

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

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

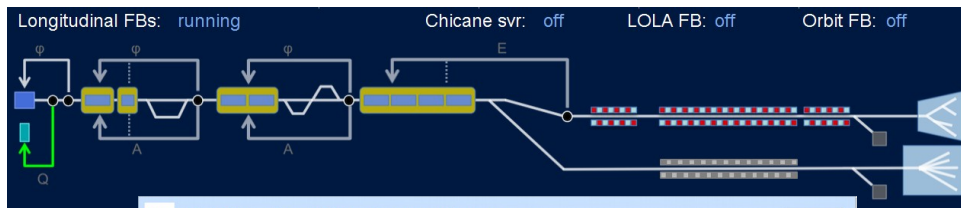


➤ Stabilisation of machine operating point

- “Slow” (Hz range): drift
- “Fast” (MHz range): bunch-to-bunch jitter

➤ Example: slow longitudinal feedback system at FLASH

- Routinely used in everyday operation



FLASH1 - slow RF Feedback controls panel

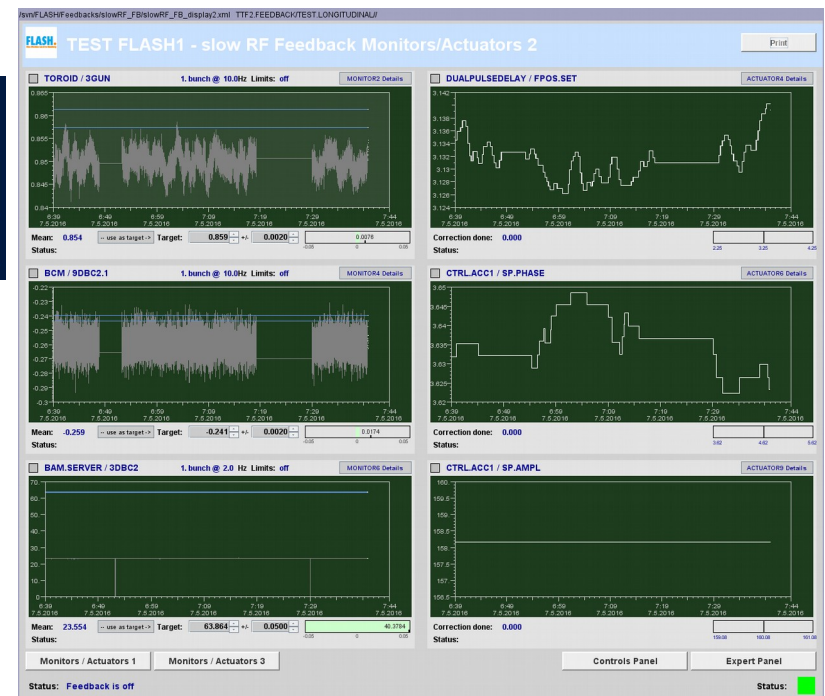
FB on/off

LASER_AT Enabled <input type="checkbox"/>	CHARGE Enabled <input type="checkbox"/>	BC3_BCM Enabled <input type="checkbox"/>
Monitor: Laser AT	Monitor: Laser 2 atten.	Monitor: Phase ACC2
Actuator: Laser Phase	Actuator: Laser 2 atten.	Actuator: Phase ACC2
Bunch: # average/bunched [Hz]	Bunch: 1. bunch	Bunch: 1. bunch
1. bunch	200	0.5Hz
GUN_PHASE Enabled <input type="checkbox"/>	BC2_BCM Enabled <input type="checkbox"/>	BC3_BAM Enabled <input type="checkbox"/>
Monitor: Gun Phase	Monitor: Phase ACC1	Monitor: HDBC3.1 (flw)
Actuator: Gun Phase	Actuator: Phase ACC1	Actuator: HDBC3.1 (flw)
Bunch: # average/bunched [Hz]	Bunch: 1. bunch	Bunch: 1. bunch
1. bunch	40	0.5Hz
GUN_AMPL Enabled <input type="checkbox"/>	BC2_BAM Enabled <input type="checkbox"/>	ENERGY Enabled <input type="checkbox"/>
Monitor: Gun Amp	Monitor: Amp1 ACC1	Monitor: ENERGY DOGLE0
Actuator: Gun Amp	Actuator: Amp1 ACC1	Actuator: Amp1 ACC67
Bunch: # average/bunched [Hz]	Bunch: 1. bunch	Bunch: 1. bunch
1. bunch	0.1Hz	200

