Large Area SiPMs for Ton-scale 0νββ with LXe TPCs

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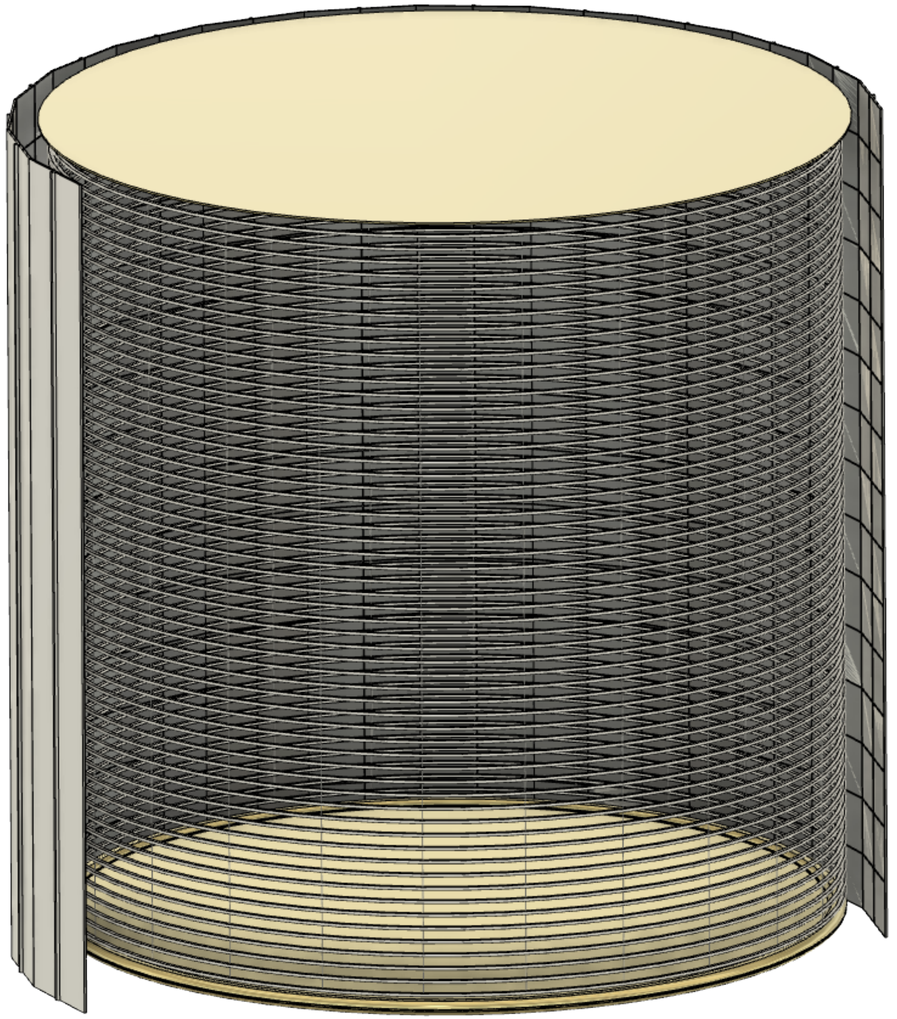
CPAD Instrumentation Frontier Workshop 2021

nEXO

nEXO — Overview and Light Readout

nEXO pCDR: https://arxiv.org/abs/1805.11142
nEXO Sensitivity and Discovery Potential: https://arxiv.org/abs/1710.05075

- Single Phase Time Projection Chamber
  - Filled with $5000\,\mathrm{kg}$ of liquid xenon
  - Monolithic design with single drift volume with $1.3\,\mathrm{m}$ drift length
- TPC barrel covered with $4.5\,\mathrm{m}^2$ of VUV-sensitive Silicon Photomultiplier
  - Radio-pure and chemically pure integration of large area SiPMs
- Aimed for energy resolution of $\sigma_E/Q_{\beta\beta} \leq 1\,\%$
  - Key driver of the energy resolution is the total light collection efficiency $\epsilon = \mathrm{PTE} \cdot \mathrm{PDE}$



