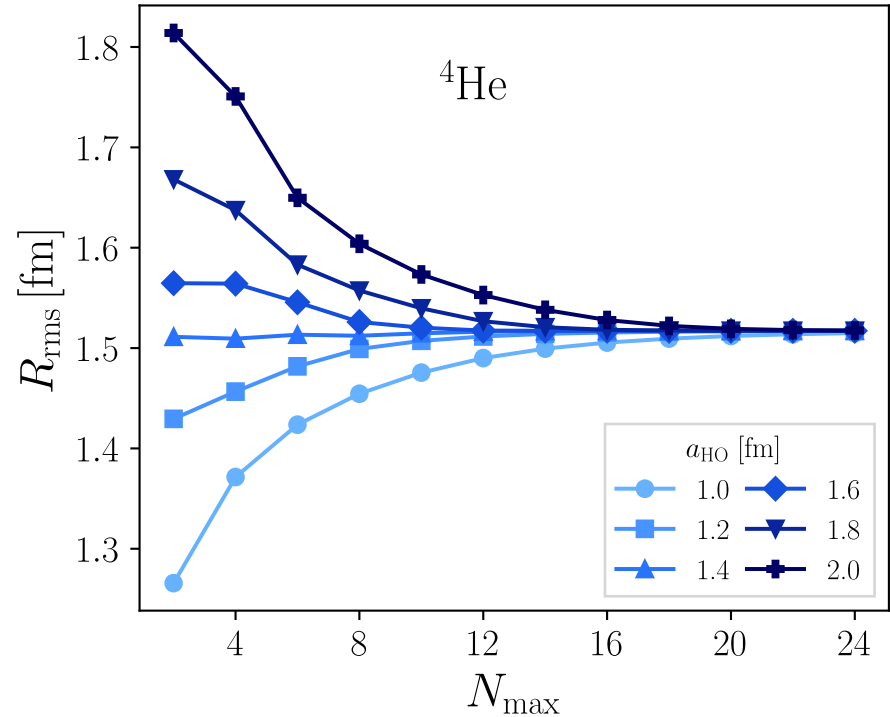


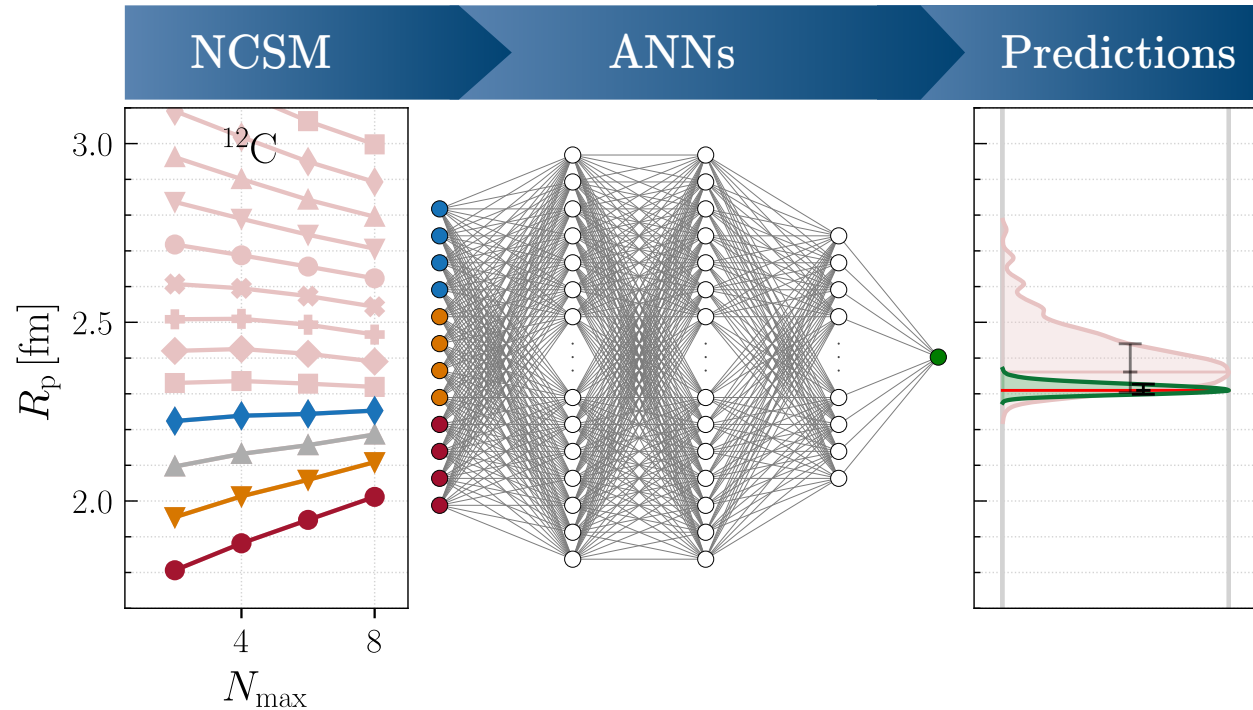
# Improved ANNs for NCSM Charge Radius Calculations

