# Status Report on the Cherenkov Detector

## From Cherenkov Module to Digitizer

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P2 Retreat Meeting
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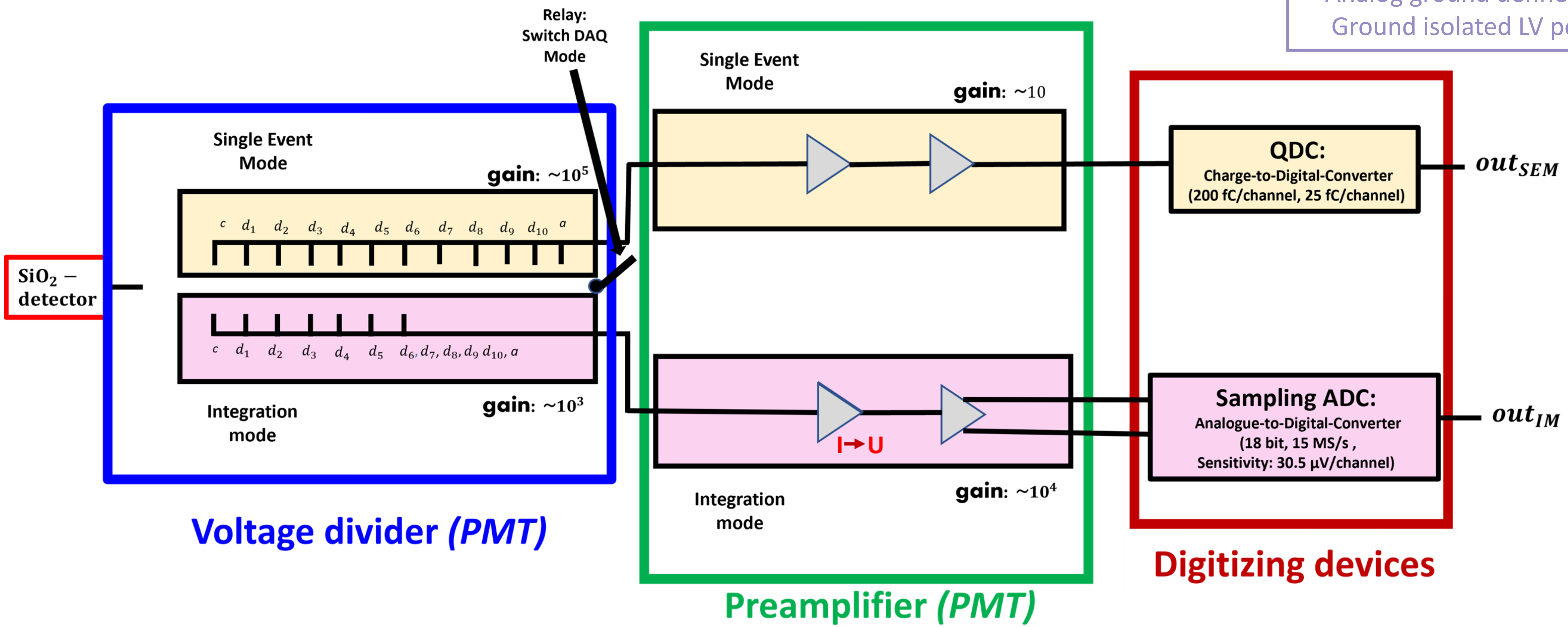
# From $SiO_2$ Detector to Digitizer: Signal Processing via DivA Board *(voltage Divider and preAmplifier Board)*

Analog ground defined via HV line
Ground isolated LV power supply

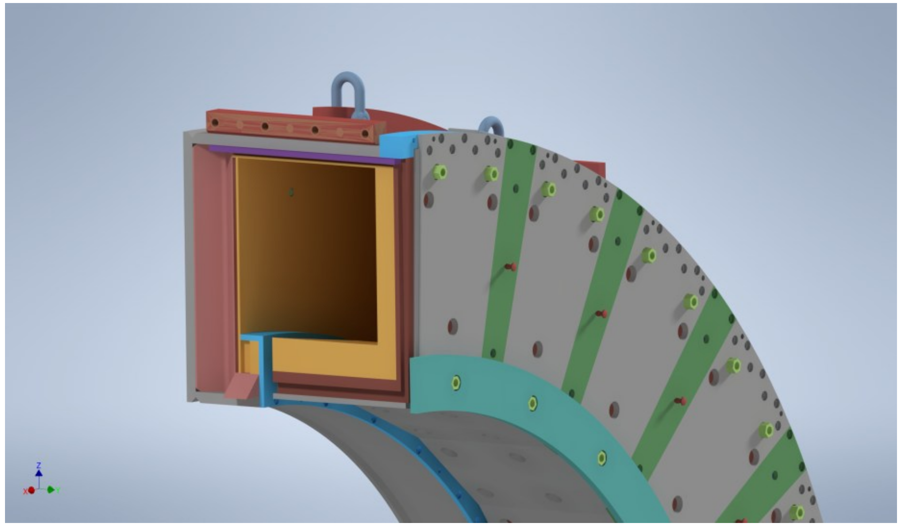



Schematic overview of the PMT signal chain in the P2 experiment. Cherenkov light from the $SiO_2$ detector are detected by the PMT and amplified. The signals are digitized using a QDC in Single Event Mode or an ADC in Integrating Mode.

# Open Tasks and Ongoing Work:
# *Cherenkov Detector Ring*

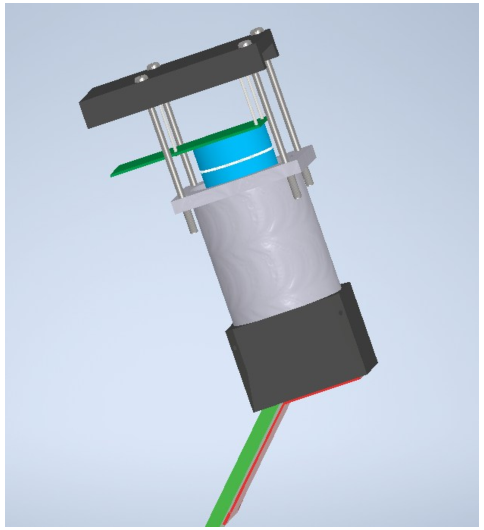
**Cherenkov Detector Ring:**

- Fused silica detector ($SiO_2$)
  → Spectrosil 2000 by HERAEUS



CAD model of the lead ring

- All 90 detectors are delivered ✓
- Lead shielding currently manufactured by MTH ✓
- Fixation: detector – PMT ✓



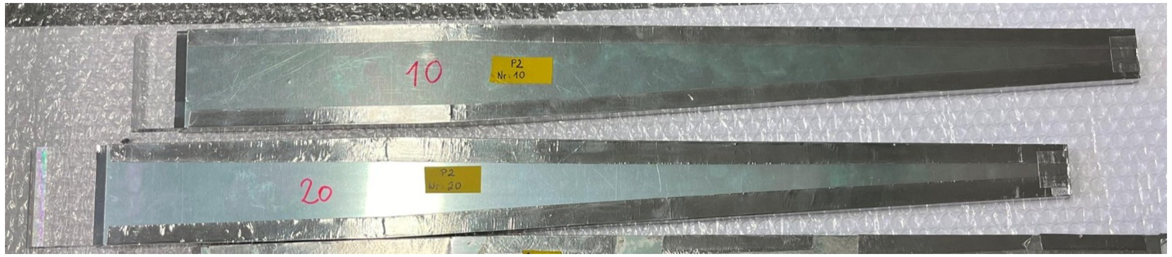
CAD model of a single PMT with mechanical mounting structure

- No lead support structure available yet ✗
- Electronics housing still needed ✗
  → Needs to be finalized

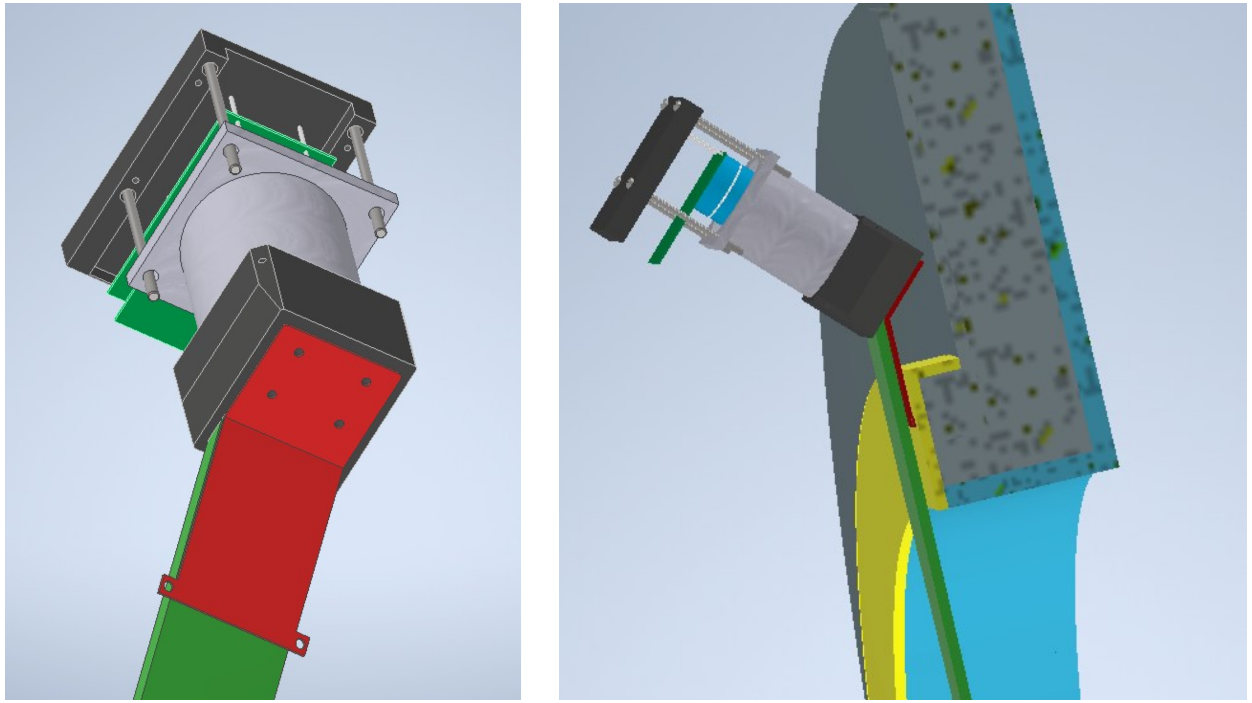
# Open Tasks and Ongoing Work:
# *Cherenkov Detector*

**Cherenkov Detector:**

- Fused silica detector ($SiO_2$)
  → Spectrosil 2000 by HERAEUS
- Mechanical detector support ❌
  → Needs to be finalized
- Wrapping detectors with Alanod 4300UP ❌




Two $SiO_2$ Cherenkov detectors wrapped in Alanod foil for optimized internal light reflection.



