Backward Endcap EMC Status

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- EMC Meeting -

09.03.2023

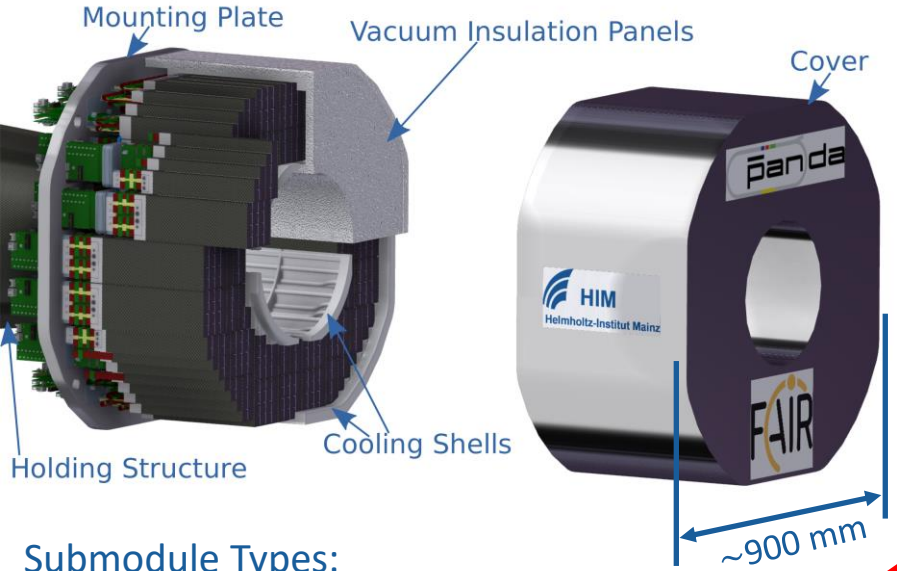
Outline

1. **FAIR Phase-0 Detector Component Status**
   - Finalising Mass Production of Detector Components
   - Electronics
   - Insulation Cover

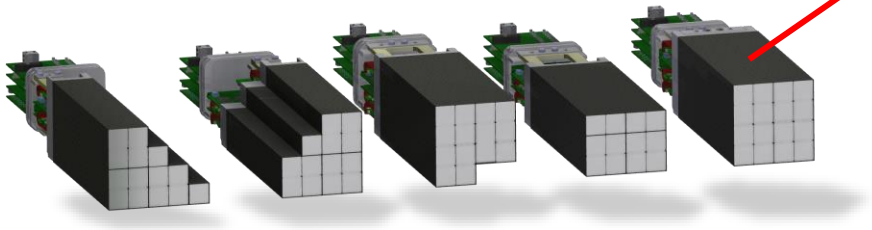
2. **Calibration of Detector Submodules**
   - Development of Procedure finished (Master Thesis)

3. **Detector Control System and Hardware Description**
   - Full EPICS Integration (new Master Thesis)
   - Improvement of DCS Web Interface
   - FAIR Phase-0 SADC Firmware

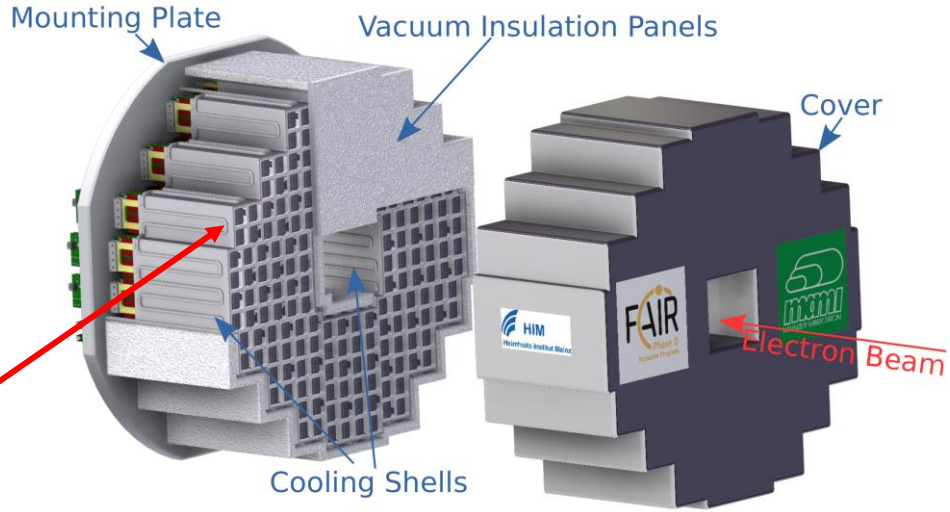
The PANDA Backward Calorimeter



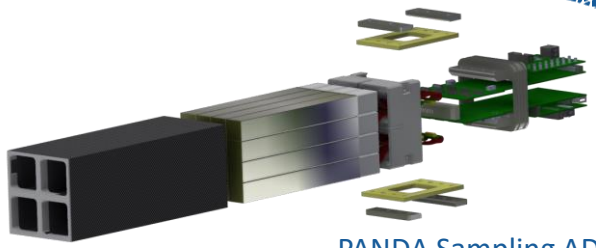
Submodule Types:



Phase-0 - Version



Detector Components



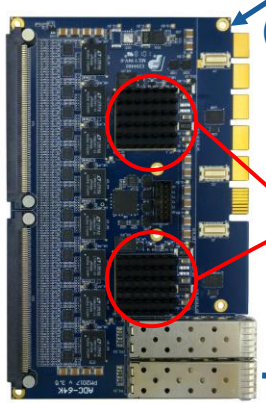
High Voltage and APFEL Control

Amplification

Temperature Readout

PANDA Sampling ADC (SADC)

(P. Mariciniewski)



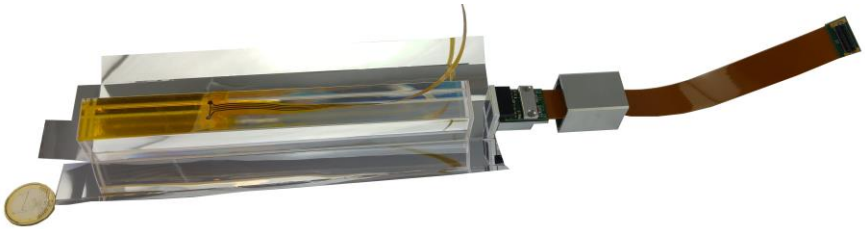
Field Programmable Gate Arrays

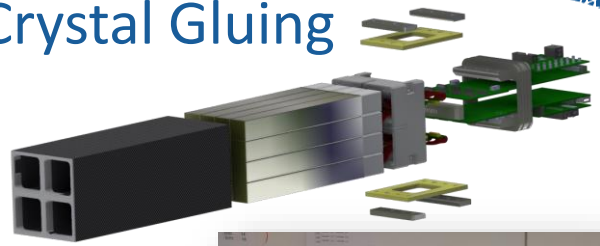
(E, T_0)

- Analogue signals from APFEL
- Transmission via Front-End electronics (green)
- Digitisation on SADC

Detector → Amplification → Transmission → ADC → FPGA → Data Concentrator → Compute Nodes

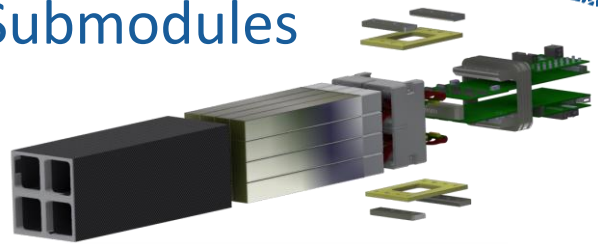
FAIR Phase-0 Detector Component Status - Crystal Gluing



