

Status Update on the Open-Source Synchronous Multi-Axis Motion Controller Solution for Large-Scale Experimental Physics Projects

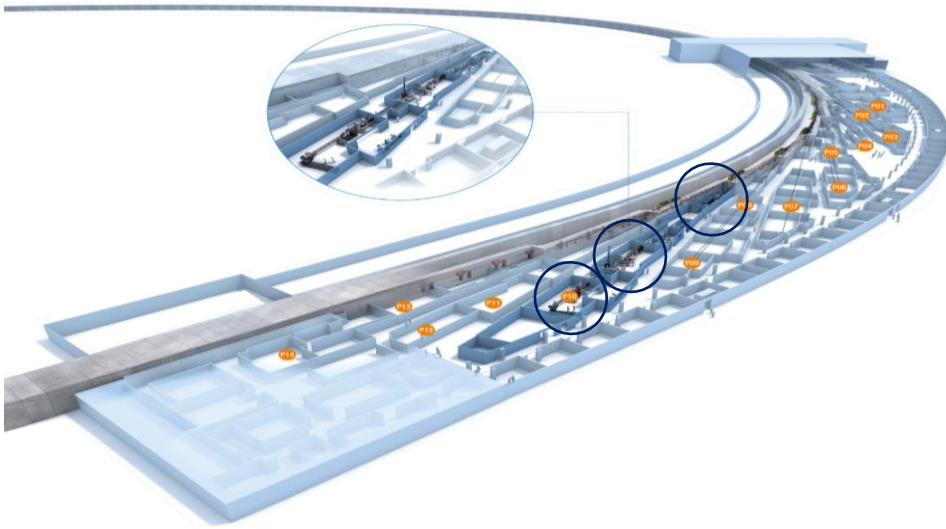
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Hamburg, 4th of December 2025

Motivation

Experimental Needs at DESY:

- Requirement to control motors in experiments.

