TWIICE 2014
Topical Workshop on Instabilities, Impedances and Collective Effects
Synchrotron SOLEIL, 16-17 January 2014

Simulation of high bandwidth feedback systems

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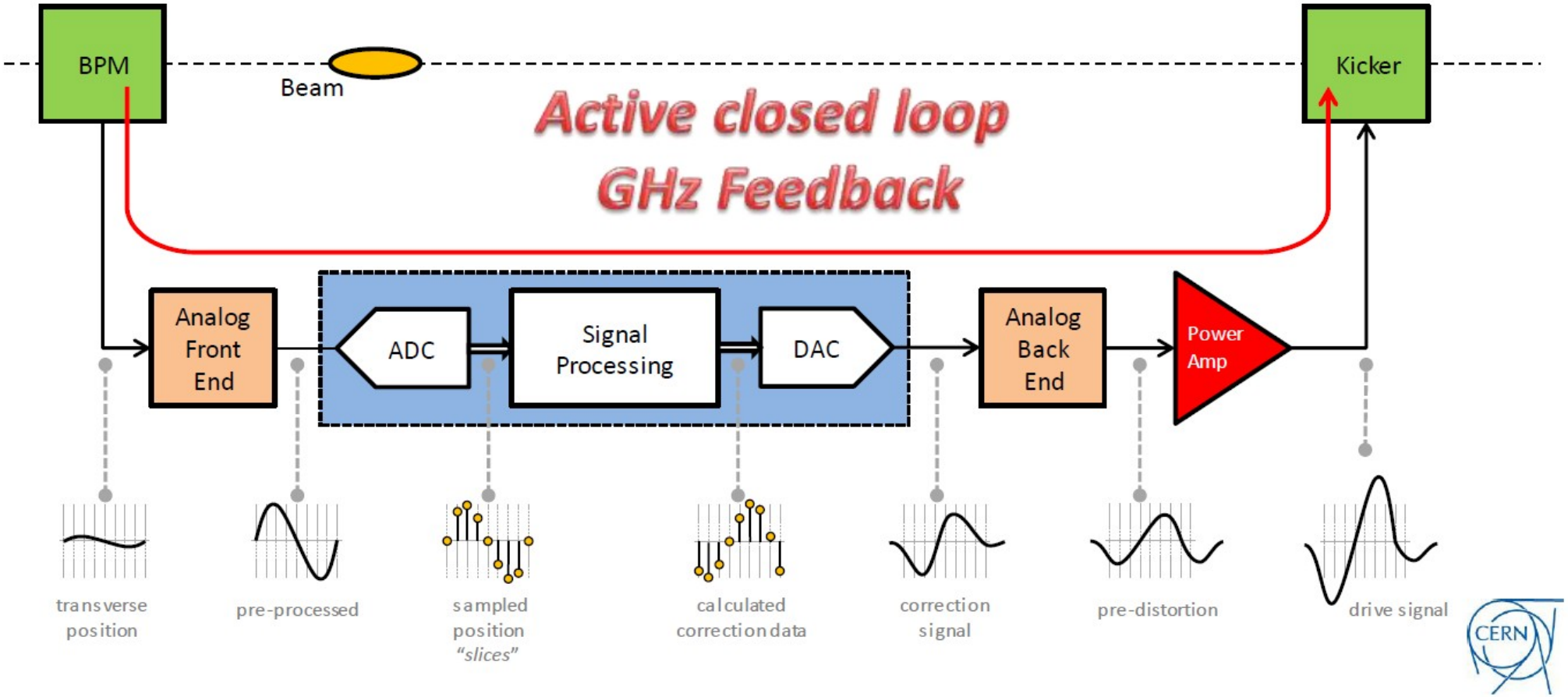
CERN

SLAC NATIONAL ACCELERATOR LABORATORY

- Feedback system
  - Basic concept – drawing – bandwidth
- Feedback parameters
  - Bandwidth – consequences
  - Other parameters – filters – consequences
- Numerical feedback model
- Feedback examples

Sketched feedback systems

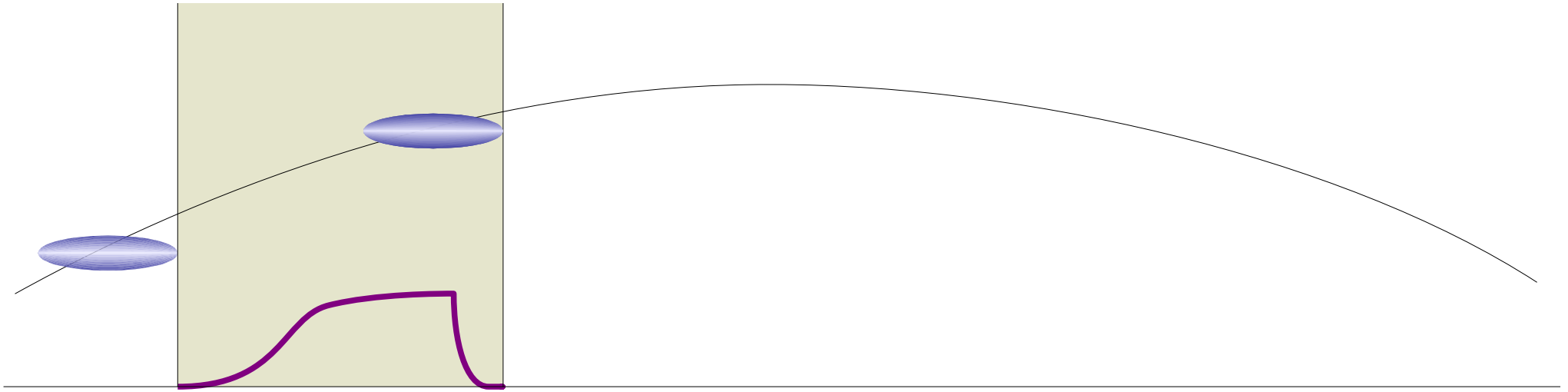
Principle of a feedback system



W. Höfle

How does bandwidth play a role?

Bunch-by-bunch damper

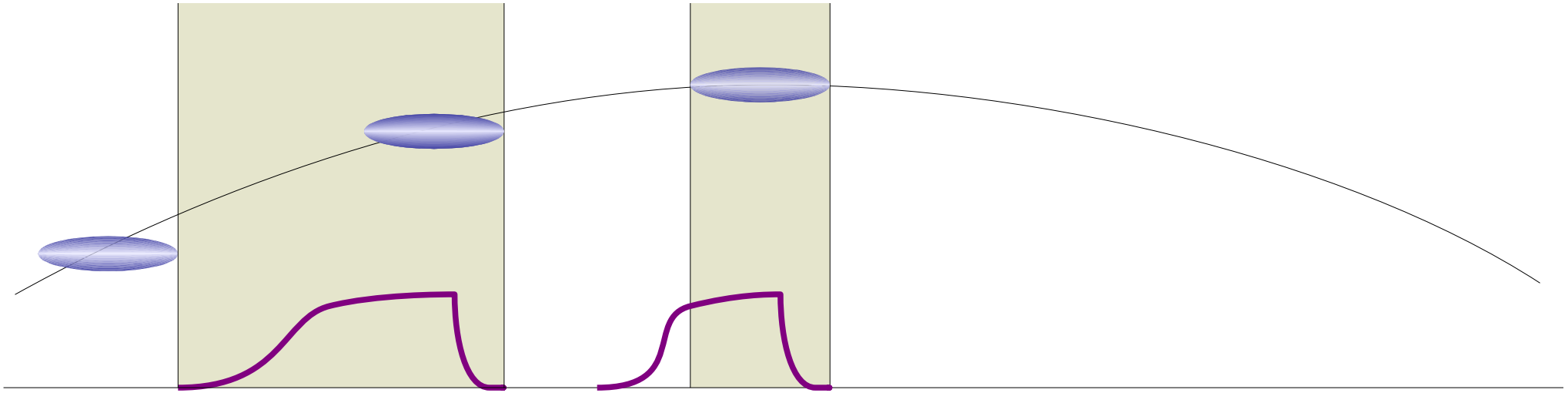


25 ns

40 MHz

How does bandwidth play a role?

Bunch-by-bunch damper

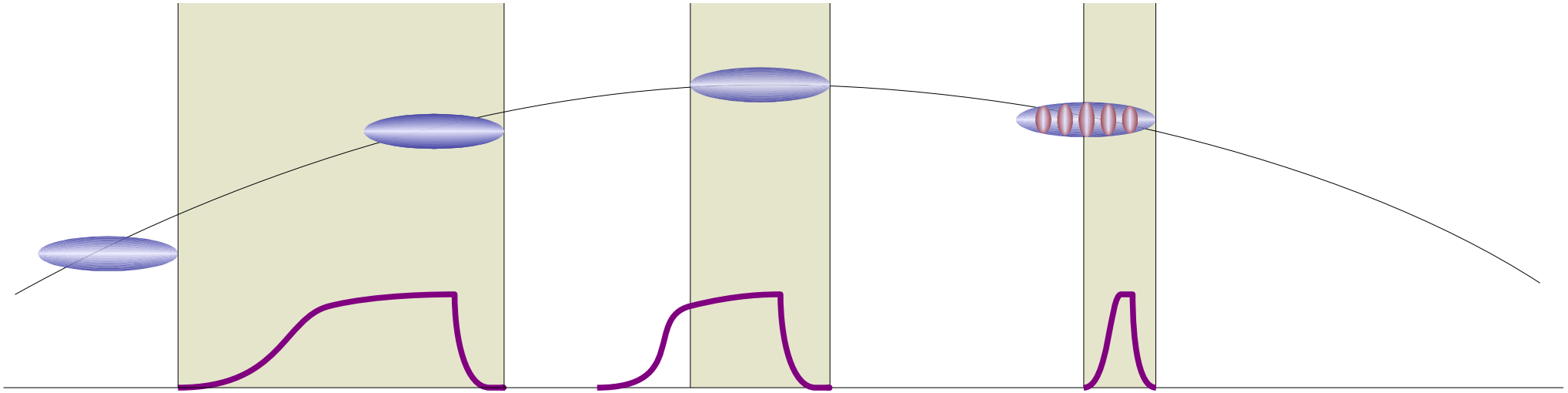


25 ns	12.5 ns
40 MHz	80 MHz

How does bandwidth play a role?

Bunch-by-bunch damper

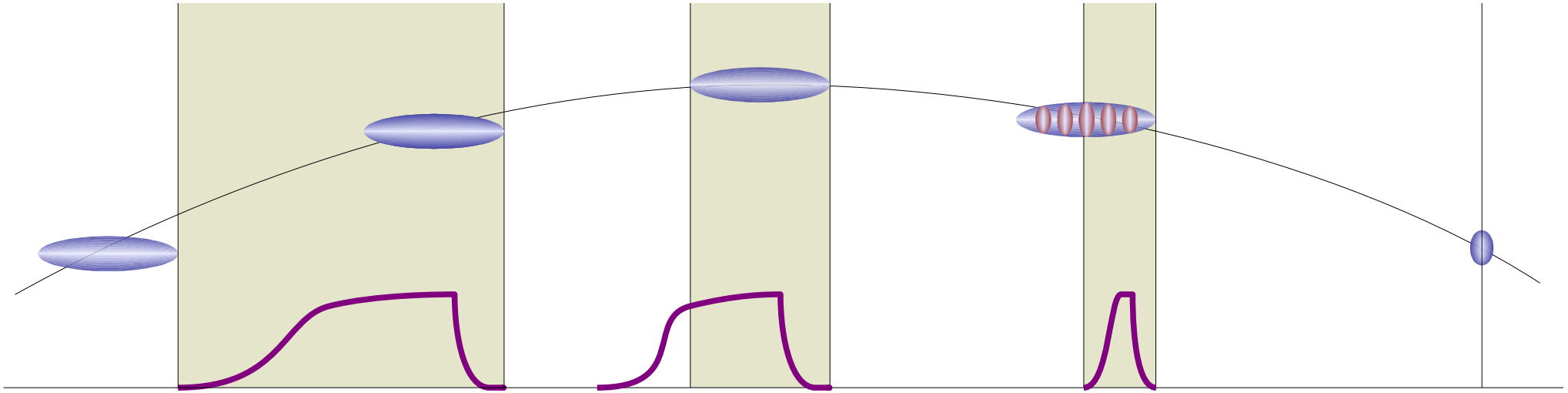
Intra-bunch-feedback



25 ns	12.5 ns	3 ns
40 MHz	80 MHz	350 MHz

How does bandwidth play a role?

