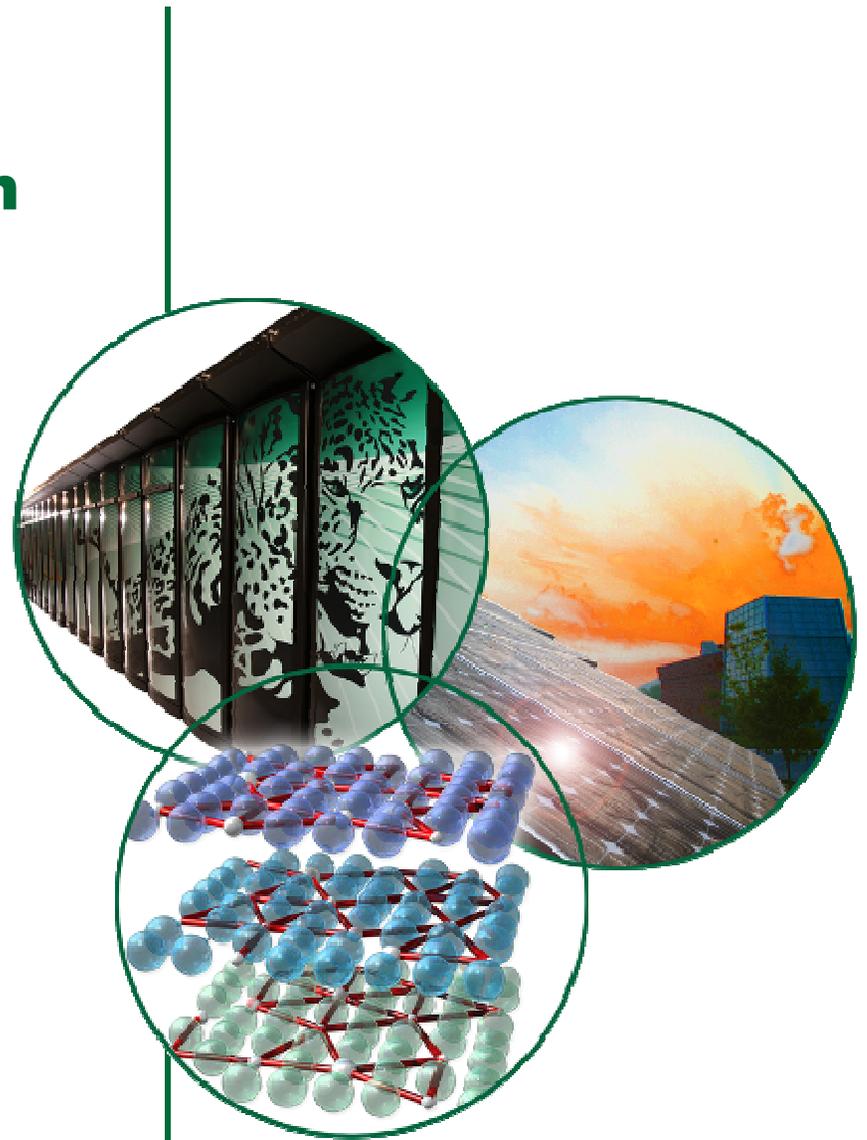


SNS Accumulator Ring Instability Damper and Beam Transfer Function Studies

Robert Hardin



Before I Begin... Many Thanks Go To:

- **Craig Deibele, Sasha Aleksandrov, Slava Danilov, Andy Webster, Jeff Bryan, Jim Diamond, George Link, Syd Murray III**

- **You... For giving me the opportunity to be here today!**

Overview

- **Introduction to the SNS facility**
- **Motivation for a ring instability damper system**
- **Basic elements of the analog system**
- **Experimental damping result highlights**
- **Fundamentals of beam transfer function measurements**
- **Beam transfer function result highlights**
- **Summary and Conclusions**

The Spallation Neutron Source:

is an accelerator-driven user facility for neutron scattering research at Oak Ridge National Laboratory in USA





2010

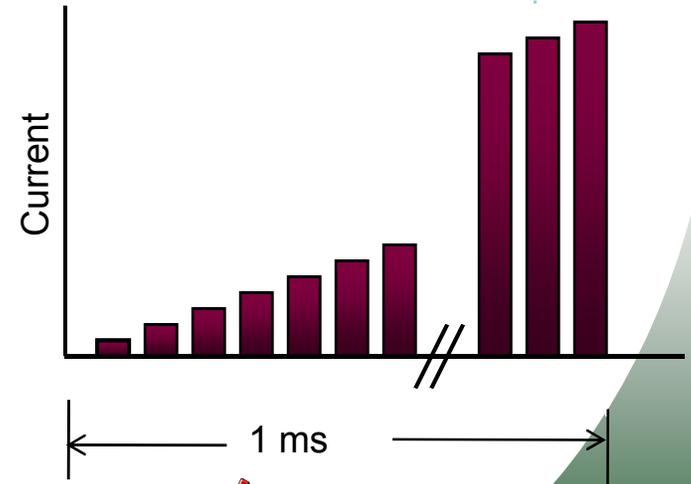
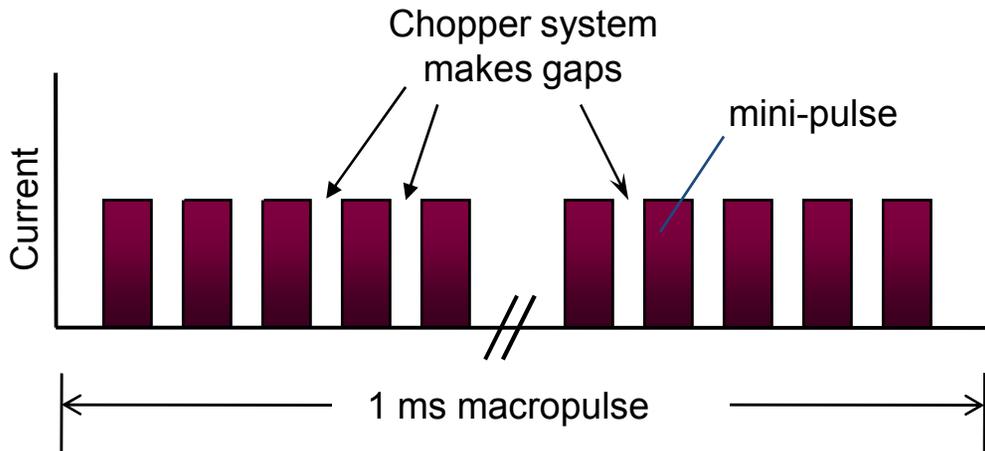
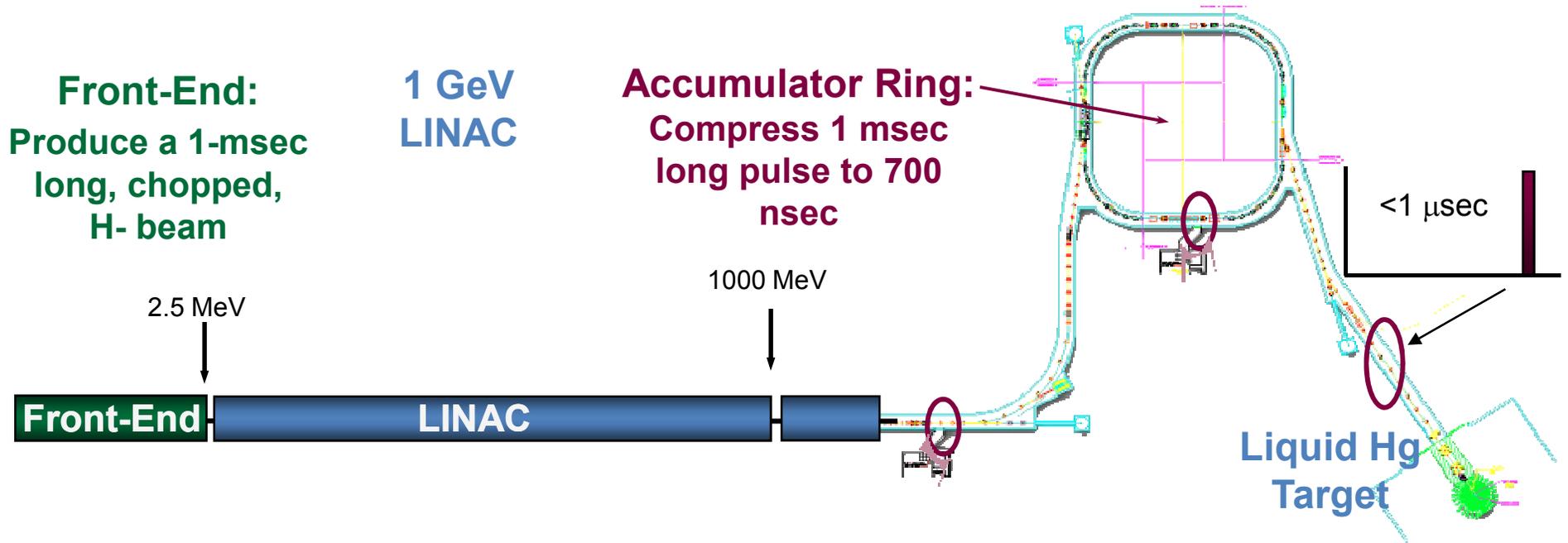
Neutrons are used for research in:
Biology & Medicine
Biotechnology & Energy
Fundamental Physics
Imaging
Magnetism
Materials
Nanotechnology
Superconductivity



**Neutron Radiograph of an
ancient Greek lamp**

www.ornl.gov

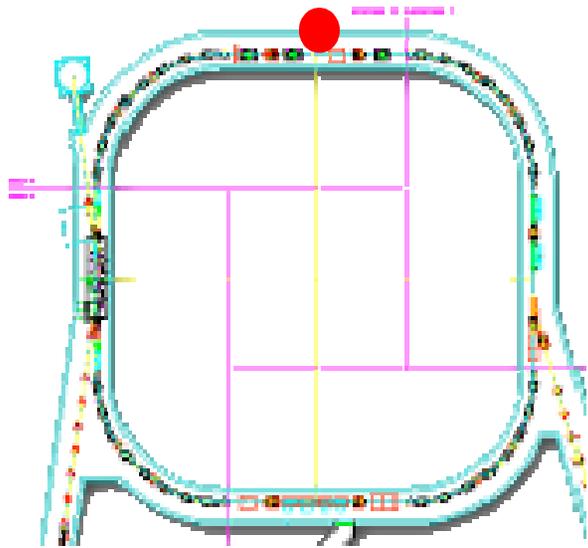
SNS Accelerator Complex



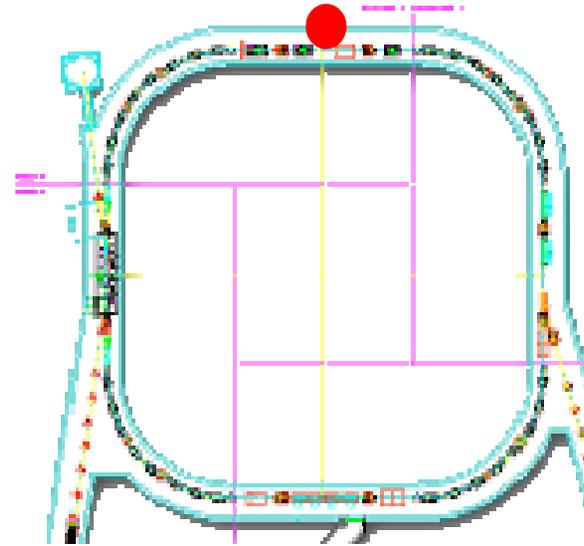
Baseline Beam Parameters

P beam on target :	1.44MW (800 kW – 1MW)
I beam average:	1.44mA
Maximum Beam energy:	1 GeV (925 MeV)
Duty factor:	6%
Rep. rate:	60Hz
Pulse width:	1ms

Proton beam follows a sinusoidal path



In a perfect world...



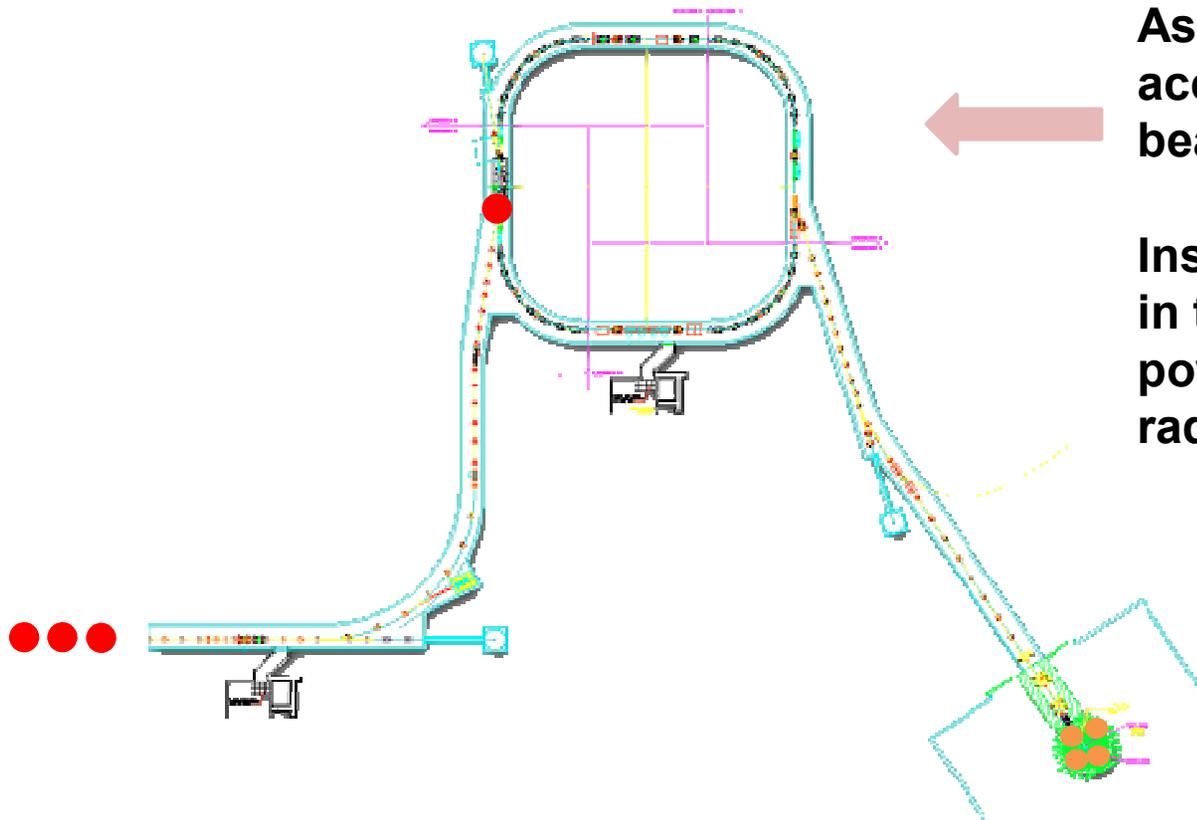
In the real world...

$$\frac{d^2z}{ds^2} + K(s)z = 0 \quad \text{Hill's Eq.}$$

“Tune” describes the number of oscillations the beam completes per revolution

Here the “Tune” is 6.2 → .2 determines the phase advance of the beam around the ring

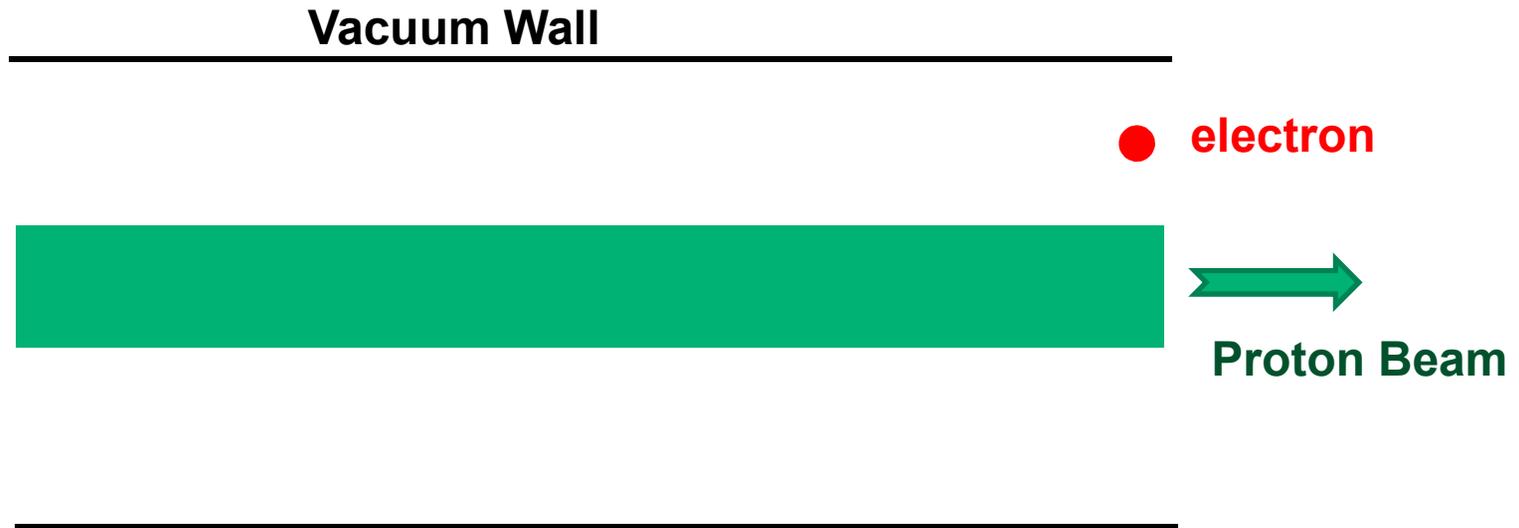
Motivation for the instability damper system at SNS



As the proton beam accumulates in the ring, the beam can become unstable.

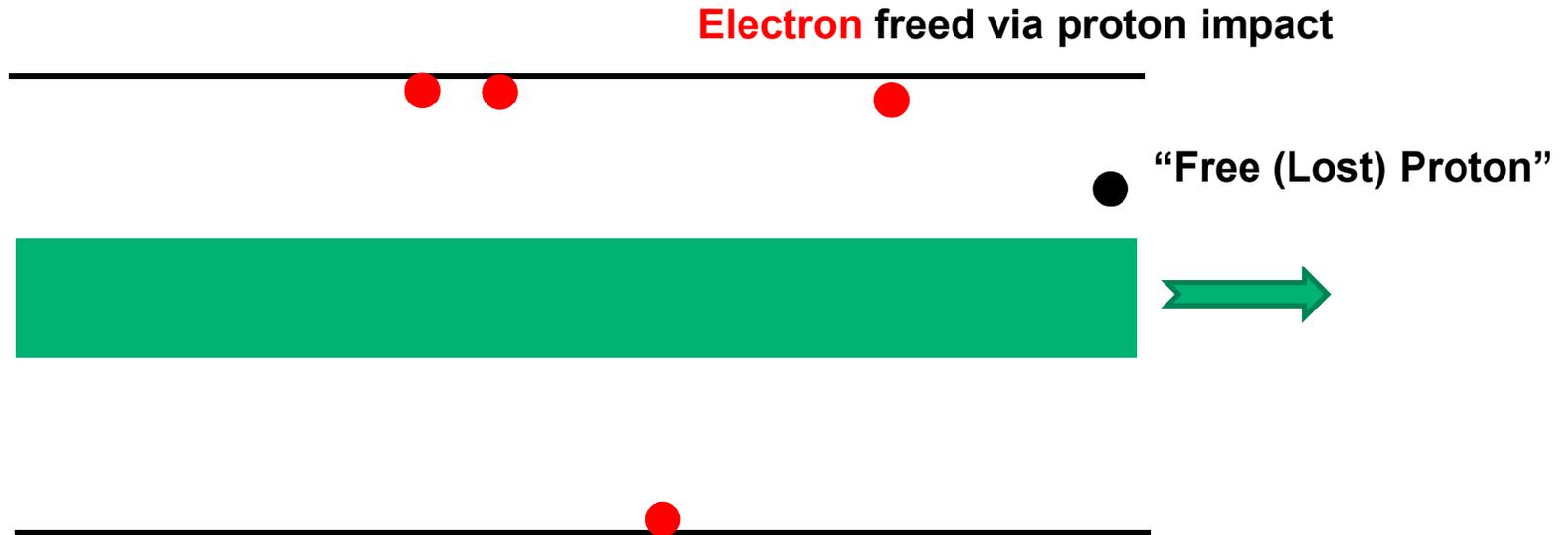
Instability can produce losses in the beam, which reduces the power to target and increases radiation in the ring.

