Microscopic description of β-decay rates of r-process nuclei

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In collaboration with

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Thomas Neff[3] **Max Pallàs**[6] **Ariel Tarifeño-Saldivia**[7,6]

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[6]Universitat Politècnica de Catalunya (UPC). [7]Instituto de Física Corpuscular (IFIC).

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Overview

- Motivation
- Global β-decay calculations within QRPA
- Sensitivity to isoscalar pairing strength.
- β-delayed neutron emission and comparison with preliminary results from BRIKEN-REP experiment.
- Quasiparticle-vibration coupling results in waiting point nuclei.
- Extension to quasiparticle-vibration coupling and deformation.

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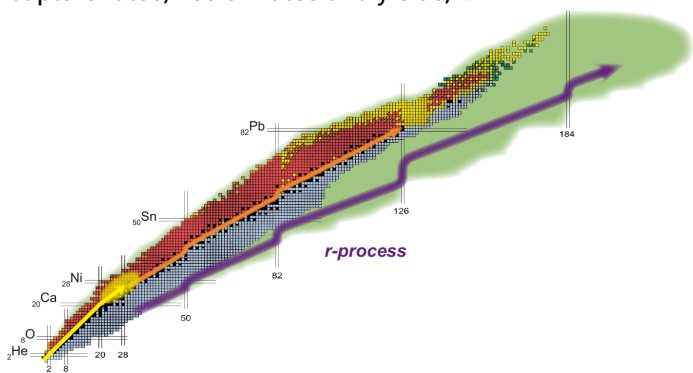
The r-process.

- Astrophysical environment should provide enough neutrons per seed
- Path not fully accessible to experiments → theoretical predictions
- Inputs: β-decay half-lives, neutron-capture rates, fission rates and yields, …

Determines the nuclear timescale for the r-process: competition with expansion timescale.



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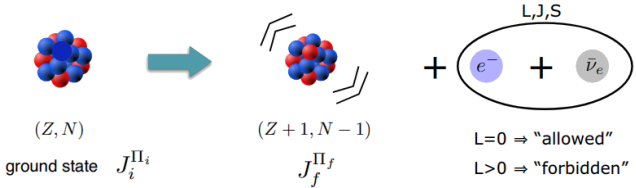
β-decay rates of r-process nuclei.



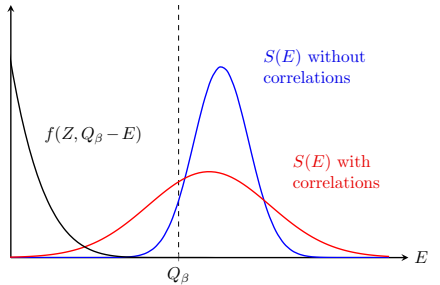
- Allowed decays (GT):

$$\lambda = \frac{\ln 2}{T_{1/2}} \propto \int^{Q_\beta} f(Z, Q_\beta - E) S(E) dE$$

$$S(E) = \sum_f |\langle f|\hat{F}|i\rangle|^2 \delta(E - E_f + E_i)$$

- Correlations relevant to the low-lying strength.

- Gamow-Teller (GT): $\Delta S = 1$
- First Forbidden: $L = 1, \Pi_i \neq \Pi_f$



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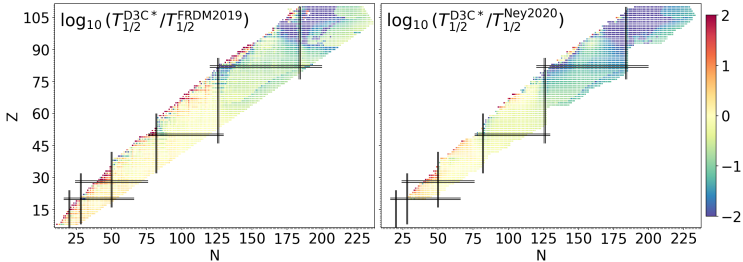
Global β-decay calculations within QRPA.

