KATRIN AND MAJORANA

Neutrino Mass Measurements Using β and ββ Decays

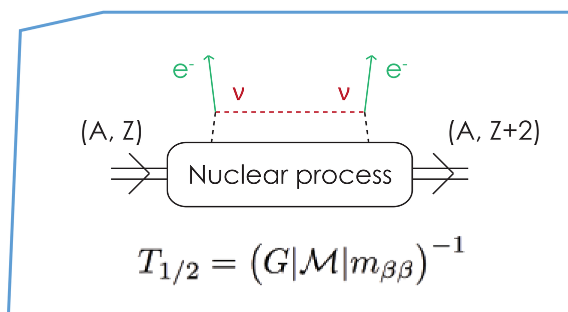
by James Loach for the LBNL Neutrino Astrophysics Group
Group leader Alan Poon (awpoon@lbl.gov)
LBNL Bldg 50, Room 5212

MAJORANA

MEASURING THE MASS OF THE NEUTRINO

NEUTRINOLESS DOUBLE BETA DECAY

In neutrinoless double beta decay (0νββ) two neutrons are converted into two protons and two electrons are emitted. The process is possible only if the neutrino is a **Majorana particle** (it's own antiparticle).



$$T_{1/2} = (G|\mathcal{M}|m_{\beta\beta})^{-1}$$

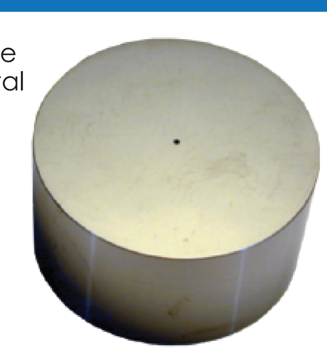
The 0νββ half-life depends on the effective Majorana neutrino mass ($m_{\beta\beta}$) and a nuclear matrix element ($\mathcal{M}$) that is difficult to calculate.

Observation of 0νββ is the only practical way to tell whether the neutrino is a Majorana rather than Dirac particle.

THE MAJORANA EXPERIMENT IS NAMED AFTER ITALIAN PHYSCIST ETTORE MAJORANA (1906-38), FIRST TO PROPOSE THE MAJORANA NEUTRINO

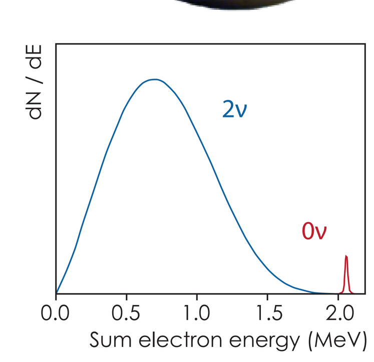
THE ISOTOPE ^{76}Ge

HPGe crystal

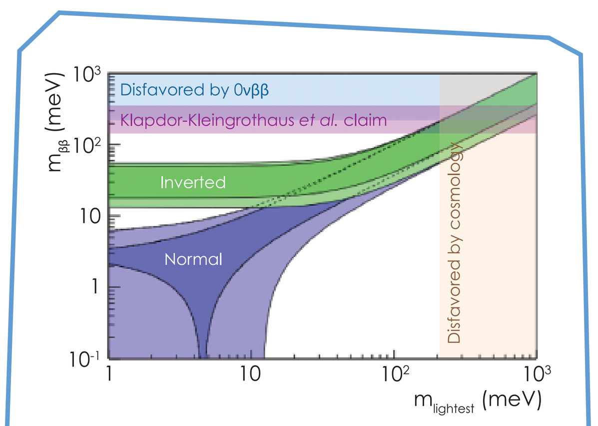


The signature of 0νββ is a peak in the summed electron energy at the reaction Q-value.

^{76}Ge is an ideal isotope to use because the source can be the detector (HPGe detectors are an established technology), the Q-value of 2.039 MeV is higher than many backgrounds and it can be enriched economically.



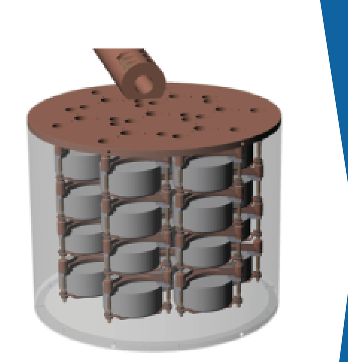
THE MAJORANA EXPERIMENT



The MAJORANA experiment aims so search for $m_{\beta\beta}$ in a region covering the **inverted** hierarchy, which is the allowed region if the ordering of the neutrino mass states is opposite to the ordering of the quarks and charged leptons.

The **MAJORANA experiment** will search for 0νββ using an array of HPGe detectors made from Ge enriched in ^{76}Ge.

