

MicroTCA-based Motion Controller

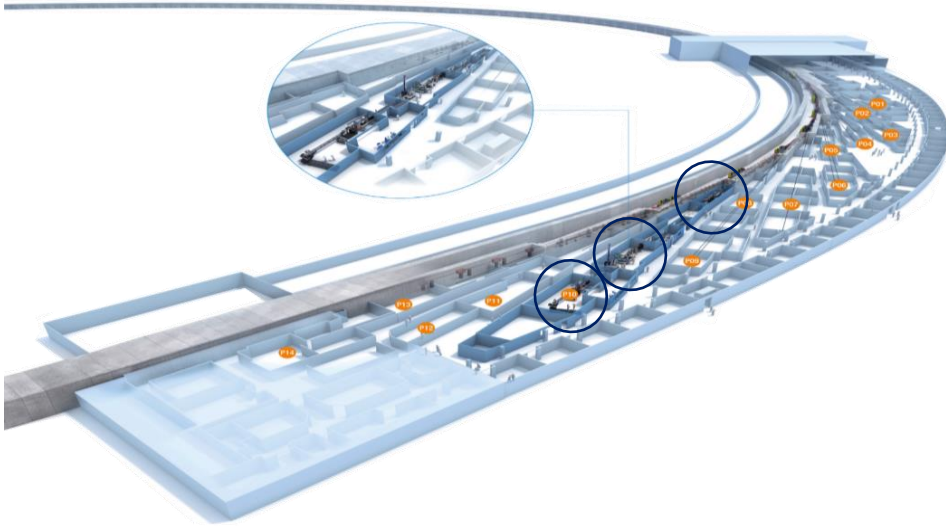
Michael Randall et al.

2026 MicroTCA/ATCA Workshop for Large Scientific Facility Control, Beijing, 16 September 2026

Motivation

DESY Experimental Needs:

- Need to control motors in experiments.

