Calibration of Detector Modules for the PANDA Backward Electromagnetic Calorimeter

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PANDA Meeting

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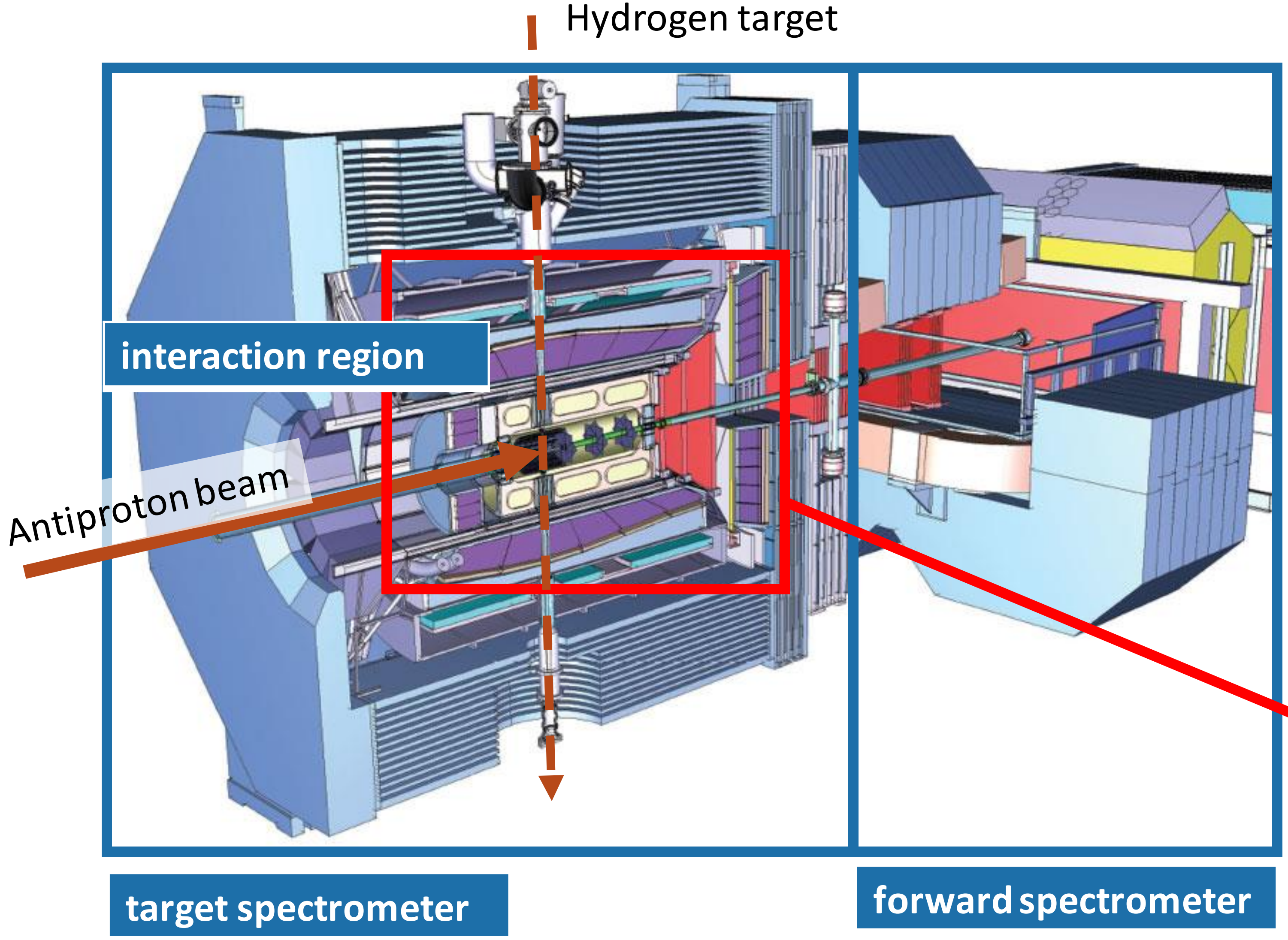
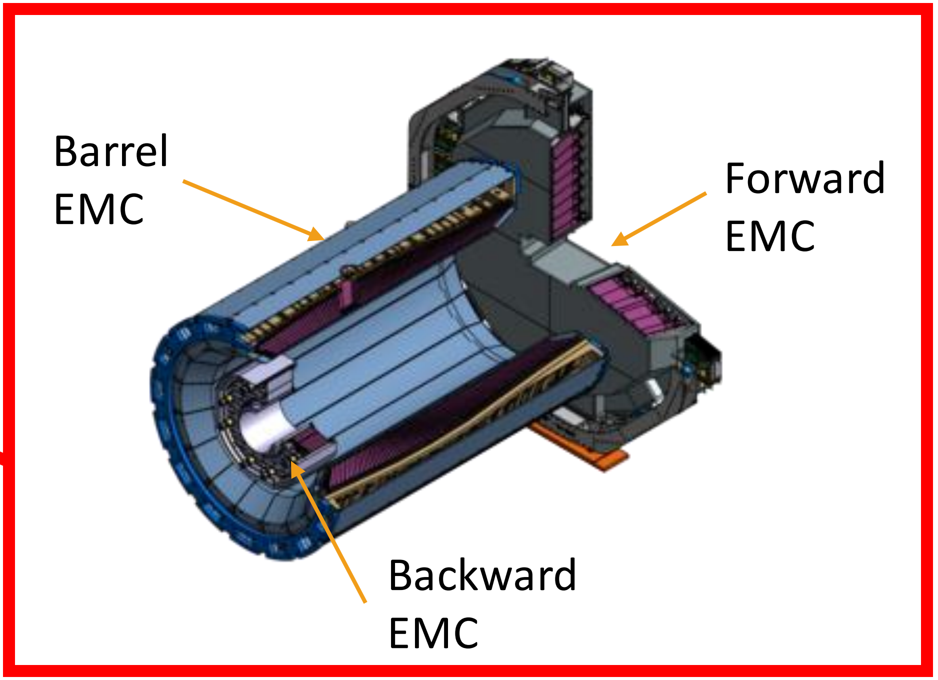
Contents

The PANDA Backward End Cap Calorimeter

PANDA: AntiProton Annihilation at Darmstadt

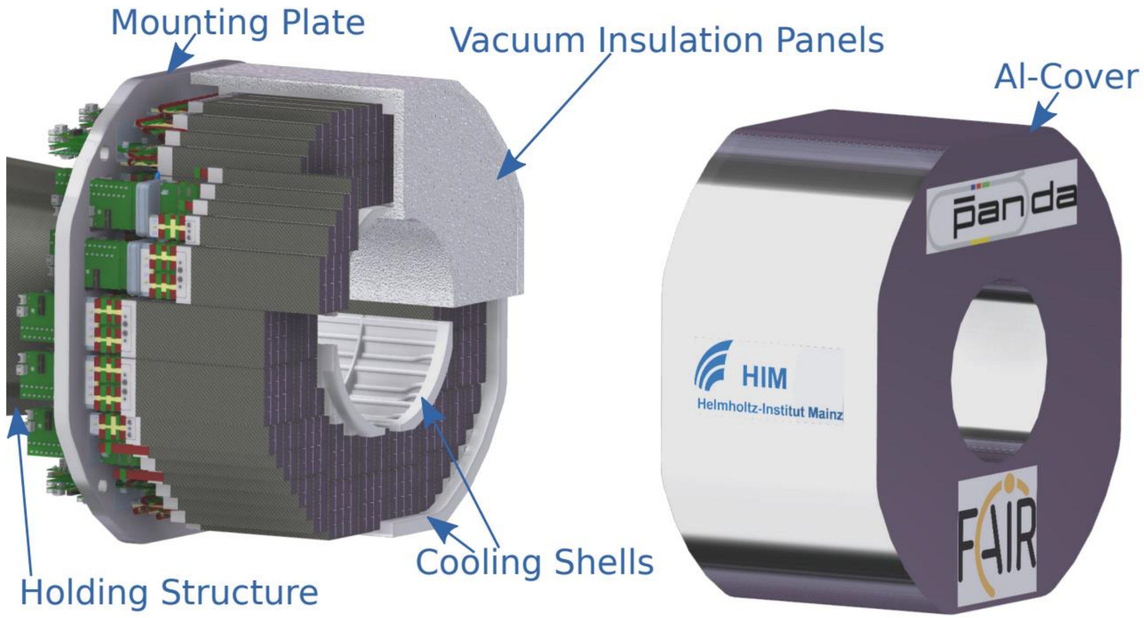


- Antiproton beam with momenta $\leq 15\,\frac{GeV}{c}$
- Luminosity $2 \times 10^{32} cm^{-2} s^{-1}$
- Relative momentum resolution $\frac{\Delta p}{p} \approx 10^{-4}$

