Instabilities Simulations with Wideband Feedback Systems: CMAD, HeadTail, WARP

K. Li [1], H. Bartosik [1], J. Cesaratto [2], J. D. Fox [2], W. Höfle [1], M. Furman [3], G. Iadorola [1], M. Pivi [2], C. Rivetta [2], G. Rumolo [1], R. Secondo [1], O. Turgut [2], S. Uemuda [2], J.-L. Vay [3]

[1] European Organization for Nuclear Research
[2] SLAC National Accelerator Laboratory
[3] Lawrence Berkeley National Laboratory

Work supported by DOE

Outline

i. Simulation models – CMAD, HeadTail, WARP

ii. Feedback system model

iii. Damping the centroid motion

iv. Electron cloud instabilities

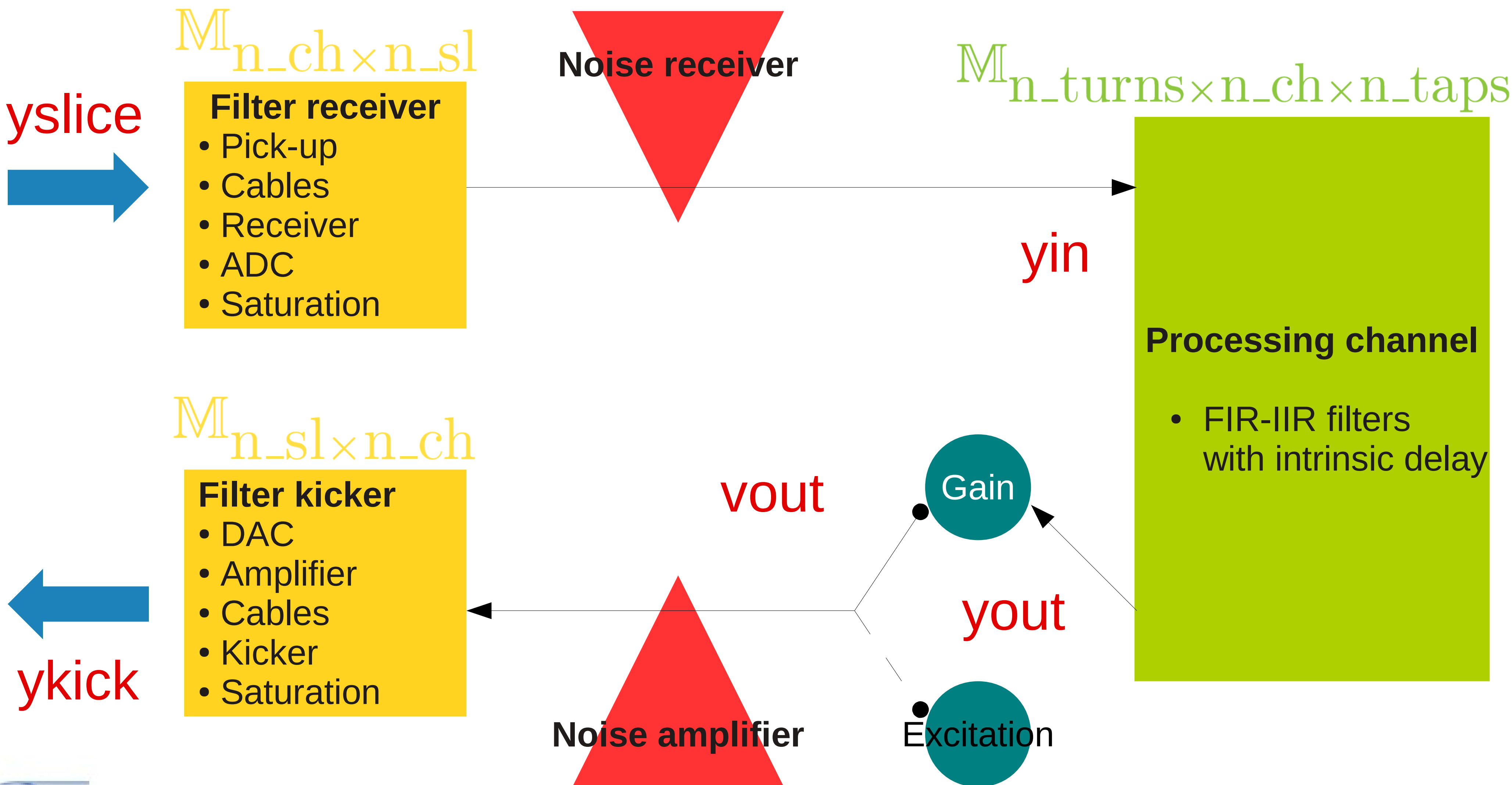
v. Damping the intra-bunch motion

vi. Conclusions and outlook

C-MAD, HeadTail, WARP - Models

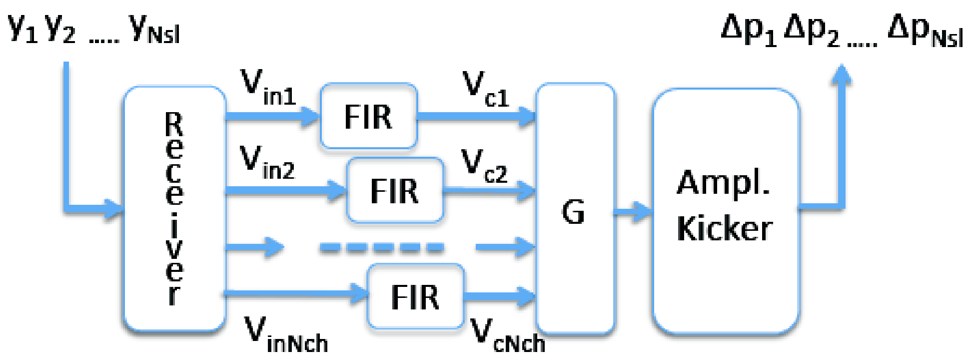
	CMAD	HeadTail	WARP
Language	Fortran	C++	Fortran with Python interface
Parallel	yes	no	yes
Optics	Smooth or lattice (MAD-X import)	Smooth or lattice (MAD-X import)	Smooth or lattice
PIC	2D FFT	2D FFT	AMR (includes space charge)
Binning	Constant space or constant charge	Constant space	Constant space
Distributions	Internal & external	Internal & external	Internal, external & build-up
Extras	IBS, radiation damping, quantum excitation	ZBASE impedance database	Build-up + tracking (strong-strong)