Monitors / Actuators 1 Monitors / Actuators 2 Monitors / Actuators 3

Expert

Status: Feedback is off

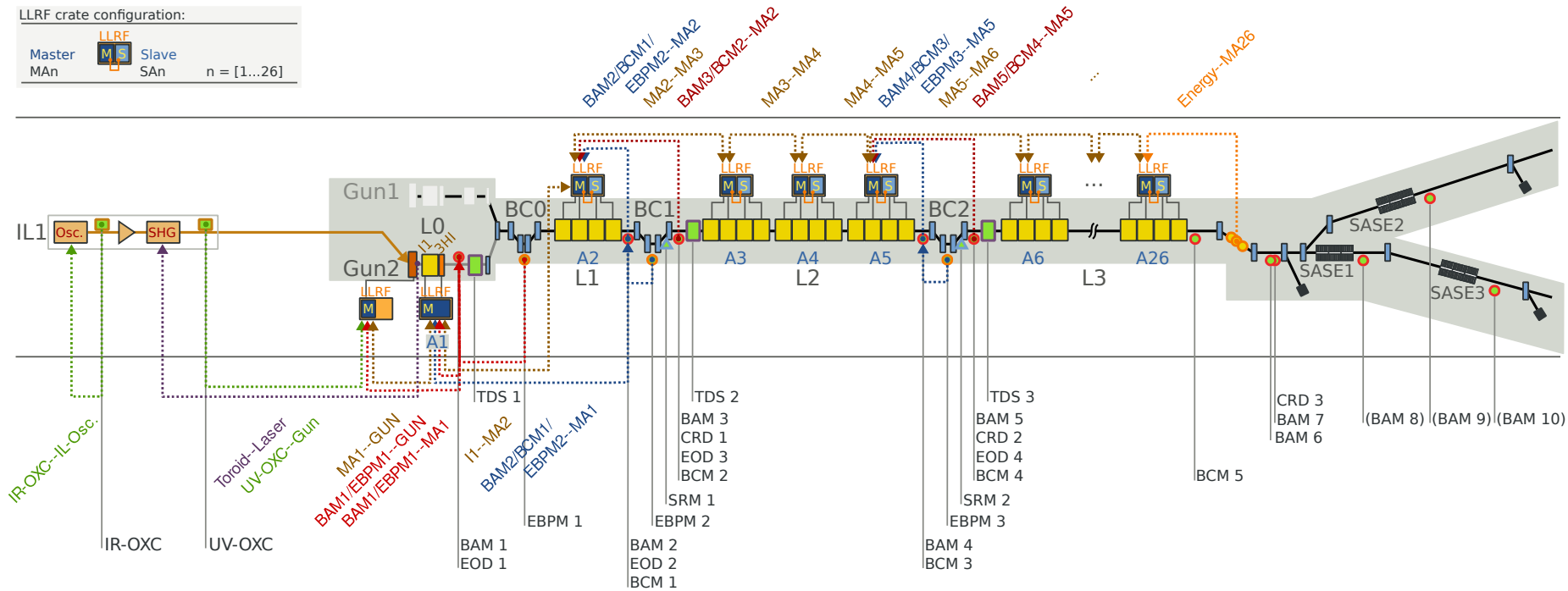


Longitudinal Feedback at European XFEL

➤ More / more complex control loops possible

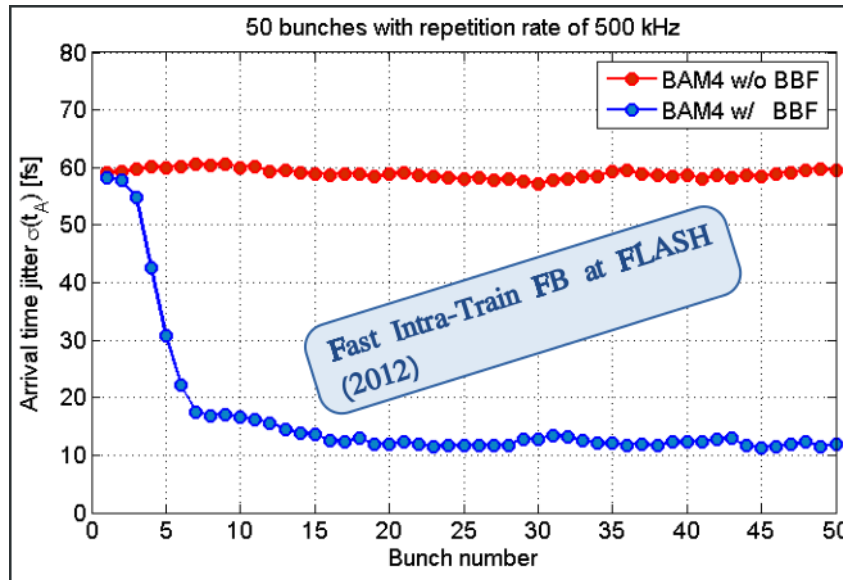
European X-Ray Free-Electron Laser

LLRF crate configuration:



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



> 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

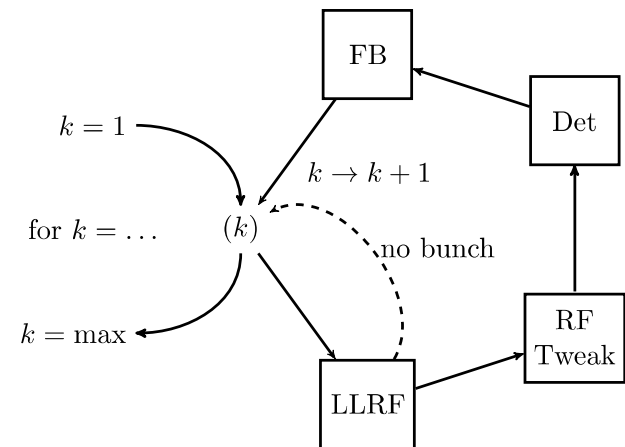
> Evaluation of individual sub-systems and full BBF model

