PREX-2 data: Revisit of Relativistic Mean Field forces

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1. Introduction

It is an interesting fact, that the proton is a charged particle since, its precise measurement is possible, however an accurate determination of the neutron distribution inside a finite nucleus suffers large uncertainties. Recently, to reduce the uncertainty of PREX data [1], the PREX-2 result is published with the neutron skin thickness as $\triangle R_{np} = 0.283 \pm 0.071$ fm [2] and point neutron distribution radius $R_n = 5.727 \pm 0.071$ fm [knowing the exact value of proton distribution radius as $R_p = 5.444$ fm [3, 4] with the corresponding charge radius $R_{ch} = 5.501$ fm [5]]. Motivated by the excellent precise measurement of the neutron skin-thickness of ^{208}Pb by Adhikari *et. al.* [2] and the results of Reed *et. al.* [6], the two couplings Λ_ω and g_ρ of the RMF Lagrangian are taken as the tuning parameters to reproduce the recent experimental R_n for G3 [7] and IOPB-I [8].

2. Theoritical formalism

We re-visited our RMF G3 and IOPB-1 parameter sets with a minimal tuning of the essential couplings, which rarely affect the global properties of the nuclear matter (NM) and finite nuclei observable. It is worth mentioning that, in general, these two forces reproduce well the known experimental data for finite nuclei and the properties of Neutron star and the gravitational waves strain in binary neutron stars merger [7, 8]. The two couplings Λ_ω and g_ρ of the RMF Lagrangian are taken as the tuning parameters to reproduce the recent experimental neutron distribution radius R_n for ^{208}Pb.

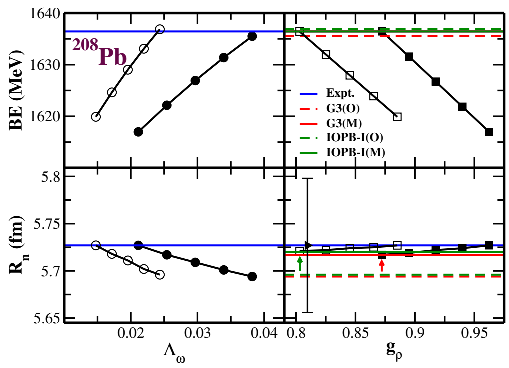

FIG. 1: The binding energy (Upper Panel) in MeV and neutron distribution radius R_n (Lower Panel) in fm with original G3(O) (dashed red) and modified G3(M) (solid red) parameter sets for ^{208}Pb as a function of Λ_ω. Similarly, for g_ρ, the IOPB-I(O) and IOPB-I(M) are in dashed green and solid green lines, respectively. The changes of BE (circle) and R_n (square) corresponding to both G3(M) (solid) and IOPB-I(M) (empty), respectively. The experimental data with error bar [2, 9] are given for comparison. The single arrow for the better clarification of R_n.

3. Results and discussion

The $\rho-$meson coupling takes care of the neutron-proton (N - Z) asymmetry in the sys-

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tem. Therefore, we made the choice of the minimal tuning of parameters like Λ_ω and g_ρ. The binding energy (BE) of the asymmetric nuclear system increases with Λ_ω, whereas decreases with the increasing g_ρ. In case of R_n, it decreases with increase of Λ_ω, while the R_n remains almost unchanged with g_ρ. In Fig. 1, we calculate the BE and R_n with variation of Λ_ω from 0.03821181 to 0.02112981 without changing g_ρ for G3 parameter set. As mentioned above, we find the increase of binding energy with Λ_ω. Then, we modify the values of g_ρ in the range g_ρ =0.962466017 − 0.872266017. In case of g_ρ, the BE decreases with increase of g_ρ without affecting the neutron distribution radius R_n. The experimental BE is shown as the dashed line. By fixing the experimental data of BE and R_n, we calibrated the Λ_ω and g_ρ combinations as (Λ_ω, g_ρ) = (0.02112981, 10.961218044) for modified G3(M) parameter set. We follow the same procedure for IOPB-I parameter set and found the modified values of Λ_ω and g_ρ as Λ_ω =0.01475398 and g_ρ =10.0907956536.

4. Summary

The NM parameters, such as the isospin dependence observable symmetric energy J, slope parameter L and some other observable are also affected significantly, which favours experimental or other theoretical predictions. The original J was 31.842 MeV and after the modification J was found to be 33.063 MeV for G3 set. Similarly, the old and new J values are 33.355 and 34.831 MeV in IOPB-I case. Both the parameters provide values, more closer to the limit set up by Reed *et al.* [6]. Thus, the re-calibration of the parameters with respect to PREX-2 is one step more accuracy for the determination of nuclear observable, exclusively for highly neutron rich systems. For G3(M) and IOPB-I(M) parameter sets, the rms deviations in binding energy, are 3.751973 and 3.5698173 MeV, and for charge radii are 0.023278 and 0.021237, respectively. The modified G3(M), and IOPB-I(M) found to reproduce the neutron distribution radius are 5.717 and 5.721 (in fm) which are in agreement with the recent empirical data [2]. An extensive version of our work can be found in [10].

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References

[1] T. W. Donnelly, J. Dubach, I. Sick, Nucl. Phys. A **503**, 589 (1989).
[2] D. Adhikari et al., Phys. Rev. Lett. **126**, 172502 (2021) .
[3] B. Frois *et al.*, Phys. Rev. Lett. **38**, 152 (1977).
[4] A. B. Jones, B. A. Brown, Phys. Rev. C **90**, 067304 (2014).
[5] A. Ong, J. C. Berengut, V. V. Flambaum, Phys. Rev. C **82**, 014320 (2010).
[6] B. T. Reed, F. J. Fattoyev, C. J. Horowitz and J. Piekarewicz, Phys. Rev. Lett. **126**, 172503 (2021).
[7] B. Kumar, S. Singh, B. Agrawal, and S. Patra, Nucl. Phys. A **966**, 197 (2017).
[8] B. Kumar, S. K. Patra, and B. K. Agrawal, Phys. Rev. C **97**, 045806 (2018).
[9] M. Wang, G. Audi, F. G. Kondev, W. J. Huang, S. Naimi, and X. Xing, Chin. Phys. C **41**, 030003 (2017).
[10] Jeet Amrit Pattnaik, R. N. Panda, M. Bhuyan, S. K. Patra, **arXiv:2105.14479 [nucl-th]**.