Investigating The Microbunching Instability at Diamond Light Source

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8 Apr 2014

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Contents

- Introduction – Diamond Light Source, CSR, & Microbunching Instability
- Instability Detection
- Dedicated setup for instability experiments
- Interferometer Installation & Results
- Future Plans.

Diamond Light Source

Energy	3 Gev
Circumference	561.6 m
Rev. Freq.	533.820 KHz
Beam Current	(typ.) 300 mA
Emittance (h, v)	2.7, 0.03 nm rad
Typical Size (h, v)	123, 6 µm

Double bend achromat lattice, 48 Dipoles, 240 Quadrupoles, 168 Sextupoles, 22 insertion devices.

Diamond can operate in numerous fill pattern modes, including hybrid, single bunch, & low-alpha optics.

I. Martin, G. Rehm, C. Thomas, and R. Bartolini, Phys. Rev. ST Accel. Beams 14, 040705 (2011).

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CSR and the Instability

- CSR - coherent synchrotron radiation generated by centripetally accelerating electrons:

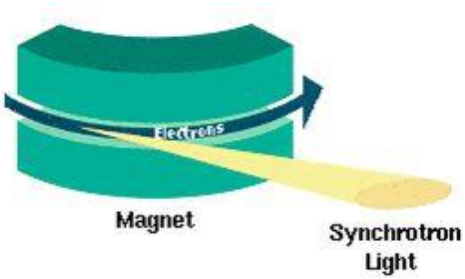
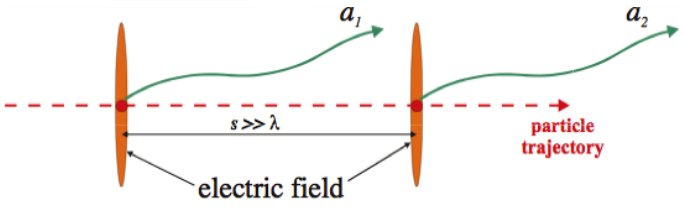
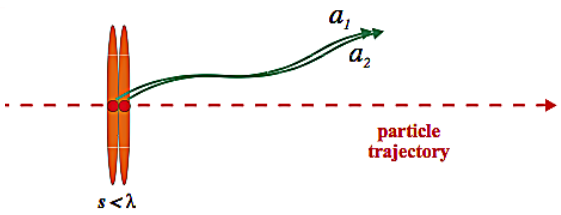


Image courtesy of
John Adams Institute



Incoherent



Coherent

Images courtesy of
Dr P. Karataev

Characterised by onset of coherent bursts of radiation, with a wavelength comparable to that of the bunch length (typ. 5 mm). Normally only observed as incoherent signal.

- Models exist to describe the instability but are non-trivial and do not provide a full description.

Theoretical model :
G. Stupakov and S. Heifets, Phys. Rev. ST Accel. Beams, **5**, 054402 (2002)

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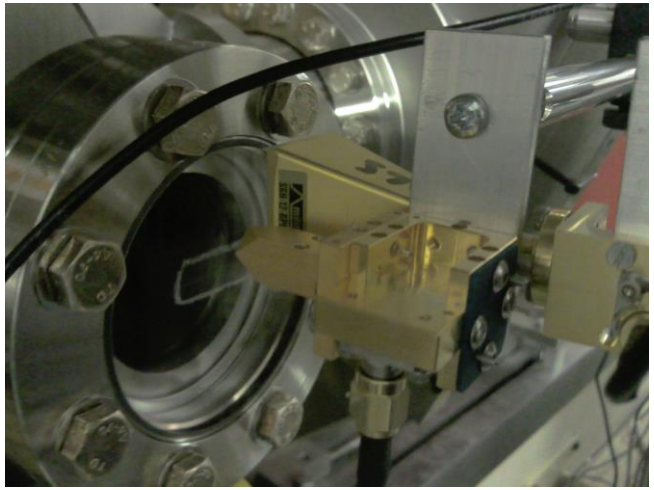
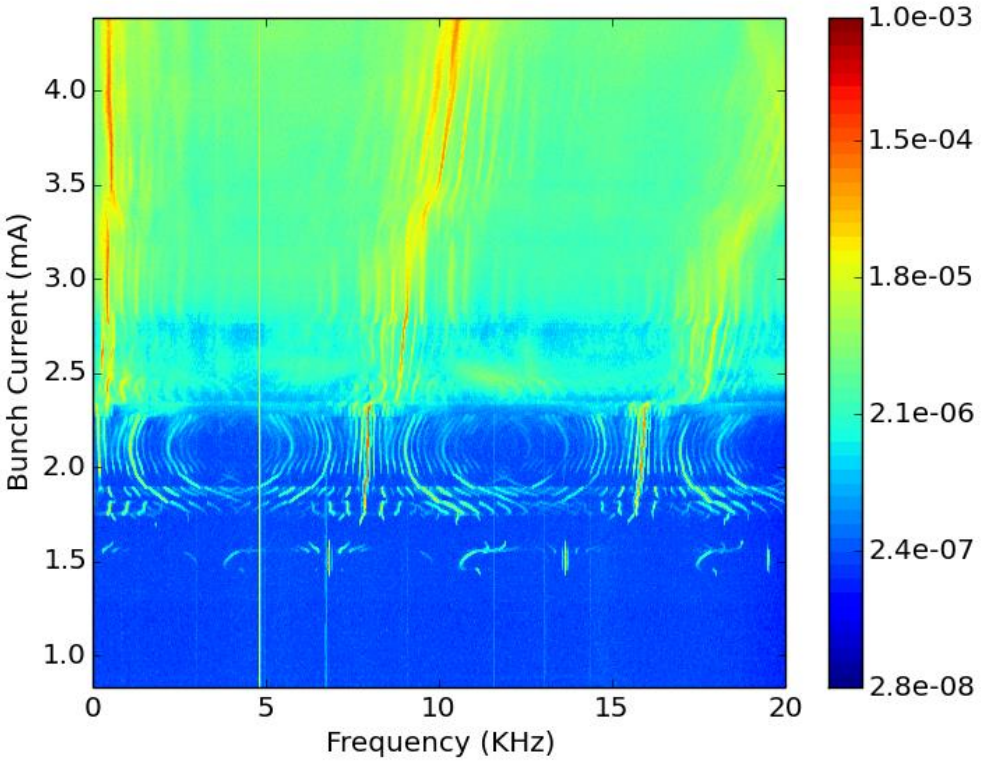
Instability Detection



- Schottky Barrier Diode (SBD) detectors, 60-90 GHz BW.
- Initial experimental setup was at a shared viewport.