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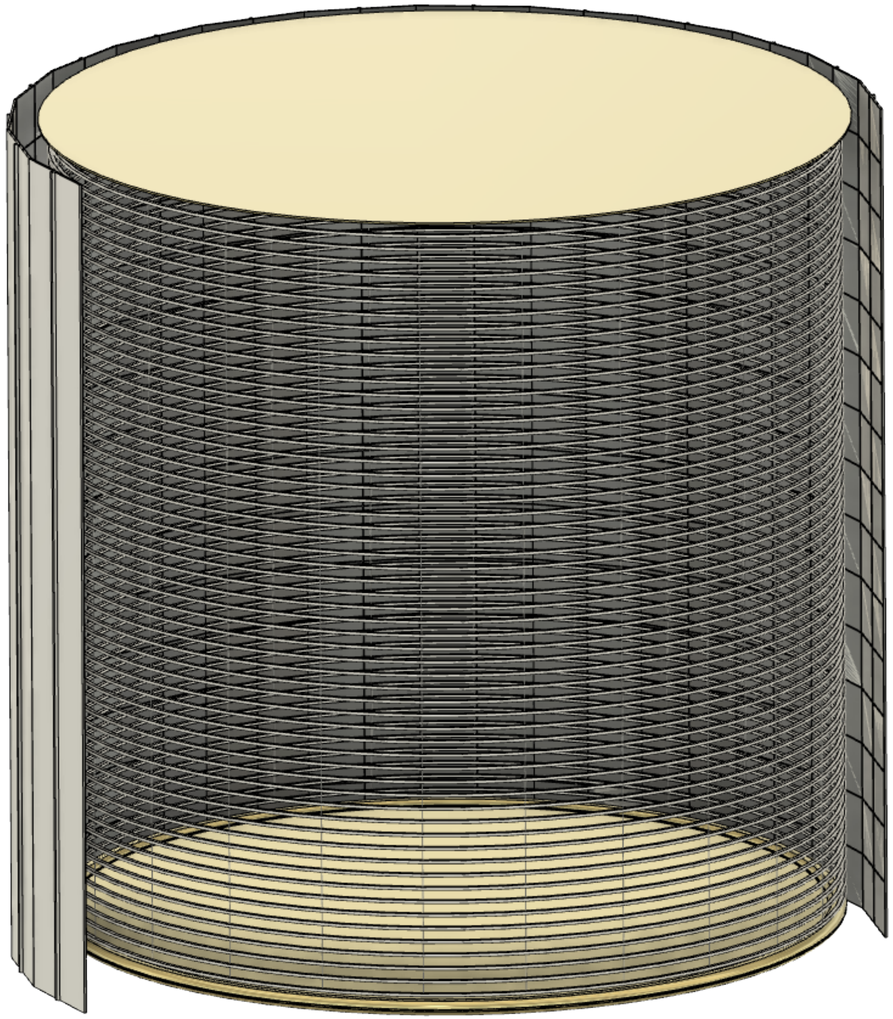


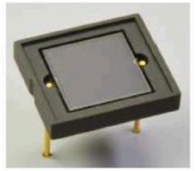
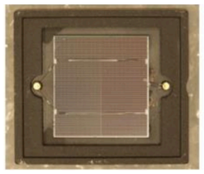
Development of a $\mathrm{Si/SiO_2}$ interposer

