Search for iso-scalar excitation of PIGMY resonance in ^{68}Ni nuclei.

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In the last years the properties of collective states in neutron-rich nuclei have been studied. In particular, special attention has been devoted to the presence of dipole strength at low excitation energy. This strength has been often associated to the possible existence of a new mode: the Pygmy Dipole Resonance (PDR). This mode is carrying few per cent of the isovector EWSR, and it is present in many isotopes with a consistent neutron excess. Therefore their appearance is more pronounced in nuclei far from the stability line but its presence has been established also for very stable nuclei like ^{208}Pb. From the experimental information, measurements involving high energy Coulomb excitation processes with heavy ion collisions have been performed at GSI on ^{132}Sn[1] as well as on ^{68}Ni[2]. Another well-established method to study the PDR is by means of nuclear resonance fluorescence (or real photon-scattering experiments) performed on semi-magic stable nuclei at Darmstadt[3]. Recently, the same nuclei have been investigated by means of the (α, α' γ) coincidence method at KVI[4]. The importance of the studies of this new mode rely also on the fact that the experimental investigation clearly show that the PDR modes are connected to the neutron excess. The strength of the PDR has been related to the neutron skins and to the density dependence of the symmetry energy of nuclear matter[5,6]. Low-lying dipole mode has been widely studied from a theoretical point of view within several microscopic many body models[7-12]. They all agree on the properties of the transition densities which show clearly that the isoscalar and isovector components are strongly mixed.

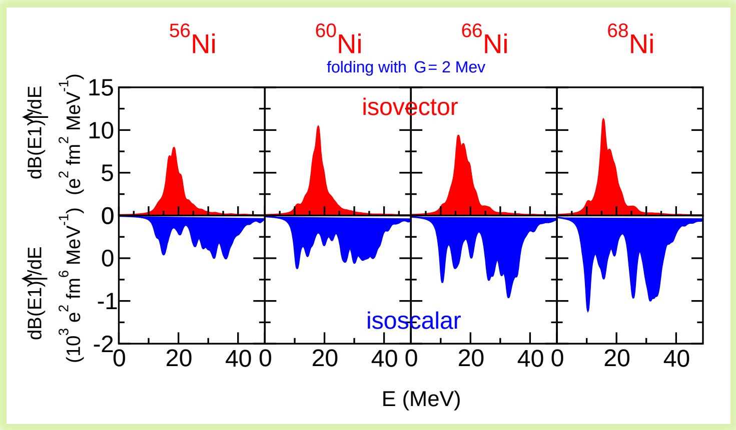

Fig. 1 RPA strength distributions for isovector (upper) and isoscalar (lower) response for four isotopes of Ni.

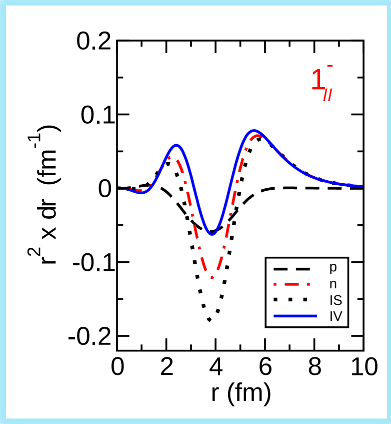

Fig. 2 RPA transition density for ^{68}Ni.

In figure 1 the dipole RPA strength distributions are reported for four isotopes of the nucleus Ni; the curves are generated by a smoothing procedure using a Lorentzian with a 2 MeV width. In the upper (lower) frame one can find the response to an isovector (isoscalar) probe. In particular they are generated by the action of the following two operators

$$O^{IV}_{1m} = \sum_{i=1}^{A} r_i \; Y_{1m}(\hat{r}_i)\, \tau^i_z \qquad ; \qquad O^{IS}_{1m} = \sum_{i=1}^{A} r_i^3 \; Y_{1m}(\hat{r}_i)$$

As soon as there is an increase of the neutron number, a small peak becomes appreciable in the isovector response and it is clearly discernible for the ^{68}Ni isotope. The corresponding peaks in the isoscalar distributions are increasing with the neutron number until it becomes dominant for the ^{68}Ni.

