TITAN TRIUMF'S ION TRAP FOR ATOMIC & NUCLEAR SCIENCE

Geant 4 Simulation of Electron Capture Branching Ratio Measurements Using the TITAN EBIT

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Introduction

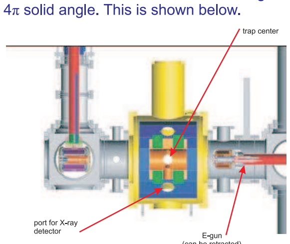
The goal of this experiment is to measure the electron capture (EC) branching ratios seen in double beta decay using TITAN's new ion trap facility at TRIUMF. These measurements are important for determining the nuclear matrix elements involved in double beta decay. So far there are no direct measurements of the EC branching ratios in these decays. By using TITAN's new electron beam ion trap (EBIT) increased sensitivity can be achieved by significantly reducing background levels.

The measurements will be performed by storing an isotopically pure sample backing free inside the trap. X-rays from the EC will be observed by high-resolution detectors placed perpendicular to the magnetic axis. Electrons from the associated β^--decay will be guided along the magnetic field lines away from the center and out of the trap. Since the magnetic field is high (6T) the electrons will not hit the X-ray detectors. A β^- detector will also be used at the trap exit for anti-coincidence measurements.

To determine the optimal geometry and experimental setup computer simulations of the experiment are now underway at TRIUMF.

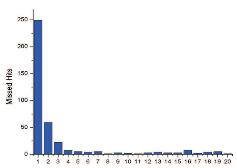
Experimental Setup

During the EC experiment the EBIT will be used without the application of the electron gun in Penning trap mode. The electron gun will be retracted to make room for the β-counter. The EBIT design also allows open access for X-ray detectors. Up to 7 detectors can be mounted covering 2.1% of the 4π solid angle. This is shown below.

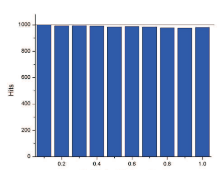


Gamma Detection

To obtain the best results possible optimization of the gamma detector and beryllium windows are needed. A silicone detector was placed along the x-axis. A beam energy of 17.5 keV was used. Gammas were emitted straight along the x-axis and the detector thickness was varied. The results are shown below.



An optimal thickness of 5 mm was found. A similar measurement for the beryllium windows was performed using the optimal detector thickness of 5 mm.

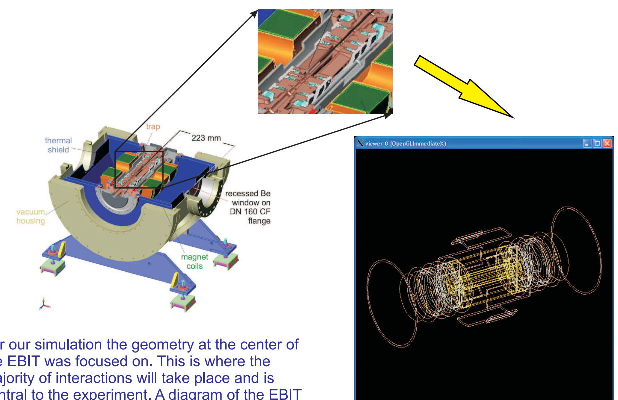


As can be seen above interactions with the beryllium window are very small so the current window thickness of 500 μm and 25 μm may be used.

The Geant 4 Simulation

Geant4 is a toolkit for the simulation of the passage of particles through matter. Geant4 has been used successfully in a variety of applications including simulations for the ATLAS detectors. It was chosen for our simulation for its flexibility and its wide range of available physics packages.

In addition to the geometry the physics processes must also be added. Some of the packages used in the simulation include multiple scattering, ionisation, Bremsstrahlung scattering, Compton scattering, and the photoelectric effect. In addition two particle types were used, electrons and gammas.



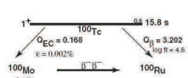
For our simulation the geometry at the center of the EBIT was focused on. This is where the majority of interactions will take place and is central to the experiment. A diagram of the EBIT is shown above. The central structure is made up of a series of cylindrical electrodes of pure copper. The electrodes are separated by insulating materials such as Al_2O_3 and Macor. The structure is then encased in an aluminum tube with windows cut out to allow a clear path to the detectors.

