Beam stabilization with MIMO controller and BBF

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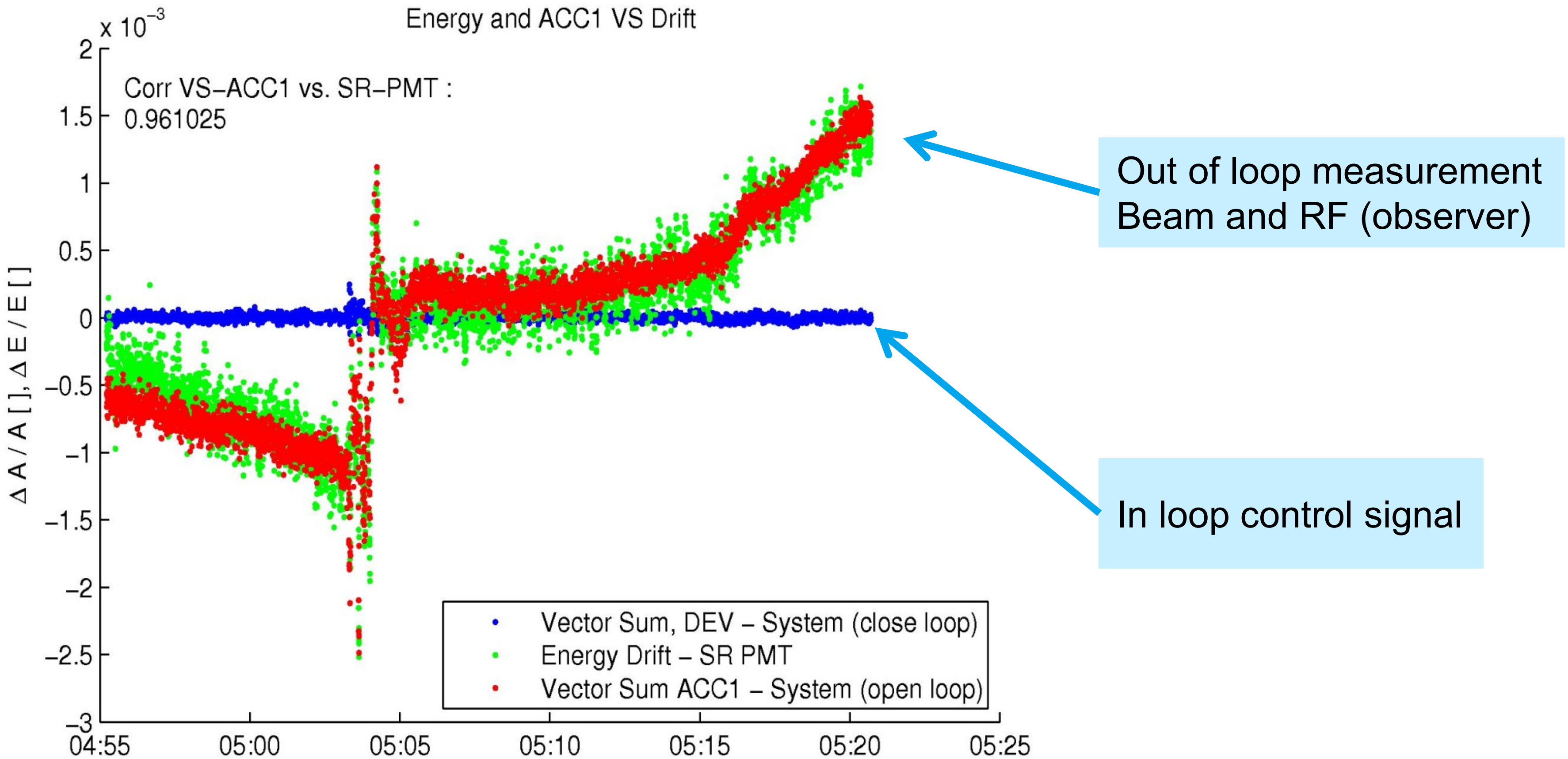
Outline

- Motivation and current implementation
  - Schematic feedback overview
- Feedback setup and limitation
  - Response matrix estimation
  - Current operation points
- Measurement results
  - Achieved arrival time stabilization
- Future integration in feedback scheme
  - Implementation proposal
  - Requirements

Arrival time stabilization

- Stable FEL operation is a user prerequisite
  - Pump-probe experiments
  - SASE intensity stabilization
  - Stabilization of electron pulse length
- Direct influence on beam orbit and energy gain
  - Arrival time imperfections accumulate trough accelerator
  - Compression variations after dispersive sections
  - Energy gain variations
- Imperfect RF regulation
  - Field detection errors and drifts in RF system
  - Accuracy
- Operability
  - Less manual tuning
  - Reduced long term drift

