A camera for monitoring xenon-doped argon in the CHILLAX detector

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Xenon-doped liquid argon

Dual phase time projection chambers (TPCs) with liquid argon or xenon are well-studied detectors, especially valued for neutrino and dark matter detectors. Each element offers some advantages depending on the application. Argon is cheaper than xenon, and its lighter mass is kinematically preferable for neutrino and low mass dark matter detection. Xenon offers superior energy resolution and threshold due to longer wavelength scintillation and lower ionization energy. It may be possible to combine these advantages, yielding an excellent coherent elastic neutrino-nucleus scattering (CEvNS) detector for reactor monitoring.

The goal of the CoHerent Ionization Limits in Liquid Argon and Xenon (CHILLAX) experiment is to achieve a xenon-doped argon ionization detector. Energy deposited into the argon can be transferred to the xenon system. The scintillation light is then shifted to longer wavelengths, so it can be directly detected by SiPMs with much greater efficiency. Further, the lower ionization energy of xenon should lead to stronger S2 signals relative to pure argon. The S2 pulse shape will also be shorter, since triplet argon excimers are long-lived but can transfer energy into much more quickly decaying xenon excimers. This improves resolution of multiple scatters.

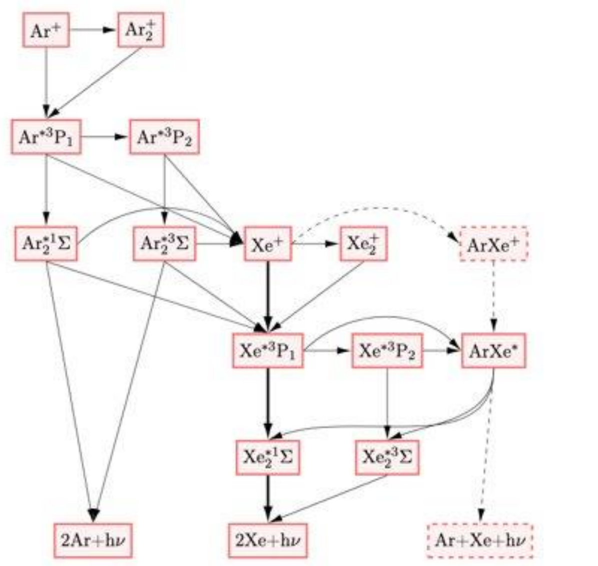


Diagram of the microphysical processes transferring energy from an argon recoil into the xenon system from *C. Galbiati et al, JINST 16 P02015 (2021)*