Characterization of SiPM performance

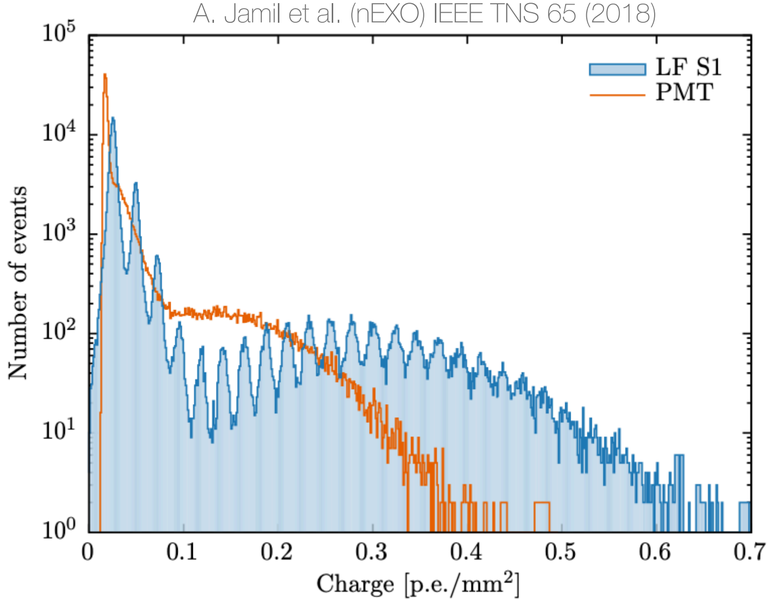
GPU Photon Transport Simulations

SiPMs for nEXO

- Advantages:
  - Low intrinsic radio-activity
  - High gain
  - Single photon resolution
  - Scalability to large areas
- Possible vendors: FBK and HPK

A. Jamil et al. (nEXO) IEEE TNS 65 (2018)



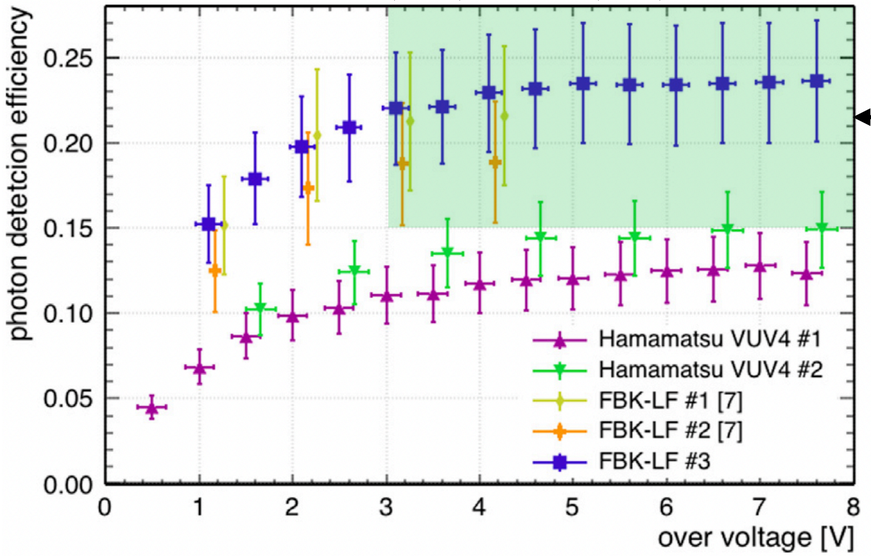
PARAMETER	VALUE
PDE	> 15%
Dark noise rate	< 50 Hz/mm^2
Correlated avalanche rate	< 20%
Overall light collection	> 3%
Overvoltage	> 3V

