Proposal for an INFN Research Network (Iniziativa Specifica)

Section I:

Title:

Structure and Reactions of Nuclei: towards a global Theory

Acronym:

Strength

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Ex MI31:

P.F. Bortignon (P.O.)
R.A. Broglia (P.O, Ass.Senior)
G. Colo' (P.Ass.)
E. Vigezzi (Dir. Ric.)

Forte collegamento
con l'esperimento -> 50% Gr. III

X. Roca-Maza (Ass. Univ.)
M. Brenna (dott.)
Y. Niu (borsa post-doc, da nov. 2013)
A. Idini (dott., fino a feb. 2013)

2009-2012:
56 pubbl. ISI
65 talks

Density Functional Theory
Collective modes
Nuclear Field Theory (Particle-vibration coupling)
Nuclear superfluidity

Transfer reactions

Nuclear equation of state (symmetry energy)
Inner crust of neutron stars
Electron capture (supernovae)

MINISTERO DELL'ISTRUZIONE DELL'UNIVERSITÀ E DELLA RICERCA

Dipartimento per l'Università, l'Alta Formazione Artistica, Musicale e Coreutica e per la Ricerca Direzione Generale per il Coordinamento e lo Sviluppo della Ricerca

PROGRAMMI DI RICERCA SCIENTIFICA DI RILEVANTE INTERESSE NAZIONALE - Bando 2012

D.M. 28 dicembre 2012 n. 957/Ric
(Il presente decreto viene pubblicato nelle more della registrazione da parte della Corte dei Conti)

PROPOSTA DI PROGETTO DI RICERCA TRIENNALE
prot. 2012EFF5EC
PARTE II

1 - Titolo del Progetto di Ricerca

Testo italiano
Teoria del nucleo atomico nell'era degli acceleratori per fasci radioattivi

Testo inglese
Nuclear Theory in the Era of Radioactive ion beam Facilities (TERF)

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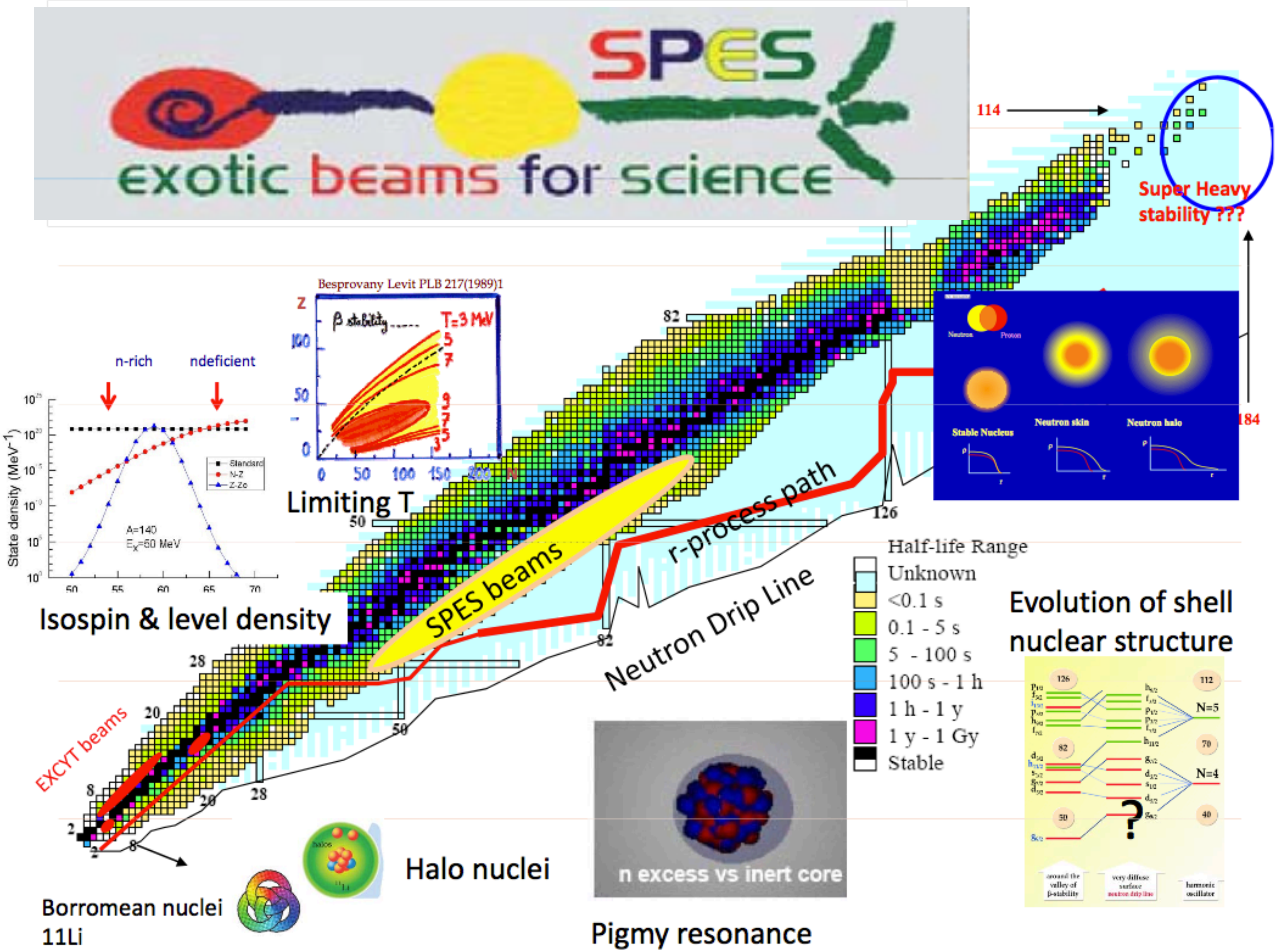
7 - Elenco delle Unità operative

