Fermilab

SLAC NATIONAL ACCELERATOR LABORATORY

Managed by Fermi Research Alliance, LLC for the U.S. Department of Energy Office of Science

Investigations of Long-Range Wakefield Effects in a TESLA-type Cryomodule at FAST

Alex Lumpkin, Randy Thurman-Keup, Dean Edstrom, Jinhao Ruan, Peter Prieto, (Fermi National Accelerator Lab)
Bryce Jacobson, Feng Zhou, John Sikora, Jorge Diaz-Cruz, Auralee Edelen, (SLAC National Accelerator Lab)

IPAC21 TUPAB274

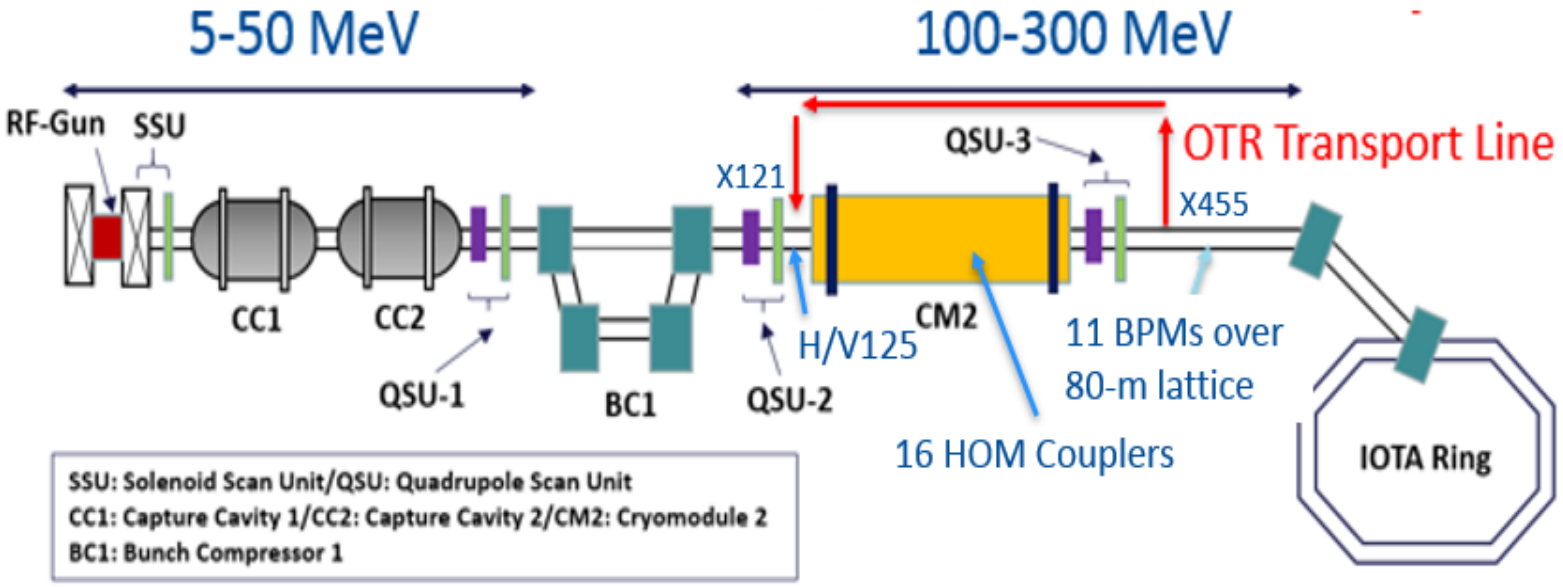
25 May 2021

Motivation: Assessment of HOM Effects on Beam Dynamics

- Investigate higher-order-modes (HOMs) in a TESLA-type cryomodule (CM2) and their effects on beam dynamics using bunch-by-bunch rf BPM data taken downstream of CM2.
- It is known that off-axis steering in accelerator cavities can lead to dipolar HOMs that can cause submacropulse centroid slewing and oscillations. (A.H. Lumpkin *et al*., PRAB 2018).
- Experiments were enabled by using 8-channels of the SLAC prototype HOM detectors for the LCLS-II Injector and the hybrid FNAL detector, all with wide-band amplifiers.
- Recorded HOMs as found in 8 cavities, using the upstream (US) and downstream (DS) couplers in sequence.
- Beam dynamics that lead to emittance dilution were observed and mitigated.

