Mean Field and Beyond Mean Field Calculations of Λ Hypernuclei

P. Veselý

Institute of Nuclear Physics,
Czech Academy of Sciences, Řež

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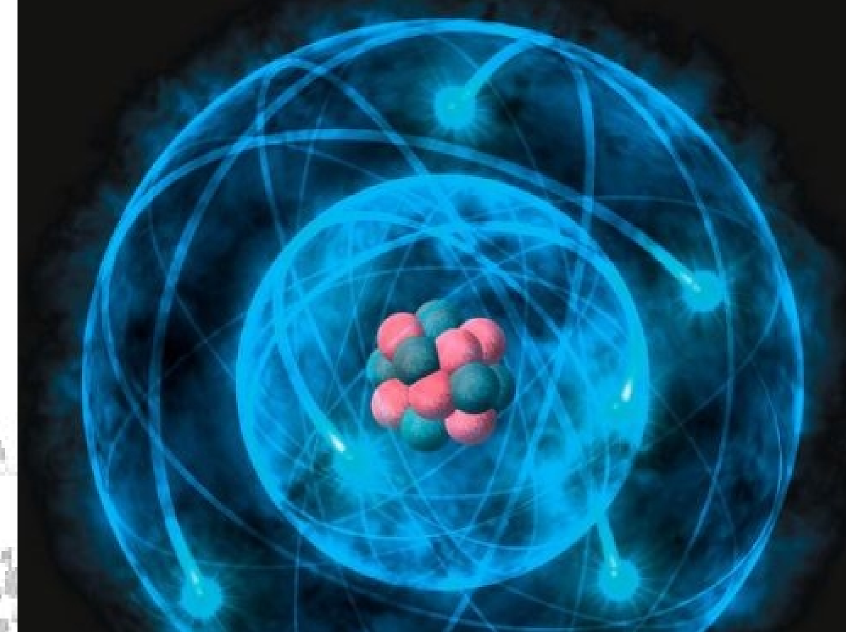
Formalism & NN interaction

$$H = T_{int} + V + V^{DD}[\rho]$$



$$T_{int} = \left(1 - \frac{1}{A}\right)\sum_i \frac{p_i^2}{2m} - \frac{1}{mA}\sum_{i<j} p_i . p_j$$

intrinsic kinetic term

2-body density-dependent int.

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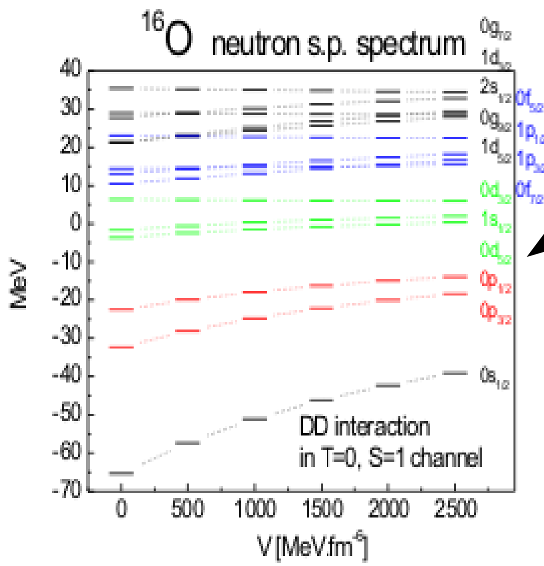
contact in S=1, T=0 channel

2-body “realistic“ NN interaction

$$V^{DD}[\rho] = \frac{C_{3N}}{6}(1 + P_\sigma)\rho\left(\frac{\mathbf{r}_1 + \mathbf{r}_2}{2}\right)\delta^{(3)}(\mathbf{r}_1 - \mathbf{r}_2)$$



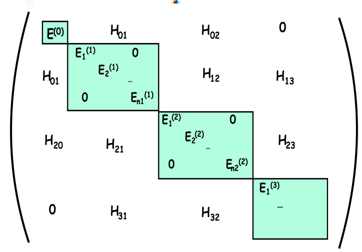
spectrum becomes more realistic

the same contribution to E_{HF} energy as pure contact 3-body interaction

$$V^{3N} = C_{3N}\delta^{(3)}(\mathbf{r}_1 - \mathbf{r}_2)\delta^{(3)}(\mathbf{r}_2 - \mathbf{r}_3)$$

