Fit of the parameters of a Skyrme type interaction using a microscopic effective interaction in the pairing channel.

Thomas LESINSKI

Institut de Physique Nucléaire de Lyon / Université Claude Bernard Lyon 1

September 30, 2005 – INT, Seattle

Collaboration

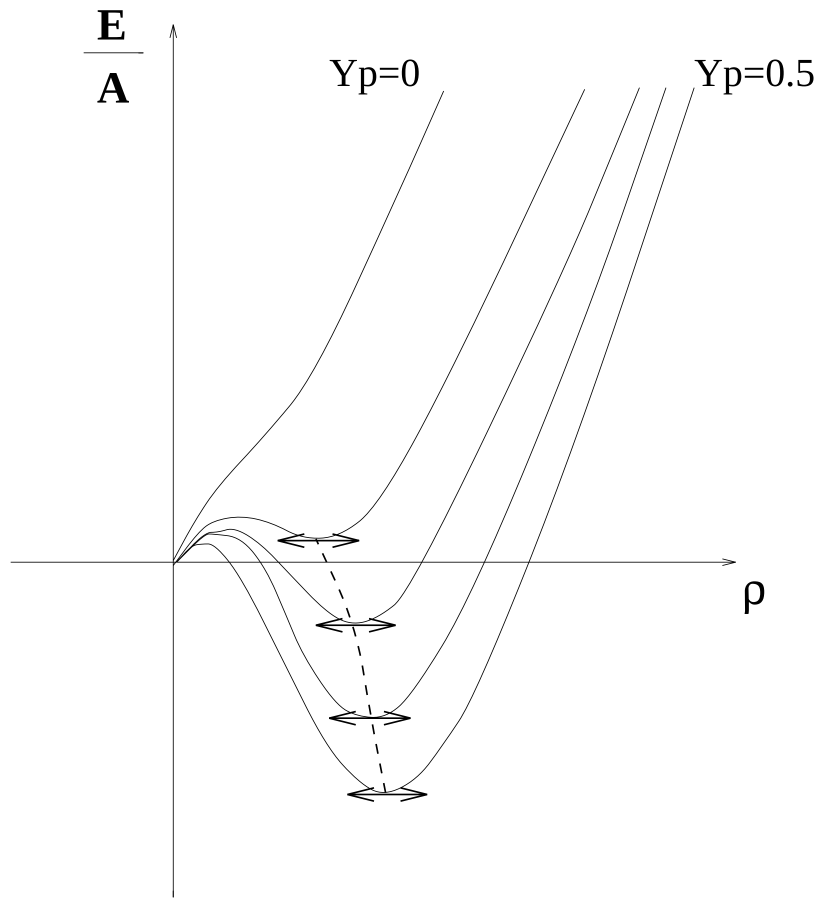
- K. Bennaceur, IPNL / UCB Lyon 1
- T. Duguet, NSCL / MSU
- J. Meyer, IPNL / UCB Lyon 1

Introduction

- Improving $E_{\mathrm{th}} - E_{\mathrm{exp}}$ taking into account properties beyond the mean field
- Microscopic pairing $\Rightarrow$ less phenomenology
- Outline
  - Starting point : SLy5
  - Finite–range microscopic pairing
  - Fit including non–magic nuclei
  - Role of the effective masses
  - Results after refit

