Dissertation

Barium Tagging in Solid Xenon for the nEXO Neutrinoless Double Beta Decay Experiment

Submitted by

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Abstract

abztrakt

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Thanks of course goes to my advisor Bill Fairbank

This dissertation is typset in LaTeX using a document class designed by Leif Anderson.

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CHAPTER 1

Introduction

start with neutrino prediction by pauli in beta decay, then talk about neutrinos and maybe even mention your dumb "extremes in experimental technique thing", but that's dumb as the main point.

And while the first indication of neutrinos came from the "missing" energy they took away from single beta decays, we now look for the mode of double beta decay which looks like single beta decay was expected to look – where there are no neutrinos. No, this is pretty dumb.

or: we search for electrons coming out in double beta decay

old stupid intro:

The study of the neutrino has required extremes in experimental technique from the beginning. Neutrinos were described by W. Pauli, who first proposed their existence to remedy an apparent violation of energy conservation in beta decay, as being [impossible to detect] [ref.]. Rather, it requires a great deal of sensitiviy, ingenuity, and hardship (just "ingenuity and hardship"? sensitivity may be redundant) to observe them, and it was [] years before they were first observed by [Reines and Cowan] in [], by [] [ref.]. (is "rather, ..." too demoting-sounding? it is absolutely not meant to be, of course)

Neutrino experiments of greater discovery power have been developed around the world, and command large collaborations of scientists. ummmmmmmm this is supposed to kind of allude to barium tagging as an extreme technique

Neutrinoless Double Beta Decay experiments like EXO are a different kind of neutrino experiment, not detecting neutrinos directly, but searching for an effect (neutrinoless double beta decay itself) which would demonstrate the Majorana nature of neutrinos. A liquid xenon experiment like EXO provides a the challenging opportuniy for another extreme experimental technique, barium tagging, where a single barium ion would be observed at a specific double beta decay site in the volume. This thesis is part of an exploration of one promising barium tagging technique. (these things may be saved for the EXO chapter... idk).

From the first formulation of beta decay theory by E. Fermi [ref.], neutrinos have provided an avenue into a world of new physics, and they continue to be such an avenue. Questions which may be answered by this up and coming generation of neutrino experiments are expected to help explain how the universe came to be this way.

[lead into barium tagging discussion]

1.1. something like "Can We Do This?", but probably not that at all.

A liquid xenon double beta decay detector allows unique access to the daughters of decays in the liquid volume. The feasibility of grabbing and detecting a single ion from the volume is what must be determined next.

1.2. This is a subsection

see original (Leif) for example of a figure and a table.

CHAPTER 2

Theory

See more Leif examples of some things.

2.1. Neutrinos

Neutrinos are chargeless leptons which only interact via the weak force and gravity.

2.1.1. proposition–discovery–flavor–oscillation–mass.

Have provided an avenue into physics beyond the SM. discovery of oscillltion, thus mass, and discovery.

2.1.2. Neutrinoless Double Beta Decay.

2.2. Barium Spectroscopy

Do we want this here? It flows more to have this theory after the proposition of the tagging technique, but maybe that's more appropriate for a talk.

2.3. Matrix Isolation Spectroscopy

(same thing)

CHAPTER 3

Enriched Xenon Observatory

The Enriched Xenon Observatory (EXO) is a set of two experiments, each a LXe time projection chamber (TPC) designed to study the double beta decay of the isotope ^{136}Xe, and ultimately to search for the zero-neutrino mode. There are several advantages to a LXe detector. Xe scintillates at [around?] [xxx] nm, which is [efficiently collected by [type that the APDs are]] [reference]; so the Xe acts as a detection medium in addition to being the source of the double beta decay [reference? I didn't make up that kind of sentence]. Xe can also be continuously purified to maintain large electron lifetimes in the LXe. Also, the ratio between observed scintillation light and remaining ionized electrons (drifted from the decay site by the TPC's electric field) exhibits a well-known microscopic anti-correlation [ref.], the understanding of which improves the energy resolution of the detector. Finally, a LXe TPC approach offers the opportunity, [fairly] unique in double beta decay, to "tag" the daughter, in this case Ba, at the site of the double beta decay event (specifically, of course, the neutrinoless ones).

EXO-200 is the first of the two experiments, and has been operational since April of 20[xx](?). It is a liquid xenon TPC designed to probe Majorana neutrino masses down to around 100 meV. [EXO instrum. paper part I] The following sections decribe the EXO-200 experiment, as well as nEXO, the next-generation tonne-scale liquid xenon TPC which is now in the design stages. EXO-200 does not have Ba tagging implemented, but it is hoped that nEXO will.

3.1. EXO-200

3.2. nEXO

CHAPTER 4

Apparatus

This chapter describes the apparatus at Colorado State University, which we have used for all described studies of Ba fluorescence in SXe after deposition in vacuum. Our main Ba source, the Ba^+ ion source/beam, is first described, as well as the measurements (using Faraday cups) used for determining the number of ions we deposit. A purely Ba neutral source is described. The co-deposit of Ba/Ba^+ with Xe gas onto a cold sapphire window, subsequent laser excitation, and finally the collection optics for the fluorescence, are described.

