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Investigations of Long-range and Short-range Wakefields on Beam Dynamics in TESLA-Type Superconducting rf Cavities (LRW/SRW): Update

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FNAL Collaborators: Alex Lumpkin (Co-PI), Chip Edstrom, Jinhao Ruan, Peter Prieto, Randy Thurman-Keup

Alex Lumpkin and Randy Thurman-Keup

Studies on 02-04-21 CC2

AST Meeting

02-18-21 CM2

12 March 2021

Objective 2: Extend SRW Data Base for ASTRA Benchmark

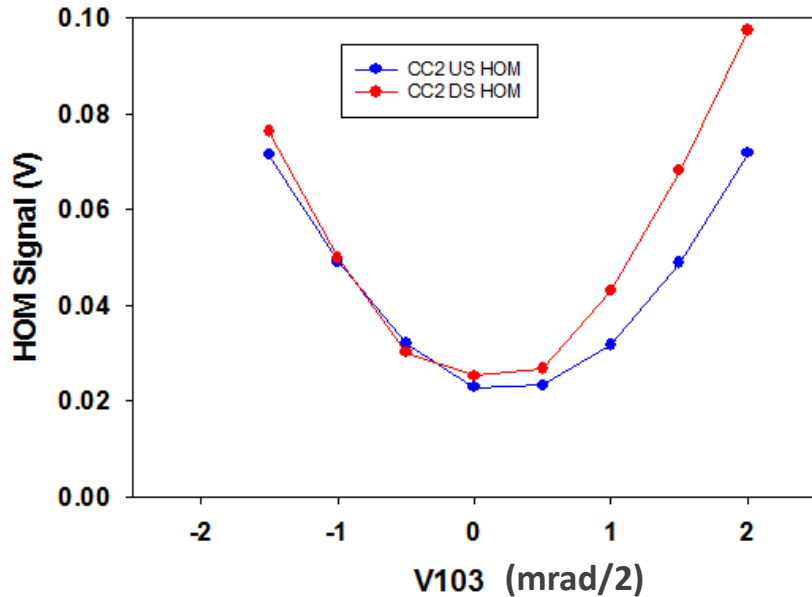
- Investigate LRW/SRW effects at lower energy: 20.5 MeV. 2x8
- Prerequisite is higher charge for streak camera imaging of SRW. Run 2 used 0.25, 0.5, 1.0, and 1.5 nC/b.
- OTR signal reduced at 20.5 MeV vs 41 MeV. Use 40 images.
- SRW kick angle will be enhanced by lower energy. Would have been more if 8 and 8 MeV split instead of 16 and 0 MeV in CC1 and CC2, respectively. Use V103 then V101 scans.
- New CC2 LRW causing beam centroid slew/oscillation will be reduced at X121 by reduced beta function. Q118-120 ON.
- SRW is a submicropulse effect so could reduce bunch # from 50 to 25 b or 10 b subject to S/N ratio and statistics. Need Q.
- Entrance slit of streak camera will set spatial acceptance window in x plane.

CC2 HOMs Probed with V103 Scan

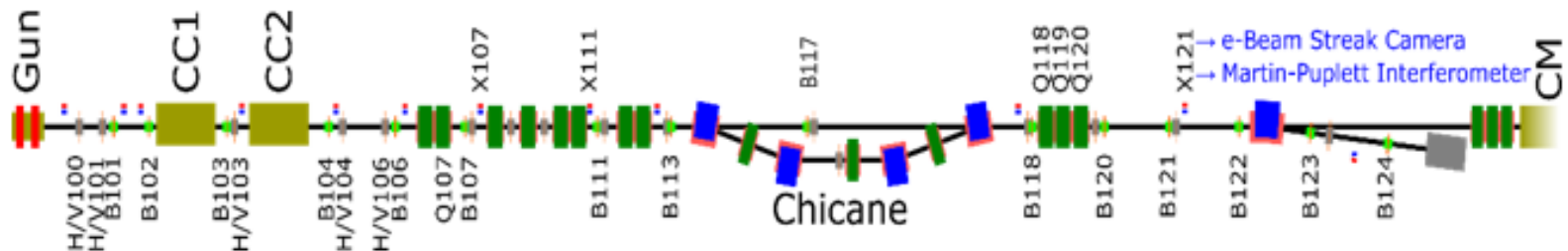
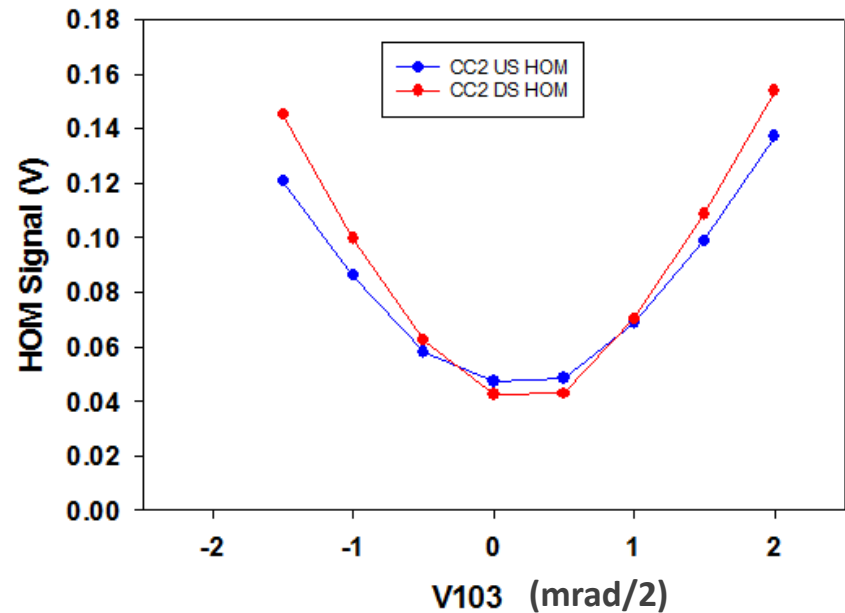
02-04-21

- HOM signals for different charges, 500 pC/b and 750 pC/b.
- 1.75-GHz band. Open iris above 500 pC/b. Double VC spot.

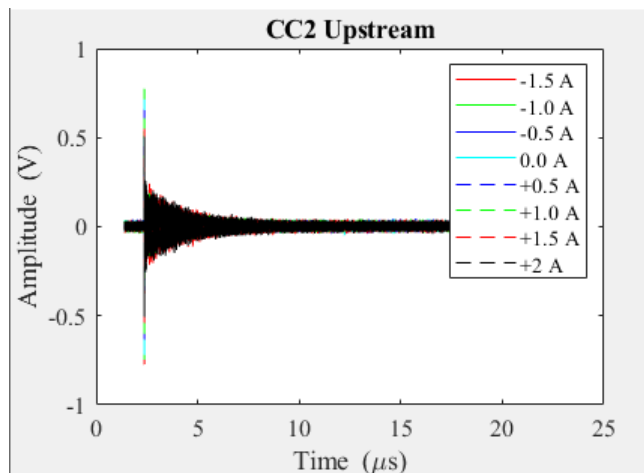
V103 Scan, HOMs 500 pC/b Hybrid box on CC2 02-04-21



