Ion Trap Application:
Fundamental weak interaction studies using ion traps

Angular Correlation

$Z$, number of protons

$\beta^+$

$\phi$

$p_r$

$Z=82$

$N=126$

$N$, number of neutrons

Cyclotron Institute
Texas A&M University

P.D. Shidling
Outline

- Ion traps in Nuclear Physics
  - Mass Measurement
  - Angular correlation measurements
  - Results
  - Ion trap facilities

Research Program at Cyclotron Institute Texas A&M University (TAMU) using Ion trap Physics Program
Types of Ion Traps used in Nuclear Physics

Paul Trap: Electrodynaminc Field

Hyperbolic Paul Trap

Linear Paul Trap

RF field yields pseudopotential

Suites for Ion manipulation: Cooling and Bunching, retardation, ion optical properties
Penning Trap: Static Electrostatic quadrupole field + Magnetic Field

\[ \sum \vec{F} = q (\vec{E} + \vec{v} \times \vec{B}) \]

Cylindrical Penning Trap

Homogenous uniform magnetic field ~ 3ppm

Precise corrections

Cyclotron frequency:
\[ f_c = \frac{1}{2\pi} \cdot \frac{q}{m} \cdot B \]

Precision:
\[ \frac{\delta m}{m} \propto \frac{m}{qBT_{rf} \sqrt{N_{ion}}} \]
Ion motion in Penning trap

Three characteristic harmonic motions:
Ion motion in Penning trap

Three characteristic harmonic motions:
(a) axial motion \((f_z)\)

Axial motion

\[
f_z = \sqrt{\frac{eU}{4\pi^2 md^2}}
\]
Three characteristic harmonic motions:

(a) axial motion \( (f_z) \)

(b) magnetron motion \( (f_-) \)

(c) modified cyclotron motion \( (f_+) \)

Radial motion:

Axial motion

\[
f_z = \sqrt{\frac{eU}{4\pi^2 md^2}}
\]

Radial motion

\[
\begin{align*}
f_- &= \frac{f_c}{2} + \sqrt{\frac{f_c^2}{4} - \frac{f_z^2}{2}} \\
f_+ &= \frac{f_c}{2} + \sqrt{\frac{f_c^2}{4} - \frac{f_z^2}{2}}
\end{align*}
\]
Ion motion in Penning trap

Three characteristic harmonic motions:
(a) axial motion \((f_z)\)
(b) magnetron motion \((f_-)\)
(c) modified cyclotron motion \((f_+)\)  
\[
\begin{align*}
\text{Axial motion} & \quad f_z = \sqrt{\frac{eU}{4\pi^2 md^2}} \\
\text{Radial motion} & \quad f_- = \frac{f_c}{2} + \sqrt{\frac{f_c^2}{4} - \frac{f_z^2}{2}} \\
& \quad f_+ = \frac{f_c}{2} + \sqrt{\frac{f_c^2}{4} - \frac{f_z^2}{2}} \\
\text{Sideband excitation:} & \quad f_- + f_+ = f_c \\
\text{Cyclotron frequency:} & \quad f_c = \frac{1}{2\pi m} \frac{q}{B}
\end{align*}
\]
Coupling Radial motions

Dipolar radial excitation at $f_-$

$\Rightarrow$ increase of $r_-$
**Mass measurement**

**Coupling Radial motions**

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

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

- $U_q$
- $r_0$
- $r$

- End Cap
- End Electrode
- Correction
- Ring
- Correction
- End Electrode
- End Cap
Mass measurement

Coupling Radial motions

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
Mass measurement

**Coupling Radial motions**

Dipolar radial excitation at $f_c$

⇒ increase of $r$

Quadrupolar radial excitation near $f_c$

⇒ coupling of radial motions, conv.