Motivation for the instability damper system at SNS (2)



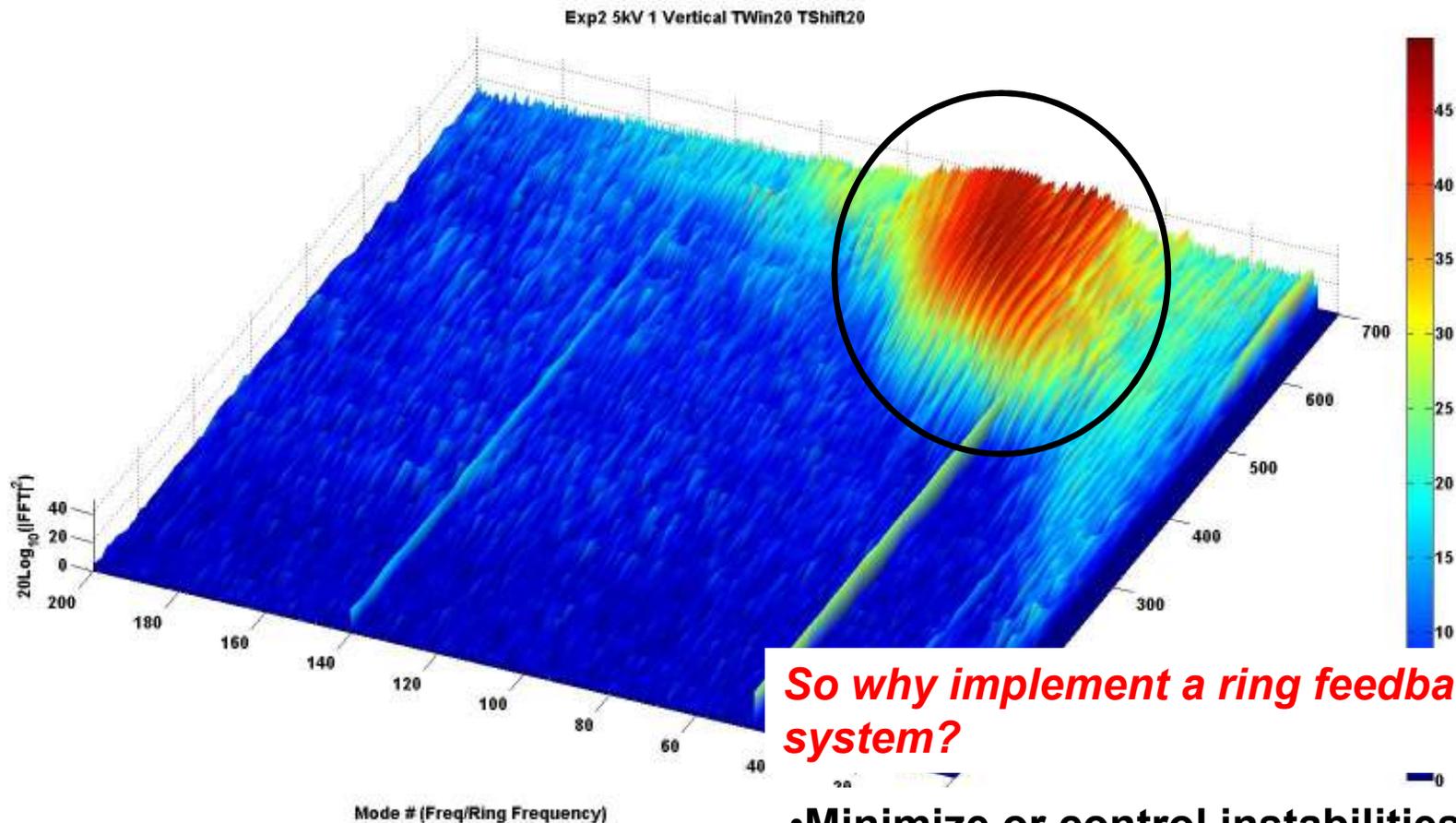
Electron can be captured by the proton bunch
“potential well” until bunch passes.

Motivation for the instability damper system at SNS (2.5)



- Lost protons can cause electrons to be produced by impacting the chamber walls.
- Electrons are accelerated/decelerated by the proton beam potential, with a net gain of energy.
- Electrons cascade (secondary, tertiary, etc.) and can survive the gap between beam passages → net gain of electrons.
- With enough electrons, the protons can be shaken (not stirred) to produce an instability.

Motivation for the instability damper system at SNS (3)



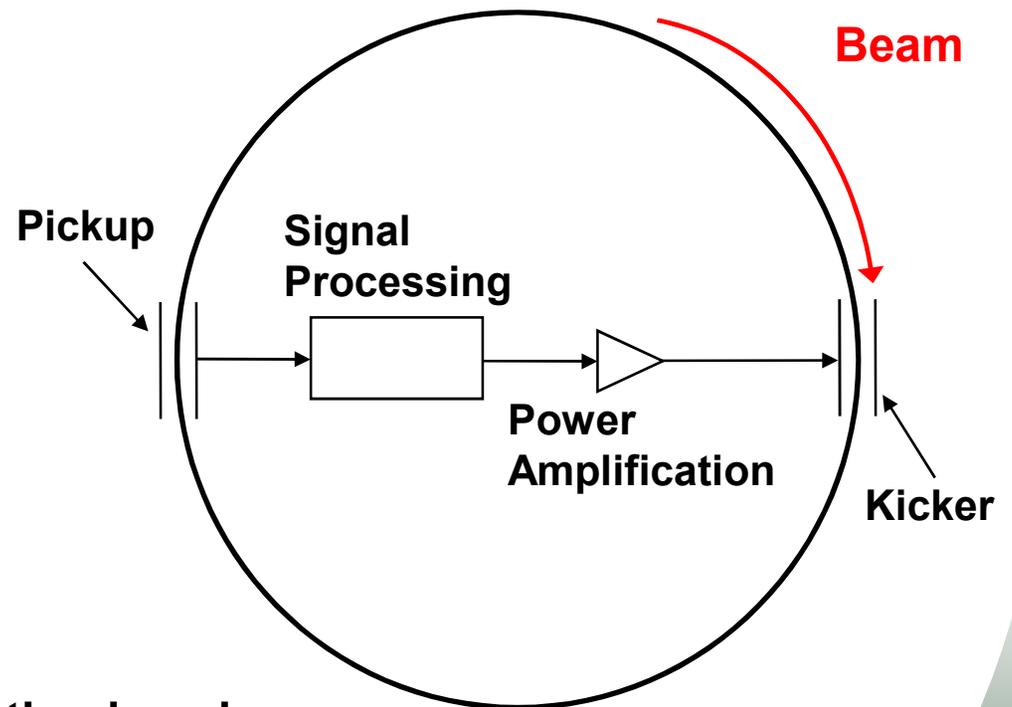
So why implement a ring feedback system?

- Minimize or control instabilities in the ring
- Reduce losses → Better performance → Higher beam intensities to target

Ring Frequency = 1044389 Hz →
Mode ≈ Frequency

Basic elements of the feedback system

- Pickup (BPM Stripline) + Cable
- Signal Processing (LLRF, Timing, Filtering)
- RF Power Amplification
- Kicker (BPM Stripline) + Cable



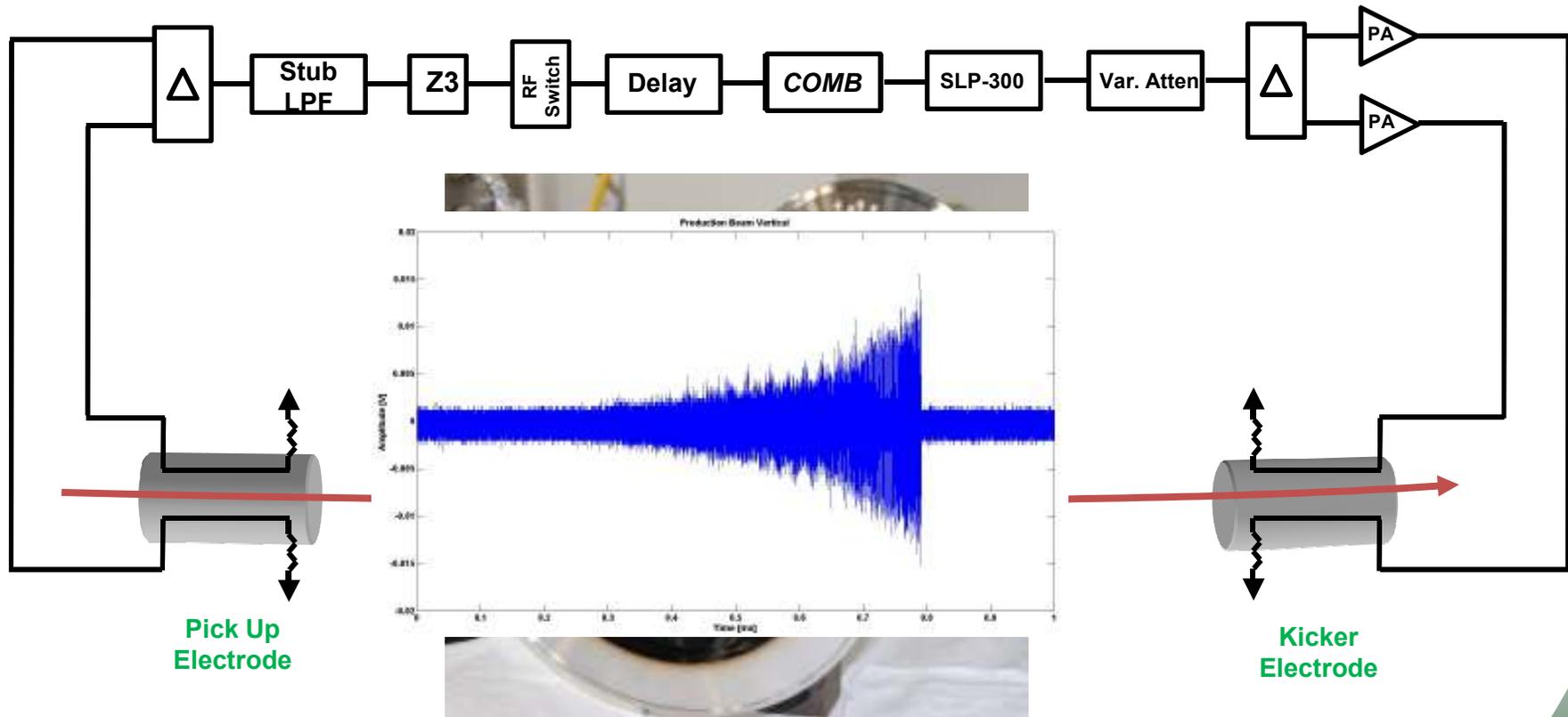
Timing delay is crucial to maximize the damping...
so that the **0.2** "Tune" produces a 90 degree phase
advance between pickup and kicker

Ring damper system overview

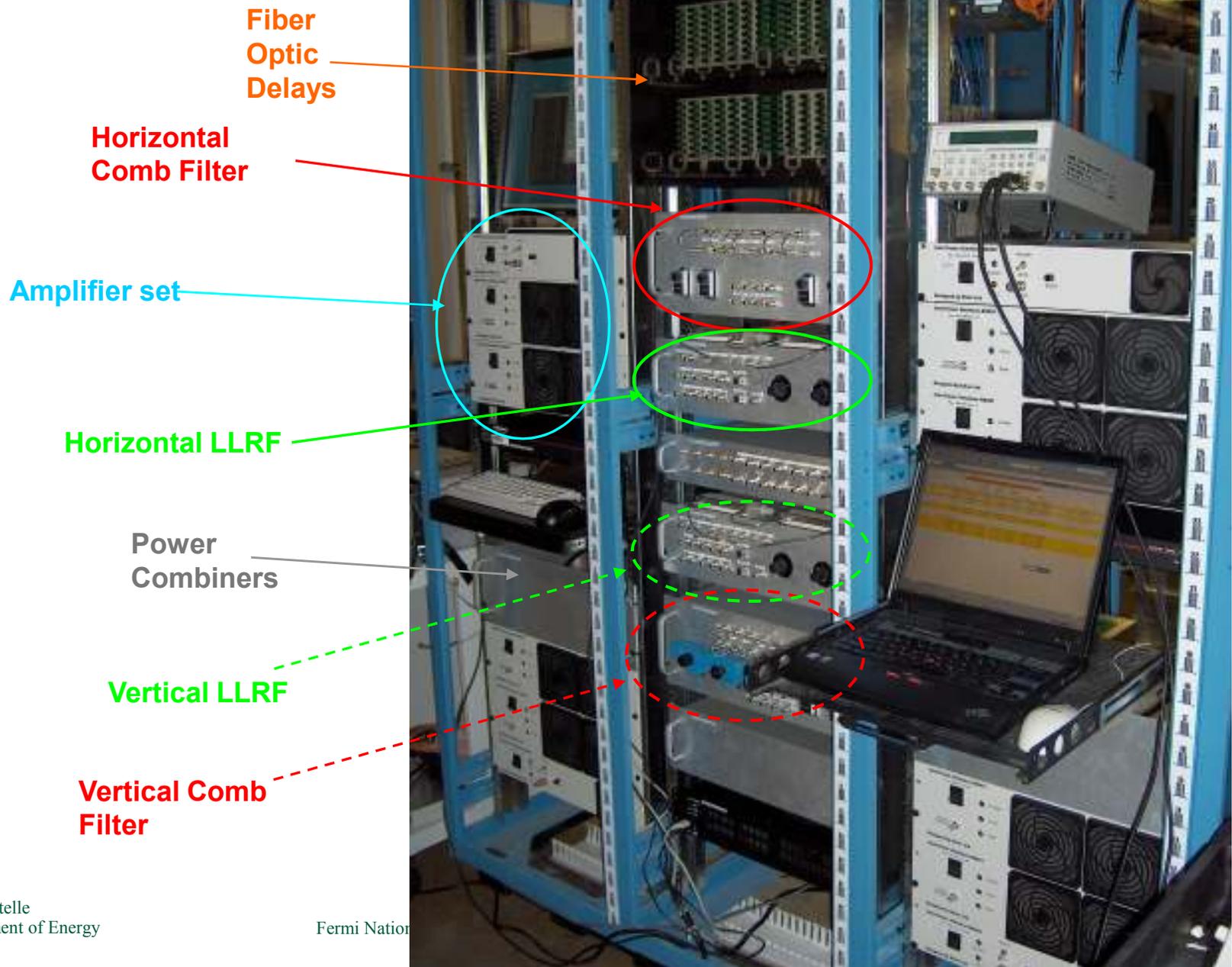
Consists of 2 independent systems

Vertical (Up and Down)

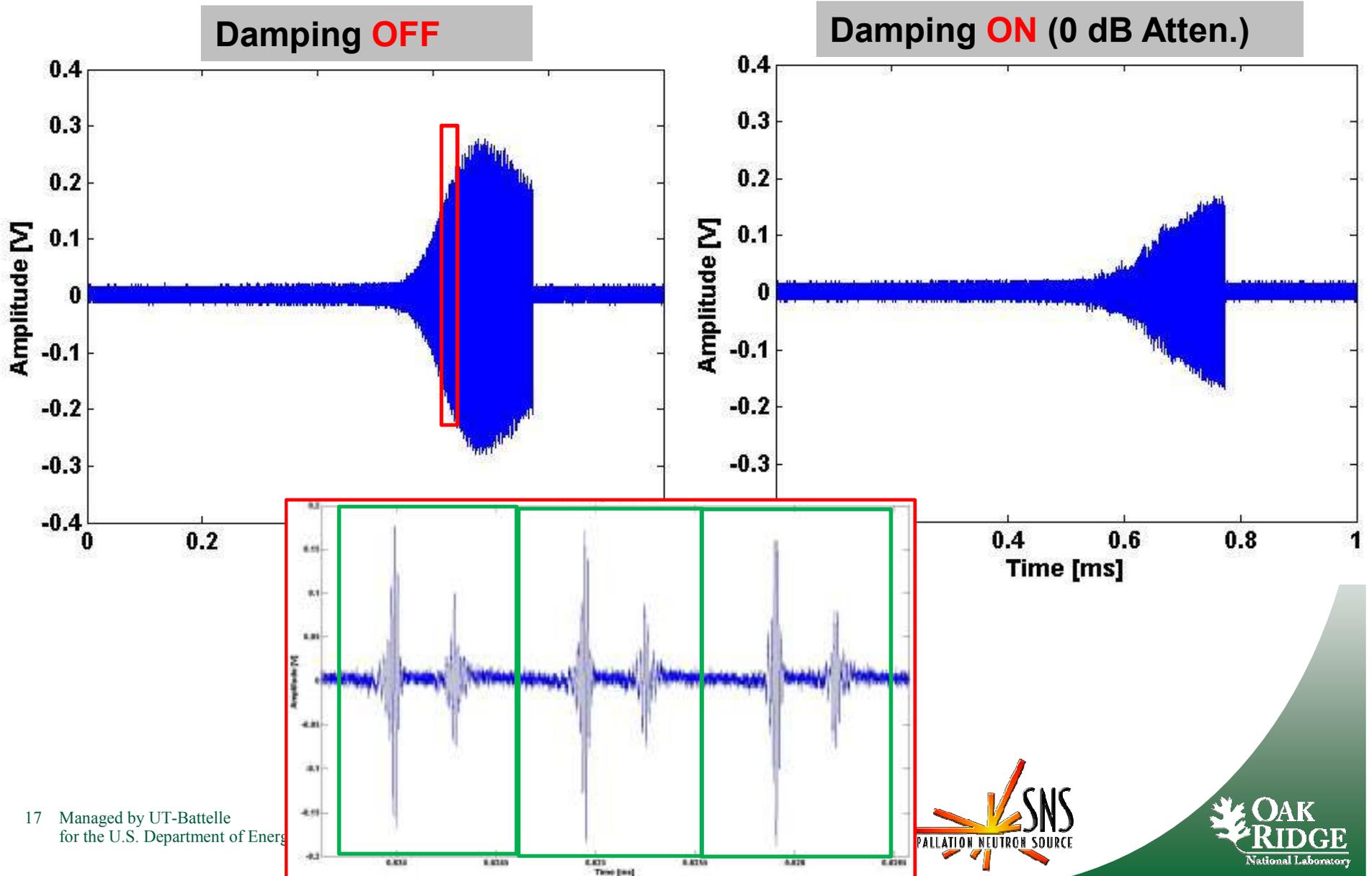
Horizontal (Left and Right)



Damper System

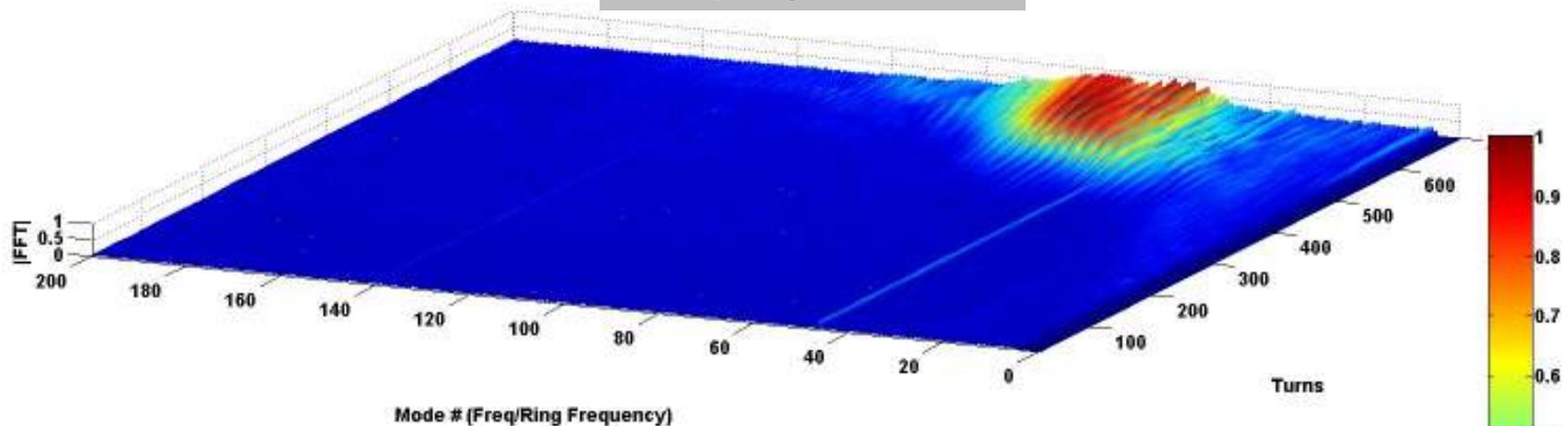


Experimental Damping Results

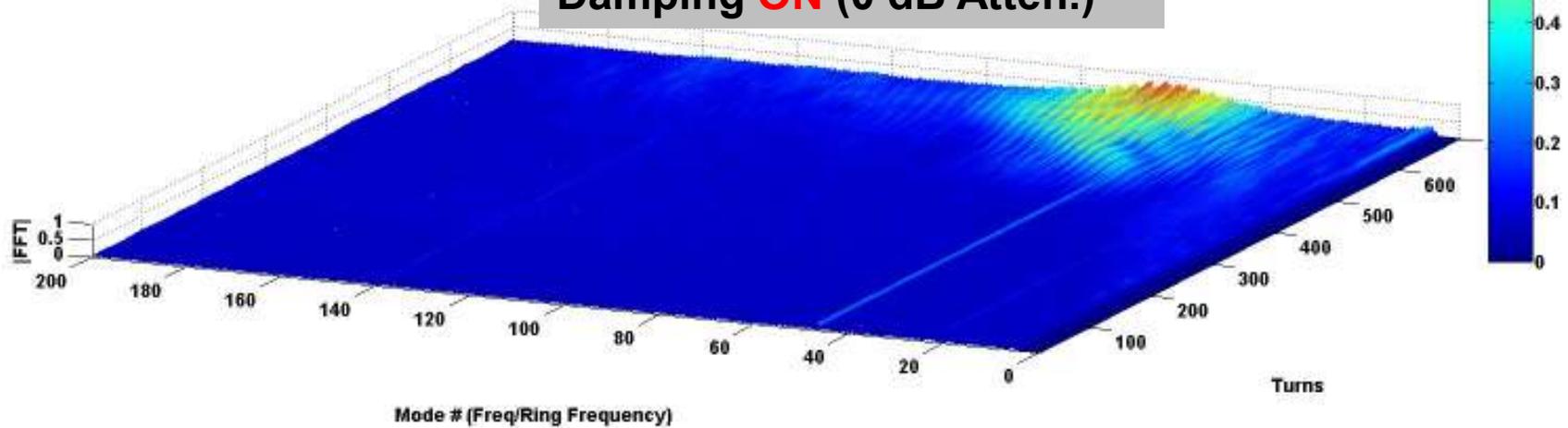


Damper has reduced the instability

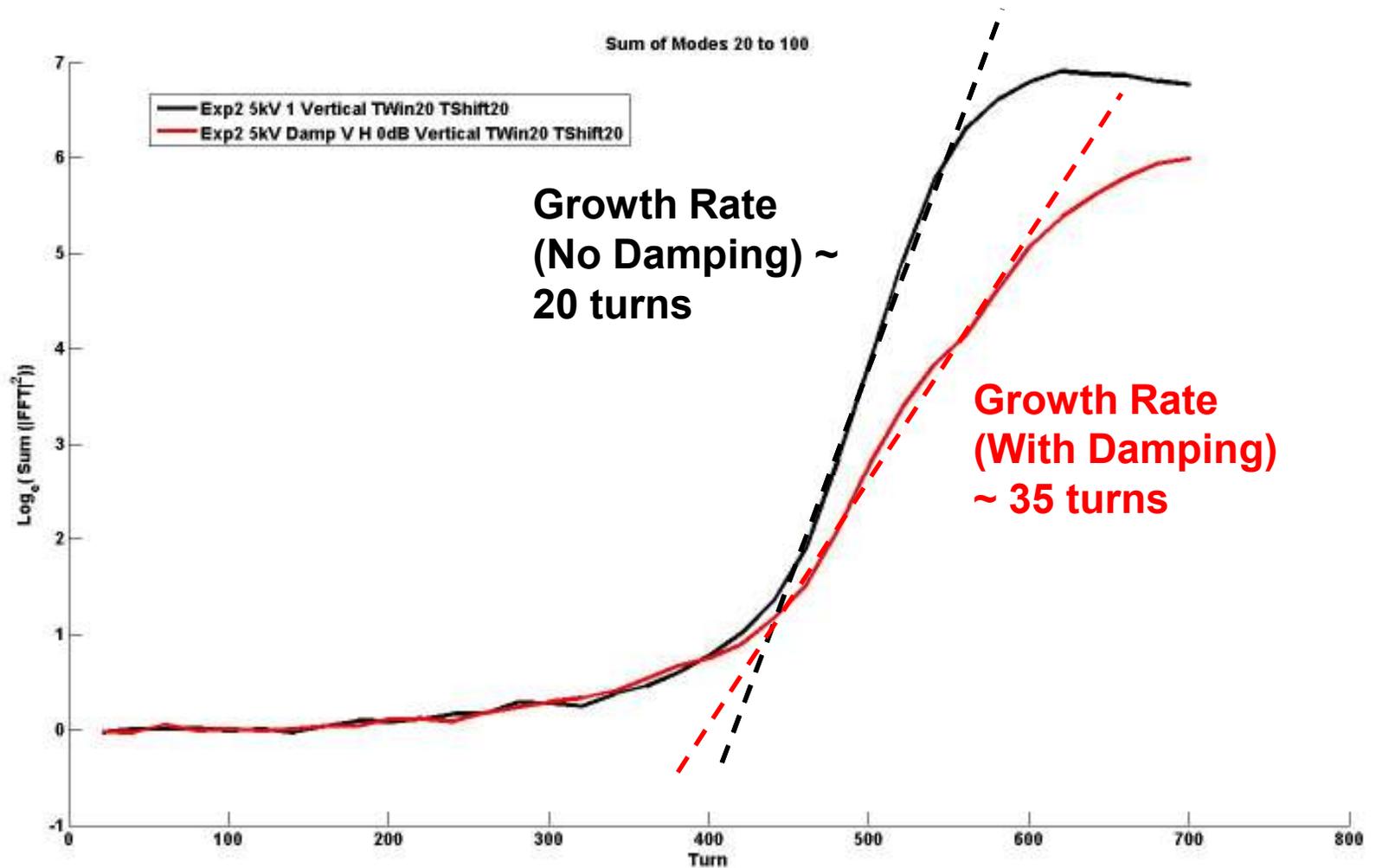
Damping **OFF**



Damping **ON** (0 dB Atten.)