Feedback system implementation



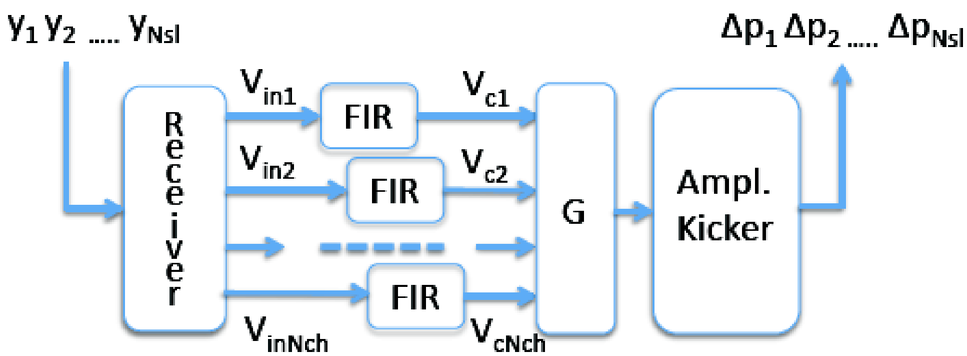
Feedback system - specifications

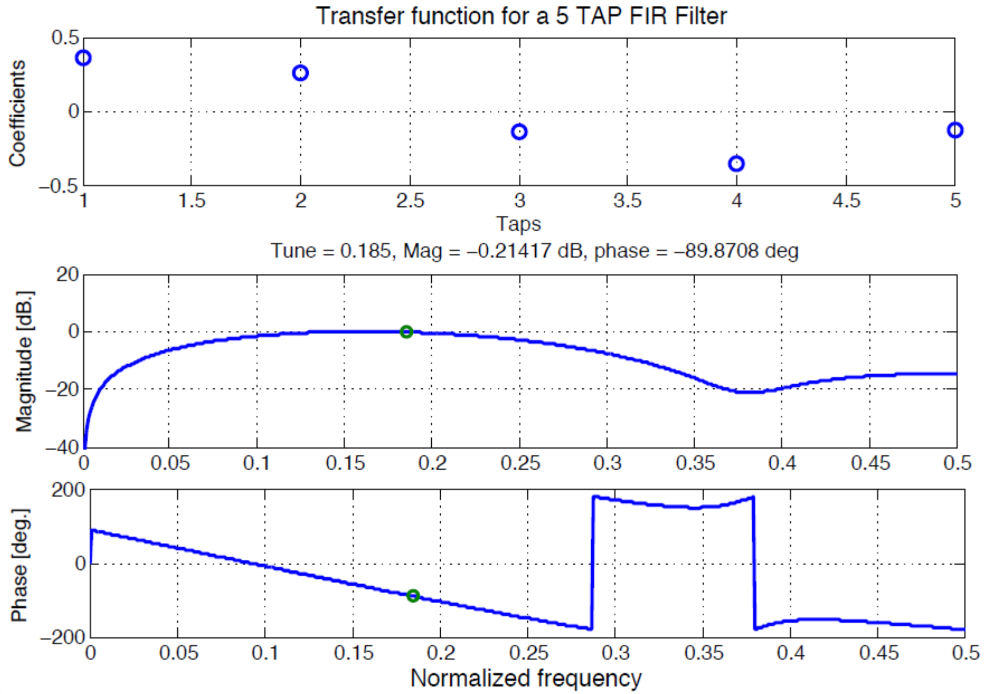
- 5 tap delay



Feedback system - specifications

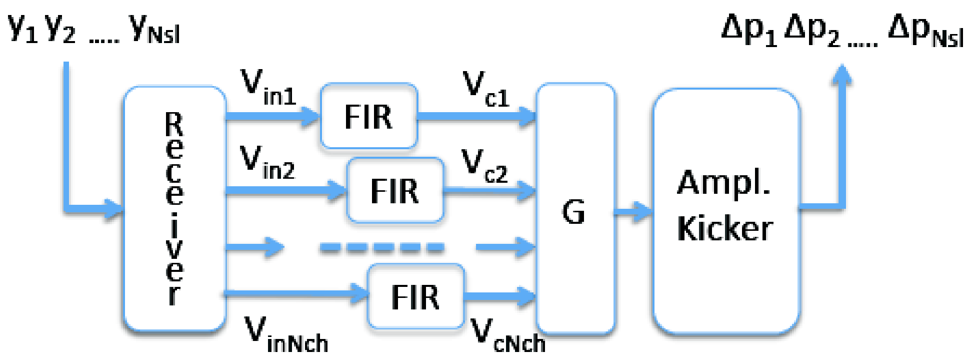
- 5 tap delay
- FIR transfer functions (left)

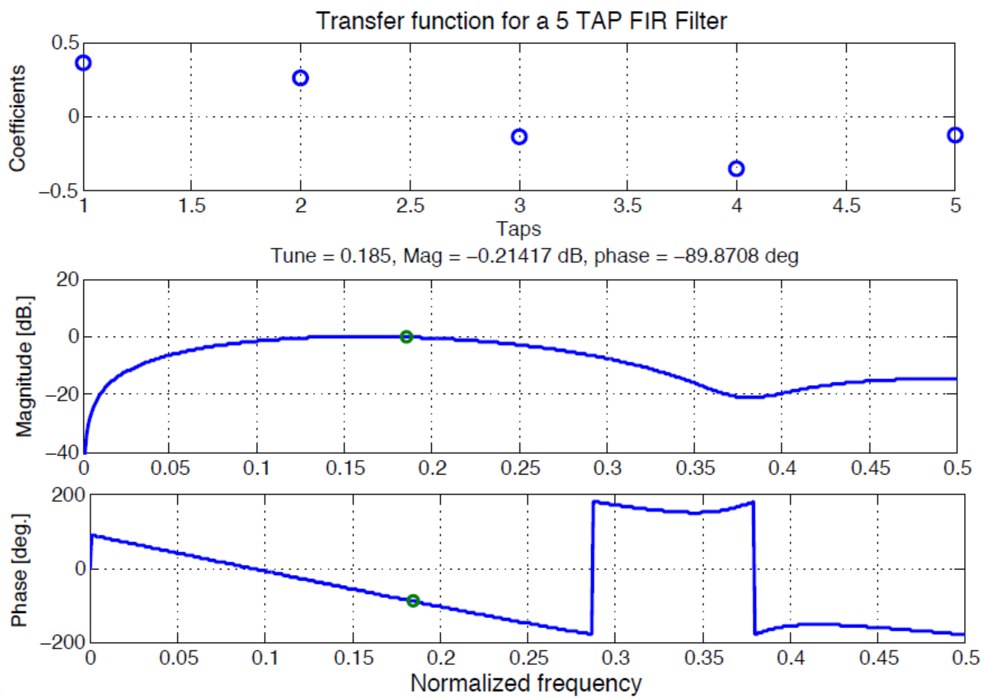


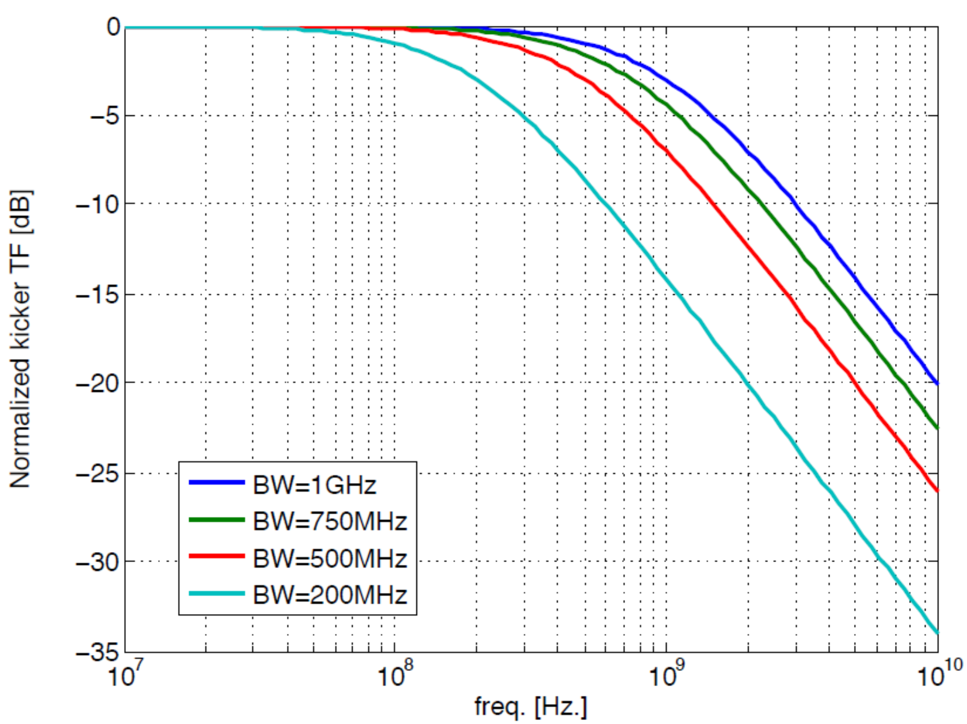


Feedback system - specifications

- 5 tap delay
- FIR transfer functions (left)
- Kicker transfer functions (right)





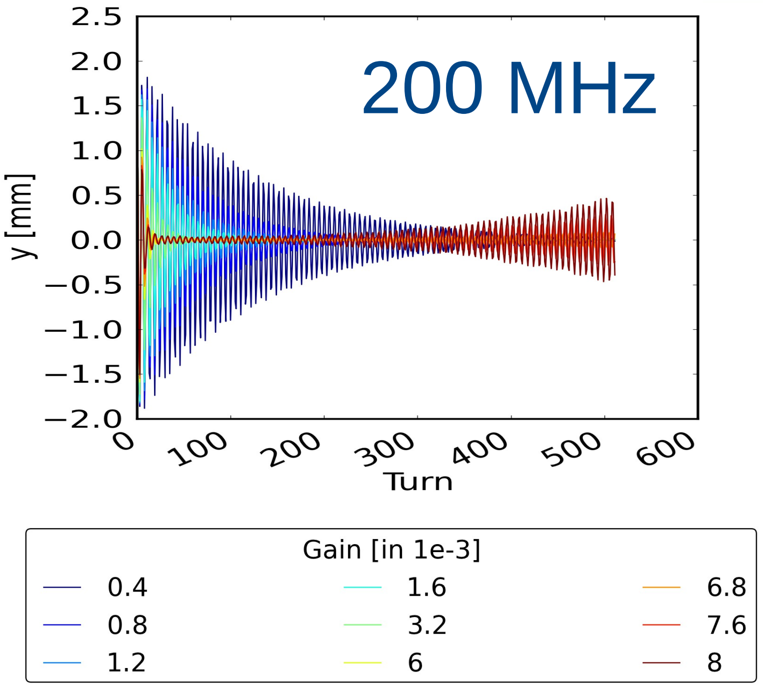


Centroid motion – gain scan

- Bandwidths:
  200MHz, 500MHz, 700MHz, 1GHz
- Perturbation: 2mm initial vertical offset → monitor bunch response