The above is an OpenGL rendering of the simulated geometry. The yellow represents the copper electrodes and the blue is insulating material. The aluminum casing is also shown in white.

For more about Geant 4 see http://geant4.web.cern.ch/geant4/

The ^{100}Tc Case

The first case examined was that of ^{100}Tc. This decay can be seen in the figure below.



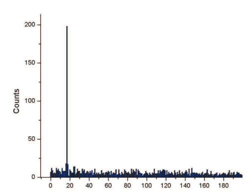
The β^--decay of ^{100}Tc has a 93% branch to the ground state and a 5.7% branch to a 1.130 MeV (0^+) state in ^{100}Ru. There are also several weak transitions that produce γ-rays. The energies produced by these γ-rays are significantly higher than the typical X-ray energies. The full spectrum of emitted gamma energies can be seen below.

Gamma and X-ray radiation:

Energy (keV)	Intensity (%)	Dose (MeV/Bq-s)
378.6 5	0.029 % 9	1.1E-4 3
499.8 ?	7.0E-4 % 21	3.5E-6 11
539.59 5	7.0 %	0.038
590.83 5	5.7 % 11	0.034 6
689.4 3	0.034 % 9	2.3E-4 6
734.7 5	0.010 % 4	7E-5 3
736.9 ?	0.00140 %	1.03E-5
822.5 3	0.068 % 18	5.6E-4 15
1024.5 5	0.034 % 9	3.4E-4 9
1130.1	8E-5 %	9E-7
1201.1 10	0.043 % 10	5.1E-4 12
1325.7 5	0.010 % 4	1.4E-4 5
1362.1 5	0.060 % 12	8.2E-4 17
1512.2 3	0.44 % 9	0.0067 13
1559.7 5	0.007 % 4	1.1E-4 6
1701.0 10	0.0014 % 7	2.4E-5 13
1847.7 3	0.041 % 10	7.5E-4 18
1865.2 5	0.013 % 4	2.5E-4 8
2121.2 7	0.0035 % 9	7.4E-5 20
2298.6 5	0.014 % 4	3.2E-4 10
2659.5 10	0.0014 % 7	3.7E-5 20

Data from www.nndc.bnl.gov

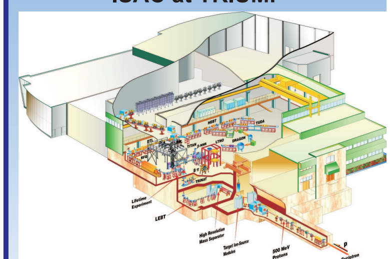
The simulation run for ^{100}Tc used the optimal detector and Be window configuration that was previously determined. The full gamma spectrum was used for the run with ~200K total events. The incident angle theta was limited to a 15° cone. To get the same results over the full 4π solid angle ~7.5×10^7 events are needed.



The resultant spectrum shown above has a detector resolution of 300 eV. The electron capture energy can clearly be seen at 17.5 keV.

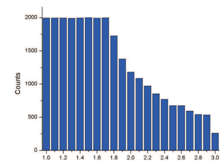
The EBIT on the TITAN platform

ISAC at TRIUMF

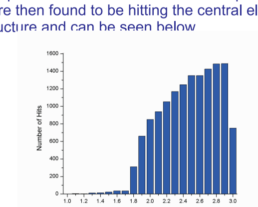


Beta Detection

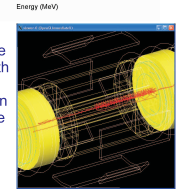
For the simulation of Beta emissions a scintillation detector of pure silicone 1 cm thick was added along the z-axis. A uniform 6 Tesla magnetic field was placed around the electrode structure and particles were randomly emitted along the z-axis.



As the electron energy was increased less particles hit the detector. This is due to the magnetic field no longer being able to alter the particle trajectory enough to avoid the EBIT components and is shown above. The particles were then found to be hitting the central electrode structure and can be seen below.



The second electrode has the smallest hole with a diameter of 5 mm and is shown here blocking the electrons.



Conclusion

Our inital results from simulation of the ^{100}Tc case are promising. That the electron capture events were able to be detected and seperated from the background demonstrates a sound experimental technique.

Still to Do

- Analysis of other cases of double beta decay
- Examine emission in a non-unifor magnetic field

References

J. Dilling, D. Frekers, and I. Tanihata, Can. J. Phys., Submitted for publication