High Speed Beam-Based Feedback

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2nd ARD ST3 Workshop

HZDR, Dresden

26.02.2014

HELMHOLTZ ASSOCIATION

DESY

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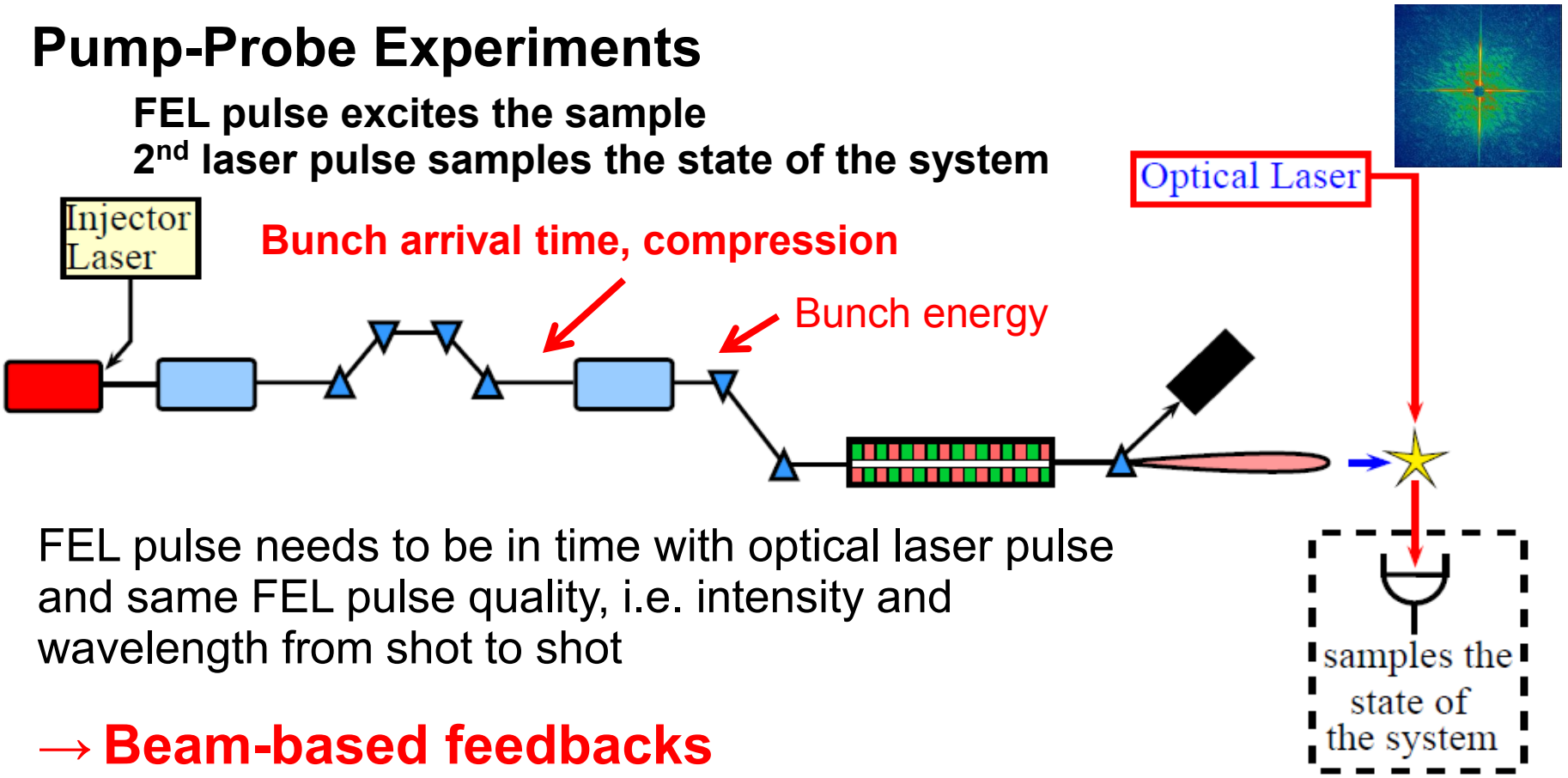
Principle of Free – Electron Laser

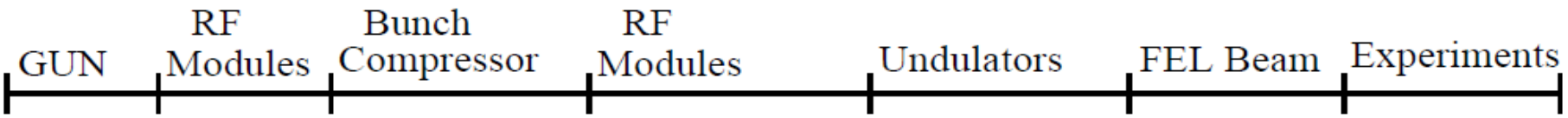
Pump-Probe Experiments

FEL pulse excites the sample
2nd laser pulse samples the state of the system



FEL pulse needs to be in time with optical laser pulse and same FEL pulse quality, i.e. intensity and wavelength from shot to shot

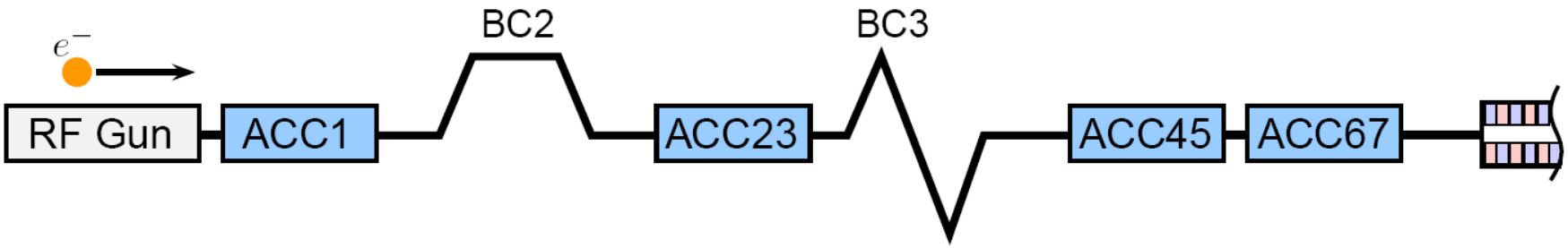
→ **Beam-based feedbacks**



Linear Accelerators at DESY in Hamburg

European XFEL – currently under construction

FLASH – in operation (test bench for XFEL)



