# Performance Evaluation of the Upgraded BAMs...

## …at FLASH

**… with a compact overview of the BAM, the interfacing systems & a short outlook for 2019.**

Marie K. Czwalinna
On behalf of the Special Diagnostics team and many others at MSK

05/02/2019 – FEL Seminar (30b/459)

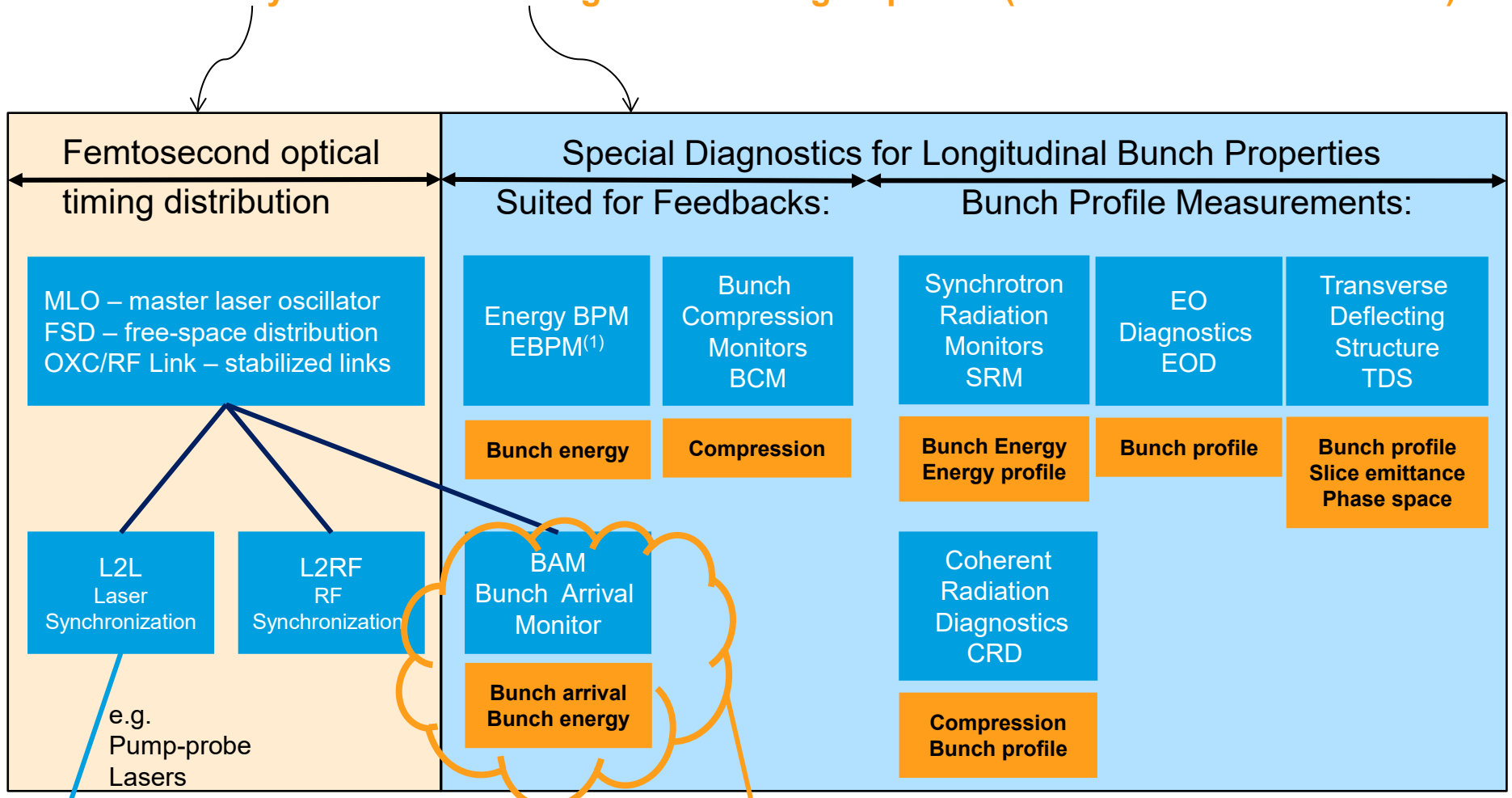
HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

FLASH.
Free-Electron Laser FLASH

DESY

# Organizational Diagram

## Responsibilities of LbSync Team and SDiag Team in the group MSK (Maschine Strahlkontrollen)




Konrad Przygodai,
Uros Mavric,
Michael Fenner,
Frank Ludwig, …
**(Hardware)**

Lukasz Butkowski,
(Radoslaw Rybaniec),
Jan Marjanovic, …
**(Firmware)**

*Martin Killenberg,*
*Jens Georg,*
*Martin Hierholzer,*
*Nadeem Shezad, …*
**(Software)**

Sven Pfeiffer,
Christian Schmidt,
Björn Lautenschlager
**(Beam-based FB, LLRF)**

*Jan Roever.*
*Martin Schäfer*
**(Construction)**

*B. Steffen,*
*+ ?*
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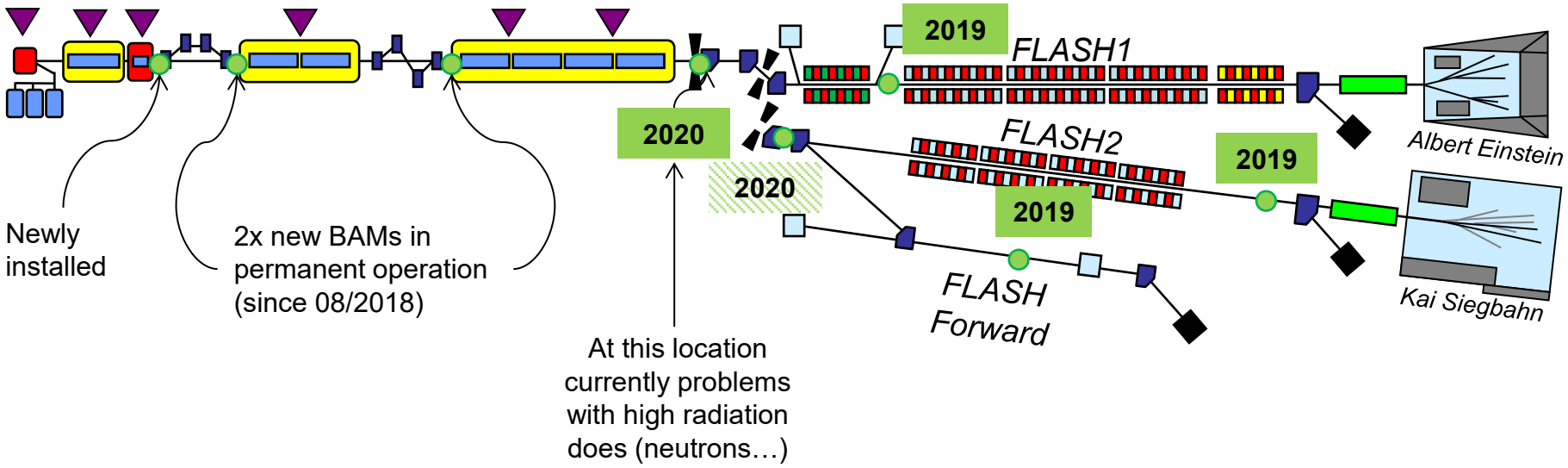
# BAMs at FLASH

