MTCA-based Accelerator And Related Control Systems at DESY

A brief overview

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12th MTCA Workshop

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HELMHOLTZ

DESY.

Outline

MTCA-based Accelerator Control Systems at DESY

1 Baseline
- The MTCA.4 Platform

Update on Digital Hardware Developments at DESY – Michael Fenner (DESY) — Wednesday

2 Accelerator User Facilities @ DESY
- XFEL Accelerator
- FLASH
- PETRA III

Looking back over 10+ years experience with MTCA LLRF systems at DESY – Julien Branlard (DESY) — Tuesday

MTCA for tests for PETRA IV and DESY II Testbeams

4 Projects
- Test Facilities: CMTB, AMTF, FALCO, TS4I, Labs, …
- SINBAD-ARES
- REGAE
- KALDERA (LUX)
- PETRA IV

Update on the DAMC-X3TIMER Development – Hendrik Lippek (DESY) — Thursday

CW Control System for the KALDERA Laser Plasma Accelerator at DESY– Tomasz Jezynski (DESY) — Thursday

5 Experiments
- EuXFEL and PETRA
- FLASH
- ALPS II

Potential applications of MTCA at synchrotron beamlines – Martin Tolkiehn (DESY) — Wednesday

MTCA for photon diagnostic and user experiments at FLASH – Stefan Düsterer (DESY) @ MTCA WS 2020

MicroTCA used in the Dark Matter experiment ALPS – Sven Karstensen (DESY) @ MTCA WS 2020

6 Summary

Accelerators and Projects at DESY

User Facilities FELs and Synchrotron + Test Facilities and ARD Projects

Baseline

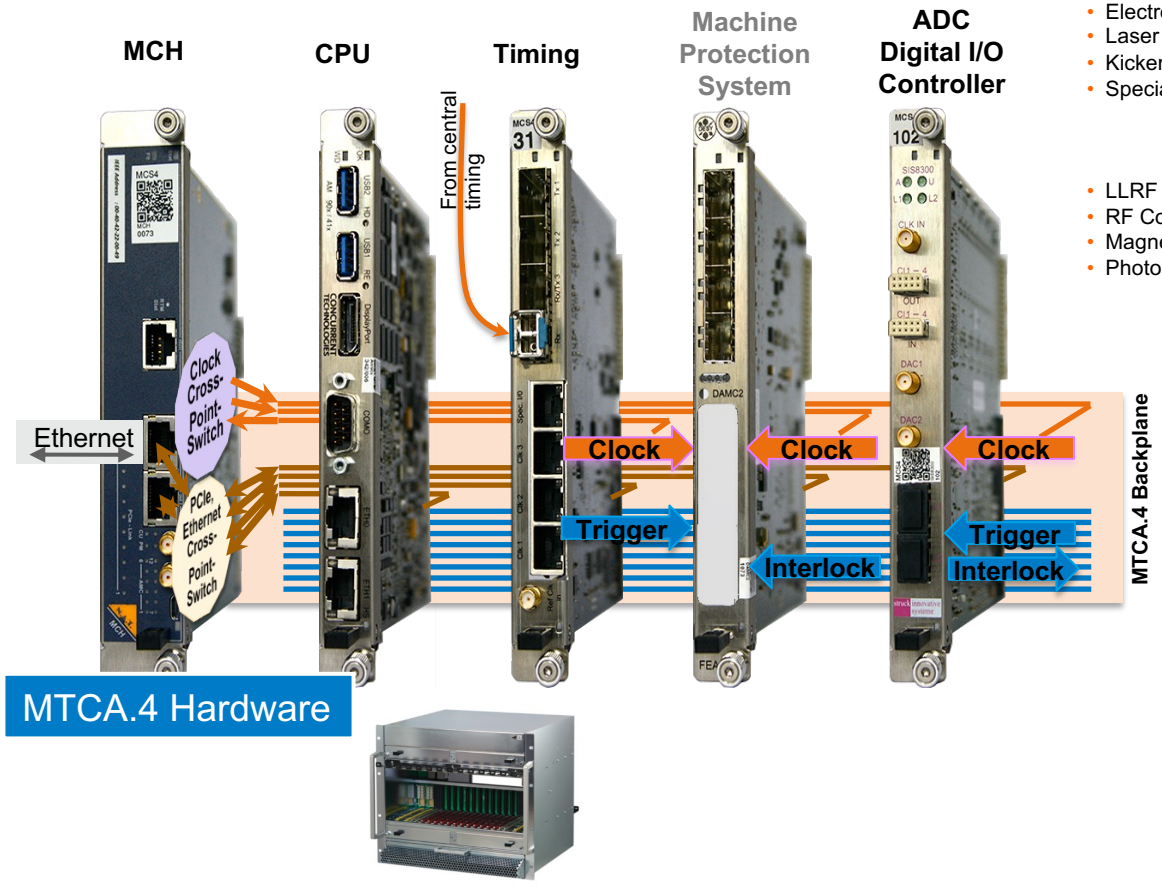
Baseline

MTCA.4 Platform as Integral Part of DESY Control System Standard

MTCA.4 platform connects and integrates well into accelerator controls landscape!

Common Hardware Platform	**MTCA.4** Platform (PICMG Standard) and applications Industry Standards (e.g. Beckhoff PLC w/ OPC-UA)
	19" rack-mountable server nodes with **remote management** (LOM, iDRAC) e.g. for data acquisition (DAQ) nodes
Common Software Framework	**DOOCS** as general control system software framework Languages: C++ w/ Python and MATLAB bindings / Java
	Linux (Debian) as standard operating system **Open Source** solutions as much as possible DOOCS for management and supervision

