The MAJORANA neutrinoless double-beta decay experiment

Alexis Schubert

Center for Experimental Nuclear Physics and Astrophysics (CENPA)
University of Washington - Seattle, WA

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$0\nu\beta\beta$ overview

The MAJORANA experiment

Summary

Oscillation experiments measure mass-squared differences and mixing angles

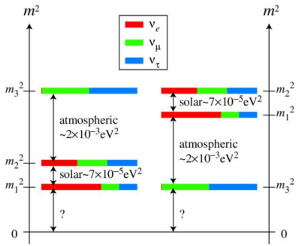


Figure from S. King Presentation at UKNF (May 2005). Available: http://hepunx.rl.ac.uk/uknf/2005-05-04/uknf-sfk-pheno.ppt

Open questions

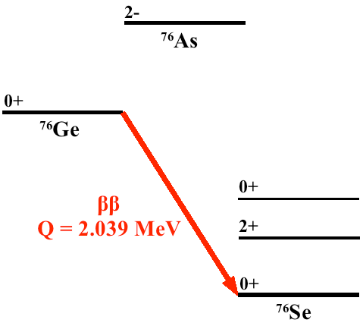
- What is the absolute neutrino mass scale?
- What is the mass hierarchy?
- Are neutrinos 'Majorana' particles? ($\nu = \bar{\nu}$)
- Do neutrinos play a role in leptogenesis?

Neutrinoless double-beta decay ($0\nu\beta\beta$) experiments can address these questions.

$2\nu\beta\beta$-decay

Allowed for even-even nuclei stable against β-decay.

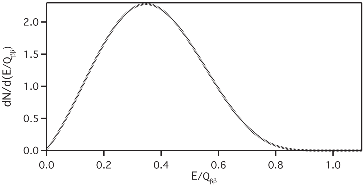
(e.g. ^{48}Ca, ^{76}Ge, ^{82}Se, ^{96}Zr ^{100}Mo, ^{116}Cd, ^{128}Te, ^{130}Te, ^{136}Xe, ^{150}Nd)



$2\nu\beta\beta$

- $(A, Z) \rightarrow (A, Z+2) + e^- + e^- + \bar{\nu} + \bar{\nu}$
- Allowed, seen in several nuclei
- $T^{2\nu}_{1/2} \sim 10^{20} y$

Energy spectrum of emitted electrons:



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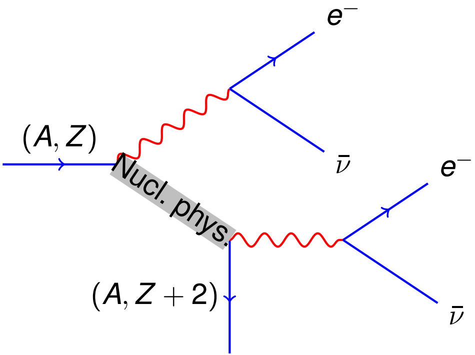

$0\nu\beta\beta$

- $(A, Z) \rightarrow (A, Z+2) + e^- + e^-$
- Not yet seen, but limits exist:
- For ^{76}Ge: $T^{0\nu}_{1/2} > 1.6 \times 10^{25} y$

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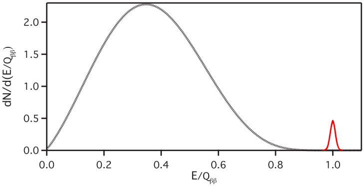
Energy spectrum of emitted electrons:



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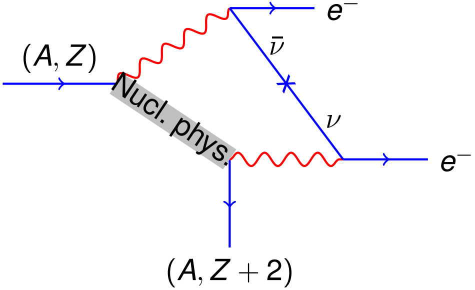


If $0\nu\beta\beta$ is seen:

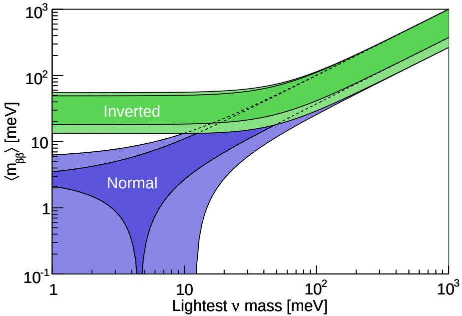
- Violates lepton number: ΔL=2
- $\nu = \bar{\nu}$ The neutrino is a Majorana particle
- We can determine effective neutrino mass from $0\nu\beta\beta$ decay rate:

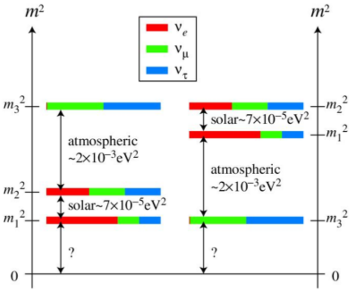
$$\left(T^{0\nu}_{1/2}\right)^{-1} = G^{0\nu}|M^{0\nu}|^2\langle m_{\nu_{\beta\beta}}\rangle^2$$

$$\langle m_{\nu_{\beta\beta}}\rangle = \left|\sum m_i U^2_{ei}\right|$$

$$= |U_{e1}|^2\, m_1 + |U_{e2}|^2\, m_2 e^{i\phi_2} + |U_{e3}|^2\, m_3 e^{i\phi_3}$$

Relating the effective mass to kinematic mass:





normal inverted

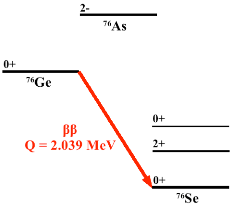
$$\langle m_{\nu_{\beta\beta}}\rangle = |U_{e1}|^2\, m_1 + |U_{e2}|^2\, m_2 e^{i\phi_2} + |U_{e3}|^2\, m_3 e^{i\phi_3}$$

MAJORANA: $0\nu\beta\beta$ in ^{76}Ge

Experiments with multiple isotopes are needed because of uncertainty in matrix element calculations.

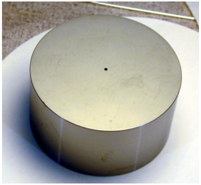
Advantages of germanium

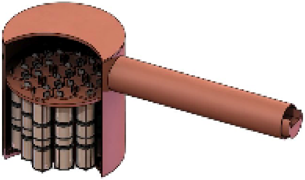
- High-purity Ge detectors = source
  - collect charge from ionization
- Q-value above many backgrounds: 2039 keV
- High resolution (~0.16% at 2039 keV)
- Background rejection (pulse-shape analysis, segmentation)
- Established ^{76}Ge enrichment technique



The MAJORANA Experiment: Demonstrator Module

- 60 kg of Ge
- 30 kg enriched in ^{76}Ge
- Analyze detector technologies: n- and p-type, segmented, point-contact, monolithic
- Detectors deployed in array of strings
- DOE and NSF support

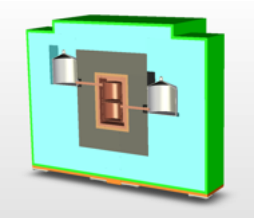




The MAJORANA Experiment: Demonstrator Module

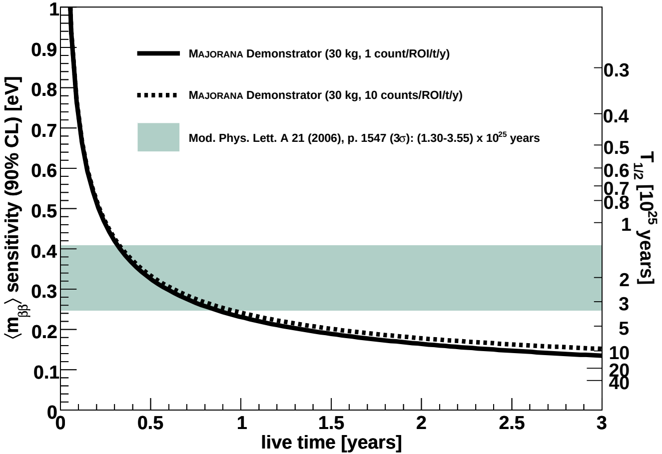
Low Background Design

- Electro-formed copper cryostat
- Passive and active shielding
- Located underground (4850' Sanford Lab (DUSEL))



