Initial Experiences With Beam Diagnostics During Sirius Commissioning

Brazilian Synchrotron
Light Laboratory

Henrique de O. Caiafa Duarte
Beam Diagnostics Group (DIGS)
on behalf of the LNLS/Sirius Team

Talk at IBIC 2020 (MOA002)
September 14, 2020

Outline

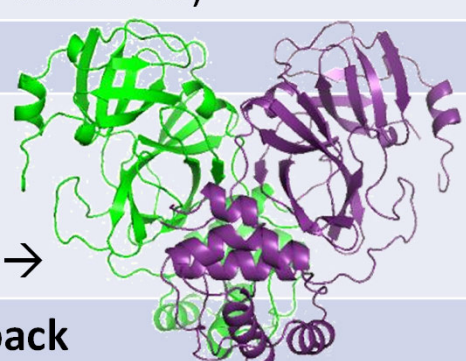
- Sirius Timeline
- Introduction
- Diagnostics Components Summary
- Fluorescent Screens (Flags)
- Current Monitors
- Beam Scrapers
- Tune Measurement System
- BbB FB System
- BPM, Stability and Measurements
- Final Comments

Sirius Timeline (2012-2019)

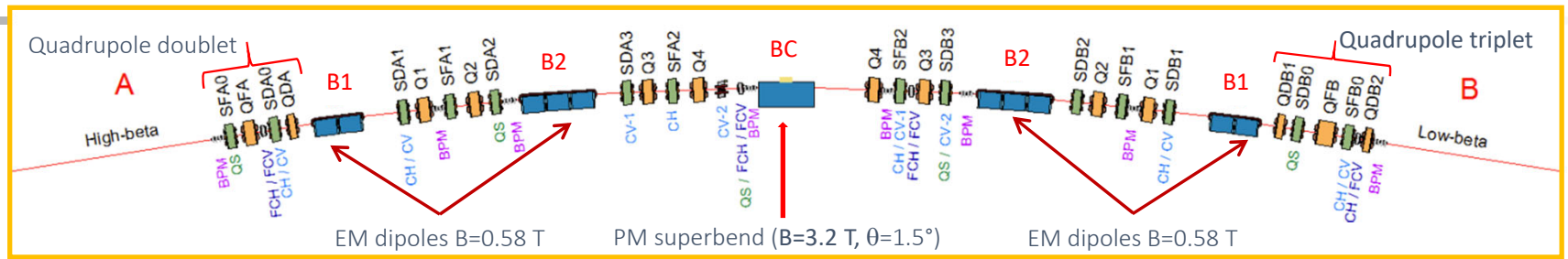
2012		- start of MBA lattice design after first MAC meeting
2015		- start of building construction
2016		- start of components production by Brazilian industry
2018	April	**- 150 MeV Linac from SINAP commissioned**
	May	- start of booster installation
	June	- start of storage ring installation
2019	08-Mar	**- first turn in the booster @ 150 MeV**
	16-Oct	**- first beam energy ramp to 3 GeV**
	22-Nov	**- first turn in storage ring with on-axis injection**
	06-Dec	- hundreds of turns without RF
	14-Dec	**- first stored beam with on-axis injection, 30 uA**
	16-Dec	- first light from superbend BC at Mogno beamline (20/40/68 keV Zoom Tomography)
	16-Dec	**- first X-ray microtomography experimental result from Mogno**

Sirius Timeline (2020)

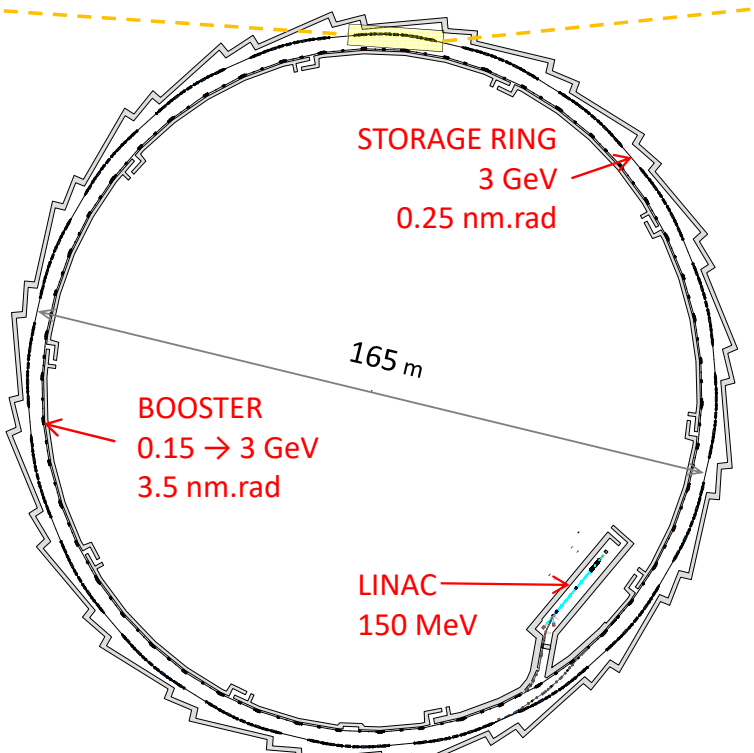
2020	20-Feb	- **first beam accumulation with non-linear kicker (NLK), 10 mA**
	16-Mar	- **shut-down to install scrapers. They are located in the injection straight**
	23-Mar	- **commissioning interrupted due to covid-19 pandemic**
	23-Apr	- **restart of beam tests in accelerators with signs of physical obstruction in the SR**
	29-Apr	- horizontal scraper has been removed
	01-May	- beam accumulation with NLK recovered
	18-May	- 1st planar undulator instalation (Manacá beamline: 5–20 keV Serial Micro and nano MX)
	29-May	- 2nd planar undulator instalation (Cateretê beamline: 3–15 keV CDI and XPCS)
	06-Jun	- start of Manacá beamline comissioning
	01-Jul	- vertical scraper removed
	03-Jul	- **beam for users at 10 mA**
	11-Jul	- **important milestone of Manacá beamline: first Sars-Cov-2 image** →
	31-Aug	- **beam for users at 20 mA with longitudinal bunch-by-bunch feedback**
	18-Sep	- 3rd planar undulator instalation (EMA beamline: 3–35 keV extreme conditions)
	18-Sep	- 4th PU instalation (Carnaúba beamline: 2–15 keV Nano-XRD/XRF and Cryo-Ptychography)



Main Parameters



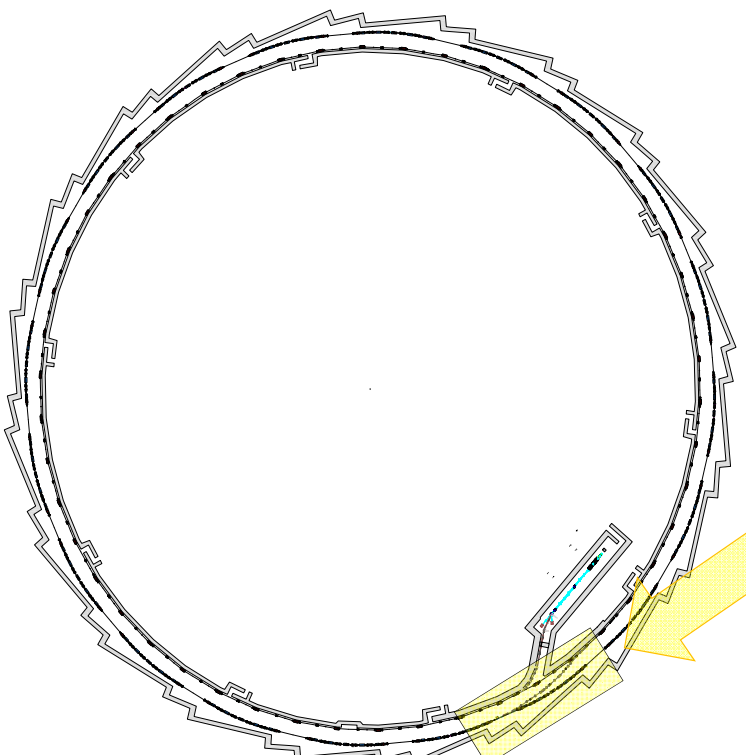
Storage Ring Parameters	
e⁻-Beam energy	**3.0 GeV**
Circumference	**518.4 m**
Lattice	**20 x 5BA, 5-fold symmetry**
Hor. emittance (bare lattice)	**0.25 nm.rad**
Ver. emittance (with undulators)	**0.15 nm.rad**
Betatron tunes (H/V)	49.11 / 14.17
Natural chrom. (H/V)	-119.0 / -81.2
Energy spread (rms)	0.85 x 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**

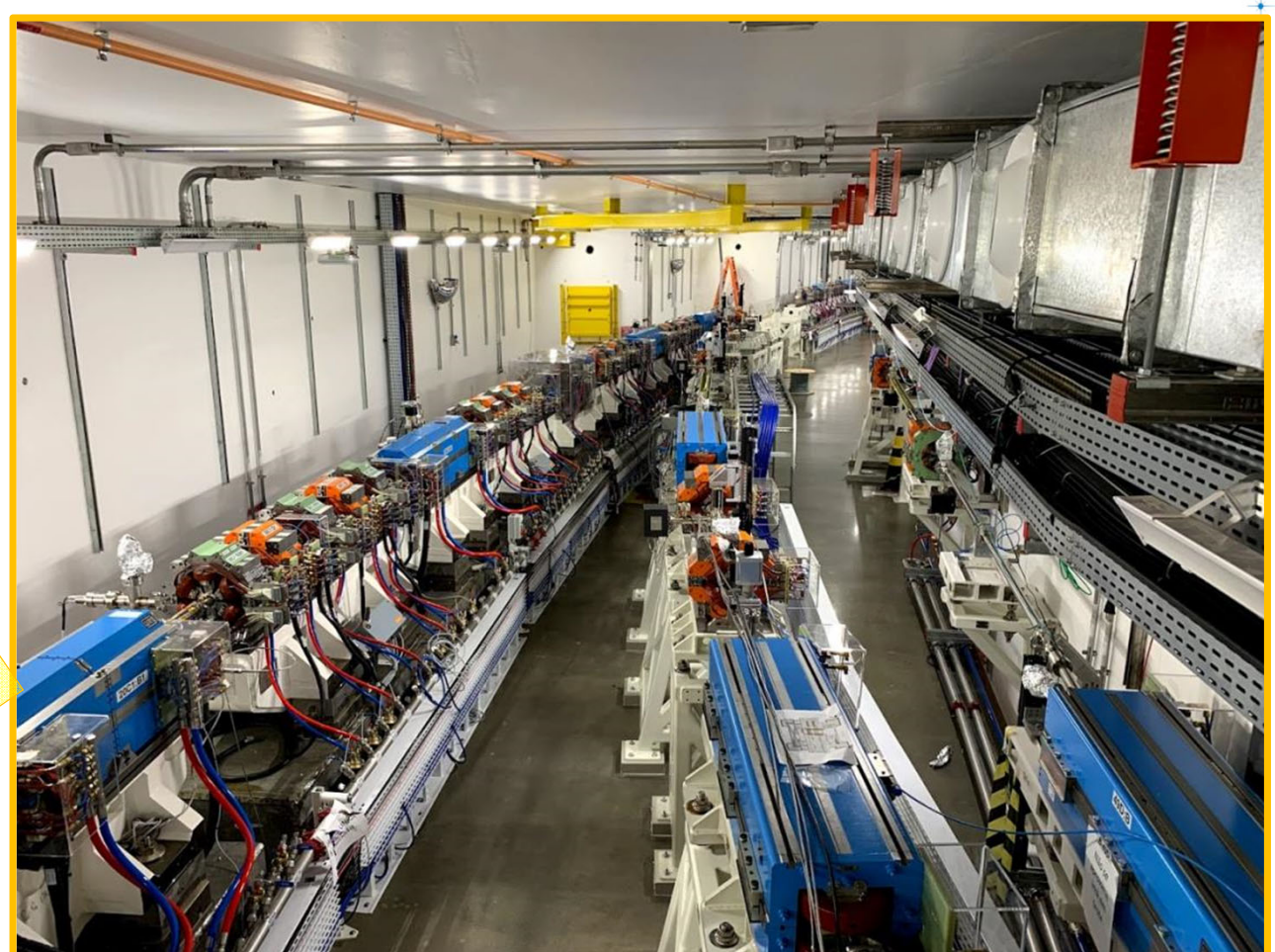


Booster Parameters	
Circumference	496.8 m
Emittance @ 3 GeV	3.5 nm.rad
Lattice	50 FODO
Cycling frequency	2 Hz

liu@lnls.br

Tunnel





Diagnostics Components Summary

Component	LINAC	LTB	BTS
FCT		***1***	***1***
ICT	***2***	***2***	***2***
Screen (Beam Flag)	***5***	***6***	***6***
Horizontal Slit		1	
Vertical Slit		1	
Stripline BPM	3	6	5
Beam Loss Monitor		tbd	tbd

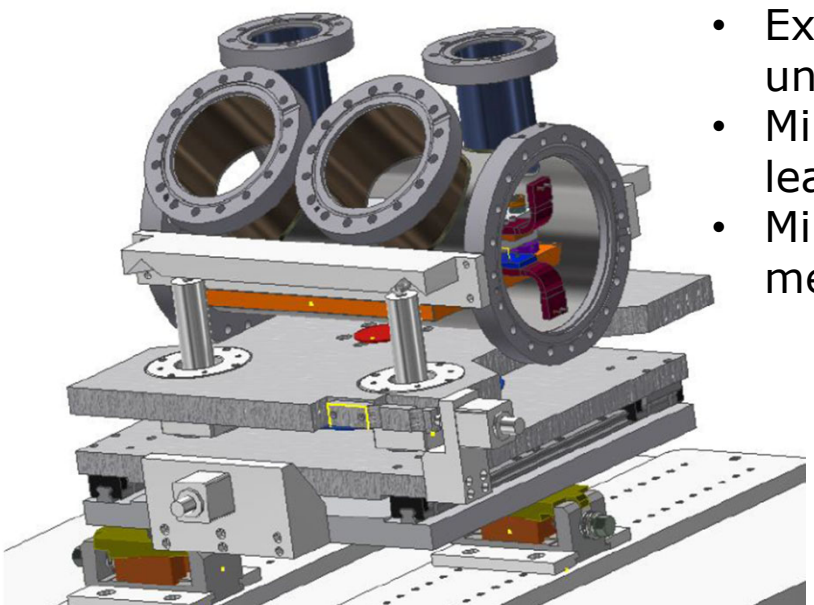
Component	Qt per Beamline
X-BPM	***2 (position+angle meas.)***

Component	Booster	Storage Ring
DCCT	***1***	***2***
Screen (Beam Flag)	***3***	
Button BPM	***50***	***160***
Front-End Photon BPM		***80***
Filling Pattern Monitor		***1***
Horizontal scraper		***1 pair***
Vertical scraper		***1 pair***
Tune shaker	***1***	***2***
Tune pick-up	***1***	***2***
Bunch-by-Bunch kicker		***3***
Bunch-by-Bunch BPM		***1***
X-ray port		1
Visible light port	1	1
Streak camera		1
Beam Loss Monitor	4	
Gas Bremsstrahlung Monitor		100

sergio@lnls.br

Diagnostics Component: X-Ray Port

- Use of a toroidal mirror (Mo/B_4C, 3.07 nm/bilayer, 140 bilayers) to focus 11 keV X-ray beam from B1 dipole;
- Source-mirror length = mirror-focal point length = 17 m
- Image: YAG-Ce screen + CCD camera **or** 2x Si222 crystals (36x magnification) + Medipix detector



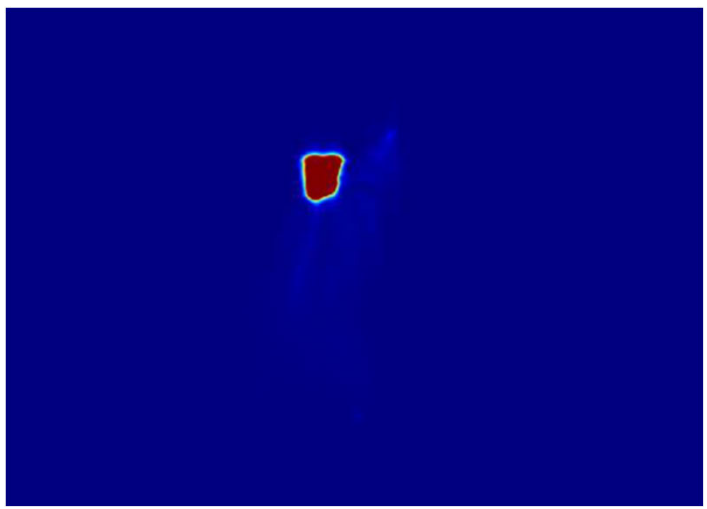
- Expected measurement uncertainty < 5%
- Mirror chamber built and leak-tight
- Mirror is under optical measurements

Component	Booster	Storage Ring
DCCT	*1*	*2*
Screen (Beam Flag)	*3*	
Button BPM	*50*	*160*
Front-End Photon BPM		*80*
Filling Pattern Monitor		*1*
Horizontal scraper		*1 pair*
Vertical scraper		*1 pair*
Tune shaker	*1*	*2*
Tune pick-up	*1*	*2*
Bunch-by-Bunch kicker		*3*
Bunch-by-Bunch BPM		*1*
X-ray port		1
Visible light port	1	1
Streak camera		1
Beam Loss Monitor	4	
Gas Bremsstrahlung Monitor		100

paulo.tarso@lnls.br; rubens.castro@lnls.br

Diagnostics Component: Visible Light Port

- Booster VL monitor:
  - Mirror + CMOS Camera



- For the **Storage Ring**, a VL extraction is being analyzed from the B2 dipole to feed a streak camera
- Hamamatsu C5680 streak camera from LNLS old storage ring operating at 119 MHz was modified to 125 MHz operation rate.

