Slides based on Haozhao Liang slides @ NSDII, Opatija 2012

Local covariant density functional constrained by the relativistic Hartree-Fock theory

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Outline

Introduction

Theoretical Framework
- Relativistic Hartree-Fock theory
- Zero-range reduction
- Fierz transformation

Results and Discussion
- Coupling strengths in different channels
- Dirac mass splitting
- Spin-isospin resonances

Summary and Perspectives

Work in progress

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Many-body systems and density functional theories

- Research on quantum mechanical many-body problems is essential in many areas of modern physics
  - ⋆ electrons in metal, atoms in molecule, electrons in atom, nucleons in nucleus ...
- Density functional theories (DFT) Hohenberg & Kohn:1964
  - ⋆ reducing the many-body problems formulated in terms of N-particle wave functions to the one-particle level with the local density distribution $\rho(\mathbf{r})$
  - ⋆ no other method achieves comparable accuracy at the same computational cost

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- Kohn-Sham scheme Kohn & Sham:1965
  - ⋆ for any interacting system, there exists a **local** single-particle (Kohn-Sham) potential $v_{\mathrm{KS}}(\mathbf{r})$, such that the exact ground-state density of the interacting system can be reproduced by non-interacting particles moving in this local potential:

$$\rho(\mathbf{r}) = \rho_{\mathrm{KS}}(\mathbf{r}) \equiv \sum_i^{\mathrm{occ}} |\phi_i(\mathbf{r})|^2$$

  - ⋆ system energy density functional:

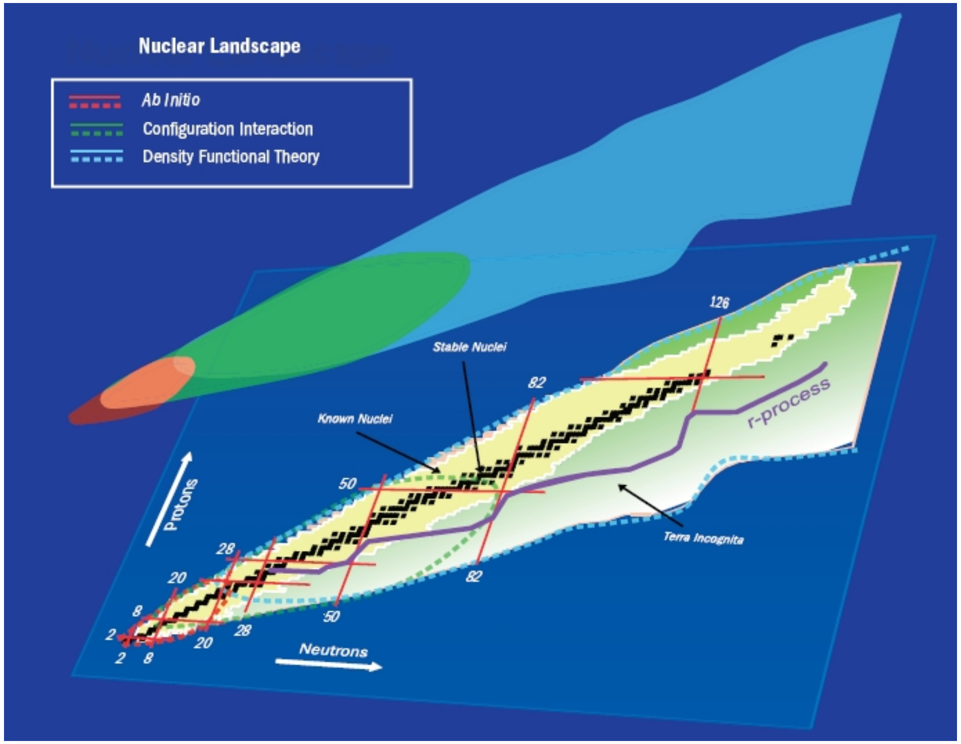
$$E = E[\rho(\mathbf{r})]$$

Nuclear DFT

- Nuclear DFT is a promising tool for investigating the ground-state and excited state properties of nuclei throughout the nuclear chart.

- Since the 1970s, lots of experience have been accumulated in implementing, adjusting, and using the DFT in nuclei.

  Petkov&Stoitsov:1991, Bender:2003, Dobaczewski:INPC2010 plenary talk



Covariant density functional theory – RH theory

- The covariant version of DFT takes into account Lorentz symmetry.
  - ⋆ Causality is preserved and spin-orbit potential emerge naturally, ...

- CDFT in Hartree level (RH/RMF theory) has received wide attention due to its successful description of lots of nuclear phenomena.

  Serot:1986, Ring:1996, Vretenar:2005, Meng:2006, Paar:2007, Nikšić:2011

  - ⋆ spin-orbit splittings
  - ⋆ EoS in symmetric and asymmetric nuclear matter
  - ⋆ ground-state properties of finite spherical and deformed nuclei
  - ⋆ collective rotational and vibrational excitations
  - ⋆ low-lying spectra of transitional nuclei involving quantum phase transitions
  - ⋆ ......

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  - ⋆ ......

Common problems in the isovector channels

- Difficult to disentangle the isovector-scalar (δ) and isovector-vector (ρ) channels, unless a tuning is performed based on selected microscopic calculations. Roca-Maza:2011
- Nuclear spin-isospin resonances, e.g., GTR and SDR, cannot be described without a direct fit to the data on their excitation energies.

Covariant density functional theory – RHF theory

- CDFT in Hartree-Fock level (RHF theory)
  - ⋆ several attempts to include the Fock term in the relativistic framework

    Bouyssy:1985,1987, Bernardos:1993, Marcos:2004

  - ⋆ DDRHF theory achieved quantitative descriptions of binding energies and radii

    Long, Giai, Meng, *PLB* **640**, 150 (2006); Long, Sagawa, Giai, Meng, *PRC* **76**, 034314 (2007);
    Long, Sagawa, Meng, Giai, *EPL* **82**, 12001 (2008); Long, Ring, Giai, Meng, *PRC* **81**, 024308 (2010)

  - ⋆ effective mass splitting in asymmetric nuclear matter can be described naturally

    Long, Giai, Meng, *PLB* **640**, 150 (2006)

  - ⋆ nuclear spin-isospin resonances can be described in a fully self-consistent way

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- RHF includes **non-local** potentials $v_{\rm HF}(\mathbf{r},\mathbf{r}')$, the simplicity of KS scheme is lost.
- RHF is much more complicated than RH theory.
- The computational cost is too expensive for including paring, deformation, projection, cranking, ...

To construct RH functionals from RHF scheme

It is therefore highly desirable

- to stay within the conventional Kohn-Sham scheme in nuclear physics
- to find a covariant density functional based on only local potentials, yet keeping the merits of the exchange terms

- Possible/promising solution: construct RH functionals from RHF scheme
  - ⋆ take the constraints introduced by exchange terms of RHF scheme into account

- We start from an important observation: RHF functional PKO2 [Long:2008]
  - ⋆ well describes the neutron-proton Dirac mass splitting in asymmetric nuclear matter and nuclear spin-isospin resonances
  - ⋆ only includes σ-, ω-, ρ-mesons, but not π-meson
  - ⋆ masses of mesons are heavy $\Rightarrow$ zero-range approximation is reasonable
  - ⋆ Fierz transformation: Fock terms $\Rightarrow$ local Hartree terms

In the present work

- To construct RH functional from RHF scheme by the following procedure
  - ⋆ start with RHF parametrization PKO2
  - ⋆ perform the zero-range reduction
  - ⋆ perform the Fierz transformation
- With such RH functional thus obtained, to investigate
  - ⋆ proton-neutron Dirac mass splitting in neutron matter
  - ⋆ Gamow-Teller and spin-dipole resonances

Goal(s)

- To verify whether the important effects of exchange terms can be maintained by the mapping from RHF functional to RH functional.