4.1. Ion Beam

4.1.1. Barium Ion Source/Acceleration. Barium ions are produced in a Colutron [type?] ion gun system [reference], as depicted in Fig. x. A solid barium charge is placed into the hollowed end of a stainless steel rod, which is then inserted into the discharge chamber, near the hot filament. The heated barium vaporizes and escapes the hollowed rod around a loosely threaded set screw at the end of the rod. The discharge chamber then fills with barium vapor. A voltage is applied to the anode plate, which then creates a discharge through the barium vapor, between the anode and the filament. The resulting plasma, containing barium ions, then escapes through the small hole in the anode plate, where it enters the acceleration potential.

The acceleration potential is 2 kV, between the ion source anode and an aperture, which constitutes the first element of the "acceleration lens" (Fig. 4.1). The voltages on this lens are chosen to approximately collimate the ion beam for passage through the ExB velocity filter.

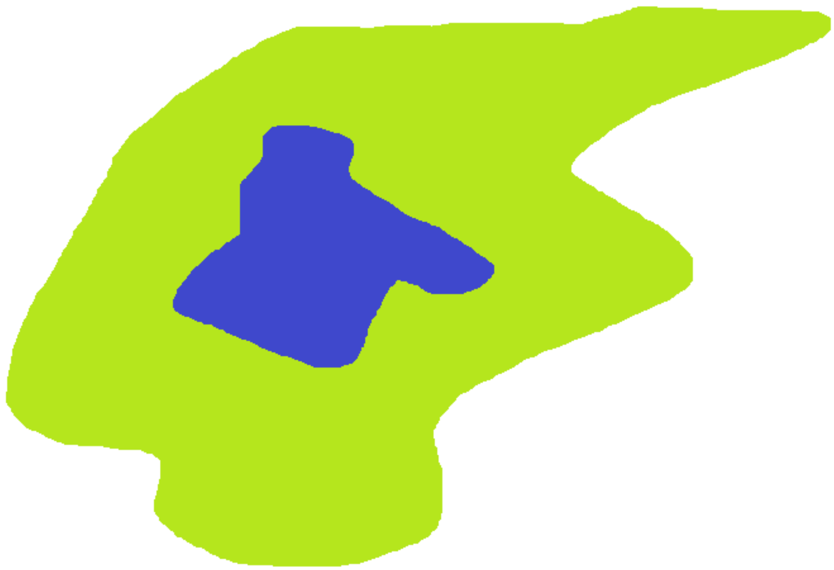

FIGURE 4.1. figyer

4.1.2. VELOCITY FILTER, LENSING. The ExB velocity filter selects Ba^+ by providing perpendicular electric and magnetic fields, which produce opposing forces on charged particles moving straight through the filter. Those fields are chosen such that those forces are equal for Ba^+, according to Eqn. 1:

$$\sigma = 1. \tag{1}$$

Other ions will be deflected, while Ba^+ will continue along the beam path.

The full ion beam is shown in Fig. xxx. The Decelerator lens can be used to reduce the beam energy, but is not needed for 2 keV beams, which are used in this work. Einzel Lens 3 focuses the beam onto the main Faraday cup, which is used during experiments to measure ion current. The final set of deflection plates, H2 and V2, are also used during experiments to steer the beam for deposits.

4.1.3. Ion Beam Pulsing.

To deposit small numbers of ions, a set of pulsing plates can be used (Fig. xxxx). When running in this mode, the pulsing plates are first placed at 200 V and -200 V to deflect the beam, and are pulsed to 0 V for 1 μs for each pulse.

The pulses can be detected by the Induction Plates. Since they use induction, they can be used to observe the pulses during an ion deposition (unlike using the Faraday cup to measure ion current during a DC deposit). An example of an oscilloscope readout of the pulsing plate signa,l and subsequent induction plate signal, is shown in Fig. 5x.

4.2. Ba Getter Source

Ba ”getters” are typically used in vacuum systems to improve vacuum by emitting Ba atoms, which grab gas molecules and hold them to the chamber walls. We employ getters as a neutral Ba source in our system.

...

It is very helpful to have a completely different type of Ba source, to rule out any source-related quirks, e.g. source-produced impurities.

4.3. Solid Xenon Matrix Deposition

The final destination of the barium ions is in the solid xenon matrix, which is deposited onto a cold sapphire window. Sapphire has good thermal conductivity, good optical transparency in the visible, and does not fluorescese in the wavelength region where barium fluoresces.

Xenon freezes around 73 K (?) at our pressures (0.5 - 1 $\times 10^{-7}$ Torr), so the window is cooled to temperatures below that. The window is held to a cold finger (Fig. 6x, picture of), cooled by a -brand- cryostat.

4.3.1. Deposition Procedure. Before barium ions are let through, xenon gas is allowed to flow, controlled by a leak valve, onto the cold sapphire window, where it freezes and begins growing the solid matrix. The Faraday cup is then retracted, to clear the path for barium ions. The cup serves as a shutter for DC deposition, or if pulsing is being used, they are performed at this time. Barium ions land in the solid xenon as the matrix continues to grow. The cup is then replaced, and the xenon leak stopped.

CHAPTER 5

Results

CHAPTER 6

Conclusions

Ba^+

APPENDIX A

Supplementary Material

make these also into separate files plz

A.1. Some Sample Material

Appendix is a strange name. Did the name for the written material come before the name of the organ? Here [**?**] is a citation in an appendix.

APPENDIX B

Another Supplement