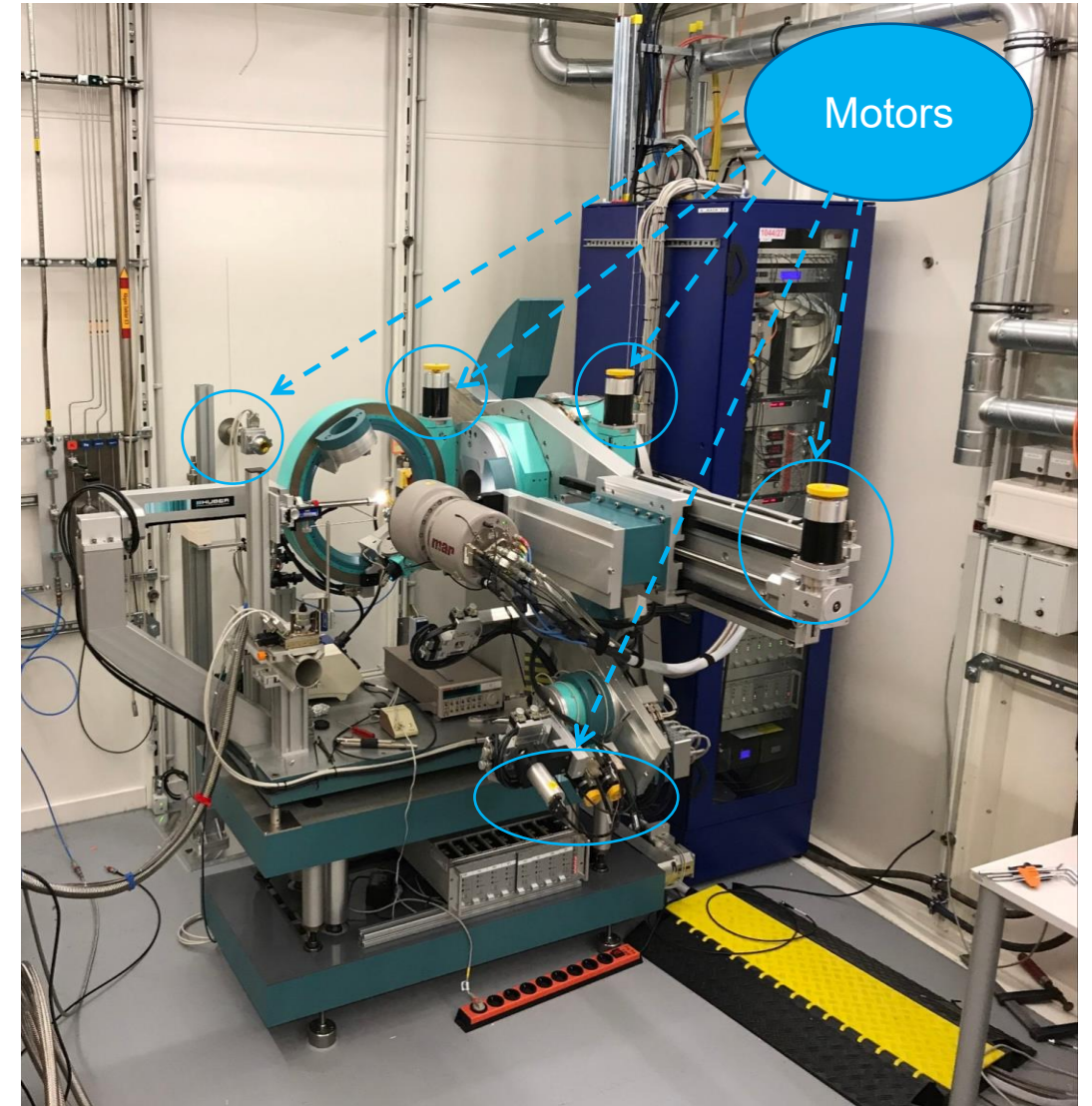


PETRA IV MicroTCA Infrastructure:

- Planned replacement for 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

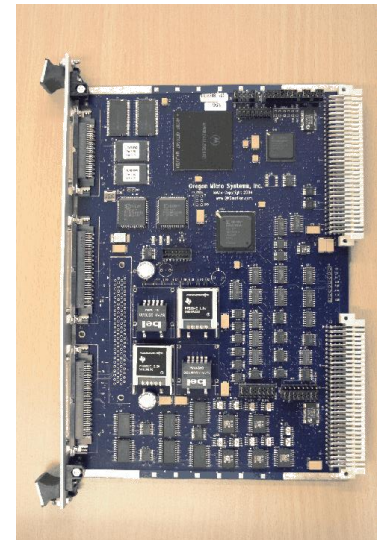
- Beamlines equipped with hundreds of existing motor drivers.
- Commercial drivers integrated into proprietary ZMX+ frame.



- Legacy hardware, but good enough to keep.
- Incompatible interface:
 - Users complain about long, stiff cables.
 - Sensitive connectors (SCSI II).
 - Four cables per frame.
 - Wide connector unsuitable for MicroTCA.
- Limited support for encoders
- Need for a drop-in replacement due to the outlined 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 motors** 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.



DAMC-MOTCTRL

ZMX+ Connection Board:

- Drop-in replacement for the deprecated interface card of the ZMX+ frame.
- Artix (XC7A50T).
- 6 LEMO 8-pin:
 - 4x Encoder Inputs.
 - 2x Direct Motor Step & Direction.
- 2 RJ45:
 - Interconnection between boards within the ZMX+ frame (daisy chain).



ZMX+ Connection board

Heterogeneous Processing:

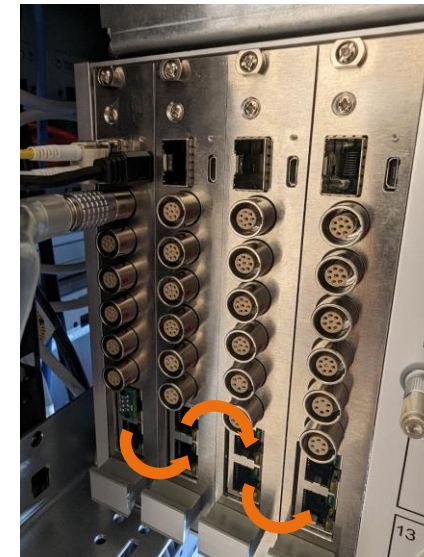
- Zynq UltraScale+ (XCZU2EG) with 2GB DDR4 32-bit.
- Kintex (XC7K160) with 4GB DDR3 64-bit.

