IPAC'21 MOPAB323

Commissioning of the LCLS-II Prototype HOM Detectors with Tesla-Type Cavities at FAST*

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SLAC NATIONAL ACCELERATOR LABORATORY

Fermilab

U.S. DEPARTMENT OF ENERGY
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∗ Work supported under contract DE-AC02-76SF00515 with the U.S. Department of Energy.
Work supported by Fermi Research Alliance, LLC under Contract No. DE-AC02-07CH11359 with the U.S. Department of Energy.
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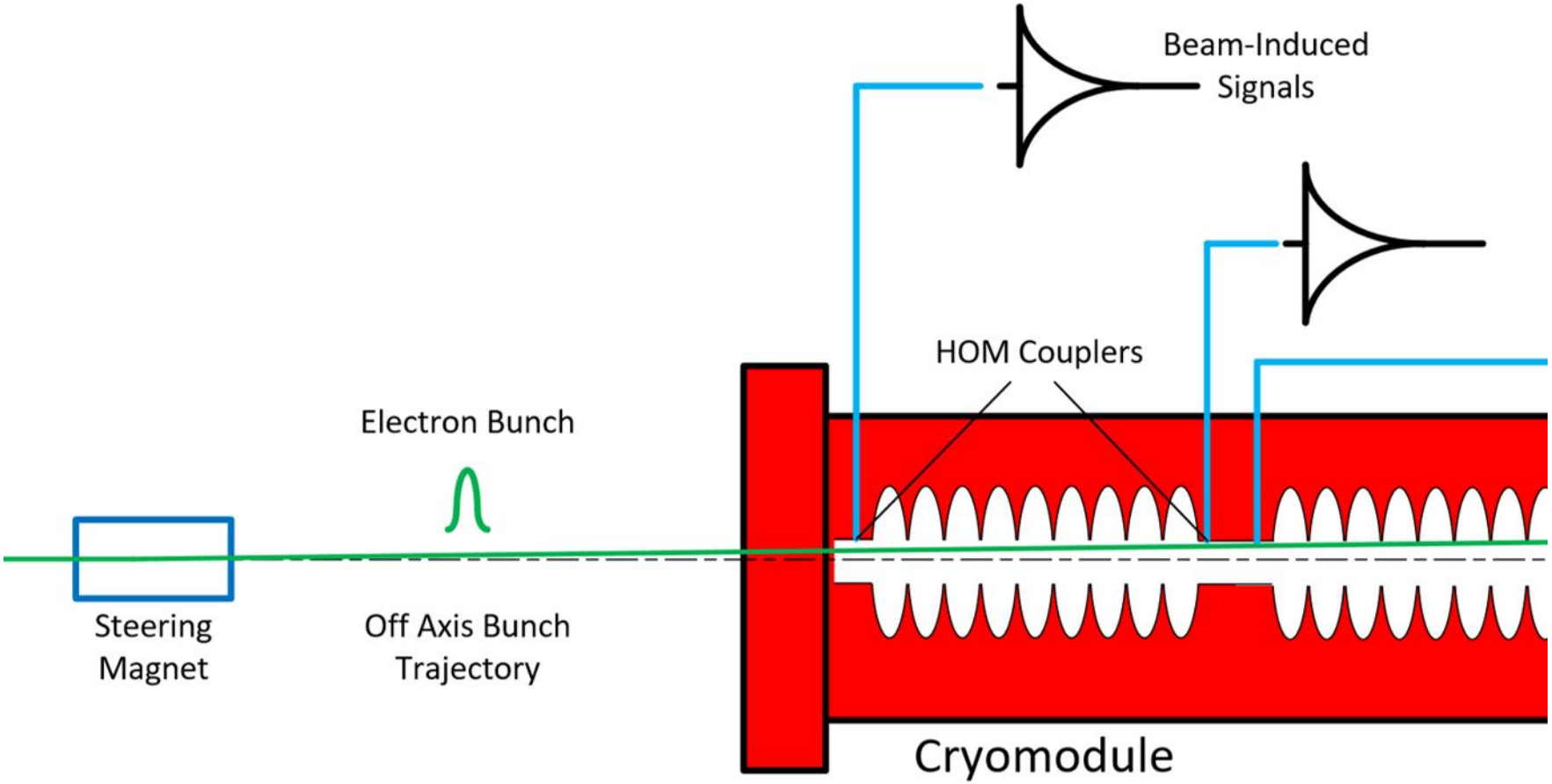
HOM Excitation



An off-axis beam excites dipole mode high order modes (HOMs)

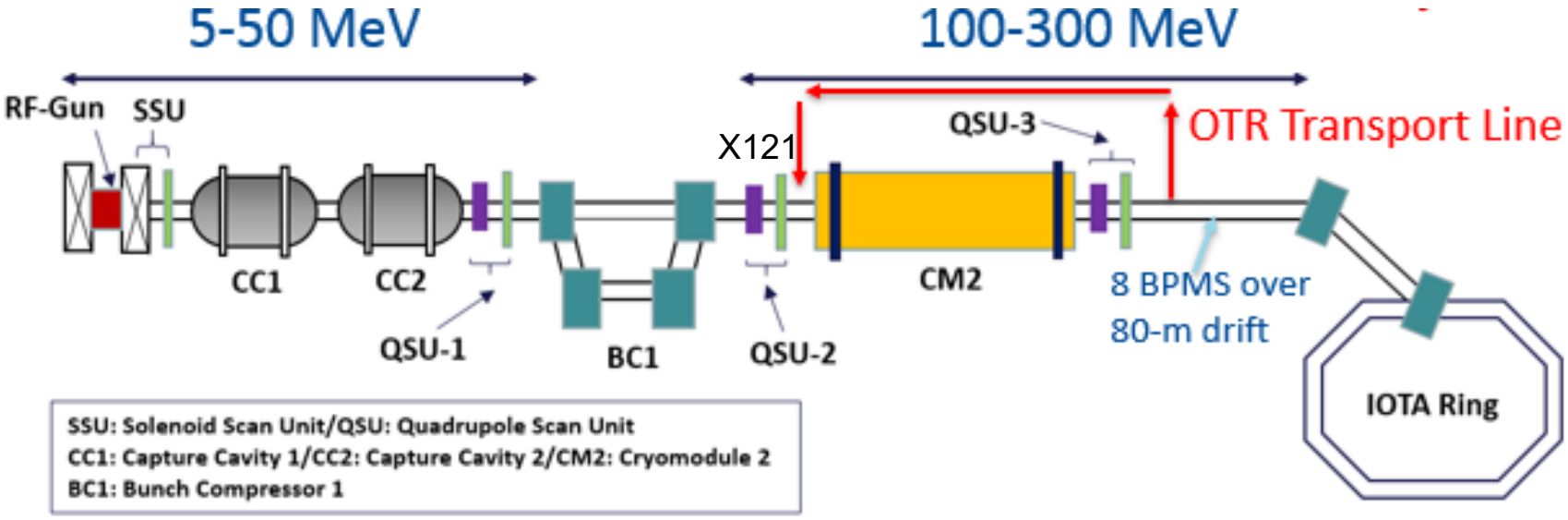
The Need for HOM Measurement and Minimization

- HOMs in RF cavities can produce increased beam emittance.
- So beam induced HOMs need to be minimized, especially with low energy beams.
- For initial commissioning of LCLS-II at SLAC, we need the instrumentation to help us accomplish this.

