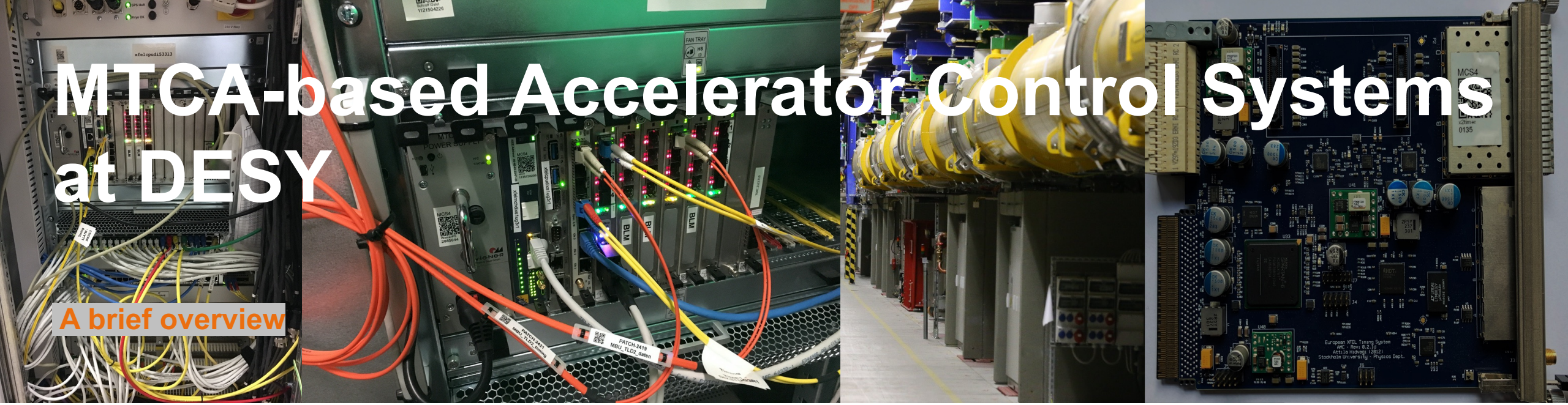


MTCA-based Accelerator Control Systems at DESY

A brief overview

Tim Wilksen

13th MTCA Workshop

Hamburg, 10.12.2024

HELMHOLTZ

DESY.

Outline

MTCA-based Accelerator Control Systems at DESY

1 Baseline

- The MTCA.4 Platform

2 Accelerator User Facilities @ DESY

- XFEL Accelerator
- FLASH
- PETRA III

3 Projects

- SINBAD-ARES and REGAE
- Test Facilities: PITZ, CMTB, AMTF, FALCO and TS4I
- Projects: PETRA IV and KALDERA