Ejection along the magnetic field lines

⇒ radial energy converted to axial energy

TOF Resonance Technique
Mass measurement

Coupling Radial motions

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

TOF Resonance Technique
Mass measurement

**Coupling Radial motions**

Dipolar radial excitation at $f_-$

$\Rightarrow$ increase of $r_-$

TOF Resonance Technique

Ion time-of-flight [\(\mu\text{s}\)]

$f_c - 4688685$ [Hz]
Mass measurement

Coupling Radial motions

Dipolar radial excitation at $f_c$ implies an increase of $r$.

$\Rightarrow$ increase of $r$.

TOF Resonance Technique

$\partial B/\partial z$
Mass measurement

Coupling Radial motions

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

TOF Resonance Technique
Mass measurement

Coupling Radial motions

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

TOF Resonance Technique
Atomic mass from frequency ratio:

\[ m = (m_{\text{ref}}) \left( \frac{f_c^{\text{ref}}}{f_c} (m_{\text{ref}} - m_e) \right) + m_e \]
Ion trap worldwide for Nuclear Physics studies

- **Operational**
  - TRIUMF TITAN facility
  - NSCL LEBIT/ SIPT facility
  - ANL– CPT facility
  - Texas A&M Univ. TAMUTRAP
  - FSU - Penning Trap facility

- **Commissioning**
  - GSI facility SHIPTRAP TRIGATRAP
  - MLL-TRAP HITRAP PENTATRAP
  - JYFL Facility JYFLTRAP
  - ISOLDE facility ISOLTRAP/REXTRAP
  - DESIR MATS PIPERADE

- **PLANNING**
  - PNPI Facility PTTRAP
  - RIKEN RIKEN-TRAP
  - RISP RISP-TRAP
  - Lanzhou trap CARIF-TRAP BRIF-TRAP
  - VECC facility VECC-TRAP
  - VECC facility VECC-TRAP
  - TRIUMF TITAN facility
  - NSCL LEBIT/ SIPT facility
  - ANL– CPT facility
  - Texas A&M Univ. TAMUTRAP
  - FSU - Penning Trap facility

The map shows the distribution of ion traps worldwide, highlighting operational, commissioning, and planning facilities in nuclear physics studies.
Importance of Atomic mass

\[ \text{Atomic mass} = N \cdot -\text{binding energy} + Z \cdot + Z \cdot \]
## Importance of Atomic mass

<table>
<thead>
<tr>
<th>Fields</th>
<th>Precision</th>
</tr>
</thead>
<tbody>
<tr>
<td>Astrophysics: r-process, rp-process, waiting points</td>
<td>$10^{-7}$</td>
</tr>
<tr>
<td>Nuclear models and formulas, Nuclear fine structure: deformation , halo nuclei</td>
<td>$10^{-7} – 10^{-8}$</td>
</tr>
<tr>
<td>Weak Interaction studies: CVC Theory, CKM Unitarity</td>
<td>$10^{-8}$</td>
</tr>
<tr>
<td>Neutrino physics: Q-value</td>
<td>$10^{-9}$</td>
</tr>
<tr>
<td>Fundamental constants, CPT</td>
<td>$\leq 10^{-10}$</td>
</tr>
<tr>
<td>Atomic physics: binding energies, QED</td>
<td>$10^{-9} – 10^{-11}$</td>
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</table>
3 Fundamental forces
Electromagnetic, Weak, Strong

12 Fundamental Fermions
Quarks \( (u, d, c, s, t, b) \)
Leptons \( (e, \nu_e, \mu, \nu_\mu, \tau, \nu_\tau) \)

Force carriers (Gauge Bosons)
\( (g, \gamma, Z, W) \)
Scalar Bosons (Higgs)
\( (H, \ldots) \)
Standard Model may require extension

- 3 Fundamental forces: Electromagnetic, Weak, Strong
- 12 Fundamental Fermions
  - Quarks \((u, d, c, s, t, b)\)
  - Leptons \((e, \nu_e, \mu, \nu_\mu, \tau, \nu_\tau)\)
- Force carriers (Gauge Bosons): \((g, \gamma, Z, W)\)
- Scalar Bosons (Higgs): \((H, \ldots)\)

why three families of Fermions
Origin of parity violation
Dark matters
Number of parameters of theory