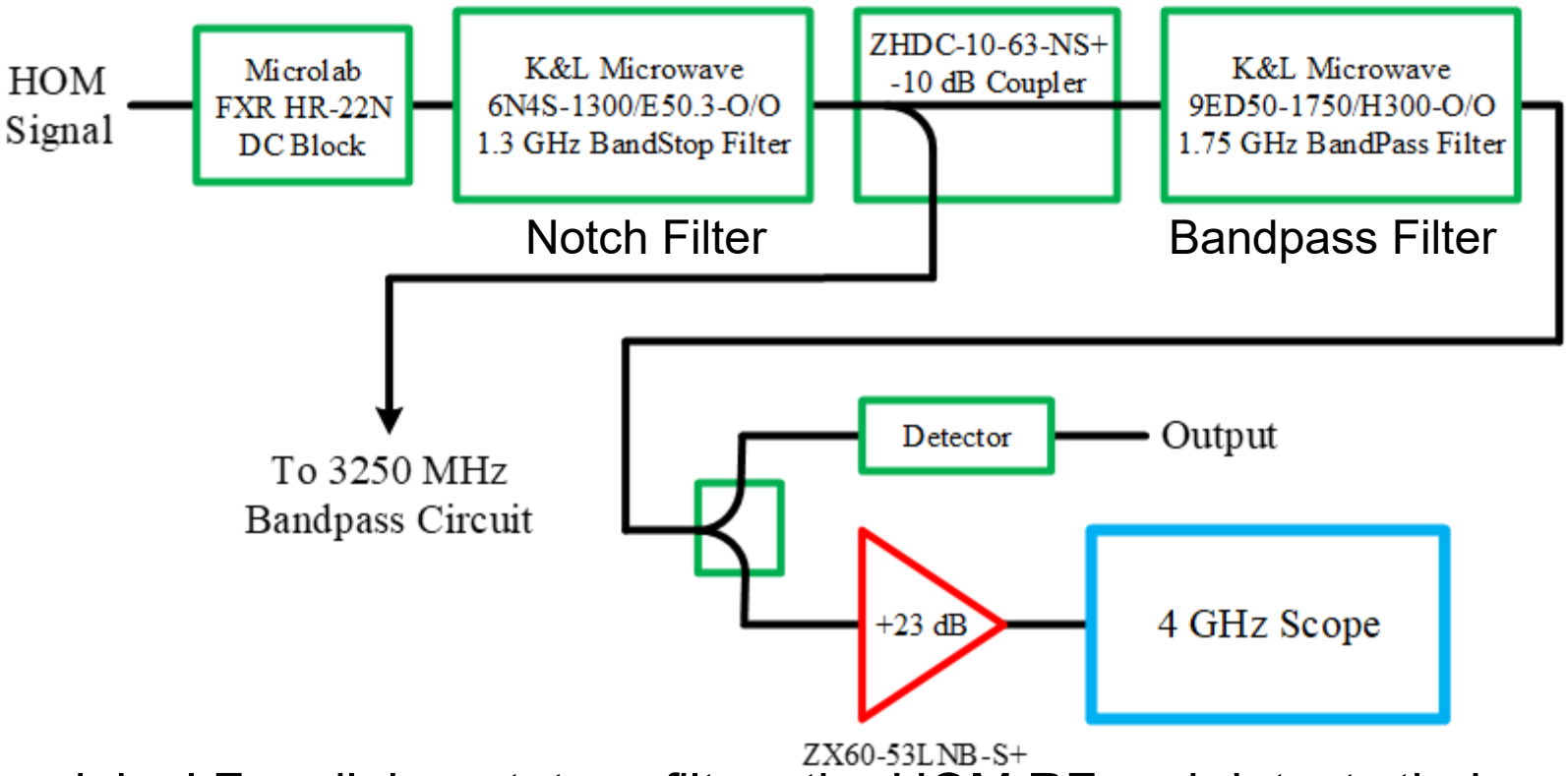
HOM Measurements at FAST: Overview

Fermilab FAST Facility

- Initial prototype testing used HOM signals from the cavity in CC1.
- Prototypes were then connected to the 8 cavity cryomodule CM2

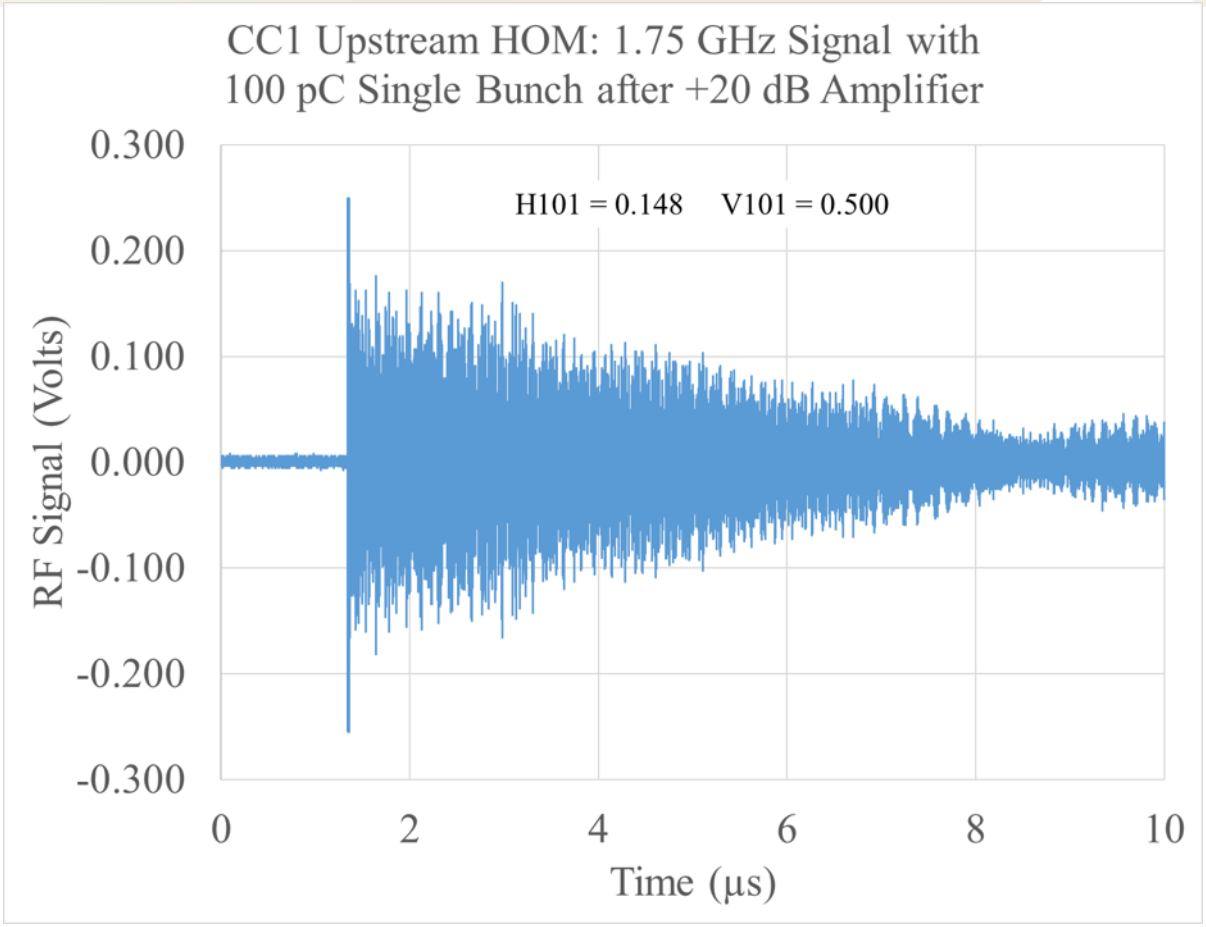


Fermilab Prototype Front End



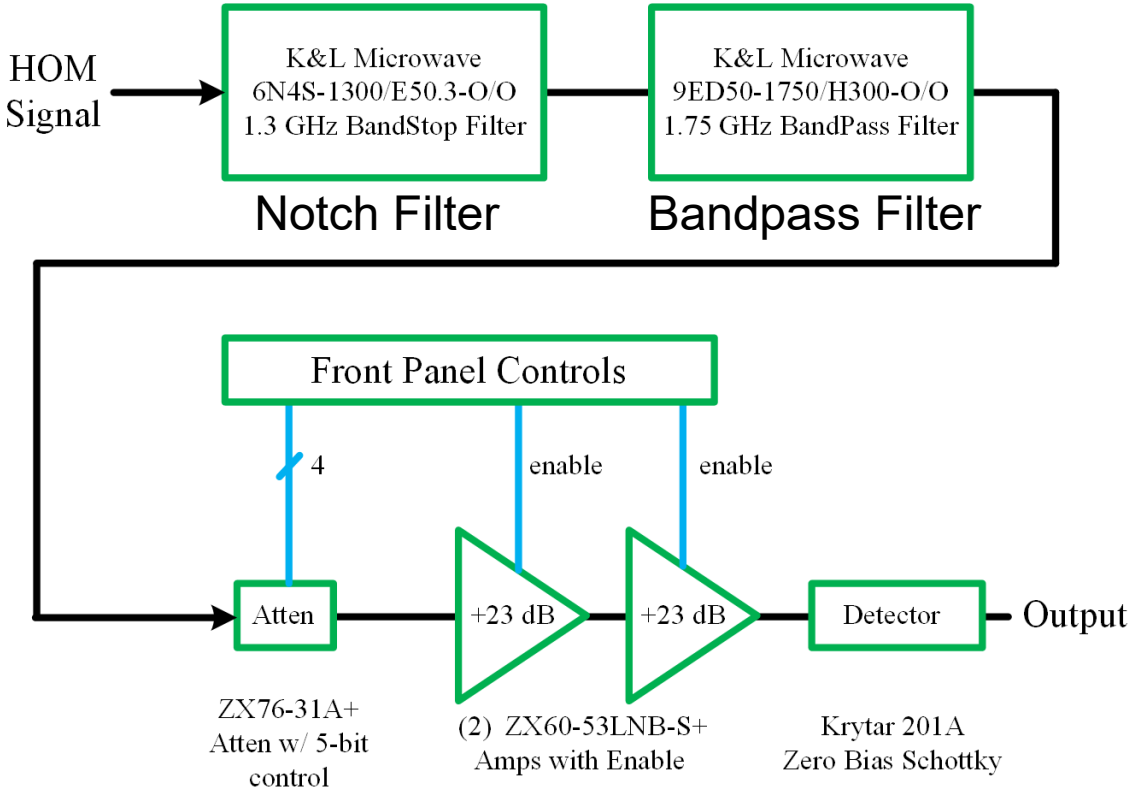
- The original Fermilab prototype filters the HOM RF and detects their magnitude with a Schottky diode.
- As a test, an amplifier was added to the filtered RF and observed on a scope

