Study of the $^{12}N(p,\gamma)^{13}O$ reaction from a (^{12}N,^{13}O) proton transfer reaction

A. Banu, T. Al.-Abdullah, V. Burjan,[1] F. Carstoiu,[2] C. Fu, C. A. Gagliardi, M. McCleskey,
G. Tabacaru, L. Trache, R. E. Tribble, and Y. Zhai
[1]*Institute of Nuclear Physics, Czech Academy of Sciences, Prague, Czech Republic*
[2]*IFIN-HH, Bucharest, Romania*

The reaction rate for the radiative proton capture on the drip line nucleus ^{12}N is studied at the Cyclotron Institute using an indirect method. The reaction is important in the hot pp chain nuclear burning in H-rich massive objects [1]. In 1986, Fuller *et al.* [2] addressed the classic problem of supermassive star evolution — *given that a nonrotating supermassive star has formed and contracted to its instability point, does the rapid nuclear burning in the subsequent collapse generate enough thermal energy to stabilize the collapse and trigger an explosion?*

They found that Population III stars with $M > 5\times10^5$ solar masses and $Z \ll 0.005$ will collapse to black holes, while stars of higher metallicity will explode. For those failing to explode, it is reasoned that in the short time before the collapse insufficient amounts of ^{12}C and other heavier nuclei are produced by the 3α-process. However, alternative paths to the slow 3α-process to produce CNO seed nuclei could change their fate. In 1989, M. Wiescher *et al*. [1] reinvestigated the reaction rates for nuclei up to oxygen and suggested several reaction sequences (hot pp chains) that would permit very massive stars with low metallicity to bypass the 3α-process. $^{12}N(p,\gamma)^{13}O$ is an important branching point in such alternative paths.

The reaction is studied here by an indirect method using the peripheral proton-transfer reaction $^{14}N(^{12}N,^{13}O)^{13}C$. The radioactive beam ^{12}N was produced and separated in MARS from a primary beam of ^{12}C at 23 AMeV with an intensity of 150 pnA impinging on a LN_2 cooled H_2 gas cell. The gas cell was operated at a pressure of 2.2 atm and its entrance and exit windows were made of havar foils 13 μm and 4 μm thick, respectively. Due to the large negative Q-value of the reaction used to produce the ^{12}N secondary beam (-18.12 MeV), the energy of the primary beam had to be large, resulting in an energy of the recoiling ^{12}N products larger than the typical energy regime of our secondary proton transfer reactions (10-12 AMeV). To bring it down to 12 AMeV where the reaction is peripheral and where we have a proven recipe for the optical potentials needed for the DWBA analysis, the energy of the beam was degraded by a 250-μm-thick Al foil right behind the gas cell.

The resulting secondary beam at a rate of ~ 2×10^5 pps, and a purity of ~ 99.8% [3] impinged on a 1.6 mg/cm^2-thick composite melamine target ($C_3H_6N_6$) at the focal plane on MARS. MARS was operated with D3 at an inclination angle of 5°. The experimental setup used is shown in Figure 1. It was also used before to study the $^{14}N(^7Be,^8B)^{13}C$ reaction [4].