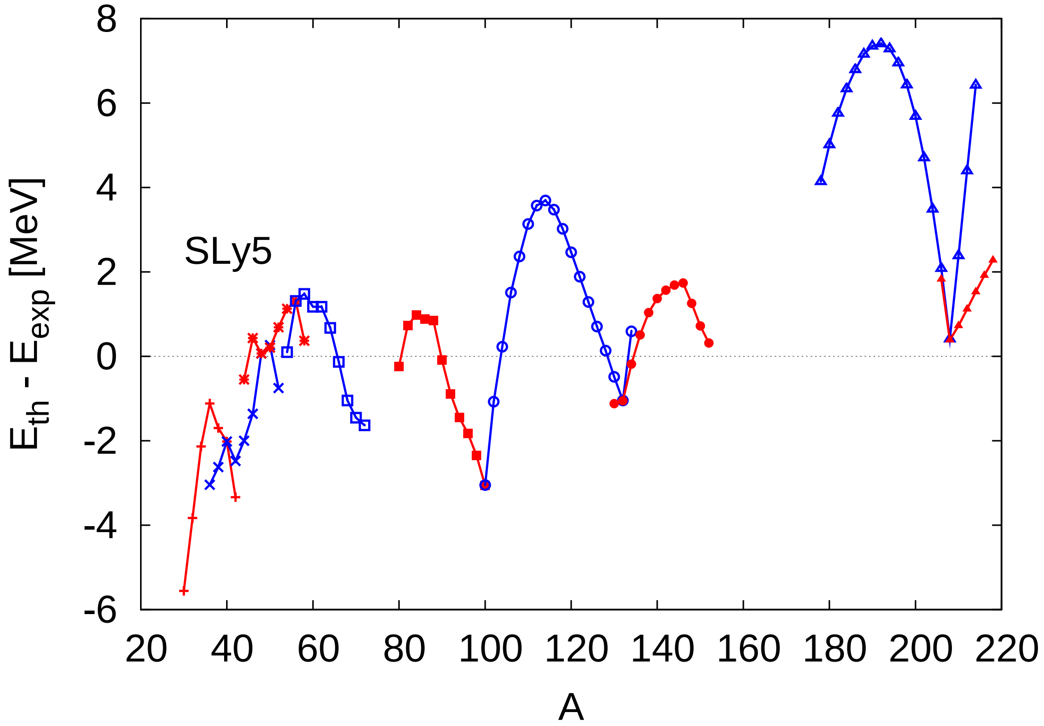
Fitting procedure of SLy4–10

- Same force at different approx. levels (E. Chabanat et. al. NPA 635 (1998) 231)
- Fitting procedure
  - Saturation energy and density
  - Neutron matter EoS (UV14 Wiringa et al.)
  - Masses and radii of doubly magic nuclei
  - $3p$ neutron splitting of ^{208}Pb
  - Surface energy of SkM*
  - Ferromagnetic instabilities under control



Known deficiencies of SLy4–10

- Arches
  - Partly related to s.p. level spacing
- Mass drift : heavy nuclei underbound



Microscopic finite range pairing

- Initial separable form, fitted on AV18 INM pairing properties (T. Duguet PRC 69 (2004) 054317)

$$V^{^1S_0}_{\text{sep}} = \lambda e^{-\alpha^2 k^2} e^{-\alpha^2 k'^2} \delta(\mathbf{P} - \mathbf{P}')$$

- Not tractable for calculations of finite systems
  - Tractable form through in-medium ladder resummation, p-h asymmetry problem
  - Bare force approximation used, to be checked microscopically
  - Efficient expression in coordinate space

$$\overline{(V^{^1S_0}_{\text{approx}})}_{i\bar{\imath}j\bar{\jmath}} = \lambda \sum_{ss'} \int d^3\mathbf{r}\ \tilde{\phi}^*_{is}(\mathbf{r})\tilde{\phi}^*_{\bar{\imath}s}(\mathbf{r}) \left[\tilde{\phi}_{js}(\mathbf{r})\tilde{\phi}_{\bar{\jmath}s'}(\mathbf{r}) - \tilde{\phi}_{js'}(\mathbf{r})\tilde{\phi}_{\bar{\jmath}s}(\mathbf{r})\right]$$

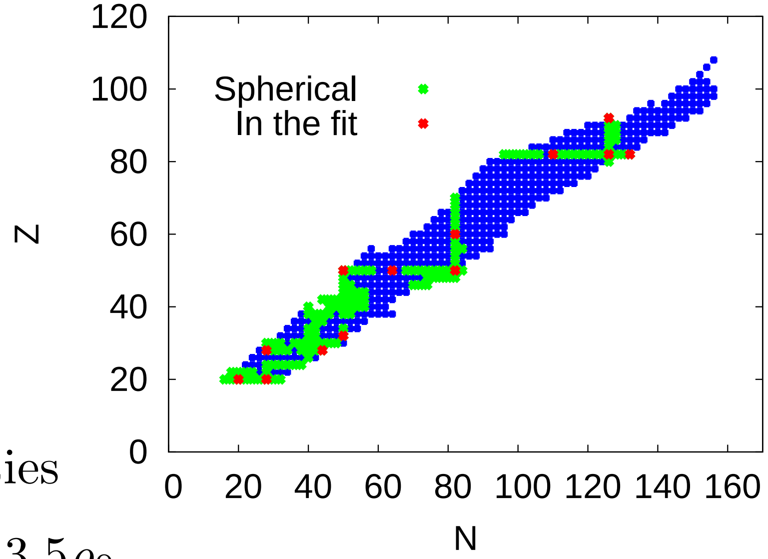
with :

$$\tilde{\phi}_{is}(\mathbf{r}) = \frac{1}{(\sqrt{2\pi}\alpha)^3} \int d^3\mathbf{r}'\ e^{-\frac{|\mathbf{r}-\mathbf{r}'|^2}{2\alpha^2}} \phi_{is}(\mathbf{r}).$$

  - Enables study of sytematics

New fitting procedure

- Approximate finite range force in the p-p channel
- Fit on :
  - Nuclear masses : doubly– and semi–magic nuclei
    - ★ Mid–shell, where the effect of arches is maximal
    - ★ Spherical approximation
  - Several nuclear radii
  - ^{208}Pb splitting and surface energy of SKM*
- Constraints
  - $K_\infty = 225$ MeV
  - Approximate control of ferromagnetic instabilities
  - SNM should be more bound than PNM at $\rho < 3.5\rho_0$



Effective masses

$$\frac{m^*}{m} = (1+\kappa_s)^{-1}$$

$$\frac{m_v^*}{m} = (1+\kappa_v)^{-1}$$

$$\frac{m_{n,p}^*}{m} = \left[\, 1+\kappa_s \pm^{(n)}_{(p)} (\kappa_s-\kappa_v)I \,\right]^{-1}$$

$$\Delta^{(2q)}E = \frac{1}{2}(E_{N-2} - 2E_N + E_{N+2})$$

- Effective masses $m^*_{n,p}$ act on shell gaps and level density
  - ⇨ Act on pairing energy
- Two parameters : m^* and κ_v
- Relevant observables
  - Binding energy error : $E_{\text{th}} - E_{\text{exp}}$
  - Two–nucleon shell gap error : $(\Delta^{(2q)}E)_{\text{th}-\text{exp}}$

