### Probing the 17F+p potential by means of elastic scattering at near barrier energies

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## Abstract

Results from the first stage of analysis of the recently performed $^{17}$F+p experiment are presented. The experiment was performed at the EXOTIC facility of Legnaro National Laboratory (Italy, LNL-INFN), where the $^{17}$F radioactive beam is available. The measurement of elastic scattering angular distributions, in a wide angular range ($\theta_{cm}$=20-160 deg) was taken over in order to probe the potential at two near barrier energies, namely: 3.5 AMeV and 4.3 AMeV. The present work, should be considered as the starting point of a general survey along drip line nuclei, aiming to a better understanding and mapping of the nuclear potential at near barrier energies.

*Keywords:* Radioactive ion beams; Elastic scattering; Nuclear potential

## 1. Introduction

Proton-nucleus elastic scattering has been traditionally used to probe the nuclear potential. In this respect, extensive studies have been performed and both phenomenological and microscopic potential models have been developed. A large amount of experimental data has been successfully interpreted through such models with at most the adjustment of only a few parameters.

By the advent of radioactive ion beams during the last years, we have the ability to extent our knowledge to regions of the nuclear landscape that previously were unaccessible. The $^{17}$F being a proton rich nucleus, with extremely small binding energy of the last proton for the ground ($S_p$ = -600 keV) and the first excited state ($S_p$=-105.13 keV), is one of the most important drip line nuclei involved in reactions of astrophysical importance. The nuclear reaction sequence $^{14}$O(a,p)$^{17}$F(p,$\gamma$)$^{18}$Ne takes place during x-ray bursts - one of the most violent explosions in the universe. The key role of this reaction sequence comes from the fact that it provides a breakout from the HCNO cycle. Accordingly, the knowledge of the nuclear parameters for those nuclei is important since can set constrains on ignition conditions and the thermonuclear runaway timescale. For these reasons, a number of studies have been performed so far focusing to the understanding of the resonance character of the p+$^{17}$F interaction [1, 2, 3, 4, 5] by the determination of the energy dependence of proton elastic scattering cross section. The experimental determination of the $^{17}$F(p,p) excitation
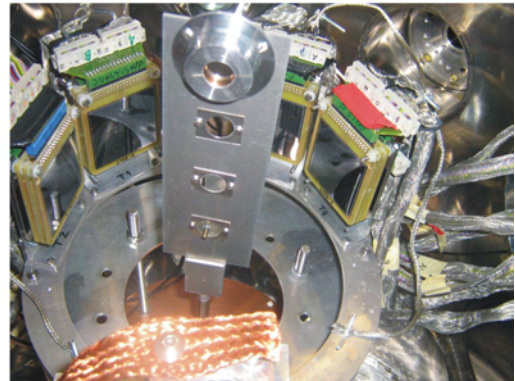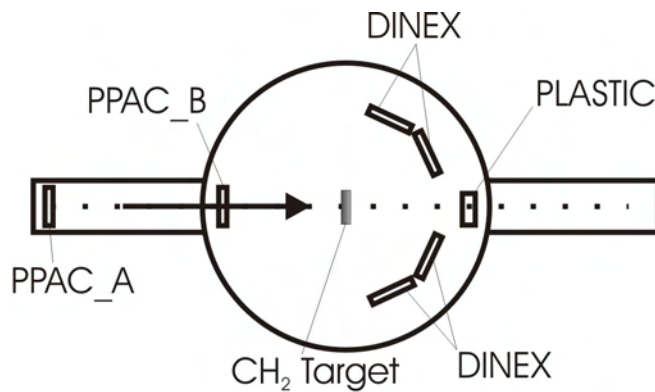
Figure 1: The experimental setup as was realized during the $^{17}$F+p experiment. In the photo of the scattering chamber the four DINEX telescopes and the target ladder can be seen.

function at low energies of astrophysical interest is important, but significant is also the role and the knowledge of the p+$^{17}$F nuclear potential which can only be determined by recording the full center-of-mass (CM) angular distribution. In this way, valuable information can be deduced for any phenomenological or microscopic calculation that includes the p+$^{17}$F interaction either as incoming and/or outgoing channel.

