The ^{90}Zr + ^{208}Pb multinucleon transfer reaction studied with PRISMA+CLARA

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I. INTRODUCTION

Zr isotopes are very suitable candidates for spectroscopic studies of nuclei populated via multinucleon transfer mechanism. ^{90}Zr can be treated as a near closed shell nucleus with N=50 and Z=40, with a gap separating the f-p shell from the $g_{9/2}$ proton orbital. Zr nuclei have been populated in two-neutron pick-up channels with (p,t) reactions [1] and in two-proton pick-up channels with (^{14}C,^{16}O) reactions [2]. Work has been recently done on ^{90}Zr via (n,n') scattering [3], where large number of final states have been reached. In the present work we exploited for the first time multinucleon transfer reactions with very heavy ions, namely the reaction ^{90}Zr+^{208}Pb at an energy close to the Coulomb barrier, to study the population pattern of excited states in nearly spherical Zr isotopes via high resolution γ-particle coincidences [4]. Both projectile and target are well known closed-shell nuclei and therefore optimum candidates for having clean experimental and theoretical [5] conditions. Experiments with closed shell nuclei using ^{40}Ca beams already showed interesting results both in inclusive [6] as well as in a very recent γ-particle coincidence measurement [7].

II. THE EXPERIMENT

The experiment has been performed with the XTU-Tandem + ALPI booster accelerator complex of the Laboratori Nazionali di Legnaro. In a $\simeq$ 48 hours run a ^{90}Zr beam has been delivered at E_{lab}=560 MeV with an average intensity of 3 pnA onto a 200 μg/cm^2 ^{208}Pb target sandwitched between two 20 μg/cm^2 C-layers. Projectile-like products have been selected at θ_{lab}=62^0, an angle close to the grazing one, with the new spectrometer PRISMA [8]. γ-particle coincidences have been performed coupling the spectrometer to the γ-array CLARA [9]. PRISMA has a solid angle of $\simeq$ 80 msr, i.e. $\pm 6^0$ horizontal and $\pm 11^0$ vertical, a momentum acceptance of $\pm$10%, and a mass resolution of 1/300, achieved via trajectory reconstruction. It consists of a magnetic quadrupole singlet, placed at 50 cm from the target, and a magnetic dipole (60^0 bending angle and 1.2 m curvature radius). The ion mass is determined from the information on the (θ,ϕ) entrance angles, (X,Y) exit positions, time-of-flight (TOF) and total energy. The entrance detector is a two-dimensional position sensitive micro-channel plate (MCP) [10], providing a start signal for TOF with subnanosecond resolution and X,Y signals with 1 mm resolutions. Ions pass through the optical elements of the spectrometer and after a path of $\simeq$ 6.5 m, enter the focal plane detector [11]. This consists of an array of parallel plates of multiwire-type (MWPPAC), providing a stop for TOF and (X,Y) position signals, derived with the delay line method, with 1 mm resolutions; it is followed by an array of transverse field multiparametric ionization chambers (IC), providing ΔE and total energy signals. Both the MWPPAC and the IC are segmented into several sections, to preserve a high resolution even when detection rates overcome several kHz. CLARA consists of 24 Clover detectors from the Euroball collaboration, placed in a way to form a 2π configuration close to the target point. PRISMA and CLARA can rotate together around the target, by means of a thin (1 mm) spherical Al sliding seal scattering chamber.

III. FIRST RESULTS

In the present experiment, and in agreement with optimum Q-values considerations, the strongest observed channels are the pick-up of neutrons and stripping of protons. Fig.1 shows, as an example, the mass distributions of Zr isotopes after gating on the nuclear charge Z=40. Nuclear charges are obtained by constructing a ΔE-E matrix including all events in the IC after proper calibration of each subanode. The mass resolution turns out to be $\simeq$ 1/220, i.e. consistent with the characteristics of the spectrometer after taking into account target and detector resolution contributions. Final mass spectra have been obtained by linearizing the X-TOF matrix for each section of the MWPPAC and considering the energy information of the IC which allows solving the indetermination on the atomic charge states. One sees events corresponding to (dominant) pick-up as well as (weaker) stripping of neutrons. The bottom (top) part of Fig.1 corresponds to the spectra obtained with (without) γ coincidences with CLARA. One observes different relative yields in mass spectra for each isotope, due to the different γ-multiplicities for the various multinucleon transfer channels populated in the reaction. The ratio of events in the two spectra for specific masses is consistent with an overall efficiency of a few % of CLARA for γ transitions in the range $\simeq$ 2 MeV.