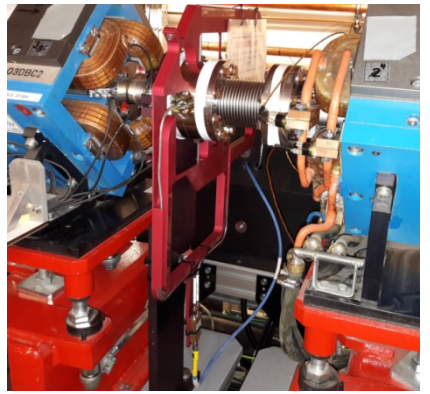
## Locations and Status

- = Since 07/2018 all BAM locations at FLASH equipped with 40GHz pickups.

| 1UBC2 | 3DBC2 | 4DBC3 | 15ACC7 | (FL2EXTR) | 1SFELC | 7FLFMAFF | 8FL2BURN |
|---|---|---|---|---|---|---|---|
| 22m | 27m | 85m | 138m | - | 185m | 203m | 243m |




RF Frontend at beamline:



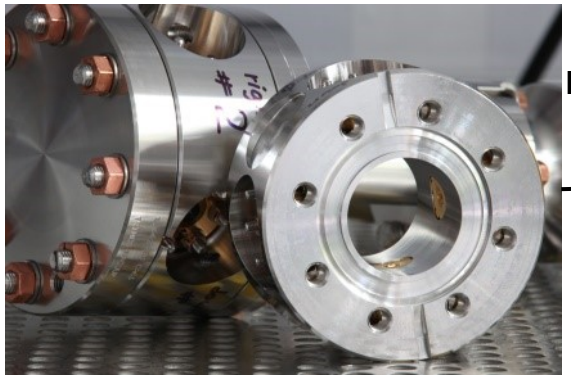
"BAM-box" with EO modulator
MTCA.4 crate (2HE) with ADCs.

→ **BAM is dependent on the progress of the upgrade of the Laser-based Synchronization System. → refer to Jost's talk.**

# BAM: Overview

## BAM Working Principle

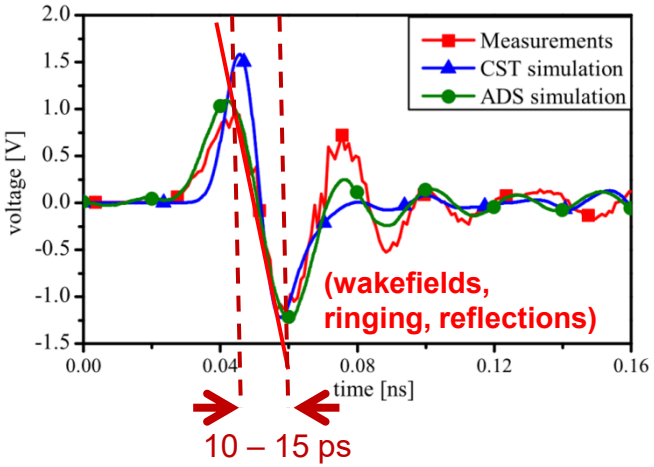
**2) RF-Pickups detect Electrical Field of electron bunch: Non-invasive, bunch-resolved**



**BW = 40 GHz**

RF Signal of 1 bunch in time domain:

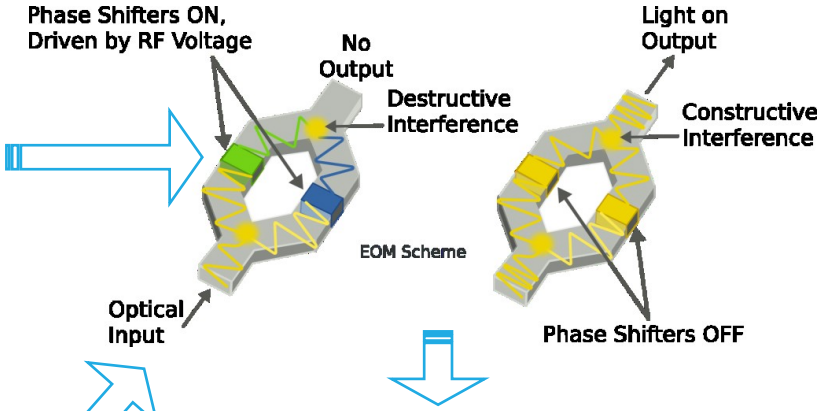
Charge dependent slope: @20pC > 0.3 mV/fs




*Ref.: PHYSICAL REVIEW STAB, 18, 012801 (2015) A.Angelovski, M.Kuntzsch, M.K.Czwalinna, et al.*

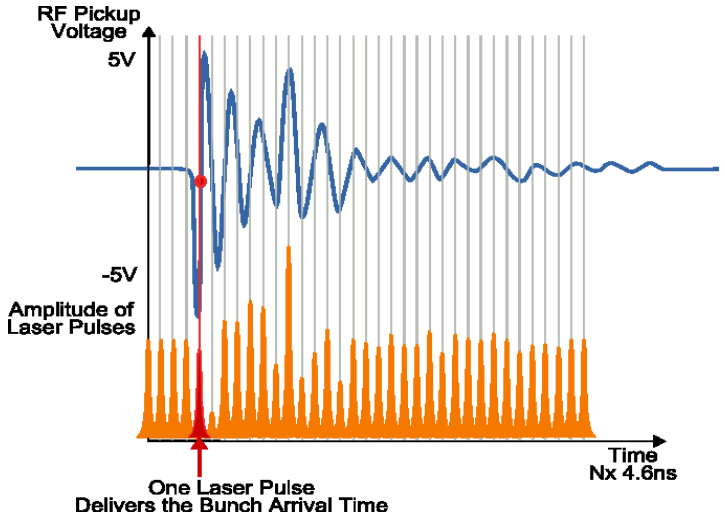
**3) Electro-Optic Modulator (commercial)**

Transfer timing/phase variation of the bunch RF signal into an amplitude modulation of a laser pulse.

