Developing the Integrating Detector Electronics Chain for the MOLLER Experiment

Brynne Blaikie

Dr. Michael Gericke, Dr. Jie Pan, Nafis Niloy

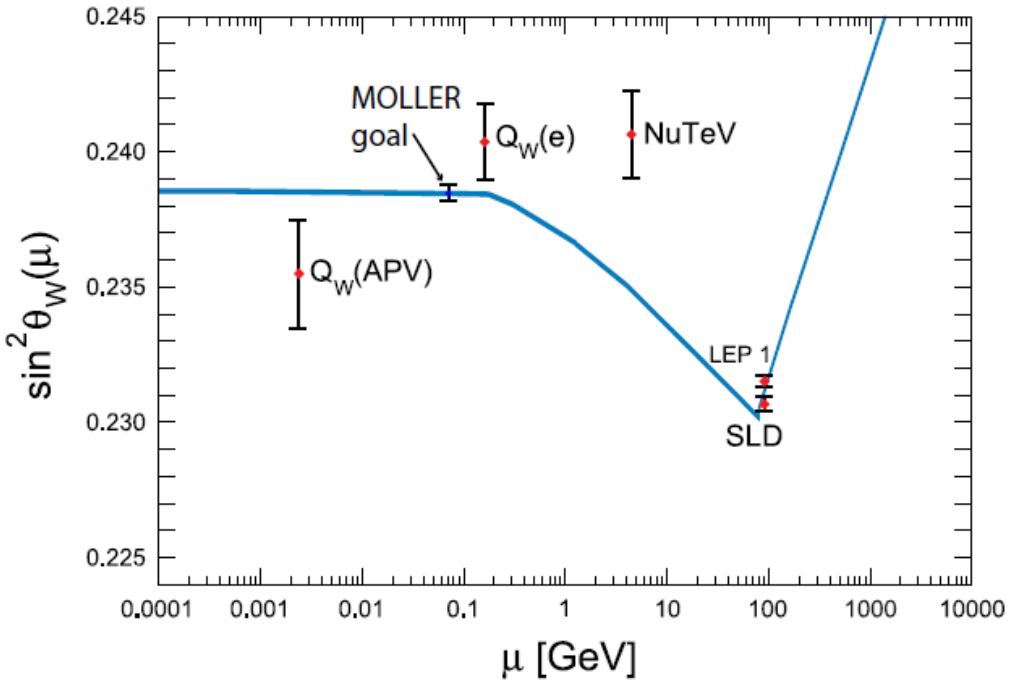
The MOLLER Collaboration

Outline

- MOLLER Motivation & Overview
- Main Detector Electronics
- October 2021 Beam Test
- Modifications
- May 2022 Beam Test

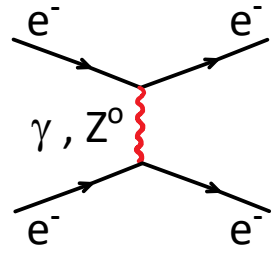
Motivation

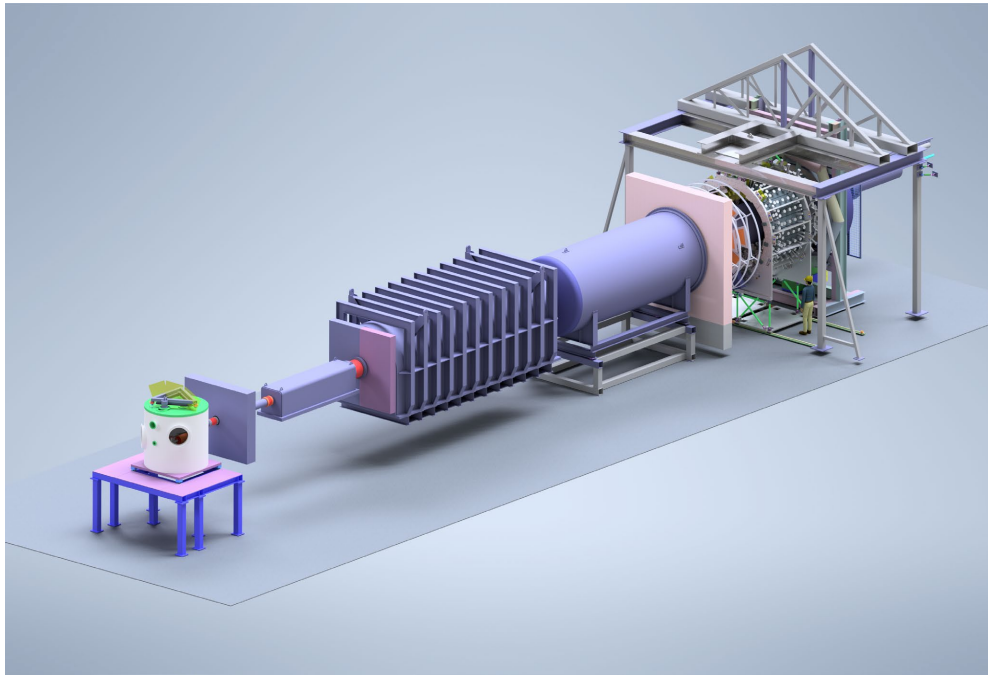
The MOLLER Project



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

$$Q_W^e = -(1 - 4sin^2\theta_W)$$





- Highest precision measurement of the weak mixing angle
- Highly polarized electron beam with a fast helicity flip rate
- Spectrometers separate the e-e, elastic and inelastic e-p
- Hall A at Jefferson Lab

