A Guide to the MOLLER Main Detector Array

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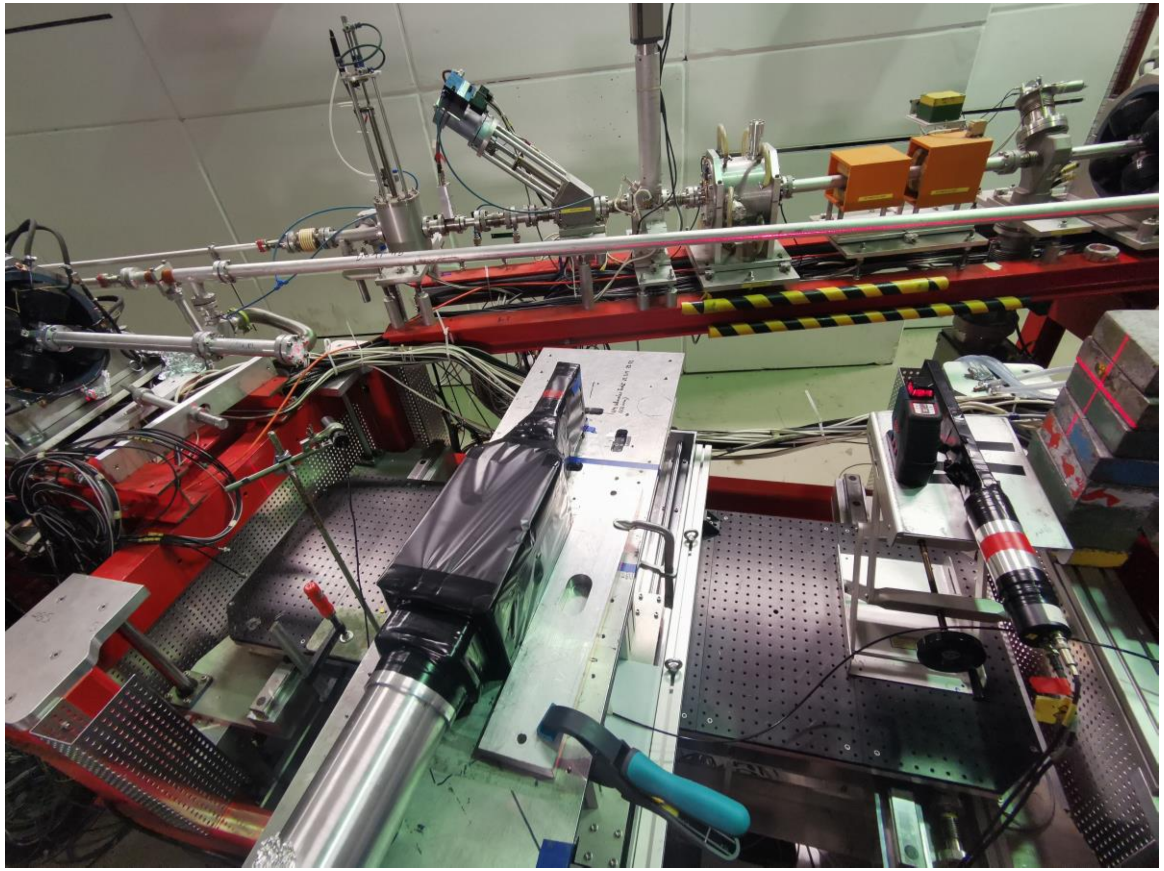
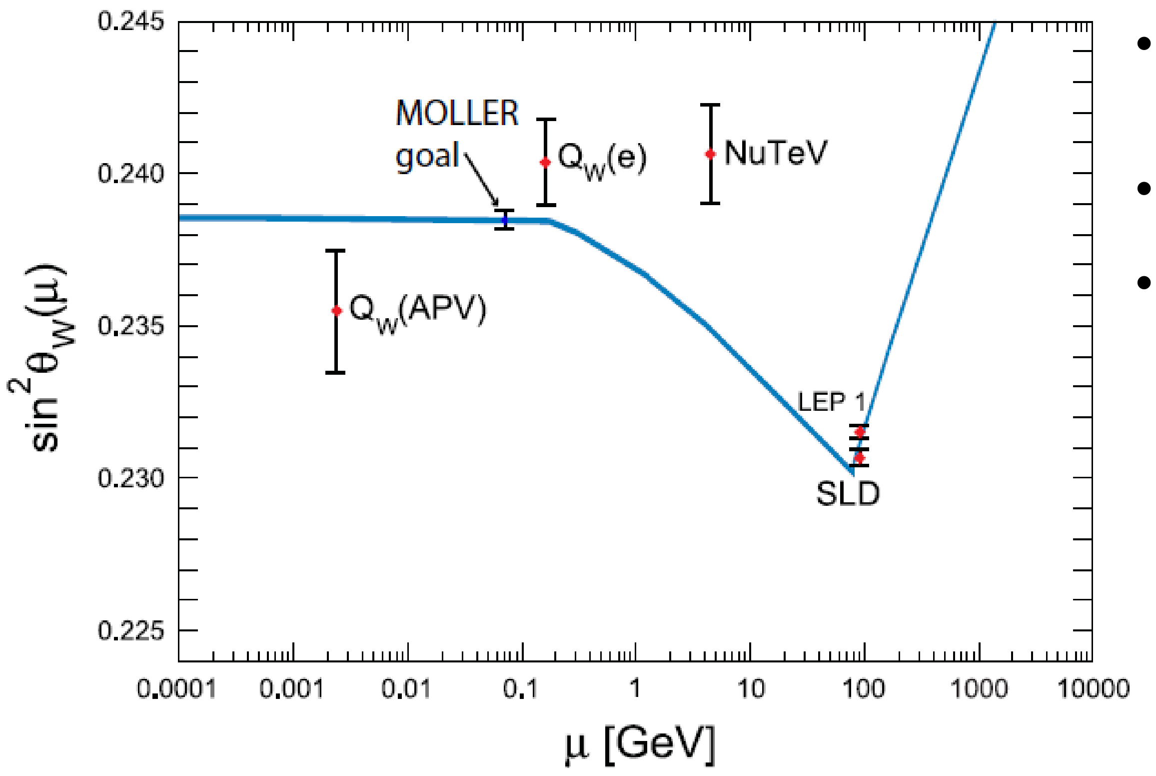
Outline

- Motivation
- MOLLER Overview
- Main Detector Array
- Electronics and Housing
- Beam Tests



Weak Mixing Angle



- The weak mixing angle is a central parameter in electroweak sector of SM
- Describes the mixing of SU(2) and U(1) spaces
- **MOLLER** will determine $\sin^2\theta_W$ at average $Q^2 = 0.0056\ \mathrm{GeV}^2$ using **parity violating electron scattering**:

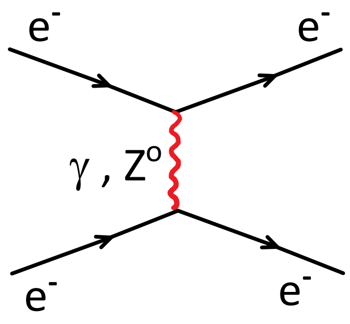
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = m_e E \frac{G_F}{\pi\alpha\sqrt{2}} \frac{4sin^2\theta}{(3 + cos^2\theta)^2} Q_W^e$$

with $\quad Q_W^e = 1 - 4sin^2\theta_W$

A_{PV} predicted to be ≈ 33 ppb

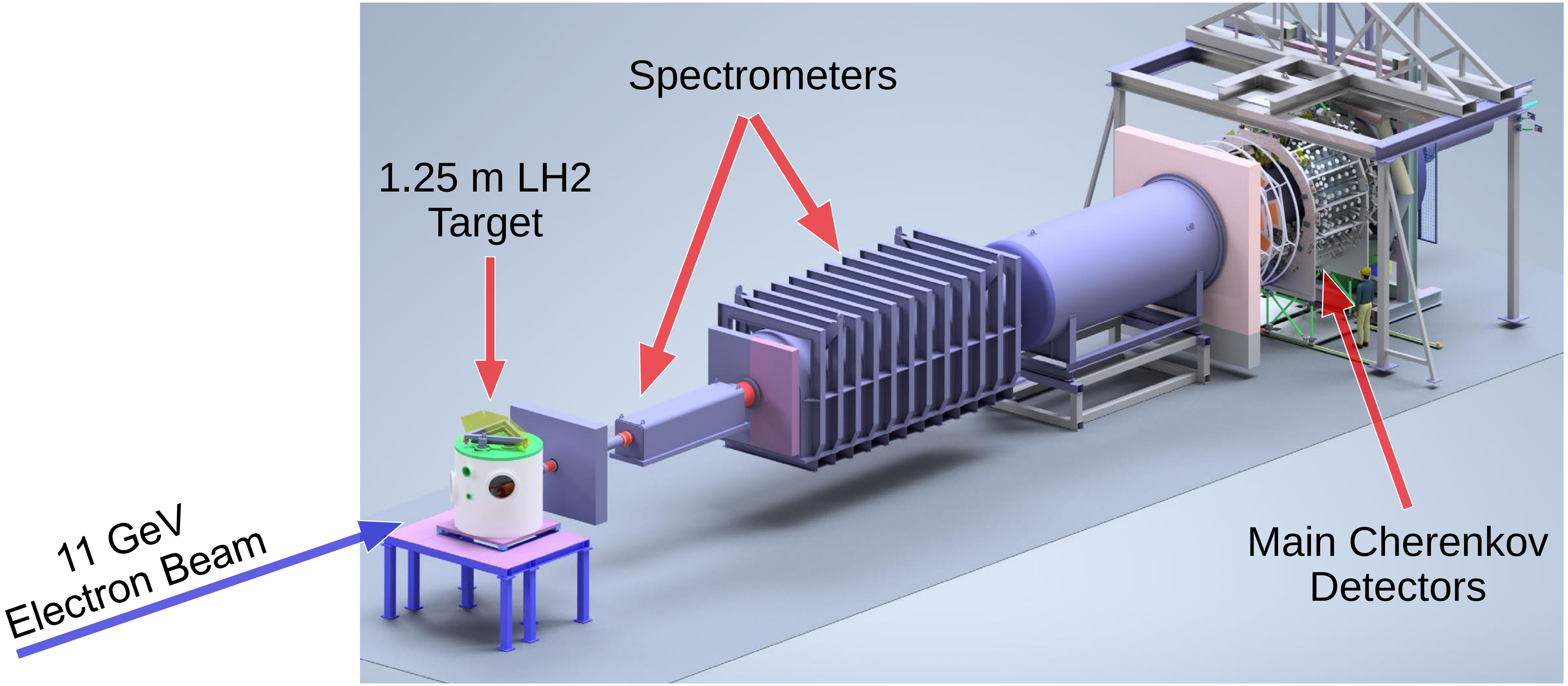
MOLLER Goal:

$\delta A_{PV} = 0.8\ \mathrm{ppb} \quad \Rightarrow \Delta Q_W^e = 2.4\% \quad \Rightarrow \Delta\sin^2\theta_W = 0.1\%$

