Measurement of the production branching ratio following nuclear muon capture

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Nuclear muon capture

Muon capture is the capture of a negative muon by a proton via a weak interaction from the 1s state of the muonic atom. The reaction creates a compound nucleus, which emits several neutrons and γ-rays.

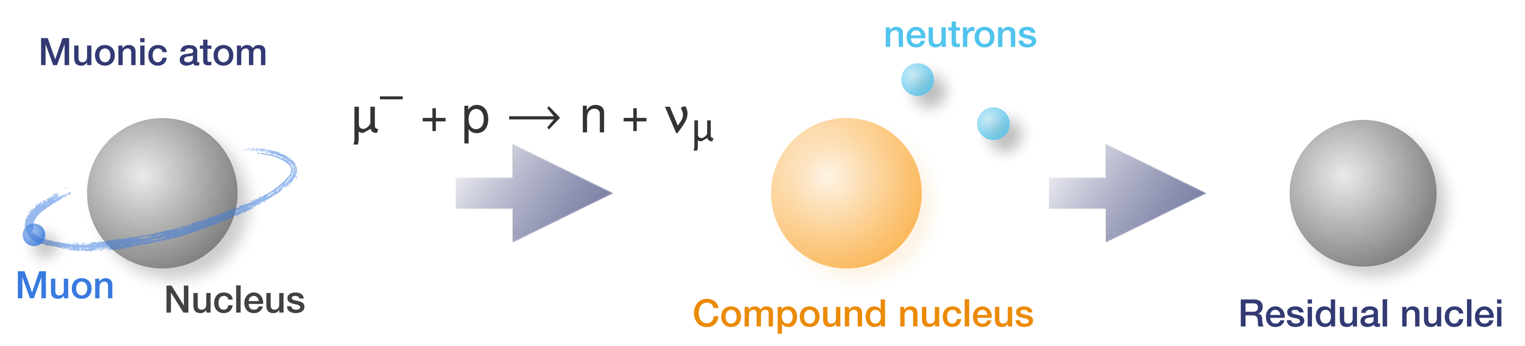

Fig.1 Reaction process of nuclear muon capture.

We investigate the energy distribution of the compound nucleus from the measurement of production branching ratio of the residual nuclei [1].

