Arrival time stabilization at FLASH and EuXFEL

CHILFEL Seminar

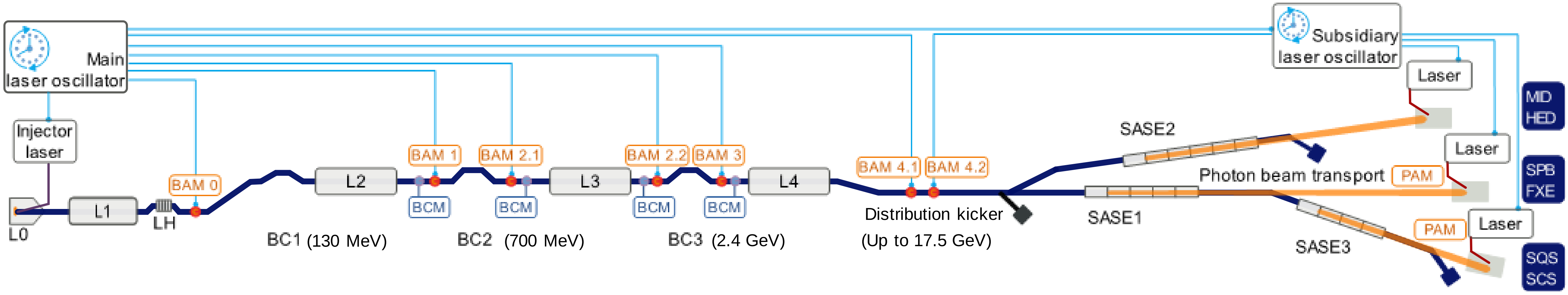
Björn Lautenschlager on behalf of MSK

Hamburg, 07.04.2022

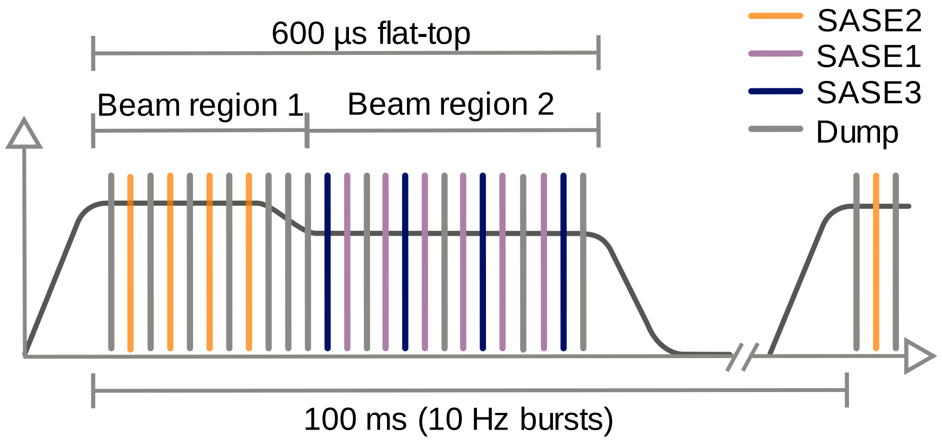
Outline

Introduction

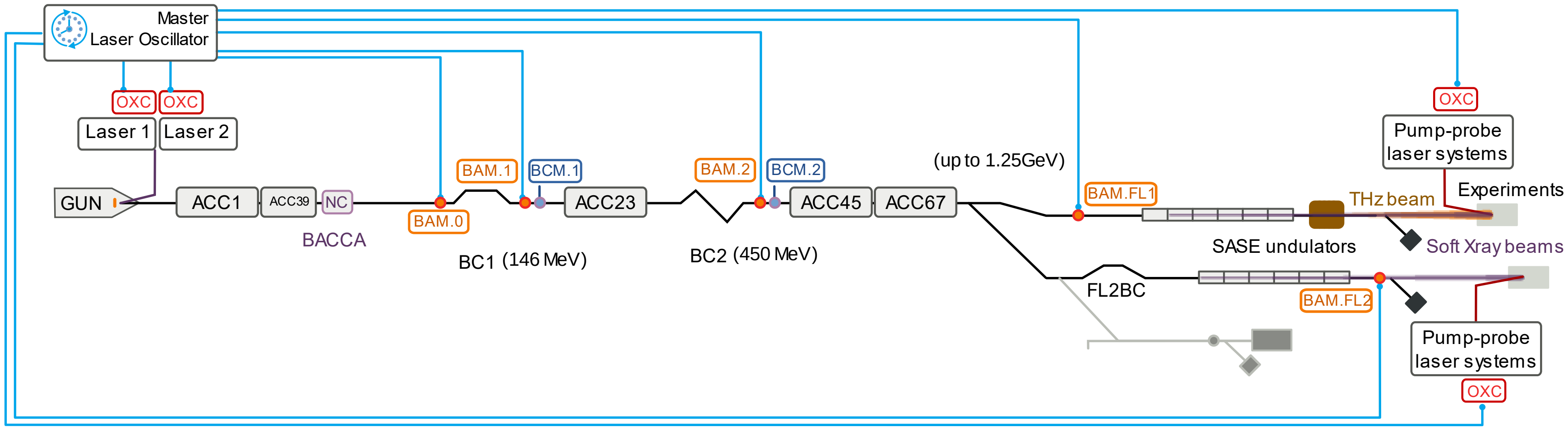
EuXFEL facility



- Total energy up to 17.5 GeV
- Bunch repetition rate up to 4.5 MHz
- Charge usually 250 pC, partly 100 pC
- 10 Hz burst mode
- Three bunch compression chicanes BC1 to BC3
- Three photon beamlines

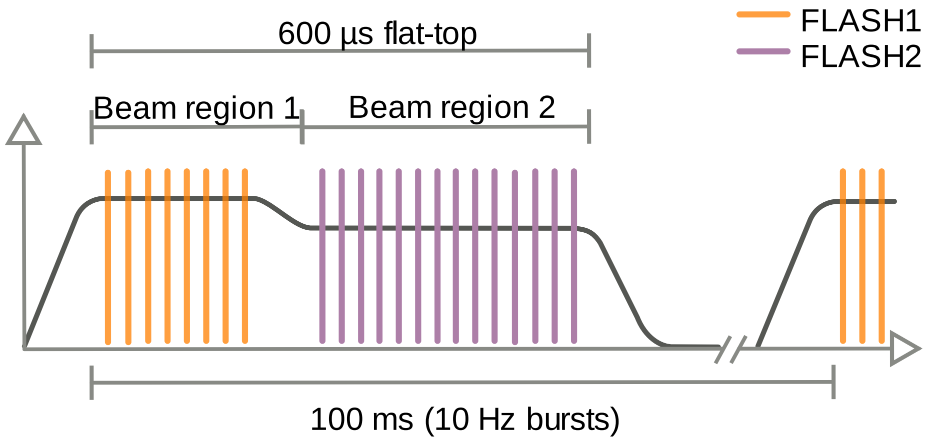


FLASH facility



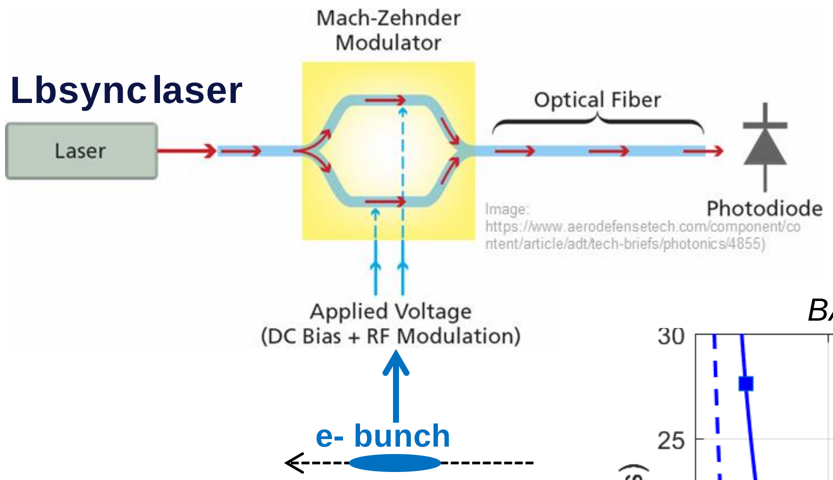
FLASH layout until end of 2021

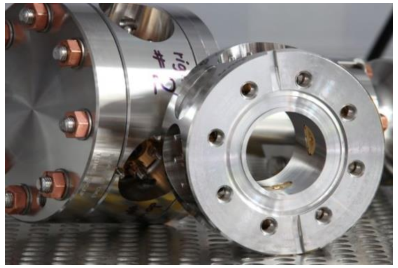
- Total energy up to 1.25 GeV
- Bunch repetition rate up to 1 MHz
- Charge between 20 pC to 1 nC
- Two bunch compression chicanes BC1 and BC2
- 10 Hz burst mode
- Two beamlines, plus FlashFOWARD



