CHIRAL INSPIRED THREE-NUCLEON INTERACTION IN NUCLEAR MATTER
(Preliminary results)

Alessandro Lovato

OUTLINE

- Nuclear Hamiltonian
- UIX three-body potential
- Chiral NN potential
- Chiral NNN potential and its local form
- Comparative study of local three-body potential in nuclear matter
- Conclusions

NUCLEAR HAMILTONIAN & N-N POTENTIAL

The non relativistic Hamiltonian describing nuclear matter is

$$H = \sum_{i=1}^{A} \frac{\mathbf{p}_i^2}{2m} + \sum_{j>i=1}^{A} v_{ij} + \dots$$

Realistic nucleon-nucleon (NN) potentials are, for example:

- **Argonne v_{18}, v_8'**
  - Mainly phenomenological
  - Local in coordinates
- **CD-BONN**
  - Based on meson-exchange
  - Nonlocal
- **Chiral N^3LO**
  - Based on **Chiral Lagrangians**
  - Nonlocal

The parameters of these potentials have been obtained by fitting the ~ 4300 data below 350 MeV in the Nijmegen NN scattering database.

⇩

They reproduce the experimental NN scattering data up to energies of 350 MeV with a χ^2 per datum close to 1.

No many-body methods are needed for the fit: these potentials have high predictive power and can be used in “ab initio” calculations.

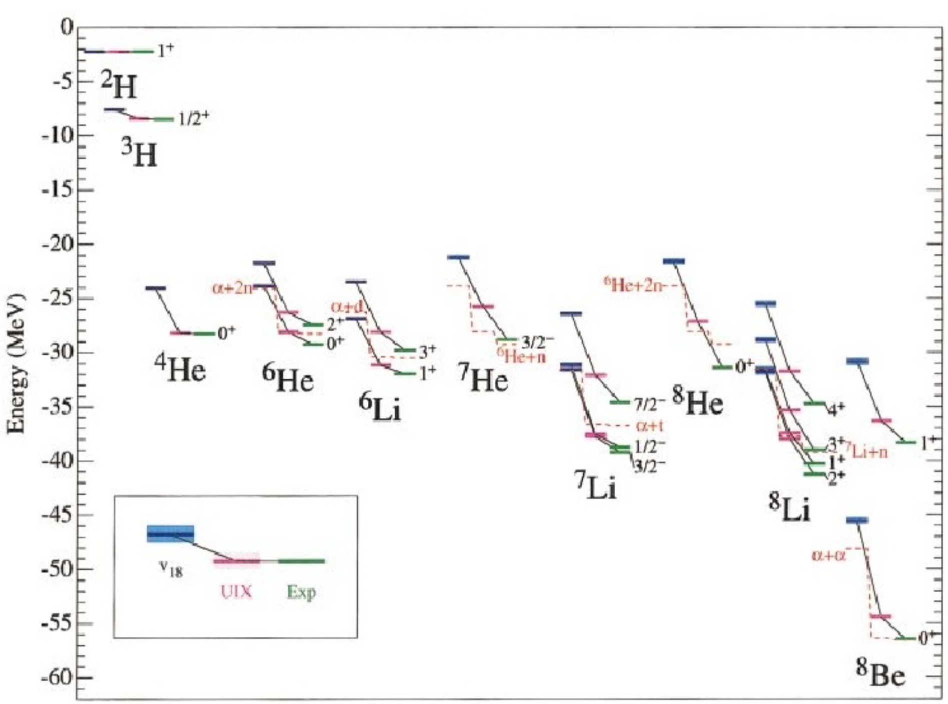
N-N POTENTIAL IS NOT ENOUGH

When two body potential only is considered:

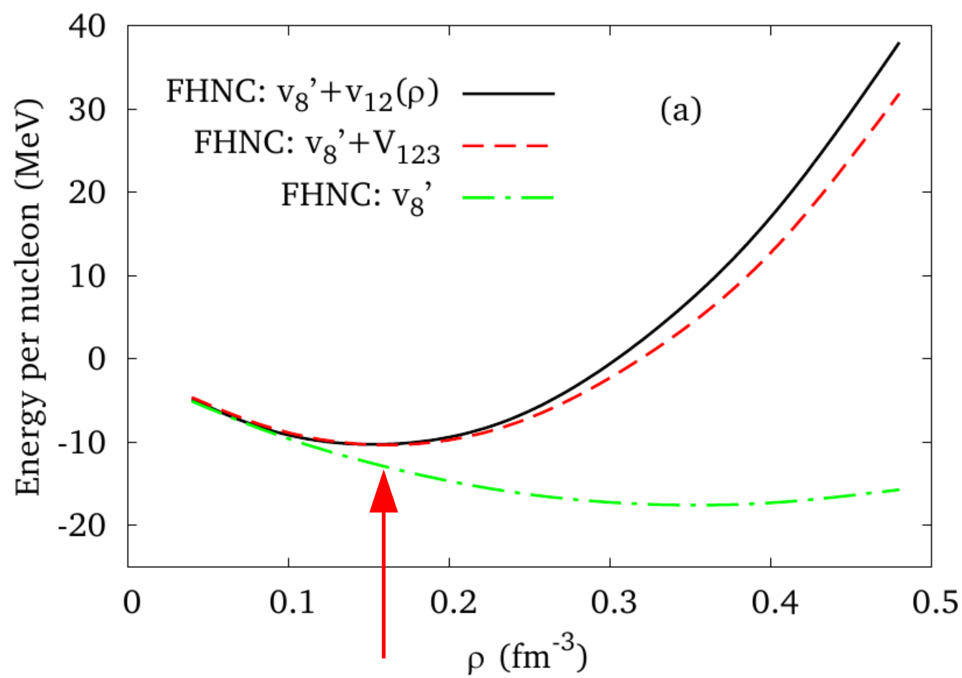
- The description of three- and four- nucleon bound and scattering states gives a χ^2 per datum much larger than 1.
- The equilibrium density ρ_0 of Symmetric Nuclear Matter (SNM) is overestimated.

Three-nucleon forces are needed !!!

Light nuclei



SNM

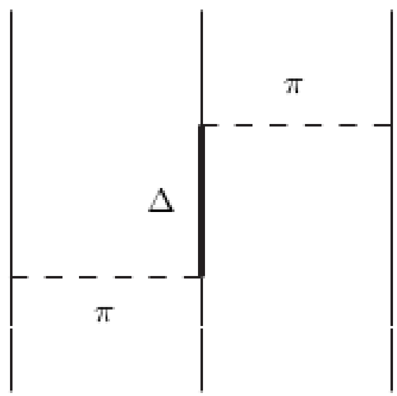


ρ_0=0.16 fm^{-3}

UIX NNN POTENTIAL

One of the mostly used three nucleon potential is UIX. It consists of two contributions

- **Fujita Myiazawa** $V^{2\pi}$: two pions are exchanged among nucleons and a Δ resonance is excited in the intermediate state.



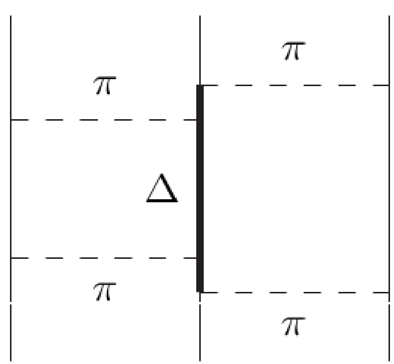
$$V^{2\pi} = A^{2\pi}(O^{2\pi}_{123} + O^{2\pi}_{231} + O^{2\pi}_{312}) \Rightarrow \text{Cyclic sum}$$

$$O^{2\pi}_{123} = \left(\{\hat{X}_{12}, \hat{X}_{23}\}\{\tau_{12}, \tau_{13}\} + \frac{1}{4}[\hat{X}_{12}, \hat{X}_{23}][\tau_{12}, \tau_{23}]\right)$$

$$\hat{X}_{ij} = Y(m_\pi r)\sigma_{ij} + T(m_\pi r)S_{ij}$$

It solves the underbinding of light nuclei, but makes nuclear matter even more overbound.

- **Phenomenological scalar repulsive term** V^R**:** introduced by Lagaris and Pandharipande in order FHNC/SOC calculation to reproduce the correct binding energy of SNM.



