SiPM Stability Tests

Lucas Darroch for the nEXO collaboration
Virtual Presentation
WNPPC 2022
February 18

- Neutrino Osc. $\Rightarrow \ m_\nu \neq 0$
- Dirac mass $\Rightarrow \ \nu_R$

Dirac mass term for neutrino:

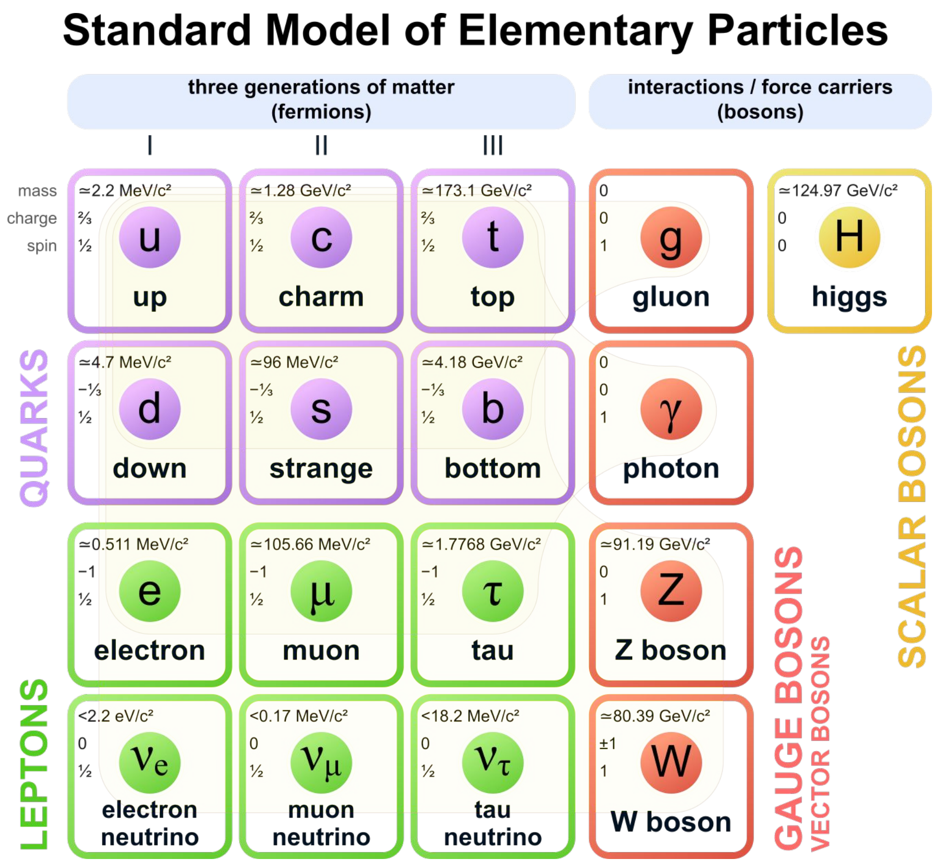
$$L_D = -m_D(\bar{\nu}_R \nu_L + \bar{\nu}_L \nu_R)$$

Why is the Dirac mass so small?

Majorana mass term for neutrino:

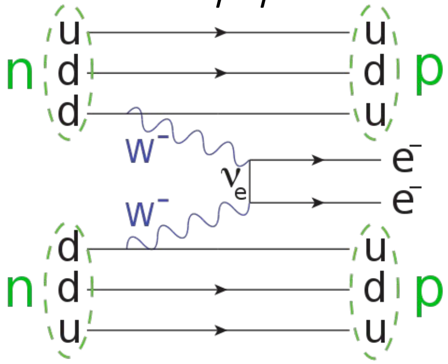
$$L_M = -\frac{1}{2} M (\bar{\nu}_R^C \nu_R + \bar{\nu}_R \nu_R^C)$$

$$\Psi^C = \hat{C}\hat{P}\Psi \ = \ i\gamma^2\gamma^0\Psi^\star$$

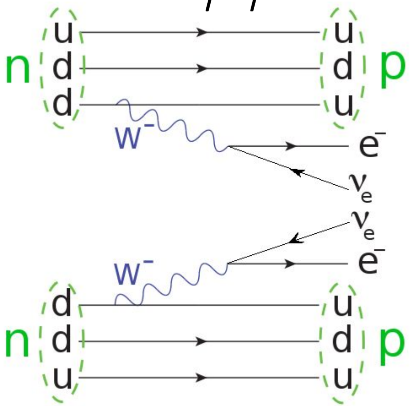


- $0\nu\beta\beta \Rightarrow \nu$: Majorana particle
- $2\nu\beta\beta$ SM process

$0\nu\beta\beta$



$2\nu\beta\beta$



$\beta\beta$ - Decay Spectrum

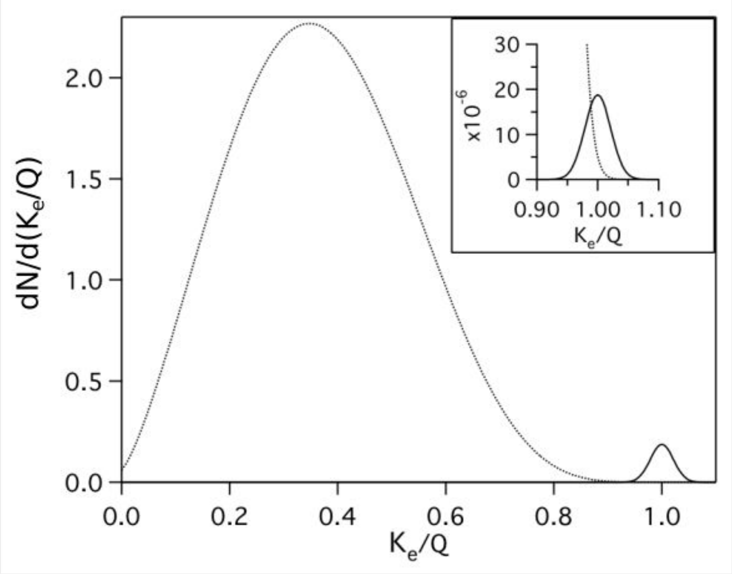
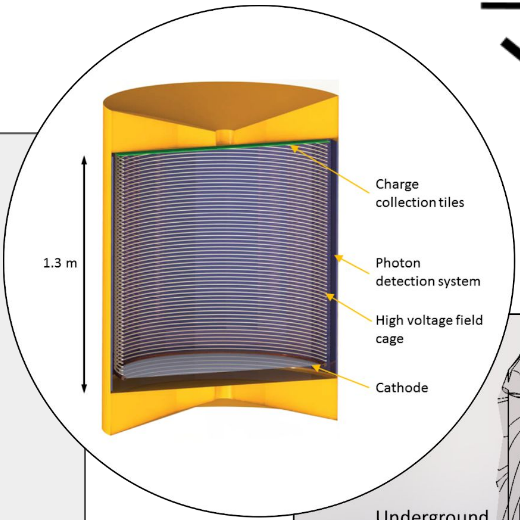


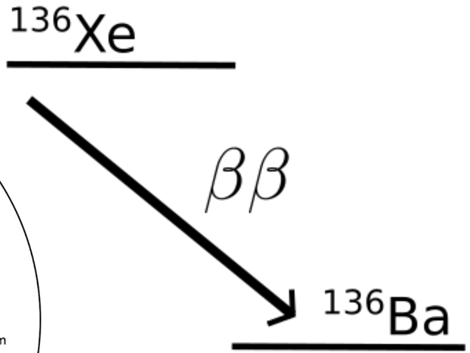
Image from Vogel, Petr. "Neutrinoless double beta decay." *AIP Conference Proceedings*. Vol. 870. No. 1. AIP, 2006.

