Perturbation Sources and Improvements of SIRIUS Beam Stability

Fernando Henrique de Sá

On behalf of the SIRIUS Team

Low Emittance Rings Workshop
Geneva, 13-16 of February 2024

SIRIUS – 4GSR in Operation

SIRIUS design parameters

Energy	3.0	GeV
Circumference	518.4	m
Emittance	250	pm.rad
Current (top-up)	350	mA

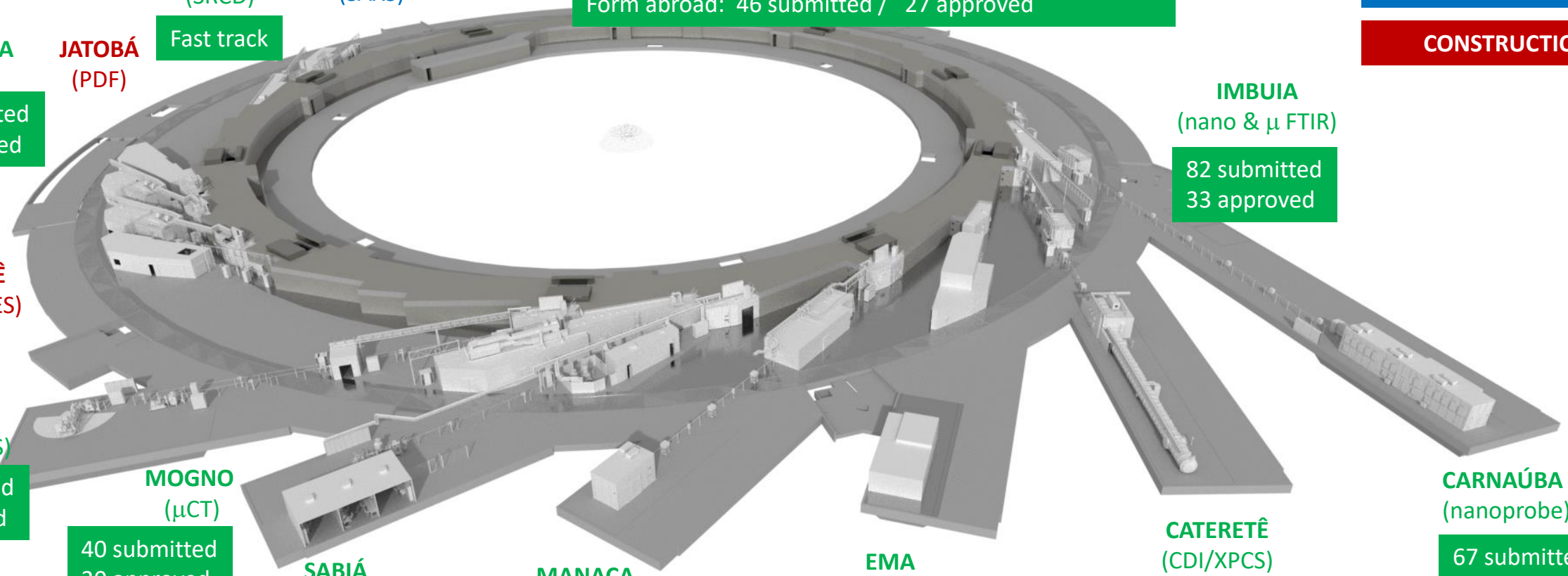
- Green-field facility
- Construction: 2012 – 2020
- Cost: US$ 500M (~85% spent in Brazil)
- 1st regular users call: Nov. 2022
- 10 beamlines in operation
- 100 mA in top-mode mode, uniform fill
- Phase-1 (end of 2024): 14 beamlines

SIRIUS Beamlines – Phase 1

https://www.lnls.cnpem.br/beamlines/

Third Cycle of Proposals (1S 2024)
Total: 422 submitted / 225 approved
From Brazil: 376 submitted / 198 approved
Form abroad: 46 submitted / 27 approved

OPERATION
INSTALLATION
CONSTRUCTION



CEDRO (SRCD) — Fast track

SAPUCAIA (SAXS)

PAINEIRA (XPD) — 46 submitted, 36 approved

JATOBÁ (PDF)

QUATI (XAFS)

SAPÊ (ARPES)

IPÊ (RIXS/ XPS) — 45 submitted, 26 approved

MOGNO (μCT) — 40 submitted, 30 approved

SABIÁ (XMCD/PEEM) — 18 submitted, 15 approved

MANACA (MX) — Fast track

EMA (Extreme Cond.) — 83 submitted, 20 approved

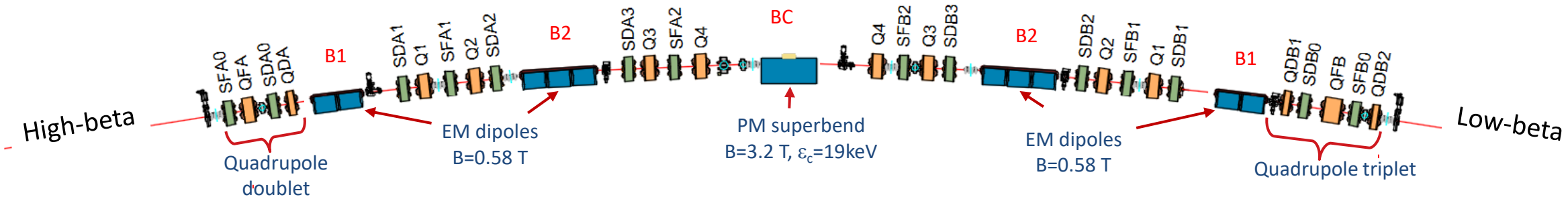
CATERETÊ (CDI/XPCS) — 41 submitted, 24 approved

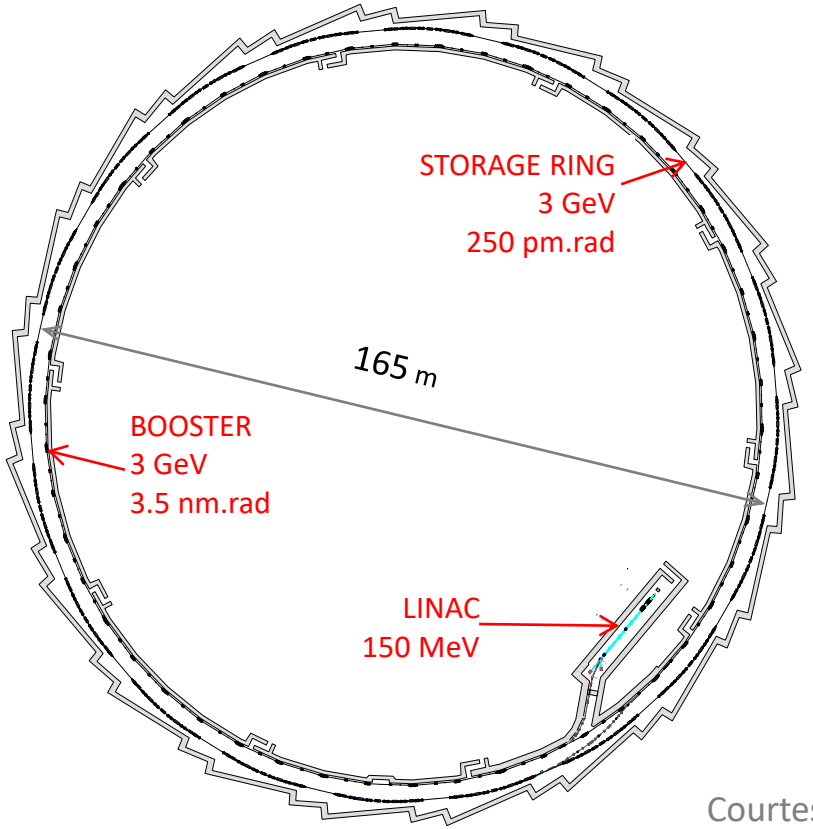
IMBUIA (nano & μ FTIR) — 82 submitted, 33 approved

CARNAÚBA (nanoprobe) — 67 submitted, 41 approved

Courtesy: Harry Westfahl

Main Design Parameters





Storage Ring parameters	
Beam energy	3.0 GeV
Circumference	518.4 m
Lattice	**20 x 5BA**
Current, top up	350 mA
Hor. emittance	**250 pm**
RF frequency	500 MHz
Emit. ratio $\varepsilon_y/\varepsilon_x$	2%

Courtesy: Liu Lin

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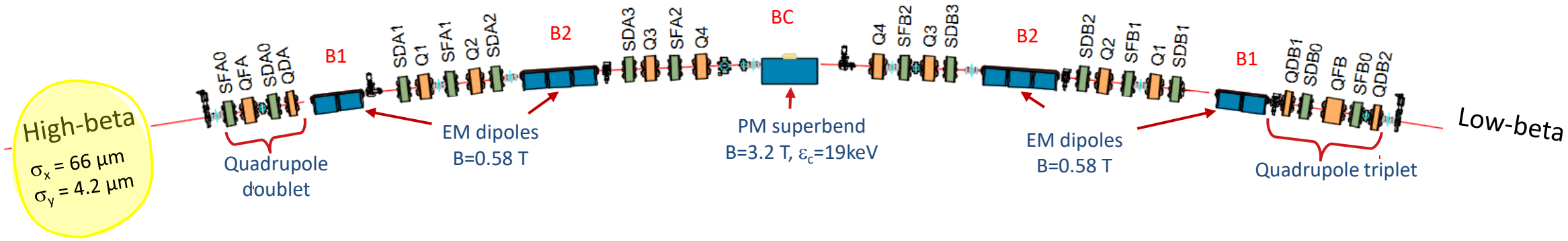

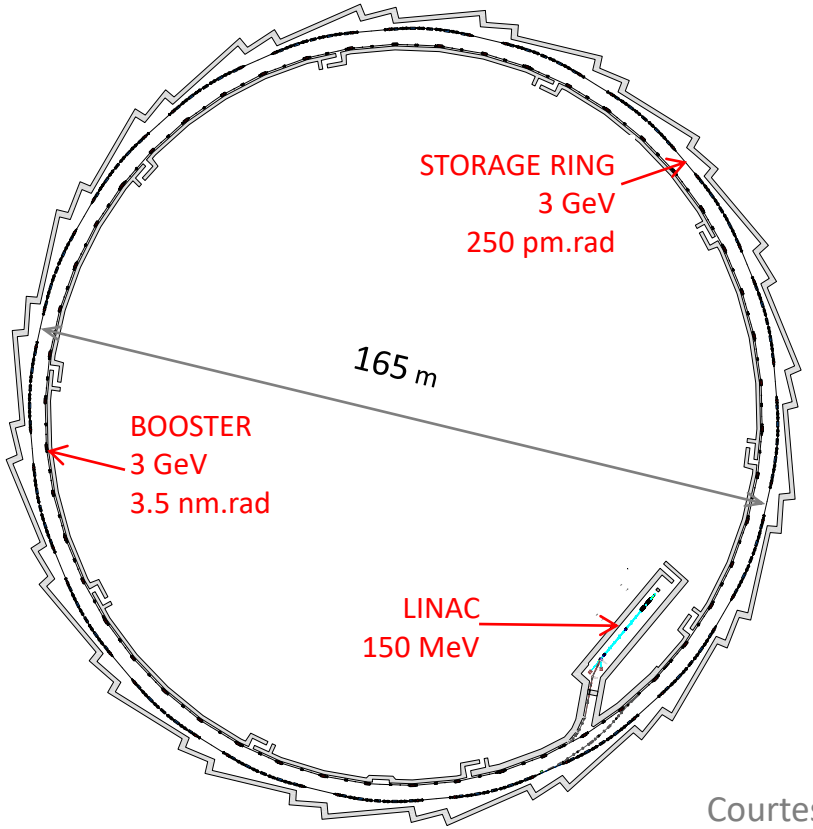

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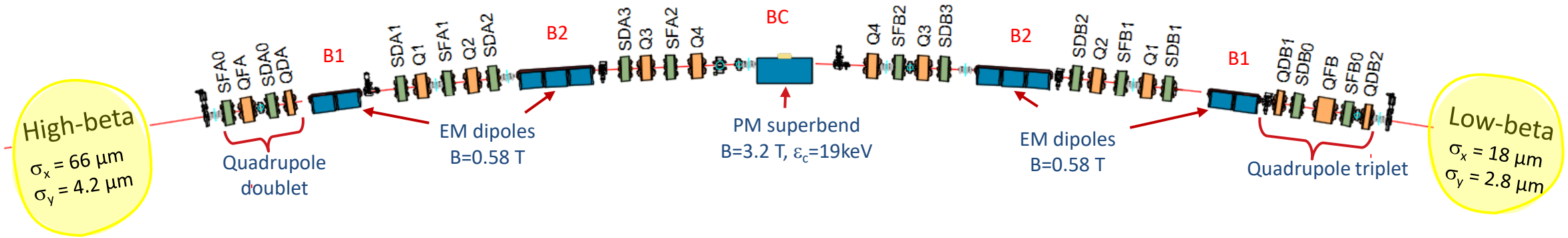

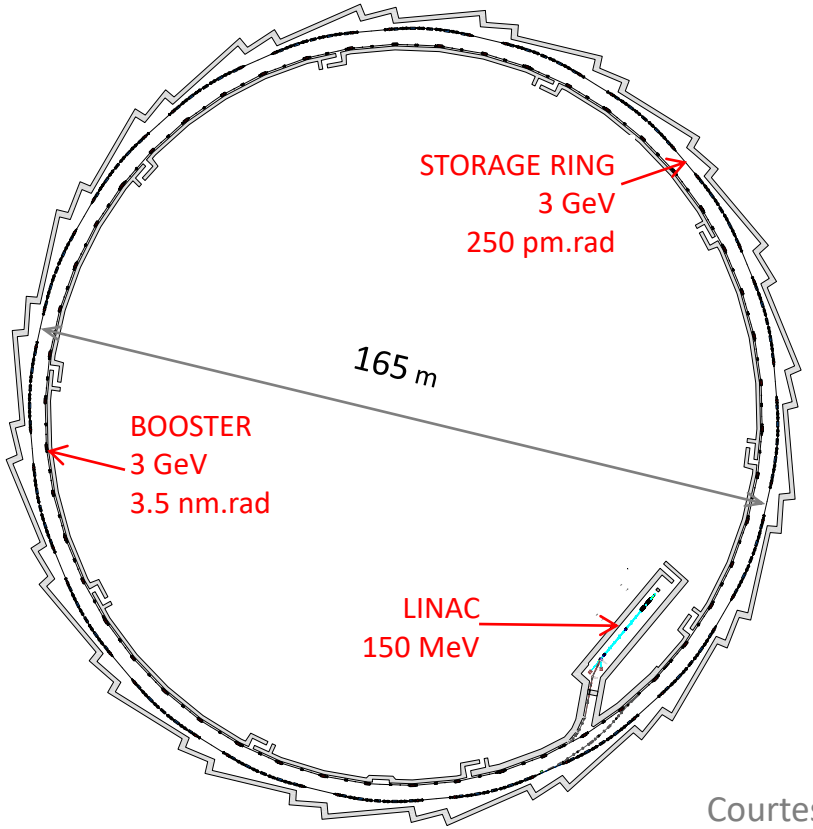

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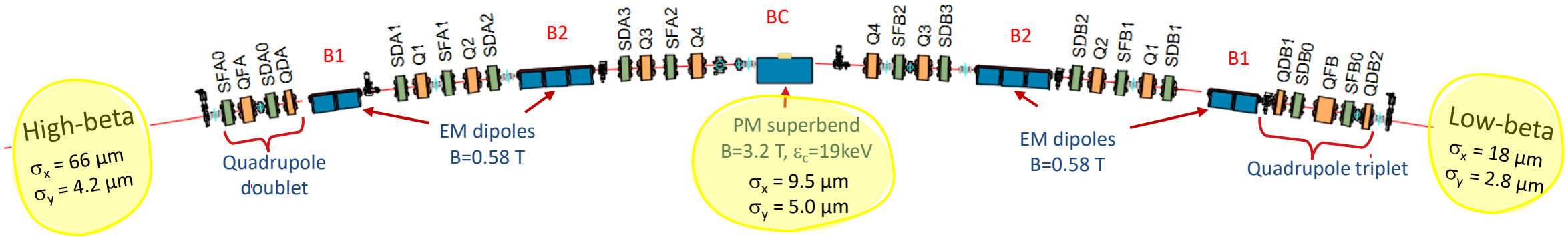

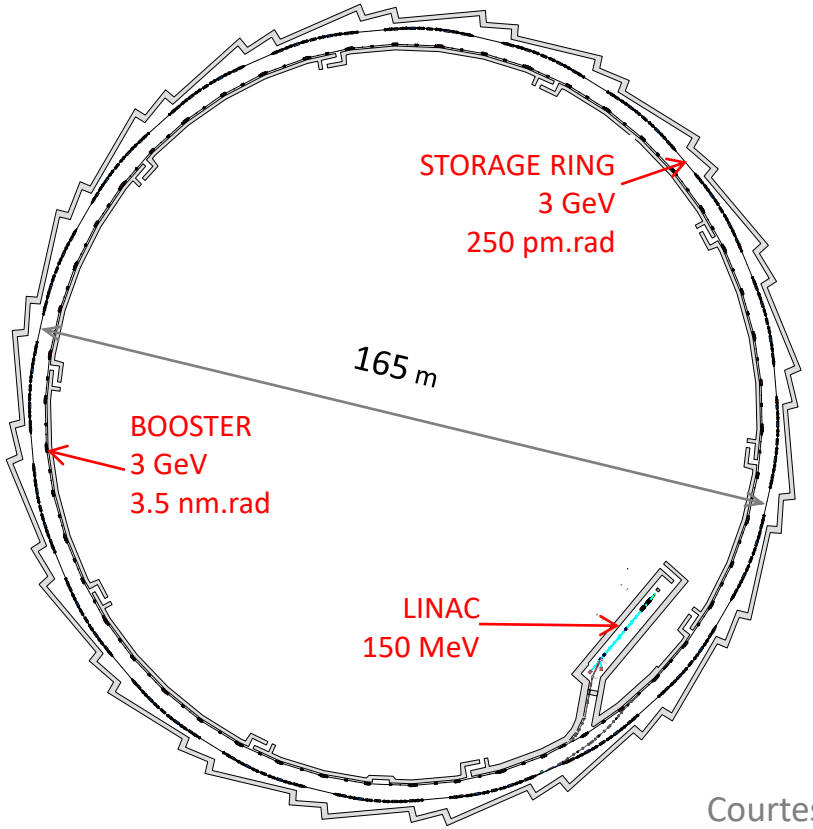

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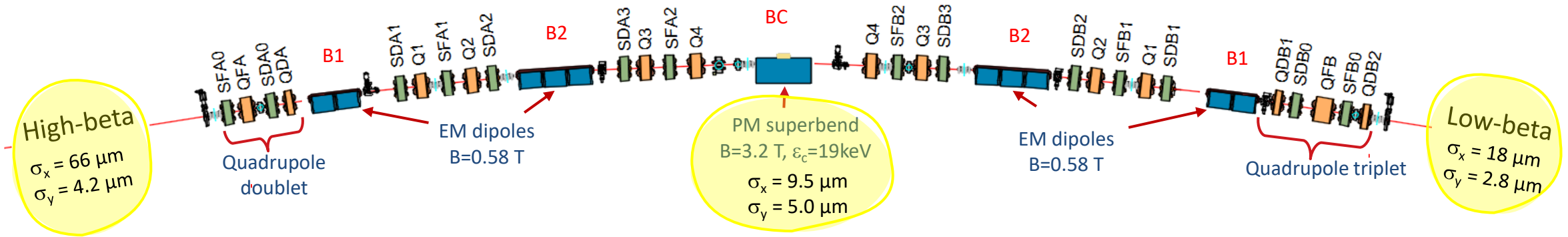

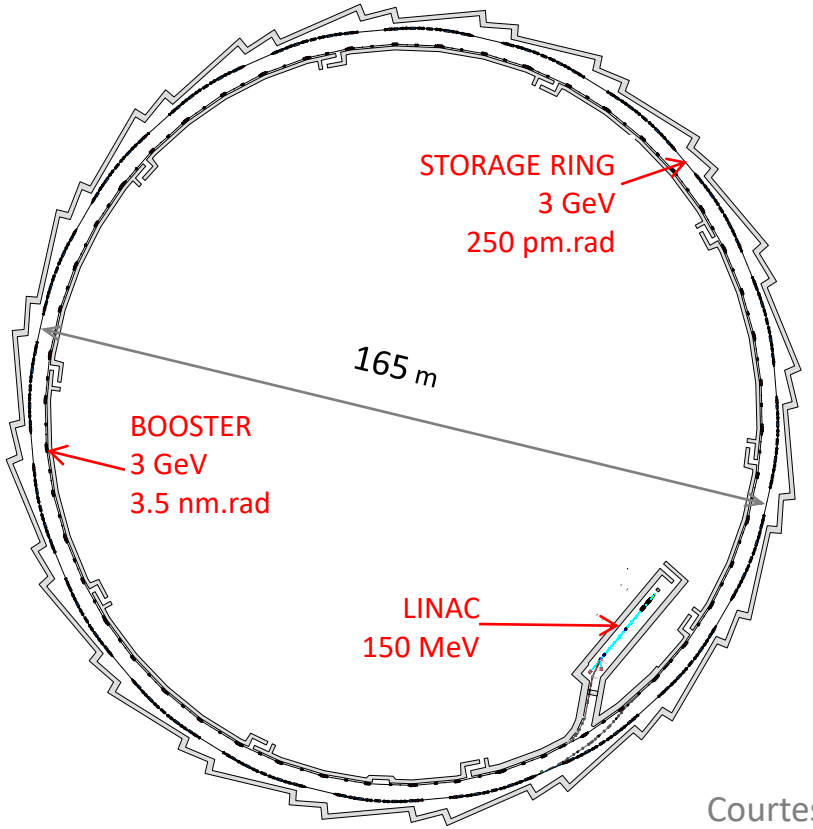

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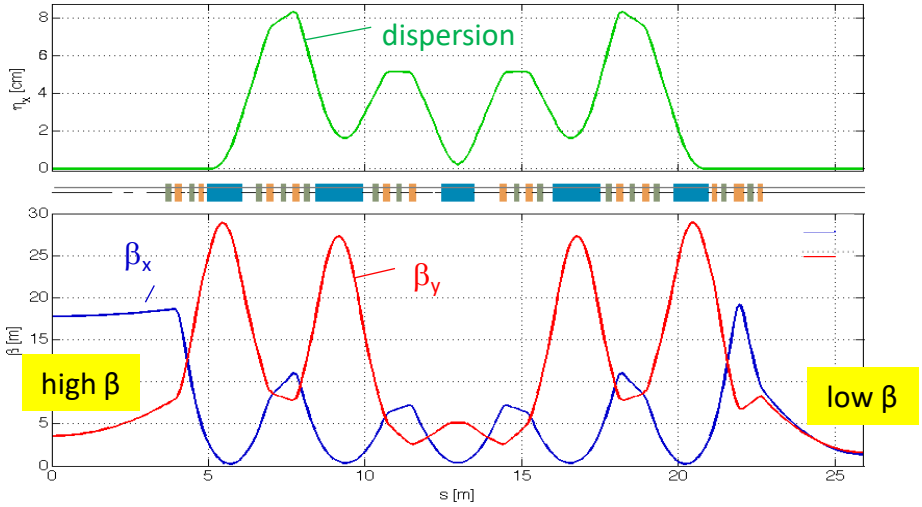

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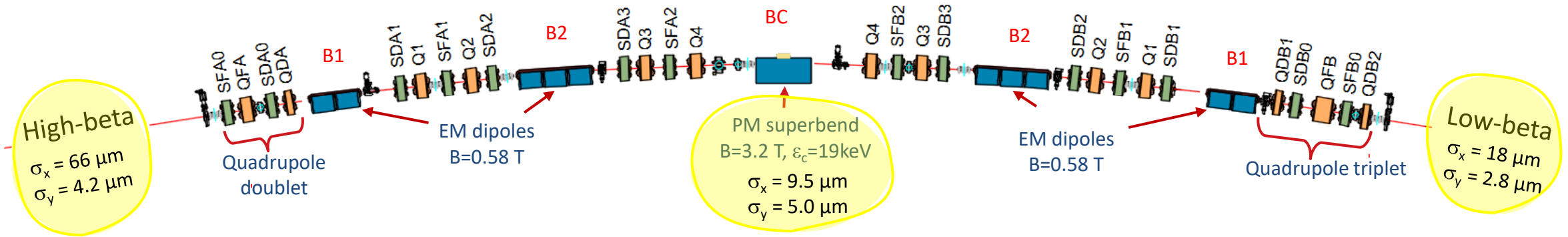

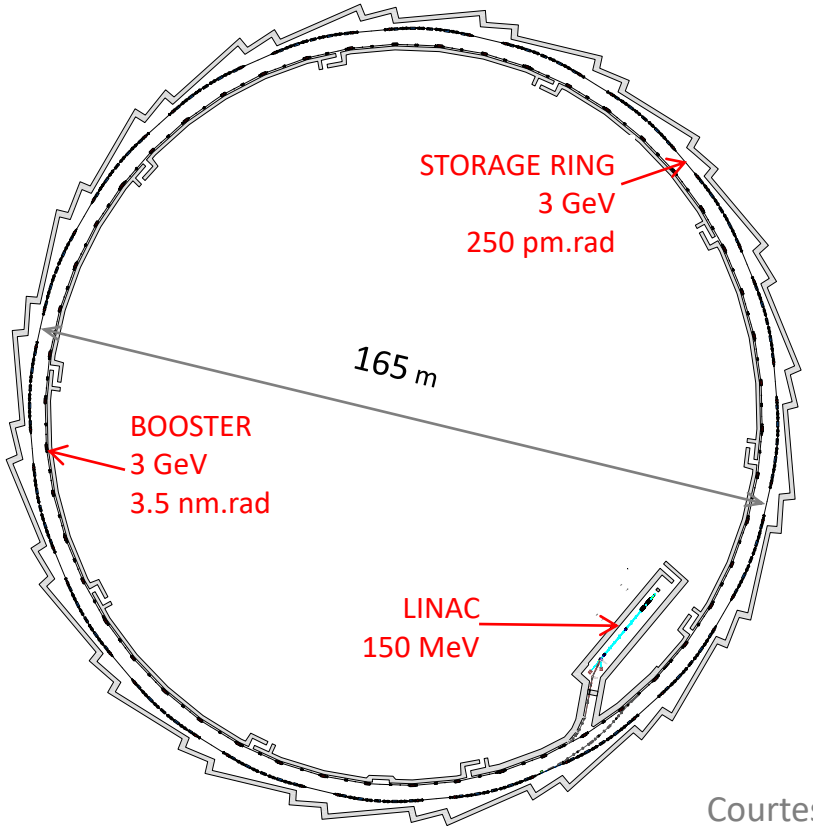

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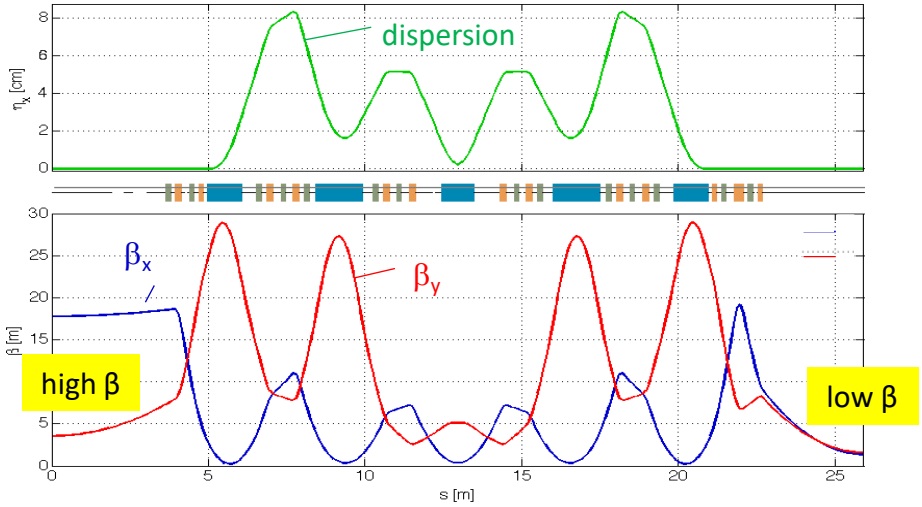

5-fold symmetric optics:

- 5 high β sections
- 15 low β sections

$\beta_x \approx \beta_y \approx 1.5$ m

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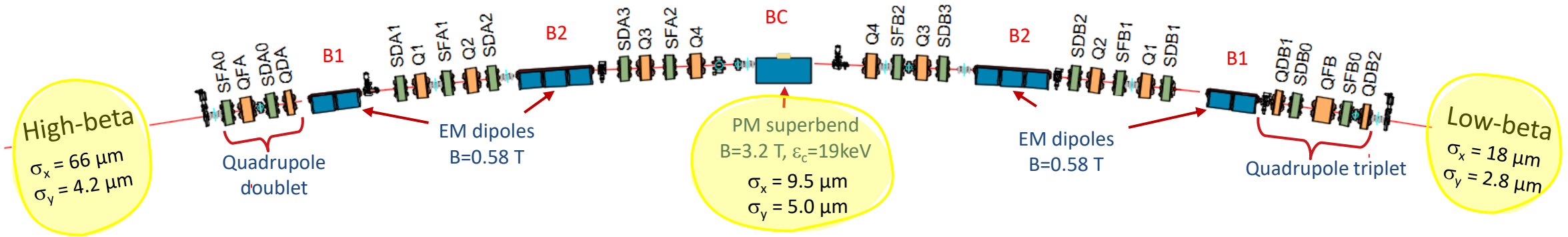

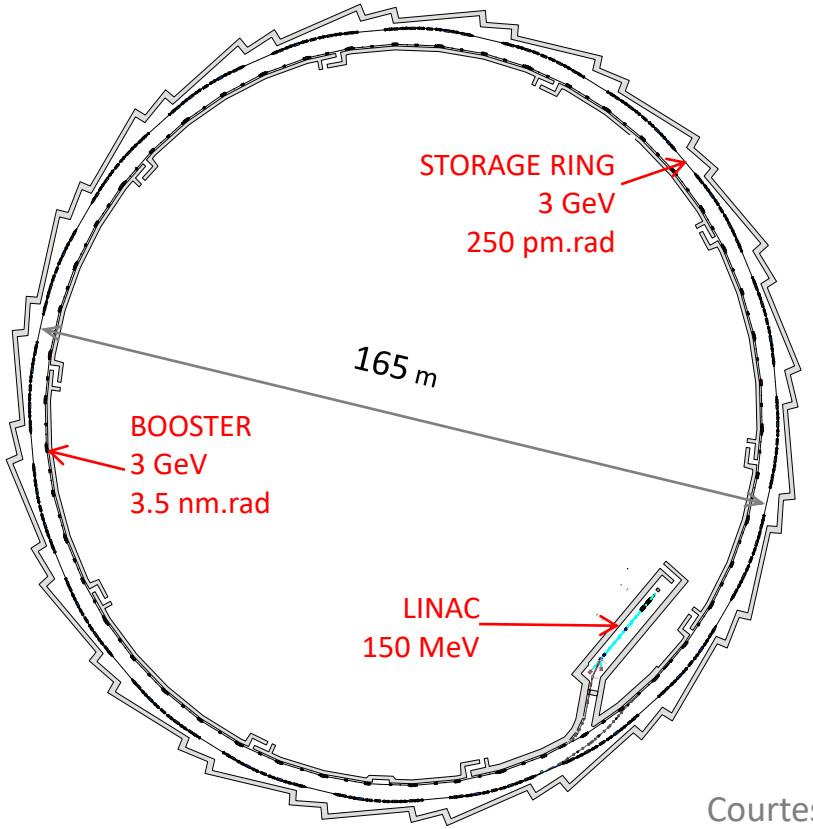

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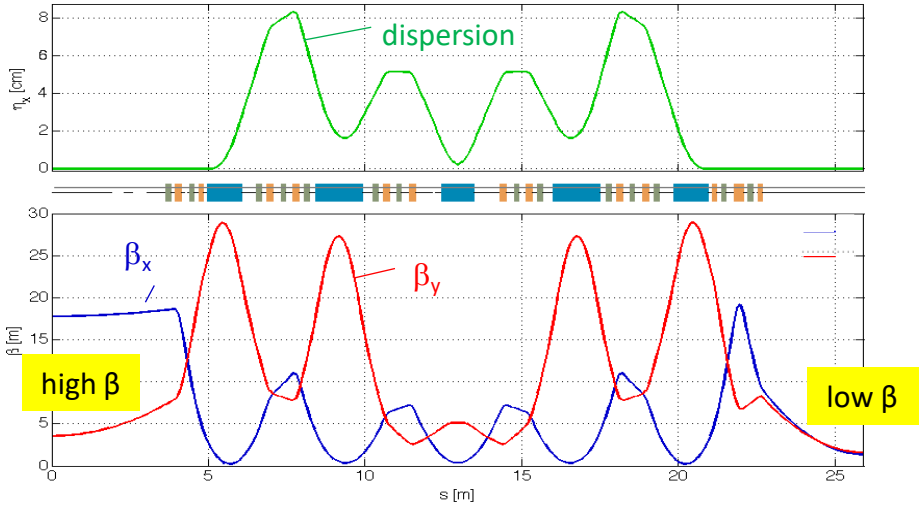


5-fold symmetric optics:

- 5 high β sections
- 15 low β sections

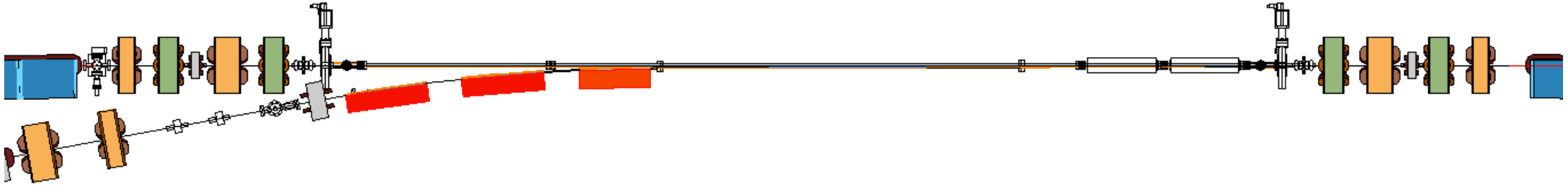
$\beta_x \approx \beta_y \approx 1.5$ m

Better matching of e⁻ and photon beam phase spaces for undulators → higher brightness