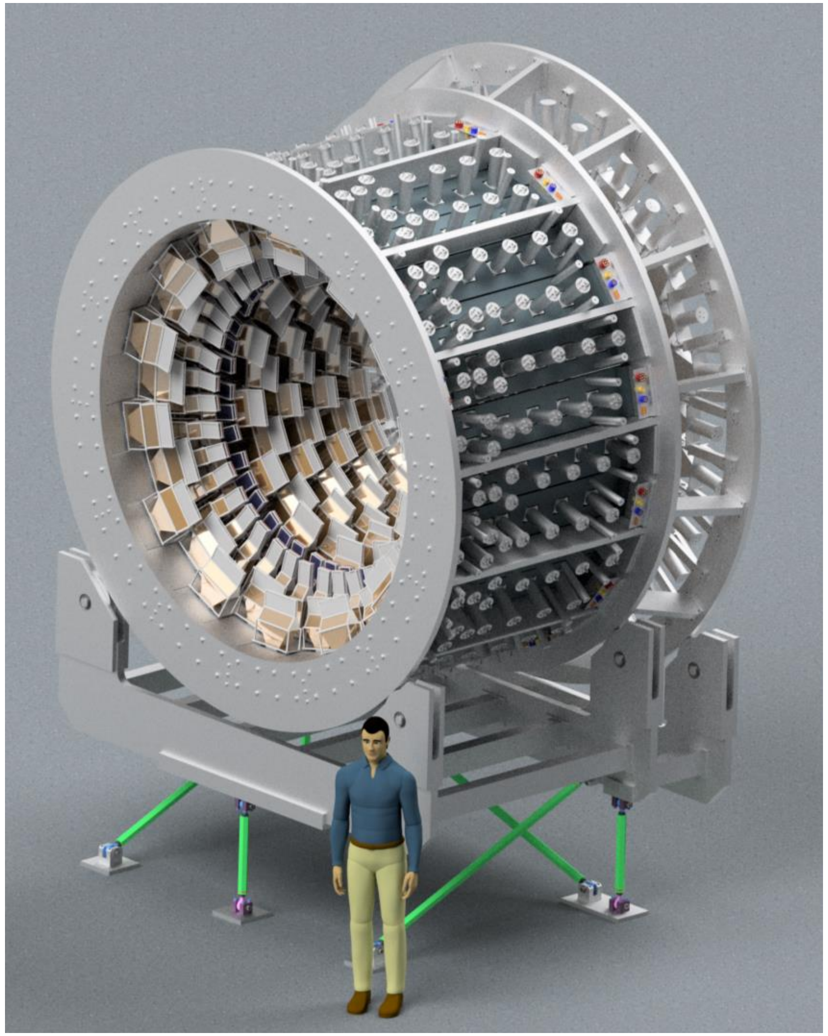


The MOLLER Experiment

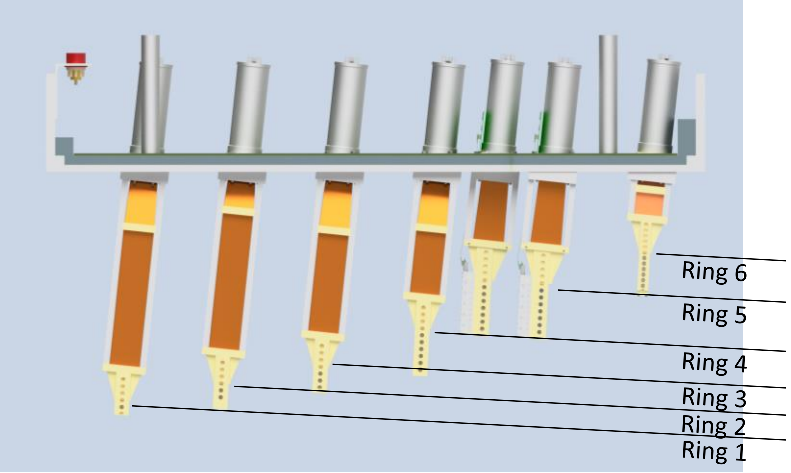
- Hall A at Jefferson Lab
- 11 GeV longitudinally polarized electron beam
- Highly polarized $\geq 90 \pm 0.5\%$ electron beam with a fast helicity flip rate

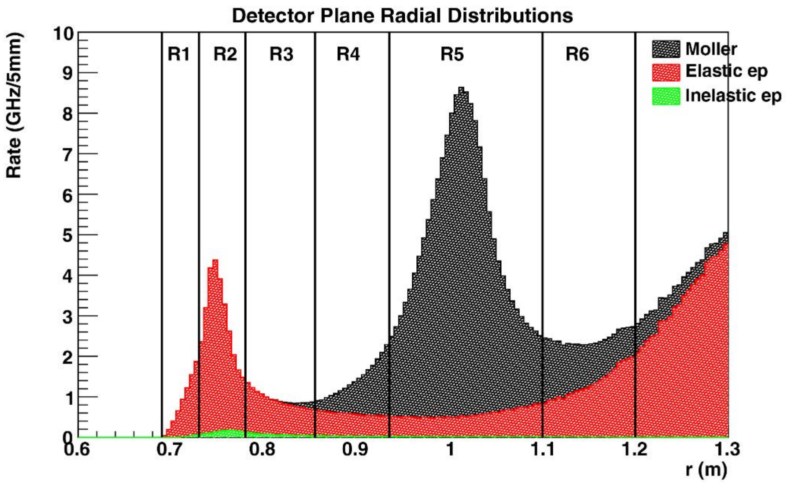


Main Detector System

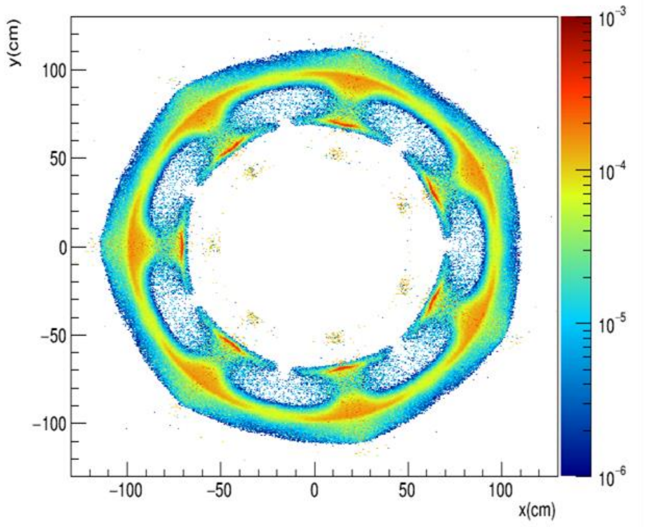


- 224 Detectors
  - Radially split into 6 Rings
  - Azimuthally split into 28 Segments
- Located 26.5 m downstream from target
  - Sufficient space for spectrometers to separate e-e and e-p peaks
- Full coverage of Møller events
- Integration and event mode data collection

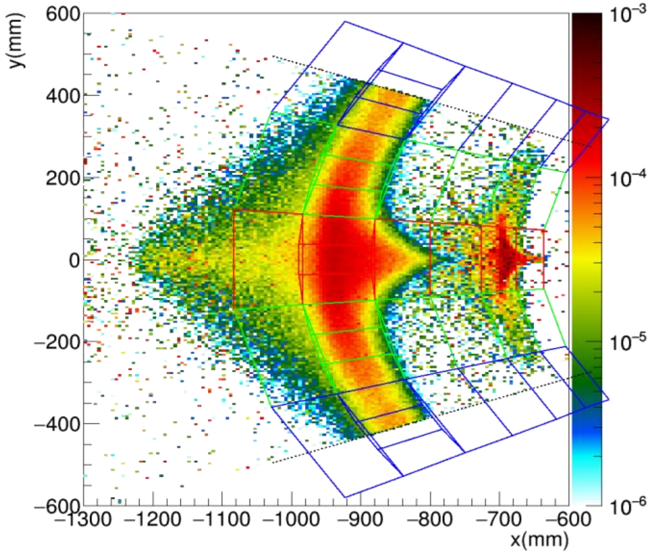




Main Detector System



rate (GHz/sep/uA/(5mm)^2) vs xy(mm^2)



