New Binding Energy Determinations of $^{3}_{\Lambda}H$, $^{4}_{\Lambda}H$, and Double-Strangeness Hypernuclei via Nuclear Emulsion and Deep Learning

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Introduction

Hypernuclei provide critical information on baryon–baryon interactions involving strangeness. Nuclear-emulsion detectors offer background-free mass measurements of single-Λ and double-strangeness hypernuclei taking advantage of their sub-micrometer spatial resolution. We tackle two key issues—the hypertriton puzzle and the insufficiently constrained interactions in the $S = -2$ sector (ΛΛ and ΞN)—using data from the J-PARC E07, the latest emulsion experiment search for double-strangeness hypernuclei. If decays of hypernuclear events could be selected solely by image analysis, approximately 10^6 single-Λ hypernuclei (including $^{3}_{\Lambda}H$) and 10^3 double-strangeness hypernuclei would be detectable. Yet conventional rule-based algorithms are rendered ineffective by abundant background tracks.

Results and Discussion

To overcome this limitation, we developed event detection methods based on deep learning. Dedicated models were trained exclusively on surrogate images generated through simulation and image transformation techniques [1, 2]. The model was applied to 0.6% of the total E07 data and identified 46 at-rest two-body decays of $^{3}_{\Lambda}H$ and 95 of $^{4}_{\Lambda}H$. Λ binding energies were then obtained by recalibrating the range–energy relation with ATIMA stopping-power calculations and μ^+ tracks, yielding $B_{\Lambda}(^{3}_{\Lambda}H) = 0.23 \pm 0.11$ (stat.) $\pm$ 0.05 (syst.) MeV and $B\Lambda(^{4}_{\Lambda}H) = 2.25 \pm 0.10$ (stat.) $\pm$ 0.06 (syst.) MeV [3]. Applying the established strategy to searching for double-strangeness hypernuclei, we uniquely identified a production-and-decay sequence of $^{13}_{\Lambda\Lambda}B$ within just 0.2% of the dataset—the first unique identification of double-Λ hypernucleus observed in E07 [4, 5]. Processing the full sample is expected to yield roughly 2×10^3 detections and several hundred identifications.

References

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