Longitudinal Diagnostics for Beam-Based Intra Bunch-Train Feedback

Status, recent studies and future plans

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on behalf of the BBF team
FEL Seminar
DESY, 2016-05-10

HELMHOLTZ ASSOCIATION

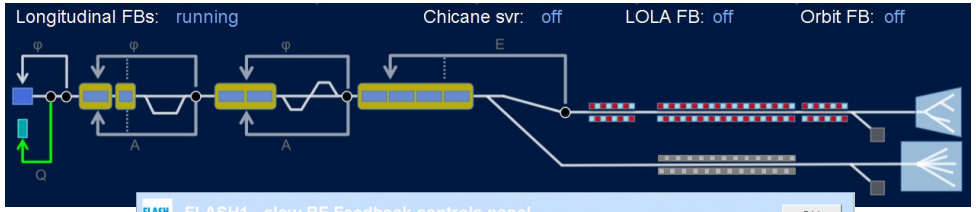
DESY

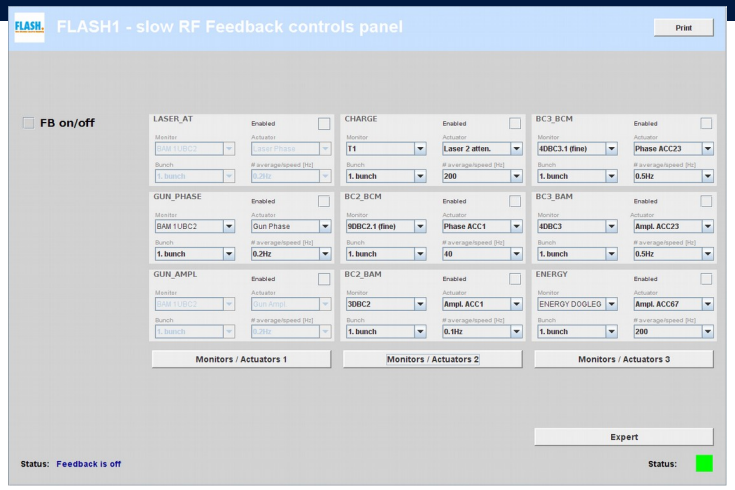
Outline

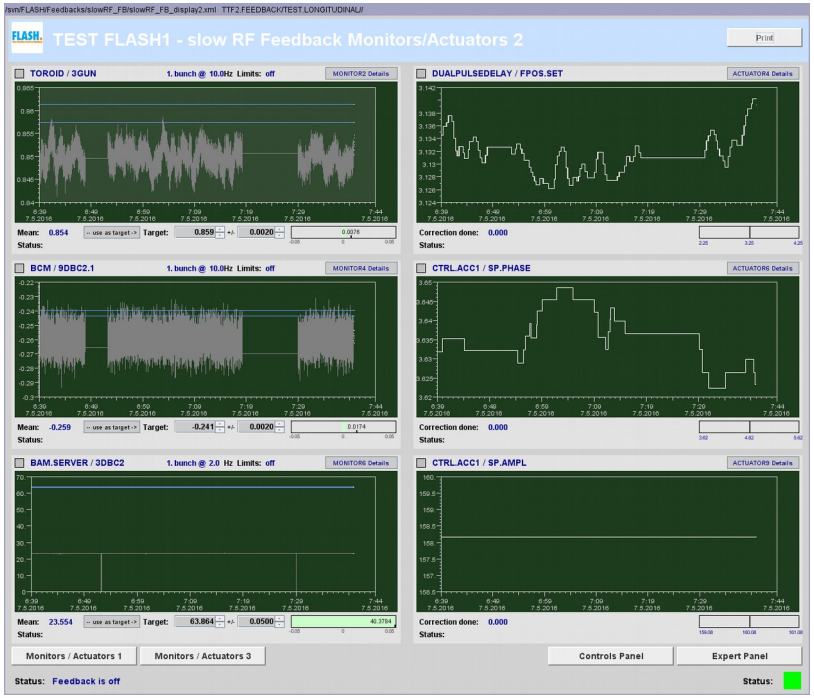
- Introduction
  - Feedback
  - Longitudinal intra bunch-train feedback
- Simulations
- Components characterisation
  - Bunch compression dependant jitter analysis
- Implementation & development
- First results
- Summary

Feedback

- Stabilisation of machine operating point
  - “Slow” (Hz range): drift
  - “Fast” (MHz range): bunch-to-bunch jitter
- Example: slow longitudinal feedback system at FLASH
  - Routinely used in everyday operation