Component	Booster	Storage Ring
DCCT	*1*	*2*
Screen (Beam Flag)	*3*	
Button BPM	*50*	*160*
Front-End Photon BPM		*80*
Filling Pattern Monitor		*1*
Horizontal scraper		*1 pair*
Vertical scraper		*1 pair*
Tune shaker	*1*	*2*
Tune pick-up	*1*	*2*
Bunch-by-Bunch kicker		*3*
Bunch-by-Bunch BPM		*1*
X-ray port		1
Visible light port	1	1
Streak camera		1
Beam Loss Monitor	4	
Gas Bremsstrahlung Monitor		100

andrei.pereira@lnls.br

Diagnostics Component: BLM

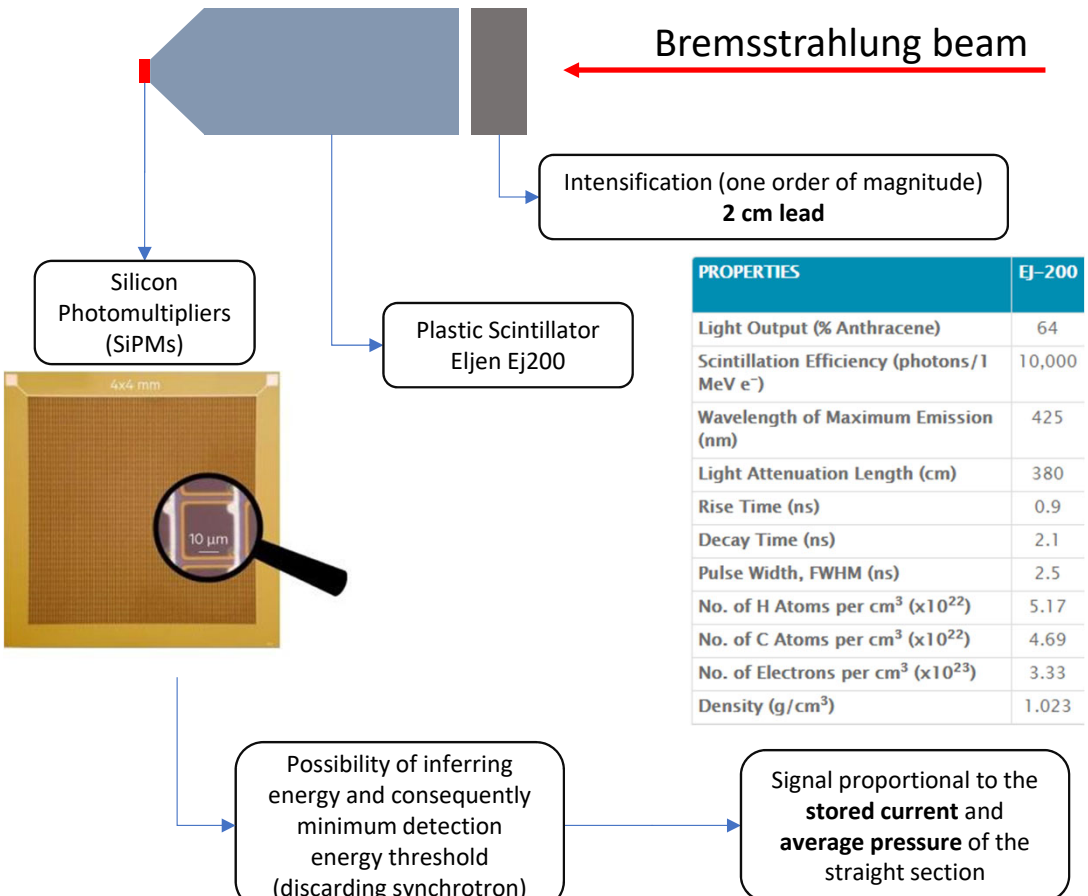
Component	LINAC	LTB	BTS
FCT		*1*	*1*
ICT	*2*	*2*	*2*
Screen (Beam Flag)	*5*	*6*	*6*
Horizontal Slit		1	
Vertical Slit		1	
Stripline BPM	3	6	5
Beam Loss Monitor		tbd	tbd

Component	Booster	Storage Ring
DCCT	*1*	*2*
Beam Flag	*3*	
Button BPM	*50*	*160*
Front-End Photon BPM		*80*
Filling Pattern Monitor		*1*
Horizontal scraper		*1 pair*
Vertical scraper		*1 pair*
Tune shaker	*1*	*2*
Tune pick-up	*1*	*2*
Bunch-by-Bunch kicker		*3*
Bunch-by-Bunch BPM		*1*
X-ray port		1
Visible light port	1	1
Streak camera		1
Beam Loss Monitor	4	
Gas Bremsstrahlung Monitor		100

- 25 BLM units from Bergoz Instrumentation
- 4 units have been used in the booster so far
  - Installed in the injection sector

sergio@lnls.br

Diagnostics Components Summary: Gas Bremsstrahlung Monitor



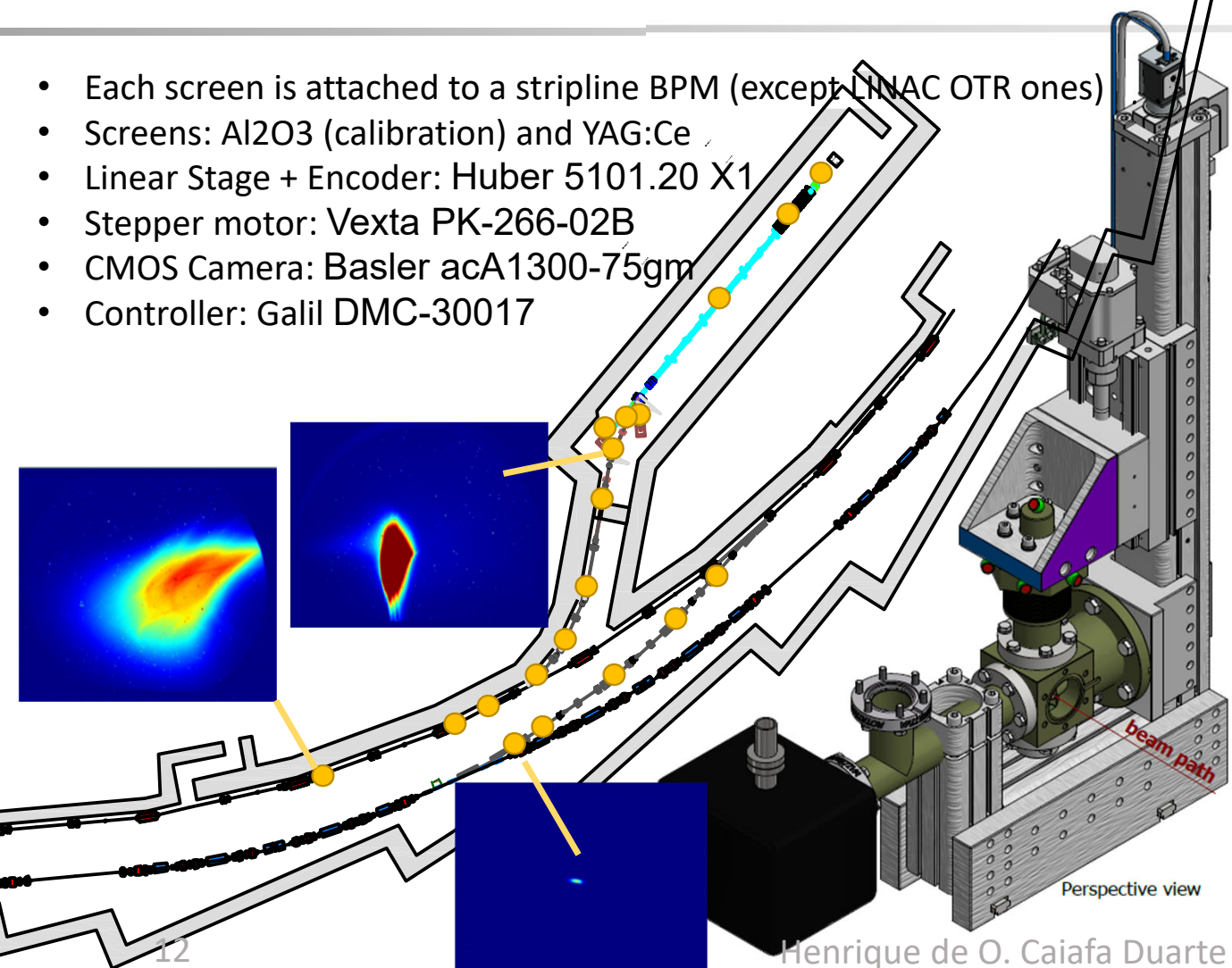
PROPERTIES	EJ-200
Light Output (% Anthracene)	64
Scintillation Efficiency (photons/1 MeV e^-)	10,000
Wavelength of Maximum Emission (nm)	425
Light Attenuation Length (cm)	380
Rise Time (ns)	0.9
Decay Time (ns)	2.1
Pulse Width, FWHM (ns)	2.5
No. of H Atoms per cm^3 ($x10^{22}$)	5.17
No. of C Atoms per cm^3 ($x10^{22}$)	4.69
No. of Electrons per cm^3 ($x10^{23}$)	3.33
Density (g/cm^3)	1.023

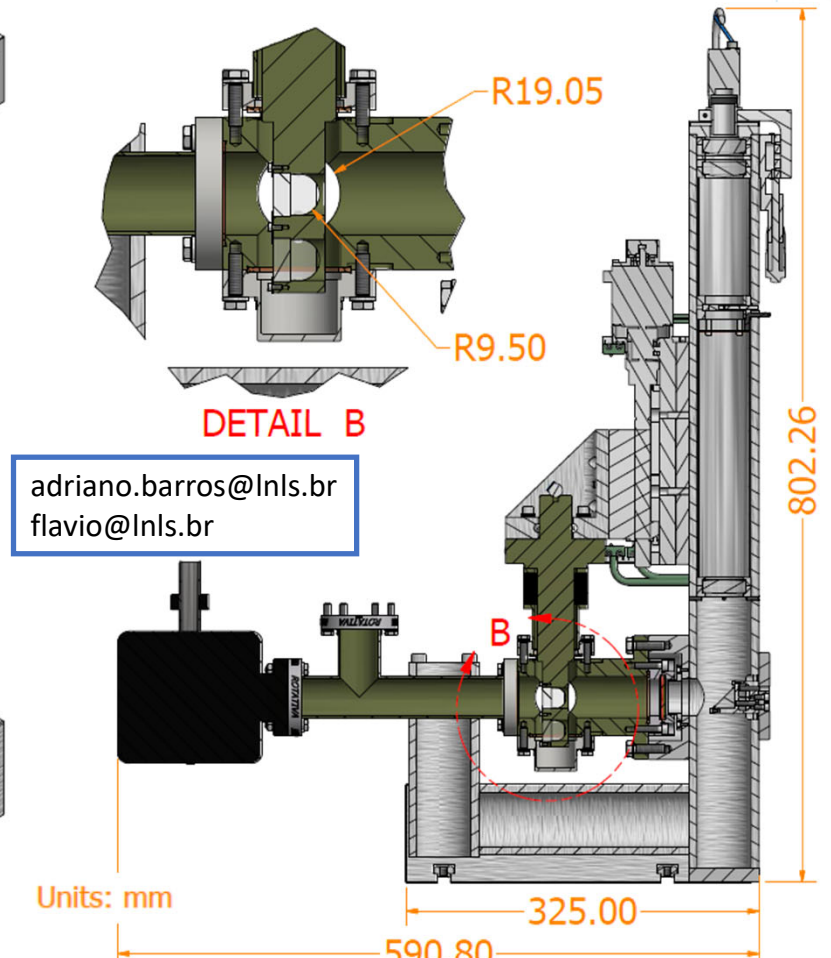
Component	Booster	Storage Ring
DCCT	*1*	*2*
Beam Flag	*3*	
Button BPM	*50*	*160*
Front-End Photon BPM		*80*
Filling Pattern Monitor		*1*
Horizontal scraper		*1 pair*
Vertical scraper		*1 pair*
Tune shaker	*1*	*2*
Tune pick-up	*1*	*2*
Bunch-by-Bunch kicker		*3*
Bunch-by-Bunch BPM		*1*
X-ray port		1
Visible light port	1	1
Streak camera		1
Beam Loss Monitor	4	
Gas Bremsstrahlung Monitor		100

fernando.bacchim@lnls.br
carlos.scorzato@lnls.br

Screens: LINAC, Booster and TLs

- Each screen is attached to a stripline BPM (except LINAC OTR ones)
- Screens: Al2O3 (calibration) and YAG:Ce
- Linear Stage + Encoder: Huber 5101.20 X1
- Stepper motor: Vexta PK-266-02B
- CMOS Camera: Basler acA1300-75gm
- Controller: Galil DMC-30017

