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Data reduction for experimental measurements within the NUMEN project

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Abstract. Within the NUMEN project, we present experimental issues and data reduction for the ^{116}Cd(^{20}Ne,^{20}F)^{116}In single charge exchange, ^{116}Cd(^{20}Ne,^{18}O)^{118}In two-proton transfer and ^{116}Cd(^{20}Ne,^{19}F)^{117}In one-proton transfer reactions at 15 AMeV incident energy.

1. Introduction

The NUMEN (NUclear Matrix Elements of Neutrinoless Double Beta Decay) project proposes an original experimental method to get information on the nuclear matrix elements involved in neutrinoless double beta decay ($0\nu\beta\beta$), exploring its connection with double charge exchange nuclear reactions between heavy-ions. $0\nu\beta\beta$ Nuclear Matrix Elements (NMEs) are at the moment evaluable only through theoretical calculations [1, 2, 3] with not satisfactory agreement between the different models. In this view, the project [4, 5, 6] aims to use Double Charge Exchange (DCE) reactions as a tool to get experimentally driven information on $0\nu\beta\beta$ NMEs. Moreover, the absolute cross sections of competing multi-nucleon transfer channels on nuclei candidate for $0\nu\beta\beta$ decay are required. Indeed, to interpret the experimental cross sections and properly isolate the DCE contribution, the description of competing processes leading to the same final channel is mandatory. These are essentially one- and two-proton and neutron transfers. The physics case and the details of the project are discussed in Refs. [6, 7]. Experimentally, it is based on the use of the Superconducting Cyclotron high resolution beams and MAGNEX magnetic spectrometer [8, 9, 10], which is a relevant instrument in the research of heavy-ion physics [11, 12, 13, 14]. High performance are indeed required, since DCE as well as multi-nucleon transfer reactions are challenging from the experimental side due to the very low cross section expected and the large experimental background of competing processes; moreover, high mass, angular and energy resolution are needed to isolate specific transitions in such heavy-ions collisions. In addition, these experiments are more sensitive at very forward angles, so an important requirement is to access energy spectra and absolute cross sections angular distributions down to zero degree. In this contribution the experimental measurement of one-proton (1-p) and two-proton (2-p) transfer as well as single-charge exchange (SCE) reaction on ^{116}Cd target through the ^{20}Ne beam at 15 AMeV is presented. The experimental issues, the solutions adopted and the data reduction procedure are discussed.

2. Experimental Setup

The experiment was performed at the INFN-LNS laboratory in Catania. A $^{20}\mathrm{Ne}^{10+}$ beam was extracted by the K800 Superconducting Cyclotron, with an energy of 15 AMeV and impinged on a 1360±140 μg/cm^2 thick ^{116}Cd target coupled to 1000±100 μg/cm^2 carbon post-stripper. The latter is added in order to decrease the contribution due to lower charge states (8^+ and 9^+) of the beam generated by the charge redistribution in the target. These ions, expecially the $^{20}\mathrm{Ne}^{9+}$ elastically scattered at forward angles, have a magnetic rigidity close to that of some ejectiles examined, e.g. $^{20}\mathrm{F}^{9+}$ for the SCE channel. Thus, they enter in the focal plane detector (FPD) acceptance, introducing a large background which damages the detector, requiring a limitation of the beam intensity. In order to further reduce these contributions, the spectrometer momentum acceptance was limited: two aluminium screens were mounted before the entrance of the focal plane to stop these unwanted ions.

The beam charge was collected by a Faraday cup located 15 cm downstream of the target. An integrated charge of 3.4±0.4 mC was measured. The outgoing ejectiles were momentum analyzed by the MAGNEX spectrometer [8] and detected by its FPD [15]. Thanks to the large momentum acceptance all the channels − 1-p, 2-p transfer and SCE − were simultaneously detected within the same magnetic fields. A representation of the measured transitions at the target is shown in Figure 1.

The measurement was performed with the spectrometer optical axis centered at $\theta_{lab} = 8°$. Thanks to the large angular acceptance of MAGNEX, an angular range of $3° < \theta_{lab} < 14°$ in the laboratory frame was covered.

