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Heavy–ion particle identification for the transfer reaction channels for the system ^{18}O + ^{116}Sn under the NUMEN Project

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Abstract. The current work is a part of the NUMEN project, which aims to deduce the nuclear matrix elements (NME) of neutrinoless double beta decay by measuring the cross sections in heavy-ion induced Double Charge Exchange (DCE) reactions. The particle identification for the competing transfer reaction channels has been studied for the ^{18}O + ^{116}Sn system at 270 MeV.

1. Introduction

Neutrinoless double beta decay, $0\nu\beta\beta$, is at the present time strongly pursued both experimentally and theoretically [1]. Its observation will determine whether the neutrino is a Dirac or Majorana particle and will provide a measurement of the average neutrino mass, which is one of the most fundamental problems in physics.
The NUMEN project [2 – 4], at INFN Laboratory Nazionali del Sud in Catania (Italy), proposes to access the Nuclear Matrix Elements (NMEs) entering the expression of the life time of the $0\nu\beta\beta$ decay by measuring cross sections of DCE reactions in a wide range of incident energies. Crucial aspects of the project are the high-resolution in the energy spectra necessary to identify the transitions of interest and the accurate measurement of the absolute cross sections at very forward angles, including zero degree [5,6]. Moreover, a peculiarity of

NUMEN is the concurrent measurement of the other relevant reaction channels i.e., one- and two-neutron transfer, one- and two-proton transfer and single charge exchange. These studies are important because they allow to isolate the direct DCE mechanism from the competing multi-nucleon transfer processes. These are at least of 4th order in the nucleus-nucleus interaction and can be effectively minimized by the choice of the proper projectile-target system and incident energy [7]. In this manuscript we discuss the experimental measurement of the system $^{18}O + ^{116}Sn$, focusing in particular on the multi-nucleon transfer channels.

2. Experimental Details and Data reduction

The following competing channels were studied: 1n-transfer $^{116}Sn(^{18}O,^{17}O)^{117}Sn$, 2n-transfer $^{116}Sn(^{18}O,^{16}O)^{118}Sn$ and 1p-transfer $^{116}Sn(^{18}O,^{19}F)^{115}In$. These correspond to the almost complete net of transfer reactions for the system $^{18}O + ^{116}Sn$. Figure 1 shows the studied reaction channels.

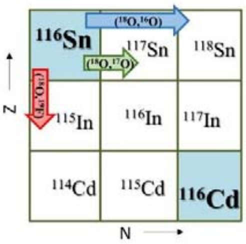

Figure 1: The net of multi-nucleon transfer reactions for the system $^{18}O + ^{116}Sn$

A beam of $^{18}O^{4+}$ ions, extracted by the K800 Superconducting Cyclotron accelerator, bombarded on 257 μg/cm^2 Sn target, at 270 MeV incident energy. The ejectiles produced were momentum-analyzed by MAGNEX [8,9,10], which is a quadrupole–dipole magnetic spectrometer characterized by a large angular (~ 50 mr) and momentum (–14.3%, +10.3%) acceptance and detected by its Focal Plane Detector (FPD) [11]. An angular range of $4^o < \theta_{lab} < 12^o$ was explored in the laboratory frame.

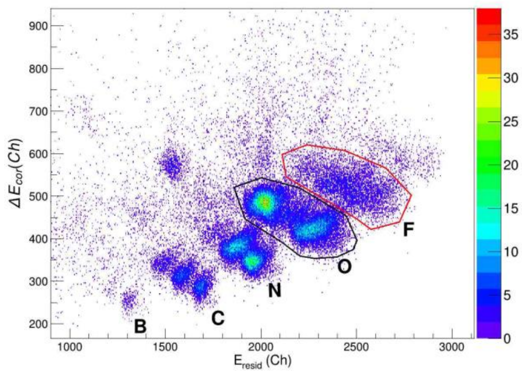

Figure 2: ΔE_{PC} - E_{resid} plot for the unselected ejectiles detected in the reaction $^{18}O + ^{116}Sn$ at 270 MeV incident energy for a single silicon detector. The other ejectiles like Boron, carbon, Nitrogen are also quite observable, apart from Oxygen and Fluorine. The graphical contours on Oxygen (black line) and Fluorine (red line) regions are also indicated.