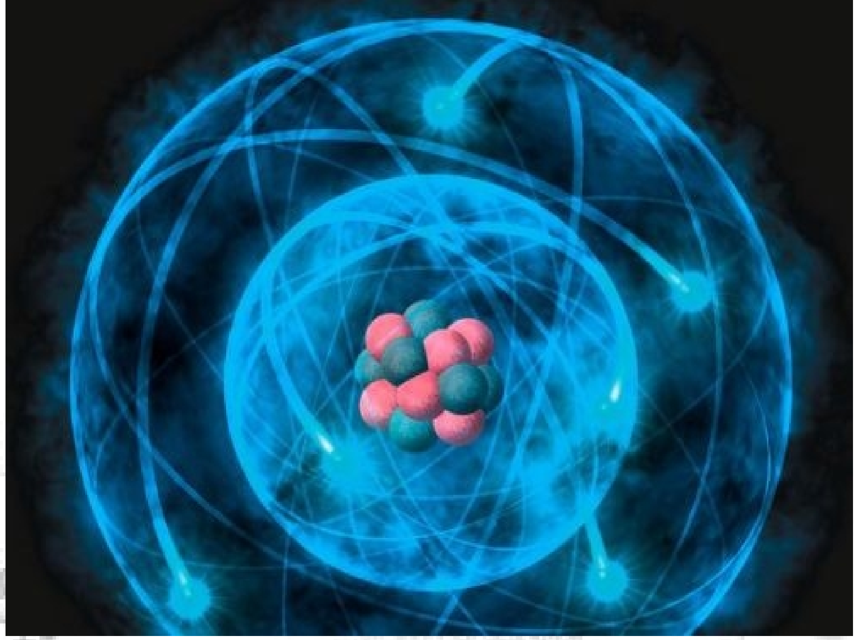
TDA phonons

$$O_\lambda^\dagger = \sum_{ph} c_{ph}^\lambda a_p^\dagger a_{\bar{h}}$$



D. Bianco, F. Knapp, N. Lo Iudice, P. Veselý, F. Andreozzi, G. De Gregorio, A. Porrino, **J. Phys. G: Nucl. Part. Phys. 41**, 025109, (2014)

Formalism & NΛ interaction



several choices for $V_{N\Lambda}$:

ΛN int. = χPT LO (H. Polinder, J. Haidenbauer, U. Meissner, **Nucl. Phys. A** 779 (2006) 244)

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contact momentum dependent force (analogy to Skyrme) H.-J. Schulze, E. Hiyama, **Phys. Rev. C** 90, 047301 (2014)

$$V_{\Lambda N}(\mathbf{r}_\Lambda-\mathbf{r}_N)=t_0(1+x_0P_\sigma)\delta(\mathbf{r}_\Lambda-\mathbf{r}_N)+\frac{1}{2}t_1[\mathbf{k}'^2\delta(\mathbf{r}_\Lambda-\mathbf{r}_N)+\delta(\mathbf{r}_\Lambda-\mathbf{r}_N)\mathbf{k}^2]+t_2\mathbf{k}'\delta(\mathbf{r}_\Lambda-\mathbf{r}_N)\cdot\mathbf{k}$$

Density dependent part

$$V_{\Lambda N}(\mathbf{r}_\Lambda,\mathbf{r}_N,\rho)=\frac{3}{8}t_3(1+x_3P_\sigma)\delta(\mathbf{r}_\Lambda-\mathbf{r}_N)\rho^\gamma\left(\frac{\mathbf{r}_\Lambda+\mathbf{r}_N}{2}\right)$$

Nijmegen+Gmatrix interaction **ESC08c**
M. M. Nagel, Th. A. Rijken, Y. Yamamoto, **ArXiv:1501.06636**v1

