Combined Multivariable Linear Feedback and Iterative Learning Control applied to the RF System of FLASH

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Flash Seminar

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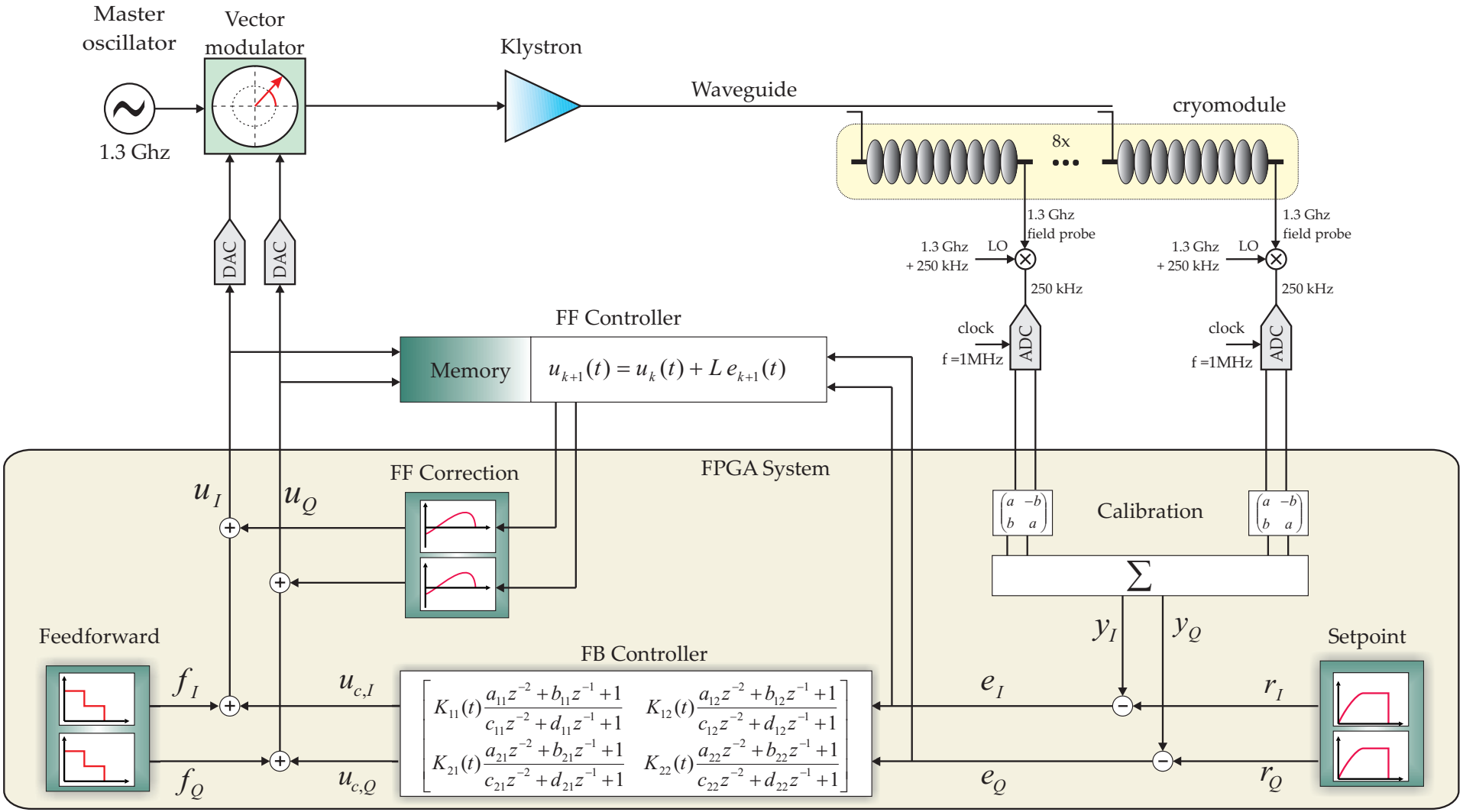
Outline

- System description and disturbance classification
- System Modeling
- Feedback controller design
- Iterative learning control
  - Implementation
  - Measurement results
- Conclusion and Outlook

Schematic view of the Control System



Disturbance classification

Repetitive

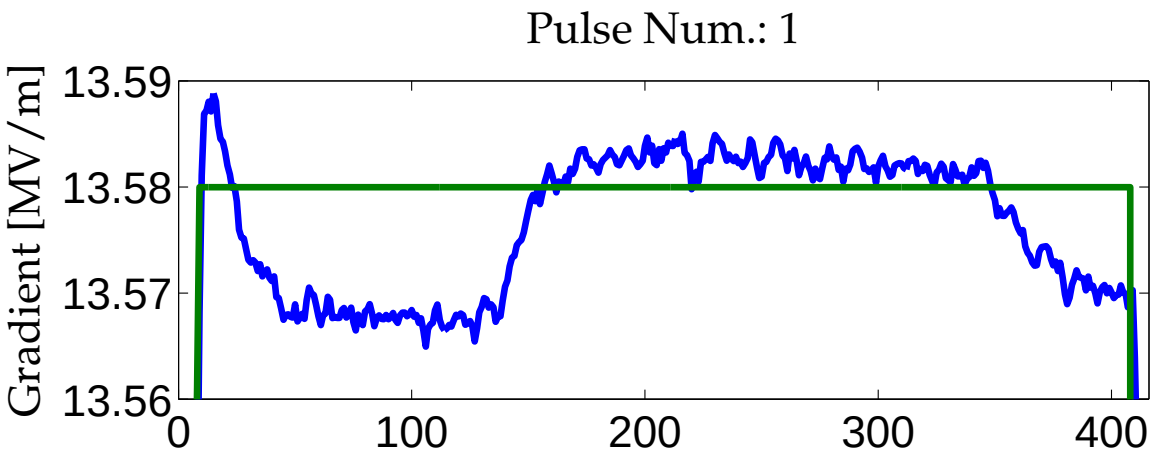
- LF Detuning
- Beam Loading
- Transitions

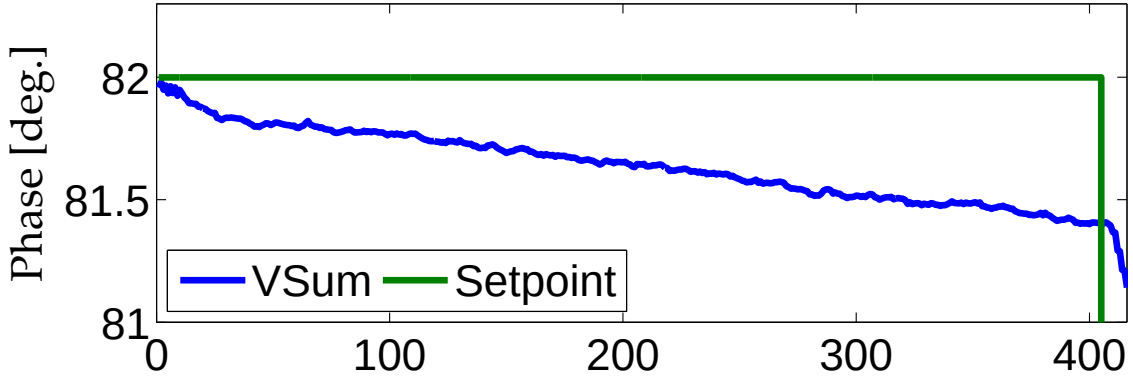
⇒ FF-Controller

Non-Repetitive

- Microphonics
- Measurement Noise
- Actuator Noise

⇒ FB-Controller

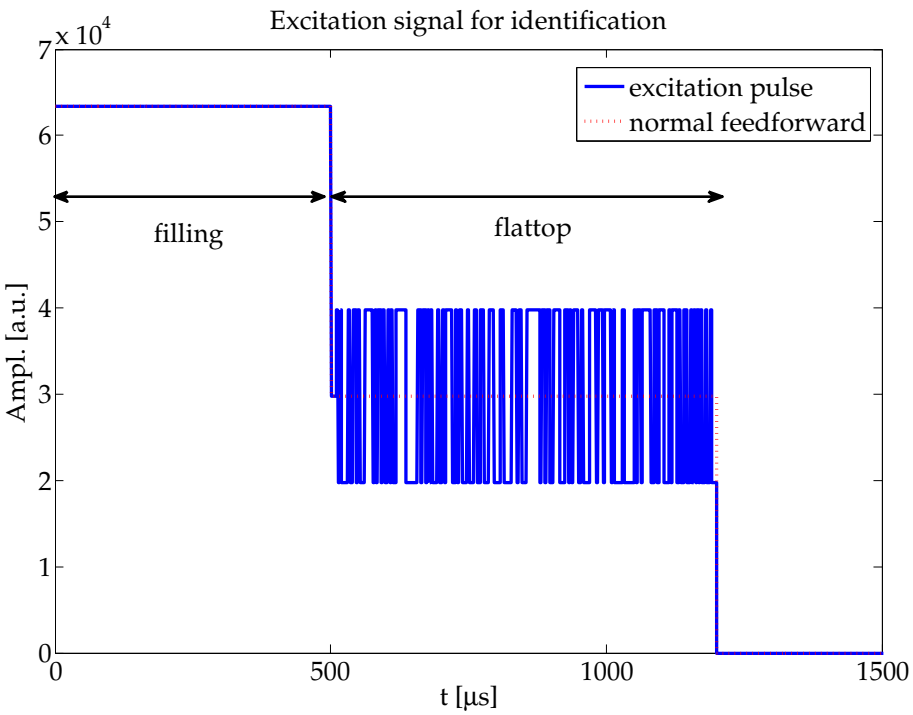




↷ Combination of both Controllers based on system model

System identification and modeling

- Appropriate model is needed for controller design
- Persistent excitation of the system
- Estimating black box model for current operation point
- Limitations due to flattop length

