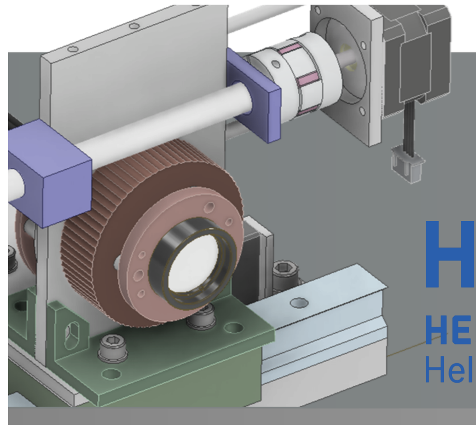
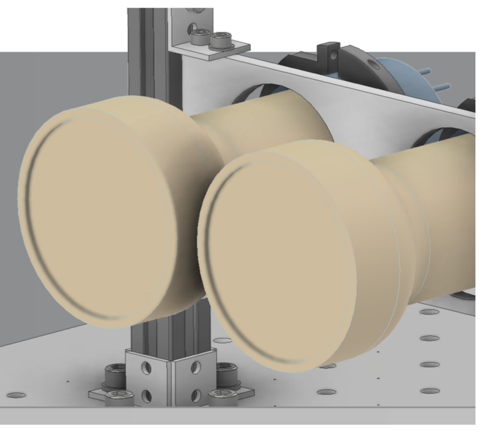


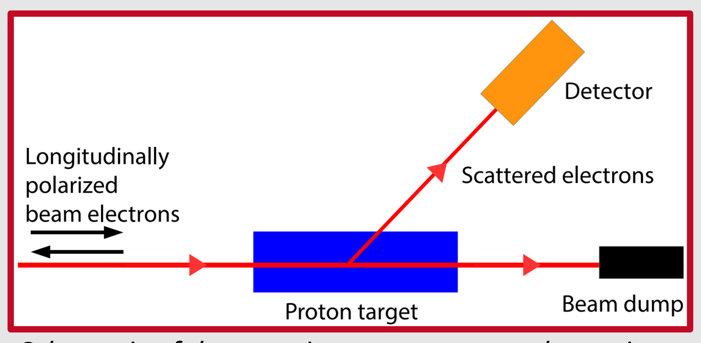
Investigations of the readout electronics of the P2 experiment at MESA



The P2 experiment

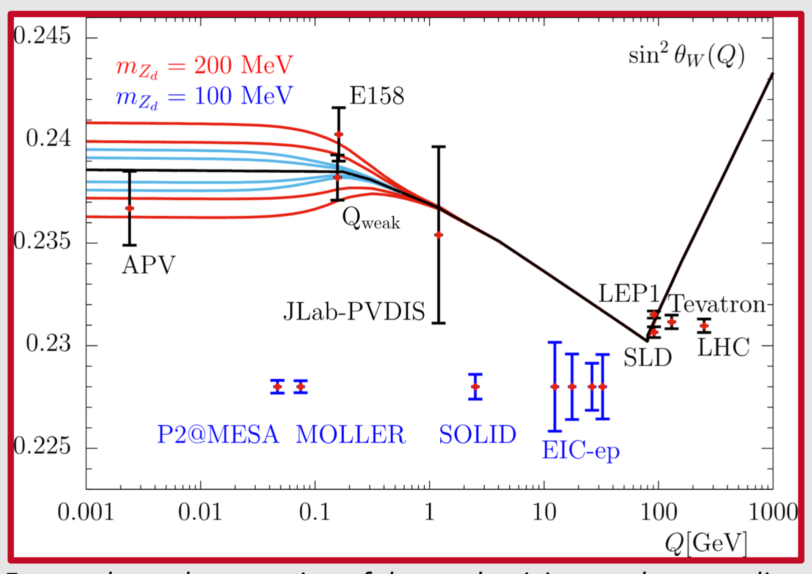
High precision determination of the weak mixing angle

Goal: Determination of weak mixing angle $\sin^2\theta_W$
Test of Standard Model of particle physics (SM):
Weak mixing angle is related to the parity violating asymmetry A^{PV} in elastic electron proton scattering



