Backward Endcap EMC Status

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- EMC Meeting -

01.06.2022

Outline

1. **Mass Production of Detector Components**
   - Crystal Gluing
   - Submodule Assembly and Test Setup
   - HV-Board Issues

2. **Backward Endcap (Phase 0 Version)**
   - Cooling and Cover

3. **Preparation of Phase 0 Test Beam**

24.03.2022

Outline

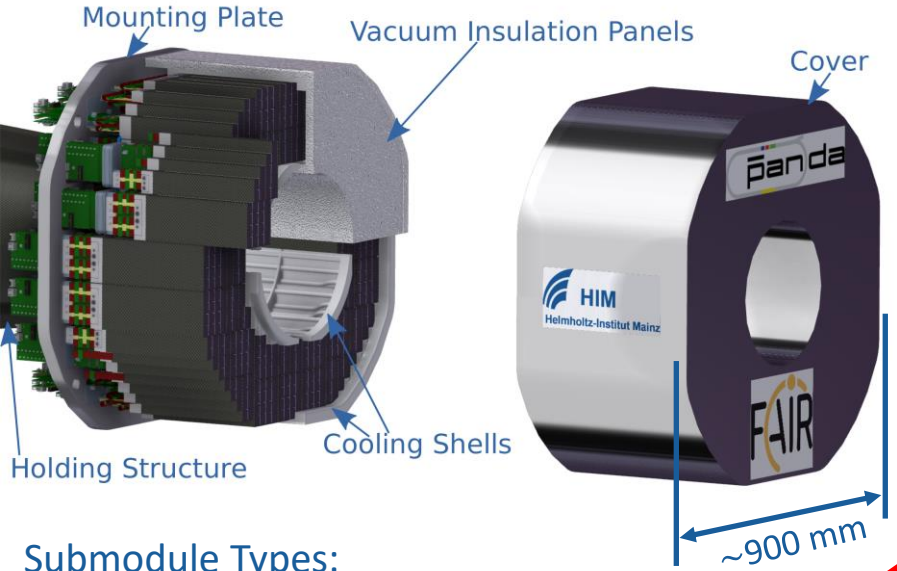
1. **Mass Production of Detector Components**
   - Crystal Gluing (Lessons Learned)
   - Submodule Assembly and Test Setup
   - HV-Board ~~Issues~~

2. **Phase 0 Test Beam April 2022**

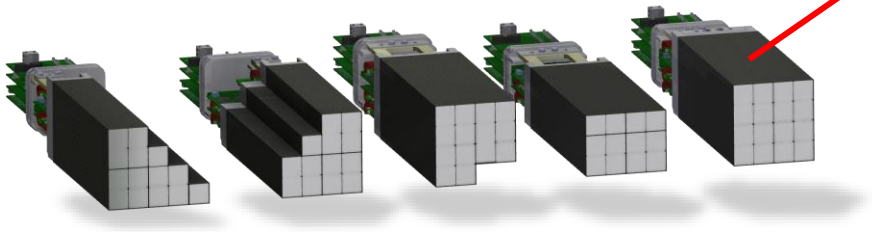
3. **Update of SADC Firmware**

today

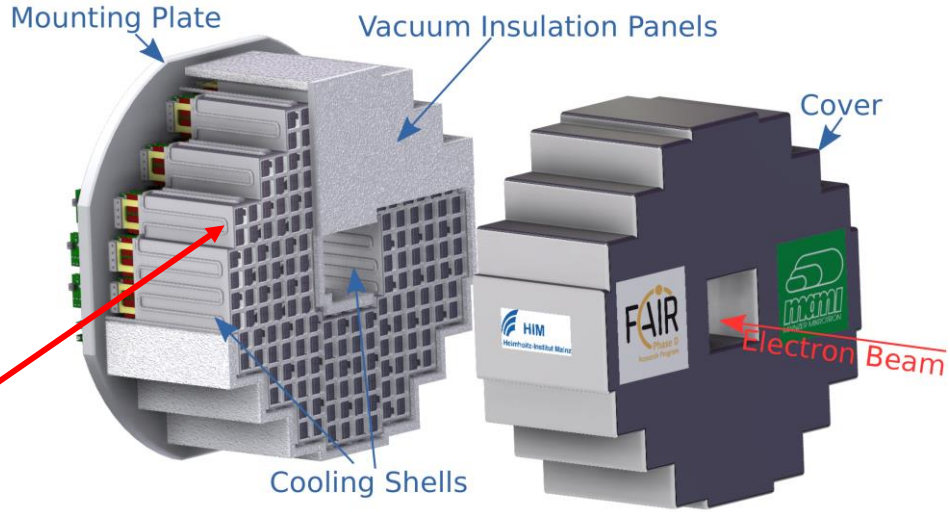
The PANDA Backward Calorimeter



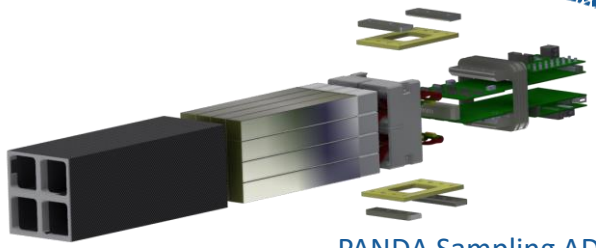
Submodule Types:



Phase 0 - Version



Detector Components



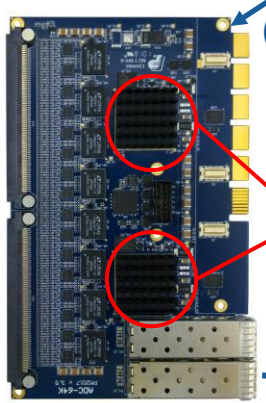
High Voltage and APFEL Control

Amplification

Temperature Readout

PANDA Sampling ADC (SADC)

(P. Mariciniewski)



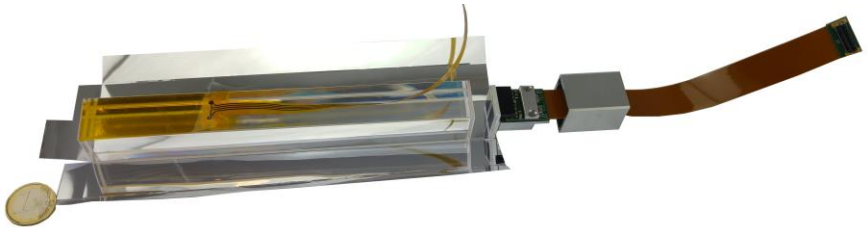
Field Programmable Gate Arrays

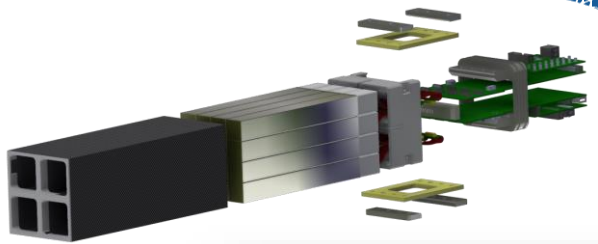
(E, T_0)

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

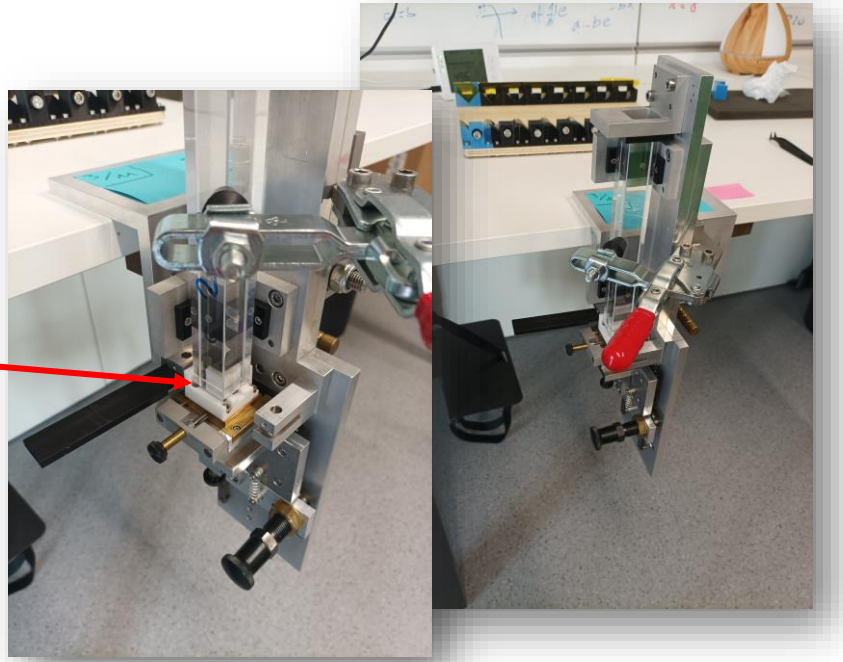
Detector → Amplification → Transmission → ADC → FPGA → Data Concentrator → Compute Nodes

