Population of pairing-vibration states in even Ca isotopes using PRISMA + CLARA

S. Szilner[1,6], L. Corradi[1], G. Pollarolo[2], S. Beghini[3], E. Farnea[3], E. Fioretto[1], A. Gadea[1], F. Haas[4], A. Latina[1], S. Lenzi[3], N.M. Marginean[1], R. Marginean[3], G. Montagnoli[3], D.R. Napoli[1], I.V. Pokrovsky[1], F. Recchia[3], M. Romoli[5], M-D. Salsac[4], F. Scarlassara[3], N. Soić[6], A.M. Stefanini[1], M. Trotta[5], C.A. Ur[3]

1 INFN, Laboratori Nazionali di Legnaro, Legnaro, Italy,
2 Dipartimento di Fisica Teorica, Università di Torino,
and Istituto Nazionale di Fisica Nucleare, Torino, Italy,
3 Dipartimento di Fisica, Università di Padova,
and Istituto Nazionale di Fisica Nucleare, Padova, Italy,
4 Institut de Recherches Subatomiques,
CNRS-IN2P3/ULP et Université Louis Pasteur, Strasbourg, France,
5 Istituto Nazionale di Fisica Nucleare, Napoli, Italy,
6 Ruđer Bošković Institute, Zagreb, Croatia

INTRODUCTION

Transfer reactions are known to be an important tool to probe nuclear structure properties. Systematic studies of light-ion induced reactions, especially (p,t) and (t,p), led to the identification of the calcium region as the only known region where the cross sections for the population of the excited 0^+ states is larger than the ground state. Those states have been recognized as multi pair-phonon states [1]. Multinucleon transfer reactions in ^{40}Ca+^{208}Pb have been studied at several bombarding energies using the time-of-flight spectrometer PISOLO [2]. In these inclusive measurements the total kinetic energy loss distributions of neutron pick-up channels display a well defined maximum that is shifted to high energy losses, leaving the ground states unpopulated. In agreement with the CWKB theory, which provide the final population of the single particle levels giving contribution to the observed maximum in the $+2n$ channel, we can infer that this maximum is essentially due to two neutrons in the $p_{3/2}$ orbital. This fact together with the known low energy spectra of ^{42}Ca suggest that these maxima correspond to the excited 0^+ states that were recognized as a pair mode. The neutron transfer channels in ^{40}Ca +^{90,96} Zr were also measured with PISOLO spectrometer at 152 MeV [3]. All Ca isotopes populated via neutron transfer behave similarly, having the maximum of total kinetic energy losses at the higher energy regions.

Using PRISMA + CLARA [4, 5], the Q-value range observed in these inclusive measurements can be studied into details by detecting γ-ray transitions between individual levels, providing a detailed information about the pair-phonon states.

EXPERIMENT AND EXPERIMENTAL RESULTS

An experiment was performed using the Tandem accelerator of the Laboratori Nazionali di Legnaro. A ^{40}Ca beam was accelerated onto a ^{96}Zr target at the incident energy of 152 MeV. Projectile like fragments were detected using the large solid angle spectrometer PRISMA, while the coincident γ rays were detected in the CLARA γ array. The ion mass and nuclear charge are determined from the information on the (θ,ϕ) entrance angles, (X,Y) exit position, time-of-flight and total energy [6–8]. The obtained mass resolution is $\sim 1/300$ and the

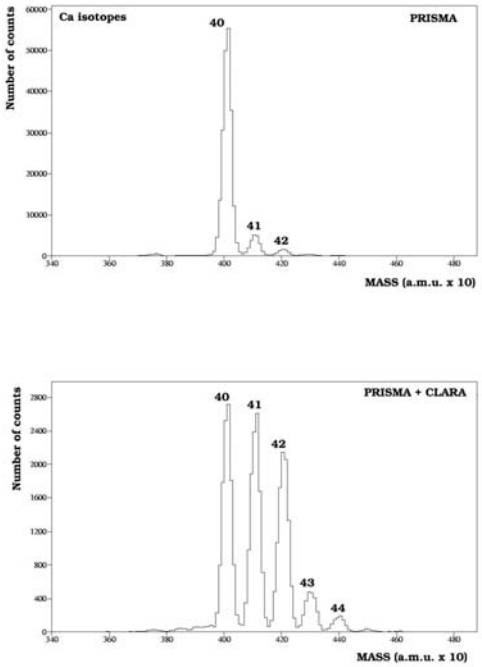

FIG. 1: Mass spectra of Ca isotopes obtained in the ^{40}Ca+^{96}Zr reaction at $E_{\rm lab}$ = 152 MeV at grazing angle without (top panel) and with (bottom panel) γ coincidences. Spectra have been obtained after gating on nuclear charge $Z = 20$, derived from the ionization chamber of the PRISMA spectrometer.

mass spectra of the Ca isotopes (gated on the $Z = 20$ in the $\Delta E/E$ matrix) are shown in Fig. 1. The top panel of the figure depicts the Ca mass distribution obtained using the PRISMA spectrometer only. The corresponding spectrum in coincidences with γ rays is shown at the bottom panel. A clear separation between Ca isotopes is observed. The different relative yields of the mass distributions are due to the different γ multiplicities of the reaction channels. The obtained ratio of events for the specific nuclei is consistent with the overall efficiency of CLARA. By gating on specific isotopes the coincident γ spectra can be obtained, and an example for $+2n$ channel, i.e. ^{42}Ca and ^{94}Zr, is shown in Fig. 2.