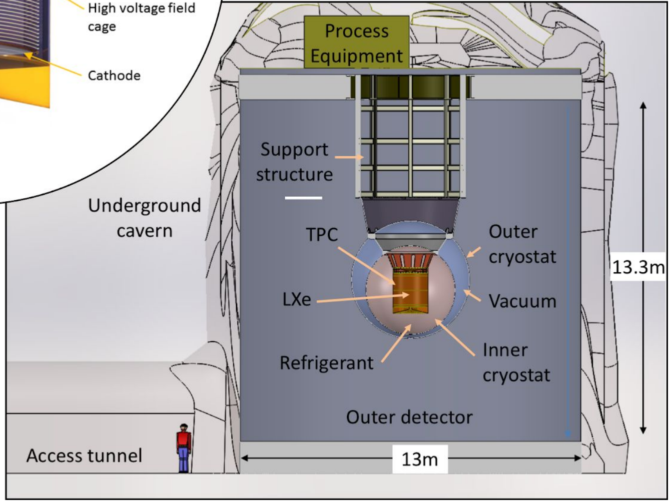
- 2vββ spectrum continuous;
- 0vββ spectrum sharply peaked

nEXO

- Single phase TPC
- 5 tonnes LXe, 90% ^{136}Xe
- Ionization and scintillation signals recorded
- Sensitivity ~10^{28} years for 0νββ half-life[1]







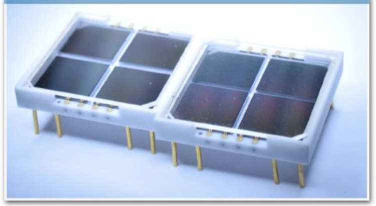
[1] Adhikari, G., et al. "nEXO: neutrinoless double beta decay search beyond 1028 year half-life sensitivity." *Journal of Physics G: Nuclear and Particle Physics* 49.1 (2021): 015104.

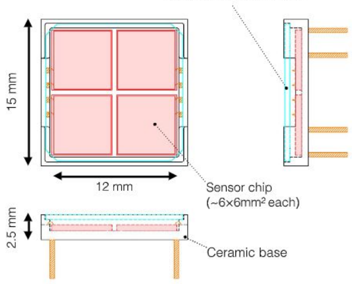
Images from Al Kharusi, S. et al. "nEXO pre-conceptual design report." *arXiv preprint arXiv:1805.11142* (2018).

Liquid Xenon Photon Detector with Highly Granular Scintillation Readout for MEG II Experiment

W. Ootani ICEPP, The University of Tokyo
on behalf of MEG II collaboration
Calorimetry for the High Energy Frontier (CHEF2019)
Nov. 25th-29th, 2019, Fukuoka, Japan

Hamamatsu S10943-4372





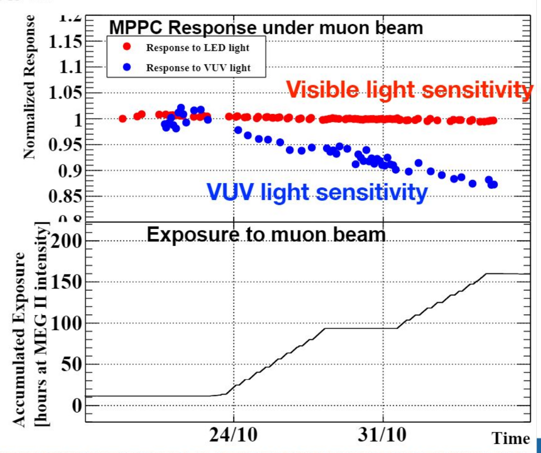
A Surprise…

- **Significant degradation of MPPC VUV-sensitivity!**
  - Seems correlated with beam ON/OFF
  - Large degradation for VUV-sensitivity (↔ slight degradation for visible light)
  - Degradation is quite fast: (~0.08%/hour)
  - We can't survive even for one year…
- **Can be a showstopper…**

Radiation	Dose (run2019)
Gamma	~10^{-2} Gy/sensor
Neutron	2.7×10^{6} n_{1MeV}/cm^2
VUV-light	~10^{14} photons/sensor

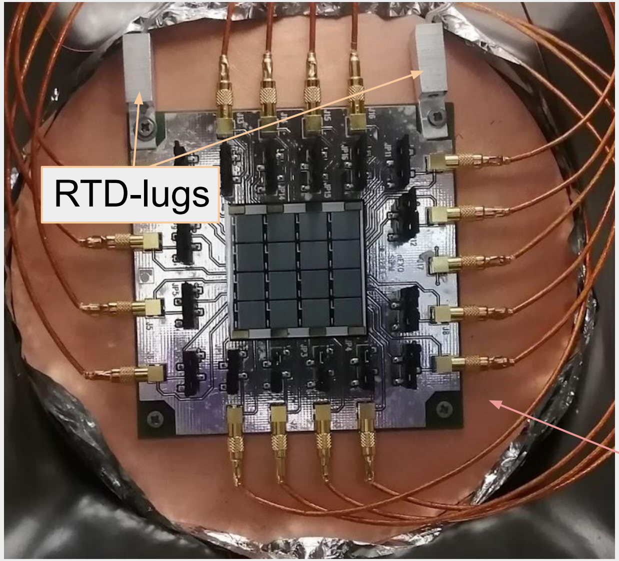
↓

Dose level is quite low

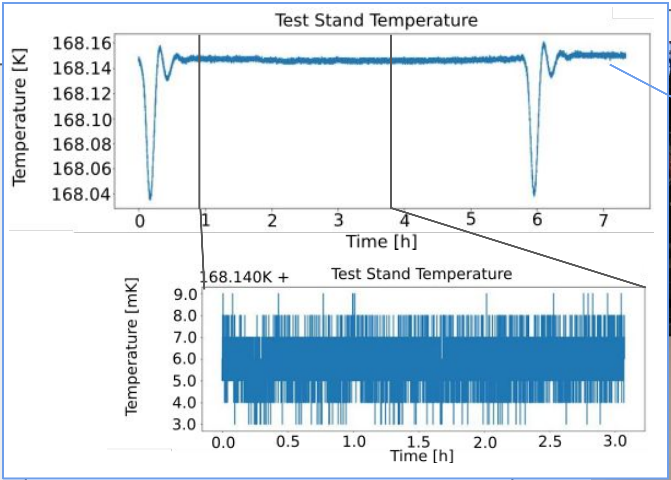


W.Ootani, "*Liquid Xenon Photon Detector with Highly* …" 14

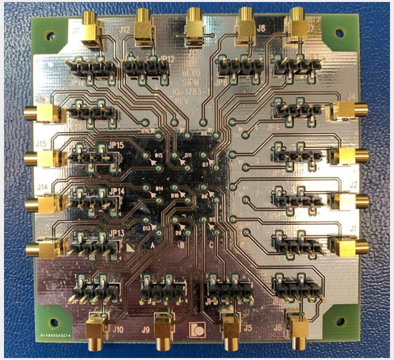
https://indico.cern.ch/event/818783/contributions/3598489/attachments/1950386/3237558/MEG_Ootani191125_compressed.pdf

