Fast Beam Based Feedback System

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Normal conducting cavity as fast beam based feedback actuator

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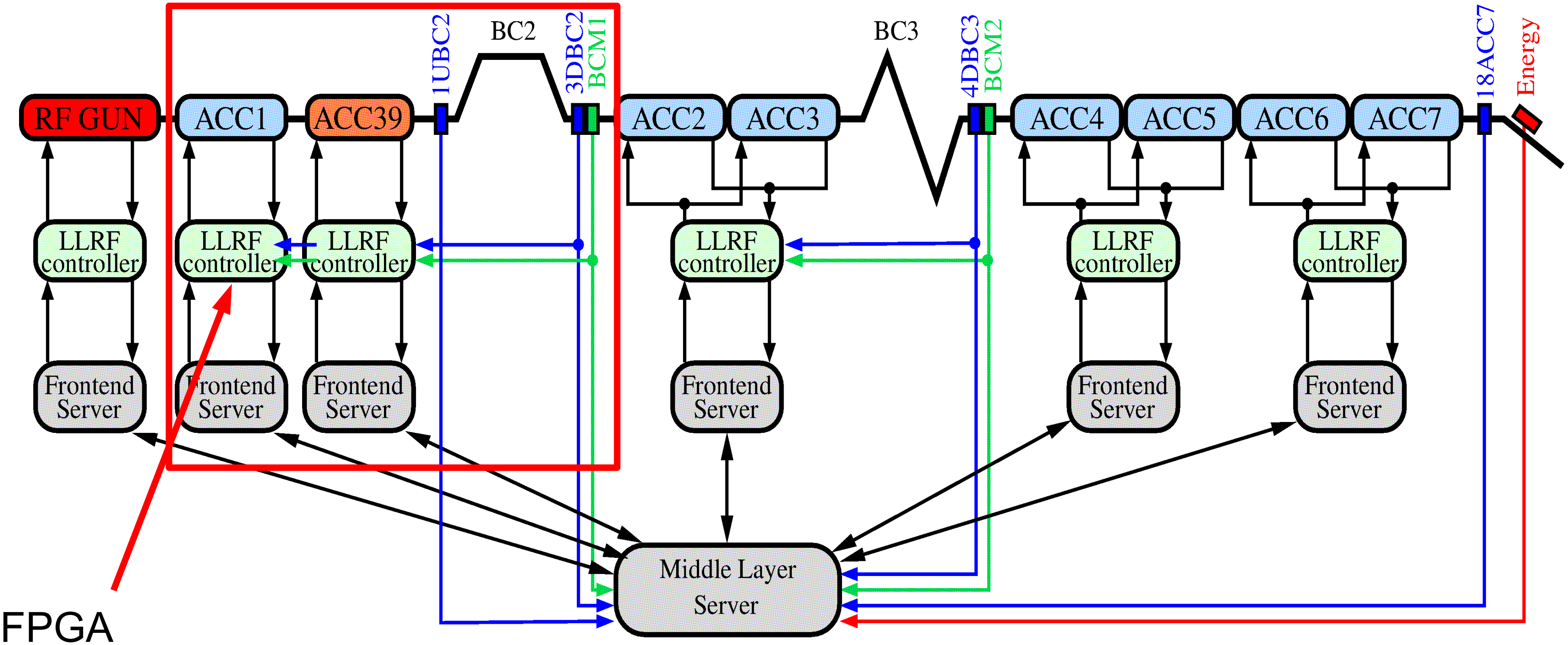
FLASH overview – Fast Beam Based Feedback

Beam Performance (BAM, BCM)

$t_A \sim \Delta E/E \sim \Delta A/A$

$C \sim \text{length}_{\text{bunch}} \sim \Delta\text{phase}$



FPGA
From bunch to bunch

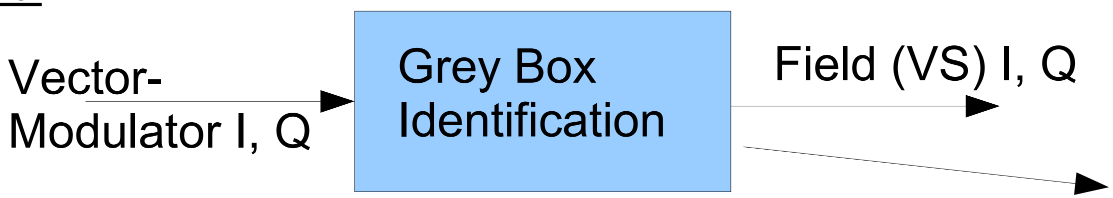
From pulse to pulse

R. Kammering and C. Schmidt
FLASH Seminar 2012

Outline: - Current BBF implementation
- Results for 2 control strategies
- Why a fast actuator?