n°	Responsabile dell'Unità di Ricerca	Qualifica	Università/Enti	E-mail	Titolo e Data di conseguimento (primo dottorato o prima specializzazione, in assenza, prima laurea) solo per linea A o linea B
1.	COLO' Gianluca	Professore Associato confermato	Università degli Studi di MILANO	colo@mi.infn.it	Dottorato: 25/09/1993 Linea d'intervento: C
2.	COLONNA Maria	Primo ricercatore	Istituto Nazionale di Fisica Nucleare	colonna@lns.infn.it	Dottorato: 15/09/1993 Linea d'intervento: C
3.	LENZI Silvia Monica	Professore Associato confermato	Università degli Studi di PADOVA	lenzi@pd.infn.it	Dottorato: 22/10/1987 Linea d'intervento: C
4.	ITACO Nunzio	Ricercatore confermato	Università degli Studi di NAPOLI "Federico II"	itaco@na.infn.it	Dottorato: 09/06/1998 Linea d'intervento: B

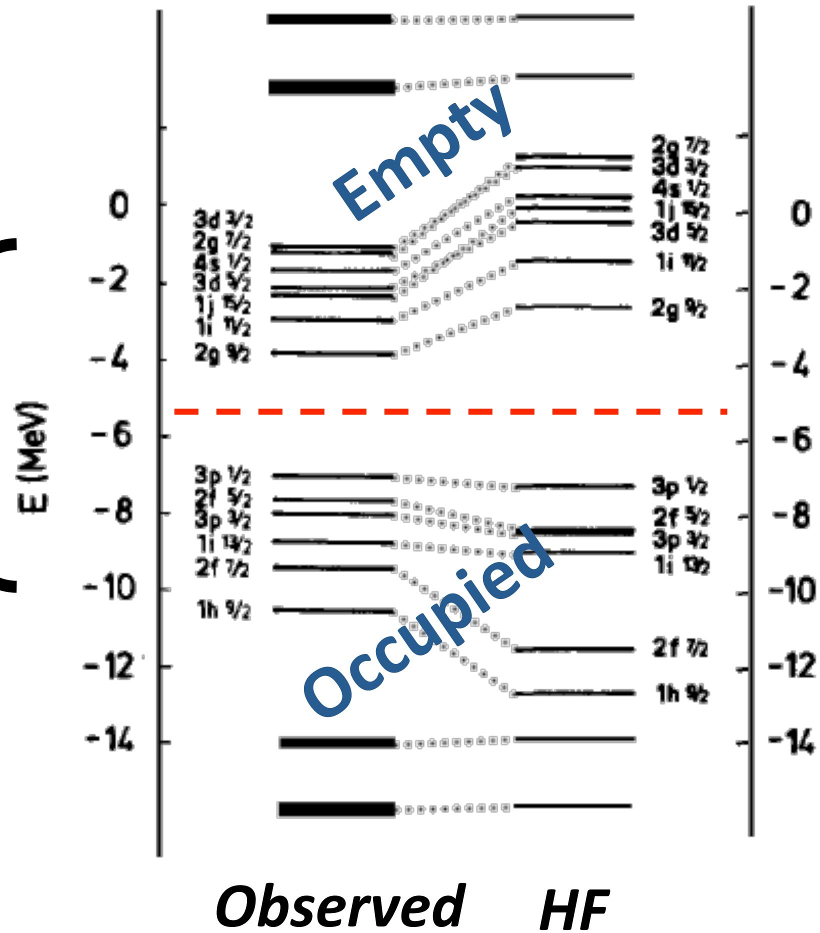

SPES
exotic beams for science
114
Super Heavy stability ???
184
Besprovany Levit PLB 217(1989)1
Z
β stability
T=3 MeV
N
Limiting T
n-rich
ndeficient
State density (MeV^{-1})
Standard
N-Z
Z-Zo
A=140
E_x=60 MeV
Isospin & level density
82
50
28
20
8
2
126
SPES beams
r-process path
Neutron Drip Line
EXCYT beams
Neutron
Proton
Stable Nucleus
Neutron skin
Neutron halo
Half-life Range
Unknown
<0.1 s
0.1 - 5 s
5 - 100 s
100 s - 1 h
1 h - 1 y
1 y - 1 Gy
Stable
Evolution of shell nuclear structure
N=5
N=4
Halo nuclei
n excess vs inert core
Pigmy resonance
Borromean nuclei
11Li

