

The Main Detector System for the MOLLER Experiment

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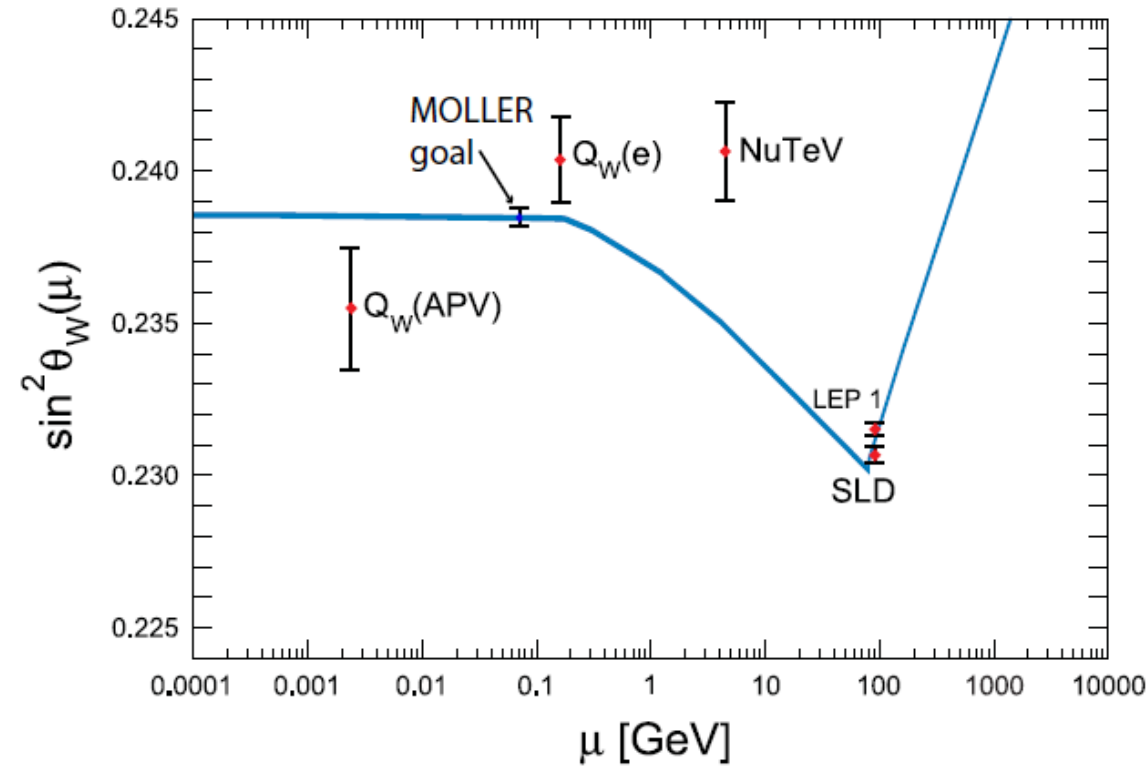
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The MOLLER Collaboration



- Motivation
- MOLLER Overview
- Main Detector Array
- Electronics
- Radiation Testing





- The weak mixing angle is a central parameter in electroweak sector of SM
- MOLLER** will determine $\sin^2 \theta_W$ at average $Q^2 = 0.0056 \text{ GeV}^2$ using **parity violating electron scattering**:

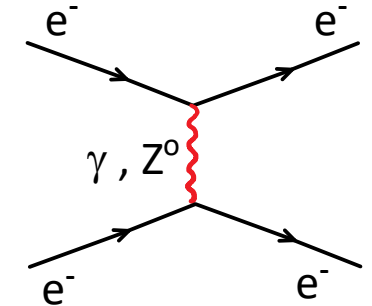
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = m_e E \frac{G_F}{\pi \alpha \sqrt{2}} \frac{4 \sin^2 \theta}{(3 + \cos^2 \theta)^2} Q_W^e$$

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

A_{PV} predicted to be $\approx 33 \text{ ppb}$

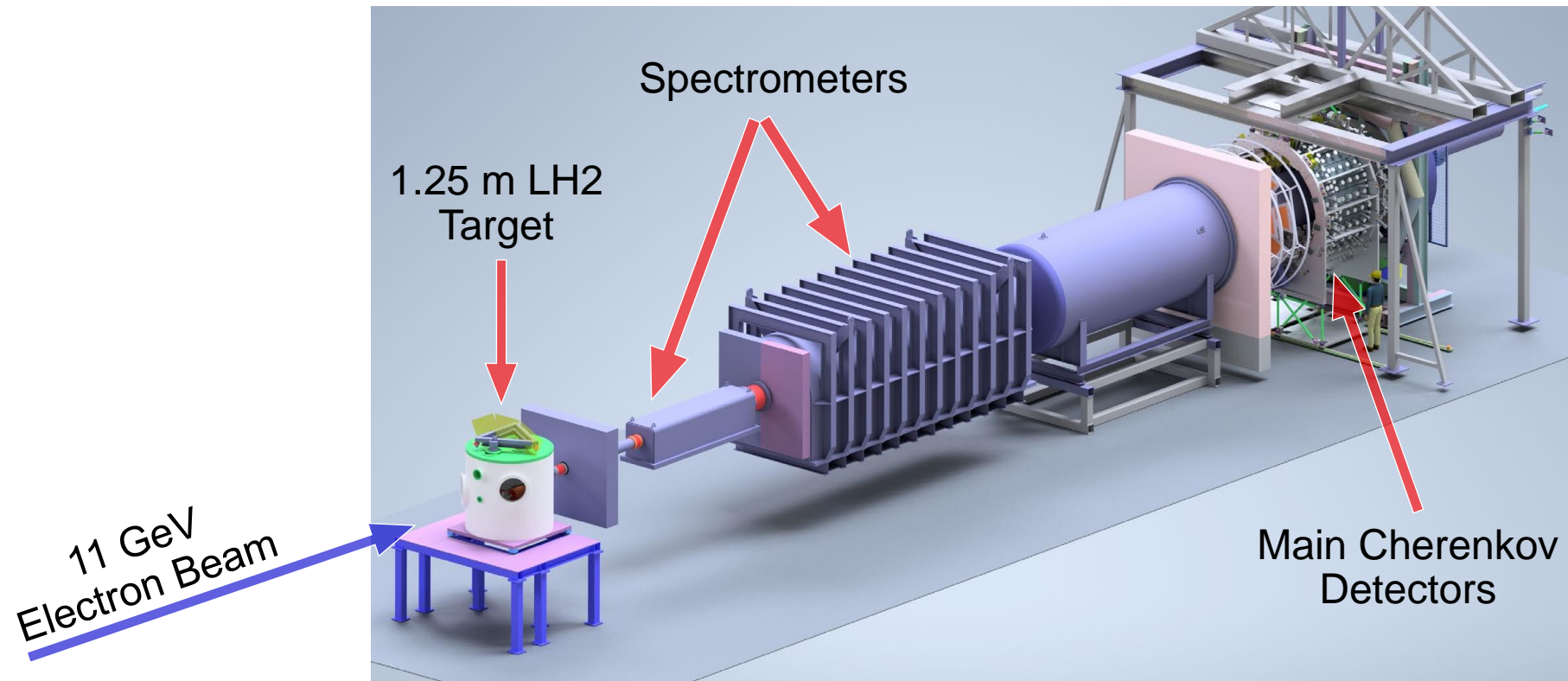
MOLLER Goal:

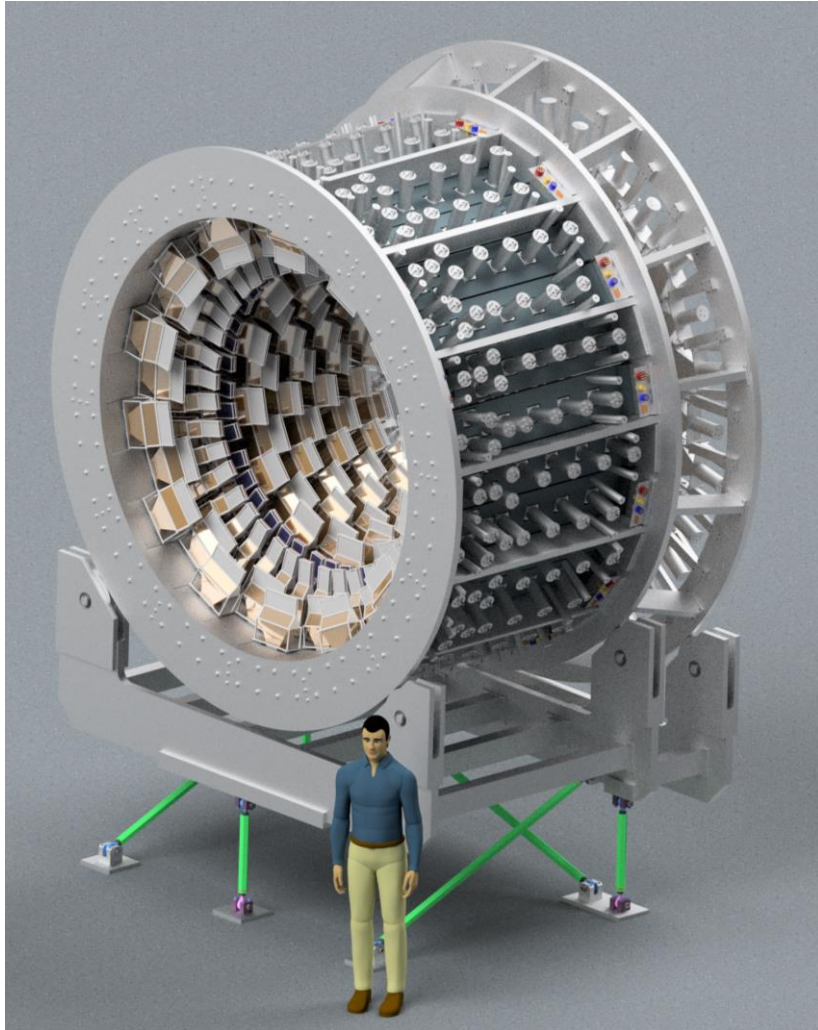
$$\delta A_{PV} = 0.8 \text{ ppb} \quad \Rightarrow \quad \Delta Q_W^e = 2.4\% \quad \Rightarrow \quad \Delta \sin^2 \theta_W = 0.1\%$$



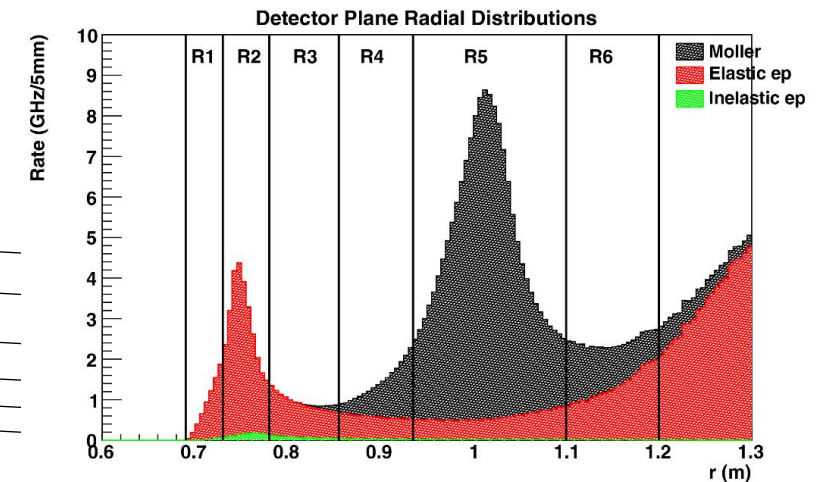
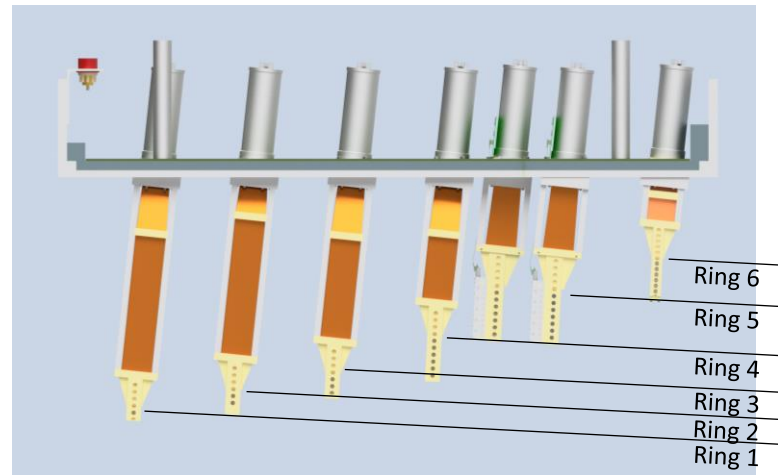
The MOLLER Experiment