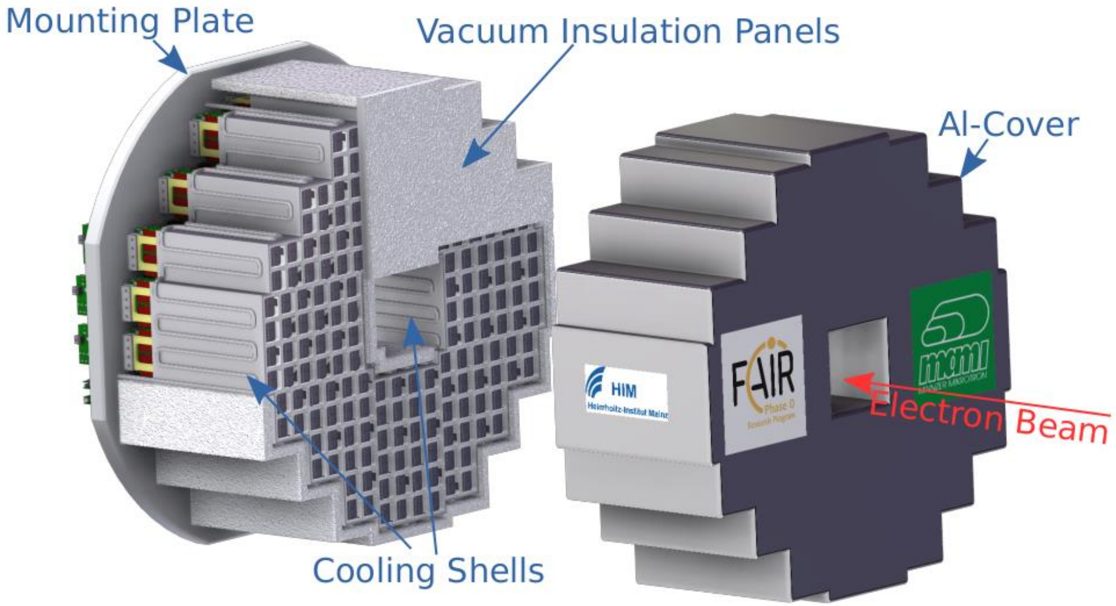


FAIR Phase-0 at MAMI

- Development of backward EMC allows usage in a FAIR Phase-0 experiment (different design but same technologies)
- More crystals used (640 instead of 524)
- Experiment: Measurement of π^0 transition form factor in primakoff process at MAMI
- Reduce uncertainty of Hadronic Light by Light contribution to muon puzzle
- 48 Submodules mounted in donut shape

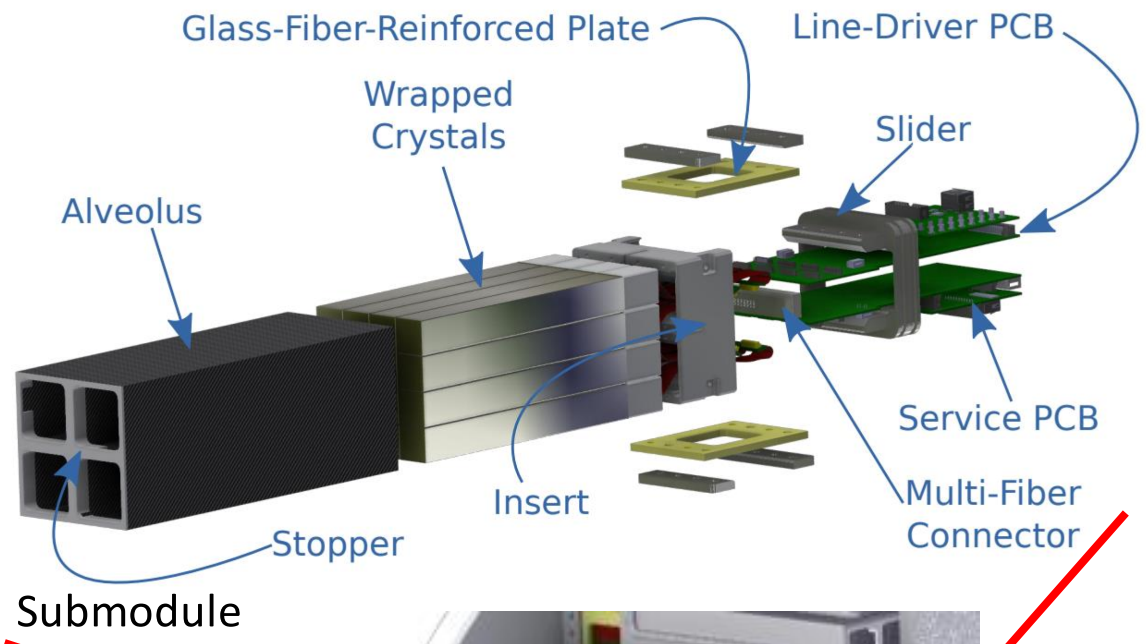


Backward Calorimeter @ PANDA



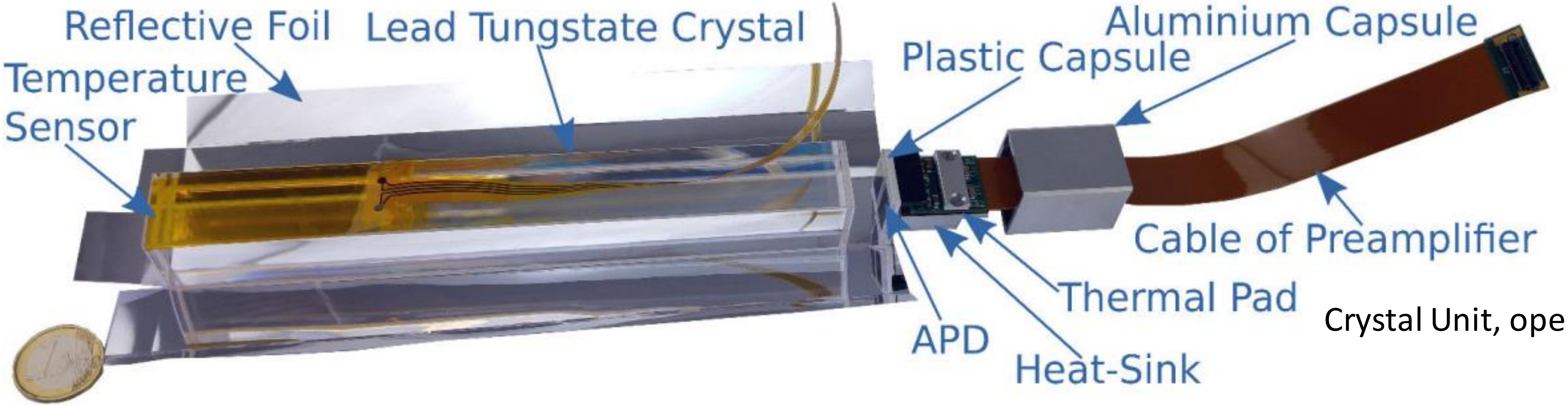
Backward Calorimeter @ MAMI

FAIR Phase-0 at MAMI

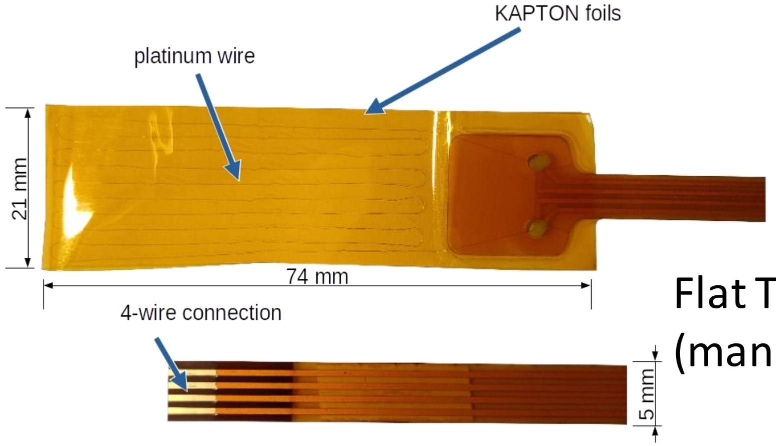


- Operated at -25 °C (entire detector volume)
- 48 submodules (4x4 and 4x2 crystal array)
- Each submodule:
  - 32 (16) photosensors
  - 4 (2) temperature sensors
  - 2 (1) high voltage distribution boards
  - own readout electronics
- In total:
  - 1280 photo sensors
  - 160 temperature sensors
  - 80 high voltage boards
  - All need to be calibrated (this work)

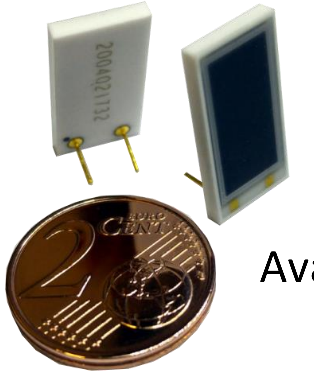
Crystal Unit



Crystal Unit, operated at -25 °C



Flat Temperature Sensor (manufactured in HIM)