3. Data Reduction

The focal plane data analysis begins with the calibration of the horizontal X_i and vertical position Y_i measured by the FPD, as described in [16]. The next step is the identification of the different ejectiles, which are first identified in atomic number (Z) and then in mass number (A) and charge state (q) exploiting a characteristic magnetic technique [17] that provides a mass resolution sufficient to clearly separate, in these conditions, the different isotopes of interest [18].

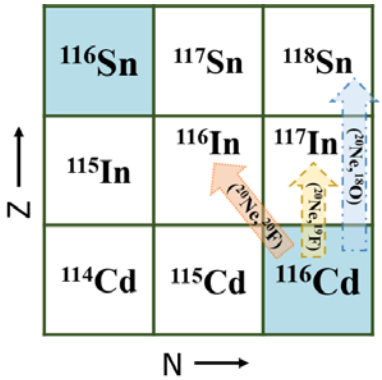

Figure 1. Reaction channels simultaneously measured using the same magnetic fields: (^{20}Ne,^{20}F) SCE in dotted ↖; (^{20}Ne,^{19}F) 1-p transfer in dashed ↑; (^{20}Ne,^{18}O) 2-p transfer in dashed-pointed ↑.

After the particle identification, the positions and angles of the selected ions measured at the focal plane are used to extract, event by event, the phase space parameters back to the collision point. To perform this back reconstruction, the global transport operator inside the magnetic elements of MAGNEX is required; setting the magnetic fields values and the geometry used during the experiment, the COSY INFINITY code [19] exploits an algebraic method to determine the spectrometer transport map (M) up to the 10^{th} order [20, 21, 22, 23]. Then, Monte Carlo simulated events are generated for each analyzed reaction channel and transported by M to the FPD, to be compared to the experimental data in order to test the accuracy of M in reproducing the high-order aberrations clearly present in the experimental scatter plots. As an example, some characteristic plots of the spectrometer for the ^{116}Cd(^{20}Ne,^{19}F)^{117}In data are shown in Figure 2 along with their simulated events.

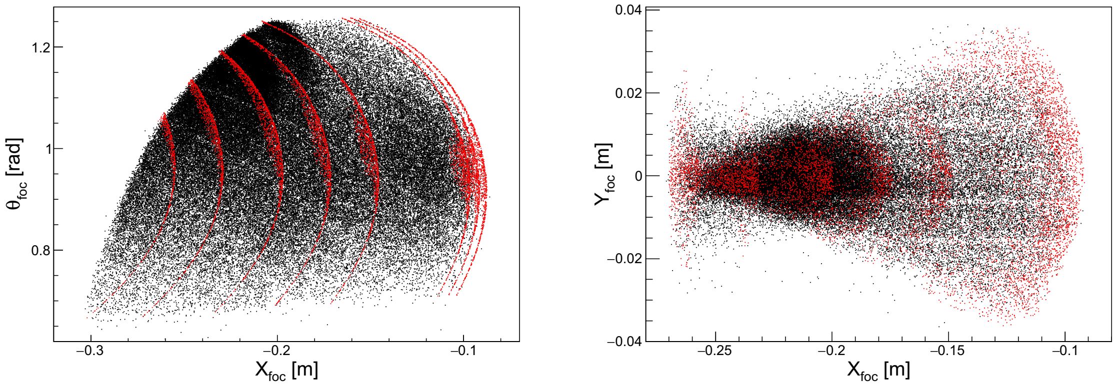

Figure 2. Correlation plots for the ^{19}F^{8+} SCE ejectile ions (black points) and simulated events for the same reaction (red points) including ground state (g.s.) and some arbitrary transitions. *Left panel:* horizontal angles θ_{foc} versus horizontal positions X_{foc} at the FPD. The first simulated profile – which corresponds to the g.s. transition – overlaps well with the experimental data. *Right panel:* vertical Y_{foc} versus horizontal X_{foc} positions at the FPD. The "half-butterfly" shape is due to the vertical non-linear focusing effect of the quadrupole field which is well reproduced by the simulated events.

Once a reliable direct matrix M is obtained, the inverse map (M^{-1}) is generated using COSY INFINITY and applied to the measured FPD data, thus returning the initial momentum vector at the target point, concluding the whole reconstruction procedure. The applicability of the described procedure to the presented data represents a relevant achievement in view of the development of the NUMEN experimental program.

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