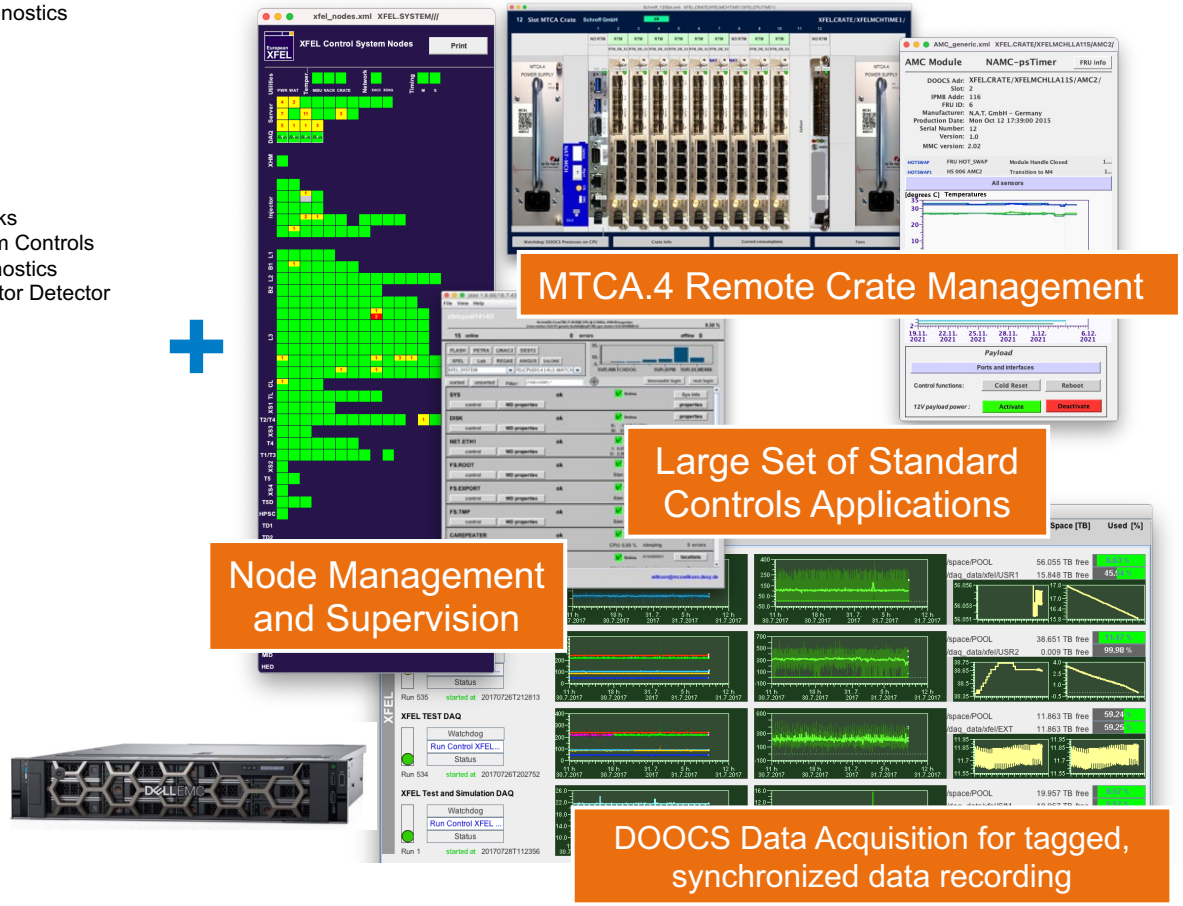
MTCA Common Modules



Application Modules (AMC + RTM)

- Electron Beam Diagnostics
- Laser Controls
- Kicker Controls
- Special Diagnostics
  - …
  - Kalypso
  - CRISP
- LLRF
- RF Coupler Interlocks
- Magnet and Vacuum Controls
- Photon Beam Diagnostics
  - Gas Monitor Detector
  - Imagers
  - …

