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Xenon Doping of Liquid Argon

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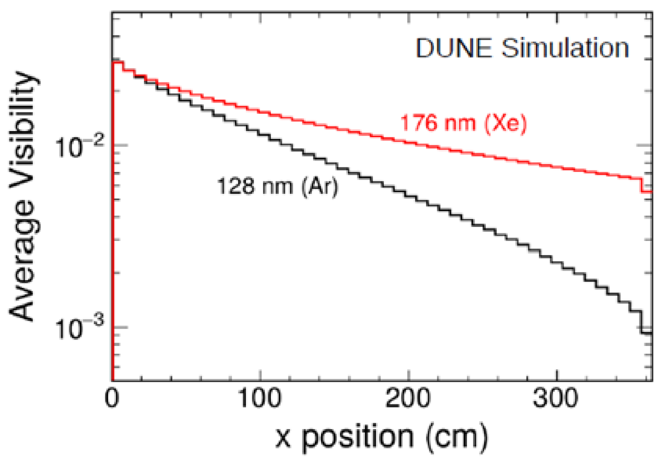
Doping liquid argon with xenon will shift the peak scintillation wavelength towards longer wavelengths. Tests were performed on photon detectors, light absorbing materials, and other equipment in preparation for an experiment on the scintillation of liquid argon doped with xenon.

Motivation

Liquid argon is an excellent medium for scintillation because it is inexpensive, has high scintillation efficiency, and can be purified easily. When an ionizing particle travels through liquid argon, it excites the argon and gives off scintillation light. This light has a wavelength of 128 nm, which is too small for most photon detectors to detect. Doping argon with xenon will shift the wavelength of the light, because xenon emits a photon at 175 nm.

Xenon doped argon is more efficient than other wavelength shifters because it is volume distributed. This method of wavelength shifting simplifies data collection and analysis because it improves light collection in large detectors, such as the Deep Underground Neutrino Experiment (DUNE).

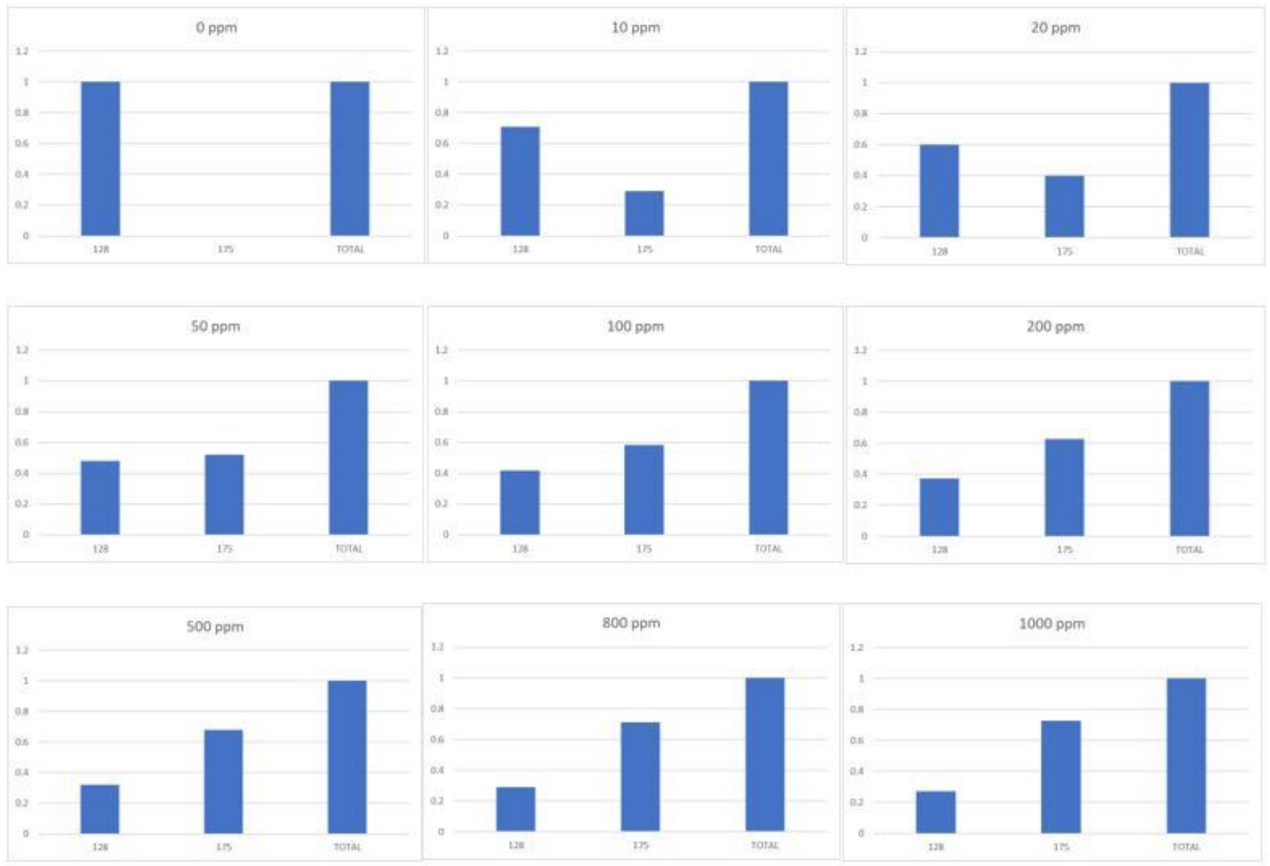
$$l^{-1} = \frac{16\pi^3}{6\lambda^4}\left[kT\rho\kappa_T\left(\frac{(n^2-1)(n^2+2)}{3}\right)^2\right]$$



