TRIMS: Testing Molecular Effects on Tritium Beta Decay

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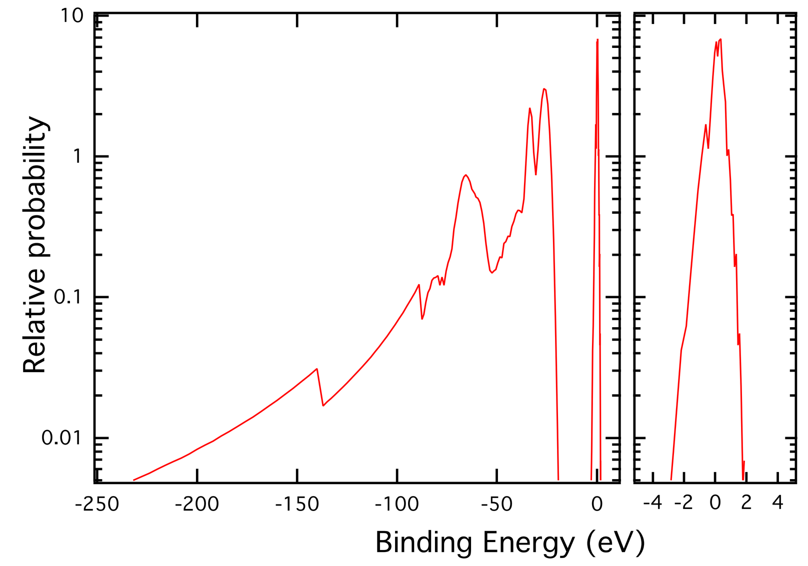
Beta Decay in HT and TT

To measure the **absolute neutrino mass scale**, experiments like KATRIN and Project 8 measure the endpoint of tritium beta decay with high precision. However, beta decay in a molecular source (like TT) can excite rotational and vibrational modes that distort the spectrum.

Precise theoretical calculations [1,2,3] explore the **molecular final-state distribution** and guide the neutrino-mass analysis [4]. But one predicted observable, the **branching ratio to the bound molecular ion**, is in profound disagreement with historical measurements [5,6].

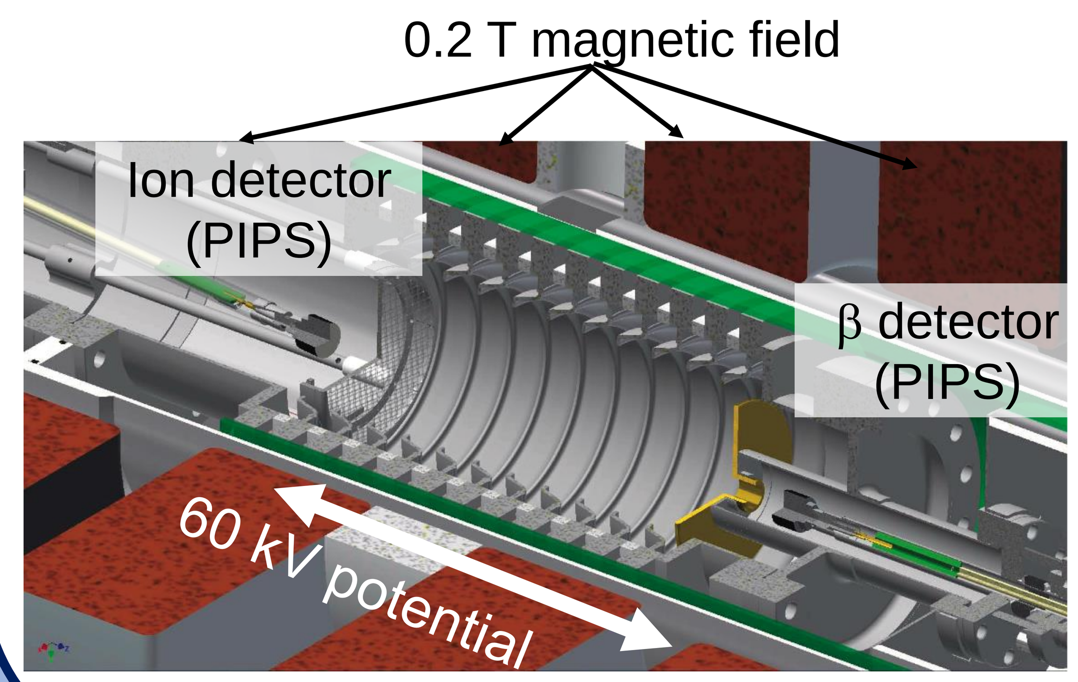
Molecule	Snell *et al.* [5]	Wexler [6]	Theory [1,2] Quasibound	Bound	Total
HT	0.932(19)	0.895(11)	0.02	0.55	0.57
TT	···	0.945(6)	0.18	0.39	0.57



Saenz et al., 2000 [1]

The TRIMS Experiment

The **T**ritium **R**ecoil-**I**on **M**ass **S**pectrometer (TRIMS) is a modern experiment to measure this branching ratio, while addressing known problems [7,8].



