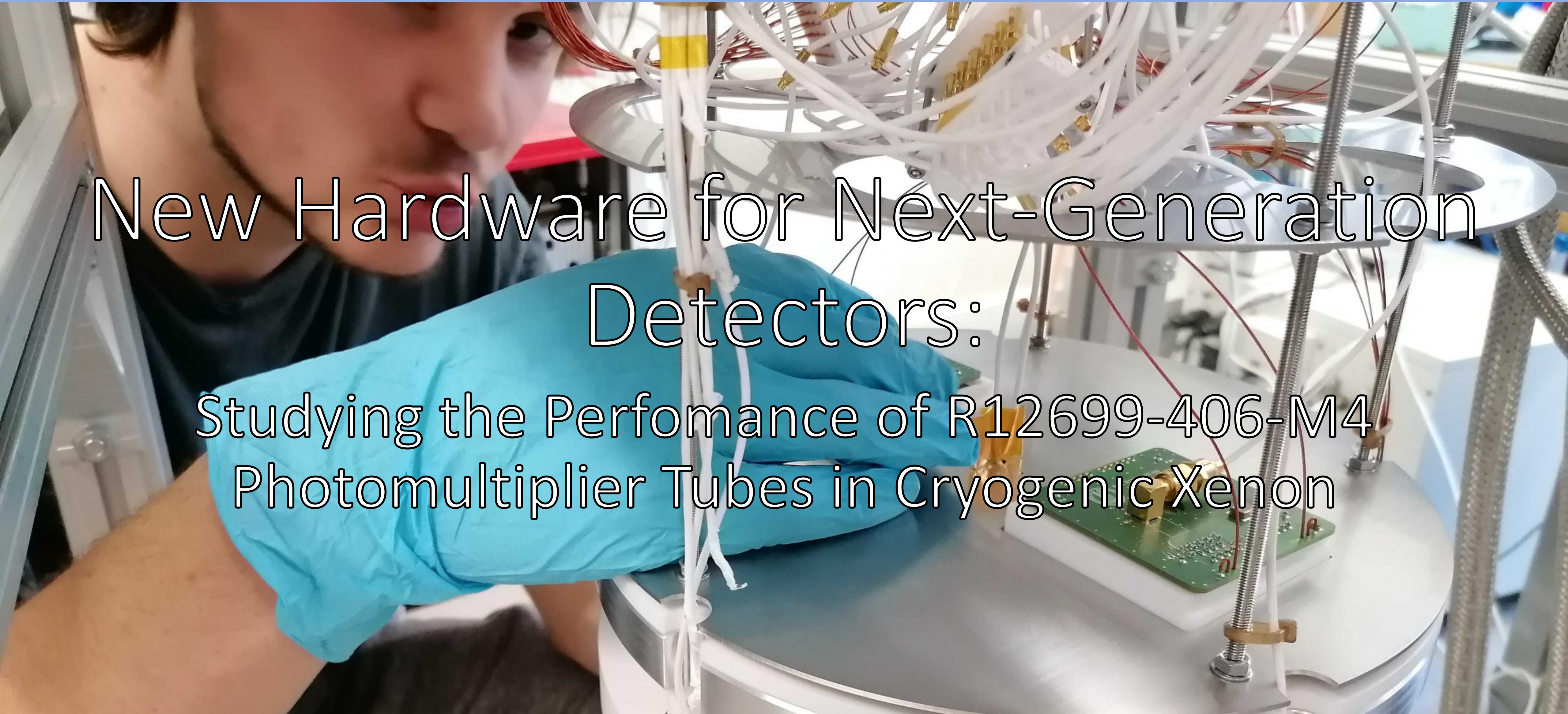
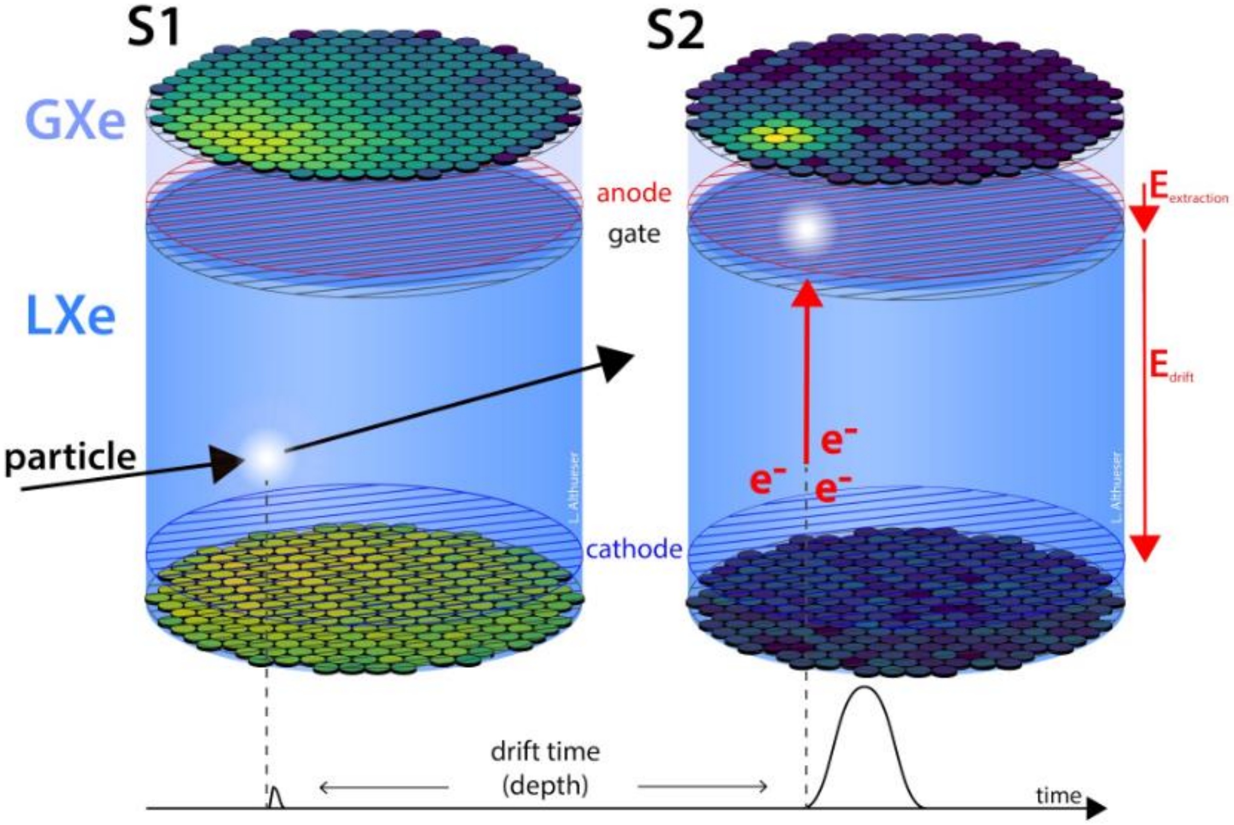
SPS Annual Meeting 2023 - Maximinio Adrover

New Hardware for Next-Generation Detectors:

Studying the Perfomance of R12699-406-M4 Photomultiplier Tubes in Cryogenic Xenon



Two-Phase Time Projection Chambers



Liquid xenon Time Projection Chambers (TPCs) provide the highest sensitivities towards Dark Matter (DM) detection in the mass range $m_\chi \approx 1 - 10^3$ GeV

DARWIN

DARk matter WImp search with liquid xenon (DARWIN)

Next generation dark matter observatory

Aims to achieve unprecedented sensitivity:

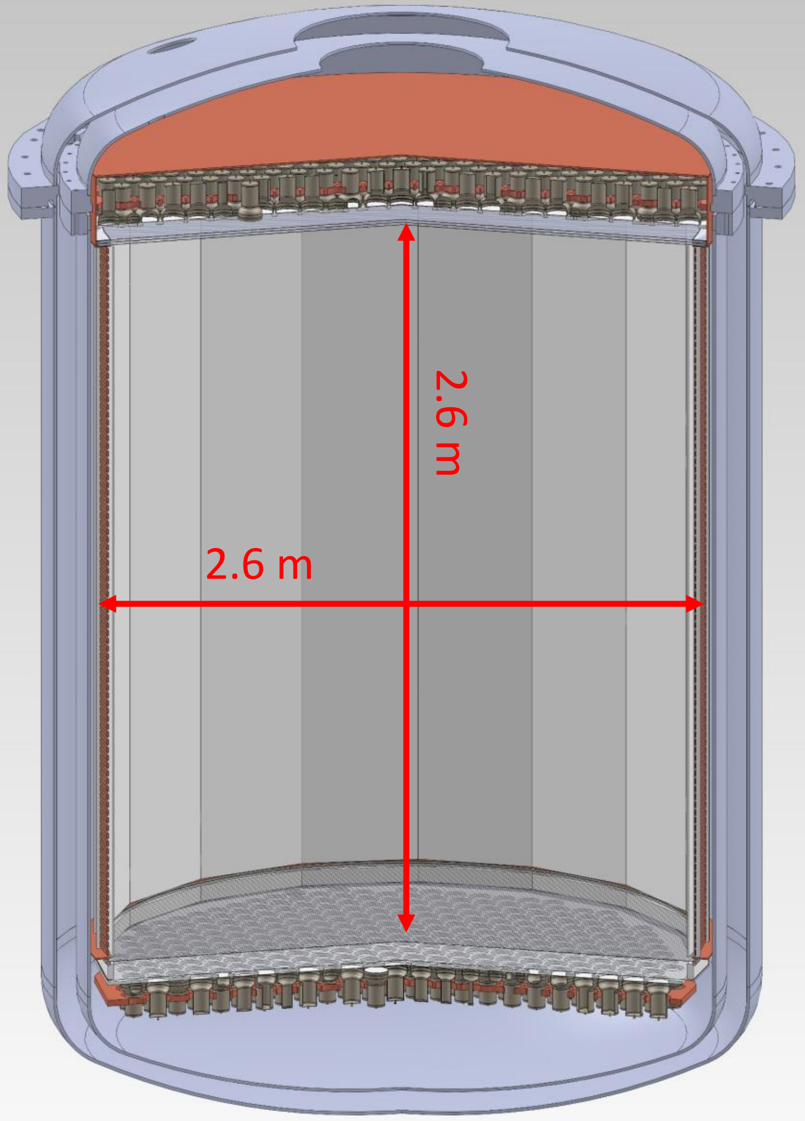
- Active LXe target of roughly 40t
    - Size comes with new challenges

