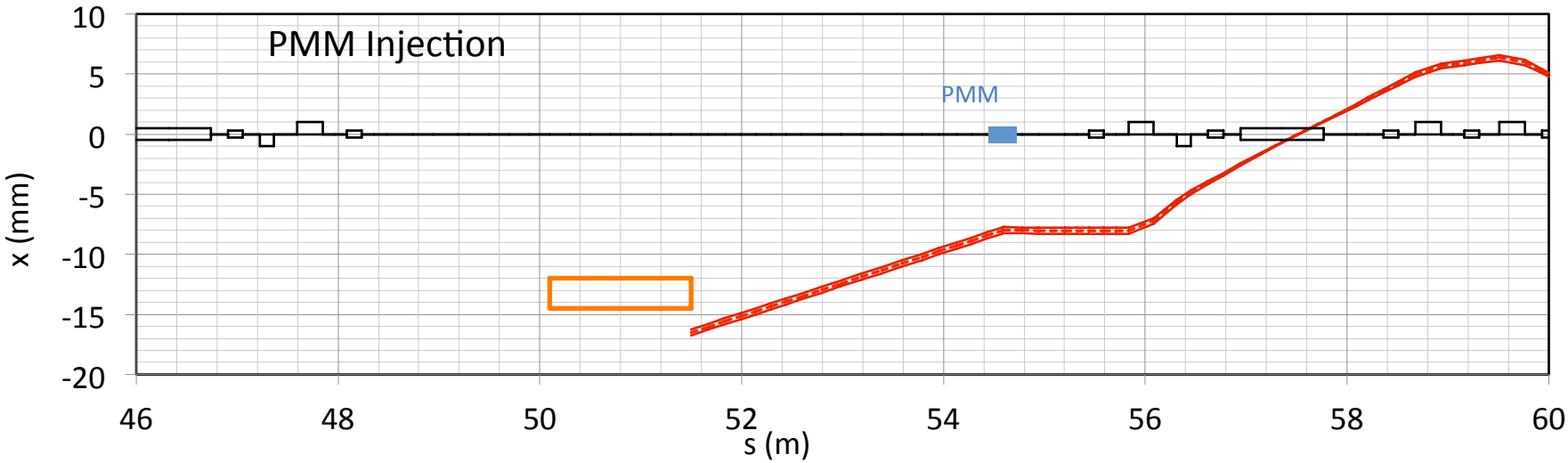
Sirius Phase-1 IDs

Beamline	Type	B_0 [T]	λ [mm]	L [cm]	K_{max}	g [mm]
Carnaúba	IVU	1.28	19	200	2.3	4.5
Jatobá	SCW	4.00	60	100	22.4	22.0
Ema	IVU	1.28	19	200	2.3	4.5
Ingá	IVU	0.94	25	200	2.2	8.0
Cateretê	IVU	1.28	19	200	2.3	4.5
Ipê	EPU	0.90	80	270	6.7	16.0
Manacá	IVU	1.28	19	200	2.3	4.5
Sabiá	EPU	0.90	80	270	6.7	16.0



Injection with Pulsed Multipole (PMM)





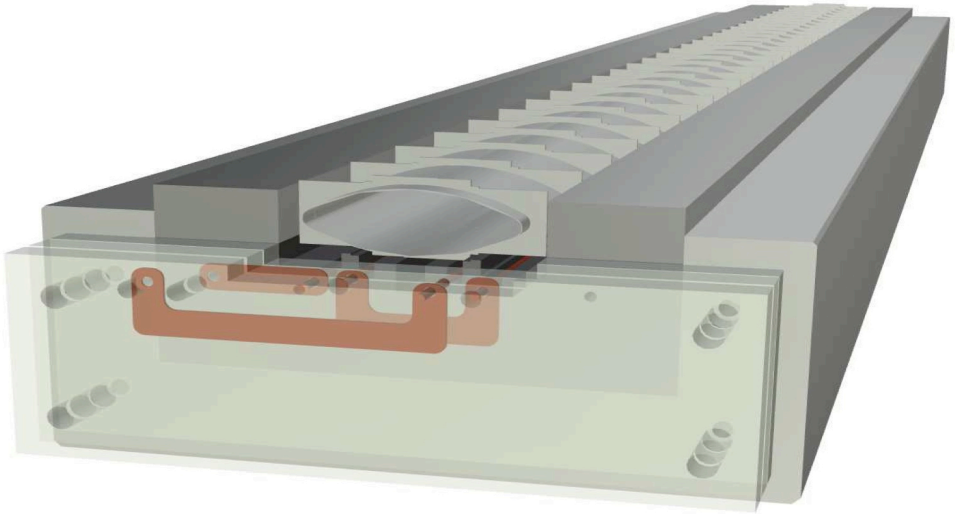
PMM characteristics		
Length	0.5	m
Deflection @ x = -8 mm	2.8	mrad
B @ x = -8 mm	0.056	T

Vertical BSC (full)	9.0	mm
Fall time	< 1.5	µs
Vacuum chamber	0.1 mm SS 316L	
Magnet yoke	Si-Fe steel	

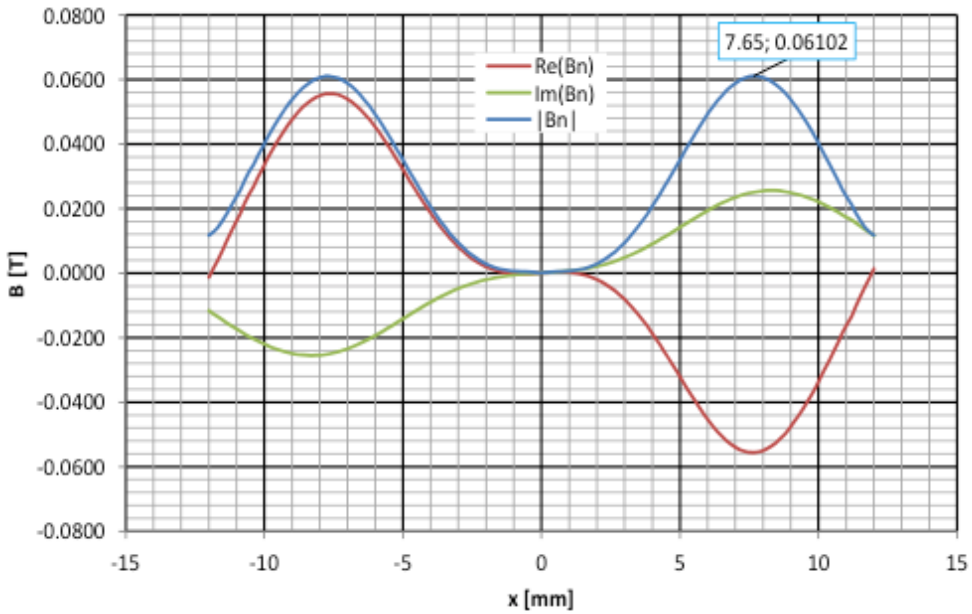
Pulsed Multipole preliminary design

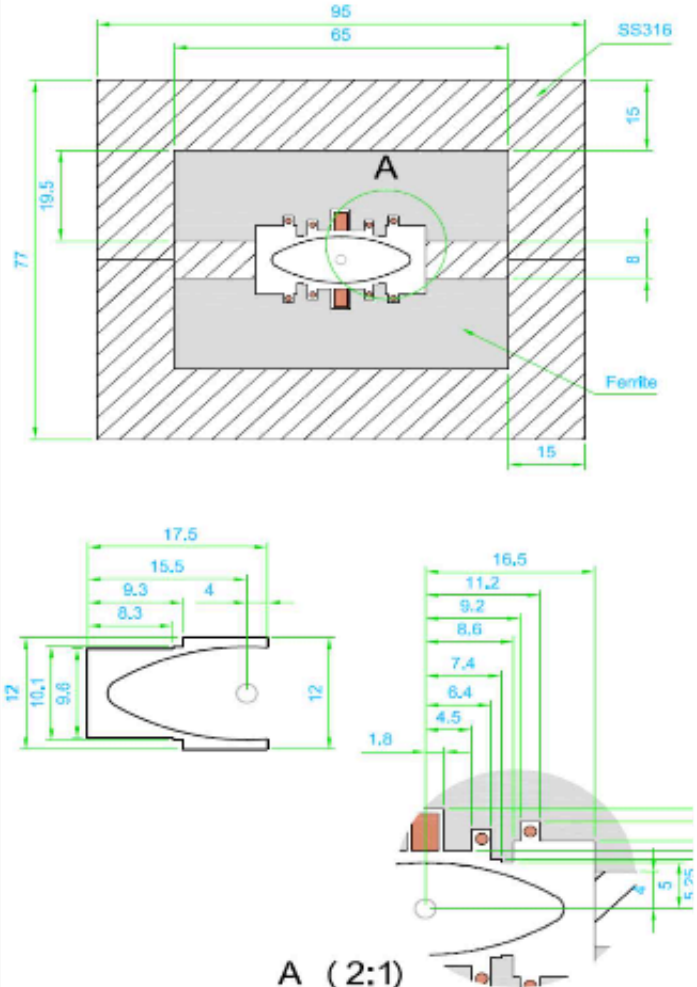
Ricardo Rodrigues

22-10-14

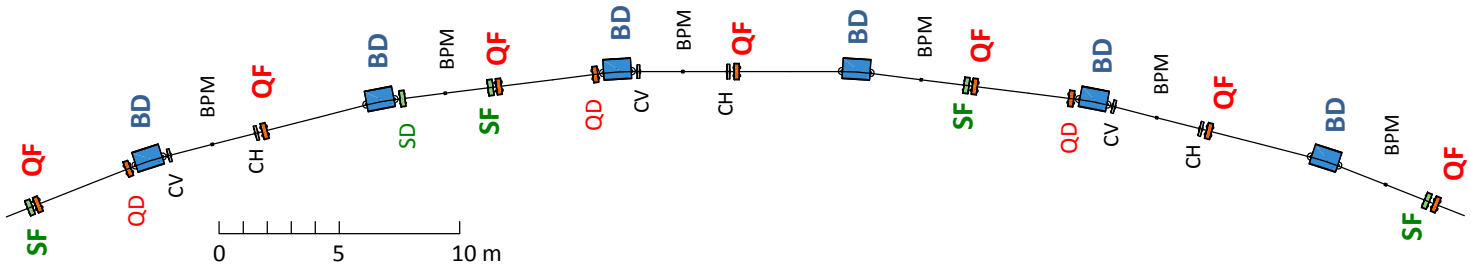


Magnetic energy 1.306 joules
Inductance 4.08E-06 Henry
Total current = 800 Amps
Voltage Drop = 884.425+I*6155.65 Volts
Flux Linkage = 0.00653135-I*0.000700354 Webers
Flux/Current = 8.16419e-006-I*8.75443e-007 Henries
Voltage/Current = 1.10553+I*7.69457 Ohms

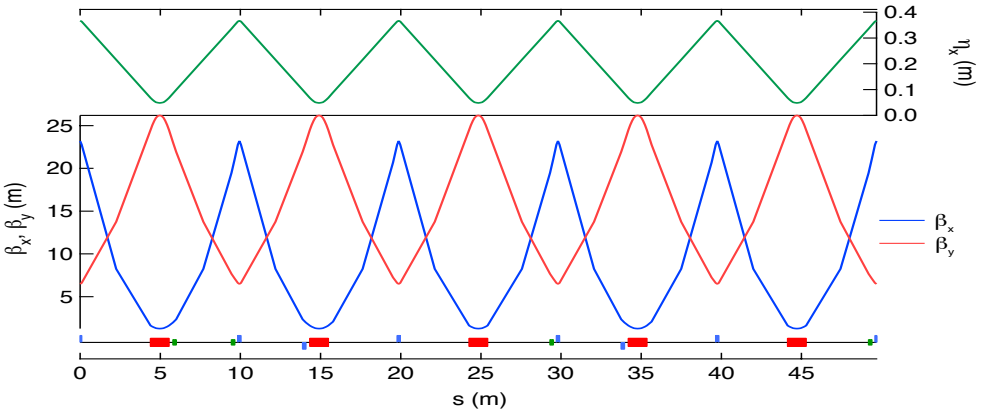


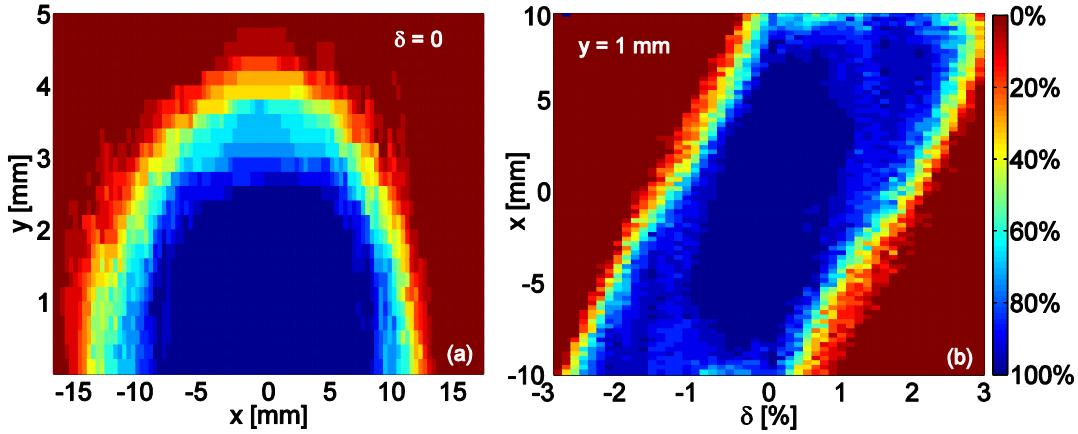


Sirius Booster



Booster	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Cycling frequency	2 Hz





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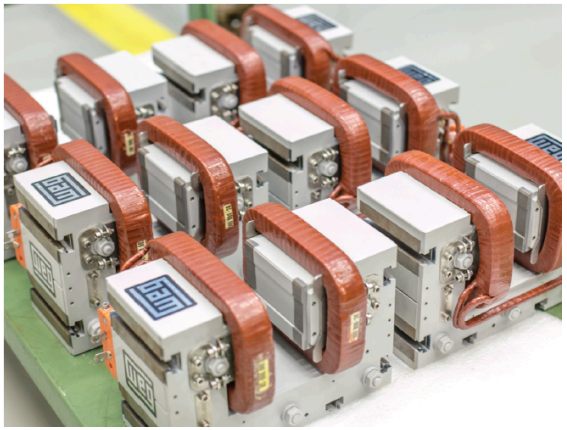
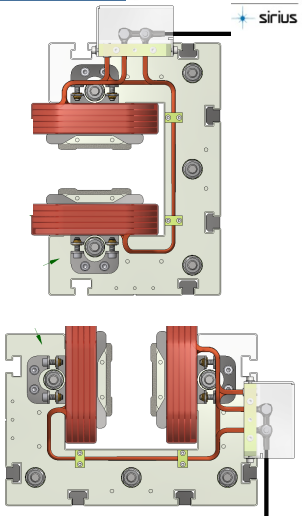
Conventional magnets production