CAD model fixation structure of a detector

# Open Tasks and Ongoing Work: *PMTs*

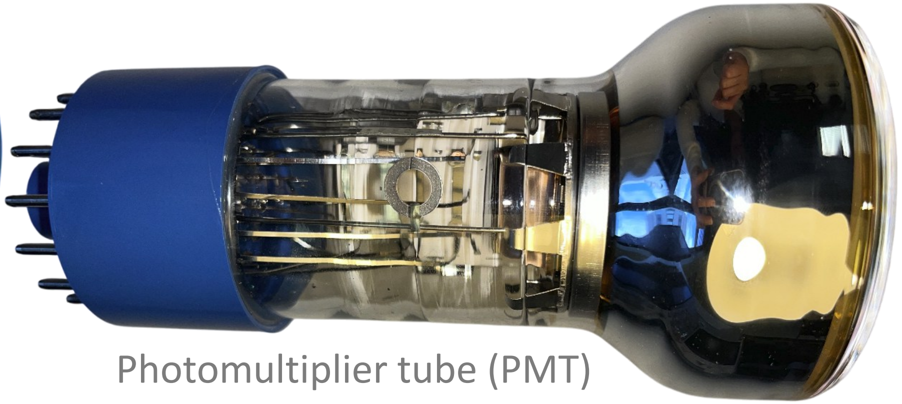
**PMTs:**

- 9305QKB PMT by ET Enterprises
  → max. cathode current: 200 nA
  → max. anode current: 100 µA

- All 300 PMTs are delivered ✓
- All 300 sockets are delivered ✓
- Gain characterization in **SEM** ✓

- Gain characterization in **IM** ❌
- Light shielding: black shrink tube ❌
- EM shielding: Mu-metal ❌
- PMT socket soldered onto DivA board ❌

PMT socket
B14A/PCLF3 by ET Enterprises



Photomultiplier tube (PMT)
9305KB by ET Enterprises

# PMT Voltage Divider Circuit and Readout Mode Switching

**Voltage divider:**

- Active voltage divider for PMTs  with 10 (5) dynodes
- Combination of resistors, capacitors, Zener diodes, FETs

**Preamplifier:**

- **SEM:** fast, pulse-based amplifier (THS3202)
  - → Singled-ended output
  - → Pulse readout via QDC
- **IM:** Transimpedance amplifier (AD8066)
  - → Transimpedance stage ($R_f$=33 kΩ)
  - + differential output
  - → Signal readout via P2ADC

Internal test current for IM mode
→ functionality check of IM amplifier chain
→ 4.5 V/ 200 kΩ

**Configuration:**

- SEM: $D_{10}$ is last dynode; high gain operation
- IM: $D_5$ is last dynode; low gain operation
- 3R-R-R-R (R = 3.3 MΩ)

**DAQ Mode Switching:**

- MOSFET-based logic
- Voltage divider reconfiguration
  - → Parallel MosFETs
- Dynode chain switching of $D_6 - D_{10}$
  - → Disconnected from chain
  - → Reconnected to anode

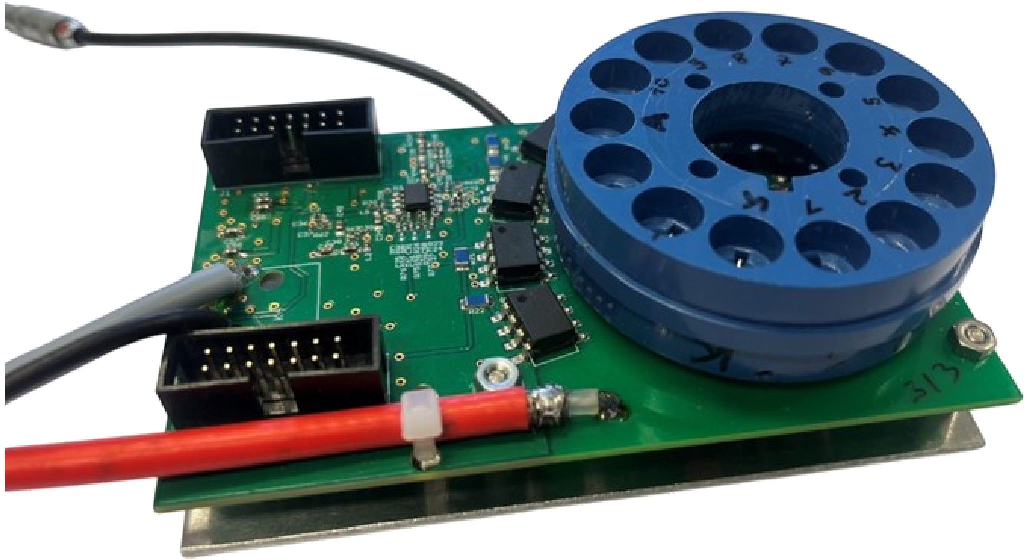
# Open Tasks and Ongoing Work: *DivA board*

**DivA board:**

- Voltage divider and preamplifier
  → DAQ Mode for SEM/IM

- Successful  beam tests of DivA board ✓
  → Enabled determination of $N_{PE}$
- Successful radiation tests of DivA board ✓
  → Signal change of 4%@6300Gray
- Successful radiation tests voltage regulators✓
  → Shotlisted 1 type per application

- Radiation test of voltage regulators ❌
- Replacing resistor by Zener diode ❌
- Production of DivA-boards ❌



Voltage divider and preamplifier (DivA) combined on one single PCB

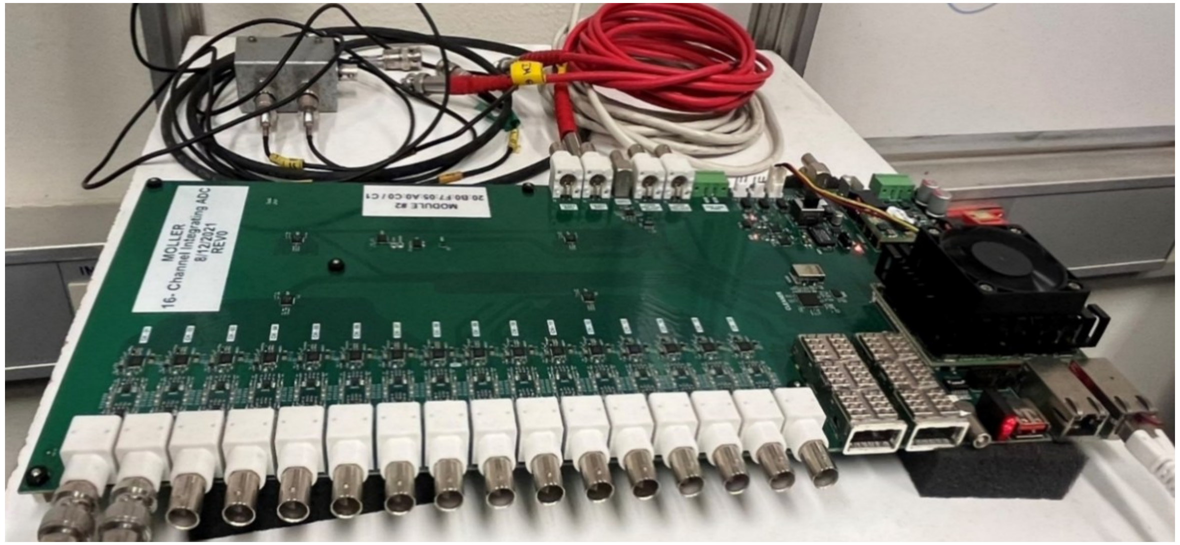
# Open Tasks and Ongoing Work:
# *DAQ*

**DAQ:**

- QDC: Charge to Digital Converter
  → Single Event Mode
- P2ADC: P2 Analog to Digital Converter
  → Integrating Mode

- QDC from CAEN ✓
  → coaxial input (BNC)

- P2ADC from MOLLER x 10 ✓
  → differential input (BNC- Twinax)
  → All 10 FGPA arrived ✓



A P2ADC (MOLLER)

# Open Tasks and Ongoing Work:
# *Cables*

**Cables:**

**DAQ SEM:**

- Cable reels arrived ✓
- All BNC connectors arrived ✓
- Cable crimping and connector installation ✗