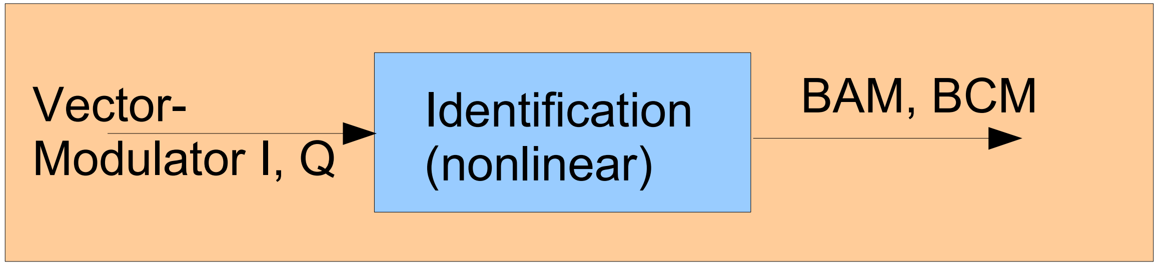
System identification

Field

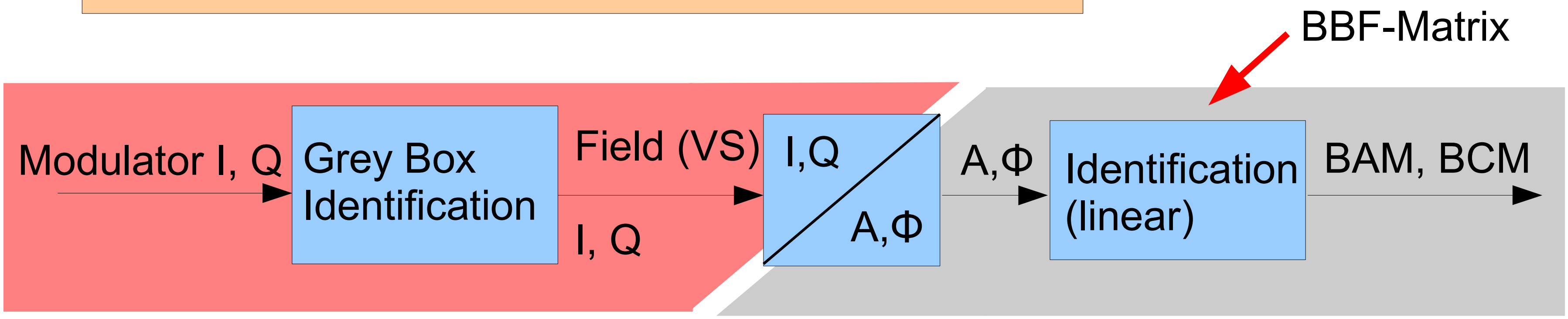


- DC Gain
- Bandwidth
- 8/9 pi mode
- Other modes

Beam



- Necessary for an optimal beam based feedback controller

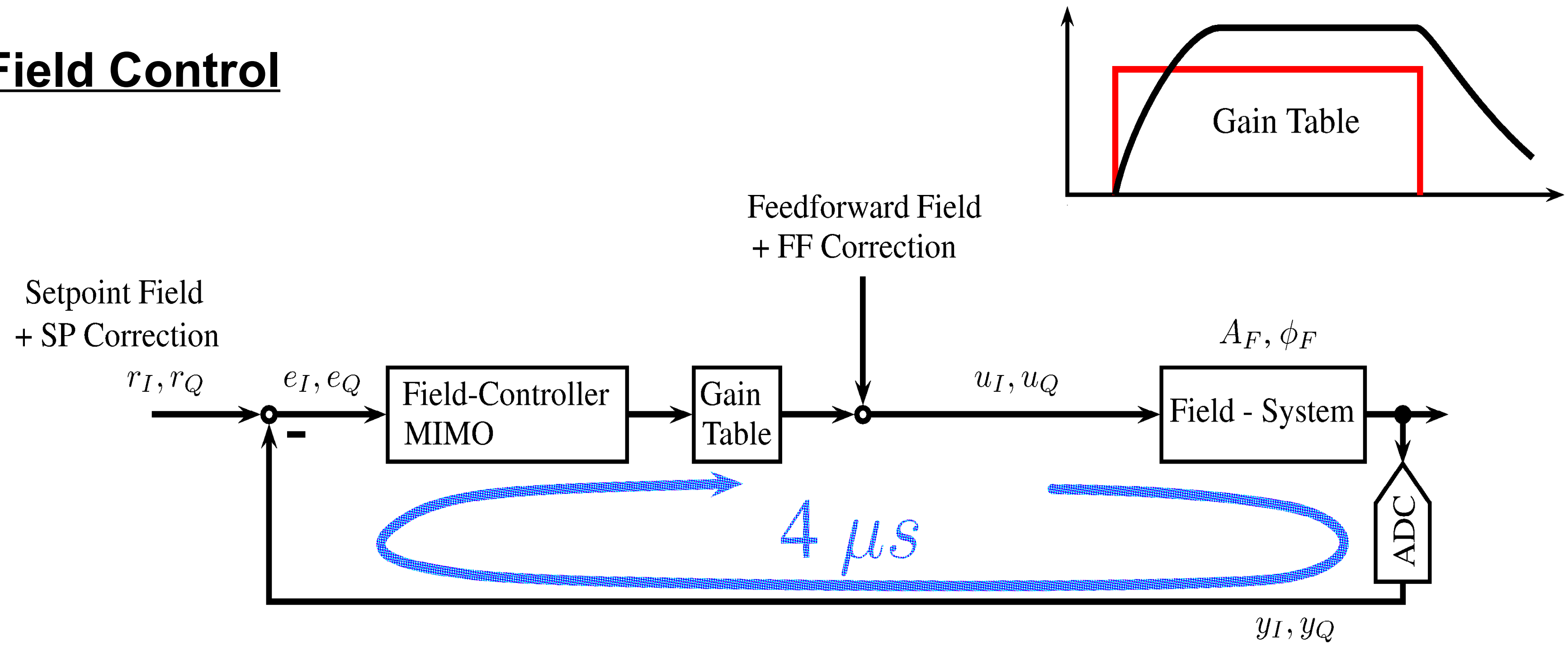


Dynamic

Static – linear
Around given Setpoint
(Dynamic with notch at 8/9 pi mode)

Beam based feedback

Field Control



Field-System: 6th order state space model

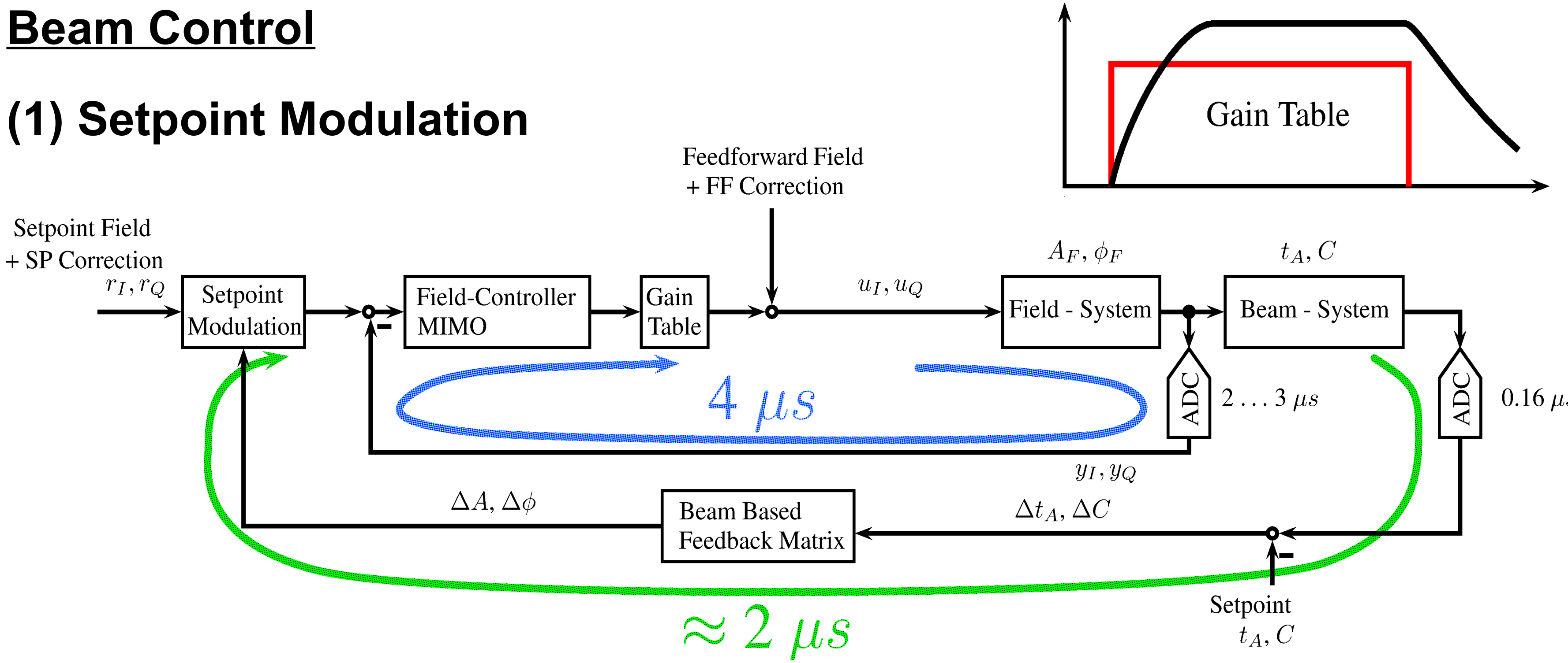
Field controller: 2nd order MIMO (multiple input – multiple output)

