MicroTCA developments and history at DESY

2025 MicroTCA/ATCA International Workshop for Large Scientific Facility Control

Chongqing University 15-17.09.2025

(recycled from last 2025 SHINE Forum)

Holger Schlarb, MSK/DESY
DESY, 17.09.2025

HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

SLAC & DESY Reliability Workshop 2005

Challenges to operate huge facilities (e.g. ILC or Eu-XFEL) with thousands of devices

Example:

- Server PC has an MTBF ~50,000 h (~99.99%)
  —> downtime per year: **53 minutes**
- With 1000 systems required to run it, it drops to 90%
  —> downtime per year: **37 days**

Courtesy: Kay Rehlich

Mean Time Between Failures

MTBF Estimates for R1304RPMSHOR

Subassembly (Server in 40C ambient air)	Server Model R1304RPMSHOR	
	MTBF (hours)	FIT (flrs/10^9 hrs)
S1200V3RPM board	371,523	2,692
Power Supply - 450W MiniERPS	967,300	1,034
Cooling Fan (1-fixed fans)	490,000	2,041
Cooling Fan (2-fixed fans)	77,680	12,873
Front Panel board	8,272,282	121
HS Backplane(4x3.5")	935,180	1,069
Totals without motherboard =	**58,300**	**17,138**
Totals with motherboard =	**50,400**	**19,830**

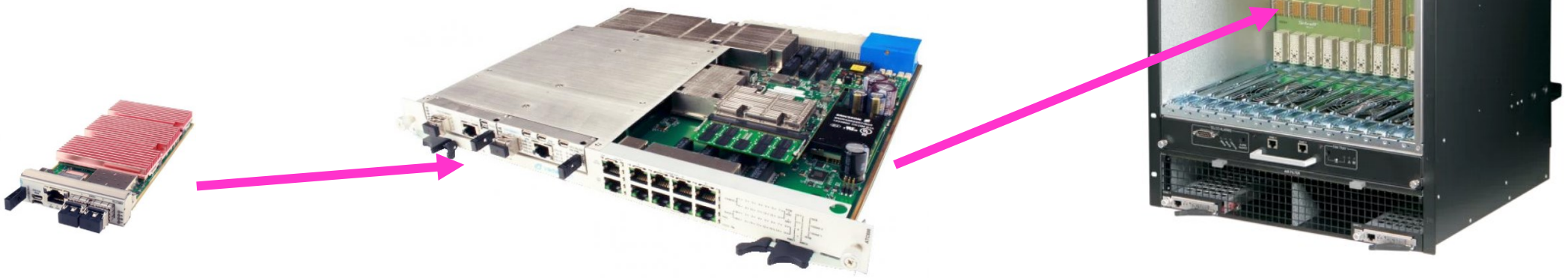
MTBF is limited by the fans

Courtesy: Kay Rehlich

ATCA: a Standard developed by the Telecom Industry

ATCA = Advanced Telecom Computing Architecture

- **Introduced in 2003**
- **Requirements**
  - **99.999% reliability → downtime per year = 5.3 minutes**
  - **Very high system throughput (full mesh architecture)**
  - **Remote management (monitoring and control)**



Courtesy: Kay Rehlich

MicroTCA: a Standard Developed by Telecom Industry

MicroTCA: 2006

A scalable family
with the same
system architecture

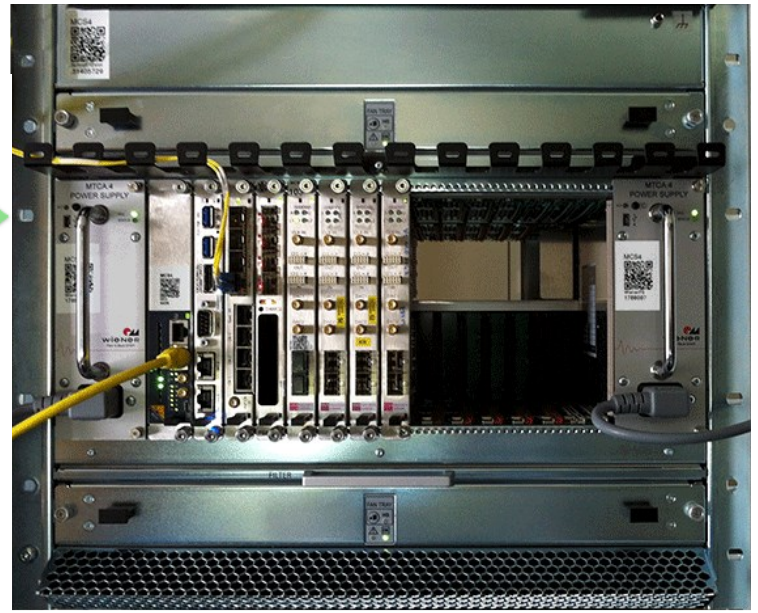
ATCA: 2003

Courtesy: Kay Rehlich

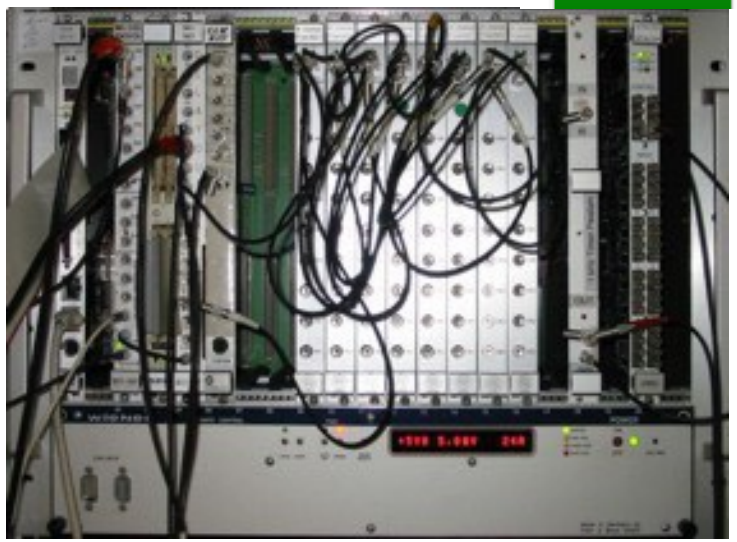
MicroTCA: a Standard Developed by Telecom Industry

- **2007 decision to use xTCA for EuXFEL**

µTCA®



- Since 1993 VMEbus
… at FLASH
- > 40 years old



- Redundancy of fans
- Redundancy of power supplies is possible
- Modern, high-speed Data transfer
- Excellent signal quality for analogue IO
- Remote management
- *Cables from the rear*
- *Internal Clock & Trigger distribution*

Performance + Functions + Availability

Courtesy: Kay Rehlich

MicroTCA: a Standard Developed by Telecom Industry

- **2007 decision to use xTCA for EuXFEL**

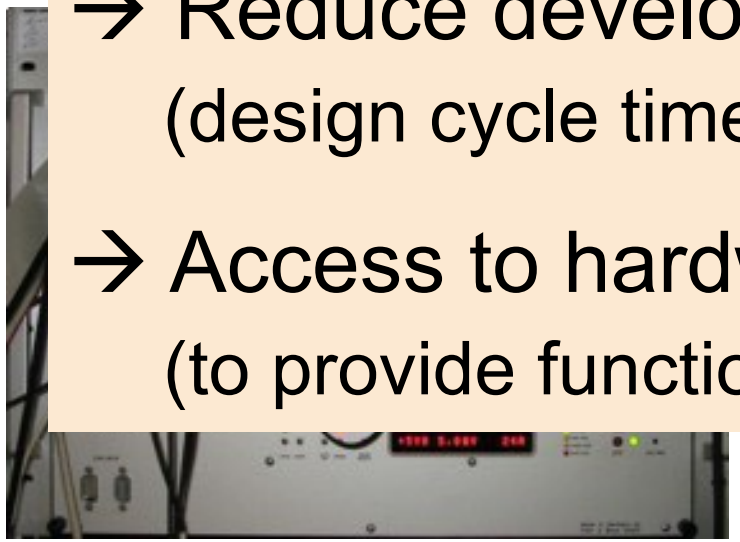
& MOSA = Modular Open System Approach

→ No vendor lock-in!
(Any company can step in)

→ Reduce development expense
(design cycle time, and manufacturing costs)

→ Access to hardware/firmware/software
(to provide functionalities we need)

