Spatially resolved laser scanning for the performance characterization of silicon photomultipliers

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McGill

nEXO and Physics Motivation

- Neutrino oscillations require extensions to the Standard Model to account for neutrino mass
- The Majorana mass mechanism implies lepton number violation

New physics!

nEXO

- Proposed experiment using tonne-scale liquid Xe time projection chamber (TPC) to detect neutrinoless double beta decay:

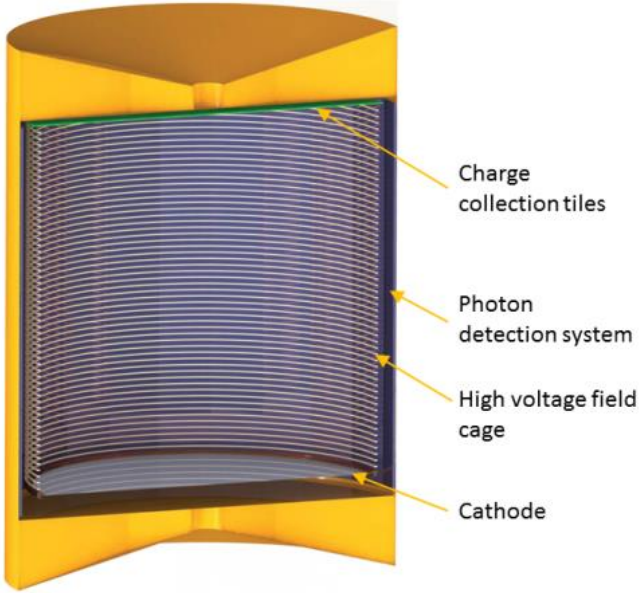
$$^{136}_{54}Xe \rightarrow {}^{136}_{56}Ba^{++} + 2e^{-}$$

- TPC features include a charge collection system and scintillation light detection

  → Scintillation light ($\lambda = 175$ nm) will be detected with VUV-sensitive SiPMs

  Gallina et al., NIM (2019) vol. 940: arXiv:1903.03663.

  Jamil et al., IEEE Trans.Nucl.Sci. 65 (2018) no.11: arXiv:1806.02220.



Source: nEXO Pre-Conceptual Design Report arXiv:1805.11142.

SiPM technology and testing

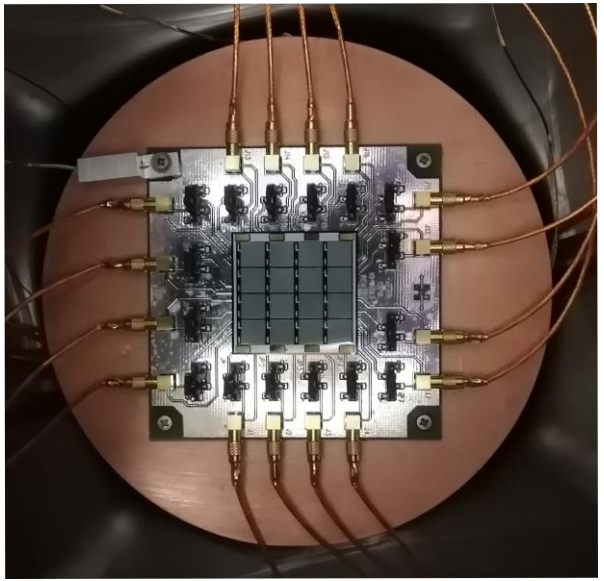
- SiPMs are becoming the photodetector of choice for noble liquid experiments
  - SPADs ($50\ \mu m \times 50\ \mu m$) connected in parallel; a single photon triggers an avalanche
- Advantages include:
  - Low radioactivity
  - Suitability at cryogenic temperatures
  - Compactness

In nEXO:

$$1\ \text{SiPM} \approx 1\ \text{cm} \times 1\ \text{cm}$$

$$1\ \text{tile} \approx 8\ \text{cm} \times 12\ \text{cm}$$

Total nEXO photo-coverage area: $\sim 4.5\ \text{m}^2$



Hamamatsu VUV4 mini-tile of 16 SiPMs.

