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Search For A Scalar Component In The Weak Interaction

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Weak interactions are described by the Standard Model which uses the basic assumption of a pure "**V**(ector)-**A**(xial vector)" character for the interaction. However, after more than half a century of model development and experimental testing of its fundamental ingredients, experimental limits for possible admixtures of scalar and/or tensor interactions are still as high as 7%.

The WITCH project (**W**eak **I**nteraction **T**rap for **CH**arged particles) at the isotope separator ISOLDE at CERN is trying to probe the structure of the weak interaction in specific low energy β–decays in order to look for possible scalar or tensor components or at least significantly improve the current experimental limits. This worldwide unique experimental setup consisting of a combination of two Penning ion traps and a retardation spectrometer allows to catch, trap and cool the radioactive nuclei provided by the ISOLDE separator, form a cooled and scattering-free radioactive source of β–decaying nuclei and let these nuclei decay at rest. The precise measurement of the shape of the energy spectrum of the recoiling nuclei, the shape of which is very sensitive to the character of the weak interaction, enables searching for a possible admixture of a scalar/tensor component in the dominant vector/axial vector mode.

First online measurements with the isotope ^{35}Ar were performed in 2011 and 2012. The current status of the experiment, the data analysis and results as well as extensive simulations will be presented and discussed.

KEYWORDS: fundamental symmetries, weak interactions, β-decay, Penning traps

1. Introduction

At the basis of the Standard Model (SM) of electroweak interactions lies the assumption about the character of the interaction: pure V-A interaction with maximum parity violation, while the other types of interaction (scalar, tensor) being excluded. However, the current upper limits for scalar/tensor coupling constants in nuclear β-decay, relative to the vector/axial-vector ones, are as high as ~7% [1]. One way to extend the Standard Model in order to build a more fundamental theory is to check its basic assumptions (e.g. the pure V-A character of the interaction). This can be done experimentally by measurements of the β-ν correlations in the β-decay. This can be very sensitive to the character of the interaction. With realistic requirements on the precision of the measurement one can look for small admixtures of different types of interactions. This adds complementary information compared to experiments discussed in review [2].

2. Experiment

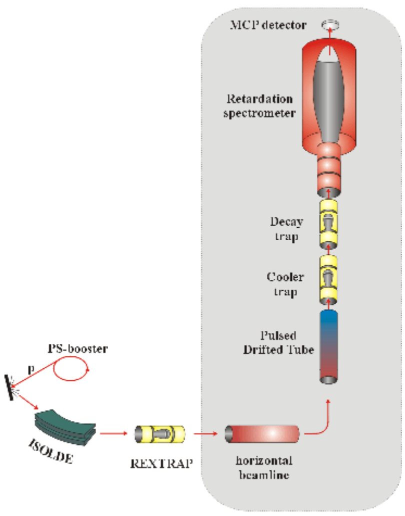
2.1 Experimental method

The β-ν correlations are experimentally studied here but due to the difficulty to detect neutrinos in a rather compact low-energy β-decay experiment the detection of emitted neutrinos is replaced by the detection of the recoiling daughter nuclei. However, the low energy of these (~eV) prevents the usage of standard radioactive samples (due to absorption in the sample). This problem can be solved by using ion/atom traps where the nuclei can decay in well-localized low energy and low density ion/atom clouds and the recoiling nuclei can escape without significant scattering/absorption.

The shape of the energy spectrum of these recoiling nuclei is very sensitive to different weak interaction modes so that a precise experimental determination of the shape of the recoil spectrum permits the determination of a possible admixture of a (by the SM forbidden) scalar component in the (allowed) dominant vector component.

2.2 Experimental setup

For precise measurements of the shape of recoil ion energy spectra after β-decay of trapped radioactive ions the online facility WITCH (**W**eak **I**nteraction **T**rap for **CH**arged particles) has been built at ISOLDE/CERN [3]. Figure shows the scheme of the WITCH experimental setup, full details are described in [4,5]. Principal components of the setup are two Penning traps (to catch and trap radioactive ions produced by the ISOLDE separator, cool them and let them decay as a scattering/absorption free radioactive β-source) and the retardation spectrometer (to probe the energy spectrum of the recoiling nuclei). These are mounted inside the big LHe cryostat housing two superconducting magnets with magnetic fields up to 9T (traps) and 0.2T (spectrometer).