Fermilab Prototype Front End



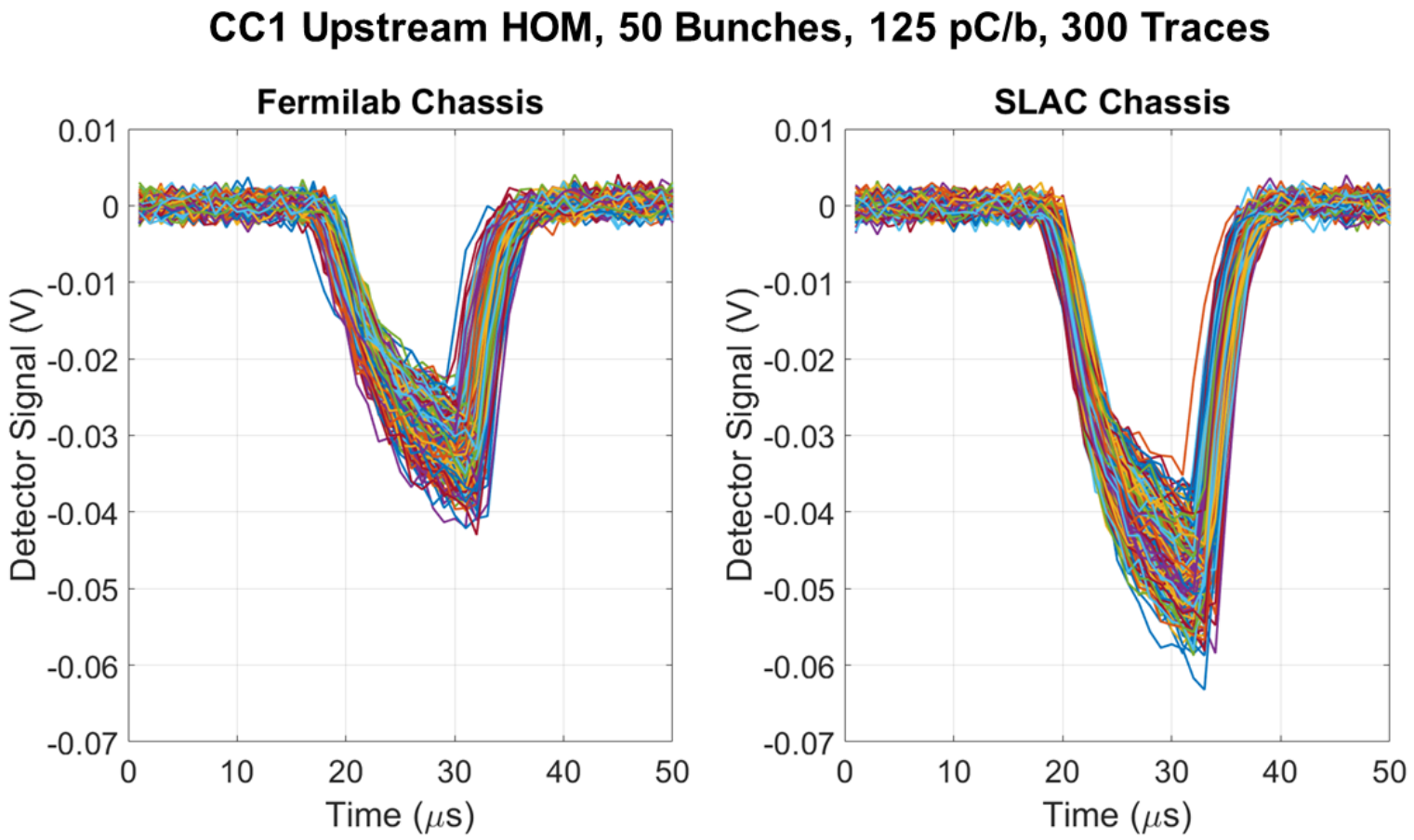
The filtered and amplified HOM signal from a single 100 pC bunch with a displacement of about 6 mm in CC1

SLAC Prototype Front End



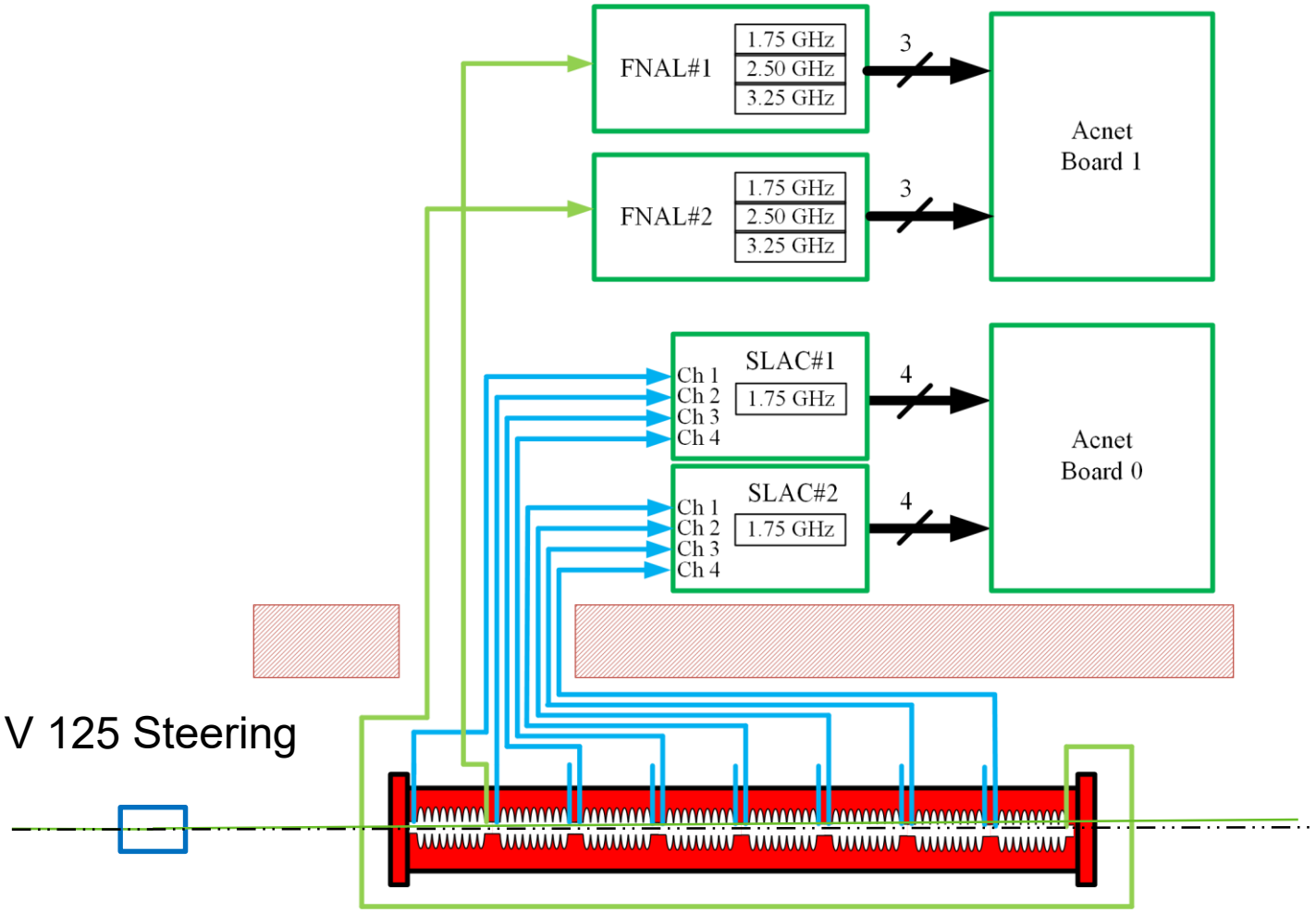
- SLAC HOM detector prototype based on the Fermilab design
- Filters and diode detector give the magnitude (not sign) of the beam offset
- The additional gain allows measurements down to 10 pC/bunch