Small H and V beam stay clear → small gap undulators

Small ID perturbation on optics → easier daily operation

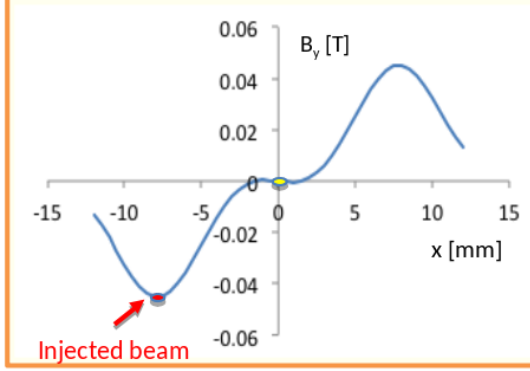
Storage Ring Injection

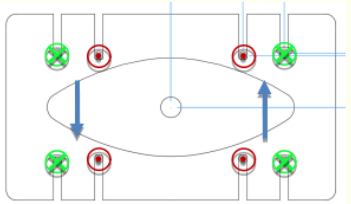


Storage Ring Injection

- NLK uses BESSY type wire configuration with titanium coated ceramic chamber (~8 µm thickness);
- Grooves were machined on the ceramic exterior to house the wires firmly

NLK for off-axis injection → beam accumulation





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

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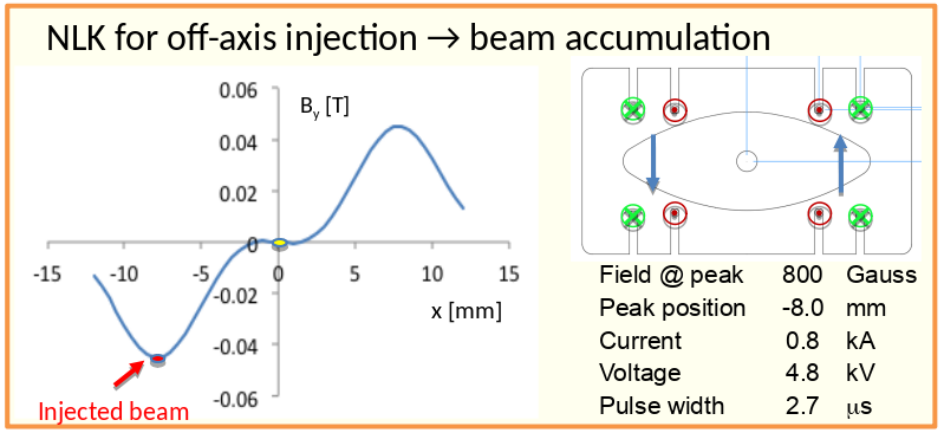

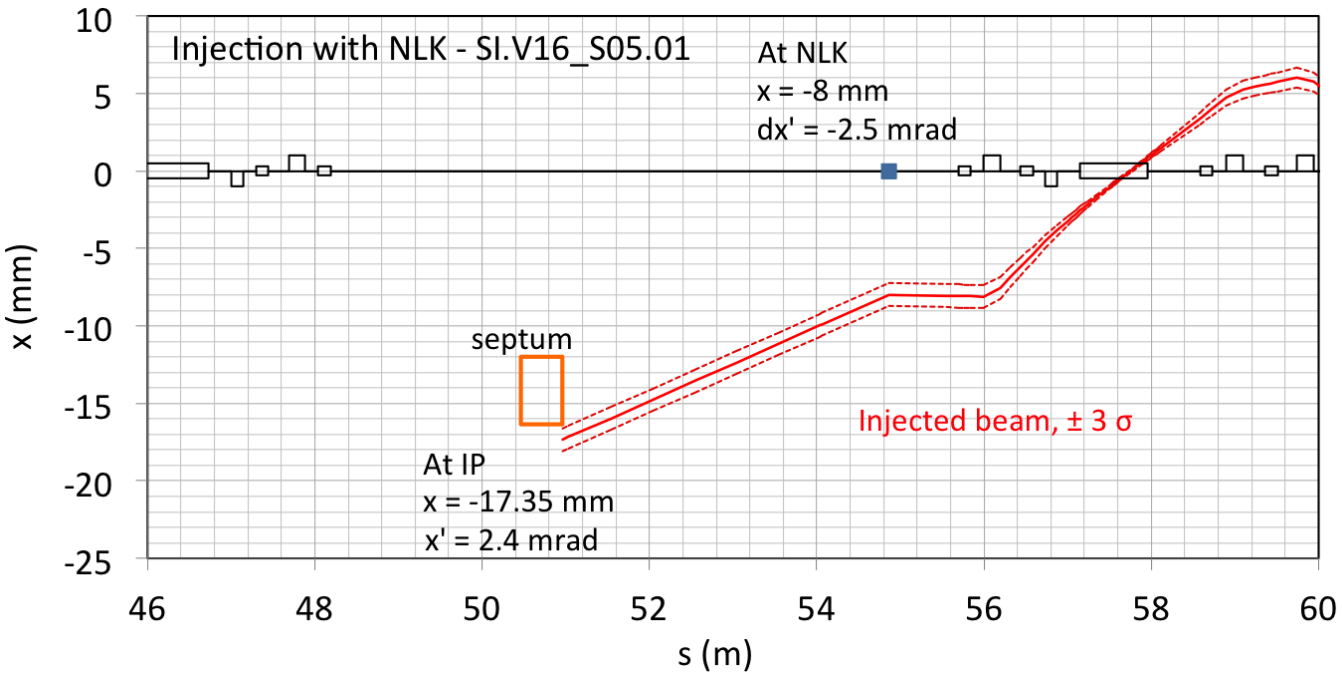

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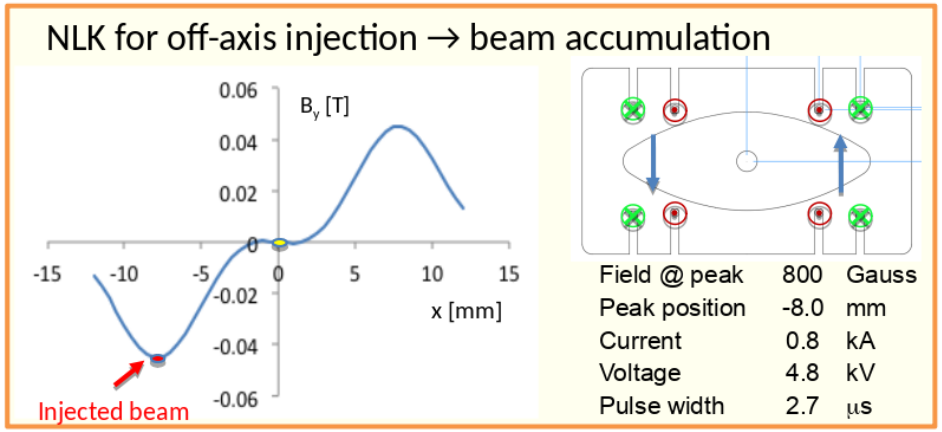

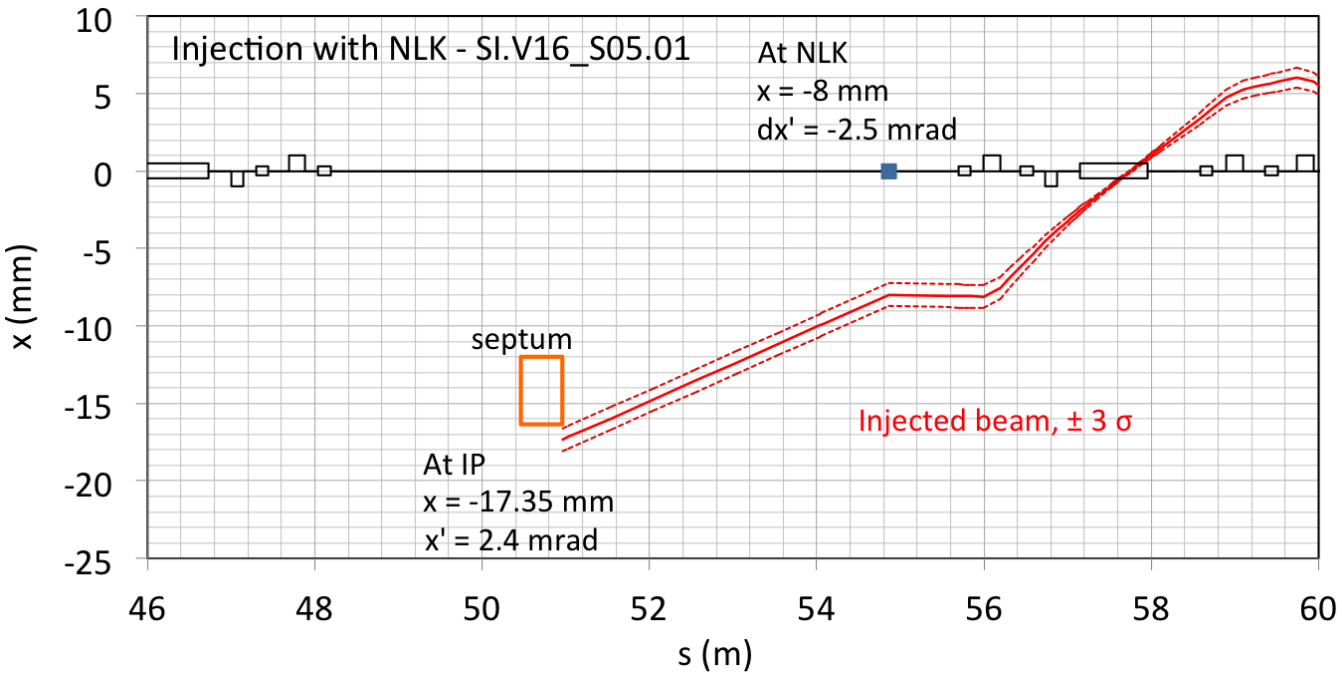

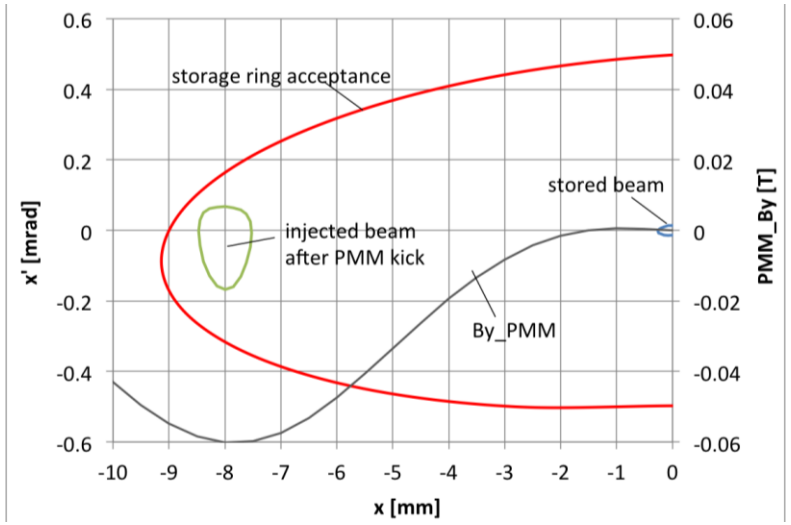

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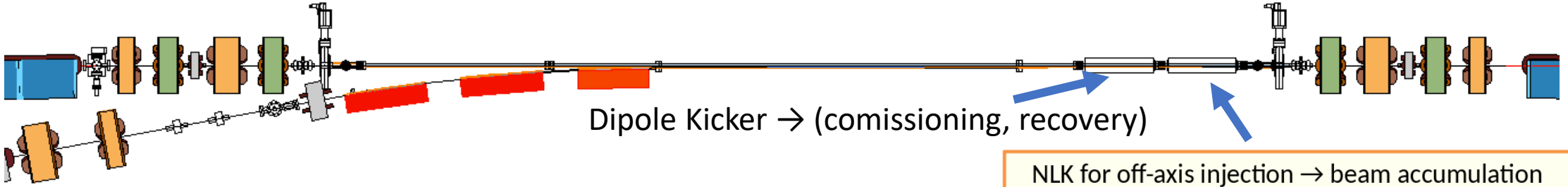

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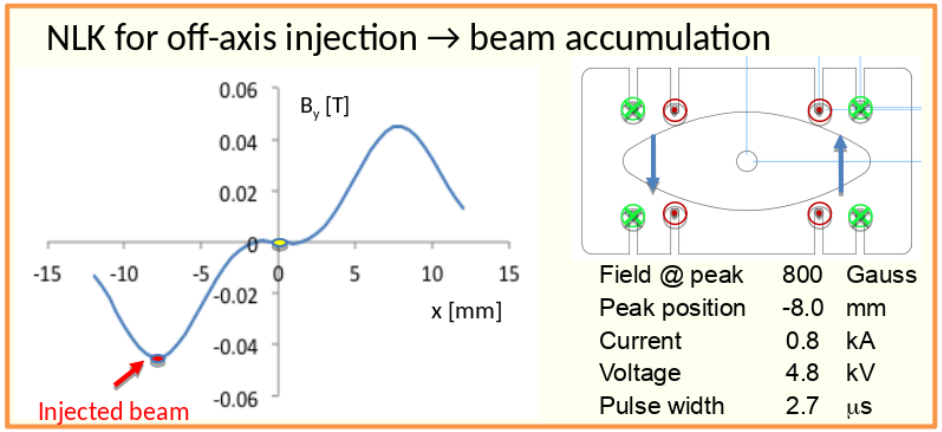
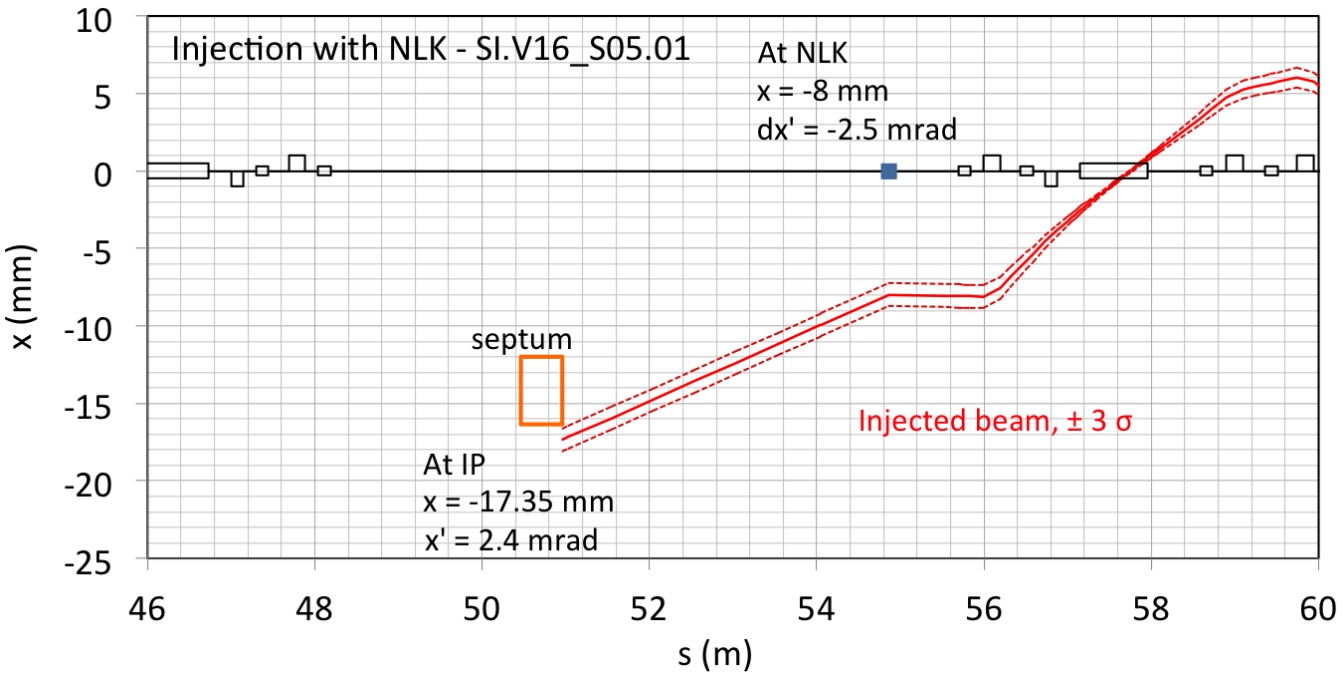
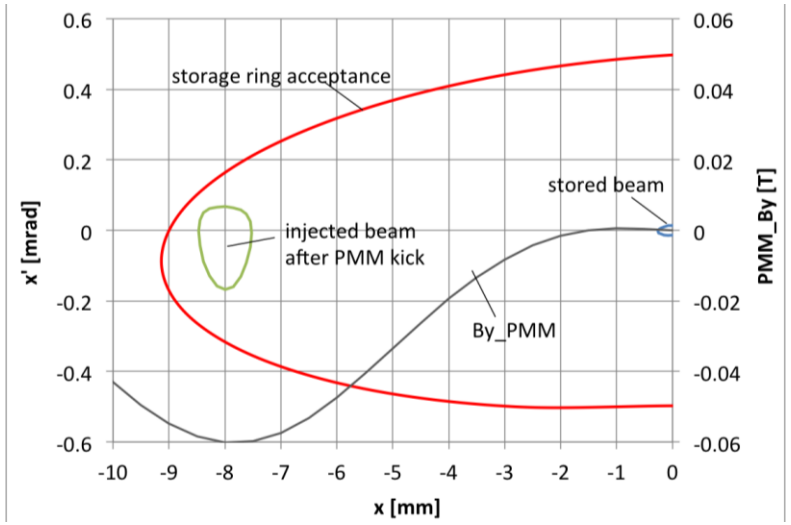


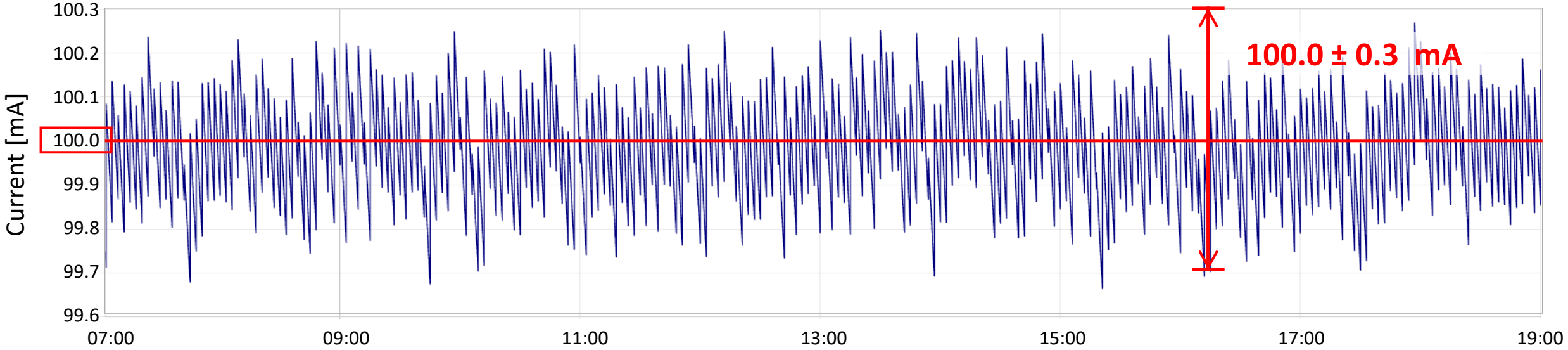




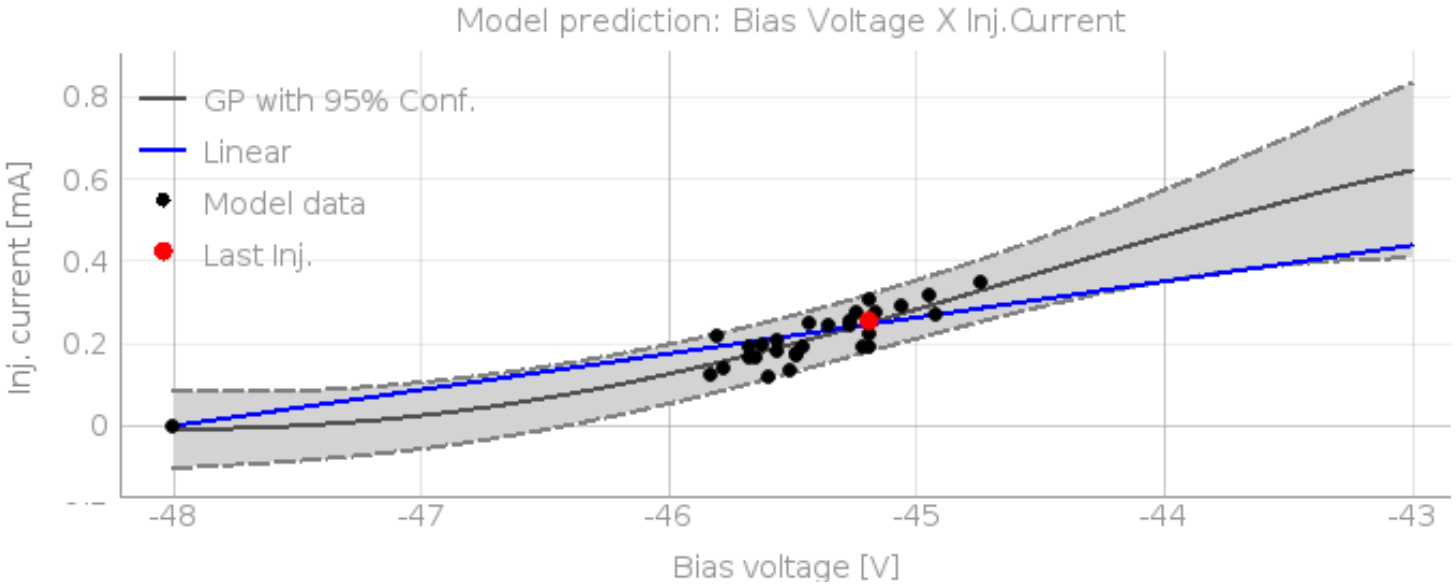
Long-Term Stability (weeks - 1 hour)

Top-up Operation

Courtesy: Ximenes Resende



- Running for users since March 2023
- Current: 100 mA
- Injection: **1 pulse every 3 min**
- uniform filling in 864 bunches
- Thermionic e-gun bias voltage used as charge control parameter



BPMs Drift and Temperature

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- BPMs Drift:
  - Operation with antennas switching helps against temp. changes;
  - BBA is performed periodically (monthly) after machine maintenances;
  - Large offsets variations detected on some BPMs;
  - Not sure about the time-scale of these variations;
  - X-BPMs not operational yet. Work in progress;
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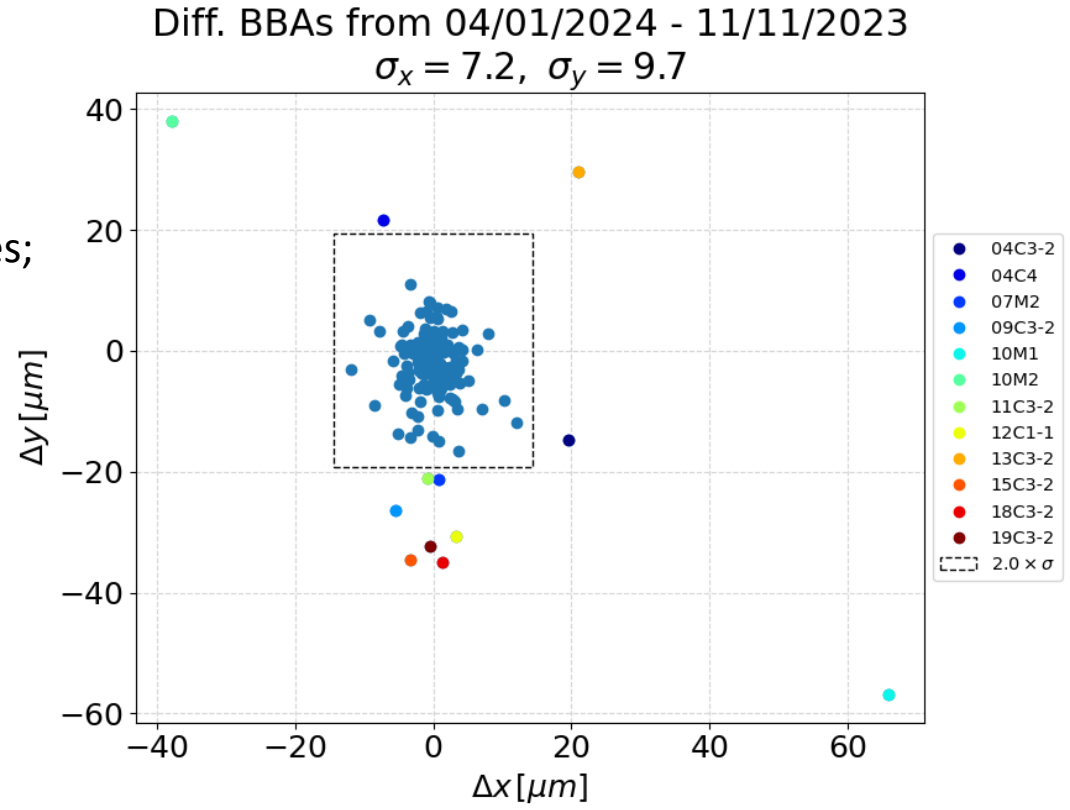

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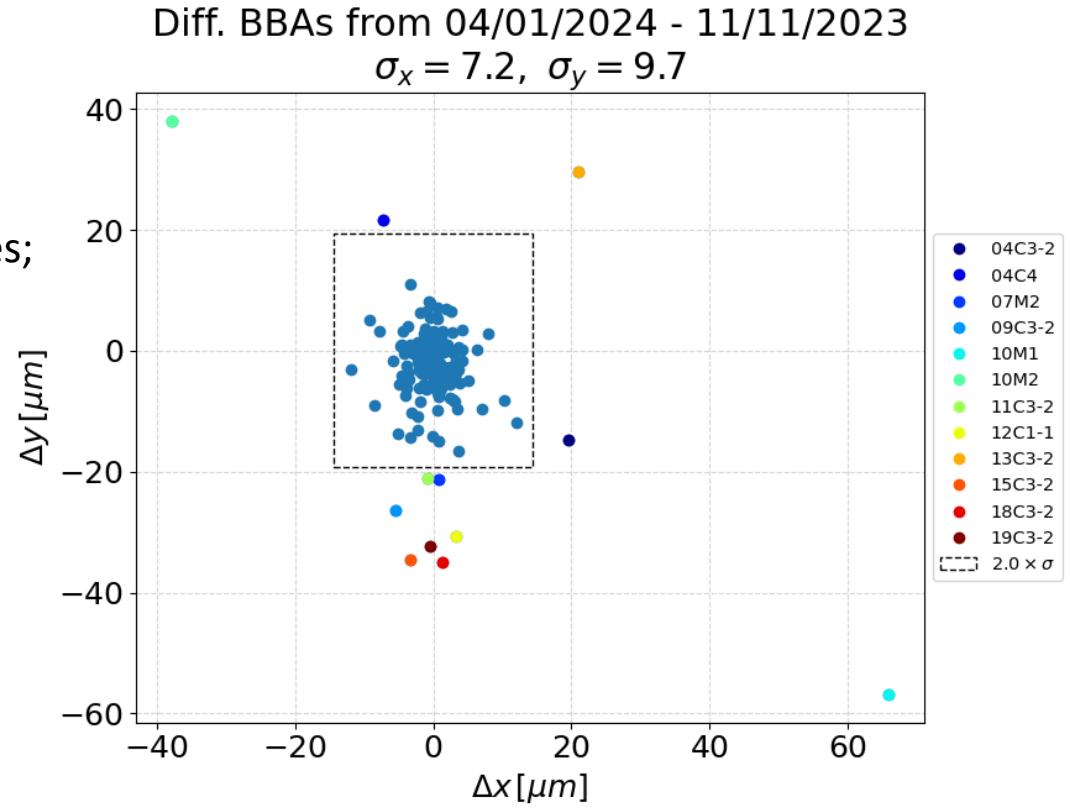

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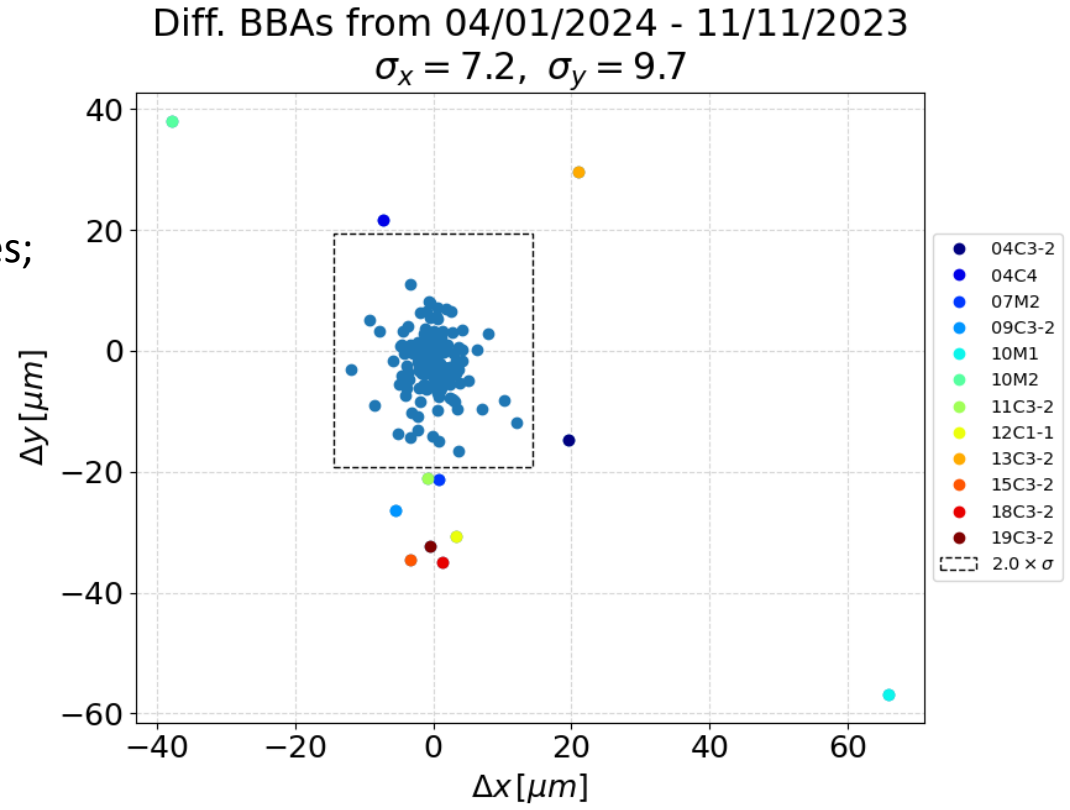
  - Daily and seasonal correlation among HLS readings, concrete temperatures, and external temps.;
  - Apparently not detrimental to beamlines experiments;
  - Large effort to improve temp. control of tunnel, water and hall;
  - Almost all temperatures under specification limits (0.1°C to 0.5°C);
  - Periodic verification of magnets temperatures.