nEXO pCDR: https://arxiv.org/abs/1805.11142

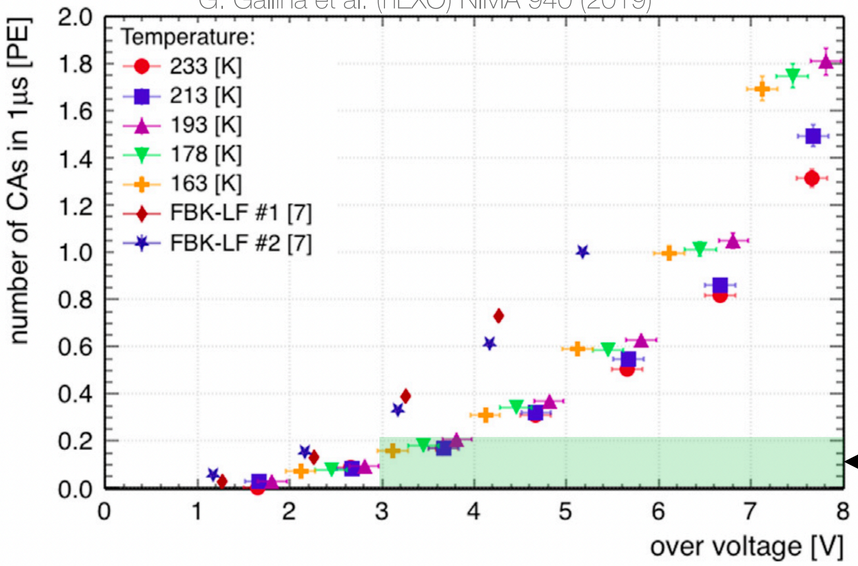
Characterization of SiPM Performance

- nEXO is running an extensive characterization campaign with several setups measuring
  - Absolute PDE in vacuum
    - Ostrovskiy et al. (nEXO) IEEE TNS 62 (2015)
    - A. Jamil et al. (nEXO) IEEE TNS 65 (2018)
    - G. Gallina et al. (nEXO) NIMA 940 (2019)
  - Have identified devices that meet our requirement
  - Working together with vendors to increase operational range