Observer based measurement of beam and RF field

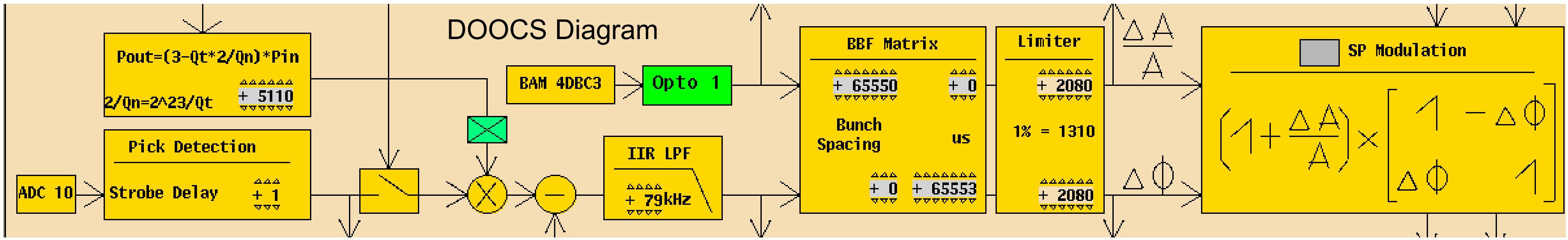


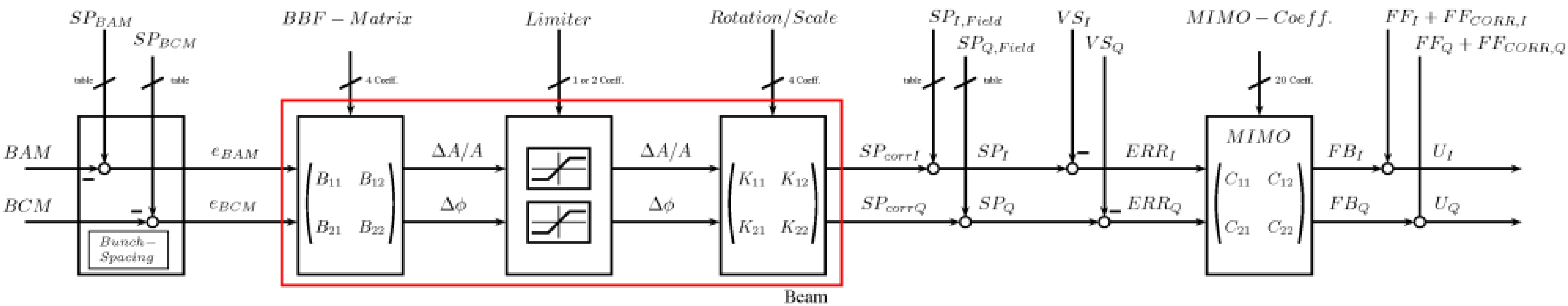
> Perfect RF field regulation does not imply perfect beam regulation!!

Current implementation

- Feedback acts on the set-point (during RF pulse)
  - Decoupling of individual feedback loops (prevention of instabilities)
  - RF controller used for reference tracking
  - Constant pulse to pulse variations done by learning FF
- Transfer function BCM / BAM to RF
  - Beam information to set-point trajectory assumed to be linear
  - Estimation of response matrix needed (static gains)
- Machine protection
  - Corrections are limited to 1% amplitude and phase variation
  - Coupled to toroid system (missing beam, charge calibration)
- Currently used for BC2 and BC3
  - Therefore amplitude and phase regulation of ACC1, ACC39, ACC23