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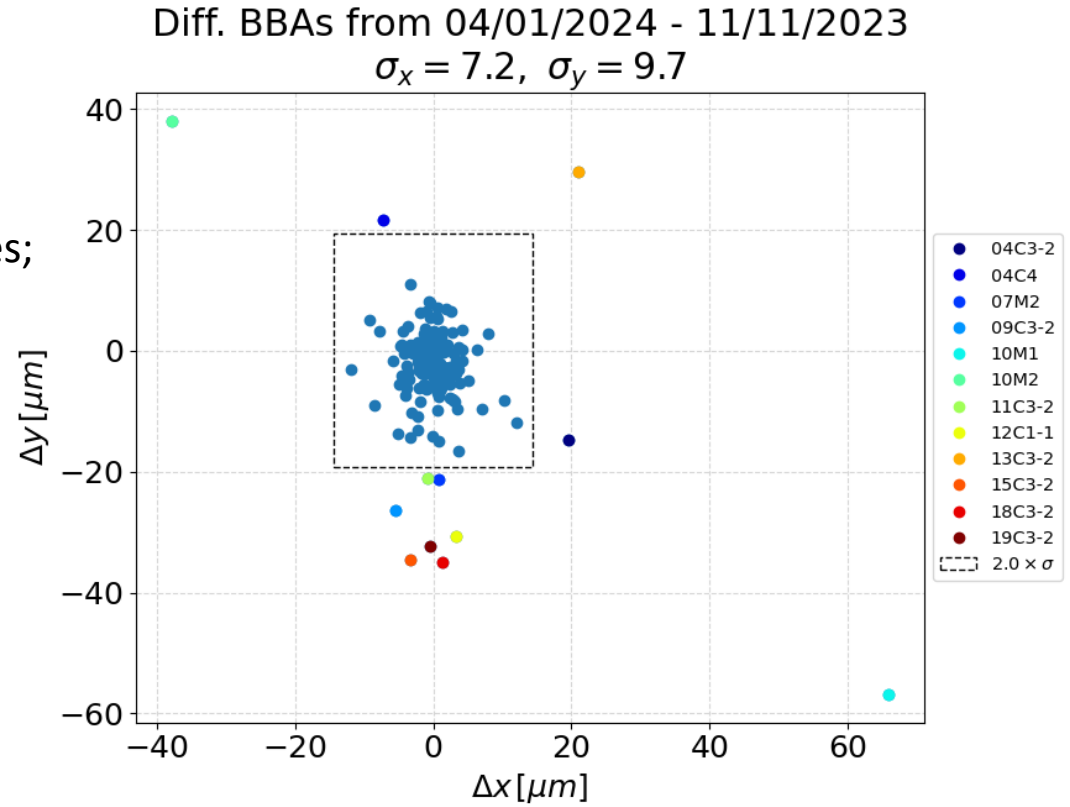
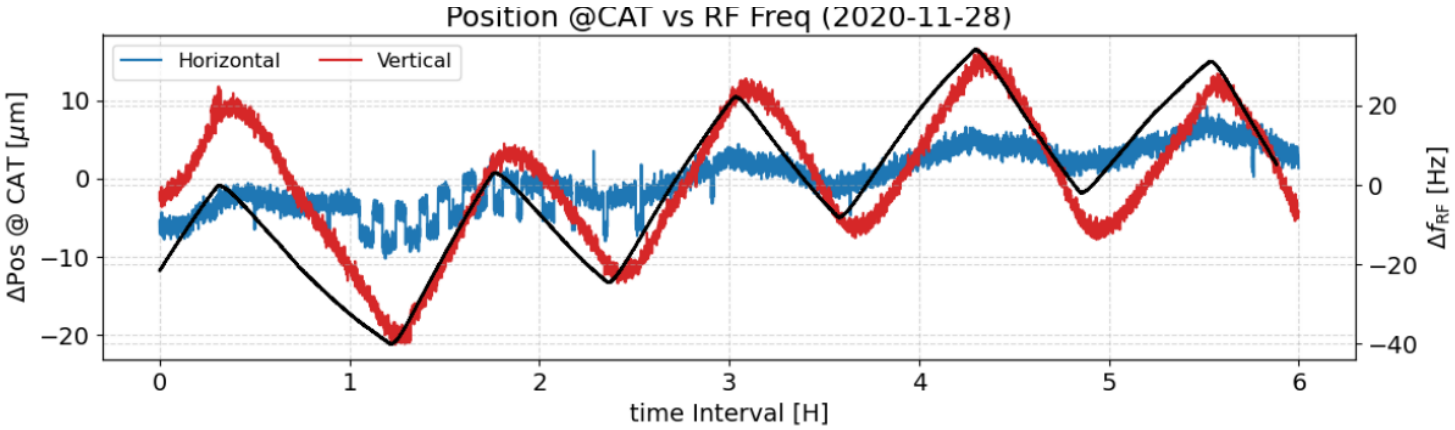
- Water well problem mitigated:
  - In early operation we noted the interference of a water well close to the building on beam position on the beamlines and on the ring circumference;
  - Problem was mitigated by changing the operation mode of the well;
  - Plans to de-activate the well are in progress;





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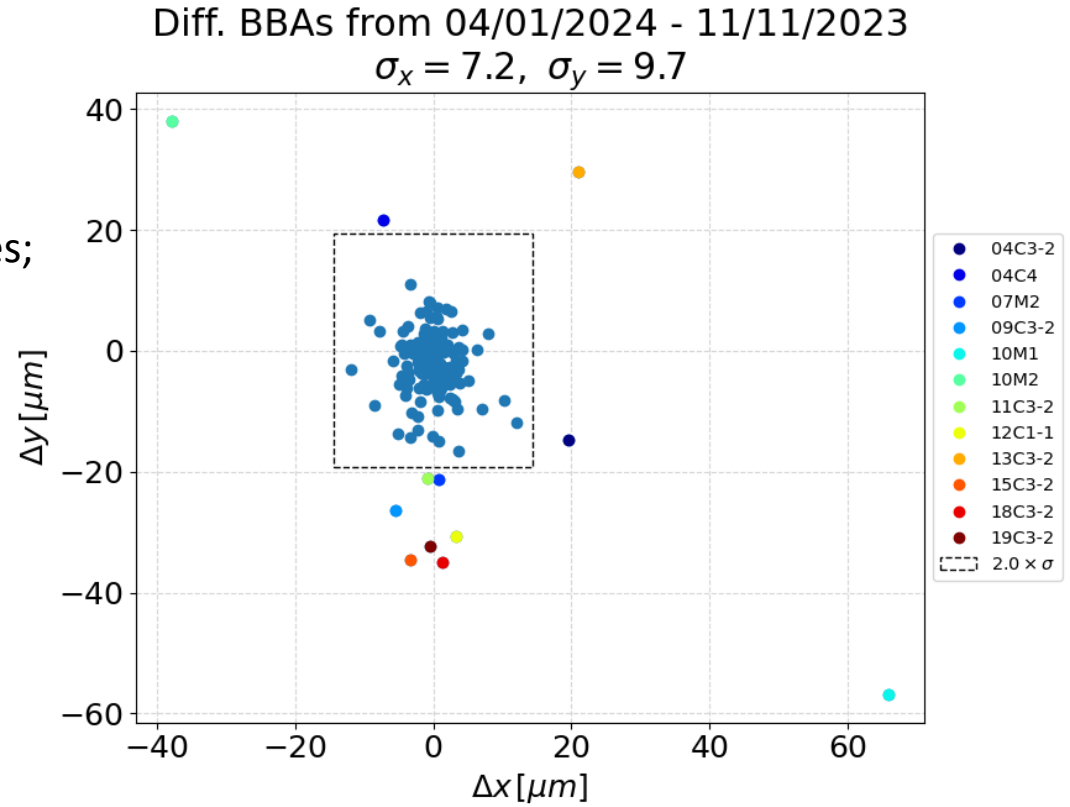
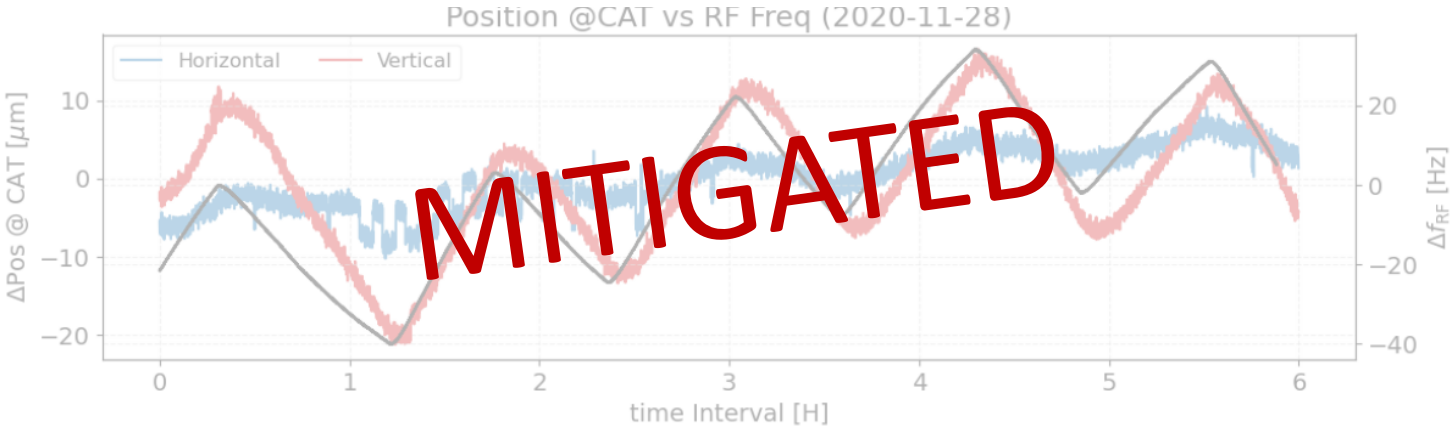
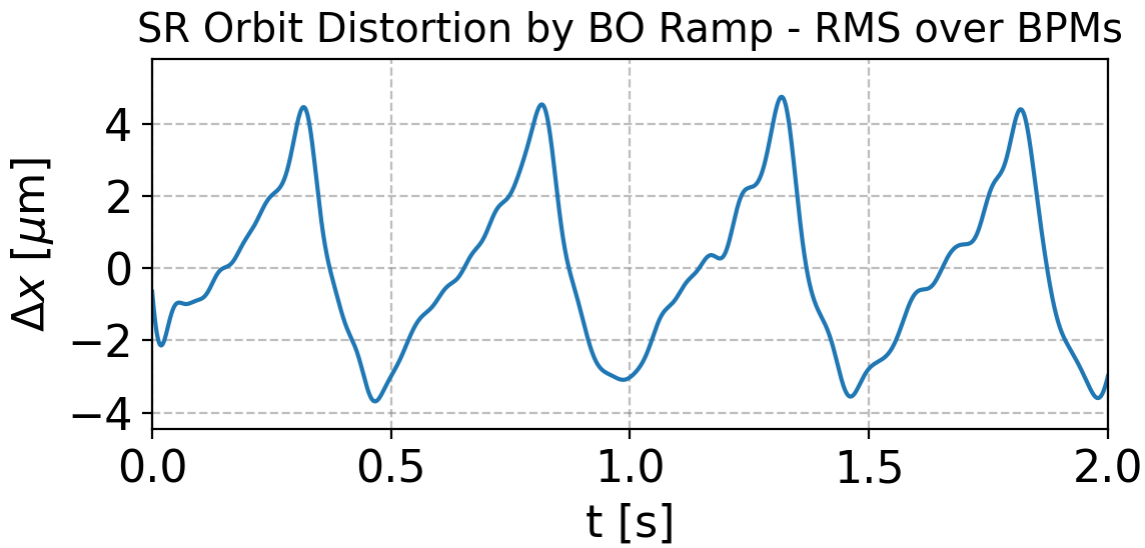


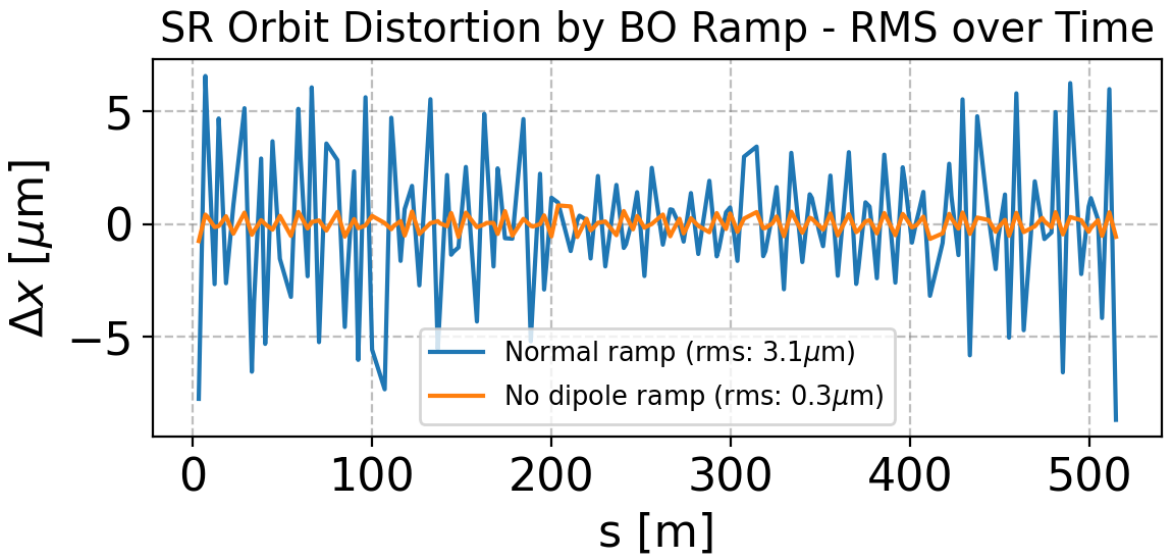


Mid-Term Stability (10^{-3} – 10^{3} Hz)

Booster Ramp (2 Hz) and Mains (60 Hz)

- Booster ramping in the same tunnel of SR:
  - In top-up operation mode, booster keeps ramping all day long;
  - Influence on the SR orbit comes mainly from Dipoles ramp;
  - Not sure whether from magnets or cables;
  - Booster RF also creates small noise on neighboring SR BPMs.





Courtesy: Murilo Alves

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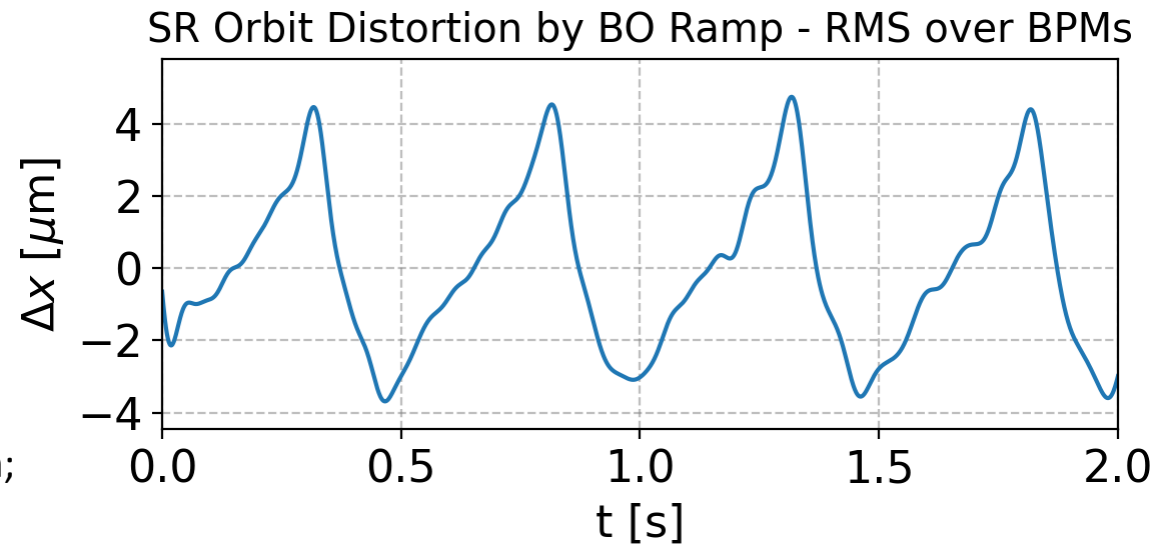
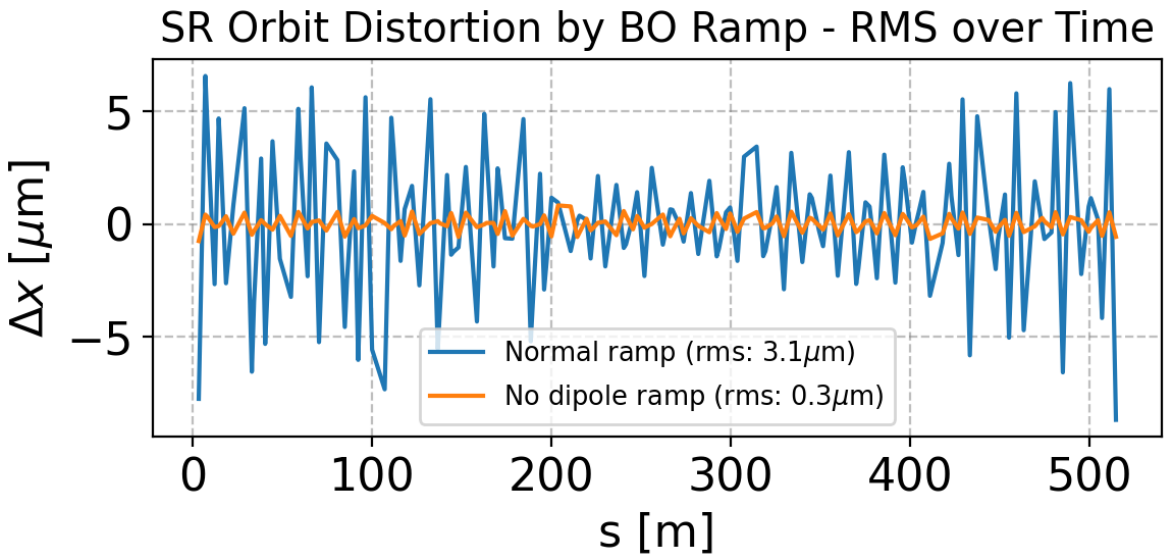
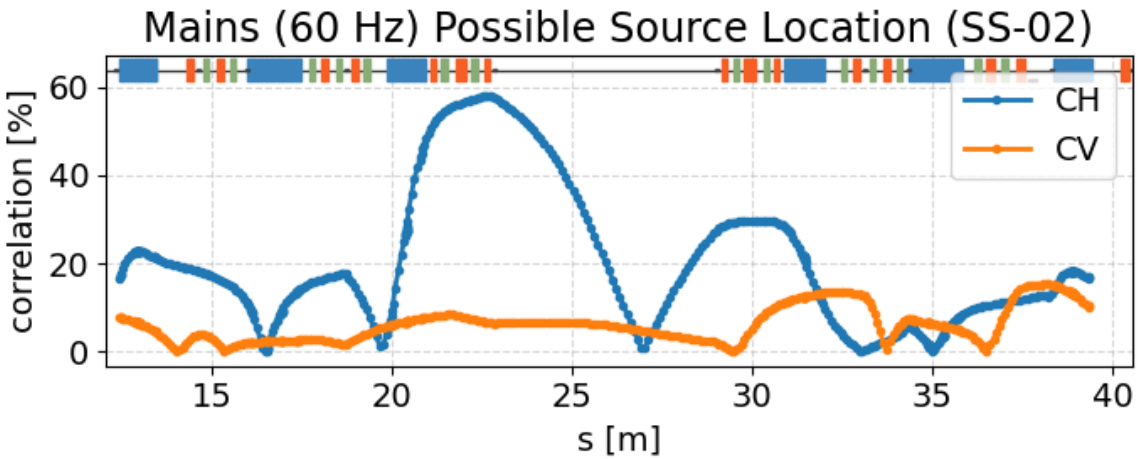
  - Influence on the SR orbit comes mainly from Dipoles ramp;
  - Not sure whether from magnets or cables;
  - Booster RF also creates small noise on neighboring SR BPMs.
- Mains perturbations:
  - Disturbance mainly on the horizontal orbit;
  - Magnets PS ripple ruled out by direct meas. and/or tests with beam;
  - Most likely cause is some grounding issue;
  - Most probable location is the SS of the RF cavity (Sector 02);
  - Before FOFB it was very detrimental to nano-focusing beamlines;
  - Currently it's not a problem, but still seen by these beamlines;







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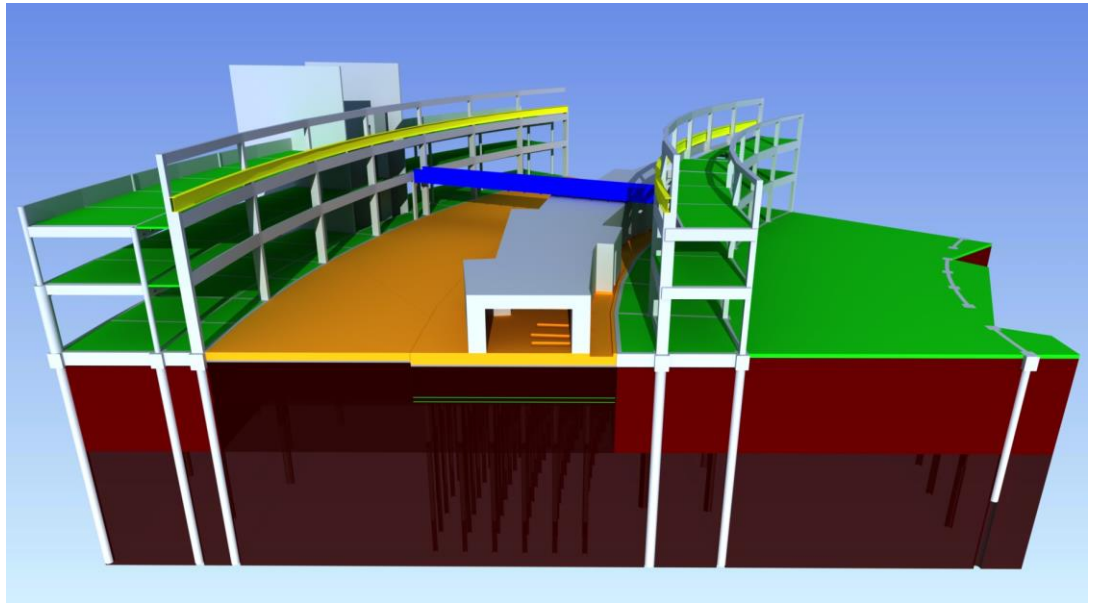
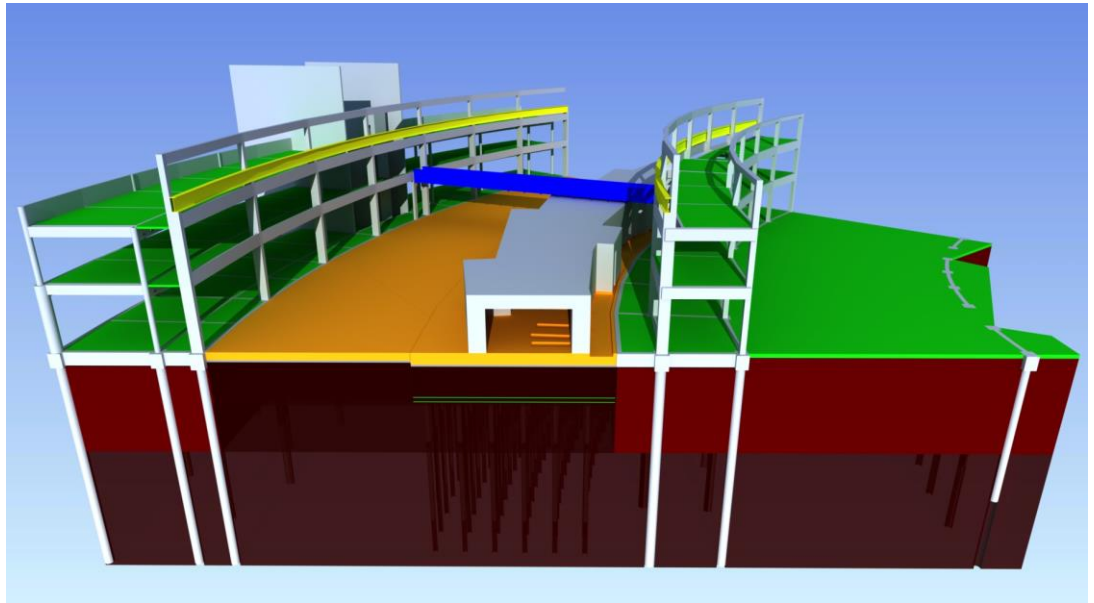
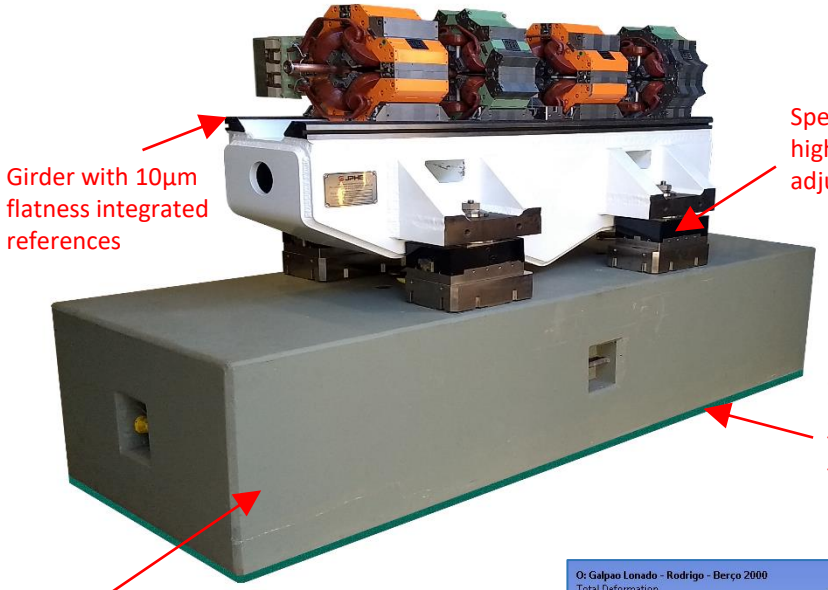
Vibrations

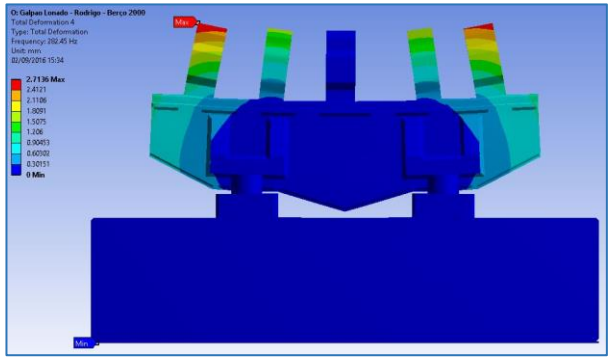


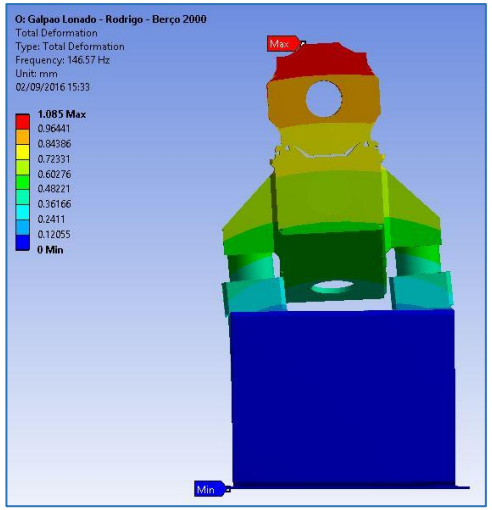
Vibrations

- High Stability Floor:
  - Binary structure for the high stability floor: A 90 (60) cm concrete slab on top of a more than 3m deep compacted layer of soil-concrete under the machine tunnel (experimental hall).
- Very rigid girder:
  - All machine componentes aligned by construction.









1st Vert. mode: 268 Hz

1st Horiz. mode: 152 Hz

Measured Values

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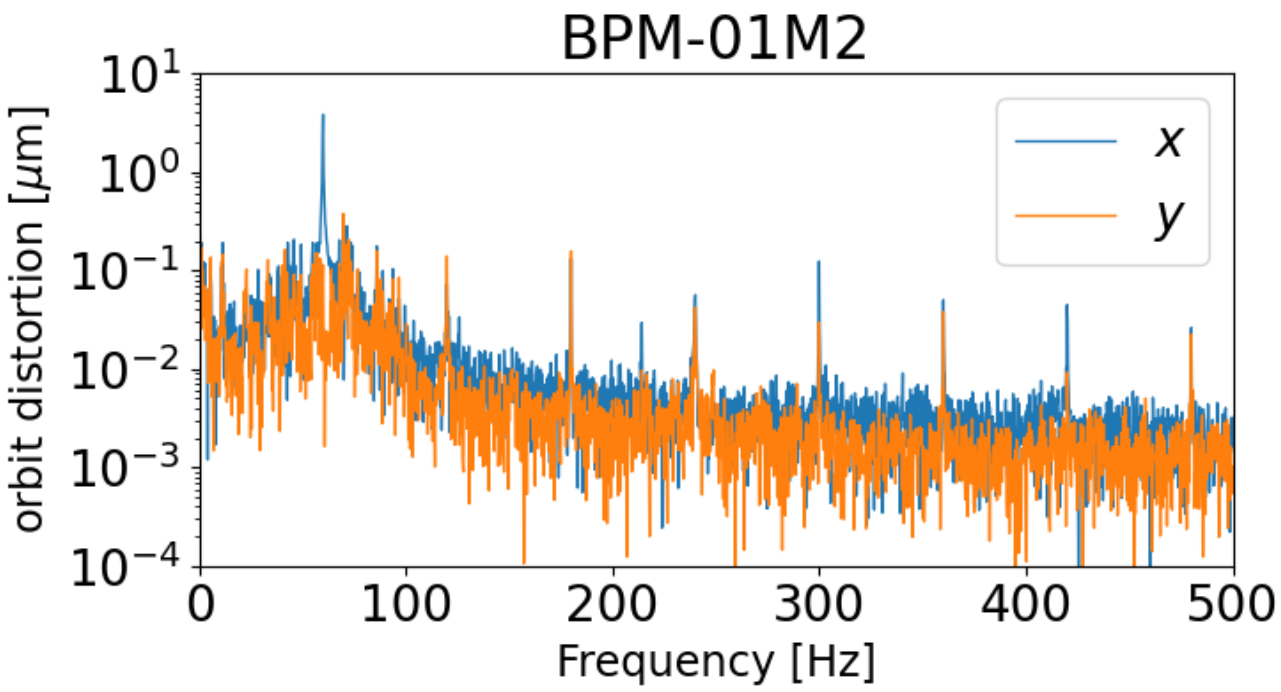

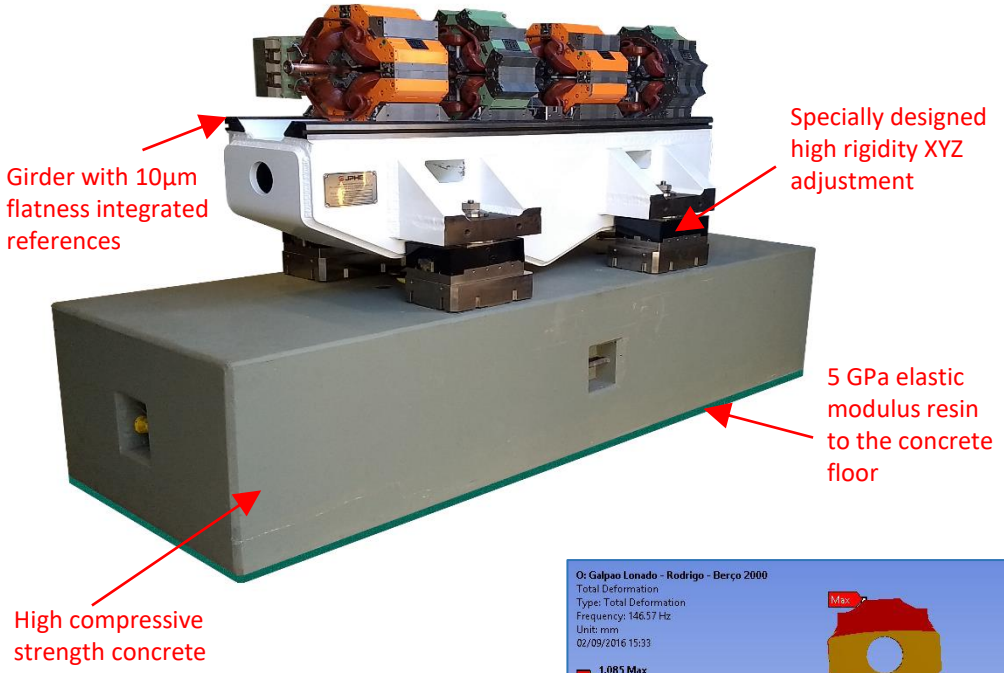

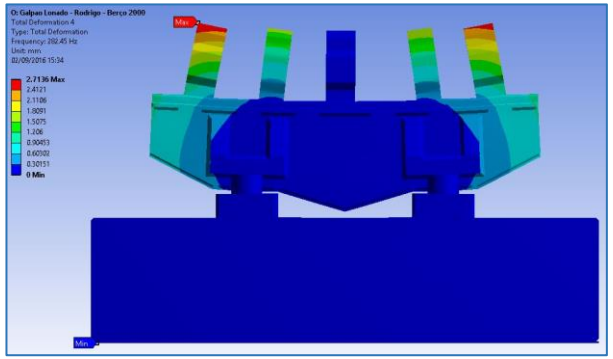

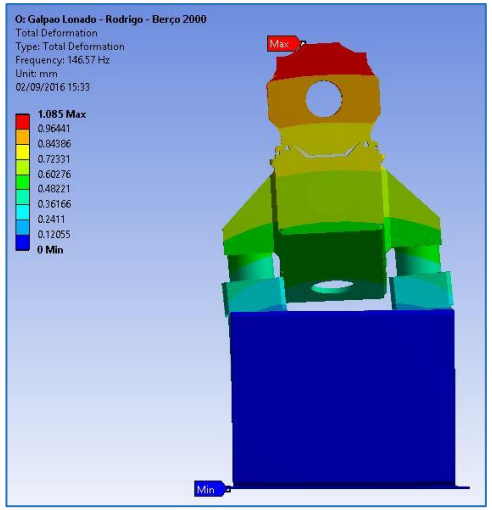

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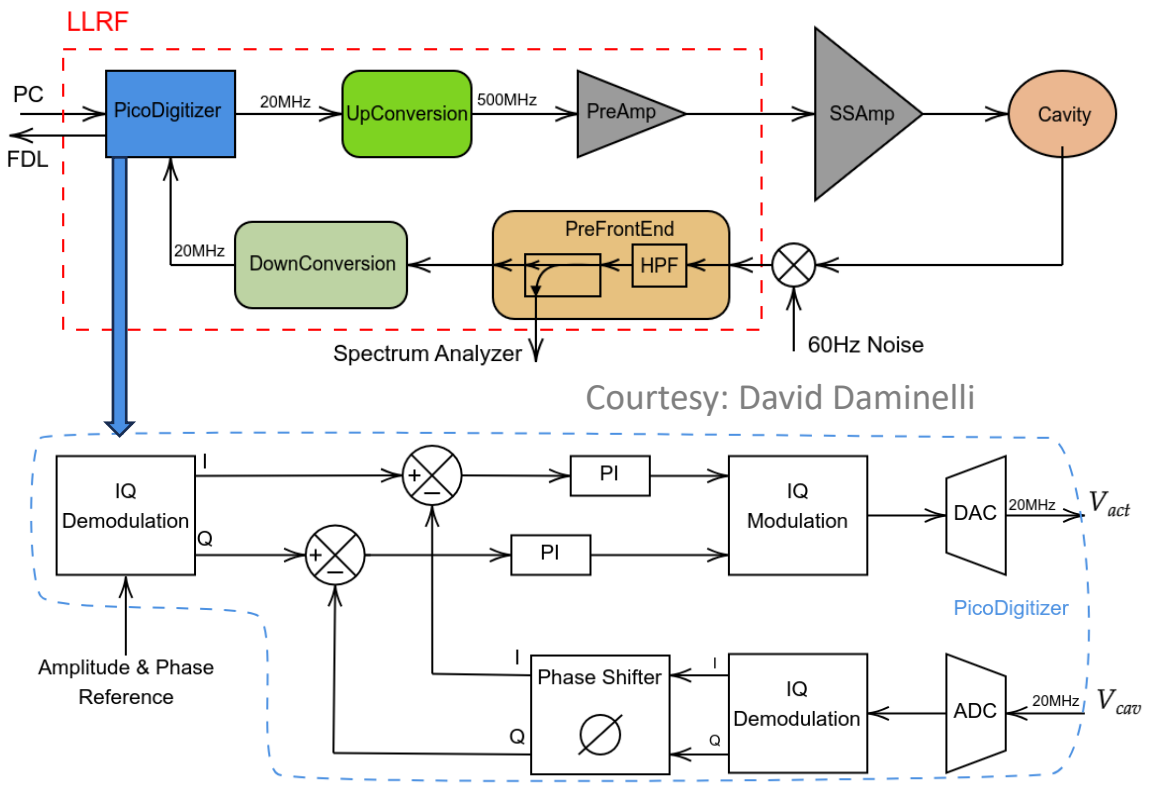
RF Plant perturbations