\ldots\ldots\ldots\ldots\ldots
Test of Standard Model

High energy collider experiment

Direct observation of New particles
Low energy precision experiments in nuclear beta decay

Nuclear $\beta$-decay = Governed by Weak Interaction

Search for “deviations/traces”

Tests of the underlying Fundamental Symmetries

High energy collider experiment

Direct observation of New particles

Low energy precision experiments

Tests of the underlying Fundamental Symmetries
Nuclear Beta decay test of SM

Test of Conservation of Vector Current (CVC)

Test of unitarity of CKM Matrix

\[ V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1 \]

Correlation experiments:

- Standard Model
- Physics beyond Standard Model
Test of Conserved Vector Current

Basic Weak Decay Equation

\[ f t = \frac{K}{G_V^2 |M|^2} \]

- \( f \) = statistical rate function : \( f(Z, Q_{EC}) \)
- \( t \) = partial half-life
- \( G_V \) = vector coupling constant
- \( |M|^2 \) = Fermi matrix element

\[ t = \ln 2 \tau \left( \frac{1 + P_{EC}}{BR} \right) \]

\( Q_{EC} \) - Decay Energy

mass \( m \) \( (Q^5 \) dependence; goes into statistical rate calculation \( (f_V) \))
Test of Conserved Vector Current

Pure Fermi transitions

Theory corrections

Radiative Corrections

Isospin symmetry breaking correction

Vector coupling constant ($G_F$)

Transition independent radiative correction

$Q_{EC}$ - Decay Energy

mass $m$ (Q$^5$ dependence; goes into statistical rate calculation ($f_V$))

$\delta'_R, \delta^V_{NS}, \Delta^V_R$ Radiative Corrections

$\delta^V_C$ Isospin symmetry breaking correction
Measure $ft$ value for several nuclear $\beta$-decay with similar decay mode (Fermi transition)

Hardy & Towner, Phys. Rev. C 91 (2015) 025501
Measure $f_t$ value for several nuclear $\beta$-decay with similar decay mode (Fermi transition)

$f_t$ value constant after theory corrections

CVC Verified

Hardy & Towner, Phys. Rev. C 91 (2015) 025501
Test of Conserved Vector Current

Studied for more than 30 years Close to 300 measurements Limited by theoretical corrections

\[ \tau = 3072.27 \pm 0.72 \text{ s} \]

CVC Theory verified @ 0.023%

Hardy & Towner, Phys. Rev. C 91 (2015) 025501

\[ |V_{ud}| = \frac{G_V}{G_F} \]

\[ V_{ud}^2 + V_{us}^2 + V_{ub}^2 = 1 \]
Unitarity of CKM Matrix

Mass Eigen states $\neq$ Weak Eigen states

$(u,d,c,s,t,b)$                $(u',d',c',s',t',b')$

Kobayashi and Maskawa: Generalized to 3 quark families

$$\begin{pmatrix} 
  d' \\
  s' \\
  b' 
\end{pmatrix} = 
\begin{pmatrix}
  V_{ud} & V_{us} & V_{ub} \\
  V_{cd} & V_{cs} & V_{cb} \\
  V_{td} & V_{ts} & V_{tb}
\end{pmatrix} 
\begin{pmatrix}
  d \\
  s \\
  b 
\end{pmatrix}$$

$$V_{ud}^2 + V_{us}^2 + V_{ub}^2 \overset{?}{=} 1$$
The 2008 Nobel Prize in Physics was awarded to Makoto Kobayashi and Toshihide Maskawa:

... for "the discovery of the origin of broken symmetry, which predicts the existence of at least three families of quarks in nature."