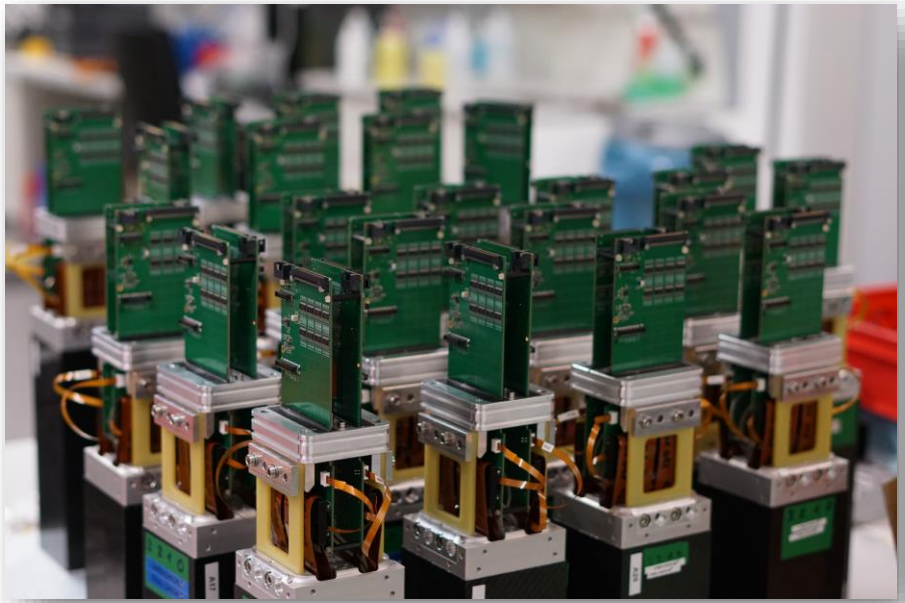


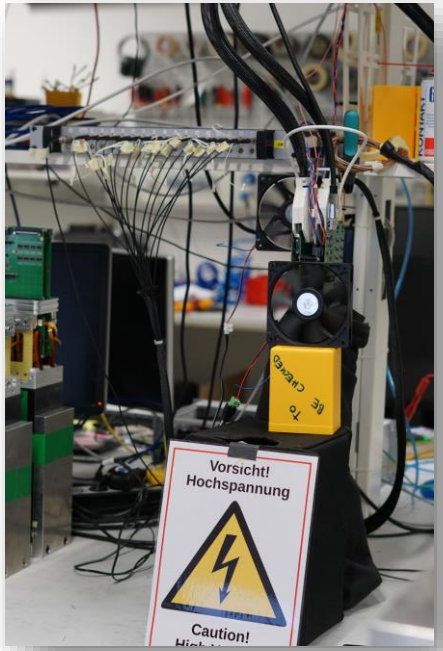
- 640/640 crystals glued ✓
- Fixtures back in Gießen ✓
- Thank you to Gießen! ♥

FAIR Phase-0 Detector Component Status - Submodules



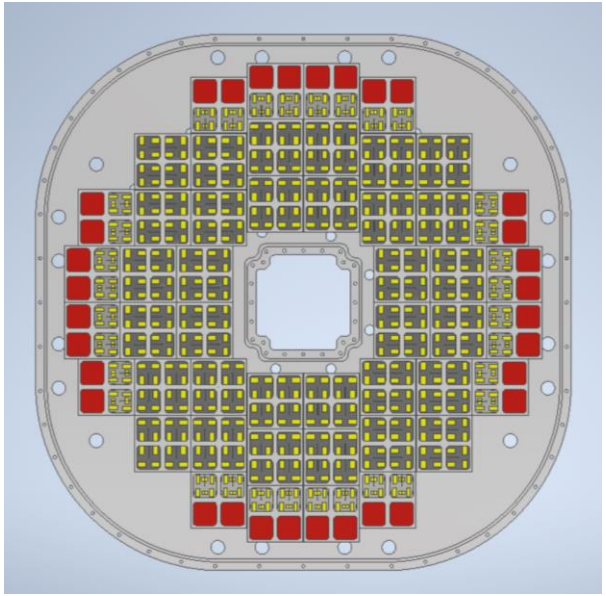
- 578/640 crystals wrapped
- 32/32 full equipped submodules are built ✓
- 32/32 full equipped submodules succeeded pre-test ✓

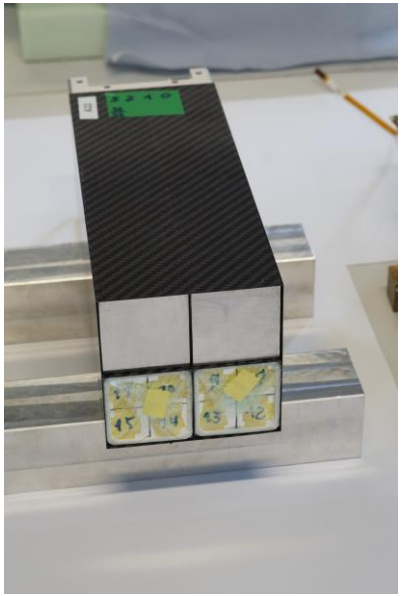


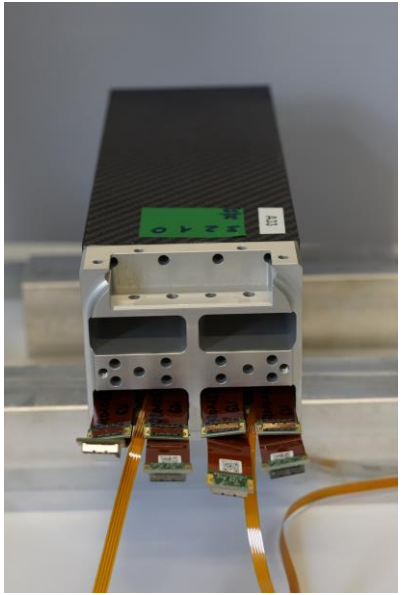


FAIR Phase-0 Detector Component Status - $^1/_2$-Submodules

- First half submodule is built 1/16
- Aluminum dummies



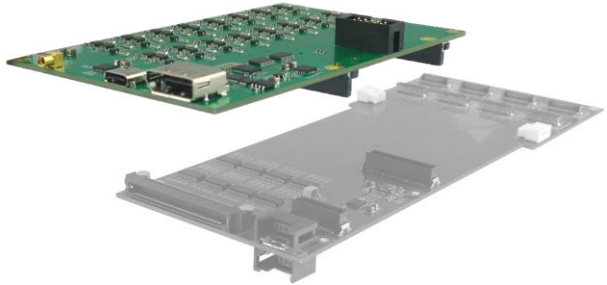




FAIR Phase-0 Detector Component Status - Electronics

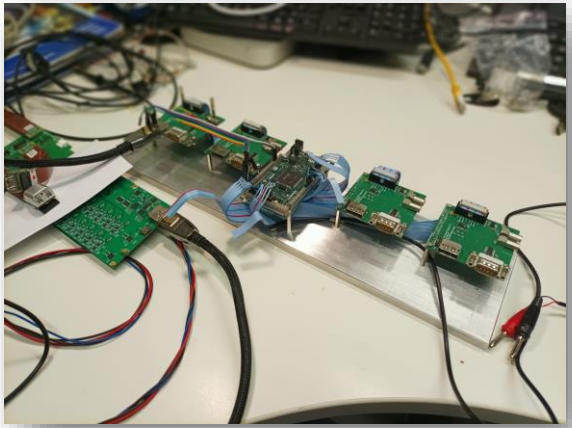
HV Distribution Board

- All components are there
- In-house assembly
- 10/55 HV board pairs (pre series)
- Rest will be assembled within the next months
- No impact on calibration of submodules