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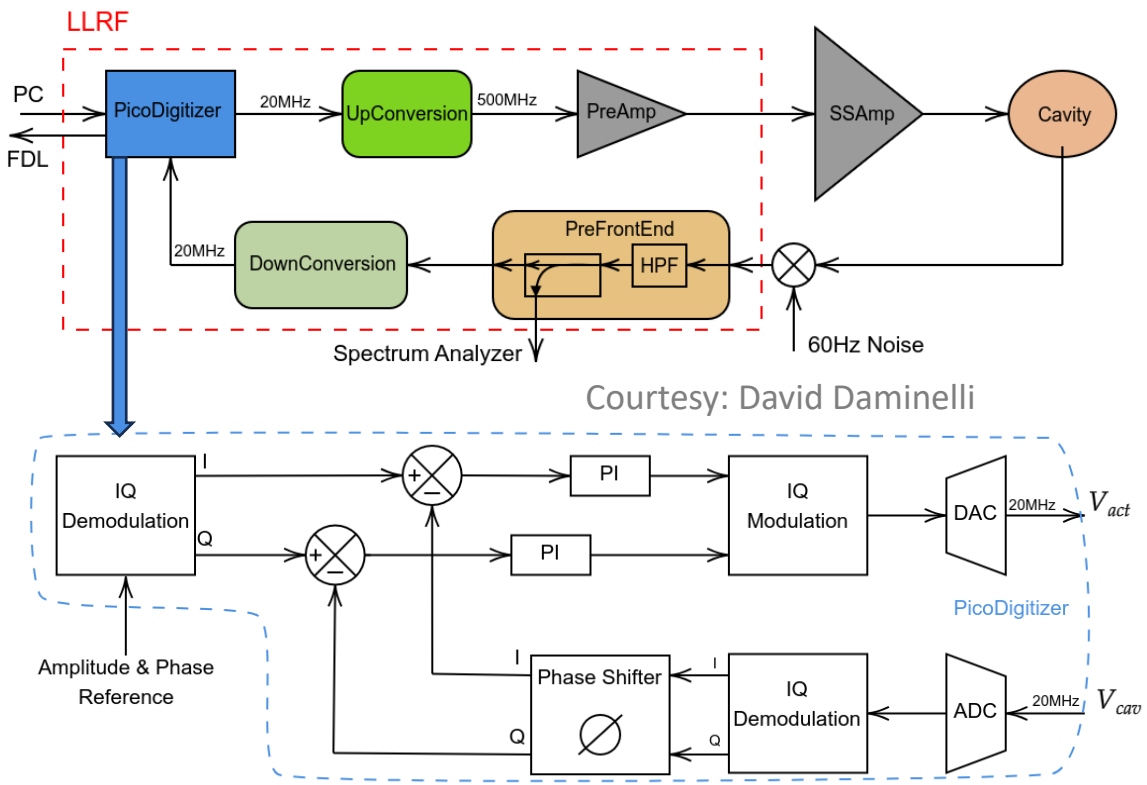
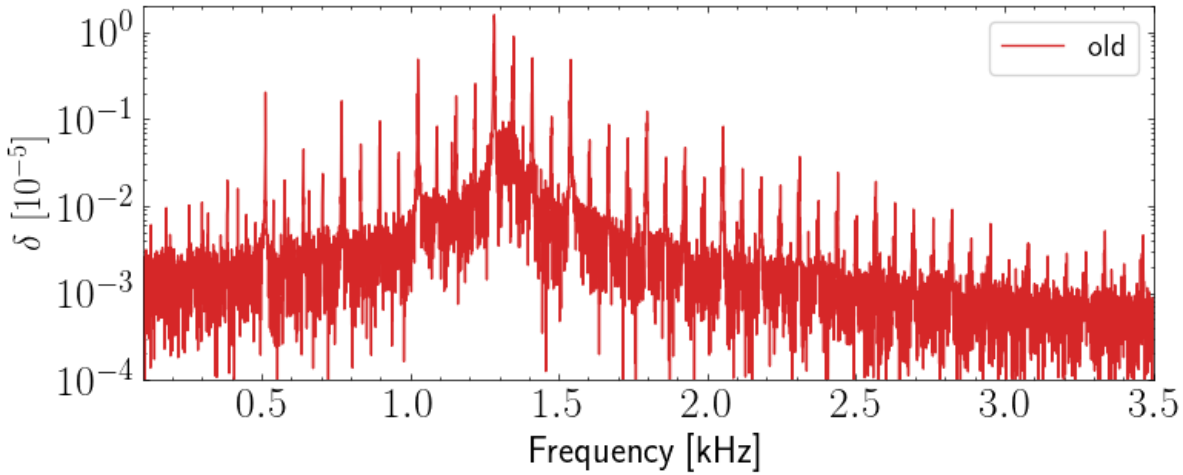
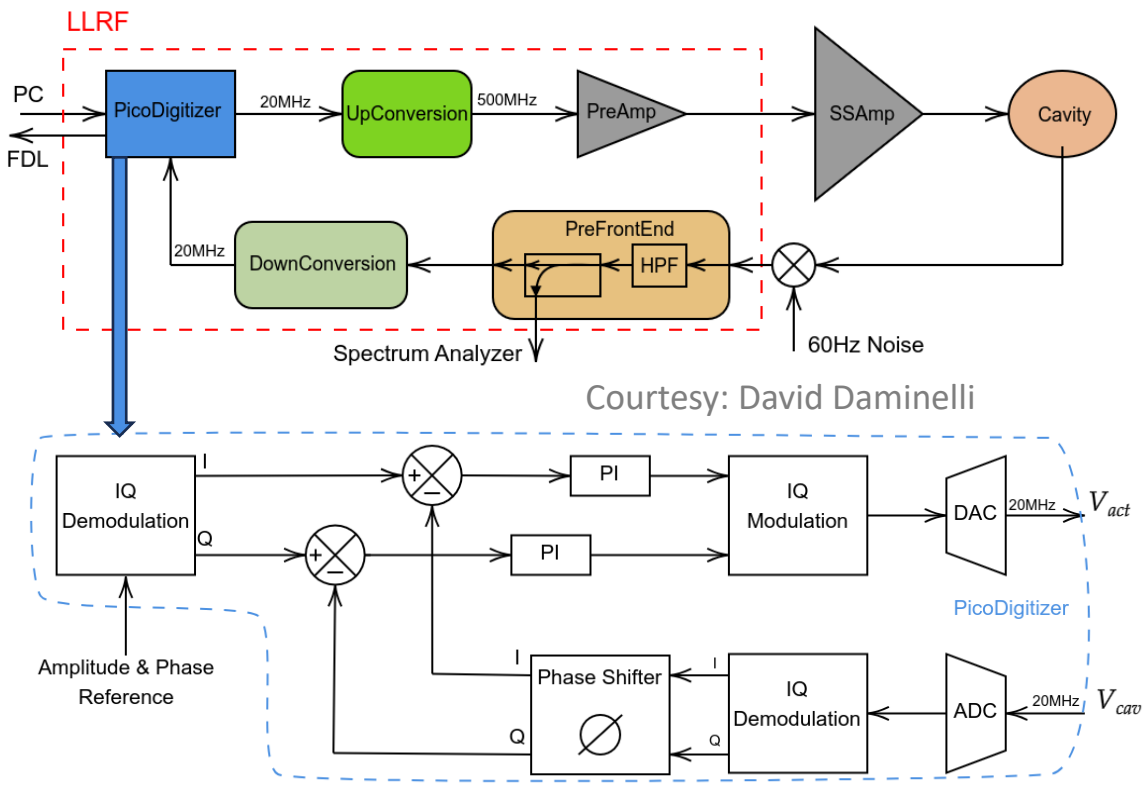


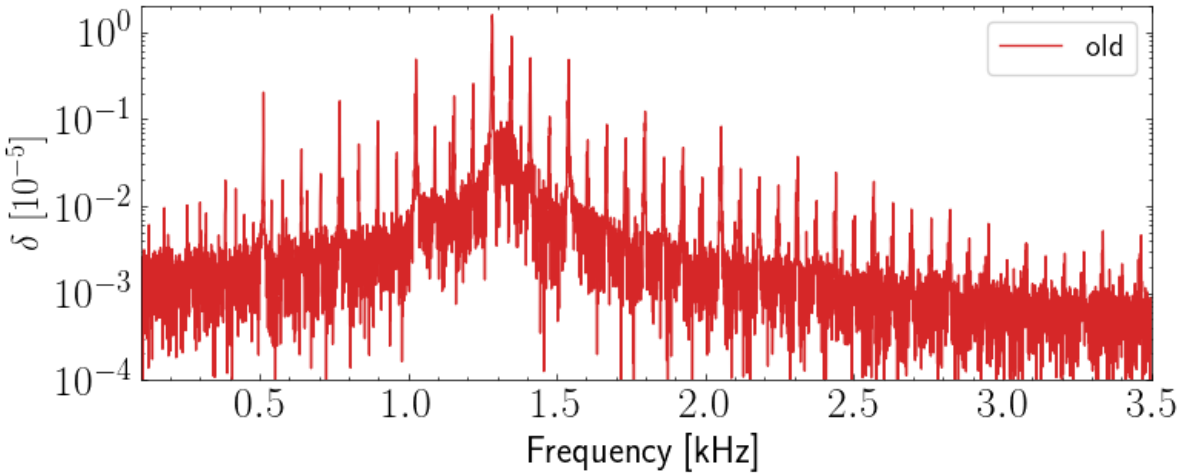
Courtesy: David Daminelli



RF Plant perturbations

- Until 2023 LLRF operated with very low PI gain (bw < 20 Hz):
  - No control of Robinson detuning;
  - Perturbations on the beam at n x 64Hz (created by DAC).
- First attempts to increase gain:
  - Perturbations of 60Hz, not present with low gains;
  - Problem in the feedback branch.
- Operation with high PI gain (bw > 3kHz):
  - Only possible after fixing the 60Hz with a high pass filter;
  - And re-evaluating how to adjust phase shifter;
  - Phase stability ~0.02° and energy stability < 2% of σ_δ.





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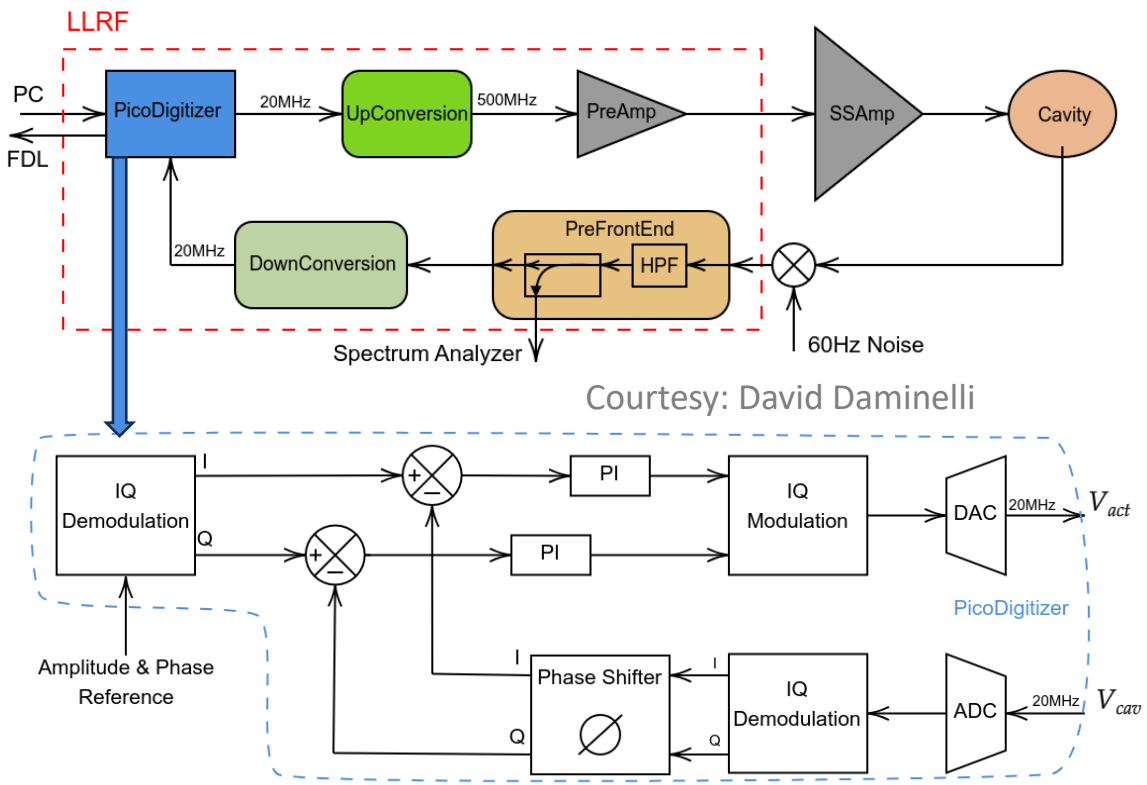

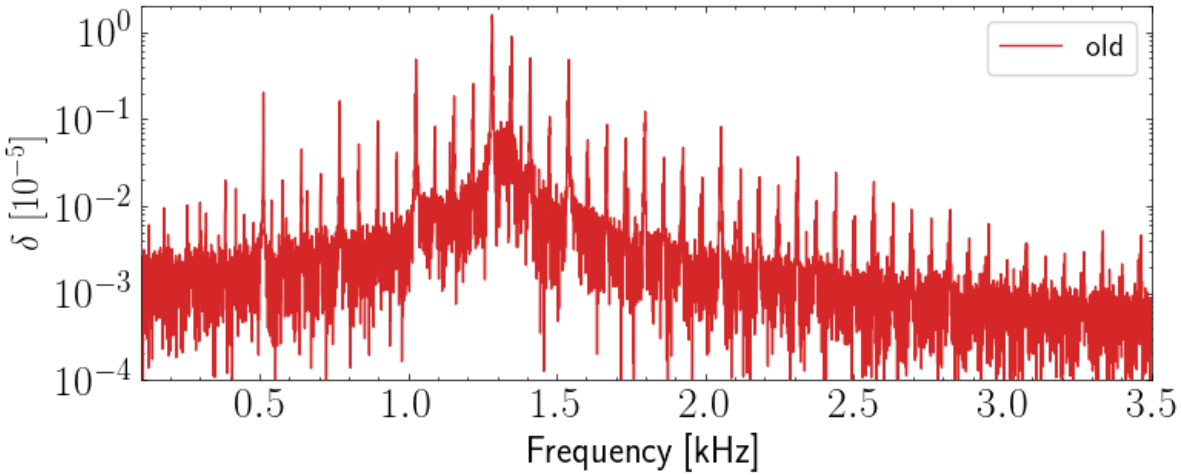

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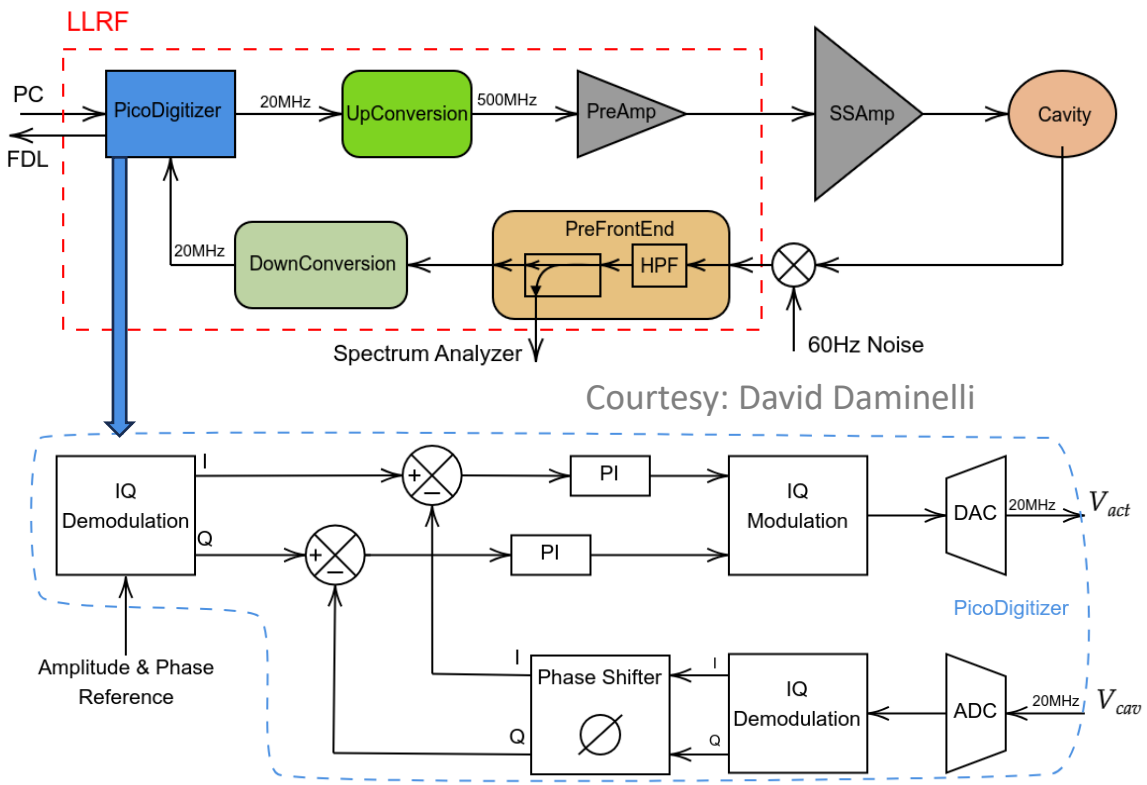

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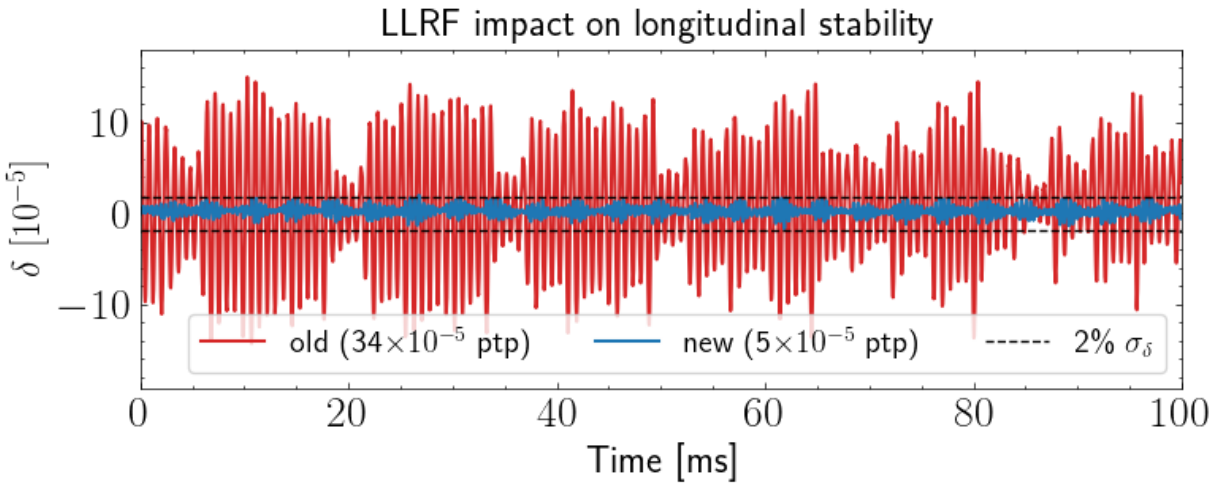
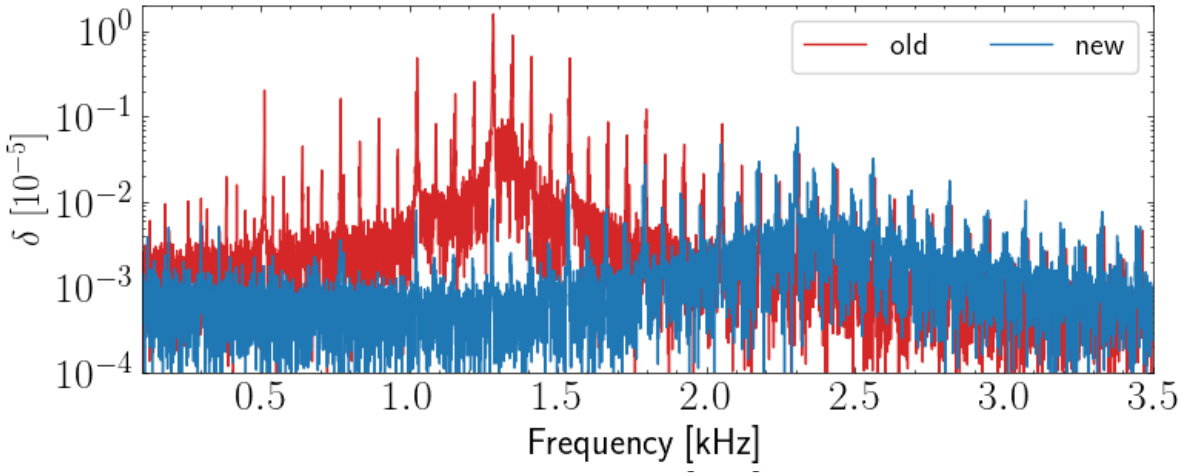
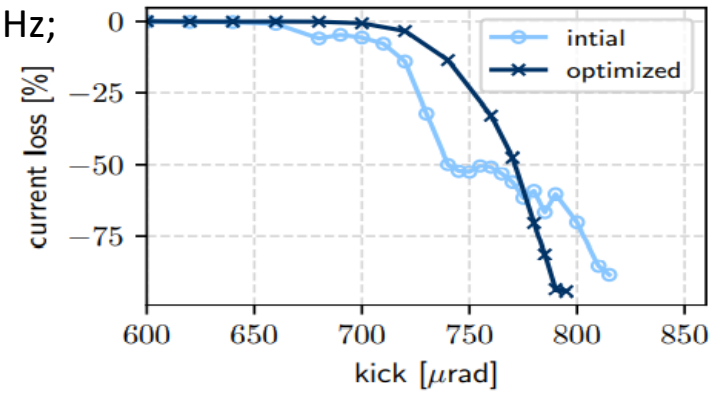




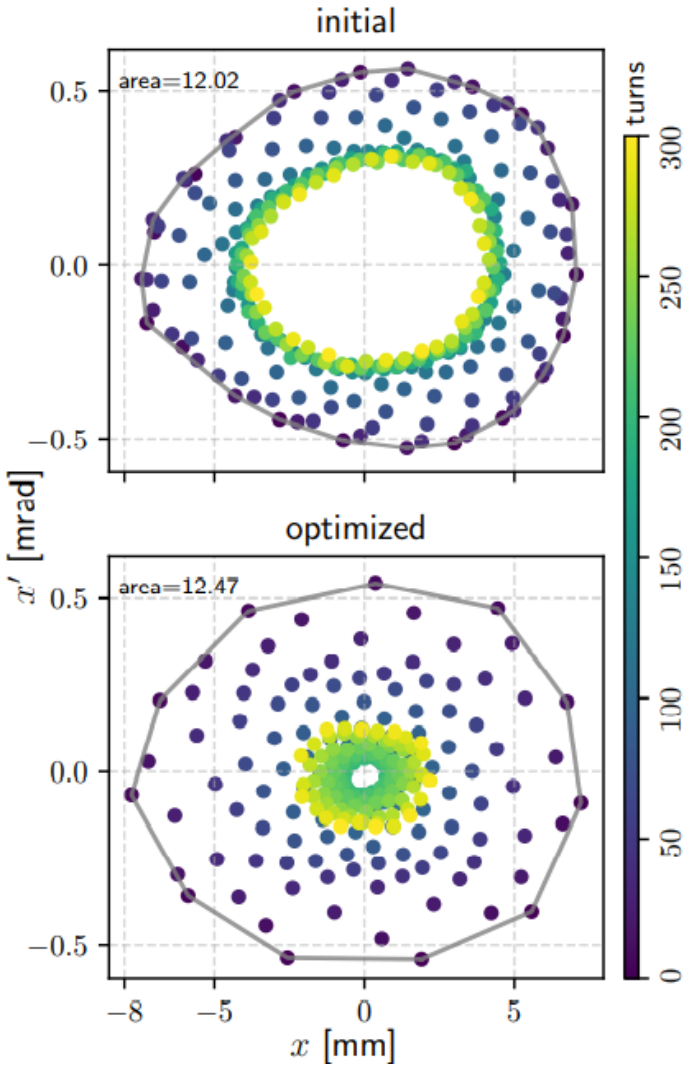
Change of Working Point

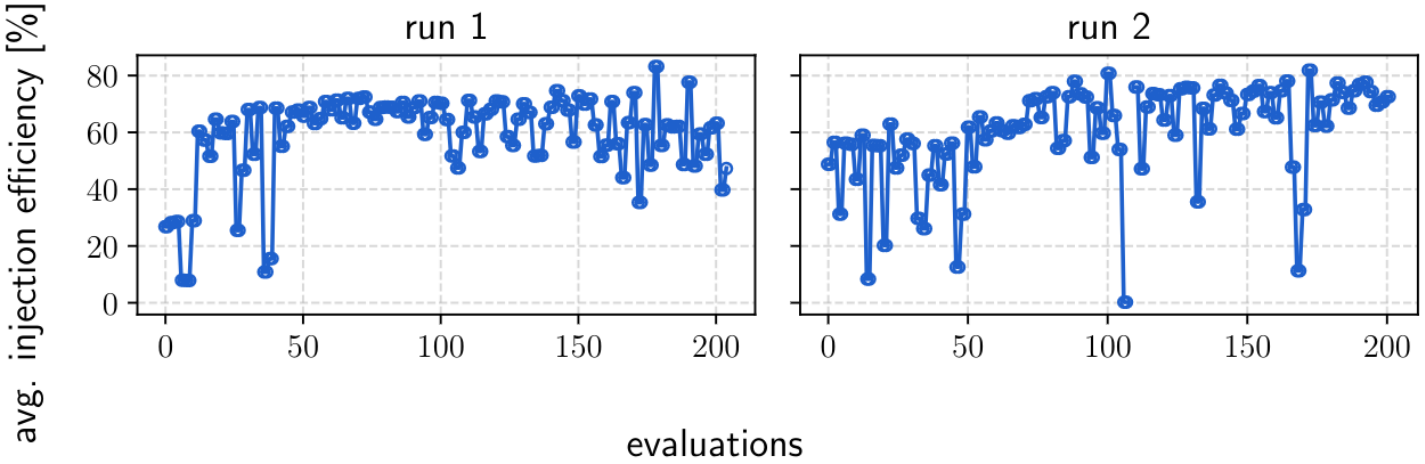
- Change of working point to higher fractional tunes to reduce orbit amp. factor;
- Old tunes: (49.07, 14.14) New tunes: (49.16, 14.22);
- Needed Non-linear Dynamics optimization:
  - Robust Conjugate Direction Search (RCDS)
    - Collaboration with Xiaobiao Huang (SLAC)
  - Objective: avg. injection efficiency of 5 pulses @ 2Hz;
  - Noise-sigma ~ 1%
  - Optimization knobs:
    - 6 achromatic + 15 chromatic familes
    - Combination of sextupoles in 13 knobs and 17 knobs
  - Injection efficiency > 95%;
  - No impact on lifetime;

Kick resilience



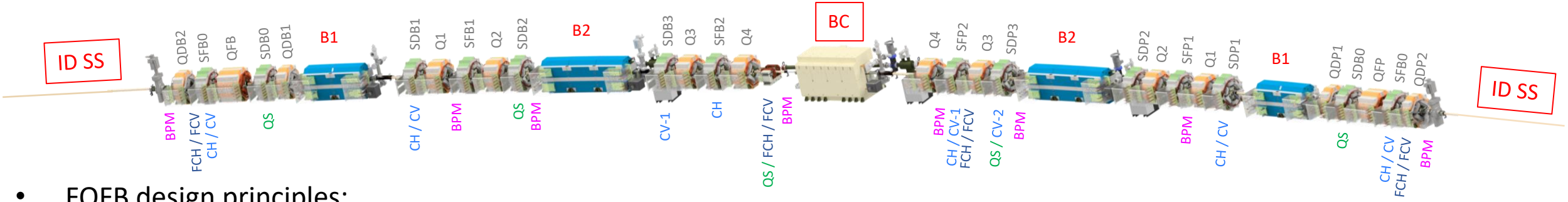
Phase space measurement





Courtesy: Matheus Velloso

Fast Orbit Feedback (FOFB)



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  - 2 BPMs, 2 FCH, 2FCV per source point (SP) → angle and pos. stability at SPs;

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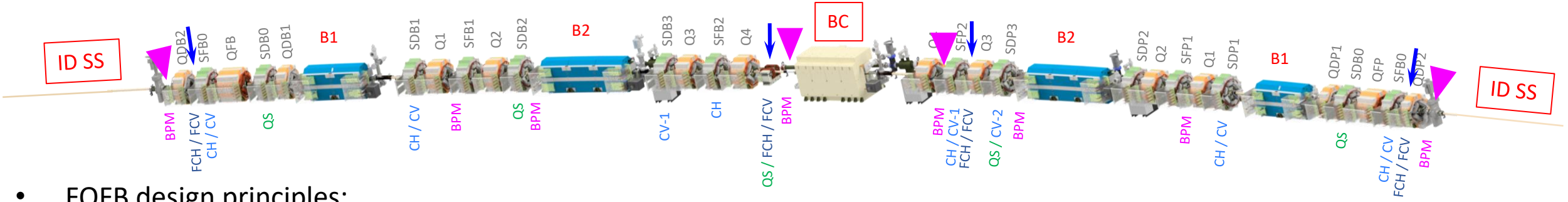

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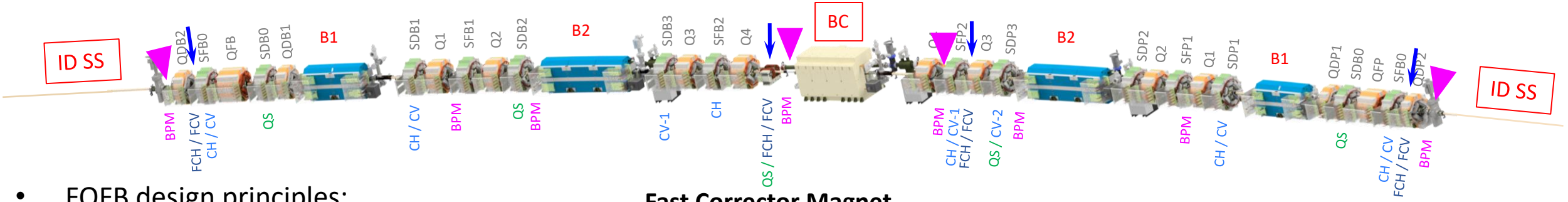
	SOFB	FOFB
BPMs	160	80 (subset of SOFB)
H Cor	120	80 (dedicated)
V Cor	160	80 (dedicated)

FOFB BPM

FAST CORRECTOR

Fast Orbit Feedback (FOFB)



- FOFB design principles:
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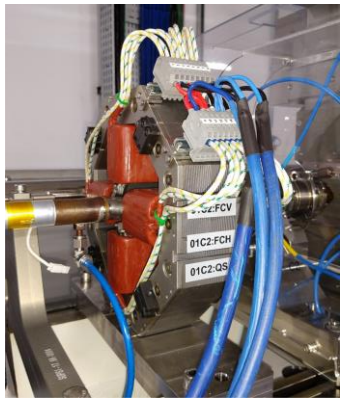
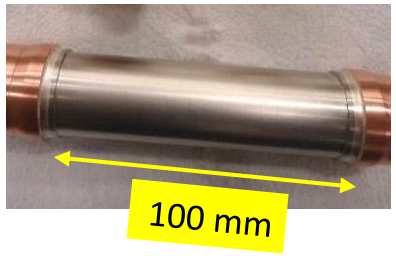
  - High bandwidth actuators (~20kHz);

Fast Corrector Magnet



- 0.5 mm FeSi steel lamination
- L = 3.3/6.6 mH (normal/skew)
- R = 80/180 mΩ (normal/skew)
- Deflection @ 3 GeV: 30 µrad

0.3 mm SS vac. chamber



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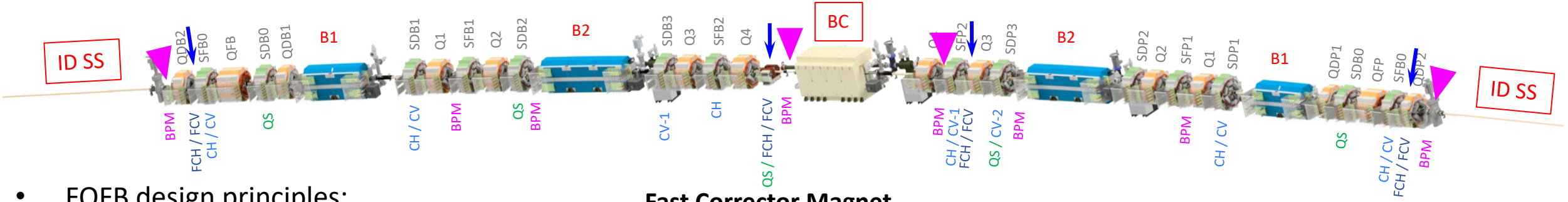

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  - High bandwidth actuators (~20kHz);
  - Highest possible update rate (48kHz, 20us): ideally data distribution (~14us) should dominate delay (not achieved, but close);
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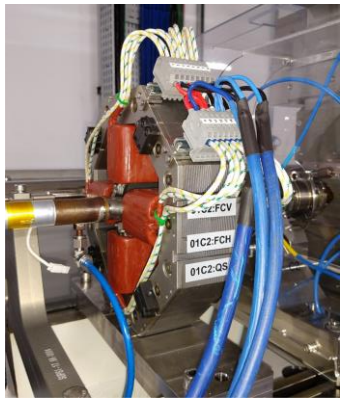

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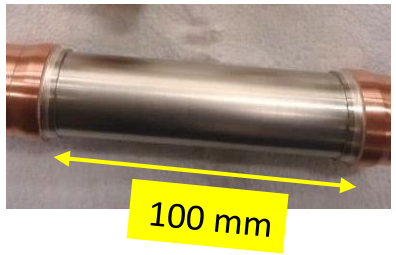

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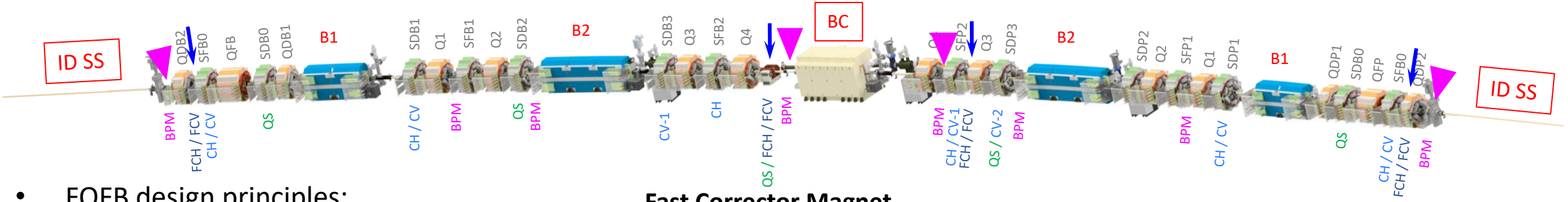

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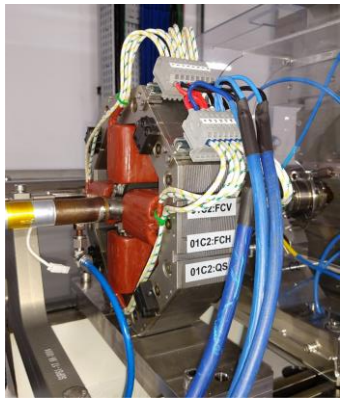
  - High bandwidth actuators (~20kHz);
  - Highest possible update rate (48kHz, 20us): ideally data distribution (~14us) should dominate delay (not achieved, but close);
  - Real-time processing in hardware (FPGA) and integration as tight as possible;

- Complementary to **SOFB @ 10 Hz**
  - Partial download (4%) of FOFB kicks at each SOFB iteration;
  - No need to update FOFB ref. orbit.