Growth rate of the active frequencies is reduced by ~ 60%

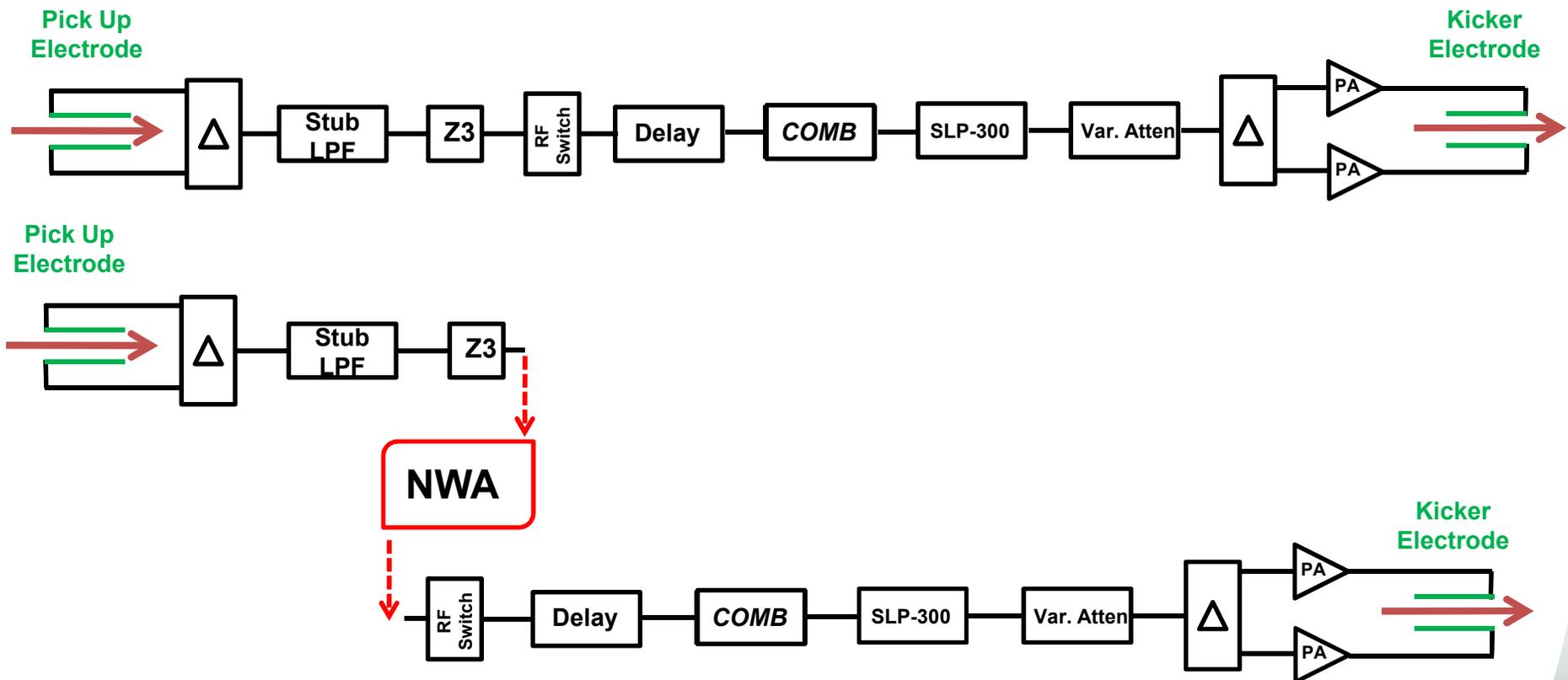


Damper system is effective...

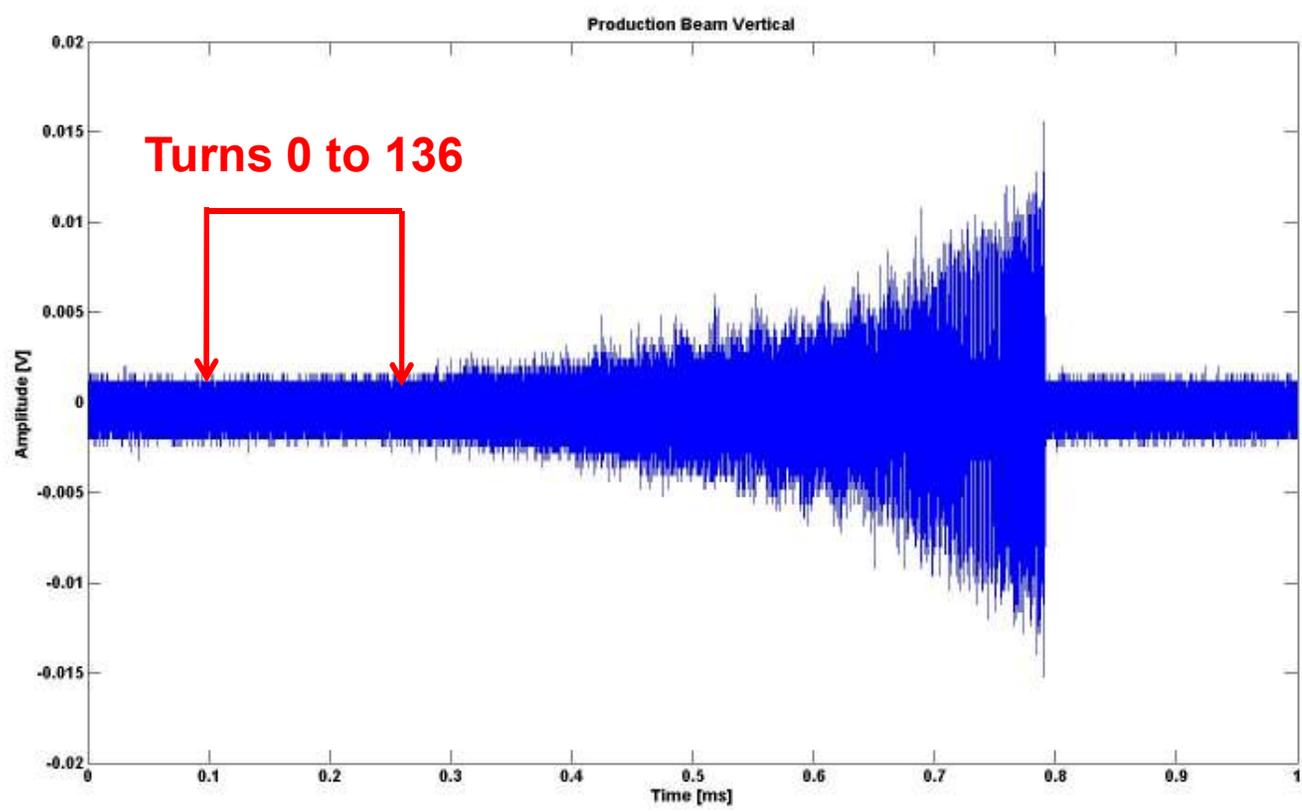
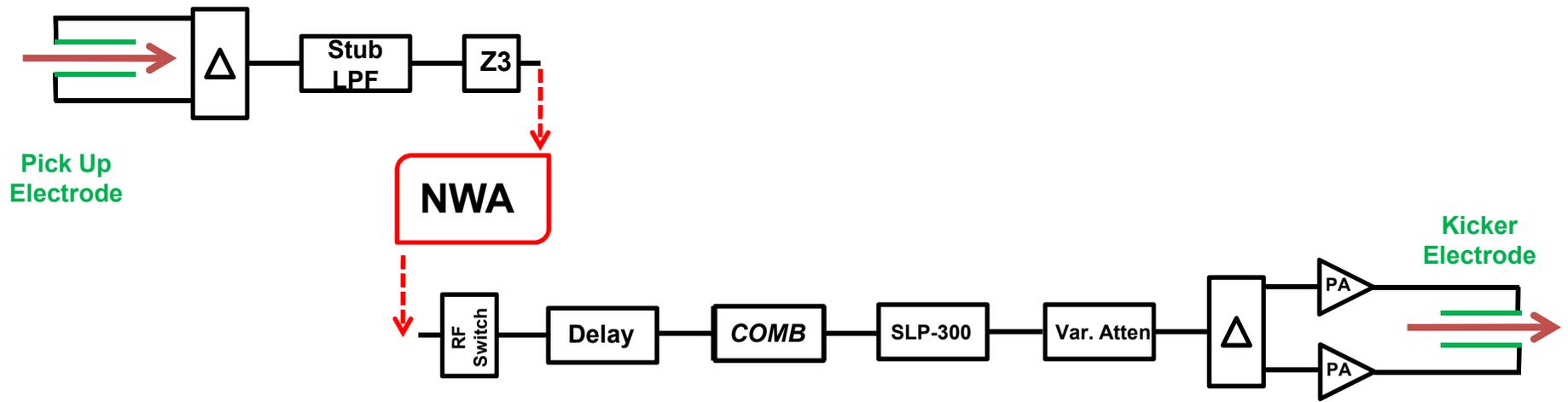
- **Continuously looking to improve the system**
 - Maximizing the bandwidth (via equalizer)
 - Minimizing magnitude and phase dispersion in LLRF system
 - Maximizing signal output to Power Amplifiers

- **Utilize the damper system to supplement the physics group observations of the beam dynamics**
 - Have been actively monitoring the beam during production and observed some unique dynamics (not discussed today).
 - Recently observed the beam may have an additional tune present, which limits the damping ability in the current configuration.
 - Employed the damper system in Beam Transfer Function measurements to observe the beam response to external excitation. (Next)

Introduction to Beam Transfer Function Measurements



Network Analyzer is used to excite the beam at a given frequency and observe the magnitude and phase of the response.

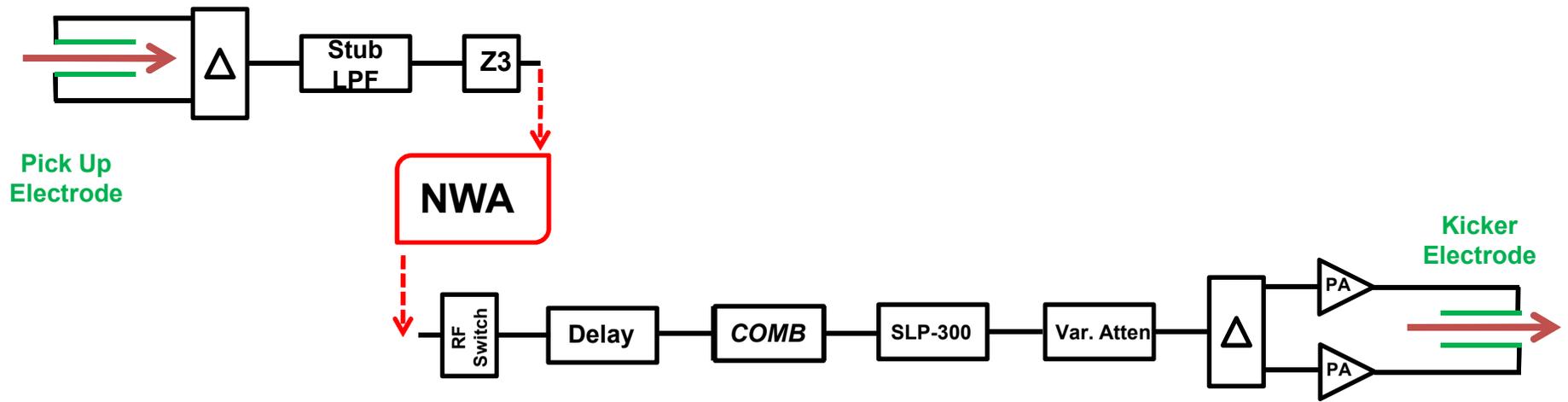


$$\underbrace{\ddot{x} + \omega_{\beta}^2 x}_{\text{beam}} = Ae^{-i\omega t}$$

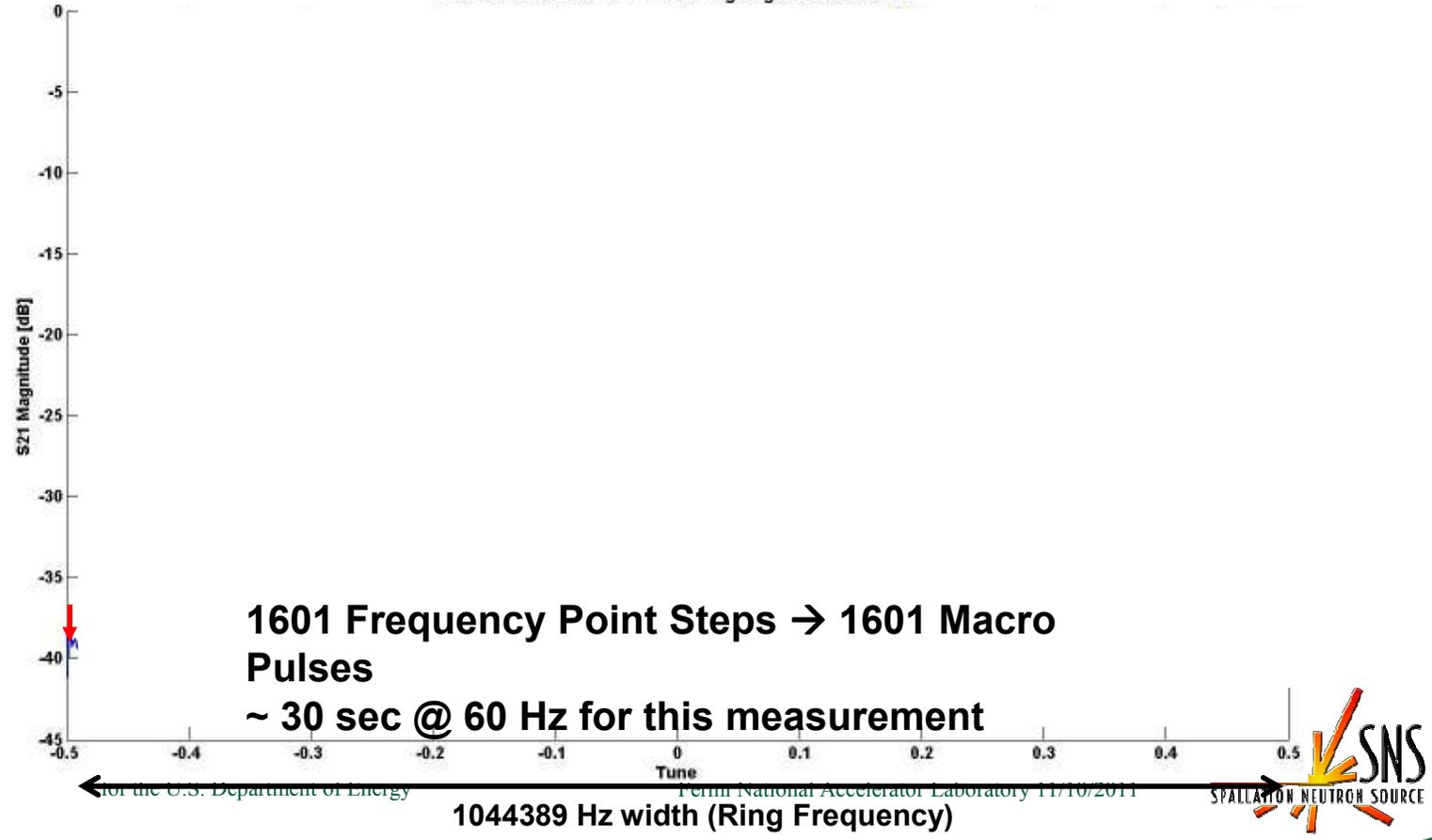
NWA excitation

Turn Window is determined by the Network Analyzer IFBW





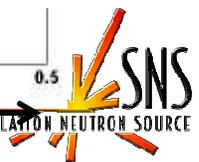
V 7kHz NoEQ NoComb 5 11 11 0 Mag Magnitude Modes: 50

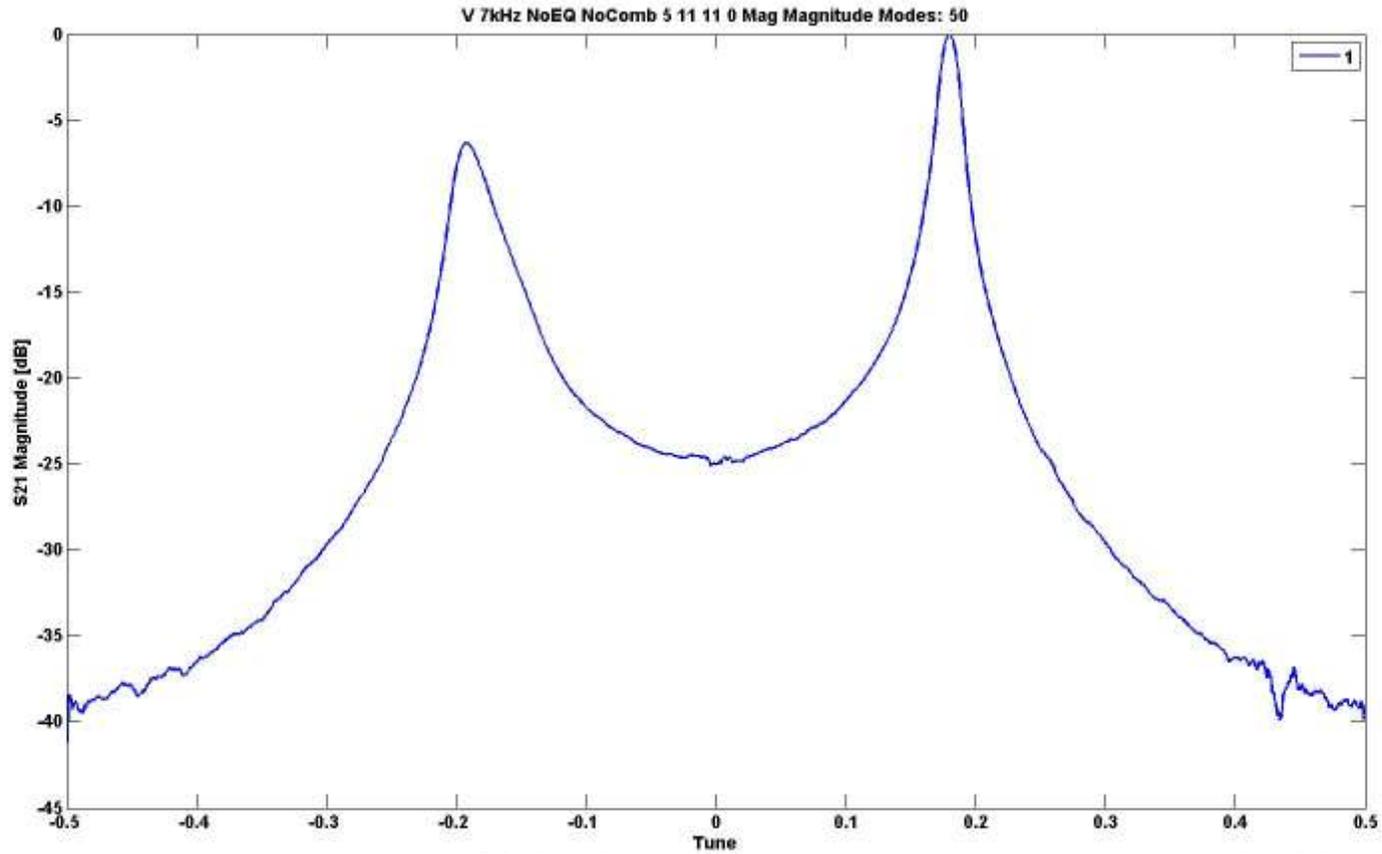


1601 Frequency Point Steps → 1601 Macro Pulses

~ 30 sec @ 60 Hz for this measurement

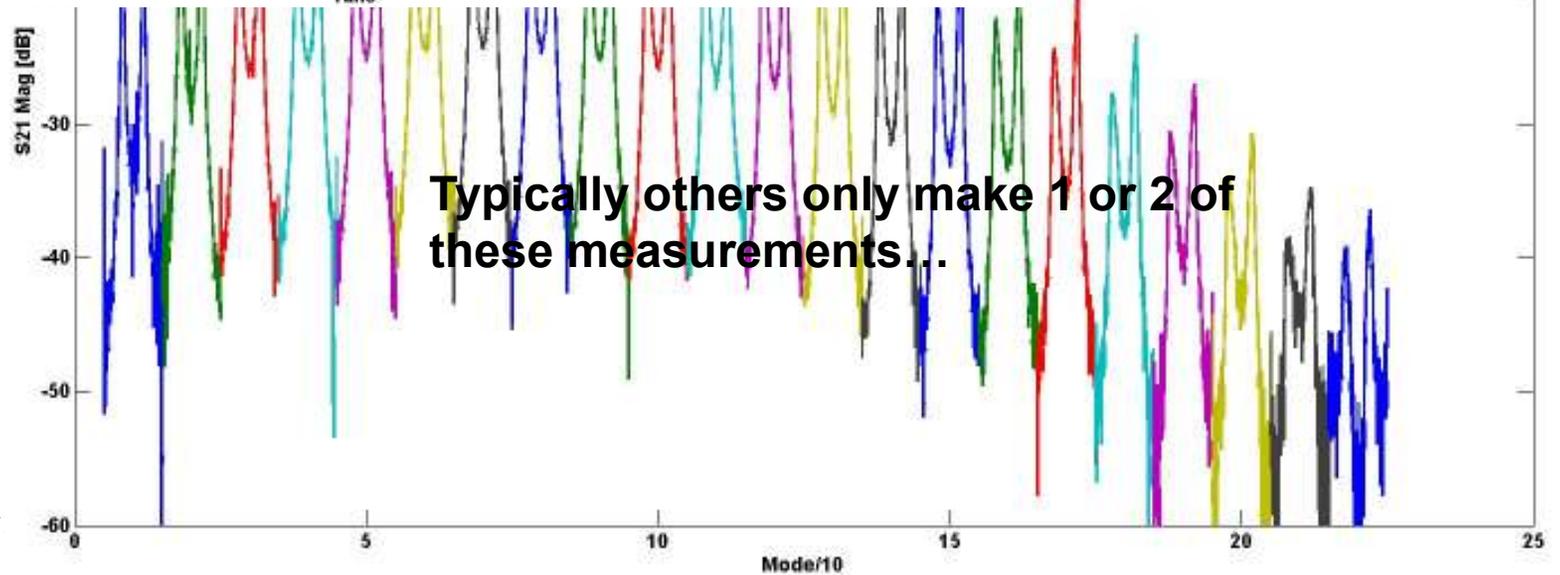
1044389 Hz width (Ring Frequency)