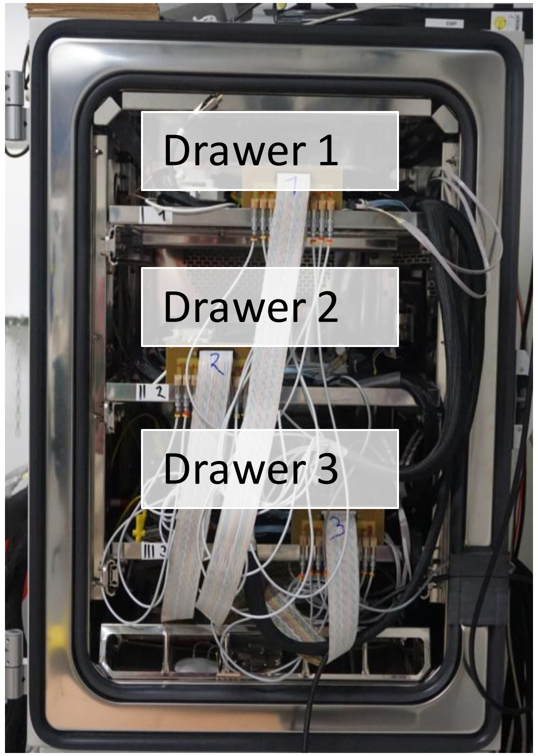
Avalanche Photo Diodes

Detector Module Calibration

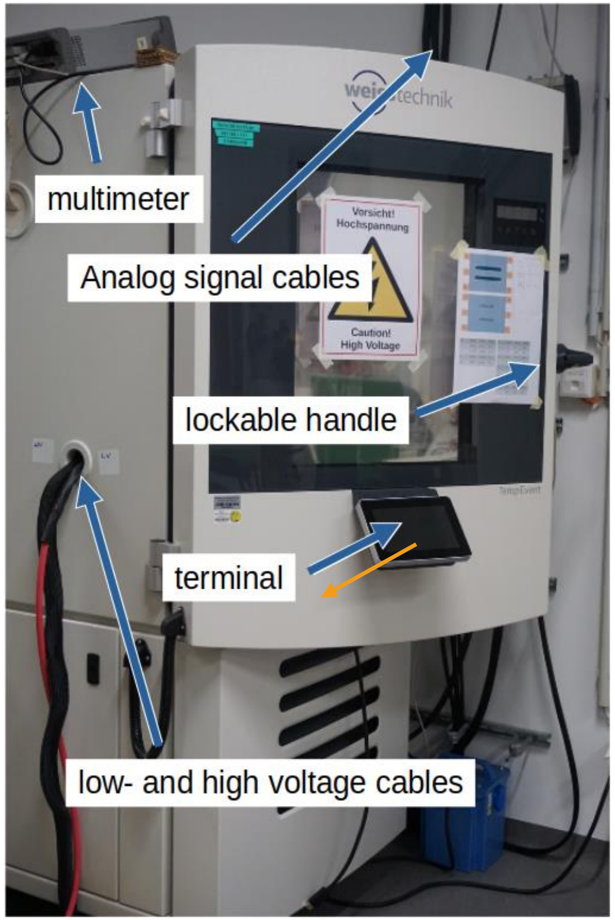
Calibration Setup
Calibration of High Voltage Boards
Characterisation of Photosensors
Calibration of Temperature Sensors
Energy Calibration with Atmospheric Muons

Calibration Environment

- Detector will be operated at -25 °C
- Need for temperature uniformity and stability
- Choice of calibration environment is a climatic chamber
  - Model „TempEvent 340/40/5“
  - Operational range from –42 °C to 180 °C
  - Provides circulating dry air
  - Accessible over network
  - Can house three submodules
  - -> three submodules can be calibrated at once
- Ingoing services:
  - Low voltage supply
  - High voltage supply
  - Lightpulser system
  - Programming interfaces
- Outgoing services:
  - Temperature readout system
  - Data acquisition (analogue signals of detector)

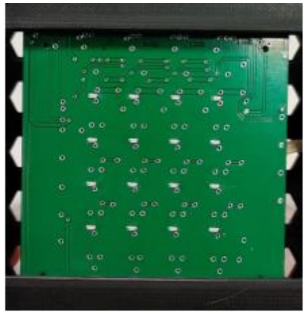


Climatic chamber open



Climatic chamber side view

Detector Calibration Setup

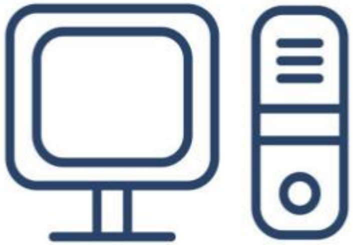


Mainz lightpulser

ISEG high voltage 500 V

wiener low voltage +-7 V

temperature readout

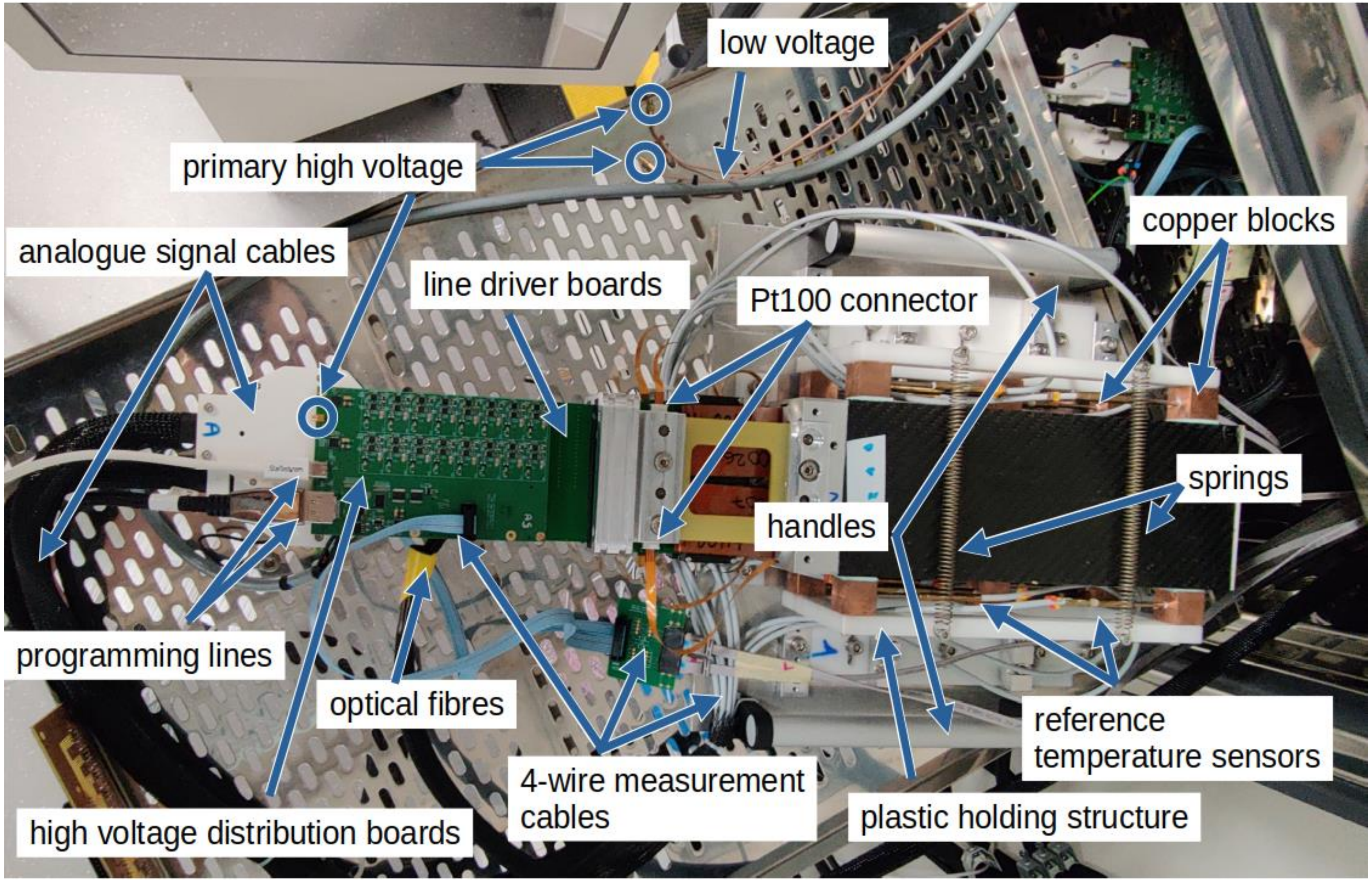


data acquisition and storing

temperature targets

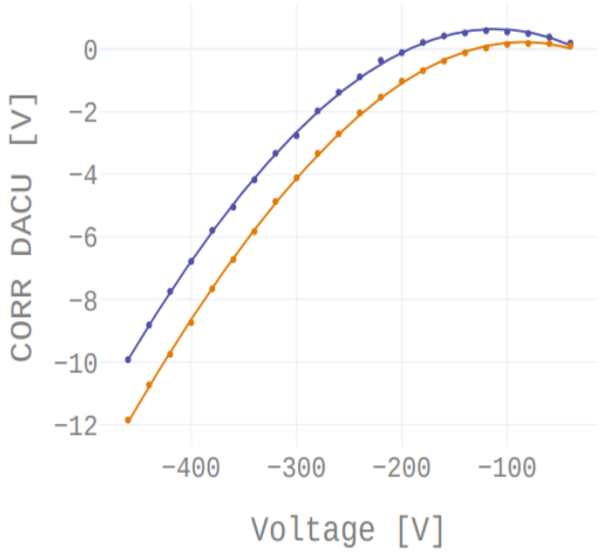
0 °C → -5 °C → -10 °C → -15 °C → -20 °C → -25 °C → -30 °C → -25 °C → -20 °C → -15 °C → -10 °C → -5 °C