- Since
... at FL
- > 40



- *Cables from the rear*
- *Internal Clock & Trigger distribution*

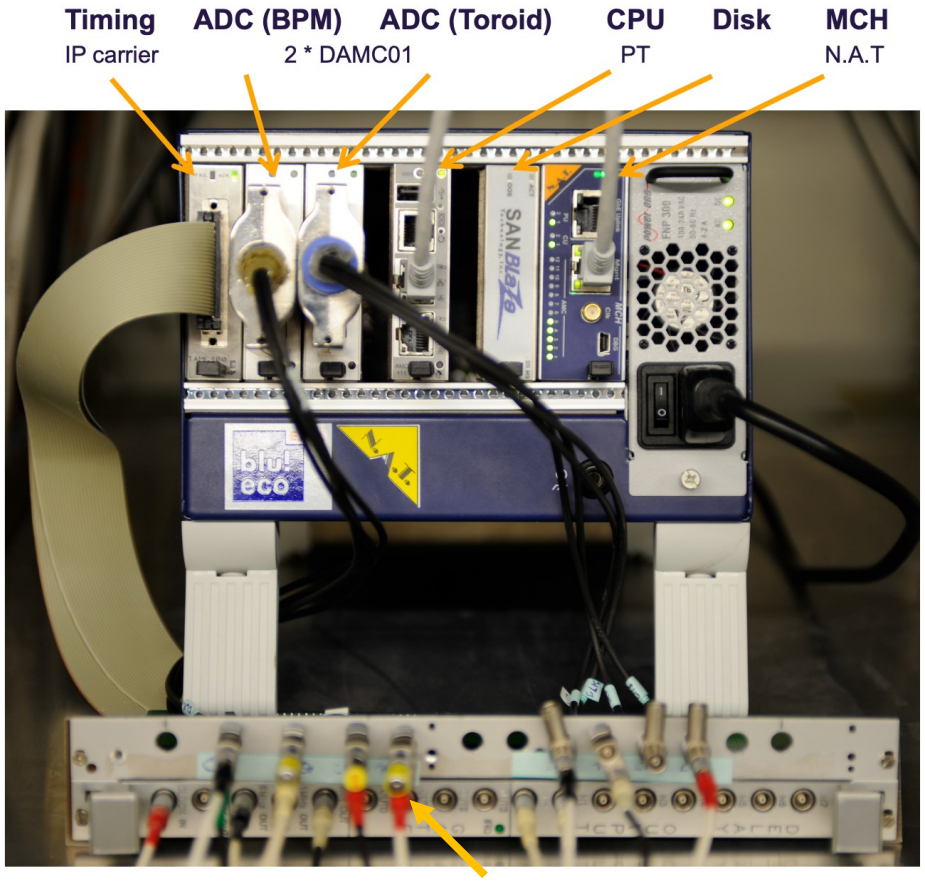
Performance
+
Functions
+
Availability

Courtesy: Kay Rehlich

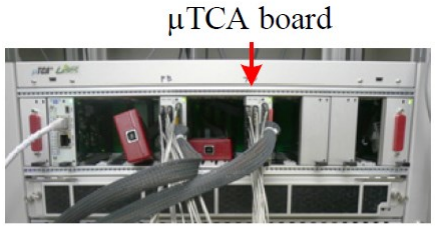
First Test System Running @ DESY 2009

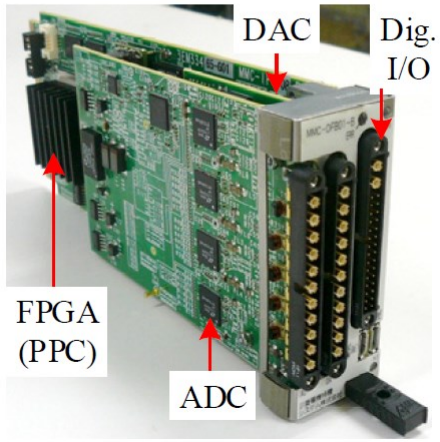
Used I/O modules:

- IP carrier to adapt the FLASH timing system
- Two channel ADC to read a Beam Position Monitor
- Two channel ADC to read the beam current



In parallel at KEK: LLRF/BPM (2010)





@Shin Michizono

First one applying MicroTCA to an accelerator

Courtesy: Kay Rehlich

Lessons Learned

- It all worked well

But:

- Not enough space on panels for cables
- Not enough space for analogue signal conditioning
- Single-size AMC is too small
- Clock and trigger distribution should be inside the crate
- …

- Conclusion: Start of MicroTCA.4 specification development **2009**

Specification of „xTCA family“

PICMG = PCI Industrial Computer Manufacturers Group

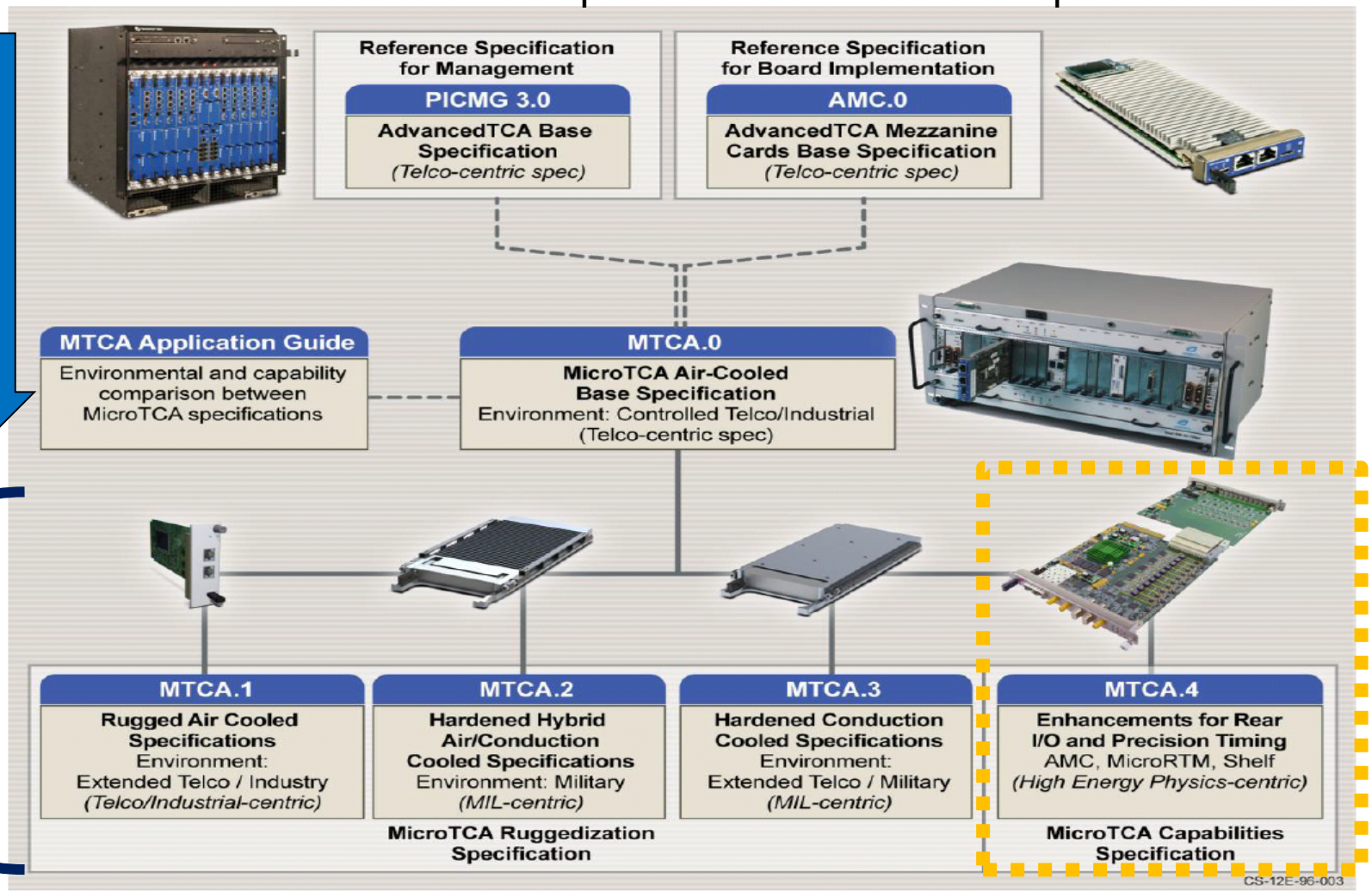


Figure 1. *The MicroTCA family of specifications maximizes reuse from its ATCA and AMC parent specifications.*

https://www.picmg.org/

- Non-profit organisation for standardization

MTCA.4 =

Micro
Telecommunications
Computing
Architecture
.4

Adopting Telcom standard to Research Needs

Ref:
MicroTCA App. Guide

MicroTCA Specifications

xTCA for Physics“ interest group (38 partners): 03/2009
- **Research institutions:** SLAC, FNAL, IHEP, IPFN, ITER, DESY
- **Industry:** Connector-, Board-, Crate-, System vendors