Bunch-by-bunch damper | Intra-bunch-feedback | Lepton machines



25 ns	12.5 ns	3 ns	0.5 ns / 21 ps
40 MHz	80 MHz	350 MHz	2 GHz / 50 GHz

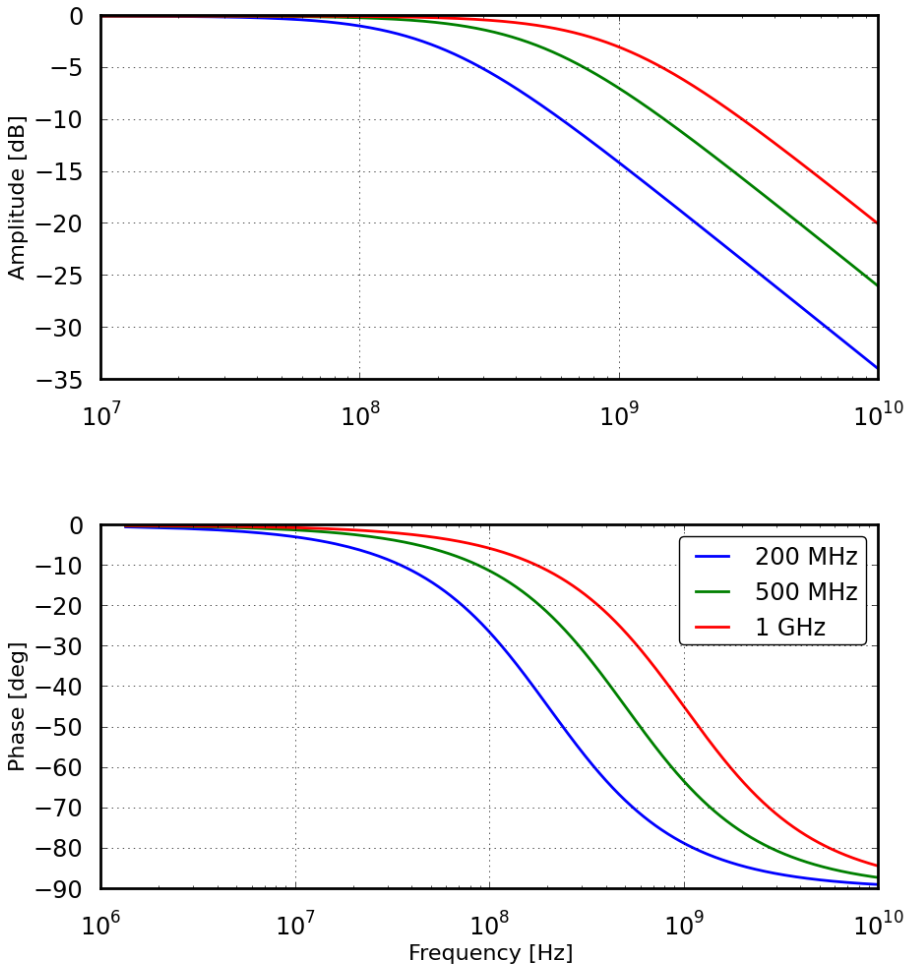
Realistic feedback systems

Bandwidth limitations

- A realistic feedback system is bandwidth limited
- As a result, the amplitude and phase responses are not flat
- Take for example a first-order low-pass filter with a one-pole roll-off:

$$H(f) = \frac{1}{1 + i\,\frac{f}{f_c}},$$

resulting in the following amplitude and phase response



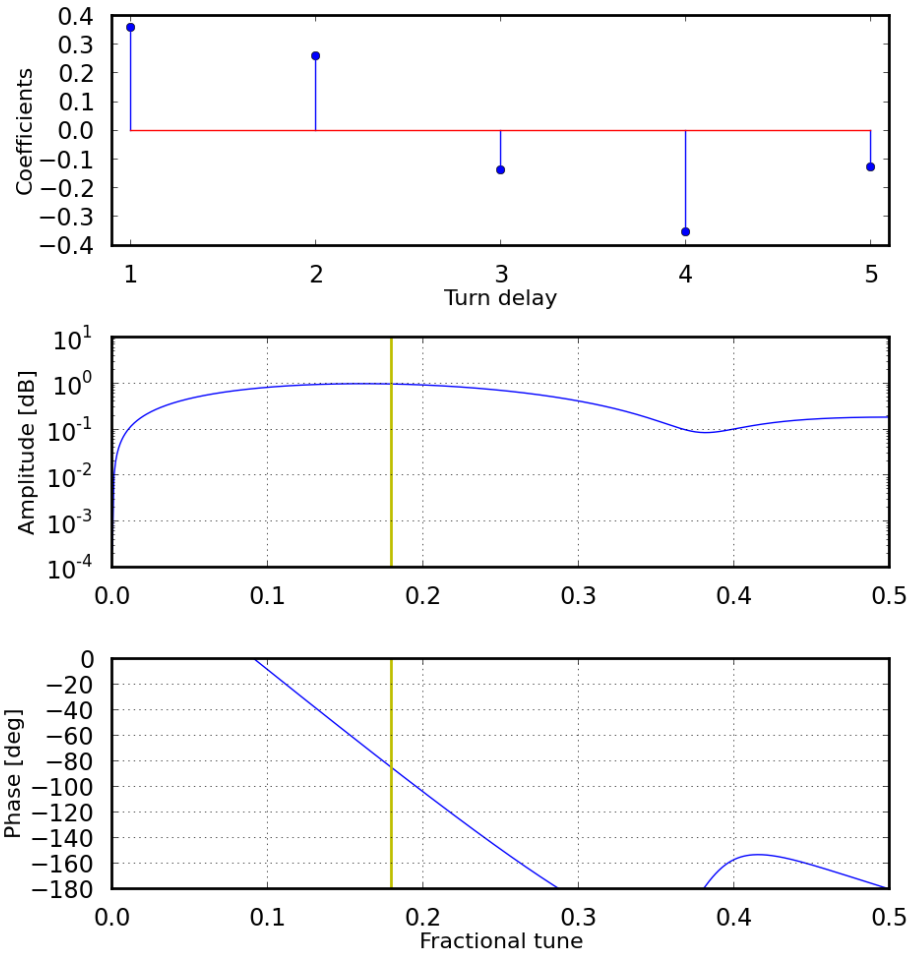
Filter design

- Realistic feedback systems often incorporate DSP filters
  - Correct for phase errors
  - Provide some means of noise filtering
- Take for example an N-taps FIR filter

$$H(z) = \sum_{n=0}^{\text{N-taps}} b_n \, z^{-n}$$

maximum amplitude response and 90 deg neg. phase shift at the fract. tune

5-tap FIR filter assuming a fractional tune at 0.18



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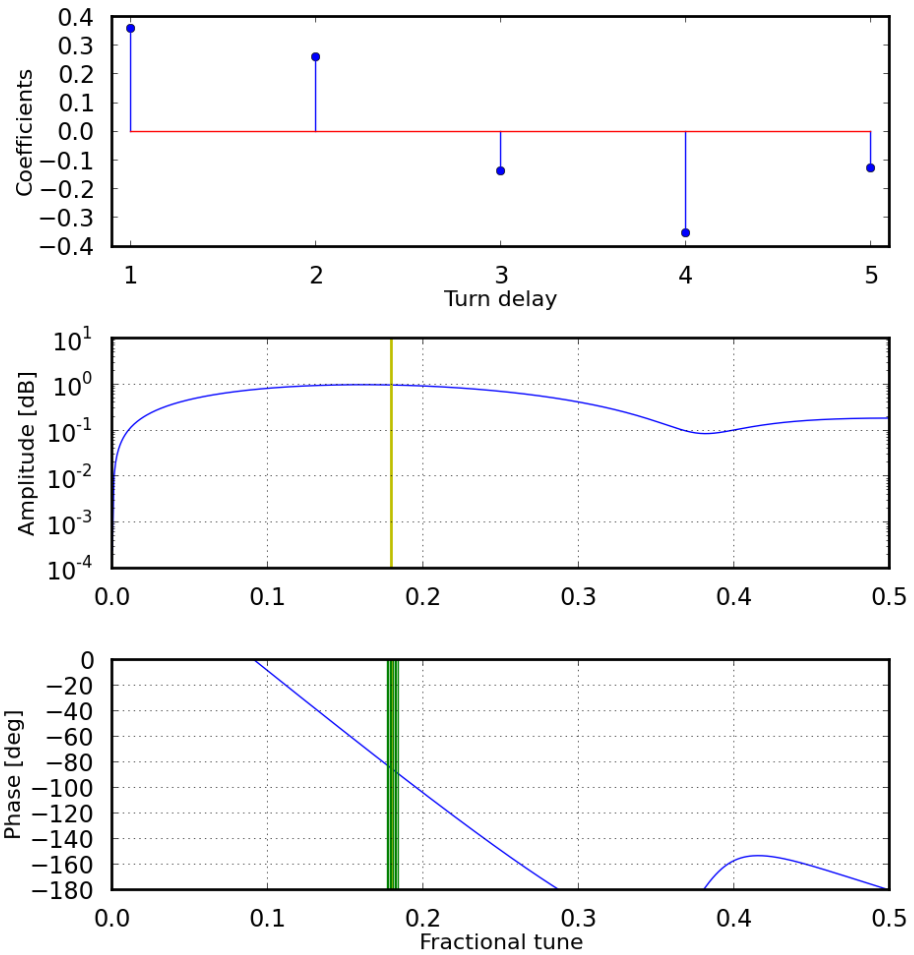
→ well matched for low Qs synchrotron sidebands

5-tap FIR filter assuming a fractional tune at 0.18
Qs = 0.001



Filter design

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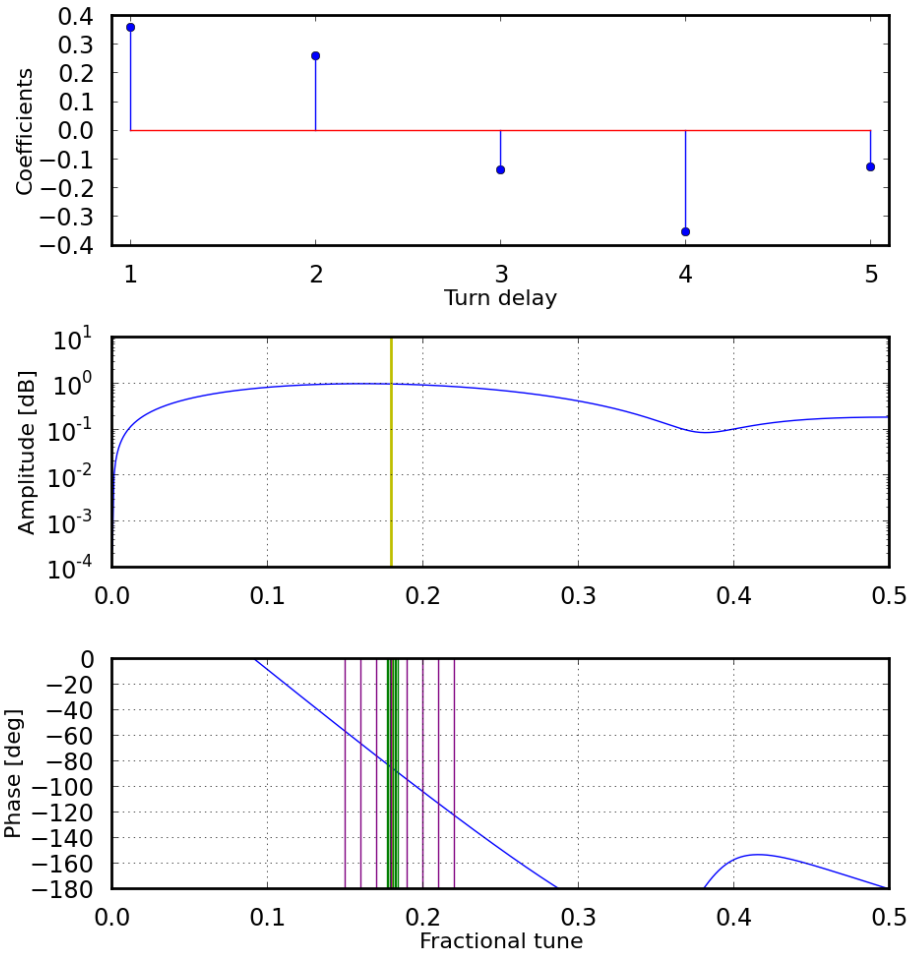
  - Provide some means of noise filtering
- Take for example an N-taps FIR filter

$$H(z) = \sum_{n=0}^{\text{N-taps}} b_n \, z^{-n}$$

maximum amplitude response and 90 deg neg. phase shift at the fract. tune
→ well matched for low Qs synchrotron sidebands
→ a problem for high Qs synchrotron sidebands