**Kobayashi and Maskawa: Generalized to 3 quark families**

\[
\begin{pmatrix}
    d' \\
    s' \\
    b'
\end{pmatrix}
= 
\begin{pmatrix}
    V_{ud} & V_{us} & V_{ub} \\
    V_{cd} & V_{cs} & V_{cb} \\
    V_{td} & V_{ts} & V_{tb}
\end{pmatrix}
\begin{pmatrix}
    d \\
    s \\
    b
\end{pmatrix}
\]

\[
V_{ud}^2 + V_{us}^2 + V_{ub}^2 \equiv 1
\]
Unitarity of CKM Matrix

\[ V_{ud}^2 + V_{us}^2 + V_{ub}^2 = ? 1 \]

- \( V_{ud} \) (nuclear \( \beta \)-decay) = 0.97417(21) Hardy2015
- \( V_{us} \) (kaon-decay) = 0.2253(14) PDG 2014
- \( V_{ub} \) (B meson decay) = 0.00415(49) PDG 2014

\[ |V_u|^2 = 0.99978 \pm 0.00055 \]

CKM unitarily satisfied to within an uncertainty of 0.05%.
Reduced hadronic uncertainty in the determination of $V_{ud}$

Chien-Yeh Seng$^a$, Mikhail Gorchtein$^b$, Hiren H. Patel$^c$, and Michael J. Ramsey-Musolf$^{c,d}$

$^a$INFAC, Shanghai Key Laboratory for Particle Physics and Cosmology, MOE Key Laboratory for Particle Physics, Astrophysics and Cosmology, School of Physics and Astronomy, Shanghai Jiao-Tong University, Shanghai 200240, China

$^b$Institut für Kernphysik, PRISMA Cluster of Excellence, Johannes Gutenberg-Universität, Mainz, Germany

$^c$Amherst Center for Fundamental Interactions, Department of Physics, University of Massachusetts, Amherst, MA 01003 and Kellogg Radiation Laboratory, Electrical & Computer Engineering, Technology Park, C.P. 731, Amherst, MA 01003-9305 (Electrical and Computer Engineering).

We analyze the universal radiative correction $\Delta R^V$ to neutron and superallowed nuclear $\beta$ decay by expressing the hadronic one-box radiative correction as an integral over the first light neutral mesons decay functions. From this integral we obtain an updated value of $\Delta R^V = 0.02467(22)$, wherein the hadronic uncertainty is reduced. Assuming other Standard Model theoretical calculations and experimental measurements remain unchanged, we obtain an updated value of $|V_{ud}| = 0.97366(15)$, raising tension with the first row CKM unitarity constraint. We comment on ways current and future experiments can provide input to our dispersive analysis.

$V_{ud} = 0.97366(15)$ (2018)

$V_{ud} = 0.97417(21)$ (2015)

$V_{ub} (B$ meson decay$) = 0.00415(49)$ PDG 2014

$|V_u|^2 = 0.99978 \pm 0.00055$
Ion trap facilities for mass measurements
Ion trap facilities for mass measurements
Ion trap facilities for mass measurements

LEBIT (USA)
- Laser ablation ion source
- Beam cooler and buncher
- Switchyard
- Plasma ion source
- 60 keV rare isotope beam
- $^{14}$O

JYFLTRAP (FINLAND)
- Detection with MCP (ground)
- Low energy transfer line
- JYFLTRAP Penning traps (HV)
- Beamline switcher
- 55 deg dipole magnet, R=500

Graphs showing mass time of flight data.
Ion trap facilities for mass measurements

LEBIT (USA)
- Laser ablation ion source
- Beam cooler and buncher
- Switchyard
- Plasma ion source
- 60 keV rare isotope beam

JYFLTRAP (FINLAND)
- 14O
- 12C
- 13C
- Beamline switcher
- 55 deg dipole magnet, R=500
- JYFLTRAP Penning traps (HV)
- low energy transfer line
- detection with MCP (ground)

