WITCH
a Double Penning Trap Experiment for Weak Interaction Studies

Michaël Tandecki\textsuperscript{a}

M. Breitenfeldt\textsuperscript{a}, S. Van Gorp\textsuperscript{a}, N. Severijns\textsuperscript{a}, M. Beck\textsuperscript{b}, P. Friedag\textsuperscript{b}, J. Mader\textsuperscript{b}, V. De Leebeeck\textsuperscript{a}, S. Roccia\textsuperscript{a}, G. Soti\textsuperscript{a}, E. Traykov\textsuperscript{a}, F. Wauters, Ch. Weinheimer\textsuperscript{b}, A. Herlert\textsuperscript{c}, V. Yu. Kozlov\textsuperscript{d}, D. Zákoucký\textsuperscript{e}

\textsuperscript{a} IKS - Leuven, Belgium
\textsuperscript{b} IKP - Münster, Germany
\textsuperscript{c} CERN - Geneva, Switzerland
\textsuperscript{d} KIT - Karlsruhe, Germany
\textsuperscript{e} NPI - Rež , Czech Republic

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1 WITCH
   - Motivation
   - Overview of the set-up
   - Penning traps
   - Retardation spectrometer

2 $^{35}\text{Ar}$ runs
   - First test run (Nov 2007)
   - Encountered issues + solutions
   - Further optimization of the system
   - Second test run (Nov 2009)

3 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 ($0^+ \rightarrow 0^+$)

$W(\theta) \approx 1 + a \frac{\nu}{c} \cos \theta$

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

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

$\frac{C_S}{C_V} < 7\%, \frac{C_T}{C_A} < 9\%$
Overview of the set-up

**WITCH:**  
Weak Interaction Trap for Charged Particles

Michaël Tandecki (IKS - Leuven, Belgium)

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Reality

Witch > Witch > Overview of the set-up

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Basics of Penning Traps

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

Three eigenmotions:
- Cyclotron motion with frequency, \( \omega_+ \)
- Harmonic oscillation in electric potential, \( \omega_z \)
- Interplay between B and E field (magnetron motion), \( \omega_- \)

\[
\omega_c = \frac{qB}{m},
\]
\[
\omega_\pm = \frac{1}{2} \left( \omega_c \pm \sqrt{\omega_c^2 - 2\omega_z^2} \right)
\]
\[
\omega_c \approx \omega_+ \gg \omega_z \gg \omega_-
\]
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
The actual trap structure
Energy conversion

\[ \frac{p^2}{B} = \text{constant} \Rightarrow \frac{E_{\text{kin}}^\perp_{\text{high field}}}{E_{\text{kin}}^\perp_{\text{low field}}} = \frac{B_{\text{high}}}{B_{\text{low}}} = \frac{9T}{0.1T} = 98.8\% \]
Due to the measurement method integral spectra are measured at WITCH instead of differential spectra.
The first 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 (about 10 ms); this prevented us from preparing the ion cloud
  ⇒ No useful recoil spectrum was obtained
  ⇒ Probable cause; bad vacuum
- Secondary ionization
  Ions were created in the spectrometer and released at certain times
Development and improvement of a VADIS (Versatile Arc Discharge Ion source) at ISOLDE

- 13/11/09: 70pA $^{35}$Cl
  $\Rightarrow$ 6e+6 $^{35}$Ar/$\mu$C, with gating; ratio 10/1
- 16/11/09: 10pA $^{35}$Cl
- Tape station measurement before run:
  $^{35}$Cl/$^{35}$Ar = 1/5
Charge exchange

- **Vacuum**
  - General purity of WITCH was improved
  - Base level of the cooler trap was improved with almost one order of magnitude ($1\times10^{-7}$ mbar $\rightarrow 1.5\times10^{-8}$ mbar)

- **Buffer gas system**
  - All plastic pieces have been replaced
  - Good pressure without any external pump
  - Additional gas purification (NEG pump)
Charge exchange

He-57 gas bottle
All-metal reducer
All-metal angle valves
Needle valve
NEG pump
Full-range gauge
Charge exchange

**REXTRAP**

50 % loss after $\sim 90$ ms

**WITCH**

10 % loss after 0.5 s

Charge exchange in REXTRAP can be tackled by increasing the operational frequency of the pulsed drift tube. A factor of two should be easily possible, a factor of 10 would be the final goal.
Observations

- 2006 ($^{124}$In): discharges when switching the spectrometer
- 2006 (off-line; $^{60}$Co$^a$ and $^{90}$Sr$^b$): discharges are caused by gamma radiation
- 2007 ($^{35}$Ar): see figure.

$^a$γ source

$^b$β source
Secondary ionization

Improvements
- Vacuum purity
- Electropolished re-acceleration electrodes

Results
- Secondary ionization of the same order was not observed anymore ($^{60}$Co, July 2009)
- There was a 20% effect on the background
- Negligible since $^{60}$Co source (30 kBq) produces way more $\gamma$’s than the expected $^{35}$Ar source
An unwanted Penning trap prevented us from ramping up the re-acceleration electrodes to their nominal values.
Trap optimization

New electronics & computer control system (based on the CS framework by GSI) lead to a tremendous improvement of the entire experiment.
Trap optimization

A low ion cloud kinetic energy is good for

- Reduction of systematic effects:
  E.g., high endcap voltages can mimick a deviation from the Standard Model value of $\alpha$
- More narrow response function (see figure)
In short

- No problems showed up during the run
- All the implemented solutions and optimizations performed well

But...
Some low-level secondary ionization is still there...

In the past this was not visible, because it was hidden in bigger discharges.
Ionization is heavily dependent on the exact voltages of the spectrometer and einzel lens electrodes.


Conclusion

- Conditions are set for a physics run on $^{35}$Ar ⇒ Cl contamination, charge exchange, huge secondary ionization issues from 2007 have been solved.
- Simulations and off-line measurements to characterize low-level ionization (& implement a solution)

Outlook

Several runs/tests planned to investigate systematics

1. $^{144}$Eu (EC decay) to measure the response function of the system
2. $^{114}$Ag to investigate systematics (high intensity ion cloud & $\beta^-$'s)
3. $^{35}$Ar to get information about the $\beta$-$\nu$ angular correlation coefficient