**High Voltage:**

- Cables there (A4) ✓
- HV-BNC connector to SHV ✗

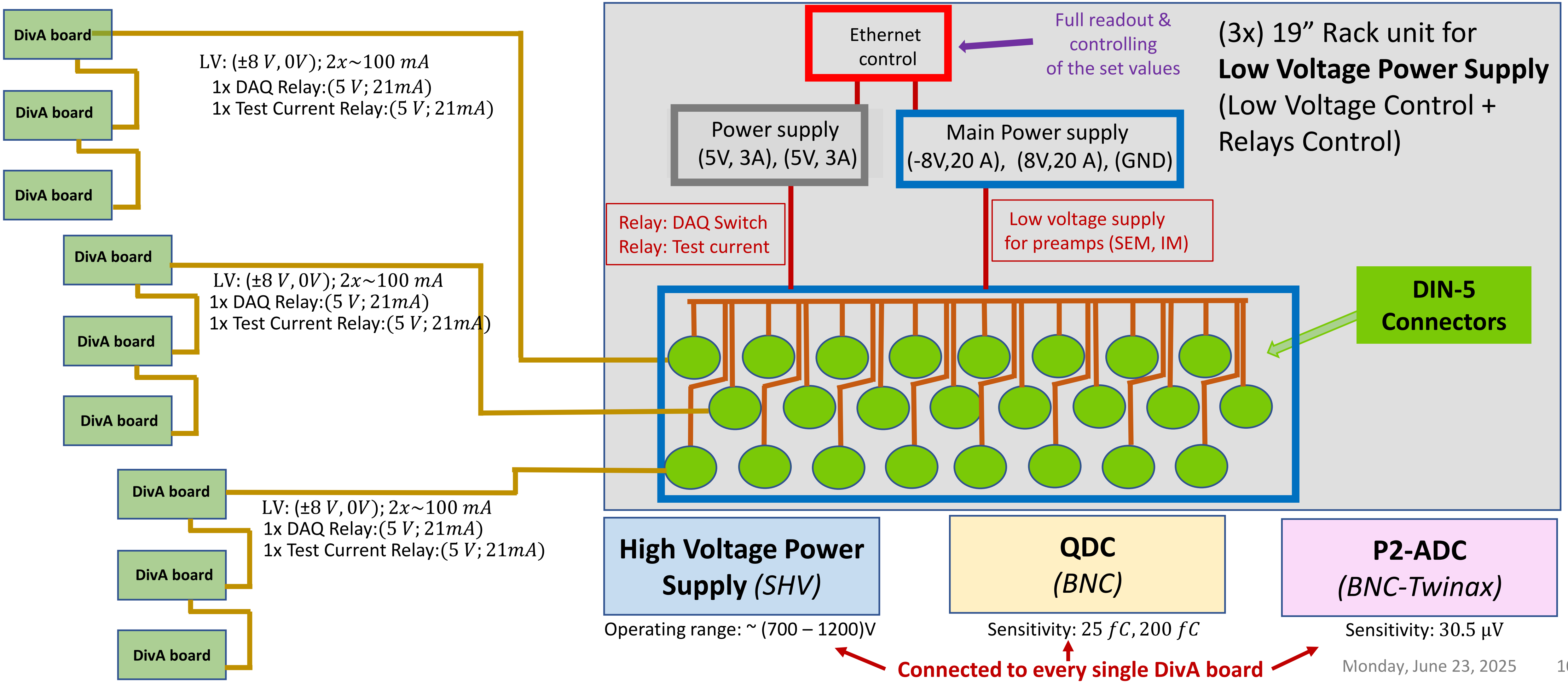
**Low Voltage:**

- Low voltage supply (Igor) ✓
- DIN-5 connector + cables ✗

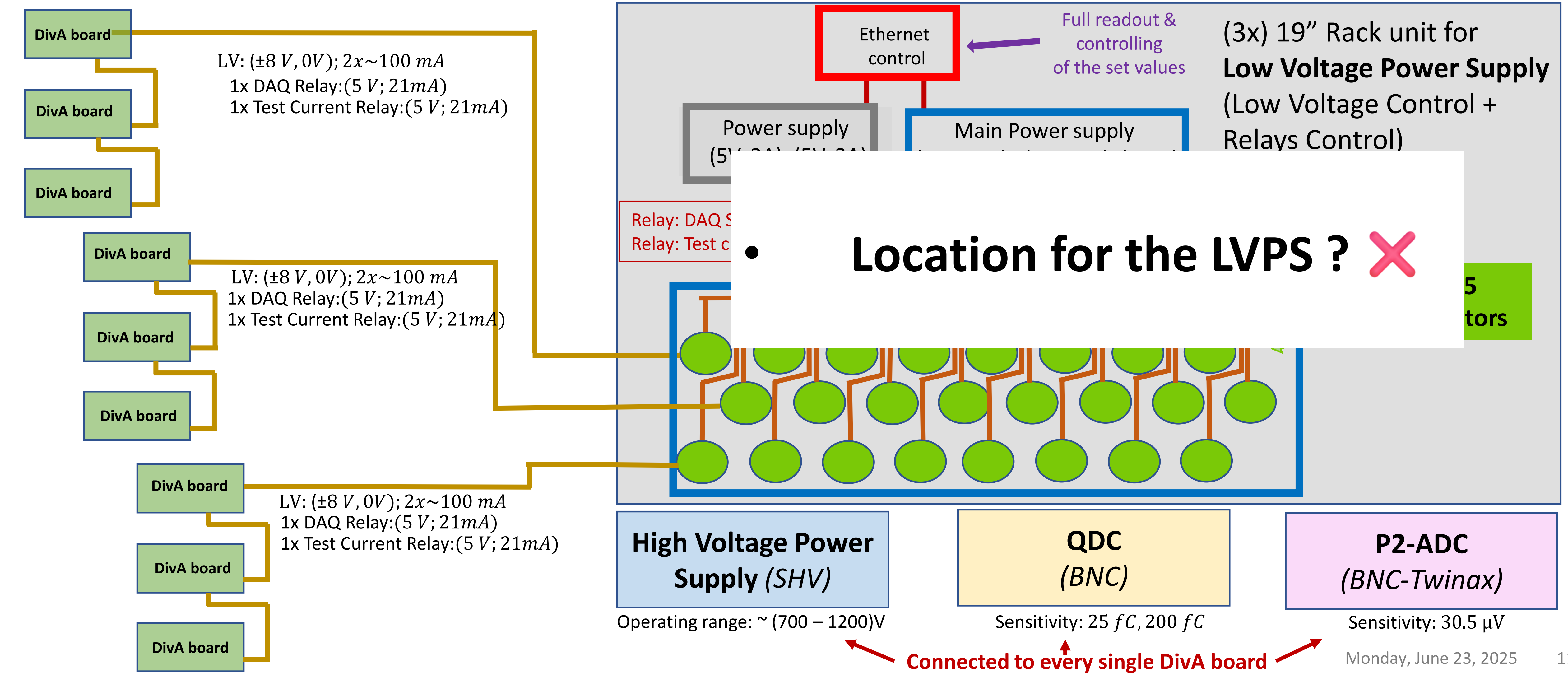
**DAQ IM:**

- Twinaxial cables over 60 m are cost-prohibitive
  → ~500 € per 30m cable
- *IDEA:*
  -Differential signal from DivA board via Single Pair Ethernet (SPE) cable
  -Four signal paths (4 boards) combined into one CAT-8 cable (4 twisted pairs) over 60 m
  →Signals split again into individual SPE-to-Twinaxial paths (input P2ADC)
- Cable test for signaling path between DivA-P2ADC ✗

# Open Tasks and Ongoing Work:
# Interconnecting *Low Voltage Power Supply + Relays*



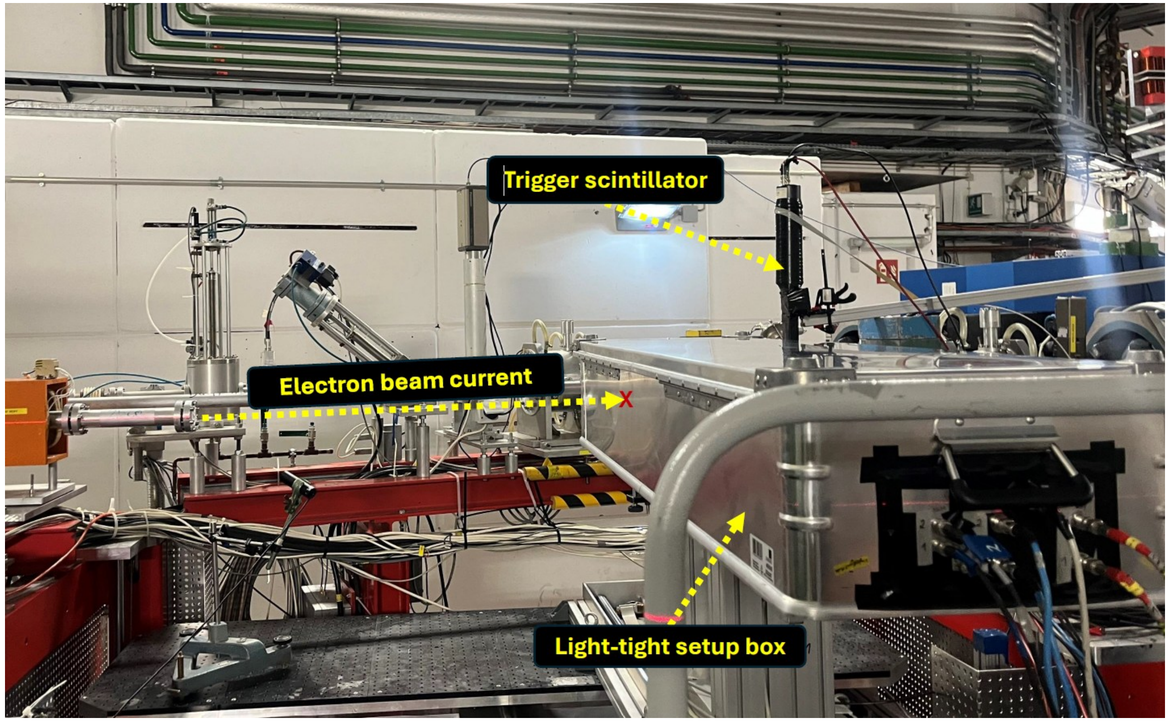
# Open Tasks and Ongoing Work




- **Location for the LVPS ?** ❌

# BACK UP

# Experimental Setup and Measurement Program Overview



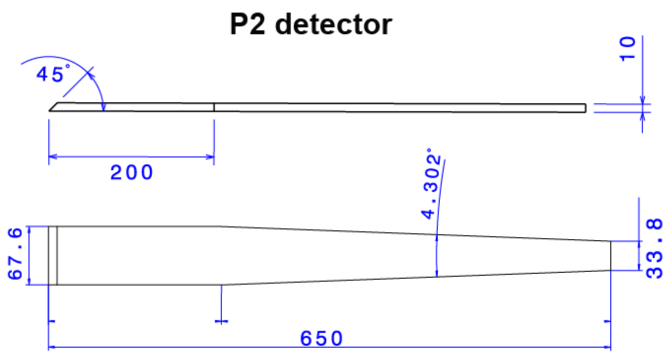

Experimental setup during beam time

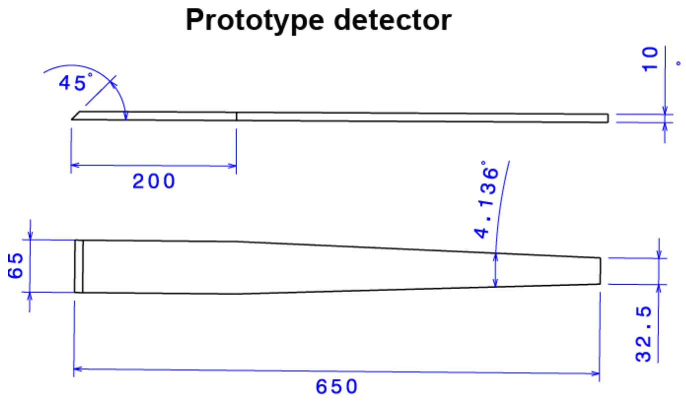
| Program | Prototype detector | PMT |
|---|---|---|
| Konfiguration A | $Q_2$ | ET520 |
| Konfiguration B | $Q_1/Q_2$ | ET518/ET520 |
| Konfiguration C | $Q_1$ | ET518 |
| Position Scan | $Q_1$ | ET518 |
| Translation Offset | $Q_1$ | ET518 |
| Rotational Angle Offset | $Q_1$ | ET518 |
| PMT-Detector-Mix | $Q_1/Q_2$ | ET518/ET520 |

| Program | P2 detector | PMT |
|---|---|---|
| Konfiguration A | $N_{20}$ | ET873 |
| Konfiguration B | $N_{10}/N_{20}$ | ET923/ET873 |
| Konfiguration C | $N_{10}$ | ET923 |
| Position Scan | $N_{10}$ | ET923 |
| Translation Offset | $N_{10}$ | ET923 |
| Rotational Angle Offset | $N_{10}$ | ET923 |
| PMT-Detector-Mix | $N_{10}/N_{20}$ | ET923/ET873 |

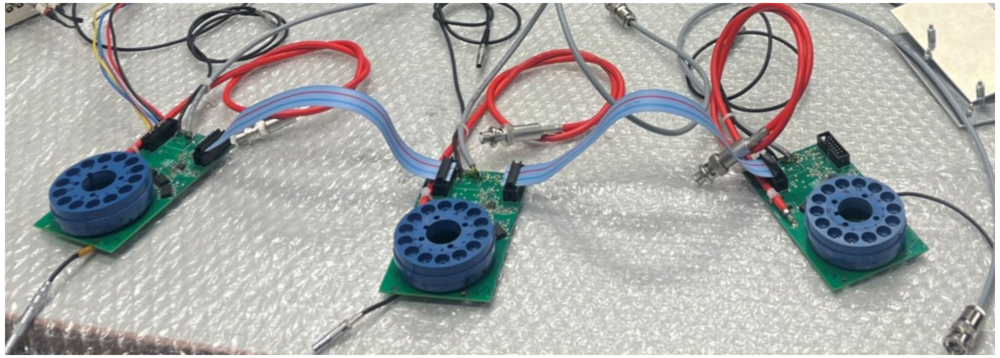
Overview of the tested configuration and measurement series