G. Gallina et al. (nEXO) NIMA 940 (2019)



G. Gallina et al. (nEXO) NIMA 940 (2019)

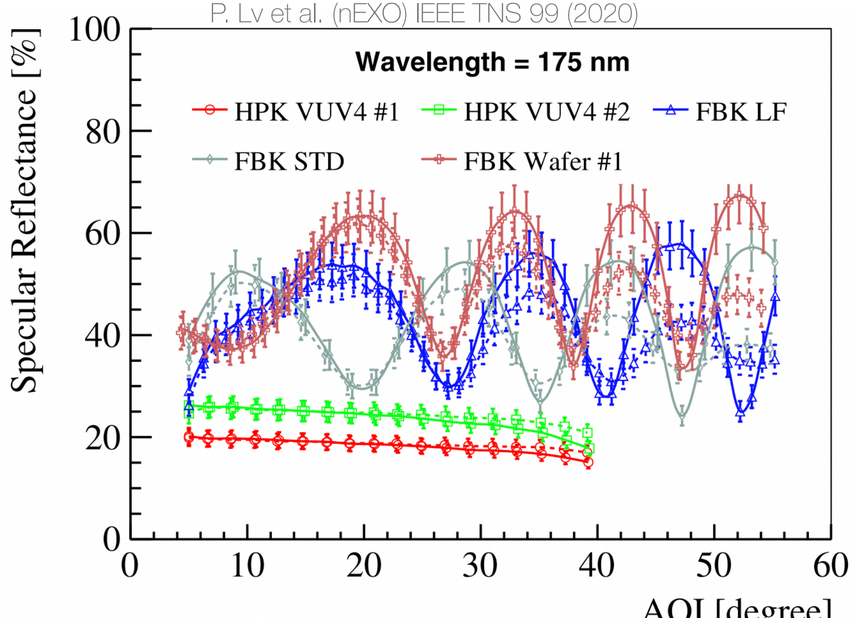


Within nEXO requirements

Characterization of SiPM Performance

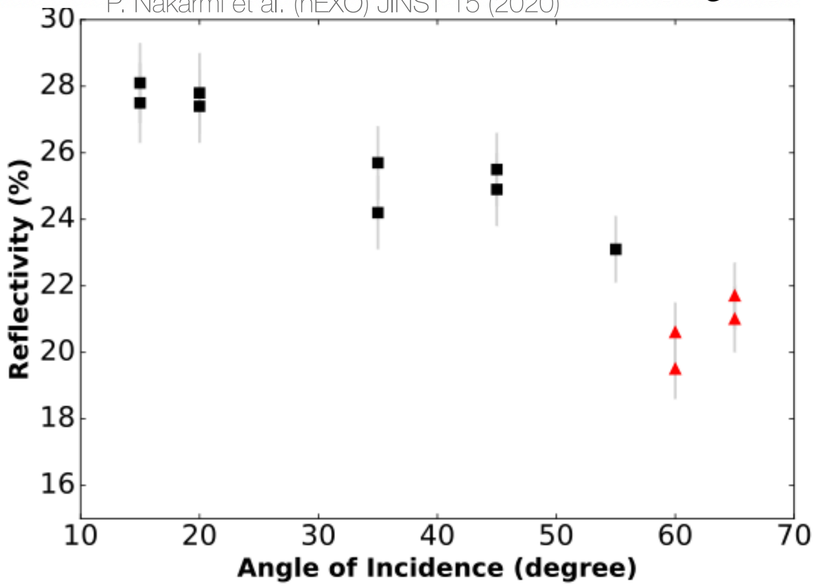
- nEXO is running an extensive characterization campaign with several setups measuring
  - Reflectivity in vacuum and LXe
    - P. Nakarmi et al. (nEXO) JINST 15 (2020)
    - P. Lv et al. (nEXO) IEEE TNS 99 (2020)
    - M. Wagenpfeil et al. (nEXO) In prep. (2021
  - Photons reflected from SiPM surface can be detected by other SiPMs
  - Reflectivity of passive TPC components crucial for good light collection efficiency

P. Lv et al. (nEXO) IEEE TNS 99 (2020)



Vacuum

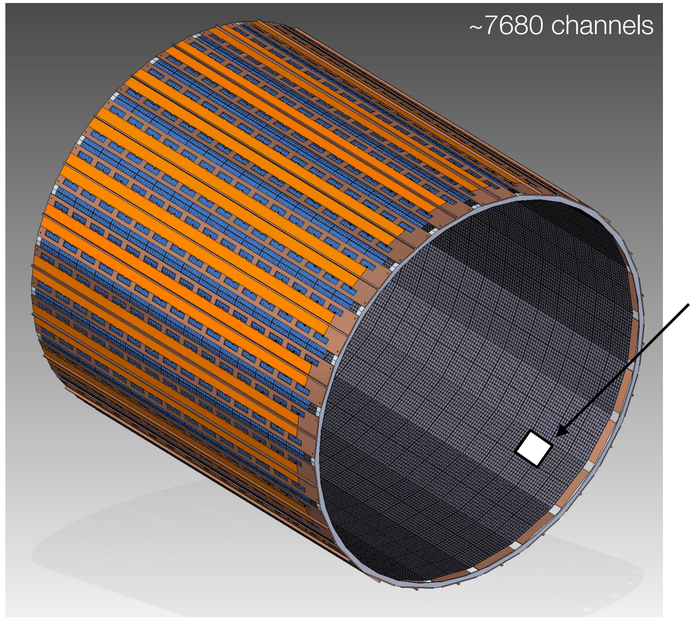
P. Nakarmi et al. (nEXO) JINST 15 (2020)