Comparison of Signals with FNAL and SLAC Prototypes When Connected to the Cavity in CC1



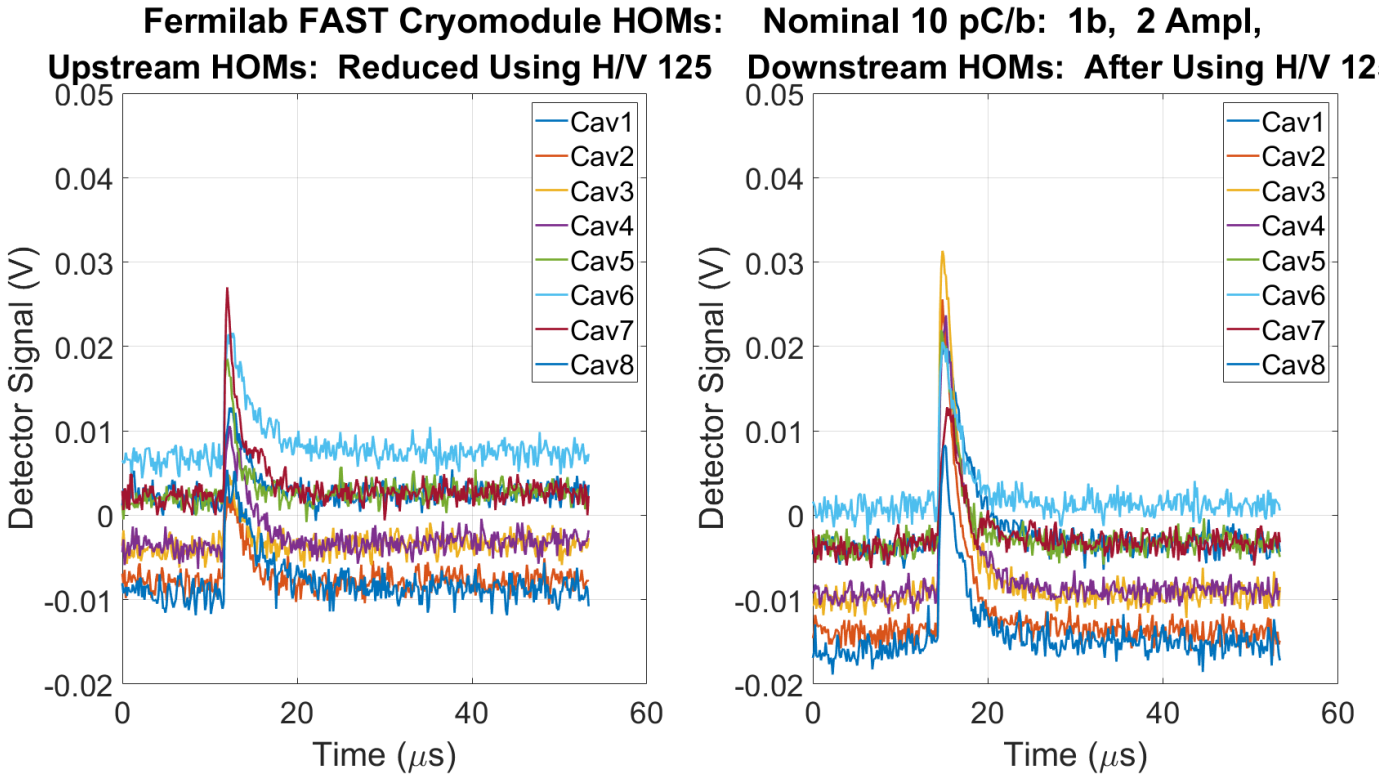
The FNAL and SLAC prototypes give a similar response to HOMs from CC1.

Connections to the FAST Cryomodule



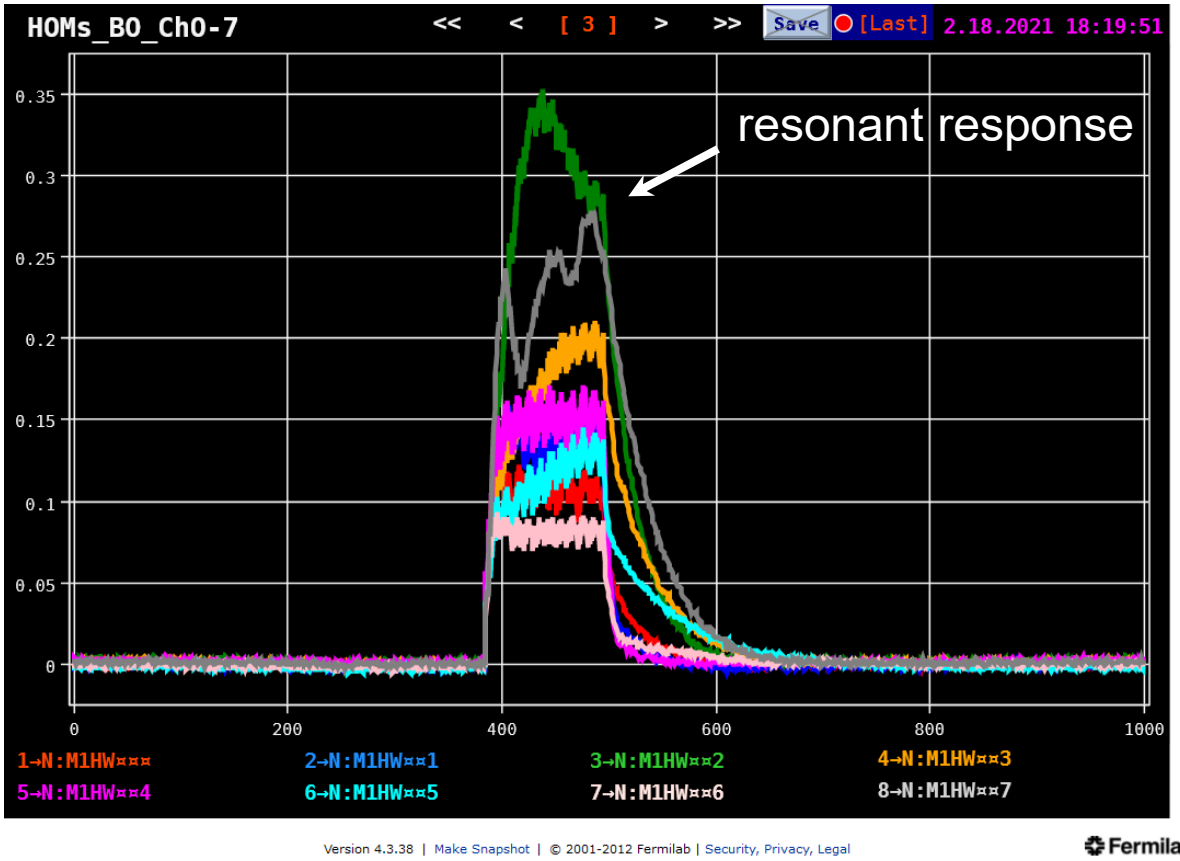
The prototypes were then connected to HOM couplers on each cavity.

