LoLX: Light-only Liquid Xenon experiment

D. Gallacher [1] on Behalf of the LoLX Collaboration

[1]McGill University, Montreal, Quebec, Canada

1. The LoLX Experiment

The Light-only-Liquid Xenon (LoLX) experiment is a modular liquid xenon prototype detector designed to perform studies of light emission, transport and detection in liquid xenon (LXe) using silicon photomulitpliers (SiPMs).

The current LoLX design uses a 3D printed cage to hold 24 Hamamatsu VUV4 Quad packages [1], which contain 4 SiPMs each. A partially assembled LoLX detector is shown in fig. 2. The detector is housed inside a cryostat located at McGill University. The cryostat is cooled with a liquid nitrogen loop, and a hot zirconium getter is used to purify gaseous xenon before condensing into LXe.

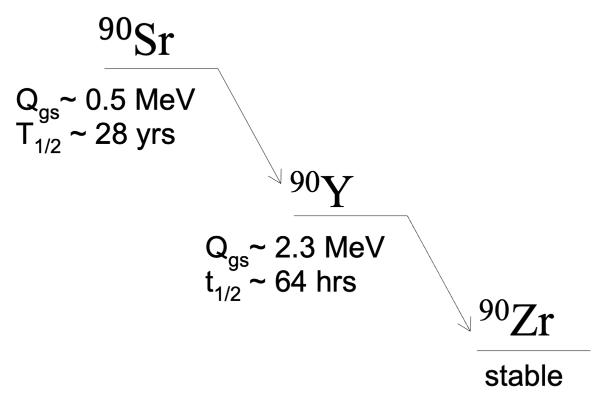

Figure 1. Decay scheme of the ^{90}Sr source used in LoLX

LoLX is fully submerged in a LXe volume and uses 96 SiPMs to measure LXe scintillation and Cherenkov radiation from a ^{90}Sr source needle (fig. 1) as shown in fig. 3.

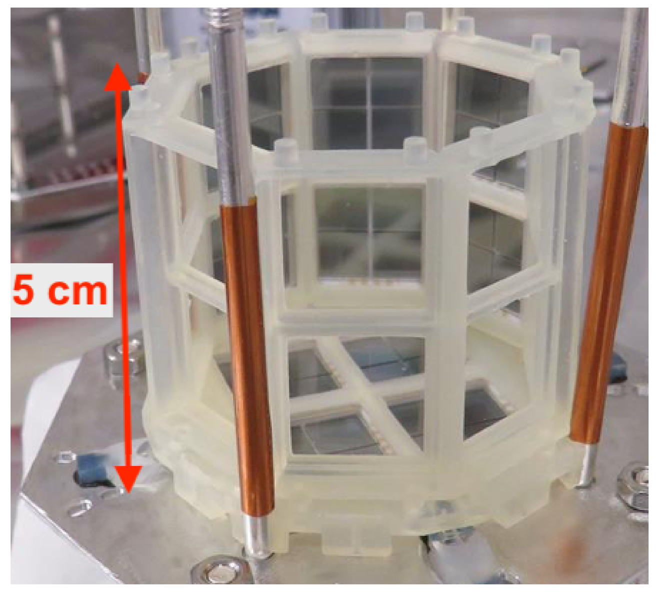

Figure 2. Partially assembled LoLX Detector, with Hamamatsu VUV4 SiPMs [1], and 3D printed cage.

2. Motivation and Physics Goals

LoLX employs wavelength filters on 23 out of 24 packages, these are used to separate scintillation light (peaked at 175 nm) from Cherenkov radiation (broad band into visible region). The SiPM filters, as shown in, fig. 4 are as follows:

1. 22 Longpass filters, allowing light > 220 nm to pass
2. 1 bandpass filter, allowing only LXe scintillation light
3. 1 unfiltered package

LoLX main physics goals aim to improve understanding of LXe detector performance, immediate goals are listed below.