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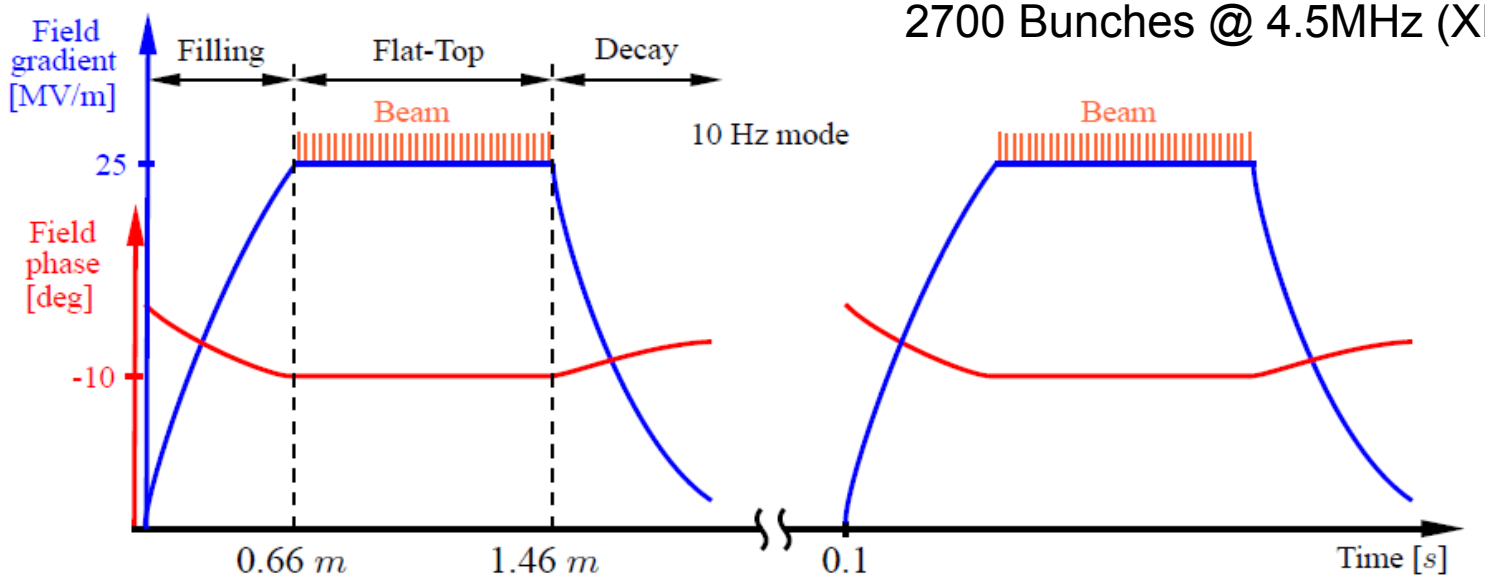
RF Field Control

Radio Frequency Field → *Control Strategies*

Pulsed operation - 10 Hz
2ms pulse length
(Filling, Flattop and Decay)

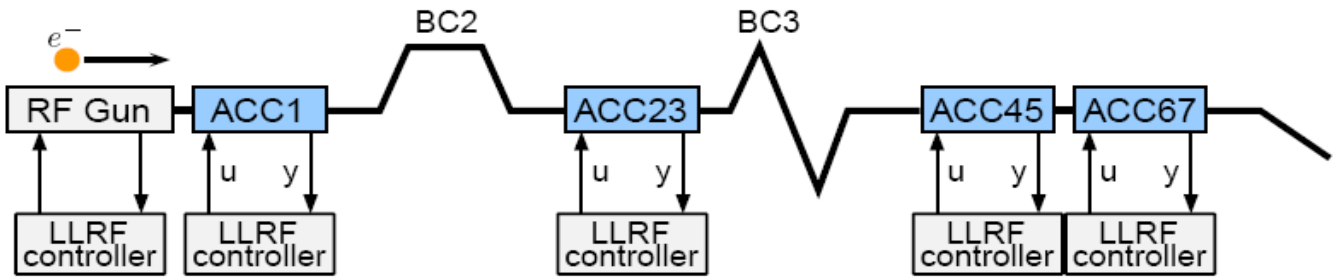
1) **Adaptation by Learning**
2) **Fast Controller (FPGA)**