Performance: $\Delta A_F/A_F < 0.01\%$; $\Delta \Phi_F < 0.01°$

Beam based feedback

Beam Control

(1) Setpoint Modulation



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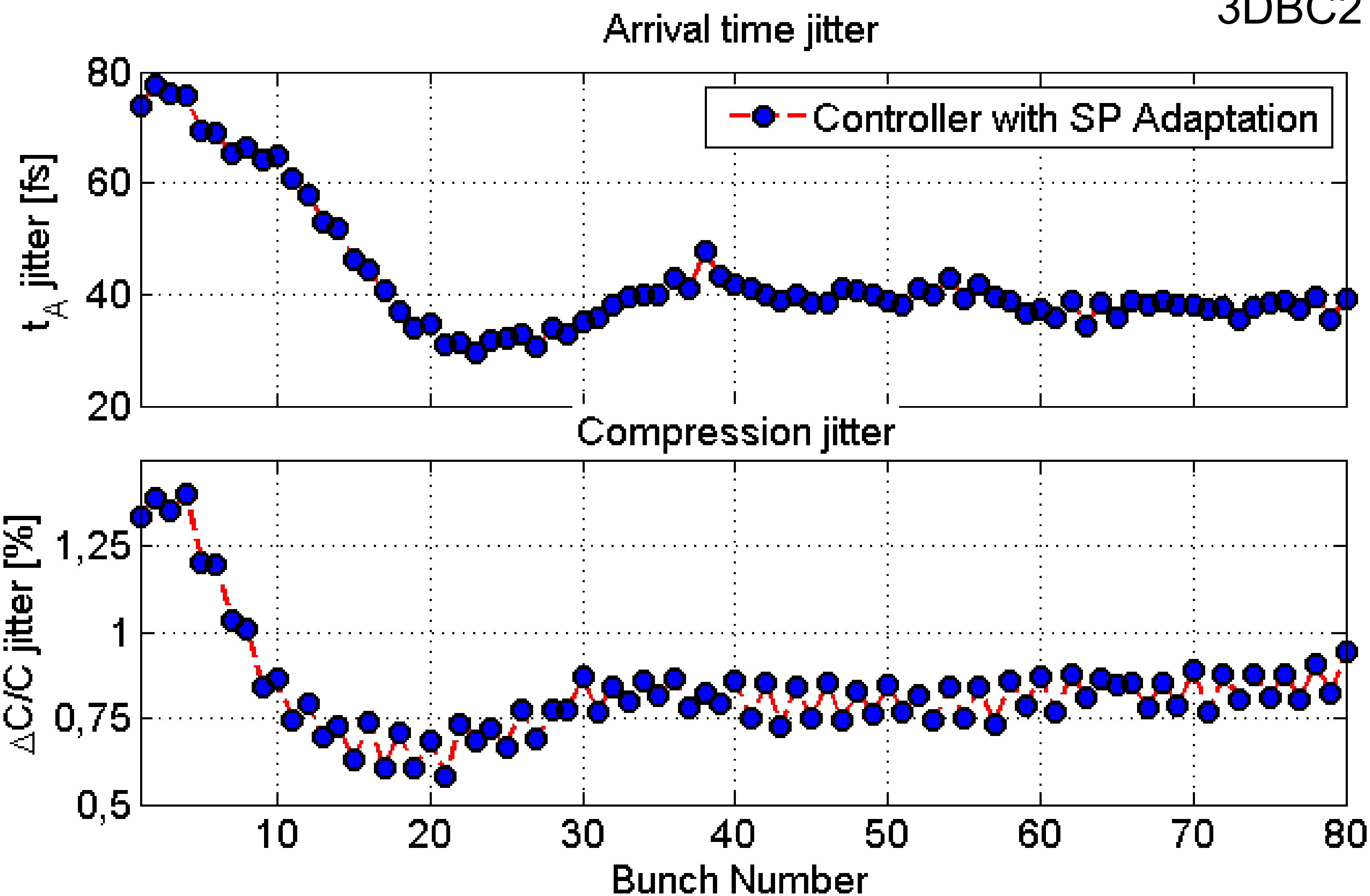
Performance: $\Delta A_F/A_F < 0.01\%$; $\Delta\Phi_F < 0.01°$

Beam-System: Linearized Static Gain
BBF Matrix: Inverse of Beam System
Performance: $\Delta t_A < 40fs$ (after 3DBC2) ; $\Delta C/C < 0.08\%$