Crystal Gluing



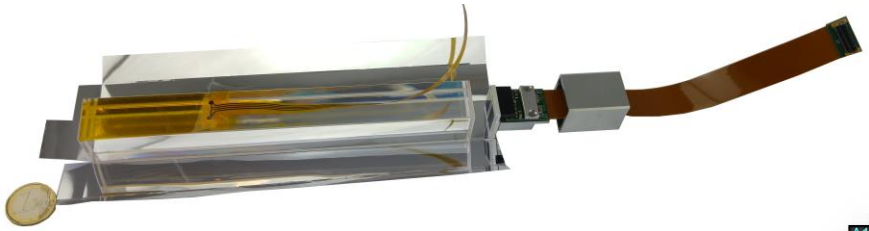


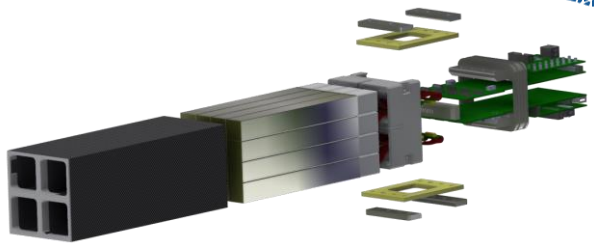
- Decision to use glue instead of optical cookies
- DOWSIL 3145 RTV-CLEAR
- Gluing fixtures from Gießen
- Small changes for Mainz crystals
- Learning process and optimisation



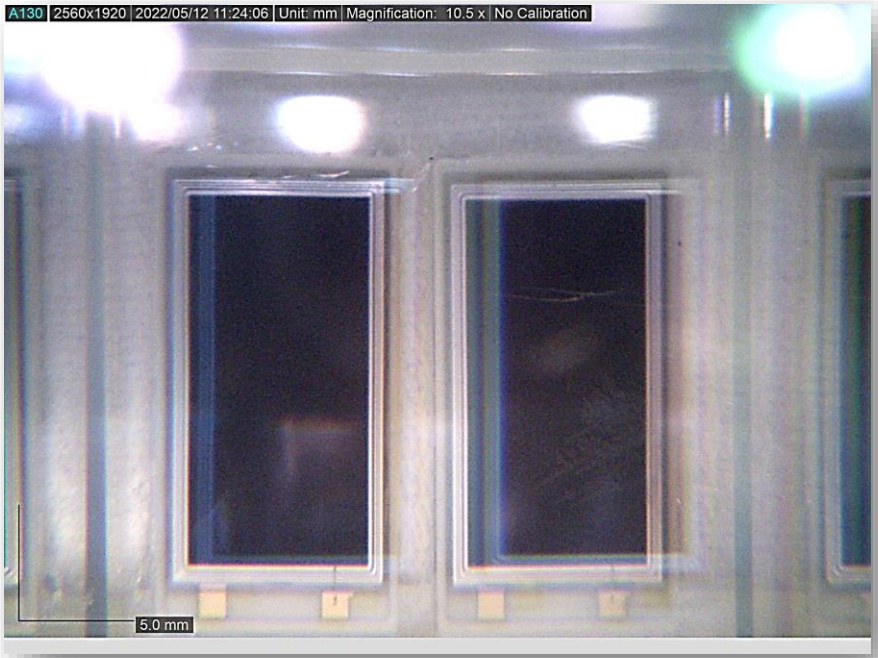
24.03.2022

Crystal Gluing – Lessons Learned

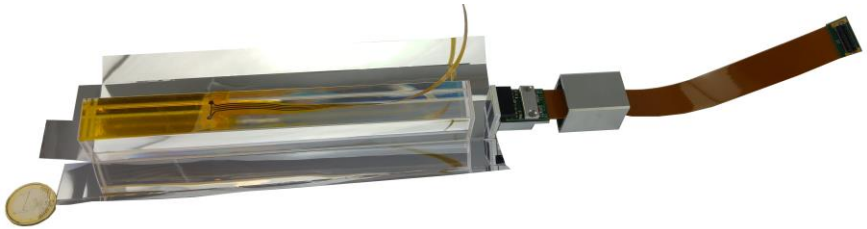


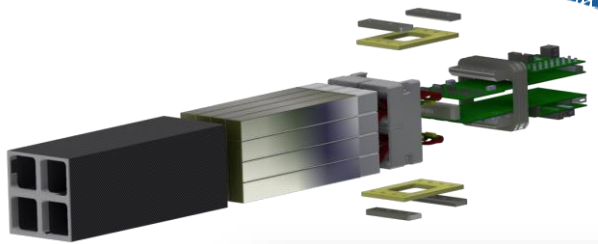


- Tree structure at adhesive surface
- Adhesive residues between APDs



Crystal Gluing – Lessons Learned



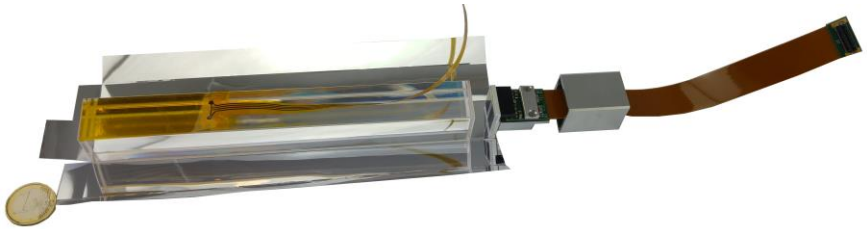


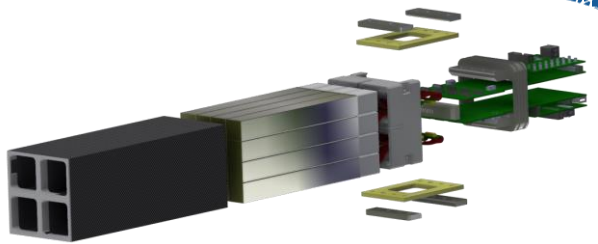
- Tree structure at adhesive surface
- Adhesive residues between APDs

Solution:

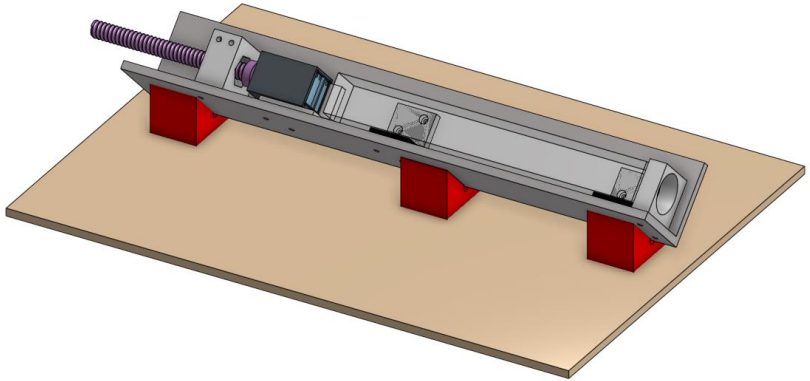
- Humidifier (45 %)
- 18 h hardening in Gießen fixture
- 10 days in simple fixture
- Removing of adhesive residues with plastic tools afterwards

