Helmholtz Zentrum Berlin

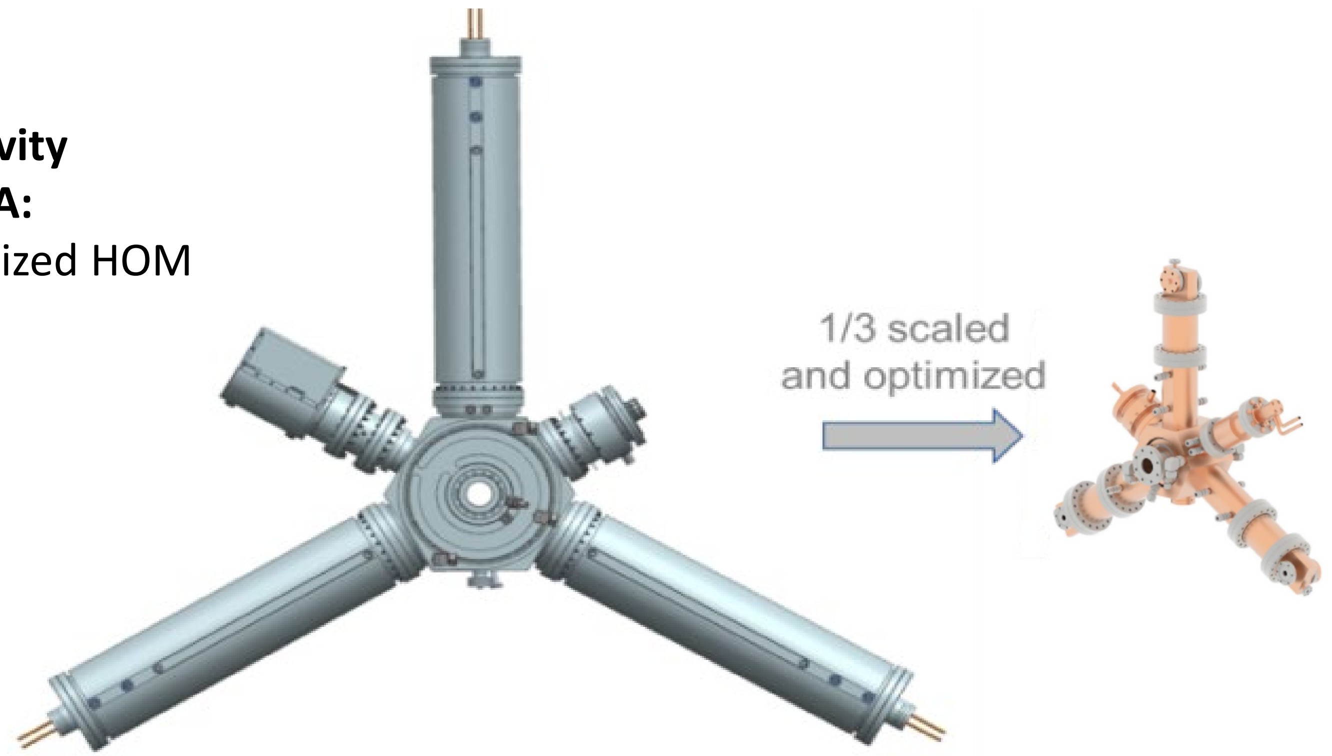
First commissioning results of the Harmonic EU cavity (ALBA Active Design) at BESSY II

A.Matveenko for ALBA/HZB/DESY 3HC collaboration

11.10.2022

HarmonLIP 2022

Proposal for
3rd Harmonic Cavity
(1.5GHz) for ALBA:
Scaled and optimized HOM damped cavity



500 MHz HOM damped normal conducting cavity

1500 MHz ACTIVE HOM damped NC cavity

BACKGROUND: MILESTONES

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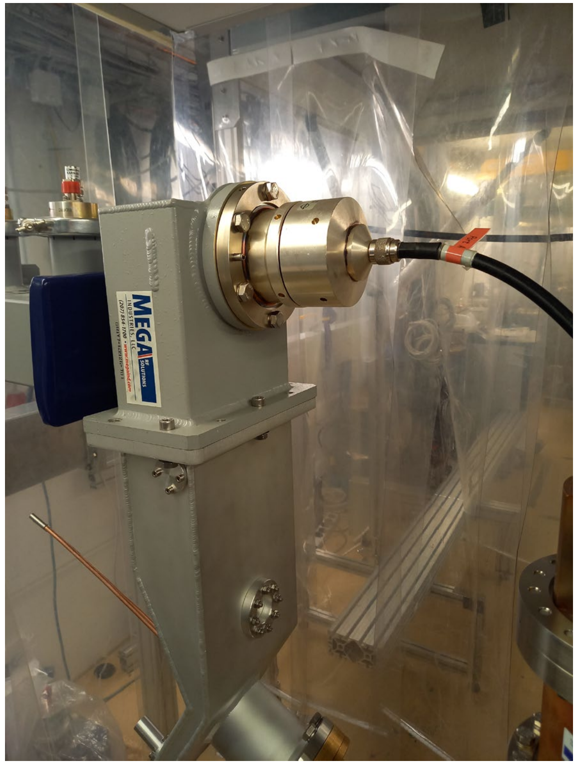
- 2015 – ALBA team started the desing of an active 1.5 GHz normal conducting cavity for CLIC Damping Ring and ALBA 3rd harmomic
- 2018 – ALBA, with EU funds, started the construction of a prototype
- September 2019 – tender for cavity production awarded to AVS & Viztro
- 2020 – collaboration agreement between ALBA, HZB and DESY for testing the cavity
- November 2021 – cavity delivered to ALBA
- December 2021 – cavity at HZB
- **February 2022 – bead pull measurements**
- **April 2022 – high power conditioning in HoBiCaT at HZB**
- **May 2022 – cavity installed in BESSY II storage ring**
- **August 2022 – commissioning with beam started**

OUTLINE

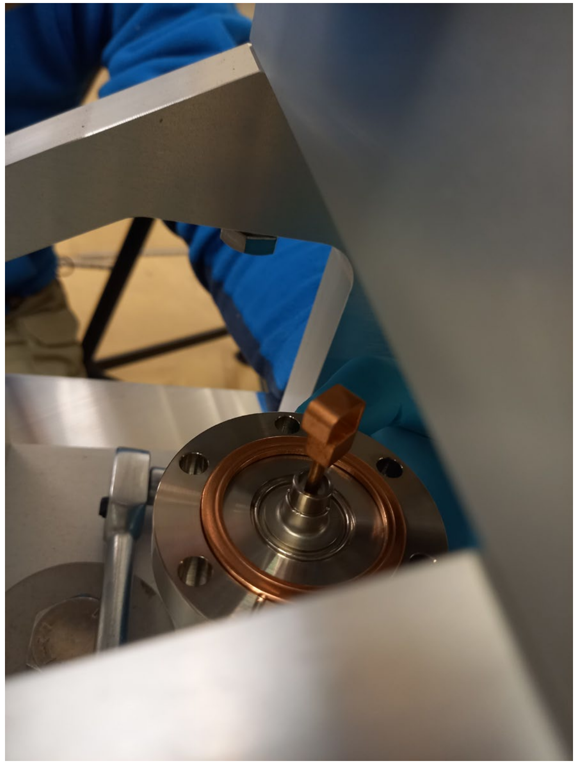
- Cavity conditioning (HoBiCaT)
    - Bead pull measurement
    - High power conditioning
- Commissioning with beam (BESSY II)
    - Passive mode
        - Park position
        - High current operation
    - Active mode
        - Conditioning without the beam
        - Low current measurements
        - High current run

3HC CAVITY IN A CLEAN ZONE FOR BEAD PULL

Port 1: main coupler (β~0.44)



Port 2: pickup antenna (modified)



BEAD PULL SYSTEM INSTALLED ON THE CAVITY FLANGES

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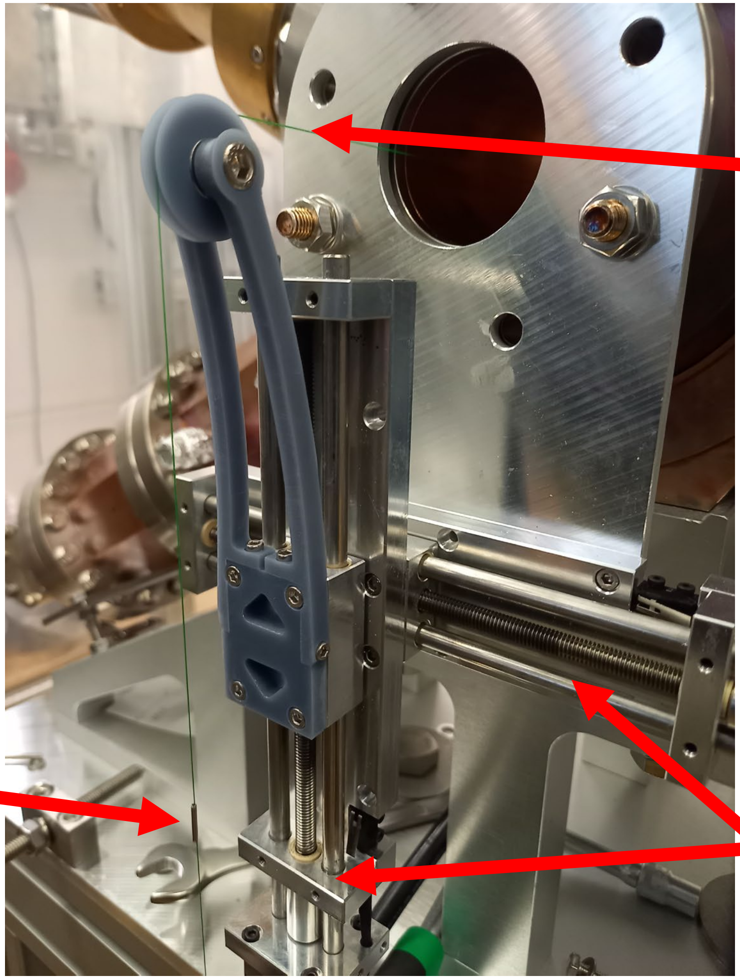
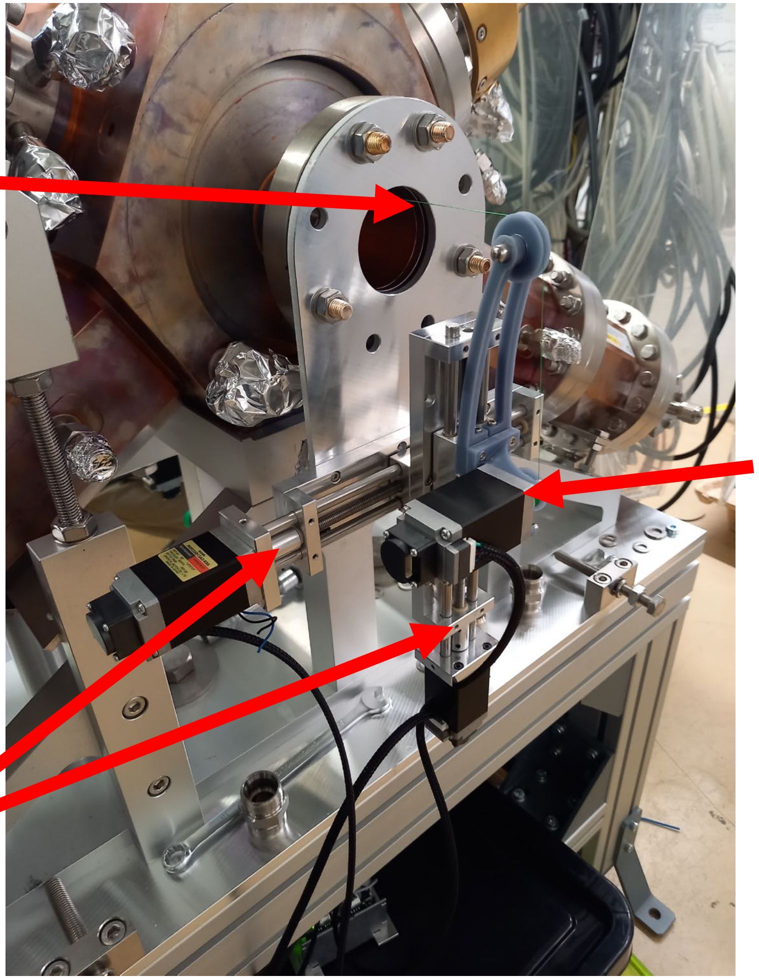