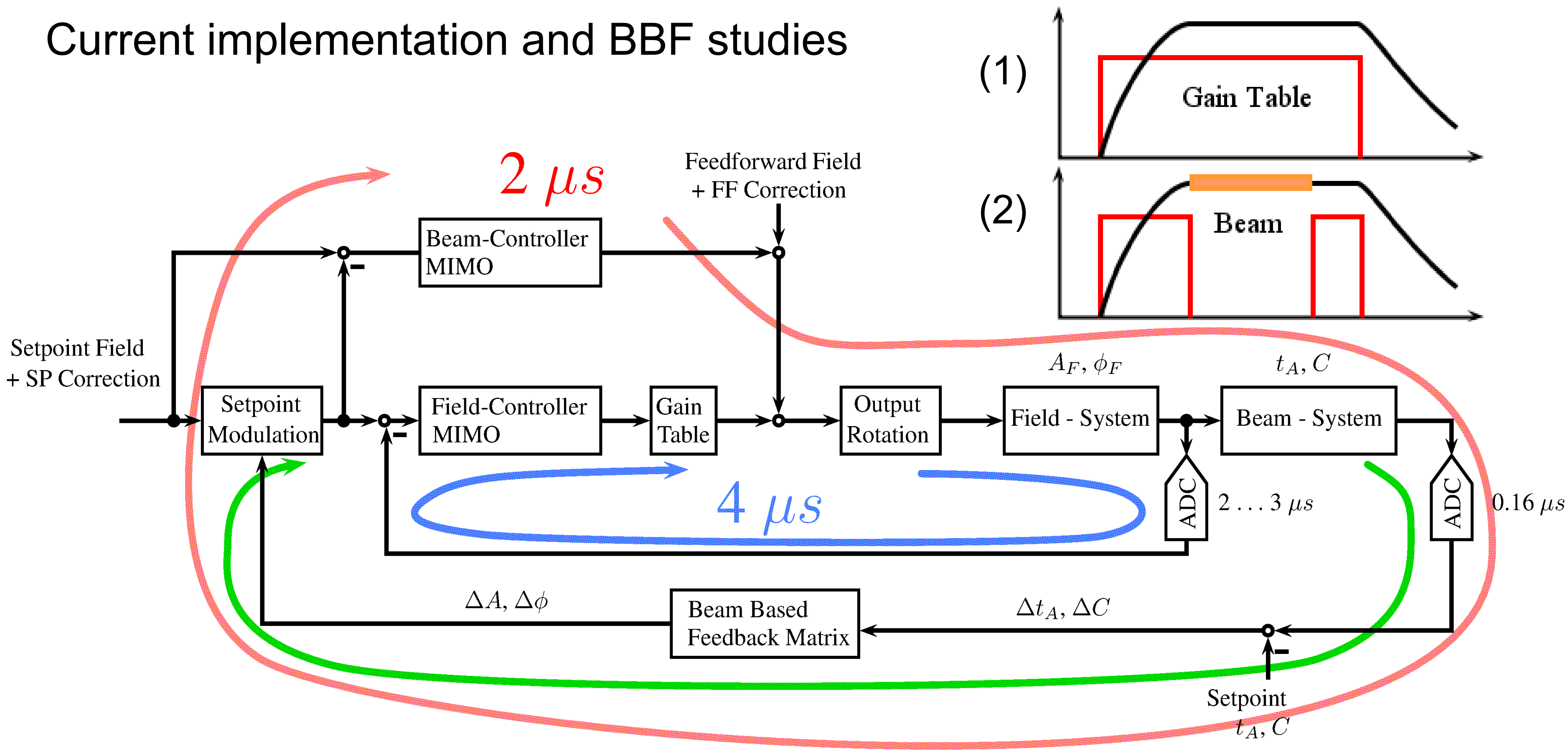
Beam based Feedback with SP Modulation

3DBC2



Beam based feedback

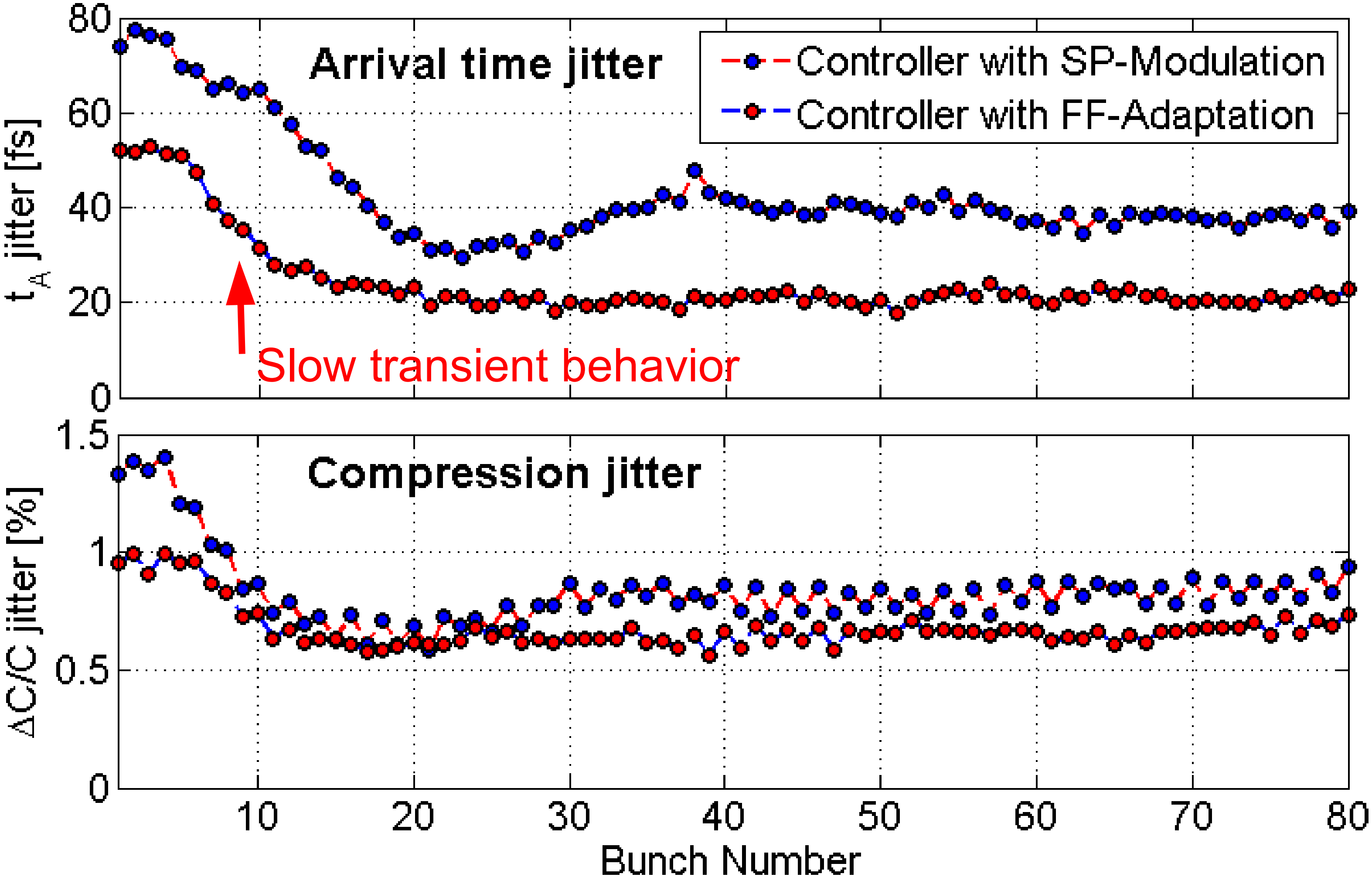
Current implementation and BBF studies



(1) SP Modulation: 4us delay (VME), 2.x us (uTCA) → 40fs (rms) after BC2
(2) FF Modulation: 2us delay

