Threshold effects in low energy isovctor dipole excitations in nuclei

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Calculations of the nuclear response function for the Isovector Giant Dipole Resonance (IVGDR) have been carried out in the past using the discretized Hartree-Fock Random Phase Approximation (HF-DRPA). In many cases they contained violations of self-consistency and a large smearing parameter. Under these conditions, low energy enhancements in the nuclear response function have been interpreted as resonances in some instances. To investigate the validity of these claims we undertook HF- Continuum RPA (HF-CRPA) and scattering phase shift calculations for the asymmetric ^{28}O and ^{60}Ca nuclei. In addition, we also calculated the Free response of the above-mentioned nuclei using a HF-DRPA scheme.

Shown in Fig.1 is the RPA response (top) for isovector dipole excitations for ^{60}Ca, calculated using the HF-CRPA scheme. The points of contention are the enhancements seen in the 5-7.5 MeV region in the RPA response.

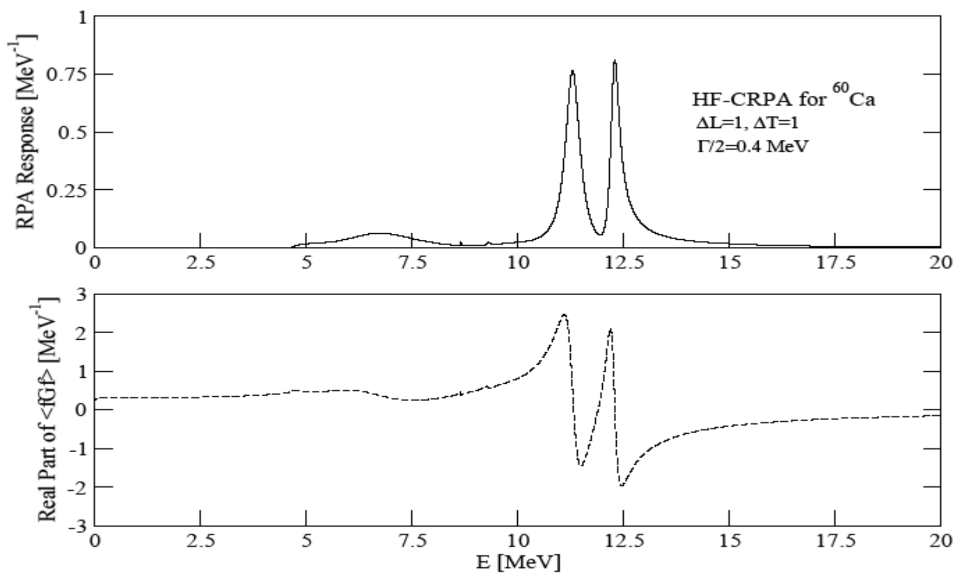

FIG. 1. Isovector Dipole Continuum HF-CRPA for ^{60}Ca with smearing Γ/2=0.4 MeV and a maximum radius of 12 fm. The imaginary part of $\langle fGf \rangle$ (RPA response) is shown on top while the real part of $\langle fGf \rangle$ is shown on the bottom. To better distinguish between the two, the real part of $\langle fGf \rangle$ is dashed.

To understand how these could come about, we illustrate the Free response for ^{60}Ca under dipole transitions calculated according to HF-CRPA theory in Fig.2. Collective excitations in the RPA are built from coherent particle-hole excitations. As such, we expect that resonances in the single-particle transition spectrum contribute the most to resonances in the collective spectrum. For single-particle resonances within the HF-CRPA theory, the real part of $\langle f G^{(0)} f \rangle$ has a pole. Referring to Fig. 2 we do not notice poles in the real part of $\langle f G^{(0)} f \rangle$ (bottom of figure) in the 5-7.5 MeV excitation energy range. The HF-CRPA scheme therefore does not predict single-particle resonances in this region.