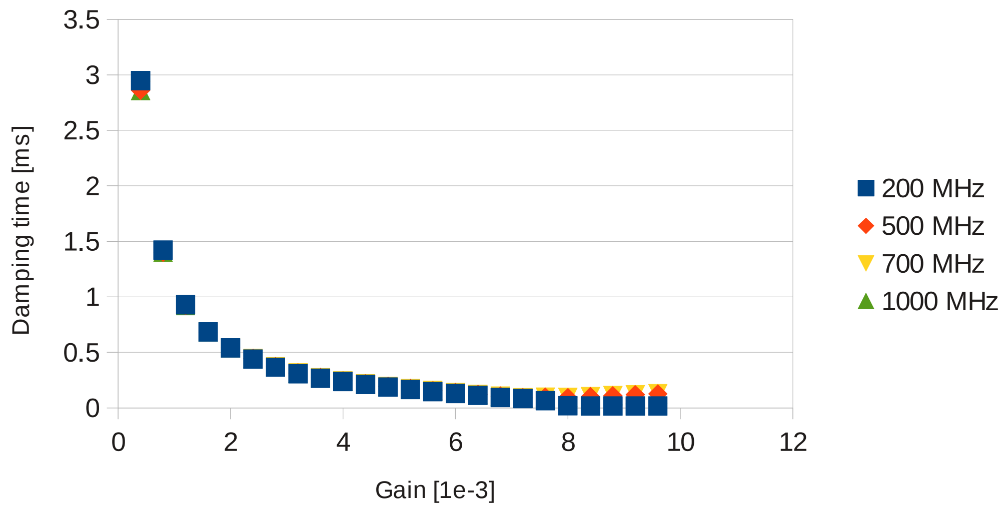
Centroid motion – gain scan

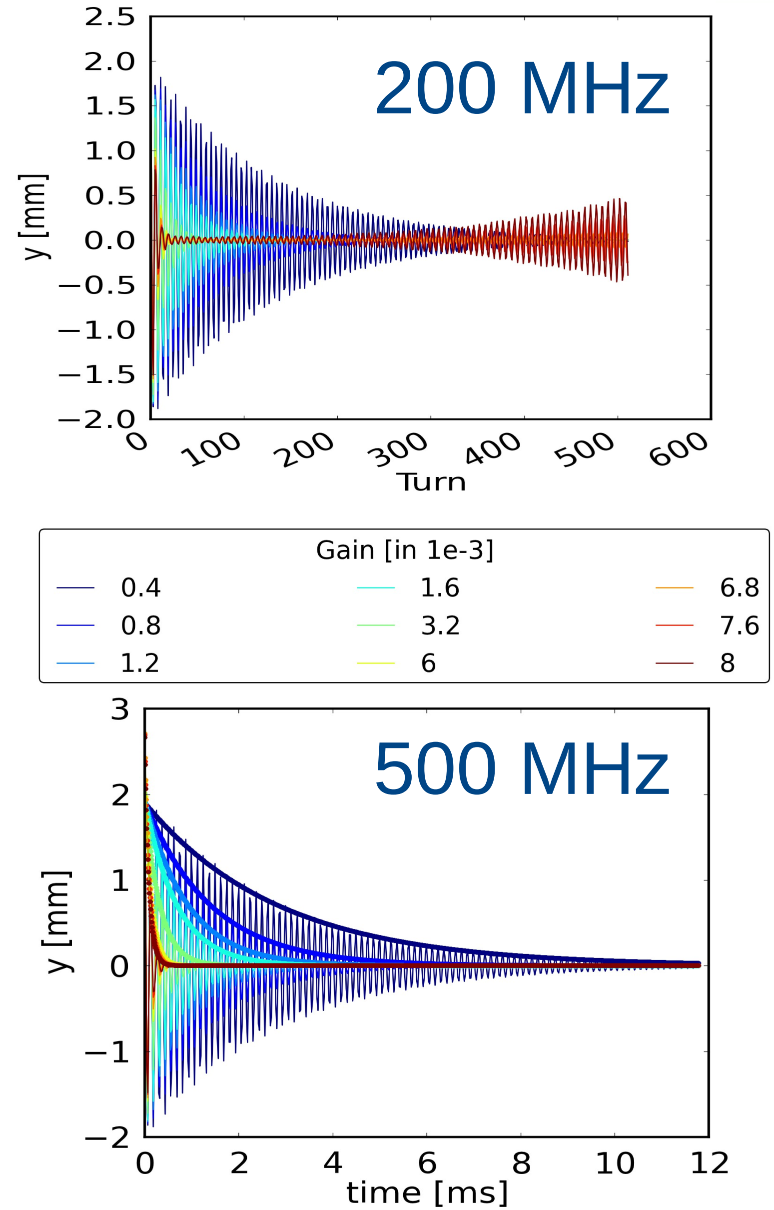
- Bandwidths:
  200MHz, 500MHz, 700MHz, 1GHz
- Perturbation: 2mm initial vertical offset → monitor bunch response
- For high gains, the limited (200MHz) bandwidth makes the system become unstable



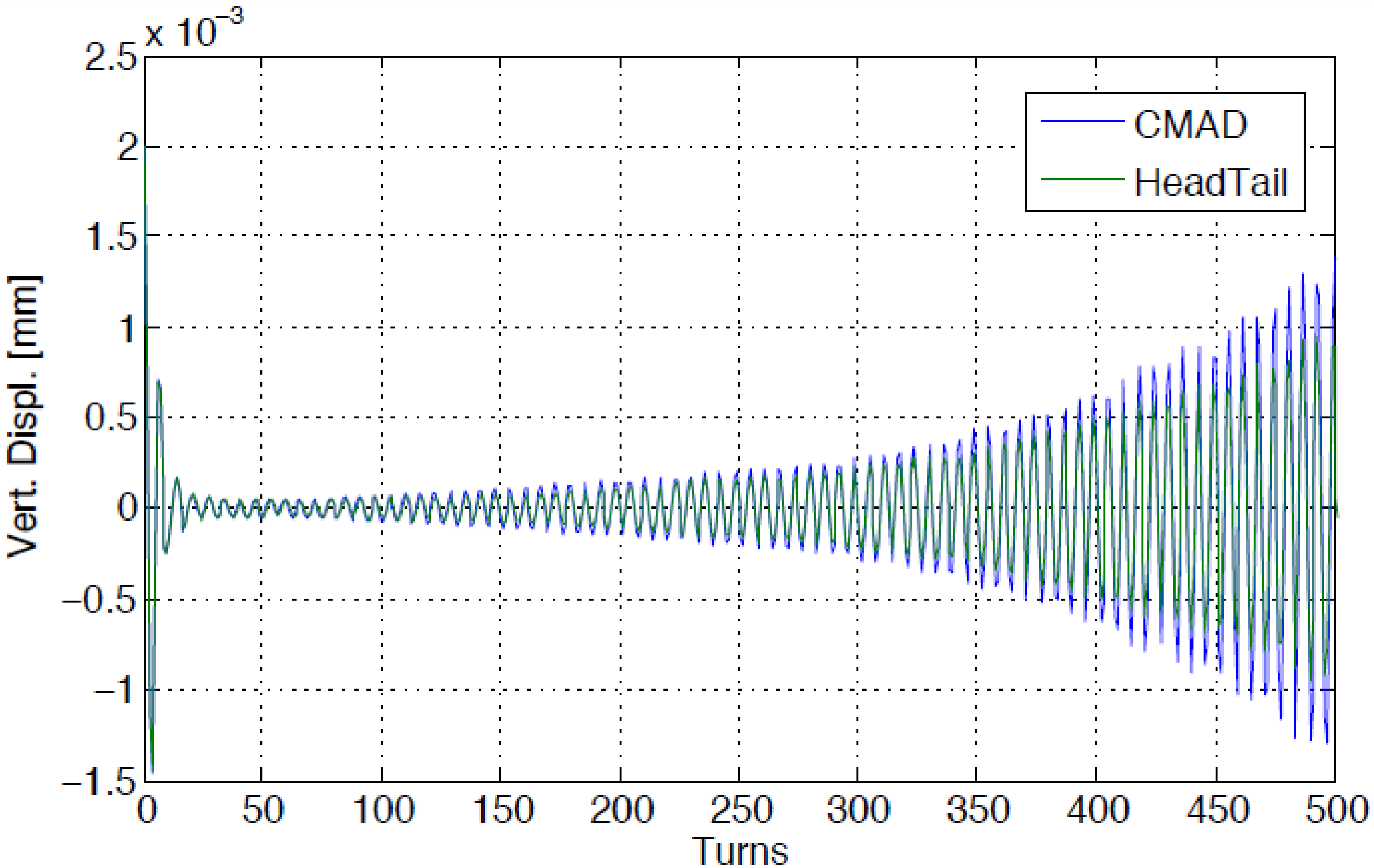
Centroid motion – gain scan

- Bandwidths:
  200MHz, 500MHz, 700MHz, 1GHz
- Perturbation: 2mm initial vertical offset → monitor bunch response
- For high gains, the limited (200MHz) bandwidth makes the system become unstable
- For all cases, the bunch response (centroid motion) to the initial perturbation is similar → the systems perform equally well





