EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

Letter of Intent to the ISOLDE and Neutron Time-of-Flight Committee

WISARD: Weak-interaction studies with ^{32}Ar decay

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Beam time requested:
Two times 3 shifts of stable beam
9 shifts of radioactive ^{32}Ar

Abstract

We propose to install a new set-up using the former WITCH superconducting magnet which will allow us to measure β−ν angular correlations in the decay of ^{32}Ar. The aim of the proposal is to search for a scalar current contribution in the weak interaction. The energy shift of the β-delayed protons emitted from the isobaric analogue state of the ^{32}Ar ground state carries information about this angular correlation. To enhance the sensitivity, protons and positrons from the decay will be measured on either side of a catcher foil in which the radioactive sample is implanted. By conditioning the protons with a positron detected in the same hemisphere or in the opposite hemisphere of the superconducting magnet the Doppler energy shift will be more or less pronounced as a function of the possible scalar current component of the weak interaction compared to the dominant vector current.

1 Introduction

The weak interaction which mediates nuclear β decay, but also some decay channels of pion decay and muon decay, is described in the standard model of particle physics as consisting of two different currents or contributions, the vector current responsible for 'Fermi-type' decays and the axial-vector current responsible for 'Gamow-Teller-type' decays. All experimental findings (see e.g. [1]) can be described with these two types of interactions. However, from a more global theoretical picture requiring only Lorentz invariance, also scalar, tensor and pseudo-scalar currents are allowed, the latter

being often neglected because of importance only at relativistic energies which is not the case of the nucleons in an atomic nucleus. In such a scenario, scalar currents could come along with the known vector currents whereas tensor currents would contribute to decays mediated mainly by the axial-vector currents. However, today only upper limits are known for these 'exotic' currents.

Limits on these currents can be either obtained from high-energy physics (e.g. LHC) or from high-precision low-energy experiments i.e. in nuclear β decay [2]. In the present proposal we follow this latter path. Most low-energy experiments use angular correlation measurements to search for the above-mentioned exotic currents. For example, the β–ν angular correlation from the decay of ^{6}He (LPCTrap) [3], ^{21}Na (Berkeley) [4], and ^{8}Li (Argonne) [5] was used to determine stringent limits on the presence of tensor currents in GT decays, where ^{35}Ar (WITCH/ISOLDE.) [6] and ^{38}K^m (TRIUMF) [7] was used to search for scalar currents. However, this β–ν correlation cannot be measured directly as the neutrino is very difficult to measure directly.

Presently the most stringent limits on the presence of scalar currents come from the average corrected Ft-value of the superallowed Fermi transitions (producing a narrow band of allowed values for scalar coupling constants which, however, stretches to infinity) and the study of the ^{38m}K [7] and ^{32}Ar [8,9] decays (cutting this band thereby limiting the coupling constants to finite values). The latter nucleus decays, beneath other channels, by a super-allowed Fermi β$^+$ decay to a state in ^{32}Cl, the isobaric analogue state IAS, which is unbound to proton emission. Due to the recoil the daughter nucleus gets from the emission of the positron and the neutrino, the proton is emitted from a moving source and is subject to Doppler Effect. In fact, if the proton is emitted in the direction in which the nucleus moves it gets a boost in energy, whereas it is slowed down, if emitted in opposite direction. As the angular distribution of the positron and the neutrino is different (see Fig.1) for the dominant vector part of the weak interaction (positron and neutrino predominantly emitted in the same direction) compared to a possible scalar current (positron and neutrino predominantly emitted in opposite directions), the measurement of the Doppler broadening of the proton energy peak from the decay of the IAS and the comparison with model predictions from the standard model with or without exotic contributions allowed the determination of one of the most stringent limit on scalar currents in the weak interaction, i.e 0.65% uncertainty of the angular correlation coefficient $a_{\beta v}$ (0.5% with ^{38m}K). In order to achieve this precise result, the experimental set-up was installed in a strong magnetic field to guide the positrons away from the proton detectors which were cooled to improve their energy resolution. However, the positrons were not detected.
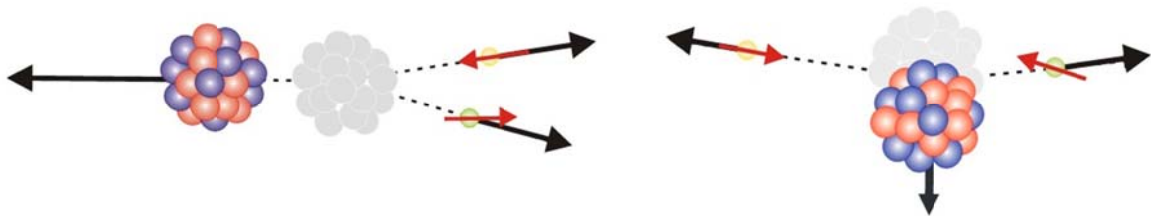