- Signal recorded is modulated to the bunch revolution frequency, over current range between 1.0 – 4.0 mA.
- Transitions with current represent switching from quasi-periodical bursting to chaotic.

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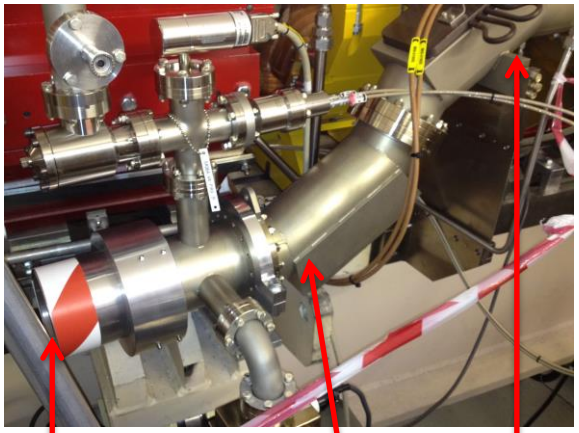
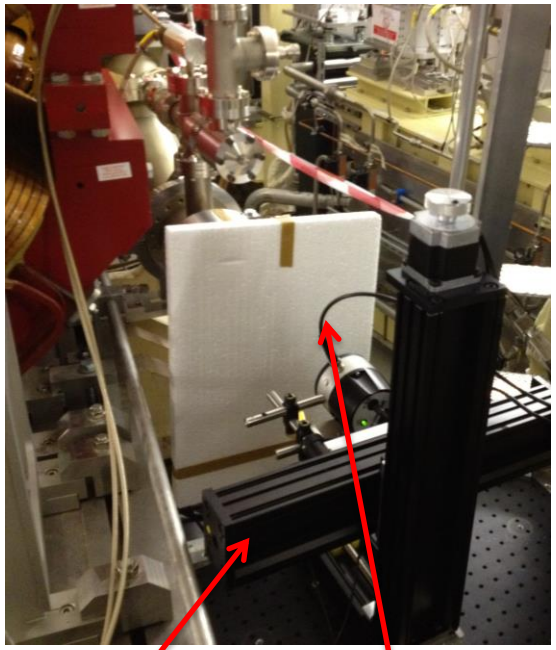
Dedicated mm-Wave Viewport



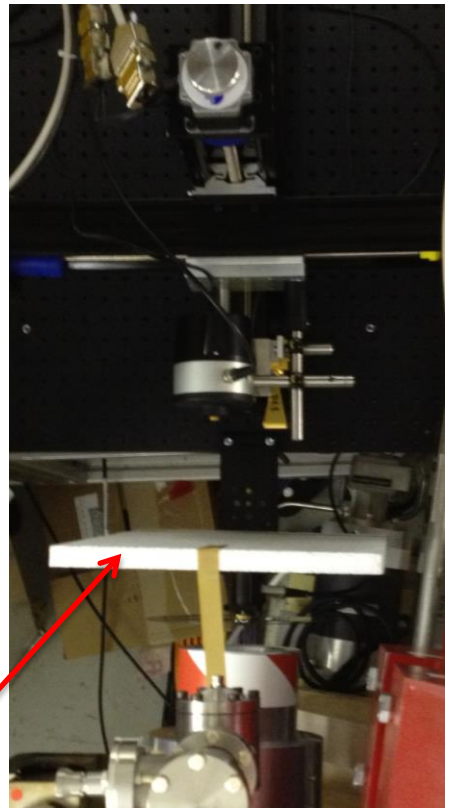
Fused Silica Viewport.

Second parallelising mirror

Cooled copper Mirror for x-ray absorption



3D stage system with amplified detectors



Hi-tech absorber for reducing background signal

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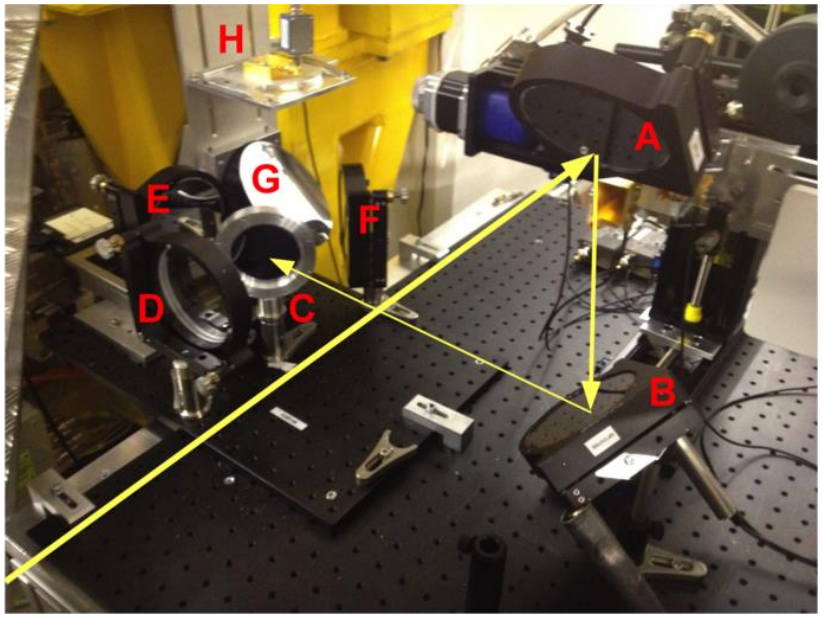
Interferometer



- Laser aligned Michelson Interferometer successfully constructed independent of previous setup.
- Available space around the table is problematic; the solution was to translate the beam with a fixed mirror followed by a plate controlled by 2 actuators
- 3D stage setup still usable, but restricted to accommodate the interferometer.