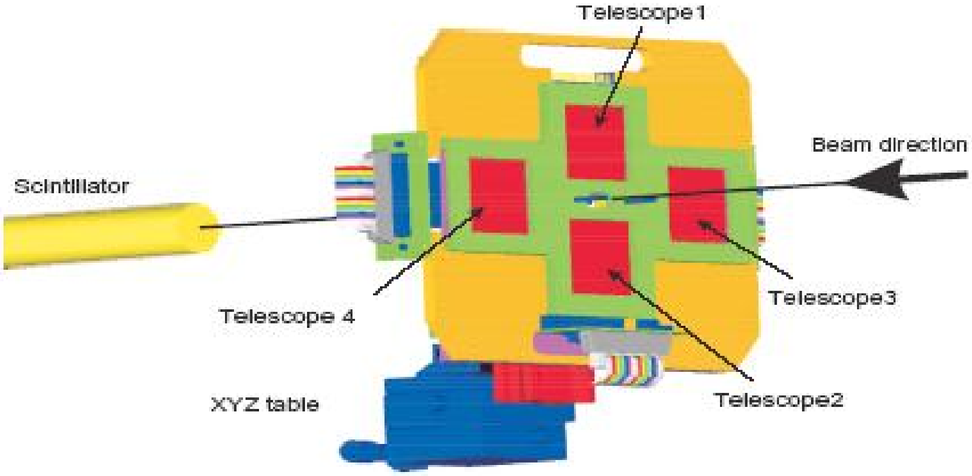

Figure 1. A 3D-view of the detector assembly. Four 5x5 cm^2 Si ΔE-E telescopes are used for particle identification and for angular distribution measurement. The 16 strip ΔE-detectors are position sensitive (PSD). A plastic scintillator positioned at 0° behind the target is employed for beam counting.

The identification of the reaction channels is shown in Figure 2 along with the elastic scattering position distributions in the four ΔE-E telescopes employed as detection system. The identification of the reaction products is marked on left side panel, including the ^{13}O well separated spots identifying the transfer on the ^{12}C and ^{14}N components in the target. Another observation worth noticing is the presence of a proton breakup channel of the ^{12}N projectile leading to a large production of ^{11}C. This is due to the small binding energy of the last proton in ^{12}N Sp=601 keV.

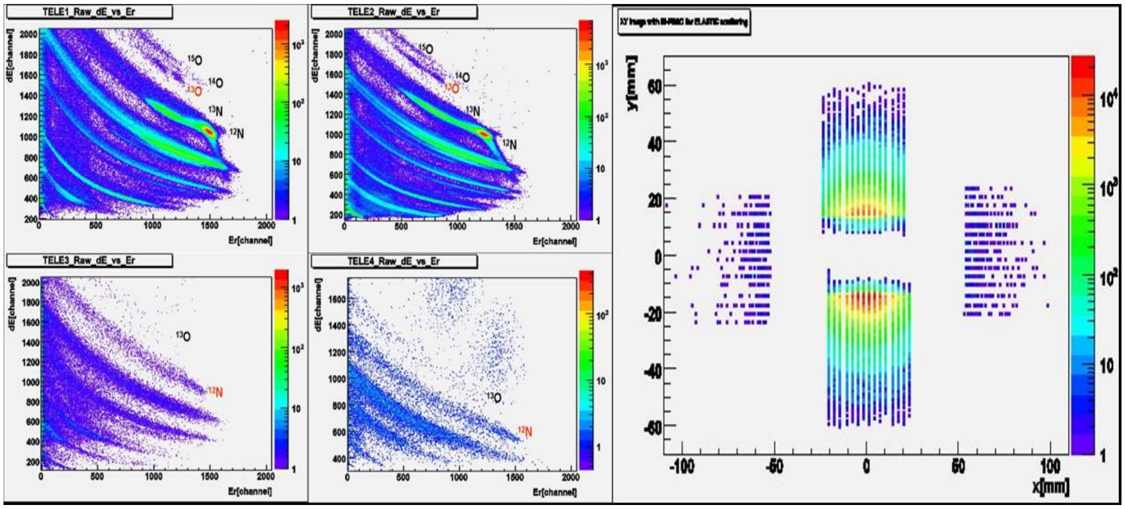

Figure 2. ΔE-E reaction channel identification (right) and the elastic scattering position distributions (left).

The data analysis procedure starts with the analysis of the elastic channel — $^{12}N(^{14}N,^{12}N)^{14}N$ — in order to determine the optical-model potential (OPM) needed for DWBA calculations performed in the transfer channel — $^{12}N(^{14}N,^{13}O)^{13}C$ — to determine the ANC (asymptotic normalization coefficient). During most of the experiment, which lasted two weeks in May 2006, in order to have good statistics for the transfer reaction, we worked at MARS settings that allowed maximum intensity of the secondary ^{12}N beam, but degraded some of its angular resolution. In the last three days of the run we closed the slits situated behind the last pair of dipoles of MARS in order to improve the angular definition of the secondary beam on target. This reduced the intensity, but allowed us to get much better elastic scattering angular distributions, with clearly visible Fraunhoffer oscillations, even for such a composite target like melamine. These data allow a more confident extraction of the optical potentials to be used in the DWBA analysis. Following we report preliminary results (shown in Figure 3) for the ANC of the system $^{13}O \rightarrow {}^{12}N + p$. In order to disentangle the elastic scattering on ^{14}N only, in March 2007 we carried out an elastic scattering measurement on a pure C-target [6]. Data analysis of this experiment is still in progress, but once completed it will enable us to extract from data a less uncertain ANC value, from which the rate of the $^{12}N(p,\gamma)^{13}O$ reaction will be evaluated.

