

SOLUÇÕES DE INSTRUMENTAÇÃO E INFRAESTRUTURA PARA AS LINHAS DE LUZ DO SIRIUS



Lucas Sanfelici

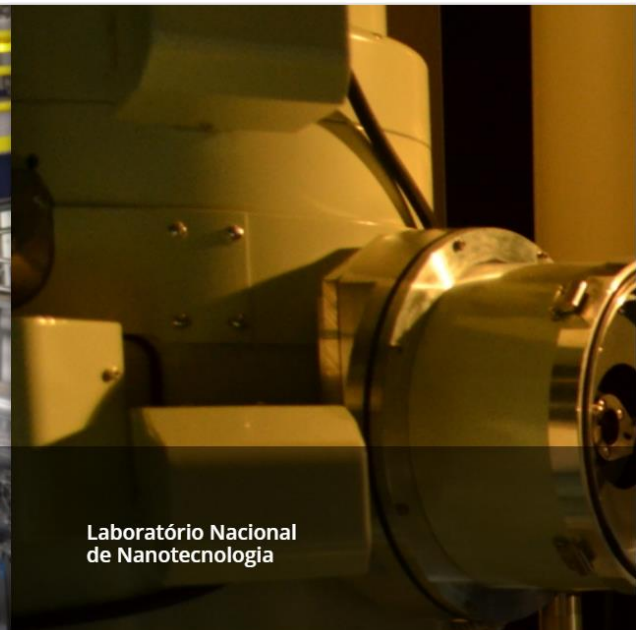
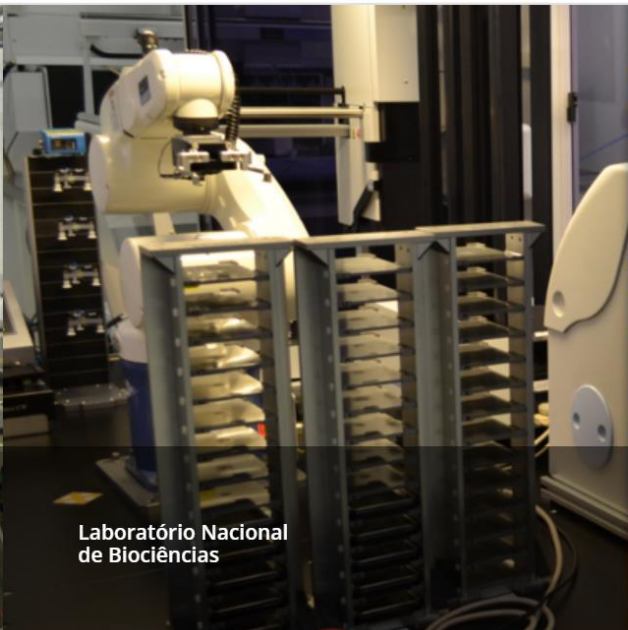
Grupo de Suporte à Instrumentação das Linhas de Luz (SIL)

Laboratório Nacional de Luz Síncrotron – Centro Nacional de Pesquisas em Energia e Materiais



Organização privada sem fins lucrativos contratada pelo MCTIC para gerir o complexo de laboratórios

CNPEM - Eixos de Atuação



**Instalações abertas a
usuários externos**



**Pesquisa e
desenvolvimento *in-house***



**Apoio à geração
de inovação**



**Treinamento, educação
e extensão**

Fontes de Luz Síncrotron pelo Mundo



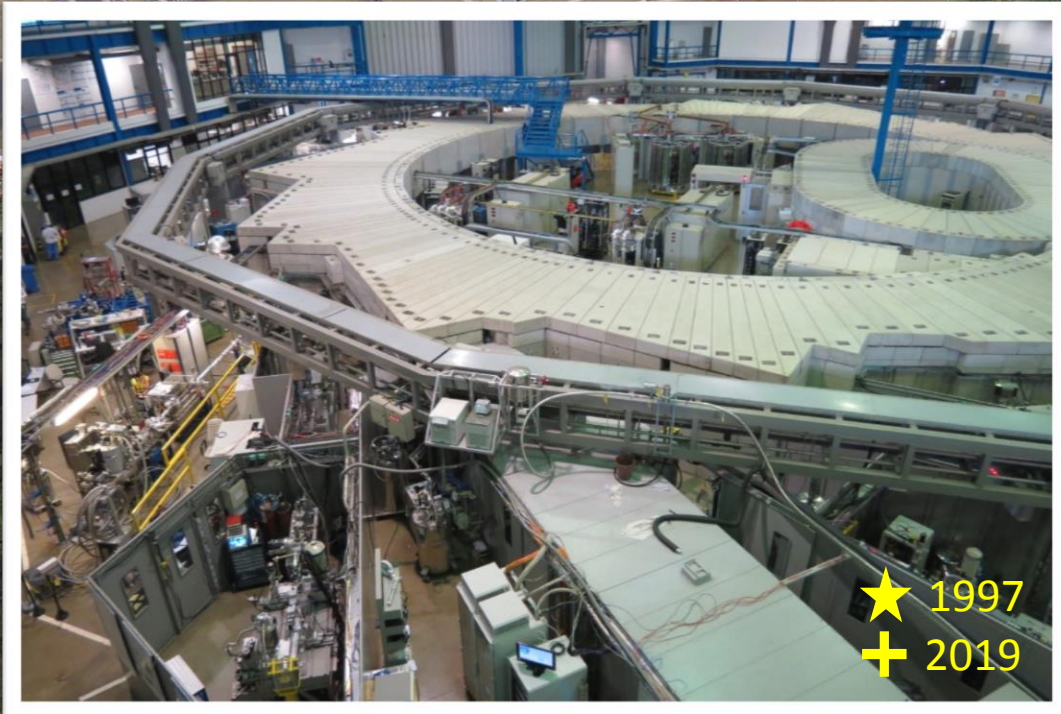
Campinas - SP



> 50 aceleradores do tipo

<https://lightsources.org/lightsources-of-the-world/>

Anéis UVX e SIRIUS



July 2019



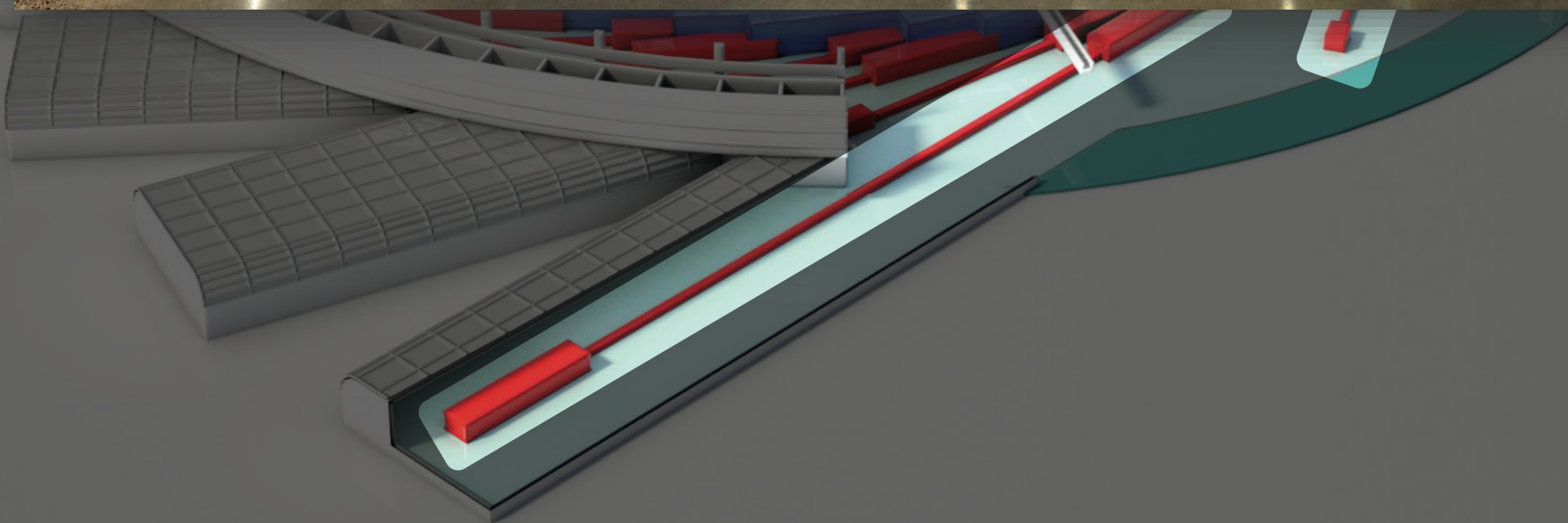


LINAC
(150 MeV)

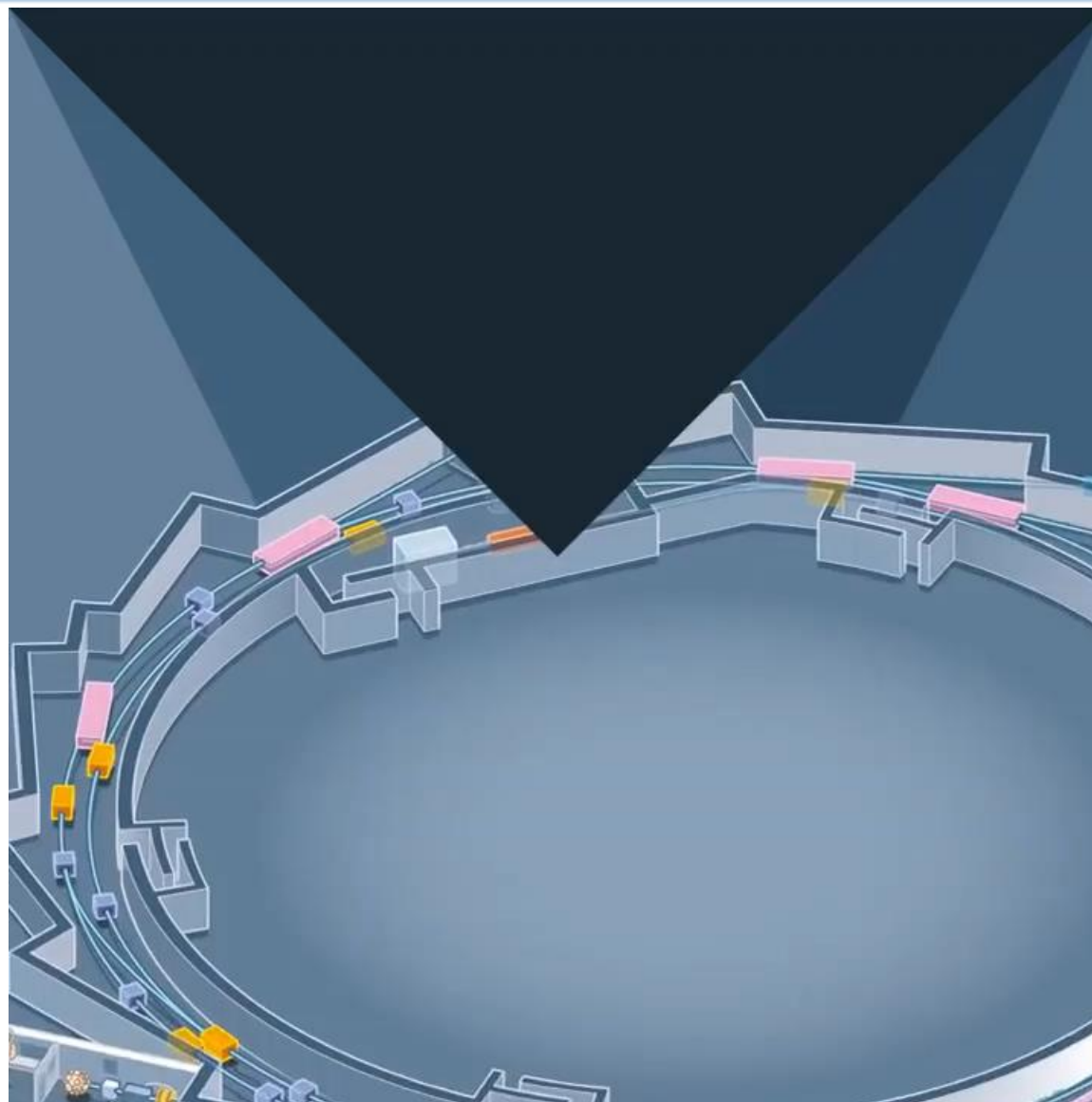




Linhas de Luz



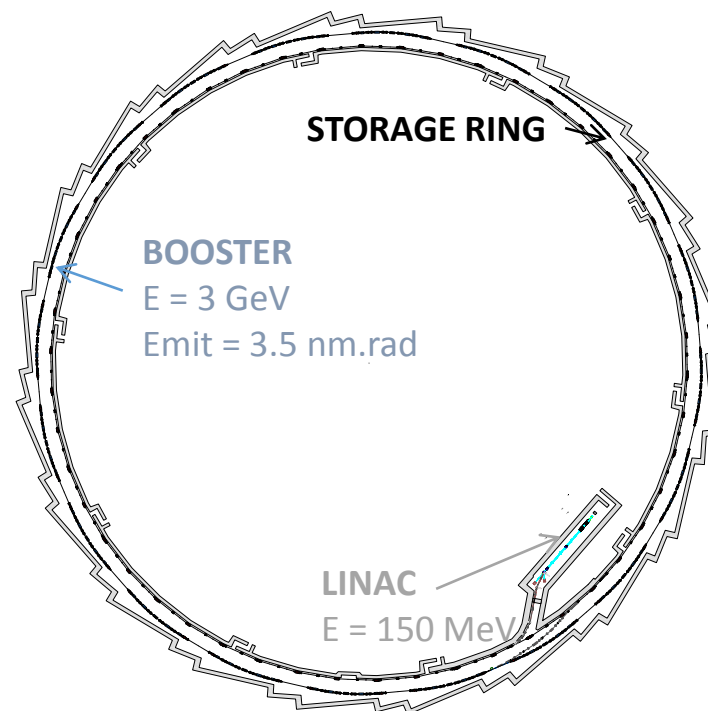
Como funciona?



Crédito: Síncrotron ALBA
https://youtu.be/b3mEmE4Gu_A

Parâmetros Principais

Sirius Storage Ring	
Beam energy	3.0 GeV
Circumference	518 m
Lattice	20 x 5BA
Current, top up	350 mA
Bunch length	8.8 ps
Energy spread	0.085 %
RF frequency	500 MHz
Hor. emittance (bare $\rightarrow$ w/ ids)	250 $\rightarrow$ 150 pm.rad
Vert. emittance	2.5 $\rightarrow$ 1.5 pm.rad
Straight section low β_x/β_y	1.35 m / 1.6 m

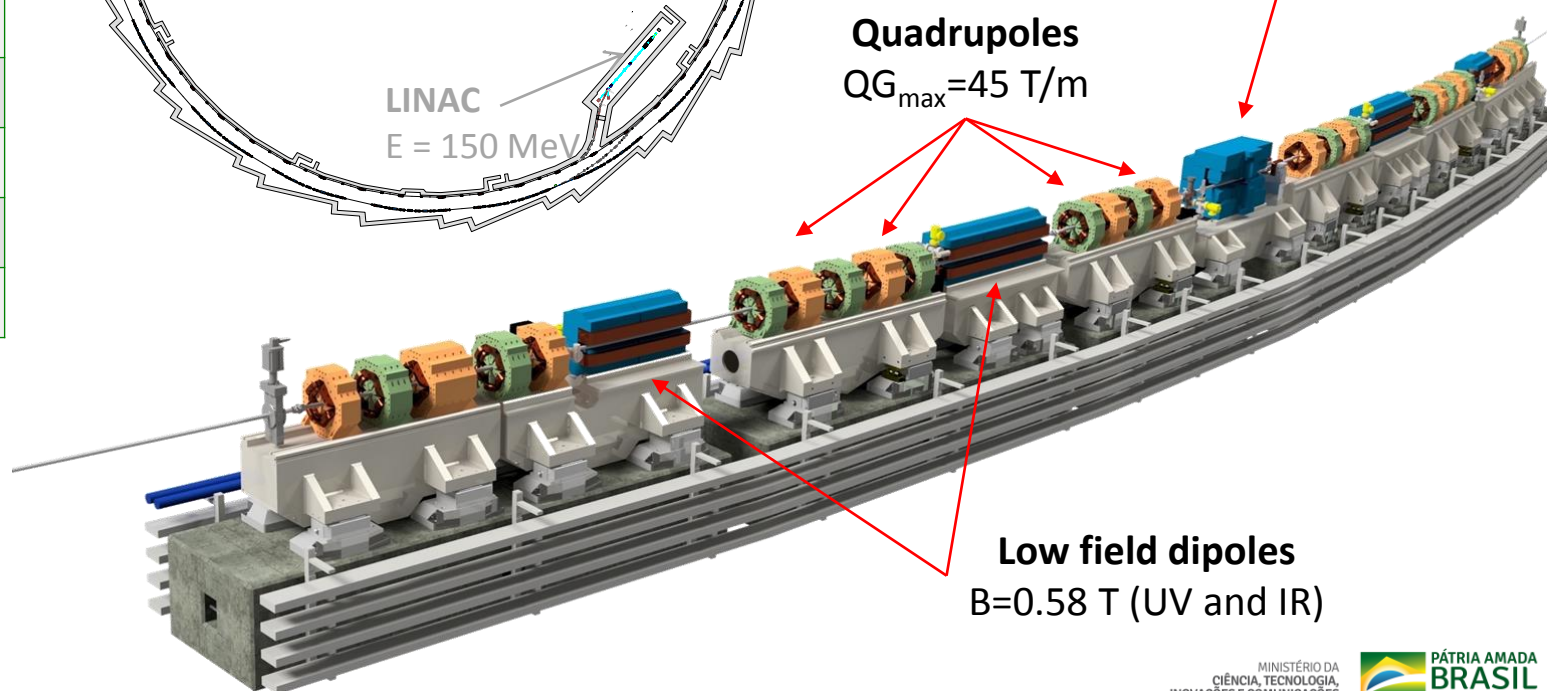


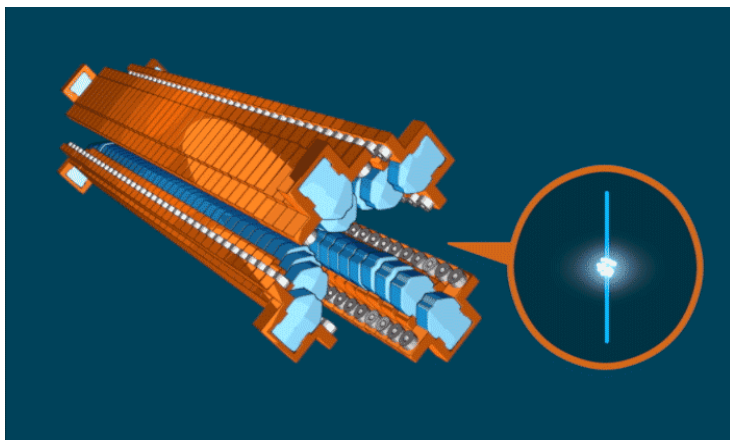
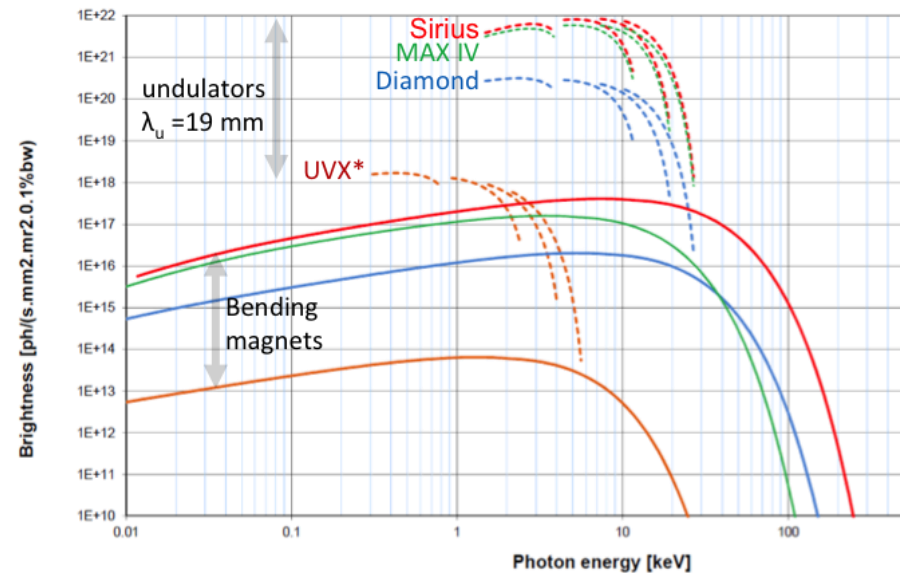
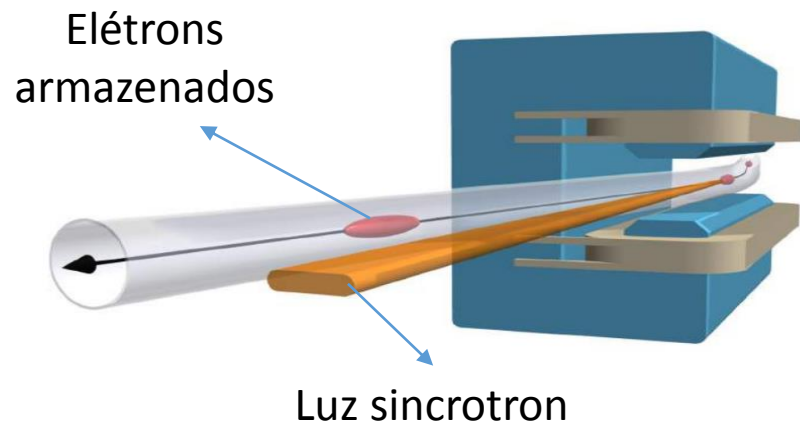
NdFeB Superbend:
B = 3.2 T (XR, $E_c = 19$ keV)

Quadrupoles
 $Q_{G_{max}} = 45$ T/m

Low field dipoles
B = 0.58 T (UV and IR)

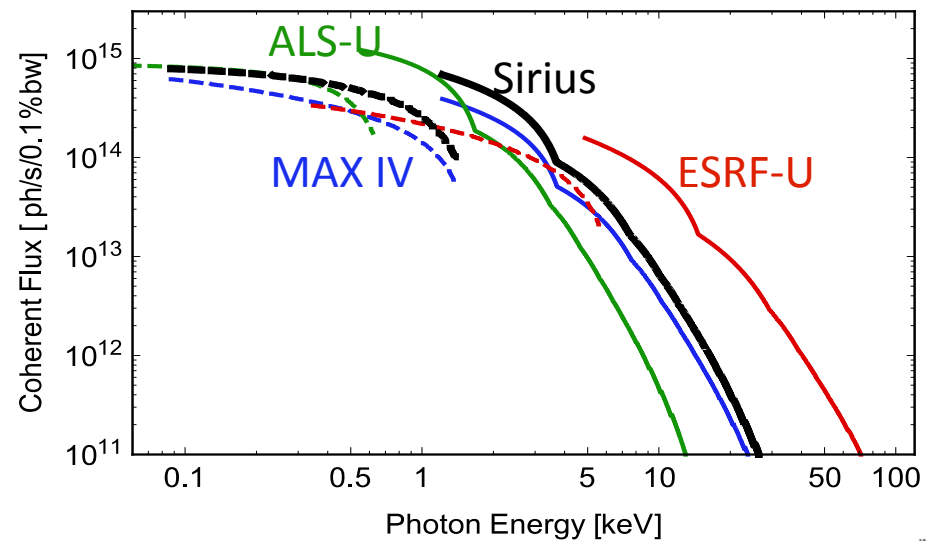
6.5/7.5 m Straight Sections
for Insertion Devices
(Undulators, Wigglers)





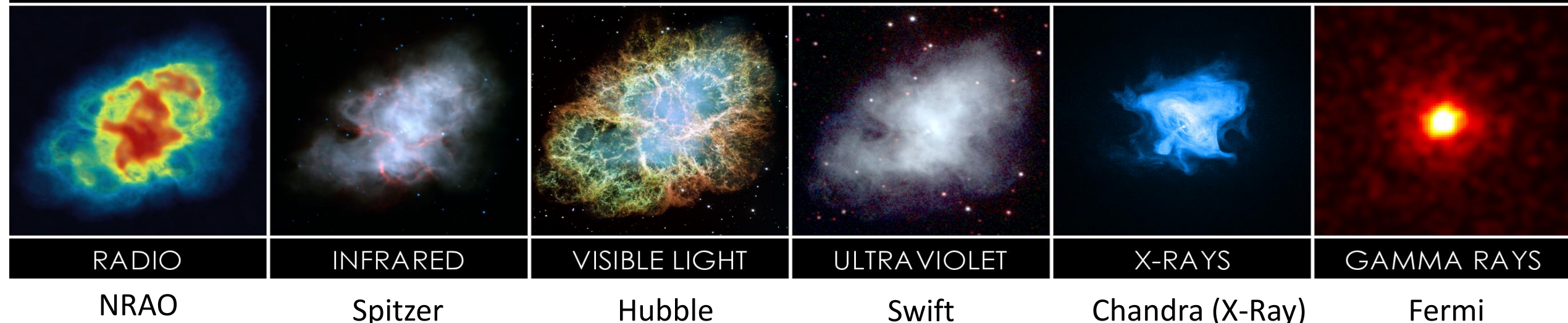
Animation from the SLAC website:

<https://www6.slac.stanford.edu/news/2016-06-15-spiraling-light-slac-x-ray-laser-offers-new-glimpses-molecules.aspx>