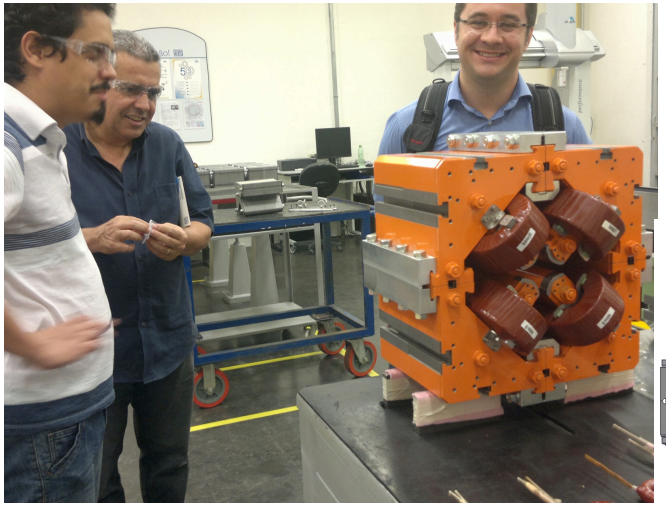
WEG – Brazilian electrical motor manufacturer

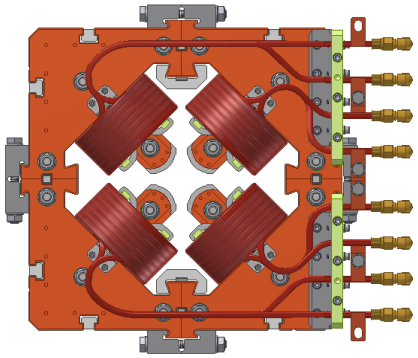
Booster H and V correctors

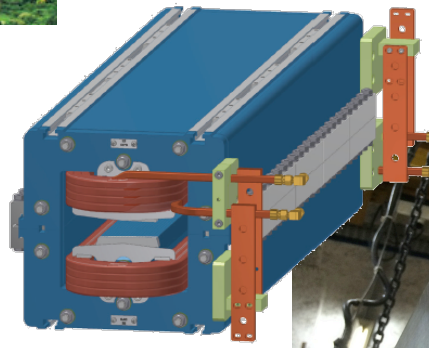




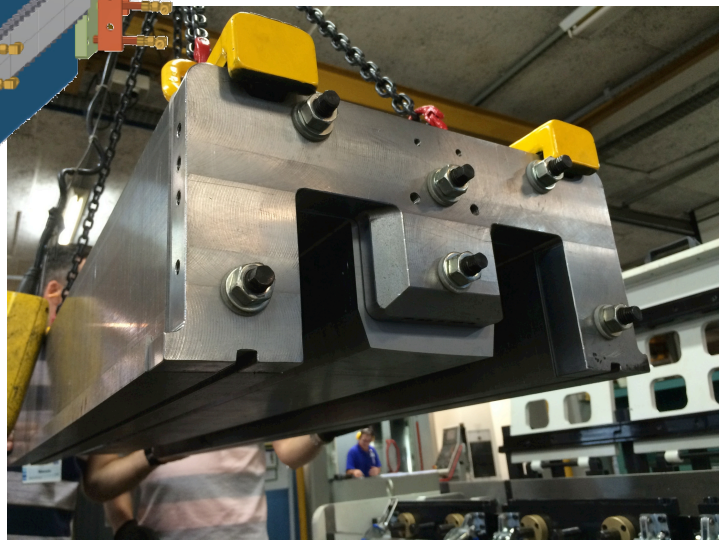
Booster Quadrupoles







Booster Dipoles

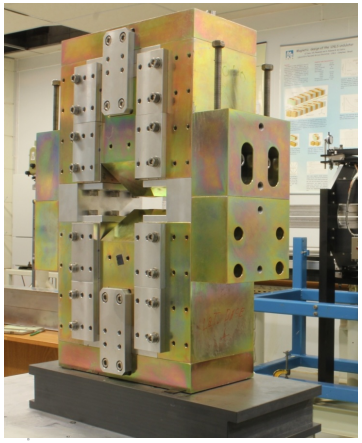


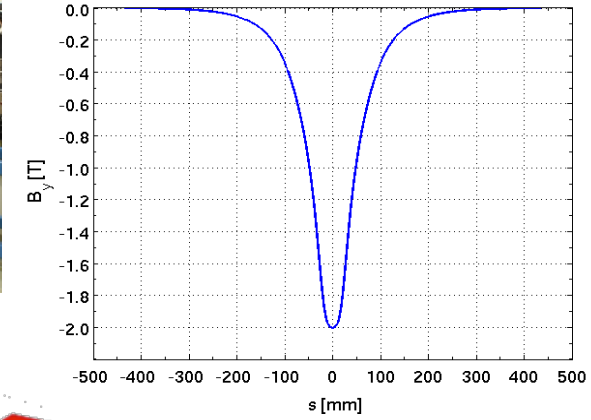
Storage ring magnets

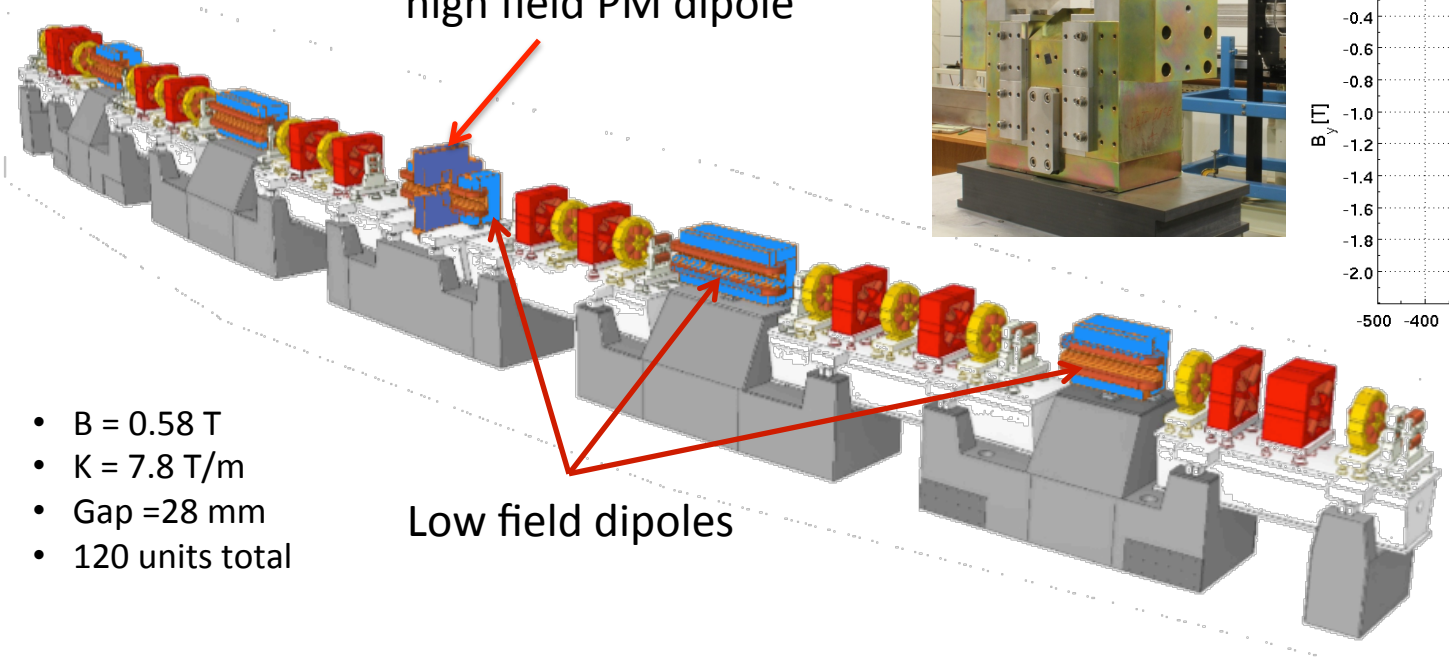
The design for the SR magnets are presently under study.

- Very tight magnetic lattice.
- High field superbend made of permanent magnet (NdFeB).
- Option for correctors (H and V, fast and slow) and skew quads combined with sextupoles under study.

- PM Superbend
- B = 2 T
- Gap = 28 mm
- Field flexibility = 6% (using lateral control gap)
- 20 units total







- B = 0.58 T
- K = 7.8 T/m
- Gap =28 mm
- 120 units total

Summary

- The Sirius project
- Buildings
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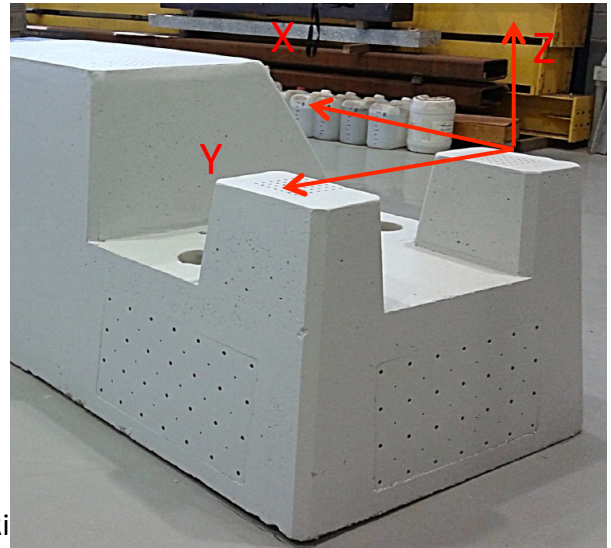
- Magnets
- Girders
- Power Supplies
- Diagnostics
- RF
- Vacuum
- Beamlines

Girder prototypes

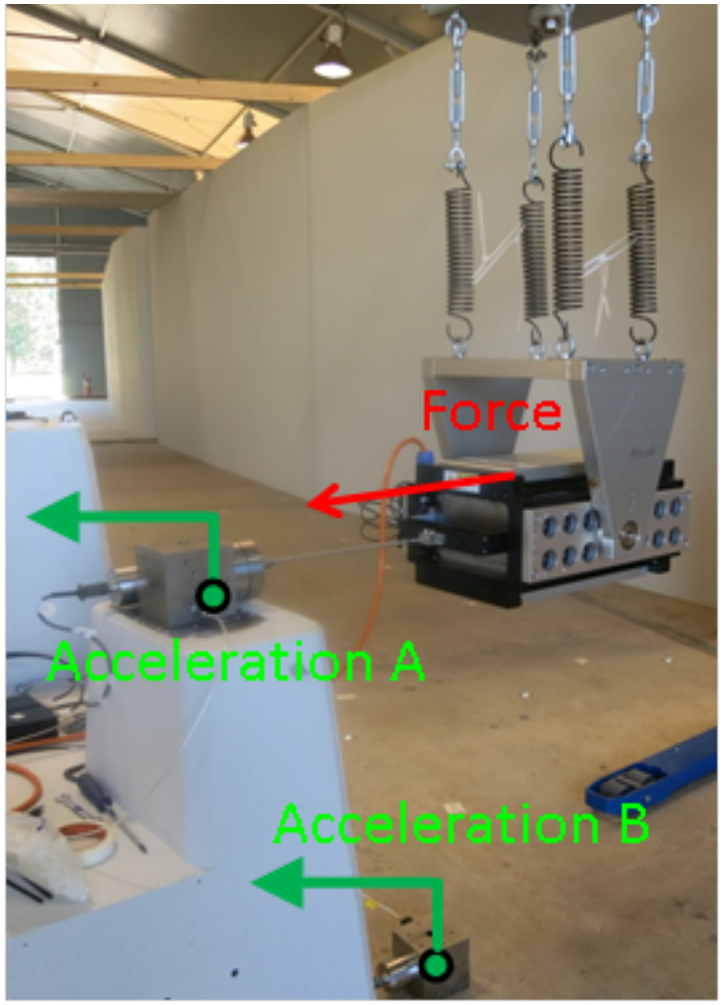
Regis Neuenschwander

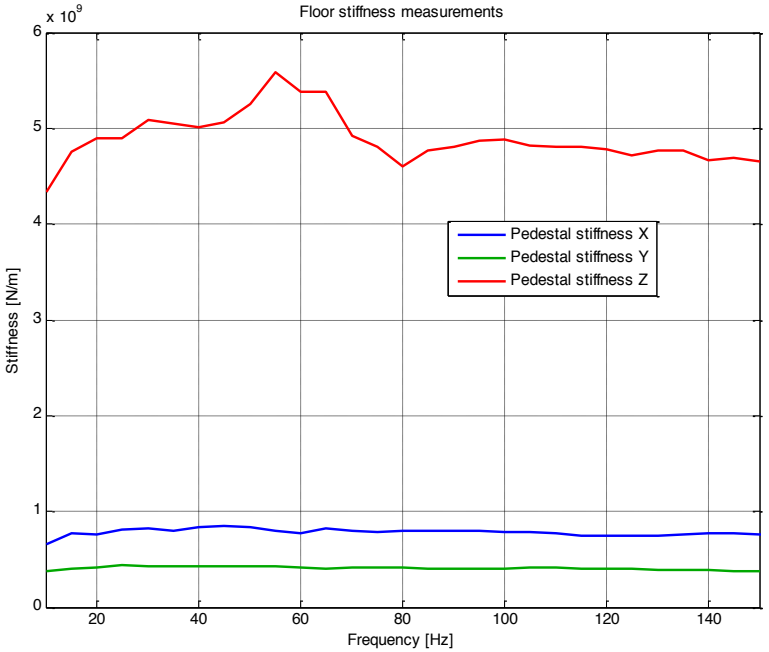
Setup for tests



Girder measurements - stiffness

Regis Neuenschwander

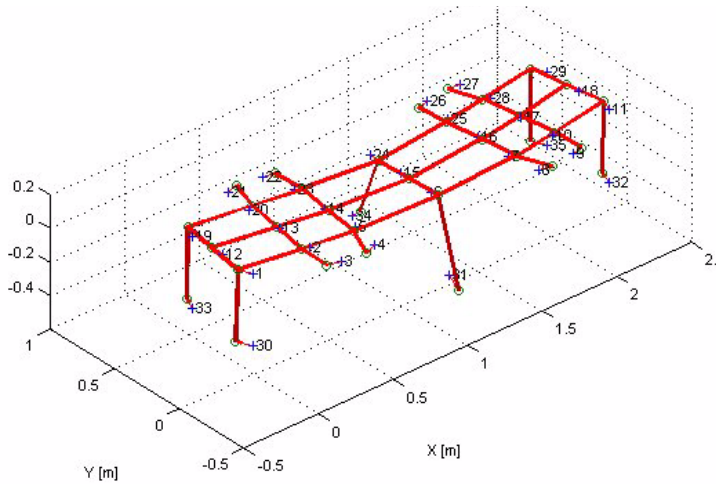


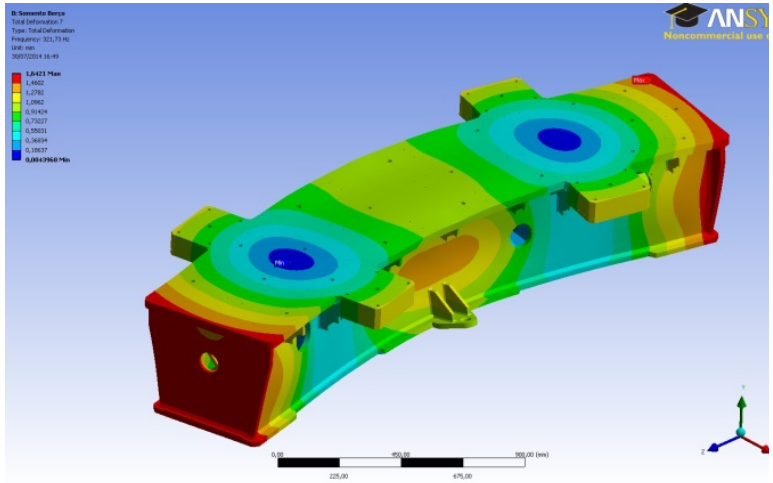


Direction	Stiff. [N/m]
X-direction	7.7e8
Y-direction	4.1e8
Z-direction, exc. floor	4.9e9
Z-direction, inc. floor	2.0e9