Arrival time measurement

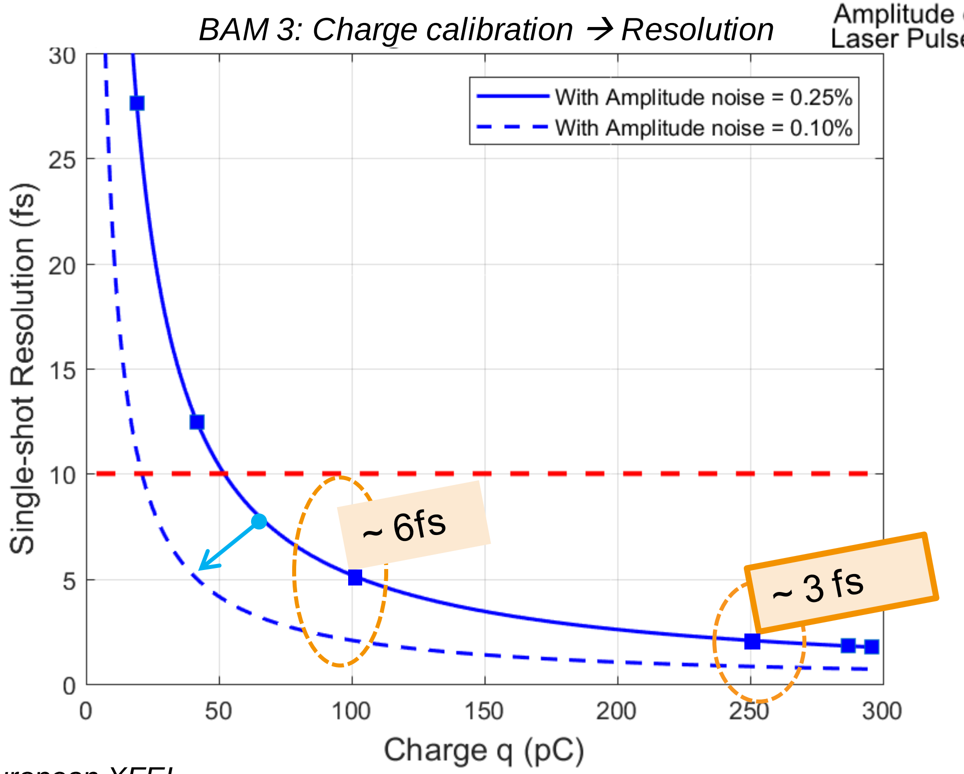
Bunch arrival time monitor - BAM

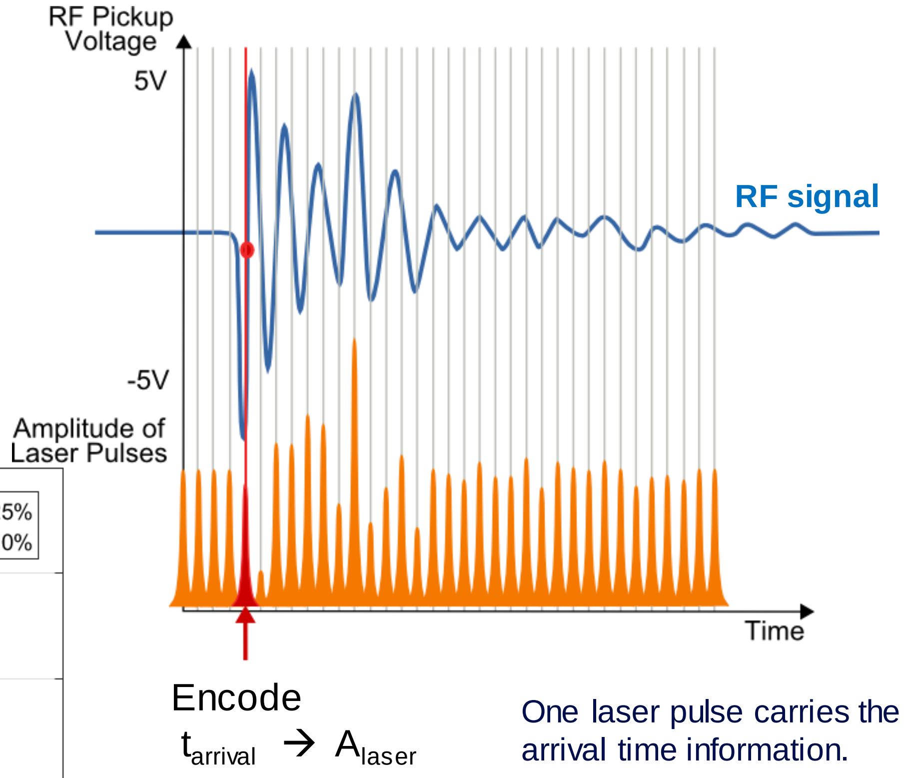




Slight dependence on beam position

2^{nd} order effect
< 30 as / µm





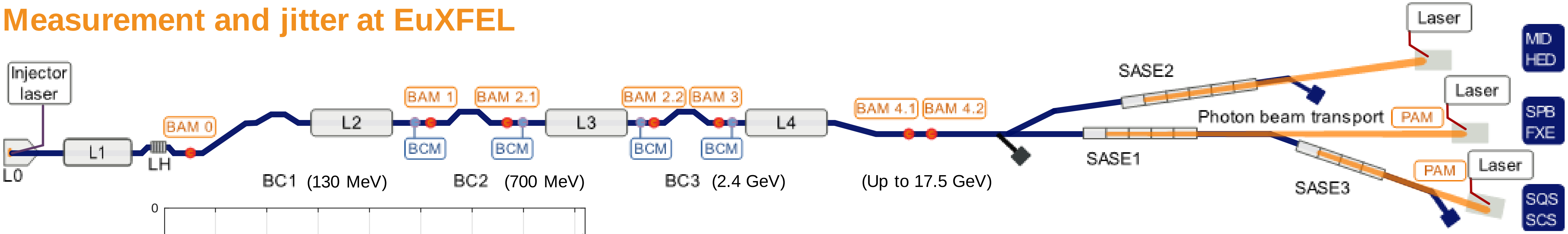
- Measurement of the relative arrival time

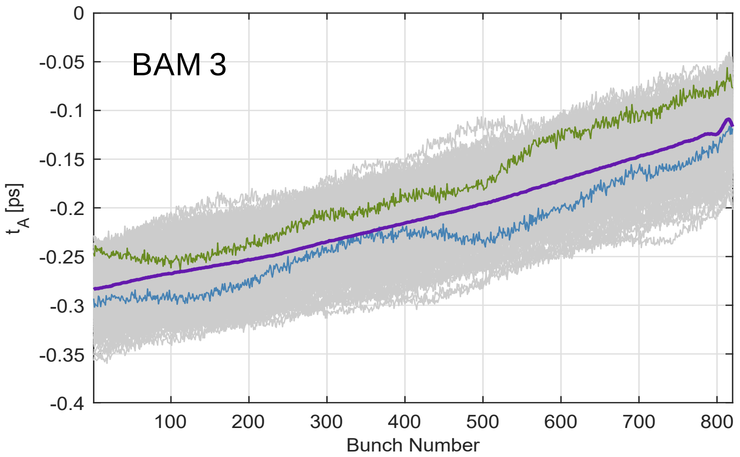
M.K. Czwalinna et all, Arrival-time stability at the European XFEL