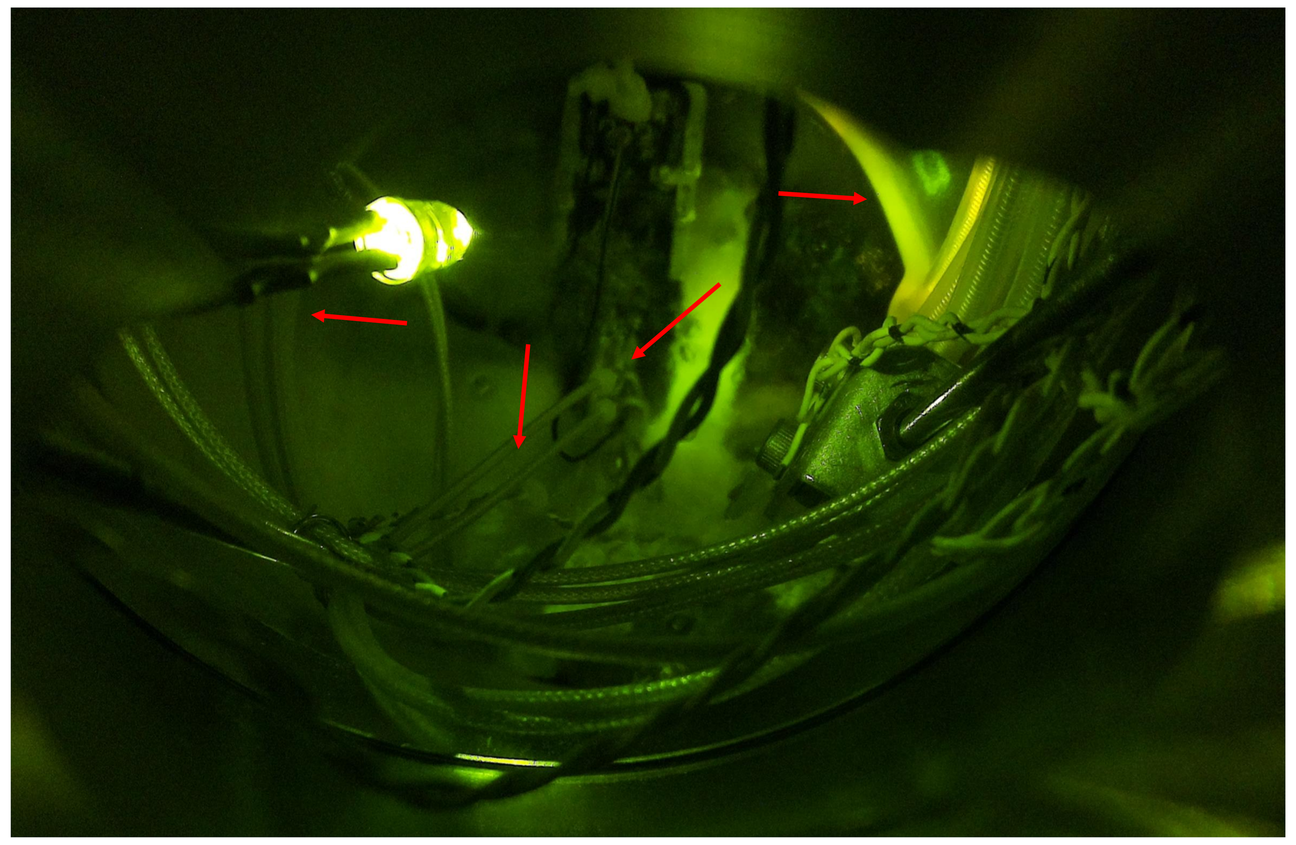
The CHILLAX detector (right) and heat exchanger (left)

Xenon is solid at liquid argon temperatures, so a xenon-doped argon detector must be carefully designed to ensure the xenon dissolves in the liquid rather than freezing. The CHILLAX cryogenic system is designed to cool and condense gas directly at the entrance to the detector volume. A heater near the detector inlet is used to keep xenon in a gaseous state until it is very near the liquid. See James Kingston's poster for more on CHILLAX.

Stability of argon-xenon mixture

During the first run with the camera, accumulation of ice upon surfaces in contact with the liquid surface was clearly visible after xenon doping. There is a thermal gradient in the detector from the room temperature flange it hangs from down to the cold liquid at the bottom, and it is expected that heat flowing down the detector may cause xenon to freeze out of solution.

As the liquid contacts warm surfaces, the argon will boil preferentially over xenon. This distillation effect increases the local concentration of xenon. If it then exceeds the solubility limit, the xenon freezes to the surface.



Xenon ice forms at the intersection of the liquid surface with other surfaces in the detector

Raspberry pi camera on cryogenic detector

To better judge the performance of the detector, and particularly the stability of xenon remaining dissolved in the liquid as opposed to freezing out, the CHILLAX team desired a view into the detector volume. At the end of December 2021, a Raspberry Pi camera was installed in the vacuum space, looking downwards into the detector volume through a viewport flange.

A challenge to using a camera in such conditions is maintaining a suitable operating temperature. Bench tests in a nitrogen-purged bag indicated that the camera's resolution degraded significantly below 200K, and it stopped working altogether around 150K.

