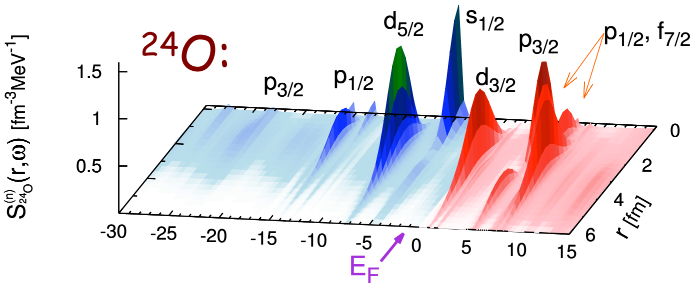
Studying nuclear correlations with electron scattering: opportunities in exotic nuclei

Carlo Barbieri — University of Surrey



Phys. Rev. Lett. ***111**, 062501 (2013)*
Phys. Rev. C ***92**, 014306 (2015)*

Collaborators

UNIVERSITY OF SURREY

A. Cipollone,
A. Rios, A. Idini, F. Raimondi

Universitat de Barcelona

A. Polls

cea
energie atomique • energies alternatives

V. Somà, T. Duguet

Washington University in St. Louis

W.H. Dickhoff,
S. Waldecker

EMMI
TECHNISCHE UNIVERSITÄT DARMSTADT

A. Carbone

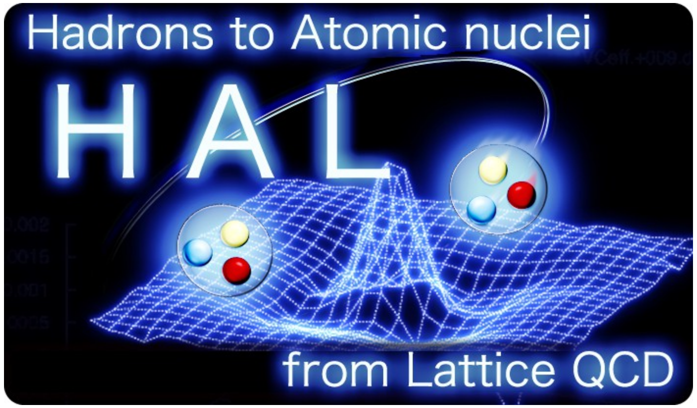
Center for Molecular Modeling

D. Van Neck,
M. Degroote

TRIUMF

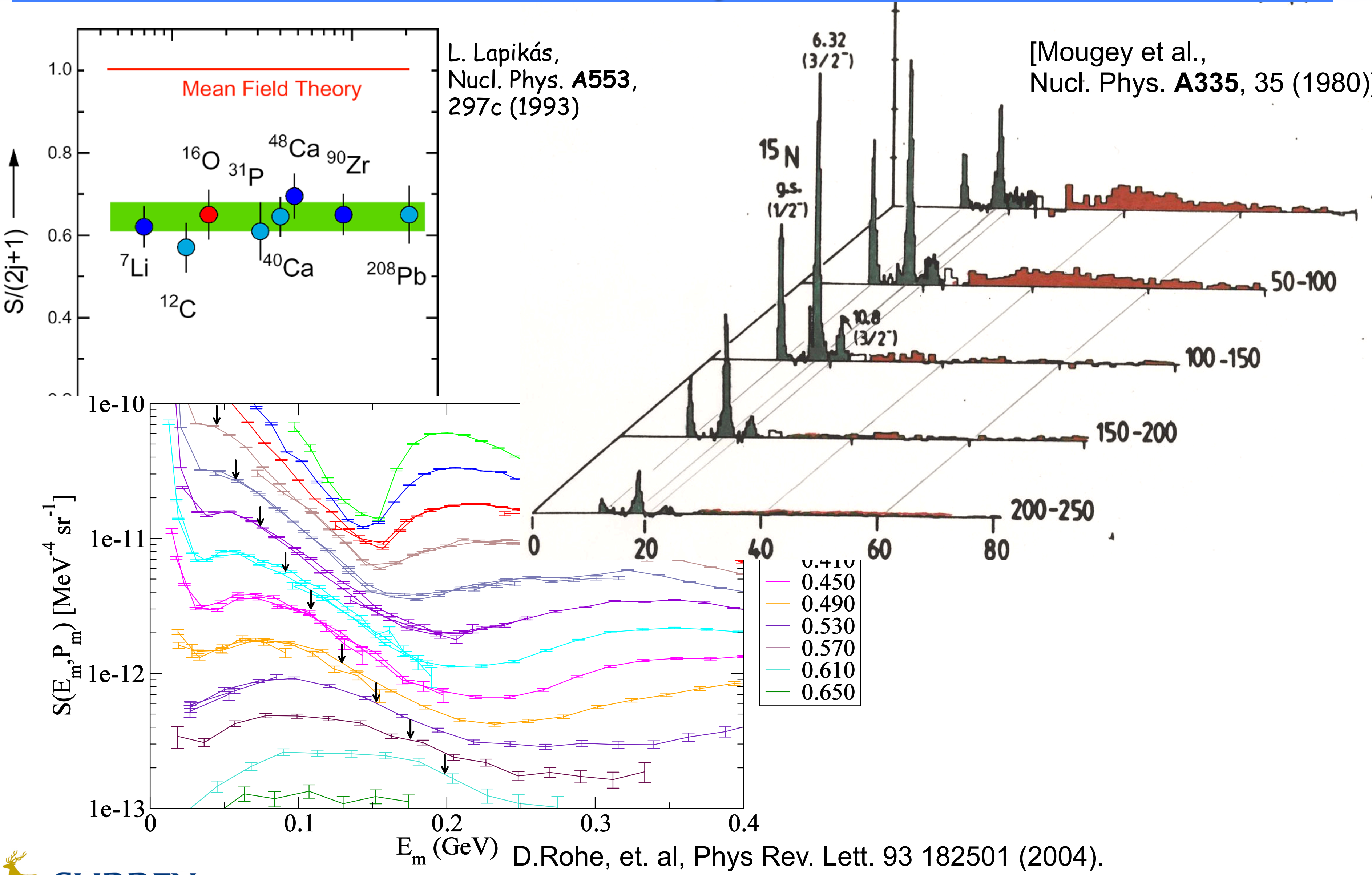
P. Navratil

M. Hjorth-Jensen



S. Aoki,	YITP Kyoto Univ.
T. Doi, T. Hatsuda, Y. Ikeda,	RIKEN Nishina
T. Inoue,	Nihon Univ.
N. Ishii, K. Murano,	RCNP Osaka Univ
H. Nemura K. Sasaki	Univ. Tsukuba
F. Etminan	Univ. Birjand
T. Miyamoto,	Univ. Tsukuba
T. Iritani	Stony Brook Univ.
S. Gongyo	YITP Kyoto Univ.

Past (e,e'p) data



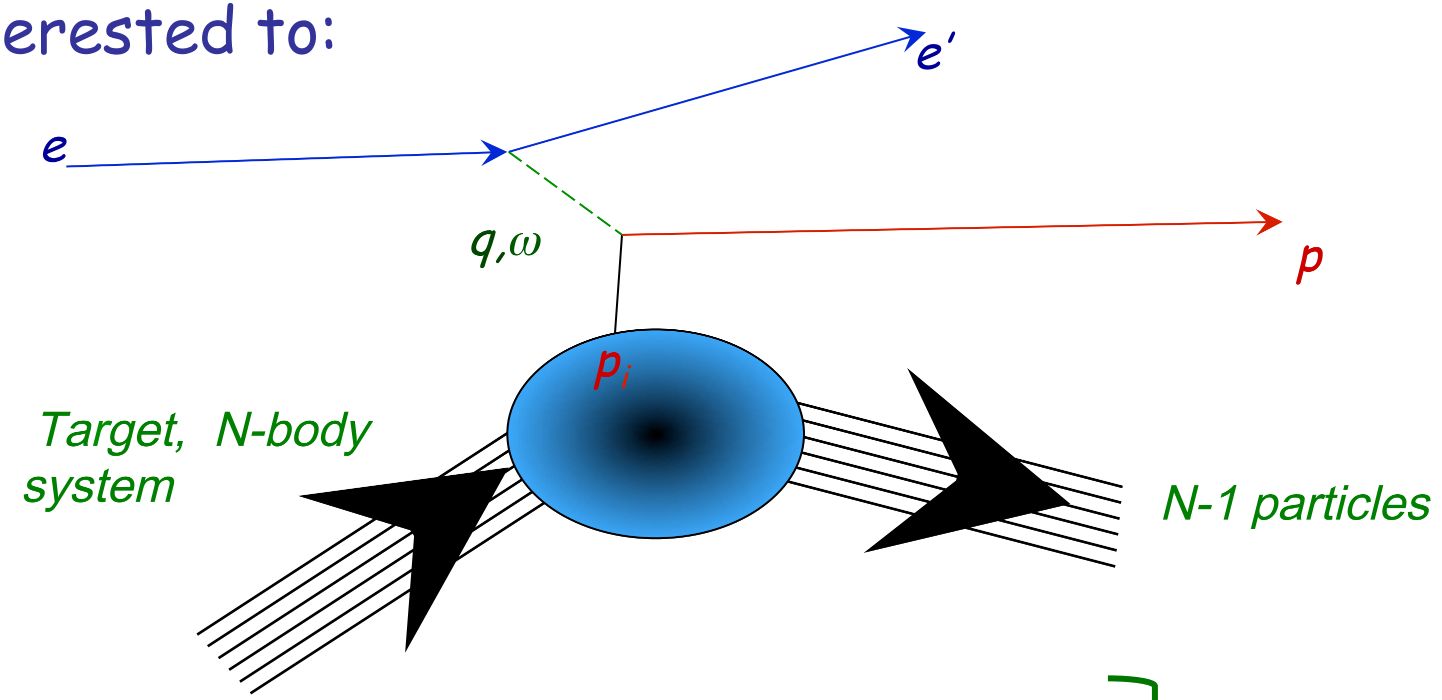
L. Lapikás,
Nucl. Phys. **A553**,
297c (1993)

[Mougey et al.,
Nucl. Phys. **A335**, 35 (1980)]

D.Rohe, et. al, Phys Rev. Lett. 93 182501 (2004).

Spectroscopy via knock out reactions-*basic idea*

Use a probe (ANY probe) to eject the particle we are interested to:



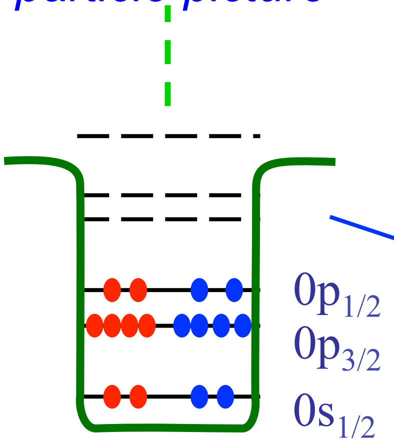
Basic idea:

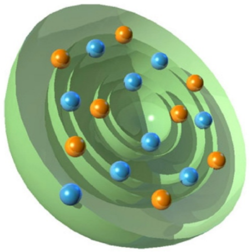
- we know, e, e′ and p
- "get" *energy and momentum* of p_i: $p_i = k_e' + k_p - k_e$
  $E_i = E_e' + E_p - E_e$

Better to choose large transferred momentum and weak probes*!!!*

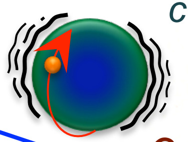
Concept of correlations

independent particle picture

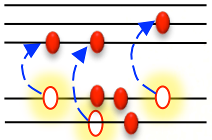




Particle-vibration coupling (PV)

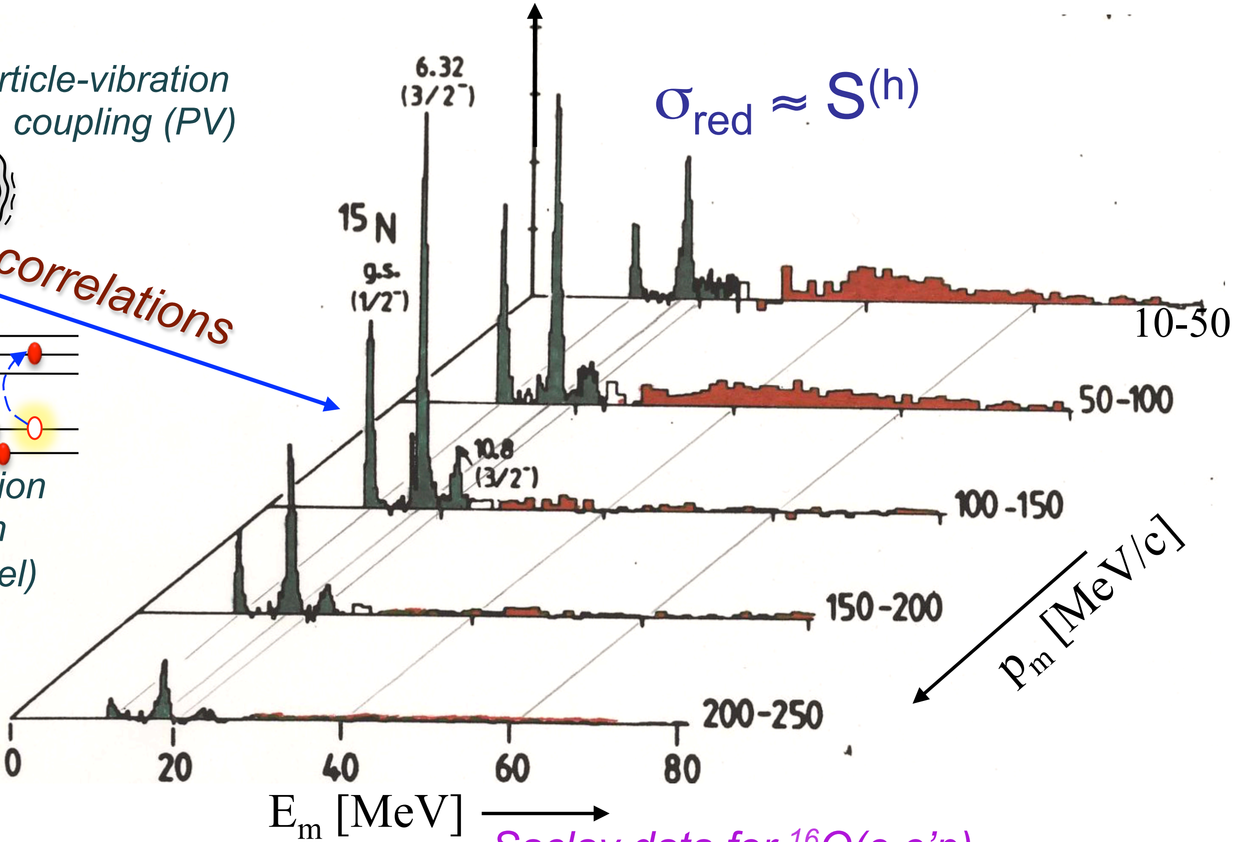


correlations



Configuration interaction (shell model)

Spectral function: distribution of momentum (p_m) and energies (E_m)



$\sigma_{red} \approx S^{(h)}$

Saclay data for $^{16}O(e,e'p)$

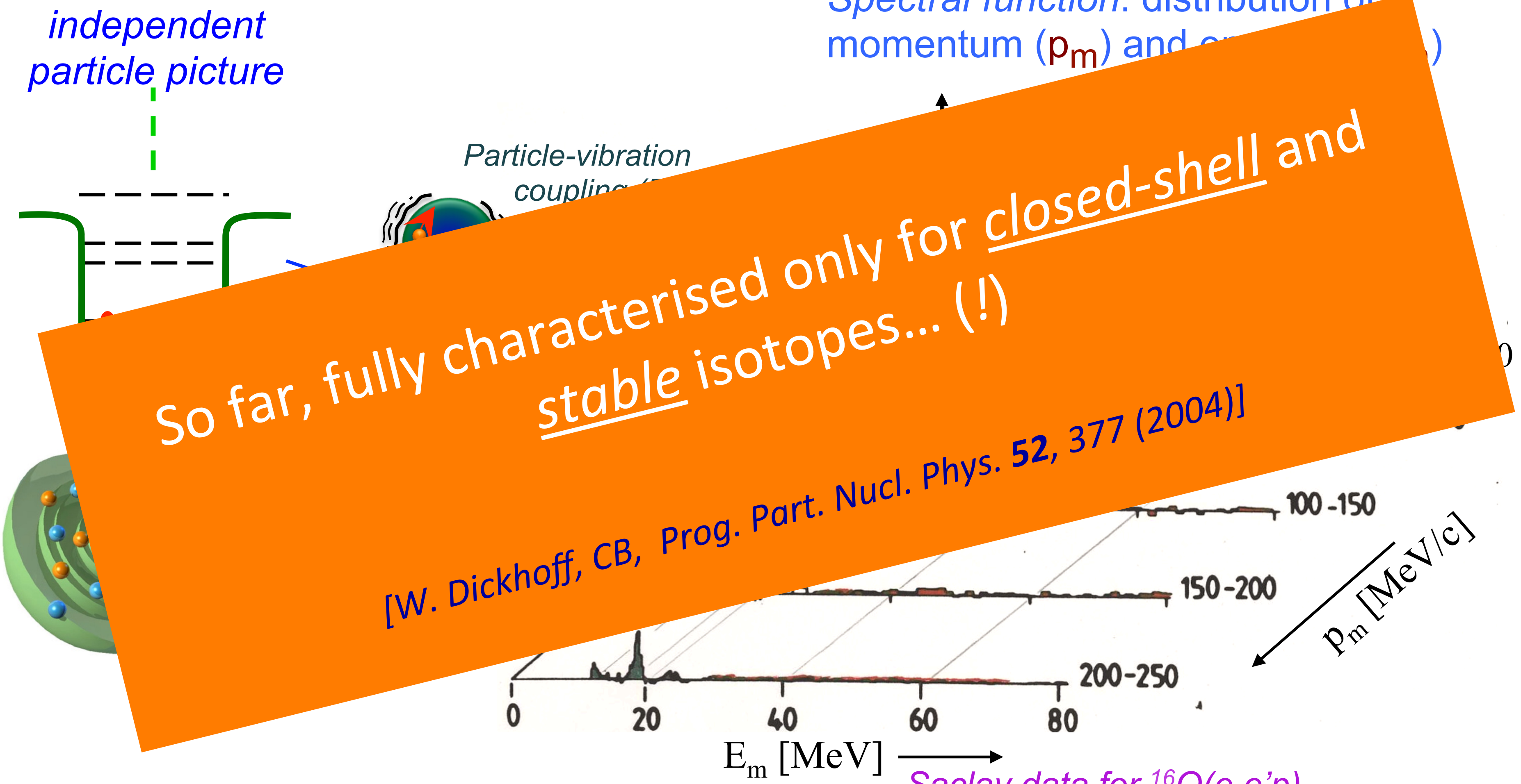
[Mougey et al., Nucl. Phys. A335, 35 (1980)]

Understood for a few stable closed shells:

*[CB and W. H. Dickhoff, Prog. Part. Nucl. Phys **52**, 377 (2004)]*

Concept of correlations

Spectral function: distribution of
momentum (p_m) and



So far, fully characterised only for <u>closed-shell</u> and <u>stable</u> isotopes… (!)