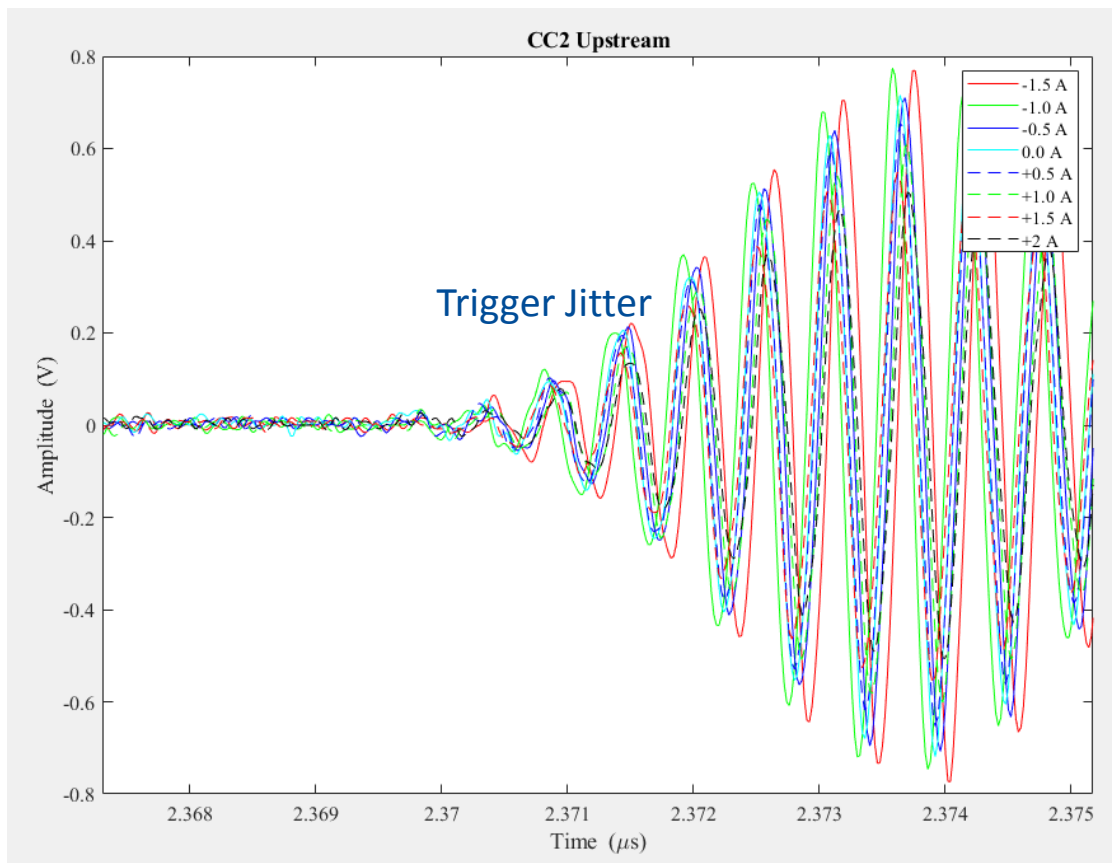
V103 Scan HOMs 750 pC/b Hybrid box on CC2 02-04-21



CC2 HOM Spectral Analysis Enabled with Better Trigger



- Look at start of signals to determine trigger jitter
 - Full range of these 8 acquisitions was 170 ps, rms was 55 ps.
- Adjust arrival time of each to coincide
 - Use frequency dependent phase adjustment



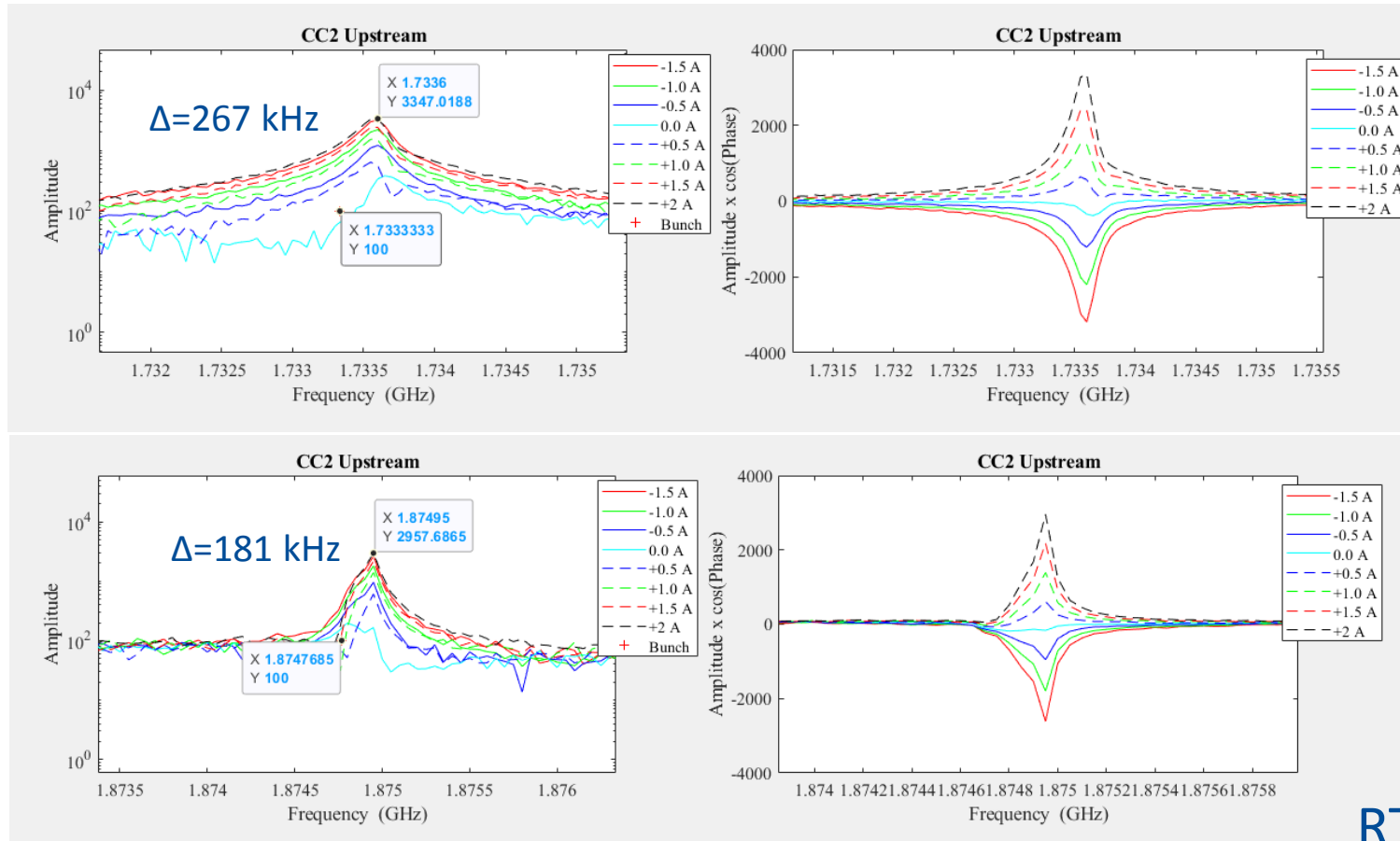
RTK Plots



CC2 V103 Scan Show HOM Near Resonances

02-04-21

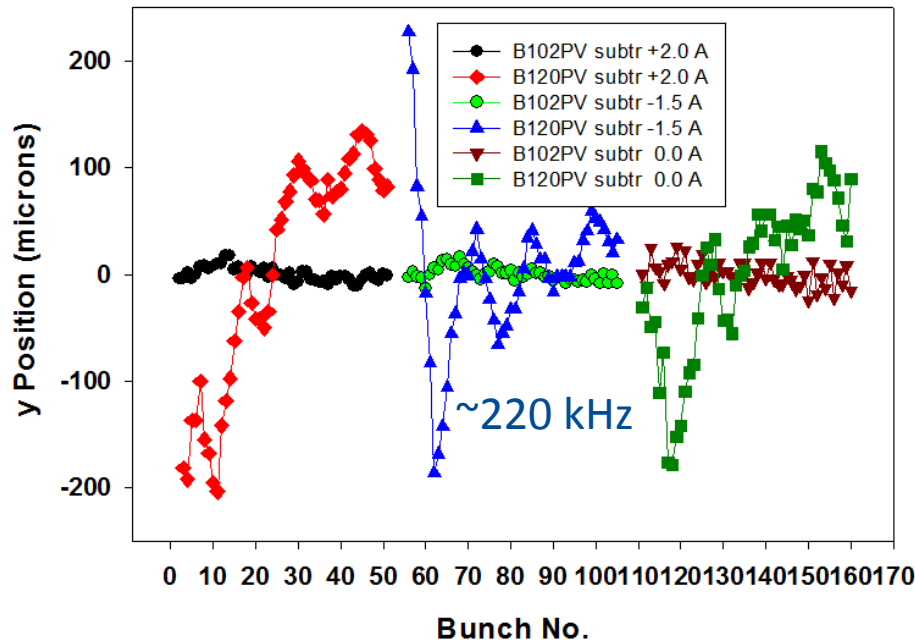
- CC2 HOM amplitude and phase information. Dipole Modes 7, 14 with diff. frequencies of 267 and 181 kHz with beam harm..