- The interferometer includes: a 100 µm thick silicon beamsplitter, 150mm linear translation stage, parabolic focusing mirror & a custom made detector holder.

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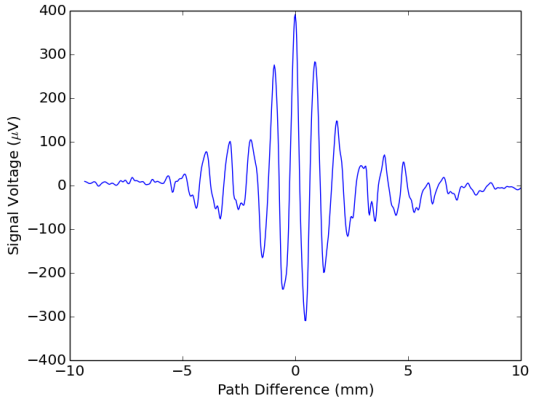
Detectors

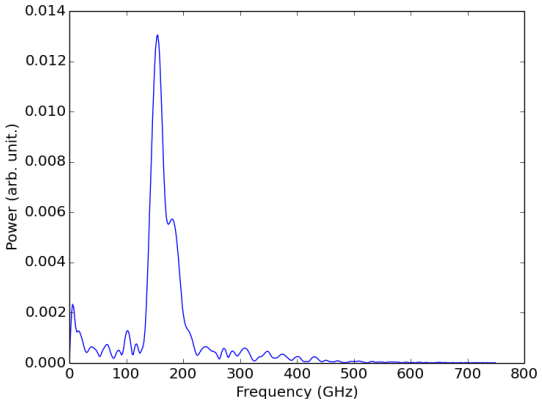
- Two types of detectors were used: Schottky Barrier Diode (SBD) detectors, and pyroelectric detectors.
- Previous experiments used smaller bandwidth SBD detectors in early stages of instability detection – larger bandwidth used to investigate higher frequencies.

Detector	**Quasi-Optical Schottky Barrier Diode**	**Pyroelectric**
Frequency Range (GHz)	100 – 1000	100 – 30,000 +
Wavelength (mm)	3 – 0.3	3 – 0.01
Responsivity (V/W)	500	70,000
Noise Equivalent Power (pW/√hz)	10	1000

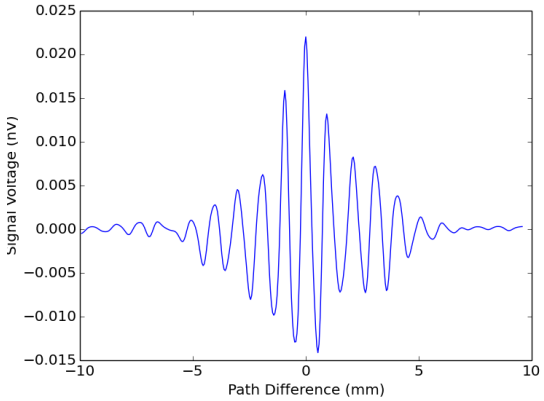
Single Bunch Interferograms

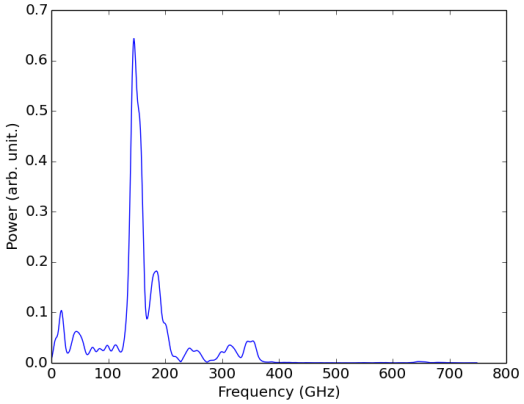
Pyro





QOD





- Spectra recorded in independent experiments
- Spectra show frequencies observed between 100 and 200 GHz, with a sharp low frequency cutoff.
- Frequency cutoff from detector sensitivity and diffraction effects in the interferometer.

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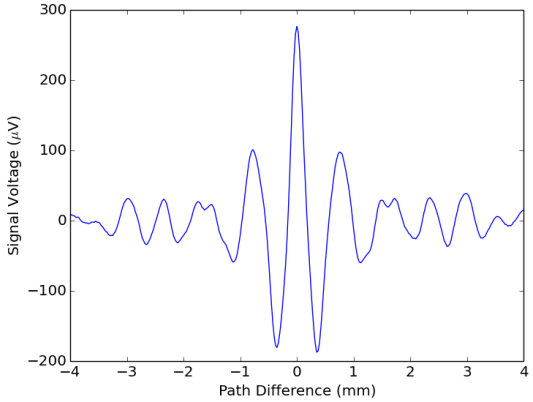
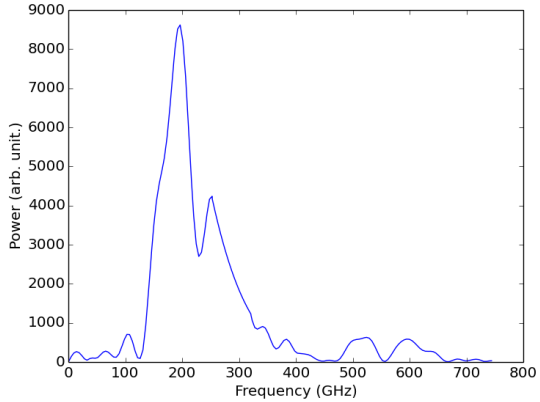
Low alpha Interferograms