5-tap FIR filter assuming a fractional tune at 0.18
Qs = 0.001, Qs = 0.01

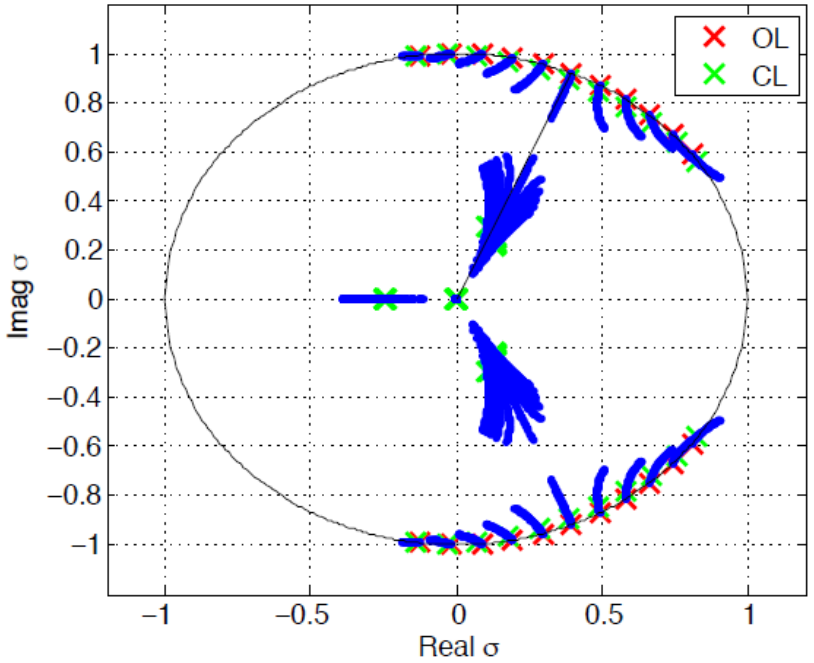


Gain and stability

C. Rivetta
3rd Joint HiLumi LHC – LARP Annual Meeting

Q20 Lattice

- For Q20 Lattice, without including the impedance / e-cloud effects, the reduced model predicts instabilities for side-bands 5-7
  - Using simple 5 TAP FIR filters, no receiver-power stage transfer functions.
  - Close to K. Li results for Q20 lattice using HT to analyze TMCI.
  - Cross check with HT / CMAD without impedances - Validate reduced model



Root Locus - 5 tap FIR - SPS Q20 Lattice

Gain and stability

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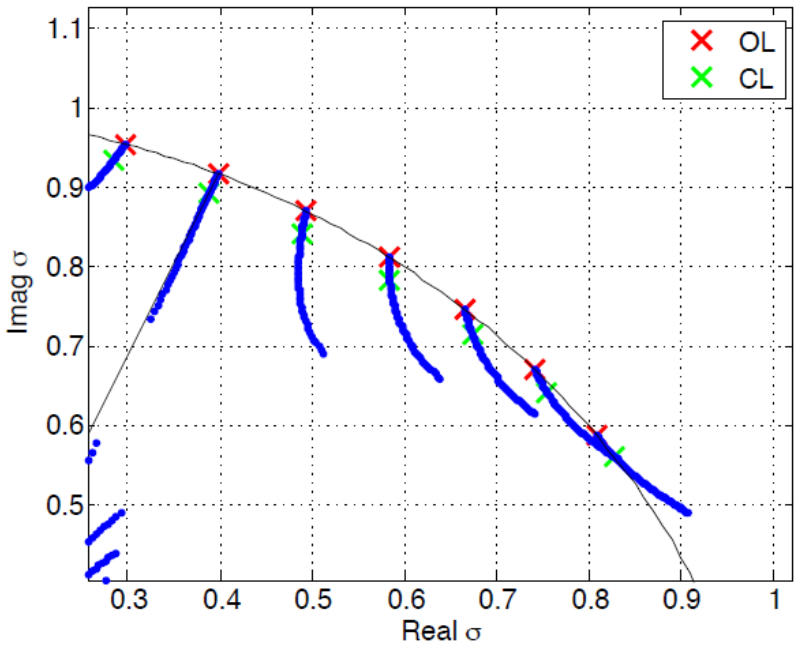
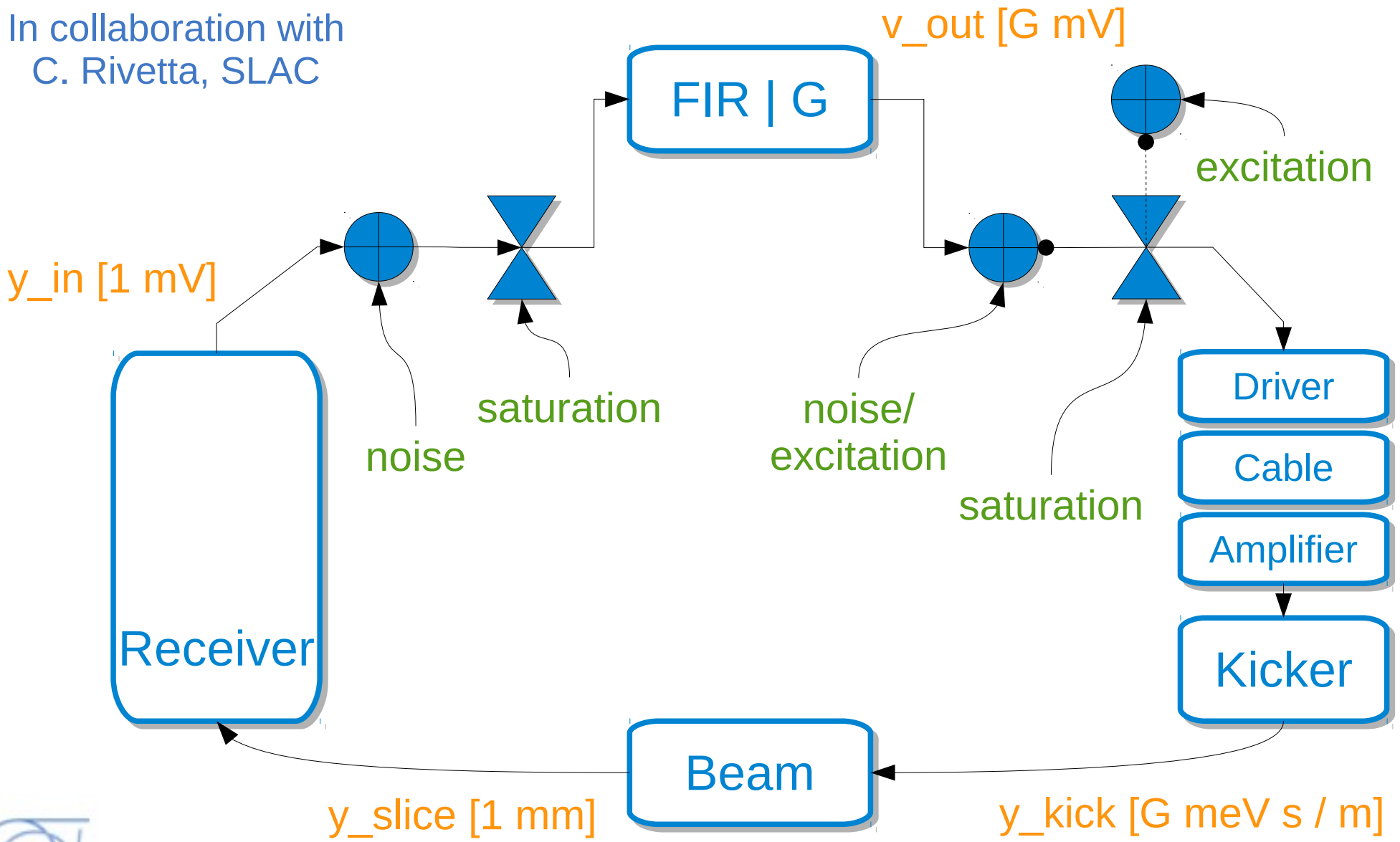


