Gamma-decay of the GDR in Coulomb excited exotic nuclei .

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Giant resonances are basic nuclear excitation modes which carry useful information on the underlying nuclear structure as well as on the effective nucleon-nucleon interaction in the medium. Although this topic has attracted much attention over several past decades, in the case of nuclei far from the stability line the investigation of collective modes is still in its infancy.
The isovector giant dipole resonace (GDR) is one of the most important and easily accessible of these collective modes. The question how the giant dipole resonance strength evolves when going from stable to exotic, weakly bound nuclei with extreme neutron to proton ratio is presently under discussion [1-4]. The general feature of the existing calculations of different types, is the redistribution of the strength towards lower excitation energies well below the giant resonanc region. The details of these redistribution are found to depend on the effective forces used in the calculations.
In literature the low-energy part of the GDR strength function is often referred as Pygmy resonance and it was proposed to arise from the vibration of the less tightly bound valence neutrons against the residual core.
Therefore measurements of the GDR strength function in unstable nuclei provide important information on the isospin dependent part of the in medium nucleon-nucleon interaction and on dipole type vibrations of excess neutrons.

So far systematic experimental information on giant resonances in exotic nuclei is still not available and only for some light halo nuclei the low-lying dipole strength was observed in electromagnetic dissociation measurements, the heaviest among them being the neutron rich Oxygen isotopes recently investigated at GSI [5]. In these experiments the process of electromagnetic excitation (virtual photon absborption) of fast projectiles by a high Z targets is used and the excitation energy is recontructed from the break-up fragments and the neutron.
However, there is another method to study the GDR response function via relativistic Coulomb excitation, namely that of the virtual photon scattering. In this case one needs to detect the γ-ray decay which is a weak branch that amount for the GDR typically to less than 10^{-2}. Until now this method has been applied to experiments performed at MSU for ^{11}Be and ^{20}O beams at bombarding energies of 77 MeV/u and 100 MeV/u , respectively . Preliminary results of these experiments (both performed with approximately 10^6 pps), are presented in references 6 and 7. The case of ^{11}Be, for which data were collected up to $E_\gamma \approx 25$ MeV [6,8], can be taken as a good example to illustrate the feasibility of this type of measurements. In that experiment it was possible to measure the entire GDR strength function and the RMS charge radius was deduced. It was found that the charge distribution of ^{11}Be is similar to that of ^{10}Be core. In what follows we discuss some of

the experimental details of the possible experiments presented in this letter of intent in comparison with the ^{11}Be experiment.

From both the existing studies on ^{11}Be and ^{20}O it is clear that the GDR γ-decay measurements following Coulomb excitation can be made more easily if one has available higher bombarding energies and in the case of heavier neutron rich nuclei. This is because of the rapid increase of the excitation cross section with beam energy and charge. In fact, at a given Z the GDR excitation function increases by approximately one order of magnitude going from 100 MeV/u to 300 MeV/u and these high bombarding energies are presently available at GSI. Here we discuss briefly 3 possible interesting studies of the γ-decay of the GDR in three different nuclei one in the very light, the second the medium-heavy and the last in the heavy mass region. They represent a good starting point for further experimental and theoretical works.

For these measurements we plan to use the Rising set up (with the cluster Ge detectors at forward angles) which includes also 8 large volume BaF_2 scintillator detectors (each one having a diameter of 14.5 cm and a length of 17.5 cm) placed at very backward angles (at ≈ 30 cm from the target). With the BaF_2 scintillators we can measure more efficiently the highest energy transitions (up to ≈ 30 MeV) . In fact, because of the rather short length of the Ge cluster detector we can measure with good energy resolution only up to 12-15 MeV [9]. We have estimated that altoghether (taking also into account the Doppler shift at backward angles) the present BaF_2 detectors have an efficiency which is ≈ 0.7 times that of the BaF_2 array used at MSU for the ^{11}Be experiment. In addition we have estimated that up to 10-12 MeV the efficiency of the Ge cluster detectors in the Rising configuration is ≈ 0.5 that of the BaF_2 scintillators.

Among the light nuclei the most interesting and feasible case is that of ^{20}O. This nucleus has been studied via neutron decay at GSI by the LAND group [5] and consequently the additional study of the gamma-decay is particularly interesting and expected go give a more complete and consistent picture providing a more stringent test to the available RPA calculations.
Recent calculations by Coló and Bortignon have shown an interesting result concerning the low-energy region of the GDR (Pygmy resonance). It was found that, in contrast with simpler expectations, in the case of ^{20}O there is more strength at lower energy than in ^{22}O showing the importance of taking into account the detail of the shell structure.
The comparison of gamma and neutron decay of the GDR in this nucleus was the main motivation of the MSU experiment mentioned above [7]. However, in that experiment (at 100 MeV/u with a 30 mg/cm^2 target) it was possible to measure γ-rays only up to 8 MeV, namely below the particle threshold. In this spectral region some structure of E1 character has been observed. Mesurements with higher energy resolutions with Ge detectors are therefore very useful for a better understanding of this spectral region. With the BaF_2 scintillators we plan to measure the part at higher energy with the objective to study not only the pygmy resonance part but also to deduce the entire strength function.