- 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

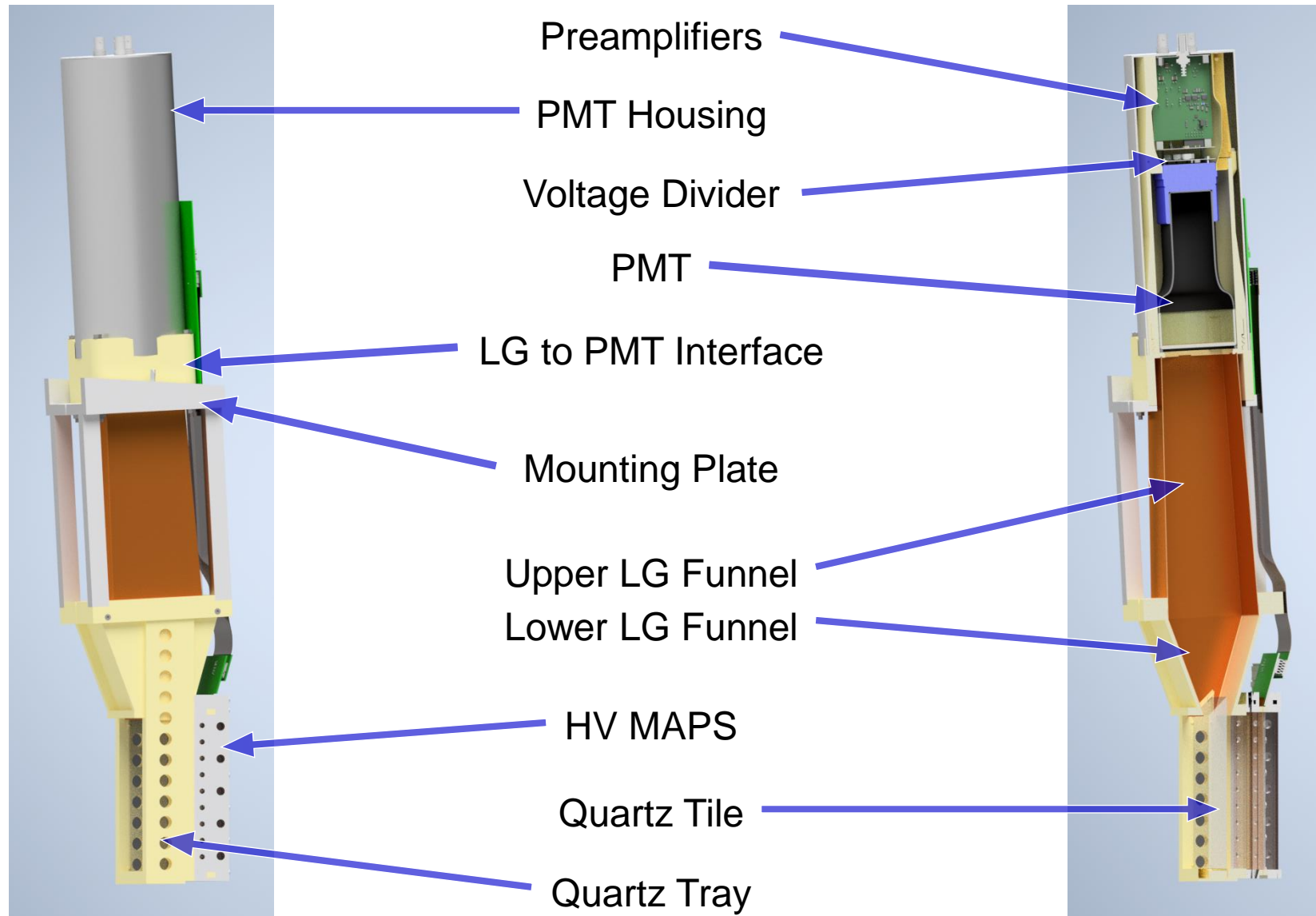




- 224 Detectors
 - Radially split into 6 Rings
 - Azimuthally split into 28 Segments
- Located 26.5 m downstream from target
 - Sufficient space for spectrometers to separate e-e and e-p peaks
- Full coverage of Møller events
- Integration and counting mode data collection



Ring 5 Module



Switchable PMT base for two different running modes

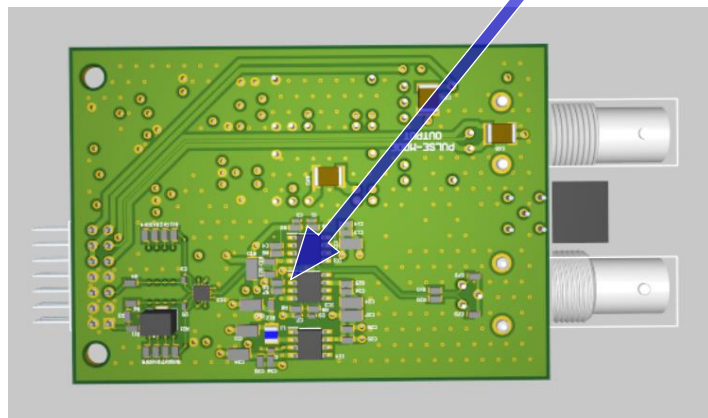
Counting Mode: higher gain, tracking and diagnostics

Integration Mode: lower gain, asymmetry measurements

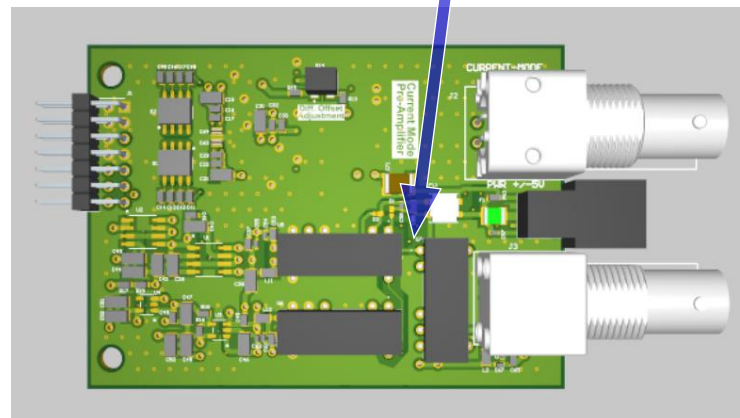
Expected absorbed dose in front-end electronics region:
60 krad

