Fast Feedback Strategies for Longitudinal Beam Stabilization

IPAC 2012, New Orleans, USA

S. Pfeiffer[1], C. Schmidt[1], M.K. Bock[1], H. Schlarb[1], W. Jalmuzna[2], G. Lichtenberg[3], H. Werner[3]

[1]DESY Hamburg

[2]Technical University Lodz
Department of Microelectronics and Computer Science

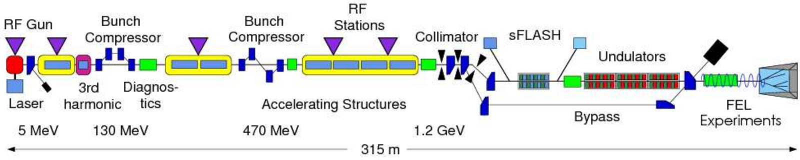
[3]Hamburg University of Technology
Institute of Control Systems

21.05.2012

Contents

FLASH (Free electron LASer Hamburg)

Energy 1.25GeV, Wavelength down to 4.12nm



Basic Components

- RF Gun - generates electrons, first pre-accelerator
- Cryomodules - increases the energy of the electrons
- Bunch Compressor - reduces the bunch length
- sFLASH and Undulators - excite the electrons to emit X-ray by SASE (Self-Amplified Spontaneous Emission) process
  - Pump-Probe Experiments

FLASH (**F**ree electron **LAS**er **Hamburg**)

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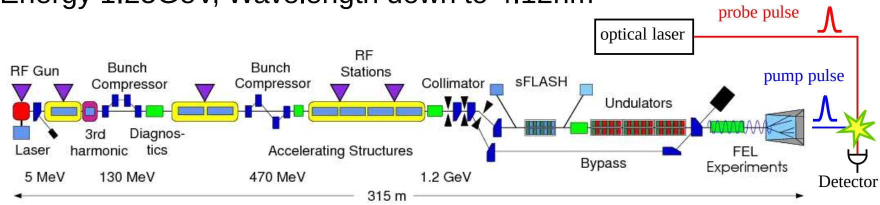

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FLASH (**F**ree electron **LAS**er **Hamburg**)

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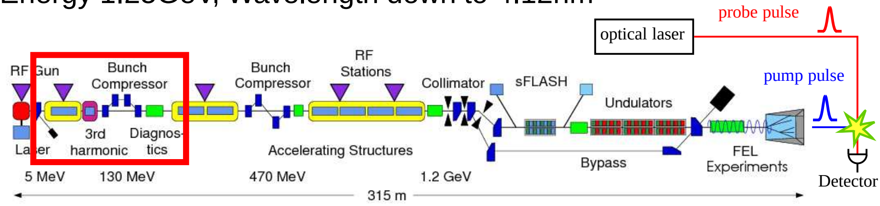
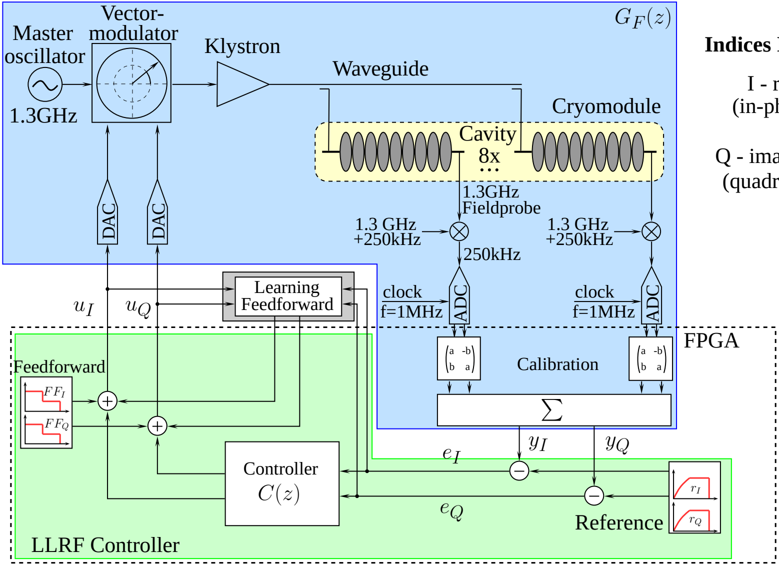