APFEL Control

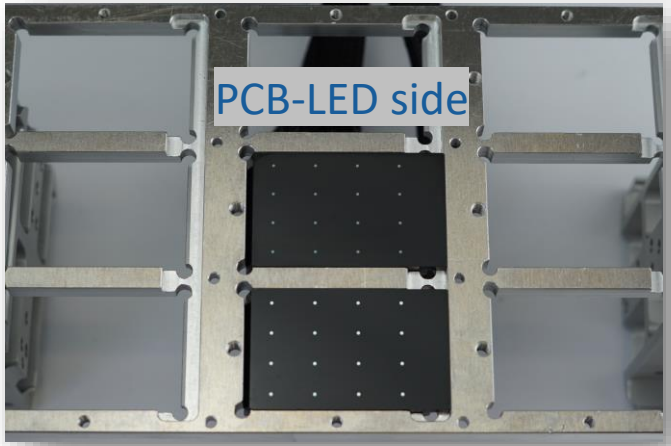
- Scalable concept for the experiment
- Microcontroller based (Arduino Due)
- 8 Submodules per microcontroller
- Plan: Control one quarter of detector (10 Submodules)
- First tests successful

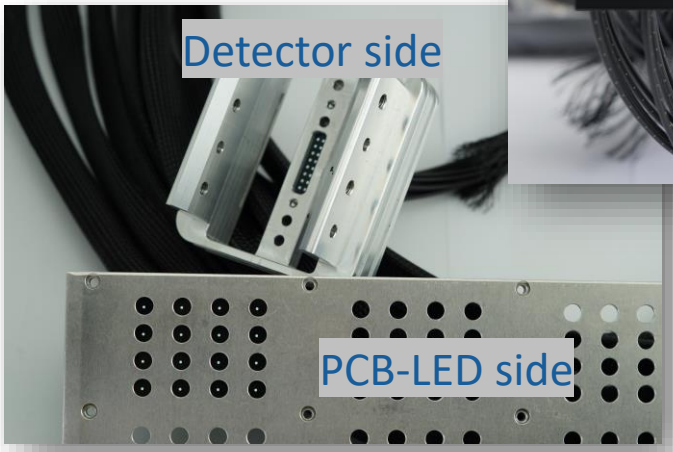


FAIR Phase-0 Detector Component Status - Electronics

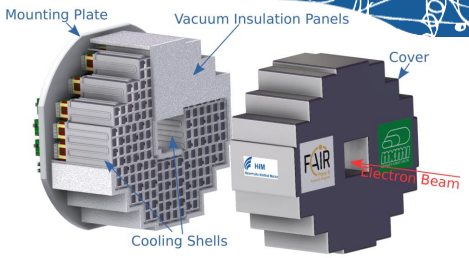
LED Light Pulser System

- Individual light intensity adjustment for each crystal channel
- One master PCB and 5 slave PCBs for up to 720 channels
- All mechanical parts are manufactured
- 10/55 light fiber bundles are assembled and polished
- PCBs about to be ordered
- All electronics components are there

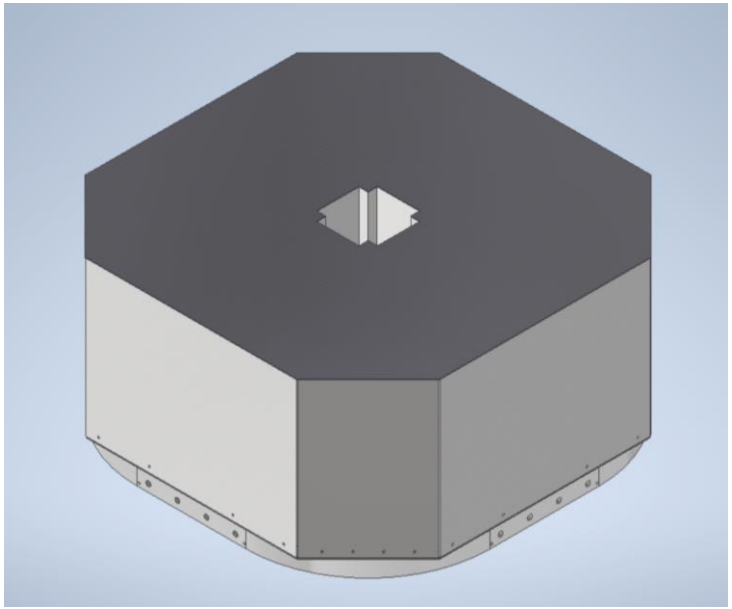


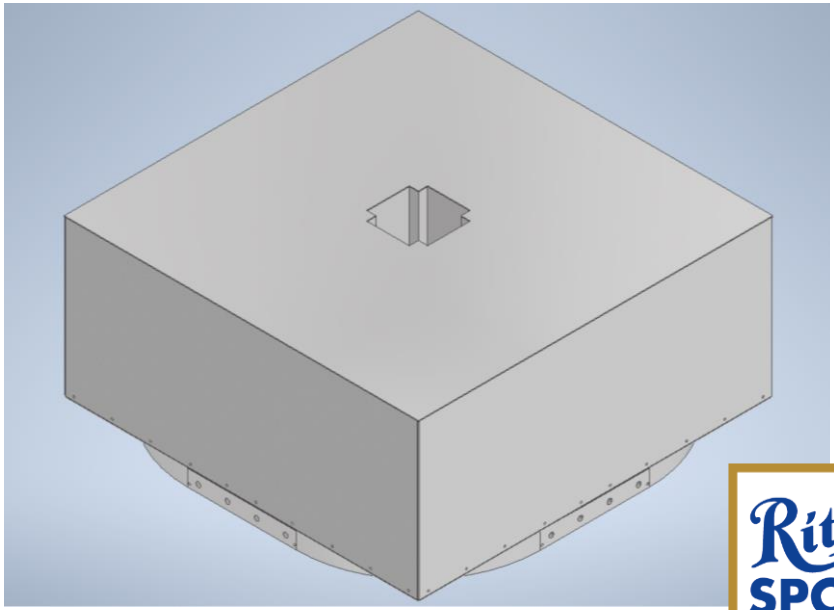


FAIR Phase-0 Detector Component Status - Cover



- Manufacturing limitations (welding, bending, …)
- The simpler the better
- Smaller volume better for cooling and homogeneity

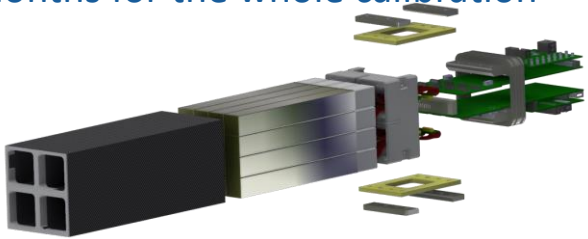




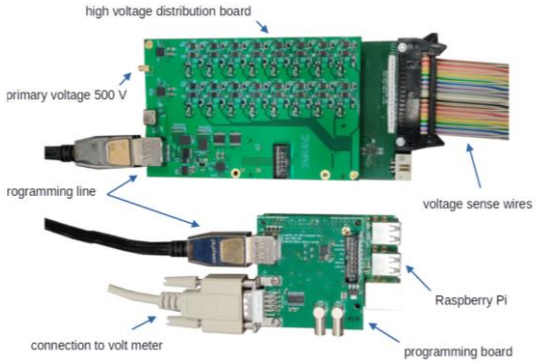
QUADRATISCH. PRAKTISCH. GUT.

