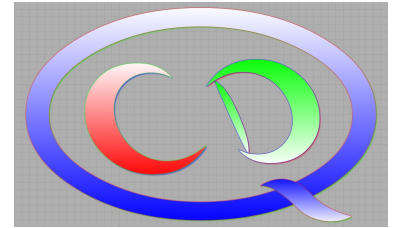


Collaborative research center CRC 110

"Symmetries and the emergence of structure"

25+5 min Vortrag



Status of Project B.6

Strangeness in hadronic and nuclear systems

Andreas Nogga, Akaki Rusetsky, Shan-Gui Zhou

Deutsche
Forschungsgemeinschaft

DFG



NSFC

National Natural Science Foundation of China

Staff

- Principle investigators:

Andreas Nogga [FZJ]

Akaki Rusetsky [Bonn]

Shan-Gui Zhou [ITP/CAS]

- Students:

Hoai Le [FZJ]

Xu Meng [ITP/CAS]

Yu-Ting Rong [ITP/CAS]

Xiang-Xiang Sun [ITP/CAS]

Kun Wang [ITP/CAS]

- Post-Docs:

Cheng-Jun Xia [ITP/CAS]

Rui Han [ITP/CAS]

- External collaborators:

Vadim Baru [Bochum], Evgeny Epelbaum [Bochum], Johann Haidenbauer [FZJ], Bingnan Lu [FZJ], En-Guang Zhao [ITP/CAS], Jie Zhao [U Zagreb, CAEP]

Overview & Outline

Strangeness in hadronic and nuclear systems

CDFT -

Study hypernuclei based on phenomenological functionals
cluster structure and shape of ordinary and hypernuclei
properties of hypernuclei
very complex systems

investigate
overlapping
mass region

Jacobi-NCSM - p-shell hypernuclei based on chiral YY, YN and NN interactions

SRG evolution required
test & improve YY, YN interactions (replace YY, YN data by hypernuclear data)
solution of Schrödinger equation based on interactions consistent QCD symmetries

Faddeev & Yakubovsky approach to s-shell hypernuclei

also based on chiral YY, YN, NN and $\bar{K}N$ interactions
SRG evolution not required but possible
direct solution of Schrödinger equation based on interactions consistent
QCD symmetries

benchmarks &
SRG evolution

$\bar{K}d$ scattering - model independent extraction of $\bar{K}N$ scattering length
direct relation to explicit chiral symmetry breaking of QCD

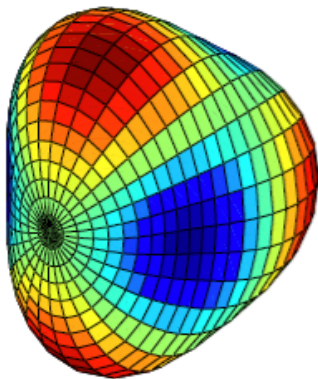
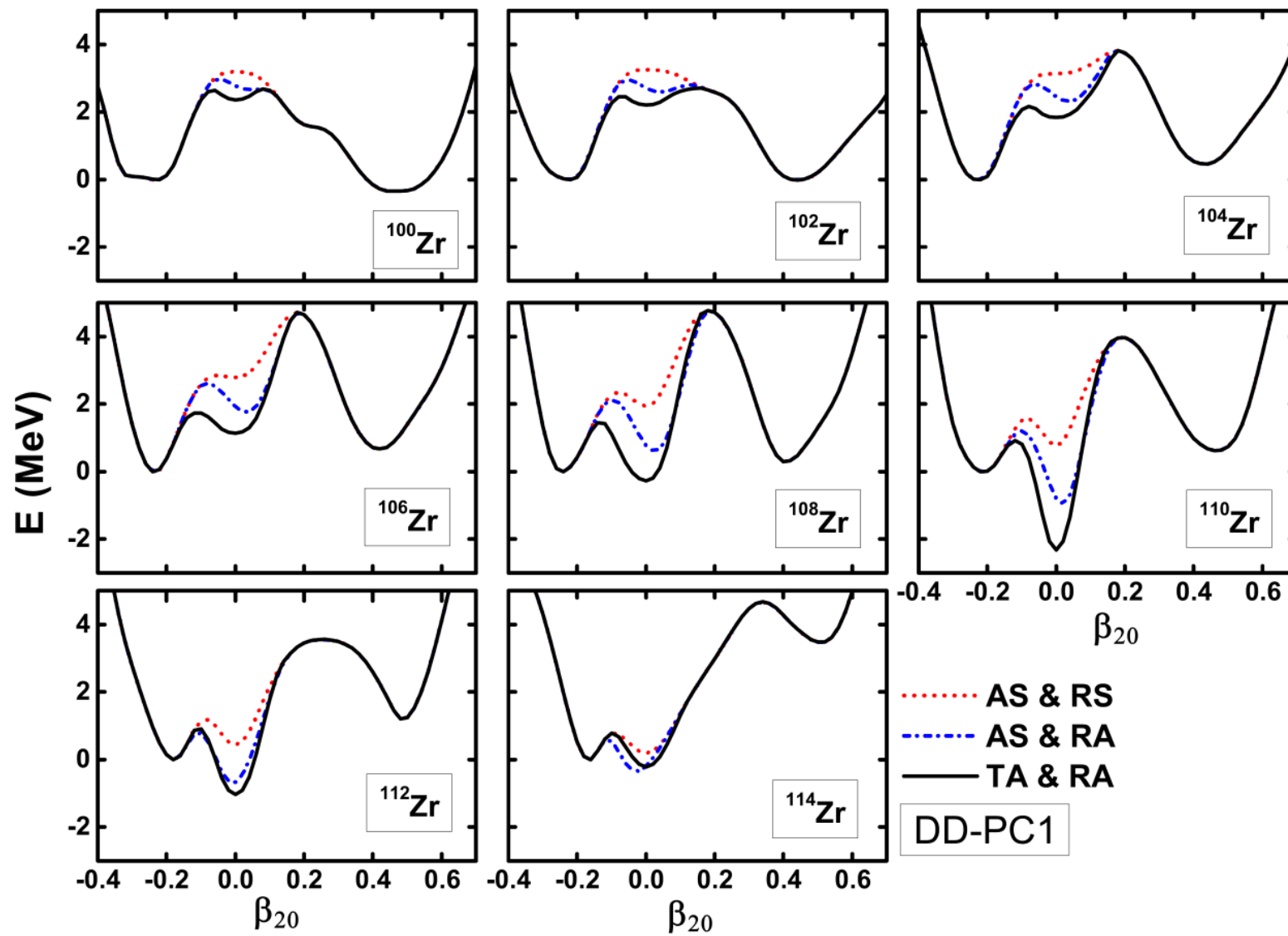
test approach
to resummations