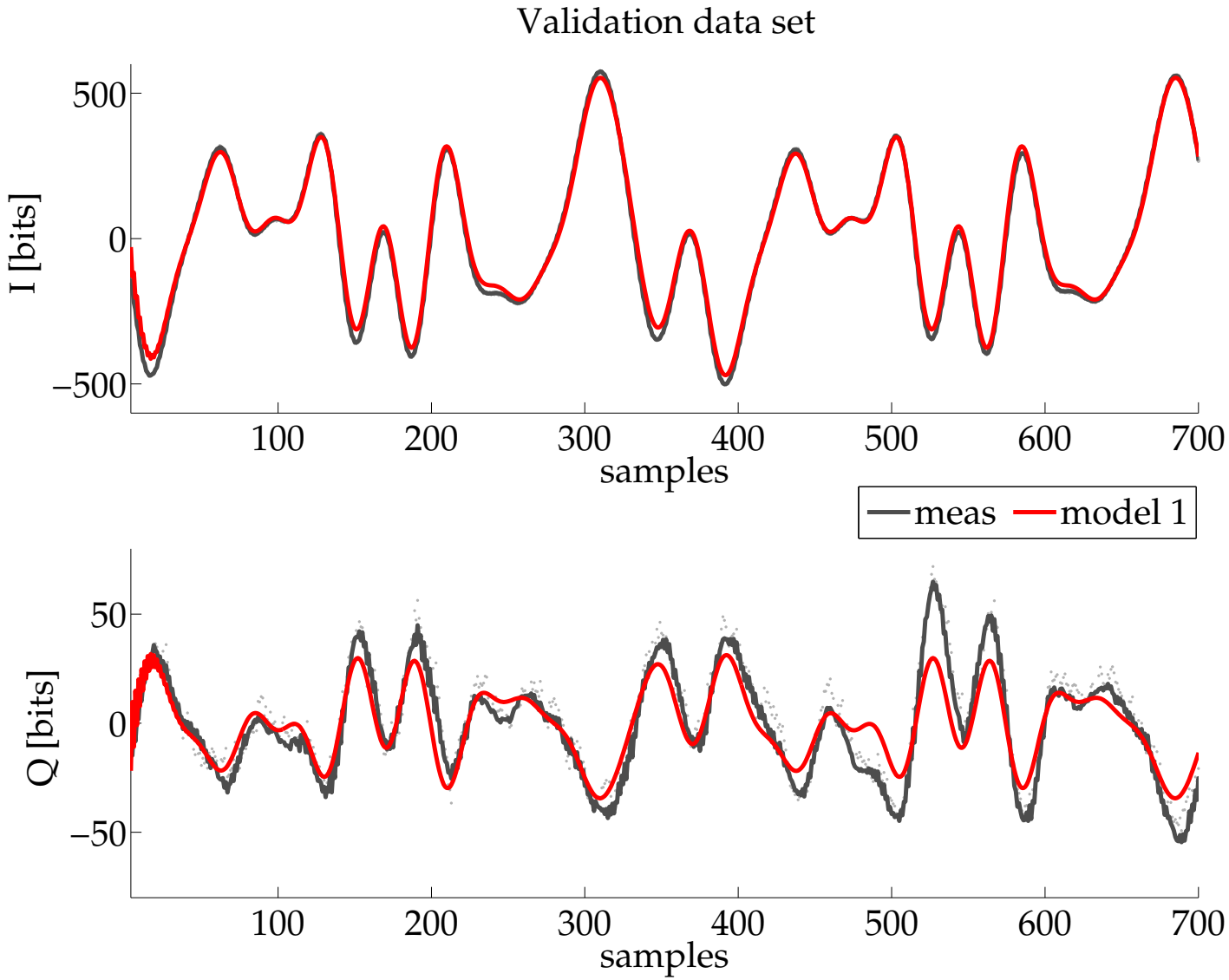


- State Space system (LTI)

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned}$$

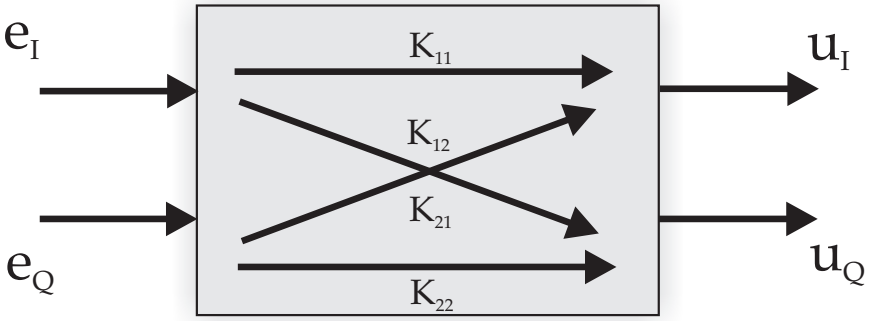
- Estimating system parameters A,B,C,D with subspace algorithm n4sid

Model validation of the system



Feedback controller design

- So far decentralized proportional FB controller is used

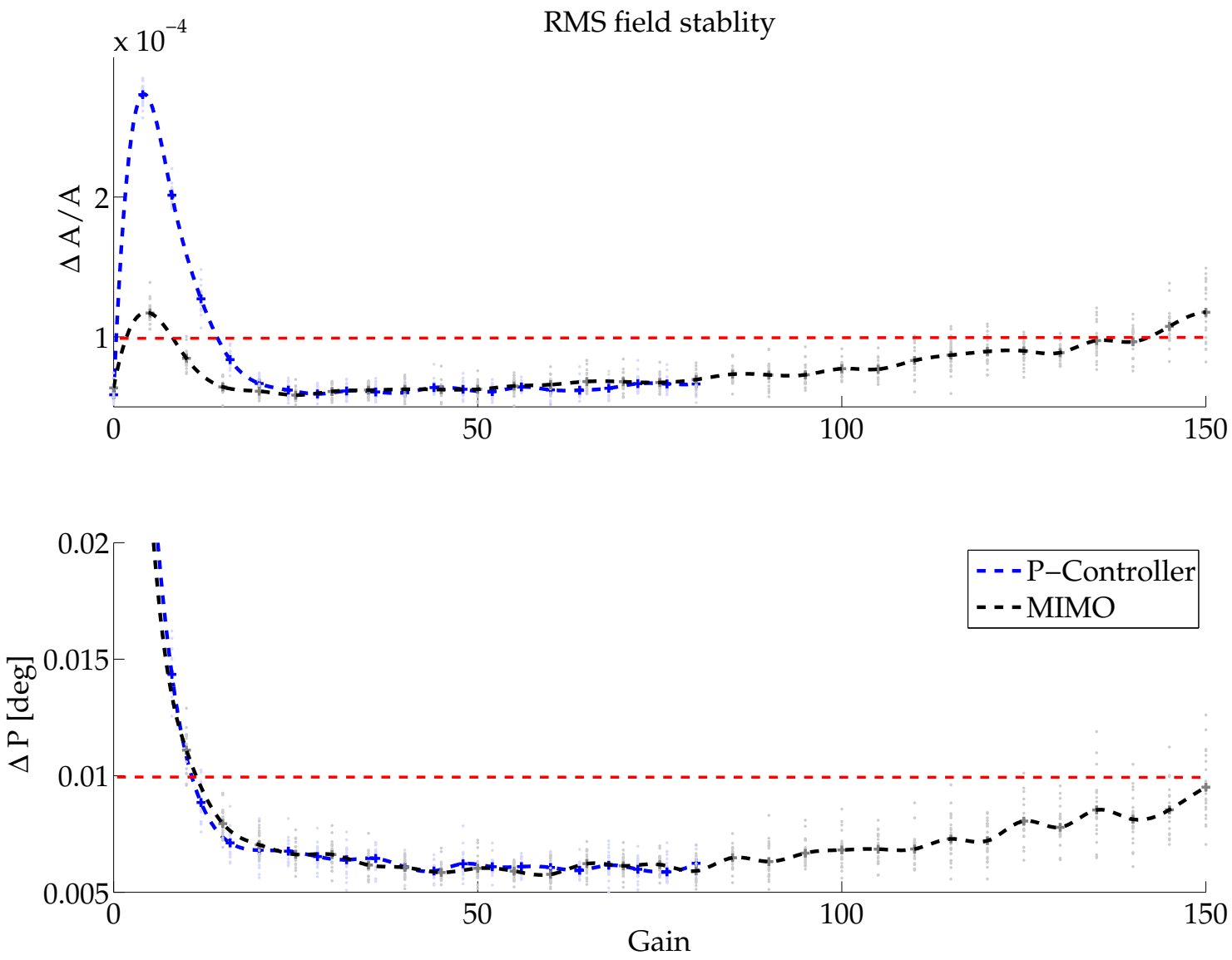


- Multivariable Input / Output Controller (MIMO)
- 2nd order controller (dynamic)

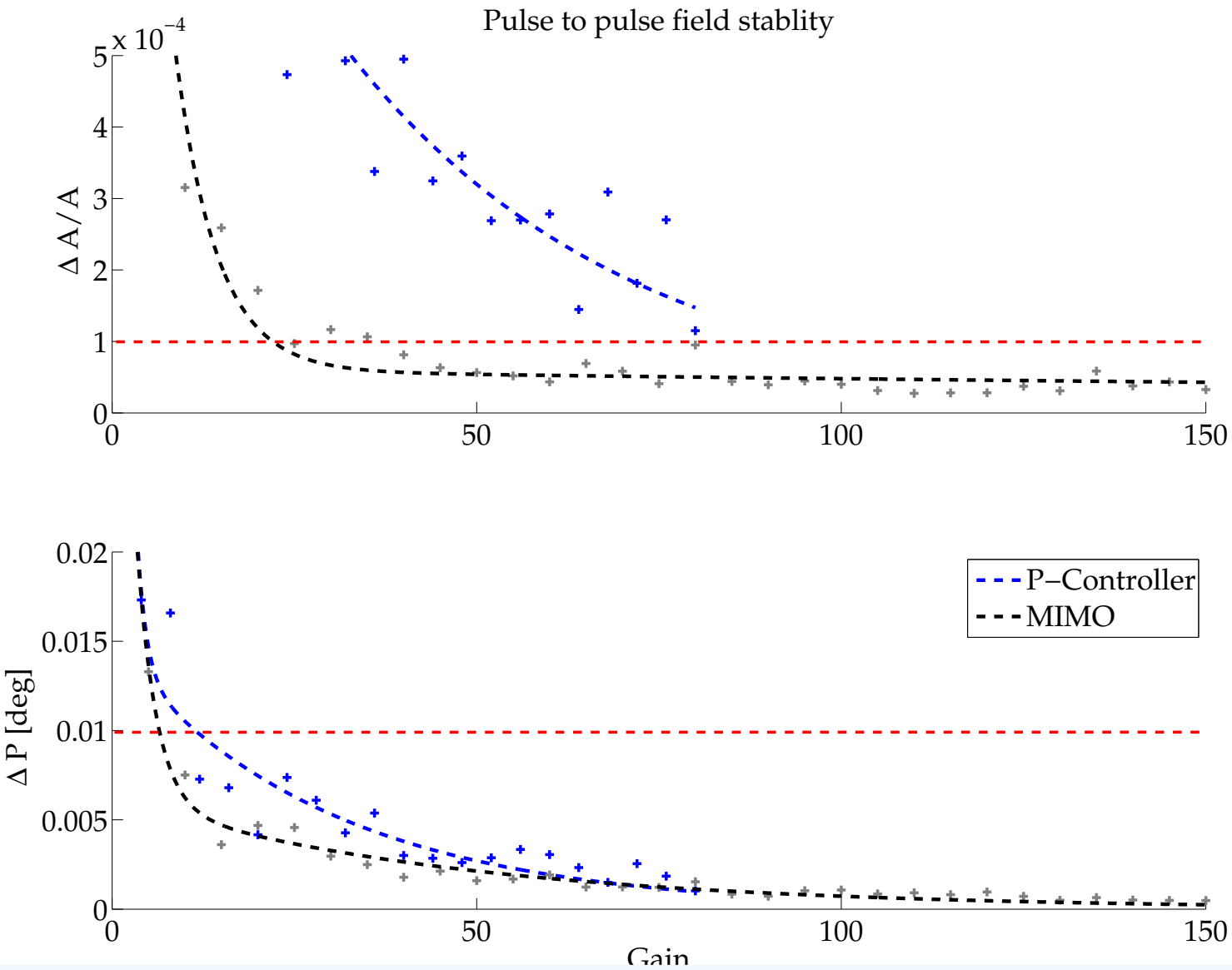
$$K_{ij}(z) = k_{ij} \frac{a_{ij} \cdot z^{-2} + b_{ij} \cdot z^{-1} + 1}{c_{ij} \cdot z^{-2} + d_{ij} \cdot z^{-1} + 1}$$

- 20 parameters have to be tuned automatically
- H_∞ design methods based on the system model
- Shaping closed loop system response