- Range  $\hbar\Omega$  or  $a_{\text{HO}}$
- Converge to same value for  $N_{\text{max}} \rightarrow \infty$
- Full convergence achieved only for few-body systems

- For heavier nuclei
  - Insufficient convergence
  - Extrapolations necessary

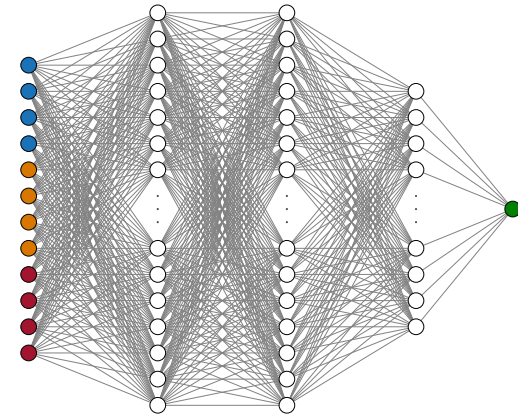
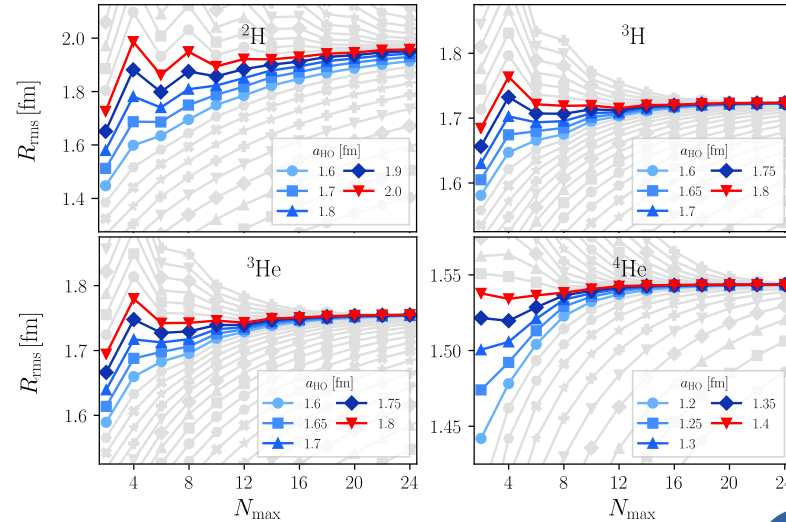


- Construct samples from  $a_{HO}$  sequences
- Most probable value as nominal result
- Statistical analysis include many-body and network uncertainties
- Pre-selecting  $a_{HO}$  sequences to mitigate evaluation artifacts