- Coincidence detection of β, ion
- Uniform acceleration gradient
- Guiding magnetic fields
- Low pressures to avoid charge exchange and recombination
- Ion-mass measurement through kinematics

$$\frac{m}{q^2} = t^2 \frac{E^2}{2K_{ion}}$$

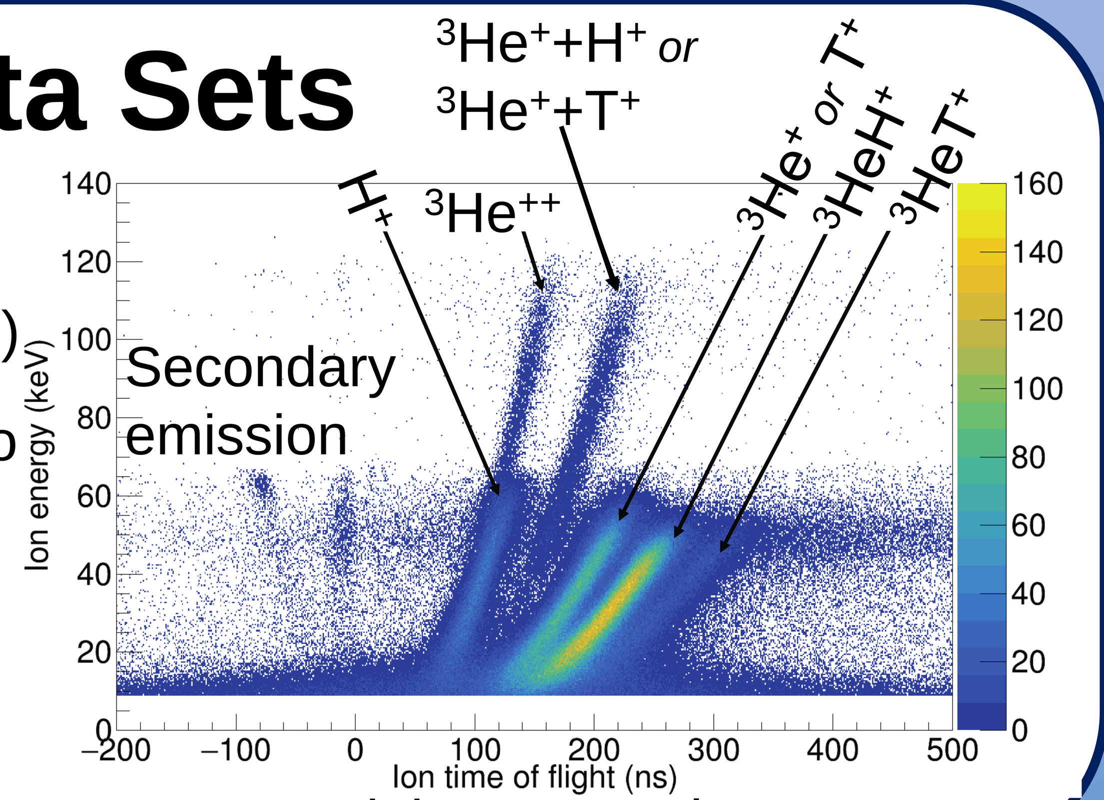
Ion mass; Ion charge; Ion time of flight (relative to β); Uniform electric field; Final ion kinetic energy

The Data Sets

TRIMS can run with a sample **rich in TT or rich in HT** (isotope exchange catalyzed by platinum-group filaments).

We **scan the ion-detector position** to account for initial ion momentum.

The effect of the **detector dead layer** on the reconstructed ion energy is modeled with SRIM [9].



