TAMUTRAP: Texas A&M University Penning trap facility

P.D. Shidling
Cyclotron Institute, Texas A&M University

Outline
- Motivation
- TAMUTRAP facility
- Mass Measurement
- Future outlook
**Motivation**

- Make a precision measurement of the angular correlation parameter.
- Compare the SM predictions to observation.

\[
\alpha_\beta^{\text{expt.}} \ ? \ \alpha_\beta^{\text{theory}}
\]

- Look for deviations as an indication of new physics.
How do we plan to test the Standard Model (SM)?

In Standard Model (SM), weak interaction is $V-A$.

**Correlation parameter**

$W(\theta) \approx 1 + a_{\beta\nu} \left( \frac{p}{E} \frac{p}{E} \cos \theta e v + b \frac{m}{E} e \right)$

$a_{\beta\nu} = 1$ => Test of SM
Beta delayed proton emitters

<table>
<thead>
<tr>
<th>RIB</th>
<th>Projectile</th>
<th>$t_{1/2}$ [ms]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{40}$Ti</td>
<td>$^{40}$Ca</td>
<td>53</td>
</tr>
<tr>
<td>$^{36}$Ca</td>
<td>$^{36}$Ar</td>
<td>102</td>
</tr>
<tr>
<td>$^{32}$Ar</td>
<td>$^{32}$S</td>
<td>98</td>
</tr>
<tr>
<td>$^{28}$S</td>
<td>$^{28}$Si</td>
<td>125</td>
</tr>
<tr>
<td>$^{24}$Si</td>
<td>$^{24}$Mg</td>
<td>140</td>
</tr>
<tr>
<td>$^{20}$Mg</td>
<td>$^{20}$Ne</td>
<td>90</td>
</tr>
</tbody>
</table>
Beta delayed proton emitters

Proton contain the information about $^{32}$Cl recoil (Doppler)

$^{31}$S + p → $^{32}$Cl

$0^+ , 2$ → $^{32}$Ar

$dn/dE$ (arbitrary units)


SM Interaction

Non SM Interaction
Coupling of T-REX to TAMUTRAP facility

Production target

BigSol, Separator; Gas-catcher; multi-RFQ

Or

Light Ion Guide; 90° bending magnet (purification)
Ion Traps

Penning Trap

Radial confinement of ions
(Linear Magnetic field)

Paul Trap

Trapping ions in one dimension
(Electrostatic field)
Commissioning of TAMUTRAP facility

- Offline Source 1
- Offline Source 2
- Beam from Heavy Ion Guide/Light Ion Guide
- Beam diagnostic FC/MCP
- Beam from RFQ
- Einzel Lens
- Deflector
- Penning Trap System
- Online Source
- Steerer
- E = 10 keV
- E = 2.5 keV
- E = 100 eV
- Control System
TAMUTRAP: Cooler/Buncher

Operating Pressure: $10^{-2}$-$10^{-4}$ mbar

He (gas cooling)
TAMUTRAP: Penning Trap

Cylindrical Penning Trap

Nuclide | Lifetime (ms) | Proton Energy (MeV) | Larmour Radii (mm)
---|---|---|---
$^{20}$Mg | 137.05 | 4.28 | 42.7
$^{24}$Si | 147.15 | 3.91 | 40.8
$^{28}$S | 180.33 | 3.70 | 39.7
$^{32}$Ar | 141.38 | 3.36 | 37.8
$^{36}$Ca | 141.15 | 2.55 | 33.0
$^{40}$Ti | 72.13 | 3.73 | 39.9
$^{48}$Fe | 63.48 | 1.23 | 22.9

