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Addendum to Proposal IS678
for the ISOLDE and Neutron Time-of-Flight Committee

Weak interaction studies via beta-delayed proton emission

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Abstract:
We propose to perform simultaneous measurements of the β-ν angular correlation coefficient ($a_{\beta\nu}$) and the Fierz interference term (b) for pure Fermi and pure Gamow-Teller transitions from ^{32}Ar using the kinematic shift technique. The proposal follows the successful proof-of-principle experiment in 2018 and a new test performed in October 2021.
The 2018 experiment allowed us to investigate statistical and systematic effects influencing the level of precision of the technique. We demonstrated its applicability by obtaining the third most precise value of $a^F_{\beta\nu} = 1.007(32)_{stat}(25)_{sys}$ for the pure Fermi transition with only 1.5 days of beam time.
The 2021 run with about 10 shifts allowed testing the completely newly designed mechanical setup, the new silicon and plastic-scintillator+SiPM detectors and the partly new data acquisition and control system. These new data should allow for an improved experimental result with a factor of 2 to 3 higher statistical sensitivity. Improvements for the systematic uncertainties still have to be evaluated. The data analysis is presently on-going.
The purpose of the present request is to obtain again the 10 shifts used in the 2021 test run to dispose again of the full beam time for a run in 2022.

Requested shifts: 10 shifts (to be added to the 14 remaining shifts)

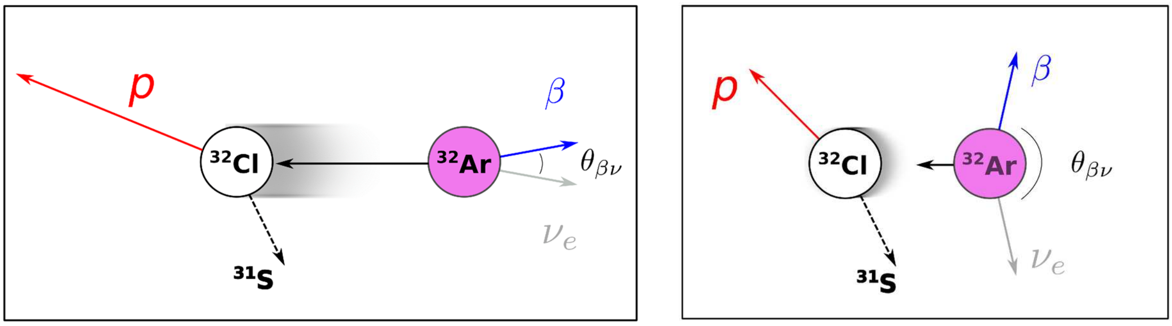
1. Motivation

The search for new physics in the electroweak sector of the Standard Model (SM) continues in many forms despite its remarkable success [1,2]. Precision beta decay experiments are ideal tools to study the existence of new gauge bosons in a way that is complementary to high-energy experiments, e.g. at LHC. The minimal description of beta decay contains only vector (V) and axial-vector (A) currents. But the full form of the beta-decay Hamiltonian allows other Lorentz invariant current contributions, such as scalar (S) and tensor (T). The present experimental limits on these coupling constants are derived from correlation and neutron life-time measurement that are known to the 0.65% level for pure Fermi transitions and 0.91% for Gamow-Teller transitions [1,2]. This level of precision does not allow one to completely rule out exotic currents and still permits sizable contributions to be accommodated without affecting the phenomenological conclusions for the weak interaction.

The SM value of the beta-neutrino angular correlation coefficient ($a_{\beta\nu}$) for the V-A structure of the weak interaction is $a_{\beta\nu}= 1$ for pure Fermi decays and $a_{\beta\nu} = -1/3$ for pure Gamow-Teller decays. The values of the Fierz interference term in both transitions is $b = 0$. Any admixtures of S or T currents to the dominant V and A currents would result in a measurable deviation from the SM value for b and/or $a_{\beta\nu}$.

2. Experimental technique and measurements

If the daughter nucleus is unstable and subject to particle emission (β-delayed), its momentum can be determined by the kinematics of the decay products [3]. When a light energetic particle is emitted from a moving source (i.e. the recoiling daughter nucleus), its energy will be subject to a kinematic shift that reflects the motion of the moving source. Thus, one can study the energy spectrum of subsequently emitted beta-delayed particles, instead of the slow heavy nuclei. One such example is the decay of ^{32}Ar, where in Fig.1 a schematic representation of the V- and S-type kinematics is shown. Applying the kinematic shift technique in the case of ^{32}Ar requires the detection of coincidences between (i) the beta-delayed proton emitted by the recoiling ^{32}Cl daughter nucleus and (ii) the preceding positron.



(a) Vector interaction (b) Scalar interaction

Figure 1: Schematic representation of the decay kinematics of a pure Fermi transition and its influence on the beta-delayed proton energy. The maximum emission probability occurs at $\theta_{\beta\nu} = 0°$ corresponding to the dominant Vector interaction, while for a Scalar contribution the maximum occurs at $\theta_{\beta\nu} = 180°$.

An outcome of the coincidence requirement is the ability to study the energy shift of the completely observed proton spectrum, rather than focusing on a single transition, thus, allowing the simultaneous determination of the correlation coefficient in pure Fermi and pure Gamow-Teller transitions. The simultaneous measurement of $a_{\beta\nu}$ and the Fierz term b for the GT transitions in our experiment will be used as a systematic check of the validity of the analysis. One important advantage of this technique when compared to more traditional measurements based on broadening effects [4] comes from the less crucial knowledge of the properties of the charged-particle detectors: the proton energy shift between proton-positron coincidence events and singles proton events are independent, at first order, to the detector response function.