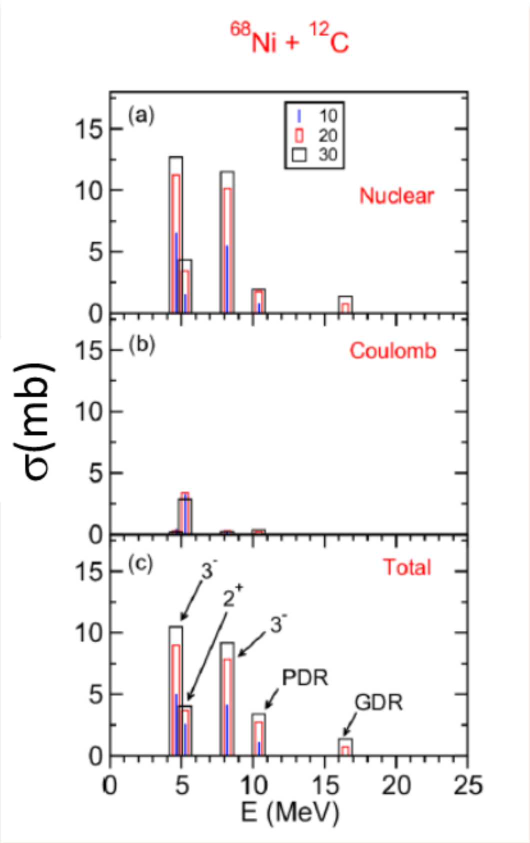

Fig. 3 cross section for PIGMY resonance excitation at 10, 20, 30 MeV/A

The low lying peaks have unusual features and these can be put in evidence by looking to their transition densities. In figure 2 they are shown for the ^{68}Ni isotope: in the picture there are the proton (dashed line) and neutron (dot dashed line) transition densities as well as the isoscalar (dotted line) and isovector (solid line) ones. One can notice that: The neutron and proton transition densities are in phase inside the nucleus and at the surface only the neutron part survives. These properties can be taken as a sort of theoretical definition of the PDR. At the interior the isoscalar part (dotted line) is much more pronounced that the isovector one (solid line) and at the surface both of them have almost the same strength. **This feature allows the possibility of studying these low lying dipole states by using an isoscalar probe in addition to the conventional isovector one.** In ref. [13] it was shown that valuable information on the nature of the PDR can be obtained by excitation processes involving the nuclear part of the interaction. In particular investigation of the PDR state can be better carried out at low incident energy (below 50 MeV/nucleon) using for instance ^{68}Ni on ^{12}C. In figure 3 the results for the nuclear and Coulomb contributions as well as the total one are shown for this case for three different incident energies (10, 20, 30 A·MeV). We would like to stress that although the Coulomb contribution for the PDR is very small a constructive interference is clearly shown in the lower frame where the total contributions are plotted. At LNS the ^{68}Ni beam was recently produced during a test experiment in the CHIMERA hall, (see fig.4). A yield of 20kHz was measured for this beam. We propose therefore to use this beam at energy around 30 A·MeV on a thick ^{12}C target (100 μm) to excite the pigmy resonance. The γ-decay of the resonance can be measured using the CsI(Tl) of the CHIMERA detector [14].

