Light only Liquid Xenon Experiment

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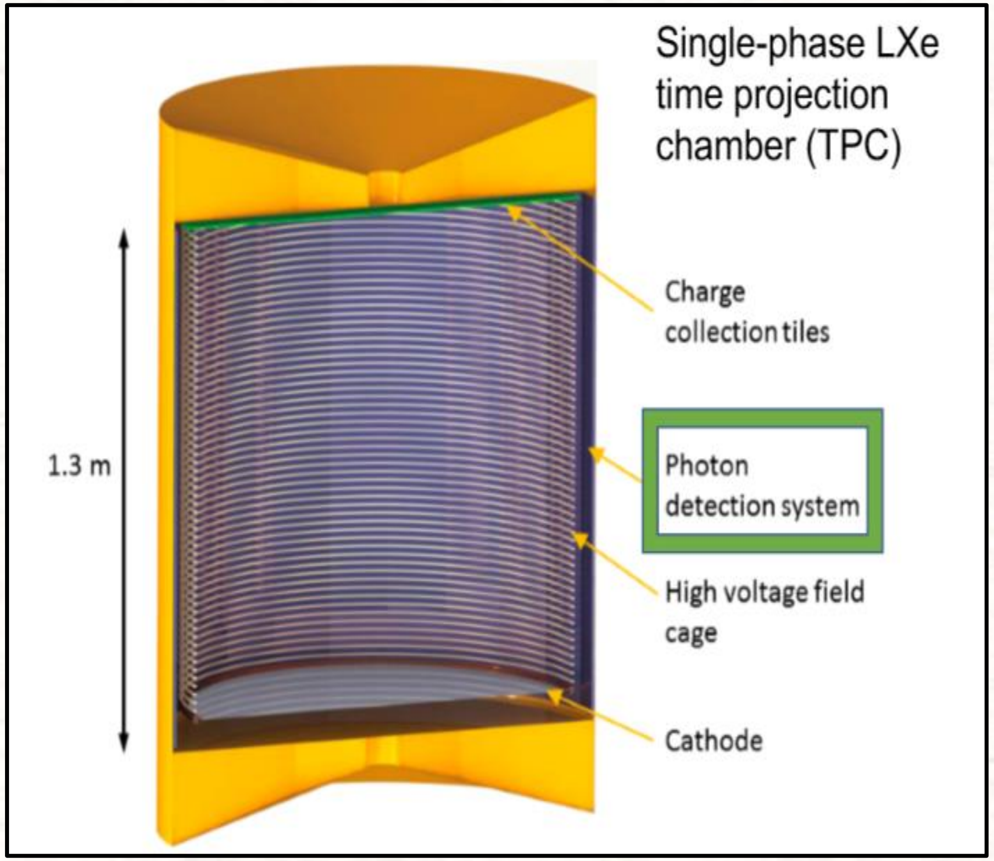
Enriched Xenon Observatory (nEXO)

- nEXO is a single-phase tonne scale Liquid Xenon (LXe) experiment
- Looking for hypothetical neutrino-less double beta decay in an isotope Xe-136
- Silicon Photomultipliers sensitive to Xenon scintillation photon (175nm) are planned to deploy in light detection system of nEXO

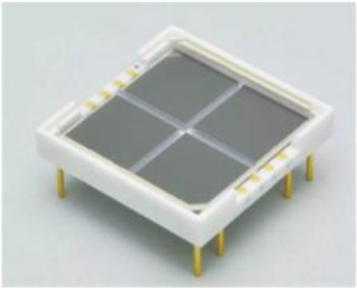
LoLX is a R&D project dedicated to SiPM based light detection system of nEXO