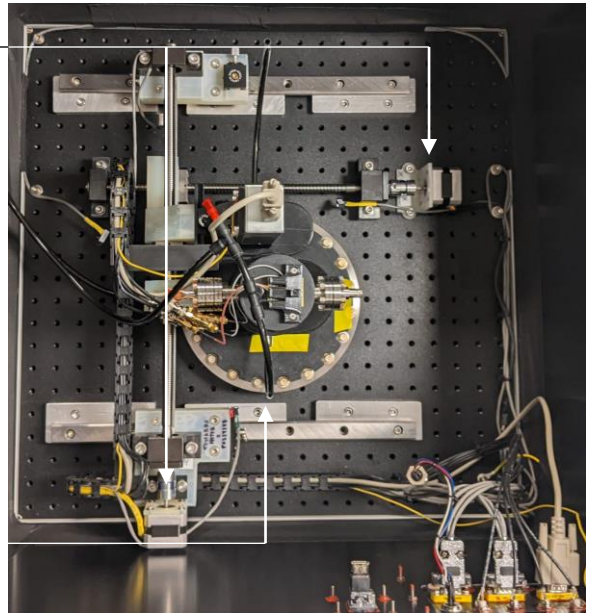
We must test a large number of SiPMs in conditions similar to deployment within a reasonable timescale for nEXO.

Optical Rail System

- Precision scanning mechanism for laser beam spot across SiPM surface
- Mobile beam spot + high coverage area

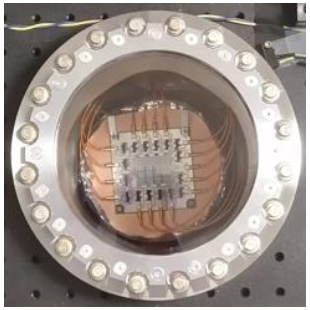
Stepper motors

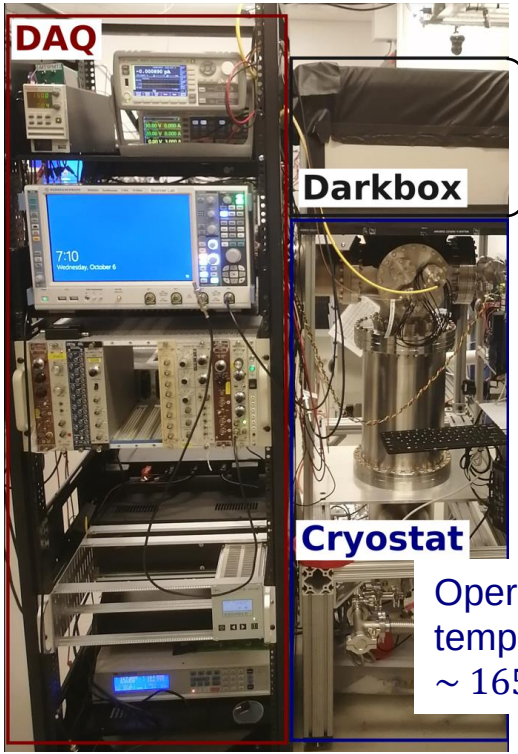
- Controlled by Python
- Step size $\lesssim 50\ \mu m$
- Motion reproducibility $< 25\ \mu m$



Viewport

Laser beam carried by optic fiber (not pictured)