Root Locus - 5 tap FIR - SPS Q20 Lattice

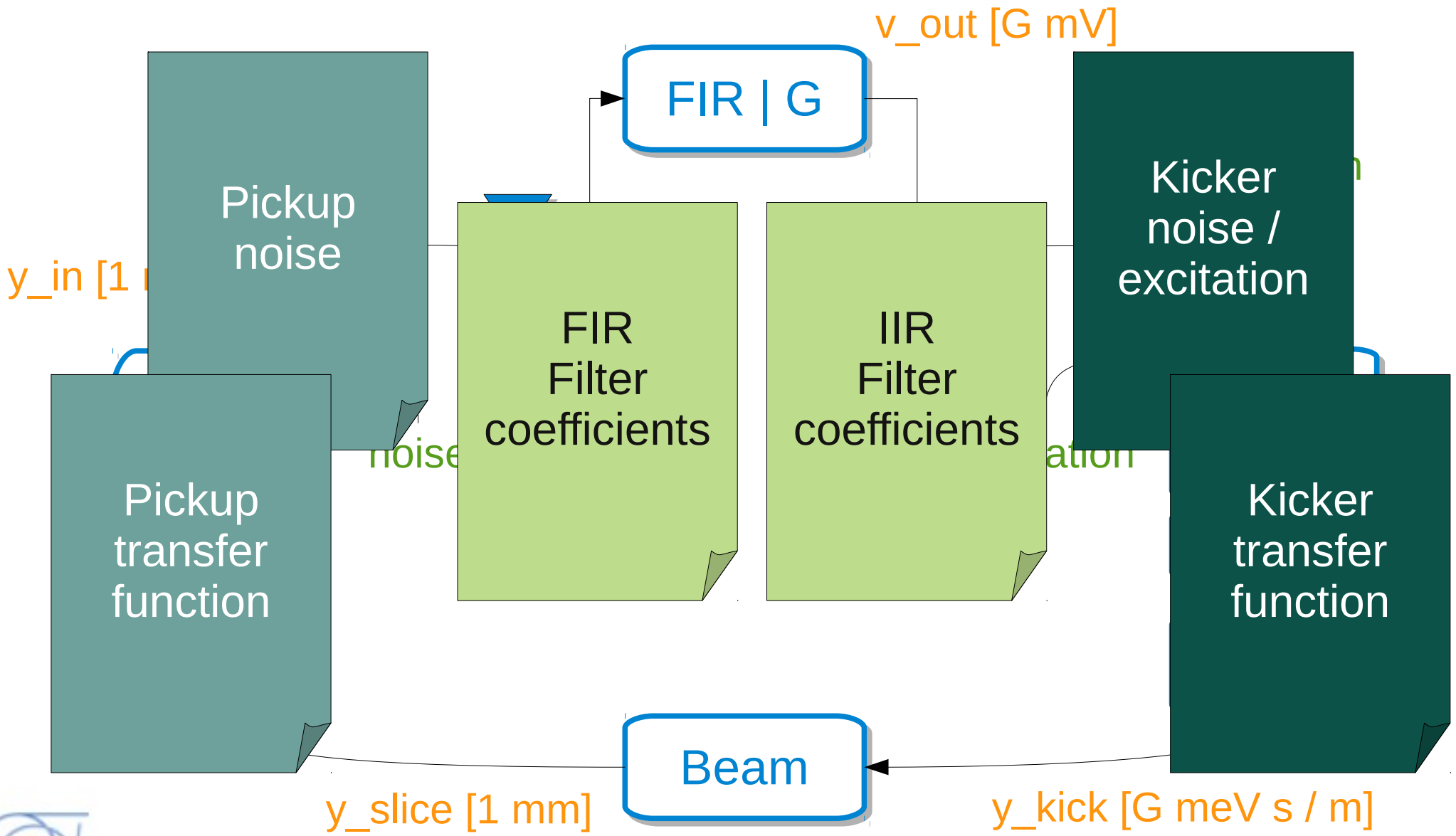
Numerical feedback model

The HeadTail feedback model

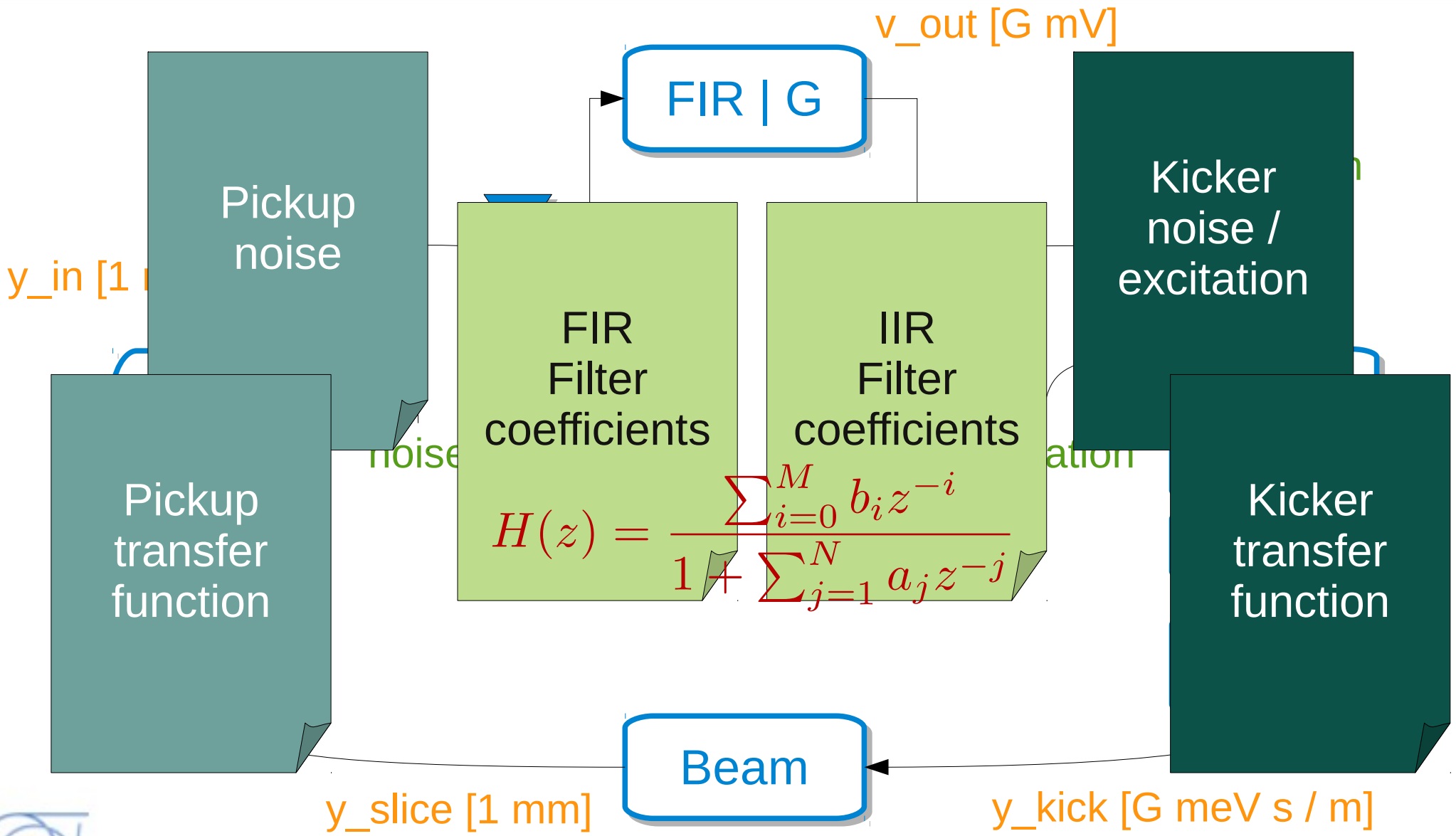
In collaboration with
C. Rivetta, SLAC



The HeadTail feedback model

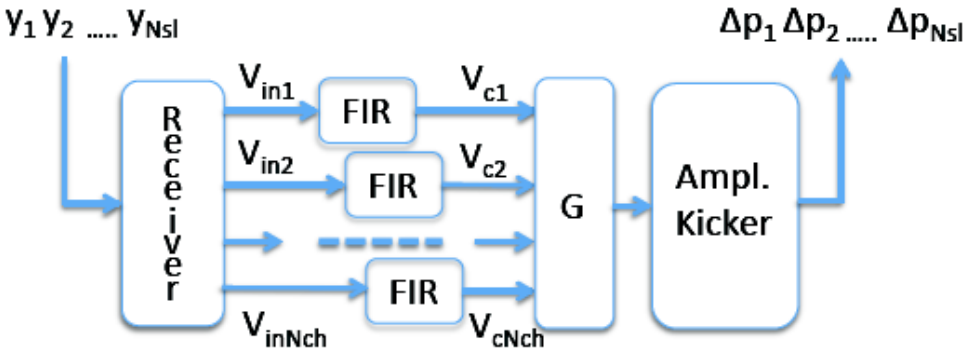


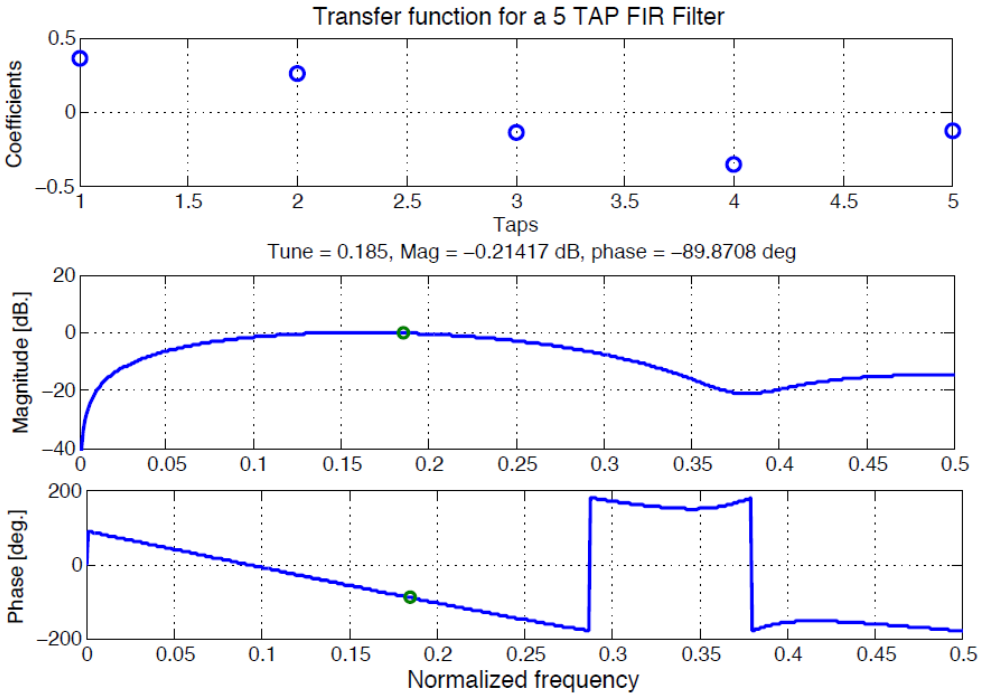
The HeadTail feedback model

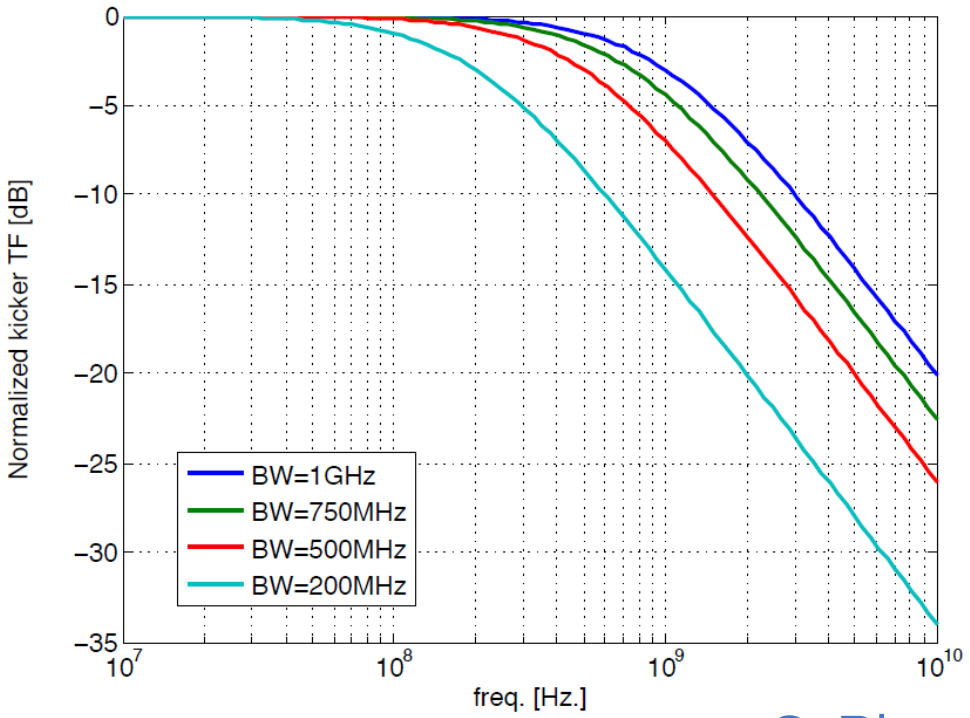


Feedback system - specifications

- 5 tap filter for adjusting the feedback phase
  (phase shift of power amplifiers not compensated, but could be compensated)
- FIR transfer functions (left)
- Kicker transfer functions (right)







C. Rivetta

Transverse mode coupling instabilities

Parameters

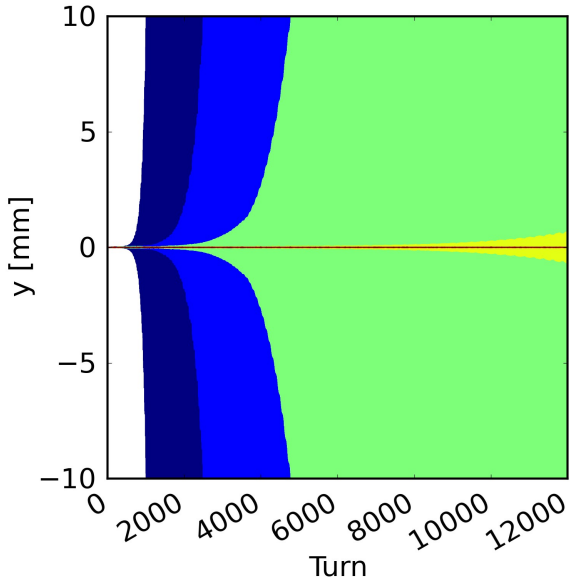
Q26 Optics

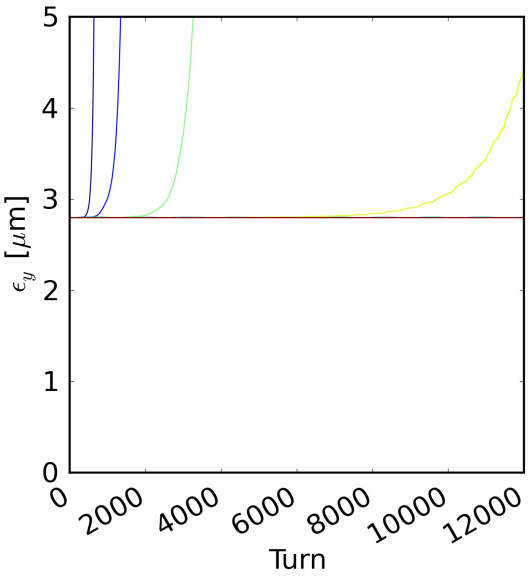
Momentum	26 GeV/c
Emittances [εx, εy, εz]	2.8, 2.8 um, 0.5 eV s
Bunch length	3.2 ns
Beta functions [βx, βy]	42, 42 m
Tunes [Qx, Qy, Qs]	26.13, 26.185, 0.0059
RF voltage	2 MV