Basic Components

- RF Gun - generates electrons, first pre-accelerator
- Cryomodules - optimal acceleration field control
- Bunch Compressor - control beam properties
- sFLASH and Undulators - excite the electrons to emit X-ray by SASE (Self-Amplified Spontaneous Emission) process
  - Pump-Probe Experiments

Overview of RF - Station

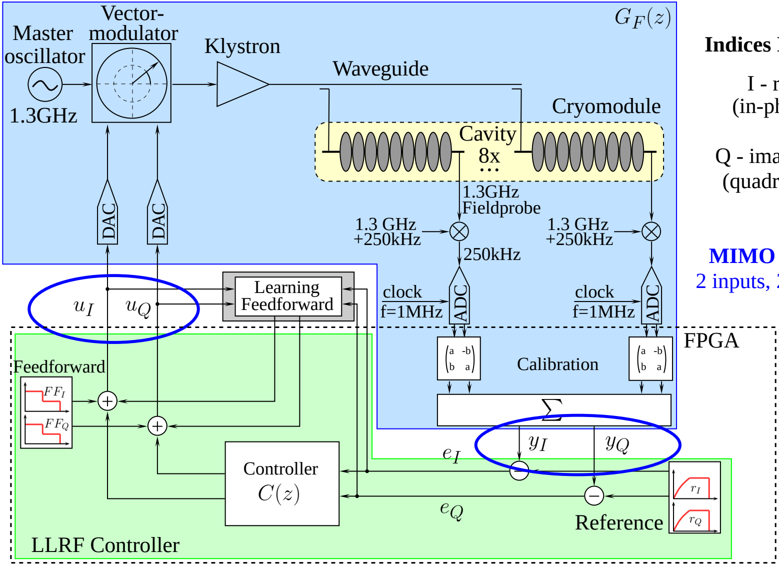


Indices I and Q

I - real
(in-phase)

Q - imaginary
(quadrature)

Overview of RF - Station



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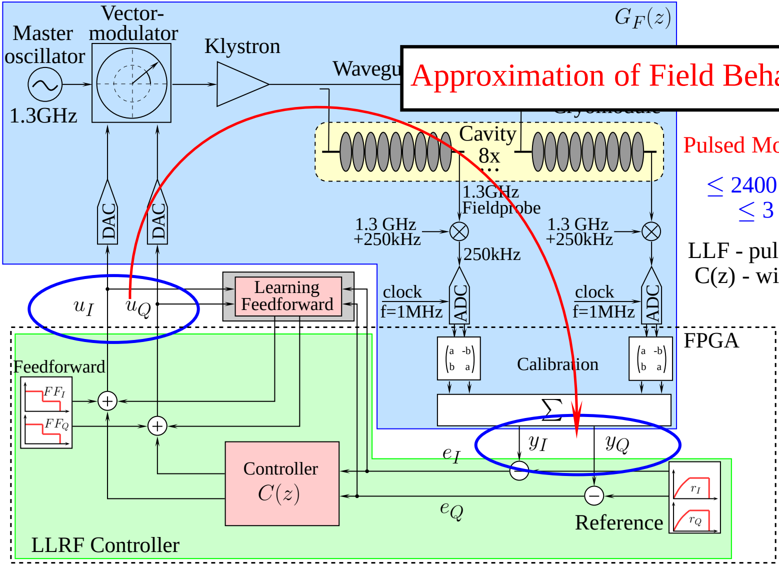
MIMO system
2 inputs, 2 outputs