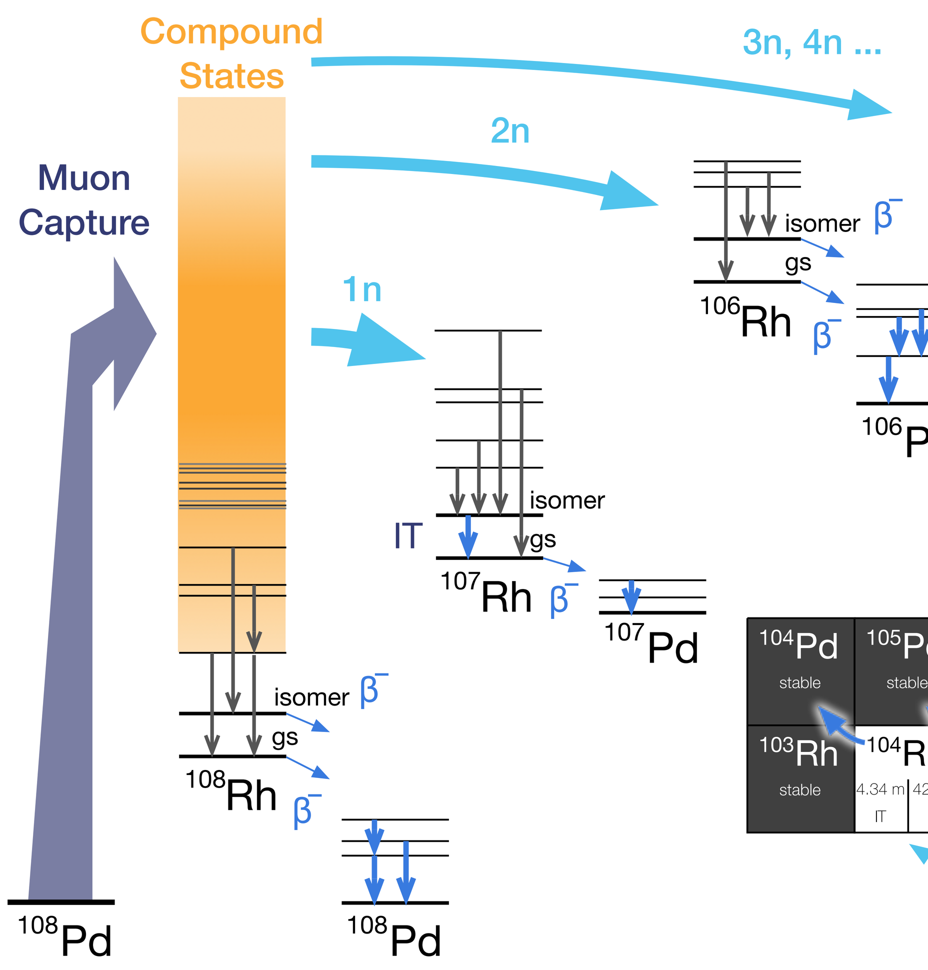

Fig.2 Schematics representation of muon capture.

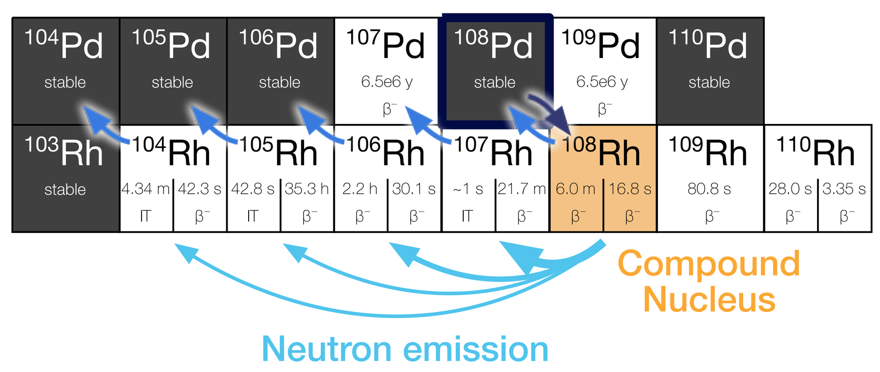

Fig.3 Part of the nuclear chart and muon capture path.

Experiment at the RIKEN-RAL muon facility

The experiment was performed at Port-1 in RIKEN-RAL muon facility [2].

Beam: negative muon (34 MeV/c, ~10 muons/pulse, 40Hz repetition)

