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Abstract. The MAGNEX magnetic spectrometer is nowadays used in the experimental measurements of rare quasi-elastic reactions between heavy ions at intermediate energy within the NUMEN project. The small cross sections involved in such processes under the large yields due to competitive reaction channels have motivated an accurate control of the background sources. In such view, the not ideal particle identification could introduce spurious contributions which have been identified and evaluated in the present analysis.

1. Introduction

The MAGNEX large acceptance magnetic spectrometer, installed at Laboratori Nazionali del Sud (INFN-LNS) in Catania, is a powerful device for the study of nuclear reactions in several systems. It has been used in a variety of nuclear physics research projects at bombarding energies between the Coulomb barrier and the Fermi energy [1, 2, 3, 4, 5, 6, 7, 8]. An accurate description of the facility and its operation procedure as well as the discussion of some relevant results recently obtained is available in Ref. [9]. Today, its use is strongly connected to the NUMEN project, whose experimental aims rely on the accurate absolute cross sections measurements of heavy-ion induced double charge exchange (DCE) reactions as well as competitive quasi-elastic processes. The main goal of the project, as widely discussed in Ref. [10], is represented by the systematic study of the DCE reaction properties to explore the connection with the neutrinoless double beta decay ($0\nu\beta\beta$) nuclear matrix elements. Due to the similarities between the two processes [10], such approach would offer novel and model-independent constraints to the $0\nu\beta\beta$ nuclear matrix element values, which are still an open question. A general issue of the DCE reaction studies is represented by the cross section suppression expected for such reactions, tipically ranging from few to hundreds nb depending on the particular case [11, 12]. In order to determine the experimental limit in the measurement of low cross section processes of the present set-up, a sensitivity study is needed. It is essential also to address the technology in view of the foreseen upgrade of the INFN-LNS facilities driven by NUMEN. Here, a method to estimate unavoidable contributions affecting the absolute cross section measurement is presented. It has been developed analyzing the ^{116}Cd(^{20}Ne,^{20}O)^{116}Sn DCE reaction data at 15.3 AMeV for which we have already shown promising results [13]. However, it can be directly applied to any other projectile-target system or reaction channel explored with the same experimental set-up.

2. Particle Identification

In the experiment a beam of ^{20}Ne^{10+} ions, extracted by the K800 Superconducting Cyclotron, impinged at 306 MeV incident energy on a 1370±140 μg/cm^2 ^{116}Cd target coupled to a 990±100 μg/cm^2 natural C foil. The latter is introduced to minimize the contribution due to 8+ and 9+ beam charge states generated by the charge redistribution in the primary target [14]. This solution, however, reduces only partially such background so that part of the MAGNEX focal plane detector (FPD) [15] was shielded by a system of movable aluminum screens to stop such ejectiles. The experiment was performed centering the spectrometer optical axis at $\theta_{lab} = 8^\circ$ so the angular acceptance in the laboratory frame was $3^\circ < \theta_{lab} < 14^\circ$. Thanks to the spectrometer large momentum acceptance, together with the (^{20}Ne,^{20}O) DCE reaction, also one-proton (^{20}Ne,^{19}F) and two-proton (^{20}Ne,^{18}O) transfer as well as single charge exchange (SCE) (^{20}Ne,^{20}F) reactions were simultaneously detected setting the same magnetic fields.

The performances guaranteed by the MAGNEX spectrometer for well identified events in terms of momentum and angle resolutions are excellent [16]. Thus, the main contributions affecting the overall spectrometer sensitivity come from the particle identification (PID) limits, due to the finite detection resolution and background contaminations. The PID technique adopted for MAGNEX is described in detail in Ref. [17]. For each ion detected by the FPD, one determines the atomic number (Z), the mass number (A) and the charge state (q). A and q are deduced by adopting a correlation between the measured position at the focal plane in the dispersive direction (X_{foc}) and the residual energy (E_{resid}) of the ejectiles. The two quantities are proportional to the ion $\frac{\sqrt{m}}{q}$ ratio. In the present experiment, the ^{20}O^{8+} ions of interest have similar $\frac{\sqrt{m}}{q}$ ratio to ^{20}F^{8+} and ^{20}Ne^{8+} ones, being 0.55907, 0.55901 and 0.55891 respectively. As a consequence, the events associated to the detection of such ejectiles share almost the same position in the $X_{foc}\%E_{resid}$ plot resulting indistinguishable in such representation. Thus, a first selection was done in the region where the three species are present in such representation.