Wire

Pulling motor

Bead

XY-tables

To counterweight

BEAD PULL

3 beads were used (calibrated afterwards in a pillbox cavity):
- Pb sphere 3.3 mm
- Dielectric sphere 10 mm (ε=2.8)
- Metallic (syringe) needle 10mm x ⃠1.3mm

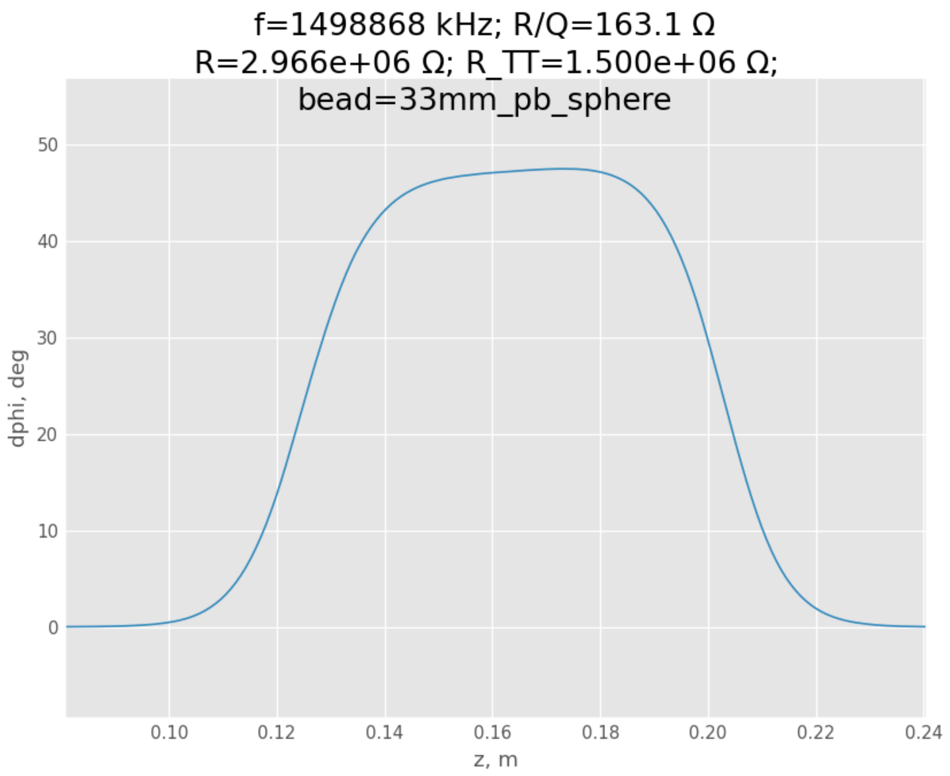
Main mode:
- high sensitivity (3.3mm Pb bead was used)
- Isolated (off resonance measurements possible)

HOMs:
- lower signal (in our case dielectric bead gives best signal to noise ratio)
- often overlapping with or close to other modes
- most modes without clear symmetry (CST simulations necessary)

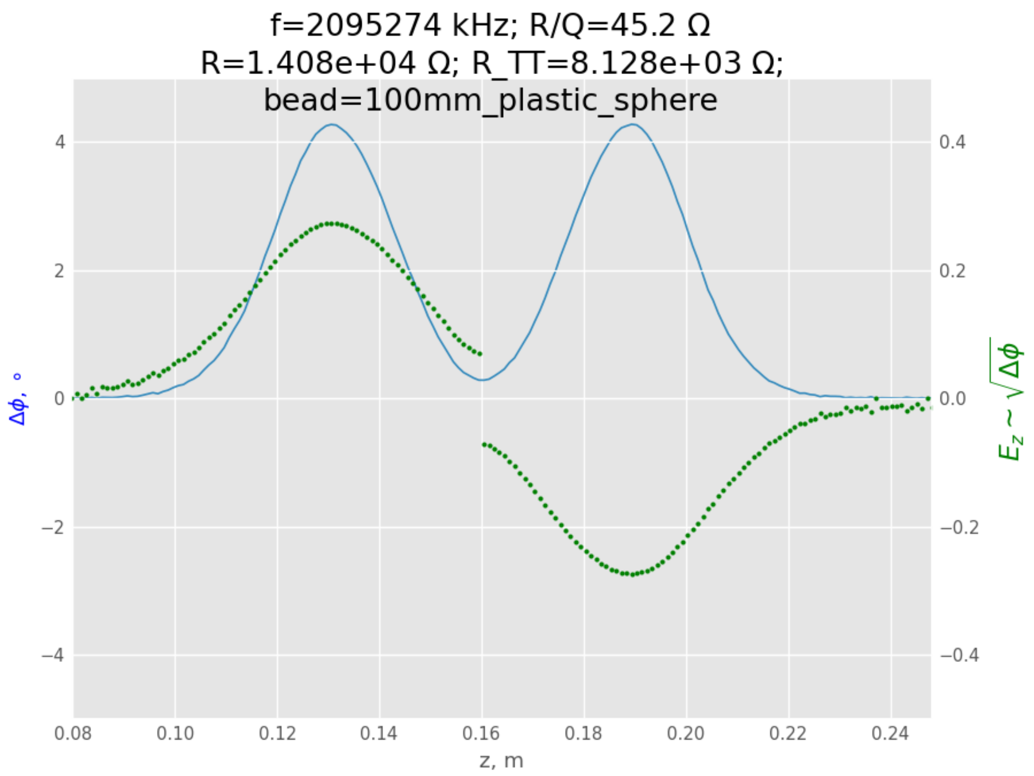
CST simulations are necessary to interpret bead pull results (thanks to W.Müller, TU Darmstadt)
- ~E^2 is measured, not E_z
- Cavity is “far from a pill box” due to many openings, mode geometry is complex
- CST mode analysis is done up to 2.9GHz
- At f > 2.9GHz the derived impedance of the modes is still an upper estimation

BEAD PULL RESULTS

Main mode (TM010)