$$V^R = U_0 \sum_{cycl} T^2(m_\pi r_{12}) T^2(m_\pi r_{23})$$

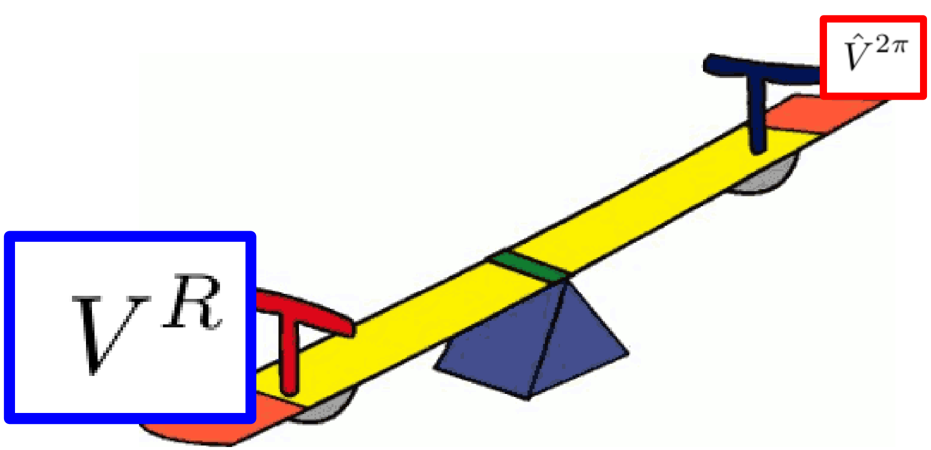
UIX NNN POTENTIAL

UIX potential has two free parameters to be fixed on experimental data

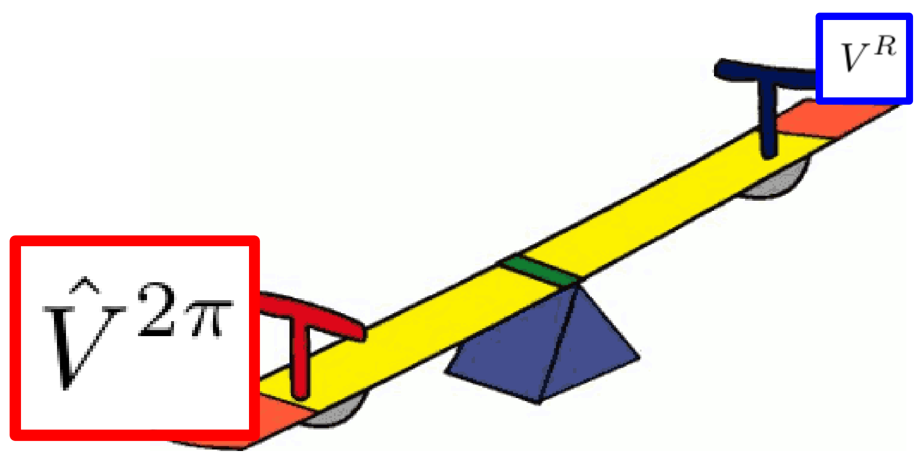
- **$A^{2\pi}$** is chosen to reproduce the observed binding energies of ^{3}H and of ^{4}He.
- **U_0** is adjusted in order for FHNC/SOC calculations to reproduce the empirical equilibrium density of SNM ρ_0=0.16 fm^{-3}.

Lagaris and Pandharipande argued that, because of correlations, the relative weight of the contribution depens upon the density of the system:

High density



Low density



UIX NNN POTENTIAL

UIX potential cannot be considered the final answer for what concerns the three-nucleon interaction issue.

Theoretical problems

Both FM and scalar repulsive terms are mainly phenomenological: there are no a priori reasons to stop at the first order in the perturbative expansion in the coupling constant g_0~10.

Adjusting U_0 to reproduce the correct value of ρ_0, that is calculated within the FHNC/SOC framework, makes the potential affected by the uncertanties of the many-body technique. Pure "ab initio" calculations are not possible anymore.

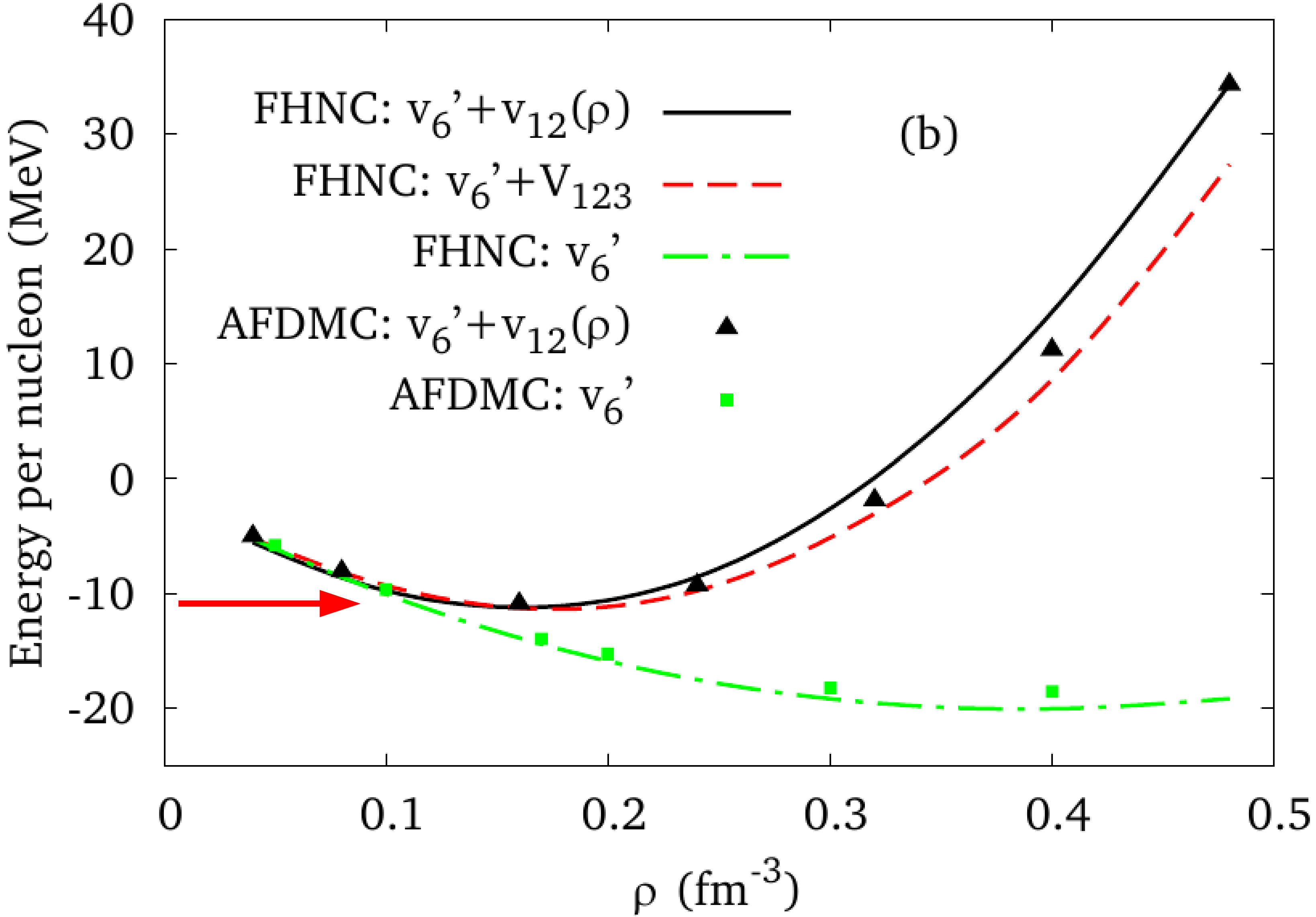
Phenomenological problems

The value of the n-d scattering lenght obtained with Argonne v_{18} + UIX is is not correctly reproduced

	$v_{18} + UIX$	Exp.
$^2a_{nd}$ (fm)	0.578	$0.645 \pm 0.003 \pm 0.007$

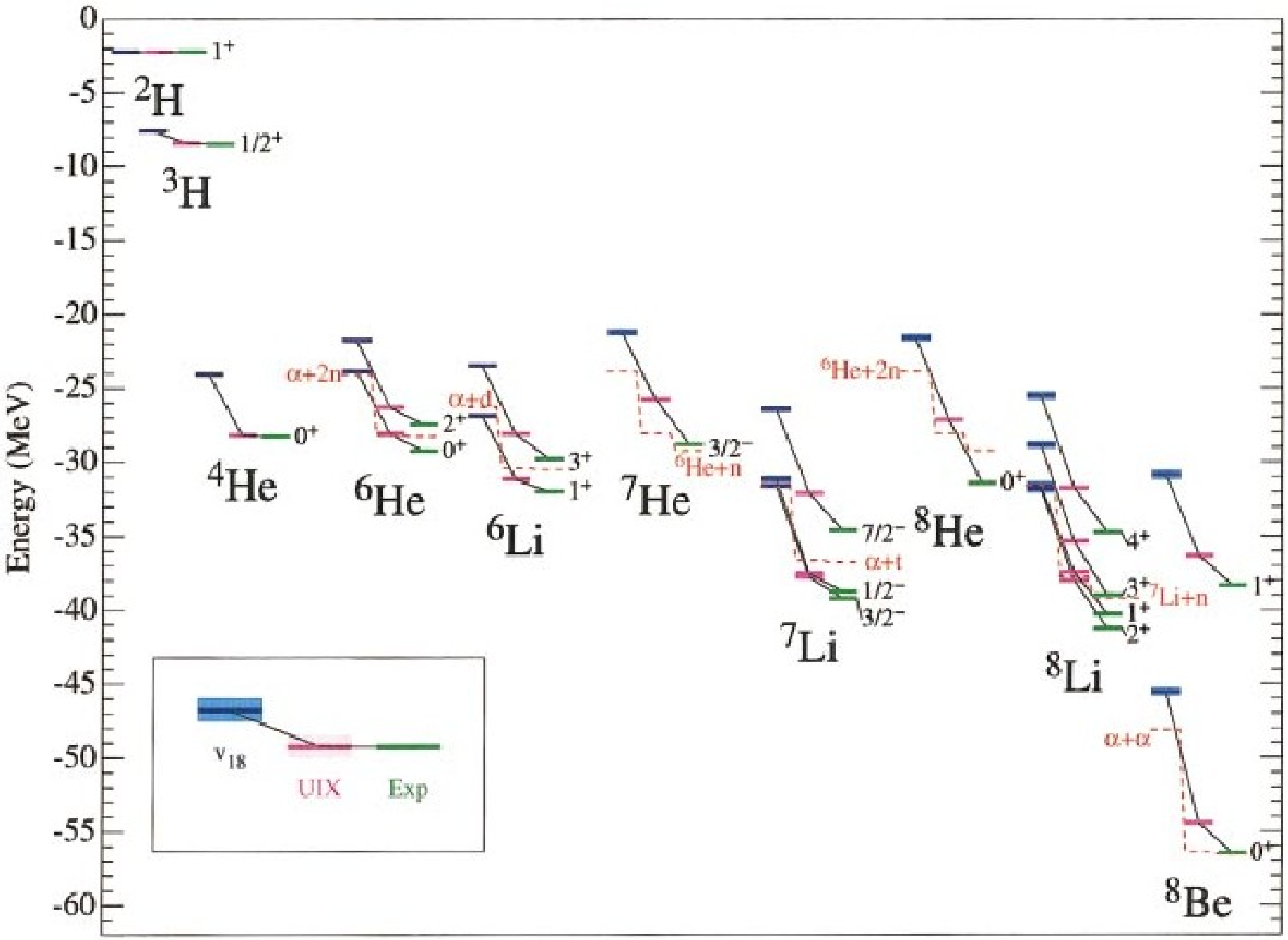
UIX NNN POTENTIAL

The binding energy of SNM at $\rho=\rho_0$ is $E(\rho_0)$= -11 MeV instead of -16 MeV



UIX NNN POTENTIAL

The spectrum of (even) light nuclei is not very well reproduced



BEYOND UIX

It is necessary to consider a more realistic three nucleon interaction, going beyond UIX

HOW ???

