BRN Study on R&D: Noble Liquid (and Gas [and Solid]) Panel

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Charge

Identify Priority Research Directions (PRDs) in instrumentation for each physics driver (including the development program with timelines) and Key Challenges that could be game changers for HEP and may have a wider impact in other disciplines and in society. Produce a report summarizing this.

We think of the PRDs as delineating and motivating a program for expanded KA25 funding and Key Challenges as keys to unlocking new money for OHEP.

What is Noble Liquid (and gas [and solid])?

- What type of physics do we do?
  - Neutrino oscillation and properties
  - Dark matter searches
  - Include double beta decay although not “officially” HEP - lots of overlap with other categories
- Technologies
  - Liquid argon and xenon detectors (single phase and dual phase TPCs, etc)
  - Gas TPCs (high pressure, low pressure)
  - New techniques - for example scintillating bubble chamber for DM/coherent scattering, or liquid helium - (some overlap with Quantum Sensing)

Activities to date

- Initial discussions among committee members to identify areas of interest
  - Production of 1 page summary at end of September on very quick timeline
- Initiation of community outreach
  - Email sent to experts and collaboration spokespeople asking for circulation within their communities - last two weeks of October
- Responses collected through google form, including option for open ended document submission
  - Link still active if you want to provide new/updated feedback!
  - 26 total responses, including some representing full collaborations or groups
    - Included 7 longer form written or slide submissions
- One page summary expanded to 3 pages based on received input in early November
  - Available from CPAD indico page

PRDs - the 5 second version

PRD #1: More signal

PRD #2: Better calibration

PRD #3: Go big…

PRD #1 - Draft

PRD #1: Develop large area, high granularity, high efficiency signal collection technologies. The signal detection from noble element detectors includes detecting charge from ionization, detection of vacuum ultra-violet (VUV) photons from scintillation, and novel channels such as bubble formation or quasiparticles. Unambiguous 3D imaging utilizing these signals necessitates R&D into novel pixel charge readout, light detection techniques directly sensitive to VUV signals, and the ability to shift VUV wavelengths to visible wavelengths, among others, to realize large area, highly efficient detectors capable of providing the imaging detail, timing, and calorimetric information and dynamic range needed by noble element detectors.

PRD #1 - Draft

The **three key challenges are**:

1) Addressing requirements for large channel count, low power consumption, resilience to single point failure, and low energy threshold requirements to enable next generation physics reach with large scale noble element detectors;
2) Improving detection of all wavelengths of light, requiring innovation with existing silicon-based detectors, exploration of non-silicon-based technologies sensitive to VUV signals, research into infrared and Cherenkov light sensors, and further development of wavelength shifting technologies and techniques;
3) Exploring further signal amplification for both light, charge, and heat collection to allow for lower detection thresholds, which could significantly increase the physics reach of these detectors.

PRD #1 - notes

- Everyone wants more signal - more light, more charge, development of new channels - more signal enables more physics
    - Better QE sensors, sensitivity to different wavelengths and ability to shift wavelength, decrease losses in detectors (reflectivity, purity), in liquid charge amplification
    - New techniques - bubbles/phonons, liquid amplification of charge, IR wavelengths, etc
- Everyone wants better resolution - similar arguments and methods
- Large overlap with Photosensors WG, will hopefully get worked out here and at BRN to better coordinate responsibility
    - One example - large area in particular needed for liquid nobles (scalability, see PRD3)

PRD #2 - Draft

Develop calibration techniques to understand the response of noble elements to very low energy nuclear recoils, to better resolve energy depositions from different particles of all energies, and to fully characterize the entire volume of very large scale liquid and gaseous detectors. Effective calibration is a critical component for any science driver, as the ability to resolve a new physics signal, reject backgrounds, tease out small shape effects, or precisely measure detector parameters requires deep understanding of detectors only possible through calibration.

PRD #2 - Draft

Four key challenges are:

1) Understanding the response of noble elements to sub-keV recoils, an essential element for dark matter experiments;
2) Uniform calibration of ton- and kiloton-scale detectors throughout their volume in the relevant energy range;
3) Detailed understanding of the electric field response;
4) Improving energy resolution, particle and event ID, and topology to resolve signals and reject backgrounds. This includes responses to particles over a wide range of energies.

PRD #2 - notes

- Calibration is an enabling concept on its own - the better we understand our detectors, the better physics we do. Without that understanding, we can’t say anything about the physics
- Everyone wants better resolution (see PRD#1) - requires calibration
    - Low energies for DM, coherent scattering, supernovae likely requires new neutron-based techniques (or at least remember neutron techniques)
    - Over large volumes for DUNE, DUNE-like, including spatial variation of E-field, etc
- Do we need dedicated facilities (e.g. specialized neutron sources/beams)?

PRD #3 - Draft

PRD#3: Develop strategies to address known and hidden challenges associated with scalability of future noble element experiments. Neutrino and rare-event search experiments continue to grow, both in physical size and in sensitivity, and with this growth comes a number of challenges. As the required sensitivity of rare-event experiments, increases, so does the need for radiologically pure materials and their high throughput screening, as well as removal of radioactive impurities. Delivering such high-purity noble-liquid targets will require advances in cryogenics and purification systems. Larger detector volumes require higher drift voltages and purity than are achieved in the current generation of experiments, necessitating advances in the design of high voltage feedthroughs and their testing. The procurement and clean storage of large quantities of noble elements is an emerging need of future experiments, as is the ability to perform isotopic separation for enriched sources (e.g. for neutrinoless double-beta decay) and background suppression (e.g. underground argon for dark matter searches). Finally, larger noble liquid detectors will produce a deluge of data that will overwhelm existing computing resources without new R&D to approach all areas of computing from data acquisition to data analysis.