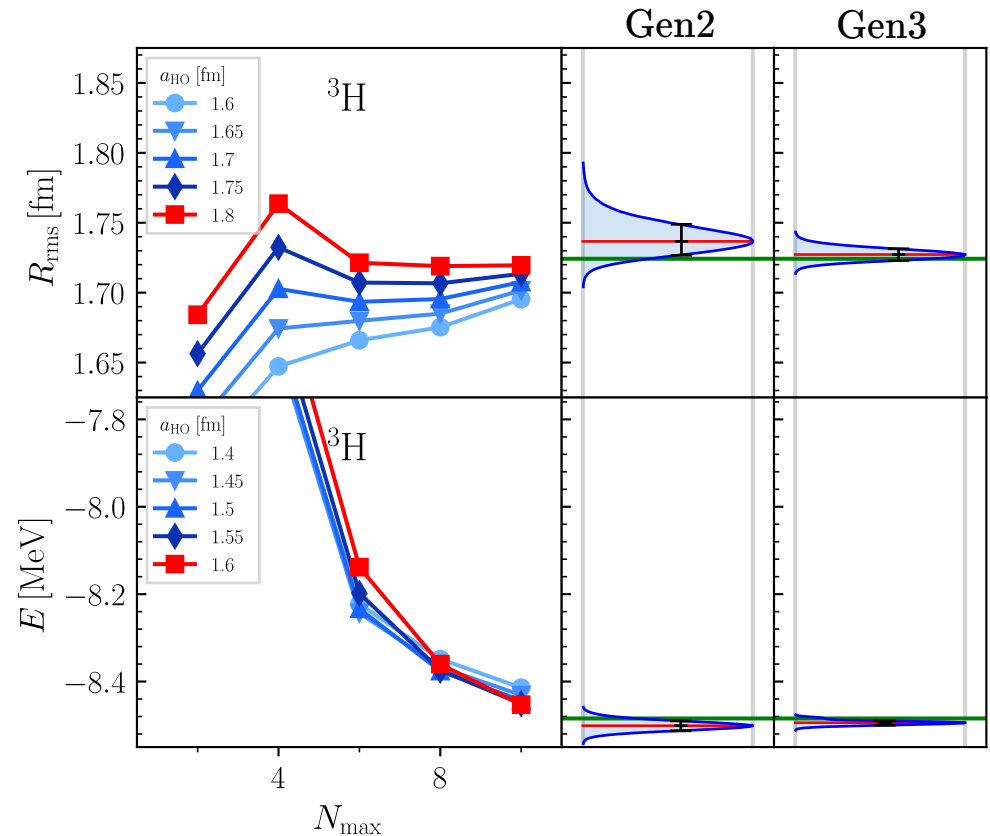
- Converged NCSM calculations for training
- 36 interactions, 4 nuclei
- Gen3 Networks for radii predictions
- Apply  $a_{\text{HO}}$  selection to improve training data
  - Flattest  $a_{\text{HO}}$  with up to 4 sequences below
  - Reduces training time