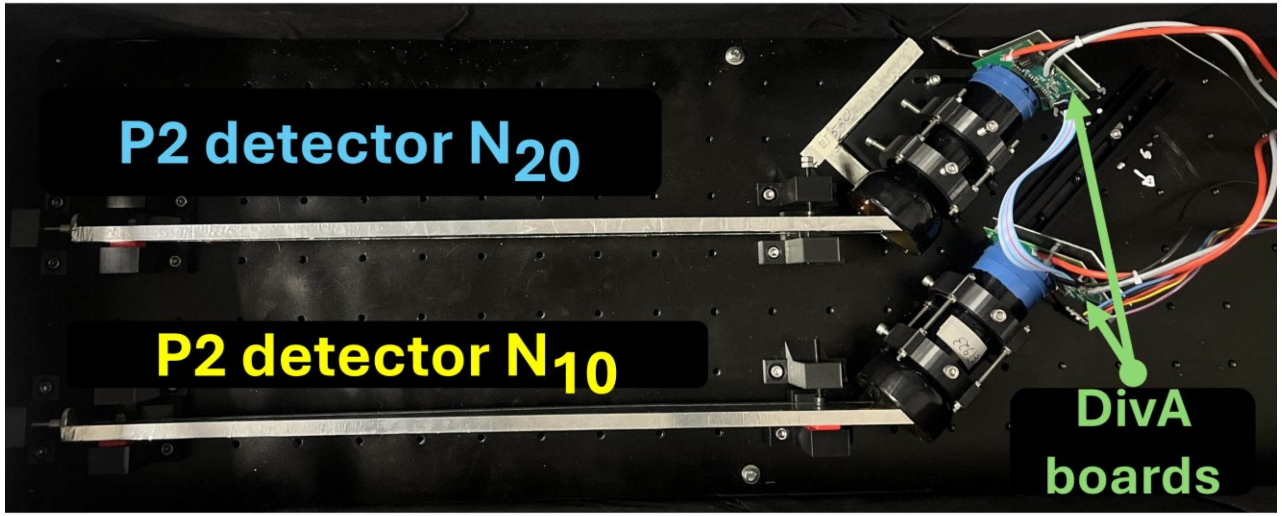
# Setup for Testing DivA boards




$SiO_2$ detector (Spectrosil 2000) from company HERAEUS
$(Q_1, Q_2)$, $(N_{10}, N_{20})$

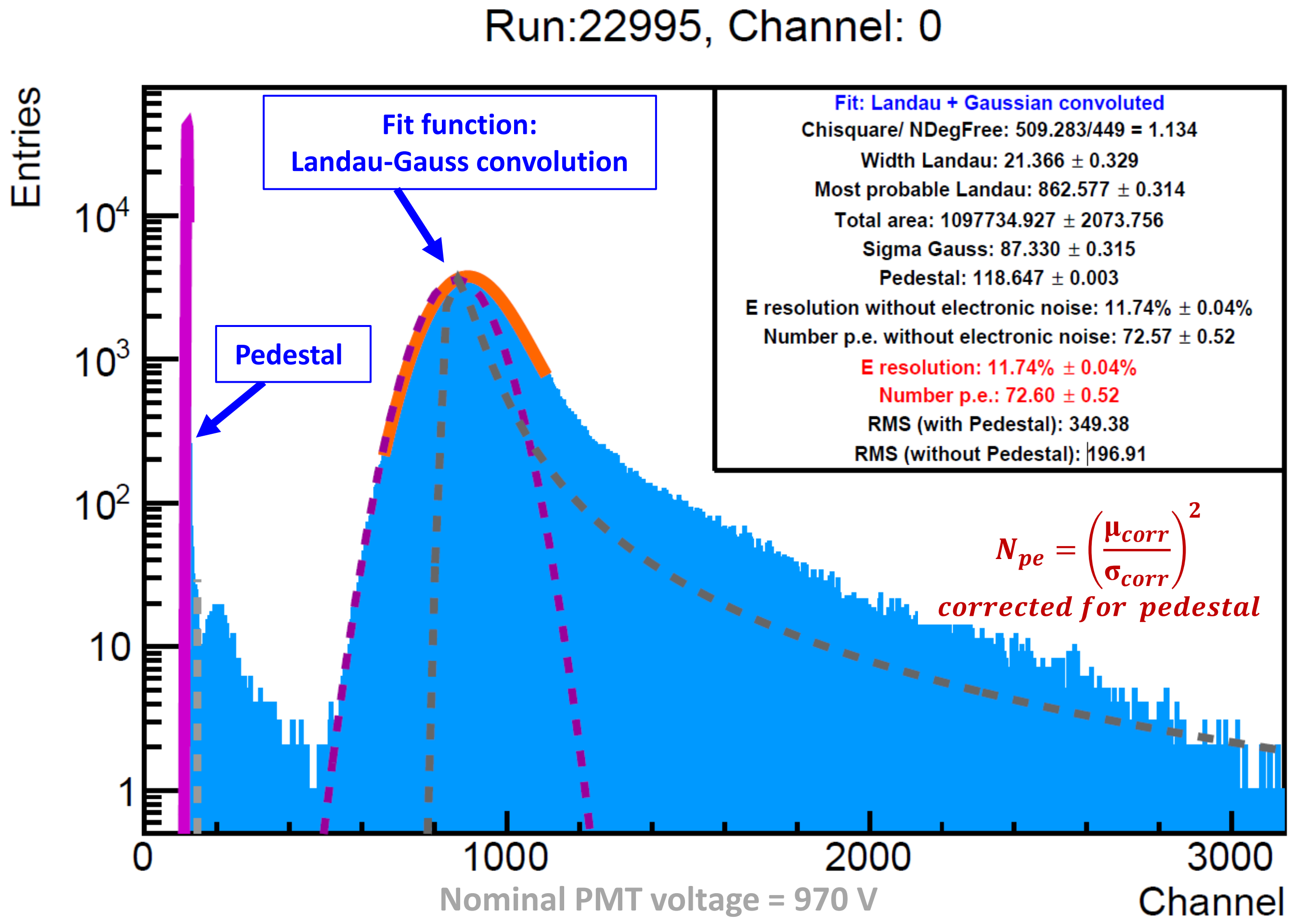




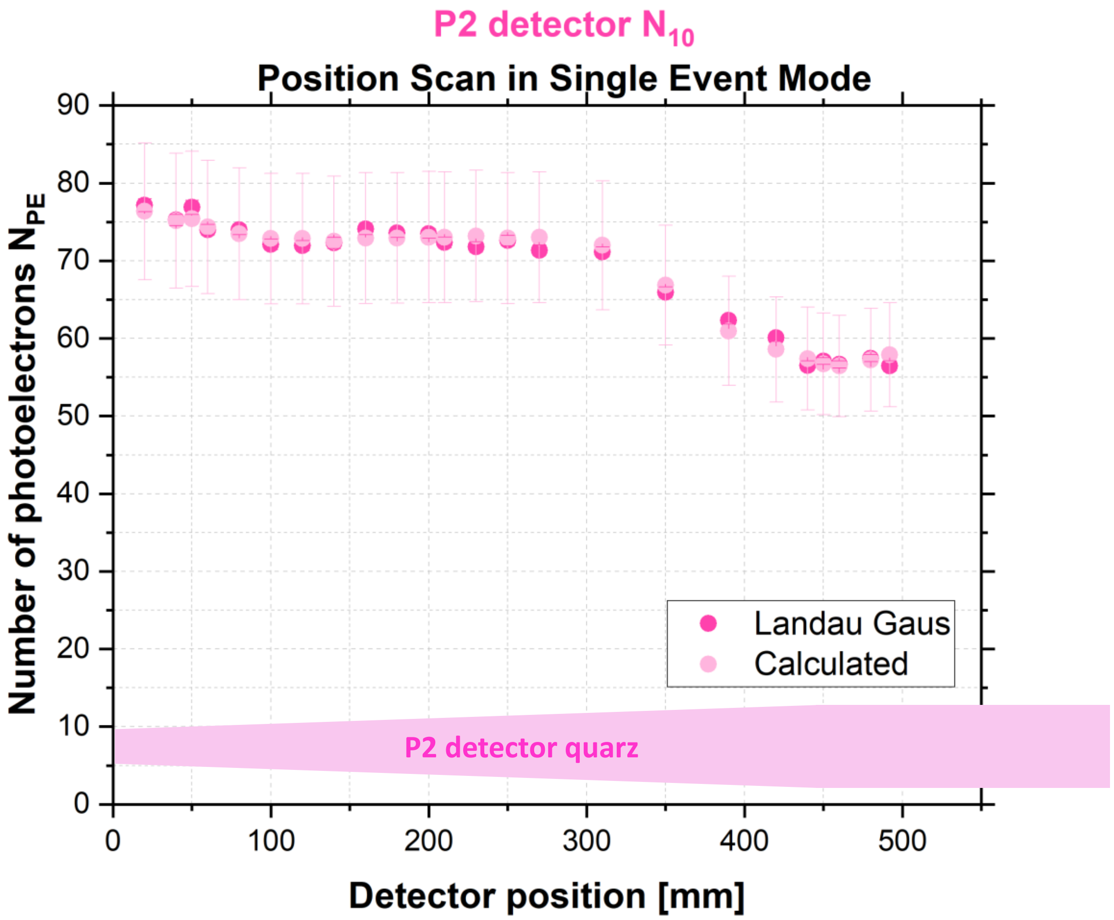

Insight of the light-tight setup box.
Two detectors connected to DivA boards

# Method: Signal Analysis in Single Event Mode (SEM)

**Single Event Mode**
**Quarz Combination**
(Landau Gaus)




Nominal PMT voltage = 970 V
DAQ Trigger: Trigger scintillator
Electron beam rate: 5 kHz
Detector position: 60 mm



# Method: Signal Analysis in Single Event Mode (SEM)

**Single Event Mode**

**Quarz Combination**

(Calculated)

Most probable Landau: $\mathrm{ch_{mpL}} = 862.577 \pm 2$

Pedestal: $\mathrm{ch_{ped}} = 118.647 \pm 2$

Number of photoelectrons: $N_{pe} = x$

Electron charge: $q_e = 1.602 * 10^{-19}\ C$

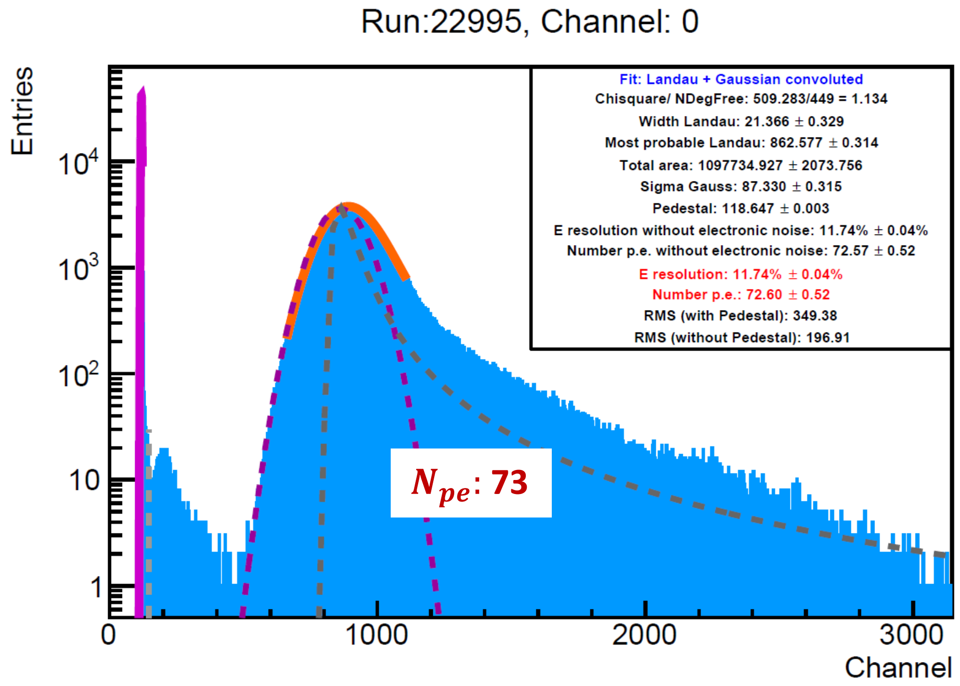
QDC sensitivity: $\xi = (200 \pm 4)\ ^{fC}/_{ch}$