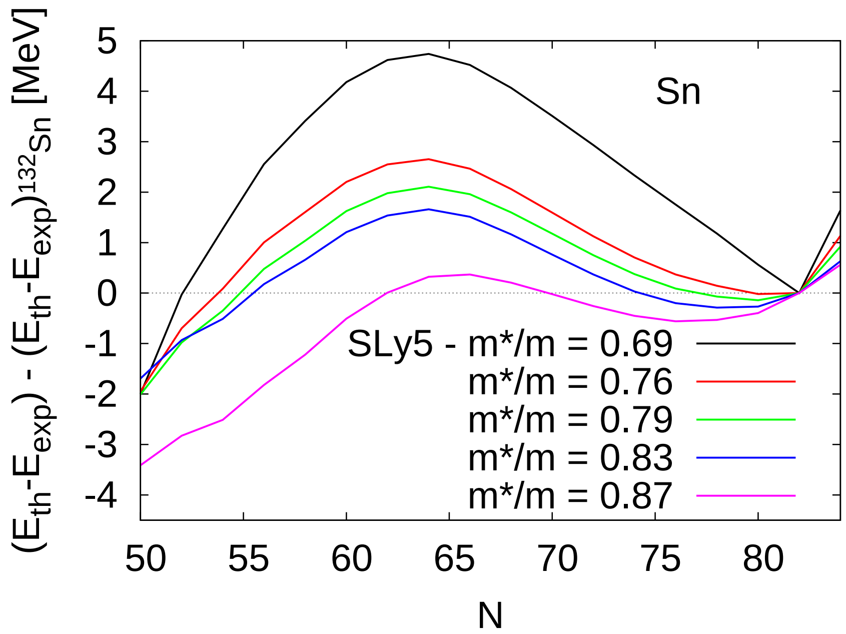
$$\text{SLy5}: \; m^*/m = 0.69, \; \kappa_v = 0.25$$