Designed by Jie Pan

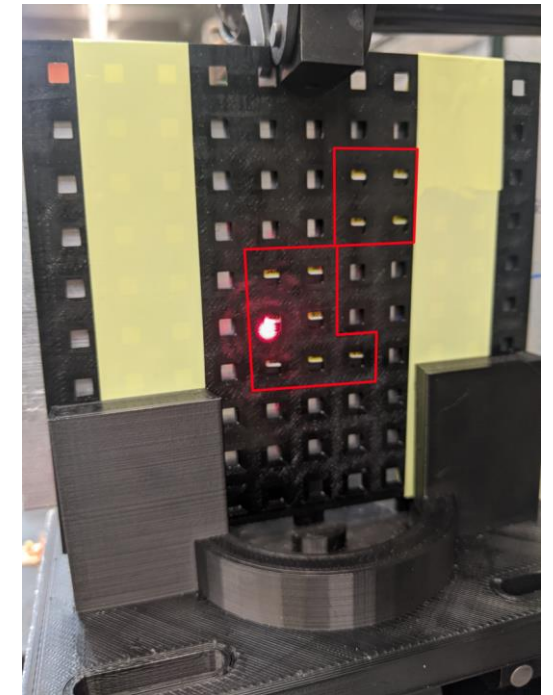
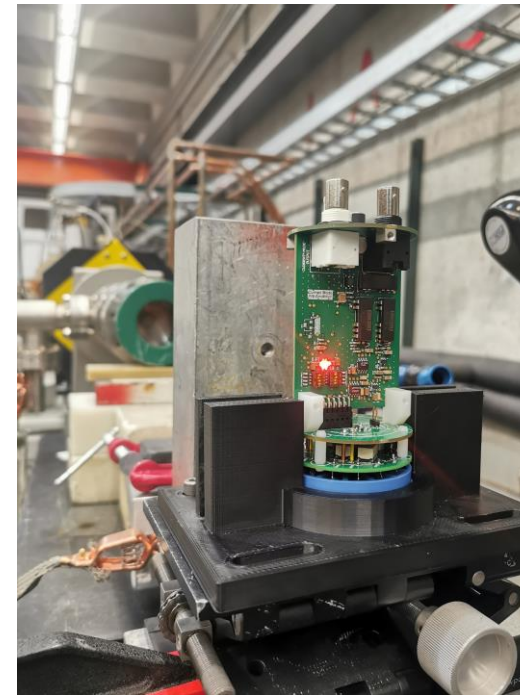
Op Amps



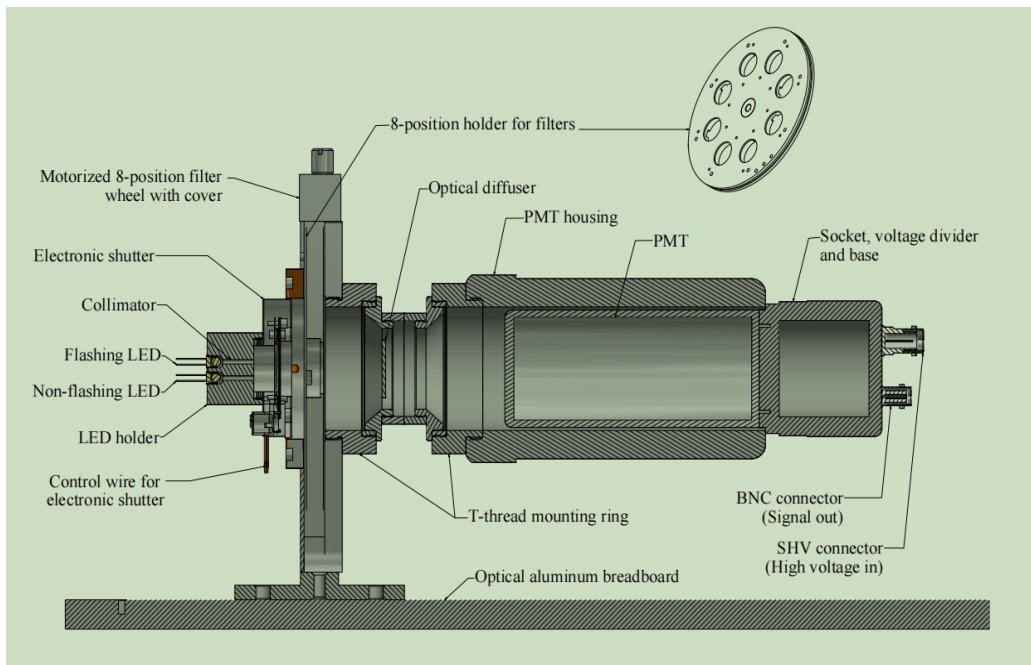
DC-DC Converters



- **Idaho Accelerator Center** in Pocatello, Idaho with the **ISU group**
 - 8 MeV pulsed electron beam, 10 mA peak current, 100 ns pulse width
 - ~1 nC/pulse
- Used collimators to localize beam dose on specific electronic chips
- Beam dose/pulse profile measured using Optically Stimulated Luminescence dosimeters
 - Each ~1 cm²
 - Placed into 3D printed tray to mimic electronic chip locations on preamplifier
- Laser used to align components in beam
- Used OSL measurements, conversion factor, and charge data to calculate dose on chips
 - ~75% dose in OSL received in chips



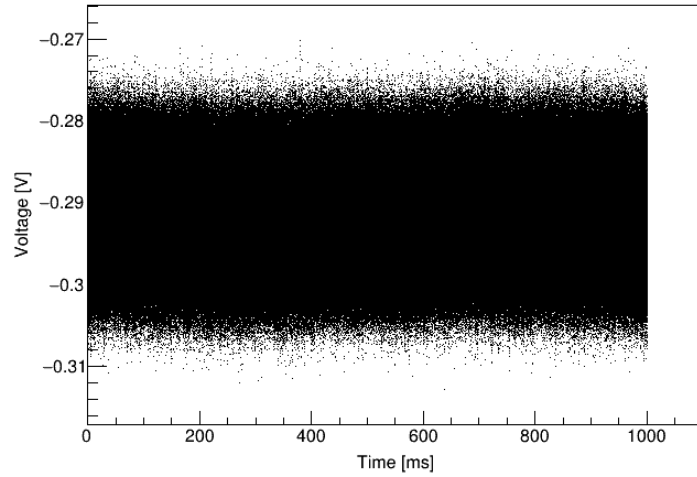
- Tested functionality between doses using 16 channel MOLLER ADC board
- Exposed PMT to set of light levels (producing 2, 5, 20, 27 nA) using constant LED and with LED off and HV off