The first phase will be the MAJORANA DEMONSTRATOR, which is designed to show that the background levels required for a tonne-scale experiment can be achieved and to test a claim for observation of 0νββ in ^{76}Ge by Klapdor-Kleingrothaus et al.



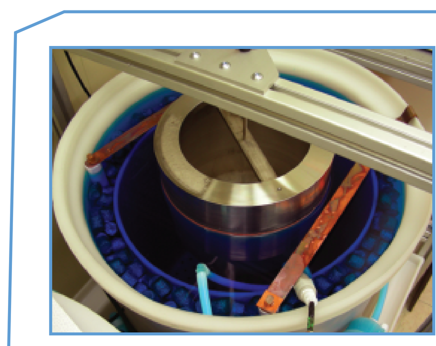
THE MAJORANA EXPERIMENT WILL BE SITED ON THE 4850 FOOT LEVEL OF THE SANFORD UNDERGROUND LABORATORY IN SOUTH DAKOTA

TECHNICAL CHALLENGES

The main technical challenge in Majorana is the **control of backgrounds**, which are reduced by sourcing or producing ultra-clean materials and running the experiment deep below ground.

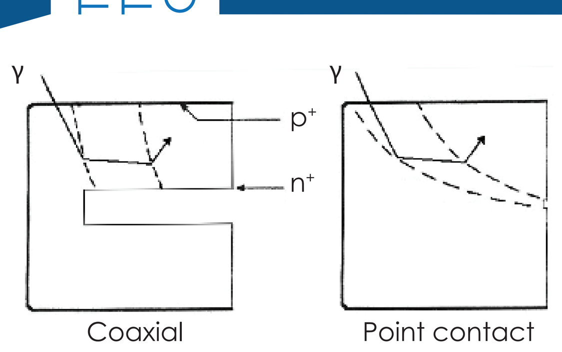
Advanced analysis techniques allow backgrounds to be further reduced offline, extending the experiment's physics reach.

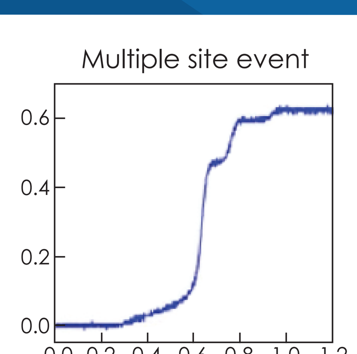
Electroforming



Copper used for critical components will be electroformed in a dedicated underground facility.

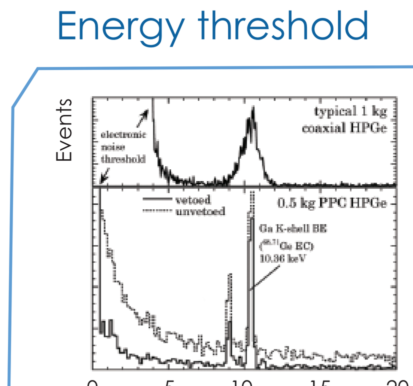
P-TYPE POINT CONTACT Ge DETECTORS





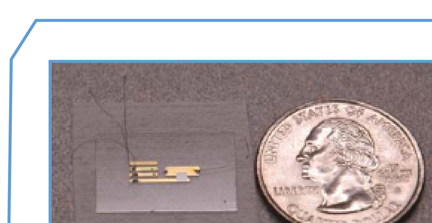
Point contact HPGe detectors were invented at LBNL. They have extremely low noise and allow single site events, characteristic of 0νββ events, to be distinguished from multiple site events, characteristic of backgrounds. The p-type variety are used in MAJORANA.

Energy threshold



Low noise means a low energy threshold. This will make MAJORANA sensitive to low energy events characteristic of interactions of **dark matter** and **axions**.

Electronics



Taking advantage of the low noise of point contact detectors requires low noise electronics. The front-end part must also be low mass and clean to avoid introducing contaminants close to the detector.

A tiny front-end electronics board developed at LBNL (see above) has operated with a **world record noise level of < 100 eV**.

THE NEUTRINO DECADE

Recent discoveries have shown that neutrinos have mass and that they oscillate between flavours. Some mass differences and mixing angles have been measured but questions remain:

- **What is the neutrino mass scale?**
- **Are neutrinos Dirac or Majorana particles?**
- And many others.

THREE WAYS TO THE NEUTRINO MASS

The are three main ways to probe the neutrino mass scale. The techniques are complementary and each is extremely challenging.

Underground

Neutrinoless double beta decay is a process (not yet observed) that yields a model-dependent mass.