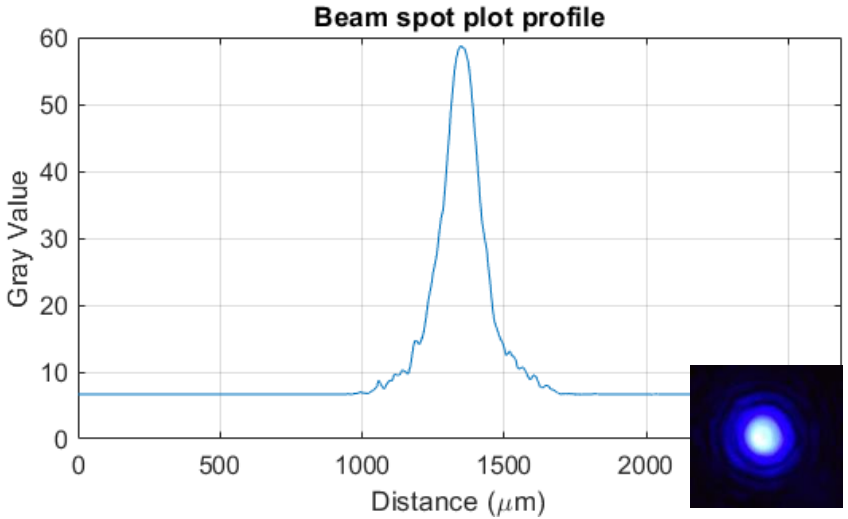




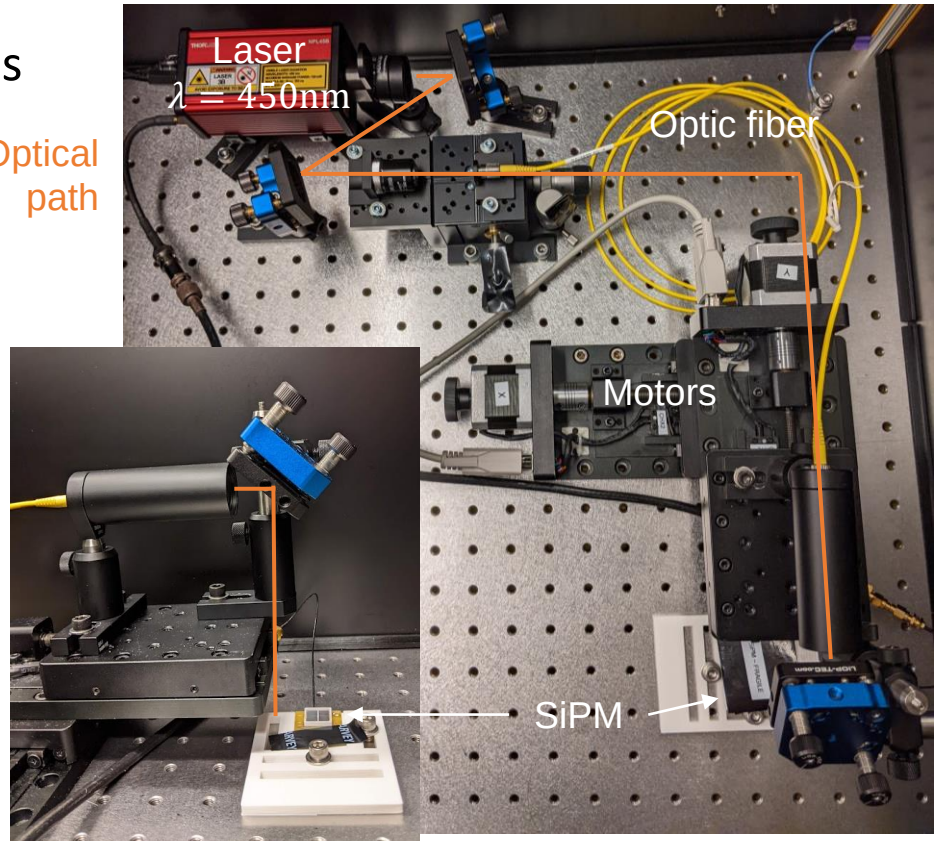
Operating temperatures $\sim 165\ K$

Mock ORS

For stage testing and SiPM measurements at room temperature



Current beam spot plot profile. Inlay: camera image with 3.45 μm pixels.
Smallest beam spot size achieved so far ~ 70 μm



Data Acquisition

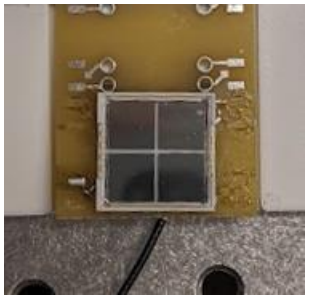
SiPM → Preamplifier → Digitizer → MIDAS (data acquisition package)

Hamamatsu VUV4

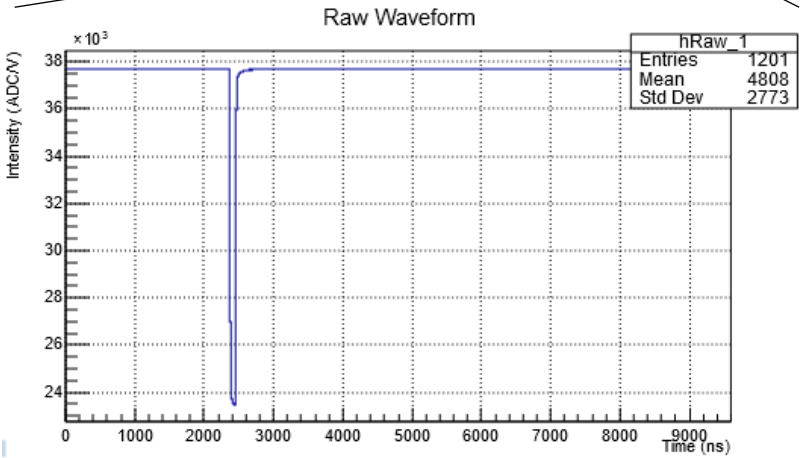
Cremat CR-113

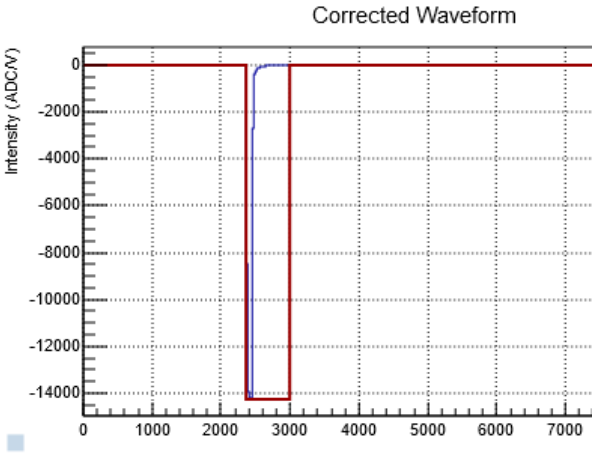
Caen VX2740

MERCI (online analysis)