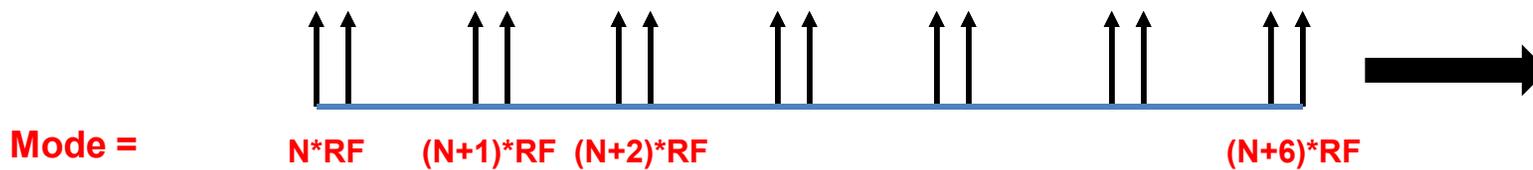




: 10 to 220

Note: Only every 10th mode is shown here

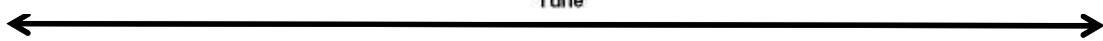
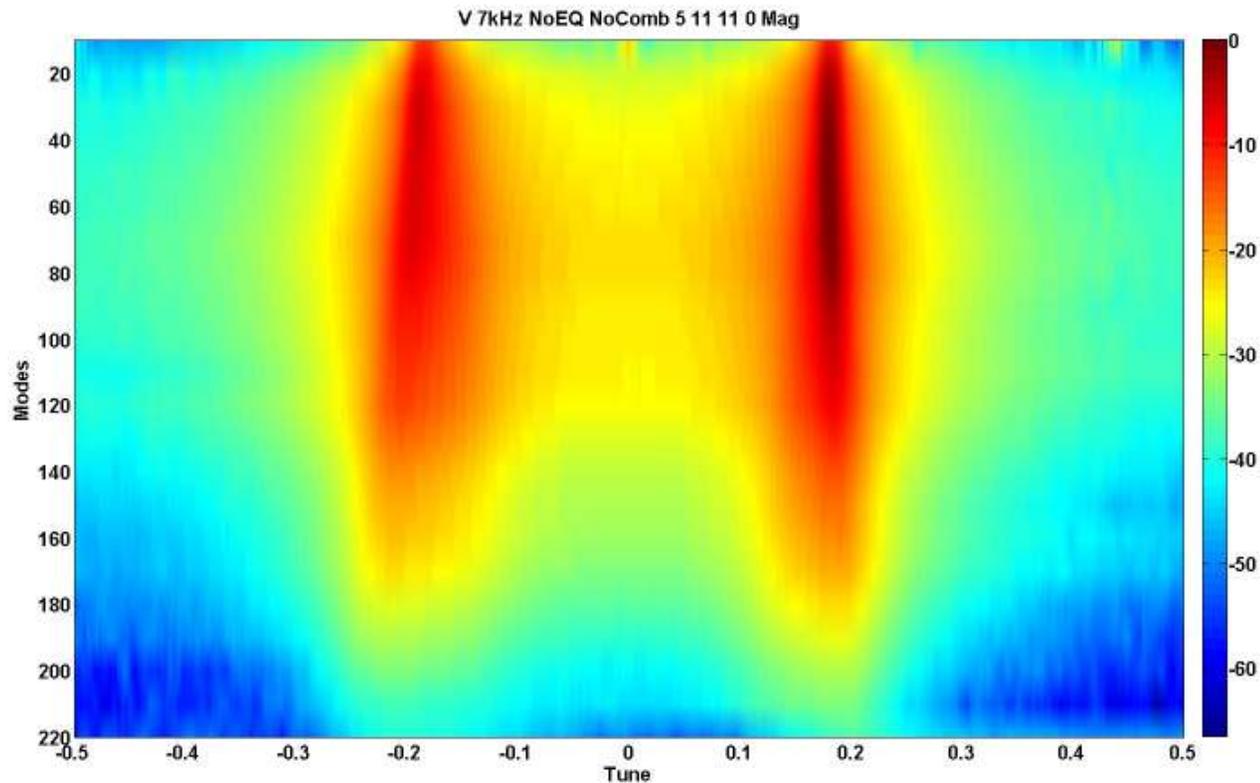
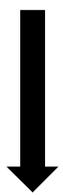




$(N+3)*RF$

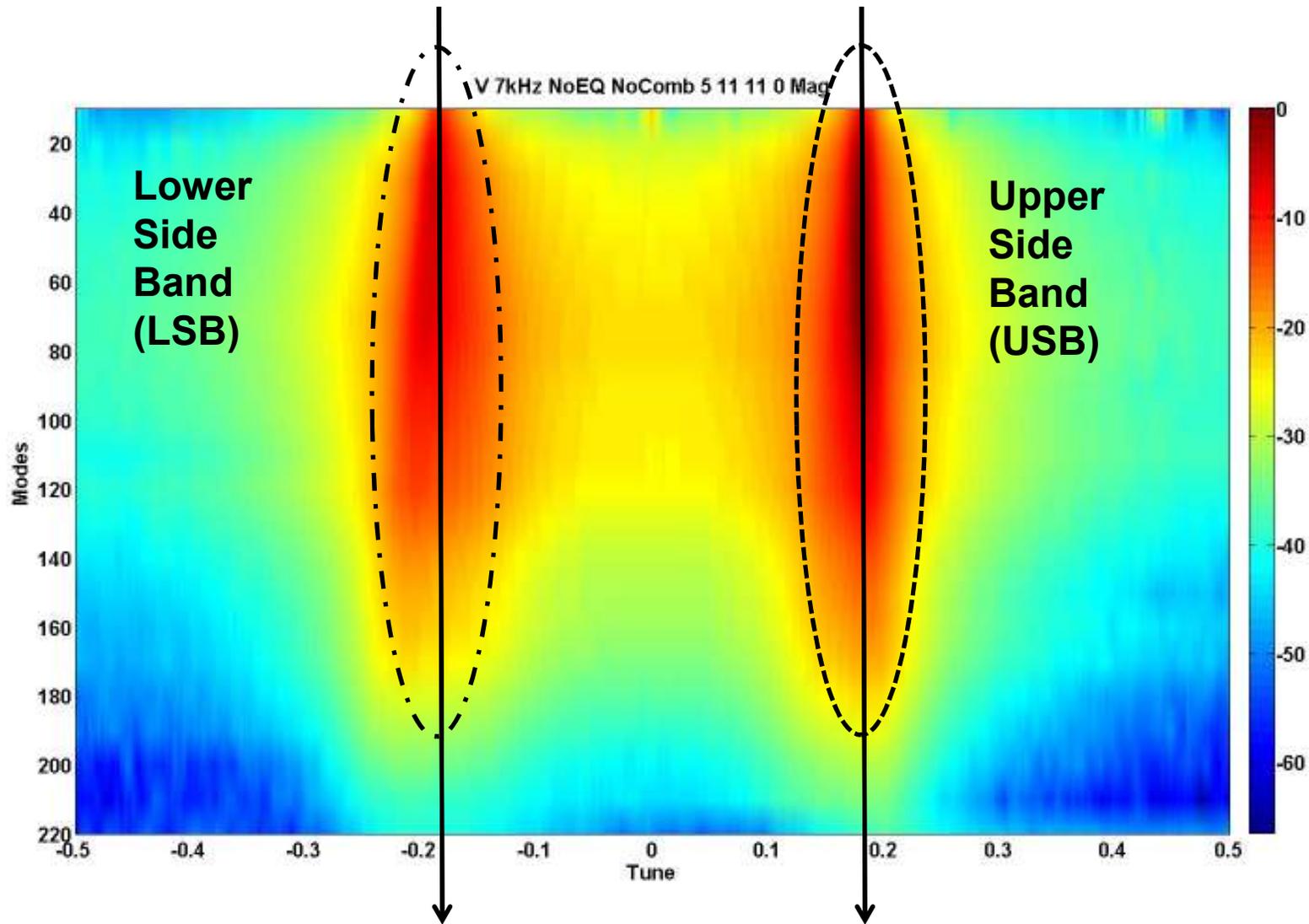
$(N+4)*RF$

$(N+5)*RF$

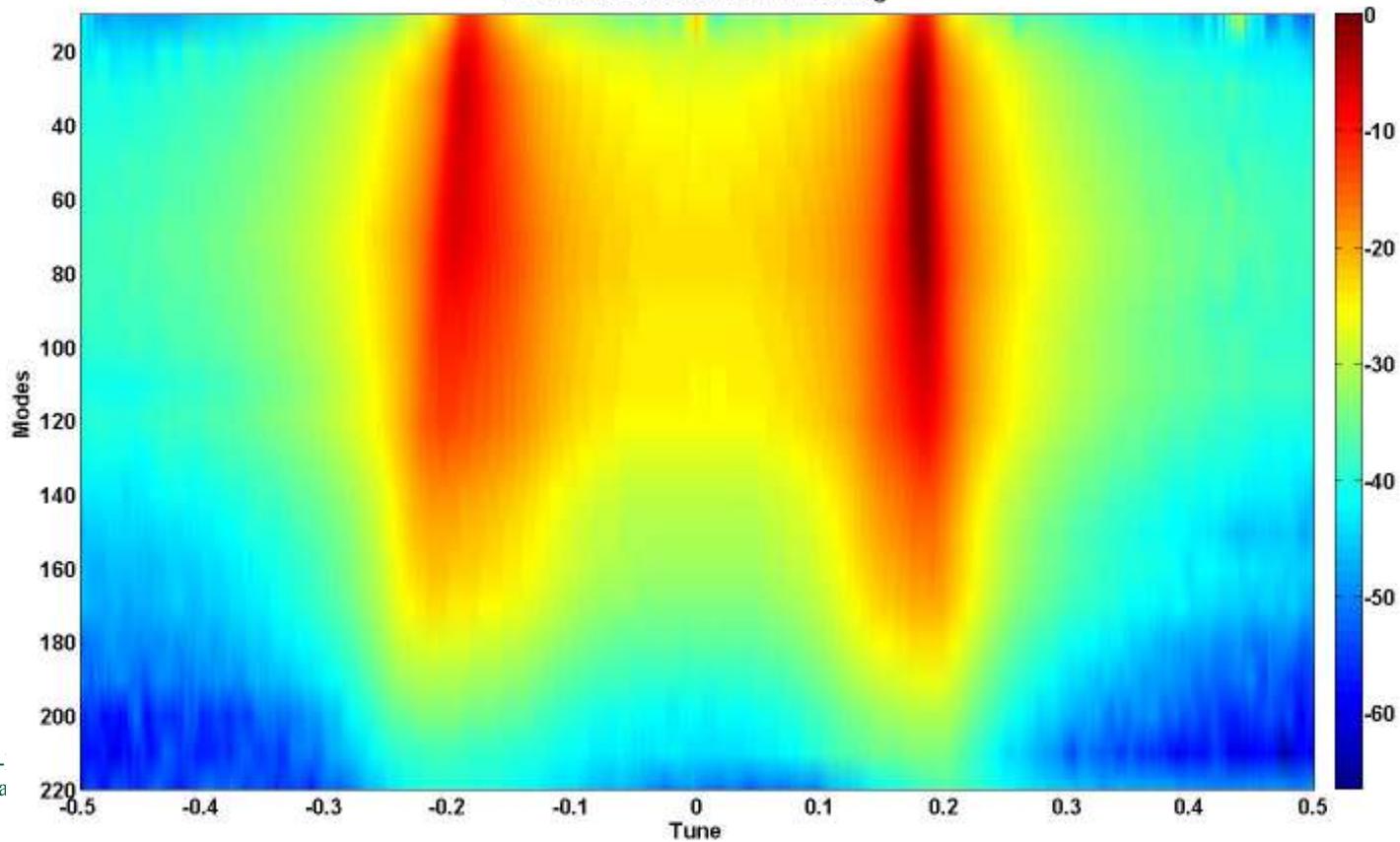
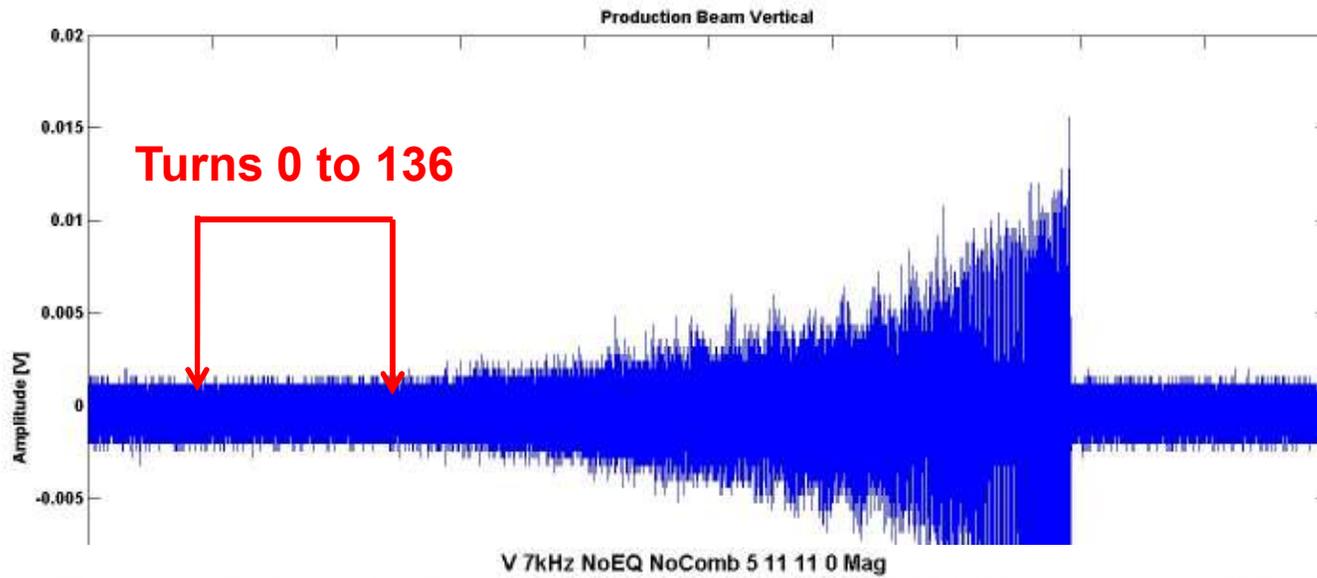


1044389 Hz width (Ring Frequency)

Make measurements into a more compact form.

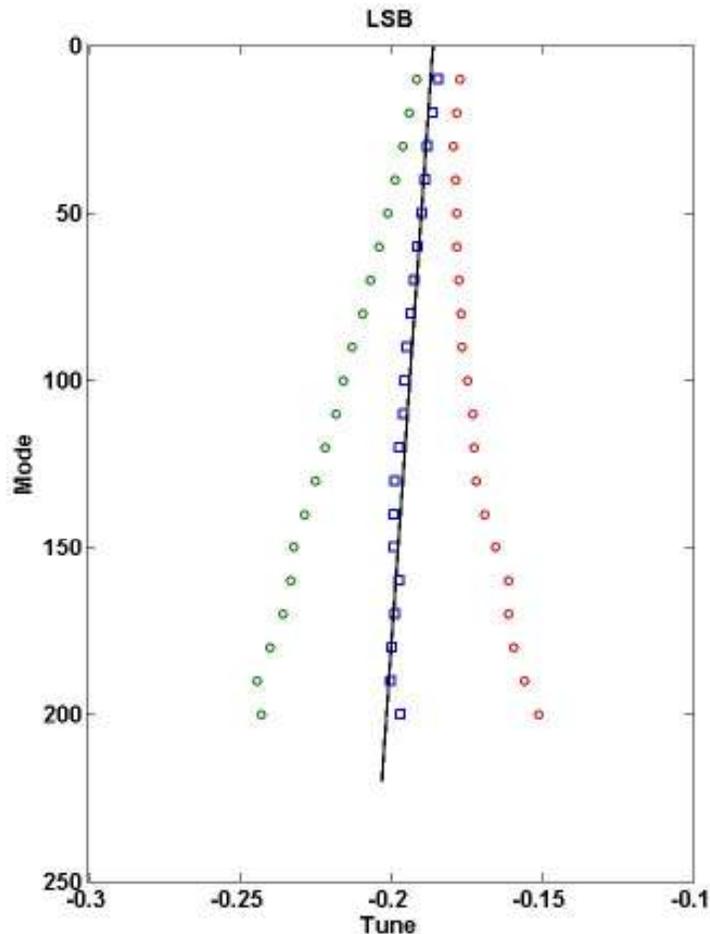


Betatron sidebands reveal the tune.

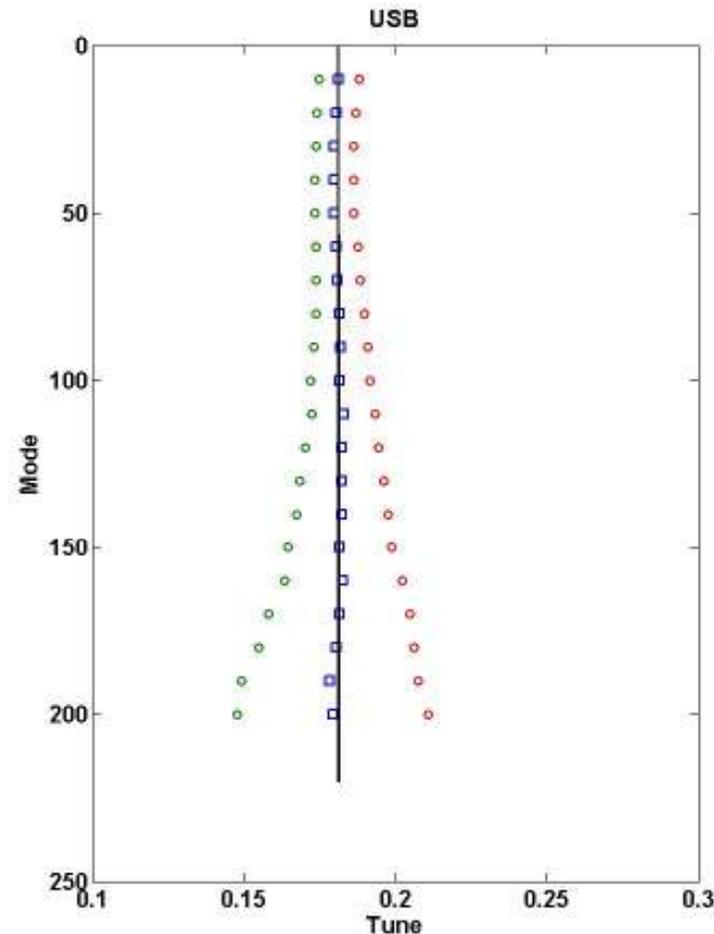


BTF Ring Tune Determination

$$\text{LSB Tune} = -7.68 \times 10^{-5} \cdot (\text{Mode}) - 0.1863$$



$$\text{USB Tune} = 7.41 \times 10^{-7} \cdot (\text{Mode}) + 0.1811$$



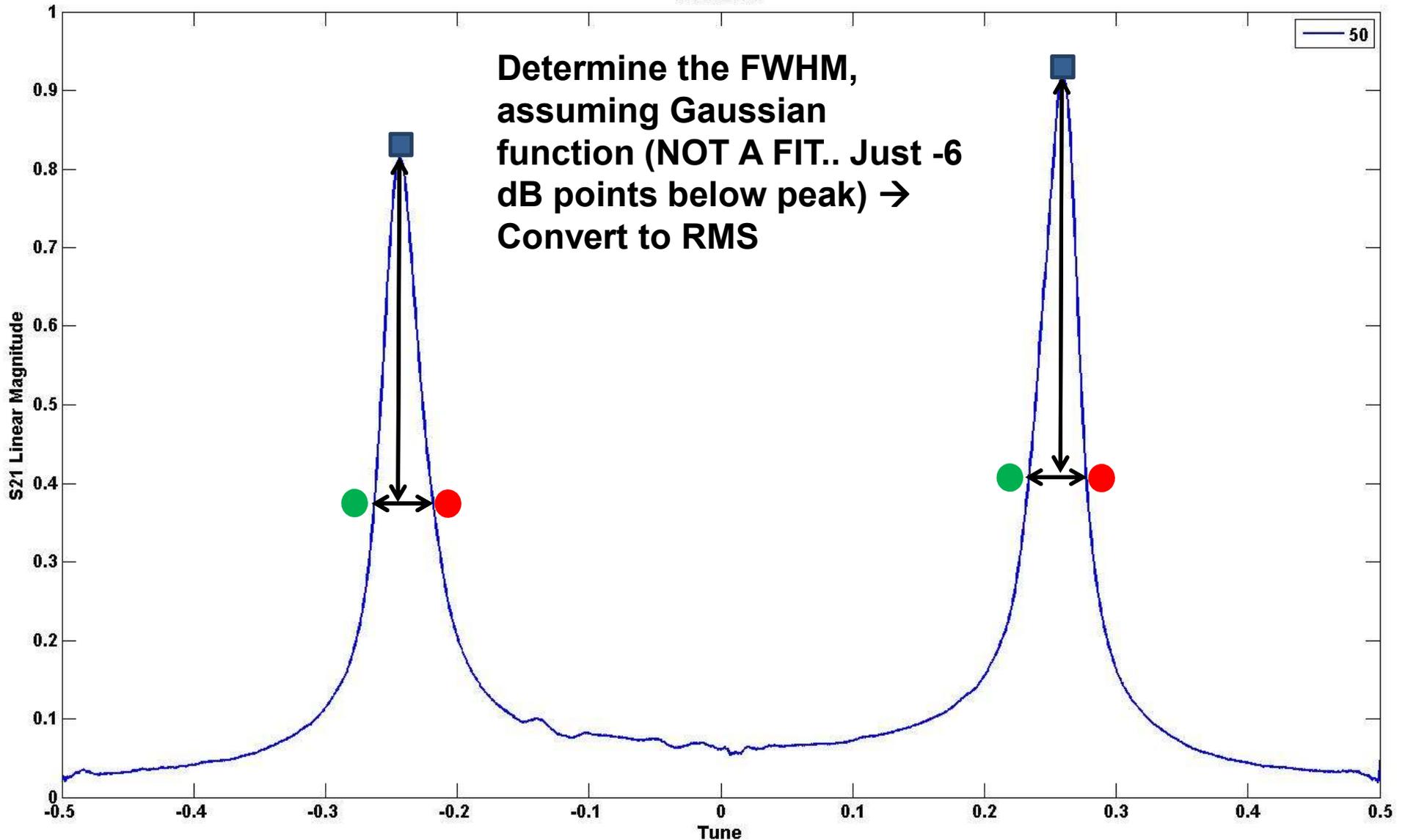
Fitting algorithm to determine the tune...