## Network Training

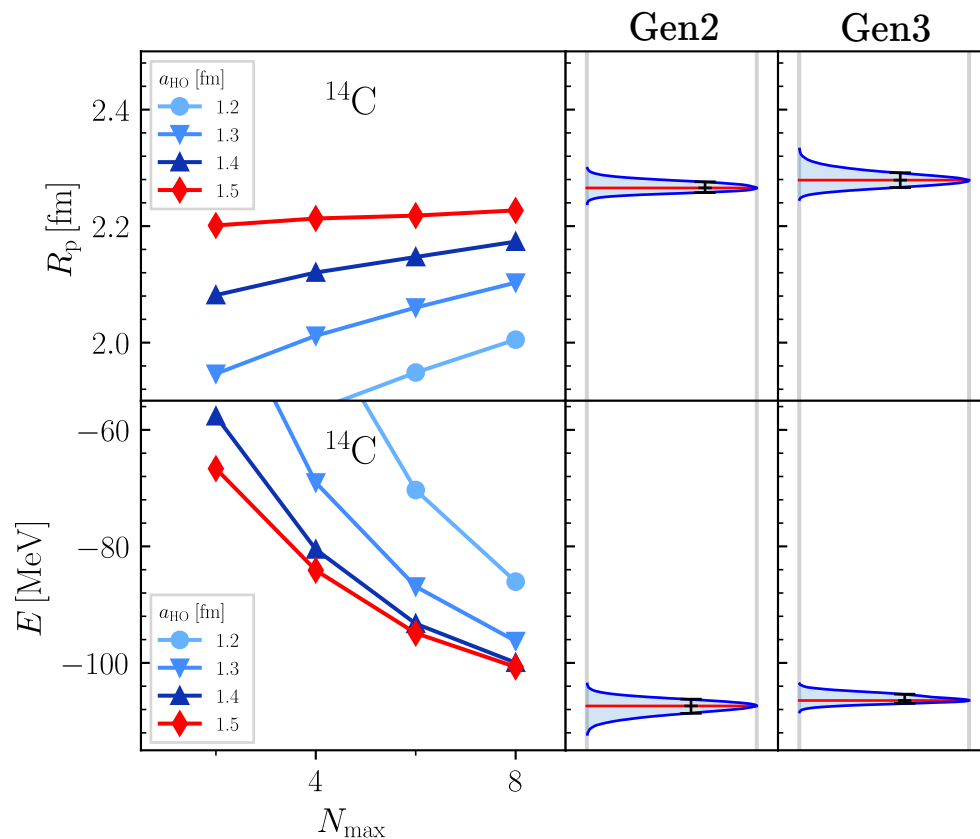


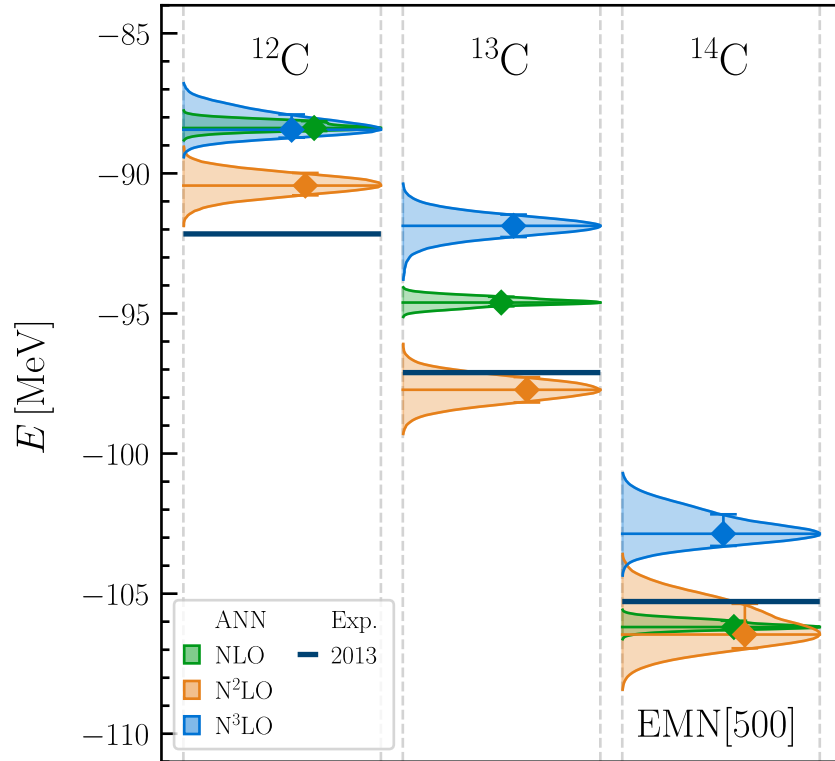
1000 networks constructed  
and trained on  $a_{\text{HO}}$  selection

- Direct comparison between Gen2 and Gen3
- Test with training data
- Optimized training yields more accurate and precise predictions

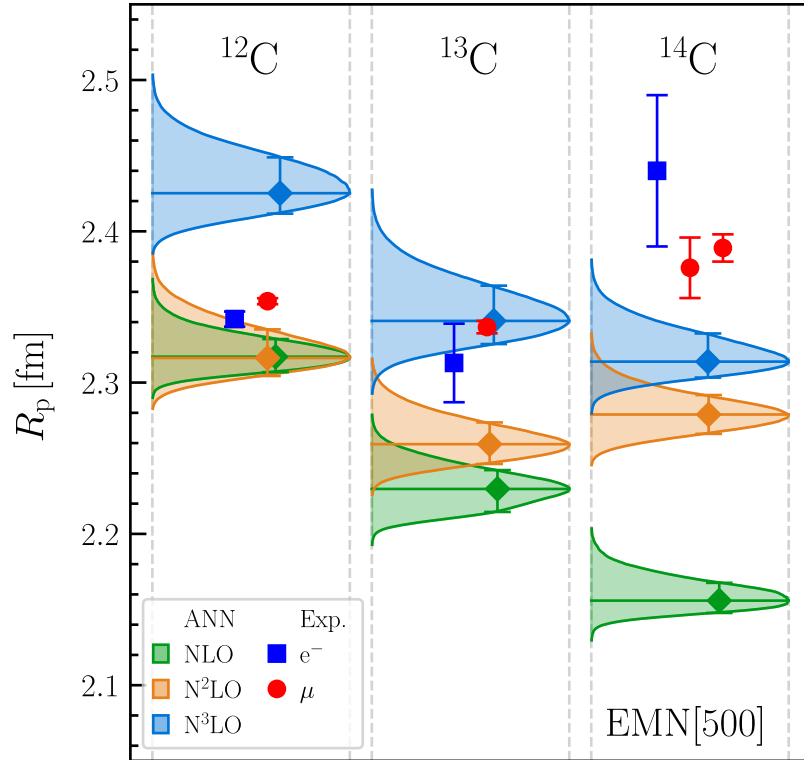


- Direct comparison between Gen2 and Gen3
- Evaluation on unseen NCSM data for  $^{14}\text{C}$
- Similar performance between both network generations
- Major effect from selection rule