MicroTCA™

PICMG® Specification MTCA.0 R1.0

Micro Telecommunications
Computing Architecture
Base Specification

July 6, 2006

µTCA™

MicroTCA.0
2006


MicroTCA®

PICMG® Specification MTCA.4
Revision 1.0

MicroTCA Enhancements for Rear I/O
and
Precision Timing

August 22, 2011

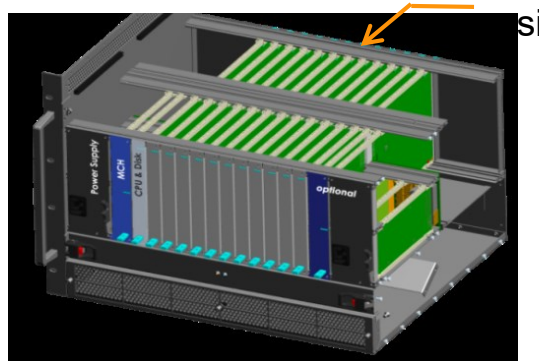
µTCA®

MicroTCA.4
2011

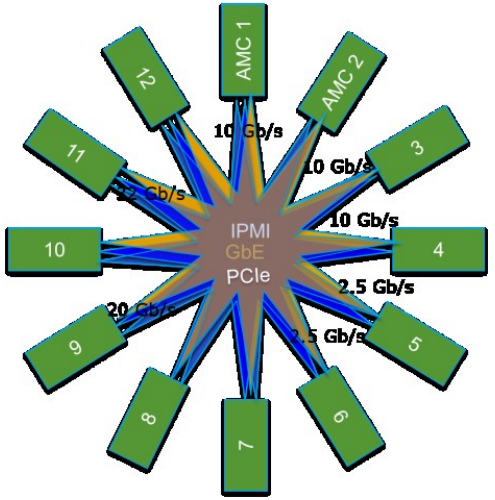
Within 2 years!!!

MTCA.4 hardware platform : Crates

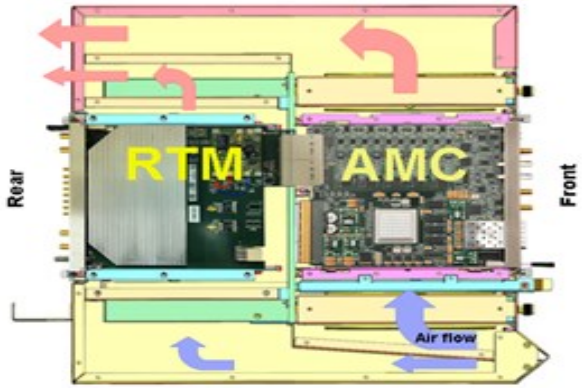
- „xTCA for Physics“ interest group (38 partners): 03/2009
  - **Research institutions:** SLAC, FNAL, IHEP, IPFN, ITER, DESY
  - **Industry:** Connector-, Board-, Crate-, System vendors
- Modular & Modern architecture
  - Reusability + PCIe + Ethernet
- High reliability
  - Redundant Power Supply / Fans
  - Remote Maintenance through management
- High Performance
  - 4x PCIe gen3 lane, 10GbE… 40 GBit/s
  - Low analog noise …
- Highly configurable / scalable
  - Small to large system
  - Different communication protocols / speed