The identification for the ejectiles were performed, firstly by identifying the atomic number (Z) using the standard $\Delta E - E$ technique based on Bethe-Bloch formula. A typical $\Delta E - E$ plot is shown in Figure 2 for a single silicon detector together with two coarse graphical contours: one includes the oxygen ejectiles (black line) and the other includes the Fluorine ejectiles (red line). The plotted parameters are the residual energy measured

by the Silicon detectors (E_{resid}) in abscissa, and in ordinate the energy loss in the gas measured by the PC counter (ΔE_{PC}) [11].
An innovative particle identification technique for the mass was introduced in ref. [12] that exploits the property of the Lorentz force, which determines the trajectory of a charged particle in a magnetic field to its momentum

$$B\rho = \frac{p}{q}$$

where p and q are the momentum and electric charge of the ion respectively, while ρ is the radius of curvature of the ion trajectory inside a dispersive element (bending magnet) with the field induction B.

In a non-relativistic approximation, the momentum p is related to the kinetic energy E and, approximately, to the residual energy measured by the silicons E_{resid}, by a quadratic relation $p = \sqrt{2mE}$, where m is the ion mass. Since the curvature ρ is related to the position at the focal plane X_{foc}, the relationship between the two measured quantities (X_{foc} and E_{resid}) is approximately quadratic with a factor depending on the ratio $\sqrt{m}/q$

$$X_{foc} = \frac{\sqrt{m}}{q}\sqrt{E_{resid}}$$

Therefore, in a X_{foc} v/s E_{resid} plot, the ions are distributed on different curves according to the ratio $\sqrt{m}/q$. The seperation between the different oxygen isotopes with the same charge state (8^+) is visible in Figure 3, where the X_{foc}-E_{resid} matrix shown is for the data selected in Figure 2, with the graphical condition on the ΔE_{PC}-E_{resid} (black line). For the present case, we chose the $^{16}O^{8+}$ ejectile (graphical cut in black), for the 2n-transfer reaction $^{116}Sn(^{18}O,^{16}O)^{118}Sn$, and $^{17}O^{8+}$ ejectile (graphical cut in red), for the 2n-transfer reaction $^{117}Sn(^{18}O,^{17}O)^{117}Sn$, as done with the graphical contour shown in Figure 3. Using the graphical condition on fluorine isotope in Figure 2 (red line), we can select the $^{19}F^{9+}$ ejectiles, for the 1p-transfer reaction $^{116}Sn(^{18}O,^{19}F)^{115}In$, as shown in Figure 4.

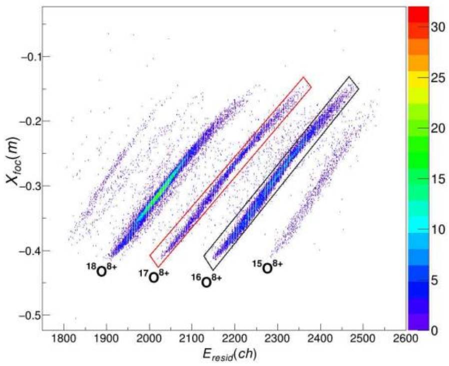

Figure 3: Typical X_{foc}-E_{resid} matrix plotted with the graphical condition of Figure 2 (black line) for the same silicon detector. The different isotopes for oxygen are seen and the graphical contours selecting the $^{16}O^{8+}$ ejectiles (black line) and the $^{17}O^{8+}$ ejectiles (red line) are also indicated.

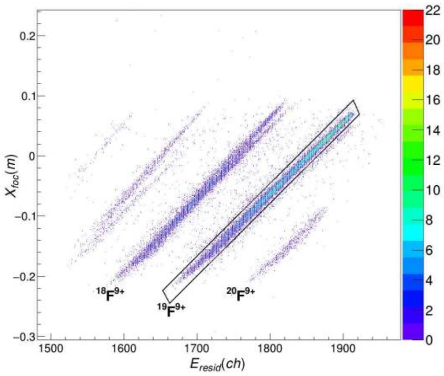

Figure 4: Typical X_{foc}-E_{resid} matrix plotted with the graphical condition of Figure 2 (red line) for the same silicon detector. The different isotopes for fluorine are seen and a graphical contour selecting the ^{19}F ejectile is also shown.

3. Summary and Conclusions

The identification procedures to separate the different ions has been carried out. Now after that the final phase space parameters has to be analyzed in detail which will provide an important information for the achieved horizontal and vertical focusing along with the aberrations [13,14]. Finally, the ray-reconstruction procedure will be applied to each set of analyzed data, according to the procedure described in refs. [15][16], in order to obtain the excitation energy spectra of the residual nuclei and the cross section angular distributions for the main transitions.

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