Isoscalar giant quadrupole resonances in $^{44}$Ca, $^{54}$Fe, $^{64,68}$Zn and $^{56,58,60,68}$Ni and the effective mass

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We carried out fully self-consistent Hartree-Fock (HF)-based random phase approximation (RPA) calculations of the centroid energies, $E_{\text{cen}}$, for the isoscalar resonances up to L=3 multipolarity for the isotopes of $^{44}$Ca, $^{54}$Fe, $^{64,68}$Zn and $^{56,58,60,68}$Ni [1]. The calculations were done using 33 different Skyrme-type effective nucleon-nucleon interaction commonly adopted in the literature. The interactions considered are associated with a wide range of nuclear matter properties. For the single particle orbits of the open shell nuclei we used the occupation number approximation to perform the calculations. We also calculated the Pearson Linear Correlation Coefficient, C, between the centroid energies of each giant resonance and every nuclear matter (NM) property.

In Fig. 1 we plot the calculated centroid energies $E_{\text{cen}}$ (shown as circles) of the isoscalar giant quadrupole resonance as a function of the effective mass, $m^*/m$. Experimental data is available for all the nuclei considered and is marked by the dashed lines. We find a strong correlation between the values of $E_{\text{cen}}$ and $m^*/m$ (C~ -0.93). As shown in the figure, we obtained the best agreement between the calculated and measured centroid energies for interactions with a value of effective mass in the range $m^*/m = 0.6$-$0.8$ in the case of $^{44}$Ca and $^{54}$Fe, whereas for all the other nuclei a slightly higher effective mass is in better agreement with the data. We note that some interactions, associated with a value of the effective mass as high as $m^*/m=1$, reproduced the $E_{\text{cen}}$ of $^{56,58,60}$Ni and $^{64}$Zn. These fluctuations in the value of the effective mass was also found in our other study regarding the region of $A = 90$ -100 [2] and remains an unsolved issue.

FIG. 1. Calculated centroid energies $E_{\text{CEN}}$ in MeV (full circle) of the Isoscalar Giant Quadrupole Resonance, for the different interactions, as a function the effective mass. Each nucleus has its own panel and the experimental uncertainties are contained by the dashed lines. We find strong correlation between this NM property and the calculated $E_{\text{CEN}}$ with a Pearson Correlation $C \sim 0.93$ for all isotopes considered.