Overview of RF - Station



Approximation of Field Behavior

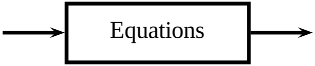
Pulsed Mode - 10 Hz

$\leq$ 2400 bunches
$\leq$ 3 MHz

LLF - pulse to pulse
C(z) - within pulse

System Description

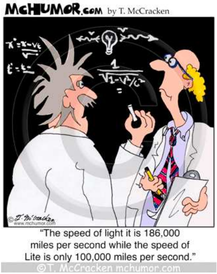
Physics



White Box Model

Engineering

Black Box Model



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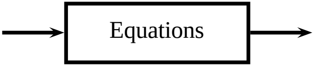

White Box Model

Engineering

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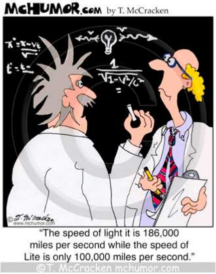
Identification Methods



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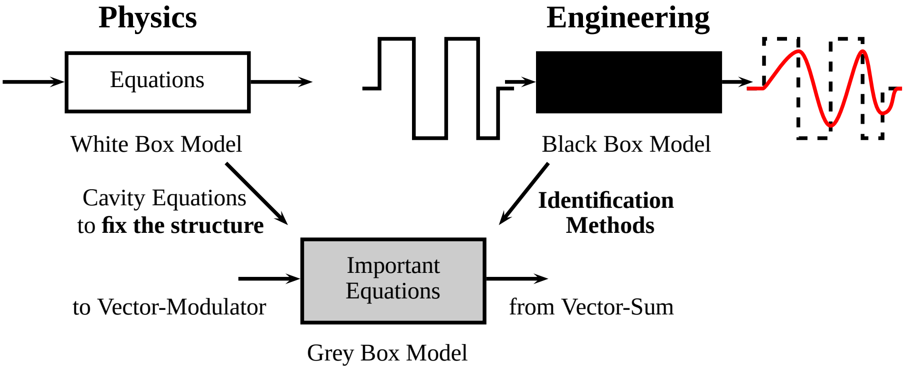
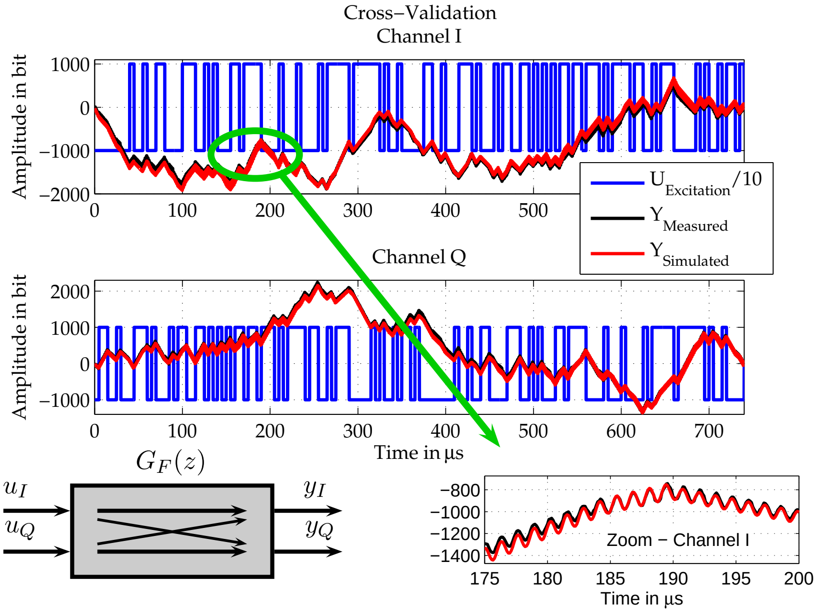