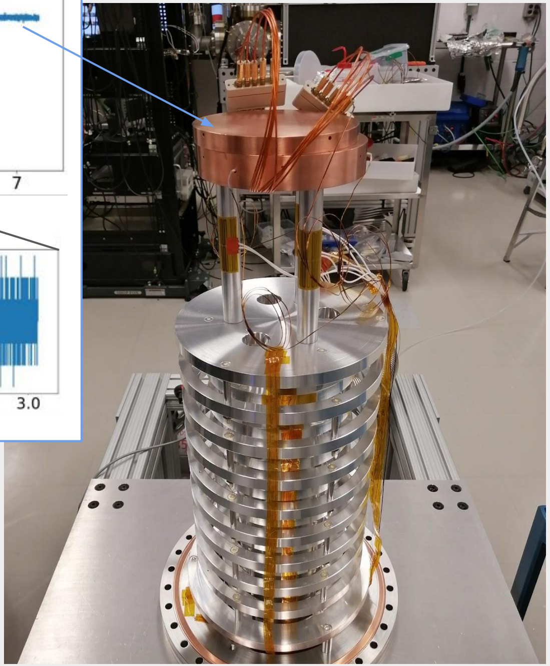


- HPK 4x4 mini tile (VUV4)
- RTD-lugs coupled to PCB



PCB designed at Brookhaven National Lab



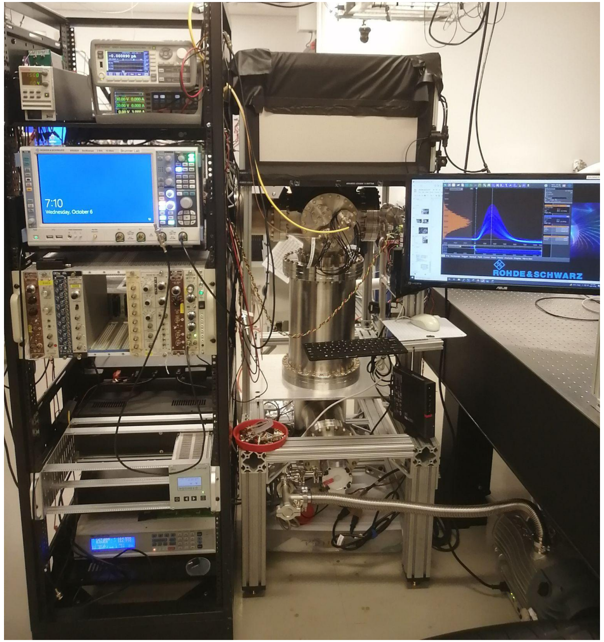


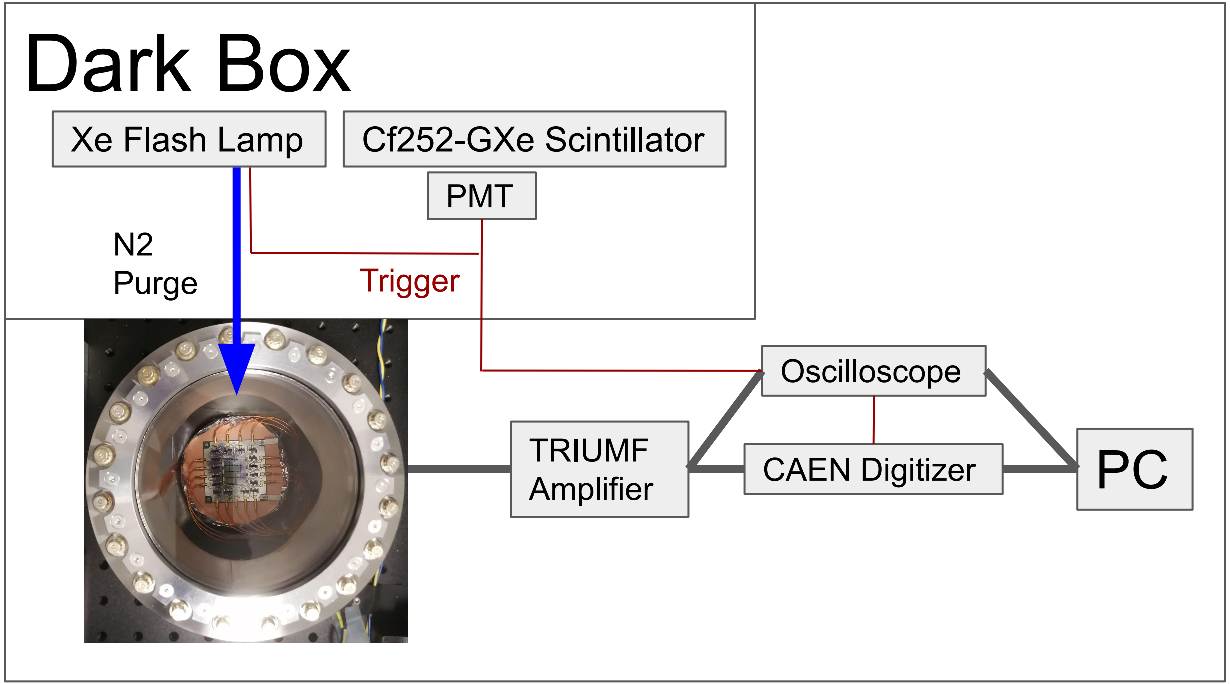
Environmental Test Stand (cryostat):

- Large surface area: A ~ 150 cm^2
- Stable operation: σ_T ~ 1 mK (3h)
- Demonstrated range: 120 - 295 K
- Turnaround time: T ~ 1 day

Characterization Measurements:

- Record scintillation spectrum from GXe excited by Cf252

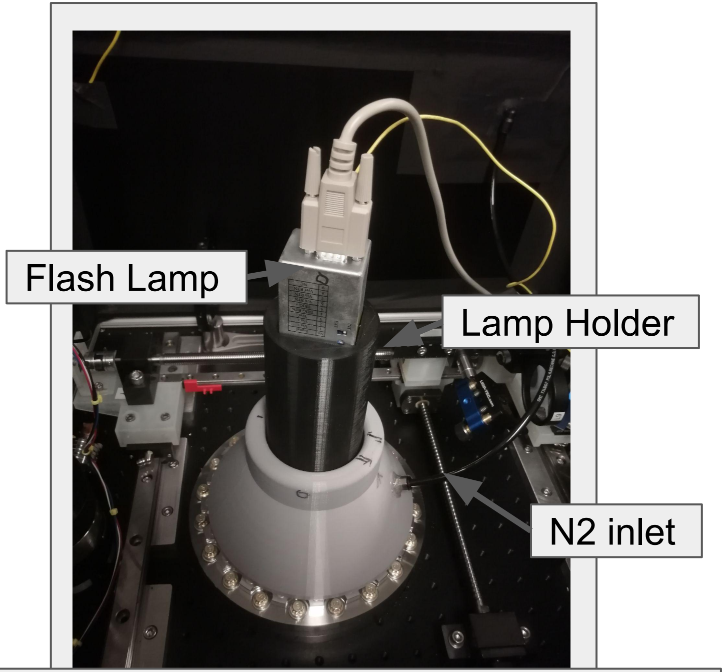




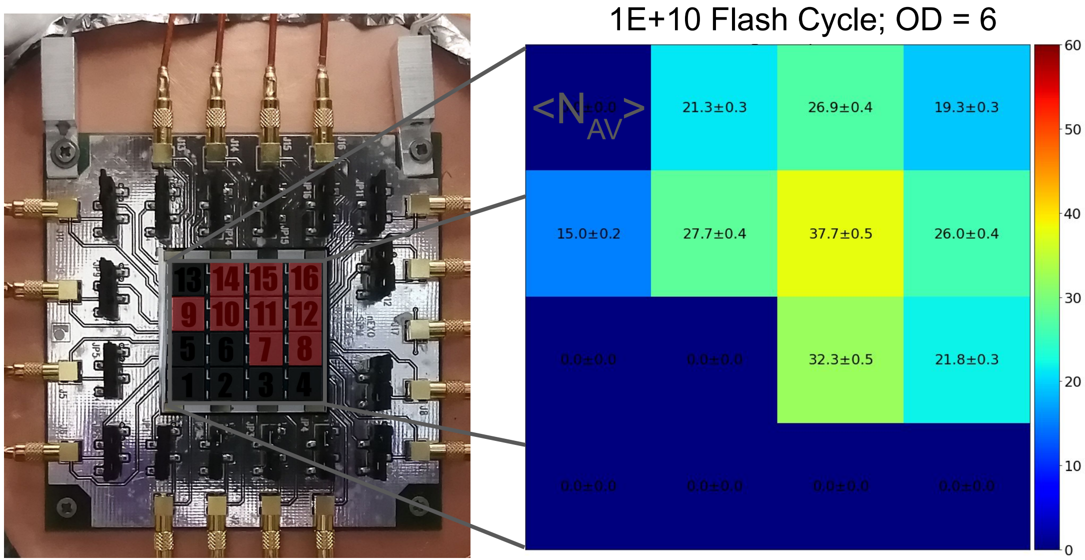
Procedure:

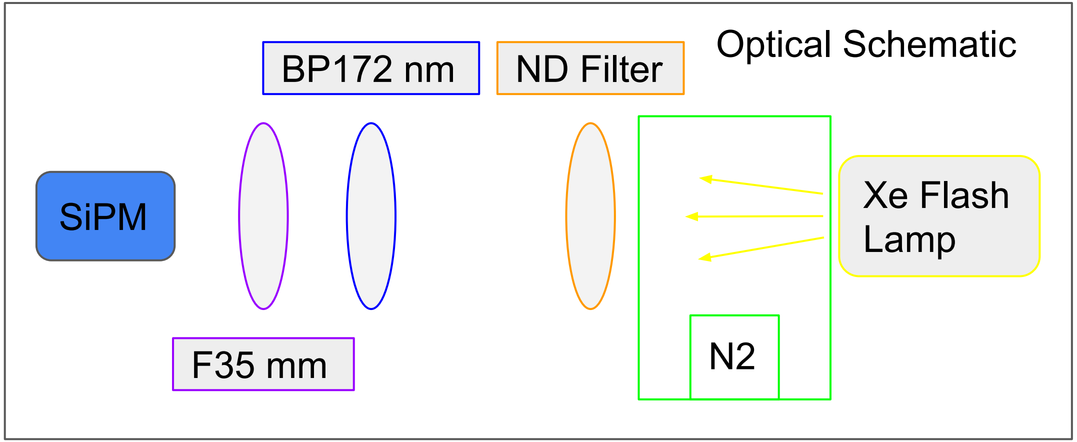
1. Characterization Measurements
2. Flashlamp lightmap
3. Flash 10^x photons (no bias on SiPM 12)
4. Return to step 1
5. When >> 10^14 /mm^2 photons flashed, anneal SiPM, return to step 1

Flash Lamp Lightmap



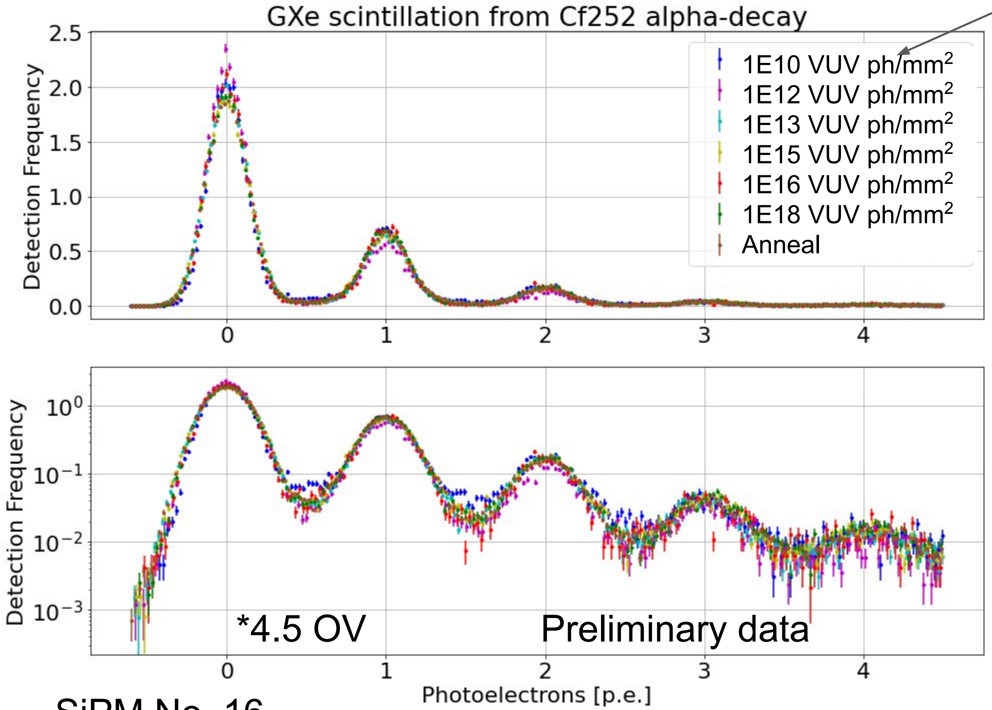
$$\langle N_{PH}\rangle = \langle N_{AV}\rangle \times 10^{(6-OD)} \div PDE$$