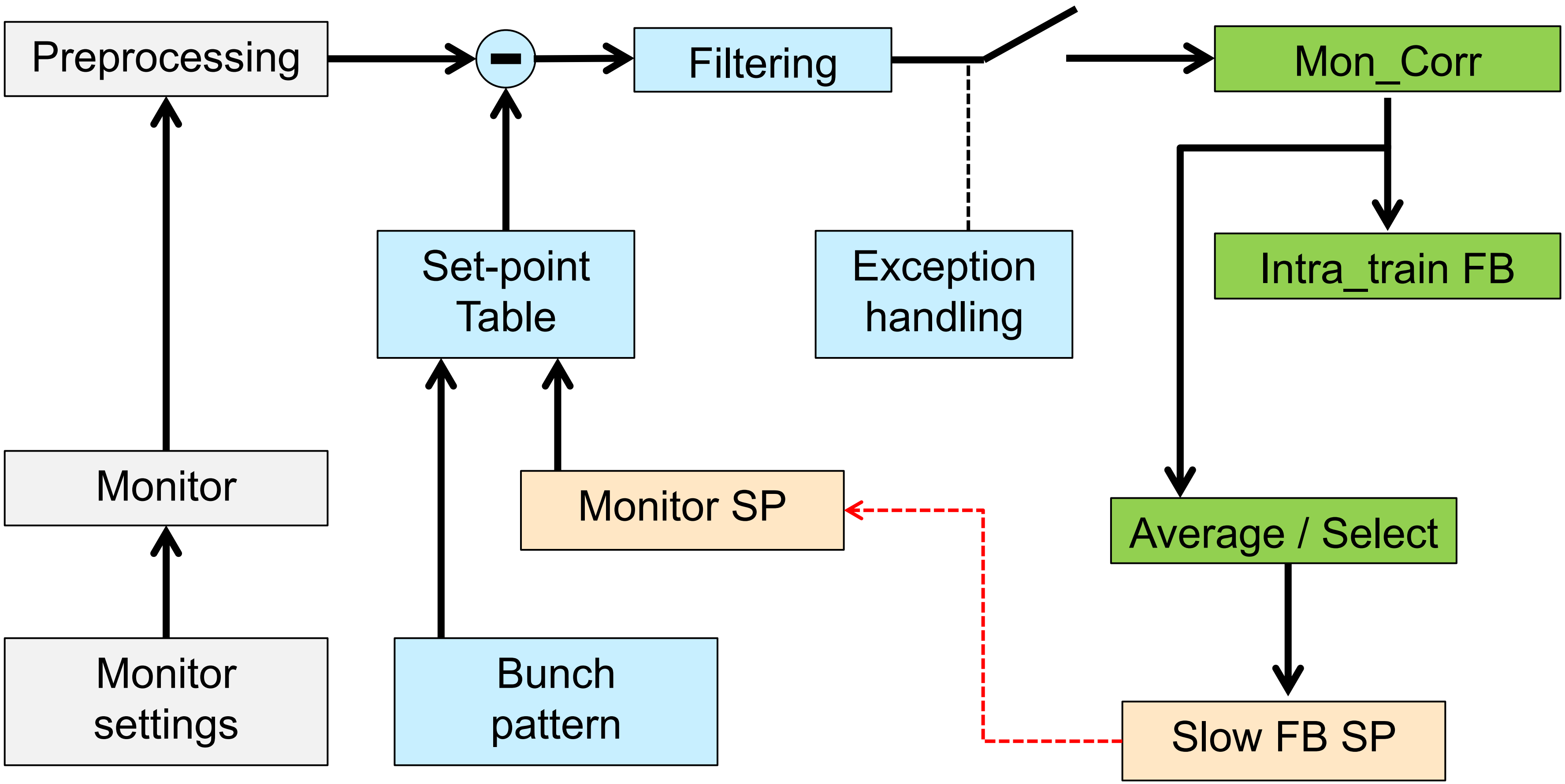
Block diagram of BBF structure





- BAM, BCM input preprocessed, conversion in Amp, Pha.
- Limiter as exception secure, modulation to SP I,Q
- Addition/correction of User RF set-point, MIMO FB

Monitor signal procession



- Should be applied to all beam monitors and OXC
- Unique structure for slow and fast FB systems

Setup of BBF

- Measurement of response Matrix
  - Static transfer function from BCM and BAM to amplitude and phase of actuator
  - Estimation of 4 (8) Matrix parameters