$$V = \frac{E[Uptime]}{E[Uptime] + E[Downtime]}$$

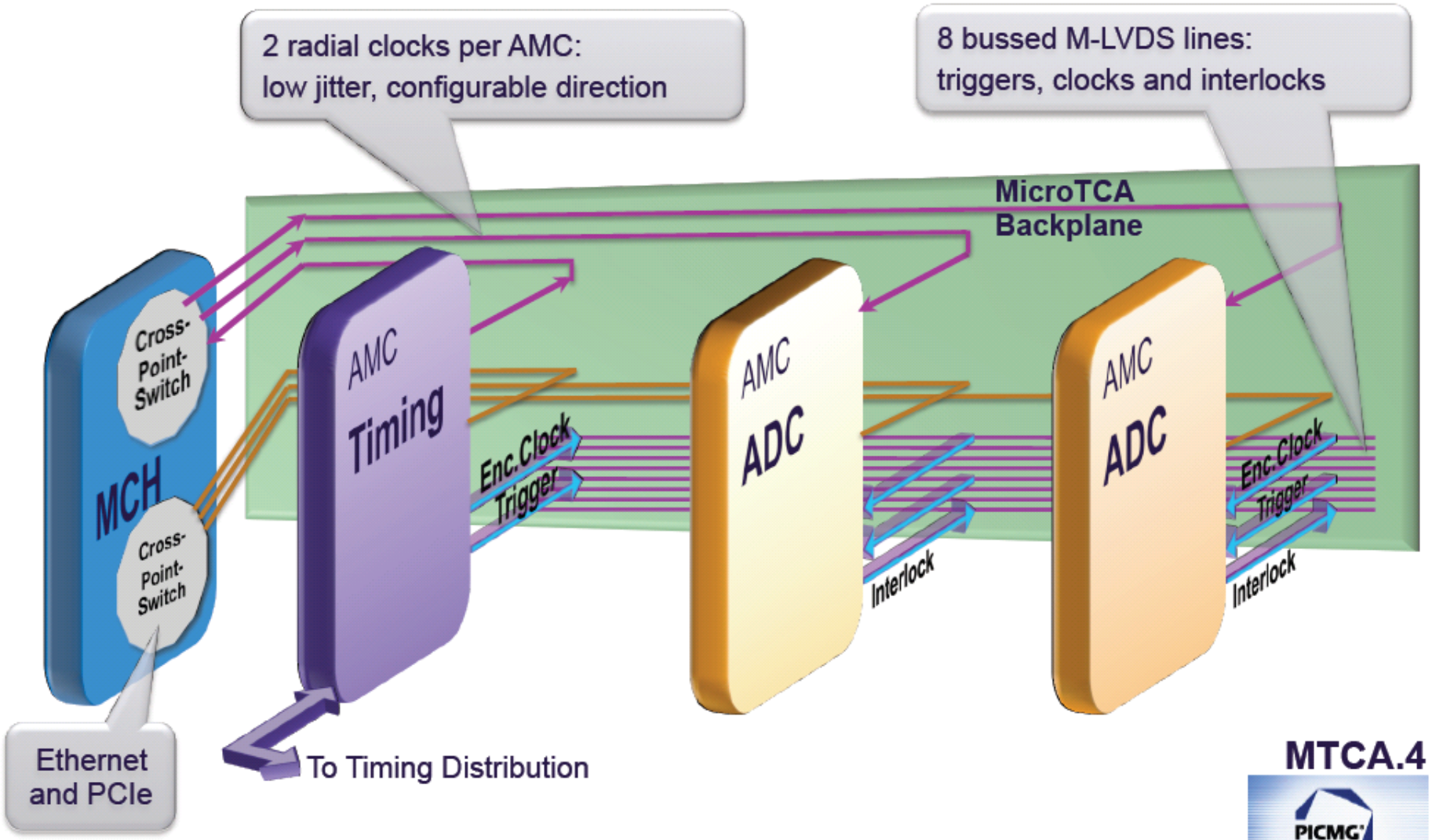


AMC – RTM concept



MTCA.4 hardware platform – precision timing/interlock

MCH = MicroTCA Carrier Hub

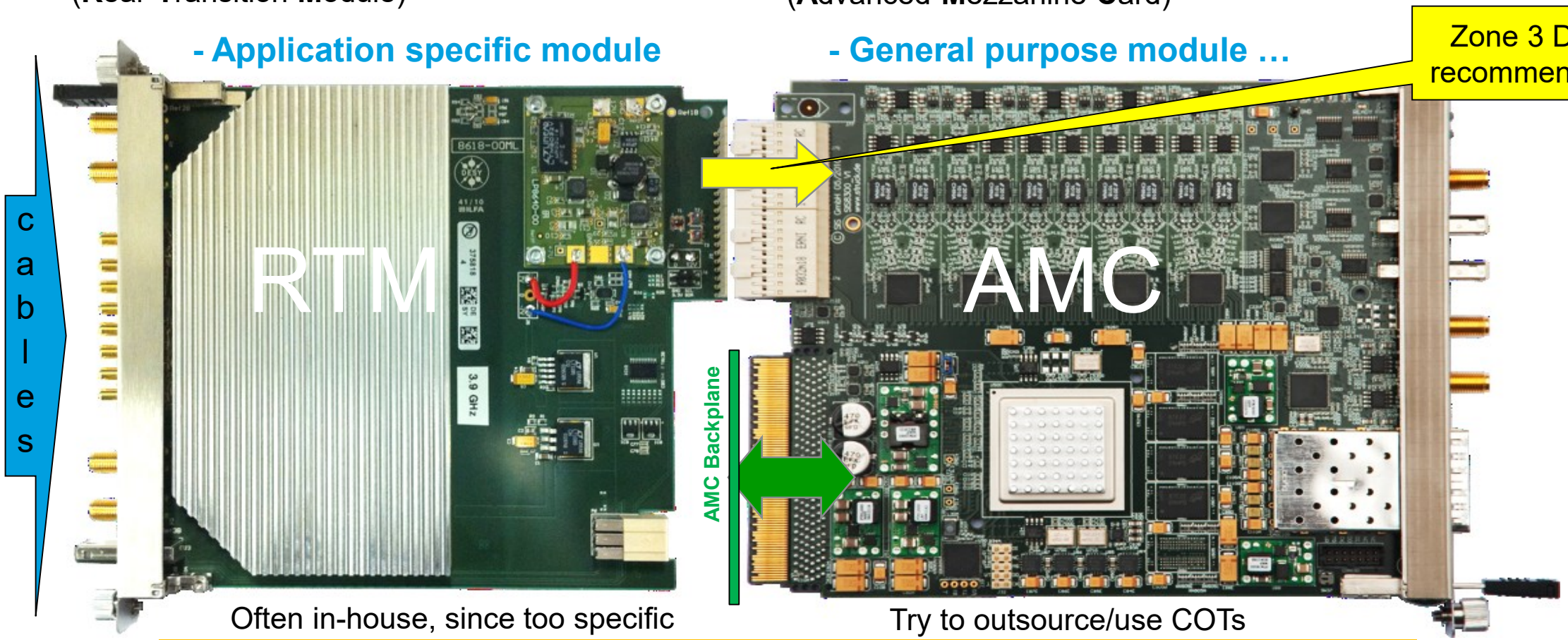


MTCA.4

PICMG

MicroTCA.4 hardware platform – Rear IO –

- **IO or Analogue Signal Conditioning**
  (**R**ear-**T**ransition **M**odule)
  - Application specific module
- **Digital Signal Procession**
  (**A**dvanced-**M**ezzanine **C**ard)
  - General purpose module …



Often in-house, since too specific

Try to outsource/use COTs

➔ AMC-RTM split is an enormous benefit for obsolescence management

➔ And to tailor the hardware project to a smaller developer group

MicroTCA Specifications

But it was a brand-new standard!!!


MicroTCA™

PICMG® Specification MTCA.0 R1.0

Micro Telecommunications
Computing Architecture
Base Specification

July 6, 2006

µTCA™

MicroTCA.0
2006


MicroTCA®

PICMG® Specification MTCA.4
Revision 1.0

MicroTCA Enhancements for Rear I/O
and
Precision Timing

August 22, 2011

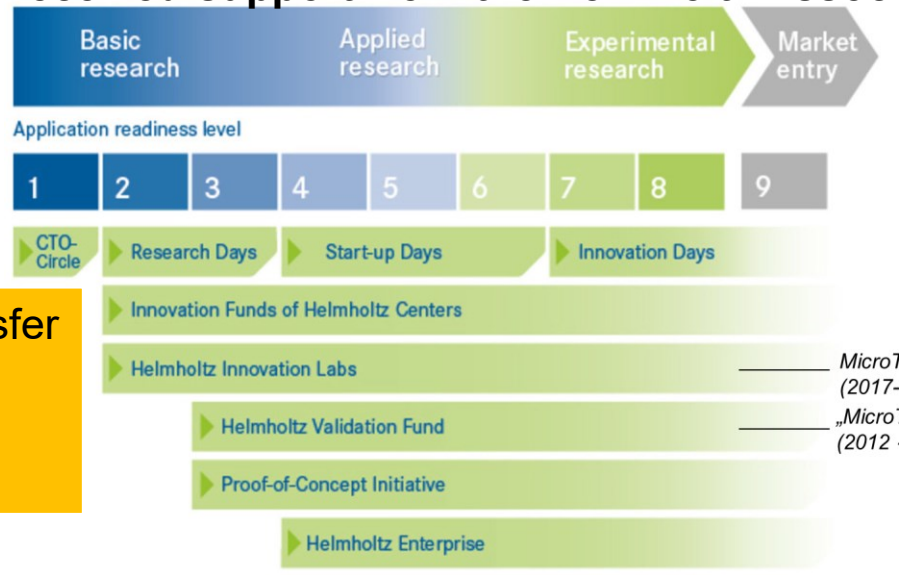
µTCA®

MicroTCA.4
2011

Market entry barriers

- Awareness
- missing technology know-how
- limited number of available products
- expensive (initial development costs)
- legacy systems in facilities
- liability of „newness“

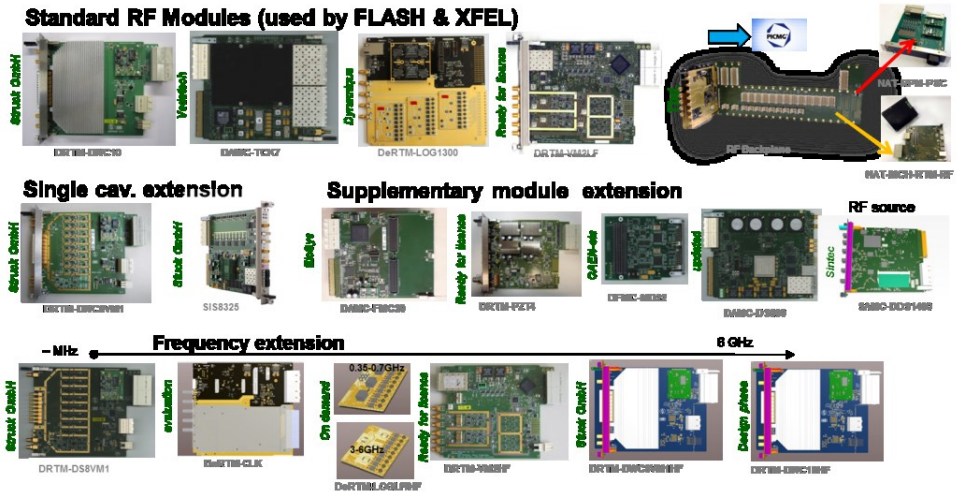
Received support from the Helmholtz Association



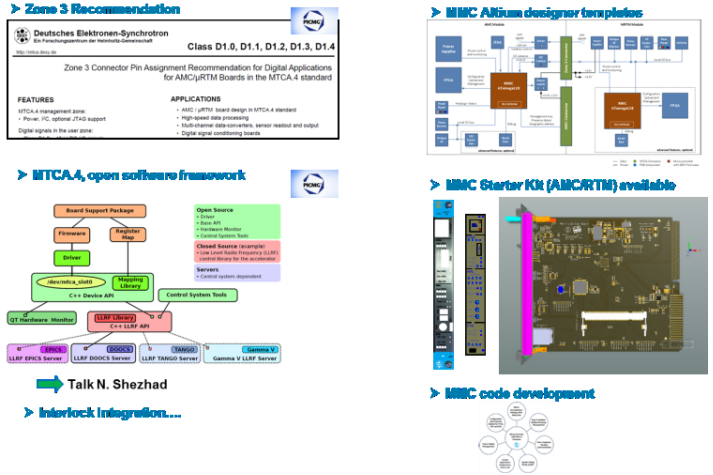
Technology Transfer funds to support dissemination of MicroTCA

Helmholtz Validation Fund (2012-2015)

➢ Boards for RF controls & other appl.

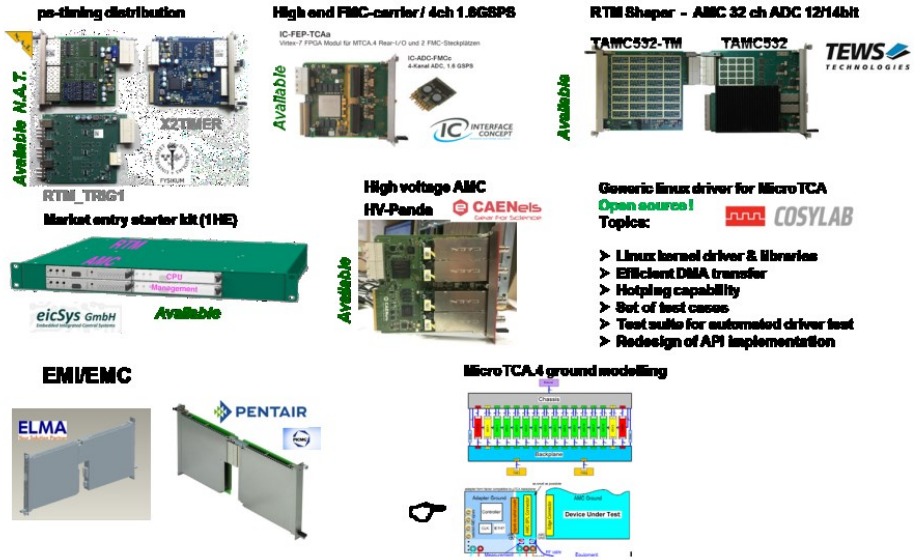


➢ Developments on standard & solutions



- 50 sub-projects were carried out and completed
- 25 new products on the market

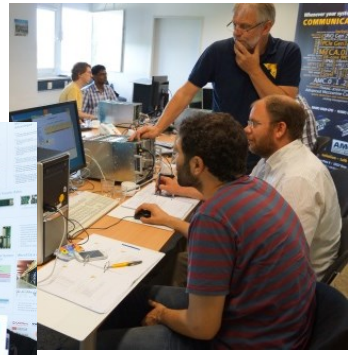
➢ Extending product portfolio on market & EMI



