PROCEEDINGS OF SCIENCE

WISArD : Weak Interaction Studies with ^{32}Ar Decay

P. Alfaurt,[a] P. Ascher,[a] D. Atanasov,[a] B. Blank,[a] F. Cresto,[b] L. Daudin,[a] X. Fléchard,[b] M. Gerbaux,[a] J. Giovinazzo,[a] S. Grévy,[a] T. Kurtukian-Nieto,[a] E. Liénard,[b] M. Pomorski,[a] N. Severijns,[c] S. Vanlangendonck,[c] M. Versteegen[a,*] and D. Zakoucky[d]

[a] *CENBG-IN2P3-CNRS, Université de Bordeaux Gradignan, France*
[b] *Normandie Univ., ENSICAEN, UNICAEN, CNRS-IN2P3, LPC Caen, Caen, France*
[c] *KU Leuven, Instituut voor Kern- en Stralingsfysica, Leuven, Belgium*
[c] *Nuclear Physics Institute, Acad. Sci. Czech Rep. Řež, Czech Republic*

E-mail: maud.versteegen@cenbg.in2p3.fr

The WISArD experiment is probing the possible existence of exotic currents in the electroweak sector using nuclear β decay, to improve the constraints on beyond Standard Model physics. The setup of the experiment underwent a full upgrade between 2018 and 2021 in preparation of a second run of data taking at ISOLDE, CERN, scheduled for October 2021. The detector stage was completely renewed to improve statistics and minimize the main systematic effects identified in a proof-of-principle run in 2018. With this upgrade, the objective is to reach the per-mil level of uncertainty on the angular correlation coefficent a and on the Fierz interference term b, in a pure Fermi transition. In this case, both parameters are directly sensitive to the possible contribution of exotic scalar currents.

**** Particles and Nuclei International Conference - PANIC2021 ****
**** 5 - 10 September, 2021 ****
**** Online ****

*Speaker

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

https://pos.sissa.it/

PoS(PANIC2021)449

1. Introduction

The weak interaction is very robustly described within the Standard Model (SM) by the "V-A" theory. In this framework, only 2 of the 5 possible Lorentz invariant currents are used to describe weak couplings: the vector and axial-vector currents. The corresponding coupling constants are $C_V \equiv 1$ and $C_A \simeq -1.27$. This restriction is based on experimental observations but not on any theoretical ground. The coupling constants for the 3 remaining currents, namely the scalar, tensor and pseudo-scalar types, are supposed equal to zero. Despite its many successes [1], it is well established that the Standard Model still leaves open questions, such as the description of dark matter, the matter-antimatter asymmetry or the origin of CP violation. The search for physics Beyond the Standard Model (BSM) is thus actively pursued, either directly at LHC by searching for new particles at the high energy frontier, or at the precision frontier by searching for deviations from SM predictions. The WISArD experiment belongs to the latter category. Using β-decay, the aim of WISArD is to probe the possible existence of exotic scalar or tensor currents.

2. Nuclear Recoil Measurement with β-delayed proton emitter ^{32}Ar

Nuclear β-decay is a powerful tool to test the SM in the electroweak sector [2, 3]. In particular, exotic currents can be probed in the decay of non polarized nuclei. In this case, the decay rate can be written as [4]:

$$dW = dW_0 \left(1 + a\,\frac{\mathbf{p}_e \mathbf{p}_\nu}{E_e E_\nu} + b\,\frac{m_e}{E_e}\right)$$

where dW_0 is the phase space factor and the Fermi function; E_e, E_ν, $\mathbf{p}_e$ and $\mathbf{p}_\nu$ are the energy and momenta of the β particle and the neutrino respectively; m_e is the rest mass of the β particle; a is the angular correlation coefficient between the two leptons and b is the Fierz interference term. The two latter parameters are directly sensitive to scalar currents in the case of a pure Fermi transition, which corresponds to $\Delta J = 0$ and no parity change between the initial and final state in the parent and daughter nuclei respectively. They are expressed as:

$$a_F \cong 1 - \frac{|C_S|^2 + |C'_S|^2}{|C_V|^2} \qquad b_F \approx \pm\mathrm{Re}\left(\frac{C_S + C'_S}{C_V}\right)$$

In the SM, $a = 1$ and $b = 0$. The β particle and the neutrino are preferentially emitted in the same direction, the nuclear recoil being maximal. In the event of BSM physics, a is expected to deviate from 1 and b from 0.