The detection efficiency of such detectors to γ-rays, as evaluated with GEANT simulations, is of the order of 30% around 10 MeV (integrating the energy released from 8 to 10 MeV). Detection efficiency and spectra quality was recently proved measuring the γ-decay of ^{12}C levels excited with proton beams during calibration runs. As an example we plot, in fig.5a, the γ-ray angular distribution, measured with CHIMERA, for the decay of the ^{12}C, 4.44 MeV level, excited trough p,p' reaction at 12 MeV proton beam energy. A typical γ-

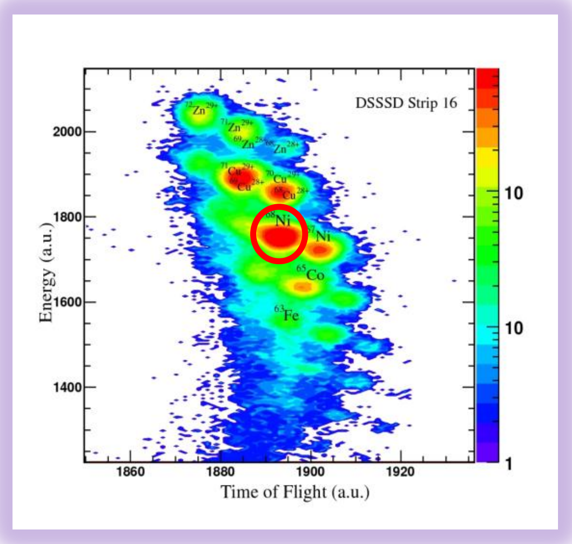

Fig.4 Identification scatter plot of ^{68}Ni fragmentation beam

ray spectrum (background in green) is also plotted in fig.5b.

In the reaction some γ-ray background can be produced due to various reaction mechanisms therefore a selective trigger is needed. Firstly we will concentrate our self only on in-elastically scattered Nickel ions with energy compatible to the pigmy resonance excitation. This should also clean from events where a neutron is emitted. We expect in fact that if a neutron is evaporated, due to its relatively low center of mass energy, it will be emitted in the lab approximately with the beam energy (around 30 MeV). Therefore this energy will be missing from our Nickel ion [15].

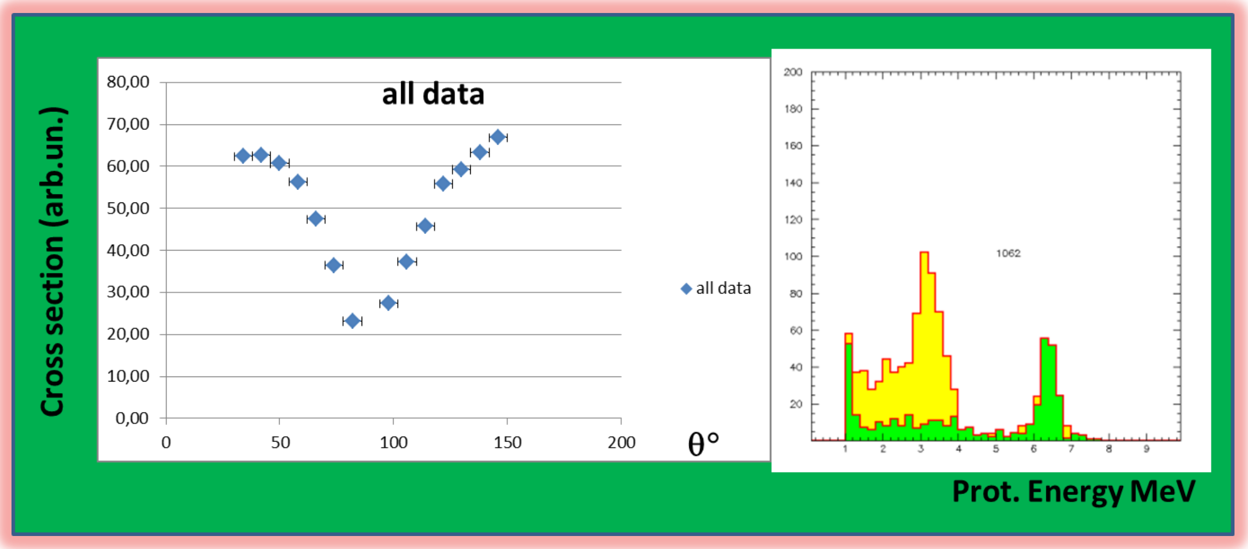

Fig.5 a) Angular distribution of gamma rays from the 4.44 ^{12}C level excited with p beam. b) gamma ray spectrum from the decay of the 4.44 MeV excited level, detected in a CHIMERA CsI.