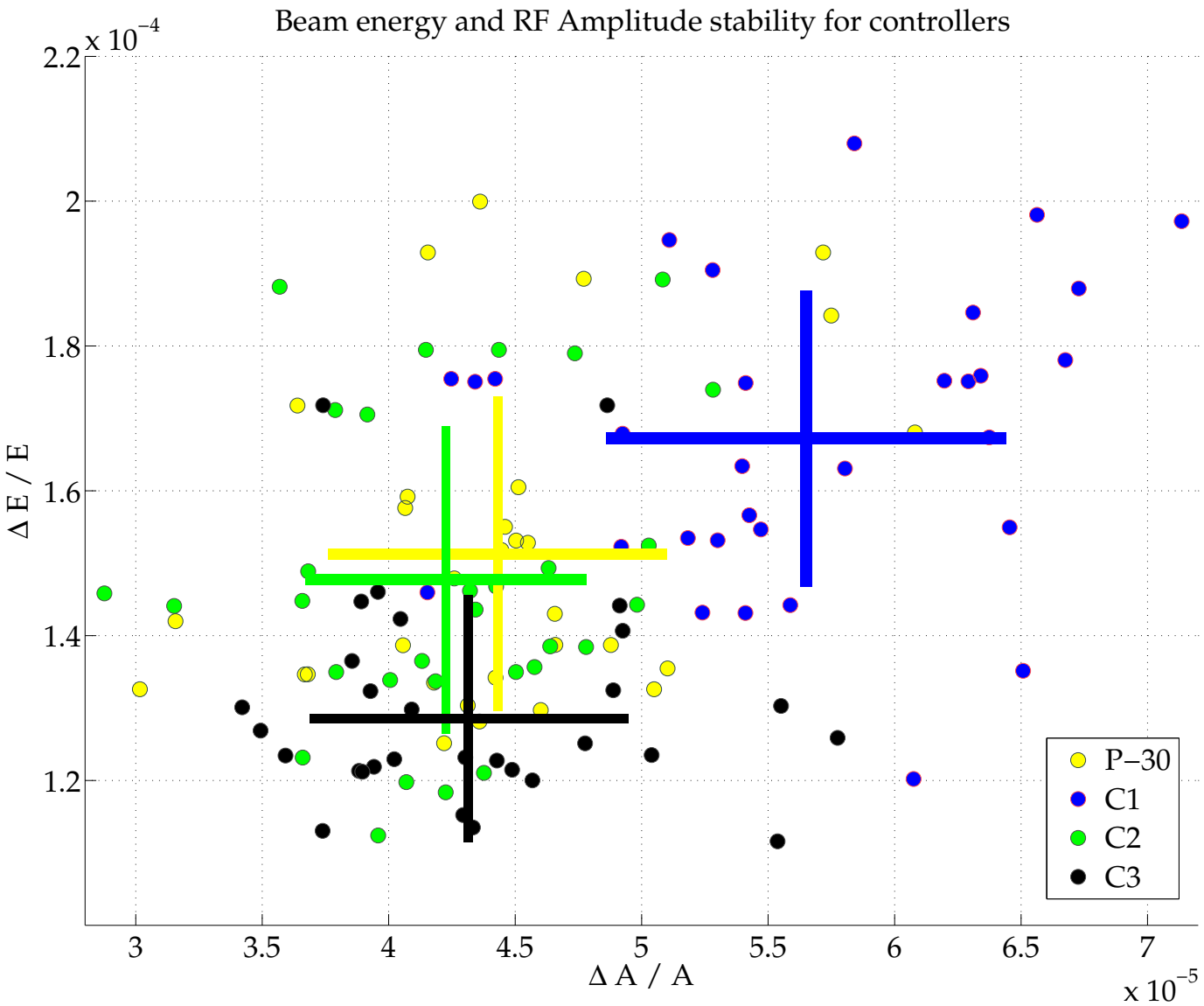
MIMO Controllers vs. proportional FB



MIMO Controllers vs. proportional FB



Validation with beam data

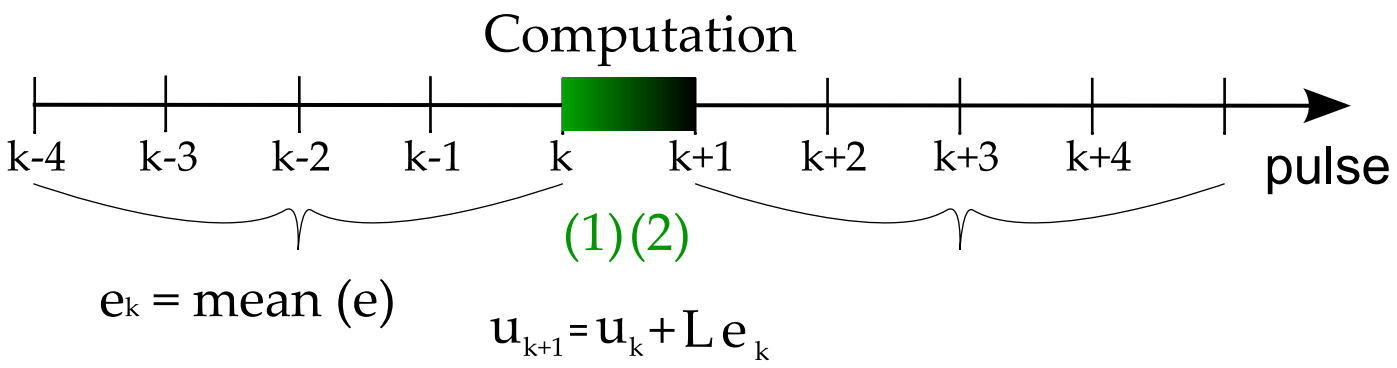


Iterative learning control (ILC)

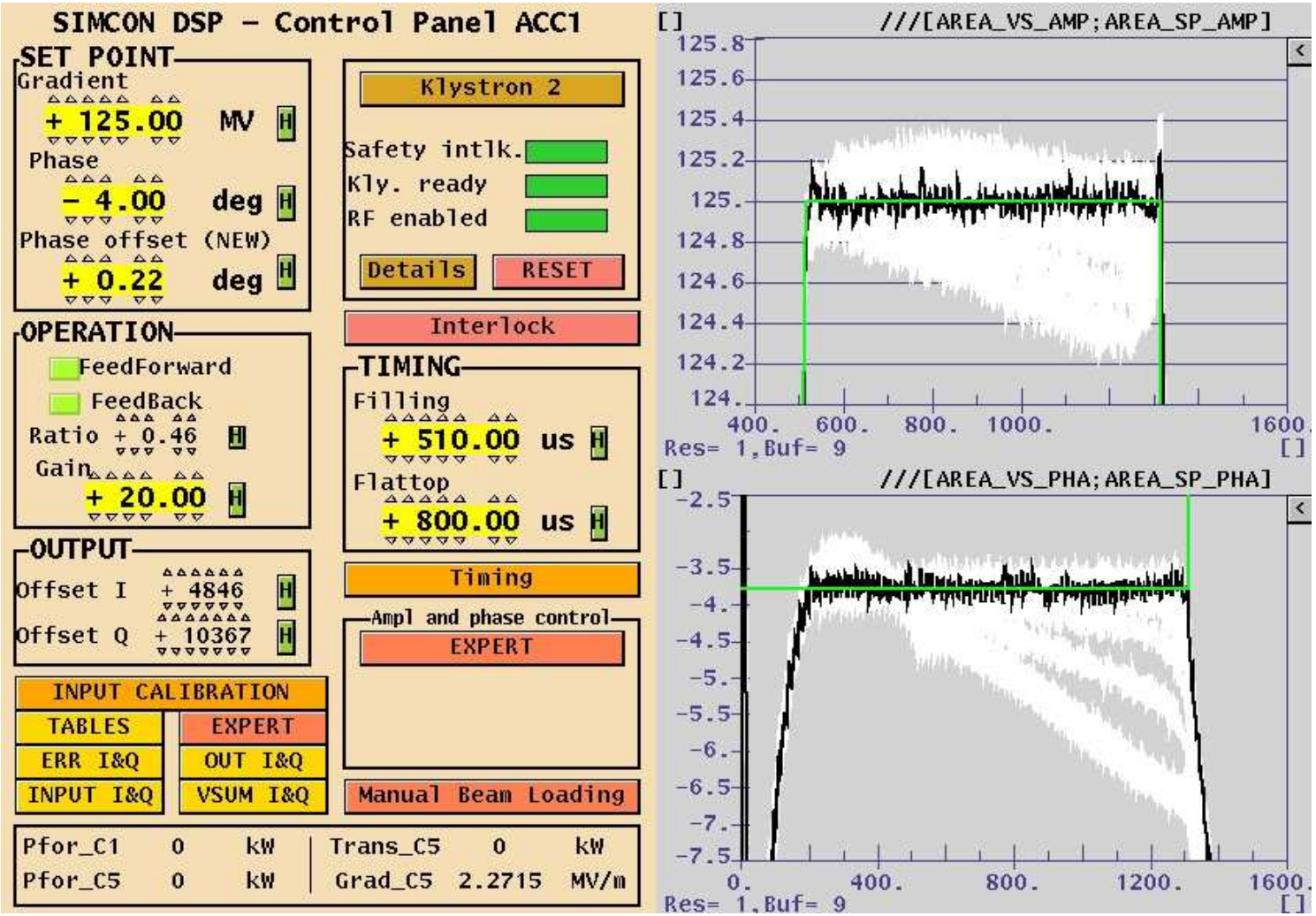
- Take information from previous pulses to optimize the Feedforward for the next pulses.
- **Issue:** Only repetitive signals can be covered!