2400 Bunches @ 3MHz (FLASH),
2700 Bunches @ 4.5MHz (XFEL)

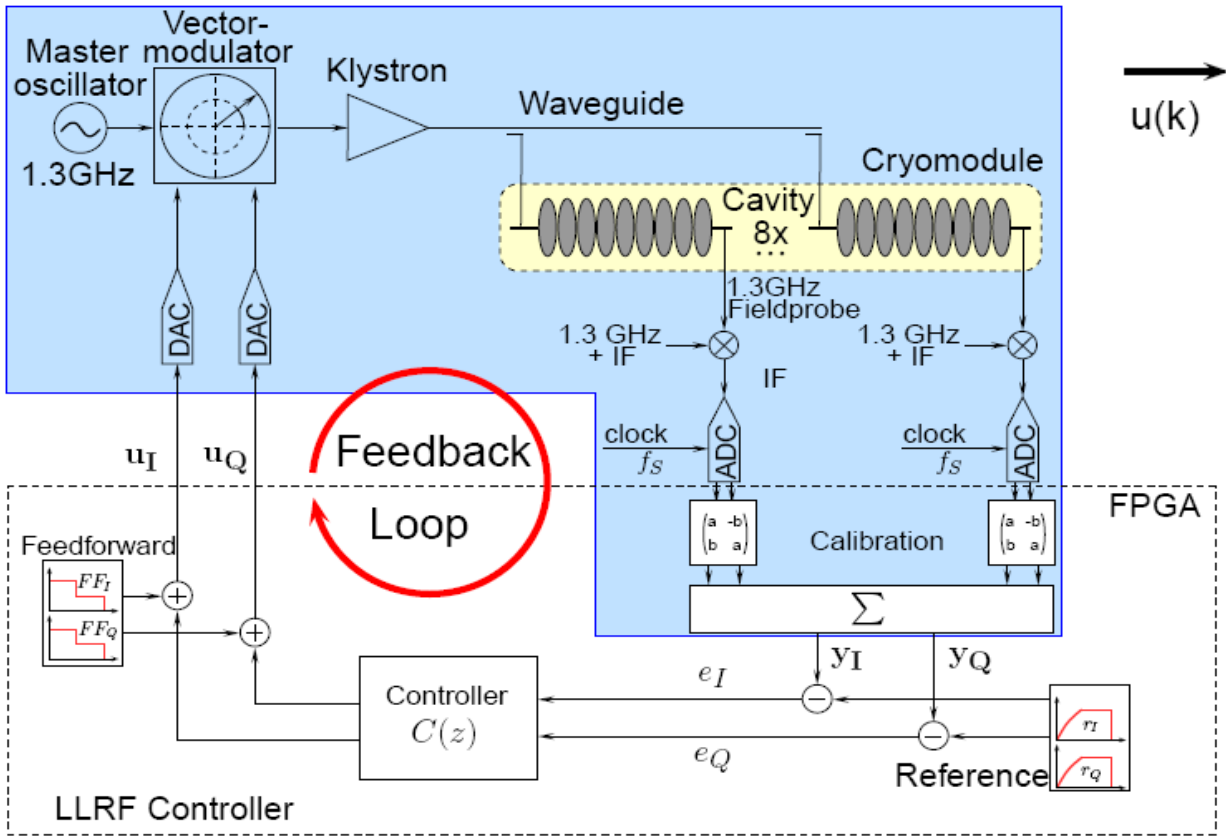


Model-Based Controller Design
to reach ΔA/A < 0.01% and Δφ < 0.01 deg.

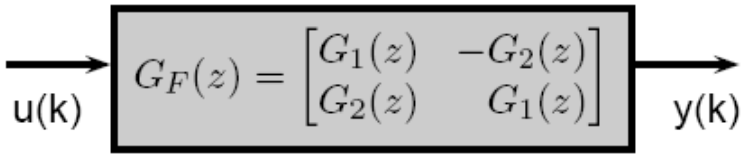
System Overview (FLASH)

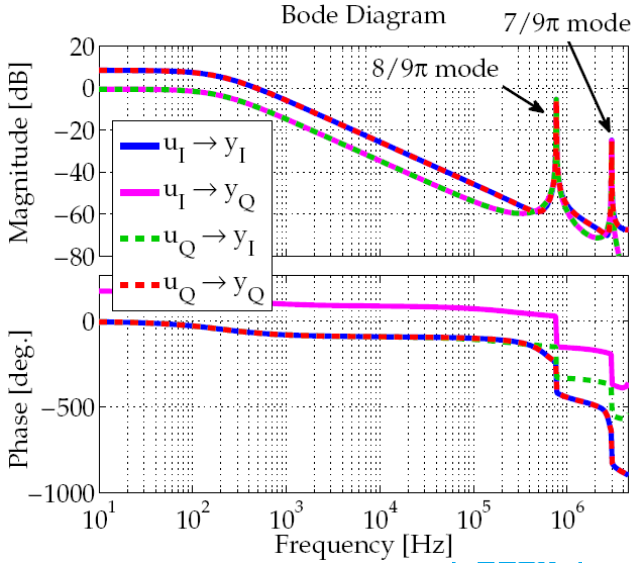


RF Field
I/Q control

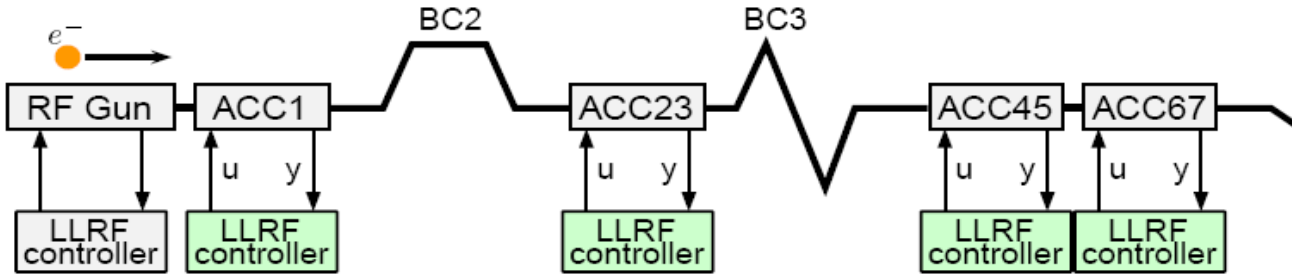


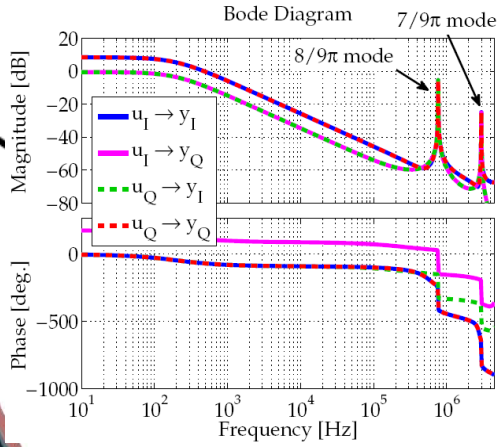
SO(2) - Grey Box Model





RF Field Controller





$$C(z) = \begin{bmatrix} C_{II}(z) & C_{IQ}(z) \\ C_{QI}(z) & C_{QQ}(z) \end{bmatrix}$$