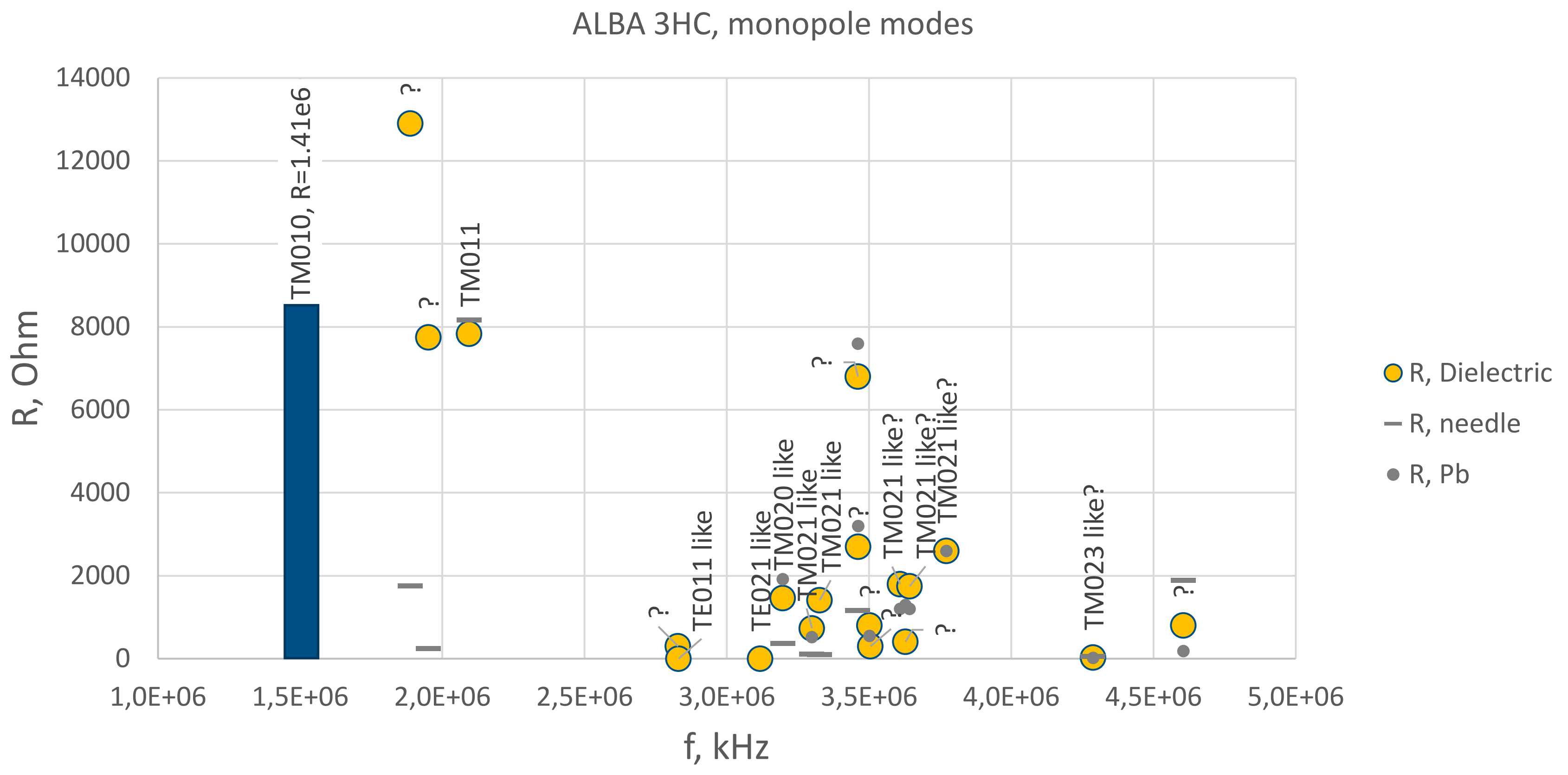
TM011 mode



R/Q very close to the expected values from CST simulations (for these modes)

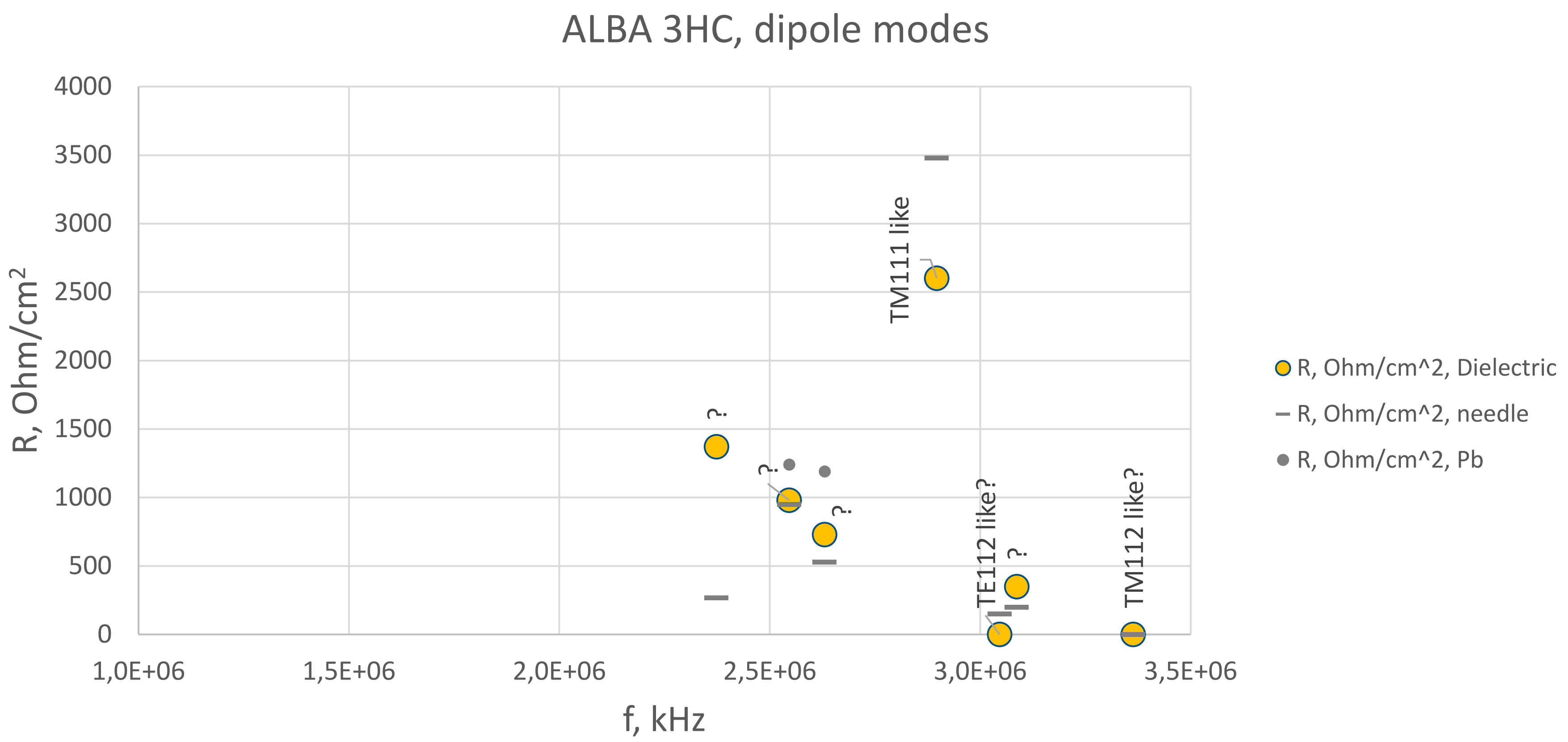
(R/Q here in accelerator definition)

BEAD PULL RESULTS



(Loaded shunt impedance in accelerator definition)

BEAD PULL RESULTS



(Loaded shunt impedance in accelerator definition at 1 cm offset)

BEAD PULL SUMMARY

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- The cavity modes correspond to the CST model (no surprises)
- Shunt impedance of the main mode as expected
- Interpretation of the bead pull results for HOMs demands CST simulations
- Most dangerous modes for longitudinal multi-bunch instability seem to be TM011 (2.092GHz) and maybe an unidentified mode at 3.461GHz

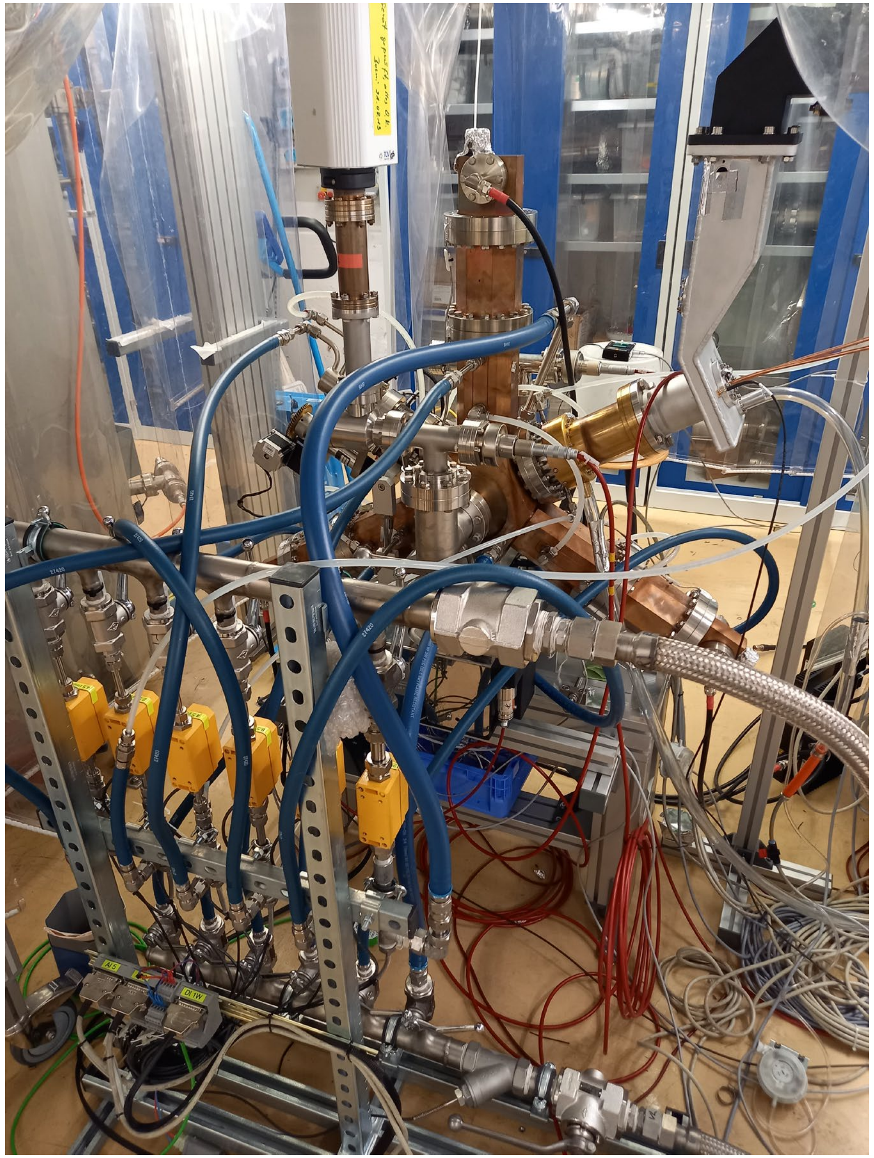
HIGH POWER CONDITIONING

After bead pull measurements were finished:

- Bake out
- Water cooling and cabling
- 15 kW SSA connected
- LLRF (ALBA) used for high power conditioning

Conditioning from 19.04.22 to 20.05.22 (part-time due to other groups working in parallel in the HoBiCaT bunker)

