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EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Status Report to the ISOLDE and Neutron Time-of-Flight Committee

IS433: Search for new physics in beta-neutrino correlations using trapped ions and a retardation spectrometer

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Abstract

After several upgrades the WITCH experiment succeeded to collect a statistically significant data set in November 2012. The status of the analysis of these data and corresponding systematic effects, which is still ongoing, is reported here.
The ion background in the system turned out to be still very high and difficult to control. Further reducing this turns out to be time and manpower consuming. It was therefore decided to further analyze the available data set and publish the result, but not continue the WITCH experiment in its present form thereafter. No on-line beam time is planned anymore. However, the apparatus is kept operational for possible off-line measurements of systematic effects in autumn 2014. For this either a beam of REXTRAP or from the WITCH ions source+RFQ will be used.
Thereafter the system could be modified in view of a different kind of measurements, not including the retardation spectrometer. This is still being discussed and will be presented to the INTC committee in due time.

Remaining shifts: 6.5

1. Motivation, experimental setup/technique

The aim of the WITCH experiment (Weak Interaction Trap for Charged particles) is to probe the existence of a scalar component in the weak interaction by measuring the shape of the energy distribution of the recoil ions from the beta decay. The shape of this distribution is sensitive to the β-ν angular correlation coefficient *a* [JAC57], which depends on the different possible couplings (i.e. interaction types) at play in the weak interaction. A relative precision of about 0.5 % or better on *a* is aimed at. The sensitivity to scalar weak currents is then similar to the present 95% upper limit of $|C_S/C_V| < 0.07$ [SEV06], and equal to the presently most precise result that was obtained in a β-ν correlation measurement, i.e. with ^{38m}K in a Magneto Optical Trap at TRIUMF [GOR05].

The isotope ^{35}Ar was selected for WITCH because it is has a nearly pure Fermi type (i.e. high sensitivity to scalar weak currents) mirror beta transition for which nuclear and higher-order (e.g. strong-interaction induced) corrections to the value of *a* are sufficiently well known and which is readily obtained with good yield at ISOLDE.

The main components of the WITCH set-up [BEC03a, BEC03b, KOZ04, TAN11a] are a double Penning ion trap system and a retardation spectrometer. The ISOLDE ion beam is transformed into bunches in REXTRAP which are then slowed down to about 100 eV in a pulsed drift cavity in the WITCH vertical beam line and injected into the 9T magnetic field where the two Penning traps are situated. In the first~~,~~ cooler ion trap they are cooled in helium buffer gas before being transferred through a ~~3~~2 mm diameter differential pumping diaphragm into the second Penning trap, the decay trap where they are left to decay.

After β decay, the recoiling daughter ions emitted into the direction of the retardation spectrometer spiral from the strong magnetic field B_{max} = 6 T in the Penning trap into the homogeneous weak field region with B_{min} = 0.1 T in the center of the spectrometer. Due to the adiabatic invariance of the magnetic flux, a fraction $1 - (B_{min}/B_{max}) \approx 98.4\%$ of the energy of the ion motion perpendicular to the magnetic field lines is converted into longitudinal energy. The latter is then probed by retarding the ions with a well-defined electrostatic potential. Ions that pass this analysis plane are reaccelerated to ~10 keV to get off the magnetic field lines and ensure 100% detection efficiency for all recoil energies and charge states. Finally, these ions are focused with an Einzel lens onto a microchannel plate (MCP) detector with an active surface of 8 cm diameter and delay line anodes providing position resolution of 1 mm. By counting ions arriving on this MCP for different retardation voltages, the integral recoil ion spectrum is obtained. The shape of this spectrum depends on a possible scalar type contribution to the weak interaction.