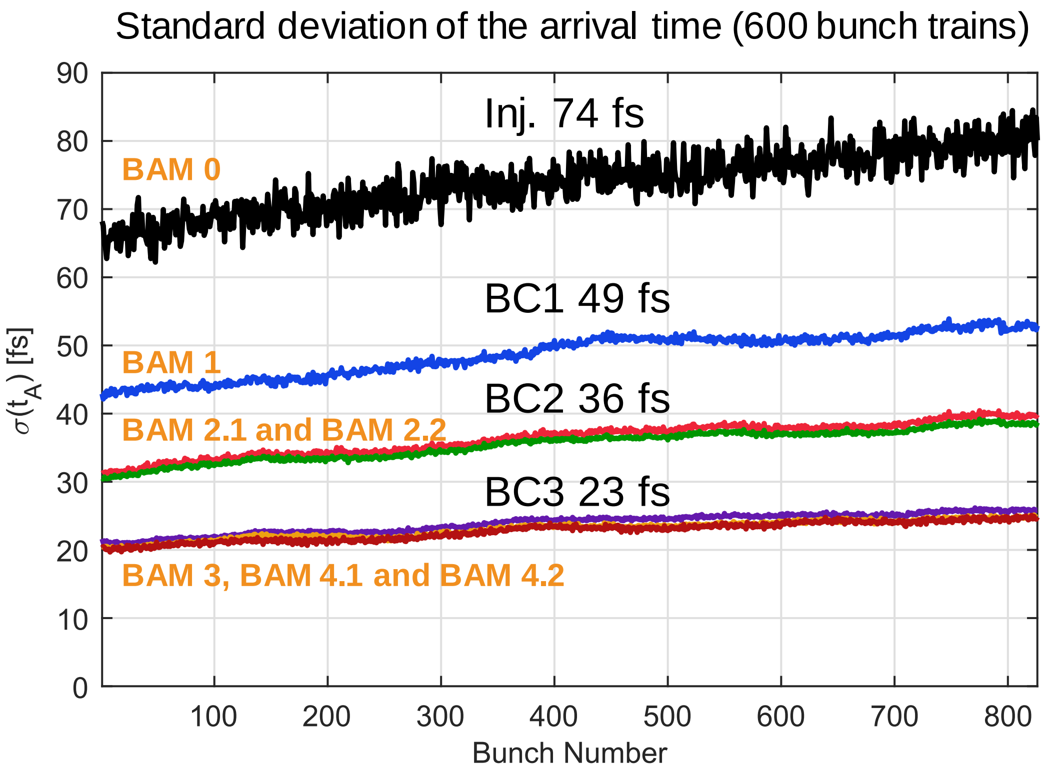
By courtesy of M. K. Czwalinna

Bunch arrival time monitor

Measurement and jitter at EuXFEL







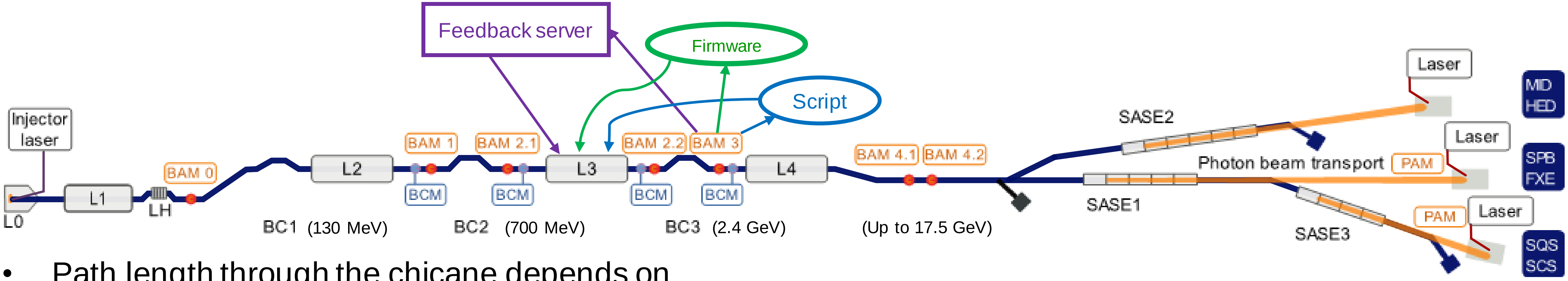
- Arrival time measurement of 600 bunch trains (gray lines)
- The arrival time jitter depends on the initial jitter $\Sigma_{t,i}$, the RF phase jitter σ_ϕ and the relative amplitude jitter $\frac{\sigma_v}{v}$

$$\Sigma_{t,f}^2 = \left(\frac{R_{56}}{c_0}\right)^2 \cdot \frac{\sigma_{V_1}^2}{V_1^2} + \left(\frac{C-1}{C}\right)^2 \cdot \frac{\sigma_{\phi_1}^2}{\omega_{rf}^2} + \left(\frac{1}{C}\right)^2 \cdot \Sigma_{t,i}^2$$

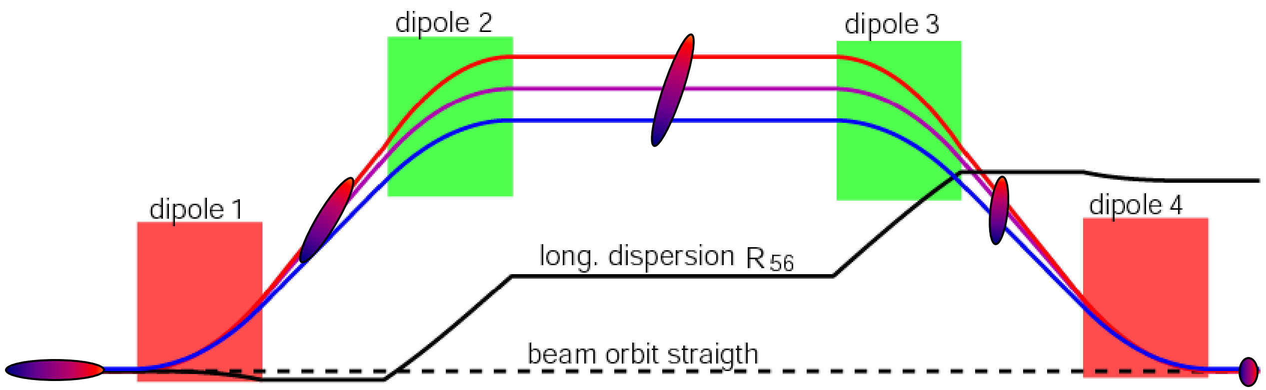
Arrival time stabilization at FLASH and EuXFEL

Different feedback loops at EuXFEL and FLASH

Basic principle of the bunch compression chicane



- Path length through the chicane depends on the energy: compression, arrival time
- Principle is used for different feedback loops.
  - Compensation of slow drifts (first bunch, server based), sumvoltage/chirp
  - Compensation of repetitive errors (mean of bunch trains, script based), amplitude/phase
  - Compensation of fluctuations along the bunch train (all bunches, firmware based), amplitude/phase, L-IBFB
- Feedback loops possible at all chicanes

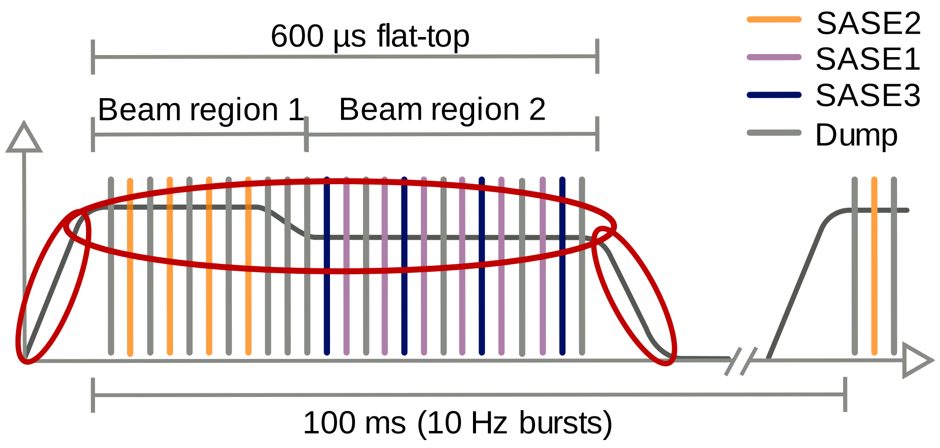


Courtesy: H. Schlarb

Feedback loops at EuXFEL and FLASH

LLRF system as actuator

- LLRF: Control of the RF-field of the accelerator modules, Amplitude A and Phase φ
- Calculates drive signal for high power provided by the klystron
- Three different parts
  - Filling
  - Flat-tops, bunches are accelerated
  - Decay