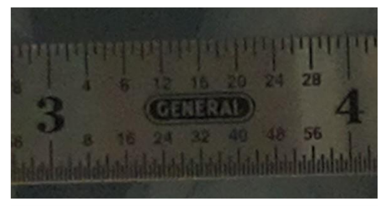


Photo of ruler taken 11" away at 290K

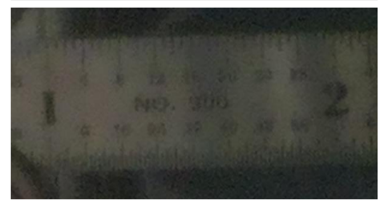
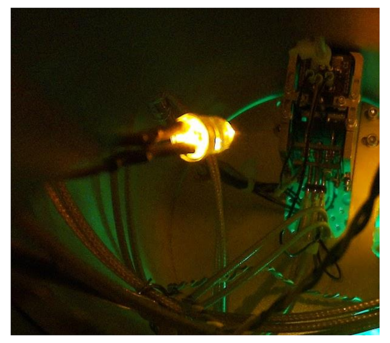


Photo of ruler taken 11" away at 175K

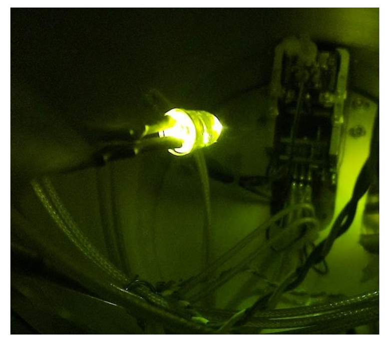
Camera mounted on top of detector

Given the liquid argon is around 87K, the camera needs to be thermally insulated from the detector and heated. Heat will not be dissipated well in the vacuum space, so overheating also must be avoided. To achieve this, the copper camera mount is coupled to the viewport via threaded PTFE rods surrounding the flange that thread into copper tabs held in place by the Conflat bolts. The camera mount, a thin flat copper piece, is held higher on the rods, and the couple millimeters of PTFE separating the mount from the stainless steel of the viewport is sufficient insulation for the heaters to keep the camera mount close to room temperature as indicated by a thermometer on the mount.

LEDs do continue to function at liquid argon temperatures. However, as they get colder, the band gap increases, causing the color and brightness to change. The voltage supplied to the LED circuit is manually changed during the cooldown to maintain sufficient illumination.



LED is orange with detector at room temperature



LED is yellow-green with liquid argon condensed in detector can

Bubbling

An unexpected observation from the camera in the first run after its installation was the presence of regular bubbling in the liquid. This is problematic for any dual phase TPC, as an unstable liquid level degrades S2 resolution. Further, in the xenon-doped argon TPC, liquid splashing onto surfaces may promote distillation and freezing of the xenon.

A modification to streamline bubbles from the liquid inlet directly to the gas phase has significantly improved the stability of the liquid surface.

Bubble chimney to suppress disturbance of liquid surface

Fairly vigorous bubbling in the detector

Thermal profile upgrades

To improve the stability of the xenon dissolved in the liquid argon, modifications have been made to decrease the thermal gradient along the detector can. A stronger thermal link from the cryocooler now directly cools the top flange of the detector, reducing heat flow down the walls. A run with this design modification has demonstrated slowed formation of xenon ice. However, there is still a clear rim of ice forming around the edge of the liquid surface, so the cooling of the detector walls above the liquid surface will be pushed further in future runs.

Upgraded solid copper thermal link between the cryocooler and top detector flange