Fast Corrector Magnet



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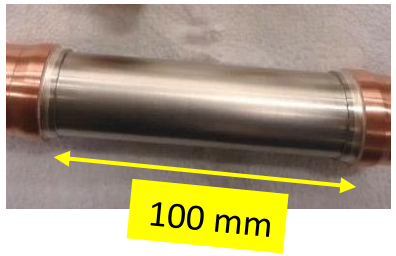

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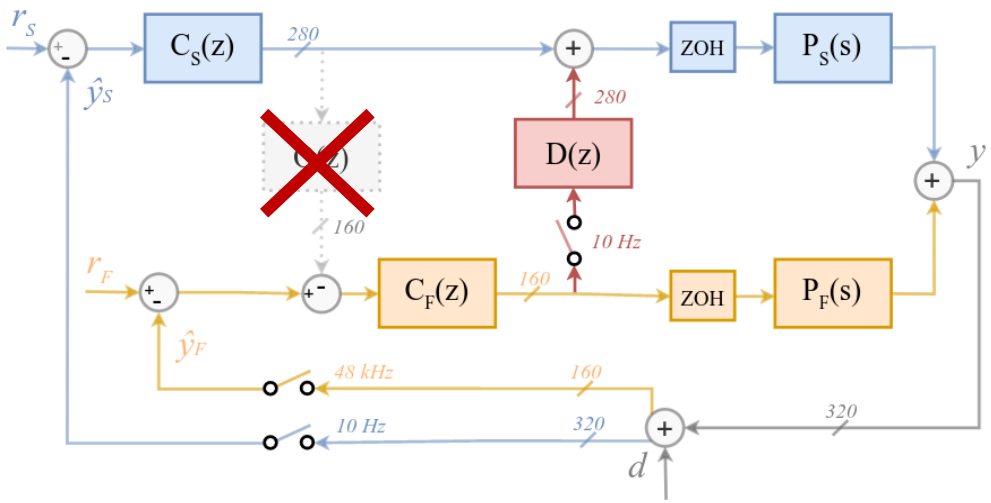
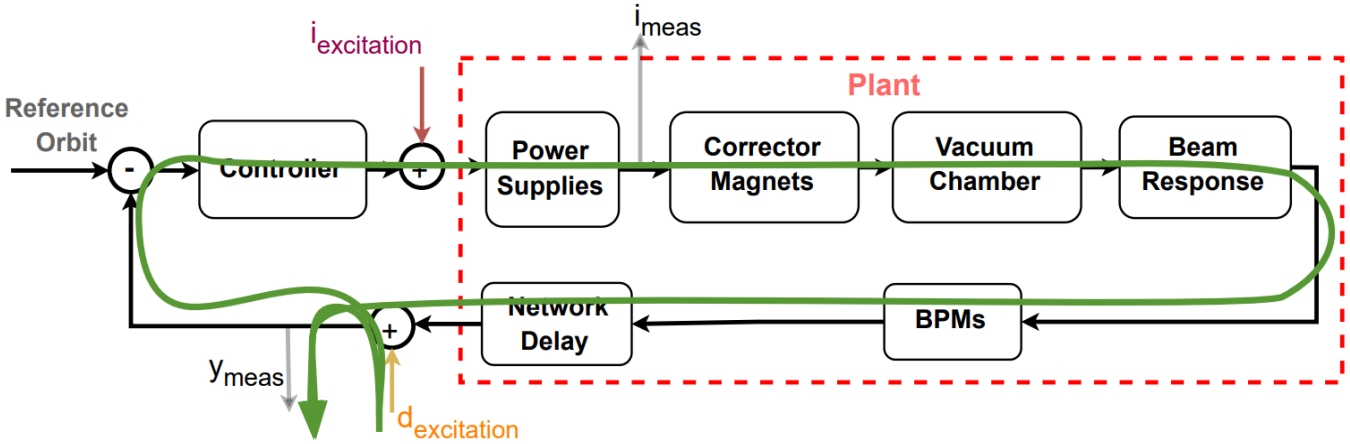


FOFB System Identification – Closed Loop

- Measured loop delay (step on BPM signal to fast corrector current change): **51 µs**



Courtesy: Daniel Tavares and Erico Rolim

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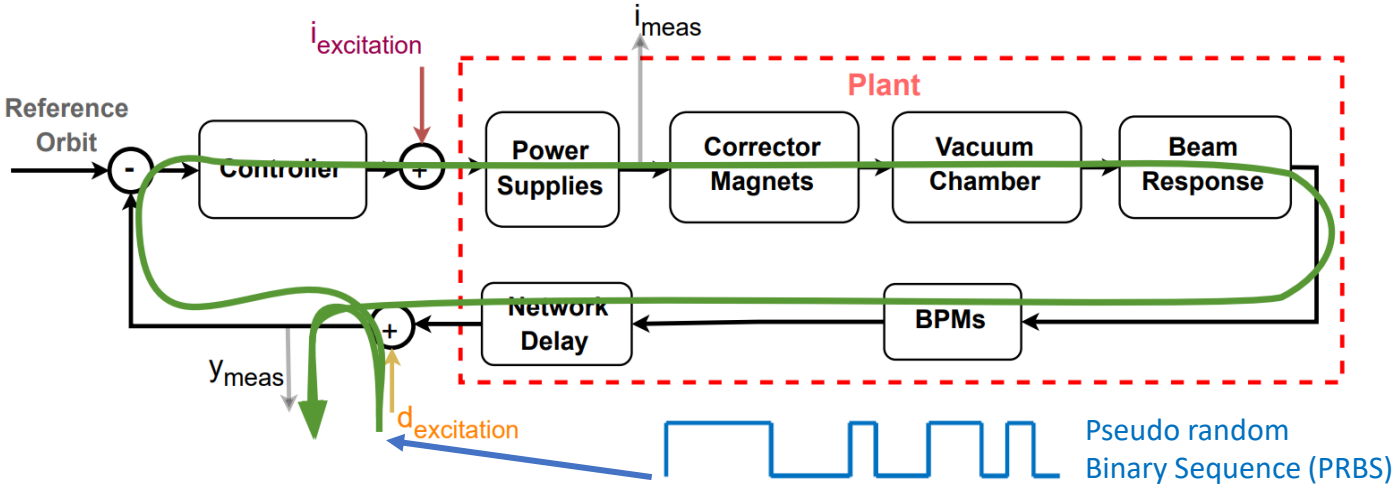

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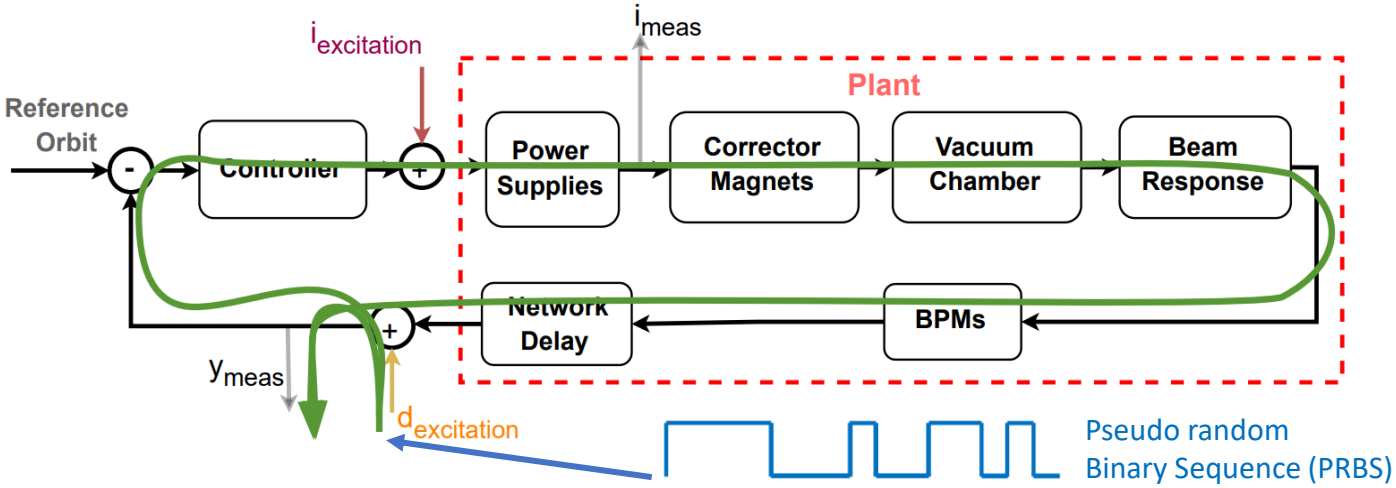
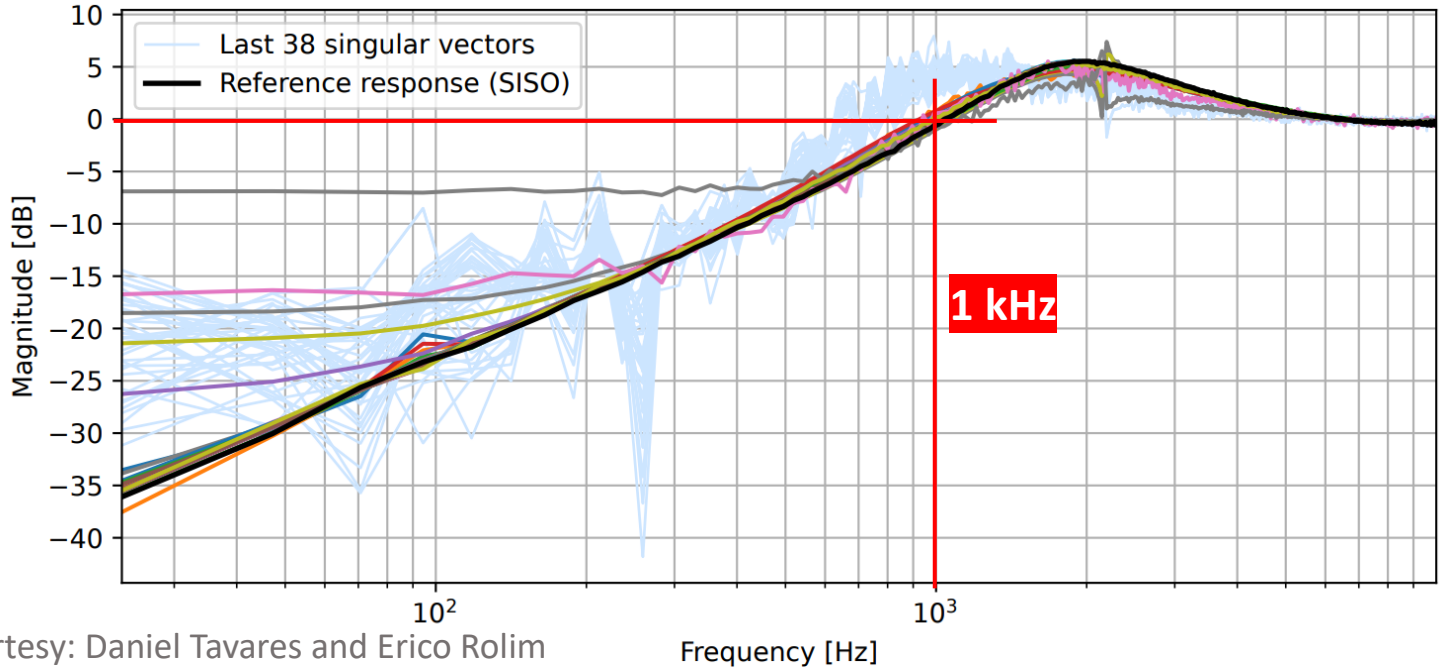
- First 118 dirs.:
  - crossover at 1kHz;
  - peak ~5.5dB.
- Similar to SISO with same gain and delay;
- Last 38 dirs. saturated actuators and could not be measured properly;
- Analysis of off-diagonal terms still missing.



Disturbance rejection response per direction



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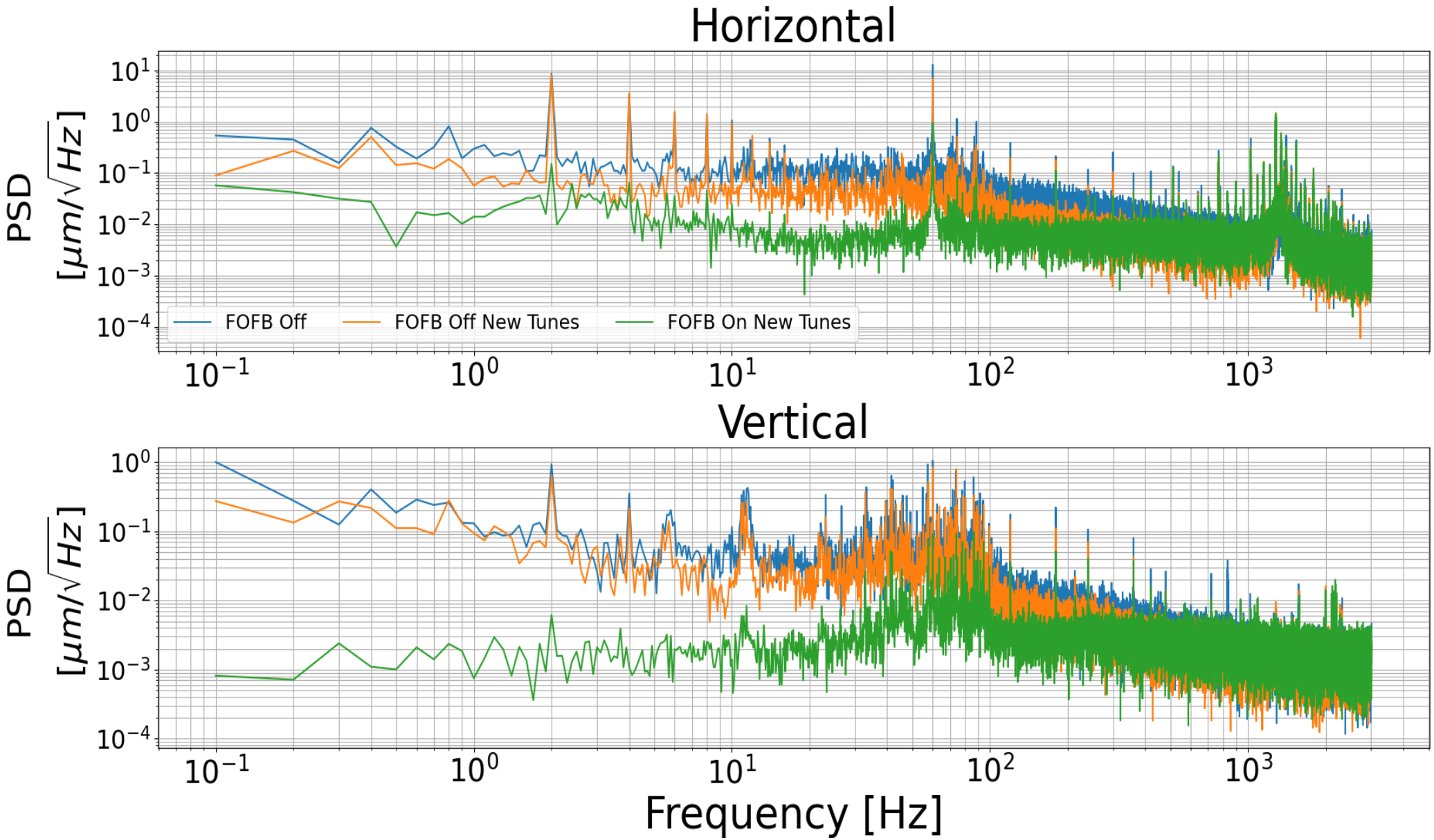
FOFB Performance (Oct 2023)



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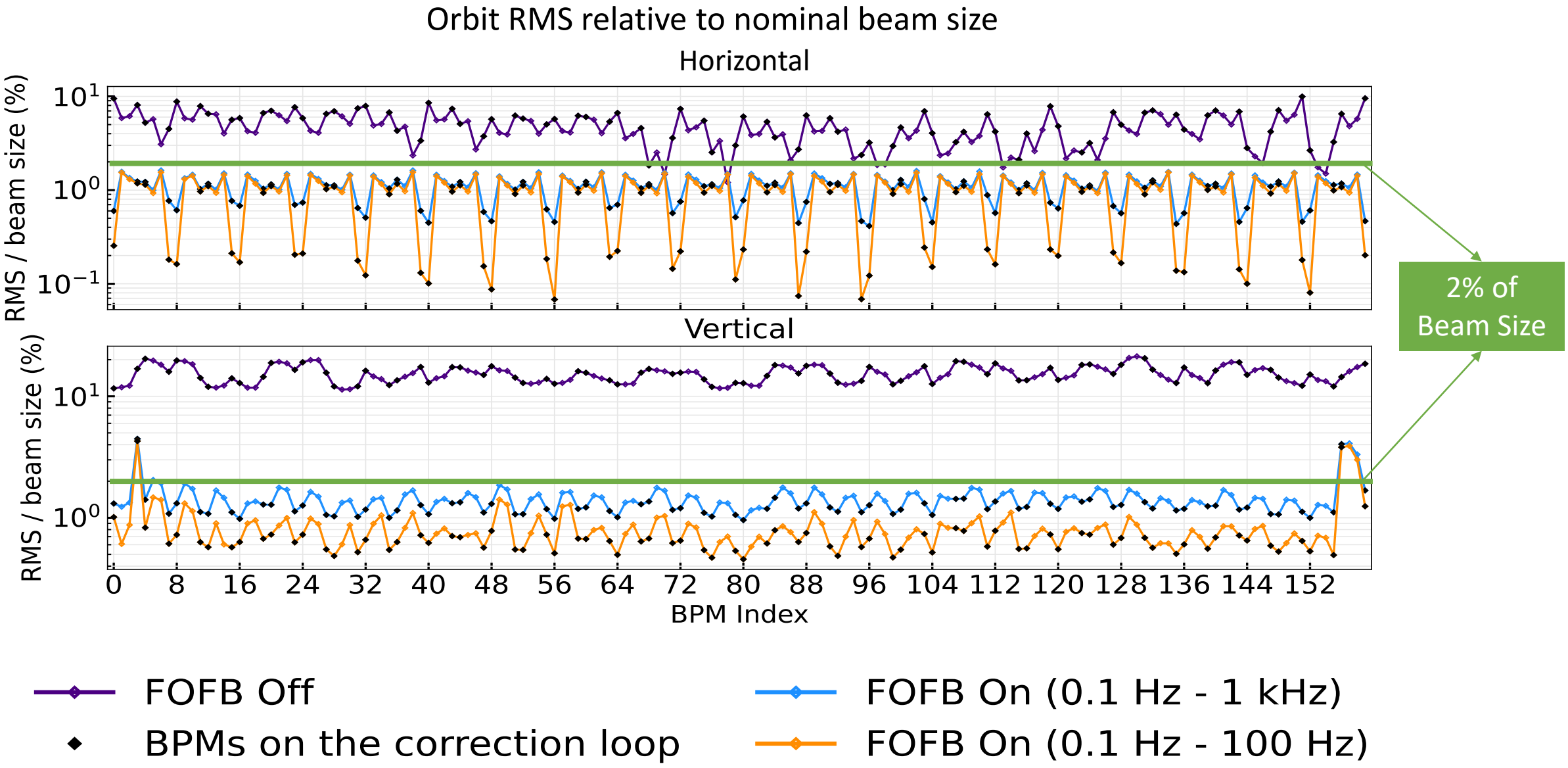

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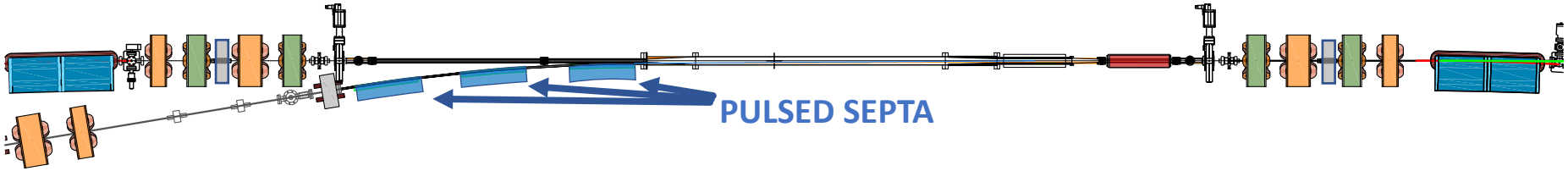
Short-Term Stability (10^3 Hz – Turn by Turn)

Injection Perturbations: Septa Leak Field



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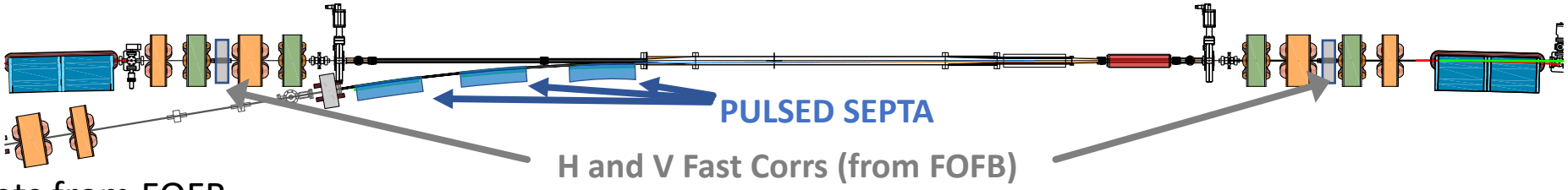

- Attempts with passive shielding were not enough;
- FF using fast corrector magnets from FOFB (~20kHz bandwidth);
- FOFB PSs do not have waveform functionality -> PS from SOFB correctors had to be used;
- Low PWM frequency (48kHz):
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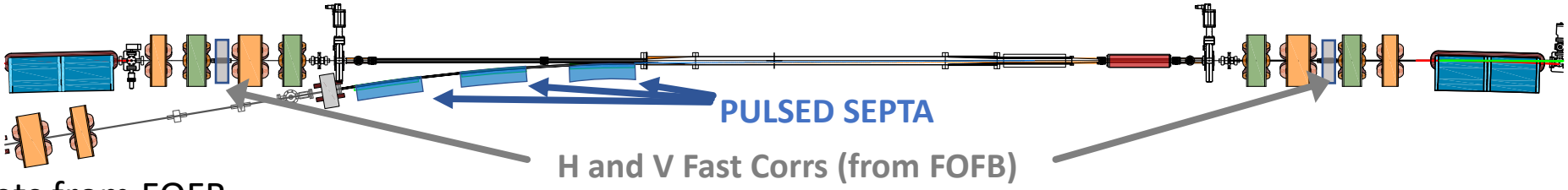

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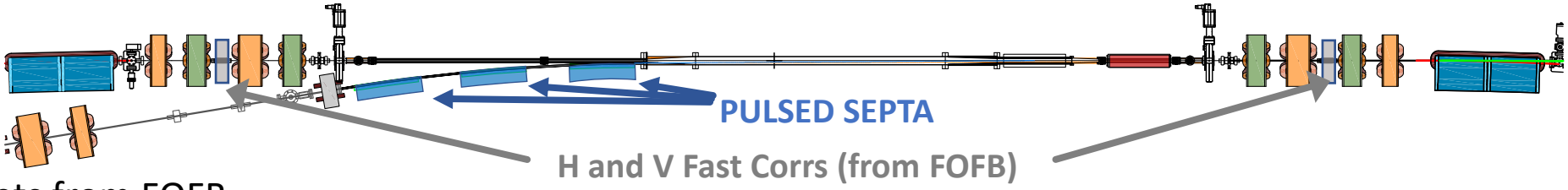

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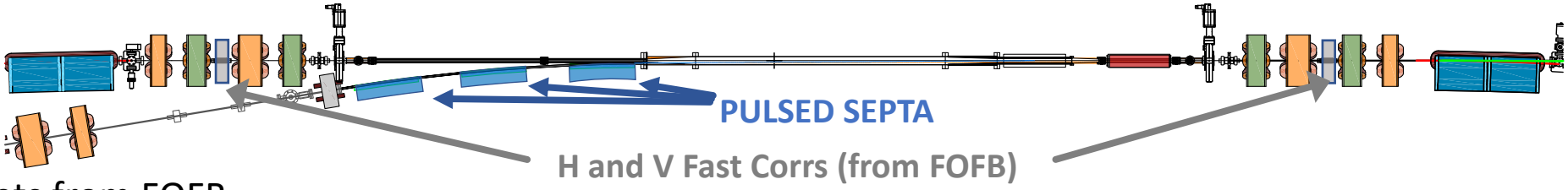

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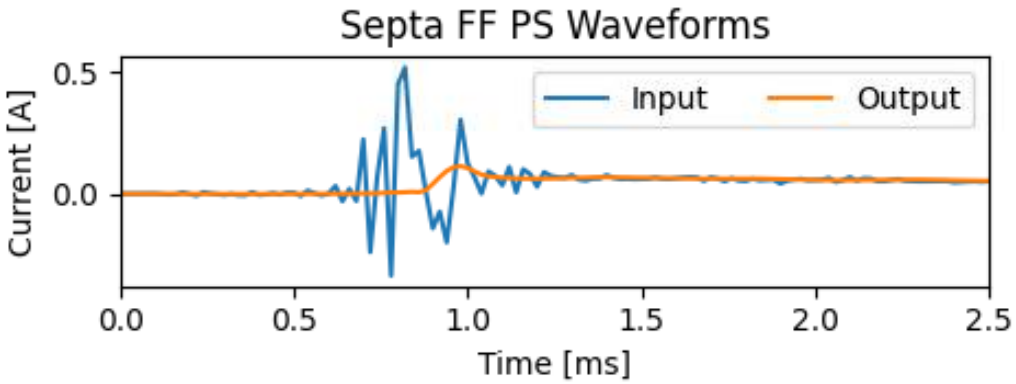

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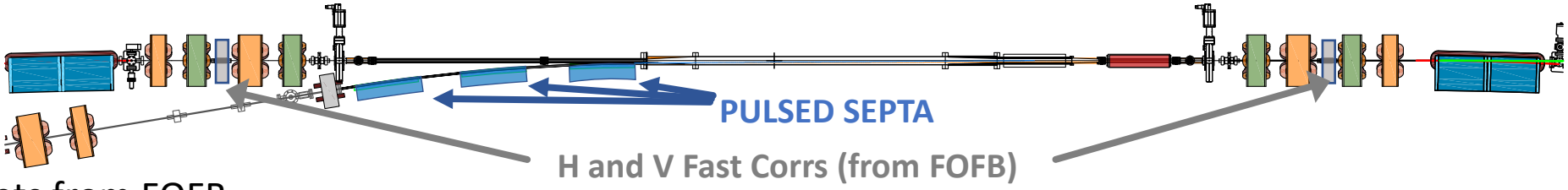

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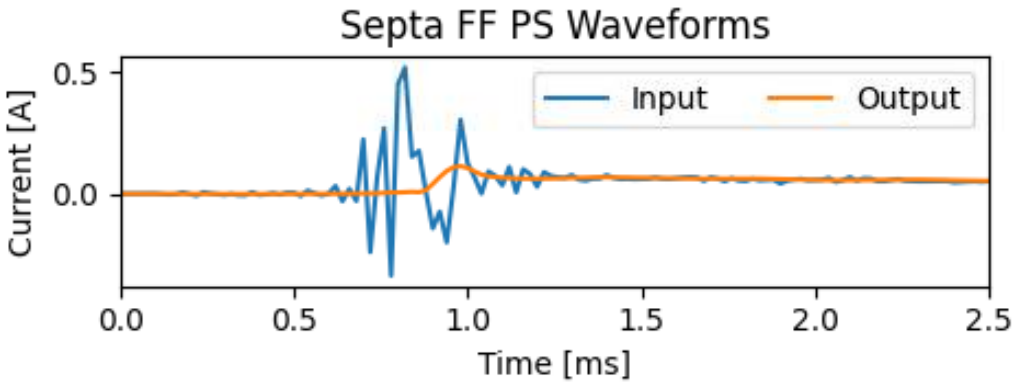

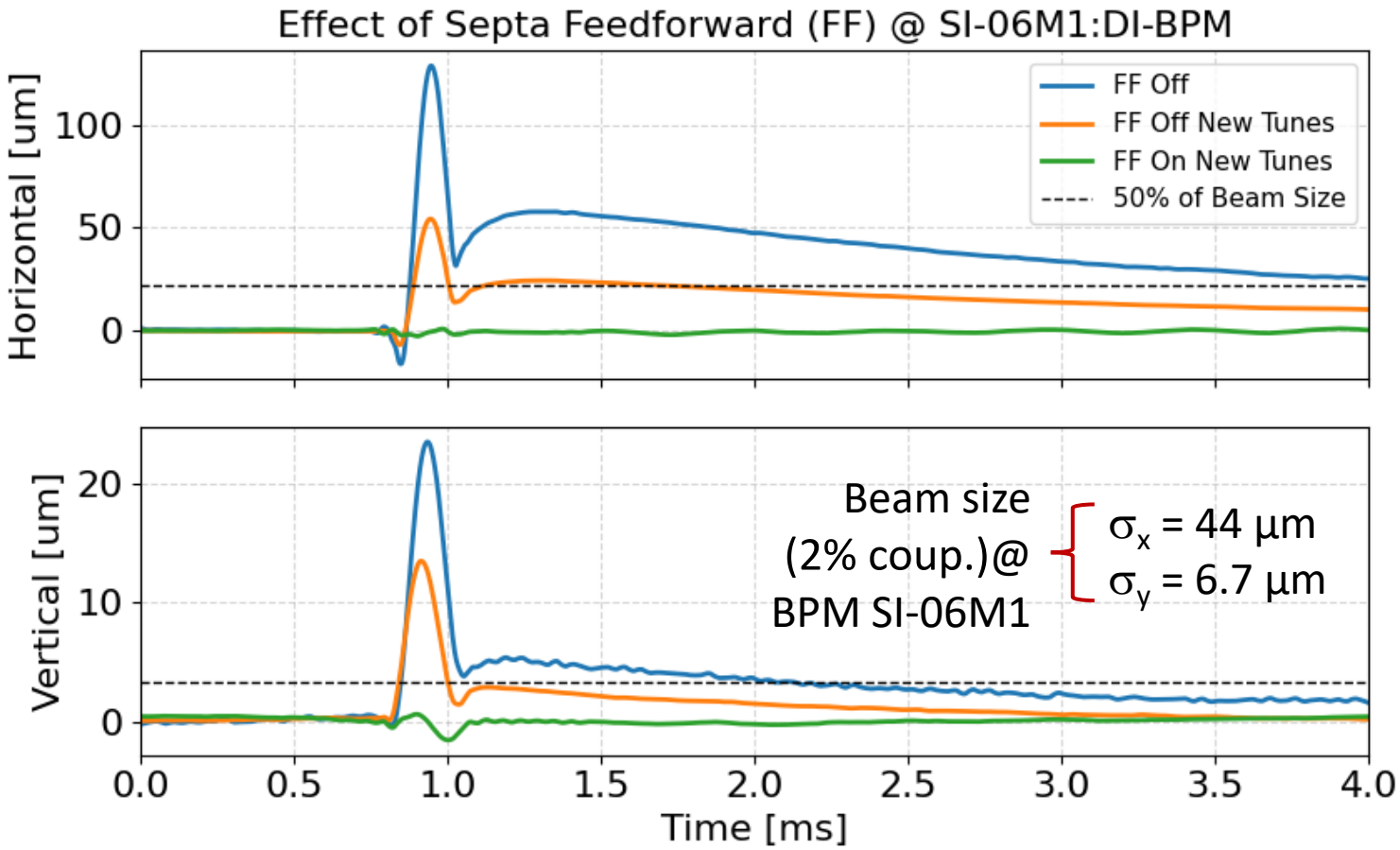

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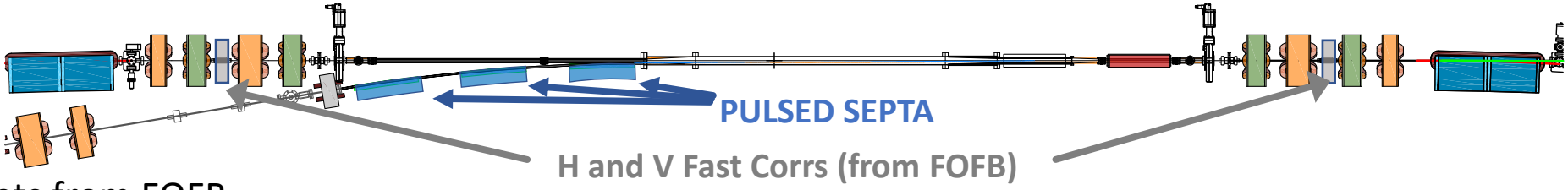