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Covariant density functional theory – RHF theory

- Effective Lagrangian density Bouyssy:1987, Long:2006

$$\mathcal{L} = \bar{\psi}\left[i\gamma^{\mu}\partial_{\mu} - M - g_{\sigma}\sigma - \gamma^{\mu}\left(g_{\omega}\omega_{\mu} + g_{\rho}\vec{\tau}\cdot\vec{\rho}_{\mu} + e\frac{1-\tau_3}{2}A_{\mu}\right)\right]\psi$$
$$+\frac{1}{2}\partial^{\mu}\sigma\partial_{\mu}\sigma - \frac{1}{2}m_{\sigma}^2\sigma^2 - \frac{1}{4}\Omega^{\mu\nu}\Omega_{\mu\nu} + \frac{1}{2}m_{\omega}^2\omega_{\mu}\omega^{\mu} - \frac{1}{4}\vec{R}_{\mu\nu}\cdot\vec{R}^{\mu\nu} + \frac{1}{2}m_{\rho}^2\vec{\rho}^{\mu}\cdot\vec{\rho}_{\mu} - \frac{1}{4}F^{\mu\nu}F_{\mu\nu} \qquad (1)$$

- System Hamiltonian

$$\mathcal{H} = \mathcal{T}^{00} = \frac{\partial\mathcal{L}}{\partial\dot{\phi}_i}\dot{\phi}_i - \mathcal{L} \qquad (2)$$

- Ground-state trial wave function

$$|\Phi_0\rangle = \prod_a c_a^{\dagger}|0\rangle \qquad (3)$$

- Energy functional of the system

$$E = \langle\Phi_0|H|\Phi_0\rangle = E_k + E_{\sigma}^D + E_{\omega}^D + E_{\rho}^D + E_A^D + E_{\sigma}^E + E_{\omega}^E + E_{\rho}^E + E_A^E \qquad (4)$$

Zero-range reduction

- Yukawa propagators of the mesons

$$D_i(\mathbf{r},\mathbf{r}') = \frac{1}{4\pi}\frac{e^{-m_i|\mathbf{r}-\mathbf{r}'|}}{|\mathbf{r}-\mathbf{r}'|}, \qquad D_i(\mathbf{q}) = \frac{1}{m_i^2+\mathbf{q}^2} \tag{5}$$

for $m_i \gg q$,

$$D_i(\mathbf{q}) \approx \frac{1}{m_i^2} - \frac{\mathbf{q}^2}{m_i^4} + \cdots \quad \Rightarrow \quad D_i(\mathbf{r},\mathbf{r}') \approx \frac{1}{m_i^2}\delta(\mathbf{r}-\mathbf{r}') \tag{6}$$

within the zero-order approximation.

- Zero-range reduction of meson-nucleon couplings

$$\alpha_S^{\mathrm{HF}} = -\frac{g_\sigma^2}{m_\sigma^2}, \qquad \alpha_V^{\mathrm{HF}} = \frac{g_\omega^2}{m_\omega^2}, \qquad \alpha_{tV}^{\mathrm{HF}} = \frac{g_\rho^2}{m_\rho^2}, \tag{7}$$

Fierz transformation (I)

- Sixteen Dirac matrices form a complete system

$$O^S = 1, O^V = \gamma^\mu, O^T = \sigma^{\mu\nu}, O^{PS} = \gamma^5, O^{PV} = \gamma^5\gamma^\mu$$

  so that any one can be expressed as a linear superposition of variants with a changed sequence of spinors,

$$(\bar{a}O^i d)(\bar{c}O_i b) = \sum_k c_{ik}(\bar{a}O^k b)(\bar{c}O_k d), \tag{8}$$

  with the coefficients c_{ik} in the so-called Fierz table Fierz:1937, Okun:1982, Sulaksono:2003

$$\begin{array}{cccccc} & S & V & T & PS & PV \\ S & \frac{1}{4} & \frac{1}{4} & \frac{1}{8} & \frac{1}{4} & -\frac{1}{4} \\ V & 1 & -\frac{1}{2} & 0 & -1 & -\frac{1}{2} \\ T & 3 & 0 & -\frac{1}{2} & 3 & 0 \\ PS & \frac{1}{4} & -\frac{1}{4} & \frac{1}{8} & \frac{1}{4} & \frac{1}{4} \\ PV & -1 & -\frac{1}{2} & 0 & 1 & -\frac{1}{2} \end{array} \tag{9}$$

- For the isospin coefficients,

$$\delta_{q_a q_d}\delta_{q_c q_b} = \frac{1}{2}\left[\delta_{q_a q_b}\delta_{q_c q_d} + \langle q_a |\vec{\tau}| q_b\rangle \cdot \langle q_c |\vec{\tau}| q_d\rangle\right], \tag{10a}$$

$$\langle q_a |\vec{\tau}| q_d\rangle \cdot \langle q_c |\vec{\tau}| q_b\rangle = \frac{1}{2}\left[3\delta_{q_a q_b}\delta_{q_c q_d} - \langle q_a |\vec{\tau}| q_b\rangle \cdot \langle q_c |\vec{\tau}| q_d\rangle\right]. \tag{10b}$$

Fierz transformation (II)

- Fierz transformation: from α^{HF} to α^{H}

$$
\begin{aligned}
\alpha_S^{\mathrm{H}} &= +\frac{7}{8}\alpha_S^{\mathrm{HF}} - \frac{4}{8}\alpha_V^{\mathrm{HF}} - \frac{12}{8}\alpha_{tV}^{\mathrm{HF}} && (11a)\\
\alpha_{tS}^{\mathrm{H}} &= -\frac{1}{8}\alpha_S^{\mathrm{HF}} - \frac{4}{8}\alpha_V^{\mathrm{HF}} + \frac{4}{8}\alpha_{tV}^{\mathrm{HF}} && (11b)\\
\alpha_V^{\mathrm{H}} &= -\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{10}{8}\alpha_V^{\mathrm{HF}} + \frac{6}{8}\alpha_{tV}^{\mathrm{HF}} && (11c)\\
\alpha_{tV}^{\mathrm{H}} &= -\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{2}{8}\alpha_V^{\mathrm{HF}} + \frac{6}{8}\alpha_{tV}^{\mathrm{HF}} && (11d)\\
\alpha_T^{\mathrm{H}} &= -\frac{1}{16}\alpha_S^{\mathrm{HF}} && (11e)\\
\alpha_{tT}^{\mathrm{H}} &= -\frac{1}{16}\alpha_S^{\mathrm{HF}} && (11f)\\
\alpha_{PS}^{\mathrm{H}} &= -\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{4}{8}\alpha_V^{\mathrm{HF}} + \frac{12}{8}\alpha_{tV}^{\mathrm{HF}} && (11g)\\
\alpha_{tPS}^{\mathrm{H}} &= -\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{4}{8}\alpha_V^{\mathrm{HF}} - \frac{4}{8}\alpha_{tV}^{\mathrm{HF}} && (11h)\\
\alpha_{PV}^{\mathrm{H}} &= +\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{2}{8}\alpha_V^{\mathrm{HF}} + \frac{6}{8}\alpha_{tV}^{\mathrm{HF}} && (11i)\\
\alpha_{tPV}^{\mathrm{H}} &= +\frac{1}{8}\alpha_S^{\mathrm{HF}} + \frac{2}{8}\alpha_V^{\mathrm{HF}} - \frac{2}{8}\alpha_{tV}^{\mathrm{HF}} && (11j)
\end{aligned}
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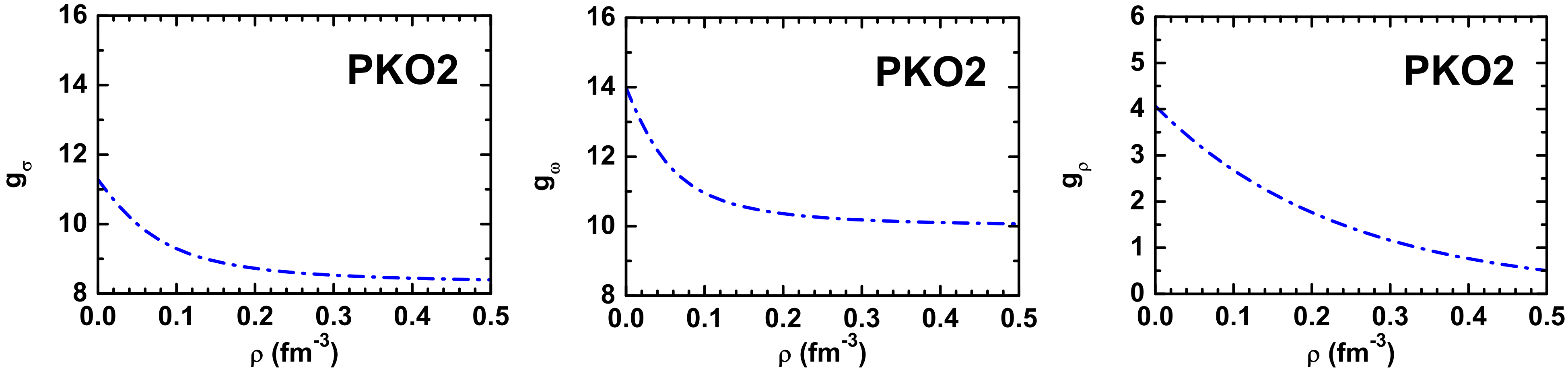
Nucleon-meson coupling strengths of PKO2