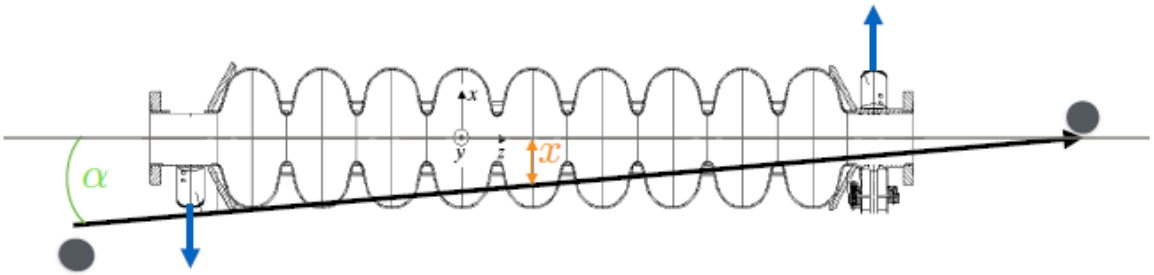
Techniques Will be Applied to FAST Cryomodule

- Possible to extend HOM studies techniques to higher charges and to the cryomodule using an 80-m lattice and 12 rf BPMs distributed in z downstream of it, 8 SLAC HOM det.
- Fermilab Accelerator Science and Technology (FAST) Facility.



EXPERIMENTAL SETUP

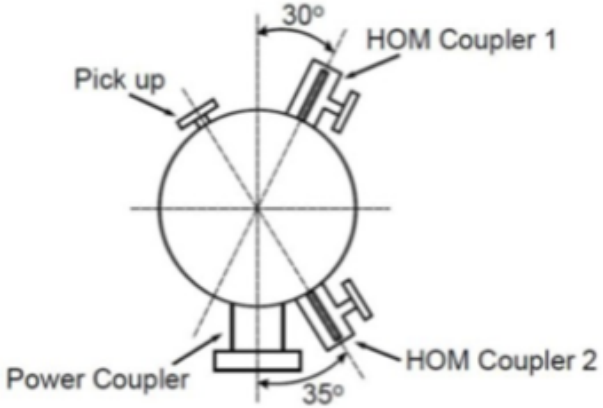
- TESLA CAVITY
  - 2 HOM couplers
- DIPOLE HOM
  - $V_x(t) \propto x \cdot e^{-\frac{t}{2\tau}} \sin(\omega t)$
  - $V_{x'}(t) \propto x' \cdot e^{-\frac{t}{2\tau}} \cos(\omega t)$

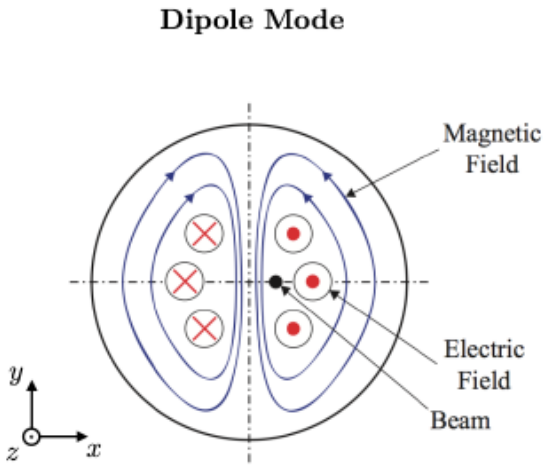


Expected HOMs in TESLA Cavities*

Mode #	Freq.(GHz)	R/Q (Ω/cm²)
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