The two-nucleon potential can be decomposed in only few different spin-space structures respecting the symmetry of the interaction. For local v_{18}, or v_8' potential for example

$$\hat{V}_{12} = \sum_{p=1}^{n} v^p(r_{12}) \hat{O}_{12}^p$$

Fitting the huge amount of NN scattering data provides the shape of the radial function v^p.

Because of the large variety of different possible structures in the three-nucleon force, **following the same phenomenological path as in the NN system and parametrizing its most general structure seems not to be feasible** without additional theoretical guidance.

⇓

Chiral perturbation theory (ChPT) is an effective field theory (EFT) of QCD which exploits its symmetries and symmetry-breaking pattern and allows to analyze the properties of hadronic systems at low energies in a systematic and model independent way.

EFFECTIVE FIELD THEORIES

- Effective field theories have proved to be an important and very useful tool in nuclear and particle physics. One understands under an effective (field) theory an **approximate theory whose scope is to describe phenomena which occur at a chosen length (or energy) range.**

- The effective field theory we are interested in **describes reactions involving pions with external momenta of the order of m_π and (essentially) non-relativistic nucleons** whose three-momenta are of the order of m_π.

- The effective Lagrangian can be used to compute low-energy observables (such as scattering amplitudes) in a systematically improvable way via an expansion in powers of

$$\frac{Q}{\Lambda_\chi}$$

Soft scale associated with external momenta or the pion mass m_π ← Q

Λ_χ → Chiral symmetry breaking scale $\Lambda_\chi \sim 500$ MeV

- Usually effective field theories are not renormalizable, actually ChPT is such that it forbids the renormalizable derivative-less interaction of the type π^4.

WEINBERG POWER COUNTING

Using certain topological identities, Weinberg demonstrated that the order of a generic Feynman diagram, i.e. the power of the soft scale Q, is given by

$$\nu = 2 + 2L - \frac{1}{2}E_f + \sum_{ikn} \underbrace{(k + \frac{1}{2}n - 2)}_{\Delta} V_{ikn}$$

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Number of loops

Number of external fermionic lines

Vertex with *i* bosonic fields, *k* fermionic fields and *n* derivatives

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CAVEAT: FEW NUCLEONS SYSTEMS

Contributions of reducible diagrams, i.e. those ones which contain purely nucleonic intermediate states are infrared divergent and do not respect the previus power counting: **infrared enhancement of the few-nucleon diagrams.**

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- L: Number of loops
- E_f: Number of external fermionic lines
- V_{ikn}: Vertex with *i* bosonic fields, *k* fermionic fields and *n* derivatives

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WEINBERG SOLVED THE ISSUE

Consider irreducible diagrams only and solve the Lippman Schwinger equation which leads to a nonperturbative resummation of the contributions resulting from reducible diagrams.

CHIRAL NN POTENTIAL

Chiral NN potential at N^3LO consists of one-, two- and three-pion exchanges and a set of contact interactions with zero, two and four derivatives. In addition, one has to take into account various isospin–breaking and relativistic corrections.

- Entem & Machleidt in 2003 performed the first fit of the Chiral N3LO potential to Nijmegen scattering data

29 Fit Parameters →

Bin (MeV)	No. of data	N^3LO[a]	NNLO[b]	NLO[b]	AV18[c]
0–100	795	1.05	6.66	57.8	0.96
100–190	411	1.50	28.3	62.0	1.31
190–290	851	1.93	66.8	111.6	1.82
0–290	2057	1.50	35.4	80.1	1.38

	N^3LO[a]	CD-Bonn [10]	AV18 [22]	Empirical[b]
Deuteron				
B_d(MeV)	2.224575	2.224575	2.224575	2.224575(9)
$A_S(\mathrm{fm}^{-1/2})$	0.8843	0.8846	0.8850	0.8846(9)
η	0.0256	0.0256	0.0250	0.0256(4)
r_d(fm)	1.978[c]	1.970[c]	1.971[c]	1.97535(85)
$Q(\mathrm{fm}^2)$	0.285[d]	0.280[d]	0.280[d]	0.2859(3)
P_D(%)	4.51	4.85	5.76	

← Predictions!

- Epelbaum et al. in 2004 did again the fit with only 26 parameters, performing a cutoff study using a different regularization scheme obtaining a similar $\chi^2 \sim 1$.

CHIRAL NN POTENTIAL

Chiral N^3LO potential results to be as accurate as Argonne v_{18} potential in the description of experimental data, moreover

Argonne v_{18}	⟺	**Chiral N^3LO**
40 fit parameters		**26-29 fit parameters**

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Argonne v_{18} **40 fit parameters**	⇔	**Chiral N^3LO** **26-29 fit parameters**

Unfortunately no local version of Chiral N^3LO exists. **We can use this potential neither in FHNC/SOC nor in AFDMC calculations.**

This is not a crucial problem since Argonne v_{18} and v_8' describe amazingly well NN scattering data and deuteron properties.

If three-body local chiral potential exists we can use this potential combined with Argonne NN potential.

⇓

MIXED APPROACH

NNN CHIRAL POTENTIAL IN CHIRAL Δ LESS THEORY

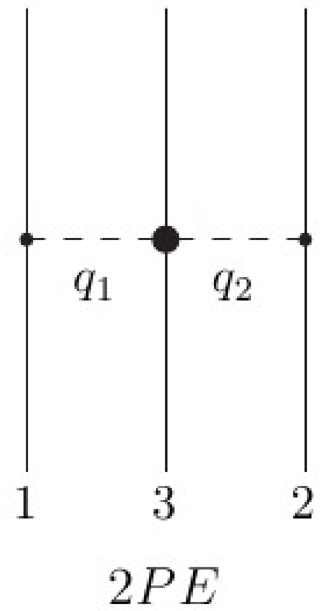
In a theory without explicit Δ degrees of freedom, the first contribution to the **chiral 3NF appears at N^{2}LO in the Weinberg counting scheme.**

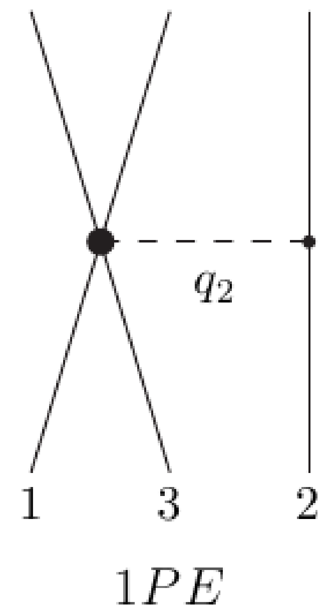
The contributions to this potential comes from three different physical processes

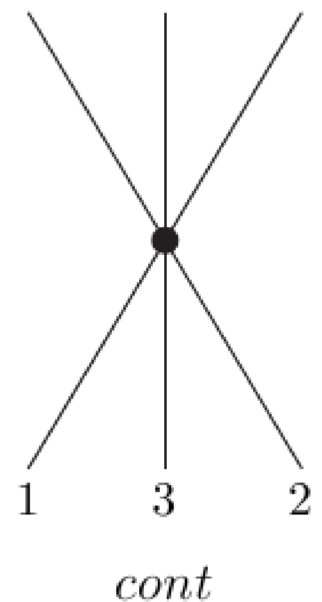
Two-pion exchange (**TPE**)

One-pion exchange (**OPE**)

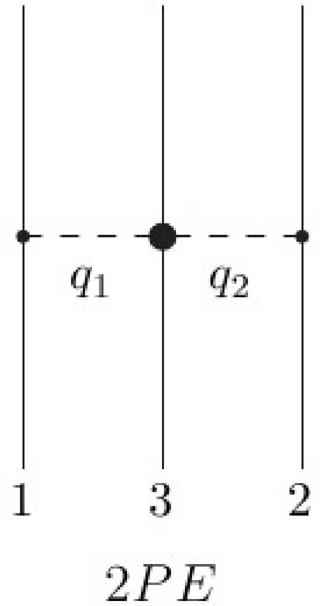
Contact interaction (**cont**)







NNN CHIRAL POTENTIAL: TPE TERM



$$\tilde{V}^{TPE}(3:12) = V_0 \frac{(\boldsymbol{\sigma}_1 \cdot \mathbf{q}_1)}{(q_1^2 + m_\pi^2)} \frac{(\boldsymbol{\sigma}_2 \cdot \mathbf{q}_2)}{(q_2^2 + m_\pi^2)} \times \left[\tau_{12}(-a + b\mathbf{q}_1 \cdot \mathbf{q}_2) - d\boldsymbol{\tau}_3 \cdot (\boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)\boldsymbol{\sigma}_3 \cdot (\mathbf{q}_1 \times \mathbf{q}_2) \right]$$

V_a **V_b** **V_d**

We are interested in the **local expression in coordinate space**

$$V^{TPE}(3:12) = \int \frac{d^3q_1}{(2\pi)^3} \frac{d^3q_2}{(2\pi)^3} F_\Lambda(q_1^2) F_\Lambda(q_2^2) e^{i\mathbf{q}_1 \cdot \vec{r}_{13}} e^{i\mathbf{q}_2 \cdot \vec{r}_{23}} \tilde{V}^{TPE}(3:12)$$