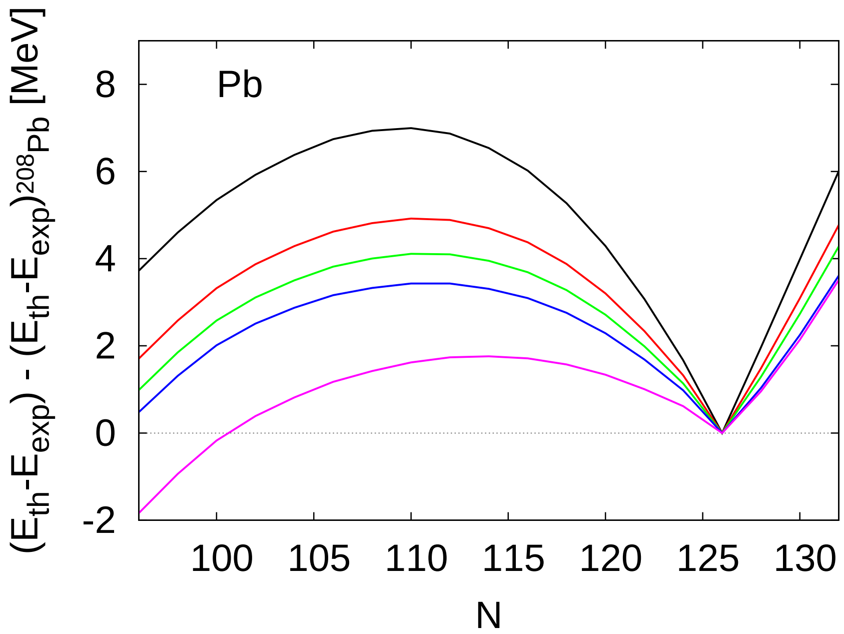
⇨ Splitting : $m^*_n < m^*_p$

Role of the effective masses

Isoscalar (m^*) – Isotopic magic series

- Arches reduced with high m^*
- Overestimation of shell effects reduced

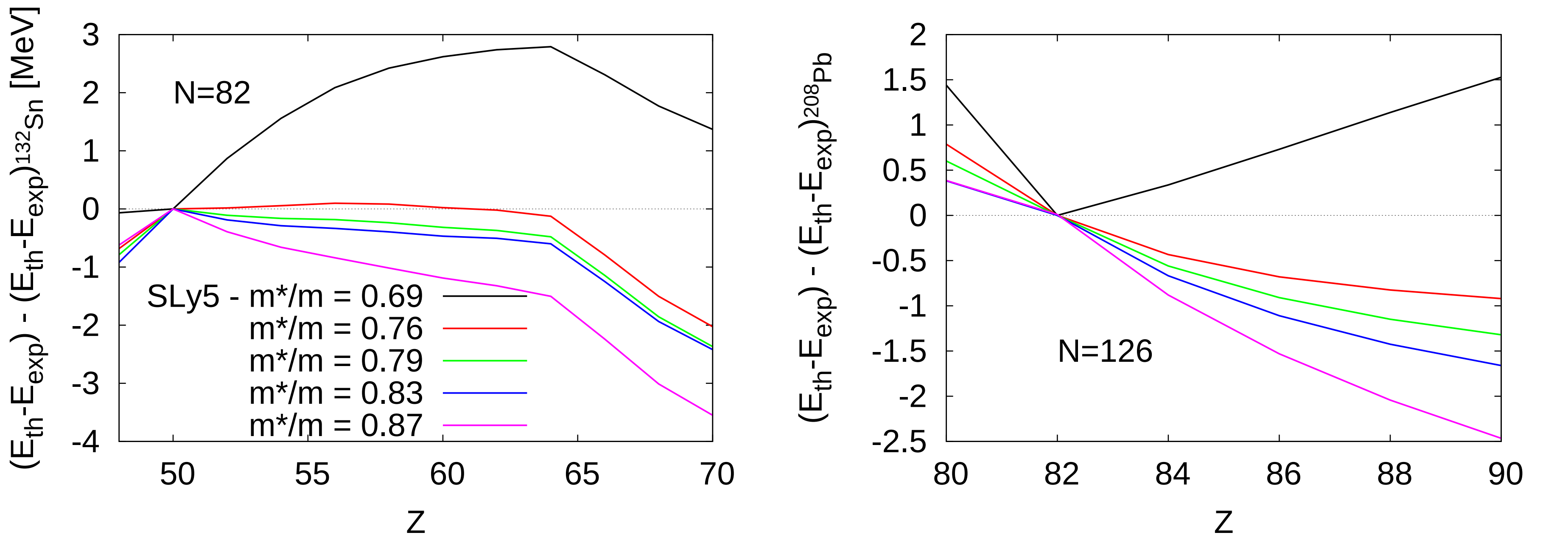




Role of the effective masses

Isoscalar (m^*) – Isotonic magic series

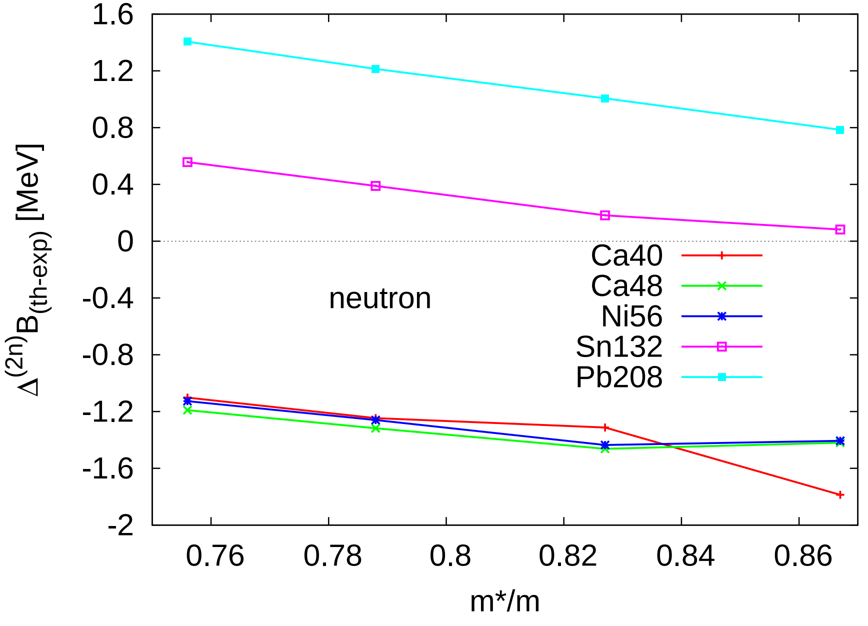
- Shell effects lowered as well – not wanted here
- Tendency of overbinding

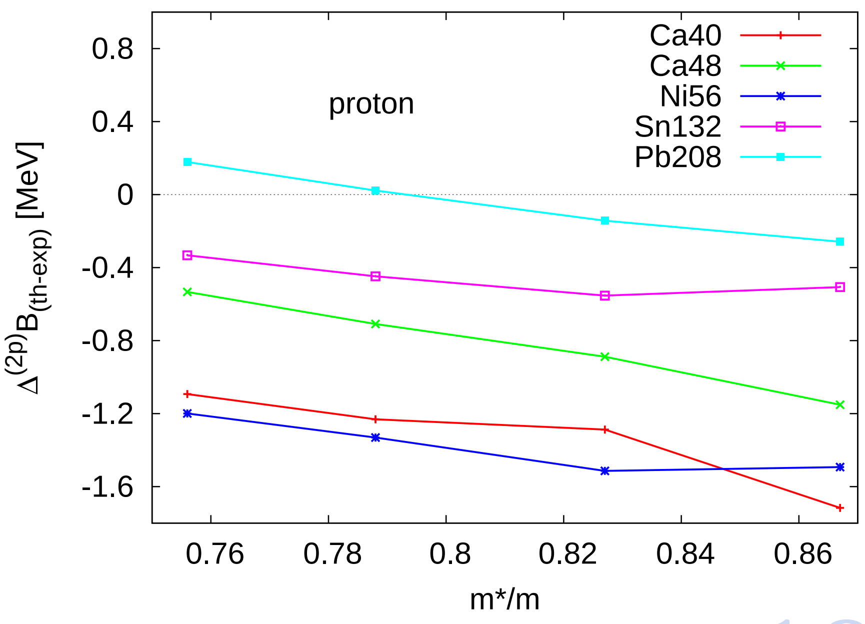


Role of the effective masses

Isoscalar (m^*) – Shell gaps

- “Heavy” shell gaps lowered with high m^*
  - OK for neutrons
  - Too low for protons
- “Light” shell gaps always too low

