Suppression Techniques for Multipass Beam Breakup

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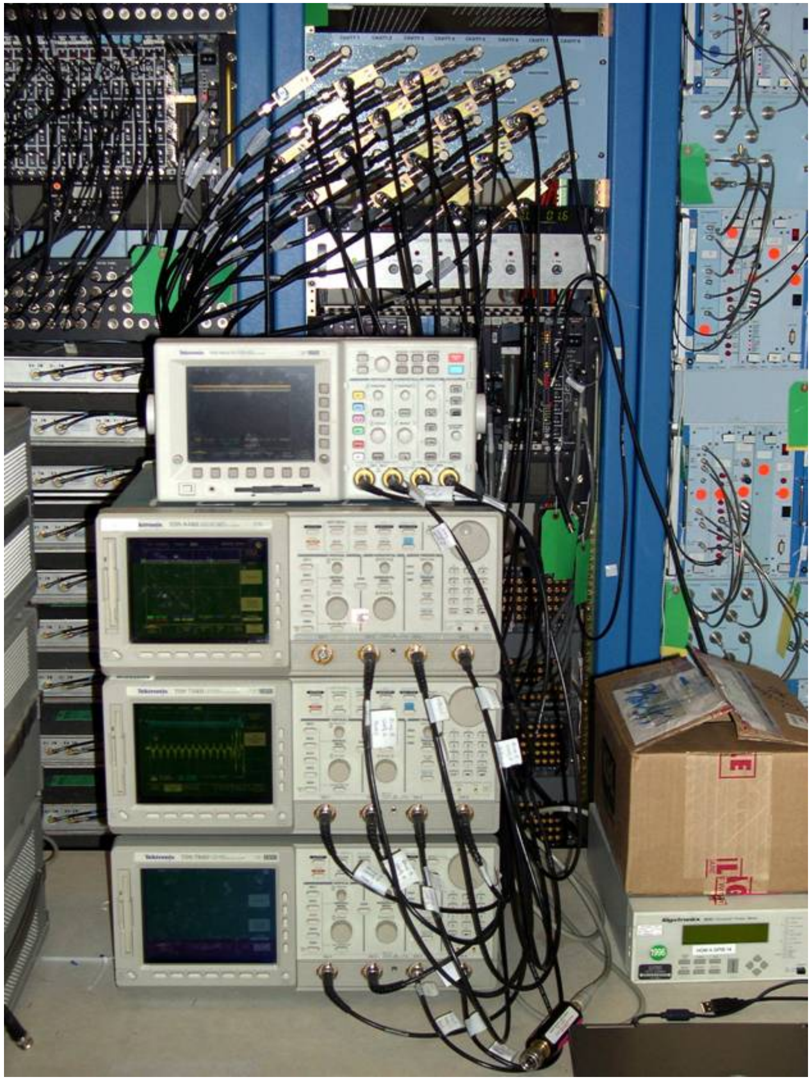
Outline

- **Methods of BBU Suppression**
- **Beam Optical Schemes**
  - Phase trombone
  - Pseudo-Reflector
- ***Q*-Damping Schemes**
  - Active damping circuit
  - 3-Stub tuner
- **Beam-based Feedback**
  - Challenges
  - Prototype system for the FEL
- **Summary and Future Plans**



Analytic Model for Multipass BBU

- For the case of a two-pass ERL with a single cavity, containing a single HOM the equation for the BBU threshold current is given by

$$I_{threshold} = -\frac{2V_{beam}}{M^{*}k(R/Q)Q\sin(\omega T_{recirc})}$$

$$M^{*} \equiv M_{12}\cos^{2}\alpha + (M_{14}+M_{32})\sin\alpha\cos\alpha + M_{34}\sin^{2}\alpha$$