Cutoff functions depending on transfered momenta

Chiral N2LOLocal potential in coordinate space is a sum of these terms

$$V_a(3:12) = aW_0\, \tau_{12}(\boldsymbol{\sigma}_1 \cdot \vec{r}_{13})(\boldsymbol{\sigma}_2 \cdot \vec{r}_{23}) y(r_{13}) y(r_{23})$$

$$\begin{aligned} V_b(3:12) = bW_0\, \tau_{12}[&\sigma_{12} y(r_{13}) y(r_{23}) + (\sigma_1 \cdot \vec{r}_{23})(\sigma_2 \cdot \vec{r}_{23}) t(r_{23}) y(r_{13}) \\ &+ (\sigma_1 \cdot \vec{r}_{13})(\sigma_2 \cdot \vec{r}_{13}) t(r_{13}) y(r_{23}) + (\vec{r}_{13} \cdot \vec{r}_{23})(\sigma_1 \cdot \vec{r}_{13})(\sigma_2 \cdot \vec{r}_{23}) t(r_{13}) t(r_{23}) \end{aligned}$$

$$\begin{aligned} V_d(3:12) = dW_0\, (\boldsymbol{\tau}_3 \cdot \boldsymbol{\tau}_1 \times \boldsymbol{\tau}_2)[&(\boldsymbol{\sigma}_3 \cdot \boldsymbol{\sigma}_2 \times \boldsymbol{\sigma}_1) y(r_{13}) y(r_{23}) + (\boldsymbol{\sigma}_3 \cdot \vec{r}_{23} \times \boldsymbol{\sigma}_1)(\boldsymbol{\sigma}_2 \cdot \vec{r}_{23}) t(r_{23}) y(r_{13}) \\ &+ (\boldsymbol{\sigma}_2 \cdot \vec{r}_{13} \times \boldsymbol{\sigma}_3)(\boldsymbol{\sigma}_1 \cdot \vec{r}_{13}) t(r_{13}) y(r_{23}) + (\boldsymbol{\sigma}_3 \cdot \vec{r}_{23} \times \vec{r}_{13})(\sigma_1 \cdot \vec{r}_{13})(\sigma_2 \cdot \vec{r}_{23}) t(r_{13}) t(r_{23})] \end{aligned}$$

Where

$$W_0 = \frac{m_\pi^6}{(4\pi)^2} V_0 \qquad z_0(r) = \frac{2}{\pi m_\pi^3} \int dq q^2 \frac{F_\Lambda(q^2)}{(q^2 + m_\pi^2)} j_0(qr) \qquad y(r) = \frac{z_0'(r)}{r} \qquad t(r) = \frac{y'(r)}{r}$$

TPE CHIRAL TERM, FM & TM

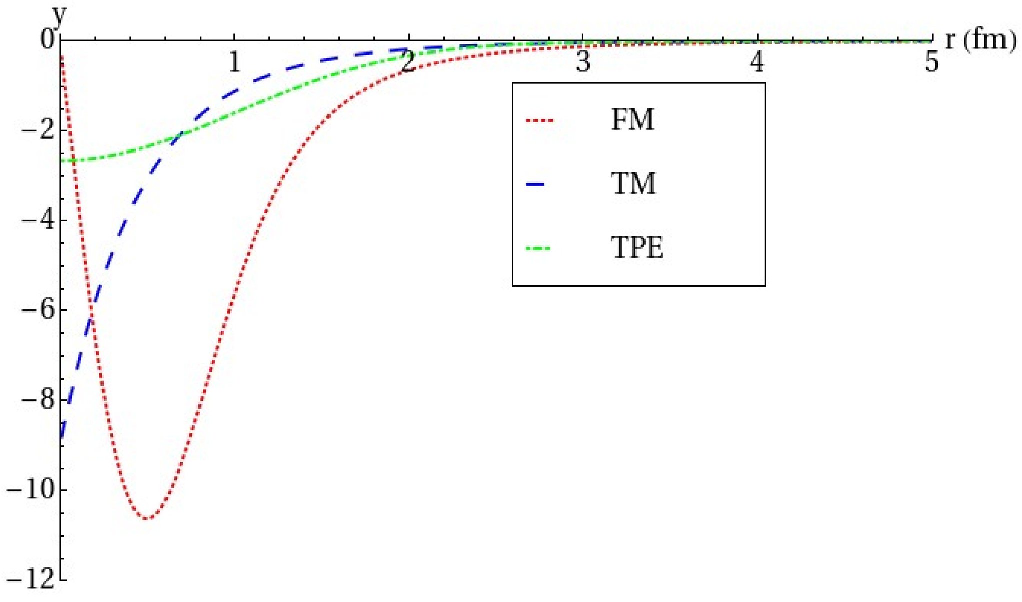
- It is easy to show that V_b and V_d correspond to the anticommutator and to the commutator term, respectively, of FM potential

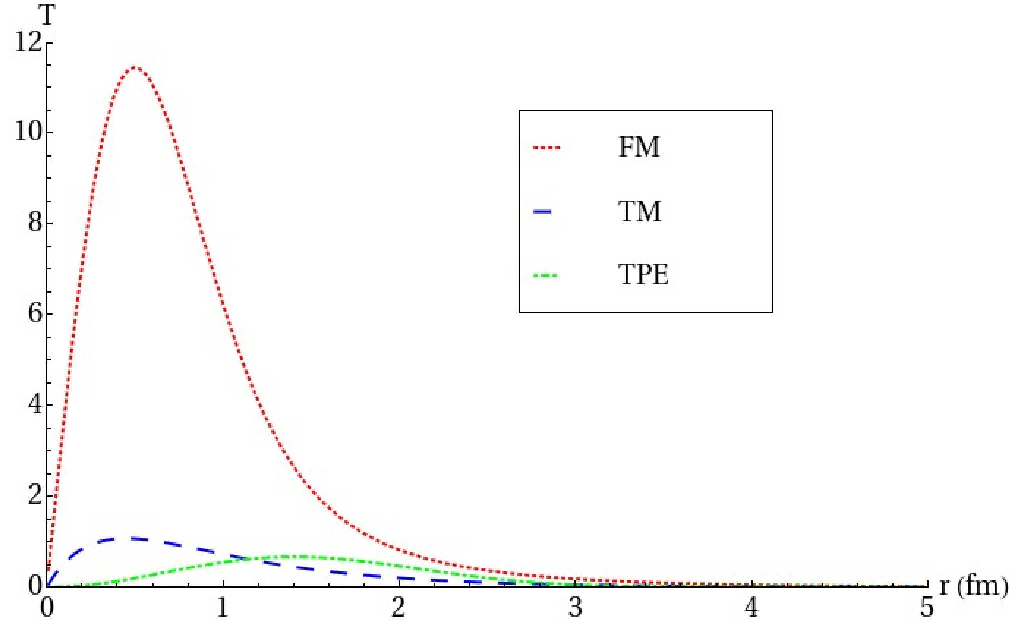
$$\begin{cases} V_b(3:12) = \dfrac{bW_0}{4}\{\tau_{13},\tau_{23}\}\{\sigma_{13}Y_{13}+S_{13}T_{13},\sigma_{23}Y_{23}+S_{23}T_{13}\} \\ V_d(3:12) = \dfrac{dW_0}{4}[\tau_{13},\tau_{23}][\sigma_{13}Y_{13}+S_{13}T_{13},\sigma_{23}Y_{23}+S_{23}T_{13}] \end{cases}$$

$$\begin{cases} Y(r) & = y(r)+\frac{r^2}{3}t(r) \\ T(r) & = \frac{r^2}{3}t(r) \end{cases}$$

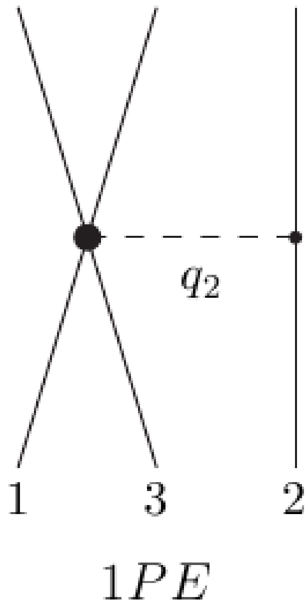
- V_a term is not present in UIX, whereas the sum of V_a, V_b, and V_d is precisely the so called Tucson Melbourne (TM) potential.

Despite the physical mechanism is different, TPE chiral term, FM and TM have the same expression. The only differences are in the radial functions and in the constants.