- **FRDM** + gross theory for FF[1]
- relativistic spherical approach with **D3C*[2]**
- non-relativistic deformed approach with SKO' (**Ney 2020**)[3]

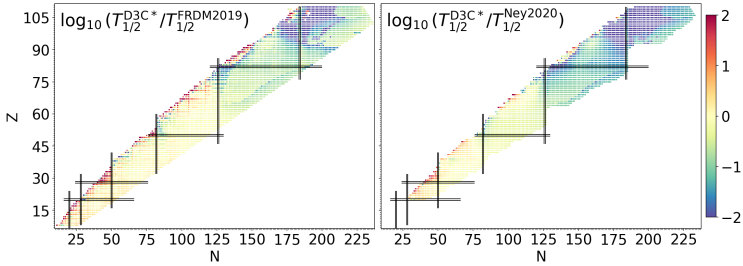


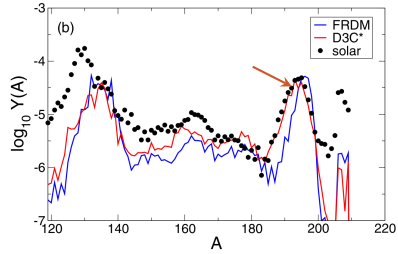
[1] P. Möller et al., Phys. Rev. C **67**, 055802 (2003), P. Möller et al., Atomic Data and Nuclear Data Tables **125**, 1–192 (2019).
[2] T. Marketin et al., Phys. Rev. C **93**, 025805 (2016), M. Eichler et al., The Astrophysical Journal **808**, 30 (2015).
[3] E. M. Ney et al., Phys. Rev. C **102**, 034326 (2020).

Global β-decay calculations within QRPA.

- **FRDM** + gross theory for FF[1]
- relativistic spherical approach with **D3C*** [2]

  shorter half-lives for $N > 126 \Rightarrow$ shift of the third abundance peak ($A \sim 195$)
- non-relativistic deformed approach with SKO' (**Ney 2020**)[3]





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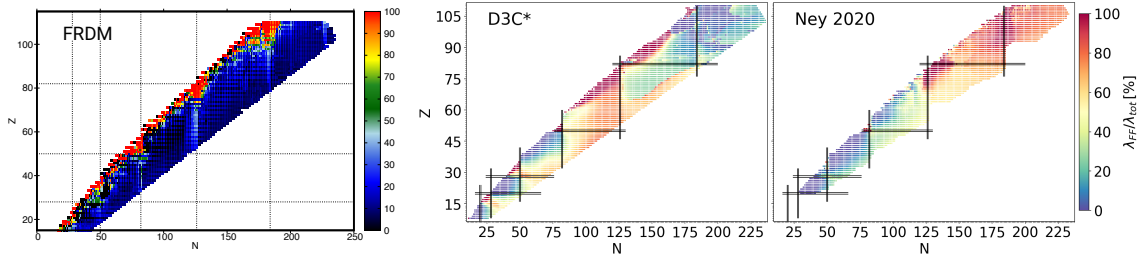

Very different predictions of the FF contribution to the rates

[4] P. Möller et al., Phys. Rev. C **67**, 055802 (2003), P. Möller et al., Atomic Data and Nuclear Data Tables **125**, 1–192 (2019).
[5] T. Marketin et al., Phys. Rev. C **93**, 025805 (2016).
[6] E. M. Ney et al., Phys. Rev. C **102**, 034326 (2020).

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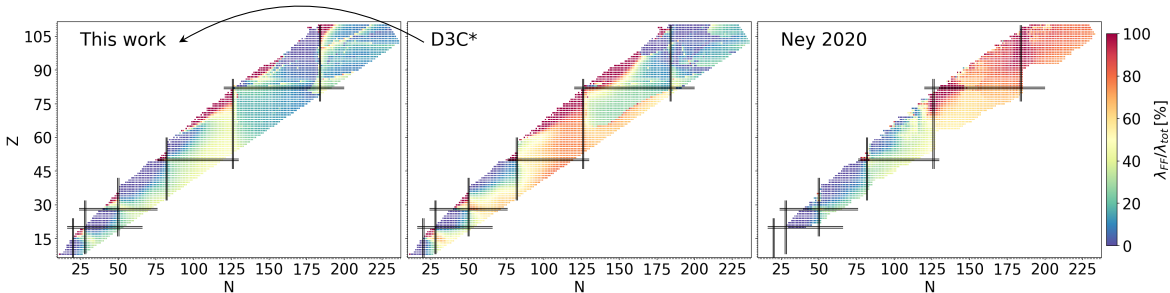
Global β-decay calculations within QRPA.

FF contribution to the rates

→ After recent corrections[7] to the RHB+RQRPA code with **D3C***



[7] C. E. P. Robin and G. Martínez-Pinedo, arXiv:2403.17115 (2024).

