DETECTING LIGHT IONS AND ELECTRONS WITH TRIMS SILICON DETECTORS

W.-J. Baek, A.P. Vizcaya Hernández for the TRIMS collaboration

Karlsruhe Institute of Technology

Carnegie Mellon University

TRIMS (Tritium Recoil-Ion Mass Spectrometer)

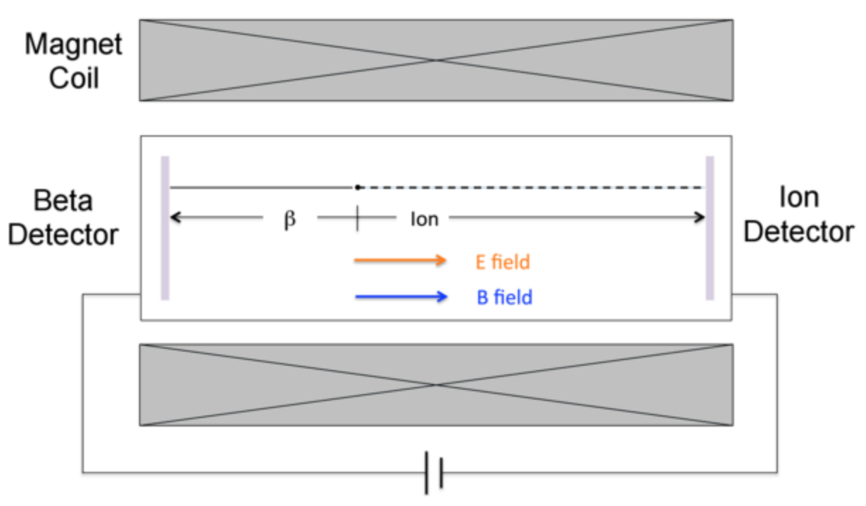

Fig. 1. Sketch of the TRIMS experiment. [1]

- 60 kV electric field
- 0.2 T magnetic field

The goal of the TRIMS experiment is to measure the molecular tritium (T_2) β decay branching ratio to the bound state $^3HeT^+$. The setup consists of a decay volume filled with T_2 gas, with one silicon detector on each end. Mass-3 (dissociated) and mass-6 (molecular) ions can be distinguished using ion energy and time of flight relative to the beta electron.

The main decay branches of T_2 are:

$$T_2 \longrightarrow {}^3HeT^+ + e^- + \overline{\nu}_e$$
$$T_2 \longrightarrow {}^3He^+ + T + e^- + \overline{\nu}_e$$
$$T_2 \longrightarrow {}^3He + T^+ + e^- + \overline{\nu}_e$$

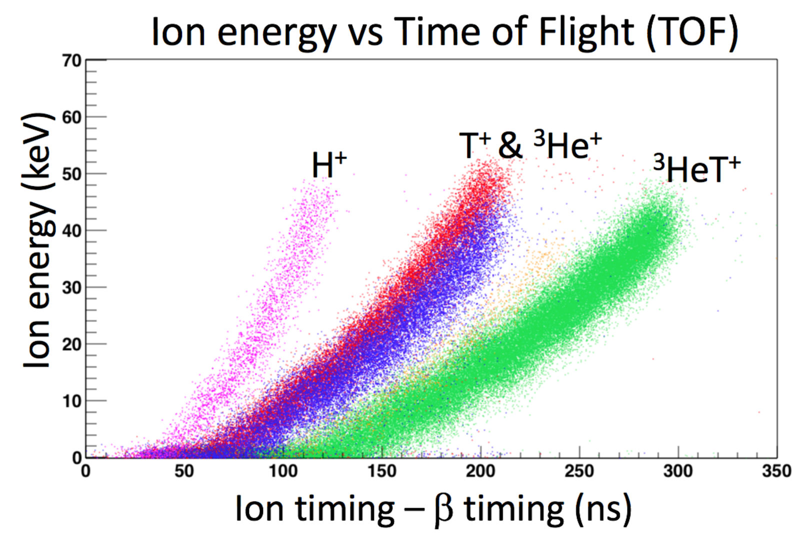

Fig. 2. Geant4 simulation of ion energy vs time of flight for H^+, T^+, $^3He^+$ and $^3HeT^+$ [1].

Interactions of ions and β electrons with silicon detectors

To understand the TRIMS energy reconstruction and compute correct branching ratios as a function of beta energy, we modeled scattering interactions inside the dead layer with SRIM [2] and KESS [3].