- Starting point: nucleon-meson coupling strengths g_σ, g_ω, and g_ρ of PKO2



Long, Sagawa, Meng, Giai, *EPL* **82**, 12001 (2008)

- Zero-range reduction

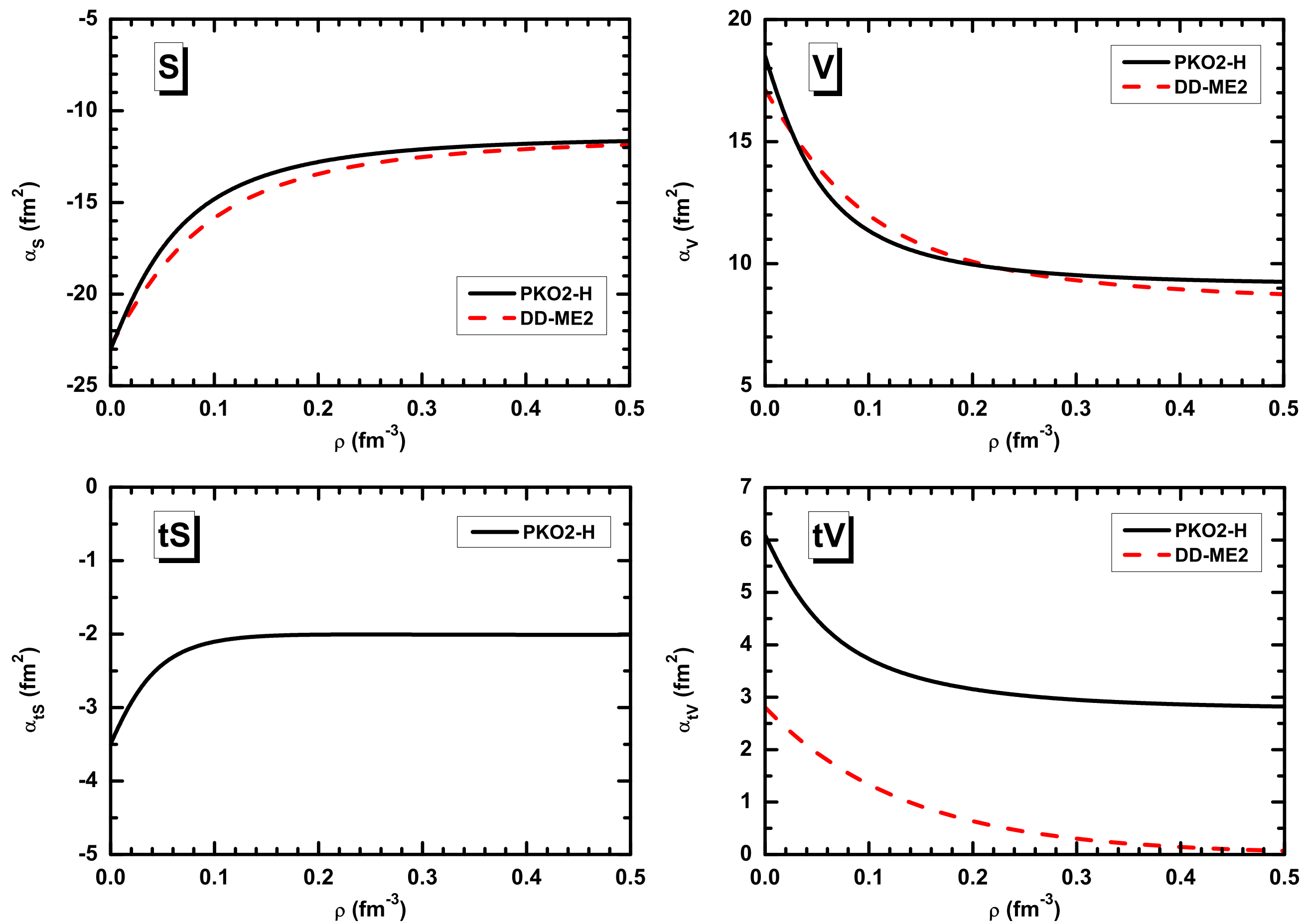
$$\alpha_S^{\mathrm{HF}} = -\frac{g_\sigma^2}{m_\sigma^2}, \qquad \alpha_V^{\mathrm{HF}} = \frac{g_\omega^2}{m_\omega^2}, \qquad \alpha_{tV}^{\mathrm{HF}} = \frac{g_\rho^2}{m_\rho^2},$$

- Fierz transformation

$$\alpha_j^{\mathrm{H}} = \sum_k c_{jk} \alpha_k^{\mathrm{HF}},$$

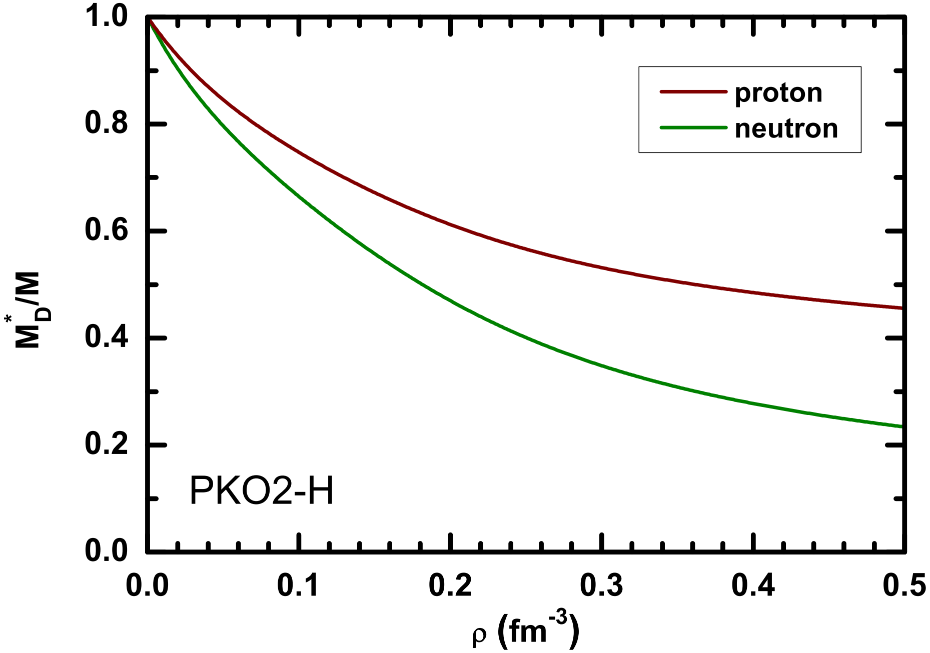
RHF equivalent zero-range coupling strengths (I)

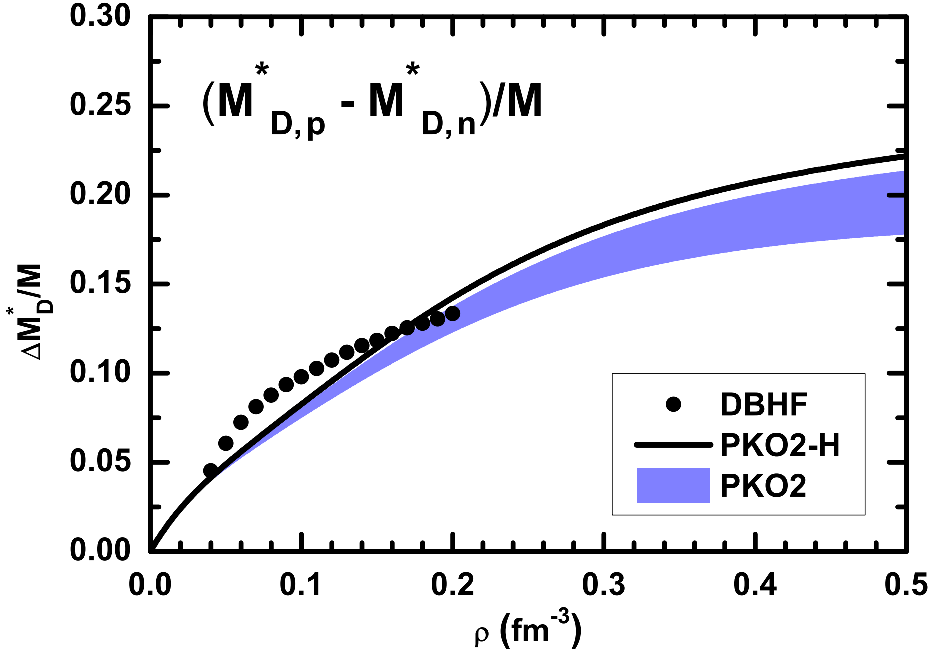
- The RHF equivalent parametrization derived from PKO2 is called "**PKO2-H**".