Girder measurements - vibration

Regis Neuenschwander

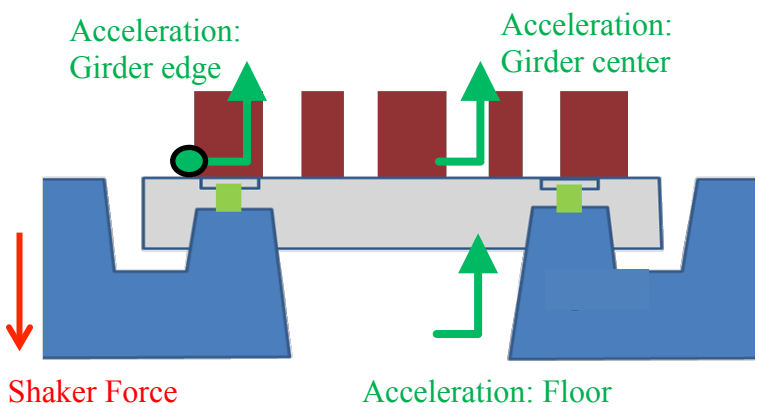


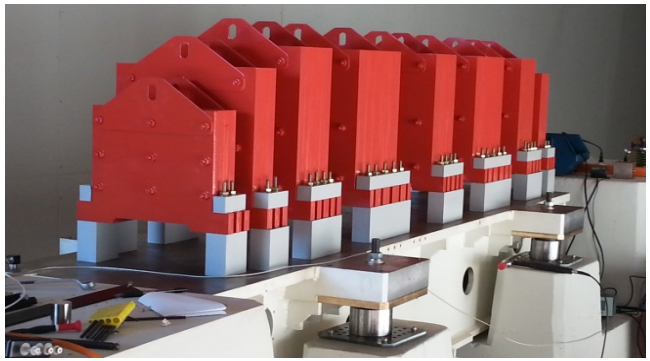


Mode	Freq. [Hz]	Calc. by FEM [Hz]
Y-bending	319	322
Torsion	333	352
Z-bending	354	354
Plate membrane mode	501	
Second order Z-bending	552	

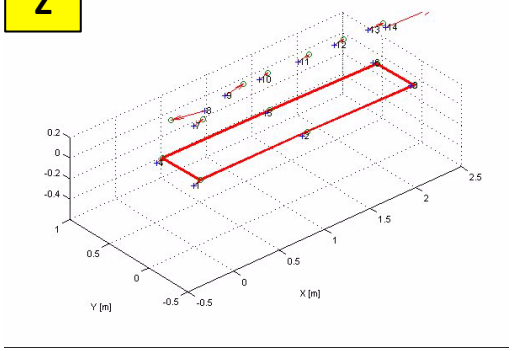
Girder measurements – transfer function

Regis Neuenschwander

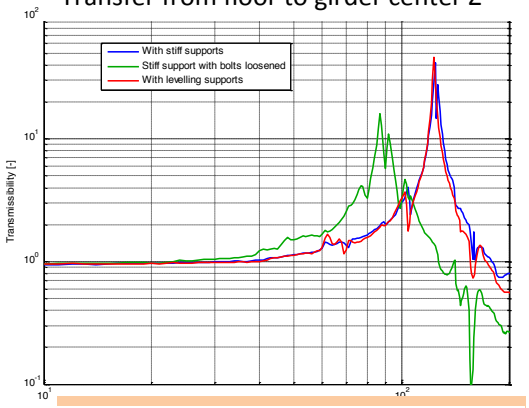




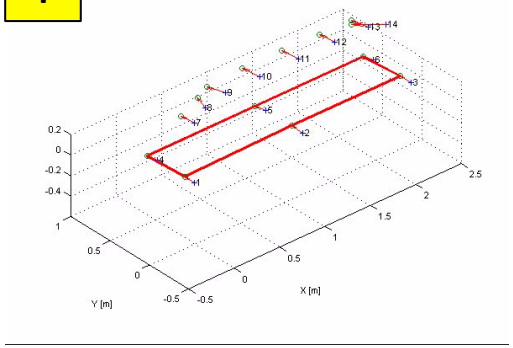
Z



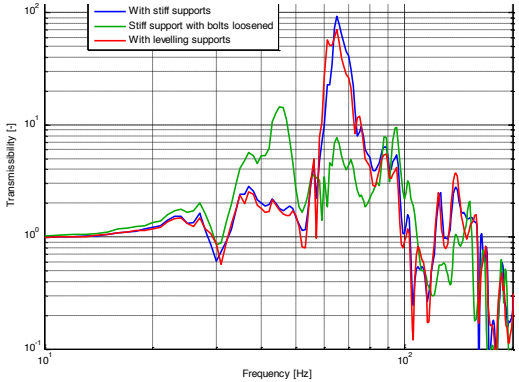
Transfer from floor to girder center Z



Y

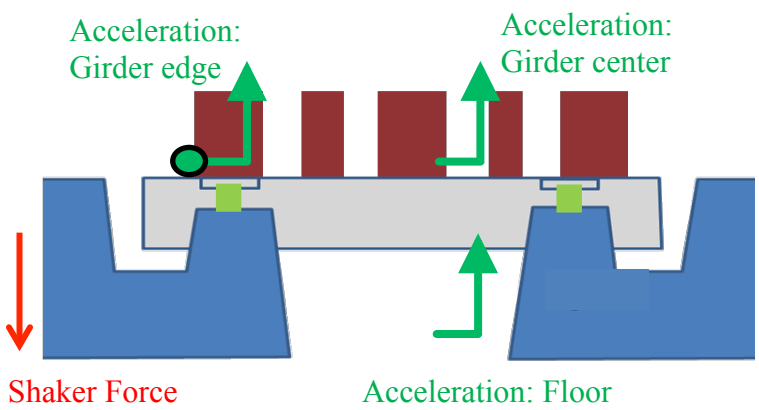


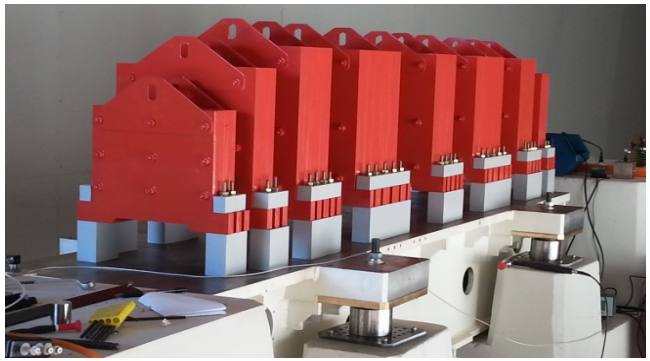
Transfer from floor to girder center Y



Girder measurements – transfer function

Regis Neuenschwander





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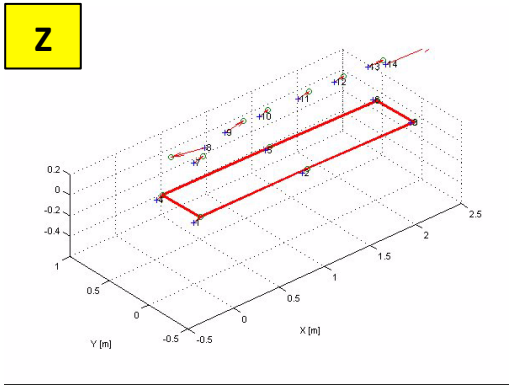
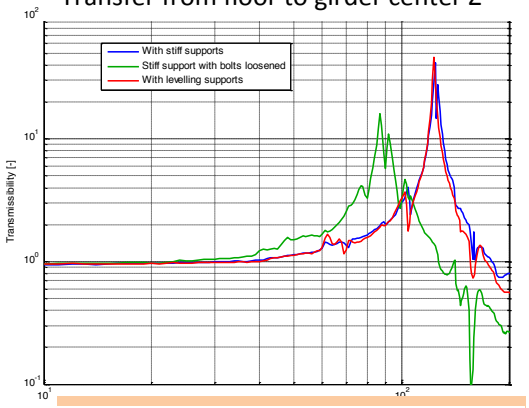


Transfer from floor to girder center Z



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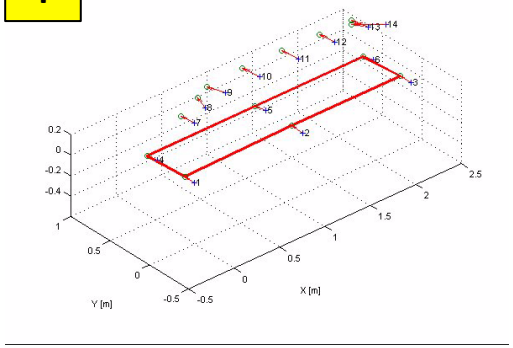
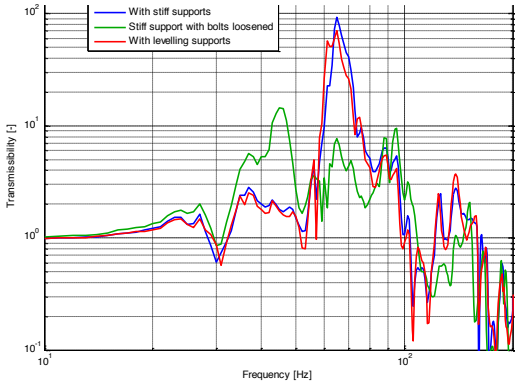
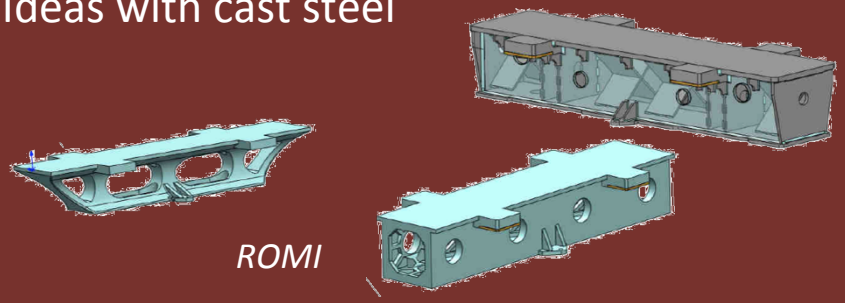


Transfer from floor to girder center Y



New Ideas with cast steel



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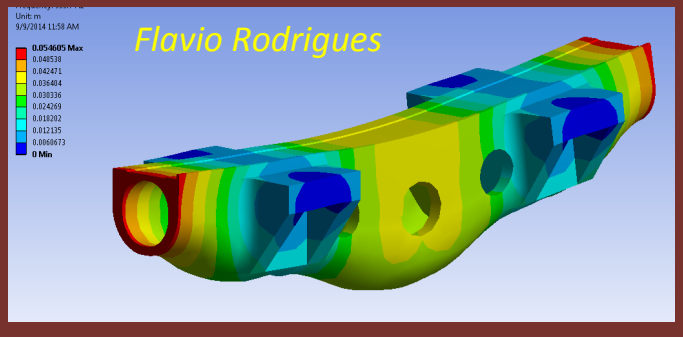

Flavio Rodrigues

Summary

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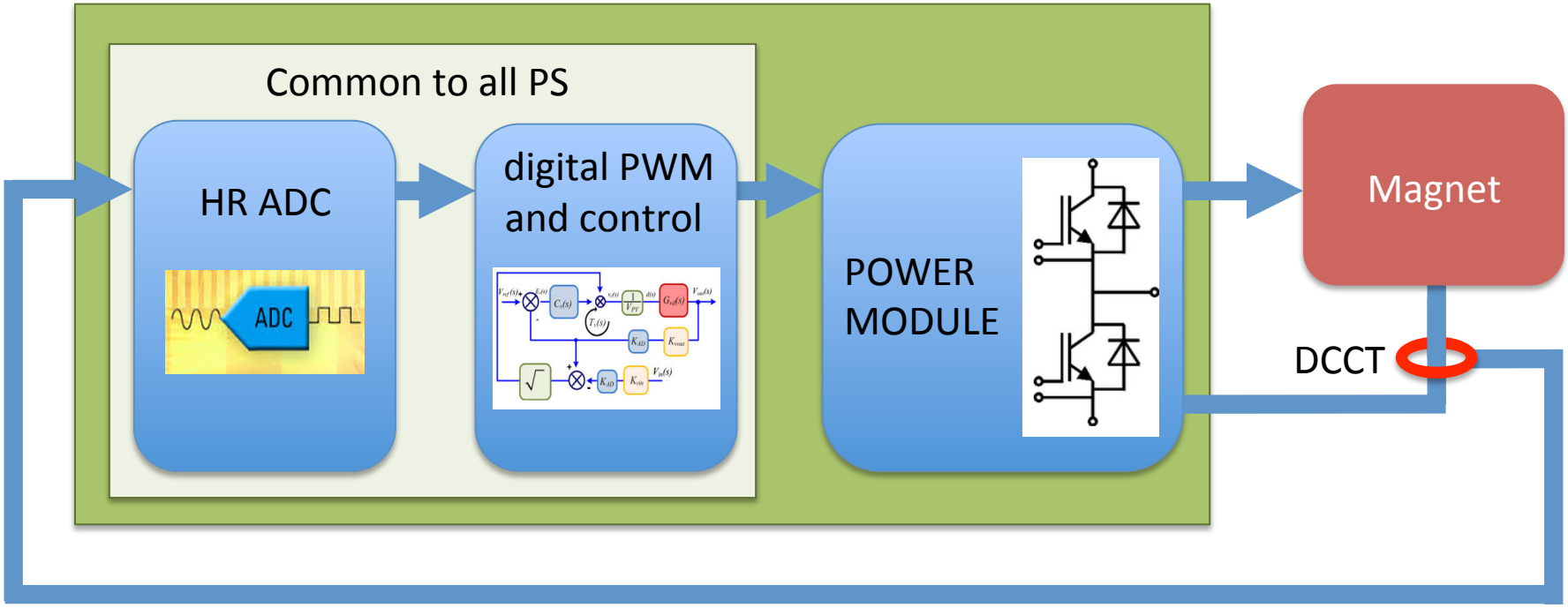
DC magnet power supplies

Cleber Rodrigues

All power supplies (~ 1000) will be controlled by a single type of high resolution digital PWM unit and a high resolution ADC. These two components are being developed at LNLS.

