Large Area SiPM Readout and Signal Processing for nEXO

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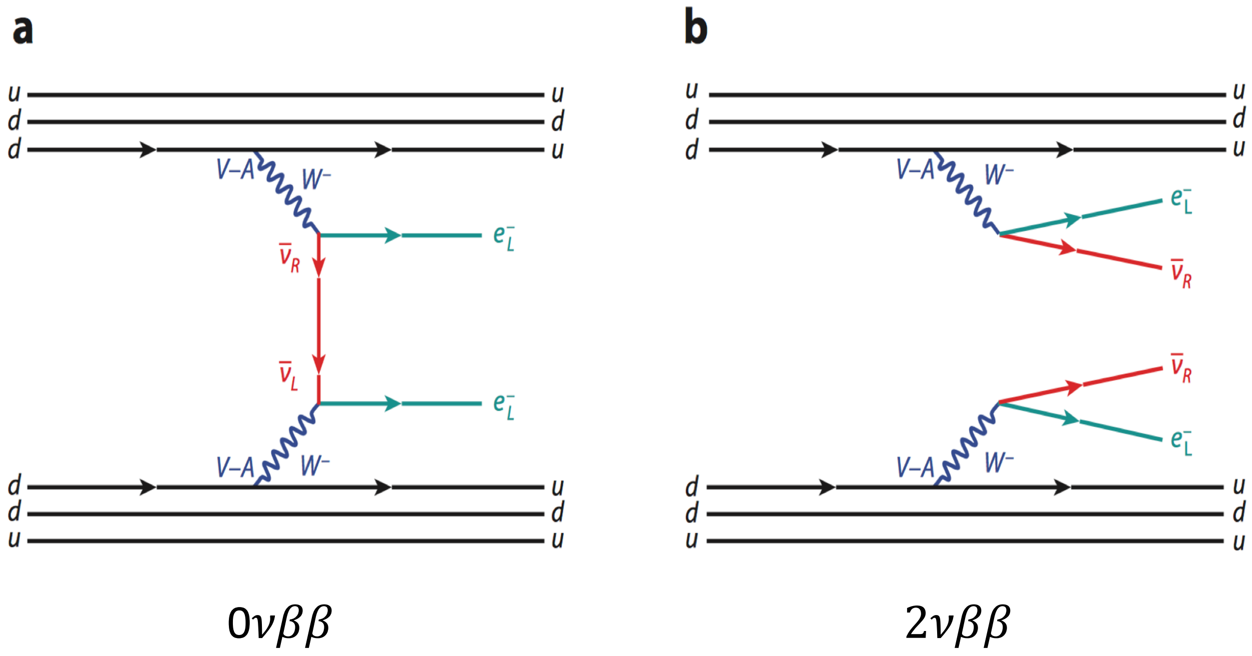
Introduction to Neutrinoless Double-Beta Decay

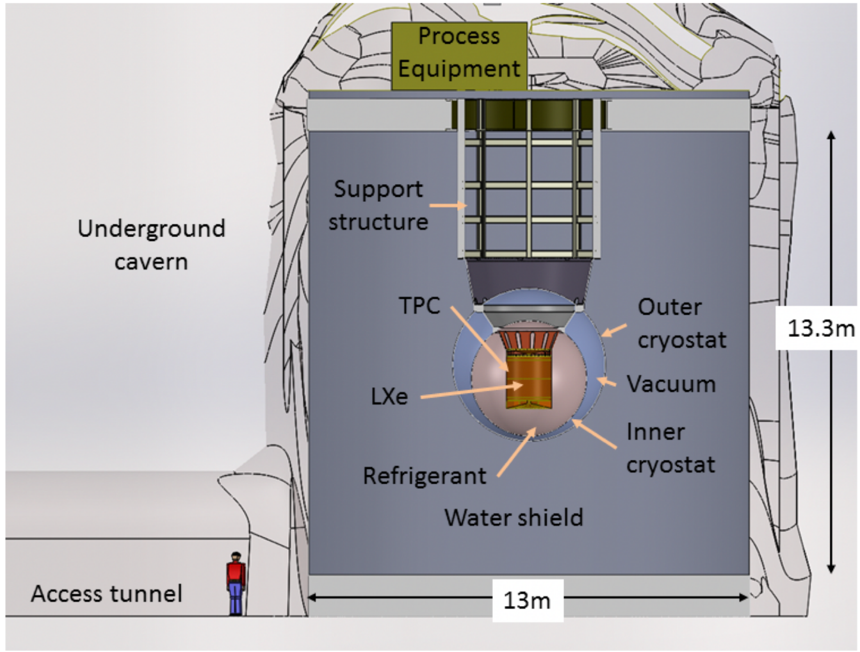
Search for *neutrinoless double-beta decay* ($0\nu\beta\beta, T_{1/2} > 10^{26}$ yr) is an active field of research with important implications for nuclear and particle physics:

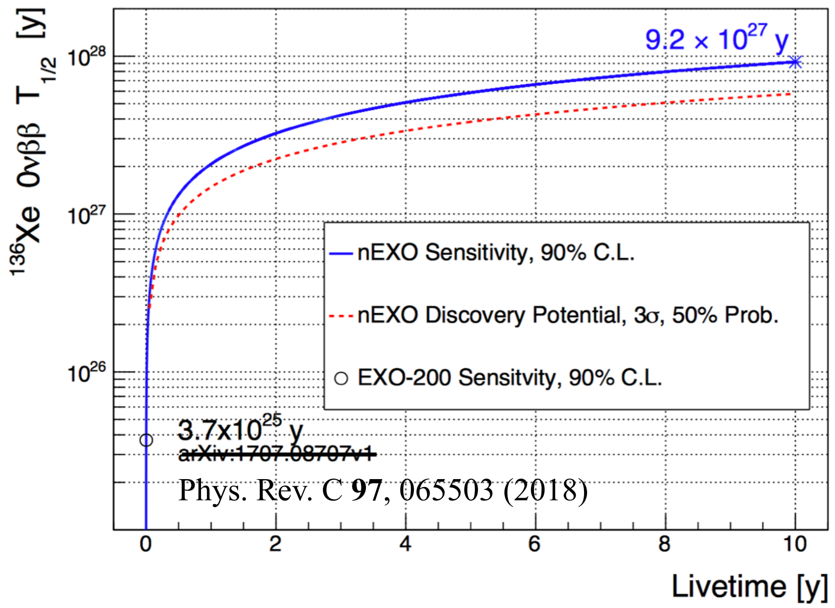
- Unlike standard $2\nu\beta\beta$, no neutrinos are emitted
- If it exists, it would imply **BSM physics**: neutrinos would have to be their own anti-particles (Majorana fermions), and lepton number would not be conserved



The nEXO Experiment

- A proposed 5-tonne liquid xenon (enriched ^{136}Xe) time projection chamber (TPC) to search for $0\nu\beta\beta$
- Allows for 3-D tracking of events
- Two primary signals from candidate events: **scintillation** (**VUV photons**, z-coordinate) and **ionization** (xy-coordinates)
- Scintillation will be collected with silicon photomultipliers (**SiPMs**) and ionization with charge collection tiles
- **Resolution** of energy deposited by candidate events is determined by light collection efficiency and charge collection efficiency





Light Collection

- Historically, photomultiplier tubes (PMTs) have been preferred as the choice light-collection device in similar experiments
- Radioactivity of PMTs is too high for nEXO requirements
- SiPMs are substantially less radioactive than PMTs
- Large area avalanche photodiodes (LAAPDs) were used in the previous generation experiment, will be replaced by SiPMs in nEXO
- In LAAPDs, the resolution is limited by electronics noise

