Spectroscopy of natural parity states in ^{20}Ne via the ^{19}F(p,α_0) and ^{19}F(p,α_π) reactions at low energies

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Abstract. The ^{19}F(p,α_0)^{16}O and ^{19}F(p,α_π)^{16}O reactions can be fruitfully exploited to probe natural parity states above the proton emission threshold in the compound ^{20}Ne nucleus. However, despite the relatively large number of data sets published in the literature, it is still not possible to draw a fully unambiguous picture of the spectroscopy of ^{20}Ne, especially close to the proton emission threshold. To contribute to clarify these aspects, we have collected and reviewed all existing data sets of the ^{19}F(p,α_0)^{16}O and ^{19}F(p,α_π)^{16}O reactions to perform, for the first time, a comprehensive *R*-matrix fit including both reactions in the bombarding energy range E_p = 0.2-10 MeV. Our analysis clarifies several ambiguities present in the literature and affecting the spectroscopy of ^{20}Ne and clearly demonstrates the importance of the ^{19}F(p,α_π) reaction to better constraint the spectroscopy parameters of the fit.

1 Introduction

The investigation of low energy nuclear reactions induced by light particles (such as p or α) is a great opportunity to probe the spectroscopy (i.e. energy levels, decay widths, and J^π) of light nuclear systems formed as the compound nucleus [1–5]. Such reactions are also relevant to collateral domains of nuclear physics, such as nuclear astrophysics [4, 6, 7] and applied research [8–10].

The ^{19}F(p,α)^{16}O reaction has been shown to be a particularly powerful tool to investigate the spectroscopy of the self-conjugate ^{20}Ne nucleus at E_x > 12.884 MeV [11, 12]. Additionally, starting from even very low proton bombarding energies (few hundreds of keV) a number of reaction channels are energetically open, including the ^{19}F(p,α_π)^{16}O, where the residual ^{16}O nucleus is left in its first excited state (E_x = 6.05 MeV) and α-group followed by γ-ray emission ^{19}F(p,α_γ)^{16}O (having E_x = 6.13, 6.92, 7.12 MeV in ^{16}O). Regarding these reactions, a large body of data has been collected over the past decades, contributing to constrain the spectroscopy of ^{20}Ne in a wide energy range [13]. Despite these efforts, several ambiguities are still affecting the many states in ^{20}Ne, demanding for more detailed analyses.
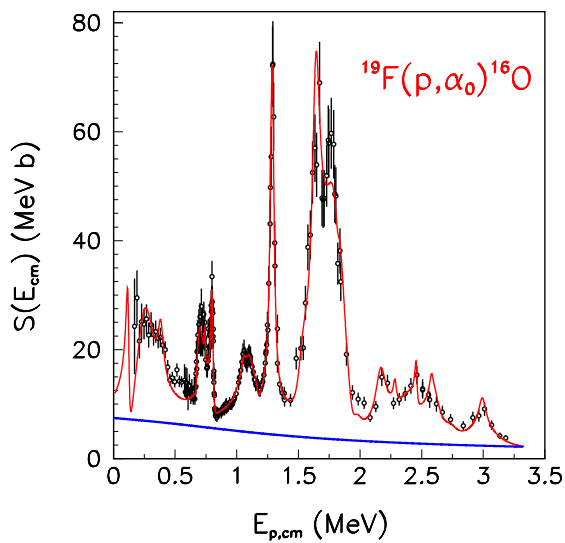
In this proceeding, we propose an extensive critical analysis of all data sets published in the literature concerning the ^{19}F(p,α_0)^{16}O and ^{19}F(p,α_π)^{16}O reactions at low bombarding energies ($E_p \approx$ 0.2-10 MeV). The obtained data sets are analyzed in terms of the R-matrix theory. For the first time, we perform a systematic and simultaneous fit of such a large data set. Our results help to improve the spectroscopy of several natural-parity states in ^{20}Ne.

2 Data sets and preliminary R-matrix analysis

In order to build a consistent set of data we have carefully reviewed all existing measurements published in the literature. For the ^{19}F(p,α_0)^{16}O, we have complemented the data reviewed in previous analysis [14], and cov-ering the incident energy range E_p = 0.2-3.5 MeV, with the high energy data of Ref. [15] ($E_p \leq$ 12.5 MeV). The latter is mandatory to constrain the contribution of direct processes, affecting the integrated cross section and angular distributions down to very low energies [6]. Our data set includes also data of the ^{19}F(p,α_π)^{16}O*(6.05 MeV) reaction. This is particularly important to increase the reliability of the R-matrix fit. In the energy regions E_p = 0.6-1.1 MeV and E_p = 1.7-2.5 MeV, we consider the data from Refs. [1, 2, 16]. We excluded from our analysis data from Ref. [17], obtained with a pair spectrometer and potentially affected by systematic indeterminations. All data sets agree reasonably in shape. Data of Ref. [16] have been normalized by a factor 0.5 in order to match with the data published in [1]. In the energy region E_p = 1.1-1.7 MeV, we used the differential cross section measured in Ref. [18] to calculate the integrated cross section, assuming the shapes of the angular distributions as recorded in [19].

We performed a comprehensive R-matrix analysis of the above discussed data set. As initial parameters of the fit, we considered the spectroscopy of ^{20}Ne as described in [13] and taking into account the findings of Refs. [6, 11]. We also included a direct contribution to the total cross section, possibly enhanced by the cluster configuration of ^{19}F, as discussed in [6, 20, 21]. The presence of an extended data set, and the simultaneous fit of more reaction channels, allow us to refine the spectroscopy of

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Figure 1. S-factor of the ^{19}F(p,α_0)^{16}O reaction as a function of the energy in the center of mass reference frame. The red line is the result of the R-matrix analysis while the blue line represents the direct contribution used to reproduce the data.

natural-parity states in ^{20}Ne in the excitation energy range E_x = 13-16 MeV. Preliminary results are shown for the ^{19}F(p,α_0)^{16}O reaction in Fig. 1, where the red line is the result of our fit procedure, while the blue line represents the expected direct contribution. The latter, has been obtained by including two broad poles in s and p waves at high energies to simulate a direct process. The overall reproduction of data is satisfactory in the whole energy range.

3 Conclusions and perspectives

In this paper, we have discussed some preliminary findings of a new comprehensive analysis of ^{19}F(p,α_0)^{16}O and ^{19}F(p,α_π)^{16}O*(6.05 MeV) data in the bombarding energy range E_p = 0.2-10 MeV. We obtained a consistent data set by carefully reviewing all previous measurements published in the literature. We used the R-matrix theory to produce a simultaneous fit of all data. The corresponding results, that will be object of a forthcoming publication, help to improve the spectroscopy of natural-parity states in ^{20}Ne.

In the near future, we will exploit recently developed arrays for charged particles [22, 23] to carry out new experimental campaigns aimed to measure, with extremely high precision, low energy nuclear reactions to improve the spectroscopy of light nuclear systems. Additionally, information obtained by large acceptance detectors used as γ-ray arrays [24], will contribute to improve our understanding of clustering in light nuclei.