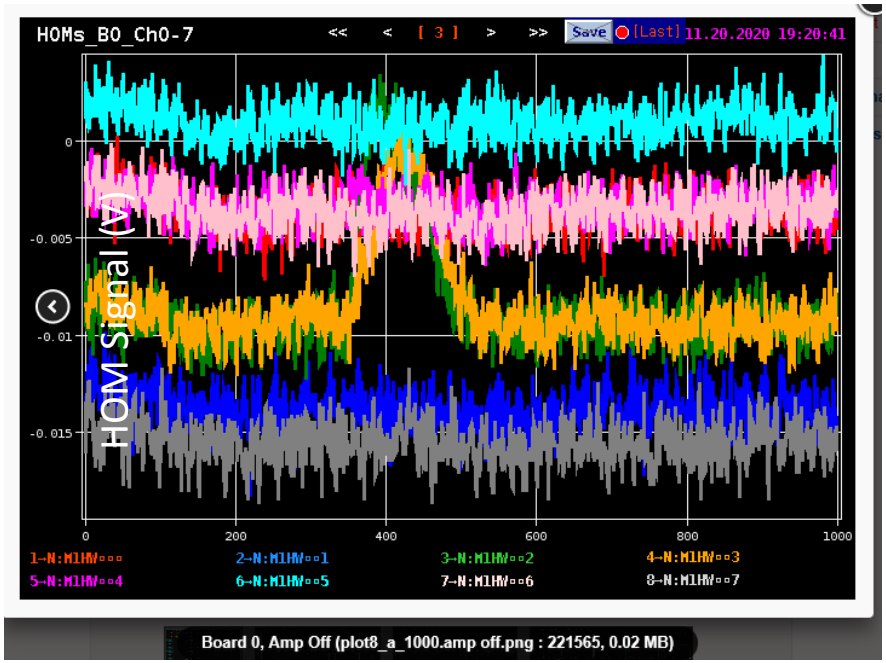


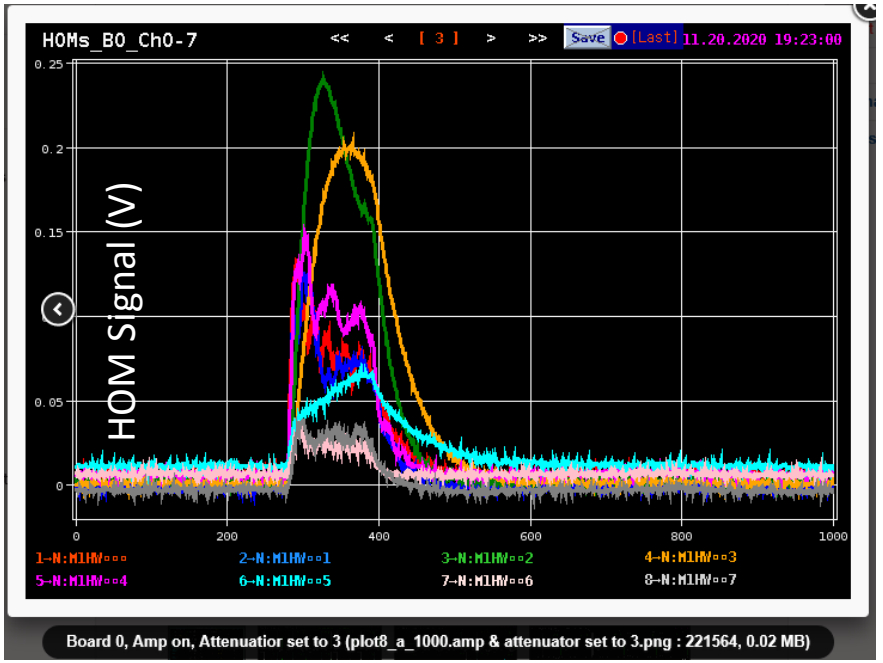


N.B. Modes excited in the cavities at frequencies Higher than the accelerating mode are HOMs.
Amplitude of specific dipole mode, $A_d \sim q \times r \times (R/Q)$

CM2 HOMs As Found with Beam to HEA 19:25 11-20-20

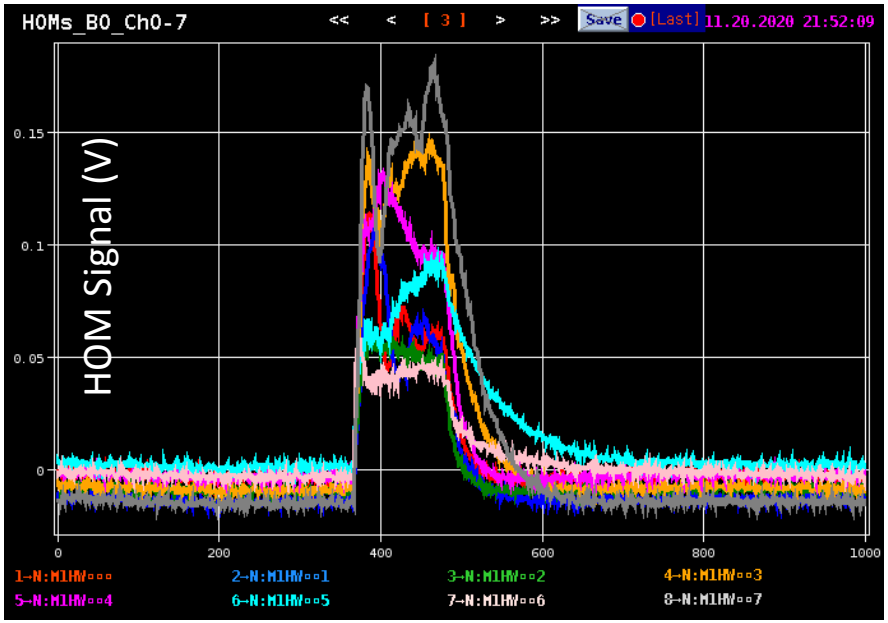
- Encountered lower signals on HOMs at box. CM2 couplers or cables or well centered? Required 1 Ampl ON for all detectors.
- C3 and C4 upstream (US) HOMs highest.
- No AMPL 1 AMPL, with attenuation of 2