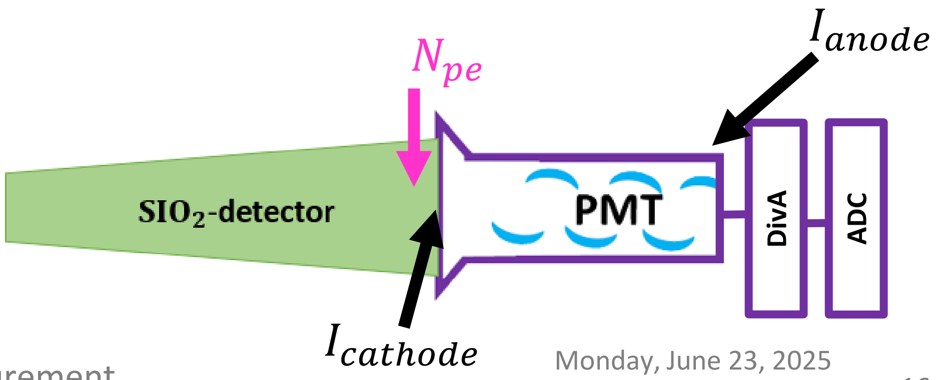
PMT gain (measured): $G_{pmt}^{preamp} = (12.68 \pm 1.46) * 10^{6*}$

$$QDC_{charge} = (ch_{mpL} - ch_{ped}) * \xi$$
$$= (862.577 - 118.647) * 200\ fC \approx 148.79\ pC$$

$$N_{pe} = \frac{QDC_{charge}}{q_e * G_{pmt}} \approx \frac{148.79\ pC}{1.602*10^{-19}\ C * 12.68*10^{6}} \approx 73$$

$$\Delta N_{pe} = \frac{1}{q_e} * \sqrt{\left[\frac{\Delta QDC_{charge}}{G_{pmt}}\right]^2 + \left[\frac{QDC_{charge} * \Delta G_{pmt}}{\left(G_{pmt}\right)^2}\right]^2} = \pm 8.5$$




*from SPE measurement

Method: Signal Analysis in Integrating Mode (IM)

**Integration Mode**

Quarz Combination

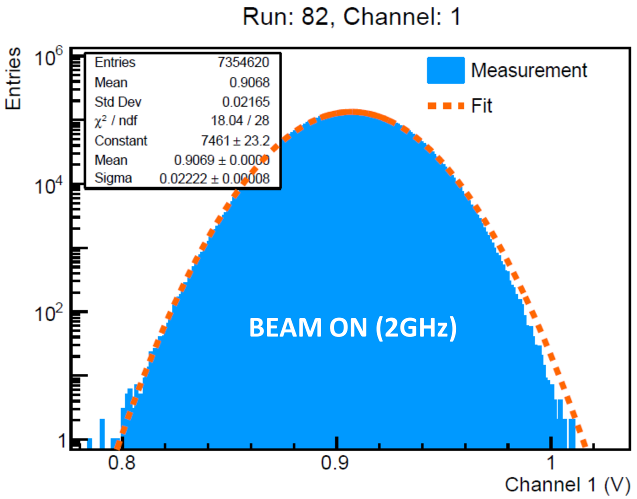
(Photoelectron statistics)

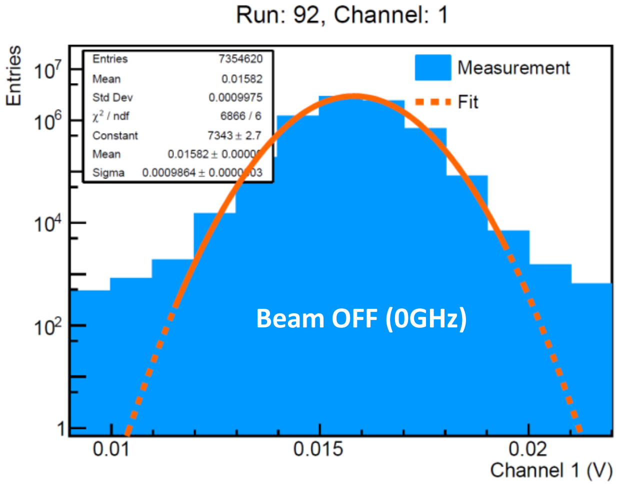
## Noise width and the photoelectron statistics

### Number of photoelectrons per electron event in the form of Shot noise

$$\boxed{\begin{aligned}\sigma_S &= \sqrt{2QI}\sqrt{B}\\ &= \sqrt{2(N_{pe}e^- G_{PMT})(N_{pe}e^- G_{PMT}R)B}\\ &= Q\sqrt{2RB}\\ \boldsymbol{\sigma_{amp}} &= \sigma_S * \boldsymbol{Z_{preamp}}\end{aligned}}$$

| | |
|---|---|
| $Q$ | Charge $n_{pe}$ times $e^-$ and $G_{PMT}$ |
| $I$ | Current at the anode |
| $B$ | is the bandwidth of the system (the smallest one in the chain) (measured:(0,35;0,36)MHz) |
| $G_{PMT}$ | is the PMT gain in integration mode (measuered:1300;1900) |
| $R$ | is the electron rate on the quartz (0-3GHz) |
| $N_{pe}$ | is the number of photoelectrons created at the cathode per electron event through the quartz |
| $e^-$ | $1.6 \times 10^{-19}\ C$ |
| $Z_{preamp}$ | Preamplification factor (measuered:62857;63000) |




**ToDo:**

**Plot in 3 different ways, to examine $N_{pe}$ and comparing with SEM results**

$$U_{amp} = I_{anode} * Z_{preamp}$$

$$\sigma_{amp} = y = \sqrt{2(Q_{anode})(I_{anode})B}\ Z_{preamp}$$

$$U_{amp} = Q_{anode}\, R\ \ Z_{preamp}$$

$$\sigma_{amp} = y = Q_{anode}\sqrt{2RB}\ Z_{preamp}$$

$$\sigma_{amp} = y = \sqrt{2(Q_{anode})(I_{anode})Z_{preamp}Z_{preamp}B}$$

$$\boxed{U_{amp} = y = y_o + N_{pe}e^- G_{PMT}\ R\ \ Z_{preamp}}$$

**Amplifier output as a function of the electron beam current**

$$\boxed{\sigma_{amp} = y = N_{pe}e^- G_{PMT} Z_{preamp}\sqrt{2RB}}$$

**Shot noise as a function of the electron beam current**

$$\boxed{\sigma_{amp} = y = \sqrt{2(N_{pe}e^- G_{PMT})U_{amp}Z_{preamp}B}}$$

**Shot noise as a function of the amplifier output**

# Integration Mode
## Quarz Combination
(Photoelectron statistics)

# Method: Signal Analysis in Integrating Mode (IM)

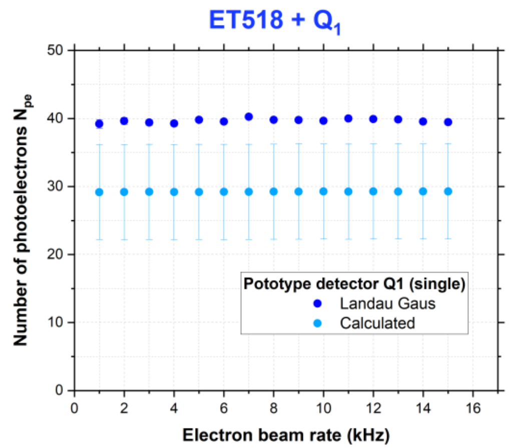
## Noise width and the photoelectron statistics

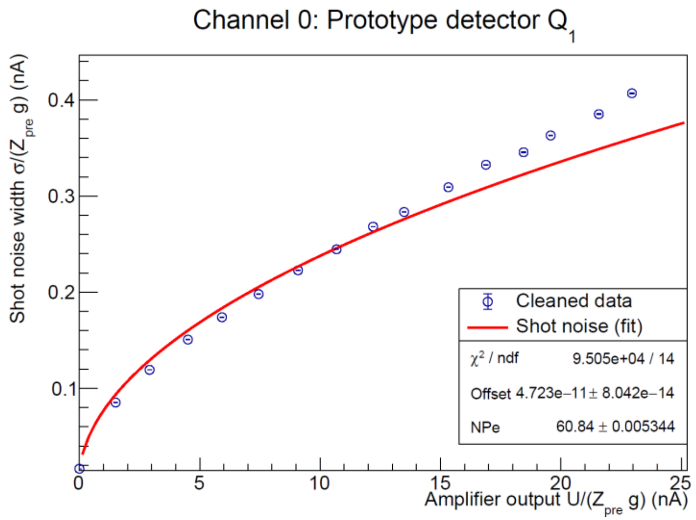
Number of photoelectrons per electron event in the form of Shot noise

$$\sigma_S = \sqrt{2QI}\sqrt{B}$$
$$= \sqrt{2\left(N_{pe}e^- G_{PMT}\right)\left(N_{pe}e^- G_{PMT}R\right)B}$$
$$= Q\sqrt{2RB}$$
$$\boldsymbol{\sigma_{amp}} = \sigma_S * \boldsymbol{Z_{preamp}}$$

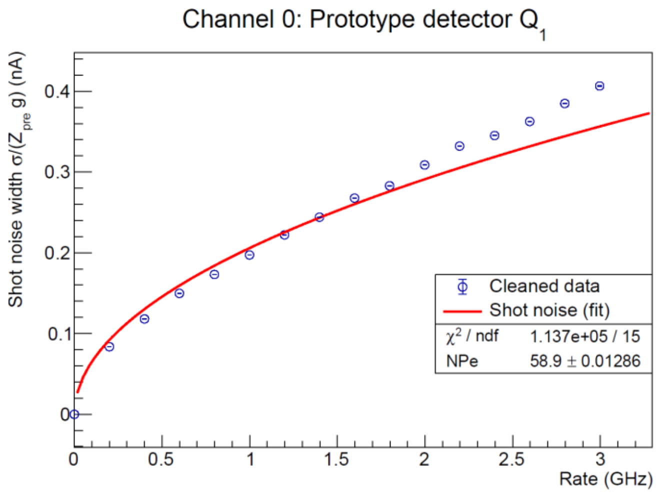
| | |
|---|---|
| $Q$ | Charge $n_{pe}$ times $e^-$ and $G_{PMT}$ |
| $I$ | Current at the anode |
| $B$ | is the bandwidth of the system (the smallest one in the chain) (measured:(0,35;0,36)MHz) |
| $G_{PMT}$ | is the PMT gain in integration mode (measuered:1300;1900) |
| $R$ | is the electron rate on the quartz (0-3GHz) |
| $N_{pe}$ | is the number of photoelectrons created at the cathode per electron event through the quartz |
| $e^-$ | $1.6 \times 10^{-19}\ C$ |
| $Z_{preamp}$ | Preamplification factor (measuered:62857;63000) |