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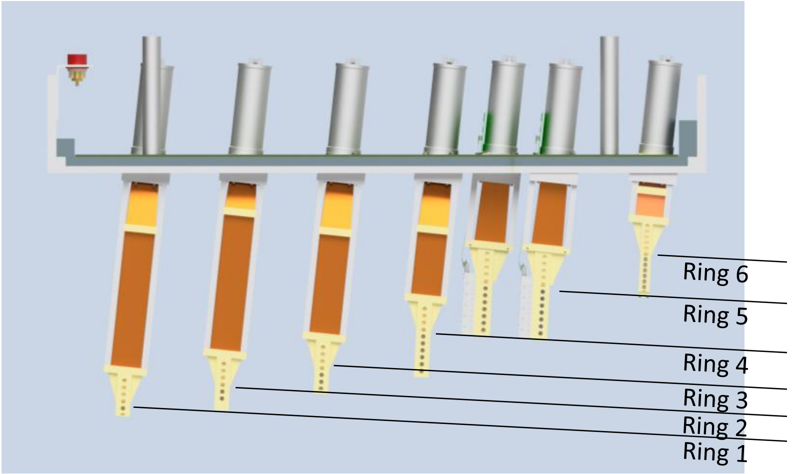
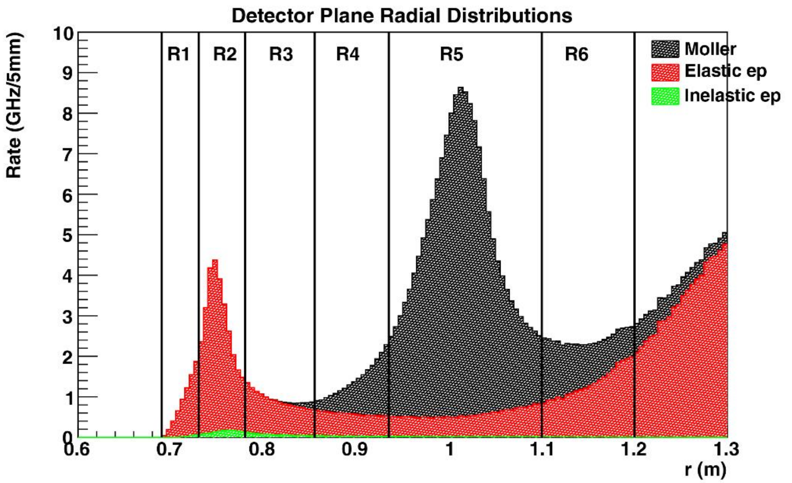
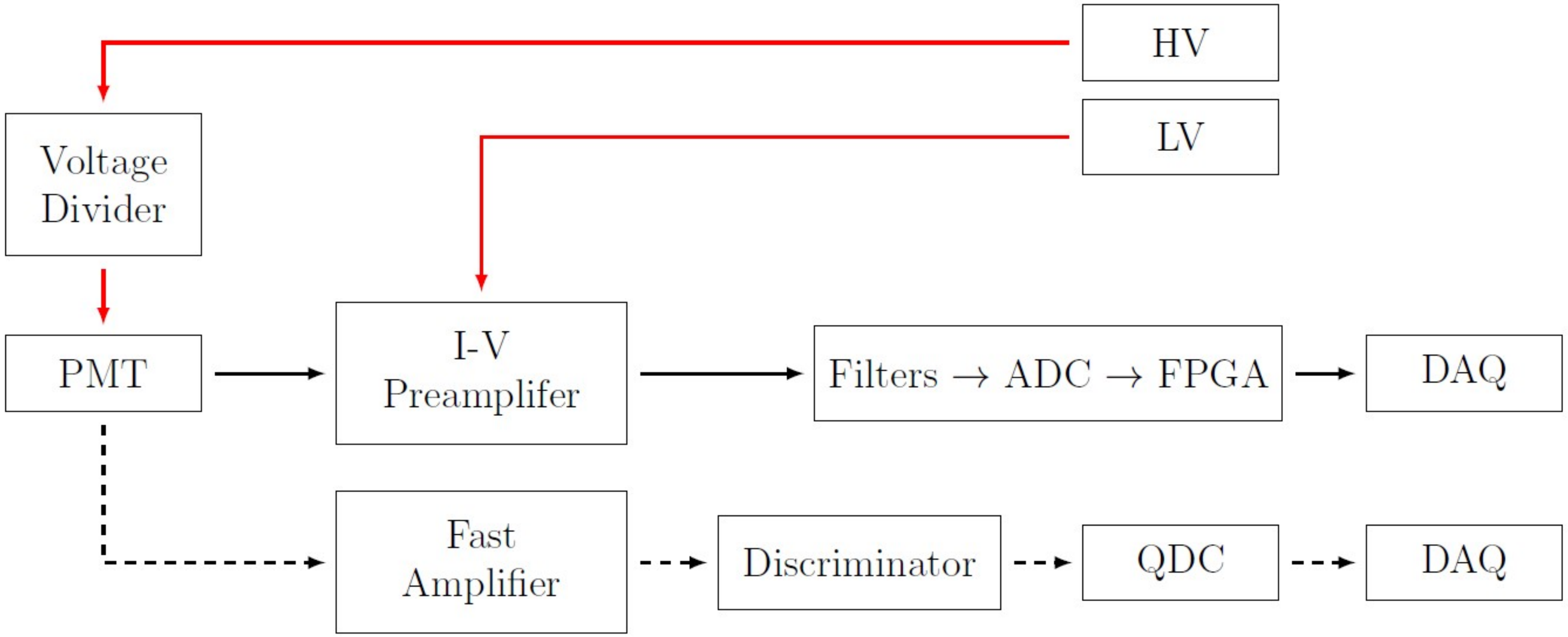