Schematic of the experiment to measure the parity violating asymmetry A^{PV}

$$A^{\mathrm{PV}} \equiv \frac{d\sigma^{+}_{\mathrm{ep}} - d\sigma^{-}_{\mathrm{ep}}}{d\sigma^{+}_{\mathrm{ep}} + d\sigma^{-}_{\mathrm{ep}}} \qquad \frac{\Delta \sin^2\theta_{\mathrm{W}}}{\sin^2\theta_{\mathrm{W}}} < 0.15\ \%$$



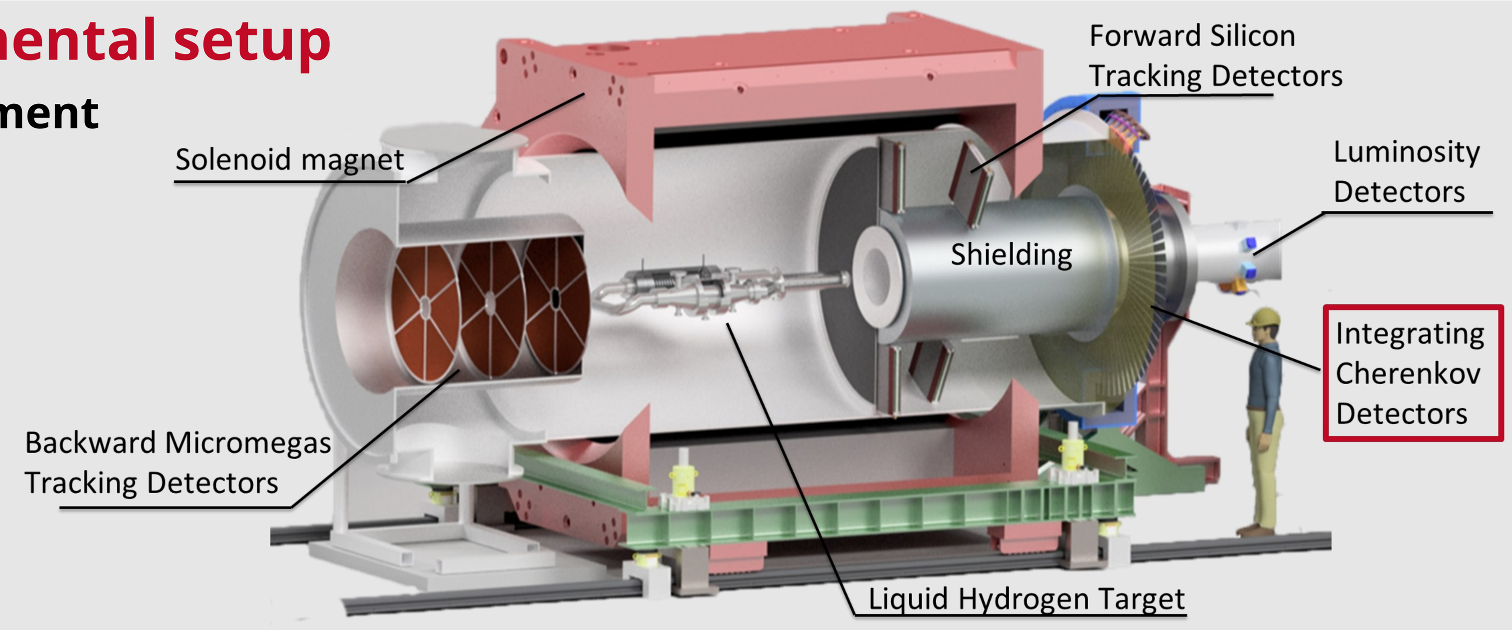
Energy dependent running of the weak mixing angle as predicted by the SM with published (black) and future (blue) results.