Radius : 90 mm
$l/r = 3.72$

Other existing Cylindrical Penning Trap

$l/r = 11.75$

M. Mehlman et al. NIMA 712 (2013) 9
Prototype Penning Trap (Commissioned)

**Radius 45 mm**

\[ l/r = 3.72 \]

\[ l = 167.5 \text{ mm} \]
Ion motion in Penning trap

Three characteristic harmonic motions:
- axial motion (frequency $f_z$)
- magnetron motion (frequency $f_-$)
- modified cyclotron motion (frequency $f_+ (\omega_+)$)

$$f_- + f_+ = f_c; \quad \text{where} \quad f_c = \frac{1}{2} \cdot \frac{q}{m} \cdot B$$
Dipolar radial excitation at $f_r$ 
$\Rightarrow$ increase of $r_r$
Mass measurement

Time-of-flight resonance technique

Dipolar radial excitation at $f_c$
$\Rightarrow$ increase of $r_c$

Quadrupolar radial excitation near $f_c$
$\Rightarrow$ coupling of radial motions, conv.

Mass measurement
Mass measurement

Time-of-flight resonance technique

Dipolar radial excitation at $f_c$
⇒ increase of $r_c$

Quadrupolar radial excitation near $f_c$
⇒ coupling of radial motions, conv.

Ejection along the magnetic field lines
⇒ radial energy converted to axial energy
**Mass measurement**

**Time-of-flight resonance technique**

- Dipolar radial excitation at $f_c$  
  $\Rightarrow$ increase of $r_c$

- Quadrupolar radial excitation near $f_c$  
  $\Rightarrow$ coupling of radial motions, conv.

- Ejection along the magnetic field lines  
  $\Rightarrow$ radial energy converted to axial energy

- Time-of-flight (TOF) measurement
Mass measurement

Time-of-flight resonance technique

Scan of excitation frequency

- Dipolar radial excitation at $f_r$
  $\Rightarrow$ increase of $r$

- Quadrupolar radial excitation near $f_c$
  $\Rightarrow$ coupling of radial motions, conv.

- Ejection along the magnetic field lines
  $\Rightarrow$ radial energy converted to axial energy

- Time-of-flight (TOF) measurement

Diagram:
- MCP Detector
- End Electrode
- Correction
- Ring
- End Cap
Determine atomic mass from frequency ratio:

\[
(2\pi f_{c\text{ ref}}) = \frac{q_{\text{ref}}B}{m_{\text{ref}}} \quad (2\pi f_c) = \frac{qB}{m} \quad m = (m_{\text{ref}}) \left( \frac{f_{c\text{ ref}}}{f_c} \right)
\]
Reference mass: $^{39}\text{K}$

$T_{\text{RF}} = 20 \text{ ms}$

$f_c = 2,766,446.72(15) \text{ Hz}$

$\text{FWHM} = 45.3(8) \text{ Hz}$
Measured mass: $^{23}\text{Na}$

$T_{RF} = 20 \text{ ms}$
$f_c = 4,688,697.92(10) \text{ Hz}$
$FWHM = 51.6(8) \text{ Hz}$
Measured mass: $^{23}\text{Na}$

$\delta m / m = 4 \times 10^{-8}$

Comparison with Literature value: $1.2 \times 10^{-8}$

$T_{RF} = 20 \text{ ms}$

$f_c = 4,688,697.92(10) \text{ Hz}$

FWHM = 51.6(8) Hz
Transport Efficiency

- RFQ efficiency ≈ 70% - 75% (Continuous Mode)
TAMUTRAP: Transport Efficiency

- Injection optics Efficiency: 80% - 85%
TAMUTRAP: Transport Efficiency

Section I
- Second Ion source
- Deflector
- Einzel Lens
- Steerer
- First Ion source
- Beam Diagnostic Station

Section II
- RFQ
- Injection Optics
- Deflector
- Extraction Optics
- Beam Diagnostic Station

Section III
- Einzel Lens
- Steerer
- Einzel Lens
- MCP Detector

Penning Trap
B = 7.019372 (2016)

Texas A&M University Penning Trap Facility (TAMUTRAP)
Beam Current 120 pA

Section I
- Second Ion source
- Beam Diagnostic Station
- Deflector
- Einzel Lens
- Steerer
- First Ion source

Section II
- RFQ
- Injection Optics
- Beam Diagnostic Station
- Einzel Lens
- Steerer
- Extraction Optics

Section III
- Deflector
- Einzel Lens
- MCP Detector

Year: 2016
Beam current: 120 pA.