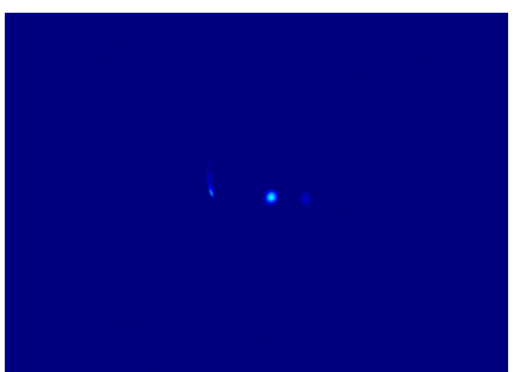


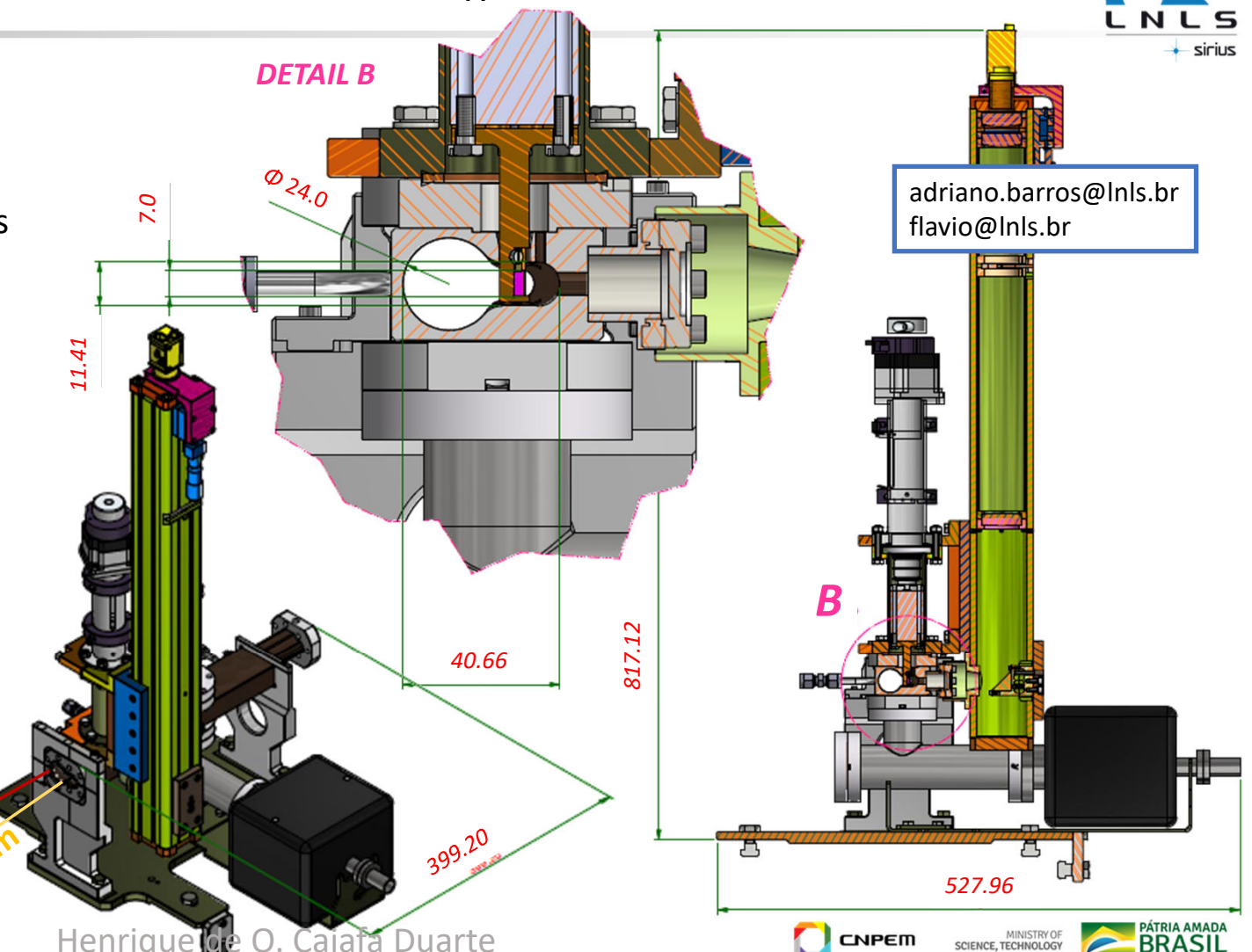


adriano.barros@lnls.br
flavio@lnls.br

Screens: Post-septa

- Monitors the injected beam
- Common chamber with the storage ring
- Same components of the regular screens

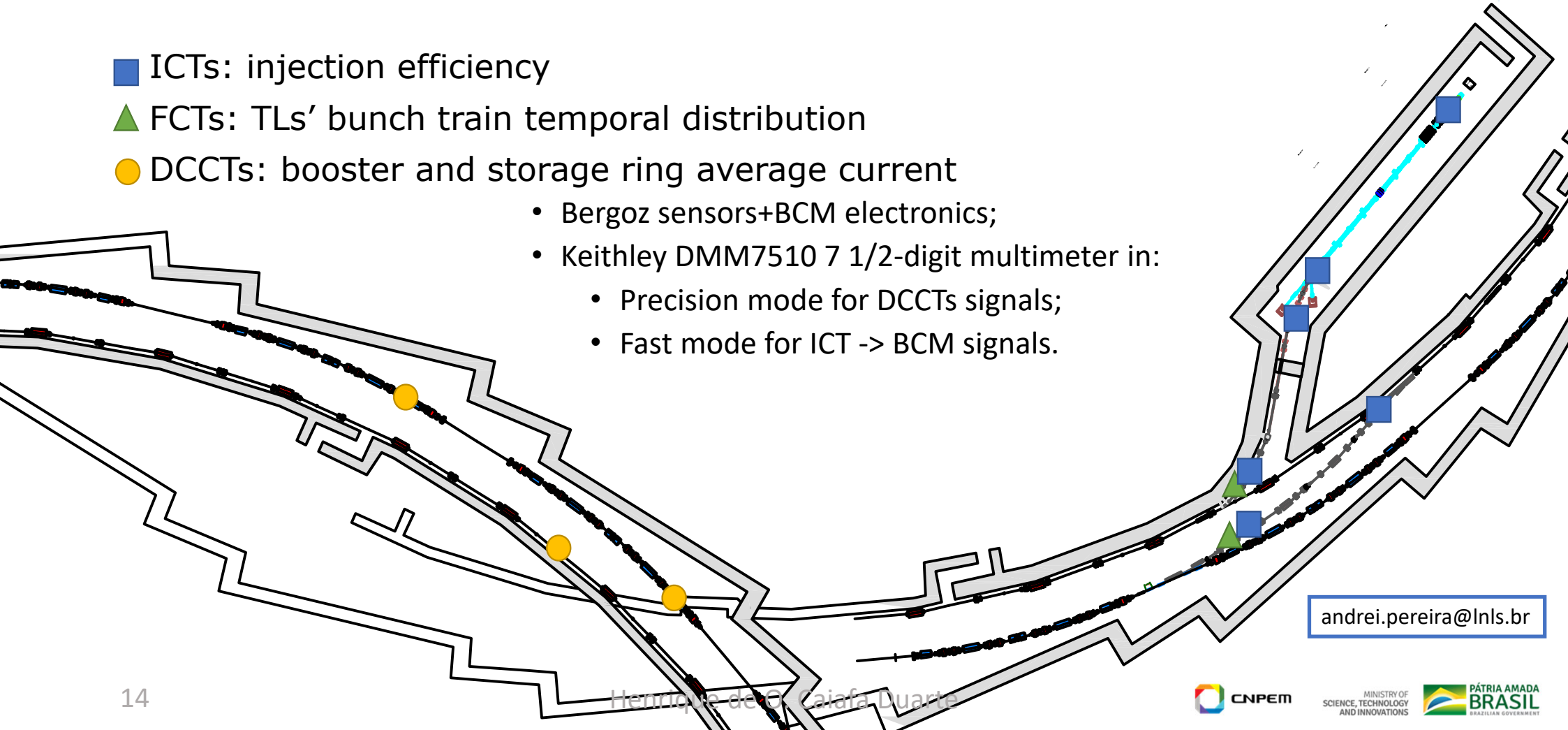




adriano.barros@lnls.br
flavio@lnls.br

Current and Charge Monitors

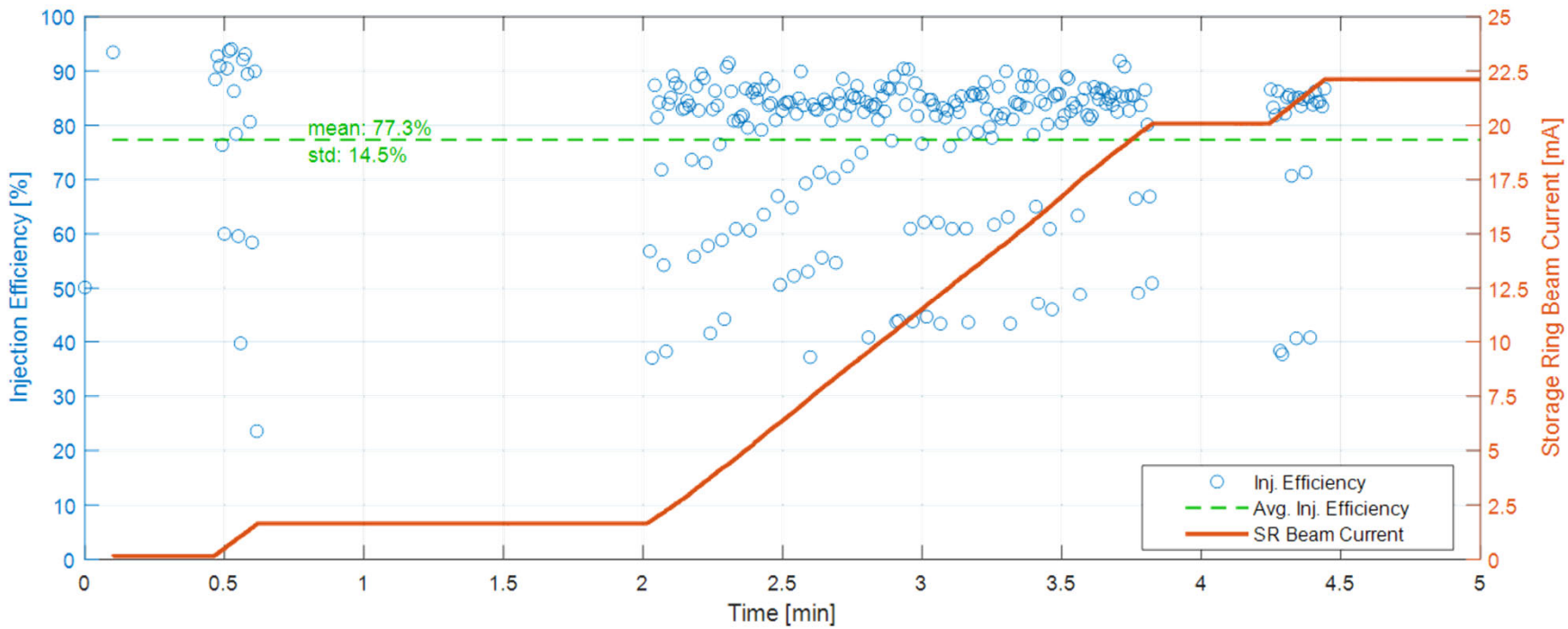
- ICTs: injection efficiency
- FCTs: TLs' bunch train temporal distribution
- DCCTs: booster and storage ring average current
  - Bergoz sensors+BCM electronics;
  - Keithley DMM7510 7 1/2-digit multimeter in:
    - Precision mode for DCCTs signals;
    - Fast mode for ICT -> BCM signals.



andrei.pereira@lnls.br

Injection Efficiency

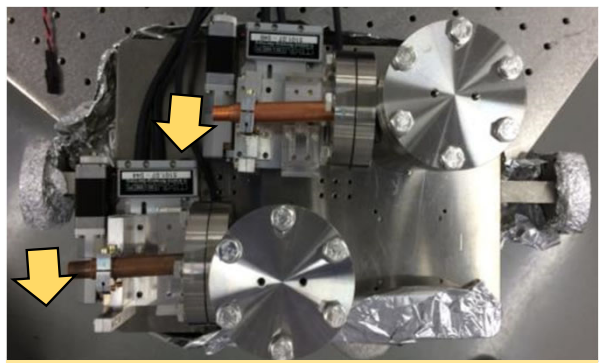
- Typical injection efficiency during operations:



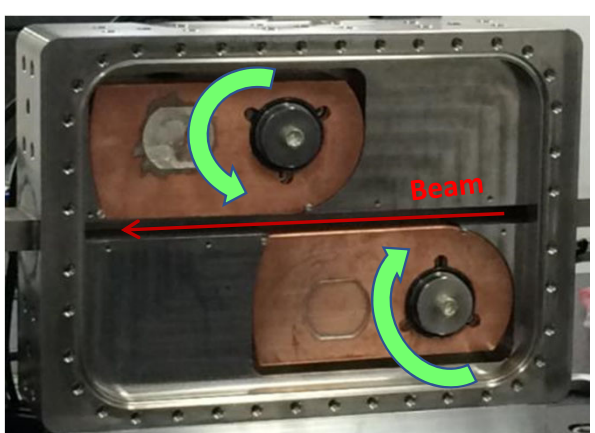
- During machine studies, efficiency usually reaches ~90% mean, ~10% std.
- EMI from septa (amplitude beating and curve slope) impedes reliable processing from the BCM electronics
- ICTs signals are currently read and processed via osciloscopes

Beam Scrapers

- Design minimizes impedance using angular motion. A linear-to-angular motion transmission is used.
  - Components used: Vexta PK-223PB stepper motor, a Huber 5101.07 X1 linear translation stage and the same rotary encoder as the beam flags
- Main design difficulties
  - Indirect blade position feedback.
  - Movement mapped by 3D measurements, but maintenance of parts require recalibration.
- Main commissioning issues
  - After installation and baking, the linear stages of the horizontal scraper were found to be offset, not allowing one blade to fully open (~ 0.9 mm after adjustments).
  - Both horizontal and vertical scrapers were removed from the ring for inspection.
  - The weaknesses are being reinvestigated with endurance tests.
  - The opposite blade stuck after the first 2 days of testing, due to electrical contact spring partially slipping out of its housing.



