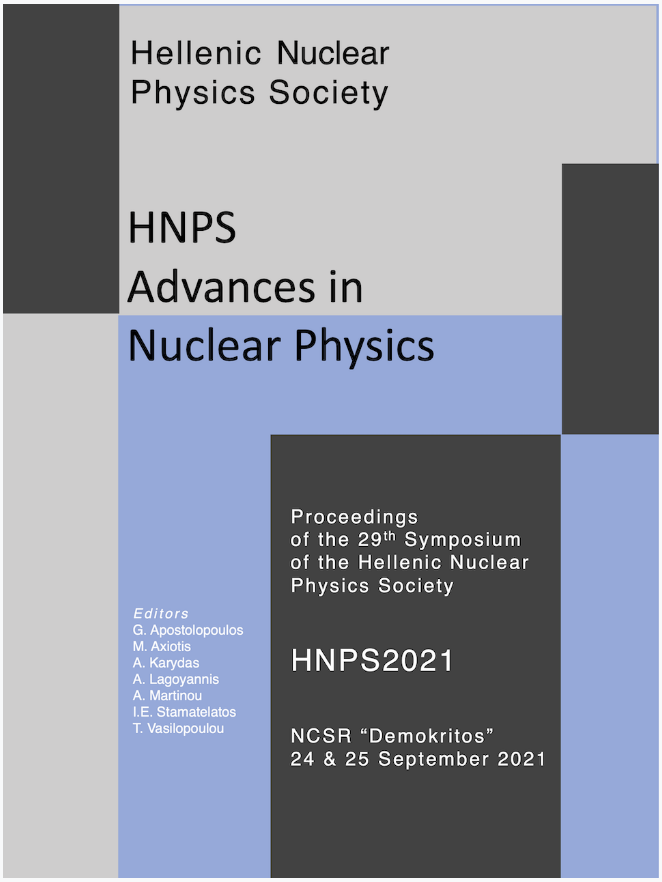
**HNPS Advances in Nuclear Physics**

Vol 28 (2021)

HNPS2021



Hellenic Nuclear Physics Society

HNPS Advances in Nuclear Physics

Editors
G. Apostolopoulos
M. Axiotis
A. Karydas
A. Lagoyannis
A. Martinou
I.E. Stamatelatos
T. Vasilopoulou

Proceedings of the 29th Symposium of the Hellenic Nuclear Physics Society

HNPS2021

NCSR "Demokritos"
24 & 25 September 2021

# Coherent elastic neutrino-nucleus scattering (CEvNS) event rates for Ge, Zn and Si detector materials

*T.S. Kosmas, V.K.B. Kota, D.K. Papoulias, R. Sahu*

doi: 10.12681/hnps.4799

**To cite this article:**

Kosmas, T., Kota, V., Papoulias, D., & Sahu, R. (2022). Coherent elastic neutrino-nucleus scattering (CEvNS) event rates for Ge, Zn and Si detector materials. *HNPS Advances in Nuclear Physics*, *28*, 261–264. https://doi.org/10.12681/hnps.4799

# Coherent elastic neutrino-nucleus scattering (CEνNS) event rates for Ge, Zn and Si detector materials

T.S. Kosmas[1], V.K.B. Kota[2], D.K. Papoulias[1], R. Sahu[3]

[1] *Division of Theoretical Physics, University of Ioannina, GR 45110 Ioannina, Greece*
[2] *Physical Research Laboratory, Ahmedabad 380 009, India*
[3] *National Institute of Science and Technology, Palur Hills, Berhampur 761 008, Odisha, India*

**Abstract** Realistic nuclear structure calculations are presented for the event rates due to coherent elastic neutrino-nucleus scattering (CEνNS), assuming neutrinos from pion-decay at-rest, from nuclear reactors and from Earth's interior. We focus on the currently interesting Germanium isotopes, $^{70,73,76}$Ge, which constitute detector materials of the recently planned CEνNS experiments. We study in addition the potential use of $^{64,70}$Zn and $^{28}$Si isotopes as promising CEνNS detectors. From nuclear physics perspectives, recently, calculations have been carried out within the framework of the deformed shell-model (DSM), based on realistic nuclear forces, and assessed on the reproducibility of spectroscopic nuclear properties. The high confidence level acquired by their agreement with experimental results and by their comparison with other mostly phenomenological calculations encouraged the use of DSM to extract predictions for the CEνNS event rates of the above isotopes. Our detailed estimation of the nuclear physics aspects of the recently observed neutral current coherent neutrino-nucleus scattering may shed light on unravelling the still remaining uncertainties for the CEνNS process within and beyond the Standard Model.