$$u_{k+1} = u_k + L\,e_k \quad k \Rightarrow \text{number of trial}$$

$L \rightarrow$ Non causal, time varying, model based filter

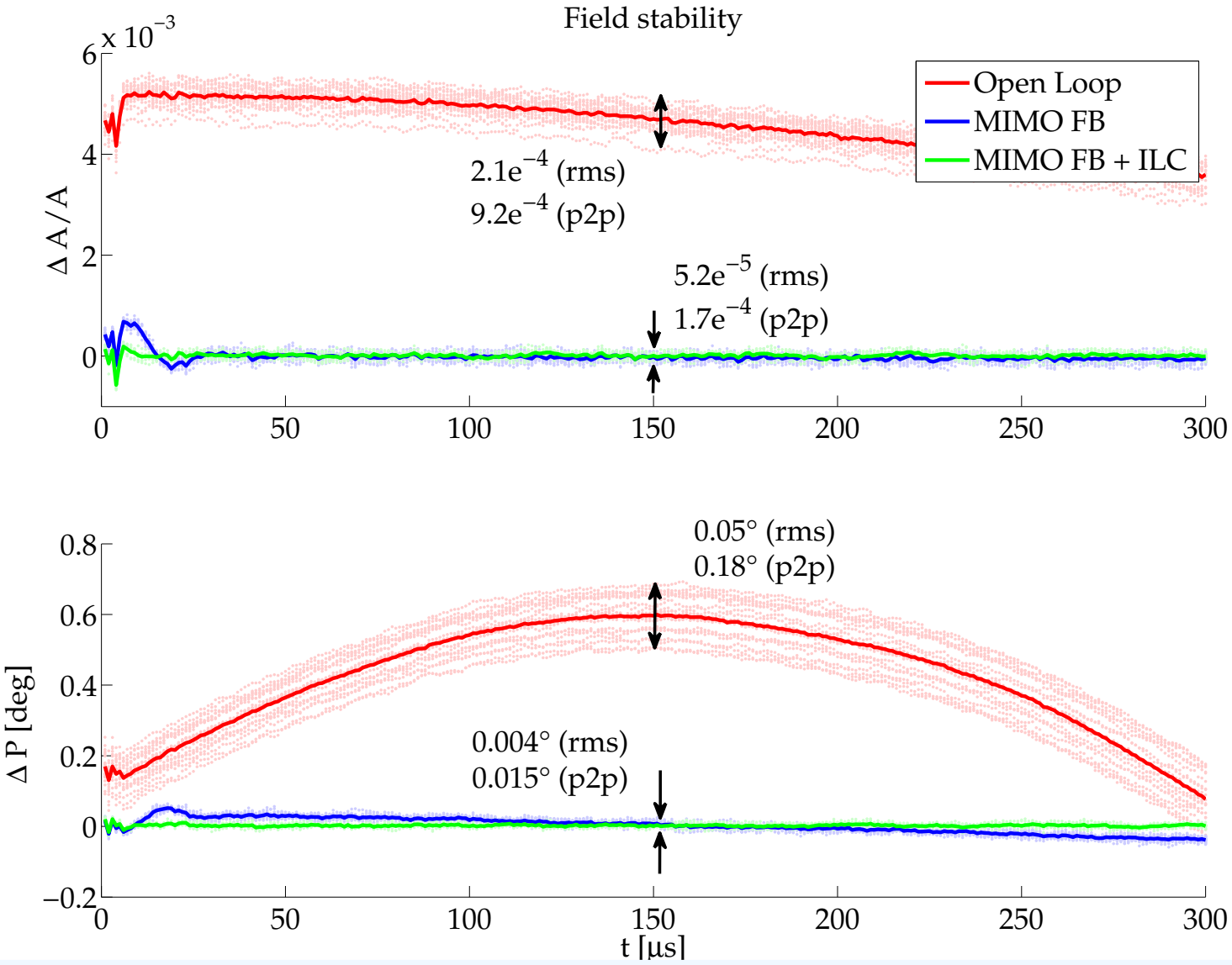


Field Adaptation using ILC

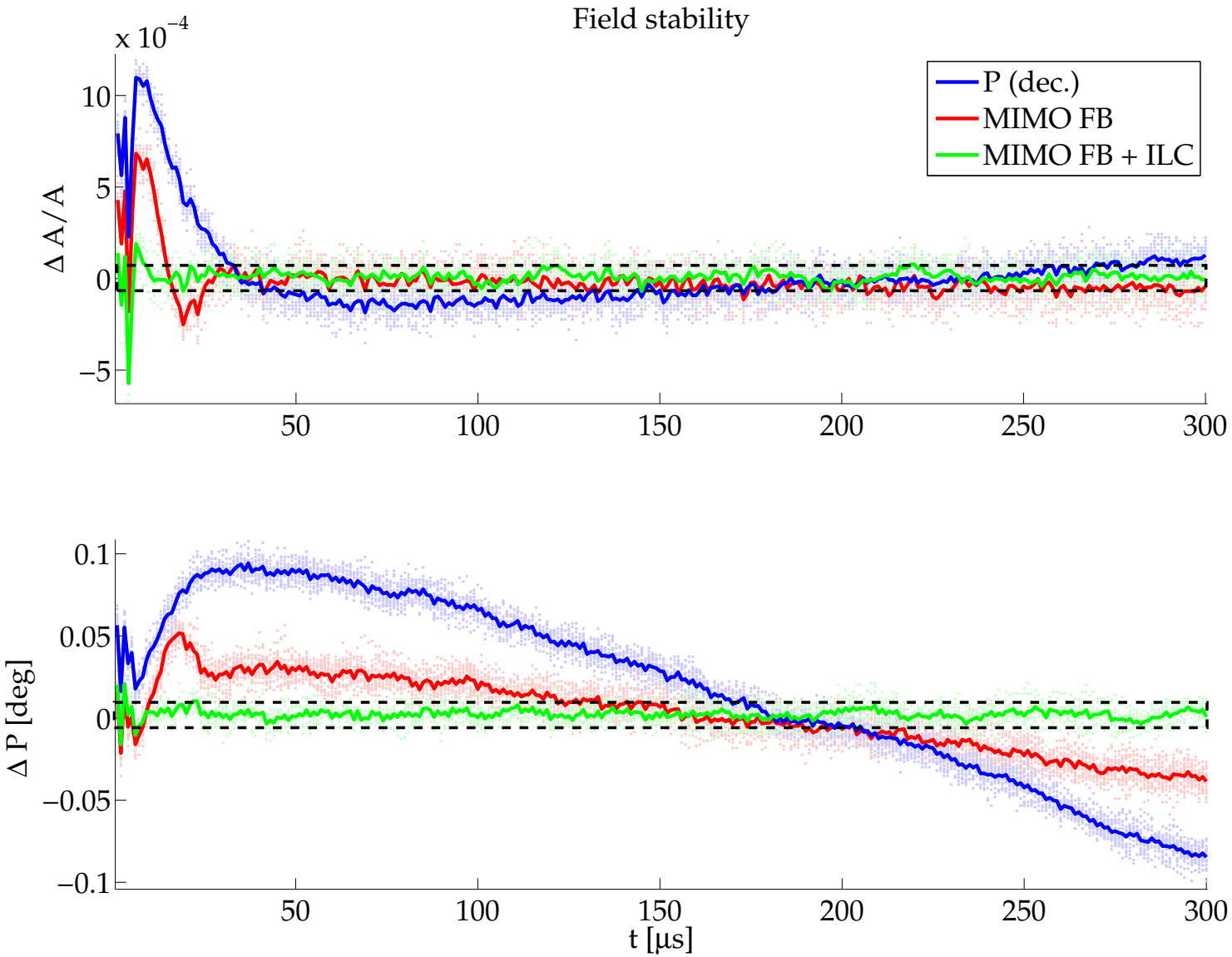


- within few steps VS-error almost compensated

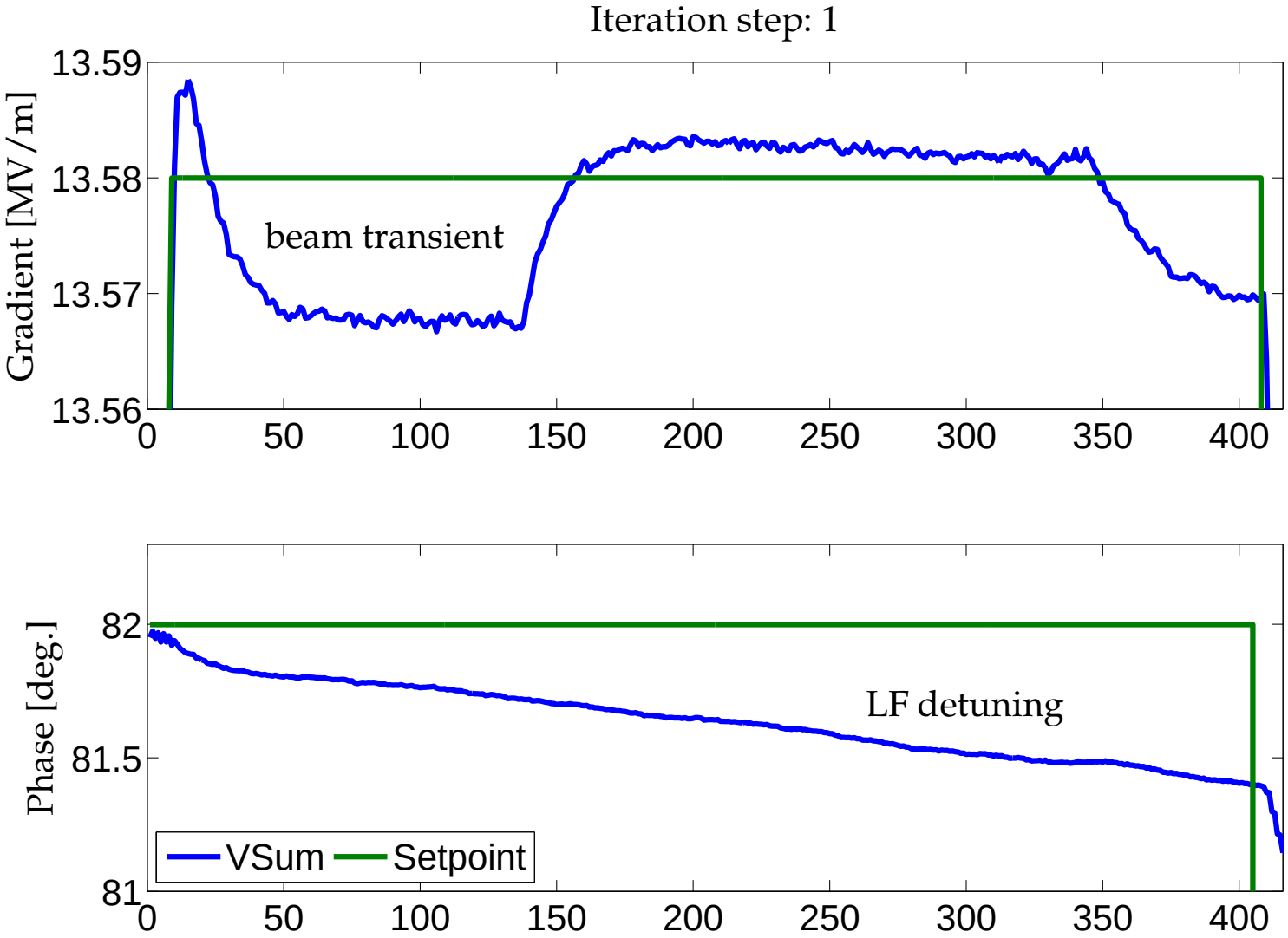
Improvements using MIMO FB and ILC



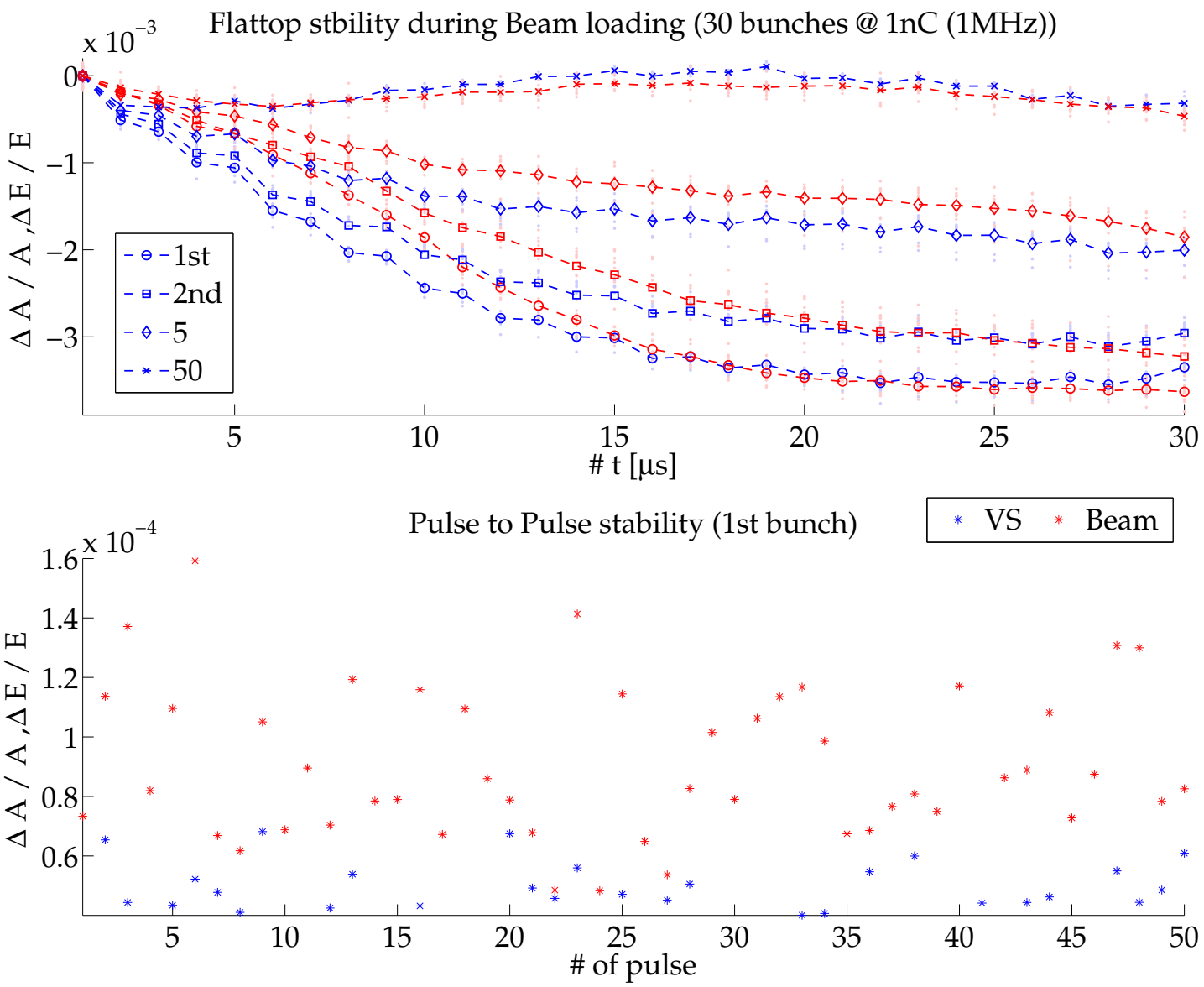
Comparison of new Controller vs. usual FB



