THE UNIVERSITY OF WARWICK

Development of an e-resource for Low Background Physics: ββ(0ν)

Project Brief

The aim of my project was to create a website that could plot data from double beta decay experiments around the world, to allow comparison between results, and convey the current status of research efforts.
The site idea was based around a similar plotter for dark matter datasets, created by the University of Berkeley- the aim being once available on the web it should enhance the reputation of the University of Warwick in the area of neutrino research.
Broadly the website should be similar in function to the Berkeley plotter, but additionaly should simplify the process for the user, making our plotter more user friendly. Visitors should also be able to submit and use their own datasets, to decrease the time staff members need to spend maintaining the site.
I was given 9 weeks for the project, over the months of July and August 2007.

Theory

Beta Decay is the process in which a neutron decays, via the weak interaction to a proton, releasing an electron and an electron anti-neutrino.

Standard Double Beta Decay therefore is when two of these decays happen simultaniously, with the emission of two electrons and two antineutrinos. There is obviously a statistical probability of this happening, so this concept is a part of the "standard model" of particle physics, and has been experimentally detected.

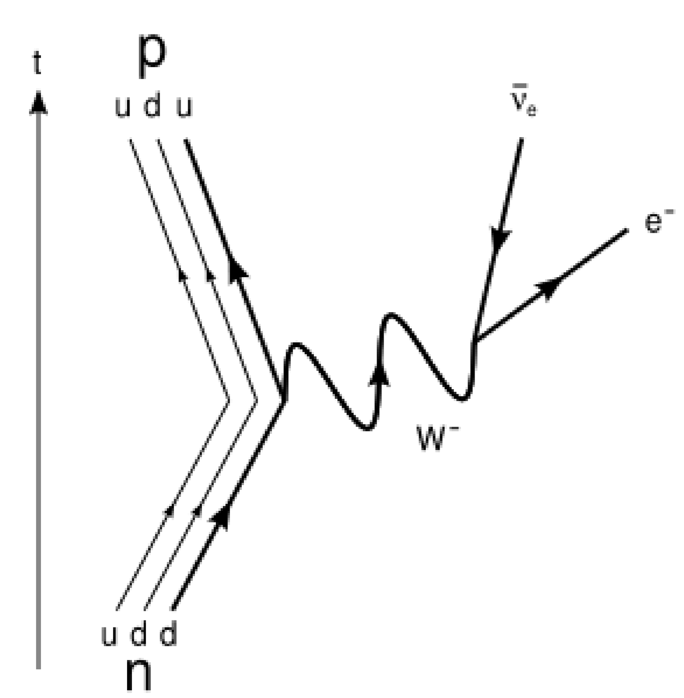

Fig. 1 - A Standard Beta Decay event represented as a Feynman Diagram. u and d represent up and down quarks, W^- is the negatively charged W boson, e^- is an electron, and Nu-bar is the electron anti-neutrino.

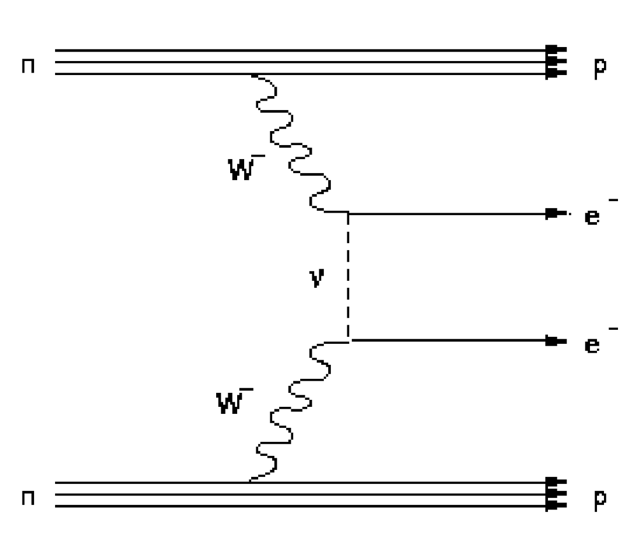

Fig. 2 - A Feynman diagram representing neutrinoless double-beta decay via majorana neutrino exchange. Symbols have the meanings explained above.

Neutrinoless Double Beta Decay is a phenomenon not predicted by the "standard model" of particle physics. Theoretical physicists predict that in some extended models two nuclei can undergo simultaneous beta decay, emitting two electrons, without the usual accompanying neutrinos.
This can take place if the neutrino is a Majorana particle, meaning that it is its own antiparticle. This process is shown in the Feynman diagram in figure two.