2nd order IIR → only 1 passband mode possible

→ 8/9 pi mode by *cavity based notch filters* on SIS8300

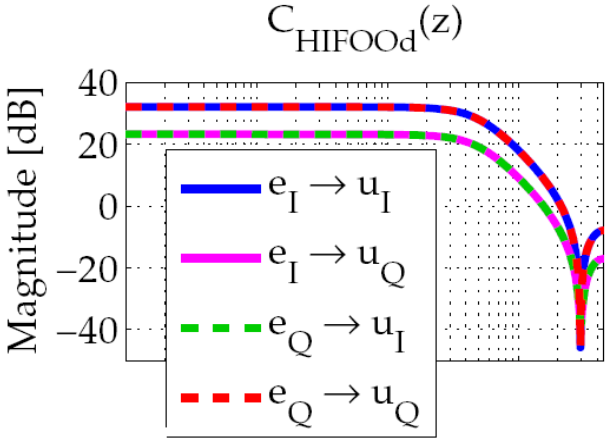
Controller Implementation on FPGA - 2nd order IIR

$$C_{ij}(z) = \frac{b_0 + b_1 z^{-1} + b_2 z^{-2}}{1 + a_1 z^{-1} + a_2 z^{-2}}$$

20 Parameters to optimize →

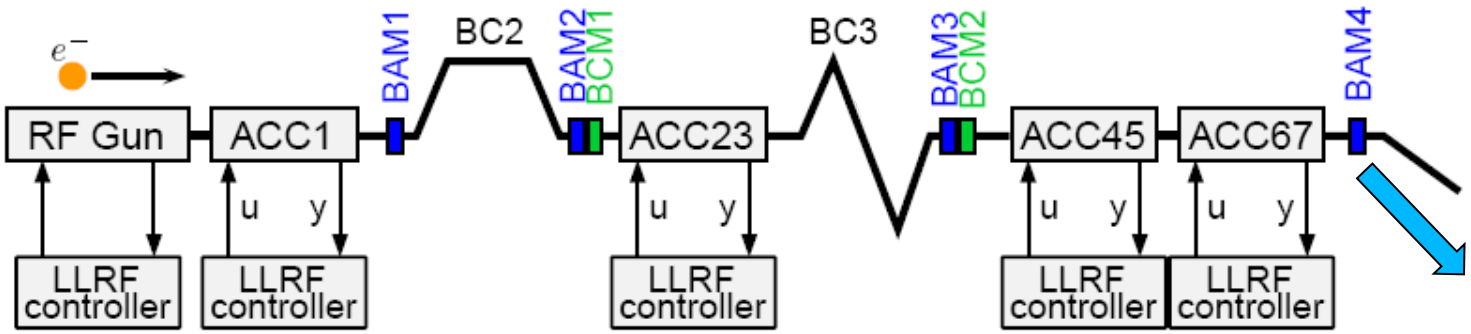
Reduced by Factor 2 → 10 Parameters

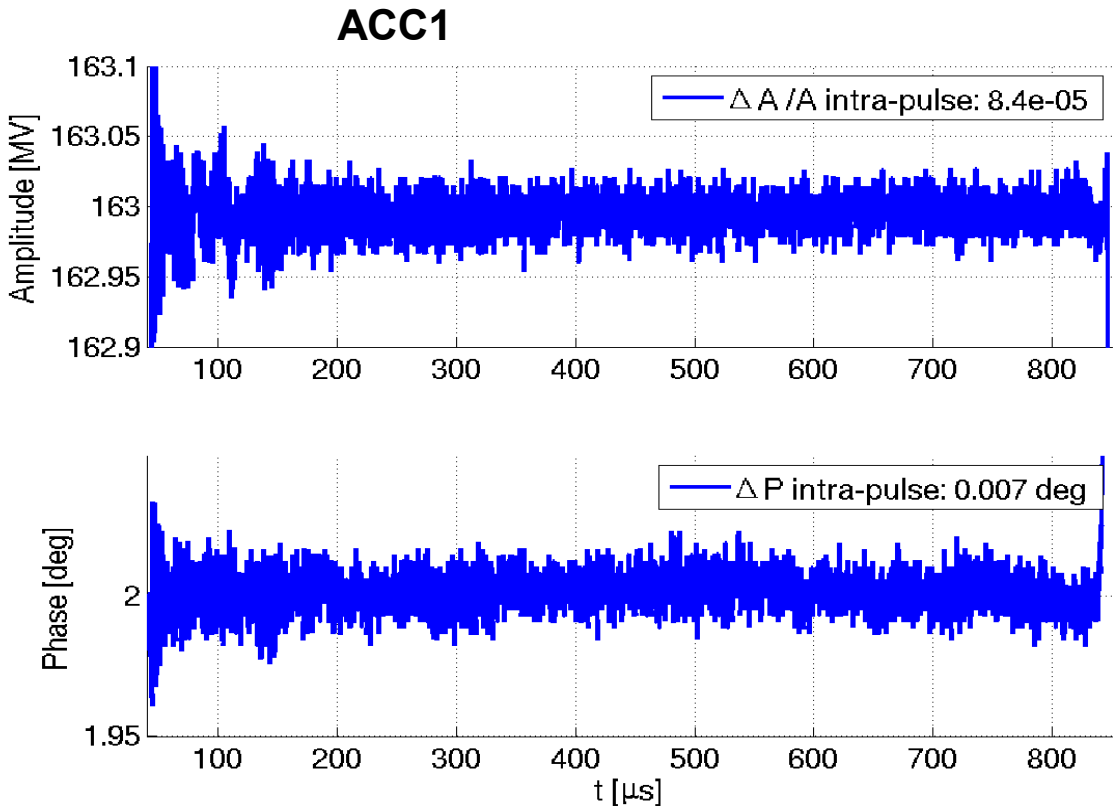
Here: $\mathcal{H}_\infty$ - Design with HIFOOd