Detector Calibration Setup

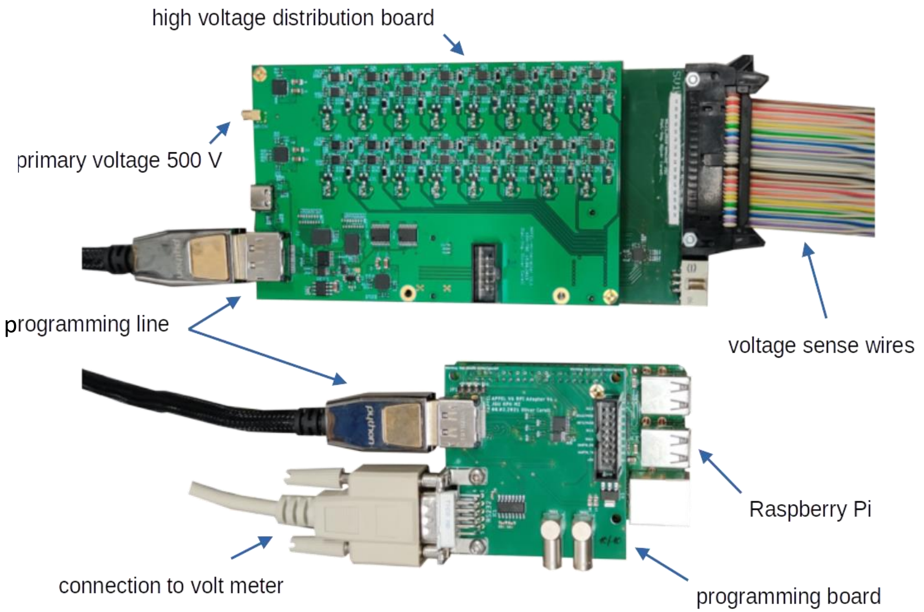


Calibration of High Voltage Boards (HV-Boards)

- HV-Boards deliver adjustable bias voltage to photosensors
- DACs and ADCs on HV-Boards have to be calibrated to accurately set and read voltages and currents
- Furthermore HV-Boards are
  - At room temperature in the experiment
  - At -25 °C in the calibration setup



- DAC correction against measured voltage
- $2\ V$ difference between warm and cold calibration
- Gain slope $\approx 15\,\frac{1}{V}$ -> 30 gain difference
  - -> cold calibration necessary



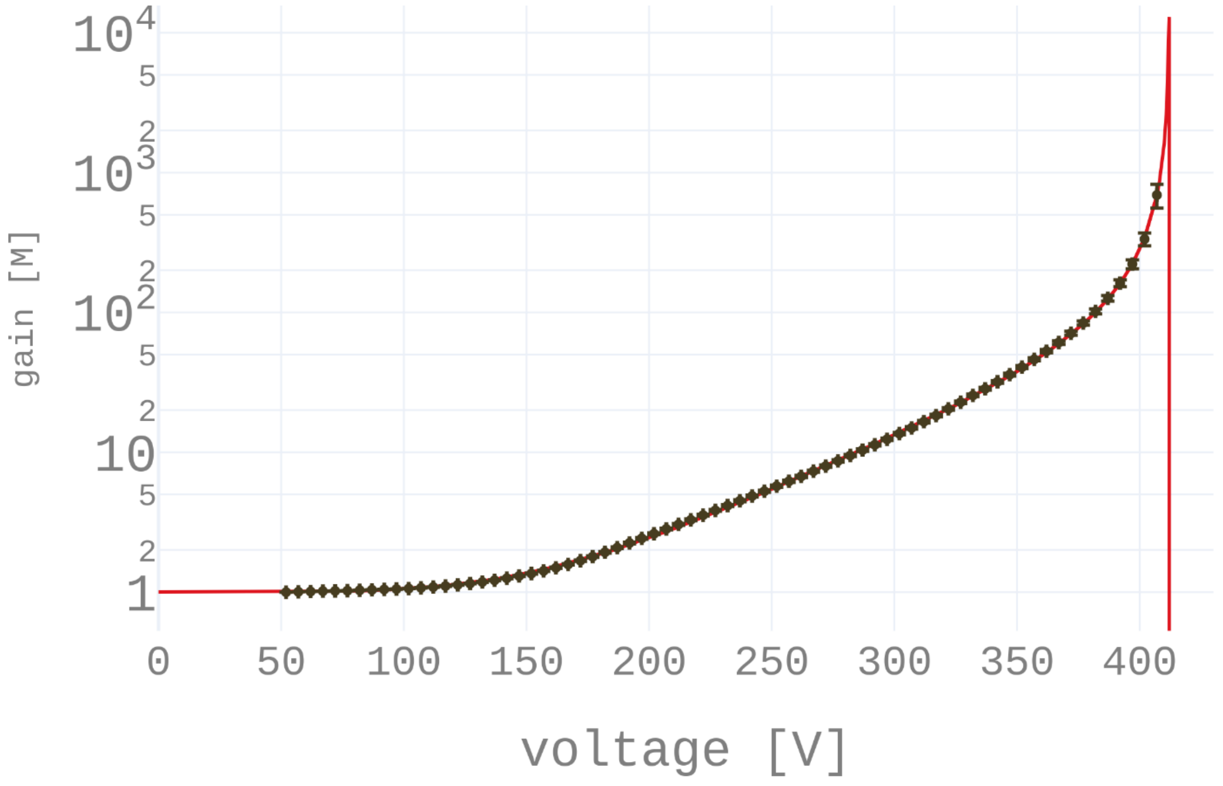
High voltage board calibration setup (provided by Oliver Corell)

Characterisation of Photosensors (APDs)

- APDs convert scintillation light into charge depending on applied bias voltage (gain)
    - Target gain: 200
- Individual gain-voltage characteristics has to be determined for each APD
- APDs have different gain-voltage characteristics
- Detector response is analysed at different APD bias voltages
- Function that describes gain-voltage:

$$M_{con}(U_b, U, k, A) = \frac{A}{1 - (U/U_b)^k} + 1 - A$$

- Common calibration technique:
    - Illuminate APD with continuous light source
    - Measure current at APD against bias voltage
    - Normalise at $U = 0\ V$



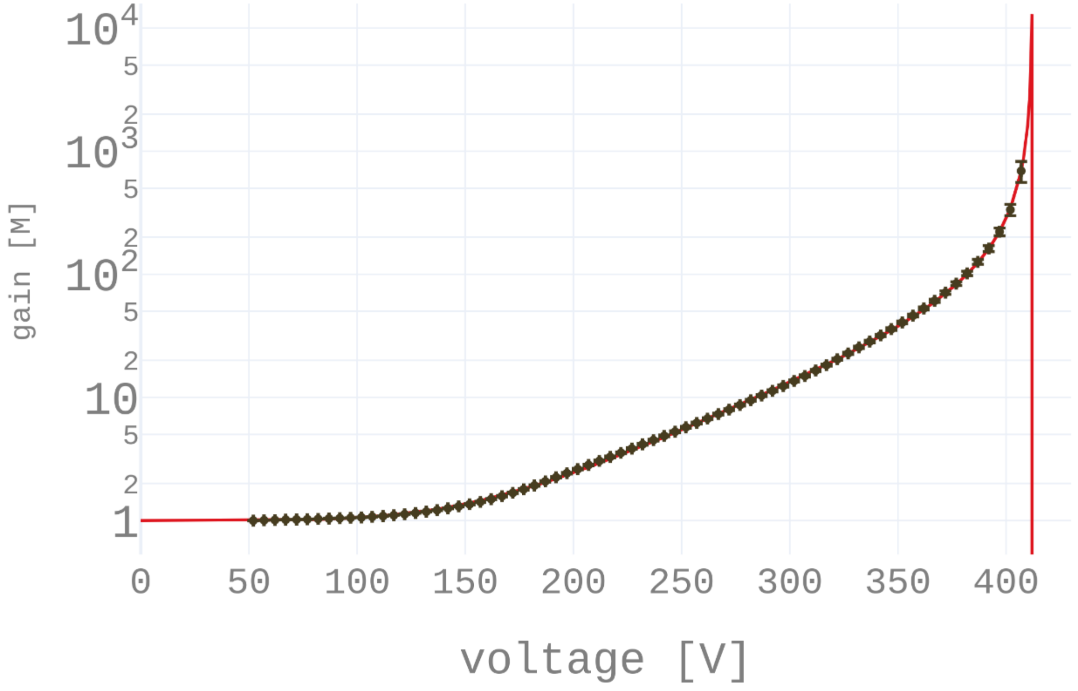
Characterisation of Photo Sensors (APDs)

- Challenges with current setup:
  - APDs are connected to charge sensitve preamplifier
  - Limited by range of ADC and integration time of ASIC
  - -> pulsed light needed to let capacitor discharge
  - -> additional term to describe gain needed (Spieler)