Into the above context, the measurement of the elastic scattering angular distributions, $^{1}$H($^{17}$F,p), in a wide angular range ($\Theta_{cm}$=20-160 deg) was taken over [6] as to probe the potential at two near barrier energies, namely: 3.5 AMeV and 4.3 AMeV. In this way the mapping of the nuclear potential will be derived together with the information about the existence or not of halo structure for the ground state of $^{17}$F.

## 2. Secondary Beam

The $^{17}$F radioactive beam was produced at the EXOTIC facility [7] at Laboratori Nazionali di Legnaro (LNL-Italy) of the Istituto Nazionale di Fisica Nucleare (INFN) by means of the In-Flight technique and by using the reaction $^{1}$H($^{17}$O,$^{17}$F)n. The $^{17}$O$^{+8}$ primary beam delivered from the LNL-XTU Tandem Van de Graaf accelerator at the energy of 105 MeV and was directed to a 5 cm long gas cell.The double walled gas cell with 2.2 $\mu$m-thich Havar foils was filled with H$_2$ under controlled pressure and temperature conditions. The energy of the secondary beam is defined from the primary beam energy as well as from the pressure of the primary gas target. Additionally, the energy loss of the secondary beam from the different beam line elements on the way to the scattering chamber has to be taken into account. For the first run the energy of the secondary beam was 64 MeV and for the second one was 77 MeV, resulting to 3.5 AeV and 4.3 AMeV at the middle point of the secondary 1mg/cm$^2$ thick CH$_2$ target. In both runs the secondary beam energy was chosen as to be outside known resonances and was measured before and after each run by the end-channel Si-detector. The selection, separation and focusing of the secondary beam is achieved by a quadrapole triplet, a 30°-bending magnet, a 1m-long Wien-filter and a second quadrupole triplet. The beam spatial profile was defined by means of four slits and a triple stack of collimators with diameters of 10 mm placed at ~ 264-324 mm upstream the secondary target. Under these conditions the resulted beam intensity at the secondary target position was $10^4$-$10^5$ pps

## 3. Experimental Setup

The beam profile during the measurement was recorded by means of a parallel plate avalanche counter (PPAC) located 750 mm upstream the secondary target providing the event-by-event position and time information for each beam particle. Each PPAC consists of a cathode plate placed between a double anode frame made by 60 wires at a distance of 1.0 mm in perpendicular orientation. In this way, position resolution for the beam particles with an accuracy of 1 mm was achieved.
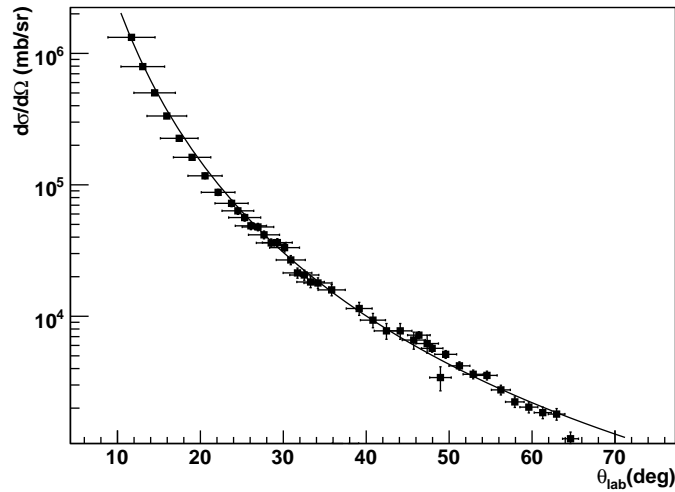
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Figure 2: The experimentally deduced angular distribution of the calibration $^{17}F+^{197}Au$ run together with the expected Rutherford scattering reaction cross section. The experimental points were deduced by taking into account the angular coverage and and solid angle for each strip as deduced from MC calculations.

The elastic scattered protons were detected by means of the DINEX Si-detector array that was coupled into the EXOTIC LNL facility. The DINEX detector array consist of four triple Si telescopes. Each telescope provides three detection stages: a) $\Delta E1$-40$\mu m$ Double-Sided-Silicon-Strip-Detector (DSSSD), b)$\Delta E2$-500$\mu m$ PAD detector and c) E-1000$\mu m$ DSSSD. The four telescopes were placed at 104 mm distance from the target position according to the configuration seen in Fig.1. With this setup the covering detection area of $4\times50\times50$ mm$^2$ corresponds to an overall solid angle of ~0.8 sr. Position information for each $16 \times 16$ striped DSSSD detector was determined from the id-number of each of the x and y strip. Considering just the y strip id an angular resolution of $1.3°$ - $3.1°$ can be achieved.