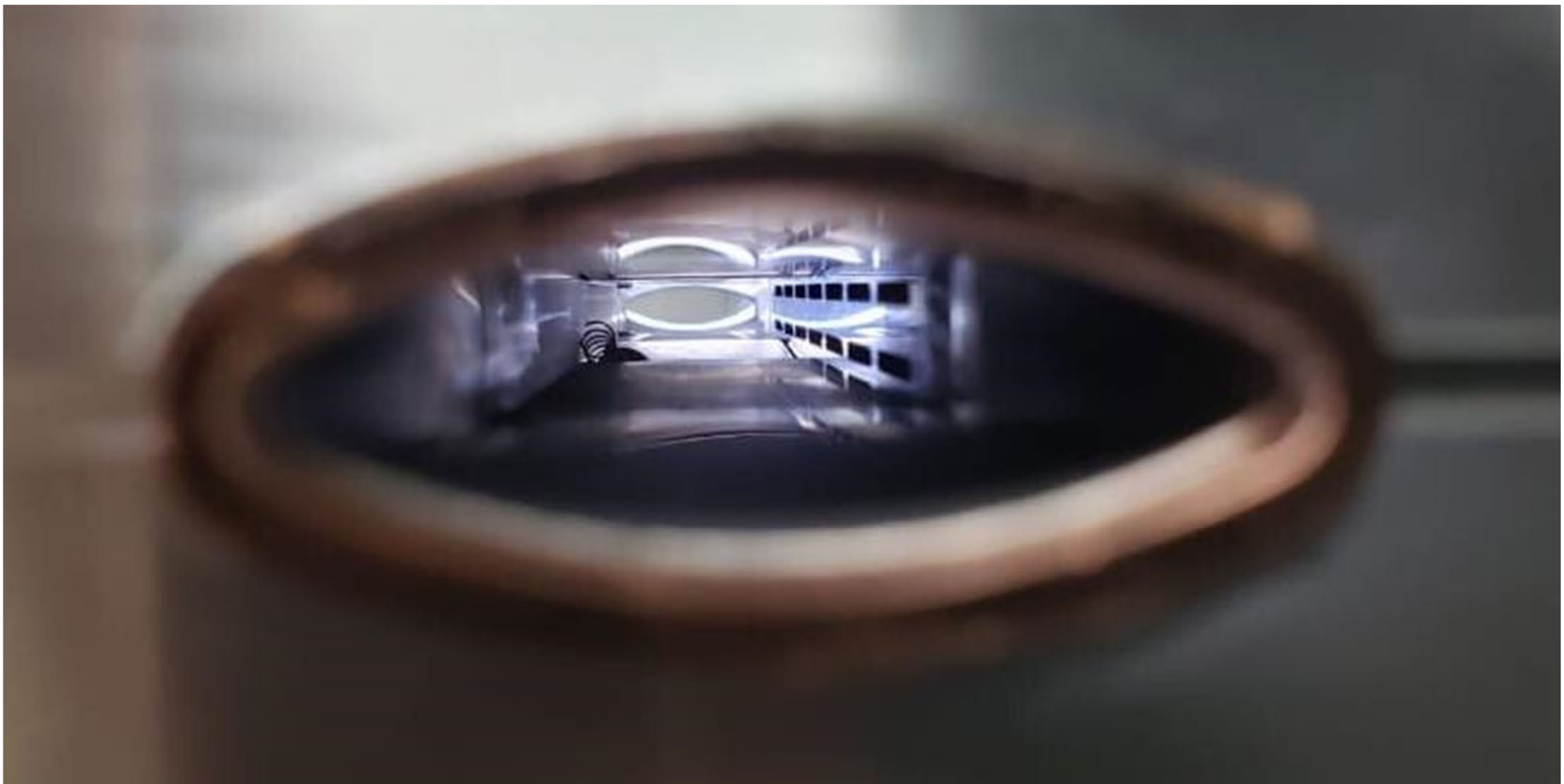
Linear Motion



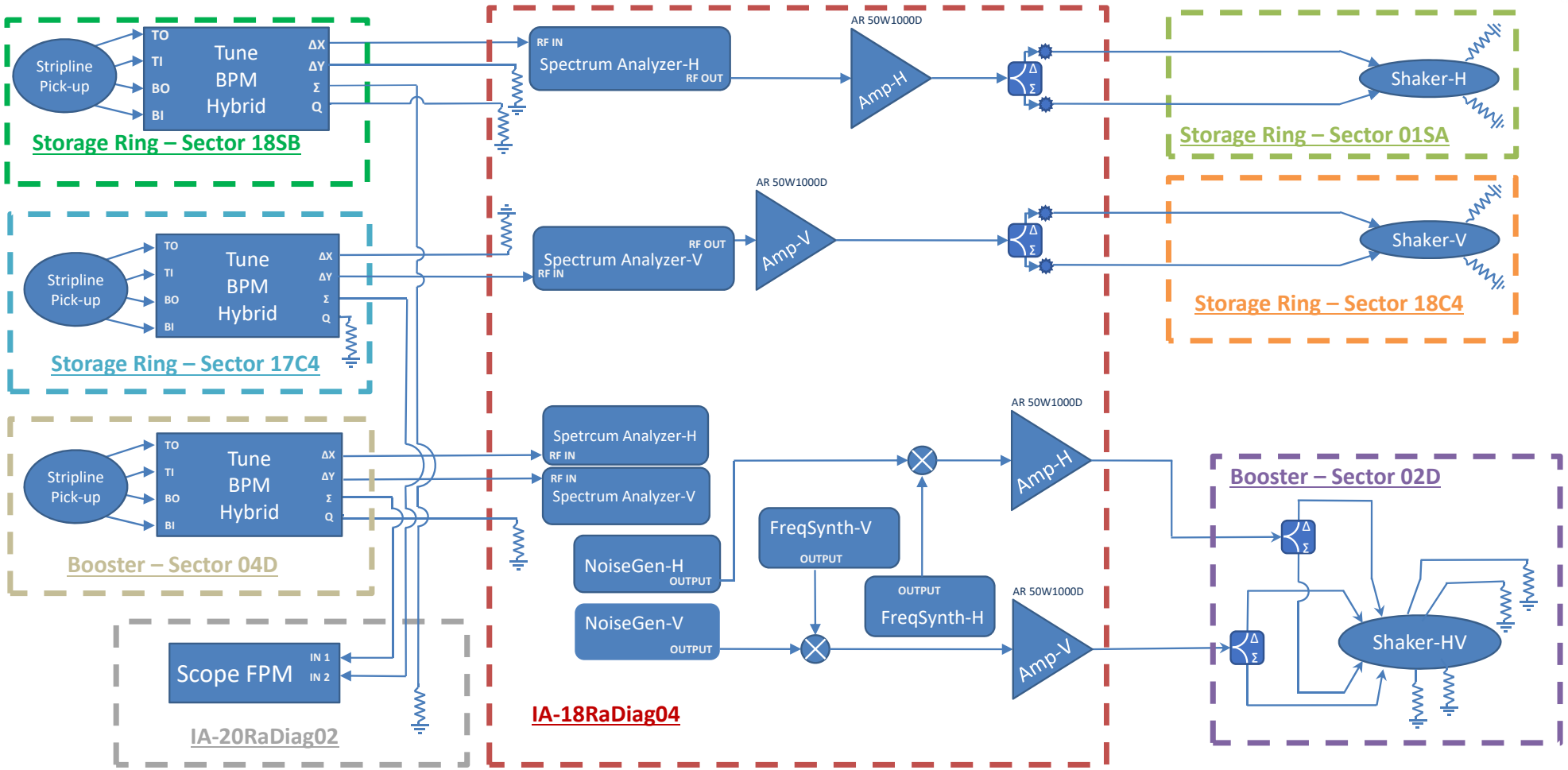
Angular Motion

rafael.seraphim@lnls.br
andrei.pereira@lnls.br

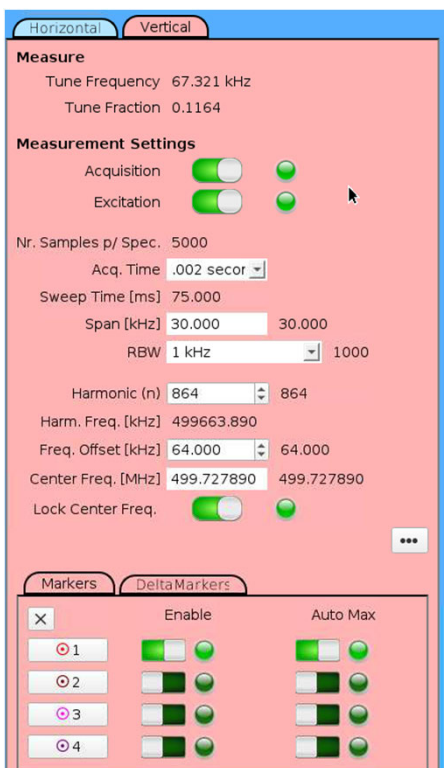
Beam Scrapers



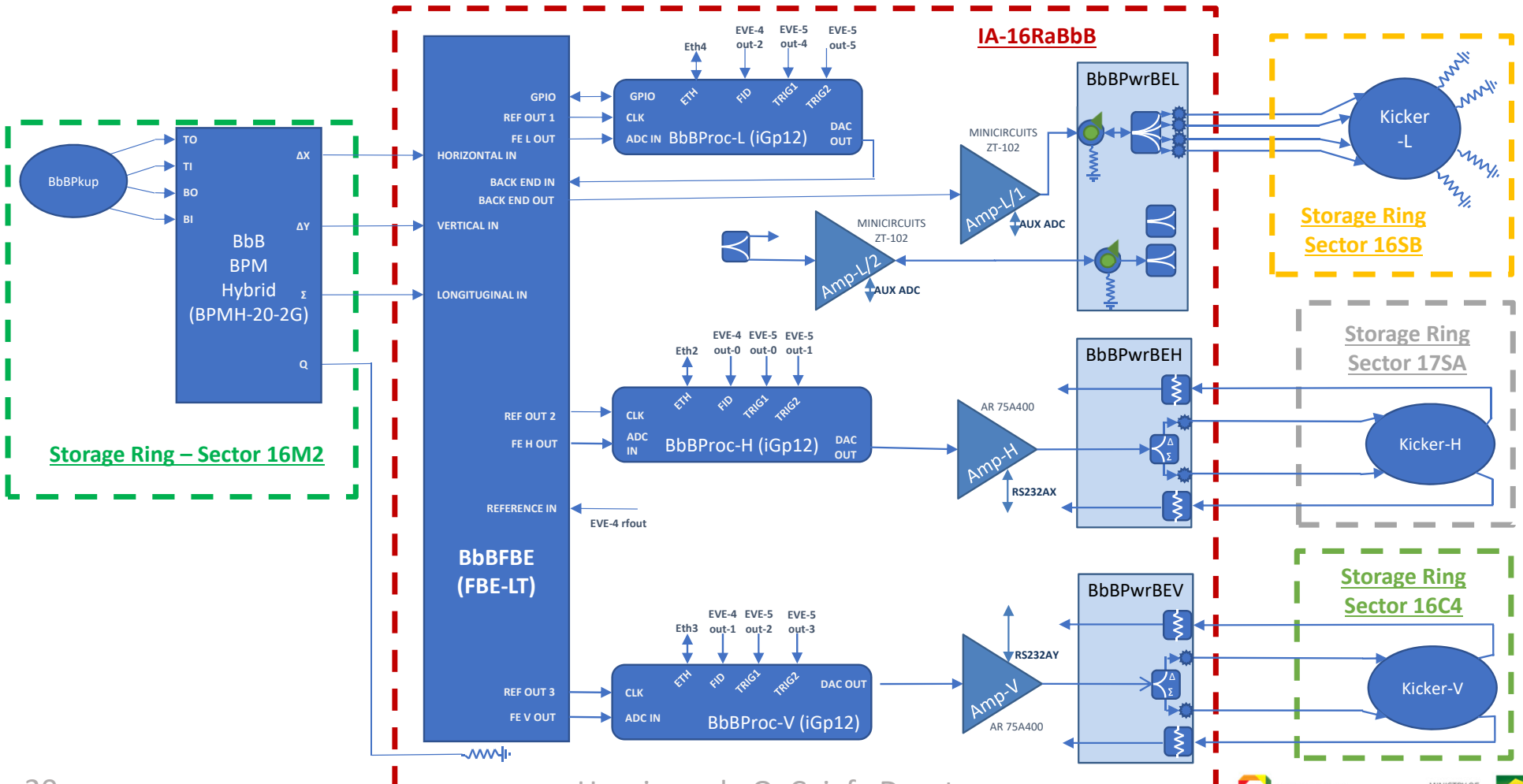
Tune Measurement System



Tune Measurement: Storage Ring

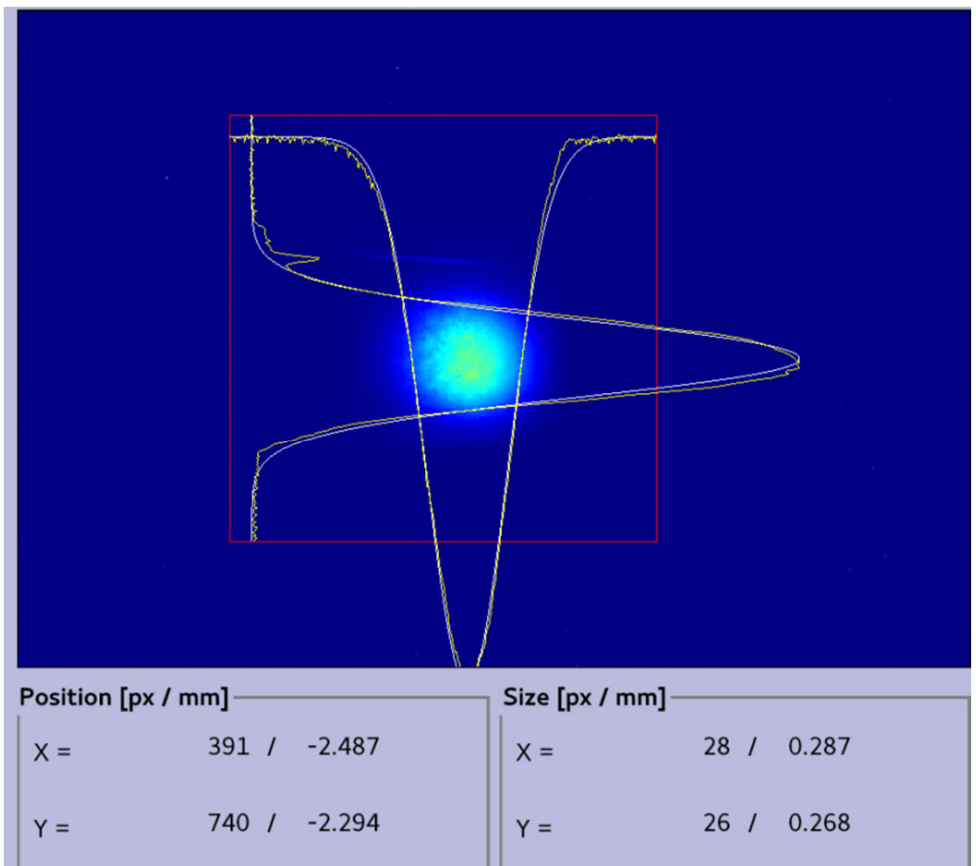


Bunch-by-Bunch FB System

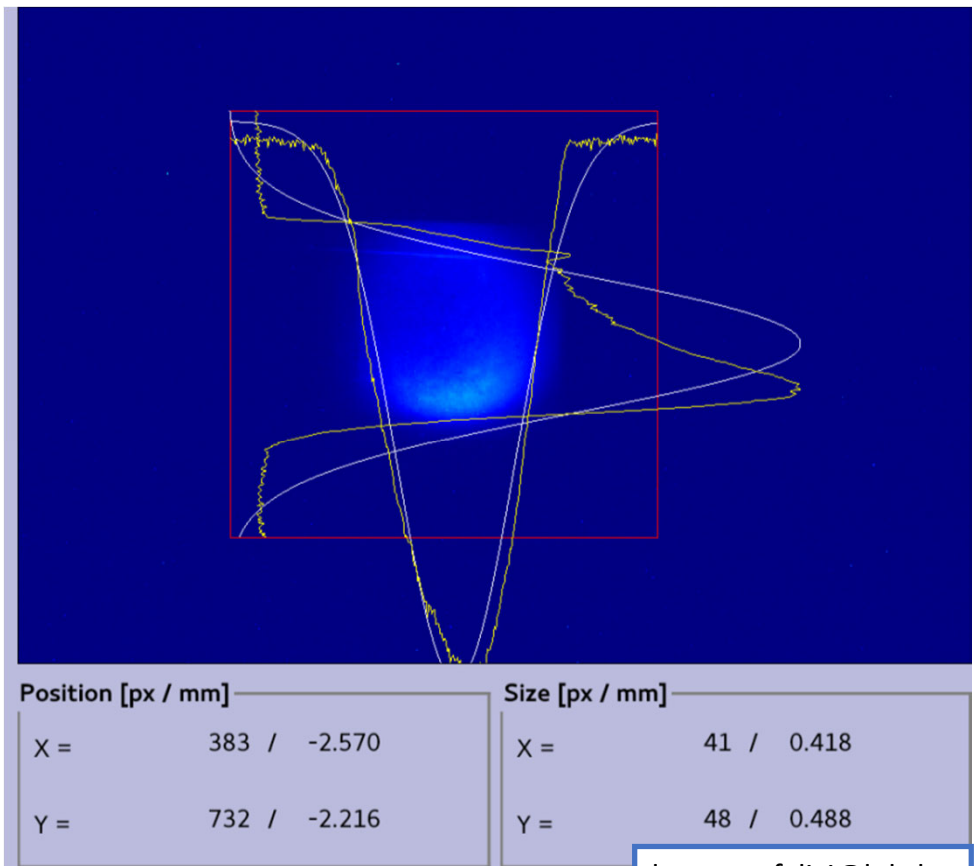


Longitudinal CBMI at Manacá Beamline

23 mA

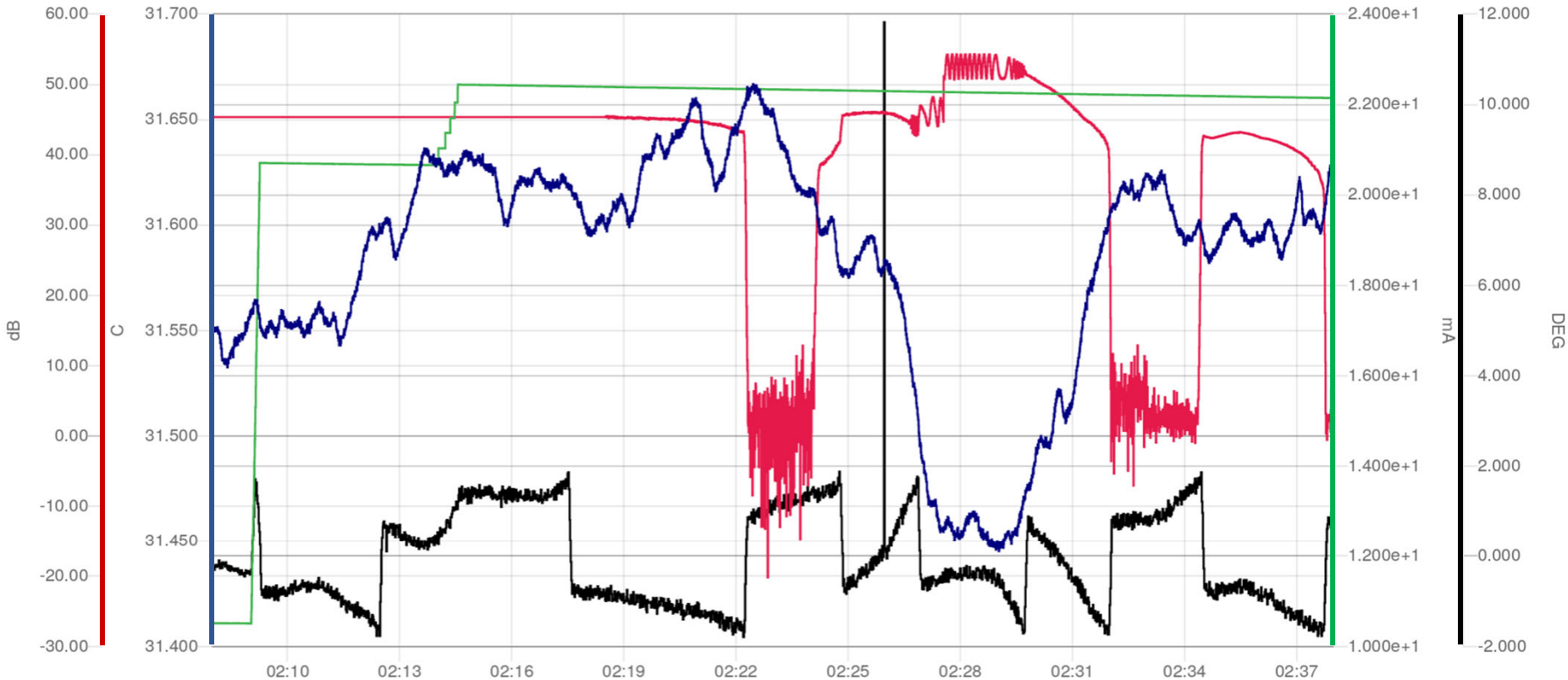


25 mA



lucas.sanfelici@lnls.br

Longitudinal CBMI + Petra 7-Cell Cavity



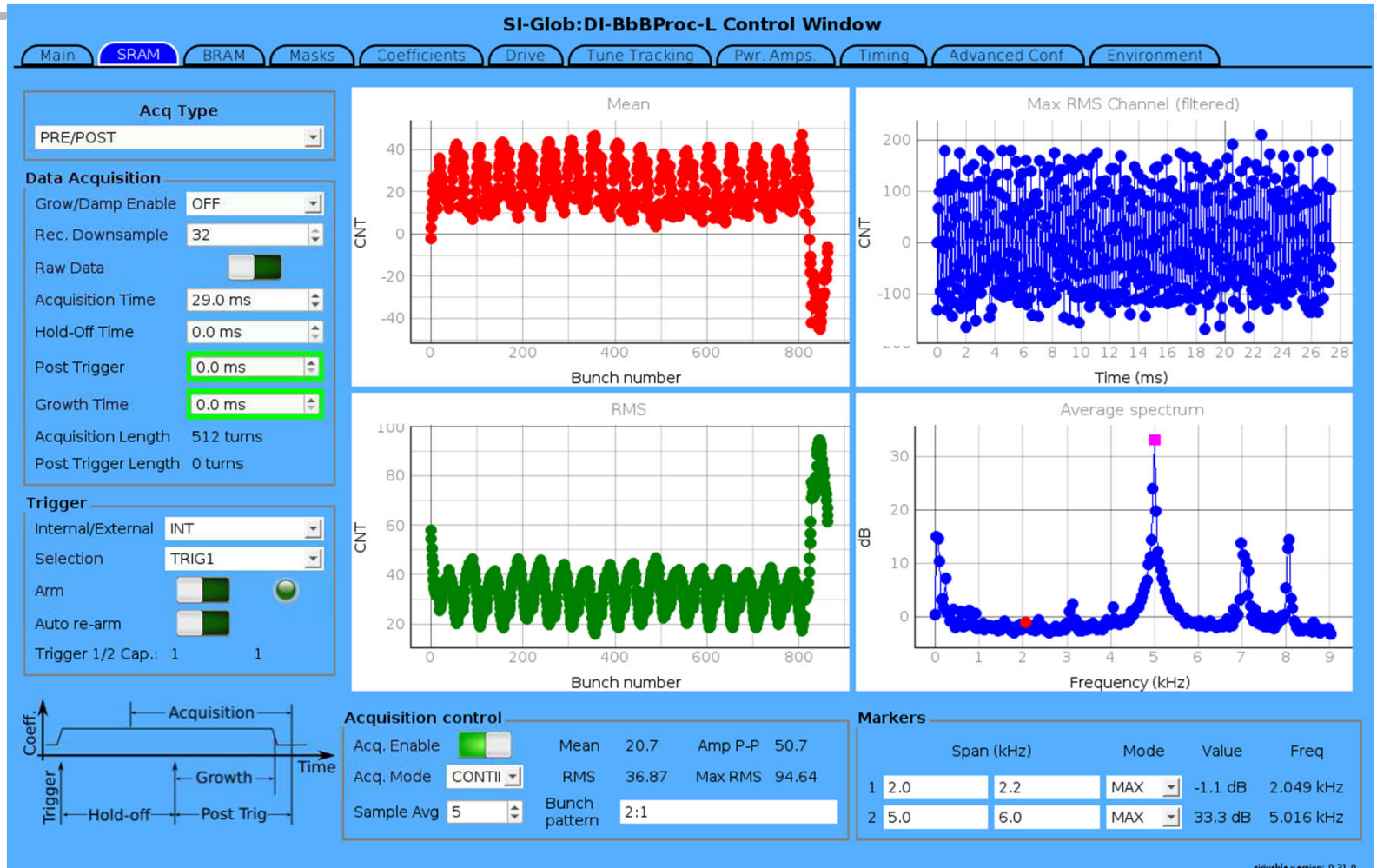
Cavity Temperature [°C]

Beam Avg. Current [mA]