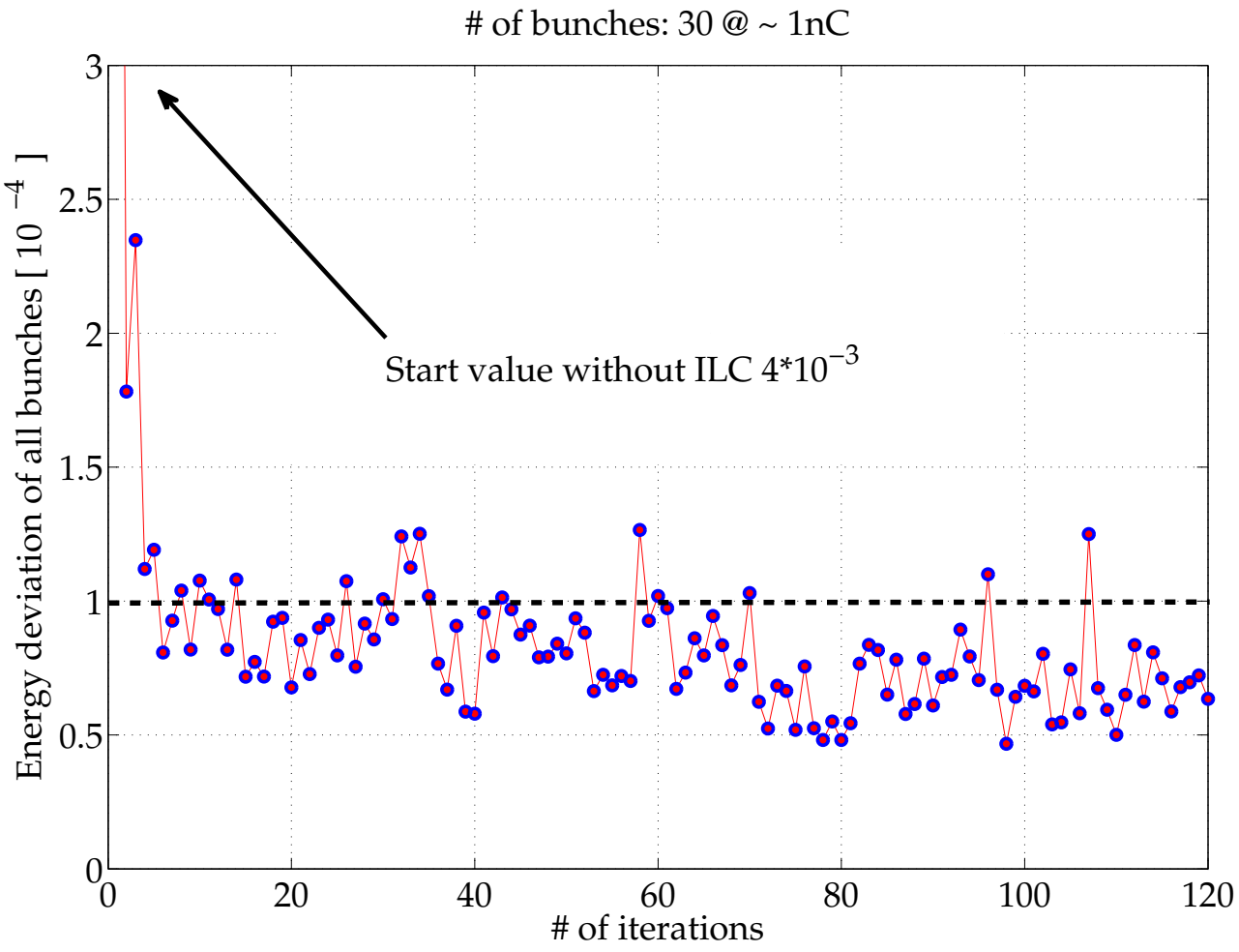
Adaptation of the RF field using MIMO FB + ILC



Correlation beam and field adaptation

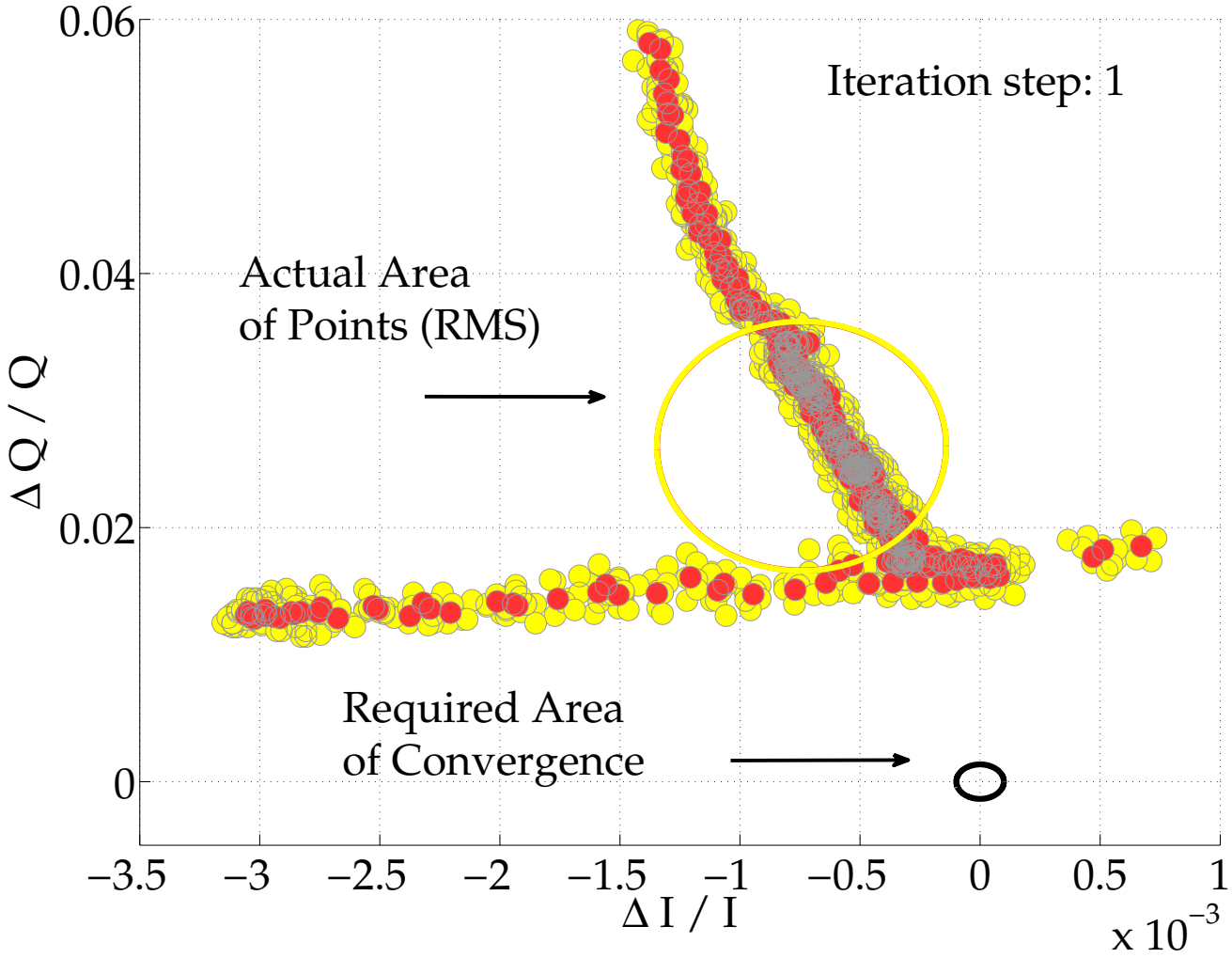


Algorithm convergence

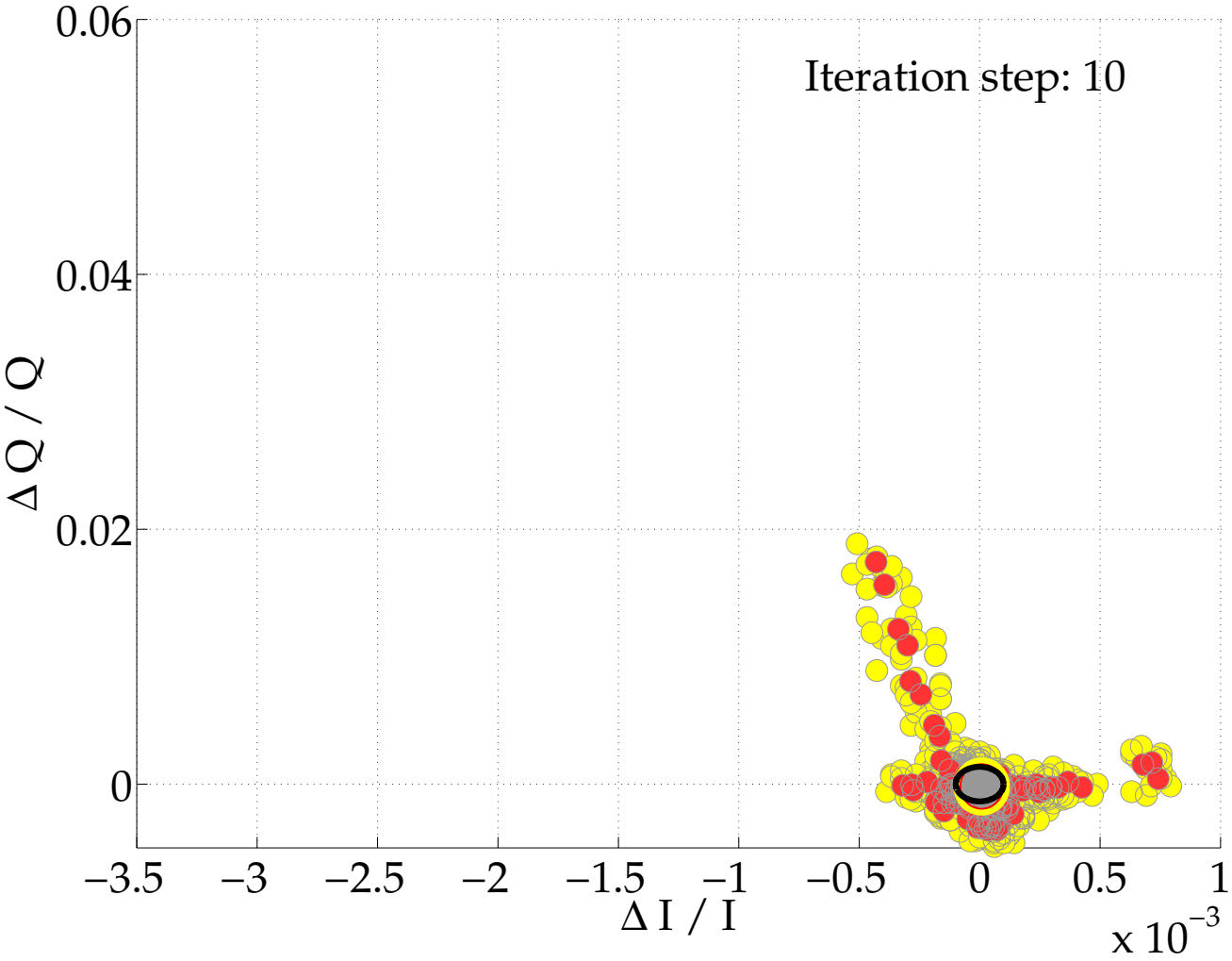


- Fast convergence but long term stable?

