Weak interaction studies with ^{32}Ar decay (WISArD)

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The WISArD experiment has been set up at CERN-ISOLDE to investigate fundamental symmetries of the weak interaction, focussing on the β-ν angular correlation coefficient of ^{32}Ar by looking at β-delayed protons emitted from the daughter nucleus ^{32}Cl. As the protons are emitted from the recoiling ^{32}Cl, their MeV-level energy distribution is Doppler-broadened by up to ±15 keV. With a suitable arrangement of detectors, this effect can lead to a kinematic shift which is sensitive to weak currents that are beyond the standard model. In particular, protons from the isobaric analogue state fed by a Fermi-type β decay allow searching for a small contribution of a potential scalar current to the dominant vector current, whereas protons from Gamow-Teller-type β decays allow searching for tensor contributions to the dominant axial-vector current. The WISArD experiment aims for a sensitivity limit of 0.1% for these exotic currents. This approach has been demonstrated recently in a proof-of-principle measurement published in Ref. [1]. This research program is extremely similar to the TAMUTRAP program [2], but as described below (Fig. 1), it is a simpler system (it doesn't involve ion trapping) and

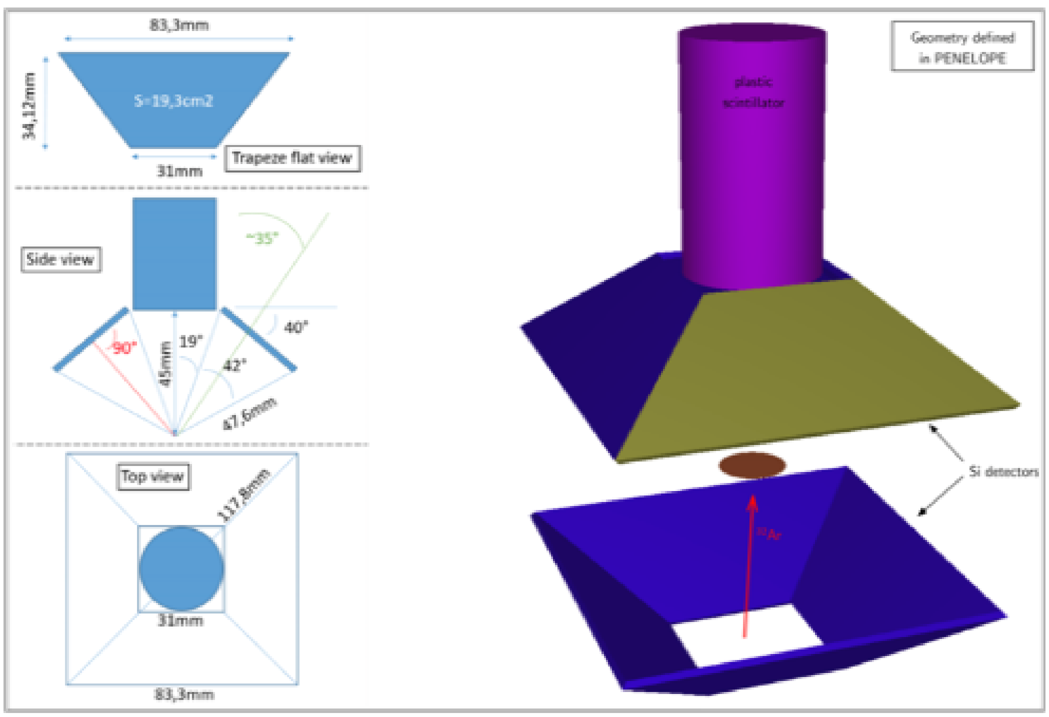

Fig. 1. Experimental setup of the WISArD experiment at CERN-ISOLDE. The right panel shows our implementation of the geometry in PENELOPE. The ^{32}Ar beam will be implanted in the catcher foil. The plastic scintillator will tag βs in coincidence with delayed protons in the upper vs. lower panel of Si detectors to measure the kinematic shift.

the beam is readily available at ISOLDE unlike at the Cyclotron Institute. Thus we have joined the WISArD collaboration out of shared interests and expertise, and expect many from this collaboration will join us in our effort at TAMUTRAP once LSTAR is commissioned and we have radioactive ion beams.

Our specific contribution to the WISArD collaboration is an independent analysis of the upcoming experiment using the PENetration and Energy Loss of Positrons and Electrons (PENELOPE) Monte Carlo program [3] to complement that of our collaborators using GEANT4. Most popular and well-known MC codes currently available (e.g. GEANT4 and EGS5) use multiple-scattering theories to allow the simulation of the global effect of a large number of interactions in a track segment of a given length or step size. These "condensed" simulation algorithms are only approximate and may lead to systematic errors, particularly if the user is not careful about setting an appropriately small step length; even if care is taken, these condensed MCs have difficulties in generating particle tracks in the vicinity of an interface. PENELOPE by contrast[1] is based on a mixed procedure to overcome the potential pitfalls of condensed MCs: soft interactions are simulated using multiple-scattering theories while hard interactions are seamlessly integrated and simulated in detail. Electrons and postirons are strongly susceptible to (back)scattering which is invariably a large concern when estimating systematic uncertainties in precision (<0.1%) β-decay measurements. Thus having a completely independent analysis of the WISArD experiment is extremely important.