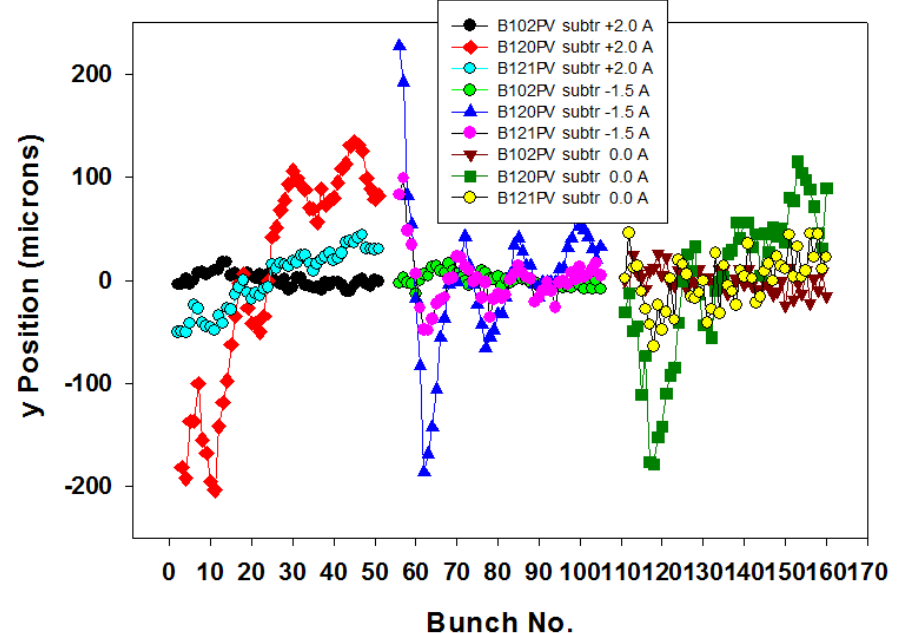
Q118-120 used to Focus Beam at X121 and B121

- The quadrupole focusing effect is shown in the reduced beam submacropulse centroid oscillation from B120PV to B121PV.
- This is summed over in the synchroscan streak image.

FAST V103 scan, 500 pC/b, 50b 02-04-21



FAST V103 scan, 500 pC/b, 50b 02-04-21



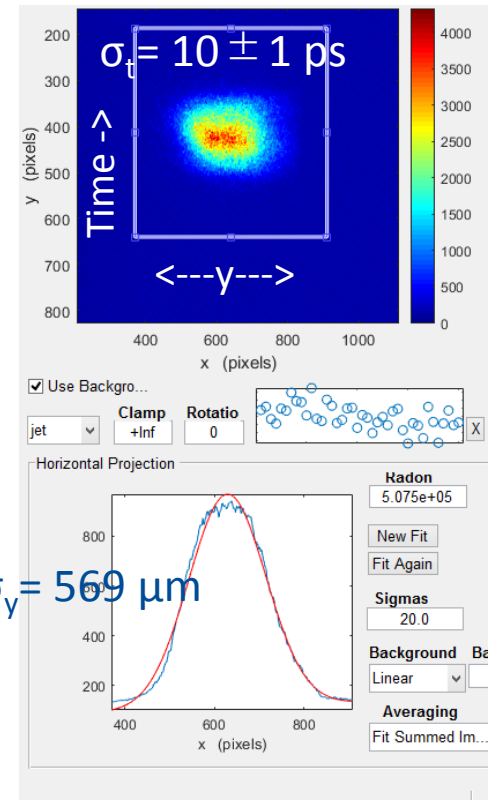
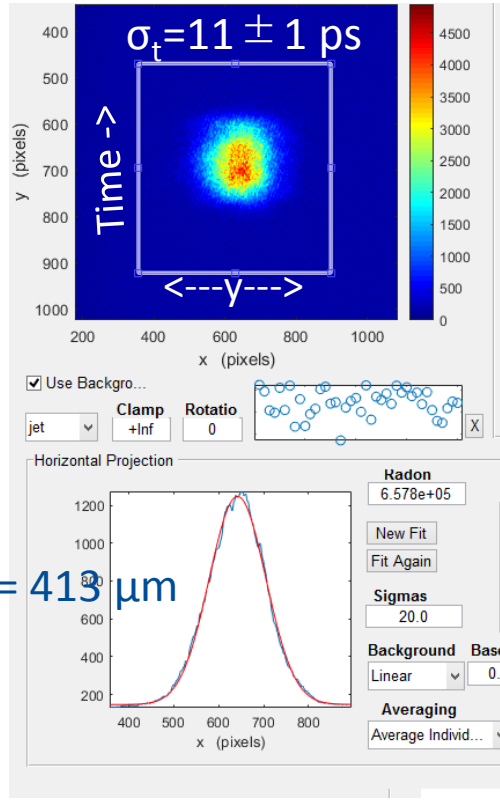
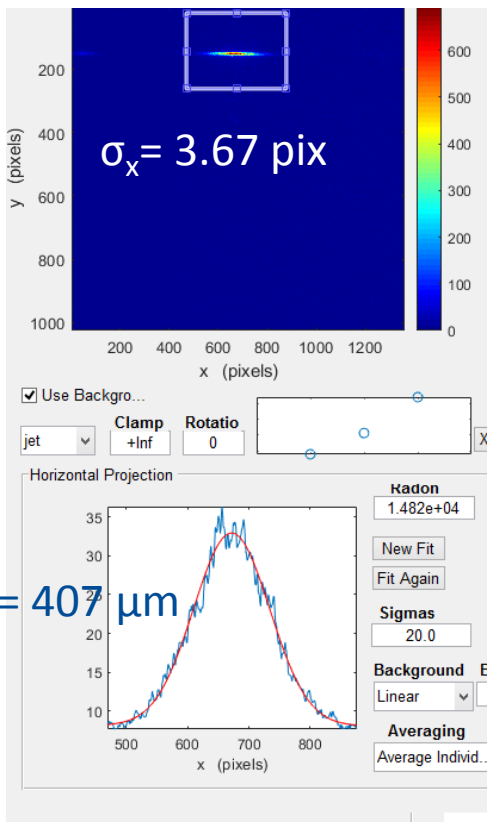
V103 Scan: X121 Streak Camera Image Effects 02-04-21

- Initial image projections for focus mode and streak images.50b.
- Streak R1, 0.5nC/b, 40 images, 38% larger y projection at -1.0 A.

Focus Mode

R1: Ref =0.0 A

R1: -1.0A, $\delta y_c = -111 \mu\text{m}$

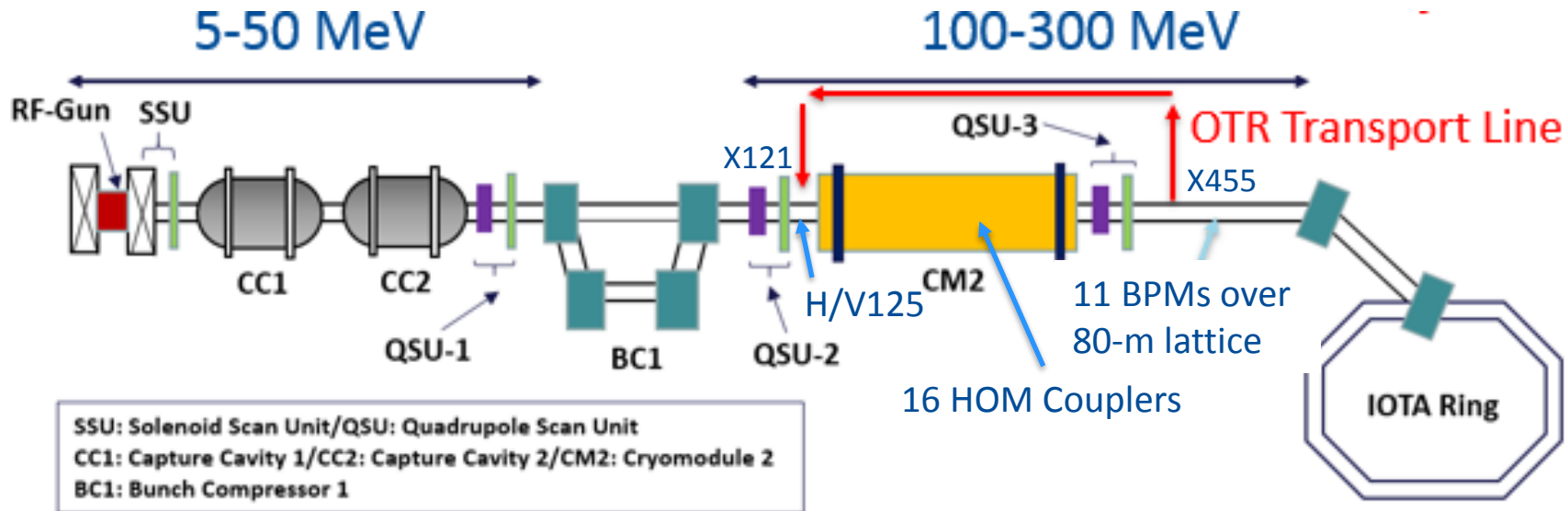


Objective 3: Evaluate HOMs in CM2 with SLAC Chassis

- Investigate HOMs in CM2 with the commissioned SLAC boxes with two amplifier options (8 ch). Setup for dipolar modes. 2x8
- Higher charges than 125 pC/b would help rf BPMs and LRWs.
- Record HOMs as found in 8 cavities, US and DS.
- Track Modes in HOM signals with Peter's new box.
- Reduce HOMs with H/V125 if possible.
- Record BPM array data in HE beamline. Record HOM spectra.
- Record data sets for Machine Learning training evaluation.
- Measure beam images in high energy (HE) beamline.
- John Sikora previously showed the SLAC chassis HOM data at 100 pC/b and lower charges, single bunch.