SFP+ Ports (5 in Total):

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

GPIOs:

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



Interconnected ZMX+ Connection boards

PETRA IV Motion Control

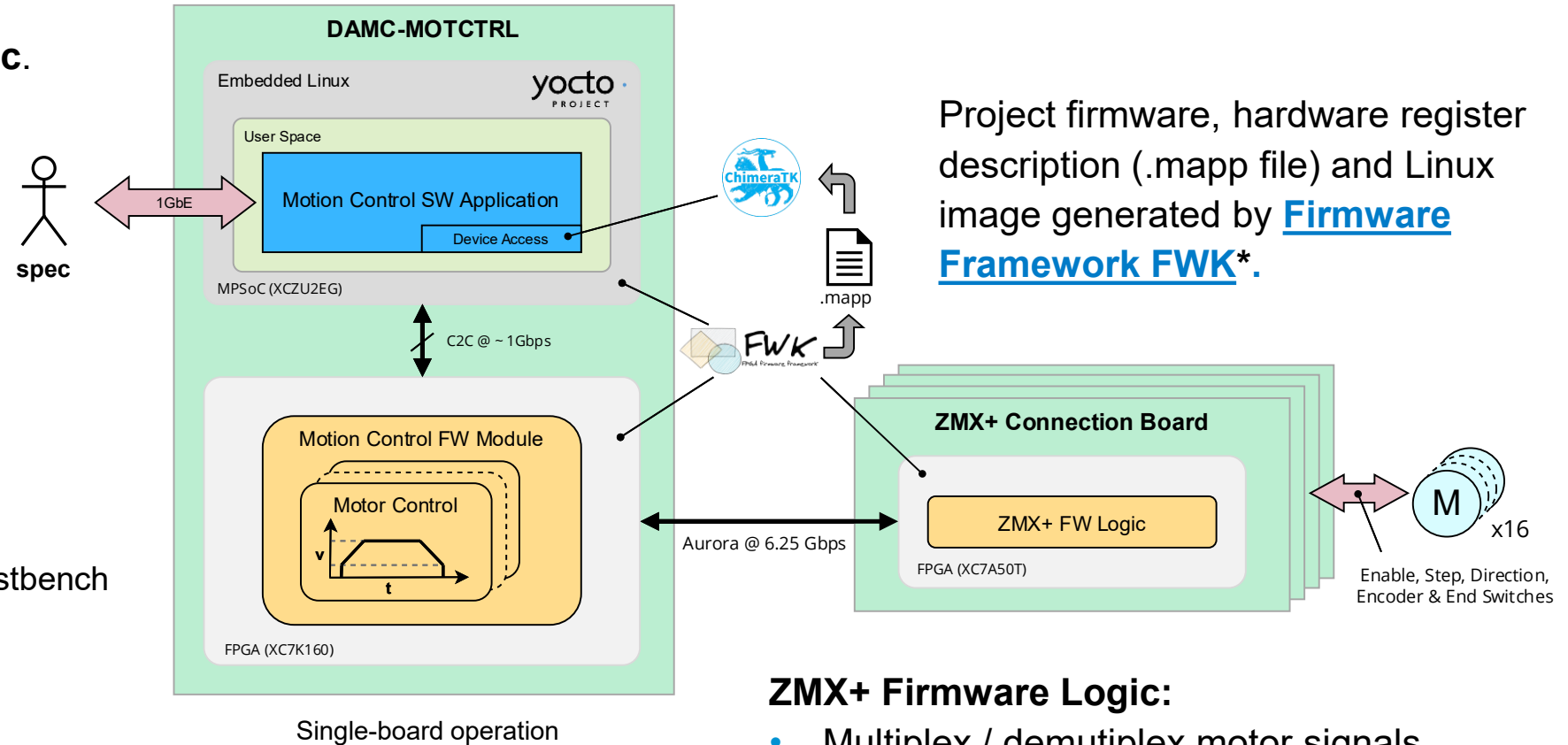
Firmware Overview – FW Version 1.2.1

Motion Control SW Application:

- Interface to external high-level instrument control software **spec**.
- Parses motion commands and orchestrates axis logic.
- Uses UIO backend of **ChimeraTK-DeviceAccess**.