➢ Support & Distribution & Marketing

booth

tutorials



MicroTCA workshop

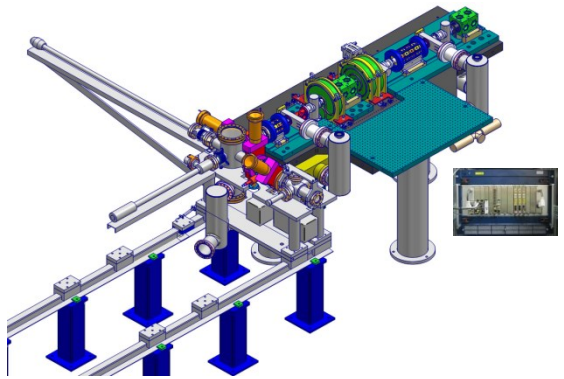
https://mtcaws.desy.de

Start small …

- Equipping of facilities …

3

2012 REGAE ~ 1 crate

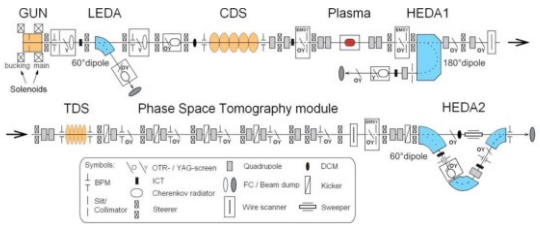


OLD slide from 2015

Labs for development ~ 15 crates > 30

Operation at accelerators ~ 30 crates > 400

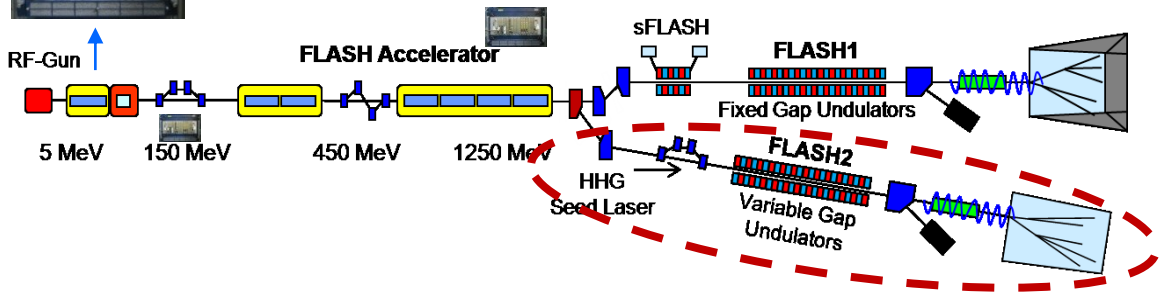
PITZ >13



> 65

2014 FLASH II ~ 20 crates

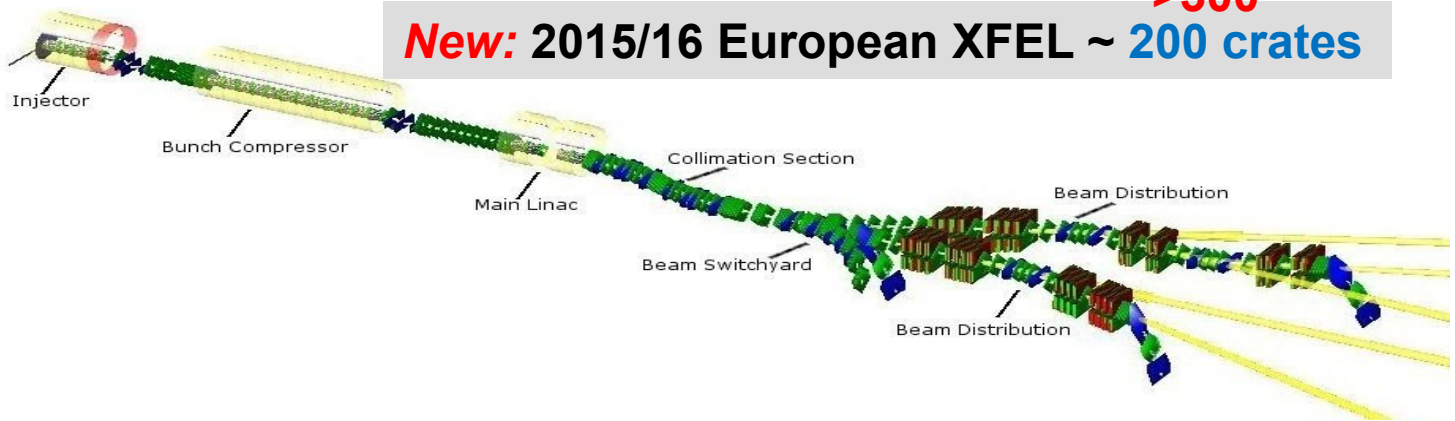
RF controls



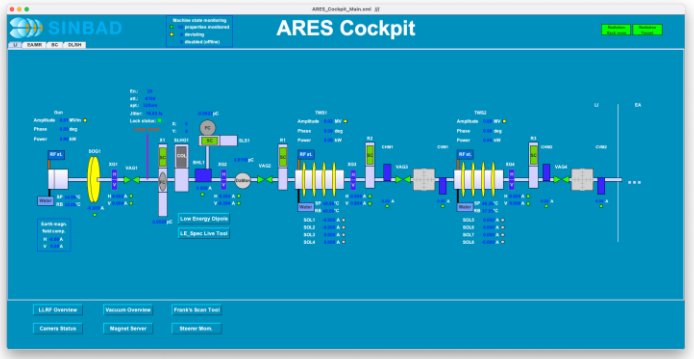
AMTF & CMTB >20

>300

***New:* 2015/16 European XFEL ~ 200 crates**



ARES test accelerator >10



+ many more FALCO, KALDERA, Ts4i,…

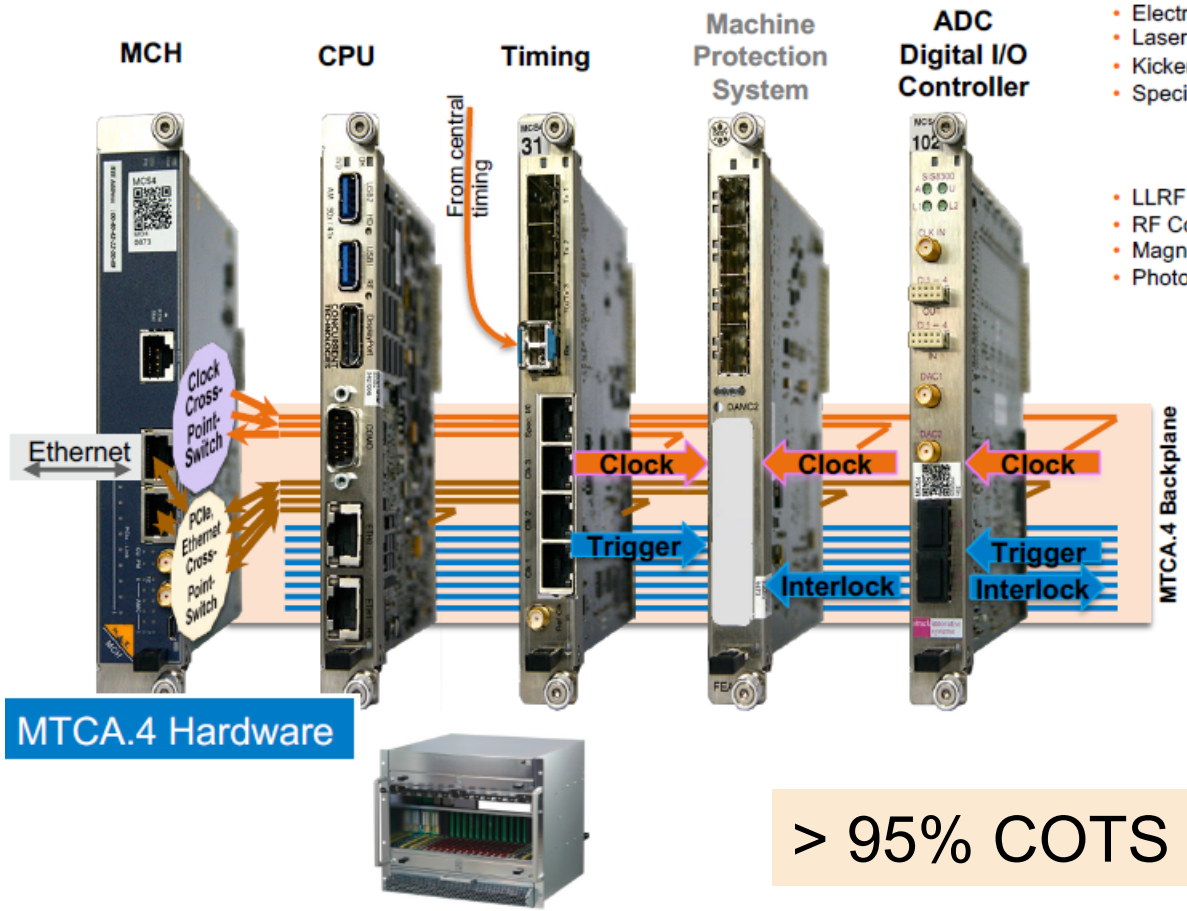