Kinetics

$$\text{Rate of Argon Light Output} = \lambda_{Ar,1}N_0 q e^{-\lambda_{1m}t} + \lambda_{Ar,3}N_0(1-q)e^{-\lambda_{3m}t}$$

$$\text{Rate of Xenon Light Output} = \frac{\lambda_m\lambda_d N_0\left(p\lambda_d(\lambda_{Xe,3}-\lambda_{Xe,1})+\lambda_{Xe,3}(\lambda_{Xe,1}-\lambda_d)\right)\left((1-q)\lambda_{1m}+q\lambda_{3m}-\lambda_d\right)}{(\lambda_d-\lambda_{3m})(\lambda_d-\lambda_{1m})(\lambda_{Xe,1}-\lambda_d)(\lambda_{Xe,3}-\lambda_d)}e^{-\lambda_d t}$$
$$+\frac{\lambda_d\lambda_m\left(p\lambda_{1m}(\lambda_{Xe,3}-\lambda_{Xe,1})+\lambda_{Xe,3}(\lambda_{Xe,1}-\lambda_{1m})\right)qN_0}{(\lambda_d-\lambda_{1m})(\lambda_{Xe,1}-\lambda_{1m})(\lambda_{Xe,3}-\lambda_{1m})}e^{-\lambda_{1m}t}+\frac{\lambda_d\lambda_m\left(p\lambda_{3m}(\lambda_{Xe,3}-\lambda_{Xe,1})+\lambda_{Xe,3}(\lambda_{Xe,1}-\lambda_{3m})\right)(1-q)N_0}{(\lambda_d-\lambda_{3m})(\lambda_{Xe,1}-\lambda_{3m})(\lambda_{Xe,3}-\lambda_{3m})}e^{-\lambda_{3m}t}$$



CONCENTRATION	ARGON	XENON
0	1	0
10	0.70999	0.29002
20	0.59950	0.40050
50	0.47889	0.52111
100	0.41692	058308
200	0.37255	0.62745
500	0.32034	0.67966
800	0.28916	0.71084
1000	0.27248	0.72752

These results were obtained by integrating equations for light output for argon and xenon over a time interval from zero to infinity.

Conclusion

The results obtained from testing SiPMs #33 and #37 helped develop a better understanding of their characteristics. A significant amount of light was observed in the liquid argon using an alpha source. The breakdown voltages were found, which establishes a lower threshold for the voltage range.