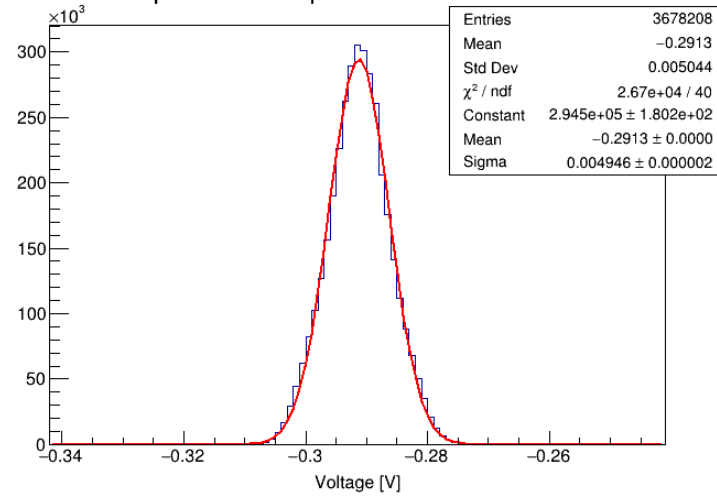
PMT Base 1 Op Amps	Dose [krad]	Total Dose [krad]
Run 0 *	106	106
Run 1	106	212
Run 2	210	422
Run 3	210	632
Run 4	106	739
Run 5	106	845
Run 6	106	950
Run 7	318	1,270
Run 8	106	1,480
Run 9	210	1,586