The same quality of the γ spectra are observed for the large range of nuclides populated in this multinucleon transfer reaction. The strongest observed channels are the neutron pick-up and the proton stripping, according to the Q-value systematics. As a preliminary result we will concentrate on the $+2n$ channel, where the strongest transitions in Fig. 2 can be identified as cascade through the yrast levels. The higher energy region, where the γ rays of the transitions from the states close to ~ 5 MeV excitation energy in ^{42}Ca are expected, strongly suggests that the states of the two-phonon structure are populated in this heavy-ion transfer reaction. The selective population of specific nuclear states observed in light-ion induced reactions was crucial in the development of the pairing model and the study of the nucleon-nucleon correlation. Heavy-ion reactions can substantially benefit by large number of transferred nucleons, still preserving the selective nature to some extent.

Reaction dynamics studies show that heavy-ion induced transfer processes populate channels at high excitation energy. This and the possibility of large angular momentum transfer allow the population of the excitation energy and spin regions not easily reached by other means. The analysis is in progress, and the first results of the observed transitions in the populated moderately neutron rich isotopes show several new transitions.

SUMMARY

The multi-nucleon transfer reaction ^{40}Ca+^{96}Zr was performed with a complete identification in mass and nuclear charge of projectile-like fragments in the spectrometer PRISMA, while the coincident γ ray transitions were measured by the CLARA γ array. The mass and charge distributions of the final products demonstrate that the multinucleon transfer reactions are powerful tool for the population of moderately neutron rich nuclei. The yields of the populated levels confirm the ability of the transfer mechanism to reach excitation energy and angular momentum regions not accessible by other mechanism. Population of the states with two-phonon structure underline that the heavy-ion induced reactions still preserve a significant degree of selectivity.

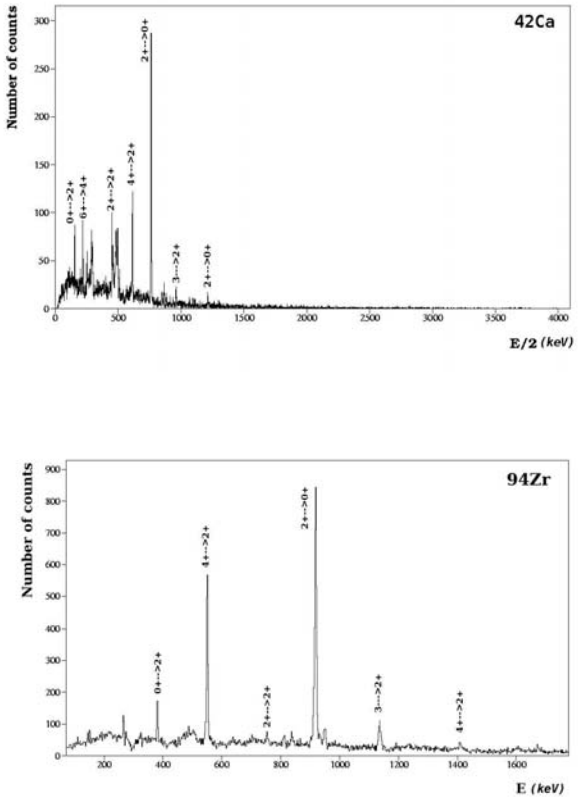

FIG. 2: Single γ spectrum obtained for the ^{42}Ca isotope after gating on mass $A = 42$ and nuclear charge $Z = 20$ (top panel), and the corresponding spectrum for the heavy partner of the binary reaction, ^{94}Zr (bottom panel). The spectrum is Doppler corrected for projectile-like (target-like) nuclei taking into account the geometry of detectors and the velocity of the ions. The final resolution of γ peaks is $\sim 0.3\%$.

[1] R.A. Broglia, O. Hansen and C. Riedel, *Advances in Nuclear Physics*, Plenum, New York, 1973, Vol. 6, p.287.
[2] S. Szilner et al, Eur. Phys. J. A **21**, 87 (2004).
[3] G. Montagnoli et al., J.Phys.(London) G **23**, 1431 (1997).
[4] A.M. Stefanini et al., Nucl. Phys. A **701**, 217c, (2002); LNL-INFN -120/97 (1997).
[5] A. Gadea et al., Eur. Phys. J. A **20**, 193 (2004).
[6] L. Corradi et al., in this Annual Report.
[7] G. Montagnoli et al., submitted in Nucl. Instr. and Meth. in Phys. Res. A.
[8] S. Beghini et al., Nucl. Instr. and Meth. in Phys. Res. A in preparation.