[W. Dickhoff, CB, Prog. Part. Nucl. Phys. **52**, 377 (2004)]

Saclay data for ^{16}O(e,e'p)
[Mougey et al., Nucl. Phys. A335, 35 (1980)]

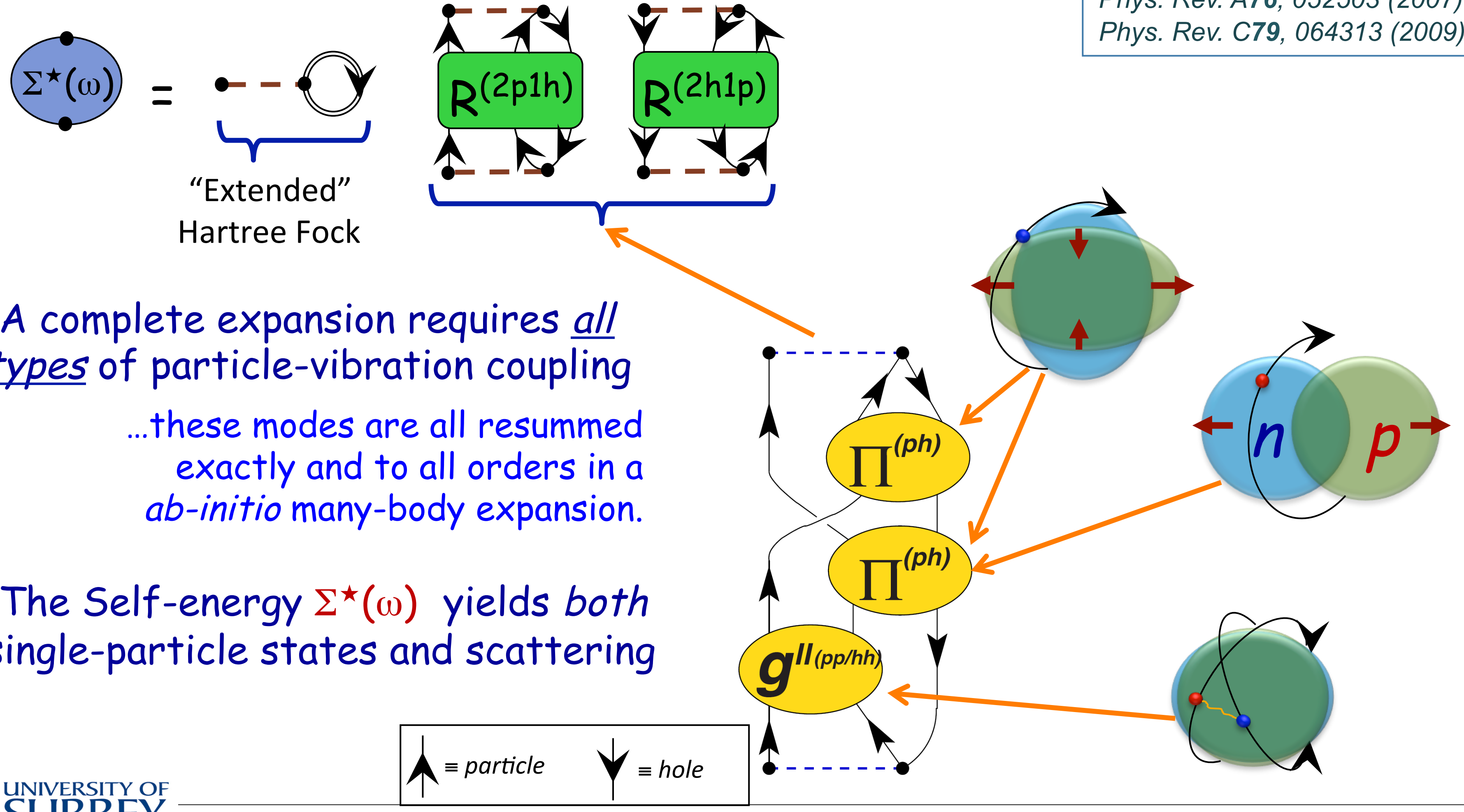
Understood for a few stable closed shells:
[CB and W. H. Dickhoff, Prog. Part. Nucl. Phys ***52****, 377 (2004)]*

Ab-Initio SCGF approaches

The FRPA Method in Two Words

Particle vibration coupling is the main cause driving the distribution of particle strength—on both sides of the Fermi surface…

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

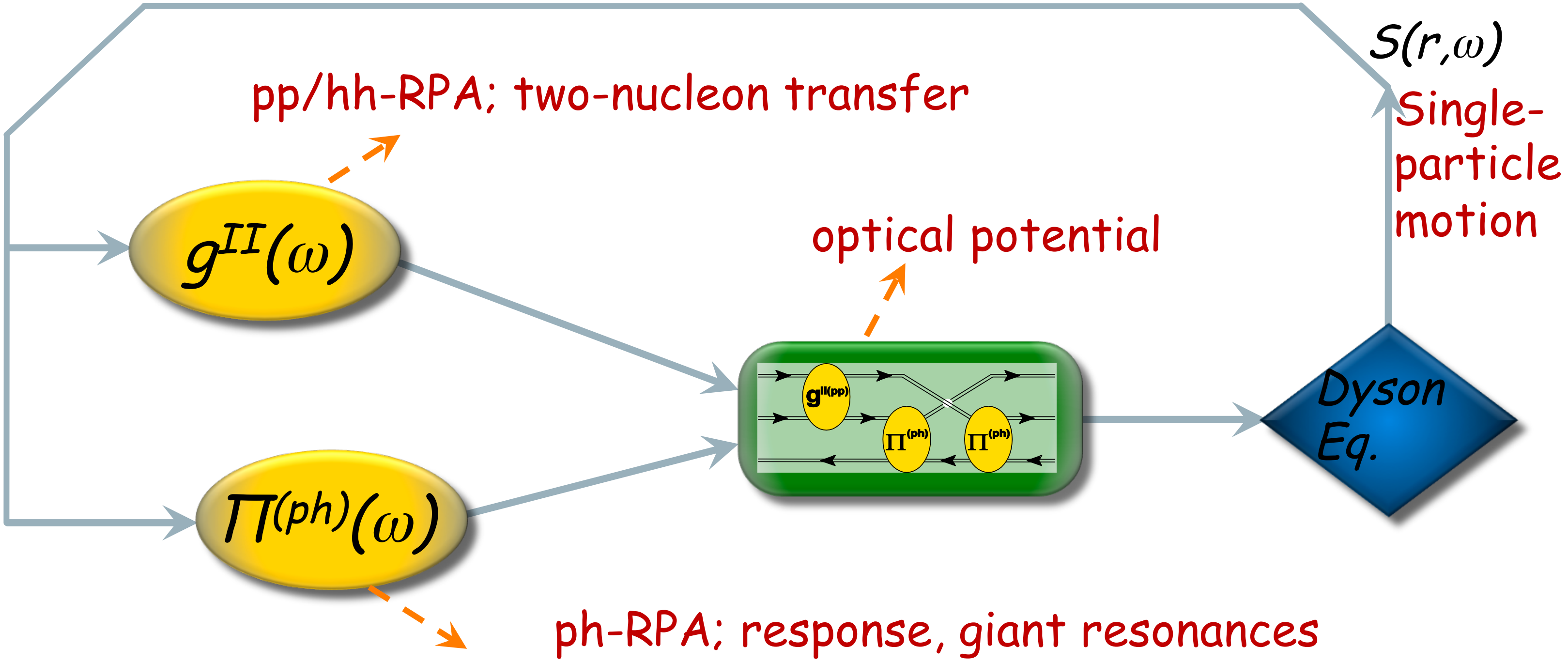


- *A complete expansion requires* ***all types*** of particle-vibration coupling

…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

Self-Consistent Green's Function Approach



$S(r,\omega)$

Single-particle motion

pp/hh-RPA; two-nucleon transfer

$g^{II}(\omega)$

optical potential

Dyson Eq.

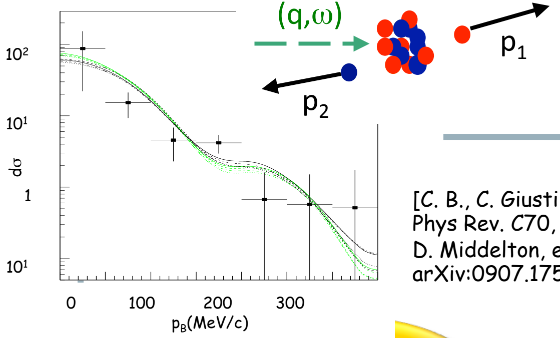
$\Pi^{(ph)}(\omega)$

ph-RPA; response, giant resonances

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

Self-Consistent Green's Function Approach

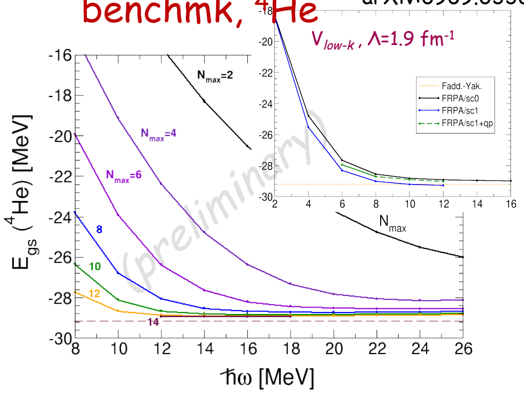
$^{16}O(e,e'pn)^{14}N$ @ MAINZ



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

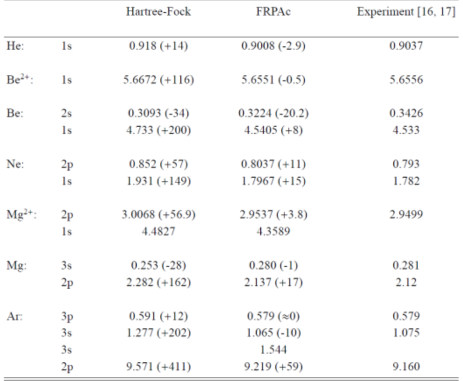
Binding energy benchmk, ^4He

[C. B.,
arXiv:0909.0336]

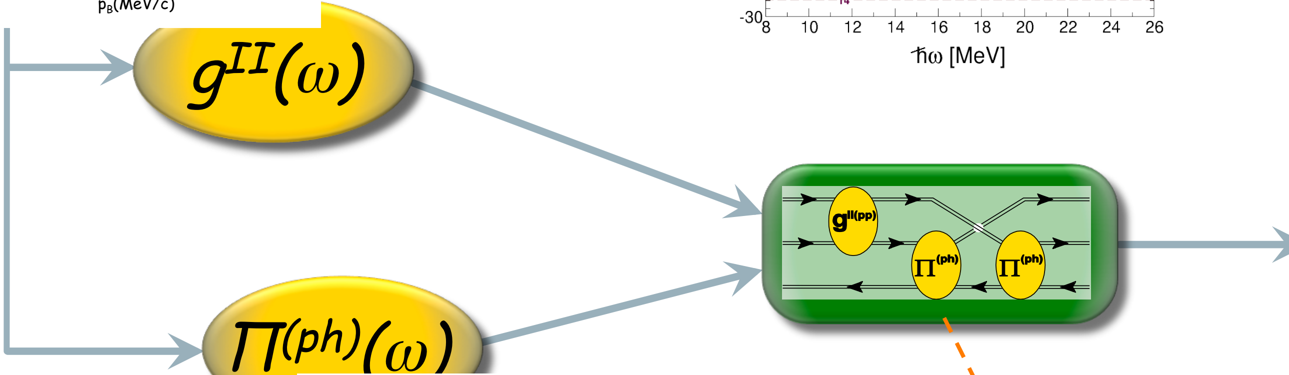


Ionization energies/ affinities, in atoms

[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

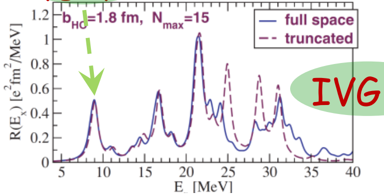


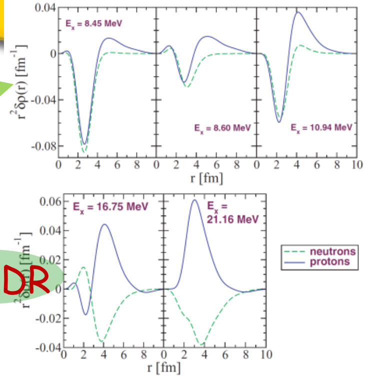
Dyson Eq.

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

Proton Pygmy

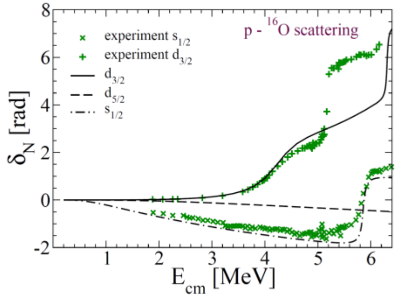
IVGDR

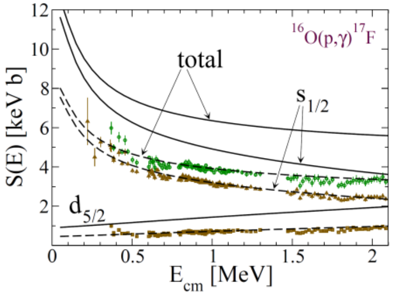




[C. B., K. Langanke, et al., Phys Rev. C77, 024304 (2008)]

$^{16}O(p,\gamma)$





[C. B., B. K. Jennings
Nucl. Phys A758, 395c (2005)
Phys Rev. C72, 014613 (2005)]

Gorkov and symmetry breaking approaches

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)

- Ansatz $\boxed{\ldots \approx E_0^{N+2} - E_0^{N} \approx E_0^{N} - E_0^{N-2} \approx \ldots \approx 2\mu}$

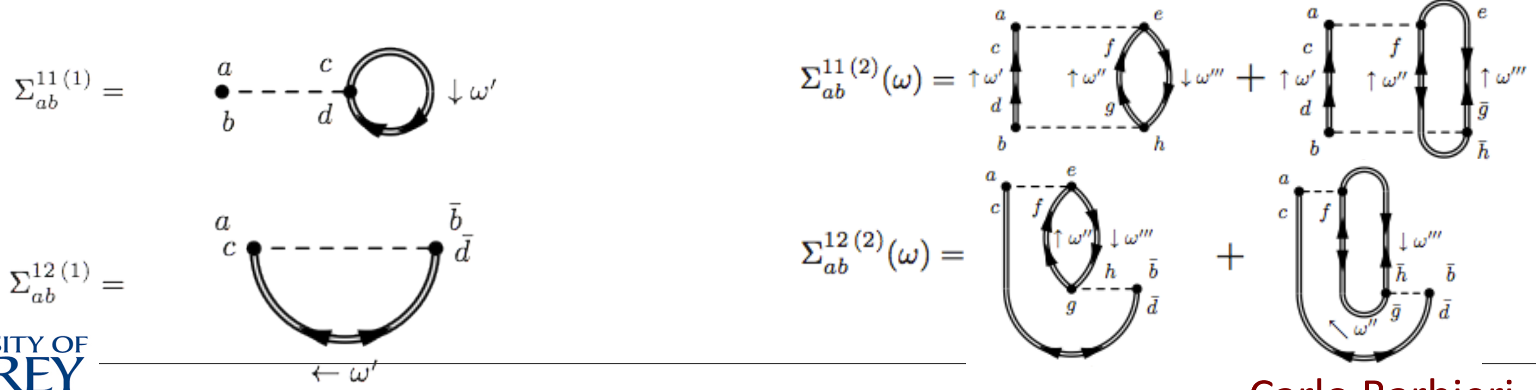
- Auxiliary many-body state $|\Psi_0\rangle \equiv \sum_{N}^{\text{even}} c_N \, |\psi_0^N\rangle$

  → Mixes various particle numbers

  → Introduce a “grand-canonical” potential $\Omega = H - \mu N$

⇒ $|\Psi_0\rangle$ minimizes $\Omega_0 = \langle\Psi_0|\Omega|\Psi_0\rangle$ under the constraint $N = \langle\Psi_0|N|\Psi_0\rangle$

- This approach leads to the following Feynman diagrams:



Approaches in GF theory

Truncation scheme:	Dyson formulation (closed shells)	Gorkov formulation (semi-magic)
1st order:	Hartree-Fock	HF-Bogolioubov
2nd order:	2nd order	2nd order (w/ pairing)
. . .	. . .	
3rd and all-orders sums, P-V coupling:	ADC(3) FRPA etc…	G-ADC(3) …work in progress

Approaches in GF theory

Truncation scheme:

Dyson formulation (closed shells)

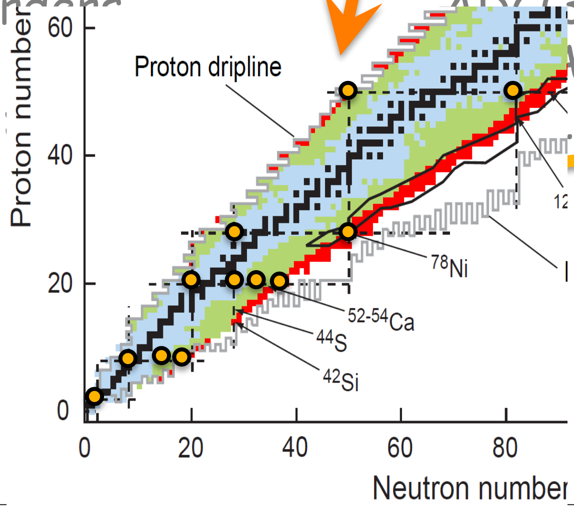
Gorkov formulation (semi-magic)

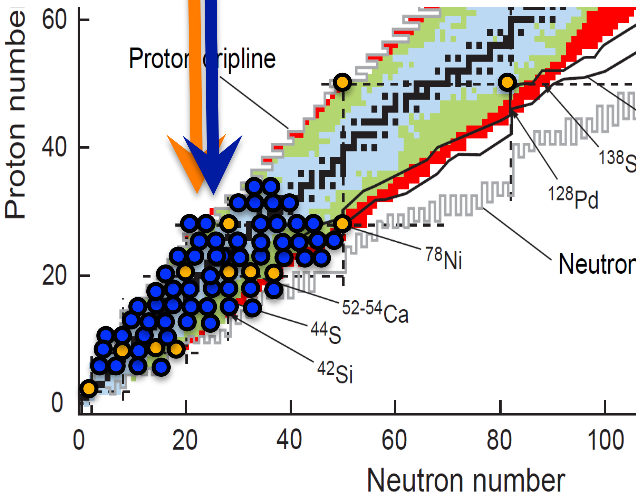
1st order: Hartree-Fock HF-Bogolioubov

2nd order: 2nd order 2nd order (w/ pairing)

. . . . . .

3rd and all-orders sums,
P-V coupling: ADC(3)



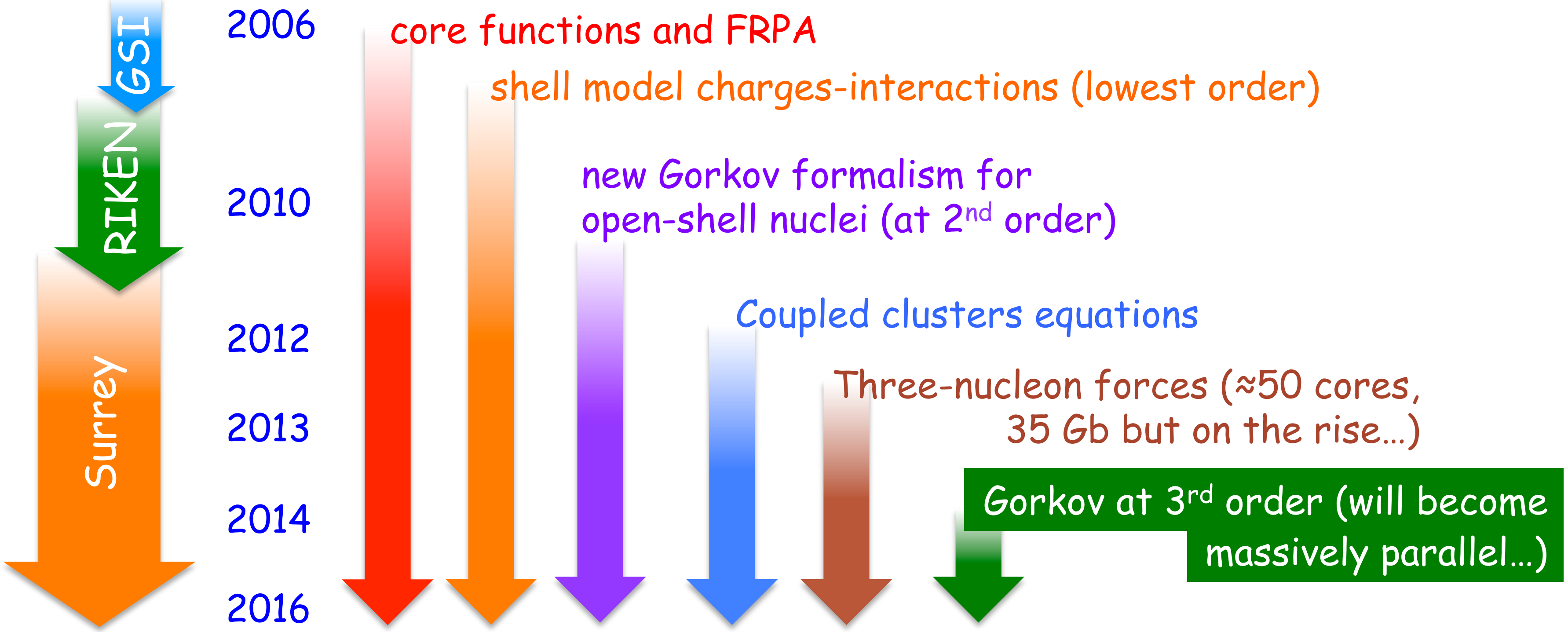


Ab-initio Nuclear Computation & BcDor code

BoccaDorata code:
(C. Barbieri *2006-14*
V. Somà 2011-14
A. Cipollone 2012-13)

- Provides a *C++ class library* for handling many-body propagators (≈40,000 lines, OpenMPI based).
- Allows to solve for nuclear spectral functions, many-body propagators, RPA responses, coupled cluster equations and effective interaction/charges for the shell model.