Extracted $N_{pe}$ in Single Event Mode

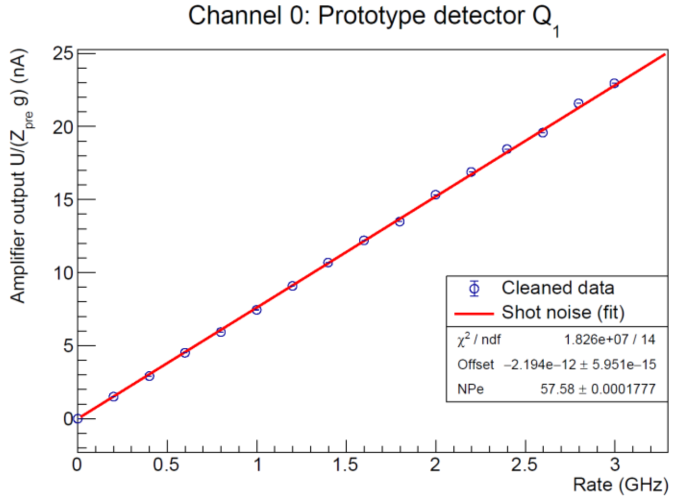



**Amplifier output as a function of the electron beam current**



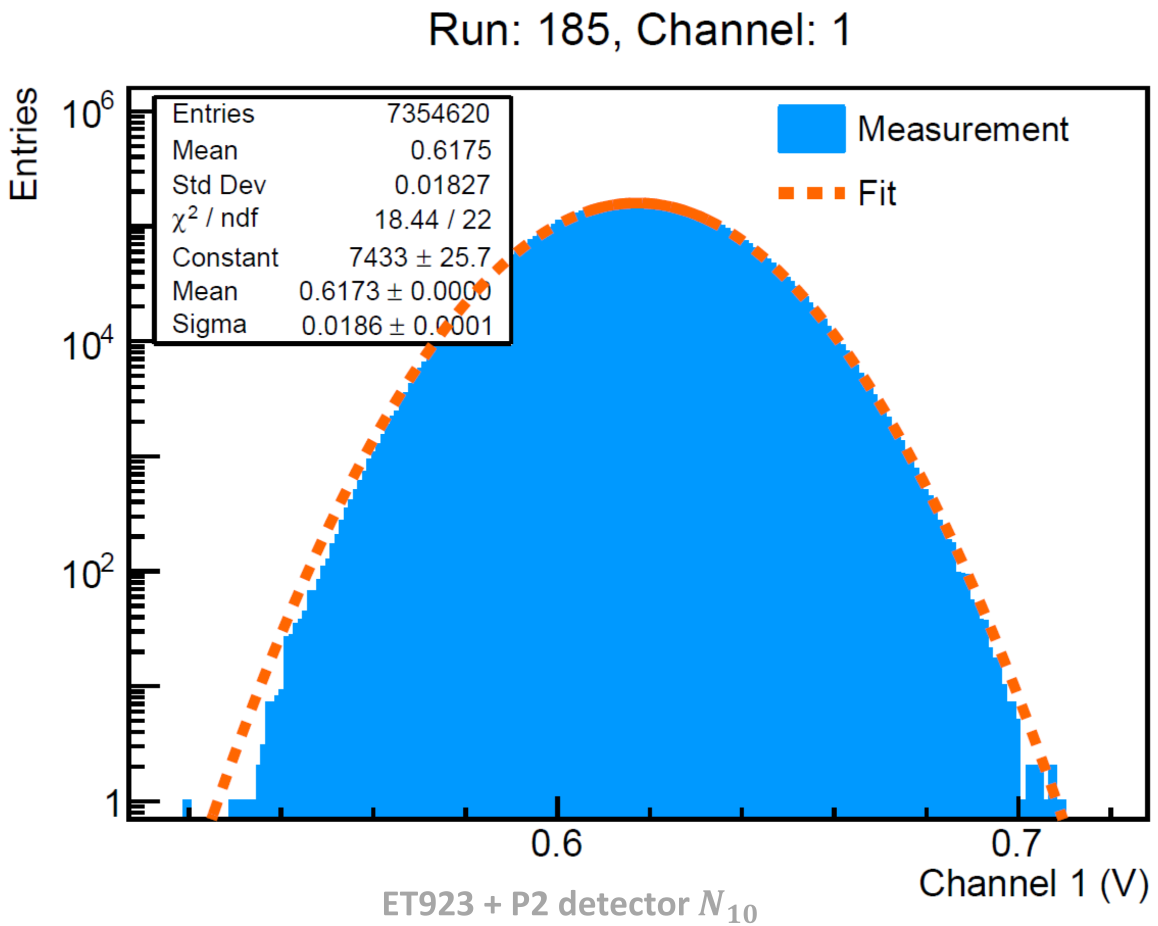

**Shot noise as a function of the electron beam current**



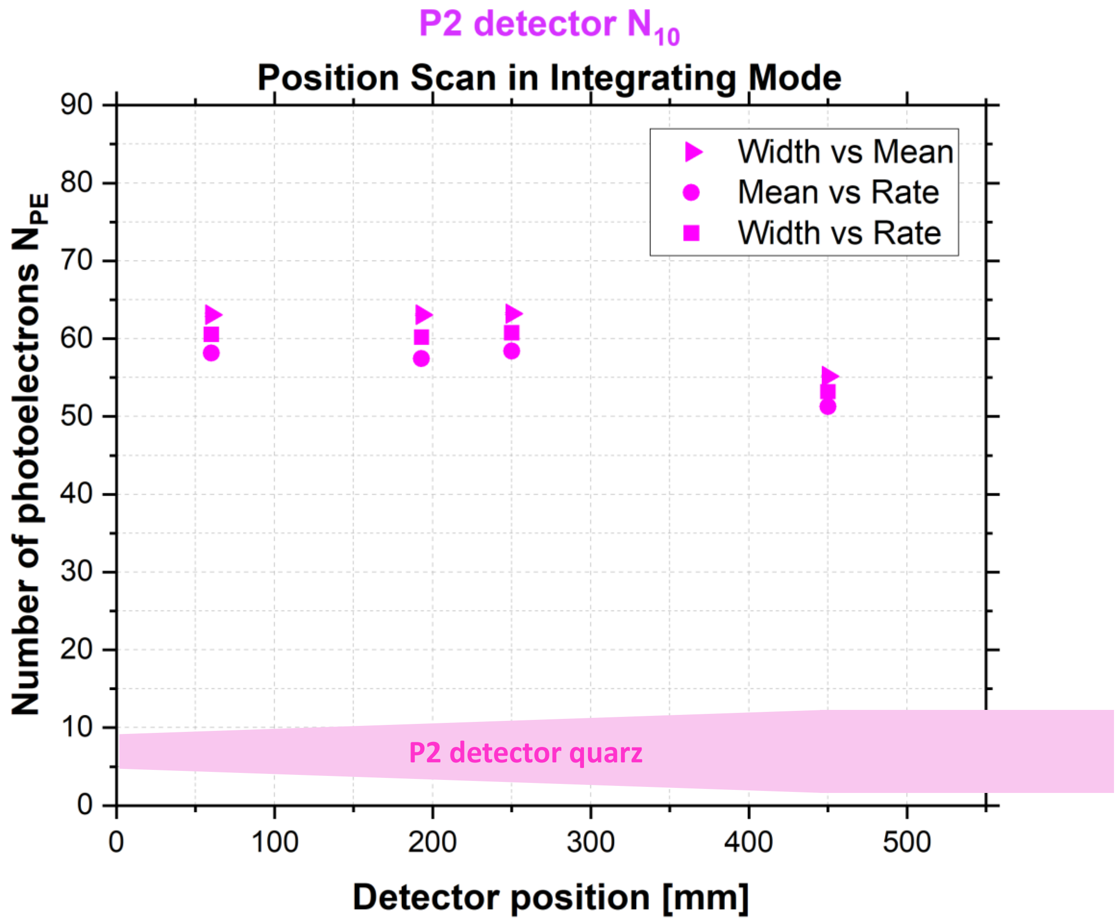

**Shot noise as a function of the amplifier output**

Method: Signal Analysis in Integrating Mode (IM)



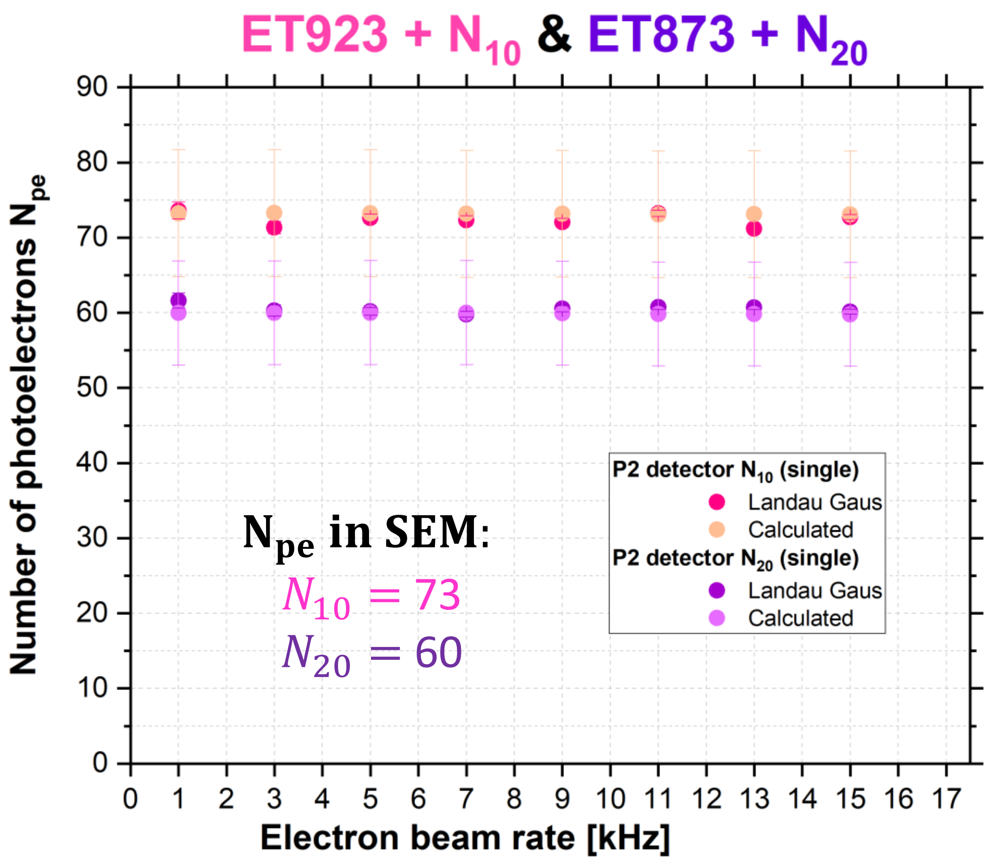



ET923 + P2 detector $N_{10}$
Nominal PMT voltage = 490 V
Electron beam rate = 1,062 GHz
Detector position = 60 mm