- Simulations
- Laboratory tests
- Machine studies



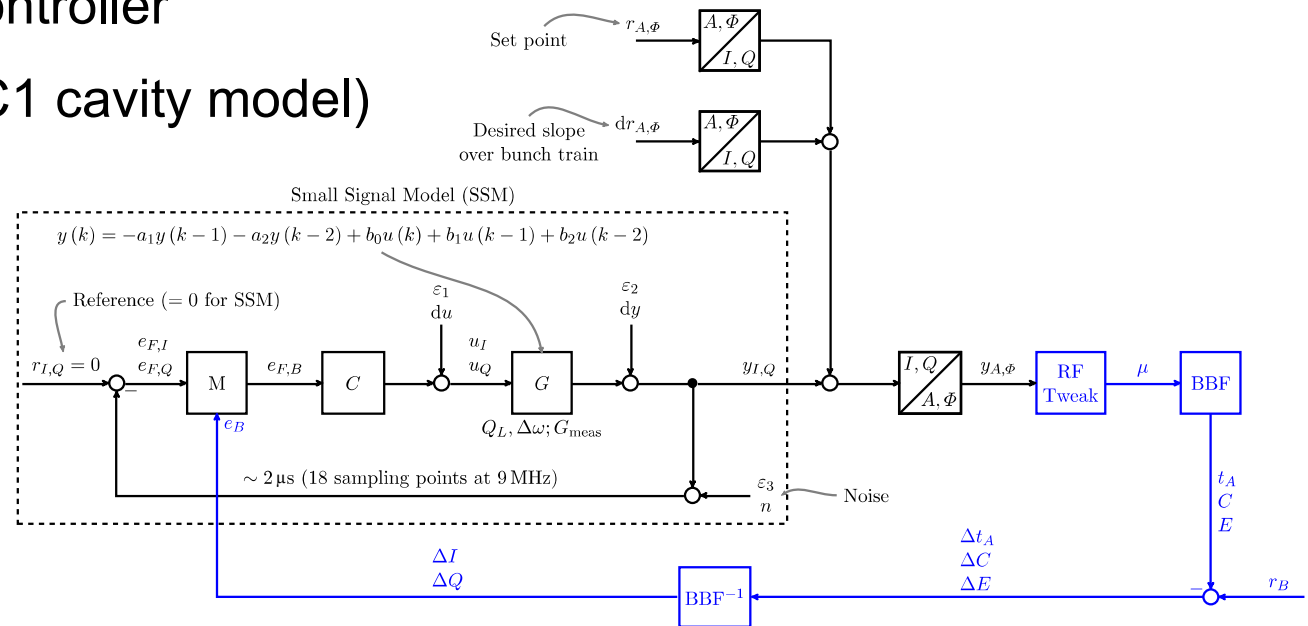
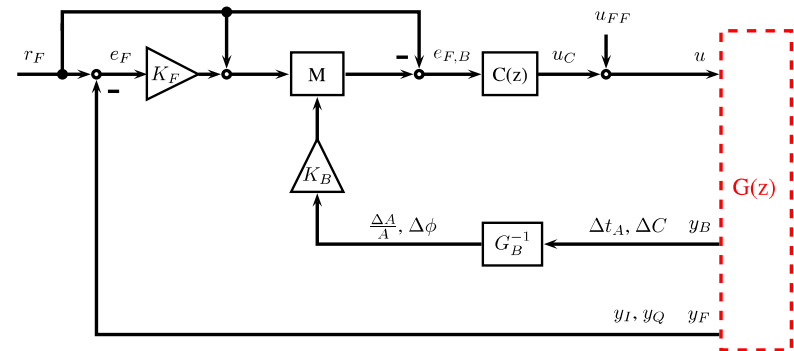
Longitudinal Beam-Based Feedback Simulations

- 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)



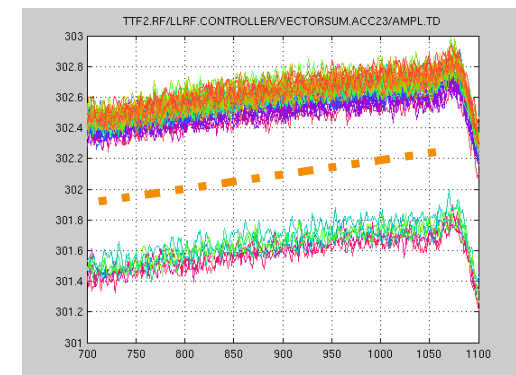
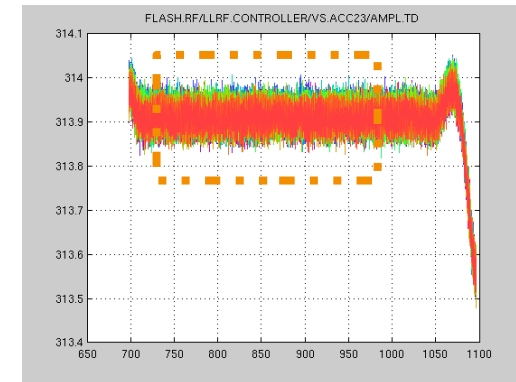
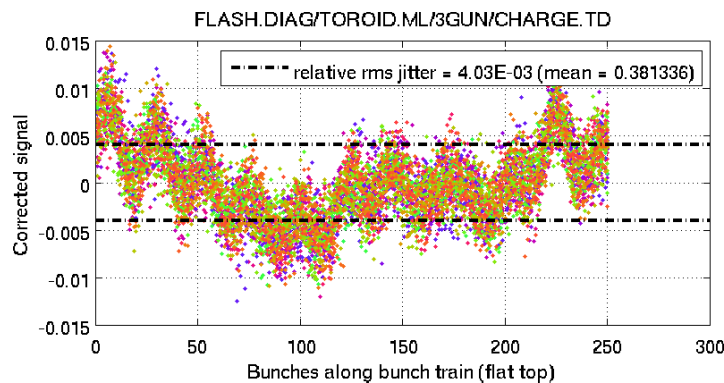
Characterisation of Monitors and Subsystems

- 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

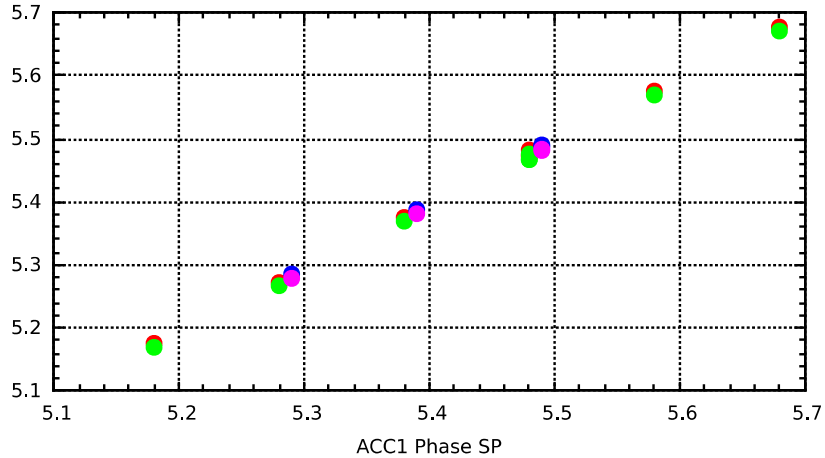
- Collection of multiple macro-pulses with (up to) 400 bunches each
- Varied compression in BC2 (ACC1 Phase) and BC3 (ACC23 Phase), let downstream slow feedbacks adapt
- For two different bunch charges: 0.4 nC and 0.1 nC
- Data analysis
 - Flat top selection
 - Removal of correlated slope
 - Removal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