Separate measurement gives the vertical tune ~ 0.1799

USB.. Pretty much a straight line... LSB on the other hand.. Currently no explanation

Additional information can be extracted from the BTF response measurements

Horz 9-20-11 0Turn WithEQ NoComb ZeroChrome Linear Magnitude
Modes: 50



Vary the Chromaticity to determine capability of BTF measurement as a diagnostic

ξ_x	-7.9	-5.33	-2.66	0
ξ_y	-6.9	-4.66	-2.33	0

*Coasting BTF theory defines the sideband frequency widths to be:

$$\partial f^- = f_0 \frac{\partial p}{p_0} \left| \eta \left(m - Q_f + \frac{\xi}{\eta} \right) \right|$$

$$\partial f^+ = f_0 \frac{\partial p}{p_0} \left| \eta \left(m + Q_f - \frac{\xi}{\eta} \right) \right|$$

$\partial f^{(\pm)}$ = RMS Frequency width

f_0 = Ring Frequency

dp/p = Momentum spread (**DETERMINED FROM ZERO CHROMATICITY CASE**)

m = Mode (**VARIABLES**)

Q_f = Fractional Tune (**VARIABLES**)

ξ = Chromaticity (**VARIABLES**)

η = Slip Factor (-.2173)

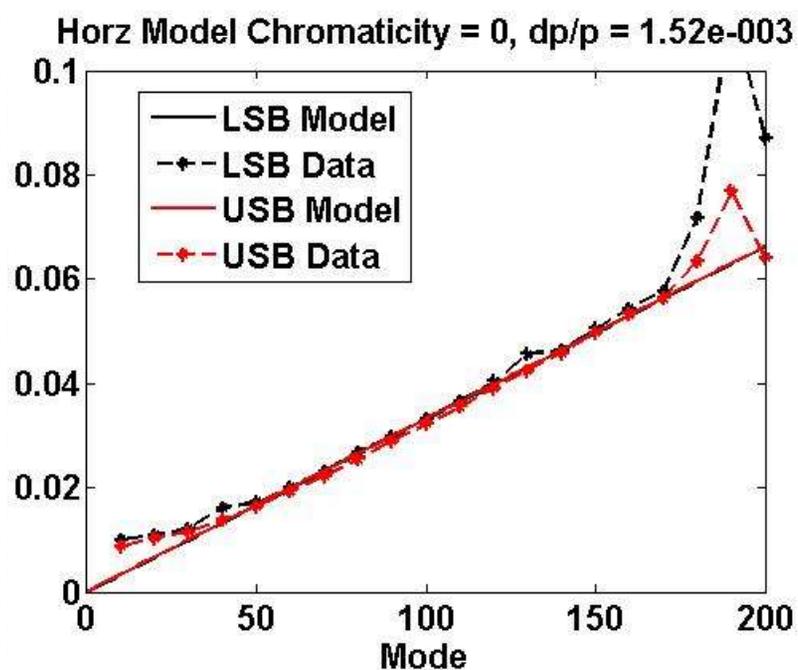
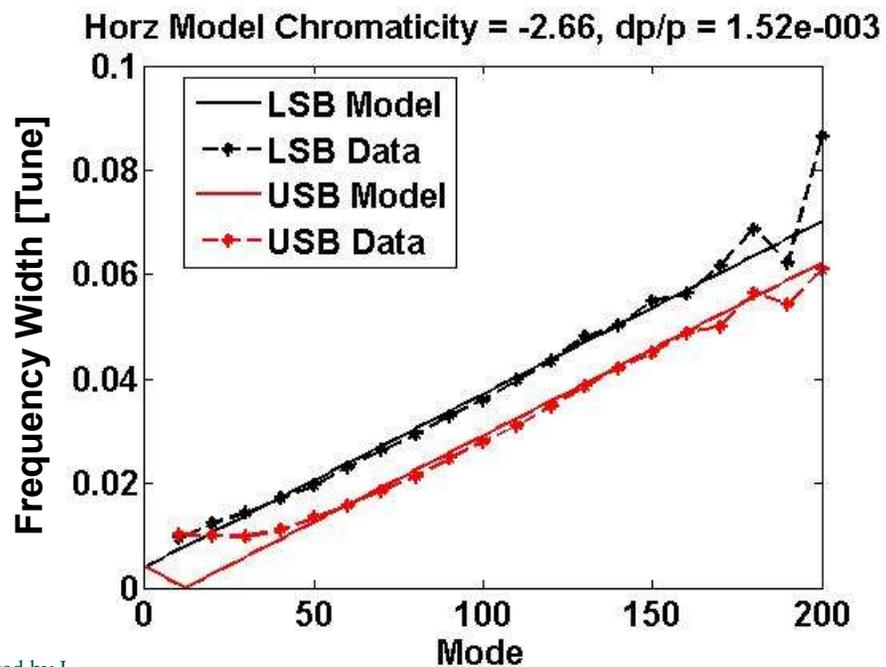
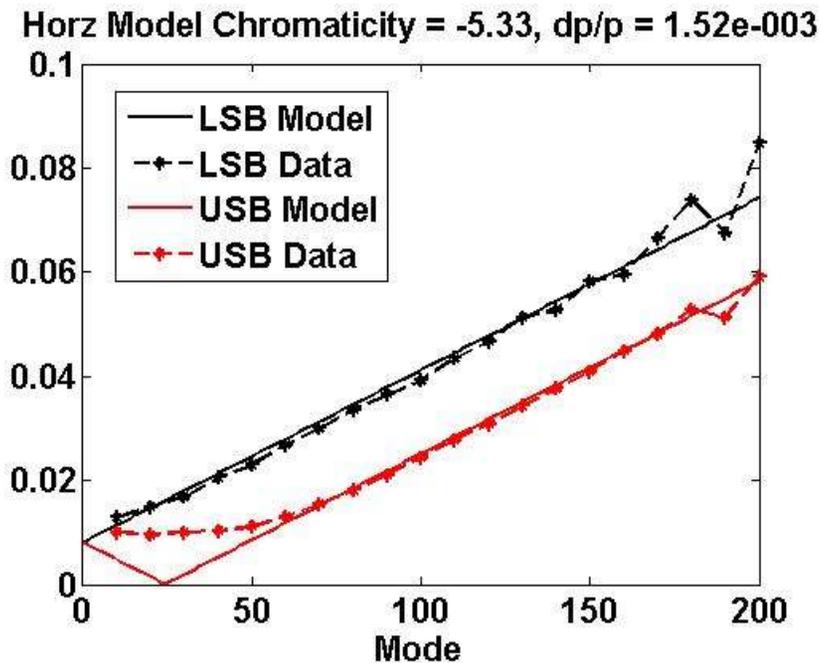
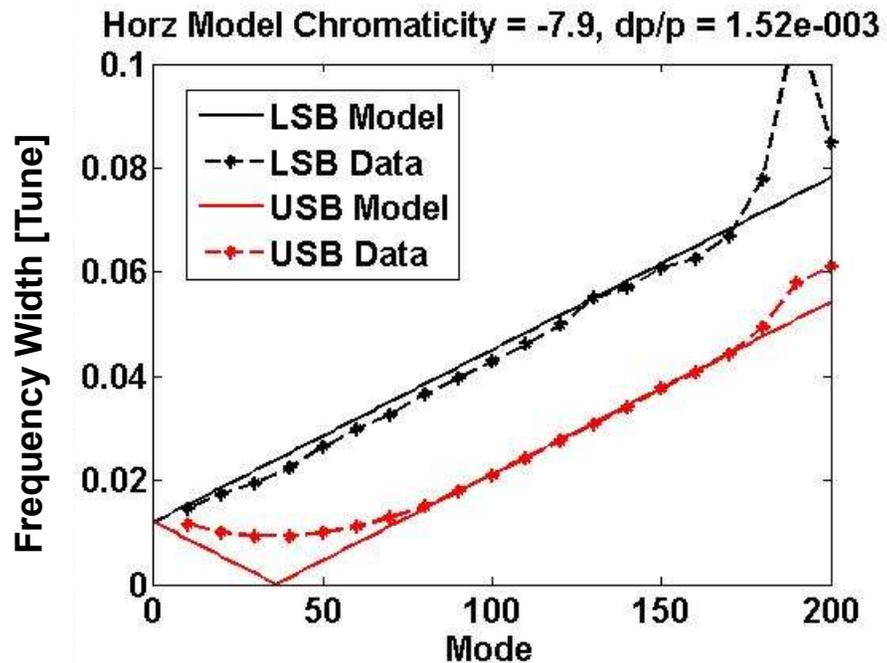
*Kornilov, et al., GSI-Acc-Note-2006-12-001

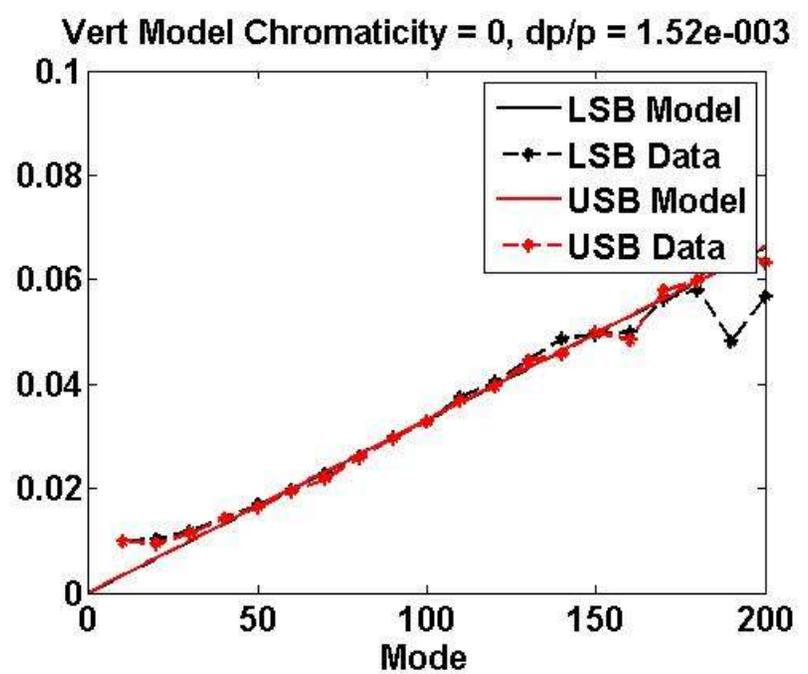
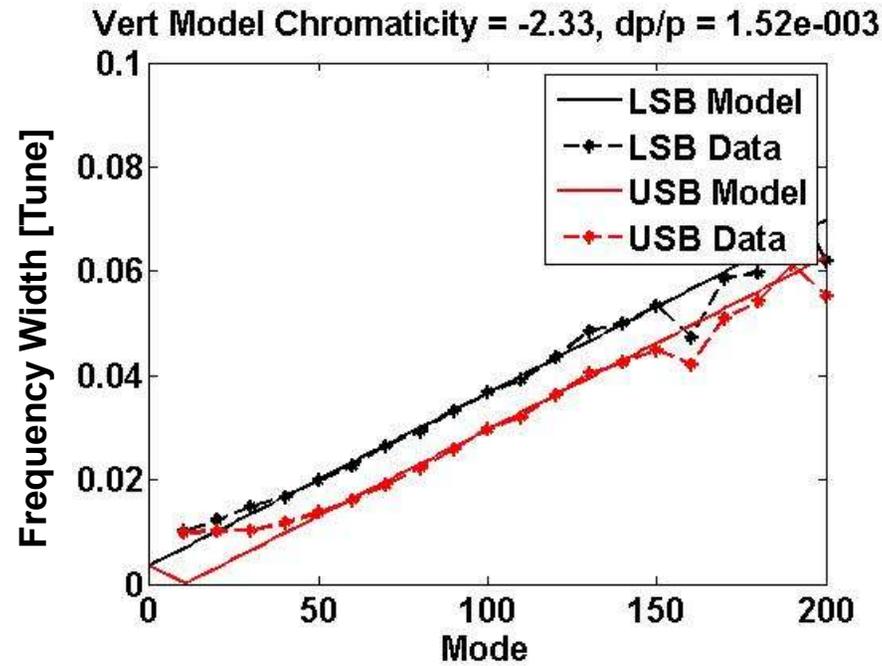
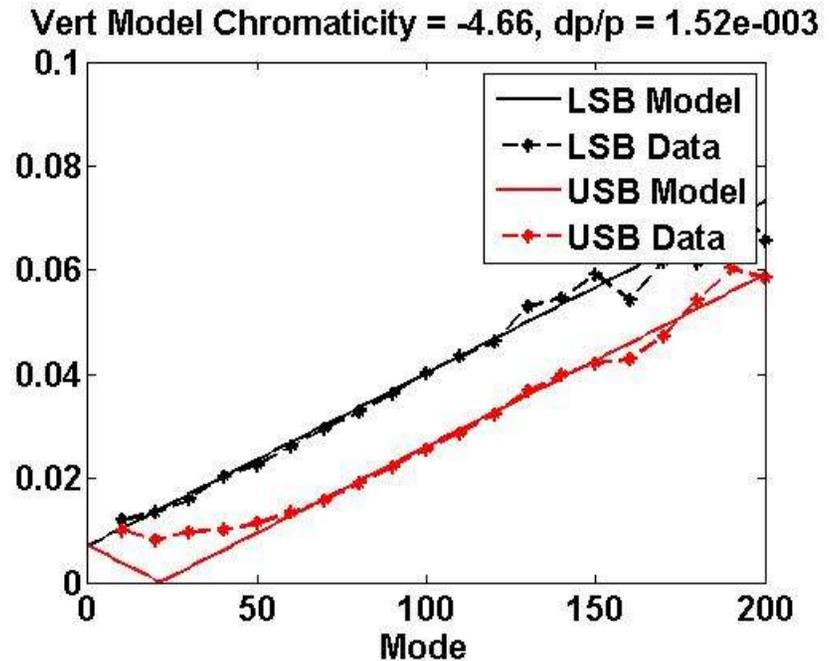
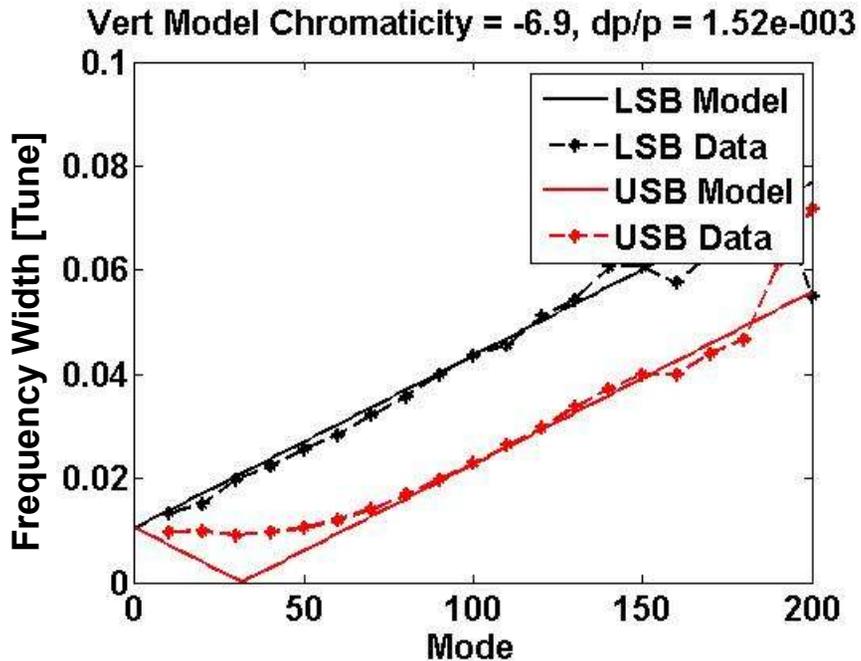
$$\frac{\partial f^-}{f_0} = \frac{\partial p}{p_0} \left| \eta (m - Q_f) \right|$$

$$\frac{\partial f^+}{f_0} = \frac{\partial p}{p_0} \left| \eta (m + Q_f) \right|$$

Zero Chromaticity



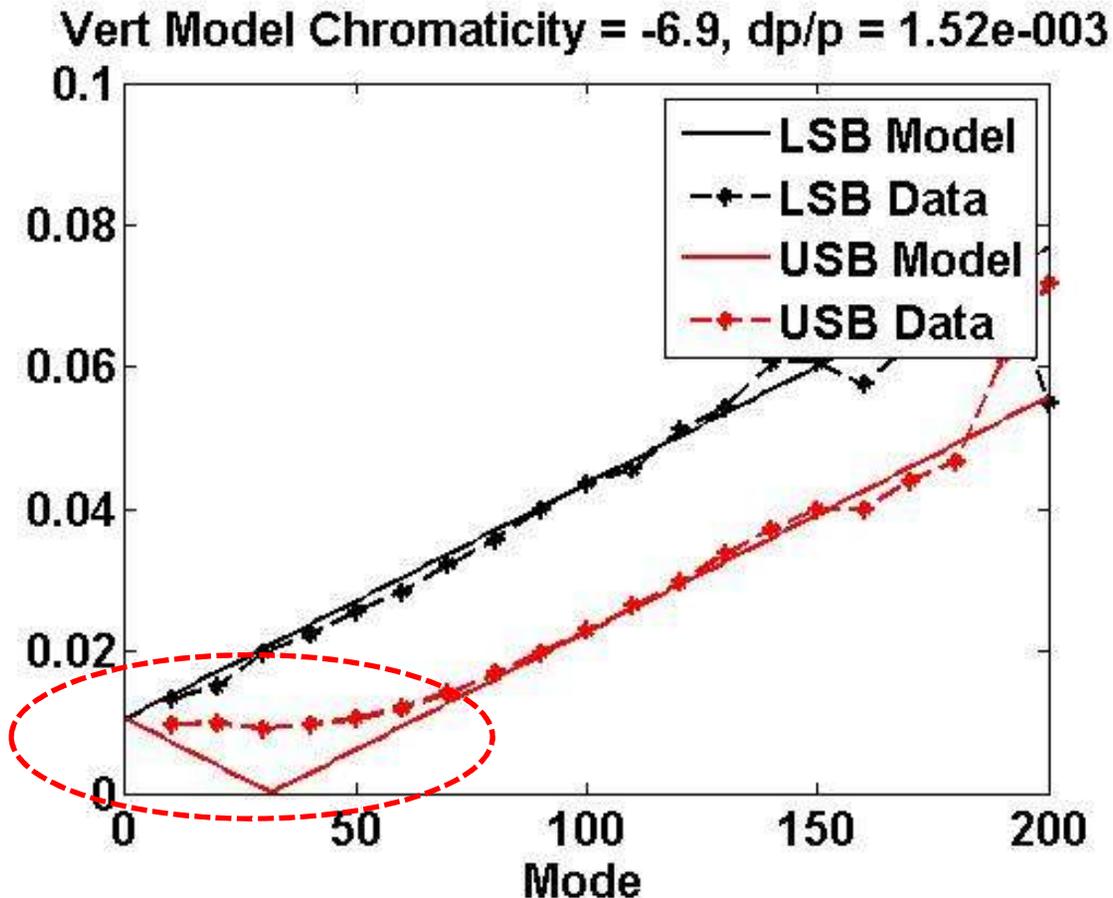




Chromaticity Measurement Results

ξ Setting	Fit ξ (Avg)	% Difference	Tom Pelaia ξ
$\xi_X = -7.9$	-7.32	7.6	-6.75
$\xi_X = -5.33$	-5.17	3.0	
$\xi_X = -2.66$	-2.83	6.0	
$\xi_X = 0$	-.45	---	
$\xi_Y = -6.9$	-6.84	.87	-5.89
$\xi_Y = -4.66$	-4.71	1.2	
$\xi_Y = -2.33$	-2.46	5.6	
$\xi_Y = 0$	-.14	---	

Tom's Chromaticity measurements use the single mini-pulse injection into the ring method. (No RF Cavities on)

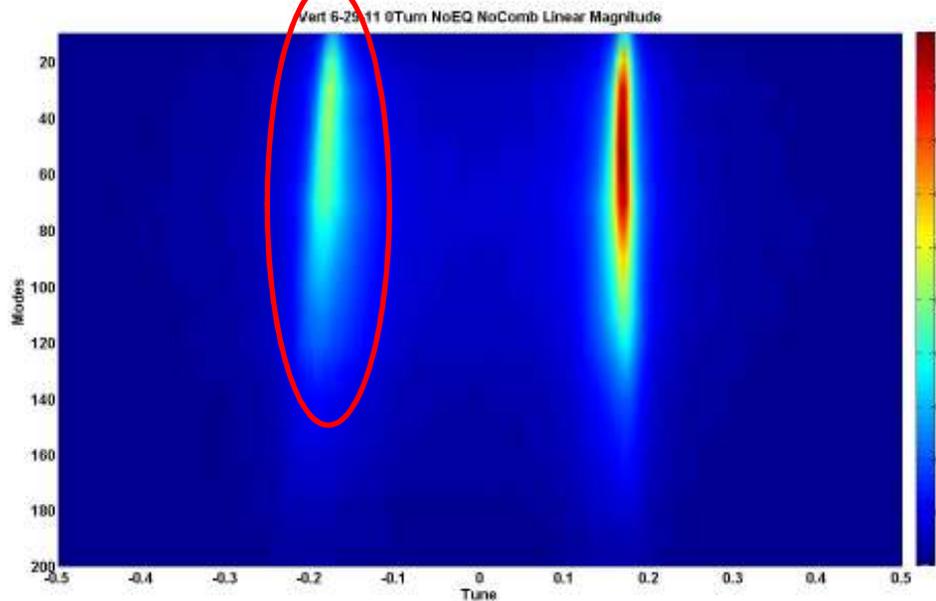


Currently we are unsure about the source of this effect. It could be due to the reduced signal acquisition time (7 kHz IFBW) which gives us the ability to only look at ~136 us of accumulation.