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- Three different parts
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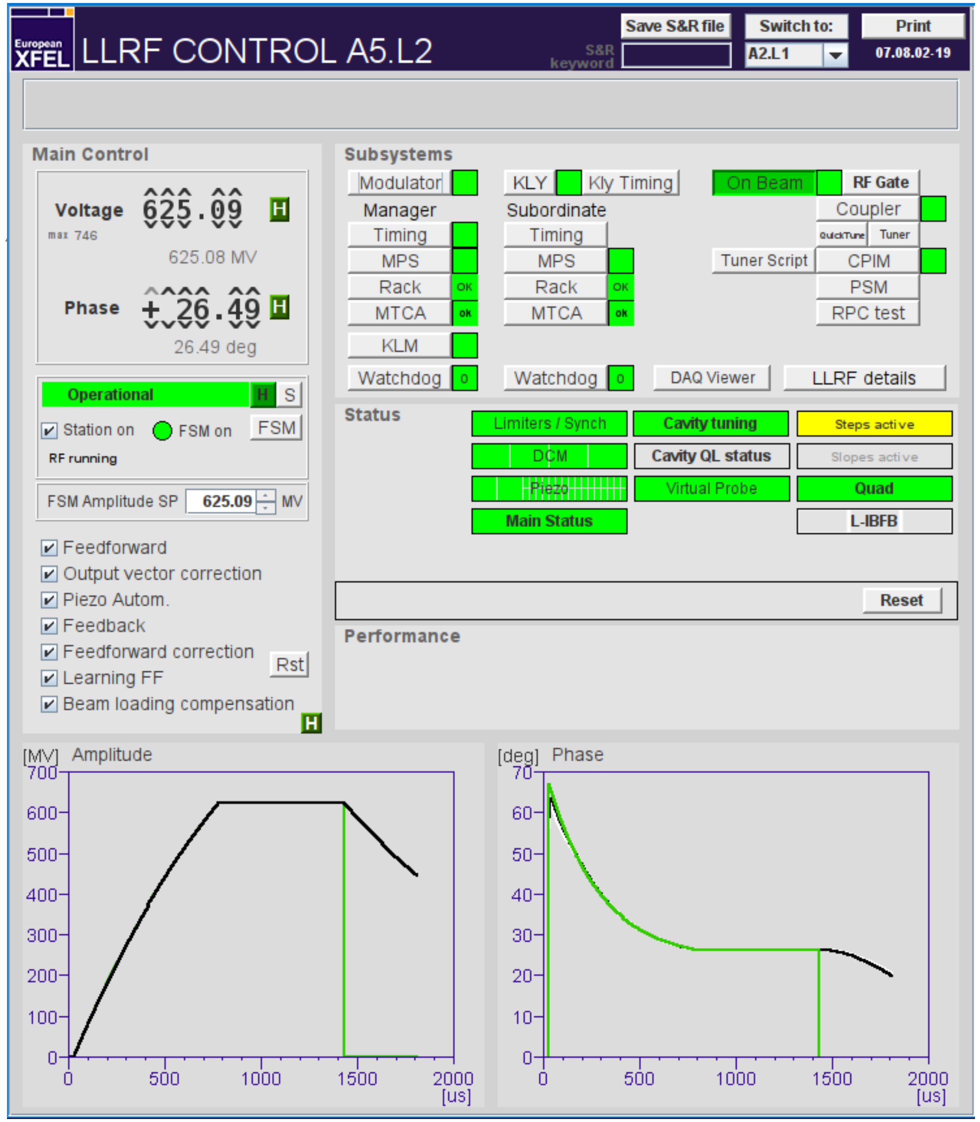
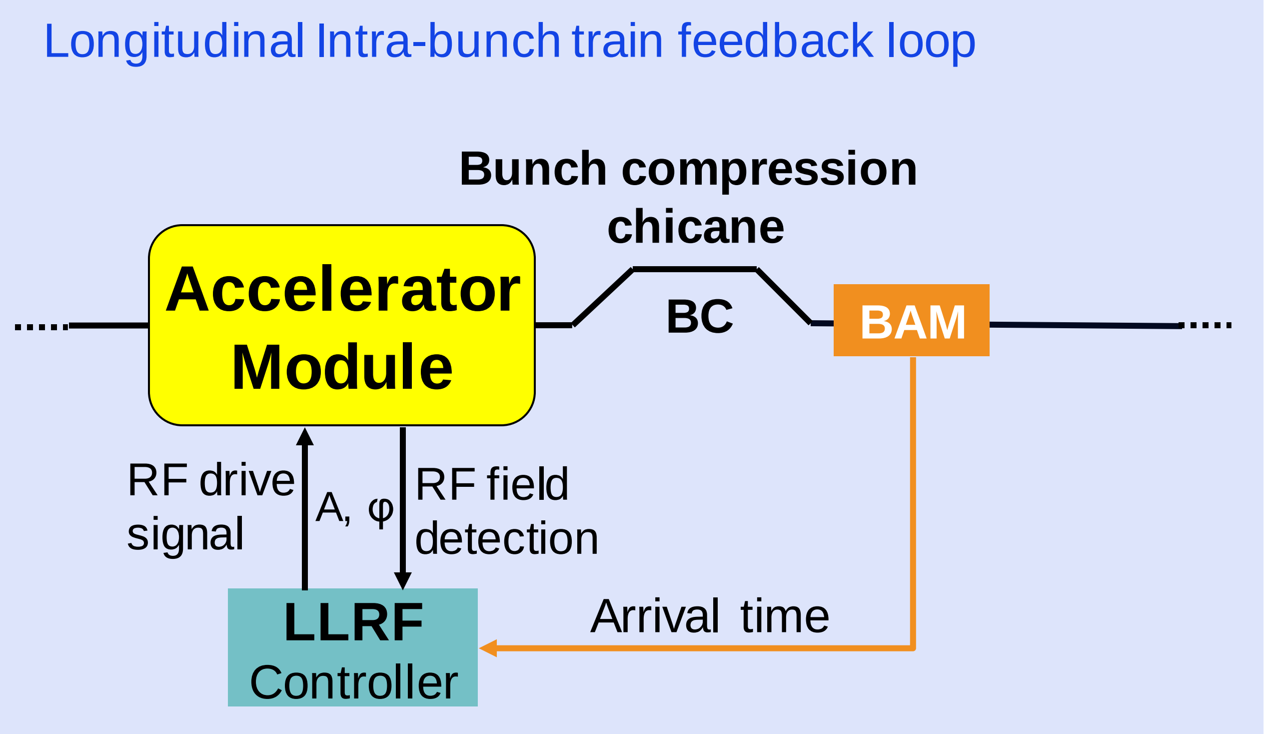
  - Decay
- Different controller types like, multi-input multi-output or learning feedforward controller
- Many additional algorithms
  BLC, DCM, …



Feedback loops at EuXFEL and FLASH

Longitudinal intra-bunch train feedback

- Arrival time set point => arrival time control error
- LLRF system combines RF field error and beam based error
- LLRF controller runs as usual (FF, Feedback, LFF, …)
- All action on firmware level (FPGA)
- Data send via optical low-latency link
- Software/Server for general settings