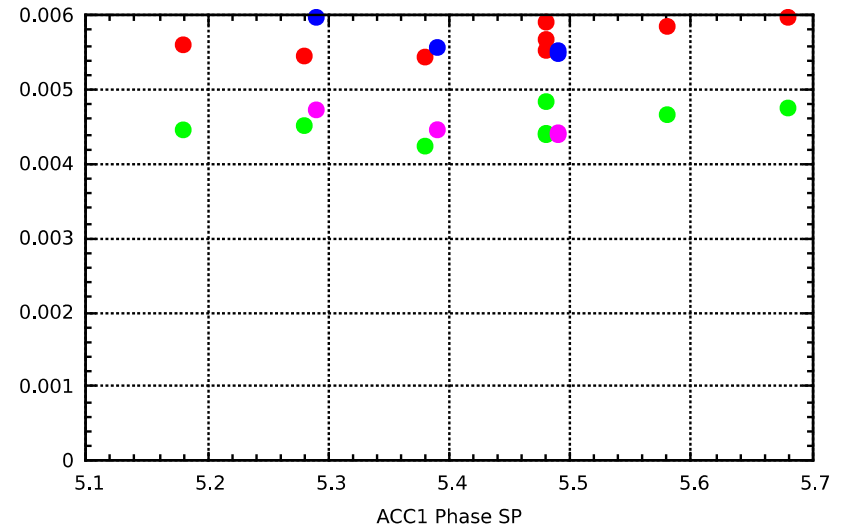
ACC1 RB Phase

ACC1, 0.4 nC (MATLAB) ● ACC1, 0.1 nC (MATLAB) ●
ACC1, 0.4 nC (DAQ) ● ACC1, 0.1 nC (DAQ) ●

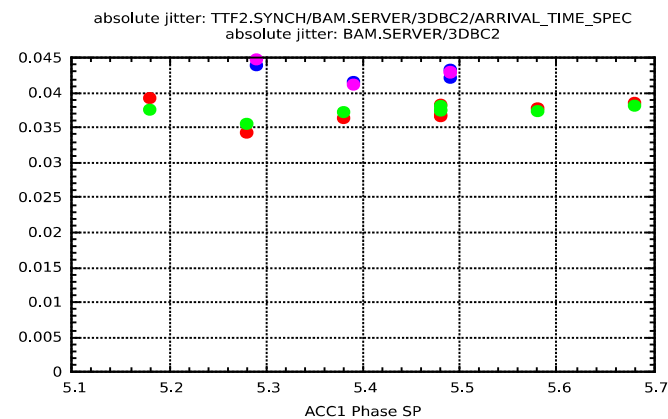
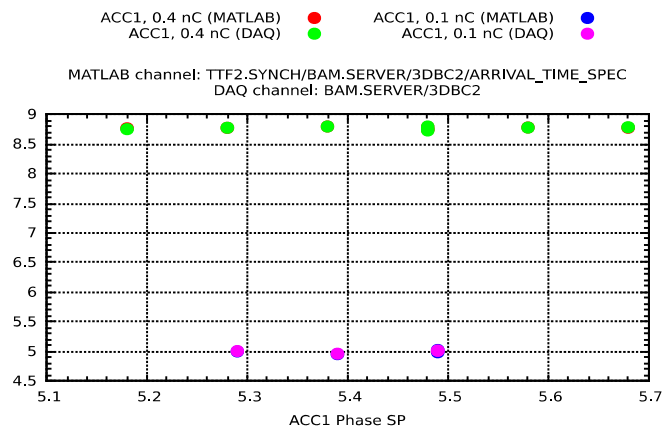
MATLAB channel: FLASH.RF/LLRF.CONTROLLER/V.S.ACC1/PHASE.TD
DAQ channel: FLASH.RF/LLRF.CONTROLLER.DAQ/V.S.ACC1(2)



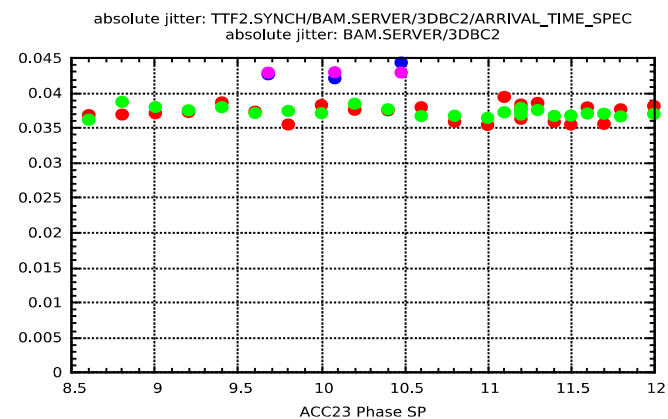
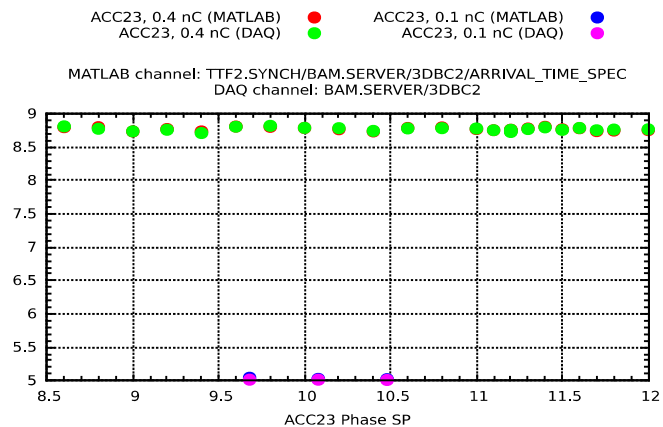
absolute jitter: FLASH.RF/LLRF.CONTROLLER/V.S.ACC1/PHASE.TD
absolute jitter: FLASH.RF/LLRF.CONTROLLER.DAQ/V.S.ACC1(2)