Control System Applications



Accelerator Facilities @ DESY

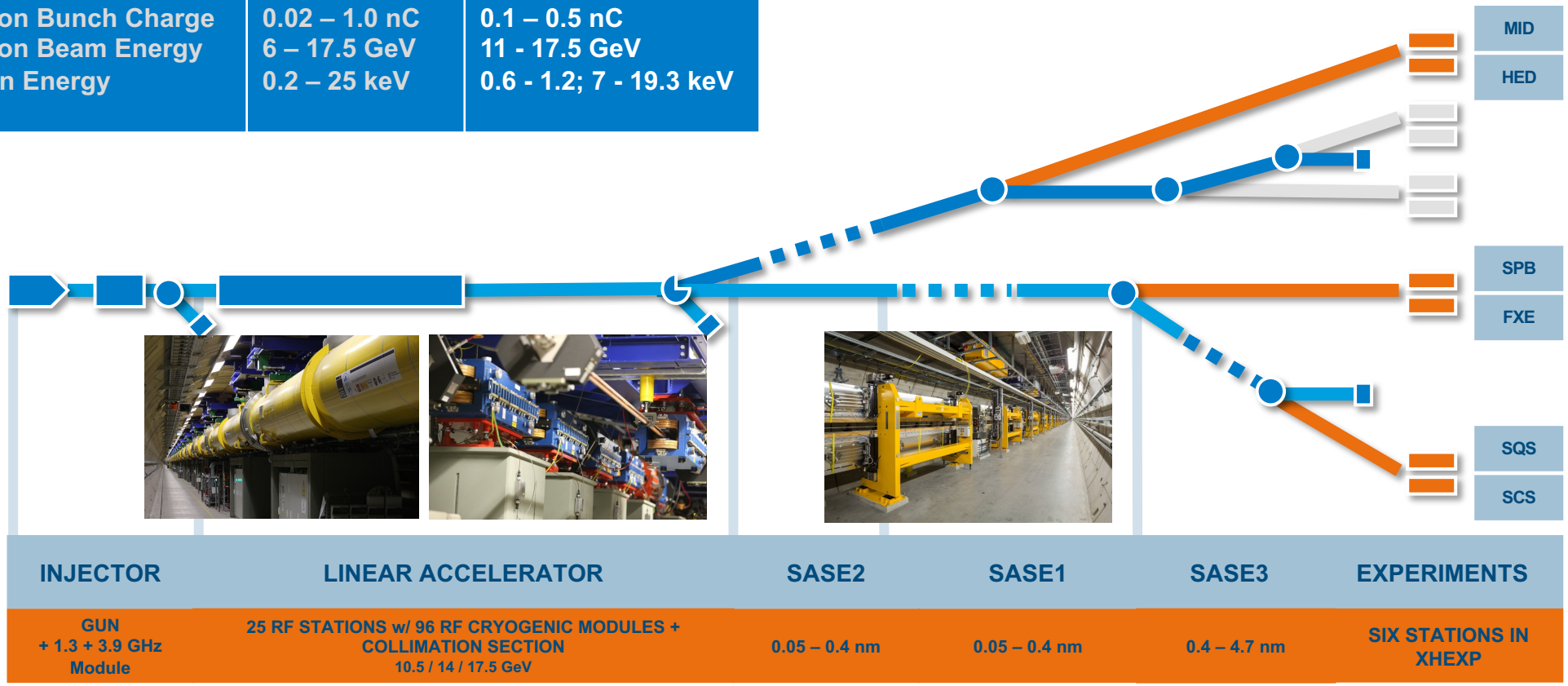
The European XFEL

Accelerator Layout

Parameters	Design	Achieved
Pulse Repetition Rate	1 - 10 Hz	1 - 10 Hz
Bunch Repetition Rate	0.5 - 4.5 MHz	0.1 - 4.5 MHz
RF Pulse (Flat Top)	650 µs	600 - 650 µs
Electron Bunches	27000 / s	27000 / s @ XTL
Photon Pulses	27000 / s	5000 / s
Electron Bunch Charge	0.02 – 1.0 nC	0.1 – 0.5 nC
Electron Beam Energy	6 – 17.5 GeV	11 - 17.5 GeV
Photon Energy	0.2 – 25 keV	0.6 - 1.2; 7 - 19.3 keV

Accelerator Control System Data Volume w/o Experiments

- More than **10 million** addressable DOOCS control system parameters
- About 700.000 local DOOCS archives plus TINE central archives
- 30 k hybrid channels (== 150 k parameters) at 10 Hz / 4.5 MHz sent to data acquisition (Accelerator DAQ)
- About **40 TByte/day** of bunch-resolved DAQ data collected currently – O (10 PB)/y – stored on 5 PByte dCache hosted by IT

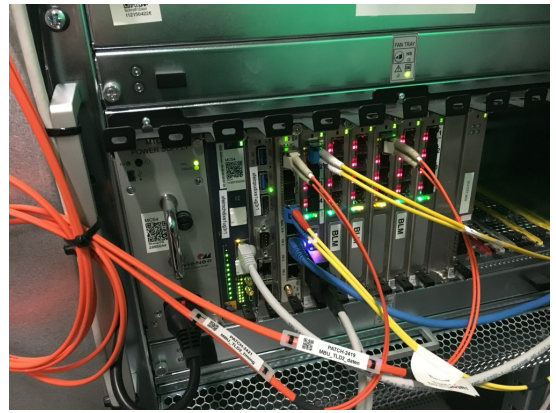


EuXFEL Status 2023

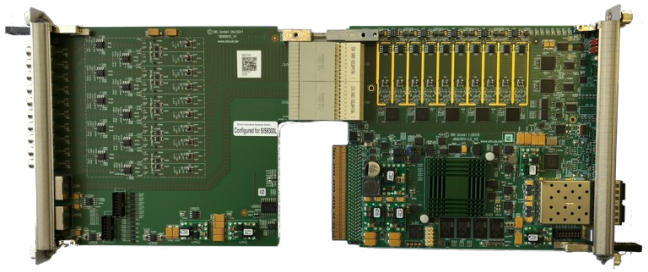
Statistics on MTCA components @ EuXFEL

- More than **30 different kinds of MTCA-based software applications** are in use

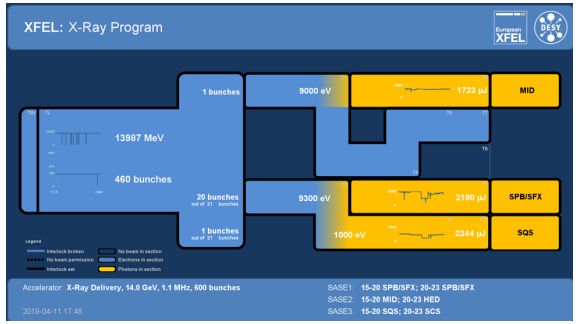
  → Essential to have a portfolio of standard solutions for efficient system integration!



- About **300 MTCA systems** as of 2023
  - More than **4200 MTCA modules** (AMC, RTM, P/S, MCH,…) installed at XFEL e.g.
    - Timing System: 420 modules
    - DAMC2 AMC: 573 modules
    - DAMC-TCK + DAMC-FMC: 49 + 62 modules
    - SIS ADC AMC and RTM: 557 modules
    - Teledyne ADQ AMC / TEWS: 49 / 20 modules



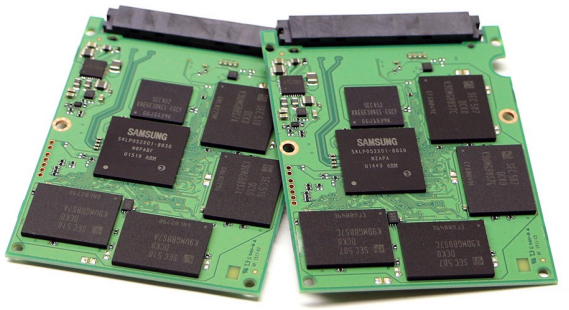
  - Many RTM solutions for diagnostics BLM, Toroid, MPS, TIL, wire scanner, …
- About 300 IPMI management server and watchdogs online – more than 2000 processes being monitored
- Core systems are running since end of 2013 and injector since 2015
- **Successful machine operations in production mode since 2017**



Experiences

Some experiences with MTCA components at the accelerator control system

- MTCA hardware is reliable.
- Issues likely related to beam operations are the prominent ones:
  - Radiation related failures w/ (radiation levels are quite normal in general though)
    - SSD and other electronics (SEU,…) in LINAC area – disk RAID saves downtime
    - Some FPGA black outs and/or memory corruption (SEU, …)
  - Communication issues MCH – CPU –FPGA: Very much dependent on used h/w and firmware combination and location (e.g. tunnel areas)
  - E.g. XFEL master timing system: 1 failure in 10 years of 24/7/365 operation (x2timer AMC, first production round)



Remote Management

Built-In IPMI capabilities of crates and modules pay off – enables easy fault resolution and saves downtime of machine operations especially during pandemic times!