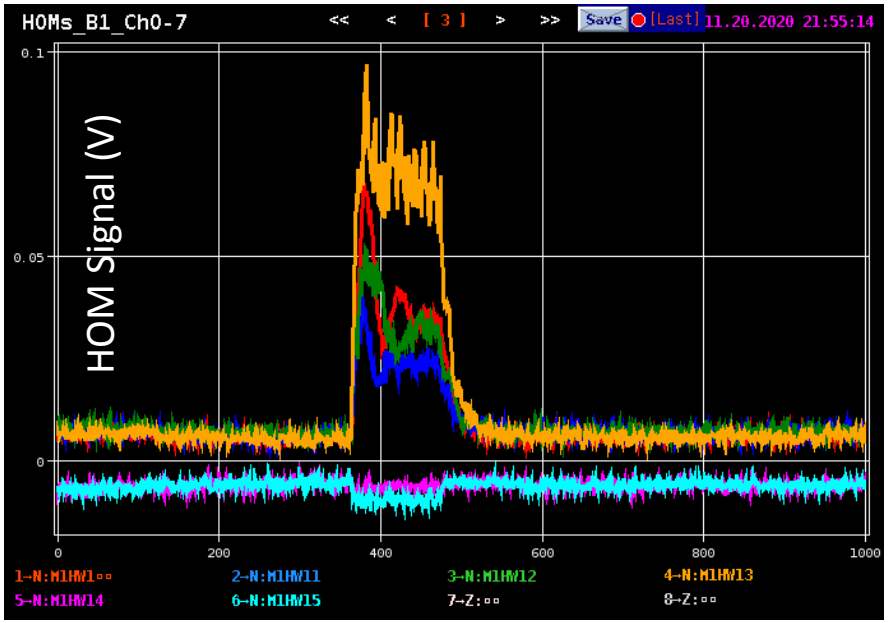




Reduced US HOMs by Adjusting H/V125; See Mode 30

- Steered in $\theta_{x,y}$ to H/V125 =0.96, 4.3 A to reduce most US HOMs
- 250 pC/b, 50 b. Board 1 has C1-DS and C8-DS with Mode 30.
- Board 0, C1-8 US 21:51 Board 1, C1,8 DS