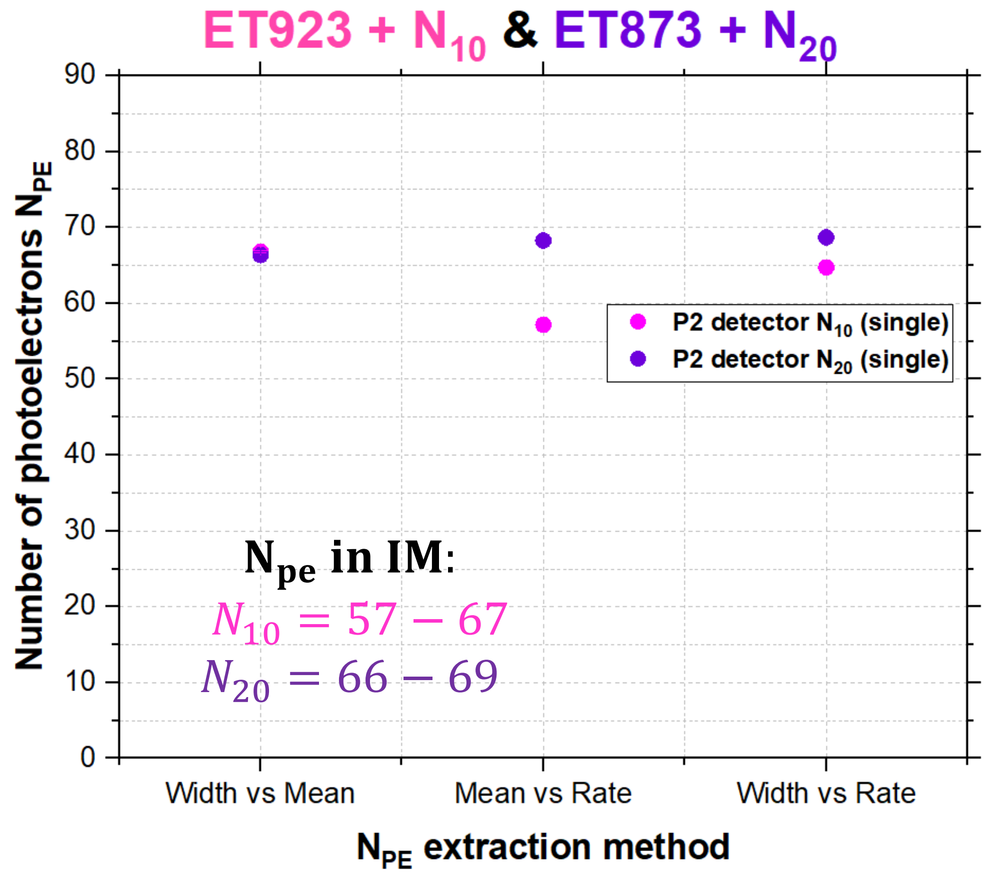


Quarz Combination

# Single Detector in Electron Beam Line
# Determination the number of photoelectrons $N_{pe}$

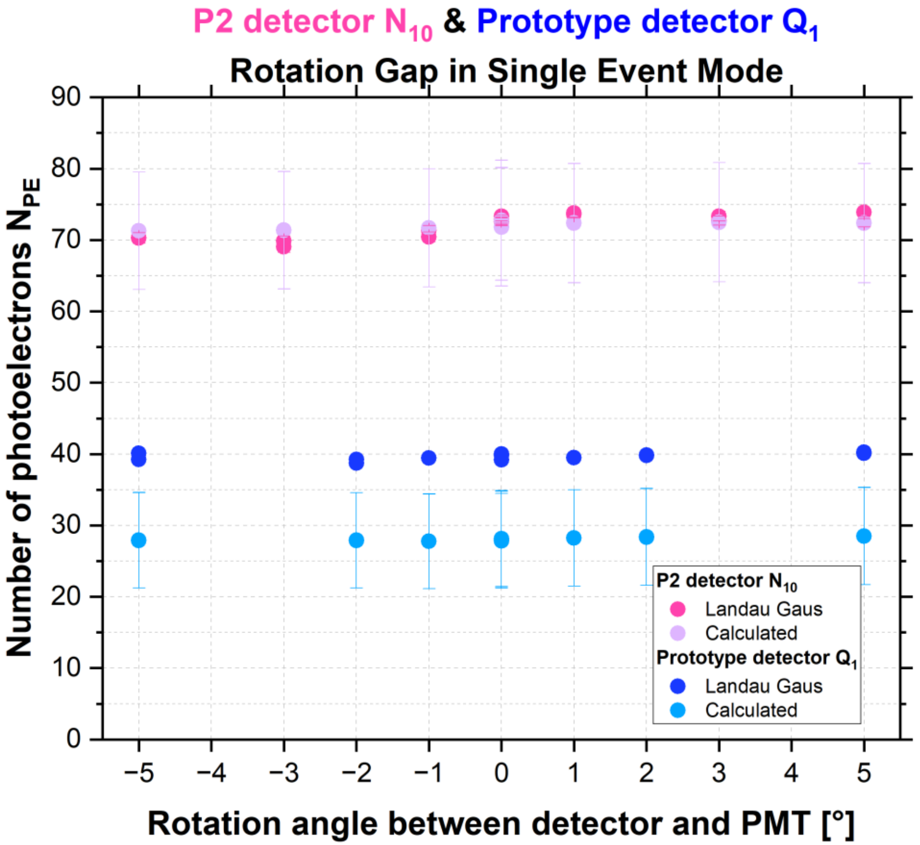



ET923 + P2 detector N10
PMT voltage = 790 V (nom. voltage)
DAQ Trigger: Trigger scintillator
Electron beam rate = 1 kHz – 15 kHz

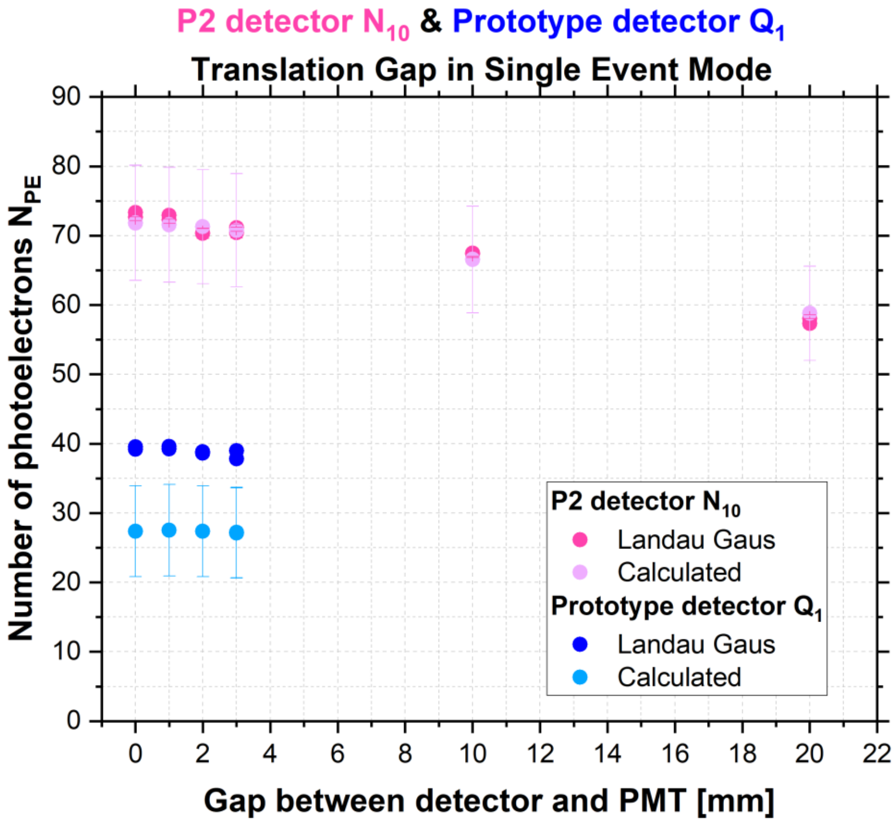



ET923 + P2 detector N10
PMT voltage = 490 V (nom. voltage)
Electron beam rate = 0 GHZ – 3 GHz

# Rotation And Translation Gap between PMT And Detector
# Determination the number of photoelectrons $N_{pe}$

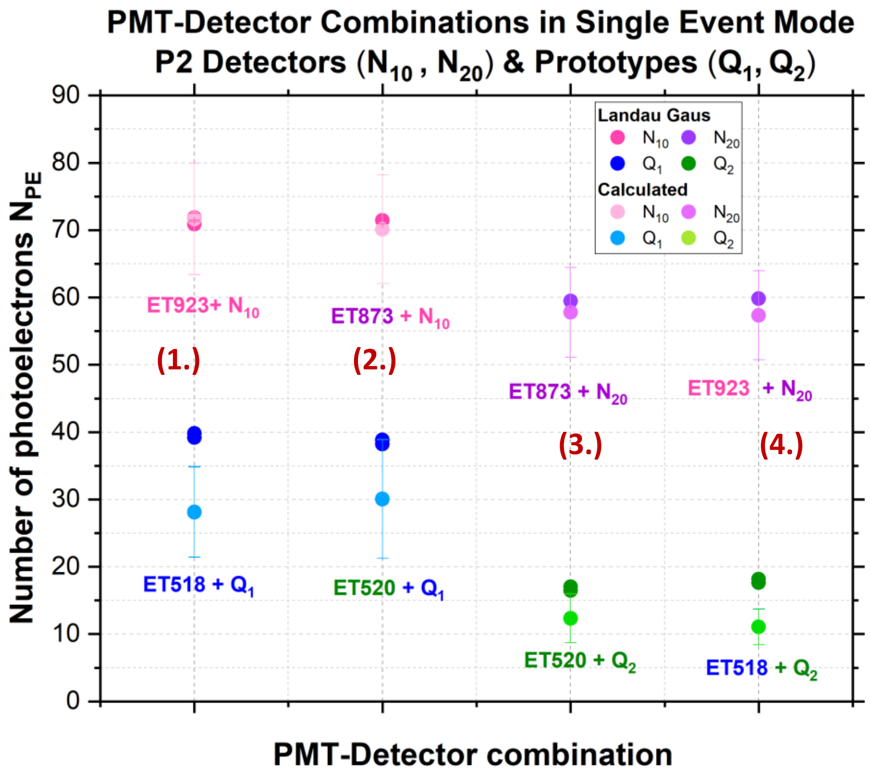



ET923 + P2 detector N10
ET518 + Prototyoe detectore Q1
Electron beam rate = 4 kHz




ET923 + P2 detector N10
ET518 + Prototyoe detectore Q1
Electron beam rate = 4 kHz

# Mixing The PMT – Detector Comination
# Determination the number of photoelectrons $N_{pe}$




P2 detectors and Prototype detectors
All PMTs are operated at their nominal voltages
Electron beam rate = 4 kHz