System Identification

- Parameter Identification within minutes - XFEL (26 RF stations)
- LTI (Linear Time-Invariant) Dynamic Model
  - Bandwidth, static gain, passband modes

System Identification - Result



Model Based Controller Design

MIMO System $\rightarrow$ MIMO controller

- Modern optimal controller design methods
  (1) H_∞-Fixed Order Optimization - discrete time (HIFOOd)
  (2) Shape the desired closed loop system behavior

- Controller Requirements
  (1.1) $\rightarrow$ Robust - system is stable for large parameter ranges
  (1.2) $\rightarrow$ Fixed controller order - FPGA
  (1.3)+(2) $\rightarrow$ Optimal - fast response
  (1.3)+(2) $\rightarrow$ Decoupling - necessary for beam based feedback

This would go beyond the scope of this talk!

... is necessary for optimal beam control!

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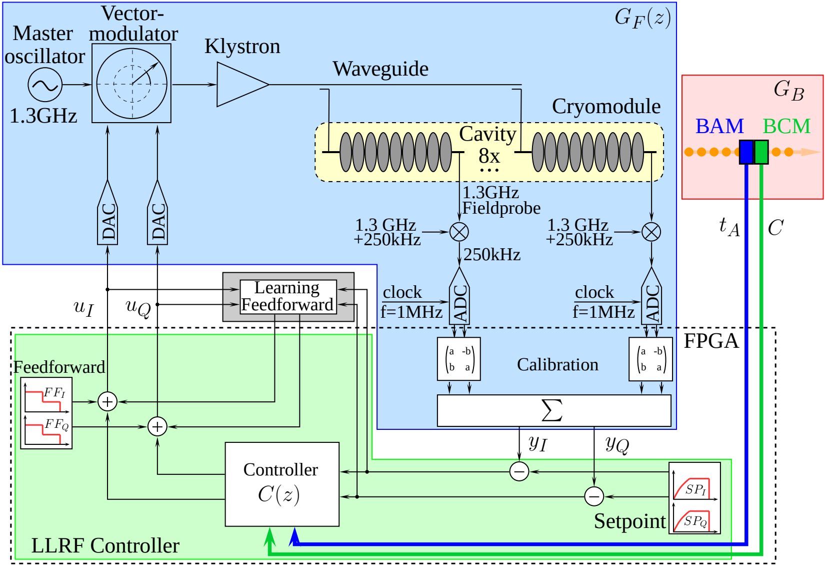
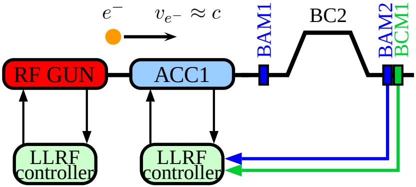
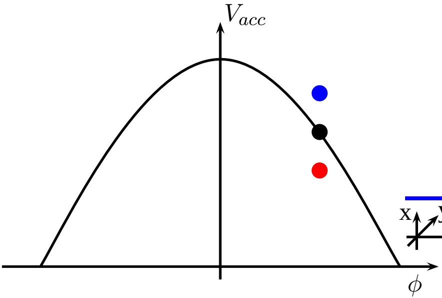


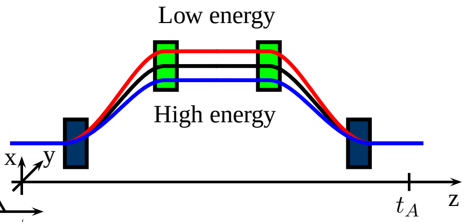
Bunch Compressor



Beam control

- $\Delta t_A \propto \frac{\Delta E}{E} \propto \frac{\Delta A}{A}$
- $\Delta C \propto \Delta \phi$





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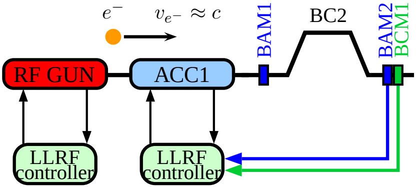