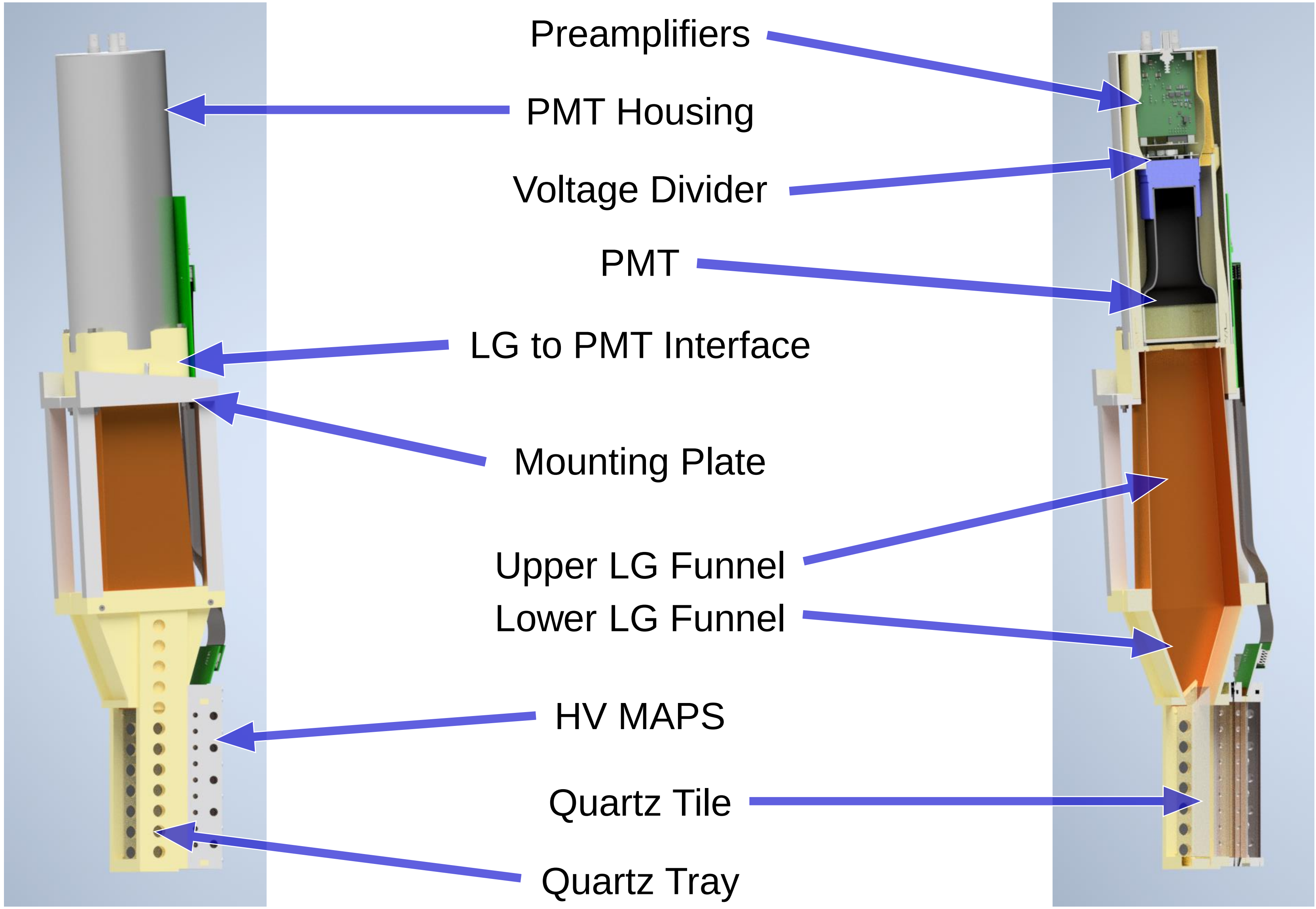


Detector Electronics

- Switchable PMT base for two different running modes: event and integration
- Event Mode: higher gain, tracking and diagnostics
- Integration Mode: lower gain, production running for asymmetry measurements



Ring 5 Module

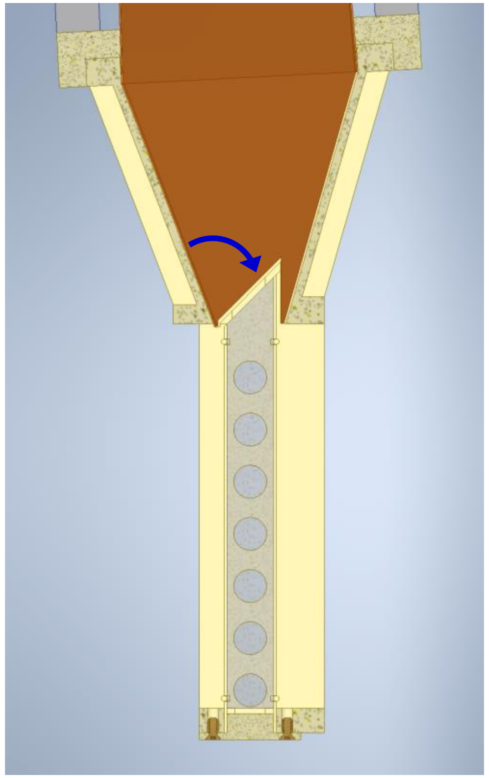


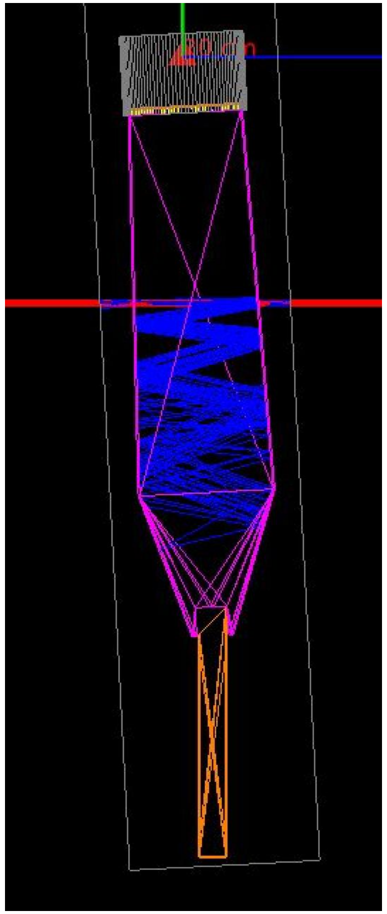
3D Printed Quartz Trays

Design Components:

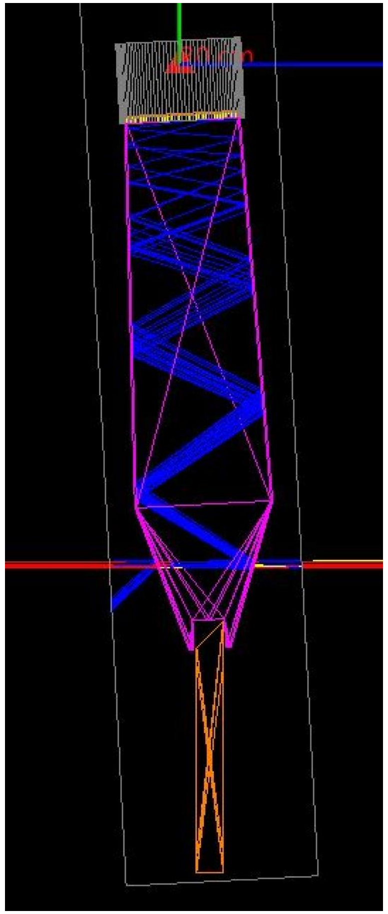
Monolithic tray combines quartz holder and lower LG funnel structure

