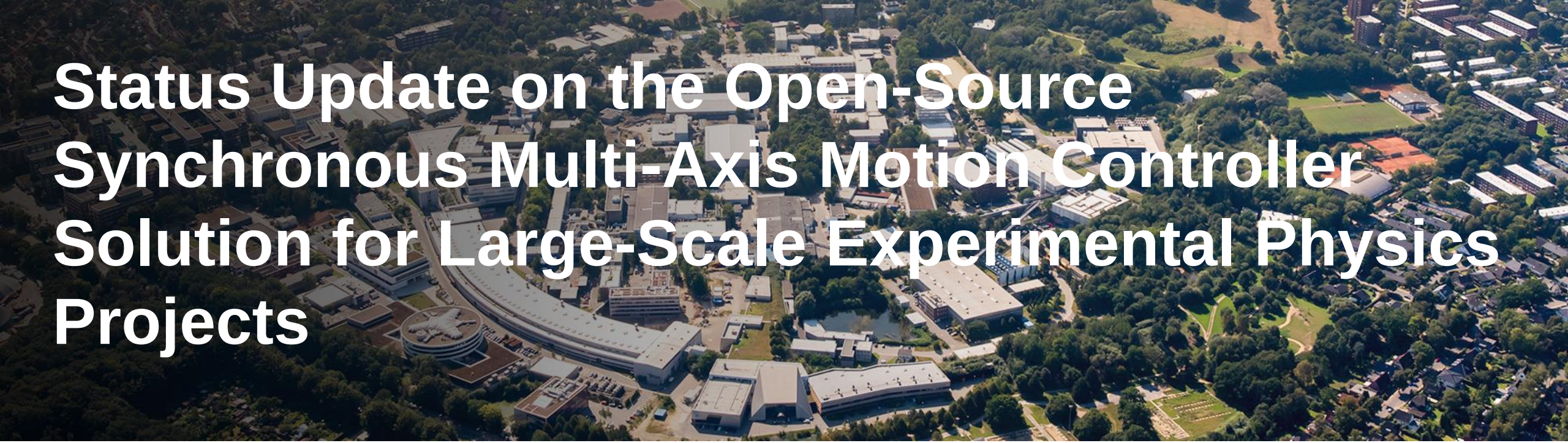


# Status Update on the Open-Source Synchronous Multi-Axis Motion Controller Solution for Large-Scale Experimental Physics Projects

Michael Randall, Cagil Guemues, Michael Fenner, Martin Killenberg, Jens Georg, Patrick Huesmann, Stanislav Chystiakov, Martin Tolkiehn, Linus Pithan

Hamburg, 11th of December 2024

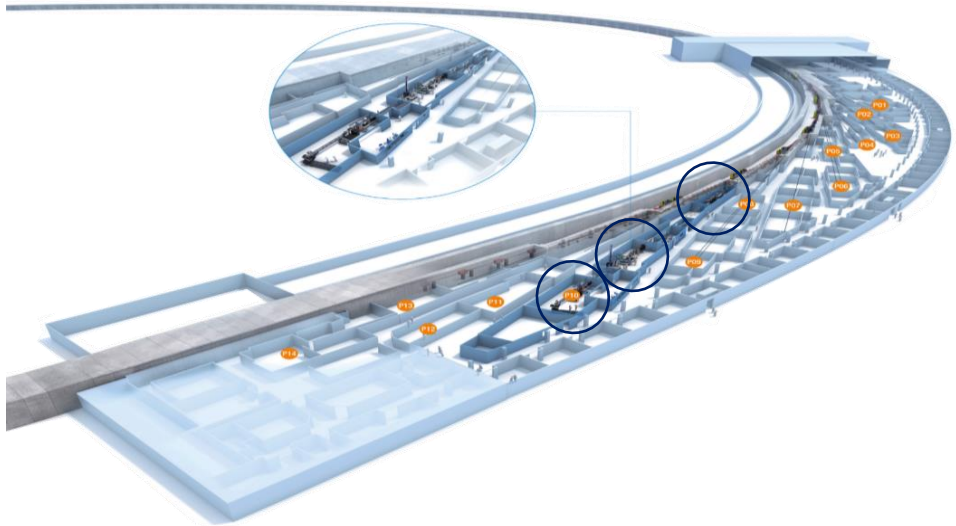
HELMHOLTZ

DESY.

# Motivation

**DESY Experimental Needs:**

- Requirement to control motors in experiments.