NNN CHIRAL POTENTIAL: OPE TERM



This term appears only in the chiral potential

$$V^{OPE}(3:12) = -\,c_D V_0^D \frac{(\boldsymbol{\sigma}_2\cdot\mathbf{q}_2)}{(q_2^2+m_\pi^2)}\Big[\alpha_1(\boldsymbol{\sigma}_1\cdot\mathbf{q}_2)\tau_{12} + \alpha_2(\boldsymbol{\sigma}_1\cdot\mathbf{q}_2)\tau_{13}$$

$$+\,\alpha_3\mathbf{q}_2(\boldsymbol{\sigma}_1\times\boldsymbol{\sigma}_3)\vec{\tau}_2\cdot(\vec{\tau}_1\times\vec{\tau}_3) + 1\leftrightarrow 2\Big]$$

The force is symmetric with respect to an interchange of particles *1* and *2*

$$V^{OPE}(3:12)\mathcal{A}_{12}|\Psi\rangle = \mathcal{A}_{12}V^{OPE}(3:12)|\Psi\rangle$$

$$\mathcal{A}_{12} = 1 - \frac{(1+\sigma_{12})}{2}\frac{(1+\tau_{12})}{2}$$

Once contracted with A_{12}, all the differen structures gives the same contribution.

$$V^{OPE}(3:12) = -c_D V_0^D \frac{(\boldsymbol{\sigma}_2\cdot\mathbf{q}_2)}{(q_2^2+m_\pi^2)}\Big[\alpha_1(\boldsymbol{\sigma}_1\cdot\mathbf{q}_2)\tau_{12} + 1\leftrightarrow 2\Big]$$

Epelbaum et al. (2002)

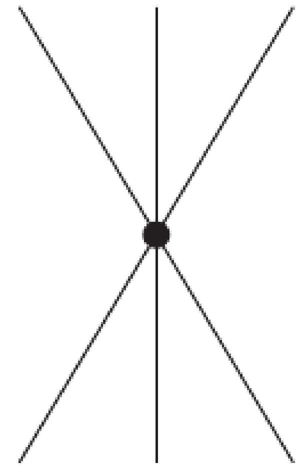
The local expression reads

$$V_D(3:12) = c_D W_0^D \tau_{12}[\sigma_{12}y(r_{23})z_0(r_{13}) + (\boldsymbol{\sigma}_1\cdot\vec{r}_{23})(\boldsymbol{\sigma}_2\cdot\vec{r}_{23})t(r_{23})z_0(r_{13})$$

$$+\,\sigma_{12}y(r_{13})z_0(r_{23}) + (\boldsymbol{\sigma}_2\cdot\vec{r}_{13})(\boldsymbol{\sigma}_1\cdot\vec{r}_{13})t(r_{13})z_0(r_{23})]$$

Because of the regulator there are no more contact terms $z_0(r)\neq\delta(r)$, and the equivalence of the different contact terms is spoiled!

NNN CHIRAL POTENTIAL: cont TERM



This term also appears only in the chiral potential

$$V^{cont}(3:12) = c_E(\beta_1 + \beta_2\sigma_{12} + \beta_3\tau_{12} + \beta_4\sigma_{12}\tau_{12} + \beta_5\sigma_{12}\tau_{23} + \beta_6(\vec{\sigma}_1 \times \vec{\sigma}_2)\cdot\vec{\sigma}_3 + (\vec{\tau}_1 \times \vec{\tau}_2)\cdot\vec{\tau}_3 + 1 \leftrightarrow 2)$$

As before, it is possible to show that, once multiplied by the antisimmetrization operator, all the terms give the same contribution. For instance

$$(\tau_{12} + \tau_{13} + \tau_{23})\mathcal{A}_{123} = -3\mathcal{A}_{123}$$

Without any loss of generality, it is possible to choice one of the independent term

$$V^{cont}(3:12) = c_E W_0^E \tau_{12}$$

The local expression reads

$$V_E(3:12) = W_0^E \tau_{12} z_0(r_{13}) z_0(r_{23})$$

Aside from the isospin factor this term resembles the UIX repulsive scalar term.

Once again, because of the regulator this is no more a contact term !!!
In principle all the different terms have to be considered.

NNN POTENTIAL PARAMETERS

Very recently Kviesky et al. performed a comparative study of UIX, TM and chiral NNLOL three nucleon interactions combined with Argonne v_{18} NN potential.

They have found the best-fit values for the three-body potentials to reproduce simultaneously the **triton binding energy** and the **doublet n-d scattering length**.

UIX: $V_b+V_d+V_E$

$A_{2\pi}^{PW}$ (MeV)	$D_{2\pi}^{PW}$	A_R (MeV)	T (MeV)	$V(2N)$ (MeV)	$V_A(3N)$ (MeV)	$V_R(3N)$ (MeV)	$B(^4He)$ (MeV)	$^2a_{nd}$ (fm)
−0.0293	0.25	0.0048	51.259	−58.606	−1.126	1.000	28.48	0.578
−0.0200	1.625	0.0176	47.472	−57.976	−0.923	2.950	28.33	0.644
−0.0250	1.25	0.0182	47.628	−57.967	−1.162	3.024	28.34	0.644
−0.0293	1.00	0.0181	47.876	−58.000	−1.369	3.015	28.33	0.643
−0.0350	0.8125	0.0191	47.998	−57.975	−1.649	3.147	28.33	0.645
−0.0400	0.6875	0.0198	48.133	−57.964	−1.897	3.249	28.38	0.645
−0.0450	0.5625	0.0198	48.414	−57.995	−2.148	3.248	28.38	0.643
−0.0500	0.50	0.0210	48.471	−57.952	−2.401	3.401	28.44	0.645
Exp.							28.30	$0.645 \pm 0.003 \pm 0.007$

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TM':$V_a + V_b + V_d + V_E$

$b\ (m_\pi^{-3})$	$d\ (m_\pi^{-3})$	c_E	$\Lambda\ (m_\pi)$	T (MeV)	$V(2N)$ (MeV)	$V_A(3N)$ (MeV)	$V_R(3N)$ (MeV)	$B(^4\mathrm{He})$ (MeV)	$^2a_{nd}$ (fm)
−2.580	−0.753	0.0	4.8	50.708	−58.144	−1.039	0.0	28.52	0.596
−8.256	−4.690	1.0	4.0	50.317	−57.366	−2.206	0.781	28.30	0.644
−3.870	−3.375	1.6	4.8	50.699	−57.641	−2.748	1.215	28.38	0.644
−2.064	−2.279	2.0	5.6	50.998	−57.940	−2.814	1.291	28.44	0.640
Exp.								28.30	$0.645 \pm 0.003 \pm 0.007$

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They have found the best-fit values for the three-body potentials to reproduce simultaneously the **triton binding energy** and the **doublet n-d scattering length.**

$N^2LO: V_a + V_b + V_d + V_E$

c_3 (c_3^0)	c_4 (c_4^0)	c_D	c_E	T (MeV)	$V(2N)$ (MeV)	$V_A(3N)$ (MeV)	$V_R(3N)$ (MeV)	$B(^4He)$ (MeV)	$^2a_{nd}$ (fm)
1.4	0.3636	−0.5	0.1	49.834	−57.278	−1.029	0.0	28.31	0.641
1.4	0.3786	−1	0.0	49.950	−57.401	−1.022	0.0	28.30	0.636
1.5	0.3735	−1	−0.03	49.839	−57.274	−1.076	0.036	28.29	0.644
1.7	0.9000	−2	−0.50	50.166	−57.181	−2.119	0.657	28.32	0.645
Exp.								28.30	$0.645 \pm 0.003 \pm 0.007$

NNN POTENTIALS IN NUCLEAR MATTER

Consider two different contribution belonging to V_E of the chiral potential that give the same contribution in the limit of infinite cutoff

$$V_E^{\tau_{12}}(3:12) = V_0^E \tau_{12} Z_0(r_{13}) Z_0(r_{23})$$
$$V_E^I(3:12) = V_0^E Z_0(r_{13}) Z_0(r_{23})\,.$$

In order $V_E^{\tau 12,I}$ to give a positive contribution to the binding energy of light nuclei ⟹ $\begin{cases} c_E^I > 0 \\ c_E^{\tau_{12}} < 0 \end{cases}$

In PNM **the expectation value of a three-body contact term is zero**. Due to cutoff effect this is not true anymore. Moreover

$$\langle \tau_{12} \rangle_{PNM} = 1 \longrightarrow \begin{cases} \langle V_E^I \rangle_{PNM} > 0 \\ \langle V_E^{\tau_{12}} \rangle_{PNM} < 0 \end{cases}$$

Inconsistency of the local formulation of N^2LO potential

We have computet the expectation value of V_E in Fermi gas of SNM and PNM

Λ (MeV)	$\langle V_E^{\tau_{12}} \rangle_{SNM}^{FG}/A$ (MeV)	$\langle V_E^I \rangle_{SNM}^{FG}/A$ (MeV)	$\langle V_E^{I,\tau_{12}} \rangle_{PNM}^{FG}/A$ (MeV)
300	-2.61	10.21	9.15
400	-3.61	8.15	5.95
500	-4.37	6.93	3.60
600	-4.87	6.30	2.15
700	-5.15	5.98	1.30
800	-5.30	5.81	0.81
teorico	-5.55	5.55	0

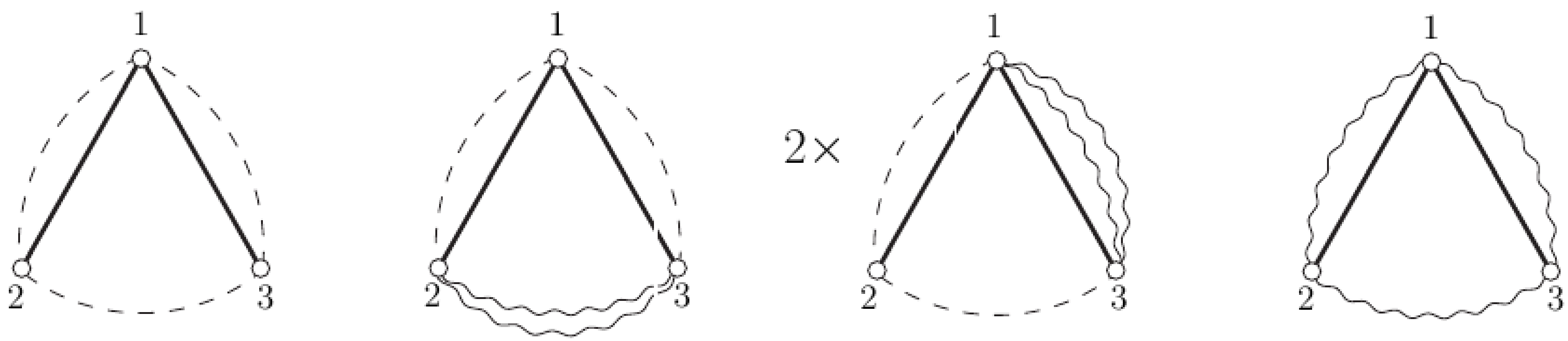
NNN POTENTIALS IN NUCLEAR MATTER: FHNC/SOC

We are implementing UIX, TM' and chiral NNLO potential in nuclear matter using both FHNC/SOC and AFDMC technique.

