Nuclear Science and Security Consortium

September Workshop and Advisory Board Meeting

ACED: Argon Capture Experiment at DANCE

September 11, 2017

Steven Gardiner
University of California, Davis
Nuclear and Particle Physics
Deep Underground Neutrino Experiment (DUNE)

The DUNE detector is a 40 kton liquid argon time projection chamber.

- Flagship domestic project for DOE Office of High Energy Physics
- More than 1,000 collaborators from 176 institutions around the world

**Physics goals**

- Test leading theory of the matter/antimatter imbalance in the universe (neutrino CP violation)
- **Observe neutrinos from a nearby core-collapse supernova**
- Search for proton decays
- Many others
Supernova neutrinos in DUNE

- Core-collapse supernovae produce tremendous numbers ($\sim 10^{58}$) of neutrinos
- DUNE will be uniquely sensitive to $\nu_e$ from a galactic SN
- Observation would be scientifically interesting
  - Supernova dynamics
  - Nucleosynthesis
  - Exotic physics (e.g., quantum gravity effects, axions)
- Complementary to optical and gravitational wave astronomy

SN1987A
(the only observation of SN neutrinos so far)

Simulated supernova neutrino events in DUNE
Motivation for ACED: Neutrons from Supernova Neutrinos

- Calculations performed by our group suggest that a significant fraction of SN events in DUNE will involve neutron emission.

- Missing the emitted neutron leads to a large error on the reconstructed neutrino energy.

- The event-by-event capture γ-ray distributions are unmeasured (would be valuable to tag these neutrons).

- The thermal (n,γ) cross section is poorly measured.
Calculations performed by our group suggest that a significant fraction of SN events in DUNE will involve neutron emission.

Missing the emitted neutron leads to a large error on the reconstructed neutrino energy.

The event-by-event capture γ-ray distributions are unmeasured (would be valuable to tag these neutrons).

The thermal (n,γ) cross section is poorly measured.
Motivation for ACED: Low Background Experiments

- Determining the neutron flux within an argon-based low background detector
- Vetoing neutron scatters (dark matter experiments) or neutron capture gammas (0νββ experiments)
- Low background detectors using liquid argon
  - DarkSide-50 / DarkSide-20k
  - DEAP-3600 / DEAP-50T
  - MiniCLEAN
  - GERDA (active shield)

EXO-200 measured the flux of neutrons in a xenon detector by fitting correlated γ capture spectra on xenon and surrounding materials.
Previous measurement on $^{136}$Xe had 7% uncertainty

We can use a nearly identical technique to obtain similar information for argon

Xe paper coauthor Tessa Johnson now a post-doc at UC Davis

Reuse many tools from Xe measurement

- Data acquisition software
- Geant4 simulation geometry
- Gas holding vessel

arXiv:1605.05794v3
ACED: Argon Capture Experiment at DANCE

- Planned measurements
  - Thermal neutron capture cross section of natural argon
  - Event-by-event correlated γ-ray cascades

- The ACED team
  - UC Davis: Bob Svoboda, Emilija Pantic, Tessa Johnson, Vincent Fischer, Leon Pickard, Jingbo Wang, Steven Gardiner
  - LANL: John Ullman
  - Boston University: Chris Grant
## Existing $\sigma(n,\gamma)$ Measurements

<table>
<thead>
<tr>
<th>$E_{\text{neutron}}$ [MeV]</th>
<th>$\sigma(n,\gamma)$ [barns]</th>
<th>uncertainty [barns]</th>
<th>year</th>
<th>author</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.53E-08</td>
<td>0.51</td>
<td>0.025</td>
<td>1969</td>
<td>N.Ranakumar+</td>
</tr>
<tr>
<td>2.53E-08</td>
<td>0.723</td>
<td>0.025</td>
<td>1965</td>
<td>R.L.D.French+</td>
</tr>
<tr>
<td>2.53E-08</td>
<td>0.63</td>
<td>0.02</td>
<td>1963</td>
<td>W.Koehler</td>
</tr>
<tr>
<td>0.005</td>
<td>0.0032</td>
<td>0.00018</td>
<td>1989</td>
<td>R.L.Macklin+</td>
</tr>
<tr>
<td>0.01751</td>
<td>0.01702</td>
<td>0.02442</td>
<td>1989</td>
<td>R.L.Macklin+</td>
</tr>
<tr>
<td>0.136</td>
<td>0.0022</td>
<td>0.0008</td>
<td>1959</td>
<td>N.A.Bostrom+</td>
</tr>
<tr>
<td>0.37</td>
<td>0.00119</td>
<td>6.00E-05</td>
<td>2014</td>
<td>M.Bhike+</td>
</tr>
<tr>
<td>0.03</td>
<td>0.00254</td>
<td>0.0001</td>
<td>2000</td>
<td>Z.Y.Bao+</td>
</tr>
<tr>
<td>0.03</td>
<td>0.00245</td>
<td>0</td>
<td>2006</td>
<td>S.F.Mughabghab</td>
</tr>
<tr>
<td>0.0234</td>
<td>0.00255</td>
<td>0.00015</td>
<td>2002</td>
<td>H.Beer+</td>
</tr>
</tbody>
</table>