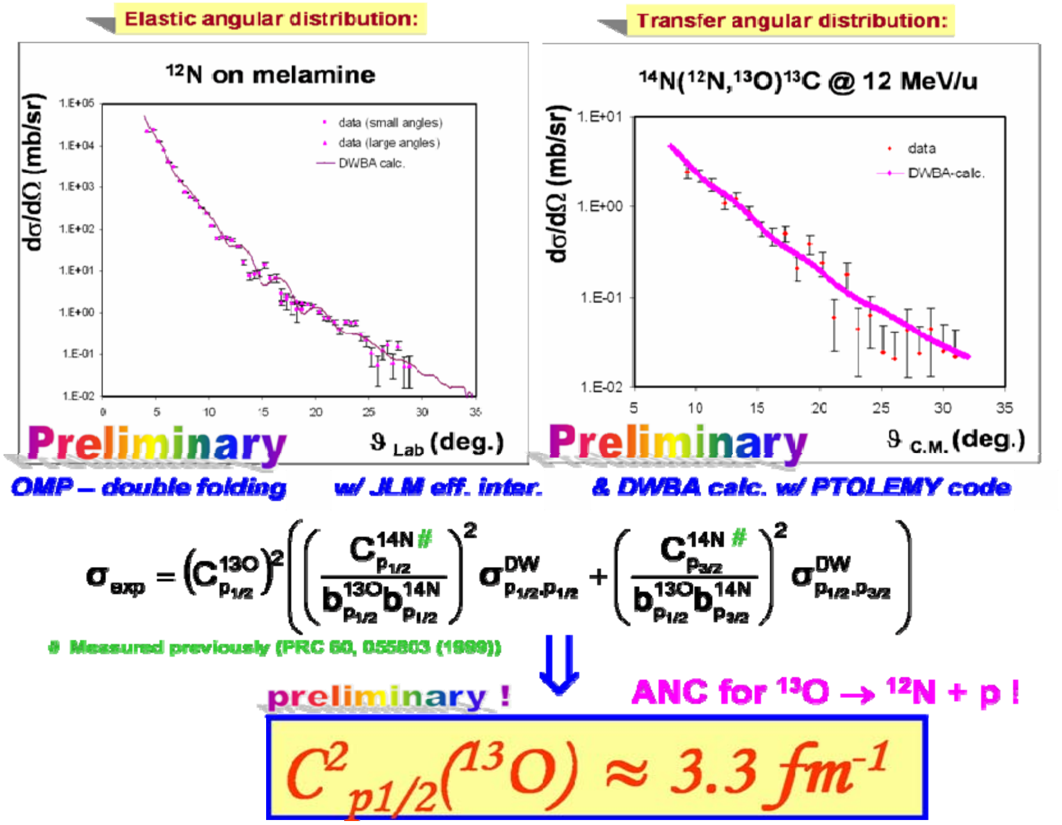

Figure 3. The angular distribution for elastic scattering on melamine (data points, left) compared with the prediction (curve) using the double folding potential procedure of Ref. [5], no parameters fitted. DWBA calculations are fitted to data to extract the ANC (right).

[1] M. Wiescher *et al.*, Astrophys. J. **343**, 352 (1989).
[2] G. M. Fuller *et al.*, Astrophys. J. **307**, 675 (1986).
[3] A. Banu *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2005 – 2006), p. I-15
[4] G. Tabacaru *et al.*, Phys. Rev. C **73**, 025808 (2006).
[5] L. Trache *et al.*, Phys. Rev. C **61**, 024612 (2000).
[6] A. Banu *et al.*, *Progress in Research*, Cyclotron Institute, Texas A&M University (2006 – 2007), p. I-24.