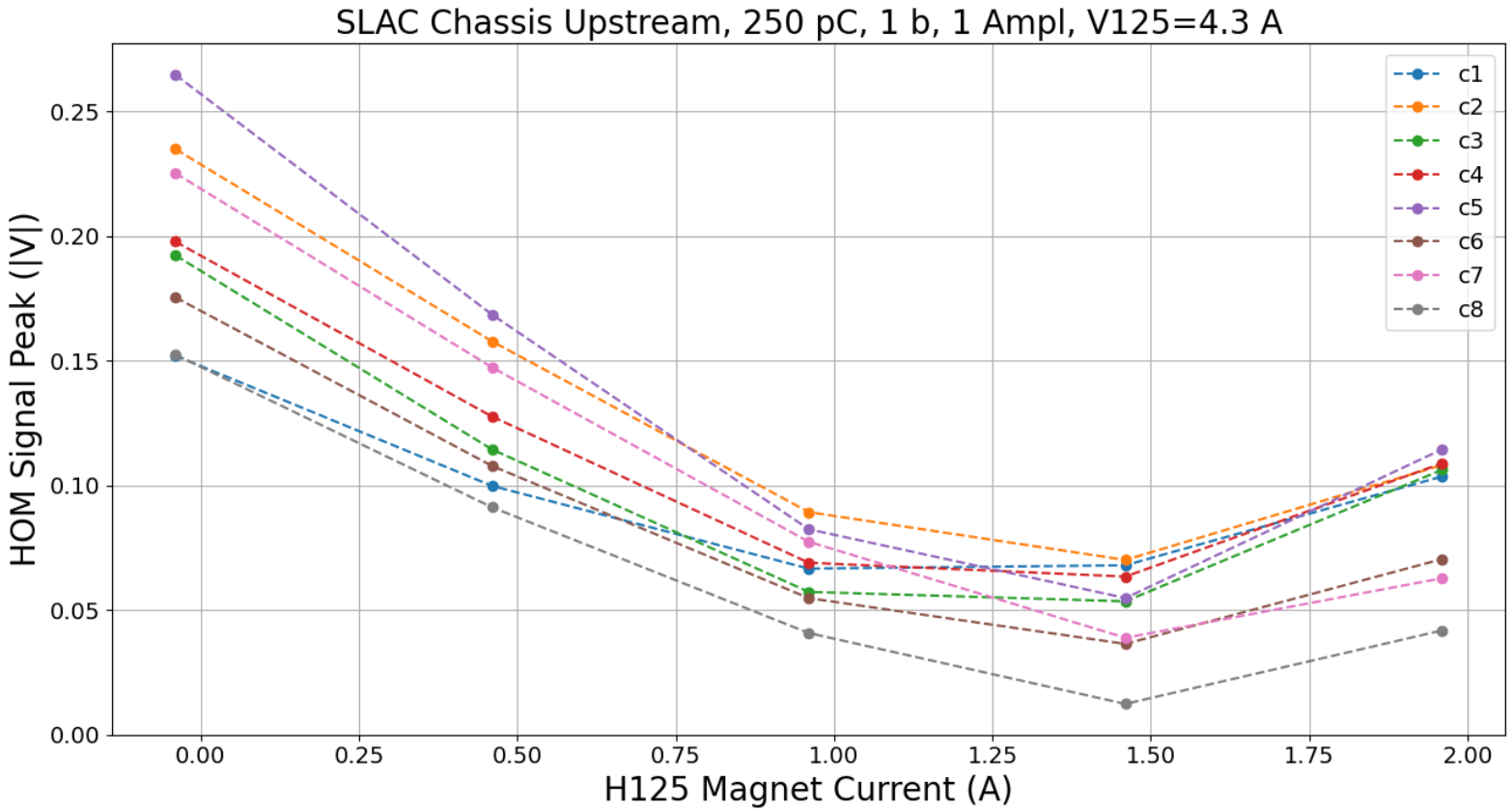


1 red	C1 US 1.75 GHz	5 purple	C5 US 1.75 GHz	1 red	C1 DS 1.75 GHz
2 blue	C2 US 1.75 GHz	6 lt blue	C6 US 1.75 GHz	2 blue	C8 DS 1.75 GHz
3 green	C3 US 1.75 GHz	7 pink	C7 US 1.75 GHz	3 green	C1 DS 2.58 GHz
4 yellow	C4 US 1.75 GHz	8 grey	C8 US 1.75 GHz	4 yellow	C8 DS 2.58 GHz

5 purple	C1 DS 3.25 GHz		
6 lt blue	C8 DS 3.25 GHz		
7 pink	---		
8 grey	---		

H125 scan for US HOMs Shows Local Minimum 12-03-20

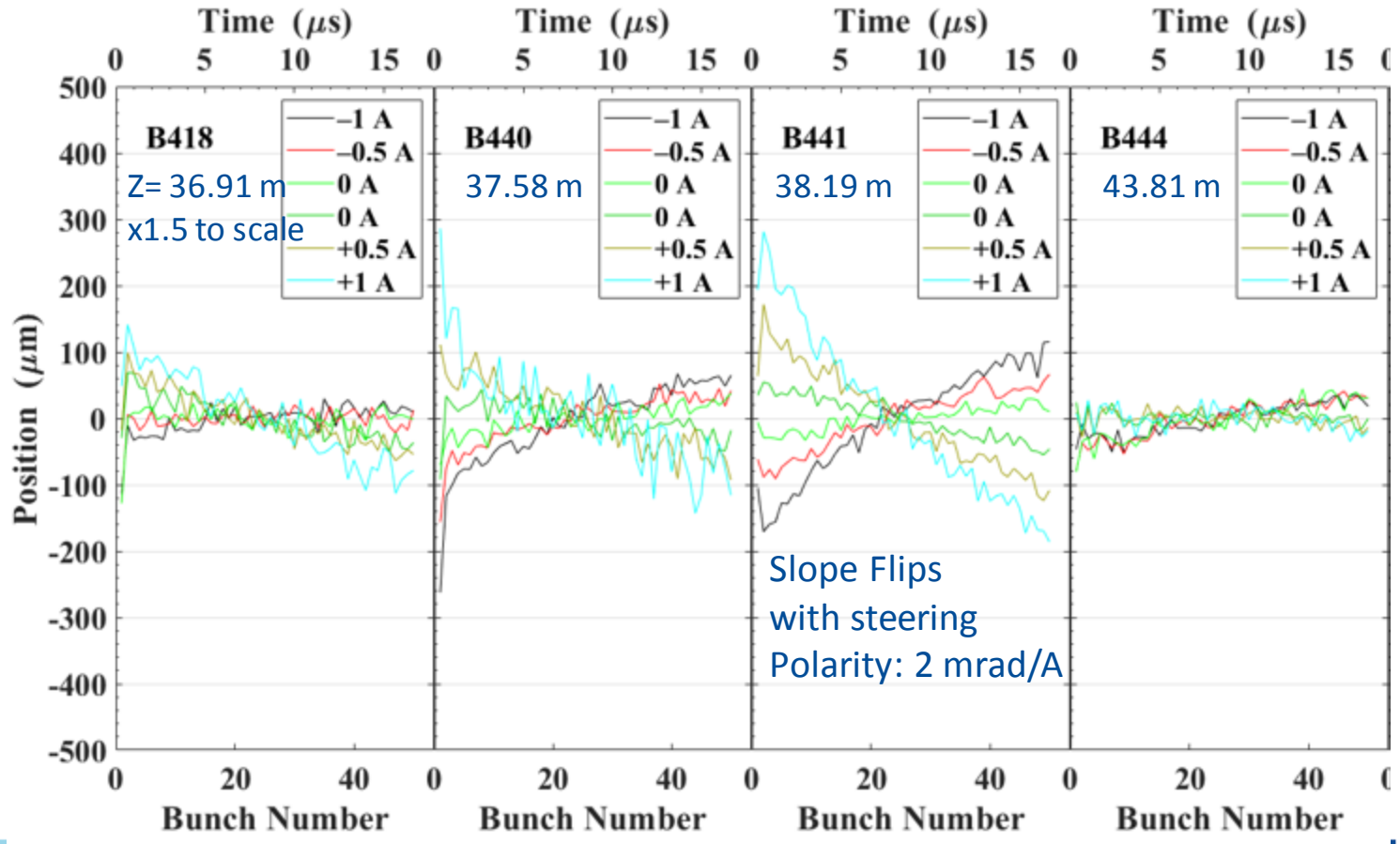
- Relative min. at +0.5 A from first reference on 11-20-20. Coordinates at B125 were different for two runs in post look.