P2 experiment electron beam:
- provided by the Mainz Energy-Recovering Superconducting Accelerator (MESA)
- longitudinally polarized electrons ($E_{Beam} = 155$ MeV)
- Interaction with liquid hydrogen target
- Flipping helicity of beam electrons (parity)

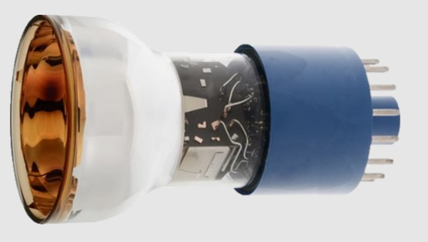
⇒ Weak mixing angle determined out of the parity violating asymmetry

Experimental setup

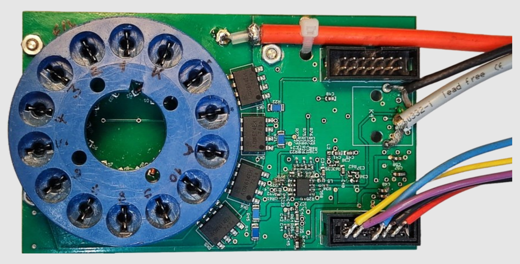
P2-Experiment



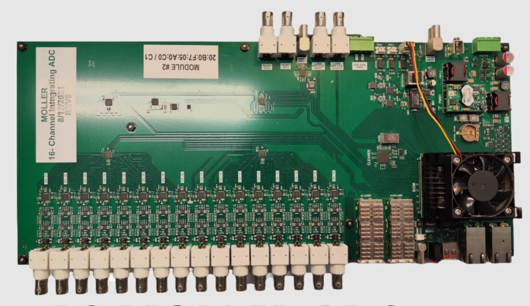
Readout electronics



Photomultiplier [PMT]
Cherenkov-Photons
→ Photoelectrons



P2-DivA Base
Current
→ Differential voltage

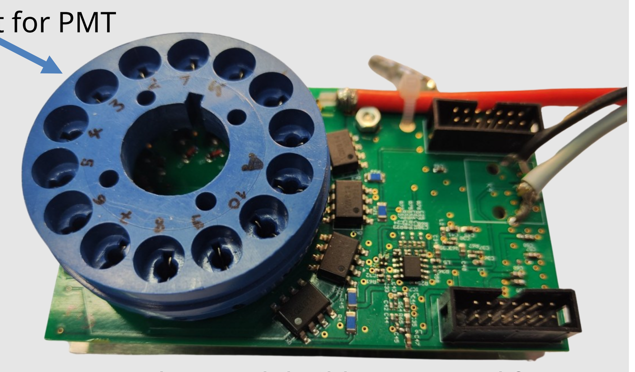


P2-MOLLER ADC
Diff. voltage signal
→ Digital data stream

Photomultiplier Base P2-DivA

Operatable in two modes: Pulse and integration mode
- Pulse mode:
  - Tracking detectors, calibration of setup
  - High gain required; all ten dynodes used
- Integration mode:
  - Cherenkov detector ring, high statistics (~160 GHz)
  - Lower gain required; only 5 dynodes
  - Current collected by the PMT anode is converted to a differential voltage signal by the P2-DivA base
- Pre-amplifier for additional signal amplification