**Keywords** neutrino-nucleus scattering, reactor neutrinos, pion decay at rest, nonstandard interactions

## INTRODUCTION

The detection signal of coherent elastic neutrino-nucleus scattering (CEνNS), i.e., the low-energy recoil of the target nucleus, is an experimental challenge while the uncertainties associated with the relevant measurements should be minimized and the accuracy of CEνNS experimental method must be improved. Theoretically, it was known that roughly speaking the CEνNS cross section has a quadratic dependence on the neutron number of the target nucleus ($\propto N^2$) which is attributed to the different strength of the respective couplings with which the protons and the neutrons of the atomic nuclei interact with the intermediate Z-boson [1]. The ground-state to ground-state transition channel, which is possible in neutral current neutrino-nucleus scattering, appears enhanced due to the fact that the proton and neutron amplitude phases corresponding to a neutrino scattering off nucleons are added coherently, and dominates the process at low energies [2]. On the other hand, the incoherent scattering cross sections are much smaller and demonstrate some well pronounced peaks of specific multipole excitations [3]. Such detailed calculations have been performed previously for various nuclear isotopes.

Over the years, the Deformed Shell Model (DSM) based on Hartree-Fock states with angular momentum projection and band mixing has been found to be quite successful in describing several nuclear properties like spectroscopic properties including spectroscopy of $N = Z$ odd-odd nuclei with isospin projection, the coherent and incoherent $\mu \rightarrow e$ conversion in the field of nuclei and double beta decay half-lives [4]. Recently, we have calculated event rates for weakly interacting massive particle (WIMP) scattering off $^{73}$Ge and elastic and inelastic scattering of neutrinos and WIMPs on nuclei. Our aim in this work is to provide reliable theoretical predictions for event rates of neutrino-nucleus scattering involving $^{70,73,76}$Ge, $^{64,70}$Zn and $^{28}$Si isotopes by using DSM for the nuclear structure functions needed for the event rates calculations. Motivated by the various experimental facilities, first, we focus on pion-decay at-rest (π-DAR) and reactor antineutrino sources. We furthermore consider Geoneutrinos, which are expected to contribute significantly to the overall neutrino background signal at the next generation large scale detectors planned to look for light WIMPs [6].

## BASIC FORMALISM

Neutrinos with energies below some tens of MeV predominately conserve the integrity of nucleons in neutrino-quark interactions with Z-boson exchange, allowing us to consider the CEνNS process using an effective neutrino nucleon interaction in which the nucleon current is a sum of vector and axial currents. The differential CEνNS cross section with respect to the nuclear recoil energy $T_A$ (the axial vector contributions is neglected in this work) reads

$$\frac{\mathrm{d}\sigma}{\mathrm{d}T_A} = \frac{G_F^2 m_A}{2\pi} \mathcal{Q}_W^2 \left(2 - \frac{m_A T_A}{E_\nu^2}\right) , \tag{1}$$

where $G_F$ is the Fermi's constant, $E_\nu$ the incoming neutrino energy while $Z$ and $N = A - Z$ denote the number of protons and neutrons, respectively. The vector weak charge, $Q_W$, encapsulates the information from the nuclear structure and is written in terms of the proton and neutron form factors $F_{p,n}(q^2)$ as

$$\mathcal{Q}_W = g_p^V Z F_p(q^2) + g_n^V N F_n(q^2) , \tag{2}$$

where the proton and neutron couplings are expressed as $g^V_p = 1/2 - 2 \sin^2 \theta_W$ and $g^V_n = -1/2$, respectively, and $q = (2\, m_A\, T_A)^{1/2}$ denotes the magnitude of the 3-momentum transfer. For the low energies involved in CEνNS, our calculations consider the low energy limit of the weak mixing angle running, hence we assume $\sin^2 \theta_W = 0.2381$.

The details of the deformed shell model have been described in our earlier publications (for details see [3,4]). In this model, for a given nucleus, starting with a model space consisting of a given set of spherical single particle (sp) orbitals with single particle energies (spe) and an effective two-body interaction specified by its two body matrix elements (TBME), the lowest energy intrinsic states are obtained by solving the HF single particle equation self-consistently. We assume axial symmetry, while excited intrinsic configurations are obtained by making particle-hole excitations over the lowest intrinsic state. Since the intrinsic states do not have definite angular momenta, states of good angular momentum are projected from the latter. However, it is worth noting that the good angular momentum states, projected from different intrinsic states, are not in general orthogonal to each other. Hence, they are orthonormalized and then band mixing calculations are performed.

## RESULTS AND DISCUSSION

We are interested in quantifying the percentage difference on the number of events calculated using our nuclear structure DSM calculations or involving effective form factor approximations. As a benchmark test case, we consider the Klein-Nystrand form factor approximation that has been recently adopted by the COHERENT Collaboration. We illustrate the difference between by evaluating the quantity $R=|R_{DSM}-R_{KN}|/R_{DSM}$ and our corresponding results are shown in Fig. 1. As can be seen, reactor neutrino experiments looking for CEνNS will not suffer from nuclear structure uncertainties, even at the sub-percentage level. On the other hand, for the case of π-DAR neutrinos which involve larger values of the momentum transfer, $R$ can be as high as 8% for $^{64}$Zn and $^{76}$Ge. We finally note that here we do not present the corresponding results for Geoneutrinos since the signal uncertainty will be dominated by the flux uncertainties, while also the momentum transfer is lower compared to reactor neutrinos. For solar, diffused supernova background and atmospheric neutrinos such results have been presented in a previous study.