Extensibility

Still growing number of MTCA components to be installed due to many (smaller) modifications of the machine

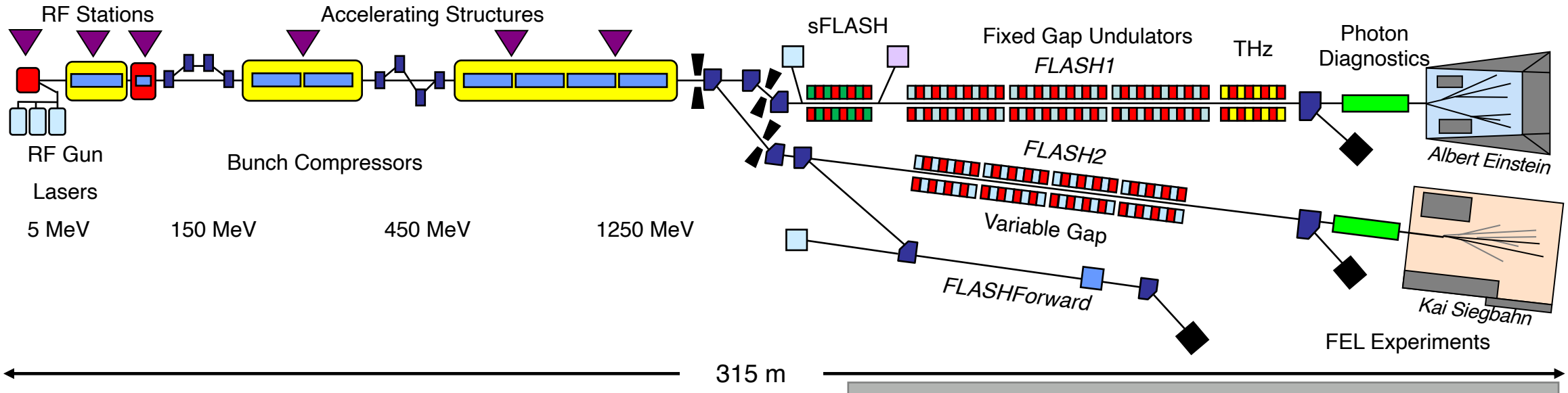
Shutdown 2025 (1 year)

New RF gun w/ longer RF pulse, optical delay lines, XFELO, ASPECT – Atto Second Pulses with eSASE and Chirp/Taper, STERN – THz source, superconducting undulator (SCU) preparations, XTCAV at SASE2, refurbishments MTCA components

FLASH MTCA-based Accelerator Controls

Accelerator Layout

The FLASH accelerator control system was the first production system at DESY using MTCA technology at DESY after serving as "test-bed"!



- About **65** MTCA systems online with **1000** MTCA modules (AMC, RTM, P/S, MCH,…) installed
- Same **30 different kinds of MTCA-based software applications** in use
- FLASHForward uses applications on MTCA specialized on and tailored to the the experiment needs
- FLASH 2 did use MTCA right from the beginning in 2013
- FLASH 1 in operation since 2005 – Migration from VME to MTCA throughout its lifecycle

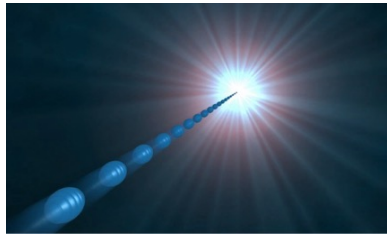
FLASHForward: Future-**OR**iented **W**akefield **A**ccelerator **R**esearch and **D**evelopment

- Electron beam-driven plasma-wakefield experiment
- Parallel operation w/ FLASH1 + 2 hence shared MTCA controls!

FLASH 1+2 Parameters	Status pre-2020+ Upgrade
Pulse Repetition Rate	10 Hz
Bunch Repetition Rate	1 MHz (3 MHz@5 Hz)
RF Pulse (Flat Top)	500 - 800 µs
Electron Bunches	10 - 5000 / s
Electron Bunch Charge	0.2 – 1 nC
Electron Beam Energy	0.35 – 1250 MeV
Photon Wavelength	4.2 - 51; 4 – 90 nm

FLASH 2020+

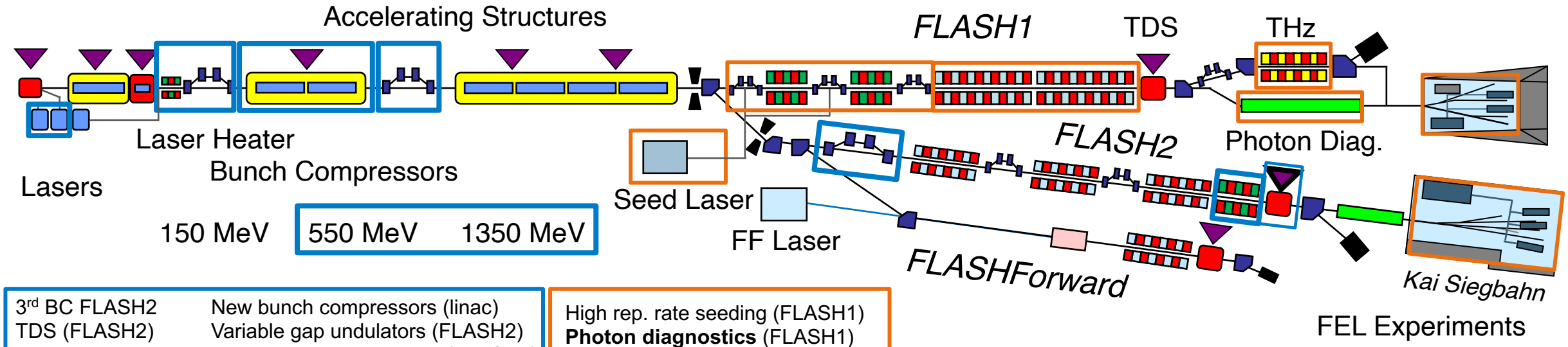
Upgrade of FLASH 2024/2025



FLASH 2020+ Project – 2 Shutdowns 2021/22 + 2024/25
- Upgrade and rebuild of FLASH/FLASH1 electron beamline
- Move entirely to MTCA platform and replace VME
- **MTCA baseline for accelerator and beamline experiments**

Ongoing migrations from VME to MTCA (2024/2025):
- Two new NEPAL-F photocathode laser systems w/ MTCA
- Former SFLASH, now seeding beam line support
- FLASH experiment beamline support systems
- Vacuum controls and monitoring
- Transverse deflecting cavity (LOLA)

Machine Protection System will become entirely MTCA-based



3rd BC FLASH2	New bunch compressors (linac)
TDS (FLASH2)	Variable gap undulators (FLASH2)
Energy upgrade	Interim pump-probe laser (FLASH1)
Laser heater	**New beamline FL23** (FLASH2)
Injector laser	Afterburner FLASH2