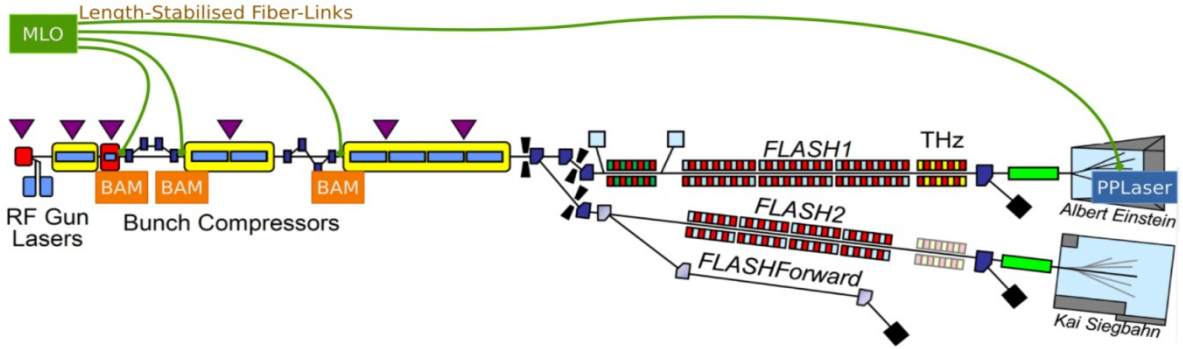



**4) Bunch Arrival Time**

Sampling of amplitude modulation with fast ADCs.

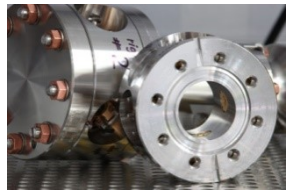



**1) Laser-based Synchronization System: Laser pulses (216 MHz) as timing reference with fs precision via length-stabilized fibers**



# BAM: System

## Components



**ODL**
Optical delay line

MLO

Link
LSU

BAM-Box

FLASH2
FLASH1

nm encoder
nm encoder

**ODL**
Optical delay line

**Optical Switch**

X

EOM

1

**EOM 40GHz**
Electro-Optical Modulator
“Low-Charge Channel”

**9dB Coupler**
Pure RF “Coarse Channel”

3

EOM

2

**EOM 20GHz**
Electro-Optical Modulator
“High-Charge Channel”

**EDFA,**
Optical Amplifier

0

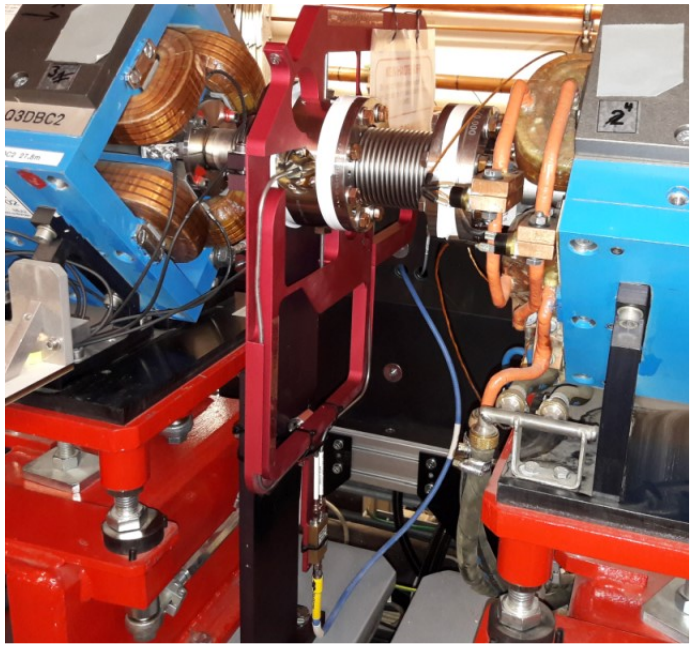
**10% tap**
For ADC clock

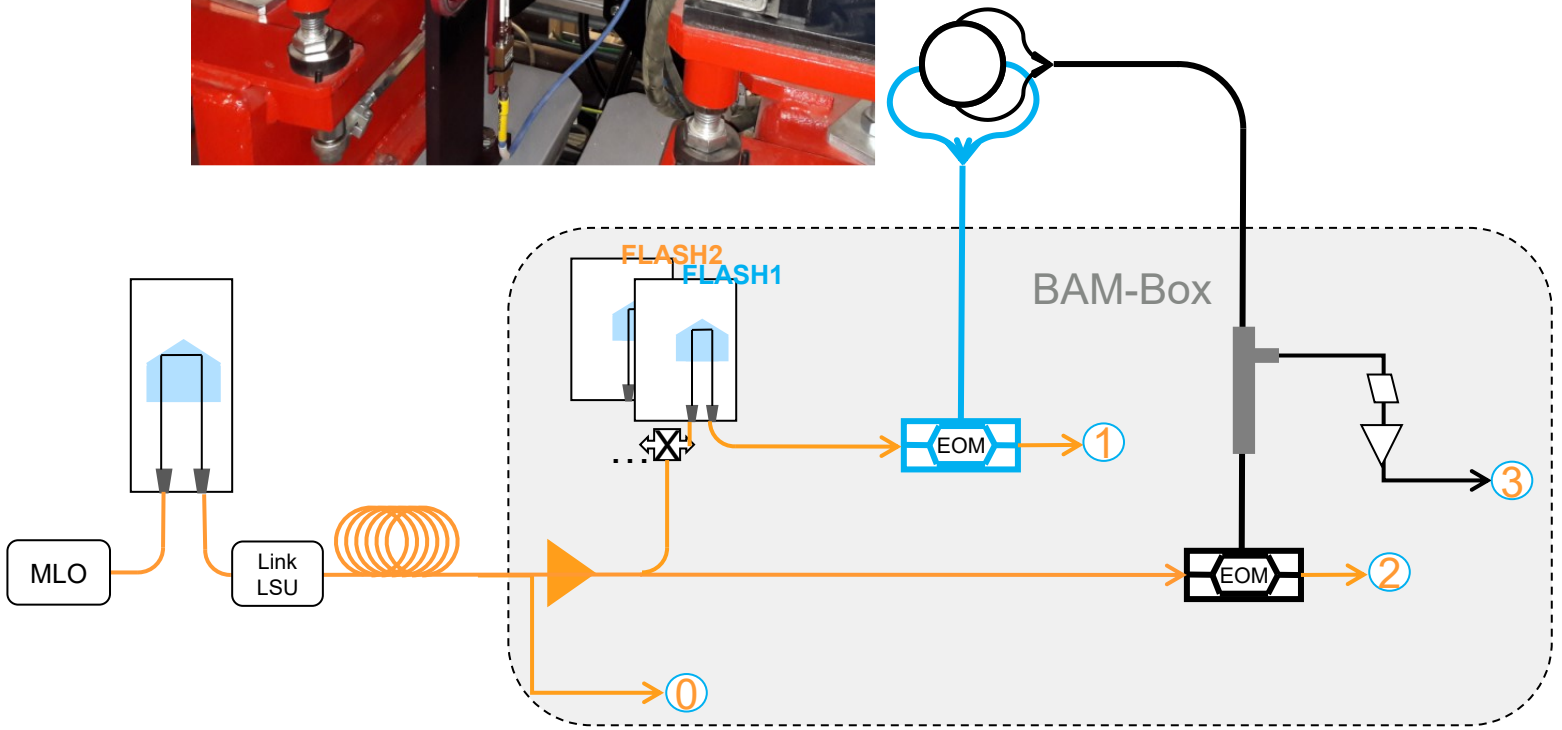
# BAM: System

## Components

BAM-Box

- … temperature regulation (Peltiers) + passive humidity stabilisation
- … laser diode driver
- … voltage control and read-back
- … humidity & temperature sensors