Socket for PMT



PMT base with build-in pre-amplifier

PMT pin connectors

PMT

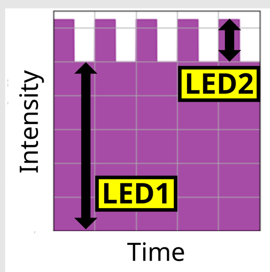
P2 Analog-to-Digital converter

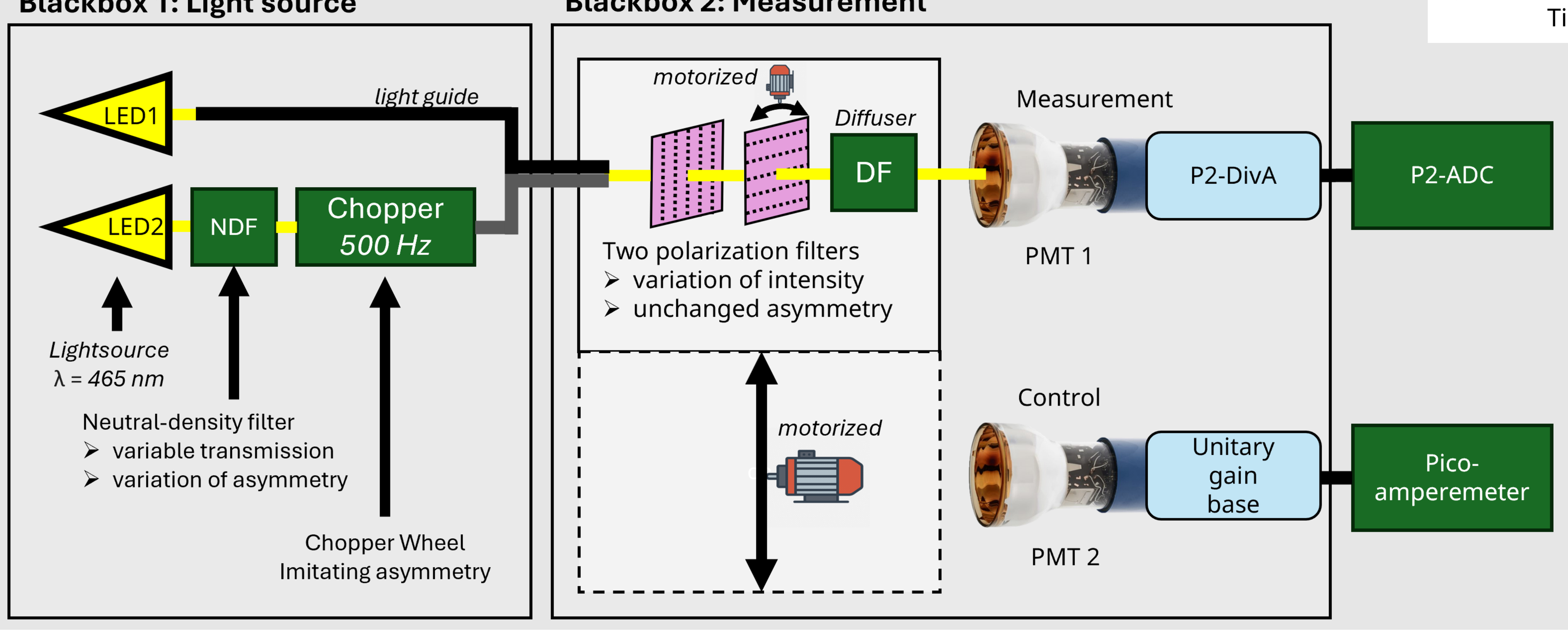
- Two DAQ-modes:
  - (Helicity-)Gated integration via on-board FPGA
  - Data stream of voltage and timestamp for all channels
- Number of channels per board: 16
- Measurement range: ±4.096 V
- Sampling frequency: 14.7 MHz
- Resolution: 31.25 µV (18-Bit ADC)
  - ➢ Connectivity to multiple PMTs
  - ➢ High sampling rate required for the extremely high electron rates and to obtain sufficient statistics