✓ Inject at higher energy

✓ Change HOM frequency

✓ Change recirculation time

✓ Damp HOM quality factor

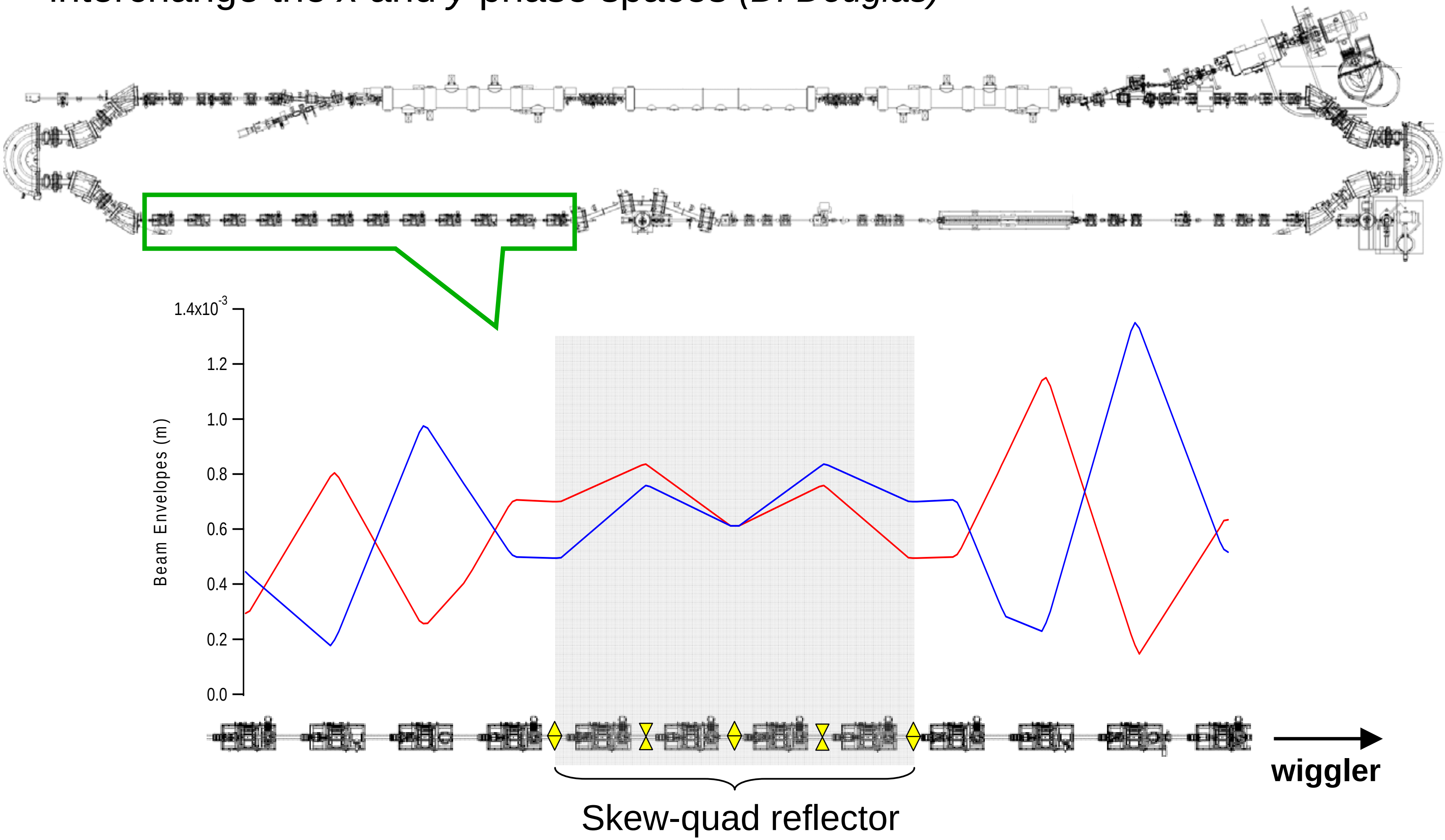
✓ Alter beam optics

- Change phase advance
- Reflect betatron planes
- Rotate betatron planes

where V_{beam} is the beam voltage at the cavity, k is the wavenumber (ω/c) of the HOM, $(R/Q)Q$ is the shunt impedance, T_{recirc} is the recirculation time and the M_{ij} are the elements of the recirculation transport matrix

Skew-Quadrupole Reflector in the FEL

- 5 skew-quadrupoles were installed in the backleg of the FEL to (*locally*) interchange the *x* and *y* phase spaces *(D. Douglas)*



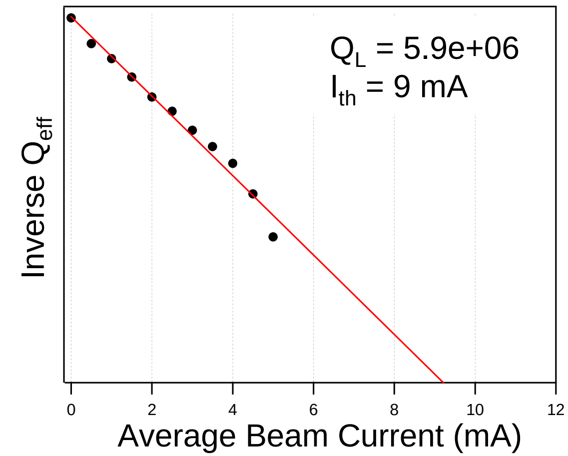
Local Reflector

- With the reflector activated, we also investigated the stability of several other potentially dangerous HOMs

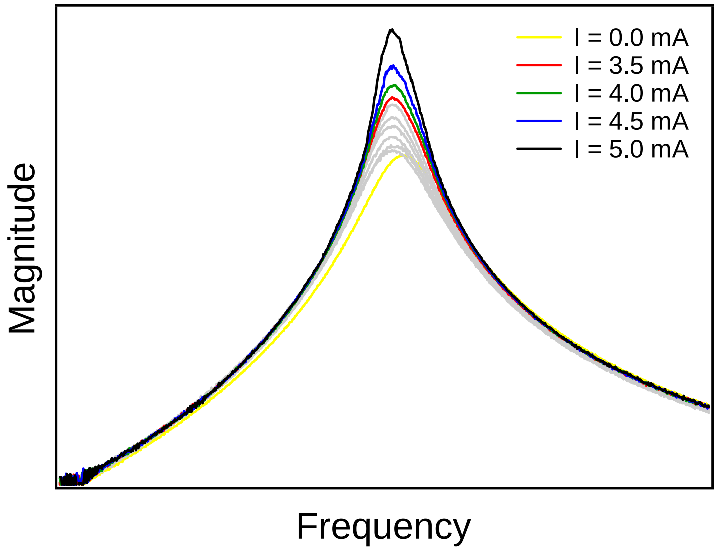
Frequency (MHz)	Loaded Q	(R/Q) (Ω)	Threshold Current (mA)	Orientation	Location
2102.607	2.61 x 10^6	29.90	7.07	x-axis	Cavity 8
2104.683	1.94 x 10^6	29.90	7.86	x-axis	Cavity 5
2106.007	6.11 x 10^6	29.90	2.85	y-axis	Cavity 7
2114.156	5.21 x 10^6	28.80	3.68	x-axis	Cavity 4
2115.201	2.17 x 10^6	28.80	8.28	y-axis	Cavity 6
2116.055	3.06 x 10^6	28.80	4.99	x-axis	Cavity 1
2116.585	6.66 x 10^6	28.80	4.18	x-axis	Cavity 7

Table 3: Summary of the MATBBU simulation showing mode properties of those HOMs which are predicted to produce threshold currents below 10 mA.