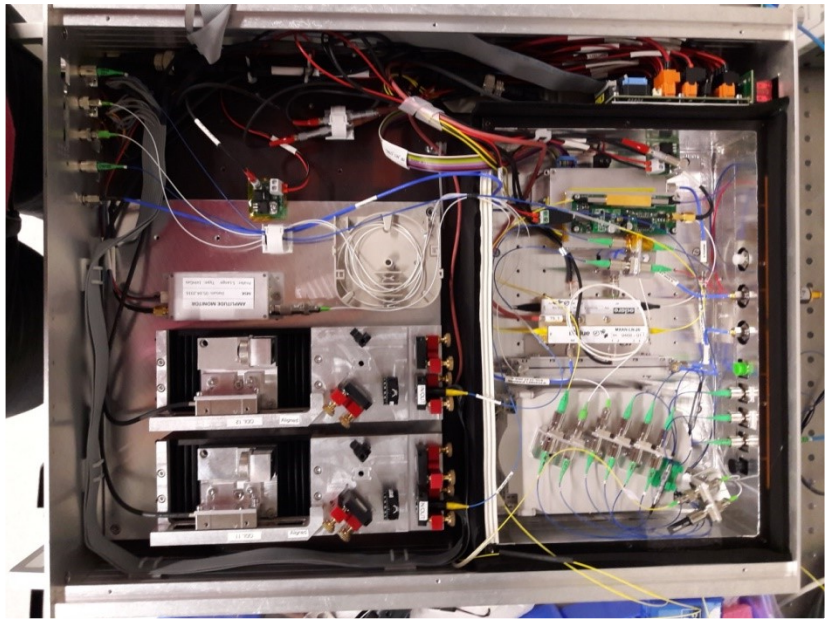
# BAM: System

## Components

BAM-Box

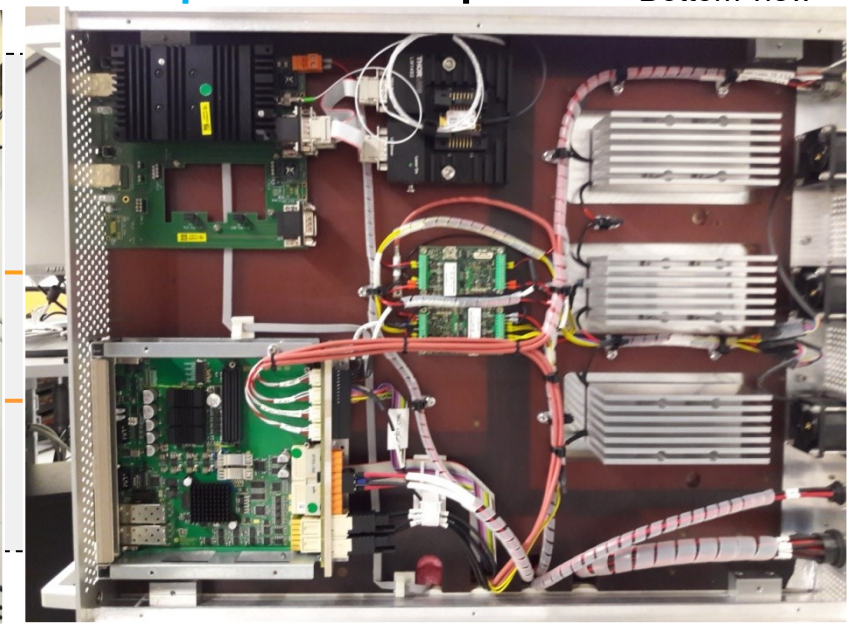
- … temperature regulation (Peltiers) + passive humidity stabilisation
- … laser diode driver
- … voltage control and read-back
- … humidity & temperature sensors