Crystal Gluing – Lessons Learned

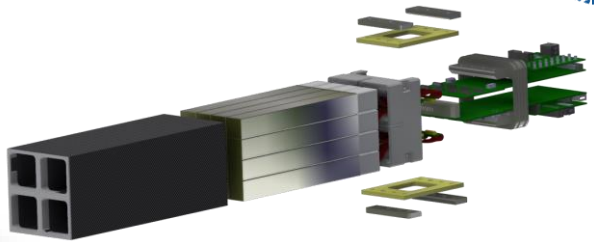


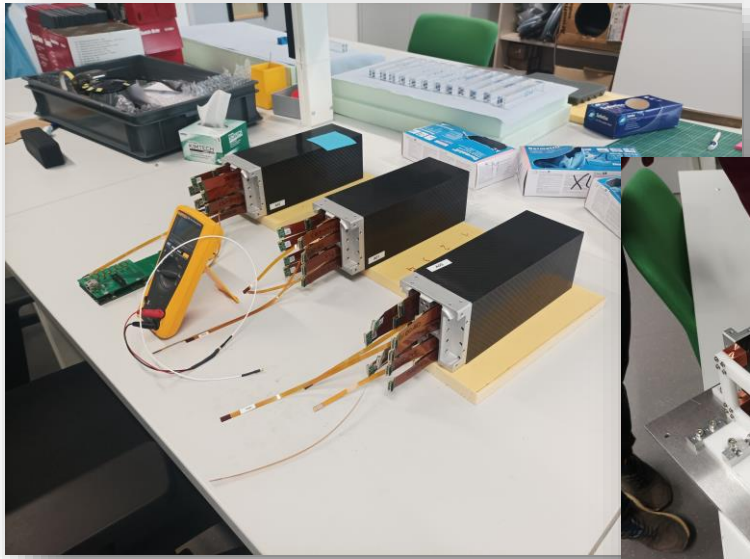


- 40 crystals per week
- 2.5 submodules per week
- Expected time to glue all crystals: 4 Months
- Gießen needs fixtures back
- Design of simplified version
- Prototype is under construction



Submodule Assembly and Test Setup

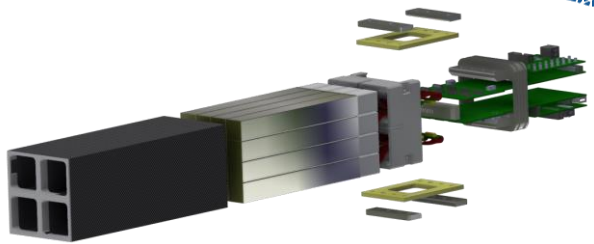


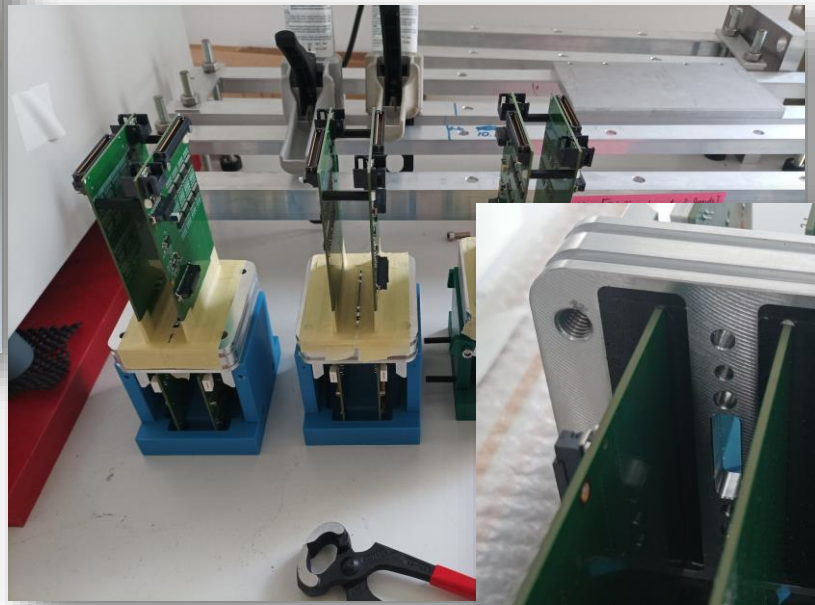


- Full electronics test
- Temperature sensor calibration
- HV – scan with light pulser
- Energy calibration with cosmics
- Three submodule at a time

24.03.2022

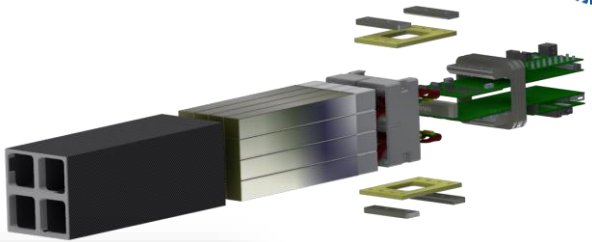
Submodule Assembly and Test Setup





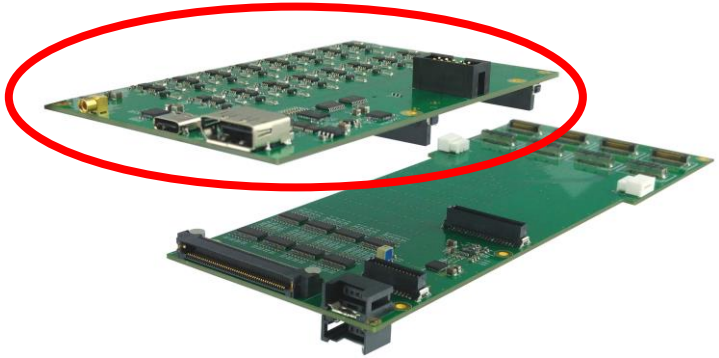
- Issues with gluing of sender boards
- Loosen of adhesive joins
- Adding of a channel to have an additional form fit
- Overworking of adhesive surfaces (sandblast)

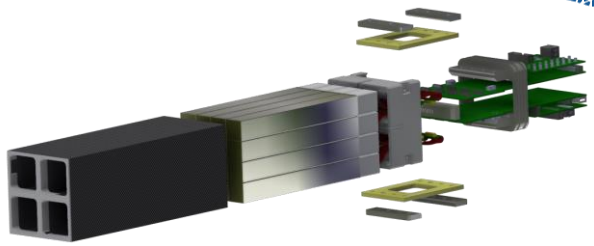
Submodule Assembly and Test Setup



- Delay in production of light pulser system due to chip shortage.
- Found alternatives (little changes at PCB layout)
- In the meanwhile: Master student develops calibration procedure (scripts) with prototypes

HV Board Issues

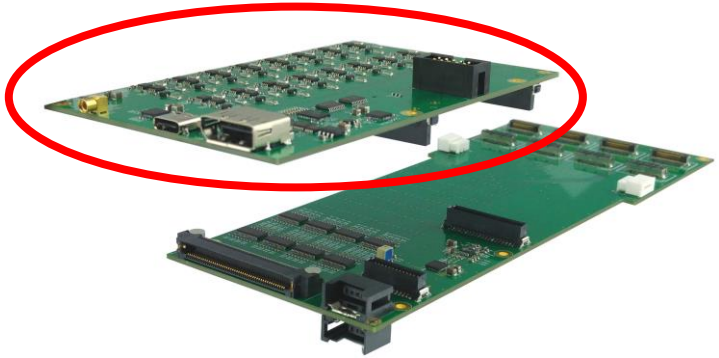


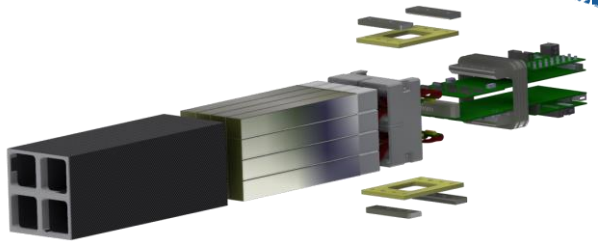


- High voltage splitter and APFEL control
- Only part which is missing
- Problems with communication (HV and APFEL)
- Control computer (PI) crashes (I2C Chip?)
- Slack joints at USB-C connector
- Tedious troubleshooting