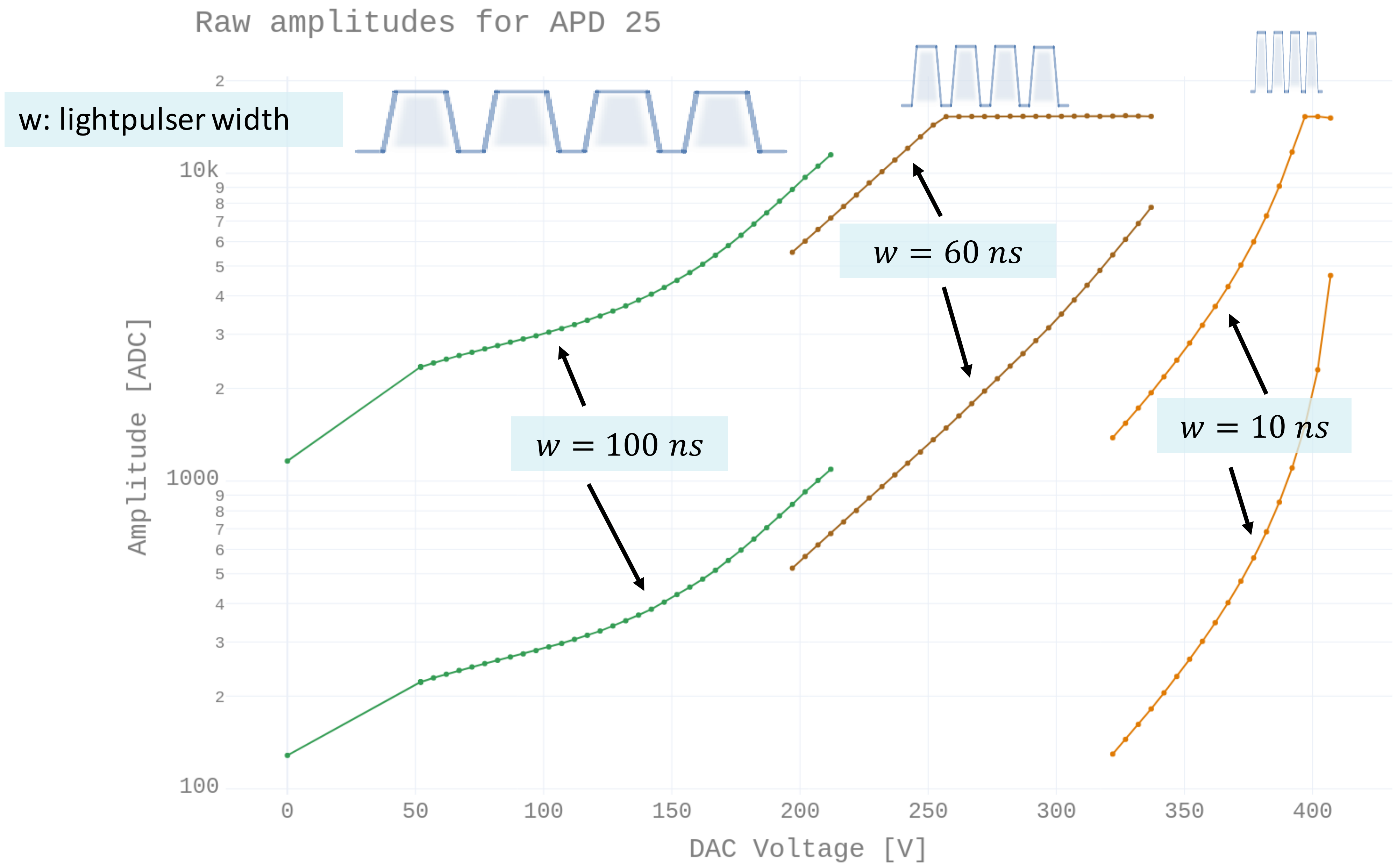
$$M_{pulsed} = M_{con}/(1 + C_d/C_i)$$

- C_i : capacitance of preamplifier
- C_d : voltage dependent APD capacitance (model)

$$C_d = p_4 \left(\frac{p_0}{\sqrt{Up_1 + 1}} - \frac{1}{1 + e^{-p_2(U-p_3)}} \right)$$



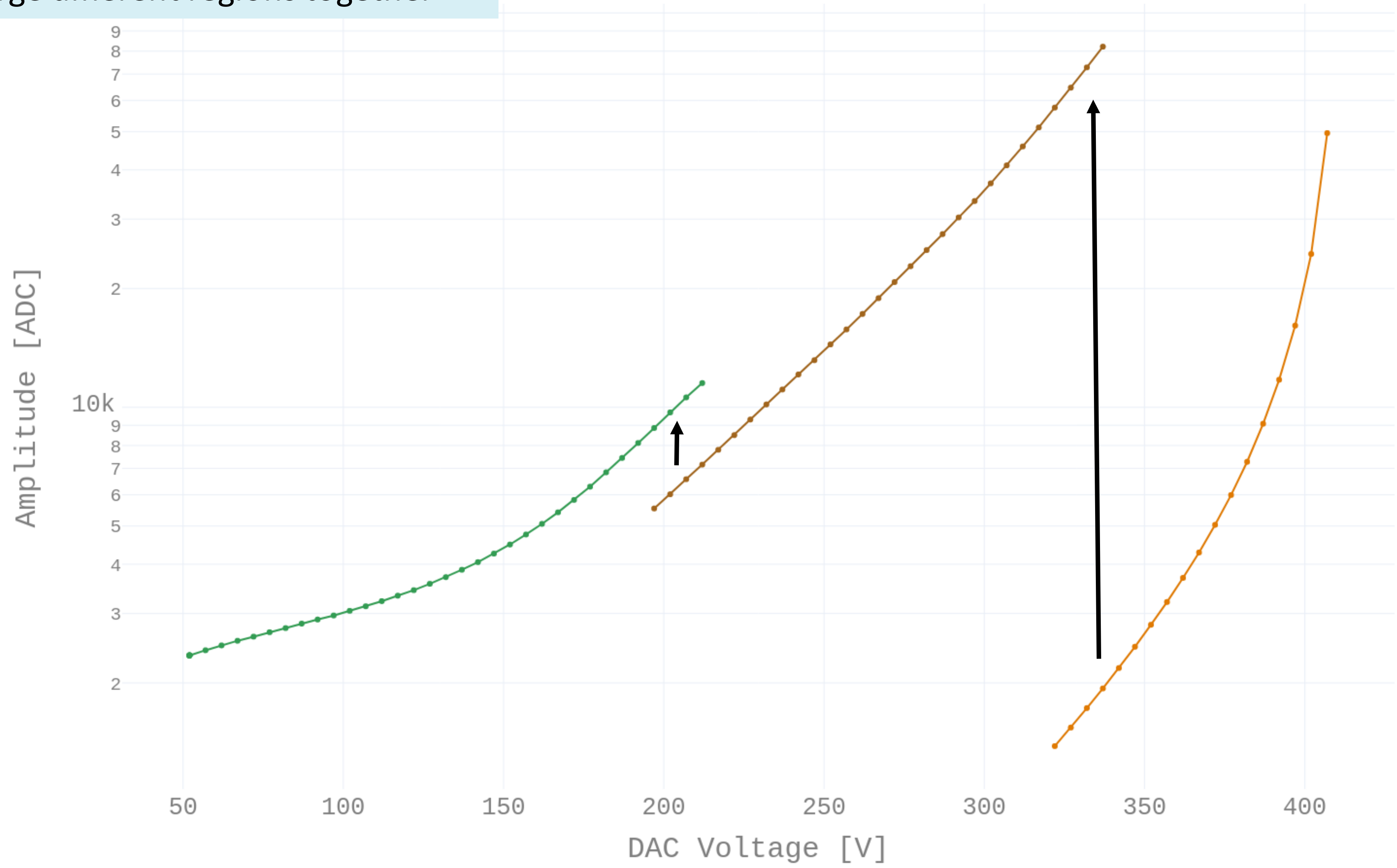
$$M_{pulsed} = p_5 \frac{\frac{A}{1-(U/U_b)^k} + 1 - A}{1 + p_4 \left(\frac{p_0}{\sqrt{Up_1+1}} - \frac{1}{1+e^{-p_2(U-p_3)}} \right)} = M_{continuous} \cdot T$$


Raw amplitudes for APD 25
w: lightpulser width
$w = 100\ ns$
$w = 60\ ns$
$w = 10\ ns$
Amplitude [ADC]
DAC Voltage [V]
100
2
3
4
5
6
7
8
9
1000
2
3
4
5
6
7
8
9
10k
2
0
50
100
150
200
250
300
350
400