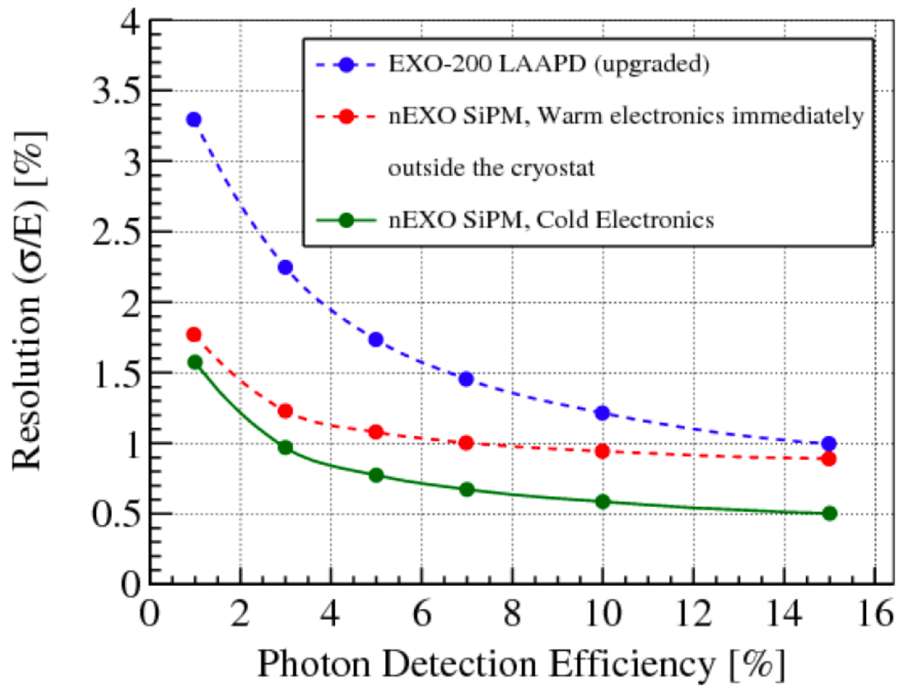
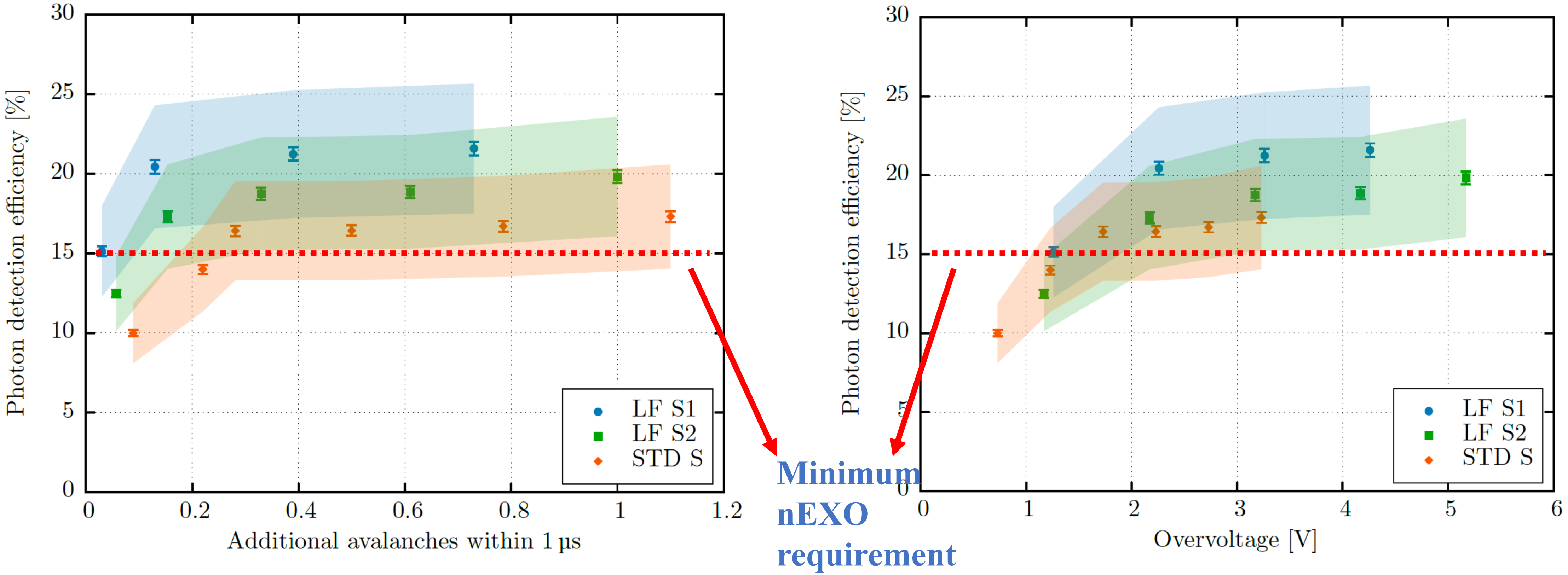


Photo-detection efficiency



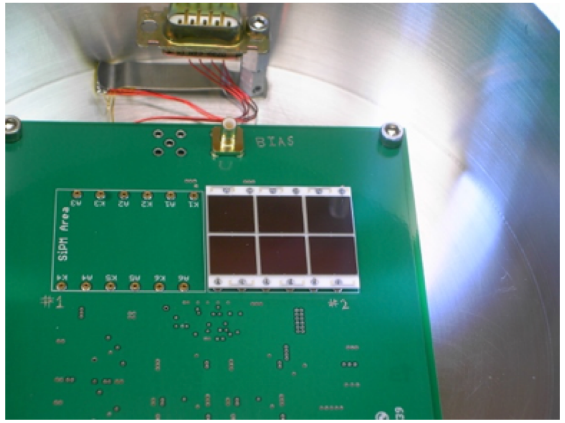
The efficiency of the low field (LF) FBK* devices tested exceeds the minimum requirements of nEXO and the optimal set point is near the beginning of the plateau. The colored bands represent the systematic uncertainties of the measurements.

*FBK: Fondazione Bruno Kessler –an Italian SiPM manufacturer

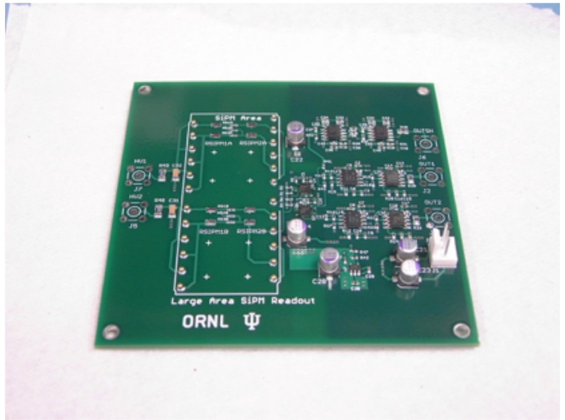
SiPM Test Setup (U of Illinois, Indiana U.)