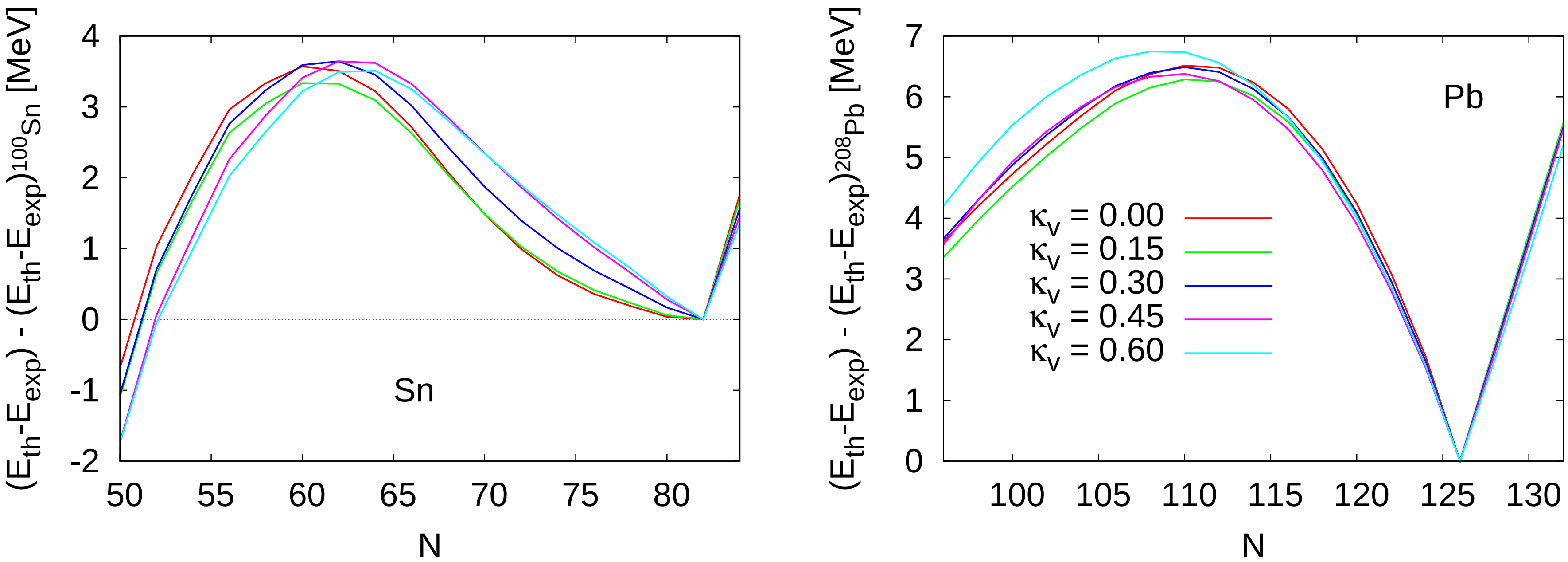




Role of the effective masses

Isovector (κ_v) – Isotopic magic series

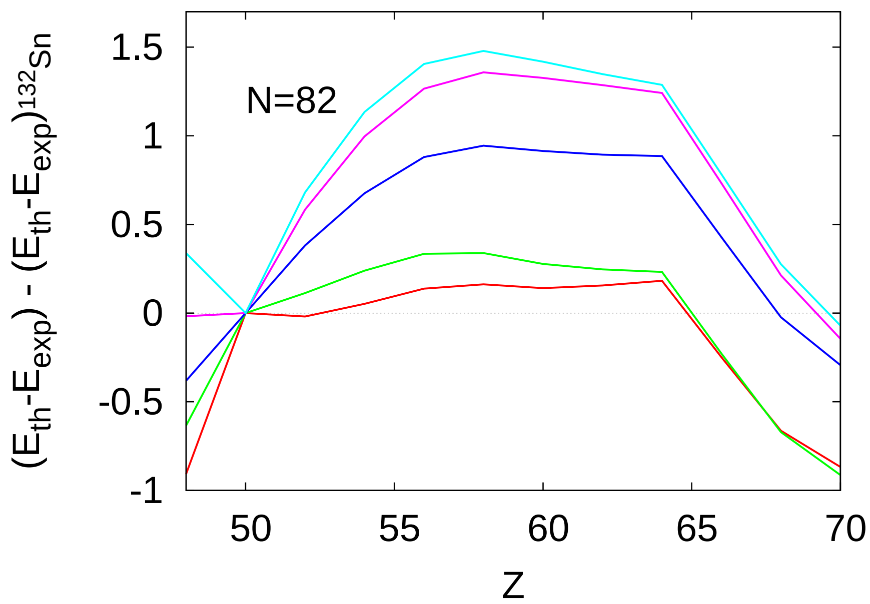
- Neutron levels show no sensitivity

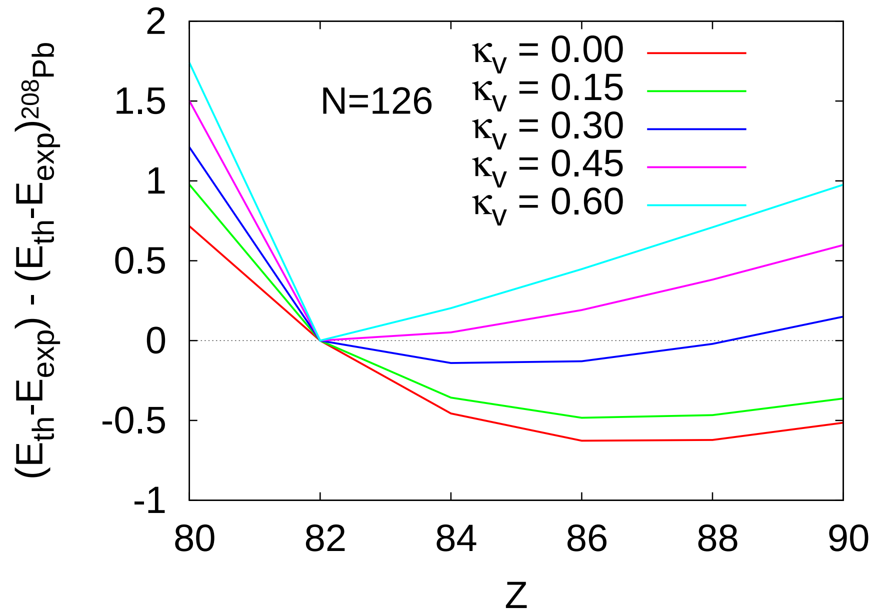


Role of the effective masses

Isovector (κ_v) – Isotonic magic series

- Low κ_v seems OK. . .
