Detector Microphysics/Characterization

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Executive Summary

Narrative

Detector microphysics and characterization is an essential component of preparing next-generation gaseous/liquid noble detectors for cutting-edge physics measurements in both the Neutrino Frontier (NF) and Cosmic Frontier (CF). The goal is a better understanding of gaseous/liquid noble detectors toward making accurate and precise measurements of charge and/or light from interactions of interest within the detectors, which in turn are necessary to obtain sensitivity to a wide range of physics phenomena. Relevant searches/measurements include dark matter searches, searches for neutrinoless double beta decay, coherent elastic neutrino-nucleus scattering measurements, probing neutrino oscillations for measurements of leptonic CP violation and other PMNS matrix parameters, measurements of supernova/solar neutrinos, and searches for proton decay and other forms of baryon number violation.

Looking toward the next generation of HEP experiments, there are a variety of requirements for instrumentation and calibration methodology in ensuring accurate and precise measurements of charge and light in detectors making use of noble elements, such as argon or xenon. First, it should be noted that both electron recoils and sub-keV nuclear recoils in xenon and argon are of interest, as the full range of relevant experiments collectively probe both types of recoils. Lower detector energy thresholds, both in the bulk liquid and at the liquid-gas interface for two-phase (liquid target with gas phase for signal gain) technology, are needed to pursue the physics measurements described above. Establishing measurements of noble element properties (e.g. diffusion, electron-ion recombination) to sufficient levels prior to running large, next-generation noble element detectors is necessary given that these experiments may not be able to make these measurements *in situ*. This includes addressing effects related to self-organized criticality (SOC) and other dynamic effects at low energies arising from the interplay of condensed matter and chemical interactions in noble liquid detectors, such as accumulations/releases of excitation energy and Wigner crystallization, which are potential backgrounds in rare event searches. Flexible user facilities (not tied to any particular group nor experiment) with both charge and light readout and fast turnaround time can promote noble element property measurements in cases where *in situ* measurements are insufficient. Such facilities would also allow for prototyping calibration equipment designed for large detectors in smaller test beds.

Many challenges exist in pursuing the precise calibration of charge and light measurements in next-generation noble element experiments. Greater background reduction at lower recoil energies is a significant challenge. Increasing light collection and quantum efficiencies well beyond current levels, in order to achieve lower energy thresholds and improve energy resolution, is a difficult problem. A variety of improvements are needed in increasing light and charge collection efficiencies in liquid argon/xenon, including improving impurity modeling, purification methods, mitigation and accounting for material degassing, and estimating electron attachment rates for impurities. There are also currently significant uncertainties concerning how non-linear detector response becomes at the lowest recoil energies relevant to low-mass dark matter searches and coherent neutrino observations. While the development of atom-level simulations of charge and light yields (such as those being pursued by NEST) to improve modeling for noble element detectors will help address this challenge, better particle and detector models are needed to extract more information from data. Additionally, training the next generation of physicists to become experts in noble detector characterization/microphysics requires funding agencies to support continued work on detector calibrations as a foundational part of physics research; this will further develop the workforce necessary to enable the physics measurements of interest at relevant experiments. Finally, given the connections between condensed matter and nuclear physics effects and their manifestation in HEP detectors, it is important to improve the communication between the BES, NP, and HEP communities on these cross-cutting topics, which is currently lacking.

Further reading

[WORK IN PROGRESS]