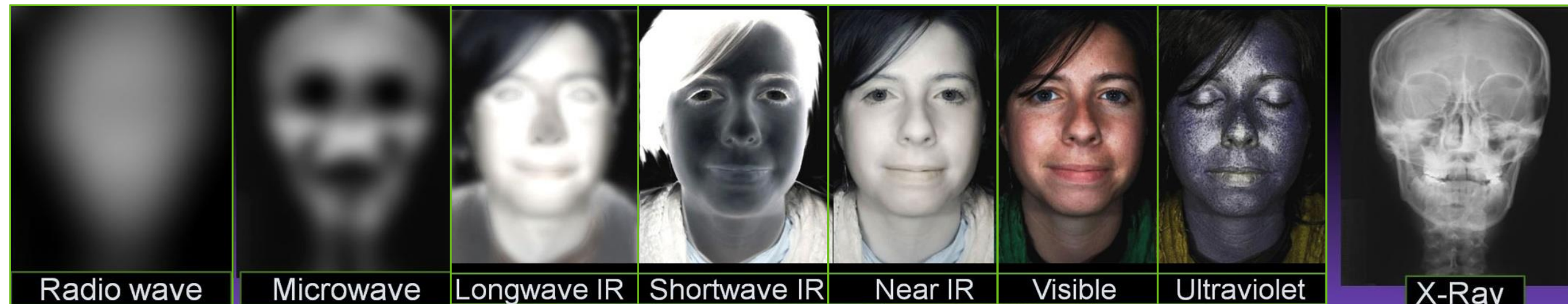


Telescópios / Câmeras

CRAB NEBULA



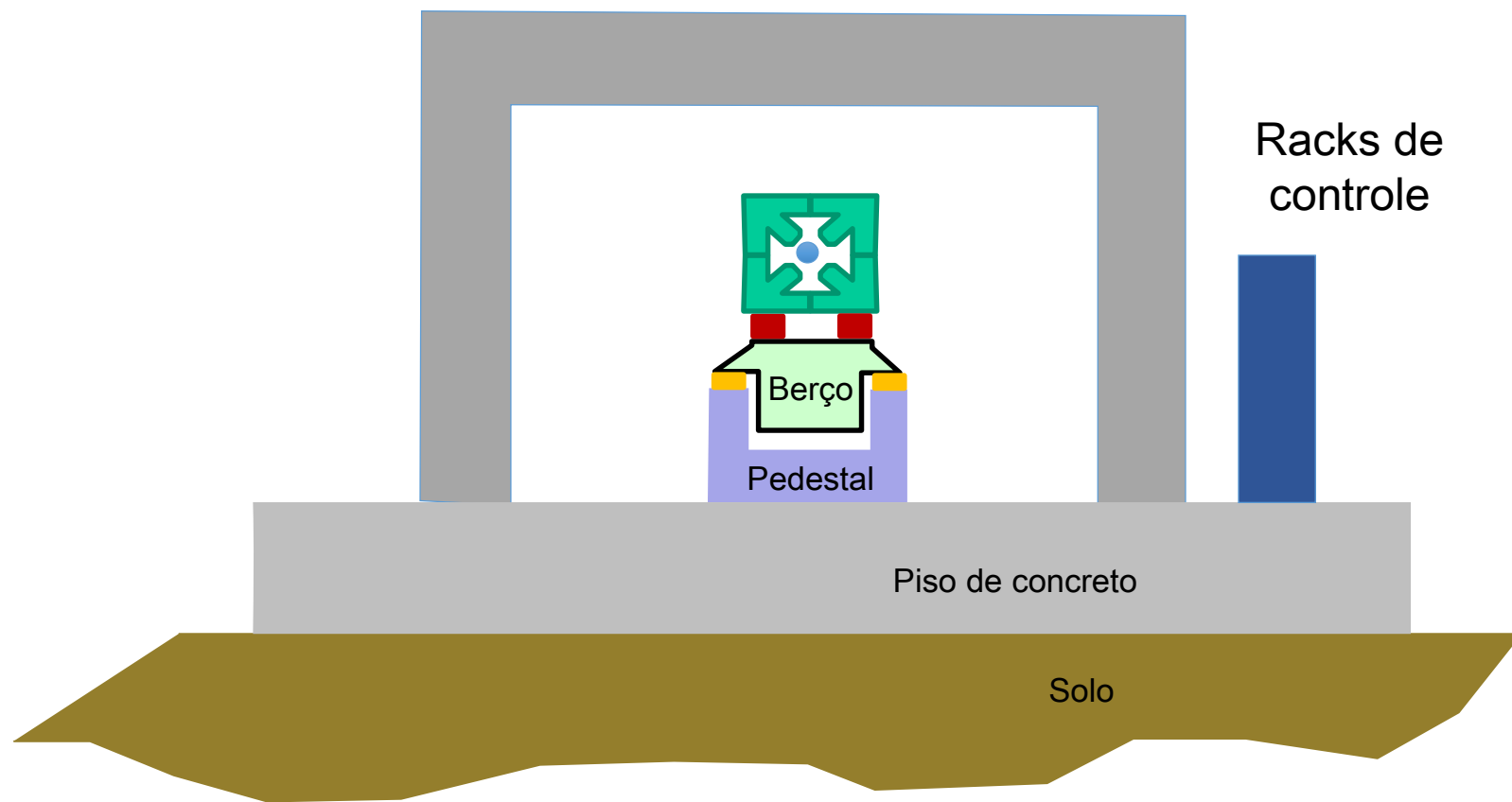
<http://www.chemistryland.com/CHM107/Final/FinalWritten.html>

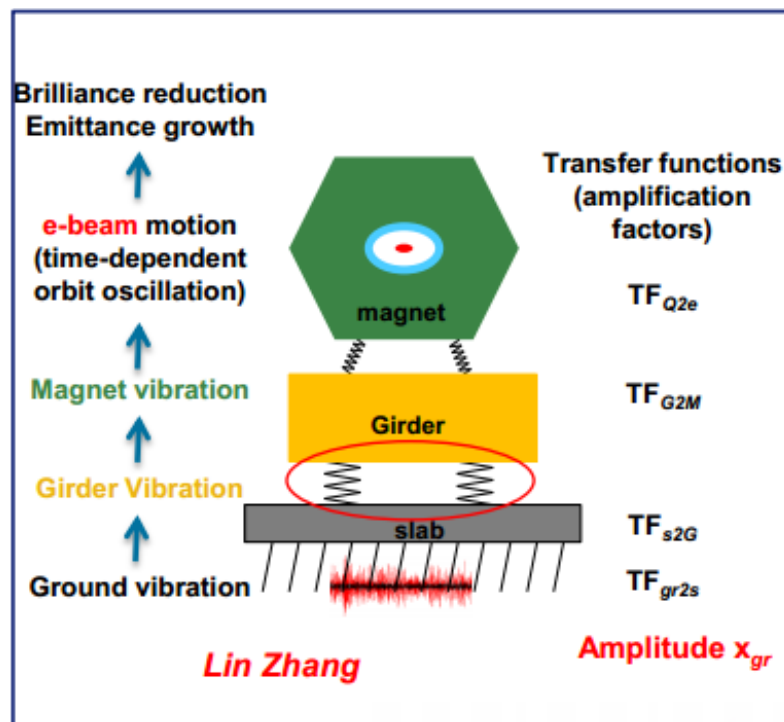


PRÉDIO

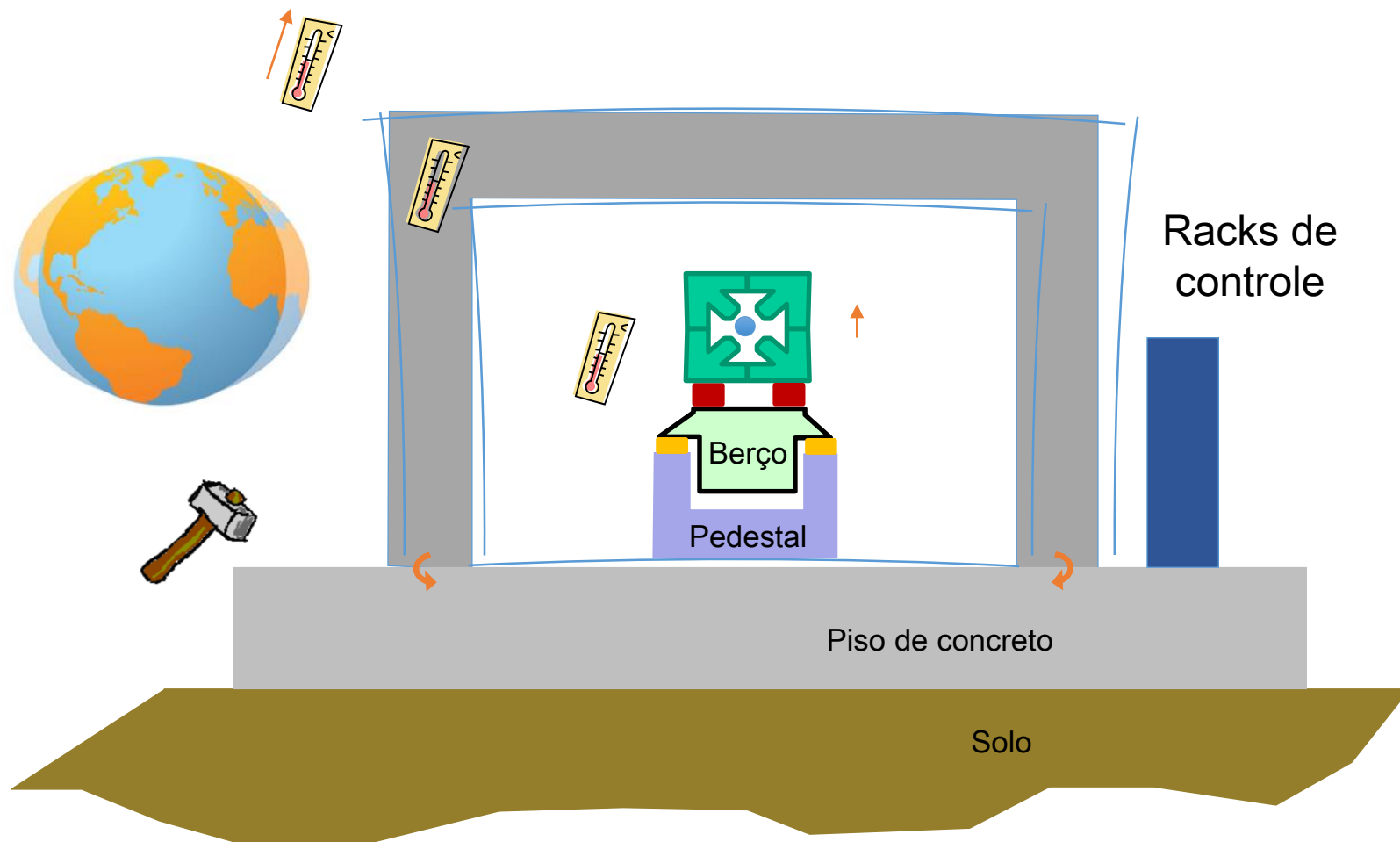


Estabilidade Mecânica – Afeta TUDO

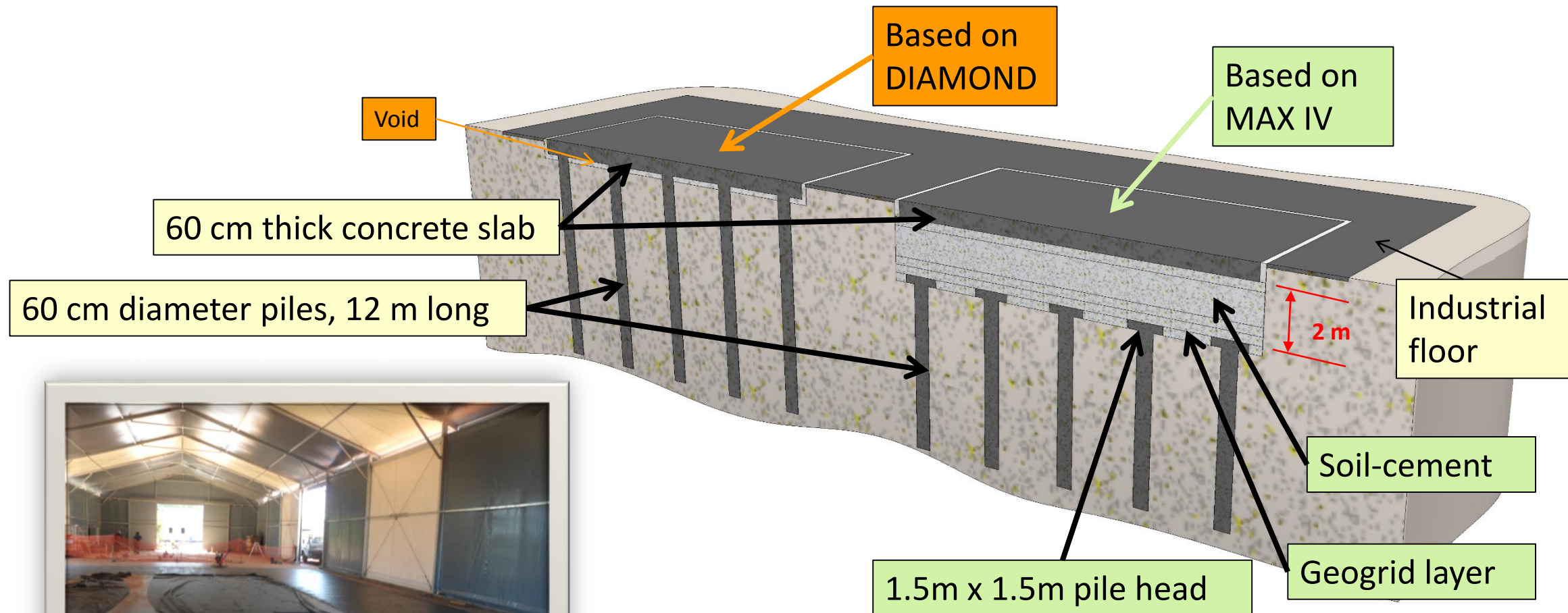




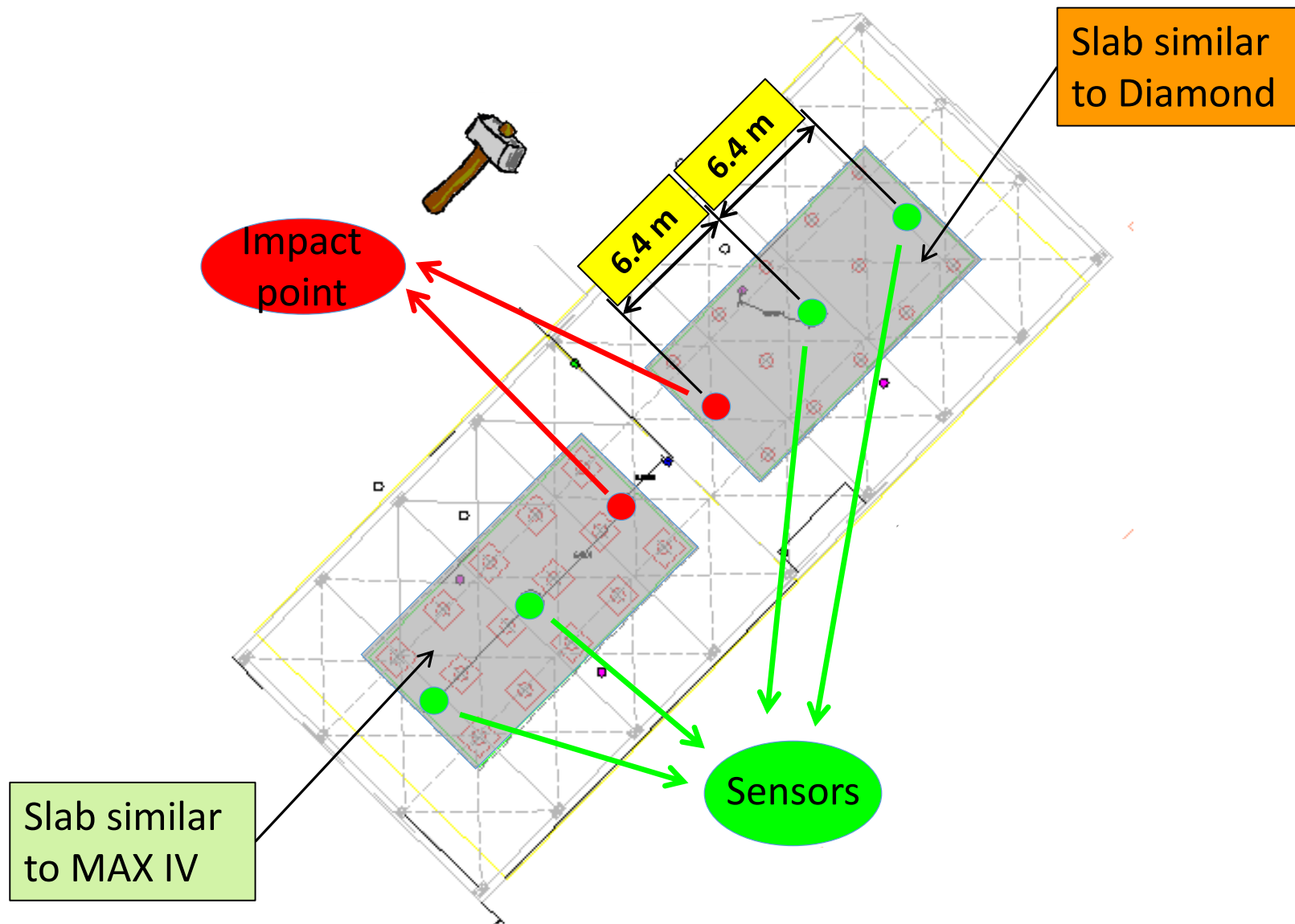
Fonte: Marion (ESRF)