ACC1 Phase



ACC23 Phase

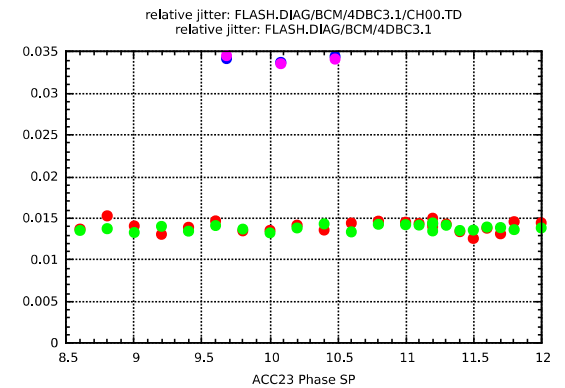
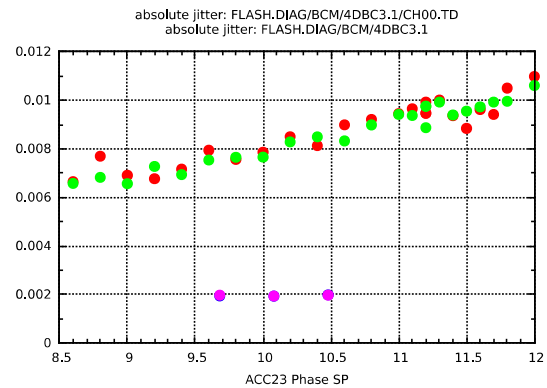
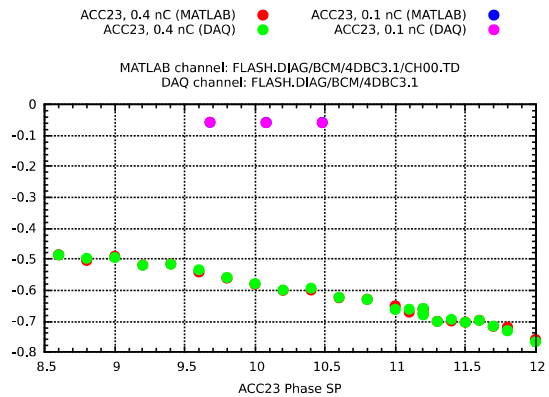
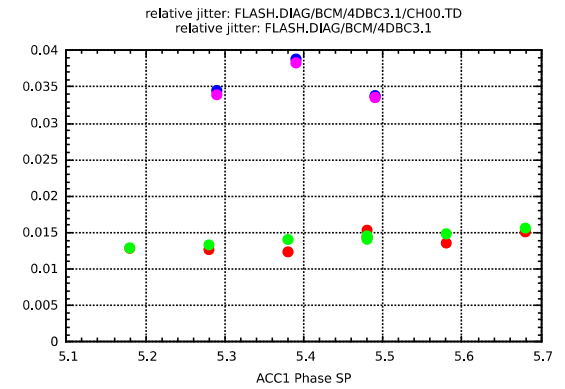
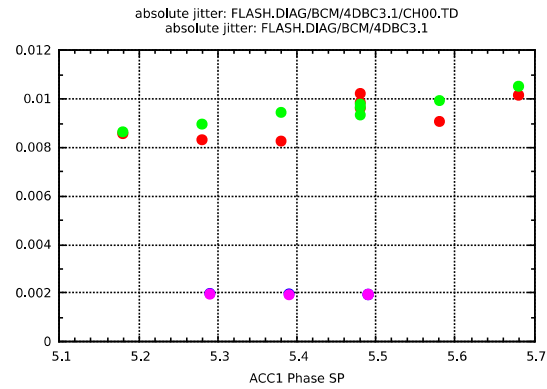
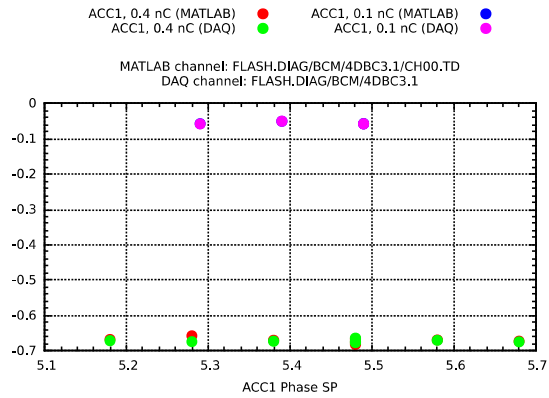