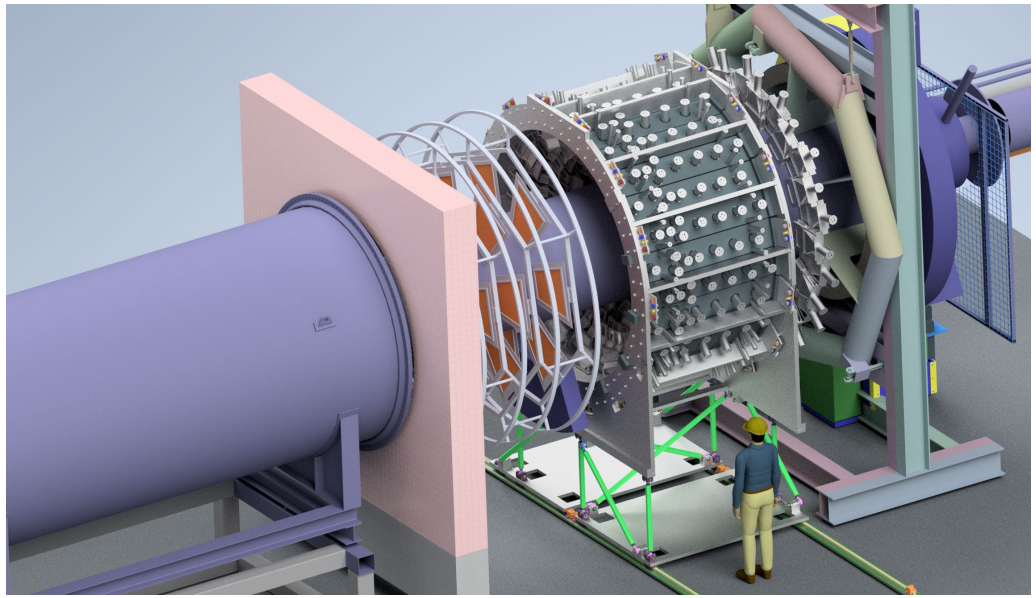
Main Detector System

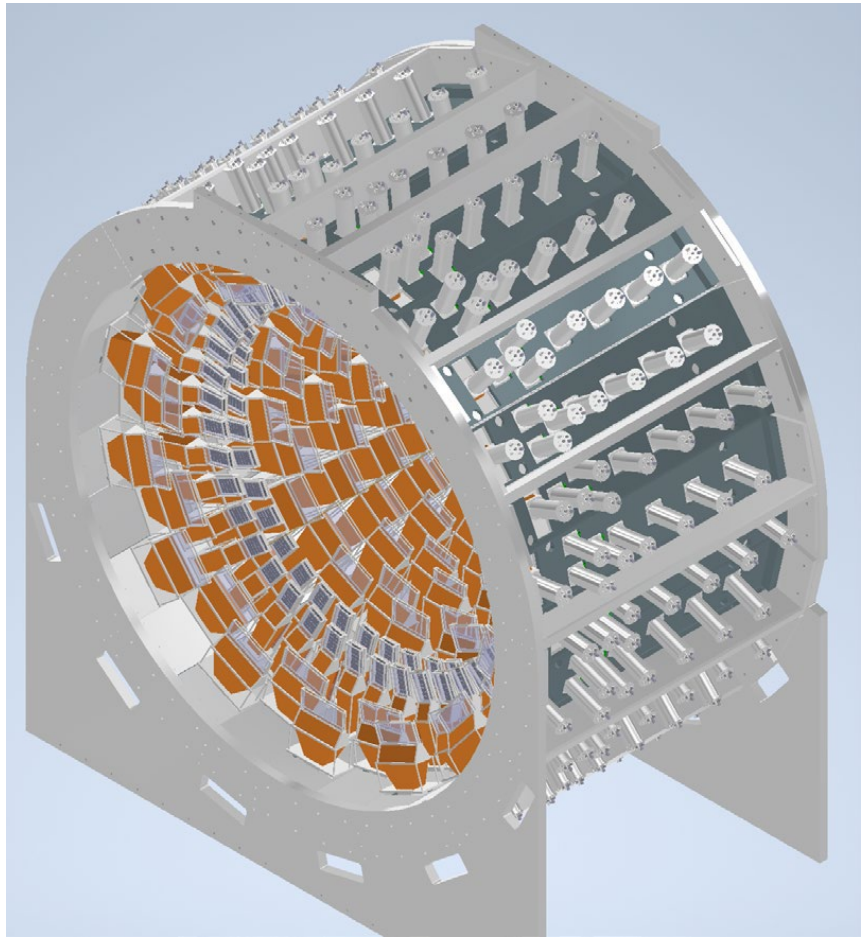
Main Detector System

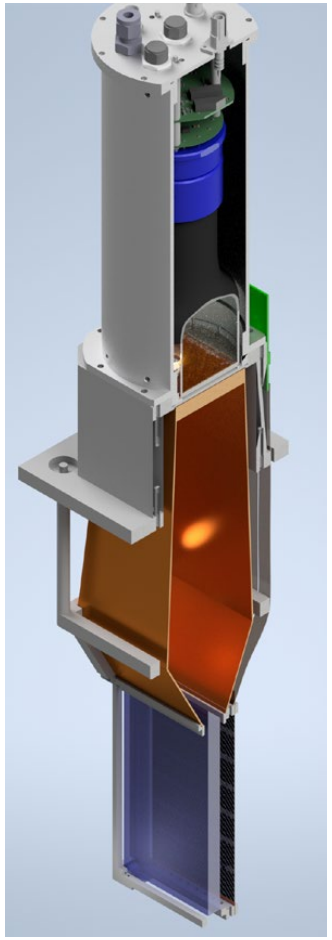
1. Quartz
2. Light Guide
3. Photo-multiplier tube and base
4. Preamplifier
5. ADC & FPGA