- We tested a set of 6 FBK LF SiPM's (6 cm^2 total area), in two configurations:
  A. All in *parallel.* All get the same V_{bias}
  B. In a configuration of 3 in parallel, *in series* with another 3 in parallel. Equality of V_{bias} is in this case forced by a resistor (thin film 42.9 MΩ) in parallel with each group of 3.
- Testing was done under very stable cryogenic conditions: **165 +/-0.1 K** and $\boldsymbol{V_{bias}}$ **+/- 0.01 V**
- Five of the SiPMs were covered, one exposed to a blue LED (same one in both configurations)

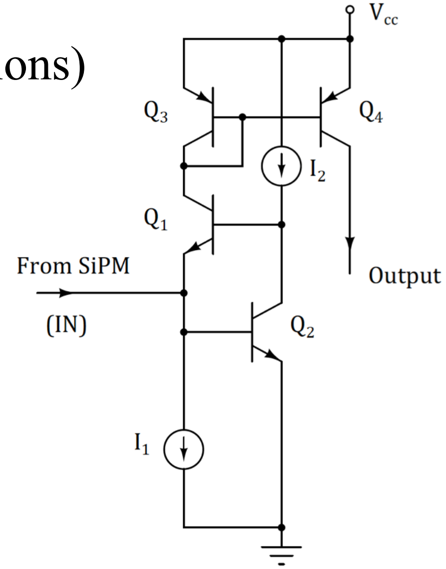

Cryo-testing chamber



6x1 cm^2 FBK SiPM mounted on a ceramic carrier board, 2.5 mW/channel



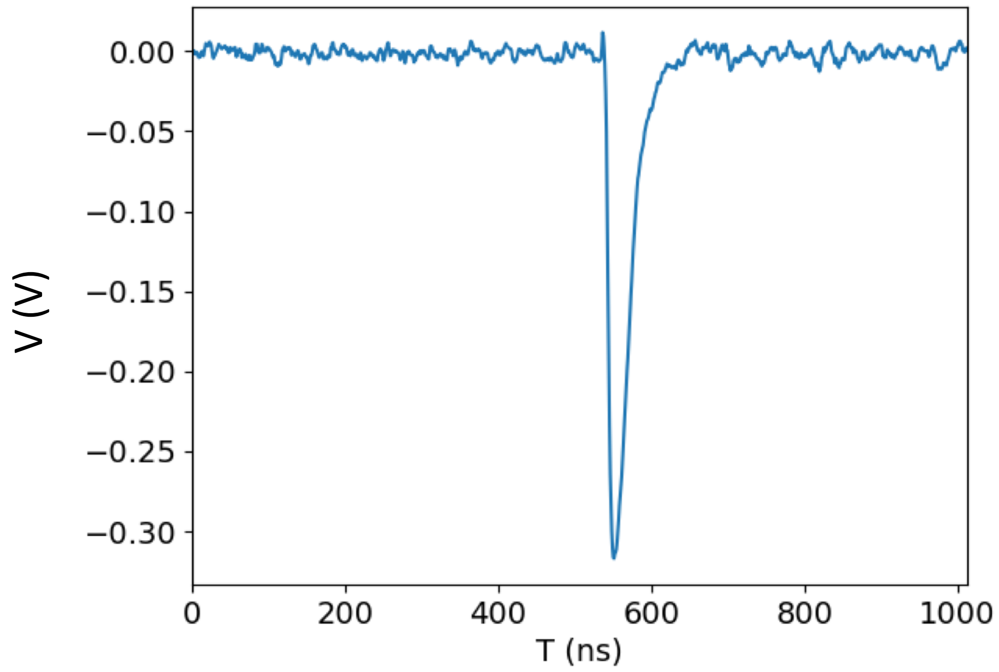
SiPM readout board, designed by ORNL (Oak Ridge National Laboratory)



