

## Study of ground state properties of isotopic chains of Gadolinium and Dysprosium using relativistic mean field model

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### Introduction

The study of nuclear structure is a cornerstone of modern physics, providing critical insights into the fundamental properties of atomic nuclei. Understanding the nuclear structure is essential for elucidating the forces that bind protons and neutrons within the nucleus, which in turn impacts various fields such as astrophysics, nuclear energy, and medical applications. Despite significant advancements, the complexities of nuclear interactions, especially in deformed and heavy nuclei, continue to pose substantial challenges. These challenges arise from the intricate balance of nuclear forces, the role of isospin asymmetry, and the deformation effects that significantly influence nuclear properties. Recent advancements in theoretical models, particularly relativistic mean field (RMF) theories, have made significant progress in addressing these challenges. RMF models, with their ability to incorporate various coupling terms, have proven effective in describing the ground-state properties of a wide range of nuclei. Innovations such as isoscalar-isovector coupling have further refined these models, allowing for a more accurate representation of symmetry energy and its impact on nuclear structure. In this work, we systematically investigate the ground-state properties of the isotopic chains of gadolinium (Z=64) and dysprosium (Z=66) using two RMF models, HPU1 and HPU2. These models incorporate isoscalar-isovector coupling to provide a more detailed understanding of nuclear interactions. Our study focuses on properties such as the quadrupole deformation ( $\beta_2$ ) and neutron skin thickness ( $\Delta r$ ) of deformed nuclei. Through this comprehensive analysis, we aim to enhance the understanding of nuclear structure and contribute to the ongoing efforts in refining theoretical models for deformed nuclei.

### Theoretical Model

The effective Lagrangian that we employed includes the isoscalar scalar  $\sigma$ , isoscalar vector  $\omega_\mu$  and isovector vector  $\rho_\mu$  mesons alongwith nucleons [1]. The total Lagrangian density is given by

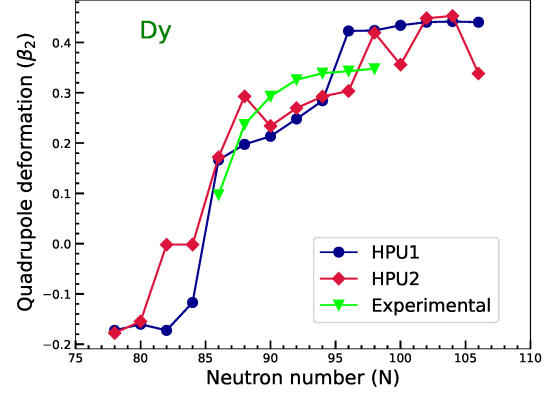


FIG. 1:  $\beta_2$  versus N in Dy isotopic chain for HPU1 and HPU2 models in comparison with experimental data.

$$\begin{aligned}
 \mathcal{L} = & \sum_{N=n,p} \bar{\Psi}_N [i\gamma^\mu \partial_\mu - (M_N - g_{\sigma N} \sigma) \\
 & - (g_{\omega N} \gamma^\mu \omega_\mu + \frac{1}{2} g_{\rho N} \gamma^\mu \tau_N \cdot \rho_\mu)] \Psi_N + \frac{1}{2} (\partial_\mu \sigma \partial^\mu \sigma - m_\sigma^2 \sigma^2) \\
 & - \frac{\bar{\kappa}}{3!} g_{\sigma N}^3 \sigma^3 - \frac{\bar{\lambda}}{4!} g_{\sigma N}^4 \sigma^4 - \frac{1}{4} \omega_{\mu\nu} \omega^{\mu\nu} + \frac{1}{2} m_\omega^2 \omega_\mu \omega^\mu \\
 & + \frac{1}{4!} \zeta g_{\omega N}^4 (\omega_\mu \omega^\mu)^2 - \frac{1}{4} \rho_{\mu\nu} \rho^{\mu\nu} + \frac{1}{2} m_\rho^2 \rho_\mu \rho^\mu \\
 & + \frac{1}{2} \Lambda_{\omega\rho} g_{\omega N}^2 g_{\rho N}^2 \omega_\mu \omega^\mu \rho_\mu \rho^\mu - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \\
 & + \sum_N e \bar{\Psi}_N \gamma_\mu \frac{1 + \tau_{3N}}{2} A_\mu \Psi_N + \sum_{\ell=e,\mu} \bar{\Psi}_\ell (i\gamma^\mu \partial_\mu - M_\ell) \Psi_\ell
 \end{aligned}$$

### Results and Discussion

In this research work, we have conducted a systematic investigation of the ground-state properties of rare-earth even-even nuclei using a deformed RMF theory. Specifically, we utilized the recently developed RMF parameter sets HPU1 and HPU2[2], which are distinguished by their inclusion of nonlinear coupling terms between isoscalar and isovector mesons—a feature not previously applied to studies of deformed nuclei. The parameter sets of both HPU1 and HPU2 models are shown in table I. The incorporation of nonlinear coupling is expected to offer a more refined depiction of nuclear interactions, particularly in addressing the symmetry energy and its influence on nu-