Target: isotopically enriched palladium: ^{104,105,106,108,110}Pd

Detector: HPGe detector

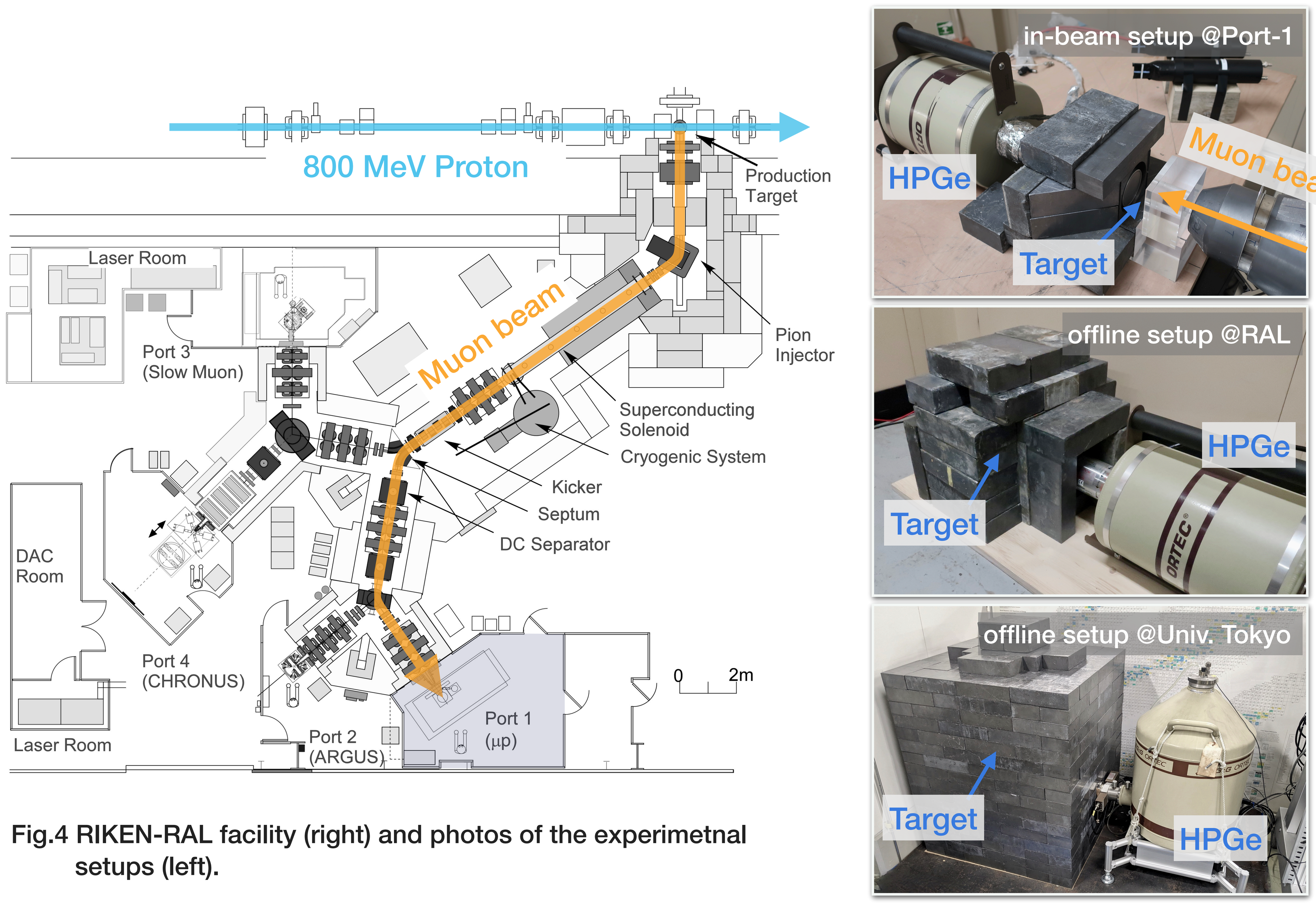

Fig.4 RIKEN-RAL facility (right) and photos of the experimetnal setups (left).

In-beam activation method

We developed an in-beam activation method to measure the production probability of residual nuclei through muon capture. Decaying γ rays were measured simultaneously with beam irradiation by exploiting the time structure of the pulsed muon beam. Combining in-beam and offline activation methods enables the measurement of the β-decaying states across a wide range of half-lives from ms to years.

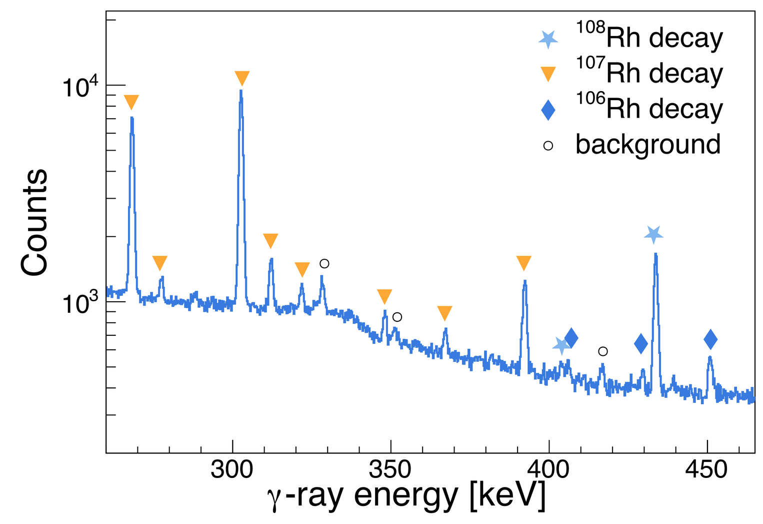

Fig.6 γ-ray energy spectrum for ^{108}Pd activation

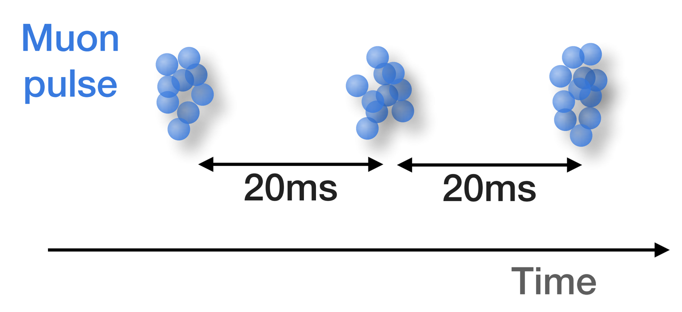

Fig.5 Time structure of the pulsed muon beam.