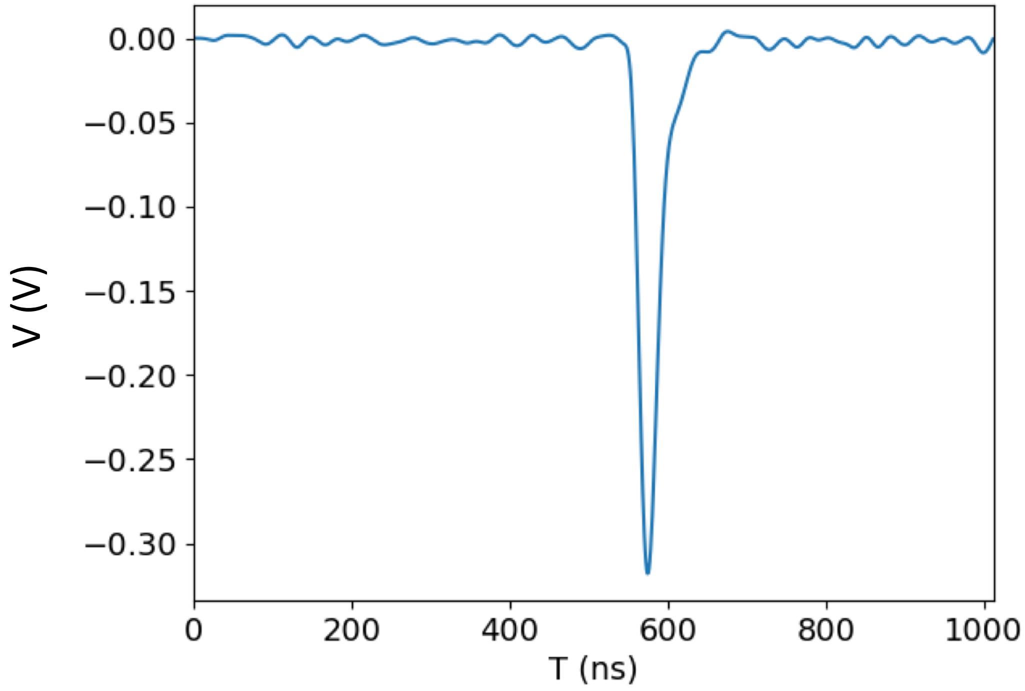
Readout circuit diagram

Single pulse waveform

Unfiltered pulse

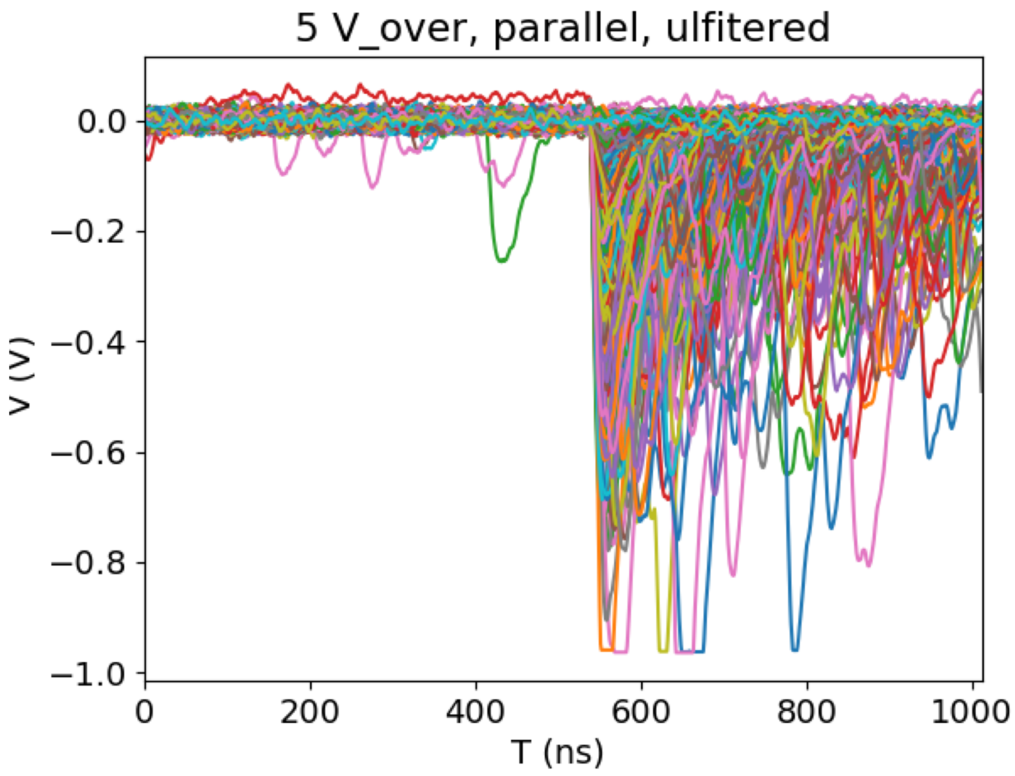