- **SiPMs in LXe** - Validate performance of VUV sensitive SiPMs in LXe and characterize their performance.
- **Optical Transport** - Compare detector results to photon transport simulations to inform simulation models.
- **Cherenkov and Scintillation Light Separation** - Characterize the separation of LXe scintillation light from Cherenkov radiation, first using spectral filters, and in the upgraded detector with timing separation.

Studies of LXe properties and SiPM characterization will inform simulation models for nEXO, the planned neutrino-less double-beta decay experiment [2], which will employ 5 tonnes of double-beta decaying isotope ^{136}Xe.

References

[1] G. Gallina *et al.*, "Characterization of the hamamatsu vuv4 mppcs for nexo," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 940, pp. 371–379, 2019.

[2] G. Adhikari *et al.*, "nEXO: neutrinoless double beta decay search beyond 10^{28} year half-life sensitivity," *Journal of Physics G: Nuclear and Particle Physics*, vol. 49, p. 015104, dec 2021.

[3] L. Galli, A. Baldini, F. Cei, M. Chiappini, M. Francesconi, M. Grassi, U. Hartmann, M. Meucci, F. Morsani, D. Nicolò, A. Papa, S. Ritt, E. Schmid, and G. Signorelli, "Wavedaq: An highly integrated trigger and data acquisition system," *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, vol. 936, pp. 399–400, 2019. Frontier Detectors for Frontier Physics: 14th Pisa Meeting on Advanced Detectors.