Talk: C. Schmidt

RF Field Controller





Optimal RF Field Control

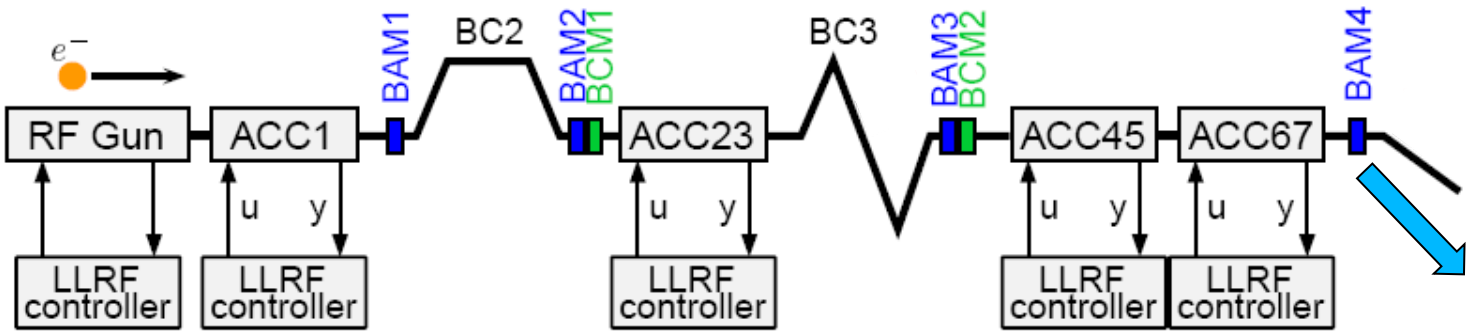
ΔA/A < 0.008 %
Δφ ~ 7 mdeg.

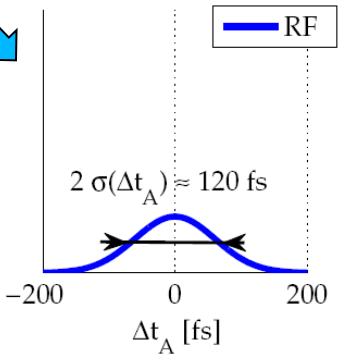
(MTCA Standard)

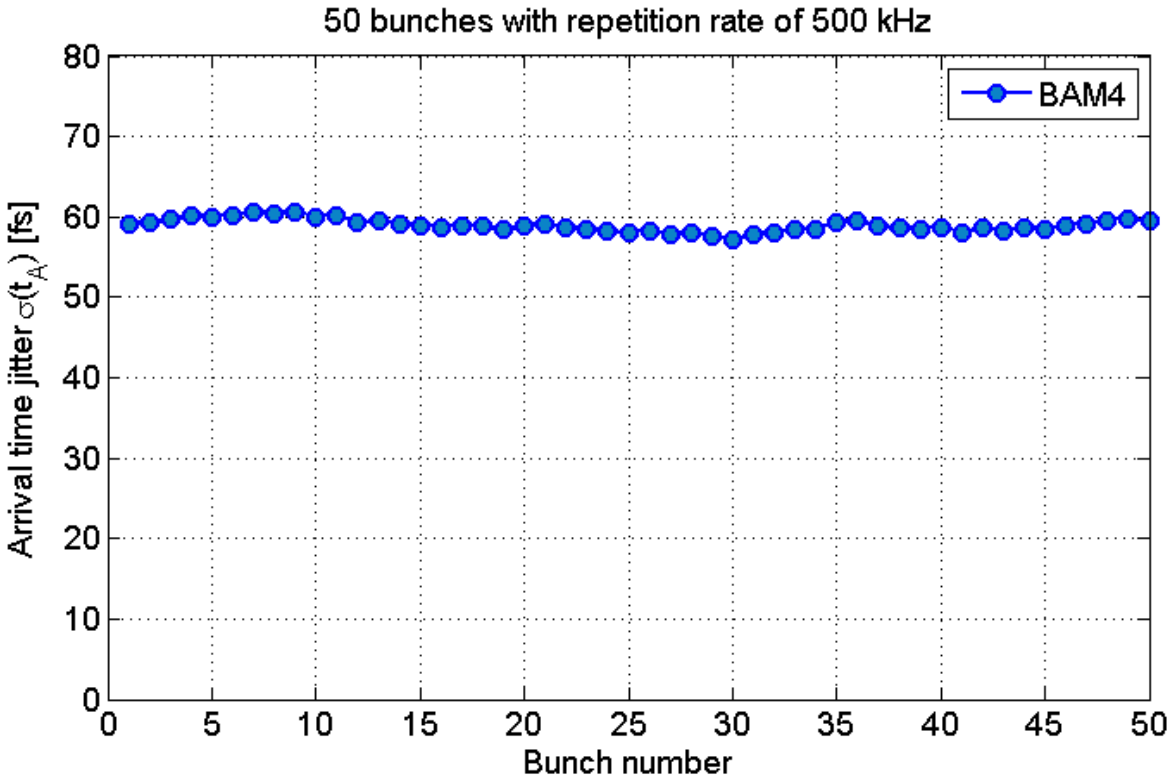
Talk:
C. Schmidt

Next:
Beam-based results
only for VME

RF Field Controller







Optimal RF Field Control

$t_A \approx 60$ fs

(VME standard)