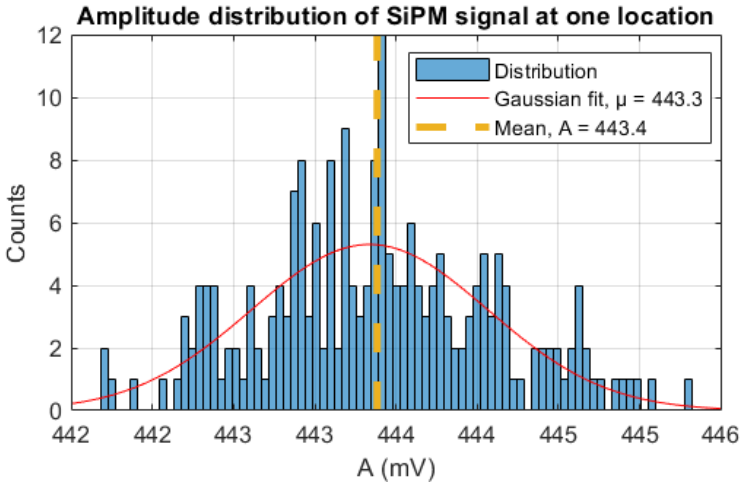
*SiPM output is the sum of all SPAD signals



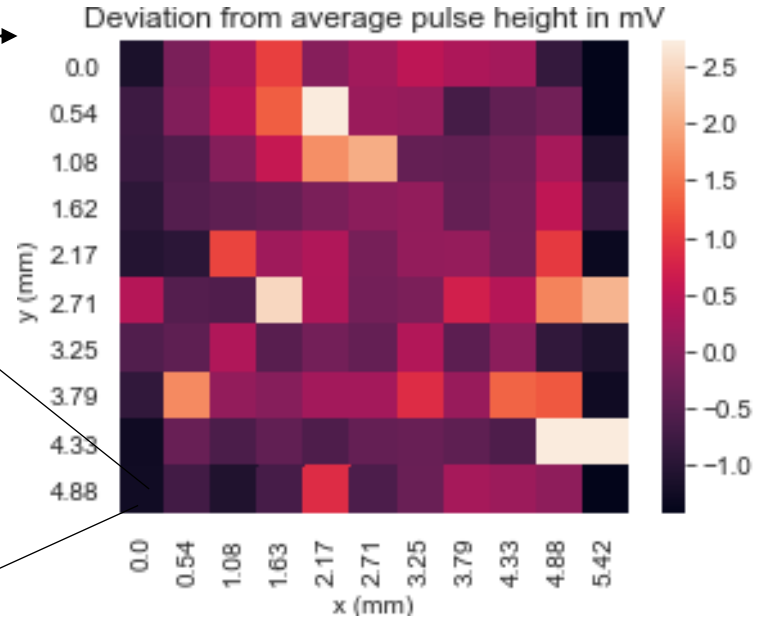


MIDAS: **M**aximum **I**ntegrated **D**ata **A**cquisition **S**ystem
MERCI: **M**odular onlin**E** multi-th**R**eaded **C**++ based waveform toolk**I**t

Early Results



Pulse height distribution at a given location for ~2000 photons each. Note that $\mu \approx \overline{A}$



Deviation from global average response at each position of a coarse raster scan. Tiles correspond to a laser beam spot position; zoom on bottom left position shows the comparative size of a SPAD.

Next Steps

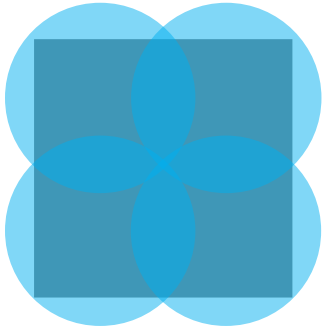
Setup and hardware

- Integrate ORS control into MIDAS and synergize with data acquisition
- Study motion reproducibility and improve beam spot size to allow SPAD by SPAD scanning

Analysis

- Investigate homogeneity of single SPAD response: if homogeneous, beam size can be increased and SiPMs can be tested in fewer steps

(Final goal: large-scale scanning!)



Summary

- Testing nEXO's large number of SiPMs on reasonable timescales and at operating temperatures requires an automated approach and high throughput
- The ORS allows for precision scanning of multiple SiPMs
- Further analysis will provide more ways of facilitating the testing process

Questions?

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nEXO Collaboration, June 2019

nEXO

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