Neutrinoless double beta decay is in theory an easily observable occurrence, as only two electrons are released they share the energy of the decay equally, producing a sharp peak in a energy spectrum plot.
However these decays have yet to be observed by experiment, suggesting a half life of around 10^{25} years or greater! (Only one claim for observation has been made, but scientific opinion is split on the strength of the evidence for this claim.)

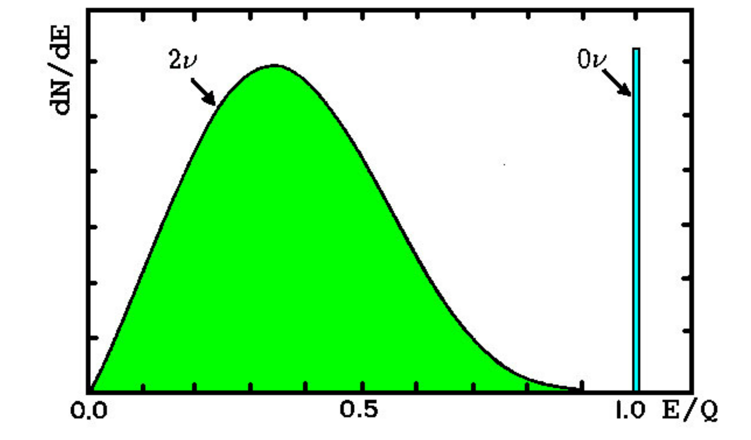

Fig. 3 - An energy spectrum plot showing the sharp double beta peak. The grey continuem is the usual spectrum for normal double beta decay, where energy is shared between four particles.

As the half-life of this process is so large even the next generation of experiments expect to only observe 2 or 3 such events in a year. This makes reducing background noise a paramount concern for such experiments!
Most experiments searching for this effect contain a source material that is known to have an allowed double beta decay transition. The greater the mass of this source material, the more decays are likely to occur in any given time. This material is surrounded by an array of detectors and trackers, that attempt to reject single beta decay events, and background noise, and produce a spectrum like that shown in figure three.
Other experiments are possible, but are not currently in such advanced form.

The Site

The website I have created during this project is coded mainly in PHP (Pre Hypertext Protocal), a server side scripting language. It stores data in XML (eXtensiable Markup Language) format, and produces graphs using the freeware jpgraph library.
The site has two sections, one which creates plots of Majorana mass vs Lightest Eigenstate values, and another which compares various existing experiments by the half life limits they predict, and by imperical quality factors.
Each section allows the user to add their own datasets, and if they have been published in a peer reviewed journal the site will automatically email them to a administrator for inclusion in the site databank. The plots produced are highly customisable, allowing the user to specify axis titles, colours, legends and allow grouping of plots.

Majorana Mass Plots

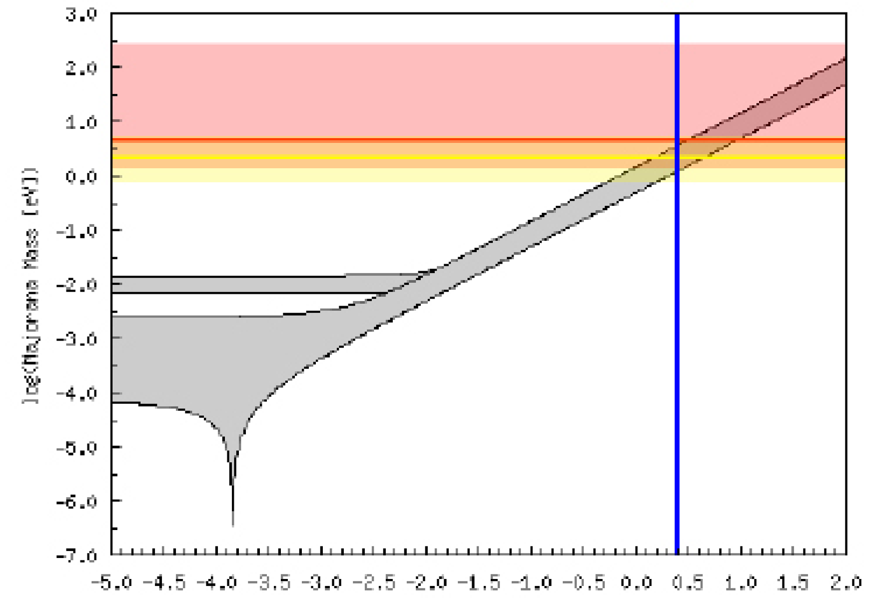

Fig. 4- Majorana Mass Plot, without legend.