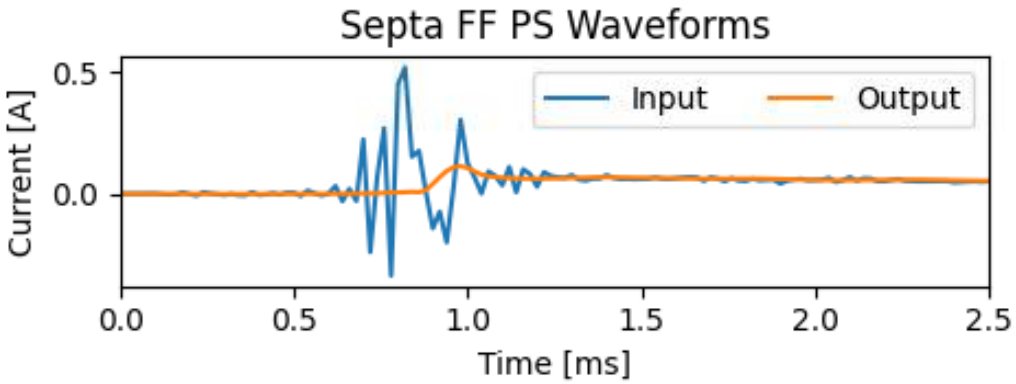

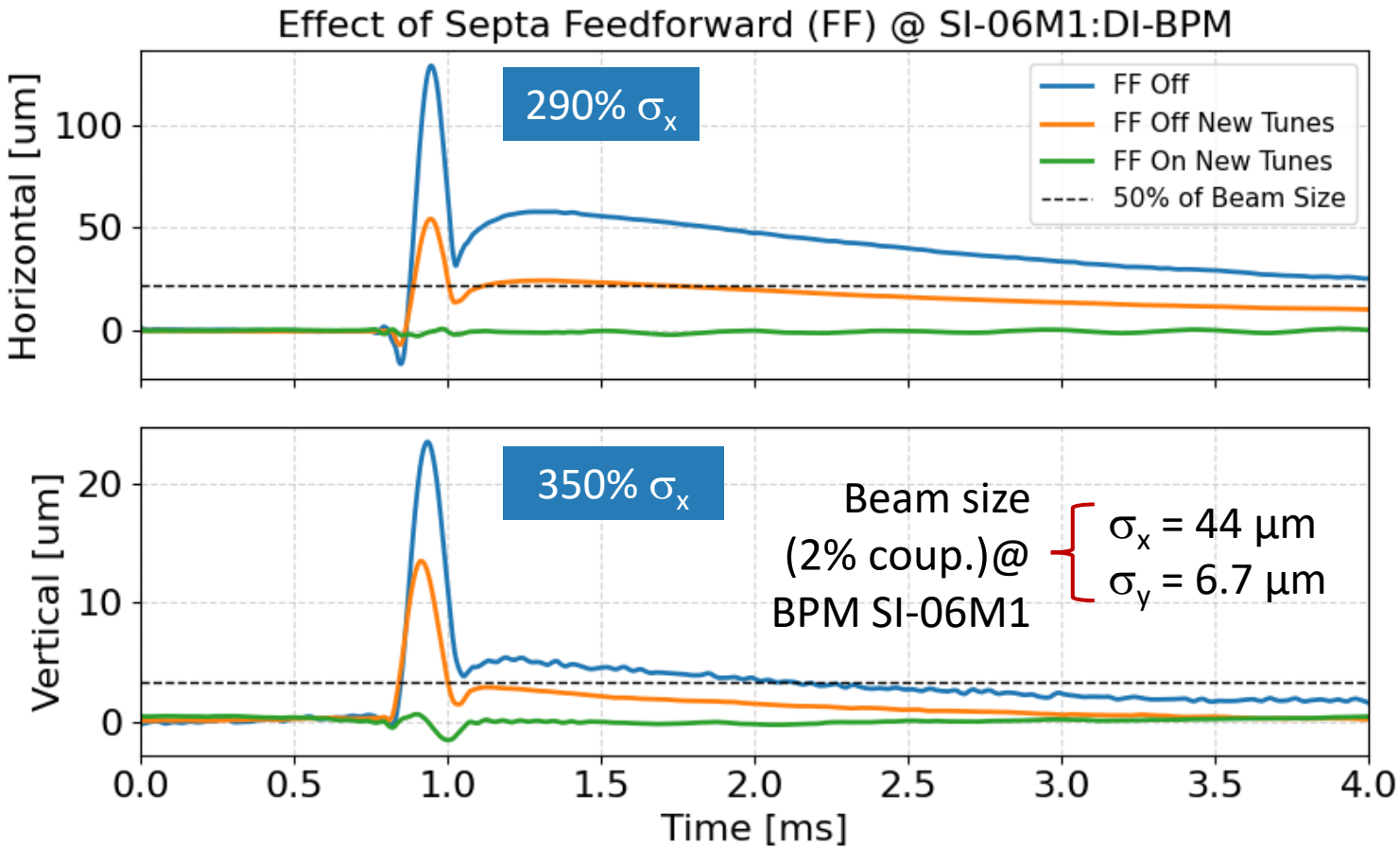

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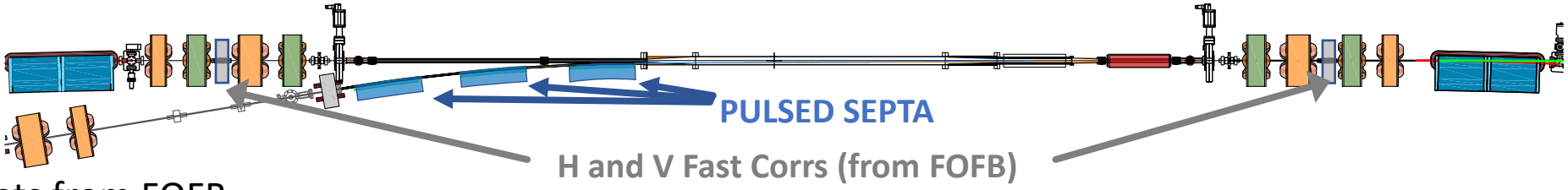

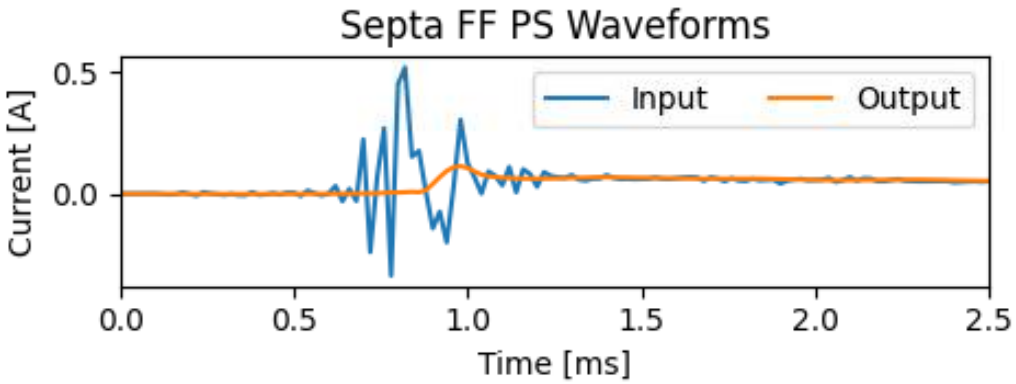

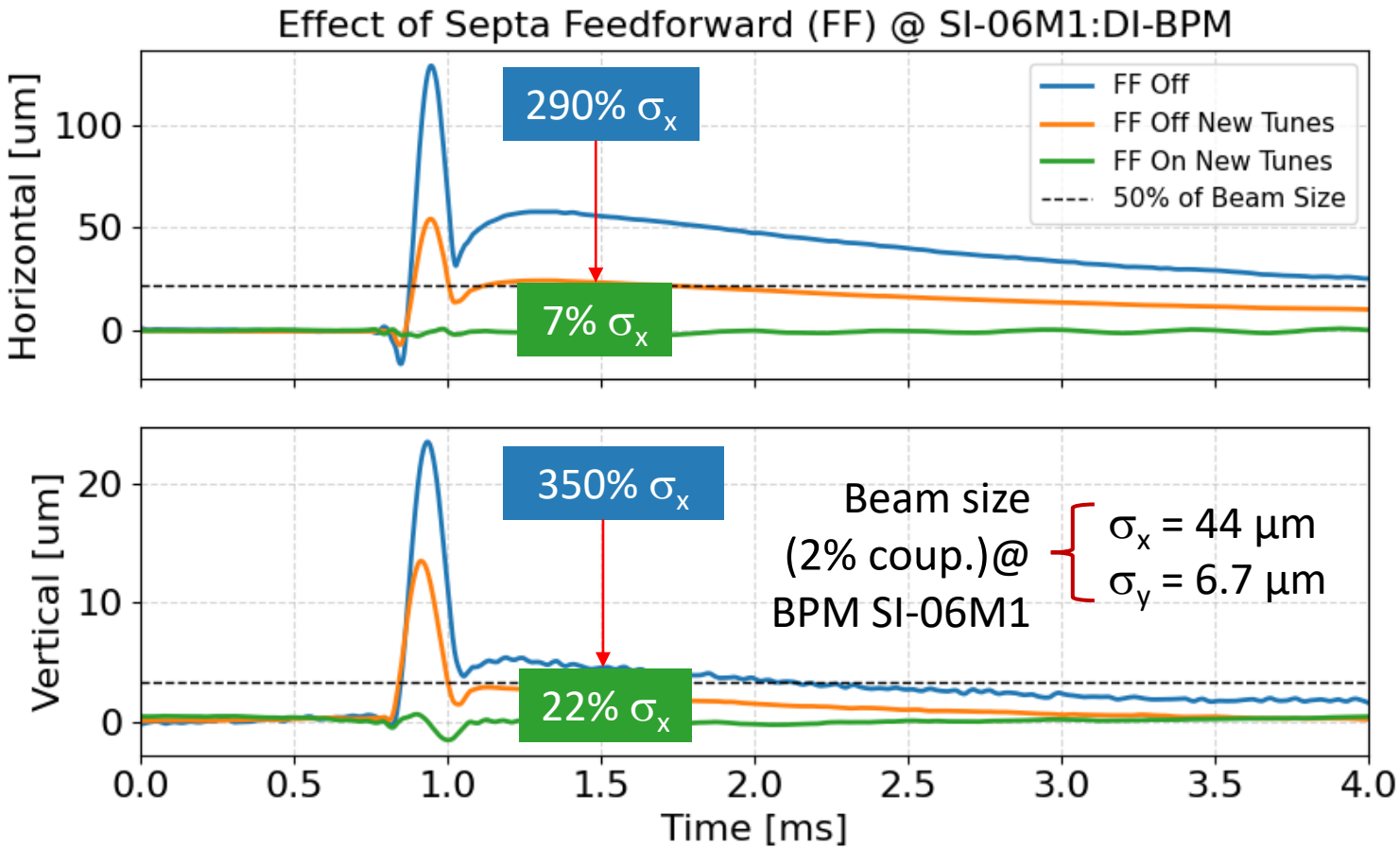

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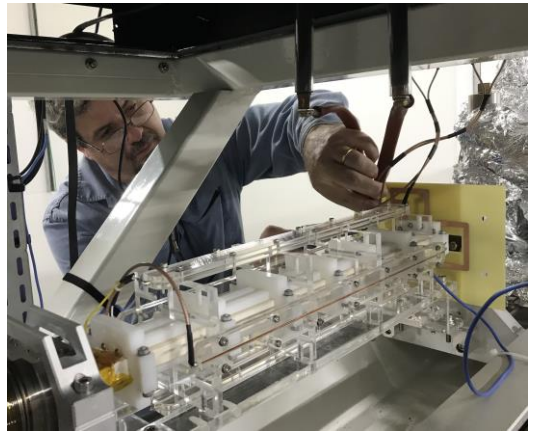

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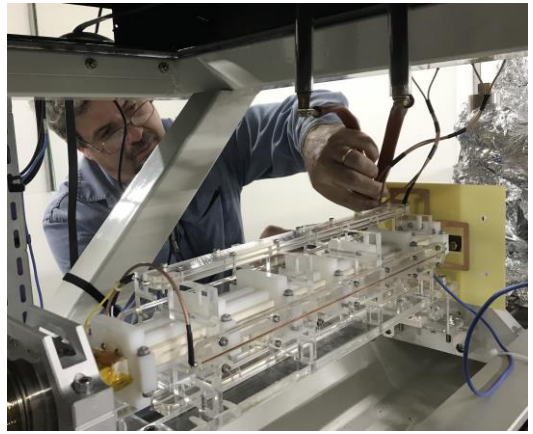

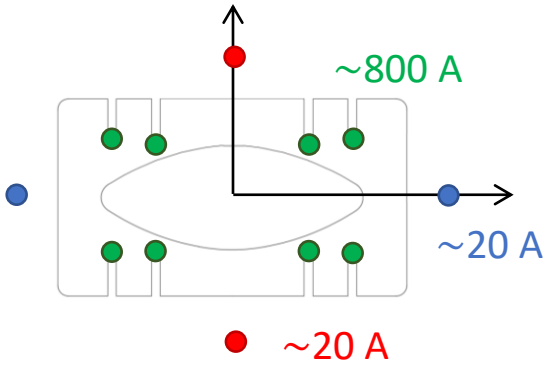

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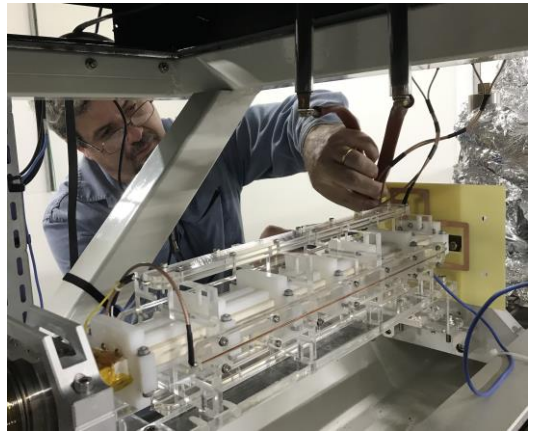

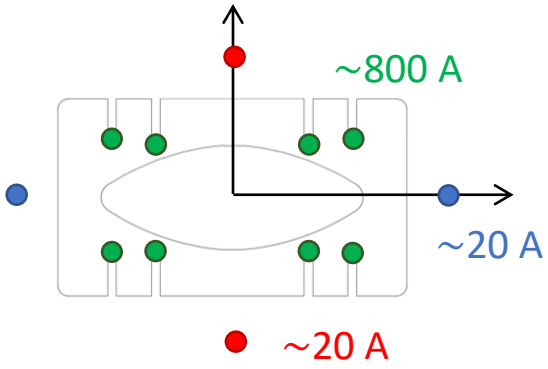

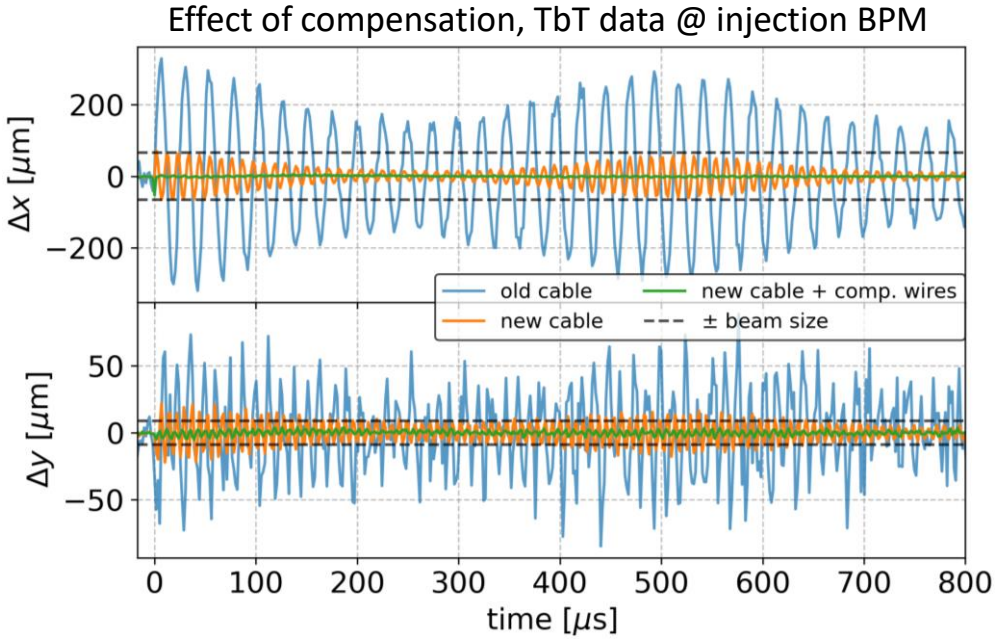

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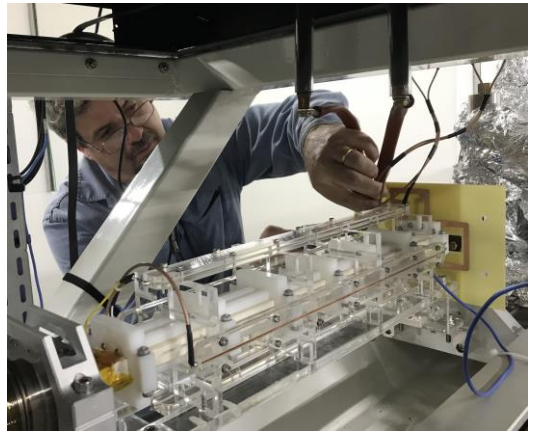

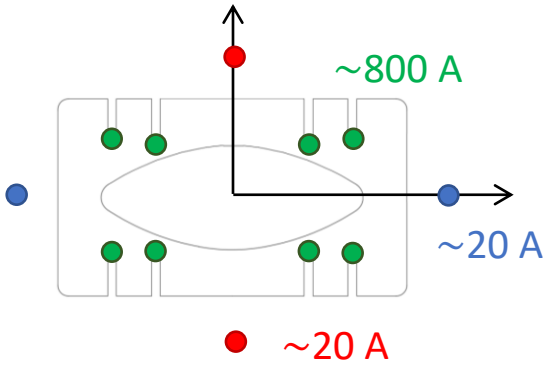

- Eddy currents from ceramic Ti coating → residual kick shape deformation and prolongation for several turns;
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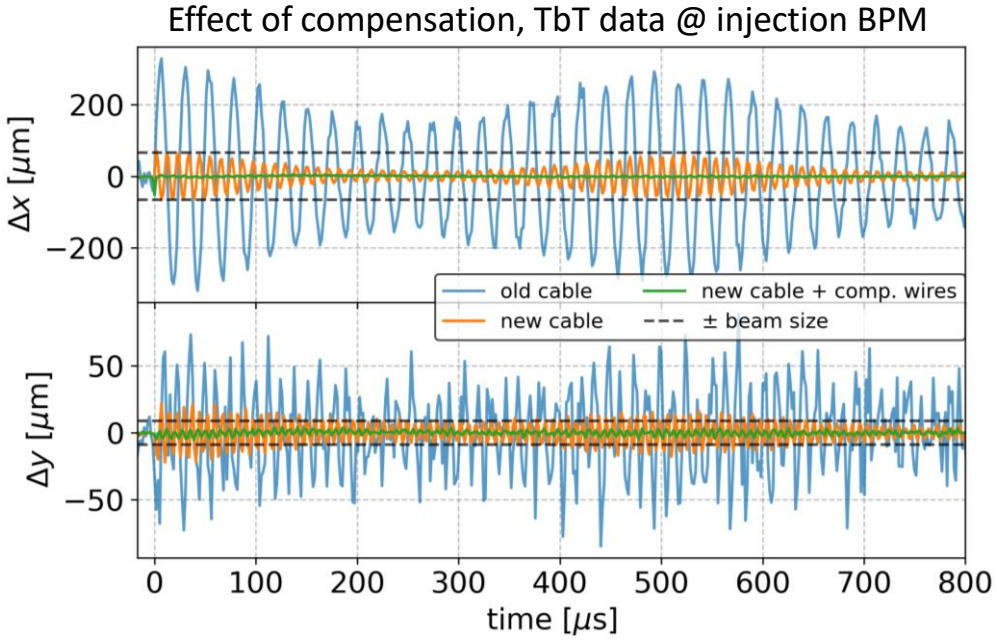

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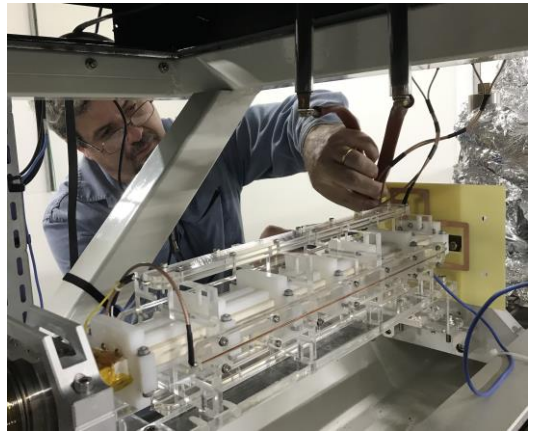

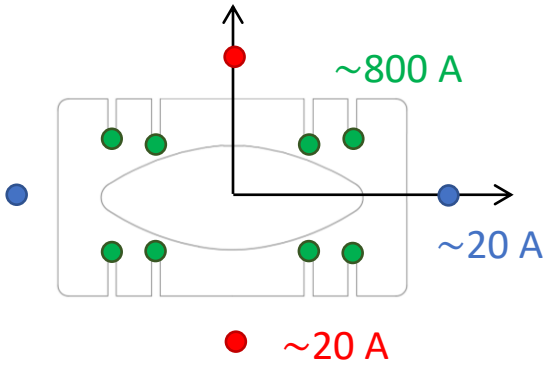

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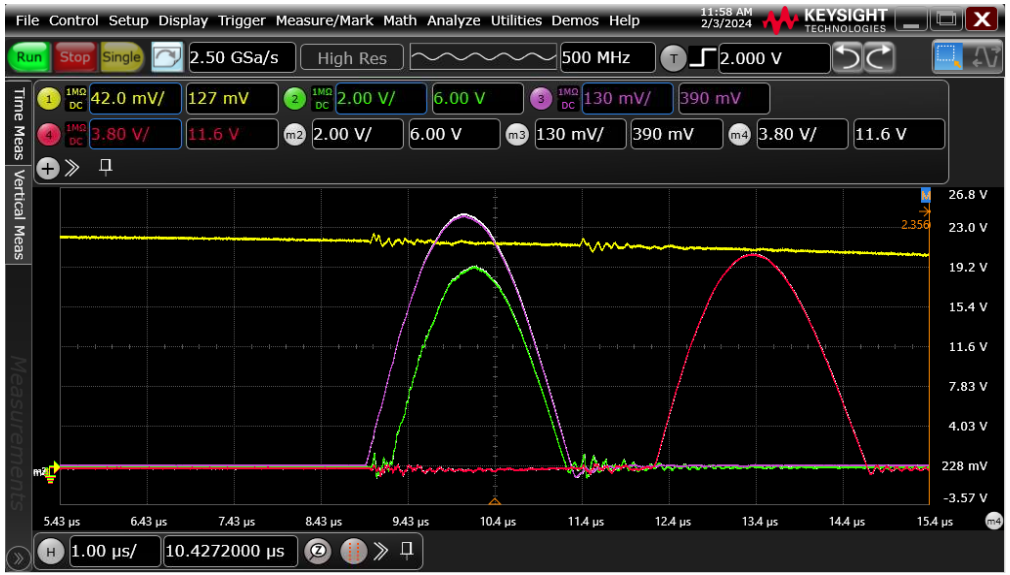
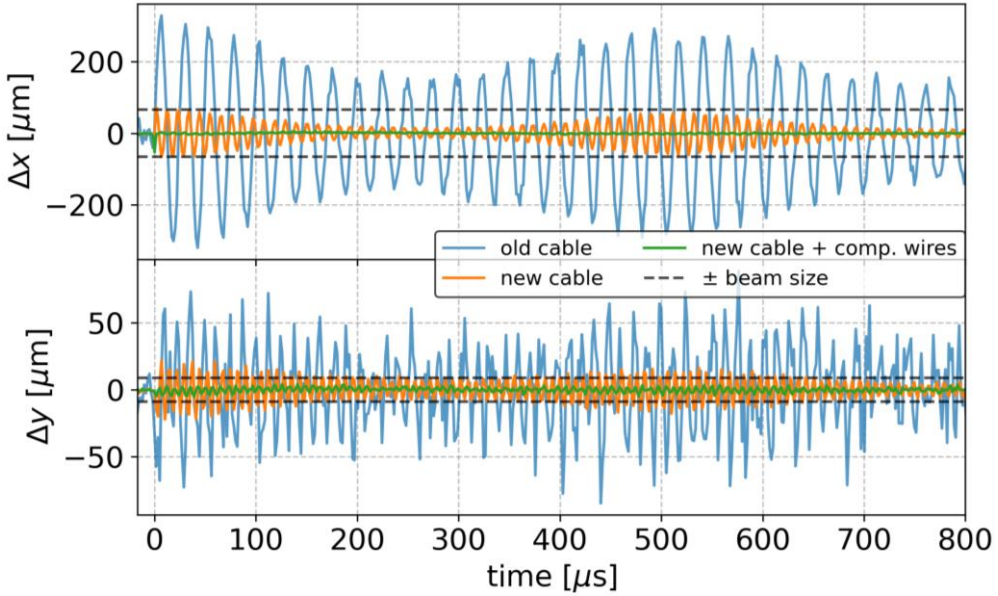


Effect of compensation, TbT data @ injection BPM



Injection Perturbations: NLK Residual Field

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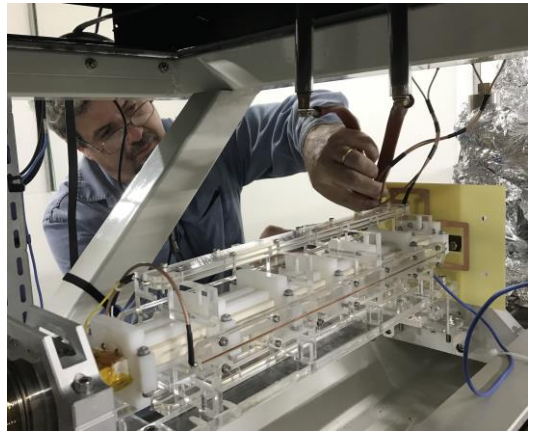

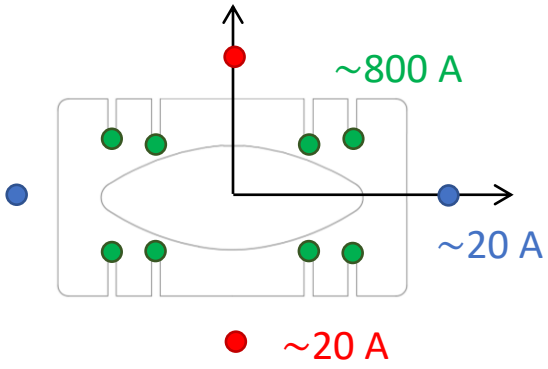

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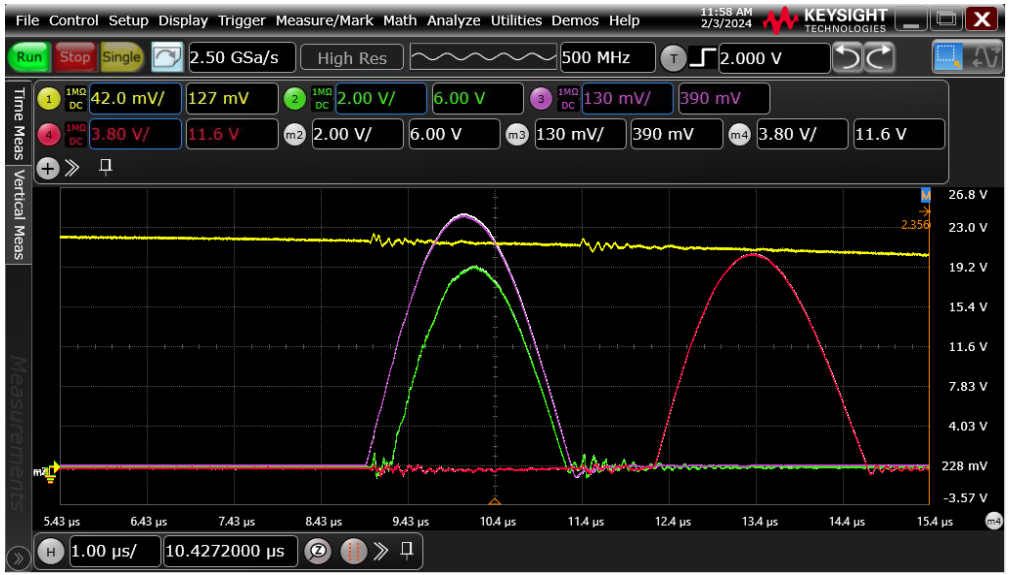

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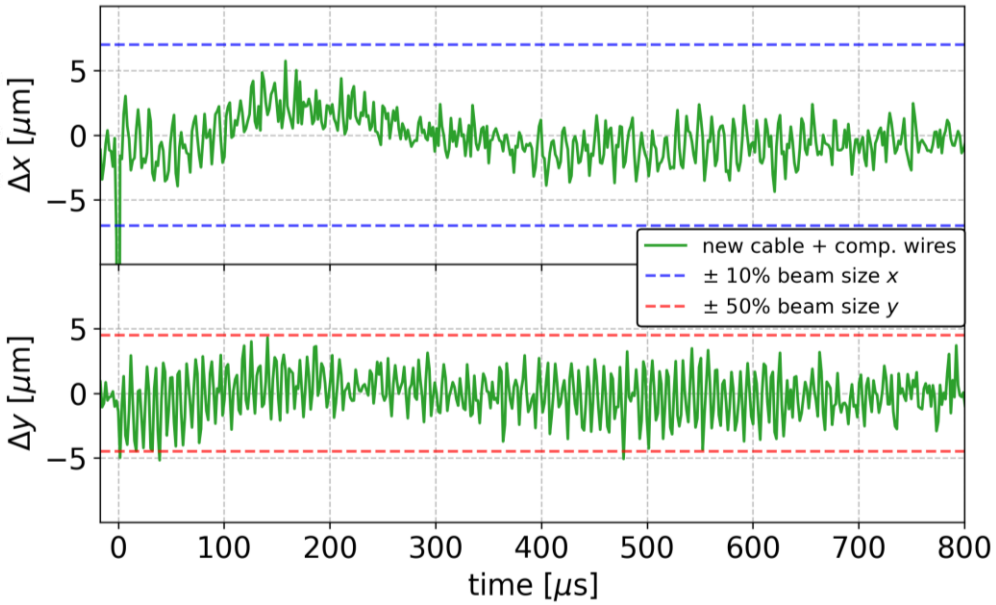

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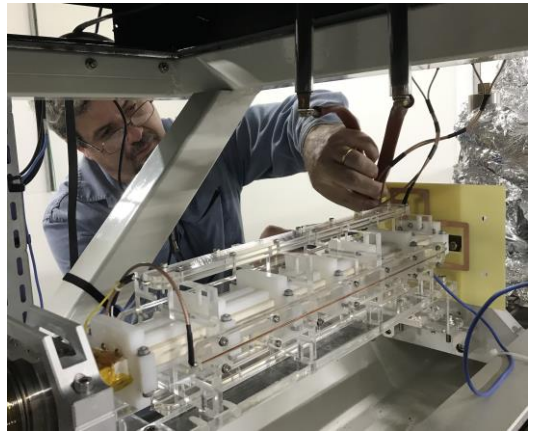

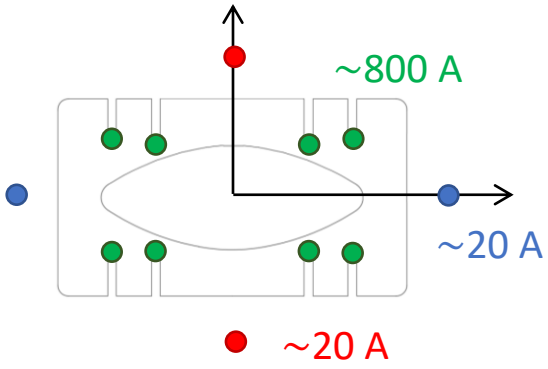

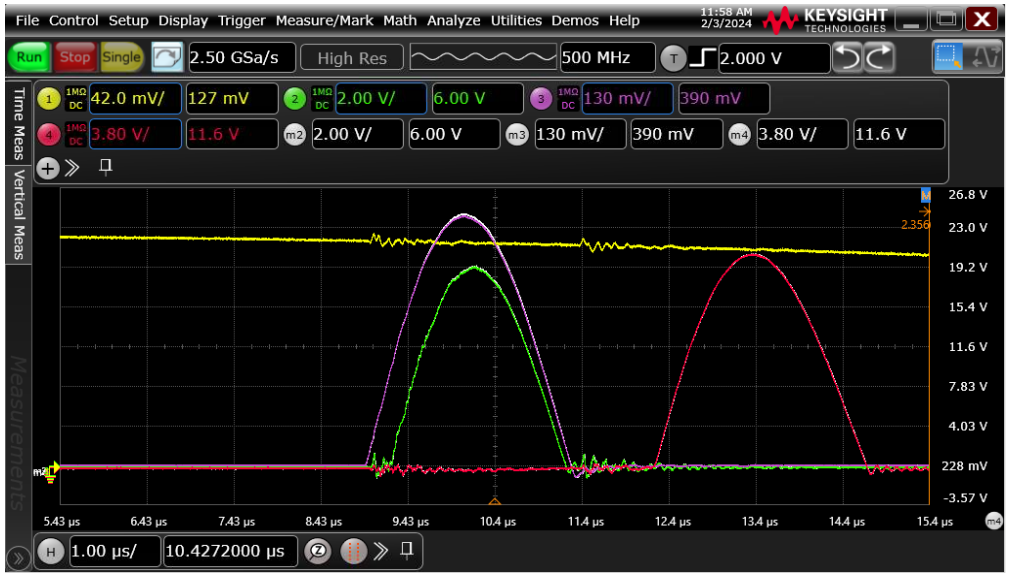

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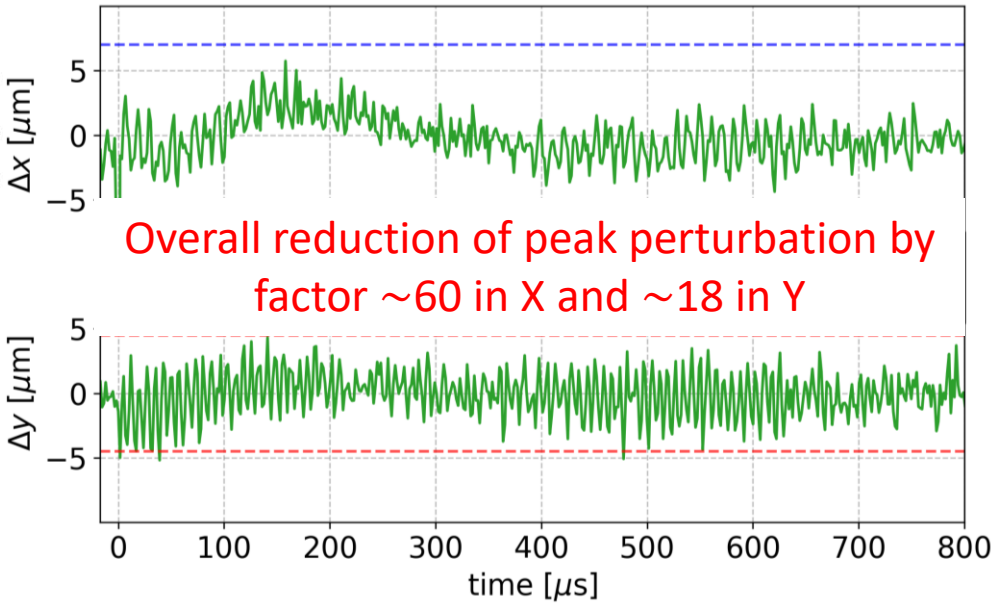

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Beam size @ injection straight $\begin{cases} \sigma_x = 68\ \mu m \\ \sigma_y = 9\ \mu m \end{cases}$

Very Short-Term Stability (Turn by Turn – $f_{RF}/2$)

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- Residual kick is well canceled by compensation wires for freqs < TbT;