After the successful proof-of-principle experiment of 2018 [5], we performed, in October 2021, a test experiment to validate the most crucial upgrades to the apparatus as compared to the proof-of-principle experiment in 2018. The beam-transport efficiency from REXTRAP to our setup improved from about 15% in 2018 to close to 90% in 2021. This includes the work done on setting-up REXTRAP in continuous mode. By using a non-flat trapping potential, we observed a stable and easy to handle ion beam with respect to beam transport leading to the improved efficiency through our beamline.

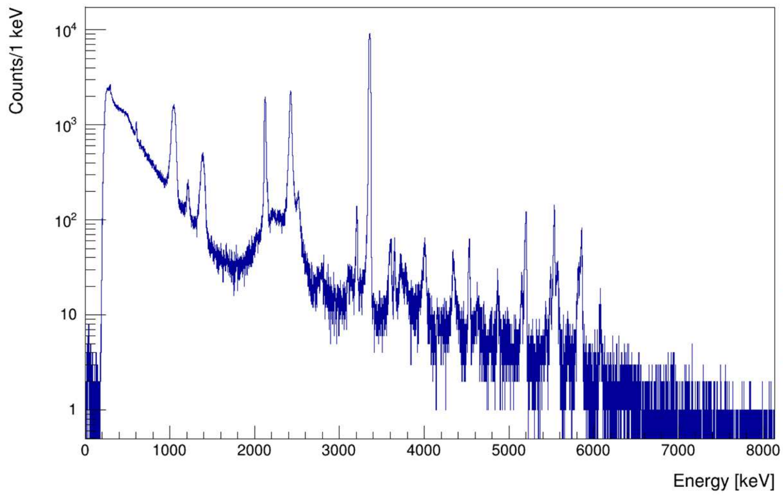


Figure 2: ^{32}Ar decay proton spectrum as acquired during the 2021 test run from one silicon detector (all five strips, all runs). The resolution obtained was 19 keV (FWHM).

The new silicon detectors have been tested with a 700 keV alpha beam of at the AIFIRA accelerator of CENBG. The energy resolution achieved was 10 keV (FWHM) compared to about 35 keV for the 2018 experiment improving the sensitivity of the experiment by a factor of 2.1. We note that we reached a resolution of less than 20 keV (FWHM) only for part of the silicon detectors in the 2021 test due to a lack of testing time. The spectrum acquired with one silicon detector is shown in Figure 2. The new proton detection covers a solid angle of about 40% improving the angular coverage by a factor of 5. Finally, the new positron detection system consists now of a 3 cm in diameter and 5 cm long plastic scintillator coupled to a matrix of nine silicon photomultipliers (SiPM, 6x6mm^2 each). Each signal of the SiPM pixel is fed in a low-gain and a high-gain preamplifier (nine high- and nine low-gains in total) to cover, on the one hand, the full beta-energy spectrum up to 10 MeV and, on the other hand, to lower the detection threshold to less than 10 keV.

Furthermore, in the 2021 test, we performed measurements with two catcher foils, a 0.8 μm Al foil and a 6 μm Mylar foil in order to evaluate the influence of the catcher in terms of positron backscattering.

3. Beam time request

Presently, some additional improvements with respect to those achieved before the 2021 run discussed above are being implemented. With these improvements and the test measurements performed in October 2021, we believe we are now ready to perform the full experiment and reach a precision on $a_{\beta\nu}$ and b of the order of 0.1-0.2%, as anticipated in the original proposal. We therefore ask for 10 shifts, the number of shifts used in the 2021 test.

Summary of requested additional shifts: 10 shifts added to the remaining 14 shifts in 1 run during 2022.

References

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[3] E.T.H. Clifford et al., Nucl. Phys. A493, 293 (1989)
[4] E. G. Adelberger et al., Phys. Rev. Lett. 83, 1299 (1999)
[5] V. Araujo-Escalona et al., Phys. Rev. C 101, 055501 (2020)

Appendix

Description of the proposed experiment

The experimental setup comprises: WISArD

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 WISArD]	☒ Existing	☒ To be used without any modification
		WISArD beam line and setup

Hazards generated by the experiment

(if using fixed installation) Hazards named in the document relevant for the fixed [COLLAPS, CRIS, ISOLTRAP, MINIBALL + only CD, MINIBALL + T-REX, NICOLE, SSP-GLM chamber, SSP-GHM chamber, or WISArD] 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	[fluid], [pressure][Bar], [volume][l]		
Electrical and electromagnetic			
Electricity	[voltage] [V], [current][A]		
Static electricity			
Magnetic field	6 T		
Batteries	☐		
Capacitors	☐		
Ionizing radiation			
Target material	[material]		
Beam particle type (e, p, ions, etc)	32,33Ar		
Beam intensity	< 10000 pps		
Beam energy	30 keV		
Cooling liquids	LHe, LN2		
Gases	He, N2		
Calibration sources:	☐		
• Open source	☐		
• Sealed source	☒		
• Isotope	90Sr, 207Bi,	4-alpha source	
• Activity	< 20 kBq	< 10 kBq	

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]		

0.1 Hazard identification

3.2 Average electrical power requirements (excluding fixed ISOLDE-installation mentioned above): *(make a rough estimate of the total power consumption of the additional equipment used in the experiment)*

none