STUDIES OF NEUTRON-RICH NUCLEI WITH THE CLARA–PRISMA SETUP AND DESCRIPTION OF THE HEAVY-ION DETECTOR DANTE*

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The Clara–Prisma setup is a powerful tool for spectroscopic studies of neutron-rich nuclei produced in multi-nucleon transfer and deep-inelastic reactions. It combines the large acceptance spectrometer Prisma with the γ-ray array Clara. Currently at Lnl is being constructed the heavy-ion detector Dante, based on Micro-Channel Plates, that will be installed at the Clara–Prisma setup. Dante will open the possibility of measuring γ–γ Doppler-corrected coincidences for the events outside the acceptance of Prisma. In this manuscript some results obtained with the Clara–Prisma setup will be discussed, in addition to the description and performance of the first prototype for the heavy-ion detector Dante.

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1. Introduction

Neutron-rich nuclei are of particular interest since the neutron excess leads to interesting phenomena, such as neutron skin and modified shell structure. These nuclei are difficult to produce, particularly in high-spin states, with fusion-evaporation reactions. However, multi-nucleon transfer and deep-inelastic reactions together with high efficiency γ-ray arrays and ancillary detectors, to identify the reaction products, are an ideal mechanism to populate and study these nuclei at high spin, in spite of the low cross section. These reactions have shown to produce a high multiplicity of γ-rays [1].

The γ-ray array Clara coupled to the large acceptance magnetic spectrometer Prisma allows the study of moderately neutron-rich nuclei populated at medium-high spin via multi-nucleon transfer and deep-inelastic reactions [2, 3]. The setup provides correlations between the in-beam prompt γ-rays detected in Clara with the reaction products analyzed by Prisma, which are univocally identified in atomic number Z and mass A. Nevertheless, all the Clara events which are outside the Prisma acceptance, do not present enough information to Doppler correct the prompt γ-rays, *i.e.* those events do not contribute to the gated γ–γ coincidence matrices. In order to recover those events, the Dante array (Detector Array for multi-Nucleon Transfer Ejectiles) is being built at Lnl. Dante is a heavy-ion position-sensitive ancillary array based on Micro-Channel Plates (MCP). This detector will allow to reconstruct kinematically event-by-event and perform the Doppler correction of the prompt γ-rays detected in Clara.

In this manuscript some results obtained with the Clara–Prisma setup will be presented, in addition to the description and performance of one of the first prototypes of the heavy-ion detector Dante, that will be installed at the Clara–Prisma setup by the end of 2005.

2. The CLARA–PRISMA setup: description and results

Prisma is a large acceptance spectrometer for heavy ions installed at Lnl [4–6]. The spectrometer has been designed to fully exploit the heavy-ion beams of the Xtu Tandem-Alpi-Piave accelerator complex [7]. Prisma presents a large angular acceptance 80 msr, a momentum acceptance $\pm 10\%$, a mass resolution $1/300$ via Time-Of-Flight, an energy resolution up to $1/1000$ and the whole setup can be rotated around the target, according to the grazing angle of the reaction, in an angular range from -20° to 130°. The mass resolution performance is achieved by software reconstruction of the ion tracks. This is done by using the position, time and energy signals provided by the entrance and focal plane detectors of the spectrometer. Clara is a γ array formed by 25 Euroball clover detectors [2]. It is coupled to the PRISMA spectrometer and its photo-peak efficiency is around 3.3%, with an energy resolution of 10 keV for a product velocity (v/c) of 10%.

Multi-nucleon transfer reactions between heavy ions at energies close to the Coulomb barrier constitute a valuable tool, to populate medium-high-spin states in neutron-rich nuclei, otherwise not accessible in fusion-evaporation reactions. As an example, the neutron-rich $N = 50$ isotones, constitute a region of interest in nuclear structure physics, that can be studied in detail with the CLARA–PRISMA setup. For instance a new doubly-magic region centred around ^{78}Ni will exist if the nucleon numbers $Z = 28$ and $N = 50$ continue to be magic on the very neutron-rich side of the stability line. In order to study the possible quenching or disappearance of the classical $N = 50$ shell gap with an increasing N/Z ratio, an experiment was performed with the CLARA–PRISMA setup. A ^{82}Se beam at 505 MeV impinged on a thin (400μg/cm^2) ^{238}U target, the PRISMA spectrometer was placed at the grazing angle of the reaction, 64°. As a result of the reaction, the $N = 50$ isotones ^{87}Rb, ^{85}Br, ^{84}Se and ^{82}Ge were populated from medium- to high-spin states, see Fig. 1. Shell-model calculations were performed for the previously mentioned isotones in order to investigate the role of the neutron-core breaking excitations and, therefore, of the $N = 50$ shell gap. As a result of this study, was observed a strong indication that, when moving away from the stability line down to $Z = 32$, the $N = 50$ gap remains constant. A detail description of this study and other recent results obtained with the CLARA–PRSIMA setup can be found in Refs. [2, 3].