TITAN (CANADA)
- RFQ
- SCI
- HCI
- MPET
- bunched beam for laser spectroscopy
- offline
- continuous rare isotope beam
Ion trap facilities for mass measurements

**LEBIT (USA)**
- Laser ablation ion source
- Beam cooler and buncher
- Switchyard
- Plasma ion source
- 60 keV rare isotope beam
- \(^{14}\text{O}\)

**JYFLTRAP (FINLAND)**
- Low energy transfer line
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- 55 deg dipole magnet, R=500

**TITAN (CANADA)**
- Continuous rare isotope beam
- RFQ
- Bunched beam for laser spectroscopy

**ISOLTRAP (Switzerland)**
- Precision trap
- Mass measurement
- Beam buncher
- Bunched spectrum at low energy
Ion trap facilities for mass measurements

LEBIT (USA)

JYFLTRAP (FINLAND)

ISOLTRAP (Switzerland)

TITAN (CANADA)

CPT (USA)
In Standard Model (SM) weak interaction is V-A
In general $\beta$ decay can also be Scalar, Tensor, V+A interaction

Measurement of *Correlation* parameter

$\beta^+ + e^-$

In Standard Model (SM) weak interaction is V-A
In general $\beta$ decay can also be Scalar, Tensor, V+A interaction

Pure Fermi transition

SM Interaction

Non SM Interaction
Measurement of *Correlation* parameter

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

In general $\beta$ decay can also be Scalar, Tensor, $V$+$A$ interaction

**Correlation parameter**

$$dW(\theta) \cong \left(1 + a_{\beta\nu} \frac{p_\nu p_e}{E_e E_\nu} \cos\theta_{ev} + \ldots\right)$$

$\beta$-$\nu$ correlation parameter
In Standard Model (SM) weak interaction is V-A.

In general $\beta$ decay can also be Scalar, Tensor, V+A interaction.

Measurement of **Correlation parameter**

$$dW(\theta) \approx \left(1 + \alpha_{\beta\nu} \frac{p_e p_\nu}{E_e E_\nu} \cos \theta_{e\nu} + \ldots\right)$$

$\beta$-$\nu$ correlation parameter

Pure Fermi Transition:

$$\alpha_{\beta\nu} \overset{?}{=} 1$$

Test of Standard Model

Jackson, Treiman and Wyld (Phys Rev 106 and Nucl Phys 4, 1957)
Ion trap facilities for angular correlation measurements
LPC TRAP, FRANCE

$\alpha_\beta^\nu$ correlation parameter in $^{35}$Ar, $^6$He

Detector Setup:

Beta-decay Paul Trap @ ANL, USA

$^8$Li $\rightarrow$ $^8$Be$^*$ $+$ $\bar{\nu}$ $+$ $\beta$

$^8$Be$^*$ $\rightarrow$ $\alpha$ $+$ $\alpha$


Ion trap facilities for angular correlation measurements

**LPC TRAP, FRANCE**

\( a_{\beta V} \) correlation parameter in \(^{35}\text{Ar},^{6}\text{He} \)

\[^{6}\text{He} \text{(Current Precision @ 3\% level)}\]

\[
 a_{\beta V} = -0.3335(73)_{\text{stat}}(75)_{\text{syst}}
\]

\[^{35}\text{Ar} \]

Precision level expected to be at 0.5\% level

---

**Beta-decay Paul Trap @ ANL, USA**

\(^{8}\text{Li} \rightarrow ^{8}\text{Be}^* + \bar{\nu} + \beta \)

\(^{8}\text{Be}^* \rightarrow \alpha + \alpha \)

\[
 a_{\beta V} = -0.3307(90)
\]

---


Ion trap facilities for angular correlation measurements

Weizmann Institute, Israel (Commissioning stage)

TAMUTRAP, Cyclotron Institute, USA (Commissioning stage)

$a_{\beta^\nu}$ correlation parameter in $^6$He

TAMUTRAP Facility aiming to perform $a_{\beta^\nu}$ & $ft$-value measurements.