the dependence on k_F parameter

symmetric and anti-symmetric LS term

$$V = V_C + V_{SLS} + V_{ALS}$$

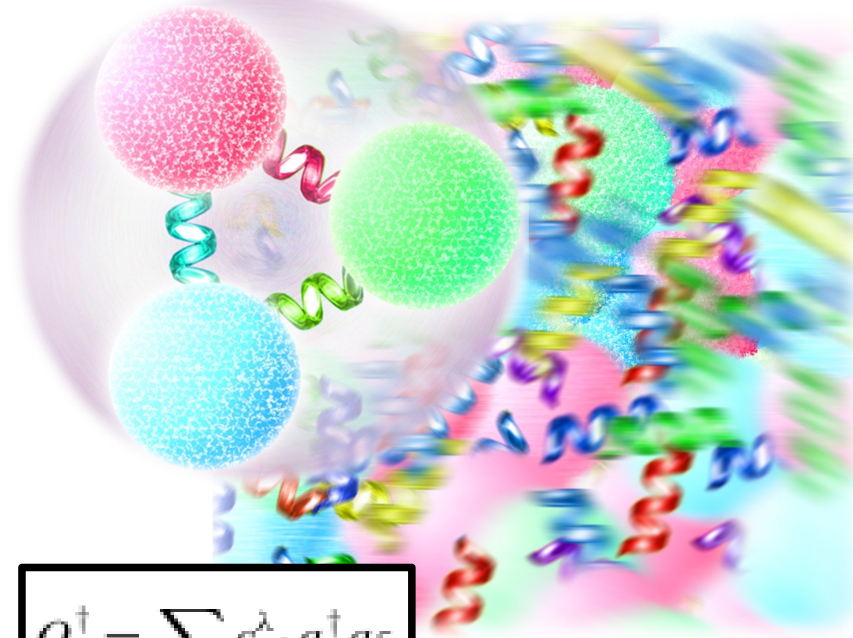
$$V_C = \sum_{i=1}^{3}\left(a_i+b_ik_F+c_ik_F^2\right)\exp\left(-r^2/b_i^2\right)$$

$$V_{SLS} = v_{SLS}(r,k_F)\vec{L}.(\vec{s}_1+\vec{s}_2)$$

$$V_{ALS} = v_{ALS}(r,k_F)\vec{L}.(\vec{s}_1-\vec{s}_2)$$

Single Λ hypernuclei (s.p. spectra)

Hilbert space $\mathcal{H} = \mathcal{H}_0 \oplus \mathcal{H}_1 \oplus \mathcal{H}_2 \oplus \ldots \oplus \mathcal{H}_n$



even-even core + Λ:

$$\mathcal{H}_0 = \{ c^\dagger_m |HF\rangle \}$$
$$\mathcal{H}_1 = \{ c^\dagger_m Q^\dagger_\lambda |HF\rangle \}$$
$$\mathcal{H}_2 = \{ c^\dagger_m Q^\dagger_\lambda Q^\dagger_{\lambda'} |HF\rangle \}$$

even-odd core + Λ:

$$\mathcal{H}_0 = \{ R^\dagger_\alpha |HF\rangle \}$$
$$\mathcal{H}_1 = \{ R^\dagger_\alpha Q^\dagger_\lambda |HF\rangle \}$$
$$\mathcal{H}_2 = \{ R^\dagger_\alpha Q^\dagger_\lambda Q^\dagger_{\lambda'} |HF\rangle \}$$

$$O^\dagger_\lambda = \sum_{ph} c^\lambda_{ph} a^\dagger_p a_{\bar h}$$

$c^\dagger_m$ ... creation operator of Lambda

$$R^\dagger_\alpha = \sum_{m\bar h} r^\alpha_{m\bar h}\, c^\dagger_m a_{\bar h}$$

$Q^\dagger_\lambda$ ... phonon excitation operator (in nucleus)

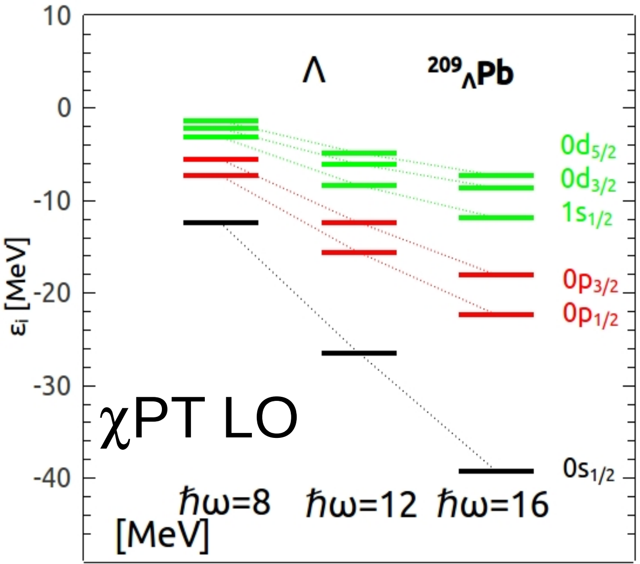
$$\begin{aligned}\hat H = &\sum_{ij} t^p_{ij} a^\dagger_i a_j + \frac{1}{4}\sum_{ijkl} V^{pp}_{ijkl} a^\dagger_i a^\dagger_j a_l a_k \\ &+ \sum_{ij} t^n_{ij} b^\dagger_i b_j + \frac{1}{4}\sum_{ijkl} V^{nn}_{ijkl} b^\dagger_i b^\dagger_j b_l b_k \\ &+ \sum_{ij} t^\Lambda_{ij} c^\dagger_i c_j \\ &+ \sum_{ijkl} v^{pn}_{ijkl} a^\dagger_i b^\dagger_j b_l a_k + \sum_{ijkl} v^{p\Lambda}_{ijkl} a^\dagger_i c^\dagger_j c_l a_k + \sum_{ijkl} v^{n\Lambda}_{ijkl} b^\dagger_i c^\dagger_j c_l b_k\end{aligned}$$