RMS Synchrotron Oscilations [dB]

Cavity Plunger Detune (°)

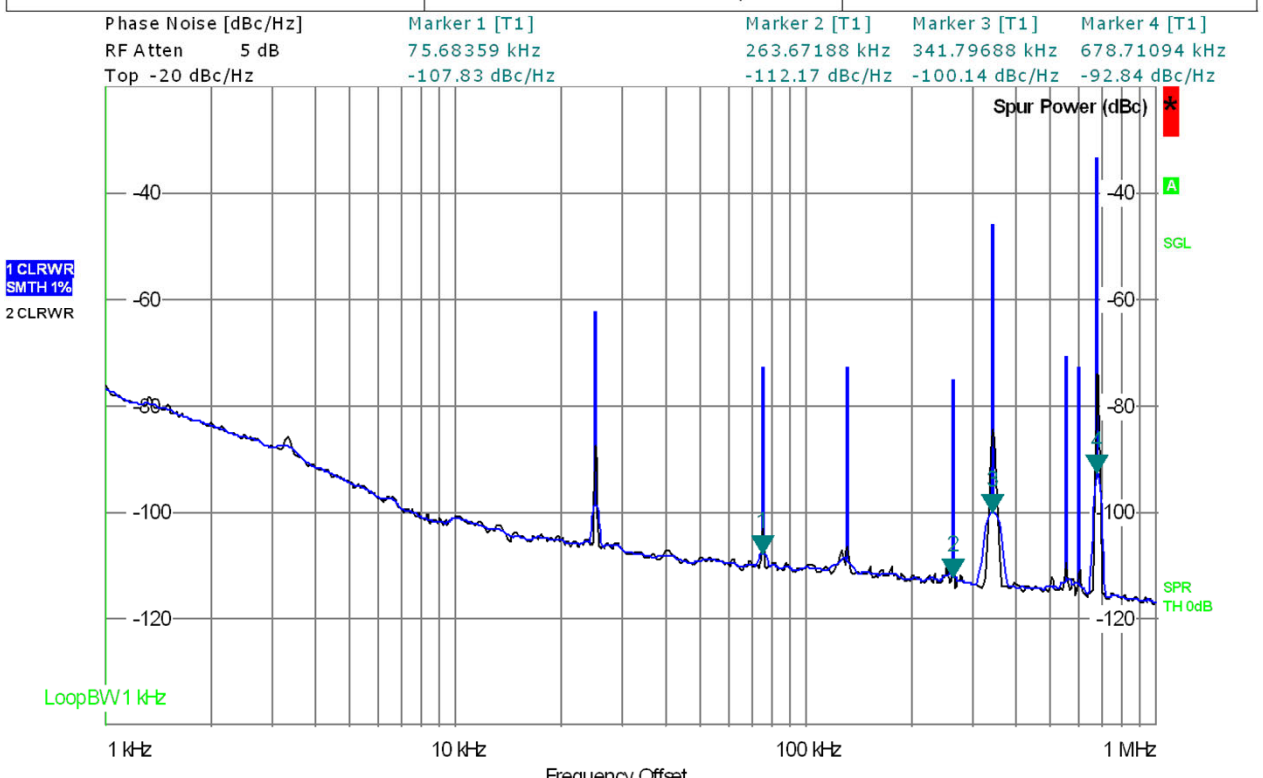
BbB FB: Longitudinal Plane Loop Closed

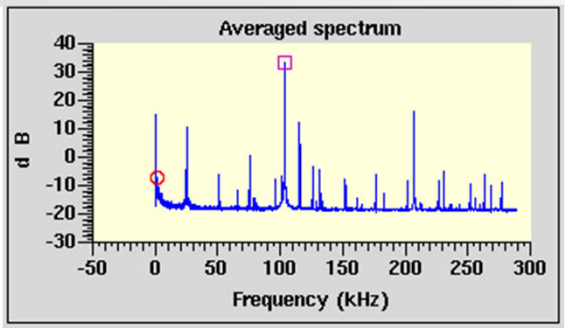


BbB FB: Disturbance from RF Clock Jitter

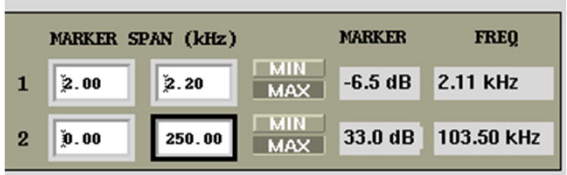
R&S FSUP 8 Signal Source Analyzer — LOCKED

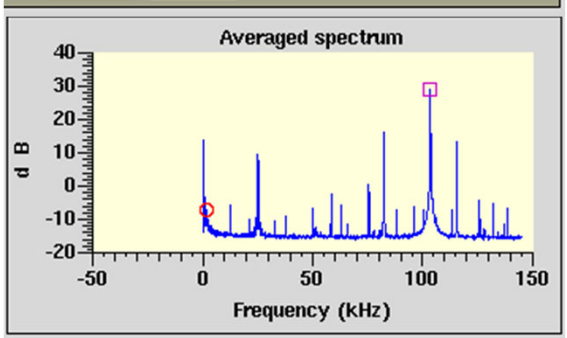
Settings		Residual Noise [T1]		Spur List			
Signal Frequency:	499.995822 MHz	Int PHN (1.0 k .. 1.0 M)	-44.4 dBc	25.161	kHz	-62.22	dBc
Signal Level:	-3.27 dBm	Residual PM	0.489 °	75.484	kHz	-72.61	dBc
Cross Corr Mode	Harmonic 1	Residual FM	3.947 kHz	131.570	kHz	-72.89	dBc
Internal Ref Tuned	Internal Phase Det	RMS Jitter	2.7146 ps	263.154	kHz	-75.22	dBc