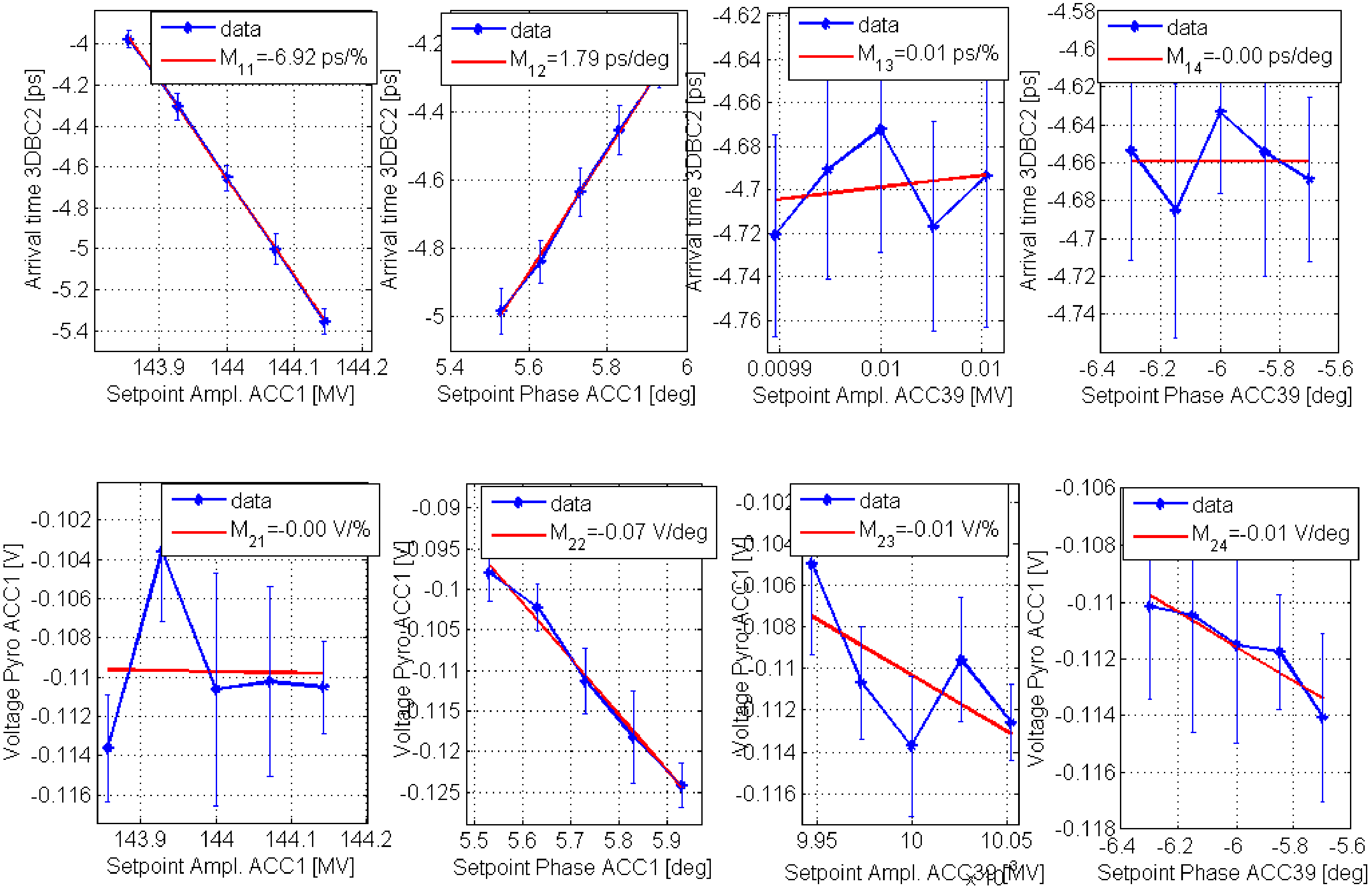
$$\begin{pmatrix} \Delta t_{BAM.BC2} \\ \Delta V_{BCM.BC2} \end{pmatrix} = \Bigg(\underbrace{\begin{matrix} K_{11} & K_{12} \\ K_{21} & K_{22} \end{matrix}}_{M} \left| \begin{matrix} K_{13} & K_{14} \\ K_{23} & K_{24} \end{matrix} \right.\Bigg) \begin{pmatrix} \Delta A_{ACC1} \\ \Delta P_{ACC1} \\ \hline \Delta A_{ACC39} \\ \Delta P_{ACC39} \end{pmatrix}$$