Error signal in I and Q



Error signal in I and Q



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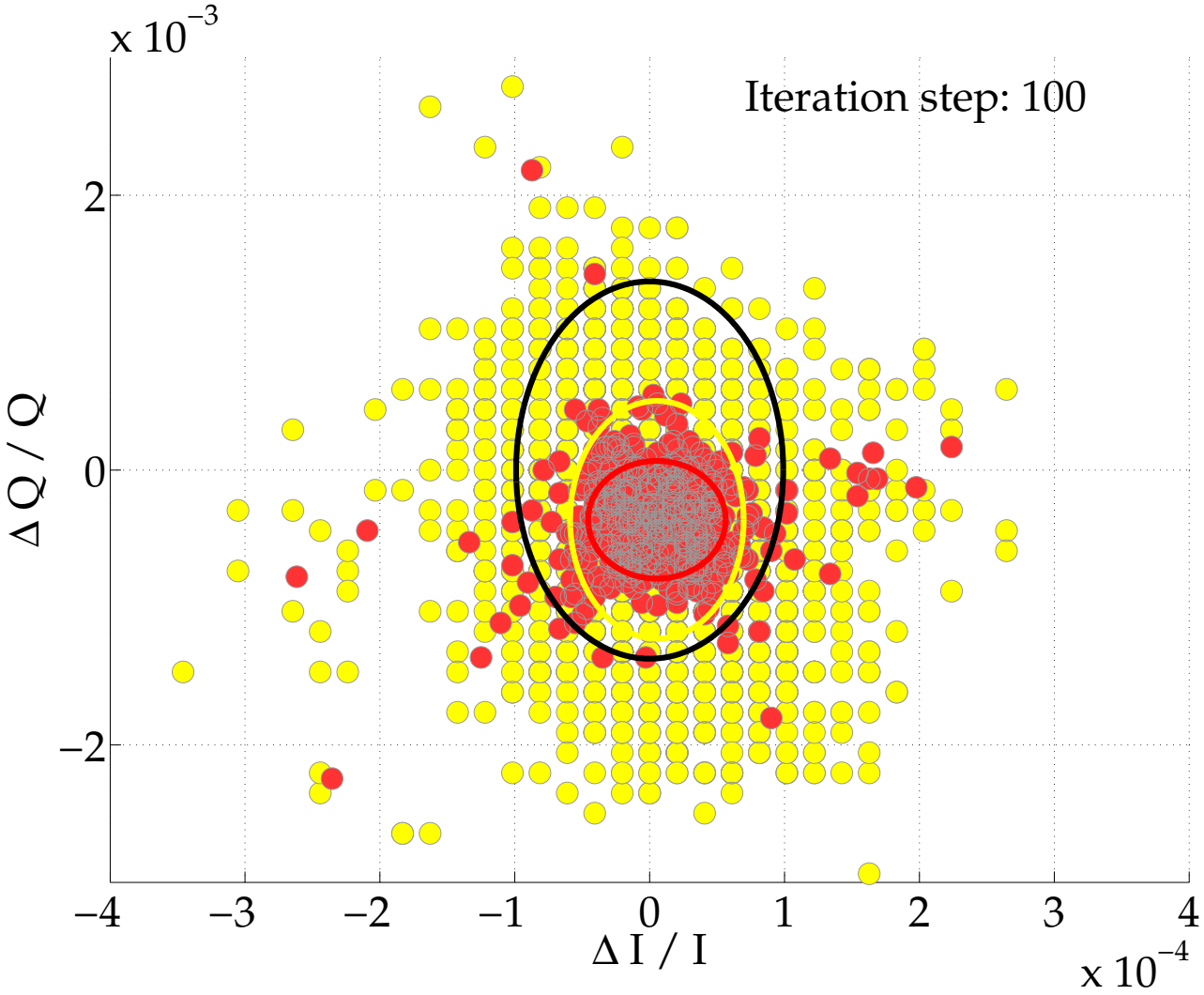
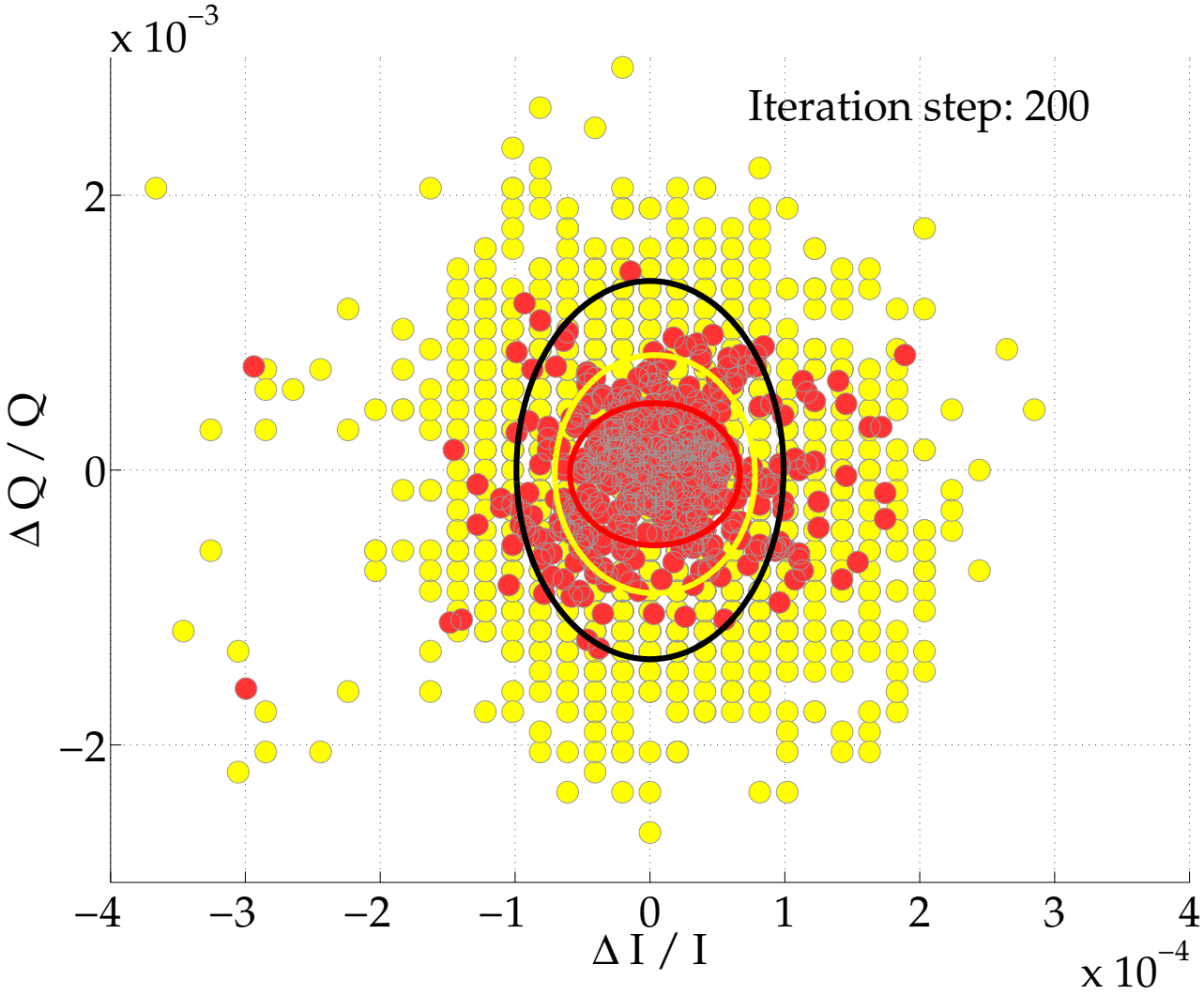
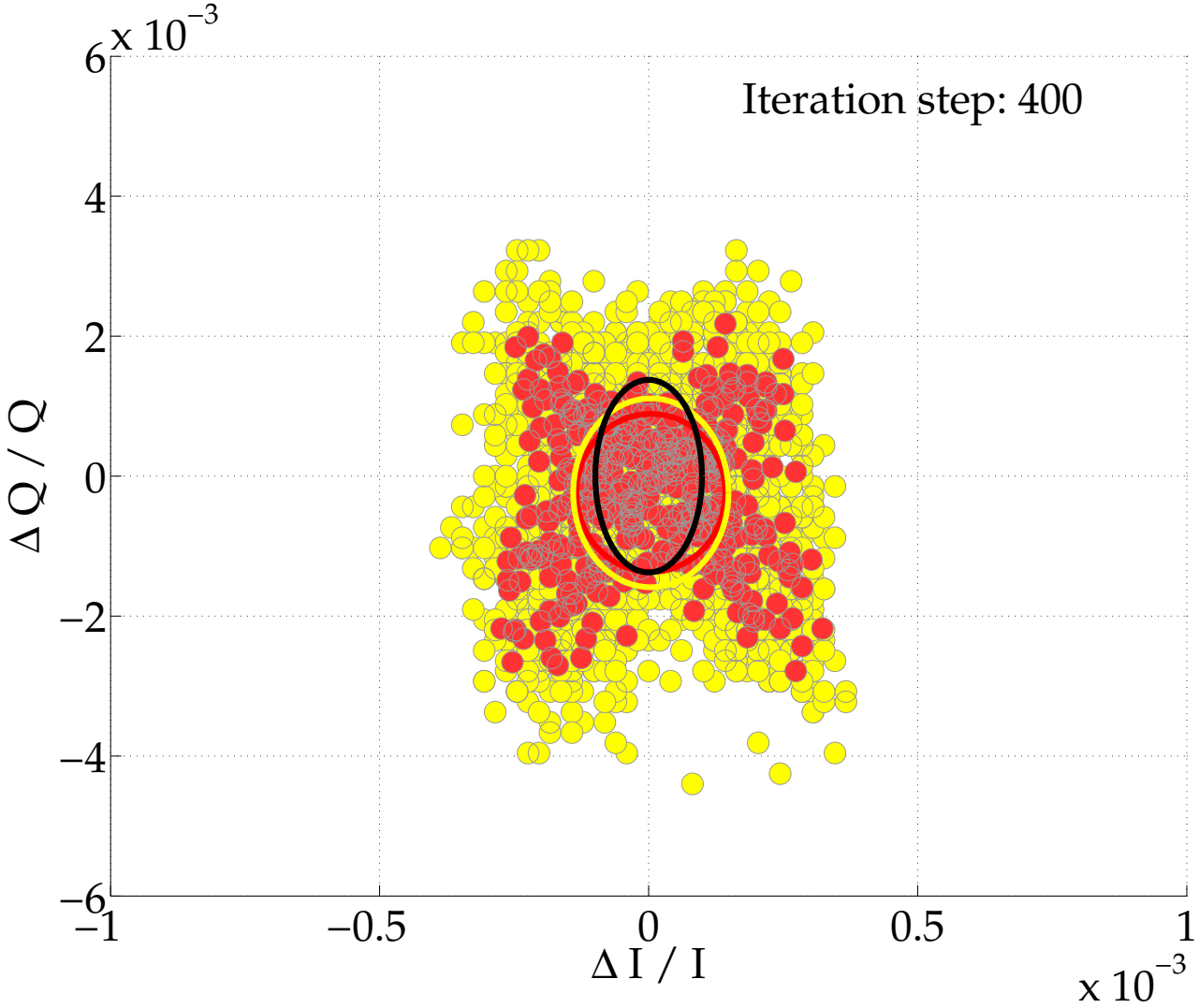