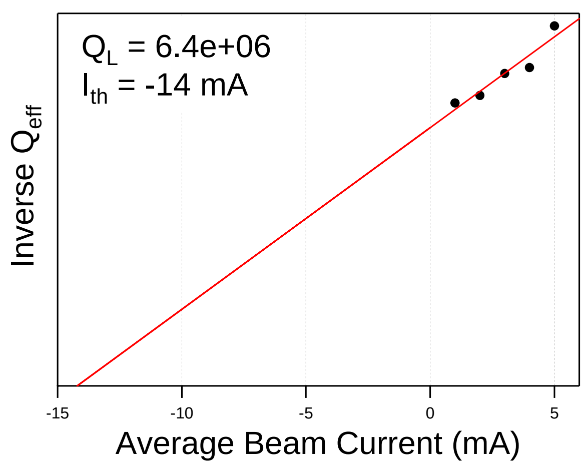
2106 MHz in Cavity 7



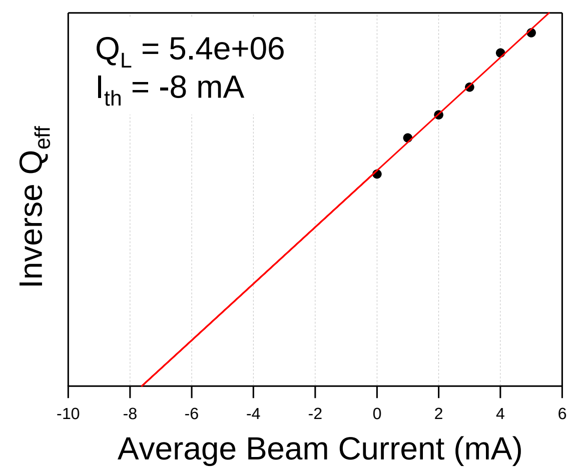
BTF of 2106 MHz with Reflector ON



2116 MHz in Cavity 7



2114 MHz in Cavity 4



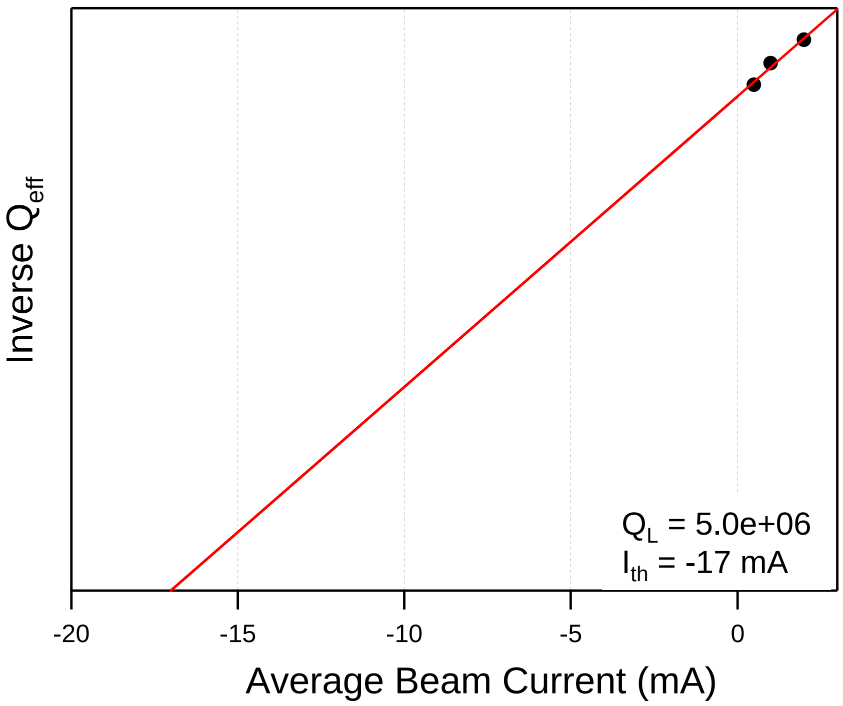
Local Reflector with a Change in Phase Advance

- Ideally we would like to create a pure 90 degree rotation from the unstable cavity back to itself

- Can you create a "*global*" rotation with a "*local*" reflector?
- **Yes**. By decreasing the vertical phase advance and then activating the local reflector, you can create a 90 degree rotation from the middle of Zone 3 back to itself *(D. Douglas)*.

- For our measurements, the vertical phase advance was changed. Only after the difference orbit measurements have been analyzed, will we know what kind of transfer matrix was generated with this change in phase advance…

2106 MHz with Reflector ON and Phase Advance Changed



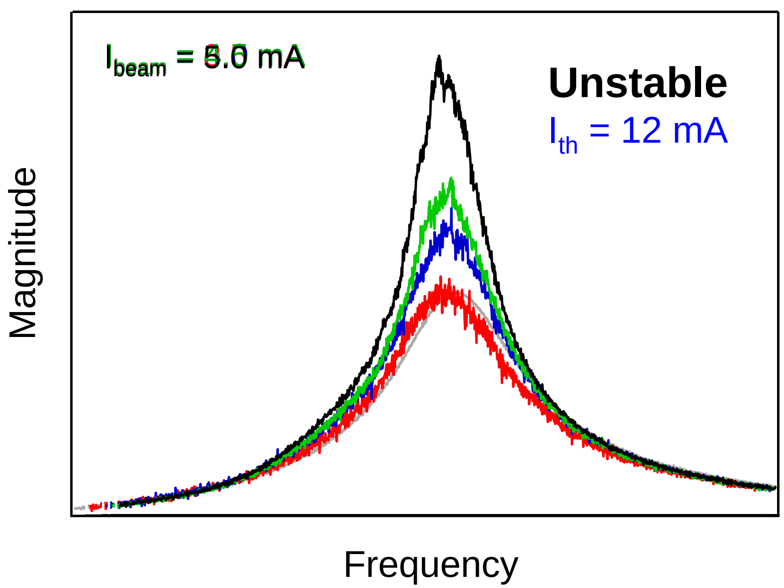
Because of the limited time setting up this configuration, the transmission was not good.

Phase Trombone

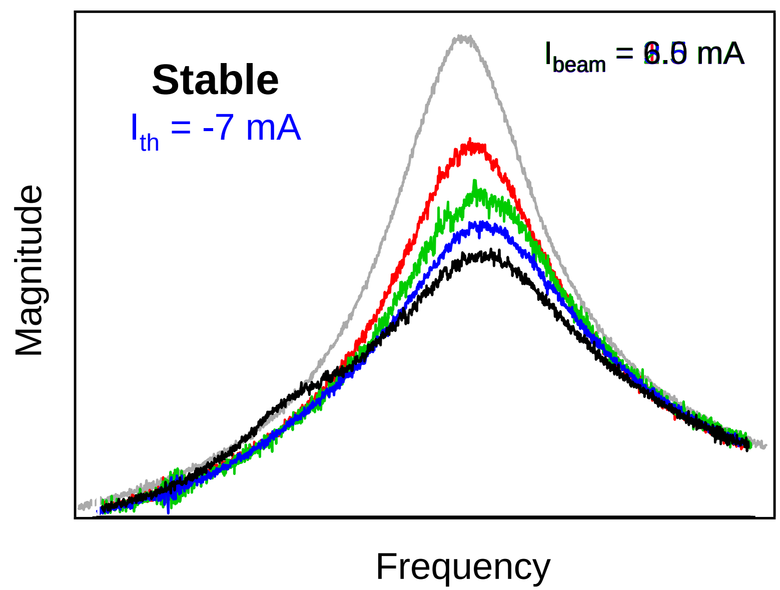
Recall… $I_{threshold} \propto \dfrac{1}{M_{12,(34)}}$