- Fixes the angle between quartz and primary mirror

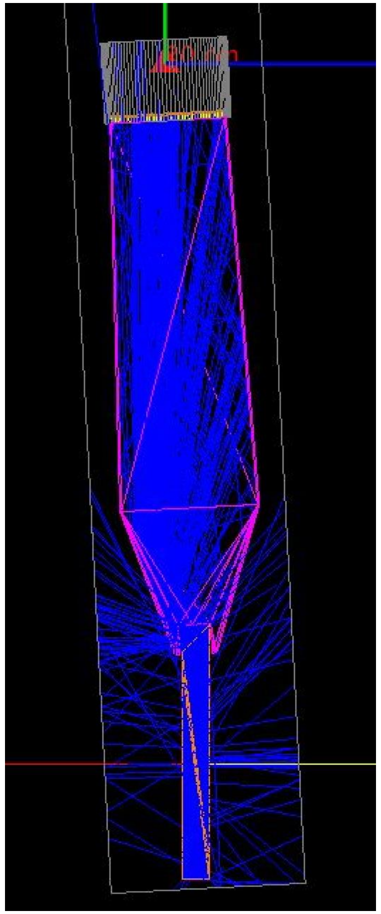




Upper guide events



Lower guide events



Quartz events

3D Printed Quartz Trays

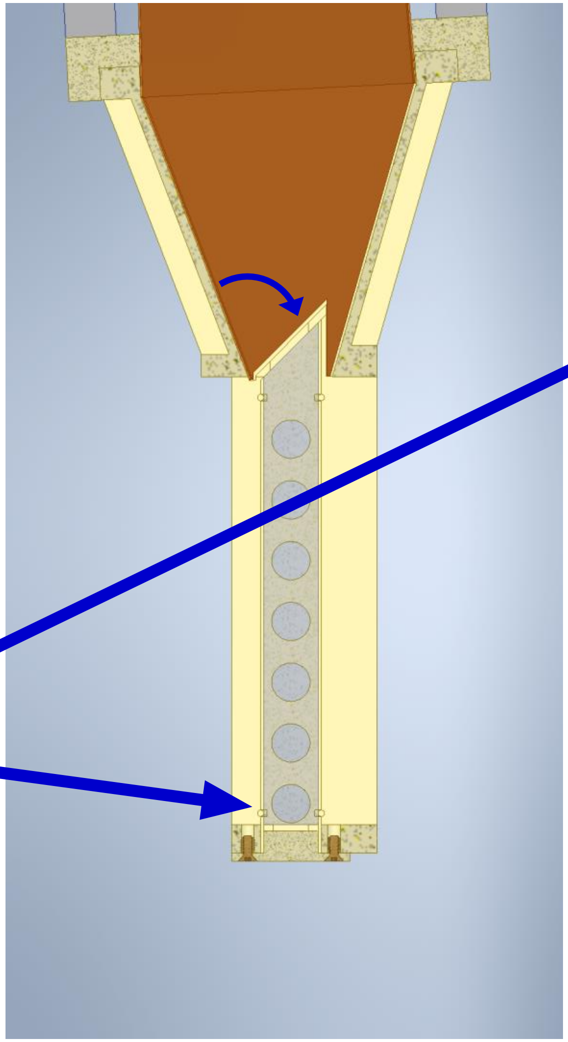
Design Components:

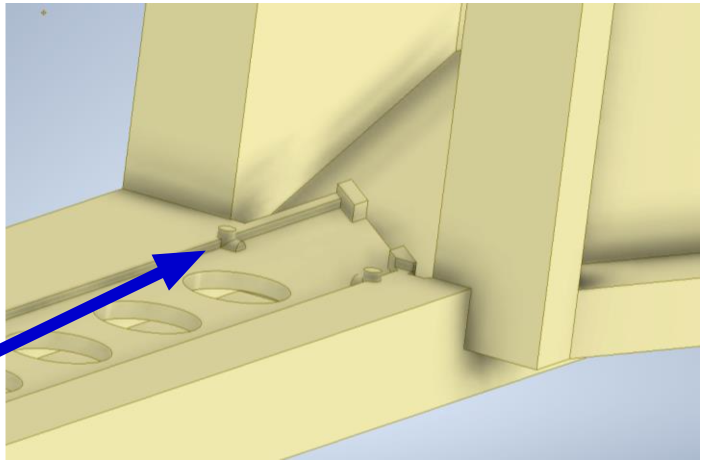
Monolithic tray combines quartz holder and lower LG funnel structure

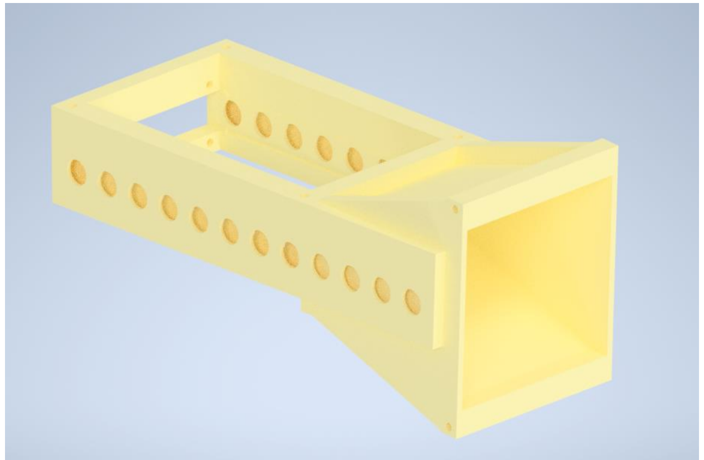
Fixes the angle between quartz and primary mirror

Removable end cap to insert and secure quartz tiles

Minimal contact points to guide and secure quartz



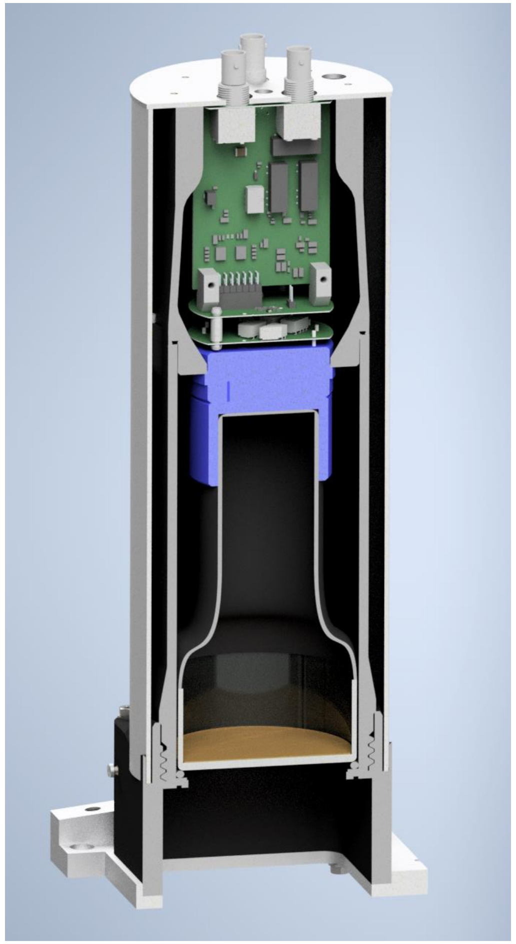




PMT Housing Design Components

Aluminium shielding: reduces signal noise

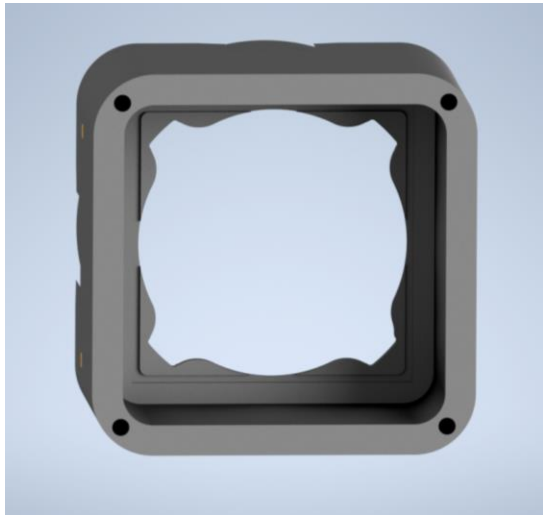
Threaded LG – PMT housing interface: ease of removal