Motion Control FW Module:

- Generic multi-axis controller.
- Verified using:
 - Universal VHDL Verification Methodology (**UVVM**),
 - Coroutine-based cosimulation testbench environment (**cocotb**).
- Wraps per-axis submodules.
 - Linear acceleration profile.
- **Clock-synchronous motion**.
- Per-axis encoder and limit switches.



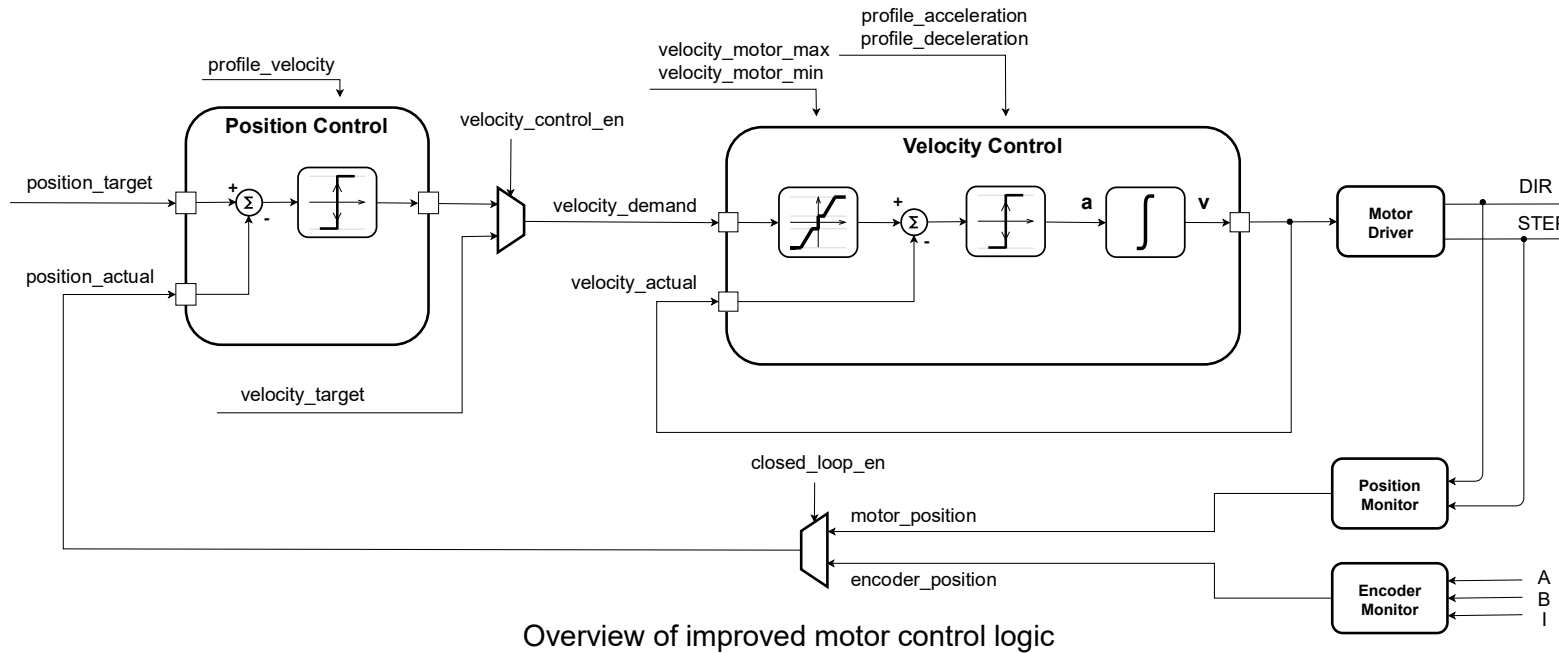
ZMX+ Firmware Logic:

- Multiplex / demultiplex motor signals.
- Apply user front panel interface.