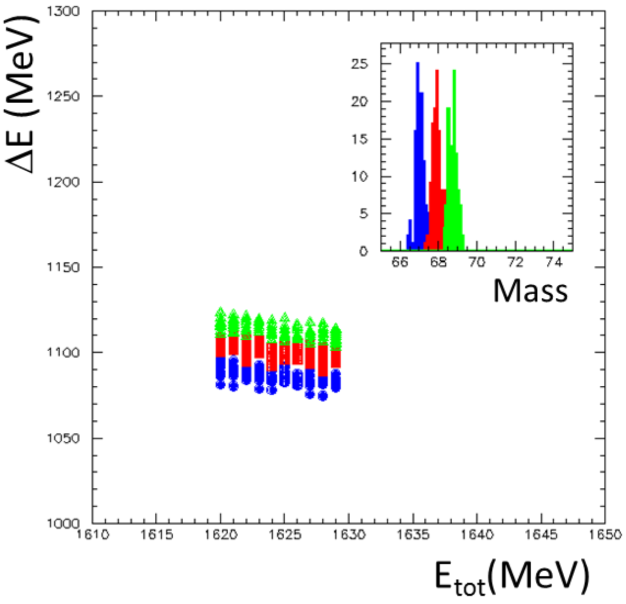

Fig.6 SRIM simulations of the energy loss against total energy of various nickel isotopes in the first two stages of a FARCOS telescope. In the inset a preliminary mass estimate is plotted.

We can very well measure the energy of Nichel ejectiles by using the new FARCOS telescopes we have recently put into operation [16]. This precise energy measurement, compared to the beam energy, is therefore a first constraint to the mass of the detected nucleus. Another important information can be given by the ΔE-Etot analysis of the event. All the energy of Nickel ions will be lost on the first two silicon stages of FARCOS (300 and 1500 micron). More in detail about 1.1 GeV will be lost in the first stage and around 500 MeV in the second stage. This fact could allow to put another constraint to the mass of detected isotope. In fig.6 we plot energy loss calculations performed with SRIM for different Nickel isotopes with the same total energy. We note that there is a difference of about 15 MeV between the energy lost in the first stage by different isotopes. Convoluting this energy loss information with the expected resolution of our detectors (around 0.3%) and taking into account the uniformity of the detector thickness we have in the 2x2 mm^2 pixel, we expect to be able to reject at least events of mass 66, so further decreasing the γ-ray background. Mass identification should in fact be a little worse than the one shown in inset of fig.6 where only straggling is taken into account.

From fig.3 one can estimate a total cross section of about 3mb. Assuming this and using a target of about 100 micron of ^{12}C i.e. $1.1*10^{21}$ nuclei/cm^2, with the 20kHz beam available, we should excite about 240 times each hour the pigmy resonance. Only about 5% of such resonances decay by emitting γ-rays. Taking into account the 30% total γ-ray efficiency of CHIMERA CsI(Tl), we can detect about 4 γ-rays each hour therefore 10 days beam time (30BTU) are necessary to collect enough statistics to extract the angular distribution necessary to demonstrate the dipolar character of the emitted γ-rays.

We need also 6 BTU proton beams of tandem energy (20 MeV if available) or at CS energy (30 or 40 MeV) for γ-rays energy calibration. Moreover we need 6 BTU 30 A·MeV ^{58}Ni beam to perform a “background” experiment, necessary to evaluate the background γ-rays contribution especially from GDR. Moreover the higher statistics available with the stable beam will allow to well establish the grids for particle identification both in FARCOS and CHIMERA telescopes.

In parallel to the main objective of the proposal, cross section measurements on projectile fragmentation of all nuclei around ^{68}Ni available in the cocktail beam will be performed. Also the population of the Pigmy resonance on all the other available beams will be investigated.

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