Recent Results from CHILLAX Xenon-Doped Argon R&D

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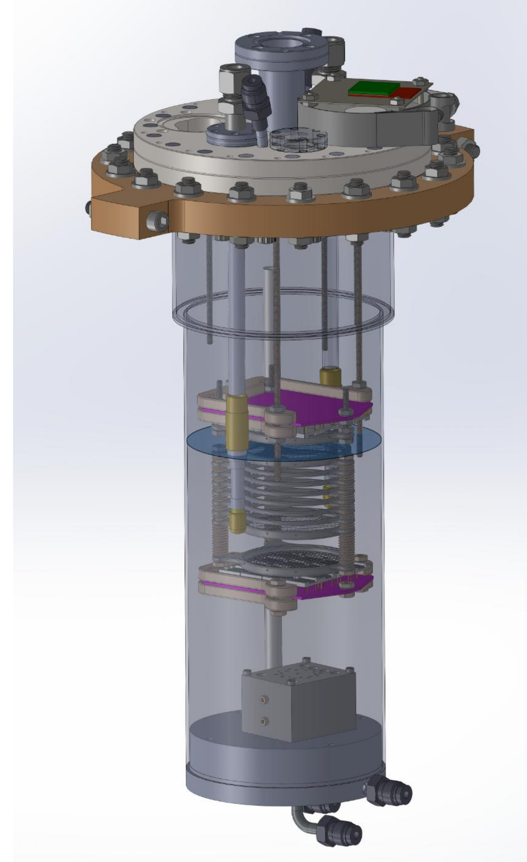
Doping liquid argon (LAr) with xenon produces a xenon-like scintillation profile at argon-like costs, combining target scalability with enhanced photon detection sensitivity. The CHILLAX experiment, demonstrating stable operation up to a record xenon concentration of 5% in liquid argon, characterizes the electroluminescence properties of these mixtures. We discuss the signal generation and detection architecture and analyze gas electroluminescence performance as a function of dopant concentration. Furthermore, we report on ongoing detector upgrades designed to improve sensitivity and support more versatile operation in upcoming studies.



A CAD model of the CHILLAX cryostat [1].

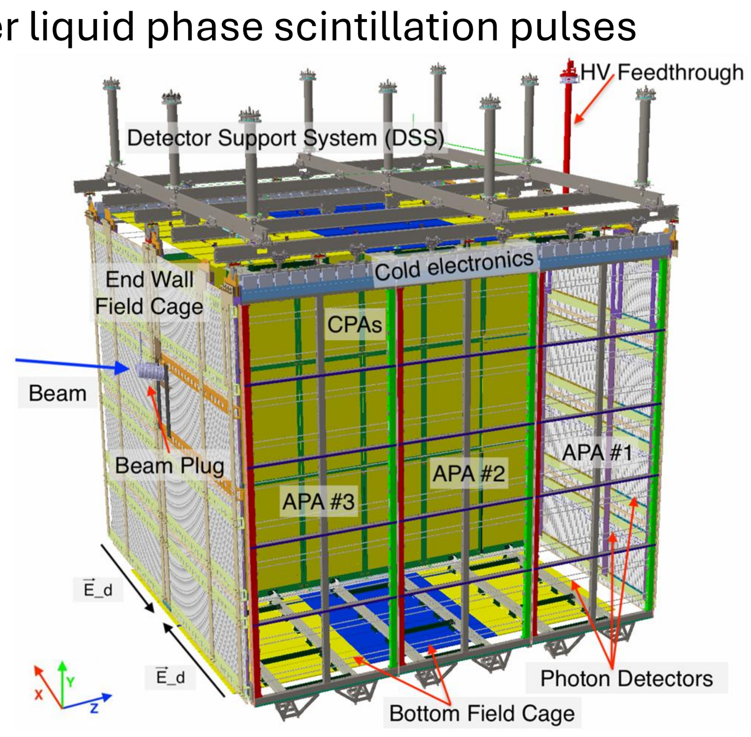
XENON-DOPED ARGON

Medium	Argon	Xenon
Relative Price	1	1900
Atomic Mass (amu)	39.94	131.3
Boiling Point (K)	87.15	165.2
Melting Point (K)	83.8	161.6
Scintillation Wavelength	128	178
Singlet lifetime in liquid [gas] (ns)	7 [6]	4 [7]
Triplet lifetime in liquid [gas] (ns)	1600 [3400]	22 [90]

Relevant data comparing argon to xenon [1].