Baseline configuration

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

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

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 Common Modules

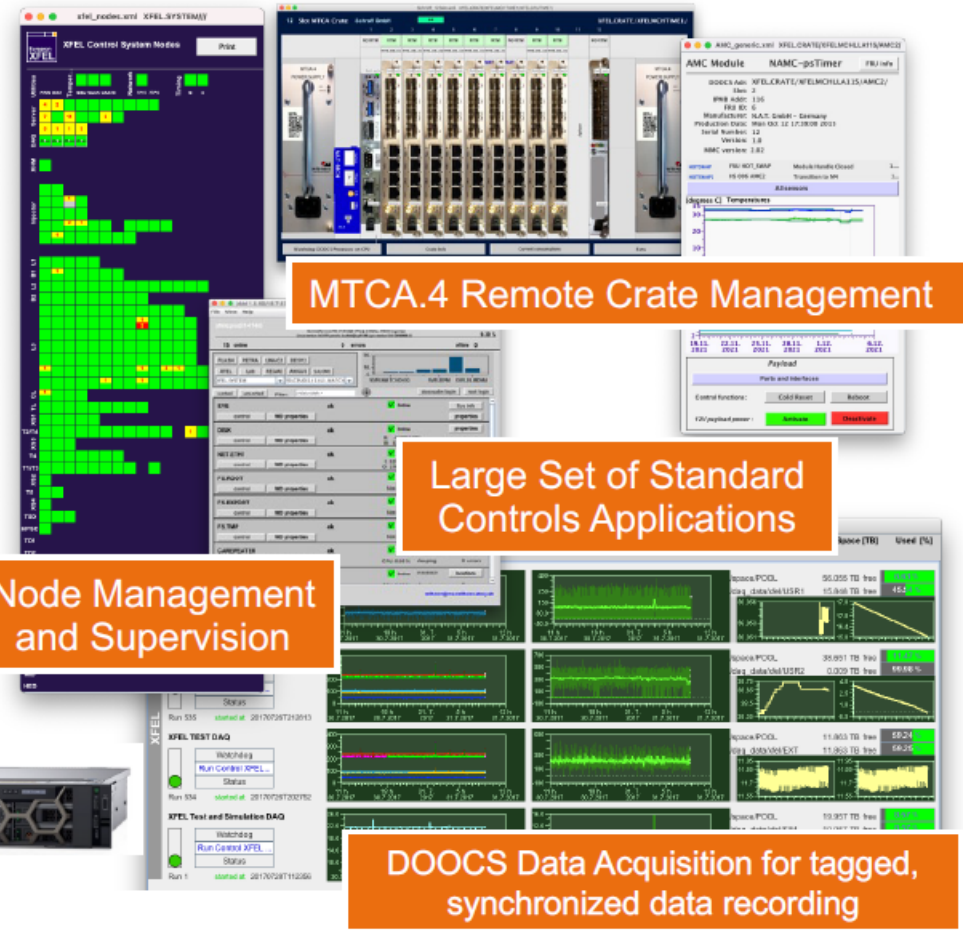


Application Modules (AMC + RTM)

- 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
  - …

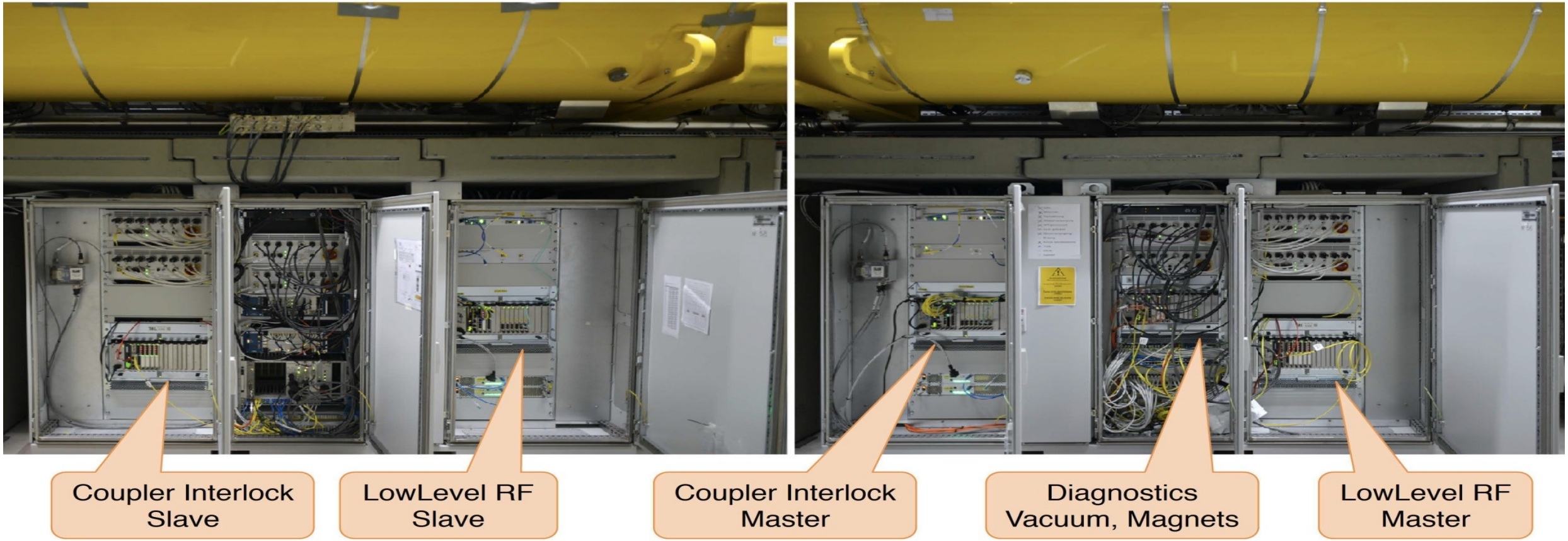
> 95% COTS

Control System Applications



European XFEL Linac

One RF Station = 4 Modules = 32 Cavities = 5 MicroTCA ≅ 50m

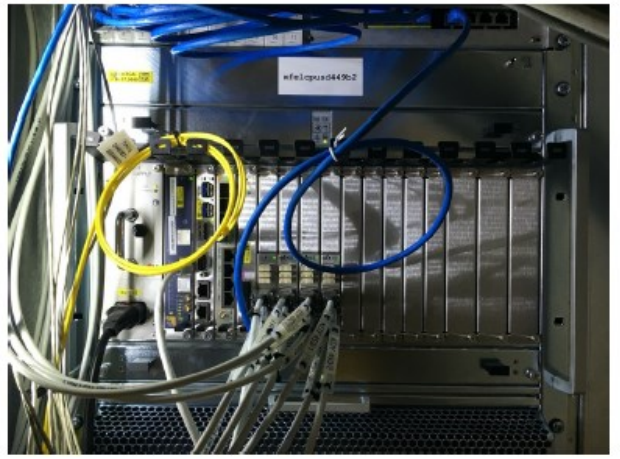


EuXFEL Status 2024

Statistics on MTCA components @ EuXFEL

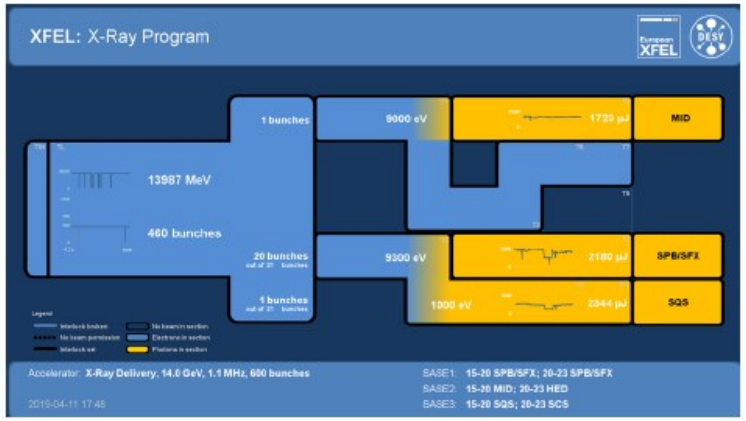
- More than **30 different kinds of MTCA-based software applications** are in use