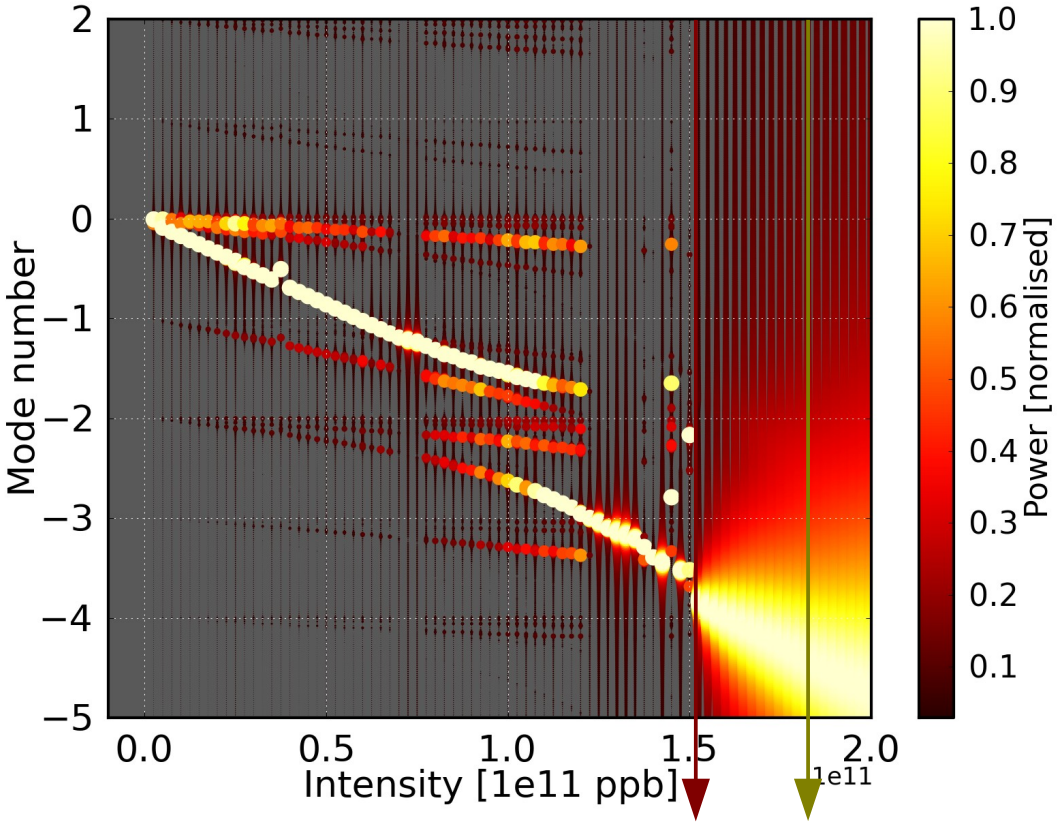
Q20 Optics

Momentum	26 GeV/c
Emittances [εx, εy, εz]	2.5, 2.5 um, 0.5 eV s
Bunch length	3 ns
Beta functions [βx, βy]	56.4, 56.4 m
Tunes [Qx, Qy, Qs]	20.13, 20.185, 0.0170
RF voltage	5.75 MV

TMCI threshold – Q26



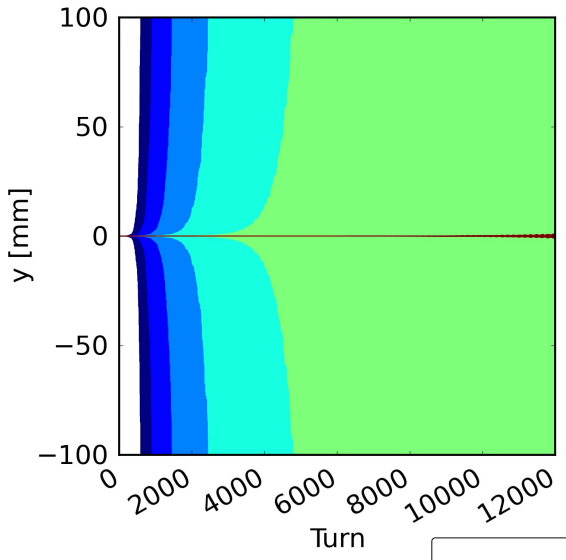


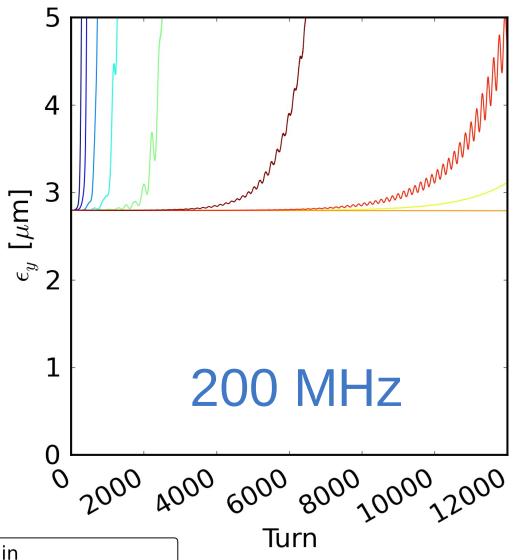


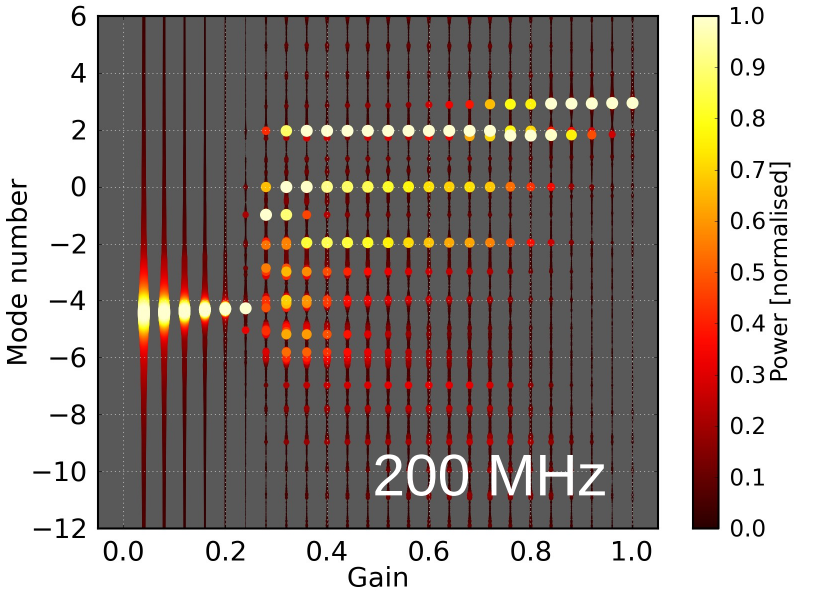
~ 1.5e11

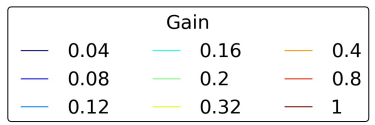
1.6e+11
1.525e+11
1.45e+11
1.375e+11
1.3e+11
1.225e+11
1.15e+11
1.075e+11
1e+11