Operational Amplifier Dosing

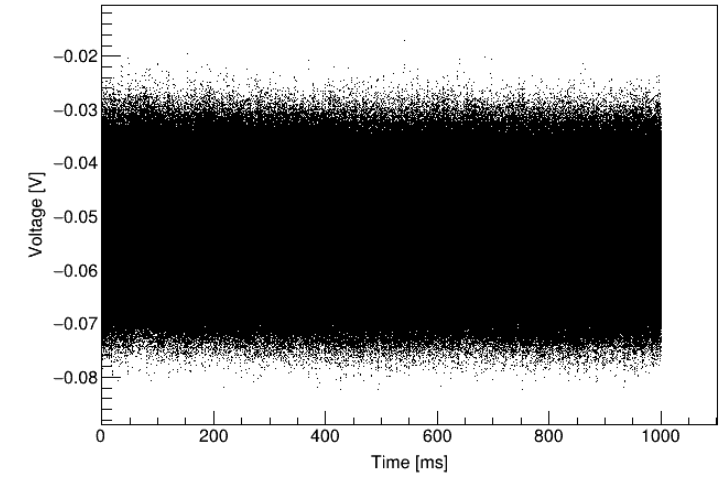
Operational Amplifier 106 krad: LED Off



Operational Amplifier 106 krad: LED Off

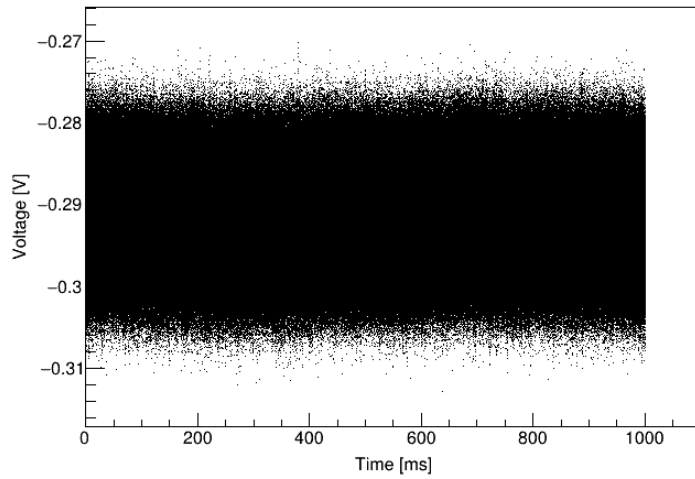


Operational Amplifier 106 krad: 2 nA

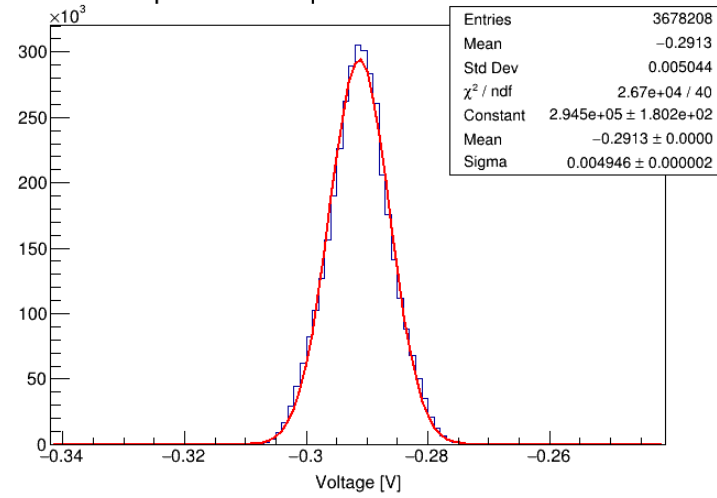


Operational Amplifier Dosing

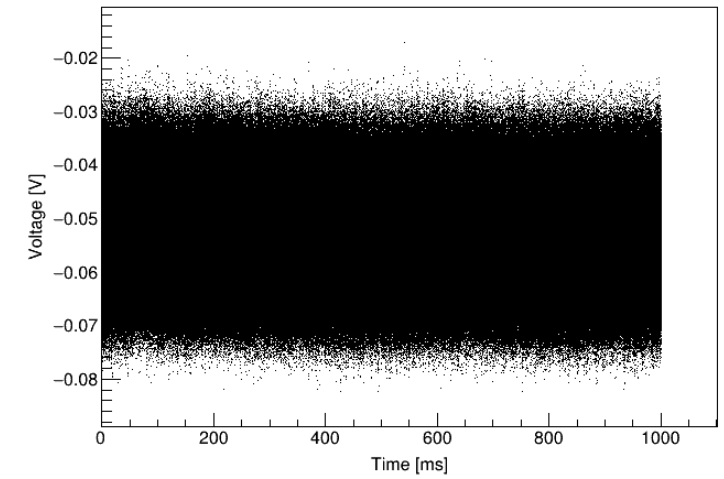
Operational Amplifier 106 krad: LED Off



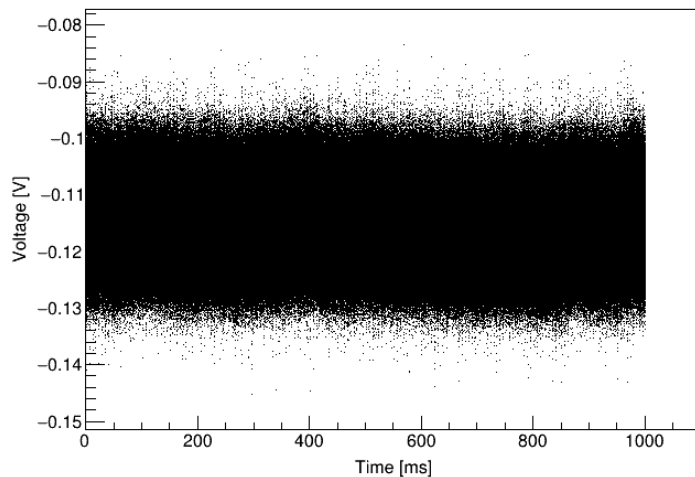
Operational Amplifier 106 krad: LED Off



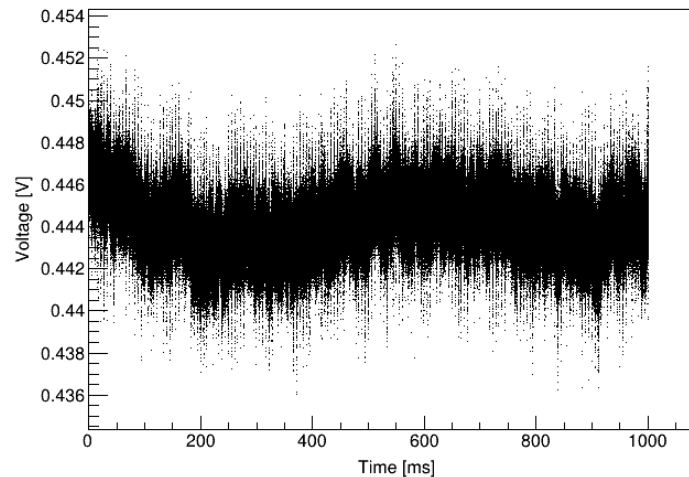
Operational Amplifier 106 krad: 2 nA



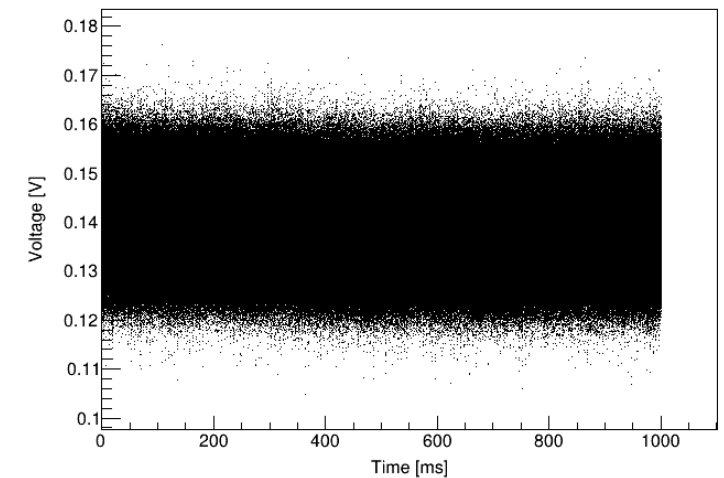
Operational Amplifier 1270 krad: LED Off