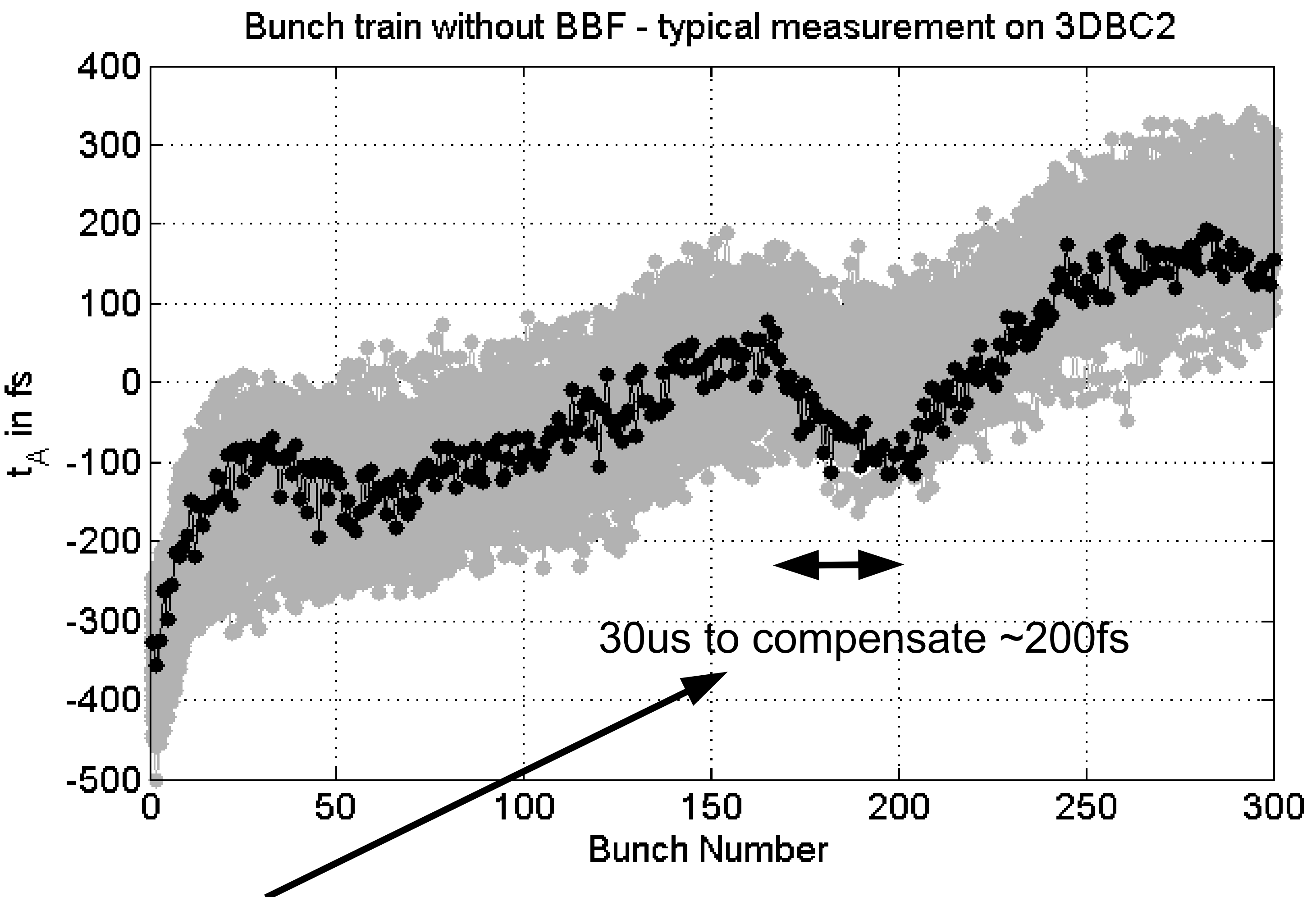
Results with superconducting cavity

3DBC2



But ...

BBF Problems



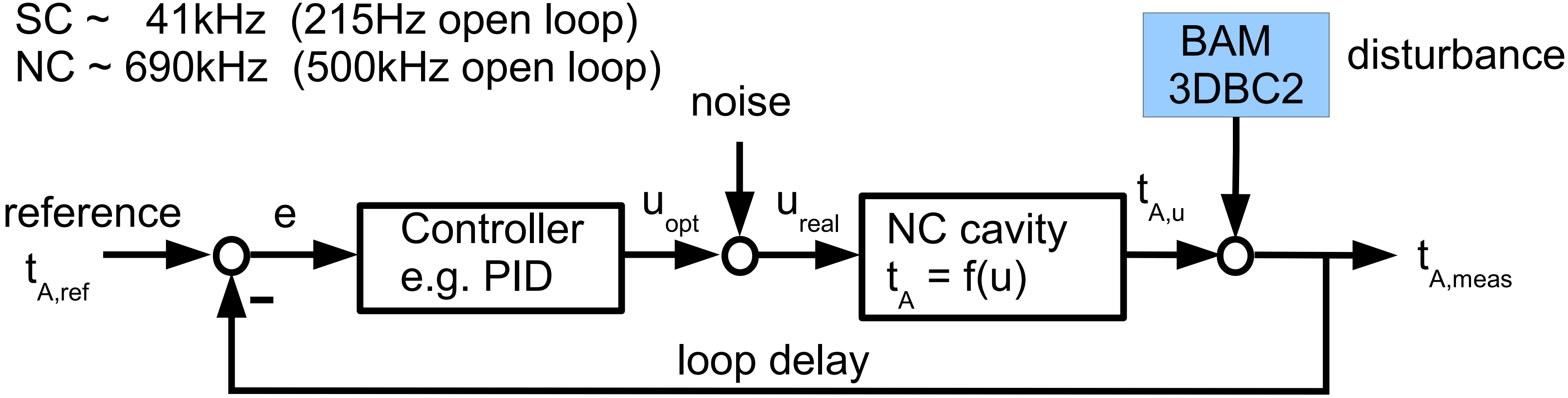
At least closed loop BW of 166kHz
→ Normal Conducting cavity
BW of 250kHz...1MHz

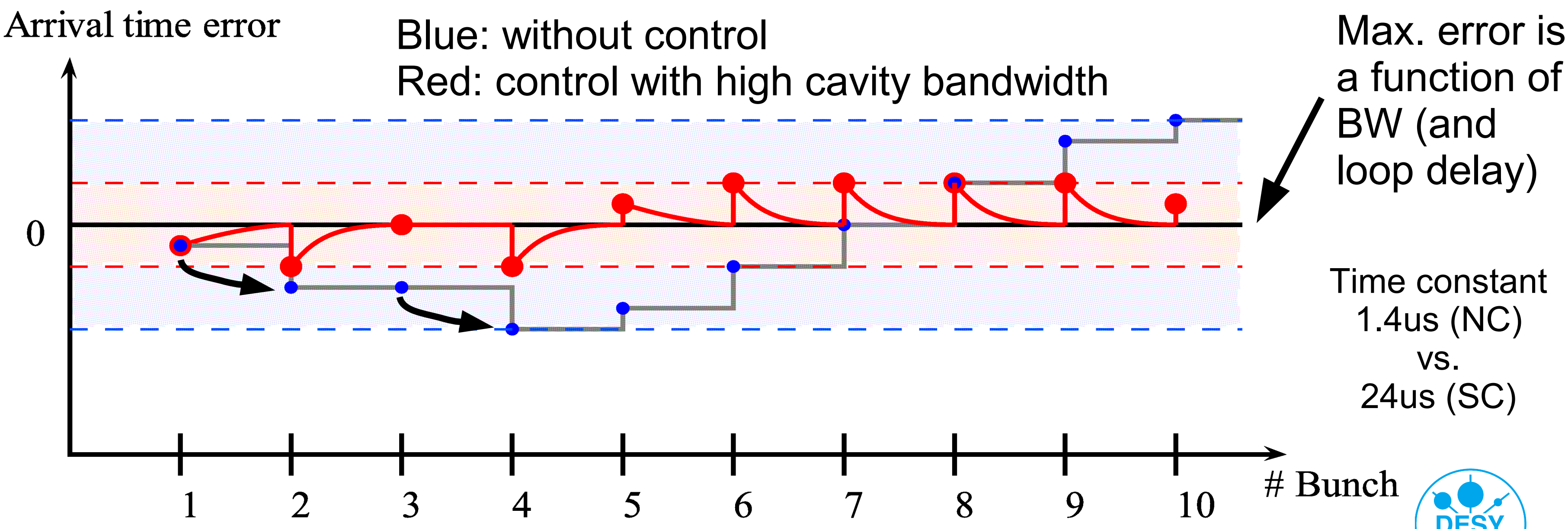
Supercon. Cav.
Open loop bandwidth (BW): ~200…300Hz
Closed loop BW : ~41kHz