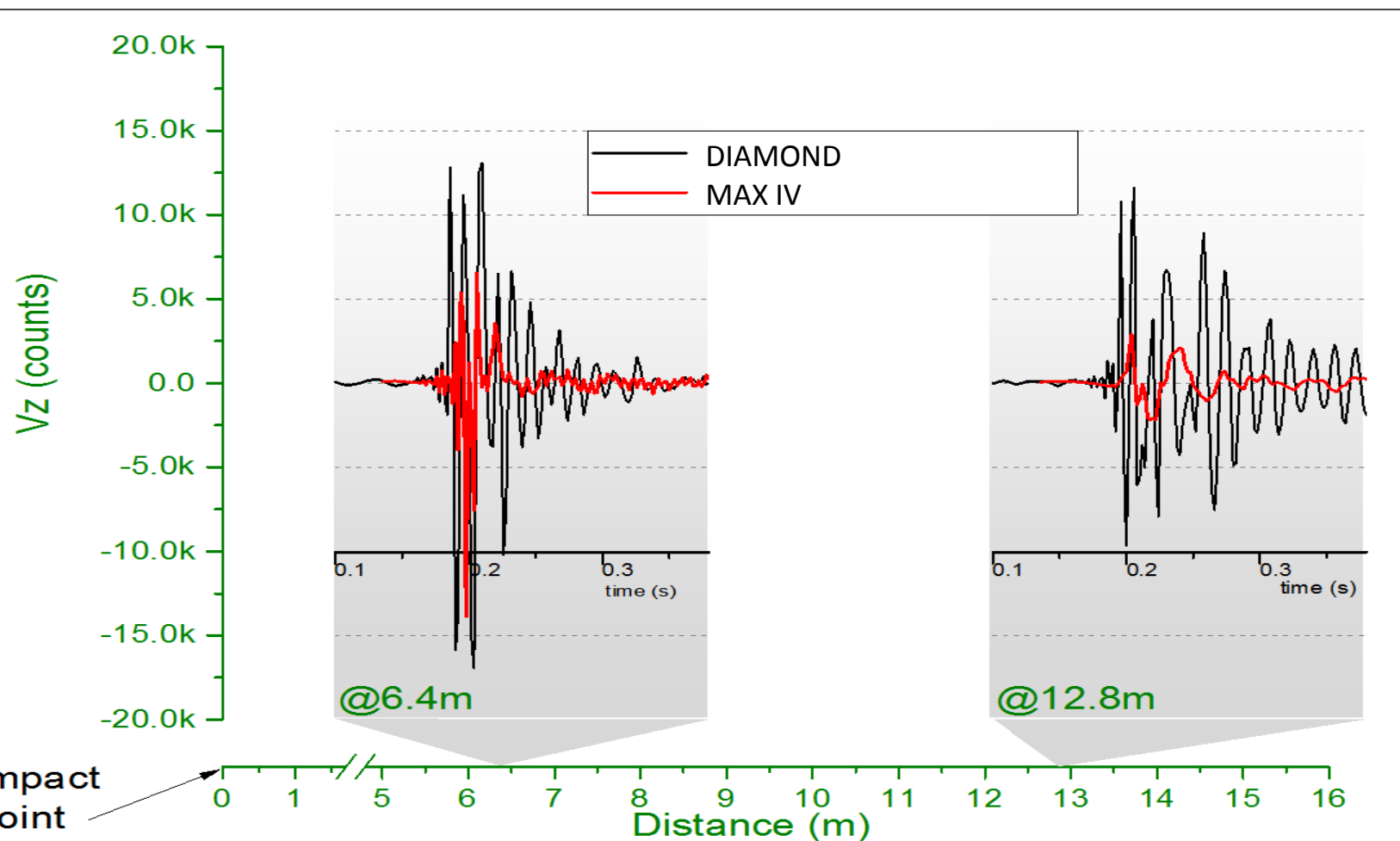
Prototipagem de Pisos



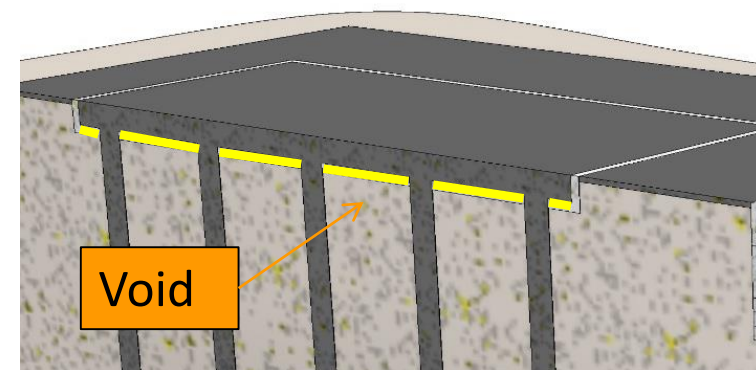
Impacto sobre a Laje



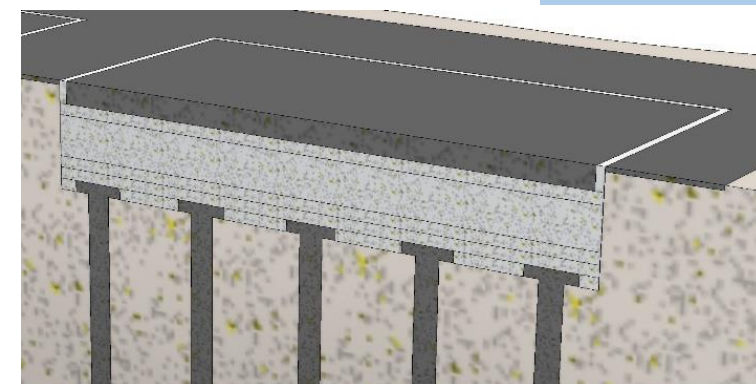
Impacto sobre a Laje



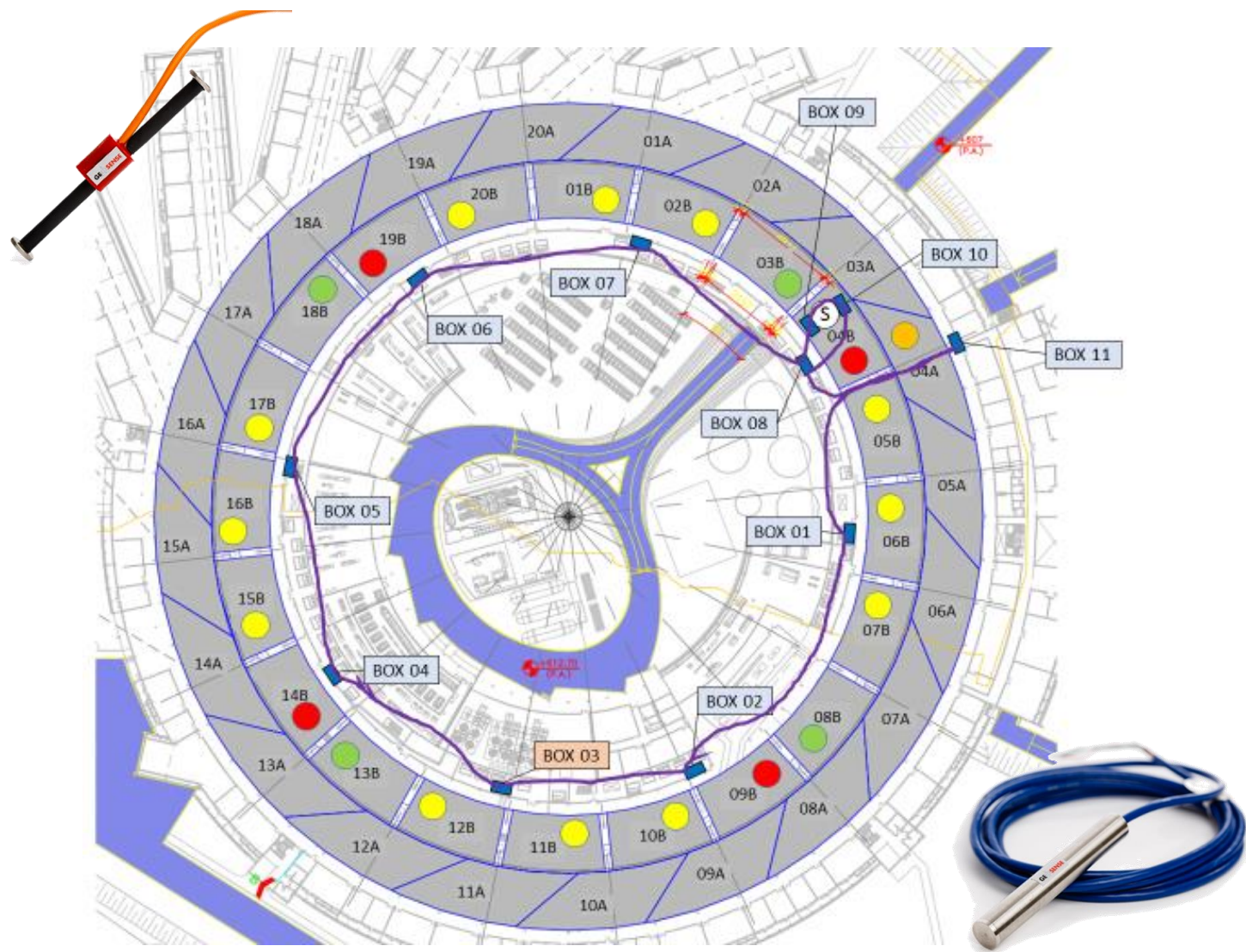
DIAMOND



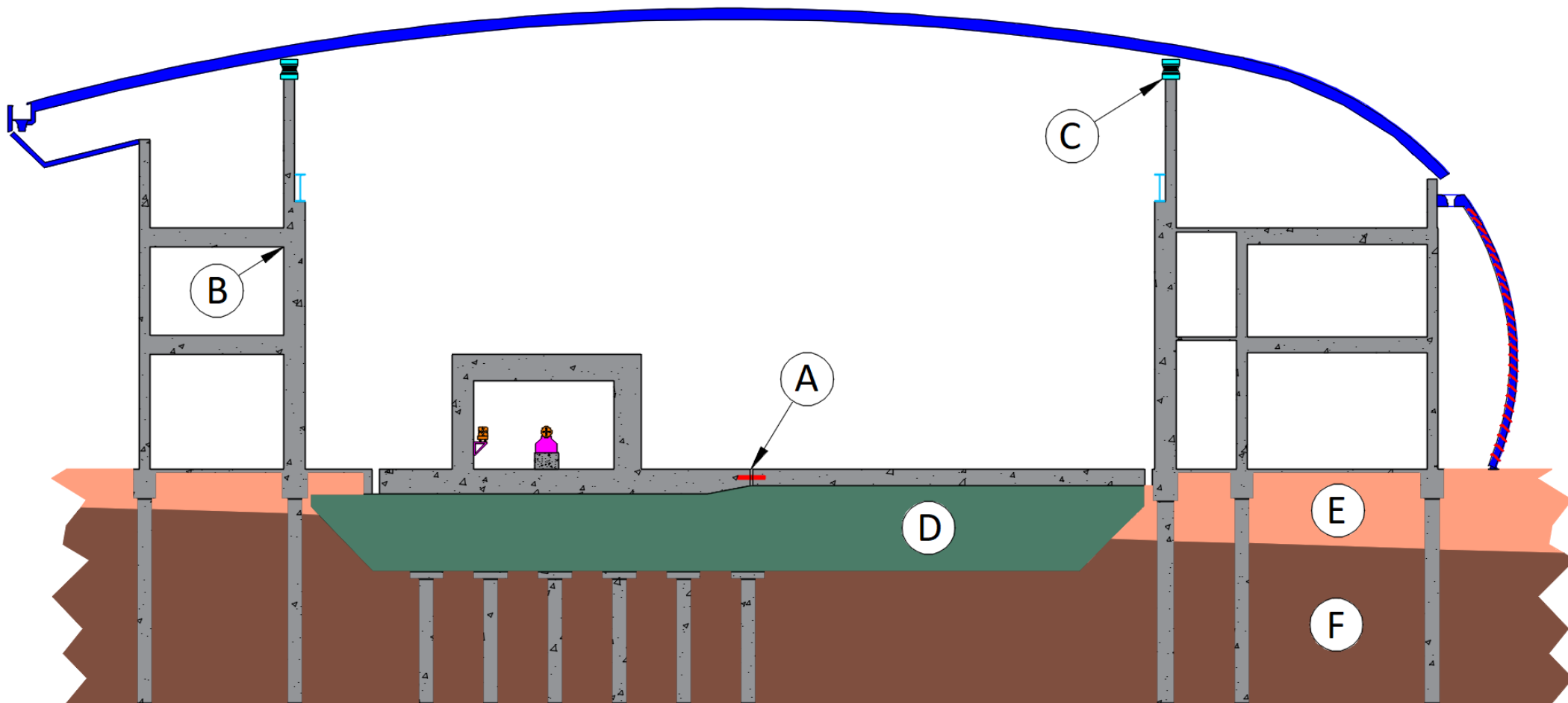
MAX IV



Instrumentação do Piso e Blindagem



Piso e Prédio



ENGECORPS
Grupo TYPESA

PAULO BRUNA
ARQUITETOS

Engineering
A Hill International Company

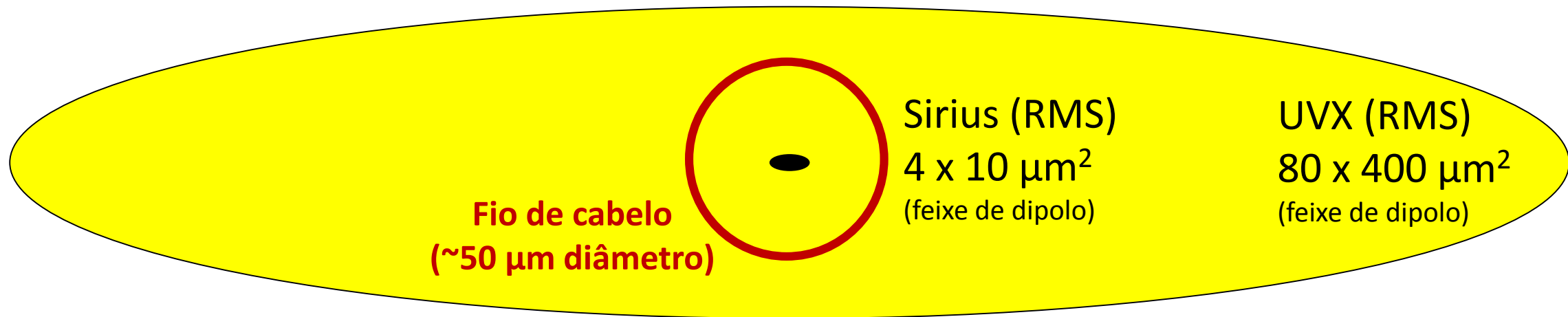
Racional

A – Junta tipo barra de transferência “Tucano Joint”
B – Lages e colunas fundidas no local

C – Sapatas de Neoprene
D – Solo-cimento

E – Aterro
F – Solo compactado

ACELERADORES



O feixe deve ser estável em $\sim 5\%$ de suas dimensões transversais considerando perturbações de diferentes escalas de tempo ($\sim$ minutos até $\sim$ milésimos de segundo)

Especificações p/ estabilidade de posição do Sirius (feixe + *eletrônica* + *mecânica*):

100 nm RMS (0.1 Hz – 1kHz)

140 nm RMS (1 hora)

5 μm RMS (1 semana)

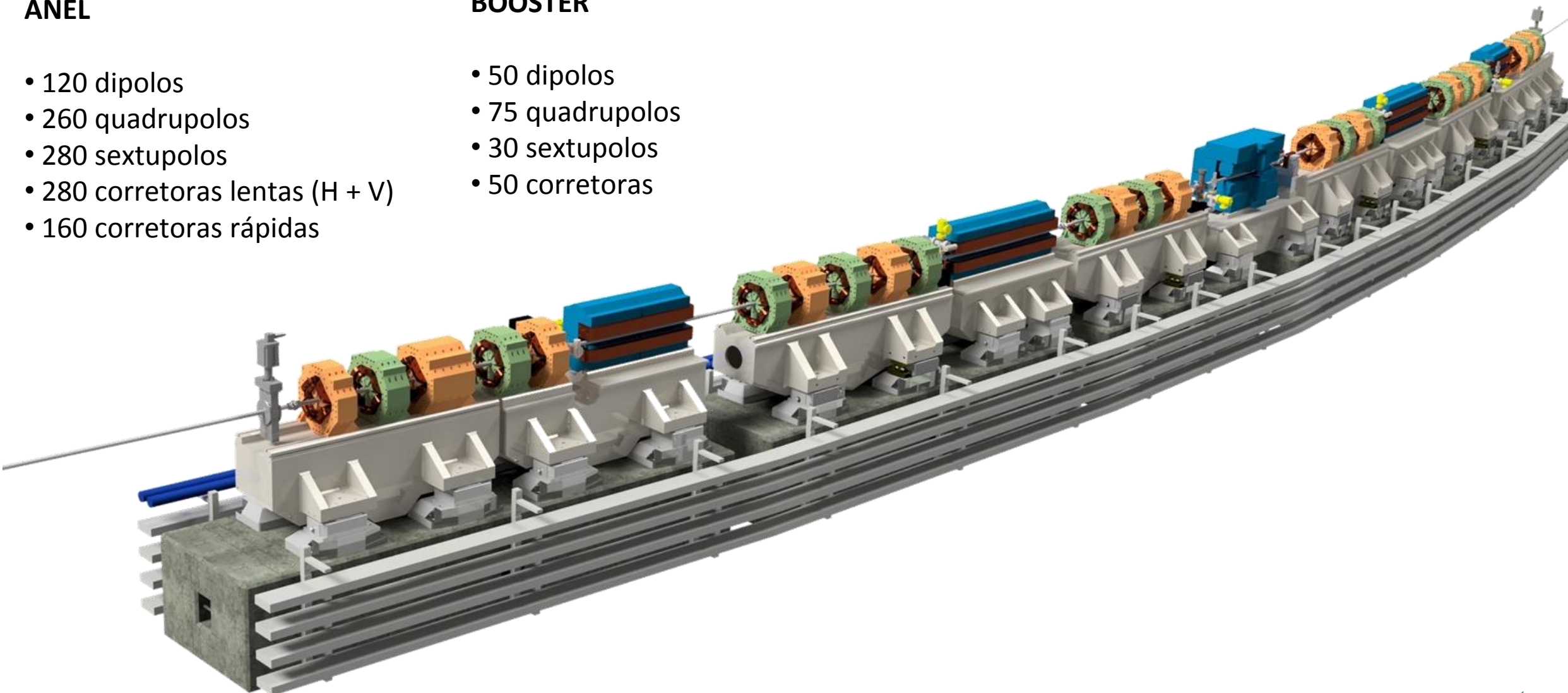
Superperíodo (x 20)

ANEL

- 120 dipolos
- 260 quadrupolos
- 280 sextupolos
- 280 corretoras lentas (H + V)
- 160 corretoras rápidas

BOOSTER

- 50 dipolos
- 75 quadrupolos
- 30 sextupolos
- 50 corretoras



Berço de Alta Estabilidade

10 mm/m flatness
girder

JPHE
CALDEIRARIA E MAQUINAS

100 MPa compressive
strength concrete

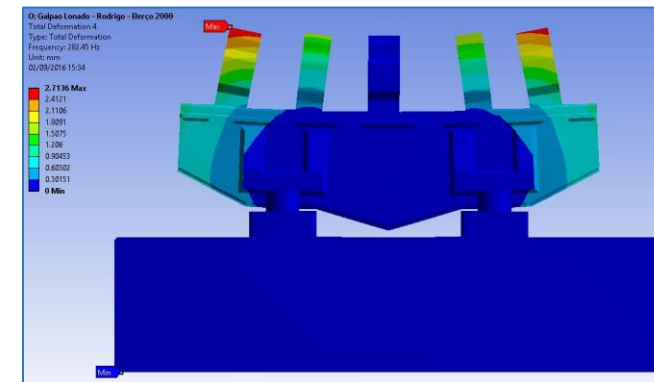
LEONARDI
pré-fabricados

Resin

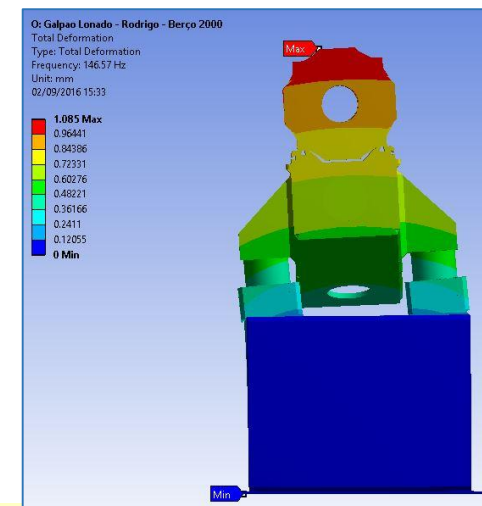
Shimtek

High stiffness
levelling units

TOYO MATIC

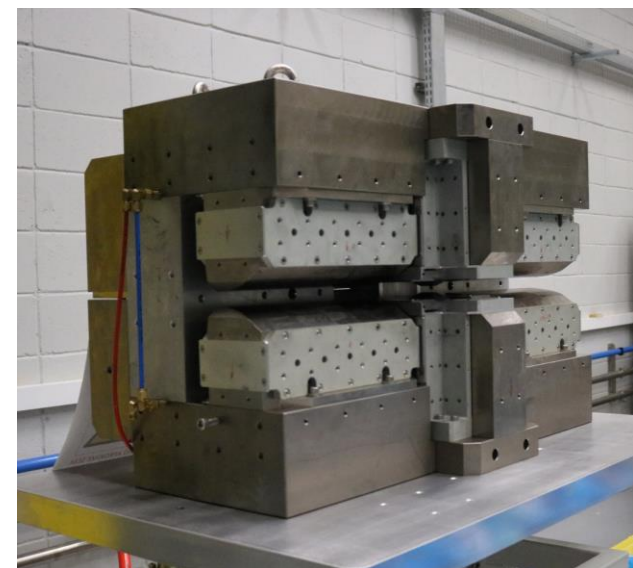
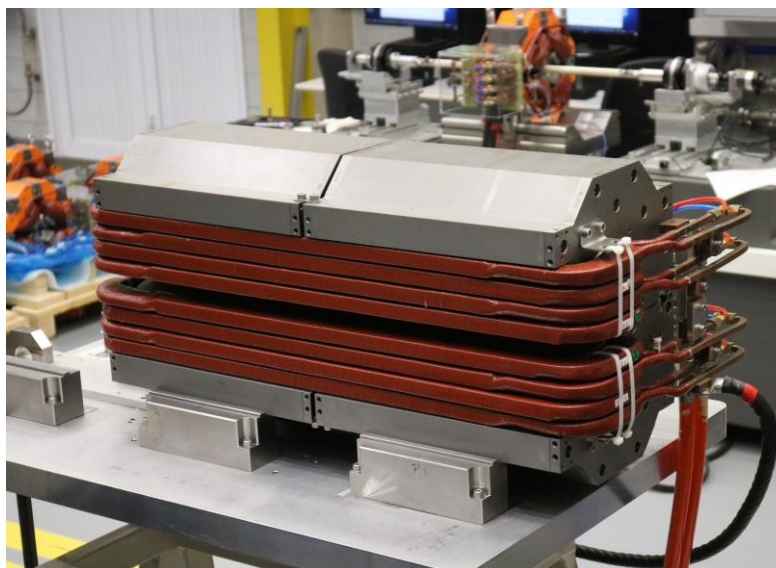
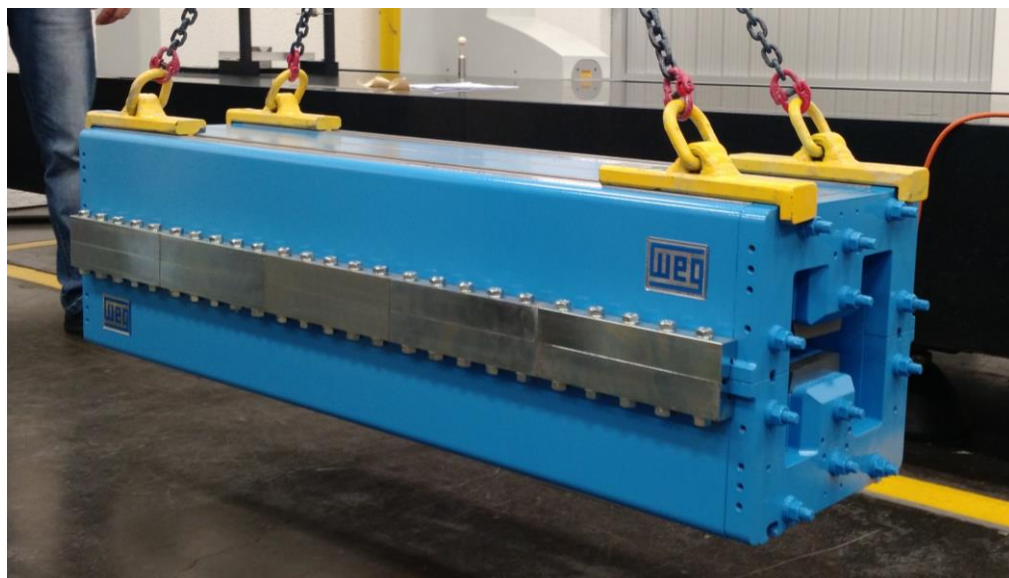
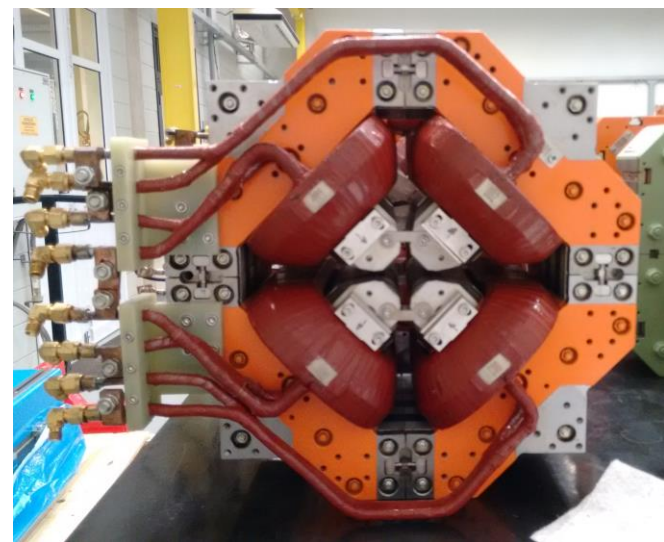
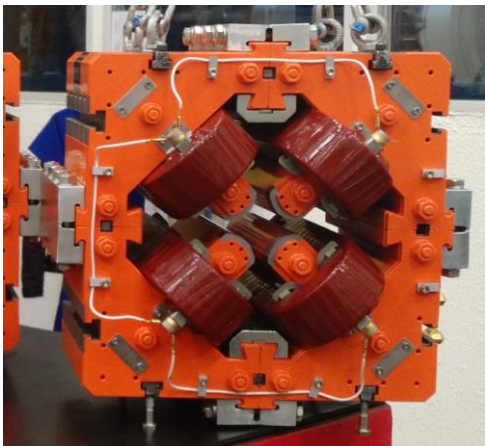


V 1st mode: 268 Hz



H 1st mode: 152 Hz

> 1000 Eletroímãs



~800 Fontes de Corrente



Model	FBP
Qt.	740
Current:	10 A
Voltage:	5 V

Model	FAP
Qt.	45
Current:	150 to 700 A
Voltage:	50 to 450 V

Model	FAC
Qt.	6
Current:	30 to 1100 A
Voltage:	50 to 800 V

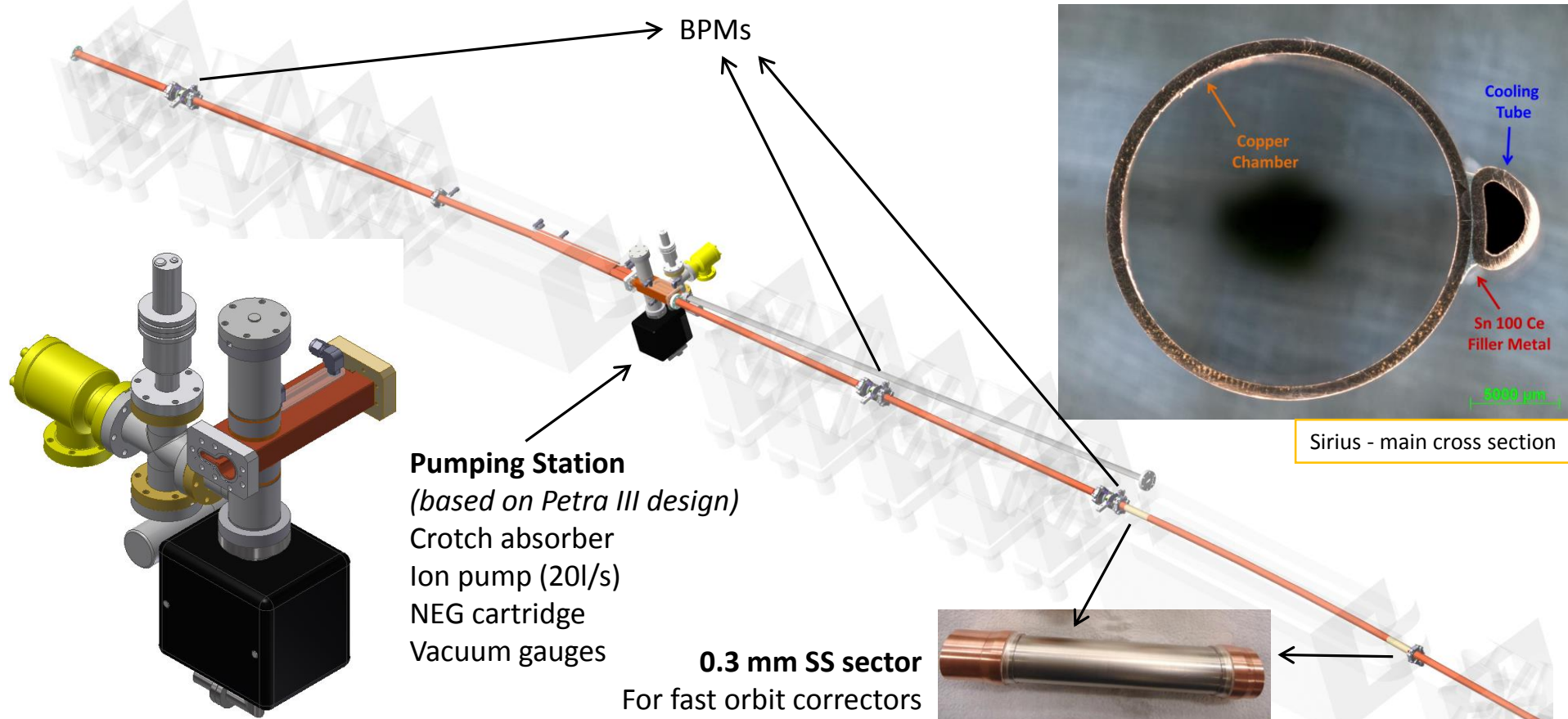
NEG – Bombeamento Distribuído

Pros (full NEG coated strategy):

- Simple chamber's design
- More compact -> space saving
- Low PSD yield -> Fast vacuum conditioning

Cons (full NEG coated strategy):

- Limited number of activations (10 ...?...30)
- High temperature bake-out for NEG activation
- Many bellows to accommodate chamber's expansion during bake-out

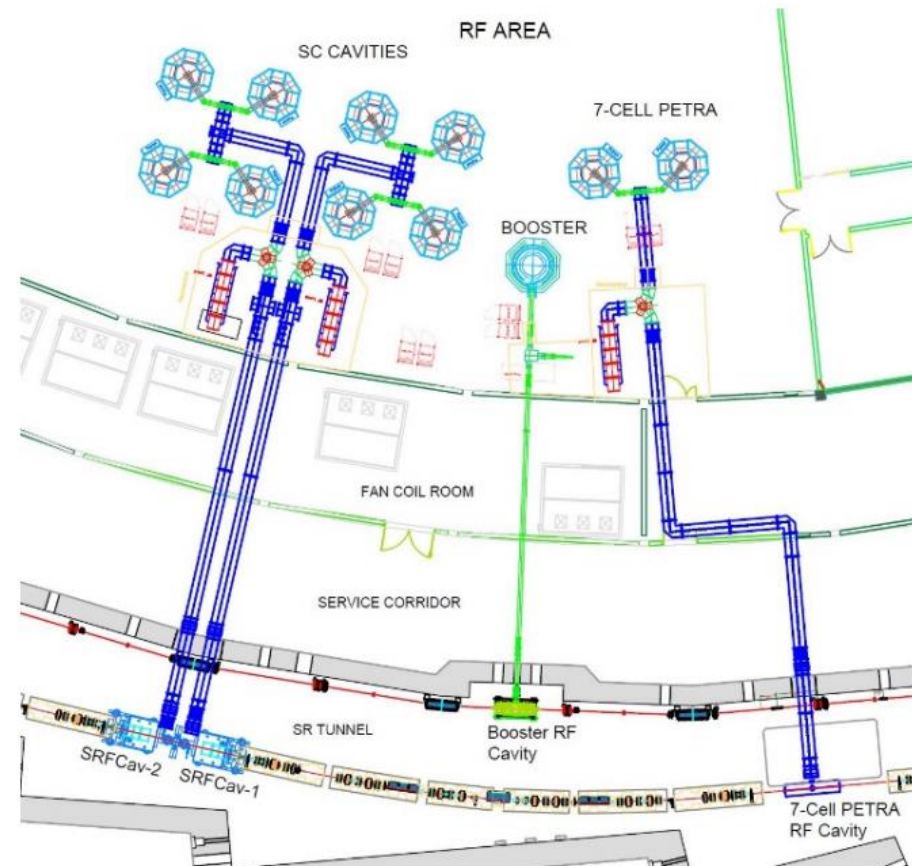


50 kW RF Tower and Cavity for the Booster



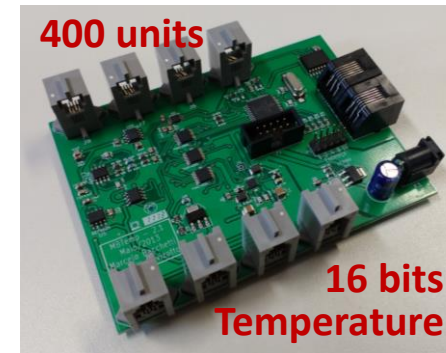
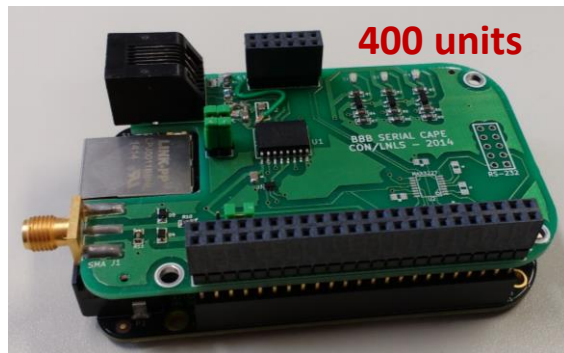
- Amplifier modules based on BLF578 transistor supplied by BBF (China) under license of Soleil
- 2 storage ring towers being assembled for NCC (Petra 7) operation at the end of this year.
- Superconducting cavity ordered from Research Instruments (RI), to be delivered in 2020.