224 detectors

28 segments of 8 detectors

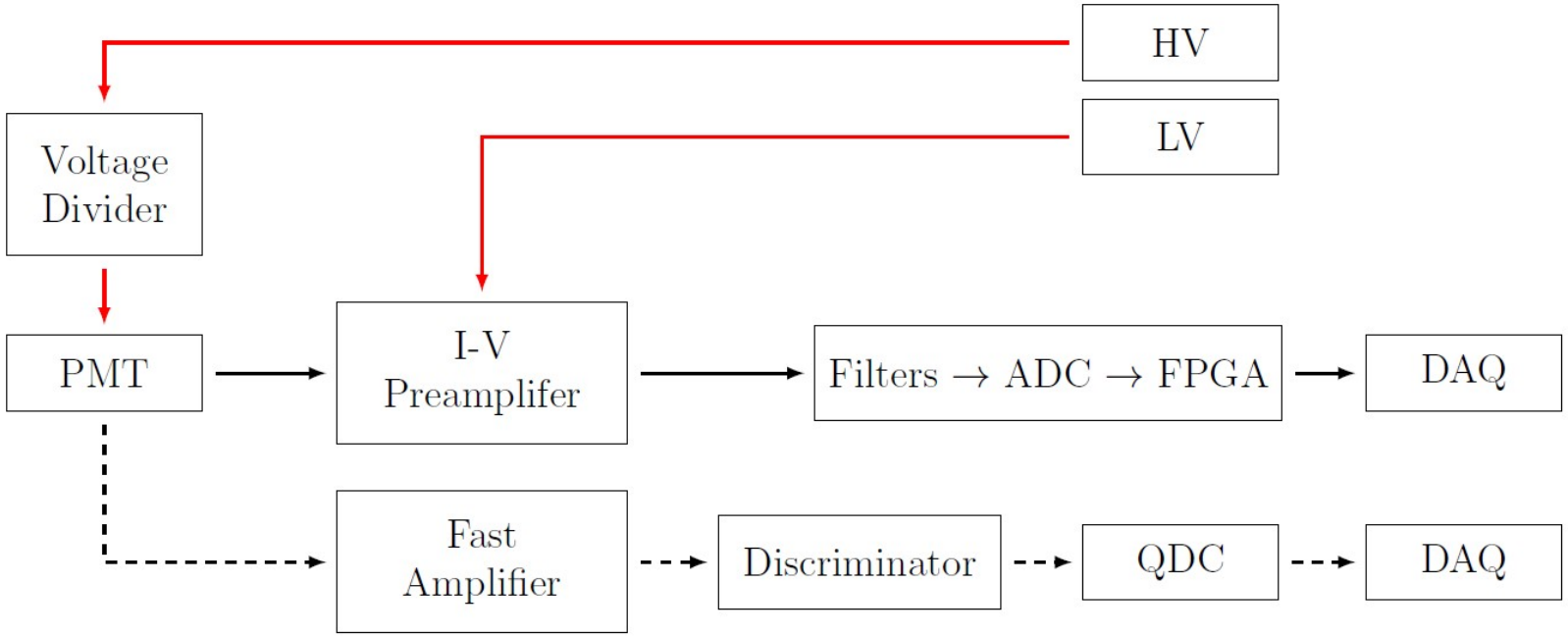






Main Detector System

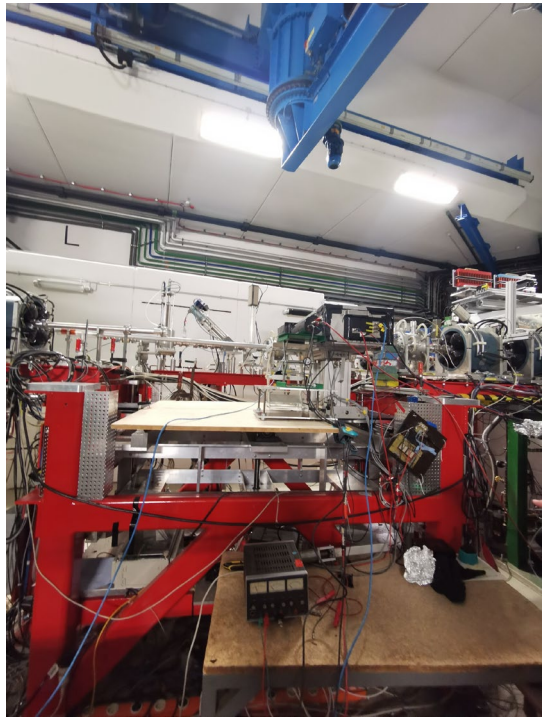
- Switchable PMT base for two different running modes: event or integration
- Event Mode: higher gain, used to check number of photoelectrons
- Integration Mode: lower gain, used for asymmetry measurements

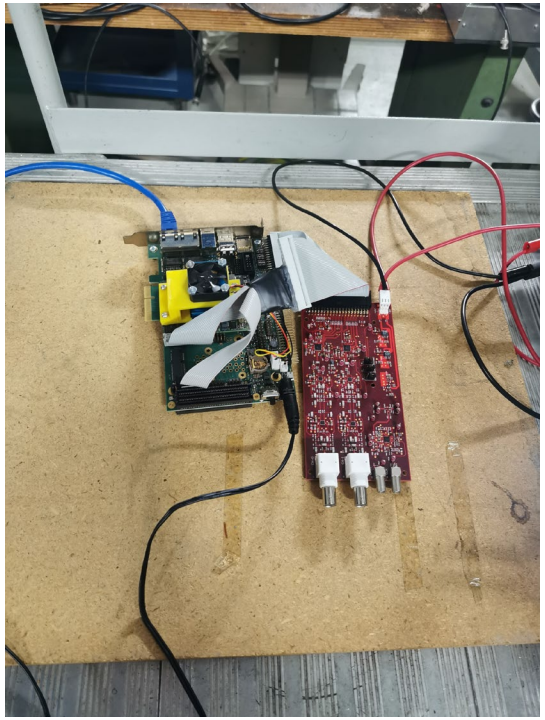


Beam Test – October 2021

October 2021 Beam Test

- 2 sets of 3D printed modules: thin and thick quartz geometries
- Combination of light sealing sleeves, light guide materials, and preamplifiers
- Two channel ADC board connected to FPGA evaluation board





Signal-to-Noise Ratio

- Verification of counting statistics operation of electronics
- Compare signal to beam off and pure electronics noise

- Shot noise for electrons moving through quartz: (integration mode)

$$\sigma_S = \sqrt{2QI}\sqrt{B} = \sqrt{2\left(n_{pe}eG_{PMT}\right)\left(n_{pe}eG_{PMT}R\right)B} = Q\sqrt{2RB}$$

- G_{PMT}, R, B can all be found through measurement and are used to calculate the number of photoelectrons
- Compare n_{pe} from event mode and integration mode measurements

- Other non-Gaussian noise sources (electronics, beam, etc.) which will cause the signal to differ slightly from the ideal scenario

Where:

G_{PMT} is the PMT gain in integration mode
R is the electron rate on the quartz
B is the bandwidth of the system (the smallest one in the chain)
n_{pe} is the number of photoelectrons created at the cathode per electron event through the quartz
$e = 1.6 \times 10^{-19}\ C$