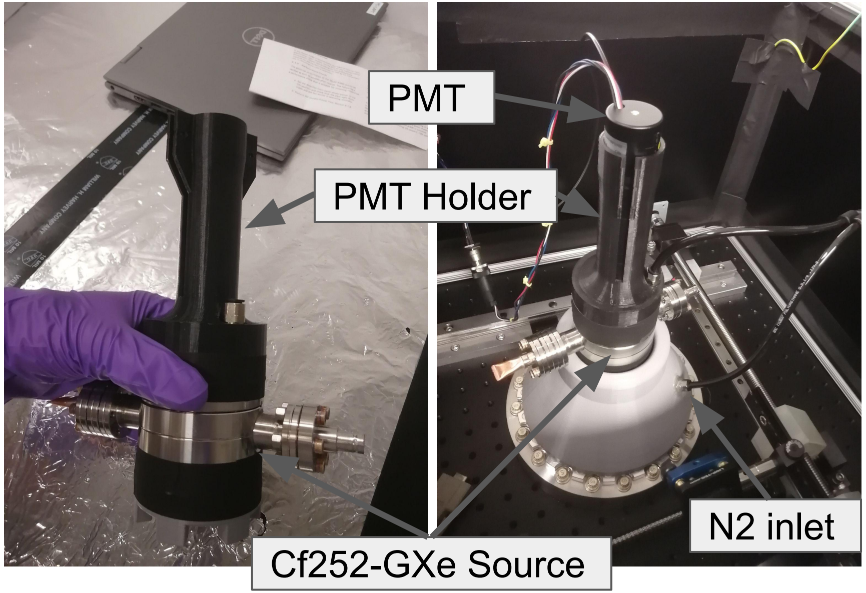
Cf252 Truncated Spectrum

$\langle N_{PH} \rangle = \langle N_{AV} \rangle \times 10^{(6-OD)} \div PDE$

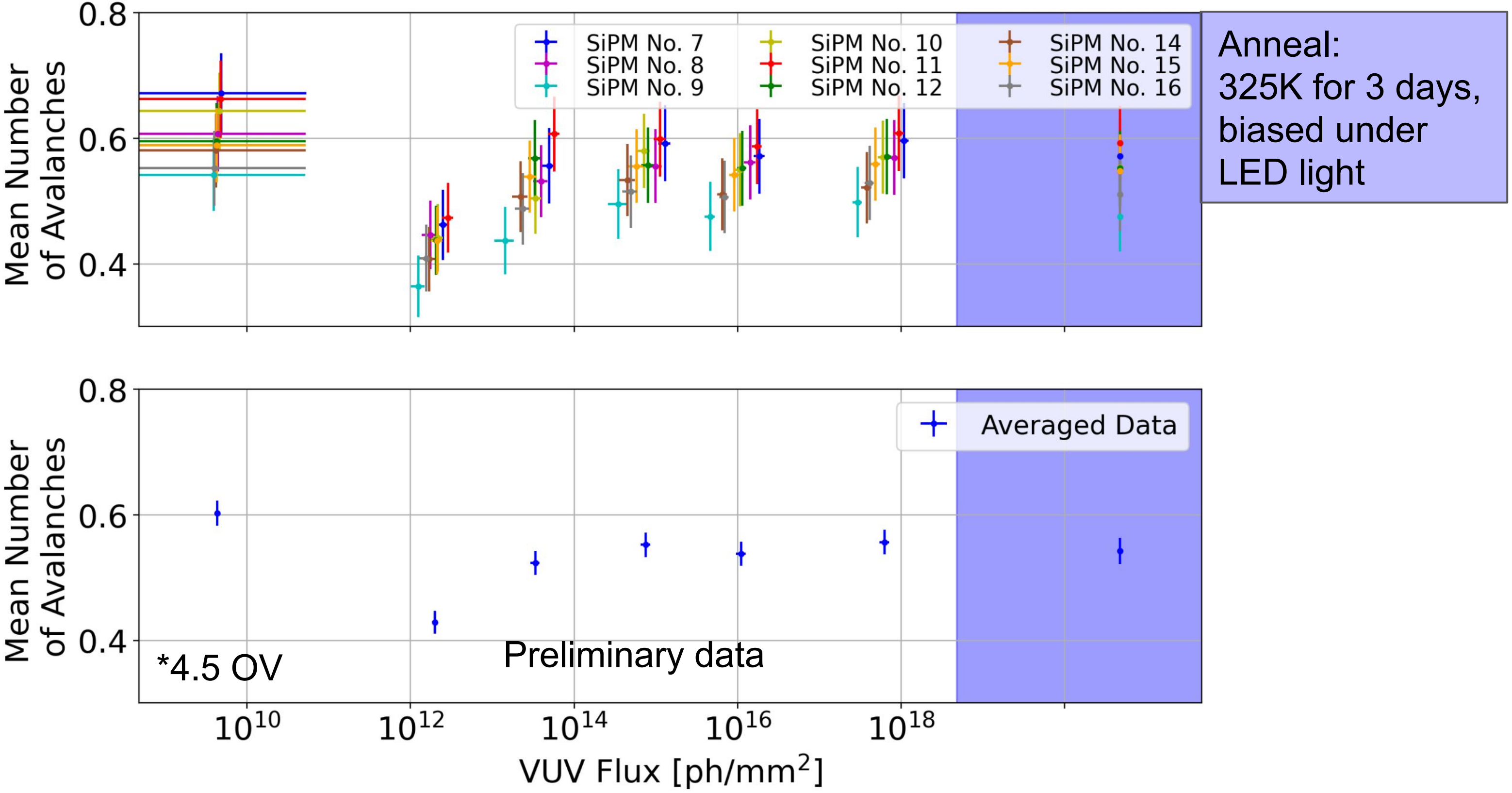


SiPM No. 16

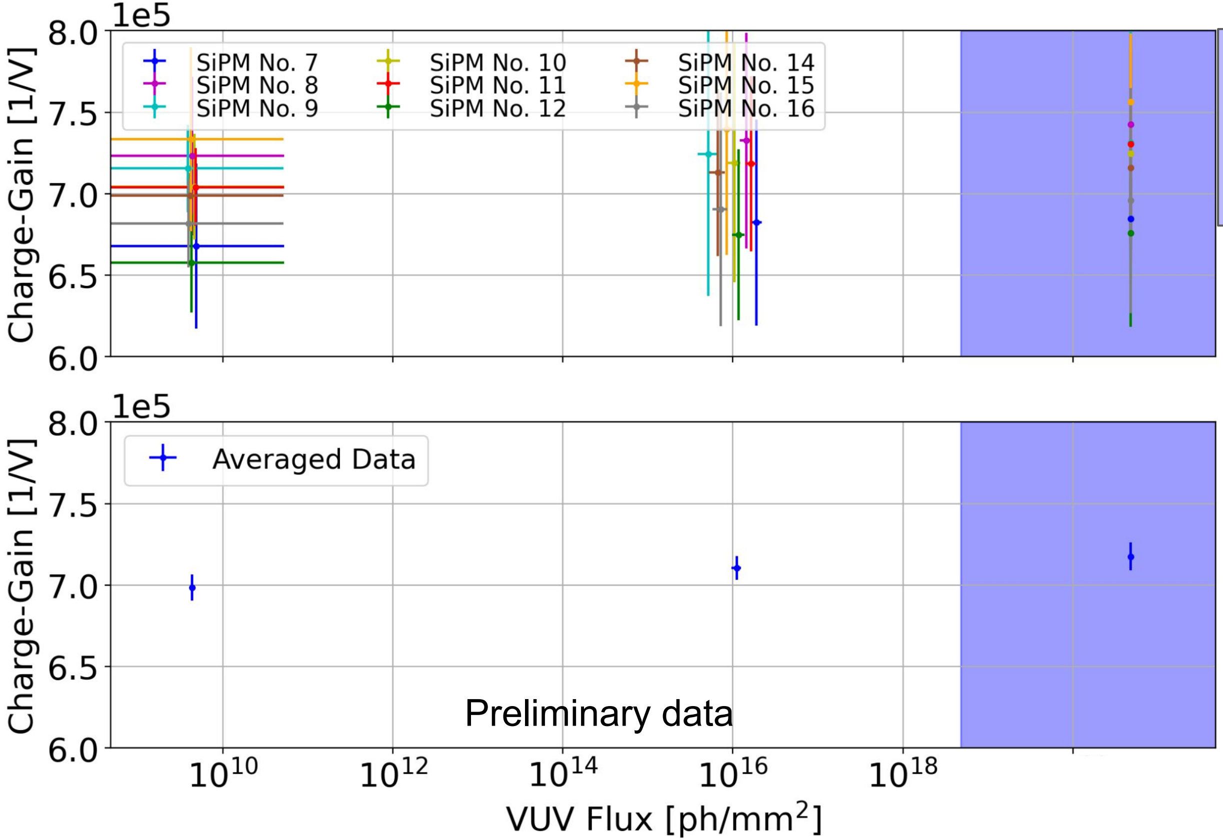
PMT used for coincidence trigger



Sensitivity to VUV Light

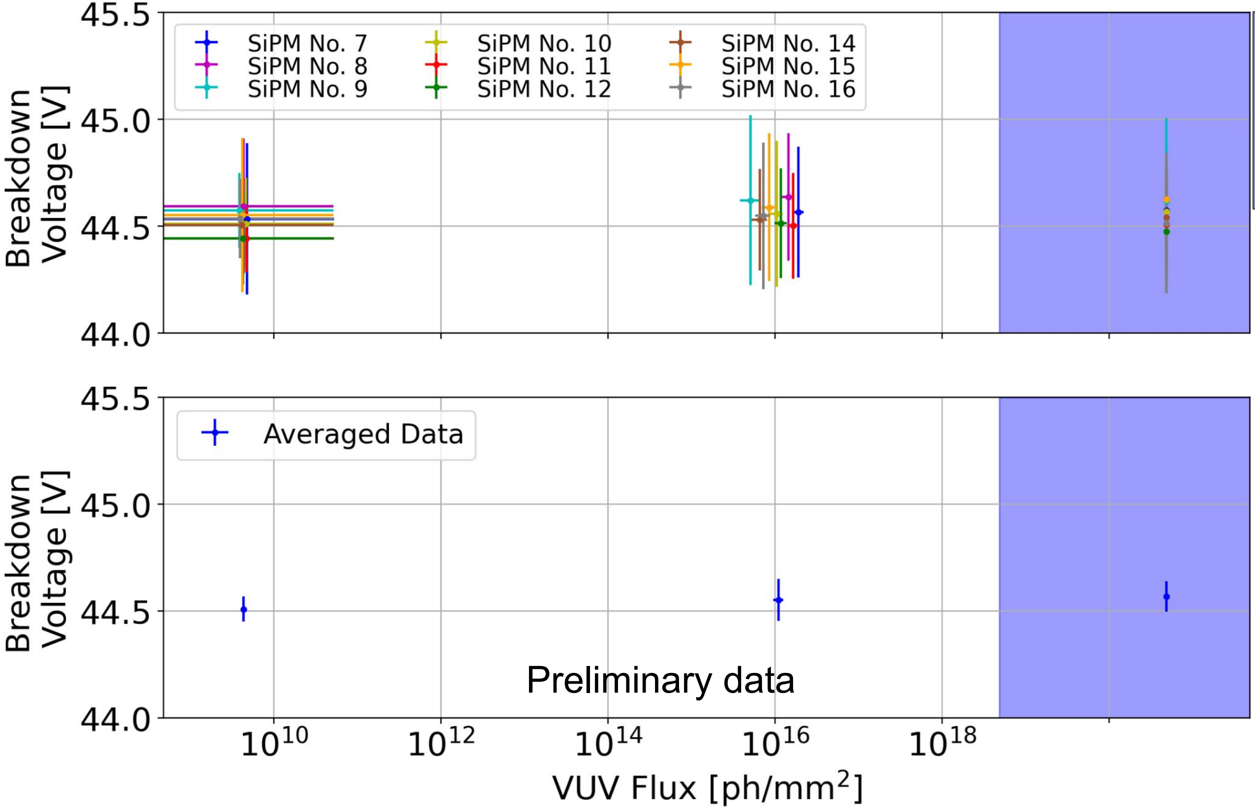


SiPM Gain



Anneal:
325K for 3 days,
biased under
LED light

Breakdown Voltage



Anneal:
325K for 3 days, biased under LED light

Conclusion

- HPK VUV4 have been tested under high density UV light
- No change observed for: PDE, Gain, Breakdown Voltage

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The nEXO Collaboration

Type 1 See-saw Mechanism

Seesaw mechanism helps make sense of light neutrinos:

$$m_\pm \approx \frac{1}{2}M \pm \frac{1}{2}\left(M + \frac{2m_D^2}{M}\right)$$