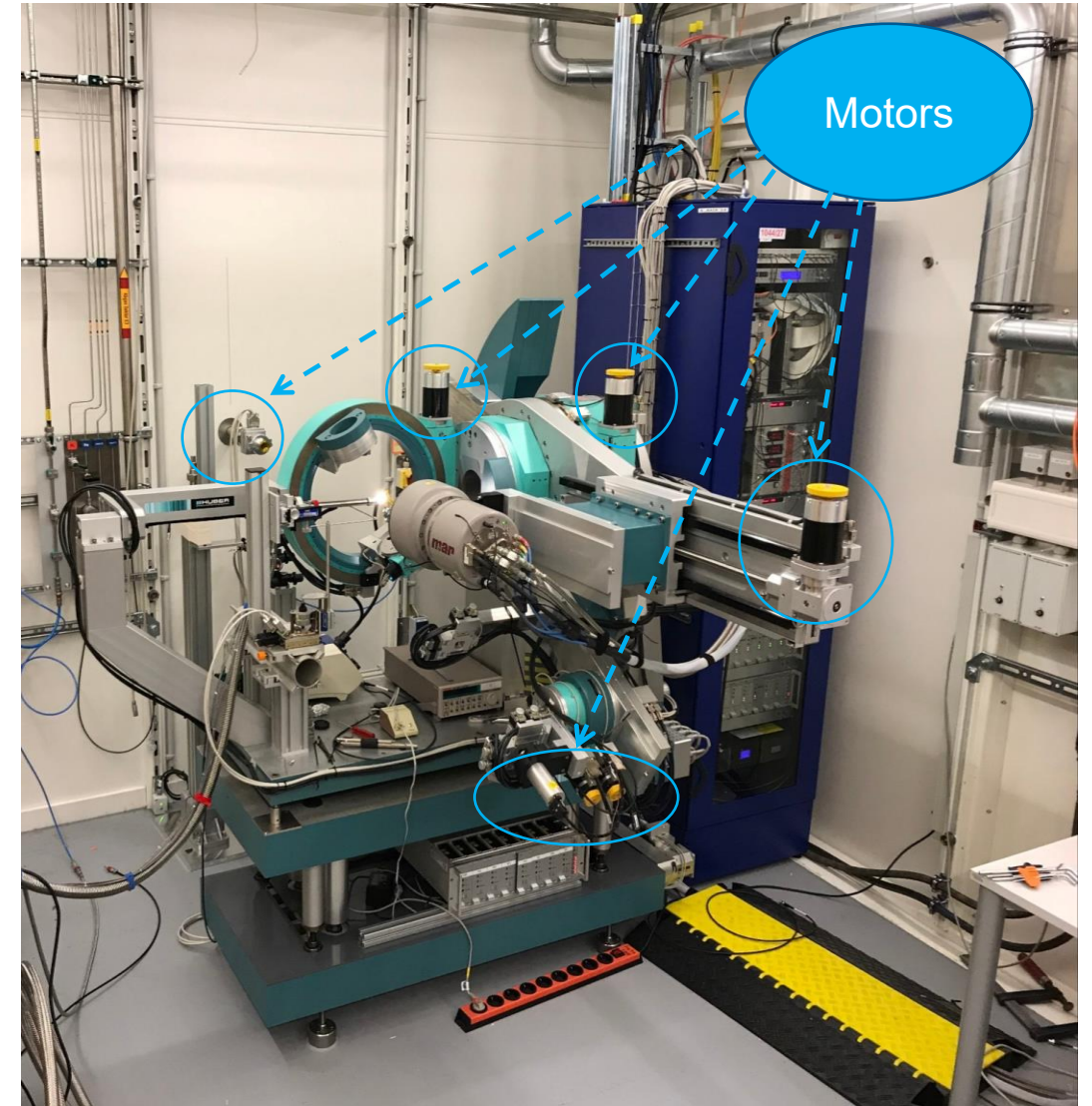


PETRA IV MicroTCA Infrastructure:

- Planned replacement of VME systems.
- Lack of a suitable multi-axis motion controller.

Enhancements Needed:

- Increase the number of motors for synchronous motion.
- Address experiment-specific requirements, such as position-triggered data acquisition.



Diffractometer at Beamline
(Martin Tolkiehn)

Large Investments on DESY Campus

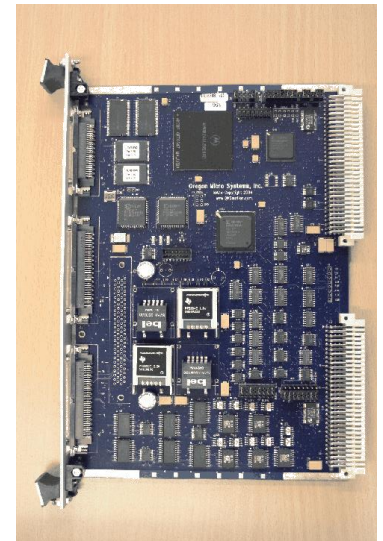
- Beamlines equipped with hundreds of existing motor drivers.
- Commercial drivers integrated into proprietary ZMX+ frames.



- Legacy hardware, but still good enough to keep.
- Incompatible interface:
 - Users complain about long, stiff cables.
 - Sensitive connectors (SCSI II).
 - 4 cables per motor driver frame.
 - Wide connector unsuitable for MicroTCA.
- Limited number of encoders.
- Need for a drop-in replacement to address these issues.



SCSI connector on back panel of DESY ZMX+ frame



VME-based motion controller - OMS MAXv

PETRA IV Motion Control

Hardware

DAMC-MOTCTRL:

- Funded by DESY Generator Program.
- MicroTCA.4-based motion controller.
- Controls up to **48 motor axes** per card.
- Replaces six VME cards, i.e. three ZMX frames can be operated with one card.
- Four SCSI cables have been replaced with a single fiber link.



Heterogeneous Processing:

- Zynq UltraScale+ (XCZU2EG) with 2GB DDR4 32-bit.
- Kintex (XC7K160) with 4GB DDR3 64-bit.