Prior to taking ^{32}Ar data for the physics measurement, the collaboration is planning to characterize the low-energy response of the plastic scintillator with a monoenergetic 30-keV electron source. This is important to understand our low-energy threshold of the detector. We have simulated this simple system in PENELOPE, and the comparison to the complementary simulation by our collaborators using GEANT4 (see Fig. 2). Even though the "PENELOPE" package was used in GEANT4, significant differences in the response function are clearly evident. We will compare both simulations to data once the characterization is completed and benchmark both MCs. Presently, we are completing the detailed geometry definitions in PENELOPE for the upcoming experiment which is tentatively scheduled at ISOLDE this fall; our participation is strongly dependent on travel restrictions due to COVID-19. We are also implementing the detailed *R*-matrix calculations of the *β*-delayed proton decay for a complete theoretical description including interferences; this *R*-matrix calculation will be the basis for the initial *β* and proton momenta input to both MCs.

[1] Note that though there is a "PENELOPE" package in GEANT4, the basic tracking algorithms are unchanged and so it is not at all the same as the true PENELOPE MC program.

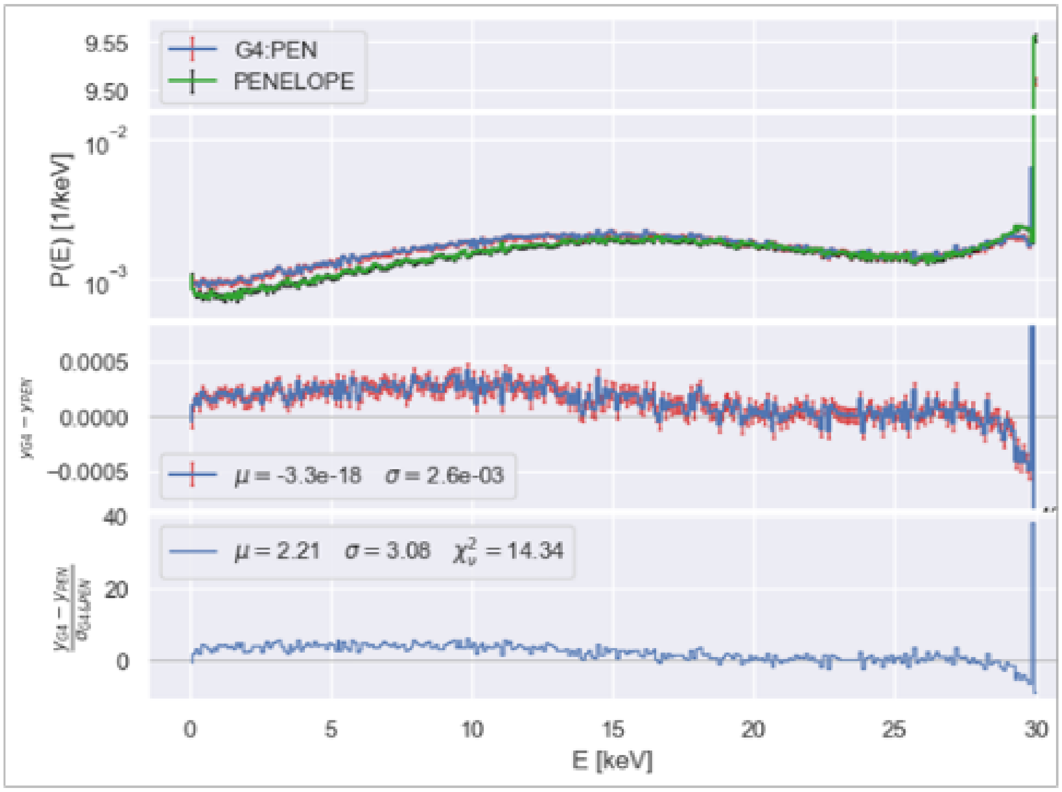

Fig. 2. Comparison of PENELOPE and GEANT4's "PENELOPE" package in a simple geometry: Monoenergetic 30-keV electrons are collimated by a stainless steel aperature and deposited in a plastic scintillator. Note that even in this very basic case, significant differences in the simulated response function are seen.

[1] V. Araujo-Escalona *et al.*, Phys. Rev. C **101**, 055501 (2020).

[2] P.D. Shidling *et al.*, Int. J. Mass Spectrom **468**, 116636 (2021).

[3] F. Salvat, NEA (2019) Workshop Proceedings, Barcelona, Spain (January 2019), OECD Publishing, Paris, https://doi.org/10.1787/32da5043-en (ISBN 9789264489950).