2. Status Report

- **Accepted isotopes: ^{35}Ar**

- **Performed studies:**

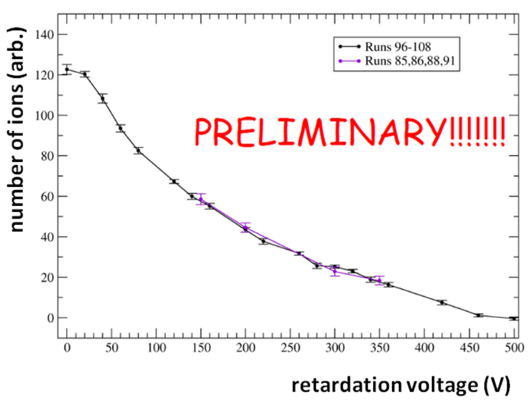
The proof of principle of the WITCH concept was demonstrated in June 2011 (with only about 5000 counts and 30% statistical uncertainty) [VAN14]). In Oct./Nov. 2011 a first high-statistics run was performed. During this run and also in the analysis a number of challenges showed up that had not been detected previously and required action:

- Timing problems with the DAQ rendered analysis extremely difficult. This was cured by using the FASTER DAQ system developed at LPC Caen in later runs.

- During the bake-out procedure the position of the central decay trap electrode changed with respect to the other electrodes. Due to this the trapped ion cloud was performing a magnetron motion around the trap centre, giving rise to an oscillatory behaviour in the MCP count rate. This was solved by replacing the Al rods of the trap support structure by Ti ones, having a smaller linear expansion coefficient.

- The image of the ion cloud on the MCP was observed to be a stretched ellipse instead of a circle. Simulations learned that the rod on which the beam diagnostic MCP detector in the retardation plane is mounted modified the potential in the spectrometer thereby deflecting ions. This was solved by moving the detector about 20 cm higher.

After solving these shortcomings a high-statistics run was performed in November 2012. About 27k cycles of 6 s were collected, each including two reference voltages (50 V and 600 V; the recoil ion endpoint energy for $^{35}Ar^{1+}$ decay is 450 eV) and two measurement voltages. Data were taken for a total of 20 different voltages. A large background was observed, which was later found to be related to the pulsing of the drift tube to slow down the ions. Half of the time was therefore spent to dedicated background runs to be able to subtract this. Ion cloud energy and efficiency calibration measurements were performed before, during, and after the experiment. A preliminary, uncorrected energy spectrum of the ^{35}Cl recoil ions from ^{35}Ar beta decay in the second Penning trap is shown below.



Analysis of these data is currently ongoing. For this extensive use is made of two simulation codes. A first one, Simbuca calculates the distribution of positions and energies of the ions in the cloud in the decay trap [VAN11]. This is used as input for the second code which performs the tracking of the recoil ions from beta decays in the decay trap, through the retardation spectrometer and towards the MCP detector.

At the same time different systematic effects and necessary corrections are being addressed in detail as well. The major systematics comes from the position and energy distributions of the ions in the decay trap. A major correction is required for the fact the efficiency of the MCP detector was found to be energy dependent (different charge states arrive with a different energy on the MCP detector). A difference of about 30% between the 1+ and 2+ charge states due to their recoil energies was found.

3. Future plans

The plan for the immediate future is to complete the ongoing study of the different systematic effects and corrections that are required to finish the analysis. This should then yield a value for the beta-neutrino correlation coefficient for ^{35}Ar. This will constitute the PhD thesis of T. Porobic.

Over the years it has turned out to be very difficult and slow to optimize the WITCH setup at ISOLDE where the demand for both stable and radioactive beams is very high, notwithstanding the very much appreciated help and efforts from the ISOLDE target/ion source group and coordinators. Unfortunately, several disturbing effects related to the use of the retardation spectrometer (e.g. ion background from different ionization mechanisms) can only be tested and investigated in detail in on-line conditions, i.e. when recoil ions from beta decays in the Penning trap are flying through the spectrometer. Even in the most recent on-line run (in November 2012) the ion background in the system turned out to be still rather high and difficult to control, although this was not seen in the off-line preparation with stable beams. Further reducing this turns out to be very time and manpower consuming with no guarantee for success. It was therefore decided to further analyze the available data set and publish the result, thereby concluding the beta-neutrino correlation experiment with ^{35}Ar with WITCH.