Calibration of Detector Submodules

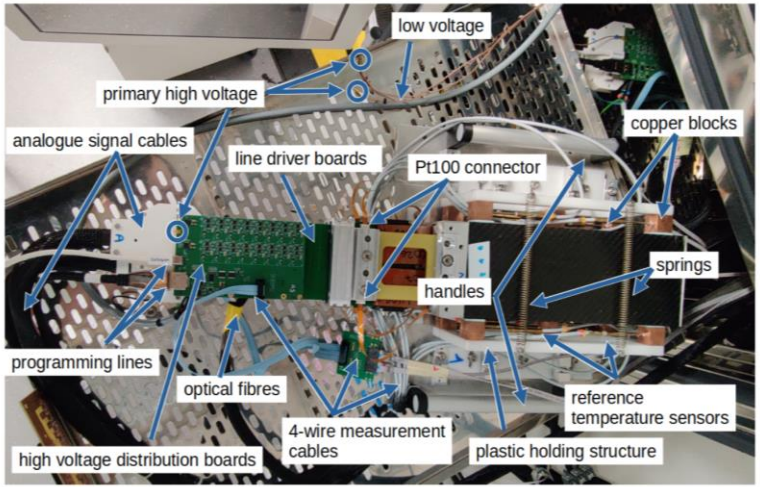
- Master Thesis finished (Samet Katilmis)
- Calibration consists of
  1. Calibration of high voltage distribution boards
  2. In-situ temperature sensor calibration
  3. In-situ APD gain determination (crosscheck)
  4. Energy calibration utilising cosmics
- Full automatised setup
- Three submodules per cycle
- 72 h per cycle
- 48 submodules (32 full, 16 half)
- ~2 months for the whole calibration



Calibration of Detector Modules for the PANDA Backward Electromagnetic Calorimeter
Master Thesis, Samet Katilmis, March 2023

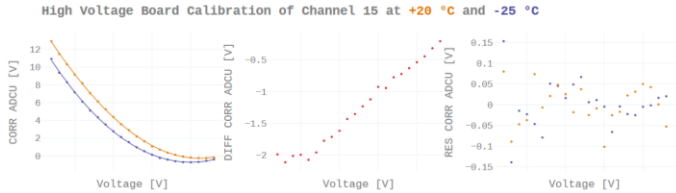


High voltage distribution board calibration setup

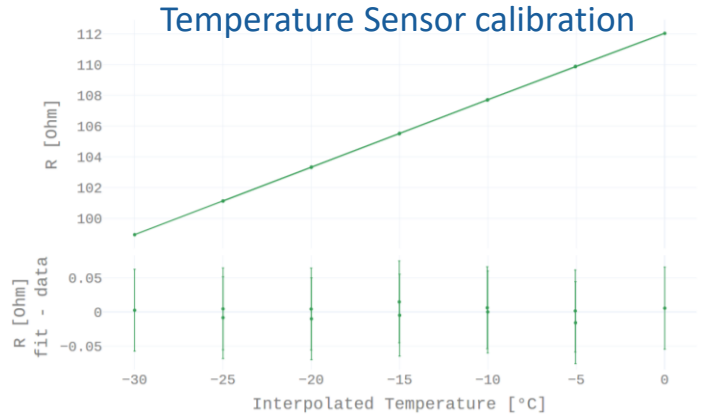


Bird's eye view of a drawer with a full equipped submodule

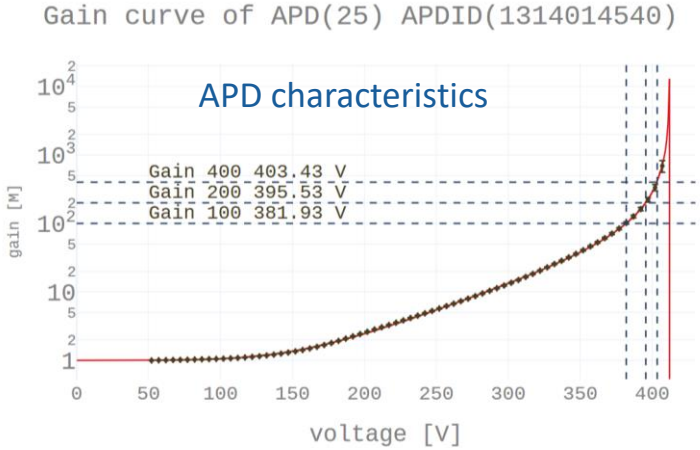
Calibration of Detector Submodules



HV distribution boards correction



Temperature Sensor calibration



APD characteristics

Output of calibration:

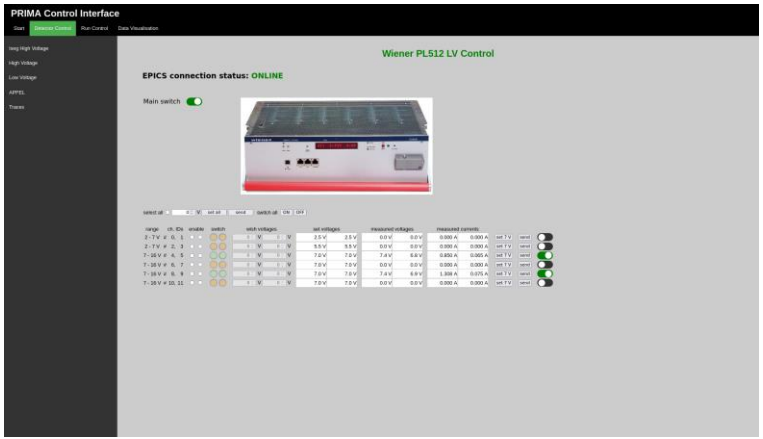
1. Data sheet for every submodule
2. Data base entries for all necessary parameters

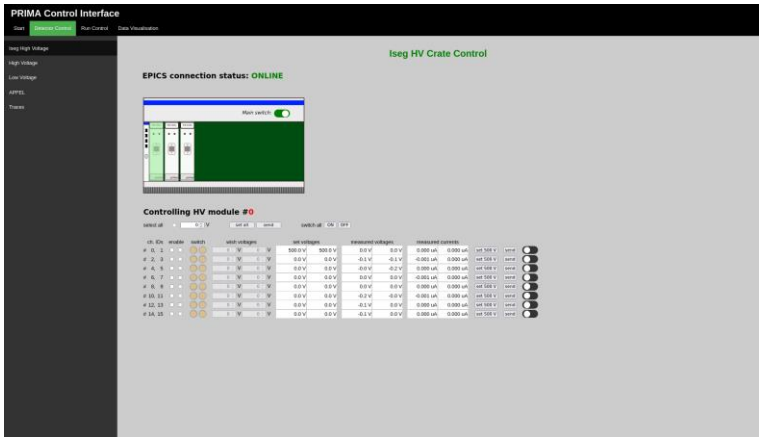
Calibration of Detector Modules for the PANDA Backward Electromagnetic Calorimeter
Master Thesis, Samet Katilmis, March 2023