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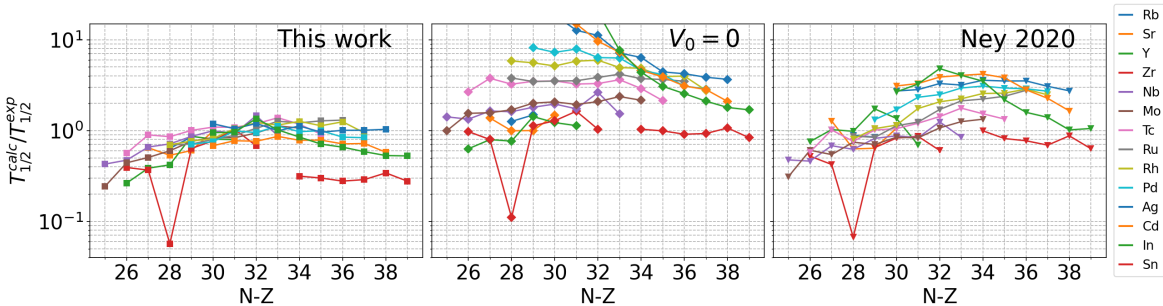
Global β-decay calculations within QRPA.

Sensitivity to isoscalar pairing strength (V_0)

- V_0 parametrisation with $N-Z$ dependence fitted to reproduce experimental half-lives.[8]

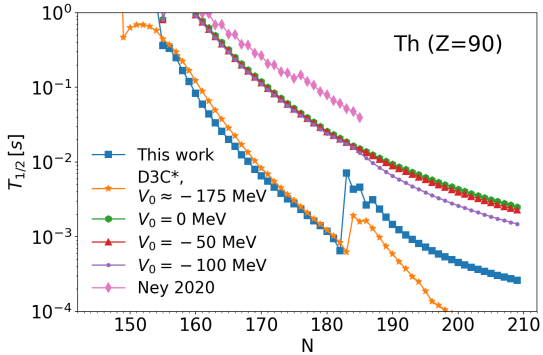


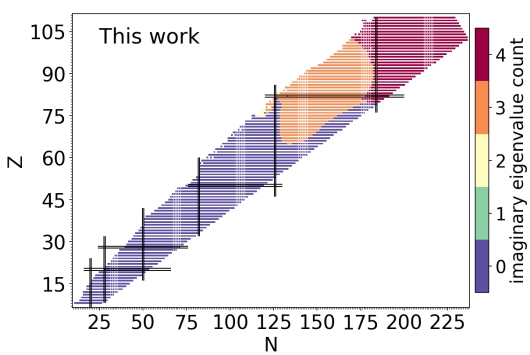
[8] G. Lorusso et al., Phys. Rev. Lett. **114**, 192501 (2015).

Global β-decay calculations within QRPA.

Sensitivity to isoscalar pairing strength (V_0)

- Large values can produce problems in the heavy and superheavy region





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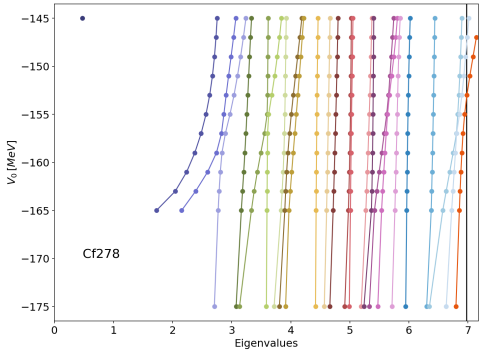
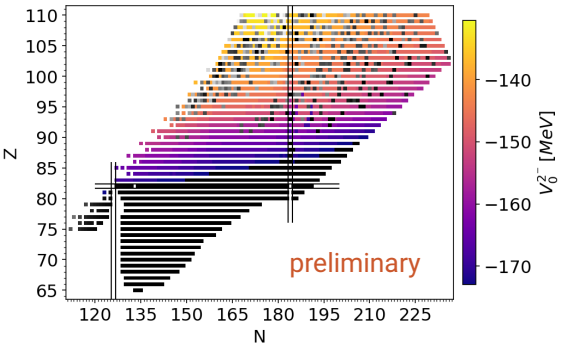
  $\rightarrow$ Evolution of eigenvalues with V_0 for 2^-





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β-delayed neutron emission: preliminary results.