In principle we do not plan any additional on-line measurements anymore for the WITCH experiment with ^{35}Ar. However, we keep the set-up operational in its present form for possible off-line measurements in order to further characterize some systematic effects, if needed. These will then be performed either with a beam from REXTRAP or from our own compact ions source + RFQ combination.

Thereafter the set-up will be modified in view of other applications, not including the retardation spectrometer, which will be presented in due time to the INTC.

Future plans with <u>available</u> shifts:

(i) Envisaged measurements and requested isotopes

In principle (i.e. as long as no unforeseen systematic effects show up in the already well-advanced analysis) no on-line measurements will be performed anymore for the experiment with ^{35}Ar. Off-line measurements are still possible (see above).

(ii) Have these studies been performed in the meantime by another group?

no

(iii) Number of shifts (based on newest yields) required for each isotope

none

isotope	yield (/uC)	target – ion source	Shifts (8h)
-	-	-	-

Total shifts: 0

4. References:

[BEC03a] M. Beck et al., Nuclear Instruments and Methods A 503 (2003) 567

[BEC03b] M. Beck et al., Nuclear Instruments and Methods B204 (2003) 521

[GOR05] A. Gorelov et al., Phys. Rev. Lett. 94 (2005) 142501

[JAC57] J. D. Jackson, S. B. Treiman and H.W. Wyld, Nucl. Phys. 4 (1957) 206

[KOZ04] V. Kozlov et al., Physics of Atomic Nuclei 67 (2004) 1112

[SEV06] N. Severijns, M. Beck and O. Naviliat-Cuncic, Rev. Mod. Phys. 78 (2006) 991

[TAN11a] M. Tandecki et al., Nuclear Instruments and Methods A 629 (2011) 396

[VAN11] S. Van Gorp et al., Nucl.Instrum. Methods in Phys. Res. A 638 (2011) 192

[VAN14] S. Van Gorp et al., submitted to Phys. Rev. Lett.

5. Appendix

1. Publications

"Space charge effects in a gas filled Penning trap"
D. Beck, F. Ames, M. Beck, G. Bollen, B. Delauré, P. Schuurmans, S. Schwarz, P. Schmidt, N. Severijns, O. Forstner
Hyperfine Interactions 132 (2001) 473-478

"Search for new physics in beta-neutrino correlations with the WITCH spectrometer"
D. Beck, F. Ames, M. Beck, G. Bollen, B. Delauré, J. Deutsch, J. Dilling, O. Forstner, T. Phalet, R. Prieels, W. Quint, P. Schmidt, P. Schuurmans, N. Severijns, B. Vereecke, S. Versyck, and the EUROTRAPS collaboration
Nucl. Phys. A701 (2002) 369c-372c

"WITCH: a recoil spectrometer for beta decay"
M. Beck, F. Ames, D. Beck, G. Bollen, B. Delauré, J. Deutsch, V.V. Golovko, V.Yu. Kozlov, I.S. Kraev, A. Lindroth, T. Phalet, W. Quint, K. Reisinger, P. Schuurmans, N. Severijns, B. Vereecke, S. Versyck, and the EUROTRAPS collaboration
Nuclear Instruments and Methods in Physics Research B204 (2003) 521-525

"WITCH: A recoil spectrometer for weak interaction and nuclear physics studies"
M. Beck, B. Delaure, V.V. Golovko, V.Yu. Kozlov, I.S. Kraev, A. Lindroth, T. Phalet, P. Schuurmans, N. Severijns, B. Vereecke, S. Versyck, D. Beck, W. Quint, F. Ames, G. Bollen and the ISOLDE, EUROTRAPS and NIPNET collaborations
Nuclear Instruments and Methods in Physics Research A 503 (2003) 567-579