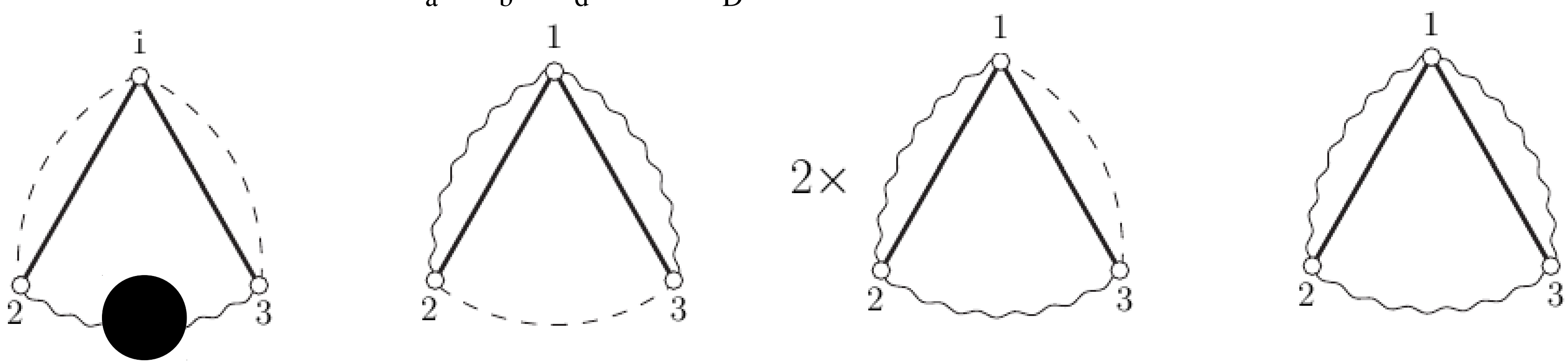
In **FHNC/SOC** (Omar lectures) the expectation value of the three body potential reads

$$\frac{\langle v_{123}\rangle}{A} = \frac{1}{3!}\rho^2 \sum_P \int dr_{12} dr_{13} v^P_{123}\, g^P_{123} \qquad g^P_{123} = \frac{A!}{(A-3)!3!} \frac{\int d\sigma \tau_{123} dx_{4\ldots A} \Phi^* F^\dagger O^P_{123} F \Phi}{\rho^3 \int dx_{1\ldots A} \Phi^* F^\dagger F \Phi}$$

For the central part V_E of UIX and TM' potential we calculated the following diagrams



For the operatorial parts V_a, V_b, V_d and V_D



NNN POTENTIALS IN NUCLEAR MATTER: FHNC/SOC

To find the minimum of the energy

$$E_V = E_V(d_c, d_t, \beta_p, \alpha_p)$$ → **SIMULATED ANNEALING METHOD**

The variational parameters are drawn from the Boltzmann distribution $\exp(-E_V/T)$

We used a Metropolis algorithm with acceptance probability

$$P_{s,s'} = \exp\left[-\frac{E(s') - E(s)}{T}\right] \qquad s = \{d_c, d_t, \beta_p, \alpha_p\} \quad s' = \{d'_c, d'_t, \beta'_p, \alpha'_p\}$$

As T is lowered, the parameters stay closer to the minimum of E_V.

Variational principle can be violated because elemenary diagrams are neglected and because of SOC approximation. To keep the violations under control we performed a constrained optimization by imposing:

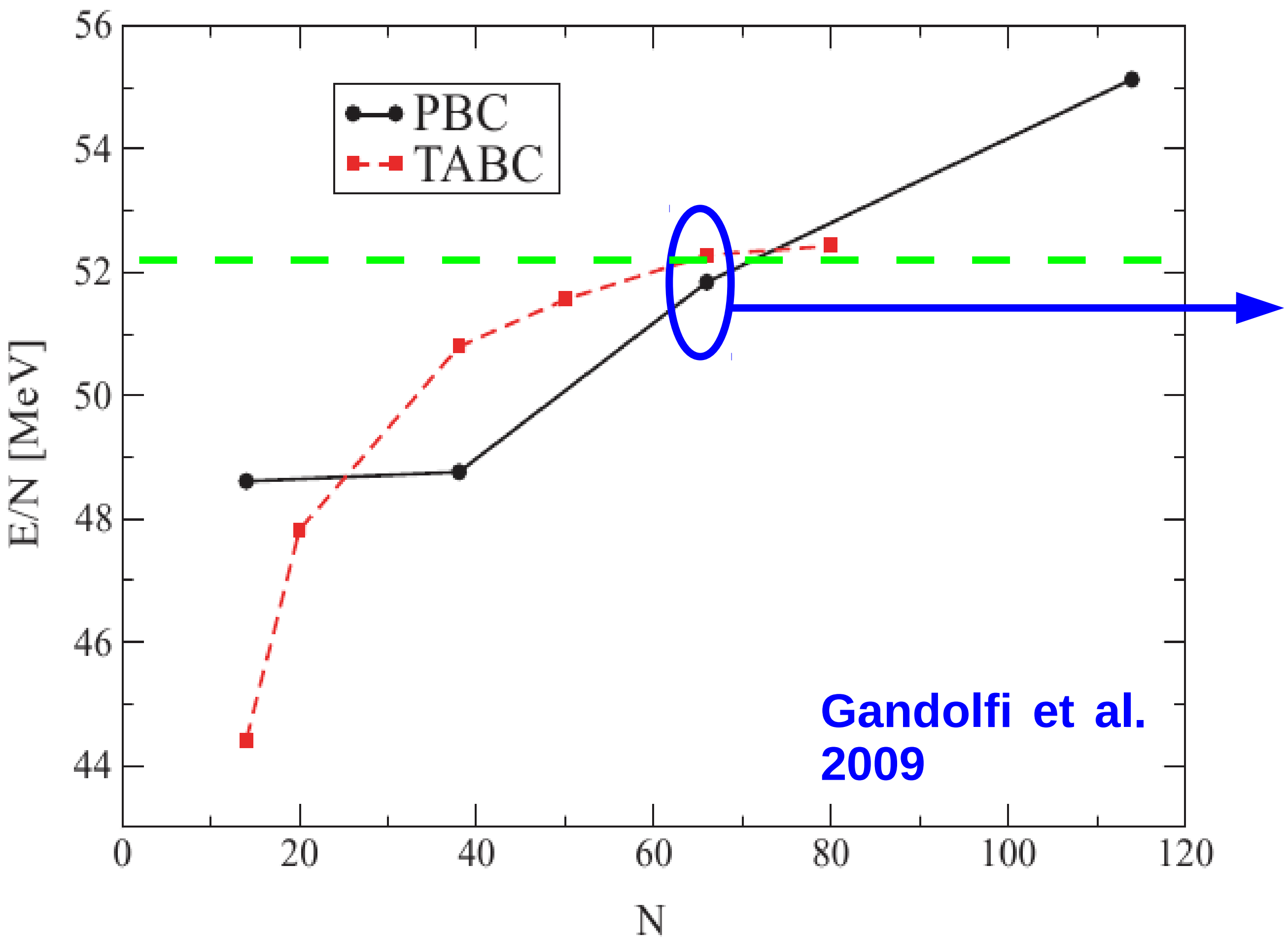
$$|E_{PB} - E_{JF}| < 10\% \, T_F \qquad \left|\rho \int d\vec{r}_{12}[g^c(r_{12}) - 1] - 1\right| < 0.03$$

Up to now the optimizations have been carried out for the following three body potentials, while for the two body interaction we stick on Argonne v_8'

- UIX
- TM1 TM2 TM3
- N^2LO 1 (for PNM only)

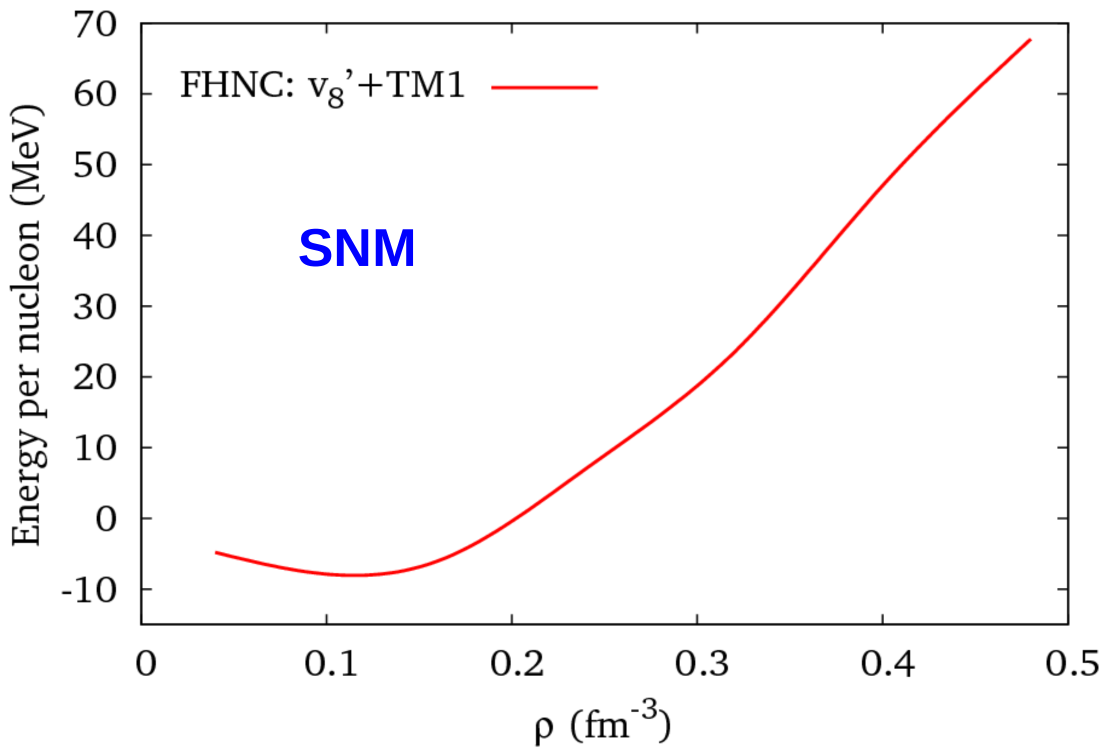
NNN POTENTIALS IN NUCLEAR MATTER: AFDMC

We carried out AFDMC simulations for PNM with **66 neutrons in periodic box system.**