4 Summary

Baseline

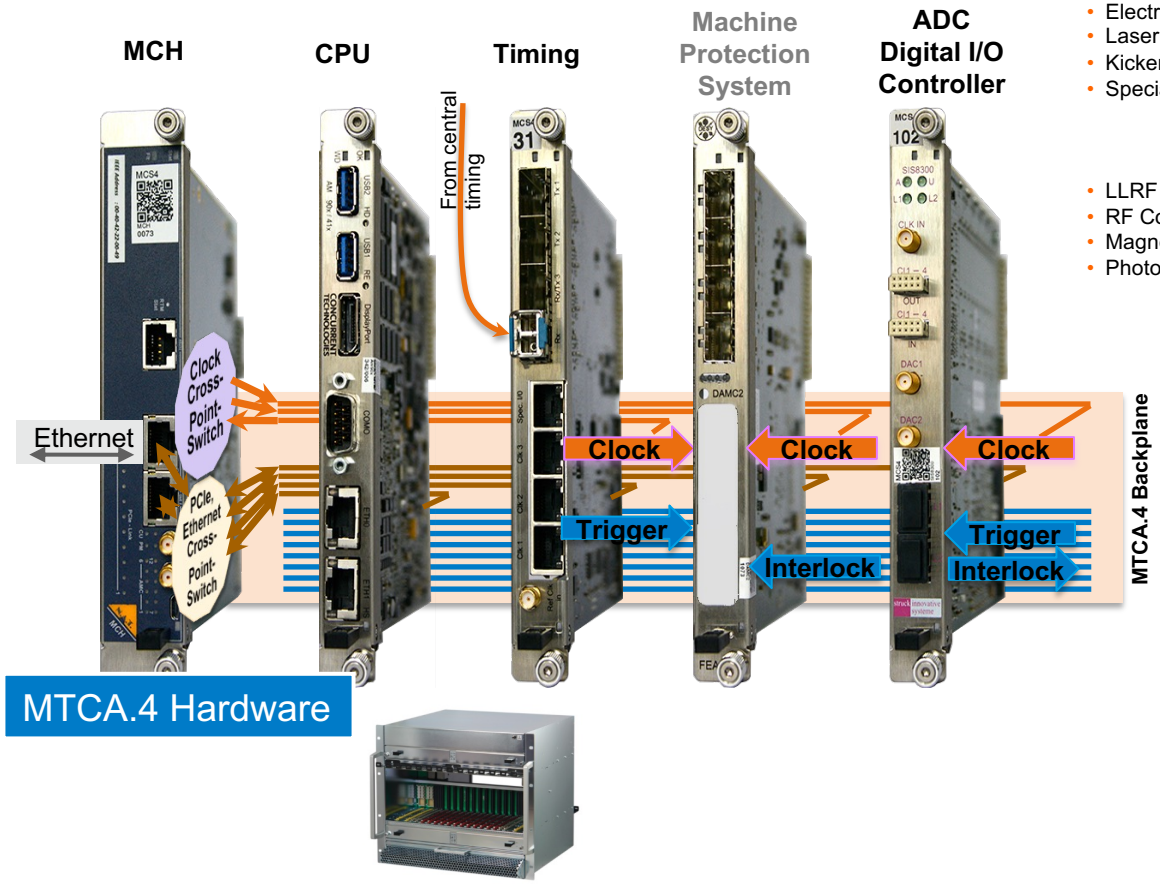
Baseline

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

Common Hardware Platform	**MTCA.4** Platform (PICMG Standard)
	Industry Standards (PLC/OPC-UA)
	Computer center grade server nodes
Common Software Framework	**Linux** as operating system
	Open Source solutions
	DOOCS as base control system software framework
	Interfaces TINE, Karabo, EPICS v3 + v7, (Tango)