Leaving the PMT fixed and swapping the quartz detectors

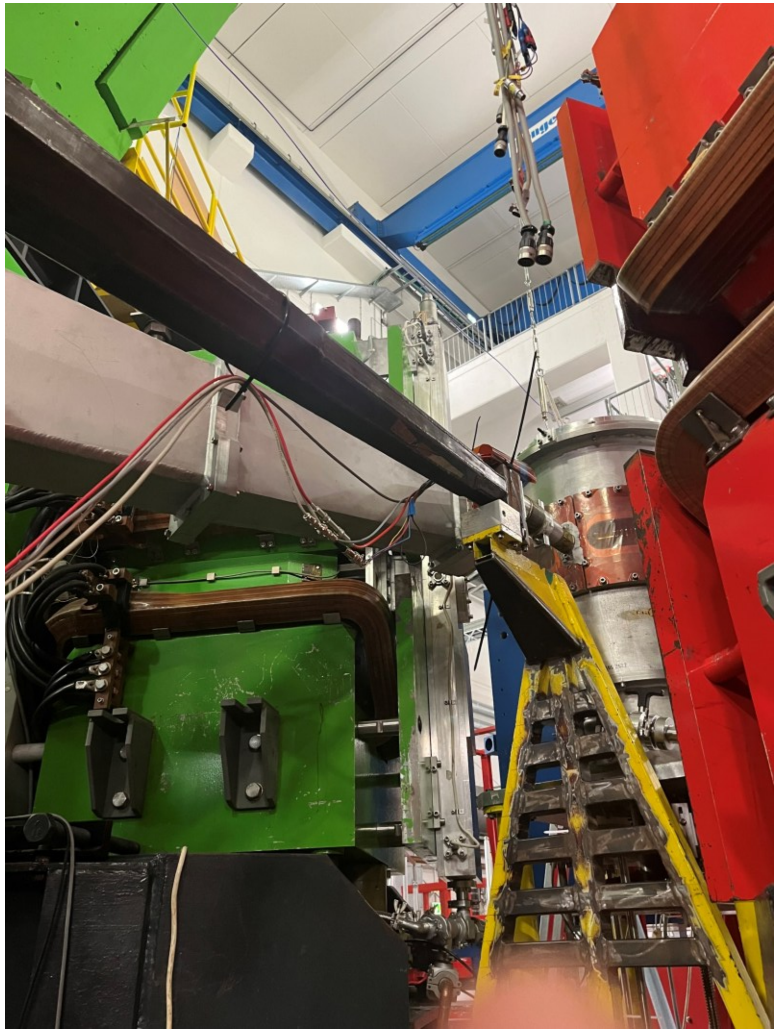
- (1.) Start with the PMT-Quartz combination for N10 like that what we have used to in the tests before
  ET923 + N10 

- (4.) Replacing quartz N10 with N20
  ET923 + N20 

- (3.) Go on with PMT-Quartz combination for N20 like that what we have used to in the tests before
  ET873 + N20 


(2.) Replacing quartz N20 with N10
ET873 + N10 

# Test of radiation hardness of the voltage divider and preamplifier



## RadFET no. 1
## (Test of Diva Board)

- **Accumulated dose: 70 Gray**
  **(~ 30/01-19/02 at X1 beam dump)**

- **Accumulated dose: 1600 Gray**
  **(~ 12/03-15/03 at A1 spectrometer)**
  - Voltage regulator are broken
  - New types of regulators are built in
  - From MOSEFET regulators
    *MCP1702T5002E/MB (LDO +5V 250mA)*
    *XC6902N501PR-G (LDO -5V 200mA)*
    to BIPOLAR regulators
    *LM2940CT-5.0 (LDO +5V 1A)*
    *LM2990T-5.0 (LDO -5V 1A)*

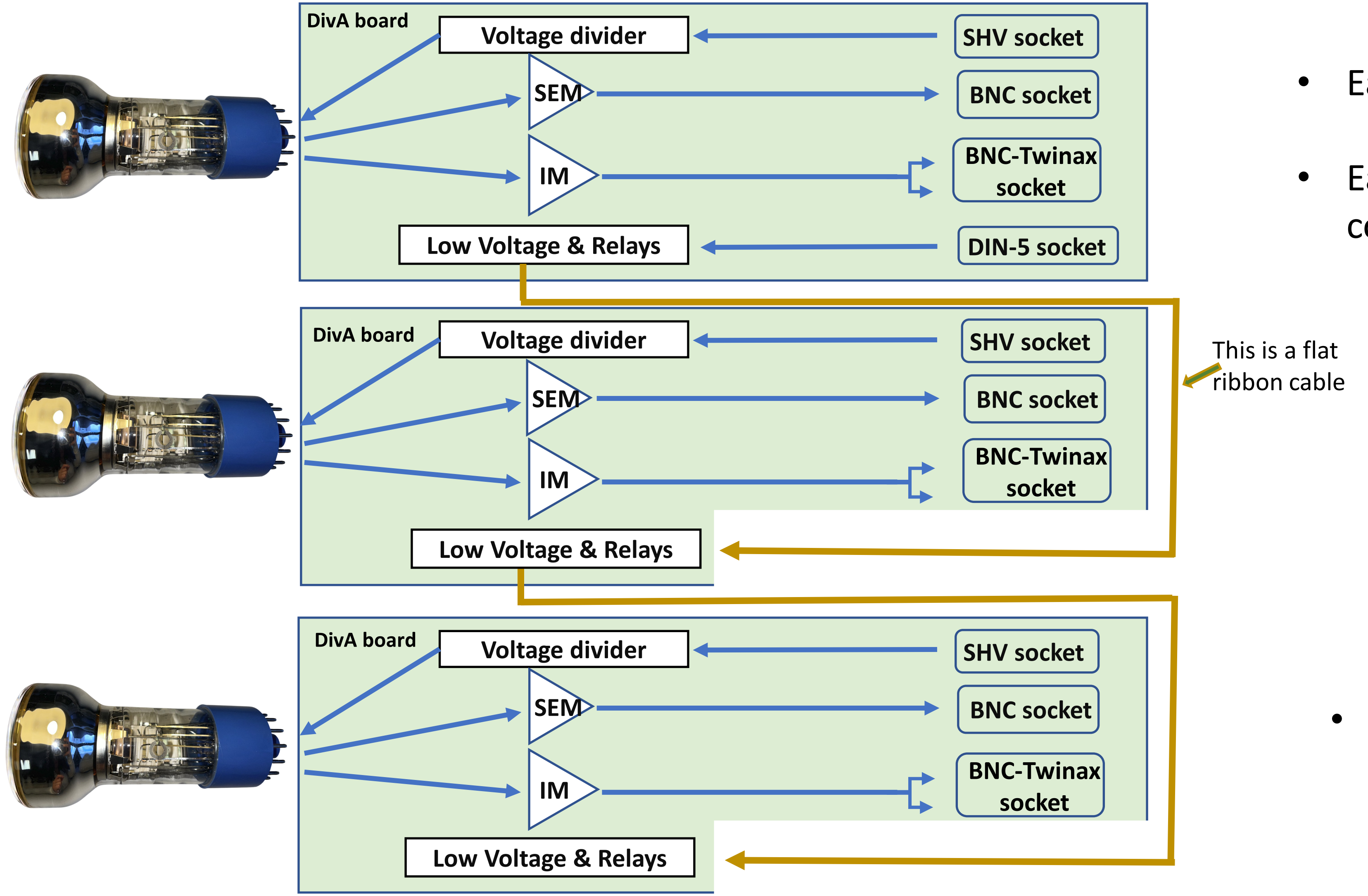
- **Accumulated dose: 6300 Gray**
- **(~ 16/04-08/05 at A1 spectrometer)**
  - Voltage regulator for 'OpAmps' and 'test current' are broken

## RadFET no.2
## (Test of voltage regulators)

- **Accumulated dose: 16000 Gray**
  **(~ 19/06-07/07 at A1 spectrometer)**
  - 24 voltage regulators are tested
    → 8 voltage regulators positive
    → 8 voltage regulators negative
    → 8 voltage regulators reference
  - Only 3 of 24 survived
    → positive: LM1117SX-5.0
    → negative: MC79M05
    → reference: ADR03

# Interconnecting DivA boards for Low Voltage Supply + Relays

# Set of 3 PMTs

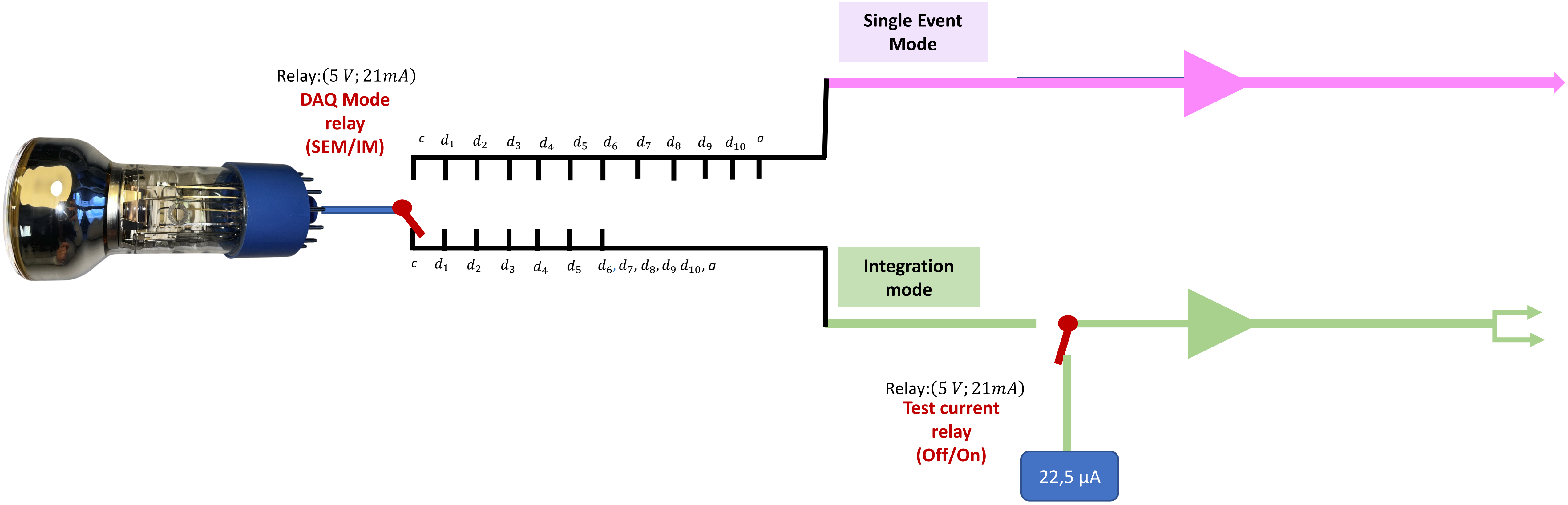



- Each detector equipped by one PMT
- Each PMT has a printed circuit board (PCB), consisting **of voltage divider** and **preamplifier**

  → **high-voltage power supply** (SHV)
  → **Single Event Mode** (BNC)
  → **Integration Mode** ( BNC-Twinax)
  → **Low-voltage power supply & DAQ relay + Test current relay** (DIN-5)

- 3 DivA boards are interconnected at the same time via pin socket connectors

# Experimental Setup and Measurement Program Overview




Test current operation