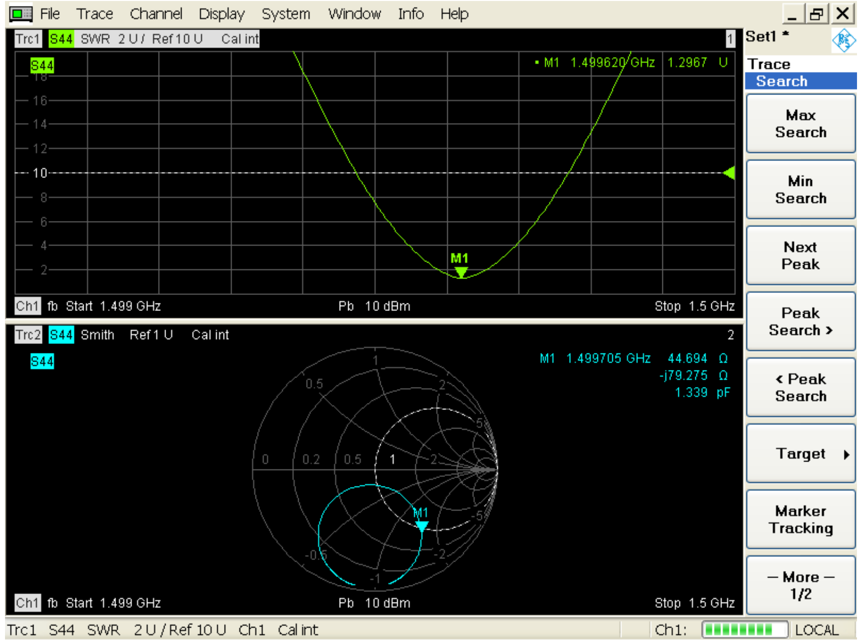
- Up to SSA limit (~14 kW) stable operation
- Multipacting bands at ~0.8kW and 2.0kW, successfully processed
- Plunger conditioned in “completely inside” position
- Temperature sensors are in expected limits ($\Delta T < 13$°C)
- “Long term” stability successfully checked (~60 hours uninterrupted at ~14kW)



BESSY II PARAMETERS

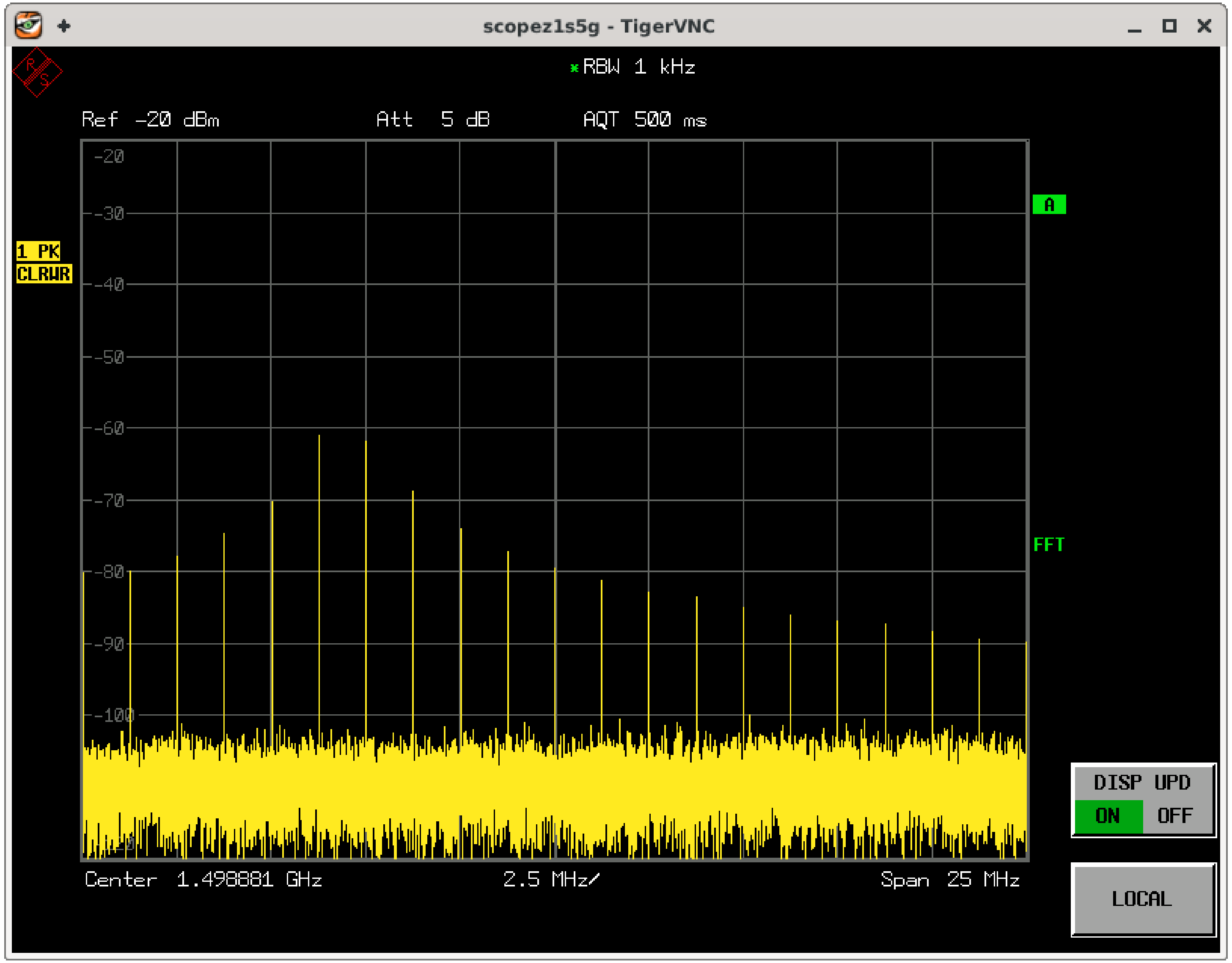
Parameter	Value
Energy E	1.7 GeV
Circumference	240m
Beam current I	300mA (up to 400mA)
Harmonic number h	400
Main RF frequency f_{rf}	500MHz
Main RF voltage V_{rf}	1.4MV (up to 2.0MV)
3rd harmonic cavities voltage	0.3MV
Revolution frequency f_{rev}	1.25MHz
Momentum compaction factor α	7.3×10^{-4}
Relative natural energy spread δ_0, rms	7.0×10^{-4}
Losses per turn	178keV + IDs + passive cavities + …
Synchrotron frequency f_s	7.6 kHz (low current, without 3rd harmonic)
Longitudinal radiation damping time τ_z	8 ms

- Transition to the ring in May 2022
- Coupling readjusted to β~0.78
- No bake out was necessary



FIRST BEAM

- Cavity parked -4.5 revolution harmonics away from the master clock
- Single bunch spectrum ->
- Injection to full current (300 mA) successful



PLUNGER FULL SCAN (3mA SINGLE BUNCH)

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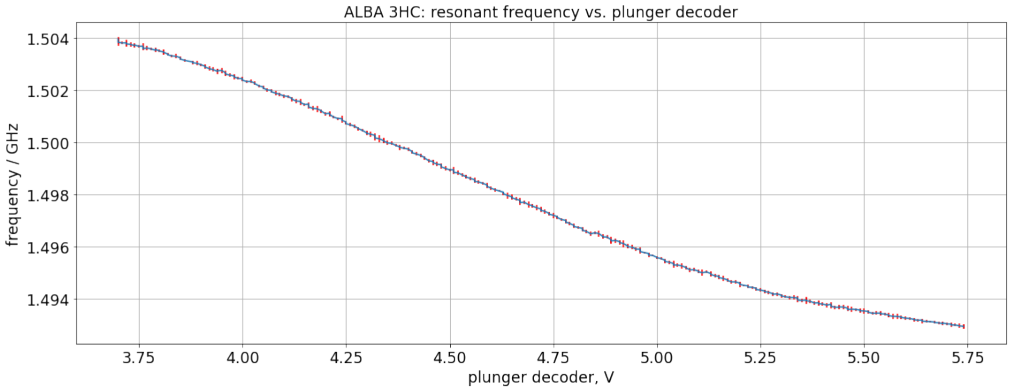
Red – plunger position read back

