Noble Elements Summary

Conveners: Jonathan Asaadi, Jen Raaf
March 22, 2021
CPAD 2021
Excellent presentations in our parallel sessions!

**Thursday**

<table>
<thead>
<tr>
<th>Title</th>
<th>Speaker</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>A Digital Tension Measurement Device for Multi-Wire Particle Detectors</td>
<td>Shion Kutoba</td>
<td>11:00 - 11:20</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Measuring trace krypton for the LUX-ZEPLIN dark matter search</td>
<td>John Silk</td>
<td>11:20 - 11:40</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Modeling Impurity Concentrations in Liquid Argon Detectors</td>
<td>Yichao Li et al.</td>
<td>11:40 - 12:00</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Purity monitoring for ProtoDUNE-SD</td>
<td>Wenjie Wu</td>
<td>12:00 - 12:30</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Low-energy Monoenergetic Neutron Production with a DD-Neutron Source</td>
<td>Will Taylor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for sub-keV Nuclear Recoil Calibrations in the LUX and LZ Experiments</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Friday**

<table>
<thead>
<tr>
<th>Title</th>
<th>Speaker</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Augmented Signal Processing in Liquid Argon Time Projection Chambers</td>
<td>Haiwang Yu</td>
<td>11:00 - 11:20</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>with a Deep Neural Network</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Using Photo-converting Depants to Improve Large LArTPC Performance</td>
<td>Joseph Zennamo</td>
<td>11:20 - 11:40</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>QPIX, a novel pixel technology for very large noble element detectors</td>
<td>Austin McDonald</td>
<td>11:40 - 12:00</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>High pressure gas TPC technology for neutrinoless double beta decay</td>
<td>Jonathan Haefner</td>
<td>12:00 - 12:20</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>searches: The NEXT program</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metastable Liquids: Breakthrough Technologies for Dark Matter and</td>
<td>Prof. Matthew Sydngs</td>
<td>12:20 - 12:40</td>
<td></td>
</tr>
<tr>
<td>Neutrinos</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Additional Talks**

<table>
<thead>
<tr>
<th>Title</th>
<th>Speaker</th>
<th>Time</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scintillation and Optical Properties of the Low-Background Scintillator, PEN</td>
<td>Mrs Brennan Hackett</td>
<td>13:00 - 13:30</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Light production in liquid and gaseous argon</td>
<td>Dr Carlos Ceval Esequel</td>
<td>13:40 - 14:00</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Improving the Proportional Scillation Signal of Liquid Argon by Xenon Doping</td>
<td>Ethan Bernard</td>
<td>14:00 - 14:30</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Modeling xenon and argon physics with the Noble Element Simulation Technique (NEST)</td>
<td>Vetri Velan</td>
<td>14:20 - 14:40</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Building low background kton-scale liquid argon time projection chambers for physics discovery</td>
<td>Christopher Jackson</td>
<td>14:40 - 15:00</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>Designing and building a pair of scintillating bubble chambers for WIMPs and reactor CEvNS</td>
<td>Rocco Copejans</td>
<td>13:00 - 13:25</td>
<td>Stony Brook, NY</td>
</tr>
<tr>
<td>HeRALD - light dark matter search with superfluid Helium-4</td>
<td>Junsong Lin</td>
<td>13:25 - 13:50</td>
<td>Stony Brook, NY</td>
</tr>
</tbody>
</table>
### Noble Elements Priority Research Directions

<table>
<thead>
<tr>
<th>Priority Research Direction (PRD)</th>
<th>Technical Requirement (TR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRD 4: Enhance and combine existing modalities to increase signal-to-noise and reconstruction fidelity</td>
<td>TR 1.3, 1.3, 2.1, 2.4, 2.5, 2.7, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19</td>
</tr>
<tr>
<td>PRD 5: Develop new modalities for signal detection</td>
<td></td>
</tr>
<tr>
<td>PRD 6: Improve the understanding of detector micro-physics and characterization to increase signal-to-noise and reconstruction fidelity</td>
<td>TR 2.8, 2.9, 3.3, 3.6, 3.9, 3.12, 3.13, 3.15, 3.17, 3.19</td>
</tr>
<tr>
<td>PRD 25: Advance material purification and assay methods to increase sensitivity</td>
<td>TR 2.3, 3.1, 3.4, 3.7, 3.10</td>
</tr>
<tr>
<td>PRD 26: Addressing challenges in scaling technologies</td>
<td>TR 2.1, 2.3, 2.4, 2.7, 2.9, 3.2, 3.5, 3.8, 3.11, 3.14, 3.16, 3.18, 3.20</td>
</tr>
</tbody>
</table>

Table 15: Table mapping Priority Research Directions to Technical Requirements.
PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Zennamo

