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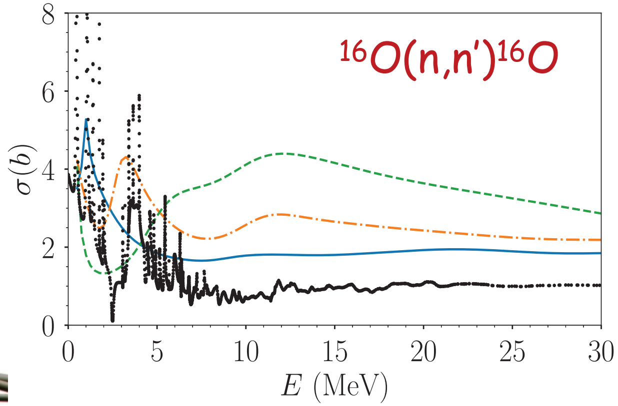
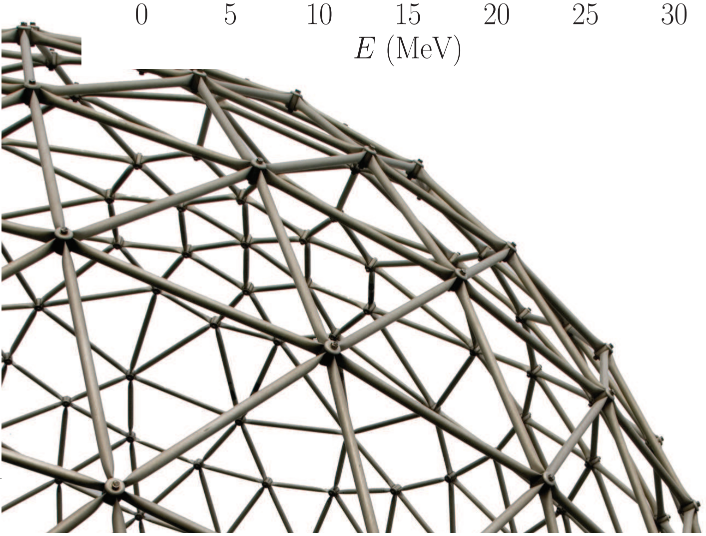
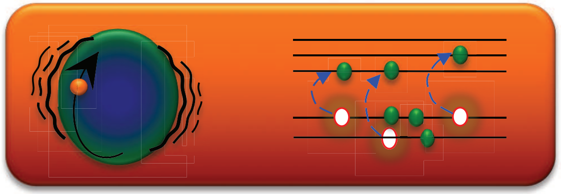
Recent ab initio studies of nuclei from self-consistent Green's functions theory

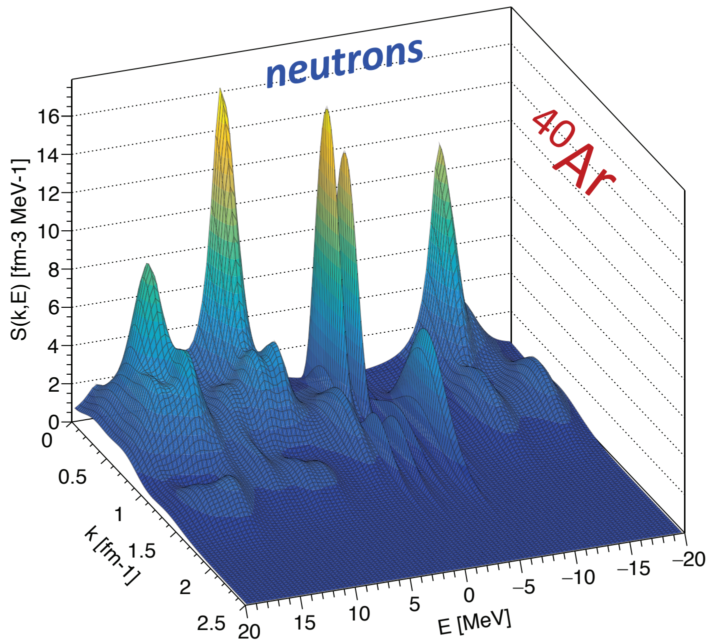
Carlo Barbieri — University of Surrey

11 December 2019

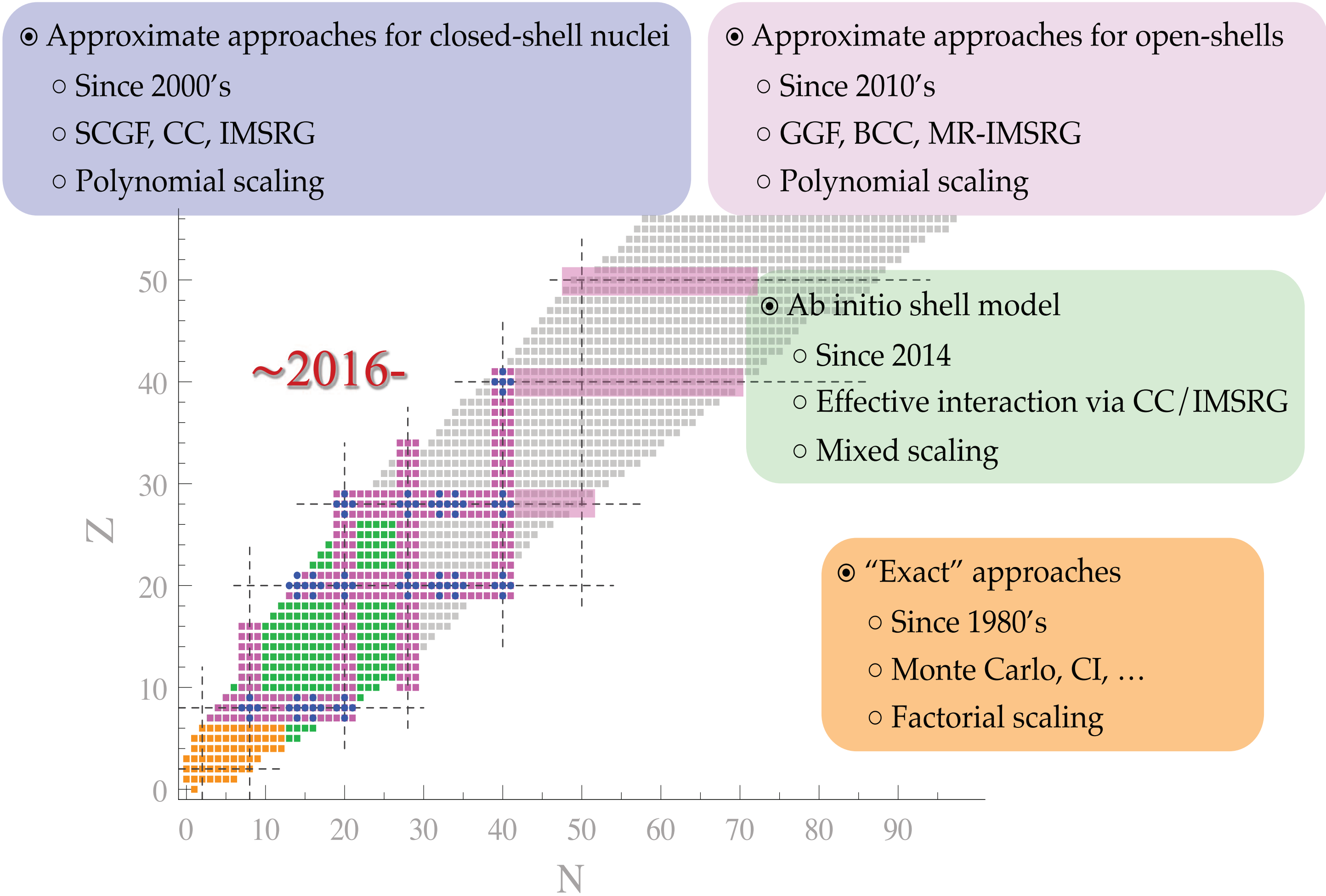








Reach of ab initio methods across the nuclear chart



Key developments for (nuclear) *SCGF*:

Dyson ADC(2), ADC(3)
Schirmer 1982

Dyson ADC(4), ADC(5)
Schirmer 1983 (formalism)

Particle-vibration coupling, FRPA(3)
CB 2000, 2007

Gorkov ADC(2): open shells!
Somà 2011, 2013

3-nucleon forces basic formalism
Carbone, Cipollone 2013

3NFs in Dyson ADC(3)
Raimondi 2018

Gorkov ADC(3) and higher orders (automatic)
Raimoindi, Arthuis 2019

Deformation – still needed…
???

Symmetry restoration – still needed…
???

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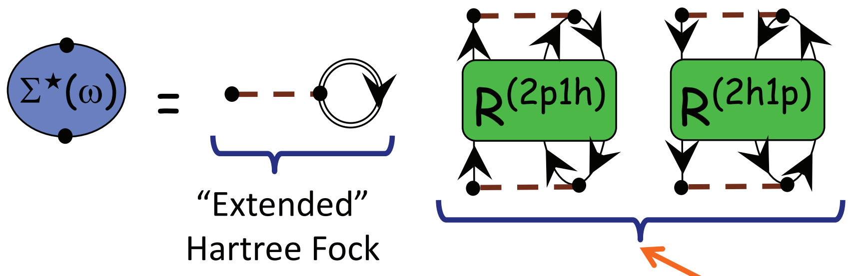
Slide, courtesy of V. Somà

The FRPA Method in Two Words

Particle vibration coupling is the main mechanism driving the redistribution and fragmentation of particle strength—expecially in the quasielastic regions around the Fermi surface…

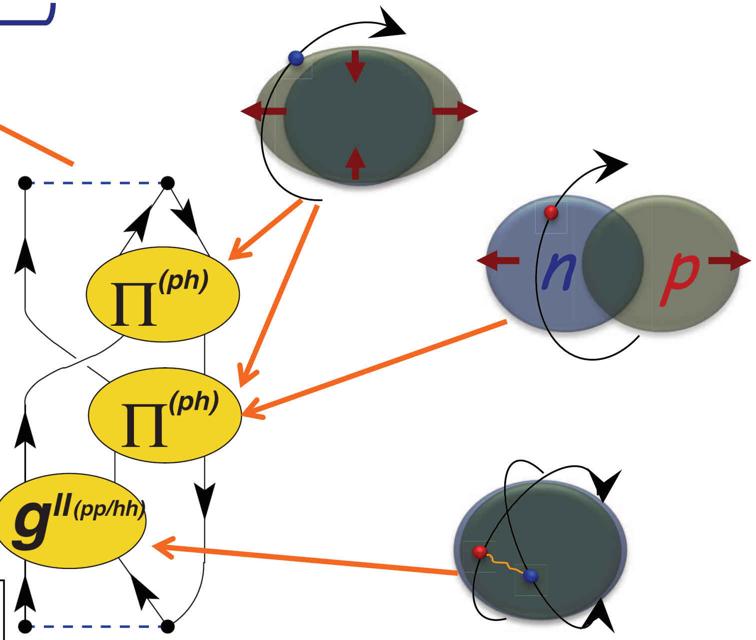
CB et al.,
Phys. Rev. C **63**, *034313 (2001)*
Phys. Rev. A **76**, *052503 (2007)*
Phys. Rev. C **79**, *064313 (2009)*

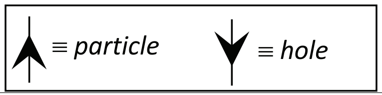


•A complete expansion requires *all types* of particle-vibration coupling

…these modes are all resummed exactly and to all orders in a *ab initio* many-body expansion.

•The Self-energy $\Sigma^\star(\omega)$ yields *both* single-particle states and scattering





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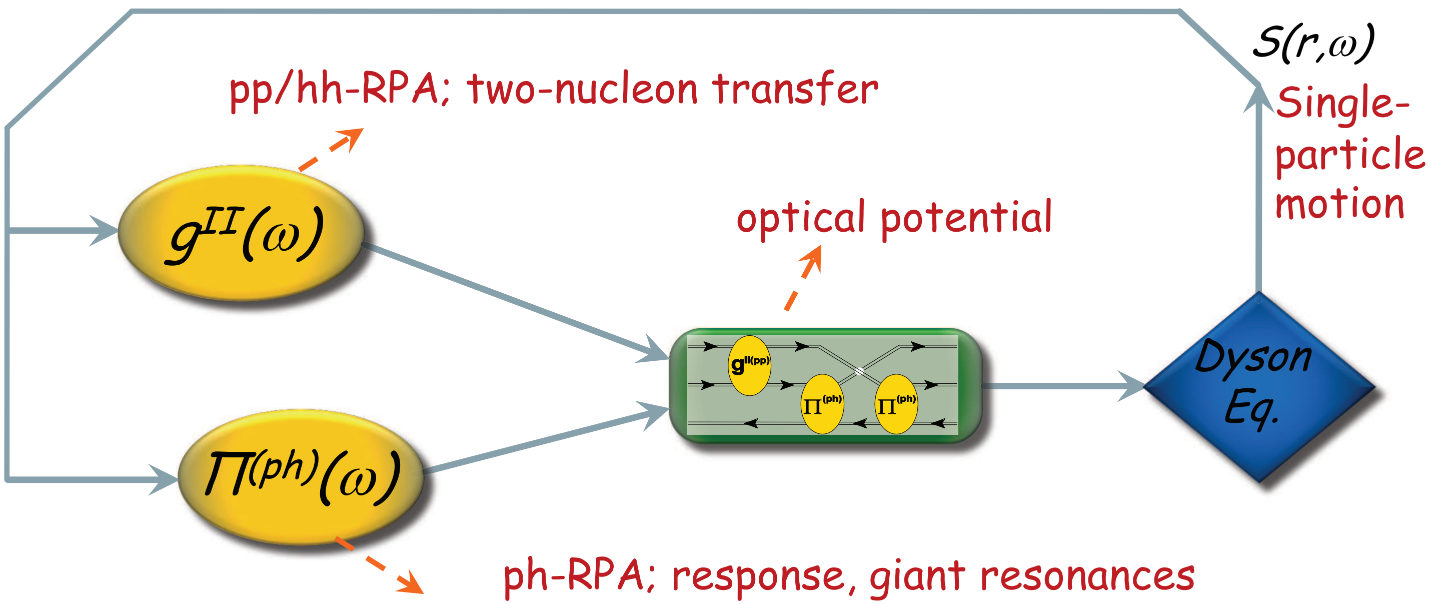
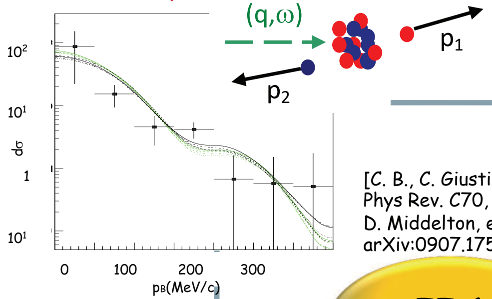
Self-Consistent Green's Function Approach



- Global picture of nuclear dynamics
- Reciprocal correlations among effective modes
- Guaranties *macroscopic conservation laws*

Self-Consistent Green's Function Approach

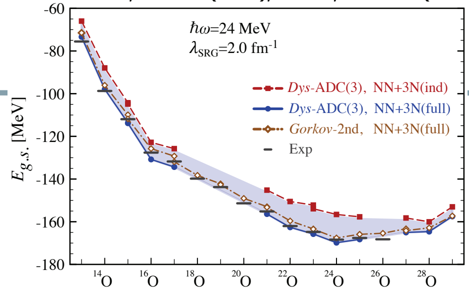
$^{16}O(e,e'pn)^{14}N$ @ MAINZ



[C. B., C. Giusti, et al.
Phys Rev. C70, 014606 (2004)
D. Middelton, et al.
arXiv:0907.1758; EPJA in print]