Comparision CMAD-HeadTail



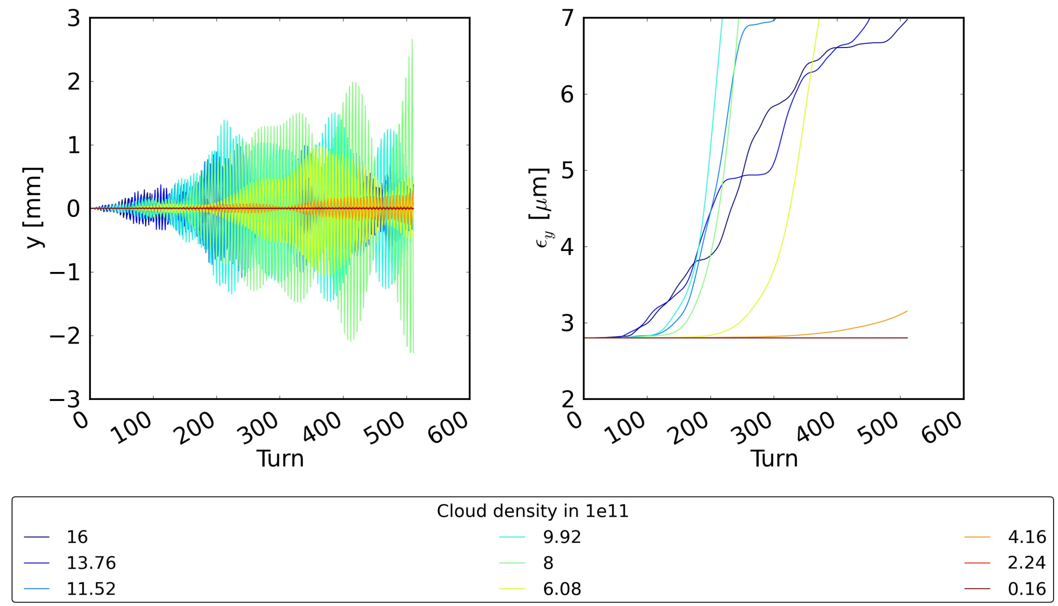
- Perturbation: 2mm initial vertical offset
- Gain g ≈ 8.5e-3

ECI – ρ_e scan

Intensity	1.1e11 ppb
Energy	26 GeV
Emittances [epsx, epsy]	2.8, 2.8 microns
Beta-functions [βx, βy]	42, 42 m
Tunes [Qx, Qy, Qs]	26.130, 26.185, 0.0059
E-cloud region	Bends

ECI – ρ_e scan

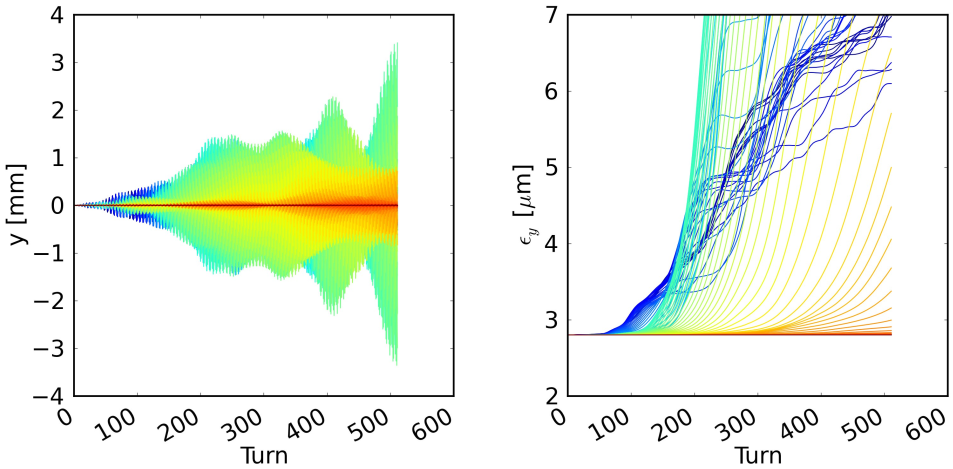
Intensity	1.1e11 ppb
Energy	26 GeV
Emittances [epsx, epsy]	2.8, 2.8 microns
Beta-functions [βx, βy]	42, 42 m
Tunes [Qx, Qy, Qs]	26.130, 26.185, 0.0059
E-cloud region	Bends



- The instability threshold is around $\rho_e \approx 4e11\ m^{-3}$

ECI – ρ_e scan

Intensity	1.1e11 ppb
Energy	26 GeV
Emittances [epsx, epsy]	2.8, 2.8 microns
Beta-functions [βx, βy]	42, 42 m
Tunes [Qx, Qy, Qs]	26.130, 26.185, 0.0059
E-cloud region	Bends

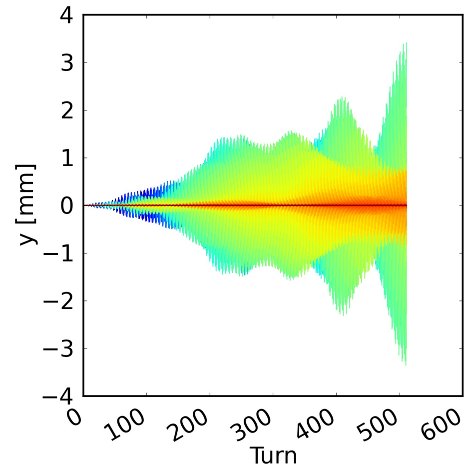


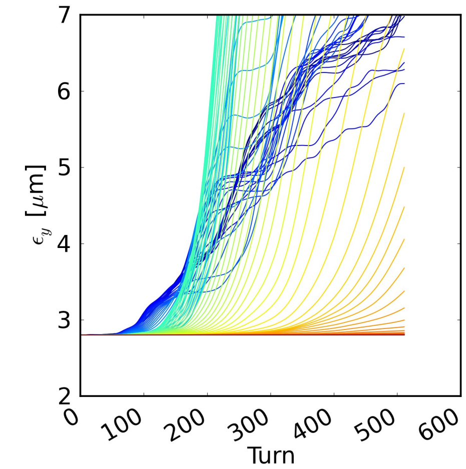
ρ_e = [1,16] x 1e11 m^{-3}

- The instability threshold is around $\rho_e \approx$ 4e11 m^{-3}

ECI – ρ_e scan

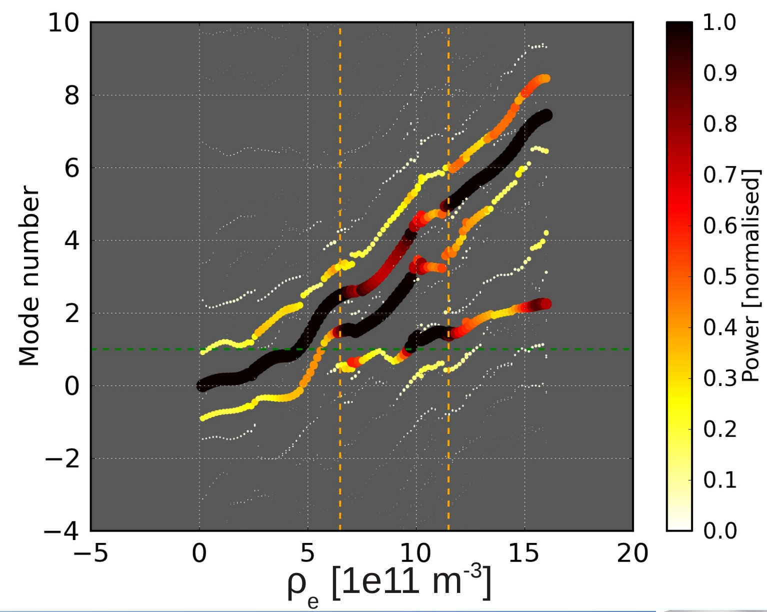
Intensity	1.1e11 ppb
Energy	26 GeV
Emittances [epsx, epsy]	2.8, 2.8 microns
Beta-functions [βx, βy]	42, 42 m
Tunes [Qx, Qy, Qs]	26.130, 26.185, 0.0059
E-cloud region	Bends