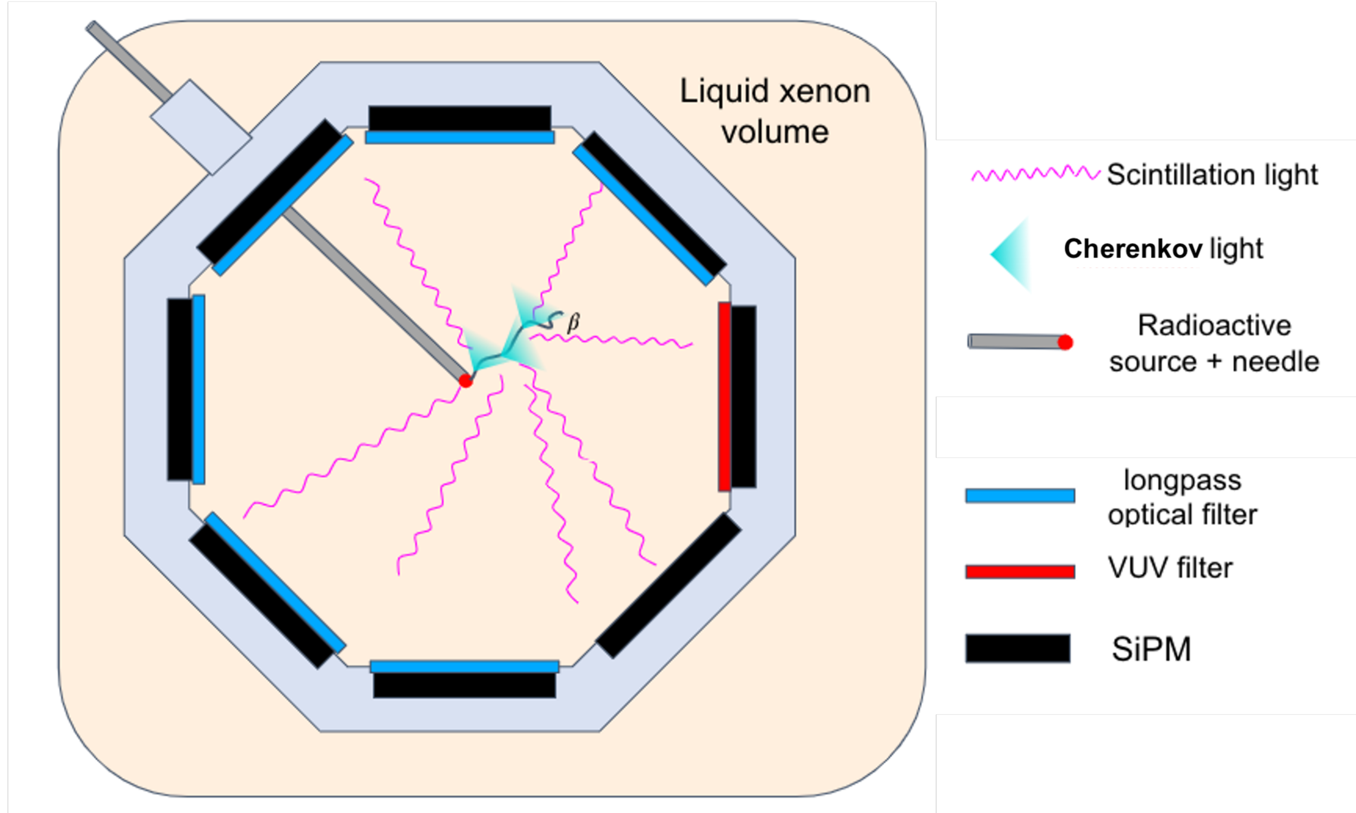

Figure 3. Diagram illustrating source decay within LoLX. The source needle tip is coated with ^{90}Sr, which has decays as shown in fig. 1

3. Light Detection and Signal Readout

The light signal readout system in LoLX is outlined below:

1. **Source** - Beta decays from the ^{90}Sr source needle produce LXe scintillation + Cherenkov light inside LoLX
2. **SiPMs** - Light propagates through LXe to the SiPMs surrounding the inner volume, scintillation light may be attenuated by the longpass filters surrounding 22/24 SiPM packages
3. **Analogue Readout** - SiPM avalanche charge is amplified by a custom RF amplifier board with a gain of 100. Longpass SiPM packages are actively summed 4:1 to reduce readout channels
4. **Analogue-to-Digital Converter** - Amplified analogue SiPM signals are converted into digital waveforms using a CAEN V1740 and stored to disk for analysis
5. **Analysis** - Baseline offset and distortion are corrected in analysis before pulse-finding is applied to extract timing, charge, and height of all pulses in each waveform and stored into a custom data-structure for subsequent analysis