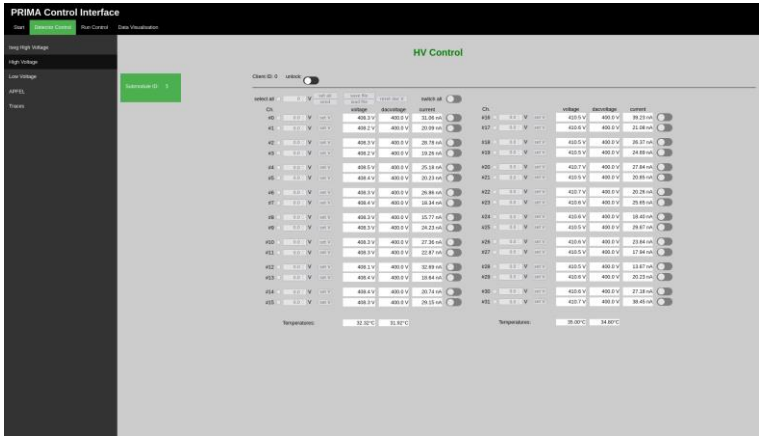
Full EPICS Integration

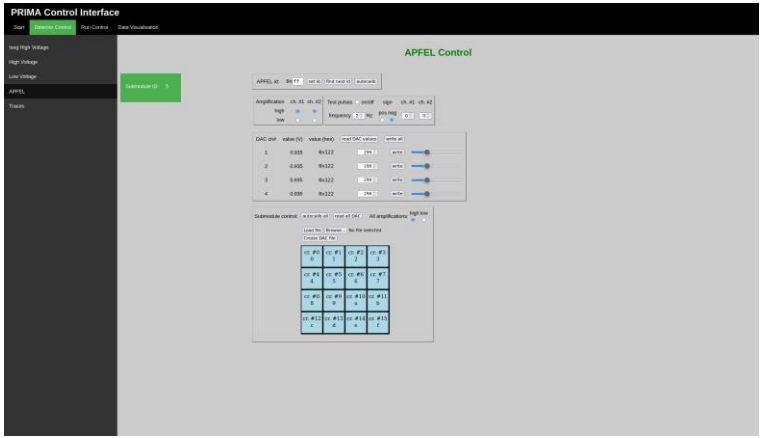
- New Master thesis started in January (Ravi Gowdru)
- Update EPICSs to latest (PANDA) standards
  - All applications containerised (Docker)
  - Modular, portable and platform independent
- Already updated:
  - High voltage
  - Low voltage
  - Light pulser
- To be updated:
  - Temperature readout
  - APFEL preamplifier
  - Front-end boards
  - Cooling
- Archiver
- Stress test with the whole DCS system

Improvement of DCS Web Interface

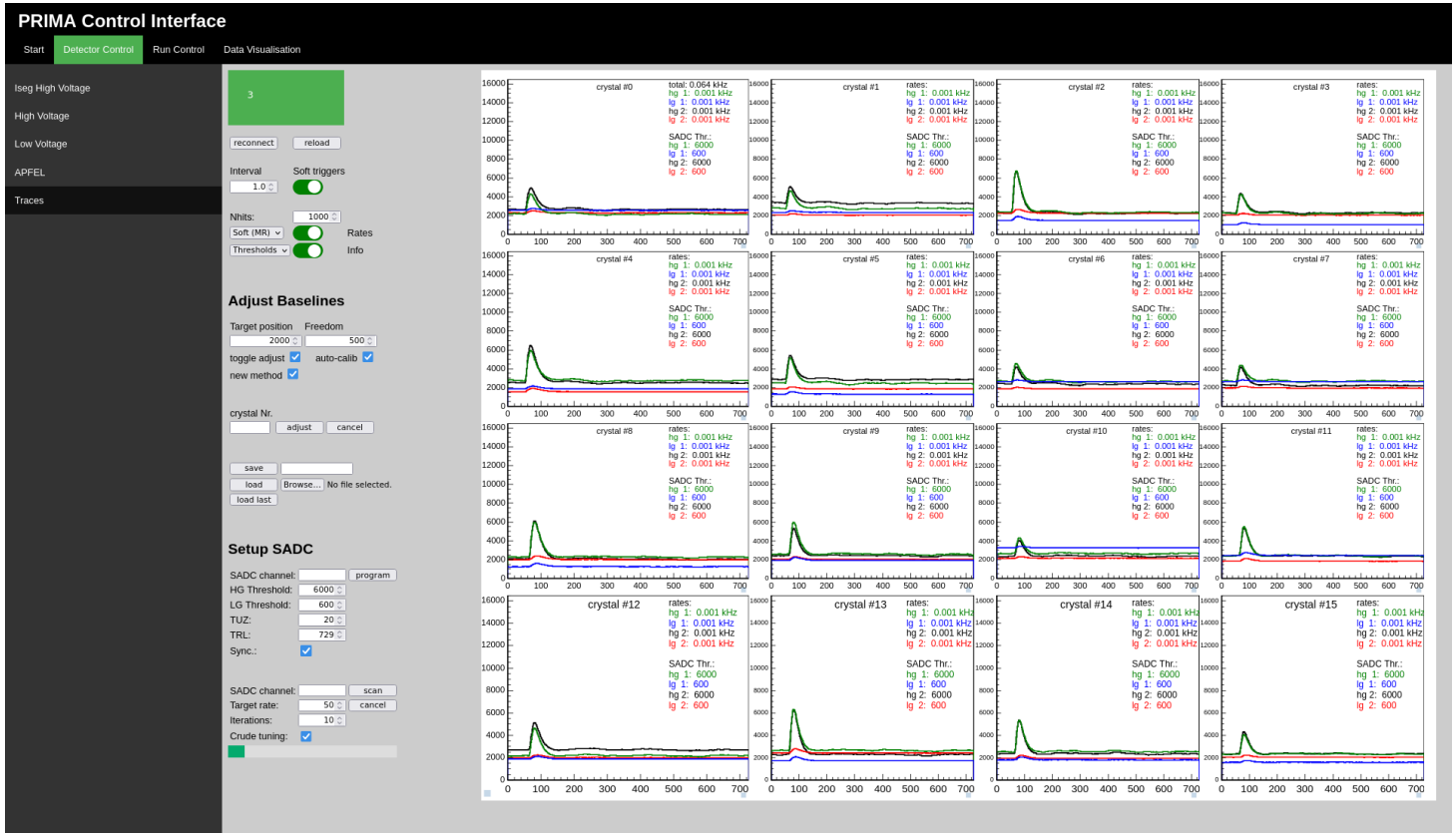








Improvement of DCS Web Interface



FAIR Phase-0 SADC Firmware

SADC V. 3.5 Mainz Firmware

- Used for all laboratory tests
- Feature extraction (hits)
- Traces recording
- Rate determination
- Status readout (thresholds and other settings)
- High hit rate capability **but unsorted hit packaging**