Photon Conversion

- These chemicals work by having an ionization energy near the scintillation photon energy
  - Convert scintillation light into ionization charge
- Literature has explored many potential choices (*), the most commonly used:
  - Tetramethylgermane (TMG), (CH₃)₄Ge
  - Trimethylamine (TMA), N(CH₃)₃
  - Triethylamine (TEA), N(CH₃CH₂)₃
- These chemicals have a long track record of demonstrations in the literature starting back in the early 1970s

Scintillation Energy
- LAr  9.6 eV
- LAr+Xe 7.0-9.6 eV

Ionization Energies
- TMG  9.2 eV
- TMA  7.8 eV
- TEA  7.5 eV
  (In LAr these drop by ~0.7 eV)

Other Benefits of Xenon-Doping

- On top of modifying the detector’s performance, ¹³⁶Xe is also a 0νββ candidate isotope
  - Doping with ¹³⁶Xe could enable a 100-ton scale search for 0νββ
- Concept: Dope DUNE FD module LAr with 2% ¹³⁶Xe (Qββ = 2.5 MeV)
  - Enabling a ~300-ton mass of xenon to sit within a 2 m fully active LAr buffer, eliminating most surface backgrounds
  - Additional background suppression comes via multiseite tagging
- To enable such a search one needs to utilize ⁴²Ar depleted LAr

---

J. Zennamo, Fermilab

1*) D.F. Anderson, Nucl. Instr. and Meth. A 242 (1985) 256
J. Zennamo, Fermilab
PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

E. Bernard

S2 Light Measurement Improvement by Addition of Xenon To Argon

Improvements in light production and sensing of the S2 pulse

- Xe – containing excimers emit at longer wavelengths that are more efficiently measured.
- Xe – containing excimers emit their light faster, shortening pulse duration.
- Xe* has a lower threshold for excitation → more excitations per drift electron

Improvements in ionization yield of the liquid (speculative)

- Xenon has a lower ionization energy that argon → more electrons per unit deposited energy
- Xenon may be ionized by the Penning process Ar* + Xe → Ar + Xe* + e⁻
An unorthodox solution: Q-Pix

- The Q-Pix pixel readout follows the “electronic principle of least action”
  - Don’t do anything unless there is something to do
- Offers an innovation in signal capture with a new approach in measuring time-to-charge (ΔQ)
  - Keeps the detailed waveforms of the LArTPC
- Take the difference between sequential resets
  - Reset Time Difference = RTD = ΔQ
- RTD’s measure the instantaneous current and captures the waveform
  - Small average current (background) = Large RTD
    - Background from $^{36}$Ar ~ 100 aA
  - Large average current (signal) = Small RTD
    - Typical minimum ionizing track ~ 1.5 nA

Q-Pix work in the context of DUNE (Supernova)

Compressing a full 10s of background in an APA with a single supernova neutrino (no cuts) on to the pixel plane the event will clearly visible.

“Don’t require a trigger from the pixel”

To achieve diffusion through the volume the system will (R&D ongoing)

A.D. McDonald

2021 March 22 J. Raaf | CPAD 2021
PRD 4: Enhance and combine existing modalities to increase S:N and reconstruction fidelity

J. Lin

Helium Roton Apparatus for Light Dark matter (HeRALD)

- Operated at mK
- Calorimeters with TES readout
  - submerged in liquid
    - Detect UV photons, triplet molecules and IR photons
  - suspended in vacuum
    - Detect UV photons, IR photons and He atoms (evaporated from quasiparticle)

Light yield measurement of superfluid He-4

- First measurement in tens of keV
- ER yield relatively flat (as expected)
- NR yield agrees pre-defined model
- Working on lower energy (~ keV)
  - ER: Compton scattering from Co-57 source
  - NR: SbBe with iron filter
PRD 5: Develop new modalities for signal detection

C. Escobar

NIR Observed Signals

Clean liquid phase:
- SiPM bias voltage variation
- Significant reduction of the observed signal on Nov 17 ~ noon

Gas 1 phase:
- Major increase of the observed signal
- Emergence of a slow component

Dirty liquid phase:
- Observed signal comparable to the end of clean liquid phase

Gas 2 phase:
- Fast component comparable with the Gas 1, ~ steady
- Increase of the total/ slow component
PRD 5: Develop new modalities for signal detection

Metastable liquids: phase transition detectors
- Snowball Chamber (super-cooled water)
- Scintillating Bubble Chamber (super-heated LAr-LXe)

The Basics: How This Works
- A pure liquid can be made “metastable,” making it sensitive to incoming particles
  - For supercooling, this involves dropping temperature below freezing sans freezing, relying on a sufficiently clean, smooth container
- Controlling the temperature and/or pressure allows one to control the thresholds in both energy as well as dE/dx or critical radius for nucleation, enabling signal vs. background discrimination (e.g., betas and gamma-rays)
  - Lower temperature means both thresholds lower, in supercooling. Like bubble chamber, but in reverse!
- Have only done water so far. What does it have to do with noble elements? - Could do Xe or Ar to capitalize on scintillation for E