Hartree-Fock mean field provides qualitative agreement with exp. data

^{208}Pb

Neutron single particle levels

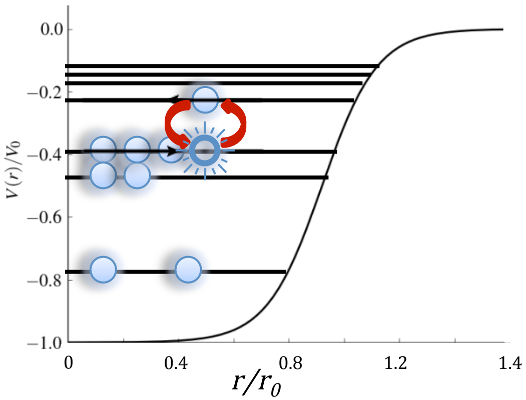
$m_k \sim 1$

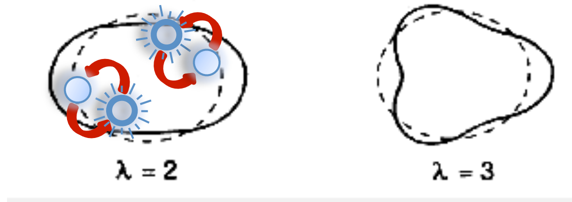