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

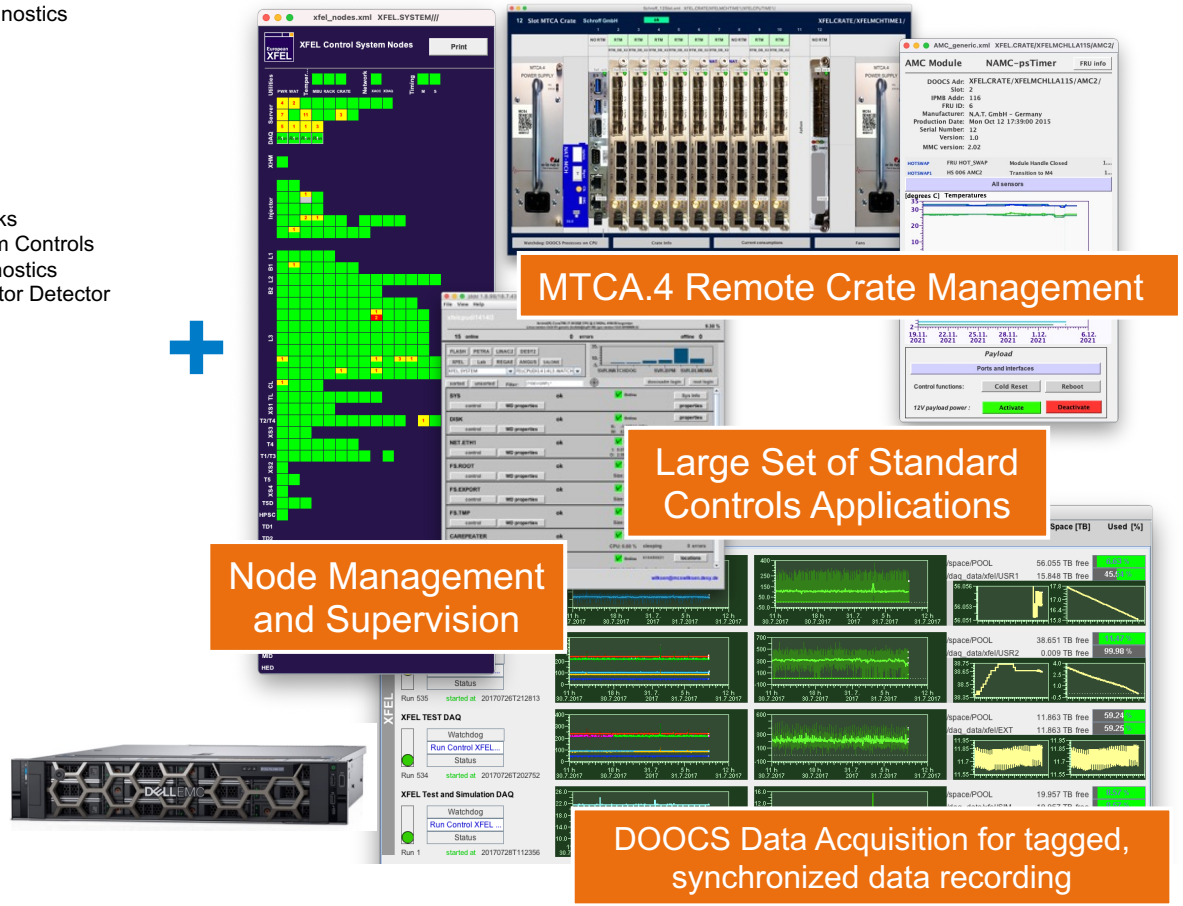
MTCA Common Modules



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

Accelerators and Projects at DESY

User Facilities FELs and Synchrotron + Test Facilities and ARD Projects

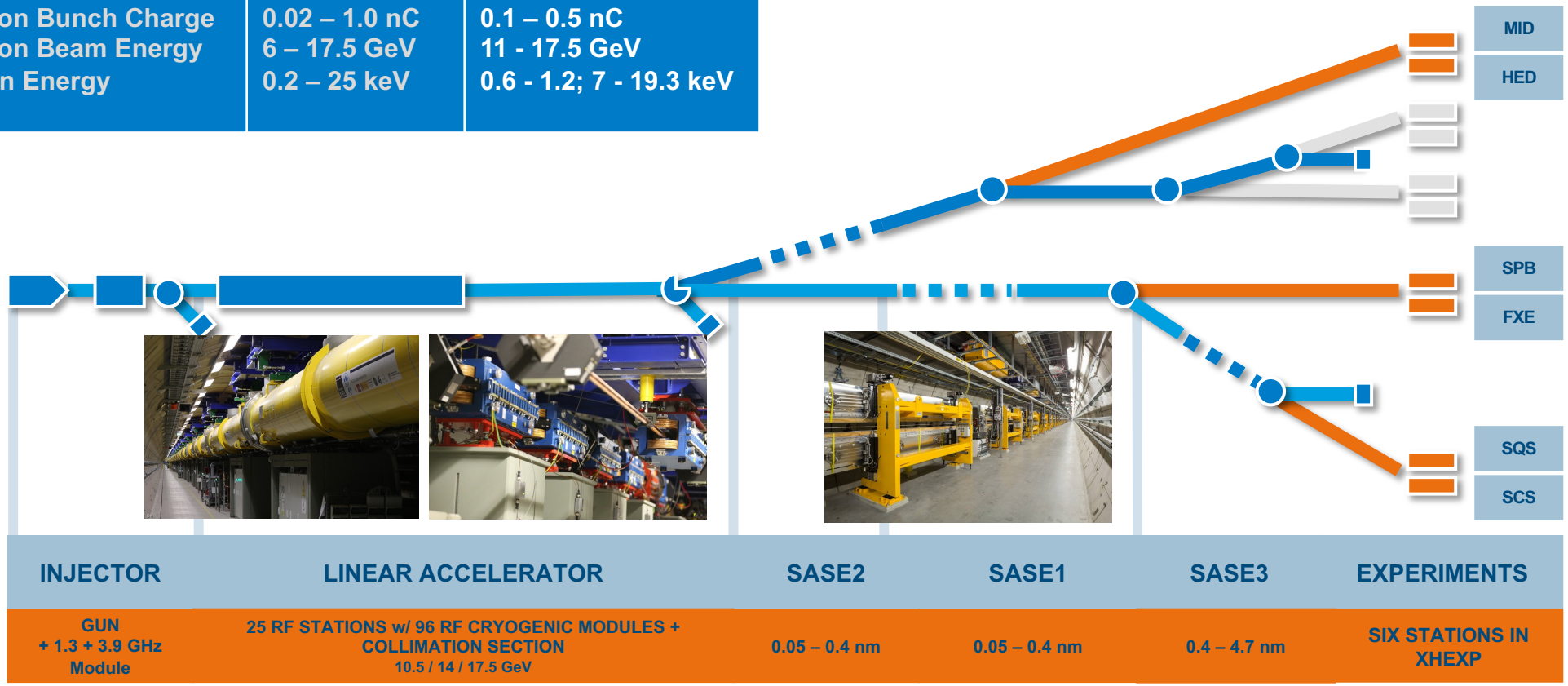
The European XFEL

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



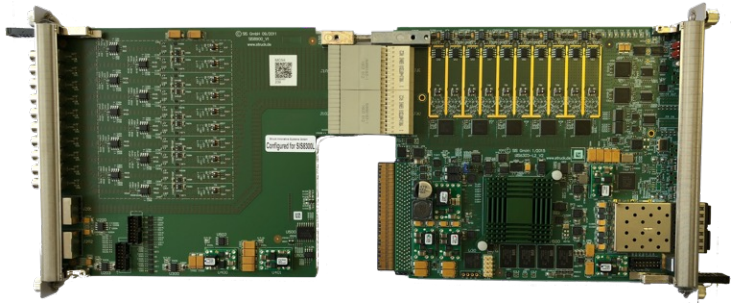
EuXFEL Status 2024

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 modular and efficient system integration!