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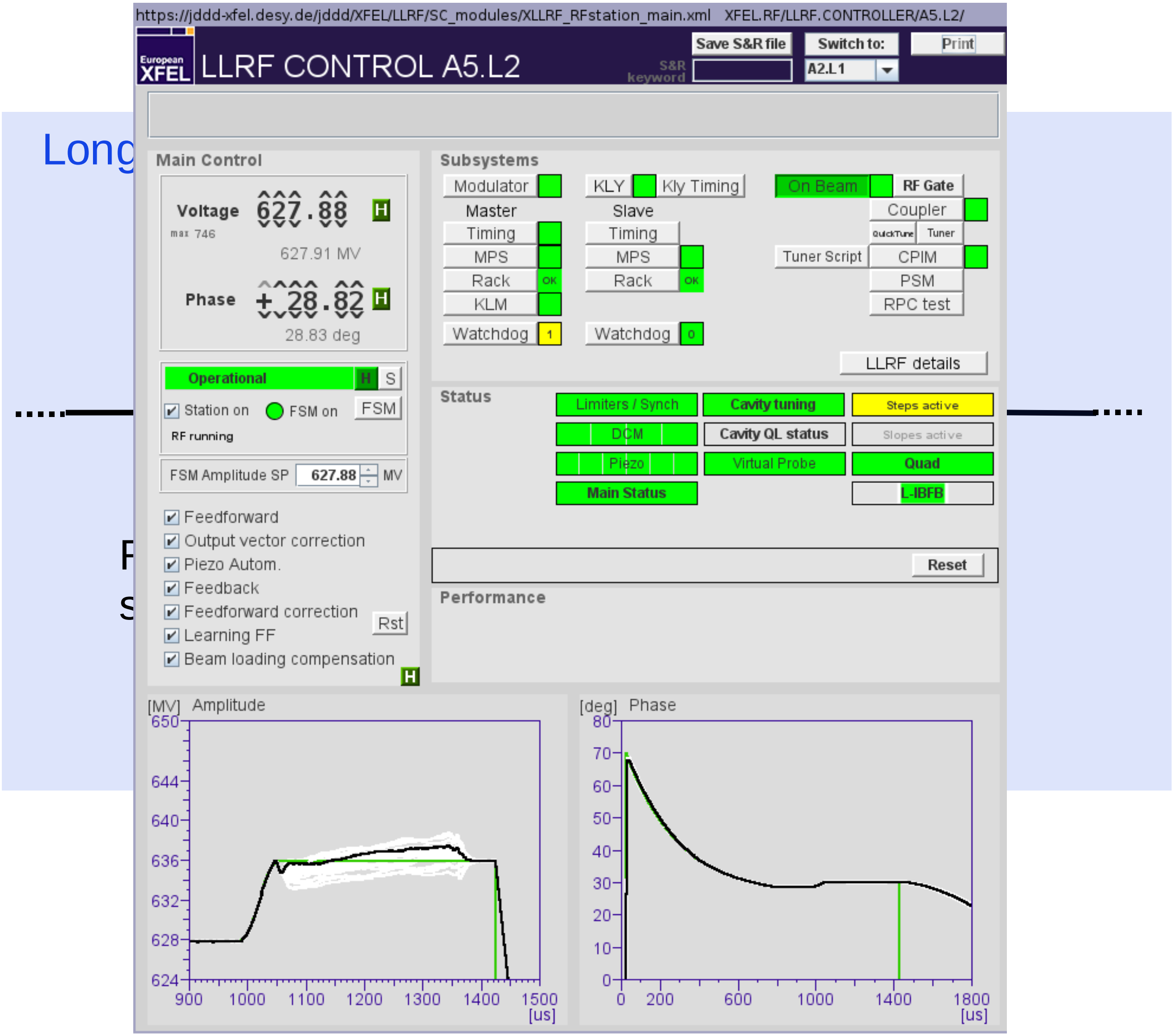
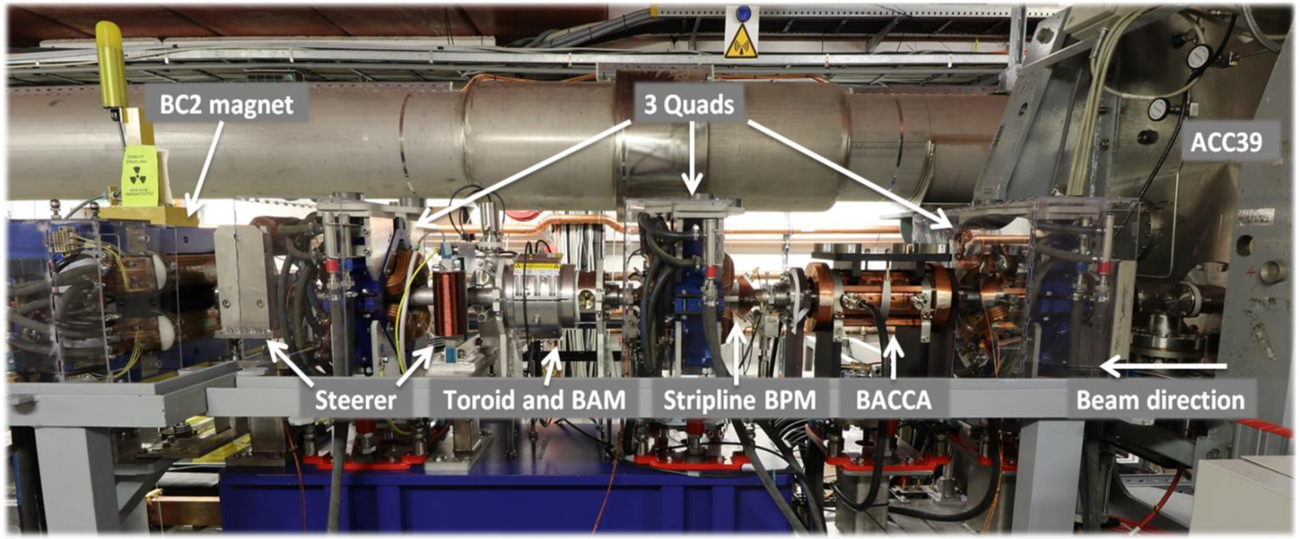


Bunch arrival corrector cavity – BACCA at FLASH

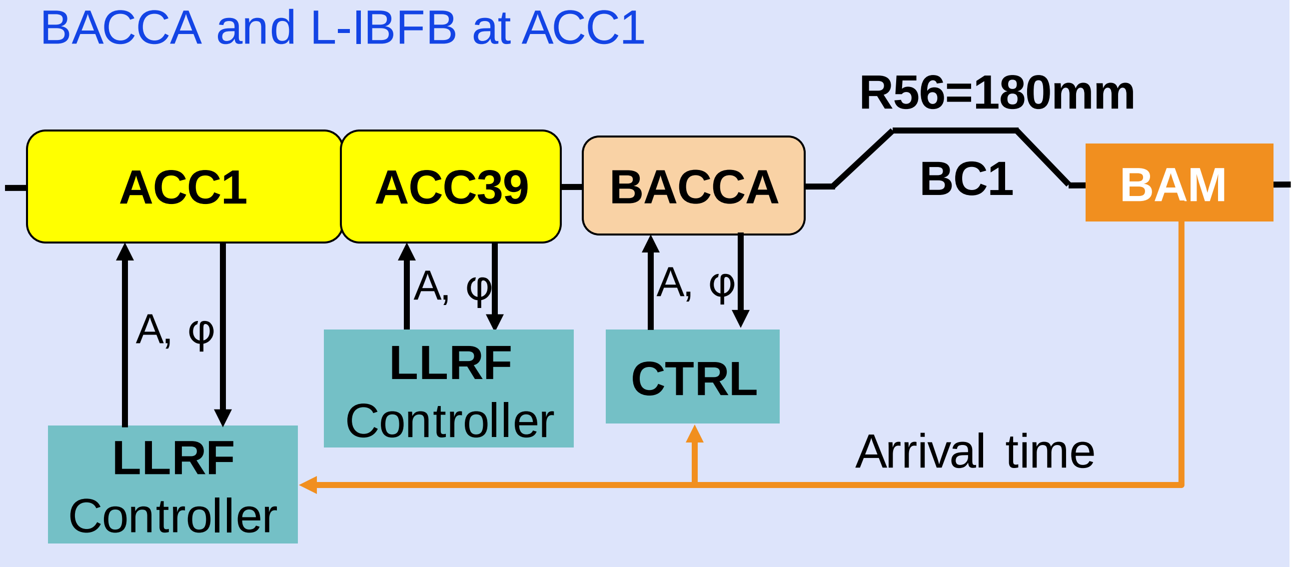
Special cavity for the FLASH facility

- Normal conducting cavity with 4 cells
- Located between the third harmonic module ACC39 and BC1
- Energy modulation range ± 50 keV
- Fast energy corrector cavity



S. Pfeiffer et all, Status Update of the Fast Energy Corrector Cavity at FLASH

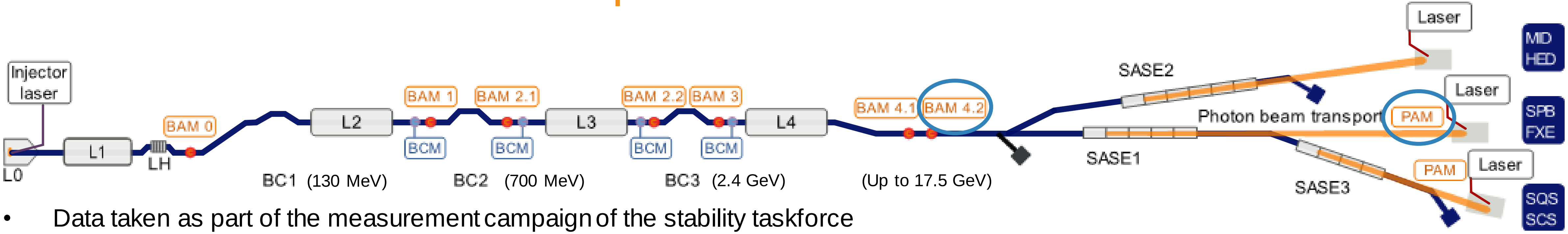
- Using the same arrival time information
- BACCA runs together with ACC1
- Idea: ACC1 acts on slow arrival time fluctuations (< 25 kHz) and BACCA on the remaining fast arrival time changes