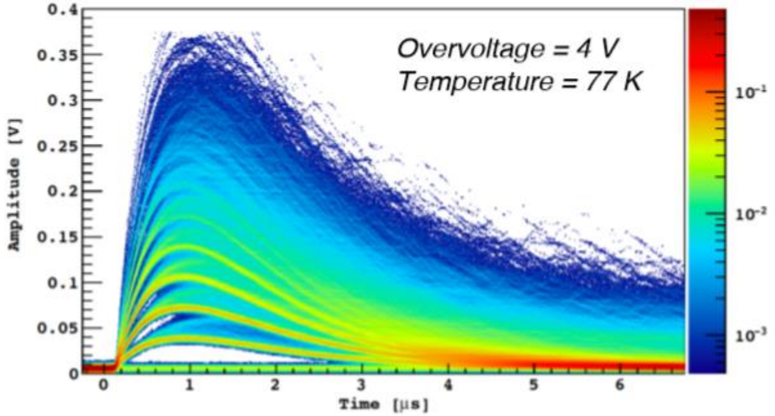
Sketch of the planned nEXO TPC; arXiv:1805.11142

Silicon Photomultipliers (SiPMs)

- Avalanche photodiode operating above breakdown voltage
- Capable to detect single photon
- High photon detection efficiency
- Operate at modest voltage



Hamamatsu VUV4 2x2 MPPC array



Example persistence plot from FBK NUV-HD-LF-HRq SiPM

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- o Sensitive to light in 175nm region (scintillation light of liquid Xenon)
- o Low mass and low radioactivity
- o Operation at noble liquid temperatures!
- o Additional correlated noise like cross-talk and after-pulsing comes into play in SiPMs.

Motivation for LoLX

Energy resolution of nEXO

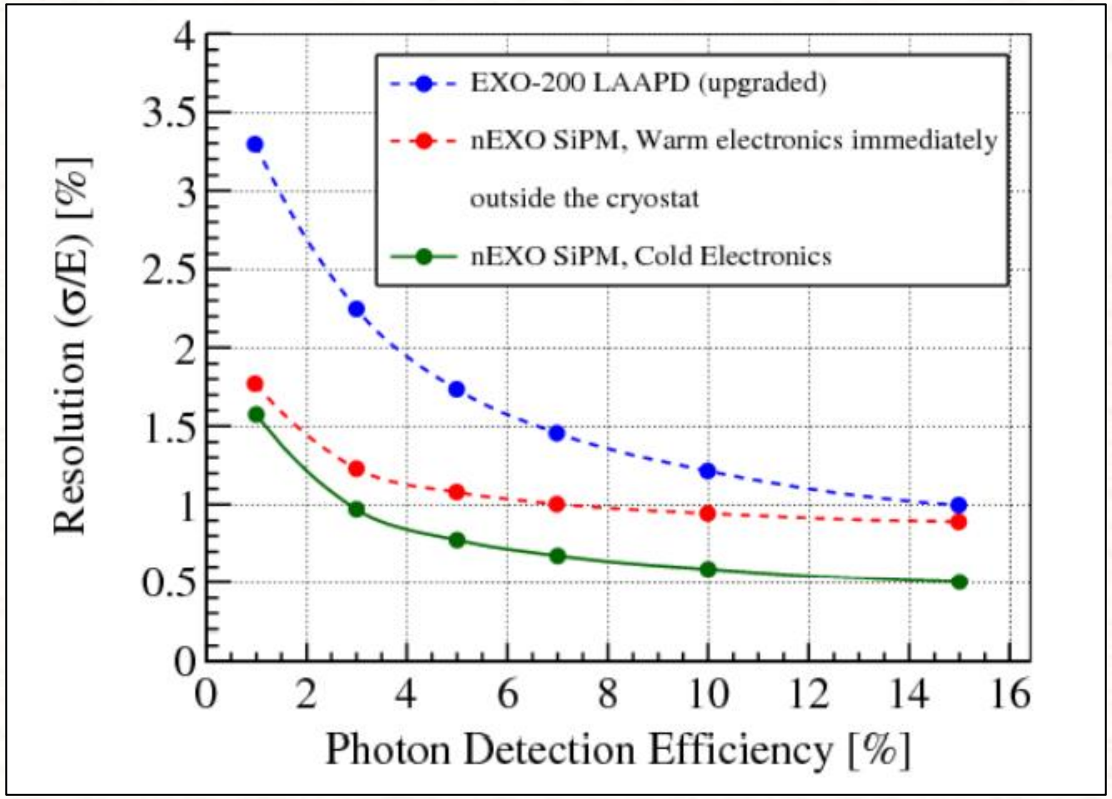
- nEXO aims to achieve 1% overall detector resolution to achieve its physics goals
- Scintillation light detection efficiency is a key factor