## 4. Data analysis

The first stage of the data analysis procedure was the determination of the angular coverage and solid angle determination for each strip of the DSSSD detectors. This was done by extensive Geant4 [8] Monte-Carlo (MC) calculations where all the details of the beam profile, of the target and the detection geometry, were taken into account. In a second stage of the analysis procedure, the deduced results from MC calculations were combined with the counting-rate per strip as resulted from the $^{17}F+$ $^{198}Au$ run at the sub-Coulomb-barrier energy of 72 MeV. At this energy a Rutherford angular distribution is expected. This run proved to be very useful for the solid angle as well as for the overall angular calibration of the DINEX-array. The results of the angular calibration procedure as resulted from the combination of the gold calibration-run and MC calculations can be seen in Fig. 2. The excellent agreement of the theoretical angular distribution with the corresponding experimental points visualize the precision of the angular calibration procedure.

Concerning the necessary analysis codes are already built and tested. Different modes of analysis were implemented in a way to reduce as much possible systematic and statistical uncertainties in the deduced proton elastic scattering angular distribution. Preliminary results for both energies at 3.5 AMeV and 4.3 AMeV can be seen in Fig. 3. The analysis is still in progress and is expected to be finalized within 2011.

## 5. Conclusions and outlook

The analysis of the experimental results for the determination of the angular distribution in a wide angular range of the $^{17}F+p$ elastic scattering at two near barrier energies is in the final stage. The deduced angular distributions for both
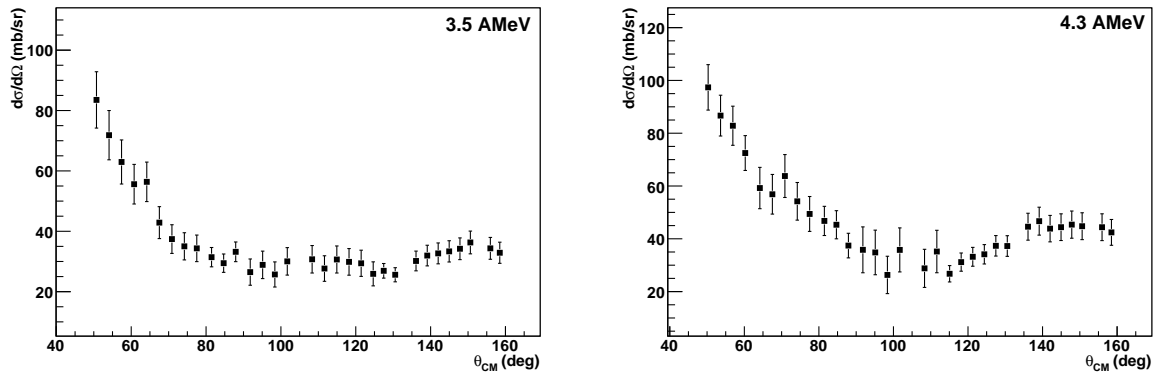
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Figure 3: Preliminary results of the deduced angular distribution at two near barrier energies (3.5 AMeV and 4.3 AMeV) for the $^{17}$F+p system.

near barrier energies will be compared with phenomenological calculations as well as with microscopic calculations towards to a better understanding and mapping of the nuclear potential. Possible halo-structure of $^{17}$F will be revealed through the analysis process by the comparison of the experimentally deduced angular distribution with microscopic JLM calculations [9]. An other indication concerning the existence of halo structure or not can be the comparison of the deduced total reaction cross section from phenomenological calculations with those from Wong's [10] estimates. Final results of the theoretical analysis are expected in close future.

In conclusion, we see that coupling the DINEX silicon detector array with the EXOTIC/LNL facility was successful. A new series of experiments was launched where the flexibility, high-segmentation and high angular coverage of the DINEX array can be efficiently combined with the EXOTIC RIB facility, towards to a better understanding and mapping of the nuclear potential near the proton drip line.

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