Studies of the ^{18}F$(p,\alpha)^{15}$O Reaction Rate with a ^{18}F Beam at the HRIBF

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The rates of the ^{18}F$(p,\alpha)^{15}$O and ^{18}F$(p,\gamma)^{19}$Ne reactions at $T = 0.1 - 0.4$ GK are necessary to understand the emission of positron-annihilation gamma rays expected from novae. Observations of such gamma rays by space-based telescopes would provide direct tests of nova models. These rates, however, are uncertain because of the unknown level structure of ^{19}Ne above the ^{18}F+p threshold. Missing levels in ^{19}Ne were searched for by stopping a 24-MeV ^{18}F beam in a thick polypropylene target, and scattered protons were detected in a silicon-strip detector. The ^{18}F$(p,p)^{18}$F excitation function has been measured from $E_{c.m.}$ = 0.3 - 1.3 MeV covering most energies of astrophysical interest, and a significant discrepancy was observed with a recent compilation of ^{19}Ne resonance parameters.

A primary target of satellite-based γ-ray telescopes is ^{18}F decay in novae [1]. The amount of ^{18}F produced in nova explosions is severely constrained by its destruction rate via the ^{18}F$(p,\alpha)^{15}$O and ^{18}F$(p,\gamma)^{19}$Ne reactions in the burning shells. Recent studies have found that the uncertainties in the ^{18}F$(p,\alpha)^{15}$O reaction rate result in a factor of ~ 300 variation in the amount of ^{18}F produced in models, and thus a more precise rate is needed at nova temperatures to understand ^{18}F production [2].

While ^{19}Ne has been extensively studied in radioactive [3,4] and stable beam [5] studies, significant uncertainties remain in the level structure of ^{19}Ne. From a comparison with the mirror nucleus, ^{19}F, there are at least 10 missing levels in the excitation energy range $E_x = 6.411 - 8.100$ MeV [6]. These levels could significantly enhance the ^{18}F+p reaction rates, and thus the properties of these levels need to be determined.

Missing levels above the ^{18}F+p threshold in ^{19}Ne were searched for by stopping a 24-MeV ^{18}F beam in a 2.8 mg/cm^2 polypropylene (CH_2) target. The ^{18}F beam was fully stripped in a thin carbon foil before the energy-analyzing magnet of the HRIBF to remove an unwanted ^{18}O contamination. Even at such a low beam energy, more than 10^4 ^{18}F ions/s were transported to the target in the fully stripped charge state. Protons from the ^{1}H$(^{18}$F$,p)^{18}$F reaction were detected at $\theta_{lab} = 8^o - 16^o$ by a double-sided silicon strip detector. Because the scattered protons lose relatively little energy in the target,