The purity testing of the MetalVelvet sample proved that it is safe to use in the main experiment. The sample only fell to a lifetime of 1 ms, which is not detrimental.

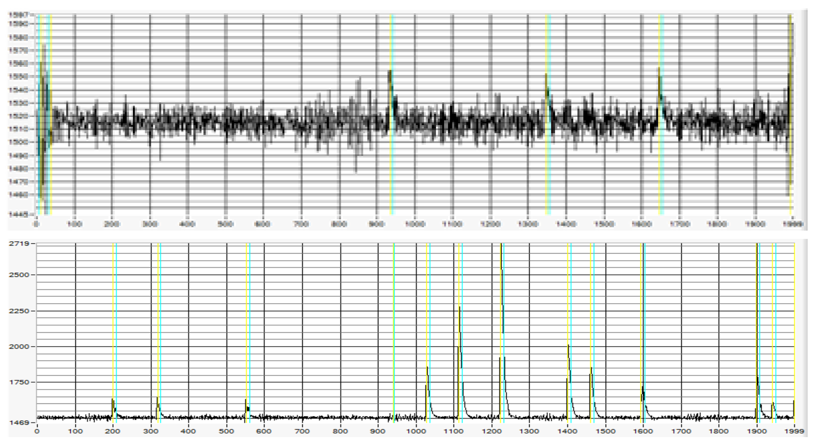
The graphs of the amount of wavelength shift per concentration establish a clear rubric for how much xenon dopant needs to be mixed with the argon. The graphs provide a visual key for determining the appropriate concentration.

Preliminary Work

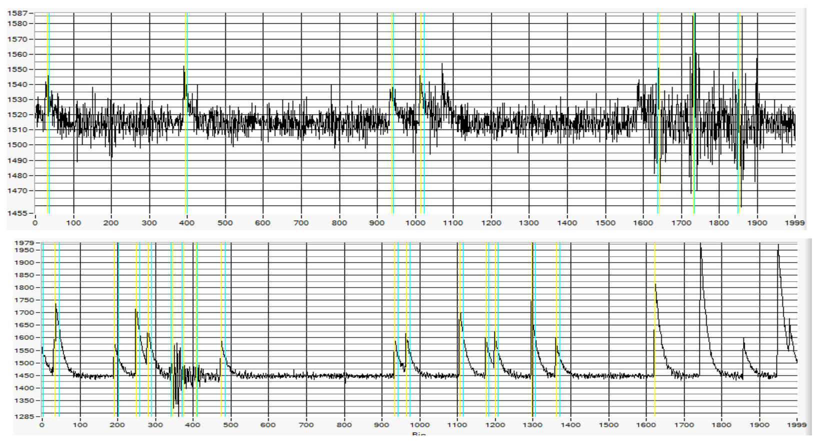
Fondazione Bruno Kessler Silicon Photomultipliers were tested using a SiPM Signal Processor to find their characteristics at room temperature and LAr temperatures using an Am^{241} source.

SIPM	CELL PITCH (μm)	CELL DENSITY (cells/mm^2)
#32	25	1600
#33	30	1156
#34	54	400
#35	24	1600
#36	30	1156
#37	54	400

Room Temperature: The breakdown voltage for SiPM #33 is 29.6V. The breakdown voltage for SiPM #37 is 28.6V. The following plots are the breakdown voltages of each SiPM and at 33V for comparison.