  - ✘ . . . but underestimates shell gaps
  - ✔ . . . but high κ_v corrects the effects of high m^*

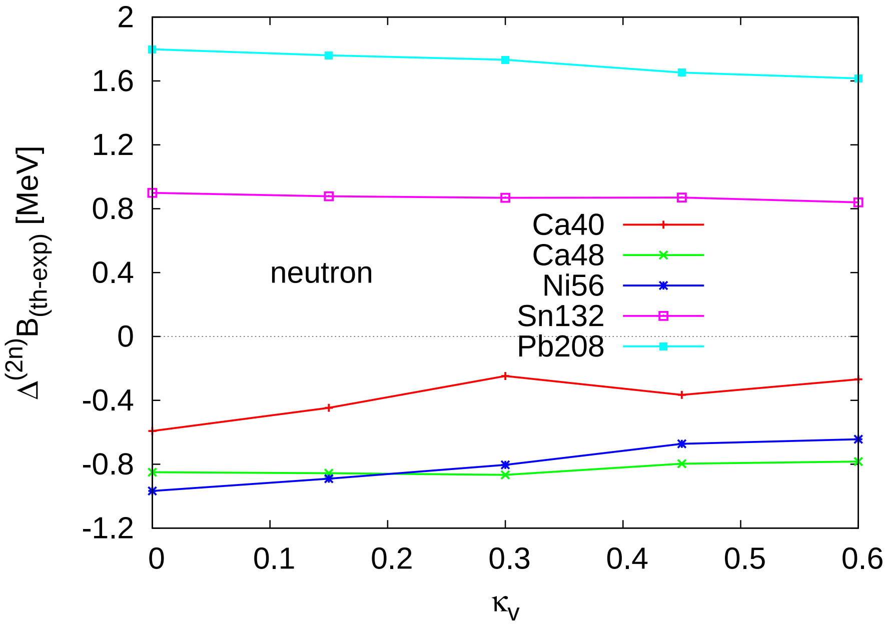


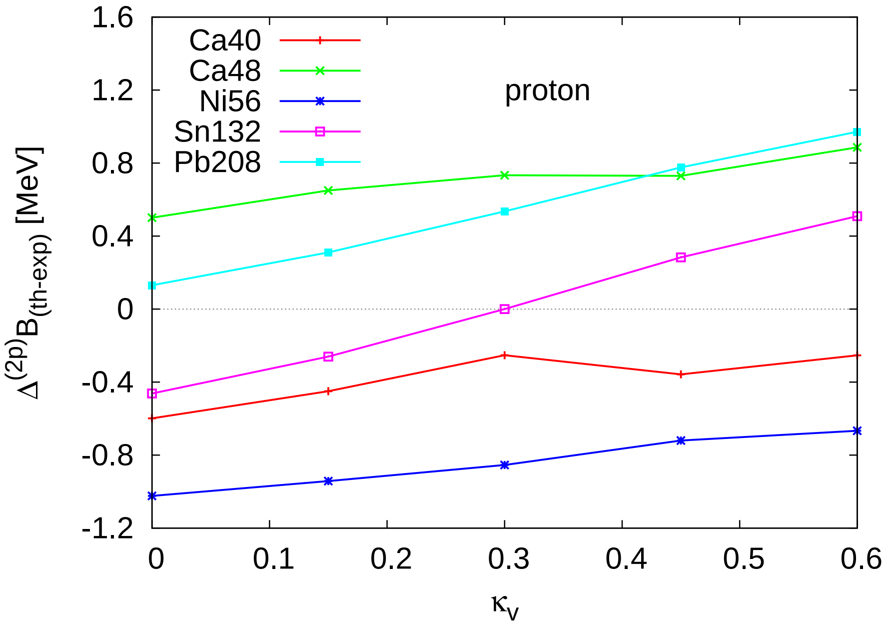


Role of the effective masses

Isovector (κ_v) – Shell gaps

- Neutron shells much less affected than proton shells
- Underestimation of proton shells with higher m^* compensated