- By all indications the 2106 MHz HOM is a *vertically* polarized mode
- We change 4 vertically focusing quadrupoles in the recirculator to vary the vertical phase advance

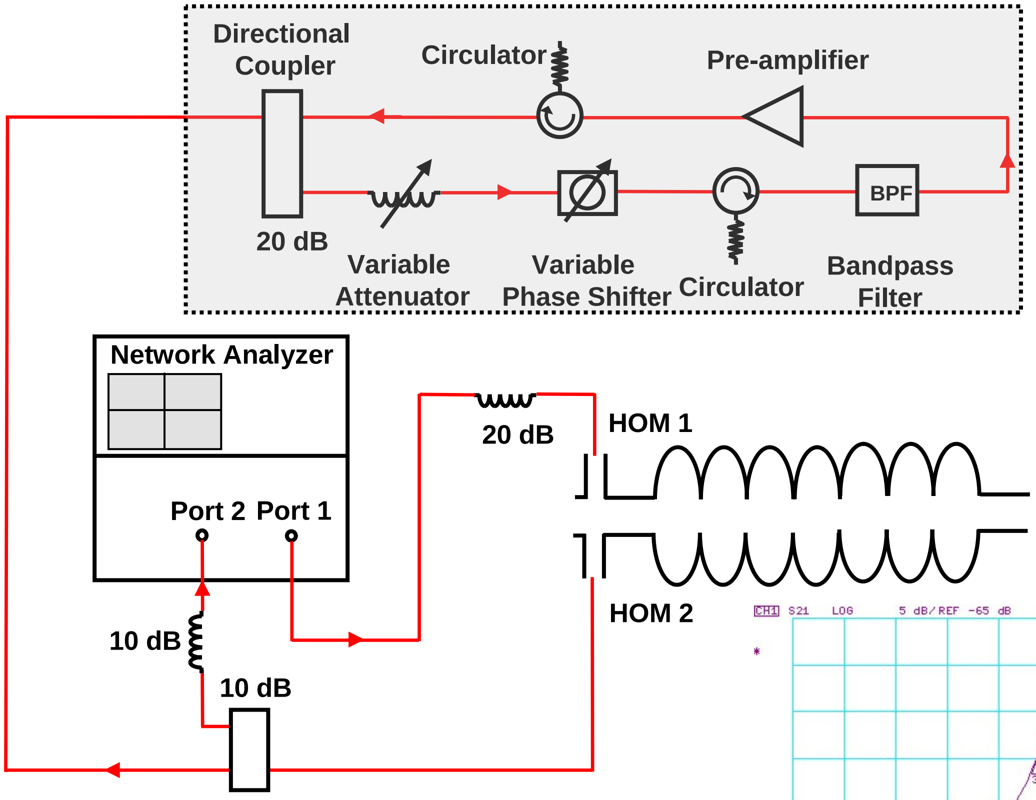
Quads changed +200 G



Quads changed +300 G



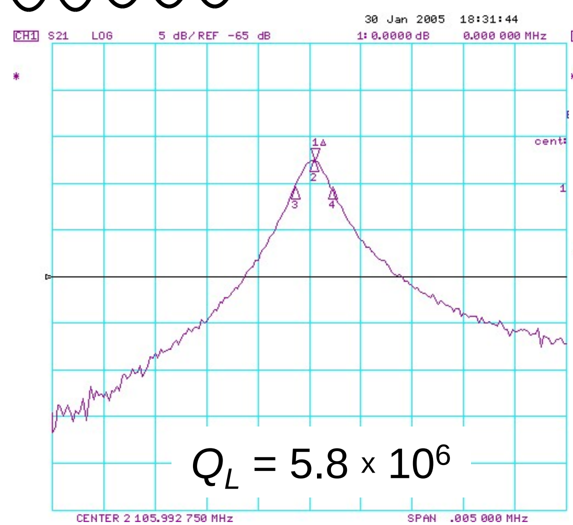
Q-Damping Circuit

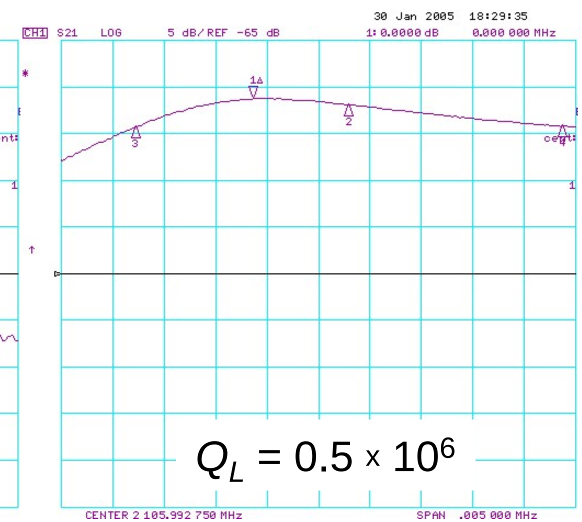


Concept: couple power from one of the HOM ports, shift it 180 degrees in phase, amplify the signal and feed it back through the same HOM port.

"Tuning Knobs": the circuit is optimized by carefully tuning the phase and gain of the feedback loop

Active damping of an HOM located at 2106 MHz. The effect of the damping (right picture) is to **decrease the loaded *Q* by a factor of ~ 10**.