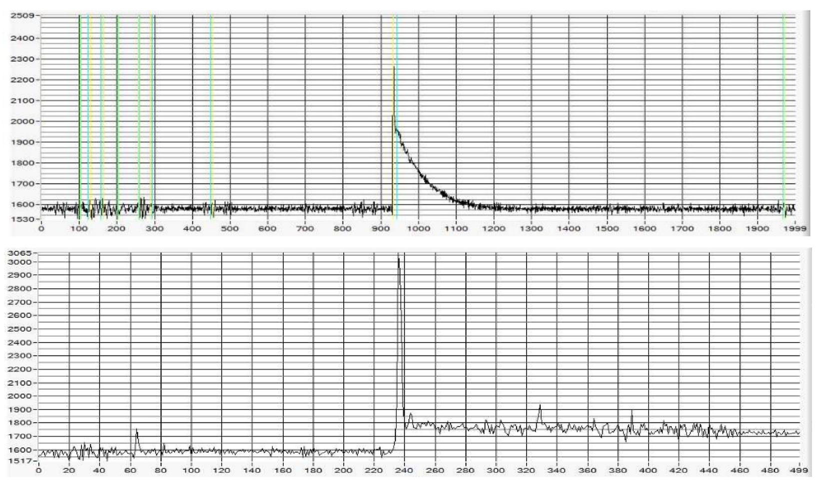


SiPM #33



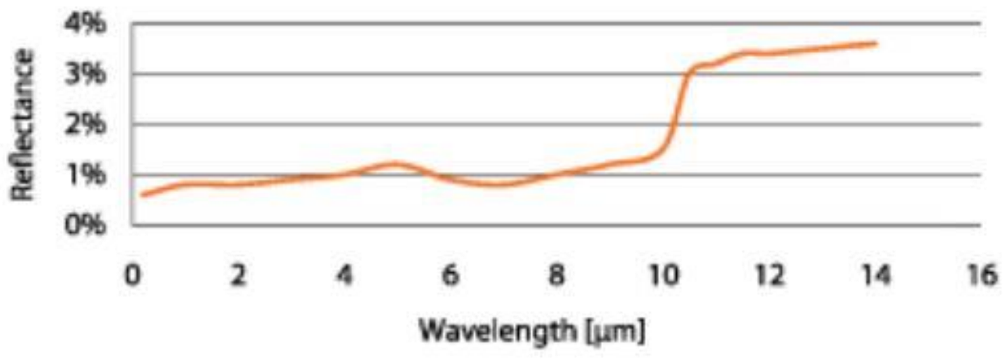
SiPM #37

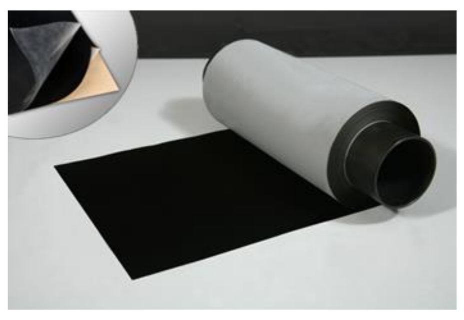
Liquid Argon Temperature: Only SiPM #37 was tested at 87K. The following plots are the typical waveform in gaseous argon (top) and the typical waveform in liquid argon (bottom). A significant amount of light is present in liquid argon.

