# Double-Beta Decay

## …is an exciting way to study neutrinos…

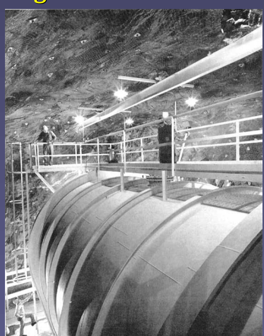
### What are neutrinos?

Neutrinos are elusive particles that are created in nuclear reactions such as in the sun, nuclear reactors, and when cosmic rays crash into the Earth's atmosphere. Since the first discovery of the neutrino, scientists have learned little about them, except that they generally stream through the Earth more easily than light through a window. Because they interact so weakly, experiments that look for neutrinos typically have to be very big and located deep underground, far away from background radiation on the Earth's surface.

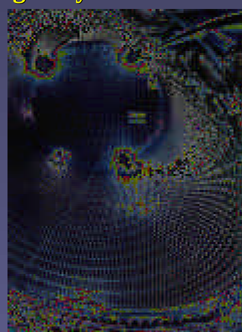
### "Radiation on the Earth's Surface???!!!"

Everything on Earth's surface is constantly bombarded by natural radiation from rocks, the sun and even distant galaxies! The signal from neutrinos is so weak that even this small amount of radiation would completely overwhelm it.

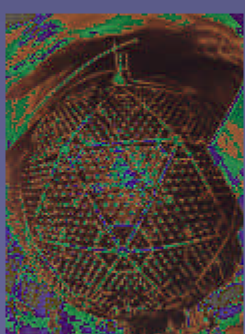
### Underground neutrino detector gallery:



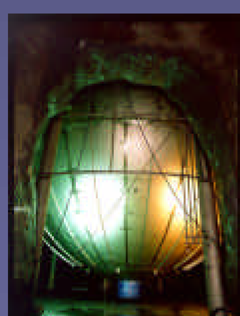
Homestake Detector, Homestake Mine Near Lead, SD - depth, 4850 ft.



Super-Kamiokande (Super K), Kamioka Mine in Japan - depth, 3250 ft.



The Sudbury Neutrino Observatory (SNO), Creighton Mine near Sudbury, Ontario - depth, 6800 ft.

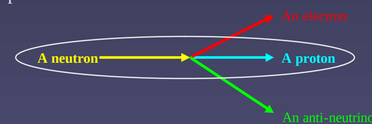


Kamioka Liquid Scintillator Anti-Neutrino Detector (KamLAND) Kamioka Mine in Japan - depth, 3250 ft.

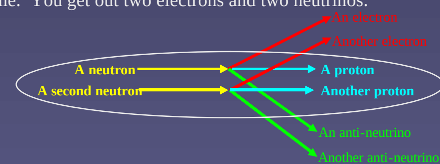
### Where does double-beta decay come in?

The experiments pictured in the neutrino detector gallery on the left have already demonstrated that neutrinos have some mass. In fact, they have determined the differences between the masses of the three types of neutrinos (electron, muon, and tau neutrinos). A sensitive method is now needed to determine the mass of one of the neutrino types to understand them all. Double-beta decay can determine the absolute scale of the electron neutrino mass.

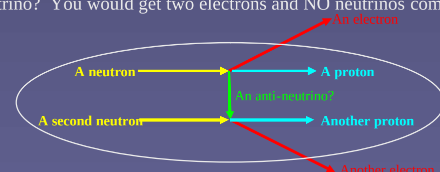
One common source of electron neutrinos is beta decay reactions. Beta decay is when a neutron within a nucleus decays by emitting an electron and an anti-neutrino, leaving behind a proton still bound to the nucleus:




You can think of double-beta decay as this happening twice, in the same nucleus at the same time. You get out two electrons and two neutrinos:




But what if, instead of getting a total of two anti-neutrinos and two electrons out of this reaction, the first anti-neutrino from one neutron was absorbed by the second as a regular neutrino? You would get two electrons and NO neutrinos coming out:




**This is neutrinoless double-beta decay!**

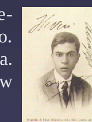
### What would it take for neutrinoless double-beta decay to occur?

The part of the third reaction above (where the neutrino gets re-absorbed) is key– The first step produces only anti-neutrinos which spiral in a right-handed way, like a football thrown by a right-handed quarterback. For the second half of the reaction to occur, this anti-neutrino has to be left-handed AND has to be a regular neutrino.

Therefore if we observe this reaction, we will have discovered:

- ➢There is no difference between neutrinos and anti-neutrinos.
- ➢The (anti)neutrino has to have a non-zero mass to flip from right-handed to left-handed.
- ➢The higher the neutrino's mass, the easier the spin flip and the faster double-beta decay is. Therefore, we can measure the mass of the neutrino by measuring the rate of decay!

### The Majorana Project



…is an experiment designed to observe neutrinoless double-beta decay and thus measure the mass of the electron neutrino. The name comes from the Italian physicist Ettore Majorana. Majorana worked out much of the theory describing how particles like neutrinos could be their own anti-particles.

### How will Majorana work?

The Majorana project is a proposed array of 500 kg (1100 lbs.) of radiation detectors made from a special isotope of the element germanium which is known to undergo two-neutrino double-beta decay. These germanium detectors will be the source of the double-beta decay and also measure the electrons that come out of the reaction. This is a drawing of one possible configuration of the experiment:

Germanium detectors must be kept cold when running. The white tanks in this drawing will hold liquid nitrogen to cool our detectors. The copper cases around them help to keep everything clean and air-tight.

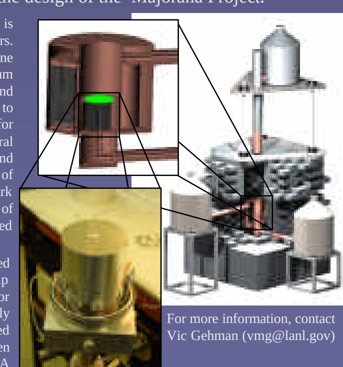
Each one of these cylinders represents one germanium detector. As you can see we are going to need LOTS of them!

### This laboratory was built to house MEGA and SEGA

MEGA and SEGA are both engineering prototypes that will support the Majorana project. One of the most exciting things about the Majorana project is that it relies primarily on existing technology, but MEGA and SEGA will help us to optimize the design of the Majorana Project.

MEGA (Multi-Element Gamma Assay) is an array of 18 germanium detectors. MEGA will help us learn to fine-tune operation of a large array of germanium detectors (particularly cooling and background rejection). In addition to helping us optimize the design for Majorana, MEGA will also have several other science goals: environmental and national security monitoring, the study of rare nuclear decays, and the search for dark matter. The green disk in the drawing of MEGA represents a sample being counted for one of these goals.

The SEGA (Segmented Enriched Germanium Assembly) detector will help us to fine-tune the electronics required for segmented detectors. It will eventually become part of the MEGA array (pictured in the above inset underneath the green disk). On the right, you can see the SEGA detector in its test cryostat.



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### The Majorana Collaboration:

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Los Alamos National Laboratory, Los Alamos, NM
Oak Ridge National Laboratory, Oak Ridge, TN
Osaka University, Toyonaka, Japan
Pacific Northwest National Laboratory, Richland, WA
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Triangle Universities Nuclear Laboratory, Durham, NC
University of Chicago, Chicago, Il
University of South Carolina, Columbia, SC
University of Tennessee, Knoxville, TN
University of Washington, Seattle, WA

And a special thanks to our friends and hosts at the Waste Isolation Pilot Plant, Carlsbad, NM