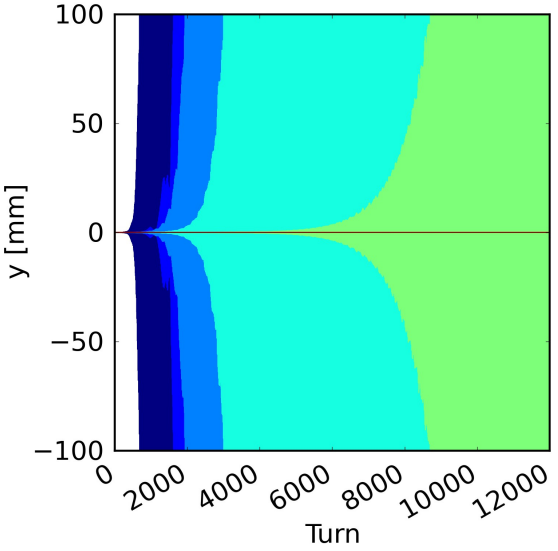
Q26 – I = 1.8e11 – gain scan

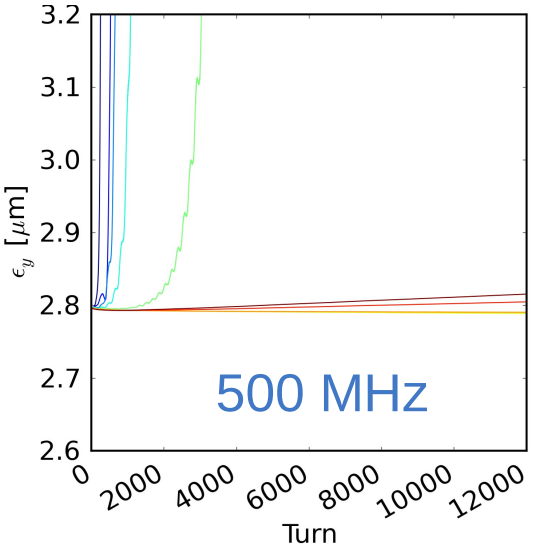


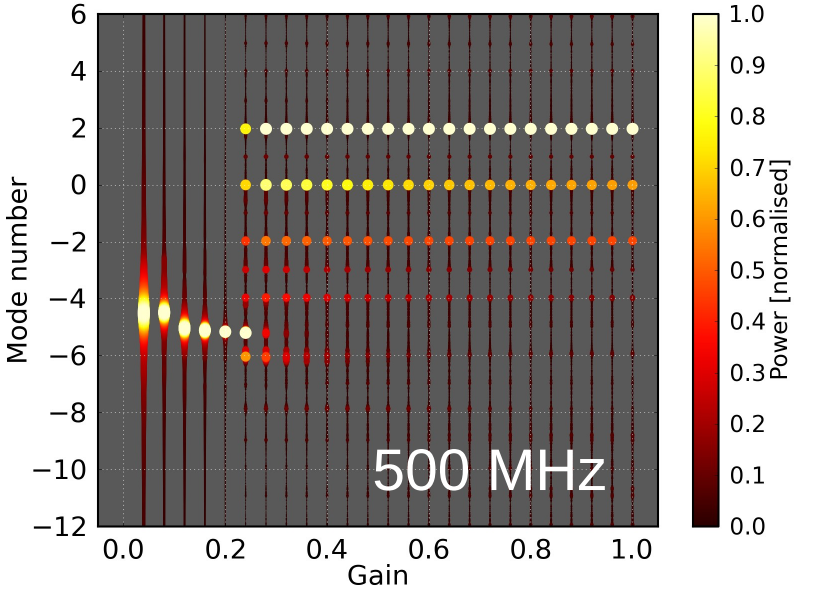




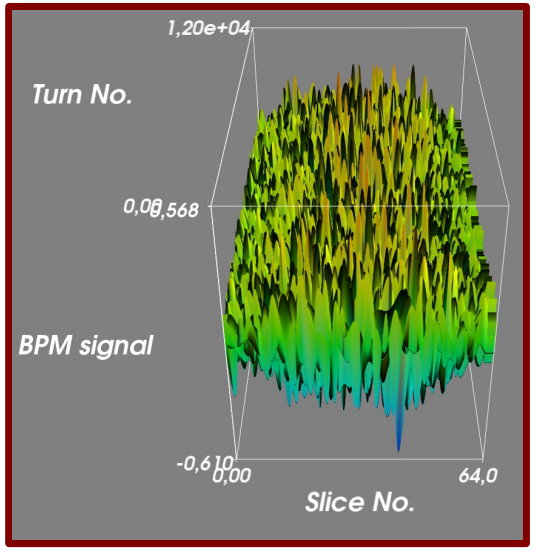


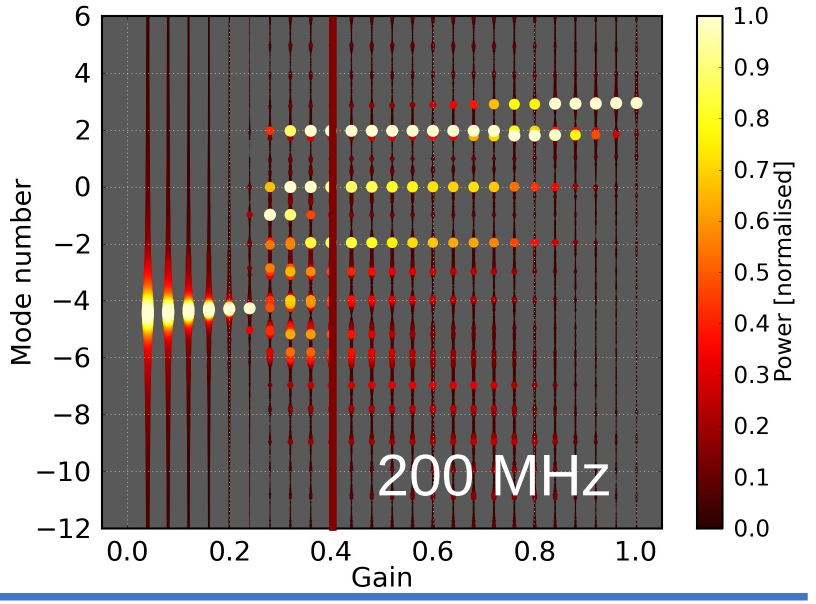


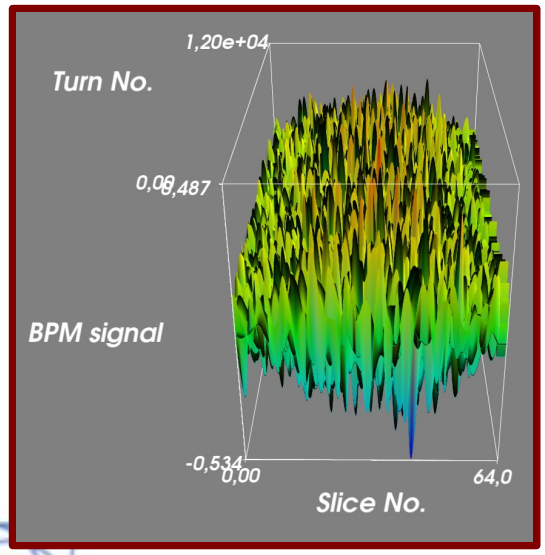


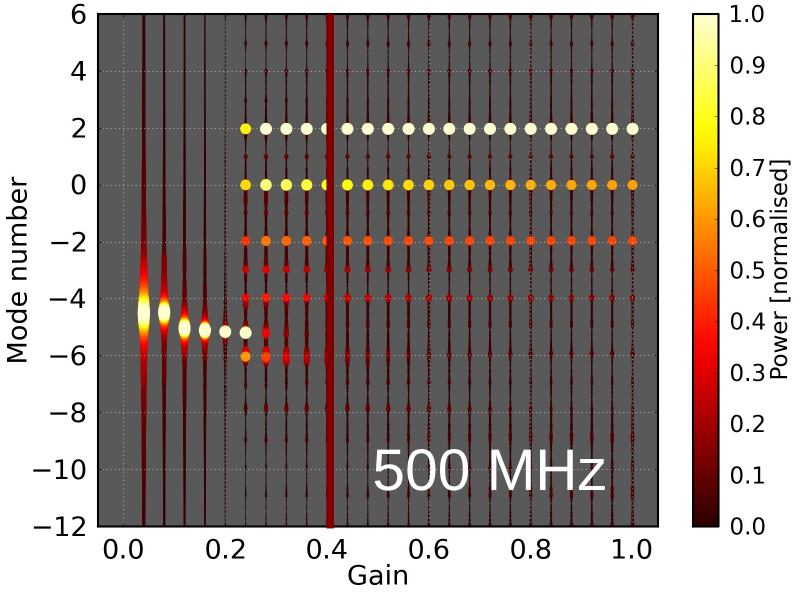


Q26 – I = 1.8e11 – gain scan









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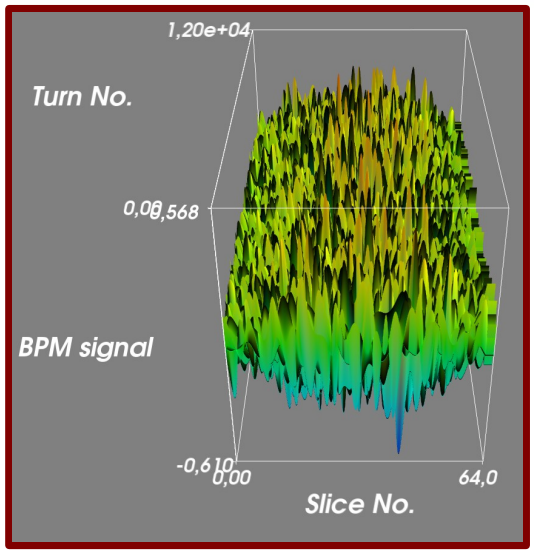
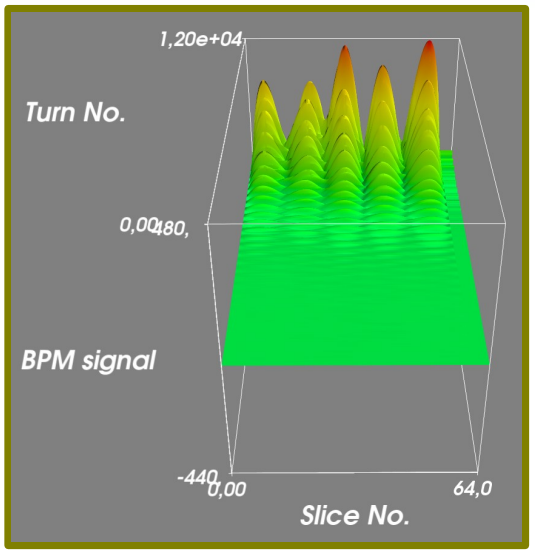
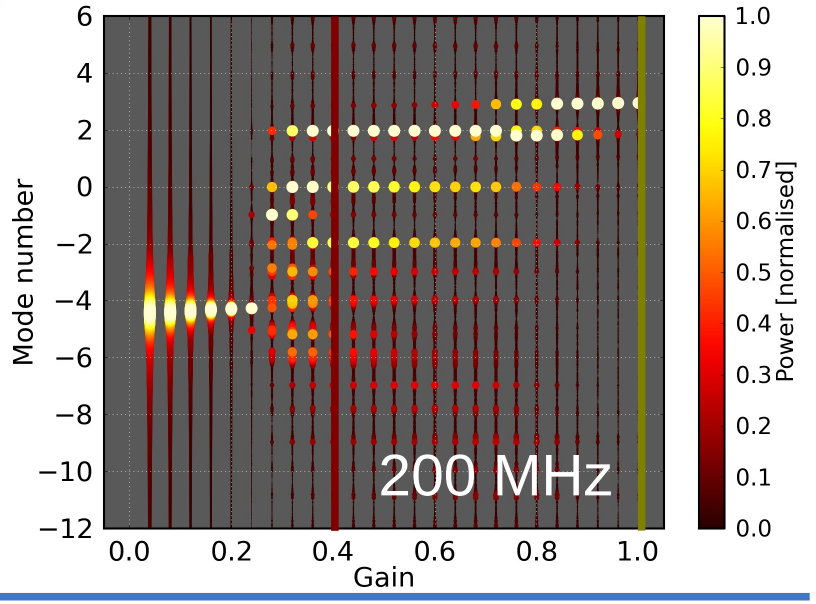
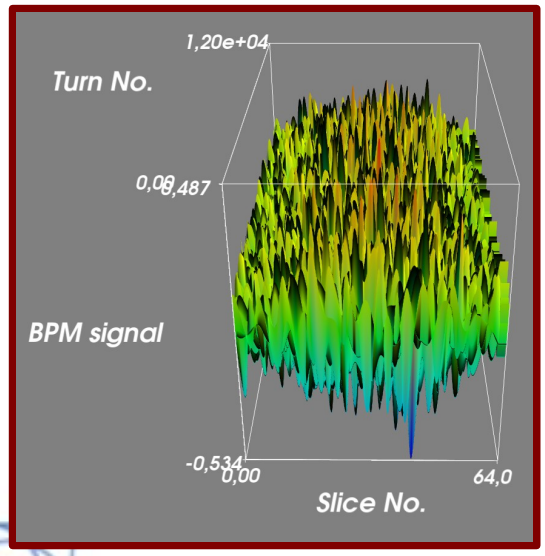
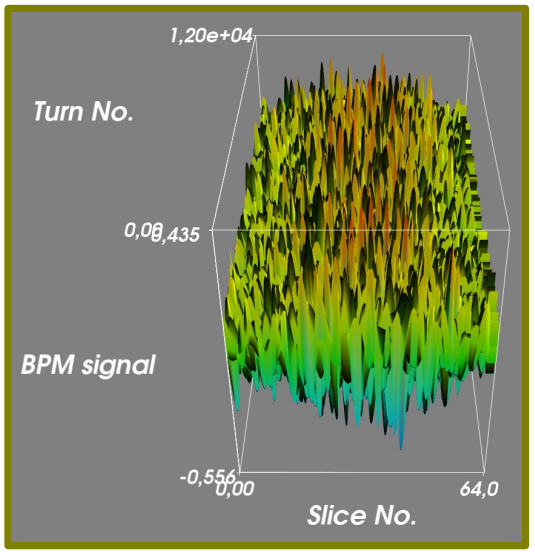
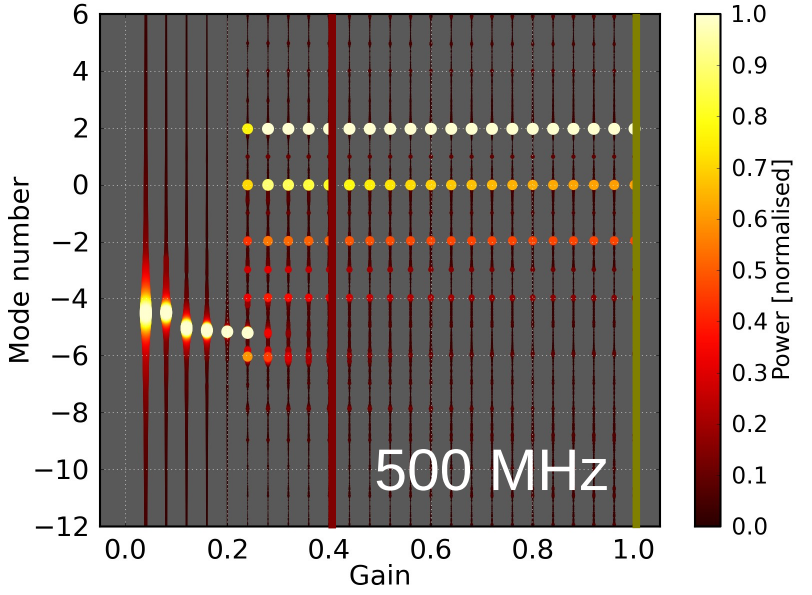