- Computation of inversed matrix scaled by monitor specific calibrations

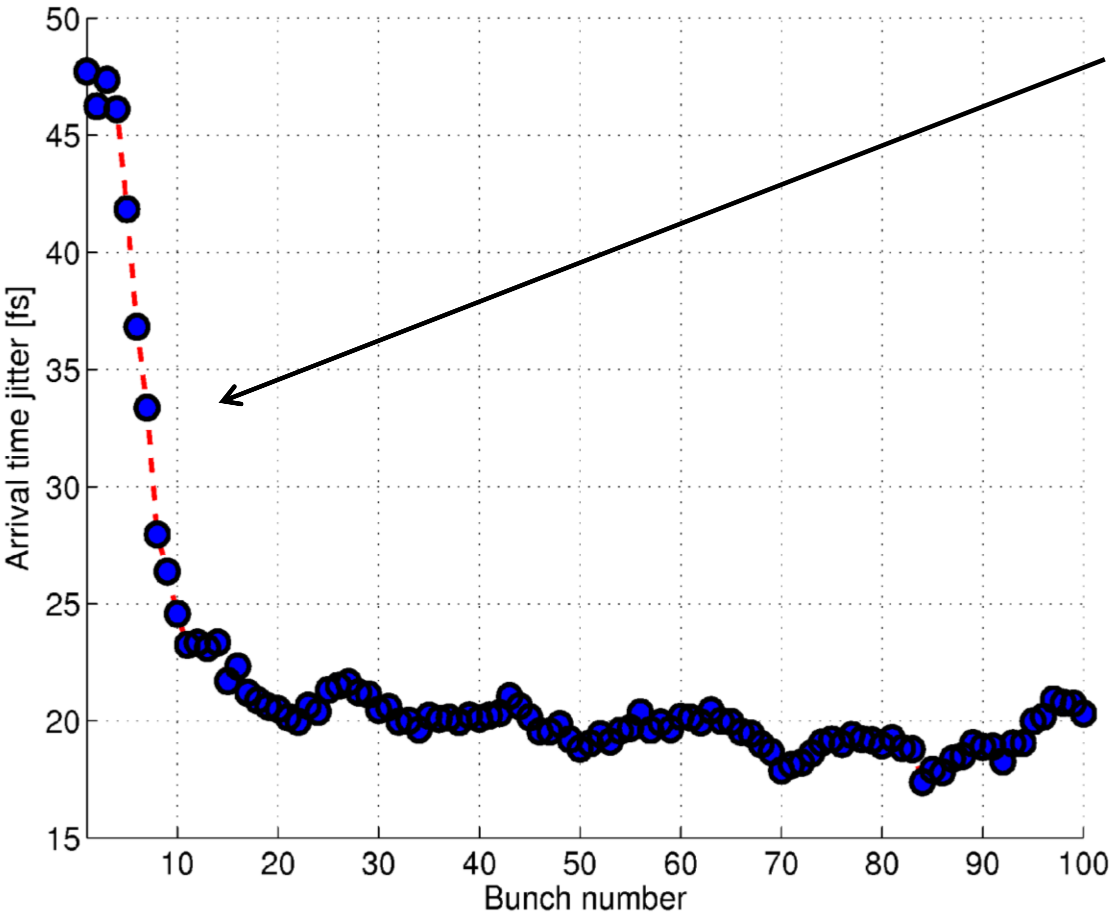
$$M_{BBF} = KM^{-1}$$

- Application of BBF matrix to feedback

Measured beam response matrix in BC2



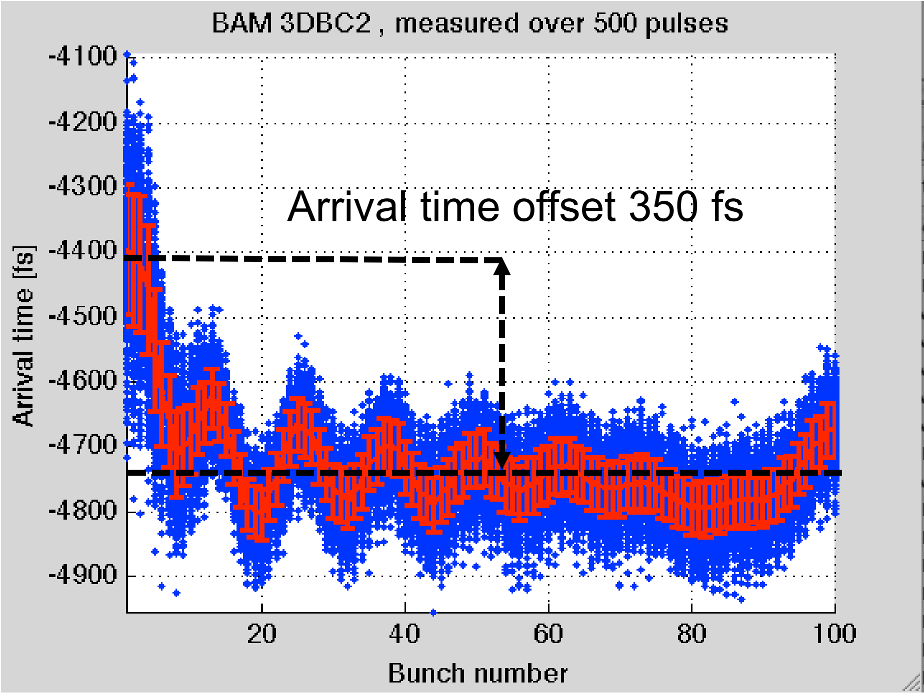
Arrival time jitter 18ACC1 over 500 pulses