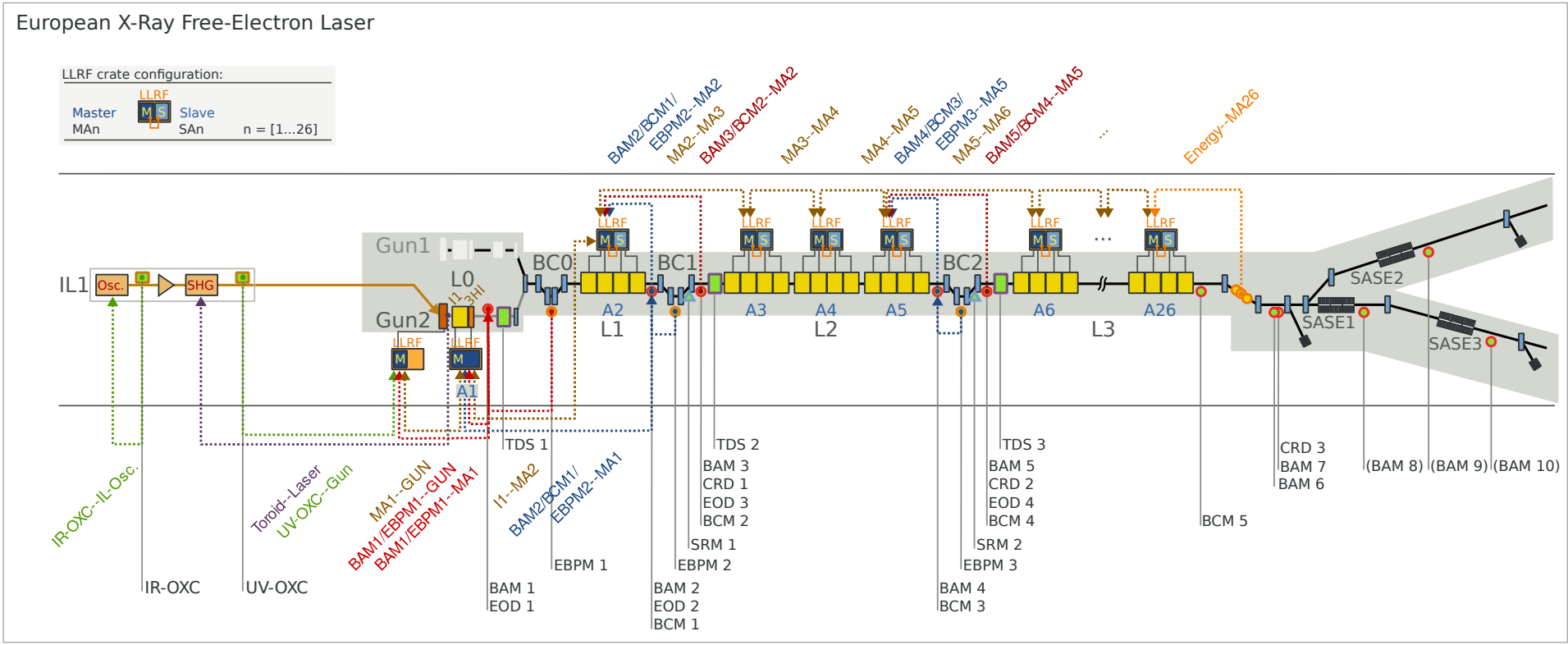






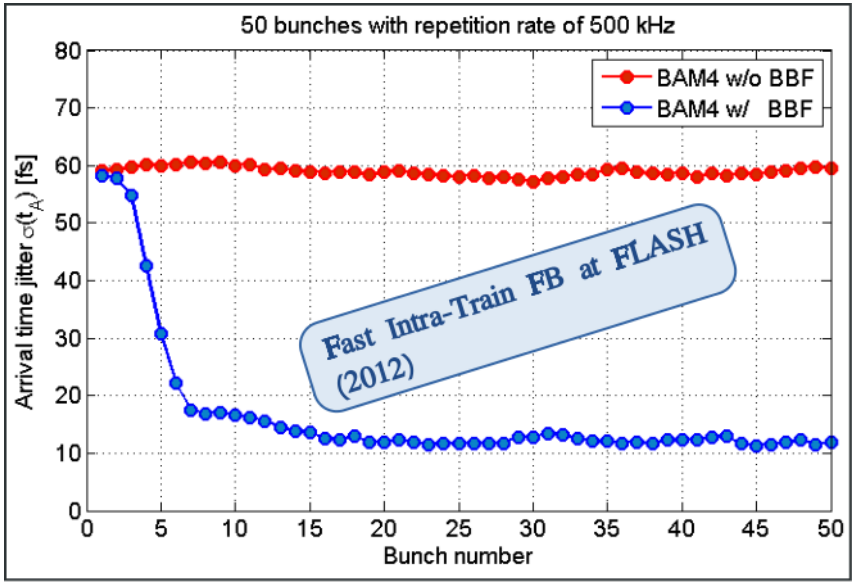
Longitudinal Feedback at European XFEL

- More / more complex control loops possible



Longitudinal Intra Bunch-Train Feedback

- Fast intra-train feedback at FLASH, 2012 (VME based system)



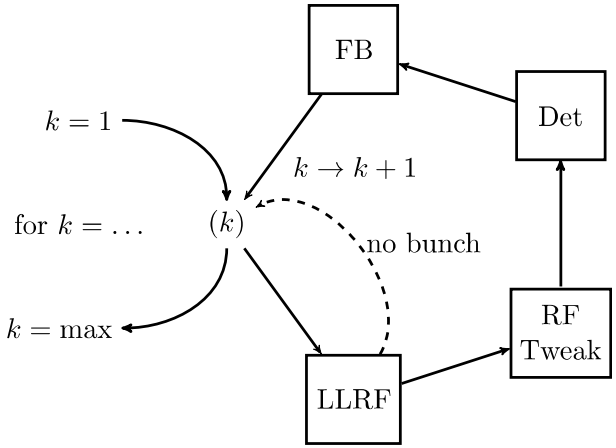
- LLRF controls already upgraded to new MicroTCA based system
- Meanwhile diagnostics in process of being upgraded to MicroTCA as well
- Re-implement fast intra-train feedback on new standard

Considerations

- Detectors + subsystems
  - Sensitivity
  - Resolution
  - Saturation
  - Error sources
  - Signal filtering
- Controllers and plants: Small Signal Model
  - LLRF cavity model
  - Loop latency
  - Different machine working points → regulation scheme, parameters
- Evaluation of individual sub-systems and full BBF model
  - Simulations
  - Laboratory tests
  - Machine studies

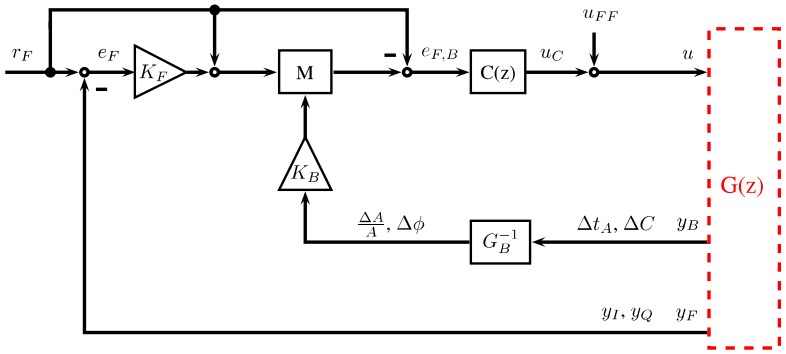
Longitudinal Beam-Based Feedback Simulations