$$\langle m|\hat H|n\rangle = \langle HF| c_m \hat H c^\dagger_n |HF\rangle =$$
$$= \delta_{mn} E_{HF} + \left[\sum_{ij} \bar v^{p\Lambda}_{imjn}\rho^p_{ji} + \sum_{ij} \bar v^{n\Lambda}_{imjn}\rho^n_{ji}\right] =$$
$$= \delta_{mn} E_{HF} + e^\Lambda_m \delta_{mn}$$

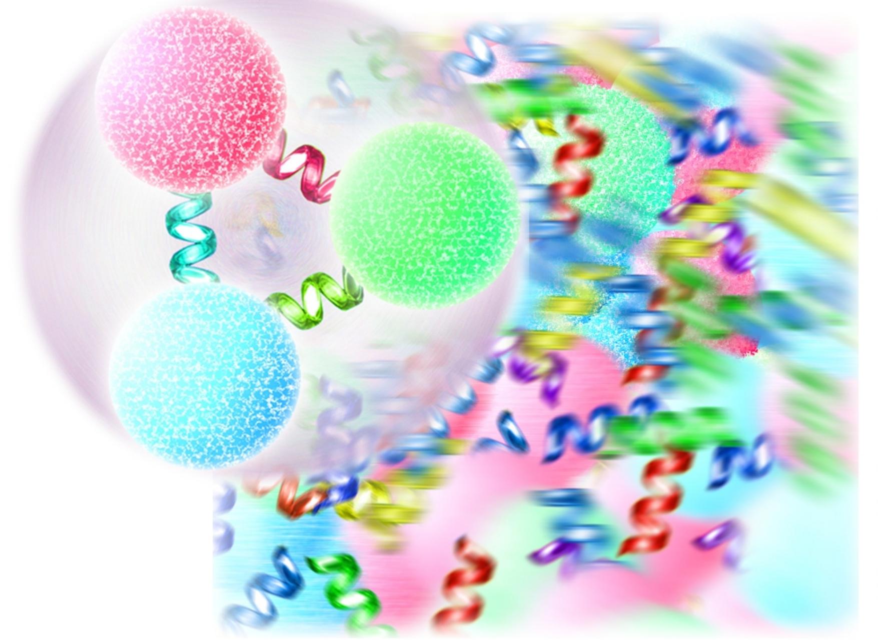
solution in the Hilbert subspace H0