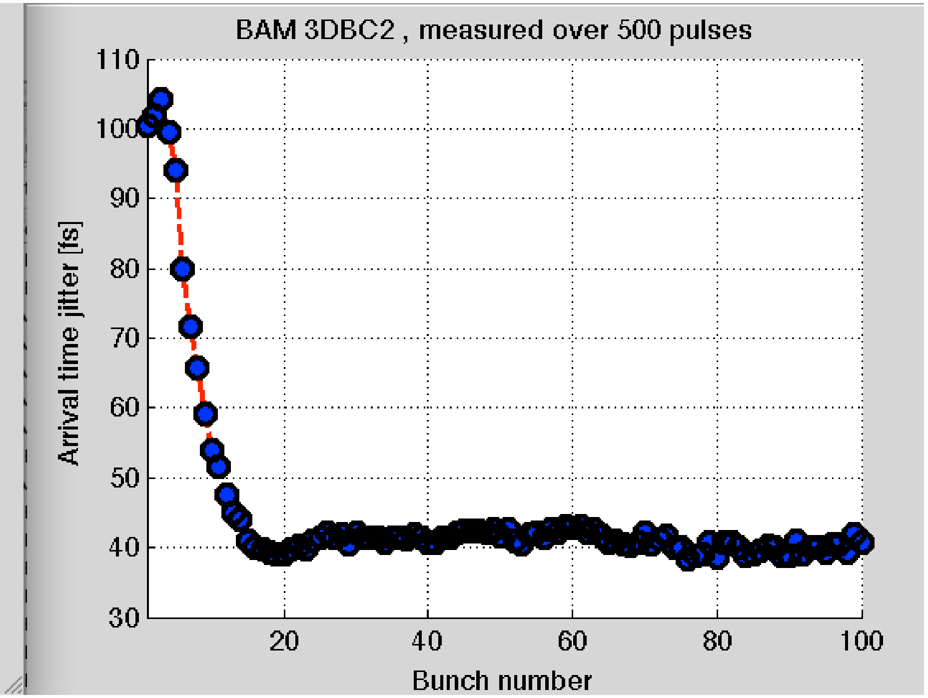


Approximatly 10 bunches are needed for arrival time stabilization

> LFF, MIMO FB, BLC and BBF (ACC1, ACC23) on

Problems to be solved for BBF



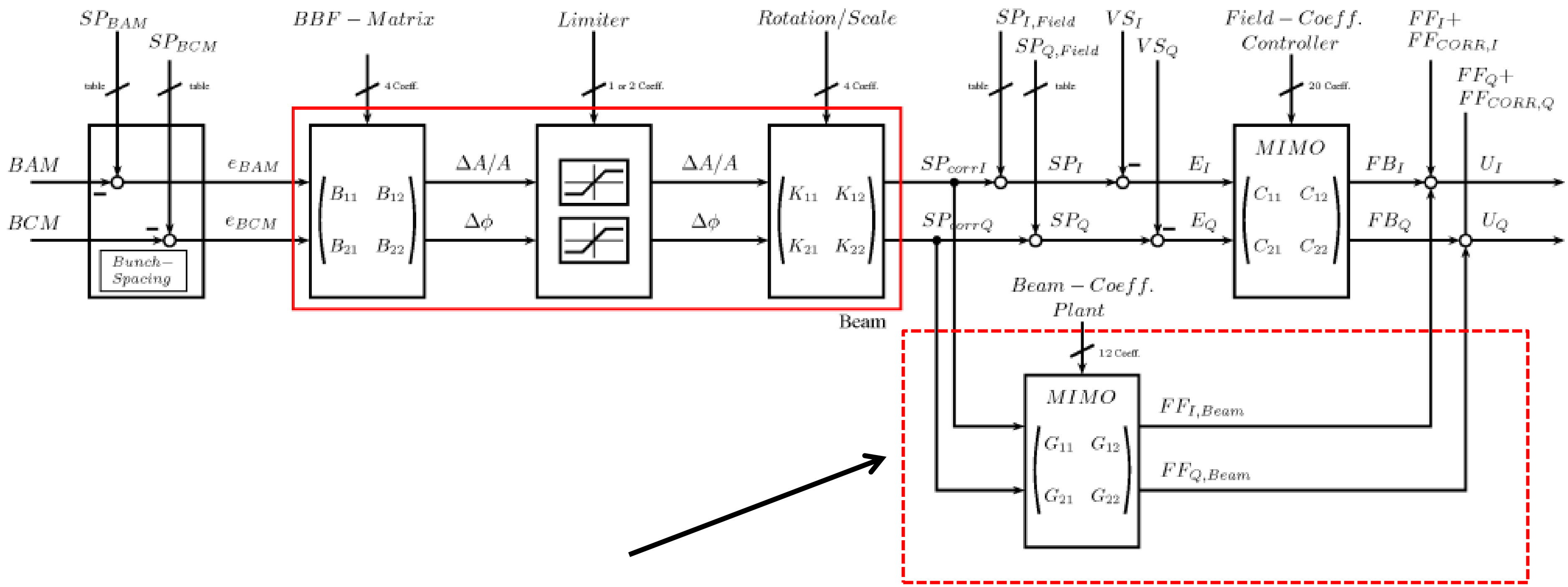


- Offset should be compensated by slow SP adaptation
- Reduced ringing, faster settling time
- Improves feedback system, stable operation