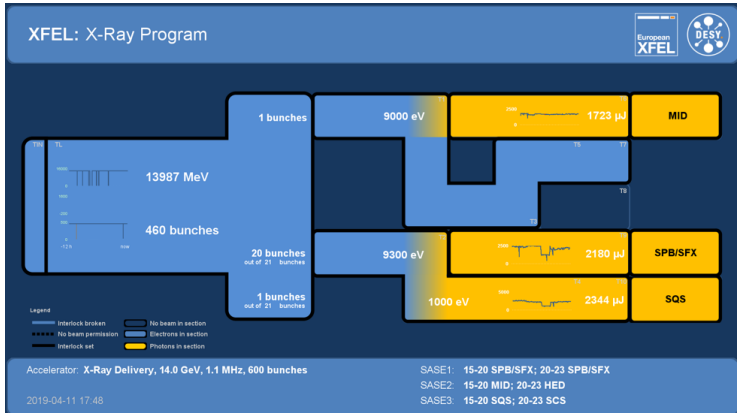
- About **300 MTCA systems** @ EuXFEL as of 2024:
  - About **4800 MTCA modules** (AMC, RTM, P/S, MCH,…) installed e.g.
    - Timing System: 328 modules
    - DAMC2 AMC: 577 modules
    - DAMC-TCK + DAMC-FMC: 51 + 57 modules
    - SIS ADC AMC and RTM: 558 modules
    - Teledyne ADQ AMC / TEWS: 48 / 20 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.

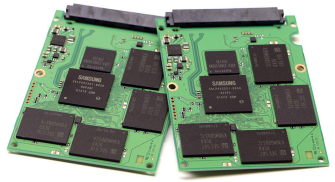
- **Successful machine operations in production mode since 2017.**



EuXFEL Status 2024 cont'd

Some experiences and news on MTCA components w/ accelerator control system

- MTCA hardware is very reliable. Core components more than 11 years in operation.
- Issues likely related to beam operations are the prominent ones (SSD, FPGA w/ SEU)
  - E.g. XFEL master timing system: 1 failure in 11 years of 24/7/365 operation (x2timer AMC, first production round)



Extensibility

Future 2025+

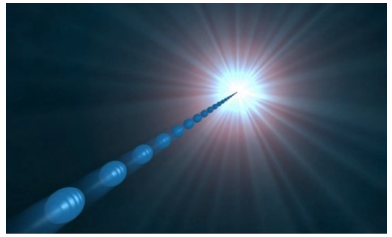
- XFEL number of MTCA components continue to grow due to many (smaller) modifications of the machine
- Some components are becoming EOL
  - First CPU generation at installation time is already EOL, still in use though, replacement available but …
    - … need future option(s)!
  - Replace TCK7 with DAMC-FMC2ZUP / FMC25 with DAMC-Z7IO (LLRF, SDIAG, …)

Shutdown July – December 2025 for 1/2 year

- New RF gun and longer RF pulse
- XFELO (Laser Oscillator Experiment)
- ASPECT – Atto Second Pulses with eSASE and Chirp/Taper,
- STERN – THz source
- SCU - superconducting undulator – XFEL GmbH
- Extension of beam diagnostics (e.g. BPM) and special diagnostics (BAM, …)
- Refurbishments MTCA components

FLASH 2020+

Upgrade of FLASH 2024/2025

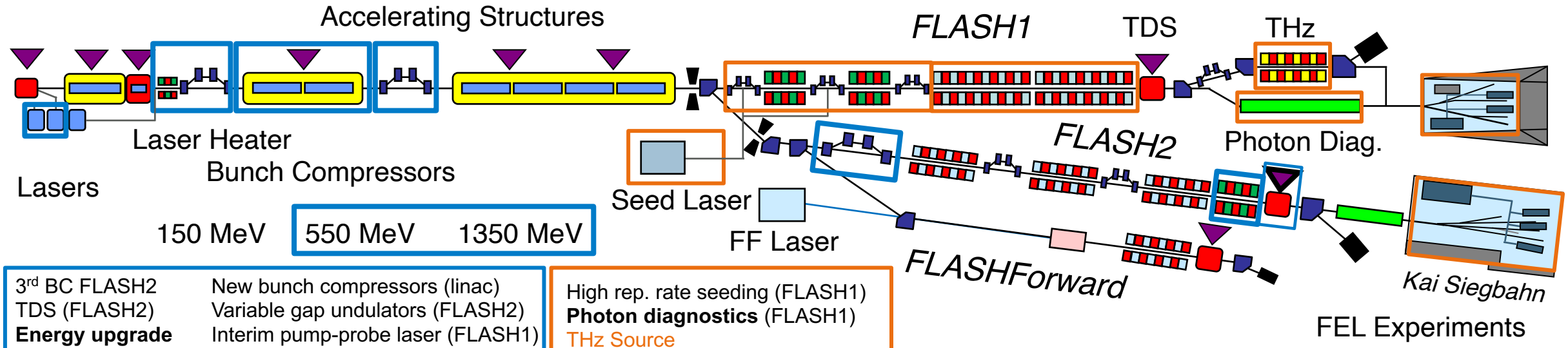


MTCA in use since 2013!