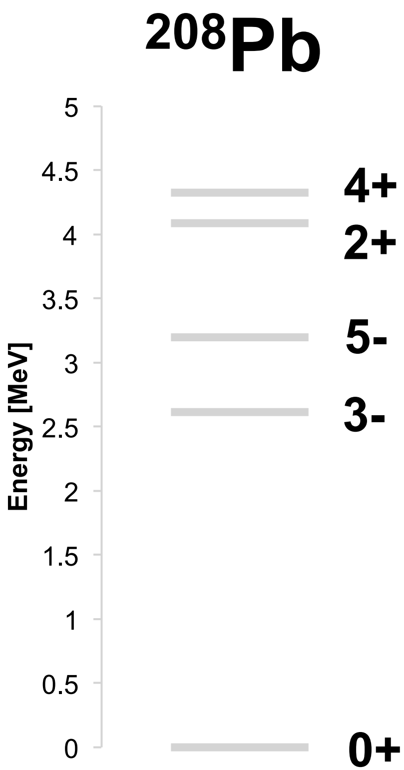
$m_k \sim 0.7$

Fock term

Teamworking

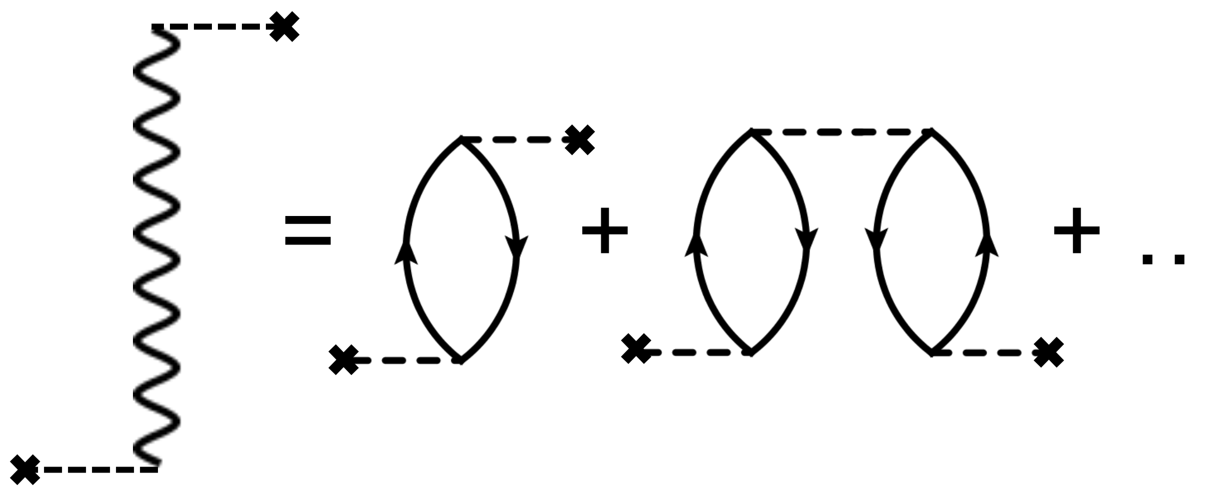






Correlated Particle-Hole excitations give rise to

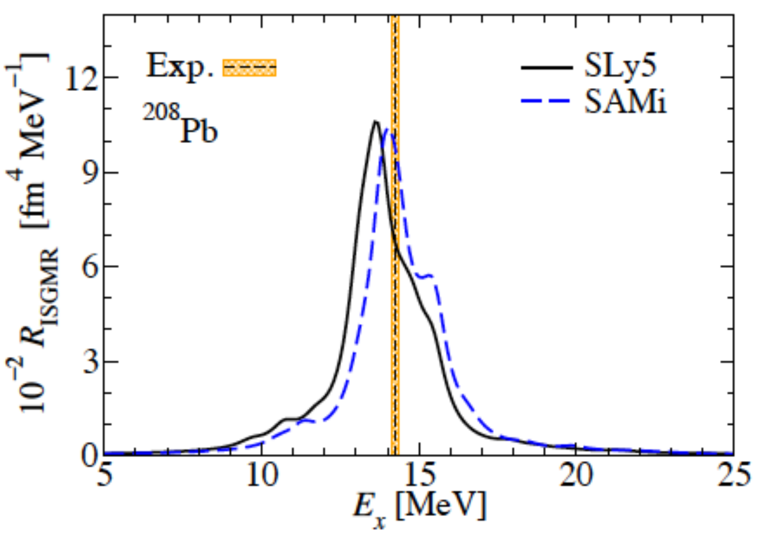
Collective Excitations.