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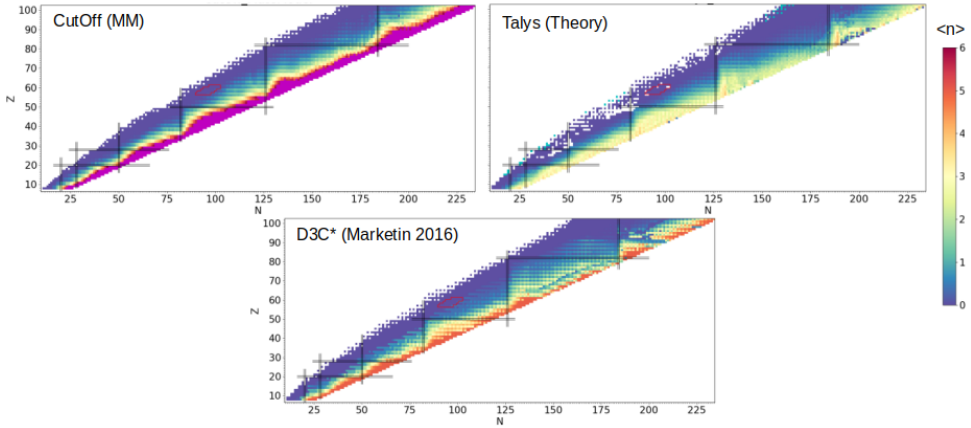

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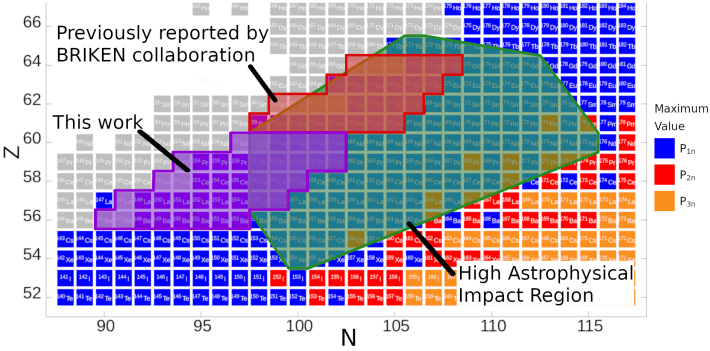
β-delayed neutron emission: Comparison to preliminary results of BRIKEN-REP experiment.

- Newly measured $T_{1/2}$ and P_{1n} values for isotopes from ^{146}Ba to ^{162}Nd.



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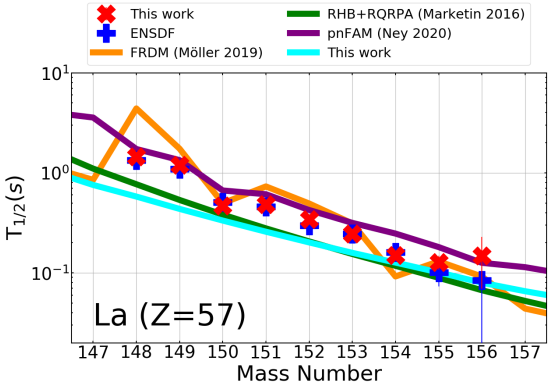
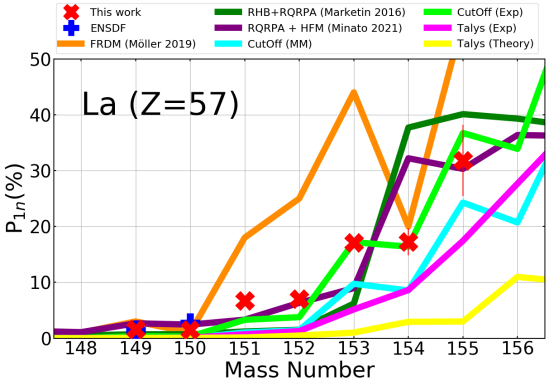
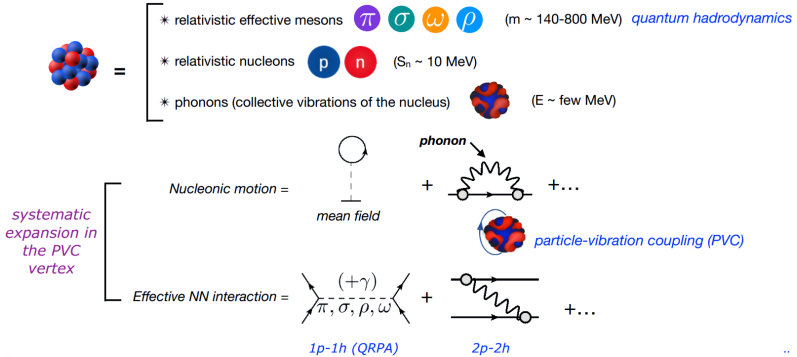