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



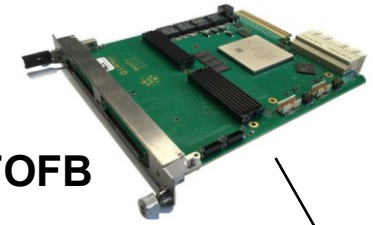
- About **300 MTCA systems** @ EuXFEL as of 2024:
  - About **4800 MTCA modules** (AMC, RTM, P/S, MCH,…) installed e.g.
    - Timing System: 328 modules
    - DAMC2 AMC: 577 modules
    - DAMC-TCK + DAMC-FMC: 51 + 57 modules
    - SIS ADC AMC and RTM: 558 modules
    - Teledyne ADQ AMC / TEWS: 48 / 20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

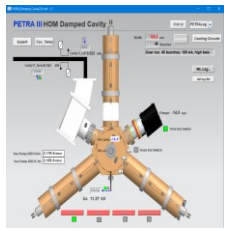


MicroTCA Modules for PETRAIV Project

Hardware portfolio PETRAIV (incomplete)



FOFB



LLRF

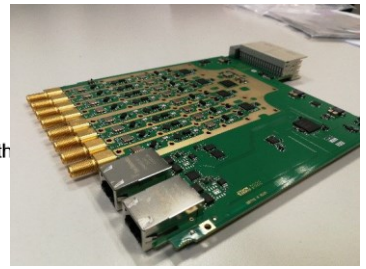
Successor of X2TIMER

X3TIMER

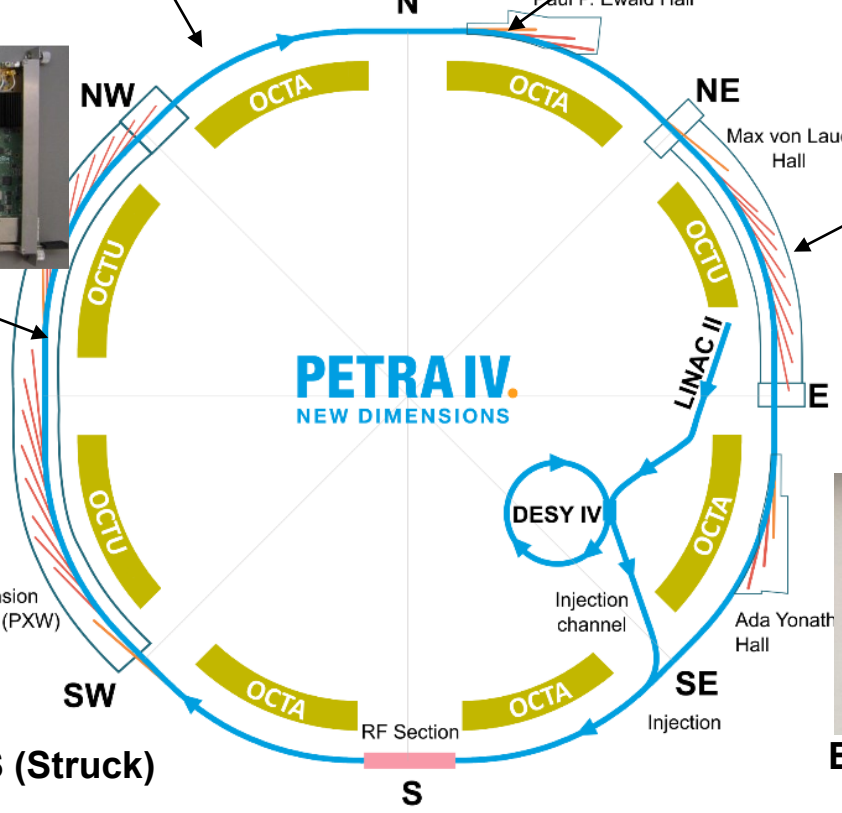
RFSoC-based MBFB

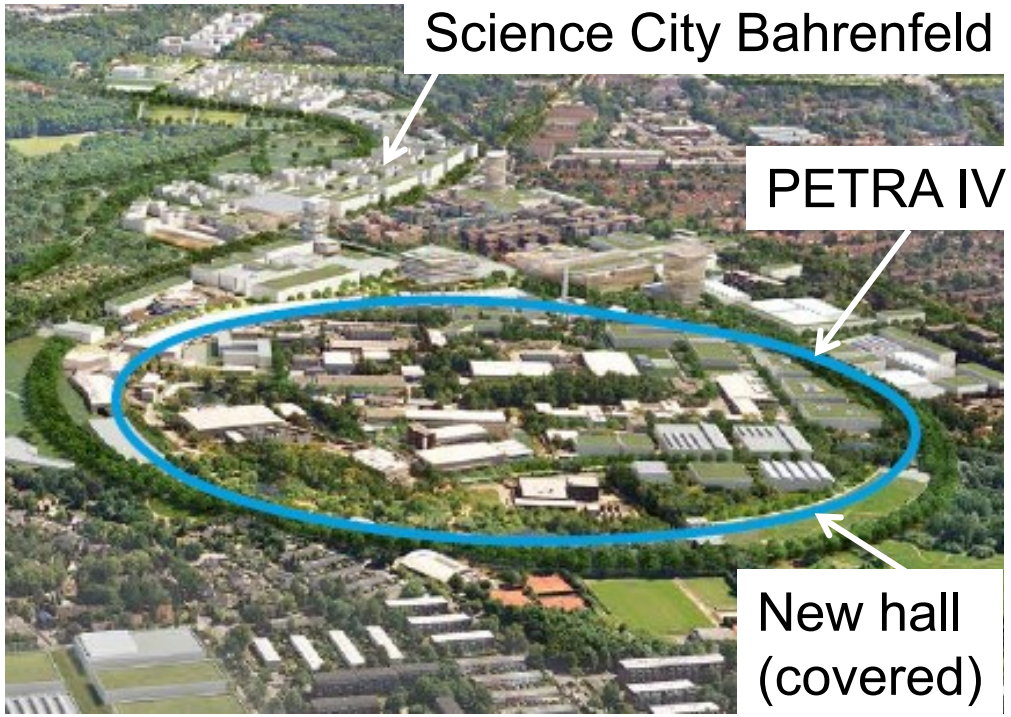
Motion Cntr

Artix e.g. MPS (Struck)



BPM System (I-Tech)





+ beamline control
&
detector readout

Expanding portfolio towards SR

Digital developments of the last years @ DESY

Strategy:

- Develop boards generically & cost efficient & for high yield product
- Non-exclusive production license to a company for dissemination

DAMC-FMC2ZUP (Supercarrier)

(DMMC-STAMP)

DAMC-FMC1Z7IO

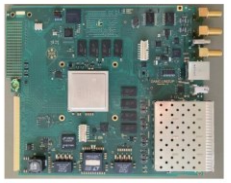
D-TACQ Solutions

D[illegible]C-DS812ZUP

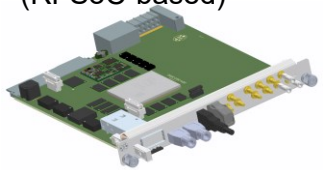
DAMC-MOTCTRL

INSTRUMENTATION TECHNOLOGIES

DAMC-UNIZUP

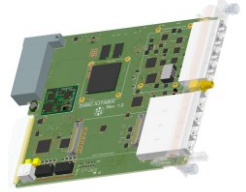


DAMC-DS5014DR (RFSoC-based)



N.A.T.

DAMC-X3Timer



2019 2020 2021 2022 2023 2024 2025

aws

atom computing

Universal Quantum

…

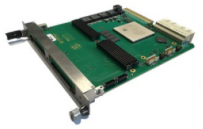
10-year list of license contracts: Struck, CAENels, AIES, Interface Concept, Sintec, MSU, MRF, Embeck, PAL, Piezotechnics, N.A.T, PWI, Durotronic, BEJING DAQ Technology, ESS, Zeiss, KVG, Atom Computing, AWS, D-TACQ, Soleil, ESO, Universal Quantum,…

Licensing Strategy

- We promote an ecosystem – this is part of the “DNA” of the group
- MSK has licensed almost all developments: components are available for us **and** for third parties
- Strategy: Concentrate on the application; purchase all standard infrastructure “off-the-shelf”.