Goal: Demonstrate backgrounds low enough to scale to 1-tonne

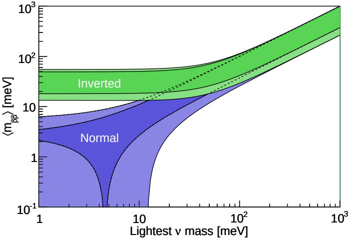
MAJORANA Demonstrator Sensitivity



Future one-tonne experiment

MAJORANA will collaborate with GERDA

- The Germanium Detector Array (GERDA) experiment
  - Also using ^{76}Ge for $0\nu\beta\beta$ search
  - Ge submerged in liquid Ar
- Sensitivity to effective neutrino mass after 10 years: $\sim$ 10s of meV



Summary

- $0\nu\beta\beta$ allows us to probe ν mass and nature
- MAJORANA will look for $0\nu\beta\beta$ in ^{76}Ge
- MAJORANA Demonstrator will test background goal
- GERDA and MAJORANA will collaborate for tonne-scale experiment

Detectors and backgrounds: Mike Marino*

*I used his slides.

Alexander Barabash, Sergey Konovalov, Igor Vanushin, Vladimir Yumatov
Institute for Theoretical and Experimental Physics, Moscow, Russia

Viktor Brudanin, Slava Egorov, K. Gusey, S. Katulina, Oleg Kochetov, M. Shirchenko, Yu. Shitov, V. Timkin, T. Vvlov, E. Yakushev, Yu. Yurkowski
Joint Institute for Nuclear Research, Dubna, Russia

Yuen-Dat Chan, Mario Cromaz, Brian Fujikawa, Donna Hurley, Kevin T. Lesko, Paul Luke, Akbar Mokhtarani, Alan Poon, Gersende Prior, Nikolai Tolich, Craig Tull
Lawrence Berkeley National Laboratory, Berkeley, California

Dave Campbell, Kai Vetter
Lawrence Livermore National Laboratory, Livermore, California

Steven Elliott, Gerry Garvey, Victor M. Gehman, Vincente Guiseppe, Andrew Hime, Bill Louis, Geoffrey Mills, Keith Rielage, Larry Rodriguez, Richard Schirato, Laura Stonehill, Richard Van de Water, Hywel White, Jan Wouters
Los Alamos National Laboratory, Los Alamos, New Mexico

Cyrus Baktash, Jim Beene, Fred Bertrand, David Radford, Chang-Hong Yu
Oak Ridge National Laboratory, Oak Ridge, Tennessee

Hiroyasu Ejiri, Ryuta Hazama, Masaharu Nomachi, Shima Tatsuji
Osaka University, Osaka, Japan

Fraser Duncan, Aksel Hallin, Art McDonald
Queen's University, Kingston, Ontario

Craig Aalseth, James Ely, Tom Farmer, Jim Fast, Eric Hoppe, Brian Hyronimus, David Jordan, Jeremy Kephart, Richard T. Kouzes, Harry Miley, John Orrell, Jim Reeves, Robert Runkle, Bob Schenter, John Smart, Bob Thompson, Ray Warner, Glen Warren
Pacific Northwest National Laboratory, Richland, Washington

Henning O. Back, James Esterline, Reyco Henning, Mary Kidd, Eliza Osenbaugh-Stewart, Werner Tornow, Albert Young
Triangle Universities Nuclear Laboratory, Durham, North Carolina and Physics Departments at Duke University, North Carolina State University, and University of North Carolina

Phil Barbeau, Juan Collar, Keith Crum, Smritri Mishra, Brian Odom, Nathan Riley
University of Chicago, Chicago, Illinois

Frank Avignone, Richard Creswick, Horatio A. Farach, Todd Hossbach, George King
University of South Carolina, Columbia, South Carolina

Tina Keller, Dongming Mei, Zhongbao Yin
University of South Dakota, Vermillion, South Dakota

William Bugg, Tom Handler, Yuri Efremenko, Brandon White
University of Tennessee, Knoxville, Tennessee

John Amsbaugh, Tom Burritt, Jason A. Detwiler, Jessica Dunmore, Peter J. Doe, Alejandro Garcia, Mark Howe, Robert A. Johnson, Michael G. Marino, Sean McGee, R. G. Hamish Robertson, Alexis G. Schubert, Brent VanDevender, John F. Wilkerson
University of Washington, Seattle, Washington