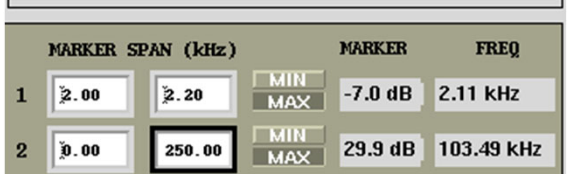


Downsampling = 1

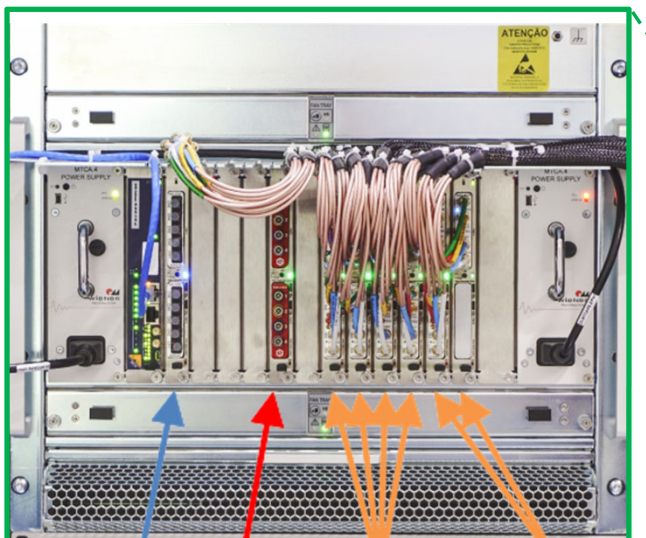




Downsampling = 2



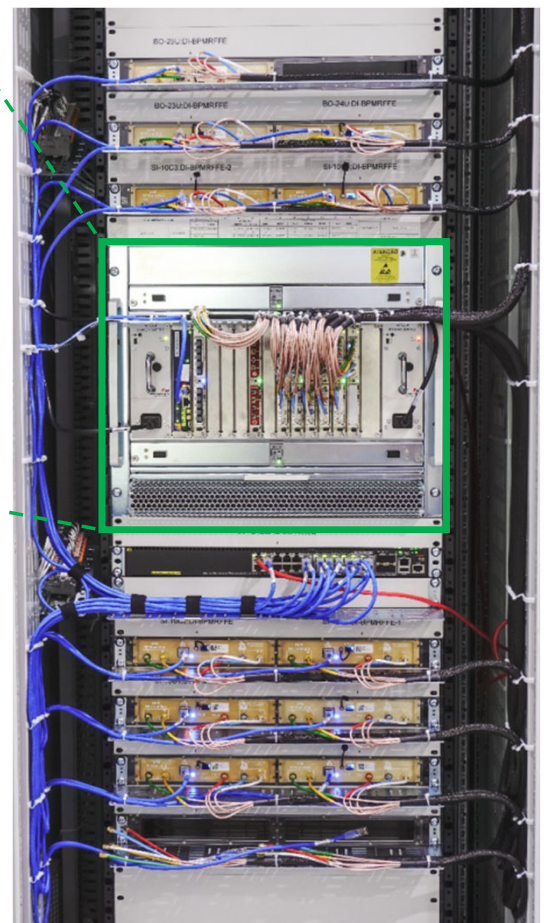
BPM Electronics

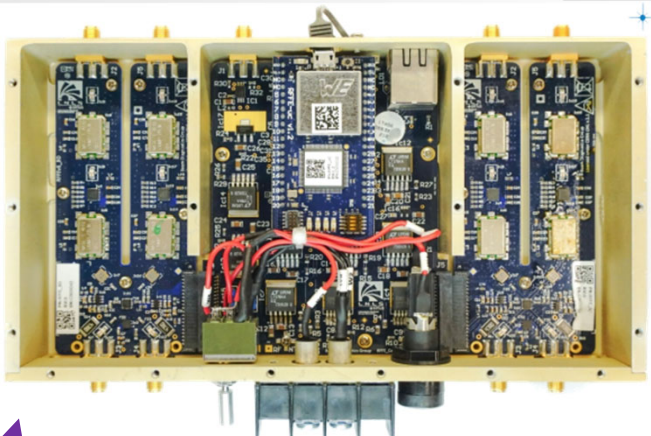


Open hardware designs and open source gateware and software codes are available at:

http://github.com/lnls-dig
https://www.ohwr.org/projects/afc

BPM Rack Front View





RFFE
500 MHz band-pass filtering
25 MHz bandwidth
Up to 35 dB amplification
2x2 channel switching
Open hardware

daniel.tavares@lnls.br
gustavo.bruno@lnls.br
lucas.russo@lnls.br

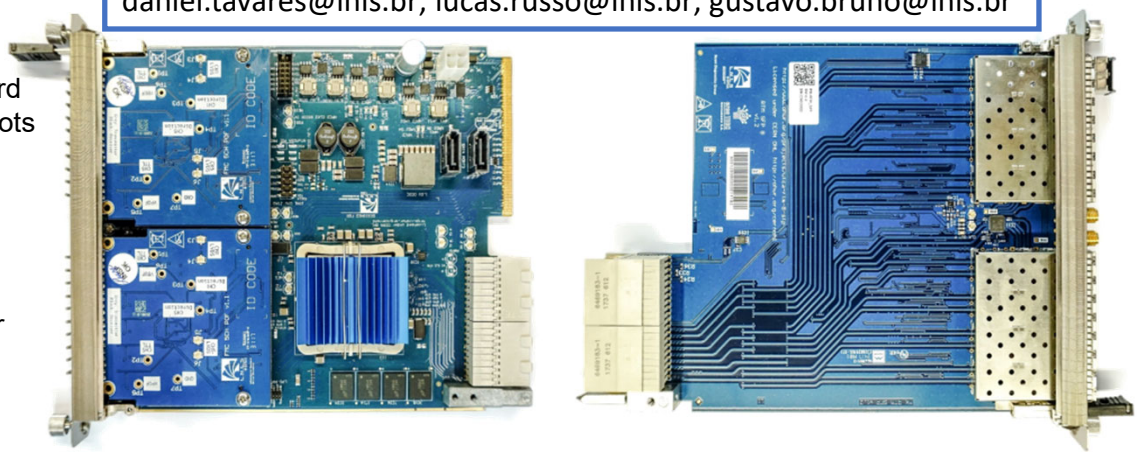
A Generic MicroTCA.4 DAQ Platform

daniel.tavares@lnls.br; lucas.russo@lnls.br; gustavo.bruno@lnls.br

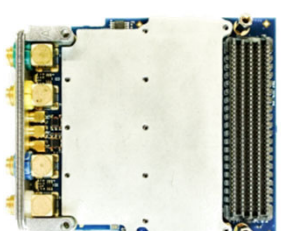
AMC FMC Carrier
Generic FPGA board with 2 FMC HPC slots and RTM-capable

Open Hardware

Usage at Sirius:
1) RF BPM digitizer
2) XBPM digitizer
3) MTCA.4 EVR
4) FOFB Controller

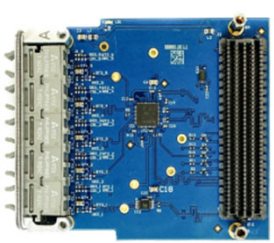


8 SFP RTM
8 SFP cage and clock resources for optical I/O
Open Hardware



FMC ADC 250 MS/s
16-bit 4-channel fast ADCs

Open Hardware

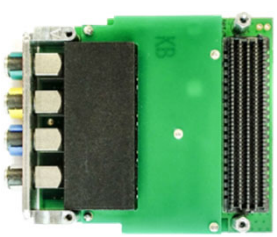


FMC POF
5-channel plastic optical fiber I/O

Open Hardware

FMC-4SFP+
4 SFP cage and clock resources for optical I/O for FOFB System

By CAENels

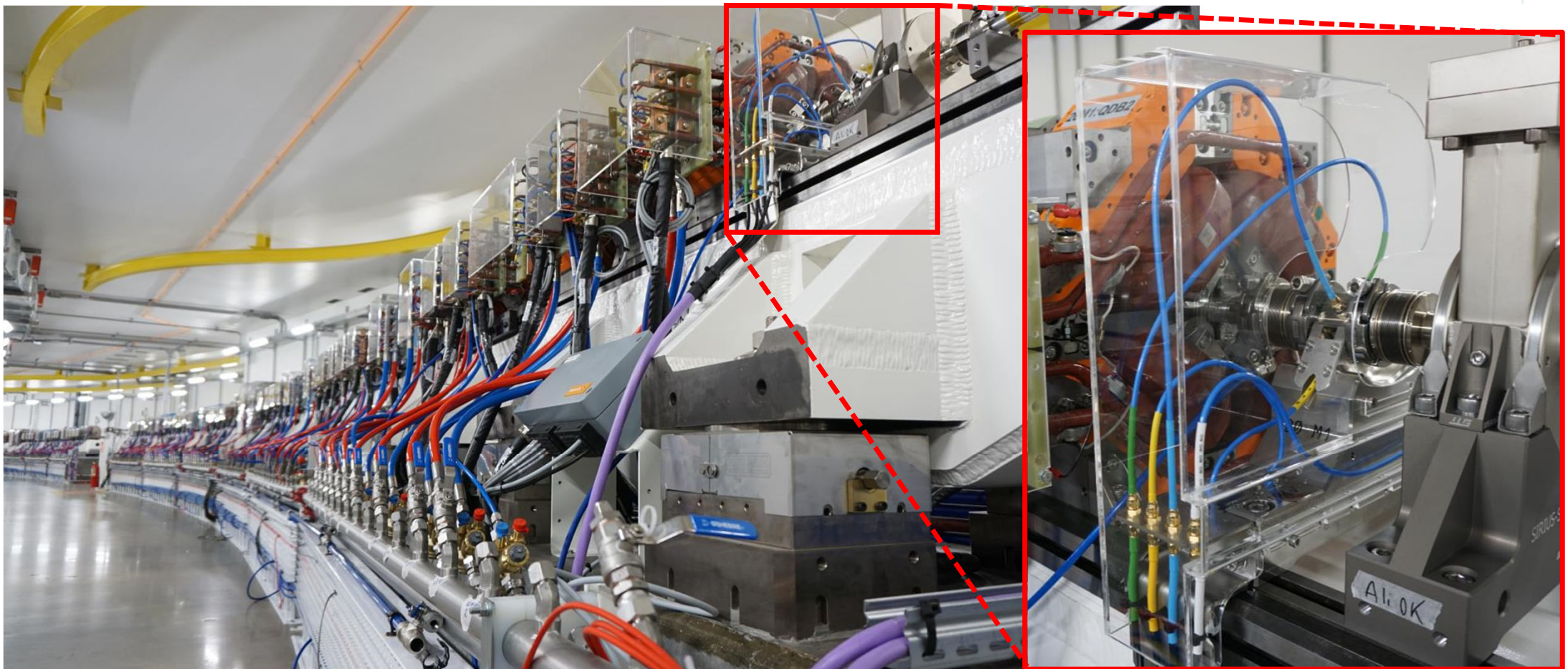


FMC-Pico-1M4
4-channel fast picoammeter

By CAENels

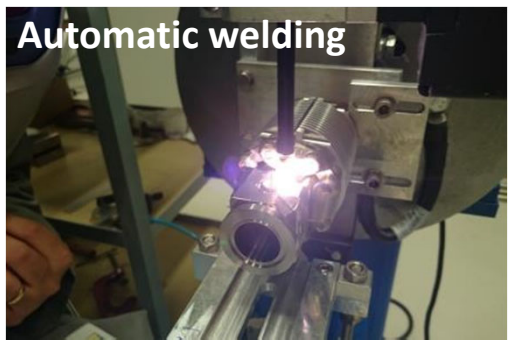
lucas.sanfelici@lnls.br

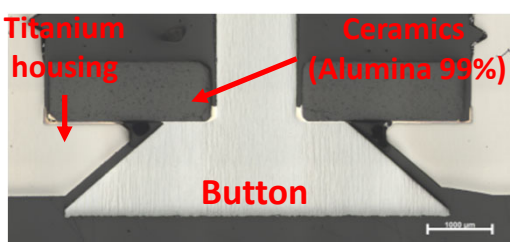
BPM Sensor

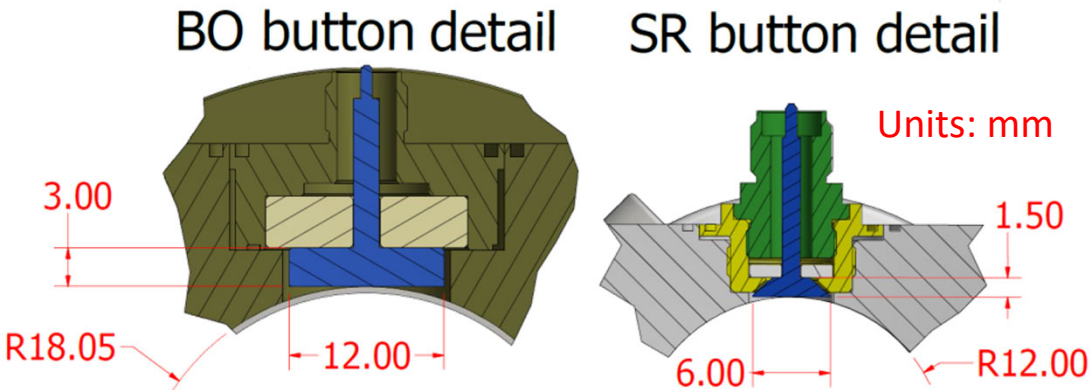


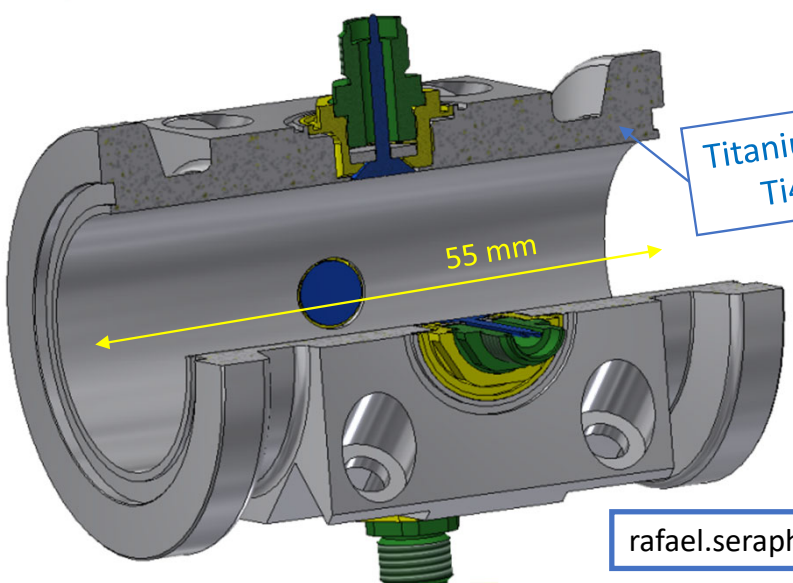
BPM Sensor

Welded buttons on Titanium body

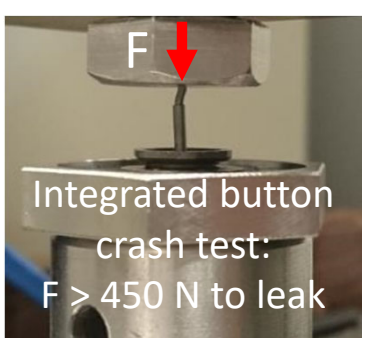








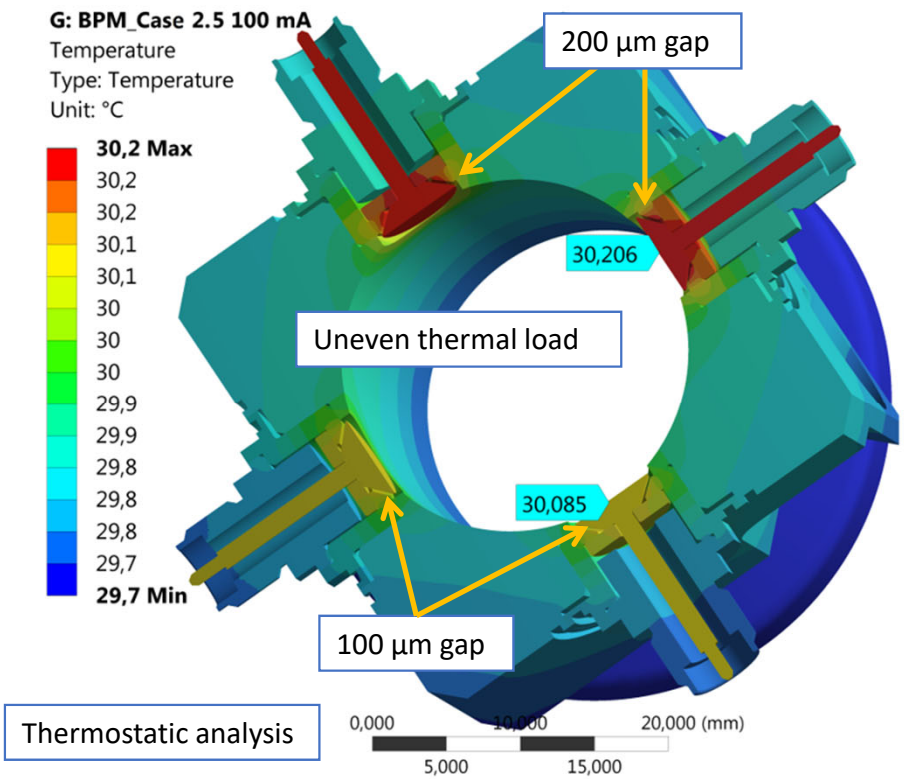
- 160 BPMs
  - All BPM parts contracted to Brazilian industry
  - In-house button assembly, brazing and welding
  - All BPMs have bellows on both sides and are referenced to the girders by design