By gating on specific isotopes, we obtain the coincident γ spectra, shown in Fig.2 for the ^{90}Zr, ^{92}Zr and ^{88}Sr isotopes, the last one reached via the $-2p$ transfer channel. The spectra have been obtained after Doppler correction for the projectile-like nuclei selected by the spectrometer, taking into account position determination at the entrance of PRISMA, the ion time-of-flight (ions travel with a v/c $\simeq$ 8-10%) and the geometry of the Clover detectors. The final resolution of γ peaks at $\simeq$ 1.5 MeV is $\simeq$ 1%.

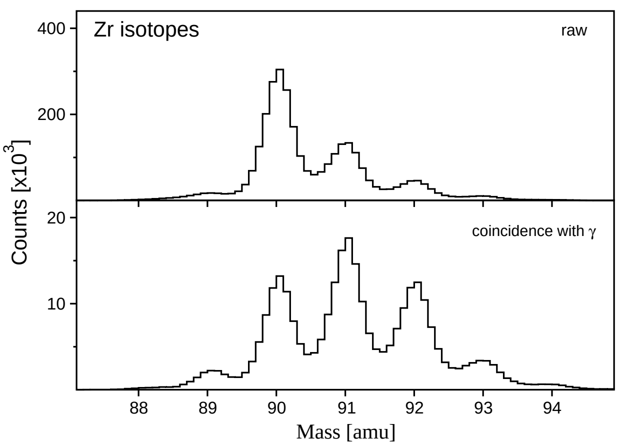

FIG. 1. *Mass spectra for Zr isotopes obtained in the reaction ^{90}Zr+^{208}Pb at E_{lab}=560 MeV and at θ_{lab} = 62^0 with (bottom) and without (top) γ coincidences. The spectra have been obtained after gating on nuclear charge Z=40, derived from the ionization chamber of the spectrometer*

In Fig.2, the strongest lines observed in ^{90}Zr are the $2_1^+ \rightarrow 0_{gs}^+$ (E$_\gamma$=2186 keV), $4_1^+ \rightarrow 2_1^+$ (E$_\gamma$=891 keV) and $3_1^- \rightarrow 2_1^+$ (E$_\gamma$=562 keV). The 2_1^+ and 4_1^+ levels are built from the $(\pi g_{9/2})^2$ configuration, and are located above the 0_2^+ state at 1761 keV, the 3_1^- is associated to the lowest octupole vibration. We also observe the intraband $4^- \rightarrow 5^-$ (E$_\gamma$=421 keV) transition, involving the $(\pi g_{9/2} \pi p_{1/2})$ configuration, and the interband $6^+ \rightarrow 5^-$ (E$_\gamma$=1130 keV) transition. In the spectrum of ^{90}Zr one sees a clear peak at E$_\gamma$=1874 keV. This corresponds to the $4^+ \rightarrow 2_1^+$ transition decaying from the high energy state at 4058 keV. We also see, clearly, the peaks at E$_\gamma$=3843 keV and E$_\gamma$=3305 keV, corresponding to $2_3^+ \rightarrow 0_{gs}^+$ and $2_2^+ \rightarrow 0_{gs}^+$ transitions, respectively.

In ^{92}Zr, reached via the $+2n$ pick-up channel, one sees transitions up to $16^+ \rightarrow 14^+$ (E$_\gamma$=1401 keV). This confirms the ability of these reactions with heavy ions to populate high spin states via large angular momentum transfer.

Analysis is in progress to determine the yield distribution of the various multinucleon transfer channels observed in the experiment and the strength of populated levels in Zr and Sr isotopes. This should also allow to study the population of states at about 4 MeV excitation energy where pair vibrational states are expected [12].

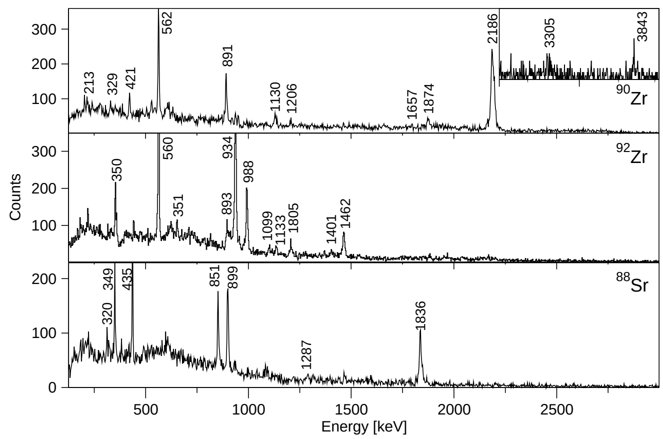

FIG. 2. *γ spectra for ^{90}Zr (top), ^{92}Zr (middle) and ^{88}Sr (bottom) isotopes, obtained after gating on proper mass and nuclear charge. The spectra are Doppler corrected for projectile-like nuclei taking into account the geometry of the particle and γ detectors, and the ion velocity. The inset shows the part of the ^{90}Zr spectrum with γ ray energies above 3 MeV.*

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