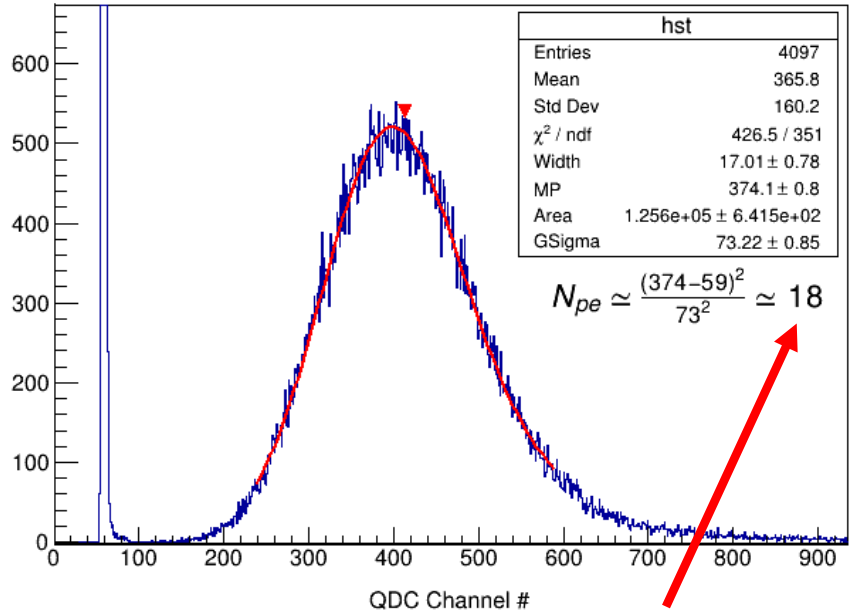
October 2021 Beam Test - Analysis

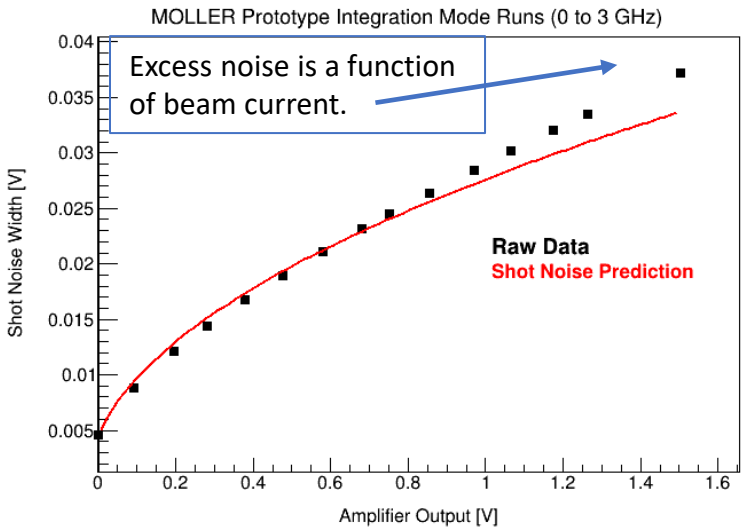
1. Extract the n_{pe} from the event mode data.

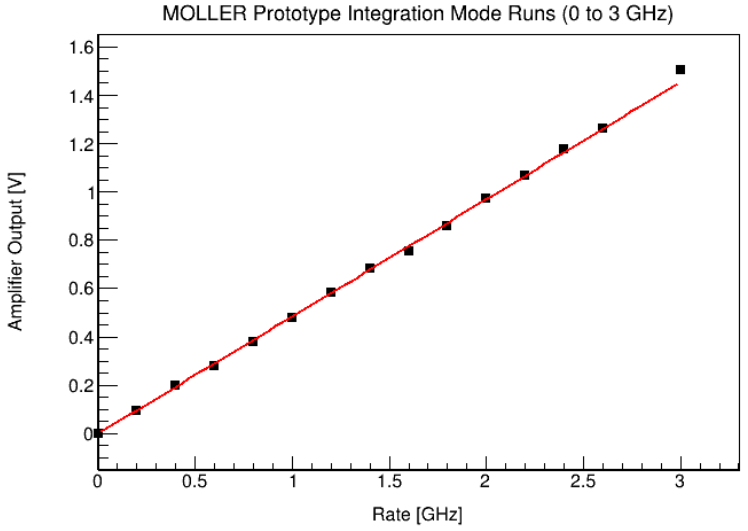
   Shown on the upper right is data for one event mode data, giving $n_{pe} \backsimeq 18$ for MOLLER prototype.

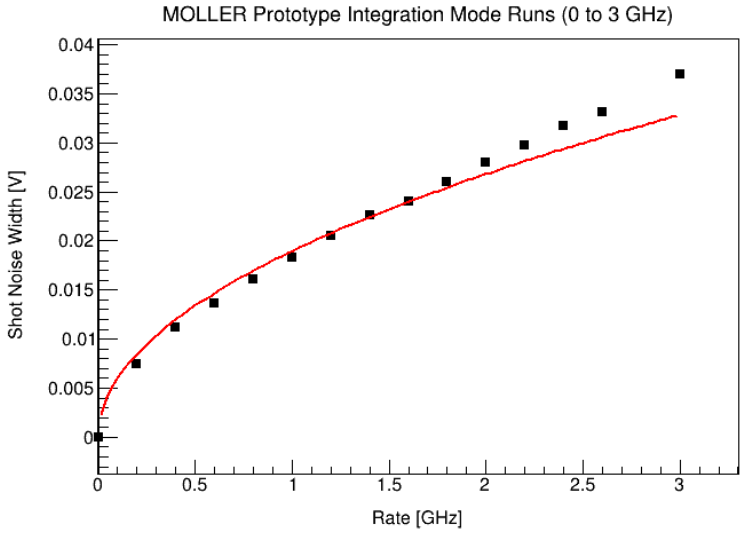
2. Make the three plots below or integration mode data.