Operational Amplifier 1270 krad: HV Off

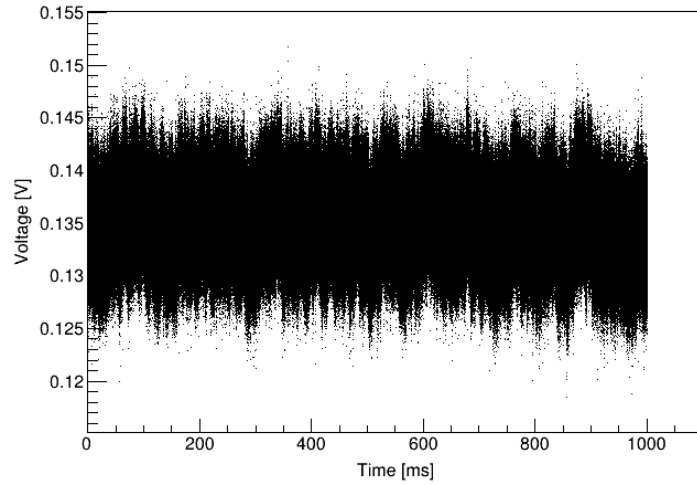


Operational Amplifier 1270 krad: 2 nA

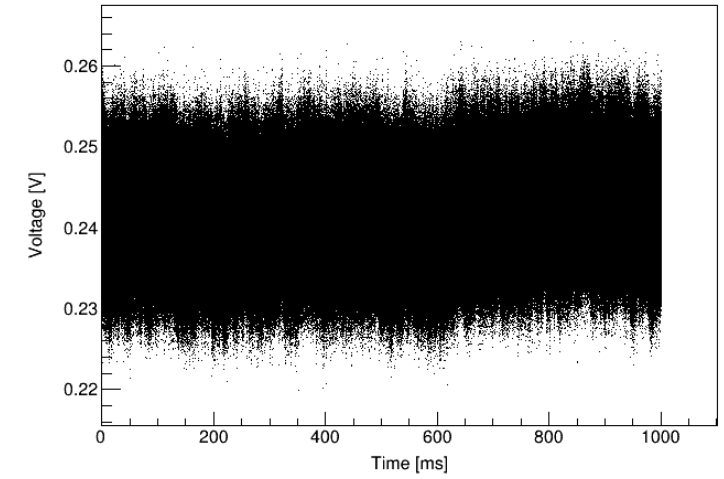


Operational Amplifier Dosing

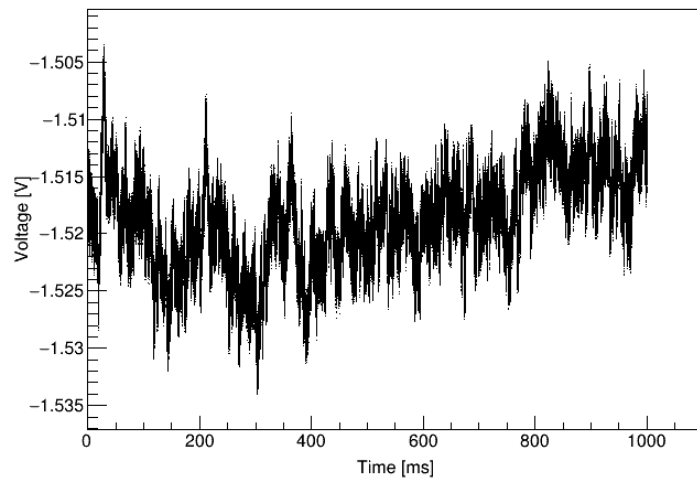
Operational Amplifier 1480 krad: LED Off



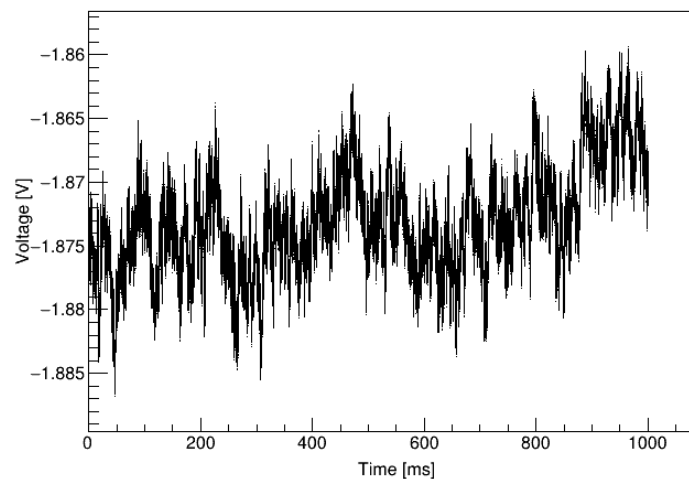
Operational Amplifier 1480 krad: 2 nA



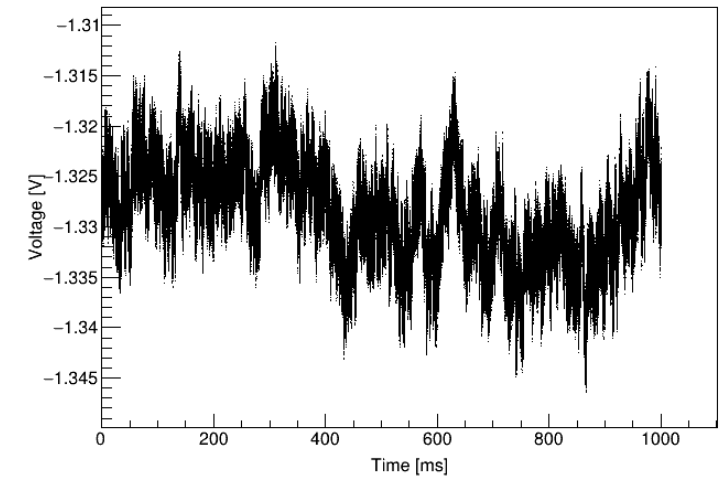
Operational Amplifier 1586 krad: LED Off