Progress with Multi-Dimensionally-Constrained CDFT

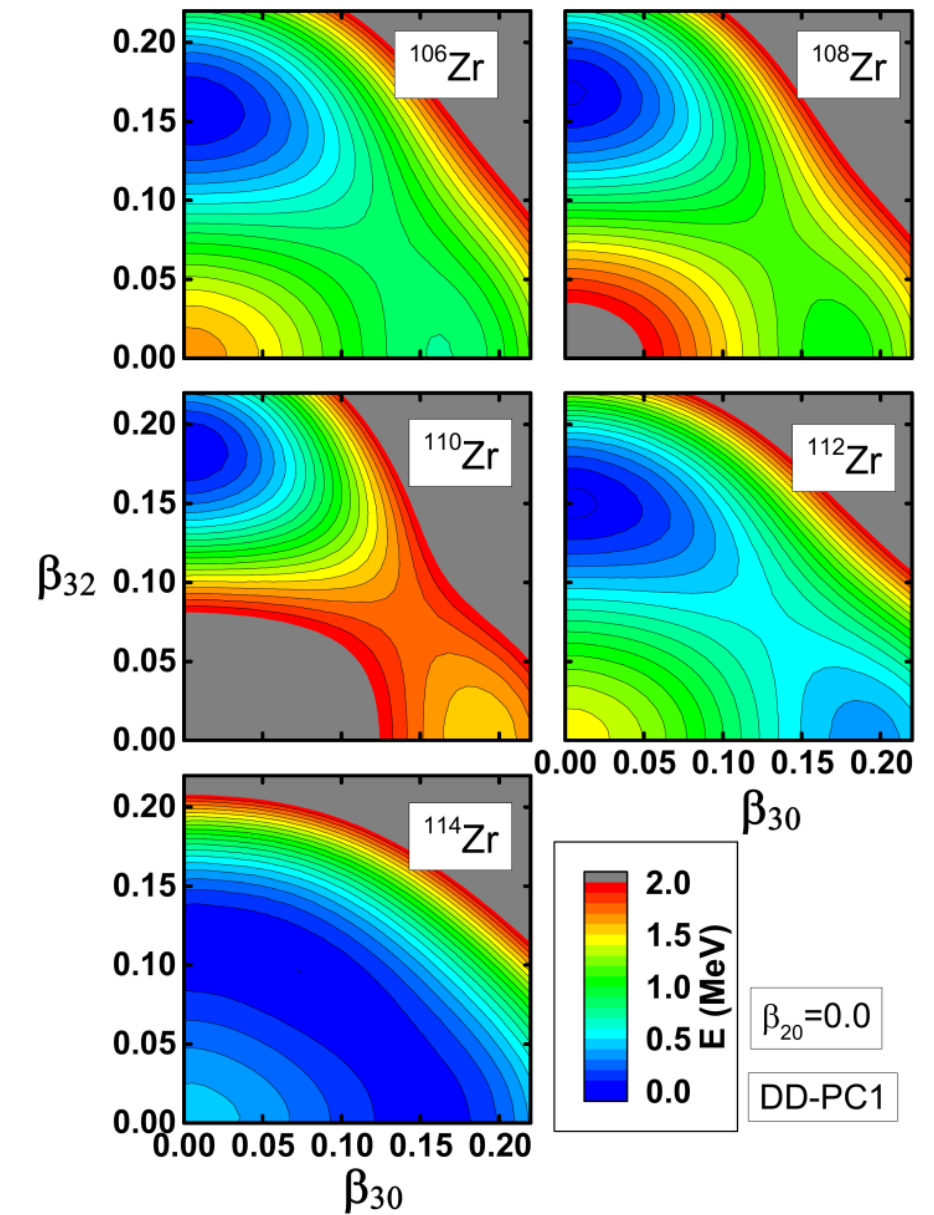
- New developments of MDC-CDFTs
 - ▶ A multidimensionally-constrained relativistic Hartree-Bogoliubov (MDC-RHB) model
 - ▶ Angular momentum projection (AMP) & parity projection (PP)
 - Recent applications of MDC-CDFTs
 - ▶ Localization effects in ^{12}C & ^{16}O
 - ▶ Tetrahedral shapes in Zr isotopes
 - ▶ Constraint clustering structure in ^{16}O
 - ▶ 1- & 2-dim PES of ^{270}Hs
 - ▶ Giant monopole resonance & incompressibility
 - ▶ Bubble & toroidal structure in superheavy nuclei
- } next slides
- } Kun Wang's talk

Results I: Tetrahedral shapes in Zr isotopes from MDC-RHB model

Jie Zhao, Bing-Nan Lu, En-Guang Zhao, Shan-Gui Zhou, PRC 95, 014320 (2017)