Extensive R&D ongoing

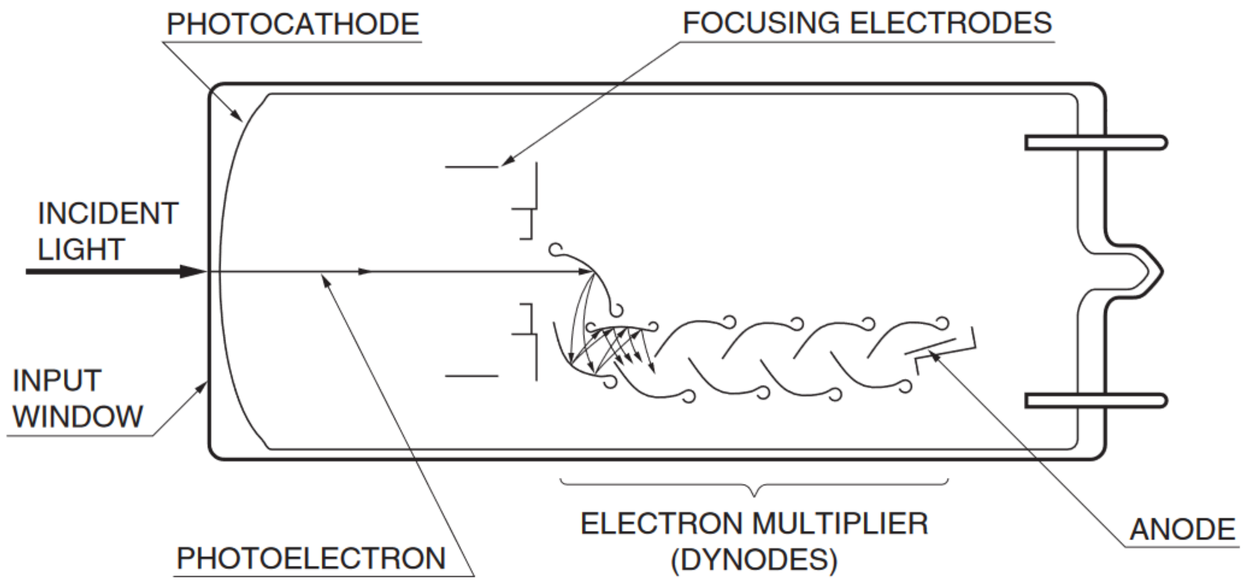
(See also 355 Paloma Cimental Chavez, Fr. 13:00)

- Require photosensors with
    - High sensitivity
    - Low backgrounds

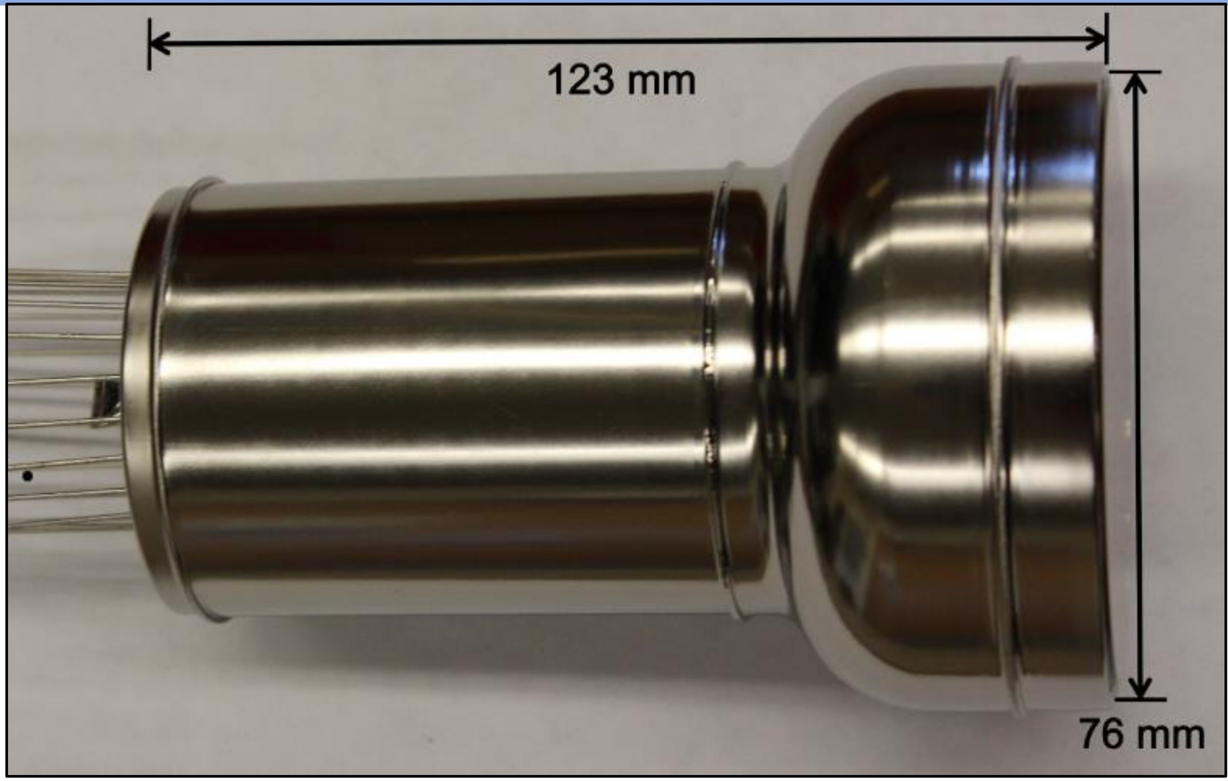
In depth discussion: 354 Mariana Rajado da Silva, Fr. 12:45