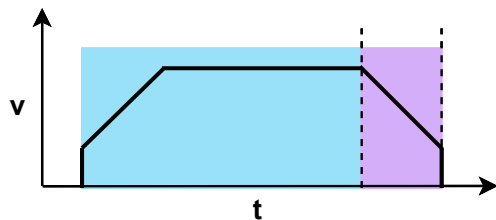
*Review talk [First Major Release of 'fwk'](#) more

PETRA IV Motion Control

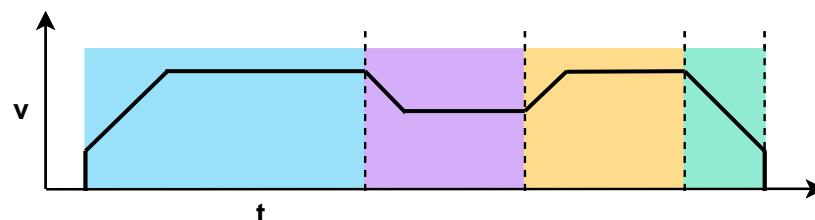
Motor Control Core – Upgrade



Overview of improved motor control logic



Simple positioning command



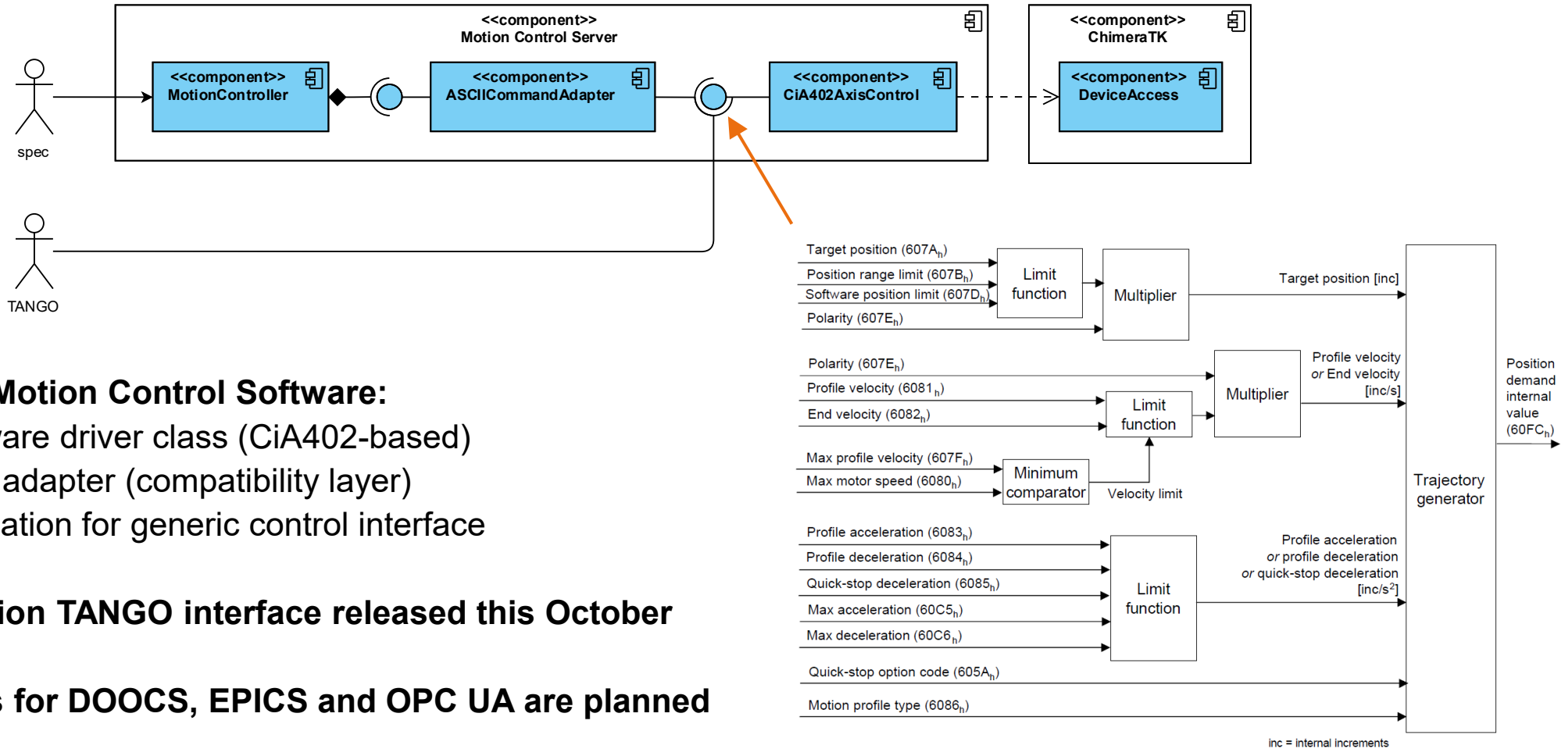
Continuous movement

Generic Control Architecture

- In line with **CANopen Profile CiA402**
- **Closed-loop operation**
- **Modes:**
 - Profile Position Mode (single-axis)
 - Interpolated Position Mode (multi-axis)
 - **Homing Mode**
- **Drift detection**
 - Position Window
 - Following Error Window
- **Drift compensation** in software
- Open for extensions
 - Complex trajectory planning
 - S-Curve acceleration

PETRA IV Motion Control

Generic Control-System Interface Based on CiA402



Object dictionary for profile position mode (CANopen CiA402)

Updated Motion Control Software:

- Hardware driver class (CiA402-based)