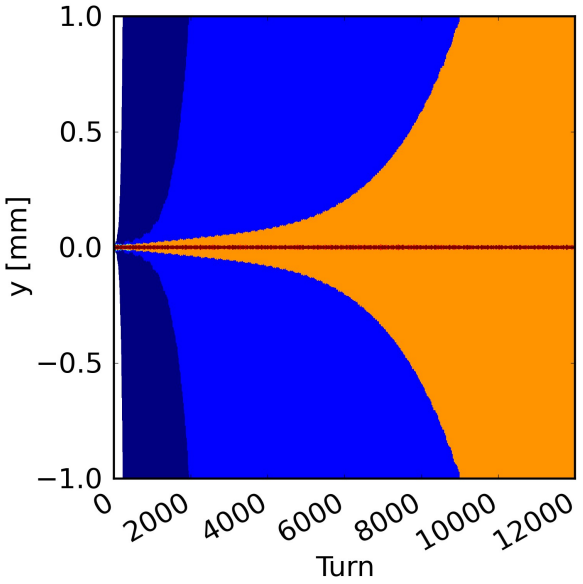


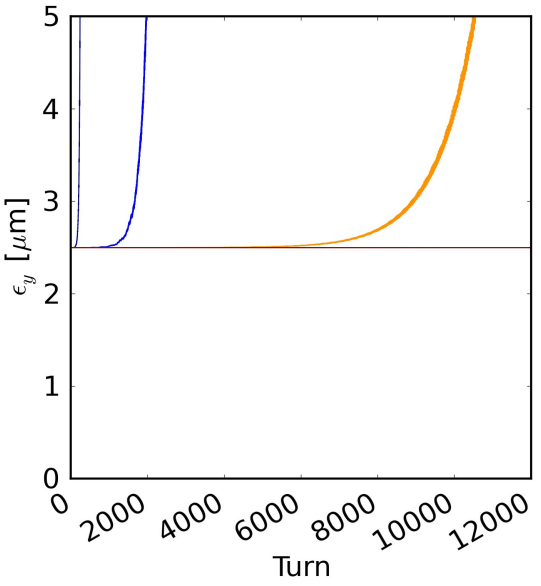


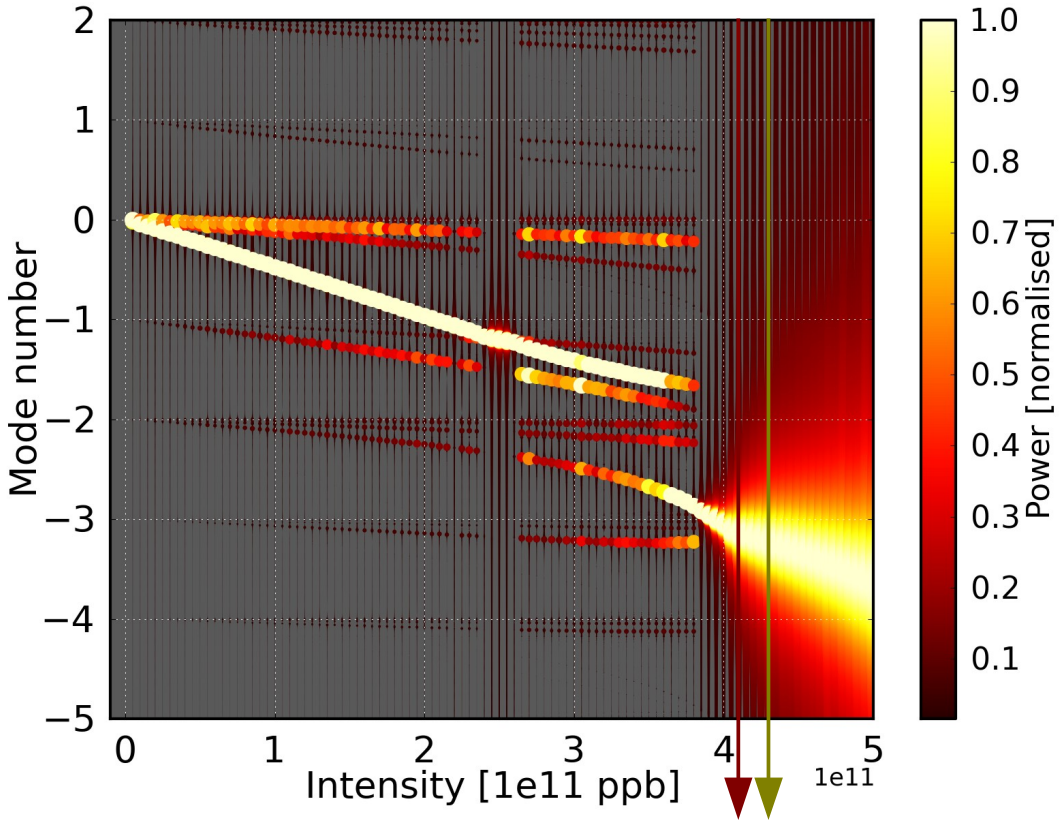




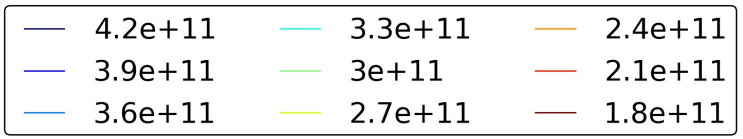
TMCI threshold – Q20



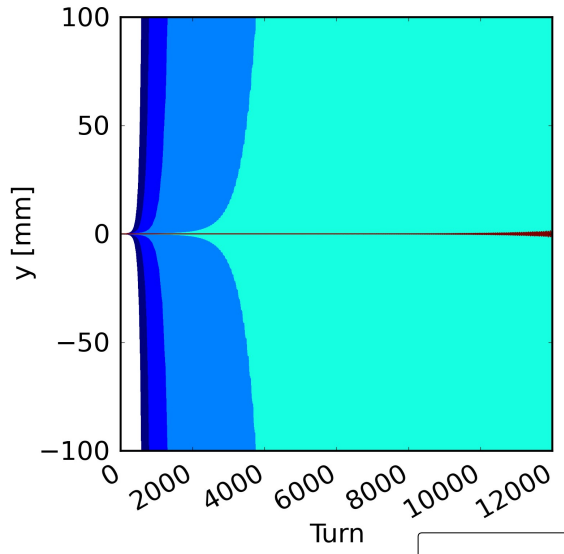


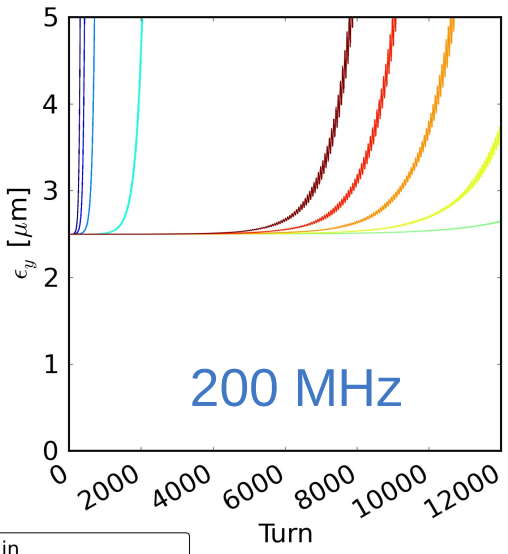


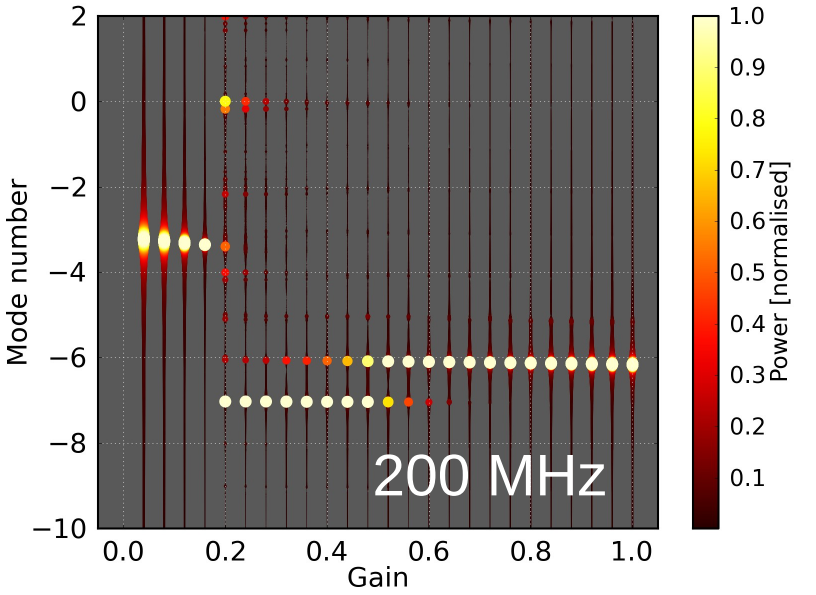
~ 4e11

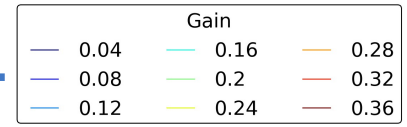


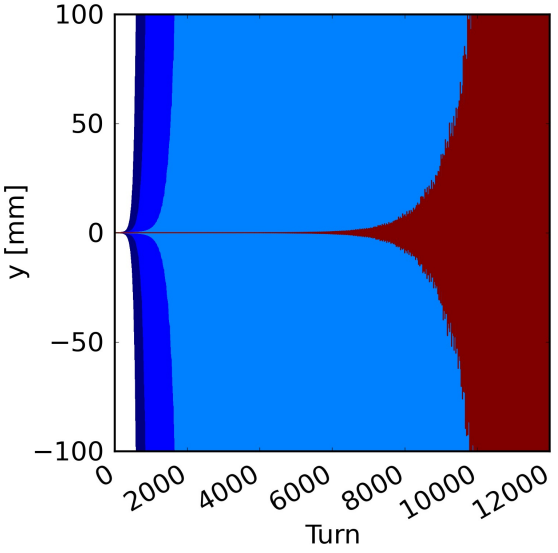
Q20 – I = 4.2e11 – gain scan

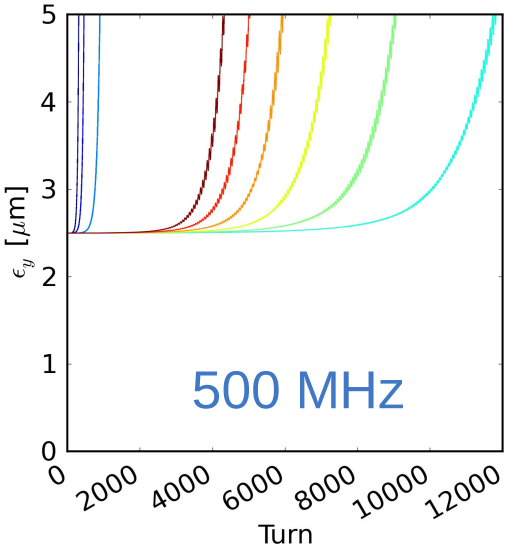


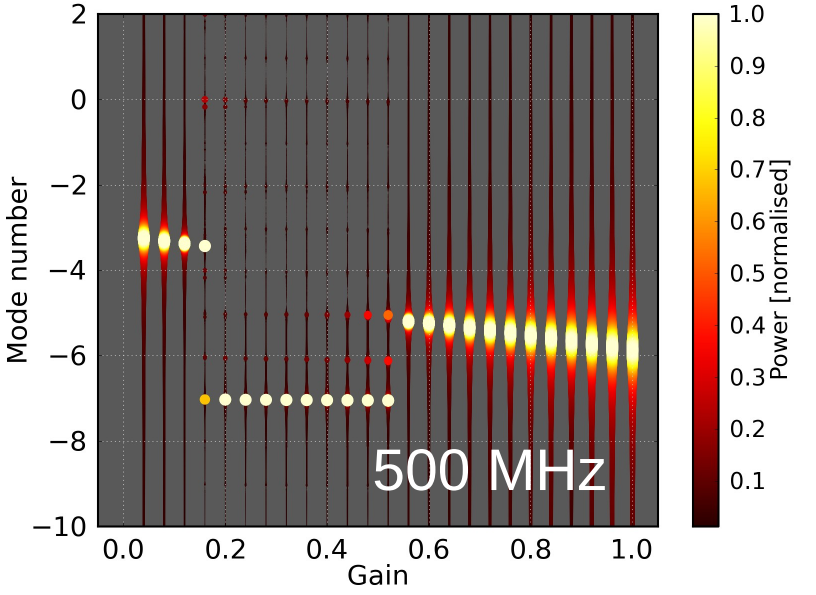




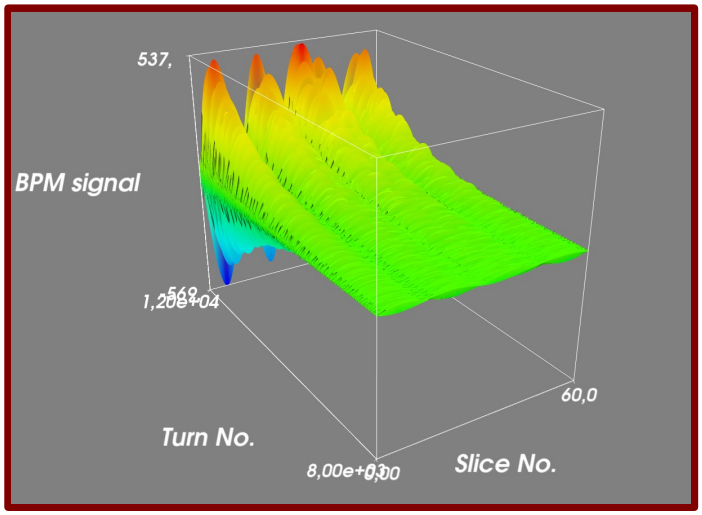


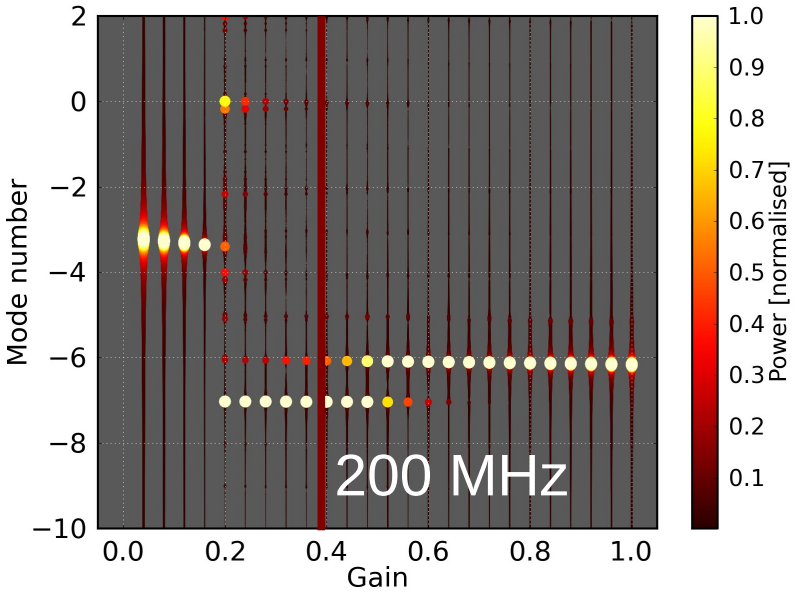


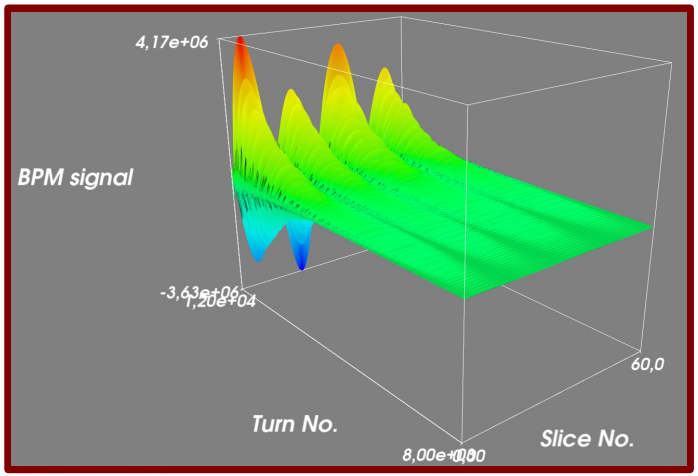


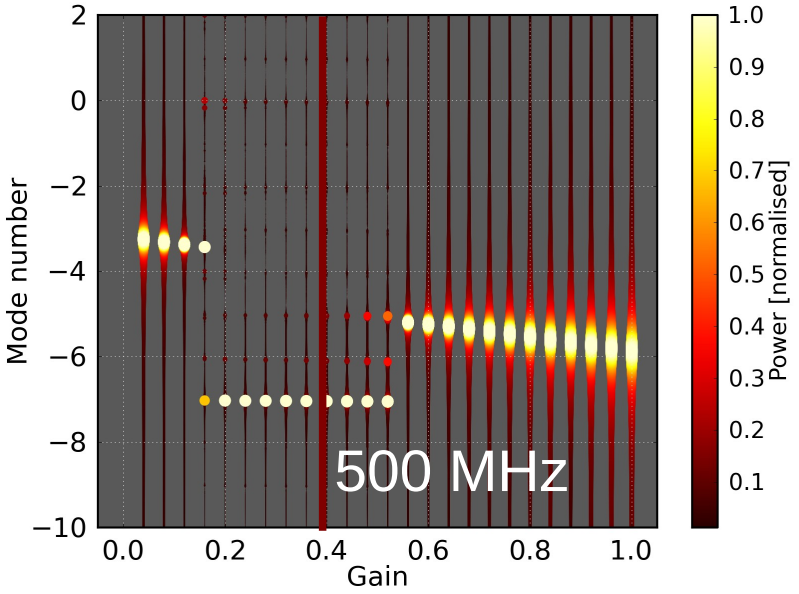