60 kW Tower for the Storage Ring (8 units)

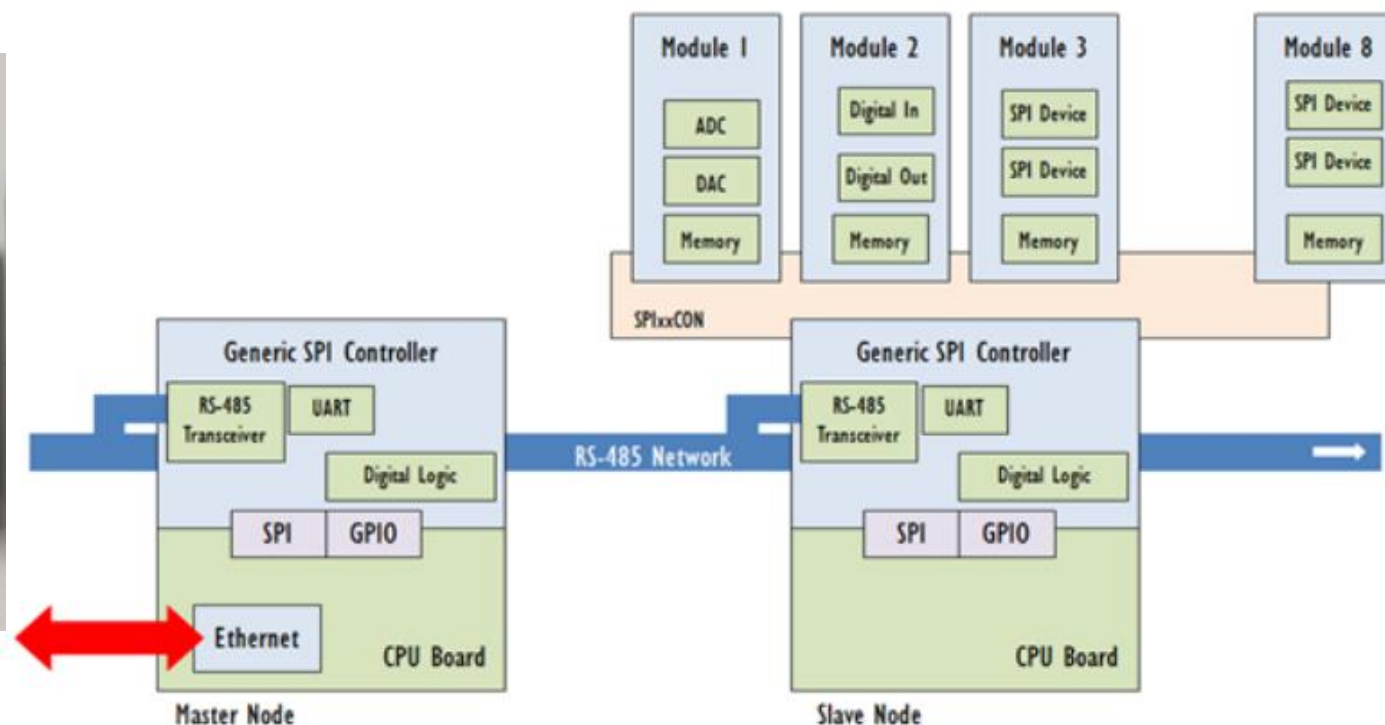


Sistema de Controle dos Aceleradores

Hardware

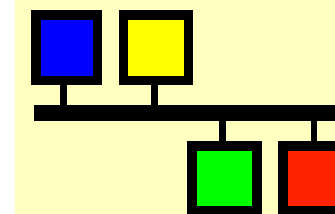


Beaglebone

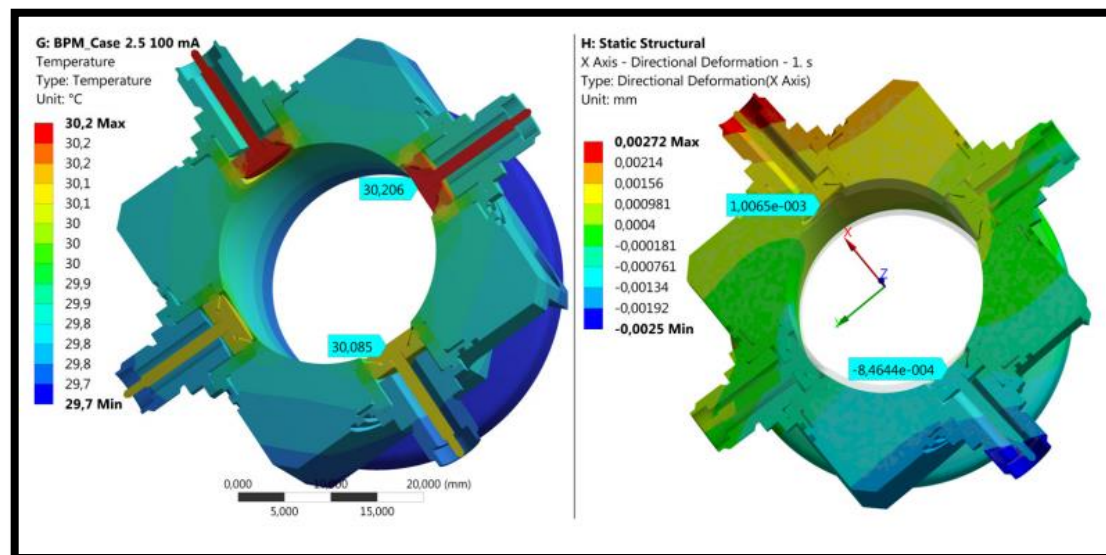
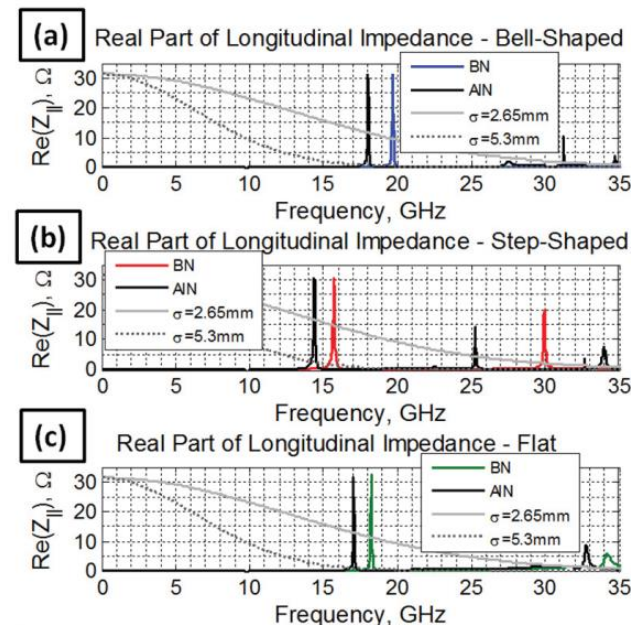
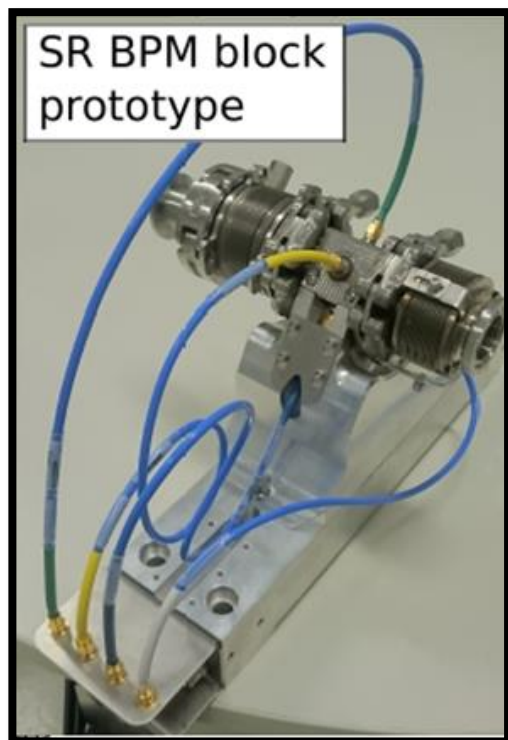
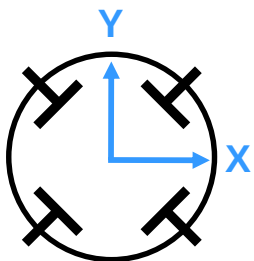


DCS - Software

EPICS



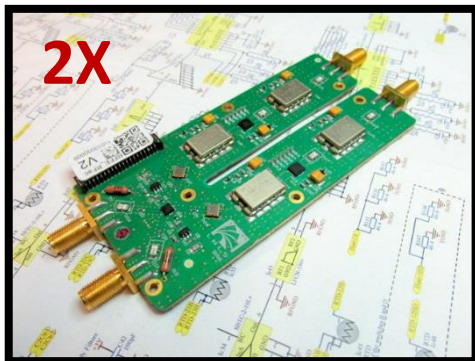
Monitor de Posição de Elétrons (BPM)



Resolução: 100 nm

Medida de Posição e Correção de Órbita

RF Front-End



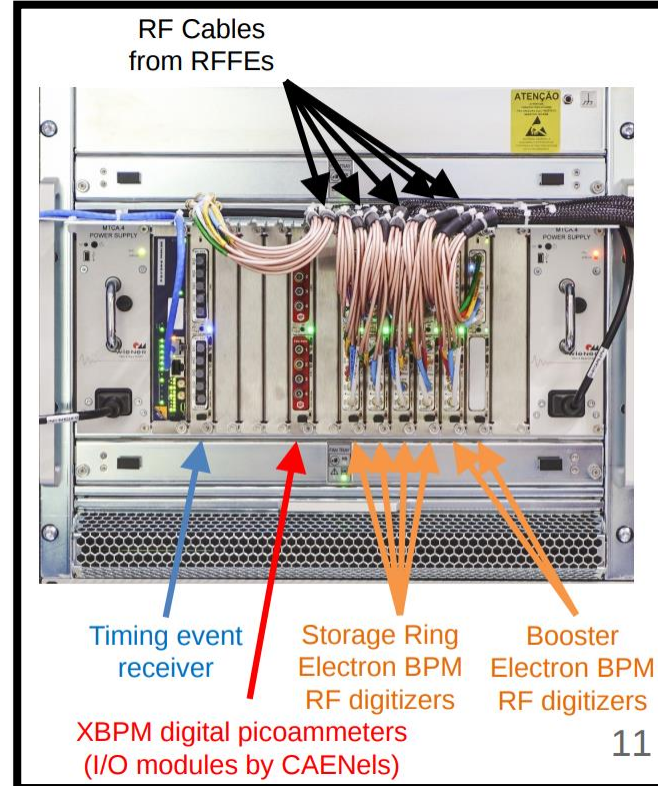
RF signals

ADC + FPGA boards



Digital signals

MicroTCA crate



Parameter	Value
Resolution (RMS) @ 0.1 Hz to 1 kHz	80 nm
Resolution (RMS) @ turn-by-turn full bandwidth	3 μ m
1 hour position stability (RMS)	140 nm
1 week stability (RMS)	5 μ m
Beam current dependence (decay mode)	1 μ m
Beam current dependence (top-up mode)	140 nm
Filling pattern dependence	5 μ m
First-turn resolution (RMS)	500 μ m
Horizontal/Vertical plane coupling	1 %

BPM Rack Front View



BPM Rack Rear view



Signal Processing, Data Acquisition and Control Platform

- System maintainability
- High-end communication interfaces enable FOFB
- DSP algorithms flexibility

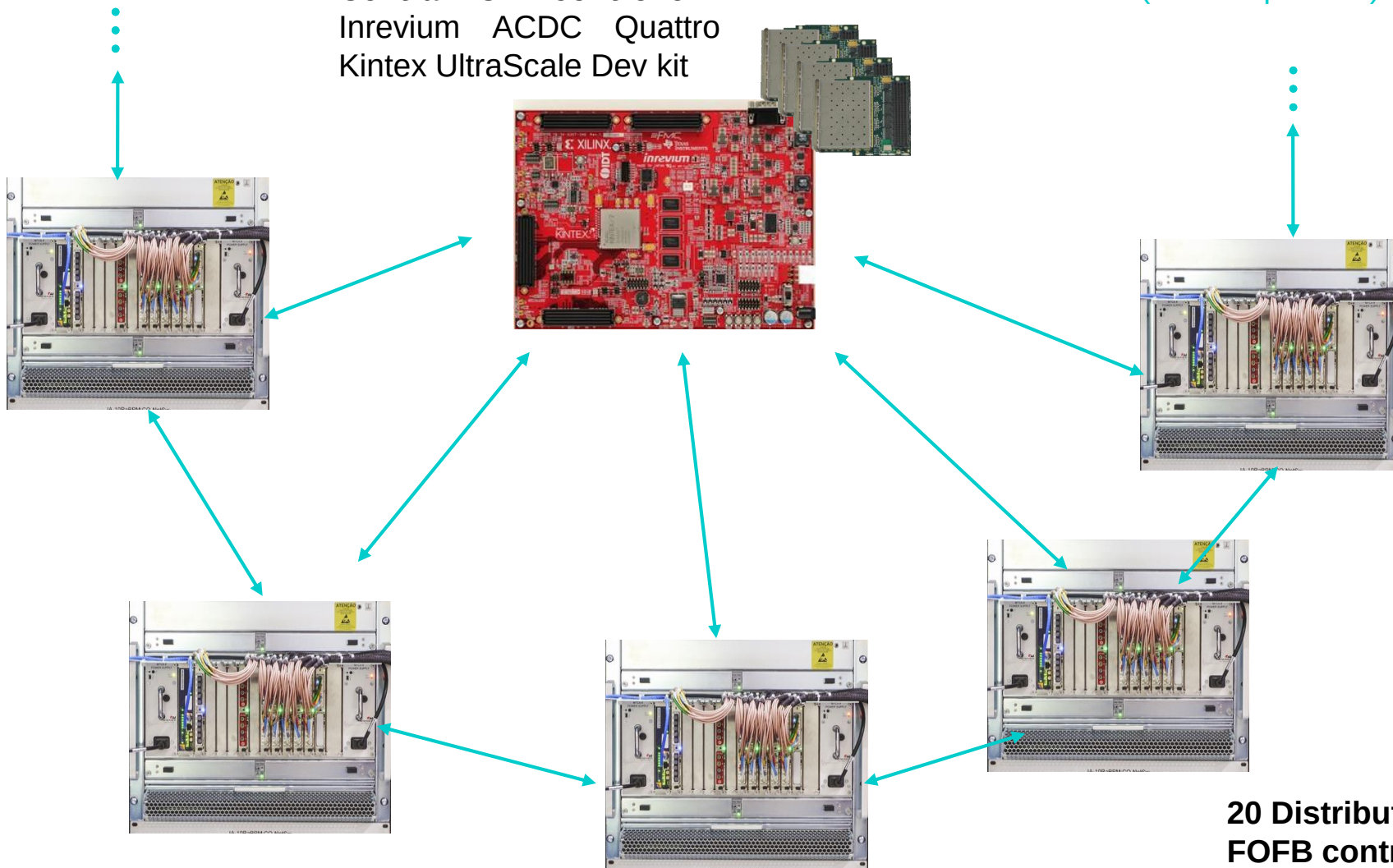
<https://ohwr.org/project/bpm/wikis/home>



Medida de Posição e Correção de Órbita

Central FOFB controller
Inrevium ACDC Quattro
Kintex UltraScale Dev kit

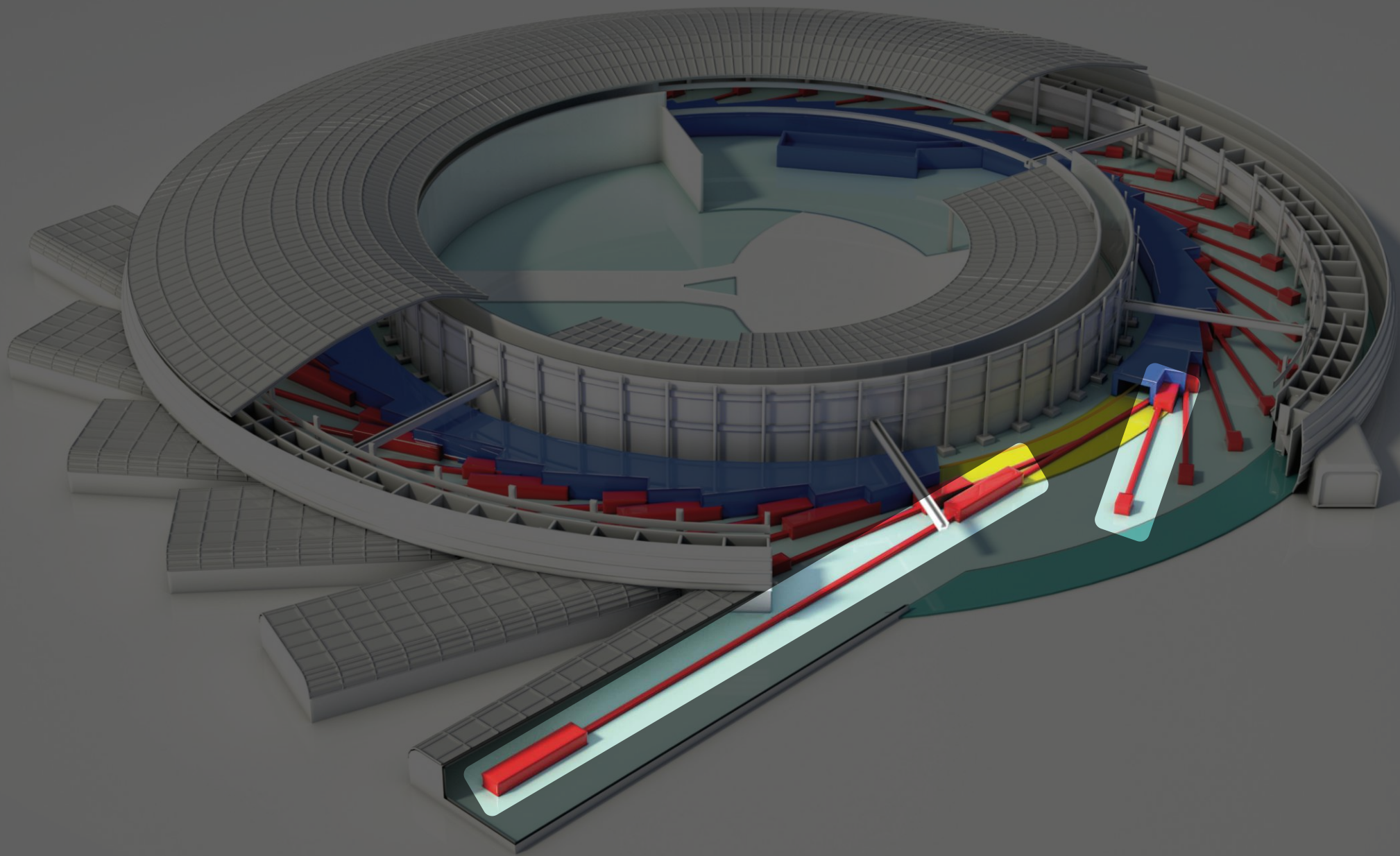
↔ OM4 multimode fibers
(6.25 Gbps links)

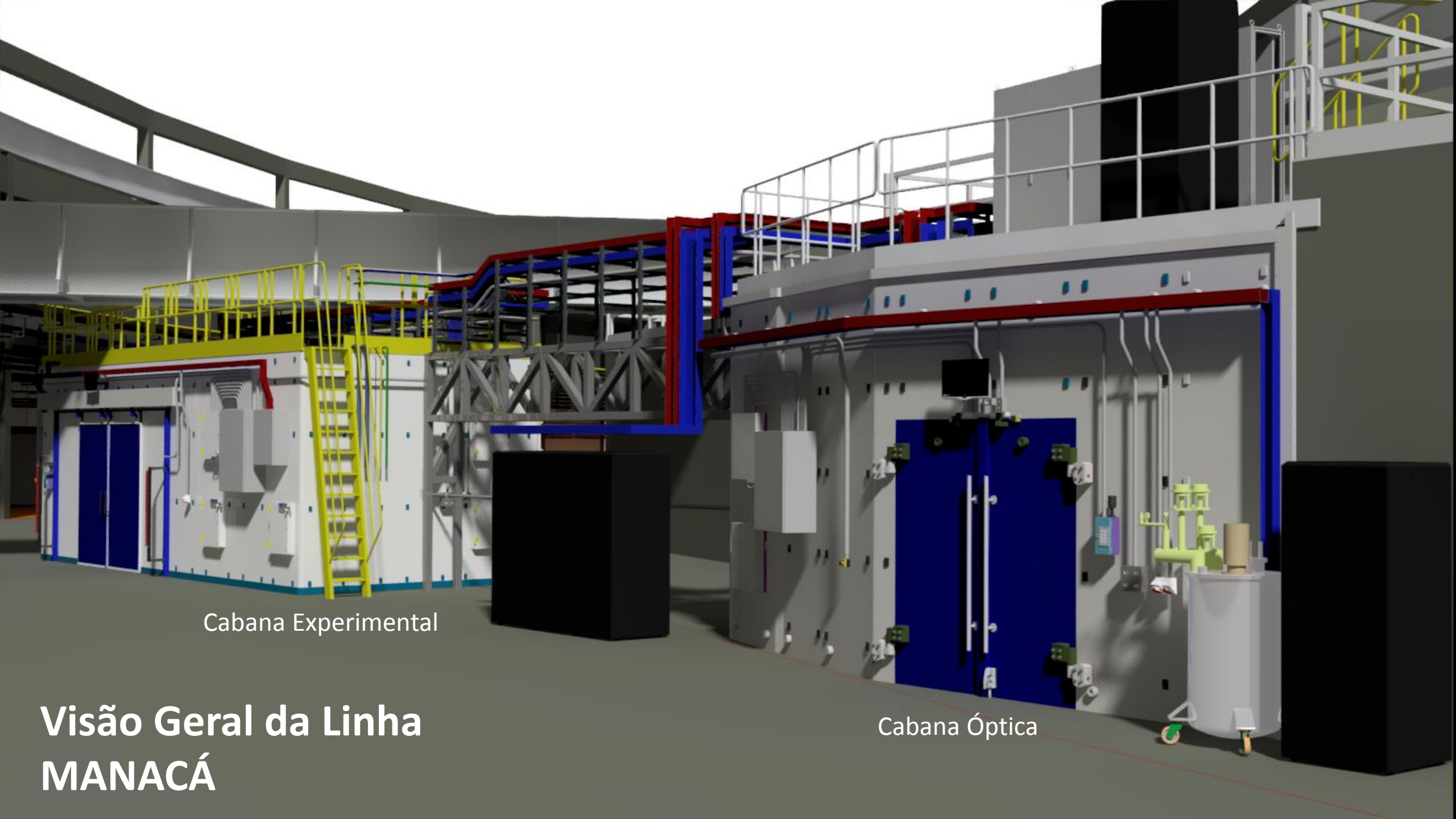


- Sistema de controle MIMO
- 320 entradas / 160 saídas
- Sensores e atuadores distribuídos ao longo de 518 m
- Taxa de amostragem em malha fechada: **100 kHz**
- Processamento do algoritmo de feedback em FPGA, distribuído em 20 nós
- Distribuição de dados determinística de dados com comunicação multigigabit (6 Gbps) por fibra óptica

**20 Distributed
FOFB controllers**
(one per BPM crate)

LINHAS DE LUZ





Cabana Experimental

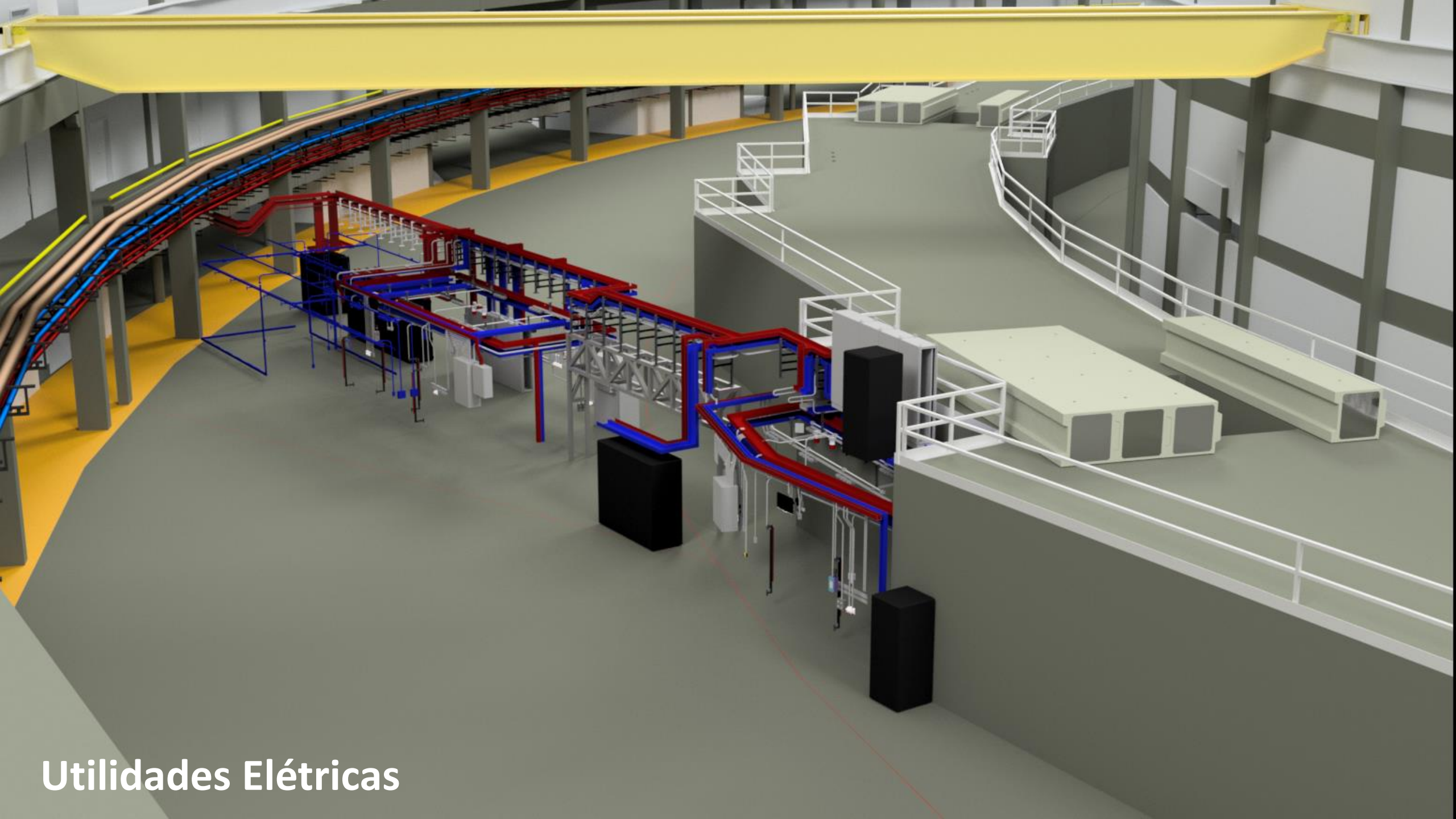
Cabana Óptica

Visão Geral da Linha MANACÁ

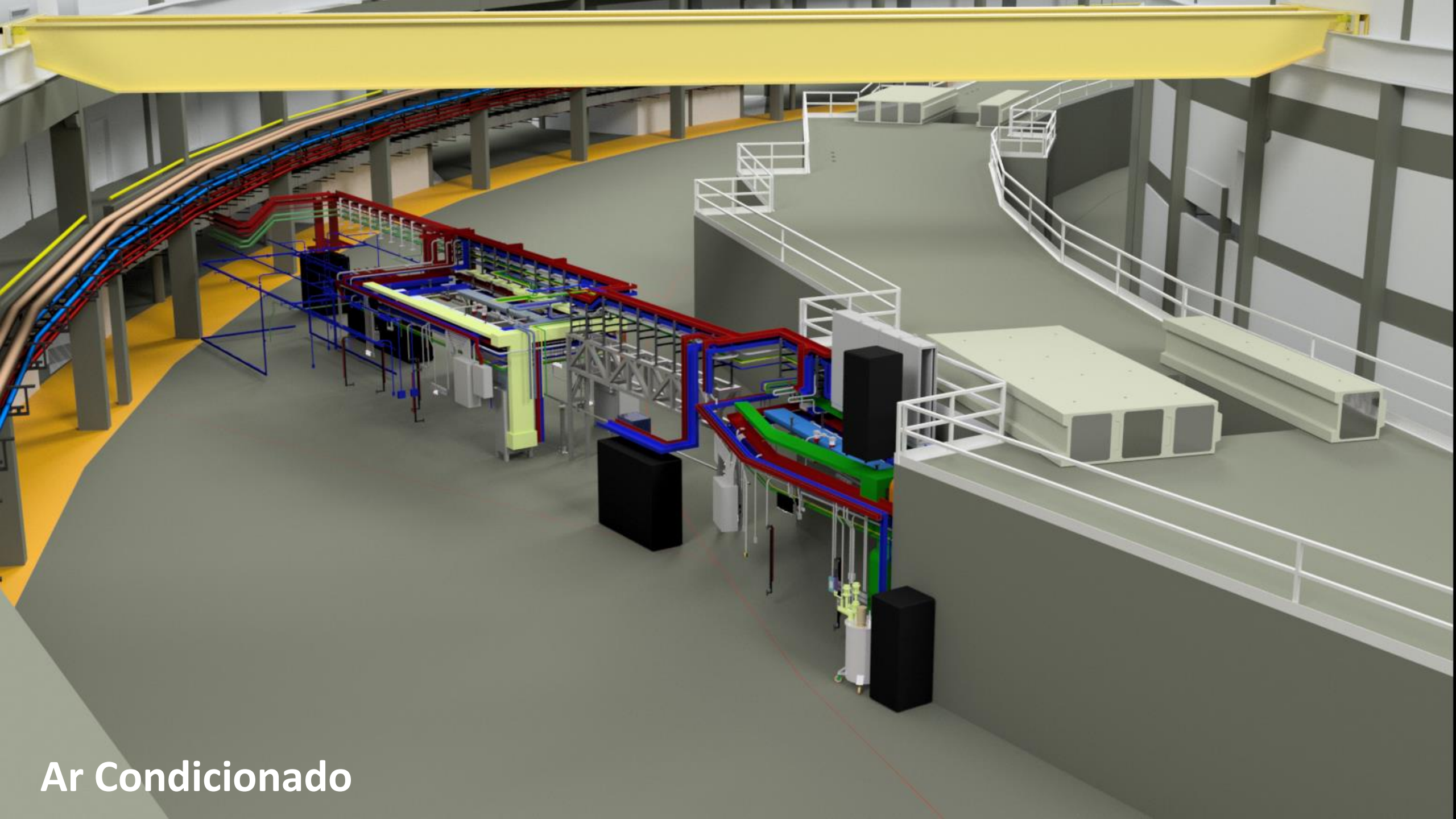
A 3D architectural rendering of the interior of the MANACÁ facility. The scene shows a large, open space with a grey floor and white walls. A prominent yellow overhead crane spans the width of the room. In the center, there is a complex arrangement of white machinery and equipment, including a large white cabinet with a ladder and various pipes and conduits in red, blue, and yellow. To the right, there are large, light-colored rectangular structures, possibly storage containers or part of the experimental setup. The overall design is industrial and functional.