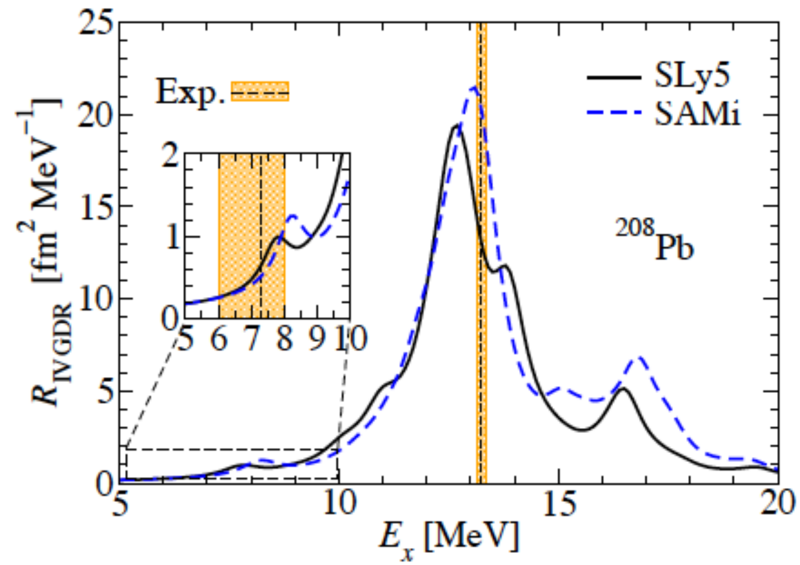


Random Phase Approximation


Many Body Systems are
coherent ensembles
They’re forced
Playing together

Searching the best effective interaction: SAMi (Skyrme-Aizu-Milano) parameter set



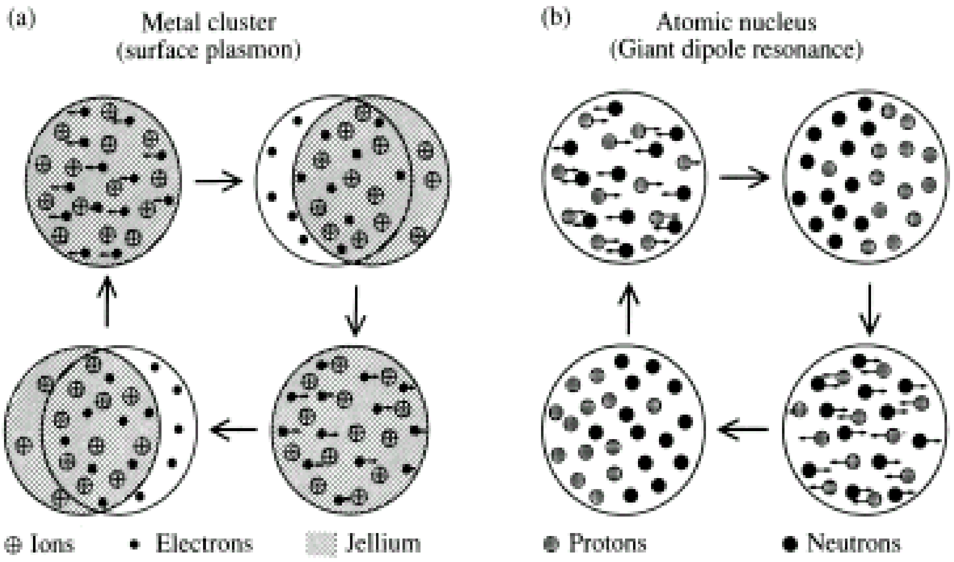


This set provides good results for both nuclear matter properties like the symmetry energy, and for GRs - including charge-exchange ones.