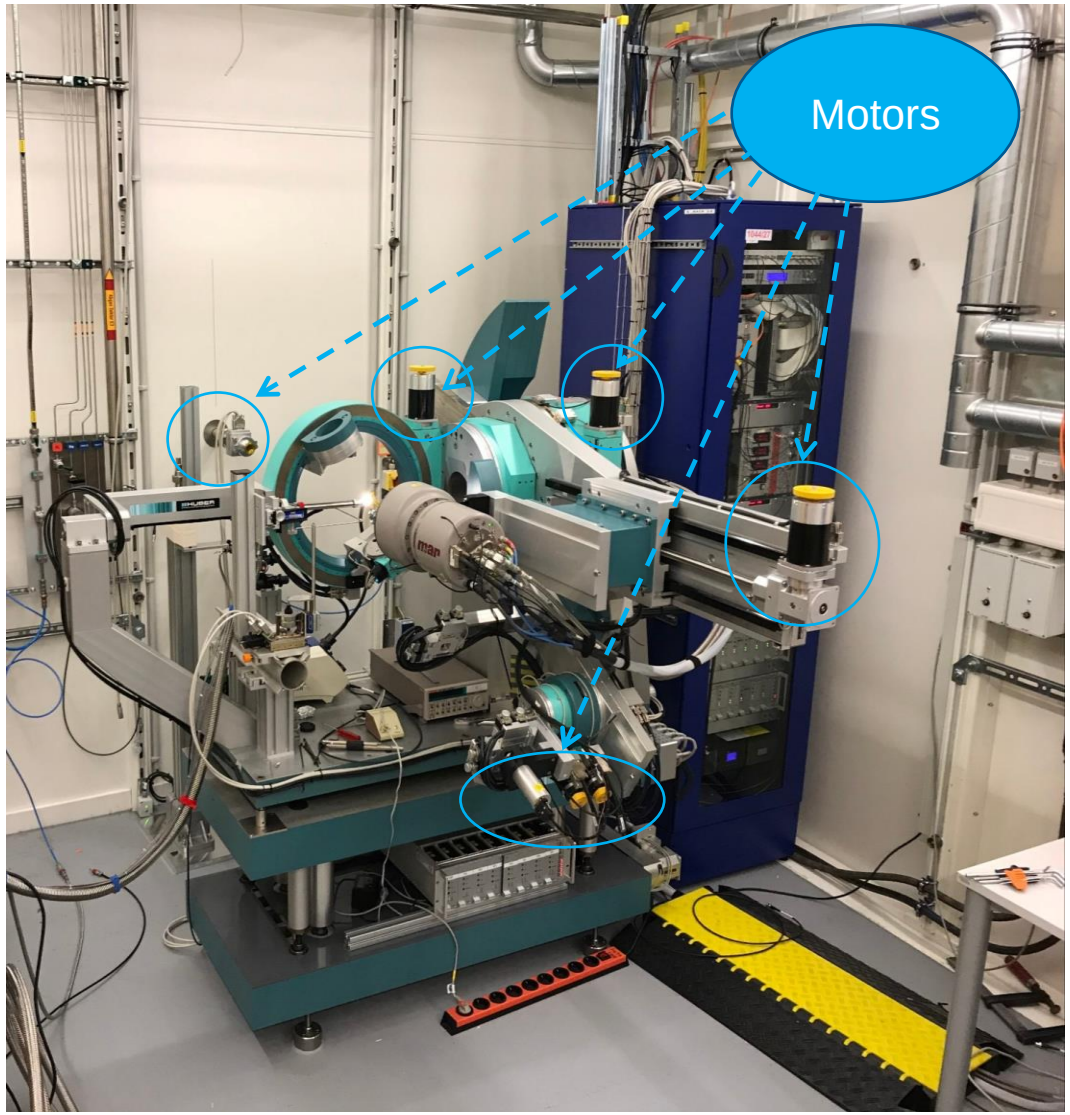


**Petra IV MicroTCA Infrastructure:**

- 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.



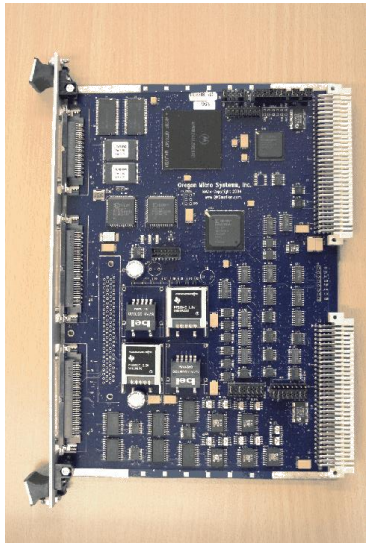

Diffractometer at Beamline
(Martin Tolkiehn)

# 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).
  - 4 cables per motor driver frame.
  - Wide connector unsuitable for MicroTCA.
- Limited number of encoders.
- Need for a drop-in replacement due to the outlined issues.