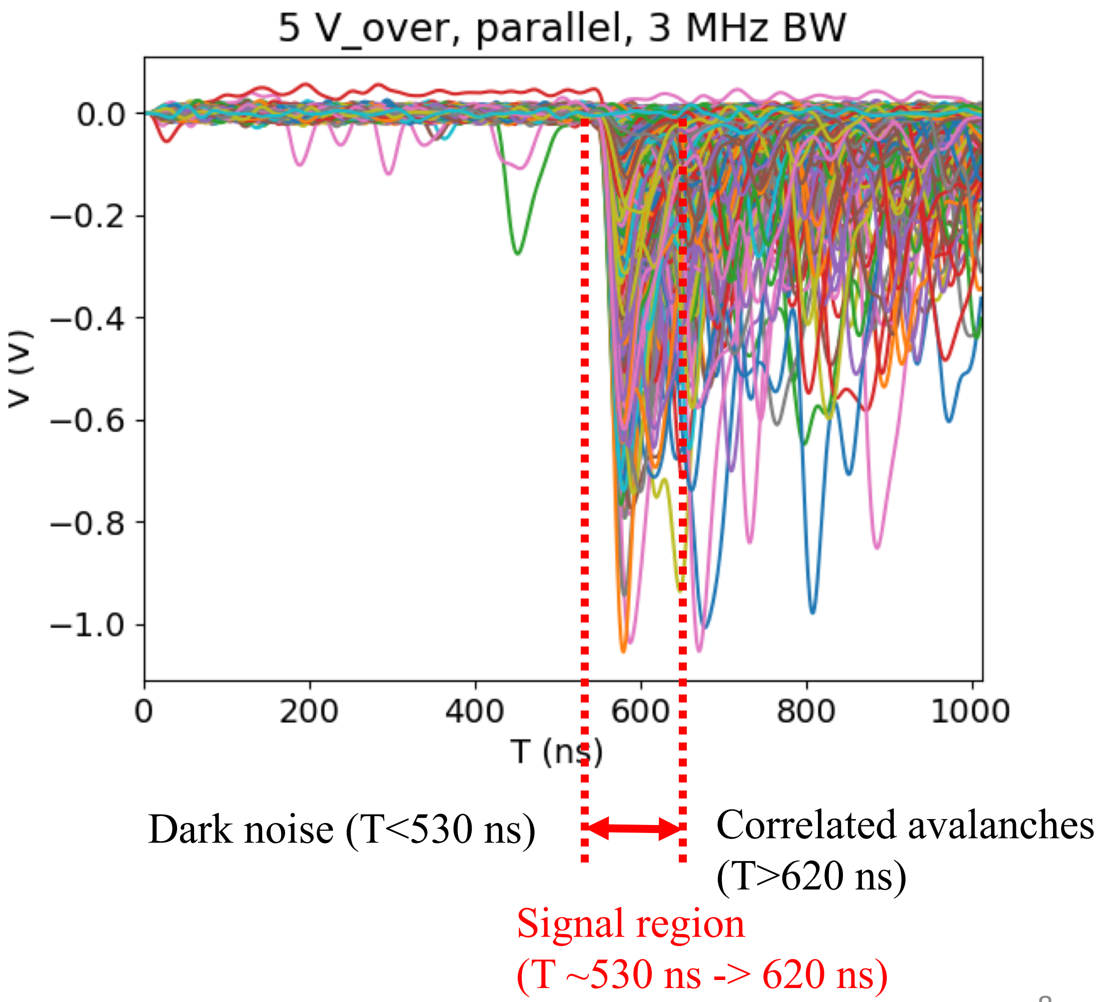
After 3 MHz bandwidth filter



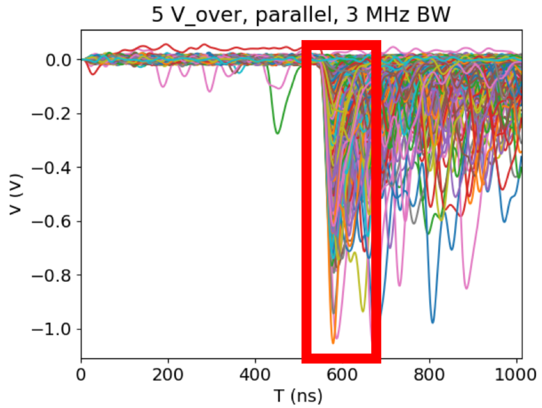
Unfiltered Waveforms

3 MHz bandwidth filter