Salas de Apoio:
Controle da
Linha/Experimento

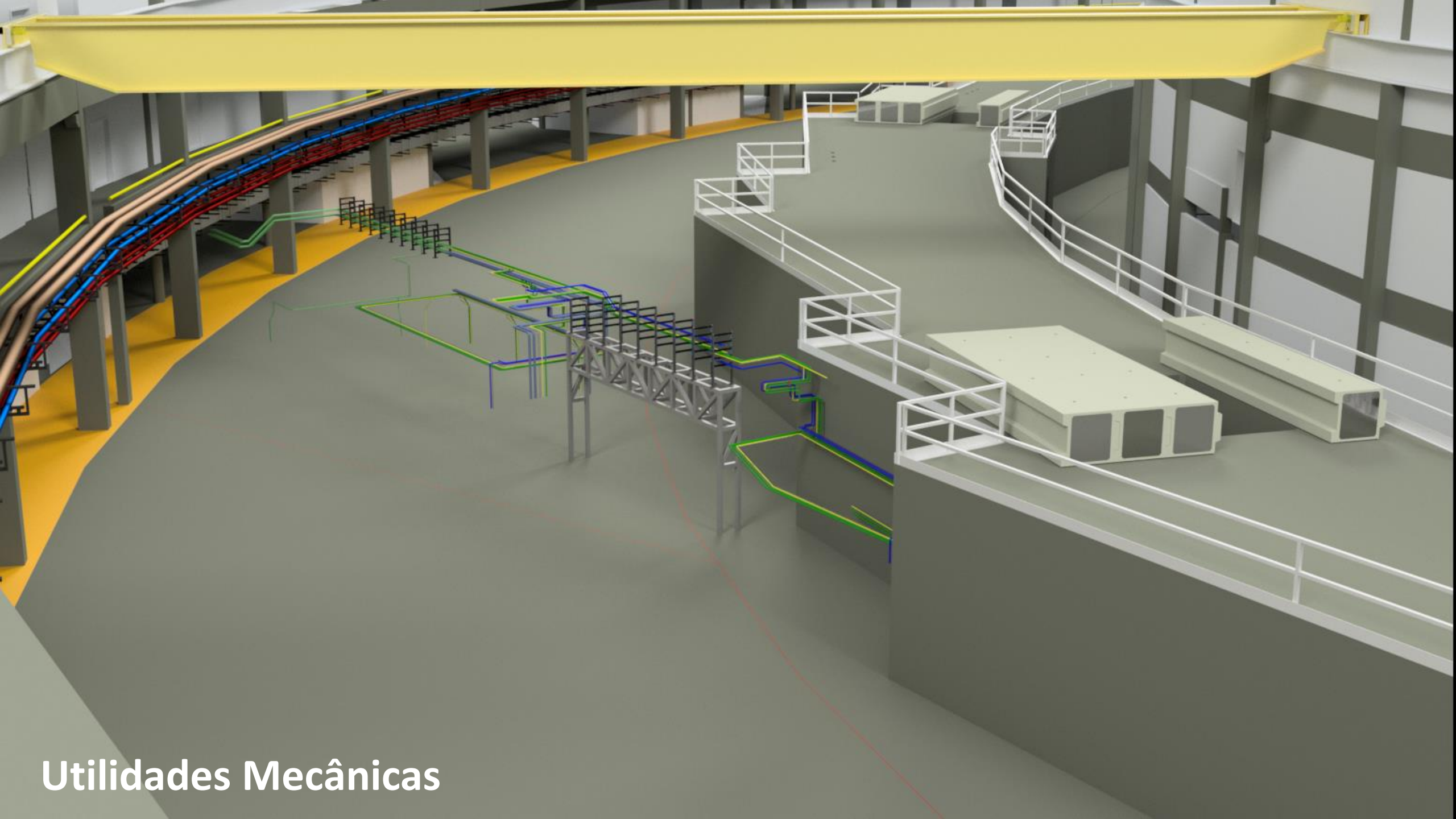
Visão Geral da Linha
MANACÁ



Utilidades Eléctricas



Ar Condicionado



Utilidades Mecânicas





JFS Engenharia
Projetos Industriais



JPA ENGENHARIA
CONSTRUÇÃO E MONTAGEM



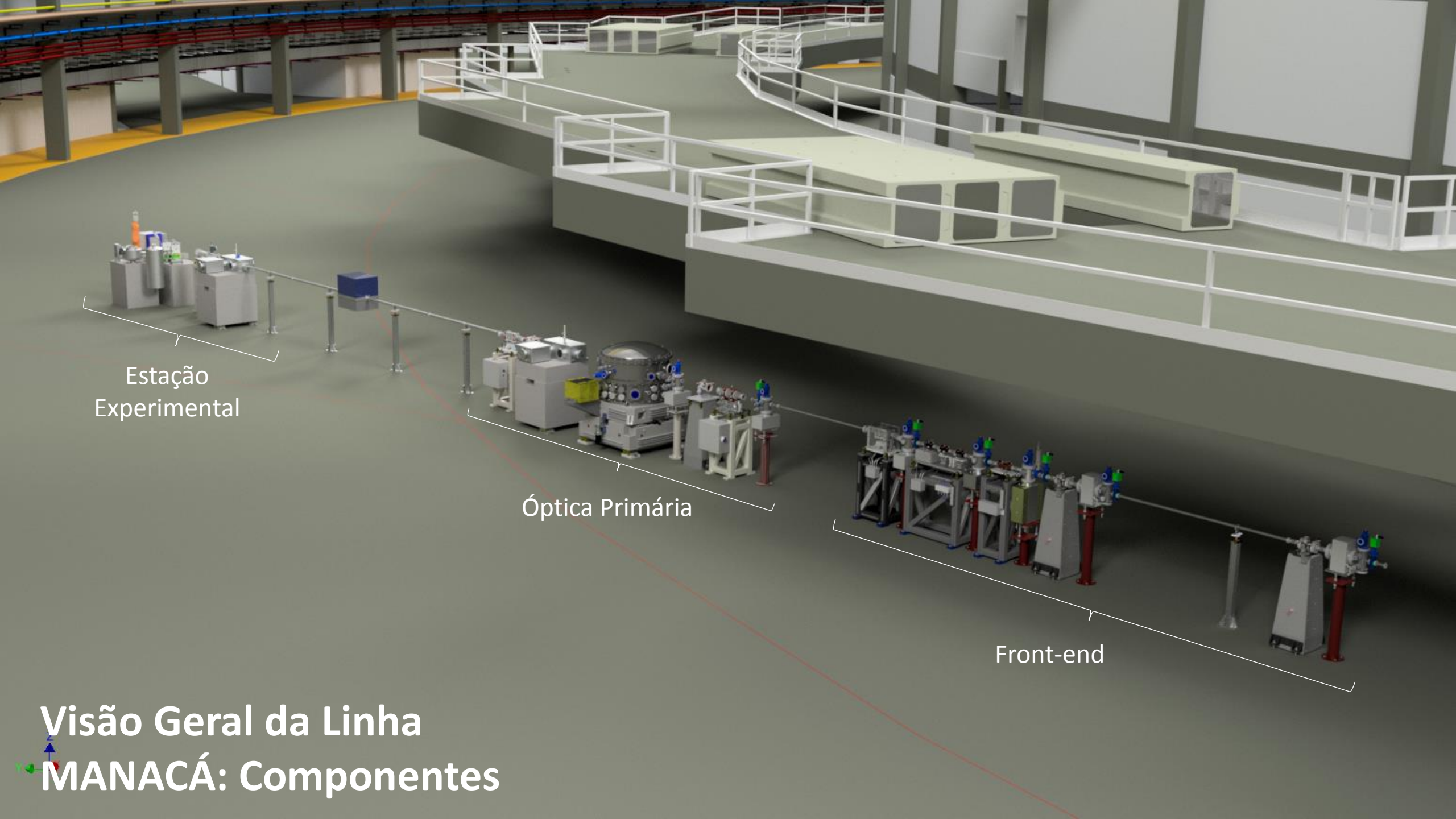
adalta
ENGENHARIA

JONFRA



BIOTEC





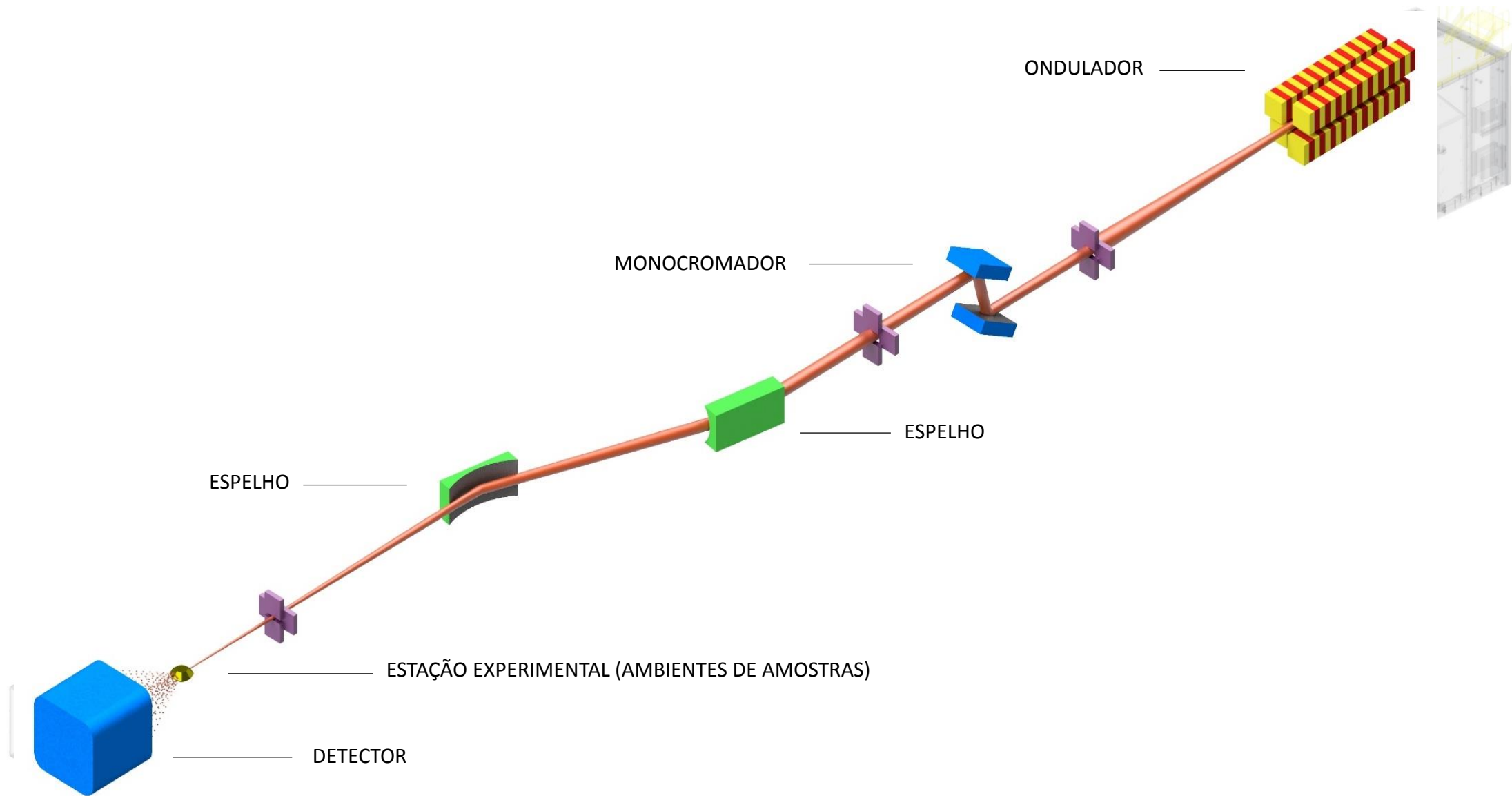
Estação
Experimental

Óptica Primária

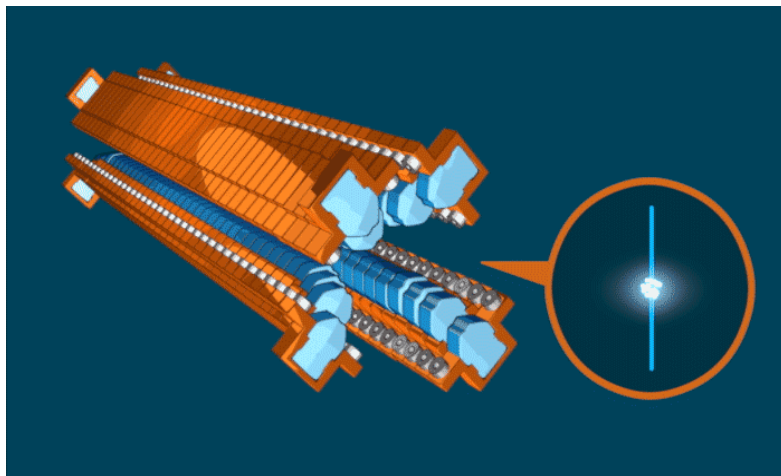
Front-end

Visão Geral da Linha
MANACÁ: Componentes

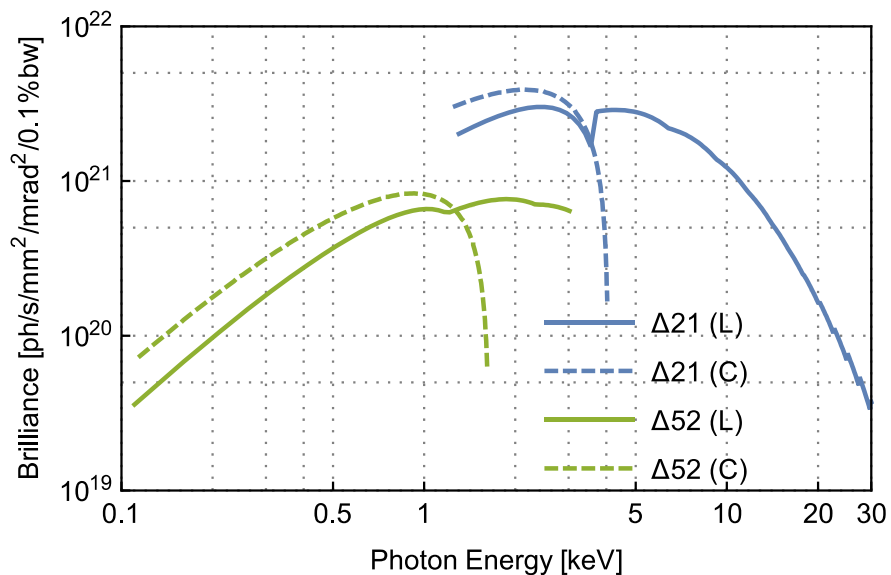
Componentes Típicos de uma Linha de Luz



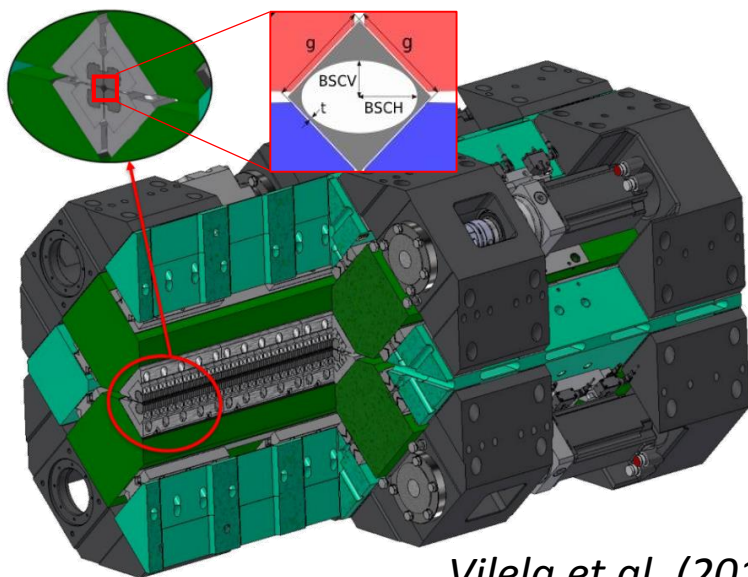
Onduladores Delta



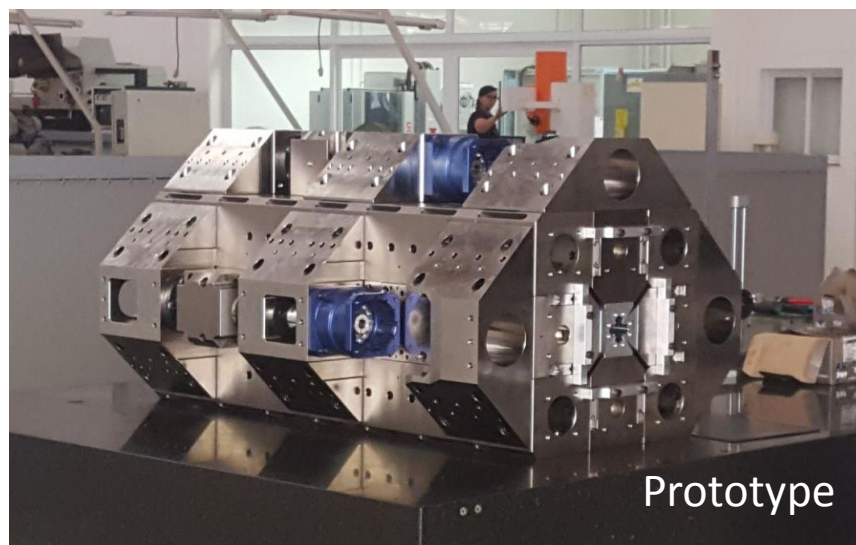
<https://www6.slac.stanford.edu/news/2016-06-15-spiraling-light-slac-x-ray-laser-offers-new-glimpses-molecules.aspx>



- So far, mostly used in free electron lasers ([Lutman et al., Nature Photonics 2016](#))
 - Needs small beam stay clear (V & H) like in Sirius
- Full polarization control
 - Circular polarization even in tender x-rays
 - Vertical polarization for side bounce monochromator
- Higher field in linear polarization
 - $B_{\max}$ Increase by a factor of $\sqrt{2}$
- Negligible effect in the beam dynamics
 - No need for active multipolar compensation in soft x-rays ([Vilela et al., IPAC2017](#))
- Simpler mechanics
 - Magnets are moved perpendicular to main forces



Vilela et al. (2018)



Prototype

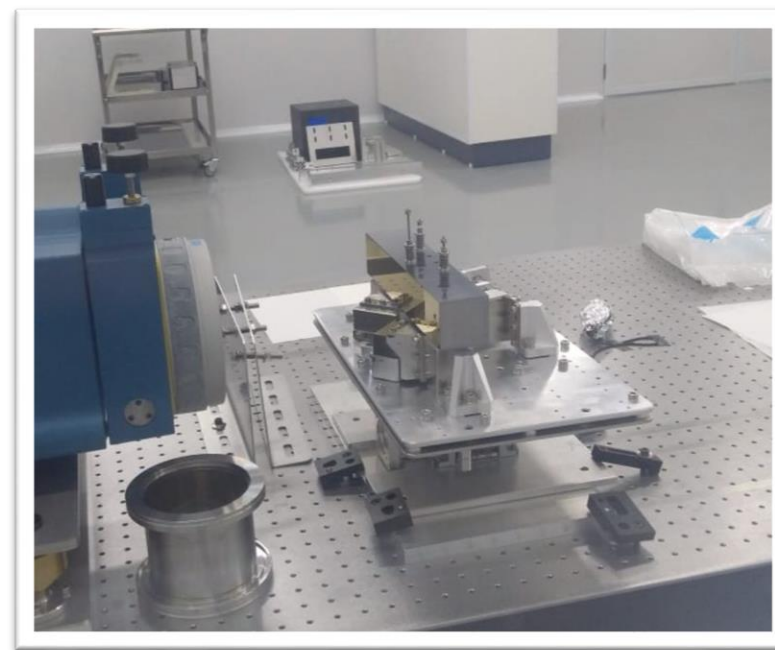
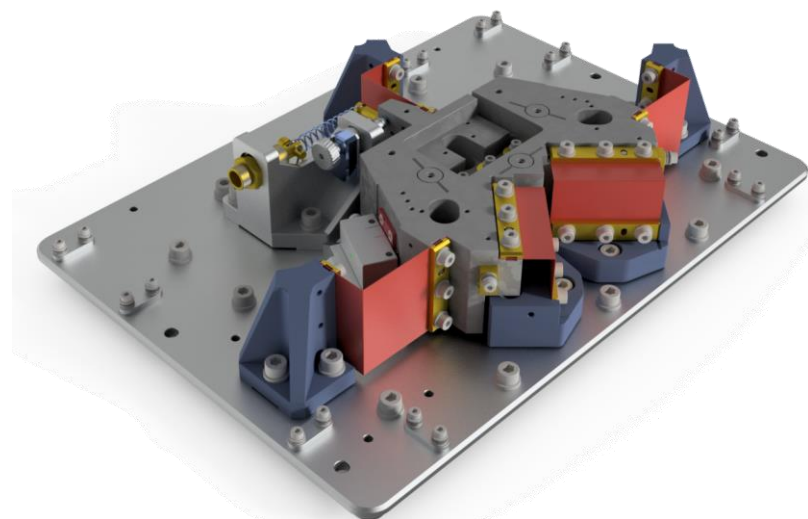
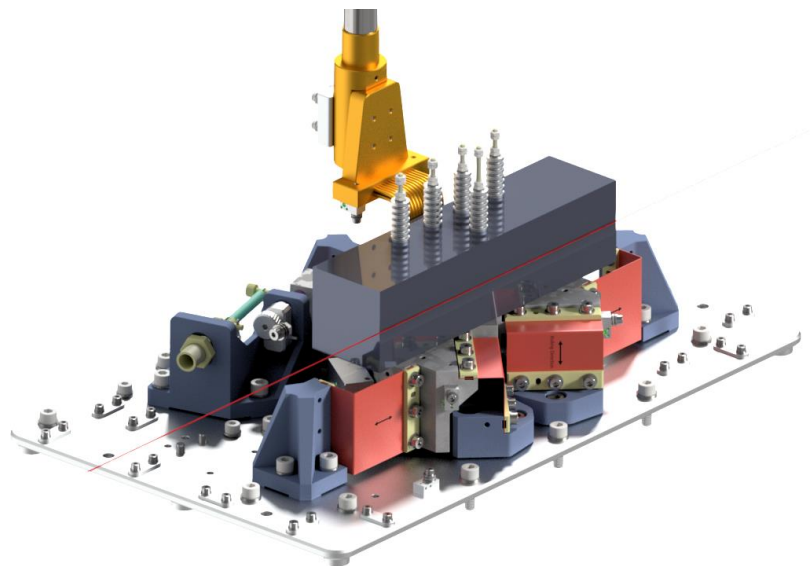
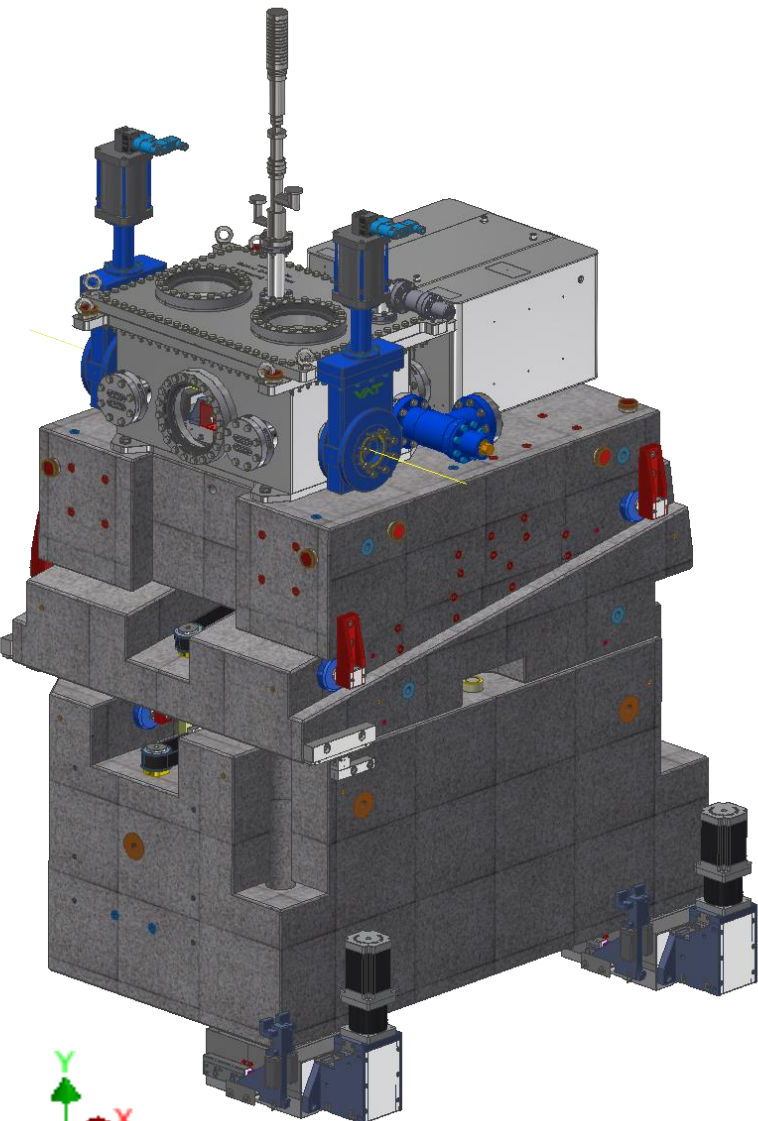