Binding energies

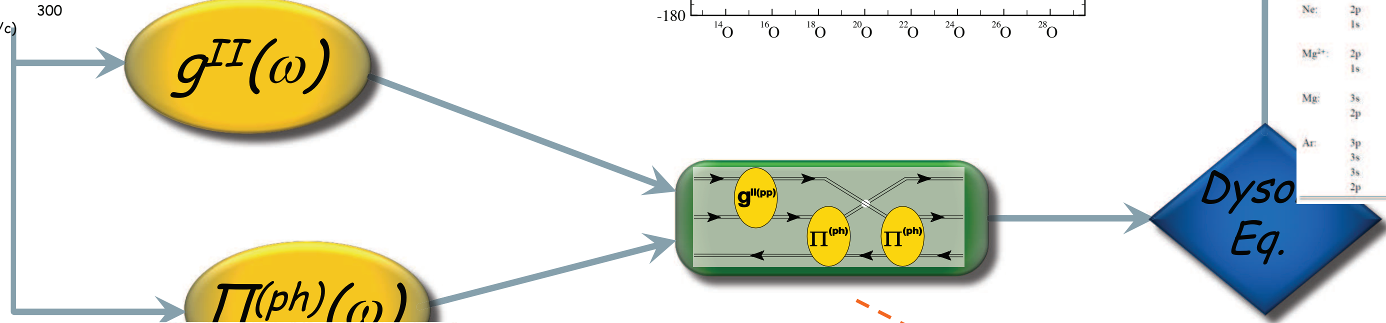
[PRL. 111, 062501 (2013),
PRC 92, 014306 (2015), PRC89, 061301R (2014)]



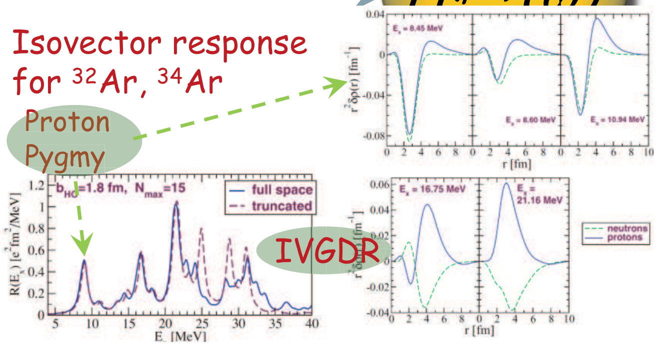
Ionization energies/ affinities, in atoms

[CB, D. Van Neck,
AIP Conf.Proc.1120,104 ('09) & in prep]

		Hartree-Fock	FRPAc	Experiment [16, 17]
He:	1s	0.918 (+14)	0.9008 (-2.9)	0.9037
Be^{2+}:	1s	5.6672 (+116)	5.6551 (-0.5)	5.6556
Be:	2s	0.3093 (-34)	0.3224 (-20.2)	0.3426
	1s	4.733 (+200)	4.5405 (+8)	4.533
Ne:	2p	0.852 (+57)	0.8037 (+11)	0.793
	1s	1.931 (+149)	1.7967 (+15)	1.782
Mg^{2+}:	2p	3.0068 (+56.9)	2.9537 (+3.8)	2.9499
	1s	4.4827	4.3589	
Mg:	3s	0.253 (-28)	0.280 (-1)	0.281
	2p	2.282 (+162)	2.137 (+17)	2.12
Ar:	3p	0.591 (+12)	0.579 (≈0)	0.579
	3s	1.277 (+202)	1.065 (-10)	1.075
	3s		1.544	
	2p	9.571 (+411)	9.219 (+59)	9.160

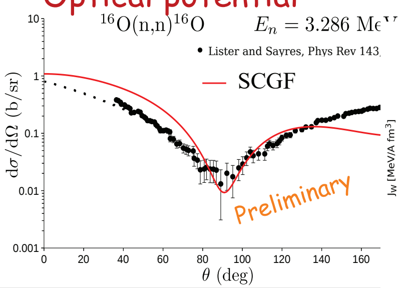


Isovector response for ^{32}Ar, ^{34}Ar

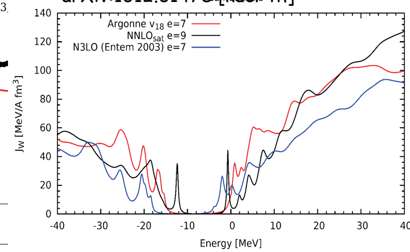


[C. B., K. Langanke, et al., Phys Rev. C77, 024304 (2008)]

Optical potential

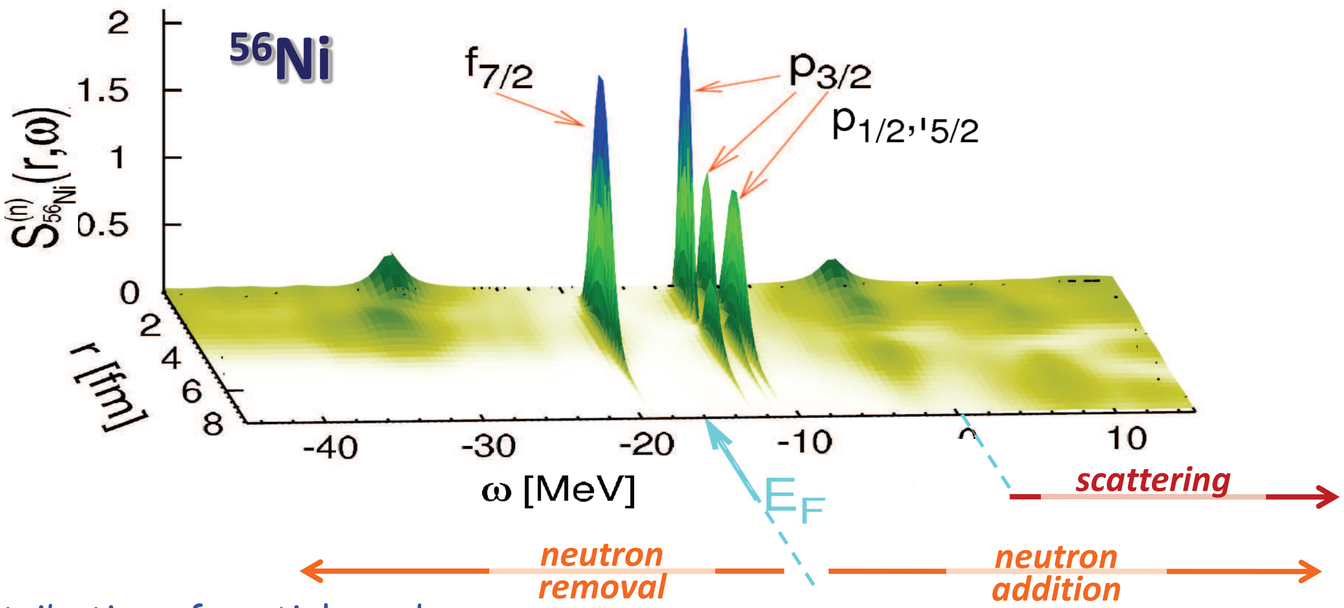


arXiv:1612.01478 [nucl-th]



One-nucleon spectral function

$$S^{p,h}(r,\omega) = \mp\frac{1}{\pi}\,\mathrm{Im}\,g(r=r';\omega)$$

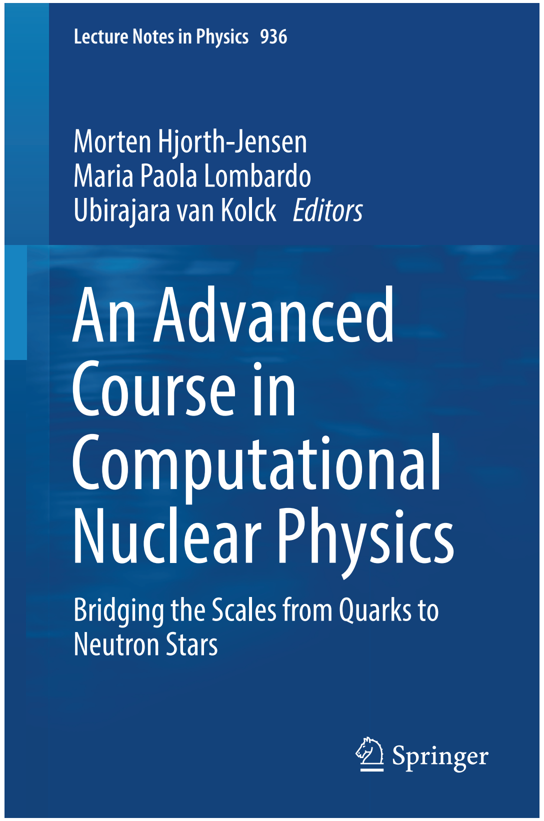


Distribution of particle and hole neutron states in ^{56}Ni

W. Dickhoff, CB, Prog. Part. Nucl. Phys. 53, 377 (2004)
CB, M.Hjorth-Jensen, Pys. Rev. C**79**, 064313 (2009)

Ab-initio Nuclear Computation & BcDor code

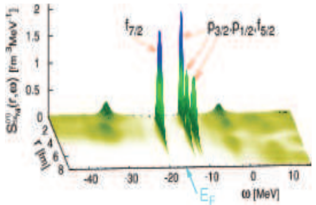
Self-consistent Green's function formalism
and methods for Nuclear Physics



CB and A. Carbone,
chapter 11 of
Lecture Notes in Physics 936 (2017)

http://personal.ph.surrey.ac.uk/~cb0023/bcdor/

Computational Many-Body Physics



Download

Documentation

Welcome

From here you can download a public version of my self-consistent Green's function (SCGF) code for nuclear physics. This is a code in J-coupled scheme that allows the calculation of the single particle propagators (a.k.a. one-body Green's functions) and other many-body properties of spherical nuclei.

This version allows to:

- Perform Hartree-Fock calculations.
- Calculate the the correlation energy at second order in perturbation theory (MBPT2).
- Solve the Dyson equation for propagators (self consistently) up to second order in the self-energy.
- Solve coupled cluster CCD (doubles only!) equations.

When using this code you are kindly invited to follow the creative commons license agreement, as detailed at the weblinks below. In particular, we kindly ask you to refer to the publications that led the development of this software.

Relevant references (which can also help in using this code) are:

Prog. Part. Nucl. Phys. 52, p. 377 (2004),
Phys. Rev. A76, 052503 (2007),
Phys. Rev. C79, 064313 (2009),
Phys. Rev. C89, 024323 (2014)

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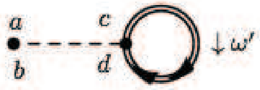
Open-shells: 1st & 2nd order Gorkov diagrams

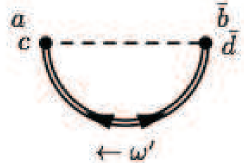
V. Somà, CB, T. Duguet, , Phys. Rev. C **89**, 024323 (2014)
V. Somà, CB, T. Duguet, Phys. Rev. C **87**, 011303R (2013)
V. Somà, T. Duguet, CB, Phys. Rev. C **84**, 064317 (2011)

- 1[st] order ⟶ energy-independent self-energy

$\Sigma^{11\,(1)}_{ab} =$

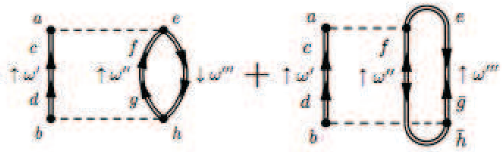


$\Sigma^{12\,(1)}_{ab} =$

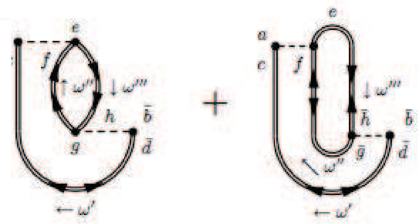


- 2[nd] order ⟶ energy-dependent self-energy

$\Sigma^{11\,(2)}_{ab}(\omega) =$



$\Sigma^{12\,(2)}_{ab}(\omega) =$



- Gorkov equations ⟶ eigenvalue problem

$$\sum_b \begin{pmatrix} t_{ab} - \mu_{ab} + \Sigma^{11}_{ab}(\omega) & \Sigma^{12}_{ab}(\omega) \\ \Sigma^{21}_{ab}(\omega) & -t_{ab} + \mu_{ab} + \Sigma^{22}_{ab}(\omega) \end{pmatrix}\Bigg|_{\omega_k} \begin{pmatrix} \mathcal{U}^k_b \\ \mathcal{V}^k_b \end{pmatrix} = \omega_k \begin{pmatrix} \mathcal{U}^k_a \\ \mathcal{V}^k_a \end{pmatrix}$$

$$\mathcal{U}^{k*}_a \equiv \langle \Psi_k | \bar{a}^\dagger_a | \Psi_0 \rangle$$
$$\mathcal{V}^{k*}_a \equiv \langle \Psi_k | a_a | \Psi_0 \rangle$$

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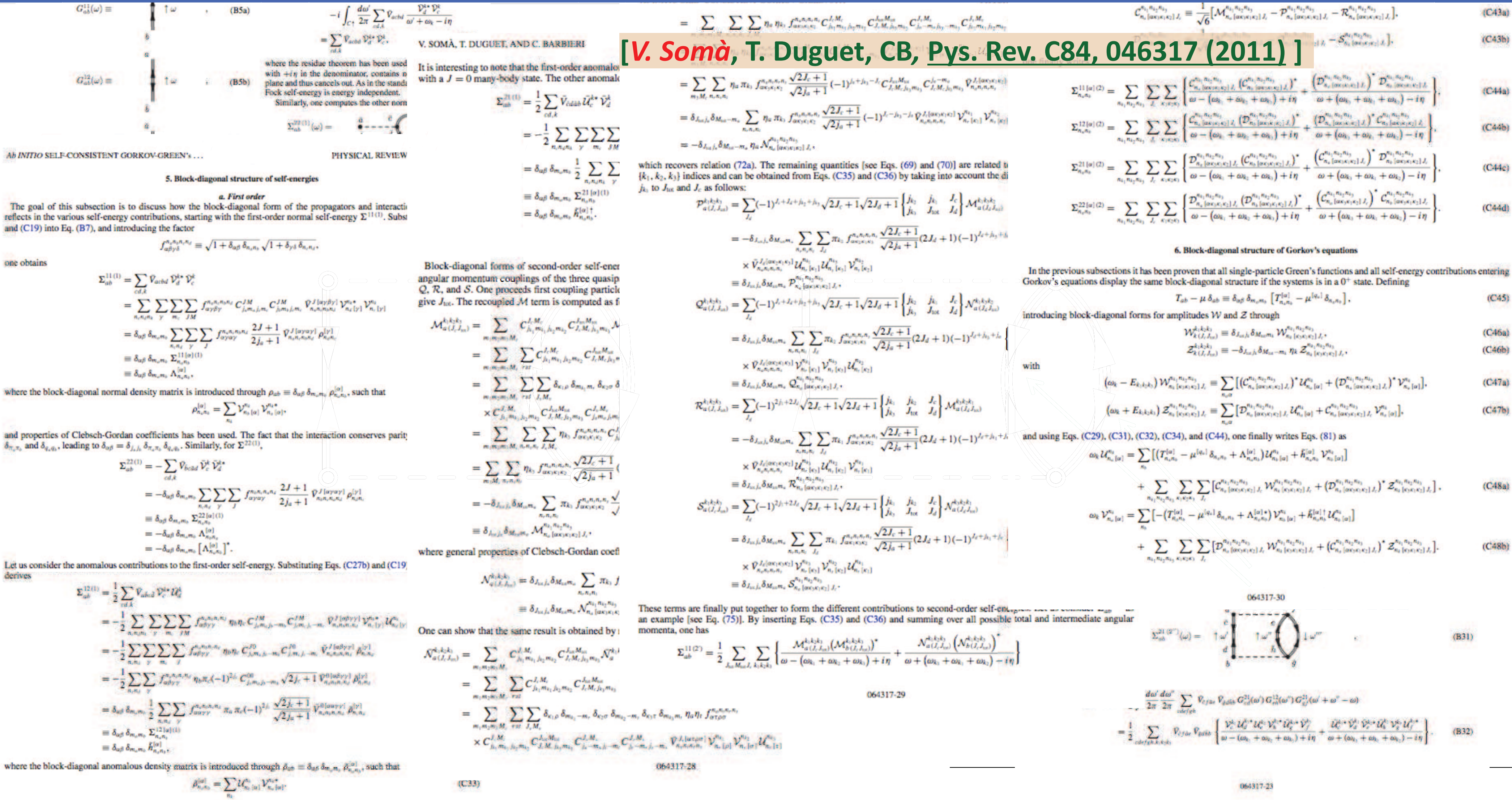
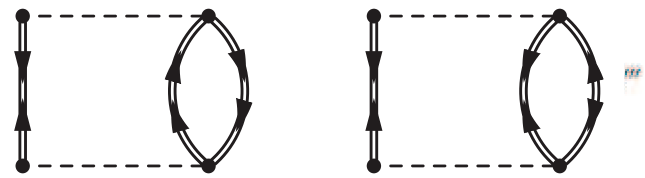
Gorkov espressions for 1st & 2nd order diagrams