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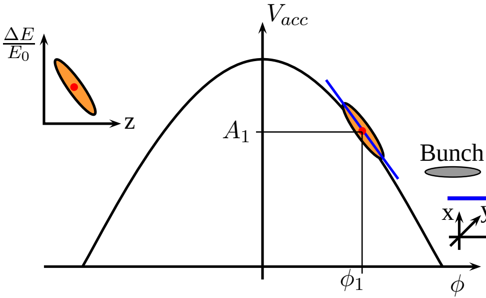

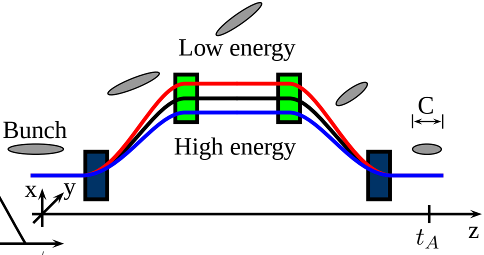

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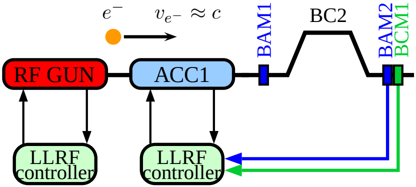
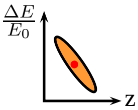


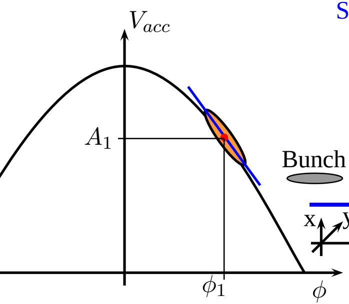
Beam control

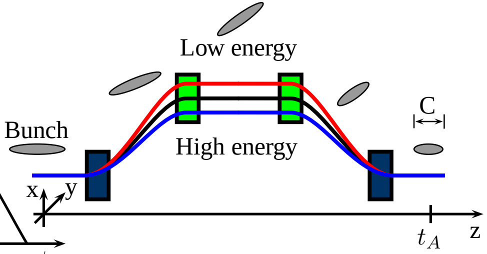
- $\Delta t_A \propto \frac{\Delta E}{E} \propto \frac{\Delta A}{A}$
- $\Delta C \propto \Delta \phi$

$$\begin{pmatrix} \Delta t_A \\ \Delta C \end{pmatrix} = G_B \cdot \begin{pmatrix} \frac{\Delta A}{A} \\ \Delta \phi \end{pmatrix}$$