Fig. 1: *The picture on the left-hand side presents a vector-type decay where the two leptons are emitted preferentially in the same direction, whereas for a scalar-type decay (right-hand side) they are preferentially emitted with an angle of 180° (in black the momentum vectors, in red the spins).*

2 Proposed experiment

In the present Letter of Intent we suggest to replace the measurement of the Doppler broadening by a measurement of the Doppler shift, keeping in mind that a shift is easier to measure with high precision than a broadening which is subject to detector resolution, noise and other effects. We propose to

measure positron-proton coincidences and thus make a "differential" measurement. Like in the measurement presented above, the experimental set-up will be installed in a strong magnetic field, generated by the former WITCH magnet [10] at ISOLDE/CERN (see Fig. 2). The ^{32}Ar sample will be accumulated constantly in the centre of the magnet on a thin catcher foil where the decay takes place. The protons, only little affected by the magnetic field, will be detected on either side of the catcher foil in cooled high-resolution silicon detectors, whereas the positrons will be guided by the magnetic field through a hole in the proton detection system to thick silicon or scintillation detectors on either side of the catcher foil, behind the proton detectors. The positron detector on the entrance side of the beam will have a hole in its centre to let the beam pass through to reach the catcher foil.
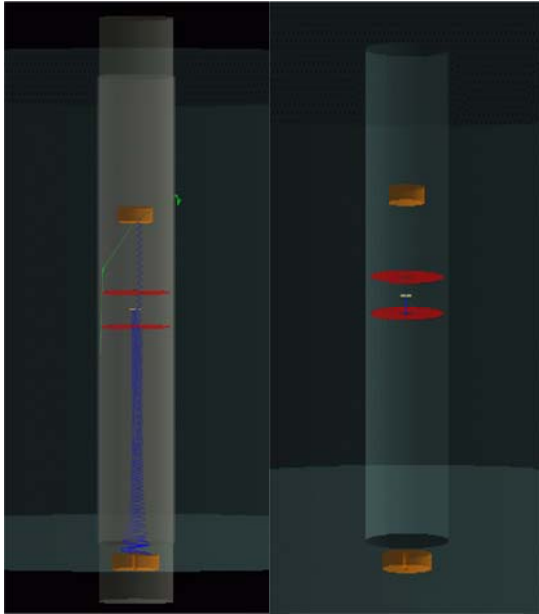

Fig. 2: The figure shows the graphics from a GEANT4 simulation with the vacuum tube, the catcher foil in the center, the proton detectors in red with a hole in the center to let pass the positrons spiraling along the magnetic field lines which go from top to bottom. The left-hand side shows a positron which is backscattered from the lower detector and finally stopped in the upper detector creating two 511 keV annihilation γ rays (in green). The right-hand side shows the proton (in blue) emitted also from the catcher.

The experiment will be installed at ISOLDE and reuse the WITCH superconducting magnet. Beams of ^{32}Ar are routinely produced at ISOLDE with intensities in excess of 500 ions per second. Therefore, several million protons from the IAS can be collected in a typical 5 days beam time. Simulations (see below) with the GEANT4 package indicate that, if a proton resolution below 10 keV can be reached, a new limit for $a_{\beta\nu}$ of the order of 0.1% is reachable. Such a measurement would thus be competitive with future LHC experiments where a similar precision is expected being reachable.