High rep. rate seeding (FLASH1)
Photon diagnostics (FLASH1)
THz Source
Flexible pump-probe lasers
New beamlines

From 2025: New seeded FEL FLASH1

Fully coherent pulses with **variable wavelength (60 – 4 nm)** **tens of fs** duration at **1 MHz repetition** rate and **variable polarization**

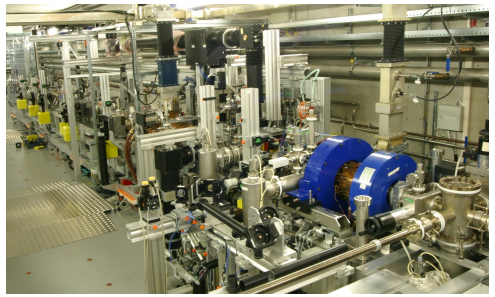
New MTCA magnet P/S controls:
Replace SEDAC with **low-cost MTCA** solution:
- **Fan-less Schroff MTCA crate**
- **Zynq-based CPU AMC** (DESY-FEA development)
- **I/O AMC** for magnet P/S control (DESY-FEA development)

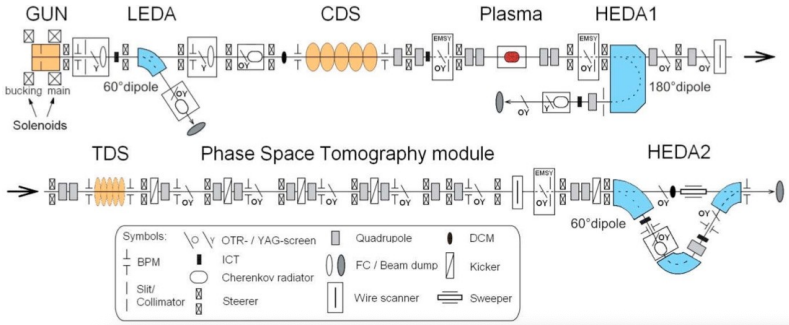
Replaced old system in 2022

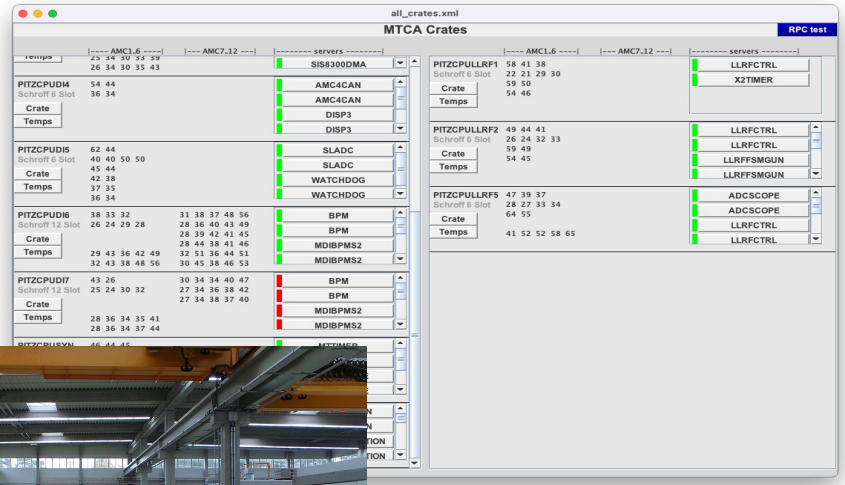
Projects - ARD et al.

DESY Test Facilities

PITZ, SRF Facilities AMTF and CMTB







- **PITZ** (Photo-Injector Teststand in Zeuthen)
  - 1.3 GHz RF photoinjector accelerator at 25 MeV/c, 5 nC electron bunches, emittances 0.7 mm mrad @ 1 nC, 10 Hz repetition rate
  - Formerly VME-based control system, meanwhile on MTCA.4 using existing solutions (LLRF, synchronization, electron beam diagnostics, etc. MSK + MDI) – 13 systems (3 LLRF / 7 + 1 diag / 2 sync)
  - **New NEPAL-P photocathode laser system** deployed by FS-LA also using MTCA.4 for controls
- **AMTF** (Accelerator Module Test Facility)
  - 3 SRF cryogenic module test bench + 3.9 GHz test bench w/ LLRF and technical interlock MTCA systems (9 deployed ones) (MSK/MSL) / CW operation at 3.9 GHz (AMTF) with SSA (MSK)
- **CMTB** (Cryogenic Module Test Bench)
  - One SRF cryogenic test bench using MTCA with CW operation 1.3 GHz (CMTB) with IOT or ELBE (HZDR) and MSK

FALCO

New test facility w/ MTCA-based controls:

- **FALCO** – RF Gun Conditioning Test Stand (Hall III / FLASH) – In Progress, ready 2024
- LLRF, RF Interlocks, Diagnostics

TS4I

New test facility w/ MTCA-based controls:

Teststand for injectors (@AMTF) exploring superconducting RF gun concepts and high-duty cycle operation modes (burst, long pulse + CW mode) for XFEL CW 2030+

- SC RF Gun @ 6 MeV with 8 m beam line and diagnostics using MTCA (LLRF, Laser, …)
- CW-mode / i.e. repetition rates **@ 100 kHz up to 1 MHz** (bunch repetition rate)

Controls Perspective: **Excellent testbed for high-rate, high-volume read-out concepts! (w/MTCA!)**