- α_S^{H} and α_V^{H} are consistent with those of DD-ME2 Lalazissis:2005
- α_{tS}^{H} appears $\Rightarrow$ proton-neutron Dirac mass splitting in asymmetric nuclear matter
- α_{tV}^{H} is modified for another delicate balance between *tS* and *tV* channels

Dirac mass and its isospin splitting





DBHF: van Dalen, *et al.*, *EPJA* **31**, 29 (2007)

- It is found that $M^*_{D,p} > M^*_{D,n}$.
- The splitting behavior in neutron matter is quantitatively consistent with the prediction of the Dirac-Brueckner-Hartree-Fock (DBHF) calculations.

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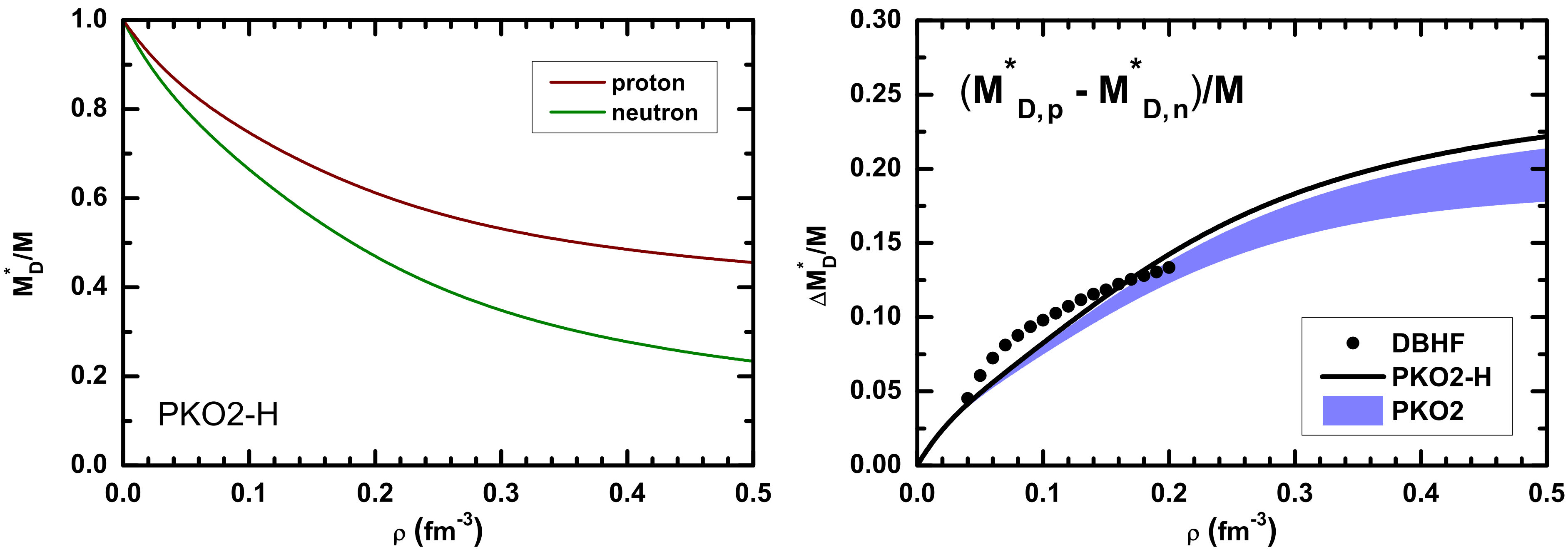

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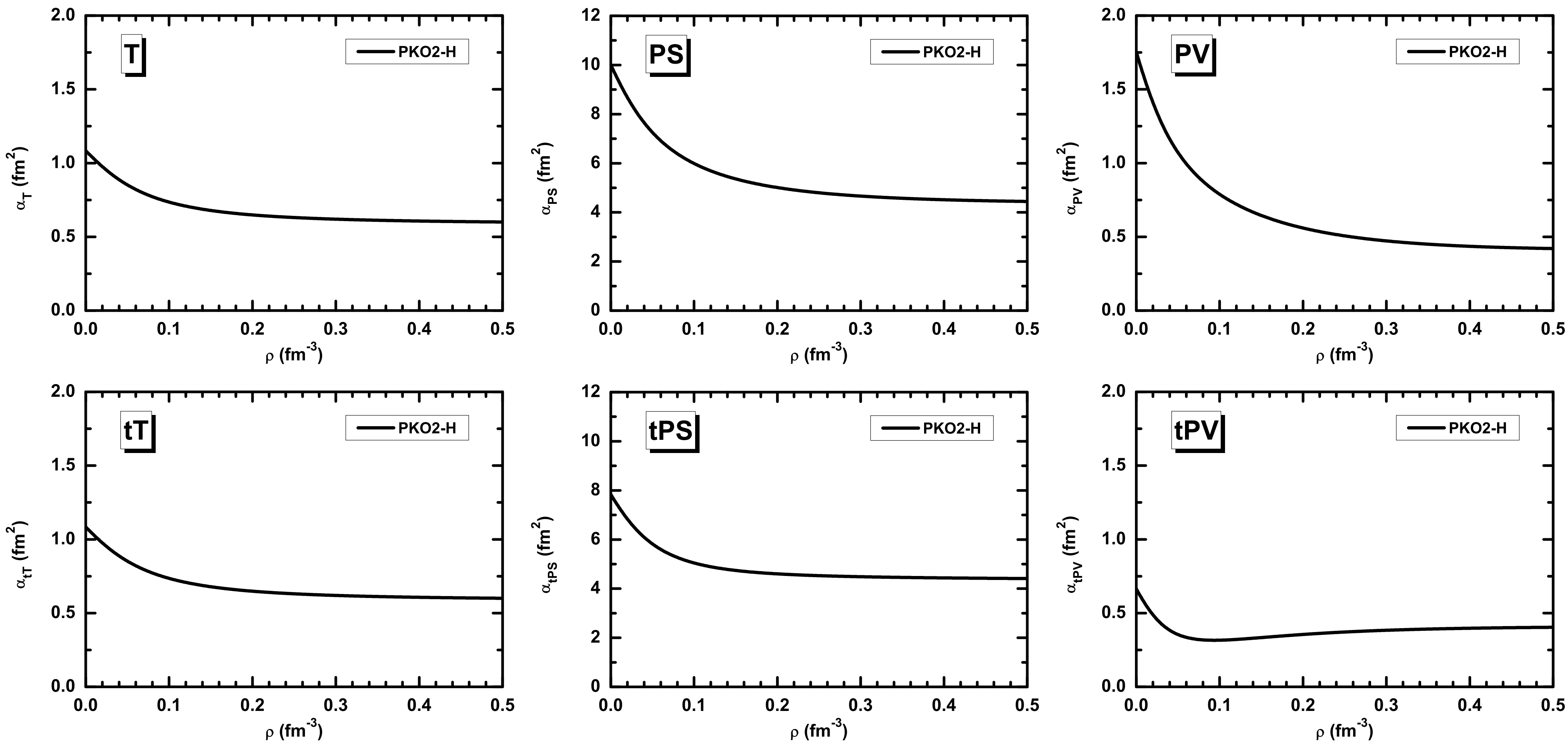
- The constraints introduced by the Fock terms of the RHF scheme into the tS channel of the present density functional are straight forward and quite robust.