Quasiparticle vibration coupling (QVC)[9]



[9] C. Robin and E. Litvinova, Phys. Rev. C **98**, 051301 (2018), C. Robin and E. Litvinova, European Physical Journal A **52**, 205 (2016).

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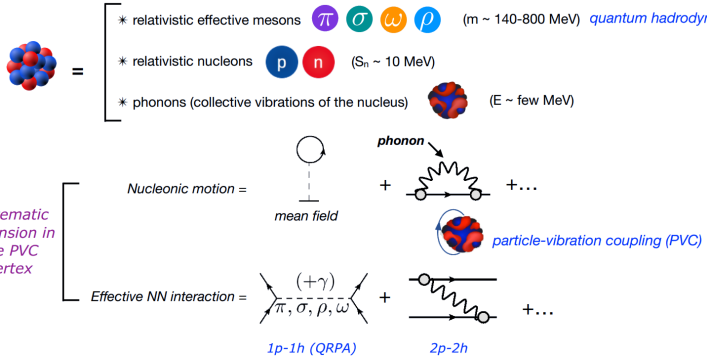

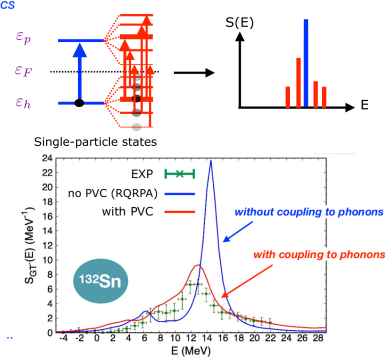

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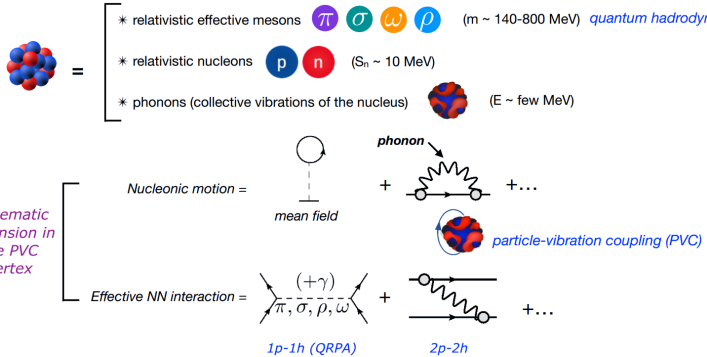
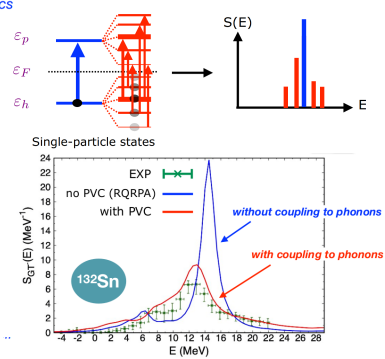
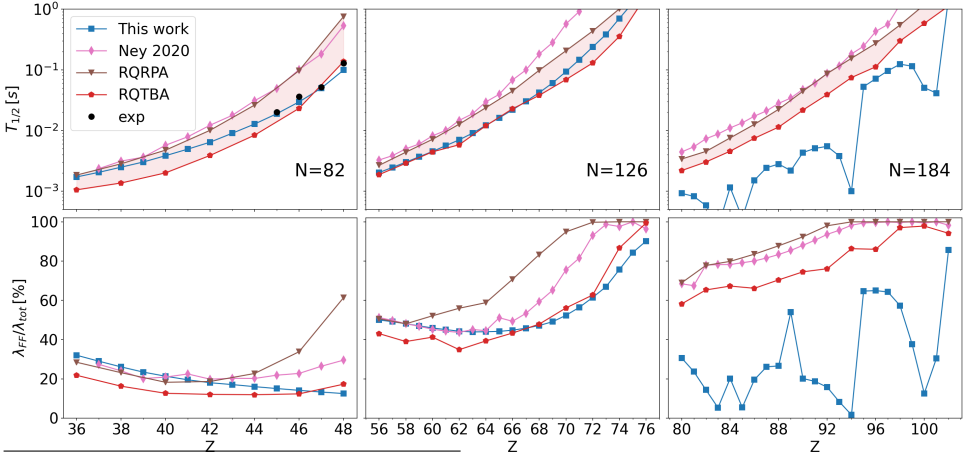




- No adjustable proton-neutron pairing.
- So far limited to spherical systems.

