# Mass measurements of neutron-rich $A \approx 90$ nuclei constrain element abundances[†]

W. Xian,[*1,*2] S. Chen,[*1,*2] S. Nikas,[*3] M. Rosenbusch,[*2] M. Wada,[*2] H. Ishiyama,[*4] D. Hou,[*5] S. Iimura,[*4,*6] S. Nishimura,[*4] P. Schury,[*2] A. Takamine,[*4] S. Yan,[*7] F. Browne,[*4] P. Doornenbal,[*4] F. Flavigny,[*8] Y. Hirayama,[*2] Y. Ito,[*9] S. Kimura,[*4] T. M. Kojima,[*4] J. Lee,[*1] J. Liu,[*1] H. Miyatake,[*2] S. Michimasa,[*10] J. Y. Moon,[*11] S. Naimi,[*4] T. Niwase,[*2,*12,*4] T. Sonoda,[*4] D. Suzuki,[*4] Y. X. Watanabe,[*2] V. Werner,[*13,*14] K. Wimmer,[*15,*16,*4] and H. Wollnik[*17]

Neutron-rich nuclei in mass region of $A \approx 90$–100, distinguished by a rapid shape transition at $N = 60$[1)] and the presence of a sub-shell closure at $N = 56$,[2)] hold particular significance for studying astrophysics. In astrophysics, neutrino-driven winds[3)] from Supernovae explosions are believed to contribute to the formation of light elements via the $r$-process. Initial observations lacked conclusive evidence of nucleosynthesis in such environments. However, a breakthrough came with the observation of GW170817, accompanied by a kilonova event. This provided the first proof of $r$-process nucleosynthesis driven by a neutron star merger (NSM).[4)] Specifically, strontium ($Z = 38$, $A = 88$) was uniquely identified in the nucleosynthesis event following GW170817.[5)] Calculations for strontium production contribute to constraining the astrophysical conditions of NSM. This study presents the first high-precision mass measurement for $^{86}$Ge, $^{88,89}$As, and $^{90,91}$Se. The shell evolutions of Ge, As, and Se of the isotopic chain were evaluated, and these new mass data constrained the uncertainties of the reaction rate calculation.

This experiment was conducted symbiotically through $\gamma$-ray spectroscopic measurements in RIBF, as introduced in the previous APR.[6)] In this experiment, 35 nuclides were measured. The masses of $^{88,89}$As were determined for the first time, and the mass uncertainties of $^{86}$Ge, and $^{90,91}$Se were reduced by two orders of magnitude. Using these new precise mass data, the Hauser-Feshbach statistical code TALYS was executed to calculate the neutron capture reaction rate. To visualize the reduction in the uncertainties of the calculated reaction rate owing to new mass data, an index $I_{error}$ is defined as

$$I_{error} = \frac{\Delta\langle\sigma v\rangle_{\mathrm{exp}}}{\Delta\langle\sigma v\rangle_{\mathrm{AME}}}, \tag{1}$$

where $\Delta\langle\sigma v\rangle_{\mathrm{exp}}$ and $\Delta\langle\sigma v\rangle_{\mathrm{AME}}$ represent the uncertainties of reaction rate based on experimental results in this study and AME2020, respectively. The logarithm results of $I_{error}$ are illustrated in Fig. 1, where the color index indicates the magnitude of uncertainty reduction for the calculated reaction rate. The most substantial improvements in precision of the reaction rate were observed for $^{85}$Ge, $^{88}$As, and $^{90}$Se, consistent with the anticipated outcome of achieving a reduction in mass uncertainties of approximately two orders of magnitude for $^{86}$Ge, $^{89}$As, and $^{91}$Se. These results underscore the importance of this study in constraining the uncertainty of $r$-process calculations.

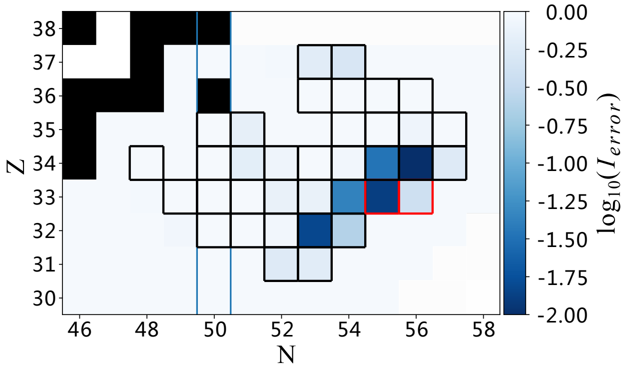


Fig. 1. $N$-$Z$ plane with color code indicating the logarithm of $I_{error}$. Black blocks represent stable nuclides.

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[*1] Department of Physics, University of Hong Kong
[*2] Wako Nuclear Science Center (WNSC), IPNS, KEK
[*3] Department of Physics, University of Jyväskylä
[*4] RIKEN Nishina Center
[*5] Institute of Modern Physics, Chinese Academy of Sciences
[*6] Department of Physics, Osaka University
[*7] Institute of Mass Spectrometry and Atmospheric Environment, Jinan University
[*8] Université de Caen Normandie
[*9] Advanced Science Research Center, Japan Atomic Energy Agency
[*10] Center of Nuclear Study (CNS), University of Tokyo
[*11] Institute for Basic Science
[*12] Department of Physics, Kyushu University
[*13] Institut für Kernphysik, Technische Universität Darmstadt
[*14] Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung GmbH
[*15] Department of Physics, University of Tokyo
[*16] GSI Helmholtzzentrum für Schwerionenforschung GmbH
[*17] Department of Chemistry and Biochemistry, New Mexico State University

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