The a and b coefficients can be accessed from a measurement of the daughter nucleus recoil, which is of the order of a few keV at the most. One of the best results to date was obtained using the β-delayed proton emitter ^{32}Ar [5]. The β Fermi transition from ^{32}Ar to the Isobaric Analog State (IAS) of ^{32}Cl is followed by the proton emission of ^{32}Cl to ^{31}S almost instantaneously, as the IAS width is of the order of 20 eV [6]. The proton is emitted in flight and a kinematic effect is expected in the proton energy spectrum. In the WISArD experiment, the sensitivity to this effect is maximized by selecting the protons emitted in the same or the opposite direction to the β particle. These events correspond to the nucleus moving either away or towards the proton detectors. A kinematic shift directly proportional to a_F and b_F is then expected in the proton detector plane.

PoS(PANIC2021)449

A proof-of-principle experiment was mounted and took data at ISOLDE, CERN, in November 2018 [7]. The detection set-up consisted of two proton detector planes, each containing four 300 μm thick silicon detector disks 30 mm in diameter and one β detector, composed of a cylindrical plastic scintillator 2 cm in diameter and 5 cm in length, coupled to a 6×6 mm^2 silicon photomultiplier from Hamamatsu (S13360-6050PE). The 30 keV ^{32}Ar beam delivered by ISOLDE was stopped in a thin mylar catcher foil at the center of the setup. The whole detection stage was placed in a 4 T magnetic field to guide the β particle emitted in the upper hemisphere to the scintillator with a 100% efficiency. The measured kinematic shift between the energy of the proton singles and the protons in coincidence with the β particle for the Fermi transition was $\Delta E_F = 4.49(3)$ keV, which is the 3rd most precise measurement on the combined coefficient of a_F and b_F: $\tilde{a}_F = 1.007(32)_{\text{stat}}(25)_{\text{syst}}$. It is worth noticing that ^{32}Ar also gives access to Gamow-Teller β transitions, which simultaneously allows the search for tensor current contributions. Figure 1 presents the constraints on scalar couplings, comparing the WISArD proof-of-principle result with previous experiments with ^{32}Ar and ^{38m}K [5, 8]. In addition, a full account of all major sources of systematic uncertainties was drawn, showing that the position of the beam implantation in the catcher foil, the energy calibration and the dead layer of the silicon detectors as well as the effect of β backscattering in the catcher and at the entrance of the plastic scintillator are the major contributions. The detection set-up was fully upgraded between 2018 and 2021 to tackle these particular points and aim for the per-mil uncertainty level.

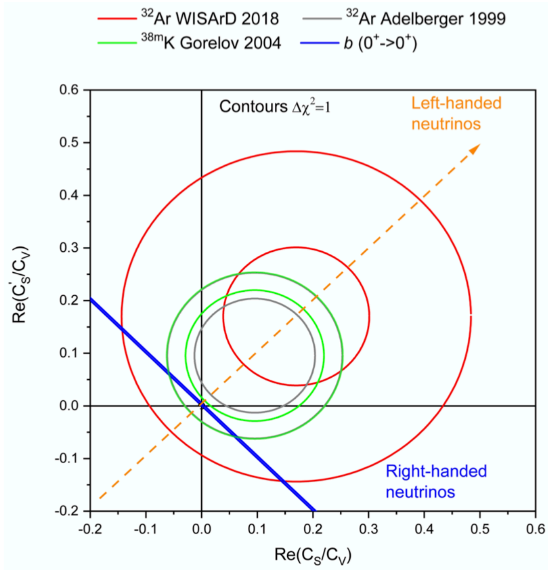


Figure 1: Present constraint on scalar currents from β decay of ^{32}Ar (red and grey) and ^{38m}K (green) as well as pure Fermi $0^+ \to 0^+$ transitions (blue).