Background discrimination techniques

- Discrimination between scintillation and Cherenkov light to explore new background rejection methods for future particle physics experiments

Fast timing light processing

- Fast timing (~10 picoseconds) light detection for temporal separation of signals will lead to advancements in Time Of Flight (TOF)-Positron Emission Tomography (PET)



Energy resolution as a function of the overall scintillation light detection efficiency at a 400 V/cm drift field. arXiv:1805.11142

Objectives of LoLX

Phase 1

- Gain experience in operating SiPMs in LXe
- Light production measurements in LXe using radioactive source Sr-90
- External cross-talk for SiPM and scintillation & Cherenkov yield measurement in LXe
- Compare the LoLX measurements with the simulations

Phase 2

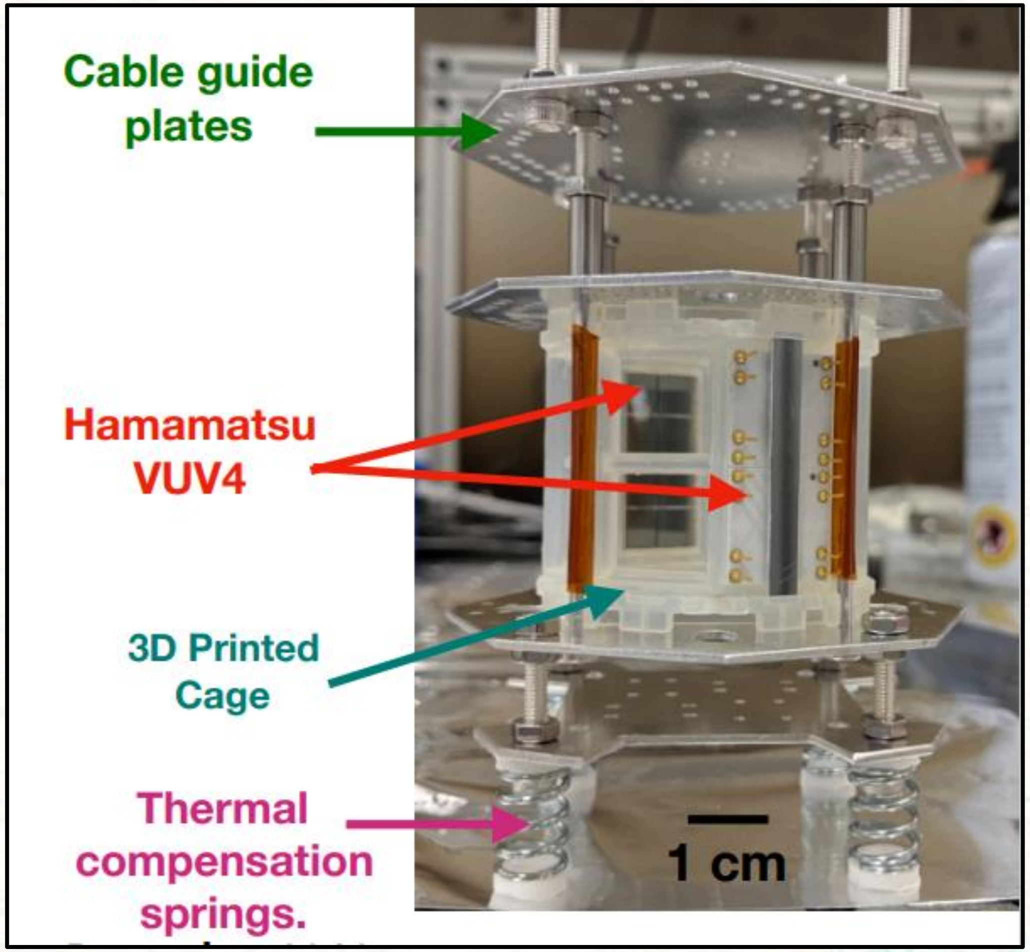
- Upgrade electronics with better resolution (~100 picoseconds)
- Study the time structure of scintillation light in LXe

