Population of yrast and non-yrast states in exotic nuclei

S. Bhattacharyya[1]*, M. Rejmund[2], A. Navin[2], E. Caurier[3], F. Nowacki[3], A. Poves[4], R. Chapman[5], D. O'Donnell[5], M. Gelin[2], A. Hodsdon[5], X. Liang[5], W. Mittig[2], G. Mukherjee[1], F. Rejmund[2], M. Rousseau[3], P. Roussel-Chomaz[2], K.-M. Spohr[5], and Ch. Theisen[6]

[1]*Variable Energy Cyclotron Centre, 1/AF Bidhan Nagar, Kolkata 700064, INDIA*
[2]*GANIL, CEA/DSM-CNRS/IN2P3, Bd Henri Becquerel, BP 55027, F-14076 Caen Cedex 5, France*
[3]*IPHC, UMR7178, IN2P3-CNRS et Universit´e Louis Pasteur, BP28, F-67037 Strasbourg, France*
[4]*Departamento de Fisica Teorica and IFT/CSIC, Universidad Autonoma de Madrid, 28049 Madrid, Spain*
[5]*School of Engineering and Science, University of the West of Scotland, Paisley PA1 2BE, Scotland, UK*
[6]*CEA-Saclay DSM/DAPNIA/SPhN, F-91191 Gif/Yvette Cedex, France*
** email: sarmi@veccal.ernet.in*

Introduction

Evolution of nuclear shell structure as a function of isospin degrees of freedom is one of the main thrust area of nuclear physics. Various reaction mechanisms have been explored to produce nuclei with extreme N/Z ratio [1]. Efforts to improve the experimental sensitivity of detection technique and theoretical modification of effective shell model interactions are going on side by side to understand the ordering of single particle states as one move towards nuclei far from stability [2]. Deep inelastic multi-nucleon transfer reactions made at energies near the Coulomb barrier have shown to be an efficient way to study neutron-rich nuclei both with sufficient excitation energy and angular momentum [3,4]. Direct identification of a particular nucleus is crucial since the most exotic species are usually produced with a cross section of several orders of magnitude smaller than those of main reaction channels.

Experimental Details

In-beam spectroscopy of extremely exotic neutron rich nuclei have been carried out using a 1.310 GeV ^{238}U beam from the GANIL cyclotron facility incident on an isotopically enriched ^{48}Ca target of thickness 1 mg/cm2 to produce neutron-rich nuclei around ^{48}Ca using deep inelastic multi-nucleon transfer reactions in inverse kinematics. The resulting target-like residues were detected and identified at the focal plane of the large acceptance spectrometer VAMOS [5], placed at an estimated grazing angle of 35^{o} with respect to the beam axis. The coincident prompt γ rays from the target-like residues were detected using segmented clover detector array EXOGAM [6] placed around the target. The event by event measurement of position and energy of the ions at the focal plane along with the known magnetic field facilitates the reconstruction of the magnetic rigidity, the mass (A), mass-to-charge ratio (A/Q) and the scattering angle after the reaction. These information along with the angle obtained between the γ ray detected by the segment of the clover detector were used to Doppler correct the gamma ray energies.

Results and Discussion

The derived mass spectrum of various elements produced from (+p, +xn) channels is shown in Fig.1. High N/Z ratio of both target and projectile favours the population towards neutron rich side of the beta stability line. Population of extremely neutron rich nuclei, such as ^{53}Ca (N/Z=1.65) and ^{58}Ti (N/Z=1.63), clearly observed from the mass plot of fig.1. These results represent the limits of present day experimental sensitivity for the detection of very low cross section. The gamma ray spectra in coincidence to a particular fragment have also been obtained. The relatively large population of non-yrast states in addition to yrast states has been observed in most of the cases, in contrast to the observed feeding of states in other studies of deep inelastic transfer measurements using only gamma-gamma coincidence information. Fig.2 shows the feeding pattern of states in case of Ca isotopes. A strong population of the states that

are of an octupole vibration nature has been already reported [4]. In addition, population of non-yrast states and the corresponding transitions from 2^{nd} 2^+ and 3^{rd} 2^+ states to the first 2^+ have been observed throughout the isotopic chain.