A very interesting neutron rich nucleus in the medium mass region for which to study the GDR is ^{68}Ni. The energy of the first 2^+ state and the corresponding B(E2) value

suggest in this case a spherical sub-shell closure at N=40 [10]. The GDR response function has been recently calculated by Coló and Bortignon within the same formalism used for Oxigen isotopes (see figure).
One can note that in the region up to ≈10 MeV there is ≈ 7 % of the EWSR (similar values were found in break-up experiment for light nuclei). It is important to stress that the knowledge of the low-lying dipole strength (Pygmy resonance) in medium mass neutron-rich nuclei is relevant for astrophysical studies such as the calculations of the element abundancies in the r-process of the nucleosynthesis as reported in [11].
However also in this case an effort should be made to measure the entire GDR strength to RMS charge radius and see if there are possible modifications of the charge distribution due to neutron excess.

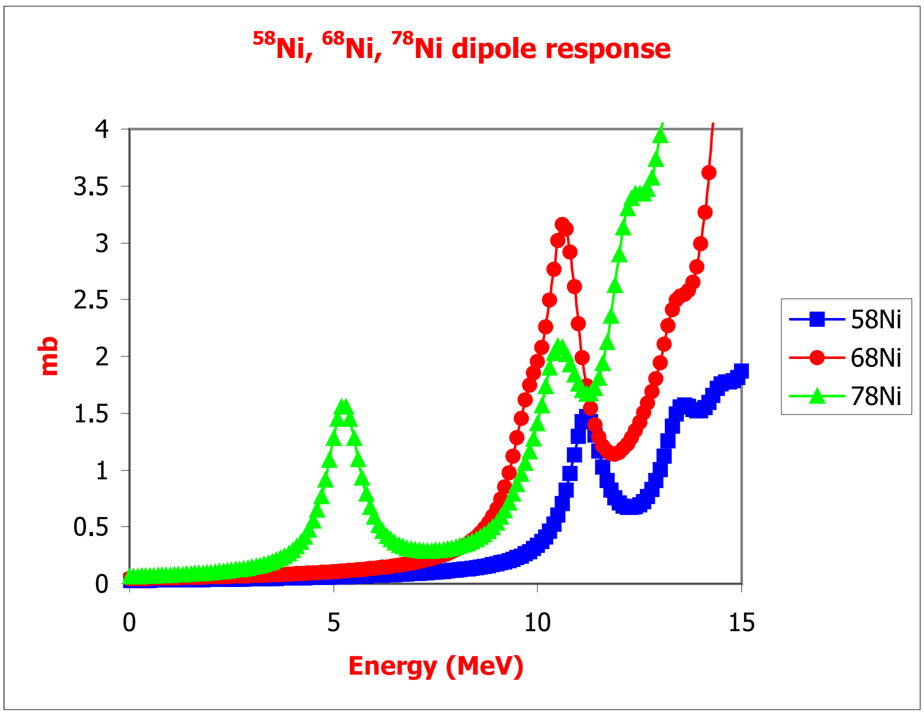

Figure 1. Low energy part of the photoabsorbtion cross section calculated as in ref [4] for Ni isotopes. The entire strength function is in [8].^{68}Ni, shown with filled circles, is the nucleus we plan to measure.

Concerning the feasibility of the measurement one expects to gain at 300 MeV/u as compared to the ^{11}Be case 3 orders of magnitude as due to the combined effect of the increase of the cross section and target thickness. Consequently one needs a number of particle of the order of 10^4 .

Another interesting topic that can be investigated in connection with the GDR in relativistic heavy unstable beams is the study of this mode built on isomeric states. The aim of such studies is twofold : to deduce the nuclear deformation and to study the damping mechanisms. In fact, it is well established that the GDR couples to the quadrupole deformation and its line shape depends on this deformation. One of the main efforts made in the last decades in connection with the GDR has been the study of this mode built on excited states. Most of this work concerns the GDR built on compound nuclei (therefore an ensemble of excited states) characterised by both finite temperature and finite rotational frequency. By contrast, the Coulomb excitation of the GDR on isomeric beams gives the unique opportunity to investigate the GDR built on specific isomeric states with well established spins at zero temperature and provides a stringent test of the theory of the damping of this mode when built on excited states. The choice of the best case to investigate depends on the results obtained with the isomer experiments (presently being analysed) made and planned at GSI using relativistic ^{238}U and ^{208}Pb [12] beams. Among the most intensively populated isomers identified in the ^{208}Pb fragmentation are two isomers with spins of 7 and 11 hbar in the neutron rich ^{200}Pt nucleus. Nuclei in this region lie between the spherical, doubly magic shell gap at ^{208}Pb and the well established deformed mid-shell rare nuclei with A~180. As such, they have long been of specific interest due to their predicted triaxial shapes [12]. Therefore a measurement of the GDR strength function built on these isomeric states could give important information which is complementary to that obtained from the low-energy discrete spectroscopy.

For these experiments one has to measure not only the prompt radiation but also the delayed γ-rays emitted from a catcher at which the coulomb excited ion beams are stopped. The typical efficiency for low-energy γ-ray detection at the stopper is 10% so that we estimate that $\approx 10^4$ pps are required. The lifetimes of these isomers is in the tens of nanoseconds regime and thus GDR measurements can be made in parallel with some of the studies of the neutron rich Pt isotopes presented in the “stopped beam proposals” [13]. More details of rates etc. will be given at the time of the submission of the proposals.

As a concluding remark we like to stress that the GSI beams with the their high bombarding energies are unique for the study of GDR by Coulomb excitation. Therefore measurements of their γ-decay for the most intense beams should be undertaken. These experimetal studies will be the first in the field of collective modes in unstable nuclei from where to learn on charge distribution, shapes and on the isospin dependence of the in medium nucleon-nucleon interaction.

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