"WITCH: Testing the Standard Model using a beta recoil spectrometer with a trapped ion cloud as source"
A. Lindroth, M. Beck, B. Delaure, V.Yu. Kozlov, N. Severijns, F. Ames, D. Beck, V.V. Golovko, I. Kraev, T. Phalet, and S. Versyck
Nuclear Physics A 721 (2003) 1103c-1106c

"WITCH, a Penning trap retardation spectrometer combination for precision studies of the weak interaction"
B. Delauré, M. Beck, V.V. Golovko, V. Kozlov, T. Phalet, P. Schuurmans, N. Severijns, B. Vereecke, S. Versyck, D. Beck, W. Quint, F. Ames, K. Reisinger, O. Forstner, J. Deutsch, G. Bollen, S. Schwarz
Hyperfine Interactions 146 (2003) 91-95

"Physics and present status of the WITCH experiment"
V.Yu. Kozlov, M. Beck, F. Ames, D. Beck, S. Coeck, P. Delahaye, B. Delauré, V.V. Golovko, A. Lindroth, I.S. Kraev, T. Phalet, N. Severijns, S. Versyck, F. Wenander and the ISOLDE and NIPNET collaborations
Physics of Atomic Nuclei 67 (2004) 1112-1118

"Fast controls for the WITCH Penning-trap radioactive source experiment"
A. Lindroth, F. Ames, D. Beck, M. Beck, S. Coeck, B. Delauré, V.V. Golovko, V.Yu. Kozlov, I.S. Kraev, T. Phalet, N. Severijns, B. Vereecke, S. Versyck and the ISOLDE and NIPNET Collaborations
Nuclear Instruments and Methods in Physics Research A 534 (2004) 551-561

"Micro channel plate response to high intensity ion bunches"
S. Coeck, M. Beck. B. Delauré, V.V. Golovko, M. Herbane, A. Lindroth, V. Yu. Kozlov, I.S. Kraev, T. Phalet, N. Severijns
Nuclear Instruments & Methods in Physics Research A 557 (2006) 516-522

"The WITCH experiment: completion of a set-up to investigate the structure of weak interactions with a Penning trap"
V.Yu. Kozlov, N. Severijns, D. Beck, M. Beck, S. Coeck, B. Delauré, A. Lindroth, P. Delahaye, F. Wenander, V.V. Golovko, I.S. Kraev, T. Phalet and the ISOLDE, NIPNET and TRAPSPEC collaborations.
International Journal of Mass Spectrometry 251 (2006) 159-172

"The WITCH experiment: towards weak interaction studies; status and prospects"
Yu. Kozlov, M. Beck, S. Coeck, M. Herbane, V. I.S. Kraev, N. Severijns F. Wauters, P. Delahaye, A. Herlert, F. Wenander (ISOLDE, NIPNET and TRAPSPEC collaborations)
Hyperfine Interactions 172 (2006) 15-22

"A pulsed drift cavity to capture 30keV ion bunches at ground potential."
S. Coeck, B. Delauré, M. Herbane, M. Beck, V. Golovko, S. Kopecky, V. Kozlov, I. Kraev, A. Lindroth, T. Phalet
Nucl. Instr. Meth. A 572 (2007) 585-595

"Ab intio simulations on the behaviour of small ion clouds in the WITCH Penning trap system"
S. Coeck, B. Delauré, M. Herbane, V. Yu. Kozlov, I.S. Kraev, M. Tandecki, F. Wauters, M. Beck, P. Delahaye, A. Herlert, S. Sturm, N. Severijns
Nucl. Instrum. Meth. A, 574 (2007) 370-384