Xenon, when doped to relatively small concentrations into argon, confers advantages to detection of its scintillation light and ionization charge.

- Wavelength shift from 128 nm to longer wavelengths
- Relative cheapness of argon
- Augmented scintillation and ionization yields
- Improved single-electron gain
- Longer Rayleigh length for scintillation
- Sharper liquid phase scintillation pulses

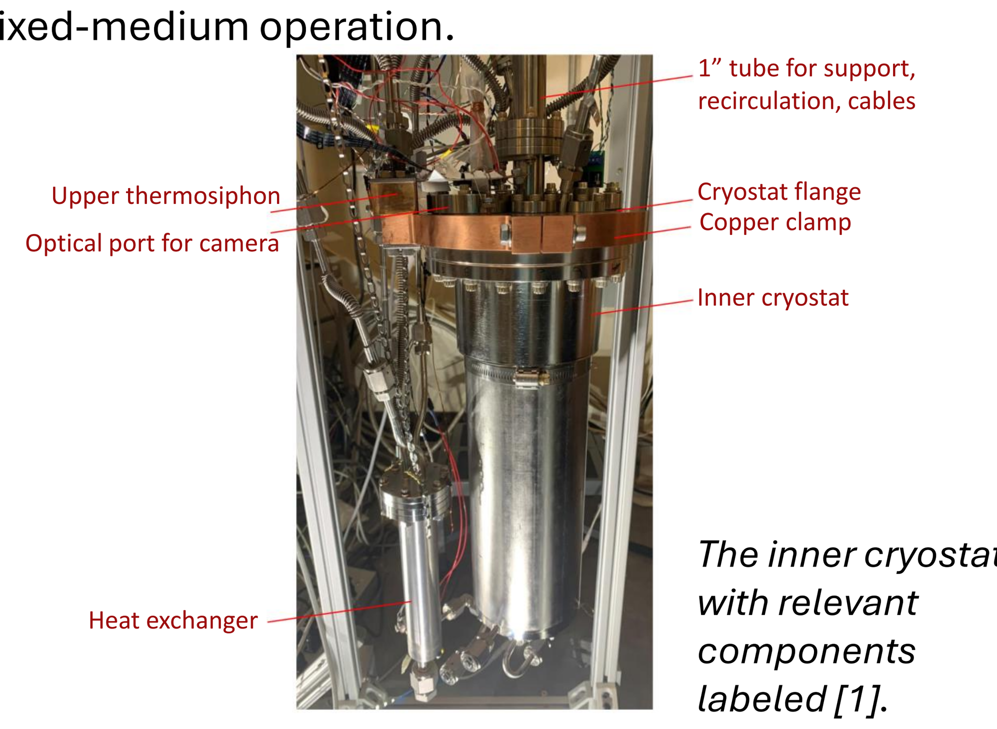


3D model of the ProtoDUNE-SP detector [2].

This work aims to develop techniques for enhancing the sensitivity of argon-based detectors which could be applied to rare event searches, real-time nuclear reactor monitoring systems, medical imaging, and more.

