Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Nuclear Physics A 788 (2007) 182c–187c
NUCLEAR PHYSICS A

Measurement of the GMR in the Unstable ^{56}Ni Nucleus using the Active Target Maya

C. Monrozeau[a], E. Khan[a], Y. Blumenfeld[a], W. Mittig[b], D. Beaumel[a], M. Caamaño[c], D. Cortina-Gil[c], C.E. Demonchy[d], N. Frascaria[a], U. Garg[e], M. Gelin[b], A. Gillibert[f], D. Gupta[a] *, F. Maréchal[g], A. Obertelli[f], P. Roussel-Chomaz[b] and J-A.Scarpaci[a]

[a]Institut de Physique Nucléaire (IN2P3/CNRS, Univ. Paris Sud), 91406 Orsay Cedex, France

[b]GANIL (DSM/CEA, IN2P3/CNRS), BP 5027, 14076 Caen Cedex 5, France

[c]Univ. Santiago de Compostela, E-15706 Santiago de Compostela, Spain

[d]Univ. of Liverpool, Dep. of Physics, Olivier Lodge Lab., Liverpool L69 7ZE, U.K.

[e]Univ. of Notre-Dame, Dep. of Physics, Notre Dame, IN 46556 USA

[f]CEA/DSM/DAPNIA/SPhN, Saclay, 91191 Gif-sur-Yvette Cedex, France

[g]Institut de Recherches Subatomiques (IN2P3/CNRS), BP 28, 67037 Strasbourg, France

The measurement of the Isoscalar Giant Monopole Resonance(GMR) in unstable nuclei remains a major experimental challenge due to low radioactive beam intensities and unfavourable conditions in reverse kinematics. At GANIL, we have tested a new experimental method based on the unique capabilities of the active target Maya to probe the GMR by the inelastic scattering reaction ^{56}Ni(d,d') at 50 AMeV. The preliminary excitation energy spectrum of ^{56}Ni presents a bump between 12 and 25 MeV where isoscalar resonances are expected.

1. INTRODUCTION

The GMR in finite nuclei is of major importance because its properties are related to the nuclear matter incompressibility K_∞. The interest in determining K_∞ stems from its impact on the nuclear matter equation of state. Moreover the incompressibility of asymmetric matter is a basic parameter in calculations describing neutron stars or supernovae.

Some significant progress in our understanding of how K_∞ can be constrained have been achieved in recent times. Namely the procedure generally adopted to extract the incompressibility from the measurement of the GMR energy is the so called microscopic approach [1]. It is based on energy functionals which allow one to calculate finite nuclei and nuclear matter on the same footing. The first step consists in constraining the energy

*Present address : Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, India

doi:10.1016/j.nuclphysa.2007.01.080

functional in order to reproduce the experimental value of the monopole energy in a given nucleus. Theoretically the best way to extract the monopole energy is by means of constrained Hartree-Fock calculations [2, 3]. Then using this constrained energy functional the value of K_∞ is extracted.

Within the non-relativistic framework K_∞ can be fixed with an accuracy of 10% [3] and no discrepancy between the use of Skyrme and Gogny forces is observed. Nethertheless the extraction of K_∞ remains in some way model dependent : non-relativistic and relativistic mean field models predict values for K_∞ which differ significantly, namely $K_\infty \approx 220-235$ MeV and $K_\infty \approx 250-270$ MeV respectively when experimental data for the GMR in ^{208}Pb are used. Part of the remaining uncertainty may well be due to our poor knowledge of the symmetry energy [3]. Therefore the investigation of the GMR along an isotopic chain and particularly in neutron rich nuclei should be relevant to probe the role played by the symmetry energy in the determination of the nuclear matter incompressibility.