SINBAD-ARES and REGAE

ARD Projects

ARES

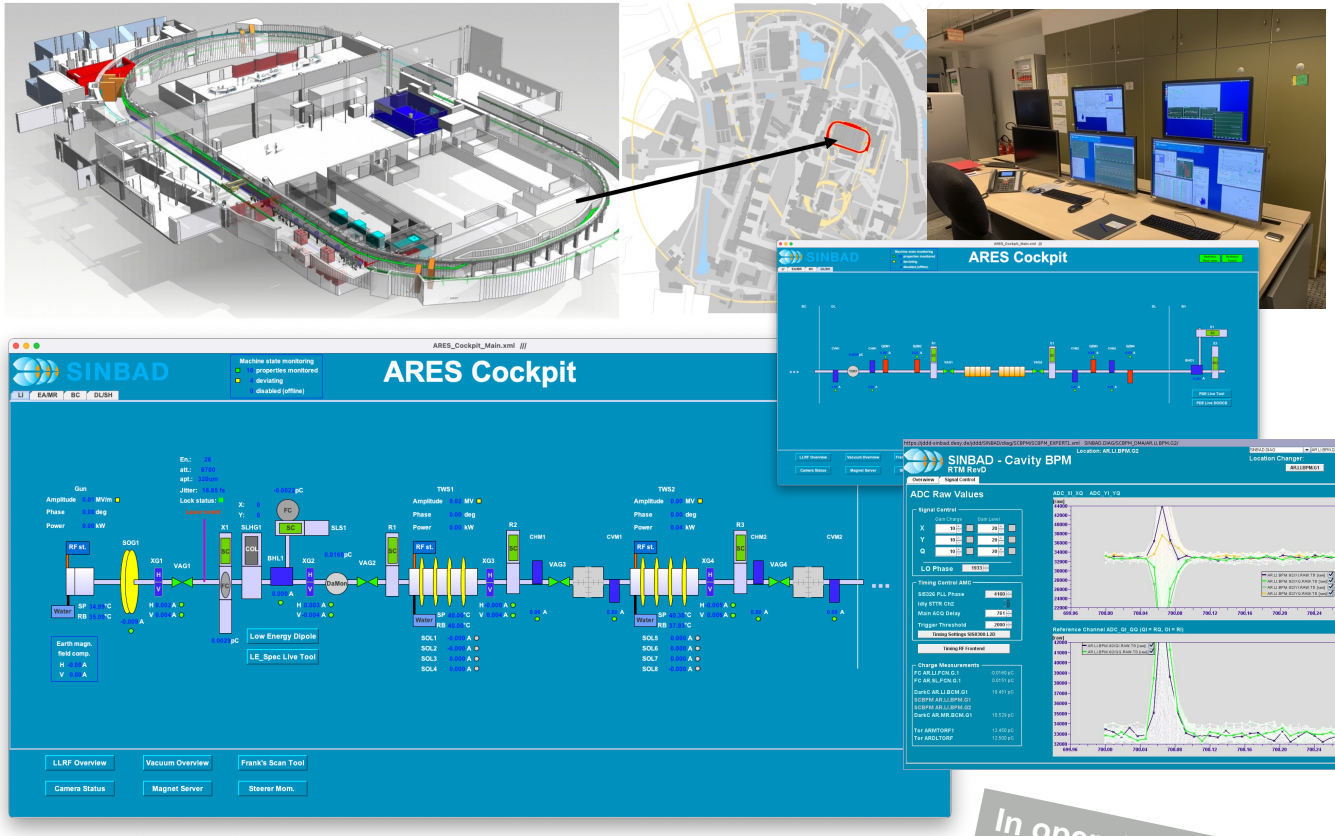
In operation since 2019

Test facility for:

- Ultra-short electron beams
- Novel diagnostics and MTCA controls (beam diag. / ML)
- High-gradient accelerating schemes
- Medical applications: VHEE and electron-based CT imaging

Photocathode Laser RF Gun w/ normal-conducting S-band electron LINAC @ 2.99 GHz for production of ultra-short bunches with two RF structures

Electrons @ 50 - 155 MeV, 0.01 - 200 pC, single pulse @ 1 - 50 Hz, 30 fs – 1 ps

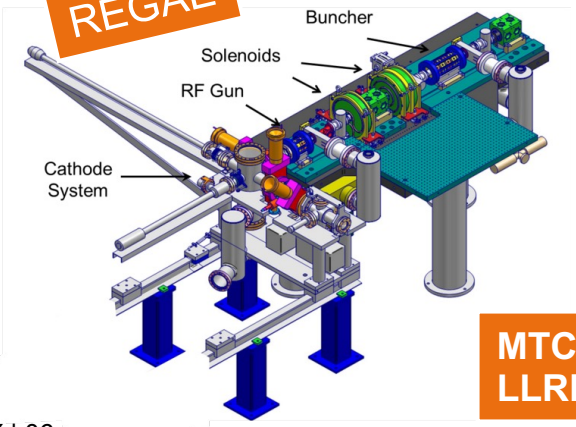


MTCA-based control system:

- Standard MTCA.4 components (Crate, MCH, CPU, Timer)
- Photocathode Laser system, experiment laser
- Synchronization & LLRF (TWS single cavity regulation)
- Beam diagnostics + New developments being tested out

10 MTCA Systems so far, more to come …

REGAE



In operation since 2011

Relativistic Electron Gun for Atomic Exploration

- Photocathode RF Gun @ 3 GHz, electrons up to 5 MeV, repetition rate 10 – 50 Hz
- Program Time–resolved Ultra-relativistic Electron Diffraction

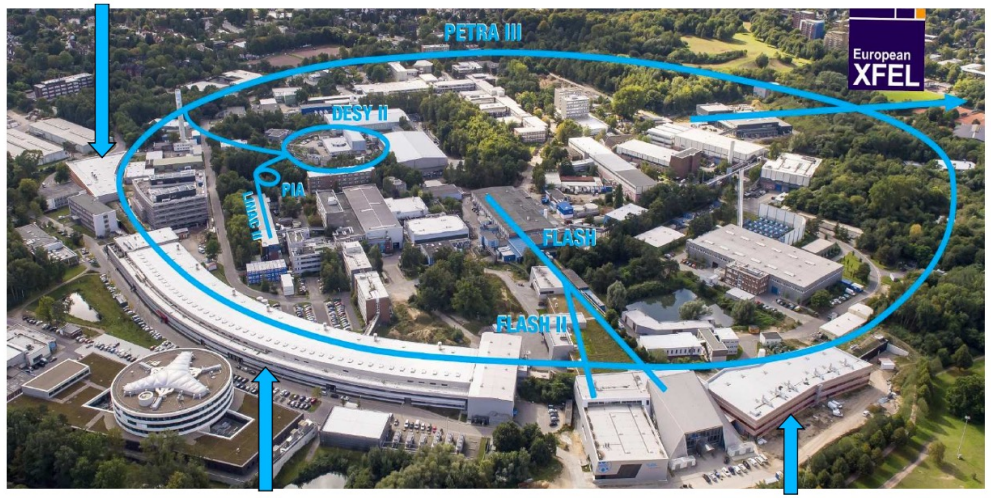
MTCA-based control system for LLRF and (Laser-Synchronization)

The PETRA IV Project

PETRA IV will be essentially a "New Machine"