X. Roca-Maza, G.C., H. Sagawa, Phys. Rev. C 86, 031306(R) (2012).

Isovector modes and symmetry energy

Neutrons and protons oscillate in opposition of phase. We expect that their properties can shed light on S.



IV Giant Dipole Resonance (IVGDR)

Nuclear matter EOS

Symmetric matter EOS

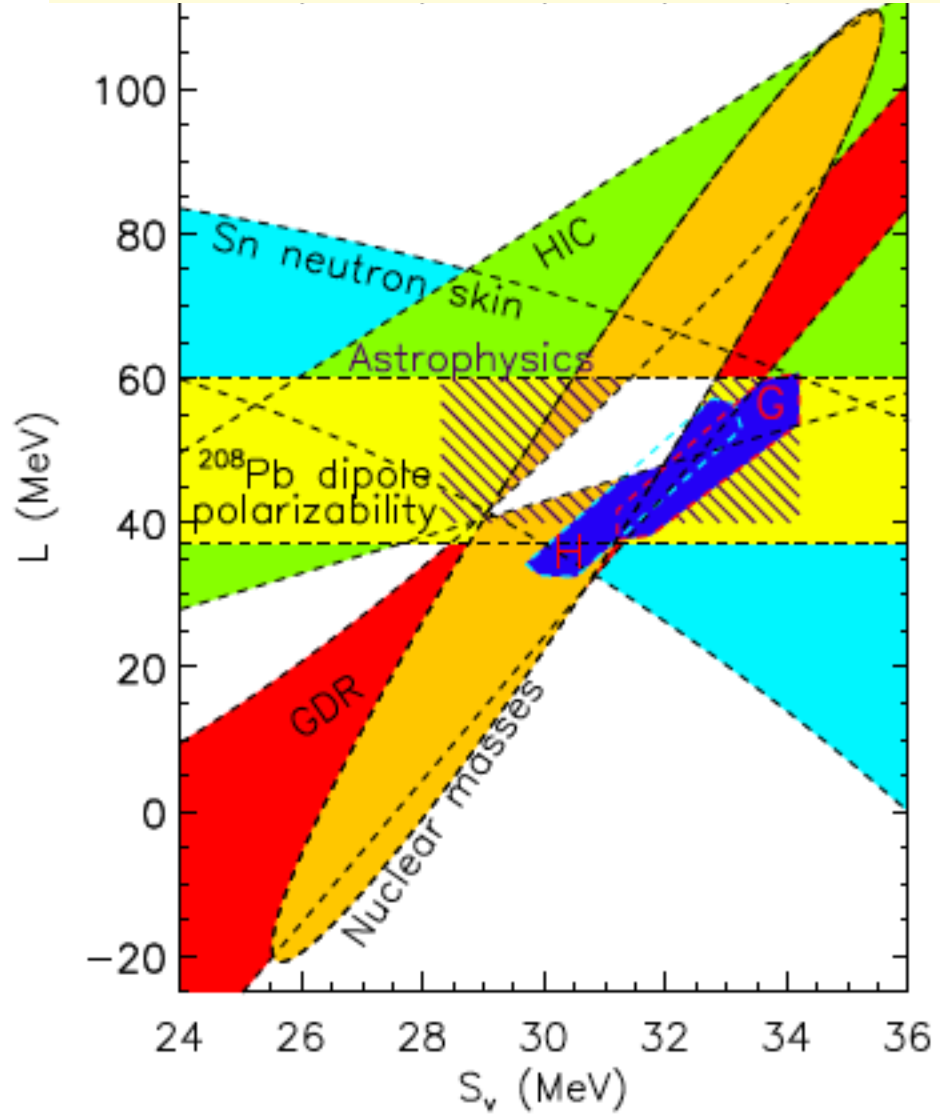
Symmetry energy S

$$\frac{E}{A}(\rho,\beta) = \frac{E}{A}(\rho,\beta=0) + S(\rho)\beta^2 \qquad \beta \equiv \frac{\rho_n - \rho_p}{\rho}$$