An additional interest of the present approach is that beyond the measurement just presented other measurements are possible with the same set-up. ^{32}Ar could be replaced with e.g. ^{20}Mg which has similar decay characteristics and allows therefore also for the determination of a possible scalar contribution in this Fermi decay. Gamow-Teller fed states could allow for the search for tensor currents with the same technique. Note that a similar project, but with a longer timescale, is being prepared at Texas A&M University (Dan Melconian et al.). There a Penning trap will be used to prepare the ^{32}Ar source. Further, a new β−ν correlation measurement with ^{38m}K, also aiming at 0.1% precision, is planned at TRIUMF (John Behr et al.). As all three experiments (will) use very different techniques leading to different systematic errors they will serve as a cross-check for each other.

The installation of this new experiment at ISOLDE was recently approved by the ISOLDE Collaboration Committee. As the previous experiments with ^{32}Ar and ^{38m}K still yield the best limits on fundamental scalar currents, it is expected that new, up to five times more precise new limits will be of prime importance and will contribute for quite some time to the constraints on physics beyond the

standard model. It is certainly also important to show that complementary approaches, like high-energy and low-energy experiments, are able to yield similar outcomes.

3 Simulation results

Monte-Carlo simulations are under way to demonstrate the feasibility of the present approach. Although our simulations are yet far from being complete, they indicate nonetheless that the goal of the present approach seems to be reachable. Fig. 3 shows a result from these simulations for a purely vector current and a purely scalar current. The difference between the two interactions is clearly evident. However, this demonstrates also that the energy resolution for the proton detectors will be crucial (less than 10 keV FWHM absolutely needed).
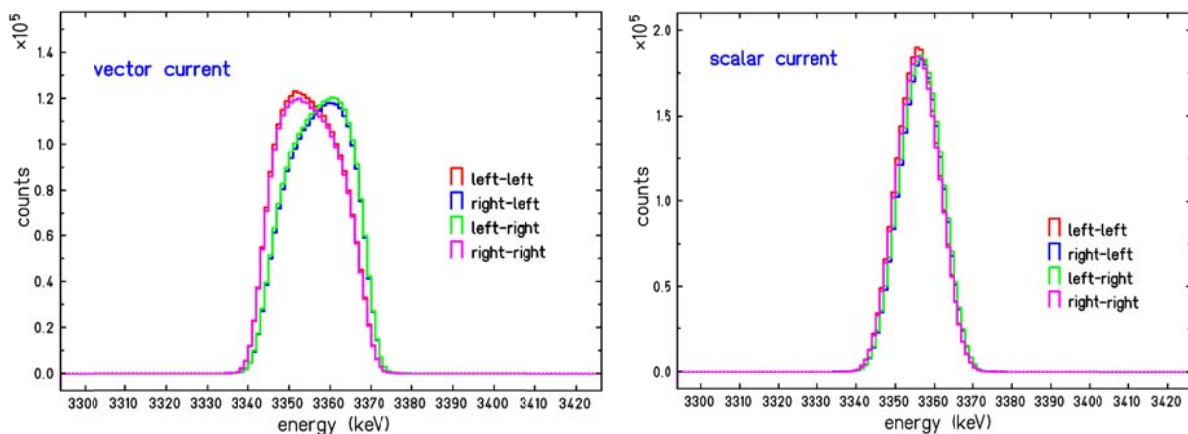

Fig. 3: MC simulations demonstrating the signal searched for. The vector current creates a Doppler effect on the proton energies, whereas for a scalar current there is basically no difference between the proton and the positron detected in the same hemisphere (left-left or right-right) and the two being observed in opposite hemispheres (left-right or right-left). In addition to the shift/deformation of the peak, the overall broader peak structure for the vector-type decay is visible. The narrower distribution of the scaler-type decay was used in past experiments to yield limits for this type of interaction. The proton peak stems from the decay of the isobaric analogue state in ^{32}Cl. The simulations were performed with a resolution of 5 keV (FWHM).