Isoscalar resonances, and in particular the GMR, have been extensively studied in stable nuclei. The best probes for their investigation are isoscalar probes such as deuterons or alpha particles at energies between a few tens and a few hundreds AMeV. Essentially no work has been done up to now for unstable nuclei, due to the very unfavourable conditions in reverse kinematics. Indeed, the GMR cross section peaks at 0° in the centre of mass frame which gives rise to very low recoil velocities for the light probe. To measure the excitation energy range between 0 to 30 MeV in reverse kinematics, it is necessary to detect the recoiling particle (d or α) with energies ranging from 100 keV to 2 MeV at angles from 0 to 40° in the laboratory frame. A standard set-up with a recoiling particle telescope such as MUST [4] would necessitate a very thin target ($\sim$ 100 μg/cm^2) to minimize straggling and thus require an intensity of over 10^7 pps which is prohibitive for current radioactive beam facilities.

With respect to these experimental constraints an active target such as Maya [5] could be the key to measuring the GMR in unstable nuclei. An active target is a gasous detector in which the detector gas also acts as target. Such a set-up has in principle an angular coverage close to 4π, a low energy threshold and a large effective target thickness. In order to test the method, we have performed inelastic deuteron scattering on the unstable ^{56}Ni nuclei at the GANIL facility. Alpha particle scattering could not be tested because the detector, like any detector target, sparked when filled with pure He.

In this paper we first present the experimental set-up. Then preliminary results such as excitation energy spectra are shown.

2. EXPERIMENTAL TECHNIQUE

2.1. The Maya active target

Active targets such as bubble chambers were developped since a long time in high energy physics. In the domain of secondary beams the archetype is the detector IKAR [6] which can be typically used at GSI energies. For the domain of lower energies a new detector called Maya was developed [7] at GANIL. The active target Maya is shown schematically in figure 1.

Maya can be characterised as a Time and Charge Projection Chamber. The electrons from the ionisation of the gas by particles drift down the electric field to amplifying wires set parallel to the beam. For a two body reaction scattered and recoiling particles are in a plane which can be determined by the drift time to wires. The amplified signal is induced on the anode, a matrix of 35 by 34 pads connected to Gassiplex chips. The Gassiplex [8] is a 16 channel analogical multiplexed ASIC developed at CERN. A hexagonal structure was chosen for these pads in order to have the best conditions for the reconstruction of the projected recoil trajectory, independant of the direction. A typical event read-out matrix is shown in figure 2.

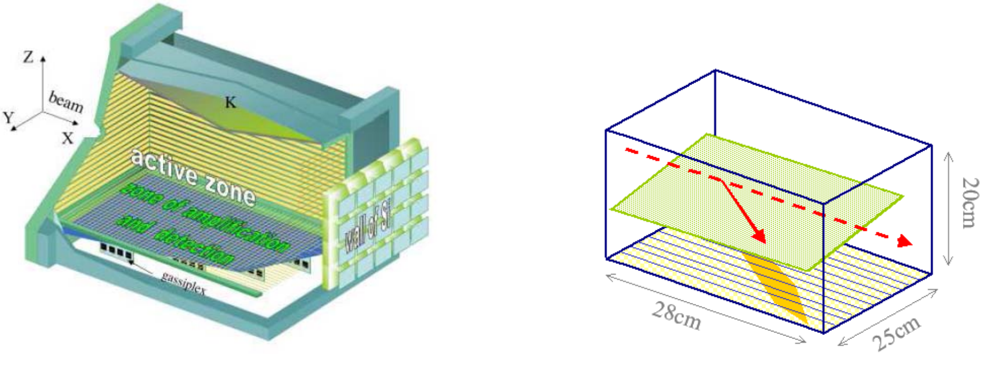

Figure 1. Schematic diagrams of the active target Maya. The secondary beam is incident from the left. Plates which are not shown in these schematic drawings prevent the beam (in dashed line in the left figure) from inducing charges in Maya. Recoiling particles produce electrons by ionising the gas. The reaction plane is determined by the drift times of electrons. From the signal induced after amplification in the anode, the 2D trajectory of the recoil is reconstructed. Ancillary Si detectors outside the active volume detect escaping recoils.