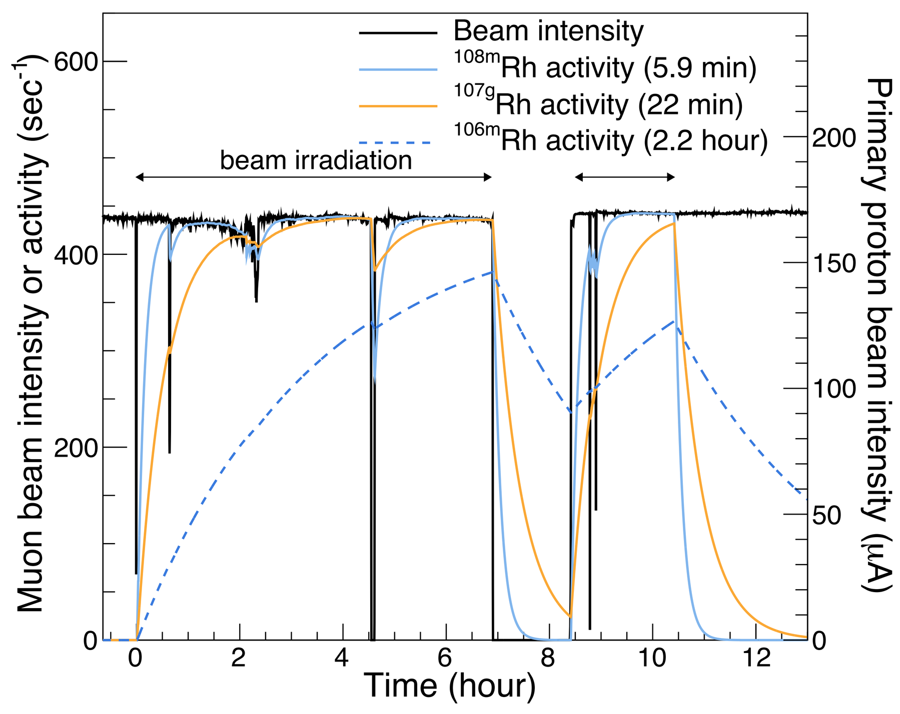

Fig.7 Time evolution of the residual activity.

Result and discussion

Energy distribution of the compound states populated by muon capture is similar to the Gamov-Teller (n,p) resonounce.

A model calculation by PHITS [3] reproduced the results well: however, the model needs improvements on

- overestimation of excitation energy,
- underestimation of the direct and pre-equibilium process, and
- fail to represent the charged-particle emission process from the compound nucleus.

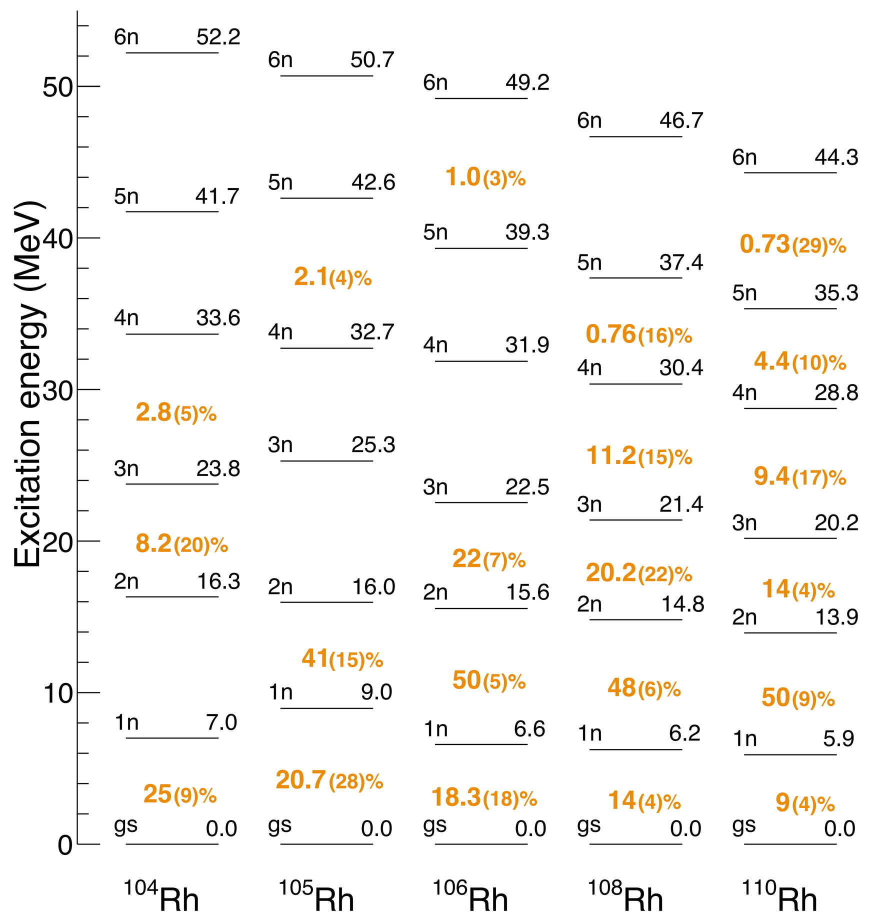

Fig.8 Neutron emission thresholds of Rh isotopes.