Pyro





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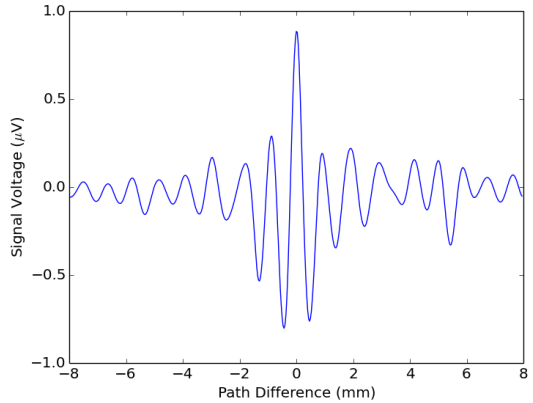

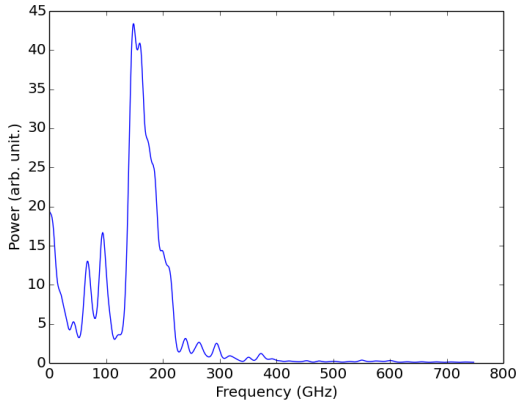

- Higher frequencies in the spectrum are observed between 100 and ~600 GHz.
- Clear differences in the spectra from two detectors, partly due to spatial resolution in the time domain scan but still an ongoing investigation.

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Summary & Future Plans

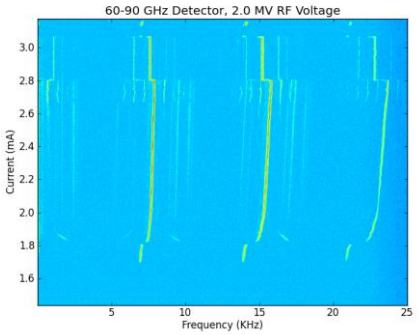
- Observed bursting over wide bunch current range, and the beam / storage ring conditions to produce the instability are well known.
- Interferometer built and installed, with interferograms successfully recorded from both a single bunch in standard optics, and from low-alpha optics setup. FFT shows coherent emissions between 100-600 GHz.
- Incomplete spectra has proven problematic, further results / investigation is required & ongoing.
- Write a Thesis!!

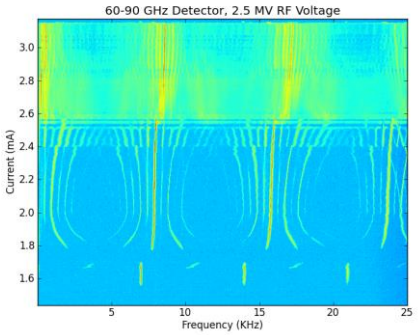
Thank You

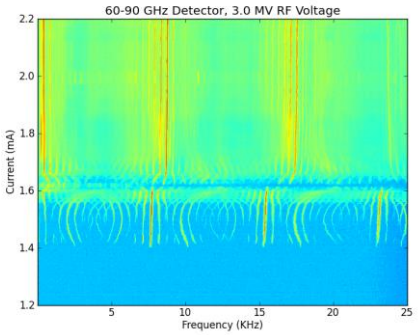
Any Questions?