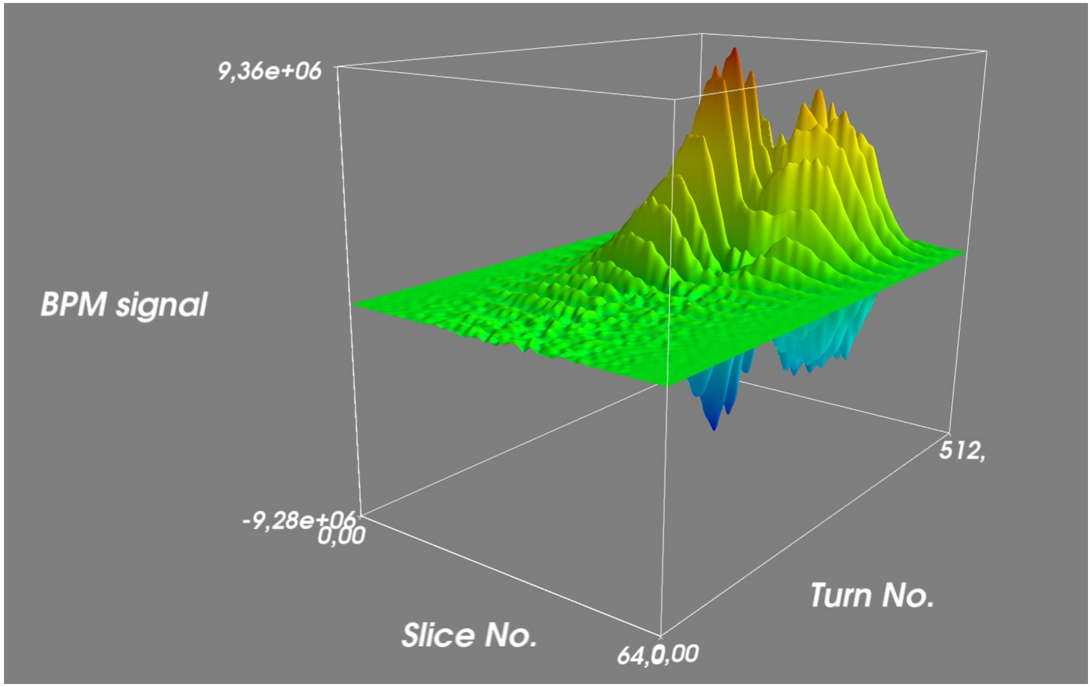


ρ_e = [1,16] x 1e11 m^{-3}

- The instability threshold is around $\rho_e \approx 4e11\ m^{-3}$
- Unstable modes are {0, -1, -2}

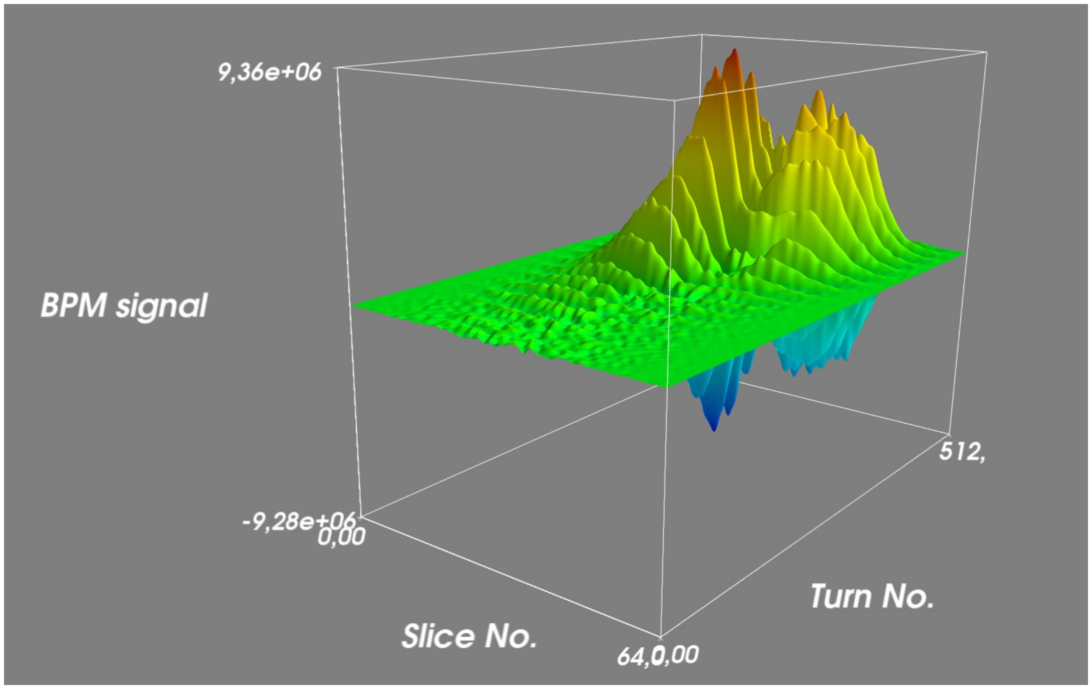


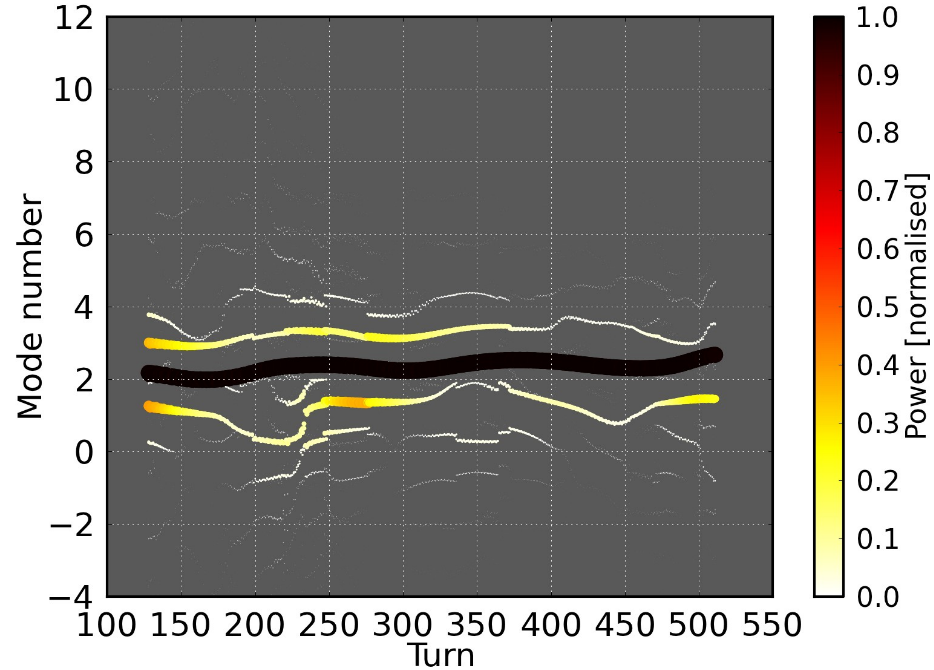
ECI – $\rho_e \approx 6e11\ m^{-3}$



- Clear coherent motion above the instability threshold

ECI – $\rho_e \approx 6e11\ m^{-3}$





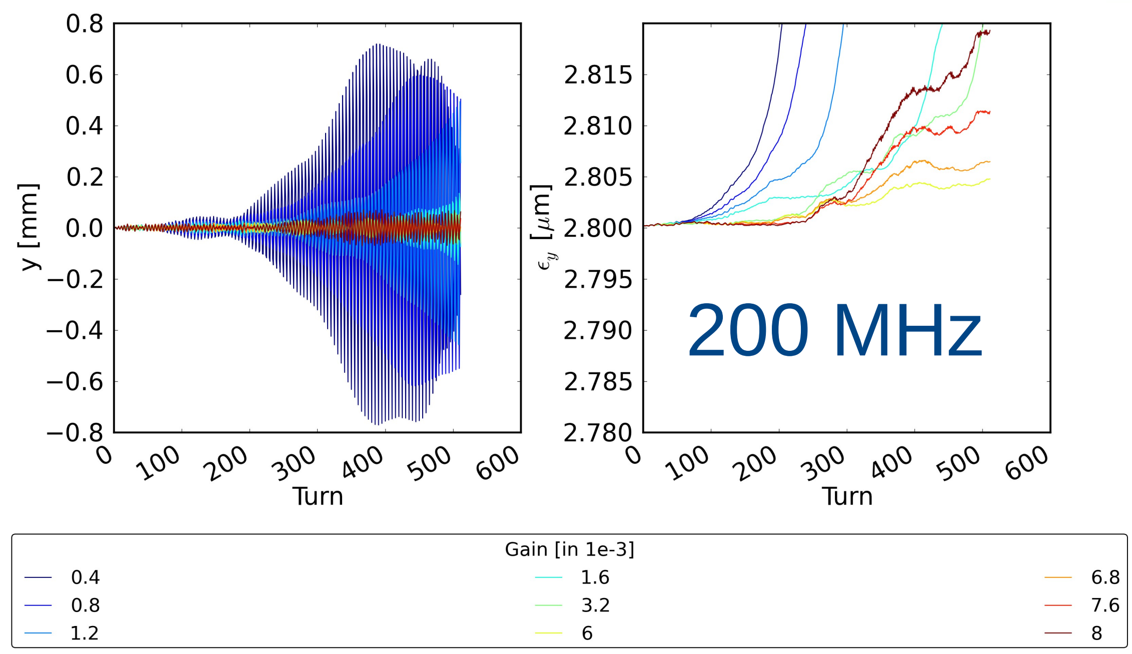
- Clear coherent motion above the instability threshold
- The mode evolution reveals the presence of predominantly modes {0, -1, -2} (shifted)

