

Study of the $^{18}\text{F}(\text{p},\alpha)^{15}\text{O}$ reaction for application to nova γ -ray emission

N. de Séréville^a, A. Coc^a, C. Angulo^b, M. Assunção^a, D. Beaumel^c, B. Bouzid^d,
S. Cherubini^b, M. Couder^b, P. Demaret^b, F. de Oliveira Santos^e, P. Figuera^f, S. Fortier^c,
M. Gaelens^b, F. Hammache^{g,c}, J. Kiener^a, D. Labar^h, A. Lefebvre^a, P. Leleux^b,
M. Loiselet^b, A. Ninane^b, S. Ouichaoui^d, G. Ryckewaert^b, N. Smirnovaⁱ, V. Tatischeff^a,
and J.-P. Thibaud^a

^aCSNSM, CNRS/IN2P3/UPS, Bât. 104, 91405 Orsay Campus, France

^bCRC and FYNU, UCL, Chemin du Cyclotron 2, B-1248 Louvain-La-Neuve, Belgium

^cInstitut de Physique Nucléaire, CNRS/IN2P3/UPS, 91406 Orsay Campus, France

^dUSTHB, B.P. 32, El-Alia, Bab Ezzouar, Algiers, Algeria

^eGANIL, B.P. 5027, 14021 Caen Cedex, France

^fLaboratori Nazionali del Sud, INFN, Via S. Sofia, 44 - 95123 Catania, Italy

^gGSI mbH, Planckstr. 1, D-64291 Darmstadt, Germany

^hUnité de Tomographie Positron, UCL, Chemin du Cyclotron 2, B-1248 Louvain La Neuve, Belgium

ⁱInstituut voor Kern en Stralingsfysika, Celestijnenlaan 200D, B-3001, Leuven, Belgium

The $^{18}\text{F}(\text{p},\alpha)^{15}\text{O}$ reaction is recognized as one of the most important reaction for nova gamma-ray astronomy as it governs the early ≤ 511 keV emission. However, its rate remains largely uncertain at nova temperatures due to unknown low-energy resonance strengths. In order to better constrain this reaction rate, we have studied the one-nucleon transfer reaction, $\text{D}(^{18}\text{F},\text{p}\alpha)^{15}\text{N}$, at the CRC-RIB facility at Louvain La Neuve.

1. INTRODUCTION

Gamma-ray emission from classical novae is dominated, during the first hours, by positron annihilation following the beta decay of radioactive nuclei. The main contribution comes from the decay of ^{18}F (half-life of 110 mn) and hence is directly related to ^{18}F nucleosynthesis during the outburst[1, 2, 3]. The $^{18}\text{F}(\text{p},\alpha)^{15}\text{O}$ reaction is the main mode of ^{18}F destruction and has been the object of many recent experiments[4, 5, 6] but its rate remains poorly known at nova temperatures. The uncertainties are directly related to the unknown proton widths of the first three ^{19}Ne levels above proton emission threshold (E_x , $J^\pi = 6.419$ MeV, $3/2^+$; 6.437 MeV, $1/2^-$ and 6.449 MeV, $3/2^+$). The tails of the corresponding resonances (at respectively $E_R = 8$ keV, 26 keV and 38 keV) can dominate

the astrophysical factor in the relevant energy range[3]. As a consequence of these nuclear uncertainties, the ^{18}F production in nova and the early gamma-ray emission is uncertain by a factor of ≈ 300 [3]. This supports the need of new experimental studies to improve the reliability of the predicted annihilation gamma-ray fluxes from novae.

2. EXPERIMENT

A direct measurement of the relevant resonance strengths is impossible due to the very low Coulomb barrier penetrability. Hence, we used an indirect method aiming at determining the one-nucleon spectroscopic factors in the analog levels of the mirror nucleus (^{19}F) by the neutron transfer reaction $\text{D}(^{18}\text{F},\text{p})^{19}\text{F}$. Assuming the equality of spectroscopic factors in analog levels, the proton width can be deduced from the calculated single particle widths[8]. The experiment has been carried out at the *Centre de Recherche du Cyclotron* of Louvain-La-Neuve (Belgium) by bombarding deuteriated polypropylene (CD_2) targets ($\approx 100 \mu\text{g}/\text{cm}^2$) with a 14 MeV ^{18}F radioactive beam (average intensity of $2.2 \times 10^6 \text{ }^{18}\text{F} \text{ s}^{-1}$ on target and $^{18}\text{O} / ^{18}\text{F} \leq 10^{-3}$ purity). The experimental setup has been described elsewhere[8] and consists of two silicon multistrip detectors LAMP and LEDA[9]. LAMP covers backwards laboratory angles and was used to measure the angular distribution of the protons, whereas LEDA covers forward laboratory angles. The levels of astrophysical interest are situated high above the alpha emission threshold (at 4.013 MeV) and mainly decay through $^{19}\text{F}^* \rightarrow ^{15}\text{N} + \alpha$. Hence, to reduce background, we required coincidences between a proton in LAMP and a ^{15}N in LEDA.