Green – P_f

Blue – P_r

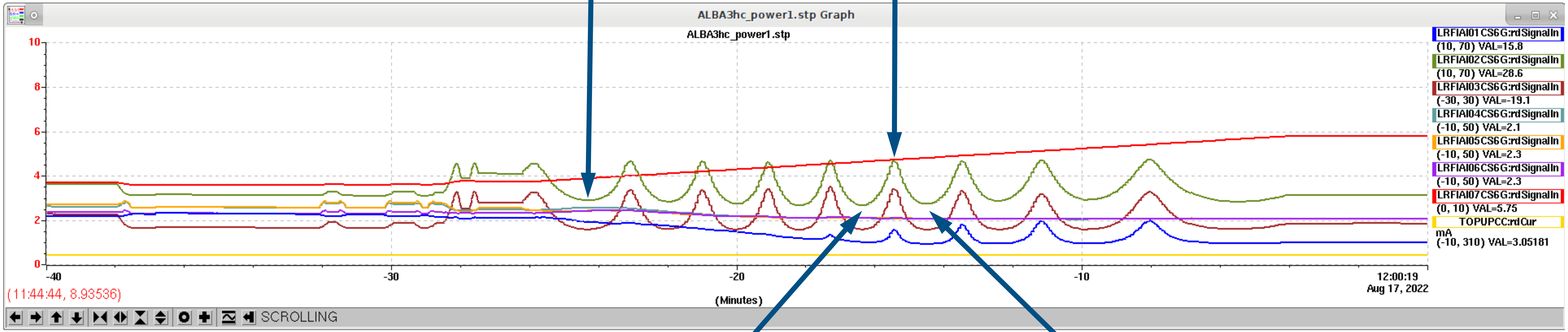
Braun – P_{pickup}



$3f_0$

Parking position

$3f_0 - 4.5f_{rev}$



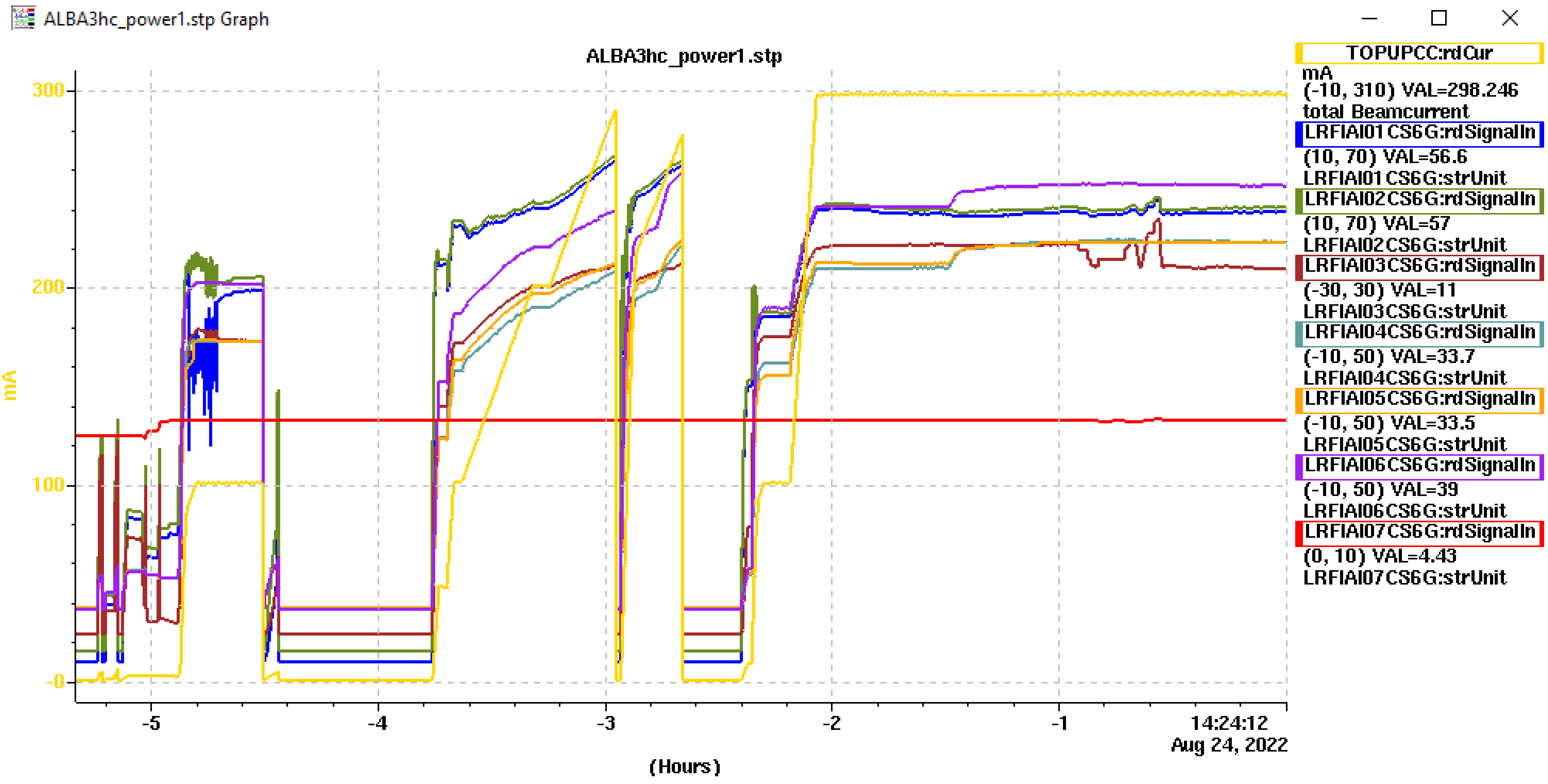
Park-shortening position

$3f_0 - 0.5f_{rev}$

Park-lengthening position

$3f_0 + 0.5f_{rev}$

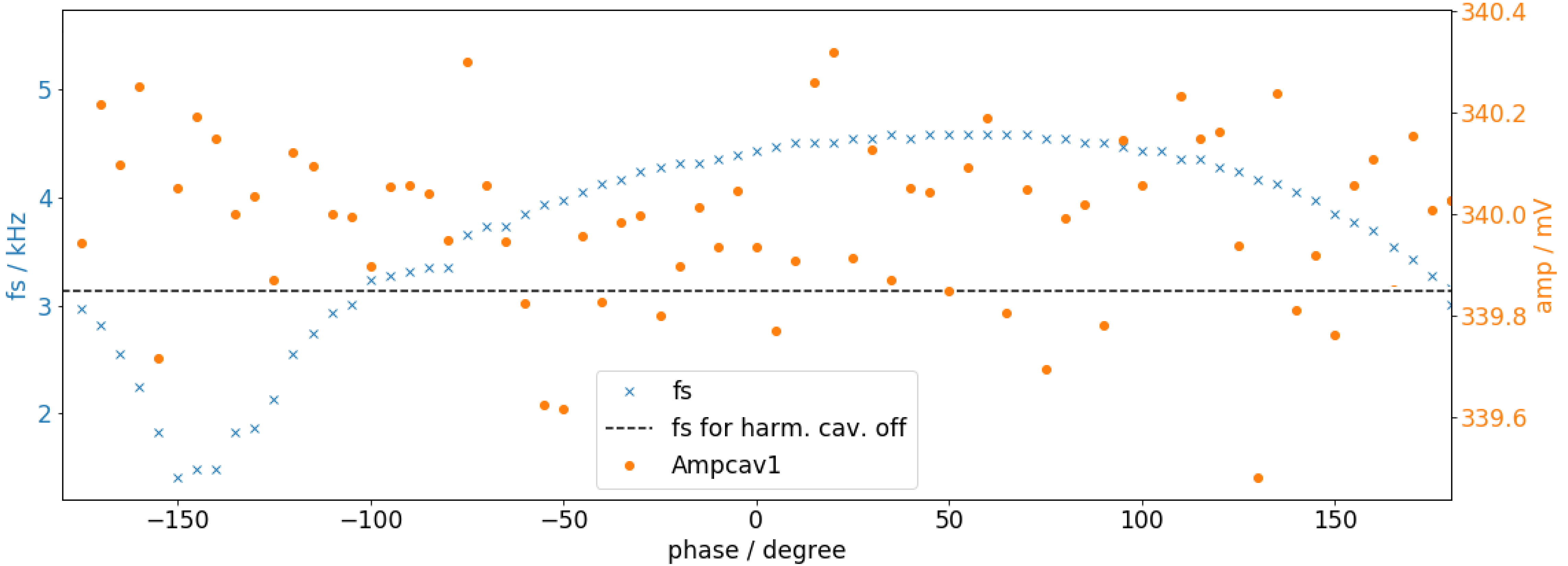
STABLE IN PARK-LENGTHENING AT 300mA



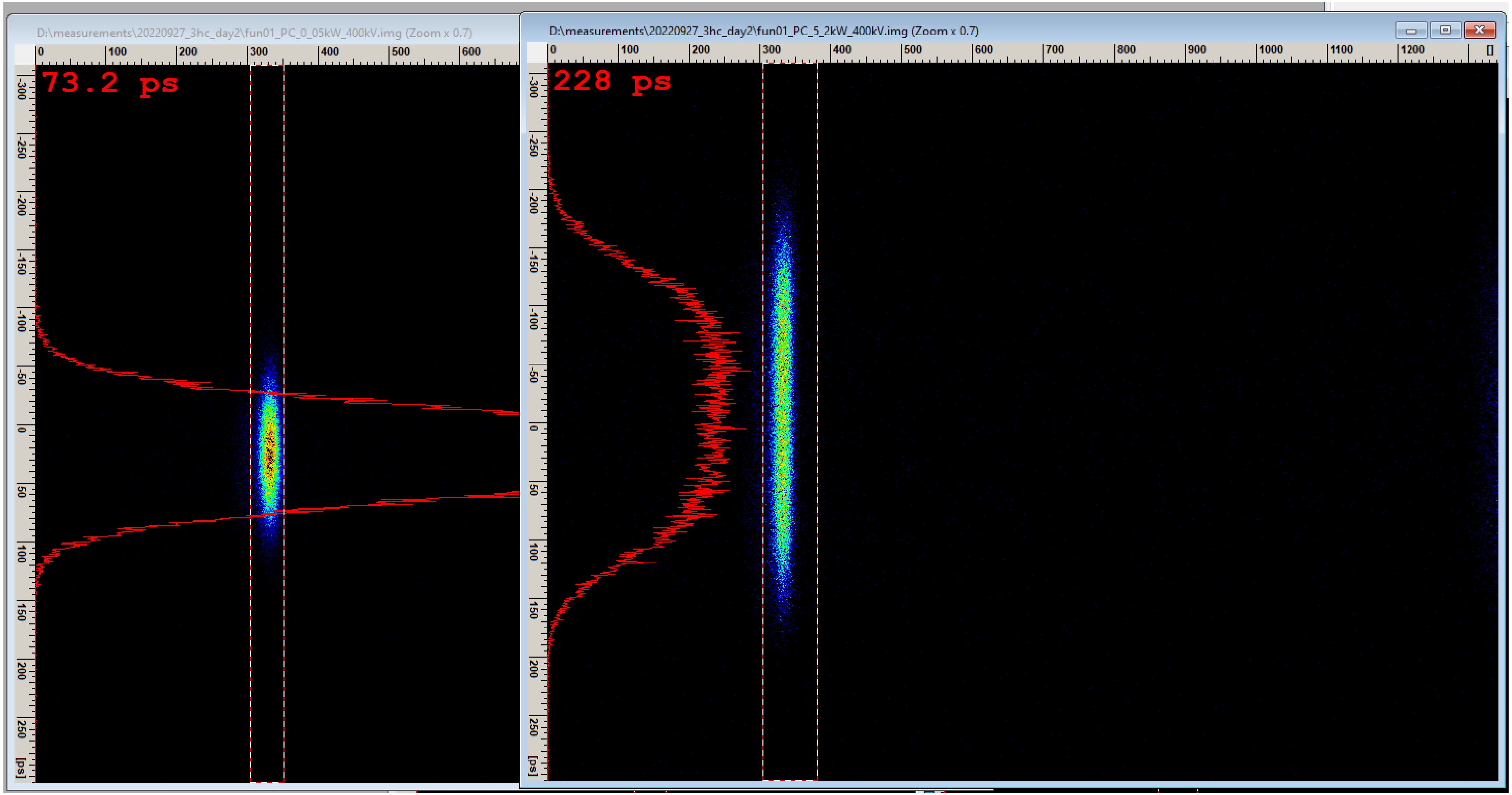
COMMISSIONING OF THE CAVITY IN ACTIVE MODE

- SSA commissioned to full power (15kW) with a water-cooled load
- Cavity conditioned to full power (15kW) without the beam
- Calibration of the cavity voltage
- Low current operation and bunch length measurements
- High current operation and stability test
- Transient beam loading measurements