Penning Trap
B = 7.019372 (2016)

Hundred Ions/sec
Section I

Beam Diagnostic Station

Second Ion source

Deflector

Beam Current < 1 pA

Einzel Lens

Steerer

Section II

Penning Trap

B = 7.019372 (2016)

RFQ

Deflector

Injection Optics

Beam Diagnostic Station

Extraction Optics

Beam Current < 1 pA

Section III

Hundred Ions/sec

Einzel Lens

MCP Detector

Year: 2017

Texas A&M University Penning Trap Facility (TAMUTRAP)
TAMUTRAP Penning trap system (180 mm diameter)

Beam energy 140 eV

Pulsing drift tube
Penning trap 180 mm diameter
Extraction section
Future outlook

- Install Penning Trap system (180 mm) by September 2018.
- Complete GEANT4 simulation and finalize the detectors.
- Couple TAMUTRAP facility to HIG/LIG.
- Begin RIB Program.
Thank you
### Calculating $^{32}$Ar requirements

<table>
<thead>
<tr>
<th>Element</th>
<th>Efficiency (%)</th>
<th>Rate After Element (p/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measurement trap</td>
<td>100</td>
<td>250</td>
</tr>
<tr>
<td>Beamline</td>
<td>95</td>
<td>250</td>
</tr>
<tr>
<td>Purification Trap</td>
<td>100</td>
<td>263</td>
</tr>
<tr>
<td>Beamline</td>
<td>95</td>
<td>263</td>
</tr>
<tr>
<td>RFQ (bunched mode)</td>
<td>50</td>
<td>277</td>
</tr>
<tr>
<td>Beamline</td>
<td>95</td>
<td>554</td>
</tr>
<tr>
<td>Magnet (coarse selection)</td>
<td>100</td>
<td>583</td>
</tr>
<tr>
<td>Multi-RFQ</td>
<td>80</td>
<td>583</td>
</tr>
<tr>
<td>Gas catcher</td>
<td>15</td>
<td>729</td>
</tr>
<tr>
<td>Big Sol</td>
<td>35</td>
<td>4,860</td>
</tr>
<tr>
<td>Production</td>
<td>100</td>
<td>13,886</td>
</tr>
</tbody>
</table>
Table 1. – Expected 88” beam intensities and energies assuming ECR2 type source, \( K=140 \) and 25% transmission.

