Probing lifetimes of short-lived nuclear resonances of astrophysical interest

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Classical novae and Type I X-ray bursts (XRBs) are among the most frequent thermonuclear stellar explosions in the Galaxy. The $^{30}\mathrm{P}(p,\gamma)^{31}\mathrm{S}$ reaction acts as a nucleosynthesis bottleneck in the flow of material to heavier masses, affecting several nova observables. The dominant source of uncertainty in the current recommended reaction rate is the γ decay width of the $3/2^+$, 260-keV resonance in $^{31}\mathrm{S}$. We have observed evidence for γ rays originating from the resonance using the Doppler Shift Lifetimes (DSL) facility at TRIUMF, which was designed for lifetime measurements in the $10^{-15}-10^{-12}$ s range [1]. We have upgraded DSL to DSL2, increasing the detection efficiency by an order of magnitude. DSL2 has been successfully commissioned during the first run of the lifetime measurement of the key $^{22}\mathrm{Na}(p,\gamma)^{23}\mathrm{Mg}$ resonance in novae [2]. The data analysis is currently in progress, and a second run has been scheduled for October 2024. Our proposal to measure the lifetime of the key $^{31}\mathrm{S}$ resonance using DSL2 has also been approved, aiming to put the $^{30}\mathrm{P}(p,\gamma)^{31}\mathrm{S}$ reaction rate on a fully experimental footing and to reduce the nuclear uncertainties in simulations of nova observables.

Under XRB conditions, the competition between the $^{59}\mathrm{Cu}(p,\gamma)^{60}\mathrm{Zn}$ and $^{59}\mathrm{Cu}(p,\alpha)^{56}\mathrm{Ni}$ reactions determines the strength of the NiCu cycle, which is predicted to have significant impacts on the modeling of X-ray burst light curves and the composition of the burst ashes. However, the experimental information on $^{60}\mathrm{Zn}$ resonances is scarce. We have designed and built a detection system that utilizes and extends the Particle X-ray Coincidence Technique (PXCT), originally developed to measure the average lifetimes in the $10^{-17}-10^{-15}$ s range for proton-unbound states populated by electron capture (EC). Our setup is able to measure the lifetimes and decay branching ratios of discrete $^{60}\mathrm{Zn}$ resonances populated by $^{60}\mathrm{Ga}$ EC/β^+ decay, as well as to address captures on excited states. The performance of the PXCT system has been thoroughly tested and is ready for the $^{60}\mathrm{Ga}$ decay experiment in the stopped-beam area of FRIB.

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