The plot to the left shows the sort of graphs this section of the site produces, showing the theortically allowed values in grey, and the experimental values with coloured bands.
The theoretically allowed values can be changed by the user to customise the plots to there specific theories.
This graph, and its legend are downloadable in PDF, PS and EPS formats.

Half Life/Quality Factor Plots

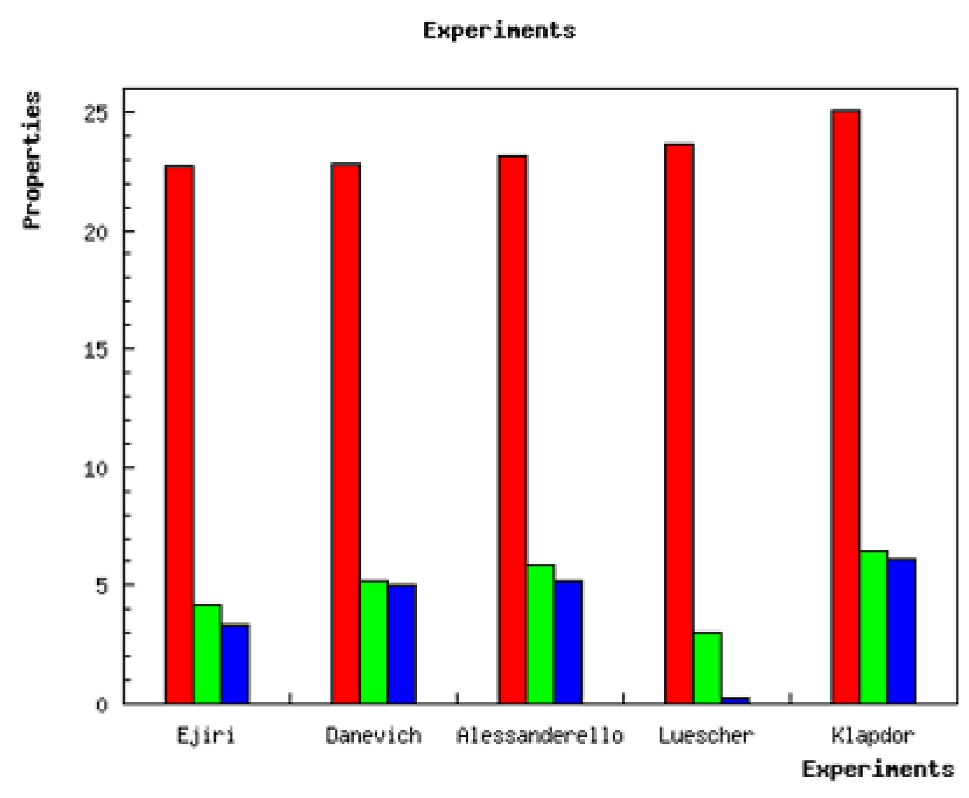

Fig. 5 - Half Life/Quality factor grouped graph showing comparable qualities. These are displayed on the same graph to allow comparison between different experimental setups.

Quality factors are explained and defined below.

These graphs can also be produced as separate plots, with one quantity shown on each for close comparison.

Legends can be produced, or removed as per the users wishes.

Quality factors F and Fd are defined in the literature as dimensionless combinations of the important qualities defining each experiment. They are defined as below:

$$f \equiv \bar{\eta}\left(\frac{a\epsilon}{W}\right)\sqrt{\frac{M}{b\,\delta E}} \qquad f_d \equiv \frac{\bar{\eta} a\epsilon}{W b \delta E}$$

Quality factors of this form were first preposed in *Avignone et al* (See References), but have been modified here with a scaling factor to enable comparison of the factors on the same graph.

Where:
- $\bar{\eta}$ = Average nuclear form factor (<Fn> x 10^{13})
- a = Isotopic abundance
- ε = Detection efficiency
- W = Molecular weight of source material
- M = Source mass (Kg)
- b = Background counts ($KeV^{-1}Kg^{-1}\,yr^{-1}$)
- δE = Energy window (KeV)

References and Thanks

Thanks:
Thanks is firstly due to Dr Yorck Ramachers and Dr Ben Morgan, without whose help and guidance the project would never have got off the ground.
Thanks is also due to the engineering department for providing computers for our use, and to Rashida and all in the physics office for help finding office space.
Finally thanks to all in charge of the URSS scheme for giving me the opportunity to do this project in the first place.

Major References:

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