Q20 – I = 4.2e11 – gain scan

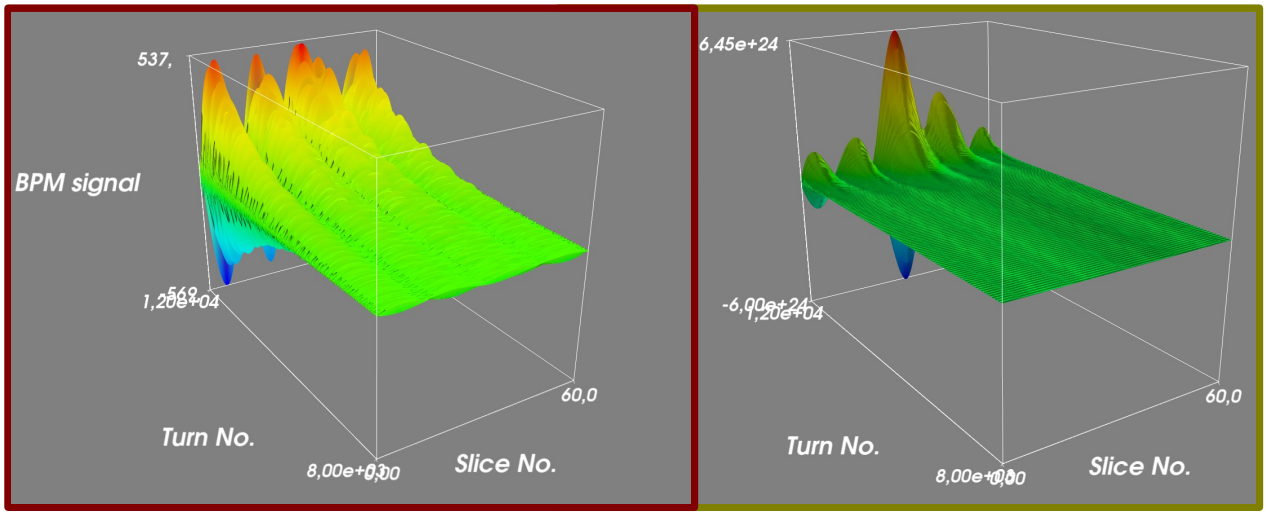


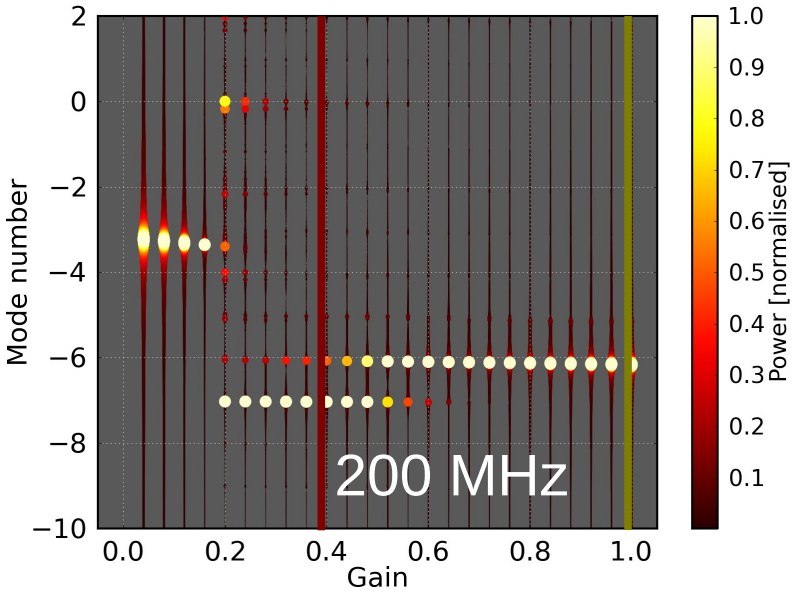


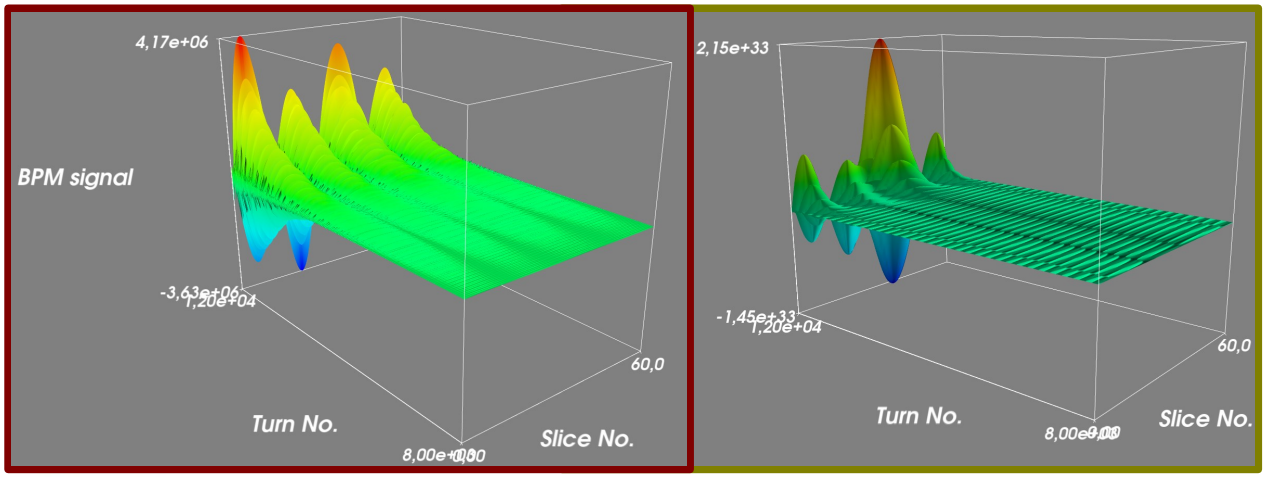


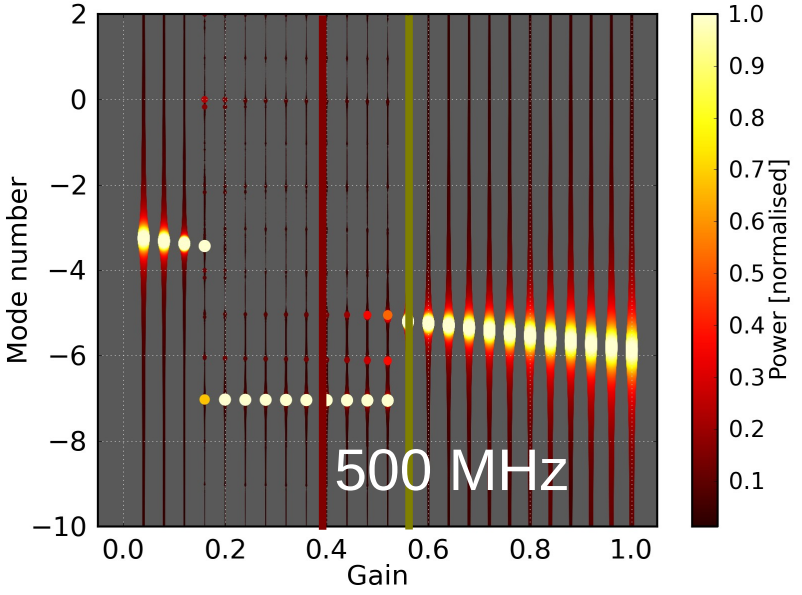


Q20 – I = 4.2e11 – gain scan









Conclusions

- Realistic feedback systems contain peculiarities and limitations
- Realistic simulations should include these features
- We have demonstrated
  - Examples of the effect of bandwidth limitations
  - Examples of digital filter design and implementation
  - Reduced model analysis
  - Multi-particle simulations of TMCI with wideband feedback
- Further studies include
  - Impact of noise
  - Impact of amplifier saturation