SFP+ Ports (5 in total):

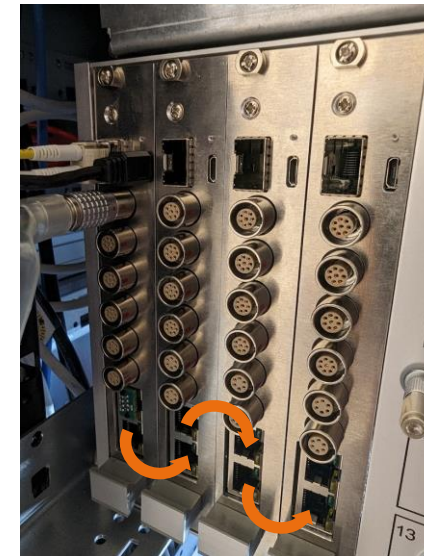
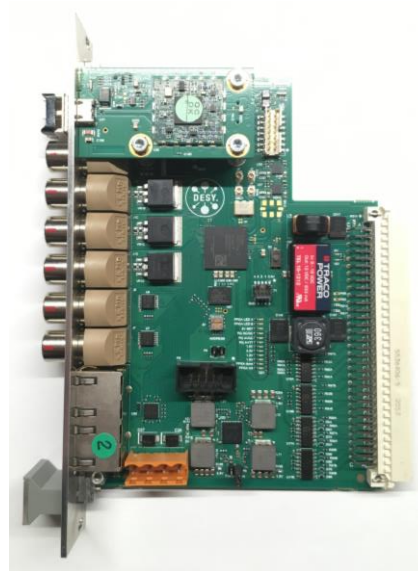
- 3x Motor interfaces.
- 2x Ring topology (EtherCAT, SERCOS).

GPIOs:

- 26-pin connector supporting 3.3V/5V GPIOs.

ZMX+ Connection Board:

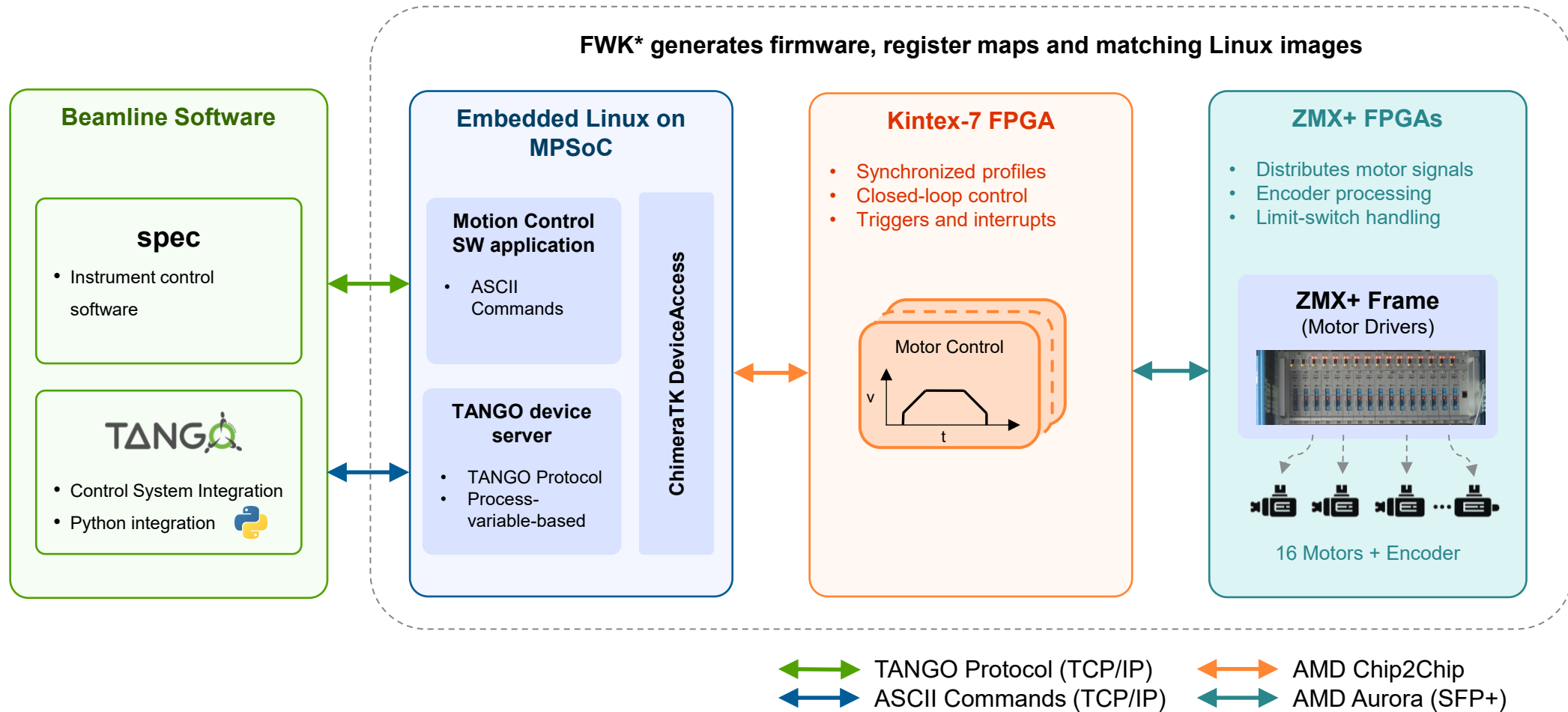
- Drop-in replacement for the deprecated interface card of the ZMX+ frame.
- Artix (XC7A50T).
- 6x 8-pin LEMO connectors:
 - 4x encoder inputs
 - 2x direct motor step/direction outputs
- 2x RJ45 connectors:
 - Interconnection between boards within the ZMX+ frame (daisy chain).