[*V. Somà*, T. Duguet, CB, Pys. Rev. C84, 046317 (2011)]



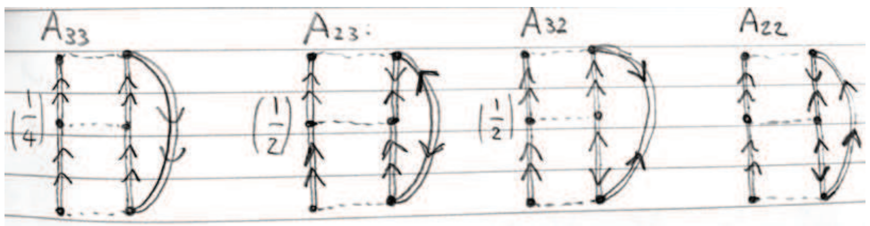
Reaching (Gorkov – 3NF – higher ordes...) is a mess

Gorkov at 2nd order and ONLY NN forces:

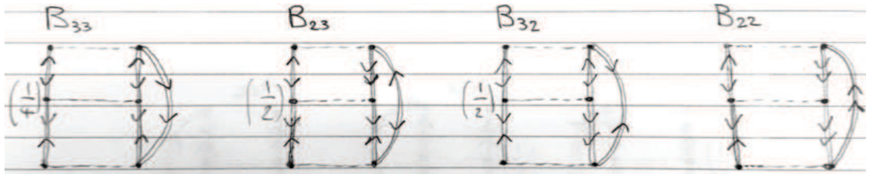
$\Sigma^{11\,(2)}_{ab}(\omega) =$ 

Gorkov at 3rd order and ONLY NN forces:

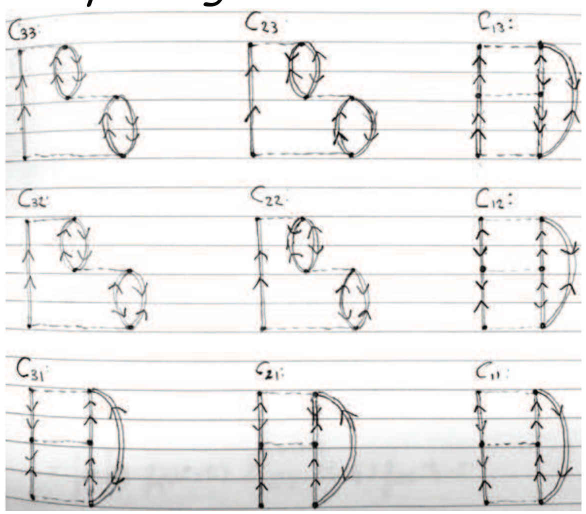
pp/hh-ladders:



hh-interactions (hh int. among pp ladders!!!)



ph-rings:



Automatic generation of diagram needed for 3NF and beyond...

→ F. Raimondi and P. Arthuis, in progress....

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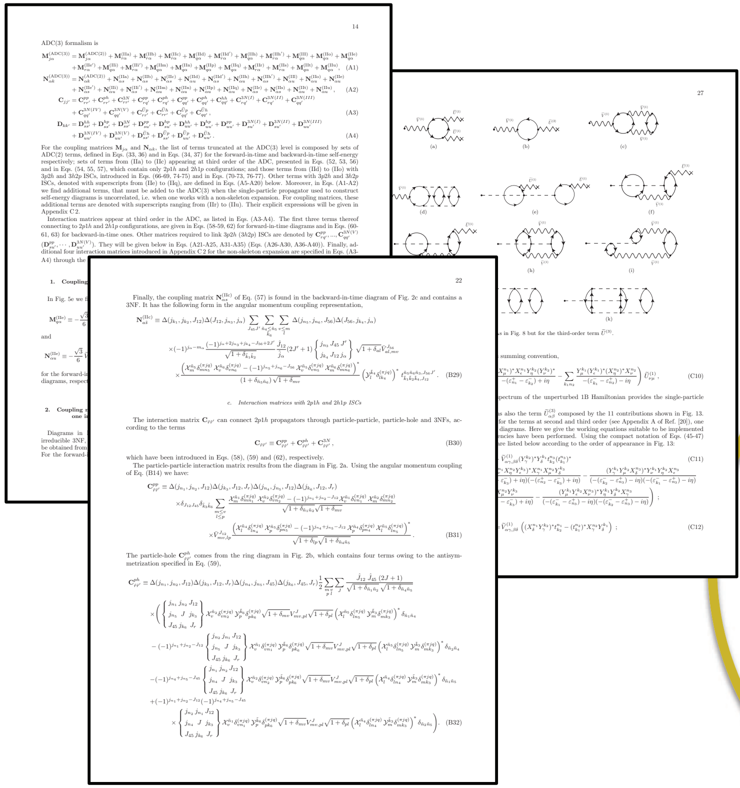
Inclusion of NNN forces

➔ 3p2h/3h2p terms relevant to next-generation high-precision methods.



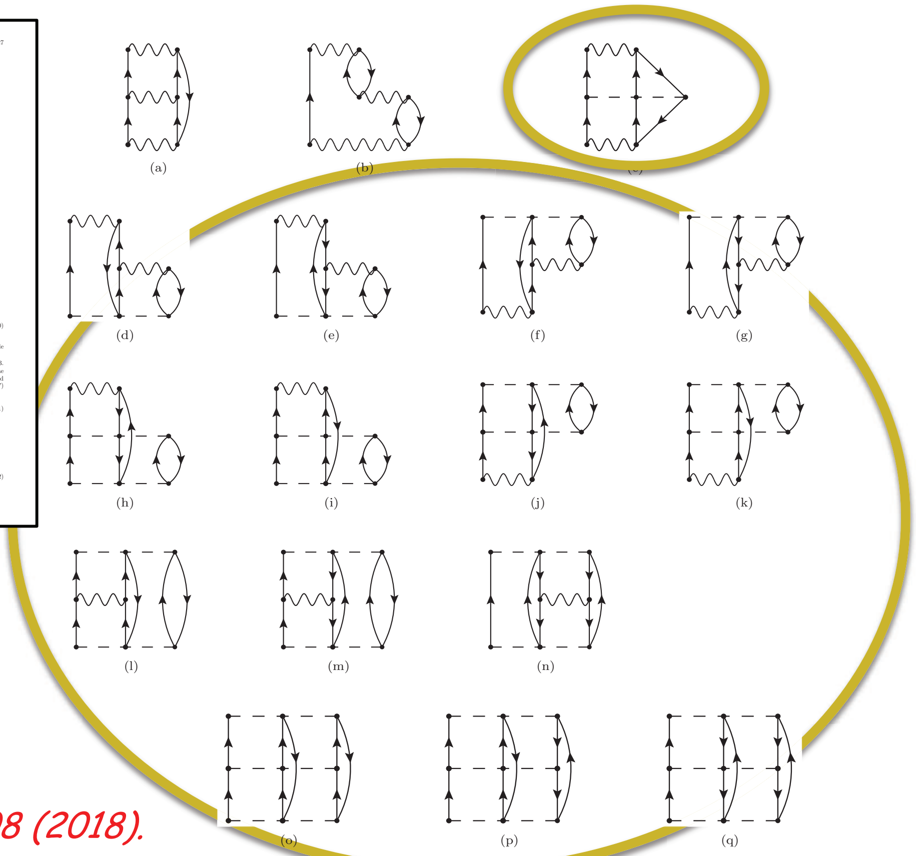


FIG. 5. 1PI, *skeleton* and *interaction irreducible* self-energy diagrams appearing at 3^{rd}-order in perturbative expansion (7), making use of the effective hamiltonian of Eq. (9).

Formalism already laid out:
F. Raimondi, CB, Phys. Rev. C97, 054308 (2018).

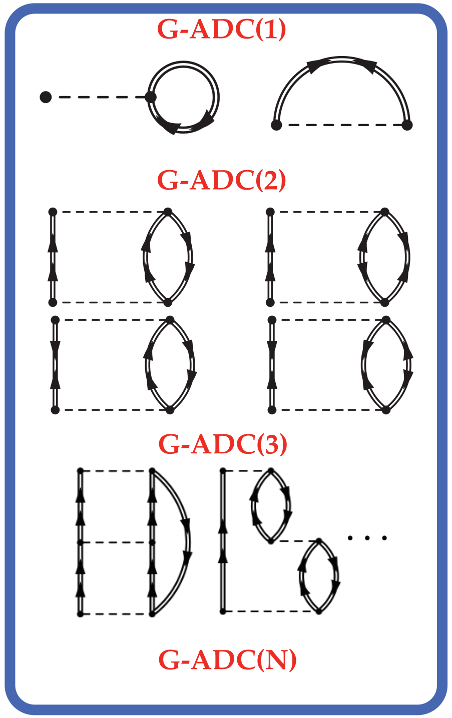
Automatic Diagrammatic Generation (ADG) of the self-energy

Goal: Drawing of self-energy Feynman diagrams and derivation of corresponding algebraic expressions are performed automatically

Background: ADG of the BMBPT expansion (P. Arthuis *et al* Comp. Phys. Comm. **240**, 202 (2019))

Feynman rules for Gorkov's self-energy
(V. Somà *et al* . Phys. Rev. C **84**, 064317 (2011))

- Symbolic computation (`Python`)
- Graph theory (`NetworkX` package)
- Formatting and drawing tools (`LaTeX`, `TikZ` package)



Features:

- Reach arbitrary order in the self-energy expansion
- Different treatments of the self-energy enabled:
  perturbative/nonperturbative(ADC); Dyson/Gorkov; interaction reducible/irreducible, etc
- Faster and less error-prone than "human" derivation

Status:

- Drawing of the valid self-energy Feynman diagrams at arbitrary order completed
- Implementation of the rules to obtain algebraic expressions for the diagrams in progress

*Work in progress by **F. Raimondi**, CEA, Saclay*

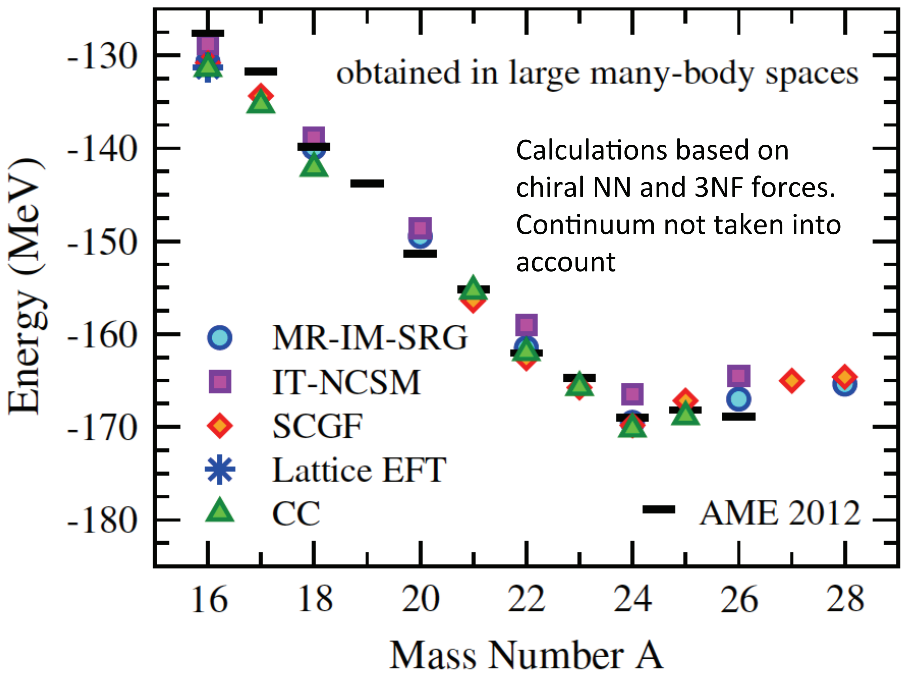
Chiral EFT interactions
and
3-nucleon forces

in mid-mass isotopes

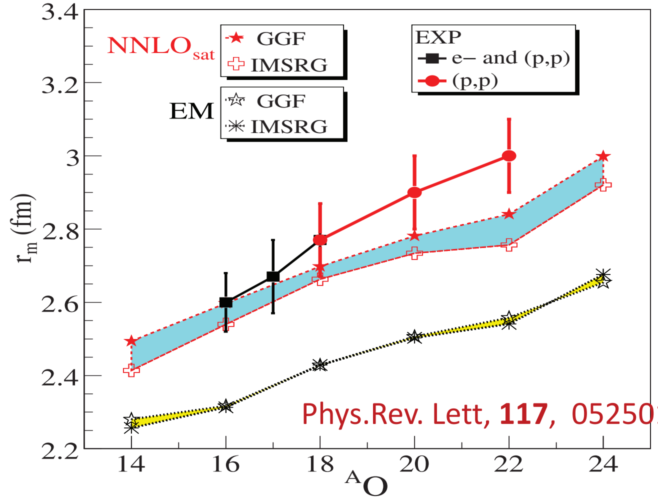
Benchmark of ab-initio methods for oxygen isotopic chain

First success of chital-EFT interactions on oxygen isotopes….

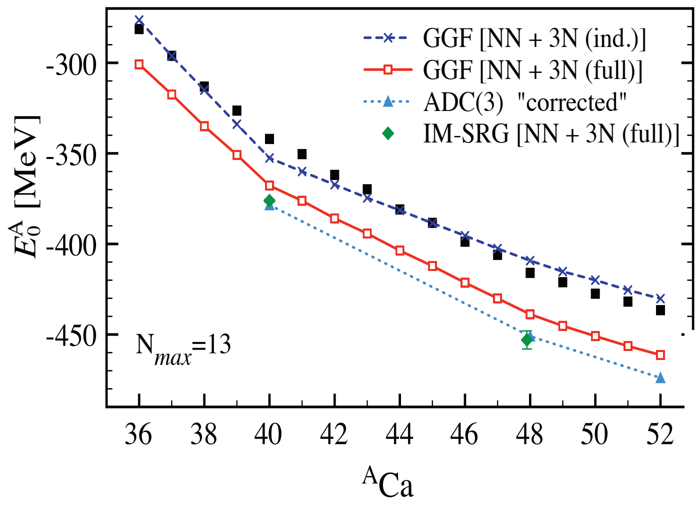
…but still poor for radii and larger isotopes:



Hebeler, Holt, Menendez, Schwenk, Ann. Rev. Nucl. Part. Sci. in press (2015)



Phys.Rev. Lett, **117**, 052501 ('16)



Phys. Rev. C**89**, 061301R (2014)

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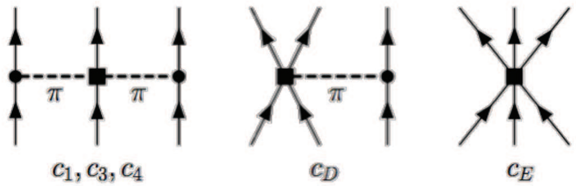
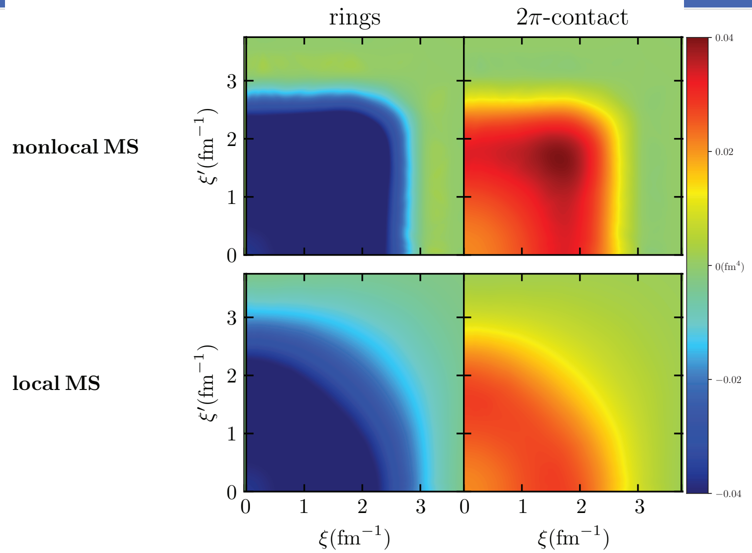
Local vs. non-local chiral N²LO NNN interaction — by P. Navrátil





$$f_\Lambda^{\rm long}(\mathbf{p},\mathbf{q}) = \exp\left[-((\mathbf{p}^2 + 3/4\,\mathbf{q}^2)/\Lambda^2)^n\right]$$