Measurement

abs. jitter



BCM 4DBC3 Fine



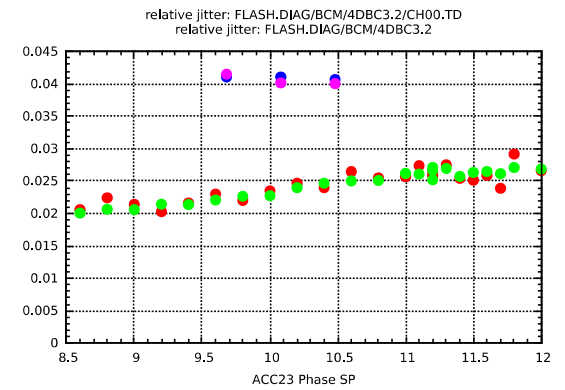
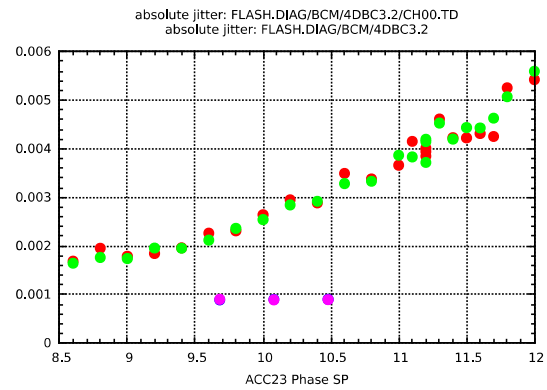
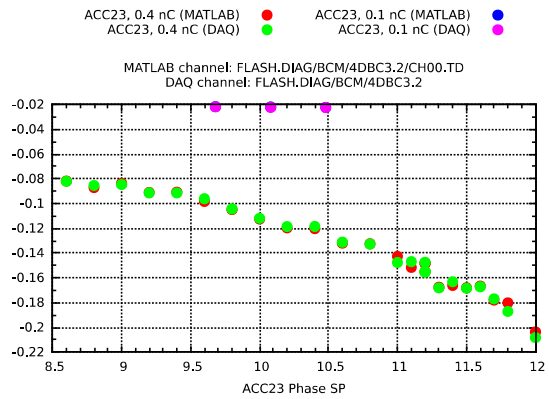
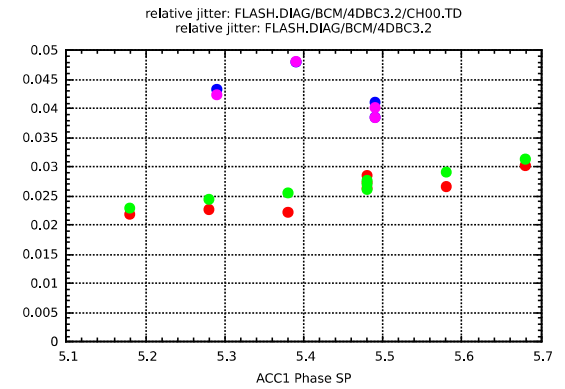
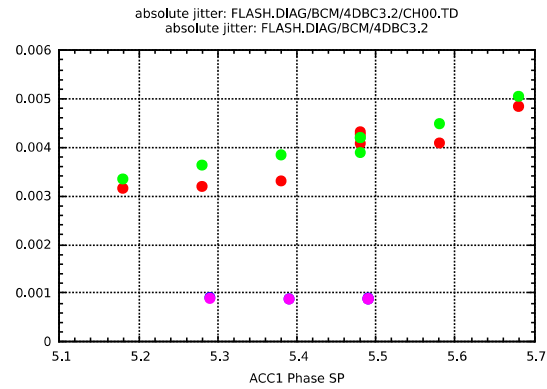
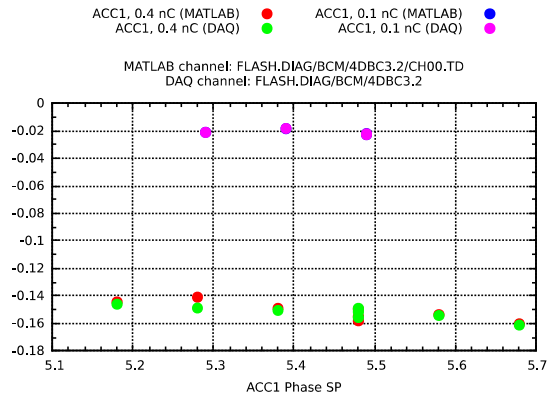
Measurement

abs. jitter

rel. jitter



BCM 4DBC3 Coarse



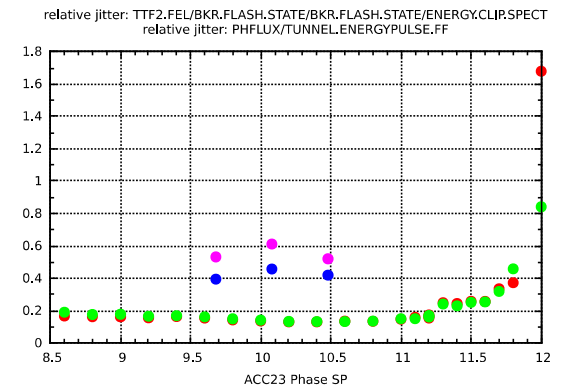
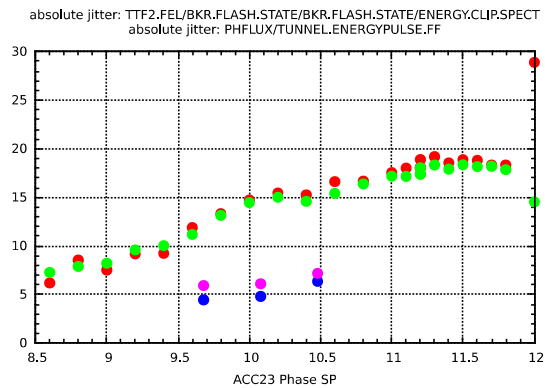
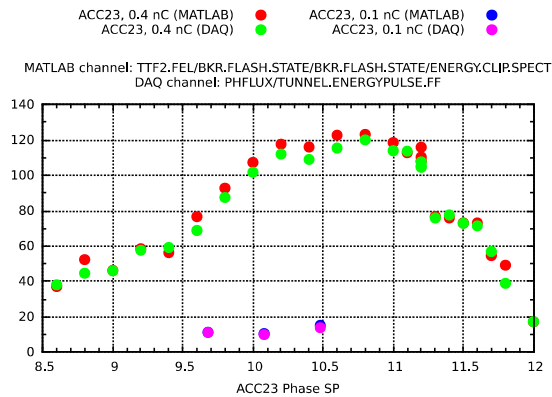
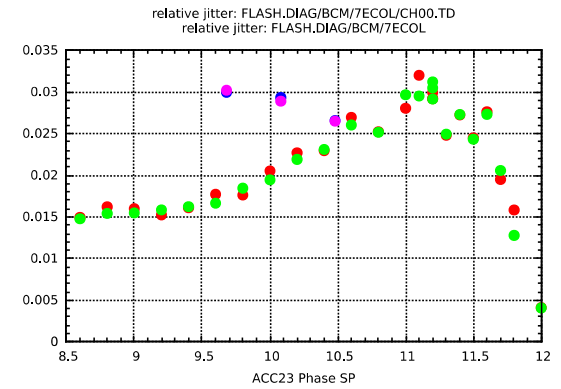
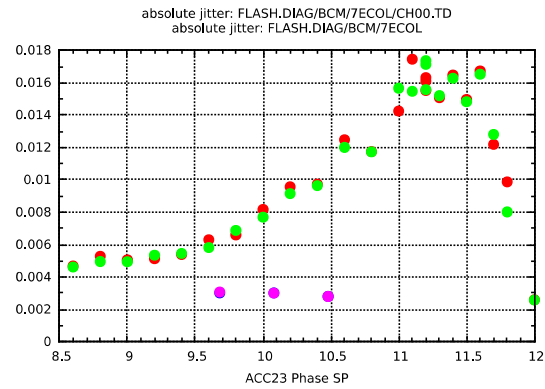
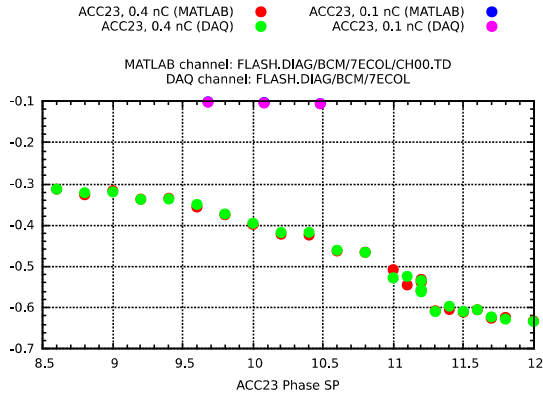
Measurement