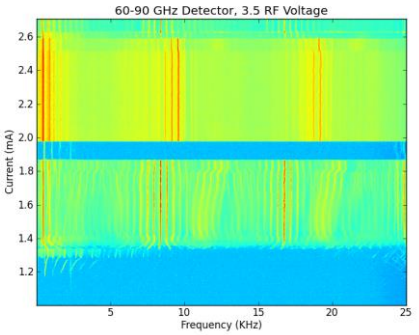
Backup Slides

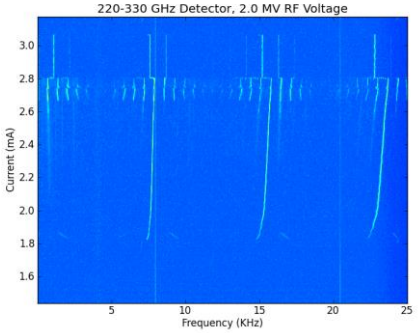
Instability Detection

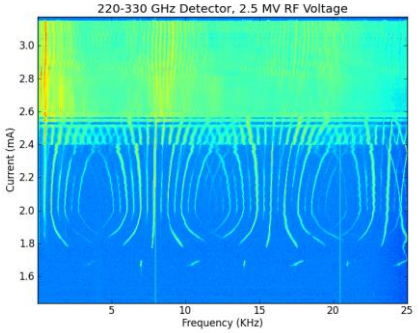


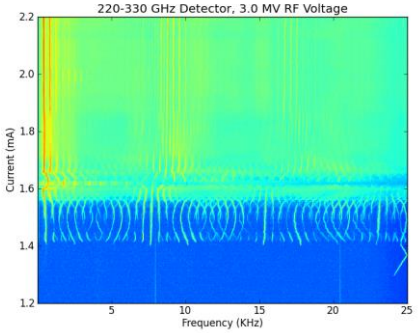


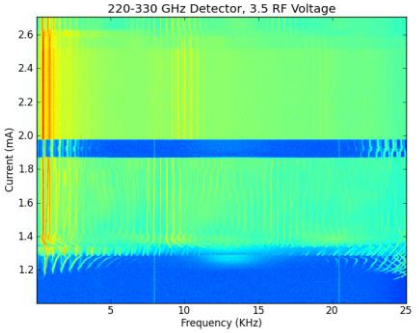












2.0 MV

2.5 MV

3.0 MV

3.5 MV

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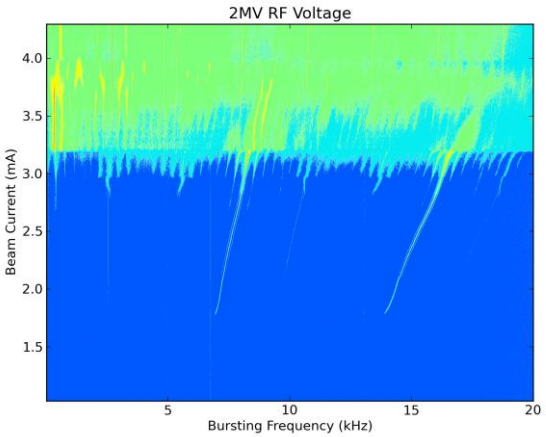
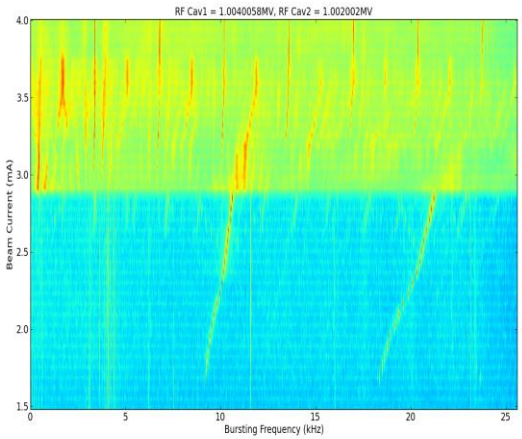
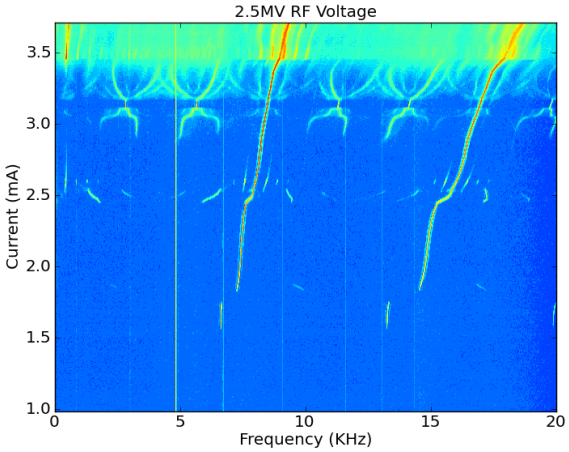
Bursting Detection