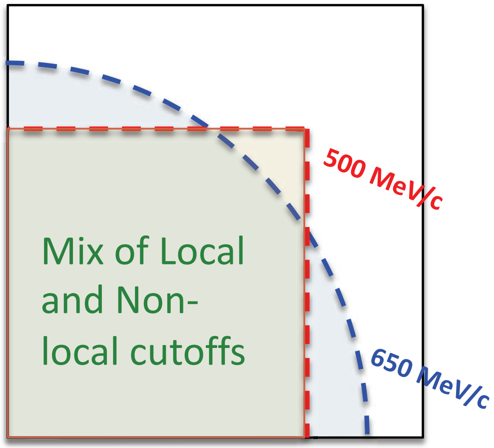
$$\left\langle \mathbf{p}'\mathbf{q}'|V_{3N}^{\rm reg}|\mathbf{pq}\right\rangle = f_R(\mathbf{p}',\mathbf{q}')\,\langle \mathbf{p}'\mathbf{q}'|V_{3N}|\mathbf{pq}\rangle\, f_R(\mathbf{p},\mathbf{q})$$

$$f_\Lambda^{\rm long}(\mathbf{Q}_i) = \exp\left[-(\mathbf{Q}_i^2/\Lambda^2)^2\right]$$

$$\left\langle \mathbf{p}'\mathbf{q}'|V_{3N}^{\rm reg}|\mathbf{pq}\right\rangle = \langle \mathbf{p}'\mathbf{q}'|V_{3N}|\mathbf{pq}\rangle \prod_i f_R(\mathbf{Q}_i)$$

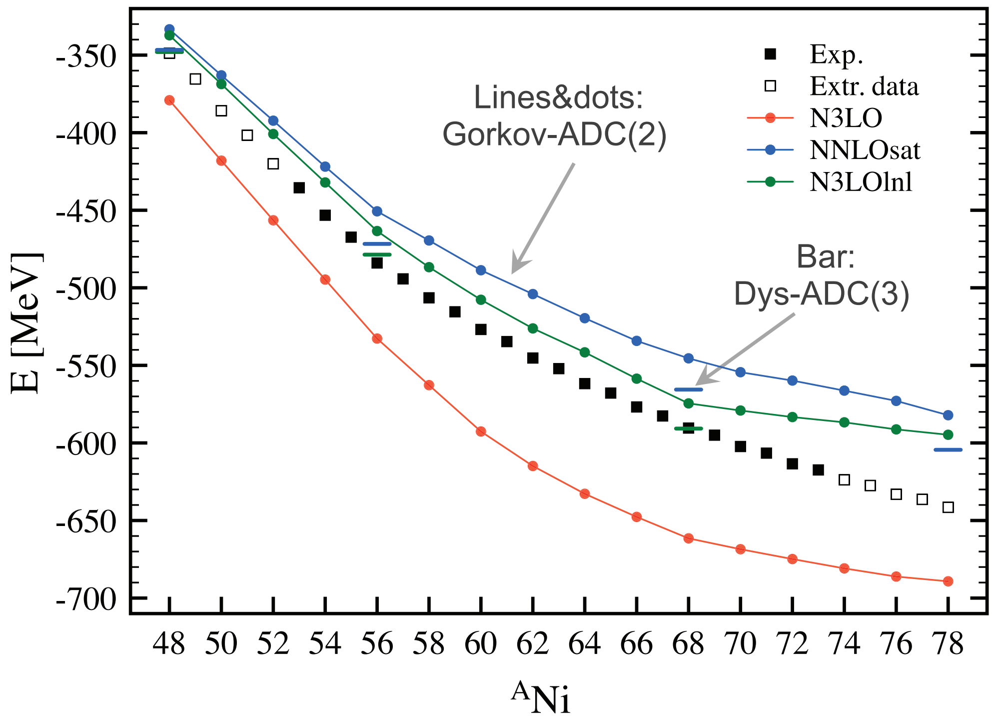
$\xi^2 = p^2 + 3/4q^2$ ≈ 3-nucleon tot. kinetic energy

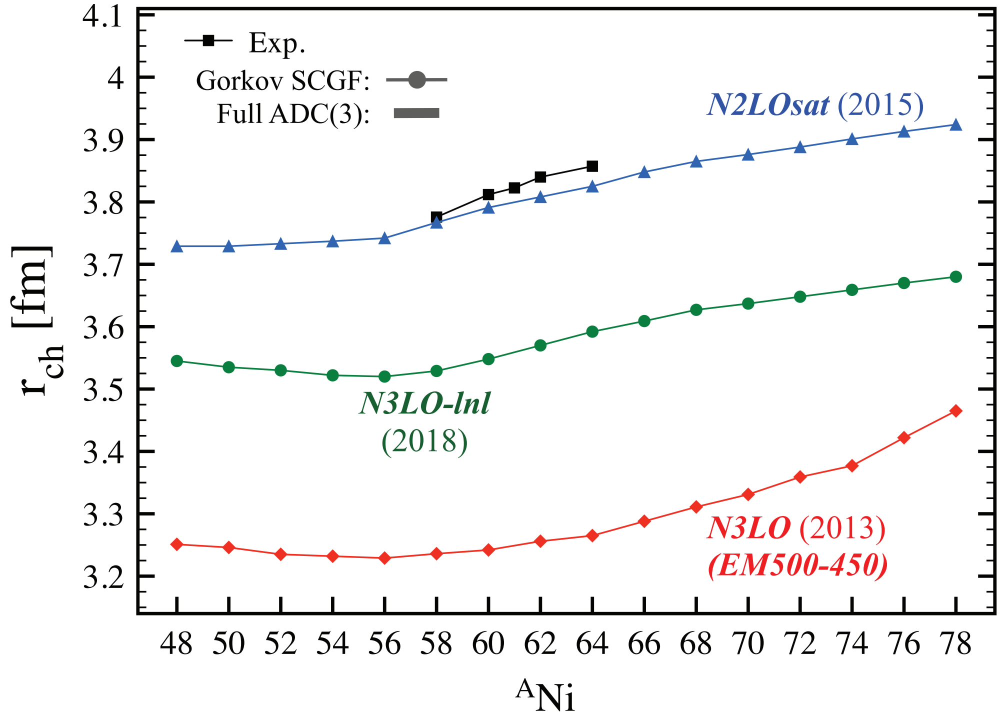
- Local: chiral N³LO NN+ N²LO 3N500
  - c_D=-0.2 c_E=-0.205 (^{3}H E_{gs}=-8.48 MeV)
- Non-local: chiral N²LO$_{sat}$ NN+3N
  - c_D=+0.8168 c_E=-0.0396 (^{3}H E_{gs}=-8.53 MeV)
- Local/Non-local: chiral N³LO NN+ N²LO
  - c_D=+0.7 c_E=-0.06 (^{3}H E_{gs}=-8.44 MeV)



Plots courtesy of K. Hebeler (from his 7/1/19 talk)

Comparison of nuclear forces – ^{A}Ni

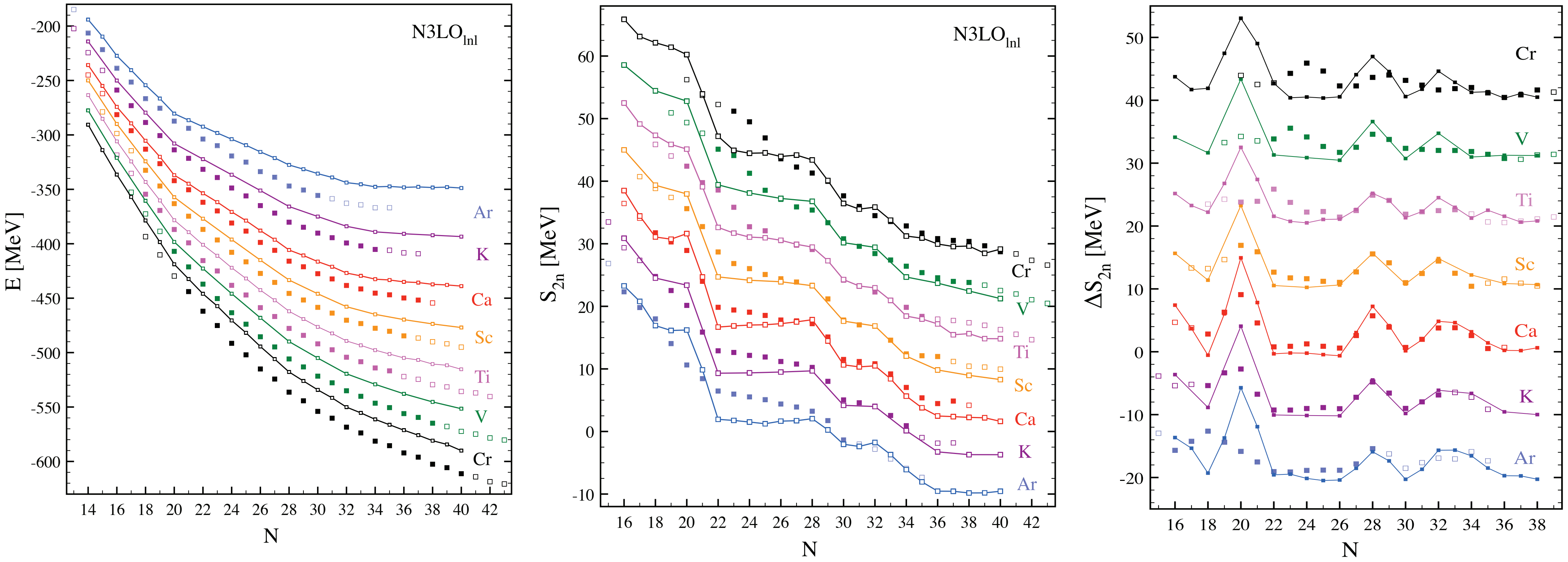




V. Somà, P. Navrátil, F. Raimondi, CB, T. Duguet, in preparation – arXiv:1907:1907.09790

N3LO(500) + nln 3NF

SCGF – Gorkov-ADC(2)



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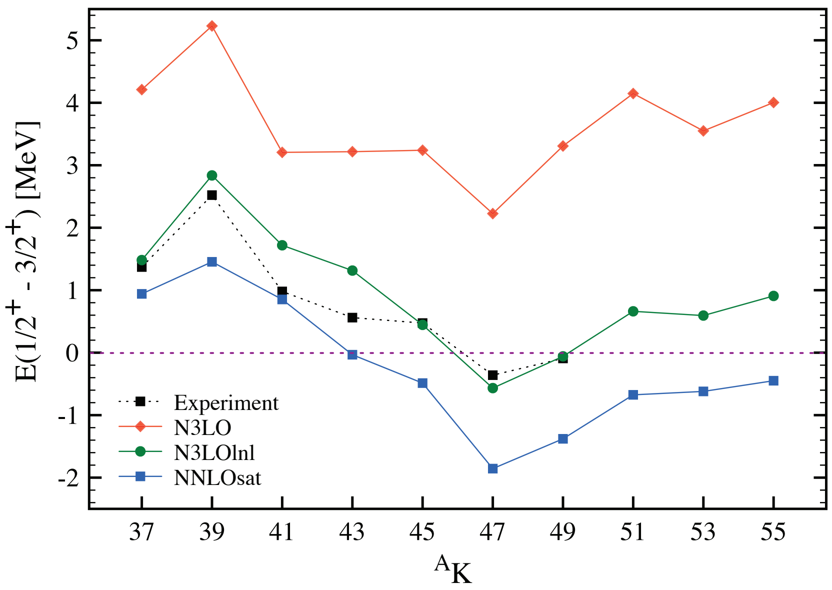
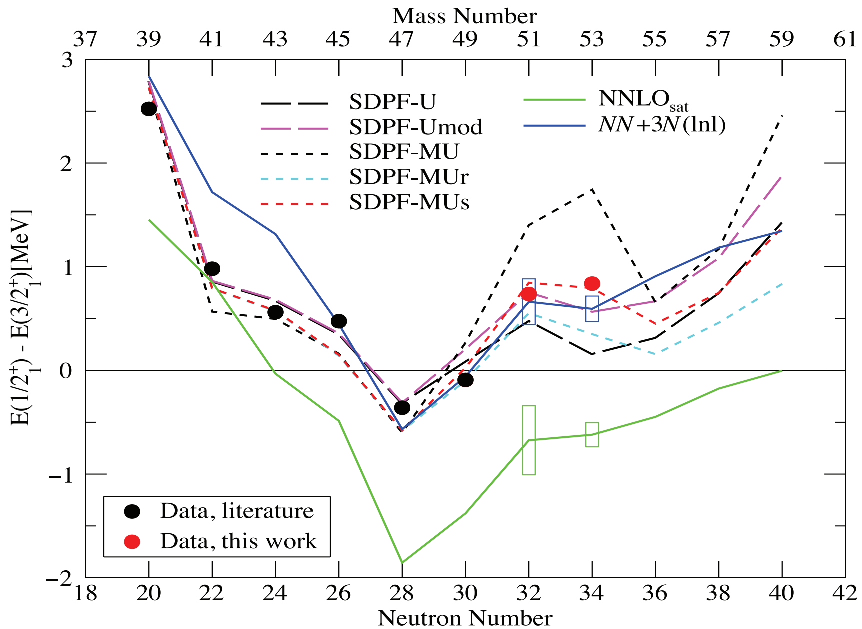
V. Somà, P. Navrátil, F. Raimondi, CB, T. Duguet, in preparation – arXiv:1907:1907.09790

$d_{3/2}$ – $s_{1/2}$ inversion in K isotopes





V. Somà, CB, *et al.*, arXiv:1907:1907.09790

Papuga et al., PRL**110**, 172503 (2013); PRC**90**, 034321 (2014)

RIKEN, SEASTAR coll. (unpublished)

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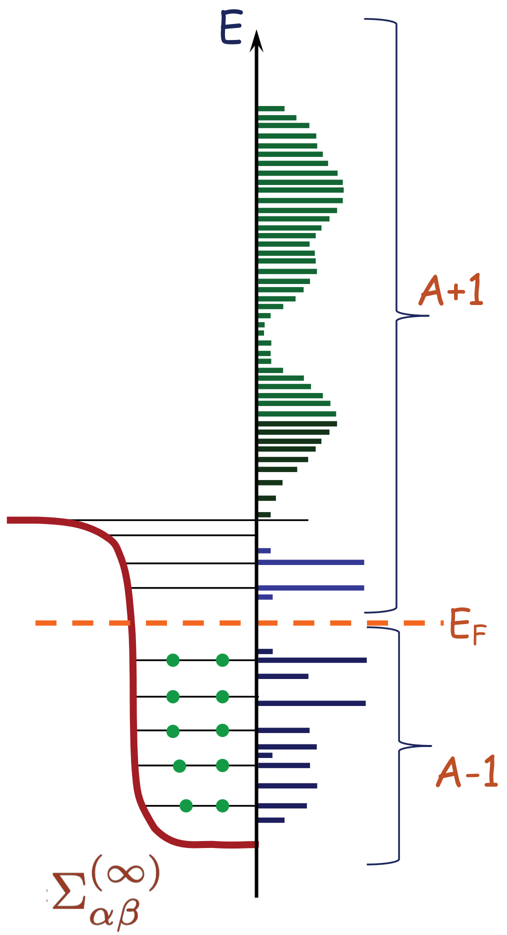
Ab initio optical potentials from propagator theory