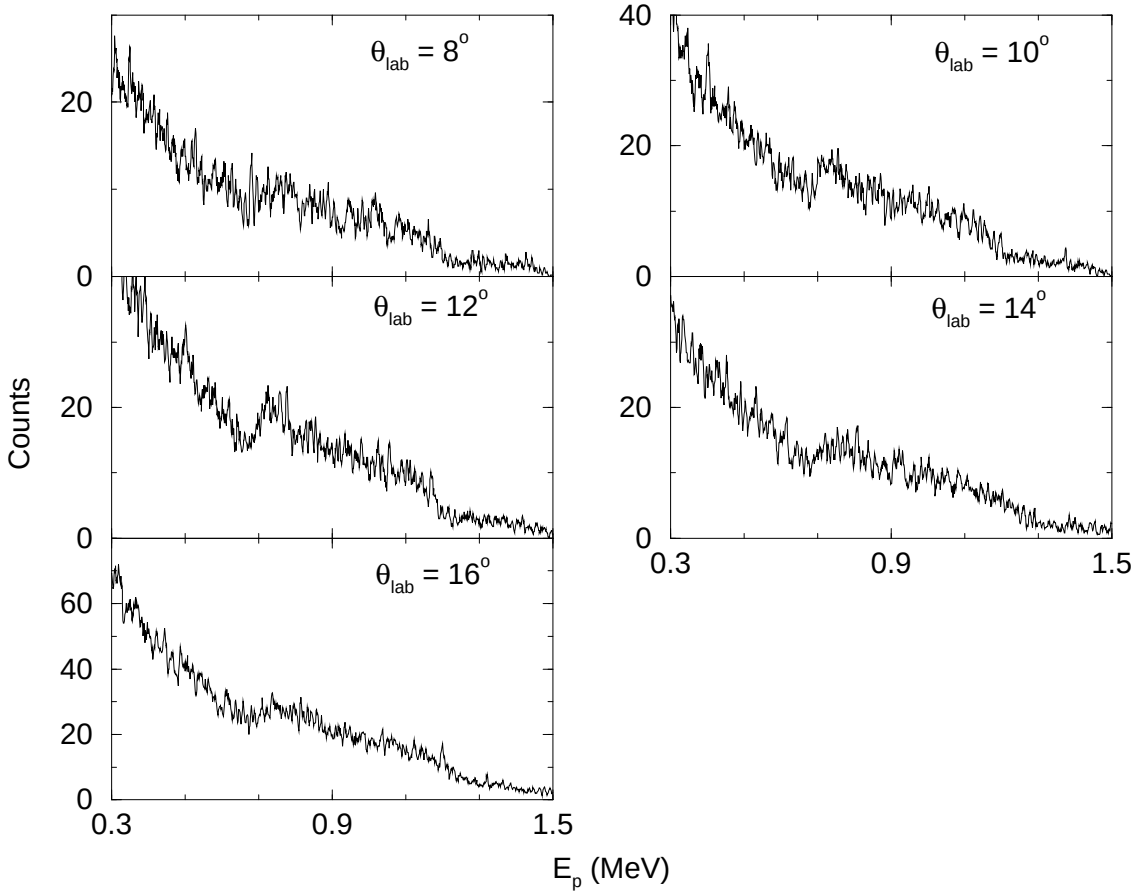

Figure 1. Proton energy spectra from the ^{1}H(^{18}F$,p$)^{18}F reaction.

measurements of the proton's energy and angle of scatter accurately determine the center-of-mass energy at which the reaction occurred [7]. A measurement of the proton energy spectrum at a fixed angle can thus be used to extract the excitation function for the ^{18}F$(p,p)^{18}$F reaction over a wide range of center-of-mass energies. The observed proton energy spectra are shown in Fig. 1. The largest scattering anomaly observed was at $E_p \sim 702$ keV ($E_{c.m.} = 665$ keV) and arises from the well studied $J^\pi = \frac{3}{2}^+$ ^{19}Ne state at $E_x = 7076$ keV [4,8]. In Fig. 1, E_p refers to the equivalent bombarding energy in normal kinematics [i.e., ^{18}F(p,p)^{18}F] and not the detected proton energy from the scattering reaction.

A comparison with a calculated excitation function is shown in Fig. 2. The calculation was made using the $R-$Matrix code MULTI [9] and uses resonance parameters from the most recent compilation [6]. This compilation includes 13 levels above the ^{18}F$+p$ threshold up to $E_x \sim 7.6$ MeV ($E_p \sim 1.2$ MeV). The large peak in the calculation arises from an expected $J^\pi = \frac{5}{2}^+$ resonance at $E_{c.m.} = 1089$ keV. The corresponding ^{19}Ne level was observed in Ref. [5] to have $\Gamma_p/\Gamma_\alpha \sim 5.25$ and a 1σ upper limit of $\Gamma < 32$ keV. A width

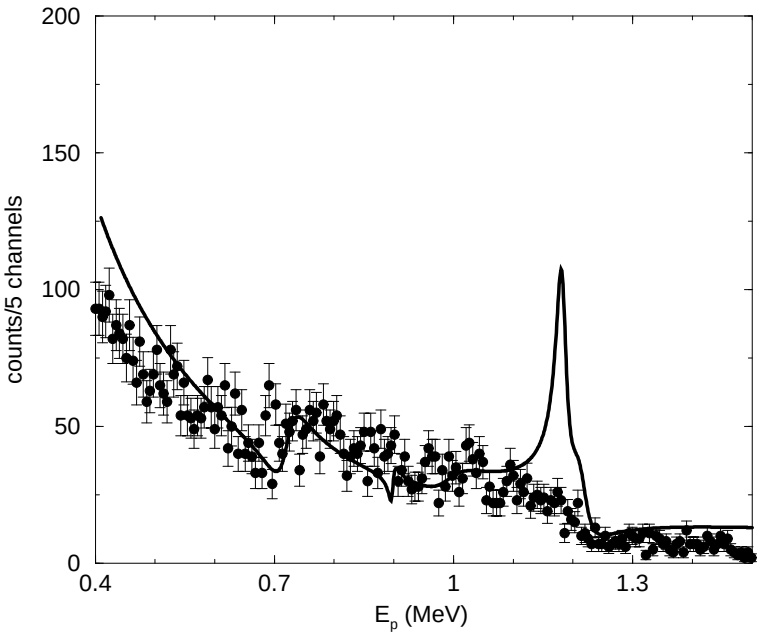

Figure 2. Comparison with the expected excitation function at $\theta_{lab} = 8^o$.

of 16 keV was adopted for this level in Ref. [6], but clearly (as seen in Fig. 2) the actual width is much smaller. The analysis is preliminary but it appears than an upper limit of $\Gamma_p \lesssim 1$ keV for this resonance will result from a combined analysis of the data taken at each angle. Upper limits on proton widths for missing levels will also be extracted.

In conclusion, knowledge of the ^{18}F$(p,\alpha)^{15}$O and ^{18}F$(p,\gamma)^{19}$Ne reaction rates at nova temperatures is critical to determining the gamma-ray flux expected from novae during the first several hours after the explosion. We have measured the ^{18}F$(p,p)^{18}$F excitation function over a large energy range to search for and measure the properties of missing ^{19}Ne levels, which may significantly enhance the rates. The observed excitation function did not agree with that expected from a recent compilation for a level at $E_{c.m.} = 1089$ keV. Upper limits will be set on the proton widths of this resonance and other resonances not observed.

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