24.03.2022

HV Board Issues





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- High voltage splitter and APFEL control
- Only part which is missing
- Problems with communication (HV and APFEL)
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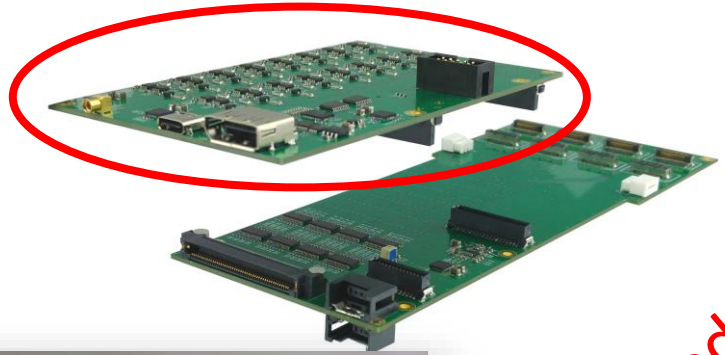
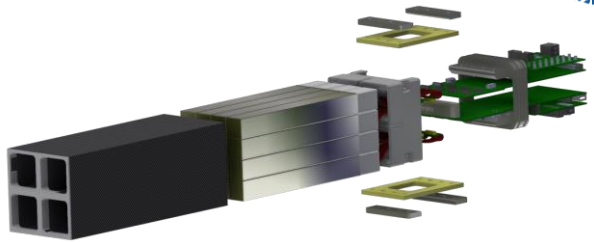
- Tedious troubleshooting

Solution:

- **Blocking capacitor was missing at board to board connector**
- **USB-C connector needs special treatment by pick-and-place machine**
- PI crashes were unrelated to the electronics (some internal driver problem)
- Last pre-series ordered (ten boards) then full batch

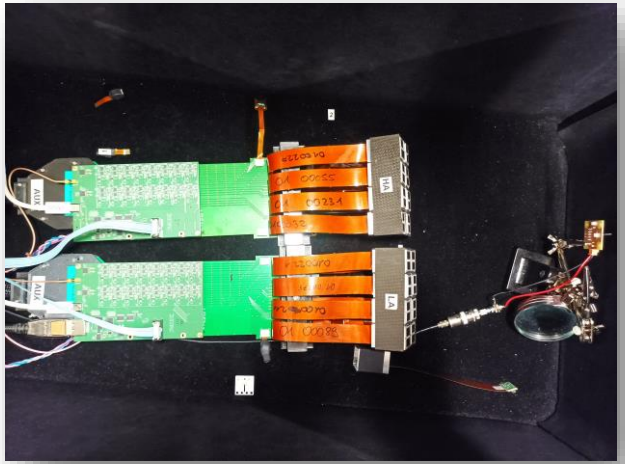
HV Board Issues



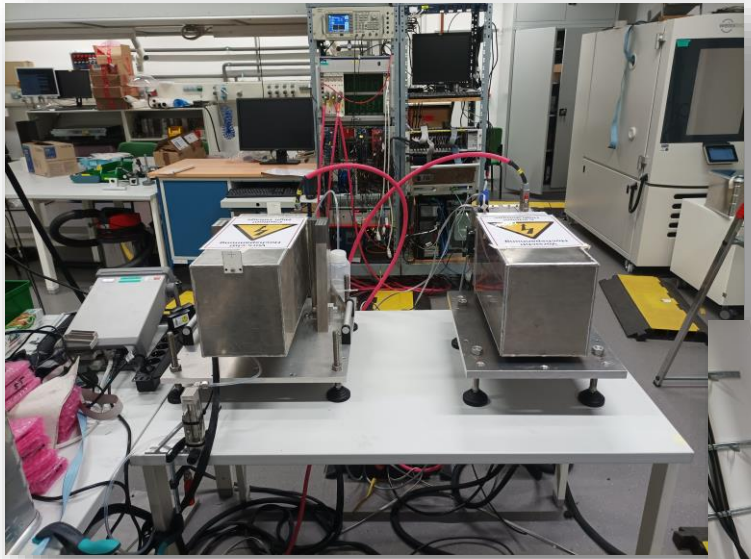


today

- Pre-series has arrived
- Extensive tests
- **Everything works fine!**
- Full batch order in preparation



Phase 0 Test Beam Preparations



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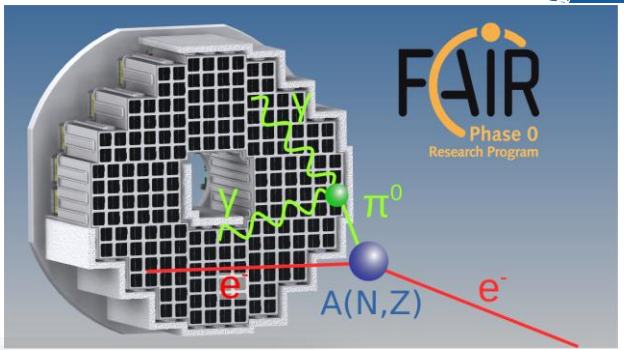
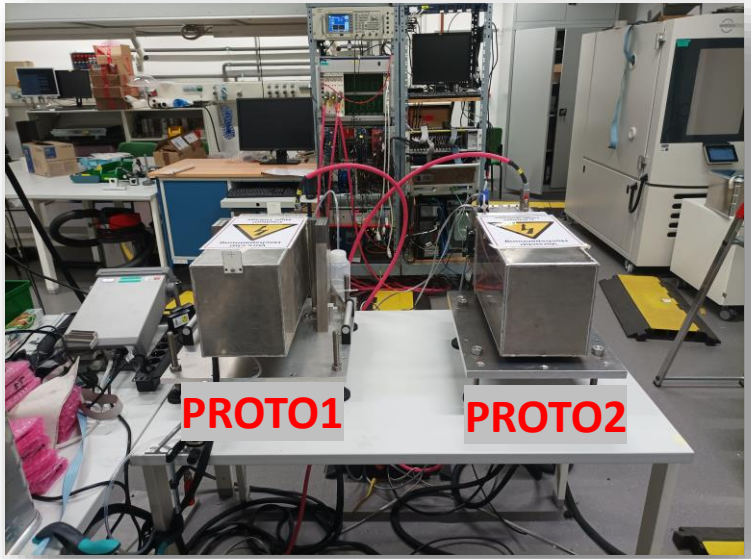
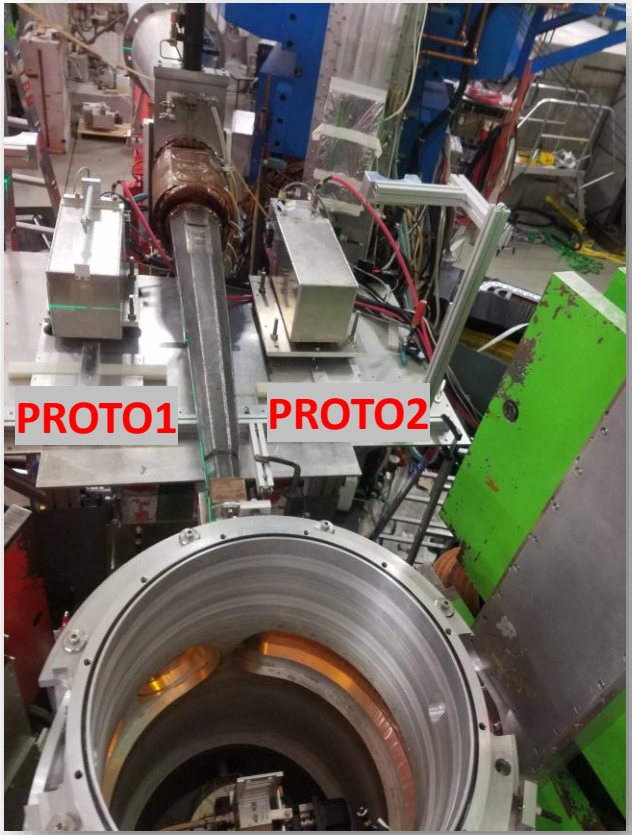


- Beam test in April (20.04.2022)
- Update of Proto16-1 (2018)
- New Proto16-2
- Readout with PANDA SADC
- Coincidence with MAMI A1 spectrometer