Photomultiplier Tubes



Source: Hamamatsu Catalog



3” R11410-21 PMT

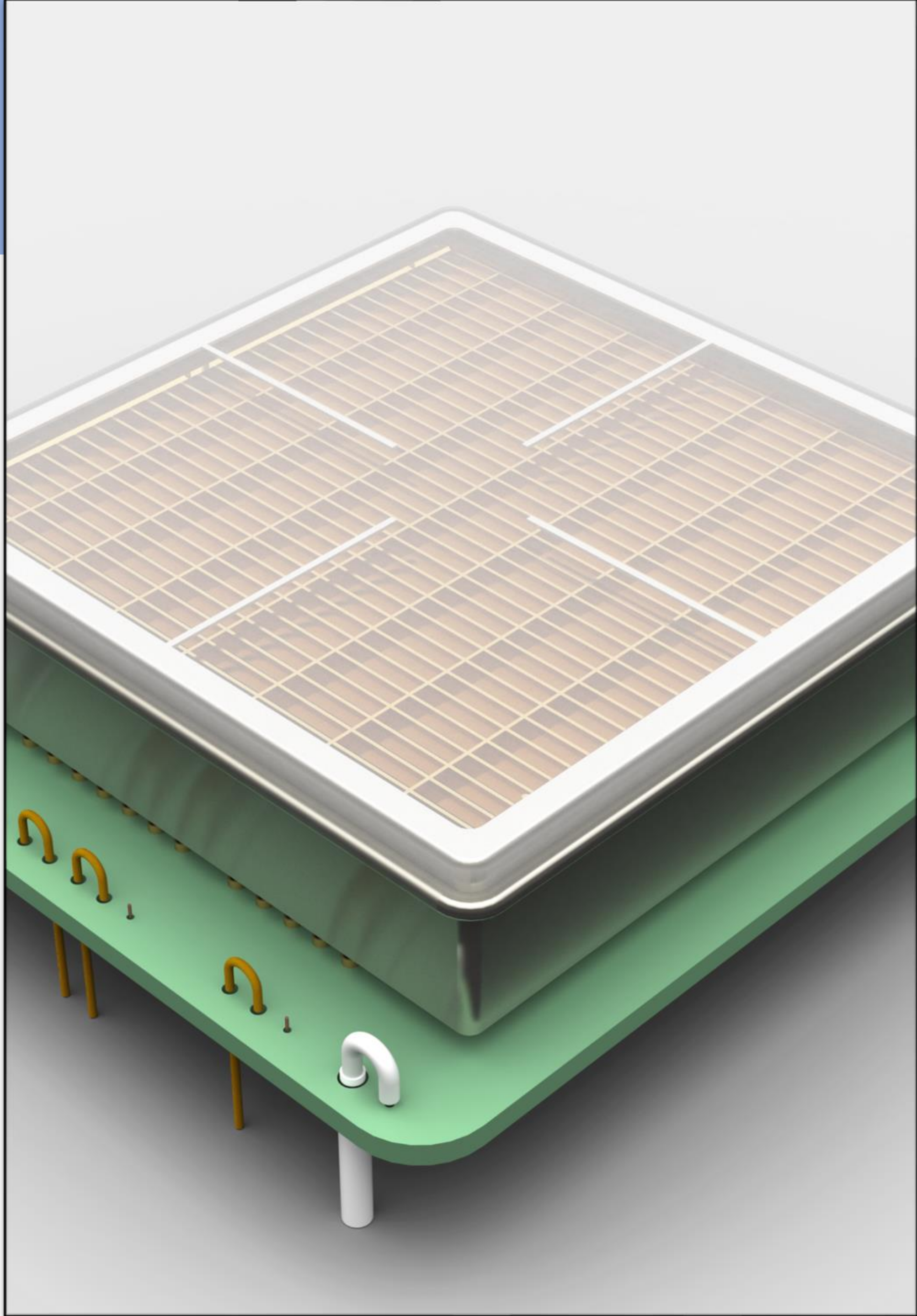
Source: JINST 12 (2017) P01024

The R12699-406-M4 2”-PMT

Hamamatsu describes it as:

Flat Panel Type Multianode PMT

- Compact form factor: 56 x 56 x 14.7 mm^3
  - Less support structure needed
  - Very fast timing
- High quantum efficiency (QE) @ 175 nm: 33%
- Large photocathode coverage: 75%
- Multianode readout possible: 2x2 anodes per PMT



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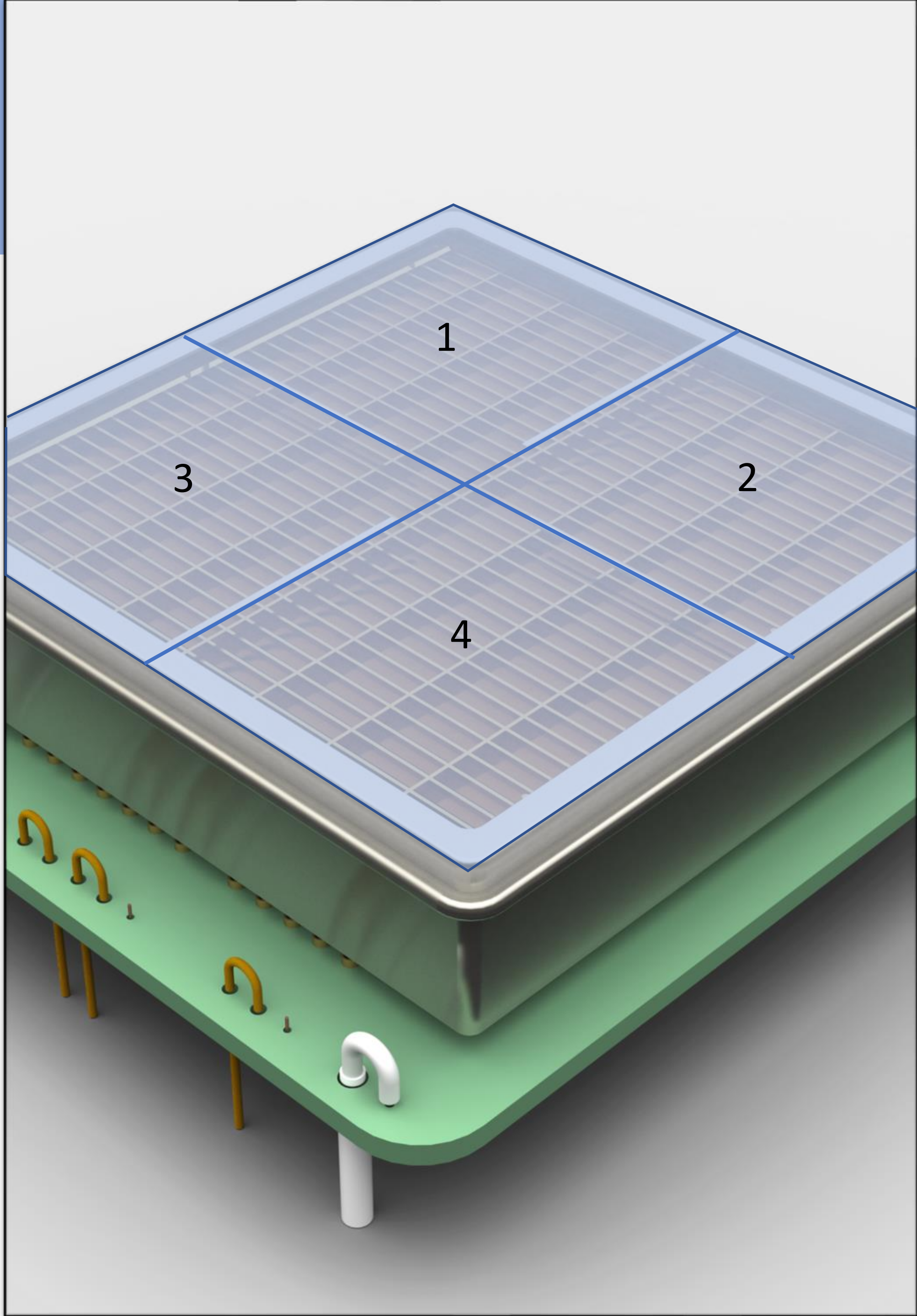