Code history:



core functions and FRPA

shell model charges-interactions (lowest order)

new Gorkov formalism for open-shell nuclei (at 2nd order)

Coupled clusters equations

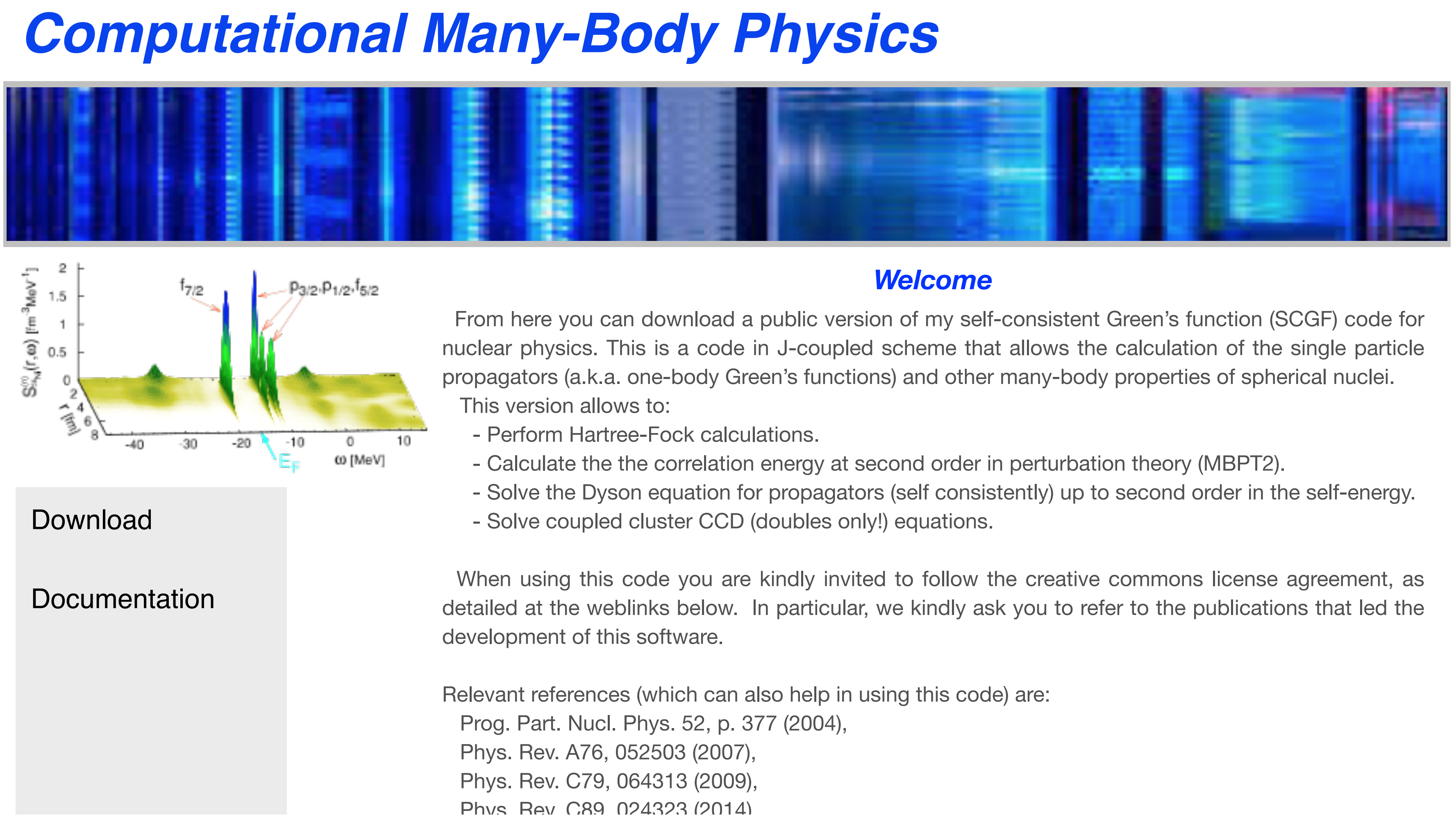
Three-nucleon forces (≈50 cores, 35 Gb but on the rise…)

Gorkov at 3rd order (will become massively parallel…)

… applications …

Ab-initio Nuclear Computation & BcDor code

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



Computational Many-Body Physics

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.

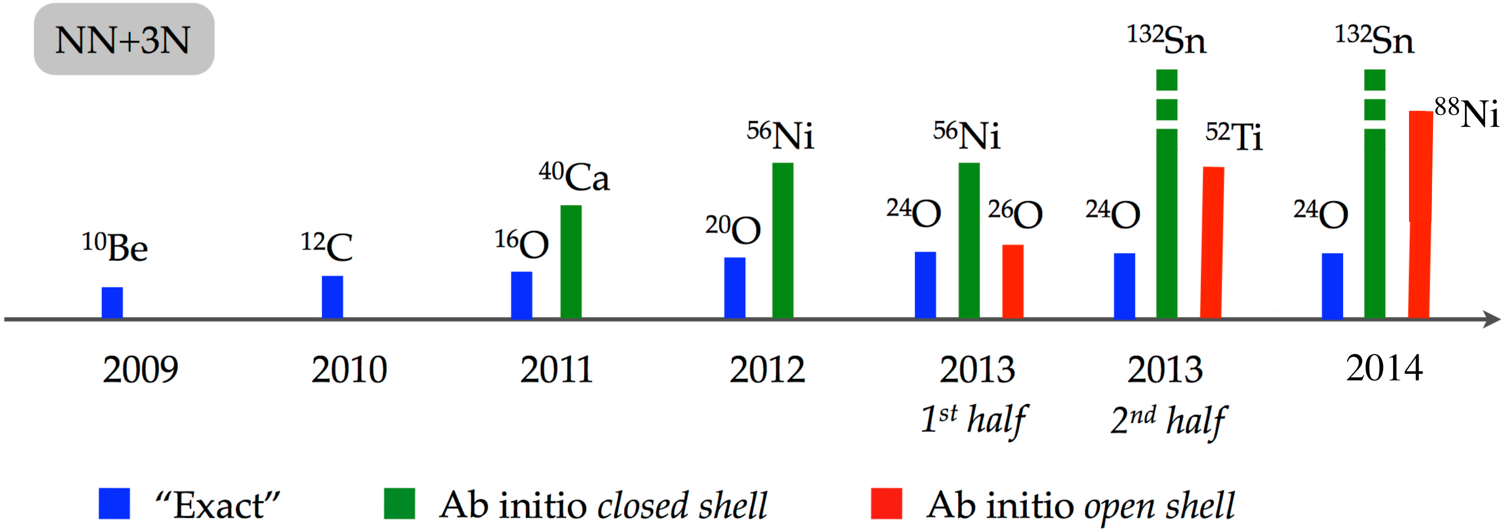
Relevant references (which can also help in using this code) are:

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

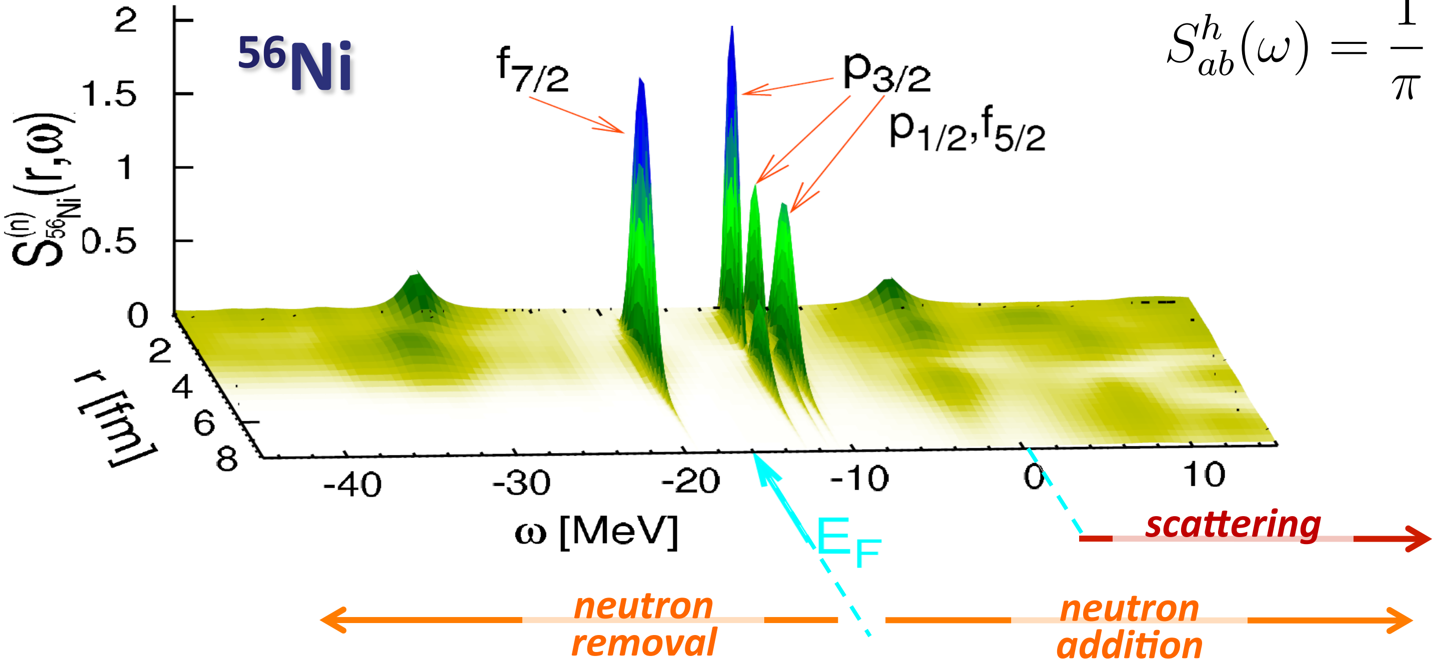
Reaching medium mass and neutron rich isotopes

➔Degenerate system (open shells, deformations…)

➔Hamiltoninan, including three nucleon forces



^{56}Ni neutron spectral function



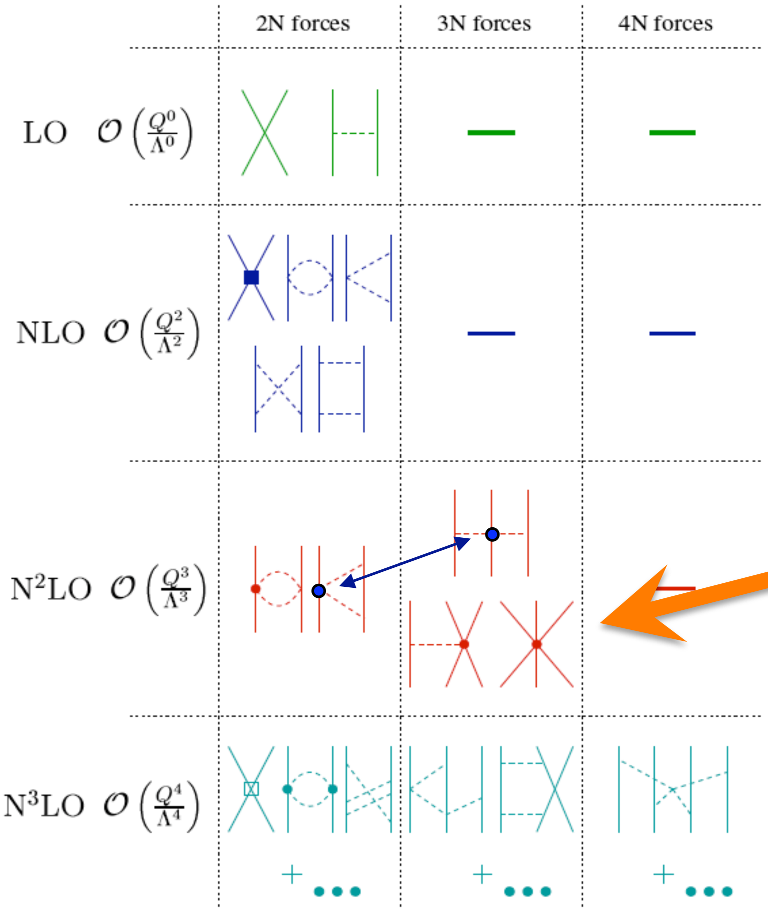
$$S^h_{ab}(\omega) = \frac{1}{\pi}\, Im\, g_{ab}(\omega)$$

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

Medium-mass isotopes from chiral interactions

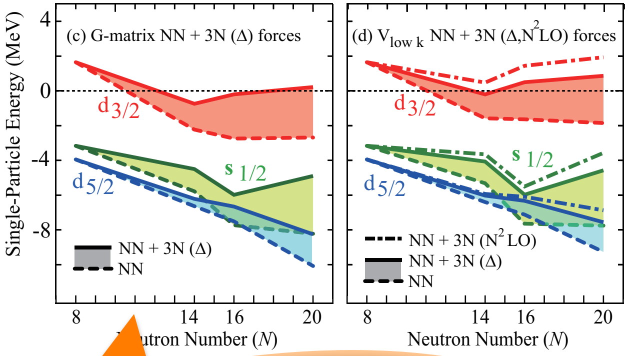
Modern realistic nuclear forces

Chiral EFT for nuclear forces:



(3NFs arise naturally at N2LO)

Single particle spectrum at E_{fermi}:

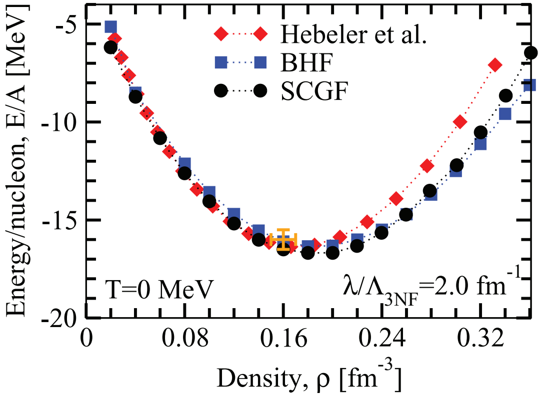


[T. Otsuka et al., Phys Rev. Lett **105**, 032501 (2010)]

Need at LEAST 3NF!!!

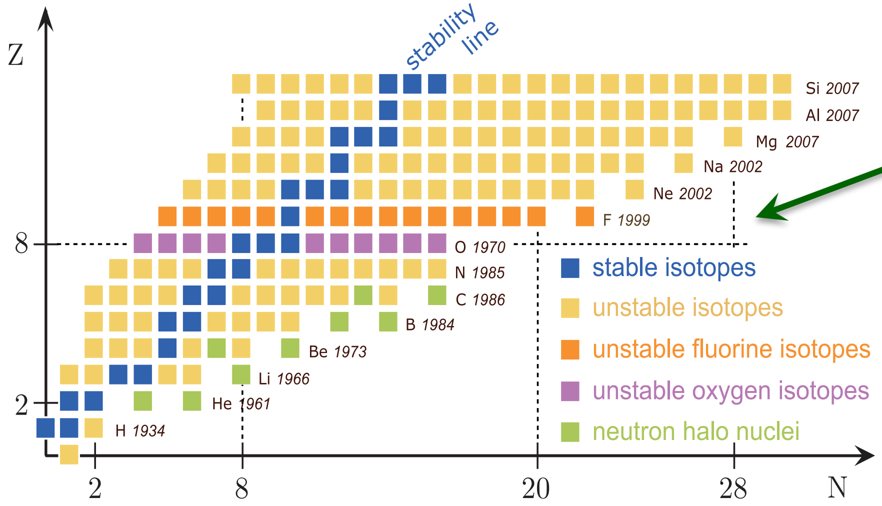
("cannot" do RNB physics without...)

Saturation of nuclear matter:



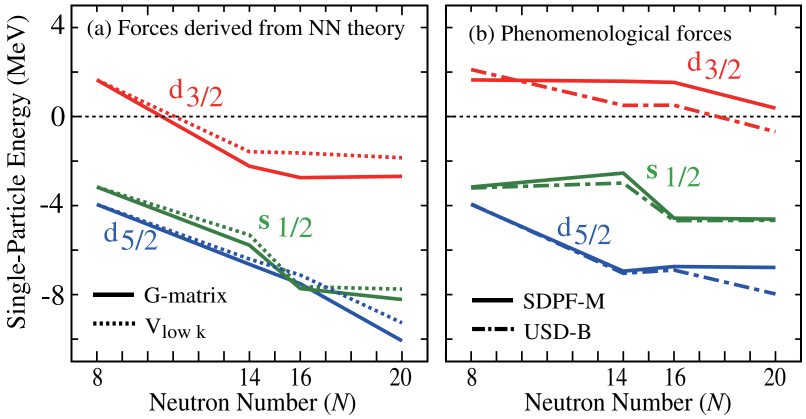
[A. Carbone et al., Phy.s Rev. C **88**, 044302 (2013)]

Oxygen puzzle…

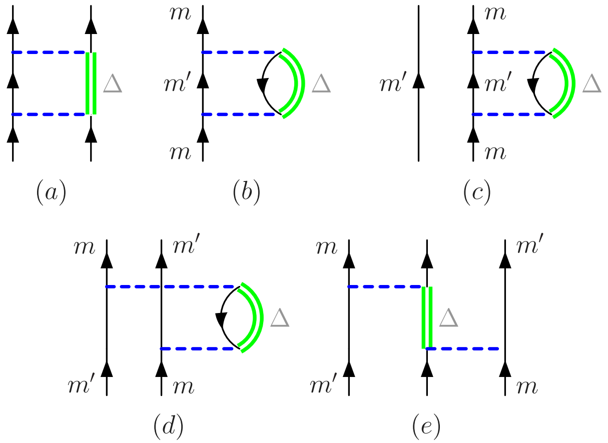


The oxygen dripline is at ^{24}O, at odds with other neighbor isotope chains.