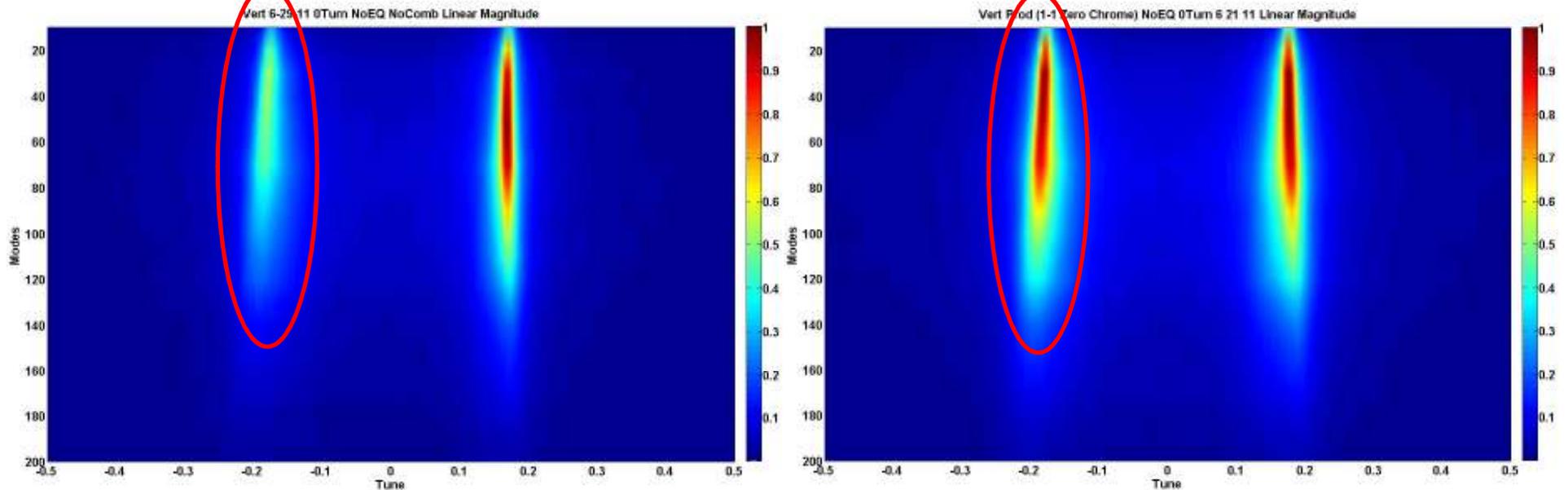
If we were to reduce the IFBW, the expectation is that the minimal measurement resolution would improve, but at the cost of having to look at a longer portion of accumulation. (Under investigation)

One additional measurement...

Typical Production ($\xi = -6.9$)



Zero Chromaticity

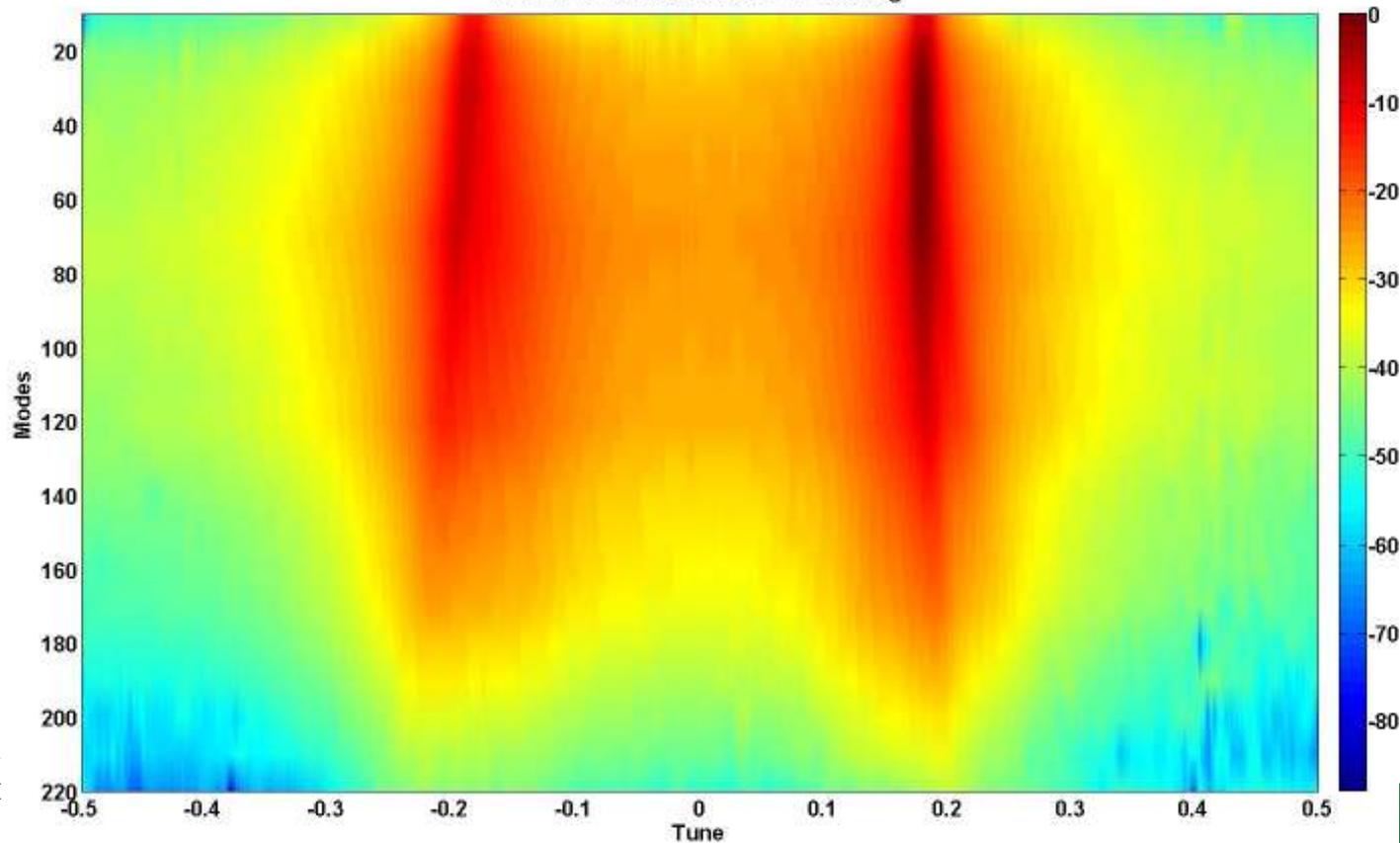
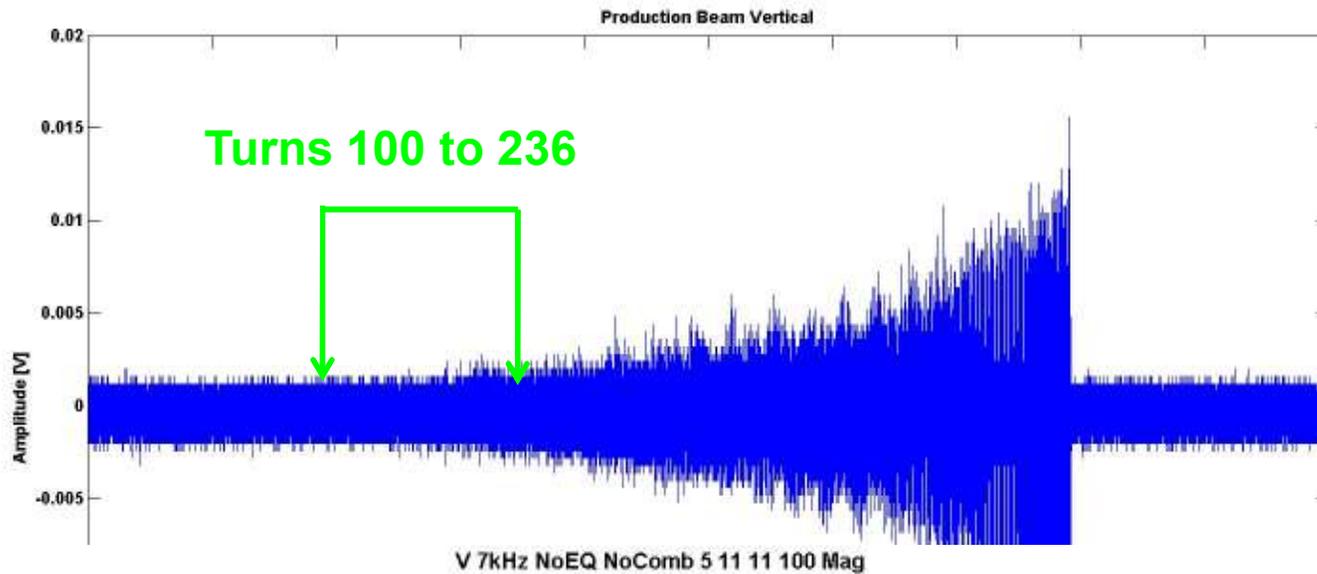


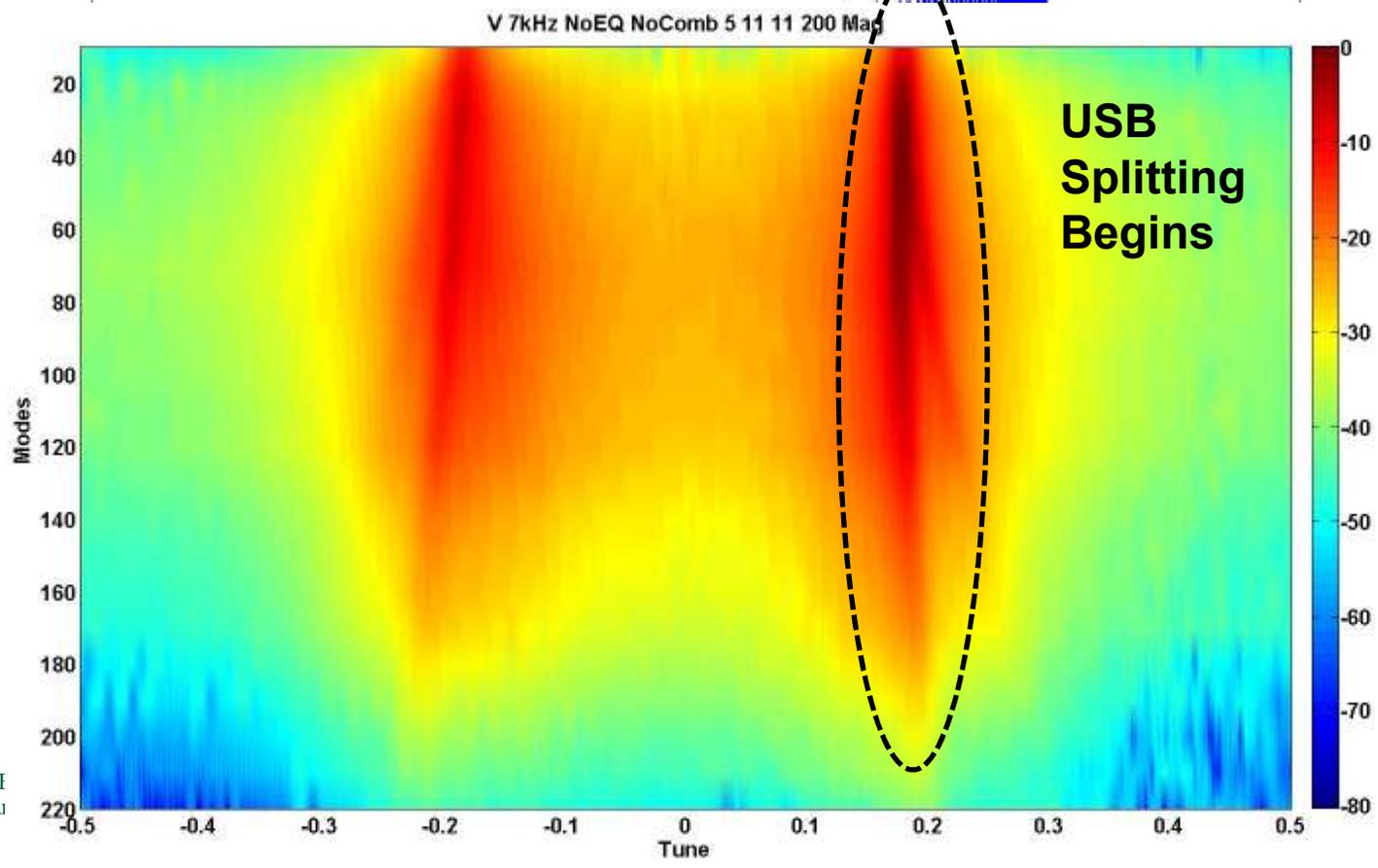
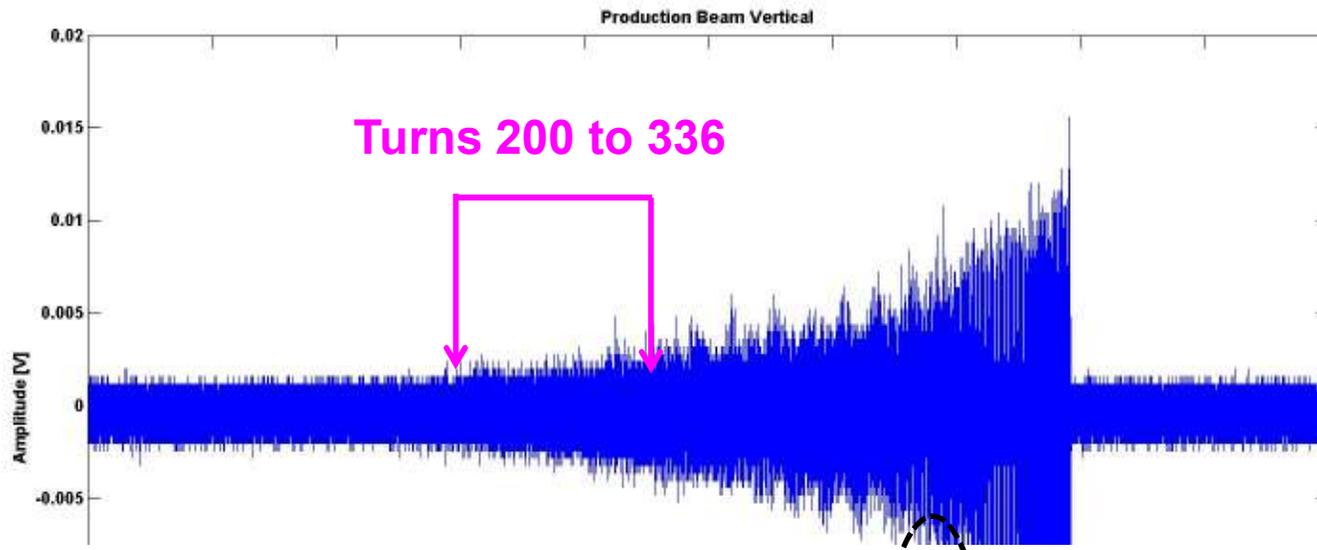
By changing the chromaticity to 0 (minimizing the tune spread) with the quadrupoles, the LSB response is essentially equal to that of the USB.

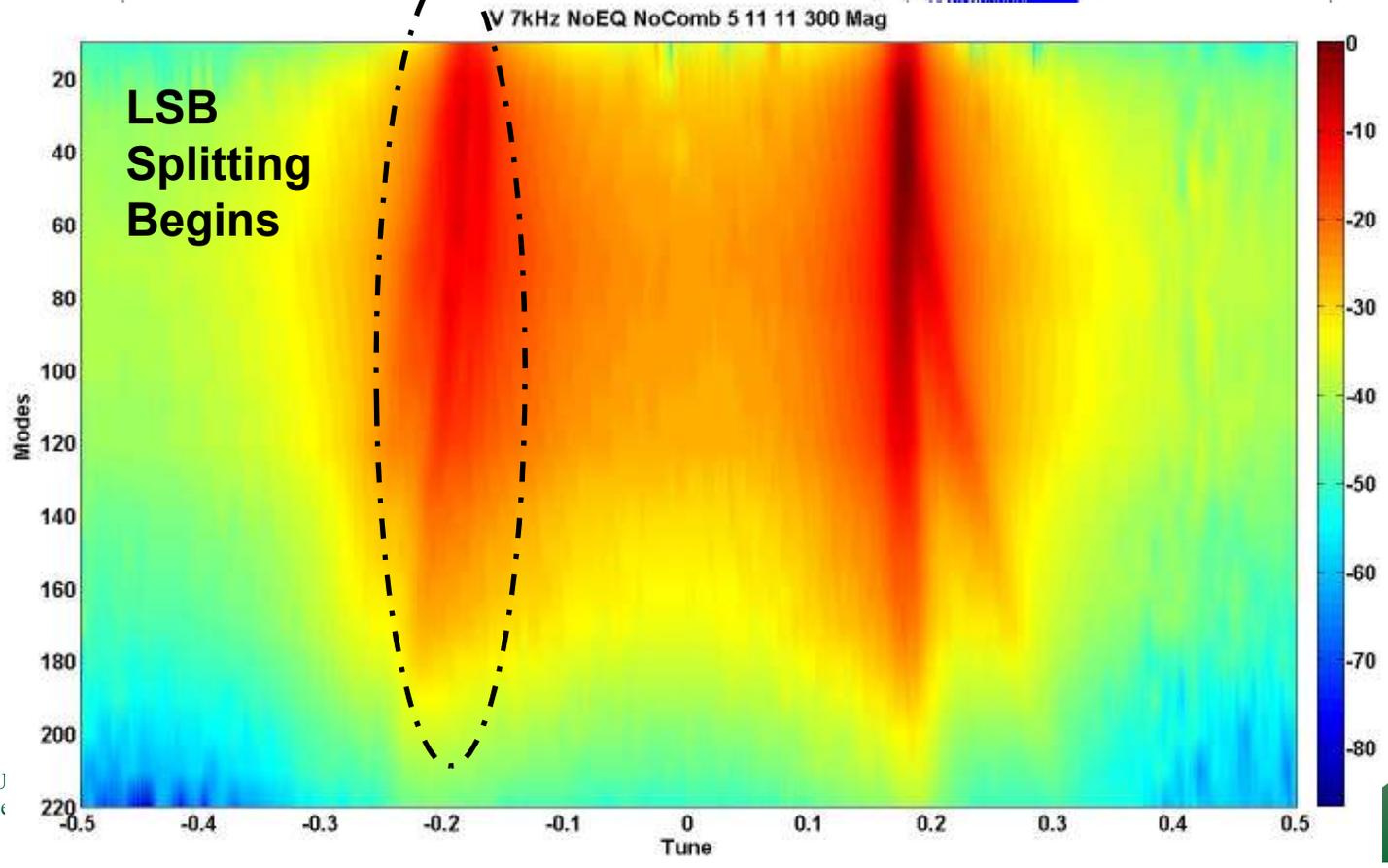
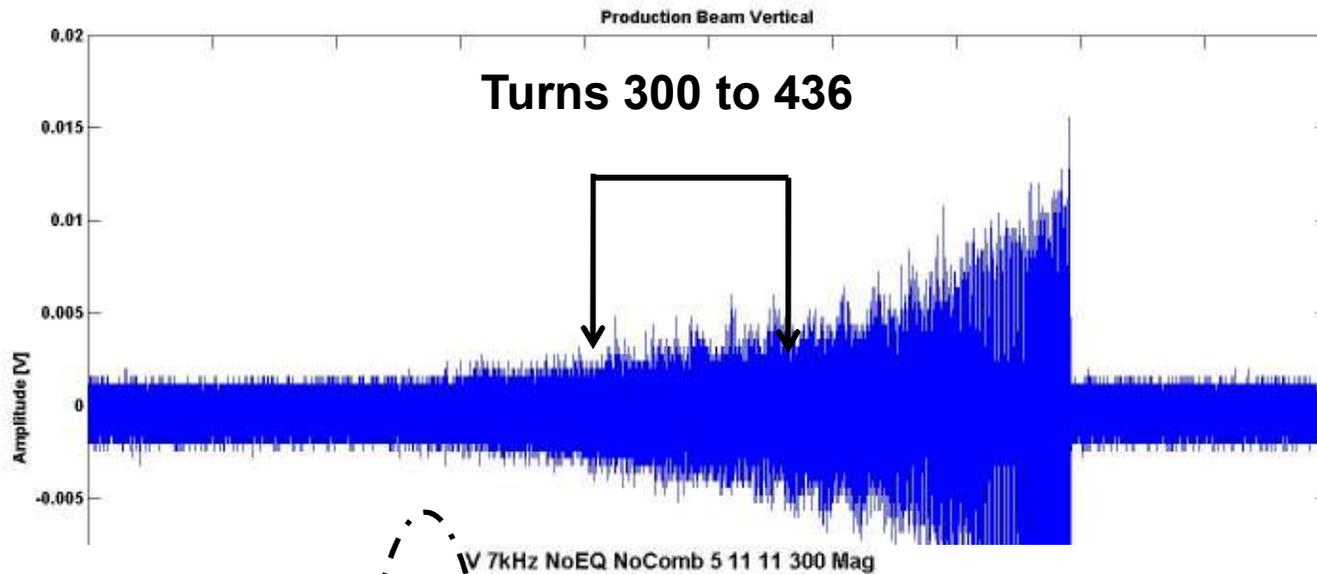
This is due to reducing the Landau damping that naturally occurs with the natural chromaticity for the LSB.