Espelho com Refrigeração Criogênica

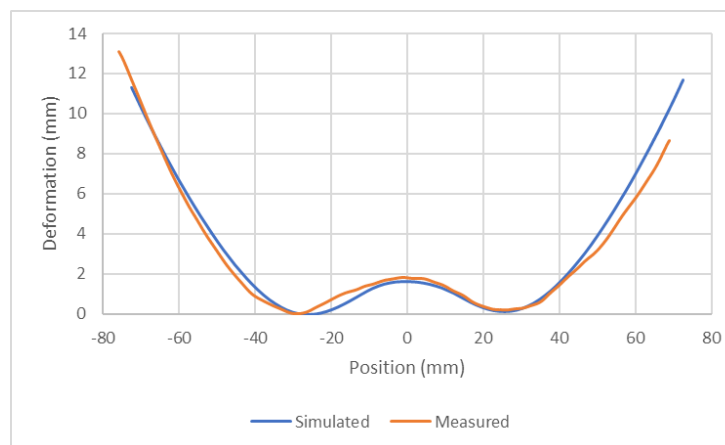
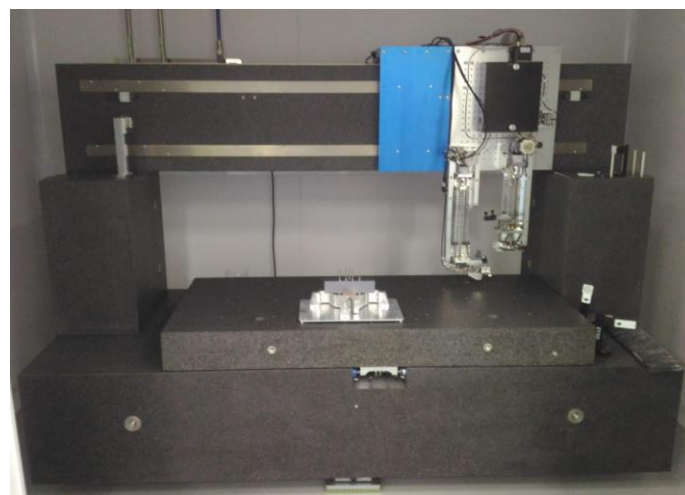
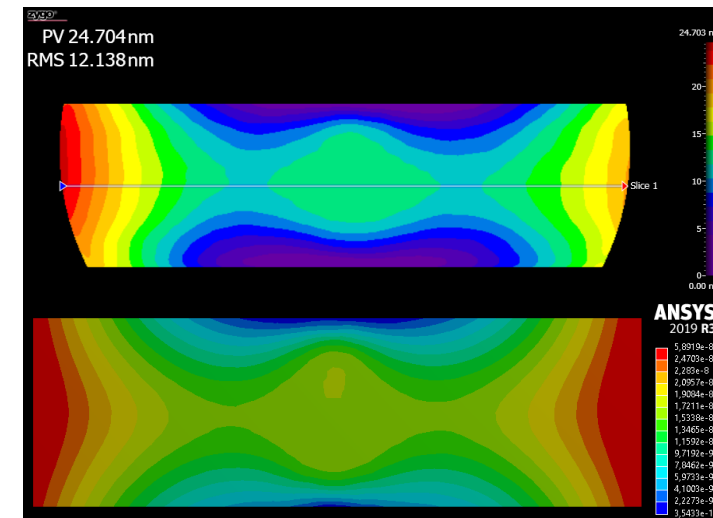
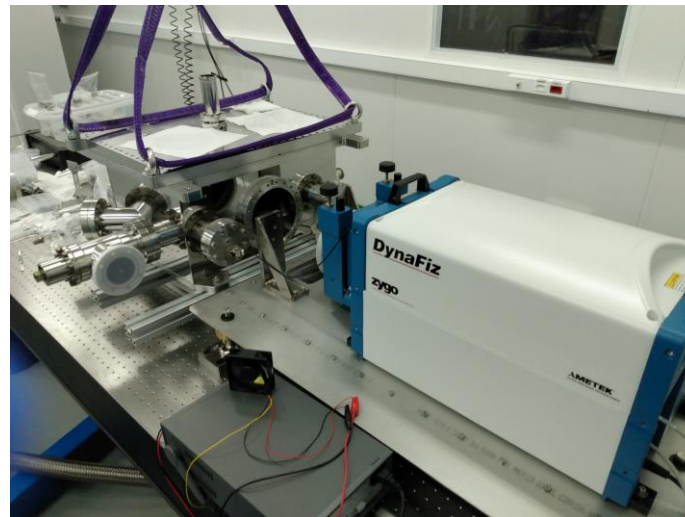
Table 1: X-ray Mirror Systems Summarized Specs

Description	Spec
<i>Ry</i> range:	> 1 mrad
<i>Ry</i> resolution:	< 100 nrad
<i>Ry</i> stability:	< 30 nrad RMS _{2.5kHz}
Resonances:	> 150 Hz
Thermo-mechanically induced slope errors:	< 50 nrad
Power load:	< 50 W
Cooling scheme:	indirect cryocooling via copper braid and cryostat

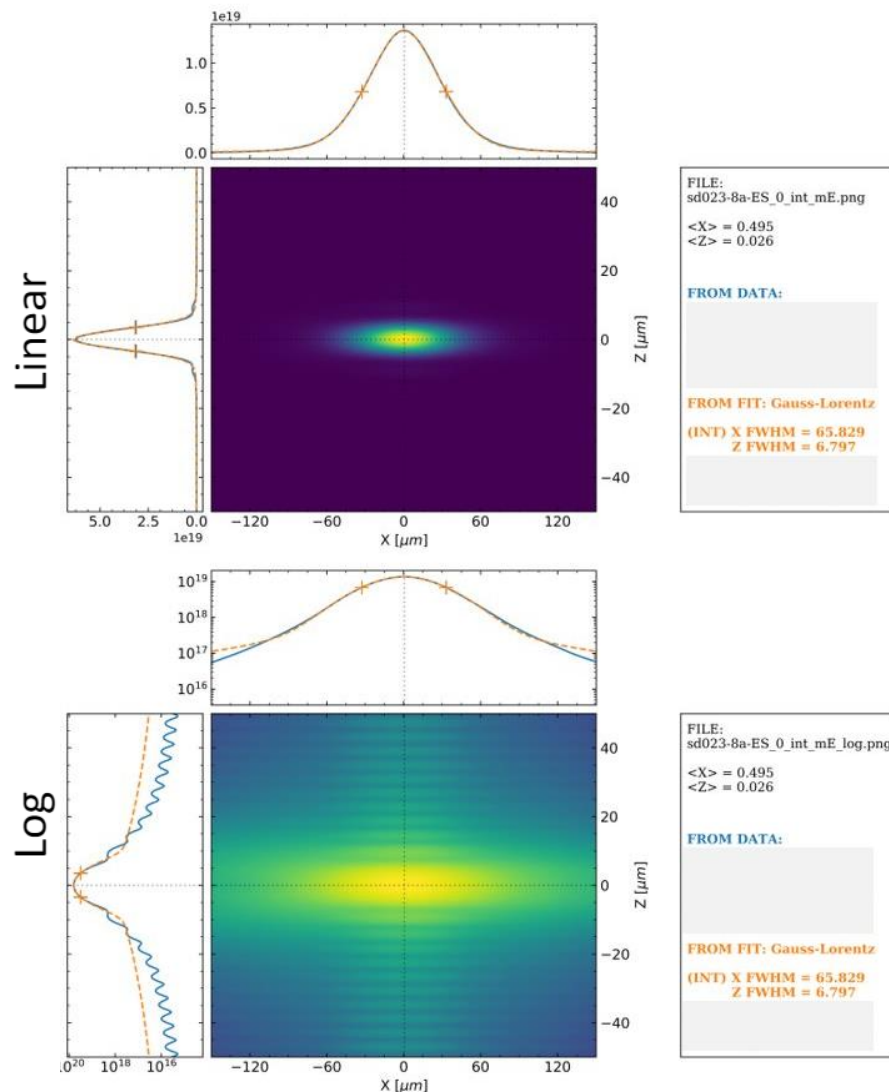


Measurement Instruments

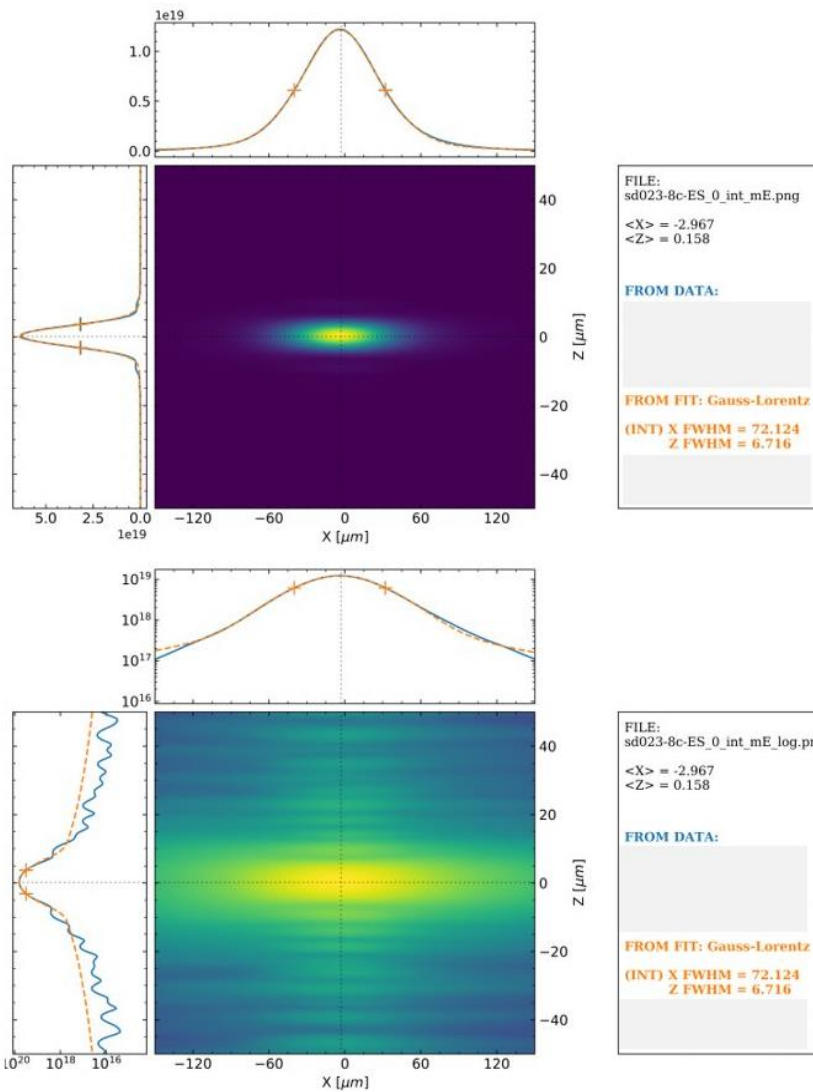
- Fizeau Zygo Dynafiz
 - Area measurements of optical surfaces
 - Sub-nm precision
 - Good for low frequency measurements
 - Difficult to measure surfaces with low radius ($< 100\text{m}$)
- Long Trace Profiler (LTP)
 - Inline measurement of optical surfaces
 - High frequency measurements
 - Measures the optical surface slope with a $f-\theta$ lens optical system
 - Difficult to measure surfaces with low radius
- Nanometer Optical Component Measuring Machine (NOM) - Assembly in progress
 - LTP with another independent system that measures using an autocollimator
 - Two measurements at the same time to increase accuracy and reliability
 - It is expected to be able to measure low radius surfaces



No Errors



Errors: All mirrors, except IPE-4-MC

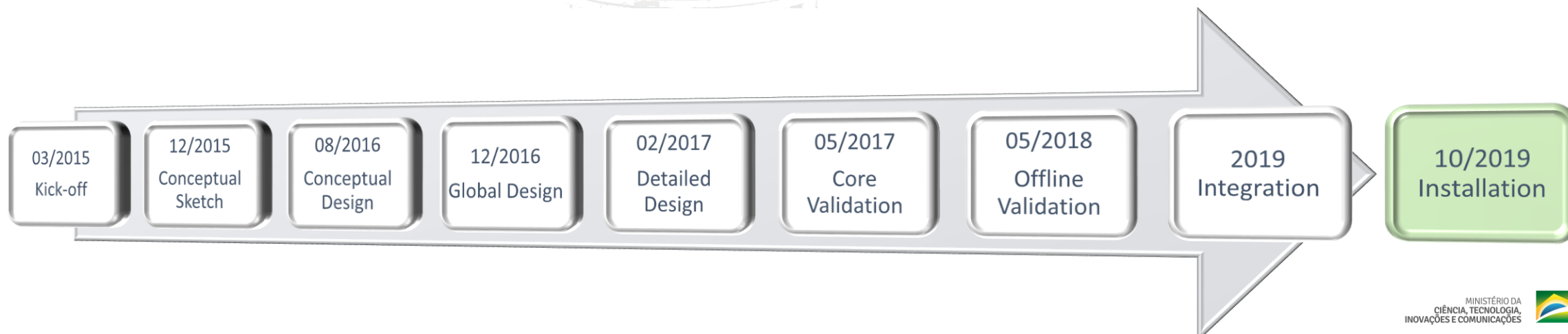
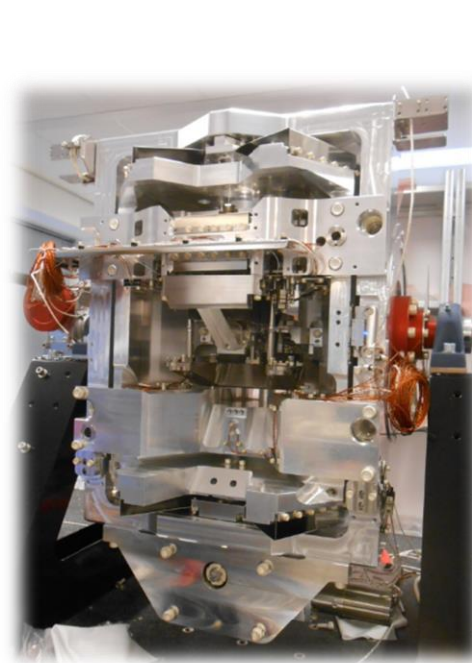
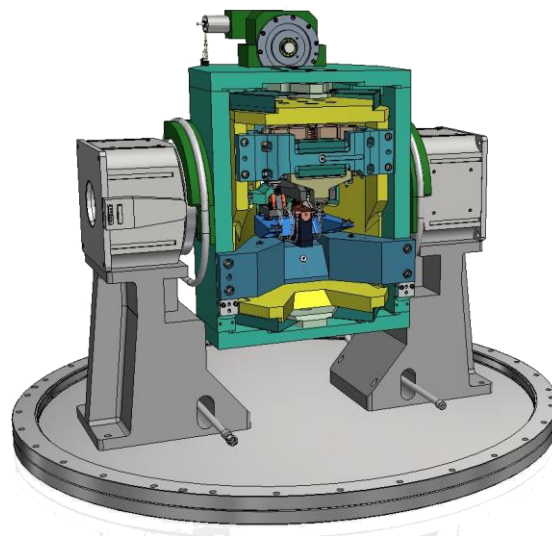
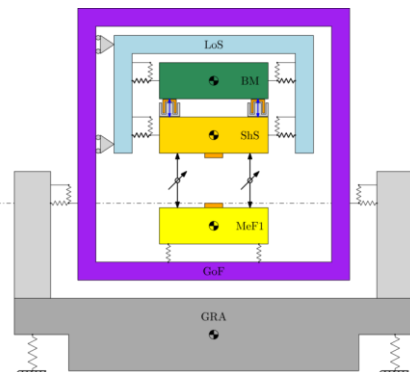
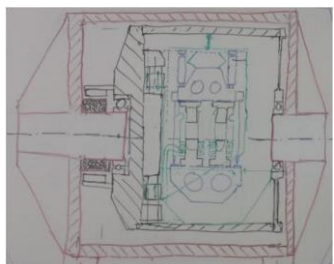


Description	Typical Specs
Power load:	0 ~ 60 W
Peak-to-Valley Error:	5 ~ 30 nm
RMS Height Error:	1.5 ~ 10 nm
Slope Error:	70 ~ 300 nrad

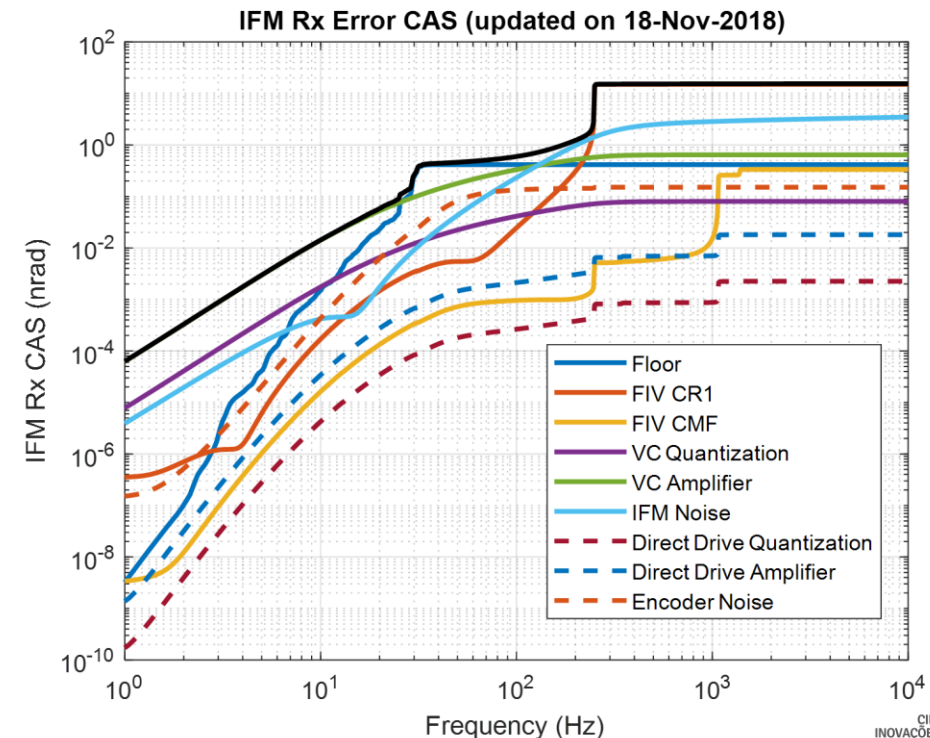
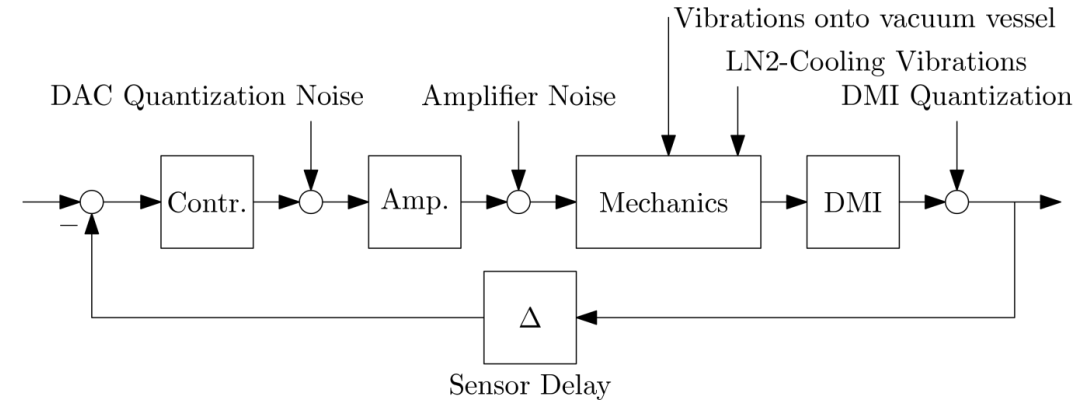
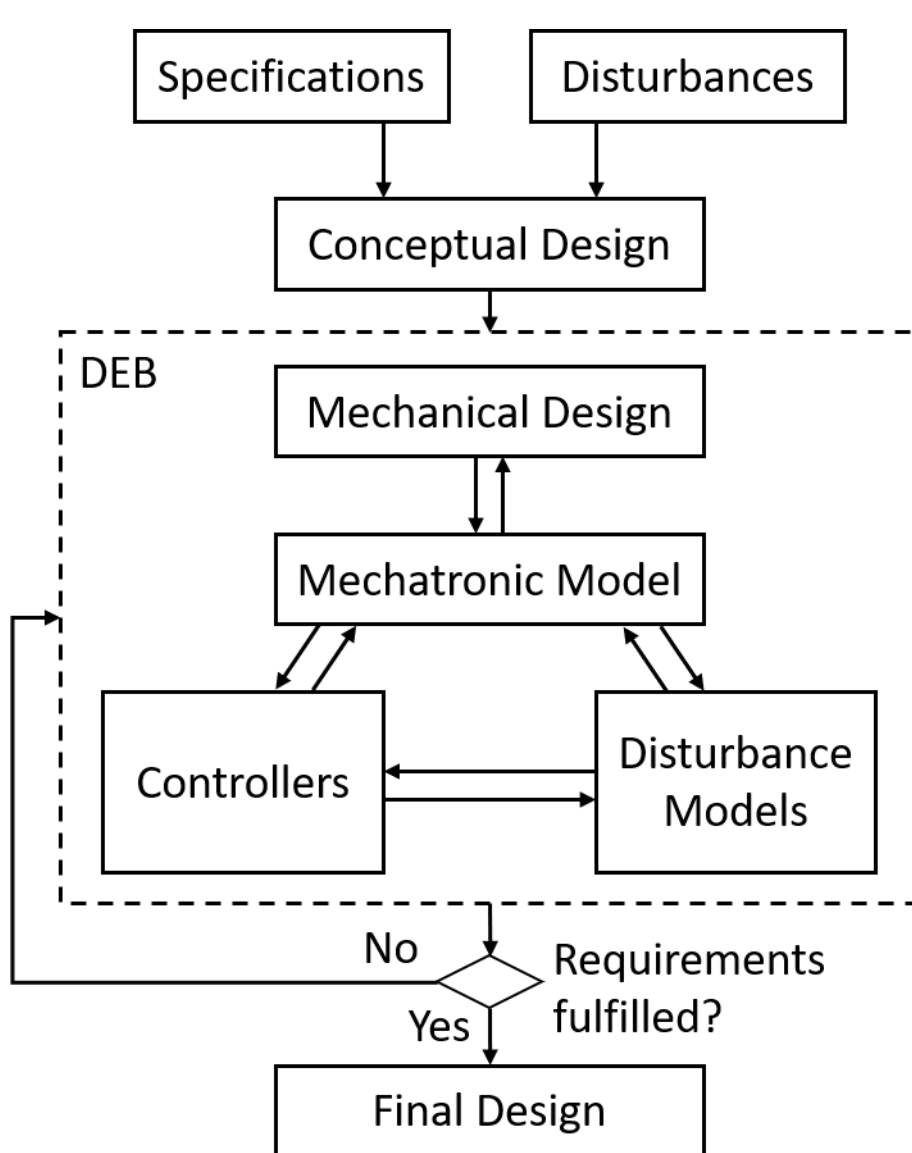