- Total detector thickness of 500 μm.
- Dead layer of 100 nm in which the energy deposited is not completely recovered in the voltage signal.

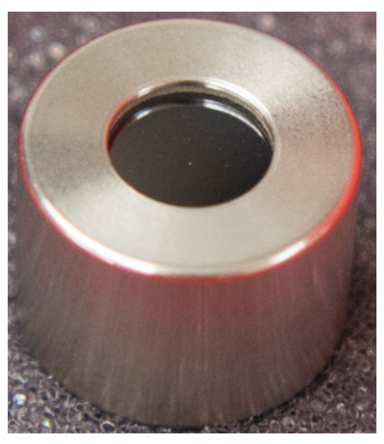

Figure 3. PIPS Canberra detector.

Ions in the silicon detector

- A silicon detector with TRIMS characteristics was simulated using the software SRIM.
- 99,999 ions were simulated per initial energy ($E_{initial}$).
- Interactions whose response depends on the ion type are especially important to obtain an accurate branching ratio.

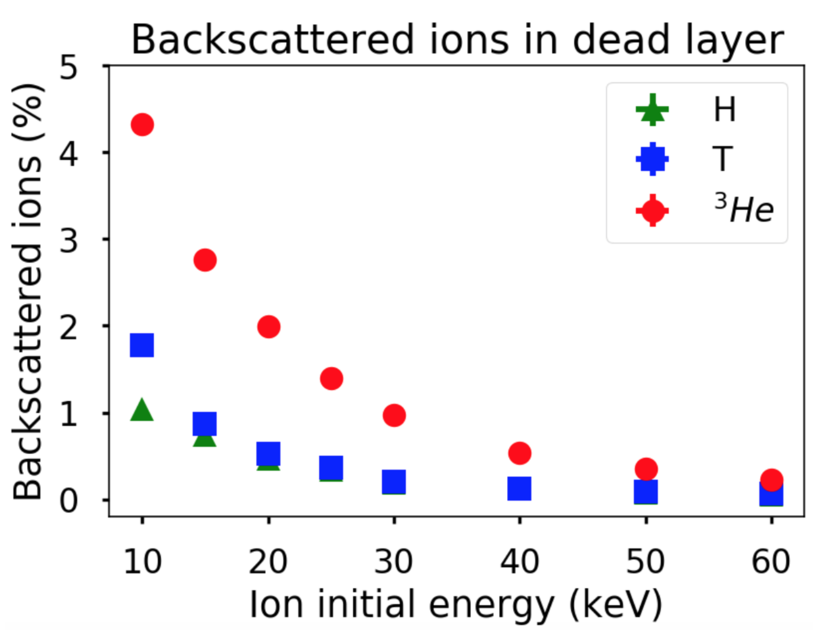

Figure 3. Percentage of backscattered ions.

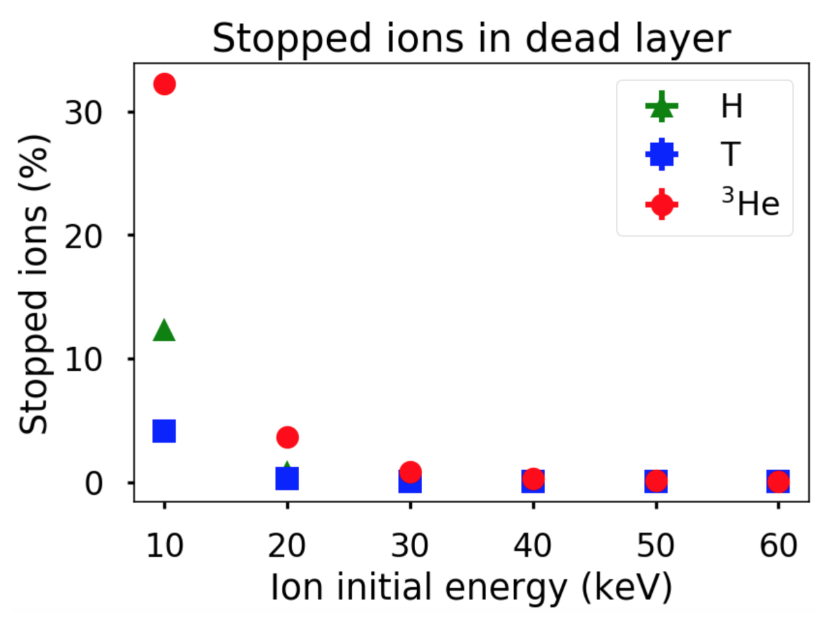

Figure 4. Percentage of stopped ions.