RHF equivalent zero-range coupling strengths (II)



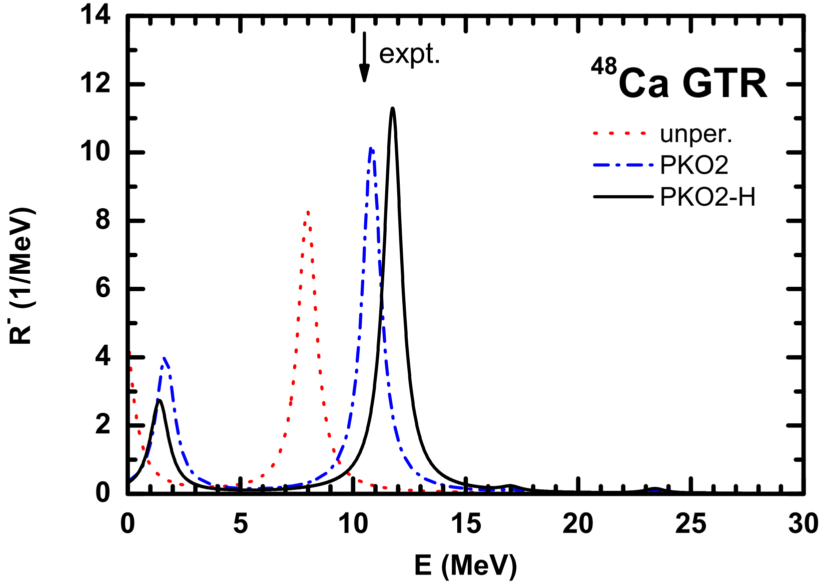
- $\alpha^{\mathrm{H}}_{(t)T}$, $\alpha^{\mathrm{H}}_{(t)PS}$, and $\alpha^{\mathrm{H}}_{(t)PV}$ are explicitly determined by exchange effects of RHF scheme
- $(t)PS$ and $(t)PV$ channels vanish in ground-state descriptions due to the parity conservation, but crucial for spin-isospin resonances

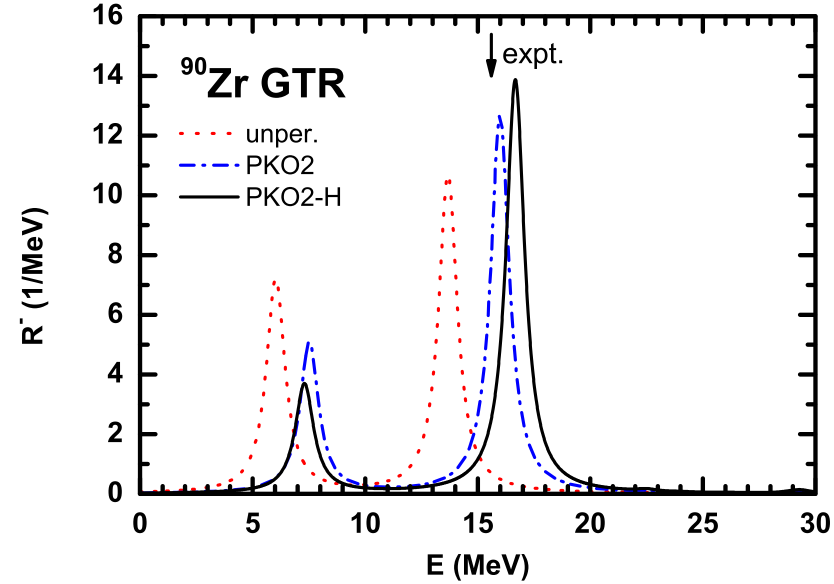
Particle-hole residual interactions in charge-exchange channel

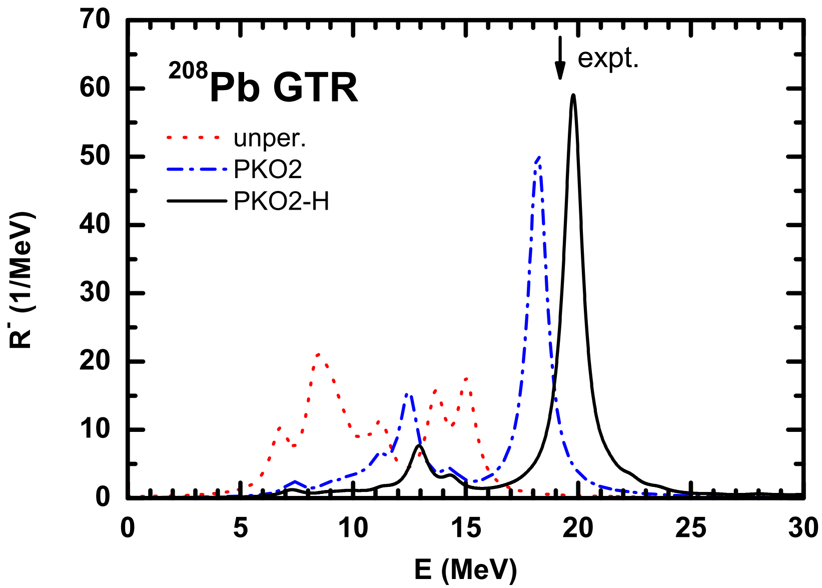
- Particle-hole (ph) residual interactions
  - tS channel:
  $$V_{tS}(1,2) = \alpha^{\mathrm{H}}_{tS}[\gamma_0\vec{\tau}]_1 \cdot [\gamma_0\vec{\tau}]_2\delta(\mathbf{r}_1 - \mathbf{r}_2), \tag{12a}$$
  - tV channel:
  $$V_{tV}(1,2) = \alpha^{\mathrm{H}}_{tV}[\gamma_0\gamma^{\mu}\vec{\tau}]_1 \cdot [\gamma_0\gamma_{\mu}\vec{\tau}]_2\delta(\mathbf{r}_1 - \mathbf{r}_2), \tag{12b}$$
  - tT channel:
  $$V_{tT}(1,2) = \alpha^{\mathrm{H}}_{tT}[\gamma_0\sigma^{\mu\nu}\vec{\tau}]_1 \cdot [\gamma_0\sigma_{\mu\nu}\vec{\tau}]_2\delta(\mathbf{r}_1 - \mathbf{r}_2), \tag{12c}$$
  - tPS channel:
  $$V_{tPS}(1,2) = \alpha^{\mathrm{H}}_{tPS}[\gamma_0\gamma_5\vec{\tau}]_1 \cdot [\gamma_0\gamma_5\vec{\tau}]_2\delta(\mathbf{r}_1 - \mathbf{r}_2), \tag{12d}$$
  - tPV channel:
  $$V_{tPV}(1,2) = \alpha^{\mathrm{H}}_{tPV}[\gamma_0\gamma_5\gamma^{\mu}\vec{\tau}]_1 \cdot [\gamma_0\gamma_5\gamma_{\mu}\vec{\tau}]_2\delta(\mathbf{r}_1 - \mathbf{r}_2). \tag{12e}$$

- For the charge-exchange spin-flip modes, the tT and tPV channels are expected to play the dominant roles, where the operator $[\boldsymbol{\sigma}\vec{\tau}] \cdot [\boldsymbol{\sigma}\vec{\tau}]$ is sandwiched by the large components of wave functions.