3. Upgrade of the WISArD setup

Figure 2 shows the upgraded detection setup. The 8 new silicon proton detectors are trapezoidal to form 2 detection caps symmetrical with respect to the catcher foil, covering a 40% solid angle. The detectors are actively cooled to reach 10-15 keV resolution FWHM at 3 MeV. A dedicated measurement was performed with 700 keV monoenergetic alpha particles from the AIFIRA accelerator [9] to determine their dead layer, which was found to be of the order of 60 nm. With this new design, the statistics is optimised and the systematic effects due to the detectors' energy resolution and dead layer are minimized.

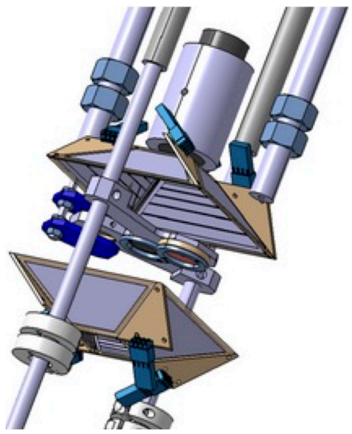
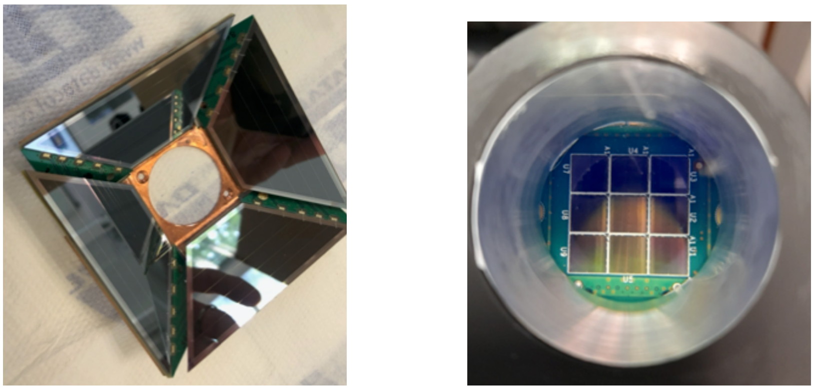


Figure 2: WISArD detection setup upgrade.

PoS(PANIC2021)449



(a) Proton detector cap **(b)** β detector

Figure 3: Upgraded detectors for the second run of data taking with ^{32}Ar in October 2021.

The beta detector was also adapted to lower the detection threshold as much as possible and minimize the impact of undetected backscattered β particles. The plastic scintillator diameter was increased from 2 to 3 cm, and an array of nine 6×6 mm^2 SiPM (J-Series from ON Semiconductor) is used to collect the light output. Using two different preamplifier gains for each SiPM signal allows us both to access the complete β spectrum and zoom in on the detection threshold to precisely characterize it. Dedicated measurements with monoenergetic electrons [10] showed that the low gain was about 210 mV for 1 MeV electrons, and a factor of 10 higher for the high gain. The catcher thickness will also be reduced to 500 nm to minimize backscattering within the foil. Figure 3 shows the four trapezoidal silicon detectors of the proton detector and the array of nine SiPM of the beta detector.

The horizontal and vertical beamlines include several electrostatic kickers, steerers, benders, drift tubes, and einzel lenses to transport the beam to the set-up. Dedicated transmission studies of the beam line transport were performed [11], showing that a 90% transmission could be reached with the proper high voltages applied to the beam optics. If reached during experiment, it would increase statistics by a factor of 8 with respect to the proof-of-principle experiment, where the high voltage modules were not adapted to the beam kinetic energy of 30 keV.