3. DATA ANALYSIS AND RESULTS

Due to the kinematics only p and α from the $\text{D}(^{18}\text{F},\text{p})^{19}\text{F}$ and $\text{D}(^{18}\text{F},\alpha)^{16}\text{O}$ reactions can reach LAMP. When considering the coincidence events each reaction corresponds to a different zone in the $(E_{\text{LAMP}} \times E_{\text{LEDA}})$ spectrum and hence can be identified. A further TOF selection in LEDA is done to discriminate the p- ^{15}N from the p- α coincidences. The excitation energy of the decaying ^{19}F levels can be kinematically reconstructed from the energies and angles of the detected protons. This has been done by taking into account the energy loss of the ^{18}F and the protons in the CD_2 target as well as the energy loss of the protons in the LAMP dead layer. The corresponding spectrum is shown in Figure 1. The resolution is not sufficient to separate the various levels but the two $3/2^+$ levels of interest at 6.497 and 6.528 MeV (the analogs of the $3/2^+$ levels in ^{19}Ne) are well separated from the other groups of levels. The spectrum is limited at low excitation energy because of the p- ^{15}N coincidence condition and at high excitation energy by the electronic threshold. However, if the coincidence condition is removed, the ^{19}F spectrum extends to the ground state and can be used for the energy calibration using isolated peaks. However the uncertainty obtained on the excitation energy around the 6.5 MeV peak (two $3/2^+$ levels) prevents a reliable extraction of the individual contribution of these two levels.

Making a selection on the 6.5 MeV peak of the coincidence spectrum (Figure 1), we obtain the preliminary angular distribution shown in Figure 2. The coincidence efficiency for each strip (angle) is determined from a Monte-Carlo simulation taking an isotropic angular distribution for the α -decay of ^{19}F as a first approximation. We used the elastic

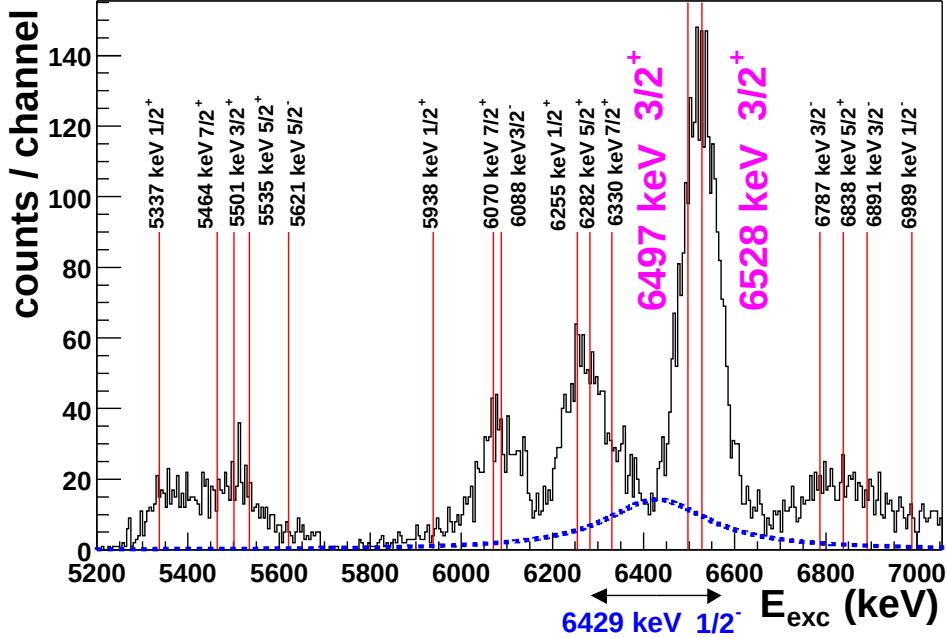


Figure 1. Reconstructed ^{19}F excitation energy spectrum for coincidence events (65% of the total statistics), showing the two $3/2^+$ levels of astrophysical interest around 6.5 MeV. Vertical lines show the known position of the ^{19}F levels populated with low transferred angular momentum ($l \leq 2$). The dashed line shows the broad $1/2^-$ level for $S = 0.15$ (see text).

scattering of the ^{18}F beam (detected in LEDA) on the ^{12}C of the target for normalization.