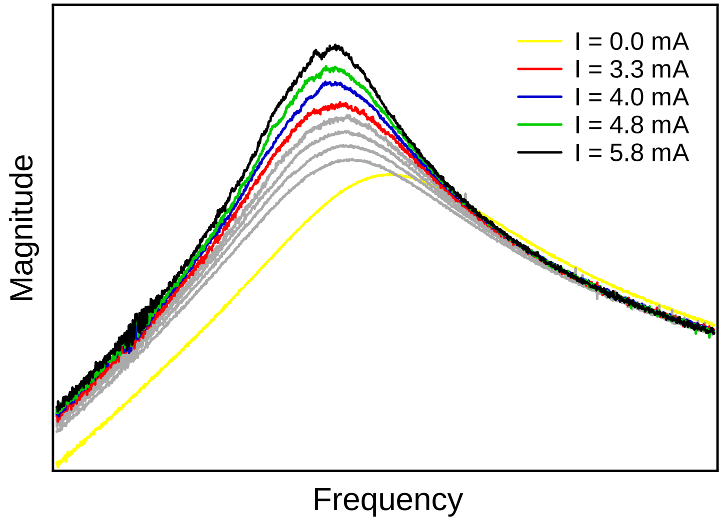
Q-Damping Circuit (cont'd…)

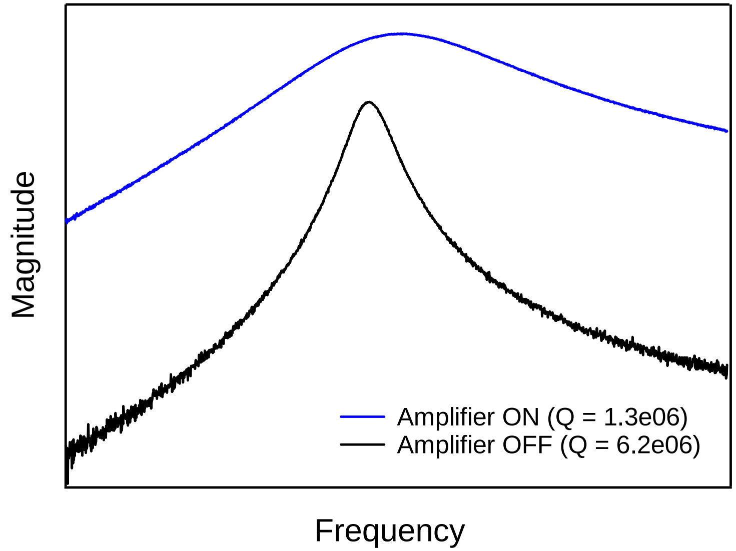
Recall… $I_{threshold} \propto \frac{1}{Q_{HOM}}$

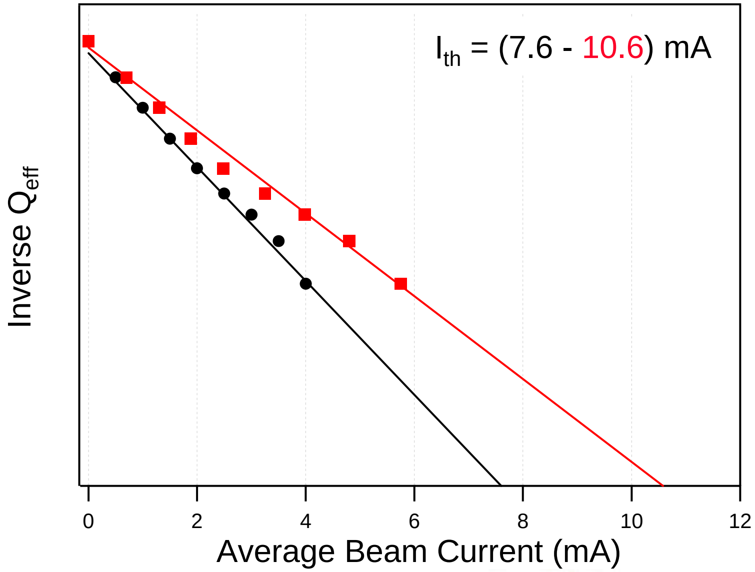
- Damping circuit easily reduced the *Q* of the 2106 MHz mode by a factor of 5

  (Above a factor of about 10, the system becomes sensitive to external disturbances)

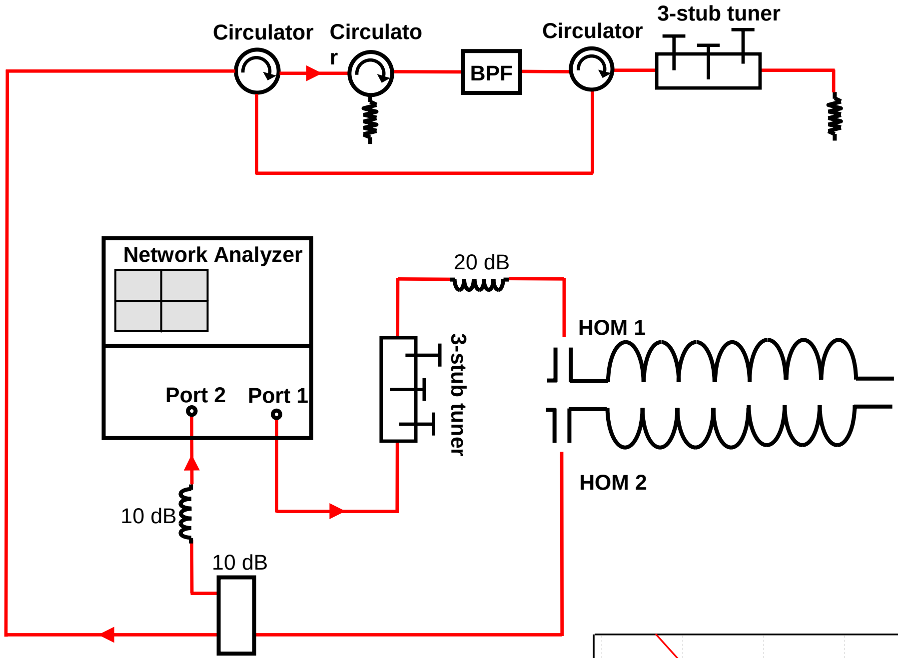
- The threshold is increased accordingly: from 2 mA to ~10 mA