Characterization with MartmotX

SPE-Response

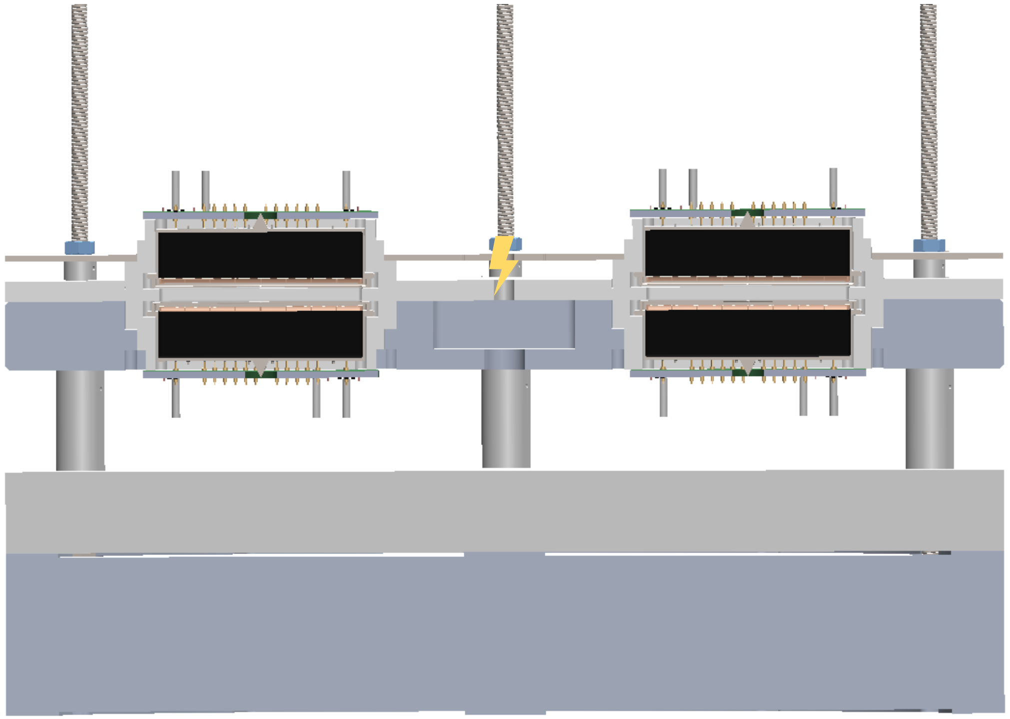
Dark Counts

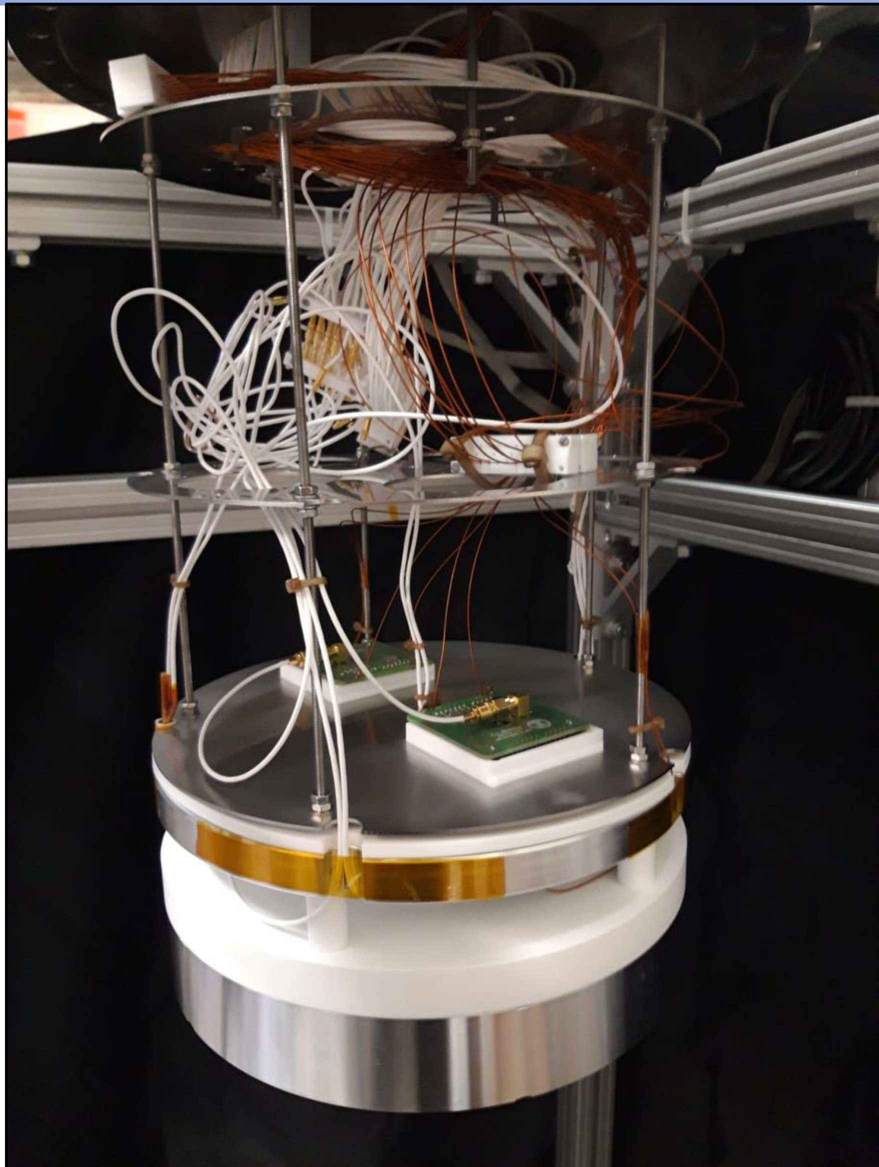
Afterpulses

Under different conditions:

- Room temperature (Vacuum)
- Cryogenic Xenon in Gas Phase (GXe): DC rate determination
- Liquid Xenon (LXe): Long term stability & Afterpulsing

MartmotX





Photomultiplier Characteristics

SPE-Response

Dark Counts

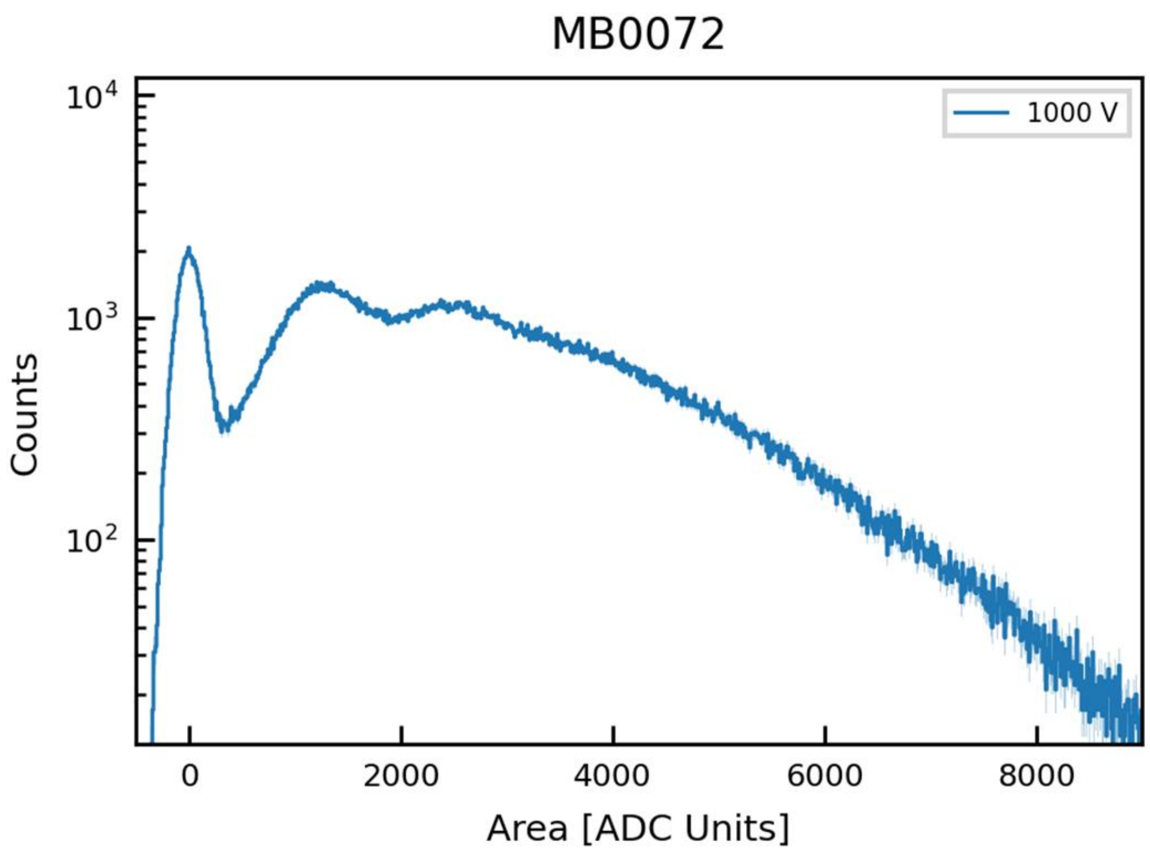
Afterpulses

Gain Calibration:

- PMT response is proportional to number of initial photoelectrons.
- Charge spectrum is characterized by the single photoelectron (SPE) distribution.
- Parameters of Interest:

  Mean of the SPE-Distribution μ (Gain)

  Width of the SPE-Distribution σ



Characterization

SPE-Response

Dark Counts

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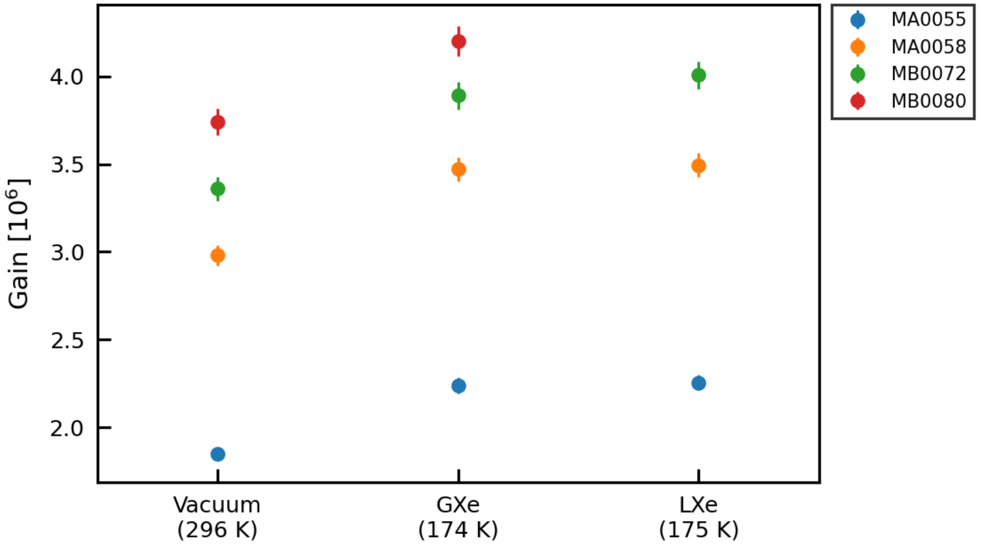


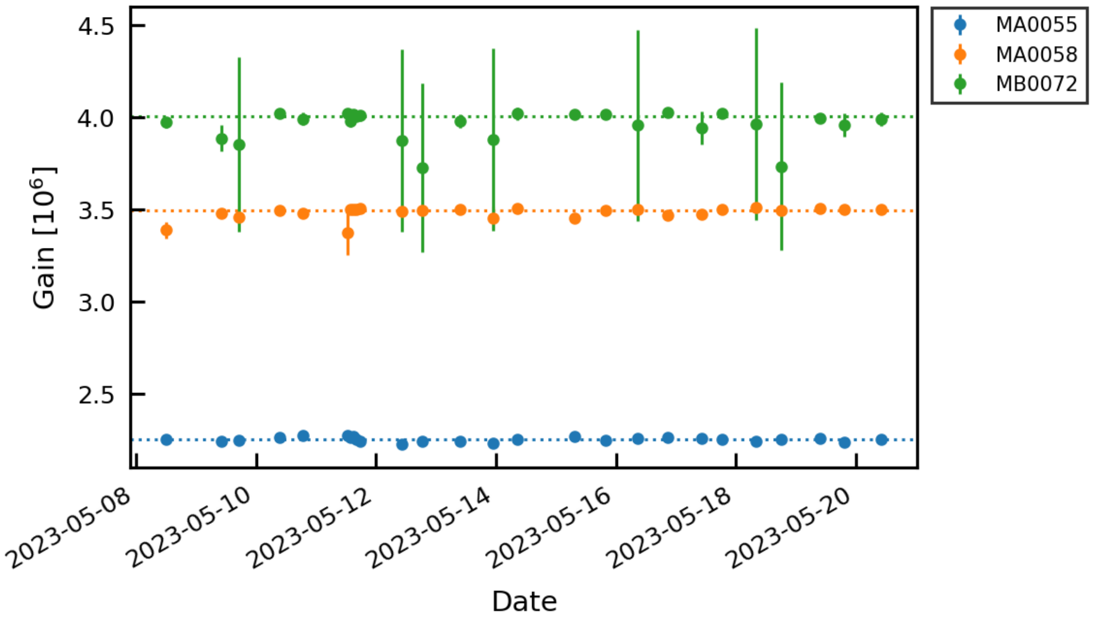
Mean Gain μ : $(3.0 \pm 0.8) \cdot 10^6$