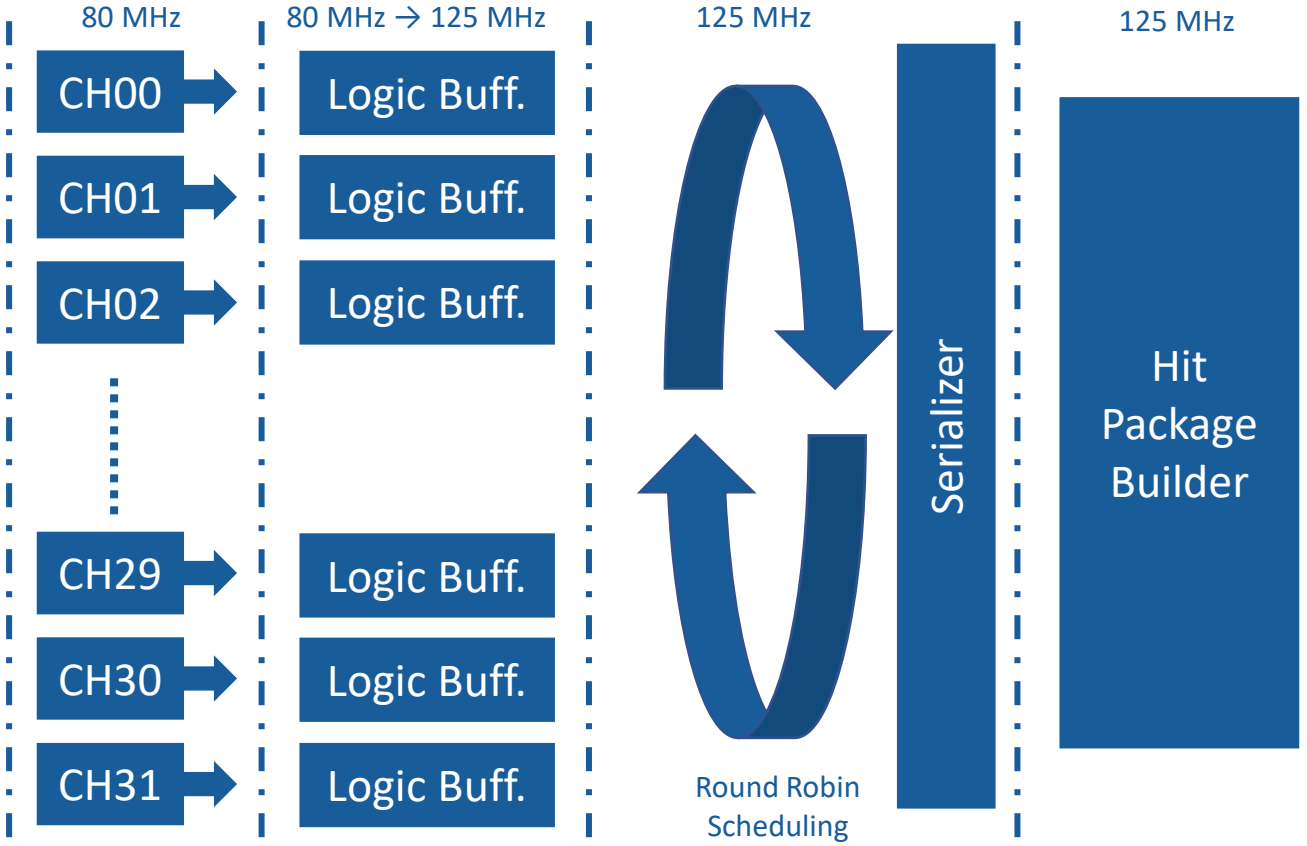
https://gitlab.rlp.net/emp/sadc_v_3_5

SADC V. 3.5 FAIR Phase-0 Firmware

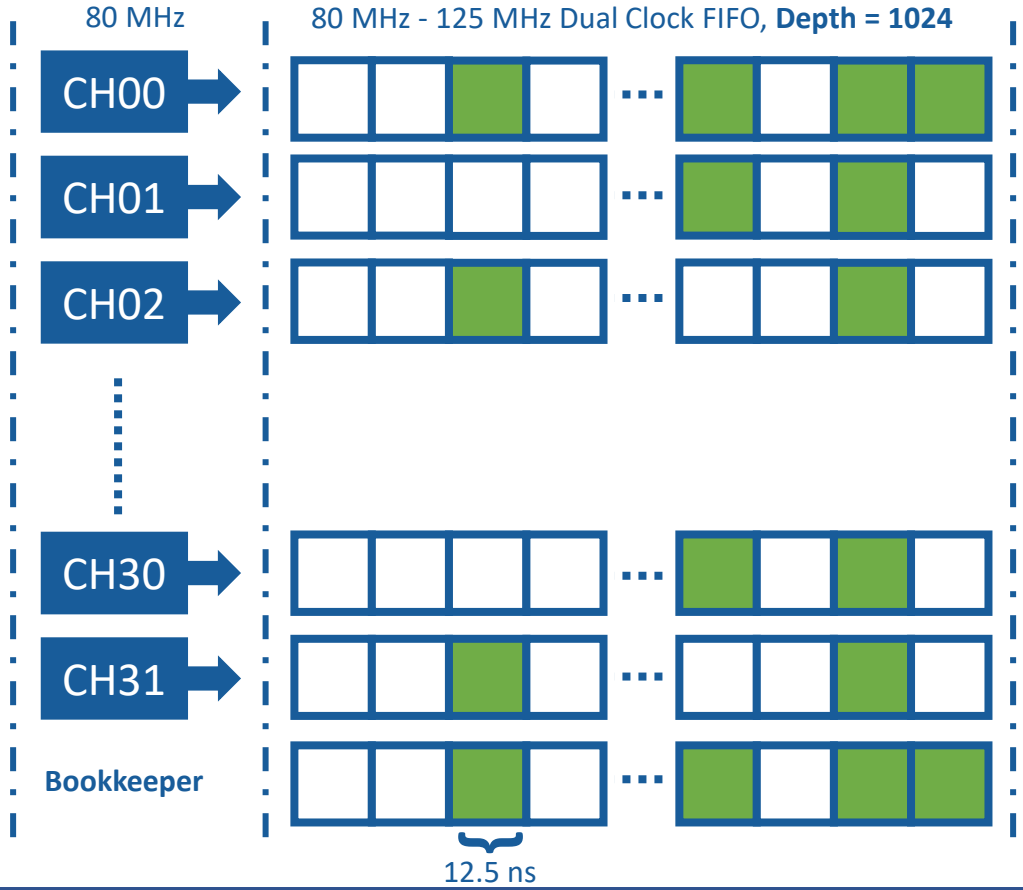
- Same core features
- Time sorted hit packaging
- Hardware trigger
- Inter FPGA communication
- Data stream → one SFP
- Data concentrator ready

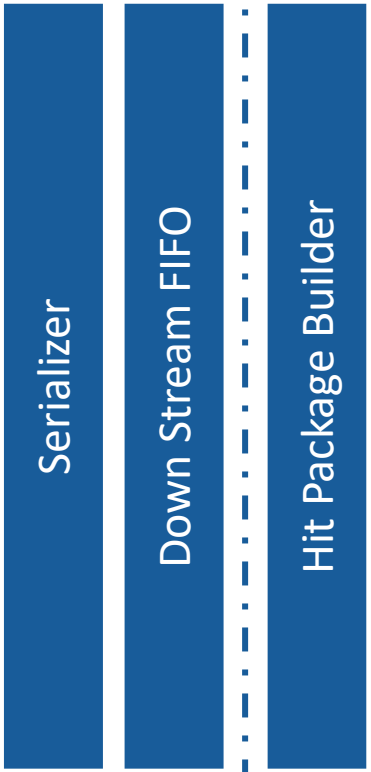
https://gitlab.rlp.net/emp/sadc_Phase-0

Unsorted Hit Structure (SADC V. 3.5 Mainz Firmware)



Sorted Hit Structure (SADC V. 3.5 FAIR Phase-0 Firmware)





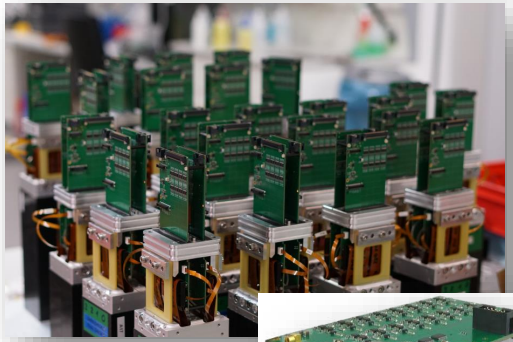
<Header>
<Raw Time>
<Num Hits> **N**
1.CH,FINETIME,AMP
2.CH,FINETIME,AMP
...
N.CH,FINETIME,AMP