Techniques Will be Applied to FAST Cryomodule

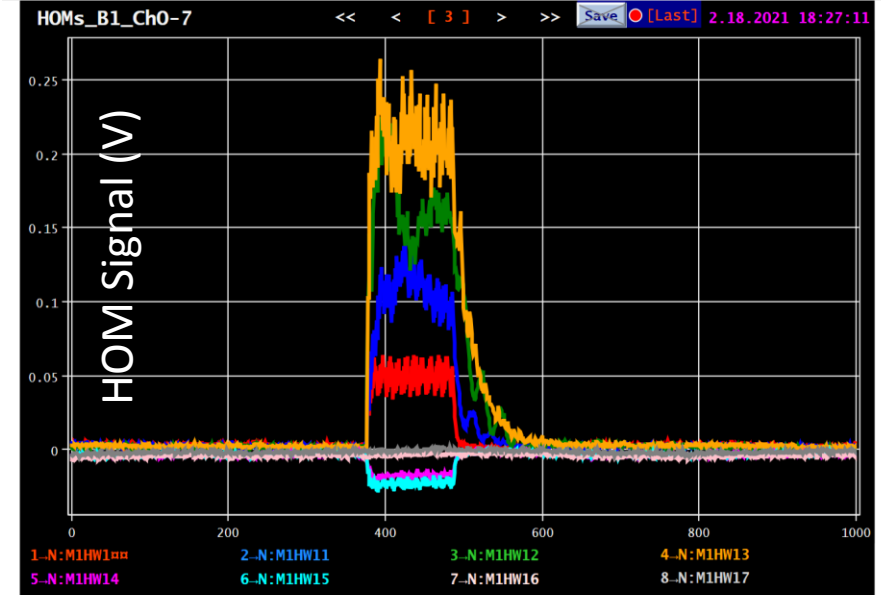
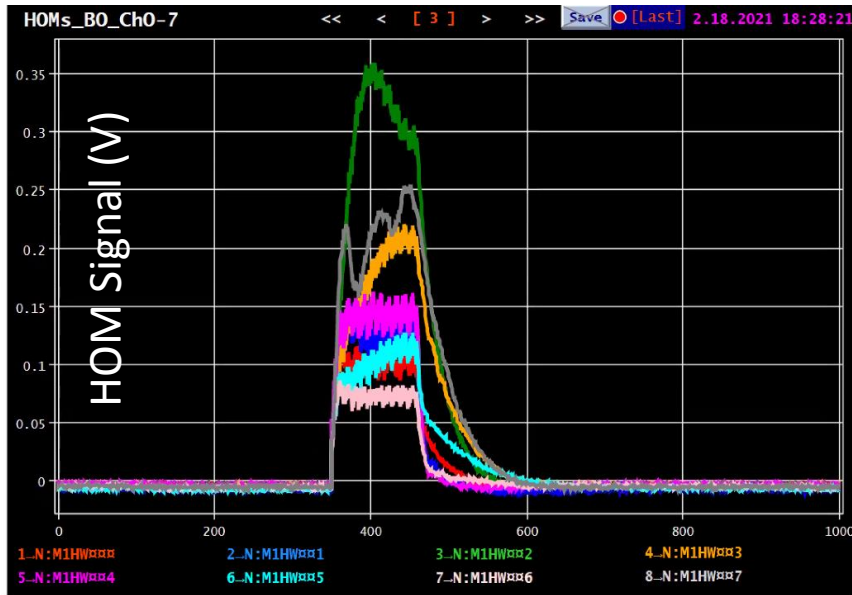
- Possible to extend HOM studies techniques to higher charges and to the cryomodule using an **80-m lattice and 11 rf BPMs** distributed in z downstream of it, 8 SLAC HOM det., Run 3
- Run at 100-MeV total energy with 25 MeV into CM2.



CM2 HOM Waveforms Seen Online

02-18-21

- US for Board 0, C1-8, DS for Board 1, C1,8: 3 HOM Bands.
- 50 b macropulse is 16.6- μ s long in waveforms below.



1 red	C1 US	1.75 GHz	5 purple	C5 US	1.75 GHz
2 blue	C2 US	1.75 GHz	6 lt blue	C6 US	1.75 GHz
3 green	C3 US	1.75 GHz	7 pink	C7 US	1.75 GHz
4 yellow	C4 US	1.75 GHz	8 grey	C8 US	1.75 GHz

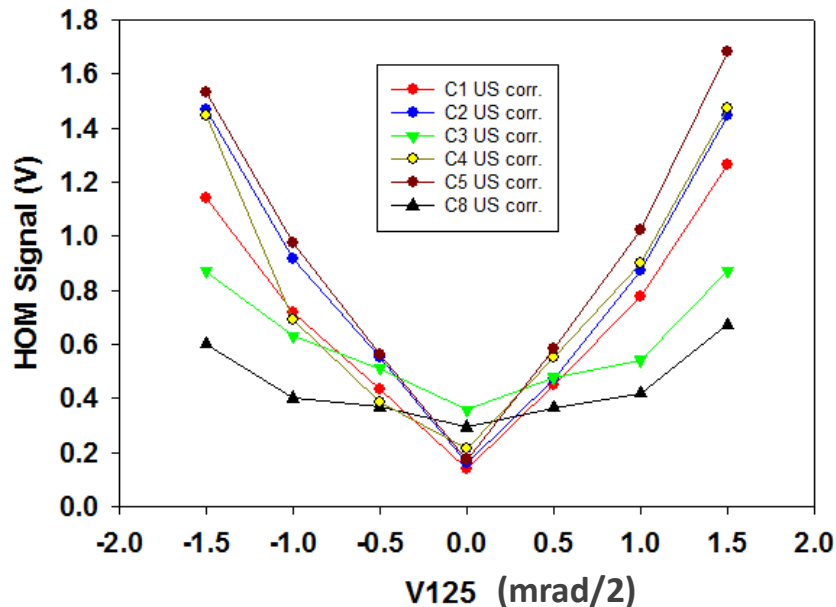
1 red	C1 DS	1.75 GHz	5 purple	C1 DS	3.25 GHz
2 blue	C8 DS	1.75 GHz	6 lt blue	C8 DS	3.25 GHz
3 green	C1 DS	2.58 GHz	7 pink	---	
4 yellow	C8 DS	2.58 GHz	8 grey	---	

V125 scan: CM2 HOMs: 8 US and 8 DS!

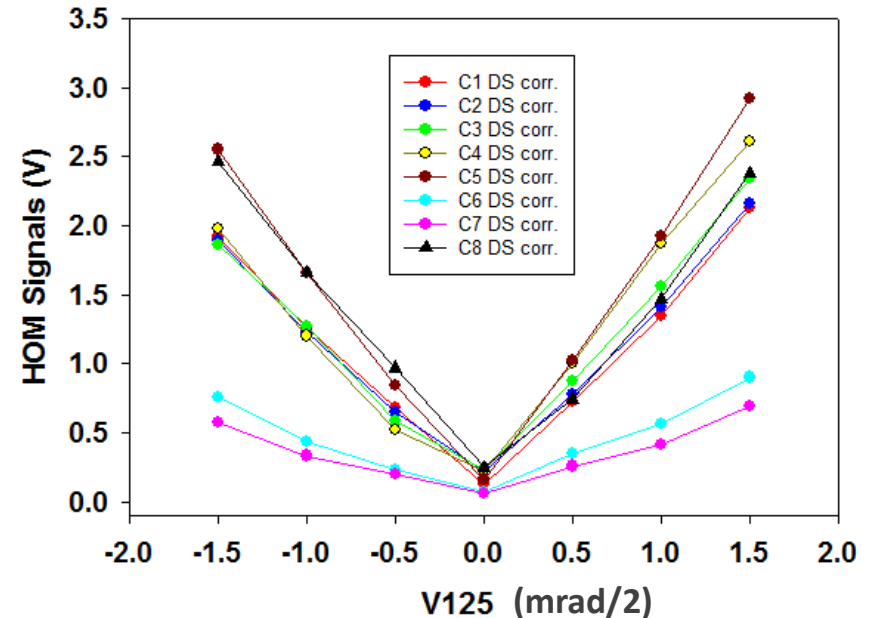
02-18-21

- Used x3 correction for SLAC attenuators at larger steerings.
- V125 Corrector provides 2 mrad/1A angles into CM2.
- Two SLAC chassis enabled these experiments on all 16 chan.