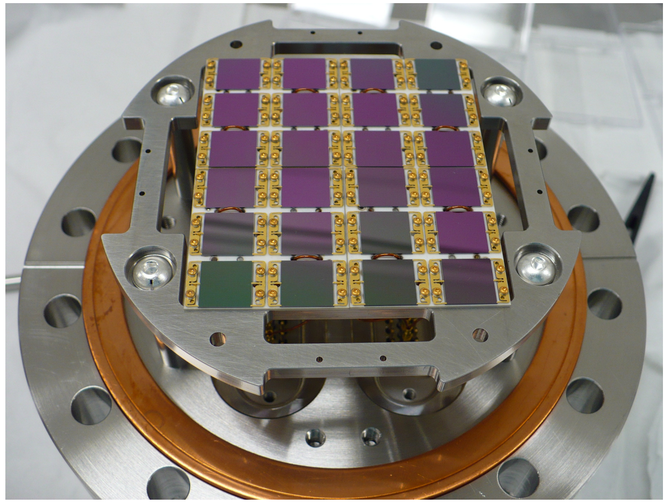
Liquid xenon

Scaling from $1\,\mathrm{cm}^2$ to $4.5\,\mathrm{m}^2$

- Modular design of photon readout system with $96\,\mathrm{cm}^2$ of SiPMs (tile module)
  - 7680 channels with a $6\,\mathrm{cm}^2$ channel size (3p2s)
- In-LXe electronics for each tile module
- Stringent requirements on radio-purity and xenon purity



24 staves covering nEXO's TPC barrel

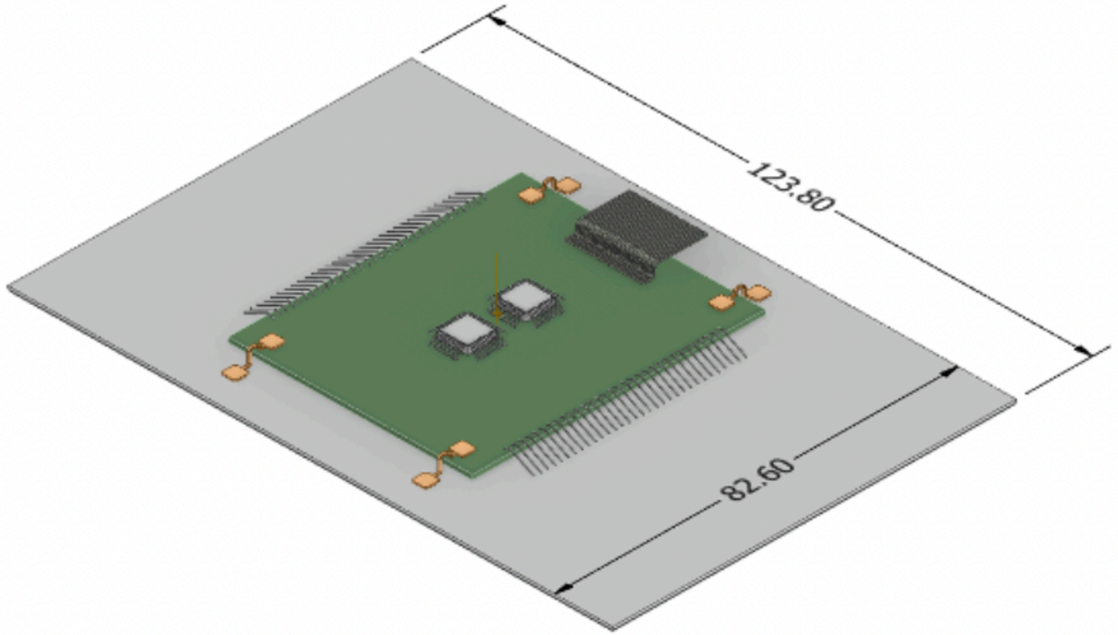


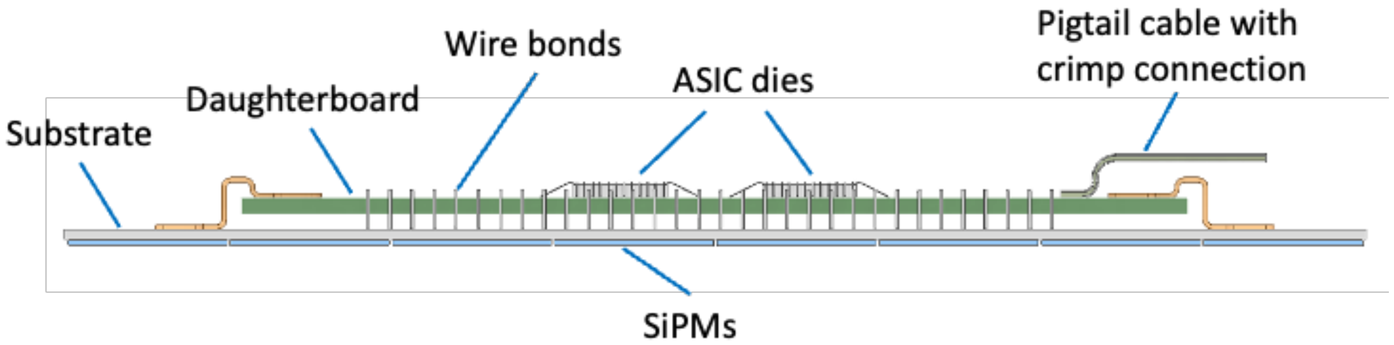
Early prototype with $24\,\mathrm{cm}^2$ of SiPMs