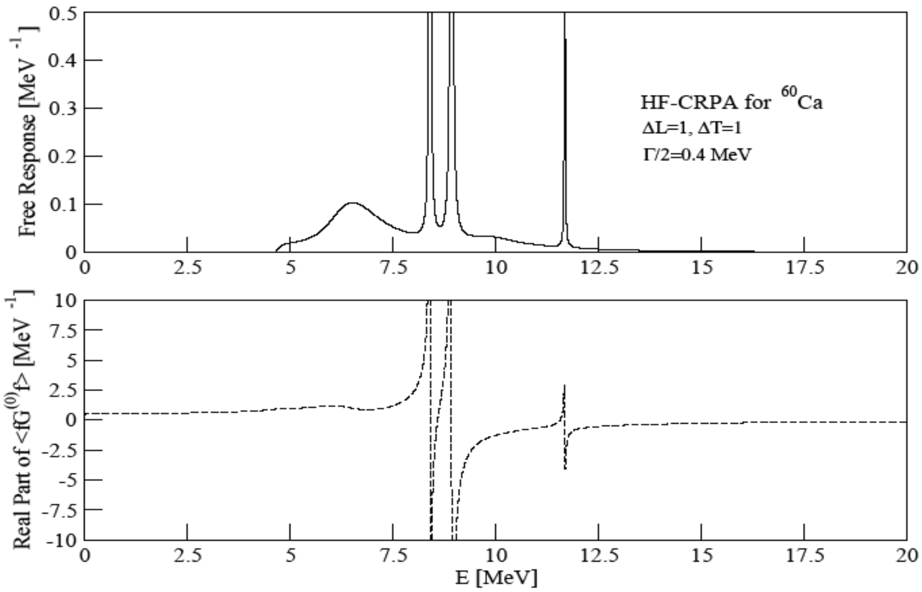

FIG. 2. Isovector Dipole Continuum HF-CRPA Free Response for ^{60}Ca with smearing Γ/2=0.4 MeV and a maximum radius of 12 fm. The imaginary part of $\langle f G^{(0)} f \rangle$ (Free response) is shown on top while the real part of $\langle f G^{(0)} f \rangle$ is shown on the bottom. To better distinguish between the two, the real part of $\langle f G^{(0)} f \rangle$ is dashed

The Free response for ^{60}Ca within the HF-DRPA is shown in Fig. 3. This approach uses a discrete continuum ensuring that all transitions to the latter are given the same aspect as bound-to-bound transitions in the Free response. Because of this, non-resonant transitions to the continuum could be interpreted as resonances. This can be seen in Fig.3 where transitions in the 5-7.5 MeV excitation energy range appear as resonances, in stark contrast to the results shown in Fig. 2.

To check our HF-CRPA results we undertook scattering phase shift derivative calculations for the two nuclei under study. The phase shift derivatives are proportional to the single-particle level densities in the continuum

$$g_{cl}(e) = \frac{1}{\pi} 2(2l+1) \frac{d\delta_l(e)}{de}, \qquad (3)$$

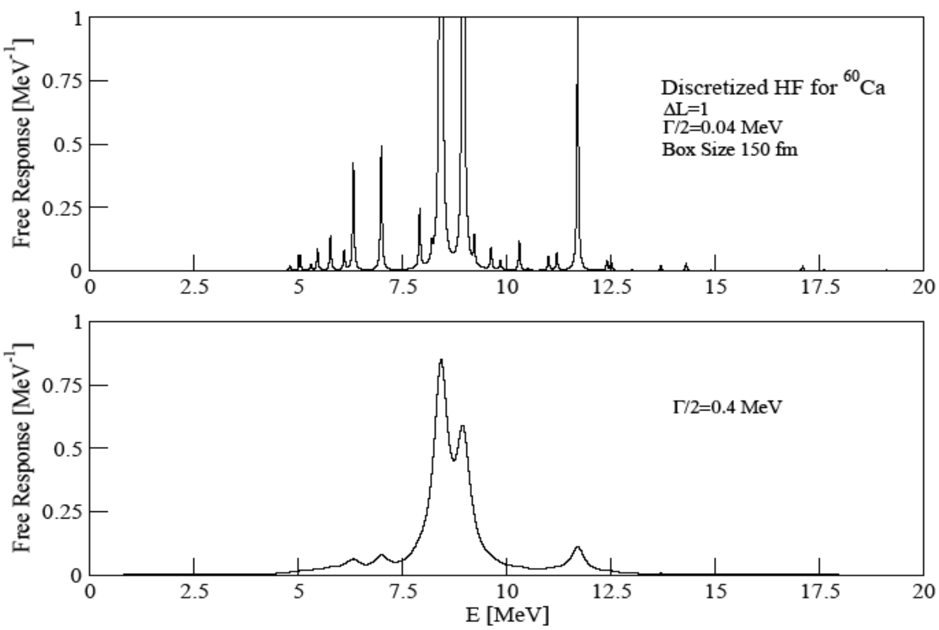

FIG. 3. Isovector Dipole Discretized HF for ^{60}Ca with a box size of 150 fm. The top part shows the Free response with smearing Γ/2=0.04 MeV while the bottom shows the Free response with smearing Γ/2=0.4 MeV.

