The Silicon-Photomultiplier Based Light Detection System for nEXO

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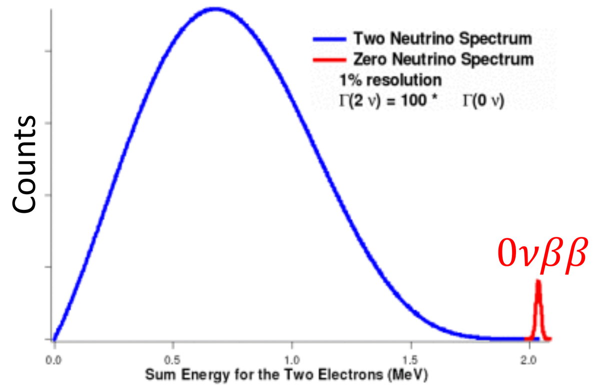
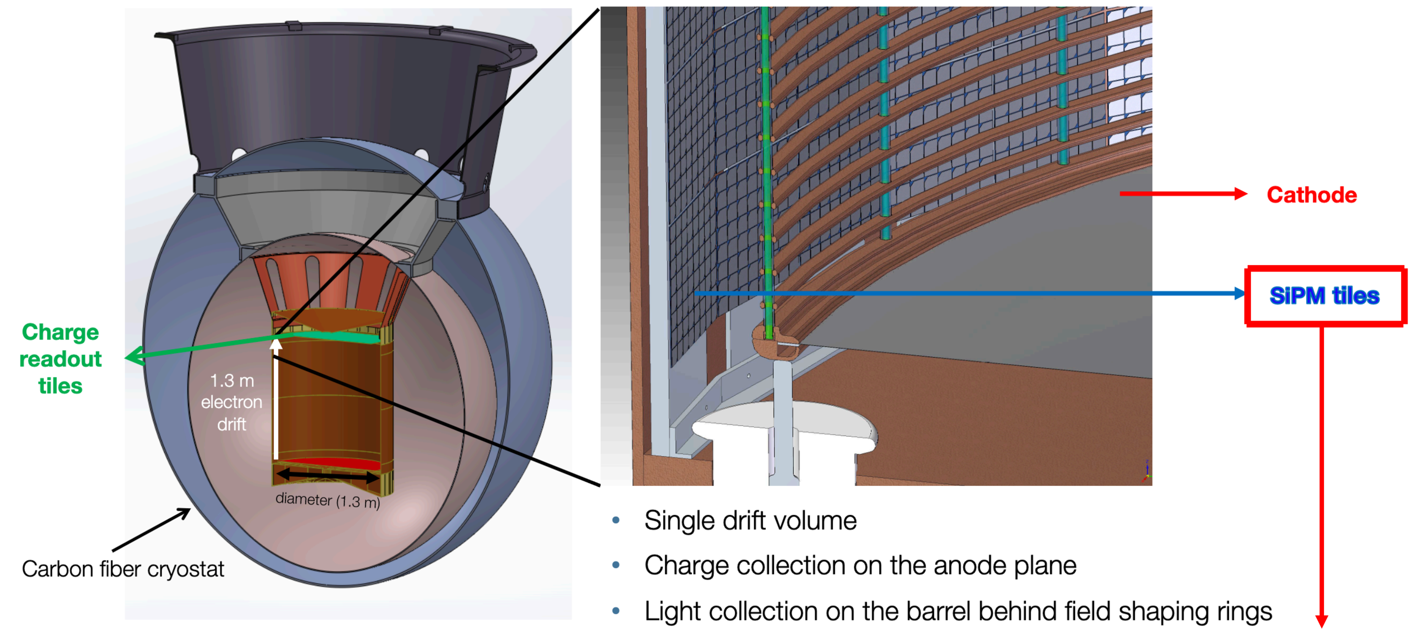
Neutrinoless double beta decay

- nEXO is a proposed tonne-scale experiment to search for neutrinoless double beta decay ($\mathbf{0\nu\beta\beta}$) of ^{136}Xe [1]:
  $^{136}\text{Xe} \rightarrow {}^{136}\text{Ba}+2e^{-}$
- The experiment will use 5 tonnes of enriched liquid xenon (LXe) in a time projection chamber (TPC) [2]
- Energy-depositing events produce *scintillation* and *ionization* signals in the LXe
- With these signals, we can reconstruct the energy and position of each event using the TPC technology