2.2. Experimental Set-Up

The secondary ^{56}Ni beam at 50 AMeV was produced by fragmentation of ^{58}Ni at 75 AMeV on a 70.5 mg/cm^2 C target using the SISSI device and sent to the SPEG area. Maya was placed on the focal plane of the SPEG spectrometer [9] which was used to purify the beam. The main contaminant of the beam, ^{54}Co is a N=Z nucleus and cannot be separated from ^{56}Ni by the time of flight . A 1 mg/cm^2 Au foil was placed at the entrance of SPEG to induce charge exchange. ^{54}Co^{26+} and ^{56}Ni^{27+} were transported through SPEG with slightly different trajectories. Just before Maya a plate stopped the ^{54}Co so that only ^{56}Ni entered Maya through a circular window made of Mylar. We added two plates above and below the beam trajectory into Maya to prevent the highly ionising beam particles from inducing charges in Maya. However, due to the angular spread of the beam, some non-interacting ^{56}Ni ions were detected. This limited the beam intensity that could be used to 5.10^4 pps, while 10^6 pps of ^{56}Ni was available.

	charges																																times
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	46	72	109	95	33	0	0	3.35
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	41	82	131	164	140	59	12	0	3.47
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	25	47	72	87	94	86	70	48	25	7	0	0	4.13
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	42	63	71	67	55	39	28	18	8	0	0	0	0	0	4.77
12	0	0	0	0	0	0	0	0	0	0	0	0	0	11	28	46	60	60	50	33	19	0	0	0	0	0	0	0	0	0	0	0	5.51
13	0	0	0	0	0	0	0	0	0	0	0	20	32	46	48	42	33	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.17
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6.94
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.72
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7.71
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30.00

Figure 2. Typical event matrix as read out for the Maya detector. The calibrated amplitude from the Gassiplex matrix is printed out for 32 columns, and the first 20 rows. The beam particle is coming from the left but does not induce charges in Maya. Only the deuteron from inelastic scattering is detected. Times on wires are printed out on the right.

The Maya active target filled with deuterium gas, at a pressure of 1050 mbar, forms a pure deuterium target of 1.6 mg/cm^2 that is equivalent to a target of 6.3 mg/cm^2 of CD_2. In that case deuterons of 700 keV, which is our effective threshold, have 5 cm long trajectories. As pointed out above, reverse kinematics generate recoil particles in a large energy domain. High energy light particles ($E \geq 2$ MeV) such as deuterons could not be stopped in the Maya gas volume. For such escaping particles, we added ancillary 500 μm Si detectors outside the active volume covering about 30 degrees around the beam direction for events in the midle of the detector. Data from these detectors have not yet been analysed and only particles stopping in Maya are considered in the following. For normalization purposes the beam was counted in a diamond detector after traversing Maya.

3. PRELIMINARY RESULTS

For each event two physical observables have to be determined in order to reconstruct the kinematics of the reaction : the energy and the angle of the recoil. The 2D recoiling angle in the plane (x,y) is reconstructed by linear least square fitting of the positions of the pads touched with a weight proportional to the amount of charge deposited. The intersection of this line with the beam axis gives the vertex of the interaction. The recoil stopping point is determined by looking for the Bragg peak in the charge distribution along the trajectory. From the drift times the reaction plane is reconstructed and it is possible to determine, for each event, the recoil angle and the range in the deuterium gas. The energy of the recoil is related to its range in the gas through tables [10]. The 3D-reconstruction of scattering trajectories in MAYA provides the kinematics of the ^{56}Ni(d,d') reaction which is shown in figure 3.

The data are then transformed into the center of mass frame using two-body kinematics. The preliminary excitation energy spectrum of ^{56}Ni is shown in figure 4. This spectrum presents a peak centered at 0 MeV corresponding to elastic and inelastic scattering. The

FWHM gives an energy resolution of 3 MeV. At energies ranging from 12 to 25 MeV a bump in the excitation energy spectrum points out the presence of isoscalar giant resonances. According to a recent study on ^{58}Ni [12] the E0 and E2 strength are located respectively at 18.4 MeV and 16.6 MeV. The spectrum stops at 28 MeV because of experimental cuts. Higher excitation energies of ^{56}Ni will be reconstructed by the analysis of the Si detectors.