Control Influence

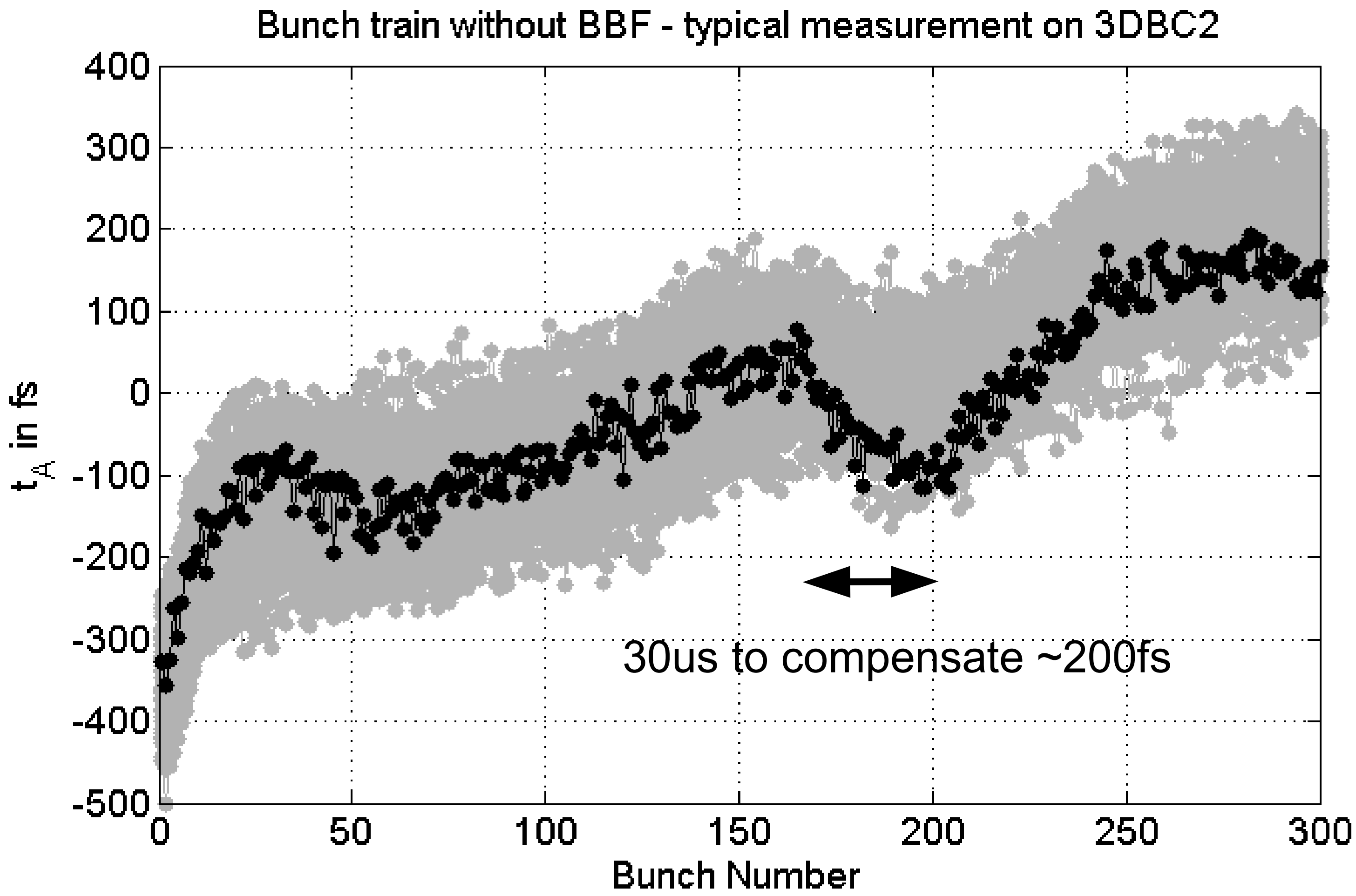
Closed loop bandwidth $t_{A,ref}$ --> $t_{A,meas}$

SC ~ 41kHz (215Hz open loop)
NC ~ 690kHz (500kHz open loop)





BBF Control by Superconducting cavity



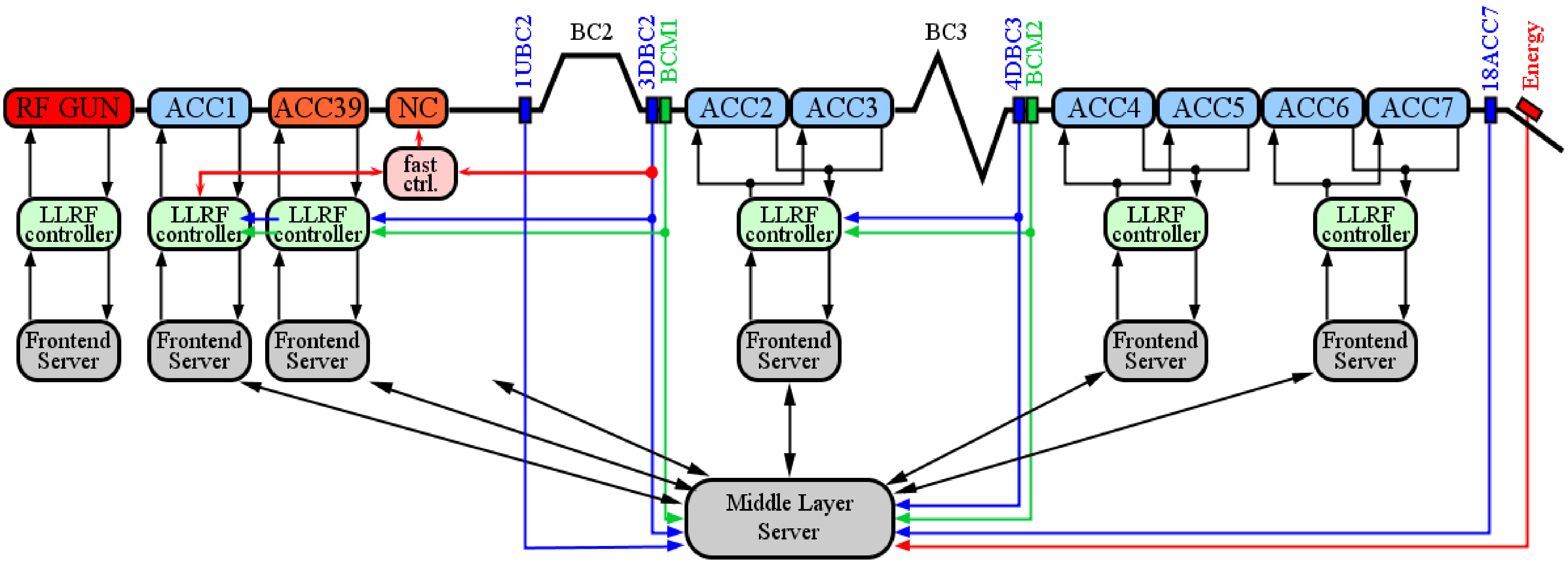
$$\Delta P_{FOR}/P_{FOR} = 2 * \Delta V/V * \tau / \Delta t$$