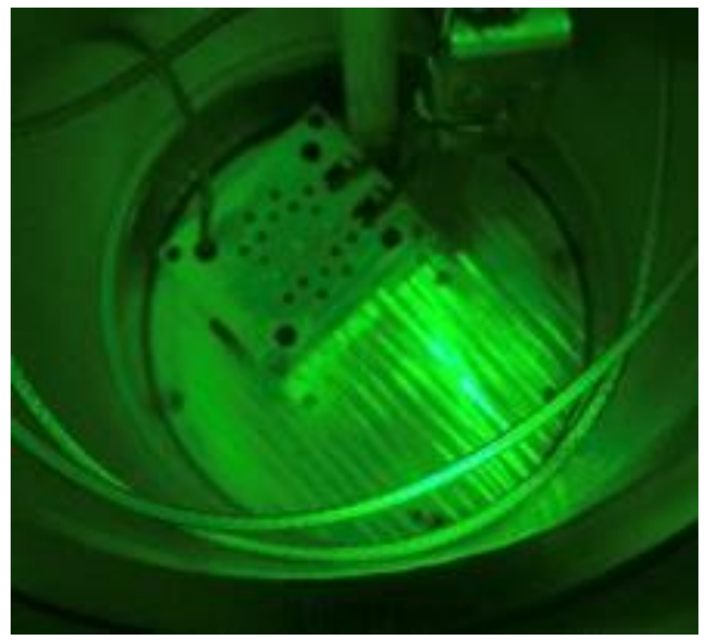
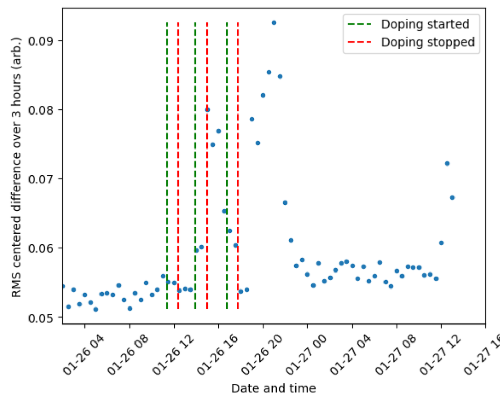


Photo demonstrating less xenon ice formation with new thermal link

Image comparison

Given the many stationary features in the detector volume, it is sometimes difficult to notice changes in the raw pictures by eye. However, the stability of the camera's view is ideal for image subtraction. The camera took photos every two minutes during the run; averaging over the photos within a half hour interval and subtracting over an earlier averaged set was useful for highlighting subtle changes.



A one-dimensional metric of image change may also be useful for quantifying system stability and correlating changes with logged operations and slow control values. In this case, RMS change in normalized images subtracted 3 hours apart does seem to respond to formation of xenon ice after doping, though it is also sensitive to changes in other conditions such as bubbling rate and slight movement.of the camera or detector components

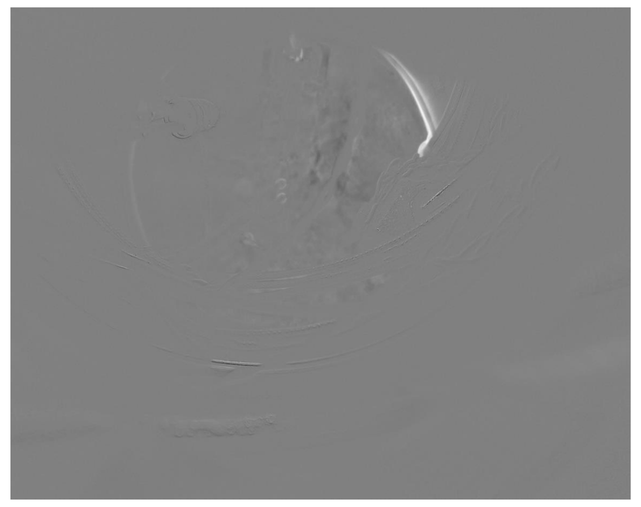


Image subtraction over 24 hour time period, revealing locations of xenon ice growth

Conclusion

CHILLAX is tackling the challenges of building a xenon-doped liquid argon TPC, which could be an excellent CEvNS detector. Installation of a Raspberry Pi camera viewing the detector volume has provided valuable insights on the detector performance. Although it is clear that xenon is freezing out of the argon on detector surfaces, progress is being made on reducing this effect.

Thanks to the CHILLAX team at LLNL for welcoming me and helping me with this project, and to the NSSC for providing the opportunity to work with them.

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