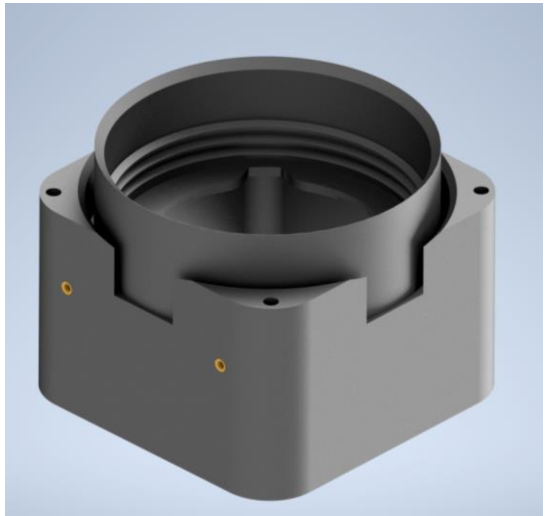


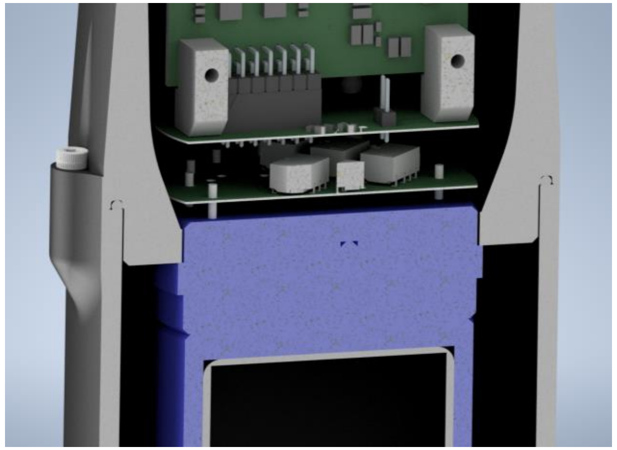
Air channels through interface:

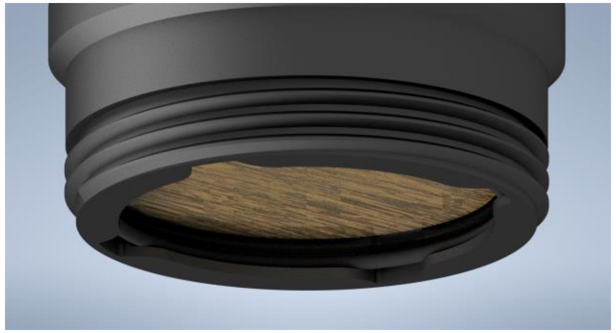
- Allows air flushing for electronics & light guides
- 3D printed threads ensure proper alignment

Internal structure: secures PMT placement



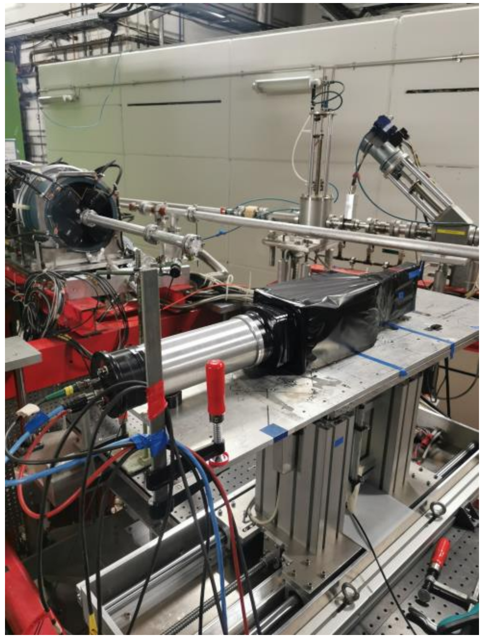


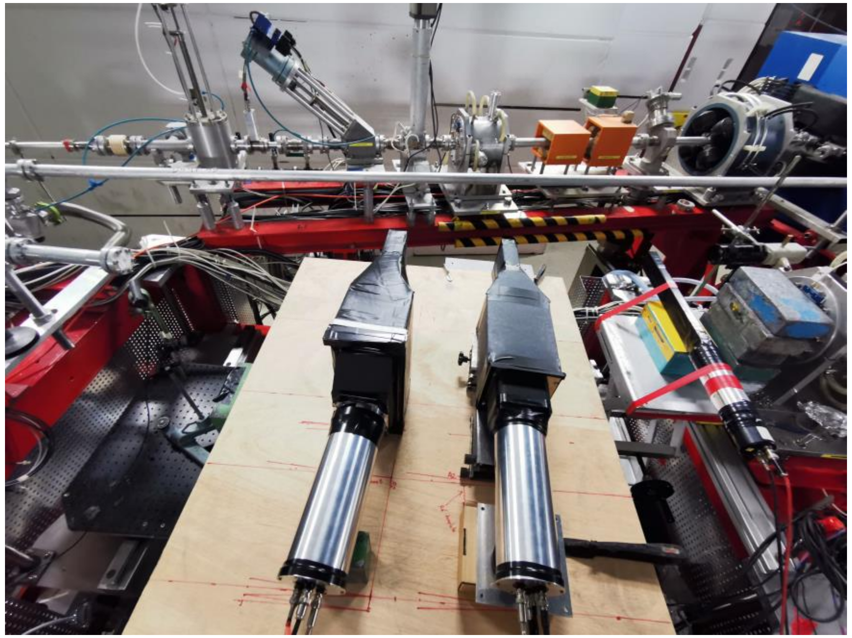




Beam Tests

- **MAMI Facility** in Mainz, Germany (with copious amounts of help from P2 group)
- Testing the electronics noise levels and signal output
- Comparing light guide and quartz materials
- Checking feasibility of design





Event Mode Data Analysis

- Identify pedestal and event peaks using the ROOT TSpectrum class
- Event peak fitted with a Landau-Gauss convolution
- The "most probable value" (MP) and the fit sigma (GSigma) were extracted to record the mean photo-electron yield