Main parameters that govern S:

$$S(\rho_0) \equiv J$$
$$S'(\rho_0) \equiv L/3\rho_0$$
$$S''(\rho_0) \equiv K_{\rm sym}/9\rho_0^2$$

M.B. Tsang *et al.*, PRC 86, 015803 (2012)
J.M. Lattimer, J. Lim, arXiv:1203.4286



Nuclear structure experiments

- Hadronic/EM probes

Milano

O. Wieland *et al.*, Phys. Rev. Lett. 102, 092502 (2009)

- Weak probes

PREX (Roma)

S. Abrahamyan *et al.*, Phys. Rev. Lett. 108, 112502 (2012).

Nuclear reaction experiments

LNS

Observational data

Need to go beyond mean field description: one nucleon transfer experiments show that single-particle have spectroscopic factors smaller than one. This can be taken into account considering the coupling with collective vibrations (Nuclear Field Theory)

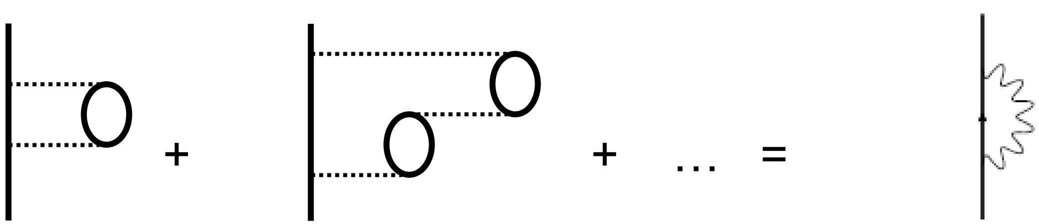
In the Dyson equation

$$[\omega - H_0]G(\vec{r},\vec{r}\,';\omega) = \delta(\vec{r}-\vec{r}\,') + \int d^3r'\Sigma(\vec{r},\vec{r}\,';\omega)G(\vec{r},\vec{r}\,';\omega)$$

we assume the self-energy is given by the coupling with RPA vibrations

$$\Sigma(\vec{r},\vec{r}\,';\omega) = \int d^3r_1 d^3r_2 \; v(\vec{r},\vec{r}_1)\Pi^{(\mathrm{RPA})}(\vec{r}_1,\vec{r}_2;\omega)v(\vec{r}_2,\vec{r})$$