CM2: V125 scan: SLAC HOMs A1 US, 400 pC/b 02-18-21



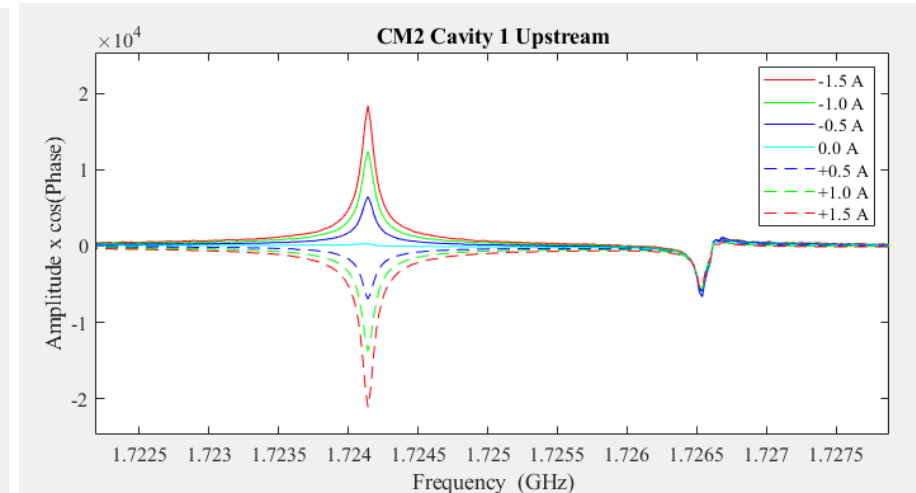
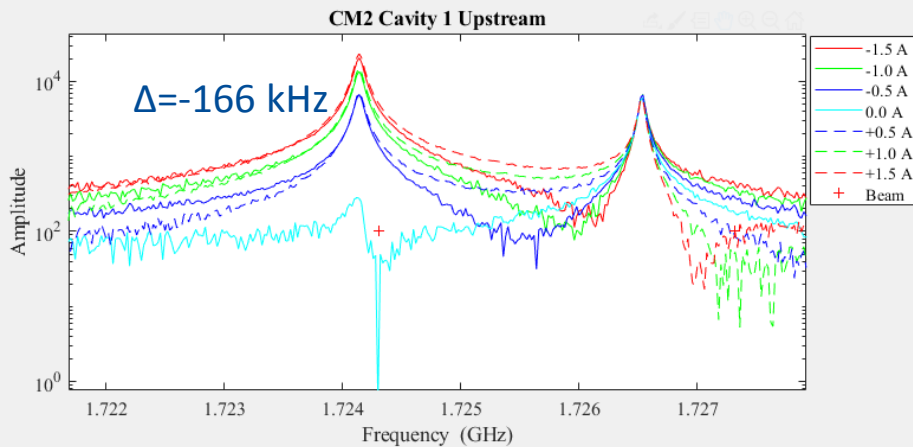
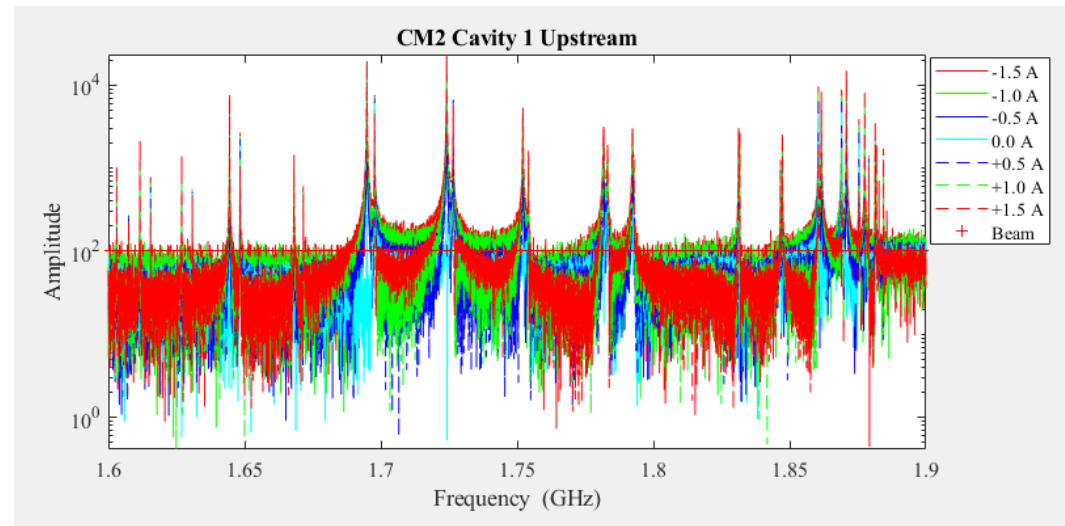
CM2:V125 Scan: SLAC HOMs A1 DS 400 pC/b 02-18-21



Comprehensive Set of Spectral Data on Vertical Polarization Mode Components Acquired on CM2

2-18-21

- C1 US example uses 2 of 32 slides from Randy.
- We show the 18 modes in passband and zoom in on Mode 7 in V125 scan. Near resonance.
- Amplitude and phase.

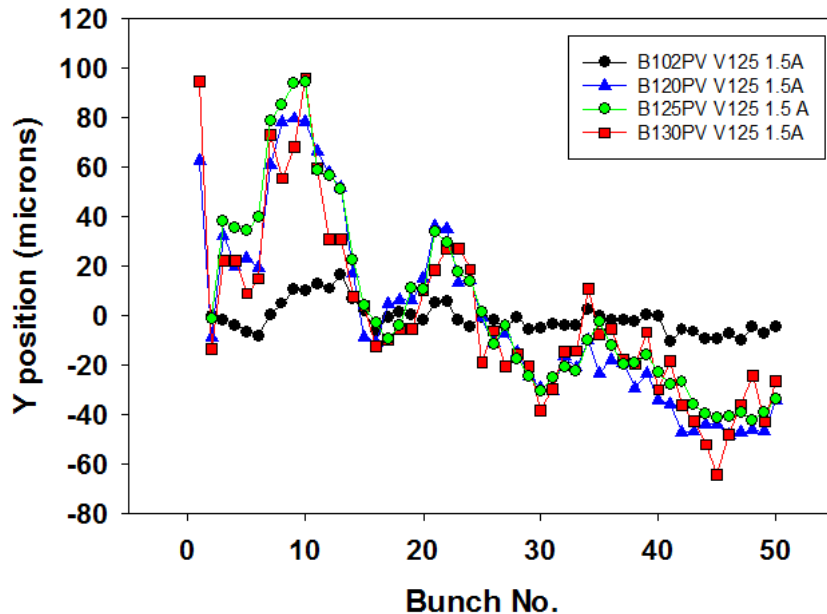


Injection into CM2 and Down Stream at B441

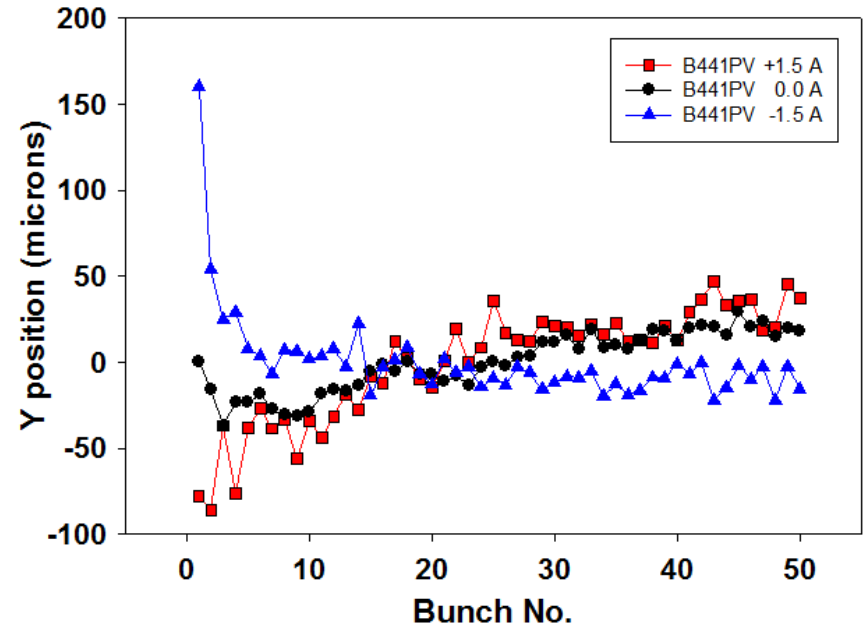
02-18-21

- BPMs show submacropulse oscillation before CM2 in B120,125, and 130 attributed to the off-resonance CC2 cavity.
- Some steering effects on submacropulse scale in B441.