abs. jitter

rel. jitter



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



Measurement

abs. jitter

rel. jitter



Implementation & Development

> People

- Łukasz Butkowski, Marie Kristin Czwalińska, 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



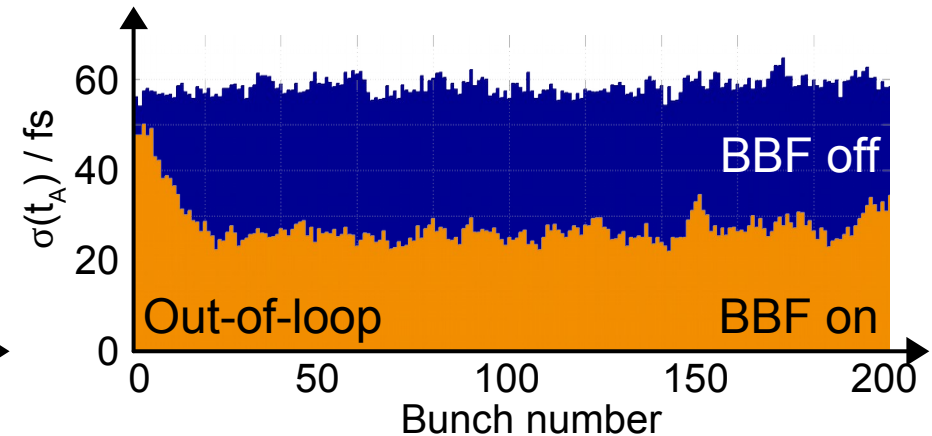
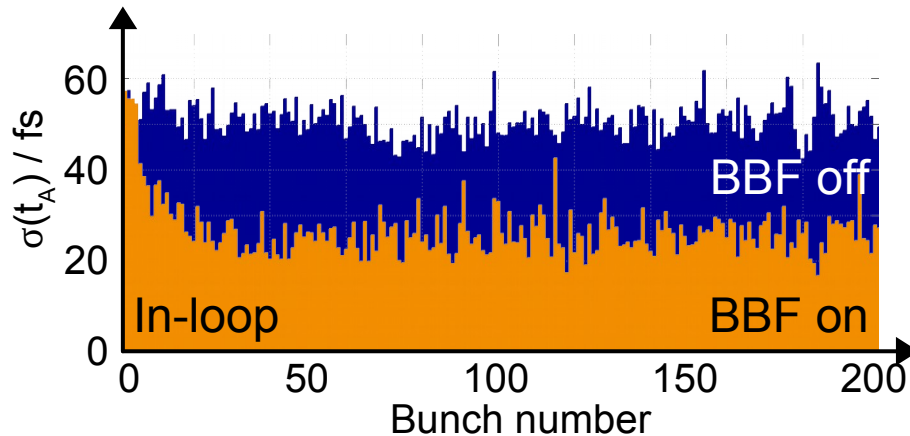
Resurrection

- 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

The screenshot displays the FLASH LLRF control interface. The navigation path is highlighted in orange: MainTaskbar (RF/LLRF) → LLRF control (ACC1) → LLRF Expert (MAIN.ACC1) → BBF (Beam based feedback).