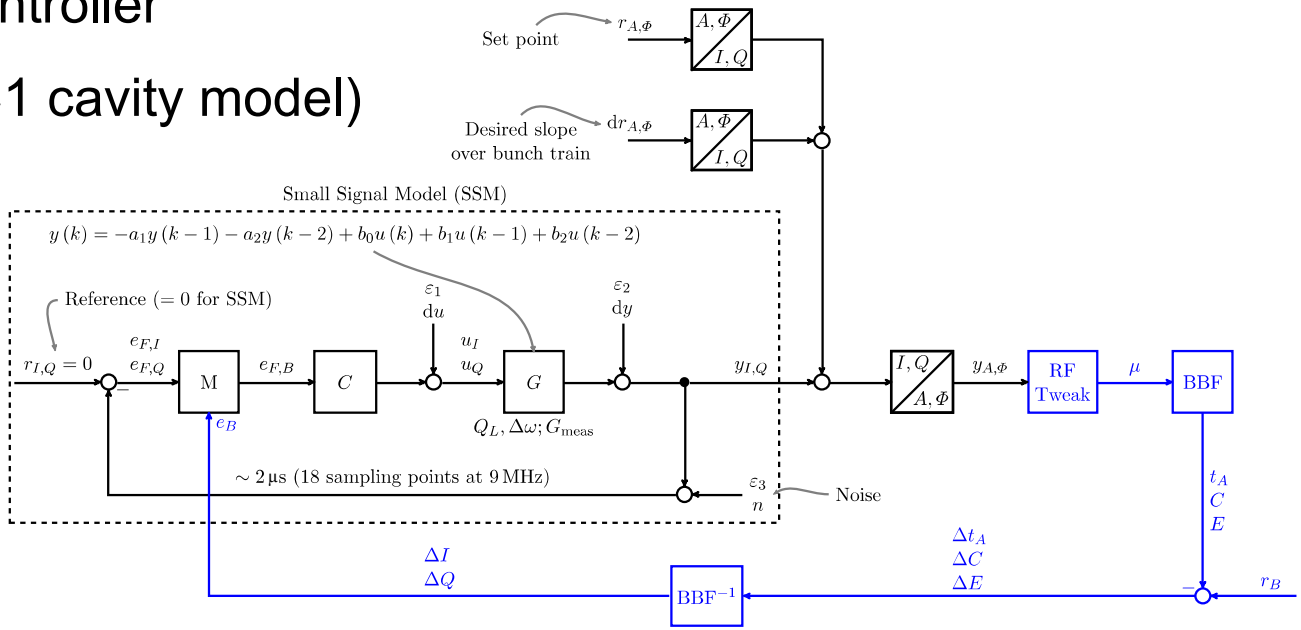
- Simulation and evaluation of the longitudinal beam-based intra bunch-train feedback for FLASH and European XFEL
- Including whole signal chain: realistic model for detectors, LLRF controllers and plants
- Including cross-coupling of individual elements
- Timing
  - Bunch pattern w.r.t. LLRF control loop
  - Signal propagation + processing
  - Controller computing time
- Investigate regulation performance
  - Identify jitter sources and impact
  - Evaluate mitigation approaches
  - Tweak control parameters



Feedback Structure

- Particle tracking: RF Tweak
- Diagnostics elements
  - Bunch arrival time monitor
  - Bunch compression monitor
  - Synchrotron radiation monitor
- LLRF MIMO controller
- Plant (e.g. ACC1 cavity model)



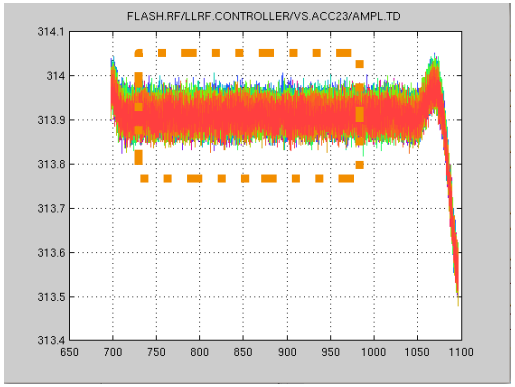


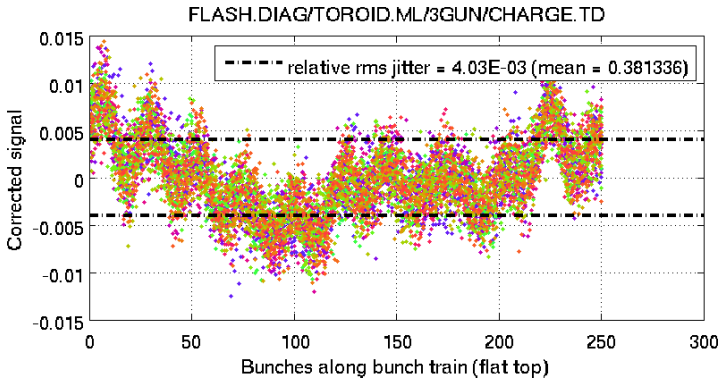
Characterisation of Monitors and Subsystems

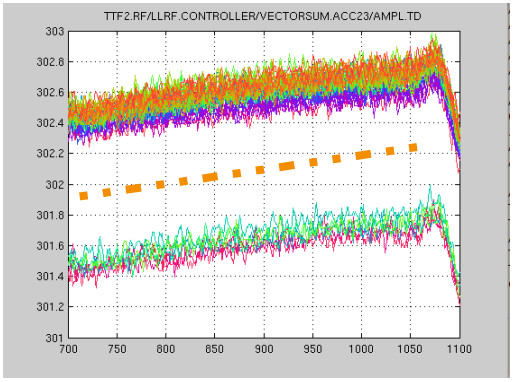
- Development shifts: 36 hours so far
- Study of beam-based feedback matrix using higher moments of energy profiles measured with a bunch-resolved SRM MHz detector
  - In cooperation with Franziska Frei & Gian Luca Orlandi (PSI)
  - 2015-06-08 (19:00 – 23:00)
  - 2015-06-12 (07:00 – 11:00)
  - 2015-08-07 (11:00 – 14:00)
- Bunch compression dependant jitter analysis
  - In cooperation with Michael Kuntzsch (HZDR)
  - 2015-11-14 (11:00 – 19:00)
  - 2016-01-29 (22:00 – 07:00)
- Implementation tests of beam-based intra bunch-train feedback
  - 2016-04-28 (23:00 – 07:00)

Bunch Compression Dependant Jitter Analysis

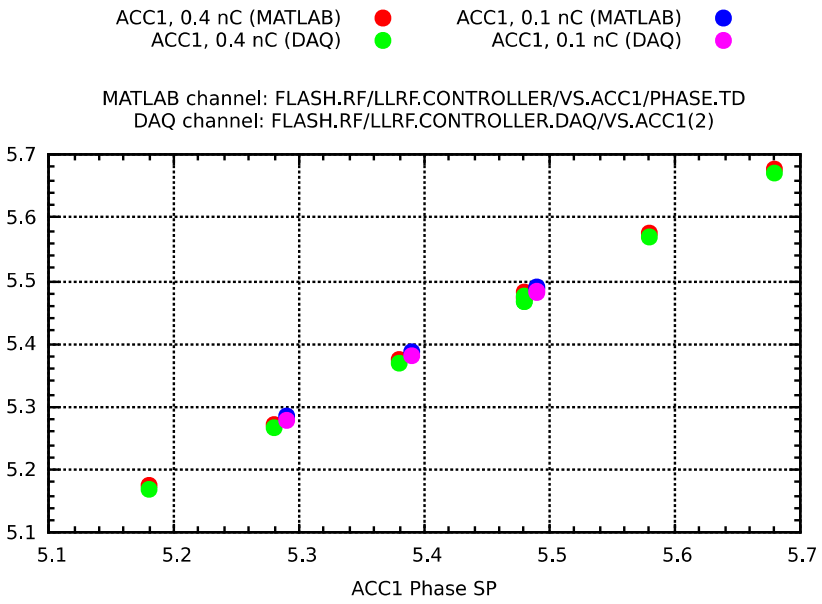
- Collection of multiple macro-pulses with (up to) 400 bunches each
- Varied compression in BC2 (ACC1 Phase) and BC3 (ACC23 Phase), let downstream slow feedbacks adapt
- For two different bunch charges: 0.4 nC and 0.1 nC
- Data analysis
  - Flat top selection
  - Removal of correlated slope
  - Removal of uncorrelated offset
  - Estimation of residual jitter over all bunches