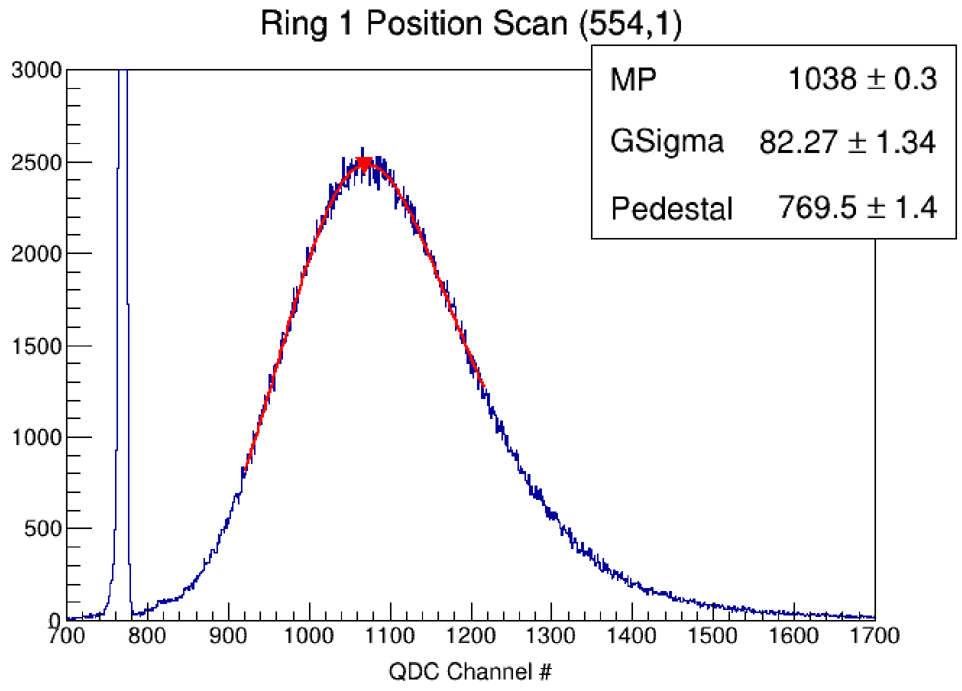
$$n_{pe} = \frac{(\mathrm{MP} - \mathrm{Ped})^2}{\sigma^2}$$

November 2022 photoelectron yields:

Ring 1 $n_{pe} \approx 9$

Ring 2 $n_{pe} \approx 15$

Ring 5 $n_{pe} \approx 21$



Overall experimental error grows with the excess noise factor

Need to keep detector resolution or excess noise limited to:

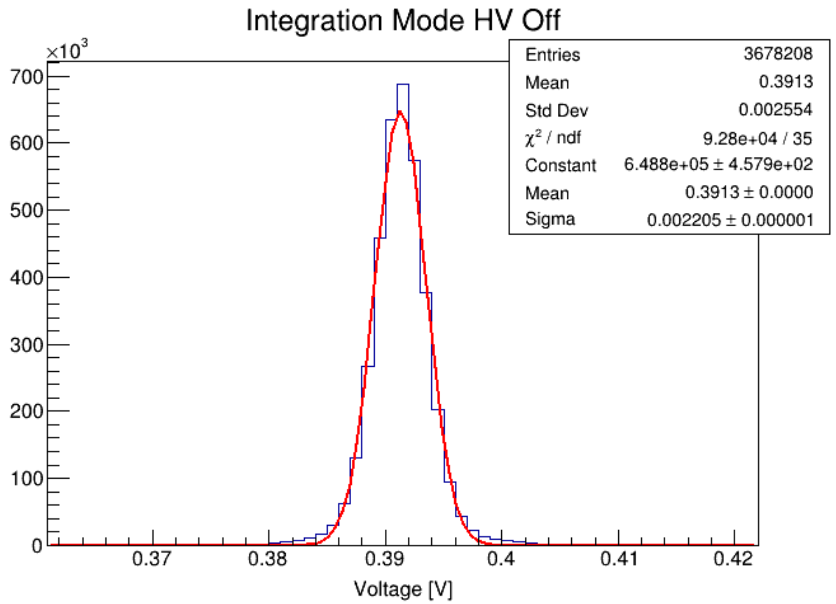
$$\frac{1}{\sqrt{N}}\left(\sqrt{1+\alpha_{exc}^2}-1\right)=\frac{1}{\sqrt{N}}\left(\sqrt{1+\delta_{Det}^2+\delta_{PMT}^2+\delta_{Elect}^2}-1\right)\leq 4\%$$

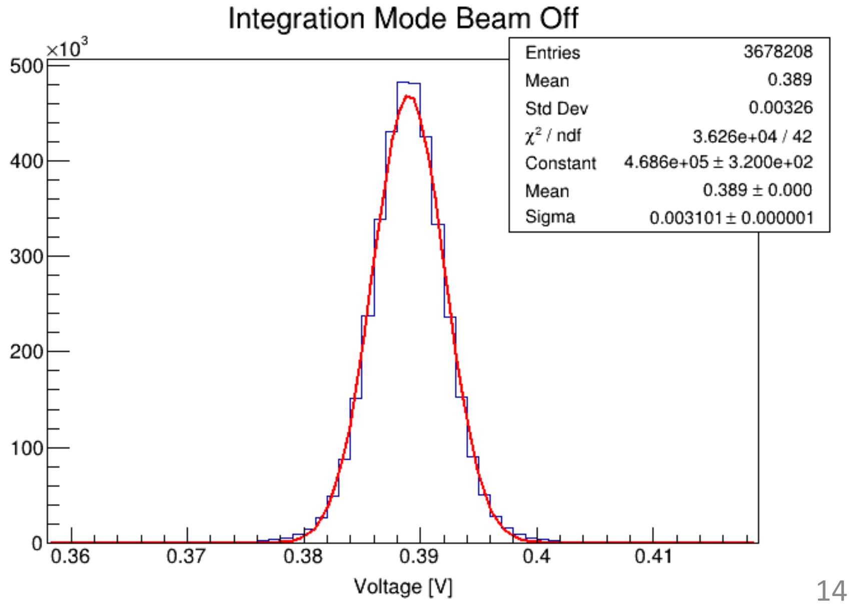
$$\delta \equiv \frac{\sigma}{V}$$

Corresponds to 1% limit goal $\sigma_{PMT} = \sigma_{elec} < 4.8\text{ mV}$ for $n_{pe} = 30$

Preamp noise signal: $\sigma_{amp} \simeq 2.21\text{ mV}$

Preamp + PMT noise signal: $\sigma_{total\ elec} \simeq 3.10\text{ mV}$





Thank You