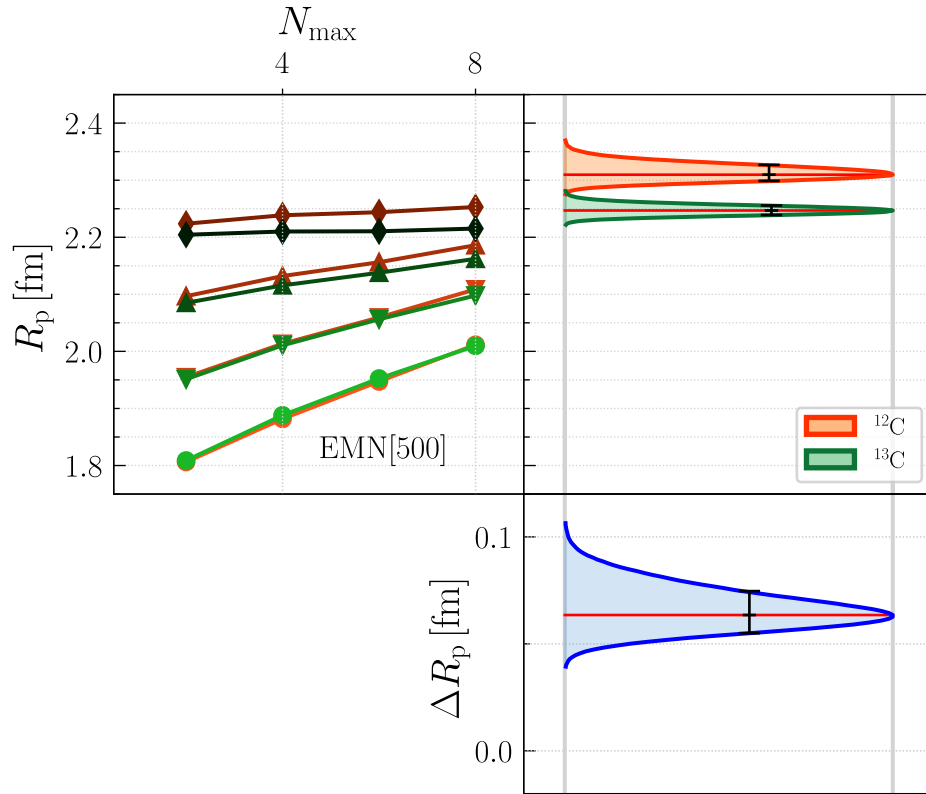




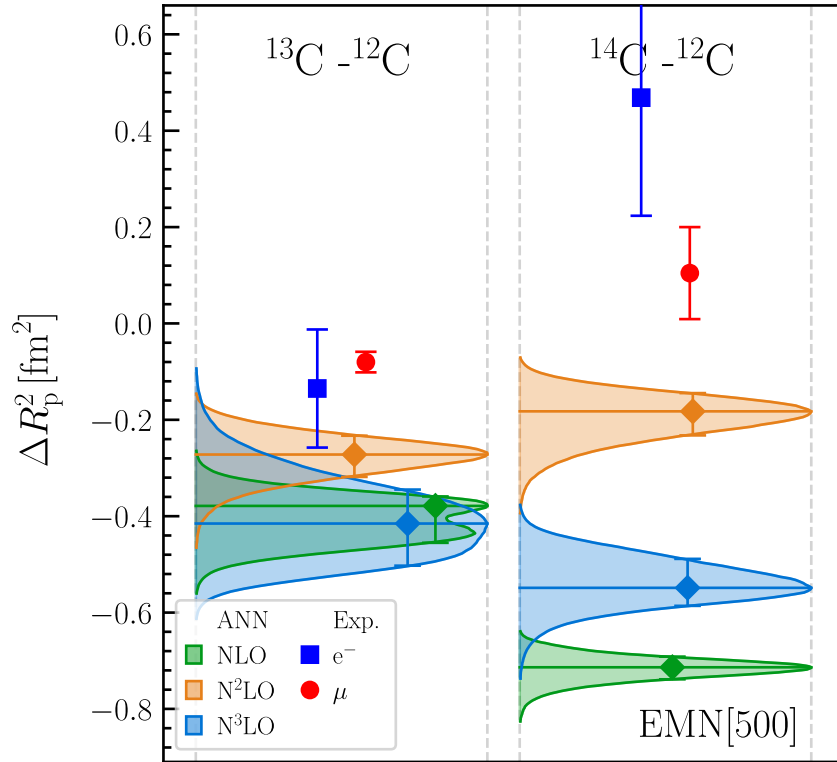
- Ground-state energy predictions
- Evaluated NCSM data of non-local interaction for different chiral orders
- Network predictions compatible with experimental data
- Results for N<sup>2</sup>LO providing closest agreement to measurements