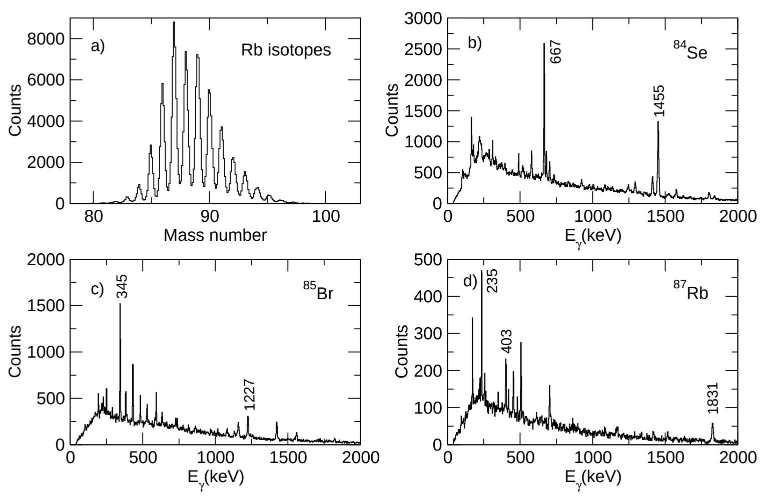

Fig. 1. (a) Mass distribution for the Rb isotopes detected by the PRISMA spectrometer, populated in the ^{82}Se+^{238}U reaction at 505 MeV of beam energy. Doppler corrected γ-ray spectra for ^{84}Se (b), ^{85}Br (c) and ^{87}Rb (d) measured with the CLARA setup, in coincidence with PRISMA.

3. The DANTE array

Dante (Detector Array for multi-Nucleon Transfer Ejectiles) is a heavy-ion position-sensitive ancillary array based on Micro-Channel Plates (MCP), being built at Laboratori Nazionali di Legnaro, that will be installed in the reaction chamber of the Clara–Prisma setup.

The first prototypes of the Dante array have been built and tested at the beginning of June 2005. They present a very similar configuration to the start detector of the Prisma spectrometer [5]. Each detector consists of a mylar foil, at the entrance, for electron production, followed by two Micro-Channel-Plates (MCP), of dimensions (40×60 mm^2), mounted in Chevron configuration. The position-sensitive anode consists of two orthogonal delay lines made from copper wires with a diameter of 100 μm, which are placed in such a way that a tin-coated cooper wire alternates with an isolated copper wire. These wires are connected to a low-noise differential preamplifier, in order to minimize the influence of fast signals from the MCP and are wound around a frame of two plexiglas rods. The rods present different diameters in each direction X and Y, in order to keep them insulated from each other and both of them from the steel reflection plate for electrons. The delay line is attached to the printed board circuit where the preamplifiers are mounted.

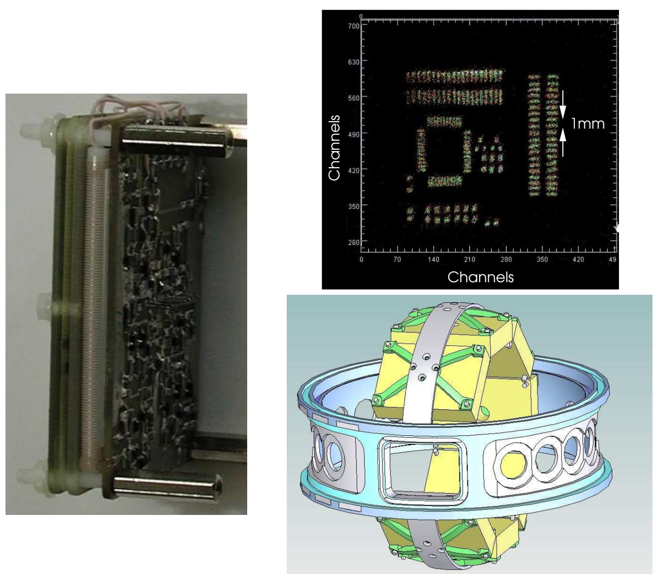

Fig. 2. View of one of the MCP prototypes of the Dante array to be installed at the Clara–Prisma setup at Lnl (left). Two-dimensional X–Y spectrum obtained from the MCP prototype detector where a suitable mask was placed in front, the test was performed with an α source (top right). Design of the Dante array at a configuration angle of 90° (bottom right).

Fig. 2 (left) shows a lateral photograph of a MCP prototype. The X and Y position are obtained from the difference in arrival time of the signal at one end of the corresponding delay line with respect to a reference time signal. The reference time signal is derived from the second MCP through a capacitor. The rise time of the fast time signals is around 2–3 ns.

The position and time resolution of the first DANTE prototype was measured placing an α source of ^{241}Am in front of the detector. The position resolution was measured to be better that 1 mm. Fig. 2 (top right) shows a two dimensional X-Y spectrum obtained placing a mask with narrow slits (1 mm) in front of the MCP entrance surface. The time resolution was extracted from a Time-Of-Flight (TOF) measurement. A small CORSET-type detector [8], providing the start signal, was placed between the α source and the DANTE prototype at around 15 cm, which provided the stop signal. The time resolution was measured in this configuration to be around 130 ps.

The final design of the DANTE array aims at maximizing the detection efficiency for the reaction products in combination with the γ–γ coincidences measured with the CLARA array. As a consequence, the MCP detectors will be placed around the grazing angle, where the cross section is largest. Fig. 2 (bottom right) shows the configuration of DANTE at 90° within the reaction chamber of CLARA. The configuration of the array will be flexible and would be varied depending on the grazing angle of the reaction.

In summary, the CLARA–PRISMA setup is a powerful tool to explore moderately neutron-rich nuclei, which were unaccessible via the traditional fusion-evaporation reactions. Results from experiments performed at CLARA–PRISMA in the spring 2004, have been presented. In addition the new ancillary MCP-based heavy-ion detector, being built at LNL, has been described. This ancillary detector coupled to CLARA will allow to measure recoil-γ–γ Doppler-corrected coincidences, for the events outside the acceptance of PRISMA. The commissioning will take place by the end of 2005.

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