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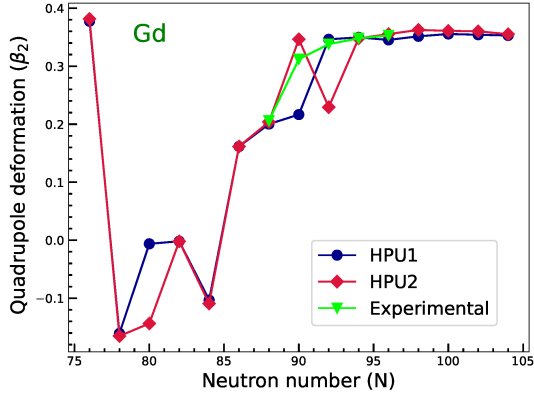


FIG. 2:  $\beta_2$  versus  $N$  in Gd isotopic chain for HPU1 and HPU2 models in comparison with experimental data.

TABLE I: The parameters of HPU1 and HPU2 models[2].  $\bar{\kappa}$  and  $\bar{\lambda}$  are presented in  $10^{-2}$  and unit of  $\bar{\kappa}$  is  $fm^{-1}$ . The mass for nucleon,  $\omega$  and  $\rho$  meson is taken as  $M_N = 939$  MeV,  $m_\omega = 782.5$  MeV and  $m_\rho = 770$  MeV

Parameters	HPU1	HPU2
$g_\sigma$	9.37959	9.91463
$g_\omega$	11.63792	12.45333
$g_\rho$	10.79751	10.65758
$\bar{\kappa}$	3.14479	2.45494
$\bar{\lambda}$	-2.51218	-1.67119
$\zeta$	-	0.00682
$\Lambda_{\omega\rho}$	0.05396	0.04745
$m_\sigma$	497.976	501.606

clear structure. In this study, we examined the isotopic chains of gadolinium (Gd), covering 15 isotopes from  $^{140}\text{Gd}$  to  $^{166}\text{Gd}$ , as well as 15 isotopes of dysprosium (Dy), spanning from  $^{144}\text{Dy}$  to  $^{172}\text{Dy}$ . In Figures 1 and 2, we display the variation of quadrupole deformation with neutron number for both HPU1 and HPU2 models, along with the available experimental data for the isotopic chains of Dy and Gd, respectively. In both cases, the quadrupole deformation parameters calculated using HPU1 and HPU2 closely align with experimental measurements, highlighting the models' ability to accurately predict the shapes of these nuclei. In Figures 3 and 4, we illustrate the neutron skin thickness as a function of neutron number for both HPU1 and HPU2 models, applied to the isotopic chains of Dy and Gd, respectively. Typically, as the neutron number rises,  $\Delta r$  also increases because additional neutrons occupy higher energy levels, extending further from the nucleus center. It is evident from the graphs that both HPU1 and HPU2 exhibit the same general trend, confirming the accuracy of both models in case of isotopic chains of both Dy and Gd.

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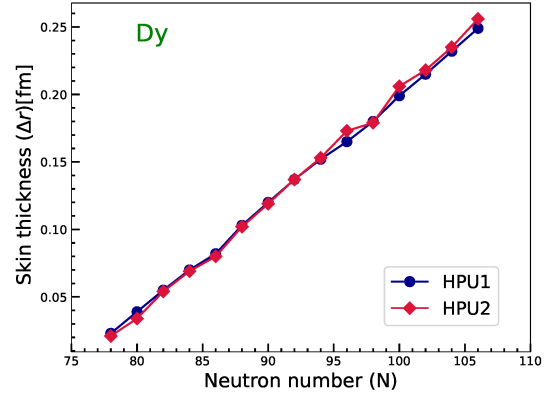


FIG. 3: Variation of neutron skin thickness with neutron number for Dy isotopic chain using the HPU1 and HPU2 models.

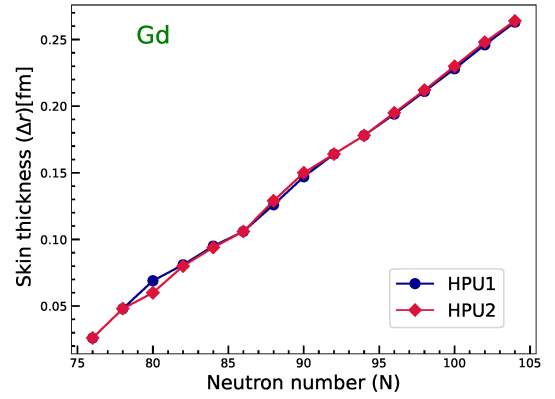


FIG. 4: Variation of neutron skin thickness with neutron number for Gd isotopic chain using the HPU1 and HPU2 models.

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