Probing key $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ resonances with innovative targets at LUNA

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The thermonuclear reaction $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ plays a key role as a potential breakout path from the CNO cycle during hydrogen burning under extreme conditions [1]. In particular, this reaction is of interest in the context of Population III stars, where the absence of initial CNO elements delays the onset of standard CNO burning. A significant enhancement of the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ rate at $T \approx 0.1\,\mathrm{GK}$ could thus trigger nucleosynthesis beyond fluorine and contribute to the calcium enrichment observed in the most metal-poor stars [2]. However, current models are limited by large experimental uncertainties in the low-energy regime, primarily due to unknown resonance contributions and background from competing channels such as the $^{19}\mathrm{F}(p,\alpha)^{16}\mathrm{O}$ reaction. A precise measurement of the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction rate is therefore essential to constrain breakout from the CNO cycle and improve our understanding of elemental production in the early universe.

The measurement is being carried out at the Laboratory for Underground Nuclear Astrophysics (LUNA), located underground at the Gran Sasso National Laboratories (LNGS), where the ultra-low background environment is ideally suited for detecting rare signals at astrophysically relevant energies. The 400 kV accelerator at LUNA is uniquely suited for this study, providing intense, stable proton beams with low energy spread, delivered onto solid targets. The current campaign focuses on the energy region between $E_{\mathrm{cm}} = 190\,\mathrm{keV}$ and $390\,\mathrm{keV}$, covering the two key resonances at $E_{\mathrm{cm}} = 213\,\mathrm{keV}$ and $E_{\mathrm{cm}} = 225\,\mathrm{keV}$, as well as the $E_{\mathrm{cm}} = 323\,\mathrm{keV}$ resonance. In particular, for the recently discovered 213 keV resonance, only upper limits of its strength are currently known, making it the dominant contributor to the reaction rate uncertainty at stellar temperatures. To reduce systematic uncertainties, three different $^{19}\mathrm{F}$ targets have been employed, including a novel chemically fluorinated target specifically developed for this experiment. Gamma rays are detected with a high-efficiency BGO detector array covering nearly the full solid angle.

Preliminary results from the direct measurement of the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction in the energy window of astrophysical interest will be presented at the Mazurian Lake Conference on Physics. A detailed characterization of the targets will be shown, along with newly determined branching ratios and resonance strengths. These findings are expected to provide new insights into the role of the $^{19}\mathrm{F}(p,\gamma)^{20}\mathrm{Ne}$ reaction in astrophysical scenarios.

[1] L. Zhang *et al.*, Nature **610** (2022) 656-660.
[2] R. J. deBoer *et al.*, Physical Review C **103** (2021) 055815.