R. Coppejans
M. Szydagis

Chamber Schematic
Model Description

- A quantitative kinetic model of impurity distribution is constructed
- Two species (Ar and impurity) in four places (gas, liquid, contact surfaces with gas/liquid)
- Each process is described by an ordinary differential equation
- The entire model is the sum of 7 processes
PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

W. Taylor

LUX DD Calibration Results

- New results from LUX2016 DD data push Qy and Ly measurements even lower in energy
- 0.27 keV/\text{n}- Qy
- 0.45 keV/\text{n}- Ly

Nuclear Recoils in Argon

Nuclear recoil argon model now deployed in main NEST code

Built using data from SCENE, ARIS, DS-50, Joshi, Aprile, Lippincott, Kimura, Doke, etc.

See CPAD 2019 talk for additional information

V. Velan
PRD 6: Improve the understanding of detector microphysics and characterization to increase S:N and reconstruction fidelity

H. Yu

Deep-Learning in Wire-Cell Toolkit

Established initial machinery for Deep-Learning in Wire-Cell Toolkit
https://github.com/WireCell/wire-cell-toolkit
- Data preparing in LarSoft/Wire-Cell
- Training with python
- Production with C++
PRD 25: Advance material purification and assay methods to increase sensitivity

De-Kryptonated Xenon

Krypton Concentration Post Chromatography

- Purity Goal
- Mass Averaged Purity
- Purity by Bottle

Cleaned xenon is put into storage pack of 12 bottles.

Result above is ~970 kg, with a total mass averaged purity of 152 ppq $^{85m}$Kr g/g, satisfying the 300 ppq purity goal.
PRD 25: Advance material purification and assay methods to increase sensitivity

B. Hackett

Conclusion

- PEN is a novel scintillating material
- It has potential applications in both noble detectors and low background experiments
- PEN has a demonstrated structural stability
  - Yield strength higher than copper at cryogenic temperatures
- Injection molding can prevent crystalline structures forming in PEN
  - Improved optical clarity
  - Alternative geometries other than commercially available films

Alternative WLS materials with low radioactivity

Also relevant for PRD #4!
PRD 25: Advance material purification and assay methods to increase sensitivity

C. Jackson

How to build this?

- Assay management
  - Radiopurity.org based assay manager
    - Interface for non-experts to request assays
    - Guided input of relevant information
    - Low background experts guide distribution of assay work
    - Tracks samples and locations
- Assay results and triage
  - Background Explorer
    - Toolkit for modeling radioactive backgrounds
    - Rapid evaluation of effect of new assay measurement on background tables
    - Originally developed for SuperCDMS by Ben Loer
    - https://github.com/bloer/bgexplorer-demo
PRD 26: Addressing challenges in scaling technologies

New techniques for measuring wire tensions in future large TPCs...

S. Kubota

A Novel Electrical Method to Measure Wire Tensions for Time Projection Chambers

Sneak peek inside the Digital Wire Analyzer

A) Capacitance/wire length dependent slope
B) Resonance Peak

1. FPGA creates square wave
2. Bandpass filter converts a square wave to a sine wave
3. A sine wave will be sent out to the selected wires by Relay Boards
4. Signal in the test wires are detected/received
PRD 26: Addressing challenges in scaling technologies

R&D to enable to ton-scale 0nuBB

**NEXT-Ton: basics**

- Require a larger detector (10x mass of N100)
- With larger size, some challenges:
  - Larger volume to calibrate
  - Longer drift distance
- Must maintain:
  - Excellent resolution
  - Topological rejection power

Two approaches developed in parallel:
- Phase 1, High Definition: incremental approach, using/improving existing technology.
- Phase 2, Barium Tagging: based on disruptive new concept (SMFI Ba++) tagging.

Phased approach:
- ~1 ton of 136Xe introduced per phase.
- Ultra pure materials. SiPMs as the only sensor.

**Phase 1:**
- Improves topological signature, improves energy resolution
- Reduces radioactive budget (no PMTs)
- Energy plane made of large area SiPMs (design similar to that of Dark Side)
- Potential to reduce SiPM dark count by cooling detector
  - 2.6 \times 10^{-4} \text{ cts}/\text{keV}\cdot \text{kg}\cdot \text{year total background rate}

**Phase 2:**
- Tracking and energy measured in anode.
- Cathode implements Barium Tagging System
- Virtually background free
Closing Remarks

- Lots of interesting results and advances in techniques, tools, and instrumentation
- Focus: how to do things at larger scale with higher sensitivity
- Looking forward to see how much farther we will be able to advance by the next CPAD!

Thank you to all the session speakers for their excellent talks!