Interposer for Large Area Instrumentation

- Two independent substrates for the holding the SiPMs (interposer) and the electronics (daughterboard)
- Pursuing two possible materials for interposer (Si/SiO_2)
- Design depends on the availability of Through-Silicon-Via (TSV) for SiPMs
- Radio-pure materials for each part of tile module already identified

Single tile module including SiPM interposer (grey) and ASIC daughterboard (green)

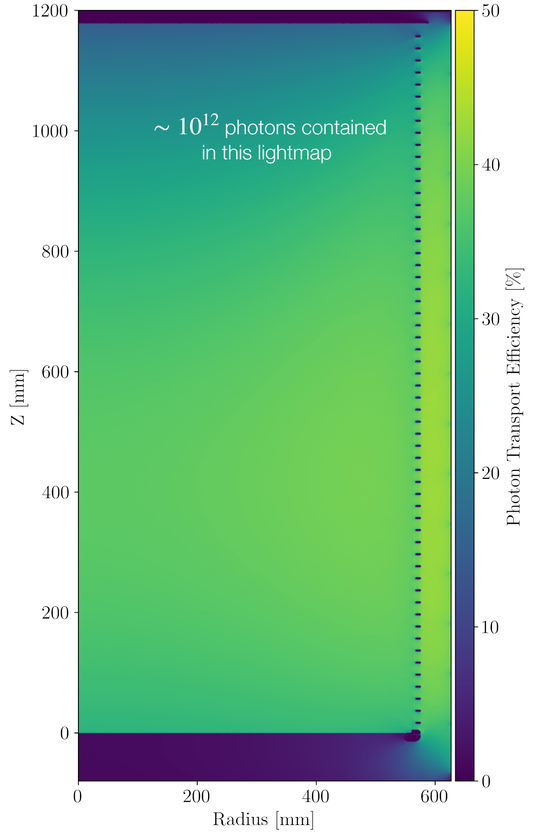


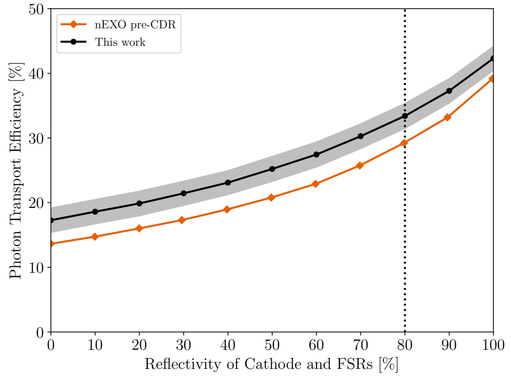


Side view of a single tile module

GPU-accelerated Photon Transport Simulations

- Rise of machine learning and video game development have opened the doors for fast GPU-based ray tracing for particle physics
  - Containerization allows for easy deployment and use on HPCs
  - Current software packages exploiting GPUs for fast light simulations: Chroma & Opticks
- Fast simulation turnaround allows exploring larger parameter space
  - SiPM channel size
  - Reflectivity of passive components in the TPC
  - TPC design