Relation to Fesbach theory:
Mahaux & Sartor, Adv. Nucl. Phys. 20 (1991)
Escher & Jennings Phys. Rev. C**66**, 034313 (2002)

Previous SCGF work:
CB, B. Jennings, Phys. Rev. C**72**, 014613 (2005)
S. Waldecker, CB, W. Dickhoff, Phys. Rev. C**84**, 034616 (2011)
A. Idini, CB, P. Navrátil, Phys. Rv. Lett. **123**, 092501 (2019)

Microscopic optical potential



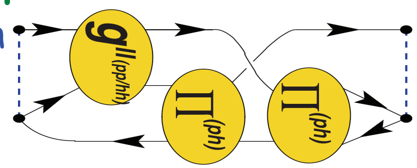
Nuclear self-energy $\Sigma^\star(\mathbf{r},\mathbf{r}';\varepsilon)$:

- contains *both* *particle* and *hole* props.
- it is proven to be a Feshbach opt. pot → in general it is *non-local !*

$$\Sigma^\star_{\alpha\beta}(\omega) = \Sigma^{(\infty)}_{\alpha\beta} + \sum_{i,j} \mathbf{M}^\dagger_{\alpha,i} \left[\frac{1}{E-(\mathbf{K}^> + \mathbf{C}) + i\Gamma} \right]_{i,j} \mathbf{M}_{j,\beta} + \sum_{r,s} \mathbf{N}_{\alpha,r} \left[\frac{1}{E-(\mathbf{K}^< + \mathbf{D}) - i\Gamma} \right]_{r,s} \mathbf{N}^\dagger_{s,\beta}$$

mean-field

Particle-vibration couplings:



Solve scattering and overlap functions directly in momentum space:

$$\Sigma^{\star\, l,j}(k,k';E) = \sum_{n,\,n'} R_{n\,l}(k)\, \Sigma^{\star\, l,j}_{n,\,n'}\, R_{n\,l}(k')$$

$$\frac{k^2}{2\mu}\psi_{l,j}(k) + \int \mathrm{d}k'\, k'^2\, \Sigma^{\star l,j}(k,k';E_{c.m.})\psi_{l,j}(k') = E_{c.m.}\psi_{l,j}(k)$$

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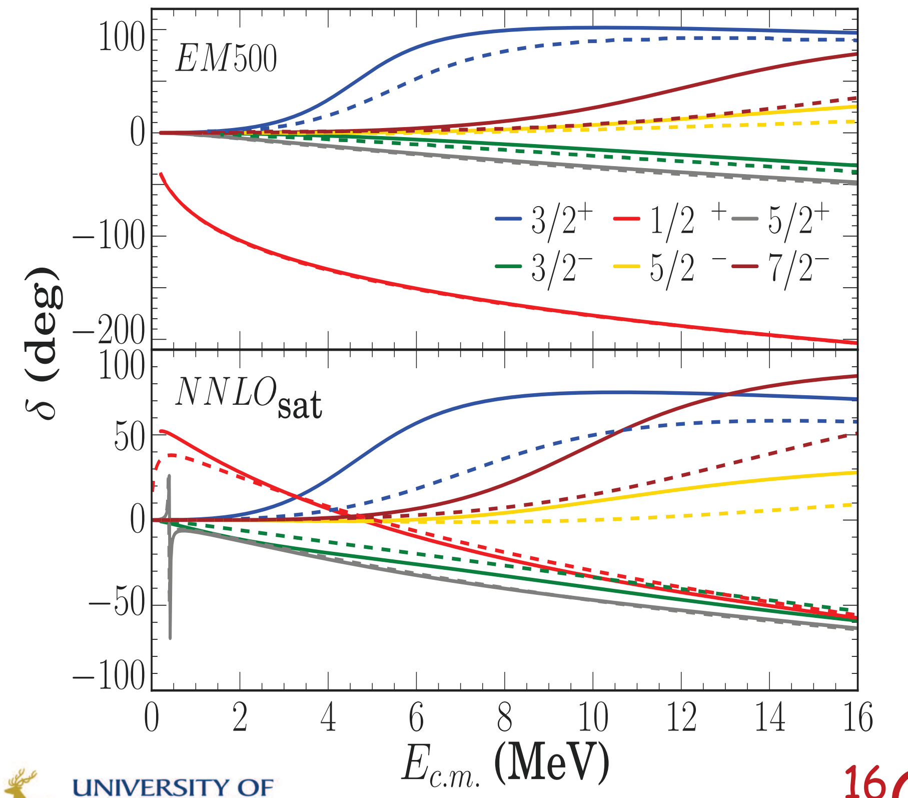
Low energy scattering – from SCGF

[A. Idini, CB, Navratil,
Phys. Rev. Lett. **123**, 092501 (2019)]

Benchmark with NCSM-based scattering.

Scattering from mean-field only:



- - - - - NCSM/RGM [**without** core excitations]

EM500: NN-SRG λ_{SRG}= 2.66 fm^{-1}, Nmax=18 (IT)
[PRC**82**, 034609 (2010)]

NNLOsat: Nmax=8 (IT-NCSM)

——— SCGF [$\Sigma^{(\infty)}$ only], always Nmax=13

$^{16}O(n,n')^{16}O$

Low energy scattering – from SCGF

[A. Idini, CB, Navratil,
Phys. Rev. Lett. **123**, 092501 (2019)]

Benchmark with NCSM-based scattering.

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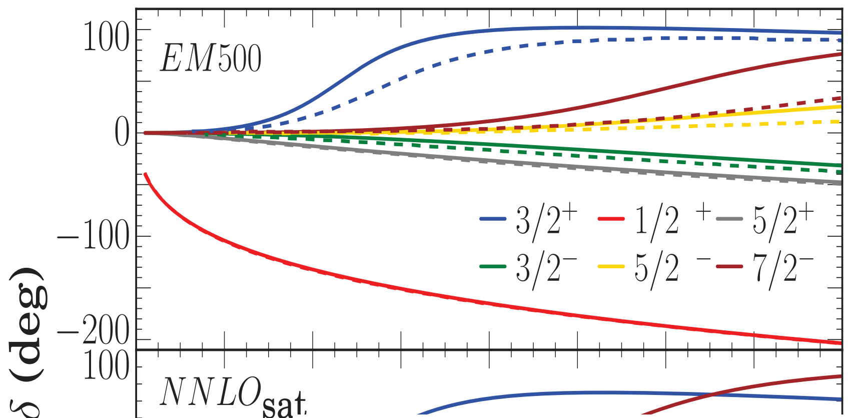
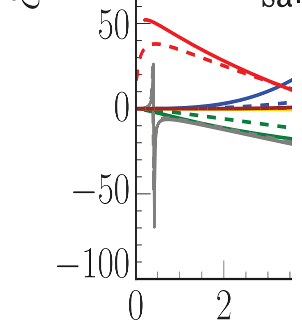
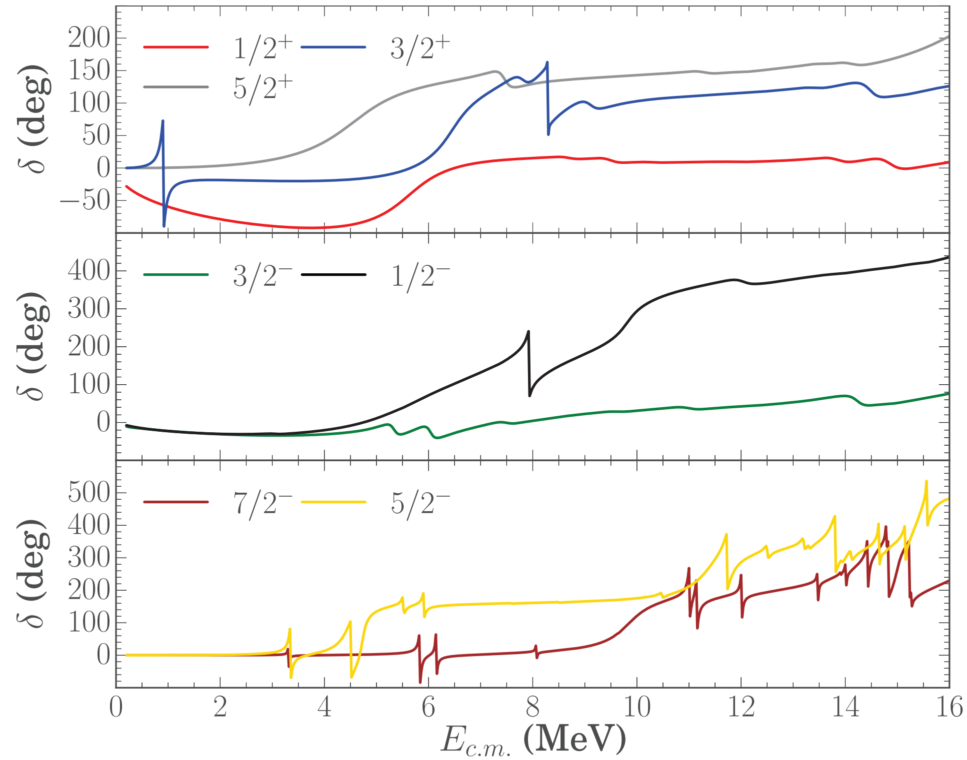




ε (MeV)	$5/2^+$	$1/2^+$	$1/2^-$	$5/2^-$	$3/2^-$	$3/2^+$	$5/2^+_*$	$5/2^-_*$	$7/2^-_*$
exp.	-4.14	-3.27	-1.09	-0.30	0.41	0.94	3.23	3.02	3.54
$NNLO_{sat}$	-5.06	-3.58	-0.15	-1.23	-2.24	0.91	4.57	3.36	3.37

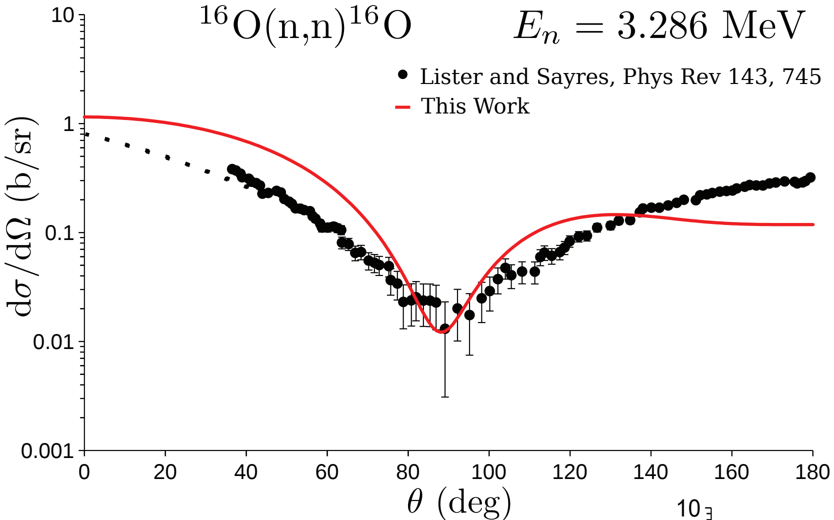
TABLE I. Excitation spectrum of ^{17}O with respect to the $n+^{16}O$ threshold, as obtained from Eq. (5) and the $NNLO_{sat}$ interaction and compared to the experiment [45]. Broad resonances in the continuum (most notably, the $5/2^+$) are computed at midpoint. The asterisks ($_*$) indicate higher excited states, above the lowest one, for each partial wave.

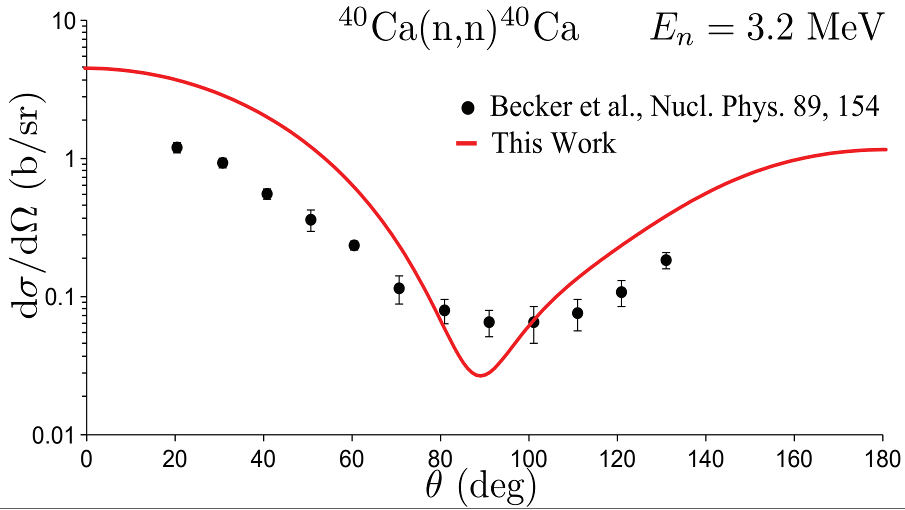
Full self-energy from SCGF:



Low energy scattering – from SCGF

[A. Idini, CB, Navrátil, PRL**123**, 092501 (2019)]

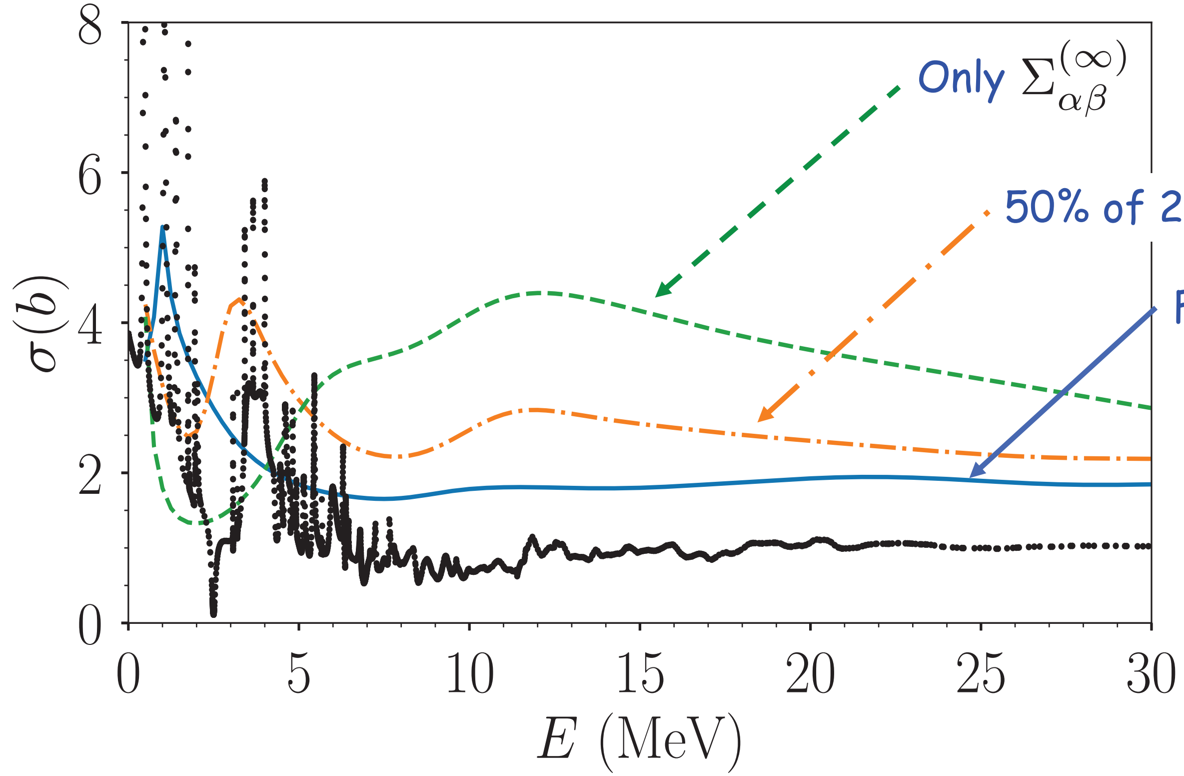




Role of intermediate state configurations (ISCs)