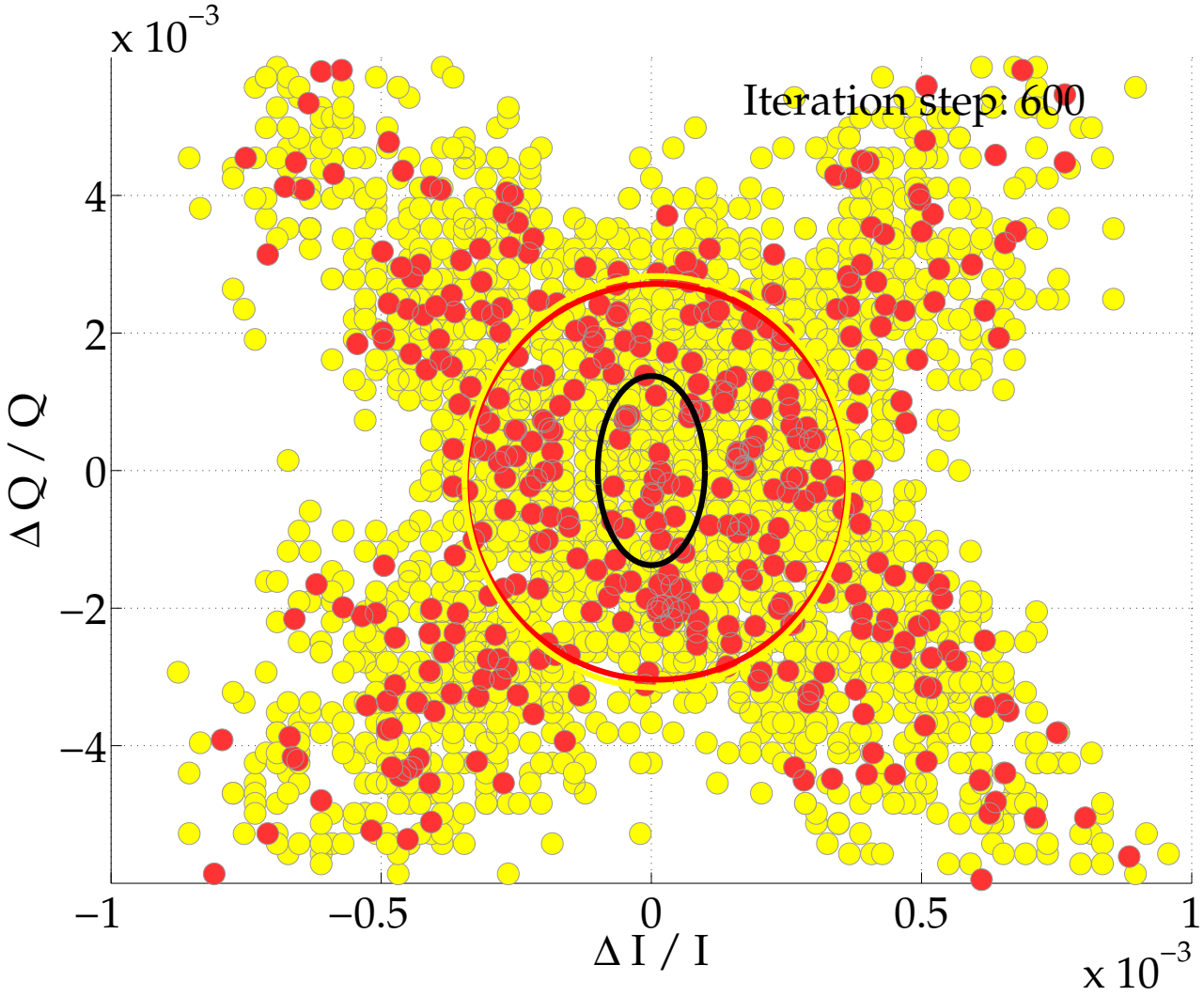
Error signal in I and Q



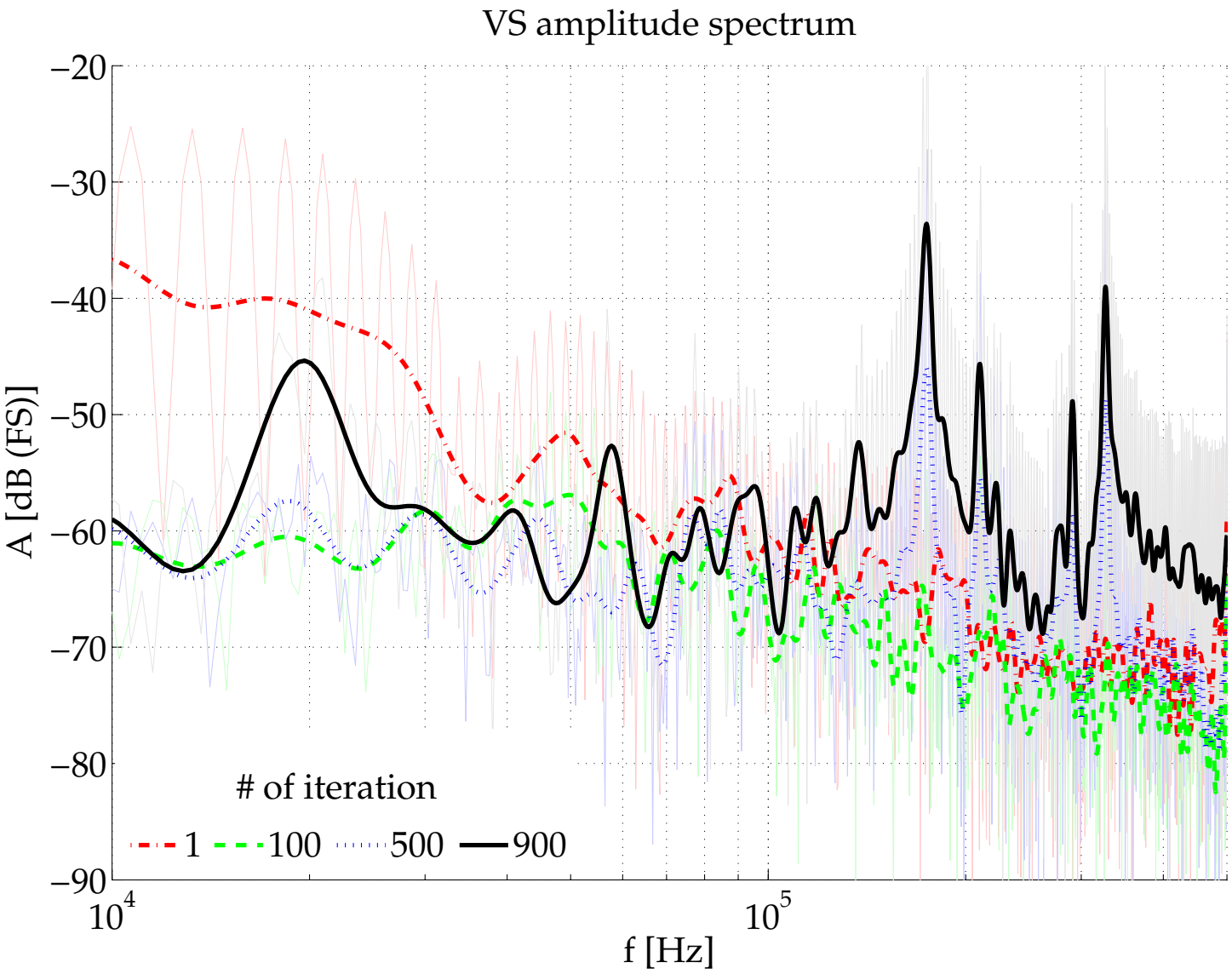
Error signal in I and Q



Error signal in I and Q

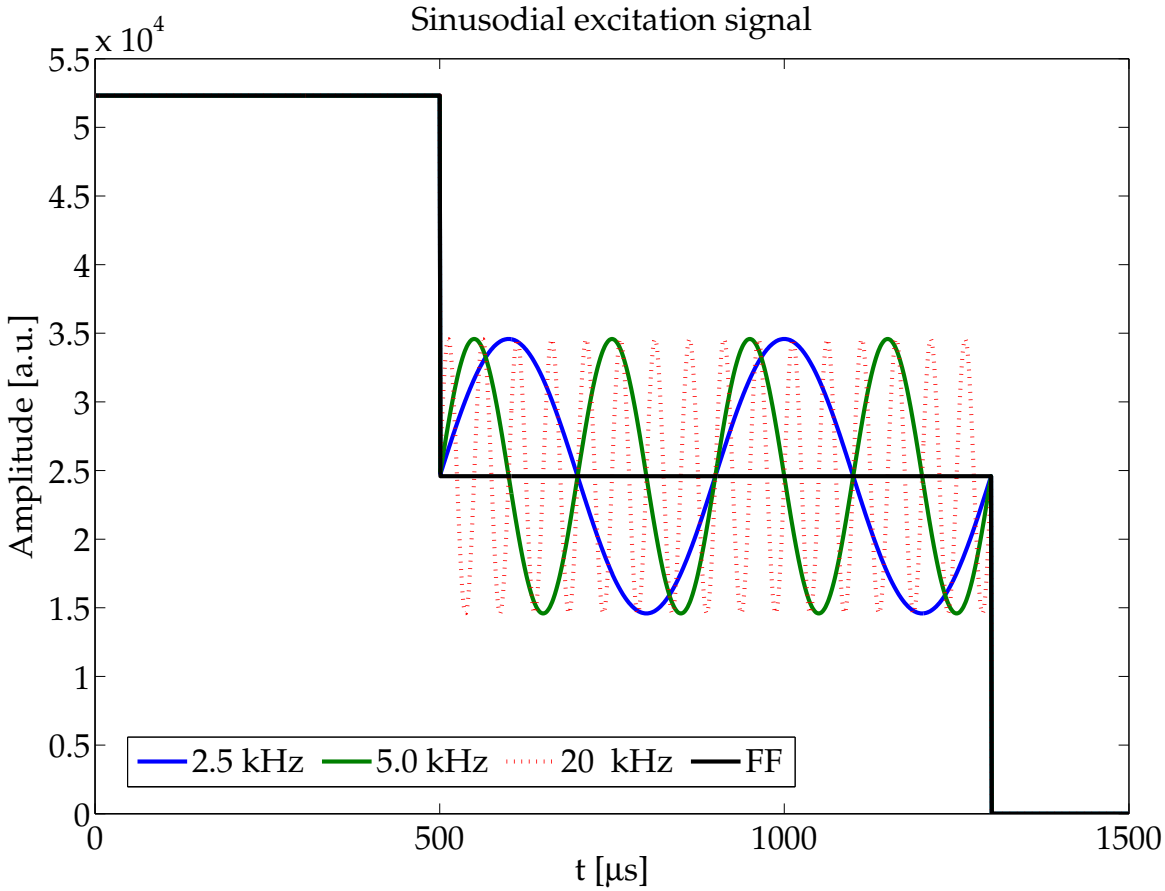


Spectrum of error signal

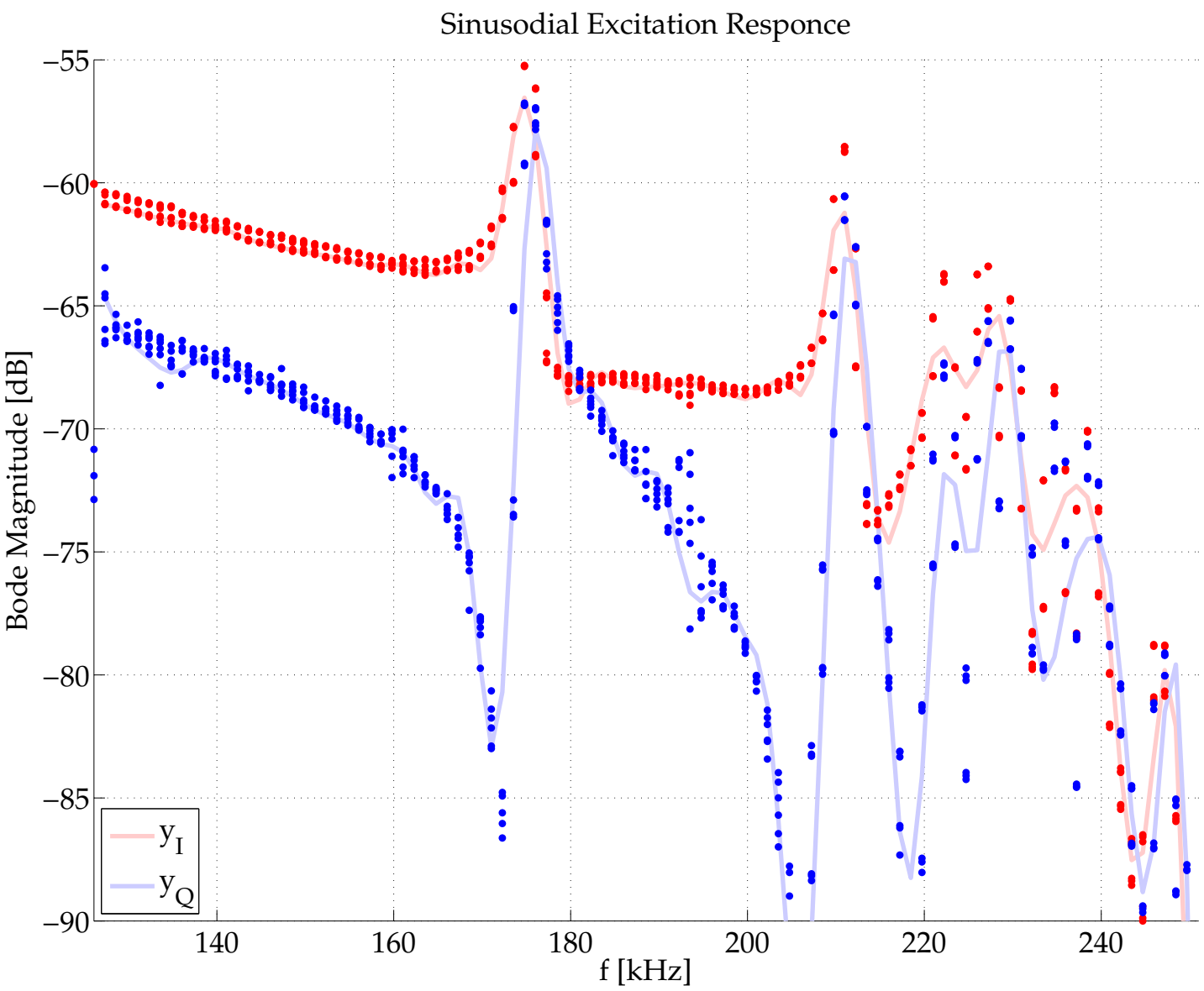


Excitation with stable oscillations

- Sweeping frequency sin-waves
- Stable uniform excitation frequency signal
- Searching for resonance peaks

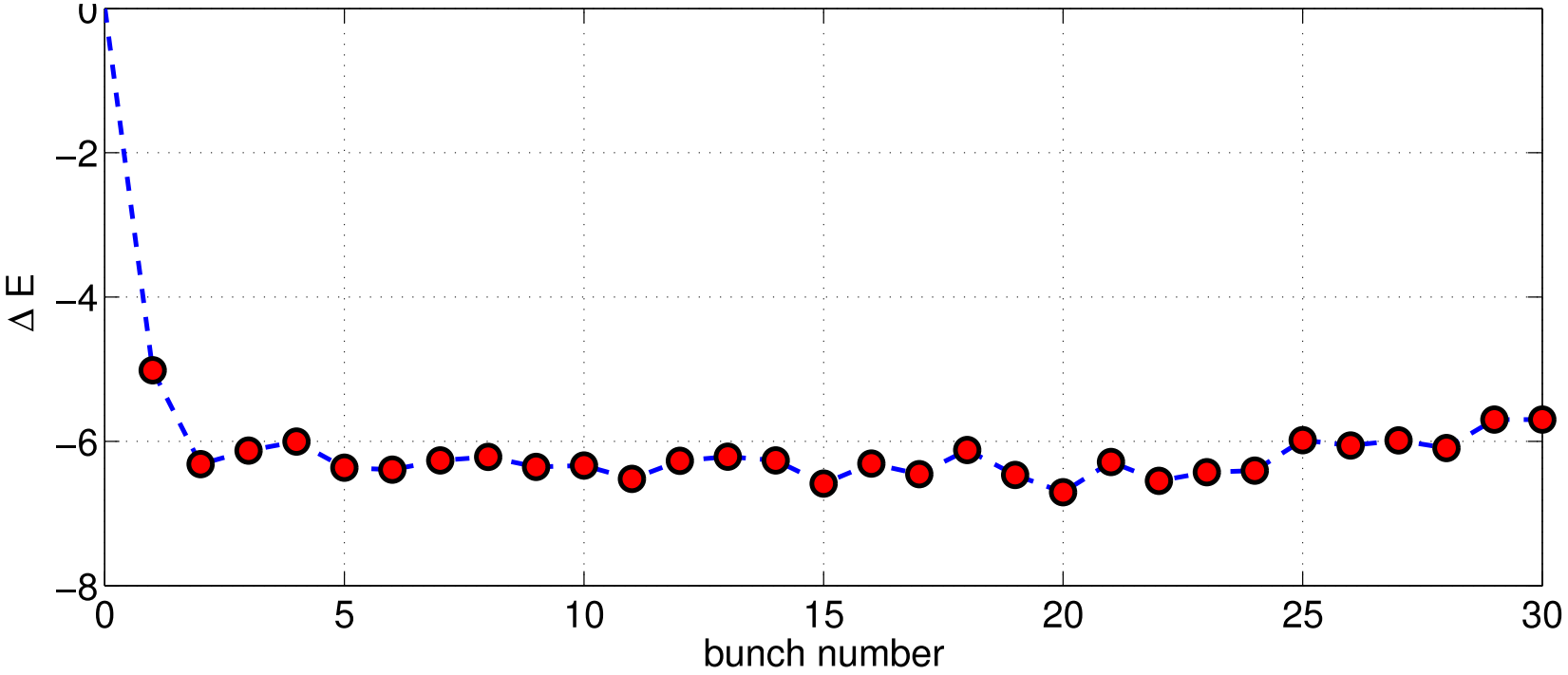