Z is then selected exploiting the correlation between the energy loss in two different sections - a proportional chamber (PC) and a drift one ($DC2$) - composing the FPD, corrected by the path length in the gas depending on the incident angle ($\Delta E_{PC}\%\Delta E_{DC2}$). In fact, by adopting such correlation gated by this first selection makes it possible to identify the ^{20}O^{8+} ions (see the contour drawn in Fig. 1(a) for a single silicon detector). Finally, exploring again the $X_{foc}\%E_{resid}$

correlation gated by the $\Delta E_{PC}\%\Delta E_{DC2}$ selection, the unambiguous identification of the $^{20}O^{8+}$ in A and q is achieved, as shown in Fig. 1(b). Therefore, by adopting a logic AND condition between the two described topological selections, the $^{20}O^{8+}$ PID is accomplished.

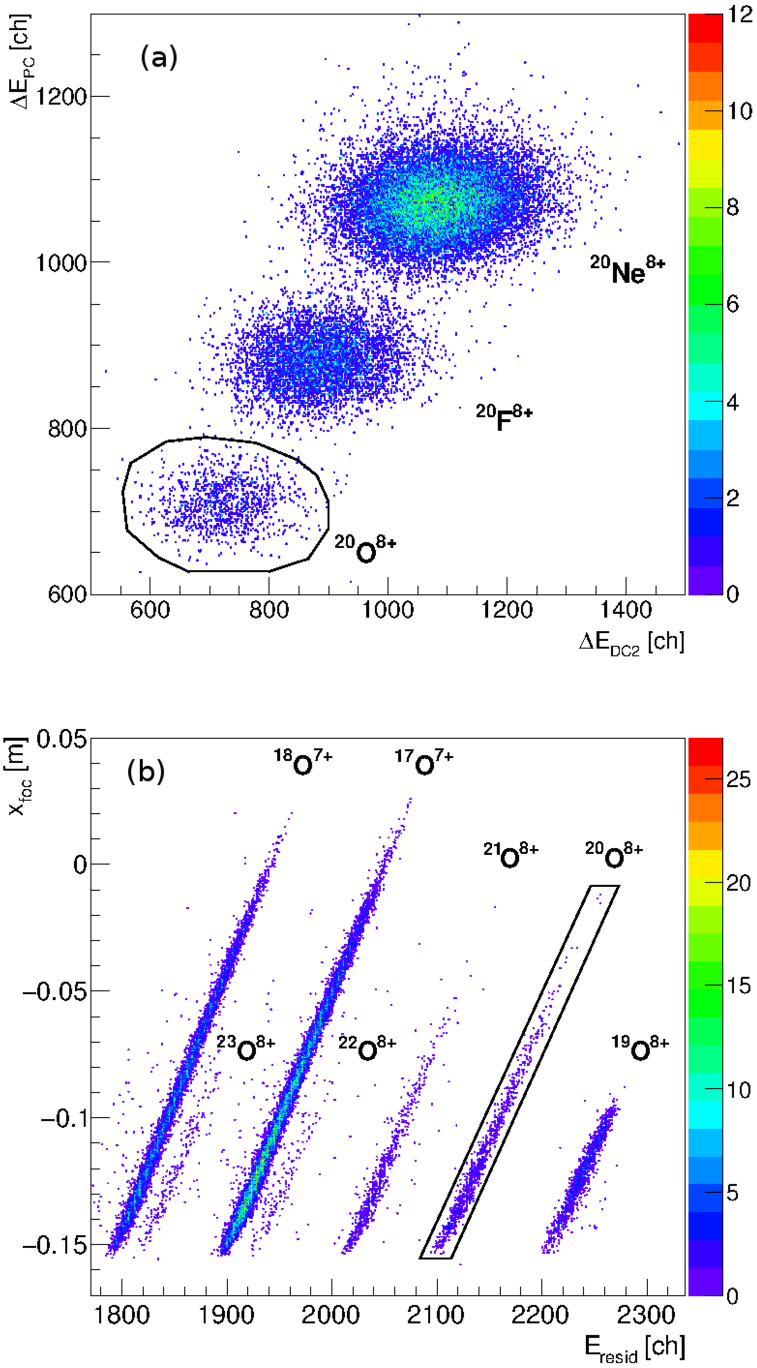

Figure 1. Particle identification technique adopted in the present experiment. Panel (a): selection in Z between $^{20}F^{8+}$, $^{20}O^{8+}$ and $^{20}Ne^{8+}$ in the $\Delta E_{PC}\%\Delta E_{DC2}$ plot. Panel (b): selection in A and q in the $X_{foc}\%E_{resid}$ representation gated by the contour drawn in panel (a).

3. Estimation of the PID background

To estimate the purity of the described PID in the measurement of the DCE channel, the effect of the topological selection defined for $^{20}O^{8+}$ ejectiles in the $X_{foc}\%E_{resid}$ representation shown in Fig. 1(b) was first studied. Such contour, in fact, selects not only the $^{20}O^{8+}$ ions but also part of the $^{20}F^{8+}$ and $^{20}Ne^{8+}$ ejectiles since the three species share almost the same position in $X_{foc}\%E_{resid}$ correlation. Plotting the ΔE_{PC} histogram gated by the mentioned topological condition causes the three loci to separate. A best fit analysis of the obtained spectrum, assuming Gaussian models for the peaks, was performed in order to distinguish the different contributions corresponding to the $^{20}O^{8+}$, $^{20}F^{8+}$ and $^{20}Ne^{8+}$ ions. In particular, the contribution of $^{20}F^{8+}$ and $^{20}Ne^{8+}$ events underneath the $^{20}O^{8+}$ peak was estimated by integrating the tails of their individual function in the $^{20}O^{8+}$ region. The latter is defined as $\pm 3\sigma$ from its centroid, consistent with the typical PID graphical selection width. The relative impurity values compared to the total identified $^{20}O^{8+}$ events are $\sim 0.1\%$ from $^{20}F^{8+}$ and $< 10^{-4}\%$ from the $^{20}Ne^{8+}$. Since the contribution due to the $^{20}Ne^{8+}$ events is considerably smaller than $^{20}F^{8+}$ one, it can be neglected hereafter.