Next: Beam-based FB to improve arr. time jitter

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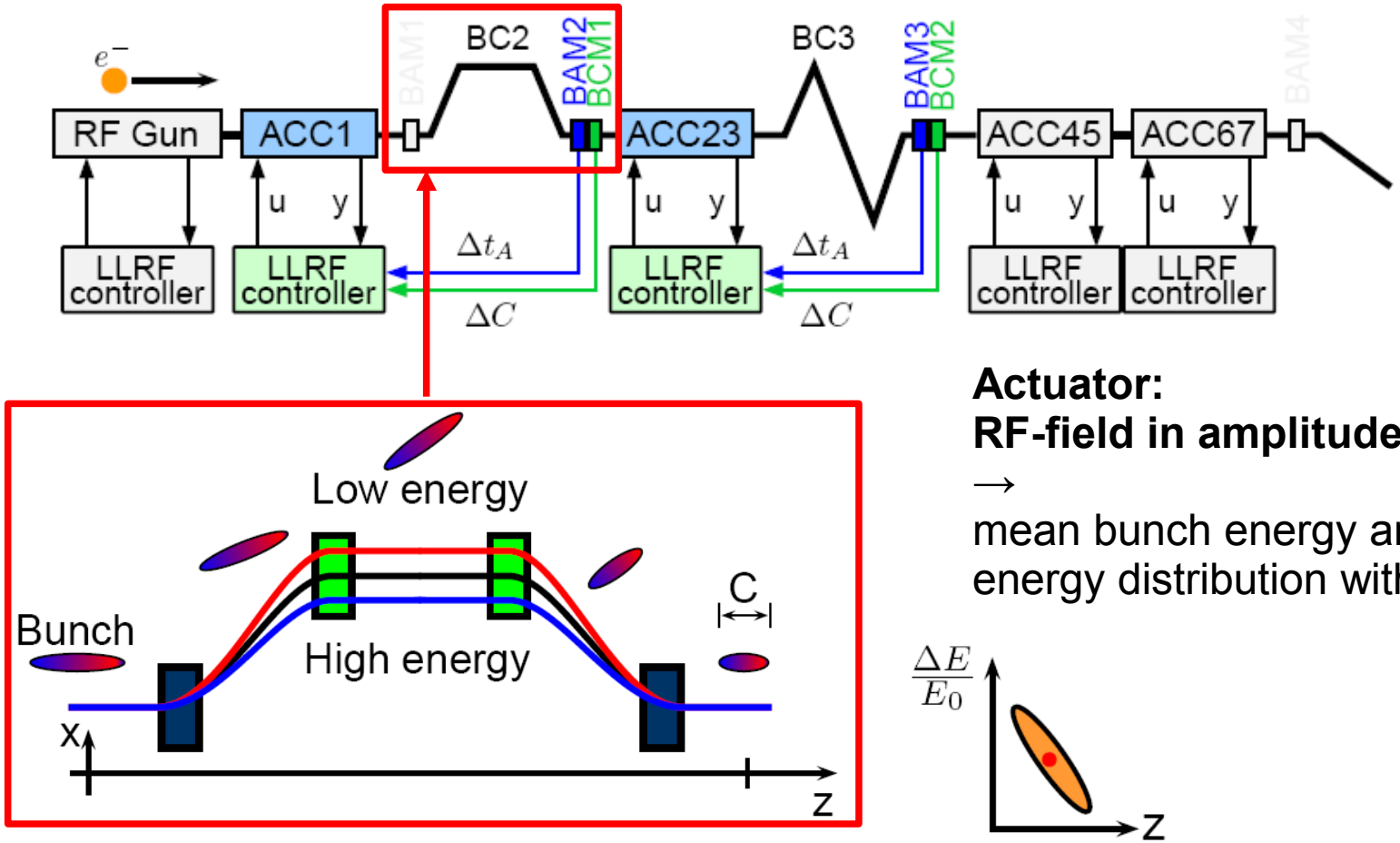
Bunch Arrival Time and Compression Feedback

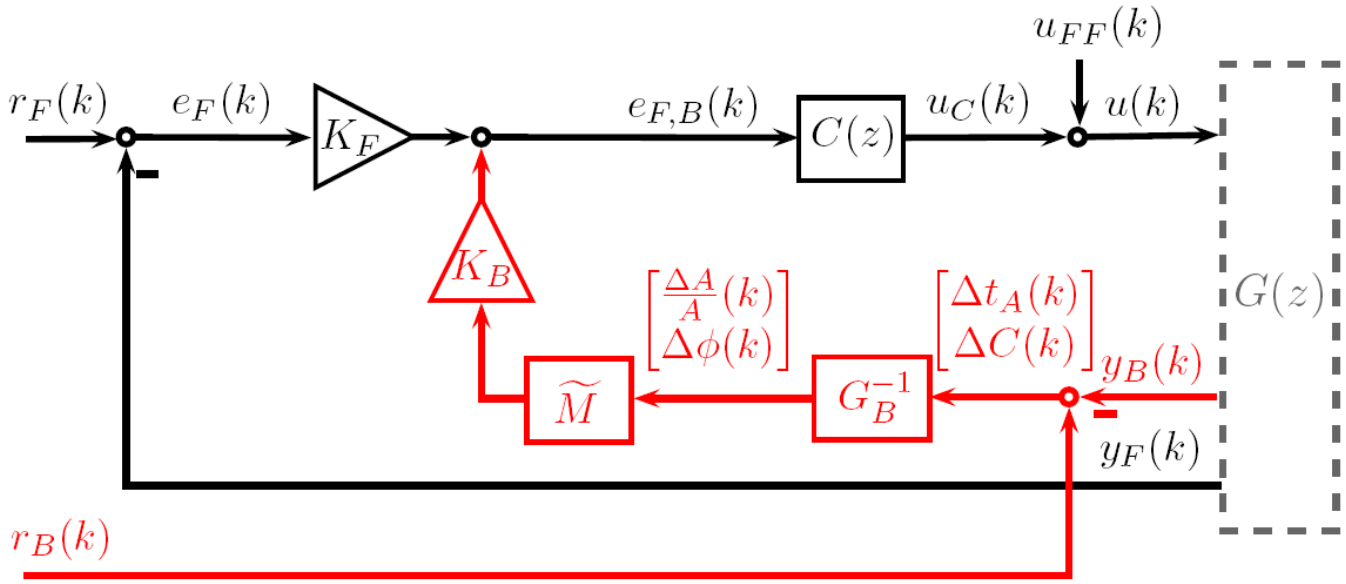
Bunch energy modulation upstream of BC to control the bunch arrival time and bunch compression



Actuator:
RF-field in amplitude and phase
→
mean bunch energy and
energy distribution within a bunch

Controller Implementation at FLASH

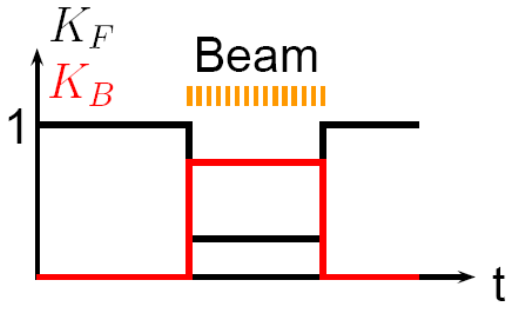
Bunch arrival time and bunch compression feedback