SCSI connector on back panel of DESY ZMX+ frame

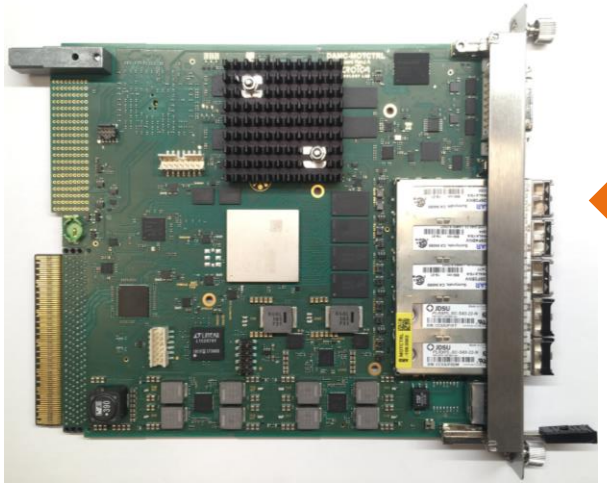


VME based Motion Controller - OMS MAXv

# Petra IV Motion Control

## Hardware

**DAMC-MOTCTRL:**
- Funded by DESY Generator Program.
- MicroTCA.4 based Motion Controller.
- Controls up to **48 motors/axis** 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.



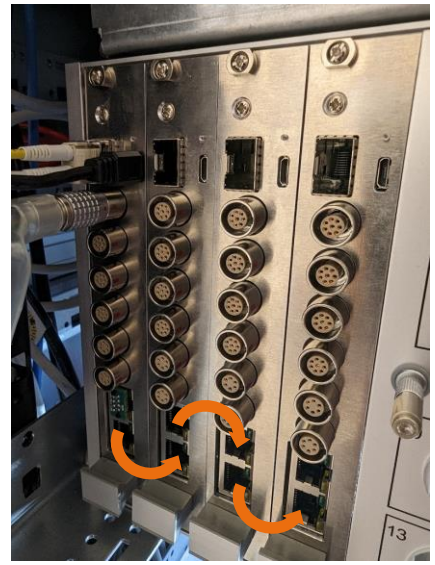
**Heterogeneous Processing:**
- Zynq UltraScale+ (XCZU2EG) with 2GB DDR4 32-bit.
- Kintex (XC7K160) with 4GB DDR3 64-bit.

**SFP+ Ports (5 in Total):**
- 3x Motor interfaces.
- 2x Ring topology (EtherCAT, SERCOS).

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

*Check out the 11th MicroTCA Workshop Talk about the Multi-axis Motion Controller