High-HT sample

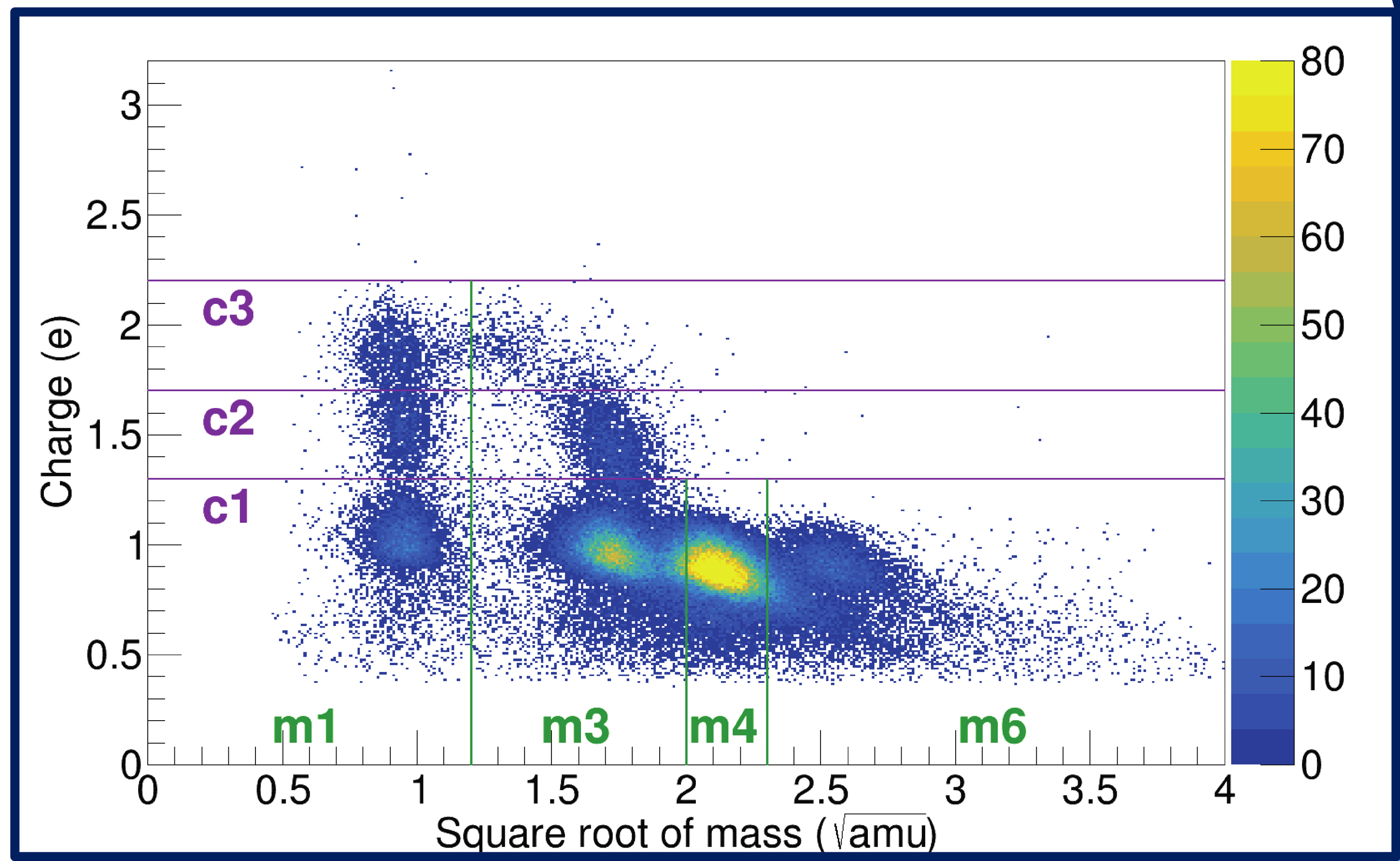
Analysis

- Apply fiducial-volume cut: 20 keV $\leq K_{ion} \leq$ 40 keV
- Plot events on charge-mass plane

$$q_{eff} = \frac{1}{V}\left(K_{ion} + K_{\beta} + K_{\beta}^{0}\right)$$

Effective charge; Electric potential; Final ion kinetic energy; Final β kinetic energy; Initial β kinetic energy (0 - 18 keV)

- Demarcate rectangular regions populated mainly by a single event type
- Use simulations and commissioning data to assess and correct for cross-contamination between regions
- Construct pure HT, TT samples from data at different concentrations
- Use scan data to deconvolve effects of finite detector size



More details may be found in the PhD thesis of Lin [8].

Results Confirm Theory

The molecular theory is the same for both HT and TT. HT data provide the most stringent test of theory: all ionic states may be distinguished, and the quasibound fraction is smaller.

For HT, we find a branching ratio of **56.51(55)%** to the bound molecular ion, in full agreement with theory.

For TT, we find **50.3(15)%**, also in agreement with theory.

Both results disagree strongly with prior measurements by Wexler and Snell. Like their results, ours integrate the data over the entire β energy range.

HT results

i	Channel	Branch (%)
	One electron	
2.	HeH^+	56.51(55)
3.	$He^+ + H$	24.98(41)
4.	$He + H^+$	5.64(45)
5.	$He^{++} + H^-$	<0.021
	Two electrons	
6.	$He^+ + H^+$	
	from He^+	11.01(49)
	from H^+	10.43(44)
7.	$He^{++} + H$	2.16(21)
	Three electrons	
8.	$He^{++} + H^+$	<0.045

Outlook

TRIMS confirms the theory of molecular final states following TT decay, used in the analysis of two modern neutrino-mass experiments. No known discrepancies with experiment remain.

We are now finalizing the analysis of all TT decay channels, and testing for effects due to β energy.

References and Acknowledgments

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CENPA Center for Experimental Nuclear Physics and Astrophysics

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