- The energy loss in the dead layer (E_l) is used to calculate the detected energy (E_d) [4]:

$$E_d \approx E_{initial} - E_l/2$$

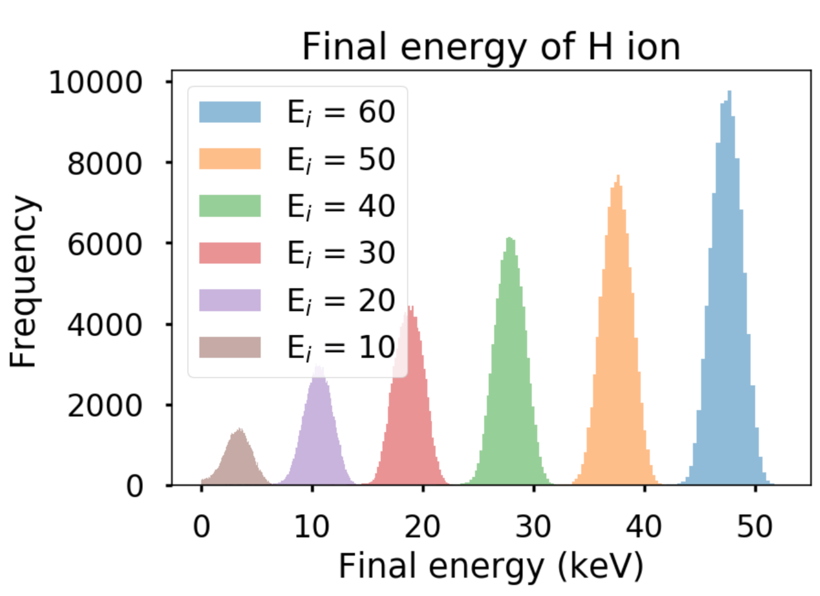

Figure 5. Histograms of the energy of an H ion after crossing a 100 nm silicon dead layer.

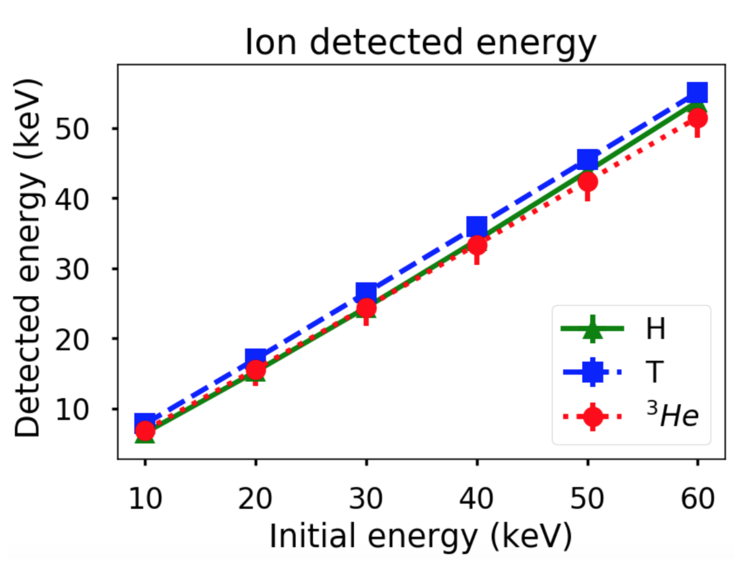

Figure 6. Energy detected for H, T and ^3He ions vs its initial energy.

β electrons in the silicon detector

Applying the package KESS [3] of the Kassiopeia software, simulations of electrons in silicon were carried out.

- Initial energy from 5 keV to 80 keV
- 2 keV steps
- 10^3 electrons in each energy range.