Cryomodule HOM Measurements at 10 pC/bunch



The signal from a single 10 pC bunch with both amplifiers enabled and a beam offset of roughly 1 mm at the entrance to the cryomodule

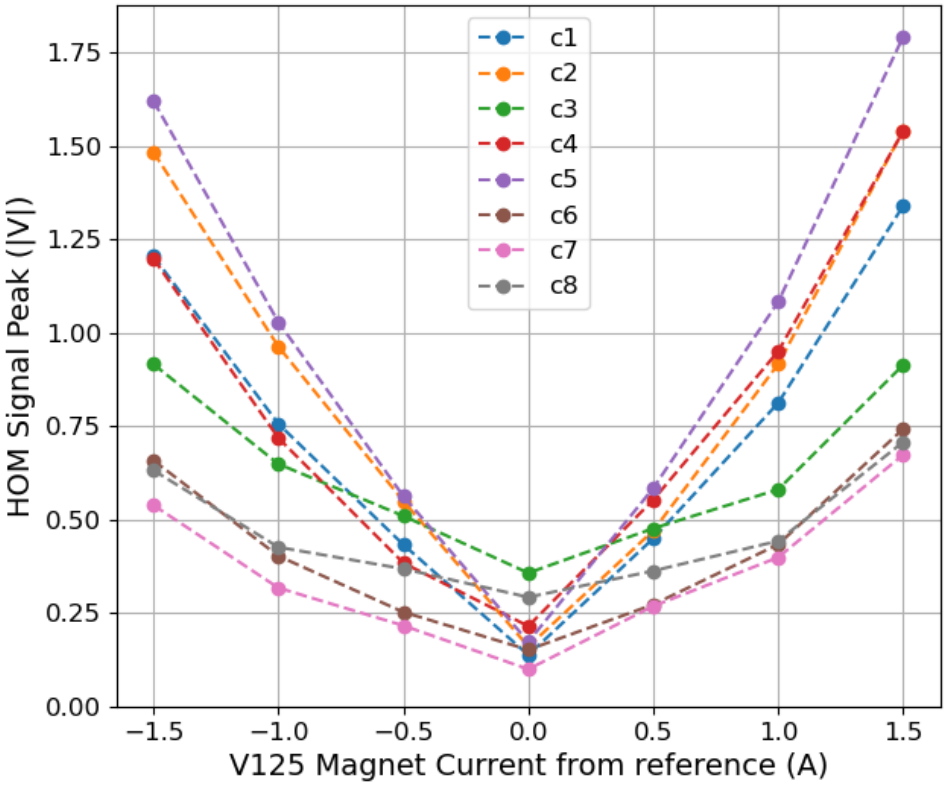
Cryomodule HOM Signals: 50 bunches 400 pC/bunch



- 50 bunches, 333 ns spacing, 400 pC/bunch, nominally on axis
- Some HOMs have a resonant response to the 50 bunches

Cryomodule HOM Measurements 400 pC/bunch

- Plot peaks of HOM signals.
- 50 bunches, 400 pC/bunch
- 1 amplifier enabled
- Steering magnet V125 used to the change beam offset.



- HOM Detected signal versus corrector magnet current
- At 1 A, this is about an 8 mm offset at the entrance to the cryomodule

Summary

- The SLAC HOM measurement front end has been tested with electron beam at Fermilab's FAST facility.
- With two cascaded amplifiers, data show a usable signal with a single bunch of 10 pC and beam offsets of roughly 1 mm.
- The controllable attenuator allows finer control of the signal level – 31 dB in 0.5 dB steps. The combination gives a sensitivity that can be varied over 77 dB.

HOM Measurements

Thanks for your interest!

Be sure to check related presentations on HOM measurements at FAST:

MOPA232 Randy Thurman-Keup

MOPA289 Jorge Diaz Cruz

TUPAB272 Alex Lumpkin

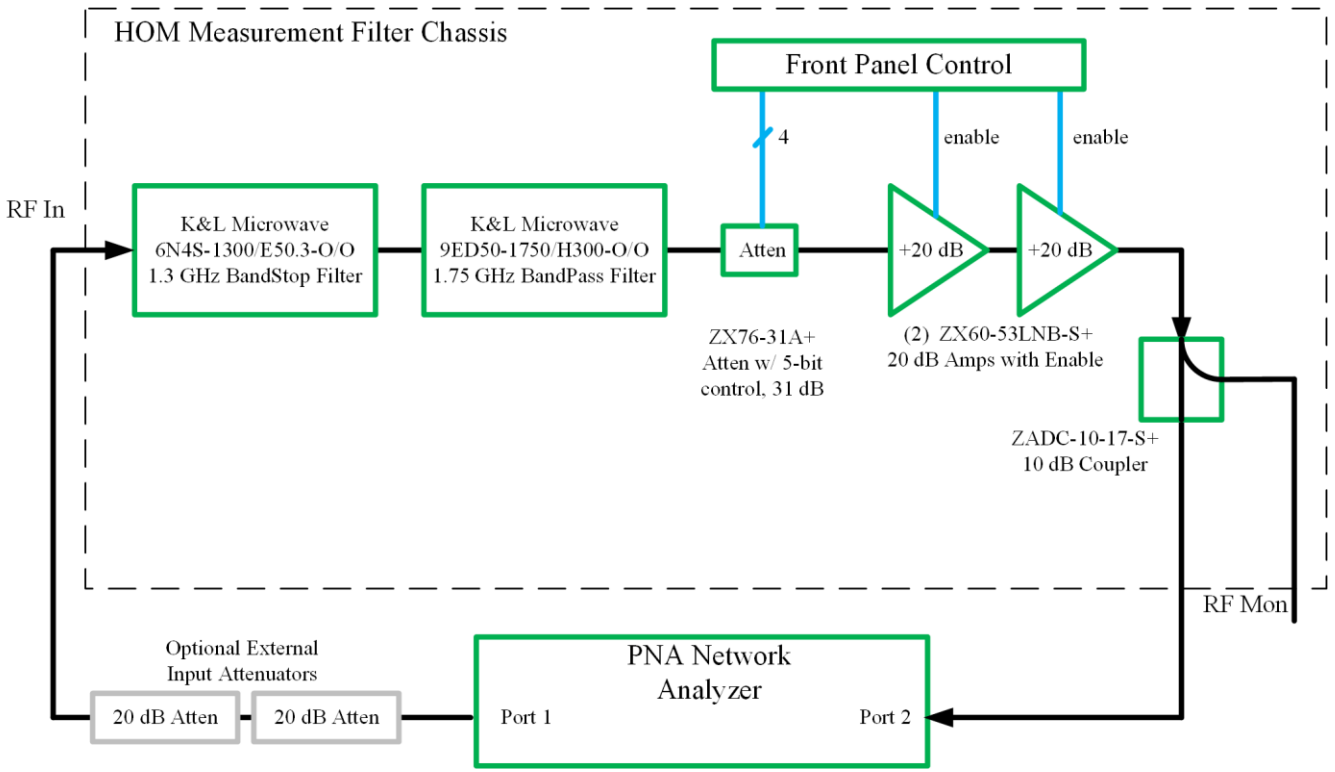
TUPAB273 Alex Lumpkin

TUPAB273 Alex Lumpkin

HOM Measurements

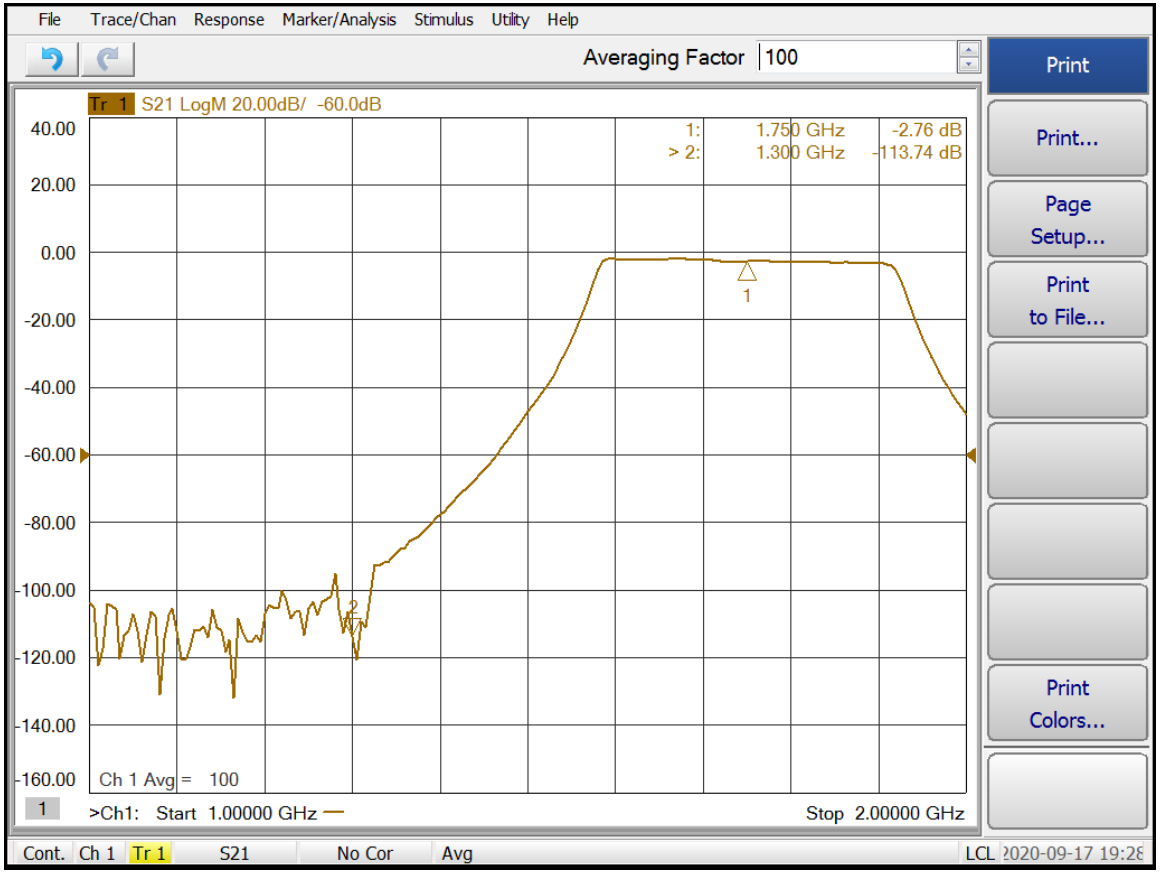
Extra Slides Follow

SLAC Prototype Chassis Bench Measurements



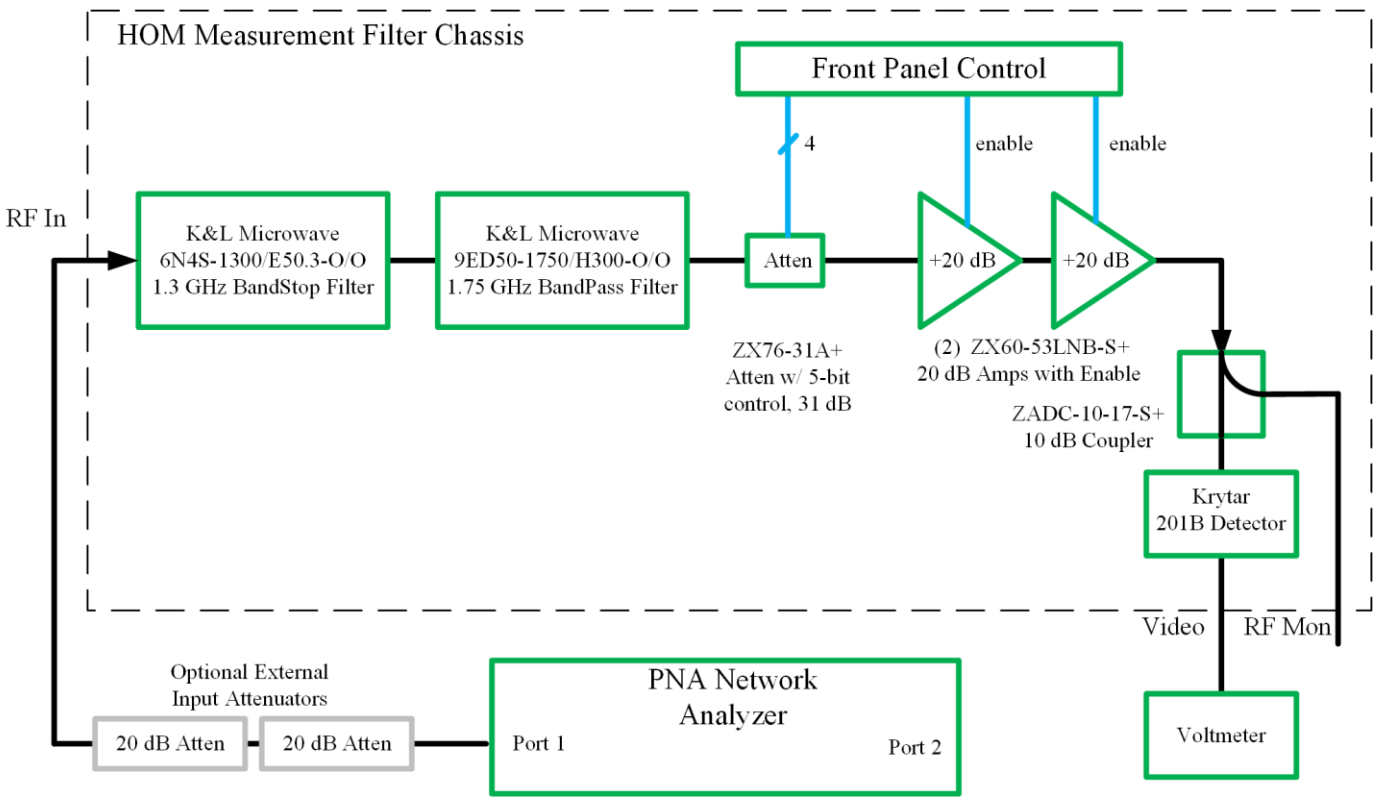
Setup to measure the RF response of a chassis channel.

SLAC Prototype Chassis Bench Measurements



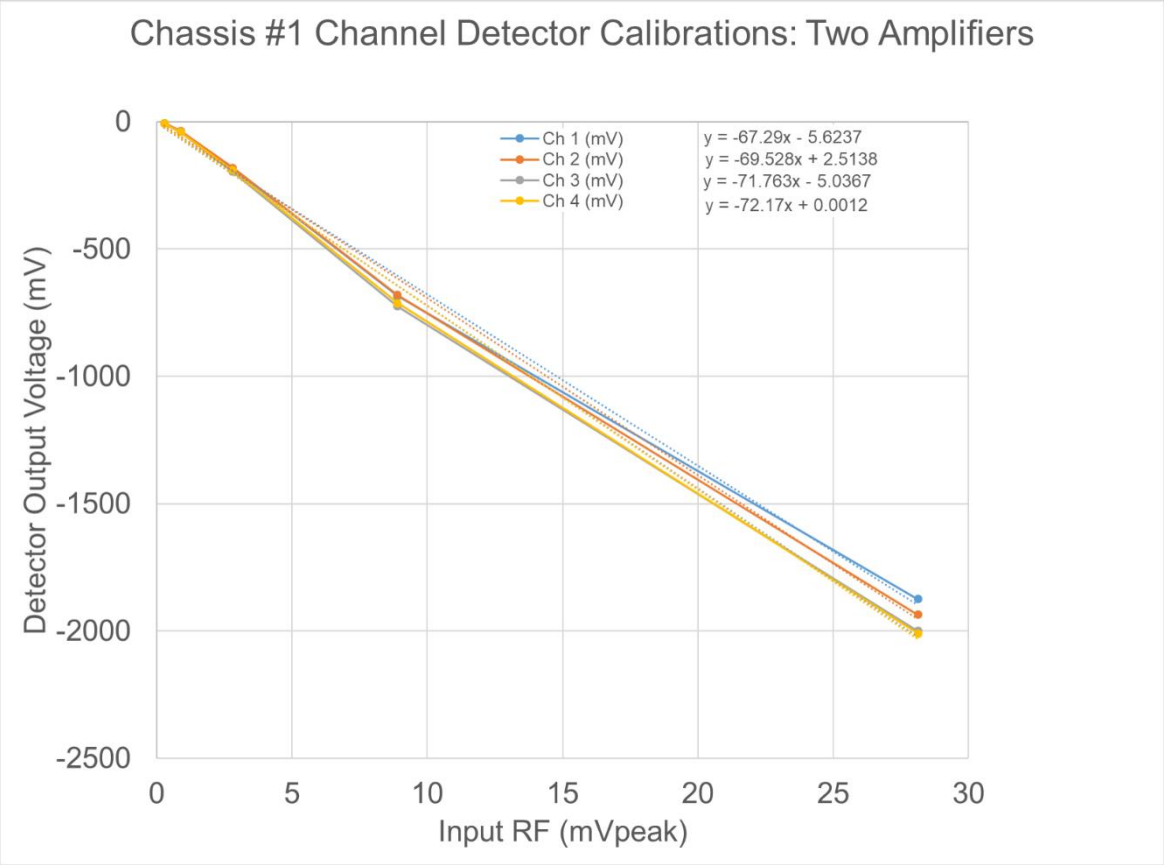
Measured channel response with two amplifiers enabled (+46 dB) and 40 dB of external attenuation.