FLASH 2020+ Project – 2 Shutdowns 2021/22 + 2024/25
- New seeded Free-Electron Laser beamline FLASH1
- Move entirely to MTCA platform and replace VME
- **MTCA baseline for accelerator and beamline experiments**

Ongoing migrations from VME to MTCA (2024/2025):
- NEPAL-F photocathode laser systems w/ MTCA
- FLASH experiment beamline support systems
- Vacuum controls and monitoring w/ MTCA
- Transverse deflecting cavity (LOLA) w/ MTCA

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

- About **65** MTCA systems online with **1000** MTCA modules
- About **30** different kinds of MTCA-based software applications
- FLASHForward uses specialized applications based on MTCA tailored to the the LPWA experiment needs

MTCA magnet P/S controls:
SEDAC replaced 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.

SINBAD-ARES and REGAE

ARD Projects

ARES

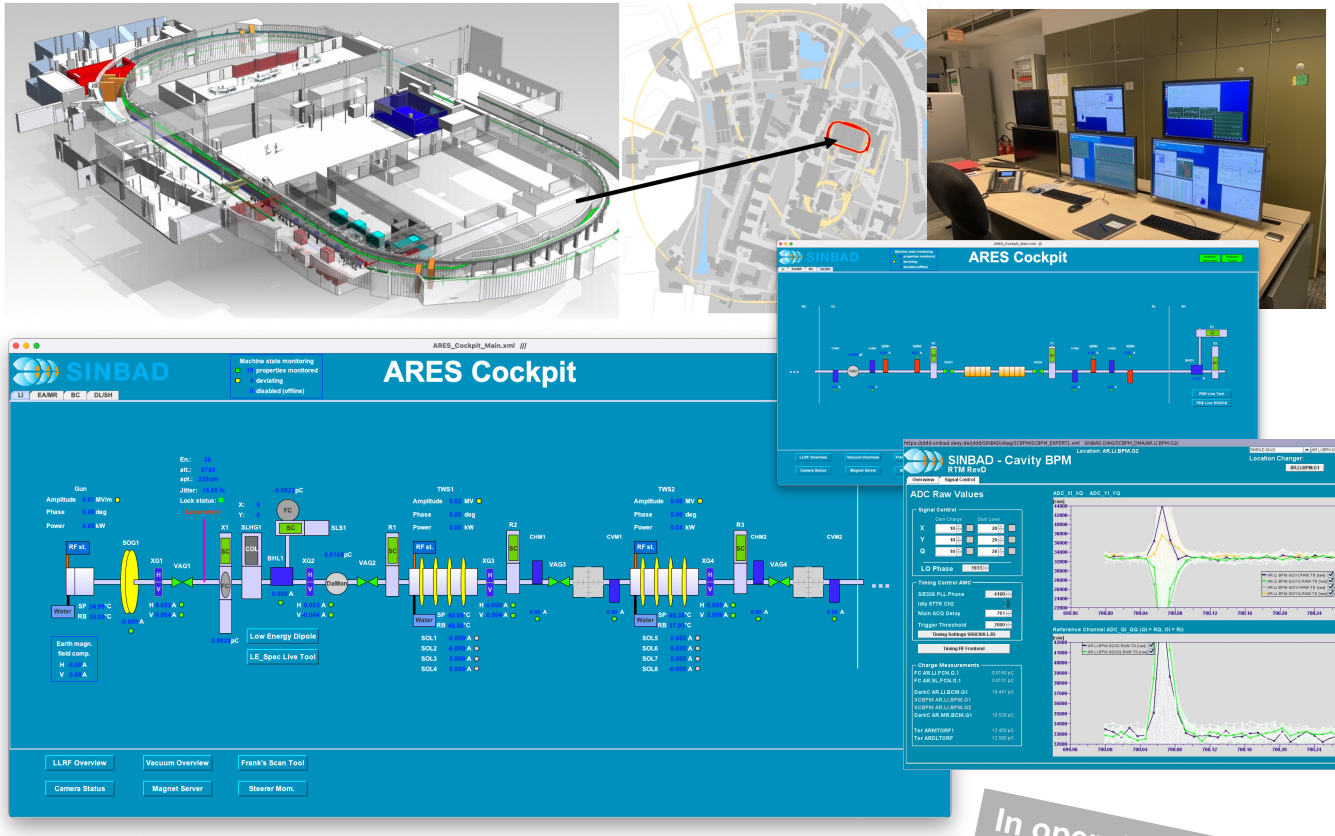
In operation since 2019

Test facility for:

- Ultra-short electron beams
- Novel diagnostics and MTCA controls (beam diagnostics and machine learning)
- 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



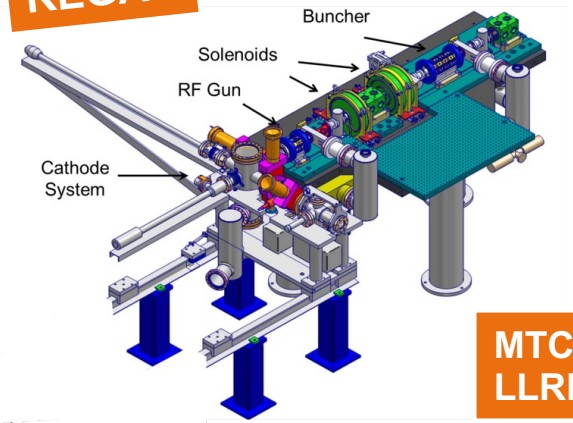
MTCA-based control system:

- 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



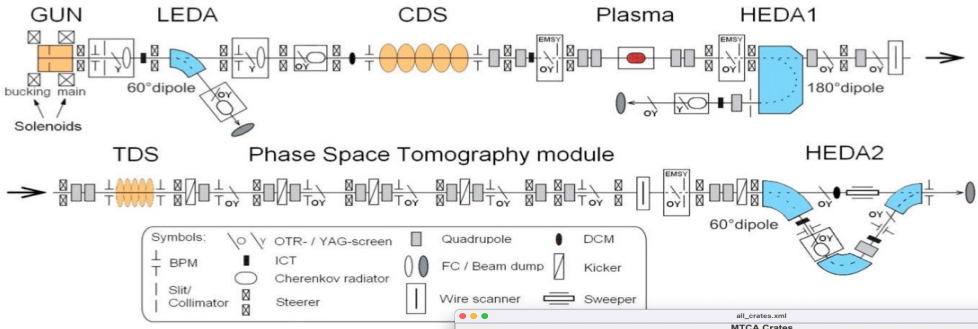
Relativistic **E**lectron **G**un for **A**tomic **E**xploration

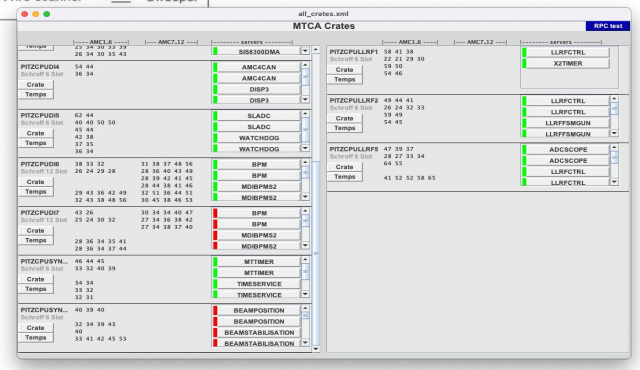
- Photocathode RF Gun @ 3 GHz, electrons up to 5 MeV, repetition rate 10 – 50 Hz
- Program Time–resolved Ultra-relativistic Electron Diffraction

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

DESY Test Facilities

PITZ, SRF Facilities AMTF, CMTB





PITZ (Photo-Injector Teststand in Zeuthen)

- 1.3 GHz RF photoinjector accelerator at 25 MeV/c, 10 Hz repetition rate
- Formerly VME-based, now MTCA.4 using existing solutions (LLRF, synchronization, electron beam diagnostics, etc. MSK + MDI) – **13 systems** (3 LLRF / 7 + 1 diag / 2 sync)
- NEPAL-P photocathode laser system deployed by FS-LA with MTCA.4 controls

AMTF (Accelerator Module Test Facility) and **CMTB** (Cryogenic Module Test Bench)

New Developments by MSK

- **MTCA system to perform cavity vertical tests** (until now only horizontal)
  HW ready, first version of FW and DOOCS server ready to be tested.
  Single cavity regulation scheme with a SIS8300-KU and a DWC8VM1.
  New implementation of a self-exciting loop (SEL) algorithm for critically coupled cavities.
- **MTCA system to perform long pulse and CW tests with an SSA**
  SSA is installed, TUEV approved - First test w/ cold cavity in CW performed last week
  SIS8300-KU with DWC8VM1 (only SW and FW are different from vertical tests).
  This R&D is motivated + supported by the High Duty Cycle program (XFEL upgrade)
- **Preparation work to replace FMC25 with Z7IO**
  Resonance control for single cavity regulation done with FMC25 + PZT4 but FMC25 is EOL Working on Z7IO (DAMC-FMC1Z7IO) as successor.

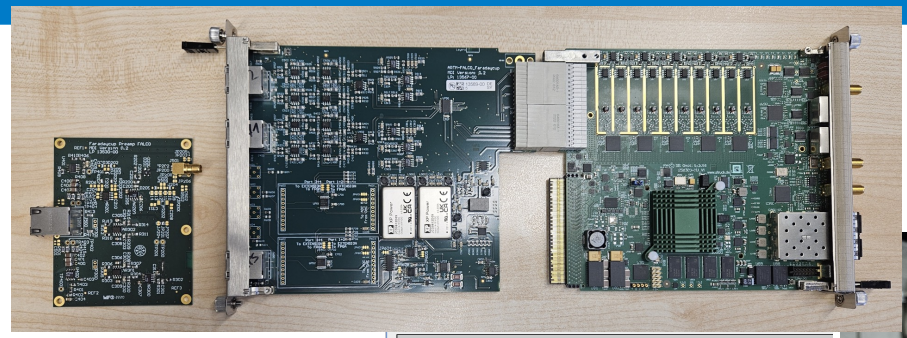
DESY Test Facilities

FALCO and TS4I

FALCO

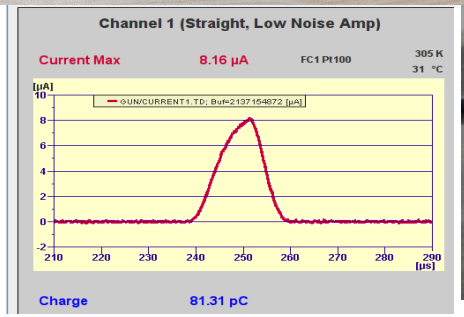
New test facility w/ MTCA-based controls since 2024:

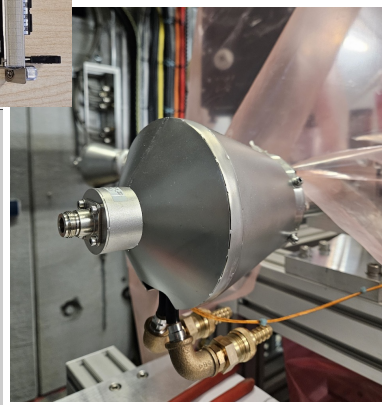
- **FALCO** – RF Gun Conditioning Test Stand (Hall III / FLASH) – In operation now!
- LLRF, RF Interlocks, Diagnostics



Example: Faraday Cup Read-out for FALCO (DESY MDI)

- Faraday Cup and „dump“ in one physical device
- Based on Struck SIS8300-KU board with MSK FWK based firmware
- In-house RTM with 2 x 2 channel (high/low gain for 2 Faraday Cups)
- Measures dark current from 100 nA – 10 mA with a max. RF length of 1 ms
- Interlock to secure the dump - based on charge (limit 1µC)





TS4I

Upcoming test facility w/ MTCA-based controls (2025/26):

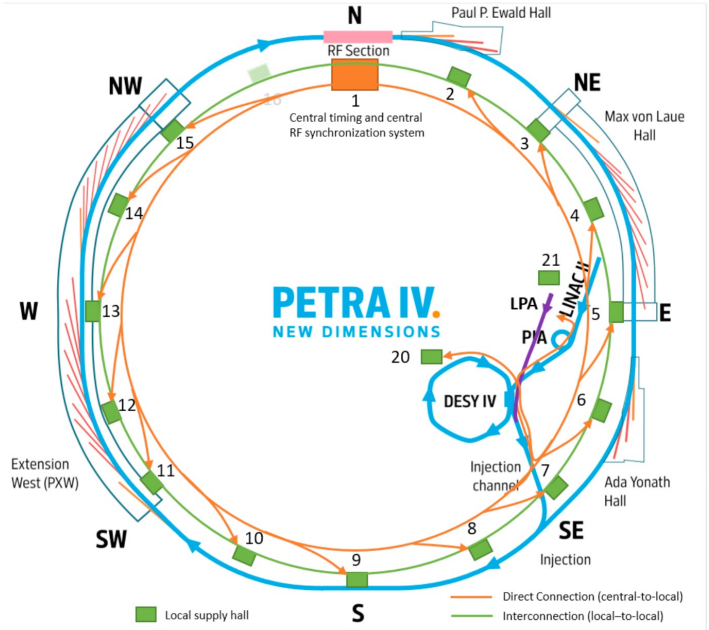
Teststand for injectors (@AMTF) exploring superconducting RF gun concepts and high-duty cycle operation modes (burst, long pulse + CW mode) for XFEL CW 2030+

- 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!)**

The PETRA IV Project

PETRA IV will be essentially a "New Machine"



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 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

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 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**

PETRA IV BPM system

- DAMC-FMC2ZUP + RTM
- Collaboration I-Tech and DESY MSK

Electron Beam Diagnostics + MPS

- SIS8172 + DESY RTM

Fast-Orbit Feedback

- DAMC-DS5014DR

The use of DAMC-UNIZUP board for the MTCA.4 BPM system for PETRA IV – Ales Bardorfer (I-Tech)