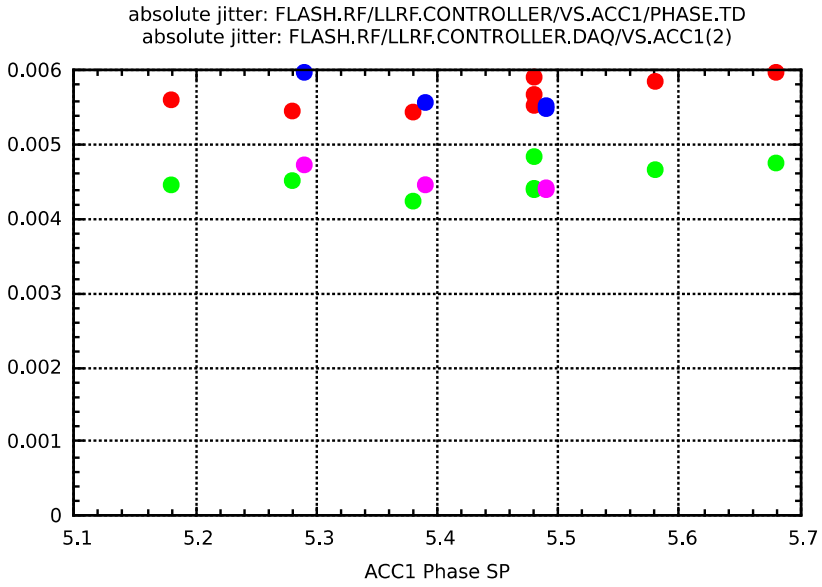






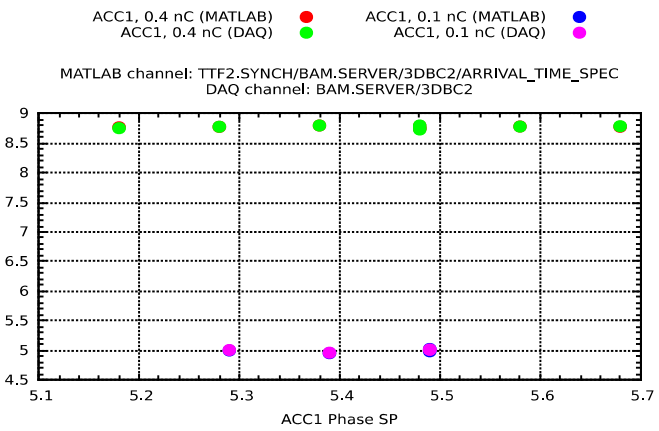
ACC1 RB Phase

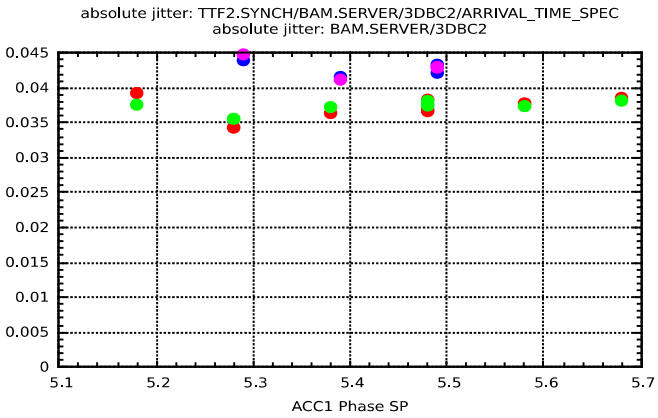




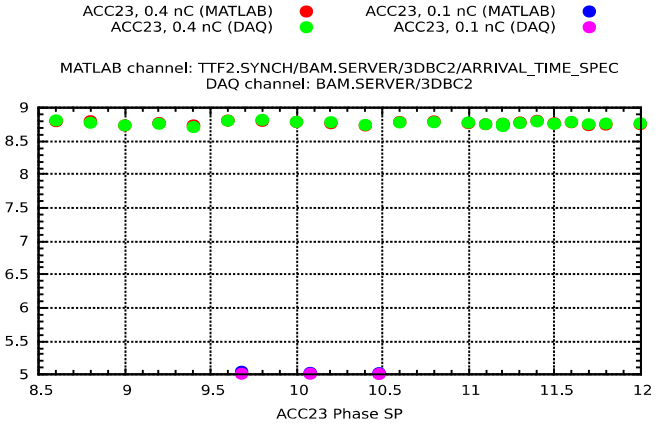
BAM 3DBC2

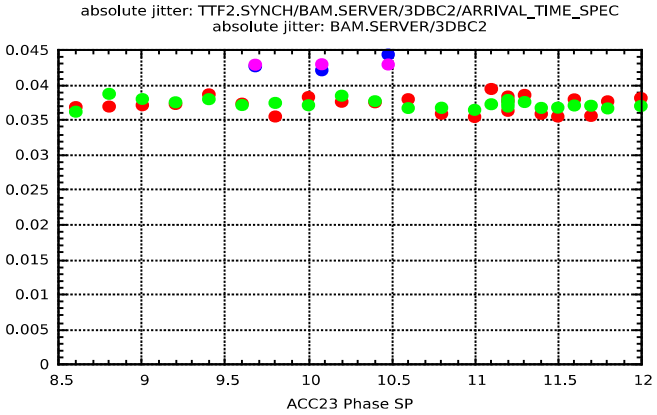
ACC1 Phase





ACC23 Phase

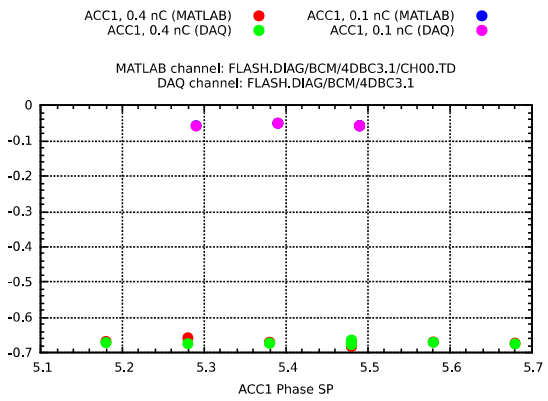


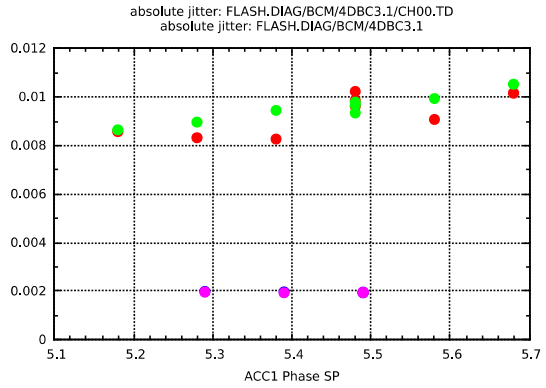


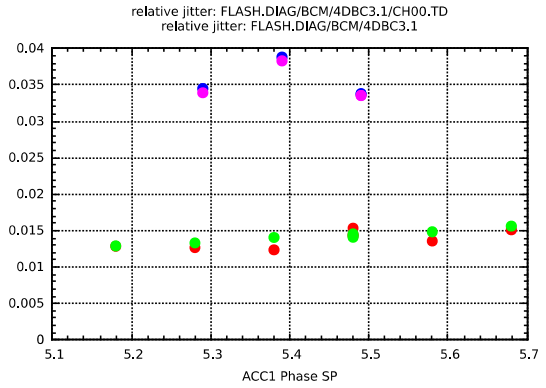