SLAC Prototype Chassis Bench Measurements



Setup to measure the diode sensitivity

SLAC Prototype Chassis Bench Measurements

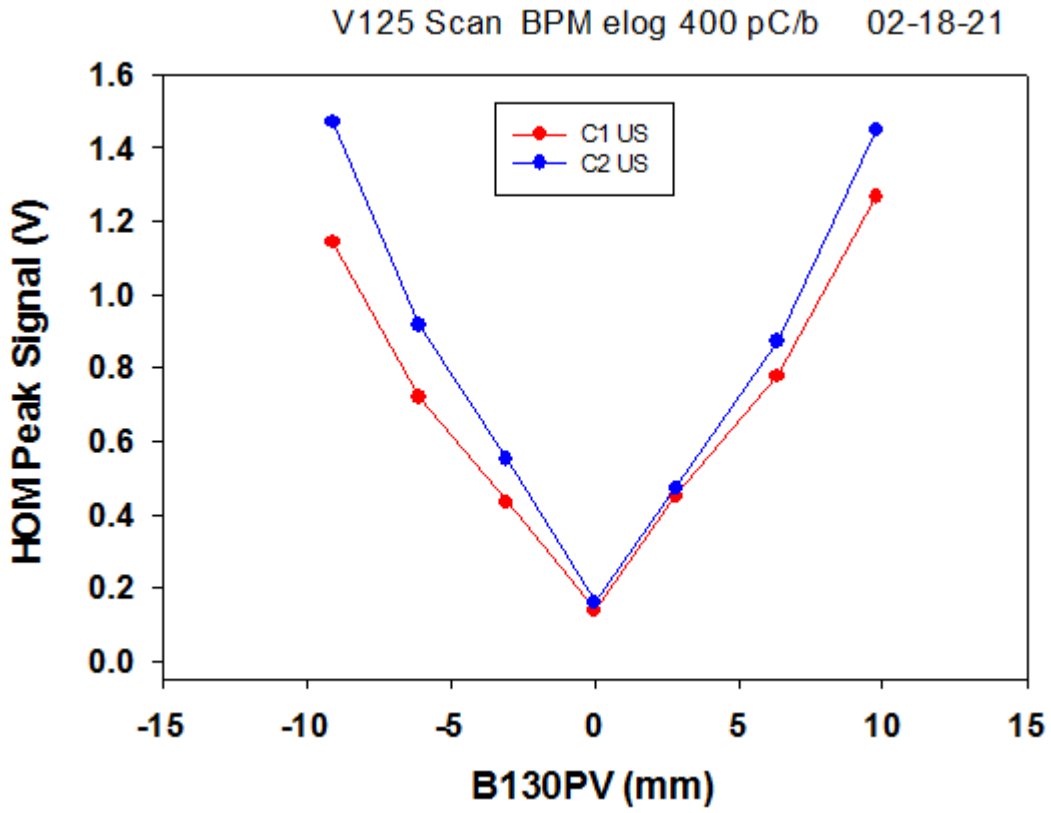


Diode sensitivity measurement with two amplifiers enabled.

Input RF is scaled assuming 40 dB of external attenuation

Cryomodule HOM Measurements: Roughly Minimized

- SLAC Detectors with a 400 pC/b 50 bunches using 1 Amplifier (+23 dB)
- Plot HOM signal versus position near the entrance to the cryomodule.
- Approx 100 mV/mm signal (0.25 mV/pC*mm)



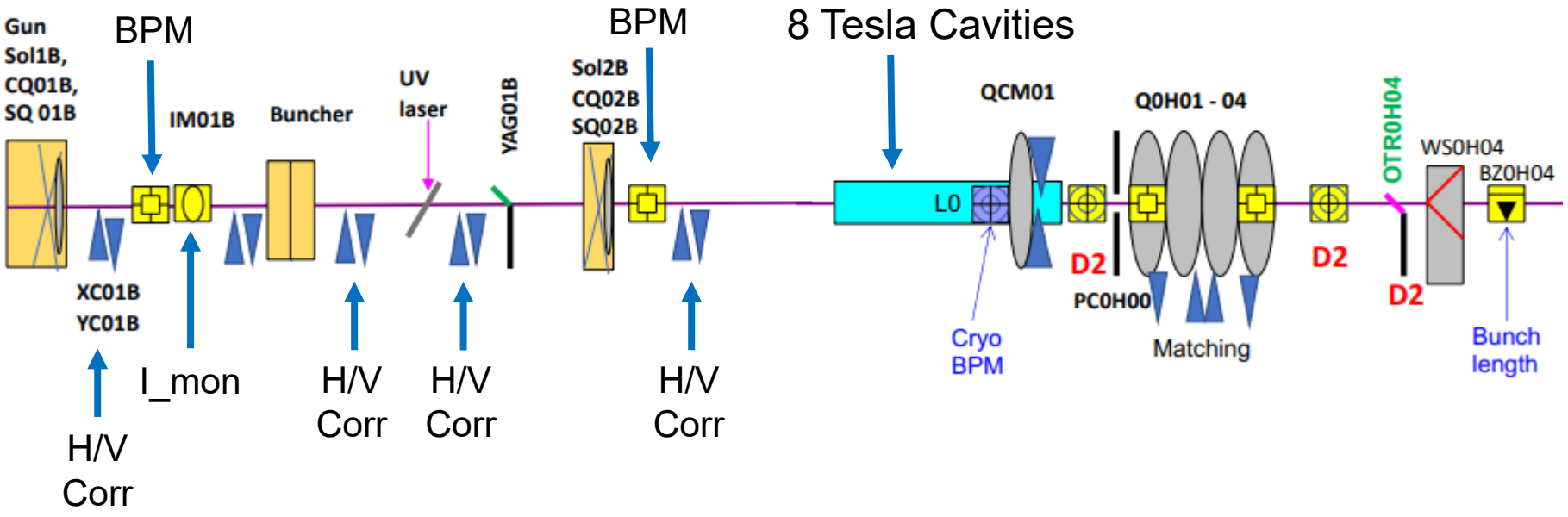
Bunch rep freq 3 MHz

Feb 2021 Data

Alex Lumpkin FNAL

SLAC LCLS-II Injector

- Sketch of the Injector for the SLAC LCLS-II
- Beam Energy 750 keV at entrance to Cryomodule