Gamow-Teller resonances



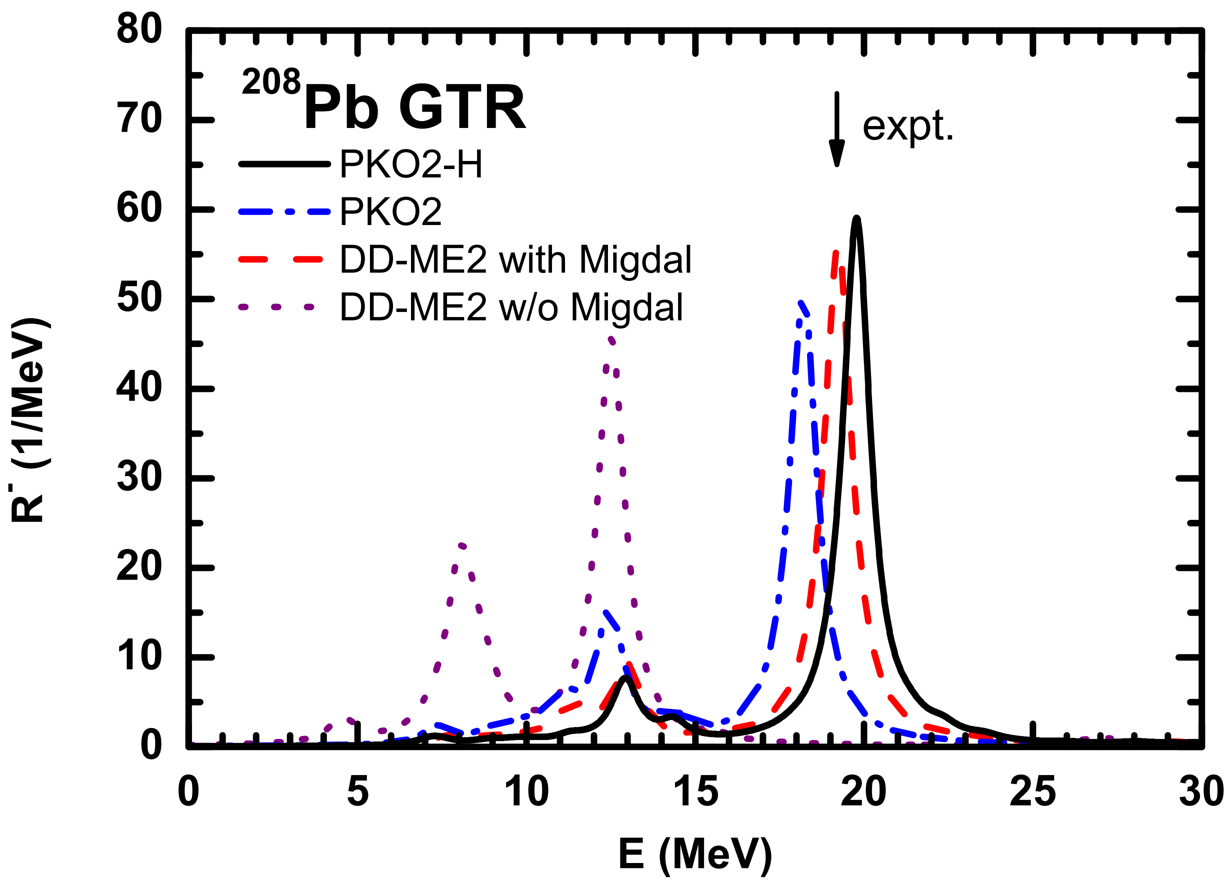




- GTR excitation energies can be well reproduced by the *ph* residual interactions of PKO2-H.
- The present results are similar as those by the original RHF+RPA.
- The difference is due to the zero-range approximation.

RHF+RPA: HL, Giai, Meng, *PRL* **101**, 122502 (2008)

Gamow-Teller resonances in ^{208}Pb

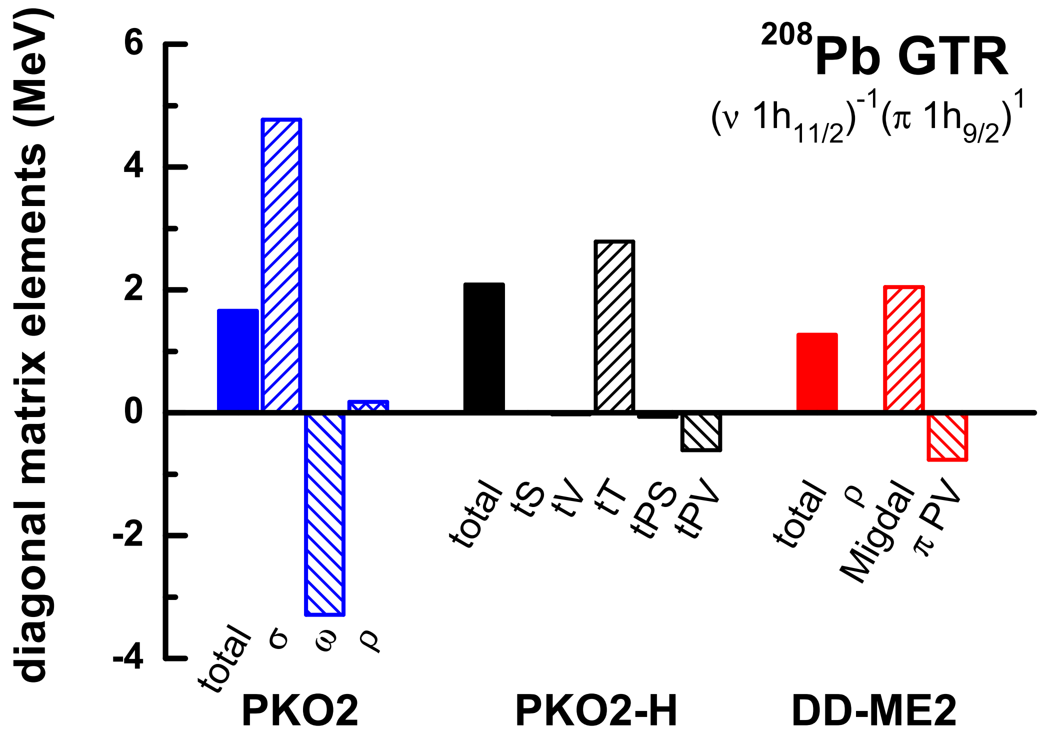


- It is fitted for DD-ME2 by adjusting the Migdal term.

RHF+RPA: HL, Giai, Meng, *PRL* **101**, 122502 (2008)

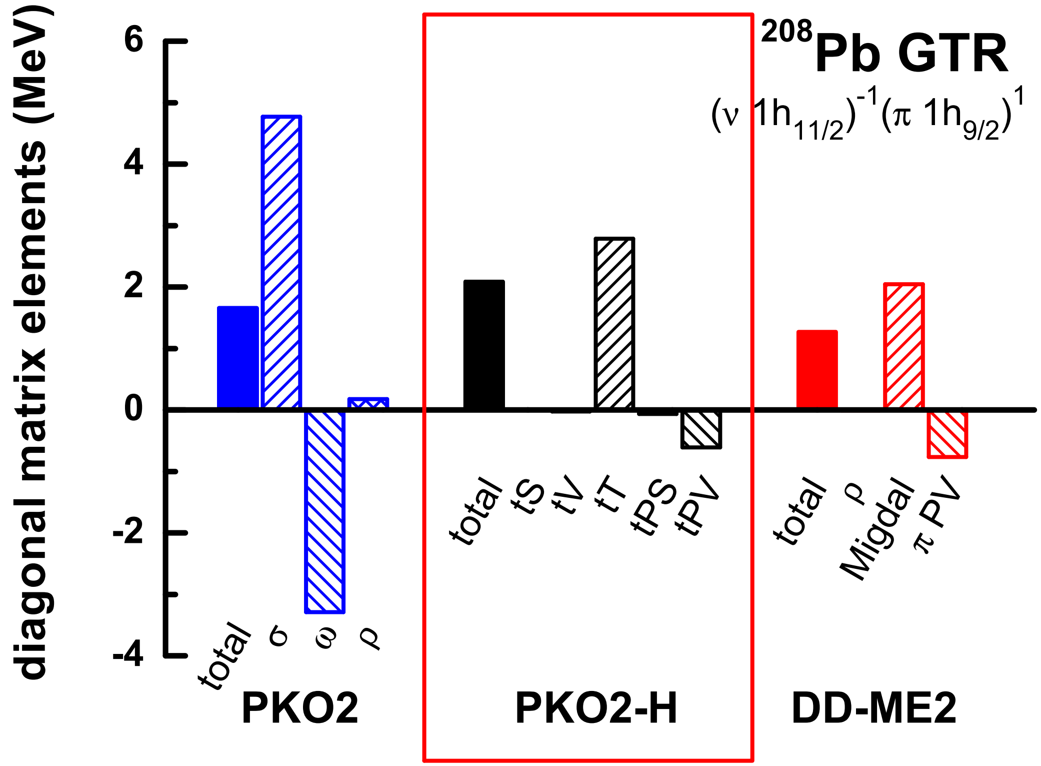
RH+RPA: Paar, Nikšić, Vretenar, Ring, *PRC* **69**, 054303 (2004)

Physical mechanisms of GTR



- In RHF+RPA (PKO2), σ- and ω-mesons play the most important role in determining the properties of GTR via the exchange terms.
- In the RHF equivalent RPA (PKO2-H), tT and tPV channels are most important, their coupling strengths are intrinsically determined by Fierz transformation.
- In conventional RH+RPA (DD-ME2), the free π residual interaction is attractive and the Migdal term is repulsive by fitting to experimental data.