Since the experimental set-up was designed to detect very low deuteron energies, the method usually applied with Maya to disentangle proton from deuterons is not applicable [7]. Consequently some proton contamintation may be expected in the excitation energy spectrum. Protons can be produced mainly by two mechanisms : the deuteron break-up and one neutron transfer (d,p) reactions. The contribution of the deuteron break-up was estimated from cross-sections measured for ^{58}Ni at 50 AMeV [11]. These data are transformed in the reverse kinematics frame, convoluted by the geometrical acceptance of Maya and normalised to experimental data. It appears that the contribution of the deuteron break-up to the giant resonance bump is small. Concerning the (d,p) reaction, the lowest energy protons are scattered at backward angles. They can not interfere with giant resonances events.

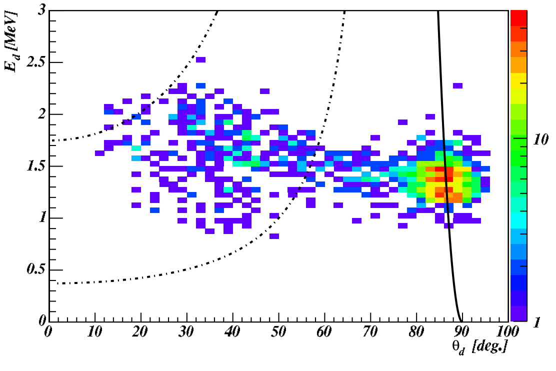

Figure 3. Experimental kinematics of the reaction ^{56}Ni(d,d') at 50A.MeV : scattered-plot of the energy of the deuteron versus angle in the laboratory frame. Lines are calculated kinematics. The solid line corresponds to elastic scattering. Isoscalar resonances are expected in the region limited by the dashed lines, between 12 and 25 MeV excitation energy.

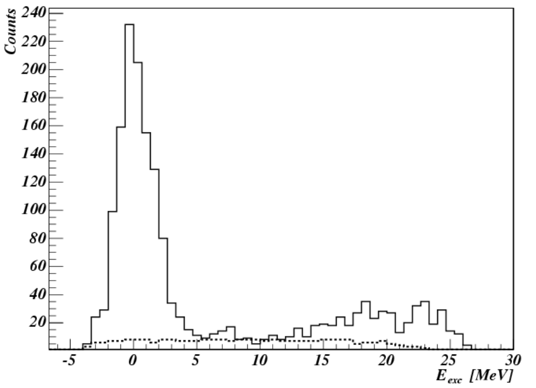

Figure 4. Preliminary excitation energy spectrum of the ^{56}Ni. The dashed line is the deuteron break-up contribution (see text), normalized so as to never overshoot the data.

4. CONCLUSION

With 15 hours of effective data taking, the excitation energy spectrum of ^{56}Ni presents some promising indications of isoscalar resonances. Our experimental method seems reliable to measure these resonances in unstable nuclei. The analysis of angular distribution should confirm these preliminary results. Even if using an active target implies to limit the intensity around 10^5 pps it makes our method relevant with respect to predicted production rates of exotic nuclei in current and future facilities.

REFERENCES

1. J.P. Blaizot, Phys. Rep. 64 171 (1980)
2. O. Bohigas, A.M. Lane, J. Martorell, Phys. Rep. 52, 267 (1979)
3. G. Colò et al., Phys. Rev. C 70, 024307 (2004)
4. Y.Blumenfeld et al., Nucl. Instr. and Meth. A421, 471 (1999)
5. W. Mittig et al., Eur. Phys. J. A 25, s01, 263-266 (2005)
6. A.A. Vorobyov et al., Nucl. Inst. Meth. 119 (1974) 509 and Nucl. Inst. Meth. A270, 419 (1988)
7. C.E. Demonchy, thesis T 03 06, Dec. 2003, U.Caen, France
8. http ://www.e12.physik.tu-muenchen.de/∼gernhaus/projects/gassipl/gassidok.html
9. L. Bianchi et al., Nucl. Instr. and Meth. A 276, 509 (1989)
10. L.C. Northcliffe and R.F. Schilling, Nucl. Data Tables A7, 322 (1970)
11. D.Ridikas et al., Phys. Rev. C 63 (2000)
12. Y.-W. Lui et al., Phys. Rev. C 73, 014314 (2006)