SPE-Resolution $\frac{\sigma}{\mu}$: < 0.5

Peak-to-Valley Ratio: > 2

@ $2 \cdot 10^6$ gain

Gain increases on average (16 ± 3)% when cooling to -100°C



Characterization

SPE-Response

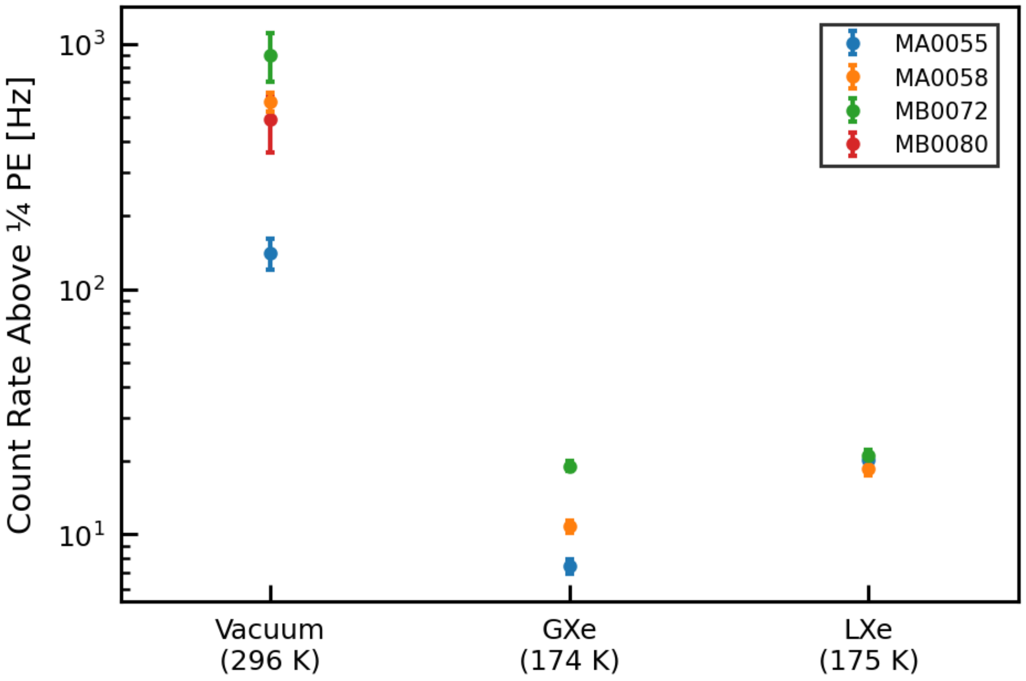
Dark Counts

Afterpulses

Spontaneous thermionic emissions of electrons in cathode material

Typically resembles SPE signal.

Parameter of interest: Rate



Mean Rate (-100° C)
R12699-406-M4: (0.5 ± 0.2) Hz/cm^2
R11410-21 : (1.4 ± 0.7) Hz/cm^2 [2]

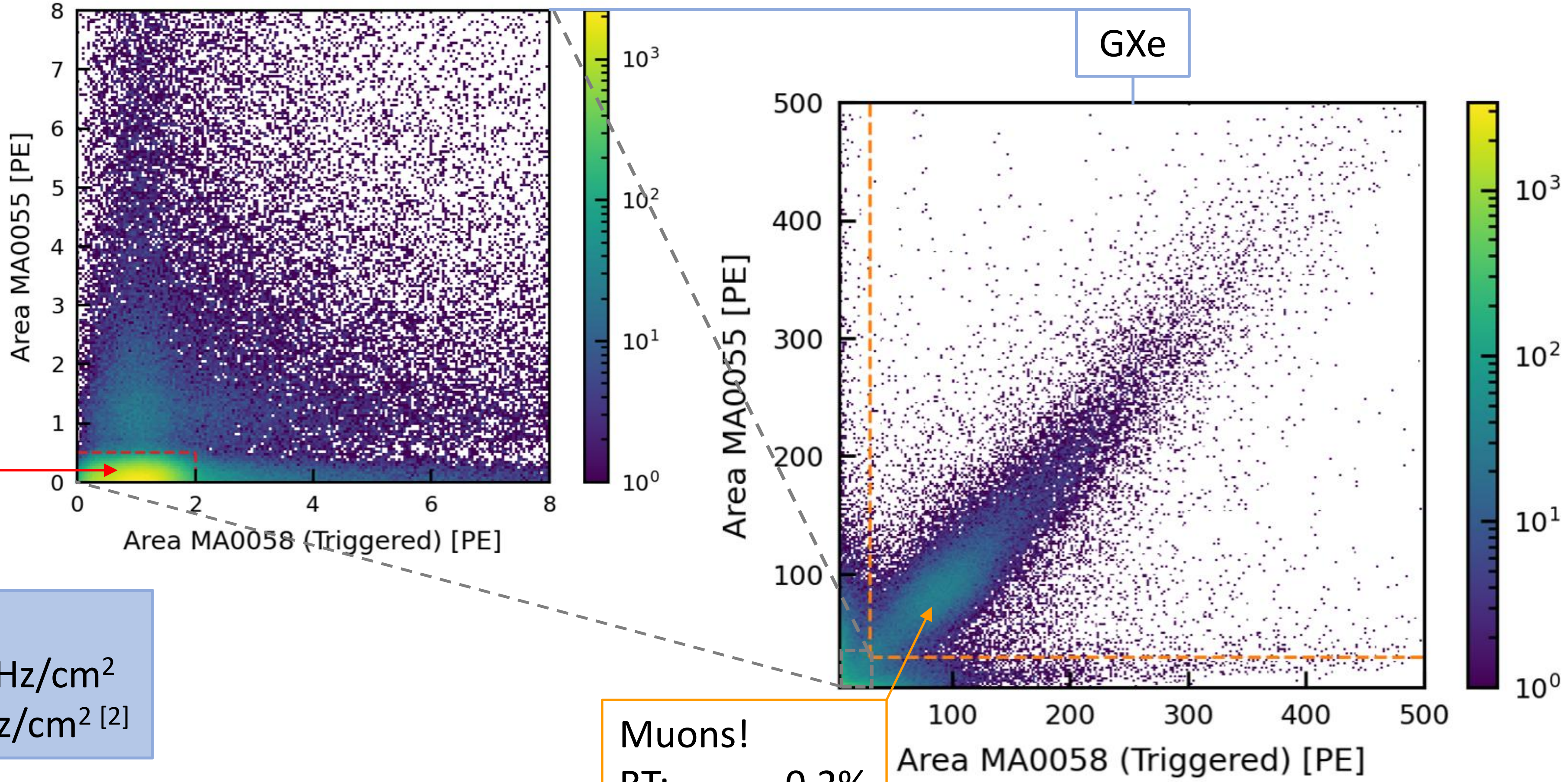
[2] JINST 12 (2017) P01024

Characterization

SPE-Response

Dark Counts

Afterpulses



Thermionic!
RT: 98%
GXe: 70%

Muons!
RT: 0.2%
GXe: 7.2%

Mean Rate (-100° C)
R12699-406-M4: (0.5 ± 0.2) Hz/cm^2
R11410-21 : (1.4 ± 0.7) Hz/cm^2 [2]