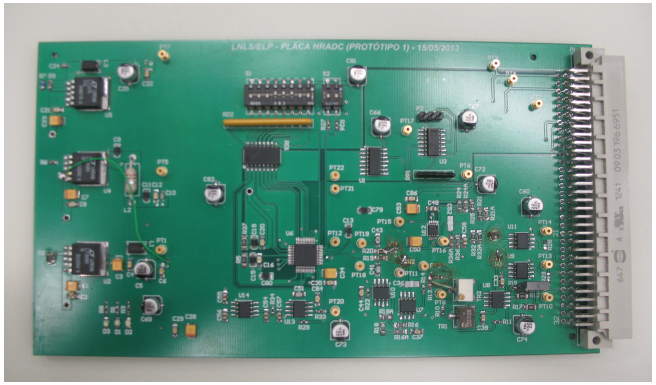


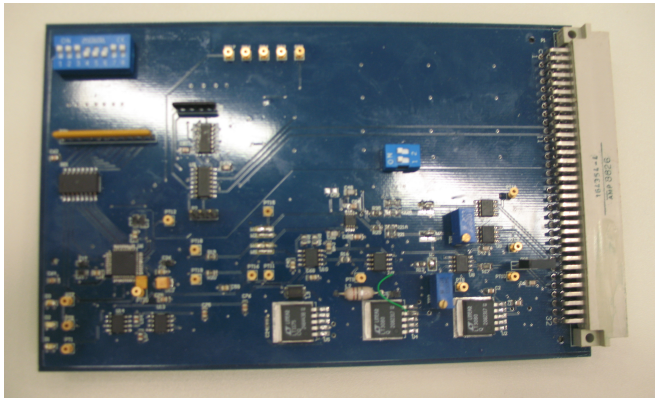
High resolution ADC board

Cleber Rodrigues

- ADC AD7634 (Analog Devices)
  - ✓ SAR, 18-bit
  - ✓ INL_{max}: ±2.5 LSB (9.5 ppm of FS)
  - ✓ up to 670 kS/s
- anti-aliasing filter (f_c = 30 kHz)
- SPI interface (40 MHz)
- Voltage external reference: MAX6350
  - ✓ TC: 1 ppm/ºC
  - ✓ 30 ppm/1000 h
- Input voltage amplifier: THS4130 (TI)
  - ✓ Input range: ±10 V
  - ✓ Fully-differential signal-chain
- Input current amplifier: INA106 (TI)
  - ✓ Input range: ±50 mA
  - ✓ Vishay precision burden resistor (TC: 2 ppm/ºC)

Parameters (wrt full scale)	V_{IN}	I_{IN}
24h stability [ppm]	3.4	4.6
TC [ppm/˚C]	1	2
Non linearity [ppm]	88	10.8

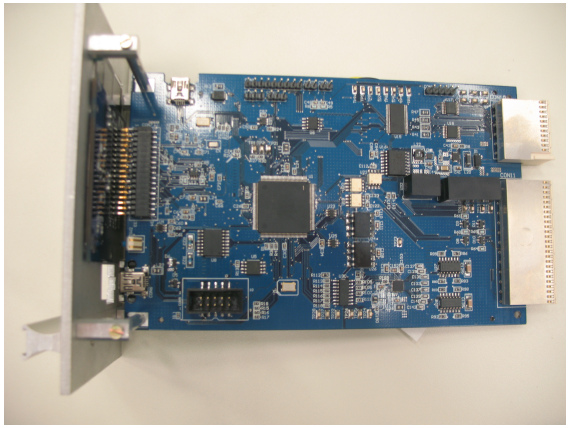




Digital PWM and control unit

Cleber Rodrigues

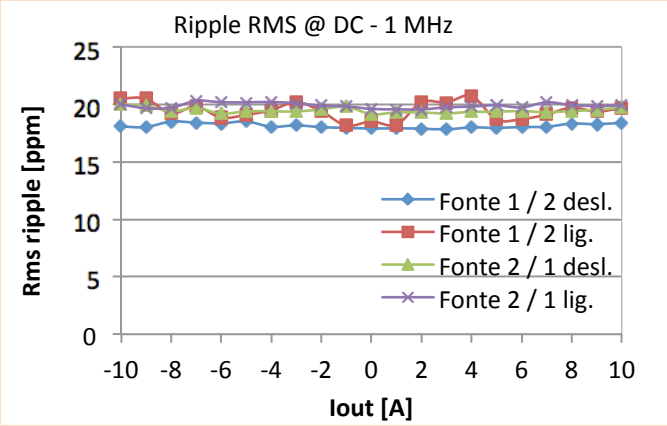
- Same hardware will be used in all power supplies.
- Controls the communication between the power supply and the high level system.
- Main characteristics:
  - ✓ 10Mbps RS-485 (control system), USB (PC control)
  - ✓ 8 High Resolution PWM outputs. Resolution = 150 ps.
  - ✓ 8 TTL inputs and 4 outputs
  - ✓ 8 analog input channels: +/-10V, 12 bits
  - ✓ Control loop up to 100KHz
  - ✓ Flexible parameters
  - ✓ Touchscreen display

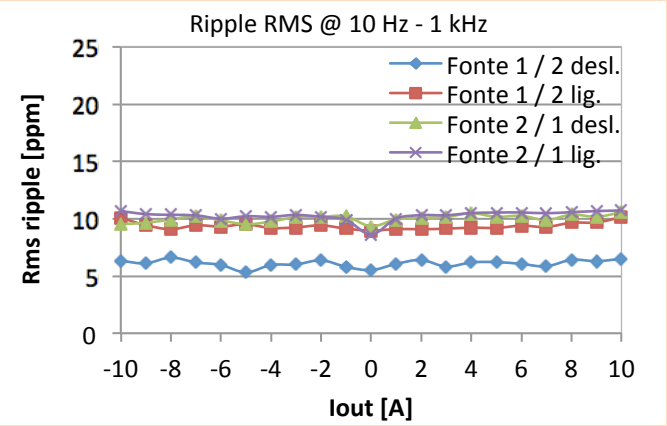


± 10 A power supply tests

Cleber Rodrigues

Ripple

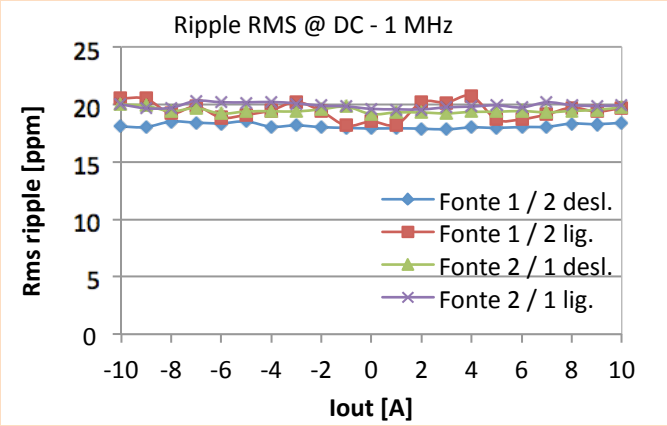


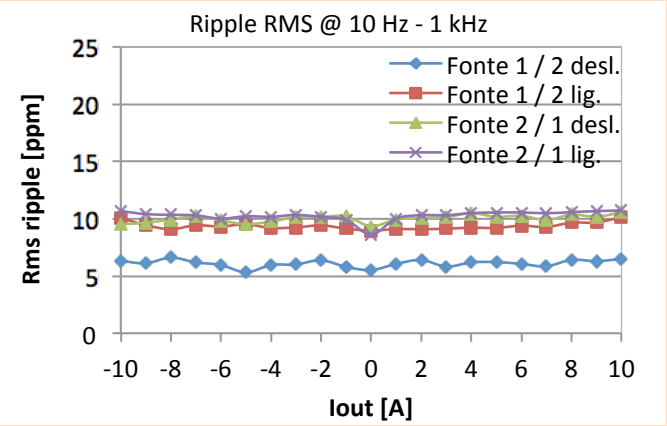


± 10 A power supply tests

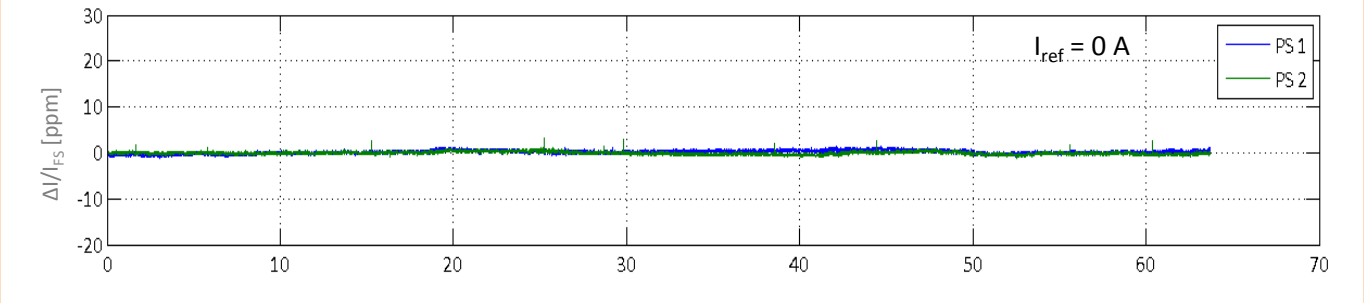
Cleber Rodrigues

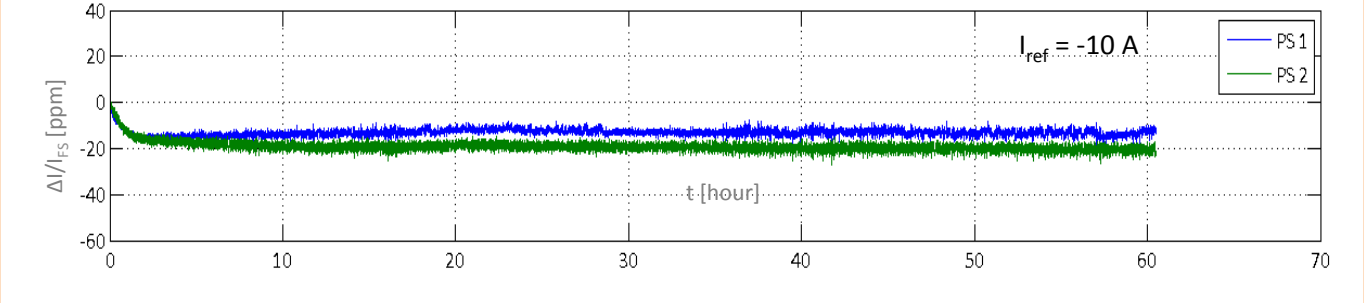
Ripple





Stability





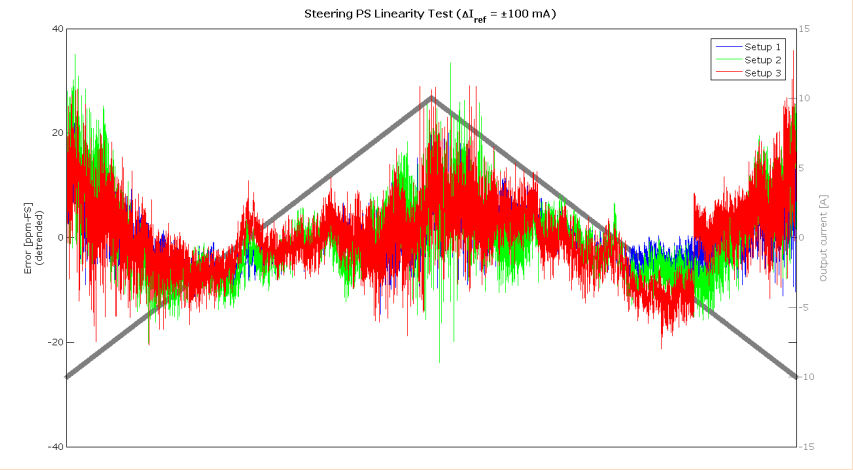
± 10 A power supply tests

Cleber Rodrigues

Linearity

Linearity test measurements

- Current: full scale variation.
- Current step of 100 mA every 25 s. 5 measurements/step.