[A. Idini, CB, Navratil, Phys. Rev. Lett. **123**, 092501 (2019)]

n-^{16}O, total elastic cross section



High order configurations, or ADC(n>>3), to be critical for fully ab initio optical potentials

$$\Sigma^{\star}_{\alpha\beta}(\omega) = \Sigma^{(\infty)}_{\alpha\beta} + \sum_{i,j} \mathbf{M}^{\dagger}_{\alpha,i} \underbrace{\left[\frac{1}{E - (\mathbf{K}^{>} + \mathbf{C}) + i\Gamma} \right]_{i,j}}_{\text{2p1h}} \mathbf{M}_{j,\beta} + \sum_{r,s} \mathbf{N}_{\alpha,r} \underbrace{\left[\frac{1}{E - (\mathbf{K}^{<} + \mathbf{D}) - i\Gamma} \right]_{r,s}}_{\text{2h1p}} \mathbf{N}^{\dagger}_{s,\beta}$$

Reaching large isotopes

(electron scattering and charge radii)

CB, P. Arthuis – **Preliminary…** (work in progress)

Electron-Ion Trap colliders…

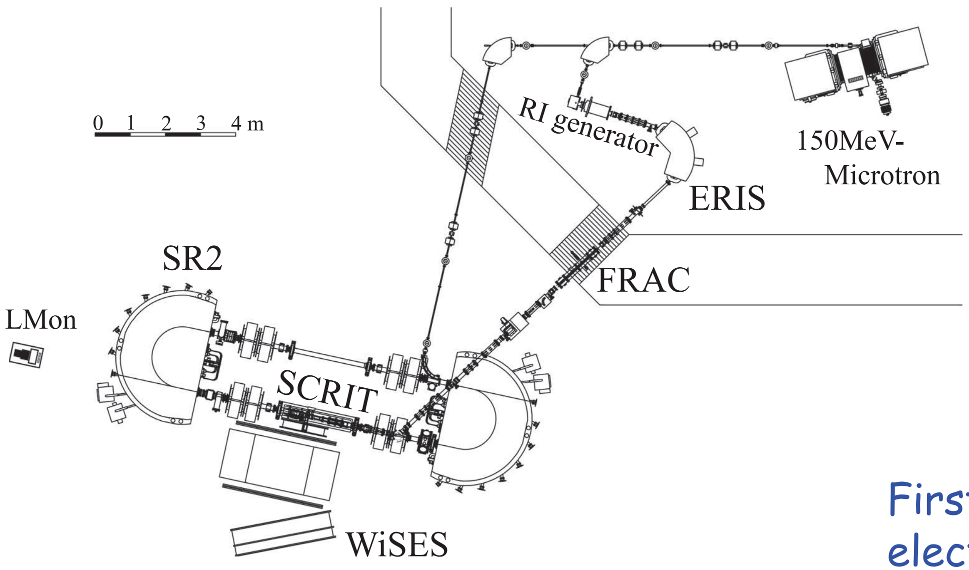


FIG. 1. Overview of the SCRIT electron scattering facility.

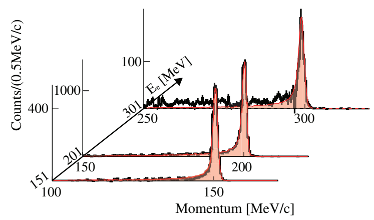
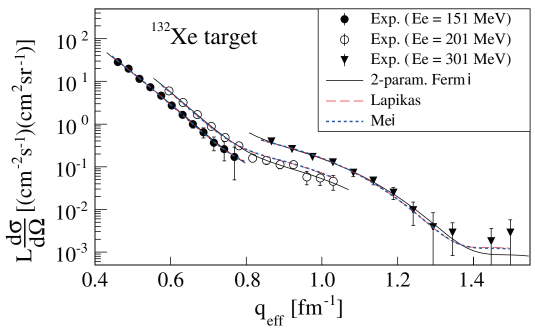


FIG. 3. Reconstructed momentum spectra of ^{132}Xe target after background subtraction. Red shaded lines are the simulated radiation tails following the elastic peaks.



First ever measurement of charge radii through electron scattering with and ion trap setting that *can be used on radioactive isotopes* !!

K. Tsukada *et al*., Phy rev Lett **118**, 262501 (2017)

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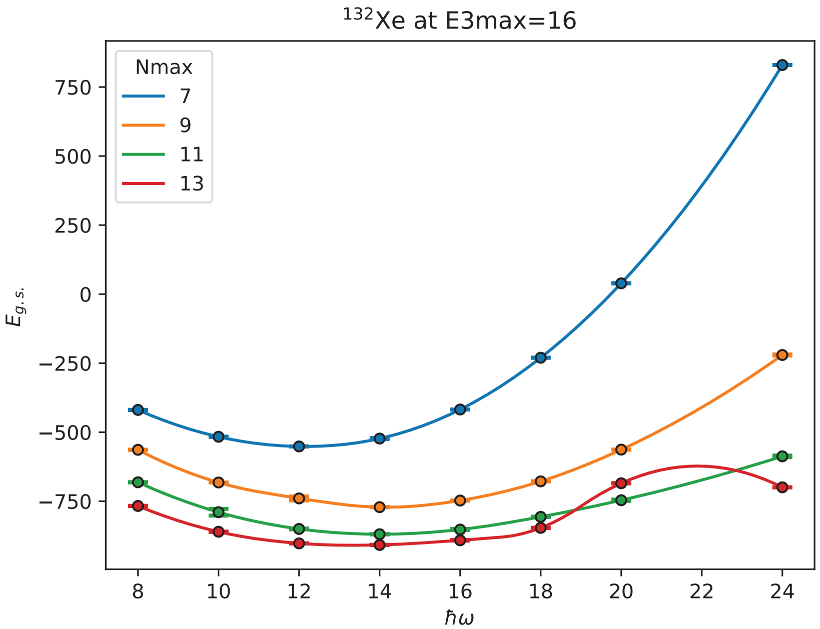
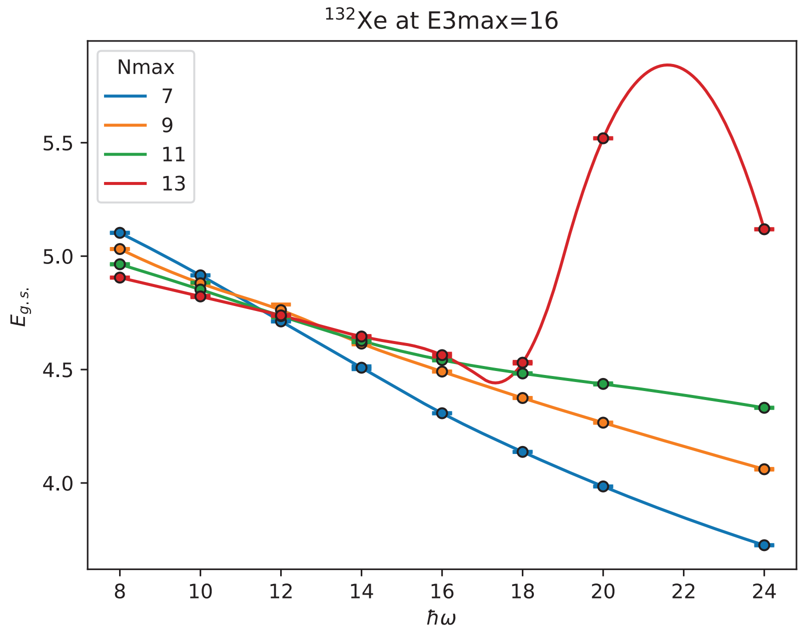
Convergence in large isotopes – e.g. ^{132}Xe

Gorkov ADC(2) with NNLOsat Hamiltonian



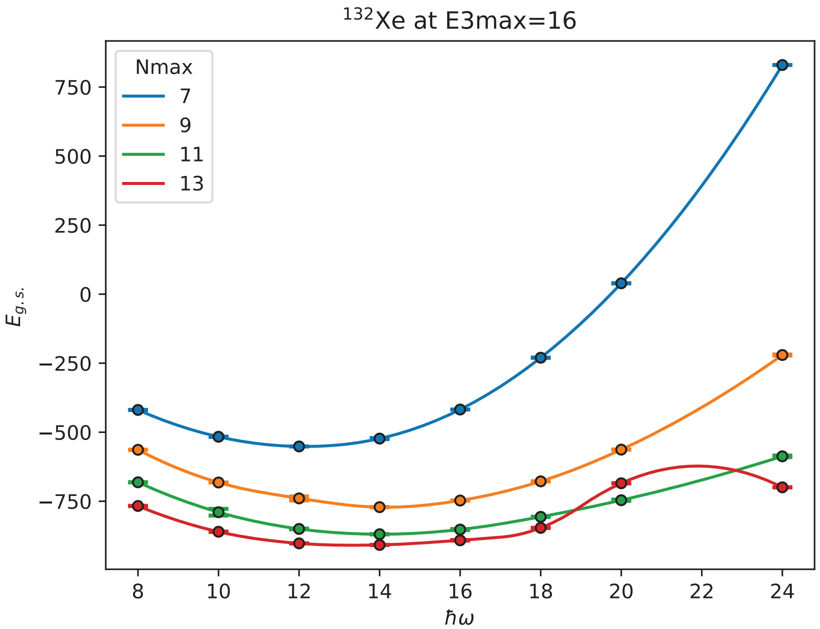


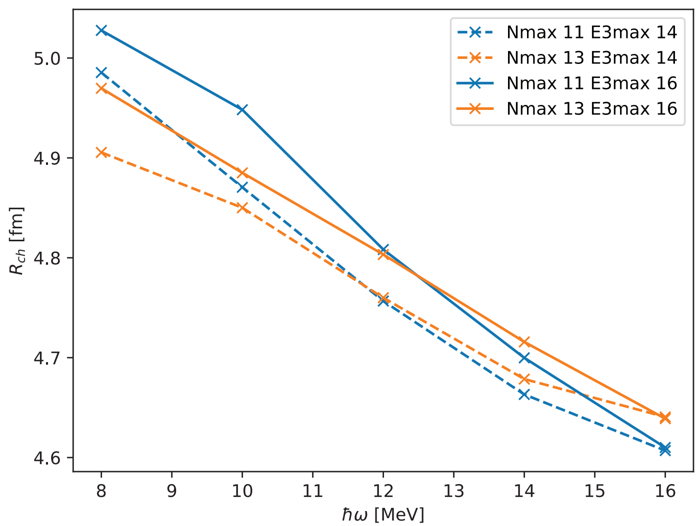
Energies still badly converging…
- Nmax converges slowly…
- E3max (# of 3NFs elements) out of control

Radii converge much better and can be bracketed!

Convergence in large isotopes – e.g. ^{132}Xe

Gorkov ADC(2) with NNLOsat Hamiltonian





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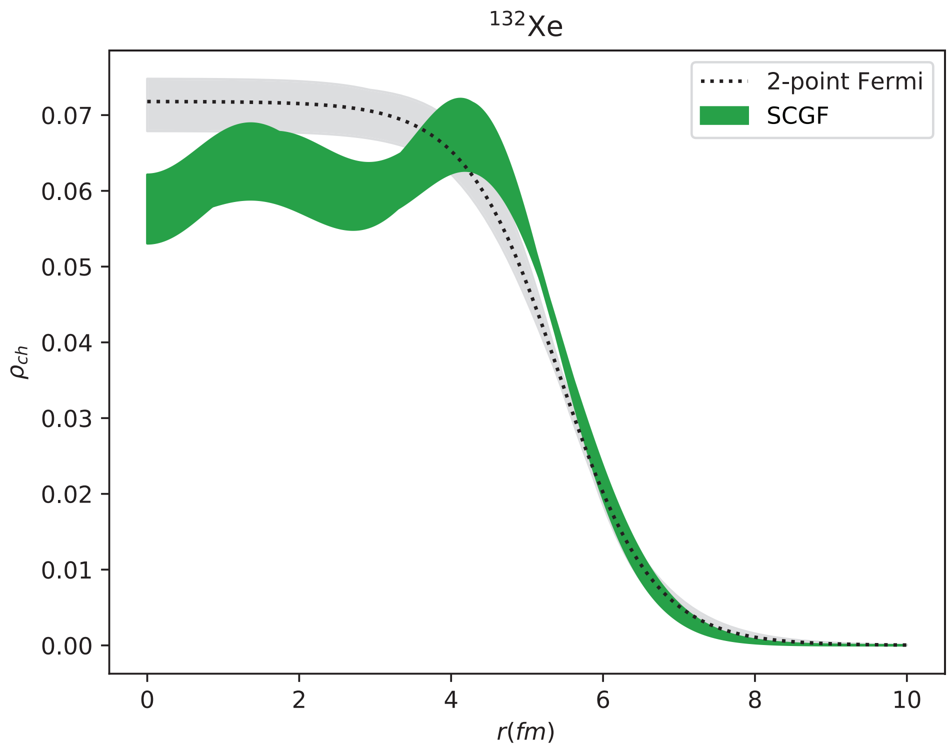

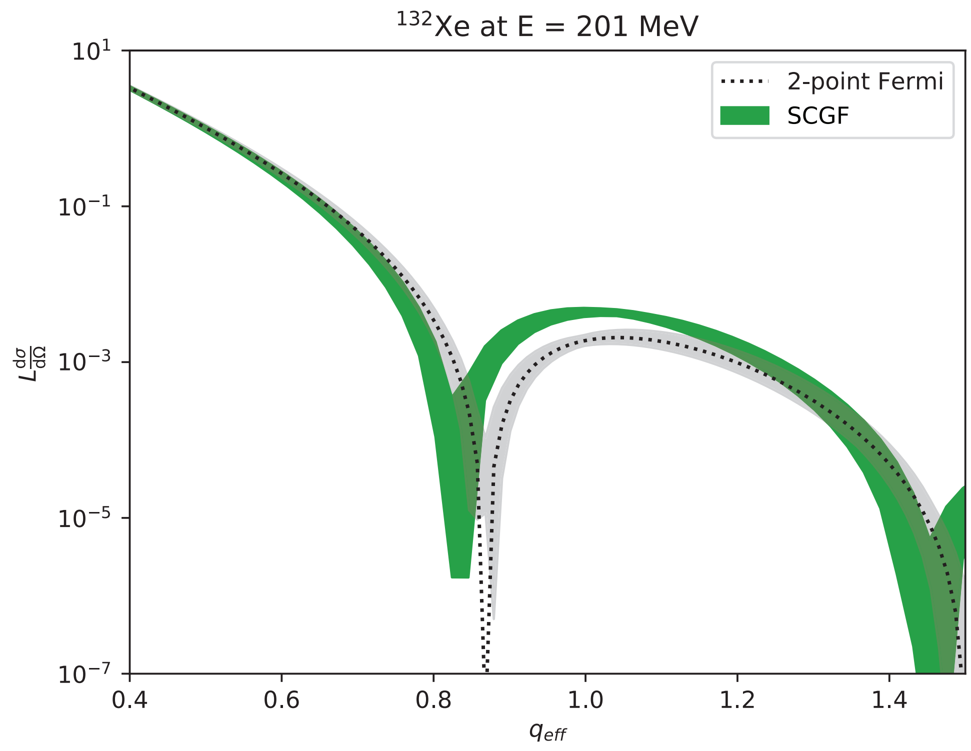

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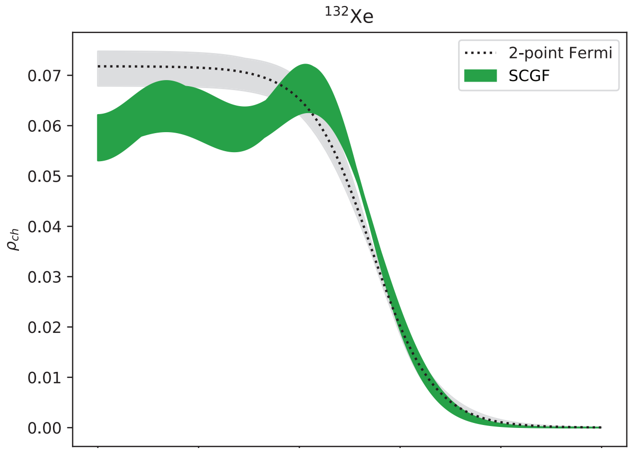
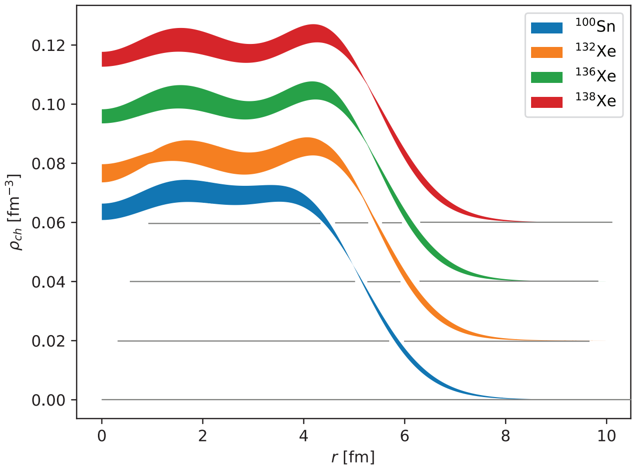
Sn and Xe isotopes

Gorkov ADC(2) and Dyson ADC(3) with NNLOsat Hamiltonian





	SCGF	Exp.
^{100}Sn	4.525 – 4.707	
^{132}Sn	4.725 – 4.956	4.7093
^{132}Xe	4.700 – 4.948	4.7859
^{136}Xe	4.715 – 4.928	4.7964
^{138}Xe	4.724 – 4.941	4.8279

Preliminary !!