Extend low amplification by amplification ratio

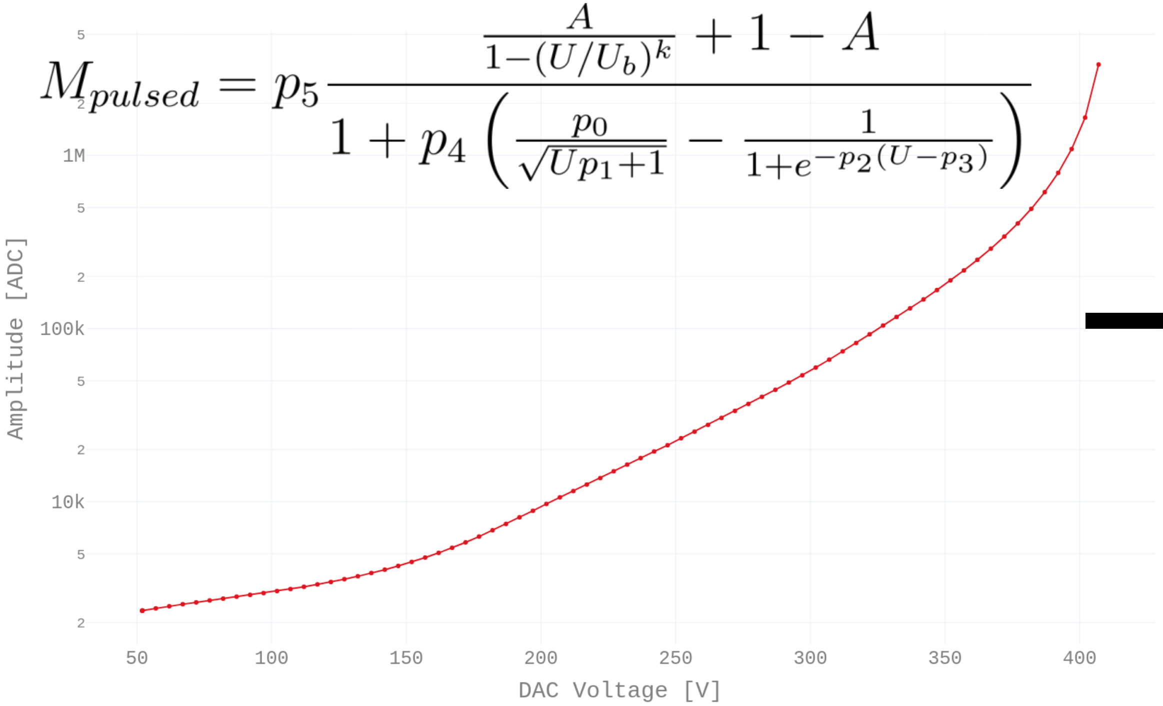
Merged LG and HG for APD 25

Merge different regions together

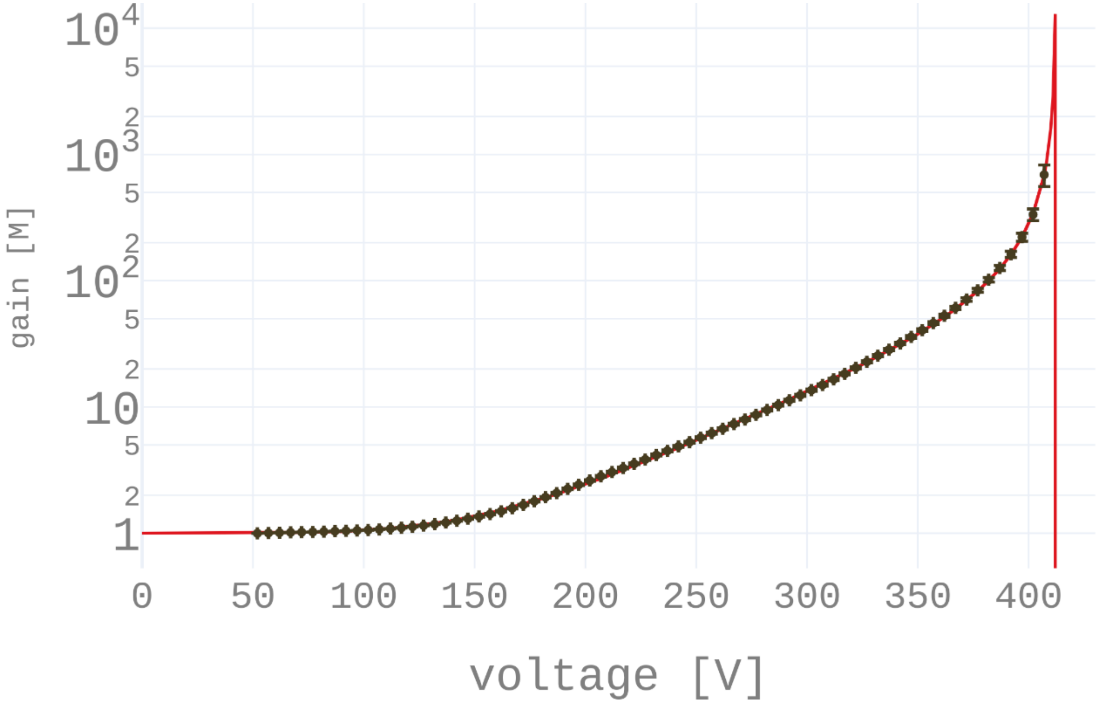


Characterisation of Photo Sensors (APDs)

- Measurement of detector signal of pulsed light at different APD bias voltages
- Sophisticated transformation to continuous gain-voltage relation
- Fit of pulsed gain-voltage relation yields parameters of continuous gain-voltage relation

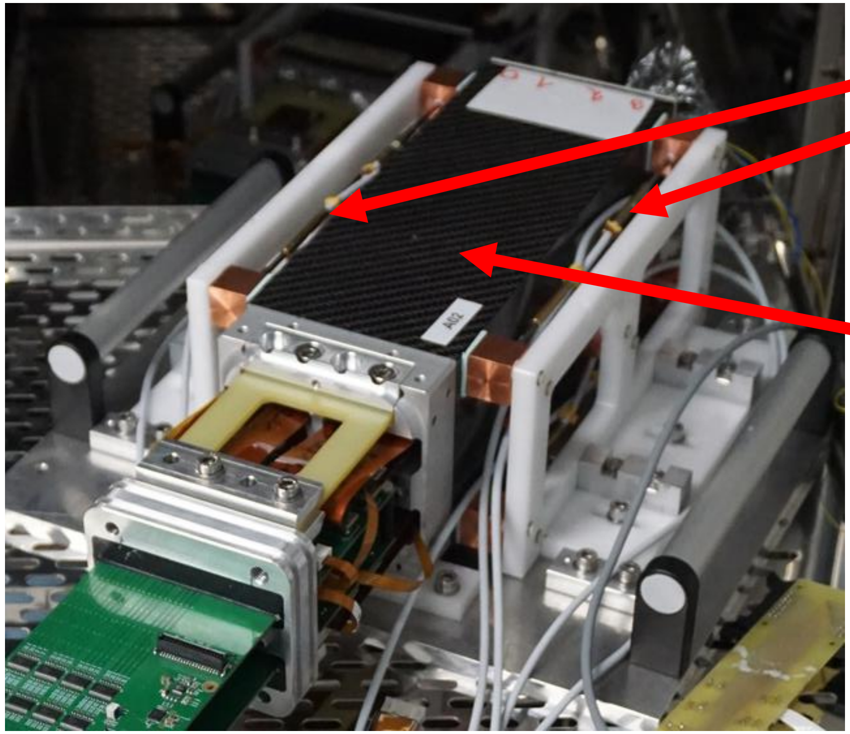


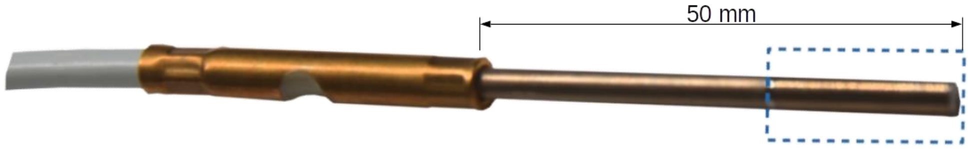
$$M_{pulsed} = p_5 \frac{\frac{A}{1-(U/U_b)^k} + 1 - A}{1 + p_4 \left(\frac{p_0}{\sqrt{U p_1 + 1}} - \frac{1}{1+e^{-p_2(U-p_3)}} \right)}$$



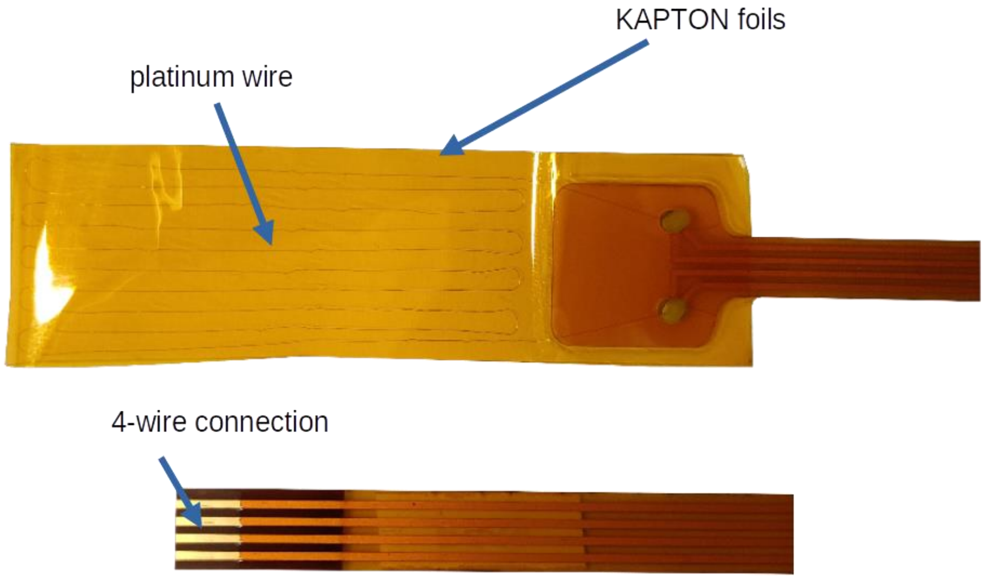
Calibration of Temperature Sensors

- 160 handcrafted flat temperature sensors with individual characteristics
- Interpolation of precise temperatures to positions of flat temperature sensors
  - -> Allows temperature determination in entire detector
- Flat temperature sensors loose calibration after mechanical stress
  - -> need to be calibrated inside submodule (in-situ)
- 10 reference sensors + 4 flat sensors per setup