   Data taken from a beam rate of 0 GHz to 3 GHz. Each plot is roughly consistent with $n_{pe} \backsimeq 18$.



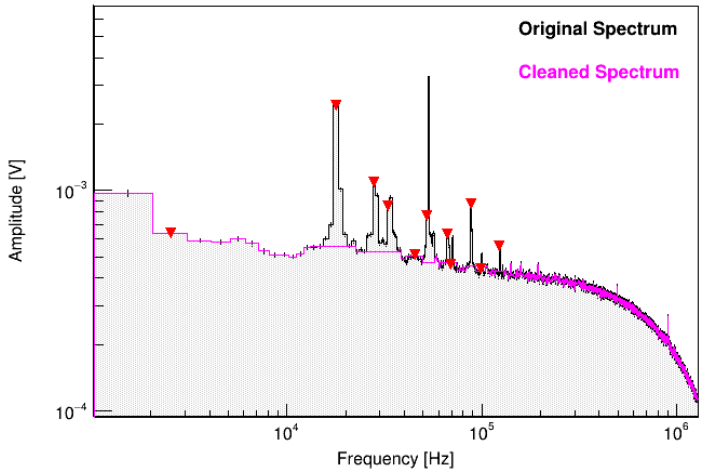


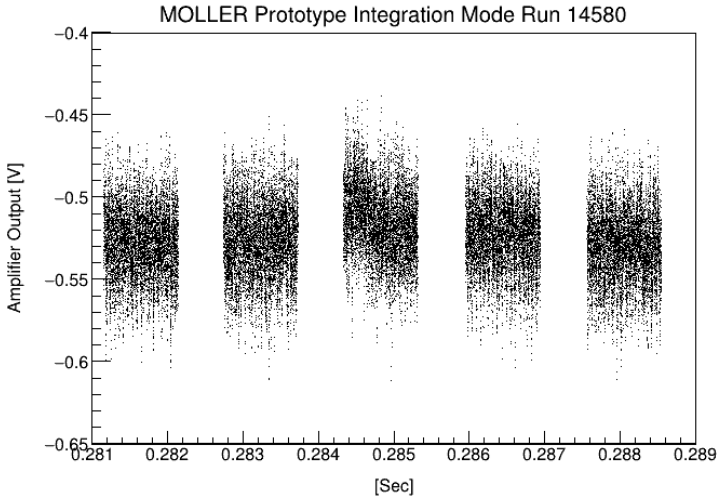


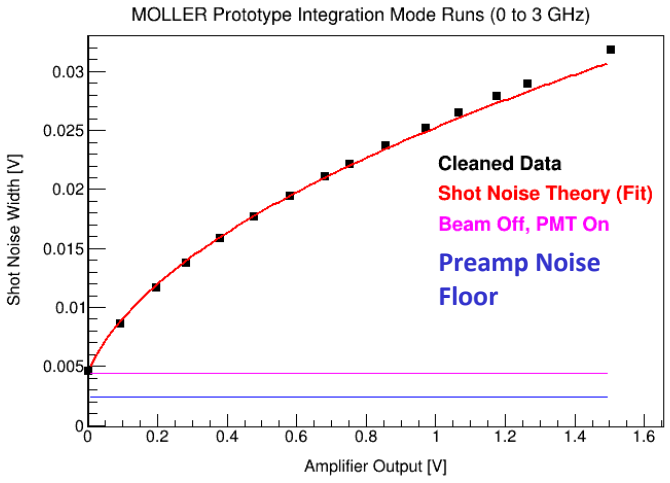


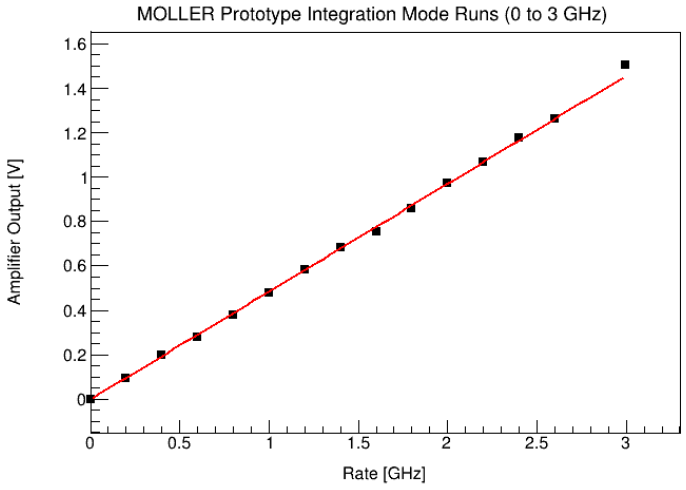
October 2021 Beam Test - Analysis

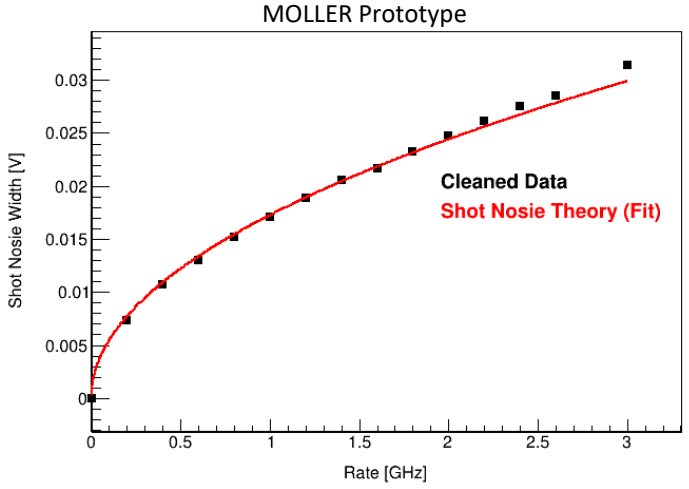
- Discrete Fourier Transform (DFT) to identify the frequency components for which the noise fluctuations occur
- Non-Gaussian noise contributions in the broadband region (10 – 100 kHz) which are identified using the ROOT TSpectrum class.