The mass separated beam of radioactive isotopes under study is produced at the ISOLDE facility. Ions from the continuous ISOLDE beam are first stopped, cooled and bunched in a preparatory Penning trap REXTRAP. A bunched 30keV beam from REXTRAP is transported to WITCH and slowed down by the **P**ulsed **D**rift **T**ube to ~10^2eV. The ions are then trapped, cooled to ~10^{-1}eV and also spatially compressed in the first Penning trap (Cooler trap) filled with pure He buffer gas. Then they are transferred and trapped again in the Decay trap (in a clean environment) and left to decay. Ions recoiling after the β-decay in the decay trap are guided by the strong magnetic field (6 or 9T) into the retardation spectrometer (placed in a 0.1T magnetic field) which blocks the ions with energy below the electrostatic retardation barrier. Ions with higher energy get further and are registered by the position sensitive MCP detector [6] serving as a „counter“. By varying the blocking retardation potential the integral energy spectrum of the recoiling ions is measured.

3. Experimental data

In 2011 a first successful online experiment with ^{35}Ar was performed. We were able to catch and cool ^{35}Ar ions in the cooler trap to sufficiently low energy, keep them for a long enough time in the decay trap at rest in order to let them decay to form a scattering-free cool radioactive β-source. We unambiguously observed recoil ions after β-decay of ^{35}Ar and measured their energy spectra (experimental data and results are described in detail in [7]). Statistics was still low but the reasons for that were identified and measures to optimize both the ISOLDE beam and WITCH setup were taken as a preparation for the next experiment. After constructing the integral recoil spectrum the value of the β-ν correlation coefficient “***a***” could be extracted albeit with rather large error bar (~30%) [7].

A new online experiment was performed in 2012 using the experience gained from the experiment in 2011. We obtained a more intensive and cleaner beam of ^{35}Ar from ISOLDE while the WITCH setup utilized better diagnostics, improved measurement systems and methodics, better transmission and a new DAQ making the dead-time negligible. The measured statistics was ~10x higher than in the 2011 experiment. Raw analysis of the experimental data was performed and raw recoil spectrum extracted but full analysis is still continuing, systematic effects are studied/simulated and also some offline tests are still necessary to correct for some of these.

4. Simulations

The simulation package Simbuca [8] was developed for simulations of the ion cloud behavior in ion traps (even for large ion numbers/densities where the ion Coulomb self-interactions cannot be neglected). This specialized program package uses the paralellisation of the computer graphics card (GPU) which is absolutely essential – long-range Coulomb interactions mean that each ion interacts with every other ion and standard calculations (using CPU) start to get unrealistic already for ~>10^3 ions while we need to simulate ~>10^5 ions in the trap. The program simulates significant space charge effects, for example the change of cyclotron and magnetron resonant frequency, change of the cloud shape and energy in traps due to self-interaction of ions.

The purpose of the simulation package SimWitch [9] is to perform Monte Carlo simulations of the recoiling ion trajectories from the decay trap through the spectrometer up to the MCP detector. Ion transport is simulated for various retardation voltages (0V–450V) and various ^{35}Cl (the recoil ion resulting from the ^{35}Ar β-decay) charge states (1^{+}- 5^{+}). Simulations are performed for the optimization of parameters before the experiment or for the analysis/correction of measured experimental data.

5. Conclusion, outlook

The experimental setup WITCH on the beam of ISOLDE proved its suitability for the high precision and high efficiency studies with very low energy particles. Several online measurements with ^{35}Ar were performed at ISOLDE, retardation (recoil) spectra of the ions produced in the β–decay of ^{35}Ar were extracted and simulations are correctly describing the ions behaviour in traps and their tracking in the setup. A first pilot experiment from 2011 with low statistics was analyzed and the value of the angular β-ν correlation coefficient ***a*** was determined (albeit with a still rather large error bar) by the WITCH experiment [7]. A subsequent online experiment in autumn 2012 with higher statistics, improved beam quality and measurement conditions is now being analyzed, with a raw retardation spectrum having been extracted already and systematic effects currently being studied as well.

We plan to finalize the analysis of these experimental data, extracting the recoil spectra, continue SimWITCH and Simbuca simulations for further understanding of the system and continue the calculations of the necessary systematic corrections to handle systematic uncertainties. More detailed experimental tests of the MCP detector efficiency will still be performed for precise correction of the experimental data. Finally we plan to extract an experimental value of the β-ν correlation coefficient ***a*** with the best possible precision and compare it with its Standard Model value.

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