$$m_- \approx \frac{m_D^2}{M} \qquad m_+ \approx M$$

- Dirac mass for neutrino ~ GeV
- Majorana mass large ~ 10^{11} GeV
- Light neutrino state ~ 10 meV

Light neutrino state dominated by left(right)-handed chiral (anti)neutrino states; heavy neutrino state dominated by right(left)-handed chiral (anti)neutrino states.

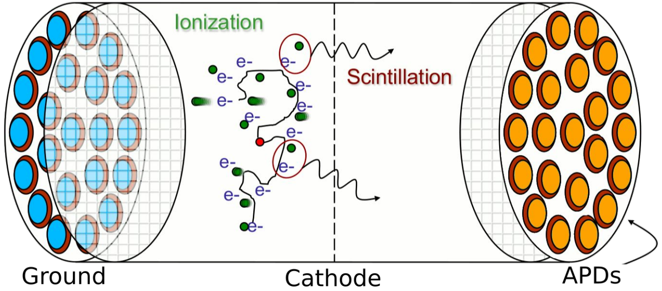
$$\nu_- \approx (\nu_L + \nu_L^c) - \frac{m_D}{M}(\nu_R + \nu_R^c)$$

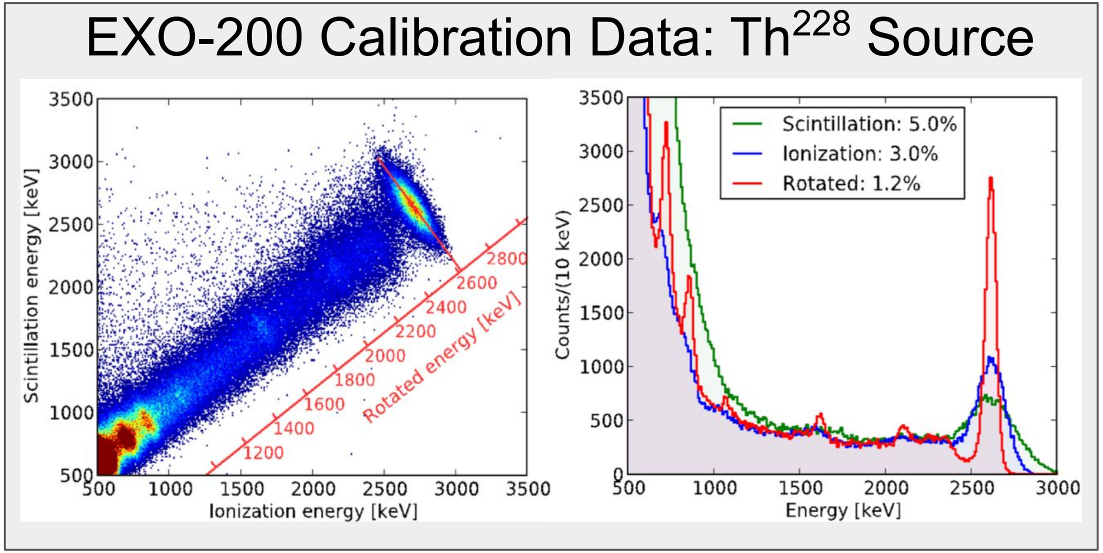
$$\nu_+ \approx (\nu_R + \nu_R^c) - \frac{m_D}{M}(\nu_L + \nu_L^c)$$

Mohapatra, R. N., et al. "Theory of neutrinos: a white paper." *Reports on Progress in Physics* 70.11 (2007): 1757.

Event reconstruction in LXe:

- Detection of scintillation and ionization signals
- Full energy reconstruction
- Full position reconstruction
- Event multiplicity