To be taken into account

- Implementation of a uniform slow feedback system to keep the RF set-point values to the beam measurements
  - (**Slow DAQ based long. feedback architecture, R. Kammering**)
- Charge and orbit dependency of beam monitors
  - **(Results on BAM studies, M.K. Bock)**
- Currently setup of feedback demands experts and time
  - check system integrity, calibration, measure response matrix …
- Accuracy and resolution limitations of beam monitors
  - BCM saturation, different monitors
- Time delay and regulation limitations of feedback
- Additional to set-point model-based FF drive

Direct integration into field drive



- Identified beam-field model
- 1st order MIMO Beam-FB controller
- Additional gain scheduling tables

Expected benefits of updated BBF structure

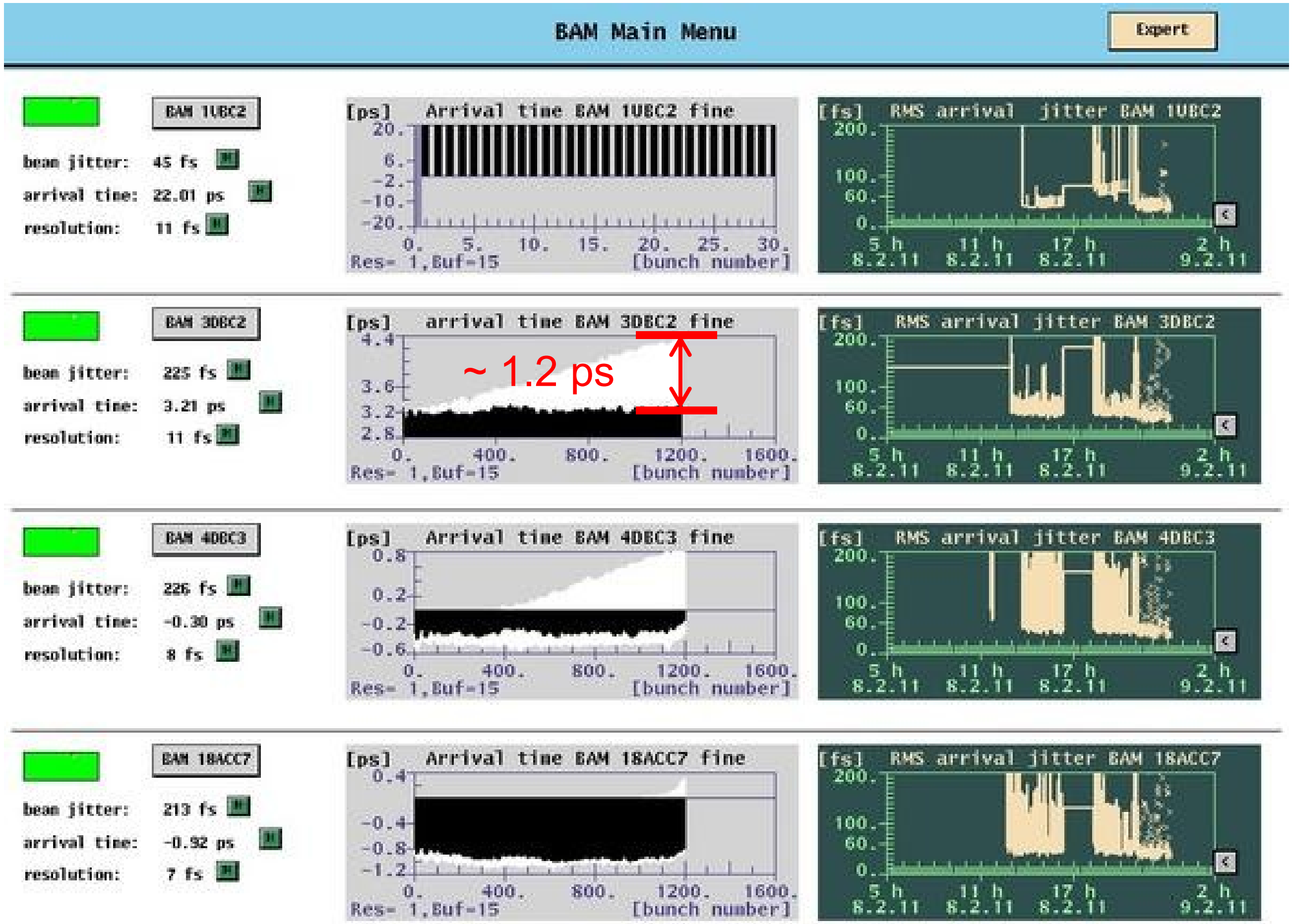
> Reduced arrival time jitter and compression fluctuations
  - Possible other controller dynamics necessary for beam monitors
  - Sensitivity of beam monitors differ from field feedback