± 10 A power supply tests

Cleber Rodrigues

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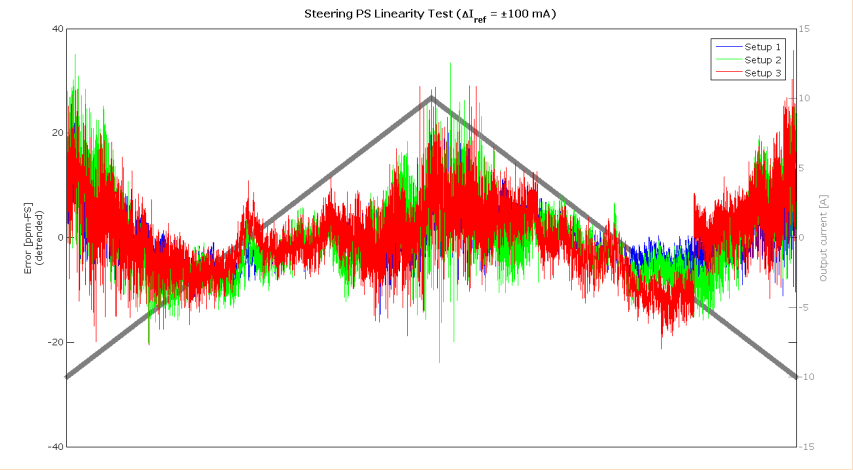
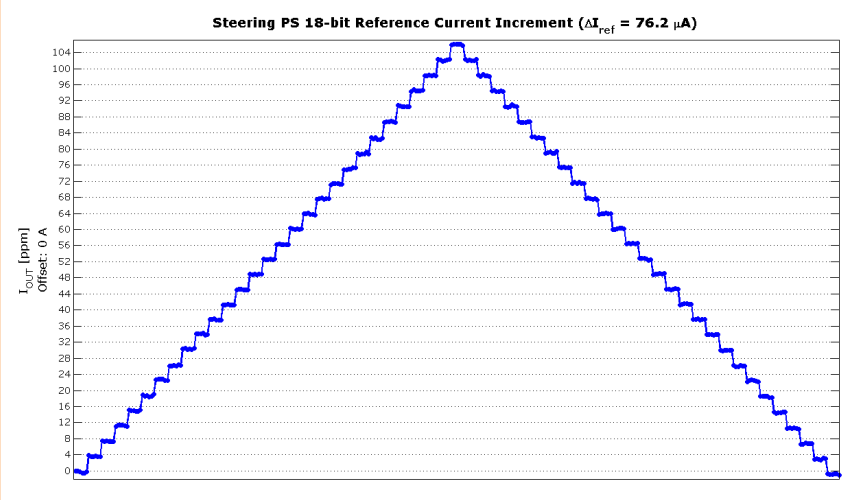


Resolution (18 bit)



Resolution test measurements

- One bit step every 25 seconds, 5 measurements/step.
- Measurements at I=0A, -5A and +5 A.

Summary

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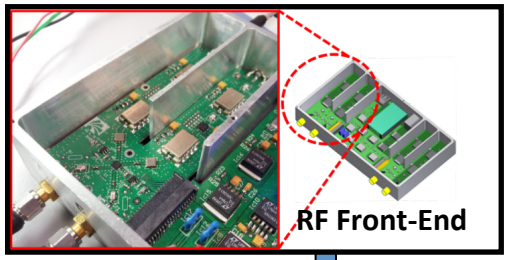
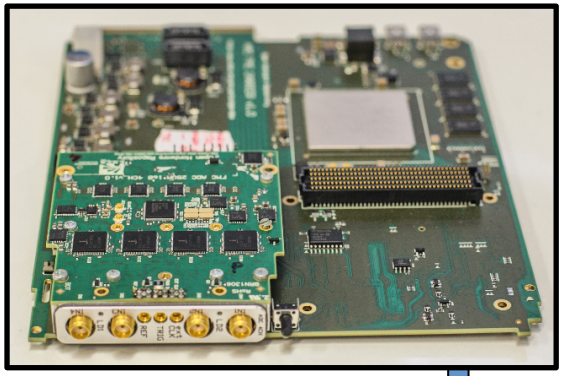
RF BPM electronics

Sergio Marques

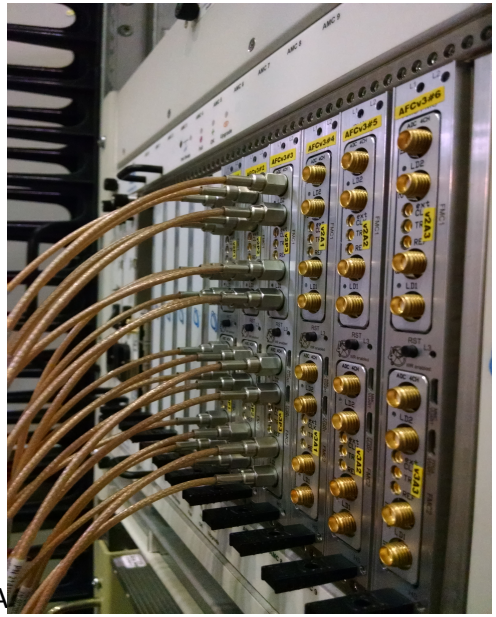


RF cables



ADC and FPGA boards

µTCA crate



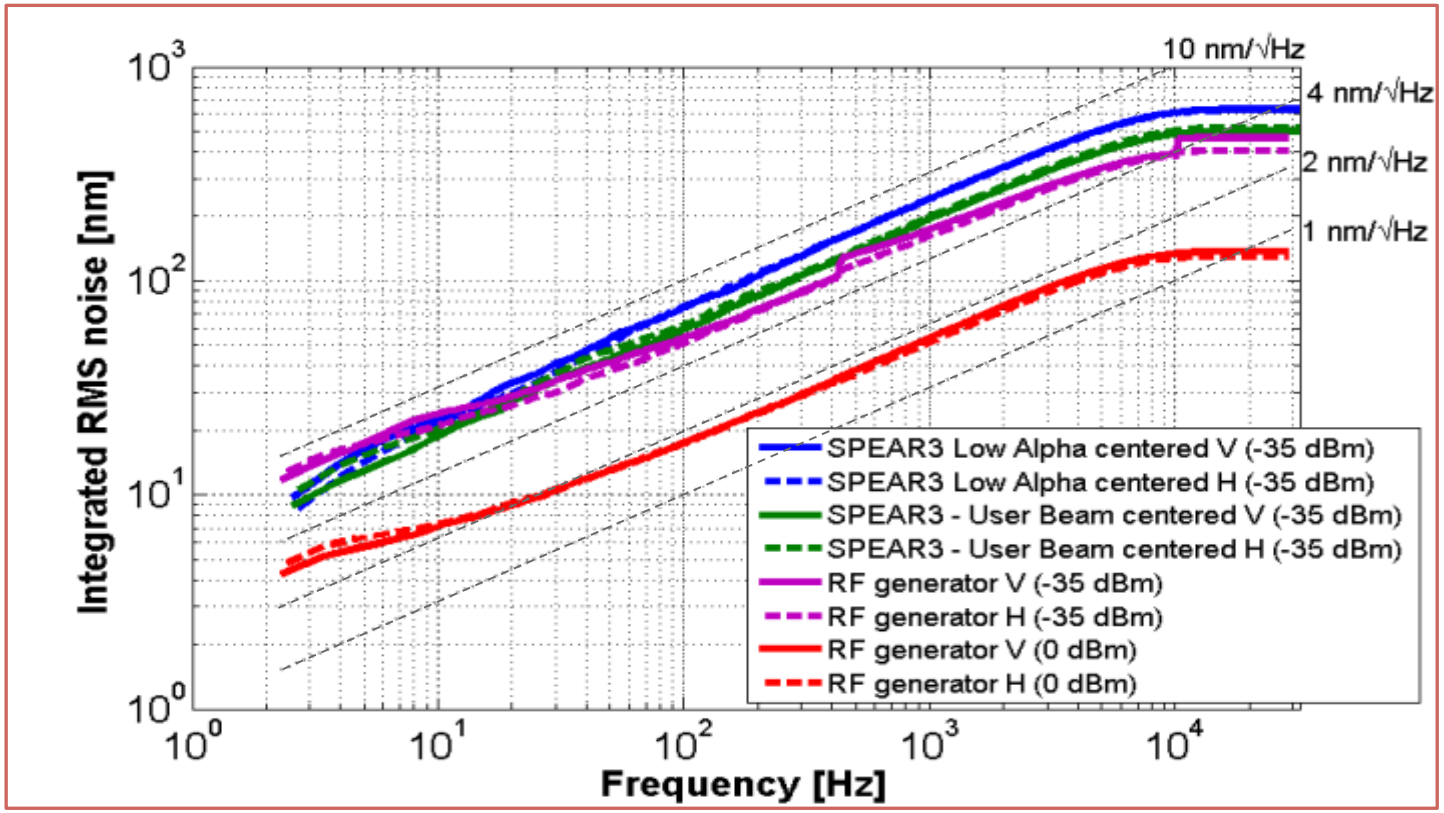
Requirements for Sirius RF BPM electronics:

Parameter	Value
Resolution (RMS) @ 0.1 Hz to 1 kHz	< 80 nm
Resolution (RMS) @ turn-by-turn full bandwidth	< 3 µm
1 hour position stability (RMS)	< 0.14 µm
1 week stability (RMS)	< 5 µm
Beam current dependence (decay mode)	< 1 µm
Beam current dependence (top-up mode)	< 0.14 µm
Filling pattern dependence	< 5 µm

RF BPM electronics tests

Sergio Marques

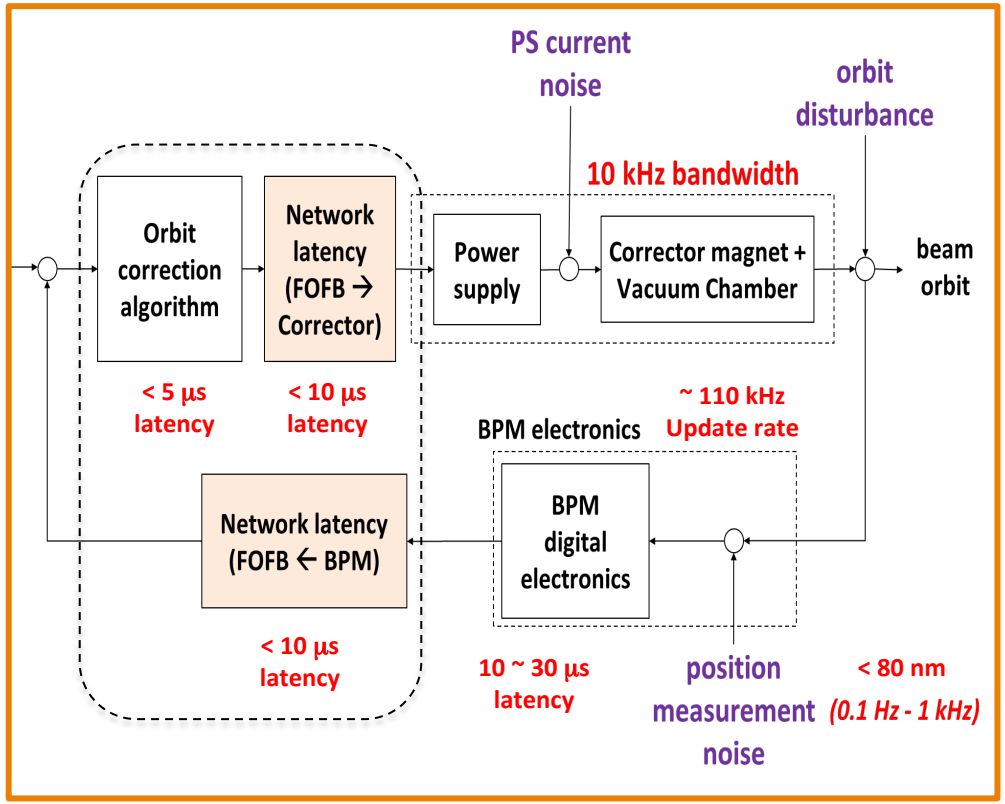
Tests with beam at SLAC (Spear 3)

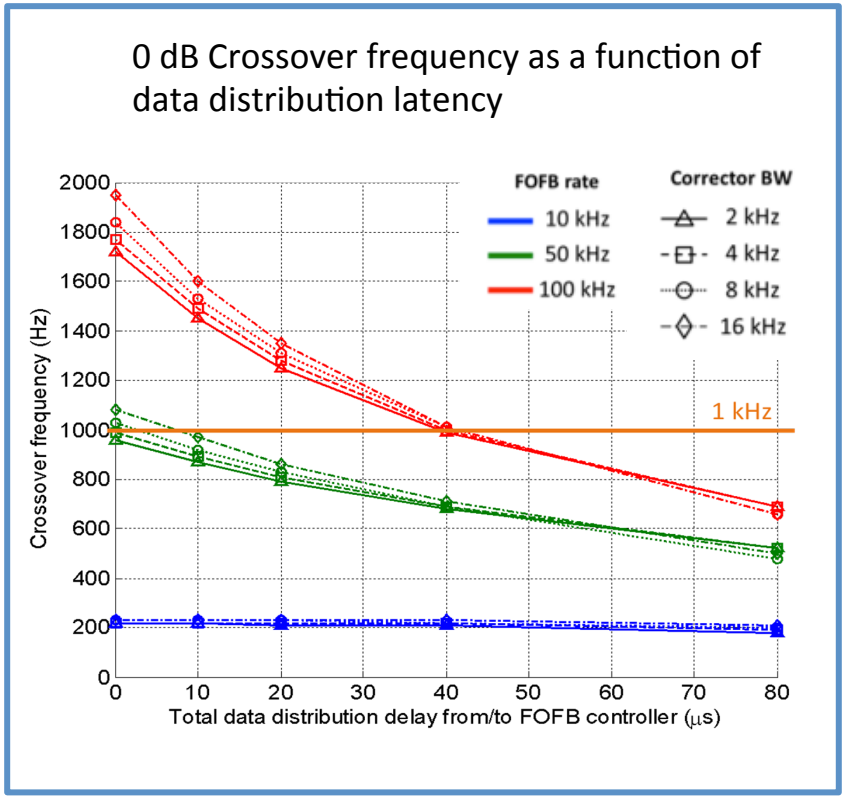


Results show that noise floor is comparable to available commercial solution.