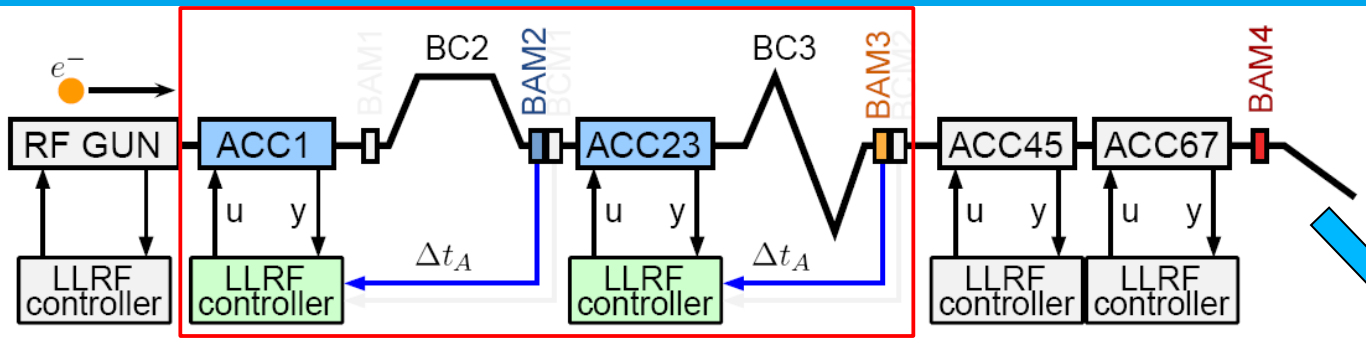
4 Inputs
2 Outputs

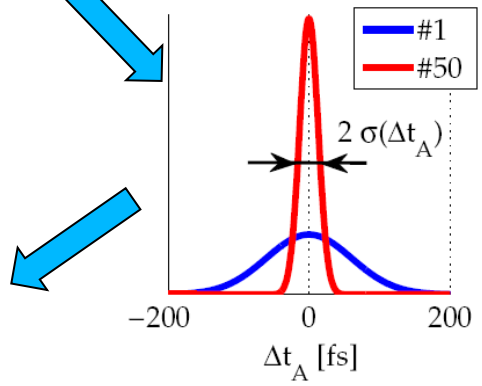
Combination of
RF Field and
Beam-Based Errors

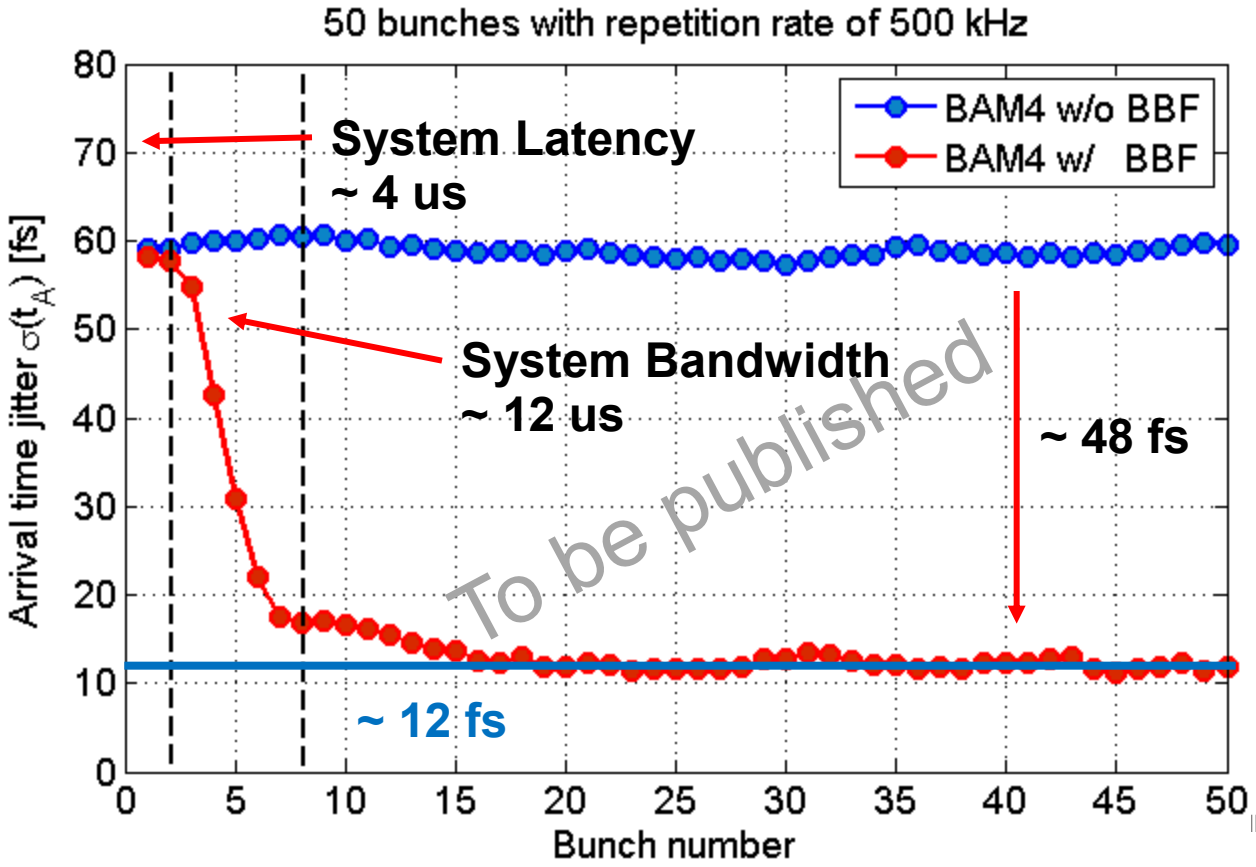
- $C(z)$ - Controller in I/Q
- $\widetilde{M}$ ... Modulation $\begin{bmatrix}\frac{\Delta A}{A}(k)\\ \Delta\phi(k)\end{bmatrix} \mapsto \begin{bmatrix}e_{B,I}\\ e_{B,Q}\end{bmatrix}$
- $K_F(k)$ and $K_B(k)$
  - $\rightarrow$ Adjusted during beam time