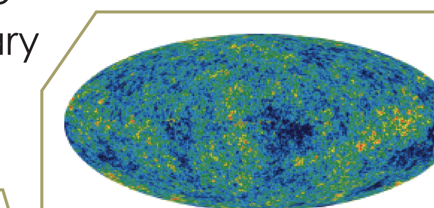
$$m_{\beta\beta} = \sum_{i=1}^{3} |U_{ei}^2 m_i| < 0.35\ \mathrm{eV}$$

Surface

The kinematics of β decays provide a model-independent method.

$$m_\beta = \sqrt{\sum_{i=1}^{3} |U_{ei}|^2 m_i^2} < 2.3\ \mathrm{eV}$$

Heavens



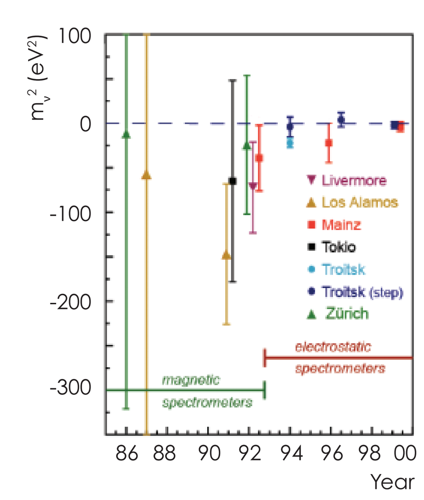
Cosmological fits are sensitive to the neutrino mass but suffer strong model dependencies.

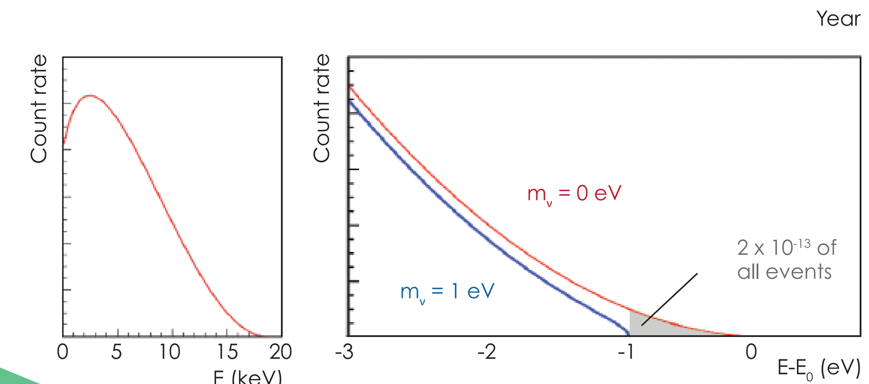
$$\sum m = \sum_{i=1}^{3} m_i < \sim 1\ \mathrm{eV}$$

KATRIN

BETA DECAY

The neutrino's existence was inferred from the beta decay electron energy spectrum. It's shape gives information on the neutrino mass (see below) and there is a long history of experiments (see right).





THE NEXT GENERATION

The goal of the next generation of experiments is an **order of improvement in the mass limit**. This requires more statistics, better energy resolution and smaller background.

An ideal source

- High luminosity
- Low end point energy
- Super-allowed decay
- Simple atomic structure

→ ^{3}H

An ideal detector

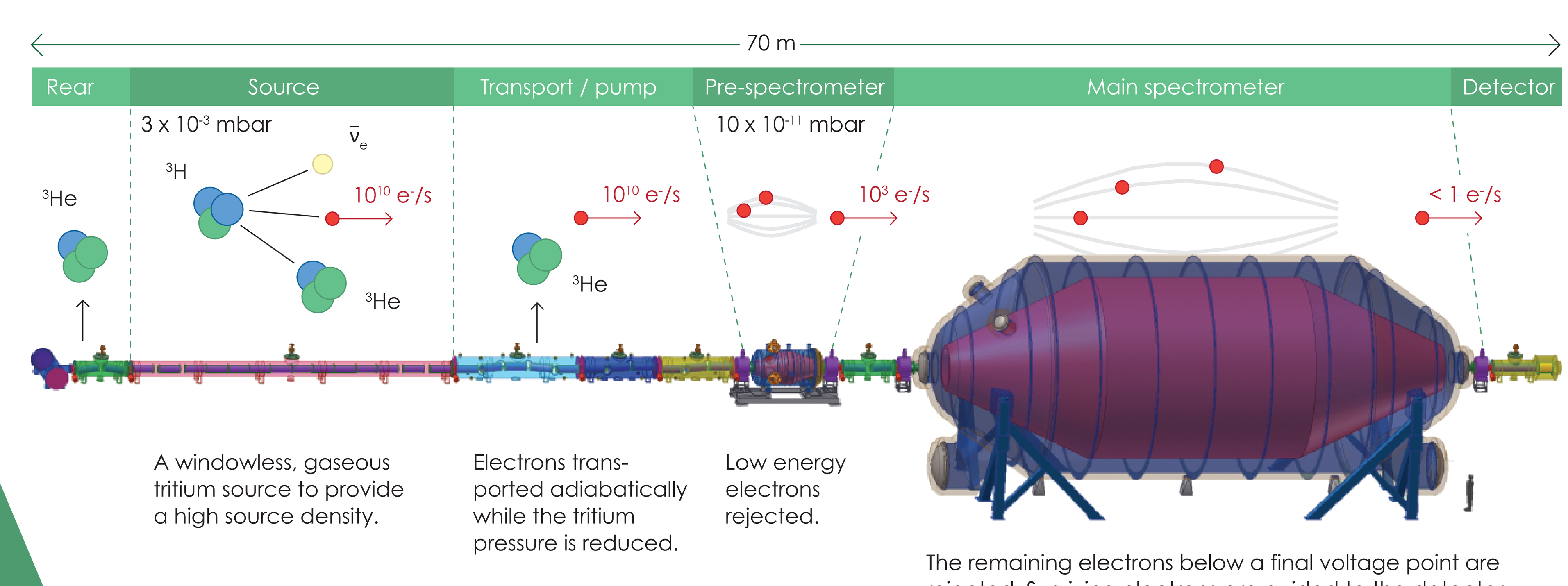
- Large acceptance
- Short deadtime, no pileup
- Good energy resolution
- Low background rate