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Energy (MeV/u)</th>
<th>Intensity (μA)</th>
<th>Isotope</th>
<th>Energy (MeV/u)</th>
<th>Intensity (μA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( p )</td>
<td>55</td>
<td>27 (14)</td>
<td>(^{20})Ne</td>
<td>28</td>
<td>3.0 (1.5)</td>
</tr>
<tr>
<td>( d )</td>
<td>35</td>
<td>21 (10.5)</td>
<td>(^{22})Ne</td>
<td>29</td>
<td>0.5 (0.25)</td>
</tr>
<tr>
<td>(^{3})He</td>
<td>45</td>
<td>11 (5.5)</td>
<td>(^{34})S</td>
<td>20</td>
<td>0.7 (0.35)</td>
</tr>
<tr>
<td>(^{4})He</td>
<td>35</td>
<td>10 (5.0)</td>
<td>(^{40})Ar</td>
<td>17</td>
<td>1.4 (0.7)</td>
</tr>
<tr>
<td>(^{6})Li</td>
<td>35</td>
<td>7 (3.5)</td>
<td>(^{40})Ca</td>
<td>17</td>
<td>1.5 (0.75)</td>
</tr>
<tr>
<td>(^{7})Li</td>
<td>25</td>
<td>8 (4.0)</td>
<td>(^{59})Co</td>
<td>11</td>
<td>0.9 (0.45)</td>
</tr>
<tr>
<td>(^{10})B</td>
<td>35</td>
<td>4 (2.0)</td>
<td>(^{78})Kr</td>
<td>10</td>
<td>0.6 (0.3)</td>
</tr>
<tr>
<td>(^{11})B</td>
<td>29</td>
<td>4.7 (2.35)</td>
<td>(^{86})Kr</td>
<td>8.3</td>
<td>0.6 (0.3)</td>
</tr>
<tr>
<td>(^{16})O</td>
<td>35</td>
<td>2.3 (1.15)</td>
<td>(^{129})Xe</td>
<td>5.6</td>
<td>0.5 (0.25)</td>
</tr>
<tr>
<td>RIB</td>
<td>Beam</td>
<td>Beam Energy (E/A)(MeV)</td>
<td>Target Thickness (mg/cm^2)</td>
<td>Beam Current (pnA)</td>
<td>Production Rate (p/s) (Target chamber)</td>
</tr>
<tr>
<td>-------</td>
<td>------</td>
<td>------------------------</td>
<td>----------------------------</td>
<td>-------------------</td>
<td>----------------------------------------</td>
</tr>
<tr>
<td>^{32}Ar</td>
<td>^{32}S</td>
<td>20 – 24 MeV/u</td>
<td>22.5 mg/cm^2 (42 mg/cm^2)</td>
<td>350 (700)</td>
<td>4.55×10^4 (1.7×10^5)</td>
</tr>
<tr>
<td>28S</td>
<td>^{28}Si</td>
<td>22 - 30 MeV/u</td>
<td>22.5 mg/cm^2 (60 mg/cm^2)</td>
<td>600 (1200)</td>
<td>7.45×10^4 (3.97×10^5)</td>
</tr>
<tr>
<td>24Si</td>
<td>^{24}Mg</td>
<td>22-30 MeV/u</td>
<td>22.5mg/cm^2 (70 mg/cm^2)</td>
<td>600 (1200)</td>
<td>2.6×10^5 (1.6×10^6)</td>
</tr>
<tr>
<td>20Mg</td>
<td>^{20}Ne</td>
<td>23 - 30 MeV/u</td>
<td>22.5mg/cm^2 (66 mg/cm^2)</td>
<td>1500 (3000)</td>
<td>6.8×10^5 (4.0×10^6)</td>
</tr>
<tr>
<td>36Ca</td>
<td>^{36}Ar</td>
<td>23-30 MeV/u</td>
<td>22.5mg/cm^2 (28 mg/cm^2)</td>
<td>700 (1400)</td>
<td>1.25×10^5 (3.1×10^5)</td>
</tr>
<tr>
<td>40Ti</td>
<td>^{40}Ca</td>
<td>23-30MeV/u</td>
<td>22.5mg/cm^2 (26 mg/cm^2)</td>
<td>750 (1500)</td>
<td>3.6×10^4 (8.4×10^4)</td>
</tr>
</tbody>
</table>
**β-ν correlation measurements**

**Uniform magnetic field**

**Penning traps**
- Increase solid angle.
- Increase sensitivity.
- Allows to detect $e$ along with $p$
How do we plan to test the Standard Model (SM) ?

Perform a $\beta$ decay experiment on short-lived isotopes.

Make a precision measurement of the angular correlation parameter.

Compare the SM predictions to Observation.

Look for deviations as an indication of new physics.

$W (\theta) \approx 1 + a_{\beta v} \left( \frac{p}{E} \frac{e}{E} \frac{p}{v} \cos \theta \right) + b \left( \frac{m}{E} \frac{e}{e} \right)$

$\beta$-$\nu$ angular correlation parameter

Test of SM

$\alpha_{\beta v} \neq 1$