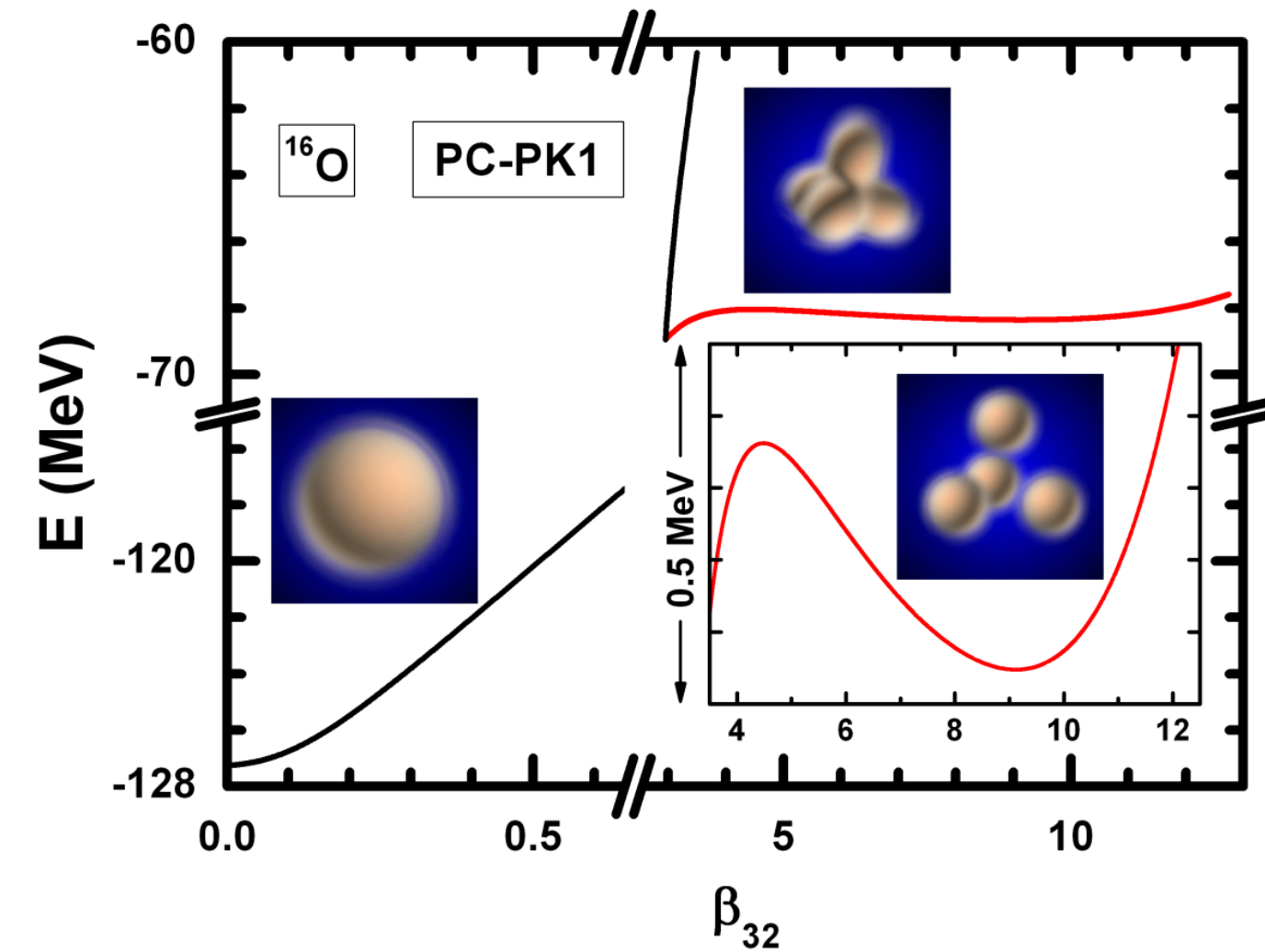


$$R(\theta, \varphi) = R_0 \left[1 + \beta_{00} + \sum_{\lambda=1}^{\infty} \sum_{\mu=-\lambda}^{\lambda} \beta_{\lambda\mu}^* Y_{\lambda\mu}(\theta, \varphi) \right]$$

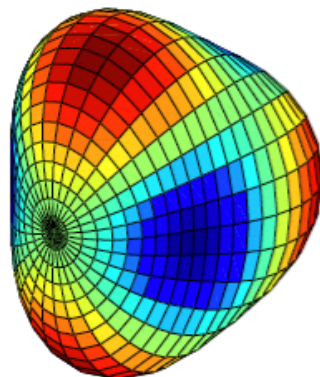
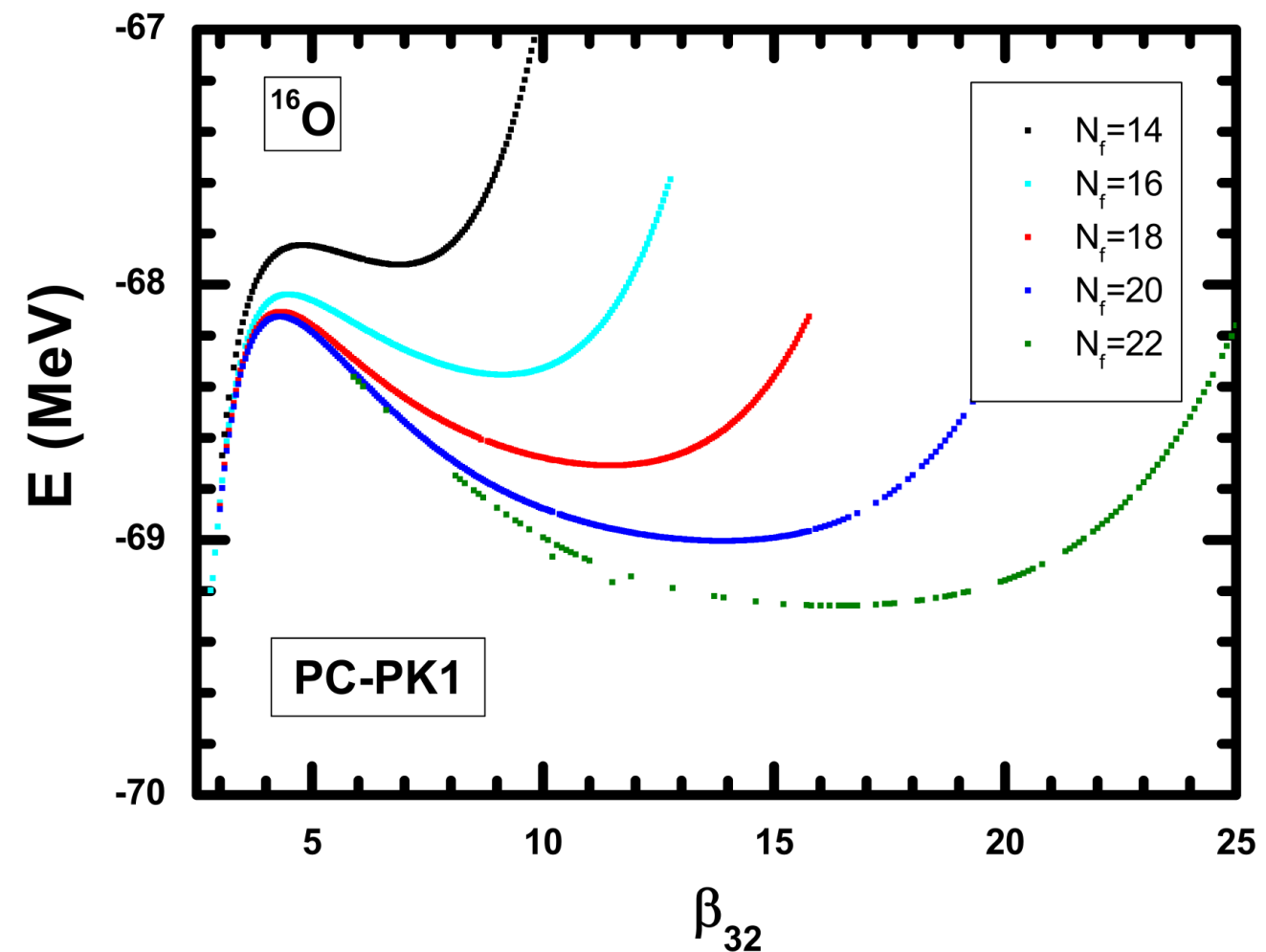