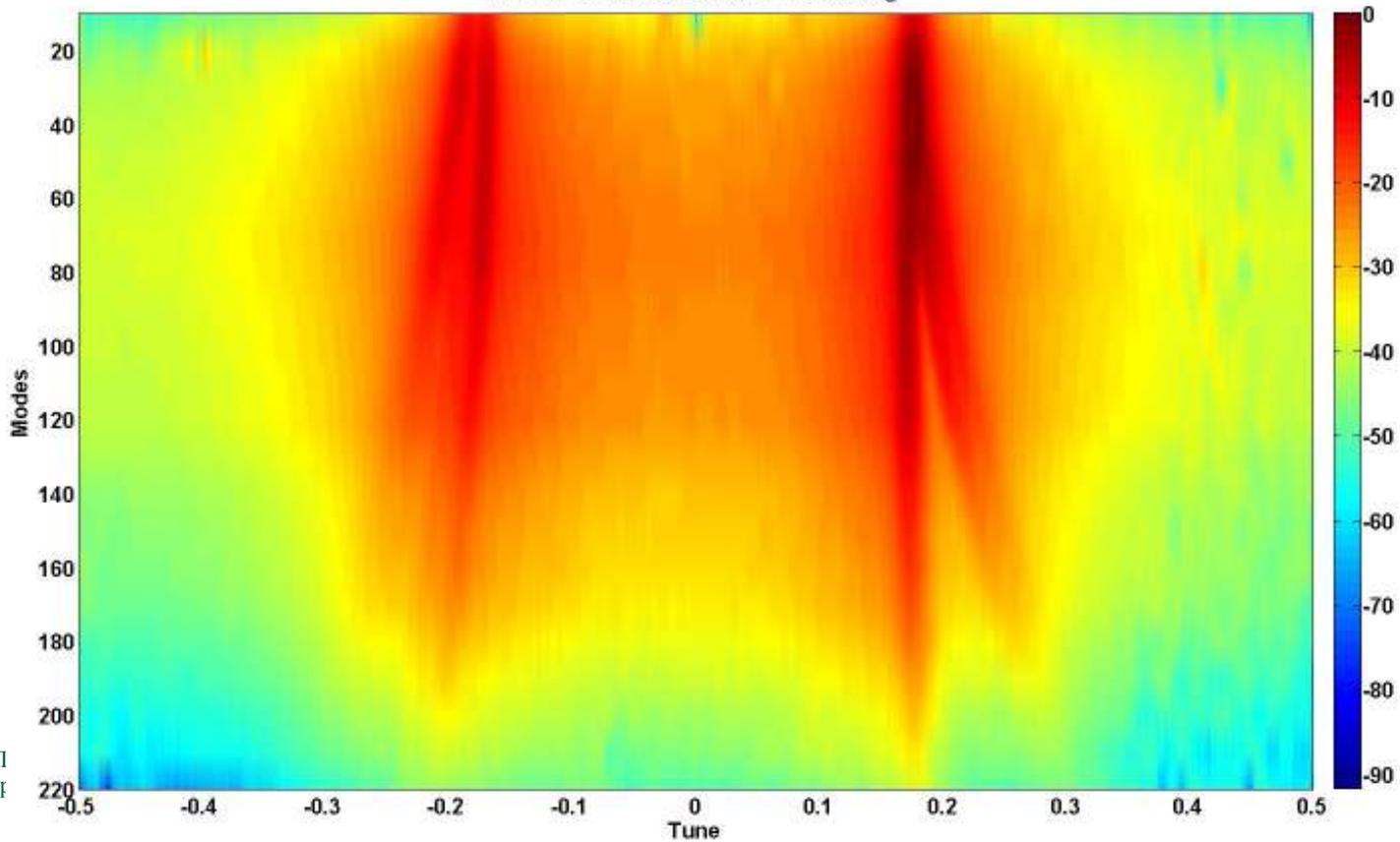
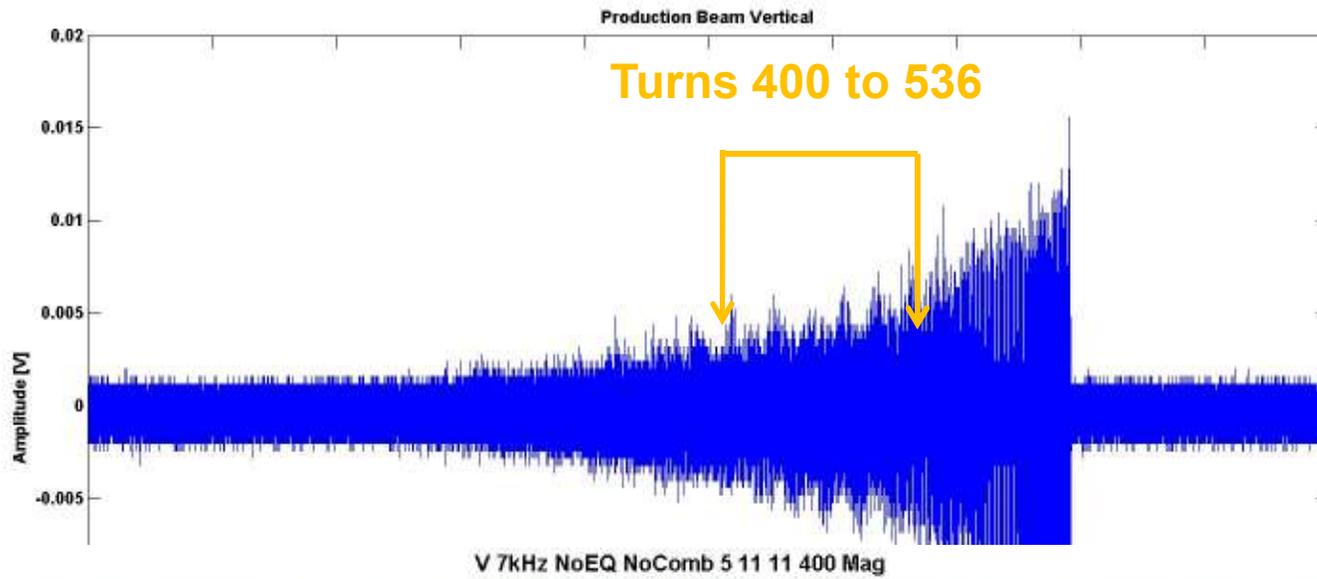
Measurement of the Ring Tune and Chromaticity are successful (during early accumulation)

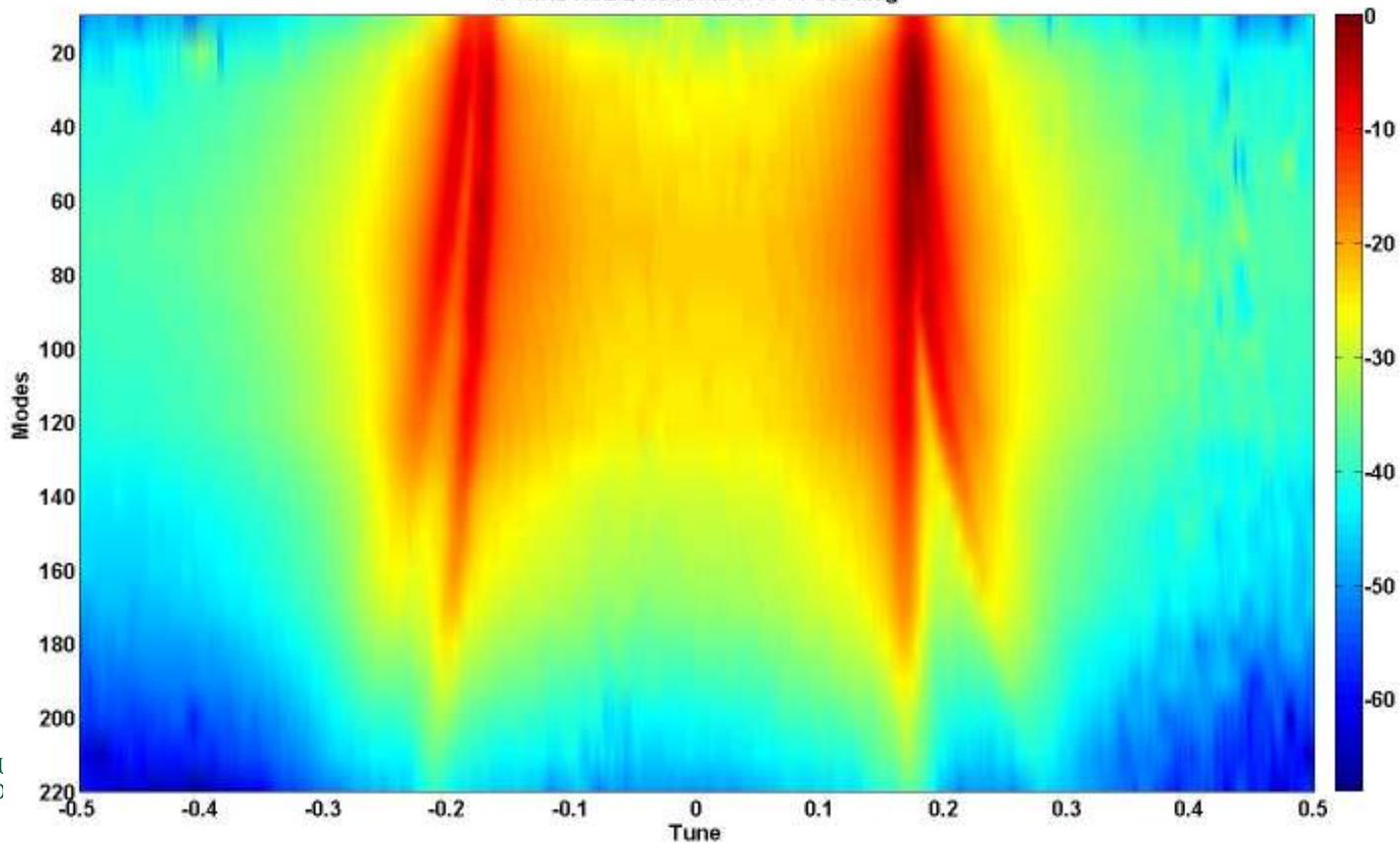
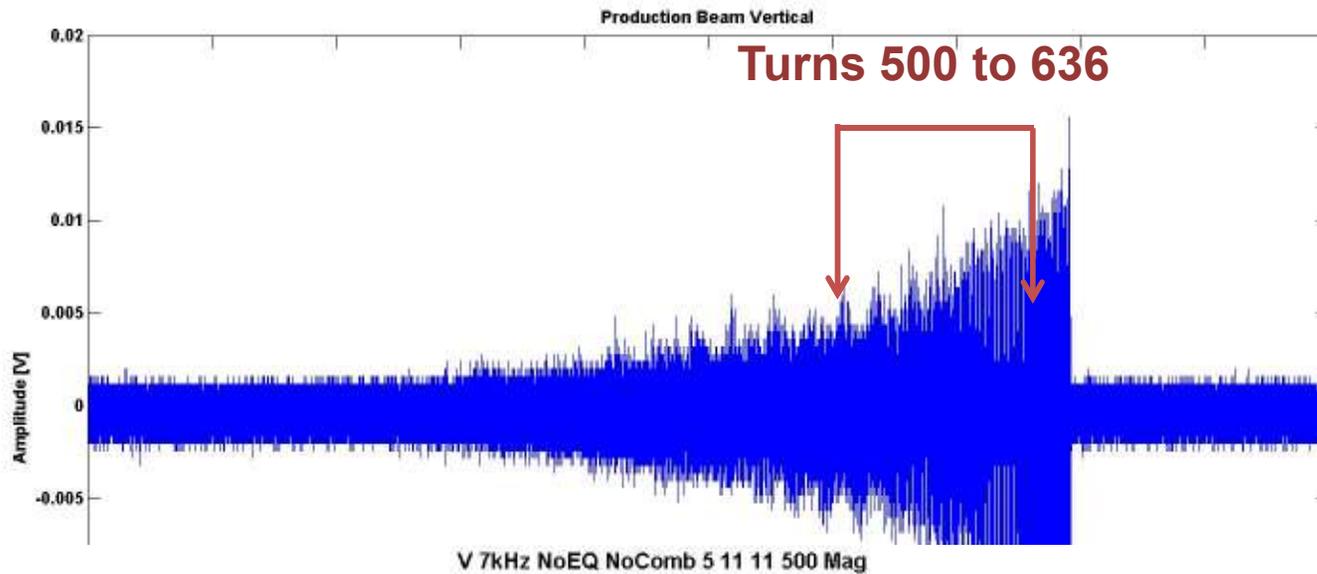
- So far the data presented has focused on the very beginning of accumulation (Turns 1-136).
- What happens when we shift our observation time to later in the accumulation cycle?

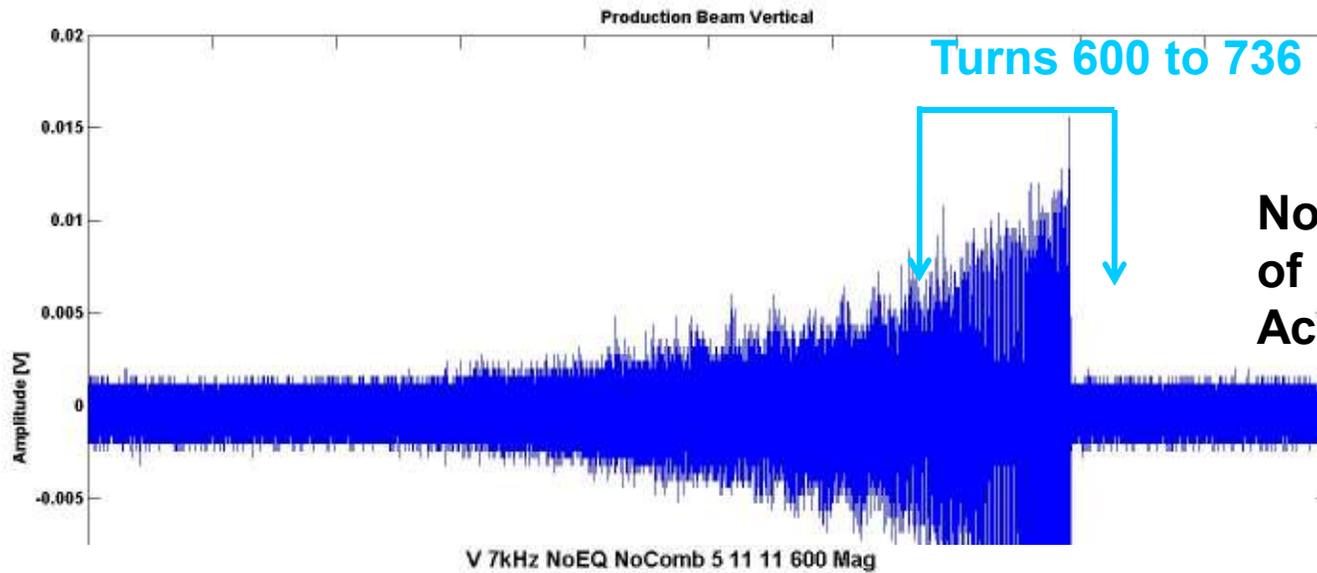




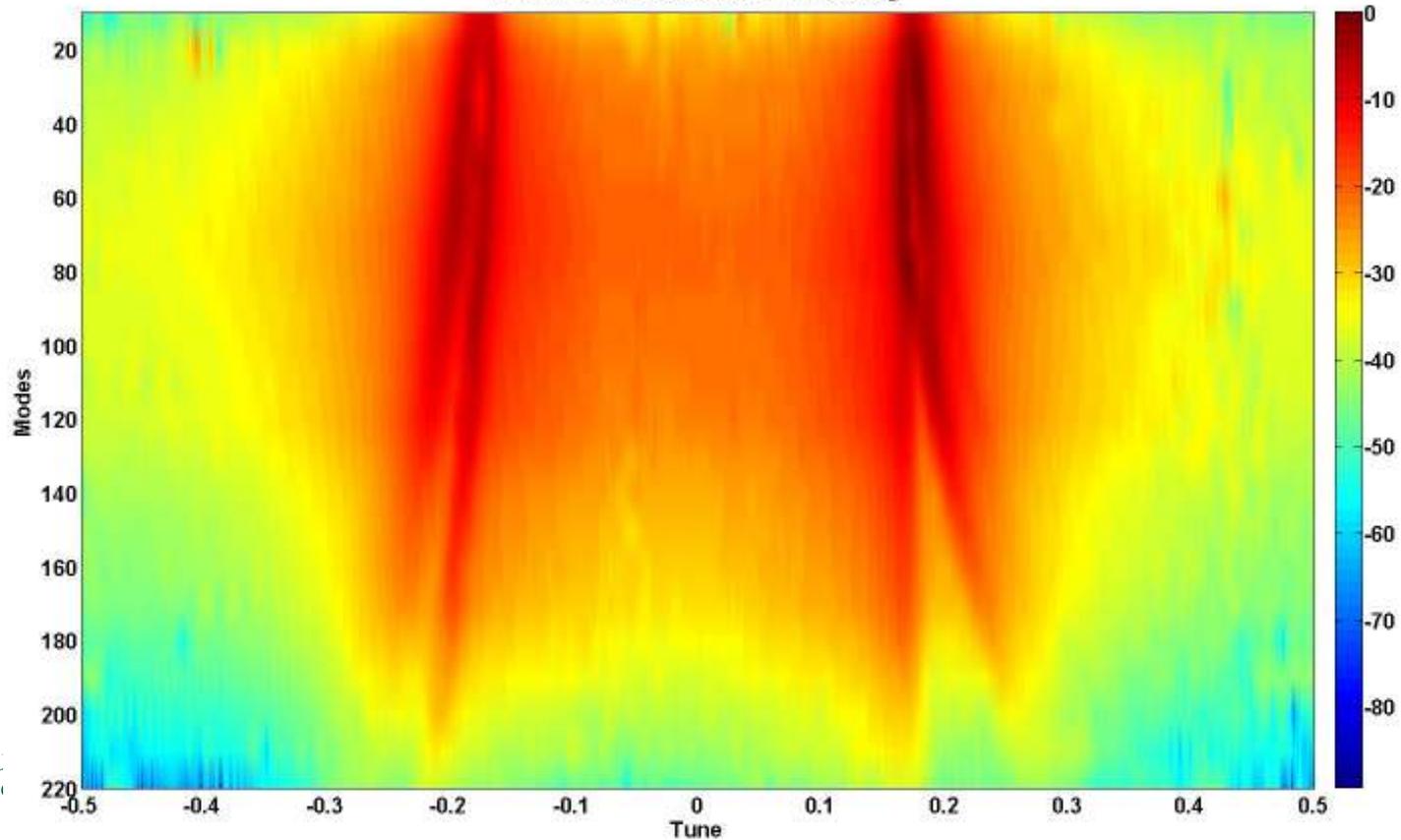








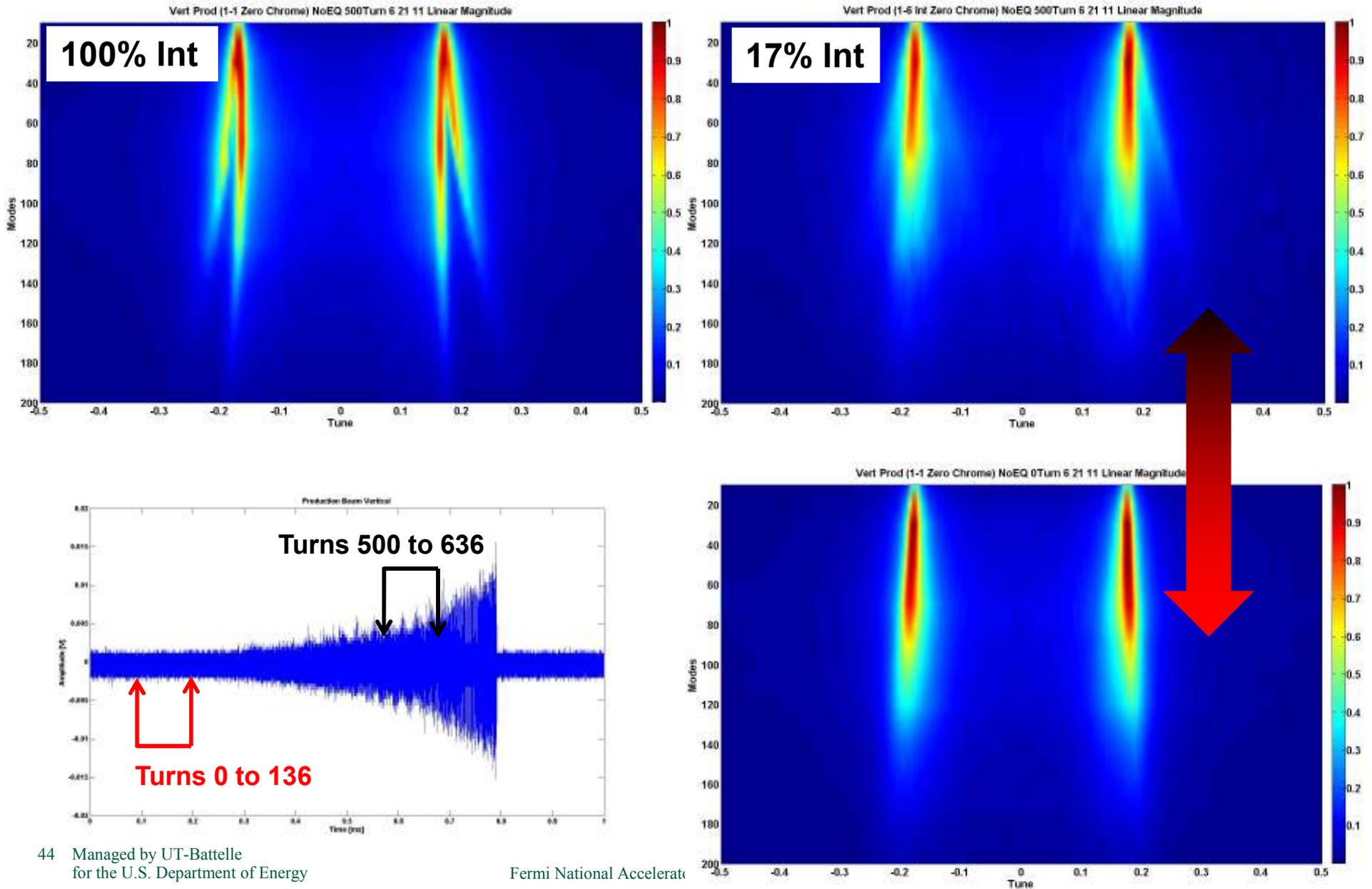
Note: 720 Turns
of
Accumulation



What happens when we shift our observation time to later in the accumulation cycle?