**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).



Interconnected ZMX+ Connection boards

# Petra IV Motion Control

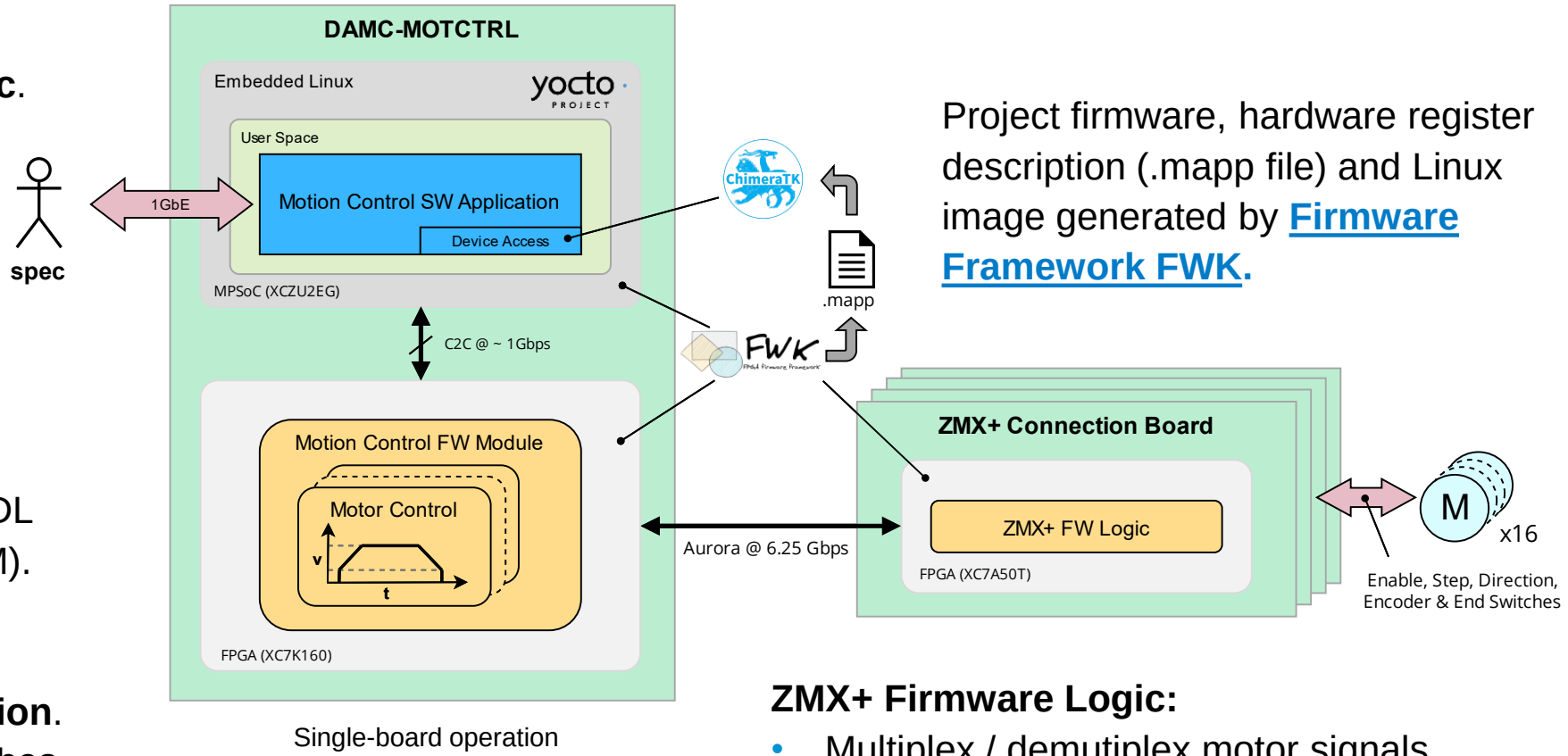
## Firmware Overview & Current State

**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 the Universal VHDL Verification Methodology (UVVM).
- Wraps per-axis submodules.
  - Linear acceleration profile.
- **Clock-edge synchronous motion**.
- Per-axis encoder and limit switches.




Single-board operation

Project firmware, hardware register description (.mapp file) and Linux image generated by **Firmware Framework FWK.**