THE CHILLAX EXPERIMENT

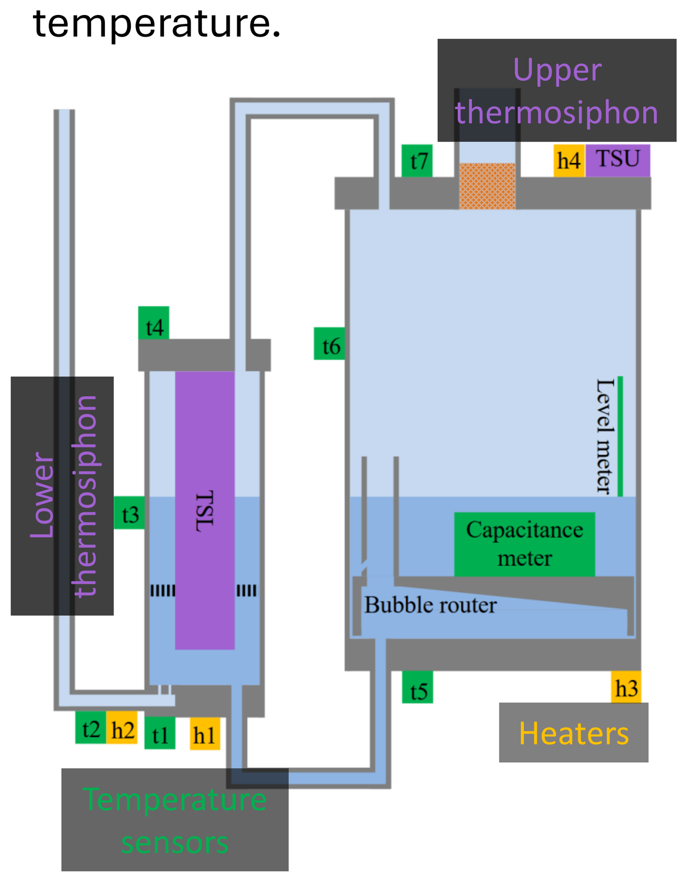
The CHILLAX experiment utilizes a mixed-medium TPC to investigate xenon doping in liquid argon, aiming to combine xenon's advantageous properties for efficiency and sensitivity with argon's cost and ease of procurement for highly sensitive detectors. The detector, pictured below, works by measuring scintillation produced in an active liquid target while drifting ionization electrons into a gas gap to generate and analyze gas electroluminescence (EL) as a function of xenon concentration [4]. As part of this work, the experiment develops techniques for stable mixed-medium operation.



The inner cryostat with relevant components labeled [1].

THERMODYNAMIC STABILITY

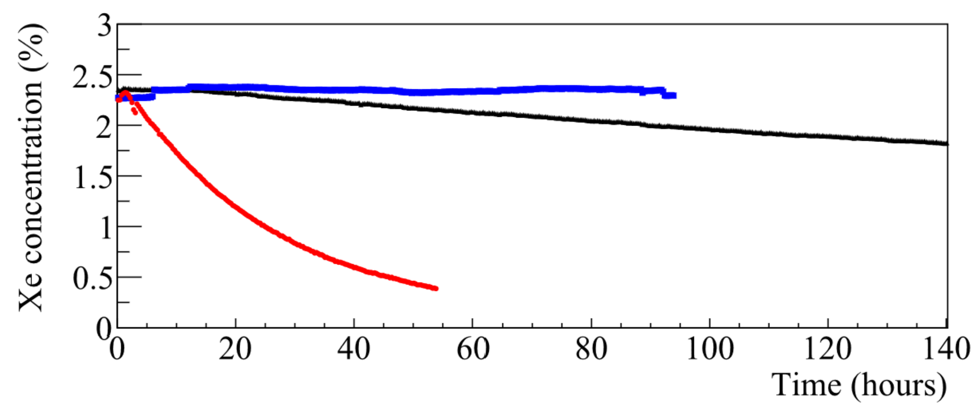
Liquid argon-xenon mixtures are susceptible to thermodynamic instabilities largely due to the disparity between argon and xenon vapor pressures at a given temperature.



Thermodynamic instabilities were found to be primarily driven by three factors:

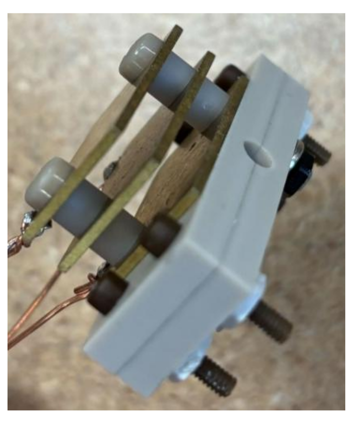
1. **Distillation during purification**
2. **Evaporation from heat ingress**
3. **Freeze-out during gas phase introduction**

A unique cryogenic circuit, sketched above, was developed for CHILLAX capable of condensing xenon-rich argon at the percent level and maintaining the stability of the mixed liquid medium under a variety of operating conditions [3]. Concentration stability tests were performed with thermal gradients from detector top to bottom of **near-zero**, **~10 K**, and **~75 K**, with [Xe] for each trial plotted below [3]. Subsequent studies demonstrated sustained xenon concentration at 5%.