AMC

DAMC-FMC2ZUP
Zynq Ultrascale+ MPSoC based Dual FMC/FMC+ Carrier Board with D1.1 RTM support



ADVANCED MEZZANINE CARDS

AMC boards (Advanced Mezzanine Card) are the key components of a MicroTCA system. Within the MicroTCA.4 crate, AMCs are placed in the front of the crate. They are connected by a high-speed backplane that carriers serial links, power and management data. Every AMC card is monitored and managed. This allows hot-plug, hot-swap, health monitoring and thermal management of the modules.

There are six standard sizes of AMCs: single and double width as well as compact, mid-size and full-size height. Every combination of width and height is valid. The power consumption of an AMC is divided into 3.3V management power plus 12V payload power.
AMC boards are used for digital processing. On every AMC board there is a controlling unit called MMC (Module Management Controller).
Plugging in the AMC board to the MTCA crate connects the board to the backplane of the crate. The backplane ensures the connection of the AMC boards with every other AMC board in the crate.
Plus, every AMC board is connected to the MCH (MicroTCA Carrier Hub), which is the overall management card of the MTCA system. The MCH gives management power to the AMCs first. This power is used to check if everything is ok with the AMC. If the MMC, the managing unit on the AMC detects no problems on the board, the MCH gives payload power to the AMC.

Clustering of AMCs in the system is possible.

DAMC-FMC1Z7IO
Cost-Optimized IO Controller Board with one FMC socket

DAMC-FMC25
AMC Dual HPC-FMC Carrier

DAMC-FMC20
AMC Dual FMC Carrier Board

DAMC-TCK7
AMC Data Processing and Telecommunication Module

X2TIMER
AMC Fast Timing System

DAM

...

RTM

DRTM-MXC
Mobile GPU Carrier

REAR-TRANSITION-MODULES

RTMs, the rear-transition-modules, are extension boards that are placed in the back of the MTCA.4 crate. They directly connect to the front AMCs via the Zone 3 connector.
The possibility to separate analogue and digital functions by moving sensitive analogue electronics to the RTM is one of the key strengths of MicroTCA.4.

DRTM-AD84
RTM 8Ch ADC, 4Ch DAC

DRTM-DWC8VM1
RTM 8 Channel Down-Converter 1 Channel Up-Converter

DRTM-DWC10
RTM 10 Channel Down-Converter

DRTM-PZT4
RTM 4 Channel Piezo Driver

DRTM-LOG1300
eRTM Local Oscillator Generation

DRTM-DS8VM1
RTM 8-Channel Direct Sampling 1-Channel Vector Modulator

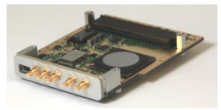
DRTM-VM2LF
RTM 2 Channel Vector Modulator Low Frequency

DRTM-VM2HF
RTM 2 Channel Vector Modulator High Frequency

DESY MMC Stamp

FMC

DFMC-DS800
FMC Direct-Sampling A-D Converter

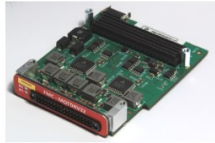


FPGA MEZZANINE CARDS

FPGA Mezzanine Card (FMC) is a standard defining I/O mezzanine cards and corresponding carrier boards. Huge ecosystem of carrier boards, both in MicroTCA format and standalone boards, provides a good prototyping platform, suitable for experimental physics and industrial applications. The FMC mezzanine format provides additional degree of modularity for a lot of I/O applications, such as ADC and DAC boards, or communications boards.

DFMC-AD16
FMC 16-channel A-D Converter

DFMC-MD22
FMC 2 channel stepper motor driver



DFMC-UNI-IO
FMC Multi-Purpose I/O Board

DFMC-TESTADP
FMC Loopback Adapter

DFMC-SFP4
FMC 4-Channel SFP+ Adapter

MicroTCA Specifications

MicroTCA.0
2006

MicroTCA.4
2011

MicroTCA.4.1
2016

Next Gen

~2025

PCIe gen5 (32 GT/s) (x 4)
220 W per AMC slot (80W)
Backward compatible

682 pages

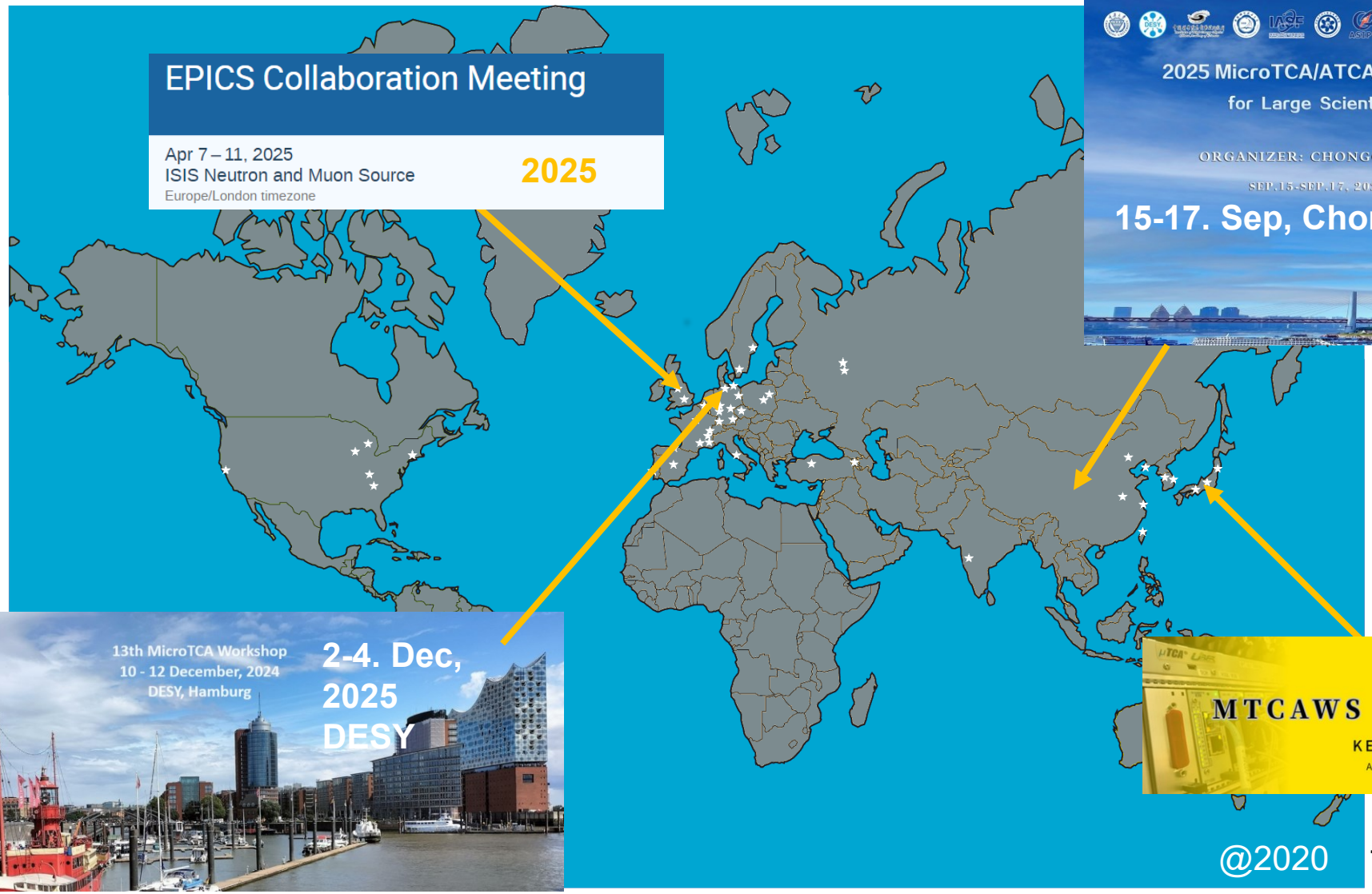
MicroTCA.0 r2
2020

764 pages

MicroTCA.0 r3
2023

Summary: It’s a worldwide growing ecosystem

https://indico.ihep.ac.cn/event/25908/



https://mtcaws.desy.de

15-17. Aug.2025
Tsukuba J-Parc

https://conference-indico.kek.jp/event/326/

Thanks for the attention

Key takeaways

- Remote management ➔ serviceability, fault detection & prediction, and reduced MTTR
- AMC – RTM split ➔ easy obsolescence management
- Modern & high-performing ➔ became enabling technology
- Modularity & configurable ➔ easy-to-extend facilities
- Mostly COTS ➔ reduces production & development resources
- License to partners ➔ for the complex board, good strategy (product owner)
- Open standard ➔ fundamental, minimise vendor lock-in
- Ecosystem grows ➔ an increasingly larger community support
- Price… ➔ depends mostly on functions (FPGA/Memory/) & QC in the company
- ➔ longevity: availability of the product for 10+ years + service
- ➔ ease obsolesces management
- ➔ pays off due to reduced cost for maintainability