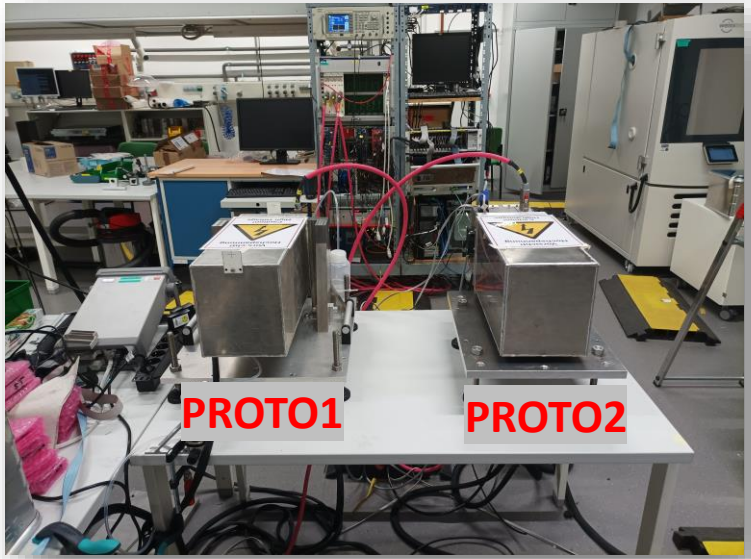
Phase 0 Test Beam

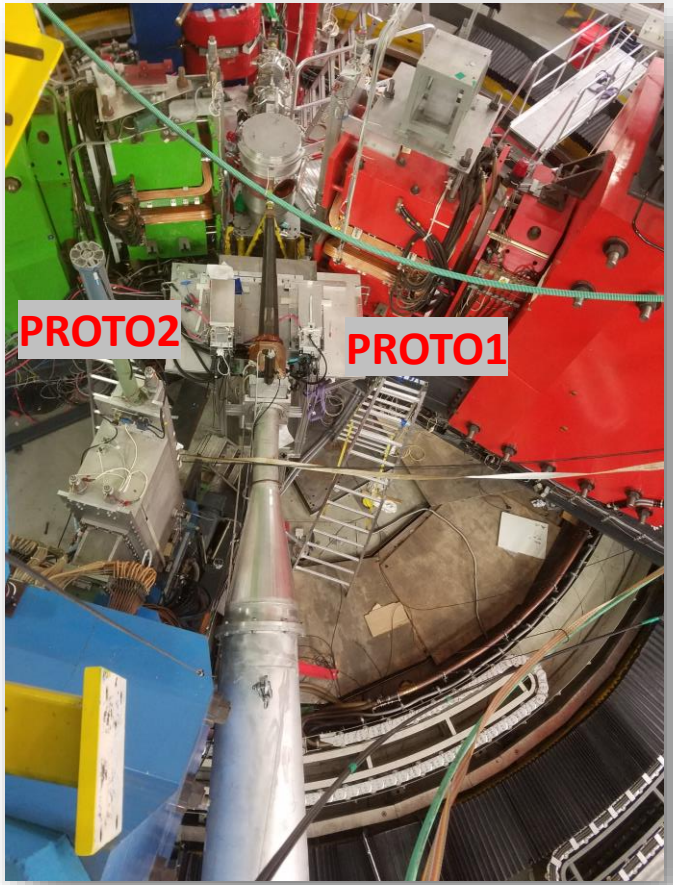




- Beam test in April (20.04.2022)
- Readout with PANDA SADC
- Coincidence measurement with both prototypes
- Coincidence with MAMI A1 spectrometer
- Beam Energy: ~~1.5 GeV~~ 855 MeV

Phase 0 Test Beam





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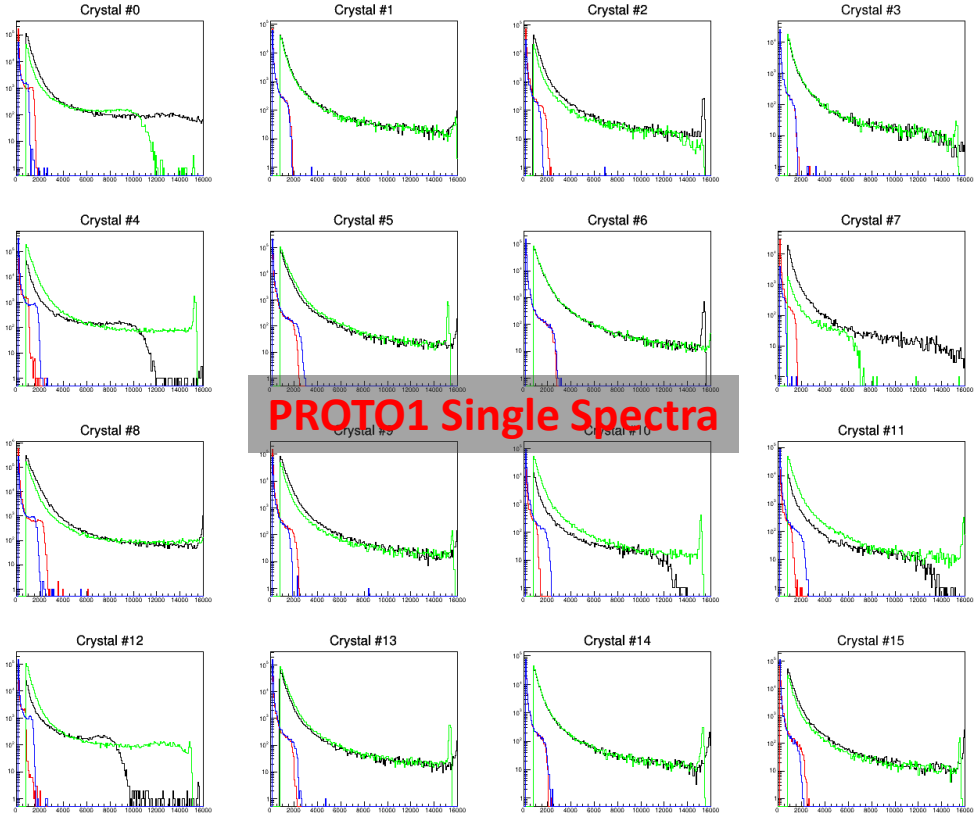
Phase 0 Test Beam – Detector Calibration via Quasielastic Scattering

- Angle: 22 °
- Beam Energy: 855 MeV
- Carbon target
- Peak Energy: 801,8 MeV
- Calibration by using endpoint of spectrum



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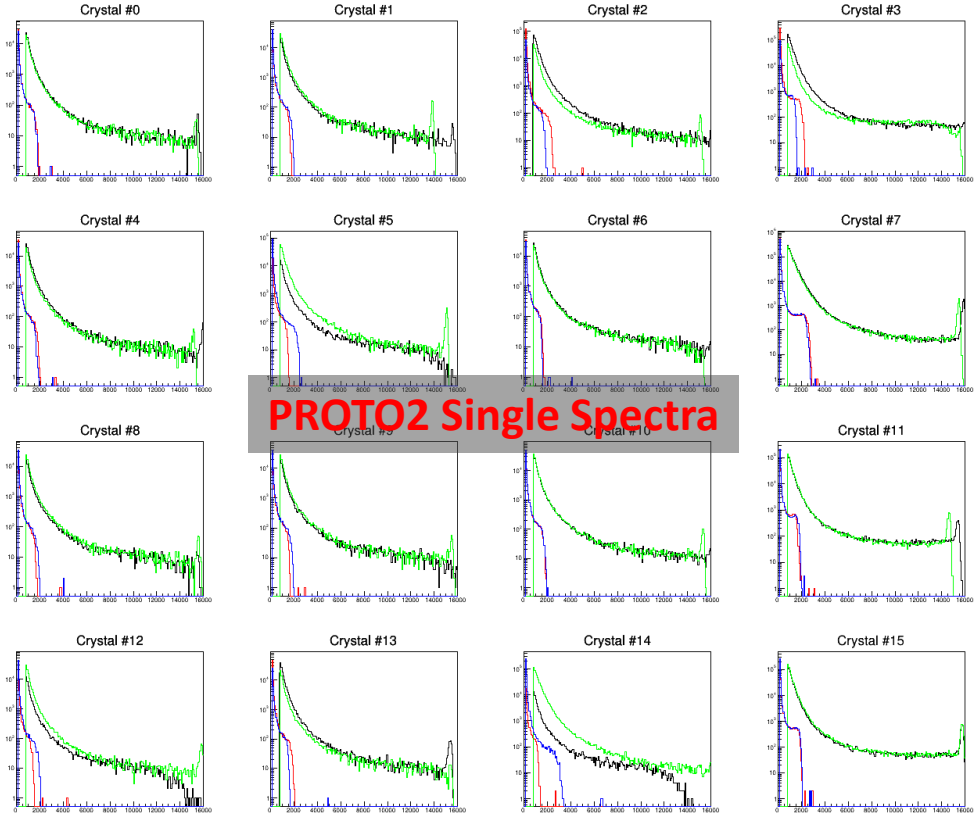