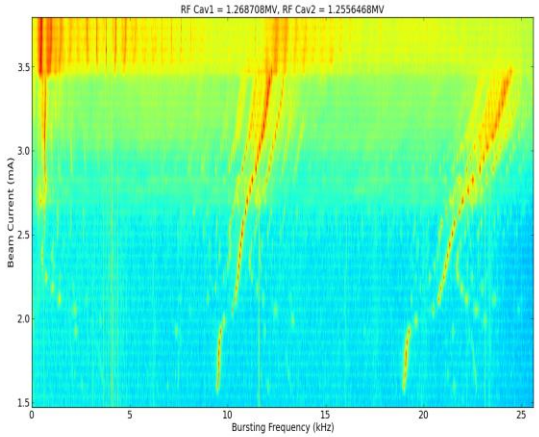
2.0 MV



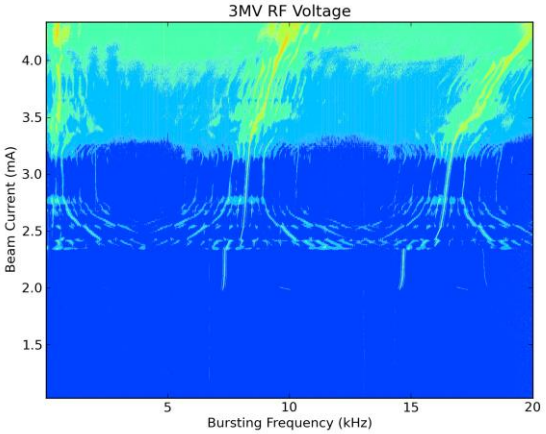


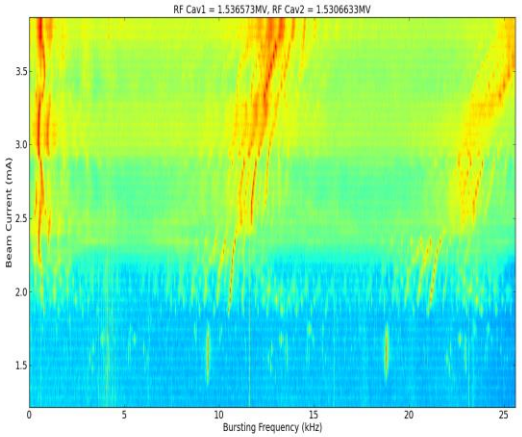
2.5 MV





3.0 MV





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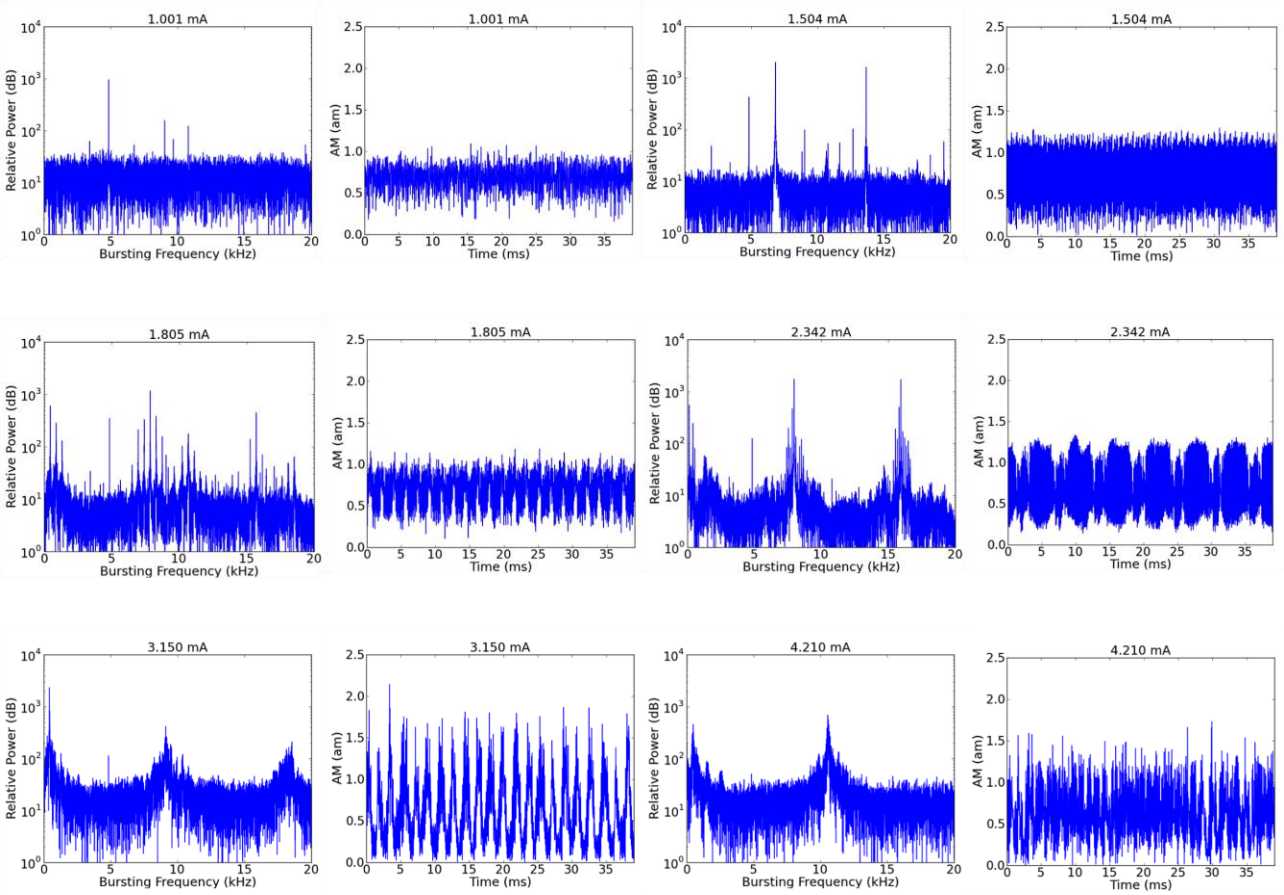
Instability Evolution



- Evolution in time and frequency domains is evident
- Instability behaving as expected
- Need further DAQ development

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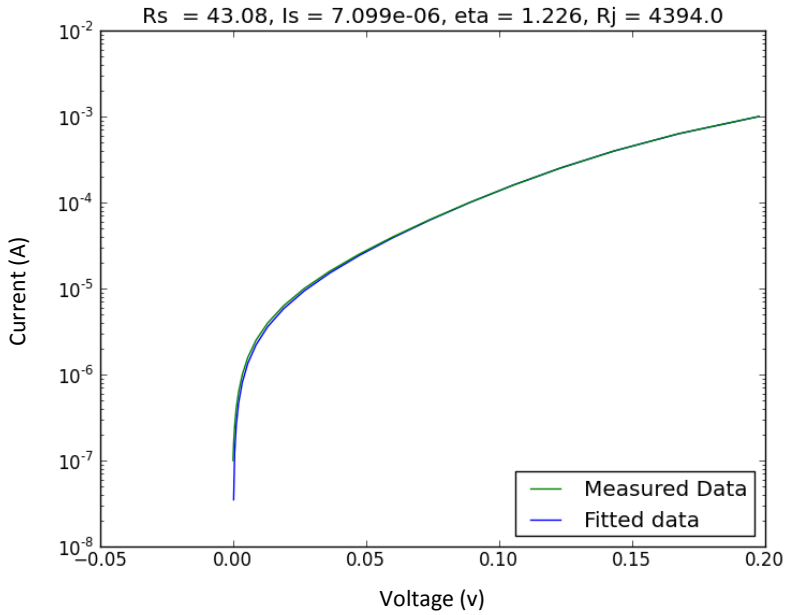
Detector Sensitivity



- Detector sensitivity depends on impedance; amplifier input impedance is 10kΩ but sensitivity quoted for 1MΩ.
- Reduced sensitivity calculated by measuring I-V characteristics of the diodes.
- Data fit shows good agreement. The reduced sensitivity of the two SBD detectors is:

60-90 GHz: 500 mV/mW (previously 700)
220-330 GHz: 1000 mV/mW (previously 1500)

$$I = I_s\left(e^{\frac{V_a - IR_s}{hV_t}} + 1\right) \quad (1)$$

$$R_j = \frac{hV_t}{I}$$

$$S_1 = S_2\left(\frac{R_L}{R_J + R_L}\right)$$

Is = Saturation Current
Va = Applied Voltage
Rs = Series Resistance
Eta = Ideality Factor
Vt = Thermal Voltage