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Electron and neutrino scattering off nuclei

N. Rocco, CB, Phys. Rev. C98, 025501 (2018)

N. Rocco, CB, O. Benhar, A. De Pace, A. Lovato, Phys. Rev. C99, 025502 (2019)

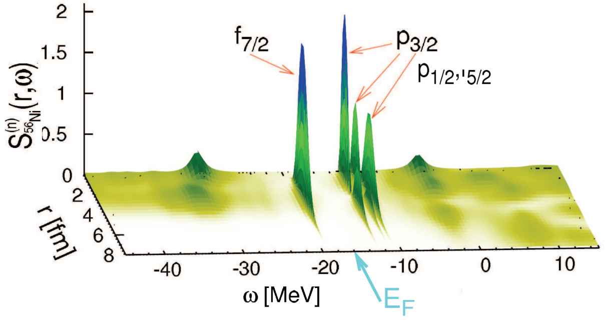
CB, N. Rocco, V. Somà, arXiv:1907.01122

Lepton-nucleon cross section

$$\left(\frac{d\sigma}{dT' d\cos\theta'}\right)_{\nu/\bar{\nu}} = \frac{G^2}{2\pi}\frac{k'}{2E_\nu}\left[\hat{L}_{CC}R_{CC} + 2\hat{L}_{CL}R_{CL} + \hat{L}_{LL}R_{LL} + \hat{L}_T R_T \pm 2\hat{L}_{T'}R_{T'}\right],$$

Nuclear structure is in the hadronic tensor:

$$W^{\mu\nu}(\mathbf{q},\omega) = \int \frac{d^3k}{(2\pi)^3} dE\, P_h(\mathbf{k},E) \frac{m^2}{e(\mathbf{k})e(\mathbf{k}+\mathbf{q})} \times \sum_i \langle k|j_i^{\mu\dagger}|k+q\rangle\langle k+q|j_i^{\nu}|k\rangle \times \delta(\omega + E - e(\mathbf{k}+\mathbf{q})),$$



$$R_{CC} = W^{00}$$
$$R_{CL} = -\frac{1}{2}(W^{03} + W^{30})$$
$$R_{LL} = W^{33}$$

$$R_T = W^{11} + W^{22}$$
$$R_{T'} = -\frac{i}{2}(W^{12} - W^{21}),$$

$$W^{\mu\nu} = \sum_f \langle 0|j^{\mu\dagger}|f\rangle\langle f|j^{\nu}|0\rangle\delta(E_0 + \omega - E_f)$$

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Lepton-nucleon cross section

$$\left(\frac{d\sigma}{dT' d\cos\theta'}\right)_{\nu/\bar\nu} = \frac{G^2}{2\pi}\frac{k'}{2E_\nu}\left[\hat L_{CC}R_{CC} + 2\hat L_{CL}R_{CL} + \hat L_{LL}R_{LL} + \hat L_T R_T \pm 2\hat L_{T'}R_{T'}\right] ,$$

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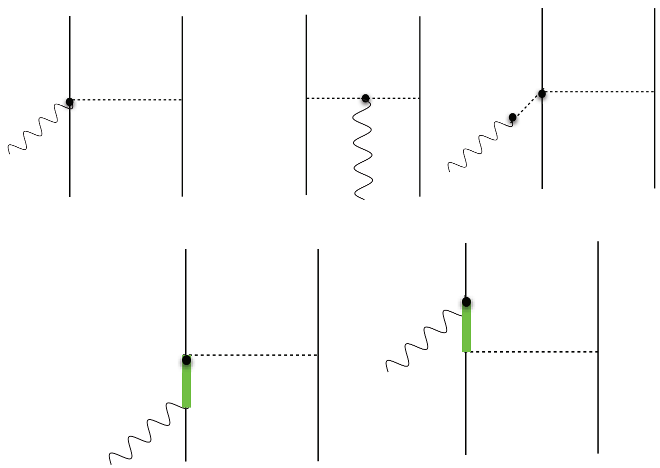
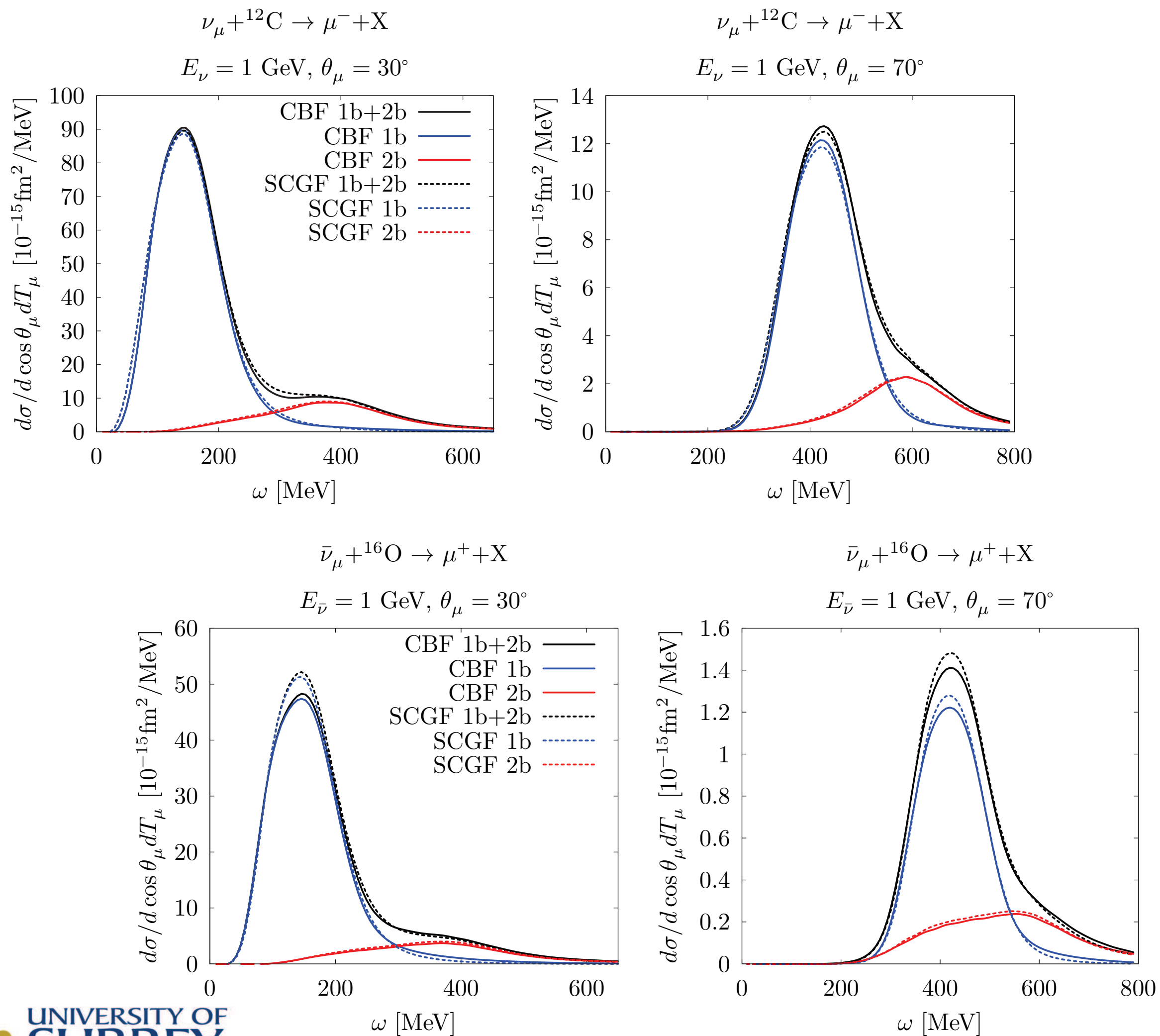
$$W^{\mu\nu}_{2b}(\mathbf{q},\omega) = \frac{V}{2}\int d\tilde E \frac{d^3k}{(2\pi)^3} d\tilde E' \frac{d^3k'}{(2\pi)^3}\frac{d^3p}{(2\pi)^3} \times \frac{m^4}{e(\mathbf{k})e(\mathbf{k}')e(\mathbf{p})e(\mathbf{p}')} P_h^{\rm NM}(\mathbf{k},\tilde E) P_h^{\rm NM}(\mathbf{k}',\tilde E') \times \sum_{ij} \langle k\,k'|j_{ij}^{\mu\,\dagger}|p\,p'\rangle\langle p\,p'|j_{ij}^\nu|k\,k'\rangle \times \delta(\omega + \tilde E + \tilde E' - e(\mathbf{p}) - e(\mathbf{p}')) . \quad (41)$$

Two-body diagrams contributing to the axial and vector responses



N. Rocco, CB, O. Benhar, de Pace , A. Lovato, Phys. Rev. C**99**, 025502 (2019)

Charged-current reaction for 1 GeV neutrinos



One-body current describe quasi elastic peak

Difference between CBF(AV18) and SCGF(NNLOsat) from 1-b terms

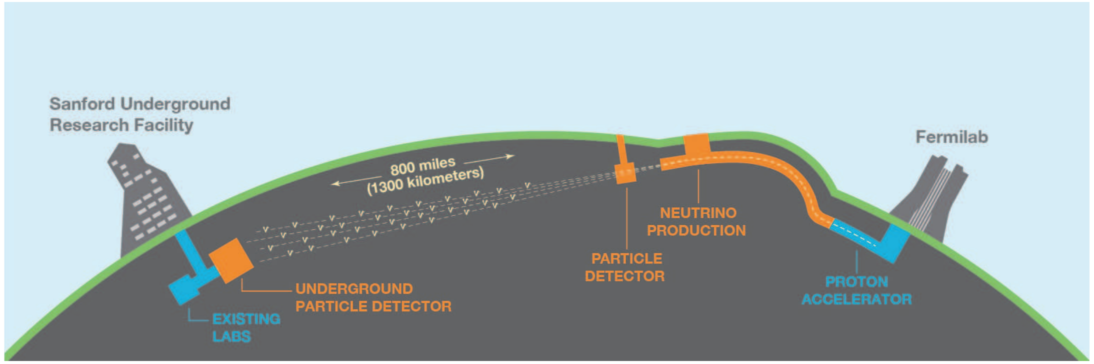
Two-body currents fiull up dip region

Missing Delta and meson emission contributions

X-sec. droppin with scattering angle

N. Rocco, CB, O. Benhar, de Pace , A. Lovato, Phys. Rev. C**99**, 025502 (2019)

Neutrino Oscillations – next generation experiments



DUNE experiment will measure long base line neutrino oscillations to:

- Resolve neutrino mass hierarchy
- Search for CP violation in weak interaction
- Search for other physics beyond SM

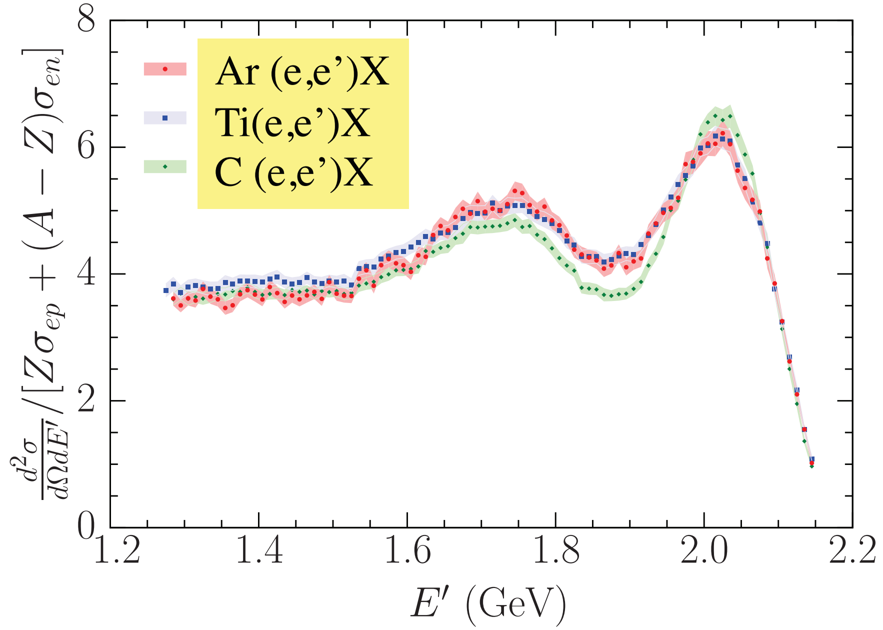
Liquid Argon projection chamber is being used. It will require one order of magnitude (20% → 2%) improvement in theoretical prediction for ν-^{40}Ar cross sections to achieve proper event reconstruction.

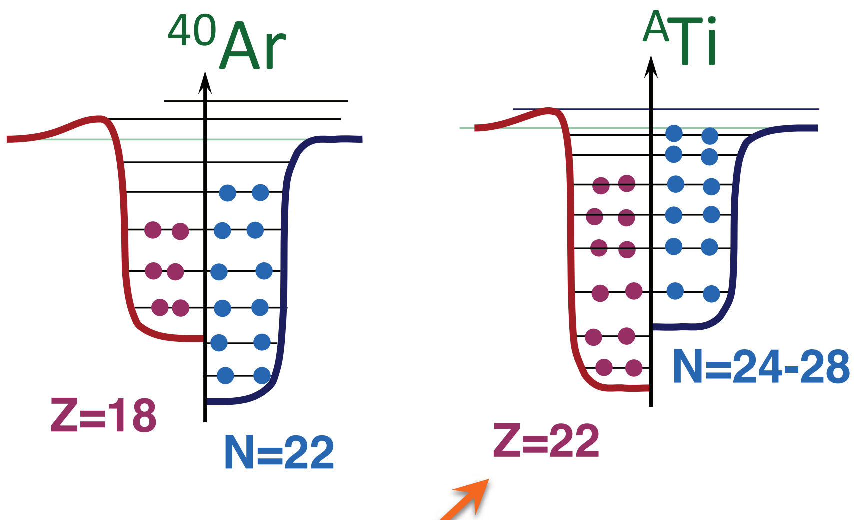
➔ Need good knowledge of ^{40}Ar spectral functions and consistent structure-scattering theories.