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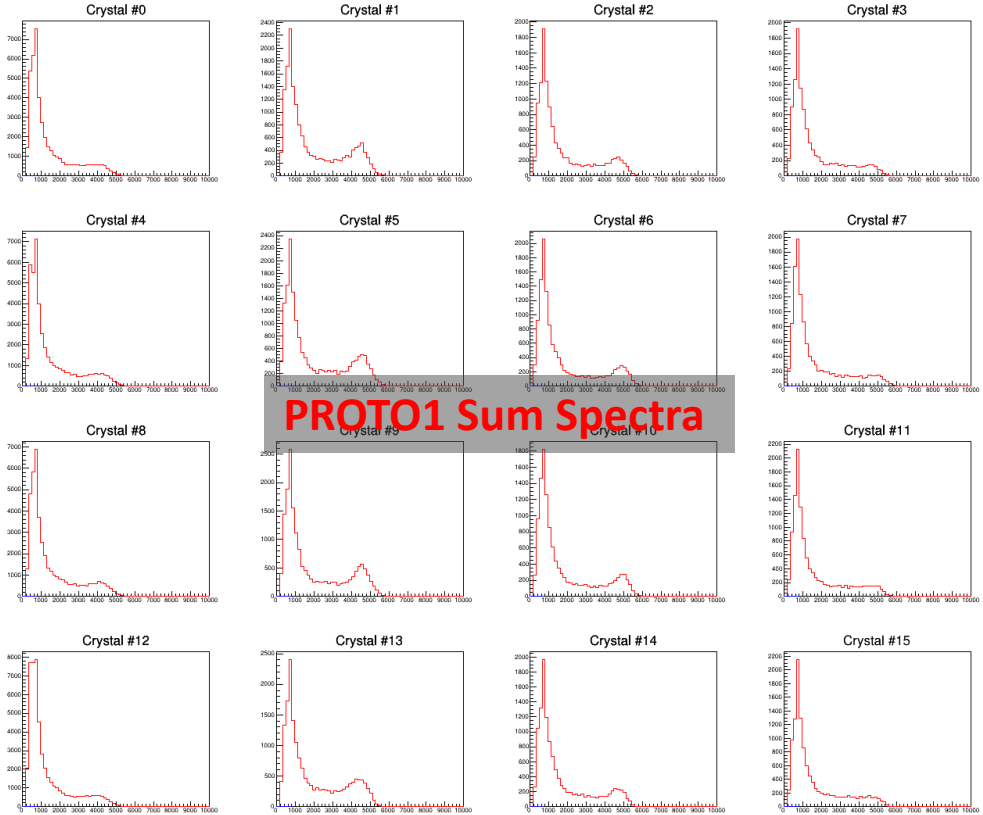

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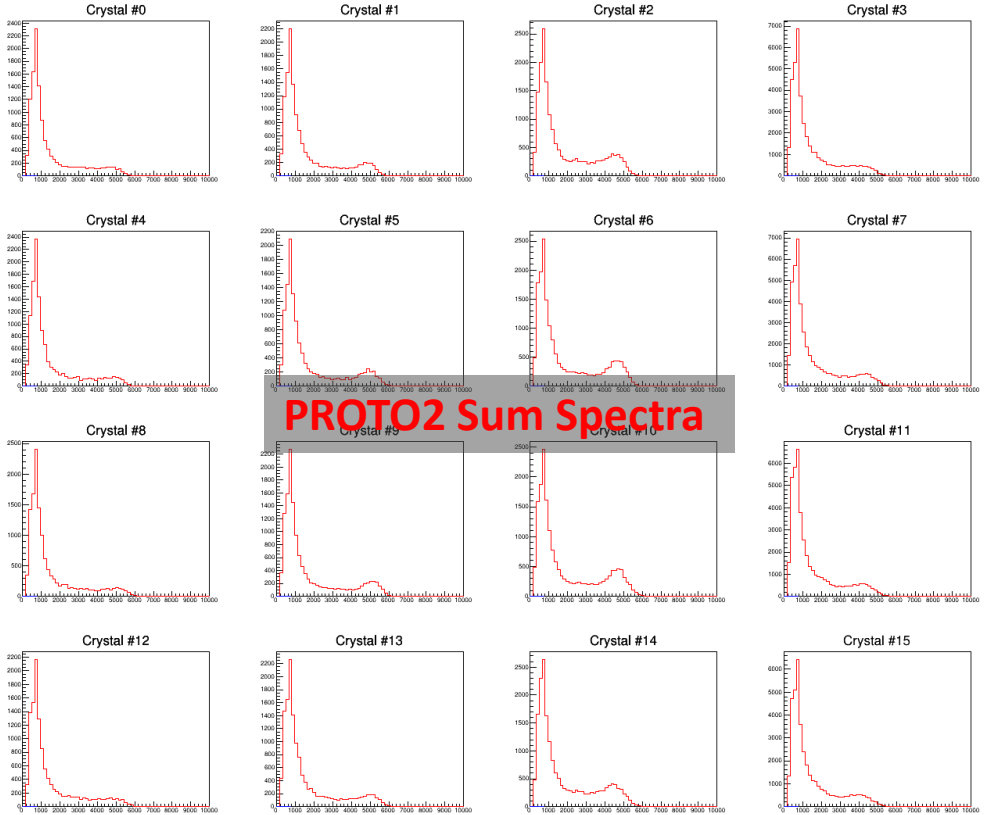