Jorge's Plot

BPM Vertical Array Data Downstream of CM2 Shows Slew!

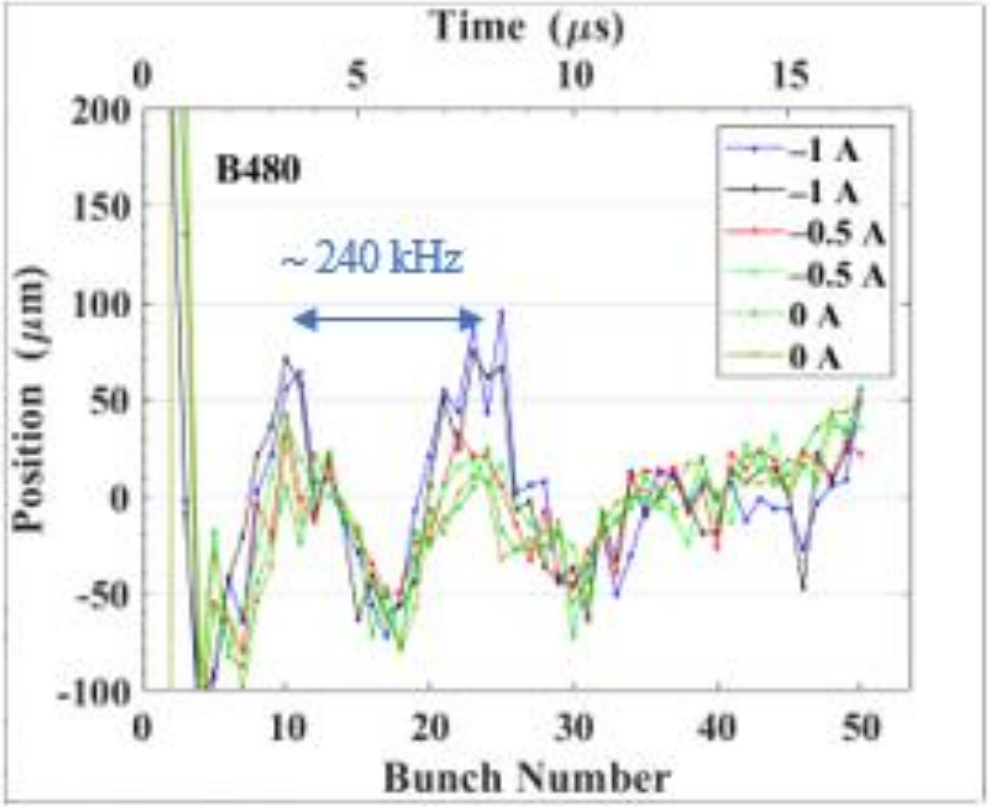
- Cold B418V data and others show offset dependence in scan. V125 corrector is 4 m before CM2. 11-20-20 +12-03-20



RTK Plot

BPM Array Data Downstream of CM2 Show Oscillation!