PRD #3 - Draft

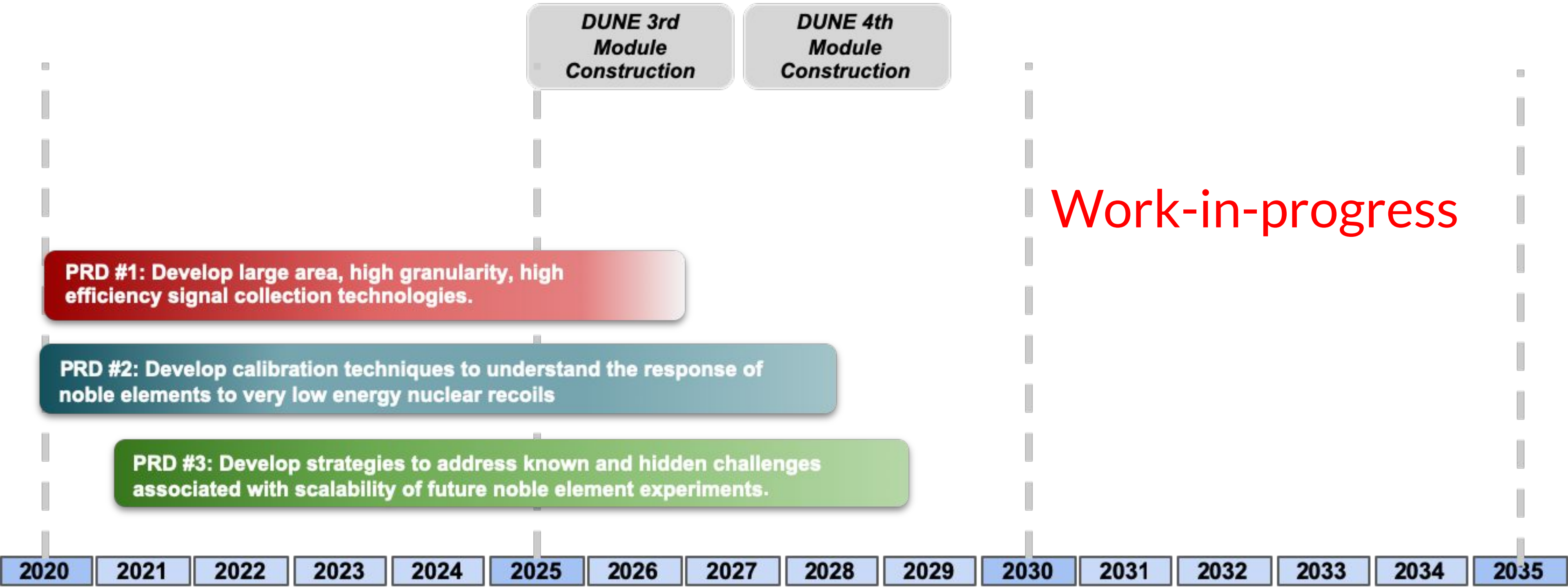
Key challenges:

1) Developing very high voltage delivery solutions, including the use of resistive materials, and understanding the dielectric properties of the different elements under different purity conditions;
2) Developing large-scale purification solutions to study the effects of and removal of impurities, including both electronegative species and radioactive contaminants;
3) Developing new solutions for screening and procurement of low-background detector materials, including electronics components such as cables, and understanding how those backgrounds generate signals in sensitive detectors;
4) Developing isotope separation and enrichment solutions;
5) Understanding how to trigger, handle, process, and analyze the exponential increase in data volumes that will come with future large scale noble liquid detectors.

PRD #3 - notes

- Bit of a catchall - size and scaling are both a major advantage of liquid noble techniques but brings new complications - several good examples in the submissions
    - Purification of both electronegatives and radioactive contaminants like radon
        - Major effect on both LArTPCs for neutrino oscillations and dual phase TPCs for dark matter
        - Requirements depend on experiment (e.g. DM, neutrino osc.)
    - Computing challenges - not obvious where this goes, but clear needs
        - Data deluge from more channels, more information
        - Simulation support - optical, physics (Geant4), etc
    - Mechanical challenges - how do you store/handle such large amounts of noble gas cleanly? How do you apply voltage at large scales?
    - Radiopurity of materials for next generation DM and neutrino experiments

Noble Elements Timeline



Next steps

- Finishing a six page expansion of the existing documents that will be done before the end of CPAD
  - Provide examples for the PRDs and challenges, reference community input, address cross cutting issues and overlaps with other working groups
- BRN meeting immediately following CPAD
  - Day 1 - streaming to community
  - Remainder - hash out final set of PRDs , key challenges, and outline final report
- BRN report to follow

Make sure we know about your ideas!

- This meeting and the first day of the BRN are the last good opportunities to get your ideas included
- We want to make sure the entire community has a chance to weigh in, to make this exercise truly reflective of what people are doing and thinking about
- Please talk to any of us here or fill out the google form or send us email
  - Andrea Pocar and Jonathan Asaadi are here in person - feel free to bug them
  - Google form is still open for submission

Comments