- Point-proton radius predictions
- Monotonic decreasing radius for NLO and  $N^3\text{LO}$  across isotopes
- $N^2\text{LO}$  shows V-shape pattern similar to experiment
- Non-trivial interaction dependence for these nuclei



- Determine observable differences by sample-wise subtraction
- New distribution inherently includes correlations between observables
- Notably reduces uncertainties



- $\Delta R_p^2$  experimentally accessible via isotope shift
- Independent from proton radius
- Radius pattern of respective orders transfers to differences
- Similar trend in  $\text{N}^2\text{LO}$  and experiment

# Improved ANNs for NCSM Charge Radius Calculations

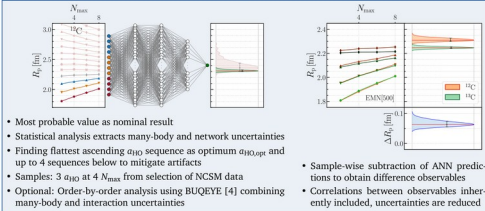


Tobias Gesser, Tobias Wolfgruber, Pieter Maris and Robert Roth

## Motivation

- Artificial neural networks (ANNs) are used to predict converged values from NCSM data [1]
- Selecting only a subset of frequencies from NCSM calculations results in more stable ANN predictions [2]
- Previous ANN generations were not trained for a specific frequency selection method
- The carbon isotopic chain is perfect to test ab initio calculations due to its rich nuclear structure [3]
- $^{14}\text{C}$  is of particular interest as one of the heavier nuclei accessible to the NCSM, and is subject to new high-precision muonic and laser spectroscopy experiments

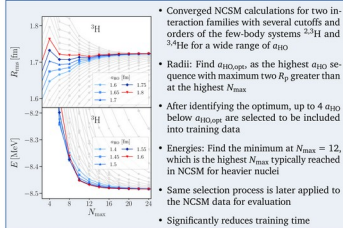
## NCSM Evaluation and Post-Processing



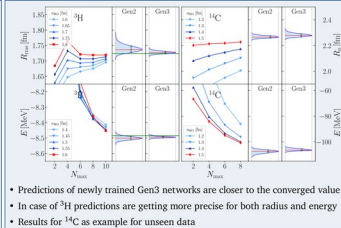
# Thanks to my group and collaborators

R. Roth, P. Maris, M. Müller,  
L. Wagner, C. Wenz, T. Wolfgruber

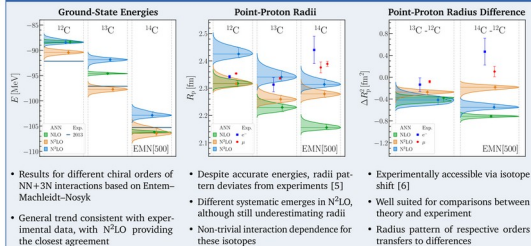
## Improved Network Training



## Network Comparison



## Carbon Isotopes



## Conclusion & Outlook

- Frequency selection applied to training data for new generation of ANNs
- Predictions for carbon isotopes from NCSM with non-local NN+3N interaction at cutoff 500 MeV
- Although results show a discrepancy to experimental findings for  $R_C$ ,  $\text{N}^3\text{LO}$  seems to show a similar decrease and increase for the radii of  $^{12,13,14}\text{C}$
- In the Future**
- Include physically motivated pseudo data to enhance network training
- NCSM calculations with new interactions by LENPIC
- Refine chiral forces with information from experimental findings on radii

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- B. Maaß et al., Phys. Rev. Lett. 122, 182501 (2019)
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- J.W. Holt et al., Phys. Rev. C 100, 044001 (2019)
- I. Sick, Phys. Lett. B 116, 212 (1982)
- W. Ruckstuhl et. al. Nucl. Phys. A 430, 685 (1984)