Nuclear-polarization correction in muonic ^{208}Pb with relativistic nuclear model

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High-precision measurements of the muonic energy levels require for the theoretical calculation to consider the effect that the bound muon distorts the nuclear structure. Although the various nonrelativistic nuclear models have been employed in the nuclear-polarization (NP) calculation, the disagreement between the theory and the experiment has been still remained[1]. In this report, we study the NP correction in muonic ^{208}Pb with relativistic nuclear model.

The nuclear-polarization energy shift due to the two-photon exchange process is given by

$$\Delta E_{NP} = i(4\pi\alpha)^2 \int d^4x_1 \cdots d^4x_4 \bar{\psi}_l(x_1)\gamma^\mu S_F^l(x_1,x_2)\gamma^\nu \psi_l(x_2) D_{\mu\xi}(x_1,x_3)\Pi_N^{\xi\zeta}(x_3,x_4)\, D_{\zeta\nu}(x_4,x_2), \quad (1)$$

where $\Pi_N^{\xi\zeta}$ is the nuclear-polarization tensor which contains all information of nuclear dynamics. In the present work, we construct the nuclear excitation states I' by relativistic mean-field approach. Then, the solutions for the intermediate states with the negative energy (antinucleon states) play an important role to obtain the gauge-invariant result[2]. We take the cutoff energies by 60 MeV for positive-energy nucleon states and −1600 MeV for negative-energy nucleon states.

The total NP corrections in muonic states are listed in Table 2. Figure 2 illustrates how much of the discrepancy is resolved by the present NP calculation. The shaded area shows the experimentally allowable region of the NP correction[3]. As found in Fig. 2, we have achieved to explain the Δp splitting energy of muonic ^{208}Pb with full-relativistic calculation. In this analysis, we found that the transverse current and the effective mass effect were indispensable to explain these anomalies.

However, there is an uncertainty with respect to the effective mass; it is well known that the relativistic Hartree approach with the vacuum polarization in the nucleon-antinucleon field suppresses the change of the nucleon mass[4]. The NP calculation based on this approach is also important to see the realistic effect of effective mass.

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Table 1: Nuclear-polarization correction (keV) to the $1s_{1/2}$, $2p_{1/2}$, $2p_{3/2}$, $3p_{1/2}$, and $3p_{3/2}$ states of muonic ^{208}Pb.

State	Relativistic(TM1)	Relativistic(NLSH)	Nonrelativistic[2]	Rinker − Speth[3]	Tanaka − Horikawa[5]
$1s_{1/2}$	−6.010	−5.840	−4.474	−4.252	−4.806
$2p_{1/2}$	−2.584	−2.385	−1.685	−1.616	−1.731
$2p_{3/2}$	−2.782	−2.493	−1.656	−1.495	−1.666
$3p_{1/2}$	−0.951	−1.149	−0.501	−0.540	−0.515
$3p_{3/2}$	−1.590	−1.462	−0.554	−0.536	−0.550

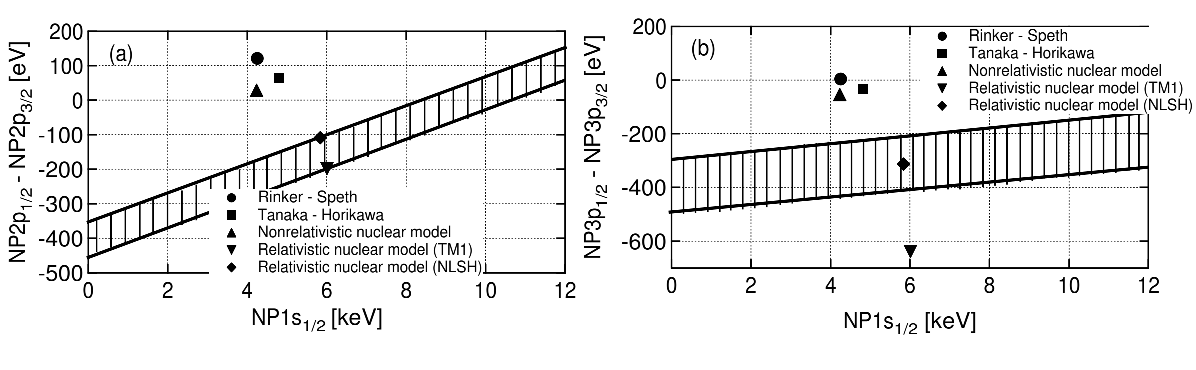

Figure 1: Splitting energy due to the nuclear polarization in the p level of muonic ^{208}Pb.

References

[1] A. Haga, Y. Horikawa and Y. Tanaka, Phys. Rev. A**66**, 034501 (2002).
[2] A. Haga, Y. Horikawa, Y. Tanaka and H. Toki Phys. Rev. C**69**, 044308 (2004).
[3] P. Bergem *et. al.*, Phys. Rev. C**37**, 2821 (1988).
[4] A. Haga, S. Tamenaga, H. Toki, and Y. Horikawa, Phys. Rev. C**70**, 064322 (2004).
[5] Y. Tanaka and Y. Horikawa, Nucl. Phys. A**580**, 291 (1994).