Characterization of readout electronics – Emulating an asymmetric light signal

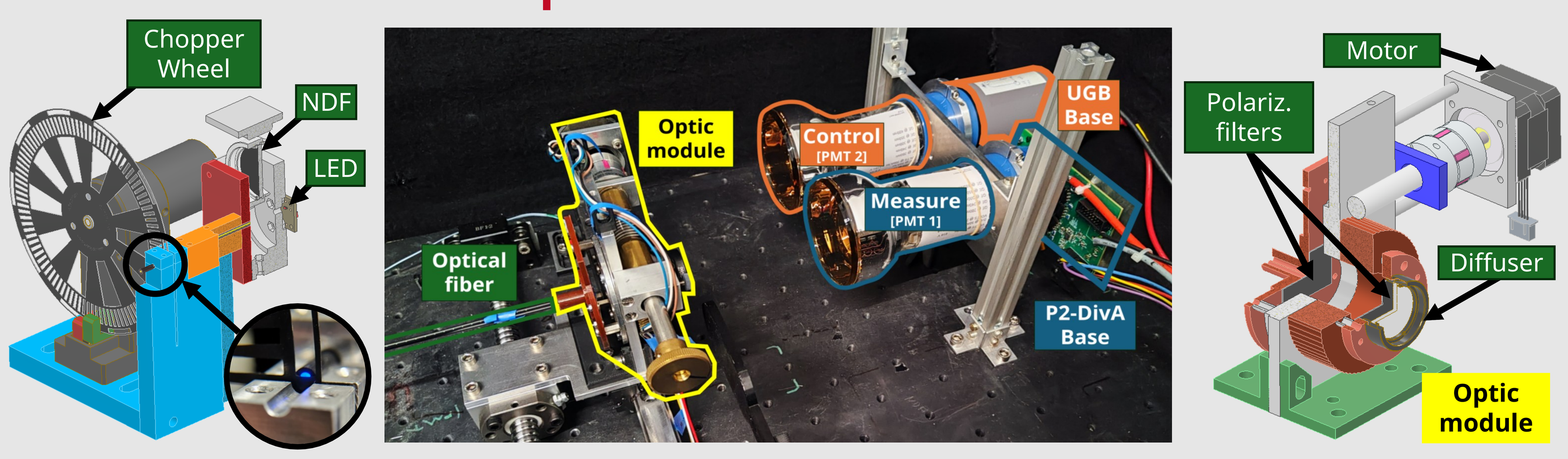
I. Scheme of measurement

- ➢ Emulate the parity violating asymmetry in the Cherenkov light
- ➢ Measure asymmetric light signal using the P2 readout electronics





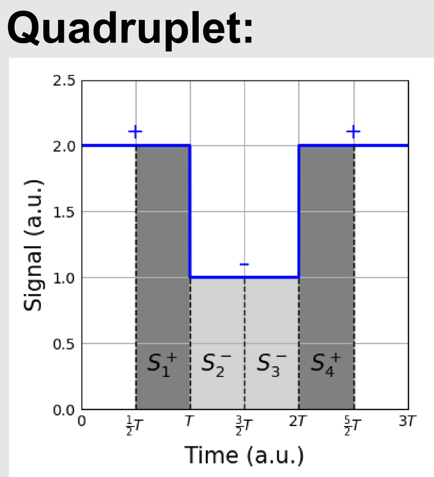
II. Measurement setup



III. Quadruplet asymmetry and test signal

No NDF – test signal

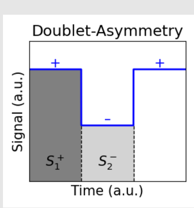
Quadruplet:

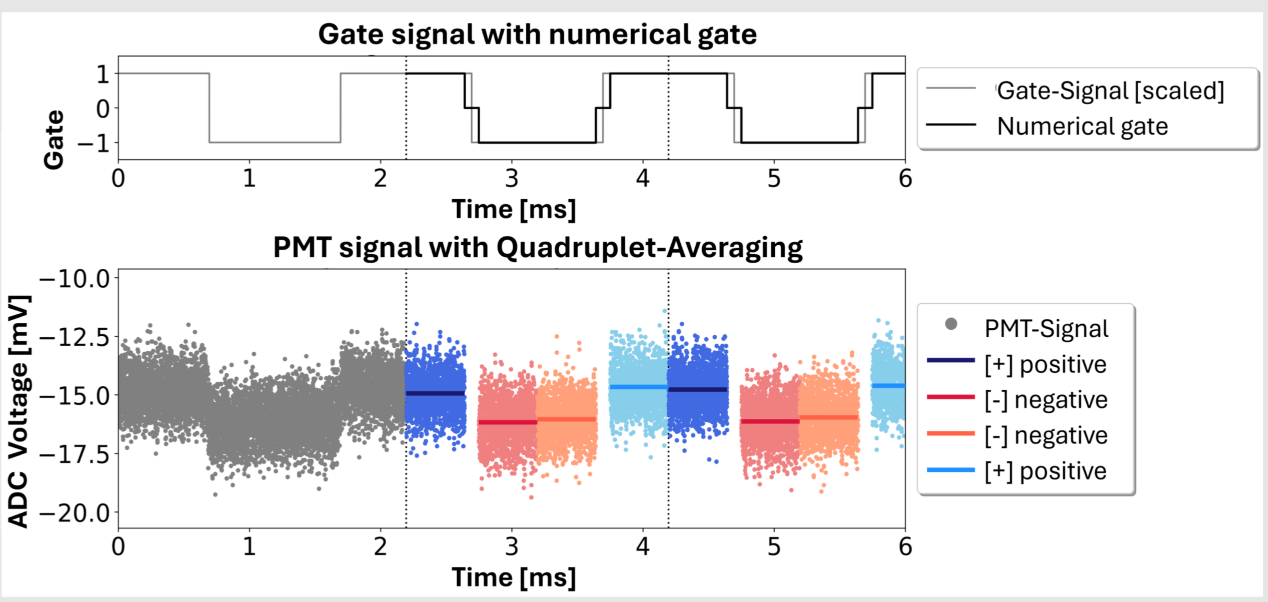


$$A_{\mathrm{Qp}} = \frac{[S_1^+ + S_4^+] - [S_2^- + S_3^-]}{[S_1^+ + S_4^+] + [S_2^- + S_3^-]}$$

Doublet:
Out of two segments
Volatile to linear drift

$$A_{\mathrm{Db}} = \frac{S^+ - S^-}{S^+ + S^-}$$





Upper: Gate signal (reference signal of the chopper control unit)
Numerical gate to exclude the transition range
Lower: Delay-corrected PMT signal (P2-ADC)
Signal sections for two "+--+" quadruplets

IV. Measurement results

NDF with OD: 3

Measured asymmetry in dependence of the PMT gain

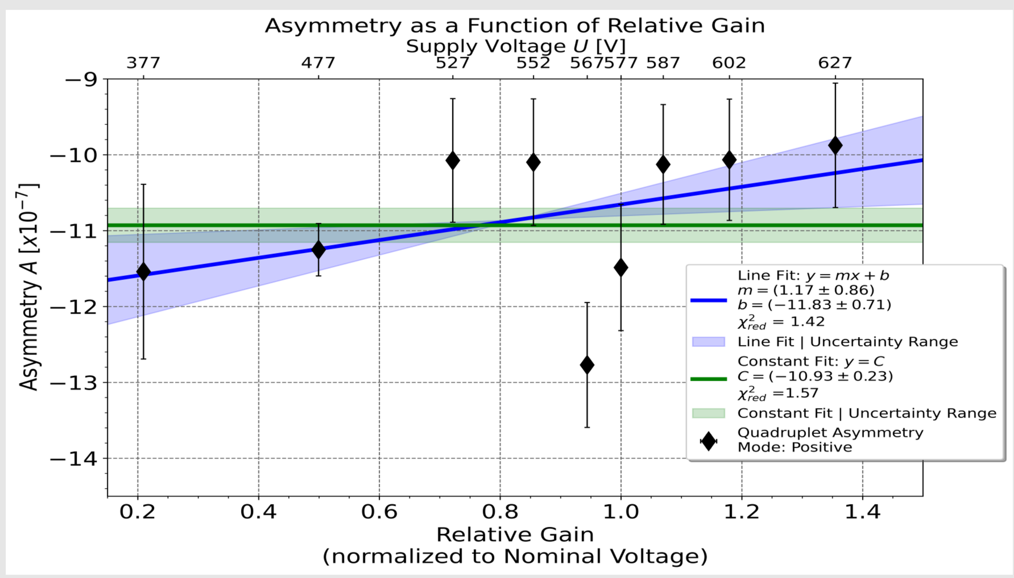
Measurement of the quadruplet asym. for different supply voltages
Nominal voltage of PMT: U = 577 V

Calculation of the quadruplet asym.:
(from Gauss-Fit of 800.000 quadruplets)

$$A_\mu(U = 577\,\mathrm{V}) = -(11.5 \pm 0.8) \times 10^{-7}$$

Comparison to calibrated asym.:

$$A_{\mathrm{NE30A}} \approx A_{\mathrm{no\ NDF}} \cdot \bar{T}_{\mathrm{NE30A}} = -12 \times 10^{-7}$$