Phase 3

- Install fast timing 3D SiPM (resolution ~10ps) in LoLX and evaluate their performance in LXe
- Temporal separation of Cherenkov and scintillation photon signals

LoLX detector (Phase 1)

- Octagonal prism geometry
- 3D printed cage to hold SiPMs
- 24 Hamamatsu Quad VUV4 SiPMs
  - 22 SiPMs are covered with long pass (longer than 240nm) optical filter
  - 1 SiPM is covered with band pass filter centred at (172±20)nm
  - 1 SiPM is left bare
- Radioactive source Sr-90 at the tip of needle at centre of detector
- Currently operational at McGill

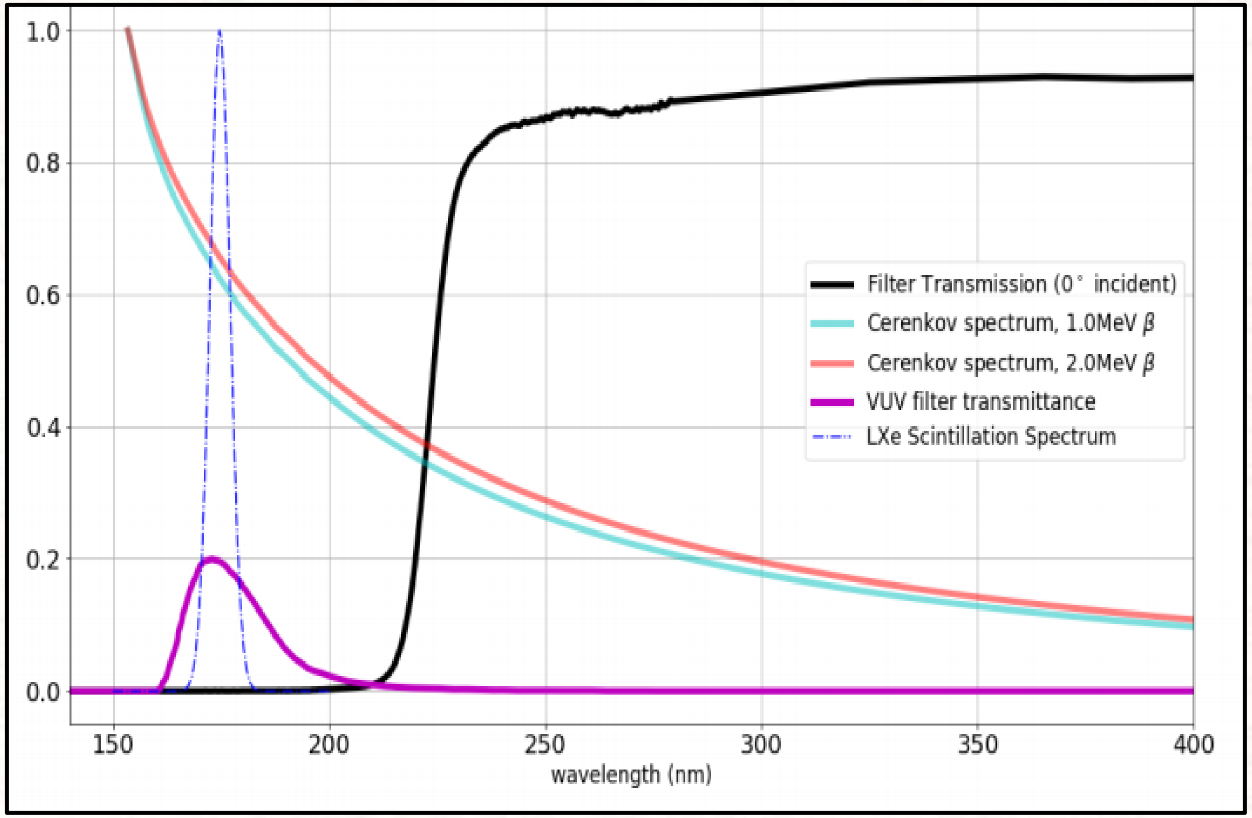


LoLX detector

Optical Filters

Long pass filters: allow long wavelength (higher than 225 nm) Cherenkov light in LXe but block scintillation photon (175 nm) to trigger SiPMs