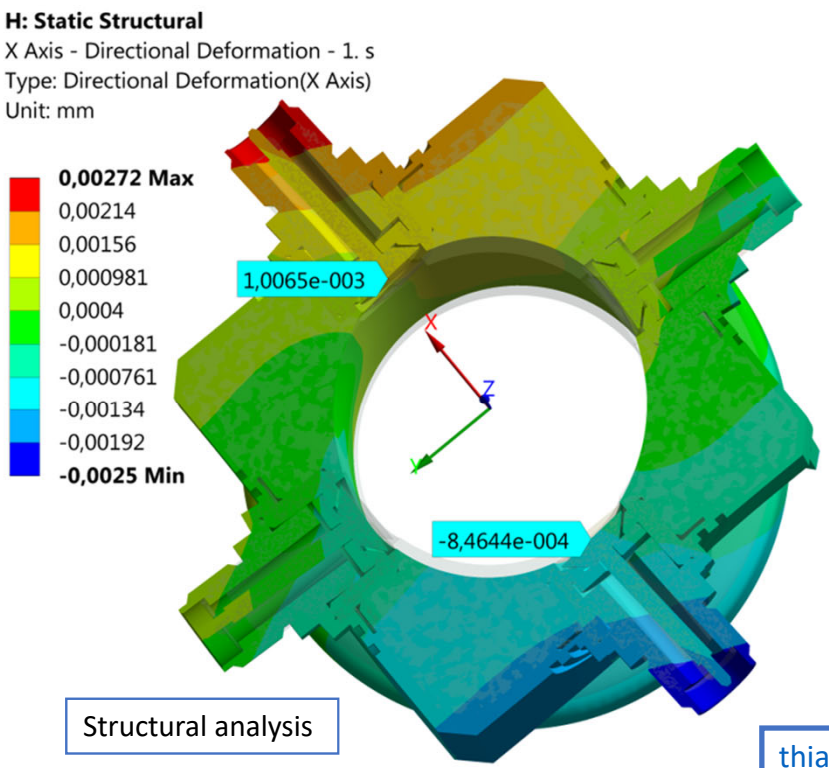
rafael.seraphim@lnls.br

BPM Deformation from Unbalaced Wake Heat Load

I_{av} = 100 mA, σ_s = 2.5 mm



Thermostatic analysis

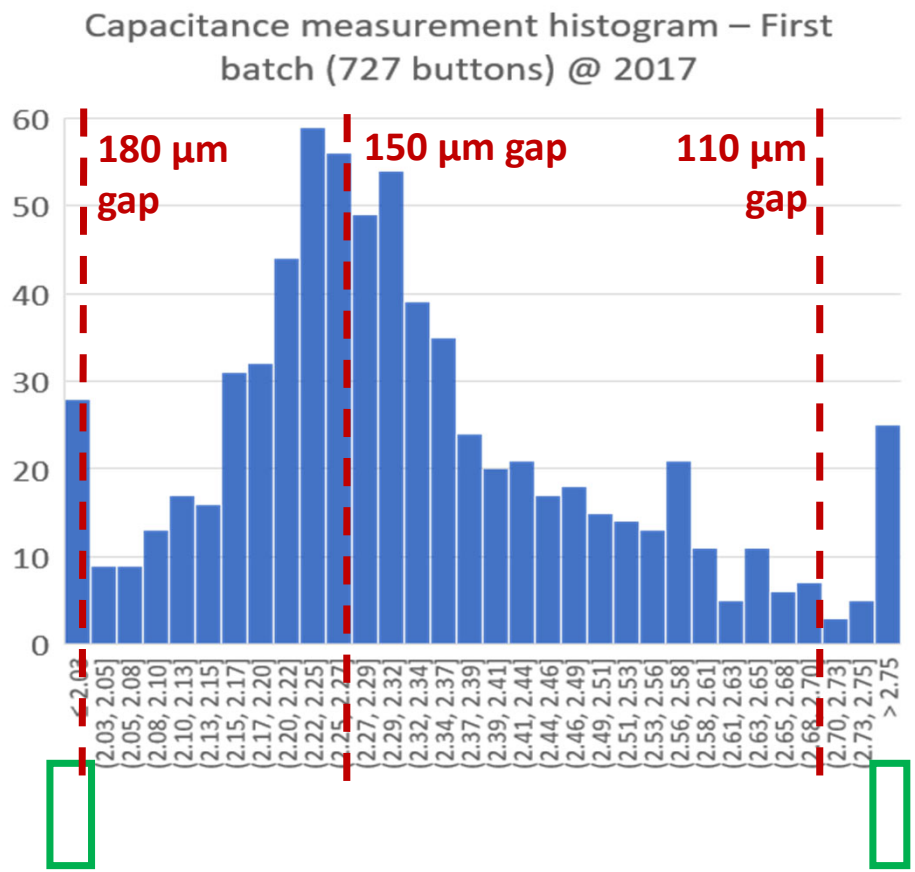


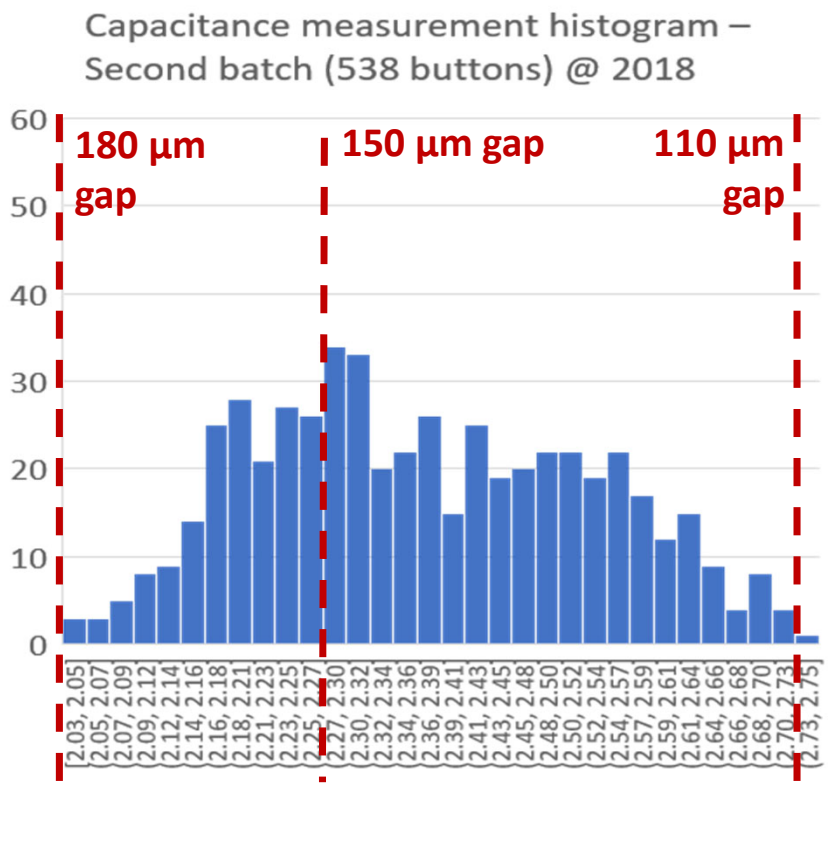
Structural analysis

thiago.rocha@lnls.br
(thermomechanical analysis)

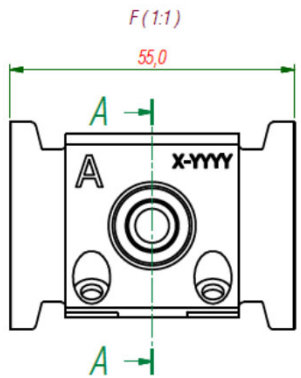
150 nm relative vertical offset: **300 nm BPM electrical center deviation** (from studies of electrical deviation). Since Sirius requires **sub-hundred nanometer stability**, sorting the buttons by similar gap size (or, close capacitance values) is required.

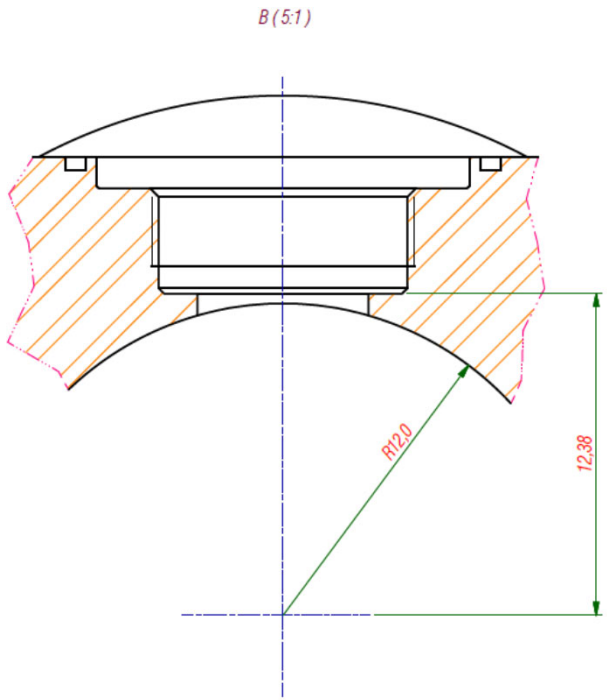
Button Capacitance Measurement



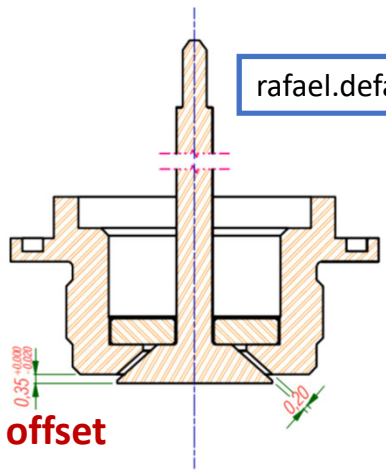


BPM Offset: Button Sorting





Housing seat offset



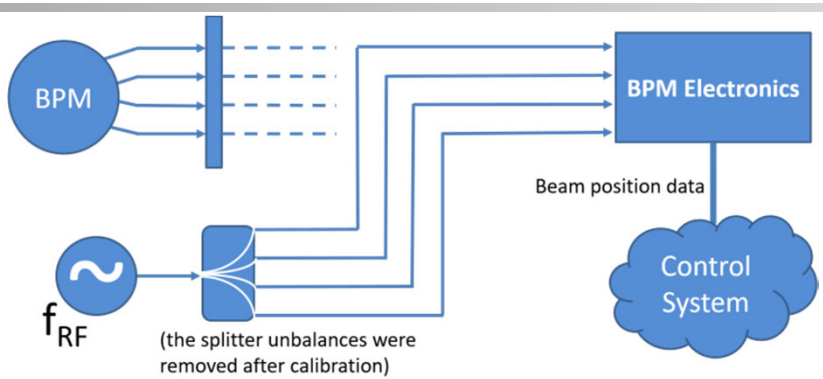
Button offset

rafael.defavari@lnls.br

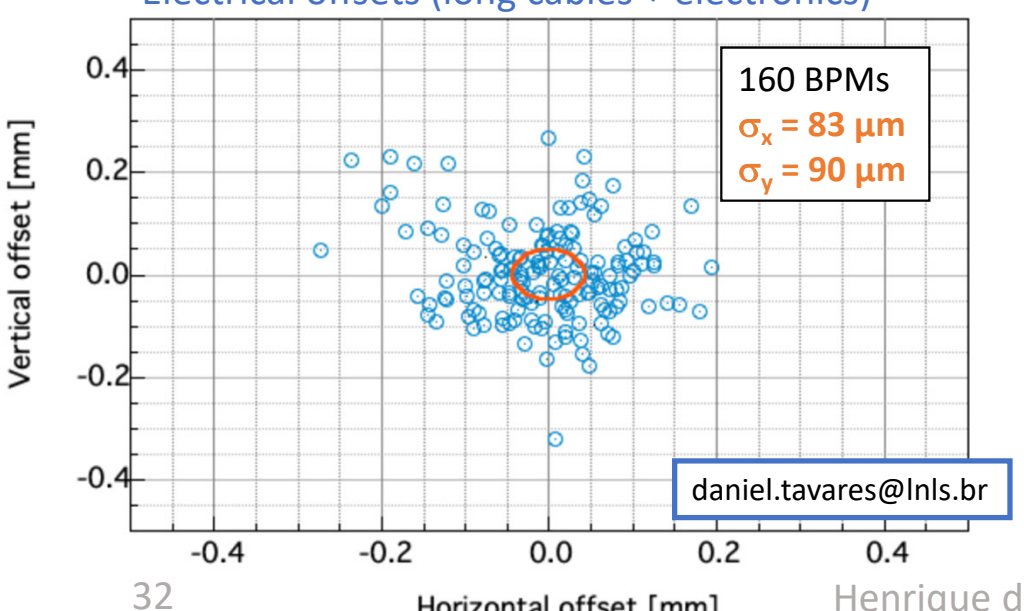
Each BPM was assembled with 4 feedthroughs with:

- Similar capacitance (< 1%) – hence similar gap sizes;
- Complementary housing seat and button offset – so the buttons face the same distante from BPM center

BPM Offset: Offset Correction and BBA

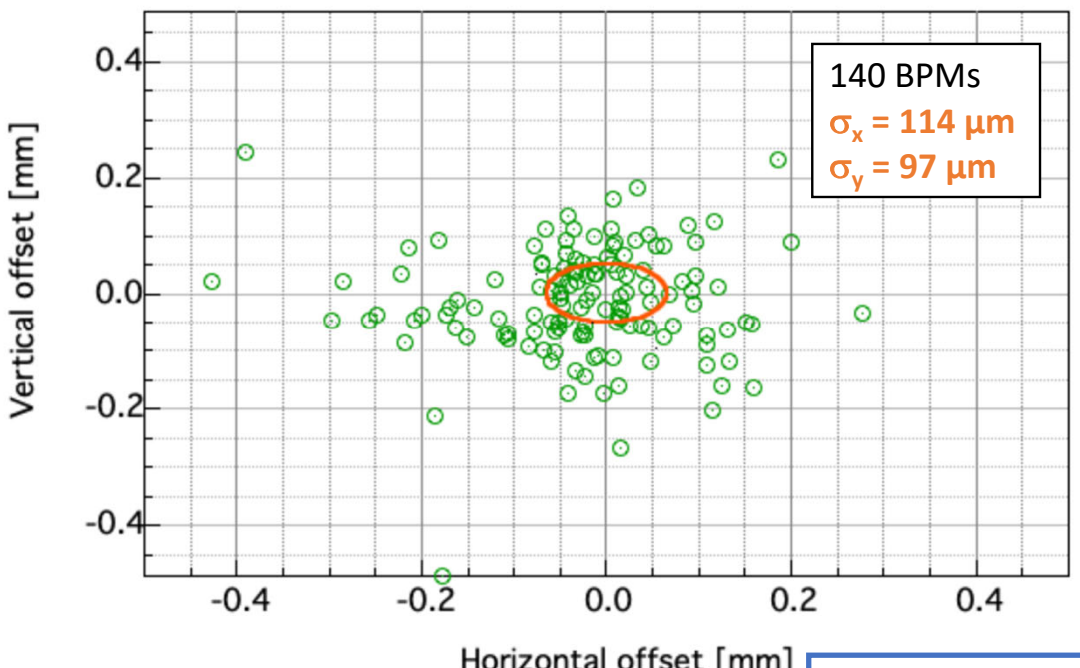


Electrical offsets (long cables + electronics)



daniel.tavares@lnls.br

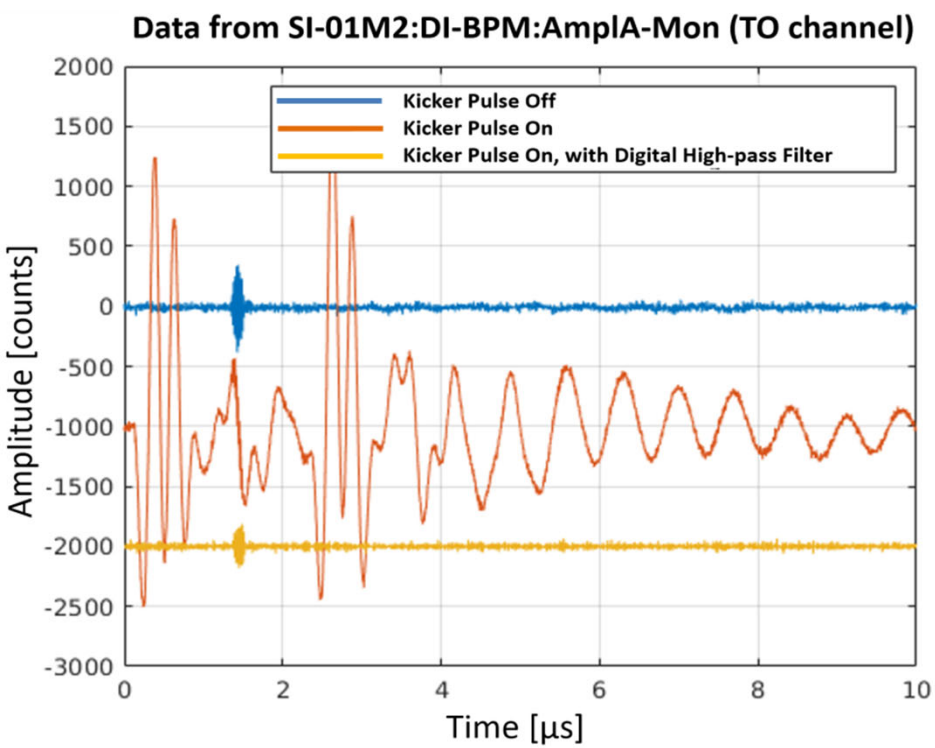
BBA offsets (after offset correction)