Fast Intratrain Controller at FLASH







- Bunch rep. Rate: 500kHz, 50 Bunche

- BAM4 is an out-of-loop measurement (highest resolution)

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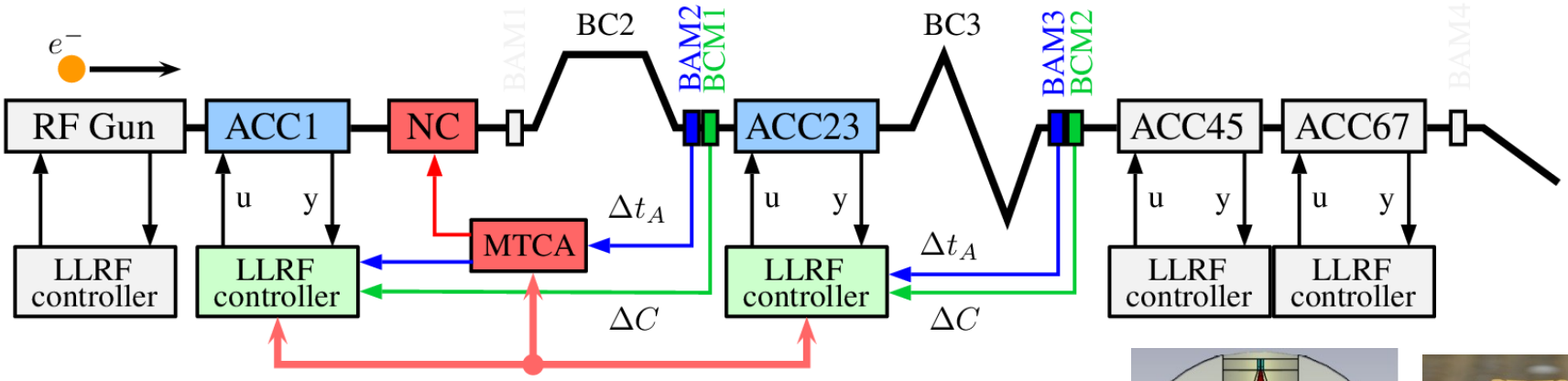
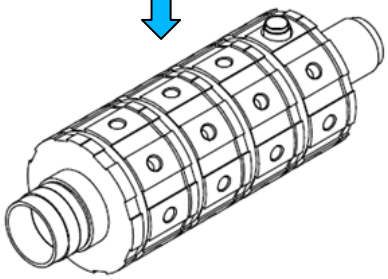
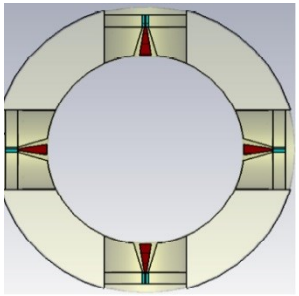
Outlook: High Speed Beam-Based Feedback

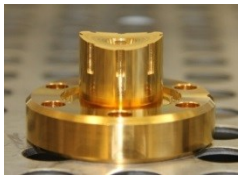
Normal **C**onducting (NC) cavity as fast actuator



- Design and Integration of NC cavity
- New BAM pickup design
  - High resolution, Low charge

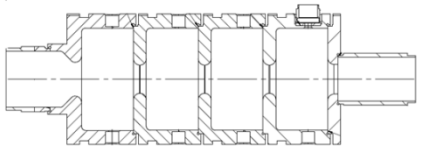




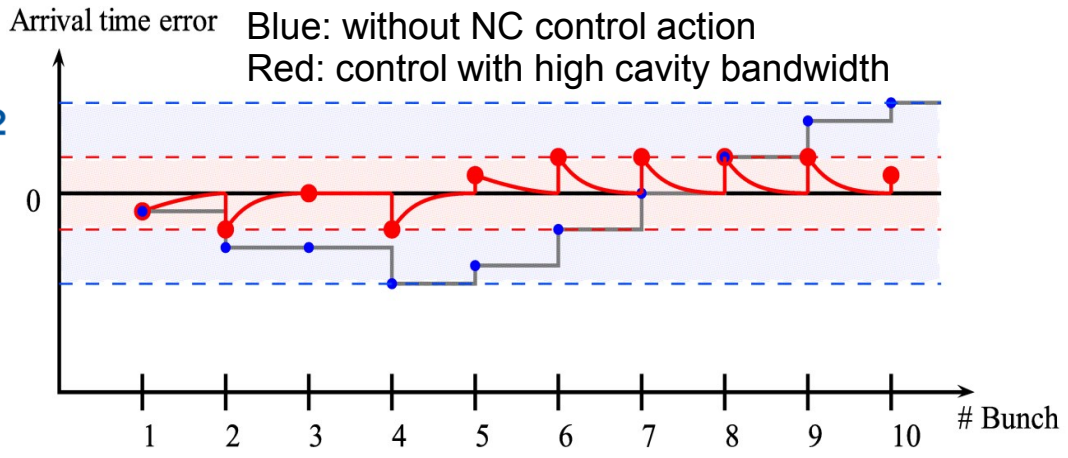


Courtesy of M.K. Czwalinna

EuCARD²



Simulation:
Blue: without NC control action
Red: control with high cavity bandwidth



Design:
Actuator Bandwidth:
NC (0.5–1.0 MHz)
Latency: ~ 0.7 us
BAM Resolution: ~fs

Goal: < 5 fs rms

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Summary and Outlook

Summary:

- Beam-based feedback for bunch arrival time and compression
  - Optimization of RF field controller
  - Integration of intra-train beam-based feedback
    - Cascaded control structure for bunch arrival time and compression

Experience at FLASH shows significant improvements for bunch arrival time and bunch compression

Outlook:

- Further improvements using a NC cavity
- Beam-based feedback for MTCA
  - Bunch Arrival Time
  - Bunch Compression
  - Bunch Energy

Thank you for your attention!

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