Spectral function for ^{40}Ar and Ti

Jlab experiment E12-14-012 (Hall A)

Phys. Rev. C 98, 014617 (2018); arXiv:1810.10575

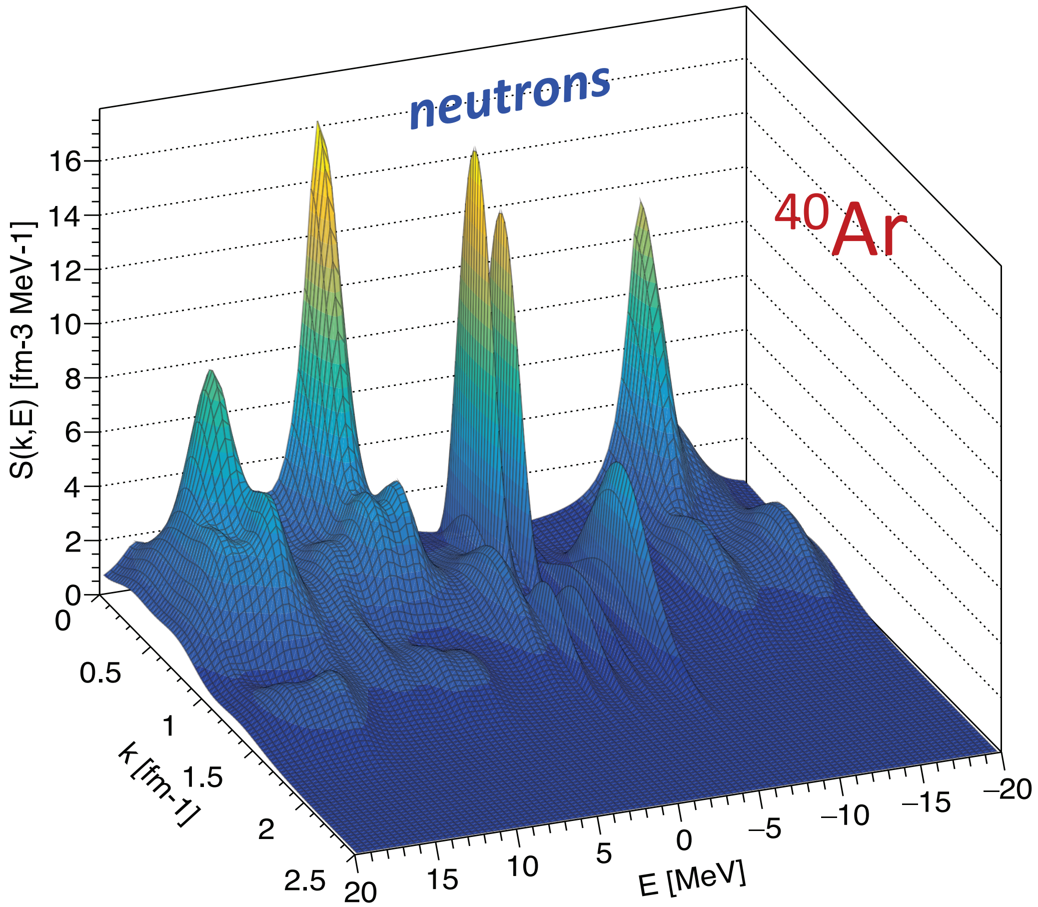




Proton distribution in Ti similar to neutron in ^{40}Ar ??

^{40}Ar(e,e'p) and Ti(e,e'p) data being analyzed

Spectral function for ^{40}Ar



- Experimental datat now available from Jlab:
  H. Dai et al., arXiv:1803.01910/ 1810.10575
- Ab initio simulations based on the ADC(2) truncation of the N2LO-sat Hamiltoninan

➔ Want validation of initial state correlation before they are implementer in neutrino-^{40}Ar simulations

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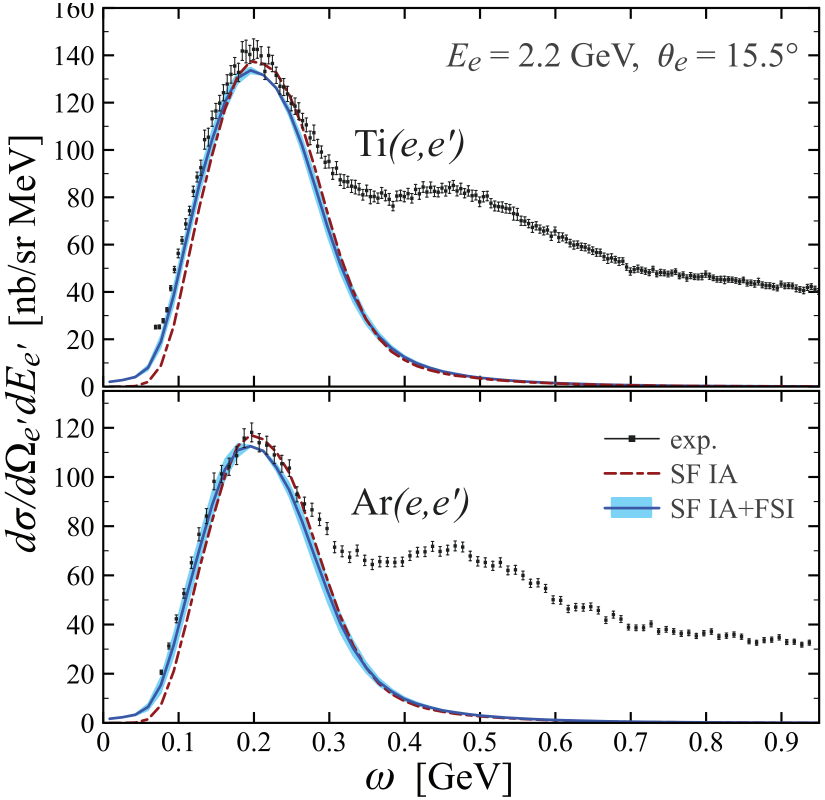
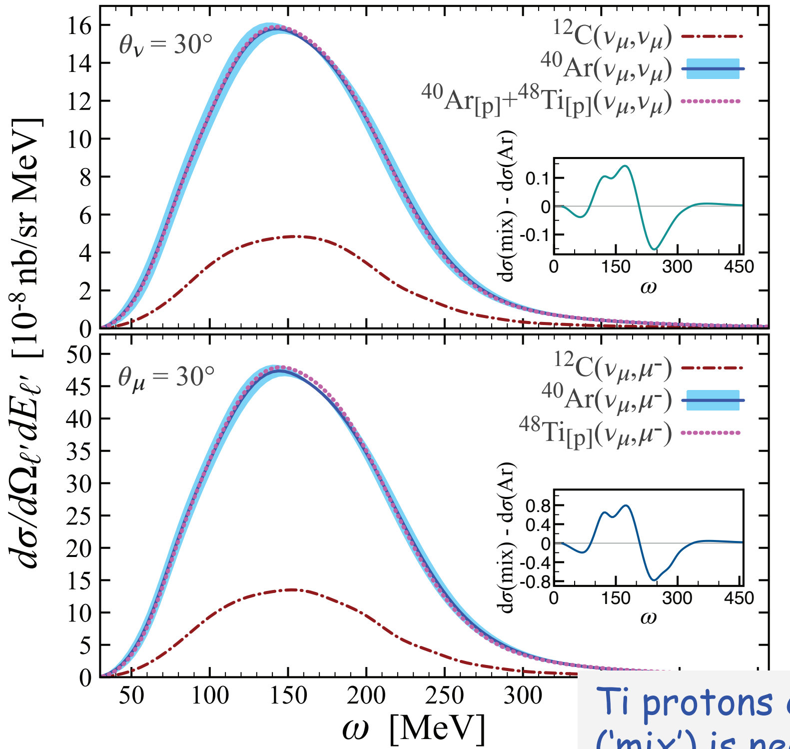
CB, N. Rocco, V. Somà, arXiv:1907.01122

Electron and ν scattering on ^{40}Ar and Ti

Jlab experiment E12-14-012 (Hall A)

[Phys. Rev. C 98, 014617 (2018)]





Ti protons contribution ('mix') is nearly identical to neutrons in ^{40}Ar.

^{40}Ar(e,e'p) and Ti(e,e'p) data being analyzed

CB, N. Rocco, V. Somà, arXiv:1907.01122 – PhysRevC in print

Collaborators

Thank you for your attention!!!

UNIVERSITY OF SURREY — ***A. Cipollone***
A. Rios, A. Idini, ***P. Arthuis, M. Drissi***

ECT* — ***A. Carbone***

cea — *V. Somà, T. Duguet,* ***F. Raimondi***

TRIUMF — *P. Navratil*

Los Alamos NATIONAL LABORATORY — *D. Lonardoni, S. Gandolfi*

Argonne NATIONAL LABORATORY — *A. Lovato ,* ***N. Rocco***

HAL — Hadrons to Atomic nuclei from Lattice QCD

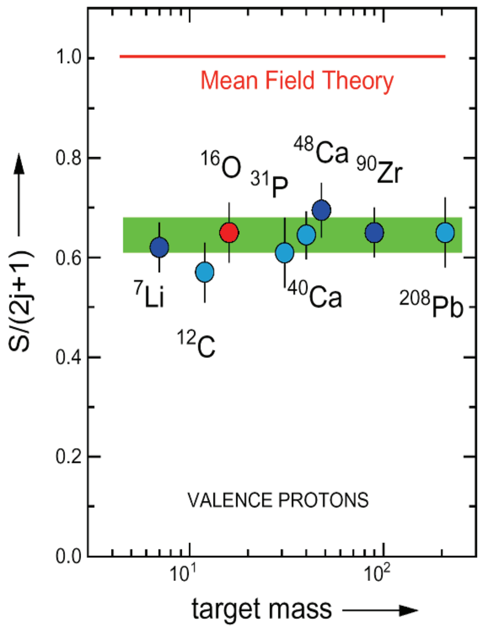
S. Aoki,	YITP Kyoto Univ.
T. Doi, T. Hatsuda,	RIKEN Nishina
T. Inoue,	Nihon Univ.
H. Nemura	Univ. Tsukuba

Backup Slides

Spectroscopic factors

Quenching of SF in stable nuclei

NIKHEF:
Nucl. Phys. A553 (1993) 297c



	$S_{p1/2}$	$S_{p3/2}$
• Short-range correlations oriented methods:		
– VMC [Argonne, '94]	0.90	
– GF(SRC) [St.Louis-Tübingen '95]	0.91	0.89
– FHNC/SOC [Pisa '00]	0.90	
• Including particle-phonon couplings:		
– GF(FRPA) [St.Louis '01] [CB et al., Phys. Rev. C**65**, (02)]	0.77	0.72
• Experiment (e,e'p):	0.63	0.67±0.07 (estimated uncertainty)

SRC are present and verified experimentally

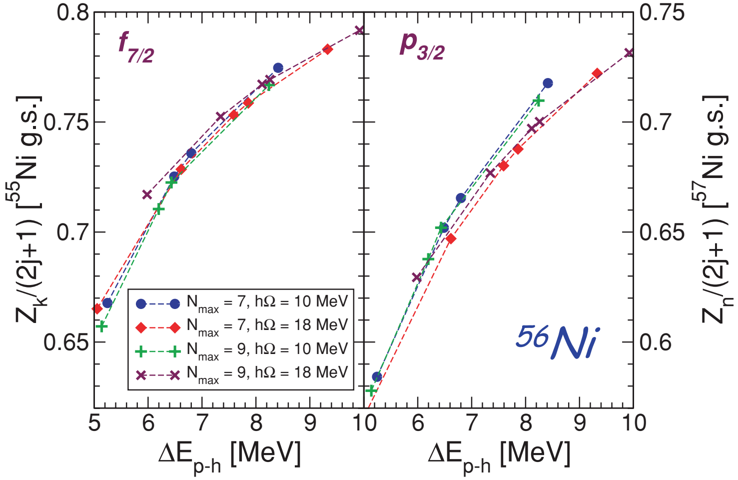
BUT the are NOT the dominant mechanism for quenching SF!!!

Z/N asymmetry dependence of SFs - Theory

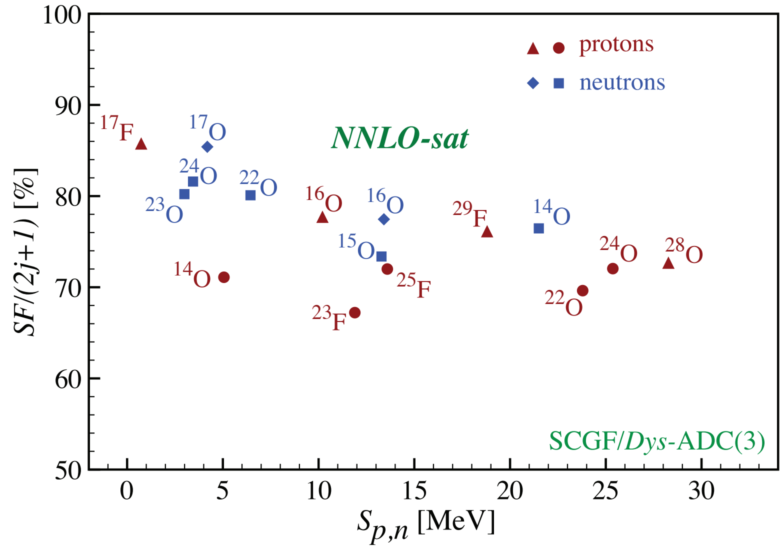
Ab-initio calculations explain (a very weak) the Z/N dependence but the effect is much lower than suggested by direct knockout

Rather the quenching is high correlated to the gap at the Femi surface.

Spectroscopic factor are strongly correlated to p-h gaps:



CB, M. Hjorth-Jensen,
Phys. Rev. C **79**, 064313 (2009)



A. Cipollone, CB, P Navrátil,Phys. Rev. C**92**, 014306 (2015)
and CB, unpublished (2016)

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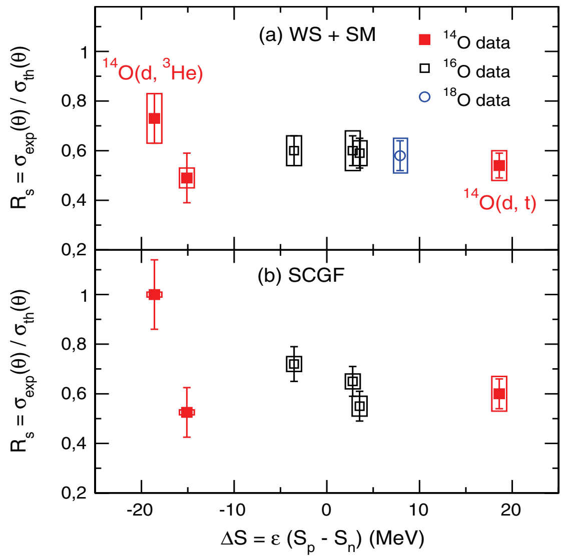
Z/N asymmetry dependence of SFs

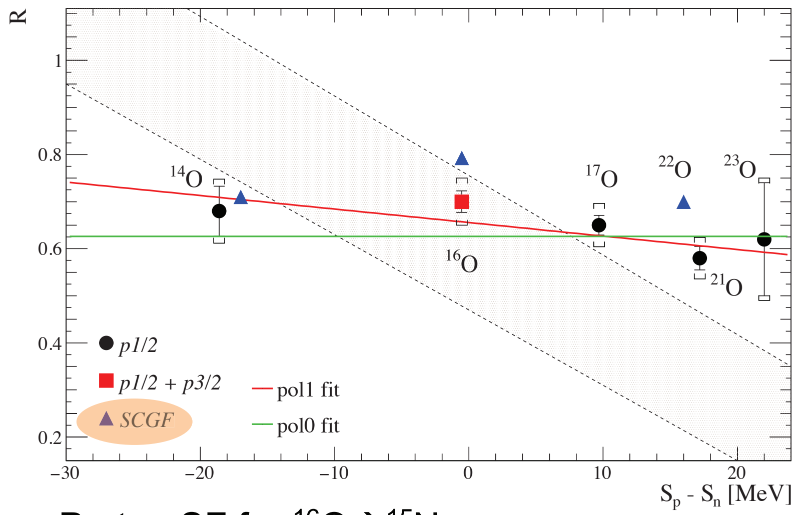
Calculated spectroscopic factors are found to be:
- correlated to p-h gaps
- independent of asymmetry
- consistent with experimental data

^{14}O(d,t)^{13}O and ^{14}O(d,^{3}He)^{13}N transfer reactions @ SPIRAL



[F. Flavigny et al, PRL **110**, 122503 (2013)]

^{A}O(p,2p)$^{A-1}$N at GSI (R^{3}B-LAND)



Proton SF for ^{16}O→^{15}N:

$p_{1/2}$: 0.78 (SCGF) 0.80 (exp.)

$p_{3/2}$: 0.80 (SCGF) 0.65 (exp. – up to cont.)

L. Atar, et al., Phys. Rev. Lett **120**, 52501 (2018)