S1 = Reduced Sensitivity
S2 = Original Sensitivity
RL = Load resistance
Rj = Junction Resistance

(1). R.Buted, Zero bias detector diodes for the rf/id market,

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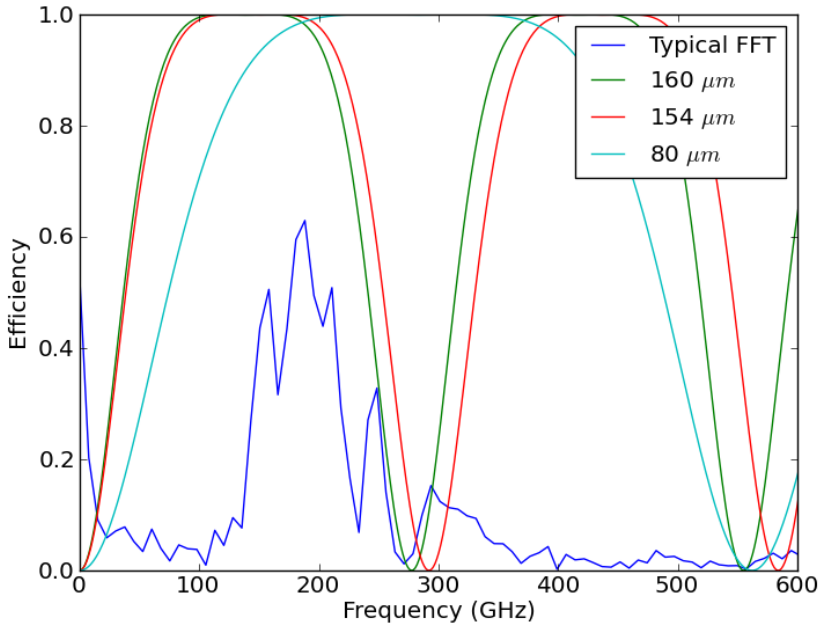
Beam Splitter



- Silicon beamsplitter has a drop in efficiency at the observed cutoff (green). Slightly thinner splitter currently installed but efficiency drop shifted slightly.
- Investigation of beamsplitter thickness shows 80 µm substantially shifts efficiency drop to ~ 550 GHz.
- Drop in efficiency at lower frequencies can be accounted for.

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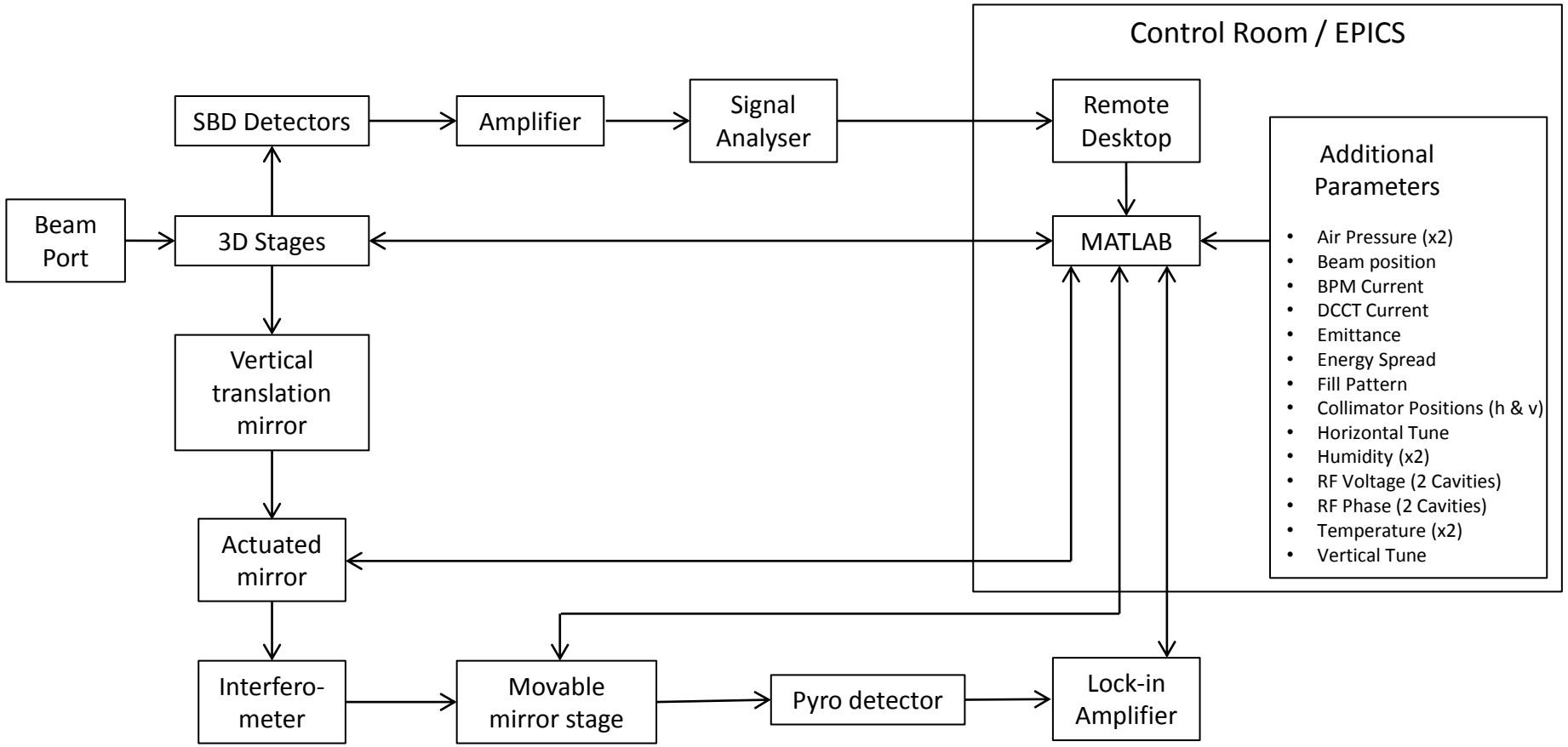
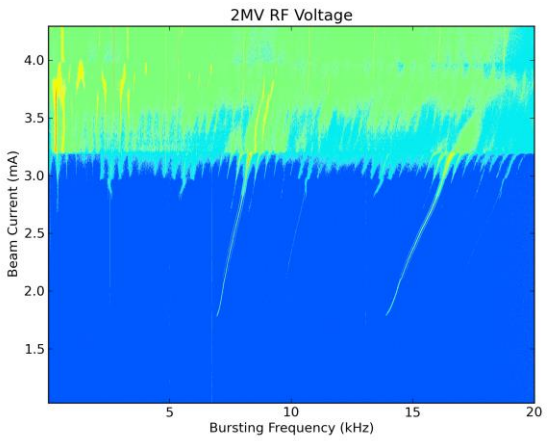
System & DAQ