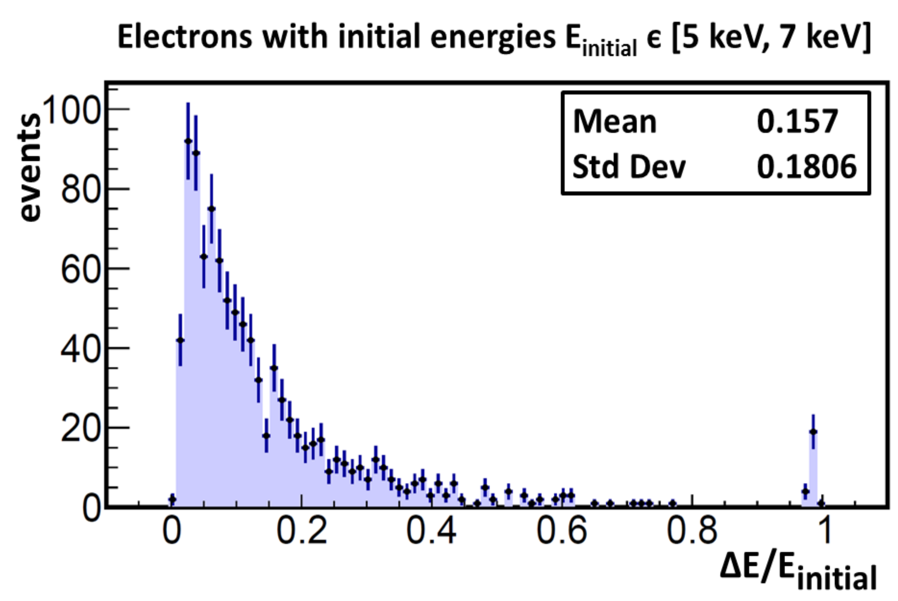

Figure 7. Relative energy loss of electrons with initial energies between 5 keV and 7 keV.

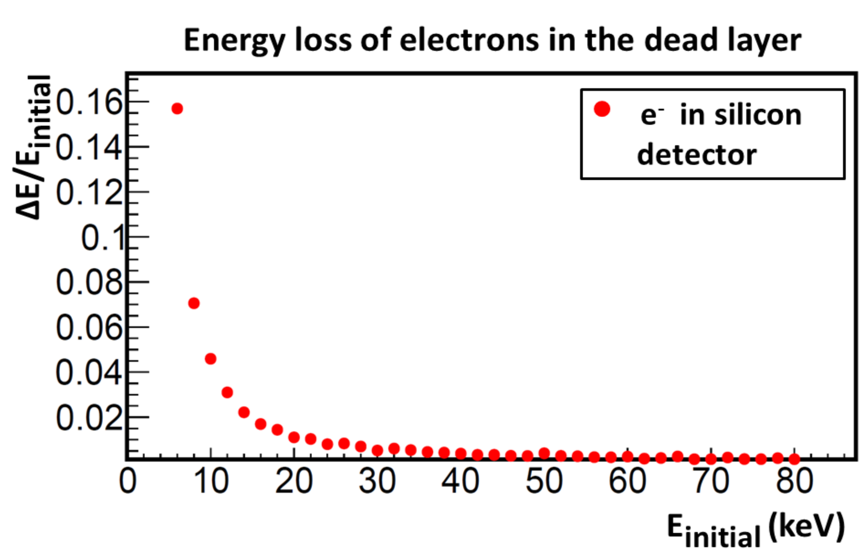

Figure 8. Mean values for the relative energy loss of electrons with different initial energies.

Conclusions

- High-energy ions are less likely to be backscattered and more likely to pass through the dead layer. ^3He ions lose more energy in the dead layer than T ions due to their nuclear charge.
- The relative energy loss of electrons in the dead layer decreases rapidly with the increasing initial energy.
- By including these results in the TRIMS simulation, we can obtain a more accurate understanding of the data.

Acknowledgments and References

- US DOE Office of Science, Office of Nuclear Physics, Award No. DE-FG02-97ER41020

[1] Laura I. Bodine. *Molecular effects in tritium beta-decay neutrino mass measurements*. PhD thesis from the University of Washington, 2015.

[2] SRIM software. James F. Ziegler. http://www.srim.org

[3] Pascal Renschler. *KESS - A new Monte Carlo simulation code for low-energy electron interactions in silicon detectors.* PhD thesis from Karlsruhe Institute of Technology, 2011.

[4] B.L. Wall, et al. *Dead layer on silicon p-i-n diode charged-particle detectors.* Nuclear Instruments and Methods in Physics Research A.

[5] Daniel Furse et al. *A Modern, Extensible C++ Particle Tracking Package.* May 2017, New Journal of Physics, Volume 19.