Results II: Constraint cluster structure in ^{16}O

Jie Zhao et al., in preparation

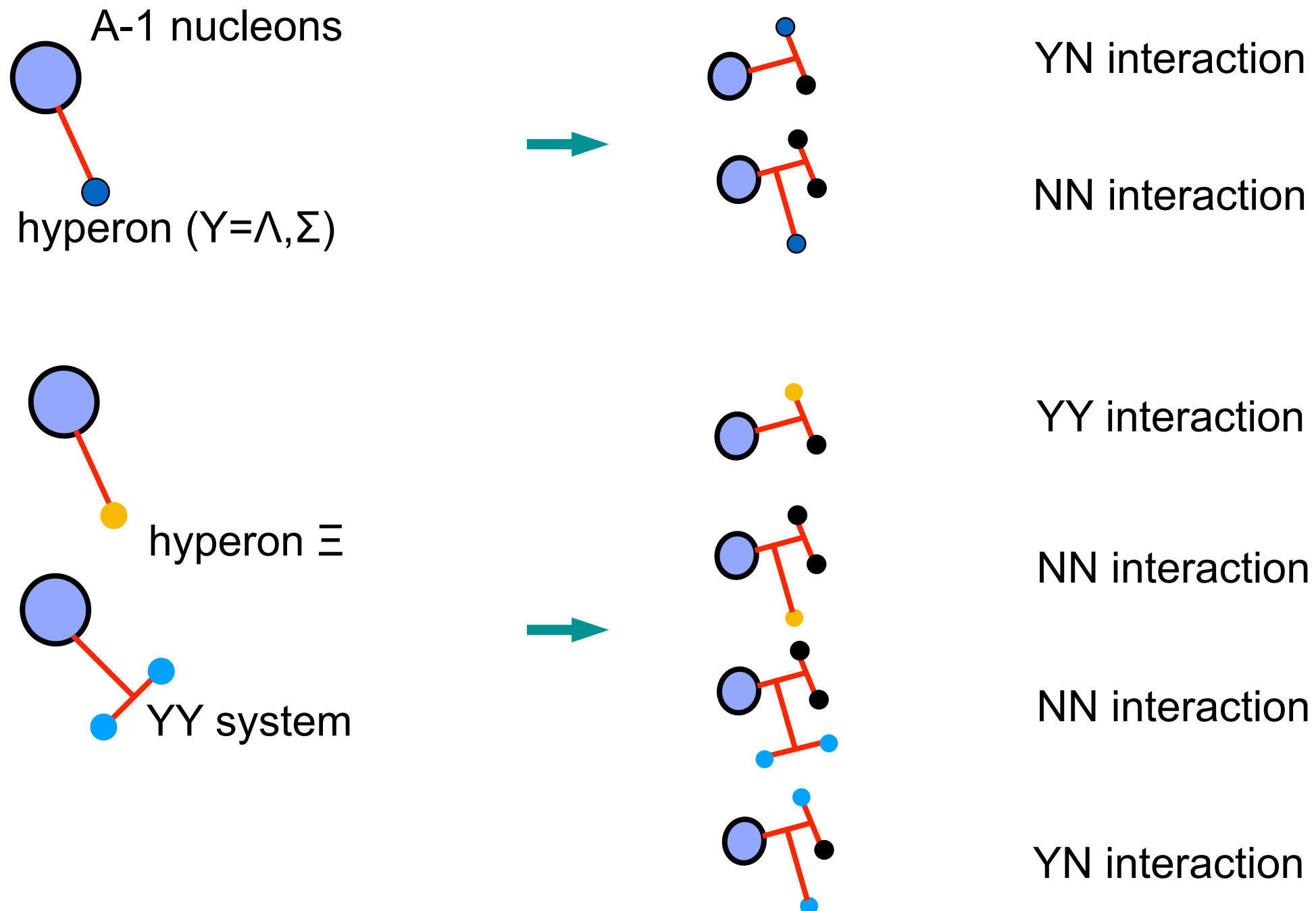


$$R(\theta, \varphi) = R_0 \left[1 + \beta_{00} + \sum_{\lambda=1}^{\infty} \sum_{\mu=-\lambda}^{\lambda} \beta_{\lambda\mu}^* Y_{\lambda\mu}(\theta, \varphi) \right]$$



Progress Jacobi-NCSM for Hypernuclei

- Transition coefficients for single and double Λ hypernuclei for two-body operators are complete



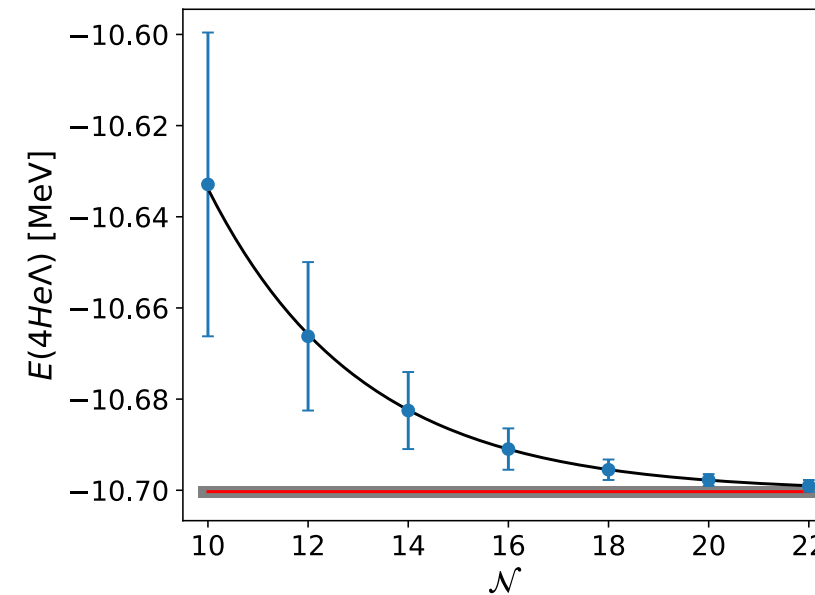
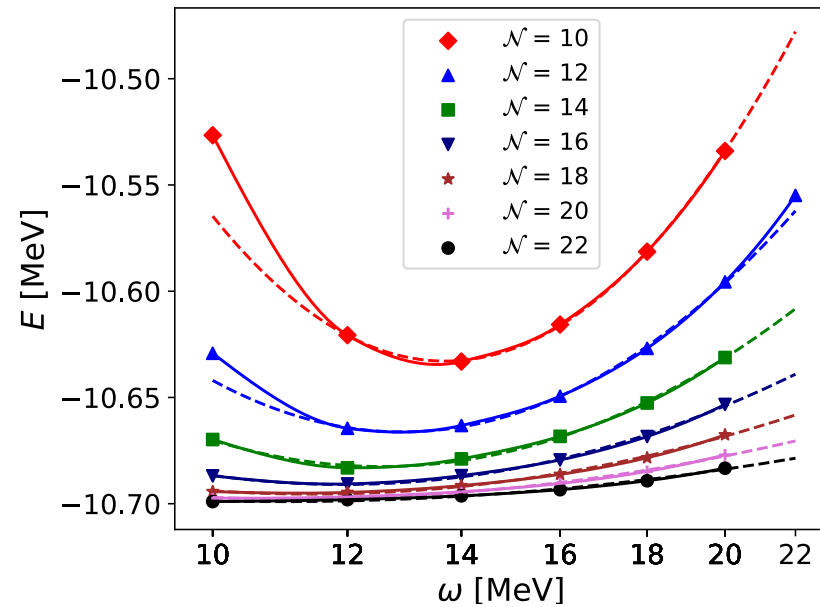
- Λ separation energies and excitation energies of single Λ hypernuclei:

$${}^4_{\Lambda}\text{He}(0^+, 1^+) \quad {}^5_{\Lambda}\text{He}(\frac{1}{2}^+) \quad {}^6_{\Lambda}\text{Li}(1^-) \quad {}^7_{\Lambda}\text{Li}(\frac{1}{2}^+, \frac{3}{2}^+)$$

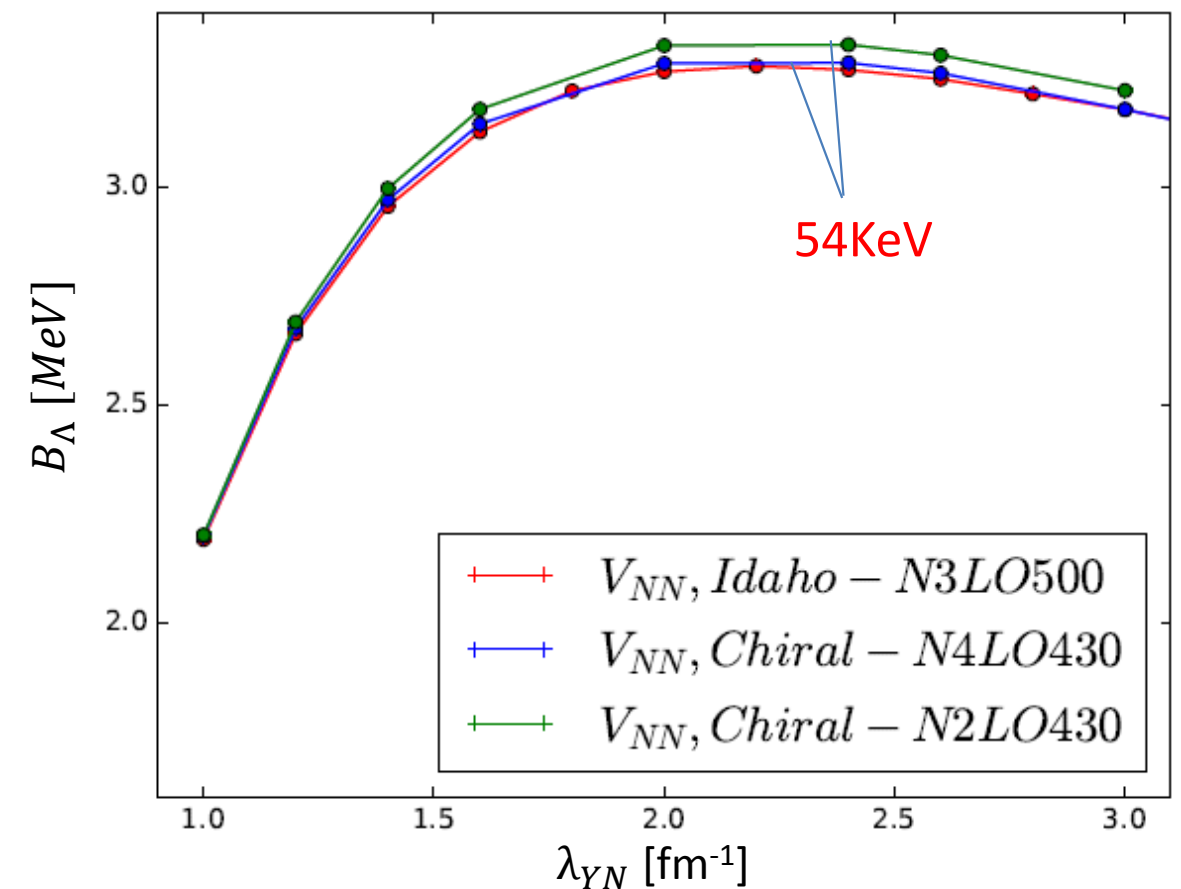
Results III: Single Λ Hypernuclei

H. Le, U.-G. Meißner, AN, in prep.

${}^4_{\Lambda}\text{He}(0^+)$



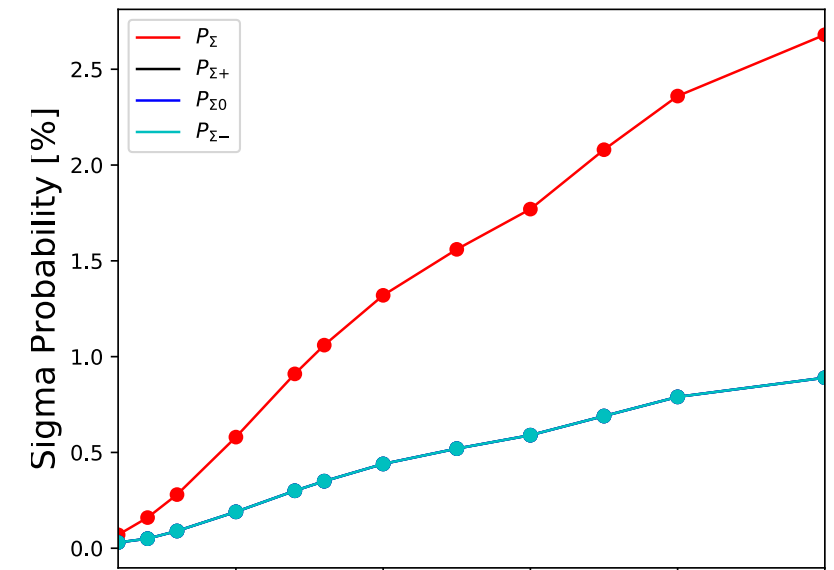
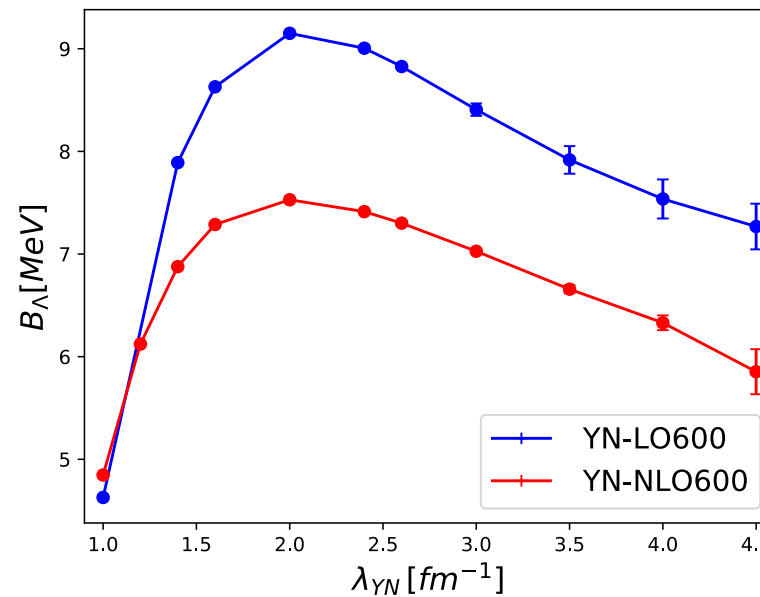
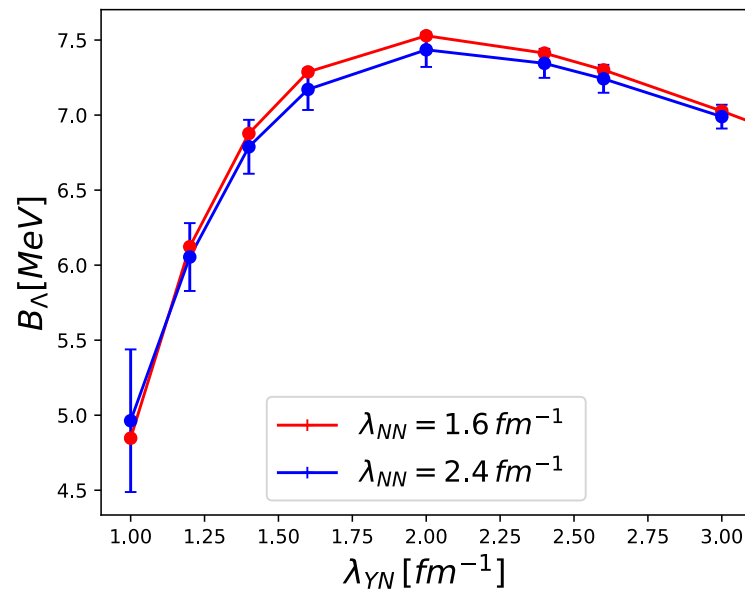
- SRG interactions (NN: Idaho, YN:LO,NLO)
- good convergence of binding and Λ separation energies
- independence of NN SRG parameter
- **strong dependence on YN SRG parameter**