Published measurements of the neutron capture cross section on argon (list compiled by J. Wang).

Thermal measurements are shown in **blue**.
DANCE: Detector for Advanced Neutron Capture Experiments

- Sphere of 160 BaF$_2$ crystals, each coupled to its own photomultiplier tube
- Nearly 4\(\pi\) coverage
- Inner $^6$LiH shell shields crystals from scattered neutrons
- Neutron energies obtained using time-of-flight
- Segmentation allows $\gamma$ multiplicity measurements
- Downstream monitors measure energy-dependent neutron beam flux
Data Taking Plan

- Expose natural argon gas (99.6% $^{40}$Ar) to neutron flux in Lujan Center flight path 14

- Argon target contained in aluminum vessel with kapton windows (borrowed from Indiana U)

- Measure flux using independent beam monitors ($^3$He, $^6$Li, $^{235}$U)

- DANCE data provide γ multiplicity and energy

- Measure backgrounds using beam-off and empty-vessel data

- Calibrate DANCE crystals by activating a gold foil in the beam

Lujan Center FP 14 Neutron Flux

arXiv:1605.05794v3
Analysis Plan: Gamma Cascades

- Subtleties in detector response make it difficult to obtain $\gamma$ cascades directly
  - Multiple scatters in crystals
  - Absorption by $^6\text{LiH}$ shield

- Extract $\gamma$ decay scheme by comparing predicted and measured event spectra

- **Problem**: high-lying levels and $\gamma$-rays are numerous, unknown, and difficult to determine theoretically
Analysis Plan: Gamma Cascades

- Statistical *distributions* of level spacings, $\gamma$ intensities are well-modeled

- The DICEBOX code produces Monte Carlo “nuclear realizations” of these distributions (complete decay schemes)

- Many realizations are compatible with input parameters

\[
S_{\gamma}^{(XL)}(E_{\gamma})
\]

*photon strength functions*

\[
\rho(E_x, J^\pi)
\]

*nuclear level density*

Analysis Plan: Gamma Cascades

**Extraction Strategy**

- Generate many nuclear realizations with DICEBOX
- Use γ distributions from each realization to simulate DANCE response
- Compare each simulation result to the measured data
- Minimize $\chi^2$ to find best-fit nuclear realization

![Diagram showing the extraction strategy](image)
Analysis Plan: Capture Cross Section

- Implement best-fit $\gamma$ decay scheme within Geant4

- Calculate detector efficiency for thermal $^{40}\text{Ar}(n,\gamma)^{41}\text{Ar}$ events
  - Use same analysis cuts as the data

- Combine with experimental measurements to obtain the cross section:

\[
\sigma(E_n) = \alpha \frac{N(E_n)}{\epsilon(E_n) \Phi(E_n)}
\]

- thermal ($E_n \approx 0.025$ eV)
- neutron capture cross section
- background-subtracted event count (from DANCE data)
- energy-independent factors (e.g., argon density)
- detector efficiency (from Geant4)
- neutron flux (from beam monitors)
Summary

- A better understanding of neutron captures in argon would be helpful for state-of-the-art physics measurements

  • DUNE supernova neutrino signal

  • Backgrounds for neutrino and dark matter experiments

- ACED will measure $\sigma(n,\gamma)$ and the correlated $\gamma$-ray cascades for thermal neutrons this fall at LANL

  • Testing of ACED components:
    • 3–4 October

  • Beam data taking:
    • First two weeks of November
Disclaimer

This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003180.

Disclaimer: This presentation was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Backup
Liquid Argon Time Projection Chambers

- Uniform electric field applied to volume of liquid argon

- Charged products from neutrino interactions create ionization tracks

- Drifting electrons create hits on wire planes

- Separate photon detection system allows $t_0$ determination (needed for z coordinate)