DOE Final Report - DOE Early Career Award - Lisa J. Kaufman

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Characterization of Backgrounds for EXO Final Report

Accomplishments

Major Goals of the Project

The 200 kg phase of the EXO experiment is underway at the Waste Isolation Pilot Plant in Carlsbad, New Mexico. The next phase of EXO, nEXO, a 5-ton LXe detector, seeks to improve the sensitivity to the neutrinoless double beta decay by 1-2 orders of magnitude. nEXO will be designed for an upgrade that will employ a barium tagging technique that will eliminate all radioactive backgrounds in the search for neutrinoless double beta decay by positively identifying the daughter Ba ion after the xenon nucleus undergoes the decay. The objectives of this proposal were to

1. Measure the gamma ray spectrum produced from epithermal and fast neutrons interacting with isotopically enriched xenon
2. Study the single-ion mobility of singly- charged Ba ions in liquid and gaseous xenon at various thermodynamic conditions under consideration for the EXO experiment.

The first objective seeks to identify and understand the production mechanism of any unknown gamma lines that may exist near the Q-value of the xenon decay resulting from inelastic scattering of neutrons with xenon. The second objective focuses on understanding how single barium ions behave in an environment of xenon and is necessary for successful implementation of the barium tagging technique.

This report summarizes the progress made during award period 2014-2017.. As stated in the original proposal, the goals for years one through three of the award are:

1. Year one (7/14-7/15): Analysis of thermal neutron measurements on ^{136}Xe at LANSCE. Begin construction for purification measurement system and xenon chamber for Ba ion mobility measurements.
2. Year two (7/15-7/16): Construct xenon target and perform neutron inelastic measurements on ^{136}Xe and ^{134}Xe at LANSCE at neutron energies up to 30 MeV, complete purification measurement system construction and commissioning, complete construction of Ba ion mobility setup. Produce bare cesium in the presence of xenon gas.
3. Year three (7/16-7/17): Perform analysis of inelastic neutron scattering data from ^{136}Xe and ^{134}Xe for neutron energies up to 30 MeV. Dissolve cesium into liquid xenon.

The scope of the original proposal changed after the grant was awarded due to the decreased budget available for the award. With the change in scope, the focus was on nEXO R&D regarding neutron background measurements and nEXO simulation removing emphasis on the barium mobility measurements due to the expense of equipment needed for this work.

Accomplishments under these Goals

We measured the thermal neutron capture cross-section on ^{136}Xe and inelastic neutron scattering from ^{136}Xe for neutron energies up to 30 MeV. In addition, we performed nEXO simulation to optimize sensitivity and initial design studies. The PI also continued in her role as the L2 co-manager for the nEXO simulations group.

Neutron measurements

We published the results of the thermal neutron measurements on ^{136}Xe (Phys. Rev. C94 (2016) no.3, 034617) and the results of the inelastic scattering on ^{136}Xe has been submitted for publication to Phys. Rev. C and is under final review (arXiv:1807.05253).

nEXO Simulation

The nEXO simulation is ongoing with the PI's efforts as co-L2 manager of the simulations group with specific emphasis on determining the sensitivity of the experiment publishing a paper with the results that motivate the nEXO experiment and its goals. A publication of the nEXO sensitivity has recently been published (Phys. Rev. C 97, 065503 (2018)).

Training and Professional Development

Graduate student, S. Daugherty worked independently to call meetings on his own in order to push forward the analysis and learned to make effective presentations to get the desired feedback in order to make progress on analysis and traveled to work with remote collaborators at LANL. He was the sole graduate student working on the analysis - learning many new software, time management and analysis skills.

In addition, post-doc Josh Albert worked tirelessly to support making these measurements at LANL and supporting the analysis and paper-writing efforts after the data had been collected.

Dissemination of Results

The thermal neutron measurements on ^{136}Xe have been published in Physical Review C (doi: 10.1103/PhysRevC.94.034617). In addition to the paper, the results of the detailed cascade model determined from our experiment has been published as supplemental material available with the paper. Previously, the cascade results were used in an EXO-200 paper reported on cosmogenic backgrounds to neutrinoless double beta decay in xenon (J. B. Albert *et al.*, J. Cosmol. Astropart. Phys. **1604**, 029 (2016)). In addition, these results were presented by graduate student, Sean Daugherty, in a poster at the Neutrino 2016 conference in London, UK in July 2016.

The simulation results are being presented at relevant meetings with NSAC and other conferences as is appropriate, and a paper reporting the nEXO sensitivity has recently been published as listed above: Phys. Rev. C 97, 065503 (2018).

Impact

The impact of our results on the field of neutrinoless double beta decay is particularly relevant to ^{136}Xe experiments. In particular, these experiments will be able to accurately determine gamma backgrounds that come from neutron capture on ^{136}Xe and accurately veto the subsequent beta decay that can be a significant background for the neutrinoless double beta decay. The cascade model determined by our experiment has been incorporated into the EXO-200 data analysis chain to develop a veto of the ^{137}Xe beta decay to improve the background. The inelastic scattering data is very relevant because these high-

energy neutrons can cause scatters that then produce gamma lines in the detector that could mimic the double beta decay signal. Knowledge of this spectrum and consequent proper shielding to prevent these scatters will reduce this as a background in future experiments such as nEXO.

The impact beyond science and technology is the training of personnel to think critically and solve problems. The work described here was a brand new analysis and detector for S. Daugherty to work with, and while he could apply tools he learned before; he had to develop new ways of thinking and problem solving to complete the analysis for the inelastic scattering data on ^{136}Xe.