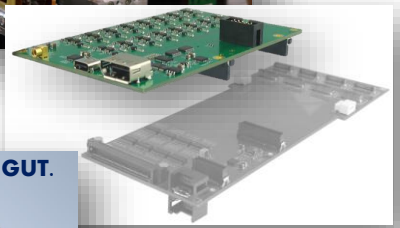
Dynamic Package Size

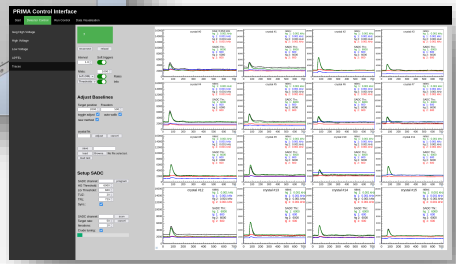
Raw Time: $[0,2^{34}-1] \cdot 12.5\ ns$
Fine Time: $[0,2^{6}-1] \cdot \frac{12.5\ ns}{64}$

Summary

- Mass production of submodules
  - All crystals are glued, fixtures back in Gießen
  - Almost all single crystal units are assembled
  - All full submodules are produced and succeeded pre-test
  - Production of half submodules is about to start
- Electronics
  - HV boards need to be assembled
  - APFEL control via microchip, test setup works
- Cover design optimisation
- Calibration of submodules
  - Procedure completely developed
  - Fully automatised
  - ~2 months for the whole calibration
- DCS and DAQ
  - EPICs integration is ongoing
  - DCS user interface
  - Phase-0 SADC firmware







The Anomalous Magnetic Moment of the Muon

Dirac Theory:

Dirac equation with EM-field:

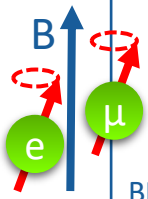
$$\left(i\gamma^\mu \partial_\mu - e\gamma^\mu A_\mu - m\right)\psi = 0$$

Nonrelativistic limit ($E \approx m$):

$$\frac{1}{2m}\left|\vec{p} - e\vec{A}\right|^2 \psi - \underbrace{\frac{e}{m}}_{\mu_s}\vec{S}\cdot\vec{B}\psi = 0$$

$$g = \frac{\mu_s}{\mu_L} = 2 \qquad a_l = \frac{g_l - 2}{2} = 0$$

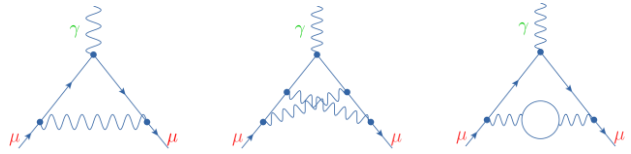
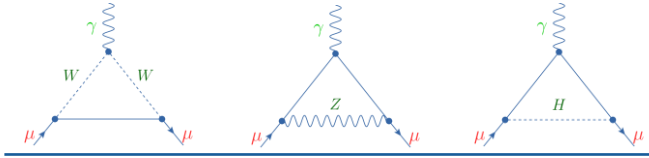
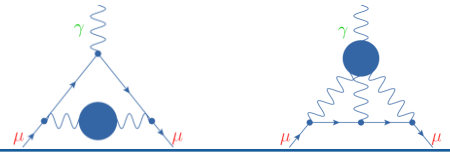
Messung:



$$\omega_L = \frac{g}{2}\cdot\frac{eB}{m} \qquad \omega_c = \frac{eB}{m}$$

$$a_\mu^{\text{Exp.}} = 0.00116592089(63)$$

BNL (E821) 2006

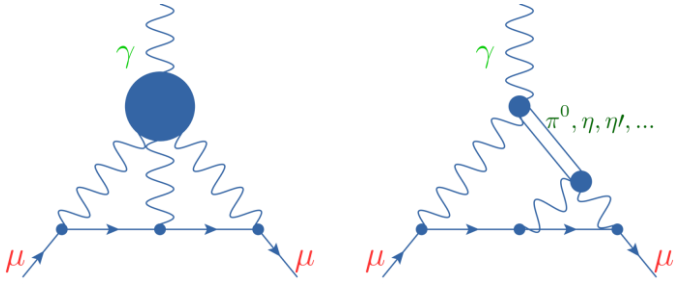
$a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{QCD}}$	Δa_μ^{SM}
	0.01×10^{-10} T. Aoyama et al. 2012
	0.10×10^{-10} C. Gnendiger et al. 2013
	Each: $\sim 3 \times 10^{-10}$ F. Jegerlehner 2019

$$a_\mu^{\text{SM}} = 0.00116591782(43)$$
$$a_\mu^{\text{Exp.}} = 0.00116592089(63)$$

4σ

Reduction of the Uncertainty on a_μ^{SM} by a Data-Driven Approach

Hadronic Light-by-Light Scattering



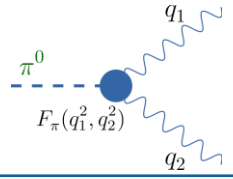
Light Pseudo Scalar Mesons, PS = π^0, η, η'

Data-Driven Approach

Integral over Transition Form Factors (TFF) $F_{\mathrm{PS}\gamma^*\gamma^*}(Q_1^2, Q_2^2)$ with virtual space-like momenta $Q_{1,2}^2$:

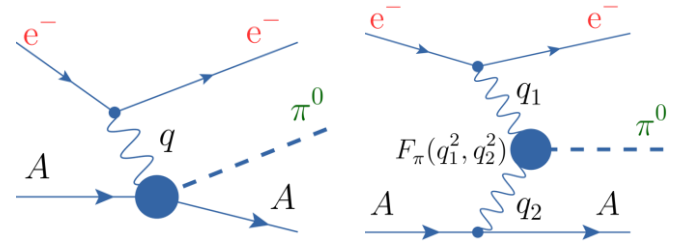
$$a_\mu^{\mathrm{HLbL,PS}} = \int_0^\infty dQ_1 \int_0^\infty dQ_2 \int_{-1}^{1} d\tau\, w(Q_1, Q_2, \tau) F_{\mathrm{PS}\gamma^*\gamma^*}(-Q_1^2, -(Q_1+Q_2)^2) F_{\mathrm{PS}\gamma^*\gamma^*}(-Q_2^2, 0)$$

Numerically greatest contribution : $F_{\pi^0\gamma^*\gamma^*}$

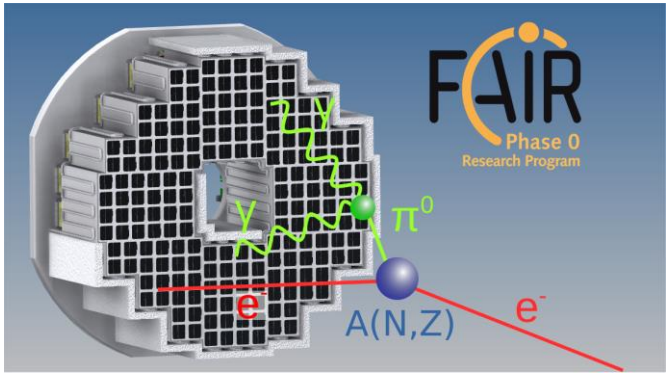


V. Pauk, M. Vanderhaeghen 2014, M. Hoferichter 2018

Primakoff π^0 Electroproduction



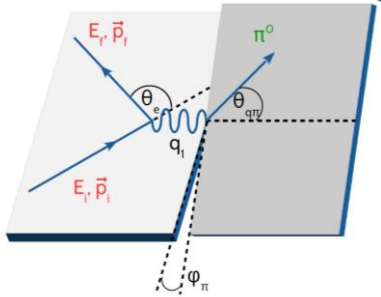
Contribution to coherent nuclear pion production