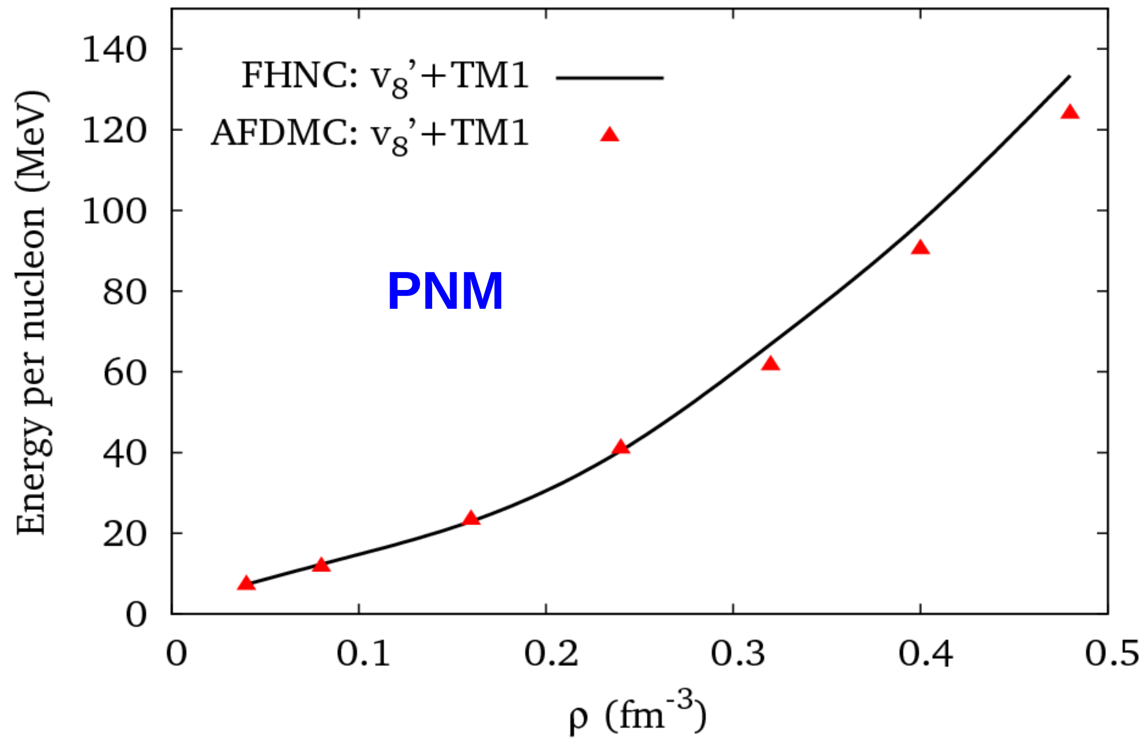
For 66 fermions difference around 2% of the asymptotic value of TABC

	$A = 14$	$A = 38$	$A = 66$	$A = 114$	∞
E/A(MeV)	56.51	53.50	55.43	56.58	55.71



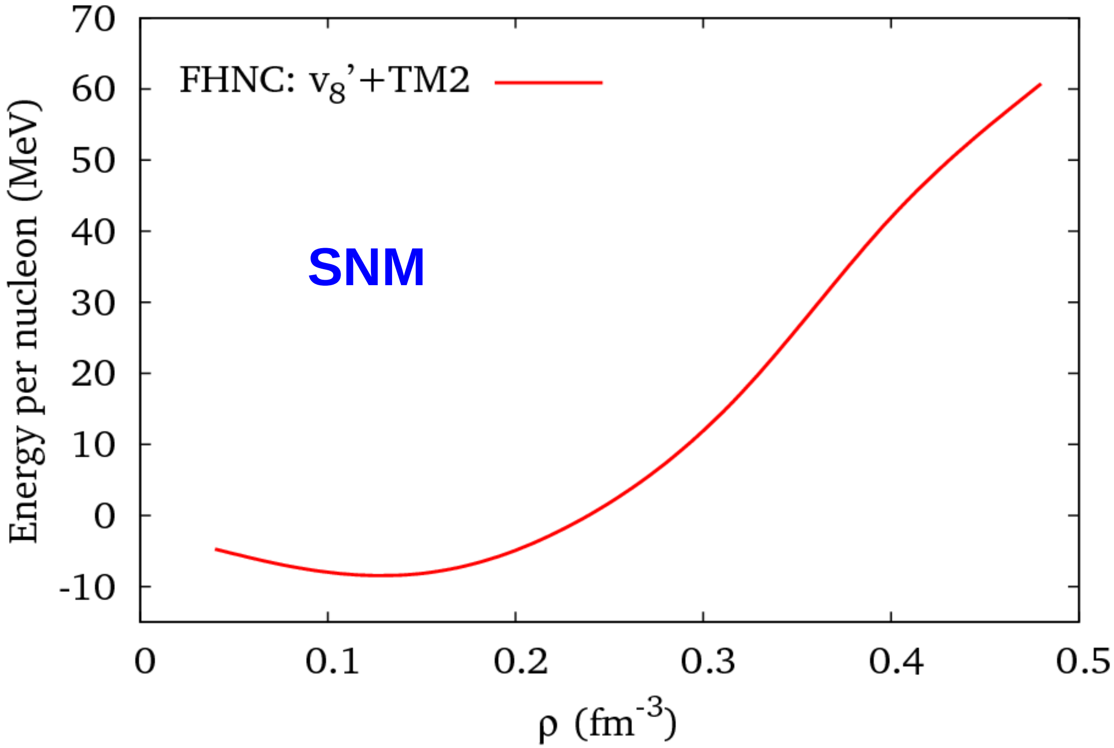
FHNC: v8'+TM1
SNM
Energy per nucleon (MeV)
ρ (fm-3)

