Nuclear size effects in Cs PNC

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Abstract

The dependence of the $6s{-}7s$ PNC amplitude in ^{133}Cs on the radius of the neutron distribution is studied. It is found that differences in neutron and proton r.m.s. radii for ^{133}Cs predicted in recent nuclear structure calculations lead to a 0.26% reduction in the $6s - 7s$ PNC amplitude; a factor of 3 greater than the change predicted in previous calculations.

1 Introduction

In the many-body calculations of the $6s - 7s$ PNC amplitude reported in Refs. [1, 2] more than a decade ago, the density associated with the vector part of the weak electron-nucleus interaction, which is expected to be approximately the nuclear neutron density, was modeled by the nuclear charge (proton) density. This approximation was tested in [2] by replacing the proton density by a theoretical neutron density obtained from a nuclear structure calculation [3] and led to a change of less than 0.1% in the predicted PNC amplitude.

In the past few years, the experimental accuracy of the PNC amplitude has been substantially improved [4] and the arguments used to estimate the accuracy of the theoretical calculations of the PNC amplitude have been re-examined [5], leading to a reduction of the estimated error in the theoretical PNC amplitude from 1% to 0.5%. Additionally, more sophisticated nuclear structure calculations have become available [6] permitting one to make more reliable estimates of effects of nuclear structure on the PNC amplitude. For these reasons, a re-examination of the dependence of the PNC amplitude on the nucleon distribution appears to be warranted.

Table 1: Fermi distribution parameters in (fm) for ^{133}Cs obtained by fitting neutron and proton distributions determined in [6].

Type	c	a	t	$R_{\rm rms}$
Neutron	5.9482	0.4946	2.1735	4.9607
Proton	5.8895	0.4010	1.7623	4.7994

2 Analysis

Since it is simplest to carry out systematic studies of nuclear distributions when analytic forms are available, the monopole parts of the neutron and proton distributions for ^{133}Cs obtained in the nuclear structure calculations of Ref. [6] are first fit to Fermi-distributions

$$\rho(r) = \frac{\rho_0}{1+\exp[(r-c)/a]},$$

where $a = t/4\ln 3$, t being the 10% - 90% fall-off distance. We normalize the distributions so that

$$\int_0^\infty \rho(r)\ r^2 dr = 1.$$

The parameters c, a and t, together with the r.m.s. radii obtained in the fit are given in Table 1, and the results of the fit are shown in Fig. 1.

The nuclear distribution function used to obtain the Cs PNC amplitude in Ref. [2] was taken to be the charge (proton) distribution function. It was approximated by a Fermi distribution with parameters $c = 5.6748$ fm and $t = 2.3$ fm. The corresponding r.m.s. radius is $R_P = 4.807$ fm, in fair agreement with the value 4.799 fm from the fit to the proton distribution given in Table 1. The parameters used in [2] were taken from Ref. [7]. It was found in [2] that replacing the proton distribution by a theoretical neutron distribution [3] led to a change the PNC amplitude of 0.08%. Here we revisit the nuclear size dependence of the PNC amplitude by investigating the dependence of the PNC amplitude on the neutron distribution.

We assume that the neutron distribution can be approximated by a Fermi distribution and we evaluate the PNC amplitude for values of c ranging from 5.5 to 6.5 fm and values of a ranging from 0.4 to 0.55 fm. We find that the PNC amplitude is almost completely insensitive to a. Additionally, we find that the PNC amplitude for the $6s-7s$ transition in ^{133}Cs is a linear function of the r.m.s. radius of the neutron distribution in the range of parameters

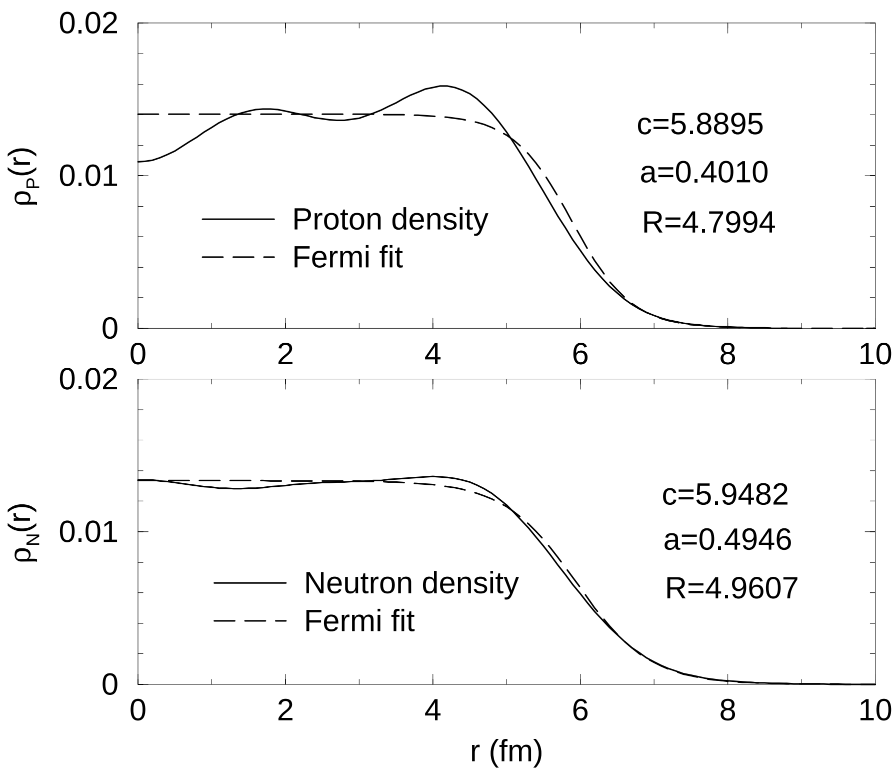

Figure 1: Neutron and proton distributions functions in ^{133}Cs, obtained from from the nuclear structure calculations of Ref. [6], are fit to Fermi distributions.