Top view, thermo-box openend



Top view, thermo-box closed

Bottom view



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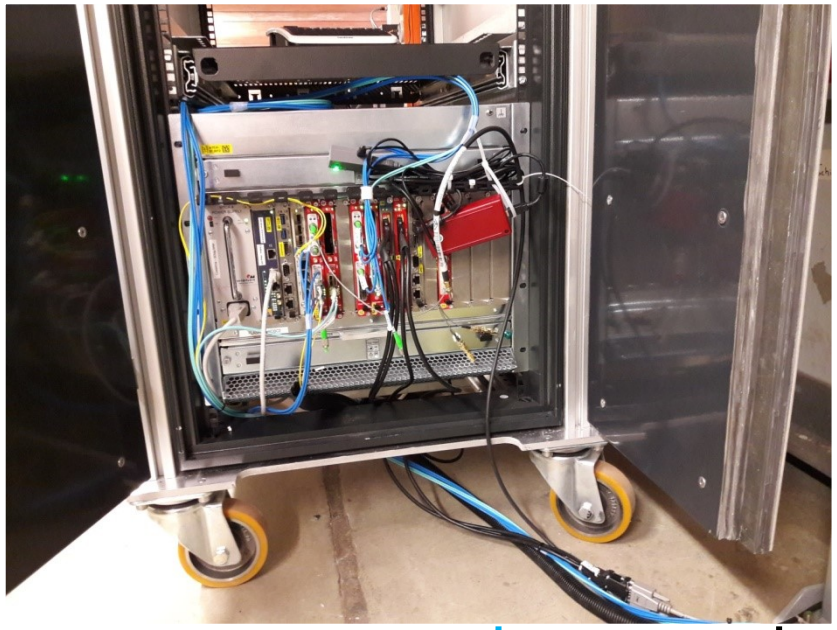
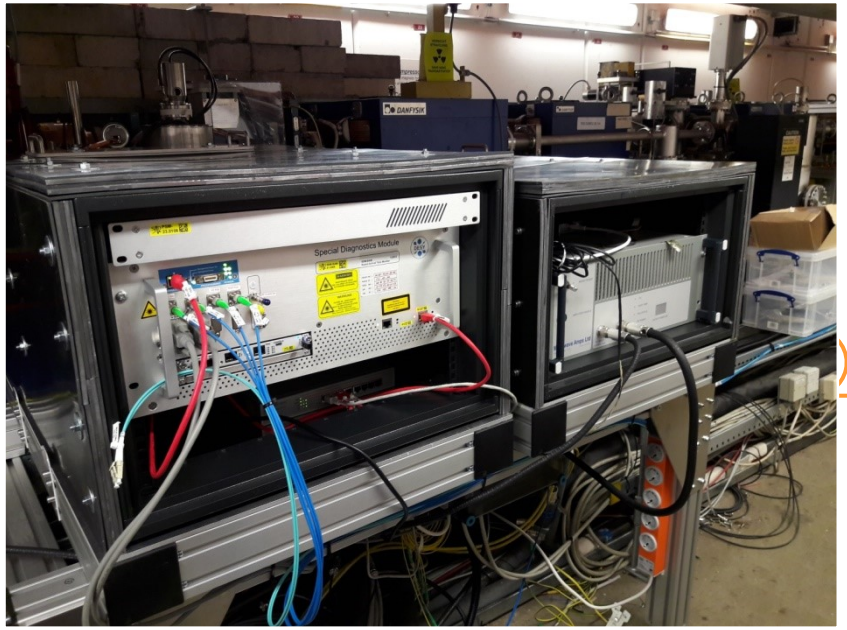
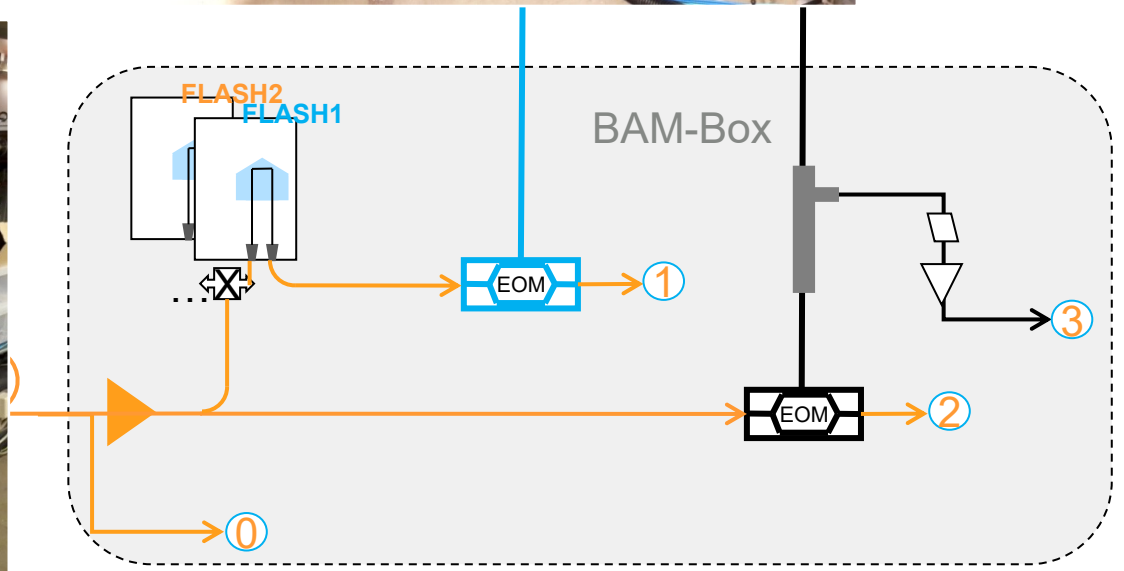


MTCA crate for 2x BAMs & space for 1x BCM

Powersupply + “BAM-box” in shielded rack (1UBC2).





# BAM: System

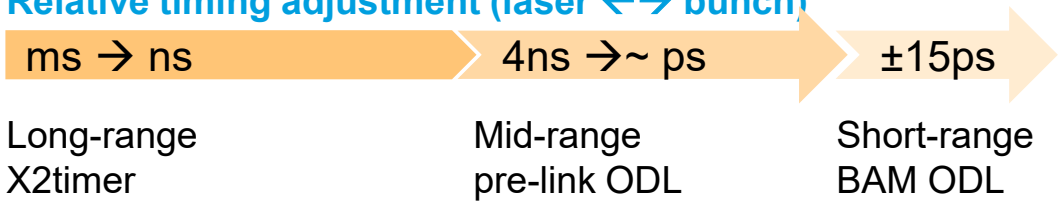
## Commissioning with beam

Preparing a BAM system for beam operation

- … temperature regulation required and needs to run stable
- … set up optical amplifier
- … check EOM transmission and set to 50%
- … scan and set ADC clocks
- … fine tune signal level on ADCs

**Dynamic Range  3-4ps only!**
Requires automation for keeping or retrieving the operation point

**Relative timing adjustment (laser ←→ bunch)**



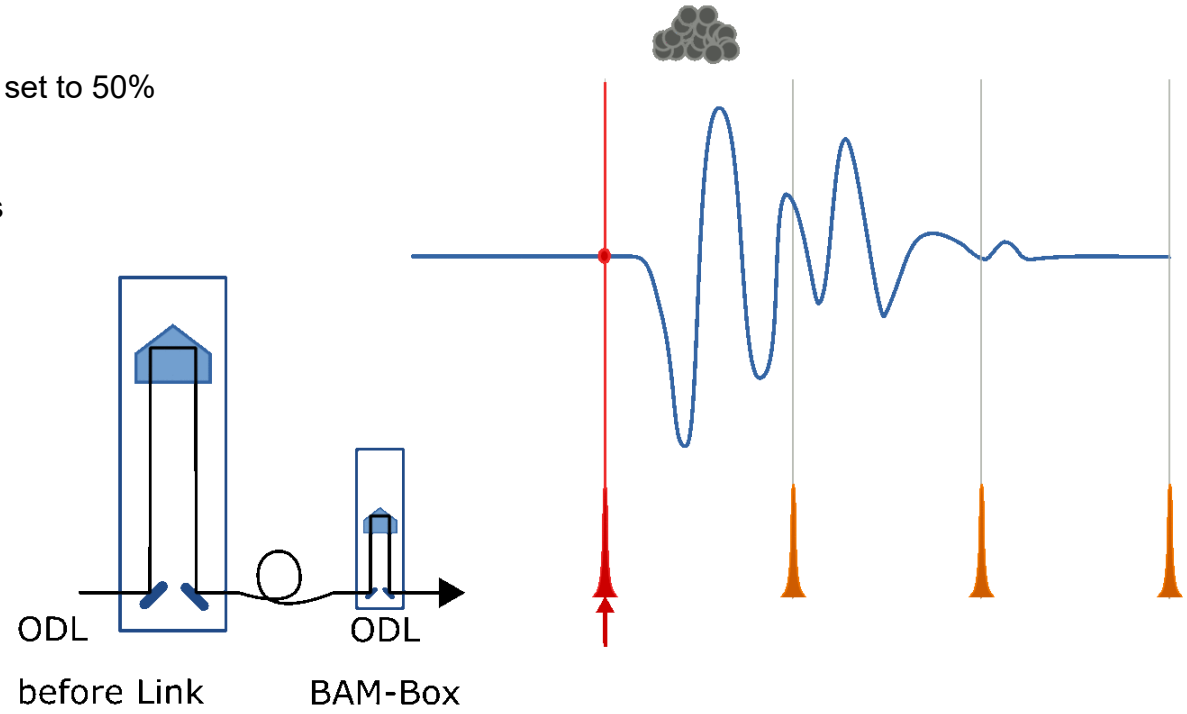
# BAM: System

## Commissioning with beam

Preparing a BAM system for beam operation

- … temperature regulation required and needs to run stable
- … set up optical amplifier
- … check EOM transmission and set to 50%
- … scan and set ADC clocks
- … fine tune signal level on ADCs