Measurement

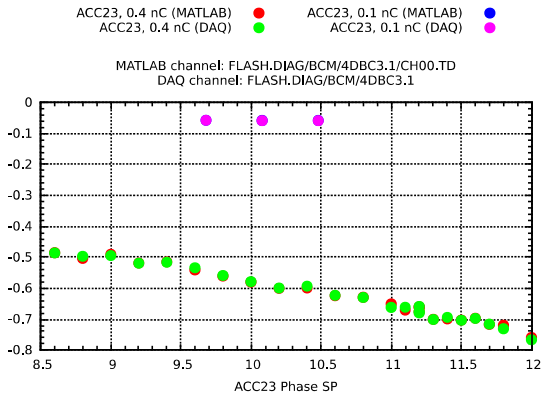
abs. jitter

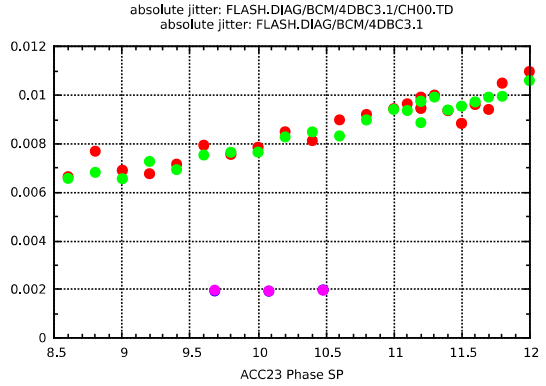
BCM 4DBC3 Fine

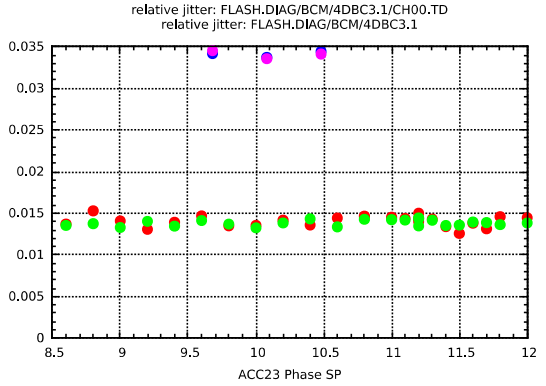










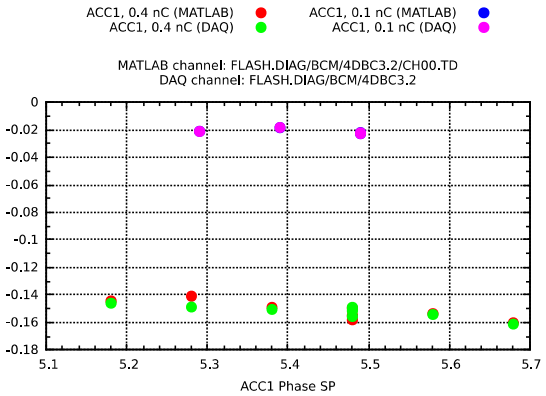


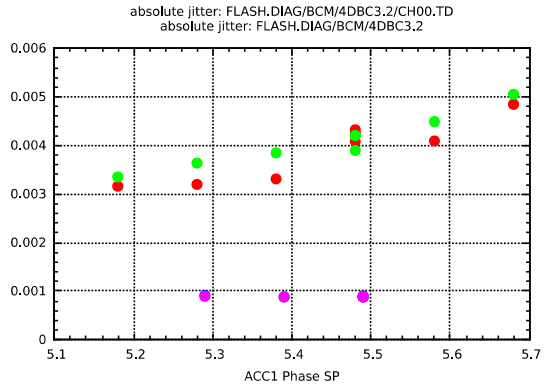
Measurement

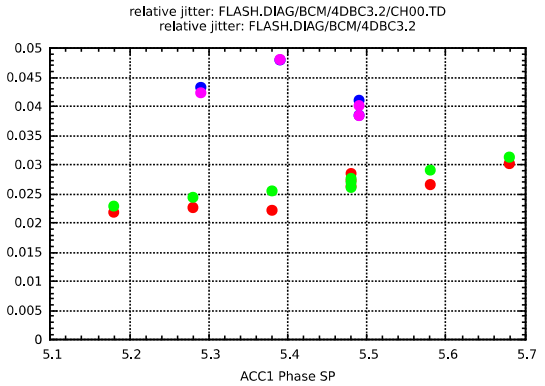
abs. jitter

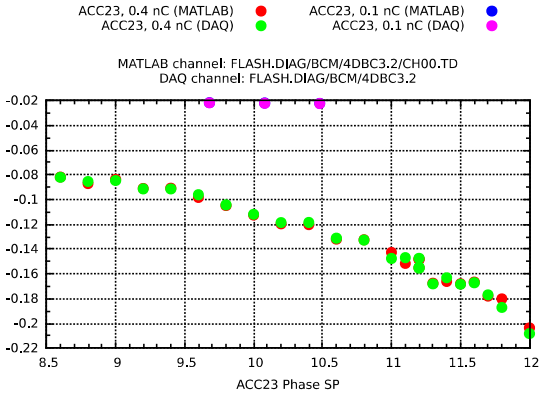
rel. jitter

