WITCH
a Double Penning Trap Experiment for Weak Interaction Studies

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11\textsuperscript{th} of November, PANIC 2008
WITCH

1. Motivation
2. Overview of the set-up
3. Penning traps
4. Retardation spectrometer

First measurements

1. Interesting isotopes
2. Proof-of-principle: $^{124}$In
3. $^{35}$Ar test

Other physics goals

1. Spectroscopy measurements

Conclusion & Outlook
Physics motivation: $\beta$-$\nu$ angular correlation

\[ H_\beta = H_S + H_V + H_T + H_A + H_P \]

e.g.: Fermi $\beta$ decay ($0^+ \rightarrow 0^+$)

\[ W(\theta) \approx 1 + a \frac{v}{c} \cos \theta \]

\[ a \approx 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2} \]

Current experimental limits:
(from nuclear & neutron $\beta$ decay)

\[ \frac{C_S}{C_V} < 7\%, \quad \frac{C_T}{C_A} < 9\% \]
WITCH: Weak Interaction Trap for Charged Particles
Reality
Basics of Penning Traps

- An axial $B$ field for radial confinement
- A quadrupole $E$ field for axial confinement

Three eigenmotions:
- Reduced cyclotron motion with frequency, $\omega_+$
- Harmonic oscillation in electric potential, $\omega_z$
- Interplay between $B$ and $E$ field, $\omega_-$

\[
\omega_c = \frac{qB}{m}, \quad \omega_\pm = \frac{1}{2}(\omega_c \pm \sqrt{\omega_c^2 - 2\omega_z^2})
\]
\[
\omega_c \approx \omega_+ \gg \omega_z \gg \omega_-
\]
Ion Cloud Manipulation

Segmented central electrode (RE)

In cooler trap

- Dipole Excitation ($\omega_-$): Mass independent removal from trap center
- Quadrupole Excitation ($\omega_c$): Mass dependent centering
  $+$ buffer gas = cooling of ion cloud
Retardation Spectrometer

\[ \frac{p^2}{B} = \text{constant} \Rightarrow \frac{E_{\text{kin}}^\perp_{\text{high field}}}{E_{\text{kin}}^\perp_{\text{low field}}} = \frac{B_{\text{high}}}{B_{\text{low}}} = \frac{9T}{0.1T} = 98.8\% \]
Retardation spectrometer

![Graphs showing data comparison]

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Choice of isotopes

- Production yield at ISOLDE: $10^6$-$10^7/\mu$C
- Half-life: $\sim$ 1 second (long enough for trapping, short enough for statistics)
- Low ionization potential
- Decay mode: $\beta^-$ ($\pm$10 times more ions than $\beta^+$)
- Stable daughter isotope
- Minimal isobaric/isomeric contamination
- Simple decay scheme

$\Rightarrow^{122g}_{\text{In}}$ (Our prime physics candidate is $^{35}$Ar)

The ground state of $^{122}$In is not produced, only $^{122}$In$^{m1,2}$

$^{124}$In was chosen; complex decay schema, and isomeric contamination.

$T_{1/2}(^{124g}_{\text{In}}) = 3.11(10)$ s, $T_{1/2}(^{124m}_{\text{In}}) = 3.7(2)$
124\textsuperscript{In} integral spectrum, November 2006

Fit Parameters

- Offset of applied potentials
- Fraction of isomeric contamination
- Overall scaling
- Background scaling
- Charge state distribution
Shake-off

- Position Auger charge distribution
- Width Auger charge distribution
- Slope $\beta$-decay charge distribution

- IT + Auger (e.g. $^{133}\text{Xe}$)
- $^{124}\text{Sn}$ electron structure: $[\text{Kr}]5s^24d^{10}5p^2$

- $\beta$ Shake-off (e.g. $^{41}\text{Ar}$)

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2. T.A. Carlson, Phys. Rev. 131 (1963) 676
The test run did not go as hoped..

- Stable $^{35}$Cl contamination
  
  At first: The Cl:Ar was 400:1
  
  Optimized: 25:1 ratio, but greatly reduced yield
  
  ⇒ Under investigation by ISOLDE’s target group

- Charge exchange

  REXTRAP: half-life of 63 ms
  
  WITCH: Even worse half-life; this prevented us from preparing the ion cloud
  
  ⇒ No useful recoil spectrum was obtained
  
  ⇒ Probably cause; bad vacuum
  
  ⇒ *improvement of our vacuum* to ensure a *pure buffer gas*
Mass resolving power of our new traps

Mass purification is done by a combination of RF excitations in the trap and buffer gas cooling

\[
\text{Mass resolution: } \frac{m}{\Delta m} = \frac{f}{\Delta f}\]

\[ (1) \]

**Figure:** $\omega_c$ quadrupole excitation on $^{133}\text{Cs}$, FWHM = 3.54 Hz, in 6T

Applications: Spectroscopy measurements with a very pure sample ⇒ Tapestation

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Interesting isotopes

Work carried out by Towner and Hardy\(^4\)

\[
\mathcal{F}_t \equiv \frac{K}{2G_F V_{ud}(1 + \Delta_{R}^V)}
\]  

- \(K\) is a combination of natural constants
- \(\Delta_{R}^V\) is a nuclear independent radiative correction - can be calculated
- \(G_F\) is the strength of the weak interaction in a purely leptonic decay - can be measured in muon experiments
- \(\mathcal{F}_t\) can be obtained from nuclear experiments
- \(V_{ud}\) - a matrix element from the CKM matrix - can be obtained by knowing all of the above parameters. In this list, \(\mathcal{F}_t\) is the less precise one.

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Conclusion

- Proof-of-principle has been performed ($^{124}$In)
- Our test run ($^{35}$Ar) did not go as smoothly as hoped...
- Preparations are on the way to do a physics run on $^{35}$Ar

Outlook

- Next year we are planning runs to check for systematics
- If everything goes well we can have a data-taking run
- Other physics opportunities are visible on the horizon