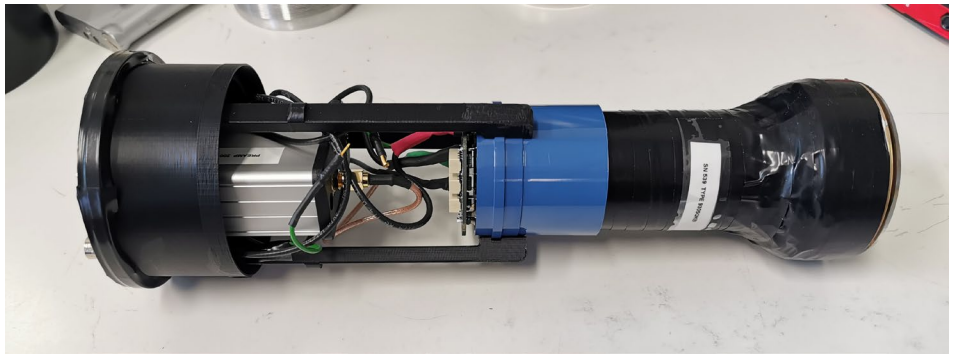


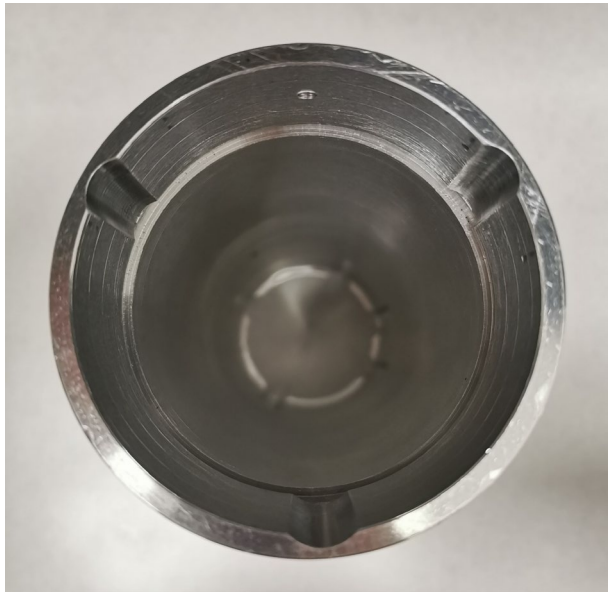




Design Modifications

Design Modifications

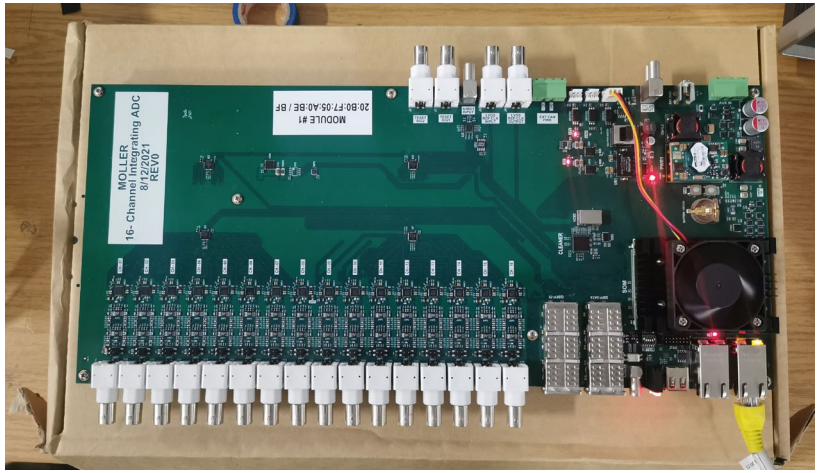


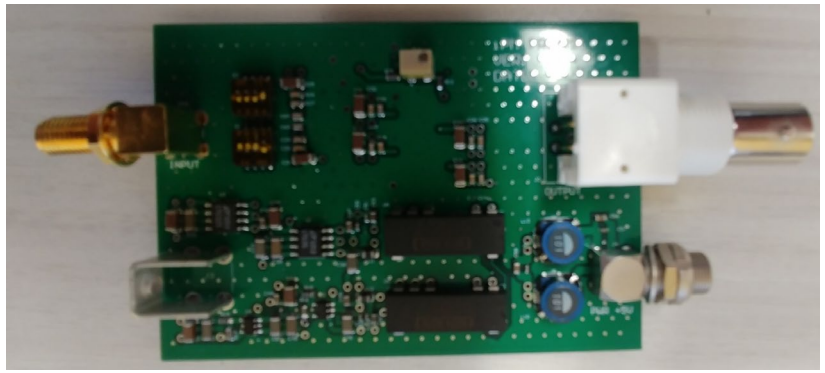


Beam Test – May 2022

May 2022 Beam Test

- Full 16 channel ADC
- Integration Mode and Event Mode with Rings 5 and 6 individually and together
- Solved a major noise source in preamplifier