- During accumulation the beam dynamics become very complex.
- To determine if the beam intensity was the root cause, experiments were performed by varying the number of pulses accumulated.
- If the intensity is the primary cause it could lead to additional problems as SNS continues to increase toward the design goal as well as interfere with the ability to damp instabilities.

Variation in beam intensity accounts for majority of BTF splitting.



Summary and Conclusions

- **Feedback damper system is effective.**
 - Continually trying to improve its effectiveness.
- **Beam Transfer Function measurements are a useful tool for monitoring beam dynamics and parameters.**
 - Can be used as an additional physics diagnostic system to measure the tune and chromaticity. (Verified)
 - Illuminates unique dynamics that have not been observed before (to our knowledge).

Once Again... Many Thanks Go To:

- **Craig Deibele, Sasha Aleksandrov, Slava Danilov, Andy Webster, Jeff Bryan, Jim Diamond, George Link, Syd Murray III**

Without them, none of this work would be possible!

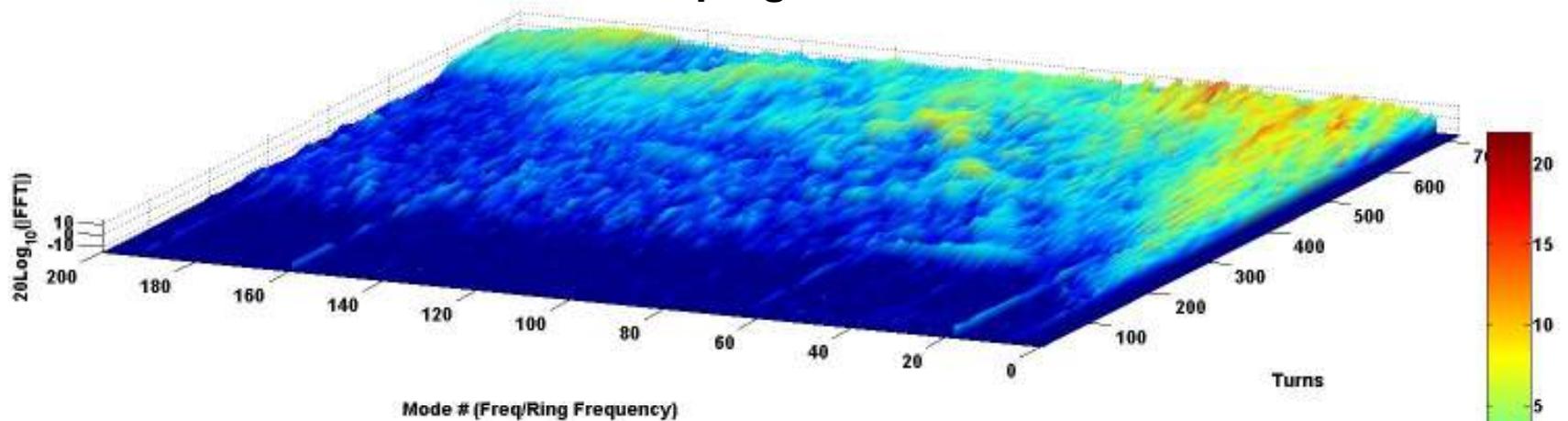
- **You... For giving me the opportunity to be here today!**

Download Completed... Begin The Questions.

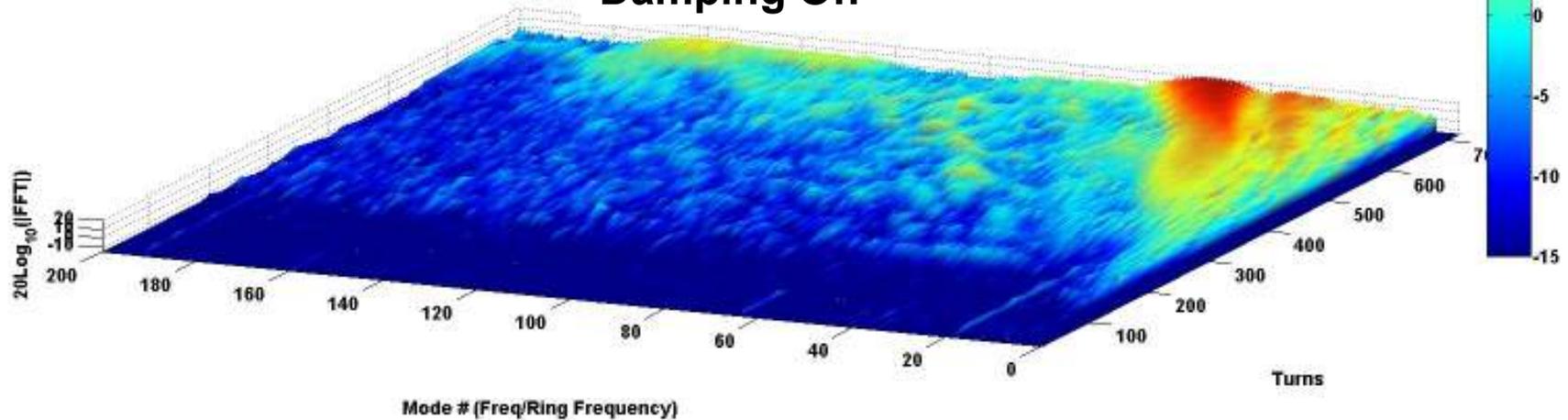


Vertical Production (~815 kW to target)

Damping On

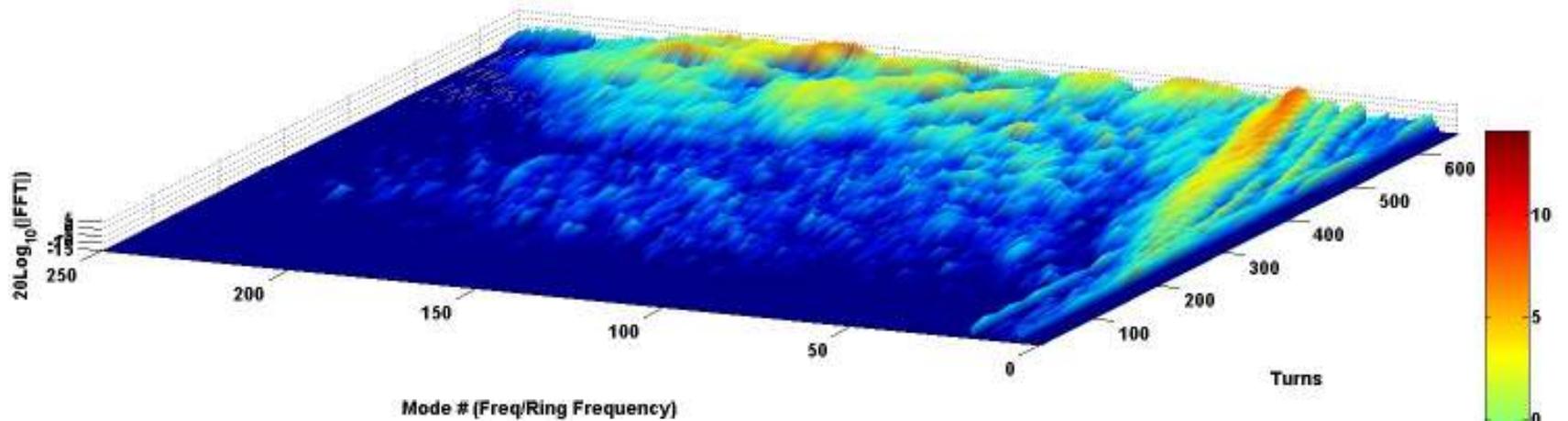


Damping Off

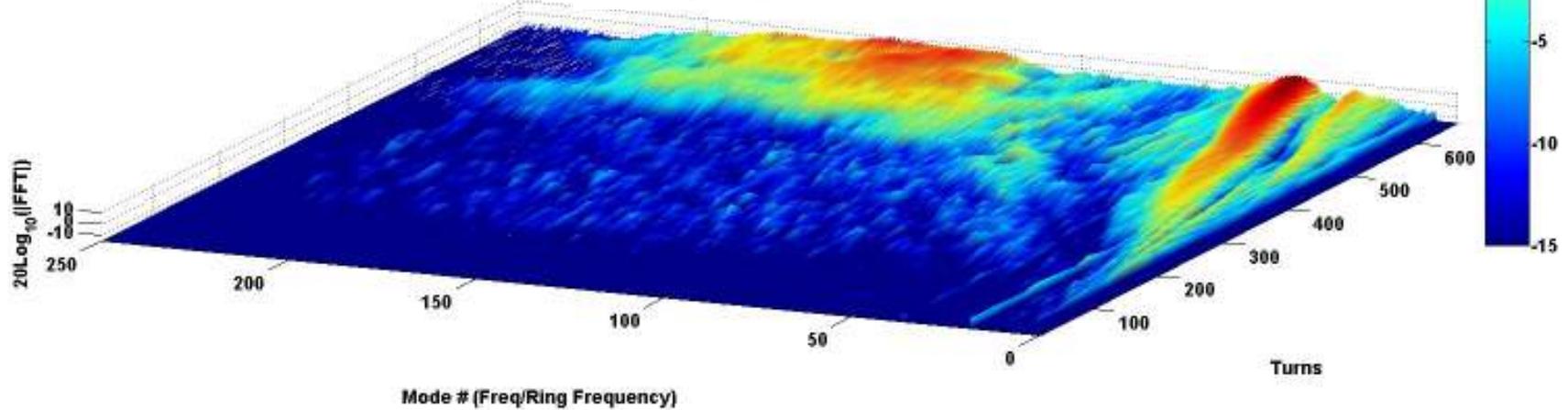


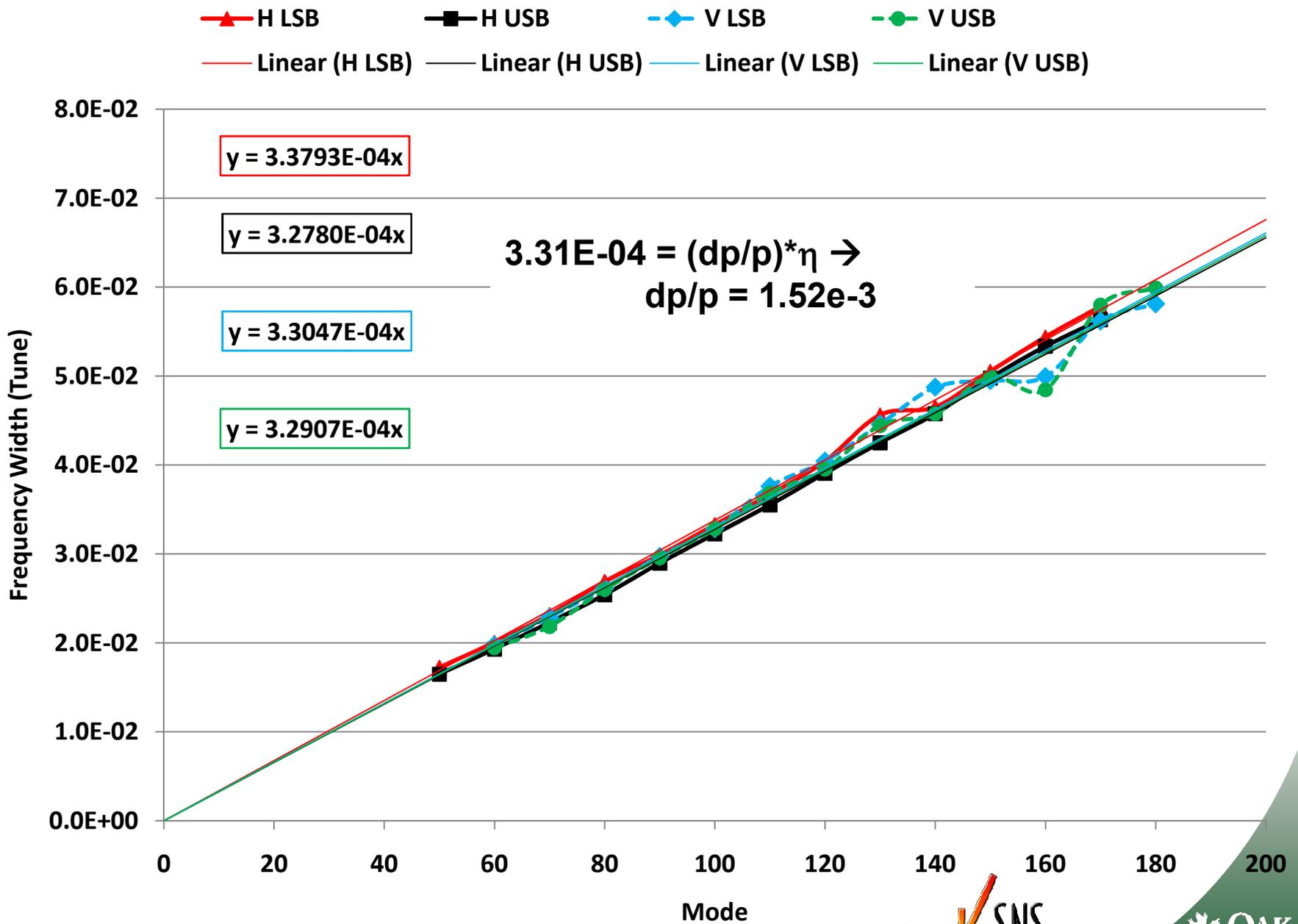
Horizontal Production (~815 kW to target)

Damping On

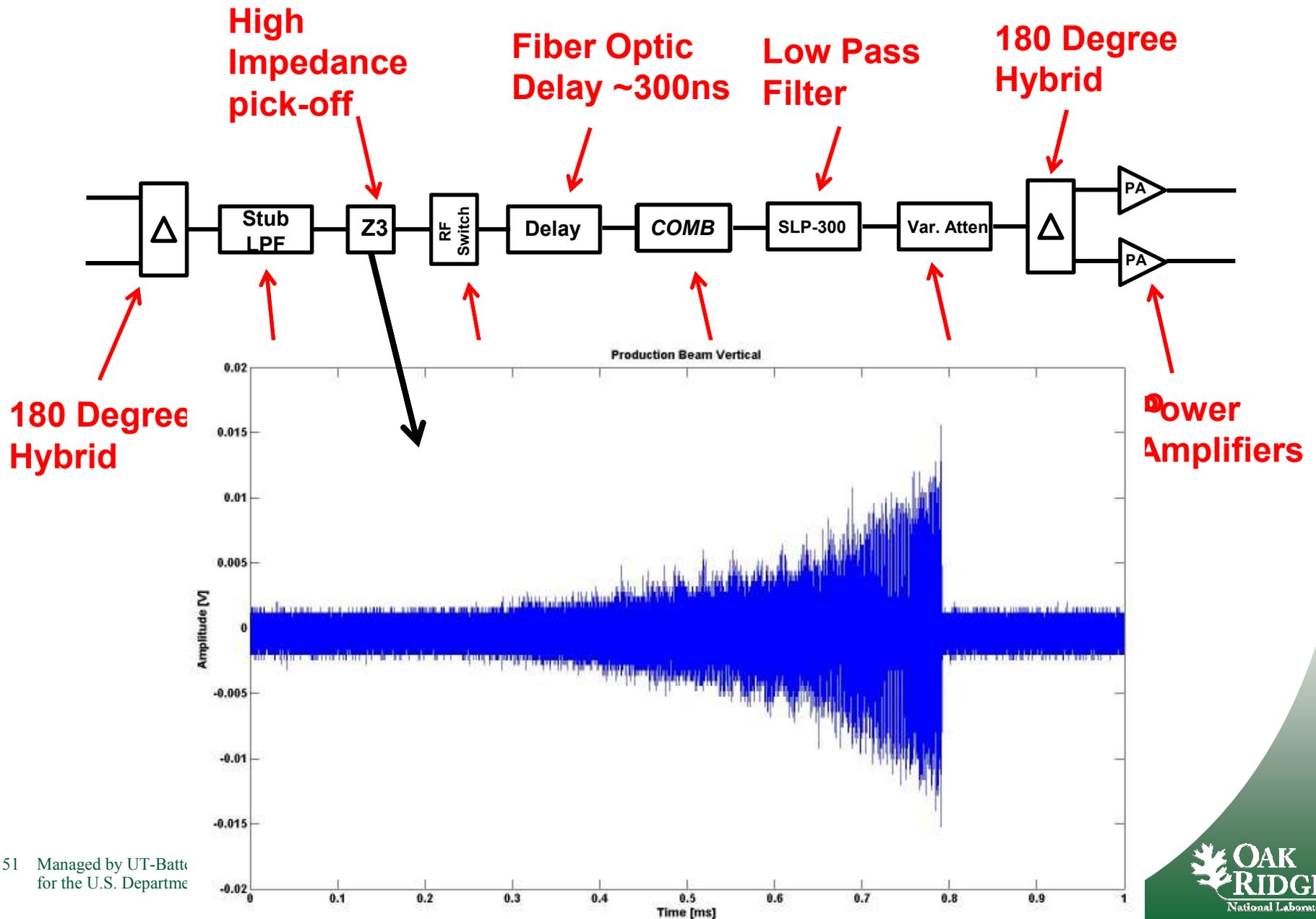


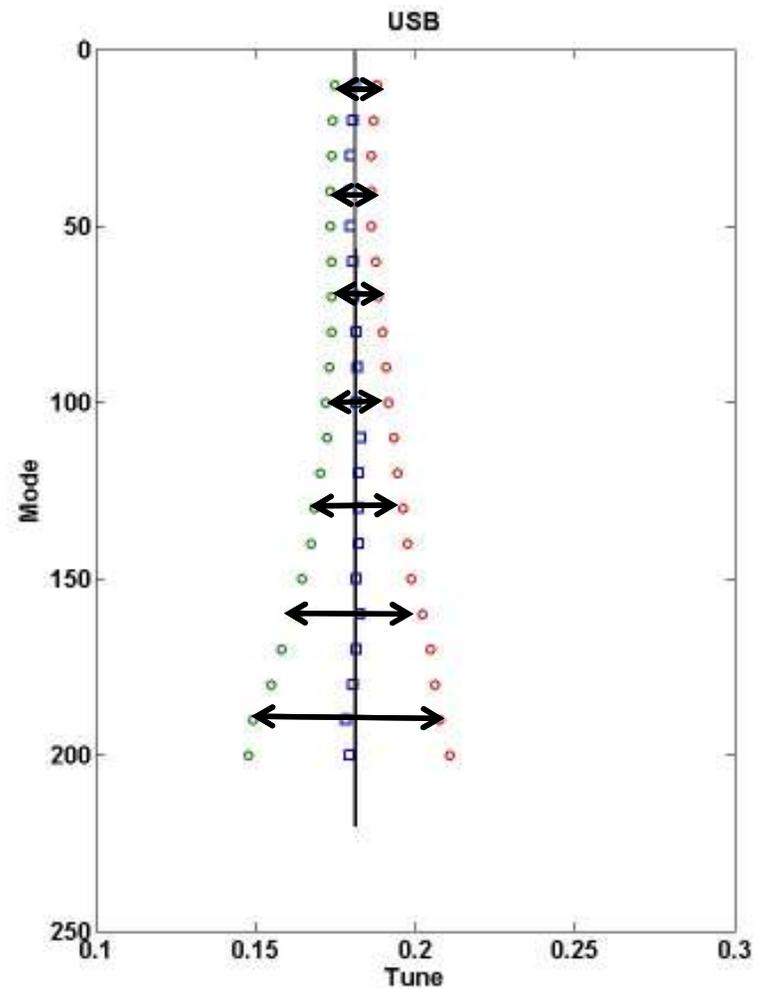
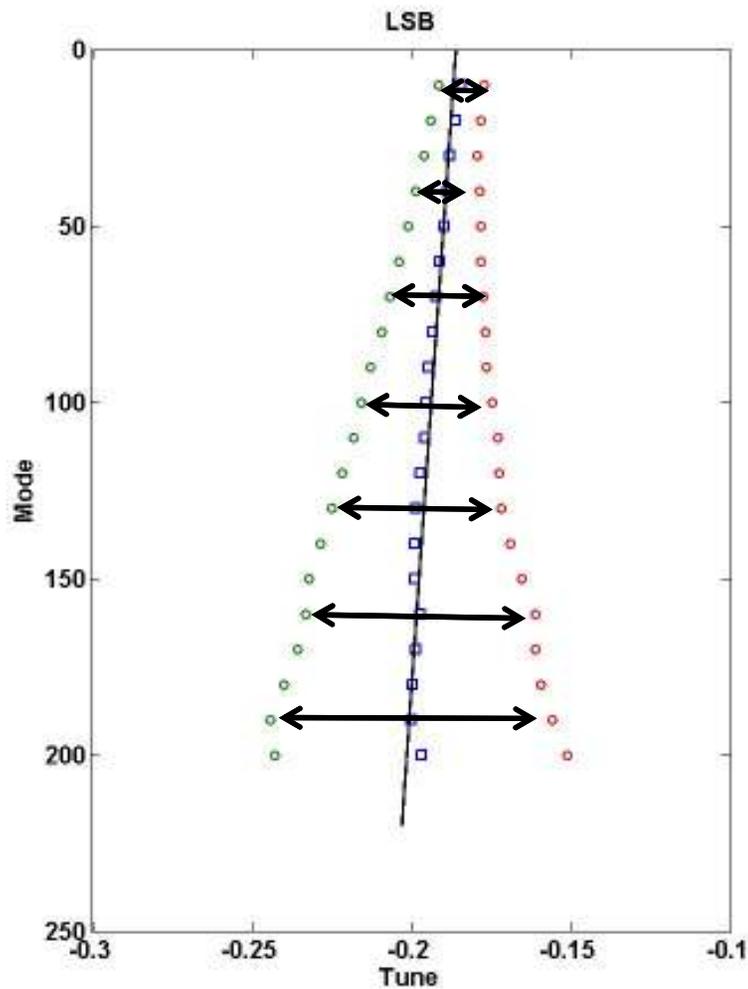
Damping Off





Ring damper system overview (2)





BTFs can also be used to measure the Chromaticity (tune spread) and dp/p (momentum spread) via the frequency spread about the response peaks.