UPGRADES

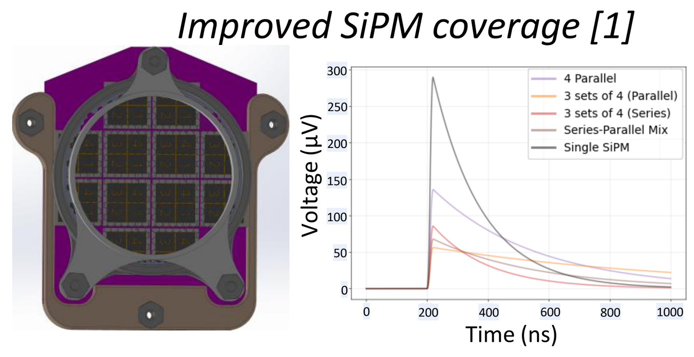
Several upgrades to CHILLAX are being implemented for future studies to improve light collection and support more versatile operation.



Liquid level meter

Amplifier cage

Improved SiPM coverage [1]

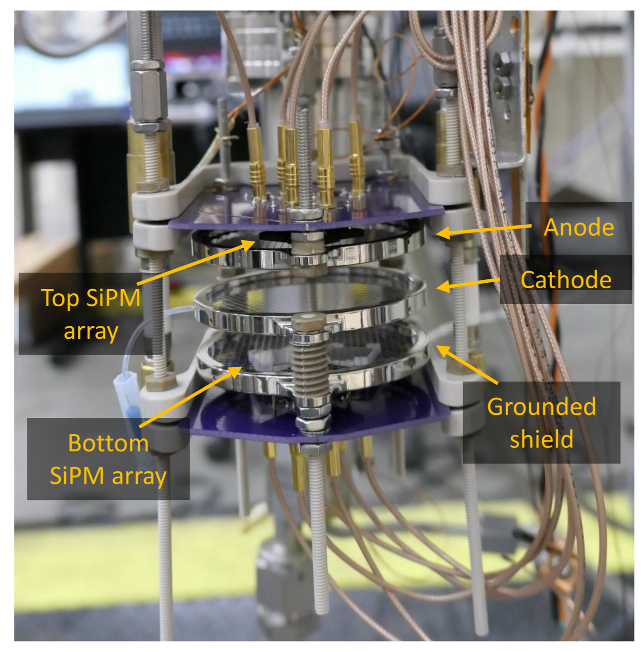


CONCLUSIONS

- The CHILLAX experiment characterizes electroluminescence properties of xenon-doped argon
- Thermodynamic techniques have been developed to introduce percent-level Xe-doped Lar to a dual phase TPC, demonstrating stable operation up to 5% [Xe]
- Enhanced electroluminescence has been exhibited with increased [Xe], timing profiles suggest energy transfer from Ar to Xe through intermediate states
- Upgrades are being made to enhance light collection and detector sensitivity, operational versatility

SIGNAL GENERATION AND DETECTION

Image of the unshielded TPC [1].



Scintillation signals in chillax are detected by an array of Silicon PhotoMultipliers (SiPMs) in the gas and liquid phases. The SiPM assemblies each contain both quartz-windowed SiPMs which are not sensitive to 128 nm light and windowless SiPMs which are.

[Xe] fundamentally alters the timing, magnitude, and detectability of the scintillation signals in each SiPM, as wavelength-shifted photons have a greater chance of penetrating the quartz windows. The timing of gas electroluminescence signals in xenon-doped argon was studied to understand the energy transfer microphysics responsible for the elongation of argon's scintillation light.

When ionizing radiation impinges on atoms in the active detector medium, it excites and ionizes electrons which subsequently de-excite and recombine to produce scintillation light in the liquid phase, or are drifted to produce scintillation light in the gas phase.