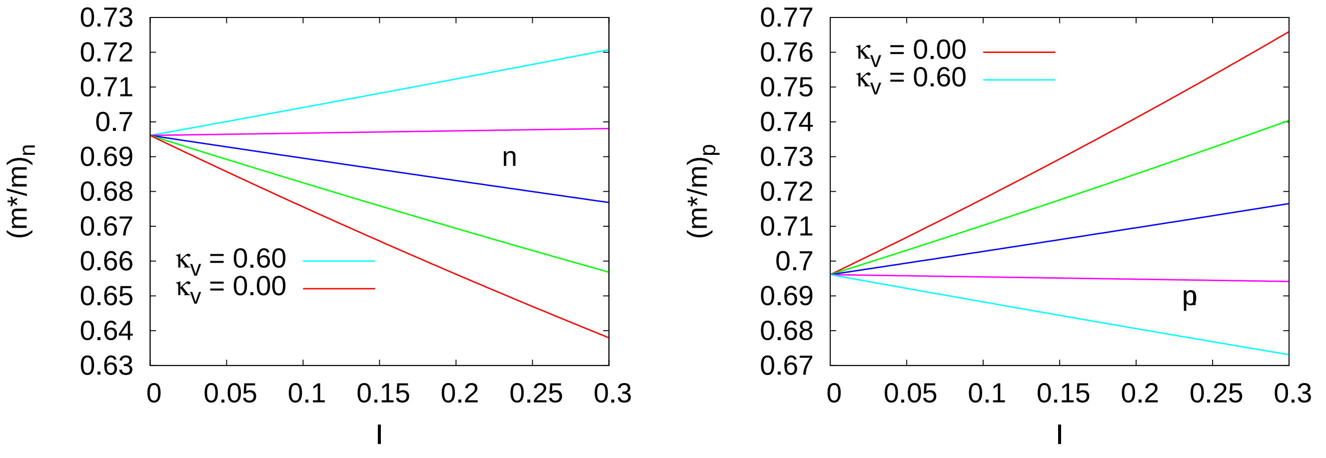




Role of the effective masses

Other indications

- Microscopic INM calculations
  - Effective mass splitting : $m_n^* > m_p^*$ for isospin asymmetry $I > 0$
  - Requires high κ_v $(m_v^* < m^*)$
- Giant resonances
  - ISGQR : $m^*/m \simeq 0.8$
  - IVGDR : $\kappa_v \geq 0.25$ (Coló et al. Phys.Lett.B 363 (1995) 5)



Role of the effective masses

Summary

- Appropriate mass fit with microscopic pairing requires
  - higher isoscalar effective mass $m^*/m \simeq 0.8$
    - ✔ Arches may be further corrected with correlations

    (M. Bender et al. PRL 94 (2005) 102503)
  - higher κ_v (low isovector eff. mass)
- Current behaviour (arches on isotopic series, less on isotonic series) consistent with
  - Too low isoscalar effective mass
  - Wrong $m_n^* - m_p^*$ splitting with asymmetry
- Shell gaps in light series too low – may be corrected by correlations
  - Pair vibrations
  - Wigner term

Fits including pairing

- m^* (through α) free
- **Fit A**
  - Polarized neutron matter asymptotically stable
  - $\kappa_v = 0$, $m^*/m = 0.78$:
    "wrong" effective mass splitting
- **Fit B**
  - Weaker constraint on polarized neutron matter EoS (for $\rho < 3.5\ \rho_0$)
  - $\kappa_v = 0.3$, $m^*/m = 0.79$:
    "good" effective mass splitting

E of 134 spherical nuclei :

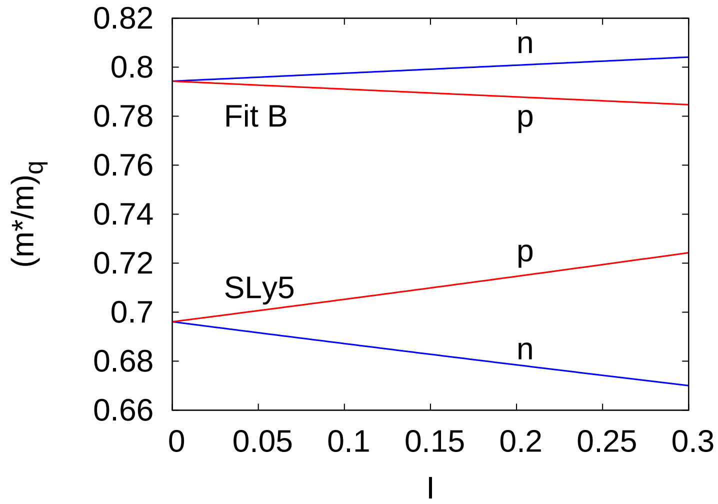
SLy5 : $\Delta E_{\mathrm{rms}} = 2.62$ MeV