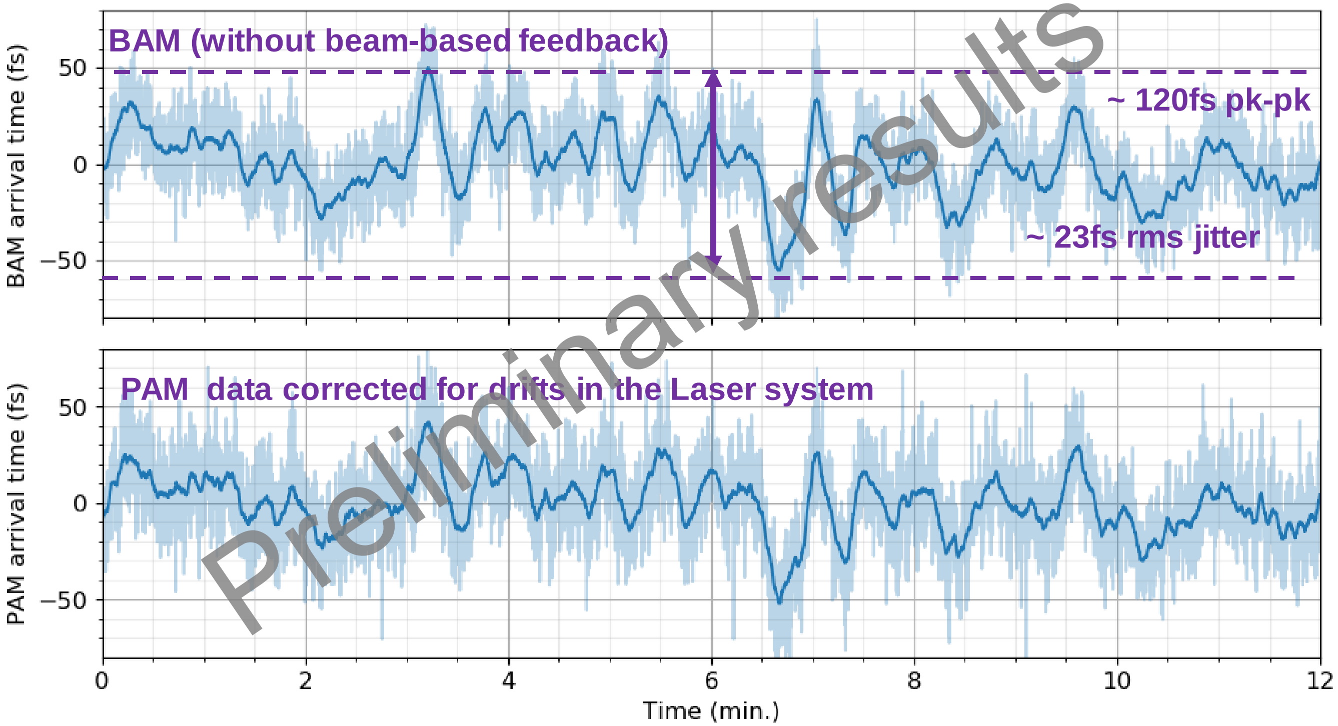
Results

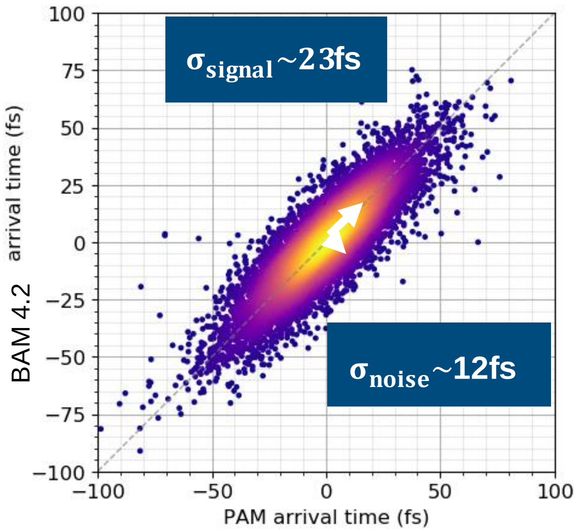
Results EuXFEL

Correlation bunch arrival time monitor – photon arrival time monitor



- Data taken as part of the measurement campaign of the stability taskforce





BAM (4.2) vs. PAM (SPB, SASE1)

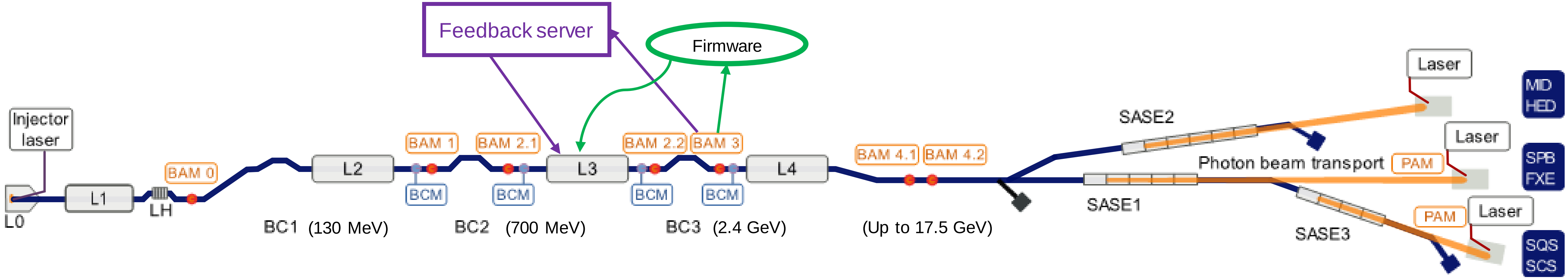
train mean-value correlations (12min data)

M.K. Czwalinna et all, Arrival-time stability at the European XFEL

By courtesy of Romain Letrun (XFEL, SPB)

Results EuXFEL

Feedback loops

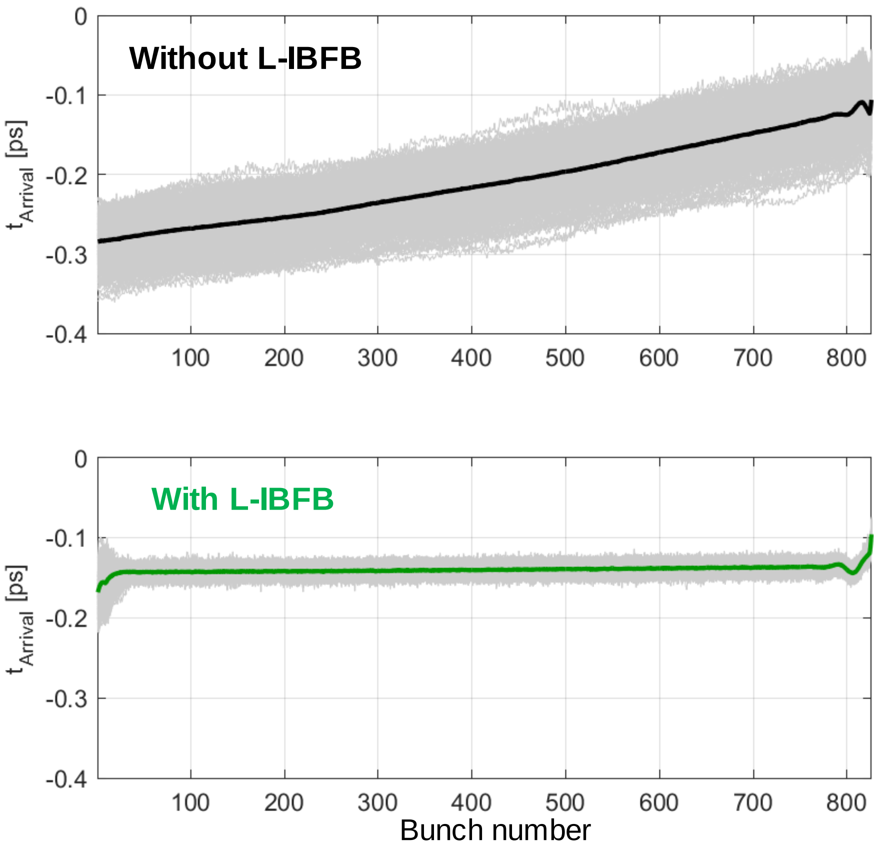


- Data taken in parallel to user experiments
- L-IBFB loop around the third chicane
  BAM 3 → A5.L3
- Slow arrival time feedback BAM 3 → Sumvoltage L3
- Bunch-to-bunch repetition rate 2.25 MHz
- Bunch charge 250 pC