Summary

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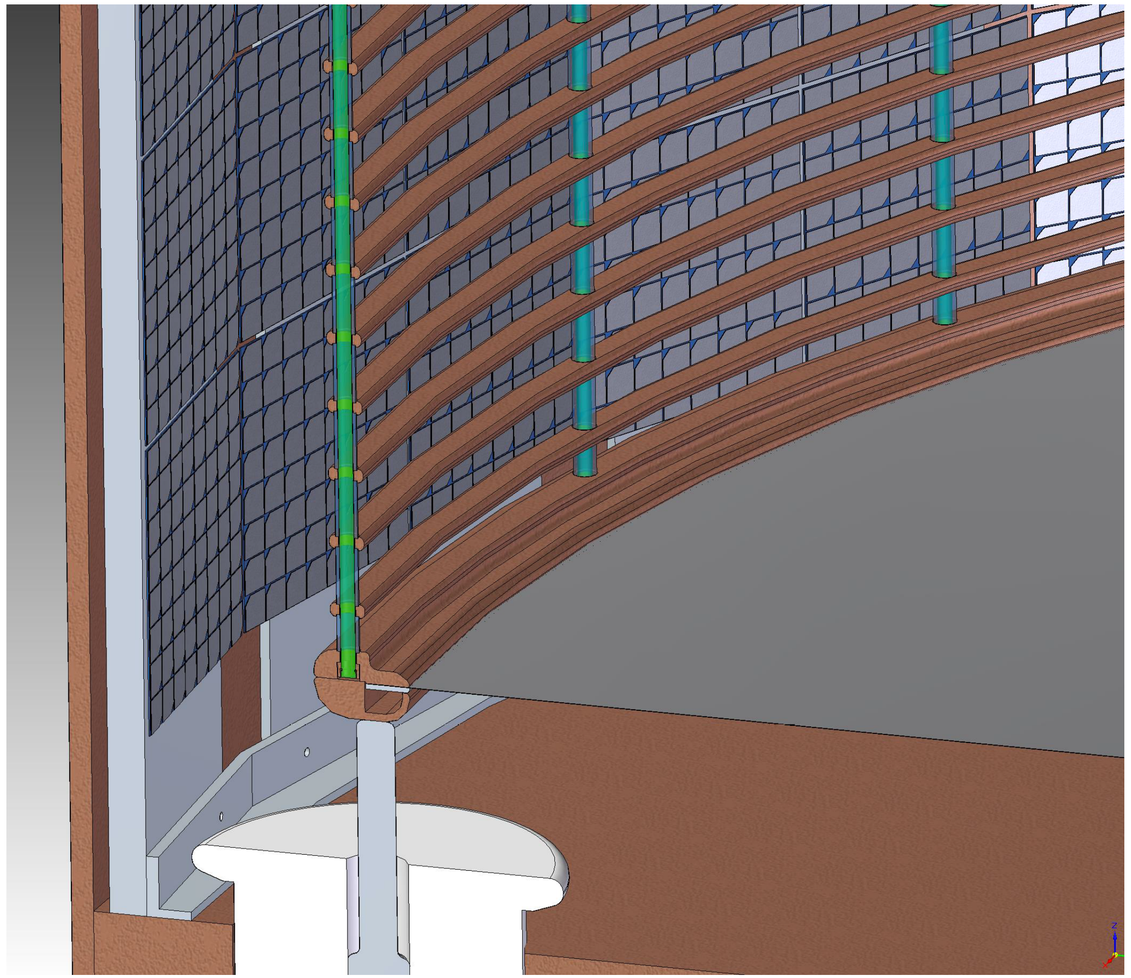
- SiPMs have matured substantially over past decades and present an attractive alternative to traditional APDs and PMTs
- nEXO is running extensive measurement campaign to
  - fully characterize performance of SiPMs at the device level
  - measure optical properties of SiPMs and passive materials in Liquid Xenon
- Large area scaling of SiPM readout requires careful design to comply with radio-purity and xenon purity requirements
- GPU-based light simulations useful to accelerated design optimization of large next generation detectors

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