Monocromador de Alta Dinâmica

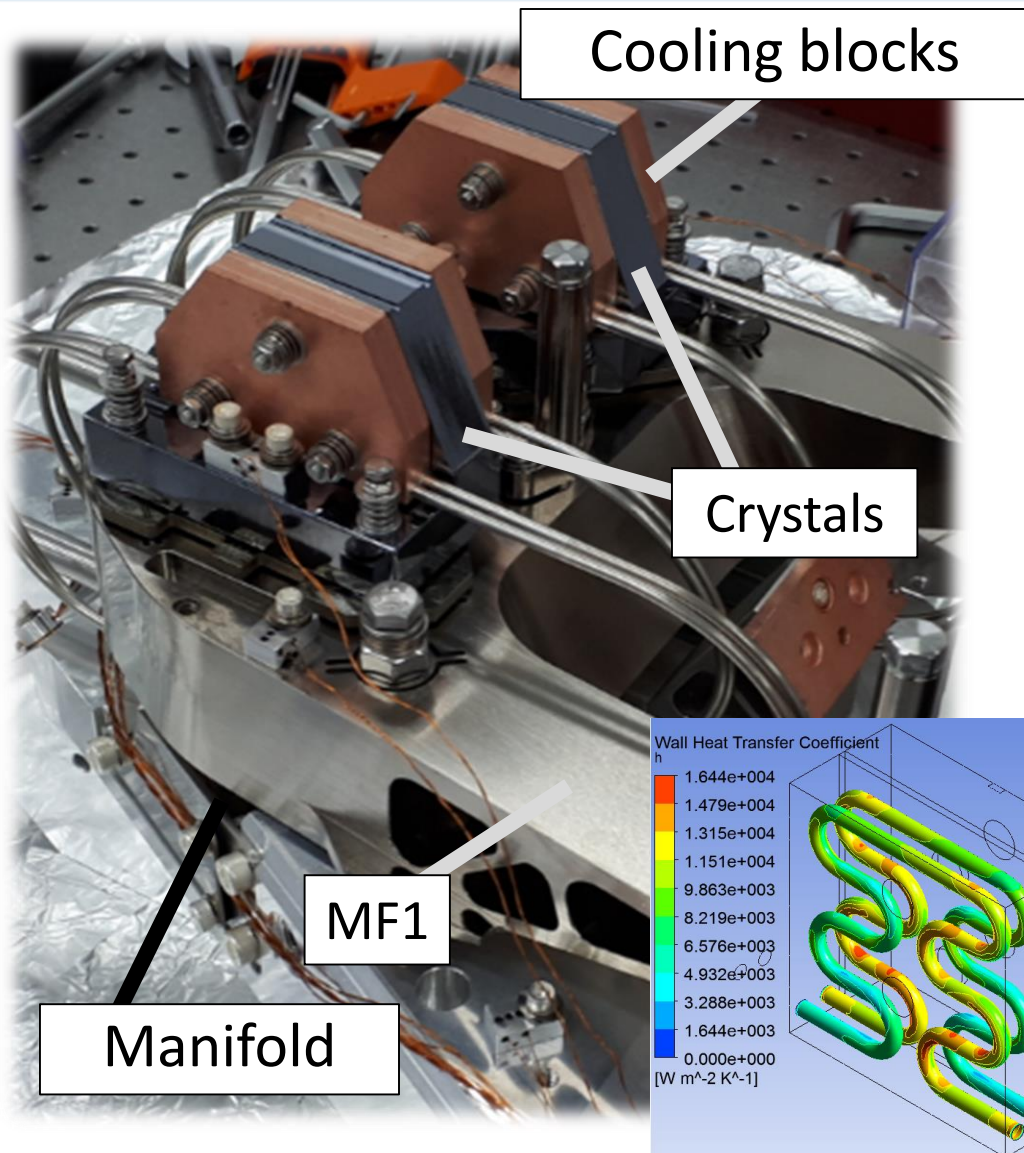
With: **MI** PARTNERS
PARTNERS IN MECHATRONIC INNOVATION



Predictive Engineering - Dynamic Error Budget



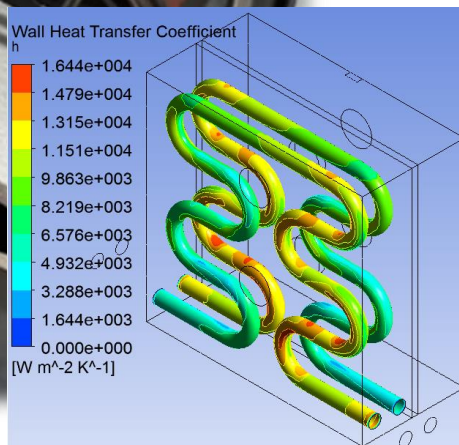
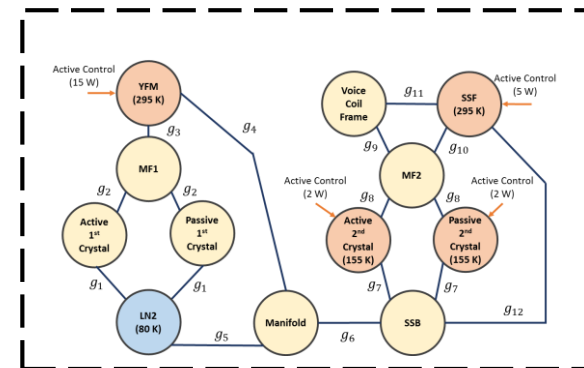
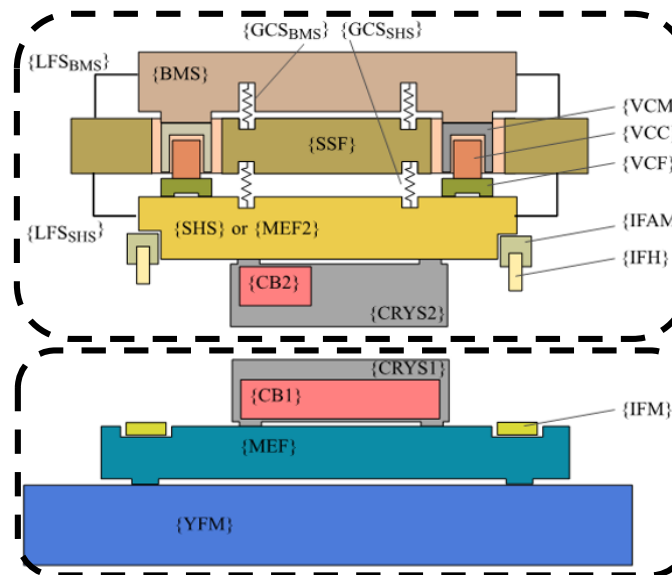
Design Examples: LN2 Manifold and Thermal Modeling



2nd
module

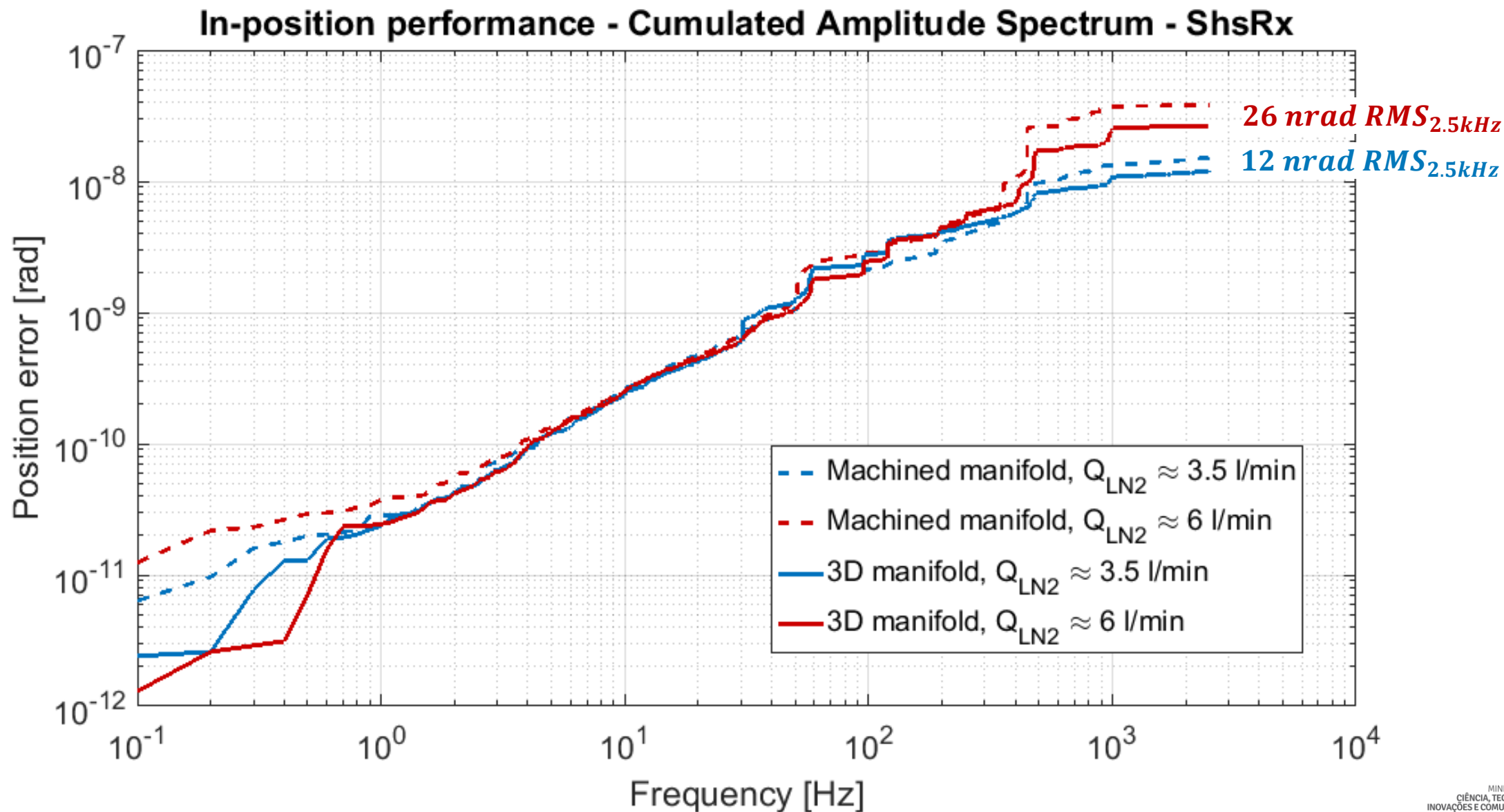
1st
module

High-dynamic core:

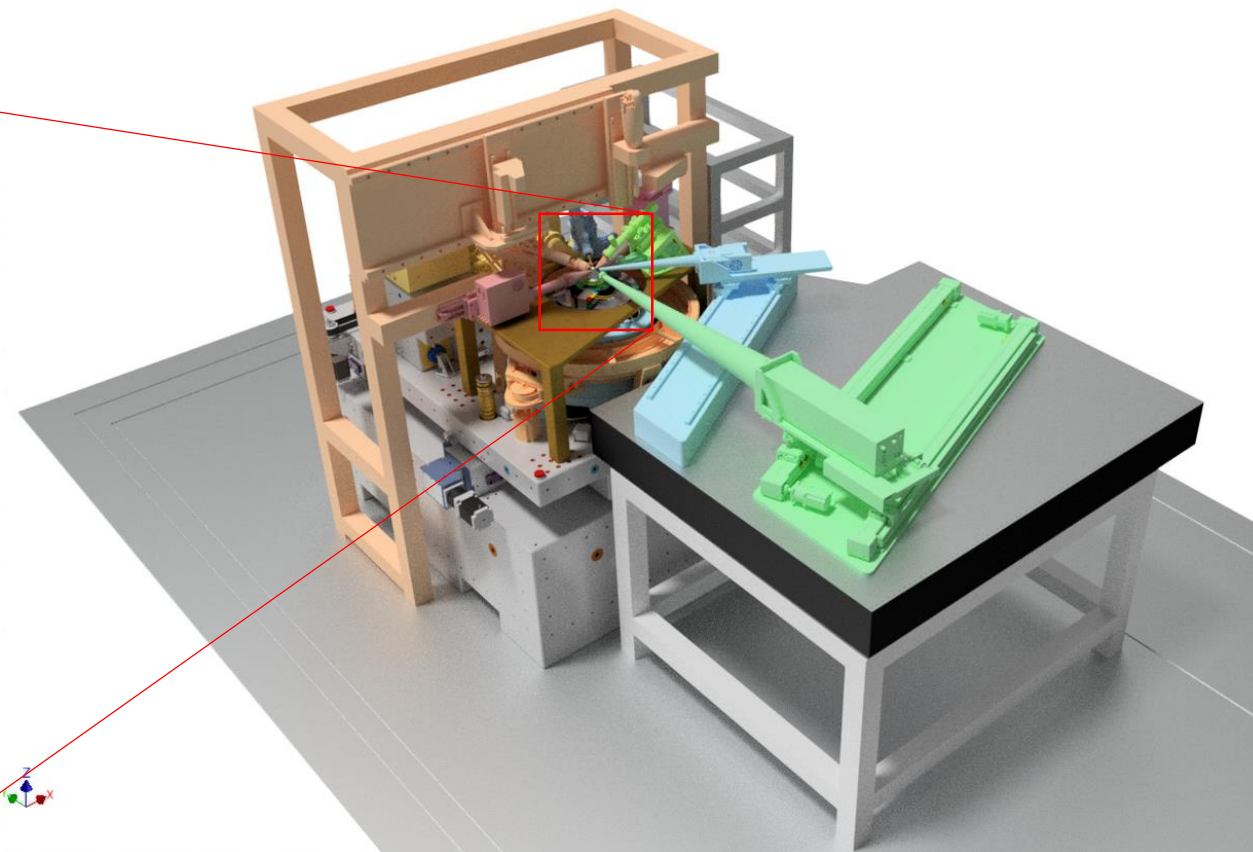
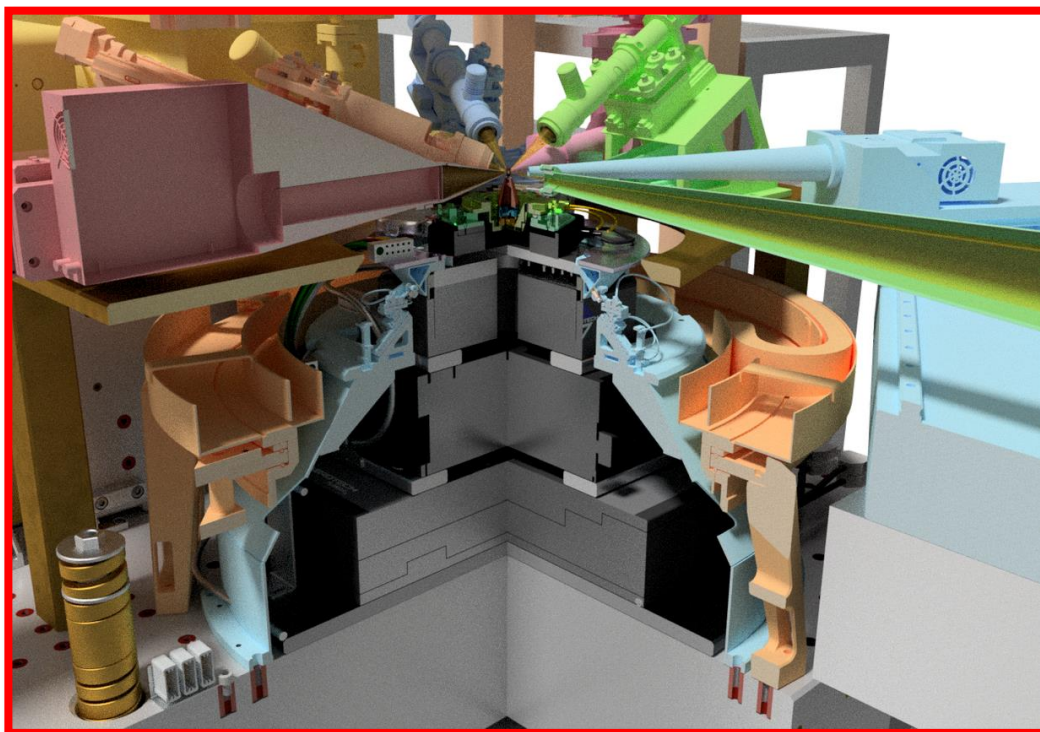


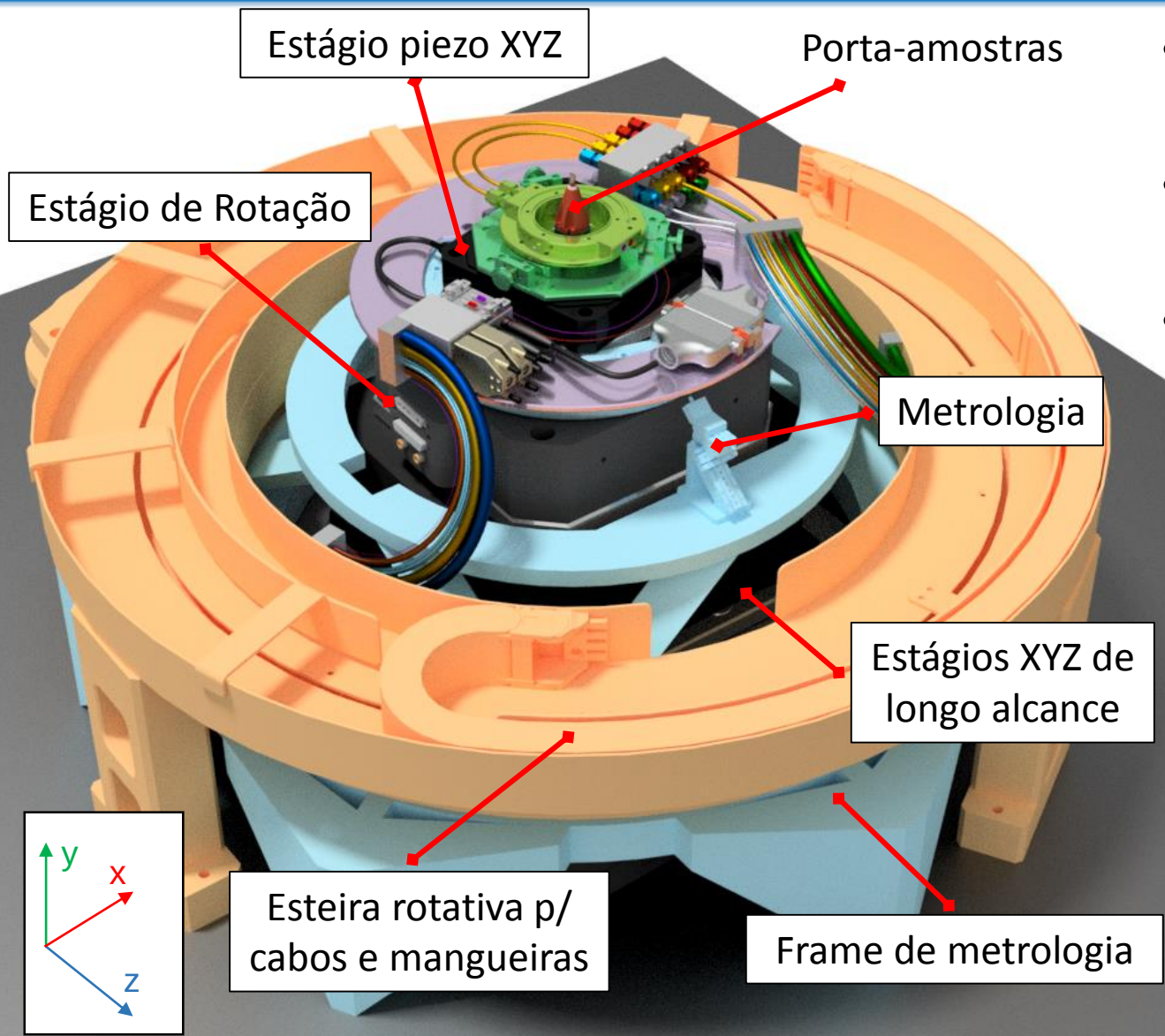
Element	Designed [K]	Experimental [K]
CR1	78	78
MF1	170	180
YFM	297	297
BRC	95	102
CR2	155	155
SHS	210	250
VCF	250	267
SSF	297	297

In-Position Performance

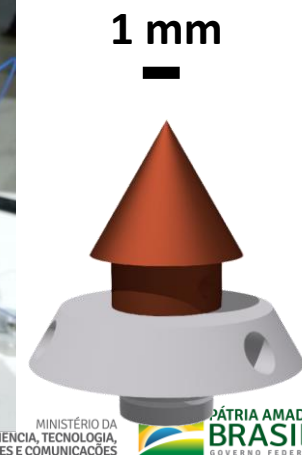
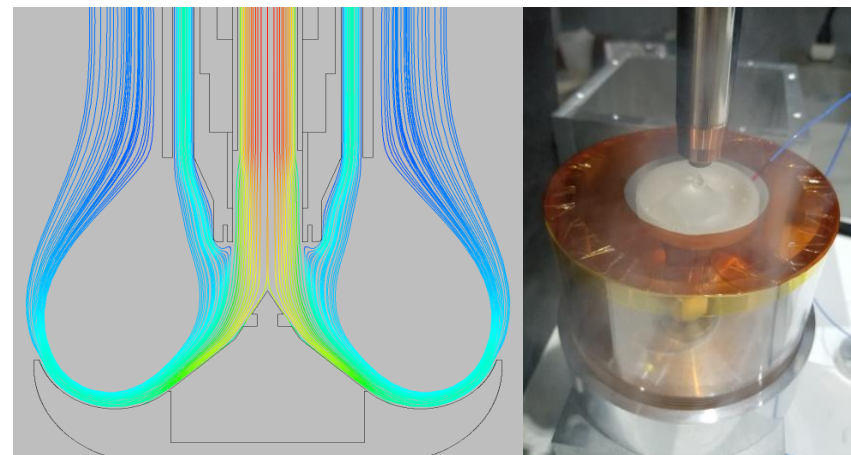


- Estação do tipo *Nanoprobe* – resolução < 10nm: Sensível à distúrbios vindos do piso, variações térmicas, acústica...
- Posicionada a 135 metros da fonte: desafio de estabilidade p/ componentes ópticos!
- Alta versatilidade de experimentos: desafios para conciliar diversas técnicas e condições ambientais
- ~150 GB de dados por segundo com processamento paralelo em tempo real!



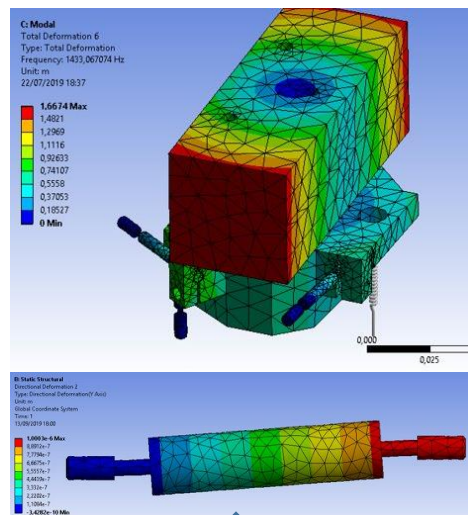


- Vias de suprimentos fixas para ambientes de amostra variados
- Esteira auxiliar para rotação de vias sem perturbar sistemas de alta precisão
- Seleção de materiais para:
 - Evitar fluorescência indesejada
 - Resistir altas doses de radiação
 - Resistir temperaturas extremas
 - Resistir à corrosão química

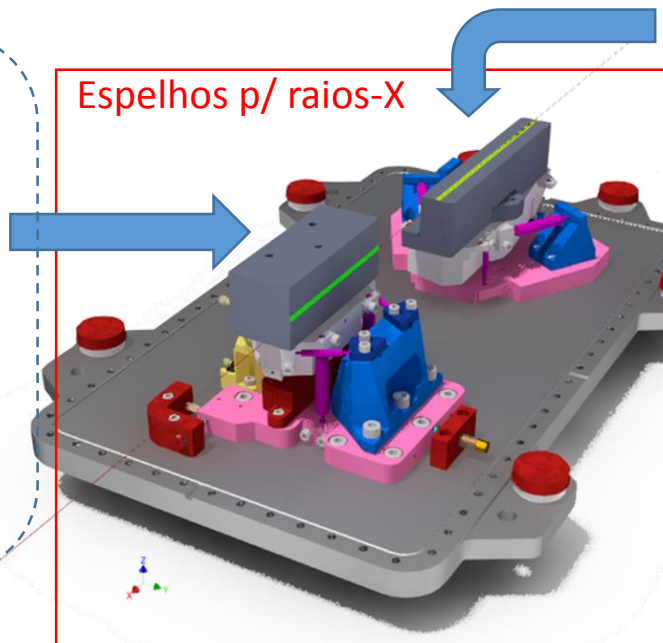


Tarumã – Par de Espelhos

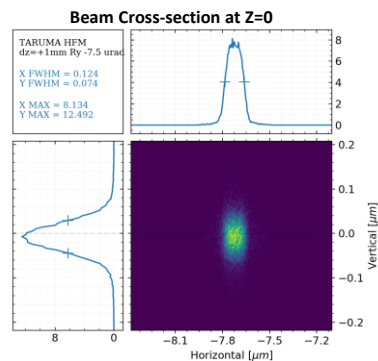
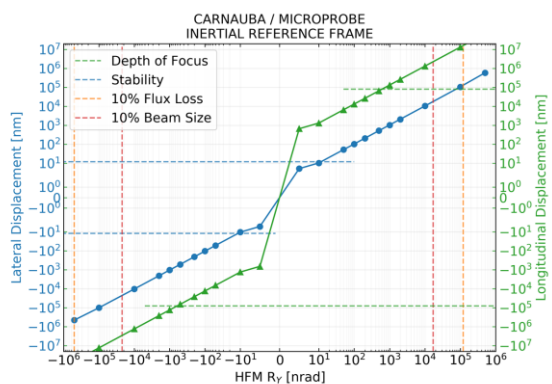
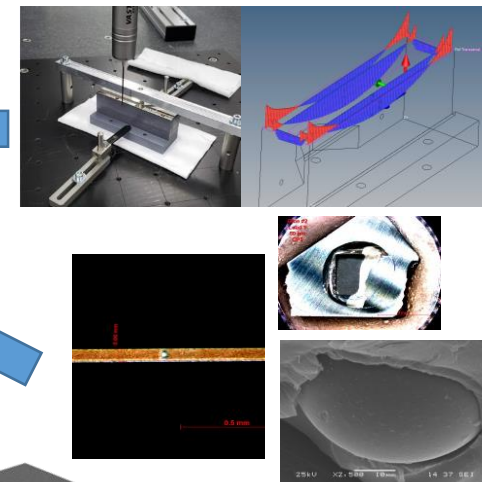
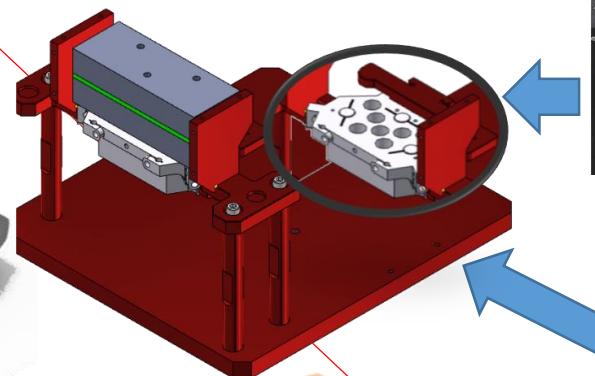
Modelagem modal