$$|m\rangle = c^\dagger_m |HF\rangle$$

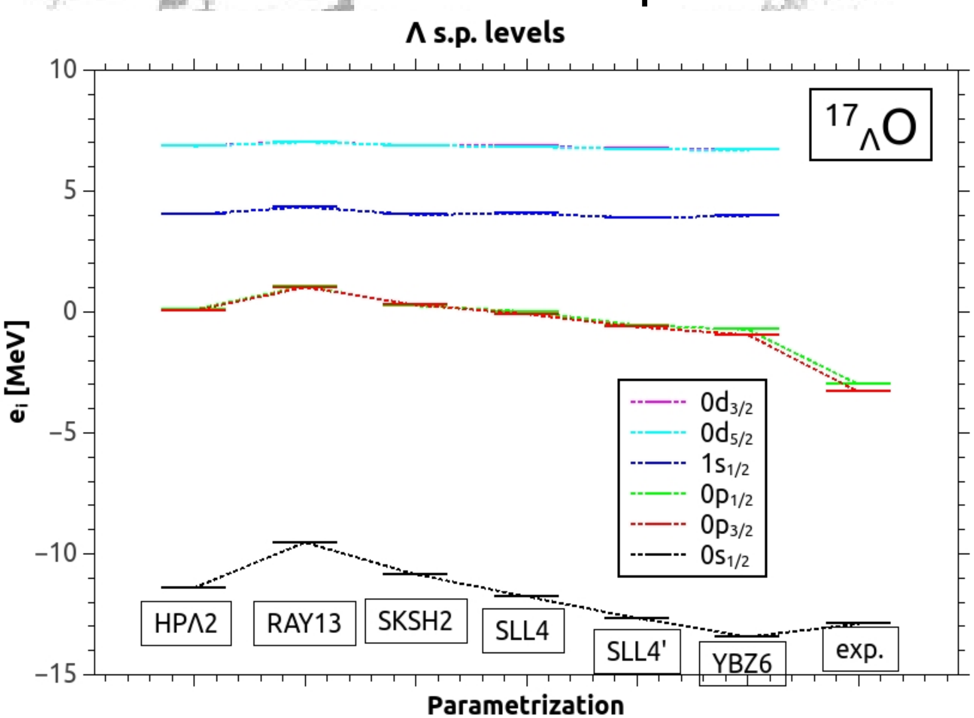
Single Λ hypernuclei (s.p. spectra)

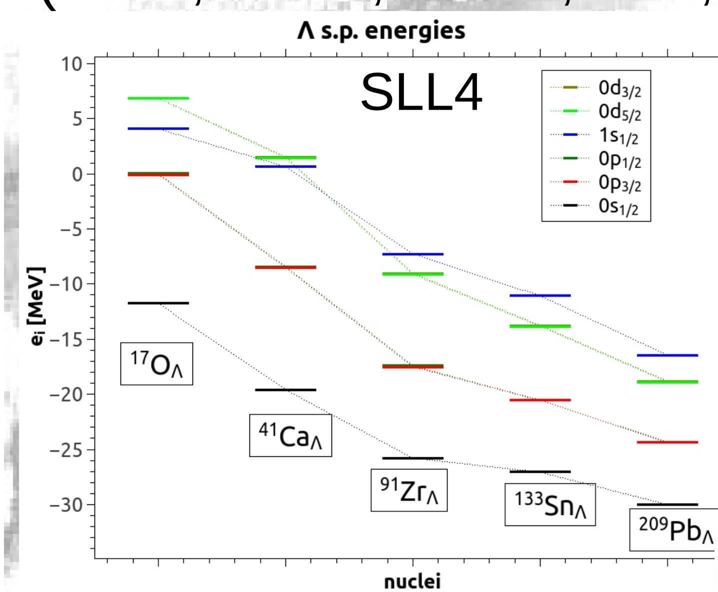


- very unstable for ħΩ
- moreover – problems with convergence
- wrong s.o. splittings



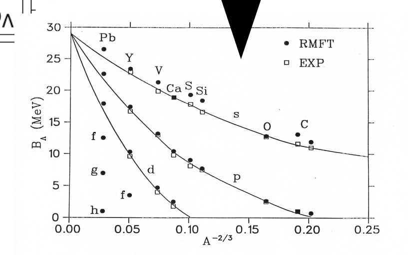
contact momentum dependent force (HPL2,RAY13,SKSH2,SLL4,SLL4', YBZ6)