"The WITCH experiment: Acquiring the first recoil ion spectrum"
V.Yu. Kozlov, M. Beck, S. Coeck, P. Delahaye, P. Friedag, M. Herbane, A. Herlert, I.S. Kraev, M. Tandecki, S. Van Gorp, F. Wauters, Ch. Weinheimer, F. Wenander, D. Zákoucký, N. Severijns
Nuclear Instruments and Methods in Physics Research B 266 (2008) 4515–4520

"Computer Controls for the WITCH Experiment"
M. Tandecki, D. Beck, M. Beck, H. Brand, M. Breitenfeldt, V. De Leebeeck, P. Friedag, A. Herlert, V. Kozlov, J. Mader, S. Roccia, G. Soti, E. Traykov, S. Van Gorp, F. Wauters, Ch. Weinheimer, D. Zákoucký, N. Severijns
Nuclear Instruments and Methods A 629 (2011) 396-405

"First detection and energy measurement of recoil ions following beta decay in a Penning trap with the WITCH experiment"
M. Beck, S. Coeck, V.Yu. Kozlov, M. Breitenfeldt, P. Delahaye, P. Friedag, F. Glück, M. Herbane, A. Herlert, I.S. Kraev, J. Mader, M. Tandecki, S. Van Gorp, F. Wauters, Ch. Weinheimer, F. Wenander, N. Severijns, and the ISOLDE collaboration
European Physical Journal A 47 (2011) 45 (9 pages)

"SIMBUCA, using a graphics card to simulate Coulomb interactions in a Penning trap"
S. Van Gorp, M. Breitenfeldt, V. De Leebeeck, S. Roccia, G. Soti, M. Tandecki, E. Traykov, F. Wauters, M. Beck, P. Friedag, J. Mader, Ch. Weinheimer, A. Herlert, V. Kozlov, D. Zákoucký, T. Iitaka, N. Severijns
Nuclear Instruments and Methods A 638 (2011) 192–200

“A compact radio frequency quadrupole for ion bunching for the WITCH experiment”
E. Traykov, M. Beck, M. Breitenfeldt, P. Delahaye, V. De Leebeeck, P. Friedag, A. Herlert, N. Geeraert, W. Heirman, P.-I. Lønne, J. Mader, S. Roccia, G. Soti, M. Tandecki, M. Timmermans, J. Thiboud, S. Van Gorp, F. Wauters, C. Weinheimer, D. Zákoucký, N. Severijns
Nuclear Instruments and Methods A 648 (2011) 1–14

2. PhD theses [including link to CDS]

Bavo Delauré - 05.02.2004 – KU Leuven
“Ontwikkeling van een elektromagnetische ionenval met vertragingsspectrometer voor precisiemetingen in de zwakke interactie”
https://cds.cern.ch/record/1642845 - CERN-THESIS-2003-052

Valentin Kozlov - 21.11.2005 – KU Leuven
“WITCH, a Penning trap for weak interaction studies”
https://cds.cern.ch/record/933167 - CERN-THESIS-2006-009

Sam Coeck - 27.09.2007 – KU Leuven
“Search for non-Standard Model physics in nuclear beta–decay with the WITCH experiment”
https://cds.cern.ch/record/1476051 - CERN-THESIS-2007-118

Michaël Tandecki – 27.05.2011 – KU Leuven
“Study of weak interaction properties with exotic nuclei”
https://cds.cern.ch/record/1642846 - CERN-THESIS-2011-329

Simon Van Gorp – 27.03.2012 – KU Leuven
“Search for physics beyond the standard electroweak model at the WITCH experiment”
https://cds.cern.ch/record/1642848 - CERN-THESIS-2012-365

P. Friedag – 14.06.2013 – Westfälische Wilhelms-Universität, Münster (Germany)
“Setup and calibration of a position sensitive microchannel plate detector and analysis of a test run optimizing the WITCH experiment”
https://cds.cern.ch/record/1642850 - CERN-THESIS-2013-250

T. Porobic - in preparation (2015) – KU Leuven