Phenomenological shell model interaction reflect this in the s.p. energies but no realistic NN interaction alone is capable of reproducing this…

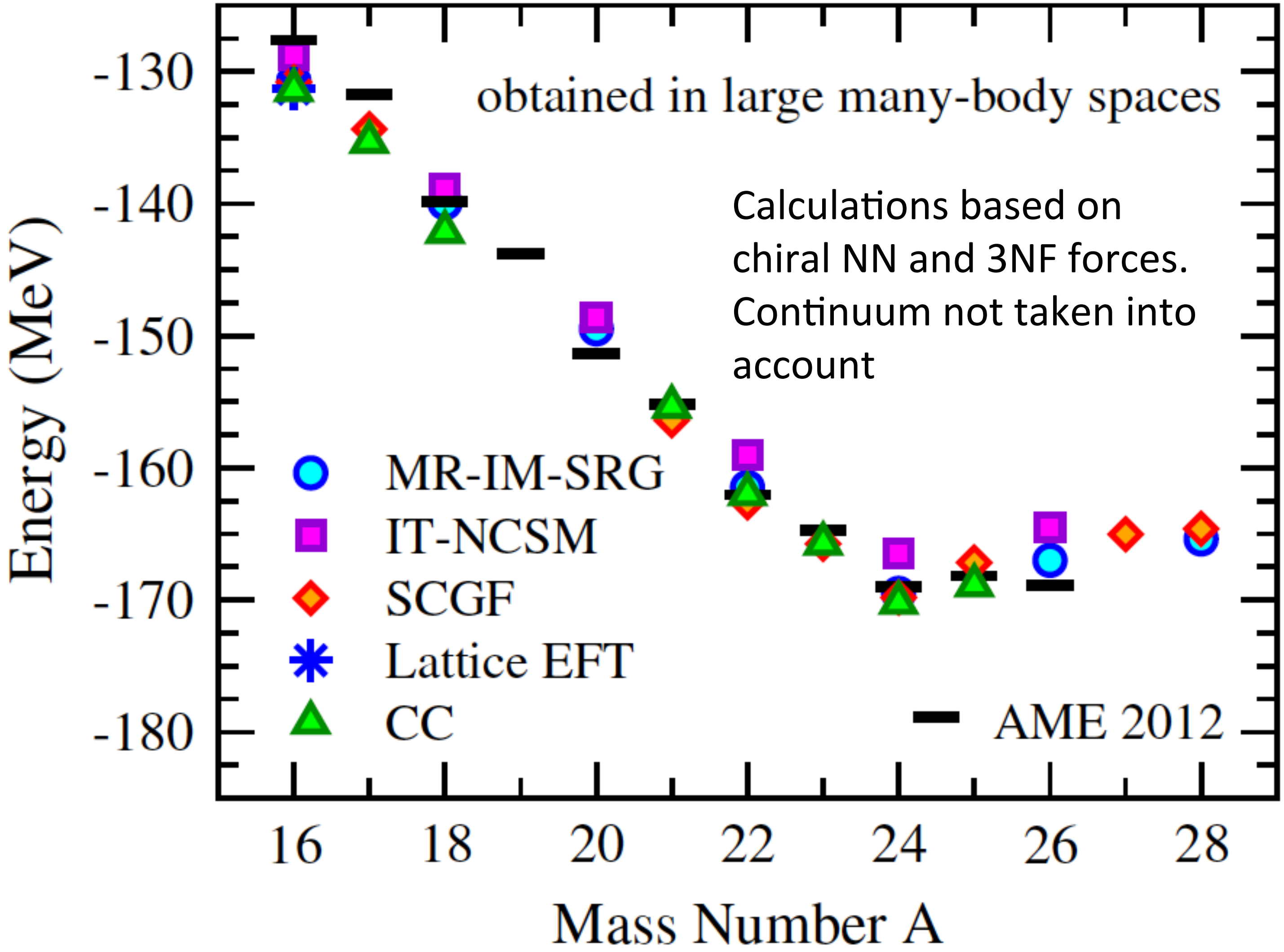


The fujita-Miyazawa 3NF provides repulsion through Pauli screening of other 2NF terms:



[T. Otsuka et al., Phys Rev. Lett **105**, 32501 (2010)]

Benchmark of ab-initio methods in the oxygen isotopic chain



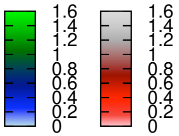
obtained in large many-body spaces

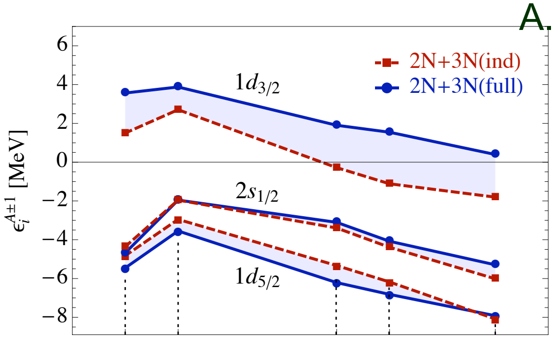
Calculations based on chiral NN and 3NF forces. Continuum not taken into account

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

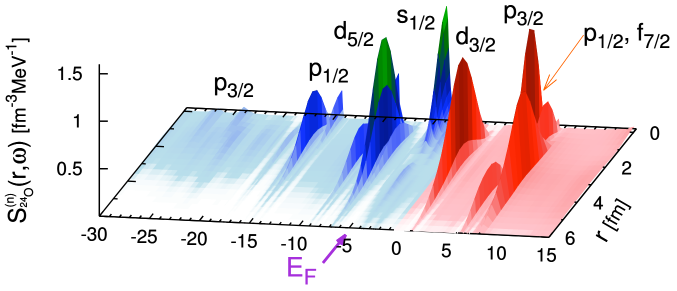
Neutron spectral function of Oxygens

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

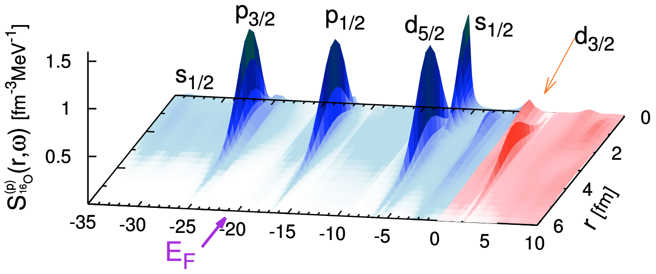




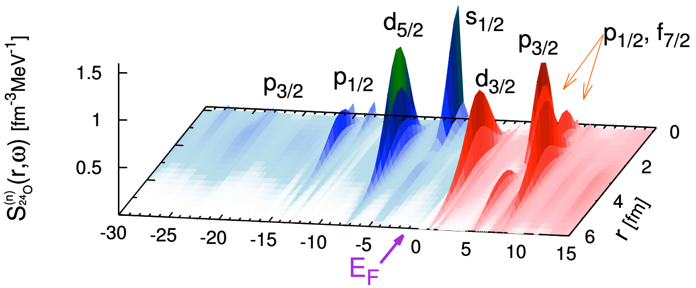
^{22}O:



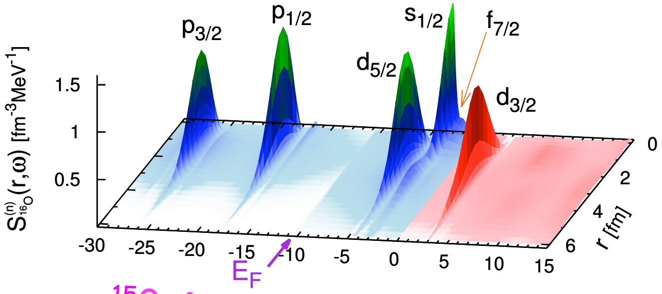
^{14}O:



^{24}O:

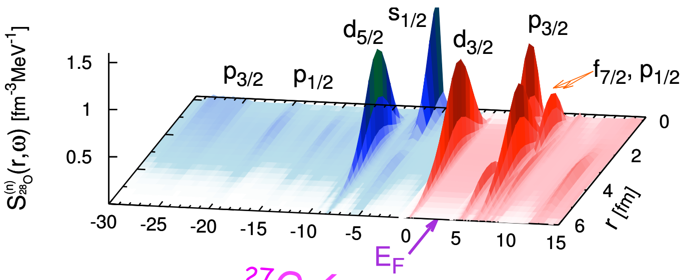


^{16}O:



^{15}O ← → ^{17}O

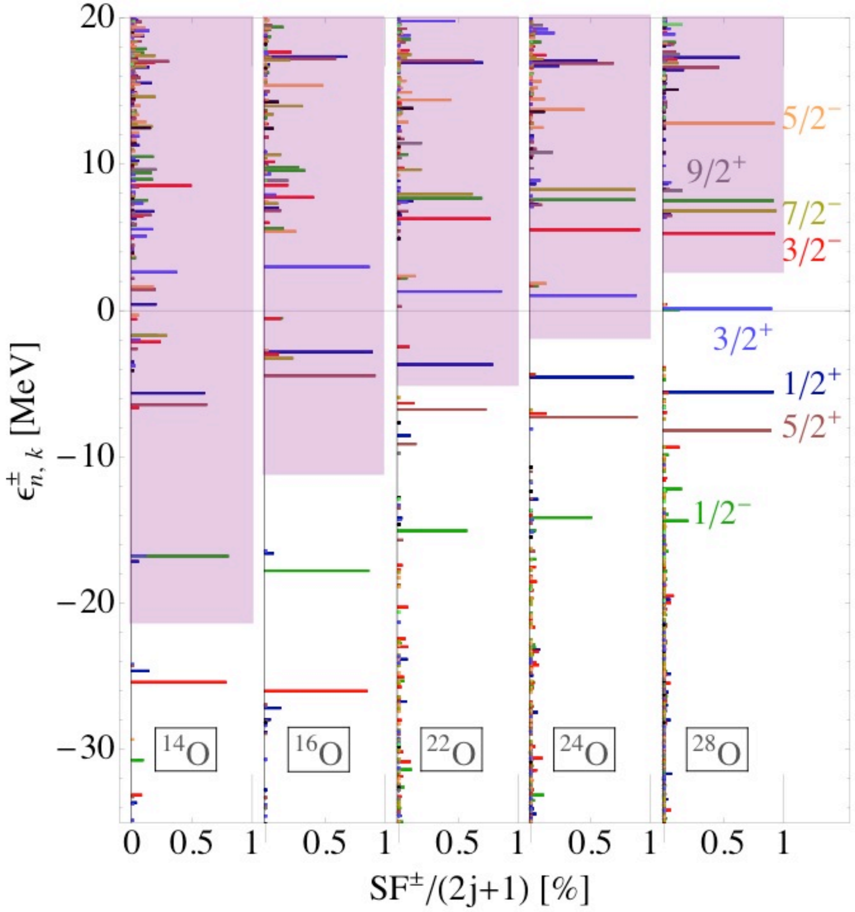
^{28}O:

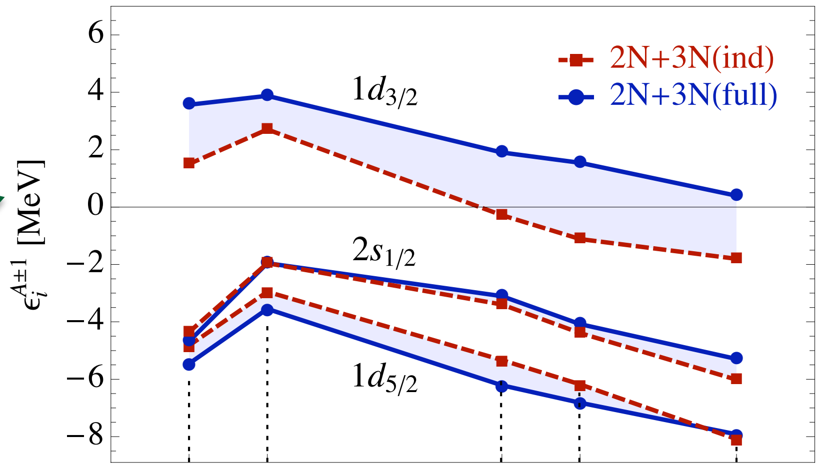


^{27}O ← → ^{29}O

Results for the N-O-F chains

A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)
and Phys. Rev. C **92**, 014306 (2015)



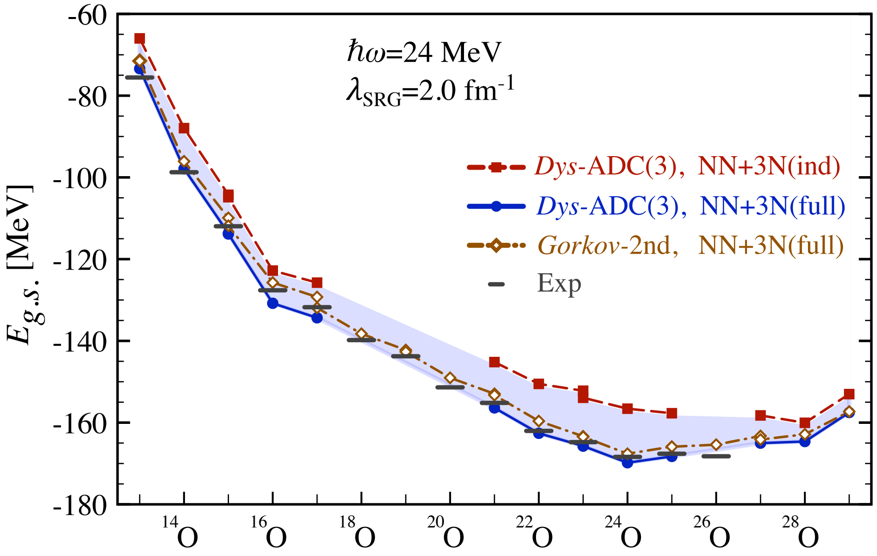


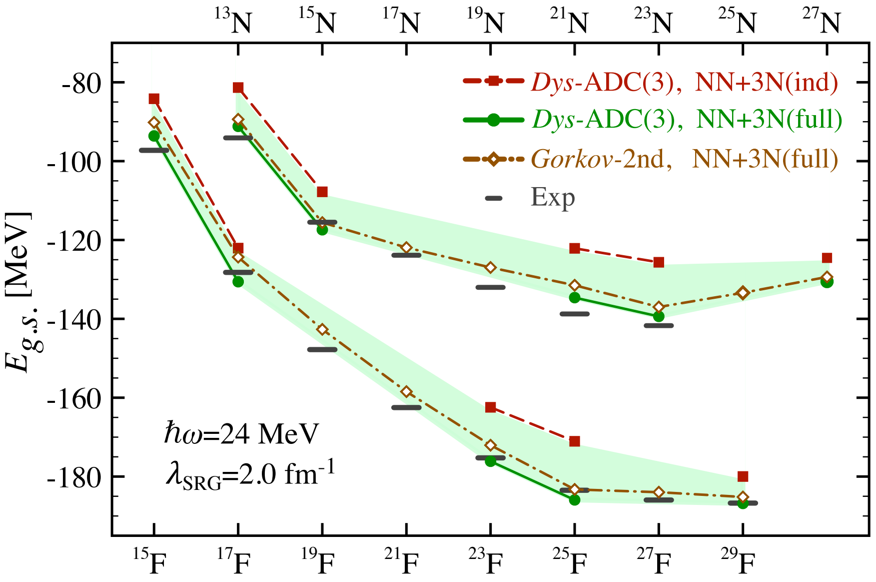
→ *$d_{3/2}$ raised* by genuine 3NF

→ cf. microscopic shell model [Otsuka et al, PRL**105**, 032501 (2010).]

Results for the N-O-F chains

A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)
and Phys. Rev. C **92**, 014306 (2015)





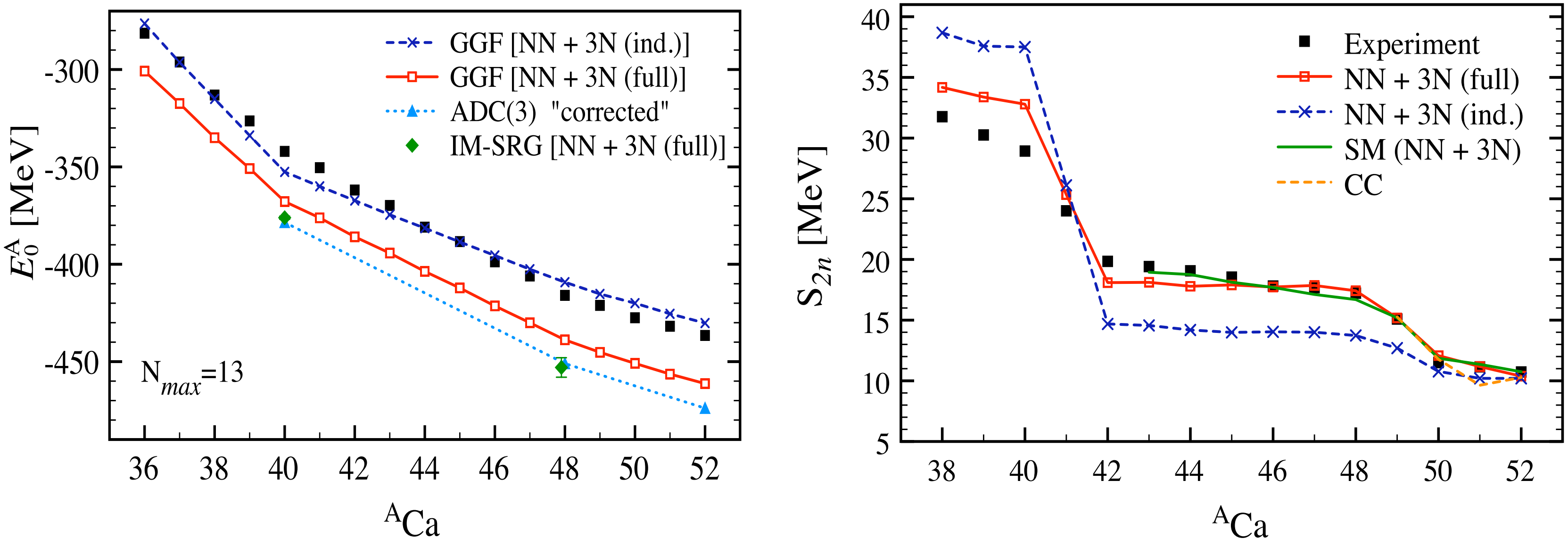
→ 3NF crucial for reproducing binding energies and driplines around oxygen

→ cf. microscopic shell model [Otsuka et al, PRL**105**, 032501 (2010).]

N3LO (Λ = 500Mev/c) chiral NN interaction evolved to 2N + 3N forces (2.0fm^{-1})
N2LO (Λ = 400Mev/c) chiral 3N interaction evolved (2.0fm^{-1})

Calcium isotopic chain

Ab-initio calculation of the whole Ca: *induced* and full 3NF investigated



→ *induced* and full 3NF investigated

→ genuine (N2LO) 3NF needed to reproduce the energy curvature and S_{2n}

→ N=20 and Z=20 gaps overestimated!

→ Full 3NF give a correct trend but over bind!