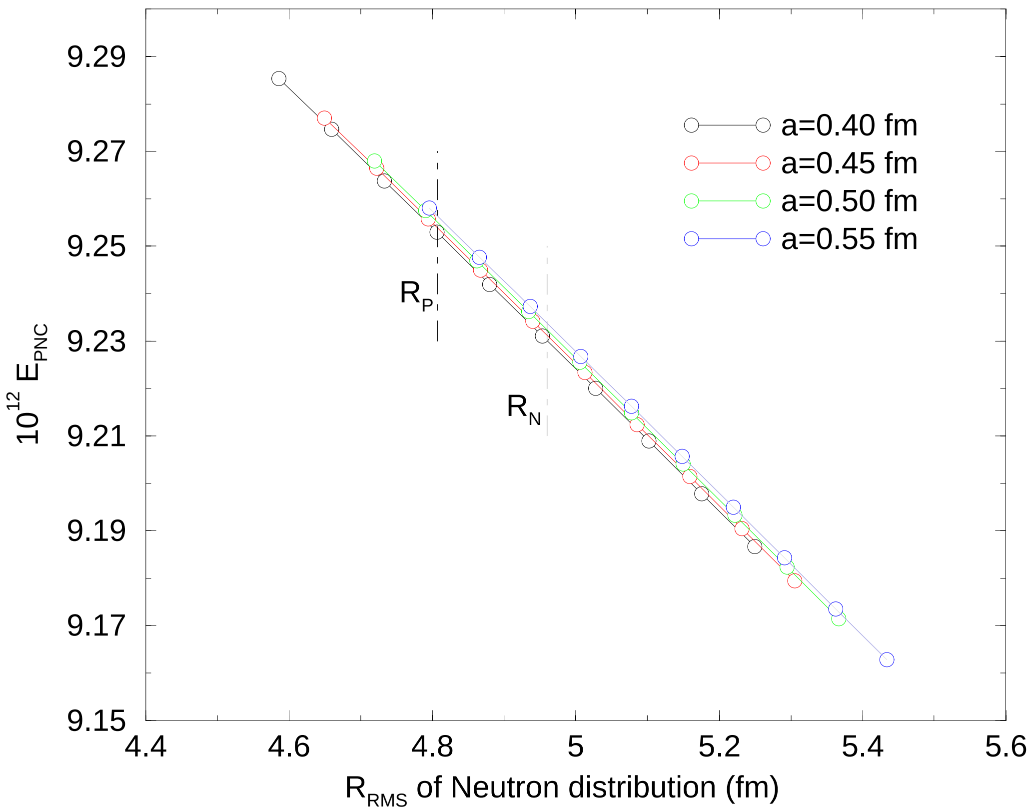

Figure 2: The PNC amplitude for ^{133}Cs is evaluated using a neutron Fermi distribution with parameters $c = [5.5..6.5]$ and $a = [0.40..0.55]$. The calculations are at the "weak" RPA level of approximation. (units: iea_0)

considered. These results are summarized in Fig. 2, where we plot the PNC amplitude calculated in the "weak" RPA approximation, against the r.m.s. radius of the neutron distribution for various values of a. The $6s - 7s$ PNC amplitude evaluated in this approximation leads to predictions within 3% of the more accurate many-body calculations of [1] and [2]. The two vertical lines labeled R_P and R_N in Fig. 2 are drawn at the positions of the proton r.m.s. radius 4.807 fm used in the calculations of [2] and the neutron r.m.s. radius 4.961 fm from Table 1, respectively. Least-squares fits to the straight lines in Fig. 2 are given in Table 2. The PNC amplitude evaluated at R_N is seen to be 0.26% smaller than the amplitude evaluated at R_P for each of the four values of a considered. A corresponding 0.26% reduction in the many-body value from [2] is expected. This reduction, together with the

Table 2: The "weak" RPA PNC amplitude for the $6s - 7s$ transition in ^{133}Cs is represented as $E_{\rm PNC}(a,R) = E_0(a) + E_1(a)R$, where a is parameter governing the thickness of the neutron Fermi distribution and R is the corresponding r.m.s radius. Values of $E_{\rm PNC}$ are given at $R_P = 4.807$ fm and at $R_N = 4.961$ fm. These values differ by -0.26% for all a in the range considered.

a	$E_0(a)$	$E_1(a)$	$E_{\rm PNC}(a,R_P)$	$E_{\rm PNC}(a,R_N)$	Δ %
0.40	9.9668	-0.1486	9.2535	9.2298	-0.26%
0.45	9.9689	-0.1488	9.2547	9.2309	-0.26%
0.50	9.9711	-0.1490	9.2559	9.2321	-0.26%
0.55	9.9735	-0.1492	9.2574	9.2335	-0.26%

revised error estimates ftom [5], leads to a revised theoretical prediction of the $6s - 7s$ PNC amplitude in ^{133}Cs:

$$\boxed{E_{\rm PNC} = 9.04(0.05) \times 10^{-12} iea_0.}$$

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