FOFB model

Sergio Marques



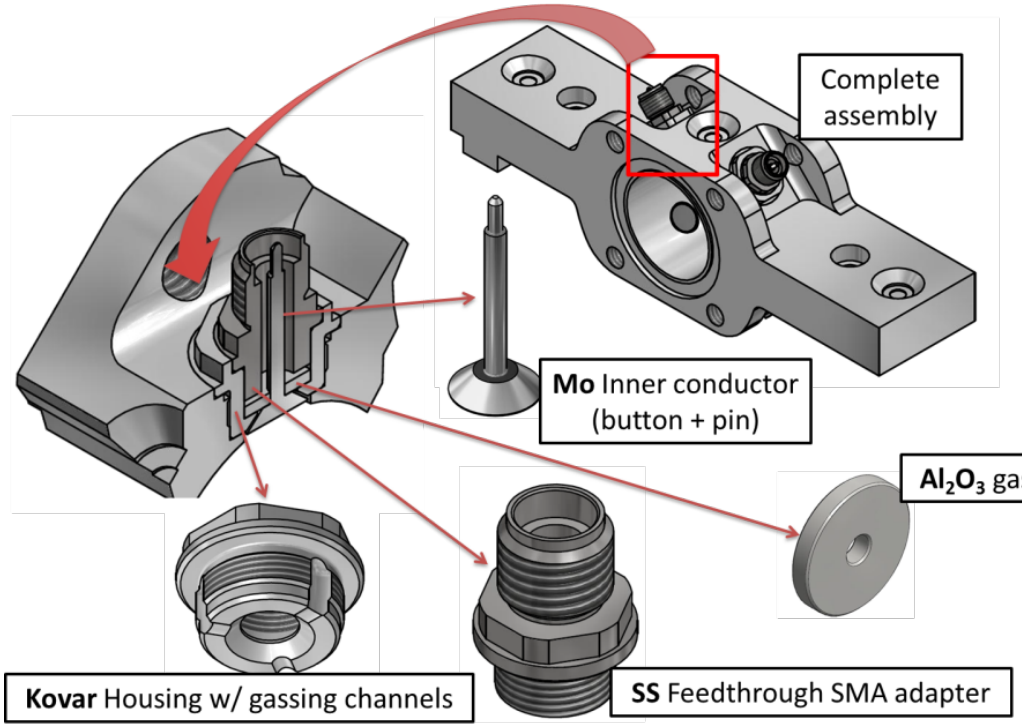


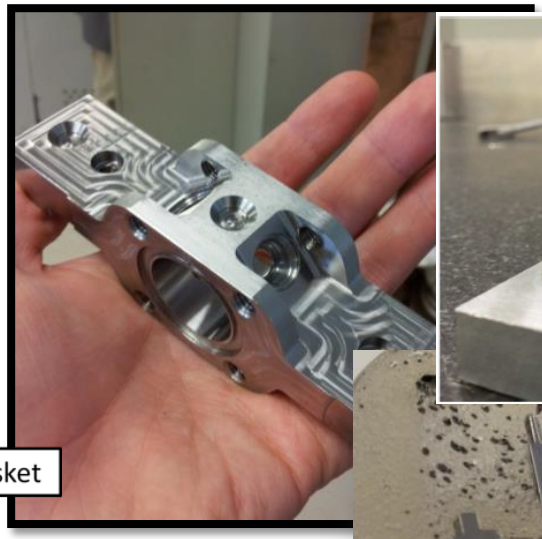
Simulation parameters:

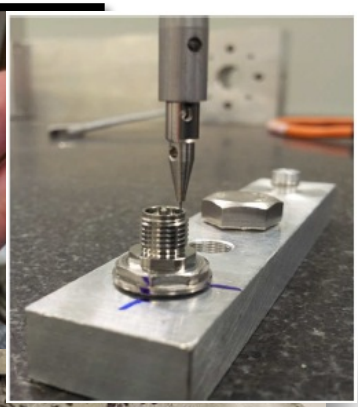
- *Update rate: from 10 kHz ~100 kHz*
- *Vacuum chamber bandwidth = 15 kHz*
- *BPM filtering group delay = 3 x FOFB sampling period (from 300 µs to 30 µs)*
- *PI controller tuned for maximum disturbances amplification of 5 dB*

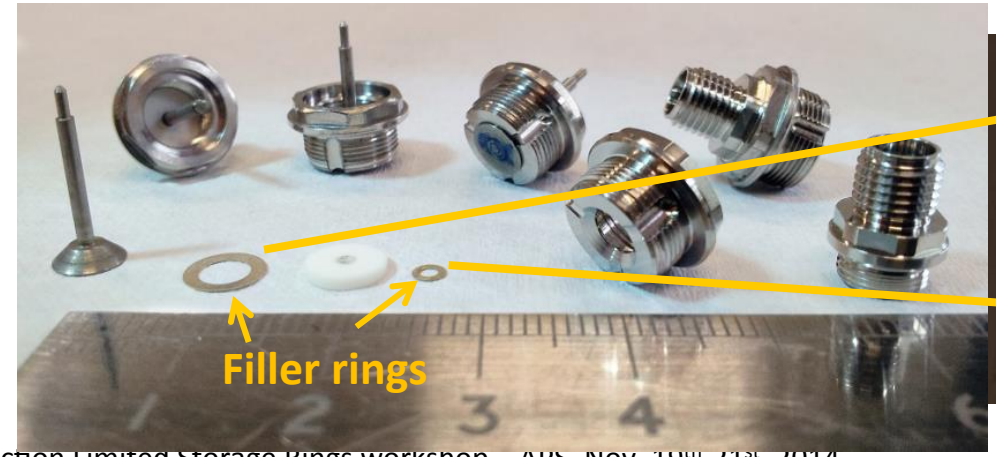
Overview: BPM (in-House) Prototype

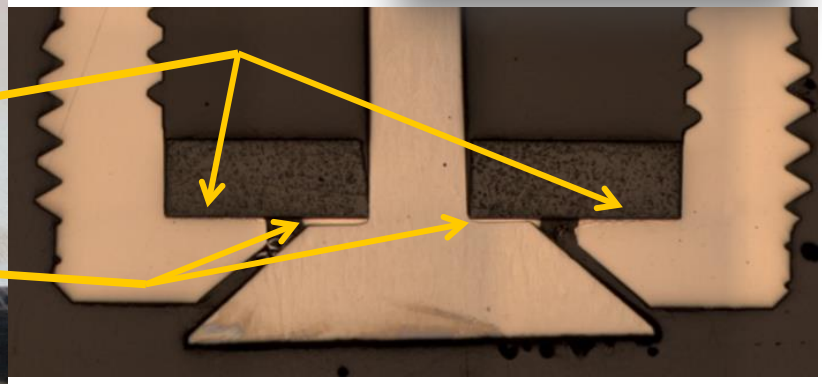
Sergio Marques





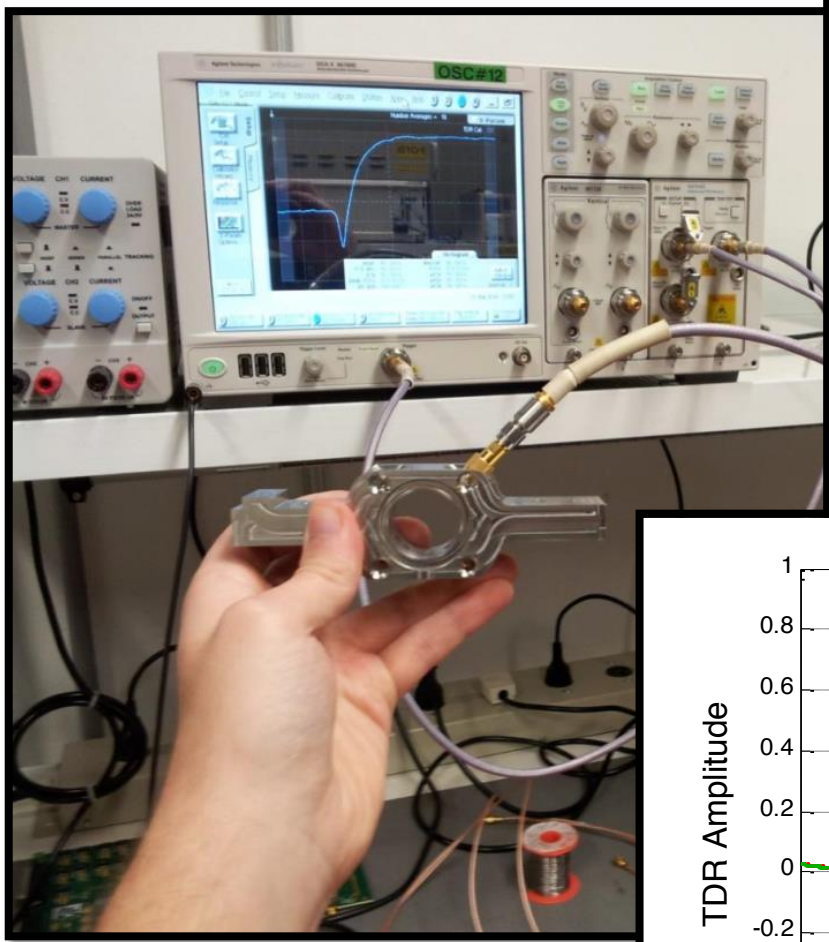


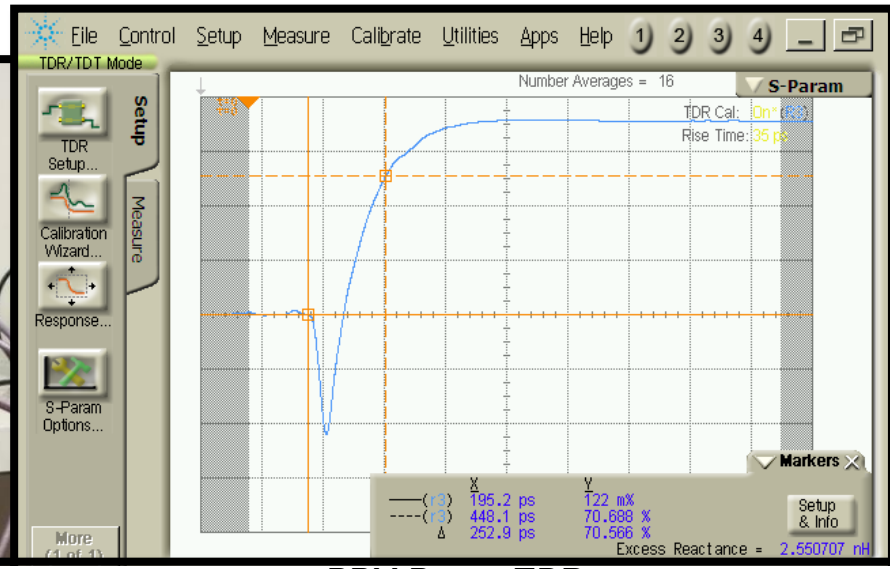


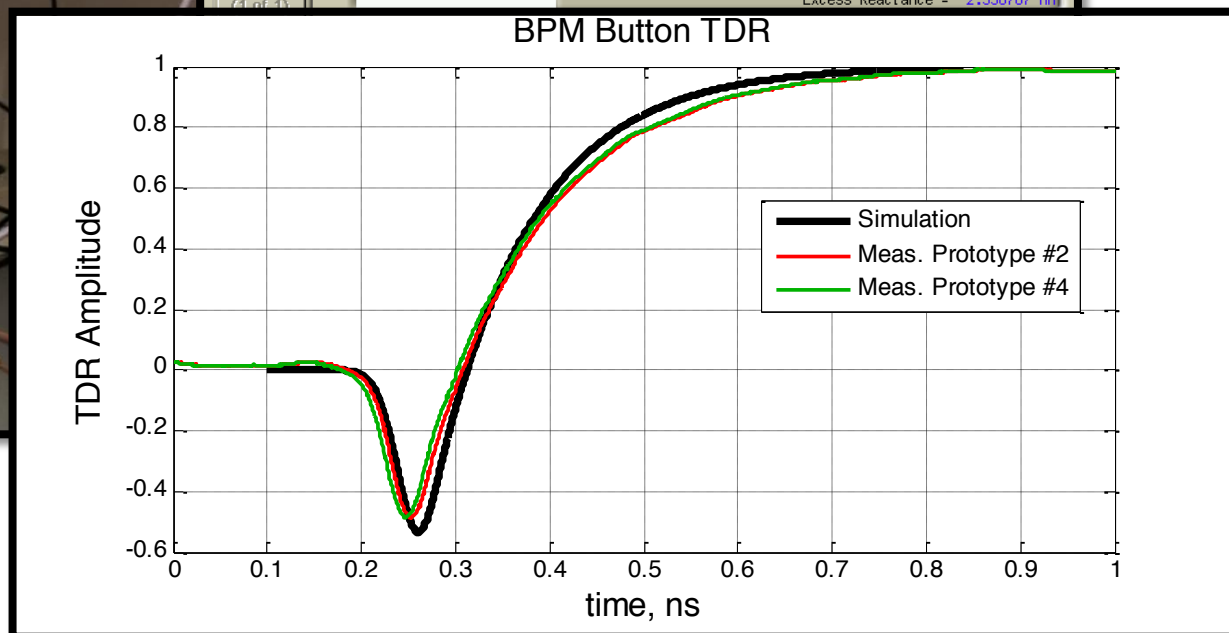


Overview: BPM (in-House) Prototype

Sergio Marques







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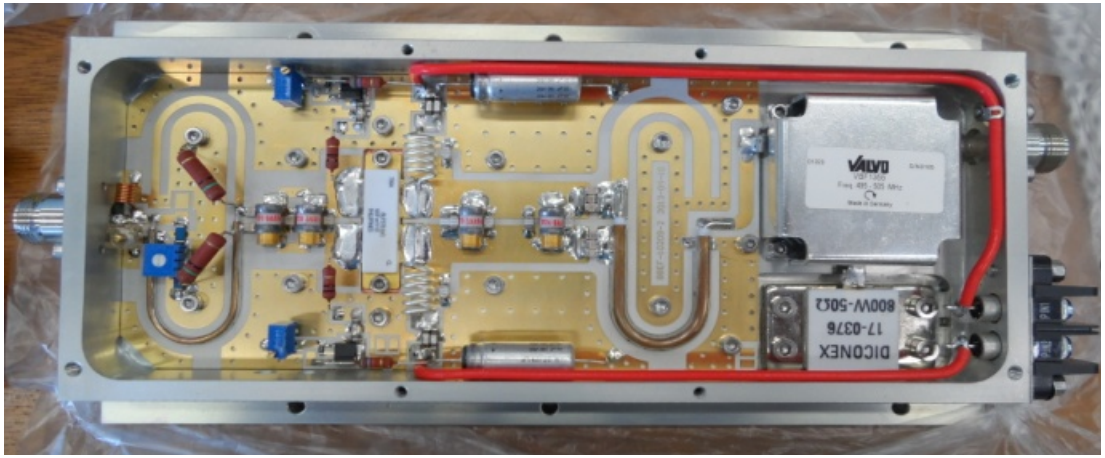
RF System