PETRA IV. NEW DIMENSIONS

Ada Yonath Hall
Extension Hall East



Max von Laue Hall

Paul P. Ewald Hall
Extension Hall North

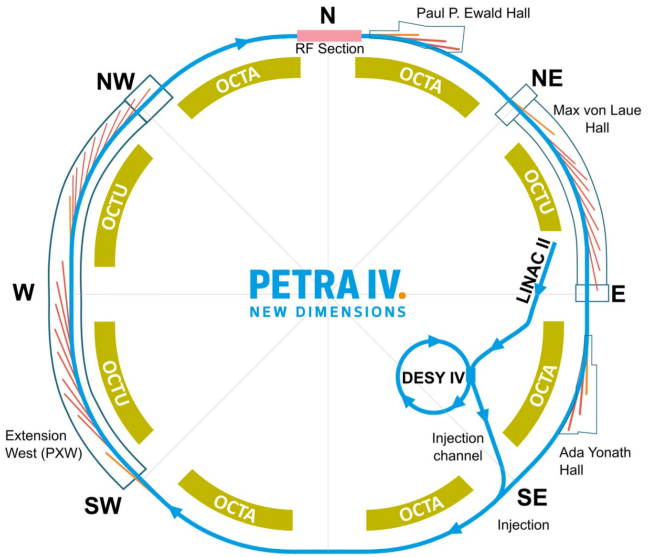
The new PETRA IV accelerator will replace PETRA III with an **ultra low emittance ring** (20 pm) adding new experimental halls in two more octants.

PETRA IV Parameters

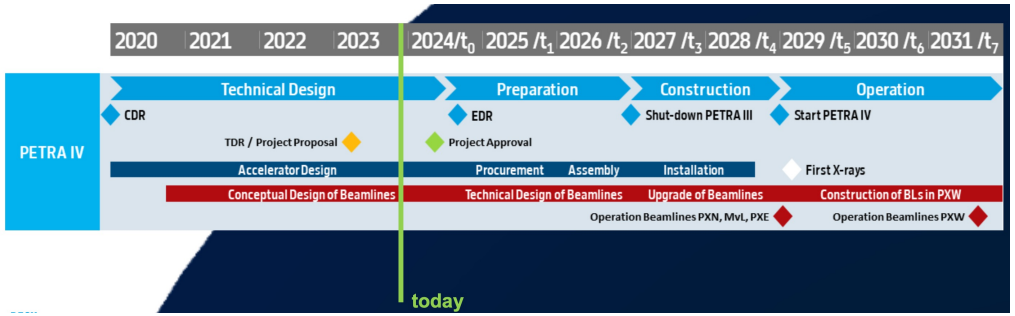
- 4th Generation light source
- 6 GeV storage ring
- Circumference 2304 m
- 500 MHz RF
- Low emittance: hor. 10 - 30 pm rad, vert. < 10 pm rad
- Timing mode + brightness mode
- Off-axis injection, top-up mode
- 30 beamlines in 4 experimental halls

PETRA IV will become a MTCA.4-based accelerator control system

- Use XFEL technology and approaches as fits – similar size as XFEL expected!
- Adapt, modify and enhance where PETRA IV requires new implementations
- New booster synchrotron DESY IV
- PETRA IV RF 500 MHz and 1.5 GHz 3rd harmonic system w/ solid state amps
- New beam diagnostics – turn-by-turn BPM data, advanced feedbacks, single bunch data capabilities - more than 4000 magnets



	H6BA
Tunes ν_x, ν_y	135.18, 86.27
Natural chrom. ξ_x, ξ_y	-233, -156
Mom. comp. α_C	$3.3\ 10^{-5}$
U_0	4.17 MeV
Standard ID section	4.7 m
Hor. Emittance w/o IDs, zero current	20 pm
Hor. Emittance with IDs, zero current	20 pm
Rel. energy spread with IDs, zero current	$0.9\ 10^{-3}$
Beta at ID	$\beta_x = 2.2\ m$ $\beta_x = 2.2\ m$
RF Voltage 1st / 3rd	8 MV, 2.4 MV



PETRA IV – Accelerator Beam Diagnostics

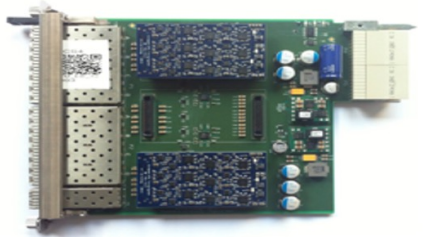
Projects for the TDR stage (MDI/MSK/MCS)

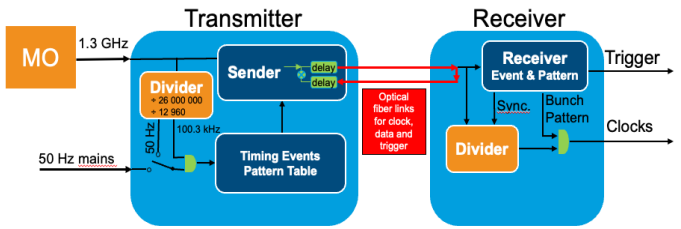
DESY MDI

- **PETRA IV BPM system**
  - DAMC-FMC2ZUP + RTM
  - In collaboration with I-Tech and DESY MTCA Techlab
- **Pre-Accelerator BPM**
  - SIS8300L2D/KU with inhouse RTM
- **HF Momo** (Movement Monitor)
  - SIS8172 with new RTM
  - Upgrade of SEDAC based system installed at PETRA III
- **Beam Loss Monitor System**
  - SIS8172 with RTM
  - Redesign of EuXFEL system
- **Bunch Current Measurement**
  - Teledyne SP Devices ADQ7 with custom made FW blocks
- **Machine Protection System**
  - SIS8172 with new RTM
  - Adaptable for EuXFEL
  - Conceptionally based on PETRA III MPS

Wednesday

The DAMC-UNIZUP processing board for the new MTCA.4 BPM system for PETRA IV– A. Bardorfer (I-Tech)





New MTCA Timing System for PETRA IV (DESY MCS/MSK)

- Based on timing system for EuXFEL - enhanced for synchrotrons
- Enhanced timing information and signal distribution compared to 3rd generation light source PETRA III
  - Event-trigger-based system, timestamp / revolution counter distribution
  - Beam-synchronous information distribution, beam modes, …
- Same timing system h/w for all four instances: accelerator, pre-accelerator, plasma injector and experiments
- Advanced hardware design based on x2timer / NAMC-psTimer: DAMC-X3TIMER
  - Xilinx ZYNQ SoC – Test currently done w/ **DAMC-FMC1Z7IO**