FAST BPMs 250 pC/b 02-18-21



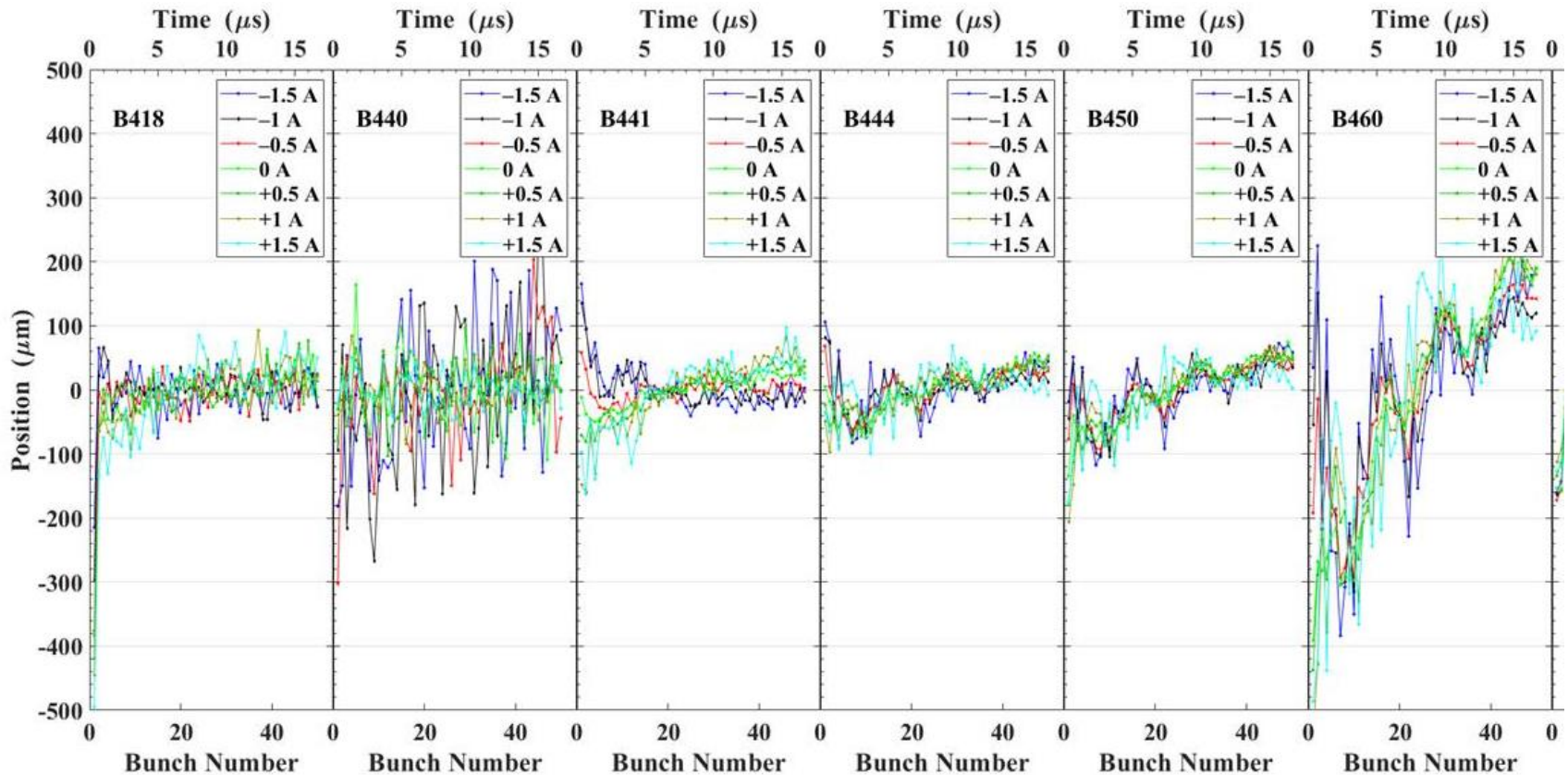
FAST V125 scan 250 pC/b 02-18-21



V125 Scan Downstream Vert. BPMs 400 pC/b

02-18-21

- Vertical Pattern (z) Changed vs Nov.-Dec. 2020.

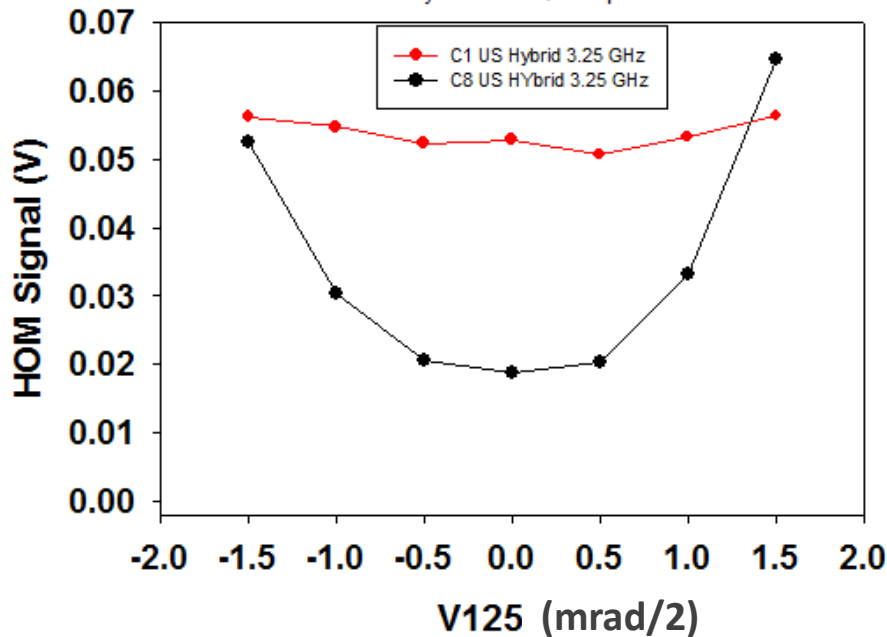


V125 scan: CM2 Q HOMs: 2 US and 2 DS

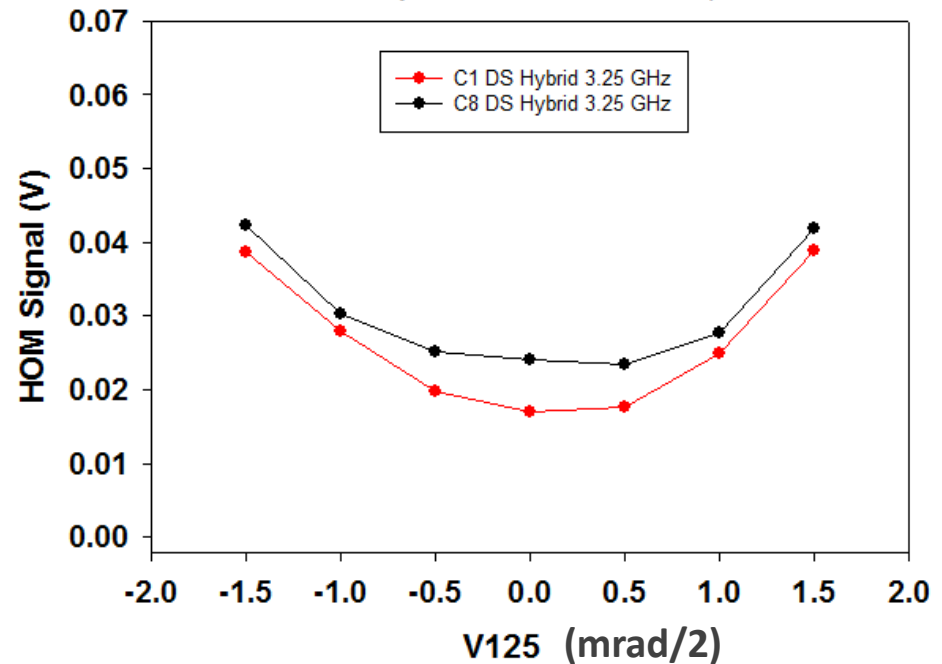
02-18-21

- Use Hybrid box to explore 3.25-GHz HOM band.
- Variations seen with scan except for C1 US.
- 400 pC/b, 50b, 100-shot average.