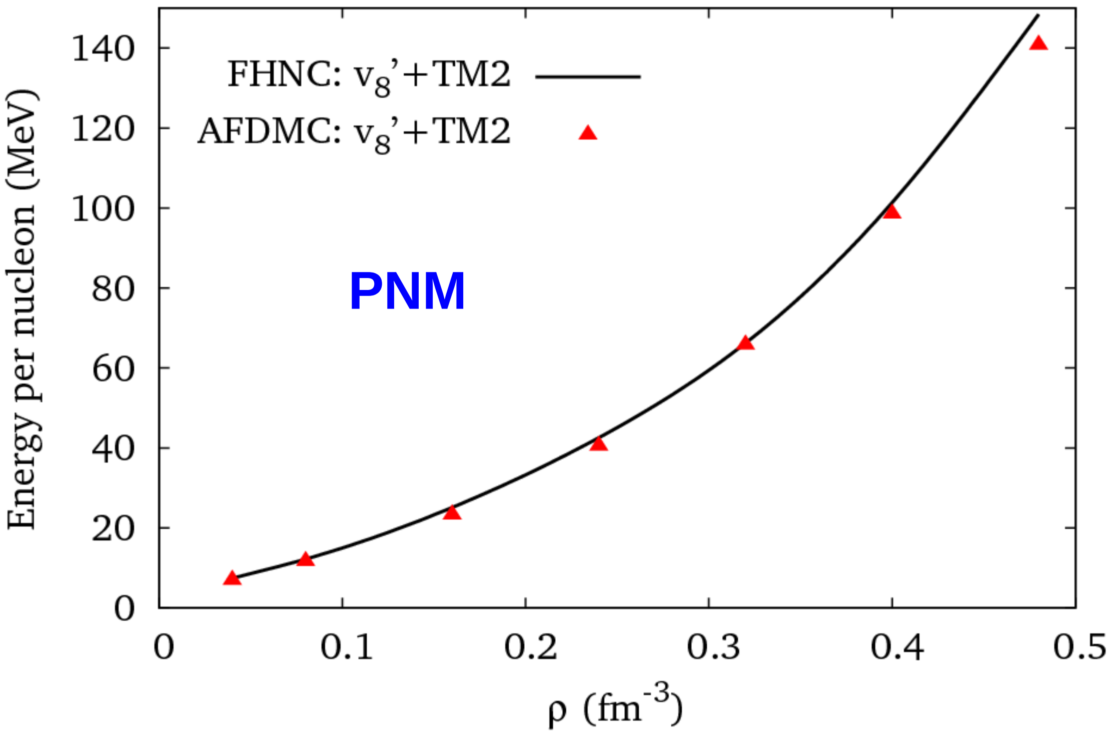
TM1 results



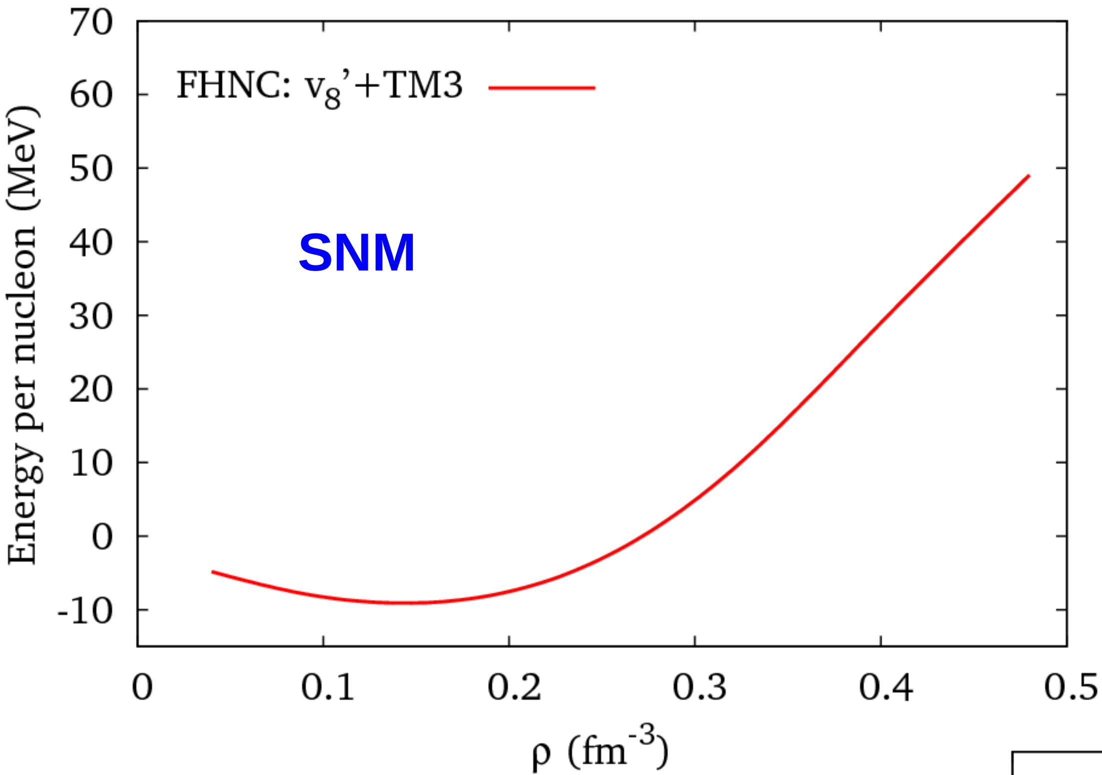
FHNC: v8'+TM1
AFDMC: v8'+TM1
PNM
Energy per nucleon (MeV)
ρ (fm-3)

TM2 results

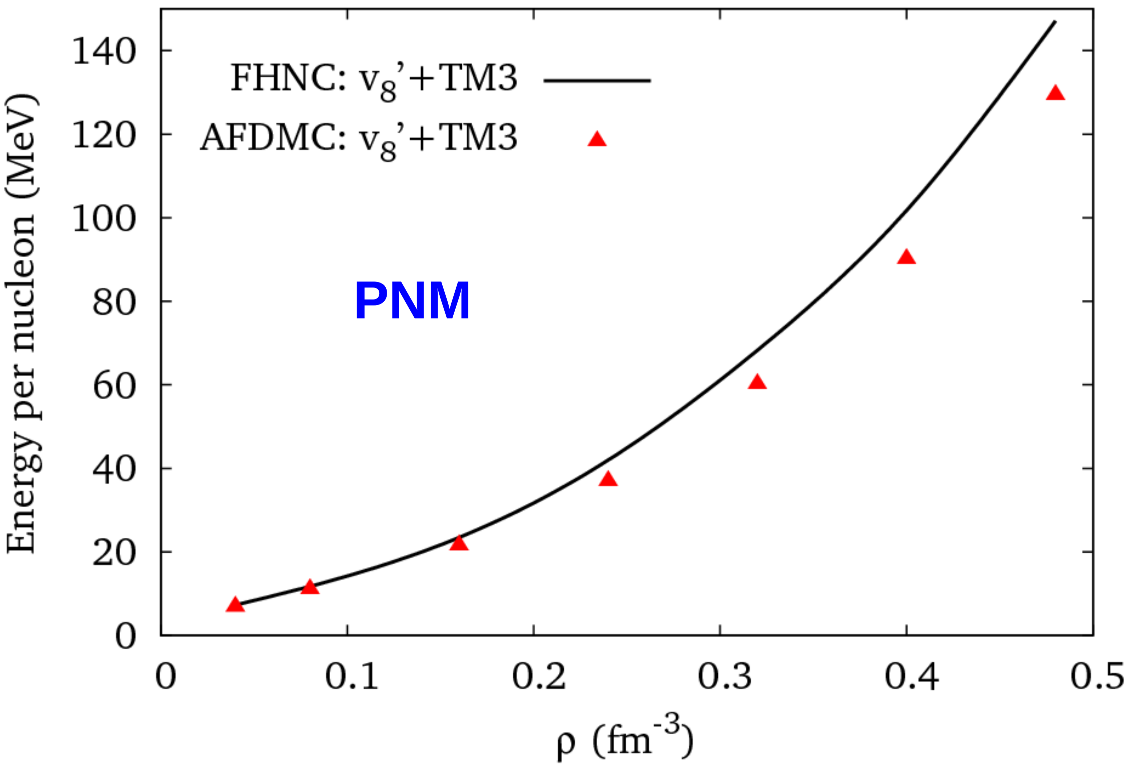

SNM
FHNC: v8'+TM2
Energy per nucleon (MeV)
ρ (fm-3)
70
60
50
40
30
20
10
0
-10
0
0.1
0.2
0.3
0.4
0.5


PNM
FHNC: v8'+TM2
AFDMC: v8'+TM2
Energy per nucleon (MeV)
ρ (fm-3)
140
120
100
80
60
40
20
0
0
0.1
0.2
0.3
0.4
0.5

TM3 results

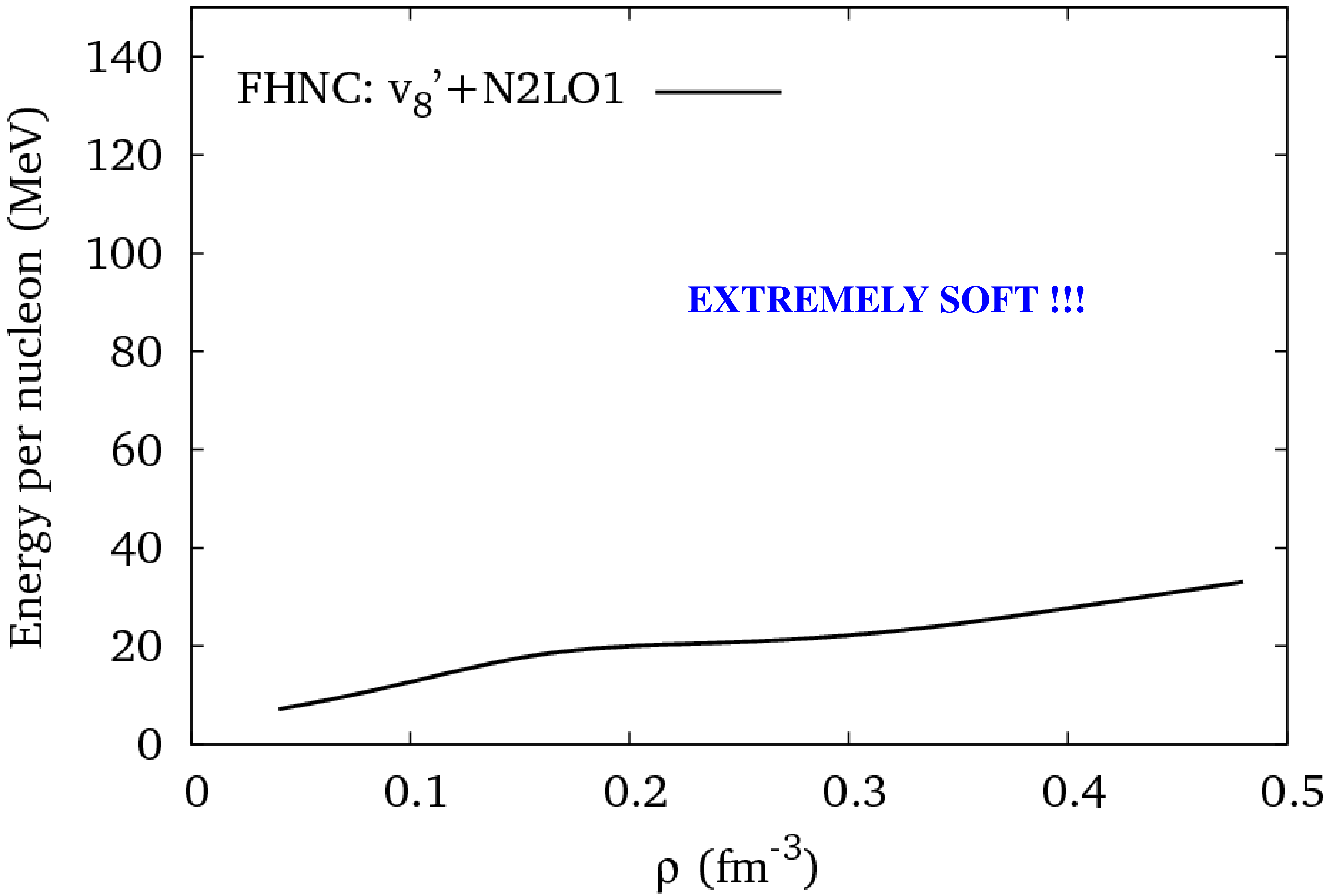


FHNC: v8'+TM3
SNM
Energy per nucleon (MeV)
ρ (fm-3)



FHNC: v8'+TM3
AFDMC: v8'+TM3
PNM
Energy per nucleon (MeV)
ρ (fm-3)

N^2LO results



CONCLUSIONS

- No one of the new potentials seems to reproduce the correct binding energy of SNM
- Chiral NNLO seems to provide a very soft PNM EoS. Probably due to the wrong treatment of V_E