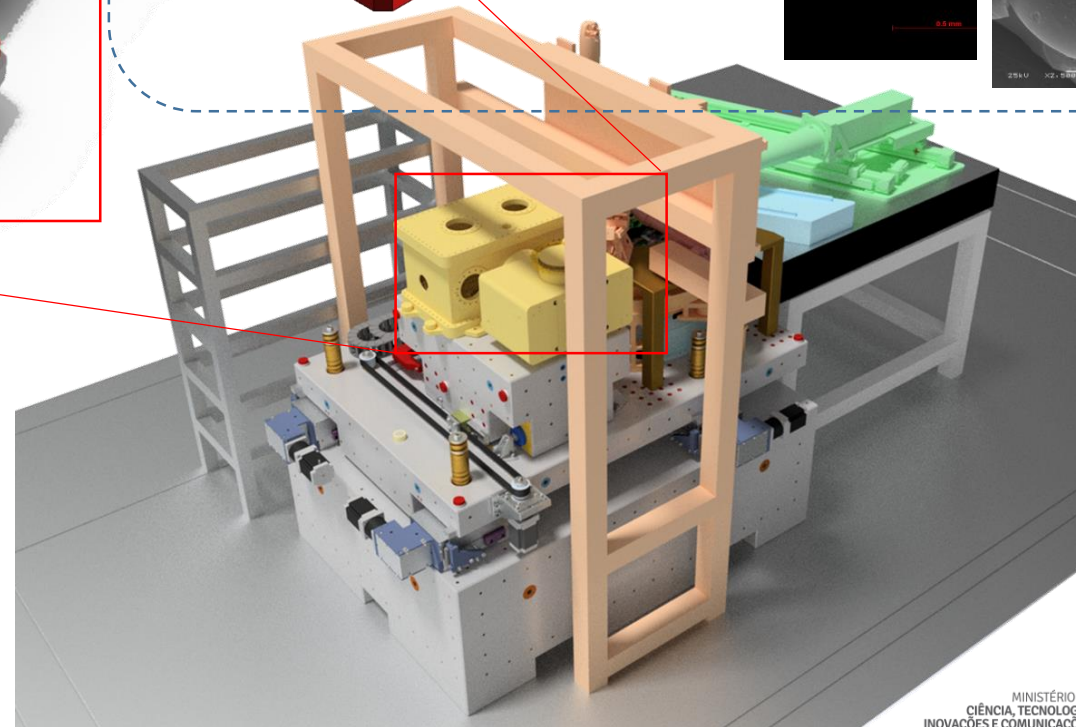
Espelhos p/ raios-X



Medidas de superfície e colagem para vácuo e rigidez



Simulações de alinhamento óptico



Tarumã – Par de Espelhos

Modelagem modal

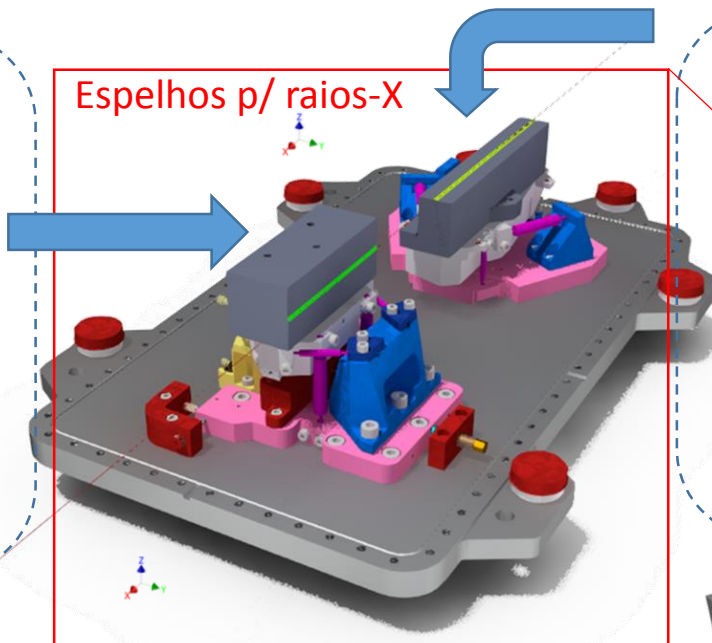
Sistemas exatamente determinados

Suportes flexíveis com comportamento linear

Frequências de suspensão > 300 Hz

Rigidez de apoios > 10^7 N/m

Espelhos p/ raios-X



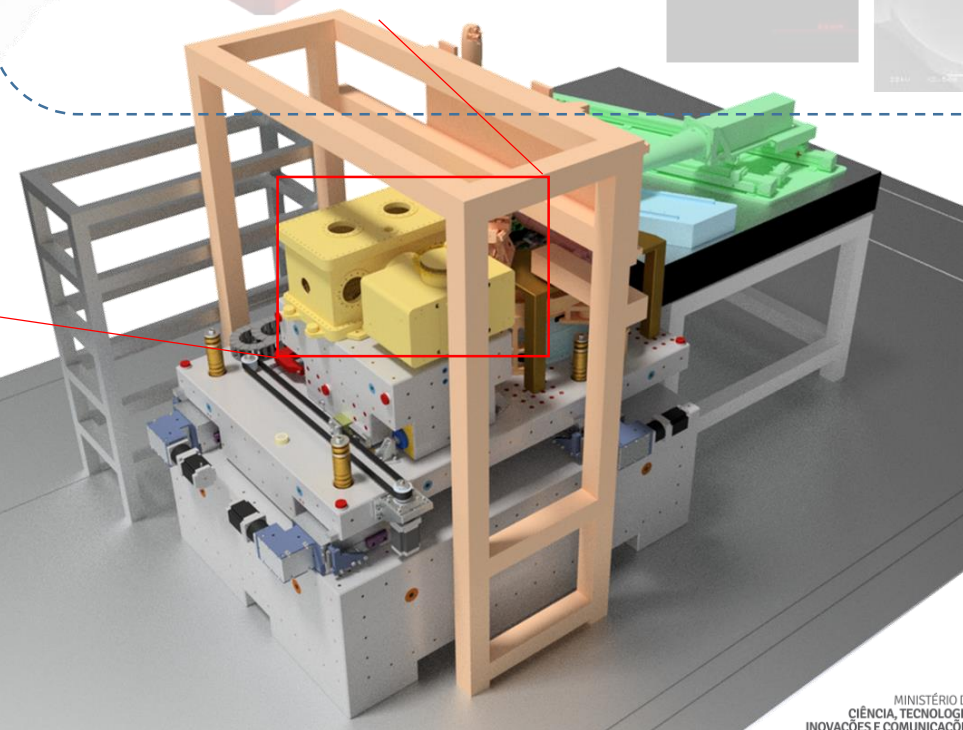
Medidas de superfície e colagem para vácuo e rigidez

Colagem de componentes para mitigar deformações por fixação (tolerância < 0.5 nm)

Estruturas flexíveis para permitir expansões térmicas

Seleção de materiais para ultra-alto-vácuo (< 10^{-11} mbar)

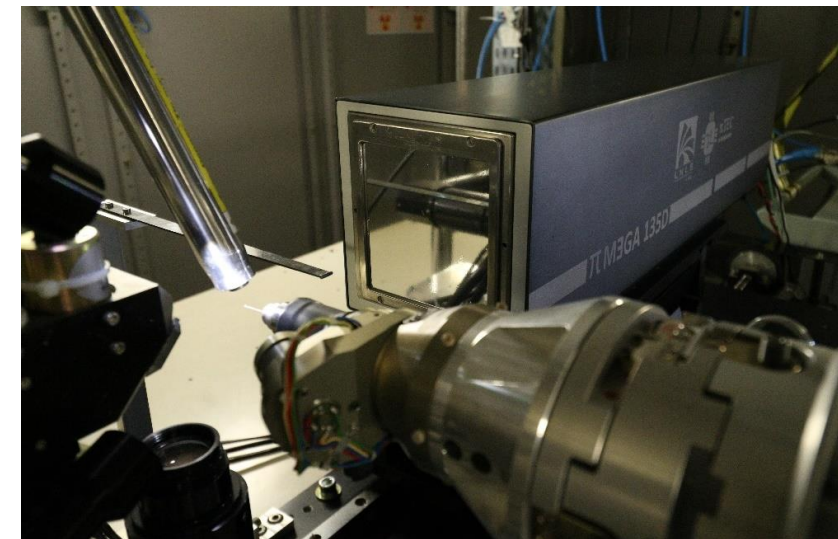
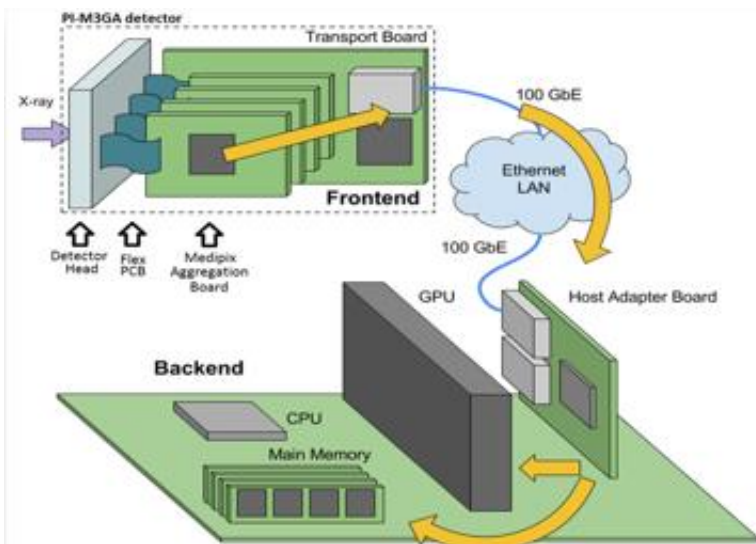
Fiducialização precisa da figura dos espelhos para mitigar erros de montagem



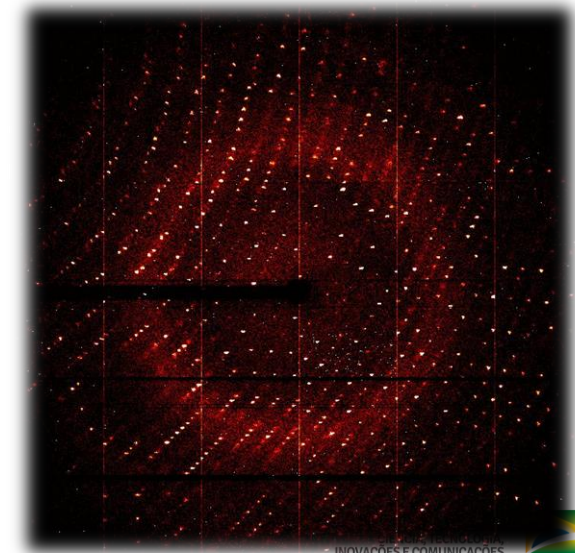
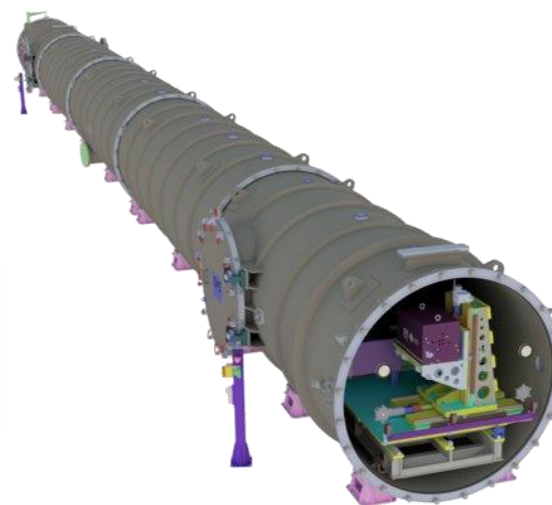
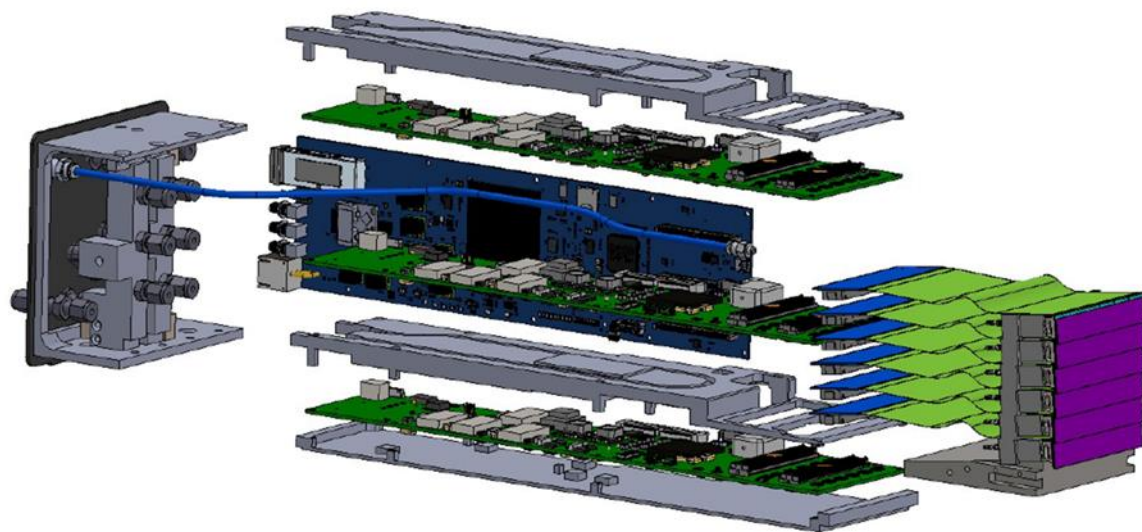
Tamanho de foco na amostra	100 nm
Tolerâncias no erro de figura dos espelhos	~1 nm; ~50 nrad
Alinhamento entre Espelhos	<20 μ m; <100 nrad
Estabilidade de Espelhos	até ~4 nrad
Estabilidade entre sistemas ópticos da linha (ao longo de 135 metros de extensão!!)	~1 μ m

Simulações de componentes ópticos

π -M3GA Detectors Project



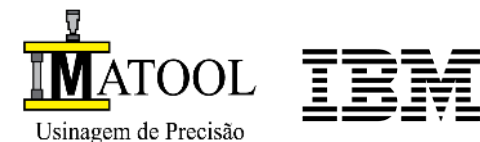
Detector Backend – Local HPC for on-flight tomography data processing and rendering



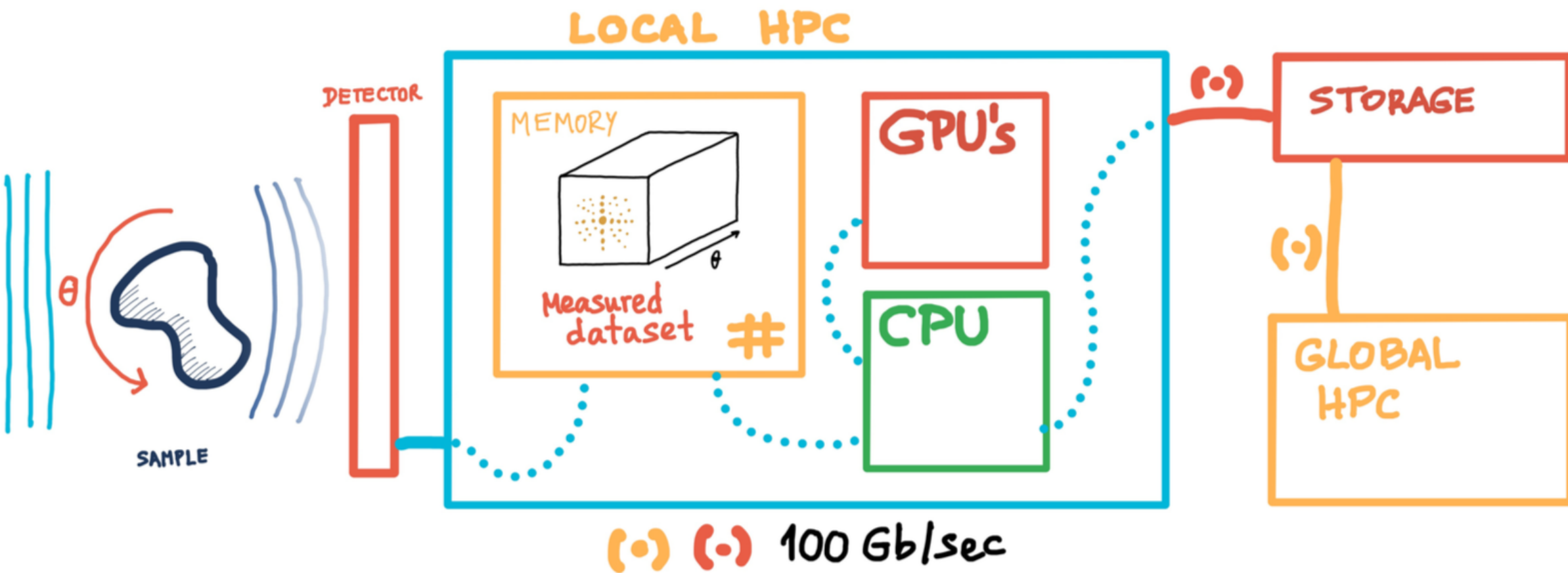
π -M3GA Family



	MOBIPIX 15D	PIMEGA 45D	PIMEGA 135D	PIMEGA 450D	PIMEGA 540D
Sensors (μm type)	300 Si / 1000 CdTe	300 Si / 1000 CdTe	300 Si / 675 Si (hexa)	675 Si (hexa)	300 Si / 675 Si (hexa)
Pixels (number / arrangement)	262,144 / 512 x 512	786,432 / 512 x 1536	2,359,296 / 1536 x 1536	1,310,720 / 256x5120	9,437,284 / 3072 x 3072
Pixel size (μm^2)	55 x 55	55 x 55	55 x 55	55 x 55	55 x 55
Detection area (mm^2)	28 x 28	28 x 85	85 x 85	14.1 x 1692	170 x 170
Active area (%)	99.7	99.6	100	100	99
Dynamic range (counts/px/s)	3×10^5	3×10^5	3×10^5	3×10^5	3×10^5
Frame rate @ 12bits (fps)	2000	600	2000	1000	1400
Throughput @ 12bits (Gb/s)	6.3	5.7	56.6	87.9	226.5
Readout mode	Continuos (no burst)	Continuos (no burst)	Continuos (no burst)	Continuos (no burst)	Continuos (no burst)
Vacuum (10^{-3} mbar)	No	No	Yes	No	Yes



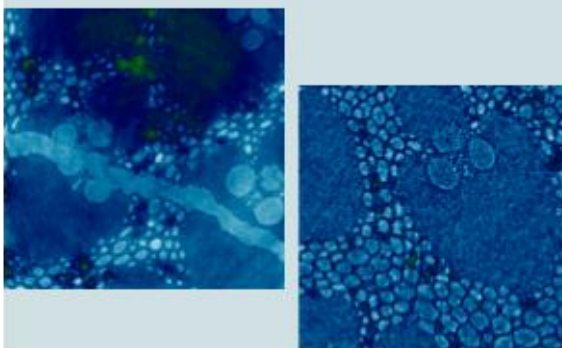
Detectors, HPC and Network



Scientific Computing (GPU-centered)

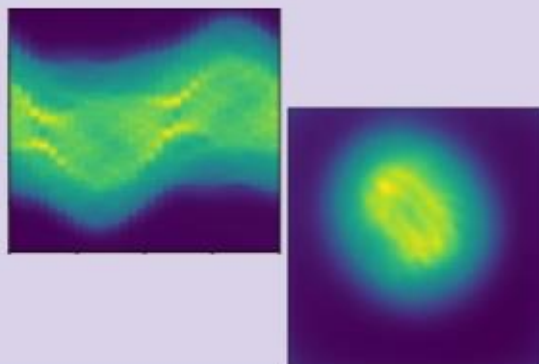
(1) Absorption Tomography

- a) Reconstruction algorithms
- b) Analytical and Iterative



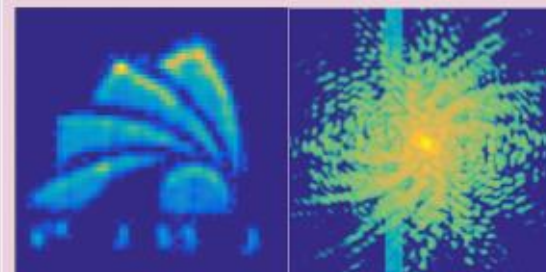
(2) Fluorescence Tomography

- a) Att. Radon transform
- b) Iterative algorithms



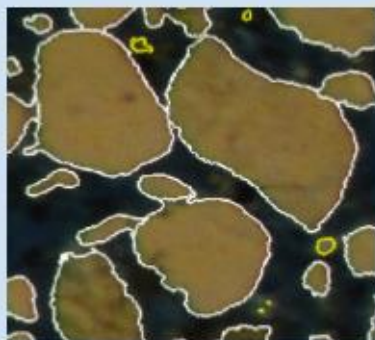
(3) Coherent Diffraction Imaging

- a) GS, HIO, Fienup algorithms
- b) New iterative methods

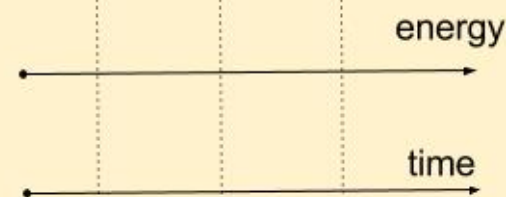
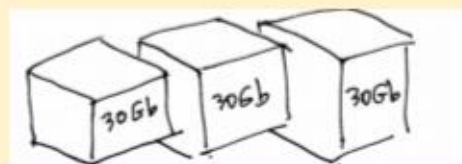


(4) Image Segmentation

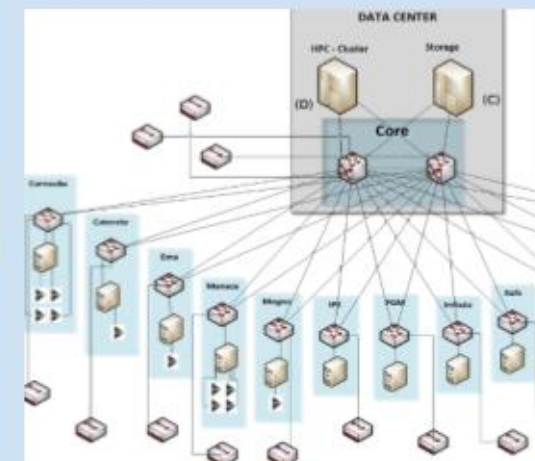
- a) Filter design
- b) Clustering algorithms



(4) Hyperspectral data



(4) Scientific Computing



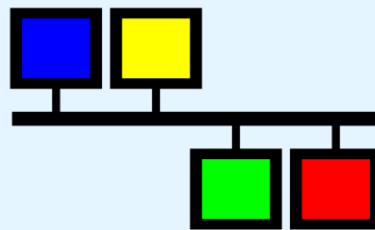
Beamline Controls

SIEMENS



MOXA's NPort

EPICS



Delta-Tau
Power Brick LV™



CompactRIO™
(RT Linux)



vmware®



Galil DMC-4183



CRONOGRAMA

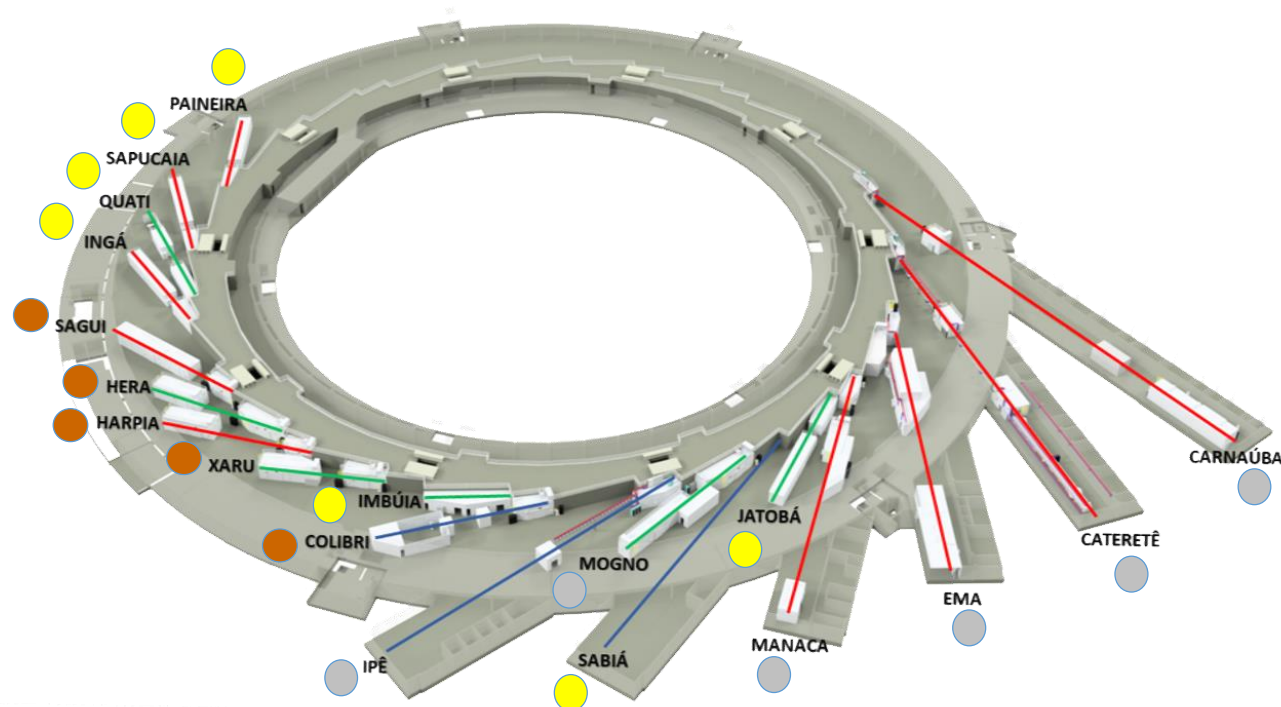
Sirius beamlines and science programs

PHASE	BEAMLINE	ENERGY (keV)	TECHNIQUES
I – A	MANACÁ	5 – 20	Serial micro and nano MX
I – A	EMA	3 – 35	Extreme Conditions
I – A	MOGNO**	20/40/70	Cone beam Tomography
I – A	CATERETÊ	3 – 12	CDI, XPCS
I – A	CARNAÚBA	2 – 15	spectro-ptychography
I – A	IPÊ	0.08 – 2	AP-RIXS; ARPES
I – B	SABIÁ	0.25 – 2.5	AP-XPS; XMCD
I – B	JATOBÁ**	30 – 200	XRD-CT
I – B	INGÁ	4 – 24	IXS
I – B	QUATI**	4 – 45	Quick-EXAFS
I – B	SAPUCAIA	4 – 24	High-Throughput SAXS
I – B	PAINEIRA	4 – 24	XPD
II	COLIBRI	0.1 – 1.5	PEEM, CDI
II	IMBÚIA**	0.001 – 1 eV	nano-FTIR
II	XARU**	4 – 45	EXAFS
II	HARPIA	5 – 30	TR-XPD
II	HERA**	30 – 120	XTMS
II	SAGUI	4 – 24	SAXS

**Based on Bending Magnets

Phase	Number of beamlines	Status
1-A	6	Construction 
2*	5	Funding 
1-B	7	Design 

* Mainly refurbished beamlines from the UVX machine



DESTAQUES

OBRIGADO!

LUCAS.SANFELICI@LNLS.BR