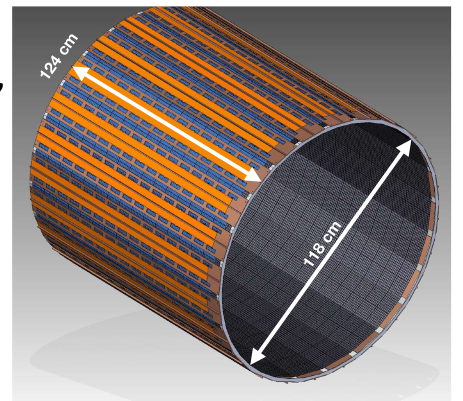


Light collection in nEXO

- We chose to use silicon photomultipliers (SiPMs) for the light-collection due to their advantages over similar technologies for single-photon detection, mainly excellent single-photon resolution, low radioactive content, and high gain (~10^6).
- We plan to implement a total SiPM area of 4.6 m^2 in our TPC to collect the scintillation signals



An energy deposit of $0\nu\beta\beta$ has a **Q-value of 2458 keV**, which produces ~7x10^4 photons in LXe, this corresponds to **less than a single photo-electron equivalent (s.p.e.) per SiPM** (for a 1 cm^2 device)

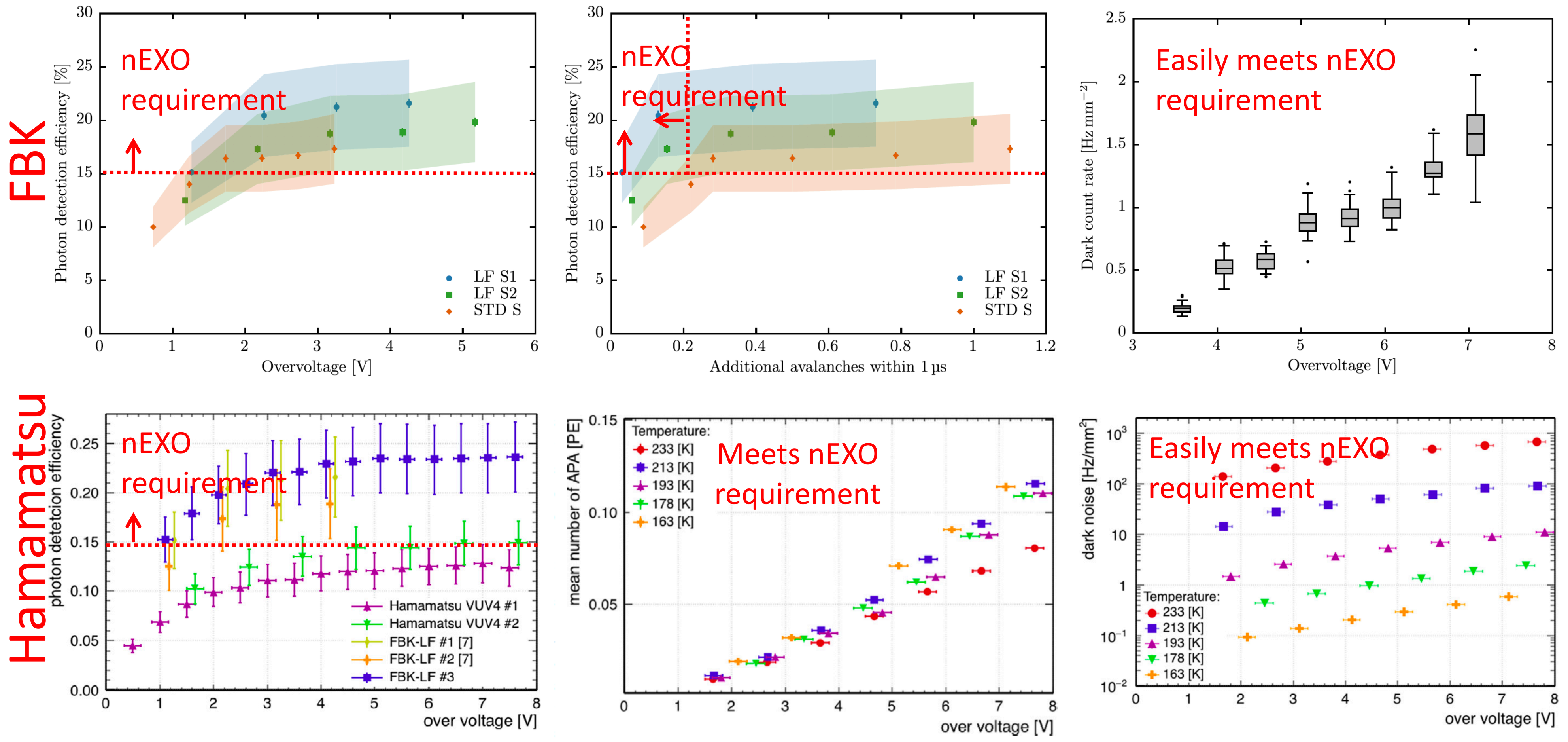


SiPM requirements for nEXO

The following requirements have been deemed necessary to achieve a target **1% energy resolution** (necessary for an unambiguous $0\nu\beta\beta$ detection) at the *Q*-value in nEXO:

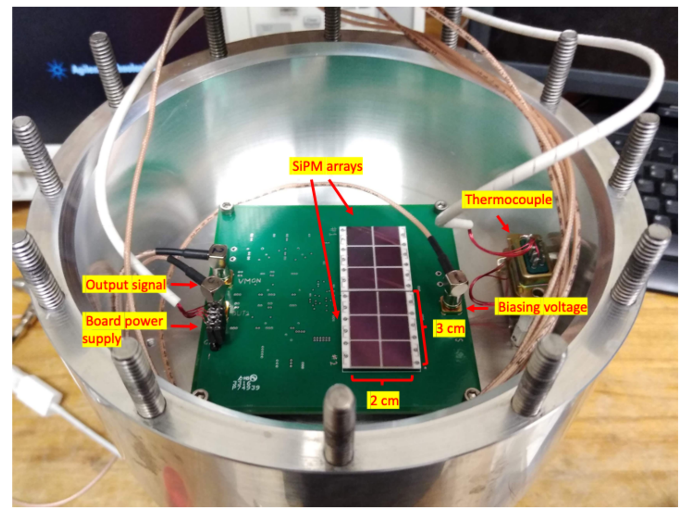
Parameters	Value
Photo-detection efficiency at 175-178nm in liquid Xenon	≥ 15%
Radio purity: contribution of photo-detectors to the overall background	< 1%
Dark noise rate at -100°C	≤ 50 Hz/mm^2
Average number of correlated avalanches per parent avalanche at -100°C within 1 μs	≤ 0.2
Single photo-detector active area	≥ 1cm^2
Capacitance per area	< 50 pF/mm^2
Gain fluctuations + electronics noise	< 0.1 PE

- We have identified two prospective SiPM vendors: FBK* and Hamamatsu
- We showed SiPM characterization results for PDE, dark noise, and correlated avalanches in [3] and [4]
- The Hamamatsu SiPMs were shown to have better dark noise and correlated avalanche values, but have a PDE that does not meet nEXO requirements