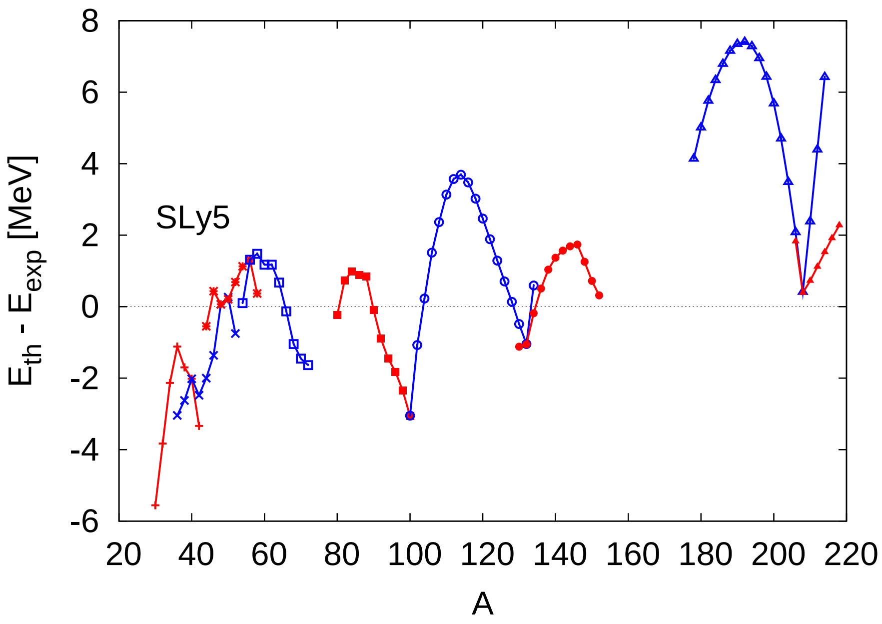
$\Delta E_{\mathrm{rms}} = 1.65$ MeV

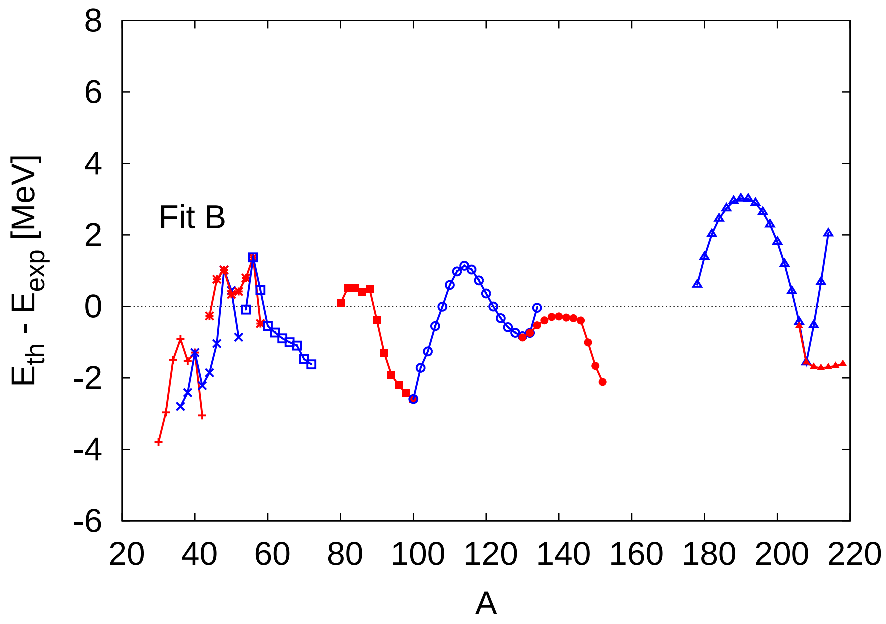
$\Delta E_{\mathrm{rms}} = 1.39$ MeV

Properties of the resulting parametrization

- ✔ SLy5 defects partly corrected
- ✔ Consistent beyond–mean–field properties
- ✔ Consistent with microscopic indications







Conclusion

- ✧ Microscopic pairing provides good phenomenology
- ✧ Including non–magic nuclei improves the accuracy of binding energies
- ✧ Binding energies can be used to constrain effective masses

✔ Values consistent with microscopic calculations / dynamics

✘ Parameter sets which predict accurate masses tend to be spin/isospin unstable

⇨ Additional terms needed in the Skyrme force !

Appendix : FR Pairing

- Bare form of FR pairing fits AV18 BCS gaps in INM.
- Approximations required for tractability in finite systems
- Exact calculations can be made in spherical approximation with bare force (involved)
- INM ladder resumation + LDA not fully satisfactory
  - ⇨ Recast of the gap equation *in the nucleus, on coordinate–space WFs*

$$\langle \mathbf{r}_1\mathbf{r}_2|\mathcal{T}^{^1S_0}|\mathbf{r}_3\mathbf{r}_4\rangle = \langle \mathbf{r}_1\mathbf{r}_2|V_{\text{sep}}^{^1S_0}|\mathbf{r}_3\mathbf{r}_4\rangle + \iiiint d^3\mathbf{r}_{5,6,7,8} \langle \mathbf{r}_1\mathbf{r}_2|V_{\text{sep}}^{^1S_0}|\mathbf{r}_5\mathbf{r}_6\rangle\langle \mathbf{r}_5\mathbf{r}_6|F|\mathbf{r}_7\mathbf{r}_8\rangle\langle \mathbf{r}_7\mathbf{r}_8|\mathcal{T}^{^1S_0}|\mathbf{r}_3\mathbf{r}_4\rangle$$

- Next step : derive approximations