Electron capture branching ratio measurements for double $\beta$ decay experiments at TITAN-TRIUMF

T. Brunner$^{1}$, C. Andreou$^{1}$, M. Brodeur$^{1}$, D. Frekers$^{1}$, S. Ettenauer$^{1}$, A. Gallant$^{1}$, R. Krüken$^{1}$, Lapiere$^{1}$, R. Ringle$^{1}$
and the TITAN-EC collaboration

TRIUMF, Vancouver "TUM, München "SFU, Vancouver "UBC, Vancouver "Universität Münster

Electron capture branching ratio measurements

**Physics beyond the Standard Model**

- Neutrino oscillation experiments:
  - Indicate that the neutrino is a massive particle [1]
  - Only provide mixing angle $\theta$ and $\sin^2\theta$
  - Experiments: SNO, SuperK, T2K

- Absolute neutrino mass:
  - Effective mass for degenerated neutrinos from He decay experiments $m_e = \frac{E}{c^2}$ [8]
  - Astrophysical limits
  - $|\beta| = \frac{m_e}{m_{CE}}$ decay experiments

- $2\nu\beta\beta$ decay
  - Allowed in Standard Model $T > 10^{24}$
  - Neutrino is a Dirac particle within the Standard Model

- $0\nu\beta\beta$ decay
  - Physics beyond Standard Model
  - Lepton number violating process $T > 1.5 \cdot 10^{25}$ [3]
  - Majorana mass term enters neutrino mass

**Theoretical models:**

- Nuclear shell model [5]
- Interacting boson model [8]
- Proton-neutron Quasi-particle Random Phase Approximation (pnQSPA) [7]

**pnQSPA**

- Adjustable particle-particle parameter $g_{\nu}$
- Fix $g_\nu$ with $2\nu\beta\beta$ decay (very sensitive on $g_{\nu}$) to calculate $M_{\nu
u}$
- $0\nu\beta\beta$ decay much less dependent on $g_{\nu}$
- Calculated $M_{\nu
u}$ vary by a factor 2-5
- $M_{\nu
u}$ need with an uncertainty of less than 20% [8]
- Same $g_\nu$ enters single $\beta$ decay and Electron Capture (EC) calculations

**Electron Capture Branching Ratio measurements ideal benchmark experiment to test theoretical models**

**Proof of principle**

- $^{107}$In ($t_{1/2}=32.4\text{ min}$) experiment to determine electron capture matrix element $M_{\nu\nu}$

**Goals for $^{107}$In experiment**

- Inject $^{107}$In into trap
- Identify $^{107}$In after trap on a Si detector
- Store radioactive ions inside trap
- Observe X-rays following an EC of ions stored inside the trap
- Identify these X-rays from EC
- Observe electrons from $\beta$ decays
- Use of Ge and LeGe detector

**Analysis of $^{107}$In spectra:**

- Spectra of 192.82 min run time
- Only one detector
- 0.02% solid angle
- Clear signature of $^{107}$In decay

**Ge detector**

- Spectrum of 69.19 min run time
- Energy resolution worse than LeGe
- Solid angle of 0.25%

**Electron Capture BR program at TITAN**

- $|\beta| = \frac{m_e}{m_{CE}}$ decay candidates that are under investigation in experiments such as Majorana, EXO, COBRA, CUORE and others [12]

**Run plan for $^{107}$Tc**

- Accumulating 10 spills in trap containing 100000 ions in trap
- Storage time of 15s calculates to 50000 $|\beta| = \frac{m_e}{m_{CE}}$ decays
- $0.9$ EC decays
- $5.6 \cdot 10^8$ detected EC in 15s
- A 10% accuracy needs 100 detected events
- $17000$ trap fills
- 20% overhead
- Total estimated time $\sim 88$ h

**FIRST observation of an electron capture of isotopes stored in a Penning trap**

**For the future**

- Apply sideband cooling to increase the number of ions inside the trap
- Test anti-coincidence during an experiment with $^{107}$Cd in July
- First EC-BR measurement for $|\beta| = \frac{m_e}{m_{CE}}$ decay matrix elements in November

**Determination of $M_{\nu\nu}$ at TITAN**

A novel approach to determine the electron capture matrix element $M_{\nu\nu}$ is being developed at the TITAN facility, using the EBIT as an open access Penning trap

- Radioactive isotopes are delivered by TRIUMF's ISAC facility
- Deceleration, cleaning and cooling of ions happens in TITAN’s RF-cropper and bouncer
- The cryogenic Penning trap (EBIT) allows the storage of $10^{10}$ to $10^{11}$ ions due to a good vacuum ($P_{\text{in}} < 10^{-10}\text{ mbar}$)
- Helmholtz coil geometry allows visible access to trapped ions
- Up to 7 X-ray detectors can be installed radially around trap to detect X-rays following an electron capture (solid angle $\sim 2.1\%$)
- A $\beta$ detector at the trap exit is used to monitor the number of ions stored inside the trap
- Spatial separation of $\beta$ and X-ray detection due to 6T B-field

**Electron capture branching ratio (EC-BR) measurements**

**Comparison of different Ge matrix elements from experiments**

**Signatures of $^{107}$In and $^{116}$Cd**

**Clear signature of electron capture of $^{107}$In and $^{116}$Cd**

**Summary**

- Electron capture branching ratio measurements are ideal benchmark experiment to test theoretical models
- Electron capture branching ratio measurements are ideal benchmark experiment to test theoretical models
- Electron capture branching ratio measurements are ideal benchmark experiment to test theoretical models
- Electron capture branching ratio measurements are ideal benchmark experiment to test theoretical models
- Electron capture branching ratio measurements are ideal benchmark experiment to test theoretical models