Wednesday

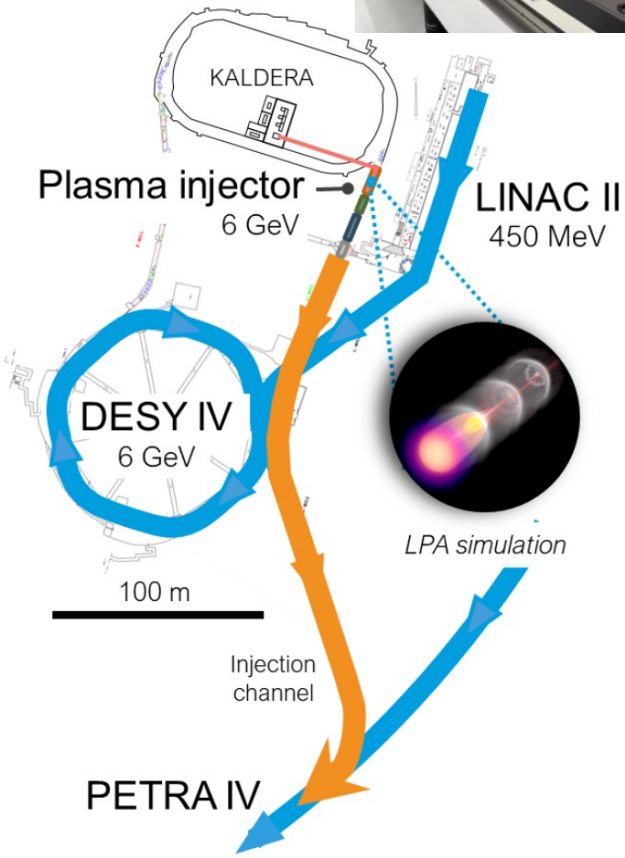
Status Update on MicroTCA based Fast Orbit Feedback System for PETRA IV – Sajid Mirza (DESY MSK)

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 plasma-wakefield acceleration techniques and feed this into the new PETRA IV storage ring!



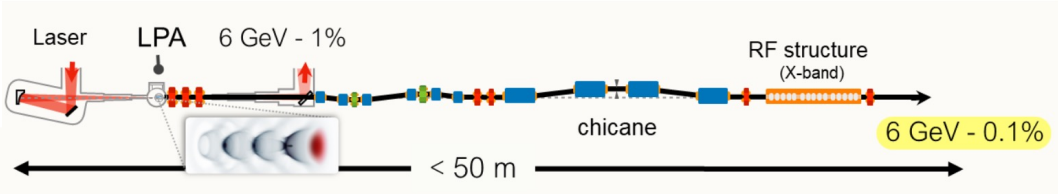
- MTCA-based controls for laser systems and injector (timing, synchronization, beam diagnostics, LLRF control ...)
- CW-System with data rates at initially 100 Hz, then 1 kHz
- Test facility w/ MTCA is operating at 100 Hz (controls) + 1 KHz with accelerator DAQ system
- First tests w/ 1kHz for Farady Cup done based on SIS8300-KU (MSK FWK) by MDI and MCS
- More diagnostics to come w/ MTCA

Wednesday

µTCA based 1kHz camera readout for KALDERA at DESY – Carsten Dülsen (DESY)

- Next Goal: Inject electrons from KALDERA beamline into DESY II at 450 MeV (until 2026)

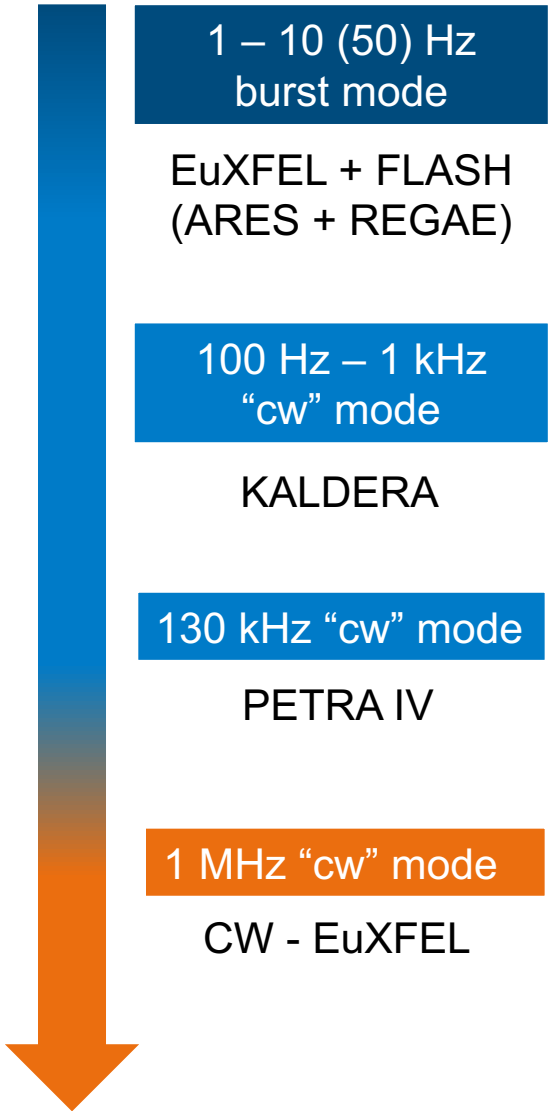
Plasma injector schematic



Summary

- Successful operation of MTCA-based controls at EuXFEL since 2017
- FLASH facility is migrating entirely to MTCA with the upgrade in 2025
- MTCA has arrived at DESY and not just at the accelerator facilities – lots of MTCA in projects, labs, standalone systems, laser controls, …
- Further standardization of applications using MSK FWK firmware, ChimeraTK hardware access layer
- ARD projects and future facility upgrades will become challenging with respect to its complexity and demands – New developments …
  - 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