Interconnected ZMX+ Connection boards

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Firmware and software architecture



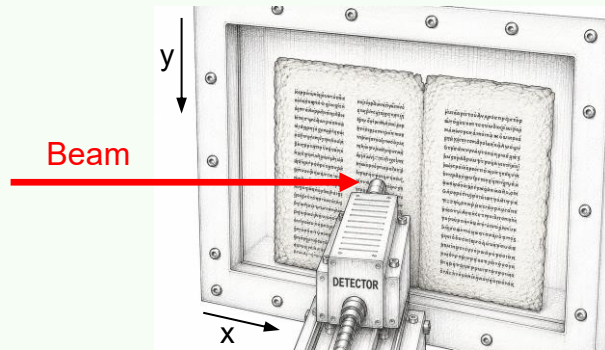
* Visit talk ["FWK: An Open-Source, Modular Framework for FPGA Project"](#)

PETRA IV Motion Control

From prototype to beamline use: P24 and P25

P24 • field validation*

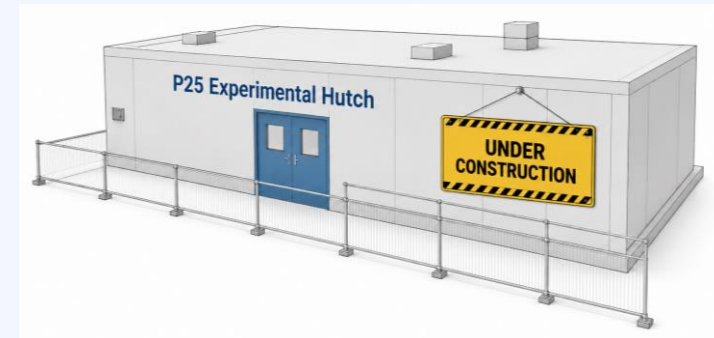
- First use in live experiments
- Established ASCII workflow using *spec*
- Real-world failure discovery
- Continuous ideas and bug reports



already operating

P25 • operational deployment

- New PETRA III beamline approaching operation
- TANGO control system
- Approximately 80 motors
- First beamline relying on DAMC-MOTCTRL

