AXION DETECTION WITH GERMANIUM DETECTORS

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OVERVIEW

MAJORANA Demonstrator
- Motivation
  - Neutrinoless double beta decay
  - Search for axions
- Design

Germanium detectors
- Semiconductor detectors
- Germanium data collection process

Detector characteristics I measured
- Leakage current
- Detector Capacitance
- Crystal axis orientation
NEUTRINOLESS DOUBLE BETA DECAY

Emission of 2 electrons from Ge-76 with no neutrinos

- Lepton number

Neutrino Mass

Majorana mass term

- Particle is its own antiparticle
- Grand Unification Theory
- Matter-Antimatter Symmetry

Image Credit: UCL NEMO Group,
http://www.hep.ucl.ac.uk/nemo/
DESIGN

- Located 4850’ underground at Sanford
- 40-kg of Ge detectors, 30-kg enriched to 86% Ge-76
- 2 independent cryostats made of ultra-clean, electroformed Cu
- Background goal: 3 counts in the 0νββ peak region of interest in a one tonne-year exposure
- Compact Pb and Cu shield + muon veto

Image Credits: Jason Detwiler
AXIONS AND GERMANIUM

Proposed particle to solve strong CP problem

Potential source of photons in Ge

Sun as point source

Crystal axis relationship

- Bragg scatter on crystal
- Energy deposition depends on plane because of electric field
- allows elimination of most background

Image Credit: Jason Detwiler
AXION DETECTION

Graph shows energy ranges that are excluded by the time of the day
Traditional method: collimated low energy radiation source
Our problems:
- thick cryostat
- 114 crystals
- Room gammas
- Noise

SEMICONDUCTOR DETECTORS

Crystal with too many/too few electrons

Incident radiation creates a hole by ionizing an electron from the valence band to the conduction one

Holes and electrons move randomly

Current flows if biased

Image Credit: Reyco Henning, UNC Chapel Hill
GERMANIUM DETECTORS

Point contact detector
~80K operating temperature
1500 V needed for bias
DATA COLLECTION AND PROCESSING

Probes detect the current
Preamplifier gives a good signal to noise ratio
Data card converts from analog to digital; trapezoidal filter
ORCA, Root
LEAKAGE CURRENT

Free electrons flowing around detector

Health of detector; noise; operating conditions

Procedure:
- Turn voltage up, from 0V to 1.5 kV by 100 V increments
- Measure current with circuit on preamp after it has settled
- 1mV=1pA
DETECTOR CAPACITANCE

Indication of where it operates as a radiation detector

Procedure:

- Bias detector
- Square wave pulser (100 mV) into HV input
- Lower voltage in steps of 100 V, except near depletion (1400 V)
- Measure amplitude of pulses

\[ Cd = \frac{Cf \times V1}{Vp \times \frac{5.62}{5.62 + 45.3}} \]

- Cf = 0.17 pF
- V1 = voltage on oscilloscope
- Voltage divider: detector resistors
- Vp = voltage in; 100 mV
Capacitance of MJ60

Capacitance at 1400 V = 2.5 pF
CRYSTAL AXIS ORIENTATION

Property of Crystal

Affects energy deposition and signal propagation similarly
- Fastest along faces of crystal
- Slowest in the middle of the faces
- Smooth transition
- Sin wave with 90 degree periodicity

Traditional Method vs. Ours:
- Point vs. plane
- Low vs. high energy

Image Credit: "Signal modeling of high-purity Ge detectors with a small read-out electrode and application to neutrinoless double beta decay search in Ge-76." *Journal of Instrumentation* 6 (2011).
CRYSTAL AXIS ORIENTATION PROCEDURE

Scan around detector at increments of 5-10 degrees with collimated radioactive source

Rise time

Calculate amplitude/energy of pulses in the energy range

![Graphs showing data analysis results.](image_url)
APPARATUS
COLLIMATOR
Radioactive Sources

**Americium 241**
- 60 keV peak
- “Button source”

**Thorium 232**
- Thallium 208
- 2615 keV peak
- Density; height
RESULTS

15 Minute Th Run 8/17/13
NOISY WAVEFORMS

From best Th run

From worst Th run
NOISE

Radioactive sources
- Thorium vs. Americium
- Attenuation coefficient of Th

Preamp noise
- Fixed by multimeter
- Possibly from high leakage current

Spiral wrapped cables—Ground loops
CONCLUSIONS

Noise is dominating signal

Positive Results
- Built a system that is capable of the measurement, with the exception of noise

Next steps
- Fix preamp
- Advanced filtering
- Superpulse
- Higher statistics

Image Credit: "Signal modeling of high-purity Ge detectors with a small read-out electrode and application to neutrinoless double beta decay search in Ge-76." *Journal of Instrumentation* 6 (2011).
ACKNOWLEDGEMENTS

Jason and the rest of the MAJORANA team
Doug Will
Deep, Alejandro, Janine, and Linda