[9] C. Robin and E. Litvinova, Phys. Rev. C **98**, 051301 (2018), C. Robin and E. Litvinova, European Physical Journal A **52**, 205 (2016).

QVC in waiting point nuclei[10]



[10] C. E. P. Robin and G. Martínez-Pinedo, arXiv:2403.17115 (2024).

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Future work: extension to QVC and deformation.

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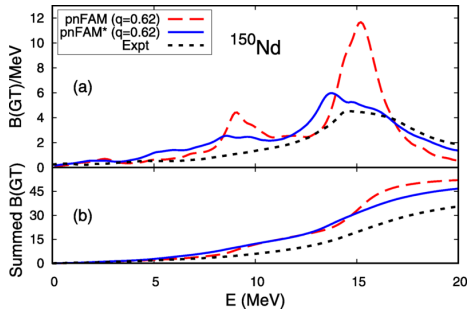
Procedure:[11,12]

- Determine phonon vertices from like-particle response.
- Add the vertices to the residual interaction of the deformed β-decay calculation[14]

(in collaboration with A. Ravlić)

Effects on the GT strength[2]



[11] E. Litvinova and Y. Zhang, Phys. Rev. C **104**, 044303 (2021), Y. Zhang et al., Phys. Rev. C **105**, 044326 (2022).
[12] Q. Liu et al., Phys. Rev. C **109**, 044308 (2024).
[13] A. Ravli ć et al., Phys. Rev. C **110**, 024323 (2024).

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Summary and outlook.

- Towards improvement of global β-decay rates and β-delayed emission probabilities calculations within relativistic description.
- At QRPA level:
  - Corrections and update of previous global RQRPA β-decay rates tabulation including correction of the isoscalar pairing strength values for heavier nuclei *(in progress)*.
  - β-delayed neutron emission probabilities measurement as a benchmark for the theory.
- Beyond QRPA:
  - Inclusion of the phonons reduces the half-lives, bringing them closer to the experiment without the need for adjustable proton-neutron pairing.
  - Ultimately, extension to include deformed like-particle phonon vertices in the deformed β-decay calculation.

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Thank you for your attention!

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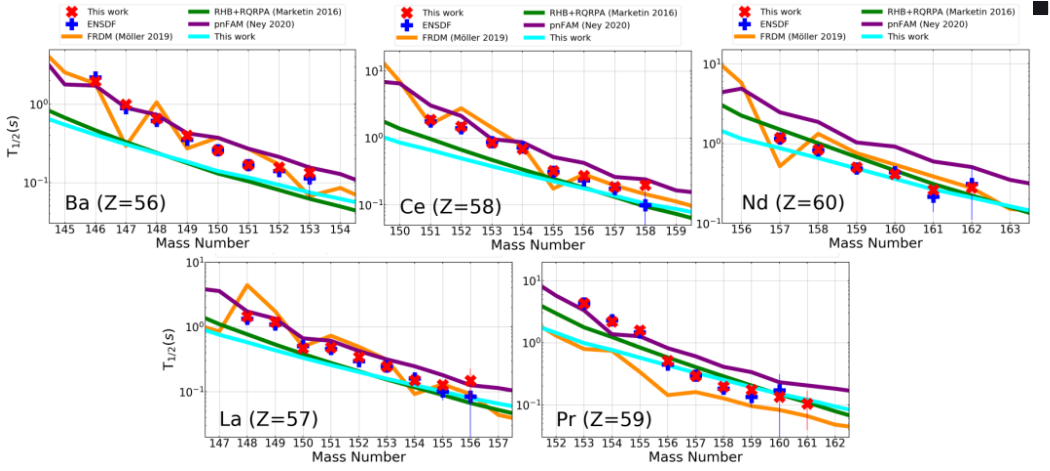
Preliminary results of BRIKEN-REP experiment.



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