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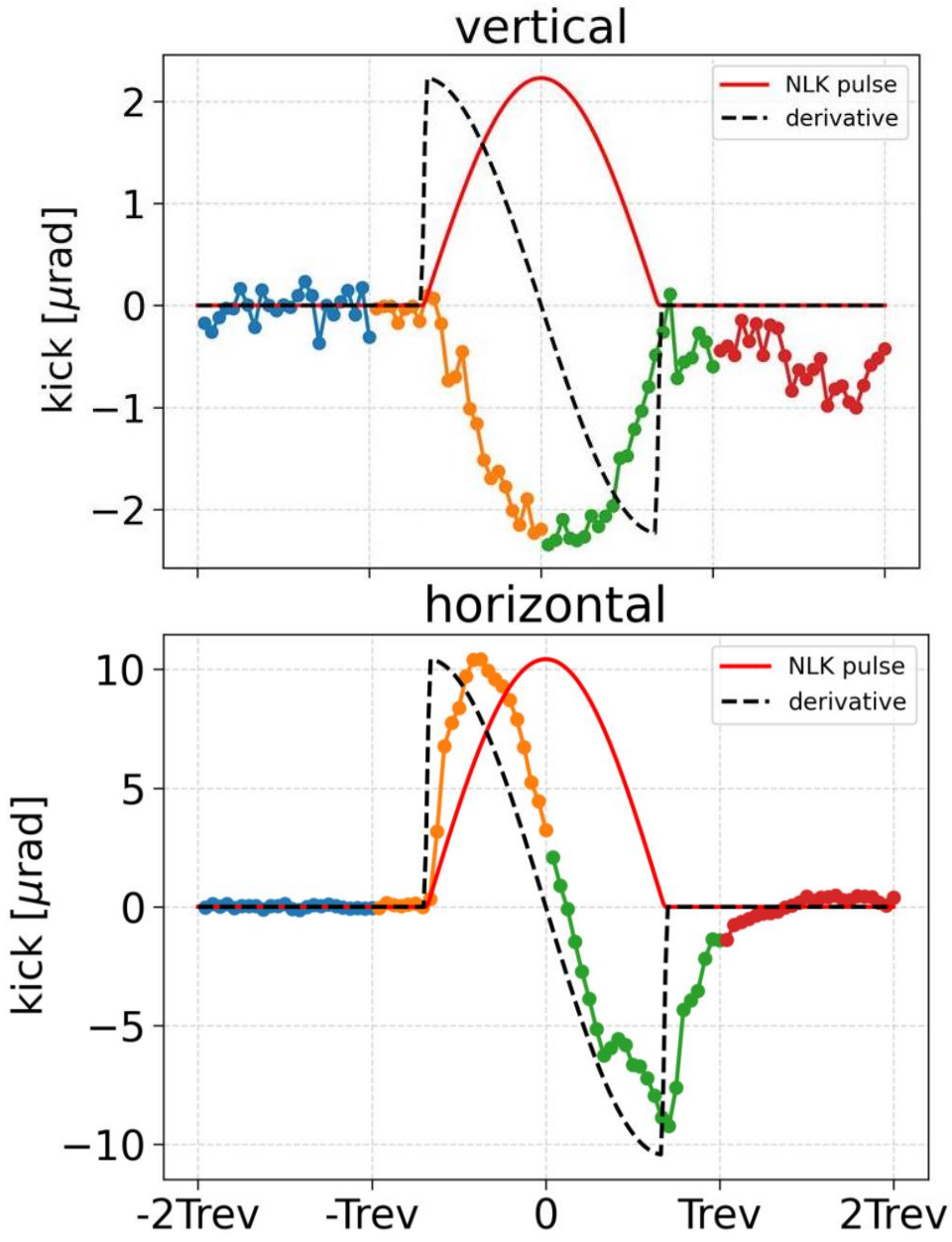
- Residual kick is well canceled by compensation wires for freqs < TbT;
- However, eddy currents distort residual kick shape (horizontal mainly);



Injection Perturbations: NLK Residual Field

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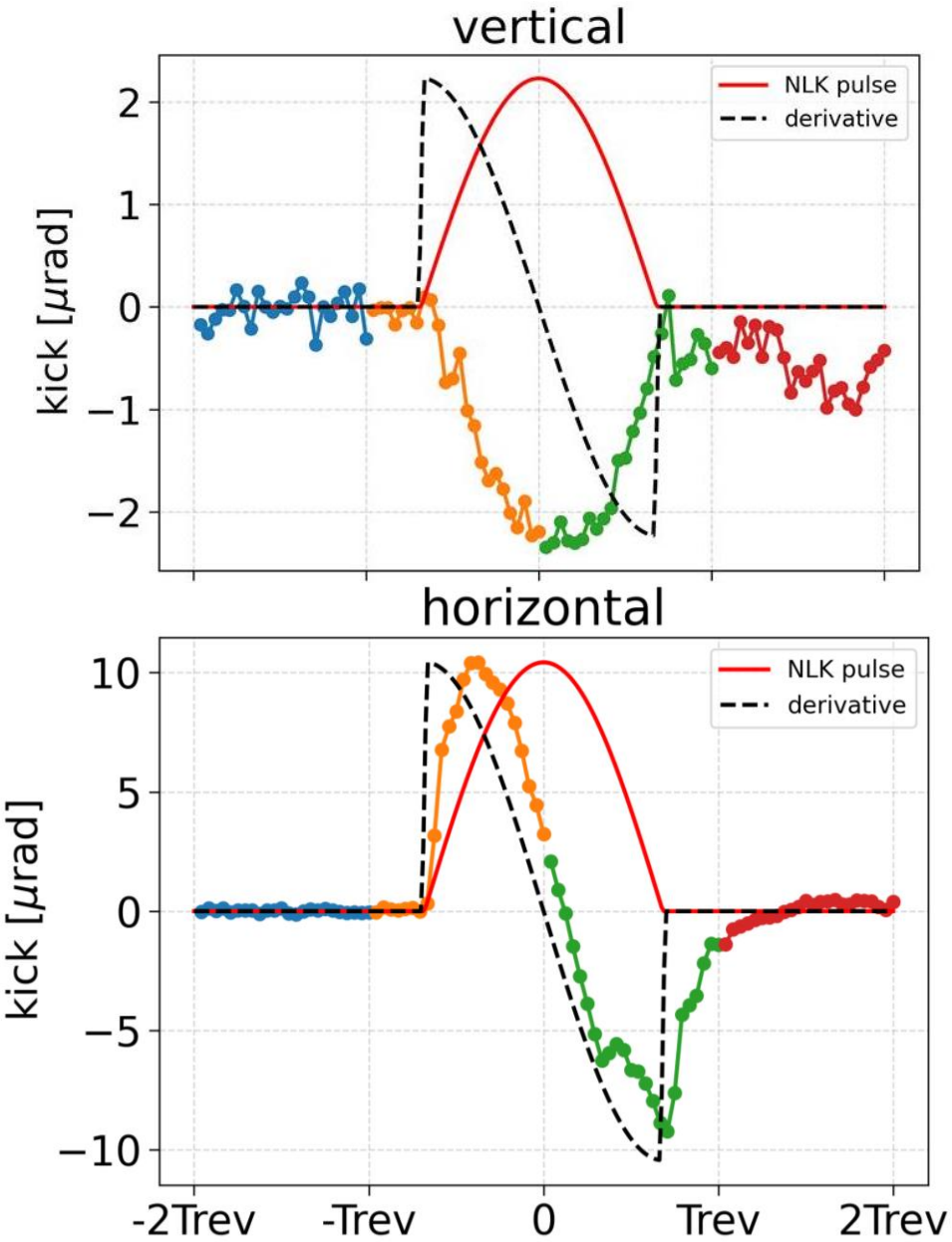
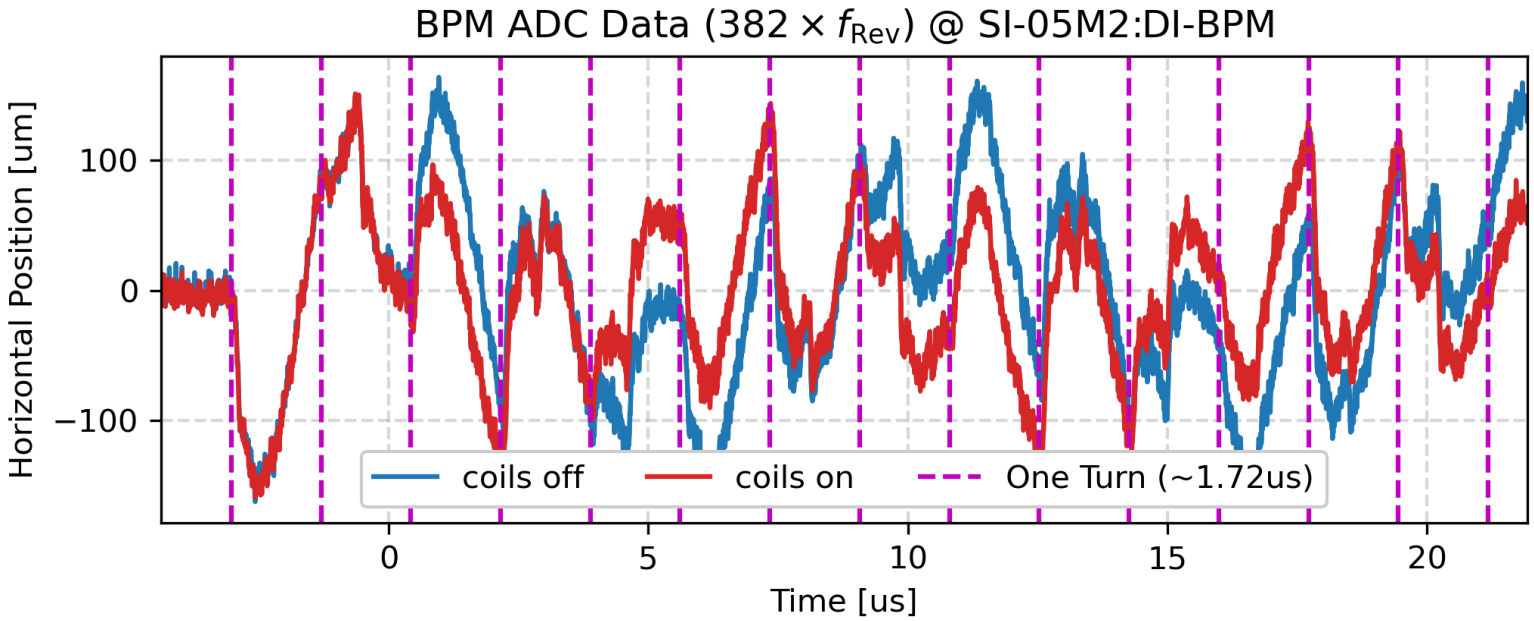
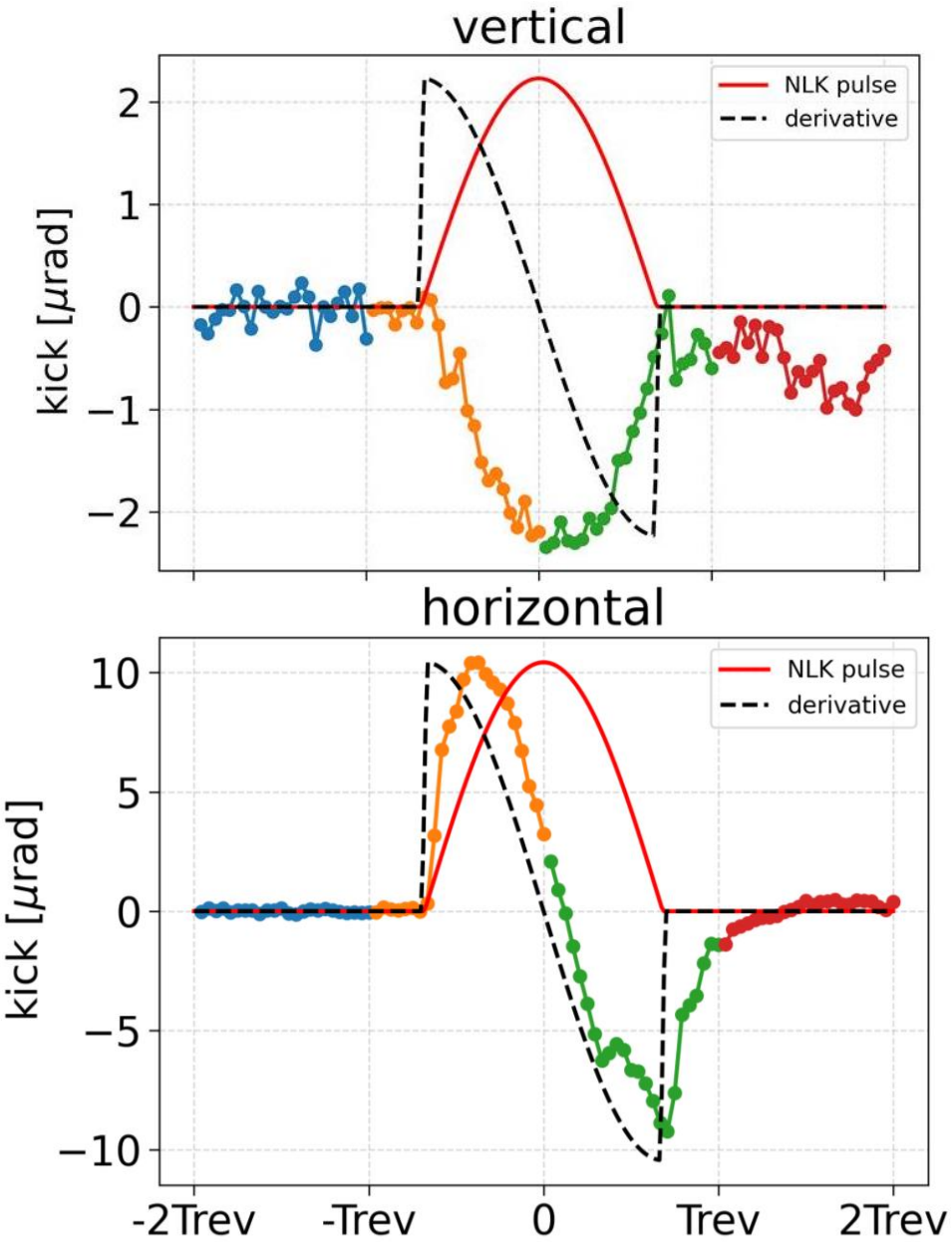
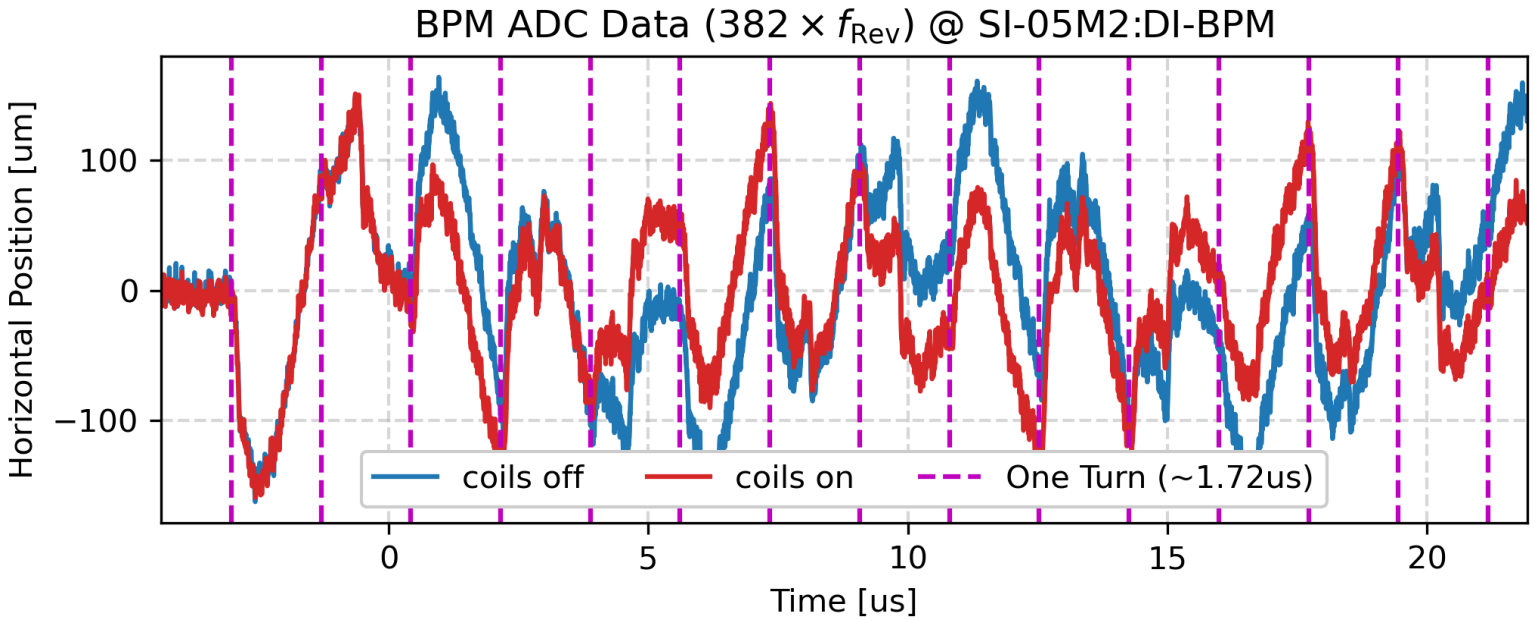




Injection Perturbations: NLK Residual Field

- Residual kick is well canceled by compensation wires for freqs < TbT;
- However, eddy currents distort residual kick shape (horizontal mainly);
- Hor. wire only cancels avg. of very large oscillation within one turn;
- A full-sine PS being designed to replace half-sine one used in hor. plane;
- Ongoing studies to use new coatings: thinner, strips, etc...;





Collective Instabilities

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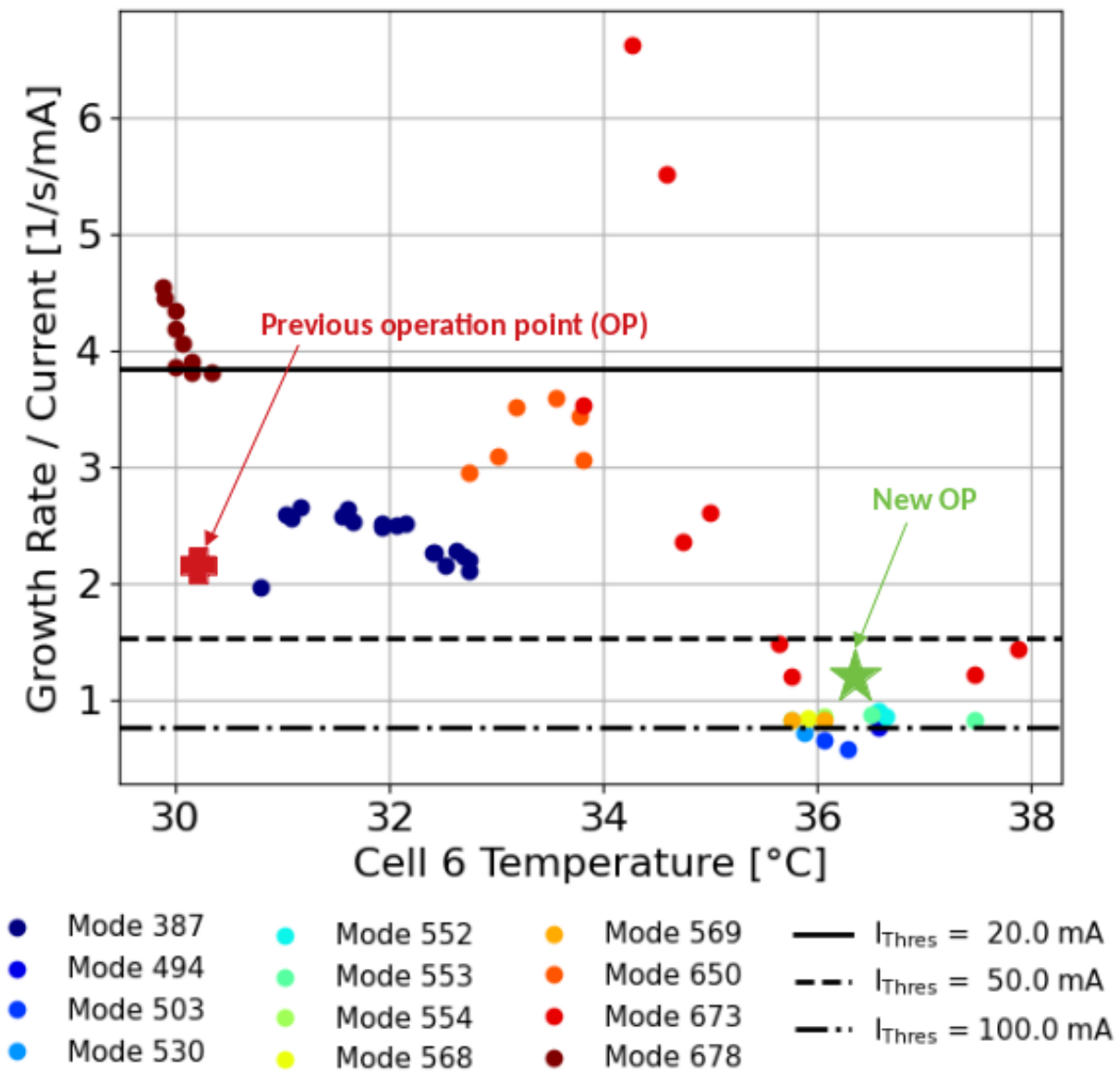
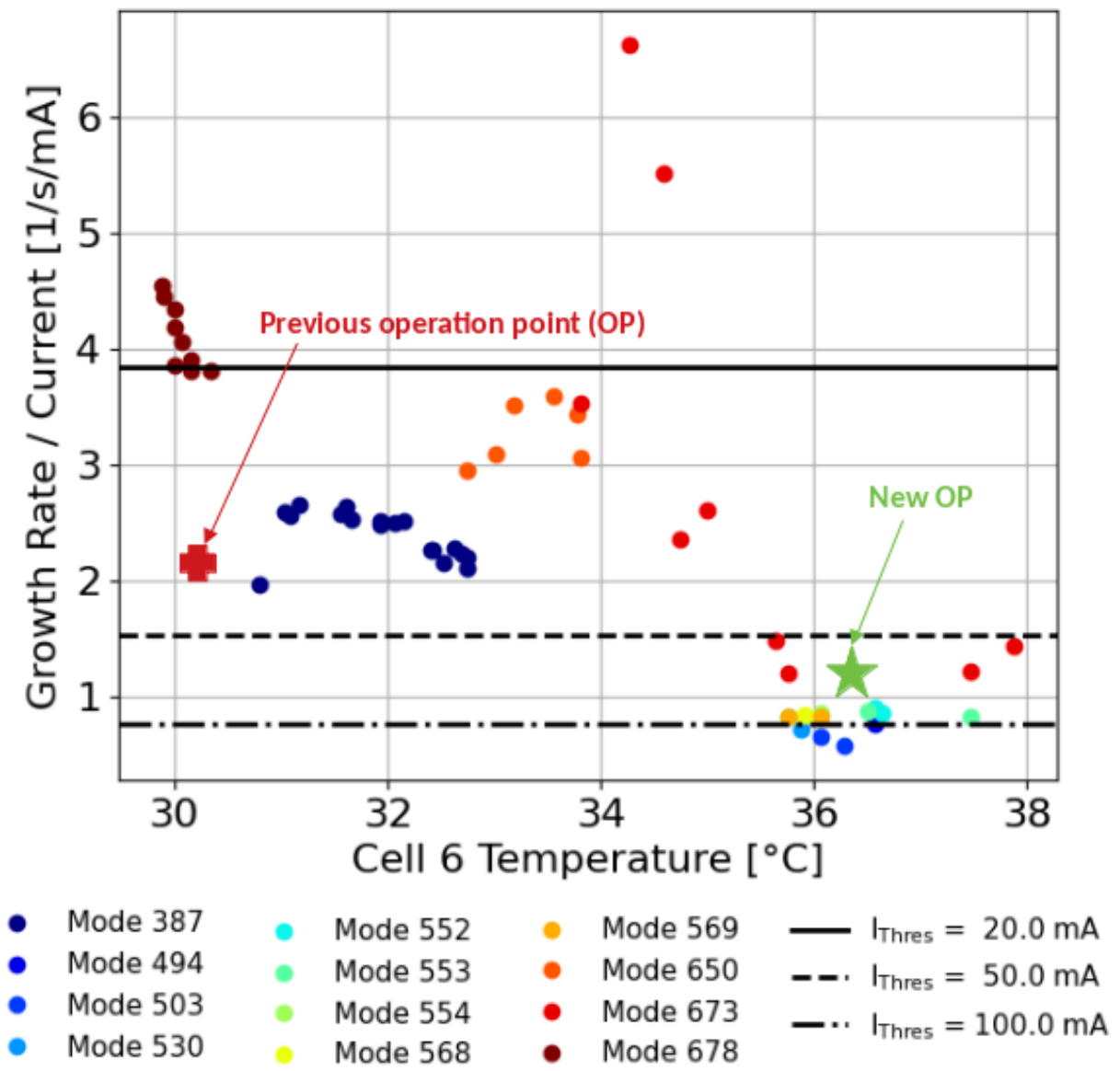


Collective Instabilities

- SR still operates with a PETRA 7-Cell cavity;
- Longitudinal HOMs -> beam unstable at 100mA;
- Stability recovered with:
  - Longitudinal BbB feedback on;
  - Cavity temperature detuning;
- SRF cavities will be installed in June 2024;
- Operation current will possibly increase to ~200 mA;
- No HOM driven instability expected;



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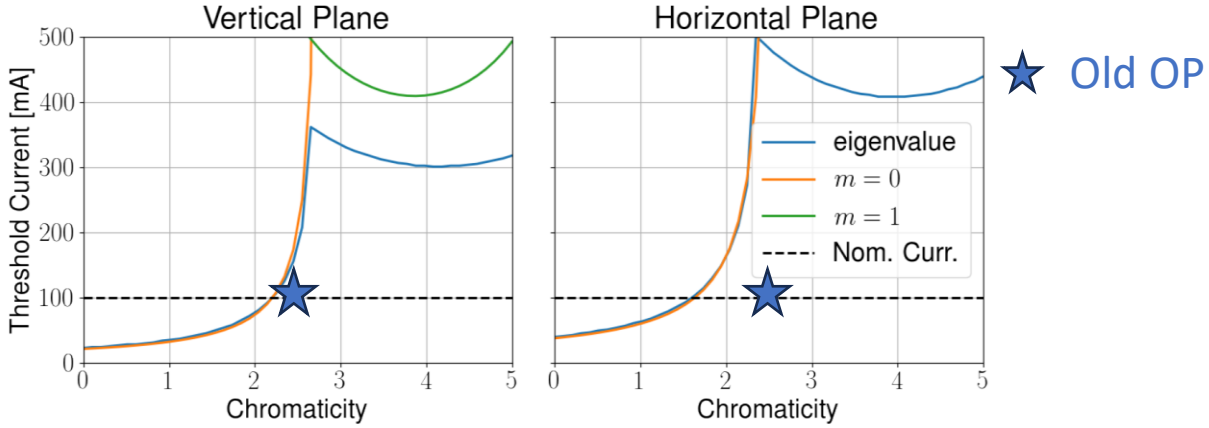

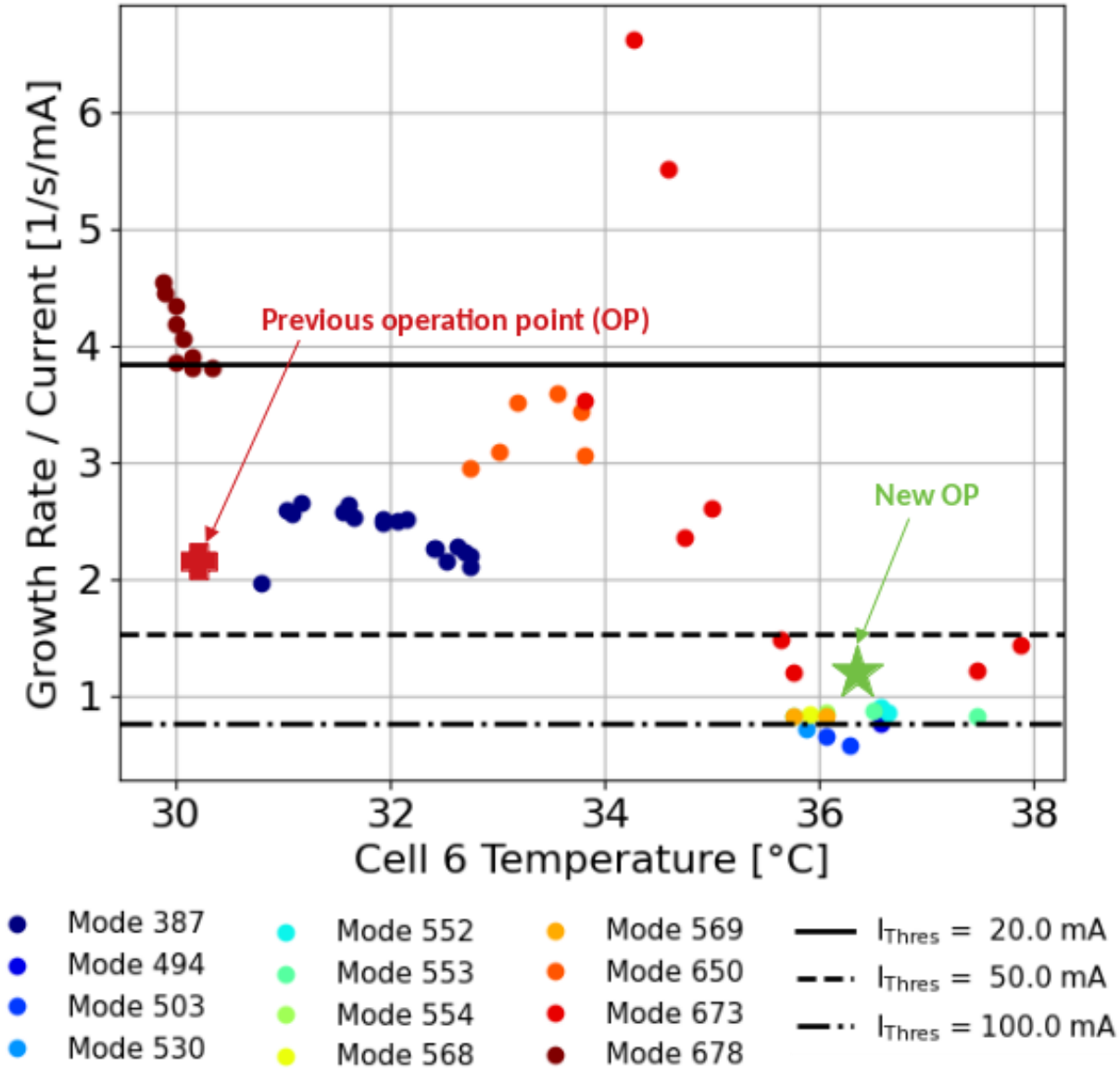

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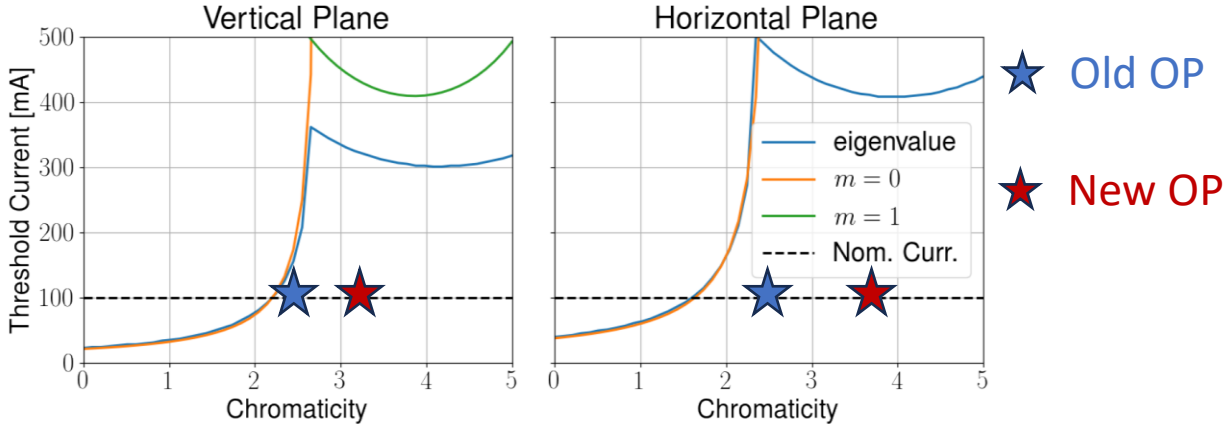