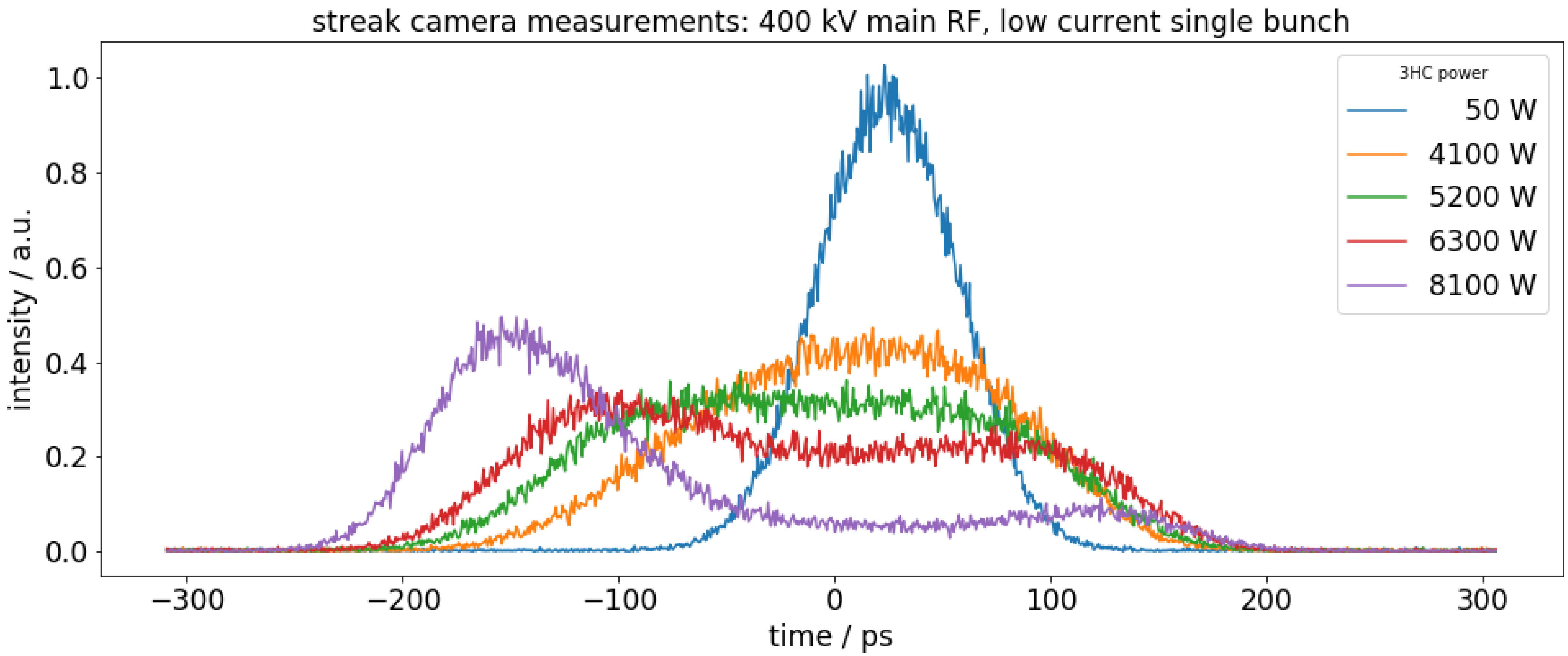
PHASE SCAN (400kV main RF, 4.1 kW harmonic)



MAX BUNCH LENGTHENING (400kV main RF)



BUNCH LENGTH (400kV main RF)



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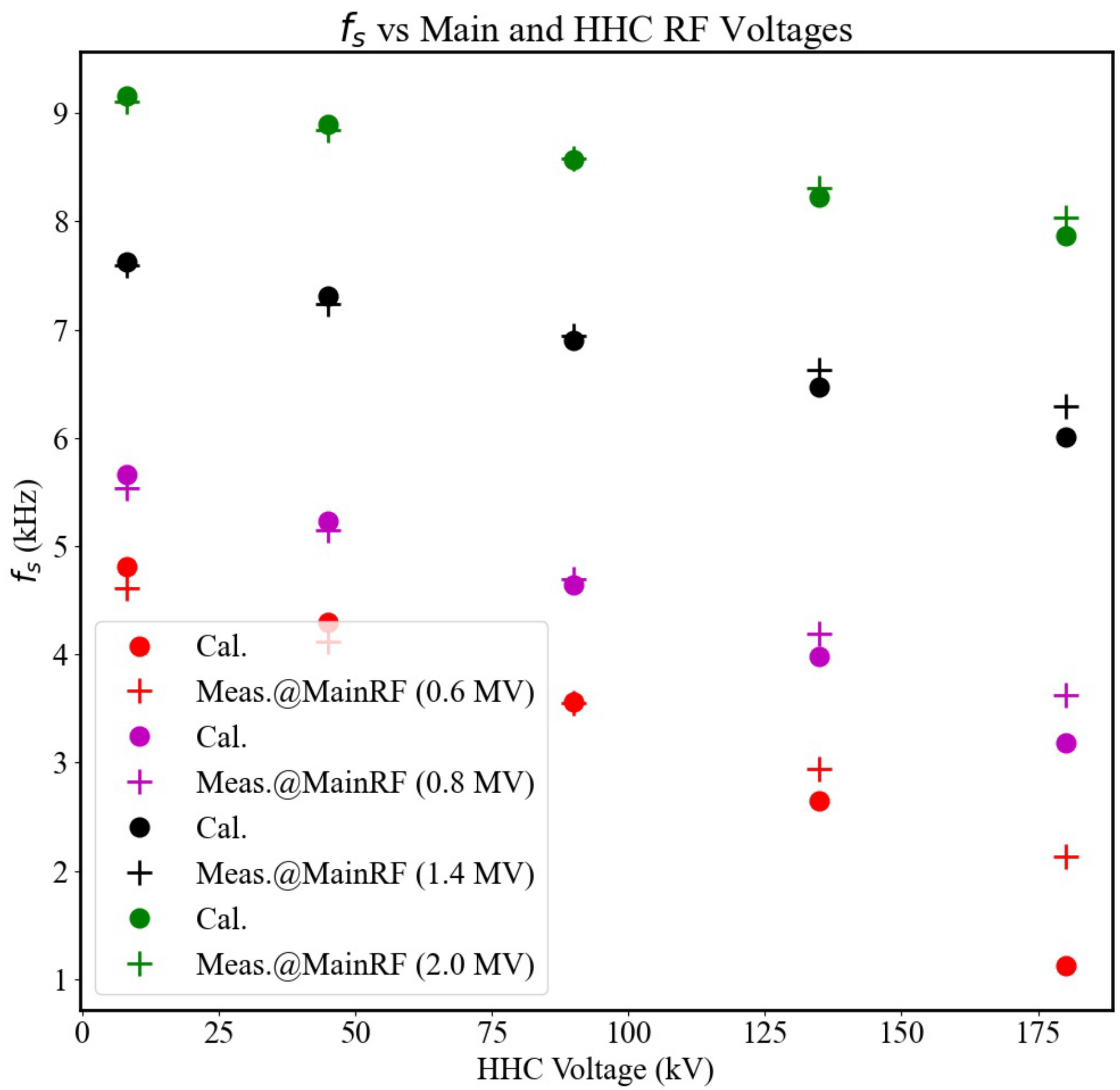
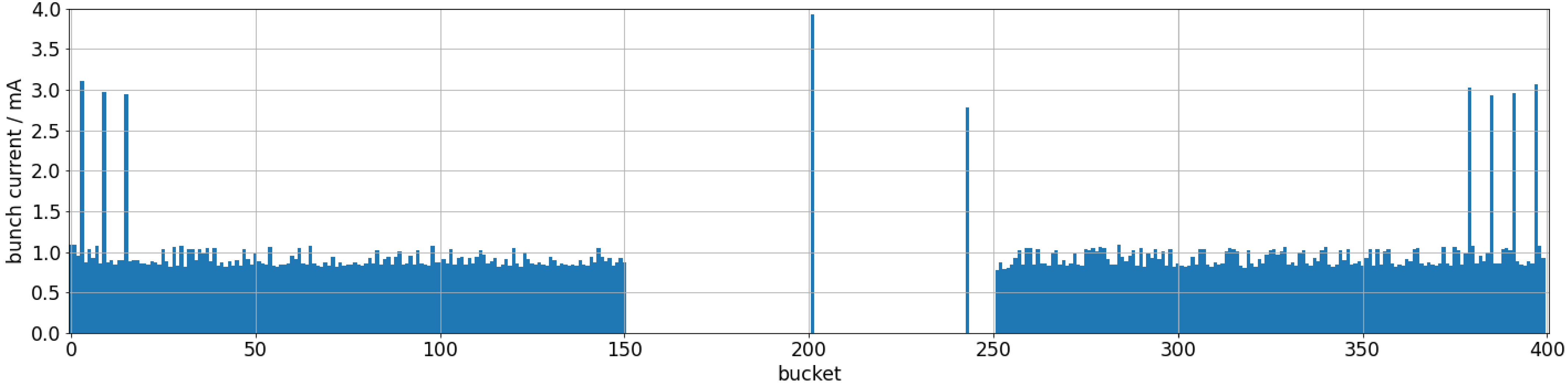
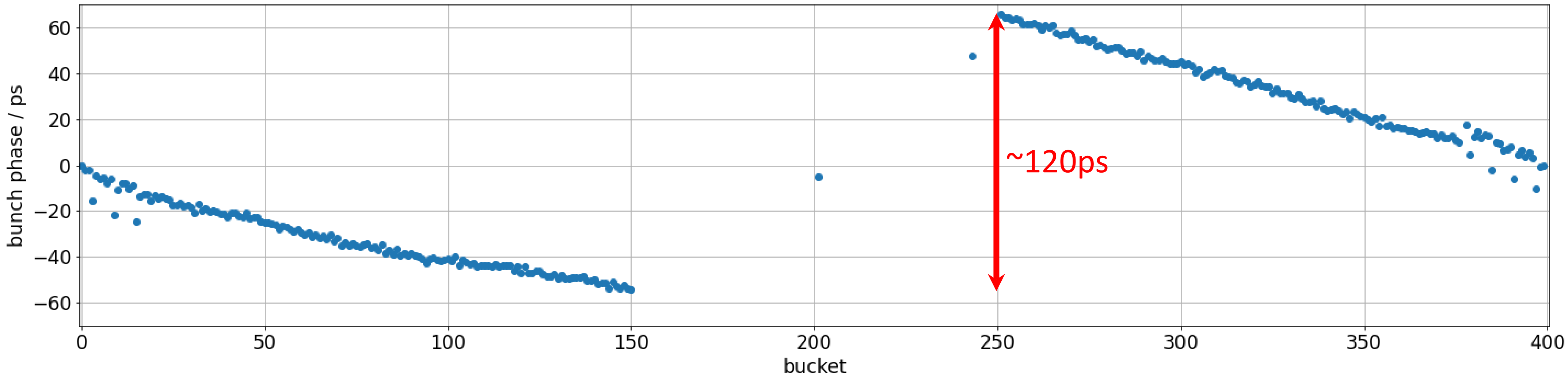
f_S FOR DIFFERENT V_1 AND V_3