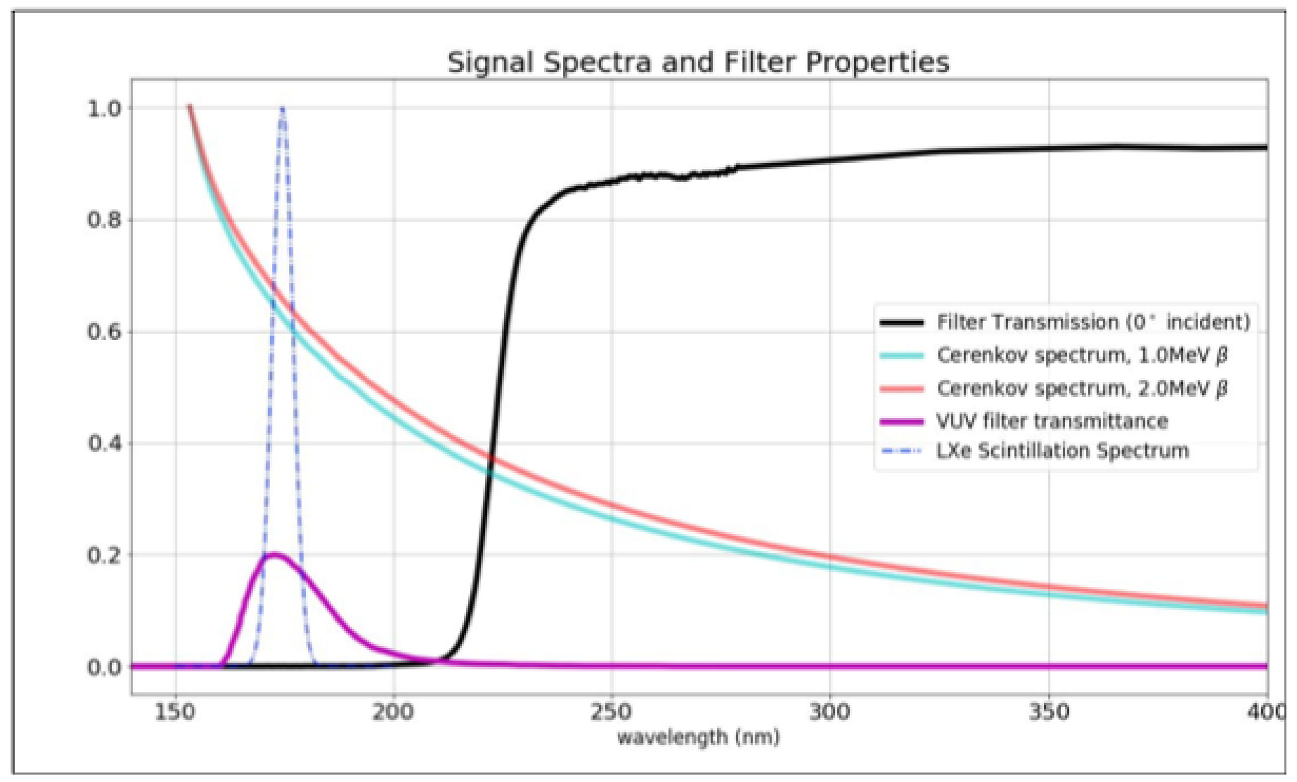

Figure 4. Transmission of LoLX optical filters overlaid with expected scintillation and Cherenkov signals

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4. Measurement Outline

- To measure the ratio of Cherenkov light to scintillation light, we trigger on any of the unfiltered SiPM channels that have more than 2 avalanches at once
- The light intensity for the longpass filtered SiPMs and the unfiltered SiPMs are normalized to the total number of SiPMs and plotted against each other for comparison
- The ratio of longpass to unfiltered signal is then compared to a GEANT4 based simulation

5. Initial Results

We compare here the ratio of total unfiltered signal to longpass filtered signal from data, normalized to the number of SiPMs in each group. The turning point in the distribution represents a combination of the transition from ^{90}Sr dominated decays to ^{90}Y decays, and the Cherenkov threshold for producing significant visible light.