**Dynamic Range 1 - 4ps only!**
Requires automation for keeping or retrieving the operation point

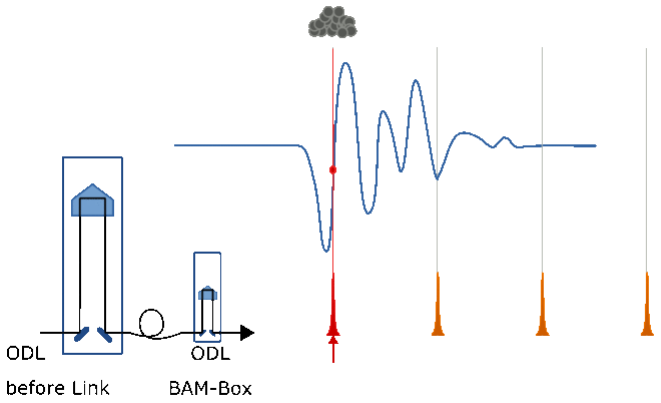



**Relative timing adjustment (laser ←→ bunch)**

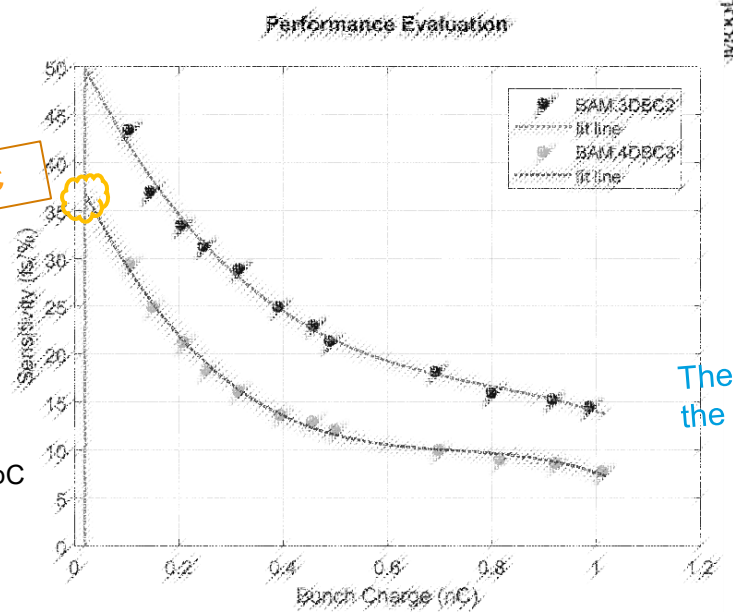
| ms → ns | 4ns →~ ps | ±15ps |
|---|---|---|
| Long-range<br>X2timer | Mid-range<br>pre-link ODL | Short-range<br>BAM ODL |

# BAM: Signal Scan @FLASH

## Sensitivity of arrival time detection & its charge calibration




2V pk-pk @20pC ⊗ RF Limiter 26GHz, 25dBm ⊗ EOM, 35GHz

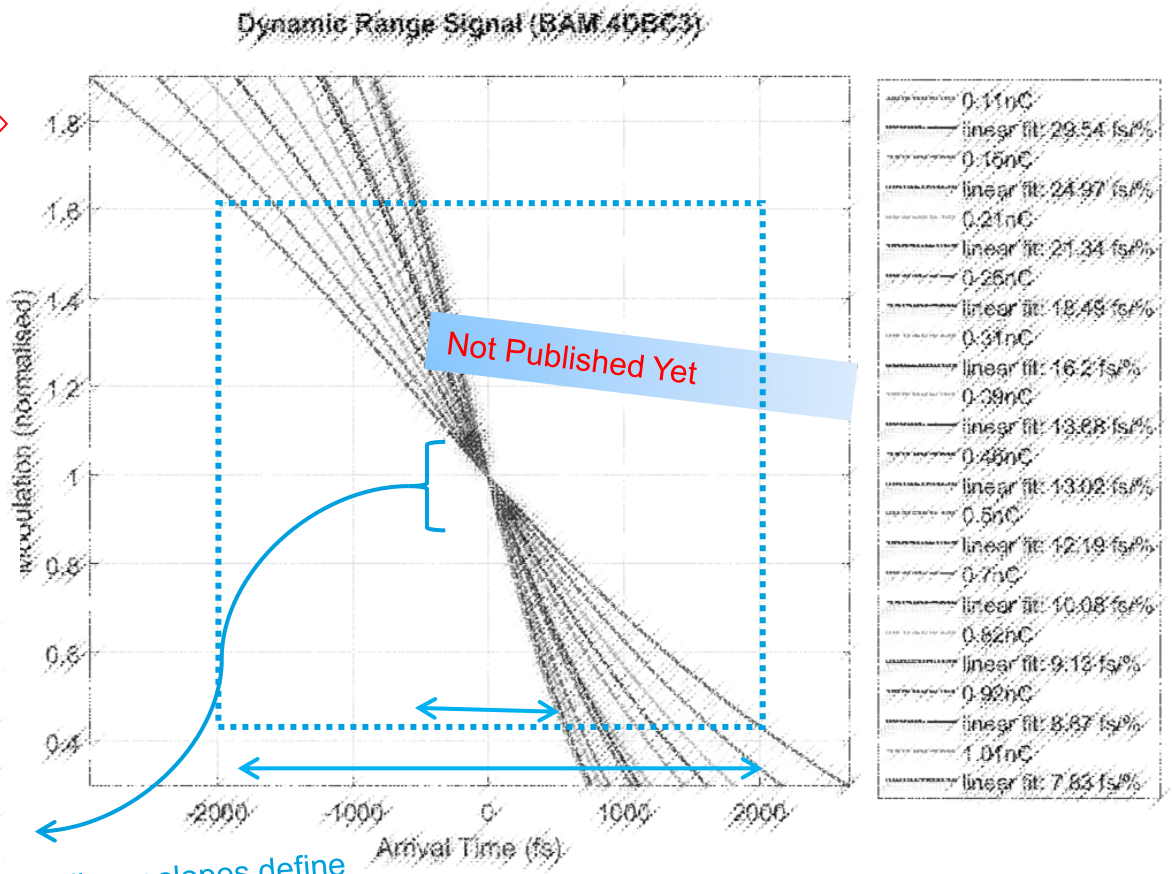



**Sensitivity 37 fs/% @ 20pC**

### Measurements performed at FLASH:

- 40GHz EOM with an RF limiter on input (26GHz bandwidth, 25dBm)
- ✓ Estimated sensitivity at design charge of 20pC fits to very well to simulation
- ✓ Resolution of <10fs possible at low charge.