MainTaskbar (RF/LLRF):

- Main Select: Main Overview, LLRF Status, RF Control, FSM, FSM Log (ACC1-7), FSM Log (Gun)
- Other: LLRF Energy Gain (DAO)
- LLRF control: ACC1, ACC39, ACC23, ACC45, ACC67, HPRF control (Klystron 3, 2, 39, 6, 5, 4)

MAIN.ACC1 (LLRF Expert):

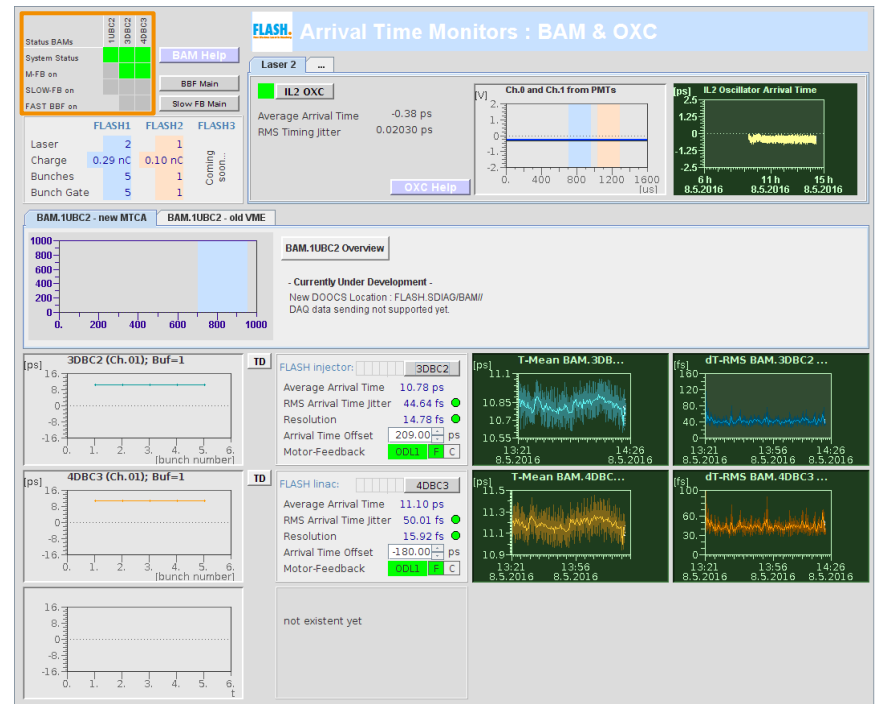
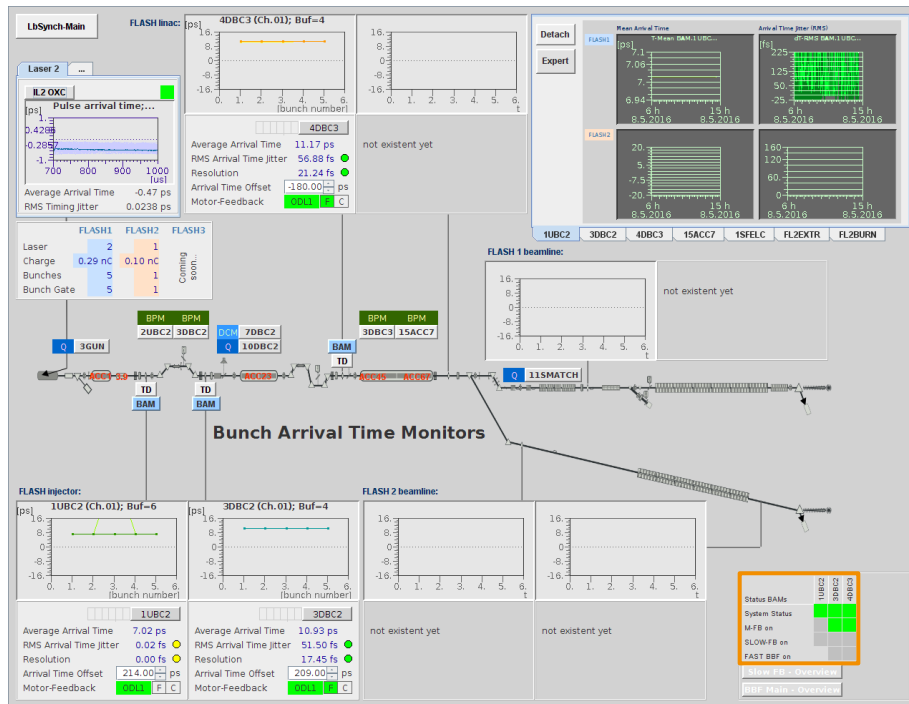
- Main Control: Voltage 160.30 MV, Phase 5.01 deg
- Status: Klystron, RF Gate EN
- Subsystems: 1st Modul (C1-C8)
- Checks: Feed-Forward, Output vector correction, Feedback, Feed-Forward correction, Learning FF, Beam loading compensation
- Amplitude graph: Shows a pulse from 0 to 160 MV over time.

BBF (Beam based feedback):

- Delay: 56957
- Parameters: Bunch space
- Graphs: Bunch Pattern from TMG, Bunch Counter from TMG, Error signal input, Arrival time, Corrected error signal
- BBF Matrix: 0.0130, 0.0000, 0.0020, 0.0000
- Scaling Factors: Amplitude 1.00, Phase 1.00
- Original BBF Matrix: 0.0130, 0.0000, 0.0020, 0.0000
- Correction term: $(1+dA/A) \times \begin{bmatrix} 1 & -\Delta\phi \\ \Delta\phi & 1 \end{bmatrix}$
- Limit: Ampl 0.02, Phase 1.00
- Beam loading compensation: Enabled, Toroid corr.
- Feedback: FB, MIMO, LFF
- Output limiter: Enabled
- Output Vector Correction: On, Ampl 1.3413, Phase -10.23, Ratio 0.425
- Beam loading compensation: Close FB?, Ampl err 0.011, Phase err 0.010
- Pulse settings: intra-pulse dA/A 0.0164%, dP 0.0095 deg, pulse to pulse dA/A 0.0013%, dP 0.0010 deg



Status Indicators Available on BAM Panels



Status BAMS	1UBC2	3DBC2	4DBC3
System Status	Green	Green	Green
M-FB on	Green	Green	Green
SLOW-FB on	Green	Green	Green
FAST BBF on	Green	Green	Green



Thank you for your attention!