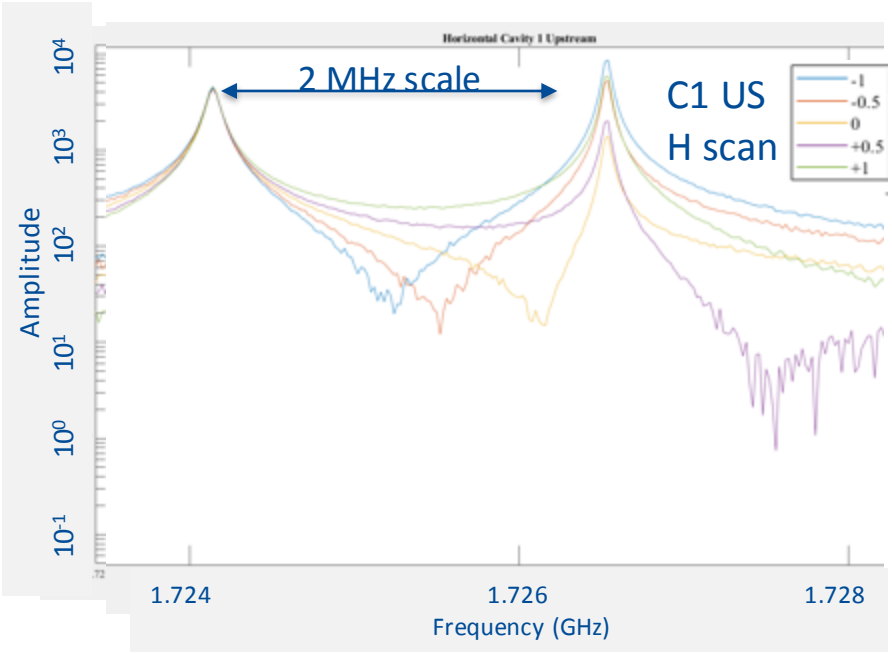
- B480V data show ~240-kHz Vertical Oscillation with offset dependence. V125 corrector is 4 m before CM2. 11-20-20
- We subtracted a linear slew for each data set. 50b used.

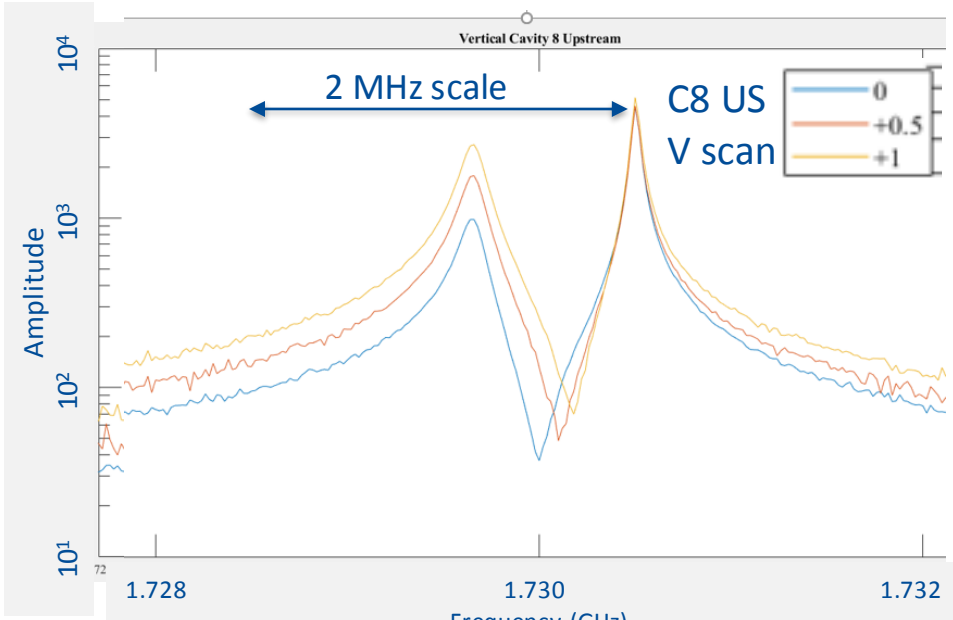


RTK Plot

HOM Spectral Data Are Rich in Information on Modes

- Within the three passbands of the FNAL box, we cover the first two dipolar passbands (1.75 GHz), the third dipolar passband (2.58 GHz), and the quadrupole band (3.25 GHz). (Centers of the pass band)
- Cavity 1 and 8 are examples of the two vendors AES and RI whose cavities have different axial symmetries. This leads to differences in the frequency splits of the polarized modes. (A. Lunin and O. Napoly)
- We also can excite each polarization with our horizontal (L) or vertical (R) steering and map steering effects of H/V125 for the individual modes. 12-03-20