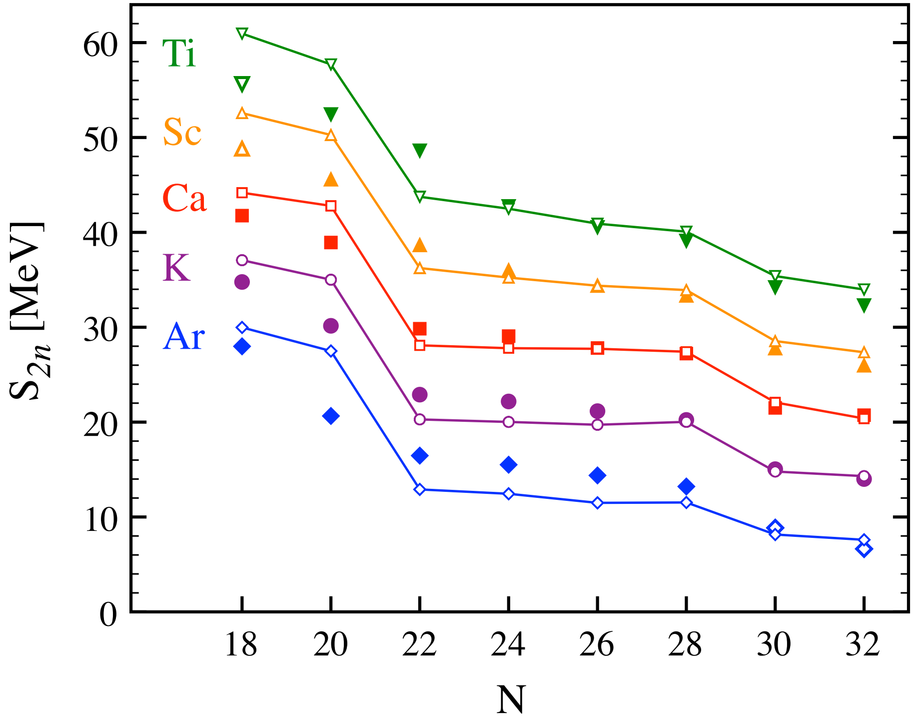
V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

UNIVERSITY OF SURREY

Neighbouring Ar, K, Ca, Sc, and Ti chains

V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

Two-neutron separation energies predicted by chiral NN+3NF forces:

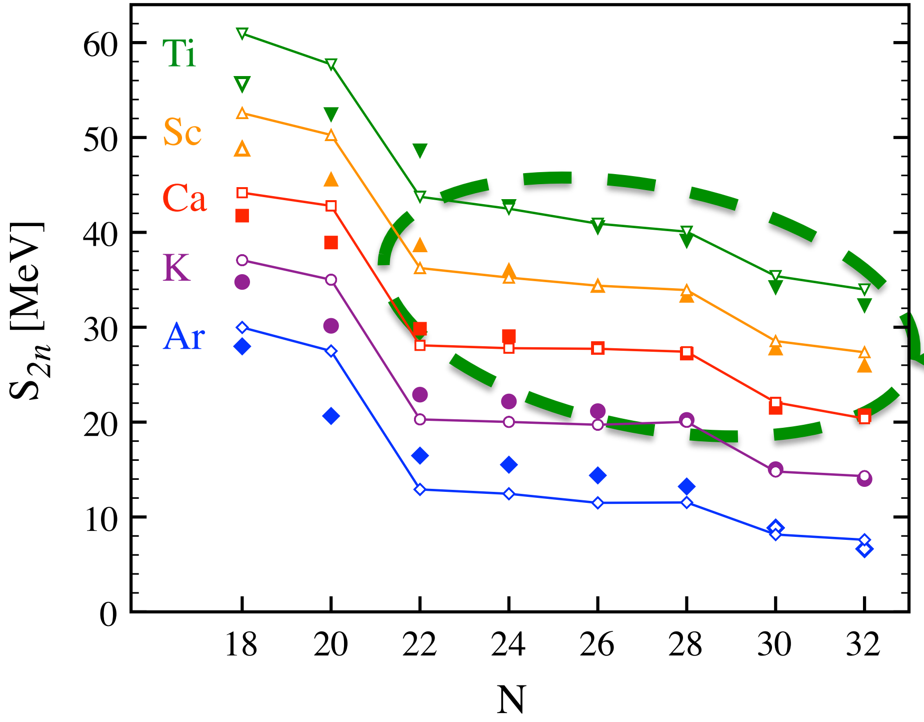


→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

Neighbouring Ar, K, Ca, Sc, and Ti chains

V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

Two-neutron separation energies predicted by chiral NN+3NF forces:



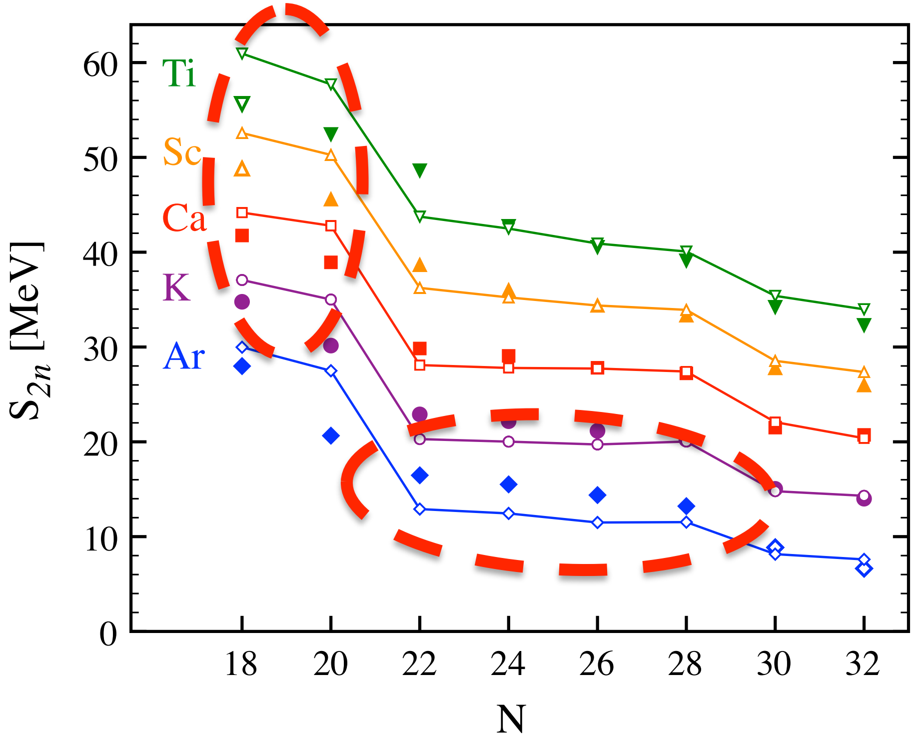
Works well in
the *pf* shell

→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

Neighbouring Ar, K, Ca, Sc, and Ti chains

V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

Two-neutron separation energies predicted by chiral NN+3NF forces:



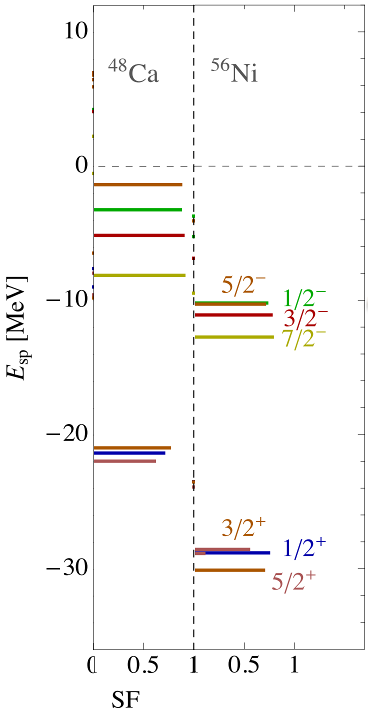
Lack of deformation due to quenched cross-shell quadrupole excitations

→ First *ab-initio* calculation over a contiguous portion of the nuclear chart—open shells are now possible through the Gorkov-GF formalism

The sd-pf shell gap

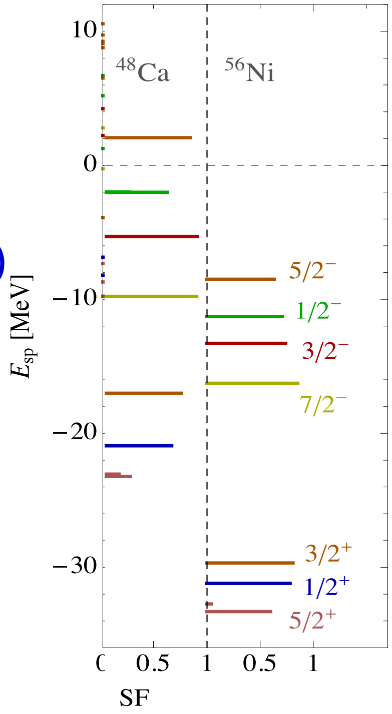
Neutron spectral distributions for ^{48}Ca and ^{56}Ni:

2N + 3NF (induced)



+3NFs (NNLO)

2N + 3NF (FULL)

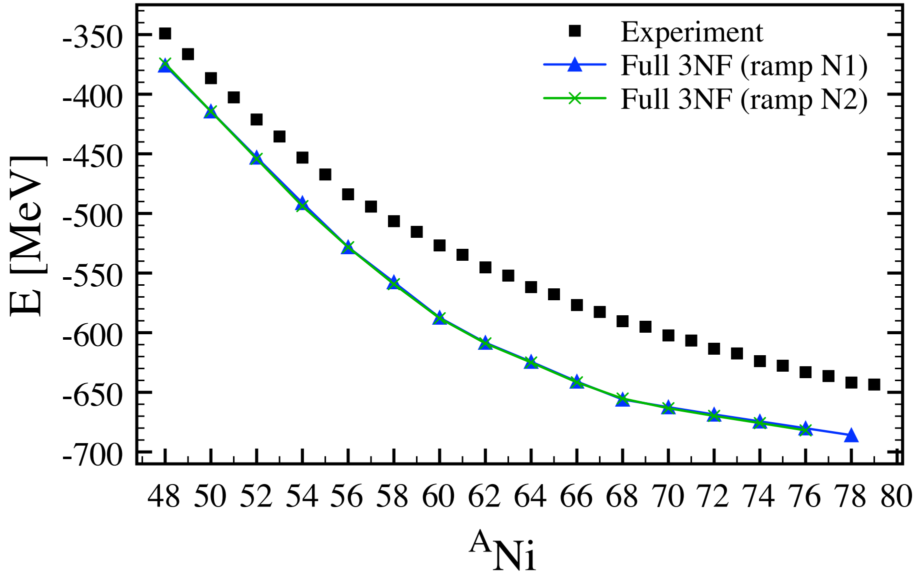


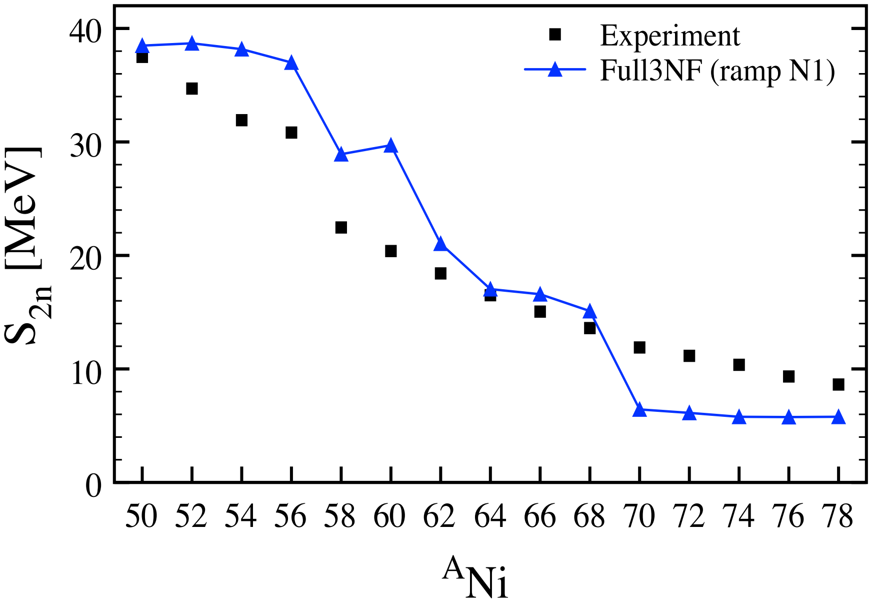
- *sd-pf separation is overestimated* even with leading order N2LO 3NF
- Correct increase of $p_{3/2}$-$f_{7/2}$ splitting (see Zuker 2003)

	2NF only	2+3NF(ind.)	2+3NF(full)	Experiment
^{16}O:	2.10	2. 41	2.38	2.718±0.210 [19]
^{44}Ca:	2.48	2.93	2.94	3.520±0.005 [20]

CB *et al.*, arXiv:1211.3315 [nucl-th]

Ni isotopic chain





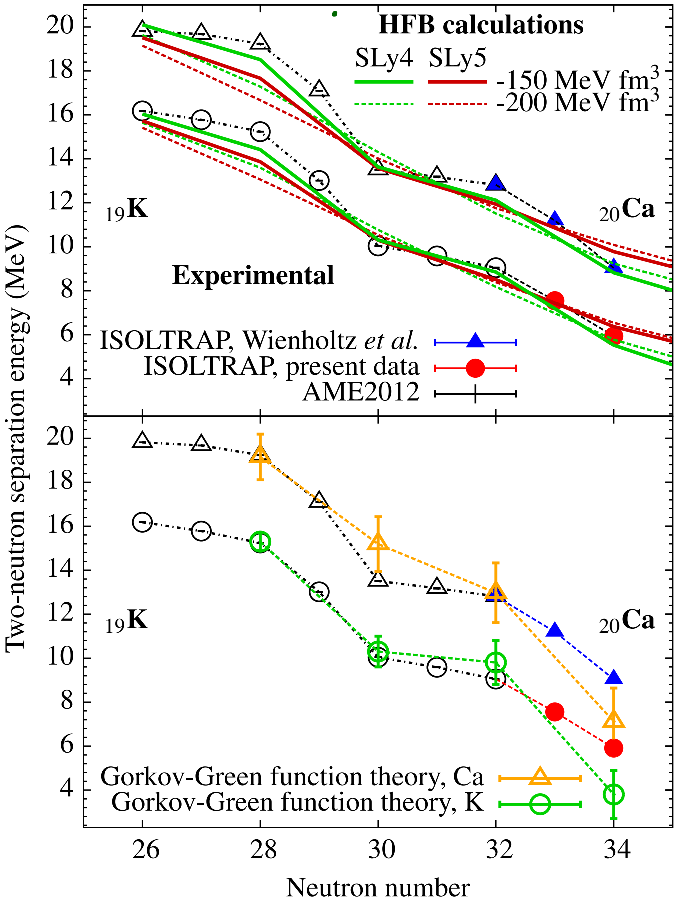
→ Large J in free space SRG matter (must pay attention to its convergence)

→ Overall conclusions regarding over binding and S_{2n} remain but details change

IM-SRG results from H. Hergert

Two-neutron separation energies for neutron rich K isotopes

*M. Rosenbusch, et al., PRL**114**, 202501 (2015)*



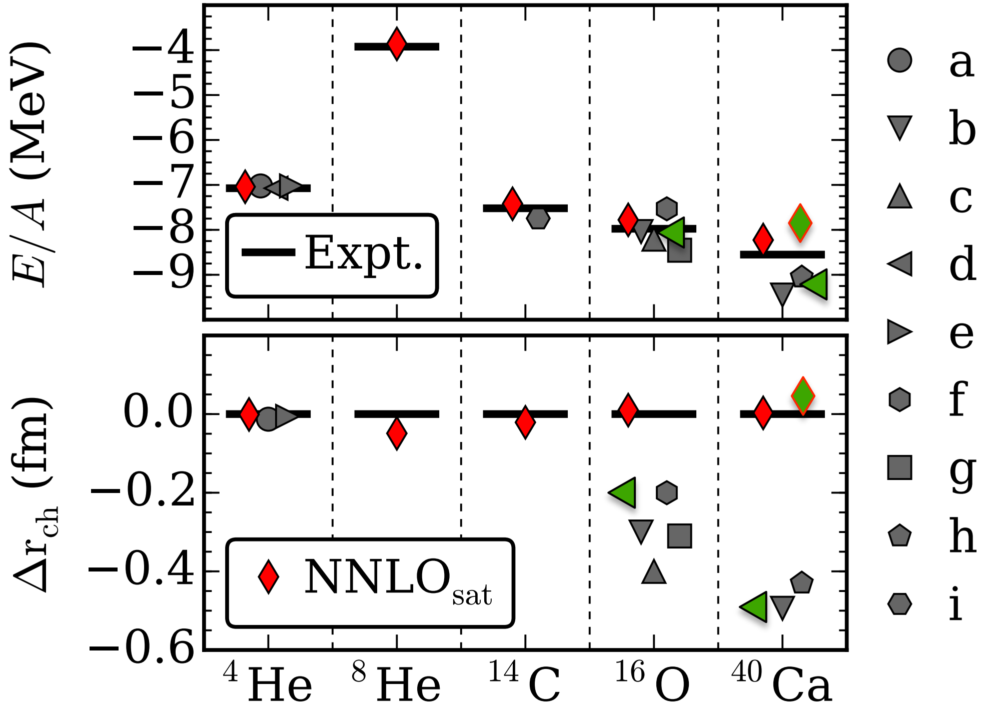
Measurements
@ ISOLTRAP

Theory tend to overestimate the gap at N=34, but overall good

→ *Error bar in predictions* are from extrapolating the many-body expansion to convergence of the model space.

NNLO-sat : a global fit up to A≈24

A. Ekström *et al.* Phys. Rev. C**91**, 051301(R) (2015)



- Constrain NN phase shifts

- Constrain radii and energies up to A≲24

➔ Provides saturation up to large masses!

◆ NNLOsat (V2 + W3) -- *Grkv 2nd ord.*

From **SCGF:**

◀ { V2-N3LO(500) + W3-NNLO(400MeV/c) w/ SRG at 2.0 fm^{-1}
A. Cipollone, CB, P. Navrátil, Phys. Rev. Lett. **111**, 062501 (2013)
V. Somà, CB *et al.* Phys. Rev. C**89**, 061301R (2014)

BE and radii for Oxygens

- New fits of chiral interactions (NNLOsat) highly improve comparison to data

- Deficiencies remain for neutron rich isotopes

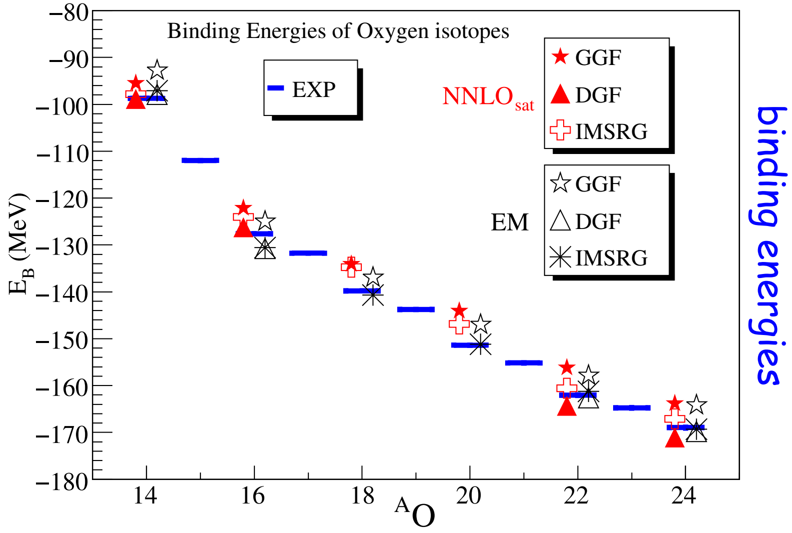
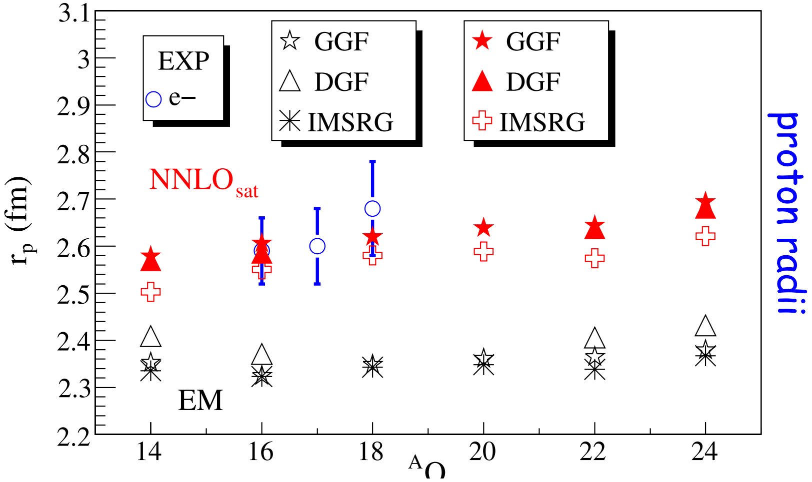
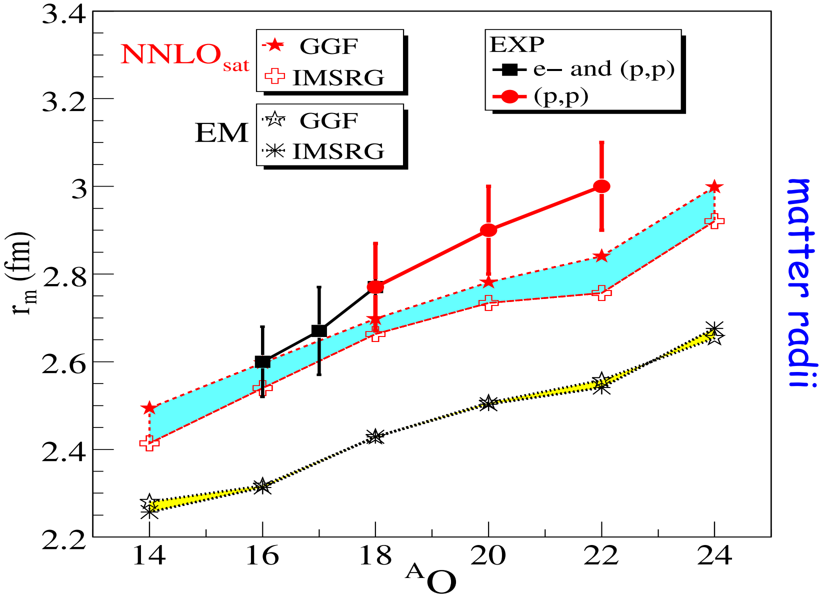


FIG. 1. Oxygen binding energies. Results from SCGF and IMSRG calculations performed with EM [20–22] and NNLO$_{sat}$ [26] interactions are displayed along with available experimental data.