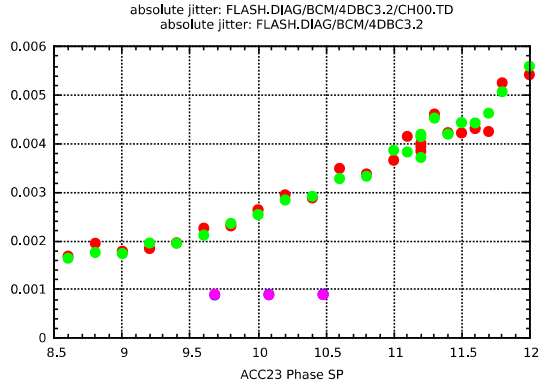
BCM 4DBC3 Coarse

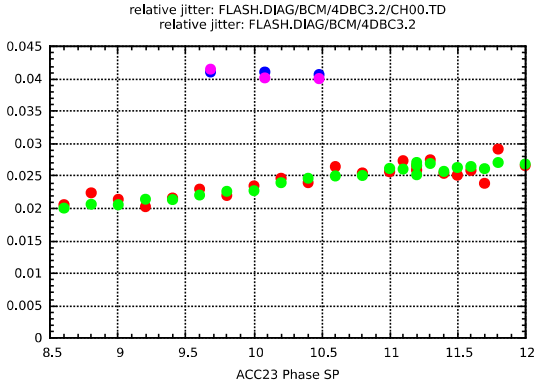










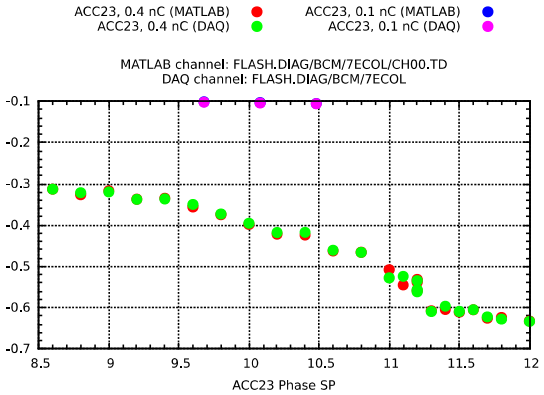


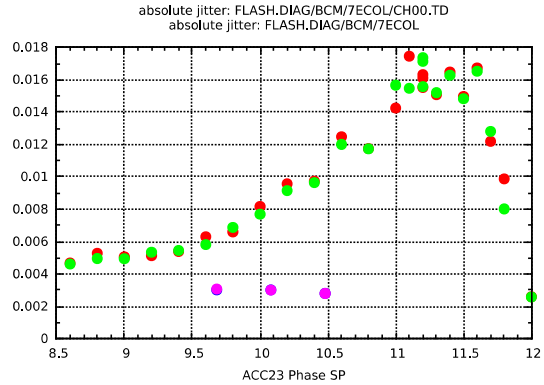
Measurement

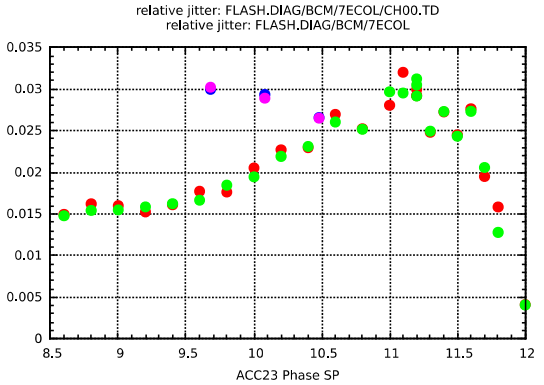
abs. jitter

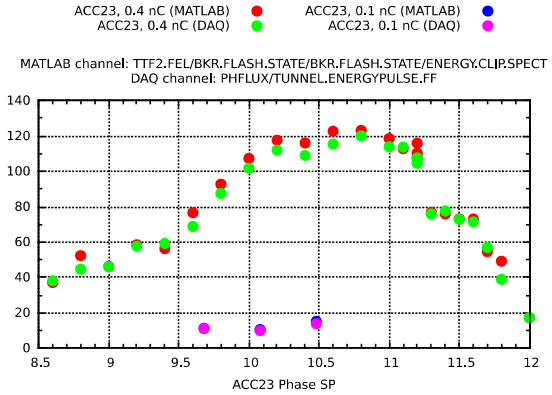
rel. jitter

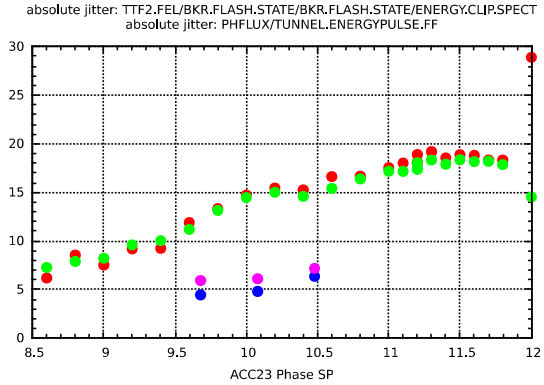
BCM 7ECOL (upper) vs. SASE (lower): ACC23 Phase