**ZMX+ Firmware Logic:**

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

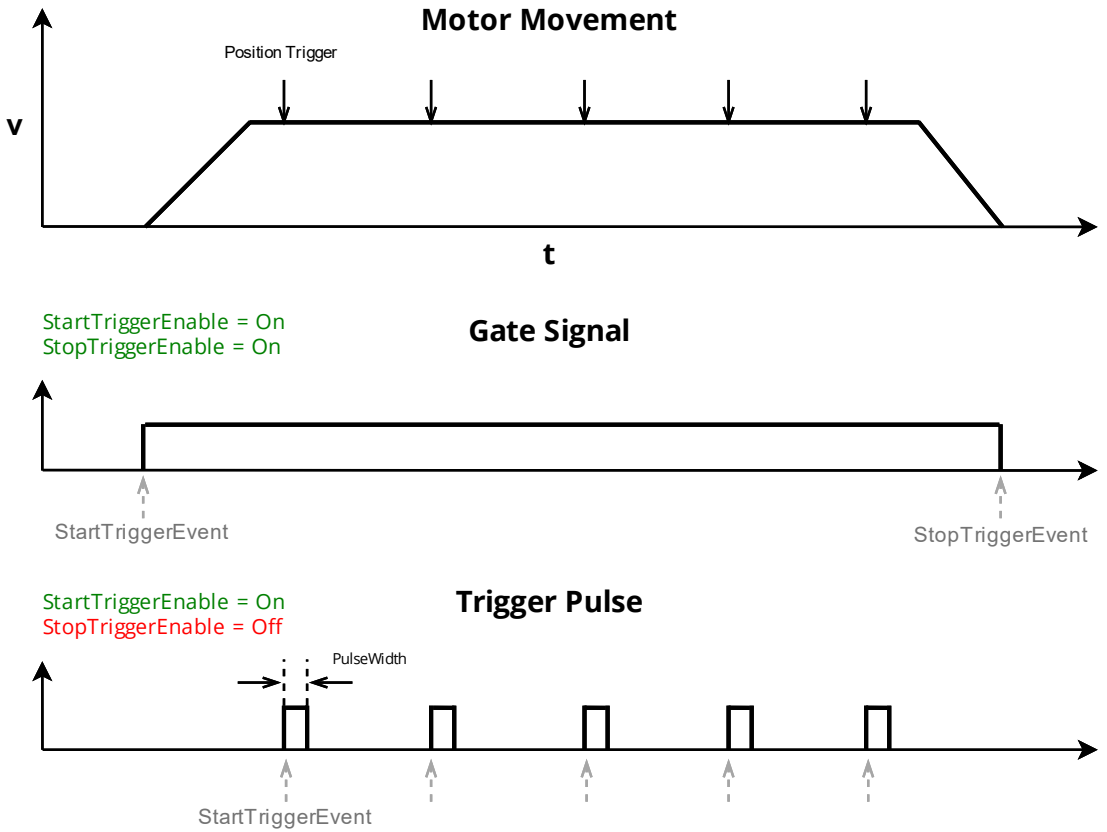
# Petra IV Motion Control

## Position Triggered Acquisition

- One of the earliest requests.
- Common solution:
  - Move-stop-trigger approach.
  - External step counter.

**New Trigger Capability Implemented:**

- Supports up to eight trigger signals.
- Trigger events:
  - Motor active.
  - Motor/encoder position change with divider.
  - Software trigger command.
- Trigger mode (rising/falling/any edge).
- Configurable pulse width.
- Routable to 24 GPIOs and µTCA backplane.




The **first version was released** and successfully applied in a live accelerator experiment. Check out the presentation materials of previous talk for more information.

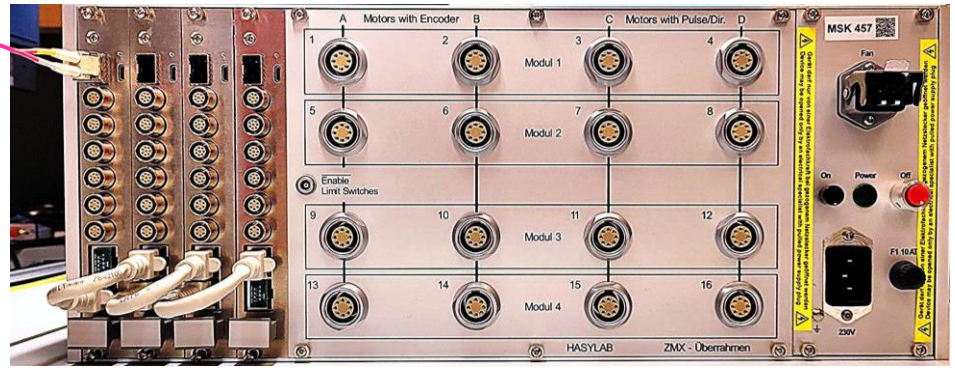
# Petra IV Motion Control

## Further Achievements / Next Steps

- **Full ZMX+ Crate Supported:** hosting 16 motor, per axis encoder and limit switches

+32 motors (soon)

Synchronization




ZMX+ Frame (backside)

- **Third Test System Operational;** additional installations scheduled for next year.
- **Valuable Feedback Loops:** Continuous user feedback driving improvements.
  - Example: Support for **absolute encoders** scheduled within the next six months.
- **Strong Demand for EtherCAT Interface:**
  - Short cycle times (<< 1 ms) and precise synchronization (<< 1µs)
  - Seamless synchronization with other commercial off-the-shelf components
  - Solution for inter-board synchronization
  - Standardized CiA402 Motion Control Profile for Control Software Integration

# Petra IV Motion Control

**Check out the source code and documentation:**

- **Open-Source Petra IV Motion Control Project**
- **Open-Source Motion Control Firmware Module**

**Contact**

Deutsches Elektronen-Synchrotron DESY

Michael Randall (FW/SW); Cagil Guemues (FW); Jens Georg (SW); Michael Fenner (HW)
MSK

www.desy.de

# Thank you