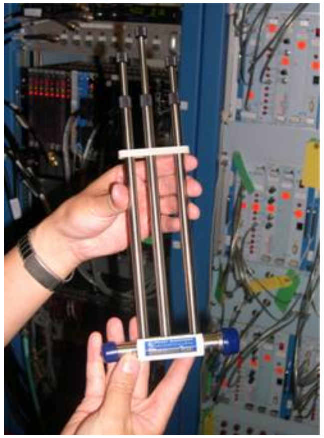


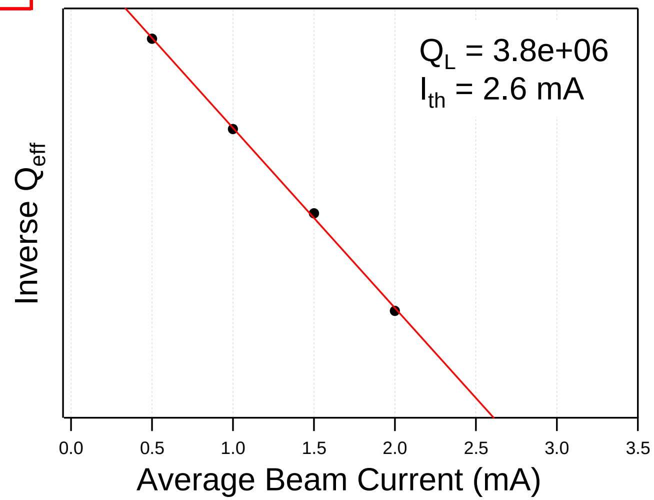


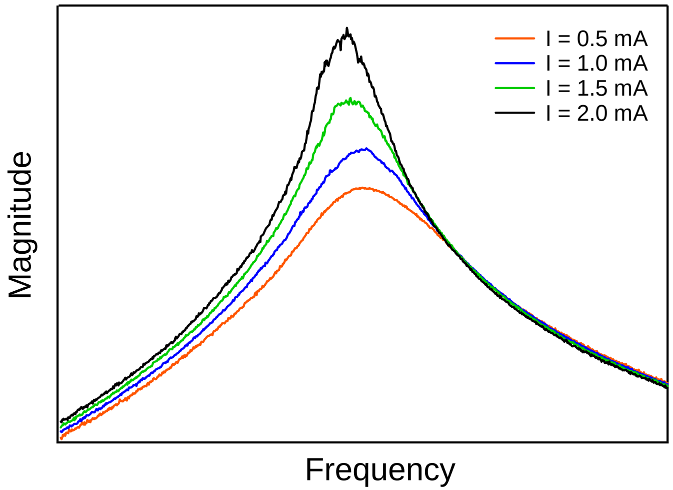
3-Stub Tuner



- The optimal setup requires a 3-stub tuner for each HOM port on the cavity
- Because it is a passive device, cable attenuation becomes a problem
- Had a difficult time – *perhaps due to a broken HOM cable from Cavity 7*







Summary of Suppression Techniques

		Effect on 2106 MHz HOM	Considerations for Implementation
Q-Damping	Damping Circuit	$5 \times I_{th}$	• Works for only *1 mode per cavity* • Not as effective at raising the threshold as beam optical methods • Long term stability of system • Does **not** effect beam optics
	3-Stub Tuner	$1.5 \times I_{th}$	
Beam Optics	Phase Trombone	*Stabilized*	• Can *stabilize* the mode against BBU • What are the effects on other HOMs? • Do they prevent reaching the requirements needed for a suitable lasing configuration?
	Pseudo-Reflector	*Stabilized*	

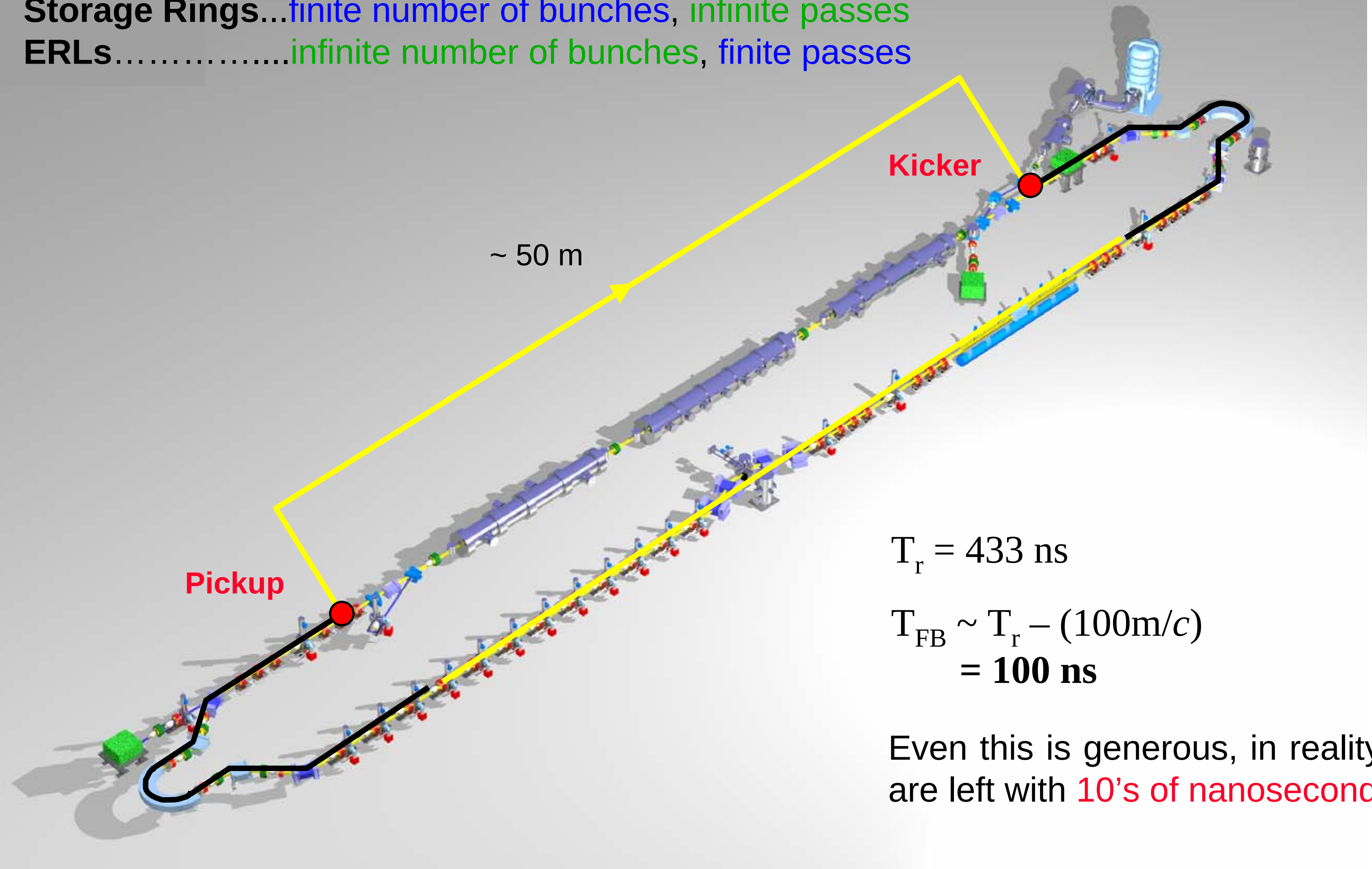
Motivation for a Beam-based Feedback System

- Would like the benefits of **both** of the BBU suppression techniques. That is, a suppression method that
  - ✓ Does not interfere with the beam optics
  - ✓ Works for more than 1 mode per cavity
  - ✓ Can suppress BBU by an order of magnitude or more
- In principle, this can be realized with a **Beam-based Feedback System**
- Consider a mode-by-mode feedback system where narrowband filters are used to detect and treat each HOM separately.
- This method offers *flexibility* in that the *phase and gain can be controlled for **each** HOM frequency*.