Thursday

Update on the DAMC-X3TIMER Development for PETRA IV - Hendrik Lippek (DESY)

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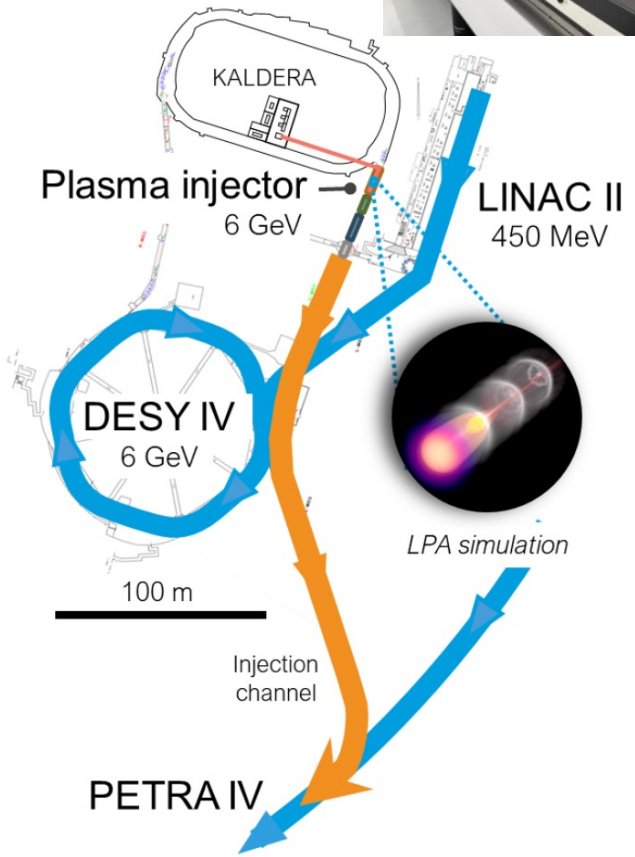
KALDERA

Plasma-Wakefield Acceleration Projects – LUX, KALDERA and PETRA IV Plasma Injector

KALDERA - KilowAtt Laser at DEsy for Revolutionary Accelerators

- ARD Project on Laser-based Plasma-Wakefield Acceleration Technologies
- Development of a laser system delivering ultra-fast laser of up to 100 TW peak power and 100 Hz up to 1 kHz repetition rate
- Produce highly stable electron beams using those laser pulses and the plasma-wakefield acceleration techniques.
- Goal: Use this plasma injector to feed the new PETRA IV storage ring.

→ KALDERA and the future plasma injector will serve the PETRA IV project.

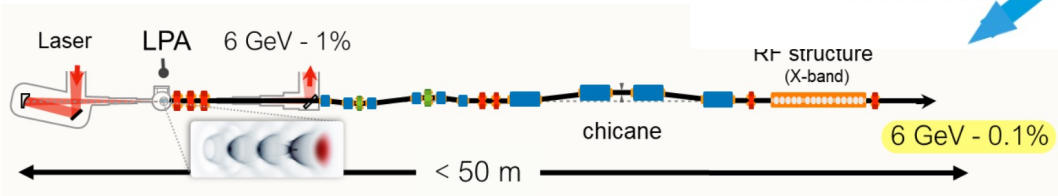


- MTCA-based controls for laser systems and injector (timing, synchronization, ...)
- Currently being build-up for the KALDERA part
- CW-System with data rates at currently 100 Hz, later 1 kHz

Thursday

CW Control System for the KALDERA Laser Plasma Accelerator at DESY–
Tomasz Jezynski (DESY)

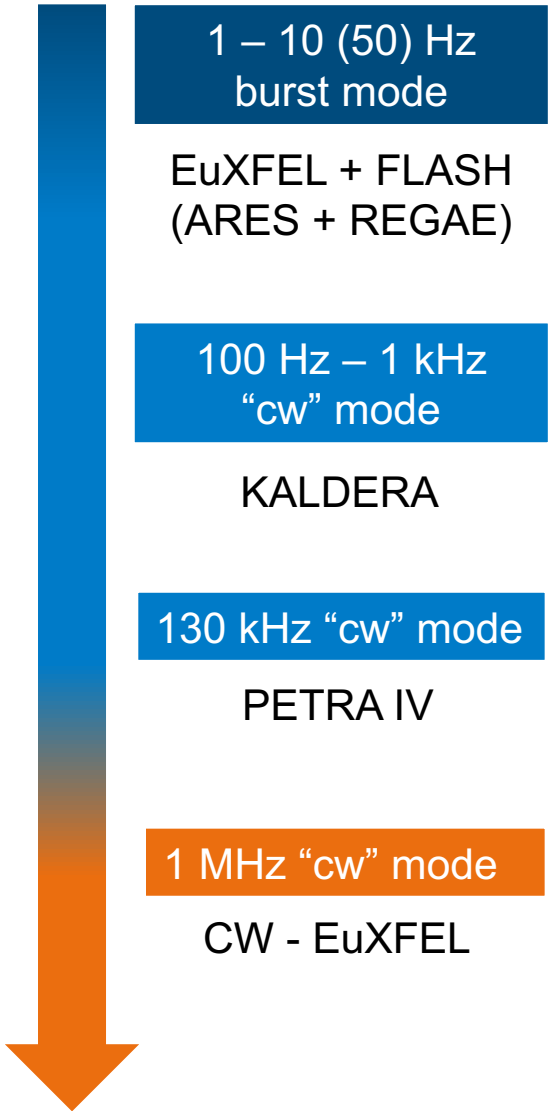
Plasma injector schematic



Summary

- Successful operation of MTCA-based controls at EuXFEL since 2017
- FLASH facility migrates entirely to MTCA with the upgrade in 2024/25
- MTCA has arrived at DESY and not just at the accelerator facilities – lots of MTCA in projects, labs, standalone systems, laser controls, …
- Standard – almost COTS-like – solutions are available and can be readily deployed for projects
- ARD projects and future facility upgrades will become challenging with respect to its complexity and demands
  - Increasing data taking rates kHz up to MHz rep rates, higher data volume

Needs continuous evolution and advancement of MTCA solutions of hardware, firmware and software!



Thank you