Physical mechanisms of GTR by PKO2-H

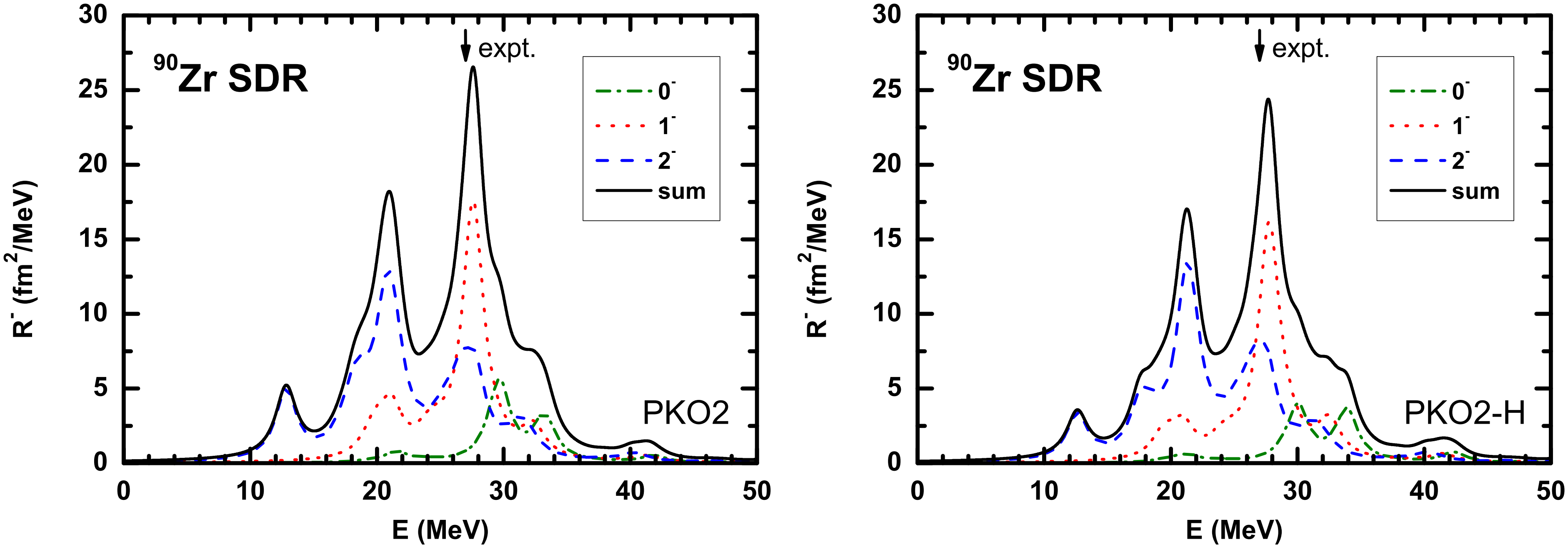


- The dominant *ph* interactions are the operator $[\boldsymbol{\sigma}\vec{\tau}] \cdot [\boldsymbol{\sigma}\vec{\tau}]$ sandwiched by large components of w.f., i.e., $[\sigma^{ij}\vec{\tau}] \cdot [\sigma_{ij}\vec{\tau}] \propto 2\alpha^{\mathrm{H}}_{tT}$ and $[\gamma_5\gamma^i\vec{\tau}] \cdot [\gamma_5\gamma_i\vec{\tau}] \propto -\alpha^{\mathrm{H}}_{tPV}$
- The net contribution is then proportional to

$$2\alpha^{\mathrm{H}}_{tT} - \alpha^{\mathrm{H}}_{tPV} = -\frac{1}{3}\left(\alpha^{\mathrm{H}}_{S} + \alpha^{\mathrm{H}}_{V}\right)$$

- Total *ph* strengths are determined by the delicate balance between S and V channels.

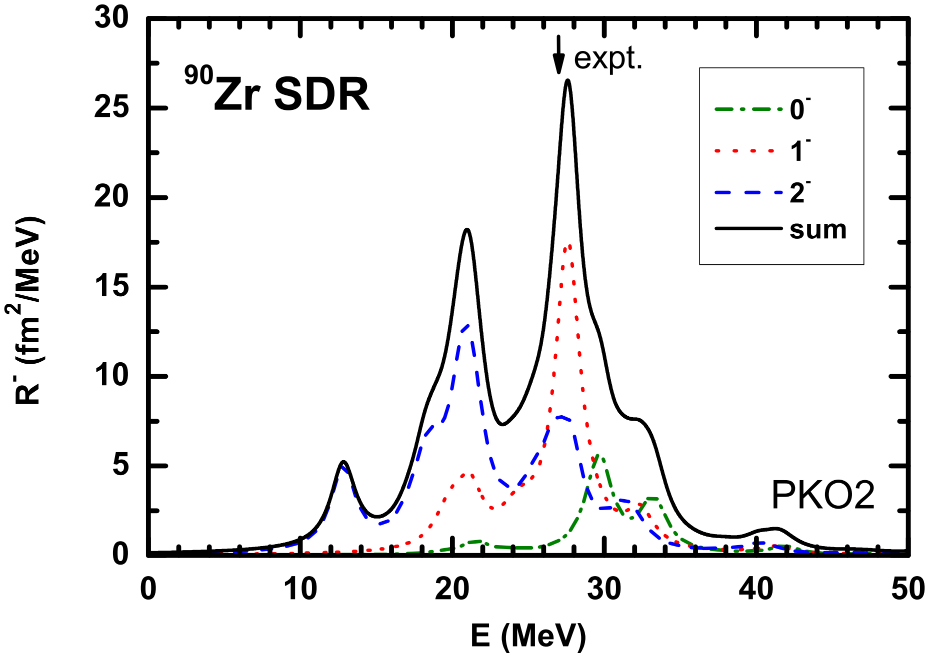
Spin-dipole resonances

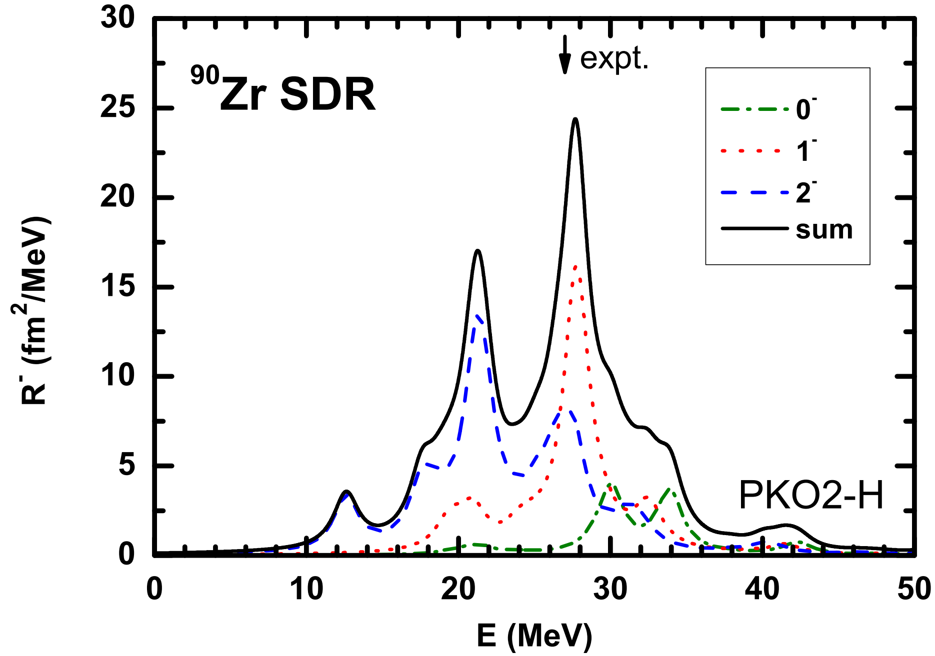


expt: Yako, Sagawa, Sakai, *PRC* **74**, 051303 (2006)

- Not only the total strengths but also the individual contribution from different spin-parity J^π components are almost identical.
- The energy hierarchy $E(2^-) < E(1^-) < E(0^-)$ can be obtained naturally in the present RPA calculations in the local scheme.

Spin-dipole resonances





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- The constraints introduced by the Fock terms of the RHF scheme into the *ph* residual interactions are also straight forward and quite robust.

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Summary

★ A new method is proposed to take into account the Fock terms in local covariant density functionals.

✓ The advantages of existing RH functionals can be maintained, while the problems in the isovector channel can be solved.

- ⋆ The neutron-proton Dirac mass splitting in asymmetric nuclear matter is in a very good agreement with the prediction of DBHF.
- ⋆ The properties of GTR and SDR can be reproduced in a natural way.

Perspectives

- This opens a new door for the development of nuclear local covariant density functionals with proper isoscalar and isovector properties in the future.

Outline

Introduction

Theoretical Framework
- Relativistic Hartree-Fock theory
- Zero-range reduction
- Fierz transformation

Results and Discussion
- Coupling strengths in different channels
- Dirac mass splitting
- Spin-isospin resonances

Summary and Perspectives

Work in progress

Work in progress - I

Project Build a local covariant energy density functional including all terms in the Lagarngian allowed by the symmetries but only considering as free parameters the ones corresponding to the S,V and tV channels, the rest of the channels will be determined by the Fierz transformations within the same Hartee scheme in a fully self-consistent manner.

