PROCEEDINGS OF SCIENCE

Average CsI neutron density distribution from COHERENT data

PoS(NuFACT2018)144

M. Cadeddu*
Physics Department, Università degli Studi, Cagliari 09042, Italy
Istituto Nazionale di Fisica Nucleare, Sezione di Cagliari, Cagliari 09042, Italy
E-mail: matteo.cadeddu@ca.infn.it

C. Giunti

INFN, Sezione di Torino, Via P. Giuria 1, I–10125 Torino, Italy

Y.F. Li and Y.Y. Zhang
Institute of High Energy Physics, Chinese Academy of Sciences, and School of Physical Sciences, University of Chinese Academy of Sciences, Beijing 100049, China

Using the coherent elastic neutrino-nucleus scattering data of the COHERENT experiment, we determine for the first time the average neutron rms radius of ^{133}Cs and ^{127}I. We obtain the practically model-independent value $R_n = 5.5^{+0.9}_{-1.1}$ fm using the symmetrized Fermi and Helm form factors. We also point out that the COHERENT data show a 2.3σ evidence of the nuclear structure suppression of the full coherence.

The 20th International Workshop on Neutrinos (NuFact2018)
12-18 August 2018
Blacksburg, Virginia

*Speaker.

1. Introduction

The COHERENT experiment [1] observed for the first time coherent elastic neutrino-nucleus scattering [2] with a small scintillator detector made of sodium-doped CsI exposed to a low-energy neutrino flux generated in the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. This process can be observed by measuring very low values of the nuclear kinetic recoil energy T. The differential cross section with a nucleus $\mathscr{N}$ with Z protons and N neutrons is given by [3, 4]

$$\frac{d\sigma_{\nu\text{-}\mathscr{N}}}{dT}(E,T) \simeq \frac{G_F^2 M}{4\pi}\left(1-\frac{MT}{2E^2}\right)\times\left[NF_N(q^2)-\varepsilon Z F_Z(q^2)\right]^2, \tag{1.1}$$

where G_F is the Fermi constant, M is the nuclear mass, $F_N(q^2)$ and $F_Z(q^2)$ are, respectively, the nuclear neutron and proton form factors, and $\varepsilon = 1-4\sin^2\vartheta_W = 0.0454\pm0.0003$, using the low-energy PDG value of the weak mixing angle ϑ_W [5]. Because of the small value of ε, the neutron contribution is dominant. Hence, measurements of the process give information on the nuclear neutron form factor, which is more difficult to obtain than the information on the proton nuclear form factor, that can be obtained with elastic electron-nucleus scattering and other electromagnetic processes. In the case of the COHERENT experiment, the coherent elastic scattering is measured on ^{133}Cs and ^{127}I, which contribute incoherently, leading to the total cross section $\frac{d\sigma_{\nu\text{-CsI}}}{dT} = \frac{d\sigma_{\nu\text{-Cs}}}{dT} + \frac{d\sigma_{\nu\text{-I}}}{dT}$, with $N_{Cs} = 78$, $Z_{Cs} = 55$, $N_I = 74$, and $Z_I = 53$. The proton structures of ^{133}Cs and ^{127}I have been studied with muonic atom spectroscopy [6]. The fit of the data to the proton rms radii gives $R_p^{Cs} = \langle r_p^2\rangle_{Cs}^{1/2} = 4.804\,\text{fm}$ and $R_p^{I} = \langle r_p^2\rangle_{I}^{1/2} = 4.749\,\text{fm}$. Hence, the proton structures of ^{133}Cs and ^{127}I are similar. Since we expect that also their neutron structures are similar and the current uncertainties of the COHERENT data do not allow to distinguish between them, we consider the approximation $F_{N,Cs}(q^2) \simeq F_{N,I}(q^2) \simeq F_N(q^2)$. We fitted the COHERENT data under this approximation assuming proton form factors $F_Z(q^2)$ for ^{133}Cs and ^{127}I given by the Fourier transform of a symmetrized Fermi (SF) distribution $\rho_{SF}(r) = \rho_F(r) + \rho_F(-r) - 1$, which is practically equivalent to a Fermi distribution.

In order to get information on the neutron distribution of ^{133}Cs and ^{127}I we considered the following parameterizations of the neutron form factor $F_N(q^2)$: A symmetrized Fermi form factor $F_N^{SF}(q^2)$ and a Helm form factor [7]. We fitted the COHERENT data in Fig. 3A of Ref. [1] with the least-squares function

$$\chi^2 = \sum_{i=4}^{15}\left(\frac{N_i^{\text{exp}} - (1+\alpha)N_i^{\text{th}} - (1+\beta)B_i}{\sigma_i}\right)^2 + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2. \tag{1.2}$$