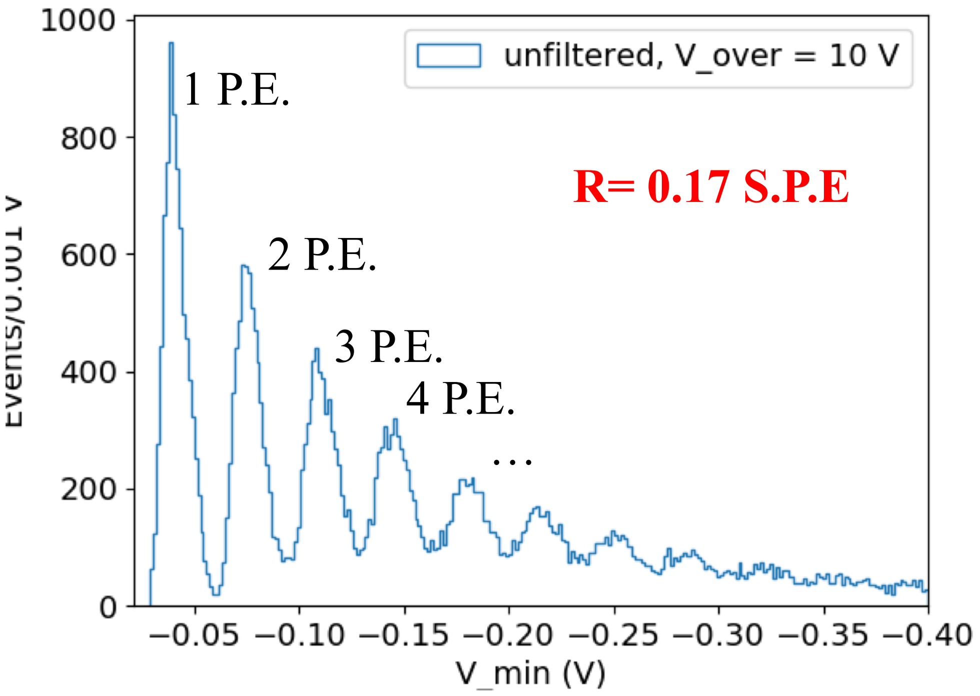




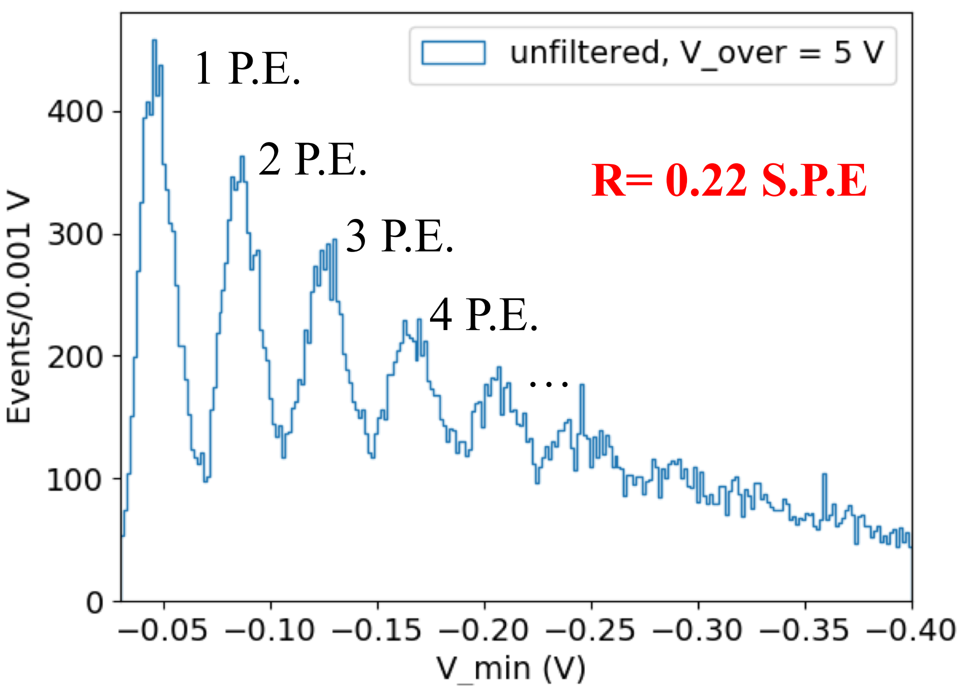
Resolution of *pulse height spectrum* (PHS) improves significantly in series configuration