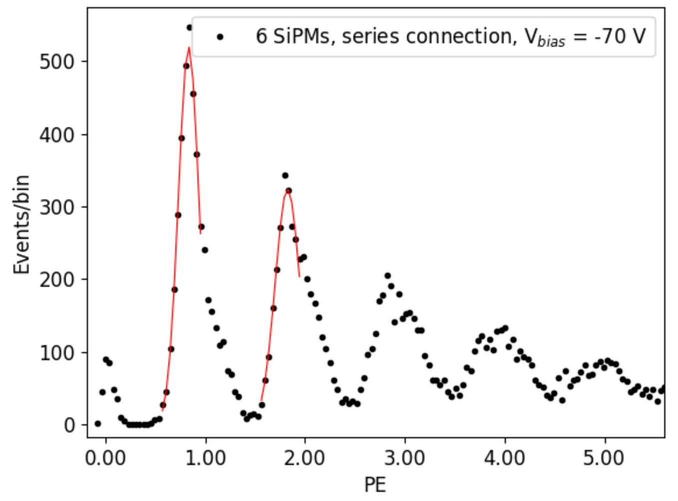


Electronics noise

- Due to the expected low light levels (< 1 p.e. per SiPM) we require low gain fluctuations and electronics noise (ENC, also denoted as σ_{SPE}) per readout channel **(< 0.1 s.p.e.)**
- In the current prototype, we have a maximum of 6 cm^2 of active SiPM area for each readout channel
- The final design for nEXO will use ASICs (application-specific integrated circuits) to read out each channel, however, we can test the electronics noise (and other SiPM parameters) using discrete-component boards

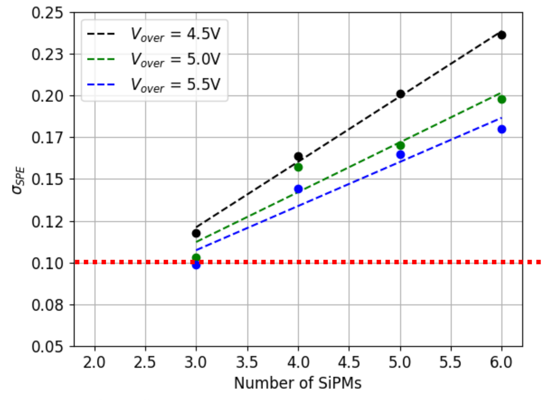


Discrete-component readout electronics

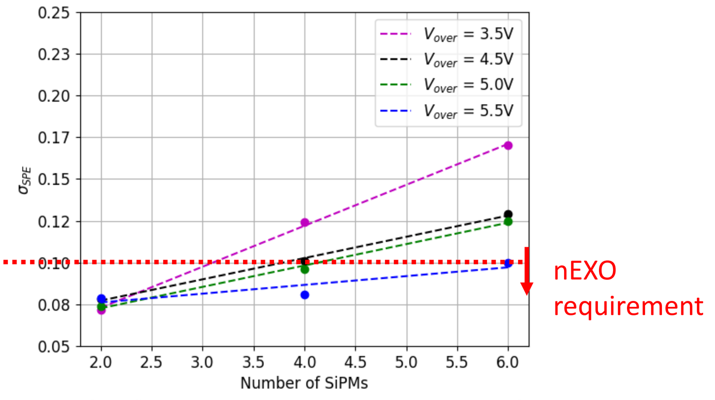


Sample photoelectron spectrum for six SiPMs biased at 5.5 V of overvoltage

- We explored several architectures for a single readout channel, using series and parallel connections and SiPM multiplicities for FBK devices
- We found that we can achieve < 0.1 s.p.e. with six SiPMs (2 arrays connected in series, with 3 SiPMs in each array) or less



Results for ENC measurements for parallel connection, all SiPMs in parallel.



Results for ENC measurements with series connection, 2 arrays (of parallel SiPMs in each array) in series.

Conclusions

The first version of the readout electronics to be implemented in nEXO has shown promising results, achieving the 0.1 SPE resolution required for the maximum number of SiPMs per channel. Other SiPM-performance parameters have already been published by the nEXO collaboration.

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References

* Fondazione Bruno Kessler, Italian SiPM manufacturer

[1] nEXO collaboration, J. B. Albert et al., "Sensitivity and Discovery Potential of nEXO toNeutrinoless Double Beta Decay,"Phys. Rev., vol. C97, no. 6, p. 065503,2018.
[2] E. Majorana, "Teoria simmetrica dell'elettrone e del positrone,"Il NuovoCimento (1924-1942), vol. 14, no. 4, p. 171, Sep 2008.
[3] nEXO collaboration, A. Jamil et al., "Vuv-sensitive silicon photomultipli-ers for xenon scintillation light in nexo,"IEEE Transactions on NuclearScience, vol. 65, pp. 2823–2833, Nov 2018.
[4] G. Gallina, P. Giampa, F. Retiere, J. Kroeger, G. Zhang, M. Ward, P. Margetak, G. Li, T. Tsang, L. Doria, et al., Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 940 (06 2019).

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