Work in progress - II

Fierz transformations

$$\alpha^H(S, V, tS, tV, T, tT, PS, tPS, PV, tPV) \rightarrow \alpha^H(S, V, tV)$$

$$\begin{aligned}
\alpha^{\mathrm{H}}_{tS}(\rho) &= -\frac{1}{15}\alpha^{\mathrm{H}}_{S}(\rho) - \frac{2}{3}\alpha^{\mathrm{H}}_{V}(\rho) + \frac{6}{5}\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{T}(\rho) &= -\frac{1}{10}\alpha^{\mathrm{H}}_{S}(\rho) - \frac{1}{5}\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{tT}(\rho) &= -\frac{1}{10}\alpha^{\mathrm{H}}_{S}(\rho) - \frac{1}{5}\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{PS}(\rho) &= \frac{1}{5}\alpha^{\mathrm{H}}_{S}(\rho) + \frac{12}{5}\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{tPS}(\rho) &= -\frac{1}{3}\alpha^{\mathrm{H}}_{S}(\rho) + \frac{2}{3}\alpha^{\mathrm{H}}_{V}(\rho) - 2\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{PV}(\rho) &= \frac{2}{5}\alpha^{\mathrm{H}}_{S}(\rho) + \frac{9}{5}\alpha^{\mathrm{H}}_{tV}(\rho), \\
\alpha^{\mathrm{H}}_{tPV}(\rho) &= \frac{2}{15}\alpha^{\mathrm{H}}_{S}(\rho) + \frac{1}{3}\alpha^{\mathrm{H}}_{V}(\rho) - \frac{2}{5}\alpha^{\mathrm{H}}_{tV}(\rho).
\end{aligned}$$

The reduction of the base of operators with which you represent your problem determines the couplings of the others. This does not mean that the mapping is *perfect* but we have checked that it approximately works for the HF $\rightarrow$ H case with PKO2.

Work in progress - III

Lagrangian

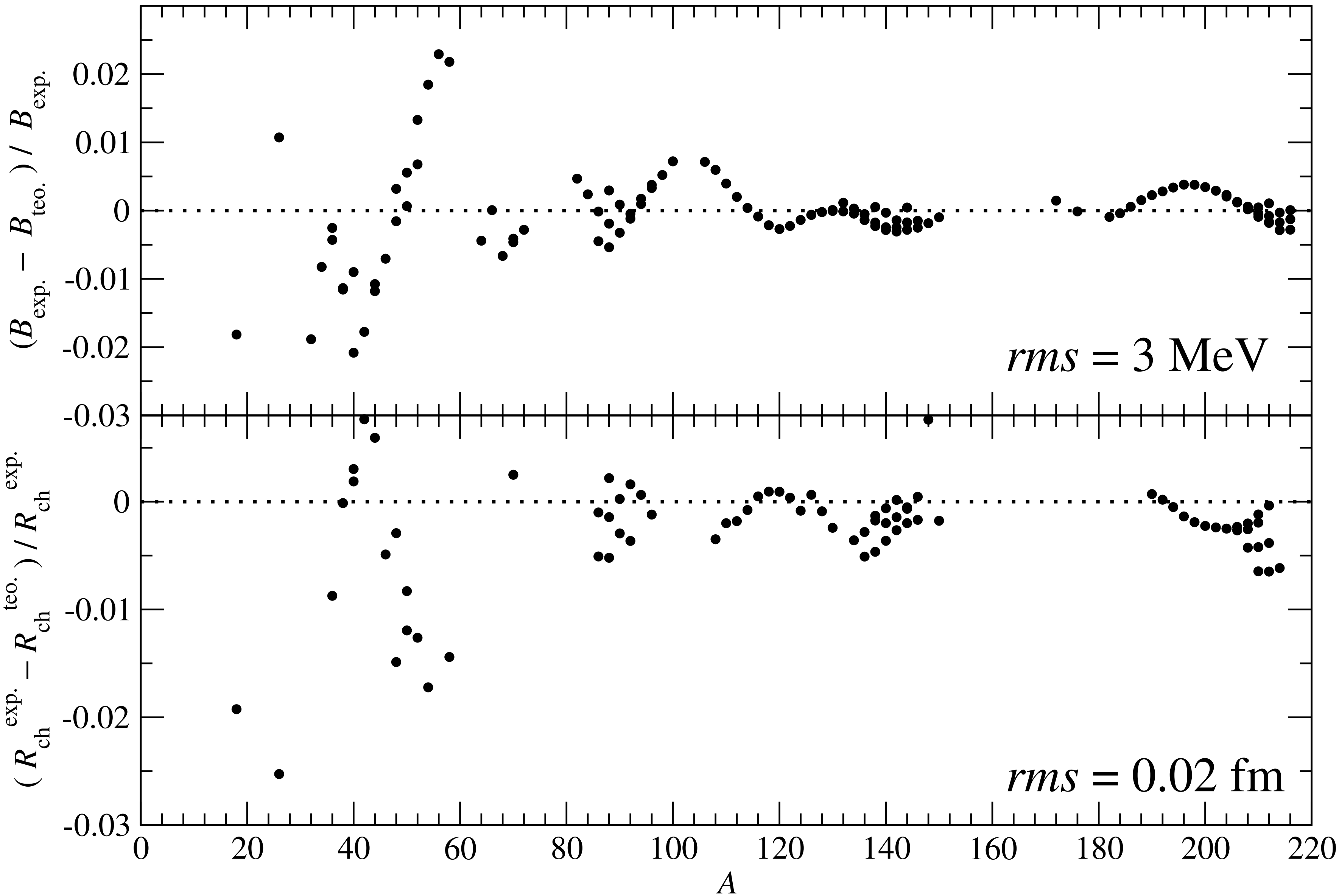
$$
\begin{aligned}
\mathcal{L} \;=\;& \bar{\psi}(i\gamma^\mu\partial_\mu - M)\psi \\
& -\frac{1}{2}\alpha_S(\bar{\psi}\psi)(\bar{\psi}\psi) - \frac{1}{2}\delta_S(\partial_\nu\bar{\psi}\psi)(\partial^\nu\bar{\psi}\psi) - \frac{1}{2}\alpha_{tS}(\bar{\psi}\vec{\tau}\psi)\cdot(\bar{\psi}\vec{\tau}\psi) \\
& -\frac{1}{2}\alpha_V(\bar{\psi}\gamma^\mu\psi)(\bar{\psi}\gamma_\mu\psi) - \frac{1}{2}\alpha_{tV}(\bar{\psi}\vec{\tau}\gamma^\mu\psi)\cdot(\bar{\psi}\vec{\tau}\gamma_\mu\psi) \\
& -\frac{1}{2}\alpha_T(\bar{\psi}\sigma^{\mu\nu}\psi)(\bar{\psi}\sigma_{\mu\nu}\psi) - \frac{1}{2}\alpha_{tT}(\bar{\psi}\sigma^{\mu\nu}\vec{\tau}\psi)\cdot(\bar{\psi}\sigma_{\mu\nu}\vec{\tau}\psi) \\
& -\frac{1}{2}\alpha_{PS}(\bar{\psi}\gamma^5\psi)(\bar{\psi}\gamma^5\psi) - \frac{1}{2}\alpha_{tPS}(\bar{\psi}\gamma^5\vec{\tau}\psi)\cdot(\bar{\psi}\gamma^5\vec{\tau}\psi) \\
& -\frac{1}{2}\alpha_{PV}(\bar{\psi}\gamma^5\gamma^\mu\psi)(\bar{\psi}\gamma^5\gamma_\mu\psi) - \frac{1}{2}\alpha_{tPV}(\bar{\psi}\gamma^5\gamma^\mu\vec{\tau}\psi)\cdot(\bar{\psi}\gamma^5\gamma_\mu\vec{\tau}\psi) \\
& -e\bar{\psi}\gamma^\mu A_\mu\frac{(1-\tau_3)}{2}\psi - \frac{1}{4}F^{\mu\nu}F_{\mu\nu},
\end{aligned}
$$

Work in progress - IV

Test

The aim is twofold. On one side, we want to test the feasibility of optimizing a localized Relativistic Hartree functional with density dependent couplings where the scalar-isovector channel is completely determined from the other spin-isospin channels via the Fierz transformations. Note that for the test presented here, the six remaining channels —i.e. isoscalar- and isovector- tensor, pseudo-vector and pseudo-scalar— are completely neglected. And, on the other side, we want to find a good starting point before fitting the complete localized functional. For testing purposes we use the same fitting procedure used to fit DD-MEδ and the DD-PC1 ansatz for the density dependence of the coupling constants is adopted.

Work in progress - V



PS and PV terms will not contribute to gs and T terms are not included for the test, we expect that they will be relevant and will be included in the future.

Work in progress - VI