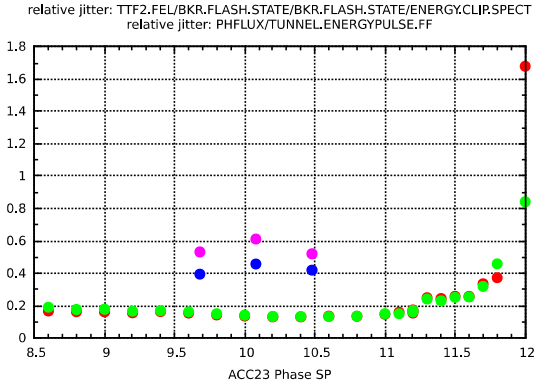












Measurement

abs. jitter

rel. jitter

Implementation & Development

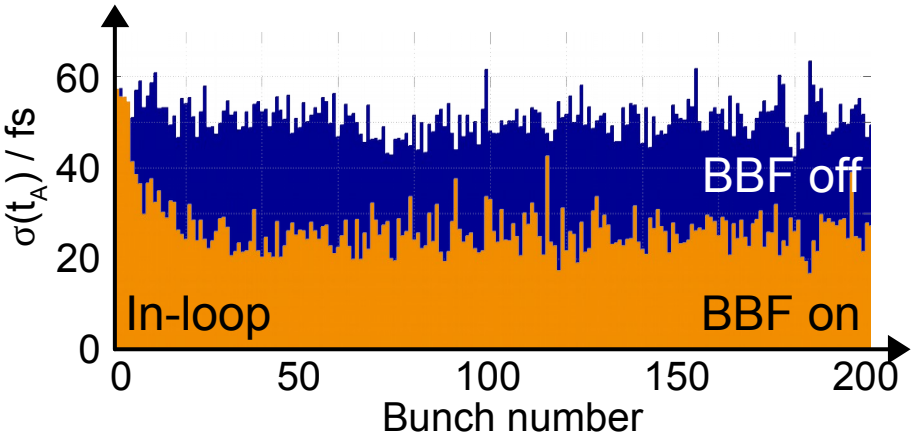
- People
  - Łukasz Butkowski, Marie Kristin Czwalinna, Hannes Dinter, Sven Pfeiffer, Adam Piotrowski, Konrad Przygoda, Radosław Rybaniec, Christian Schmidt, Michele Viti
- MicroTCA BAM hardware, firmware + server development
- Tests performed during Synchronisation Maintenance shifts
- Development of the BBF enabled LLRF firmware + server and tests on the FLASH-Teststand
- Communication link between BAM and LLRF MicroTCA crates

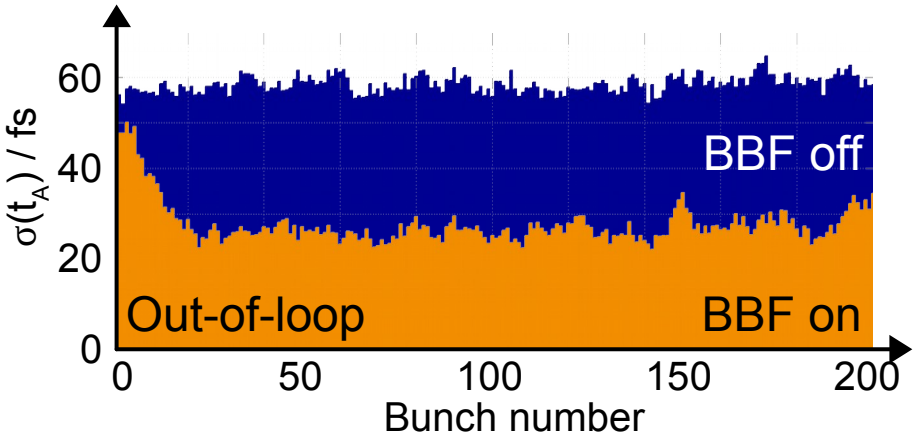
Resurrection

- 8 hours development shift on 2016-04-28
- Successful tests of all sub-systems
  - BAM.3DBC2 on MicroTCA front end
  - Updated ACC1 LLRF firmware + server and BAM firmware
  - Established communication between BAM and LLRF systems
- Successful regulation tests
  - 200 bunches (1 MHz)
  - 100 bunches (500 kHz)
  - Controller parameters not yet optimised
- In parallel: tests with intra bunch-train charge feedback (also benefiting from long bunch trains)

First Results

- 200 bunches @ 1 MHz, bunch charge 0.3 nC
- Bunch-to-bunch rms arrival time jitter recorded over 100 macro-pulses (controller parameters not yet optimised)





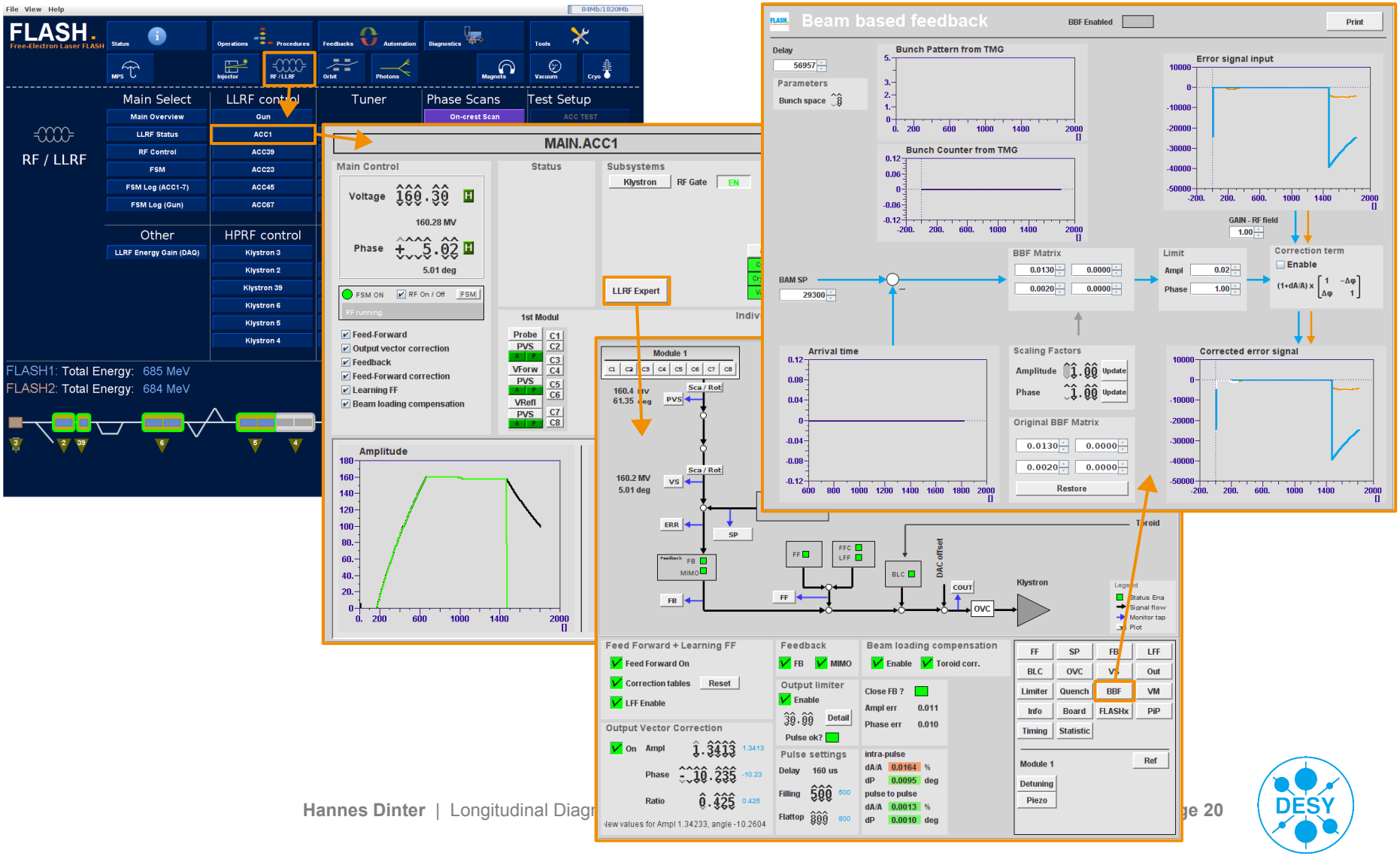
System	In-loop	Out-of-loop
Monitor	BAM.3DBC2	BAM.4DBC3
BAM front-end	MTCA system in Synch hutch, data patched through to ACC1/39 crate in tunnel	VME system in tunnel
Feedback OFF	~50 fs	~60 fs
Feedback ON	~25 fs	~25 fs
Resolution	11 fs (not optimised)	15 fs