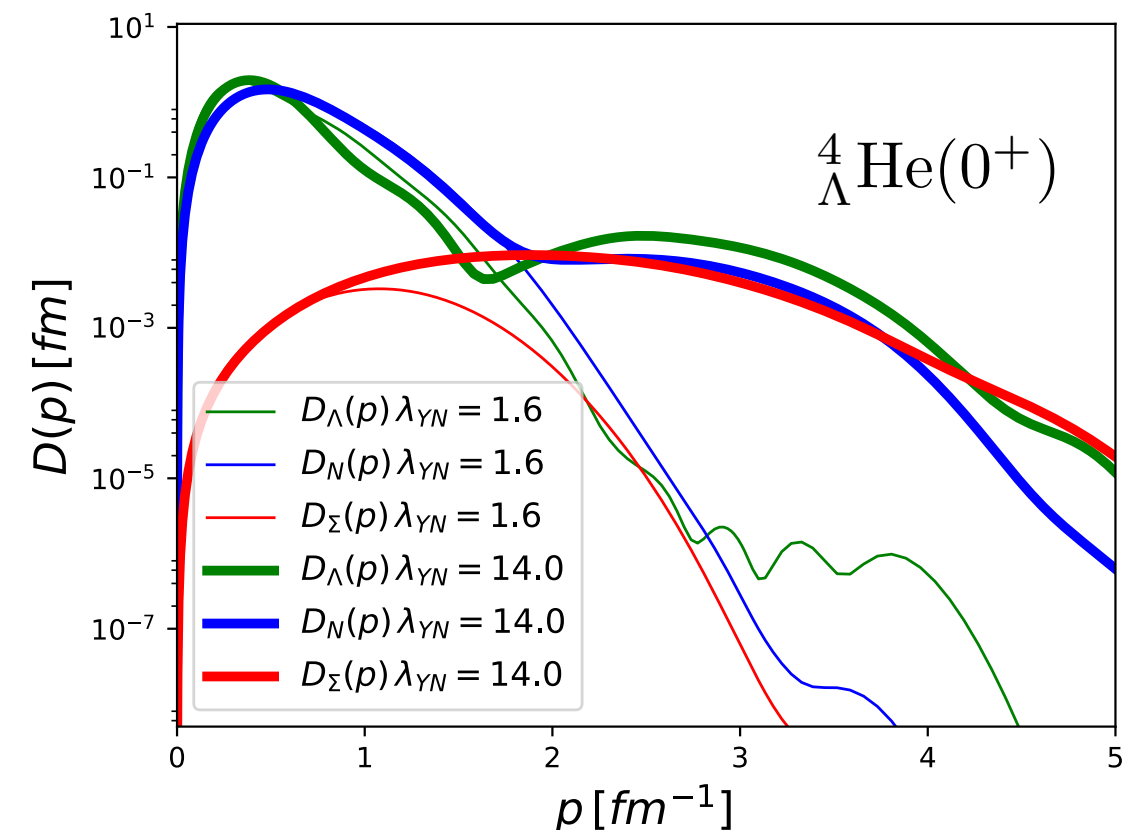
Results III: Single Λ Hypernuclei

H. Le, U.-G. Meißner, AN, in prep.

$${}^5_{\Lambda}\text{He}(\frac{1}{2}^+)$$



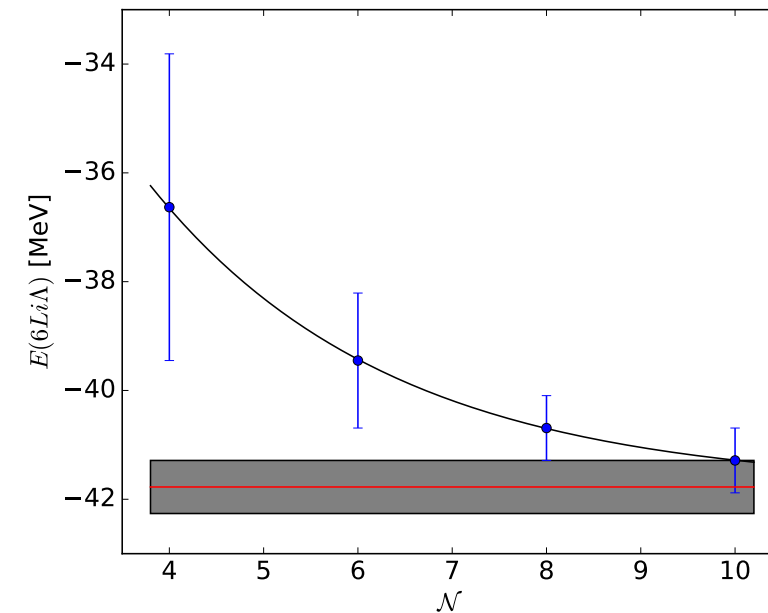
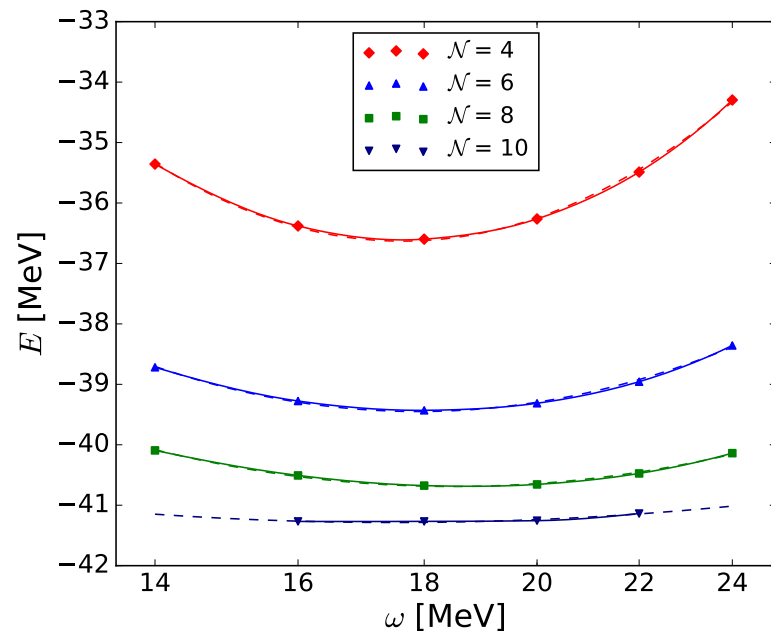
- SRG interactions (NN: Idaho, YN:LO,NLO)
- good convergence of binding and Λ separation energies
- independence of NN SRG parameter
- **strong dependence on YN SRG parameter**
- dependence on YN SRG related to Σ probability