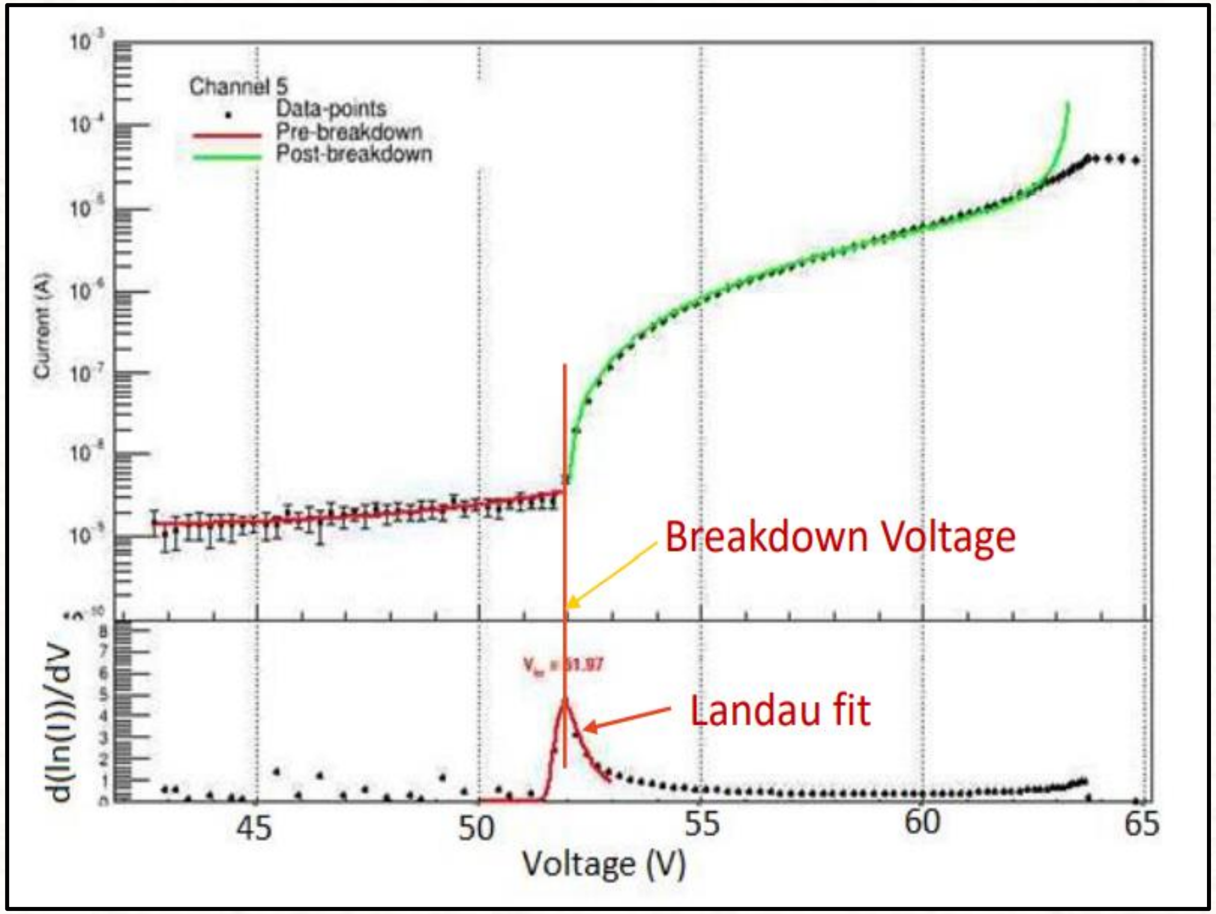
Band pass filter: centres at (175±20) nm allowing scintillation photons in LXe to trigger SiPM