About the A and q identification purity estimation, an analogous procedure was followed. The contour in the $\Delta E_{PC}\%\Delta E_{DC2}$ representation shown in Fig. 1(a) was adopted to explore the selected events in the $X_{foc}\%E_{resid}$ correlation. Due to the better intrinsic resolution of both X_{foc} and E_{resid} compared to ΔE_{DC2} and ΔE_{PC} [16, 17] it emerges that the impurity contribution to the $^{20}O^{8+}$ events from the mass and charge identification procedure is much smaller (average peak-to-peak distance of $\sim 20\sigma$) compared to the one coming from the atomic mass identification. However, few and isolated events are present between the well-separated loci in the $X_{foc}\%E_{resid}$ representation, not belonging clearly to any of them. Such spurious events do not appear to be distributed according to a clear pattern. Thus, assuming a constant density distribution, the amount expected underneath the peak corresponding to $^{20}O^{8+}$ ions in the $X_{foc}\%E_{resid}$ representation was estimated. The latter is defined as the interval spanning $\pm 3\sigma$ around the center of gravity of the peak corresponding to $^{20}O^{8+}$ ions. Typical values in different silicon detectors are $< 0.3\%$ over the total identified $^{20}O^{8+}$ ion number.

The described procedure can provide an estimation of the overall sensitivity of the cross section measurements achieved with the MAGNEX set-up for two-body reactions.

4. Conclusion

We have presented a method to quantify the PID impurity and background of the MAGNEX magnetic spectrometer, considering the $^{116}Cd(^{20}Ne,^{20}O)^{116}Sn$ reaction data. They come from the finite resolution in the energy loss measurements inside the gas chambers and from uncorrelated events returned by the silicon detectors. From such analysis it will be possible to estimate the minimum significant cross section measurable with the present MAGNEX set-up, which is a crucial quantity for the aims and the future developments of the NUMEN project.

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