- high momentum tail for Σ important
- surprisingly large Σ component in $A=5$!



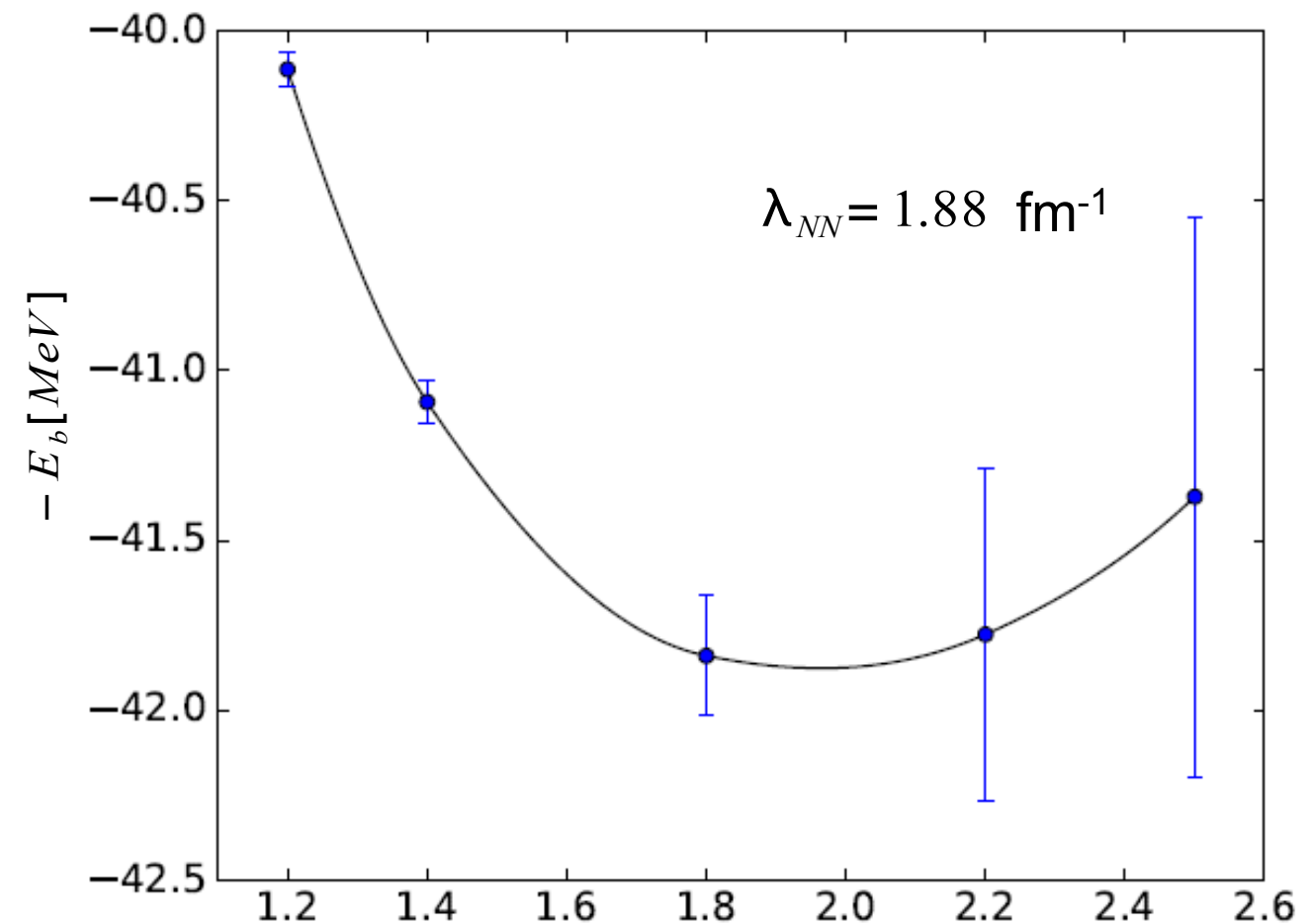
Results III: Single Λ Hypernuclei

H. Le, U.-G. Meißner, AN, in prep.

${}^7_{\Lambda}\text{Li}(\frac{1}{2}^+)$



- SRG interactions (NN: Idaho, YN:LO)
- good convergence of binding for λ up to 2 fm^{-1}
- **strong dependence on YN SRG parameter**
- dependence on NN SRG parameter currently investigated
- extension of model space to $N=12$