Operational Amplifier 1586 krad: HV Off

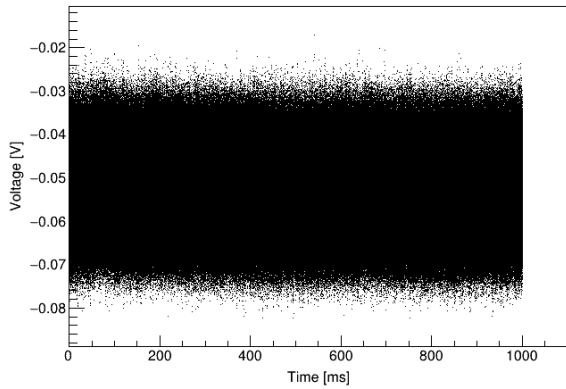


Operational Amplifier 1586 krad: 2 nA

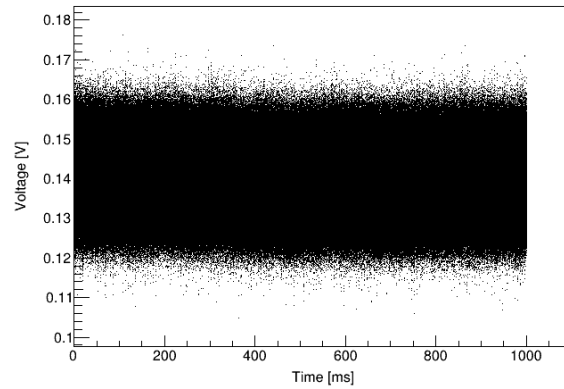


Operational Amplifier Dosing

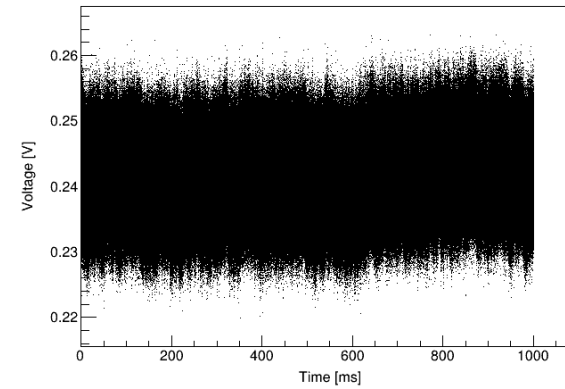
Operational Amplifier 106 krad: 2 nA



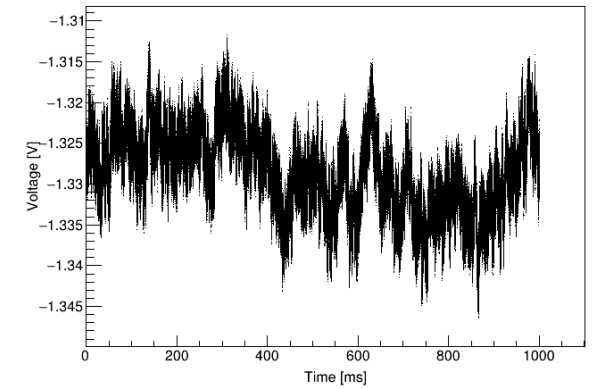
Operational Amplifier 1270 krad: 2 nA



Operational Amplifier 1480 krad: 2 nA

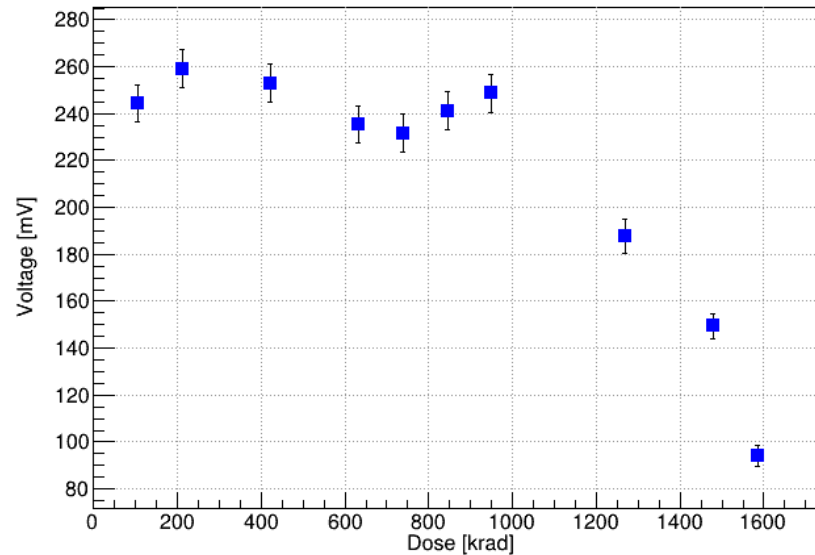


Operational Amplifier 1586 krad: 2 nA

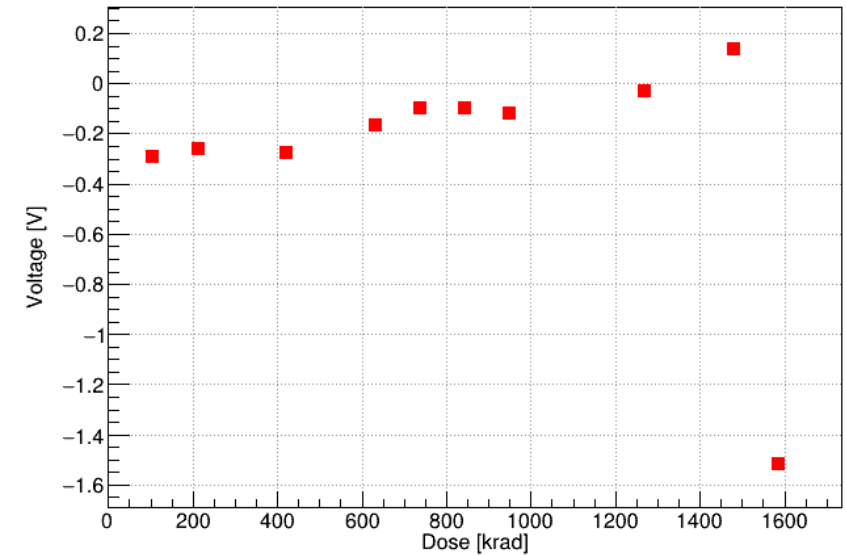


- Started to fail <1270 krad
- Noticeable gain loss and offset shift
- 60% voltage drop in 2 nA by 1586 krad
- Sufficiently radiation hard for MOLLER

Voltage Drop for 2 nA



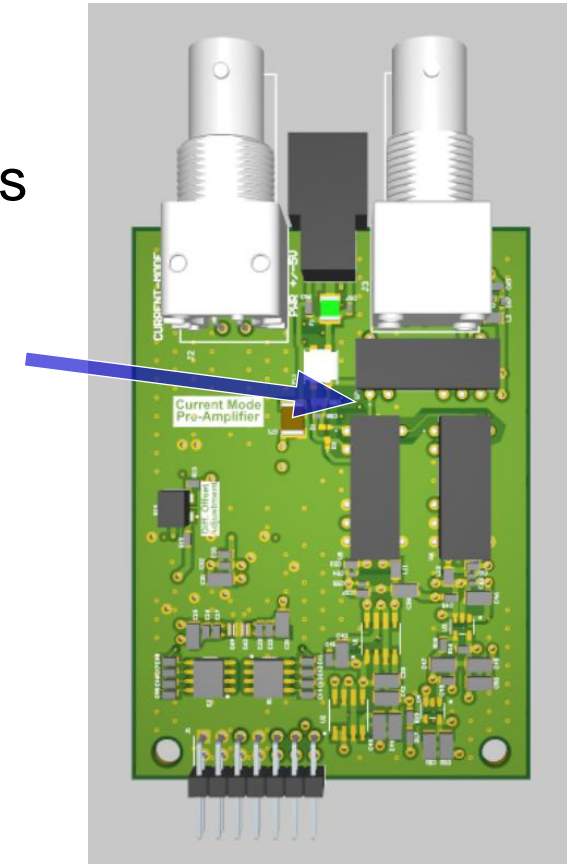
Voltage with LED Off



- Applied LV power to preamplifier after initial dose
- Immediate increase in current draw
- Chips became extremely hot
- Repeated dosing on previous PMT base with smaller increments
 - Failure between 50 – 100 krad

PMT Base 2 DC-DC Converters	Dose [krad]	Total Dose [krad]
Run 1	206	206

PMT Base 1 DC-DC Converters	Dose [krad]	Total Dose [krad]
Run 1	10.5	10.5
Run 2	42	52
Run 3	53	104



- MOLLER main detector array design nearly complete
- Radiation testing of detector electronics underway
- Integration mode amplifiers sufficiently radiation hard

- Require further testing of DC-DC converters and other radiation sensitive components
- Possible updates to integrated PMT base

- Plans to install MOLLER in 2025
- Commissioning start of 2026



Thank You

with massive thanks to the ISU group