Intra-bunch – $\rho_e \approx 6e11\ m^{-3}$ – gain scan

- Perturbation: electron cloud
- Bandwidths: 200MHz, 500MHz, 700MHz, 1GHz

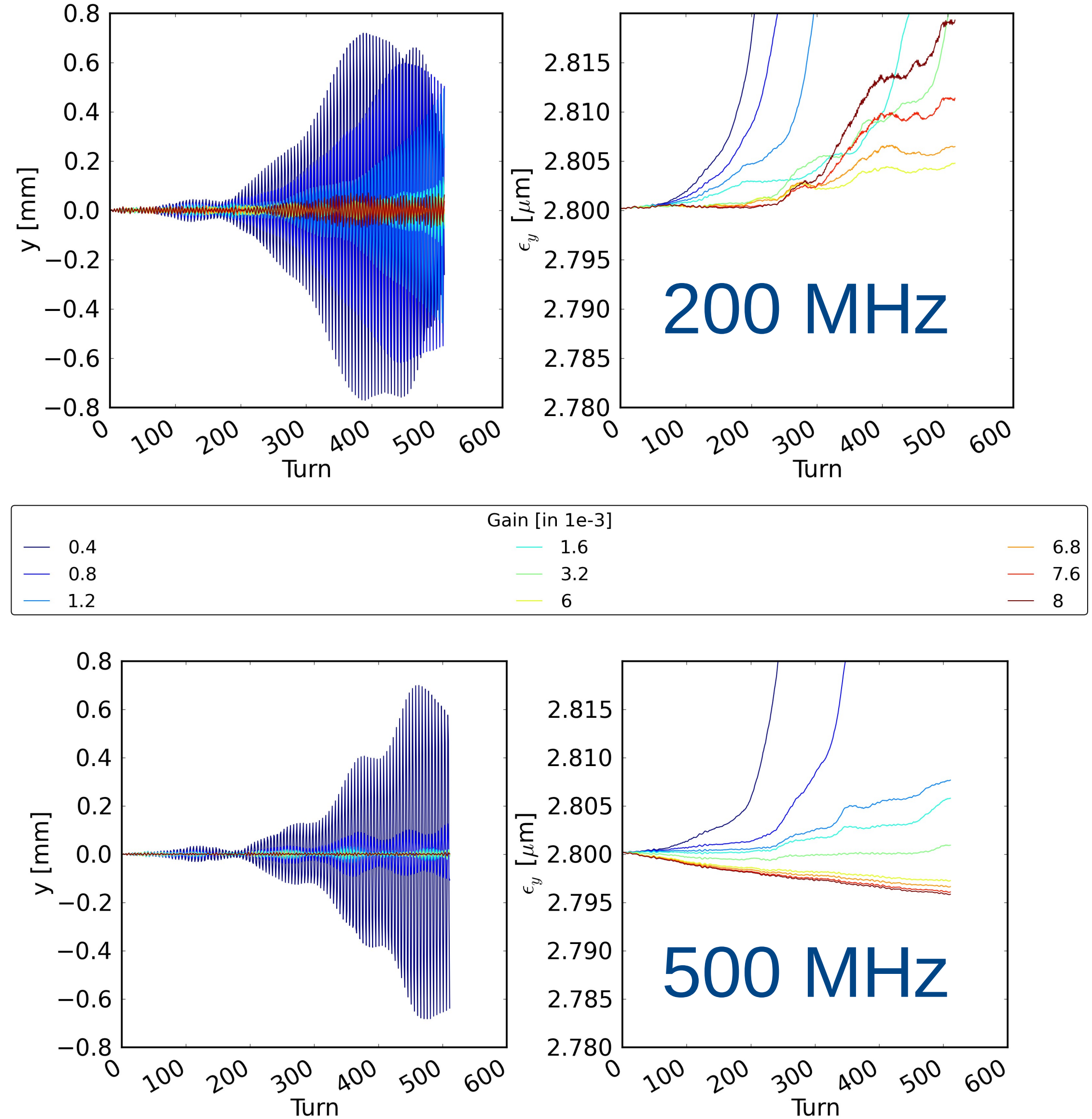
Intra-bunch – $\rho_e \approx 6e11\ m^{-3}$ – gain scan

- Perturbation: electron cloud
- Bandwidths: 200MHz, 500MHz, 700MHz, 1GHz
- For high gains, the limited (200MHz) bandwidth makes the system become unstable



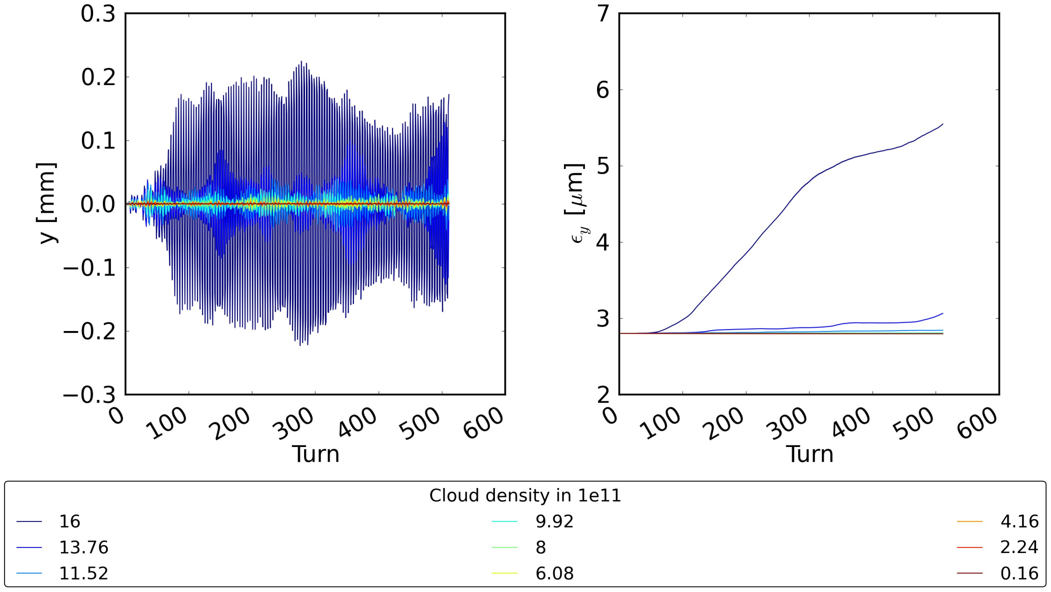
Intra-bunch – $\rho_e \approx 6e11\ m^{-3}$ – gain scan

- Perturbation: electron cloud
- Bandwidths: 200MHz, 500MHz, 700MHz, 1GHz
- For high gains, the limited (200MHz) bandwidth makes the system become unstable
- A gain of 6e-3 appears to damp the ECI