Static Matrix







Fast Feedback Strategies

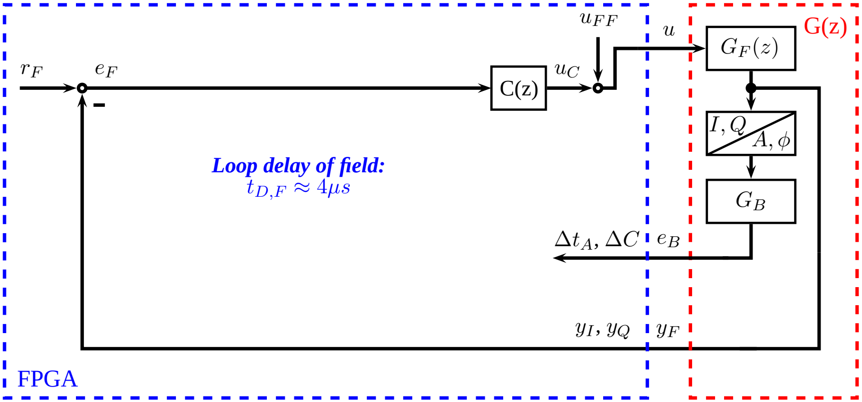
Field Feedback Loop

No Beam Control

Field stability $\frac{\Delta A}{A}$

$\approx 0.01\%$

Δt_A after 1st BC

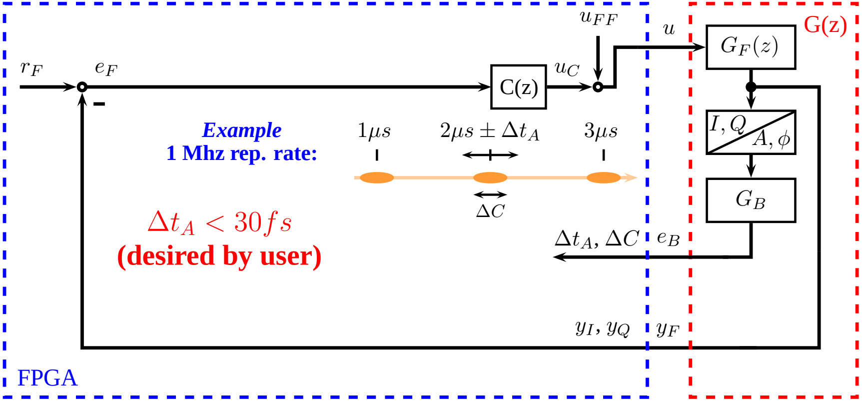


Fast Feedback Strategies

Field Feedback Loop

No Beam Control

Field stability $\frac{\Delta A}{A}$ $\approx 0.01\%$ → Δt_A after 1st BC $\approx 75fs$

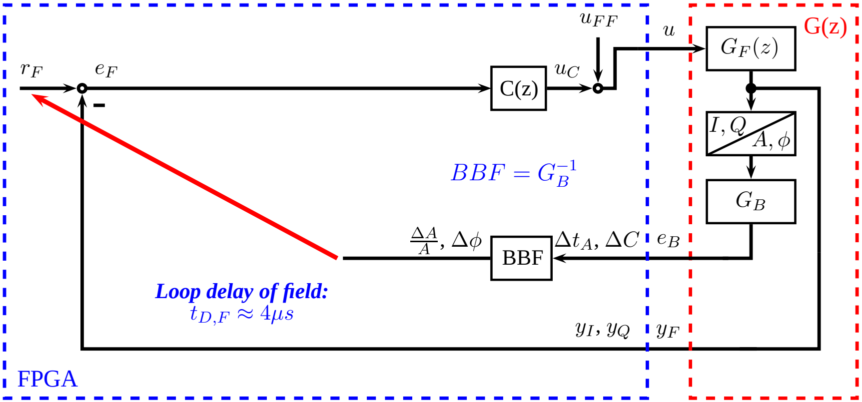


Fast Feedback Strategies

Field Feedback Loop

Set-Point Change by Beam

Field stability $\frac{\Delta A}{A}$ $\approx 0.005\%$ ← Δt_A after 1st BC $\approx 40fs$



Fast Feedback Strategies

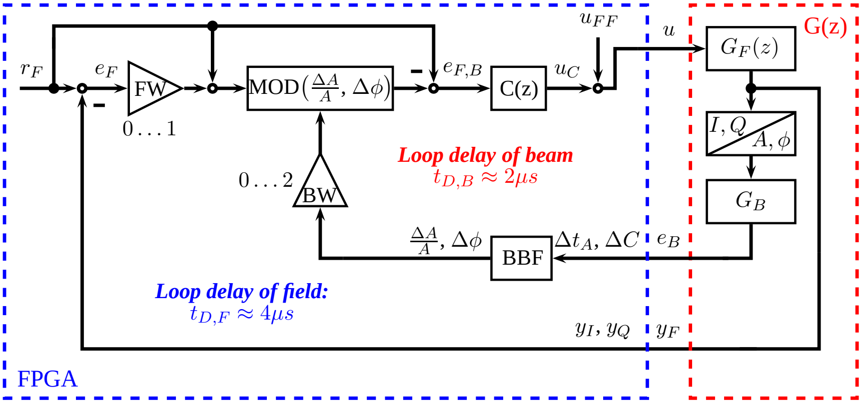
Cascaded FB Loop
Field - and Beam Weighting