The phase shift derivatives were calculated by two methods. The first involved the use of the asymptotic form of the solutions to the radial Schrodinger equation. In the second method the scattering phase shift derivatives were calculated using the Green's function method as given by

$$g_l(\epsilon) = \lim_{\alpha\to\infty, R\to\infty} 2(2l+1)\frac{1}{\pi}\int_0^R dr\left[\mathrm{Im}G_l(r,r',\epsilon+i\alpha) - \mathrm{Im}G_{0l}(r,r',\epsilon+i\alpha)\right]_{r=r'} \quad (4),$$

where G_l and G_{0l} are Green's functions as given in Ref. [1] and which include a proper treatment of the continuum as described in Ref. [2]. The second term G_{0l} is associated with the free Hamiltonian. In both Green's function and the asymptotic form approaches, a resonance is characterized by a peak in the phase shift derivative with the phase shift passing through $\pi/2$.

Fig. 4 illustrates the results of the phase shift calculations. From the top, we list the integral of the imaginary part of the Green function with interactions, the integral of the imaginary part of the Green's function associated with the free Hamiltonian and the difference between the two integrals which, according to Eq. (2) is proportional to the phase shift derivative. The result shown in the bottom part is proportional to the scattering phase shift derivative calculated with the first method.

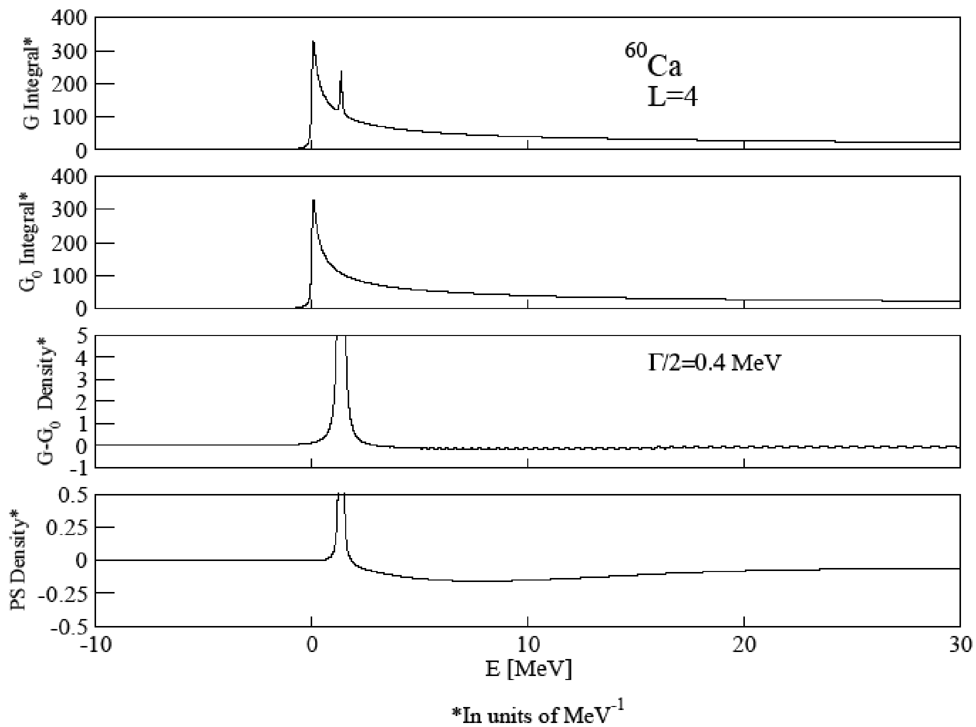

FIG. 4. Single-Particle Level Density for ^{60}Ca, for L=4. The results are plotted as functions of state energy. A resonance at 1.36 MeV is found. A smearing of Γ/2=0.4 MeV was used in the Green's function calculations.

The lowest resonance found in the ^{60}Ca spectrum from the scattering phase shift derivative occurred at 1.36 MeV corresponding to a transition from a neutron 0f bound state with total excitation energy of 9.312 MeV, which is higher than our region of 5-7.5 MeV. This confirmed our HF-CRPA results, which indicated no resonance in the Free response in that particular energy range. The resonance is shown in the bottom two sections of Fig. 4. Similar results were obtained for ^{28}O.

Owing to our HF-CRPA results which show no pole in the real part of the RPA response, and scattering phase shift results, which indicated no single-particle resonances, in the 5-7.5 MeV range, we conclude that the enhancements seen in the collective response of both ^{28}O and ^{60}Ca in the same region are not resonances.

[1] S. Shlomo, V. M. Kolomietz, and H. Dejbakhsh, Phys. Rev. C **55**, 1972 (1997).

[2] S. Shlomo and G. Bertsch, Nucl. Phys. **A243**, 507 (1975).