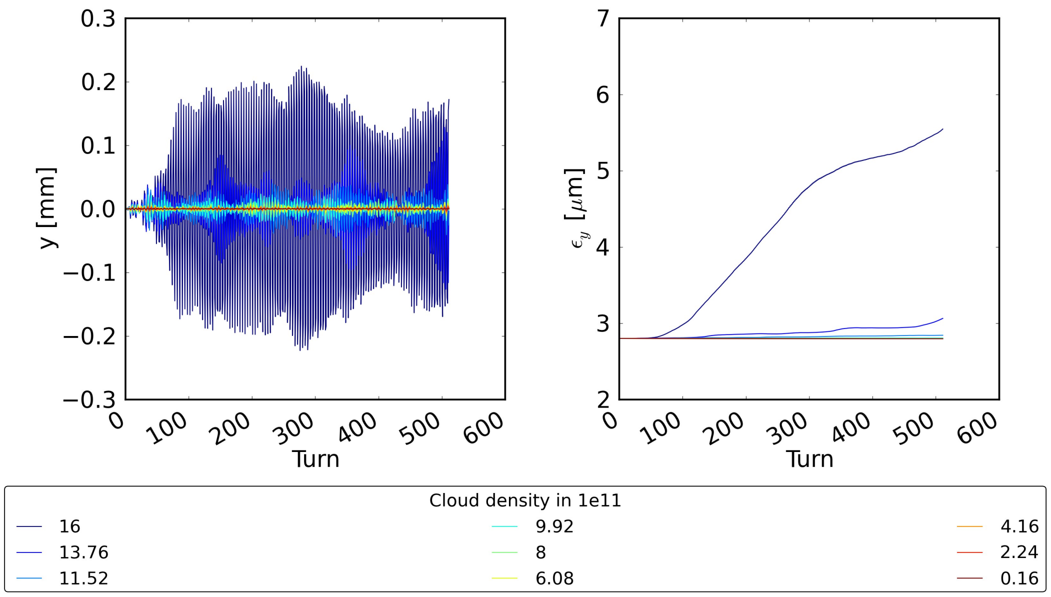
500MHz – ρ_e scan – gain = 6e-3

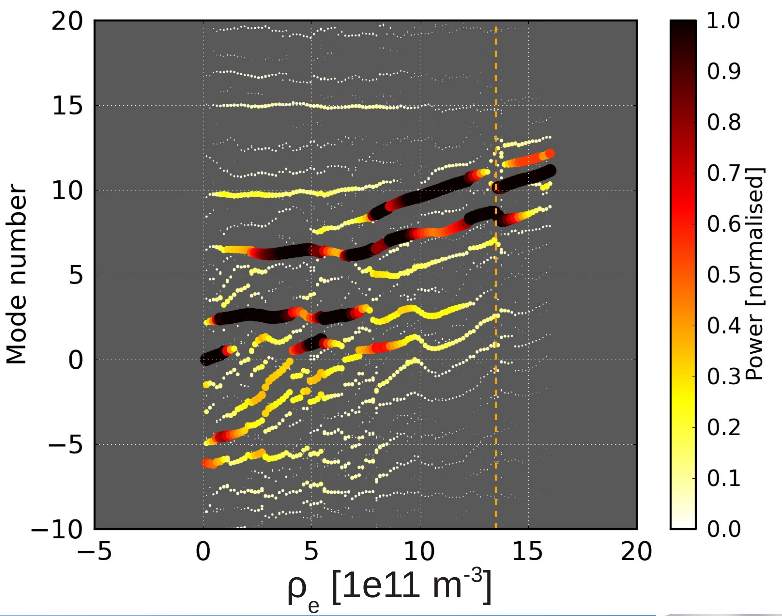
- Coherent motion is damped within the range ρ_e = [1,10] x 1e11 m^{-3}



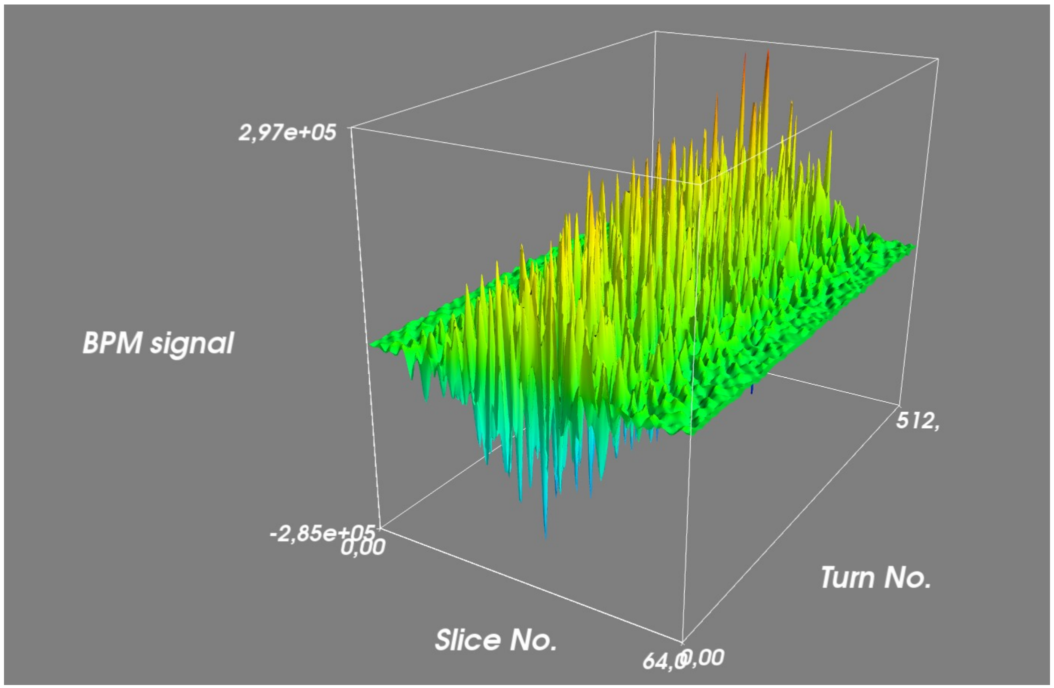
500MHz – ρ_e scan – gain = 6e-3

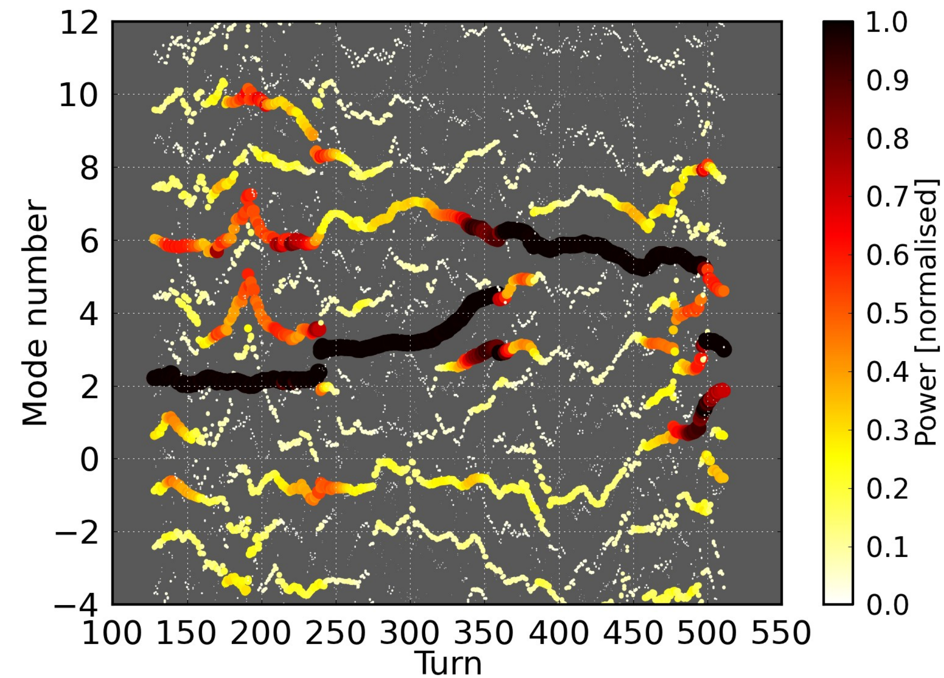
- Coherent motion is damped within the range ρ_e = [1,10] x 1e11 m^{-3}
- The power in modes {-1,0,1} is effectively diminished
- The remaining power appears to be distributed over a wide range of modes