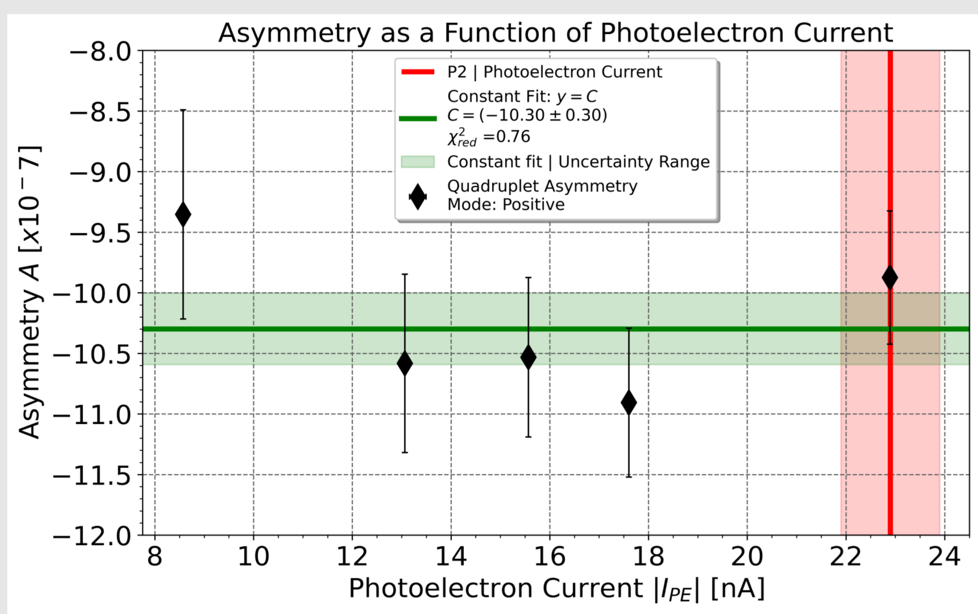
Measured asymmetry in dependence of the photoelectron current

Rotating the second polarization filter to alter the light intensity
⇒ Asymmetry unchanged

Photoelectron current estimated for P2:

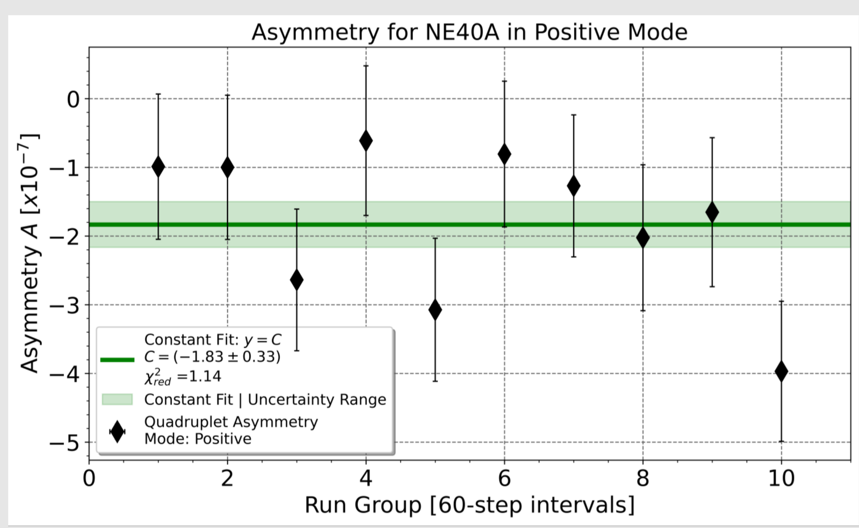
$$I_{\mathrm{pe}}^{\mathrm{P2}} \approx (23 \pm 1)\ \mathrm{nA}$$

For this measurement:
- Five polarization filter settings
- I_{pe} between 8.5 and 23 nA



Limit test of measurement setup: Asymmetry $\mathcal{O}(10^{-7})$

NDF with OD: 4



Neutral density filter with optical density of four
⇒ Transmission in the order of 0.01%
⇒ Smallest asymmetry possible with current setup

Quadruplet asym. determined from Constant Fit:

$$A_{\mathrm{C\text{-}Fit}} = (-1.83 \pm 0.33) \times 10^{-7}$$

Comparison to calibrated asym.:

$$A_{\mathrm{NE40A}} \approx -1.1 \times 10^{-7}$$

V. Outlook

- Improvement of the measurement setup
  ⇒ Photodiode to control LED stability, better NDF filter setup and optical fiber coupling
- Longer data taking for better statistics
- New ADC-Firmware enabling on-chip signal integration and quadruplet calculation

Moran Neher | P2 collaboration | Johannes-Gutenberg University Mainz

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