- ASCII adapter (compatibility layer)
- Foundation for generic control interface

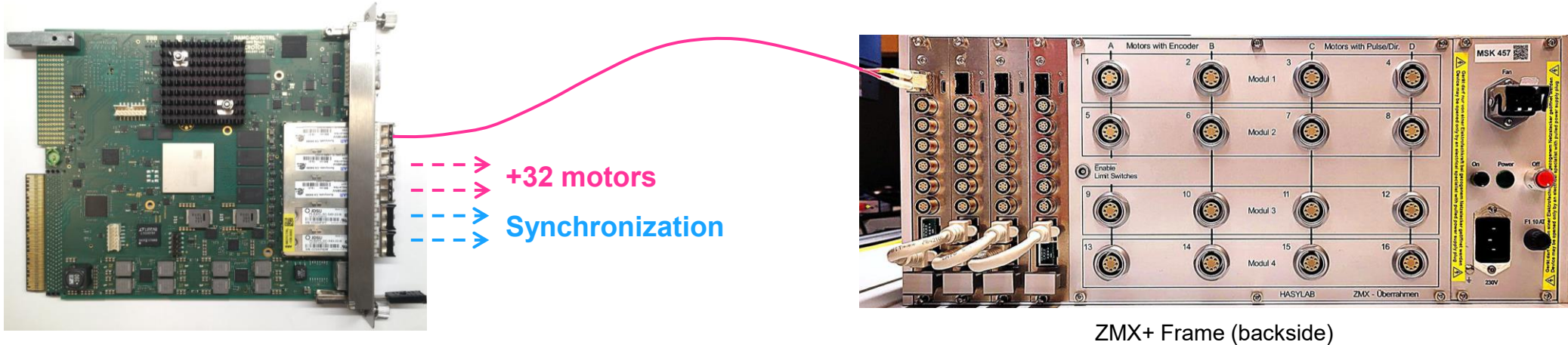
First version TANGO interface released this October

Interfaces for DOOCS, EPICS and OPC UA are planned

PETRA IV Motion Control

Next Steps

- Support for absolute encoders via BiSS (nearly completed)
- Extension to 48 motors: 3 x ZMX+ Crates, hosting 16 motor, per axis encoder and limit switches each. **(on hold)**



- Fixture for performance and release test (initial work started)
- Native EtherCAT Interface:
 - Short cycle times ($\ll 1$ ms) and precise synchronization ($\ll 1\mu\text{s}$)
 - Seamless synchronization with other commercial off-the-shelf components
 - Solution for inter-board synchronization

Thank you

Also visit [“MicroTCA for photon beamlines - on-the-fly scans with spec”](#)

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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