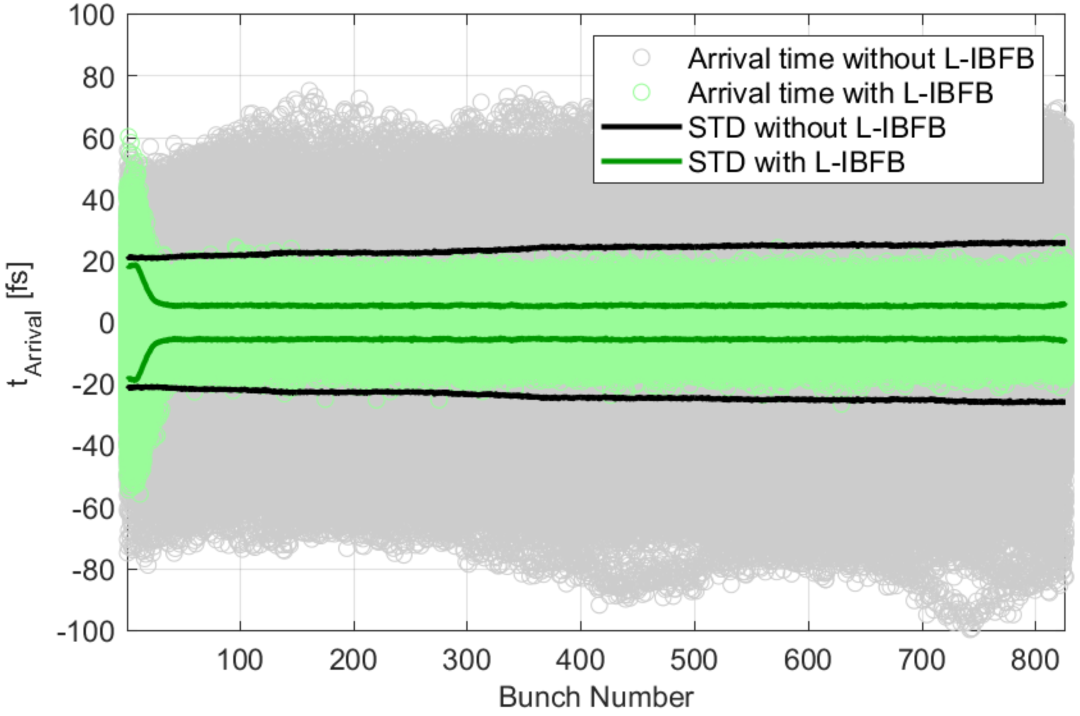
Results EuXFEL

L-IBFB at LLRF station A5

- Arrival time of more then 800 bunches
- 600 bunch-trains (gray lines)



Mean free arrival time and standard deviation of 600 bunch-trains

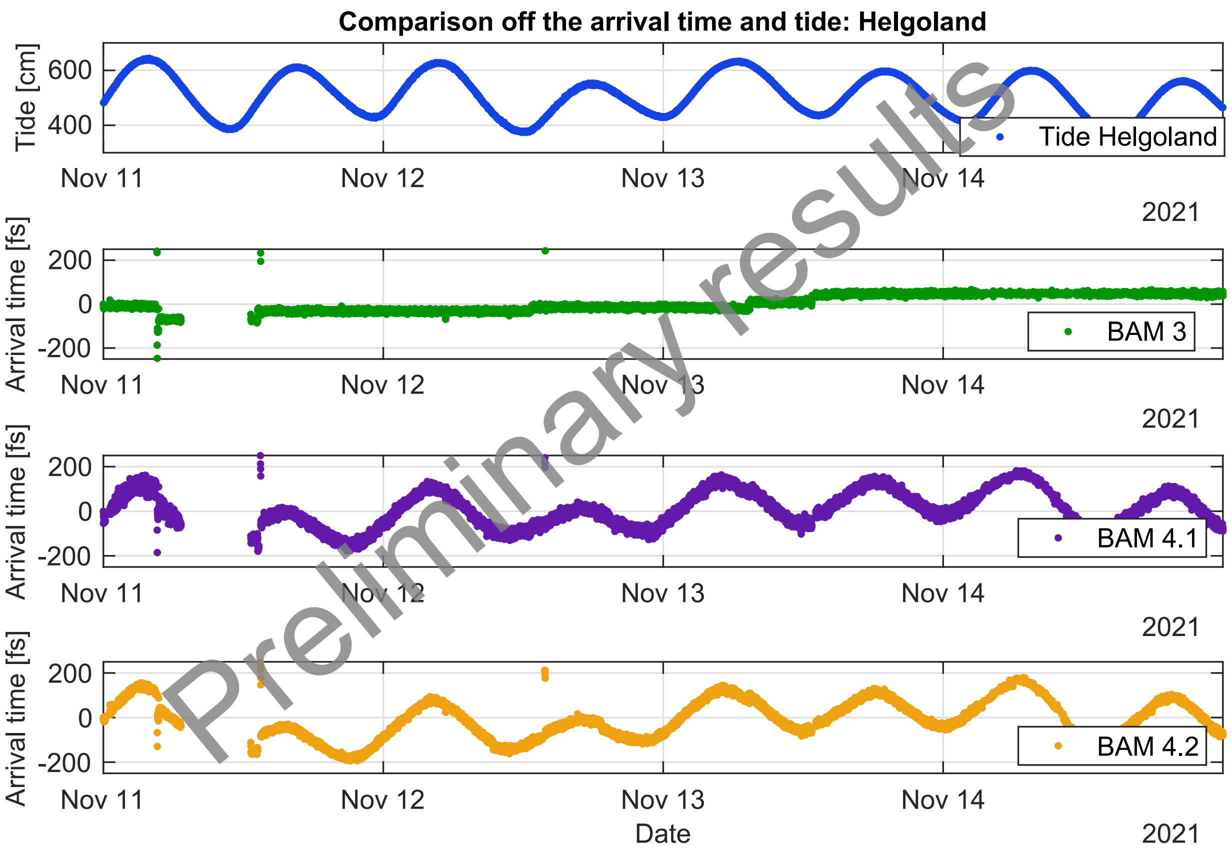


- L-IBFB pushes arrival time stabilities below 10 fs (rms).
- Steady state value reached after 10-15 µs

Results EuXFEL

Long term drifts due to ground motion under investigation

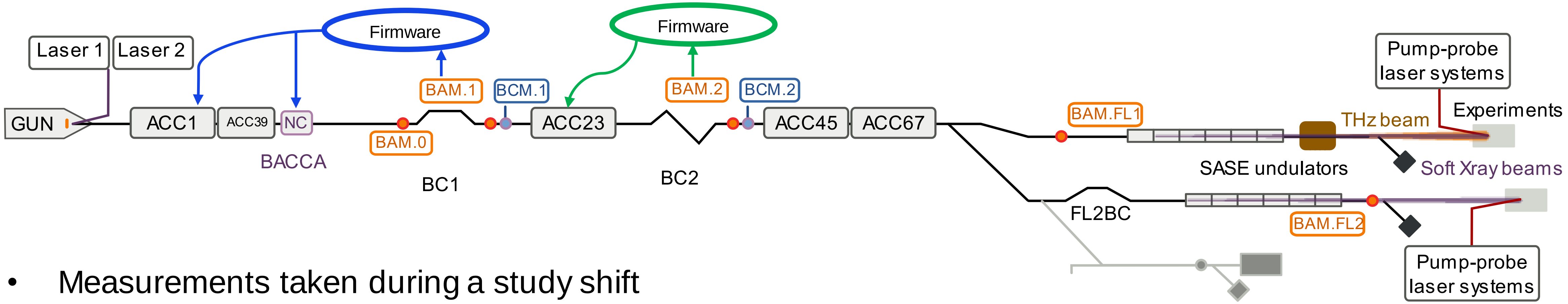
- L-IBFB at A5 runs stable over days, BAM 3
- Drifts measured with the BAM 4.1 and 4.2
- Distance between BAM 3 and BAM 4.1(4.2) 1.5 km – lengthening effect
- Period of ~12 hours
- Tide measured near Helgoland (north sea)
- Under investigation