Series



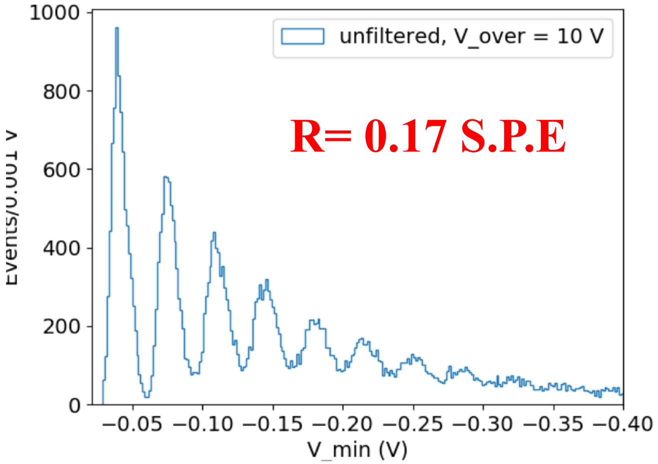
Parallel

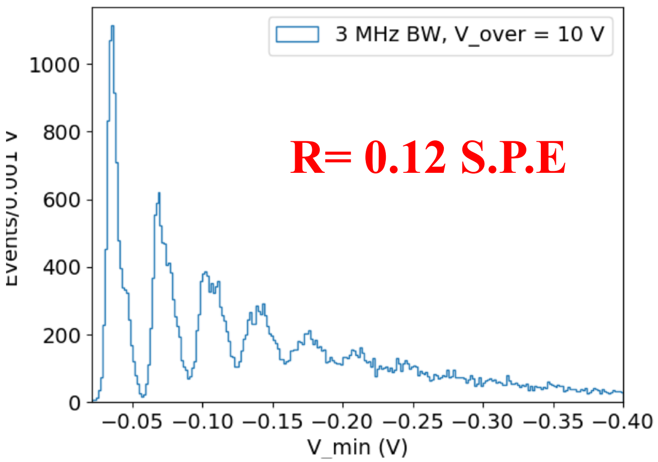


*Note: $V_{over}^{series} = 2V_{over}^{parallel}$

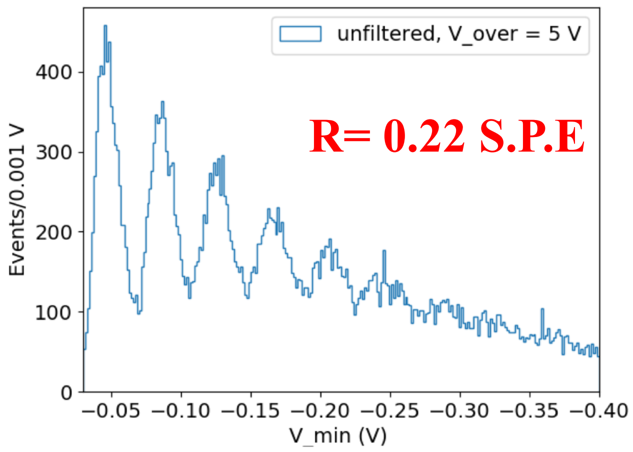
Resolution can be furthered improved with filtering

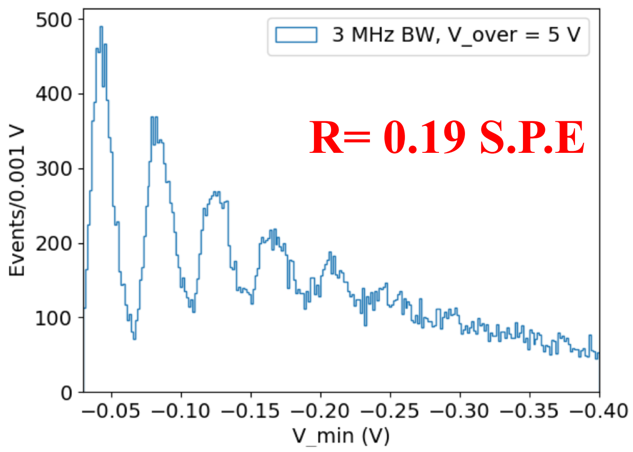
Series





Parallel





Results

Series

V_{over} (V) -single SiPM	Unfiltered Resolution (SPE)	Filtered Resolution (SPE)
5	0.17	**0.12**
4.5	0.2	0.13
4	0.2	0.14
3.5	0.19	0.15

Parallel

V_{over} (V) -single SiPM	Unfiltered Resolution (SPE)	Filtered Resolution (SPE)
5	0.22	**0.19**
4.5	0.24	0.21
4	0.26	0.23
3.5	0.29	0.25

Summary and conclusions

- $0\nu\beta\beta$ is an excellent decay mode to search for physics beyond the Standard Model
- With nEXO we will be able to reach a $0\nu\beta\beta$ search sensitivity close to $\tau_{1/2} = 10^{28}$ years
- Energy resolution is determined largely by photo-detection efficiency
- The nEXO collaboration has undertaken a R&D campaign to test and characterize *VUV-sensitive SiPMs*
- We have developed a baseline readout design for *large area* SiPMs
- Single photoelectron resolution (important for energy resolution) in FBK SiPMs is best in series connection, as expected from theoretical predictions, however, radioactivity considerations (from added resistors) might be a concern
- Next step is to fully develop an ASIC design for reading out the SiPMs

Acknowledgements

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- We thank our nEXO Collaborators for discussions in the development of this work

Extra slide

nEXO papers, describing the detector, the experiment's sensitivity and some results from the R&D

- "nEXOpCDR" arXiv:1805.11142 [physics.ins-det], May 2018
- "Sensitivity and Discovery Potential of nEXO to $0\nu\beta\beta$ decay" Phys. Rev. C **97**, 065503 (2018)
- "Characterization of an Ionization Readout Tile for nEXO" J.Inst. 13 P01006 (2018)
- "Characterization of Silicon Photomultipliers for nEXO", IEEE Trans. NS 62, 1825 (2015)