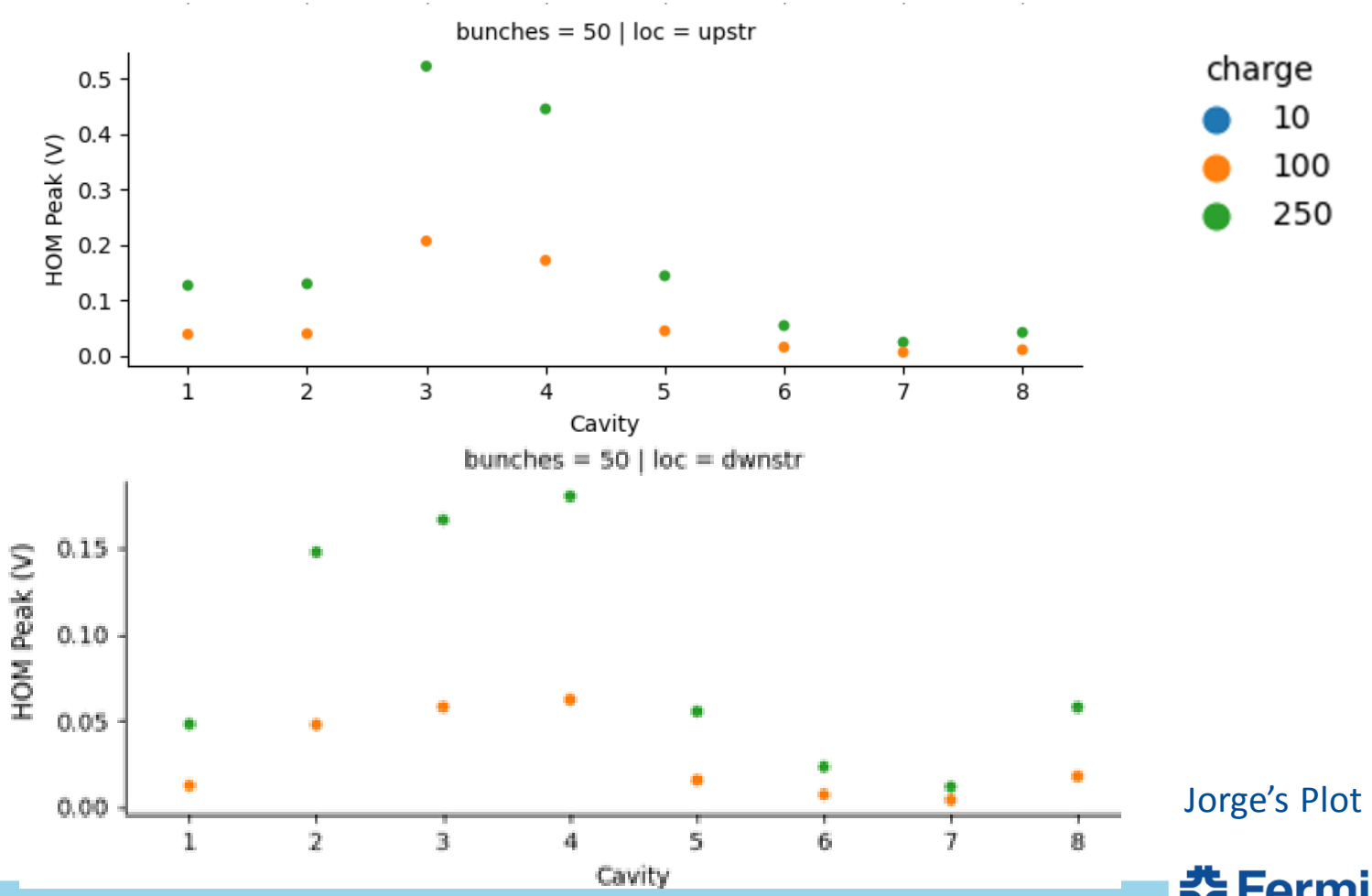


Summary

- The HM detectors and rf BPMs were used to evaluate off-axis steering effects in a cryomodule at FAST for the first time.
- US HOM signals seemed reduced compared to those of CC1 and CC2, even when minimized in the latter. Used Amplifiers.
- Significant submacropulse centroid slewing and oscillations were observed downstream of CM2.
- These emittance dilution effects were mitigated by minimizing the HOMs and the observed slewing.
- Spectral data are rich in C1 (AES) and C8 (RI) info. Cavity axi-symmetry effects differ from two vendors.
- These combined effects are being evaluated for machine learning training. (MOPABxxx).

CM2 HOMs "As Found" with Beam to HEA 11-20-20

- Look at CM2 C1-8 HOMs, US and DS as found with beam to HEA and correction at H103.



Jorge's Plot rev.