Relative Klystron Power

$\Delta V/V = 0.03\%$ (6.3ps/%) , τ = 735us , Δt 30us

$\Delta P_{FOR}/P_{FOR} =$ 1.5% → Not the upper limit

Normal conducting cavity at FLASH

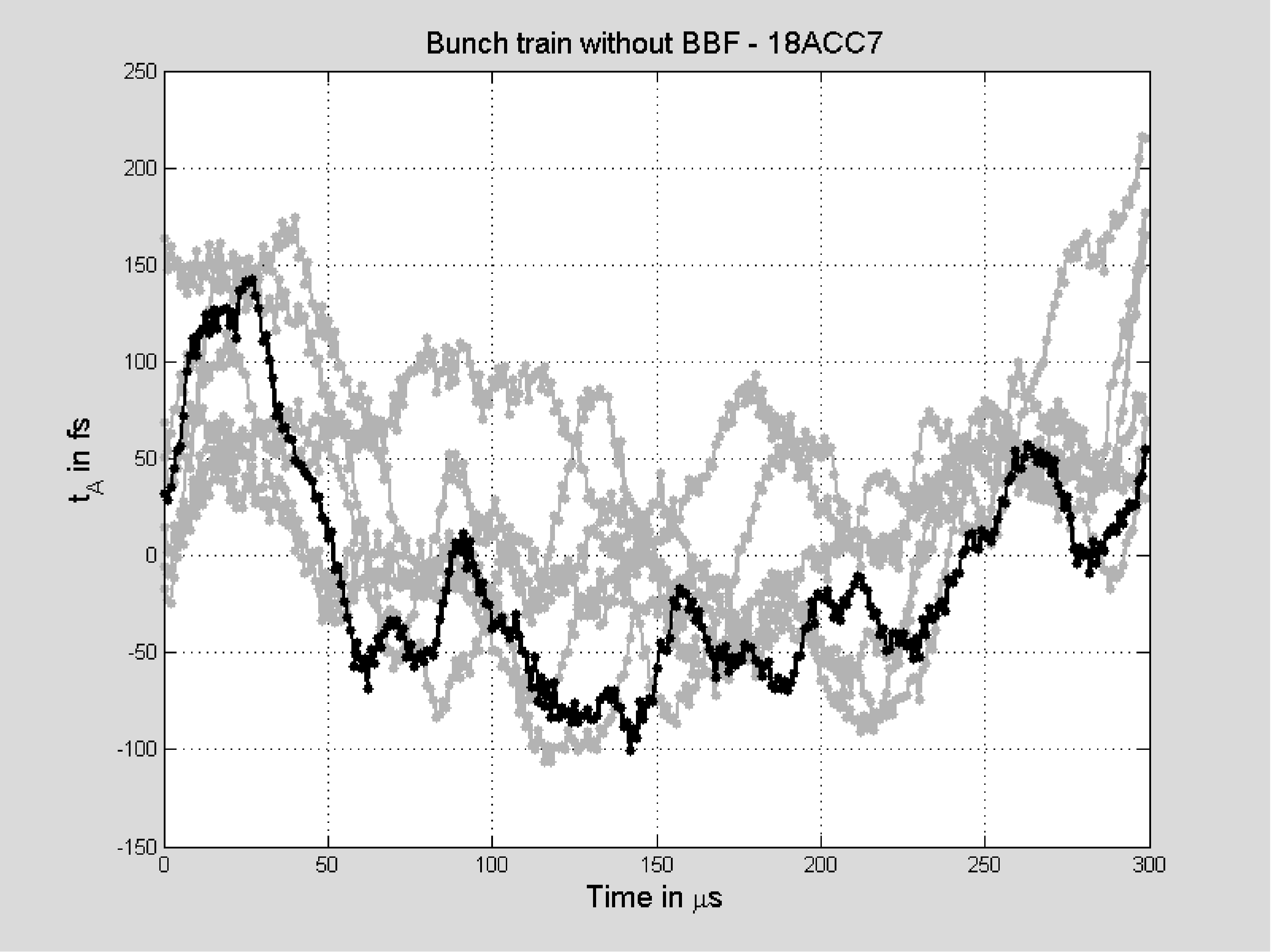


Normal conducting cavity:
Bandwidth of 250kHz … 1000kHz
Latency fast controller: 0.7 … 1.5us
Max. gradient for correction: ± 75kV
Fast control of bunch to bunch fluctuations