System response to excitation in channel I

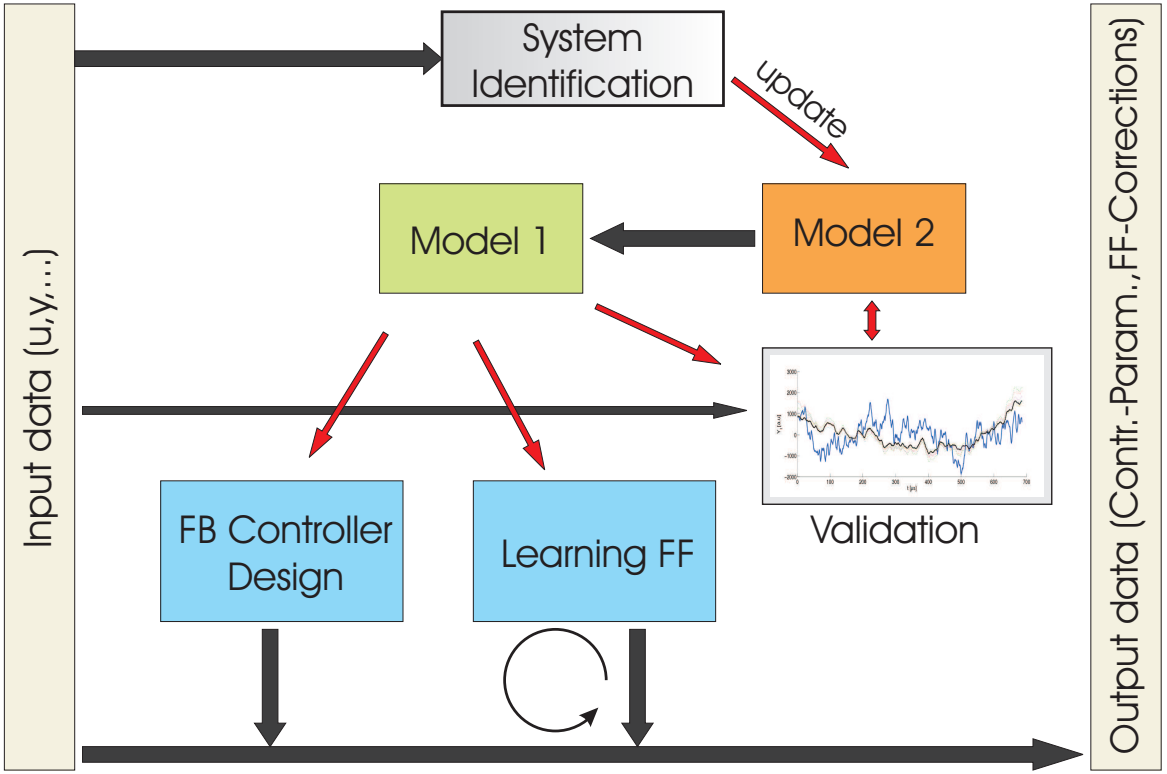


Conclusion and Outlook

- System modeling procedure reliable
- Designed MIMO-FB controller improves field regulation
- Iterative learning control algorithm successfully tested
- Compensation of beam loading and detuning effects



Model based controller design



- Frequently offline updating the system model by using black box identification methods
- Feedforward and Feedback Controller design