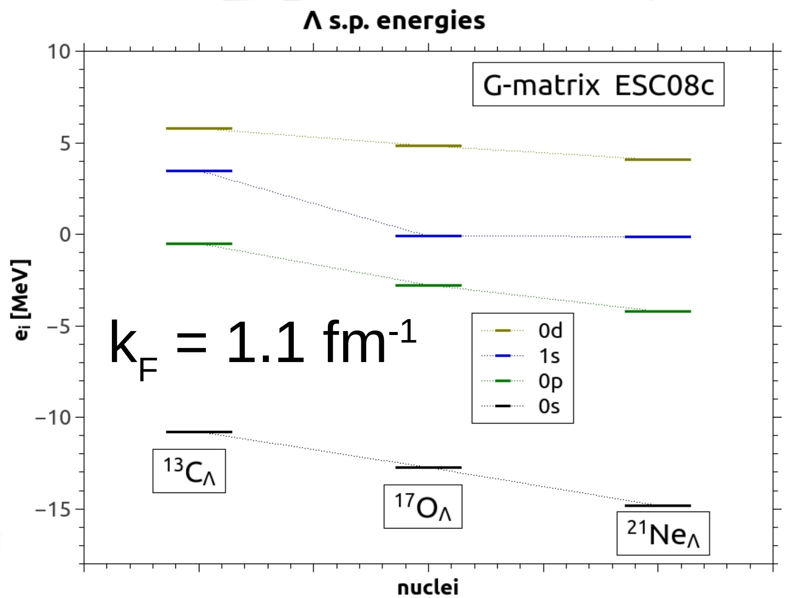


1) HPΛ2 (Nucl. Phys. A 886, 71(2012))
2) RAY13 (Nucl. Phys. A 367, 381 (1981))
3) SKSH2 (Z. Phys. A 334, 349 (1989))
4) SLL4 (Phys. Rev. C 90, 047301 (2014))
5) SLL4' (Phys. Rev. C 90, 047301 (2014))
6) YBZ6 (Prog. Theor. Phys. 80, 757 (1988))

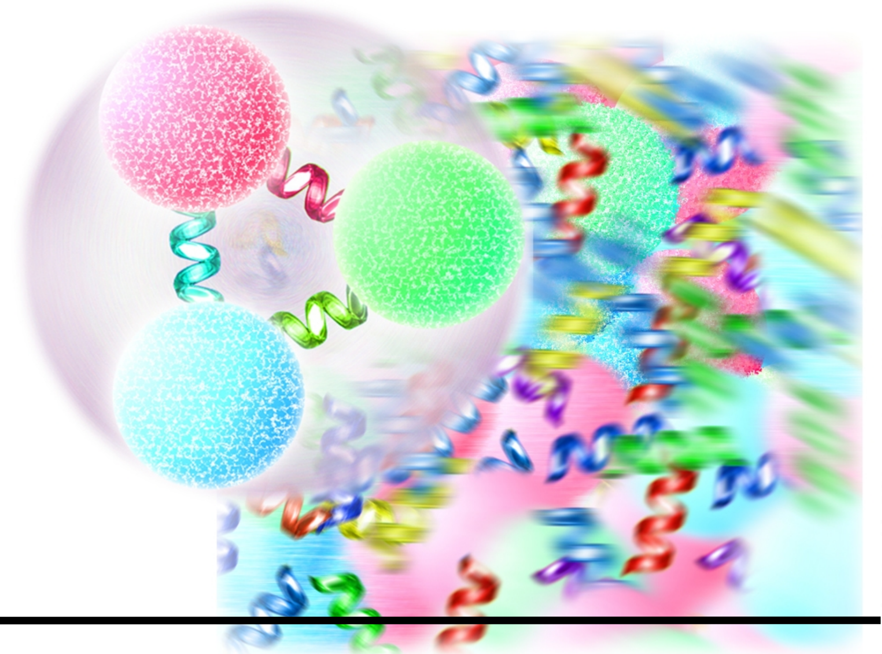
“empirical“ bindings



Single Λ hypernuclei (s.p. spectra)



realistic gaps between s & d shells

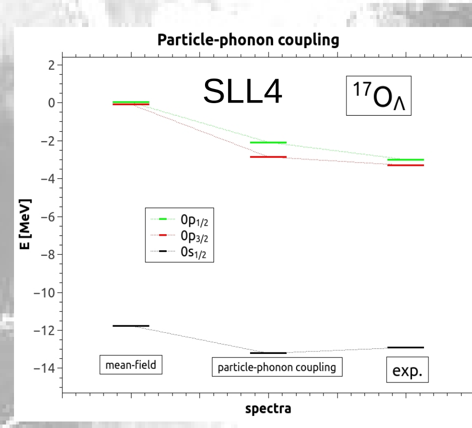


Open questions:

- behavior of s.o. splitting (the role of SLS and ALS terms in Hamiltonian must be examined)
- too big gap between $1s_{1/2}$ & 0d levels (the role of tensor force & Λ-Σ coupling must be examined)

Outline:

- tensor force & Λ-Σ coupling & NNΛ force
- adding Lambda-Phonon coupling
- even-odd+Λ systems
- odd-odd+Λ systems
- deformed code for Mean Field



… quite a lot of work!

List of collaborators: E. Hiyama, J. Mareš
F. Knapp, N. Lo Iudice, G. De Gregorio

E. Hiyama

J. Mareš

N. Lo Iudice

F. Knapp

G. De Gregorio