→ Spectrometer

The KATRIN main spectrometer arrives in Karlsruhe, Germany.

THE KARLSRUHE TRITIUM NEUTRINO EXPERIMENT

The **KATRIN experiment** will measure the energy spectrum of electrons from the beta decay of tritium, very close to the 18.6 keV endpoint energy. It will have a mass sensitivity of 0.2 eV.



A windowless, gaseous tritium source to provide a high source density.

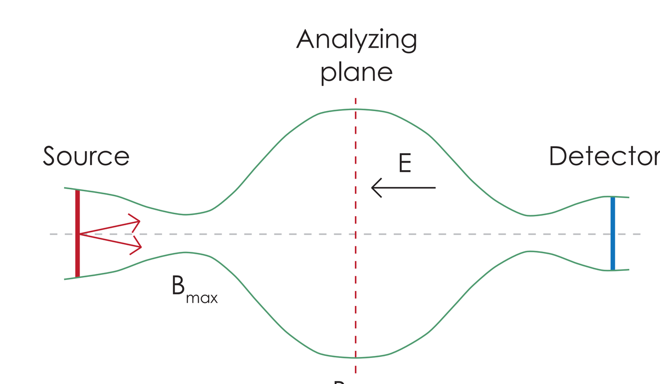
Electrons transported adiabatically while the tritium pressure is reduced.

Low energy electrons rejected.

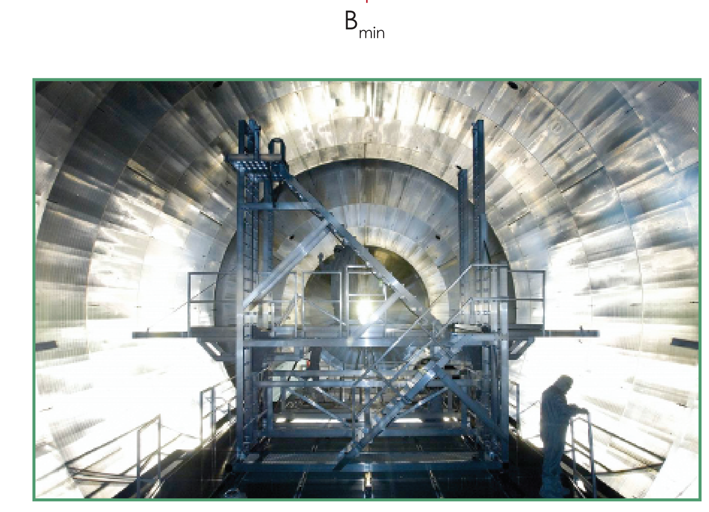
The remaining electrons below a final voltage point are rejected. Surviving electrons are guided to the detector.

THE KATRIN SPECTROMETERS

The KATRIN spectrometers are MAC-E filters (electrostatic filters with magnetic adiabatic collimation). The electrons are collimated by a magnetic field and exposed to a retarding electric potential through which they can pass only if they have sufficient energy.



The **pre-spectrometer** rejects all electrons < 200 eV below the endpoint. The **main spectrometer** provides a finer energy resolution of 0.93 eV with an input field of 4.5 T, an output field of 6 T and a field in the analysis plane of 3 x 10^{-4} T.



Inside the main spectrometer.