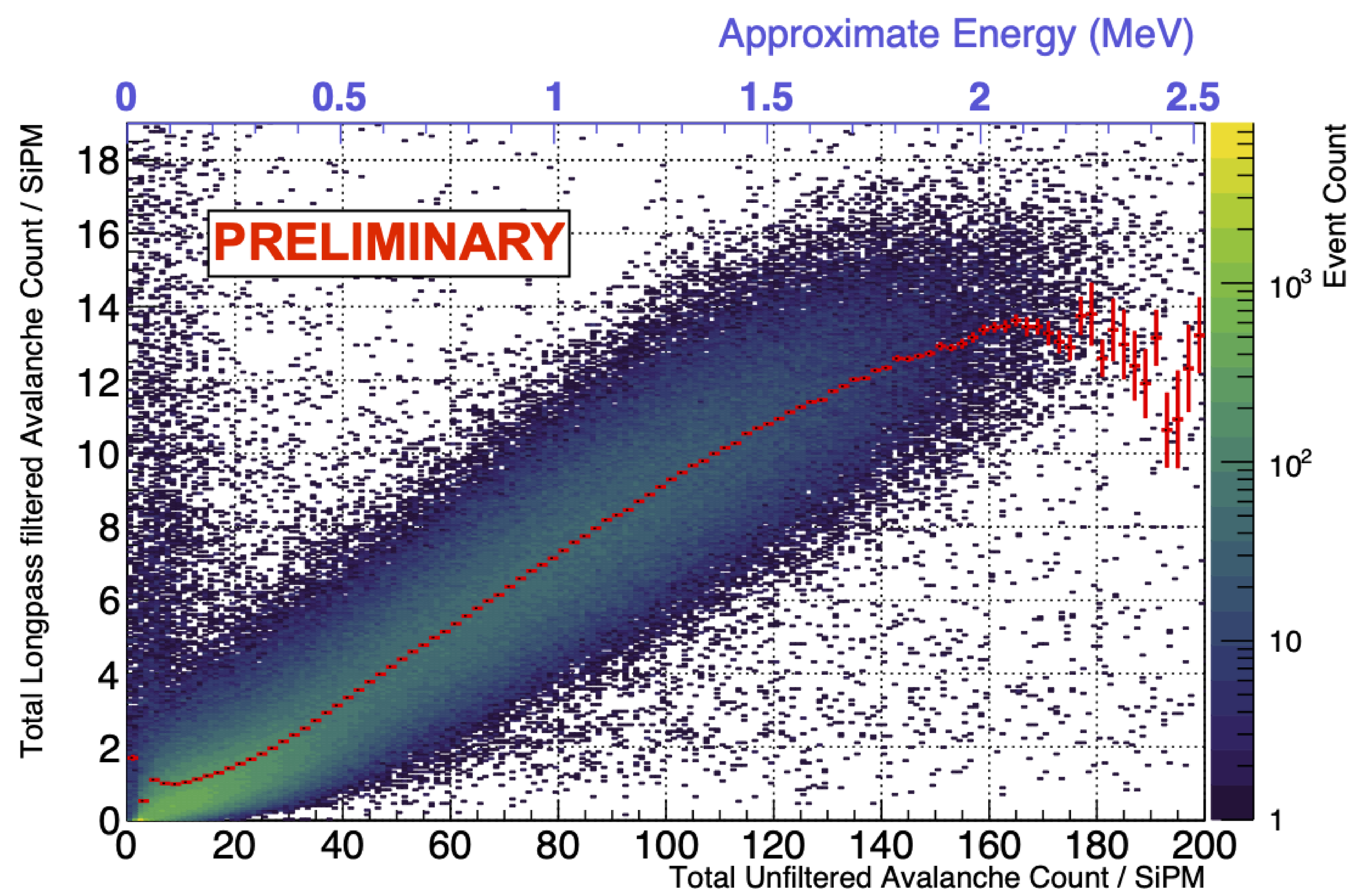

Figure 5. Distribution of total longpass filtered signal versus unfiltered SiPMs signal, shown with the profile of the distribution overlaid in red. The turning point is clearly visible here at ~20 avalanches in the unfiltered channels, ~250 keV in beta energy.

6. Discussion and Next Steps

Analysis

Due to suspected background sources of visible light, the yields in the longpass filtered channels from data are substantially higher than the expected yields from simulation. Significant fluorescence of the 3D printed cage has been measured ex-situ at McGill University, and is the leading hypothesis to explain the excess in data. Plans to replace the current cage with an aluminum support structure are underway and will enable detailed measurements of Cherenkov yields.

Upgrades and Future Plans

LoLX has begun a series of upgrades, targeting key areas of difficulty in the current design. These areas include, cryogenics, data-acquisition and purity considerations.

The current LN2 cooling system will be replaced with a cryo-cooler system in the summer of 2022, this will enable long-term studies of SiPM performance in LXe.

The data-acquisition (DAQ) system has been upgraded from CAEN V1740 digitizers, to custom ADCs, known as the 'WaveDAQ', on loan from the MEG-II collaboration [3]. The upgraded DAQ system is capable of digitizing at rates between 1-5 GSPS and is being commissioned. The upgraded DAQ will enable timing separation studies of Cherenkov from LXe scintillation with O(100 ps) timing.