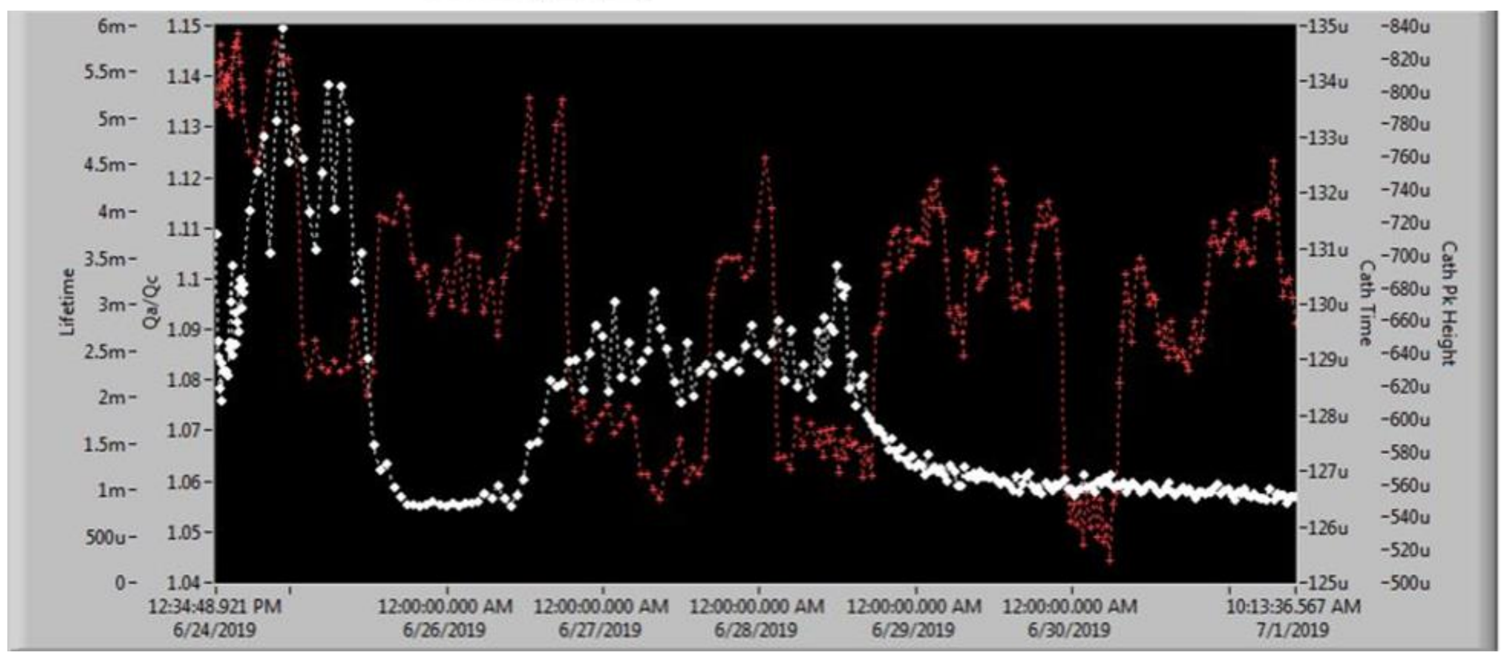


Purity Test

A light absorbing material named “MetalVelvet” was proposed to be utilized to absorb scattered light rays inside of the test chamber. MetalVelvet absorbs 99% of incident light over a wide range of wavelengths (from vacuum ultraviolet to infrared). Using this material along the inside of the test chamber would prevent reflected light from interacting with the detector and introducing systematic uncertainties in the data. MetalVelvet is not guaranteed to work at 84K, so it needed to be tested inside the cryostat LUKE.







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References

[1] Akimov, D., Belov, V., Konovalov, A. & Kumpan, A. Fast component re-emission in Xe-doped liquid argon. *Journal of Instrumentation* (2019).
[2] Buzulutskov, A. Photon emission and atomic collision processes in two-phase argon doped with xenon and nitrogen. *Europhysics Letters* **117**, (2017).
[3] Grace, E.: Calculation and Measurement of the Rayleigh Scattering Length of the Scintillation Wavelength of Liquid Argon for Dark Matter and Neutrino Detectors, (2017).
[4] Hitachi, A.: Photon-mediated and collisional processes in liquid rare gases. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment.* **327**, 11–14 (1993).
[5] Knoll, G.F. Radiation Detection and Measurement. John Wiley and Sons Inc. (2010).
[6] Kubota, S., Hishida, M., Himi, S., Suzuki, J. & Ruan, J. The suppression of the slow component in xenon-doped liquid argon scintillation. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* **327,** 71–74 (1993).
[7] MetalVelvet coating: Optical black coating, https://www.acktar.com/product/metal-velvet-2/.
[8] Neumeier, A., Dandl, T., Heindl, T., Himpsl, A. & Oberauer, L. Intense vacuum ultraviolet and infrared scintillation of liquid Ar-Xe mixtures. *Europhysics Letters* **109,** (2015).
[9] Piatek, S. What is an SiPM and how does it work?, https://hub.hamamatsu.com/jp/en/technical-note/how-sipm-works/index.html.
[10] Wahl, C. G. *et al.* Pulse-shape discrimination and energy resolution of a liquid-argon scintillator with xenon doping. *Journal of Instrumentation* **9,** (2014).

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