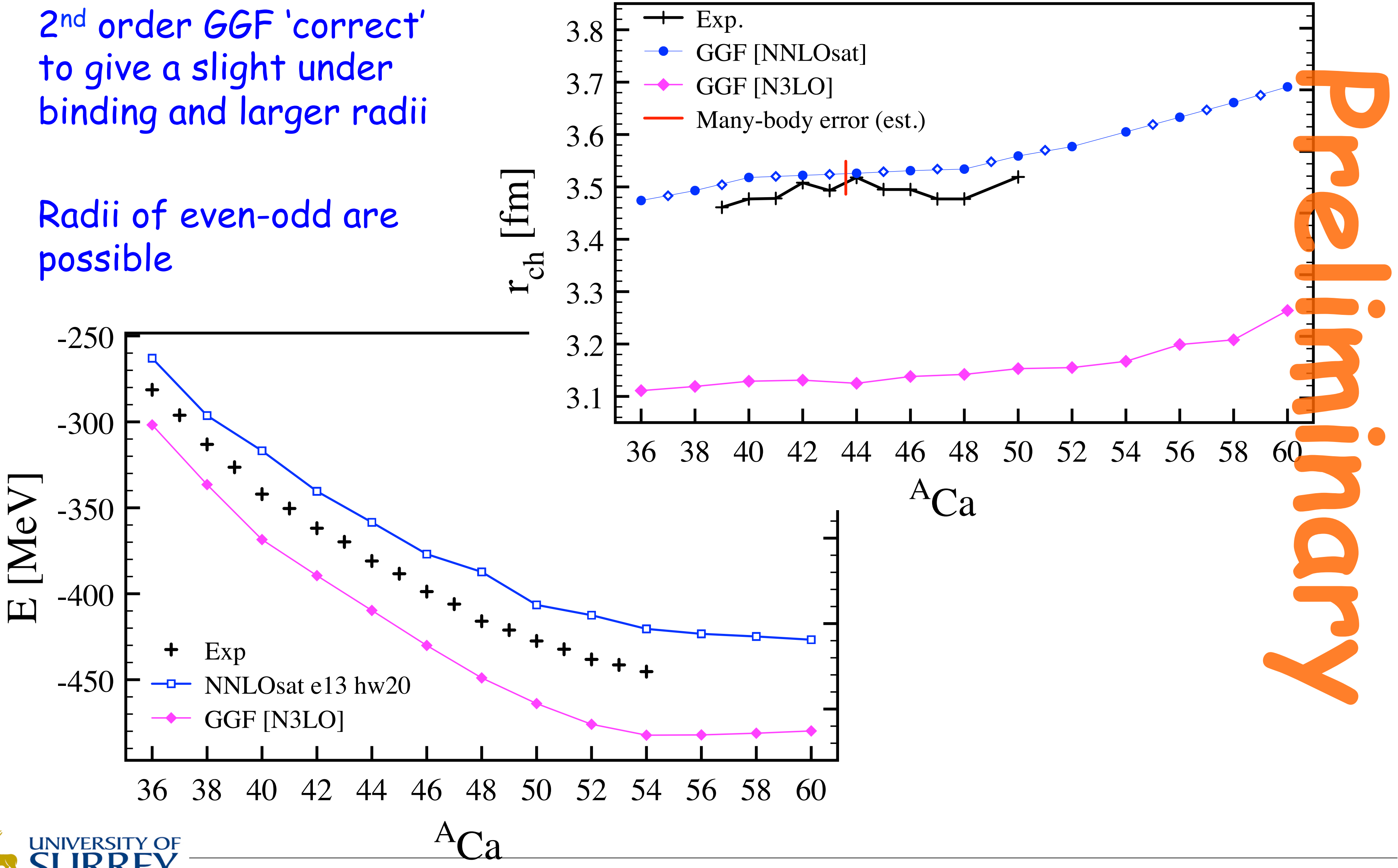


V. Somà, V. Lapuox, CB, et al., *in preparation*

BE and charge radii in ^{A}Ca

2nd order GGF 'correct' to give a slight under binding and larger radii

Radii of even-odd are possible

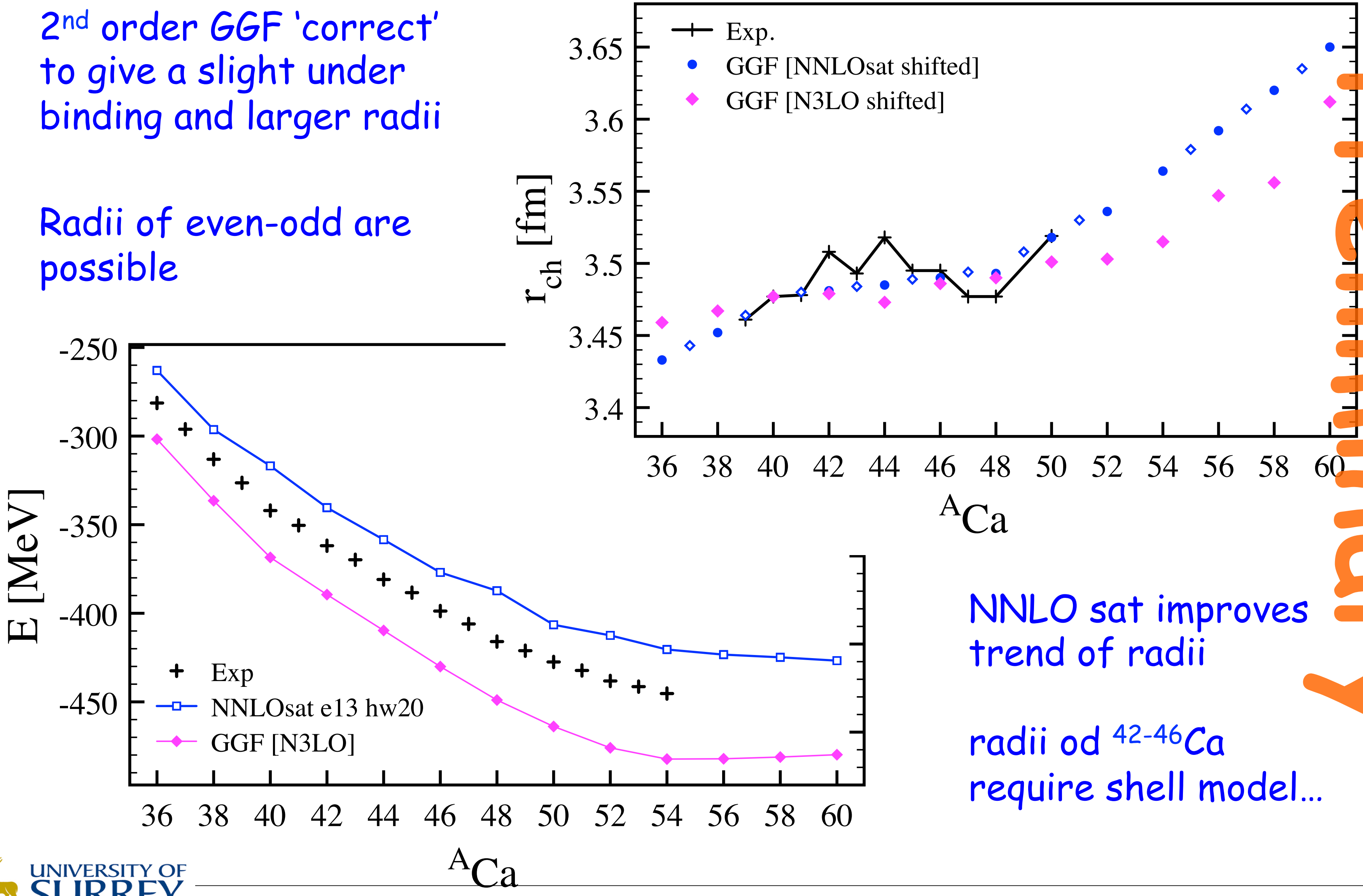


UNIVERSITY OF SURREY

BE and charge radii in ^{A}Ca

2^{nd} order GGF 'correct' to give a slight under binding and larger radii

Radii of even-odd are possible



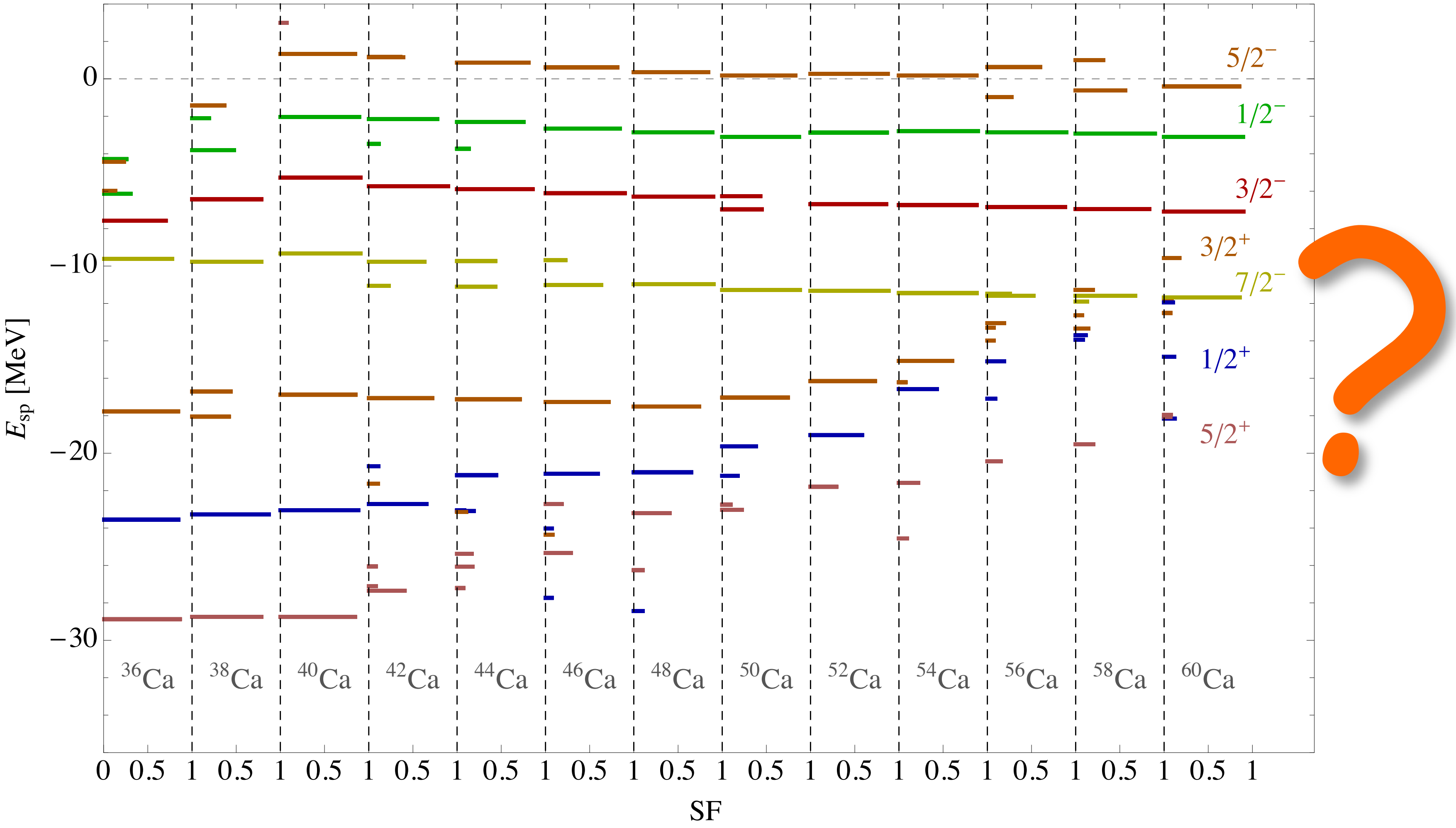
Preliminary

NNLO sat improves trend of radii

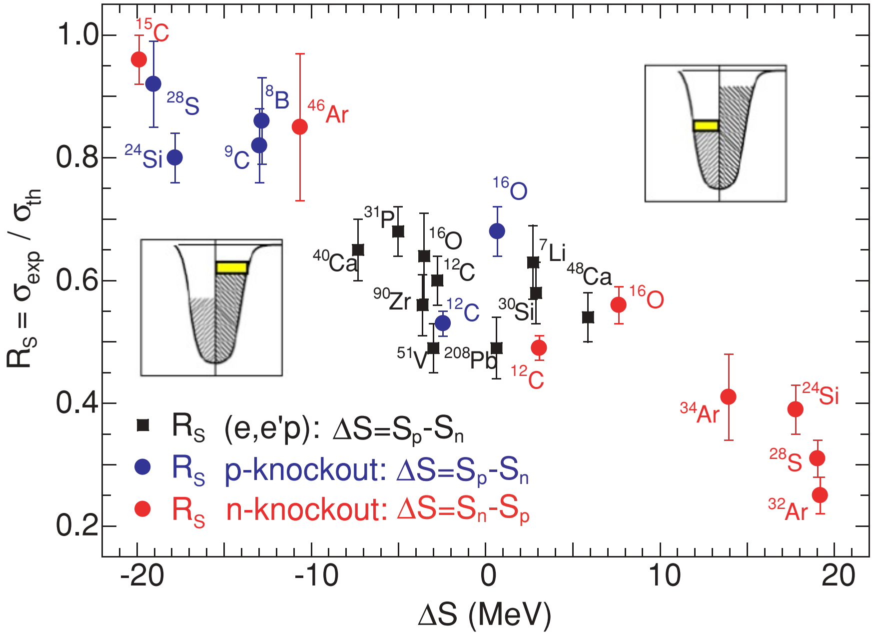
radii od $^{42-46}$Ca require shell model…

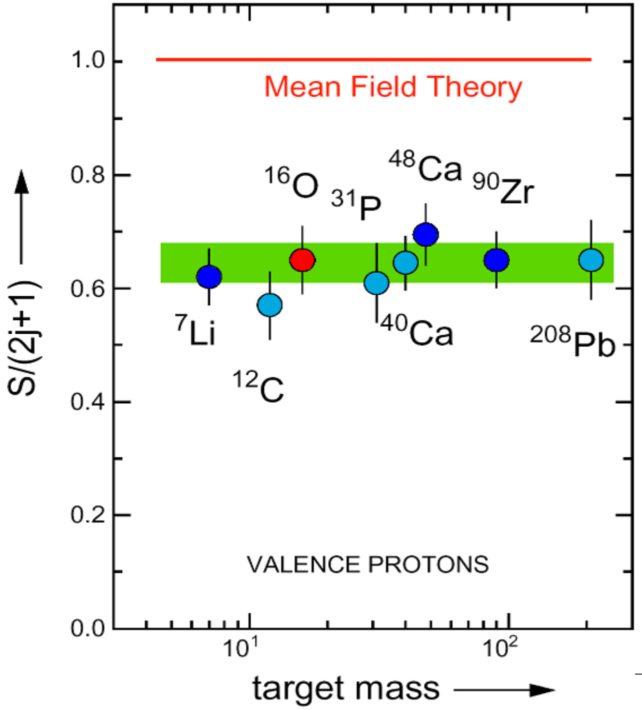
Ca neutron spectral distributions @ 2nd order

NN(N3LO500-EM) + 3NFs(NNLO400) at λ_{SRG}=2.0/fm



Spectroscopic Factors

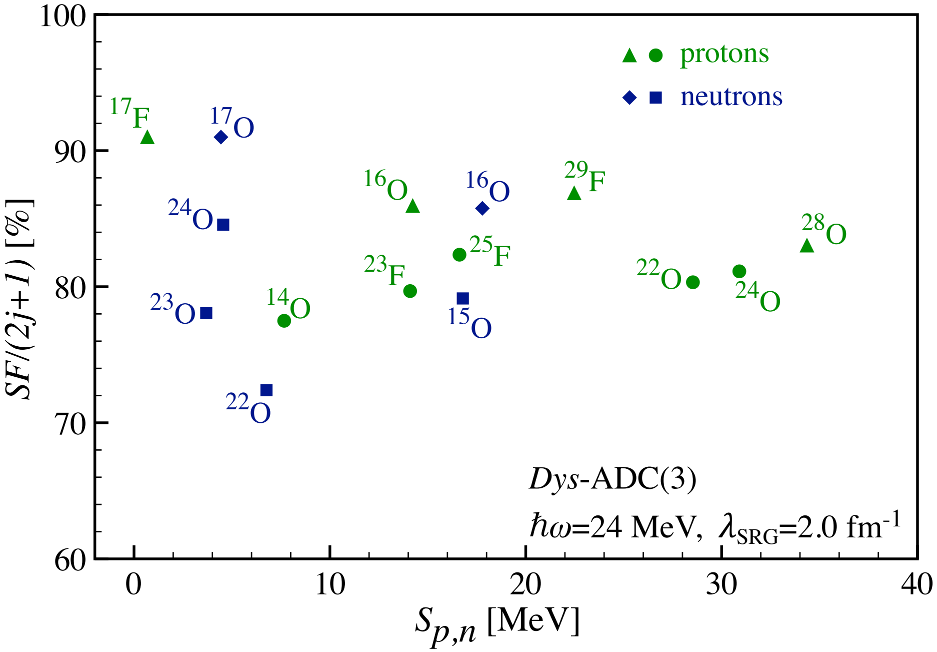




Z/N asymmetry dependence of SFs - Theory

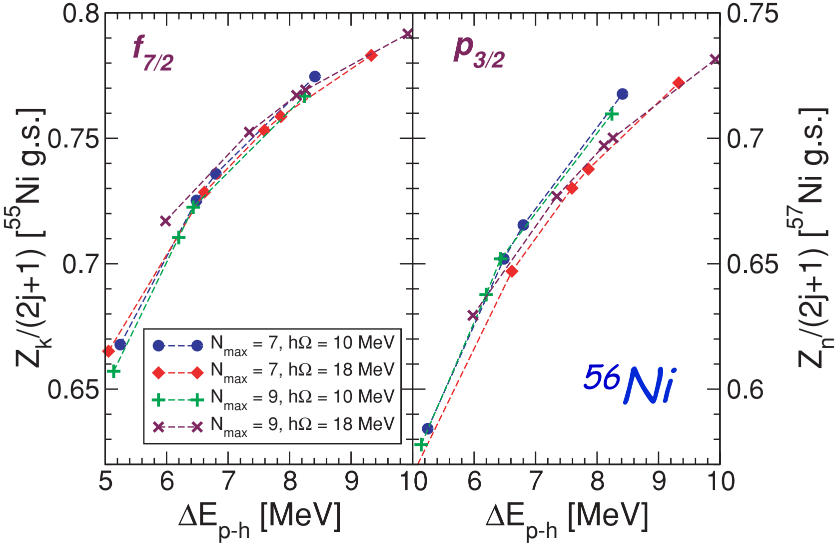
Ab-initio calculations explain (a very weak) the Z/N dependence but the effect is much lower than suggested by direct knockout