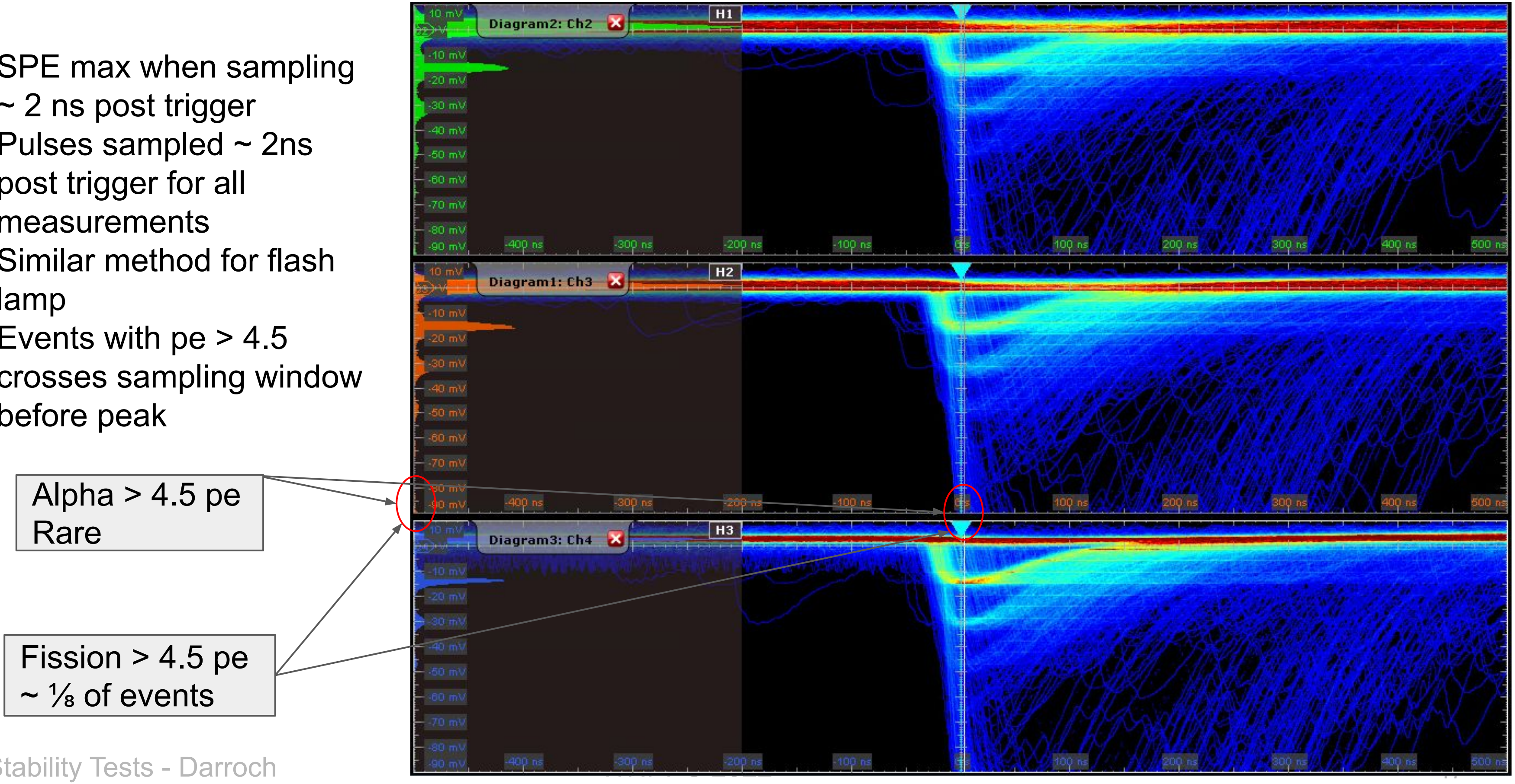




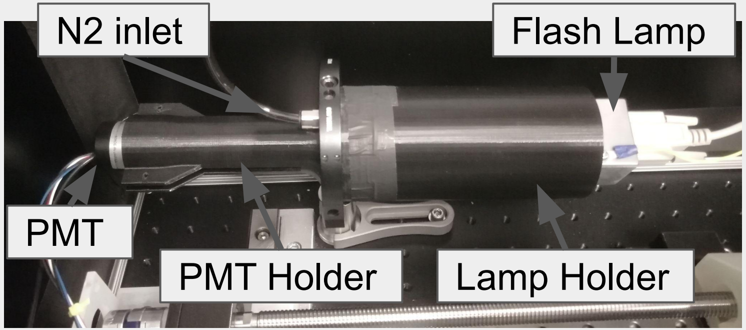
Images from Albert, J. B., et al. "Improved measurement of the 2νββ half-life of 136 Xe with the EXO-200 detector." *Physical Review C*89.1 (2014): 015502.

Amplitude Sampling

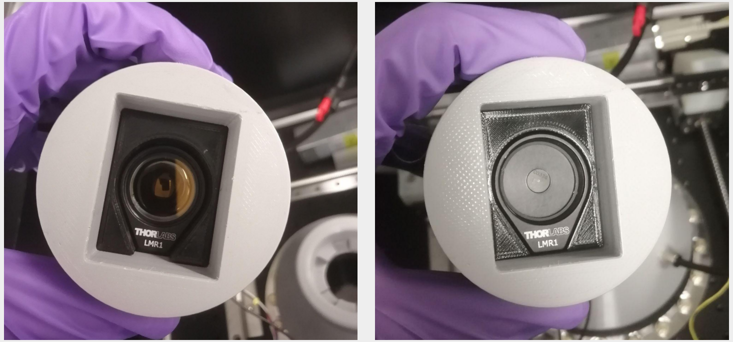
- SPE max when sampling ~ 2 ns post trigger
- Pulses sampled ~ 2ns post trigger for all measurements
- Similar method for flash lamp
- Events with pe > 4.5 crosses sampling window before peak