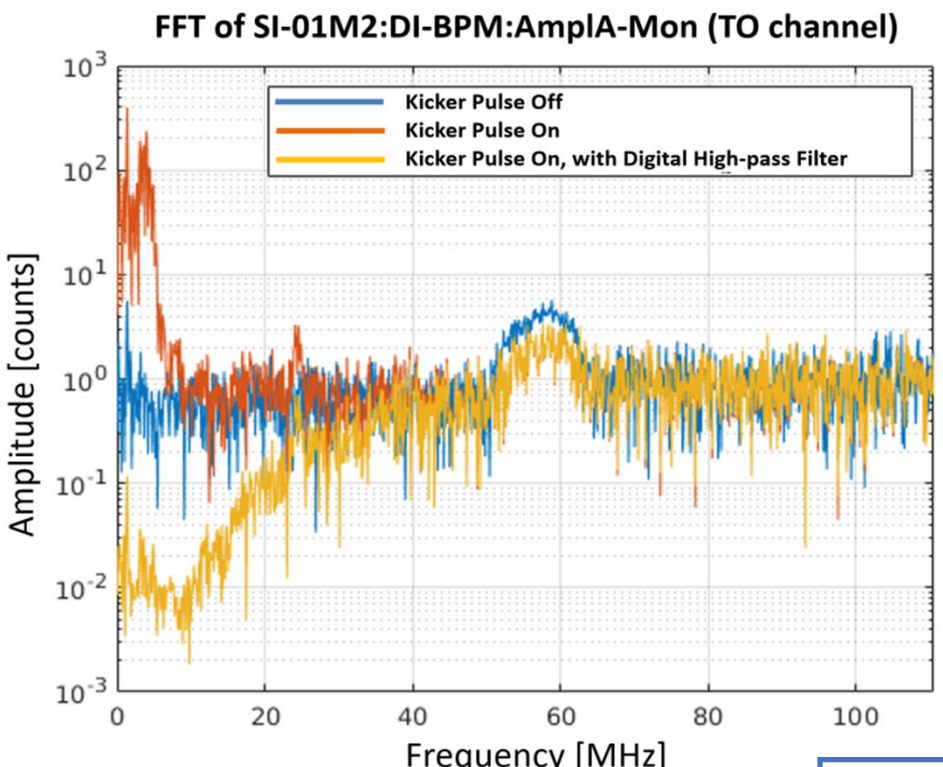


fernando.sa@lnls.br
murilo.alves@lnls.br
liu@lnls.br

BPM: Injection Kicker EMI Filter

Implementation of a high-pass 13 taps FIR filter, cut-off frequency @ 35 MHz



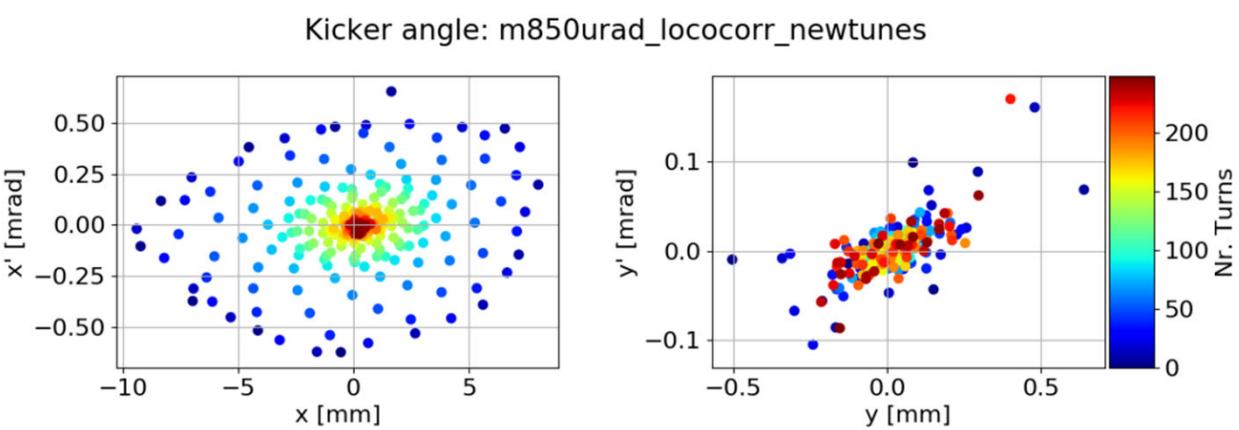


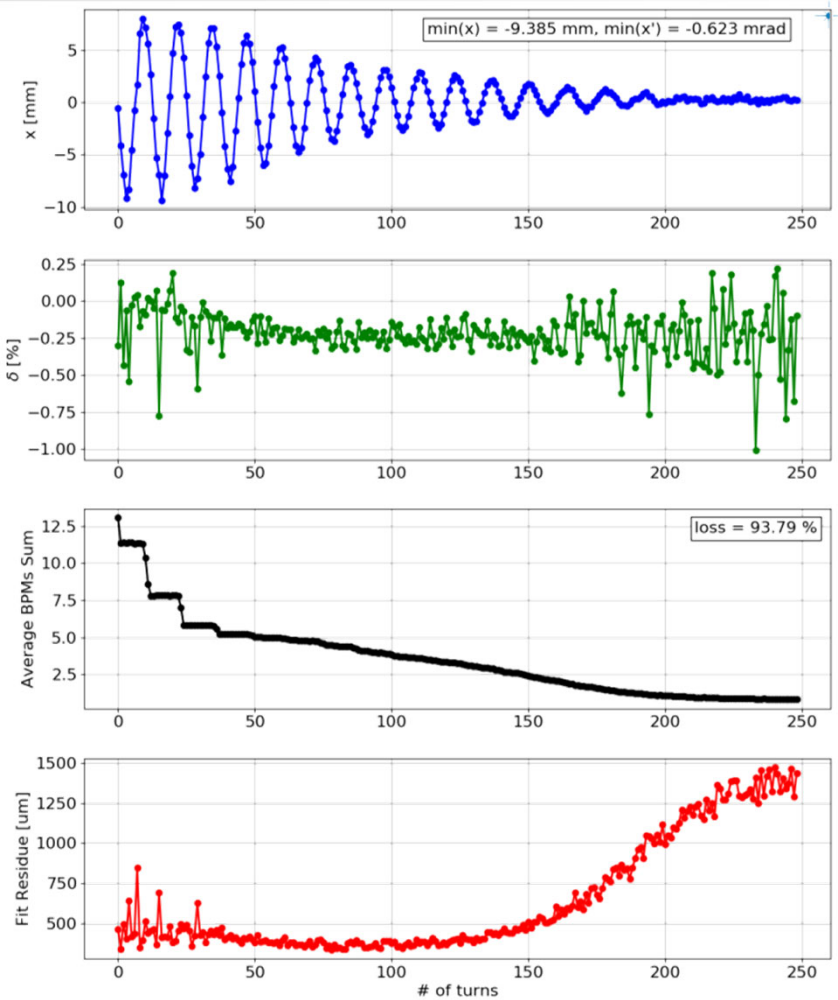
daniel.tavares@lnls.br

Dynamic Apperture Fitted Measurements

- All BPM readings (TbT data) were fitted with the nominal machine model for each turn: position and angle at the kicker location extracted as result;

- Measured dynamic apperture of **–9 mm**

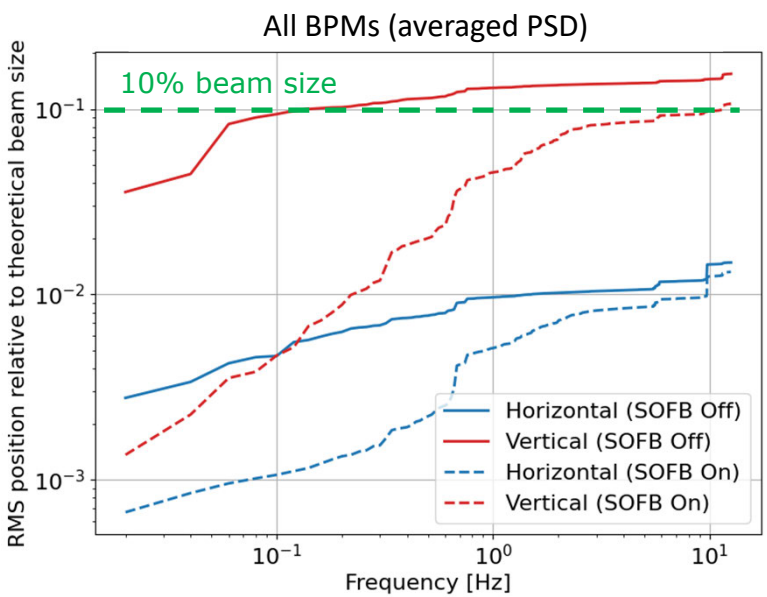


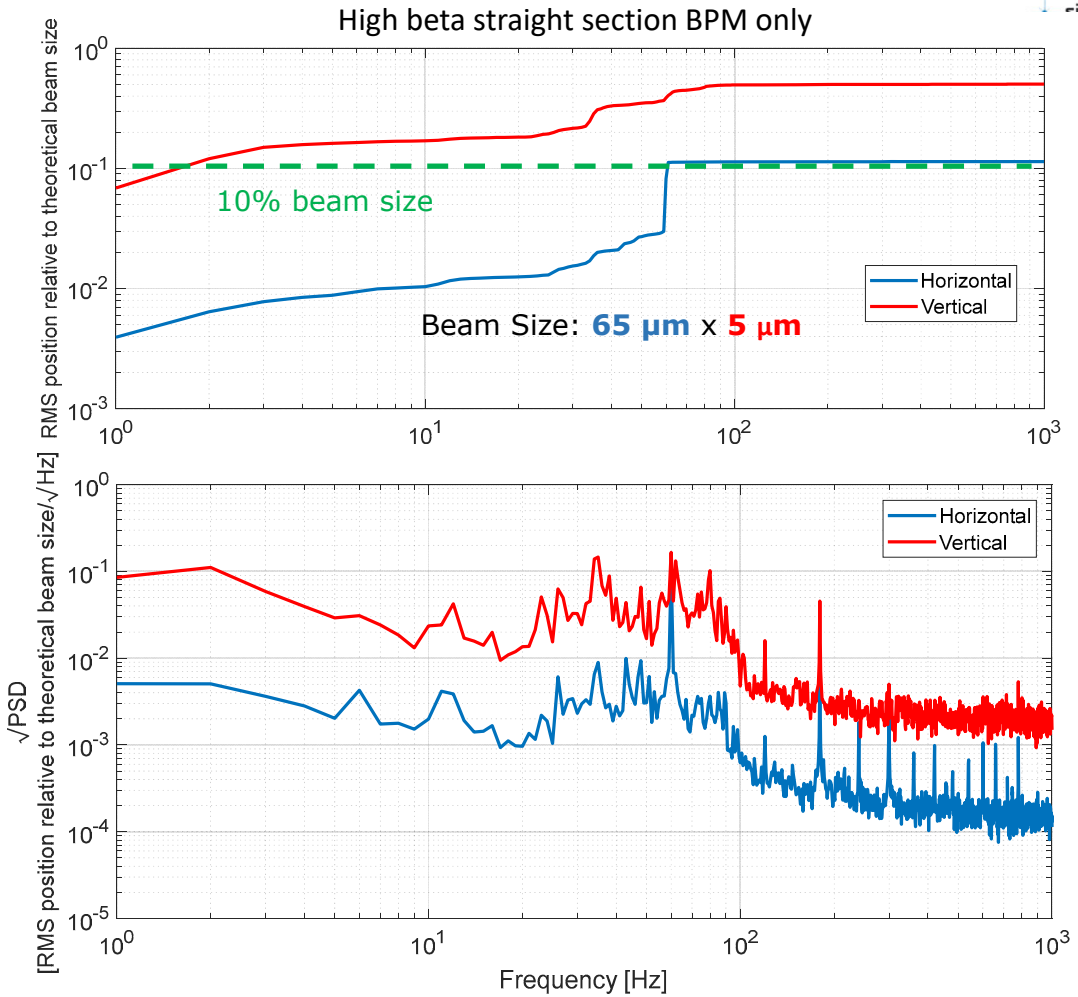


fernando.sa@lnls.br; murilo.alves@lnls.br; liu@lnls.br

Orbit Stability

- Orbit correction currently operates at 25 corrections/s
  - Attenuates thermal effects and ID phase changes only
- Machine time needed to continue studies with XBPM
- Tunnel temperature stability improvements ongoing
- Investigations and improvements are needed: interferences from mains and booster 2 Hz ramping, vibrations, "cultural noise"
- FOFB expected to come online Q2/2021





fernando.sa@lnls.br; murilo.alves@lnls.br; daniel.tavares@lnls.br; liu@lnls.br

Final Comments

- The booster commissioning in paralel with storage ring instalation led to an intermittent schedule
- Emittance measurements not available yet: diagnostics beamline under review
- Streak camera not installed yet
- EMI issues with charge measurements
- Beam loss: Commercial PIN diodes BLMs used for booster commissioning and in-house developed Gama detectors in the storage ring. Commercial PMT-based BLMs can be considered for upgrades/cross-checks
- Both horizontal and vertical scrapers are under test after design changes
- Orbit stability improvements are demanded
- Screens: success (but could be less expensive)
- Standardization of components has proven fruitful already: motors, cameras, digitizers (ICTs and DCCTs) etc.
- Bunch-by-bunch feedback longitudinal system running for users and improvements are ongoing


Thank you!