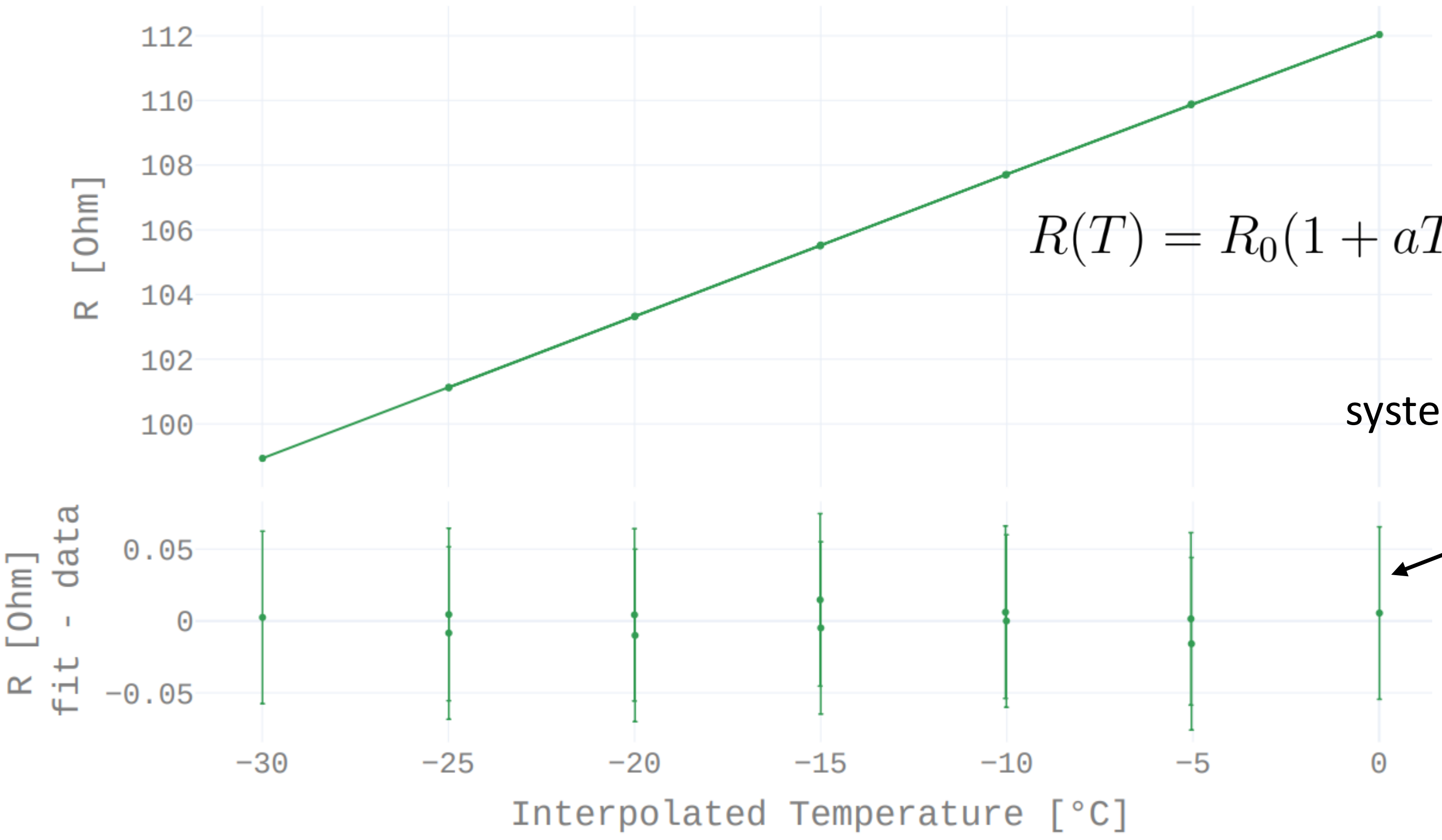
Reference Temperature Sensors (Pt100)



Flat Temperature Sensors (inside Submodule)

Calibration of Temperature Sensors

Interpolation of precise temperatures to positions of flat temperature sensors
-> yields resistance-temperature relation (quartic function)

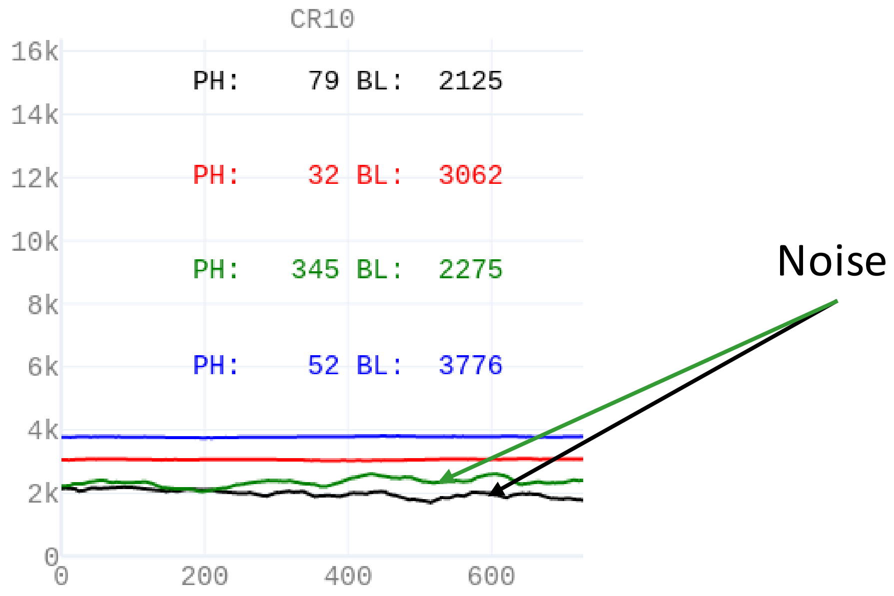


$$R(T) = R_0(1 + aT + bT^2 + cT^3(T - 100°C))$$

systematical errors from readout device

Energy Calibration with Atmospheric Muons

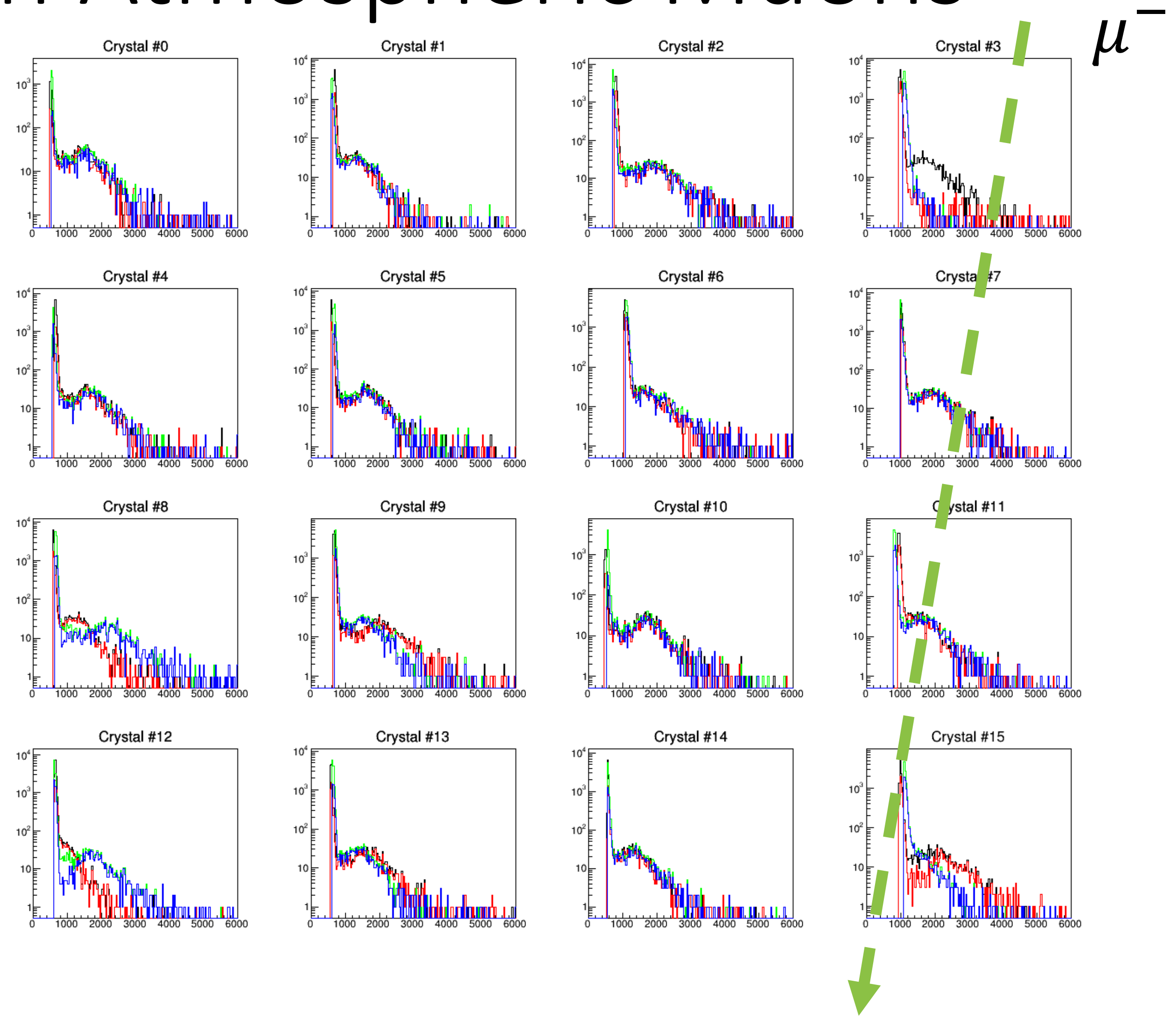
- The goal is first energy calibration
- Mapping of detector signal to energy
- Atmospheric muons deposit $\approx 10\,\frac{MeV}{cm}$ in lead tungstate
  - Peak at $\approx 25\ MeV$
- First energy calibration must be done with gain 400 because noise level of setup is too high



Energy Calibration with Atmospheric Muons

- Spectra of atmospheric muons
- Mapping of detector signal to deposited energy
- Atmospheric muons deposit $\approx 10\,\frac{MeV}{cm}$ in lead tungstate
  - Peak at $\approx 25\ MeV$