Scaled scintillation and Cherenkov spectra overlayed with filter data taken at normal incidence

SiPM IV curves

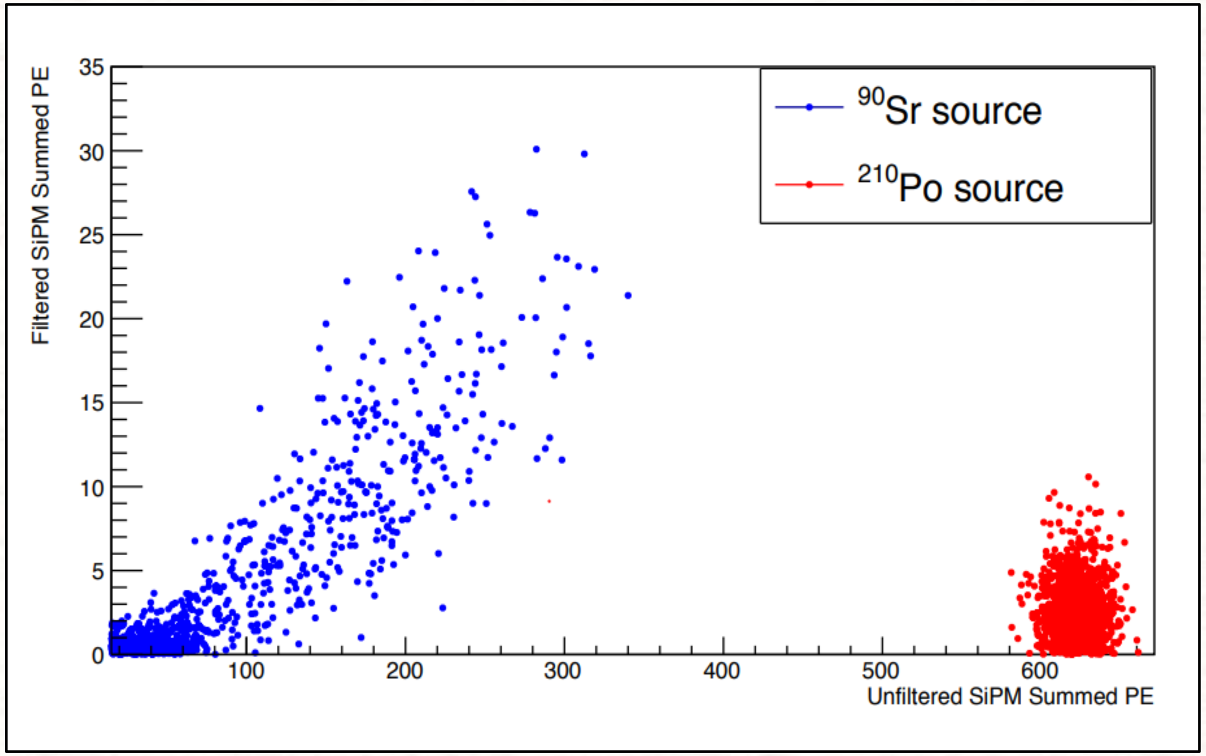
- IV characterisation for all 96 SiPMs
- Working on improving I-V fit for SiPMs.
- I-V fit functions used to extract the key parameter "**Breakdown Voltage**" for operation of SiPM
- Dark noise rate, after-pulsing probability, crosstalk probability can be extracted with some other measurements
- Developing I-V curve analysis as a quick tool for quality assurance for SiPMs for nEXO



Current as a function of reverse voltage for single SiPM channel in LoLX. The I-V curve taken at 21° C.

Cherenkov and scintillation discrimination

- Preliminary simulation results using GEANT4 with input ex-situ optical measurements for all detector materials and components
- Sr-90 as beta source and Po-210 as alpha source
- A correlation between scintillation (unfiltered) and Cherenkov (filtered) signals can be seen for beta events
- Alpha events seen by unfiltered (Bare and band pass filter) as expected



Preliminary simulation results comparing the expected signals for beta and alpha events in LoLX phase 1.