### Electro-Optical measurement of BAM signal:




These linear slopes define the sensitivity of the BAM

**Dynamic Range 1 - 4ps only!**

Polynomial Parameter (4th or 5th order)
→ look-up table for charge dependent slope change
→ upgrade: should be described with a steady parameterized function

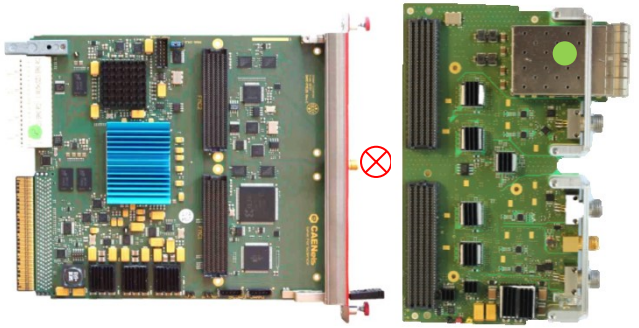
# BAM: Time Resolution

## Comparison to old BAMs & system limitations

**Read-Out Electronics**

*DESY, AMC FMC25*

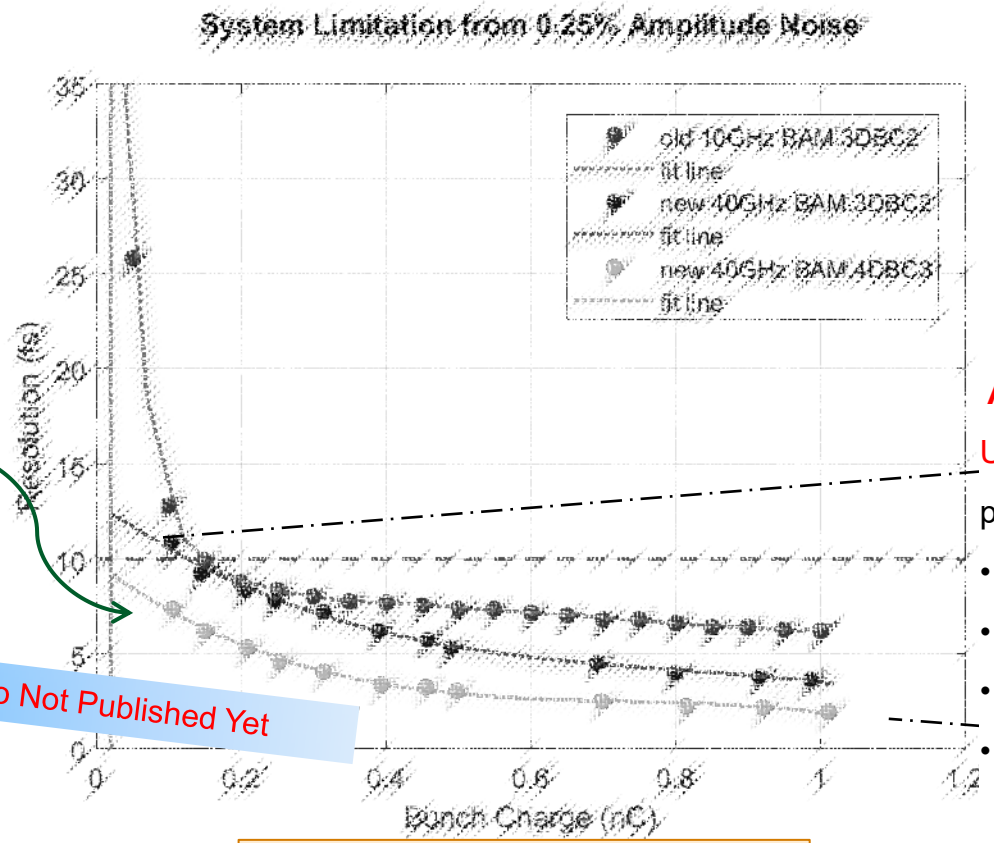
FMC DSBAM,
customised by DESY



**Resolution = Sensitivity • Accuracy**
(dynamic property)

**Sensitivity** is charge dependent:
**< 37 fs/% @ 20pC**

**Accuracy** depends on signal readout
(amplitude noise, EO modulator, ADC, ..)
Currently best performance:
**2.5 •10-3**




Also Not Published Yet

**Resolution of better than 10 fs over large bunch charge range.**

**Amplitude Noise is the new limiting factor**

Under investigation:

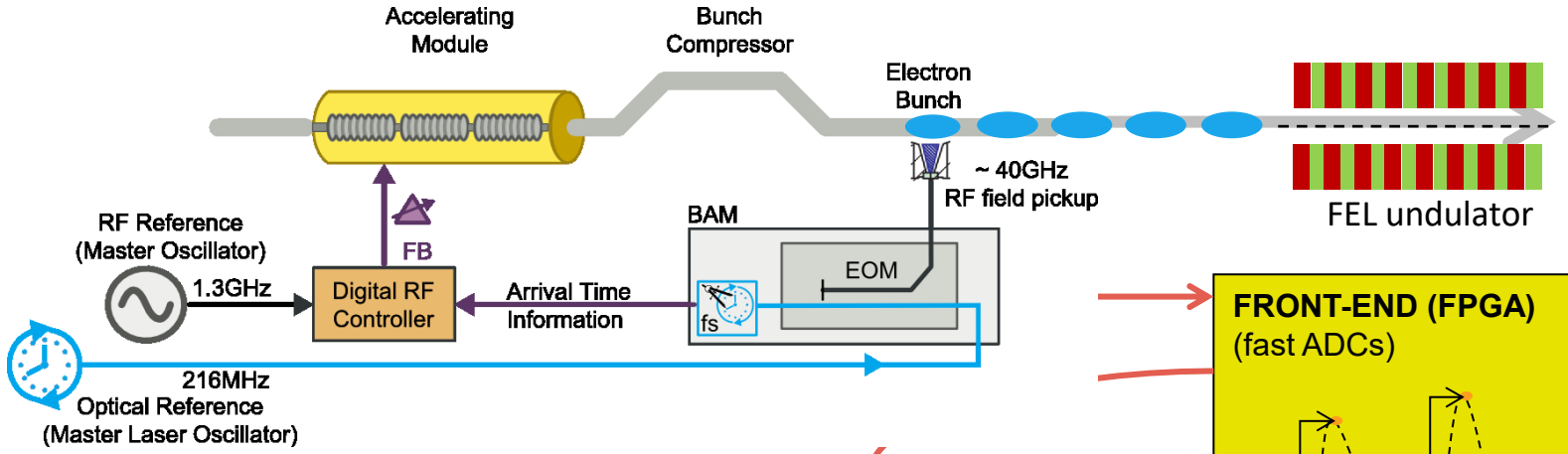
proportion of contribution from ….