The beam implantation profile was identified as a the third major source of systematics. A dedicated position sensitive detector is under development to characterize the ^{32}Ar source position, size and shape. Based on F1551-01 MCP detectors from Hamamatsu, its resolution was shown to be well below 1 mm during tests with an ^{241}Am α source. This detector will be placed at the position of the catcher for dedicated characterization runs.

4. Conclusion

The WISArD experiment, installed at ISOLDE, CERN, aims to lower the constraint on BSM physics in the electroweak sector, by probing the existence of exotic scalar currents in nuclear β decay down to the per-mil level of uncertainty. The angular correlation coefficient a and the Fierz interference term b, which are directly sensitive to the scalar coupling constant, are accessed using

PoS(PANIC2021)449

the β-delayed proton emitter ^{32}Ar. The daughter nucleus recoil due to the emission of the two leptons is deduced from the kinematic shift of the protons with or without β particle coincidence.

A proof-of-principle experiment successfully validated the measurement principle. The result is compatible with the SM and is the 3rd most precise result on $\tilde{a}_F$ for a pure Fermi β transition. A full account of all major sources of systematic errors was drawn. These have been tackled in a complete upgrade of the set-up to reach the per-mil level of uncertainty in a second run scheduled in October 2021. The proton and beta detectors were modified to increase resolution, reduce dead layer and decrease detection threshold. A new position sensitive detector was developed to characterize the beam spot position, size and shape. The detection solide angle and the beam line transmission were optimized to increase statistics.

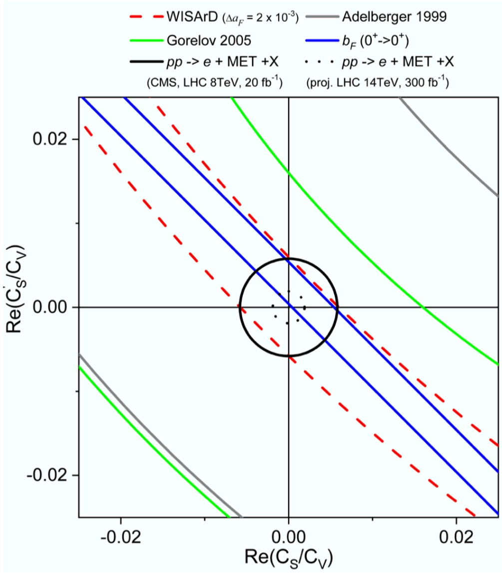


Figure 4: Expected new constraints on scalar currents with WISArD second run, compared to future direct search of BSM physics at LHC.

Figure 4 shows the expected constraints for the second run of WISArD. Six days of ^{32}Ar beam time have been accepted by the ISOLDE PAC, together with 0.5 days of ^{33}Ar for calibration of the proton detectors and 1.5 days of stable beam for beam line tuning. To reach the expected uncertainty of 0.2% and be competitive with future search at LHC, 3×10^7 $\beta - p$ correlated events must be accumulated.

References

[1] Particle Data Group, P.A. Zyla et al, Prog Theor Exp Phys, 2020, 8, 083C01 (2020)

[2] M. Gonzalez-Alonso et al, Prog. Part. Nucl. Phys. 104, 165 (2019)

[3] A. Falkowski et al., JHEP 04 126, (2021)

[4] Jackson, J. D., S. B. Treiman, and H. W. Wyld, Jr., Phys. Rev. 106, 517)1957)

[5] E.G. Adelberger at al, Phys. Rev. Lett. 83 1299 (1999)

[6] A. Garcìa et al, Hyperfine Int. 129, 237-248 (2000)

[7] V. Auraujo-Escalona et al., Phys. Rev. C, 101, 055501 (2020)

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

[9] P. Barberet et al, Eur. Phys. J. Plus 136, 67 (2021)

[10] C. Marquet et al, J. Inst. 10, 09, (2015)

[11] Lukas Nies, CERN-STUDENTS-Note-2018-155

PoS(PANIC2021)449