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



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

Spectroscopic factor are strongly correlated to p-h gaps:



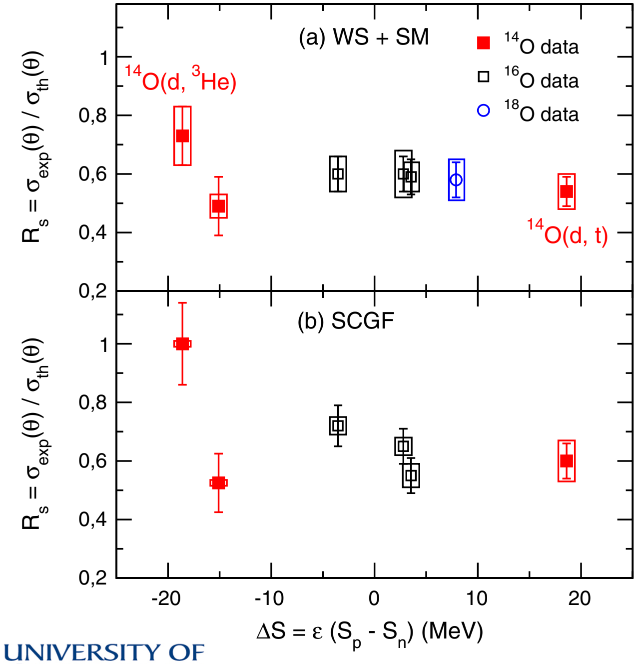
CB, M. Hjorth-Jensen,
Phys. Rev. C **79**, 064313 (2009)

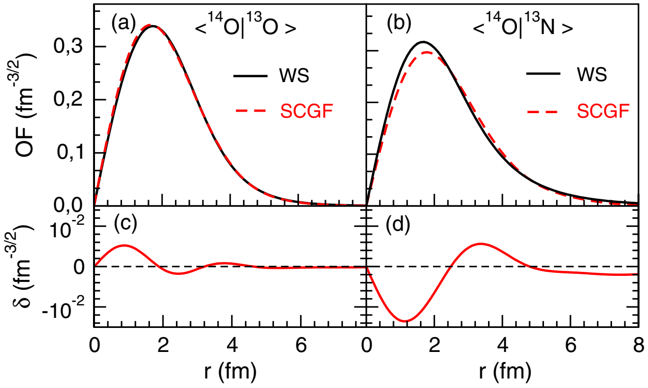
Single nucleon transfer in the oxygen chain

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

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

Reaction	E^* (MeV)	J^π	$R^{\rm HFB}_{\rm rms}$ (fm)	r_0 (fm)	$C^2S_{\rm exp}$ (WS)	$C^2S_{\rm th}$ $0p + 2\hbar\omega$	R_s (WS)	$C^2S_{\rm exp}$ (SCGF)	$C^2S_{\rm th}$ (SCGF)	R_s (SCGF)
^{14}O (d, t) ^{13}O	0.00	$3/2^-$	2.69	1.40	1.69 (17)(20)	3.15	0.54(5)(6)	1.89(19)(22)	3.17	0.60(6)(7)
^{14}O $(d, {}^3$He$)$ ^{13}N	0.00	$1/2^-$	3.03	1.23	1.14(16)(15)	1.55	0.73(10)(10)	1.58(22)(2)	1.58	1.00(14)(1)
	3.50	$3/2^-$	2.77	1.12	0.94(19)(7)	1.90	0.49(10)(4)	1.00(20)(1)	1.90	0.53(10)(1)
^{16}O (d, t) ^{15}O	0.00	$1/2^-$	2.91	1.46	0.91(9)(8)	1.54	0.59(6)(5)	0.96(10)(7)	1.73	0.55(6)(4)
^{16}O $(d, {}^3$He$)$ ^{15}N [19,20]	0.00	$1/2^-$	2.95	1.46	0.93(9)(9)	1.54	0.60(6)(6)	1.25(12)(5)	1.74	0.72(7)(3)
	6.32	$3/2^-$	2.80	1.31	1.83(18)(24)	3.07	0.60(6)(8)	2.24(22)(10)	3.45	0.65(6)(3)
^{18}O $(d, {}^3$He$)$ ^{17}N [21]	0.00	$1/2^-$	2.91	1.46	0.92(9)(12)	1.58	0.58(6)(10)			





- Overlap functions and strengths from GF
- Rs independent of asymmetry

Quenching of absolute spectroscopic factors

[CB, *Phys. Rev. Lett.* **103**, 202520 (2009)]

…with analogous conclusions for ^{48}Ca

Overall quenching of *spectroscopic factors* is driven by:

SRC → *~10%*

part-vibr. coupling → *dominant*

"shell-model" → *in open shell*

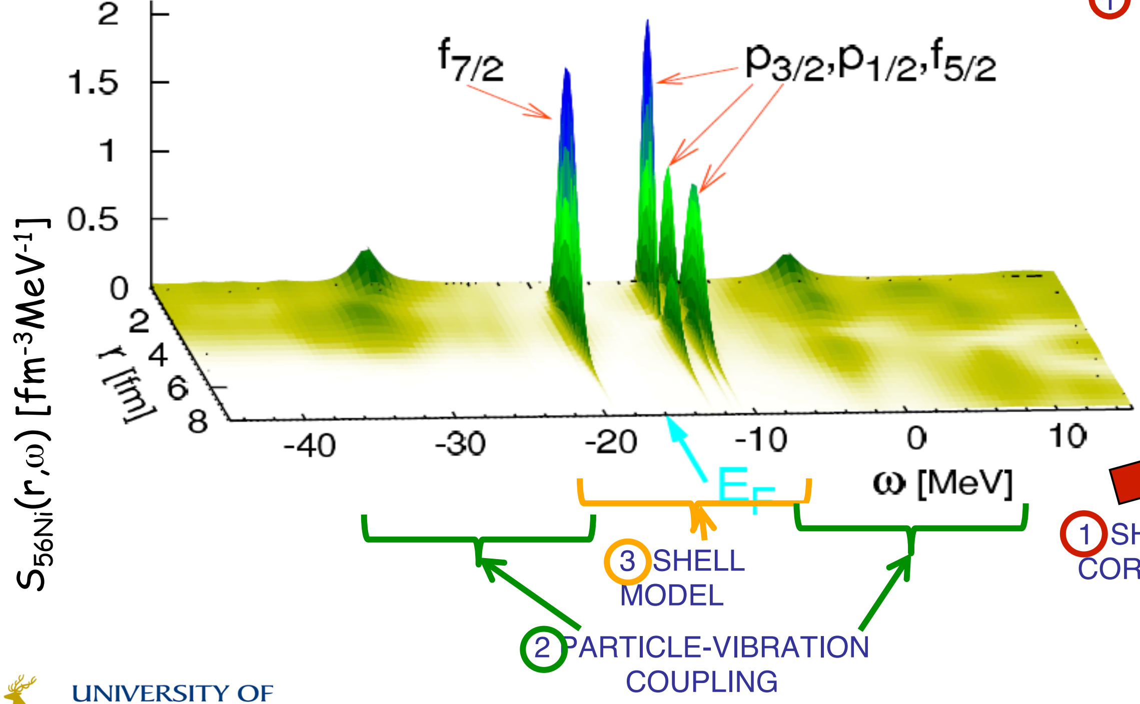
	10 osc. shells			Exp. [30]	$1p0f$ space		
	FRPA (SRC)	full FRPA	FRPA $+\Delta Z_\alpha$		FRPA	SM	ΔZ_α
^{57}Ni:							
$\nu 1p_{1/2}$	0.96	0.63	0.61		0.79	0.77	-0.02
$\nu 0f_{5/2}$	0.95	0.59	0.55		0.79	0.75	-0.04
$\nu 1p_{3/2}$	0.95	0.65	0.62	0.58(11)	0.82	0.79	-0.03
^{55}Ni:							
$\nu 0f_{7/2}$	0.95	0.72	0.69		0.89	0.86	-0.03

^{57}Ni

^{55}Ni

① ②+③ ③

$$Z_\alpha = \int d^3r \, |\psi_\alpha^{overlap}(\mathbf{r})|^2 = \left. \frac{1}{1-\frac{\partial\Sigma_{\hat\alpha\hat\alpha}(\omega)}{\partial\omega}} \right|_{\omega=\varepsilon_\alpha}$$



③ SHELL MODEL

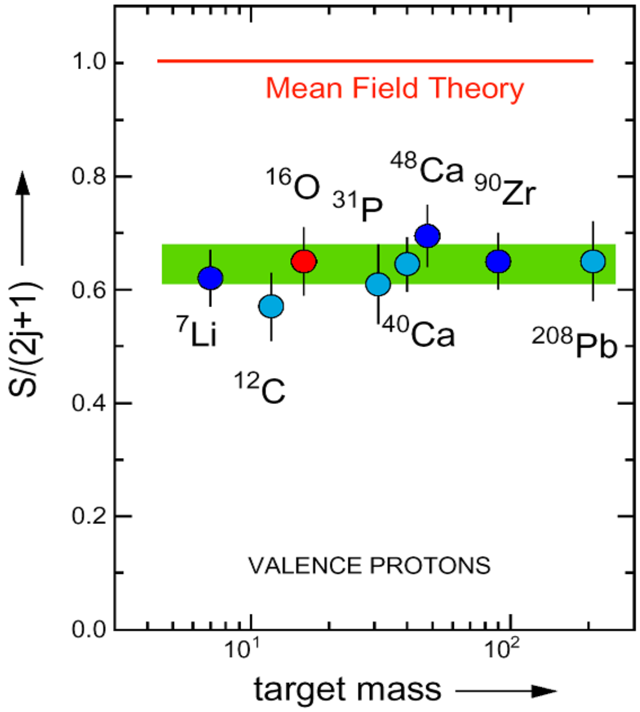
② PARTICLE-VIBRATION COUPLING

① SHORT RANGE CORRELATIONS

Quenching of SF in stable nuclei

Nucl. Phys. A553 (1993) 297c

NIKHEF:



A common misconception about SRC:

"The quenching is constant over all stable nuclei, so it must be a short-range effect"

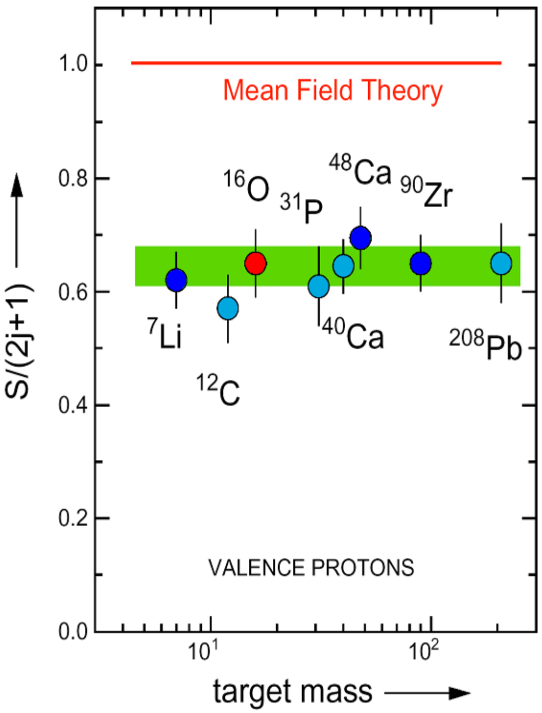
Actually, NO!

All calculations show that SRC have just a small effect at the Fermi surface. And the correlation to the experimental p-h gap is much more important.

[W. Dickhoff, CB, Prog. Part. Nucl. Phys. **52**, 377 *(2004)*]

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]	0.77	0.72
[CB et al., Phys. Rev. C**65**, (02)]		
Experiment:	0.63	0.67 ±0.07 (estimated uncertainty)

SRC are present and verified experimentally

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

Short-range correlations (SRC)

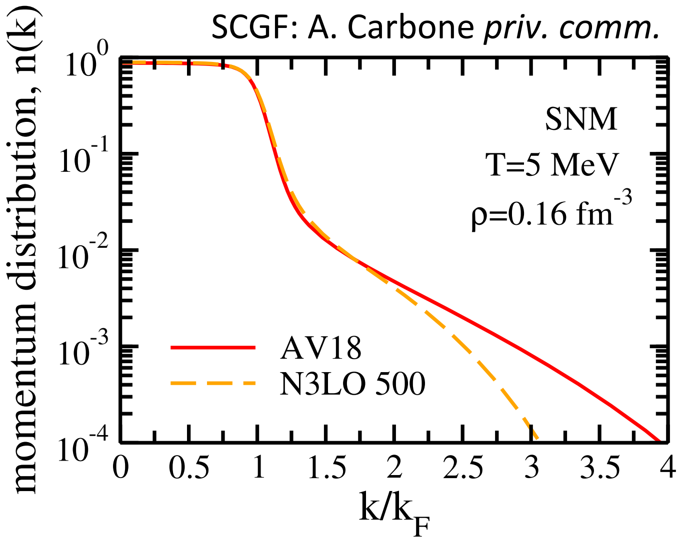
Where can one see these??

High momentum components – where are they?

Momentum distribution:

$$n(k) = \int_{-\infty}^{\varepsilon_F^-} d\omega \; S^{(h)}(k,\omega)$$

- High k components are found at high missing energies

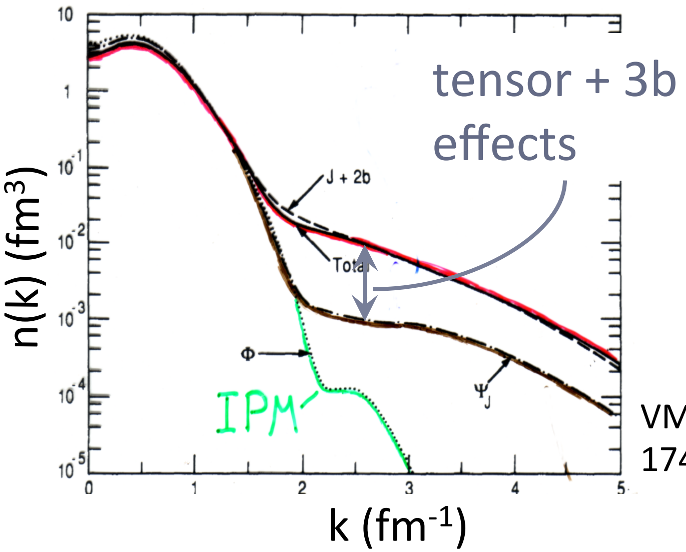

SCGF: A. Carbone *priv. comm.*

- *Short-range repulsion in r-space*
←→ strong potential at large momenta

- *A complication: the nuclear interaction includes also a tensor term (from Yukawa's meson meson exchange):*

$$S_{12} = 3(\vec{\sigma}_1 \cdot \hat{r})(\vec{\sigma}_2 \cdot \hat{r}) - 1$$

→ interaction amog 2 dipoles!!!!!!

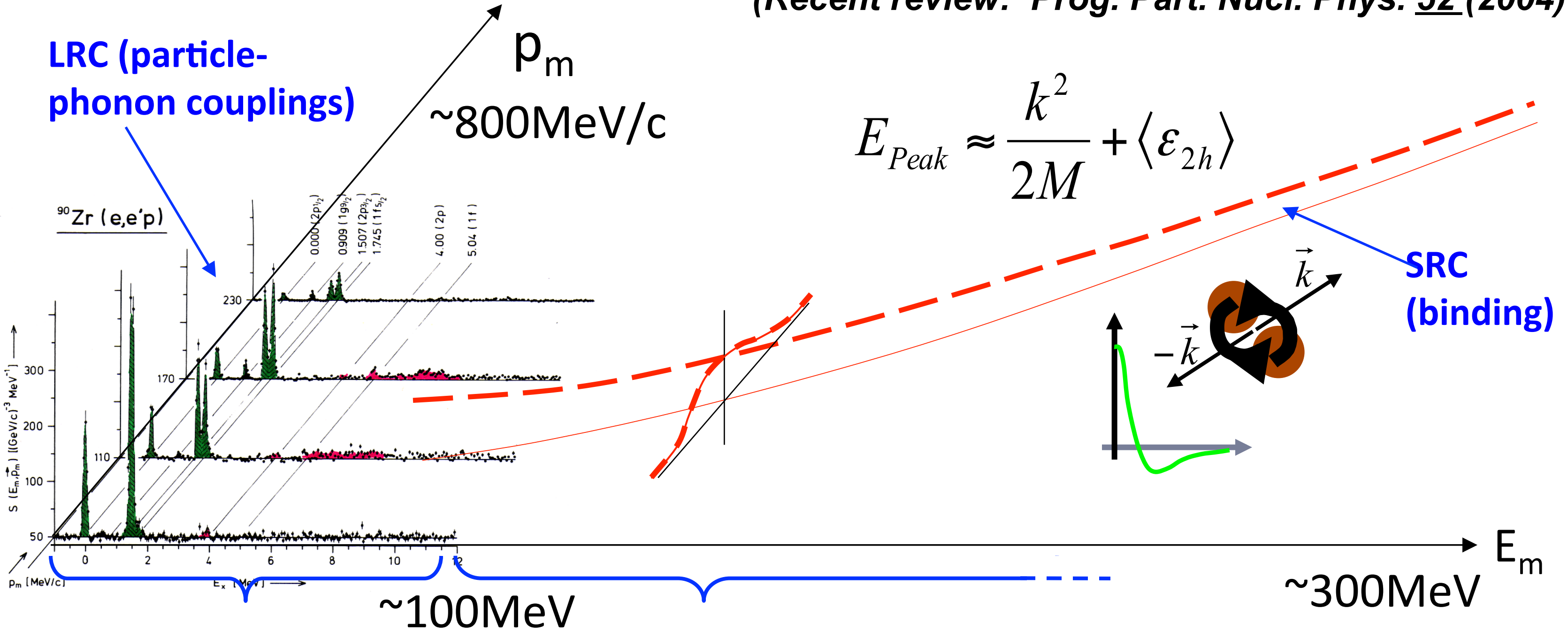


tensor + 3b effects

VMC: PRC46, 1741 ('92)

Distribution of (All) the Nuclear Strength

(Recent review: Prog. Part. Nucl. Phys. 52 (2004) 337.)