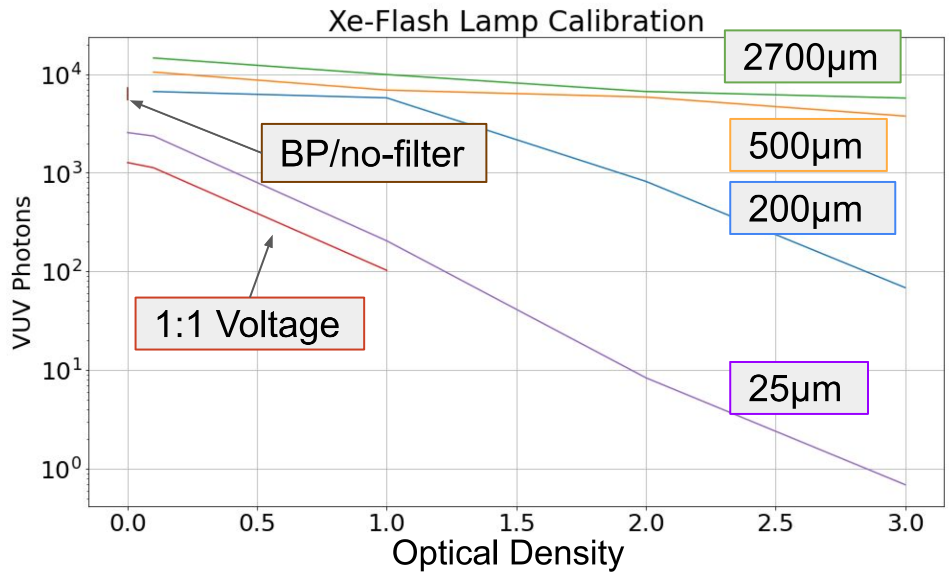
Filter Calibration

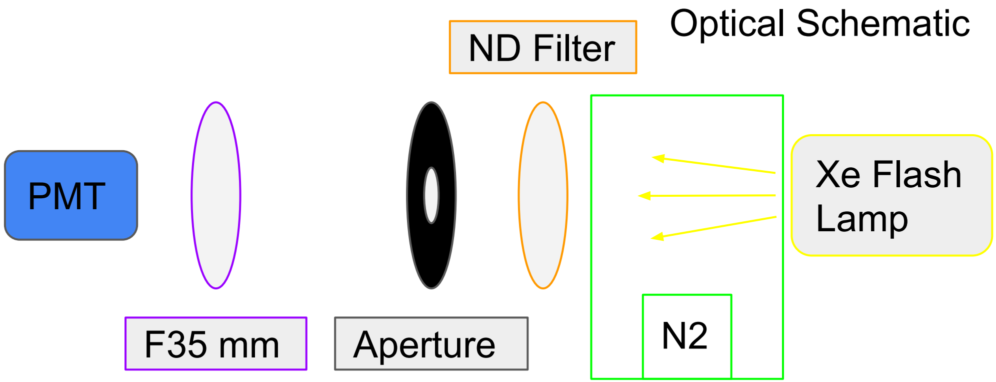


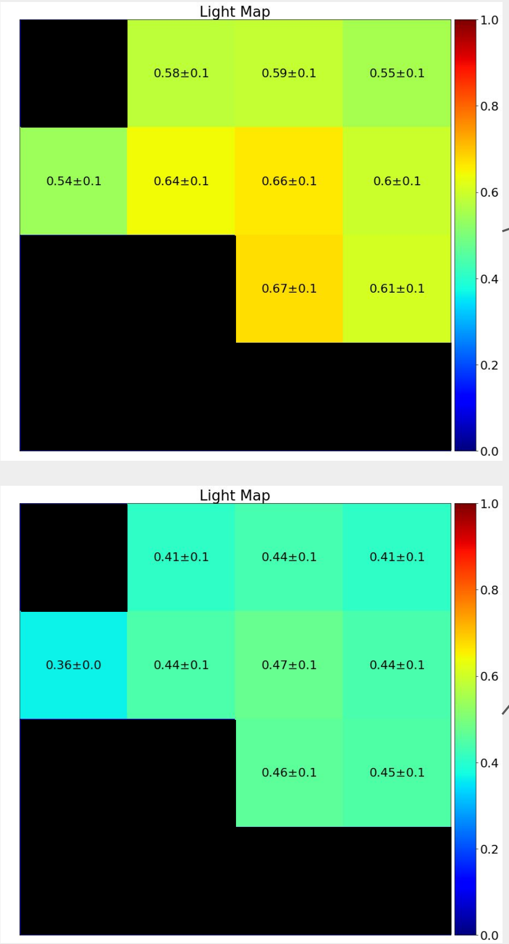
Testing setup for lens/filter characterization

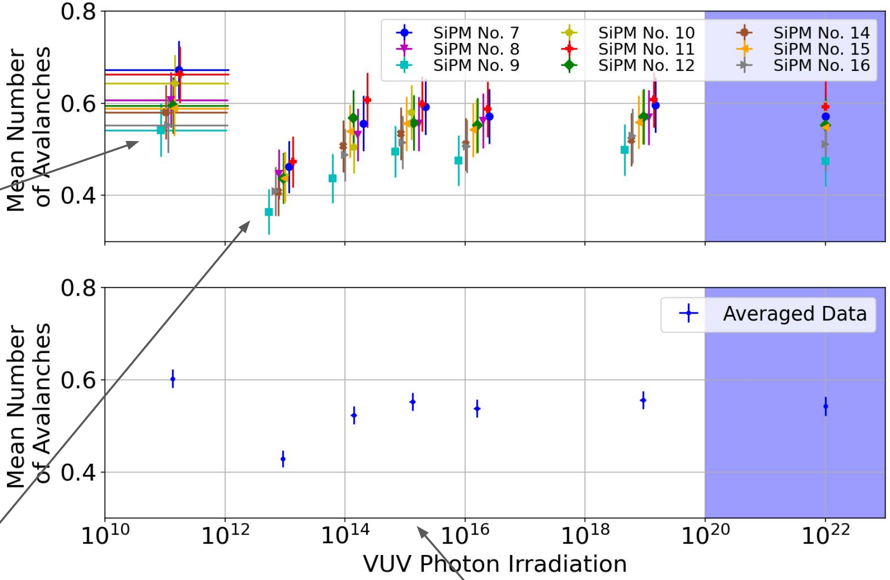


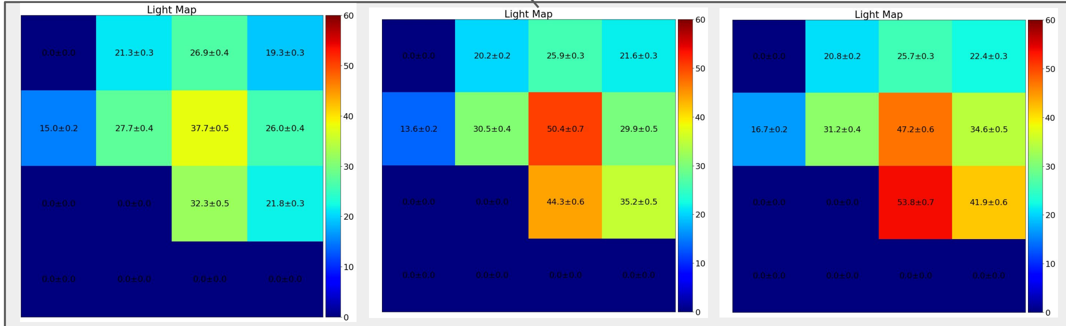
Lens, filter, and aperture mounted inside of the Lamp Holder









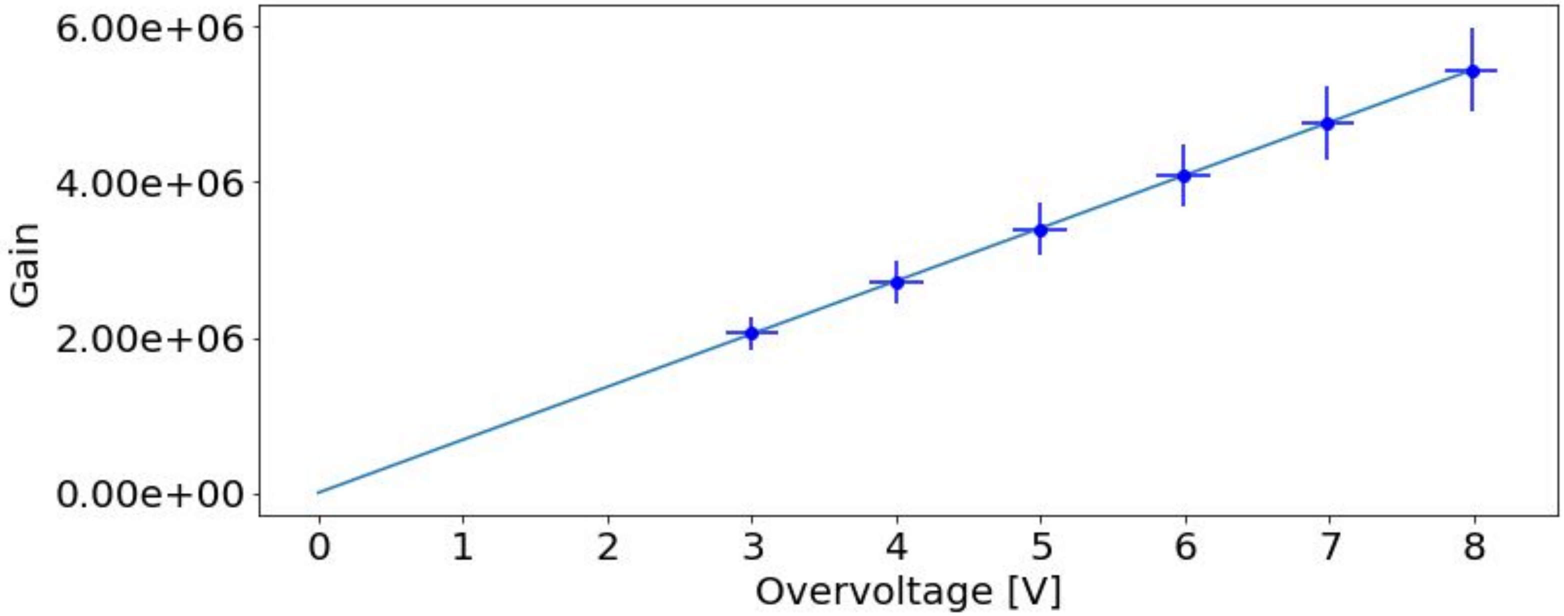


SiPM

$\langle N_{AV} \rangle$ from Cf252-GXe source

$\langle N_{AV} \rangle$ from flash calibration; OD decreases over experiment

Charge-Gain



Flash Cycle: 1.0e+12 VUV ph
SiPM No. 16.0
Breakdown Voltage: 44.5 +/- 0.2 V
Charge-Gain: 681832 +/- 26958 1/V
Capacitance: 1.09e-13 +/- 3.05e-16 F