

^7Be asymptotic normalization coefficients from $^3\text{He} + ^4\text{He}$ elastic scattering and validation of extrapolation methods

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We present the first direct determination of asymptotic normalization coefficients (ANCs) for the ground and first excited states of ^7Be from $^3\text{He} + ^4\text{He}$ elastic scattering phase shifts. The analysis draws upon the classic datasets of two older low-energy measurements, long considered difficult due to internal inconsistencies and the absence of systematic uncertainties. Employing single-level R -matrix fits, the mapping between reduced widths and ANCs, and Bayesian inference, we reconstruct posterior distributions and quantify uncertainties. A key innovation of this study is the application and validation of the extrapolation method developed by our group, specifically designed to extract ANC values in cases where direct low-energy information is lacking. Benchmarking against the latest measurements [Paneru *et al.*, *Phys. Rev. C* **109**, 015802 (2024)], which reported only R -matrix fits with fixed ANCs, confirms the predictive power and robustness of our approach. Our findings show that ANCs deduced from older scattering measurements are systematically lower than those inferred from radiative capture, thereby confirming earlier indications of a discrepancy between the two methods. This work demonstrates both the originality and reliability of the extrapolation method as a powerful tool for ANC determination in nuclear astrophysics.

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I. INTRODUCTION

Asymptotic normalization coefficients (ANCs) determine the amplitude of the asymptotic behavior of the overlap function for the bound-state wave functions of nuclei $a = (bc)$, b and c . The residue of the $b + c$ elastic scattering partial-wave amplitude at the bound-state pole $a = (bc)$ is articulated in terms of the ANC for the virtual decay $a \rightarrow b + c$. The general properties of the ANCs are discussed in the review paper [1]. The role of ANCs is especially important in determining the cross sections for peripheral nuclear reactions, in particular, reactions with charged particles at low energies, which are inaccessible for direct measurement due to the large Coulomb barrier. The most important class of such processes are astrophysical nuclear reactions in the cores of stars. ANCs determine the overall normalization of the cross sections and astrophysical S factors for direct radiative capture reactions and resonant reactions proceeding through subthreshold resonances occurring at astrophysically relevant energies [2–4]. One of the important astrophysical reactions is the $^3\text{He}(\alpha, \gamma)^7\text{Be}$ radiative capture. This process is the primary reaction for

chains II and III of the $p - p$ chain of hydrogen burning in stars.

The $^3\text{He}(\alpha, \gamma)^7\text{Be}$ process, despite its critical significance, still holds a mystery. The cause is that, even after substantial experimental endeavors, a singular characterization of the low-energy cross section remains unobtainable [5]. The low-energy $^3\text{He}(\alpha, \gamma)^7\text{Be}$ radiative capture represents a peripheral direct transition from a continuum to a loosely bound state. Given this scenario, it's often assumed that the S factors are presumed to be an accurate way of ascertaining the ANCs of the final bound states. Yet, the most extensive Bayesian analysis indicated that it did not hold true [6]. The Bayesian method (see Appendix), as opposed to the usual χ^2 minimization, enables a complete analysis of the probability distribution of the model's parameters (in the current scenario, ANCs $C_{3/2}$ and $C_{1/2}$, which correspond to the virtual decays $^7\text{Be}(3/2^-; 0 \text{ MeV}) \rightarrow \alpha + ^3\text{He}$ and $^7\text{Be}(1/2^-; 0.429 \text{ MeV}) \rightarrow \alpha + ^3\text{He}$ channels, respectively). As presented in [6], the two-dimensional posterior resulting from the Bayesian analysis of the effective field theory (EFT) predictions [7,8], utilizing exclusively radiative capture data, exhibited a notably wide span for the ^7Be ANCs (refer to Fig. 12 of [6]). It renders ^7Be as an excellent laboratory for research.

One of the reasons is that despite contemporary astrophysical S_{34} factors being measured at extremely low energies with an accuracy under 9% [9,10], the S_{34} factor does not exhibit proportionality to the square of the final bound state ^7Be ANCs $C_{3/2}$ and $C_{1/2}$.

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