CM2:V125 Scan Hybrid US-Q 400 pC/b 02-18-21



CM2: V125 Scan Hybrid HOMs DS-Q 400 pC/b 02-18-21



Summary

- Very successful shifts with V103 scan on CC2 (2-4-21) and V125 scan looking at the CM2 HOMs with two SLAC chassis and Peter's new HOM box (2-18-21). **First HOM phase info.**
- **CM2 HOM signals are reduced compared to those of CC1 and CC2. Used 1 wideband Amplifier in each HOM channel.**
- We have reduced HOMs by steering at H/V125, ~4m upstream of CM2. Scans provide data base for Mach. Learning Training.
- Randy has **first HOM mode amplitude and phase results in CM2 for vertical polarization components.**
- Plan to process data towards beam offset monitor (BOM) in C1.
- **We need the critical H125 scan shift under these conditions with B130 working and higher charges as on 2-18-21. Requested, but not approved by ISC last week (Non-technical).**

Complementary and diverse

Capabilities:	ATF	AWA	BELLA	FACET-II	FAST
Operation model:					
National User Facility	✓			✓	
Accelerator Stewardship	✓				
Collaboration models		✓	✓		✓
Beams and accelerators:					
~100 MeV electrons	✓	✓			✓
10 GeV electron beams				✓	
10 GeV positron beams				planned	
High charge electron bunches		✓			
Proton beams					planned
NC S-band and X-band	✓			✓	
NC L-Band		✓			
SC L-Band linac					✓
Storage ring					✓
Lasers:					
TW class 0.8 μm laser (Ti:Sapphire)	✓		✓	✓	
PW class 0.8 μm laser (Ti:Sapphire)			✓		
TW class 10 μm laser (CO ₂)	✓				
Plasmas:					
Plasma capillaries	✓ (2 cm)	✓ (2 cm)	✓ (10 cm)		
Gas Jets	✓		✓	✓	
Heat pipe oven				✓	
Hollow channel		✓		✓	

V. Yakimenko, Sept. 24, 2020

EXPERIMENTAL SETUP

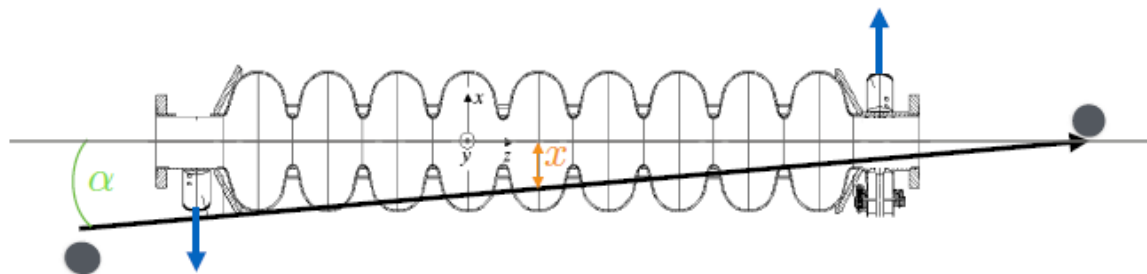
HIGHER ORDER MODES

> TESLA CAVITY

- 2 HOM couplers

> DIPOLE HOM

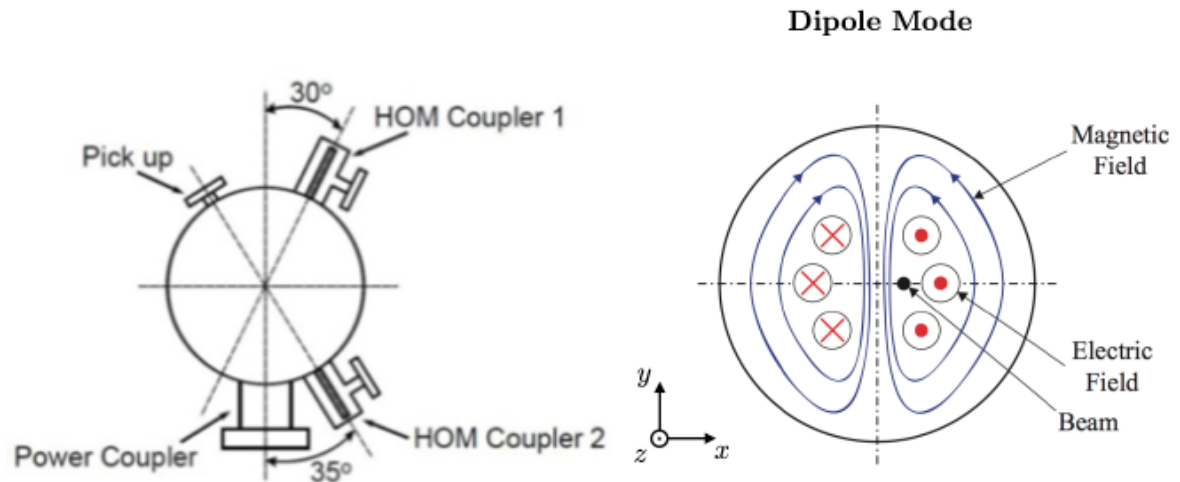
- $V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t)$
- $V_{x'}(t) \propto x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t)$



Expected HOMs in TESLA Cavities*

Mode #	Freq.(GHz)	R/Q (Ω/cm^2)
MM-6	1.71	5.53
MM-7	1.73	7.78
MM-13	1.86	3.18
MM-14	1.87	4.48
MM-30	2.58	13.16

*R. Wanzenberg, DESY 2001-33

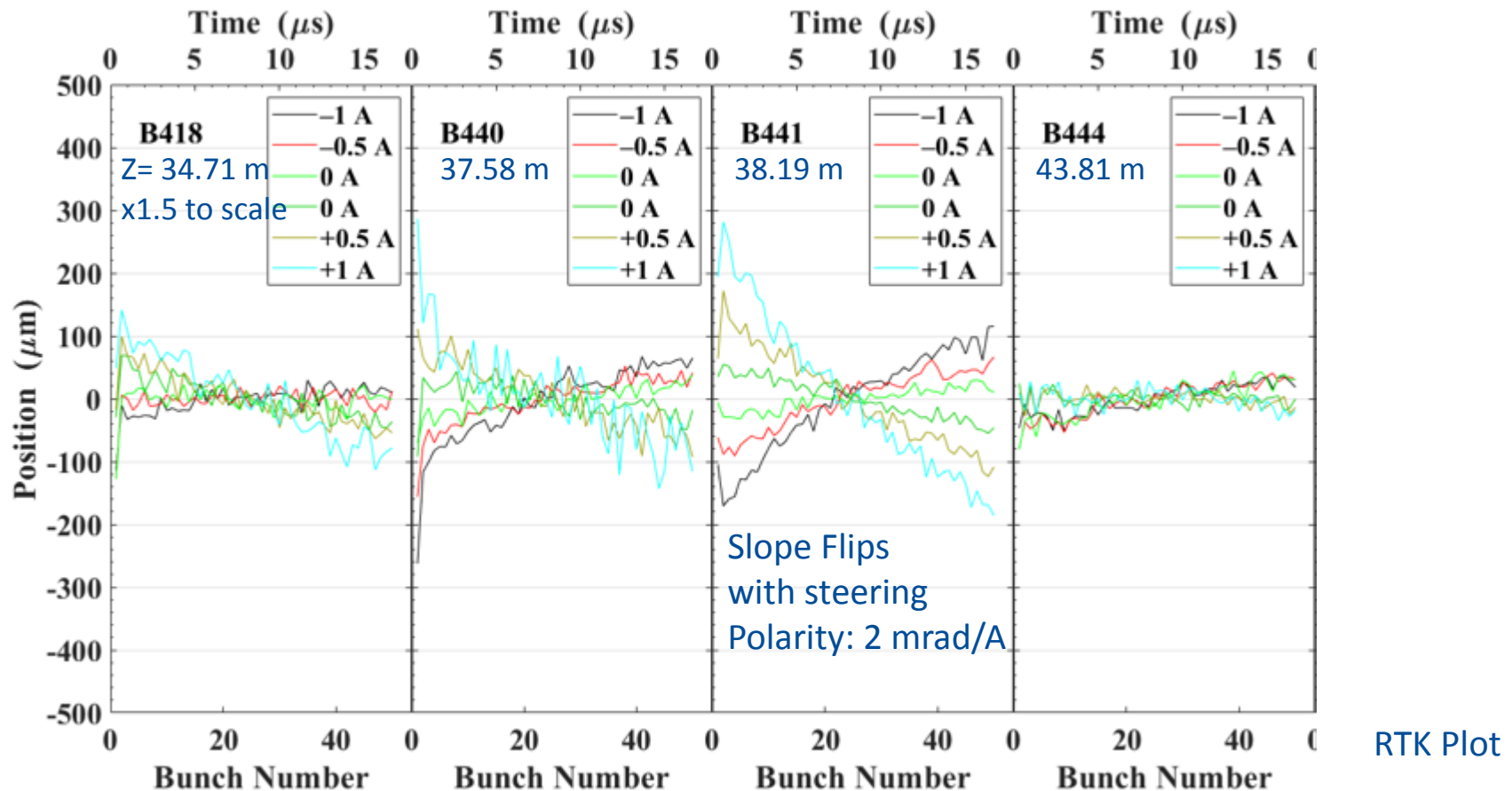


N.B. Modes excited in the cavities at frequencies higher than the accelerating mode are HOMs.