Summary

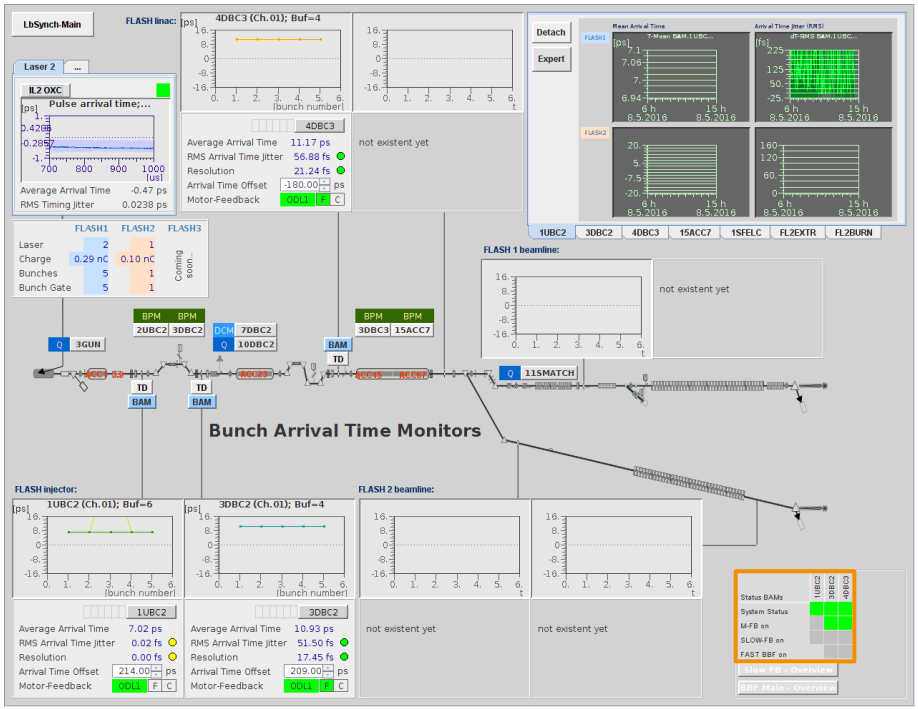
- Characterisation of monitors and subsystems
- Longitudinal beam-based intra bunch-train feedback simulations
- Proof of principle with MicroTCA system successful
- Next development shift: this Friday, 2016-05-13 (8 hours)
- Further tests of controller and subsystems
- Optimise regulation parameters
- Evaluate performance for different machine set-ups
- Make use of full MIMO controller including bunch compression signals
- Eventually: everyday operation

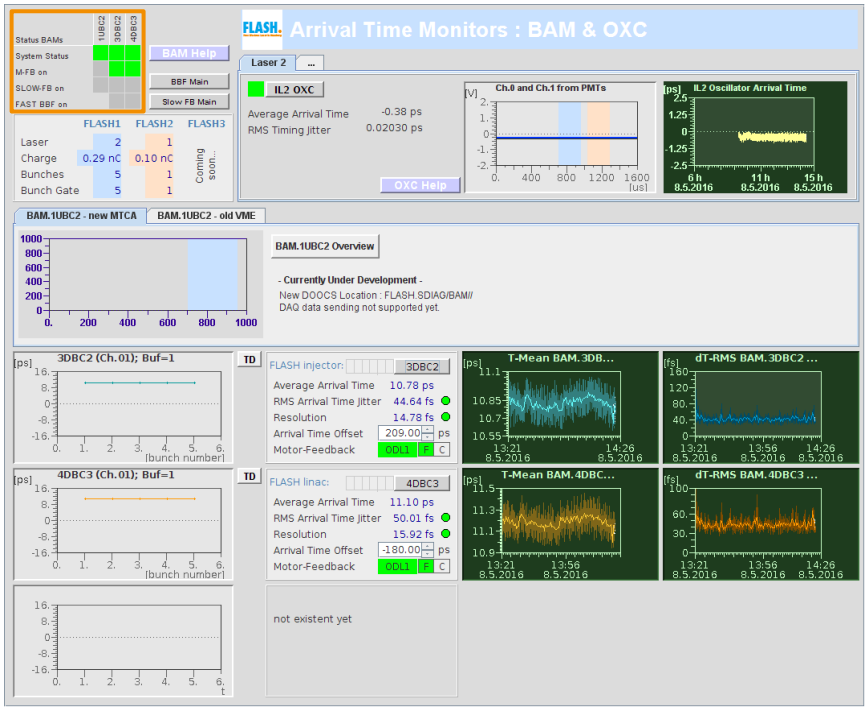
Controls

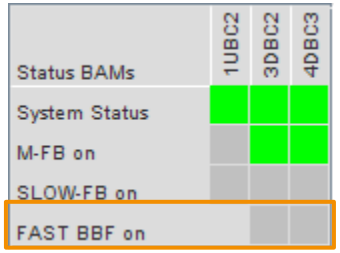
> MainTaskbar > LLRF > ACC1 > LLRF Expert > BBF



Status Indicators Available on BAM Panels







Thank you for your attention!