Phase 0 Test Beam – Detector Calibration via Quasielastic Scattering

- Angle: 22 °
- Beam Energy: 855 MeV
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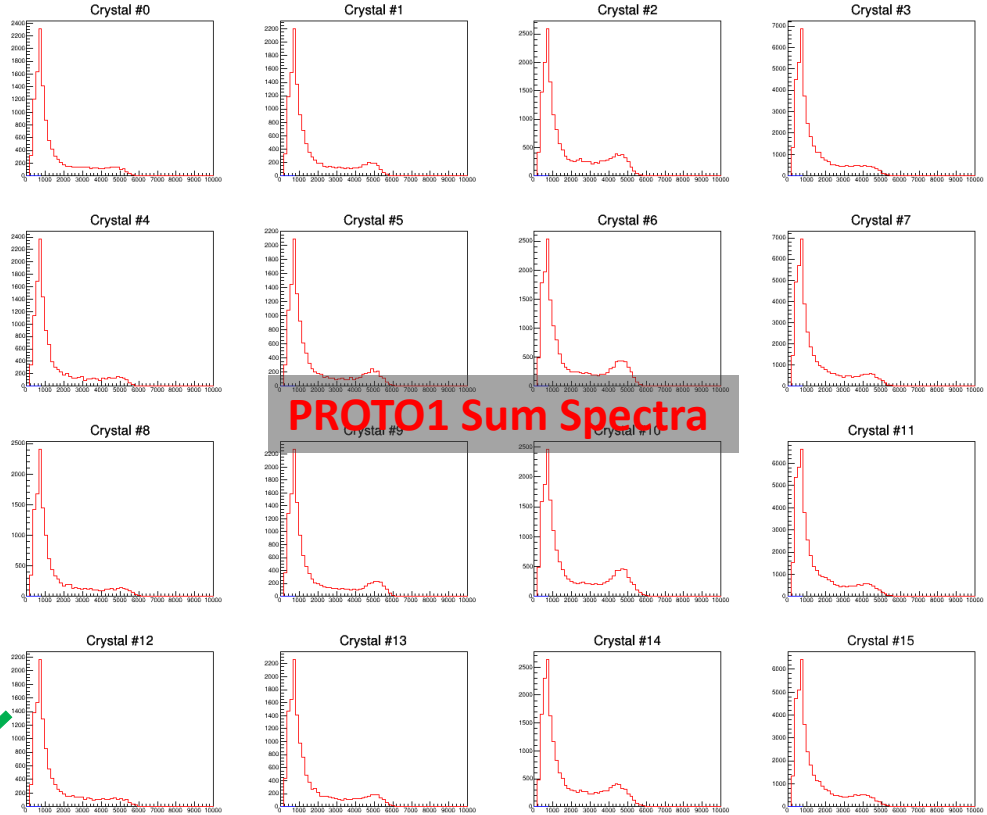
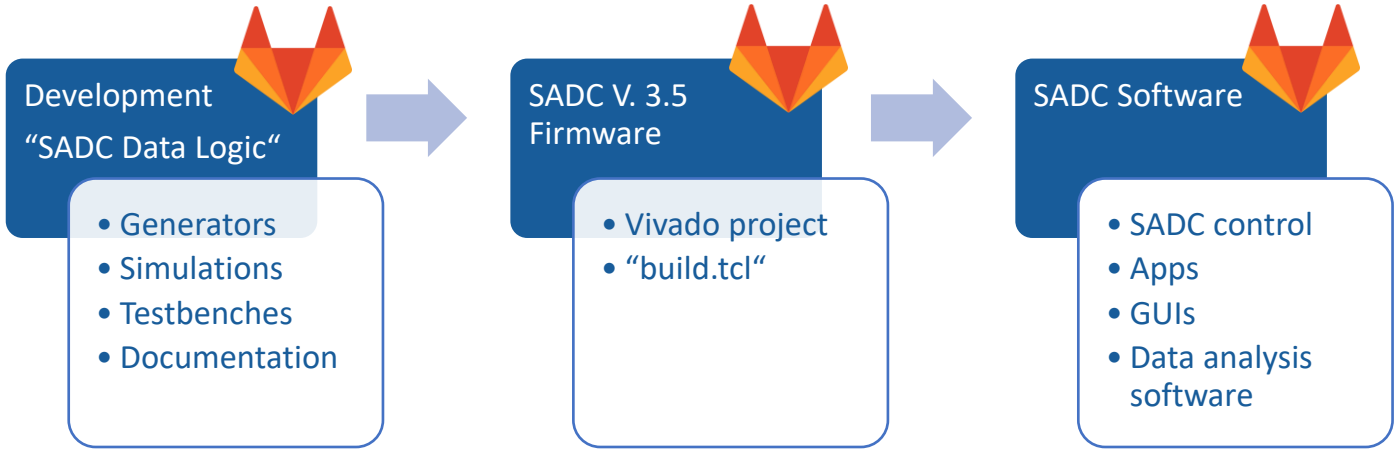
- Peak Energy: 801,8 MeV
- Calibration by using endpoint of spectrum
- Analysis is ongoing:
  - Software to match events by timestamps ✓



Latest Firmware (and Software) Developments

- Debugging of issues discovered in test beam
- More efficient implementation of delay modules
- C++ implementation of UDP receiver
- Data analysis software



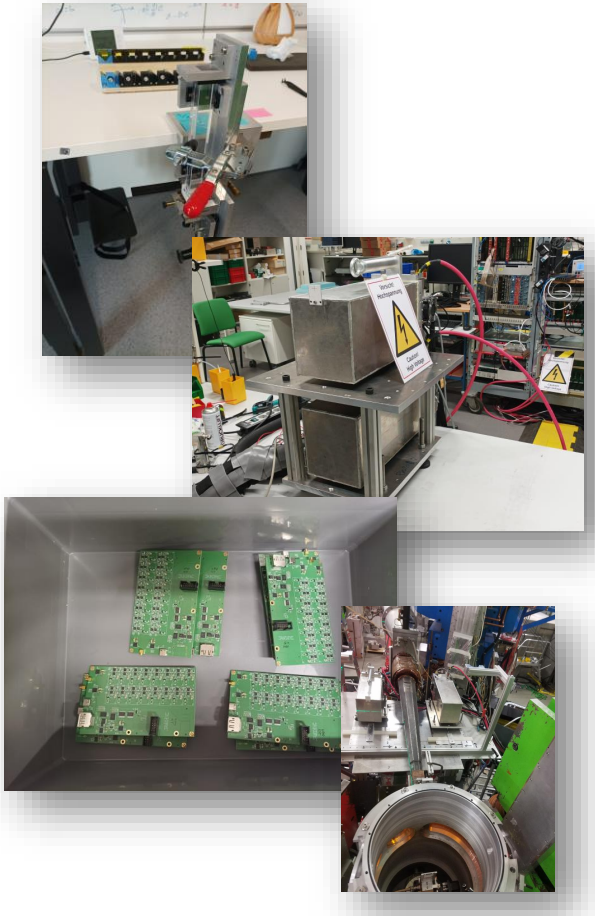
https://gitlab.rlp.net/emp/sadc_data_logic

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

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

Summary

- Mass production of submodules is ongoing
  - Optimization of gluing process
  - Design of simple gluing fixtures
- Development of submodule calibration procedure by using prototypes
  - Running system in climate chamber is expected at the end of July
- Issues with HV board solved (really!)
  - Last pre-series arrived
  - Test results are positive
  - Full batch order under preparation
- Test Beam was successful
  - Prototypes were working without any problems
  - Managed to measure coincidence events with both prototypes, PMTs and A1 spectrometers
  - Analysis is ongoing
- SADC firmware and software updates are available



The Anomalous Magnetic Moment of the Muon

Dirac Theory:

Dirac equation with EM-field:

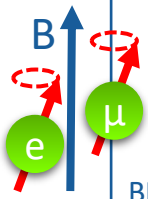
$$\left(i\gamma^\mu \partial_\mu - e\gamma^\mu A_\mu - m\right)\psi = 0$$

Nonrelativistic limit ($E \approx m$):

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

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

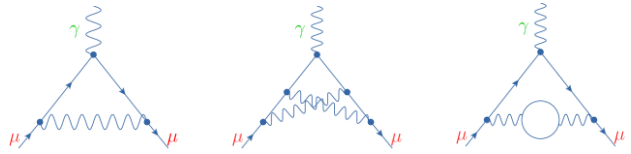
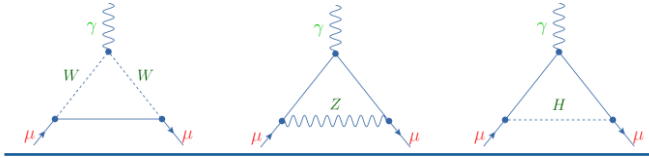
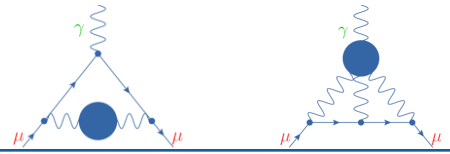
Messung:



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

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

BNL (E821) 2006

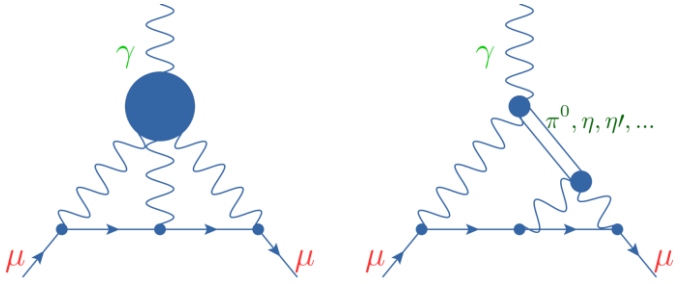
$a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{EW}} + a_\mu^{\text{QCD}}$	Δa_μ^{SM}
	0.01×10^{-10} T. Aoyama et al. 2012
	0.10×10^{-10} C. Gnendiger et al. 2013
	Each: $\sim 3 \times 10^{-10}$ F. Jegerlehner 2019

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

4σ

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

Hadronic Light-by-Light Scattering



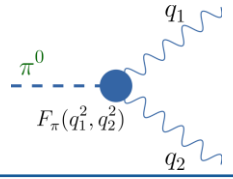
Light Pseudo Scalar Mesons, PS = π^0, η, η'

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 $Q_{1,2}^2$:

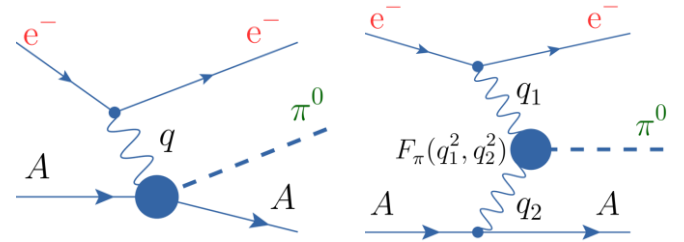
$$a_\mu^{\mathrm{HLbL,PS}} = \int_0^\infty dQ_1 \int_0^\infty dQ_2 \int_{-1}^{1} d\tau\, w(Q_1, Q_2, \tau) F_{\mathrm{PS}\gamma^*\gamma^*}(-Q_1^2, -(Q_1+Q_2)^2) F_{\mathrm{PS}\gamma^*\gamma^*}(-Q_2^2, 0)$$

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

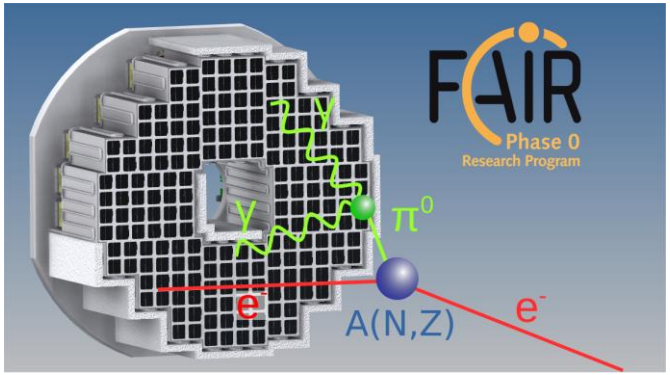


V. Pauk, M. Vanderhaeghen 2014, M. Hoferichter 2018

Primakoff π^0 Electroproduction



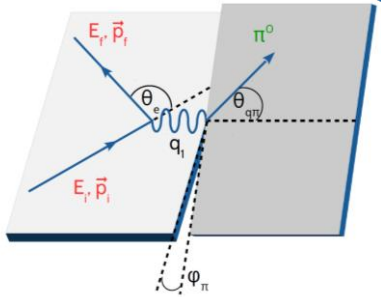
Contribution to coherent nuclear pion production



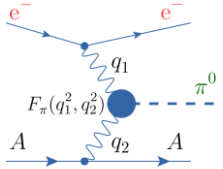
- Full developed FAIR detectors in stand-alone experiments
- PANDA backward calorimeter for FAIR Phase-0 at MAMI

The Primakoff π^0 Electroproduction

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



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



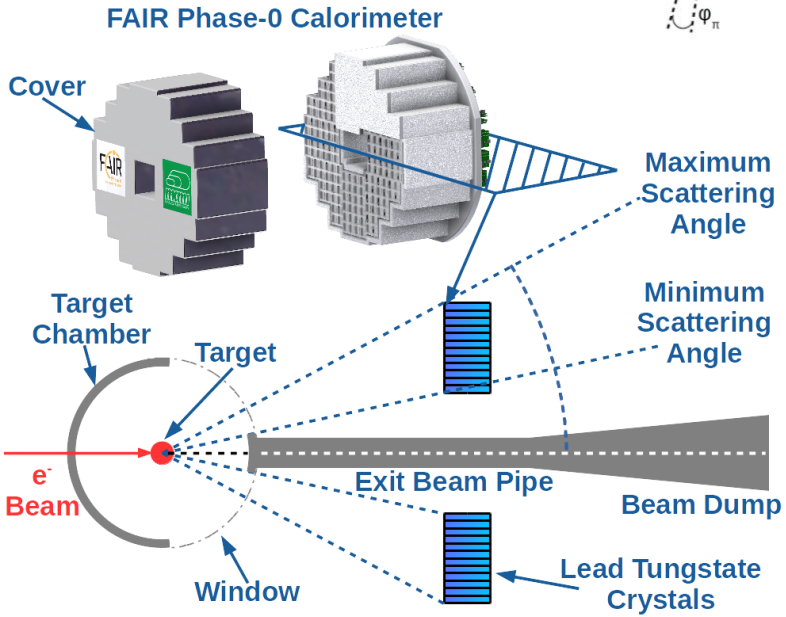
Kinematics: Minimizing of $\vec{q}_2$

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

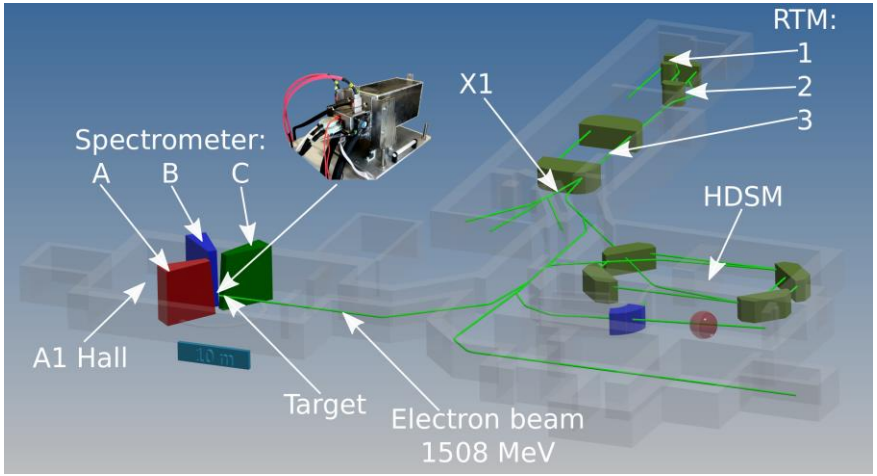
→ **Measurement at small forward angles**

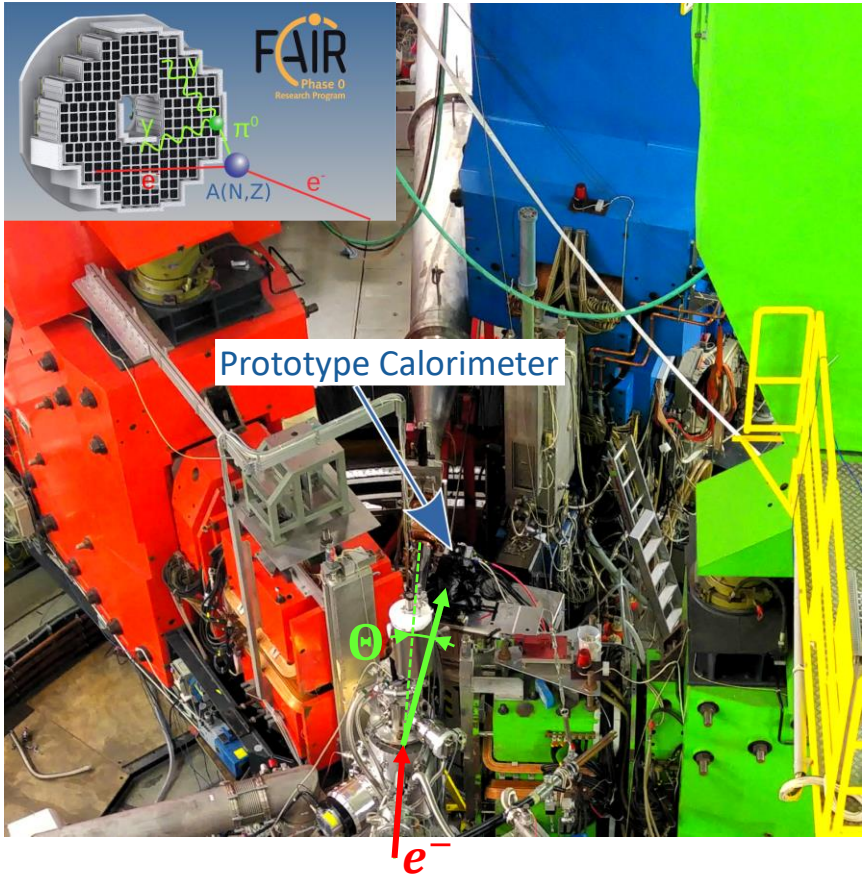
→ $\boldsymbol{-q_1^2 = Q^2 = [0.01, 0.05]\ GeV^2}$

→ $\boldsymbol{\Theta = 5° - 15°}$



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?**