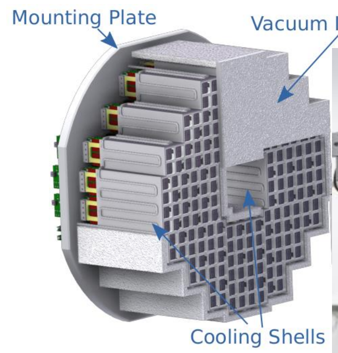
- 16 crystals of one submodule
- ■ High gain 0, o low gain 0, o high gain 1, o low gain 1
- Low gain amplification scaled to high gain
- APD setting at gain 400
- Neighboring APDs are matched (same peak position)
- Most crystals deliver visible 25 MeV peak
  - -> results agree with APD characterisation (besides outlier)

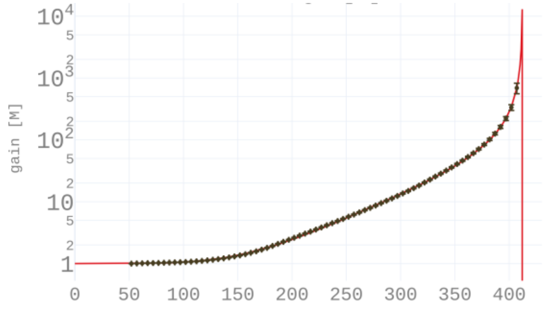


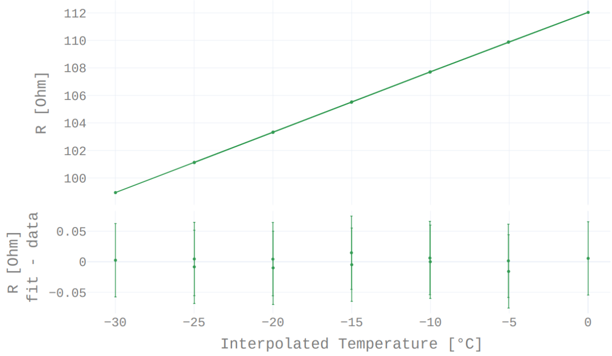
Summary and Outlook

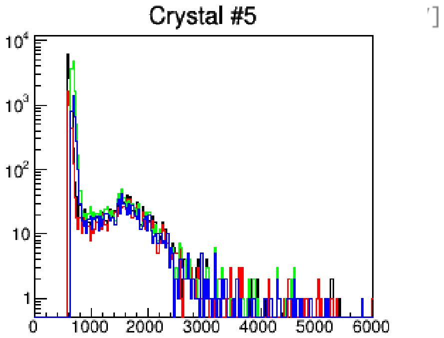
- Backward calorimeter will be used in experiment at MAMI
- Following fully automated methods developed:
  - DAC & ADC calibration of high voltage Boards
  - Gain determination of APDs
  - Temperature calibration of Pt100 Sensors
  - Energy calibration using atmospheric muons

- Estimated time consumption:
  - 3 submodules fit in climatic chamber
  - 72 hours per cycle
  - Two cycles per twice a week
  - -> 48 Submodules take 8 weeks net



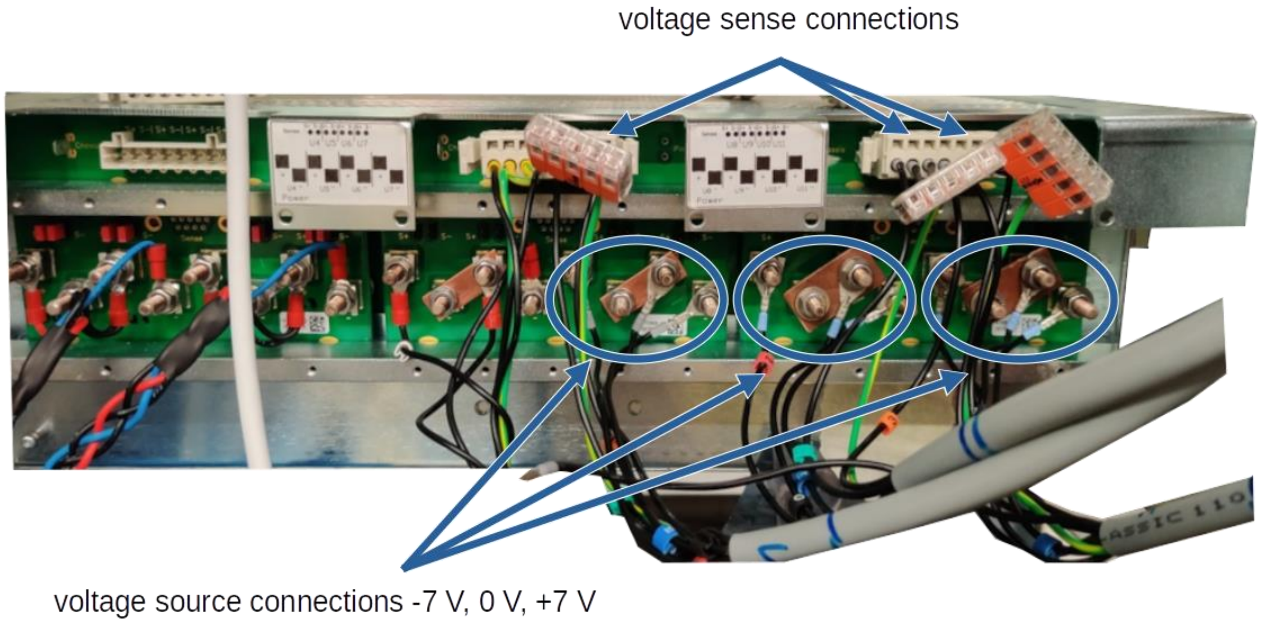




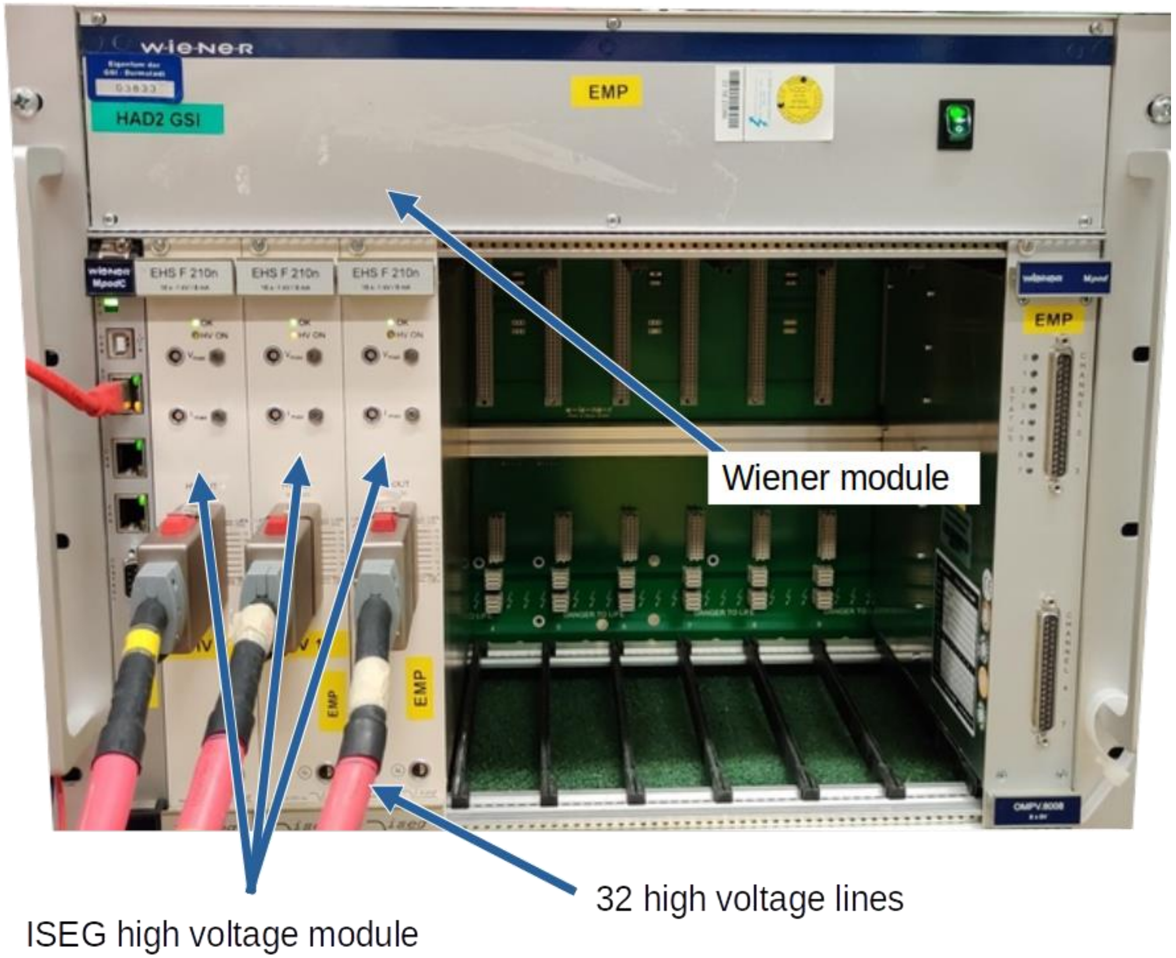


Power Supplies

- Photo sensors need high voltage
- Electronics of submodules need low voltage



Wiener Low Voltage Module Back Plane



ISEG High Voltage Modules

Light Pulser System

- No real beam available -> no electromagnetic showers -> no scintillation light
- Simulate scintillation light (420 nm in lead tungstate) with LEDs
- LED matrix provides pulsed light for individual crystal units
- Adjustable pulse width, height and frequency