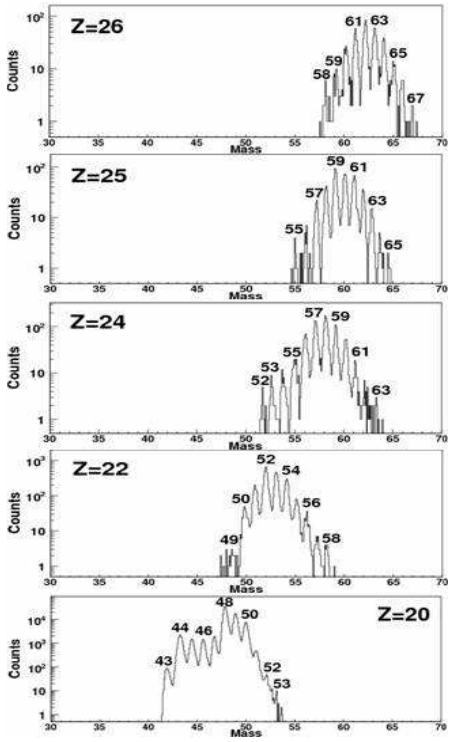

Fig. 1: The reconstructed mass spectrum for a single Si detector at the focal plane for various elements obtained for a selected charge state.

This was further verified in the Ar isotopes, especially in ^{40}Ar where even the population of the 2^+_3 was observed rather than the population of a 6^+ state. The experimental ratio of transition energies de-exciting the 2^{nd} and 1^{st} 2^+ states has been shown to be used to probe the development of non-axial deformation in case of ^{48}Ar [7].

Summary

In summary, the present results show that the high selectivity of a large acceptance magnetic spectrometer coupled to a gamma array is an efficient experimental device in identifying new neutron-rich nuclei produced with small cross sections.

References

[1] O. Sorlin and M. G. Porquet, Prog. Part. Nucl. Phys. **61** (2008) 602.
[2] E. Caurier *et al.*, RMP **77** (2005) 427.
[3] R. Broda, J. Phys. G **32** (2006) R151.
[4] M. Rejmund *et al.*, PRC **76** (2007) 021304(R).
[5] S. Pullanhiotan *et al.*,Nucl. Instrum. Methods **A593** (2008) 343.
[6] J. Simpson *et al.*, Heavy Ion Phys. **11** (2000) 159.
[7] S. Bhattacharyya et al., PRL 101 (2008) 032501.

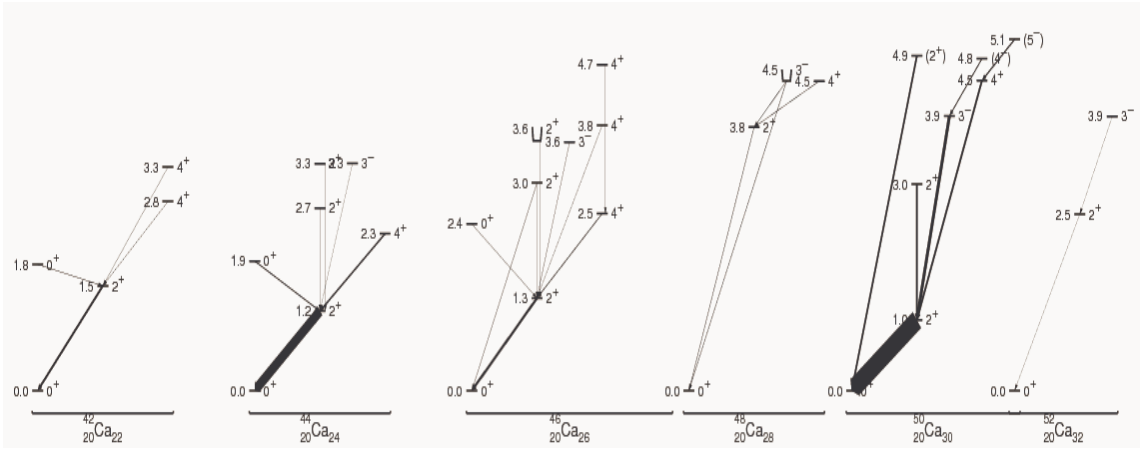

Fig. 2: Population of yrast and non-yrast states in Ca isotopes