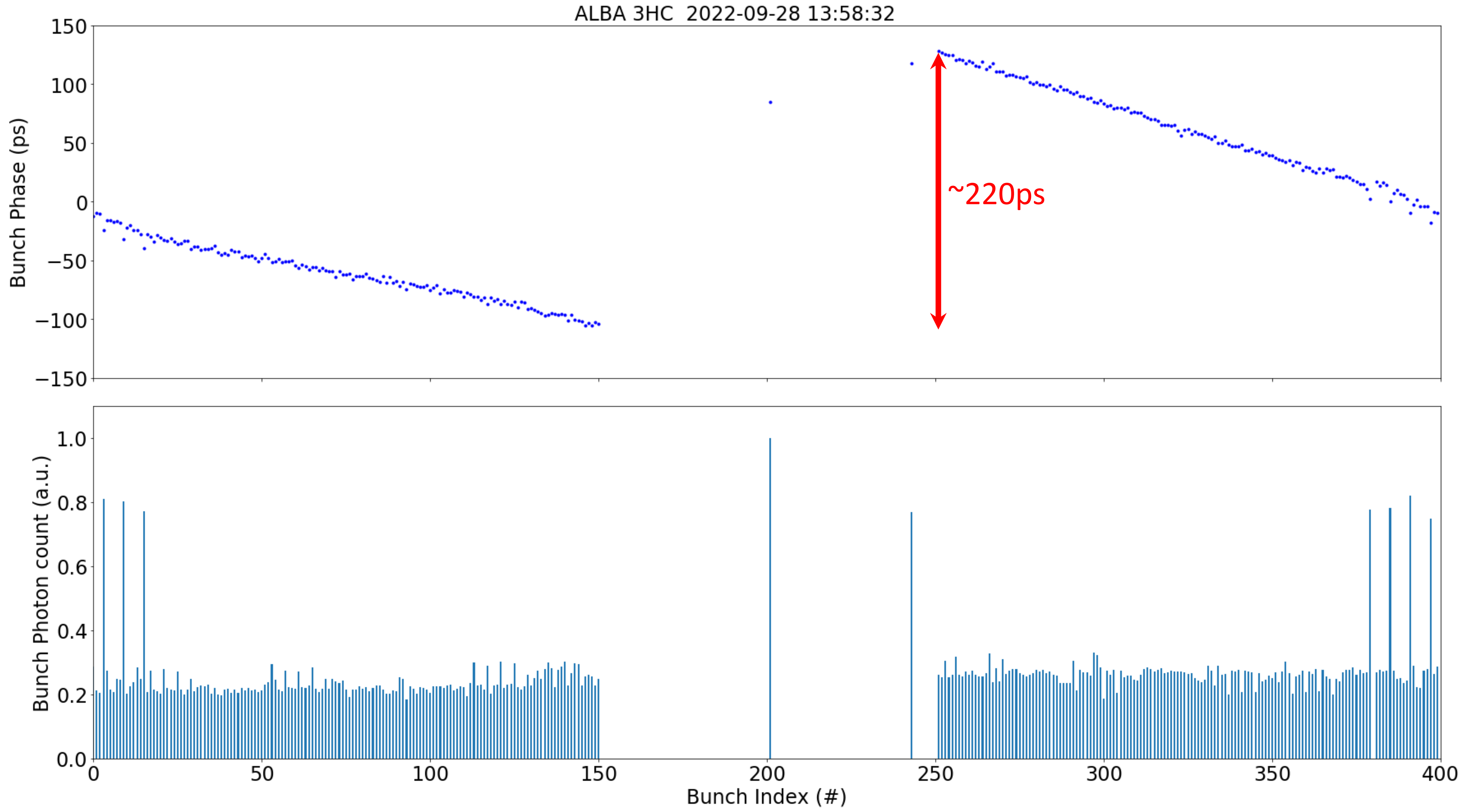


BESSY II TRANSIENT BEAM LOADING
STANDARD USER MODE (4 x 3RD HC PASSIVE (3KW))