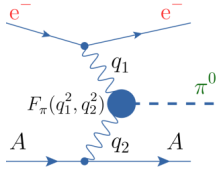
- Full developed FAIR detectors in stand-alone experiments
- PANDA backward calorimeter for FAIR Phase-0 at MAMI

The Primakoff π^0 Electroproduction

$$\left(\frac{d^5\sigma}{dE_f d\Omega_f d\Omega_\pi}\right)^{EP} = \frac{\lambda(q_1^2, q_2^2)}{8\pi^3 v_i}\alpha^2 Z^2 |\vec{p}_\pi| \frac{E_f}{E_i}\frac{1}{q_1^4 \vec{q}_2^4}\cdot\left[2(\vec{p}_i\vec{r})(\vec{p}_f\vec{r}) + \frac{1}{2}r^2 q_1^2\right]\cdot |F_{em}(\vec{q}_2^2)|^2$$



$$\lambda(q_1^2, q_2^2) \propto |F_\pi(q_1^2, q_2^2)|^2$$



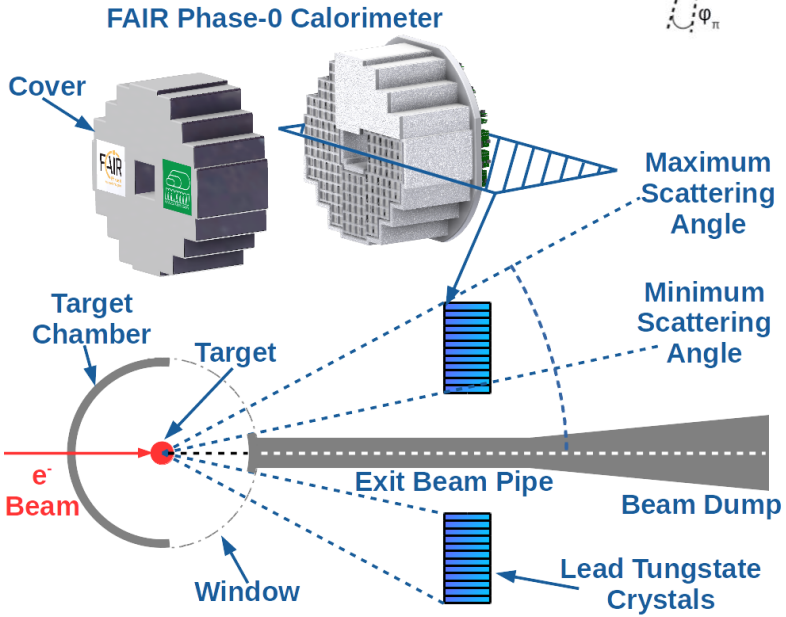
Kinematics: Minimizing of $\vec{q}_2$

1. E_π maximized
   1. $E_\pi \cong E_i - E_f$
   2. $E_i \sim 1200$ MeV
   3. $E_f \sim 300$ MeV $- 700$ MeV
2. $Q^2 = 2E_iE_f(1-\cos(\Theta_e))$ small
   1. Θ_e small
   2. Θ_{q_1} small
3. $\Theta_{q\pi}$ within a few degree
4. Lorentz boost of photons

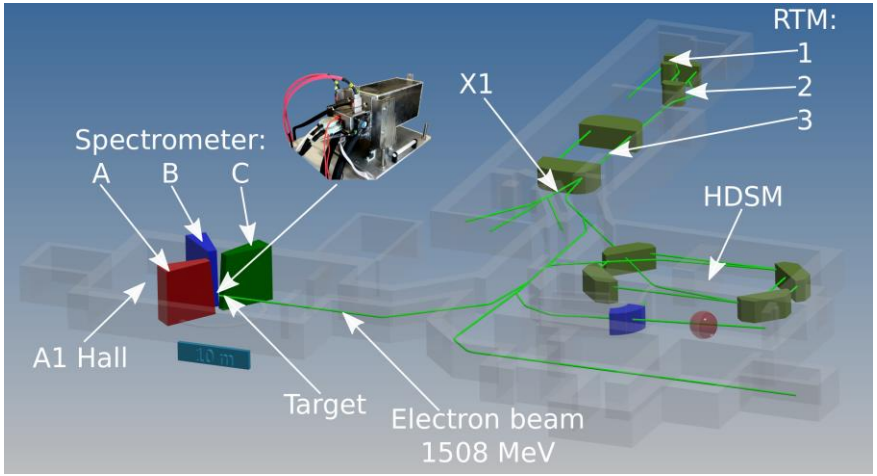
→ **Measurement at small forward angles**

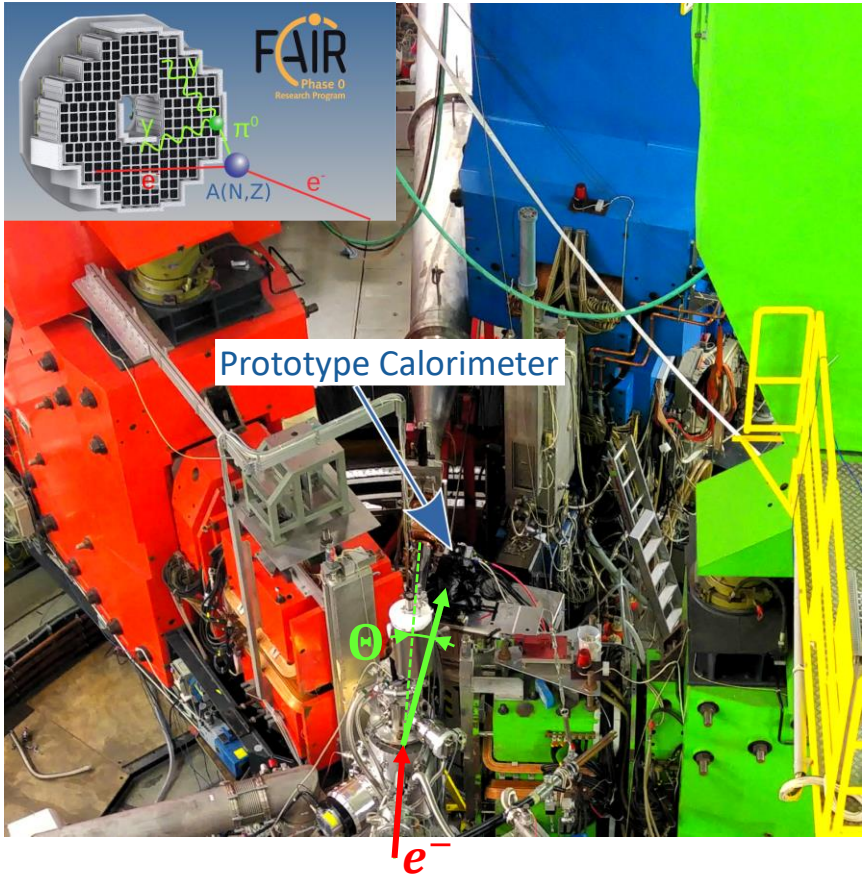
→ $-q_1^2 = Q^2 = [0.01, 0.05]$ GeV^2

→ $\Theta = 5° - 15°$



Exploratory Measurements and Simulations for FAIR Phase-0





- Determination of $\pi^0\gamma\gamma$ transition form factor
  → hadronic light-by-light contribution to $g_\mu - 2$
- Version of PANDA backward calorimeter
- Electron scattering at heavy nucleus (**Tantalum, Z=73**)
- Measurement in **forward direction**
- Strong low energy electromagnetic background
- **Relative energy resolution at small scattering angles?**