- Compared Miro-Silver and UVS light guide materials
- Preliminary results: photoelectron numbers on par with simulation



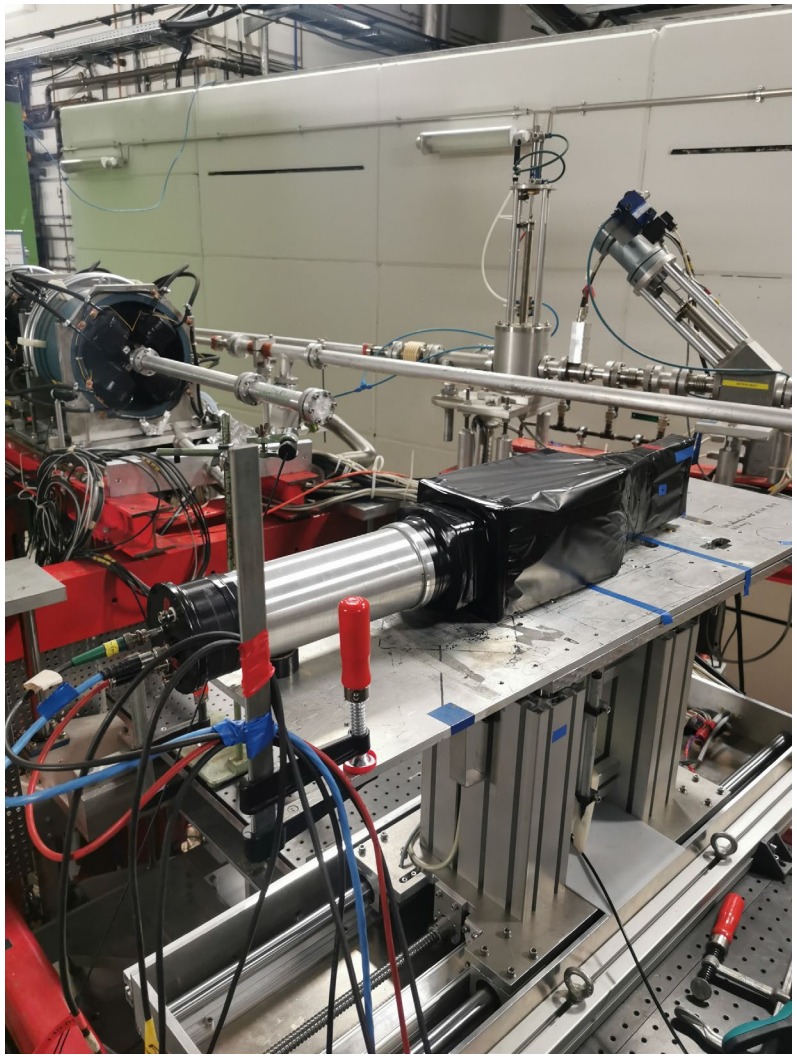


Future Plans

- Analyze data for updated electronics

- Complete simulations and design for other rings
- Develop prototypes for other rings

- Combining all detector designs for full segment beam test in Fall 2022



Thank You