Control Room / EPICS
SBD Detectors
Amplifier
Signal Analyser
Remote Desktop
Additional Parameters
Air Pressure (x2)
Beam position
BPM Current
DCCT Current
Emittance
Energy Spread
Fill Pattern
Collimator Positions (h & v)
Horizontal Tune
Humidity (x2)
RF Voltage (2 Cavities)
RF Phase (2 Cavities)
Temperature (x2)
Vertical Tune
Beam Port
3D Stages
MATLAB
Vertical translation mirror
Actuated mirror
Interfero-meter
Movable mirror stage
Pyro detector
Lock-in Amplifier

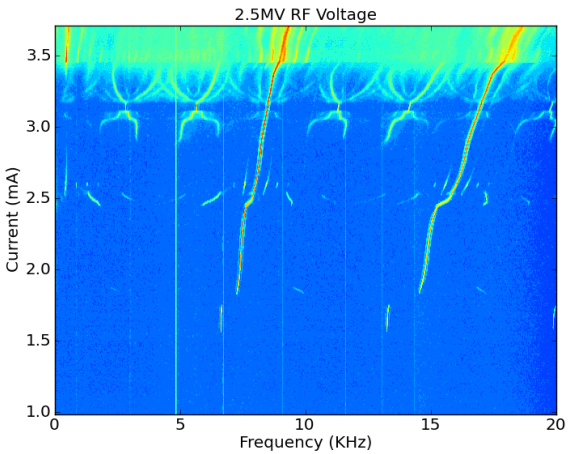
Instability Detection

- Schottky Barrier Diode (SBD) detectors, 60-90 GHz BW.
- Variations in RF cavity voltage, spectrum recorded for beam current between 1.0 – 4.0 mA
- Initial experimental setup was at a shared viewport (area divided by tape on window)

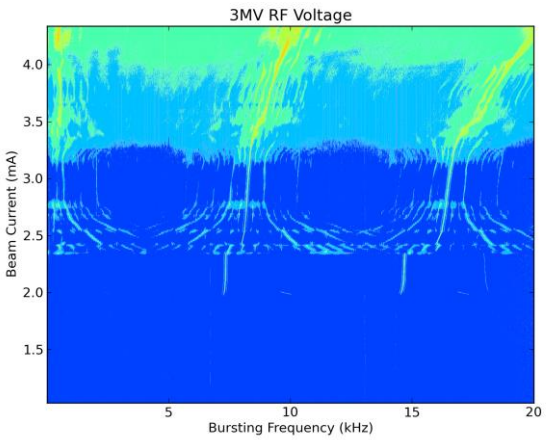
2.0 MV



2.5 MV



3.0 MV



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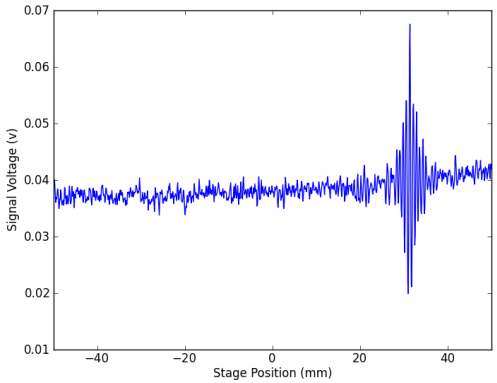
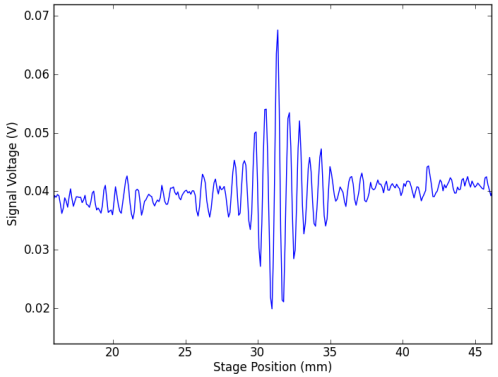
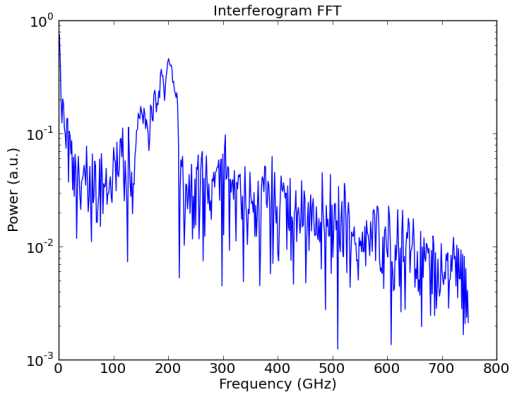
Low alpha Interferograms







- Clear interference observed. Natural decay in signal with stage position from intensity drop-off with distance
- FFT of the region around the interferogram reveals signal between approximately 150-250 GHz.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