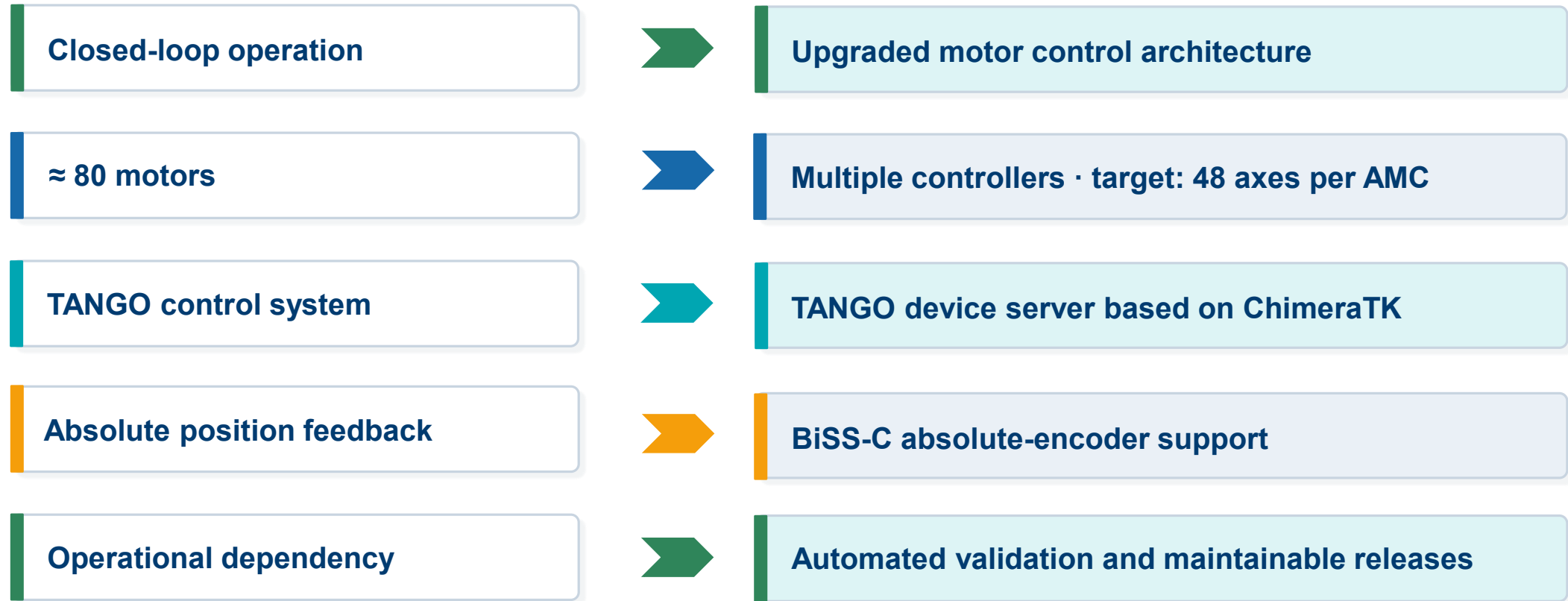


boards delivered · integration active

* Revisit talk ["MicroTCA.4 solution for photon station"](#)

PETRA IV Motion Control

Development roadmap driven by P25 requirements

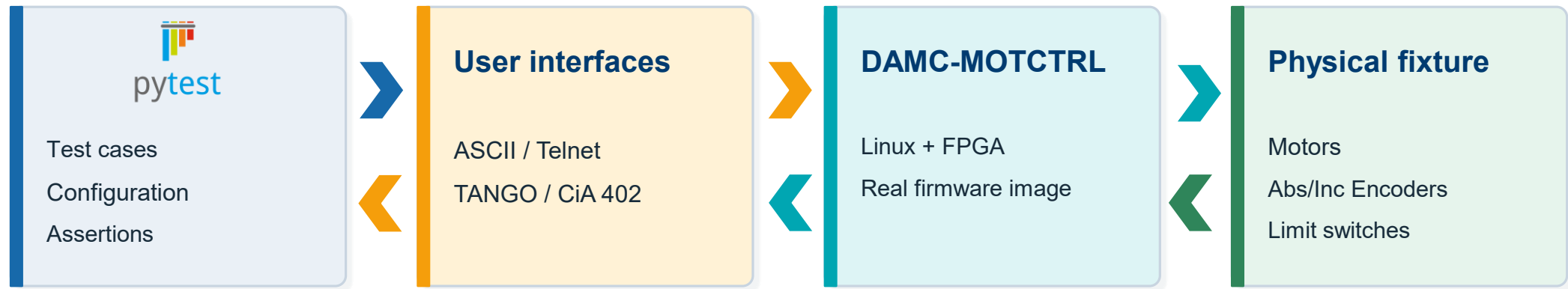


Boards delivered · software integration underway

PETRA IV Motion Control

Automated hardware-in-the-loop testing

- Motion control can be safety-critical
- Logic testbenches and manual system tests
- Pytest-based hardware-in-the-loop testing started in October 2025



Static tests:

- Commands & parameter limits

Dynamic tests:

- Single-axis & multi-axis motion
- Closed-loop motion & burn-in
- Stops, limits & triggers

Regression protection

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Scaling from 16 to 32 and toward 48 axes



Initial state:

- Motor control logic ready
- Single SFP connection
- Software polling



Hardware interrupts missing

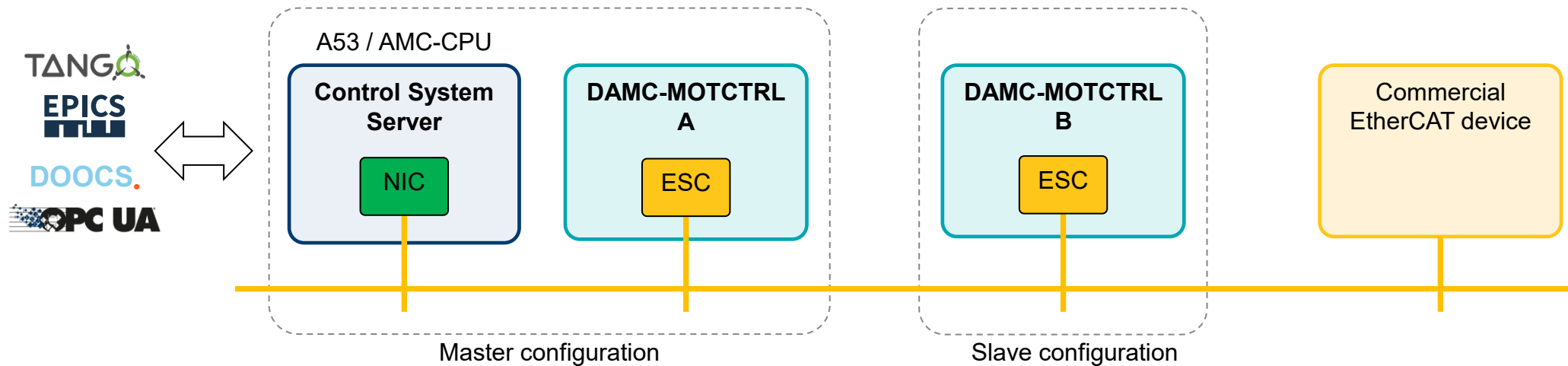
Progress:

- New FWK / DesyRDL ✓
- Vivado / Vitis / Yocto upgrade ✓
- Interrupt tree ✓
- Three SFP connections ✓
- Implementation & timing closure ✓
 - 89% LUT utilization
 - Timing closure passed
- TANGO testing in progress
- Firmware project ready ✓
 - ~120% LUTs on current FPGA
- Larger pin-compatible FPGA
- Two variants planned:
 - XC7K160T for 16 axes
 - XC7K325T for 48 axes

PETRA IV Motion Control

Synchronizing multiple controllers with EtherCAT

- Control system interface as EtherCAT master
- Motion controller as a pure EtherCAT slave



- Three technical discussions with Beckhoff, including ETG participation
- Discussions supported the technical feasibility
- Open decision: license vs. develop the ESC

Thank you

Check out the source code and documentation:

- [Open-Source PETRA IV Motion Control Project](#)
- [Open-Source Motion Control Firmware Module](#)

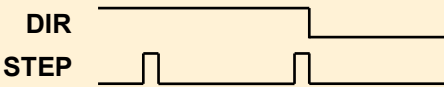
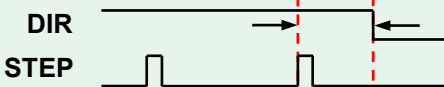
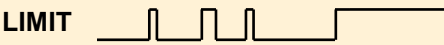
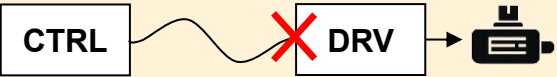
Contact

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PETRA IV Motion Control

What P24 experiments taught us

Observation	Root cause	Firmware correction
Occasional lost motor steps	Direction-signal hold violation 	Corrected direction timing 
False limit-switch events	Short electrical noise pulses 	≈ 250 ns FPGA glitch filter 
Communication loss not detected	SFP module in error state 	 Link-state monitoring +  traffic watchdog

Beamline feedback directly improves firmware quality