500MHz – $\rho_e \approx 6e11\ m^{-3}$ – gain = 6e-3



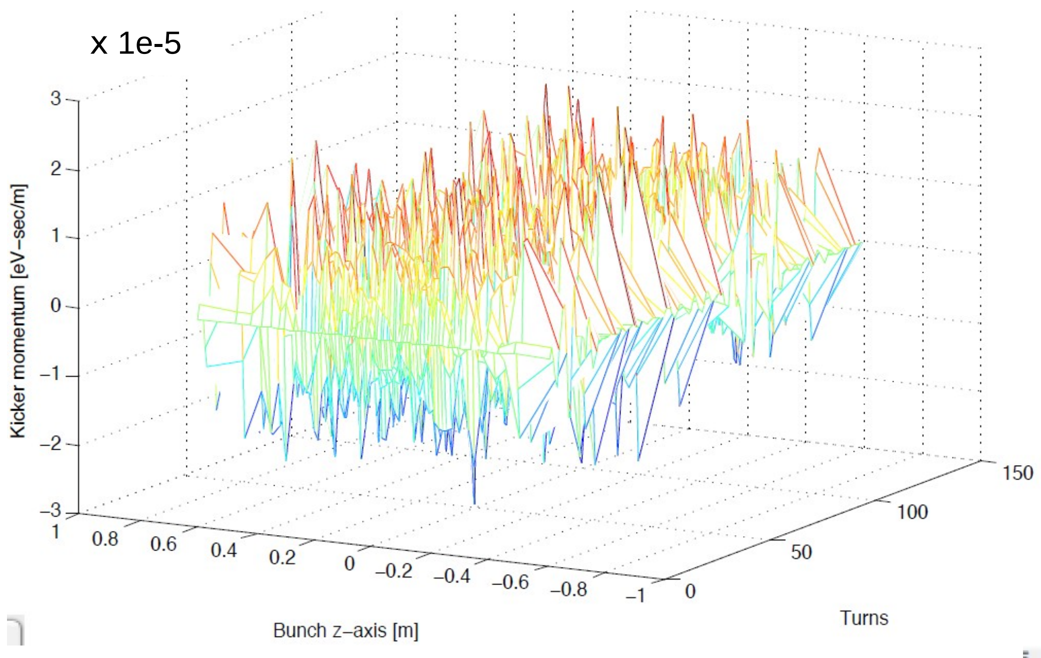


- Clear damping of the coherent motion
- Remaining power is distributed over modes {2,6}

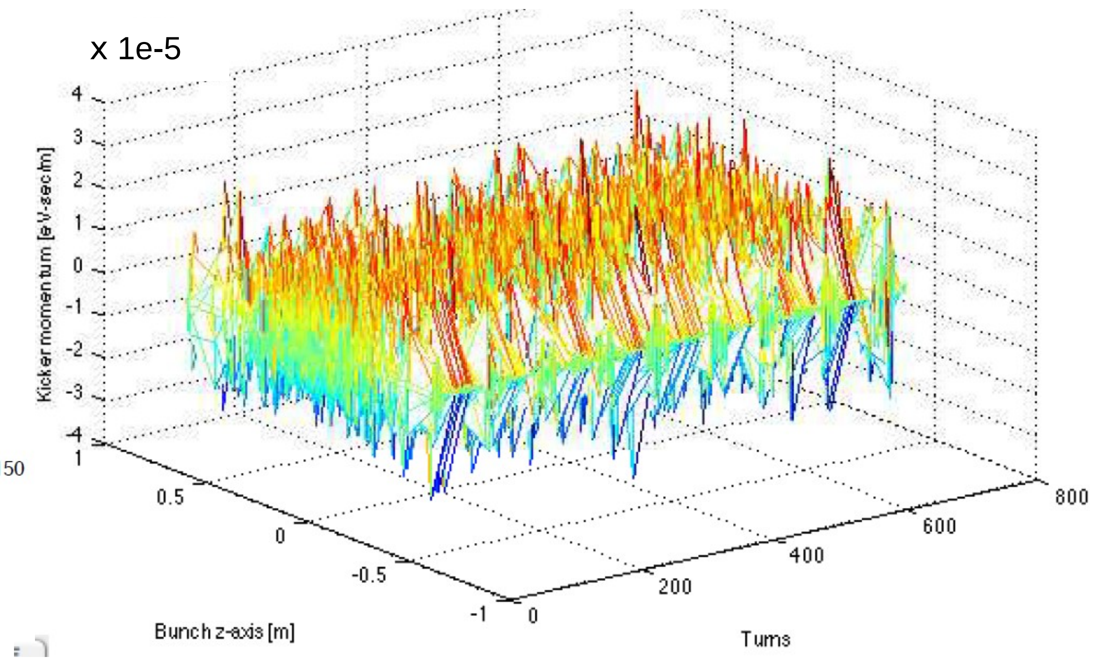
Feedback power required

Kick applied to individual bunch slices by the feedback system

Feedback ON: no electron cloud

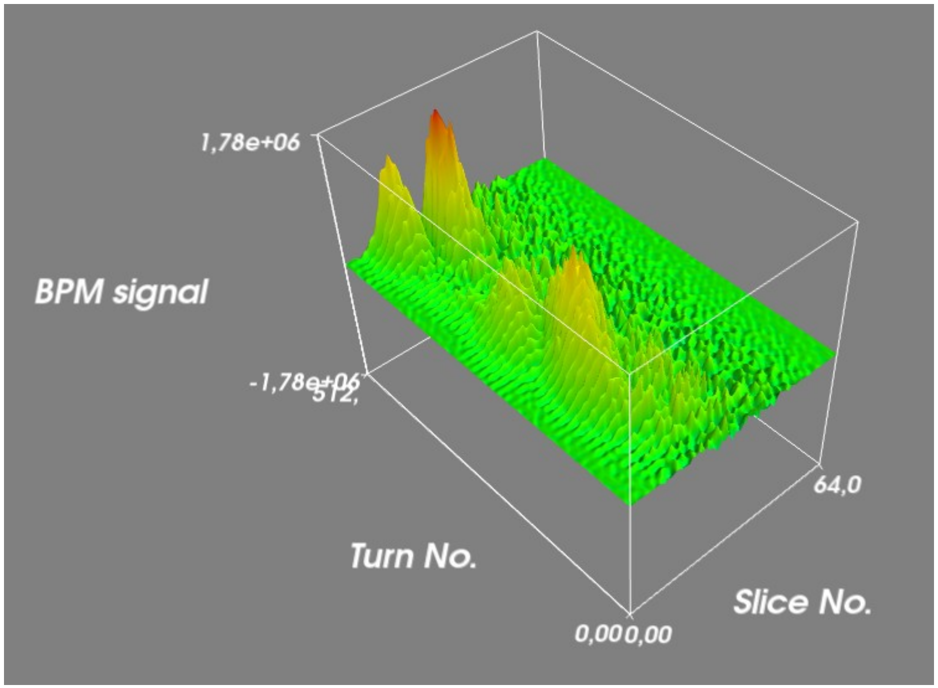


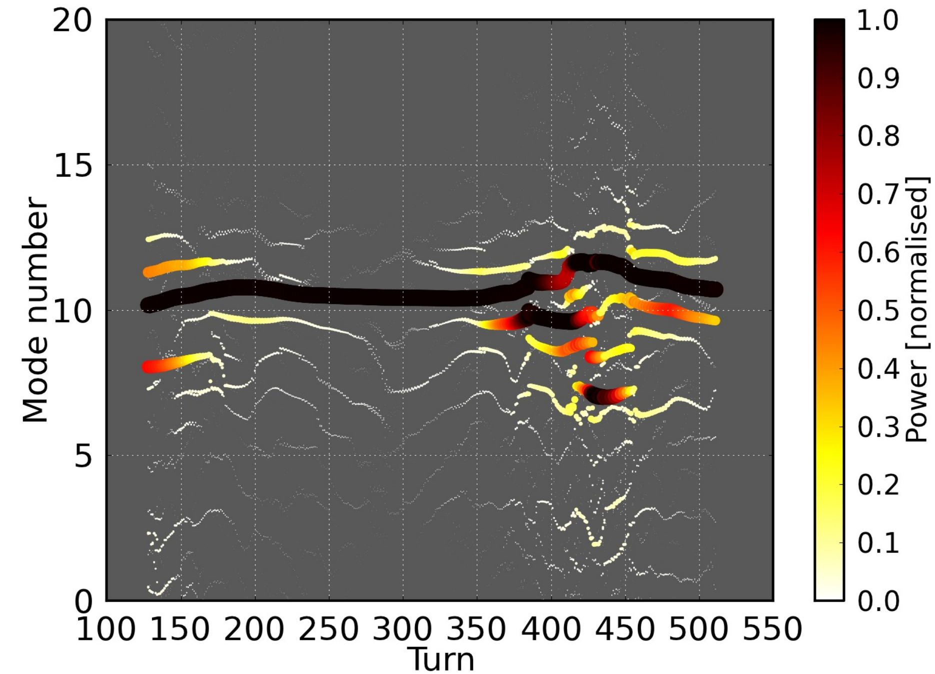
Feedback ON: ecloud density 5e11/m3



Same scale: Low feedback power is required to stabilize the beam in the presence of electron cloud

500MHz – $\rho_e \approx$ 14e11 m^{-3} – gain = 6e-3





- Clear re-emerging of the coherent motion
- Power is concentrated predominantly in modes {6} (shifted)

Conclusions & outlook

- Successful implementation of realistic feedback system into multi-particle instability codes
- Mode analysis of ECI reveals unstable modes up to mode 2 (for the investigated configuration)
- 200MHz feedback is insufficient to damp ECI
- 500MHz feedback provides damping within for gains > 6e-3
- Study the impact of noise on the feedback effectiveness

Thank you for your attention!