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Research program at TAMUTRAP facility

Pure Fermi transitions

Theory corrections

\[ t^{0^+ \rightarrow 0^+} \equiv f t^{0^+ \rightarrow 0^+} (1 + \delta'_R)(1 + \delta^V_{NS} - \delta^V_C) \]

\[ = \frac{K}{2 G_F^2 V_{ud}^2 C_V^2 (1 + \Delta^V_R)} \]

Isospin symmetry breaking correction \((\delta^V_C)\)

- Mixing of states of same spin
- Difference in \(n\) and \(p\) radial wave functions

\[ \delta_C = \delta_{c1} + \delta_{c2} \]

Model dependence
Research program at TAMUTRAP facility

Pure Fermi transitions

\[ t^{0^+ \rightarrow 0^+} = f t^{0^+ \rightarrow 0^+} (1 + \delta'_R) (1 + \delta^V_{NS} - \delta^V_C) \]

\[ = \frac{K}{2G_F^2V_{ud}^2C_V^2(1 + \Delta^V_R)} \]

Theory corrections

EXPERIMENT

\[ t = \ln 2 \tau \left( \frac{1 + P_{EC}}{BR} \right) \]

Isospin symmetry breaking correction \((\delta^V_C)\)

- Mixing of states of same spin
- Difference in \(n\) and \(p\) radial wave functions

\[ \delta_C = \delta_{c1} + \delta_{c2} \]

Needs experimental verification for large corrections
Superallowed Transitions

![Graph showing superallowed transitions with elements labeled such as Ca, Mg, Si, S, Ar, and Ti. The graph plots δc [%] vs. Z of daughter.]

- Stable isotopes are represented in black.
- Superallowed transitions are represented in red with a label T = 2.
Superallowed Transitions

- Large correction is predicted for $T = 2$ transition.
- Measurements will allow to test and verify these corrections.
- New cases to test the CVC Theory.
- New cases for $V_{ud}$.

Beta delayed proton decay
Proton contain the information about $^{32}\text{Cl}$ recoil (Doppler)

$^{31}\text{S} + p \rightarrow 0^+, 2 \quad ^{32}\text{Ar}$

$^{32}\text{Cl}$

$\beta^+ + p \rightarrow ^{32}\text{Cl}$

$\nu_e$  

$\beta^+ + \nu_e \rightarrow \text{Daughter nucleus}$

$\beta^+$  

$\nu_e$  

$\text{Vector}$  

$\text{Scalar}$

Penning trap $\beta - \nu$ correlation parameter

- Penning traps
  - Increase solid angle.
  - Increase sensitivity.
  - Allows to detect $e$ along with $p$

Beta & Proton in same hemisphere

Beta & Proton in different hemisphere

Total

Proton energy [MeV]

### Nuclide and Lifetimes

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Lifetime (ms)</th>
<th>Proton Energy (MeV)</th>
<th>Larmour radii (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{20}$Mg</td>
<td>137.05</td>
<td>4.28</td>
<td>42.7</td>
</tr>
<tr>
<td>$^{24}$Si</td>
<td>147.15</td>
<td>3.91</td>
<td>40.8</td>
</tr>
<tr>
<td>$^{28}$S</td>
<td>180.33</td>
<td>3.70</td>
<td>39.7</td>
</tr>
<tr>
<td>$^{32}$Ar</td>
<td>141.38</td>
<td>3.36</td>
<td>37.8</td>
</tr>
<tr>
<td>$^{36}$Ca</td>
<td>141.15</td>
<td>2.55</td>
<td>33.0</td>
</tr>
<tr>
<td>$^{40}$Ti</td>
<td>72.13</td>
<td>3.73</td>
<td>39.9</td>
</tr>
<tr>
<td>$^{48}$Fe</td>
<td>63.48</td>
<td>1.23</td>
<td>22.9</td>
</tr>
</tbody>
</table>