[2] JINST 12 (2017) P01024

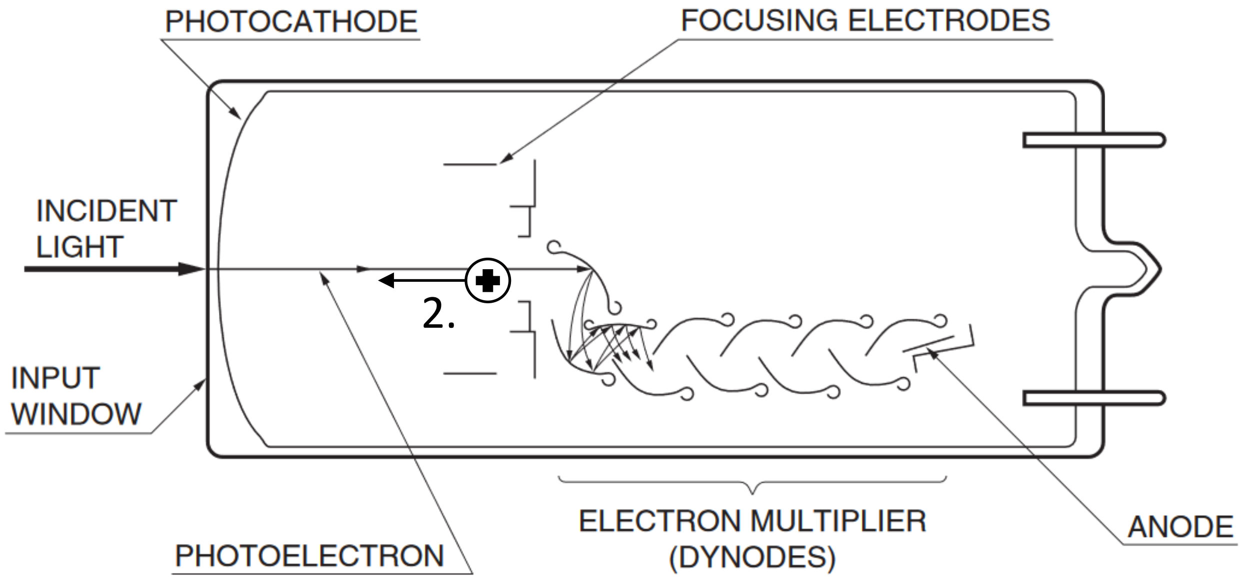
Characterization

SPE-Response

Dark Counts

Afterpulses

1. Photoelectrons backscattering from first dynode (ns)[3]
2. Ionized residual gases drift to cathode (10^2ns – µs)[3]



Source: Hamamatsu Catalog

[3] Hamamatsu PMT Handbook

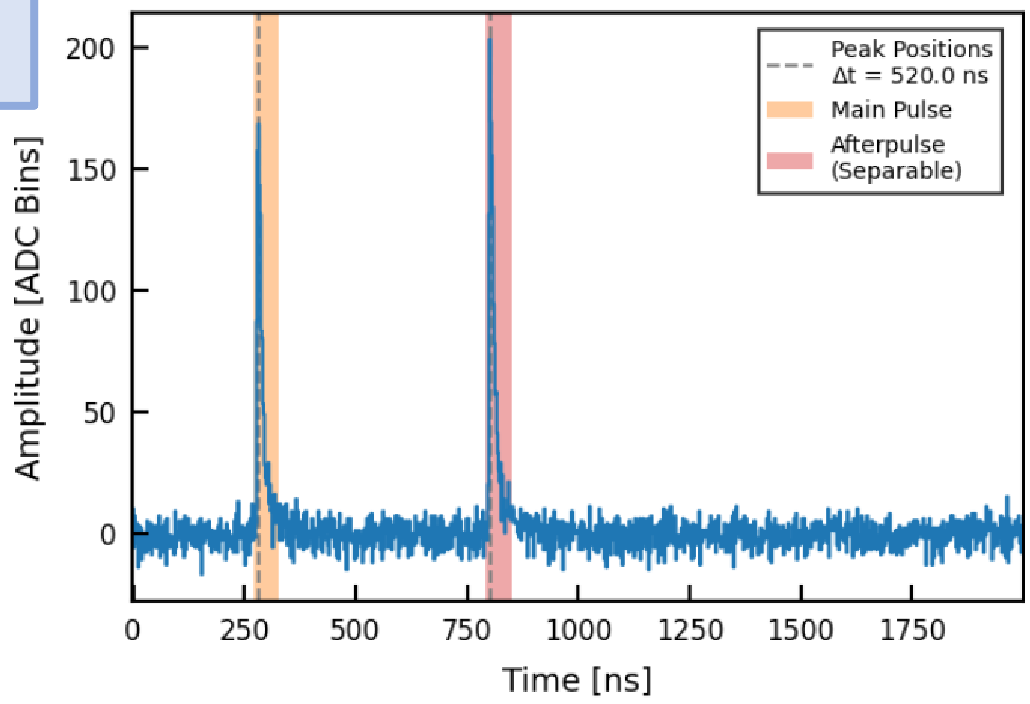
Characterization

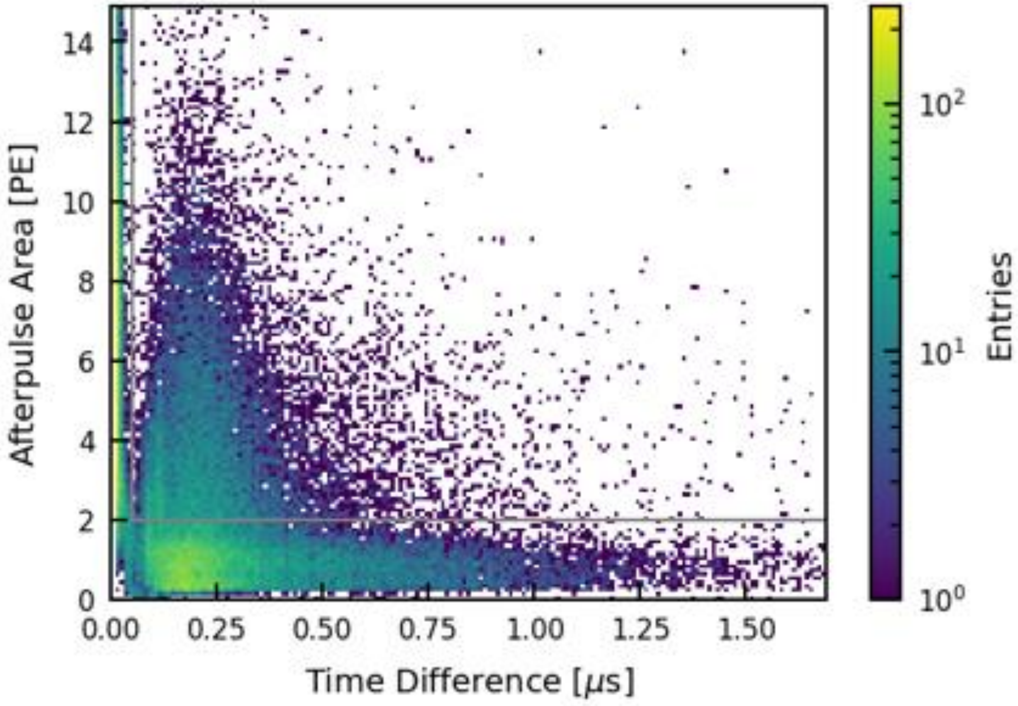
SPE-Response

Dark Counts

Afterpulses

Afterpulsing expected order of magnitude faster than R11410-21 PMTs





Observed AP Rate: $(9 \pm 2) \cdot 10^{-3} PE^{-1}$

Summary & Outlook

Pro:

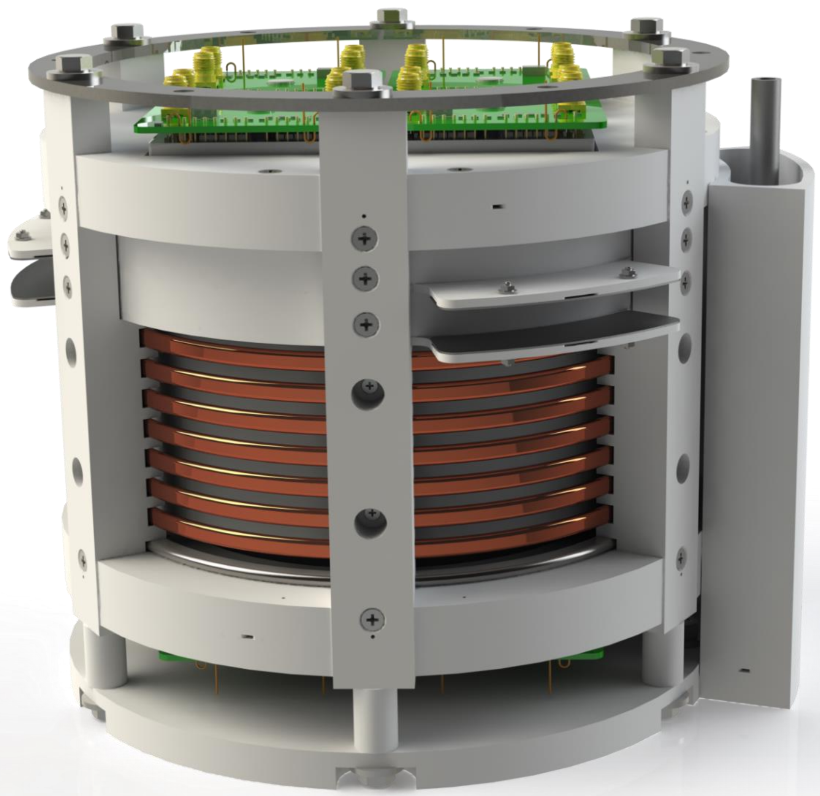
- Compact form factor
  - Large Packing Density
  - Fast Time Response
- Low DC rate
- High QE @ 175nm
- Stable under cryogenic conditions

Con:

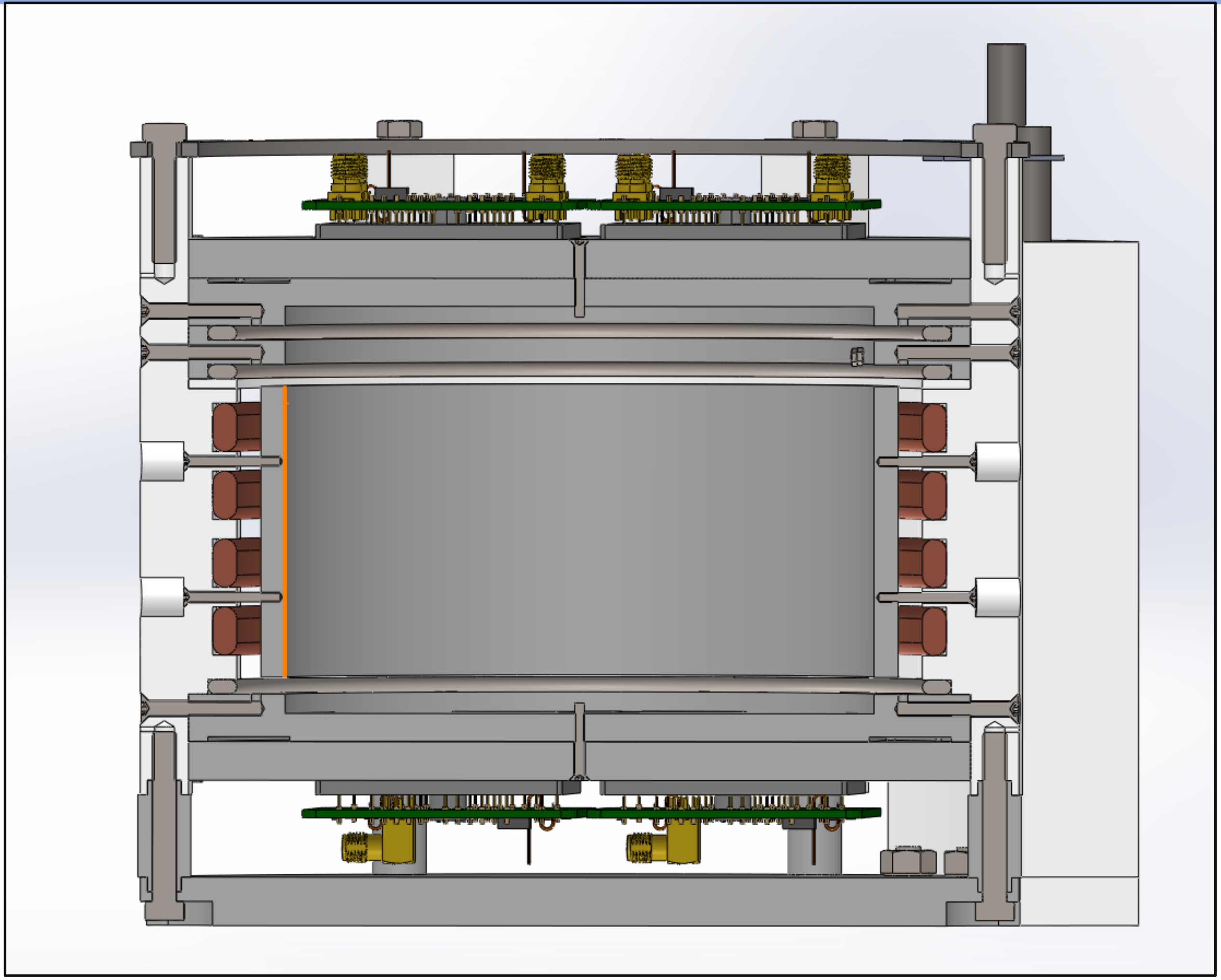
- Afterpulses tend to merge with signal

Next Steps:

- Long term stability measurement ongoing for additional pair of PMTs
- Energy calibration with low energy radioactive Source
- Kg-scale TPC with 2x4-PMT-arrays in final design stages as proof of concept.



Backup



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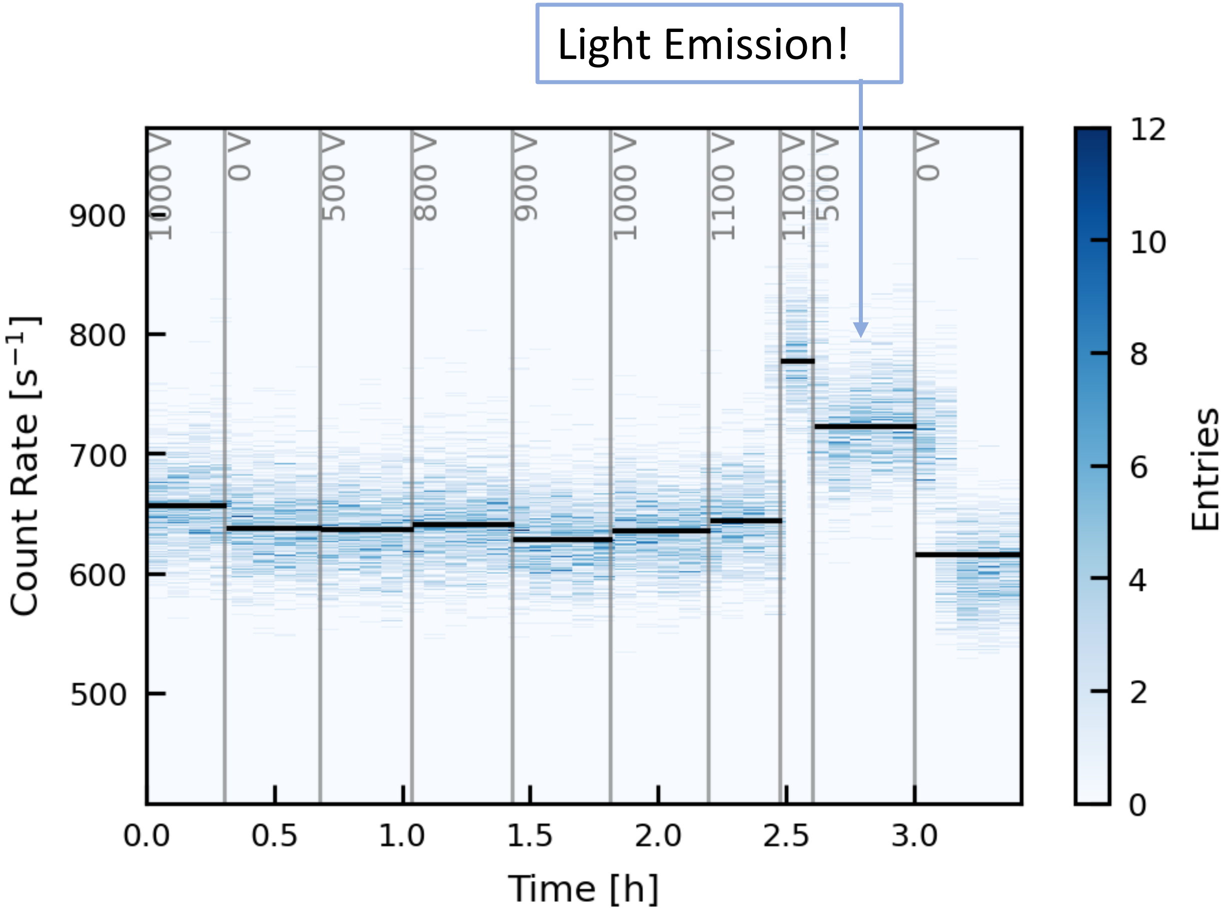
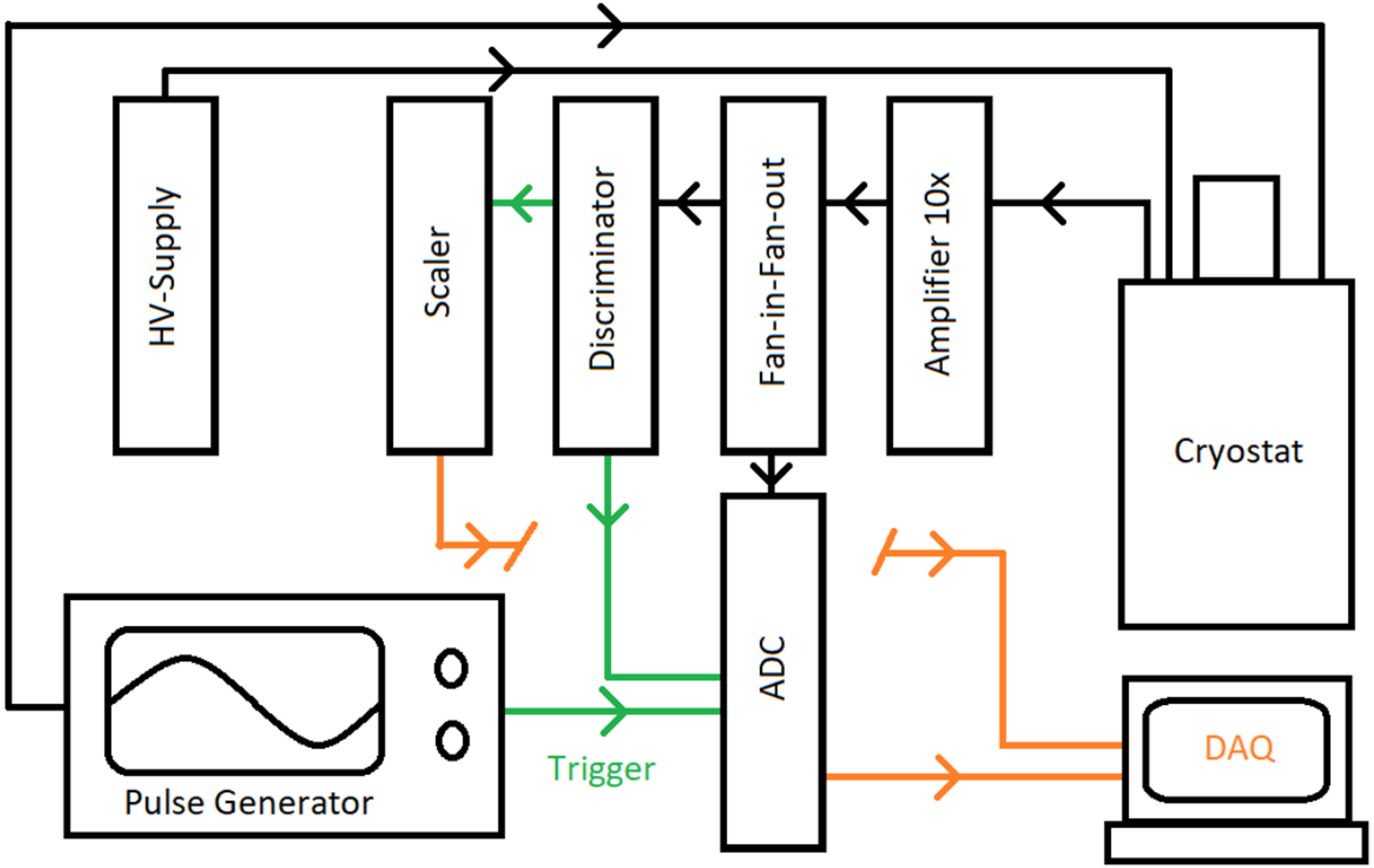