> *"The only possibility for realizing an active feedback system, therefore, appears to be one in which all potential breakup modes are separately detected and the resulting correction signals are fed back independently at appropriate points in the early orbits of recirculation. If such a system could be realized technically it would be prohibitively expensive."*
> Recirculating Electron Accelerators *R. Rand* (1984)

Bunch-by-Bunch Feedback: Challenges

Storage Rings...finite number of bunches, infinite passes
ERLs……………...infinite number of bunches, finite passes



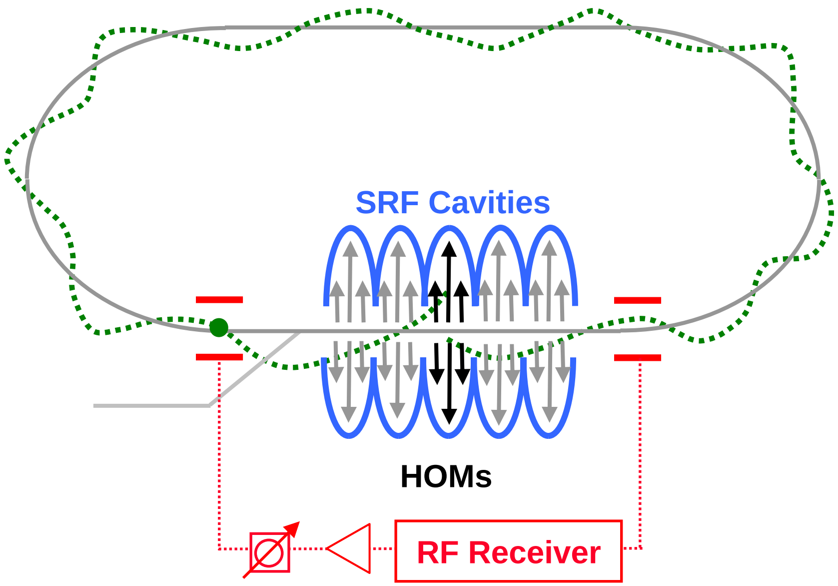
T_r = 433 ns

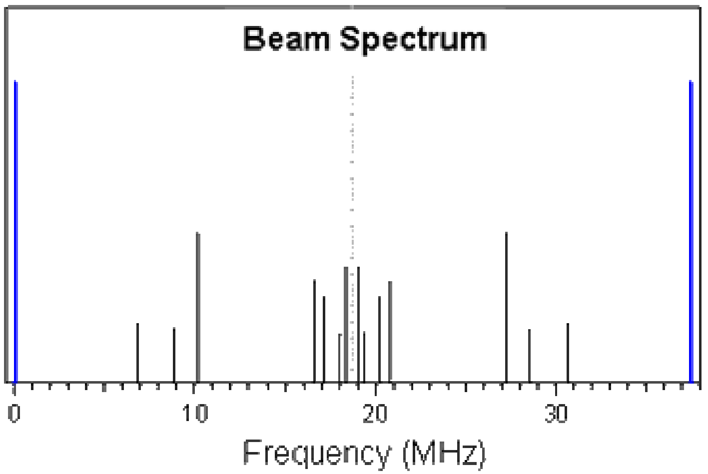
$T_{FB} \sim T_r - (100\text{m}/c)$
= 100 ns

Even this is generous, in reality you are left with 10's of nanoseconds

Mode-by-Mode Feedback: A Promising Alternative

- Consider the beam spectrum: dangerous HOMs manifest themselves as side-bands of the beam harmonics
  - I. The feedback system selects a particular frequency and provides the appropriate phase shift and gain to the signal
  - II. The signal is then used to drive a stripline kicker which modulates the beam in such a way that the beam *damps* the mode on the second pass





- This scheme is promising because it is reminiscent of two previously proven experimental techniques:

1. Beam Transfer Function

+

2. Active Damping Circuit

Mode-by-Mode Feedback: Schematic

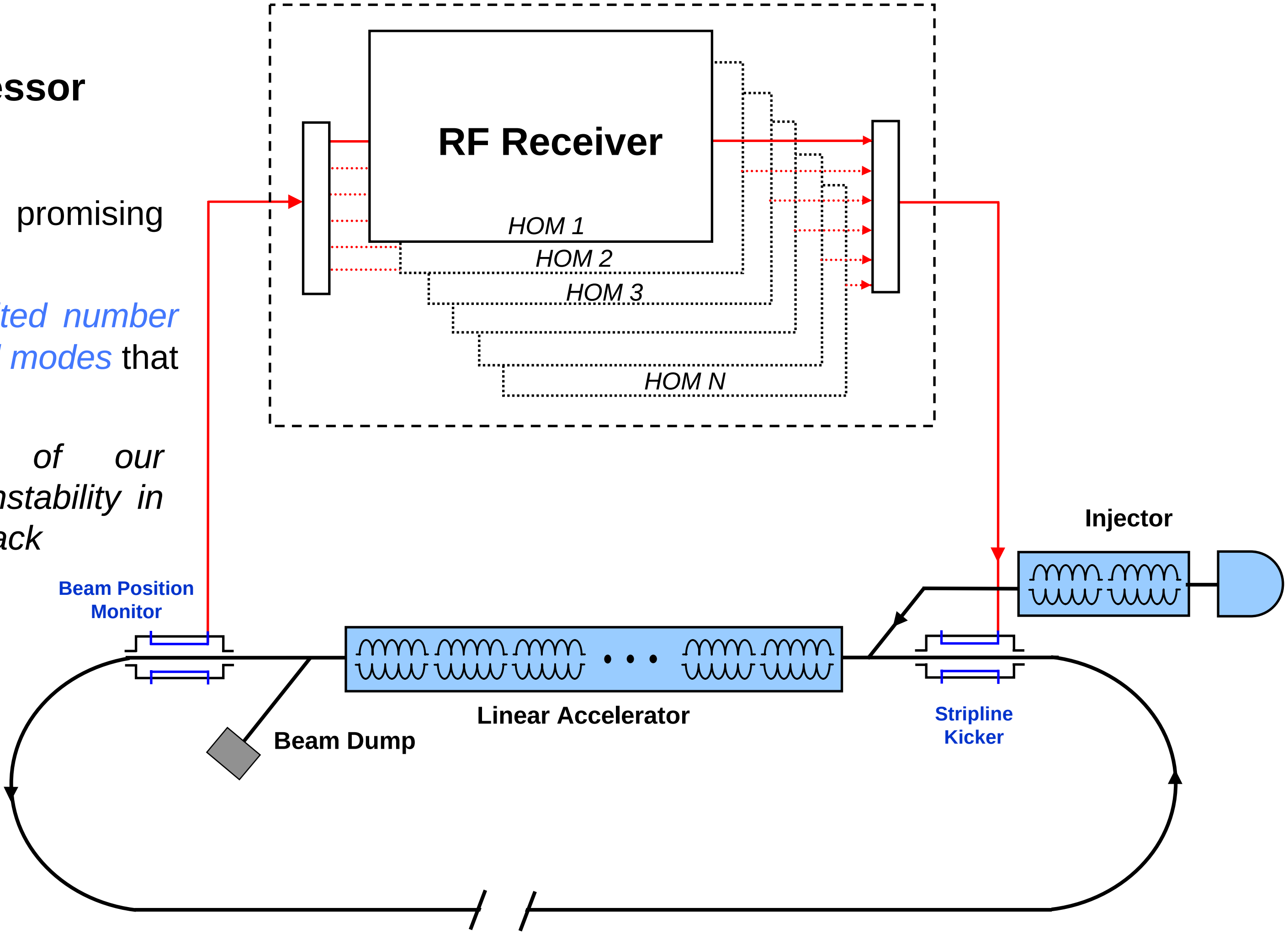
Essential components of a feedback system:

1. **Detector**
2. **Signal Processor**
3. **Corrector**

Q. Why is this a promising system for the FEL?

A. The FEL has a *limited number of well characterized modes* that cause BBU.

Take advantage of our knowledge of the instability in designing the feedback



Summary and Future Plans

- **Summary**
  - Several methods proved to be effective at raising threshold current
  - It was demonstrated that using beam optical schemes, the dangerous HOM could *stabilized* (i.e. it can no longer cause BBU)

- **Future Plans**

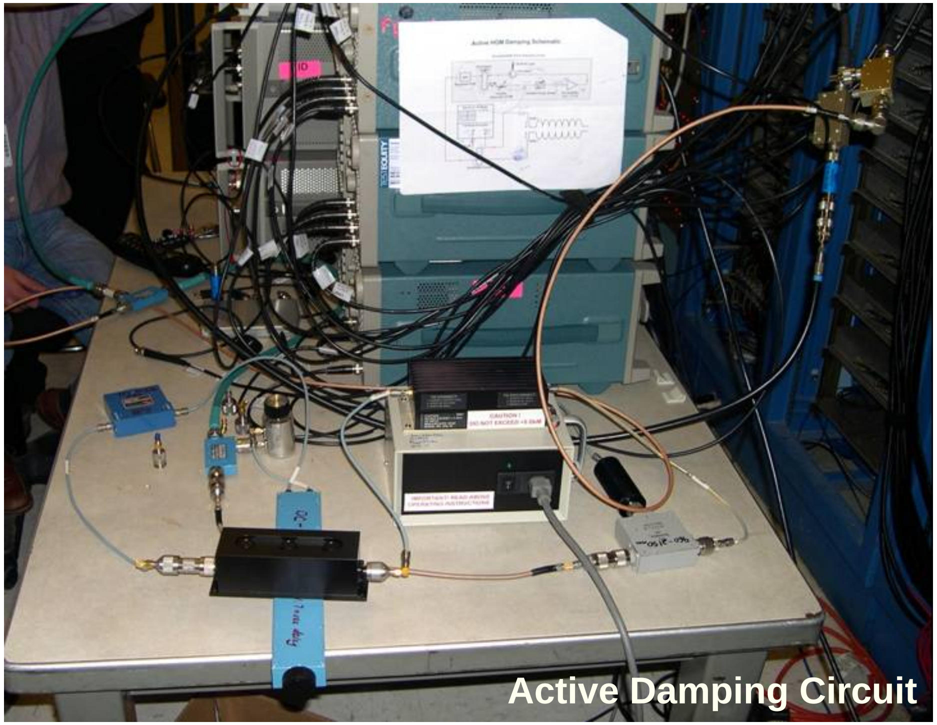
Benchmark BBU Simulation Codes

- Measure HOM polarizations
- Perform BBU simulations using measured machine optics

Suppress via beam-based feedback

"The best of both worlds"

- Does not effect beam optics
- Works for more than 1 mode per cavity
- Potential for stronger suppression that currently attainable with *Q*-damping



Active Damping Circuit

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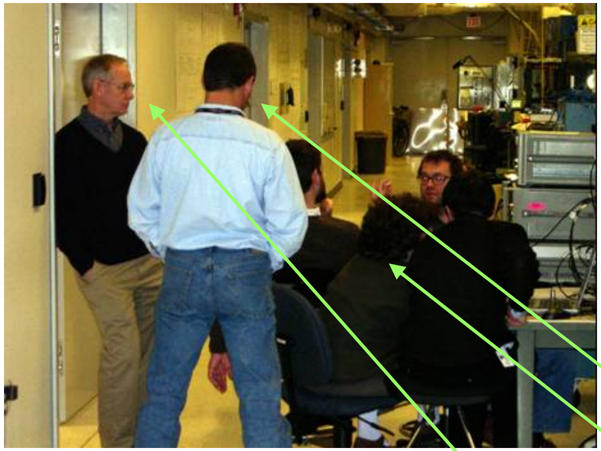

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