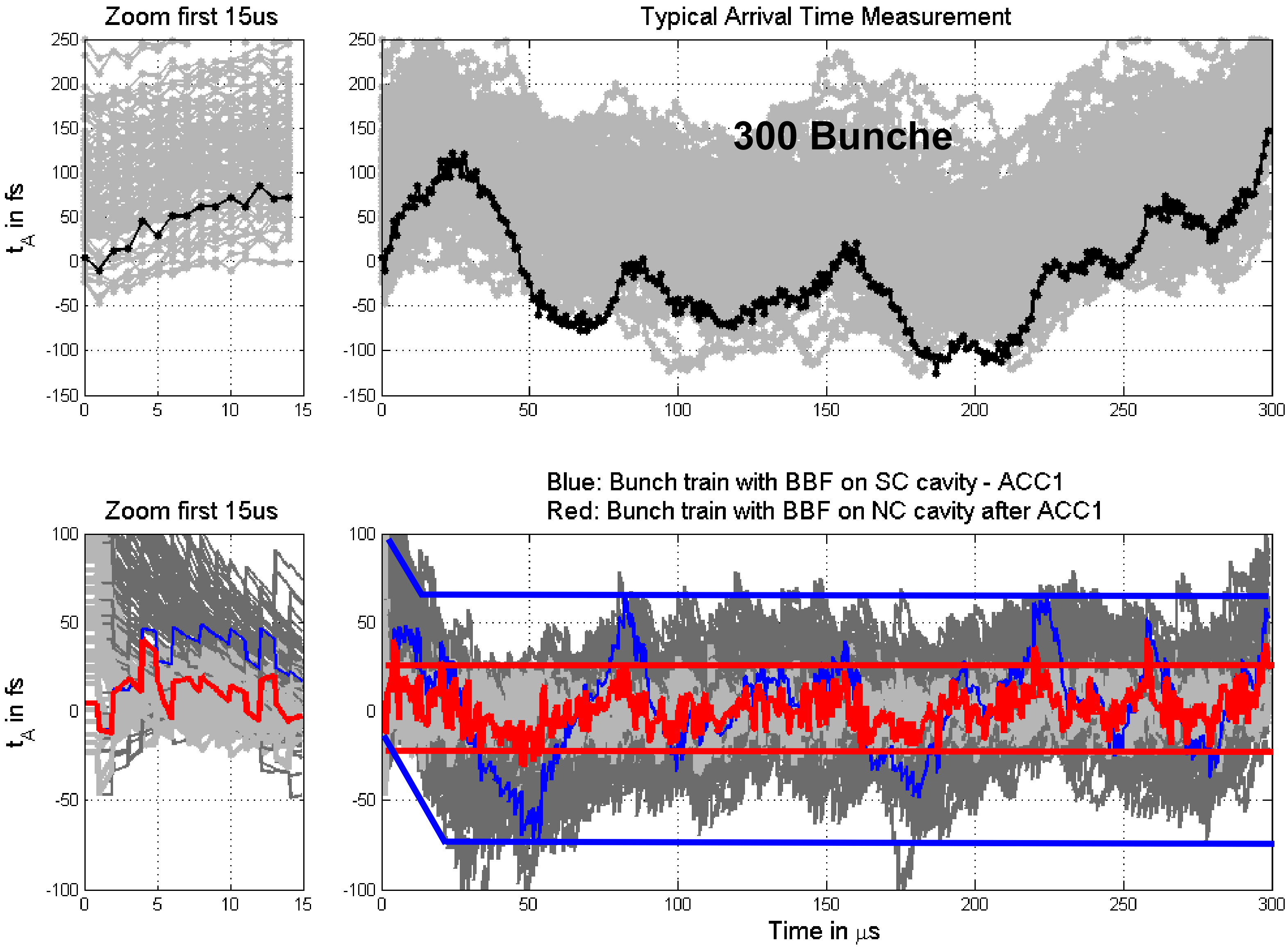
Super conducting cavity:
Bandwidth of 200Hz … 300Hz
Latency LLRF controller: 2us (uTCA)
Depends on setpoint and quench limit
Control of pulse to pulse fluctuations

Simulation of SC and NC with real BAM measurements...

Measurement at 18ACC7 – without BBF



SC vs. NC Control – Simulation with real Measurements



18ACC7

SC:

f_{3dB}=215Hz

t_D = 2us

15-25bunche

25fs rms

NC:

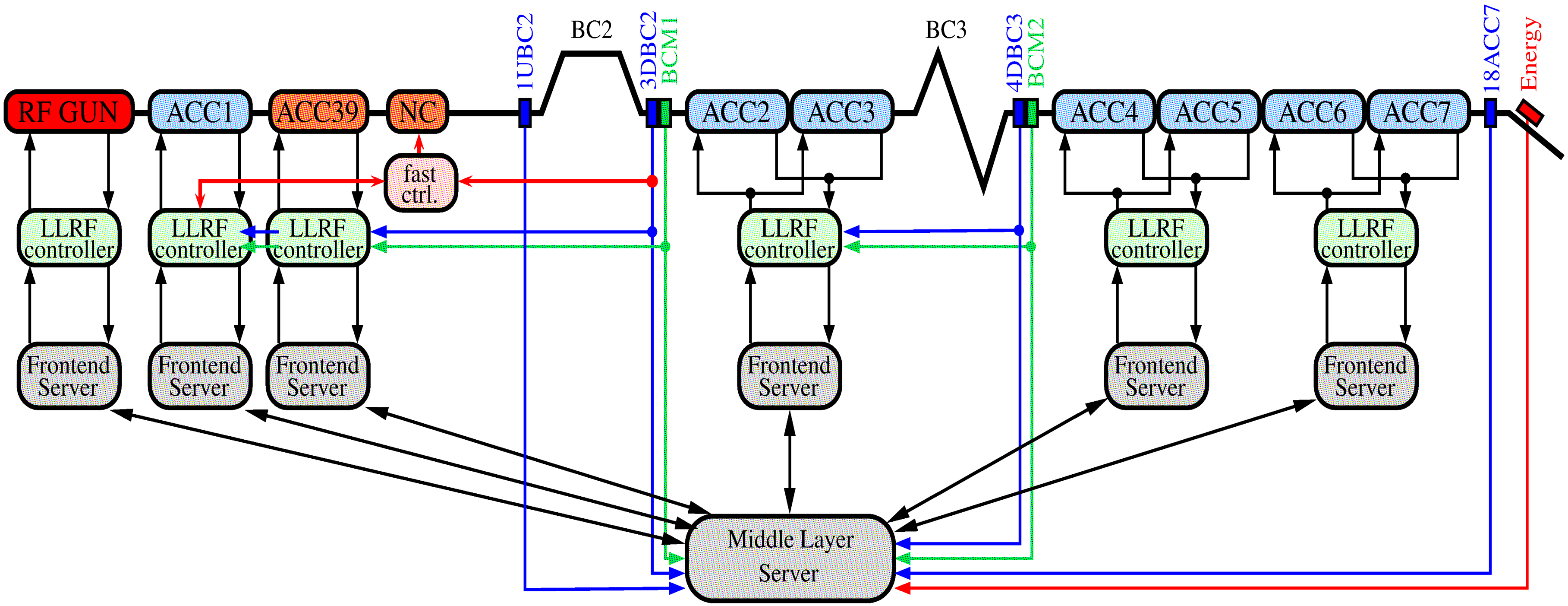
f_{3dB}=500kHz

t_D = 1us

2-3 bunche

10fs rms

Final implementation at FLASH



Final control design of SC and NC cavity:

- Clever combination of both controllers
- Exchange BAM and control data to optimize the performance of BBF
- SC for BAM pulse to pulse fluctuations
- NC for fast bunch to bunch fluctuations
- FLASH 2 – 2 different flattops –> fast BAM control to use full flattop length

Conclusion

- Why a normal conducting cavity?
  - Performance
    - SC – limited by closed loop bandwidth and latency
    - SC – much more Klystron power to modulate the output
    - NC – ratio of input/output action is about 95%
    - NC – no choice to act against fast fluctuations
  - Optimize performance of fast fluctuations
    - Arrival time (5...10fs)
    - Compression

    → Increase performance by a factor of 2.5 - 4
  - 2-3 (NC) instead of 15-25 (SC cavity) bunches for stabilization
  - FLASH 2 – e.g. 2 different gradients
    - faster transient arrival time stabilization
    - 2 full flattops with best beam properties

Thank you for your attention!