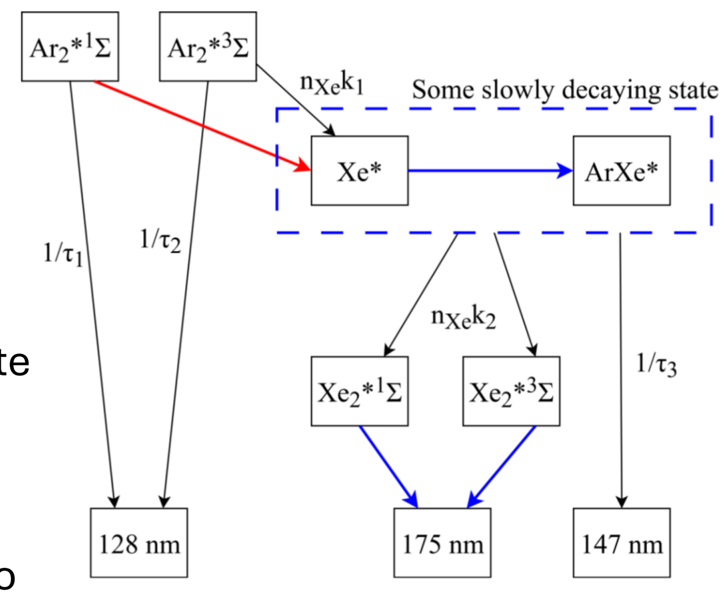


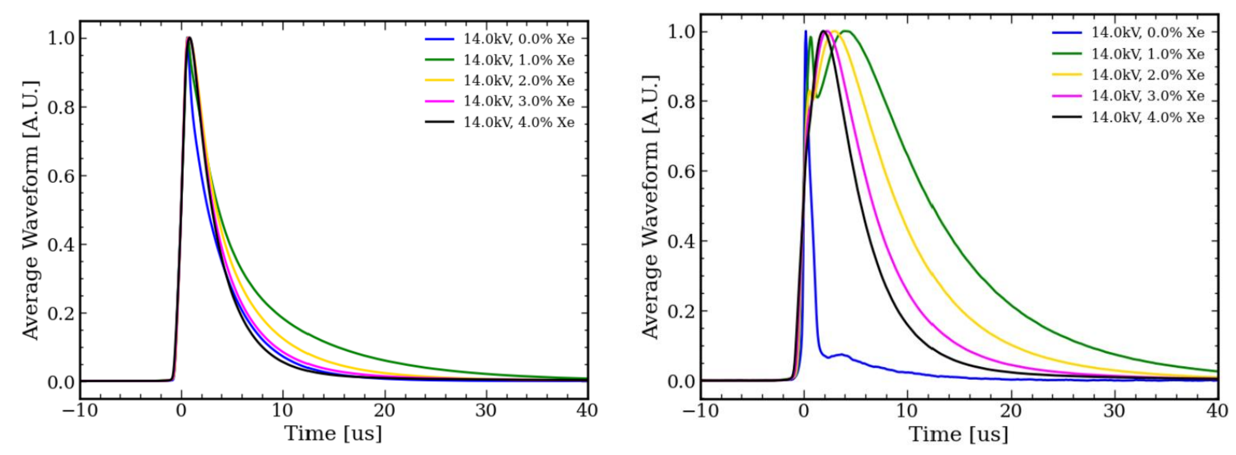
Diagram detailing hypothesized Ar-to-Xe energy transfer chain [4].

ENHANCED ELECTROLUMINESCENCE

Significant enhancement of gas electroluminescence with xenon doping was observed. The shape of the electroluminescence waveform changes with xenon content demonstrating energy transfer from longer-lived argon excimers to shorter-lived xenon excimers through intermediate states, and light emission from multiple excitonic and molecular sources including:

- Delayed xenon-mediated transfer and excimer formation
- Neutral bremsstrahlung
- Xe_2* production through intermediate state, Xe* or ArXe*
- Either Xe* or ArXe* emission at 147 nm

Quantitative models fit with these assumptions reproduce the average waveforms accurately.



Waveforms seen by a top windowless (left) and windowed (right) SiPM [3].

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FURTHER READING

[1] J. W. Kingston, "Studies of Xenon-Doped Argon for Rare Event Searches," Ph.D. dissertation, Dept. Physics, Univ. of California, Davis, CA, USA, 2026.
[2] A. Abed Abud *et al.* (DUNE Collaboration), "Doping liquid argon with xenon in ProtoDUNE Single-Phase: effects on scintillation light," *J. Instrum.*, vol. 19, p. P08005, Aug. 2024.
[3] E. P. Bernard *et al.*, "Thermodynamic stability of xenon-doped liquid argon detectors," *Physical Review C*, vol. 108, no. 4, p. 045503, Oct. 2023.
[4] J. W. Kingston *et al.*, "Gas Electroluminescence in a Dual Phase Xenon-Doped Argon Detector," *arXiv preprint arXiv:2510.02261*, Oct. 2025.

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