- … Optical noise in the links of synchronization signal
- … optical fiber amplifiers,
- … optical noise in the BAM EO-frontend
- … electronic noise on the BAM read-out card (photodiode, amplifier, ADC, clock jitter, cross-talk, …)

# BAM: Data Usage

## Monitoring, feedback operation and post analysis of timing jitter

Slow BAM FB:
- Removes arrival-time drift
- Seconds to minutes scale




**FRONT-END (FPGA)**
(fast ADCs)

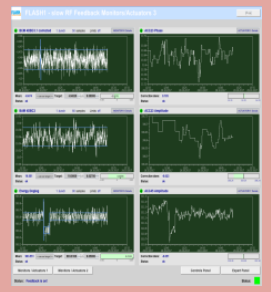


Not modulated — Modulated pulses

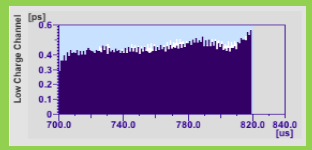
**Front-end BAM SERVER**
TIME CALIBRATION, BUNCH ARRIVAL TIME RESOLUTION, STATISTICS, …

Slow Longitudinal FB (DOOCS DAQ Server)

Arrival Time ⇄ Energy FB ACC1 or ACC23



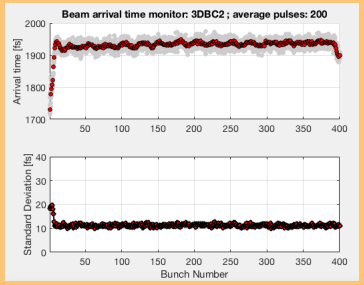
**DAQ**



BUNCH ARRIVAL TIME RESOLUTION STATUS….

Digital LLRF Controller (on FPGA)

Arrival Time ⇄ FB as Field error correction in ACC1 or ACC23




Fast BAM FB:
- Removes arrival time slope across bunch train
- Reduces pulse-to-pulse jitter (latency + adaptation time of few µs)

Control room:
- Machine setup
- Fine tuning during SASE setup
- Monitoring during user run

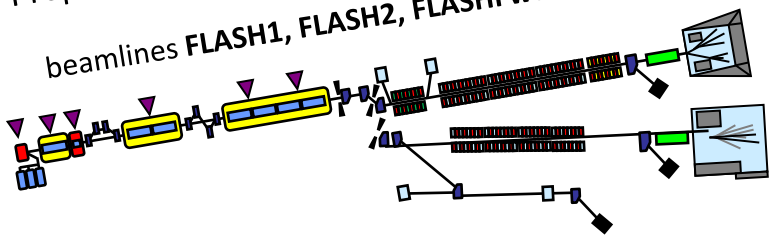
User Experiment
…for post analysis, data sorting

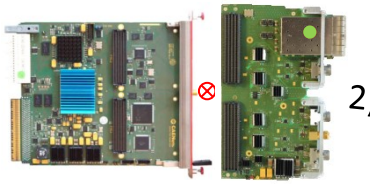
# Outlook

## Activities planned for this year

3) Prepare installation of 2-3 further **BAMs** :

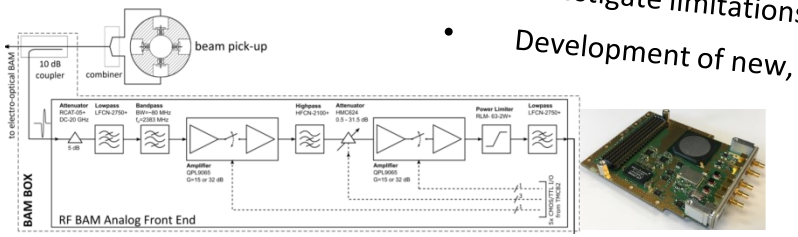
beamlines **FLASH1, FLASH2, FLASHFwd**





2) Hardware (with support from experts)

- Investigate limitations → revise existing hardware
- Development of new, pure RF coarse channel

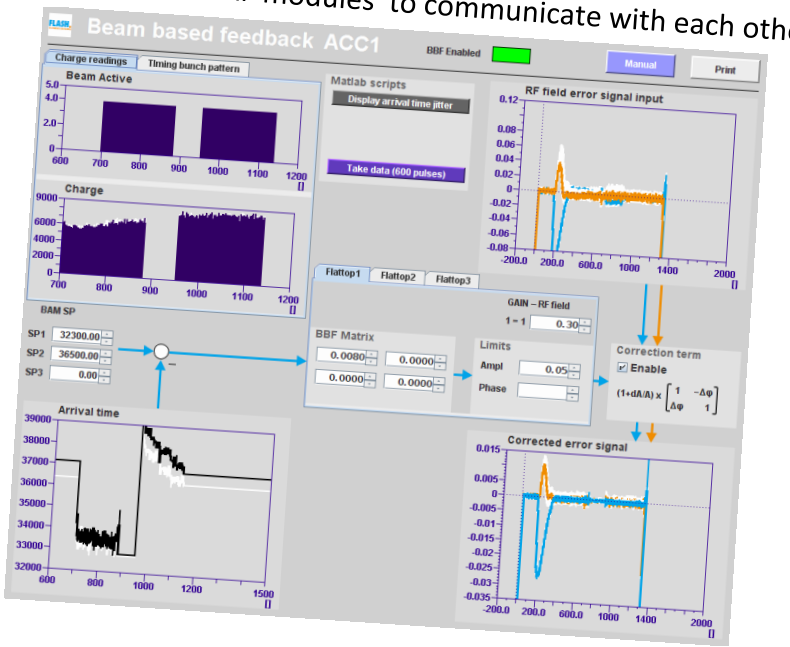



J.Zink, et al., High-Speed direct Sampling FMC, for Beam Diagnostic and Accelerator Protection Applications, Proceedings of IBIC2018,Shanghai,China

Thank you!

1) **Concentrate on automation & improved algorithms**

- Software / Firmware
  - Mainly additional automation required, e.g. operation of optical switch, time overlap find+retrieve
- Commission and improve Beam-Based Feedback concept
  - Parallel operation FL1,FL2 + parameter optimisation
  - Integrate BCM signals
  - Slow and fast loops, at different RF modules to communicate with each other




4) Stronger collaboration with HZDR for Diagnostics

- Concentrate on BAM + beam-based feedback activities
- later also BCM integration