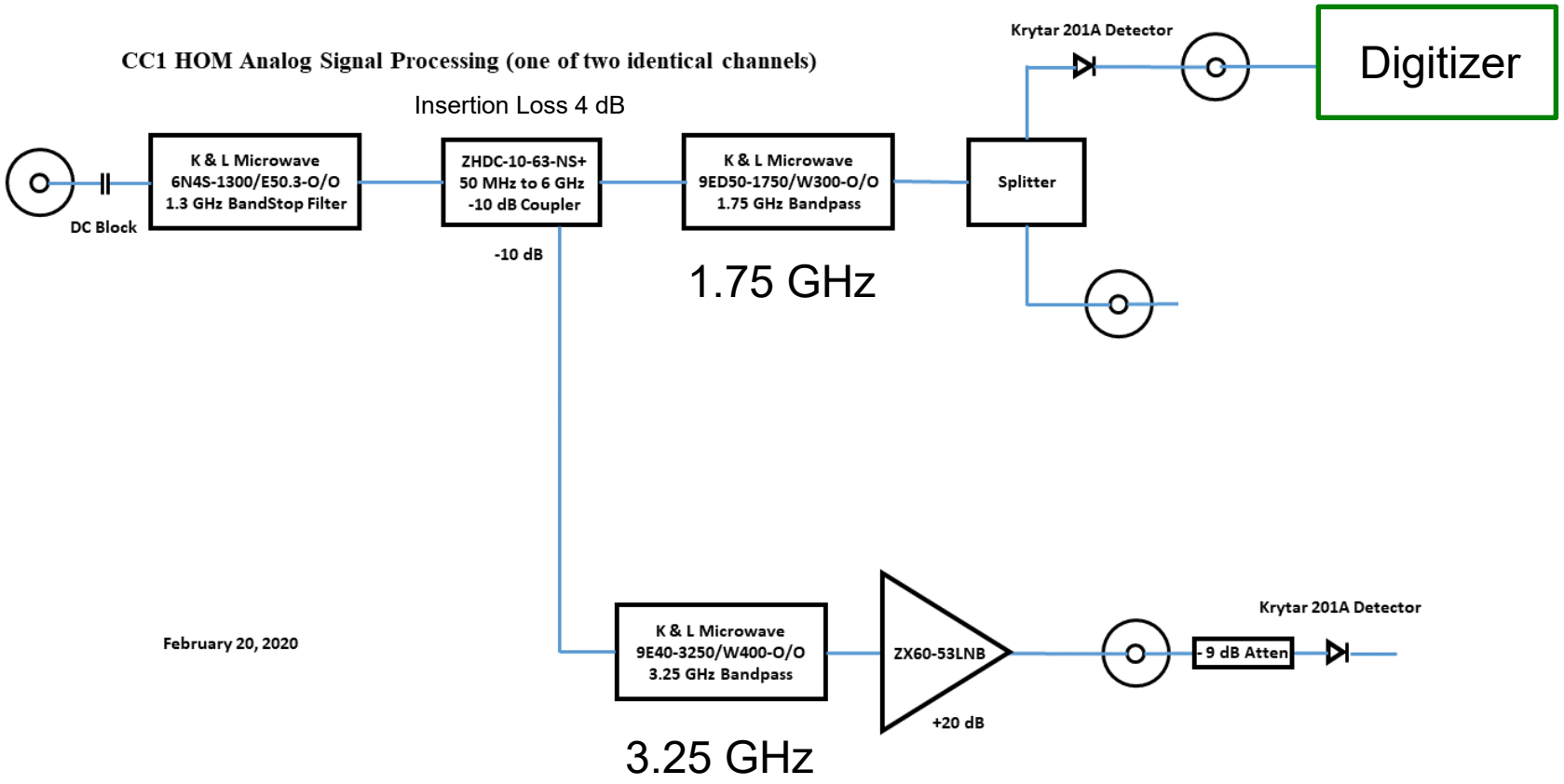
SLAC Requirements for a Beam Offset Monitor

- At LCLS-II, we need to have a functioning HOM measurement system during beam commissioning as an aid in minimizing wakefield-induced emittance dilution.
- LCLS-II maximum bunch frequency is 1 MHz, initially << 1 MHz
- LCLS-II maximum bunch charge 300 pC, initially expect min of 10 pC.

- So single bunch, 10 pC/b beam at FAST would be used to check that the SLAC hardware meets the design specifications for LCLS-II.
- The SLAC Chassis are based on the Fermilab HOM Box (Peter Prieto).

HOM Measurements

Fermilab HOM Box (Peter Prieto)



HOM Signals:

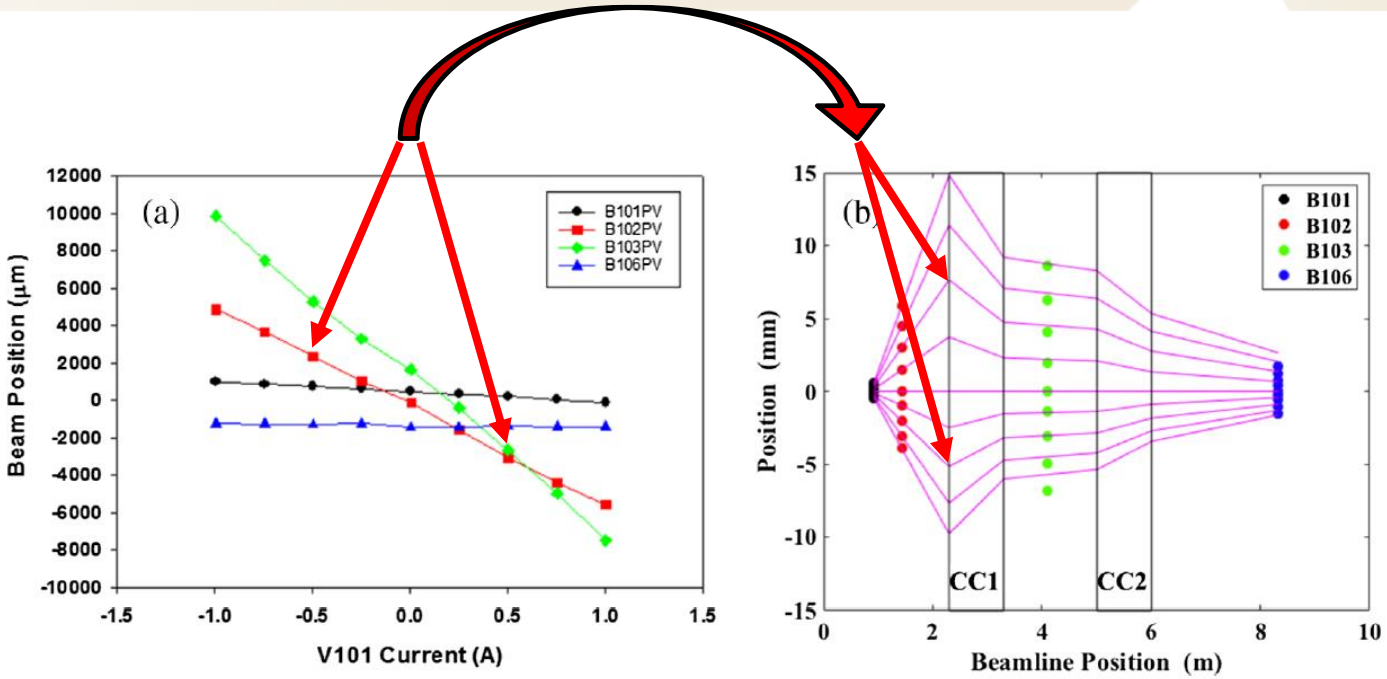


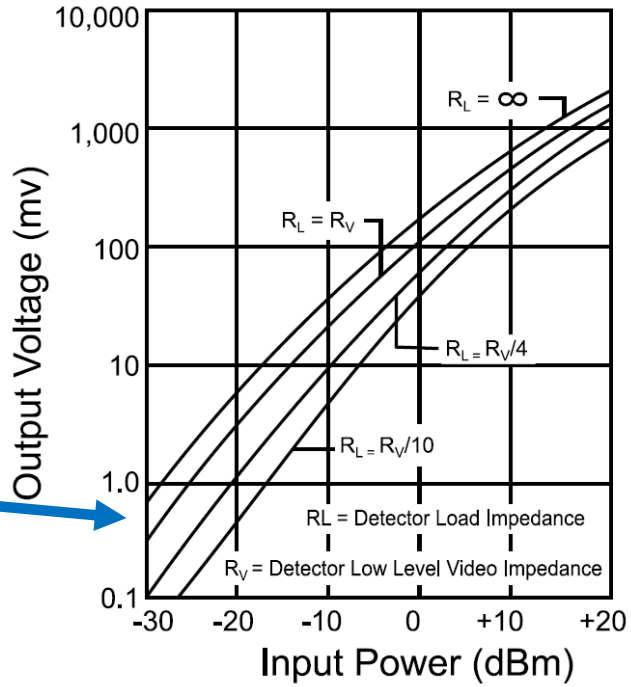
FIG. 3. (a) Macropulse-averaged vertical beam positions tracked with rf BPMs before, between, and after the two capture cavities versus the V101 corrector settings. (b) Beam positions relative to the 0-A case as a function of BPM position for a sequence of V101 corrector settings.

- From Lumpkin: PHYSICAL REVIEW ACCELERATORS AND BEAMS 21, 064401 (2018)
- A current of +/- 0.5 A in V101 gives ~ +/- 6 mm or so at CC1

HOM Signals

ZERO BIAS SCHOTTKY DETECTORS

TYPICAL OUTPUT VOLTAGE vs. INPUT POWER CURVES FOR VARIOUS R_L/R_V RATIOS at T_a=20°C



Low signal limit

- Detector signal is < 1 mV at -30 dBm (High Z input)
- This is about 10 mV RF amplitude.