External cross talk

- External cross talk events occurs when avalanche photons escape the SiPM and trigger another SiPMs
- It leads to false counting of photon signals in the detector that could degrade the detector resolution
- Emitted photons are in Infra-Red(IR) range
- Band pass filter block these photons to trigger the SiPM, while long pass filters will allow them to pass.

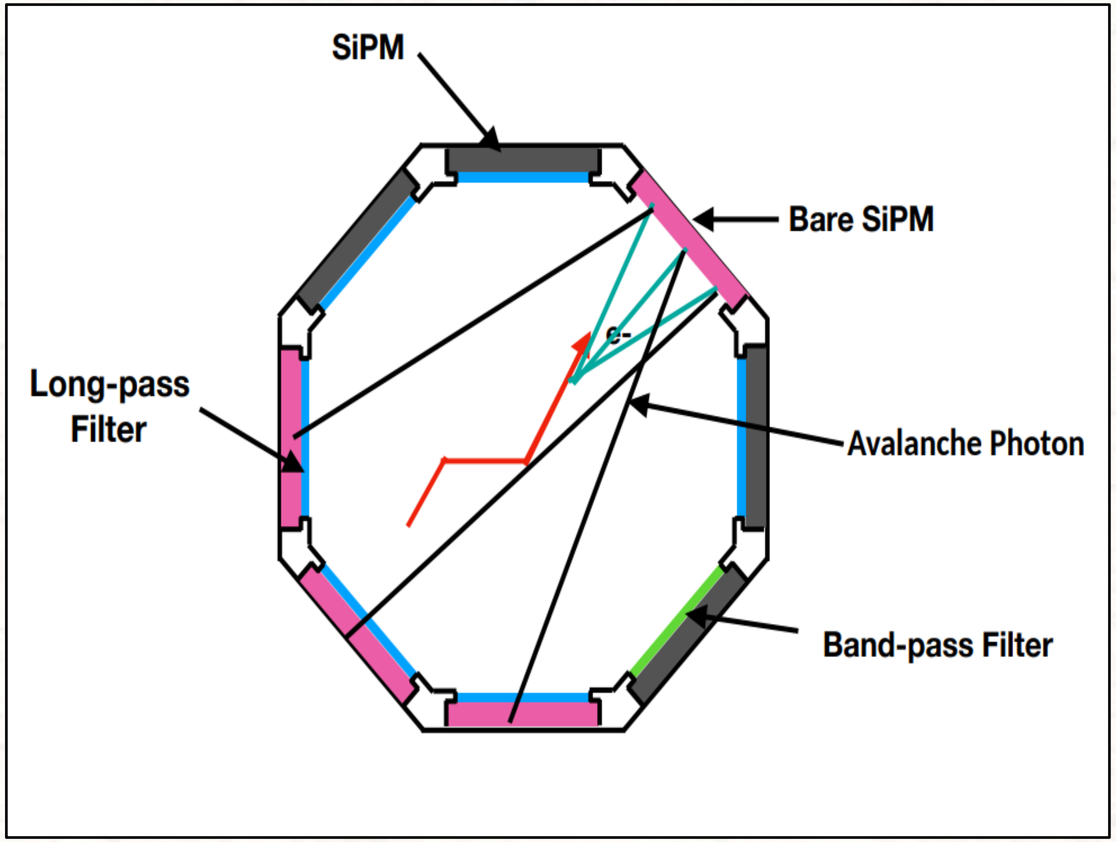
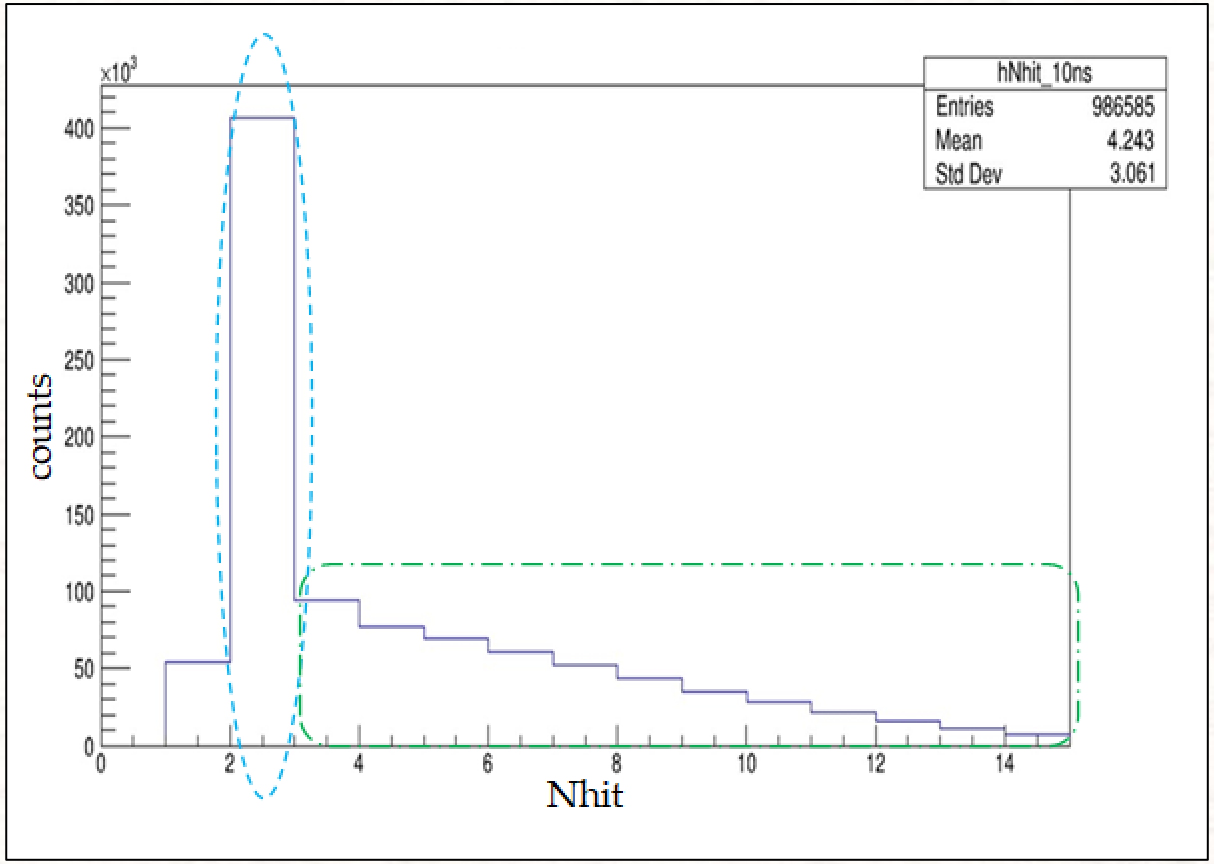


Diagram showing the external cross-talk by photons coming from bare SiPM triggering another SiPMs

External cross-talk measurements

- The data set was taken in cold nitrogen gas with an objective of measuring the external cross-talk between SiPMs
- Nhit represents the number of channels being hit in a single event
- Nhit = 2 may be mainly contributed by external cross-talk events and Nhit > 2 may be light induced events
- A detailed data analysis and simulation for external cross talk is still in progress



Number of channels hit within a narrow time window in a single event

Conclusions

- Successfully commissioned and installed the LoLX in cryostat and is operational at McGill
- In July 2020, LoLX was first operational in cool nitrogen gas. This run focussed on measuring the external cross-talk in SiPMs
- In Dec 2020, Xenon was condensed in the cryostat. A test physics data was taken in LXe
- I-V curve analysis used to extract SiPM working parameters.
- Data analysis and simulations for the measurements are ongoing.
- Physics data in Liquid Xenon is planned for LoLX in coming weeks

LoLX group

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