Milestones

2016/2

- Calculation of the recoil corrections to the $\bar{\Lambda}$ Kd scattering length → to be finalized soon
- Implementation of a bound state Faddeev code for $S = -2$ three-baryon systems → in progress
- Detailed study of possibilities for the existence of ${}^3_{\Lambda}n$ state → in progress
- Generation of $S = -2$ NCSM states and implementation of transitions to ΞN -(A-2) states. → done ✓
- The dependence of shape and clustering effects in light hypernuclei on the effective interactions → not done

2017

- Formulation of the EFT framework for the $\bar{\Lambda}$ Kd scattering in terms of a dimer field corresponding to the $\Lambda(1405)$ → formalism is used within B4, will be implemented here as well
- Extension of the Faddeev code to scattering → requires bound state code, will be started soon
- Detailed study of ${}^3_{\Lambda\Lambda}n$ and ${}^3_{\Lambda\Lambda}H$ → requires bound state code, will be started soon
- Implementation of transitions to YN -(Y-A-3) NCSM states ($S = -1$ YN pairs) → done ✓
- Further study of the dependence of shape and clustering effects in light hypernuclei on the effective interactions. → Not done.
- Evaluation of the finite-size corrections in the dimer formulation.
- Study of $\bar{\Lambda}$ Kd scattering solving Faddeev equations and comparison to previous results → requires scattering code
- Implementation of a bound states Yakubovsky code for $S = -2$ four-baryon systems → requires bound state code, will be started soon
- Addition of non-perturbative 3BFs to the 3-body Faddeev code → in progress for single Λ code
- First $S = -2$ calculations for ${}^4_{\Lambda\Lambda}He$ within the NCSM → currently doing ${}^6_{\Lambda\Lambda}He$
- Study of the Hoyle-like state and the tetrahedron-like state in normal and hypernuclei. → done for normal nuclei
- Extension of the MDC-RMF model to including multi- Λ → in progress

Publications

1. J. Behrendt, E. Epelbaum, J. Gegelia, Ulf-G. Meißner, A. Nogga, "Two-nucleon scattering in a modified Weinberg approach with a symmetry-preserving regularization," *Eur. Phys. J. A* **52** (2016), 296 [[arXiv:1606.01489](#) [nucl-th]]

2. P. Maris, S. Binder, A. Calci, E. Epelbaum, R. J. Furnstahl, J. Golak, K. Hebeler, H. Kamada, H. Krebs, J. Langhammer, S. Liebig, U.-G. Meißner, D. Minossi, A. Nogga, H.D. Potter, R. Roth, R. Skibinski, K. Topolnicki, J.P. Vary, H. Witala, "Properties of ^4He and ^6Li with improved chiral EFT interactions," *EPJ Web Conf.* **113** (2016) 04015.

3. Jie Zhao, Bing-Nan Lu, En-Guang Zhao and Shan-Gui Zhou, "Tetrahedral shapes of neutron-rich Zr isotopes from a multidimensionally constrained relativistic Hartree-Bogoliubov model," *Phys. Rev. C* **95** (2017) 014320 [[arXiv:1606.08994](#) [nucl-th]].

4. Cheng-Jun Xia and Shan-Gui Zhou, "Stable strange quark matter objects with running masses and coupling constant," *Nucl. Phys. B* **916** (2017) 669-687.

5. Bing Wang, Kai Wen, Wei-Juan Zhao, En-Guang Zhao and Shan-Gui Zhou, "Systematics of capture and fusion dynamics in heavy-ion collisions," *At. Data Nucl. Data Tables* **114** (2017) 281-370 [[arXiv:1504.00756](#) [nucl-th]].

6. Shan-Gui Zhou, "Structure of Exotic Nuclei: A Theoretical Review," in T. Kibedi, D. Leinweber, C. Simenel, A. Thomas, R. Young and J. Zanotti (eds.), *PoS (INPC2016)*, 2017, 373 [[arXiv:1703.09045](#) [nucl-th]].

7. Hoai Le, Ulf-G. Meißner, A. Nogga, "Jacobi No-core Shell Model for Hypernuclei," in *Proceedings of the International Workshop on Chiral Forces in Low Energy Nuclear Physics* (ed. J. Golak, S. Skibinski), 2017 [[arXiv:1705.01530](#) [nucl-th]]

8. A. Wirzba, J. Bsaisou, A. Nogga, "Permanent electric dipole moments of single-, two- and three-nucleon systems," *Int.J. Mod. Phys. E* **26** (2017), 1740031 [[arXiv:1610.00794](#) [nucl-th]].

Summary & outlook

Unified view on several aspects of strangeness in hadrons and nuclei

CDFT for ordinary and hypernuclei nuclei

- clustering structure O and shape of Zr has been investigated
- multi Λ systems will be added soon
- dependence of shape and clustering effects in light hypernuclei on the effective interactions
- compare to NCSM results for very light systems, e.g. ${}^7_{\Lambda}\text{Li}$ and ${}^9_{\Lambda}\text{Be}$
- investigate densities for range of light hypernuclei comparing to NCSM

Jacobi-NCSM for hypernuclei

- good progress for NCSM: results for single Λ hypernuclei, implementation for $S=-2$ system
- hypernuclei binding and excitation energy show some sensitivity to YN interaction
- but strong dependence on SRG cutoff indicates YNN force contribution
- implementation of YNN effective interactions
- investigation correlations of separation energies

Faddeev- and Yakubovsky calculations

- Faddeev bound state codes exist for ANN bound state, 3N system and three non-identical particles
- General code for arbitrary particles is currently implemented and will allow $S=-1, -2$ three-baryon systems and KNN

Kd studies

- recoil corrections are in progress
- synergy with B4 is important for the Kd studies
- comparison of non-perturbative approach based on FY to perturbative treatment with partial resummations

B4

comparison of densities
better guidance for new functionals
extended range of nuclei

benchmarks,
range of SRG parameters

comparison of
perturbative and non-
perturbative approach