Source tidal data: www.pegelonline.wsv.de

Results FLASH

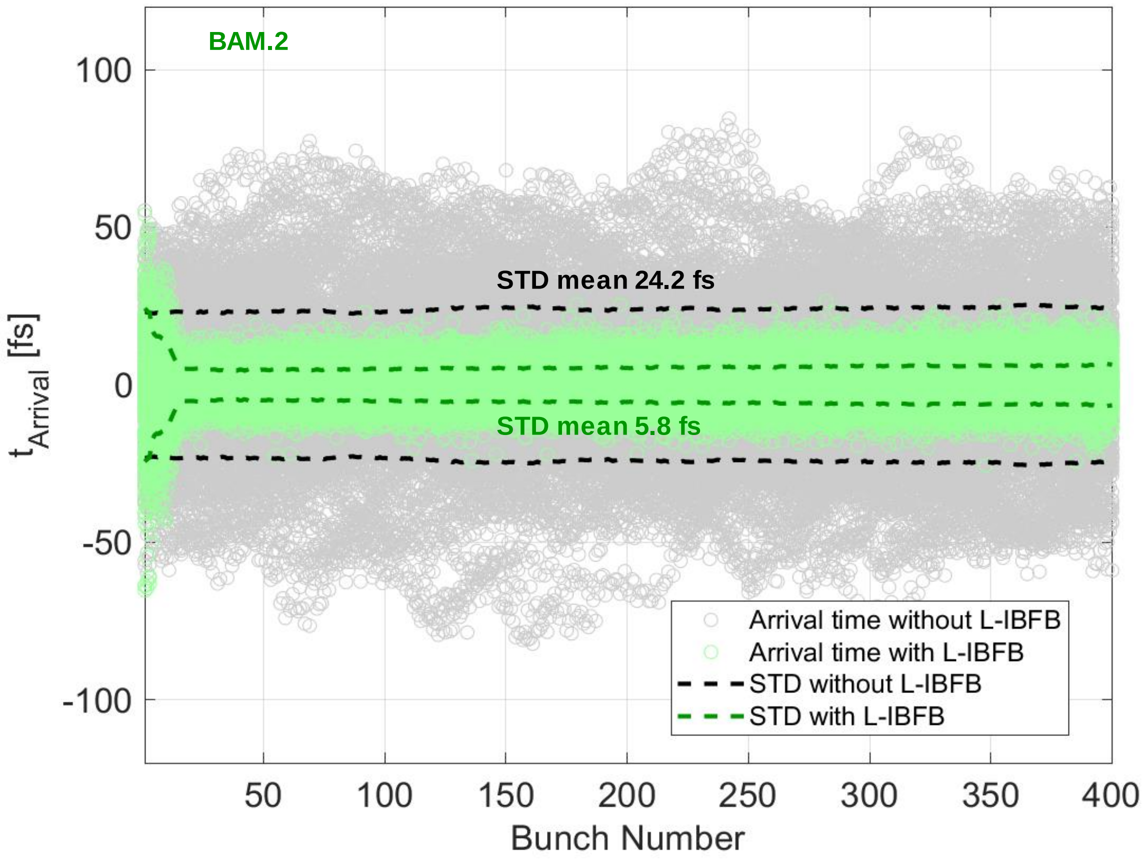
Data taken during measurement shifts



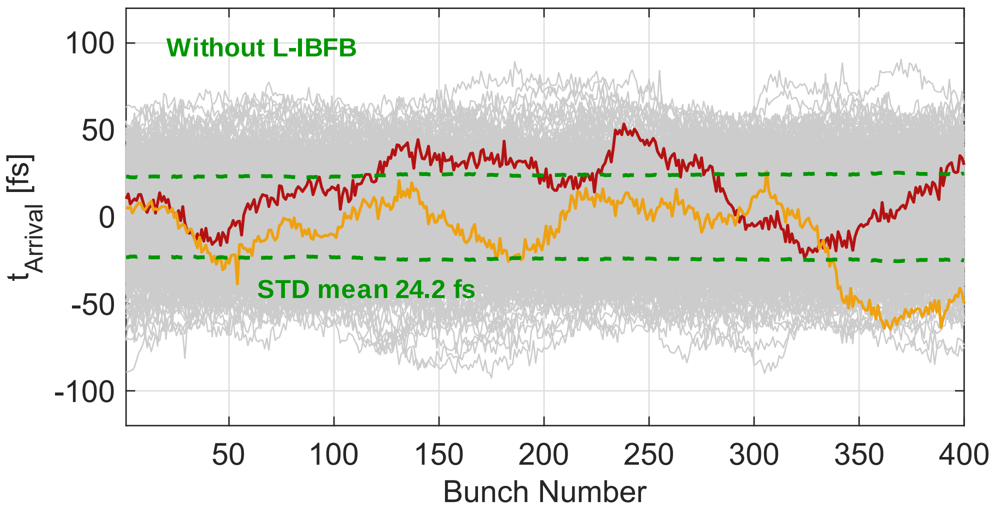
- Measurements taken during a study shift
- First L-IBFB loops around BC1
  BAM.1 → ACC1 and BACCA
- Second L-IBFB loop around BC2
  BAM.2 → ACC23

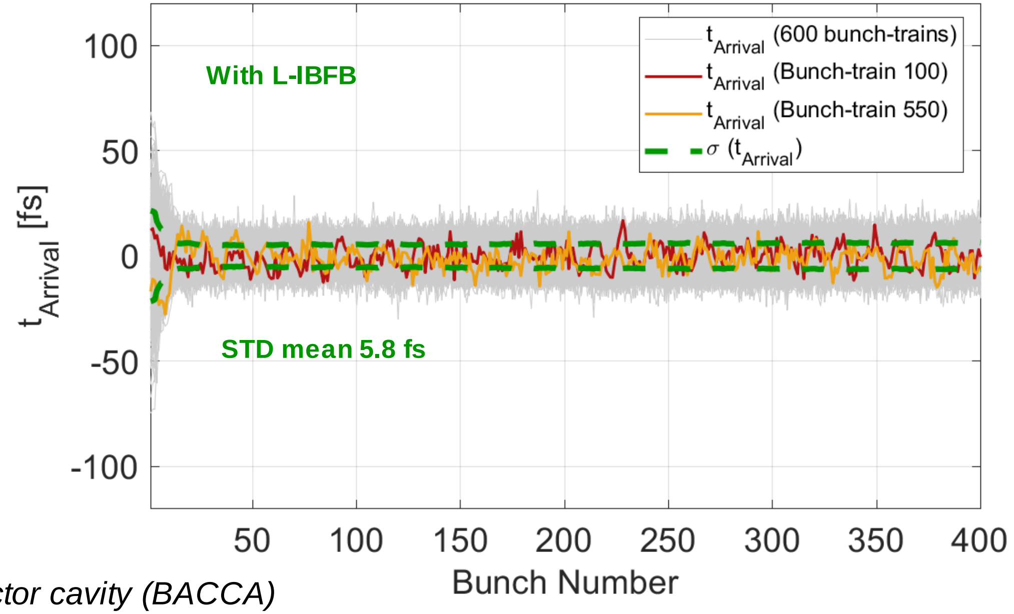
Results FLASH

Data taken during measurement shift



Mean free arrival time BAM.2





B. Lautenschlager et all, Arrival time stabilization at FLASH using the bunch arrival corrector cavity (BACCA)

Summary and Outlook

Summary

- BAM reaches resolution down to 3-4 fs
- Correlation between BAM and the PAM measurements.
- At XFEL and FLASH arrival time stabilities down to 5 fs (rms).
- At XFEL the L-IBFB loop BAM 3 → A5.L3 runs stable over days. Available for daily operation.
- At FLASH the two L-IBFB loops BAM.1 → ACC1 and BAM.2 → ACC23 available for daily operation
- BACCA expert knowledge necessary

Outlook

- Long term drifts due to ground motions (tidal effect) but also other aspects of ground motion – disturbances coming from the oceans.
- For EuXFEL three new BAMs close to the experiments.
- Measurement campaign together with the experiments are ongoing. PAM measurement. Intra-train behavior
- R&D project: laser pulse arrival time monitor – LAM
- FLASH major upgrade ongoing, new accelerator modules, laser heater, refurbishment of the BC chicane, …

- L-IBFB with compression signal.
- BAM: ongoing improvement, automation
- Development of a feedback manager.
  - Better incorporation of the different feedback loops
  - Proper exception handling
  - Automation – one button solutions

Thank you

Contact

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