For each energy bin i, N_i^{exp} and N_i^{th} are, respectively, the experimental and theoretical number of events, B_i is the estimated number of background events extracted from Fig. S13 of Ref. [1], and σ_i is the statistical uncertainty. α and β are nuisance parameters which quantify, respectively, the systematic uncertainty of the signal rate and the systematic uncertainty of the background rate. The corresponding standard deviations are $\sigma_\alpha = 0.28$ and $\sigma_\beta = 0.25$ [1]. We considered only the 12 energy bins from $i = 4$ to $i = 15$ for which the COHERENT collaboration fitted the quenching factor in Fig. S10 of Ref. [1]. The theoretical number of coherent elastic scattering events N_i^{th} in each energy bin i depends on the nuclear neutron form factor and it is given by

$$N_i^{\text{th}} = N_{CsI}\int_{T_i}^{T_{i+1}} dT \int_{E_{\min}} dE\, A(T)\,\frac{dN_\nu}{dE}\,\frac{d\sigma_{\nu\text{-CsI}}}{dT}, \tag{1.3}$$

where N_{CsI} is the number of CsI in the detector, $E_{\text{min}} = \sqrt{MT/2}$, $A(T)$ is the acceptance function given in Fig. S9 of Ref. [1] and dN_ν/dE is the neutrino flux from the SNS integrated over the experiment lifetime. Figure 1 (left) shows the COHERENT data as a function of the nuclear kinetic

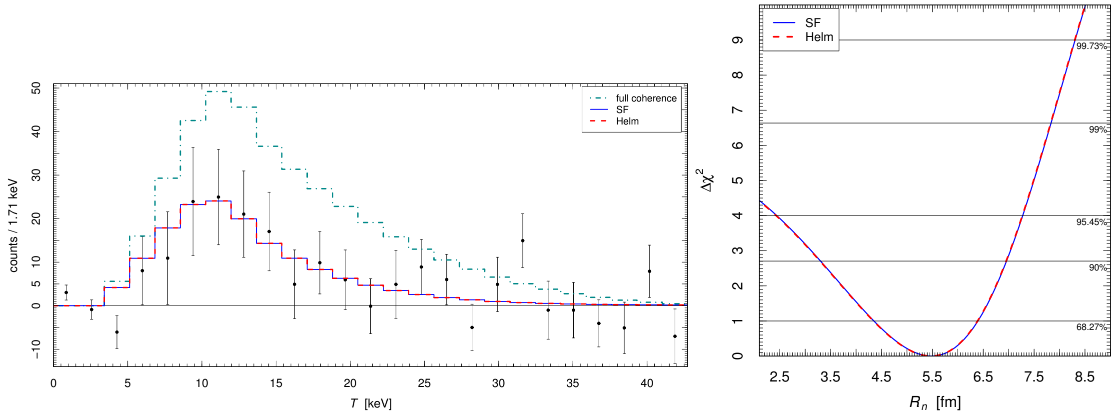

Figure 1: (Left) COHERENT data versus the nuclear kinetic recoil energy T together with the theoretical prediction in the case of full coherence (cyan dash-dotted), the best fits using the SF distribution (blue solid) and Helm (red dashed) form factors. (Right) $\Delta\chi^2 = \chi^2 - \chi^2_{\text{min}}$ as a function of the neutron rms radius R_n obtained from the fit of the COHERENT data using the SF and Helm form factors.)

recoil energy T together with the predictions in the case of full coherence, i.e. all nuclear form factors equal to unity. Then we fitted the COHERENT data in order to get information on the value of the neutron rms radius R_n, which is determined by the minimization of the χ^2 in Eq. (1.2) using the symmetrized Fermi and Helm form factors. The hypothesis of full coherence has a p-value of 1.9% and there is a 2.3σ evidence of the nuclear structure suppression of the coherence (see in Fig. 1 (left) the corresponding best-fit results). Figure 1 (right) shows the corresponding marginal values of the χ^2 as a function of R_n. One can see from both figures that the two parameterizations of the neutron form factor fit equally well the data and give practically the same result:

$$R_n = 5.5^{+0.9}_{-1.1}\,\text{fm}. \tag{1.4}$$

This is the first determination of the neutron rms radius of a nucleus obtained with neutrino-nucleus scattering data [4]. Note also that it is practically model-independent, because it coincides for the symmetrized Fermi and Helm form factors which correspond to reasonable descriptions of the nuclear density.

References

[1] D. Akimov et al. (COHERENT), *Science* **357**, 1123 (2017).

[2] D. Z. Freedman, *Phys. Rev.* D**9**, 1389 (1974).

[3] K. Patton et al., *Phys. Rev.*, C**86**, 024612 (2012).

[4] M. Cadeddu et al., *Phys. Rev. Lett.* **120**, 072501 (2018).

[5] C. Patrignani et al. (Particle Data Group), *Chin. Phys.*, C**40**, 100001 (2016).

[6] G. Fricke et al., *Data Nucl. Data Tabl.*, **60**, 177 (1995).

[7] R. H. Helm, *Phys. Rev*, **104**, 1466 (1956).