Amplitude of specific dipole mode, $A_d \sim q \times r \times (R/Q)$

BPM Vertical Array Data Downstream of CM2-C8 Show Slew!

- Cold B418V data and others show offset dependence in scan. V125 corrector is 4 m before CM2 and $\sim 2\text{ mrad/A}$. 11-20-20 +12-03-20
- Mean of each array subtracted from each bunch position for the plots.

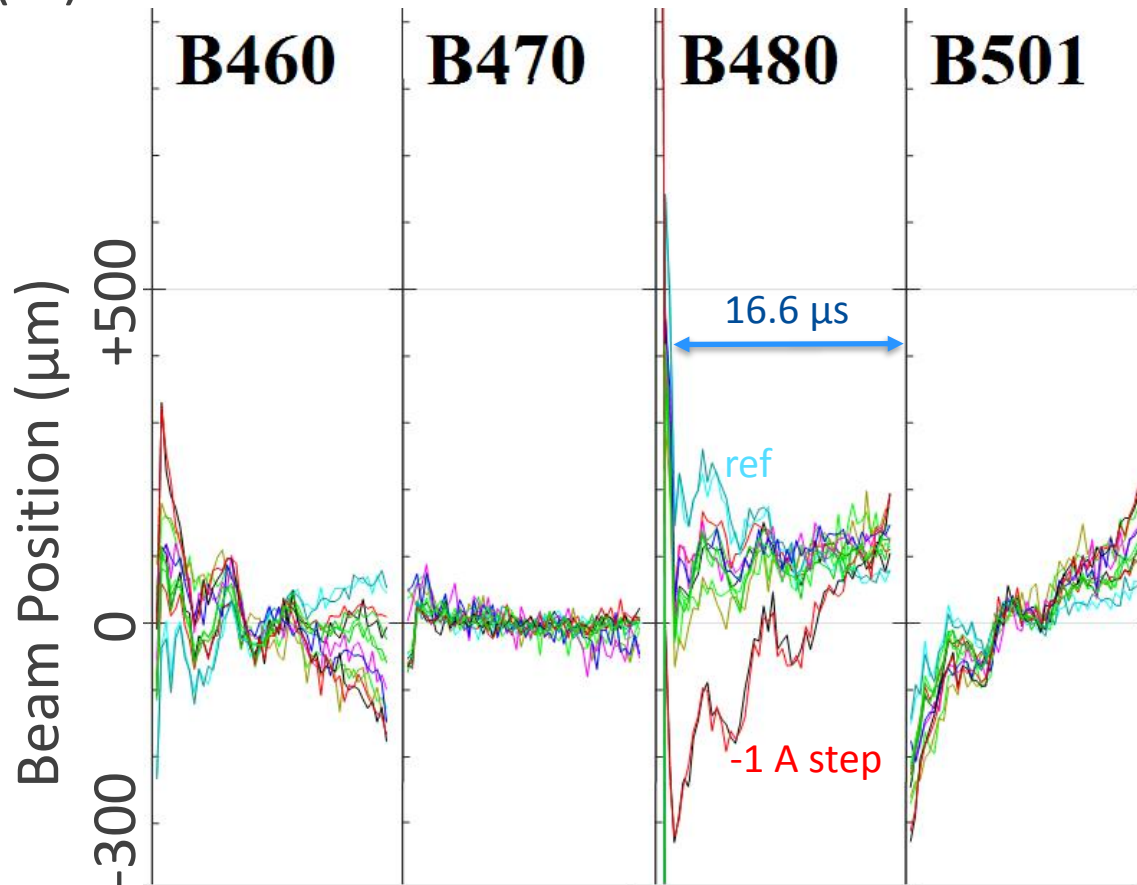


HE Beamline BPM Effects(T) During V125 Scan

11-20-20

- Some submacropulse centroid oscillations are seen in BPM array data for 50 b or 16.6 μ s: **~ 240 kHz diff. freq. plus slew.**

Z (m) = 64.332 81.566 98.880 107.221 C8_c at 33.603

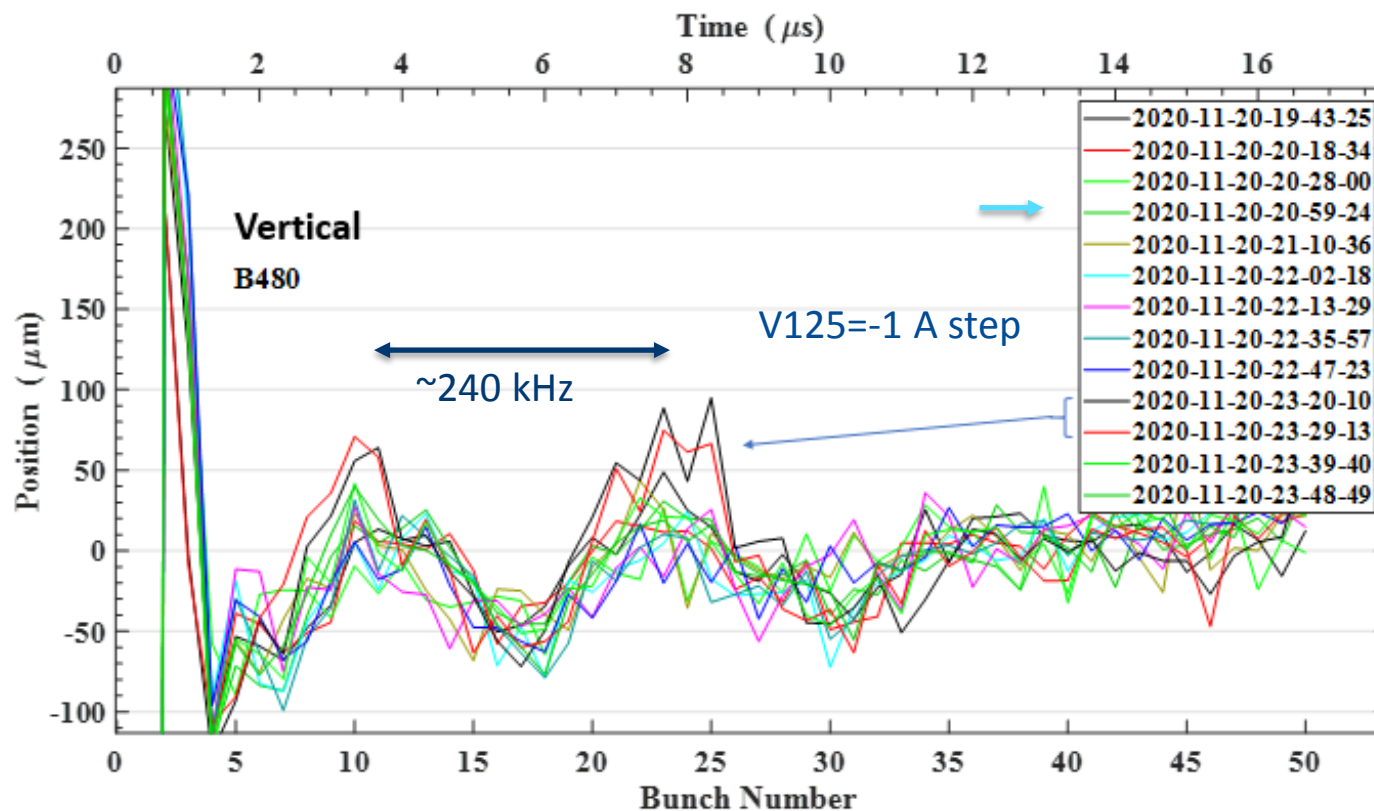


RTK Plot rev.



BPM Array Data Downstream of CM2 Show Oscillation!

- B480V data show ~240-kHz Vertical Oscillation with offset dependence. V125 corrector is 4 m before CM2. 11-20-20
- Randy subtracted a linear slew for each data set. 50b sort.



RTK Plot rev.