Field stability $\frac{\Delta A}{A}$

$\approx ?\ \%$

Δt_A after 1st BC

$\approx ?\ fs$



Fast Feedback Strategies

Cascaded FB Loop

Field - and Beam Weighting

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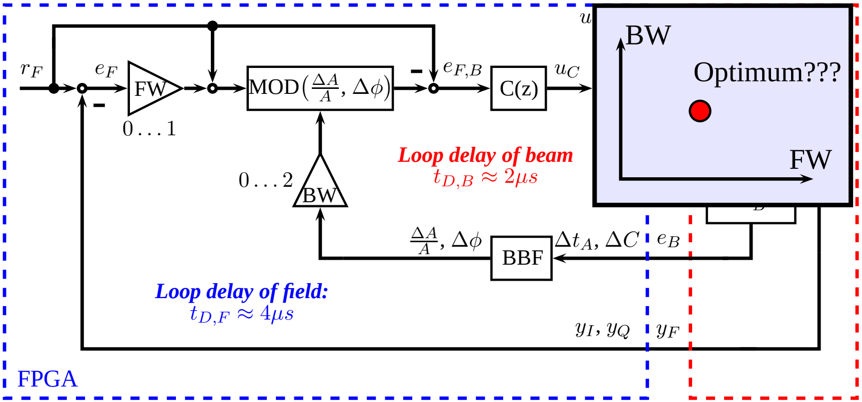
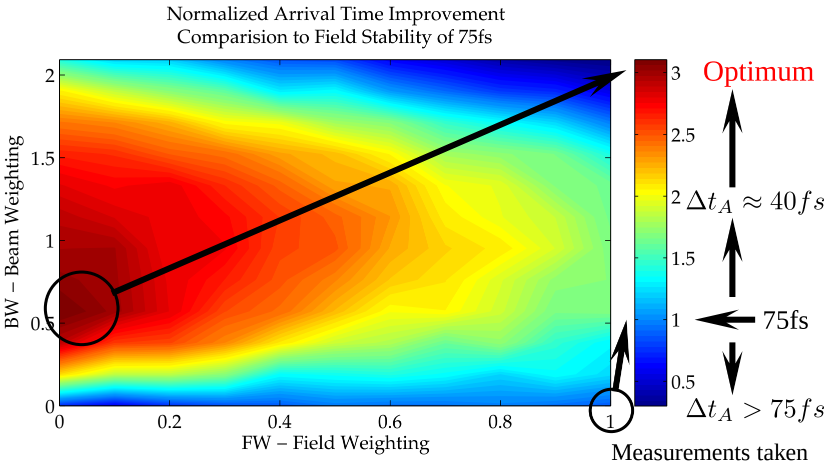


Fast Feedback Strategies

Cascaded FB Loop

Field - and Beam Weighting

Field stability $\frac{\Delta A}{A}$ $\approx 0.003\%$ ← Δt_A after 1st BC $\approx 24fs$



Measurements taken at FLASH 04/2012

Conclusion & Outlook

- Model based design
  - Usable for all RF stations - fast and reliable
  - Necessary for optimal field and beam control
- Fast feedback strategies for longitudinal beam stabilization
  - Only field control $\Delta t_A \approx 75 fs$
  - Beam based setpoint adaptation $\Delta t_A \approx 40 fs$
  - Cascaded field - beam controller $\Delta t_A \approx 24 fs$
- **Outlook ...**
  - Update same structure before 2nd BC section
  - uTCA

Thank you for your attention...

HELMHOLTZ ASSOCIATION DESY DMCS TUHH Technische Universität Hamburg-Harburg