Read-Out Chain



Characterization

Model Independent Method

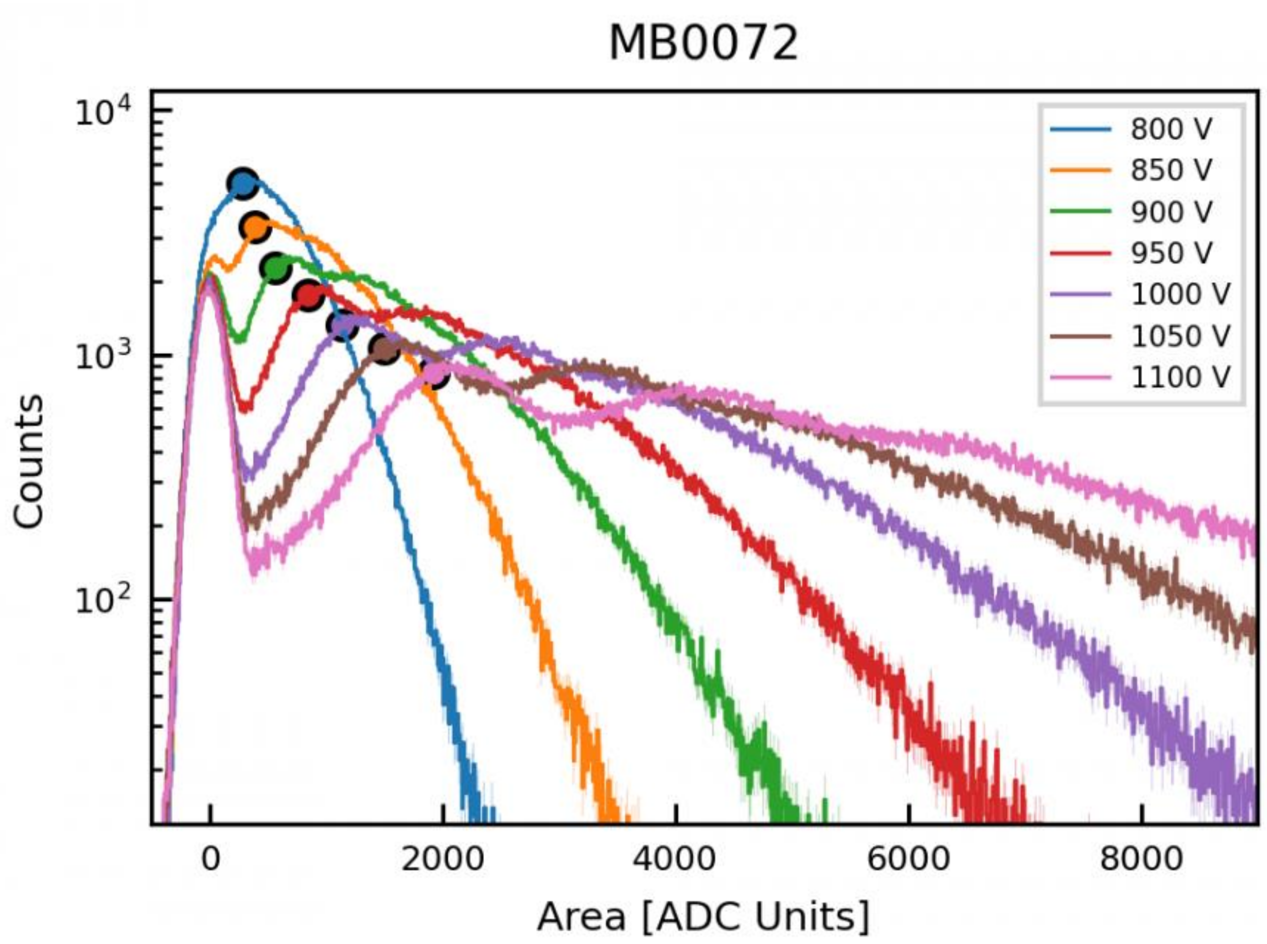
- Calculate first two moments of SPE distribution from 'LED on' and 'LED off' samples. [4]

$$E[\psi] = \frac{E[T] - E[B]}{\lambda}$$

$$V[\psi] = \frac{V[T] - V[B]}{\lambda} - E^2[\psi]$$

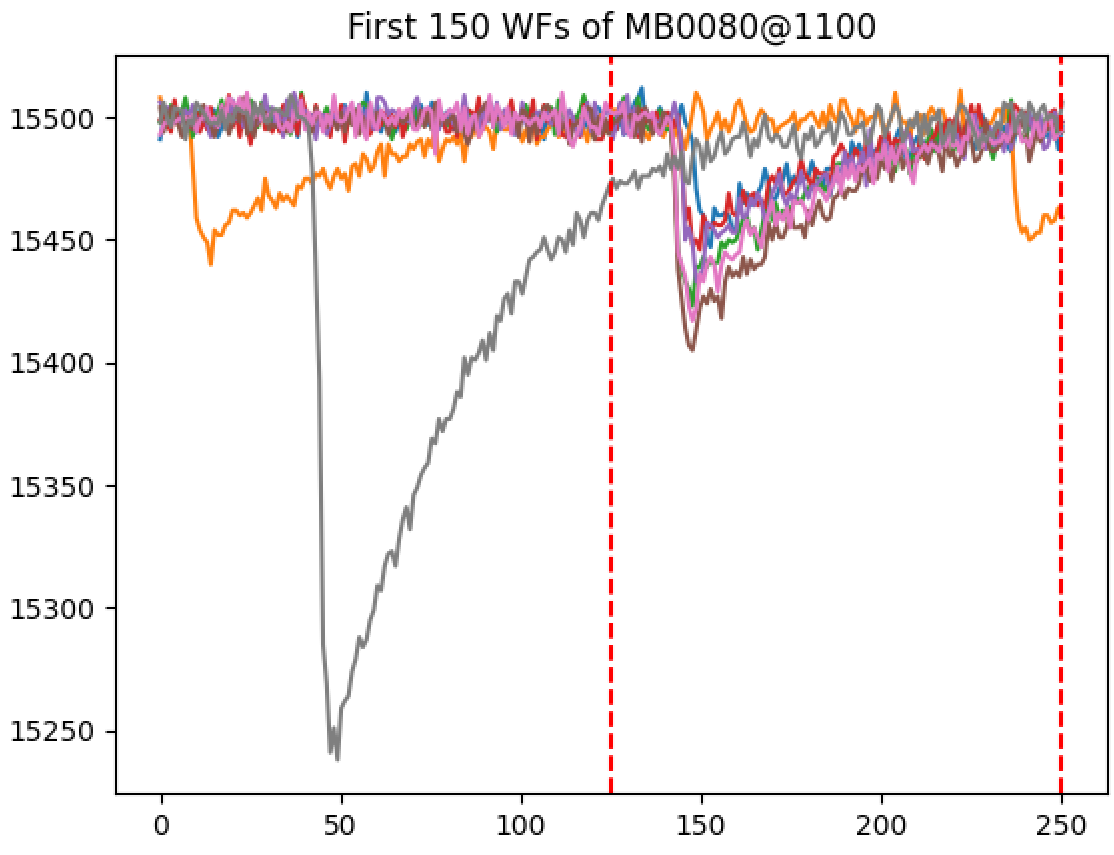
$$P(0|\lambda) = exp(-\lambda)$$

$$\lambda = -ln(P(0|\lambda)) = -ln(N_0/N)$$



[4] Nucl. Instrum. Methods Phys. Res. Sect. A (2017) P. 35-46

MB0080



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15300
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0
50
100
150
200
250