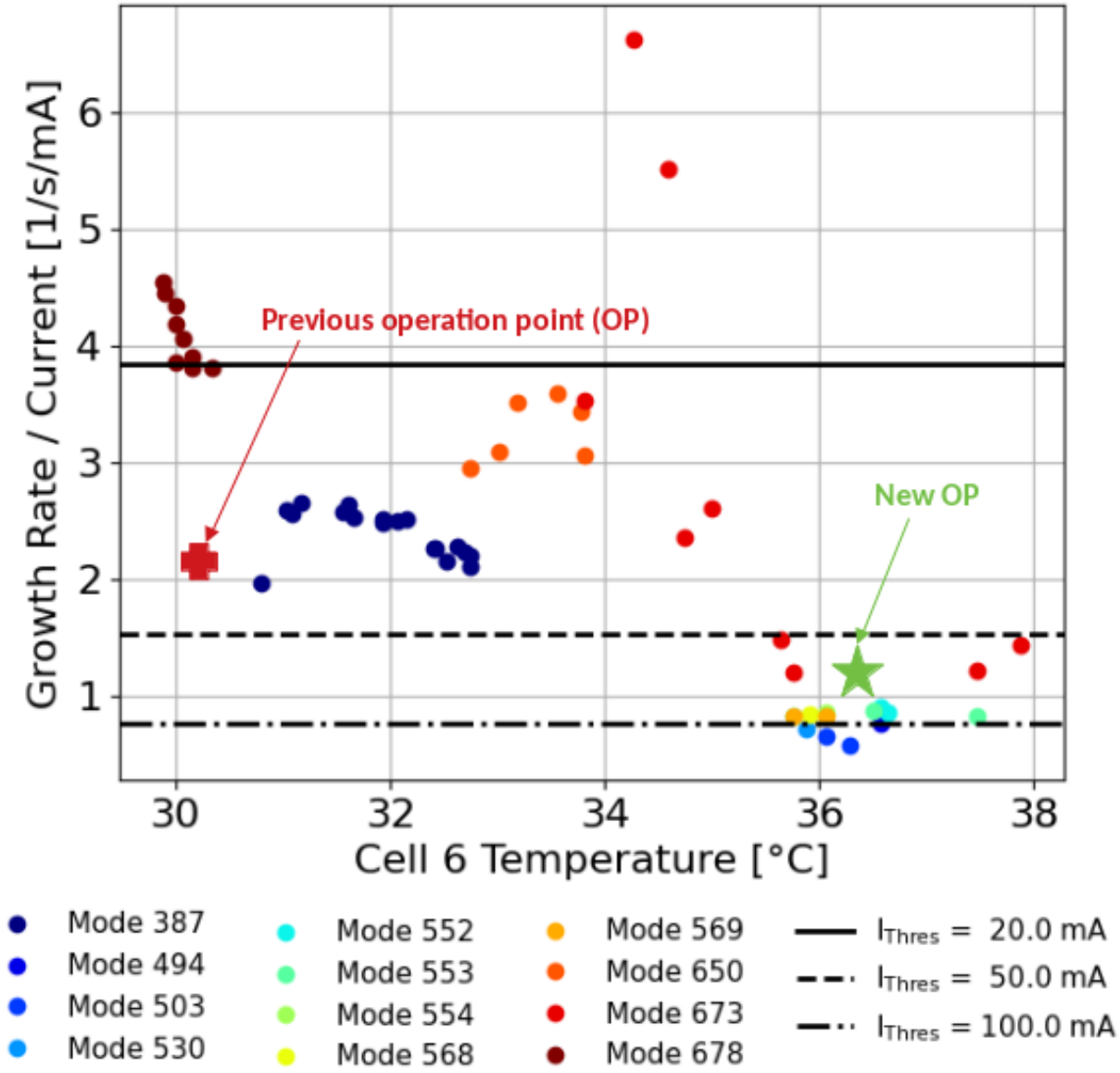

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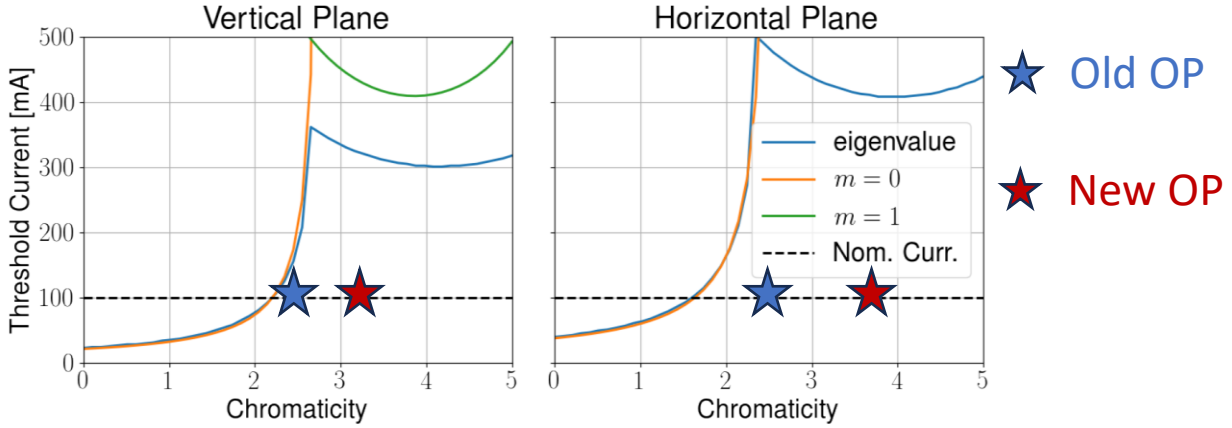

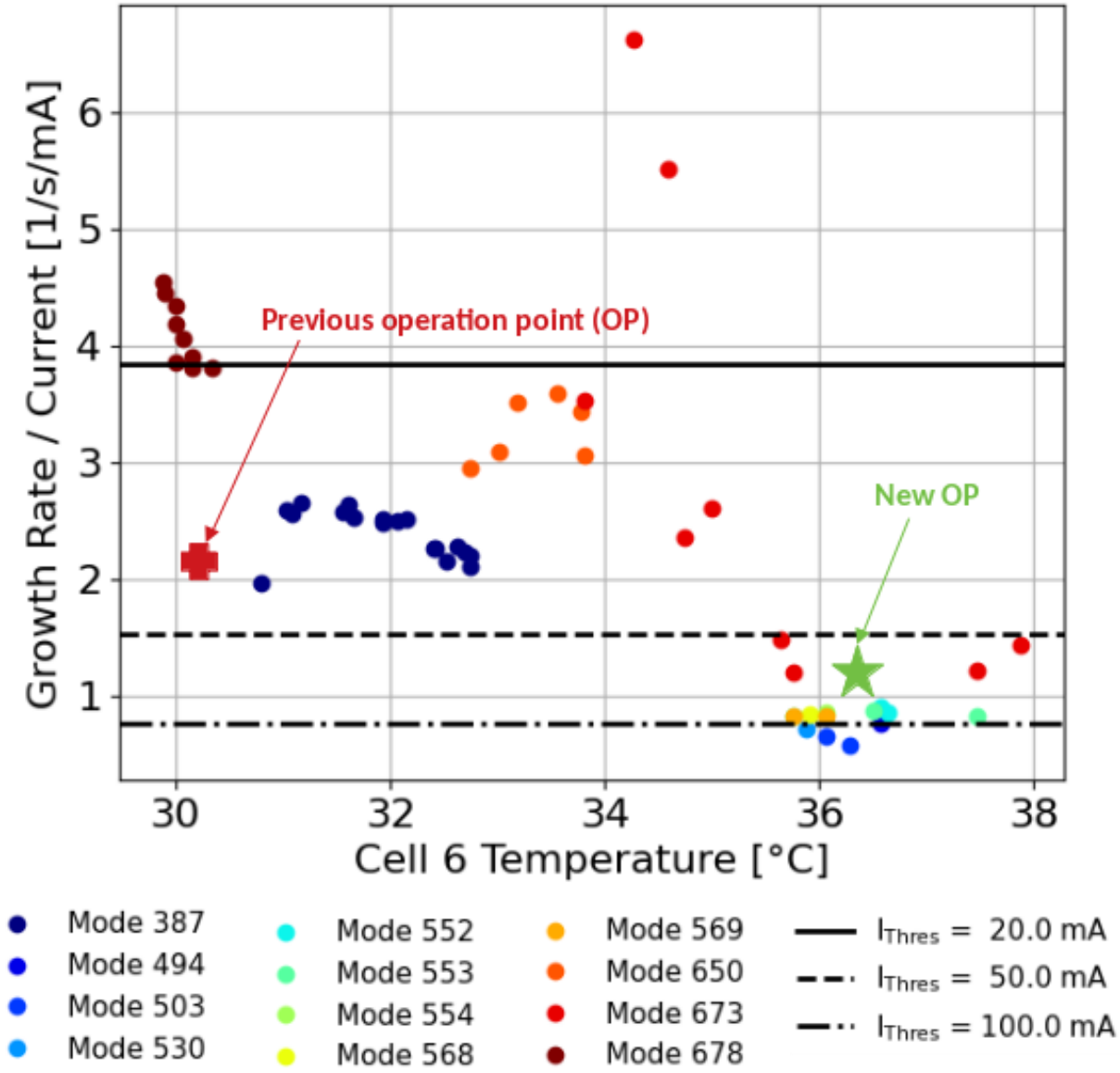

Collective Instabilities: Transverse Planes

- BbB-V On
- (Cx, Cy) = (3.8, 3.2)
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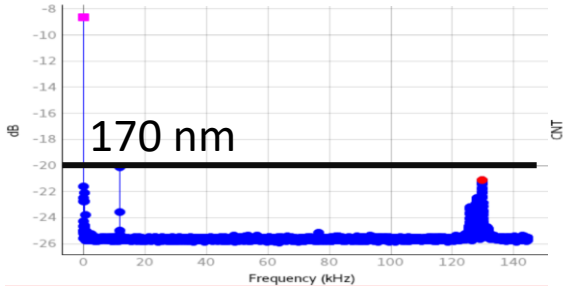
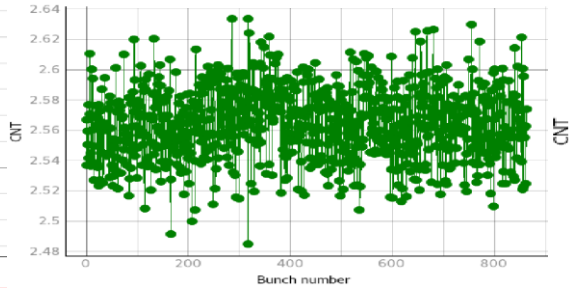
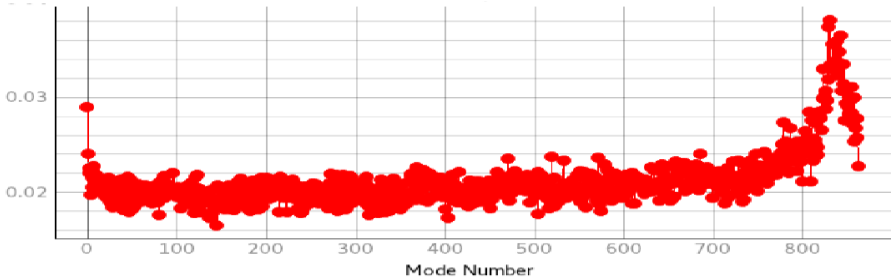
Average Spectrum



RMS Over Bunches



Coupled Bunch Modes Amplitudes



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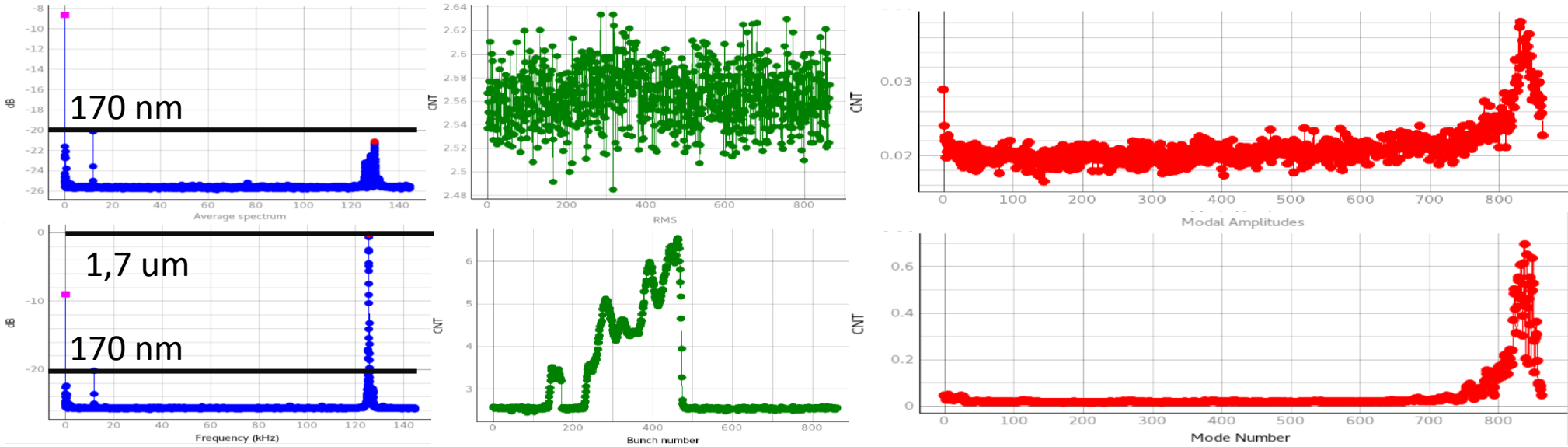

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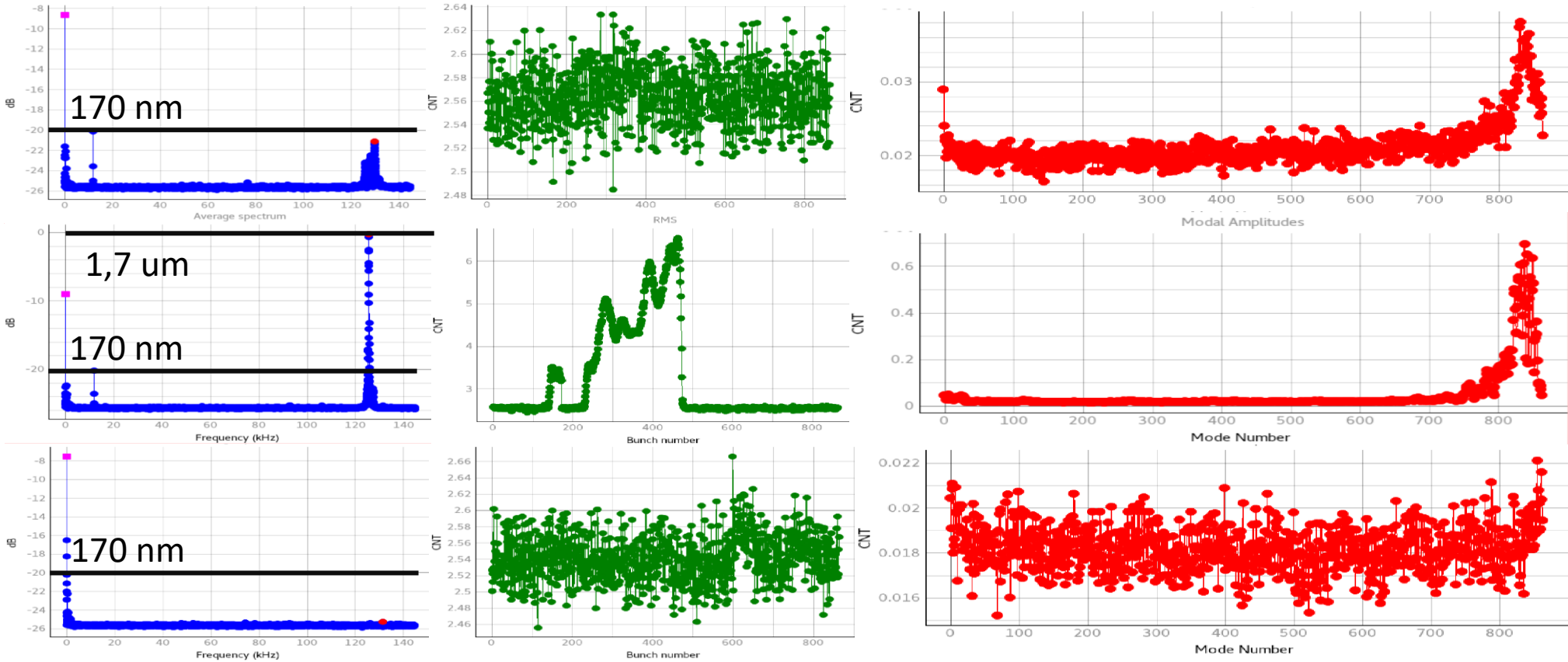

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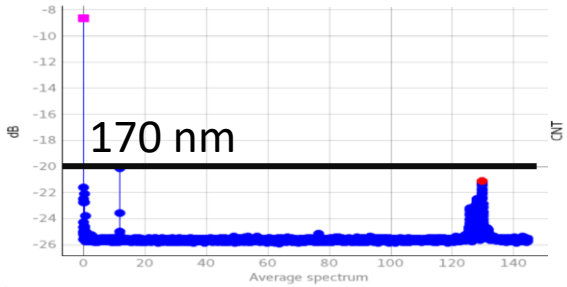

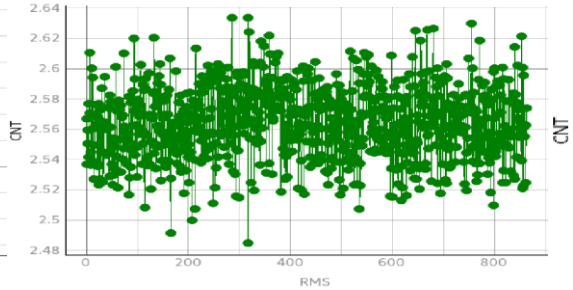

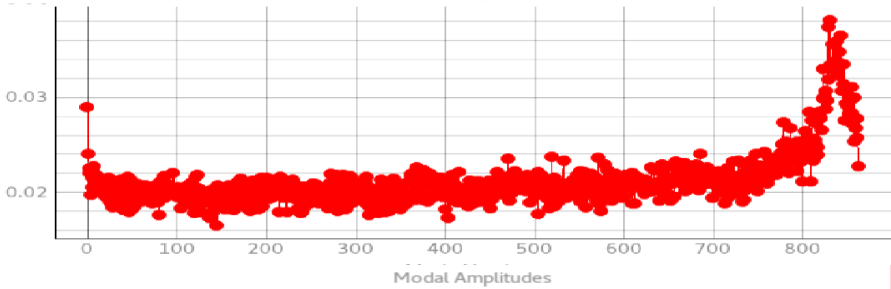

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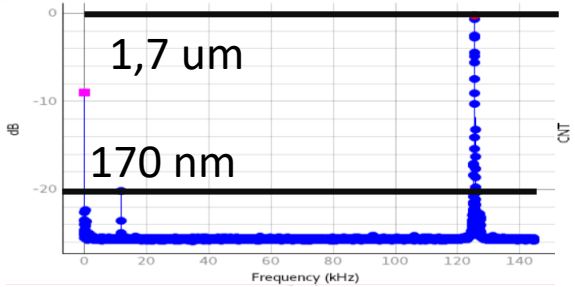

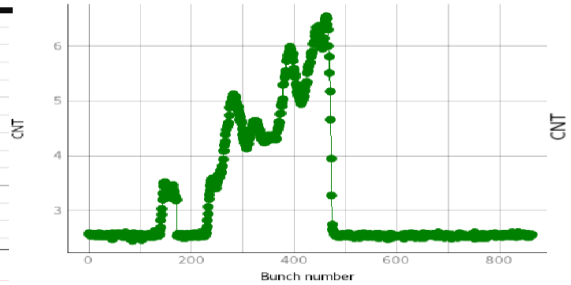

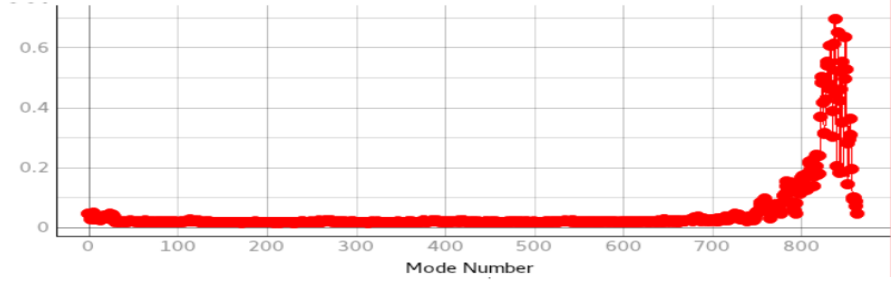

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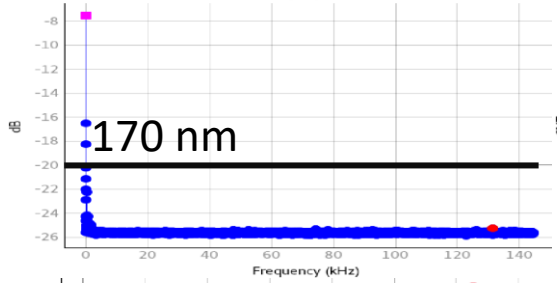

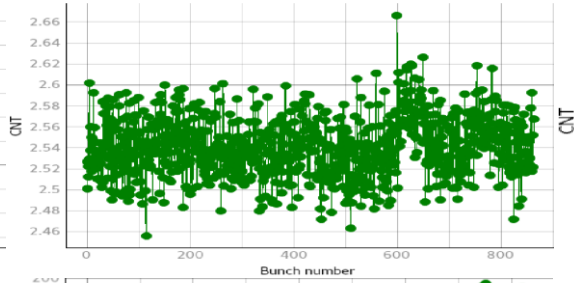

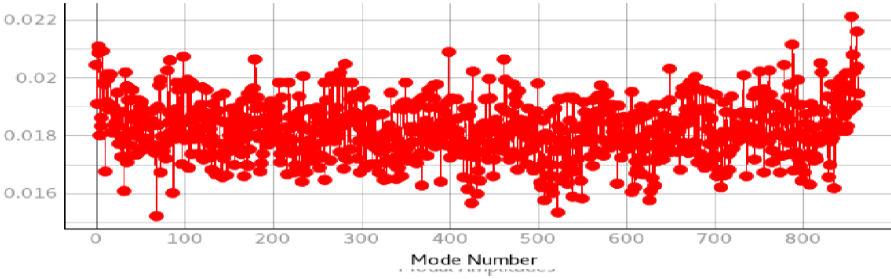

- BbB-V Off
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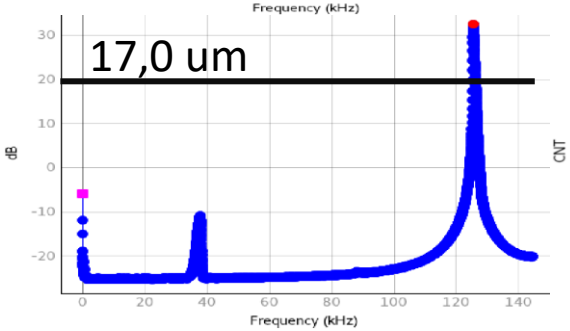

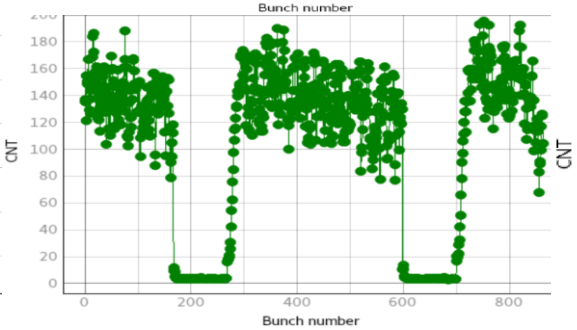

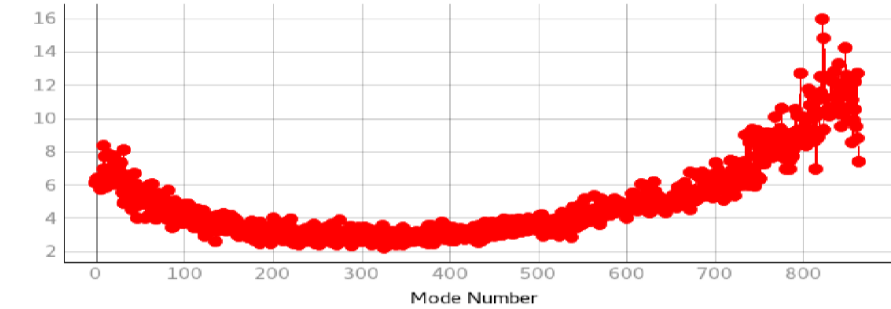

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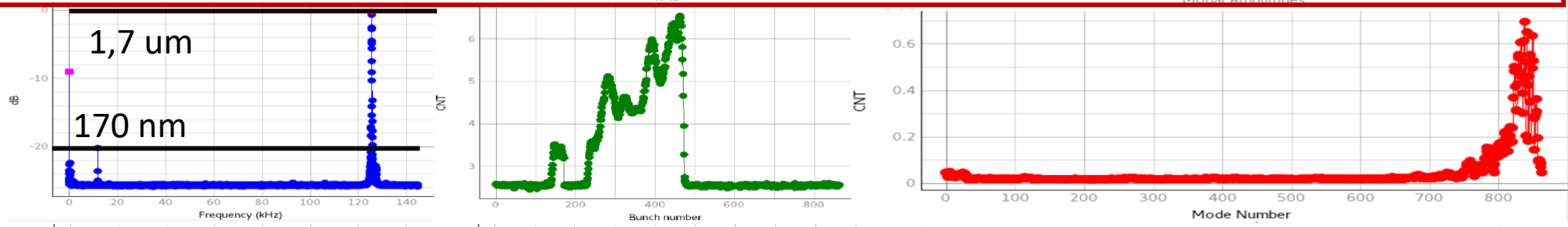

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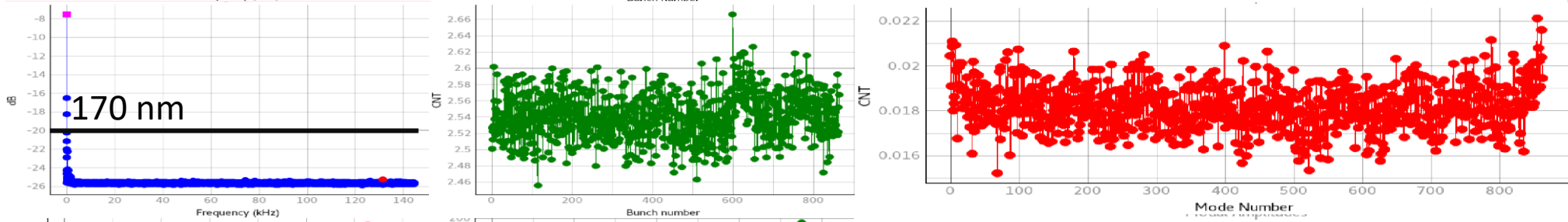

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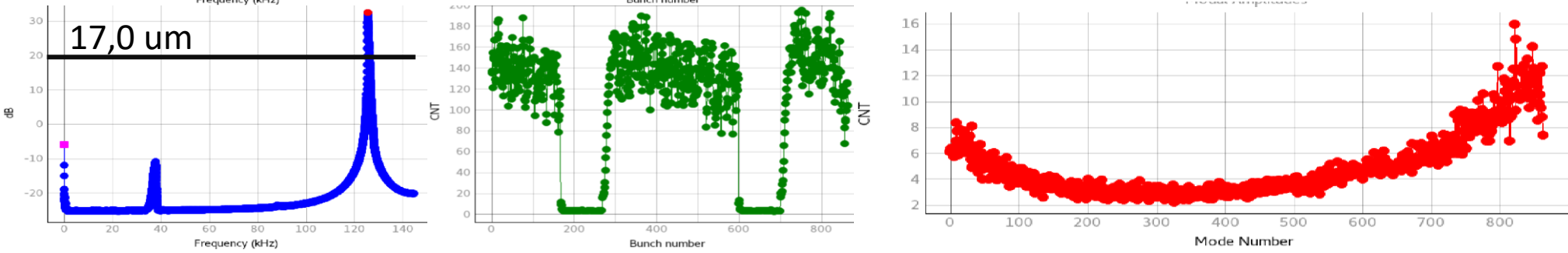

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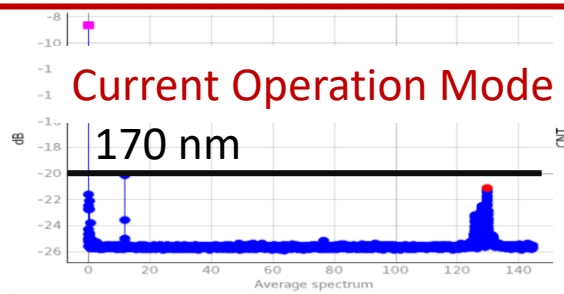

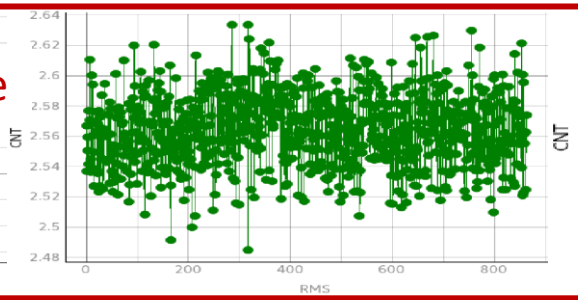

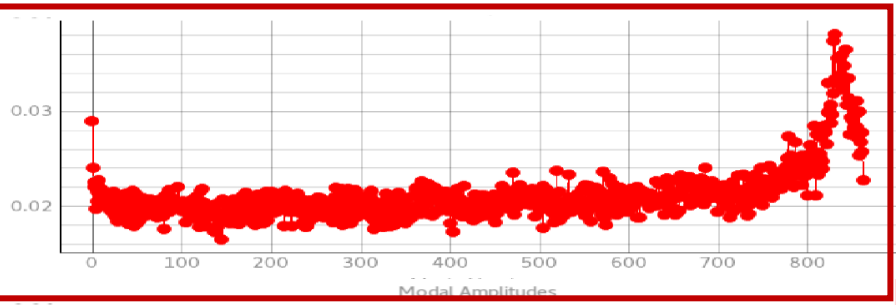

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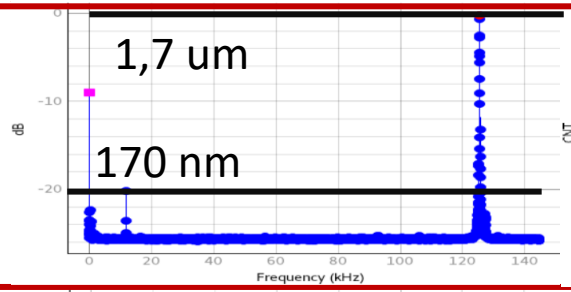

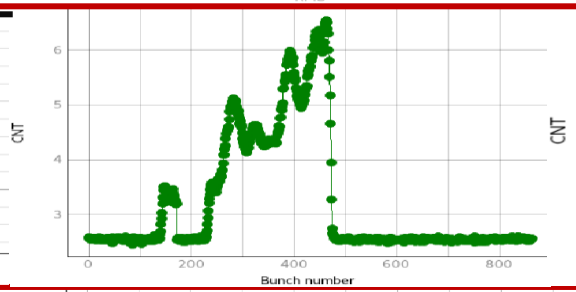

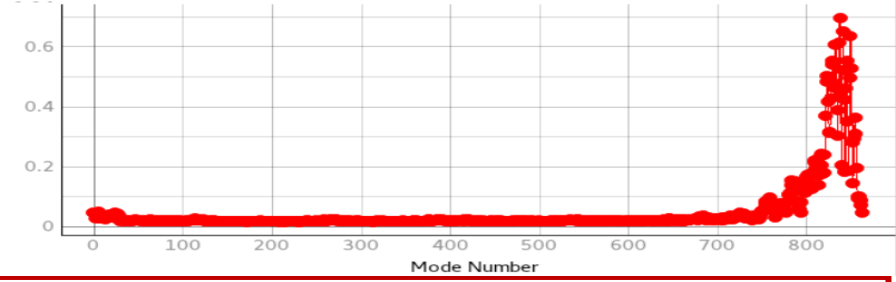

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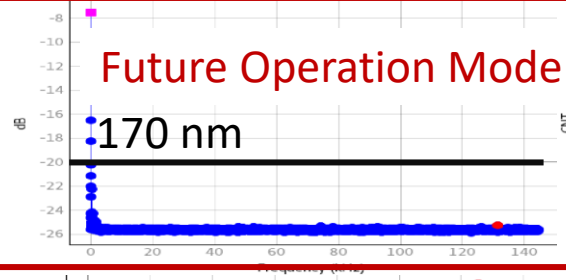

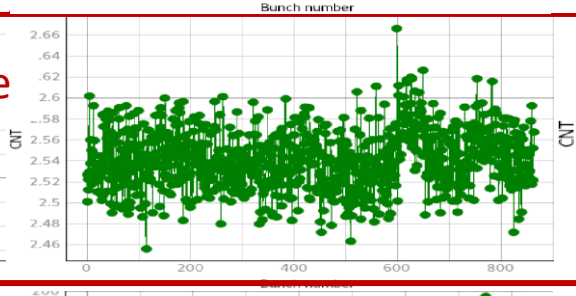

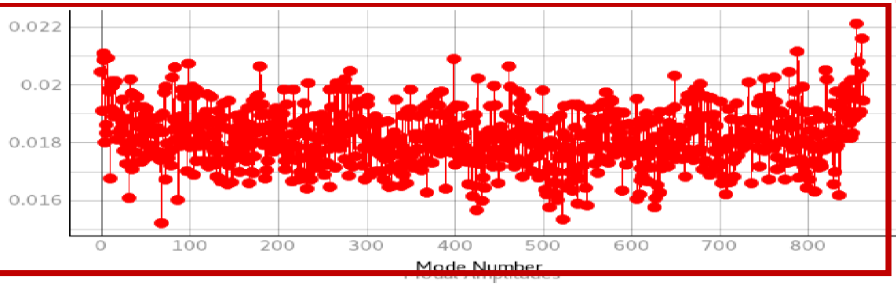

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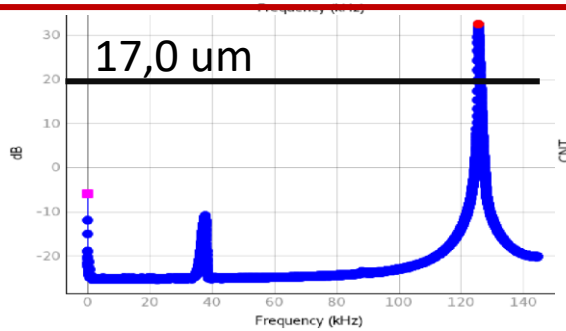

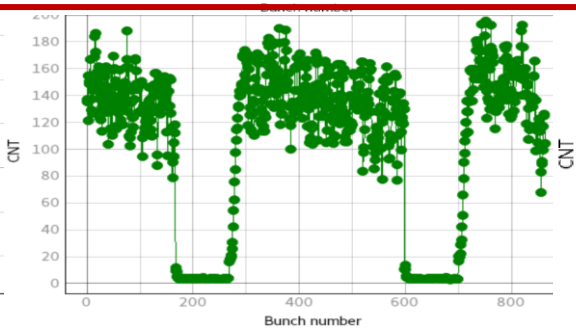

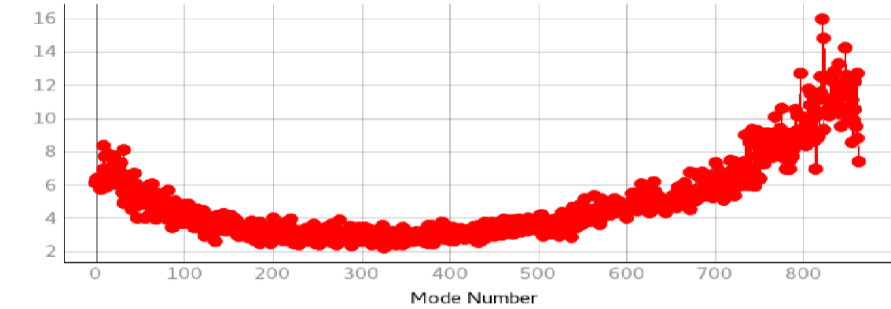

Summary

Summary

- A few important subjects not addressed in this presentation:
  - Effect of IDs on orbit: Feedforward with correctors as close as possible to ID and/or FOFB;
  - Tune variation due to IDs and drifts: Currently is small, but feedback loop is planned;
  - Effect of IDs on equilibrium parameters: Not observed with current IDs, but is priority for the near future;

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- Short-term stability was largely improved, but still needs enhancements in both areas: septa leak field and NLK perturbations;

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Thank you for your attention!

Thanks also to Liu Lin, Murilo Alves and all my colleagues that helped putting this presentation together.