The solid lines in Figure 2 correspond to theoretical DWBA calculations with nuclear potential from Ref. [10] for different transferred angular momentum ($l = 0, 2$). This nuclear potential has been determined by studying a similar neutron transfer reaction $^{19}\text{F}(d,p)^{20}\text{F}$ at the same center-of-mass energy (subcoulomb transfer) where no compound nucleus component was seen[10]. The comparison between the shapes of the theoretical and experimental angular distributions indicates a predominant $l = 0$ transfer for the sum of the contributions of the two $3/2^+$ levels. The value obtained for the total spectroscopic factor is $S_{tot} \approx 0.2$. Although no peak is seen in Figure 1 corresponding to the $1/2^-$ level ($E_x = 6.429$ MeV, $\Gamma = 280$ keV) due to its large total width, it is possible to derive an upper limit for the spectroscopic factor of $S \lesssim 0.15$ assuming an $l = 1$ transfer.

The important consequence of these preliminary values is that the contribution of these resonances to the destruction rate of ^{18}F *cannot* be neglected but remains compatible with the nominal rate[3]. The rate uncertainty is reduced by a factor of ≈ 5 in the temperature range of novae, mainly due to the reduced contribution of the $1/2^-$ level. The impact on the rate for the two $3/2^+$ ($S_{tot} \approx 0.2$) is more important at low temperature[8].

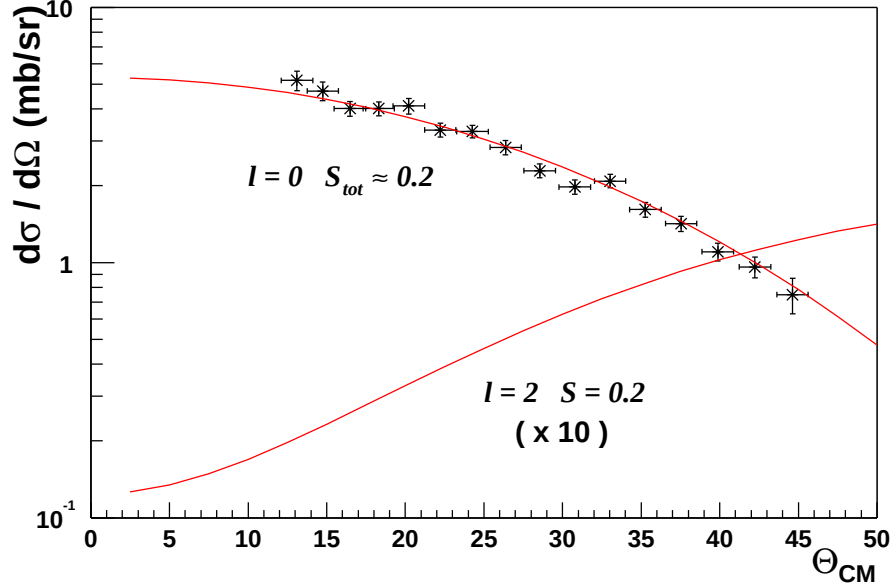


Figure 2. Comparison between the experimental angular distribution of the 6.5 MeV peak and DWBA calculations for different transferred angular momentum. The vertical error bars are only statistical whereas the horizontal ones are the angular width of each strip as seen from the target.

4. ACKNOWLEDGMENTS

This work has been supported by the European Community-Access to Research Infrastructure action of the Improving Human Potential Programme, contract N° HPRI-CT-1999-00110.

REFERENCES

1. J. Gómez-Gomar, et al., *MNRAS* **296**, 913 (1998).
2. M. Hernanz, et al., *Astrophys. J.* **526**, L97 (1999).
3. A. Coc, et al., *Astron. Astrophys.* **357**, 561 (2000).
4. J.-S. Graulich, et al., *Phys. Rev.* **C63**, 011302(R) (2000).
5. D.W. Bardayan, et al., *Phys. Rev.* **C63**, 065802 (2001).
6. D.W. Bardayan, et al., *Proceedings of the International Conference on Classical Nova Explosion*, Sitges, Spain, 20-24 May 2002, AIP, 2002.
7. M. Cogneau, et al., *Nucl. Inst. and Meth.* **A420**, 489 (1999).
8. N. de Séreville, et al., *Proceedings of the International Conference on Classical Nova Explosion*, Sitges, Spain, 20-24 May 2002, AIP, 2002, nucl-ex/0206014.
9. T. Davinson, et al., *Nucl. Inst. and Meth.* **A454**, 350 (2000).
10. M.E.O de López, et al., *Nucl. Phys.* **51**, 321 (1964).