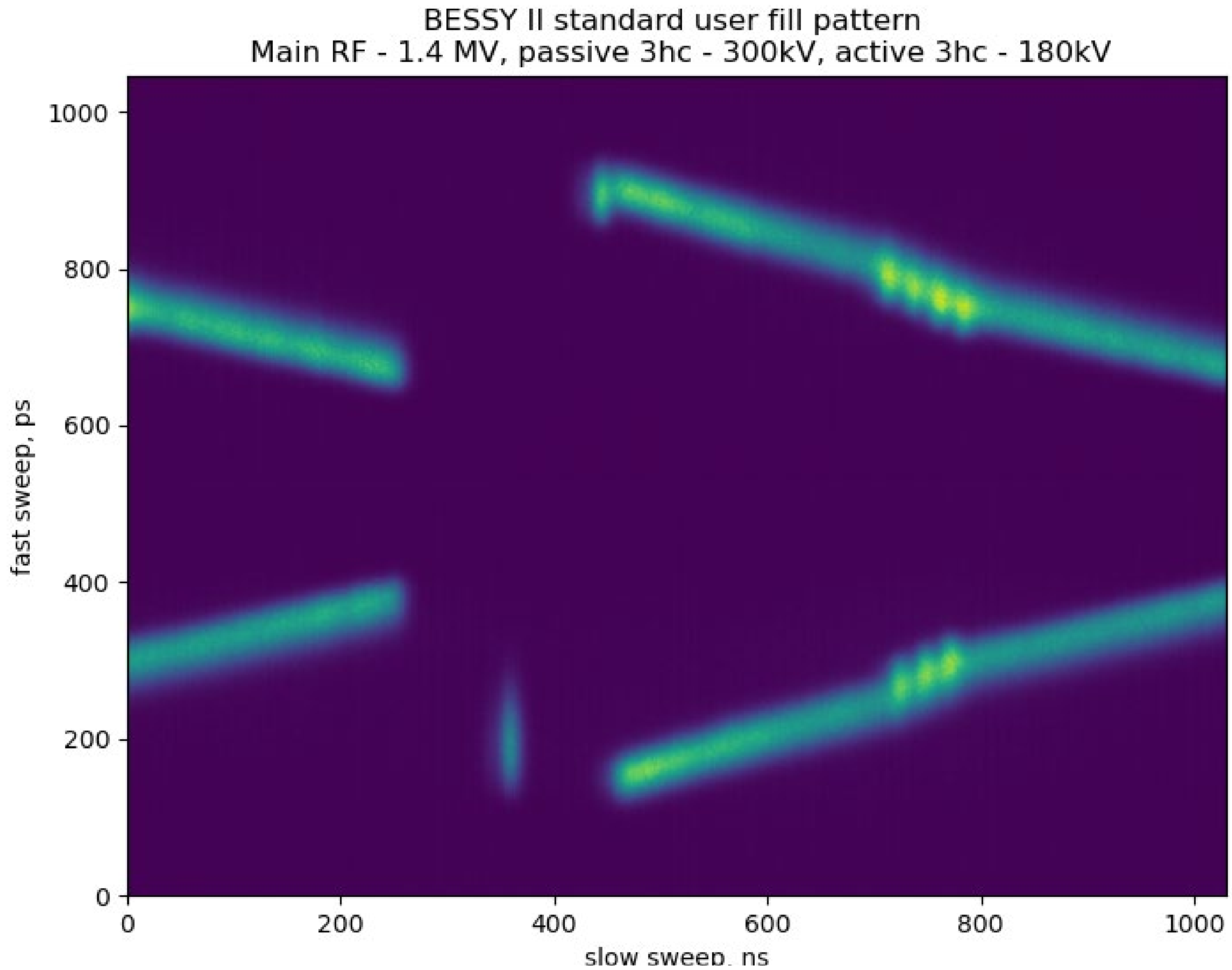


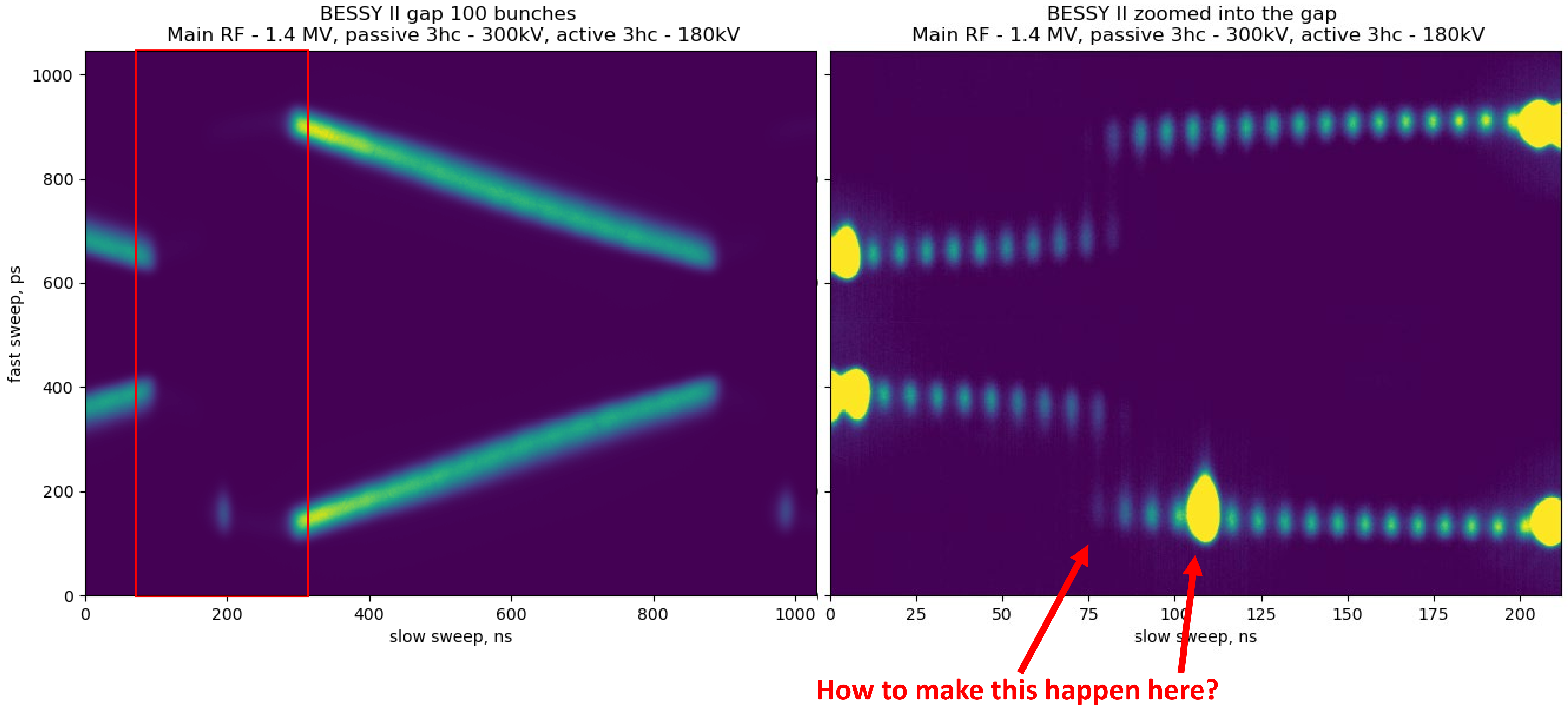


TRANSIENT BEAM LOADING: 4 x 3RD HC PASSIVE (3KW) + ACTIVE (180KV) CAVITY



TRANSIENT BEAM LOADING

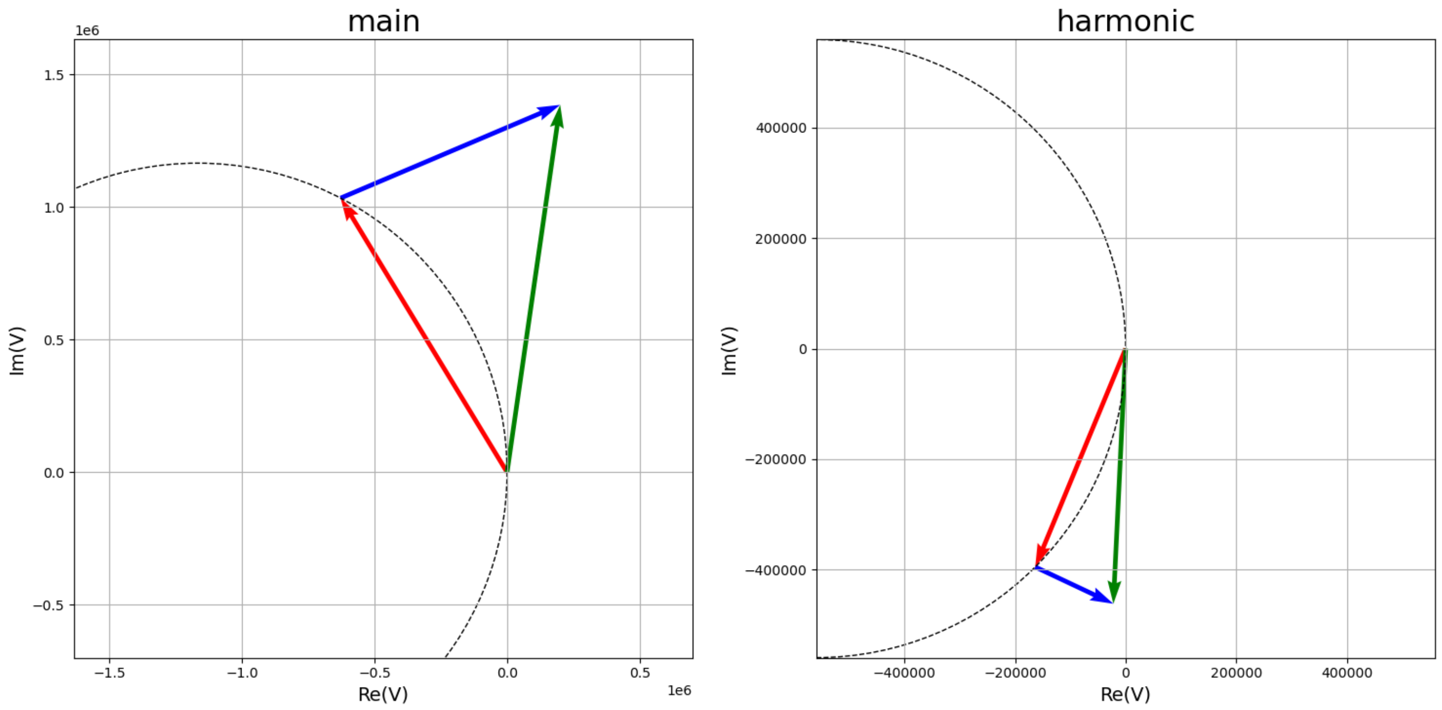




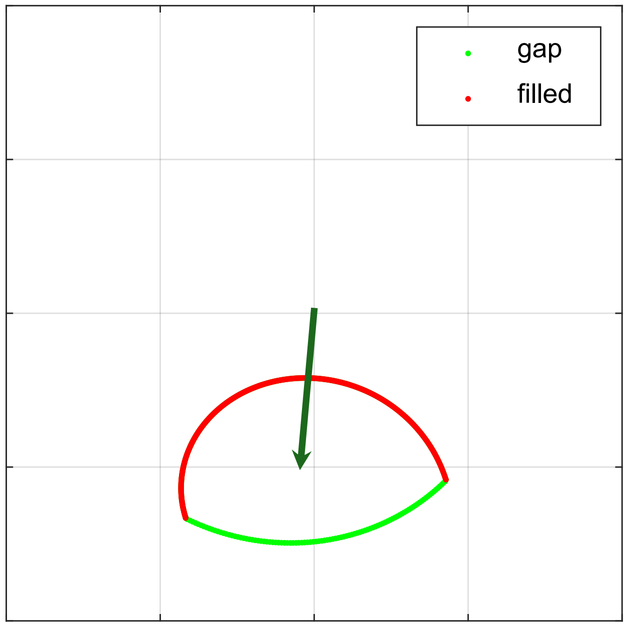
BESSY II gap 100 bunches
Main RF - 1.4 MV, passive 3hc - 300kV, active 3hc - 180kV
fast sweep, ps
0
200
400
600
800
1000
slow sweep, ns
BESSY II zoomed into the gap
Main RF - 1.4 MV, passive 3hc - 300kV, active 3hc - 180kV
0
25
50
75
100
125
150
175
200
slow sweep, ns
How to make this happen here?

No transient beam loading

Phasors of main and 3rd harmonic RF



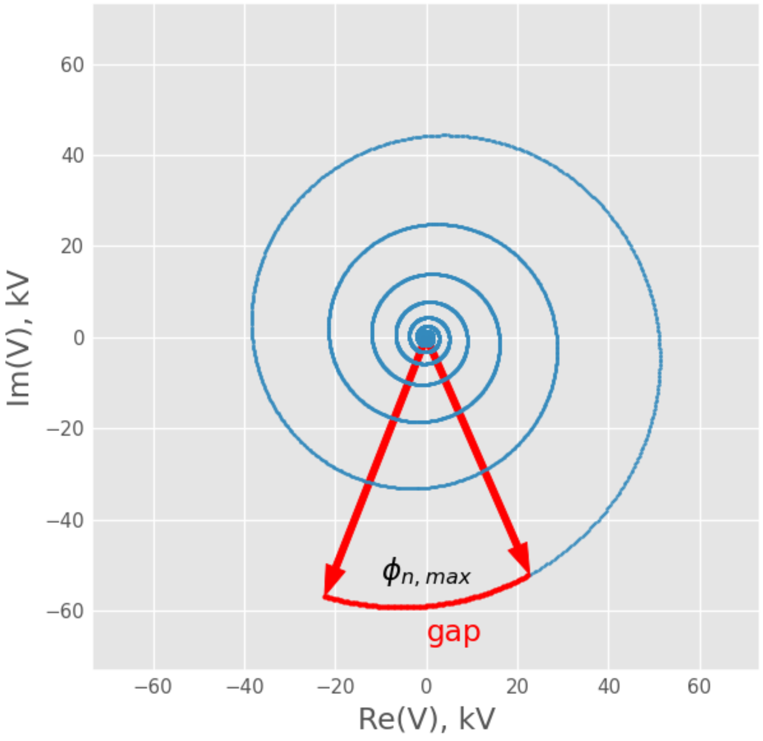
With transient beam loading



For transient compensation the generator should do the same contradanse (fast feed forward)

TRANSIENT BEAM LOADING

Phasor diagram for harmonic cavity with transient beam loading



Estimation of the transient over a gap:

$$\Delta t = \frac{nI_0}{V_0}\frac{R}{Q}T\frac{1}{1-kn}$$

n - harmonic number

I_0 - beam current

V_0 - amplitude of the main RF

T – gap length, s

k – ratio of amplitudes of harmonic to main RF

$\frac{R}{Q}$ - shunt impedance

(be careful to use this expression! There are many assumptions made during derivation)

With BESSY II parameters in standard user operation, one gets $\Delta t = 100$ps, close to the measured value of 120ps

SUMMARY

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- Harmonic EU cavity (ALBA Active Design) is being commissioned in BESSY II storage ring
- Bead pull measurement and high power conditioning were made in HoBiCaT
- Commissioning with beam started in BESSY II
  - Successful operation in passive mode
  - Operation with voltage amplitude up to **180kV** (**15kW** wall losses)
  - Successful operation in active mode with up to **300mA** beam current with BESSY II standard user fill pattern
  - Bunch lengthening up to **factor 3.1** is demonstrated
- Further foreseen studies:
  - transient beam loading
  - longitudinal multi-bunch instability
  - Long term operational stability

Parameter	Value
frequency	1500MHz
Plunger range	-7 … +4 MHz
R/Q (accelerator definition)	163Ω
Q0	14000
demonstrated voltage	180kV
demonstrated wall losses	15kW
stable operation with beam current	300mA
Installation length	0.3 m

ACKNOWLEDGMENTS

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