**Cylindrical Penning Trap**

$l/r = 11.75$

**Inner diameter of the trap to contain decay products (protons, electrons):**

at least:

diameter = 170 mm
Cylindrical Penning Trap

- **Nuclide**
- **Lifetime (ms)**
- **Proton Energy (MeV)**
- **Larmor radii (mm)**

<table>
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<td>Fe</td>
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<td>22.9</td>
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</table>

- **l/r** = 11.75
- **l = 1000 mm**
- **r = 180 mm**

Inner diameter of the trap to contain decay products (protons, electrons):
- **at least:**
  - **diameter = 170 mm**
Cylindrical Penning Trap

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Radius : 90 mm
$l/r = 3.72$
Cylindrical Penning Trap

\[
\begin{align*}
\text{Radius} : & \quad 90 \text{ mm} \\
\text{l/r} : & \quad 3.72
\end{align*}
\]

Trap dimensions are also optimized to perform high precision mass measurement.

Nuclide \quad \text{Lifetime (ms)} \quad \text{Proton Energy (MeV)} \quad \text{Larmour radii (mm)}

\[
\begin{array}{ccc}
\text{Mg} & 137.05 & 4.28 \\
\text{Si} & 147.15 & 3.91 \\
\text{S} & 180.33 & 3.70 \\
\text{Ar} & 141.38 & 3.36 \\
\text{Ca} & 141.15 & 2.55 \\
\text{Ti} & 72.13 & 3.73 \\
\text{Fe} & 63.48 & 1.23
\end{array}
\]

\[
\begin{align*}
\text{Detector} \\
\text{End} : & \quad z_e = 80.00 \text{ mm} \\
\text{Ring} : & \quad 2z_r = 29.17 \text{ mm} \\
\text{Gap} : & \quad z_0 = 0.50 \text{ mm} \\
\text{Compensation} : & \quad z_c = 71.36 \text{ mm} \\
\text{Total} : & \quad z_{tot} = 167.44 \text{ mm} \\
\text{Radius} : & \quad \rho_0 = 90.00 \text{ mm}
\end{align*}
\]

Trap dimensions are also optimized to perform high precision mass measurement.

M. Mehlman et al. NIMA 712 (2013) 9
Penning Trap: $l/r = 3.72$

Mass measurement of $^{23}\text{Na}$:

$$M_{\text{diff}} = \text{calc} - \text{AME} = -0.3 \pm 1.3 \text{ keV}$$

(a 0.06 ppm measurement)
TAMUTRAP – FACILITY

Trap for Proton decay studies
TAMUTRAP – FACILITY

- World’s largest open geometry Penning trap facility (Unique Design).
- Correlation measurements (β-delayed proton decay).
- $ft$-value measurement

Trap for Proton decay studies
High precision measurements using ion traps provide a valuable input to weak interaction studies.

Several ideas and extension to the existing ion trap techniques are being implemented.

Several Ion trap facilities are getting ready for measuring correlation parameter @ 0.1% level.

TAMUTRAP facility is a unique facility:
- Measurement of correlation parameter ($a_{\beta v}$)
- $ft$ value measurement (mass, half-life, branching ratio)
- Decay station.....
Funding Support:  
The **DOE** and **State of Texas**

**DOE DE-FG02-93ER40773, Early Career ER41747**
Ion Trap Group

@ Cyclotron institute, Texas A&M University

Funding Support:
The DOE and State of Texas

DOE DE-FG02-93ER40773, Early Career ER41747
In-Flight (Heavy Ion Guide)  
Or  
ISOL type (Light Ion Guide)
Ion trap facilities for mass measurements

Prog. Part. Phys. 91(2016) 259-293
Penning trap for correlation & ft measurements

TAMUTRAP Facility aiming to perform $a_{\beta v}$ & $ft$-value measurements for $\beta$-delayed proton emitters