> Decoupling from field feedback controller dynamics
  - Gain scheduling depending on beam conditions
  - Controller input weights

> Reduced response time
  - Depending on max. closed loop bandwidth of combined system
  - Possible filtering of beam monitor signals, reduced oscillations

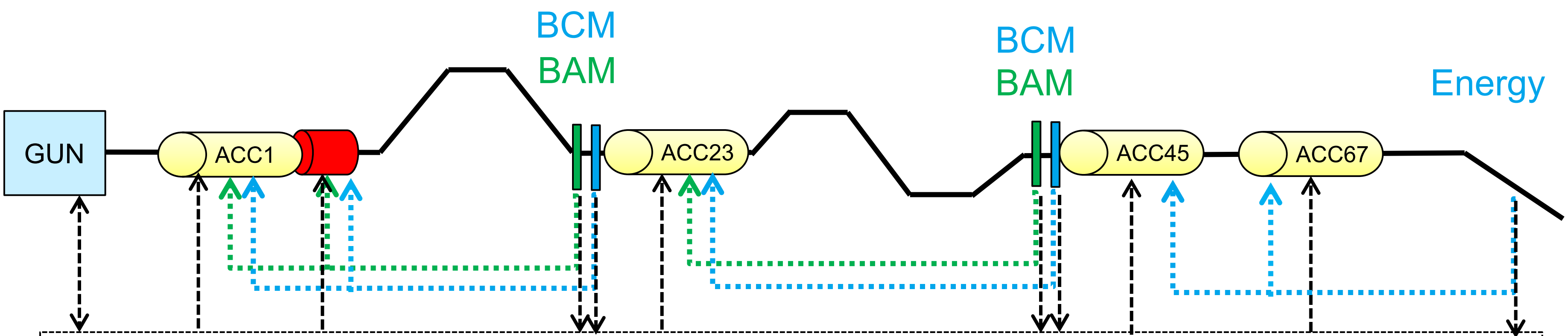
> Combination with slow feedback system
  - Keep monitor signals ~ mean free due to SP adaptation (drifts)
  - Update time distribution: 10 Hz ITFB , 1-5 Hz slow SP FB,
  - 1/10 Hz SP correction (residual tilts, oscillations)

Set-point modification



> …using BAM measured arrival time slope

Block diagram of integrated slow FB scheme



Measured response matrix

$$\begin{pmatrix} SP.A_{ACC1} \\ SP.P_{ACC1} \\ SP.A_{ACC39} \\ SP.P_{ACC39} \\ SP.A_{ACC23} \\ SP.P_{ACC23} \\ SP.A_{ACC45} \\ SP.P_{ACC45} \\ SP.A_{ACC67} \\ SP.P_{ACC67} \end{pmatrix} = \begin{pmatrix} K_{11} & K_{21} & \cdots & & \cdots & K_{61} \\ & \ddots & & & & \\ & & \ddots & & & \\ & & & \ddots & & \\ & & & & \ddots & \\ & & & & & \\ & & 0 & & & \vdots \\ & & & & & K_{69} \\ & & & & & K_{610} \end{pmatrix} \begin{pmatrix} BAM_{1UBC2} \\ BAM_{BC2} \\ BCM_{BC2} \\ BAM_{BC3} \\ BCM_{BC3} \\ E_{Dogleg} \end{pmatrix}$$

- Causality
- Individual weighting
- Extend by OXC
- DAQ data
- Limits and update rate

Summary

- Fast longitudinal FB commissioned and operated at FLASH
- Achieved arrival time stabilization of < 20 fs for >80 bunches over 500 pulses !
- Setup for user pump probe experiments with fast kickers before undulator

To be done:

- Improvement of monitor operability, availability
- Automated response matrix determination and application
- Combination with model based direct feed forward drive
- Integration in full FB scheme
- Further reduction of arrival time jitter below 10 fs ….

Thanks for your attention