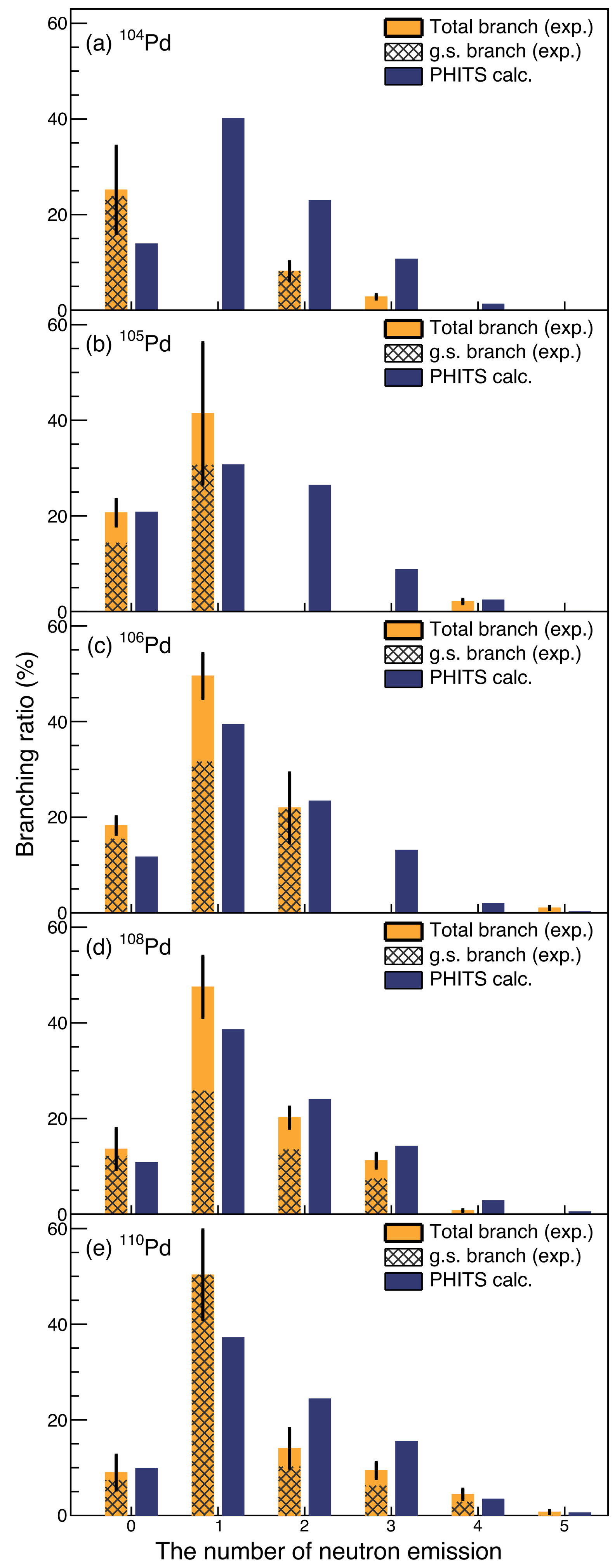

Fig.9 Production branching ratio for Pd isotopes.

Conclusion

We have investigated energy distribution of the compound nucleus produced by nuclear muon capture. A new method of the in-beam activation was developed to obtain the radioactivity of short half-lives. As for the first application of the new method, we measured the production branching ratios of muon capture for five palladium isotopes: ^{104,105,106,108,110}Pd. For the first time, this study provides concrete experimental data on the distribution of production branching ratios without any theoretical estimation or assumptions in the interpretation of the data analysis.

References

[1] M. Niikura et al., Phys. Rev. C 109, 014328 (2024).
[2] T. Matsuzaki et al., Nucl. Instrum. Methods A 465, 465 (2001).
[3] T. Abe et al., J. Nucl. Sci. Technol. 54, 101 (2017).