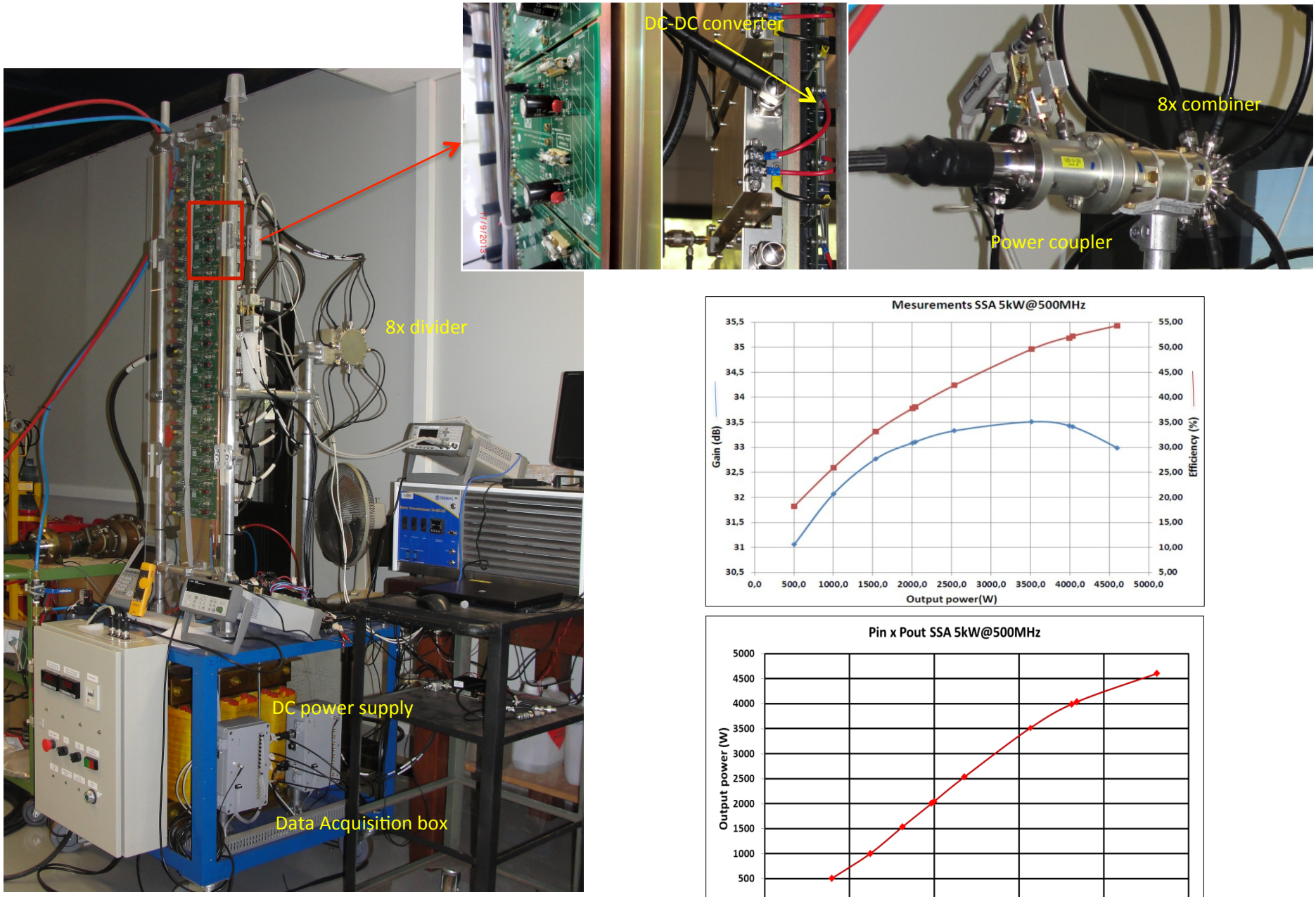
Ruy Farias

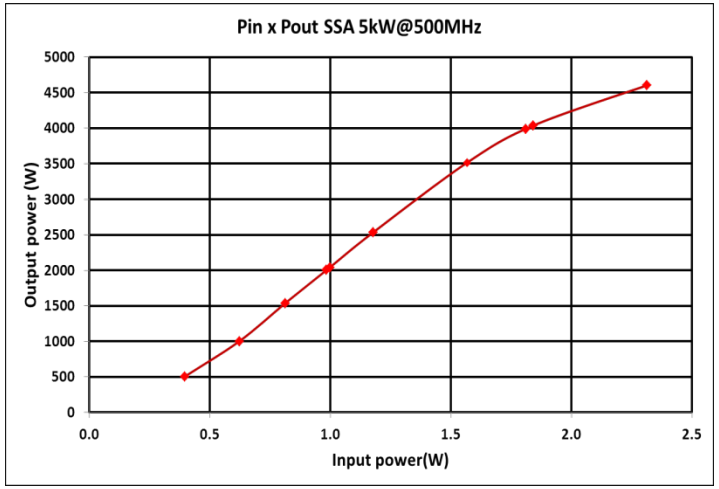
- Booster RF System
  - One 5-cell Petra cavity driven by a 45 kW Solid State Amplifier
- 4 kW Prototype for the booster Solid State Amplifier (1/12)
  - Module with BLF578 NXP power LDMOS transistor – 600W maximum output power
  - Improvements for higher output power: soldering, components in the output line
  - 4 kW amplifier assembled for validation of components (modules, power supplies, power detectors, combiners etc) and data acquisition system.
  - Fatigue tests: RF on – RF off (2 min) > 7000 cycles (~20 yrs operation)
  - Tested for maximum power and 3 Hz cycling for more than 500 h without failures



500 MHz Amplifier Module
Gain = 17.46 dB (55.5 X) @ 500W;
= 17.70 dB (60 X) @ 300W;

Ruy Farias





4kW (8 x 500W) @500MHz SSA prototype

Summary

- The Sirius project
- Buildings
- Accelerator Physics
- Magnets
- Girders
- Power Supplies
- Diagnostics
- RF
- Vacuum
- Beamlines

Storage ring: **Vacuum system layout**

Rafael Seraphim

Compact lattice and small aperture magnets

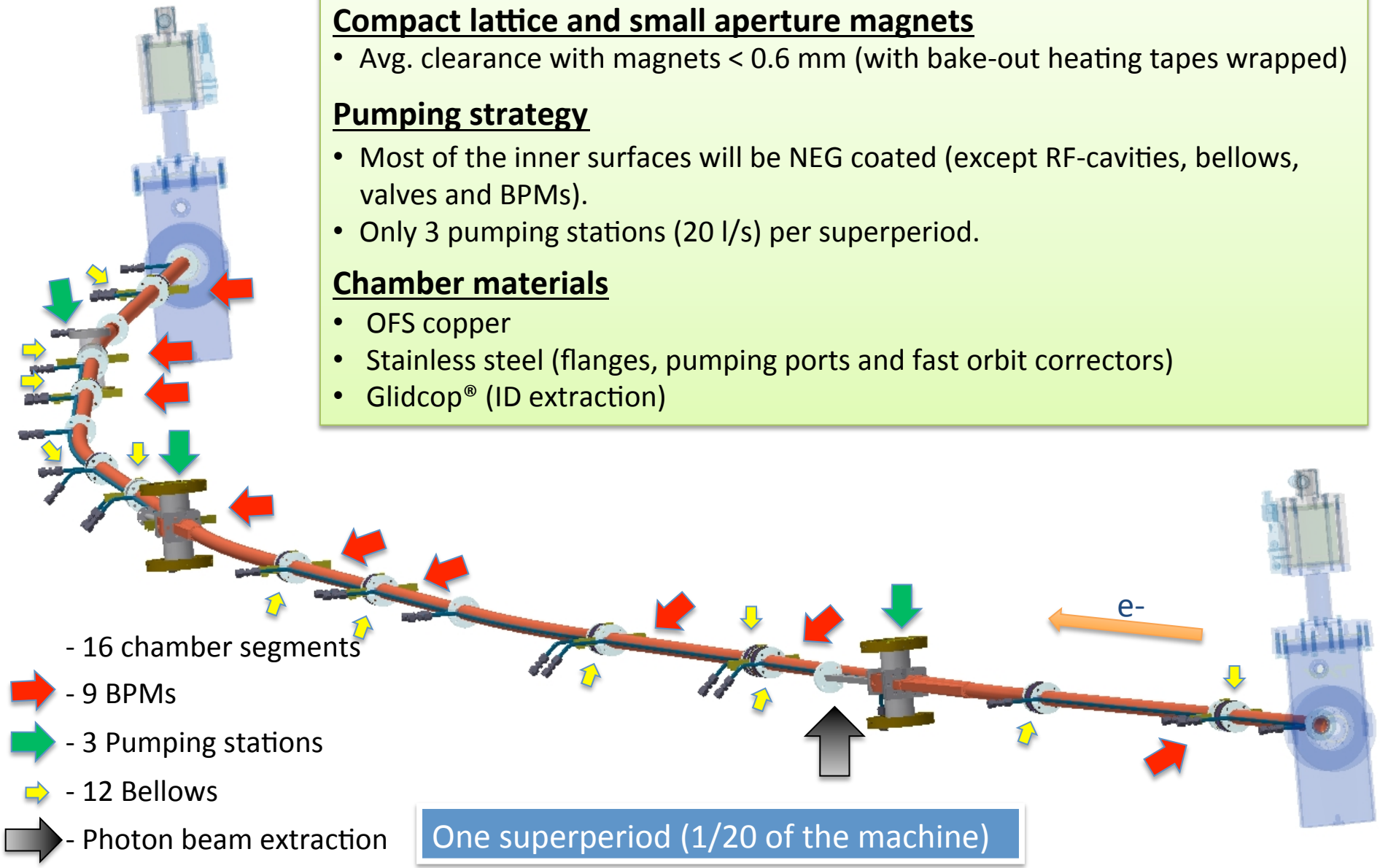
- Avg. clearance with magnets < 0.6 mm (with bake-out heating tapes wrapped)

Pumping strategy

- Most of the inner surfaces will be NEG coated (except RF-cavities, bellows, valves and BPMs).
- Only 3 pumping stations (20 l/s) per superperiod.

Chamber materials

- OFS copper
- Stainless steel (flanges, pumping ports and fast orbit correctors)
- Glidcop® (ID extraction)



One superperiod (1/20 of the machine)

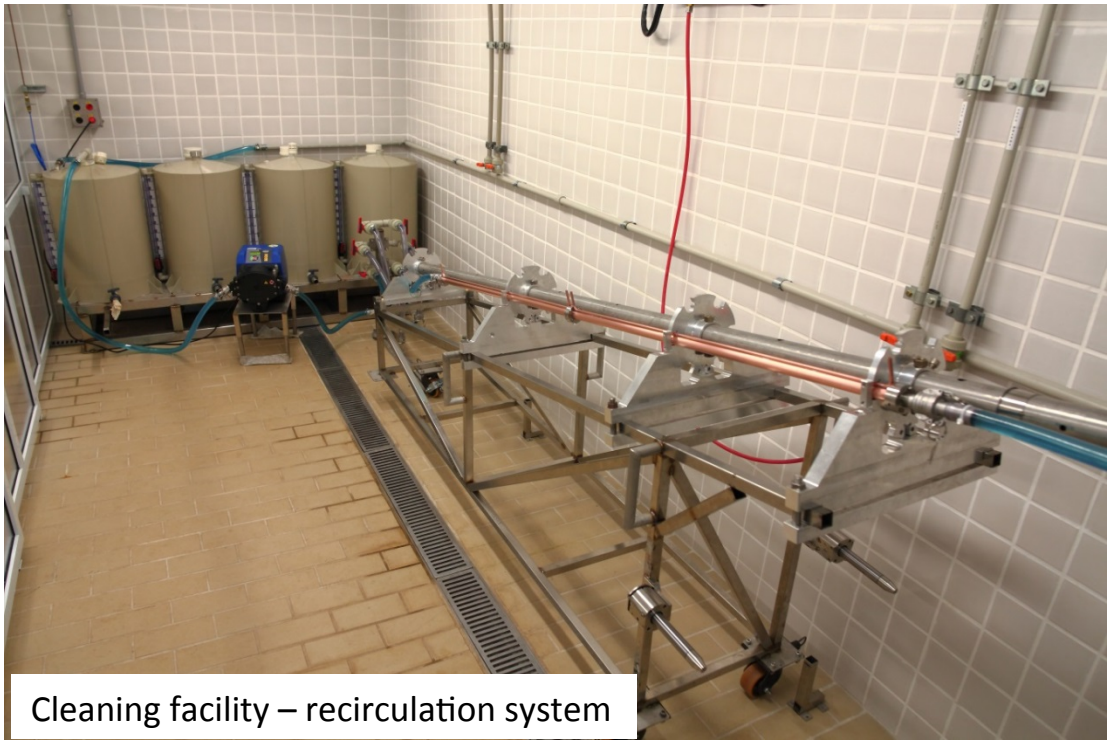
Storage ring: **Cleaning process and NEG coating**

Rafael Seraphim

A new cleaning procedure has been developed to avoid agressive chemicals

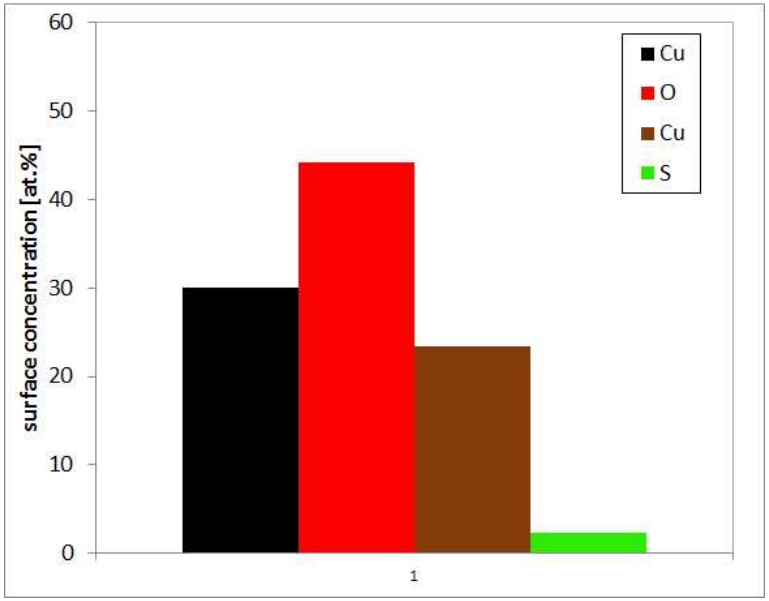
- 10% ammonium persulfate + 0,1% amonium acetate (etching ~ 15 µm)
- 5% H_2O_2 (helps to remove silver insoluble residuals)
- 5% ammonium citrate (passivation)

-- Surface roughness < 0.4 µm (Ra) --



Cleaning facility – recirculation system

XPS analysis – LNLS cleaned surface



Cleaning quality criteria:

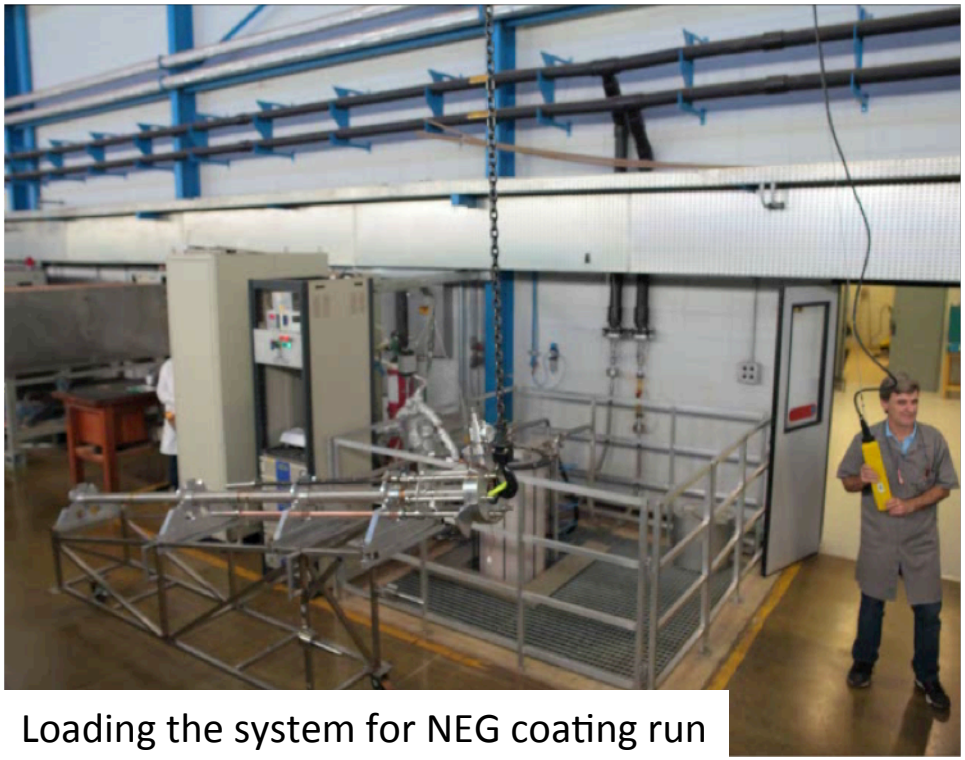
- Atomic % C < 44
- Halogens (ex. F, Cl) < 1%
- Other contaminants will be analyzed

Storage ring: Cleaning process and NEG coating

Rafael Seraphim

Main characteristics

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



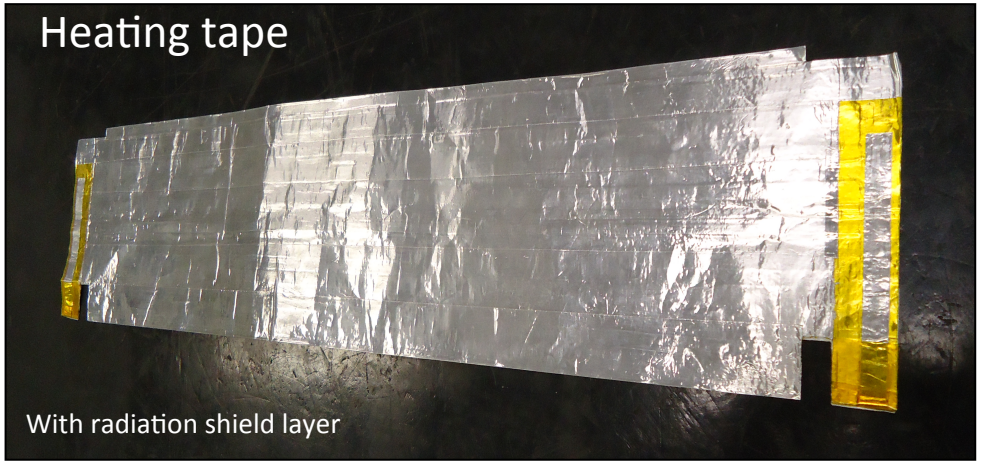
Loading the system for NEG coating run

Storage ring: **Bake-out for NEG activation**

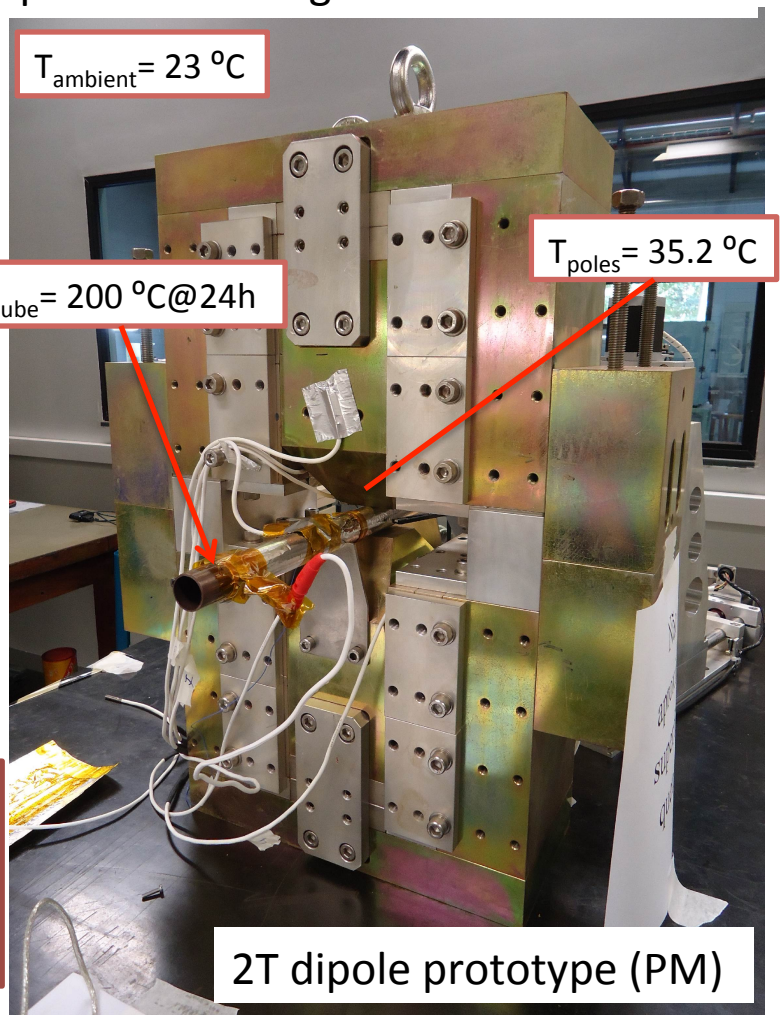
Rafael Seraphim

In-situ bake-out for NEG activation (200 °C@24h)
An thin polyimide heating tape (developed by a Brazilian company) is used.

- Thickness < 0.4 mm
- Max. operation temperature 210 °C



Impact of in-situ NEG activation on permanent magnets.



Magnet heating results

ΔT_{poles} = 12.2 °C

ΔT_{PM} = 8.8 °C

Summary

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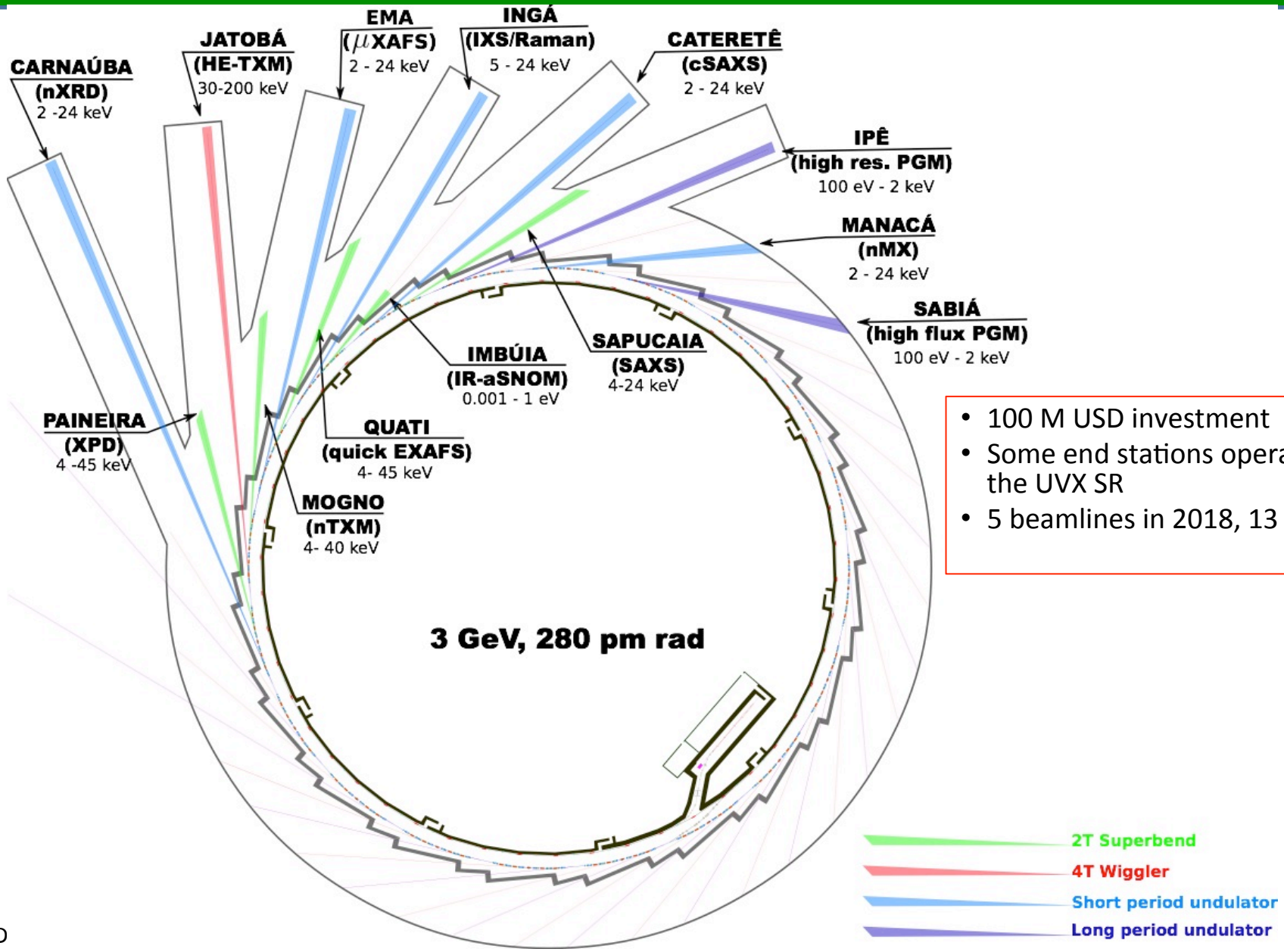
Beamlines

Harry Westfahl Jr.



- 100 M USD investment
- Some end stations operating at the UVX SR
- 5 beamlines in 2018, 13 in 2020

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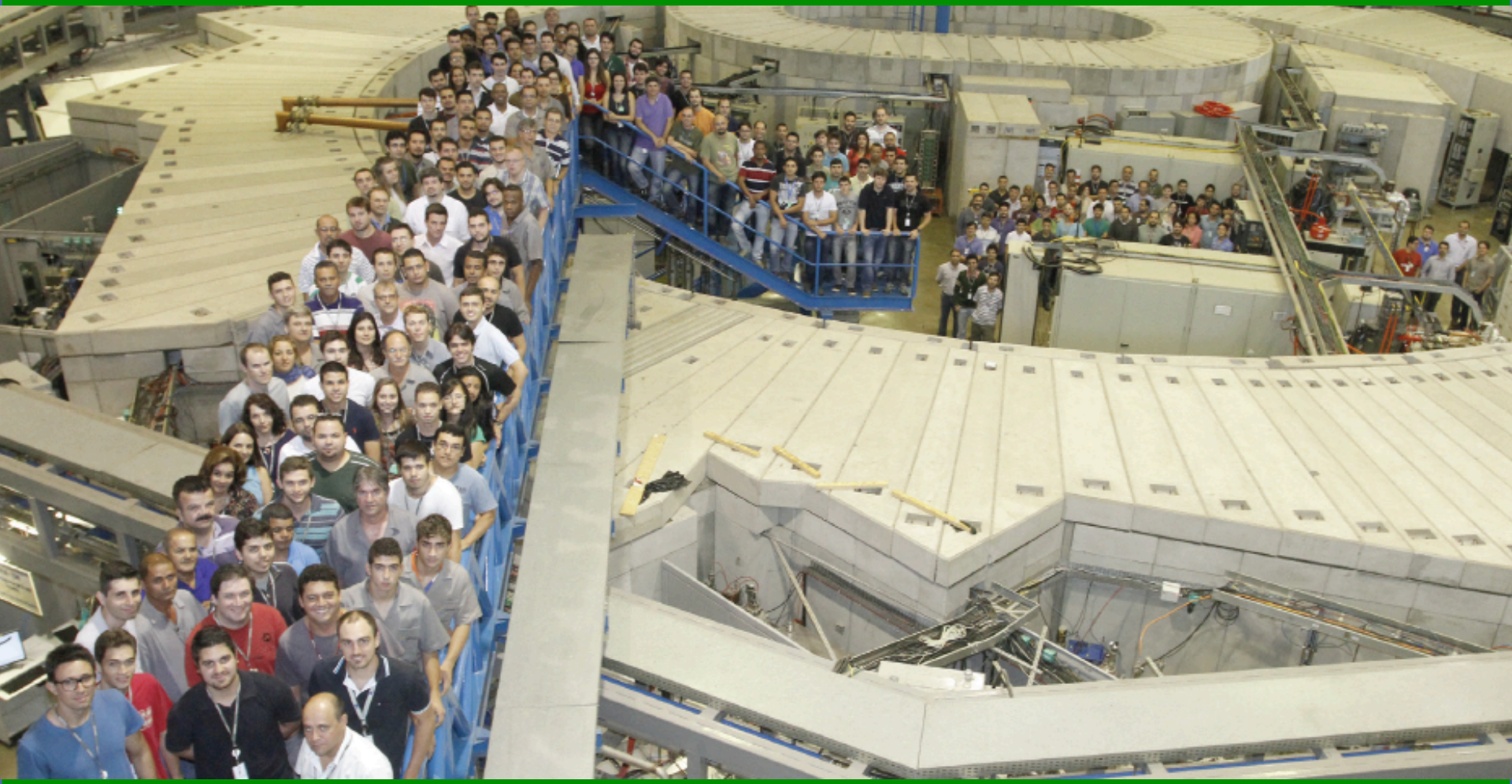
Thank you!