LRC (particle-phonon couplings)

SRC (binding)

$$E_{Peak} \approx \frac{k^2}{2M} + \langle \varepsilon_{2h} \rangle$$

strength: ~85%

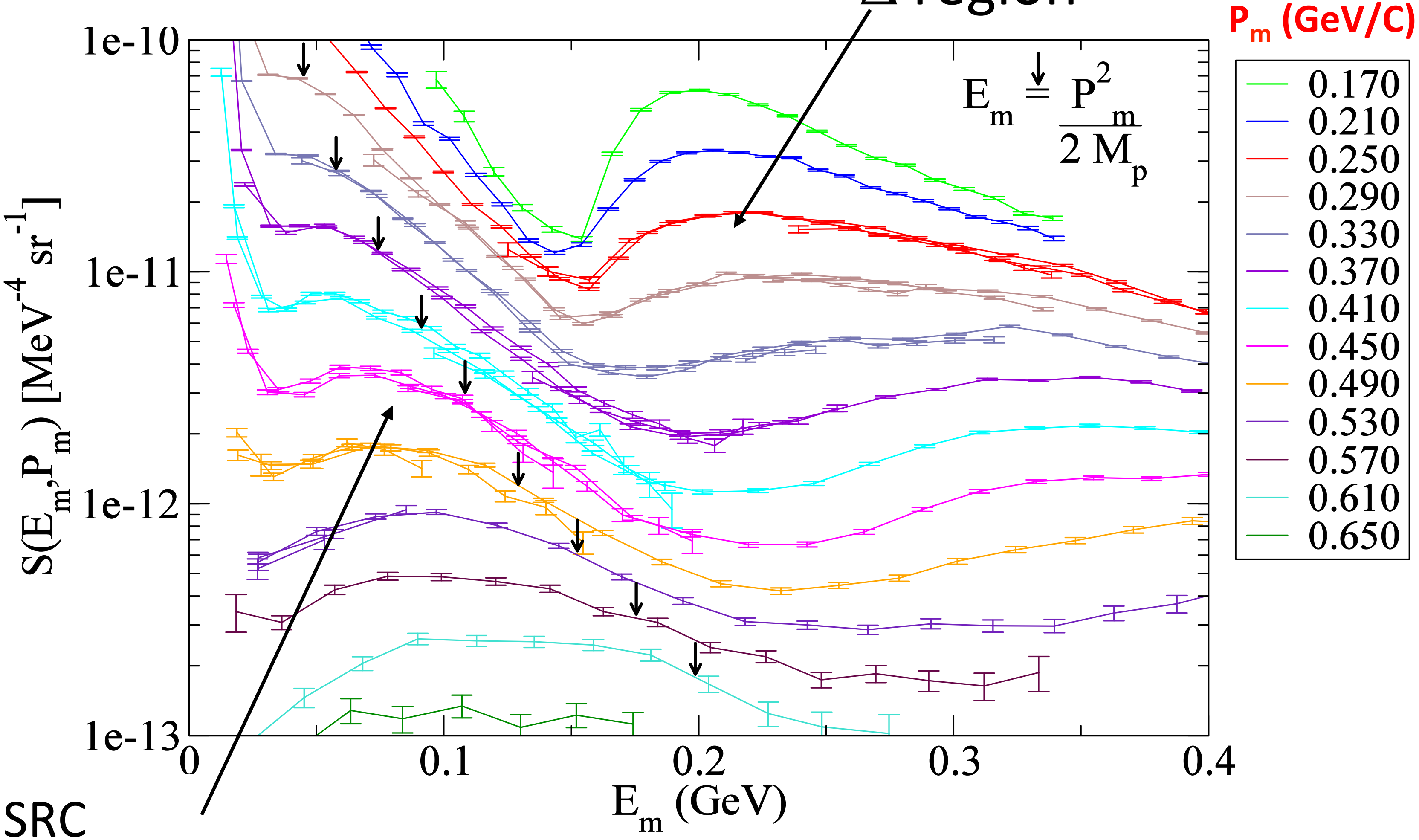
~15%

Interest in short range correlations:

- a fraction of the total number of nucleons:
  - ~10% in light nuclei (VMC, FHNC, Green's function)
  - 15-20% in heavy systems (CBF, Green's function)
- can explain up to 2/3 of the binding energy [see ex. PRC51, 3040 ('95) for ^{16}O]
- influence NM saturation properties [see ex. PRL90, 152501 ('03)]

Spectral strength of ^{12}C from exp. E97-006

Δ region



SRC
correlations

D.Rohe, et. al, Eur. Phys. J. A17, 349 (2003),
Phys Rev. Lett. 93 182501 (2004).

Theory vs. measured strength - I

- About 0.6 protons are found in the correlated region:

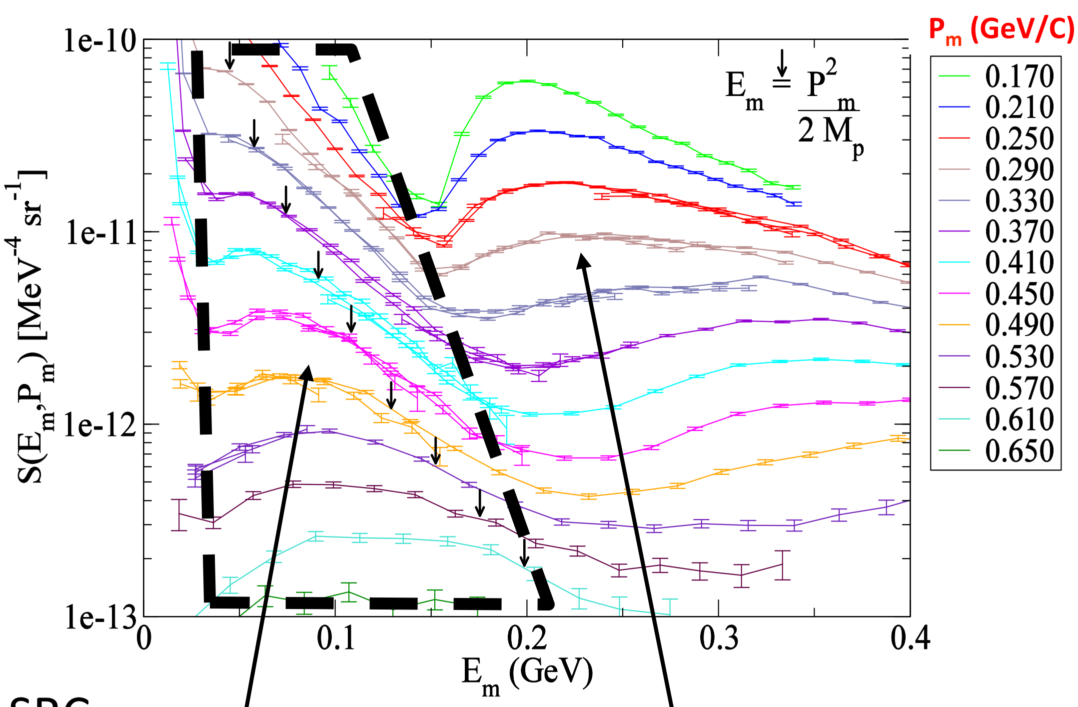
TABLE I. Correlated strength, integrated over shaded area of Fig. 2 (quoted in terms of the number of protons in ^{12}C.)

Experiment	0.61 ± 0.06
Greens Function Theory [28]	0.46
CBF Theory [3]	0.64

→in good agreement with early theoretical predictions!

- what about the position of the peak?

D.Rohe, et. Al,
Eur. Phys. J.
A17, 349 (2003)
PRL93 182501 (2004)



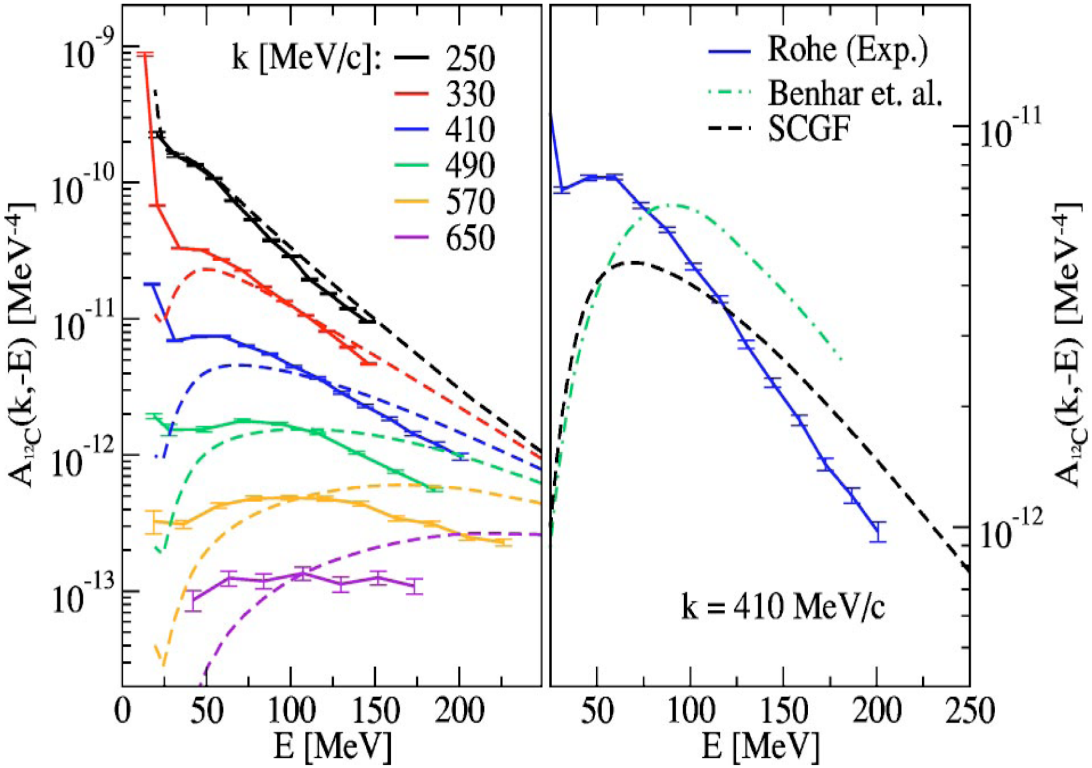
SRC correlations

π emission

Theory vs. measured strength - II

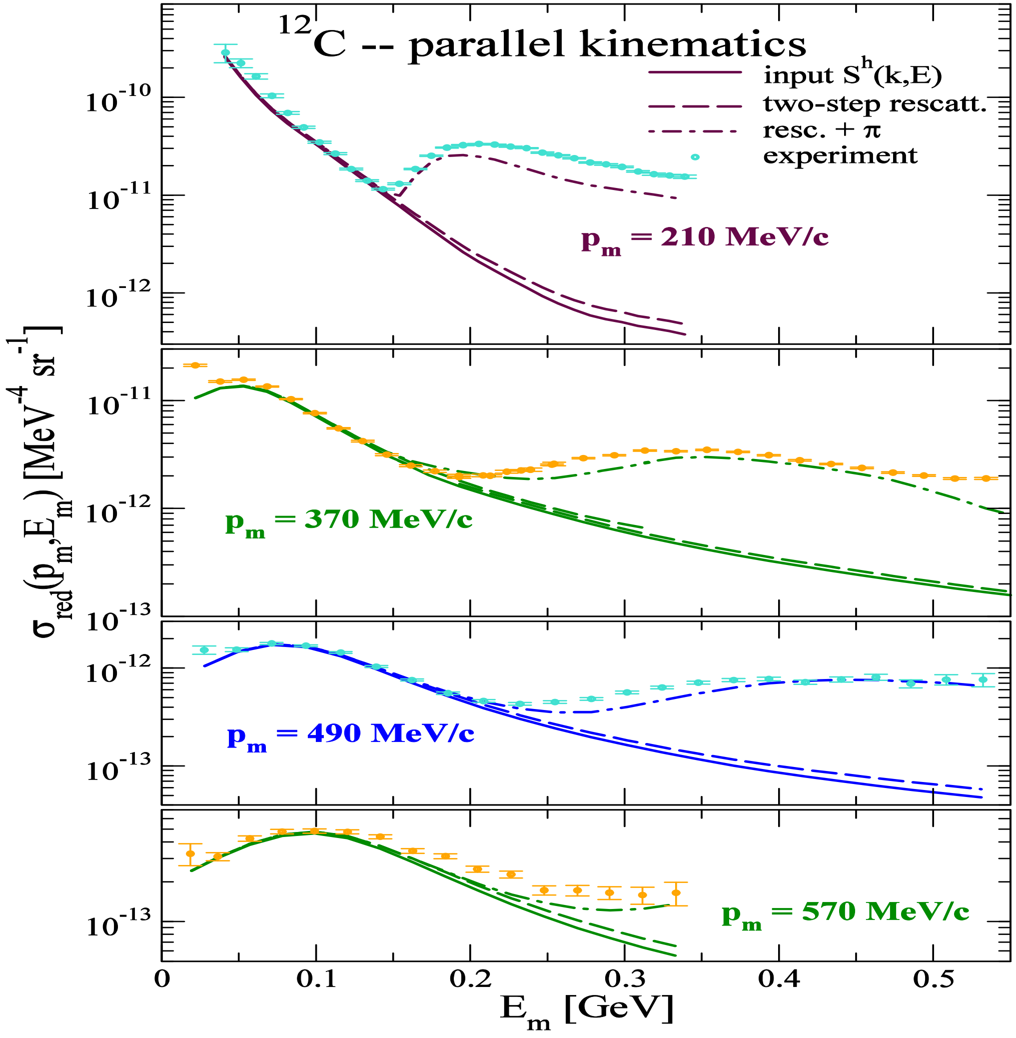
- Theory reproduces the total amount of correlated strength and its shape

- The exact position of the correlated peak depends on the particular many-body approach and (NN interaction?) used.



Phys. Rev. C70, 0243909 (2004)

Comparison to Experiment in Parallel Kinematics – ^{12}C

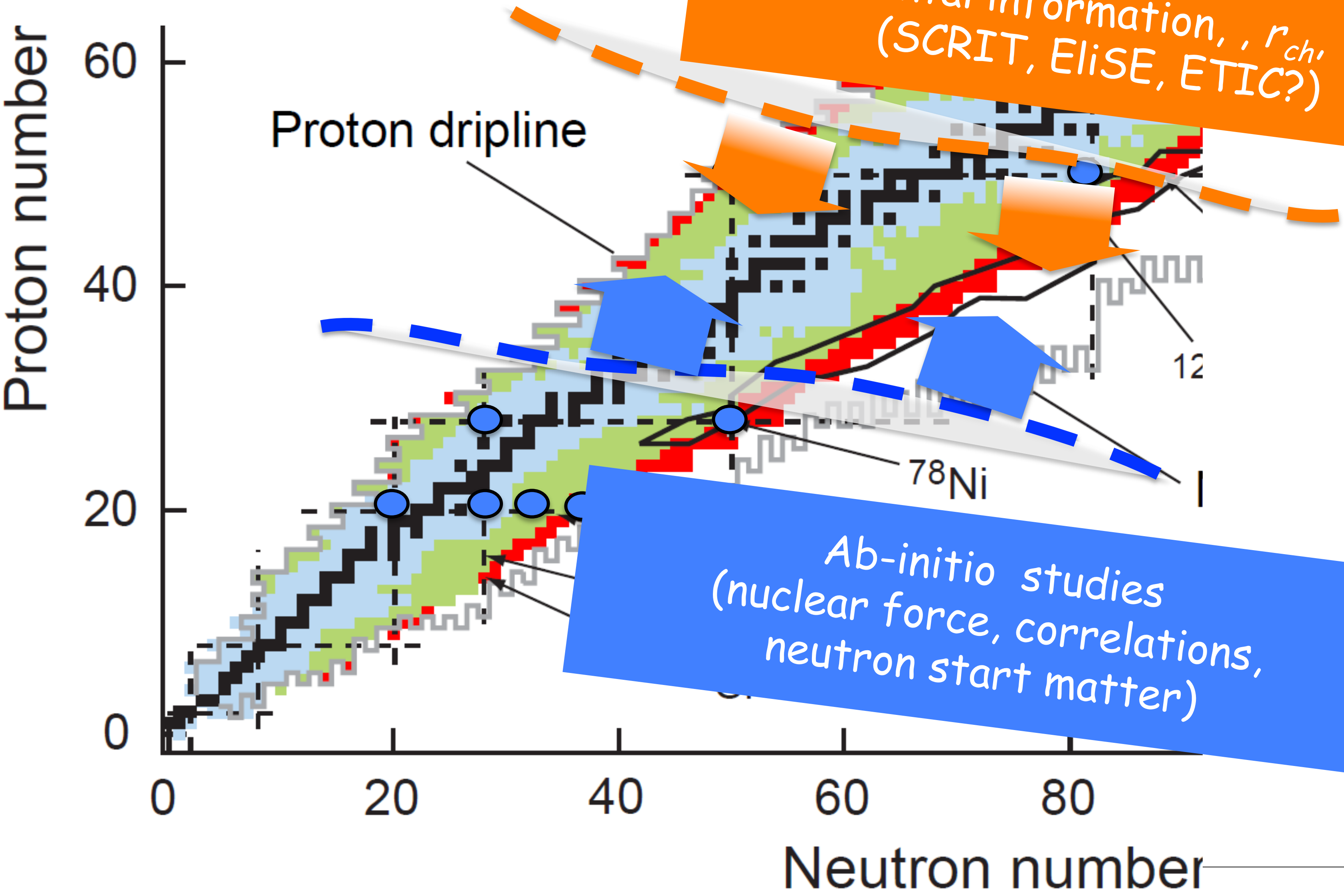


Pion production at very high missing energies

Q^2=0.4(Gev/c)^2
beam: 3.3GeV
p_f = 1 – 2 GeV

CB et. al. Phys. Lett. B608 47 (2005)

unstable isotopes from e⁻ scattering



Experimental information, , r_{ch}, $\rho(r)$, …
(SCRIT, EliSE, ETIC?)

Ab-initio studies
(nuclear force, correlations,
neutron start matter)

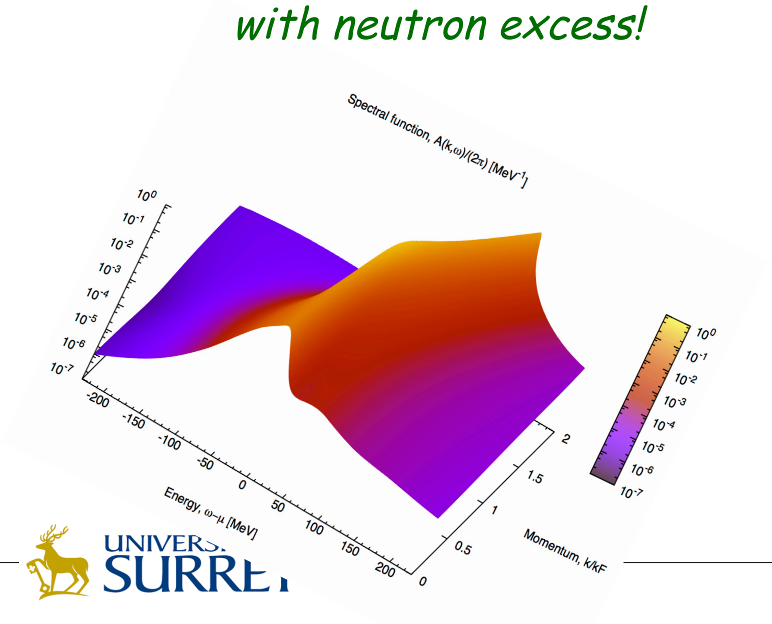
Summary

→ *Leading order 3NF are crucial to predict many important features that are observed experimentally (drip lines, saturation, orbit evolution, etc…)*

→ *Experimental binding is predicted accurately up to the lower sd shell (A≈30) but deteriorates for medium mass isotopes (Ca and above) with roughly 1 MeV/A over binding.*

→ *New fits of chiral interaction are promising for low-energy observables*

→ *Spectroscopic factors and strength distributions: SITLL UNKNOWN for most isotopes and of high relevance to understand structure and correlations with neutron excess!*



Thank you for your attention!!!

Collaborators

A. Cipollone,
A. Rios, A. Idini, F. Raimondi

A. Polls

V. Somà, T. Duguet

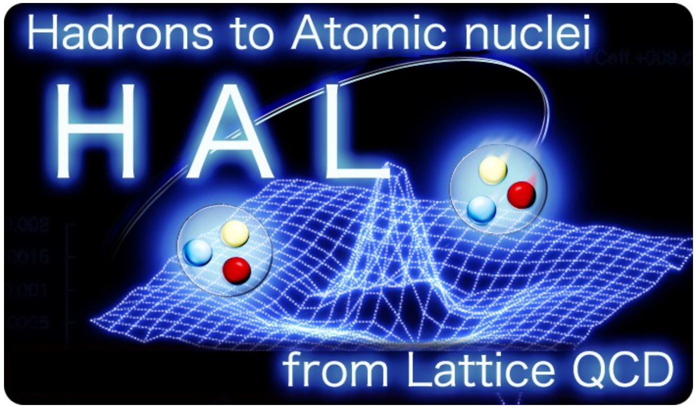
W.H. Dickhoff,
S. Waldecker

A. Carbone

D. Van Neck,
M. Degroote

P. Navratil

M. Hjorth-Jensen



S. Aoki,	YITP Kyoto Univ.
T. Doi, T. Hatsuda, Y. Ikeda,	RIKEN Nishina
T. Inoue,	Nihon Univ.
N. Ishii, K. Murano,	RCNP Osaka Univ
H. Nemura K. Sasaki	Univ. Tsukuba
F. Etminan	Univ. Birjand
T. Miyamoto,	Univ. Tsukuba
T. Iritani	Stony Brook Univ.
S. Gongyo	YITP Kyoto Univ.