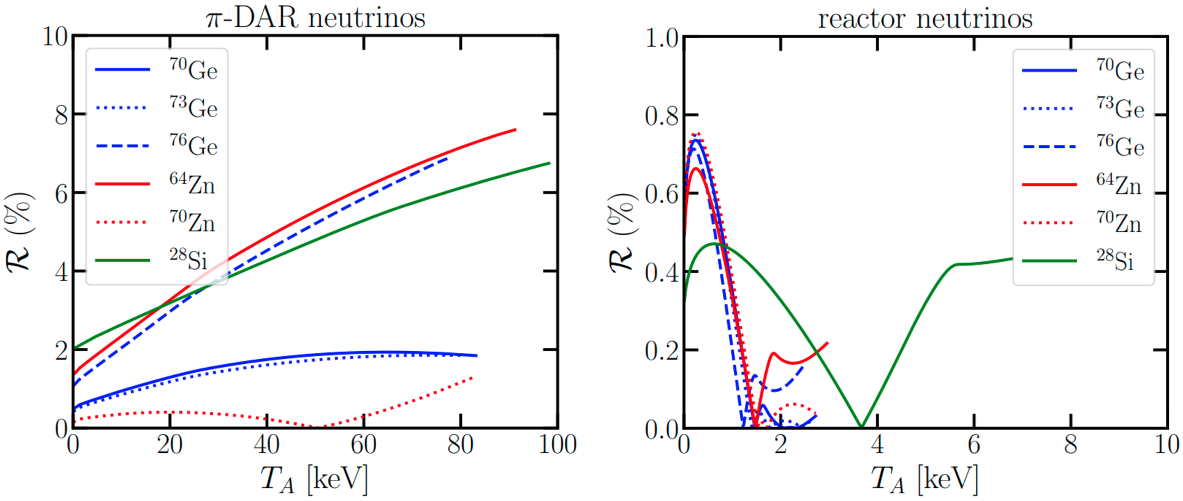


**Fig. 1**. *Percentage difference between DSM calculations and those involving the effective Klein-Nystrand form factor parametrization. The results are presented for the case of π-DAR neutrinos (left) and reactor neutrinos (right) as a function of the nuclear recoil energy for various nuclei [5].*

## CONCLUSIONS

Our main aim in the present study was to perform calculations of the CEvNS event rates for the Ge-detectors chosen in ongoing and designed CEvNS experiments. We also studied Zn and Si which are considered promising target materials of experiments aiming to measure CEvNS events. The nuclear structure calculations have been carried out with a high level of reliability, by considering crucial information from the nuclear structure. The detailed nuclear physics aspects came out of the DSM method which involves realistic two-body interactions and is assessed on the reproducibility of experimental microscopic nuclear properties. Highly accurate calculations such as those provided here, are valuable for discriminating the expected signal from the various isotopic admixtures contained in Germanium or Zinc detectors, the use of which has been proposed for reducing the experimental uncertainties. We have considered typical experimental configurations, exposed to neutrinos from π-DAR, reactor antineutrinos and Geoneutrinos, while to the best of our knowledge, the present work is the first nuclear physics-based study with regards to Geoneutrino signals. We compared our theoretical event rates with those calculated on the basis of the widely adopted form factors (e.g., the phenomenological Klein-Nystrand) and we concluded that especially for the SNS neutrinos the differences can be of the order of ten percent. On the other hand, we have verified that reactor antineutrino facilities with sub-keV thresholds as well as large scale direct dark matter detection experiments looking for light WIMPs uncertainties may be neglected for very low momentum transfer involved in the CEvNS process.

## Acknowledgements

The research of DKP is co-financed by Greece and the European Union (European Social Fund-ESF) through the Operational Programme «Human Resources Development, Education and Lifelong Learning» in the context of the project "Reinforcement of Postdoctoral Researchers-2nd Cycle" (MIS-5033021), implemented by the State Scholarships Foundation (IKY).

## References

[1] D. Z. Freedman, PRD9 p. 1389 (1974)
[2] D. K. Papoulias, T. S. Kosmas, and Y. Kuno, Front.in Phys. 7 p. 191 (2019)
[3] R. Sahu, D. K. Papoulias, V. K. B. Kota, and T. S. Kosmas, PRC 102 p. 035501 (2020)
[4] V. K. B. Kota and R. Sahu, *Structure of Medium Mass Nuclei: Deformed Shell Model and Spin-Isospin Interacting Boson Model,* CRC Press, 2016.
[5] T. S. Kosmas, V. K. B. Kota, D. K. Papoulias, R. Sahu, arXiv:2111.08488 [nucl-th]