4 Time line of the project

We are in the process of preparing a grant request to the French ANR for funding of two young researchers and material to be installed in the superconducting magnet. Leuven has already hired a PhD student who will work permanently on the present project (to a large extent at ISOLDE) and will put in an additional funding request in next spring. If accepted the funding from both countries will start in September 2017.

The present Letter of Intent requests test beam time to

- test the beam tuning to WITCH/WISARD with a new control system to be put into place starting from January 2017 with stable beams
- perform first on-line tests with a preliminary set-up consisting of detectors already in our hands

With the funding requests hopefully accepted we can start purchasing new and tailor made detectors, electronics and extensions of the present WITCH data acquisition to envisage a first real run before the long shut-down end of 2018.

5 Beam time request

We would like to have **stable beam for two periods of 1 day each** to test the new control system and to optimise injection in the superconducting magnet. For this purpose a Faraday cup will be installed in the place of the catcher.

To test the ^{32}Ar production and its transport to WITCH/WISARD and to take first data for a proof-of-principle, we require **3 days of ^{32}Ar** beam. For the present LOI, the beam intensity is not very critical, but we expect about 300-500 pps.

Bibliography

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Appendix

DESCRIPTION OF THE PROPOSED EXPERIMENT

The experimental setup comprises: *WITCH/WISARD and beam line to it*

Part of the Choose an item.	Availability	Design and manufacturing
[if relevant, name fixed ISOLDE installation: COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WITCH]	☐ Existing	☐ To be used without any modification
		WITCH traps etc dismounted. Rest of equipment needs to be built

HAZARDS GENERATED BY THE EXPERIMENT

(if using fixed installation) Hazards named in the document relevant for the fixed WITCH installation.

Additional hazards:

Hazards	[Part 1 of the experiment/equipment]	[Part 2 of the experiment/equipment]	[Part 3 of the experiment/equipment]
Thermodynamic and fluidic			
Pressure	[pressure][Bar], [volume][l]		
Vacuum			
Temperature	[temperature] [K]		
Heat transfer			
Thermal properties of materials			
Cryogenic fluid			
Electrical and electromagnetic			
Electricity	Detector HV (≈200V)		
Static electricity			
Magnetic field	6 [T]		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)	32Ar		
Beam intensity	Several 10**2		
Beam energy	30 keV		
Cooling liquids	LN2, LHe		
Gases	[gas]		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☐ [ISO standard]		
• Isotope			
• Activity			

Use of activated material:			
• Description	☐		
• Dose rate on contact and in 10 cm distance	[dose][mSV]		
• Isotope			
• Activity			

Non-ionizing radiation

Laser			
UV light			
Microwaves (300MHz-30 GHz)			
Radiofrequency (1-300MHz)			

Chemical

Toxic	[chemical agent], [quantity]		
Harmful	[chemical agent], [quantity]		
CMR (carcinogens, mutagens and substances toxic to reproduction)	[chemical agent], [quantity]		
Corrosive	[chemical agent], [quantity]		
Irritant	[chemical agent], [quantity]		
Flammable	[chemical agent], [quantity]		
Oxidizing	[chemical agent], [quantity]		
Explosiveness	[chemical agent], [quantity]		
Asphyxiant	[chemical agent], [quantity]		
Dangerous for the environment	[chemical agent], [quantity]		

Mechanical

Physical impact or mechanical energy (moving parts)	[location]		
Mechanical properties (Sharp, rough, slippery)	[location]		
Vibration	[location]		
Vehicles and Means of Transport	[location]		

Noise

Frequency	[frequency],[Hz]		
Intensity			

Physical

Confined spaces	[location]		
High workplaces	[location]		
Access to high workplaces	[location]		
Obstructions in passageways	[location]		
Manual handling	[location]		
Poor ergonomics	[location]		

Hazard identification