In a diagrammatic way



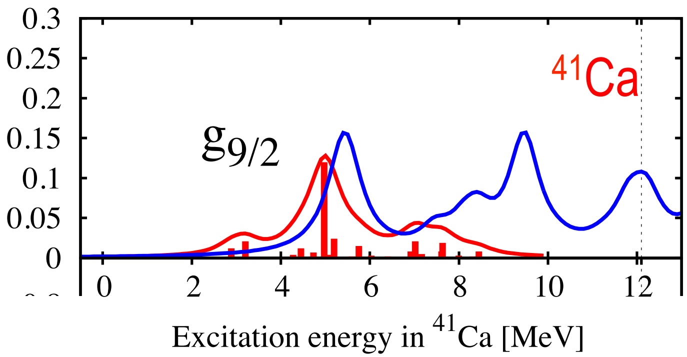
Particle-vibration coupling

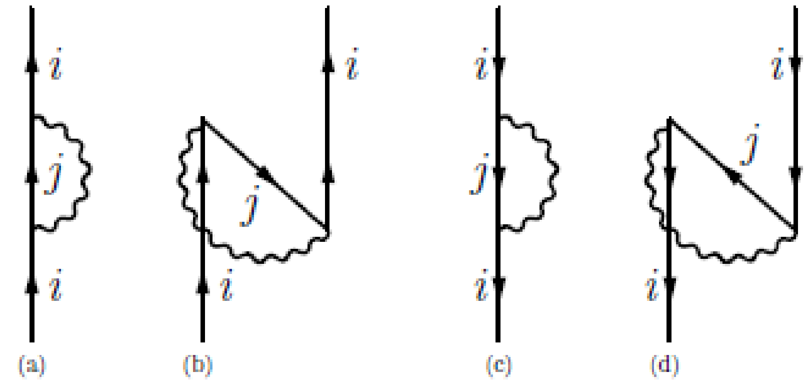
Microscopic calculations

- Starting from exact many-body equations the lowest-order approximation to PVC is calculated using consistently an effective interaction (Skyrme). Refitting should be necessary.

- S.p. states: r.m.s. deviations th. vs. exp. below ≈1 MeV (^{40}Ca, ^{208}Pb …) G.Colo', H. Sagawa, P.F. Bortignon, PRC 82, 064307 (2010).

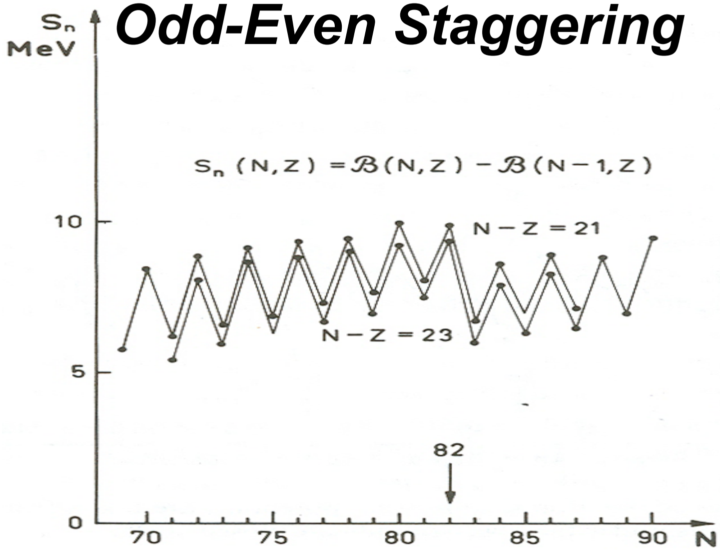
- Implementation in the continuum. K. Mizuyama, G. Colo', E. Vigezzi, PRC 86, 034318 (2012).





Nuclear Superfluidity

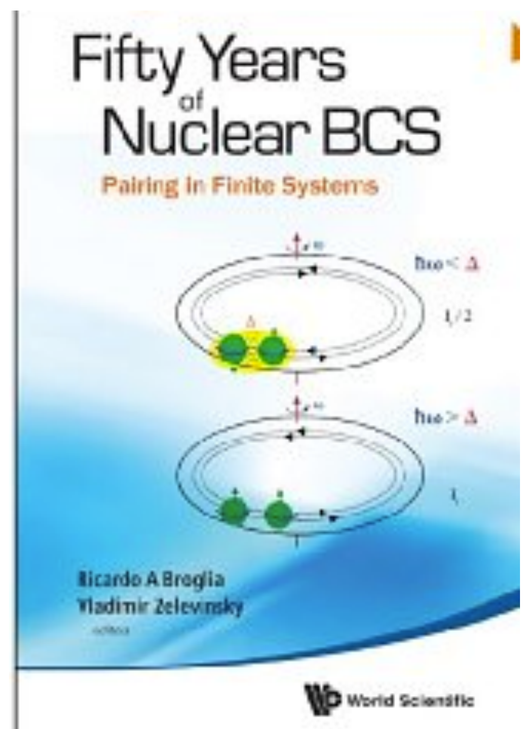
Odd-Even Staggering



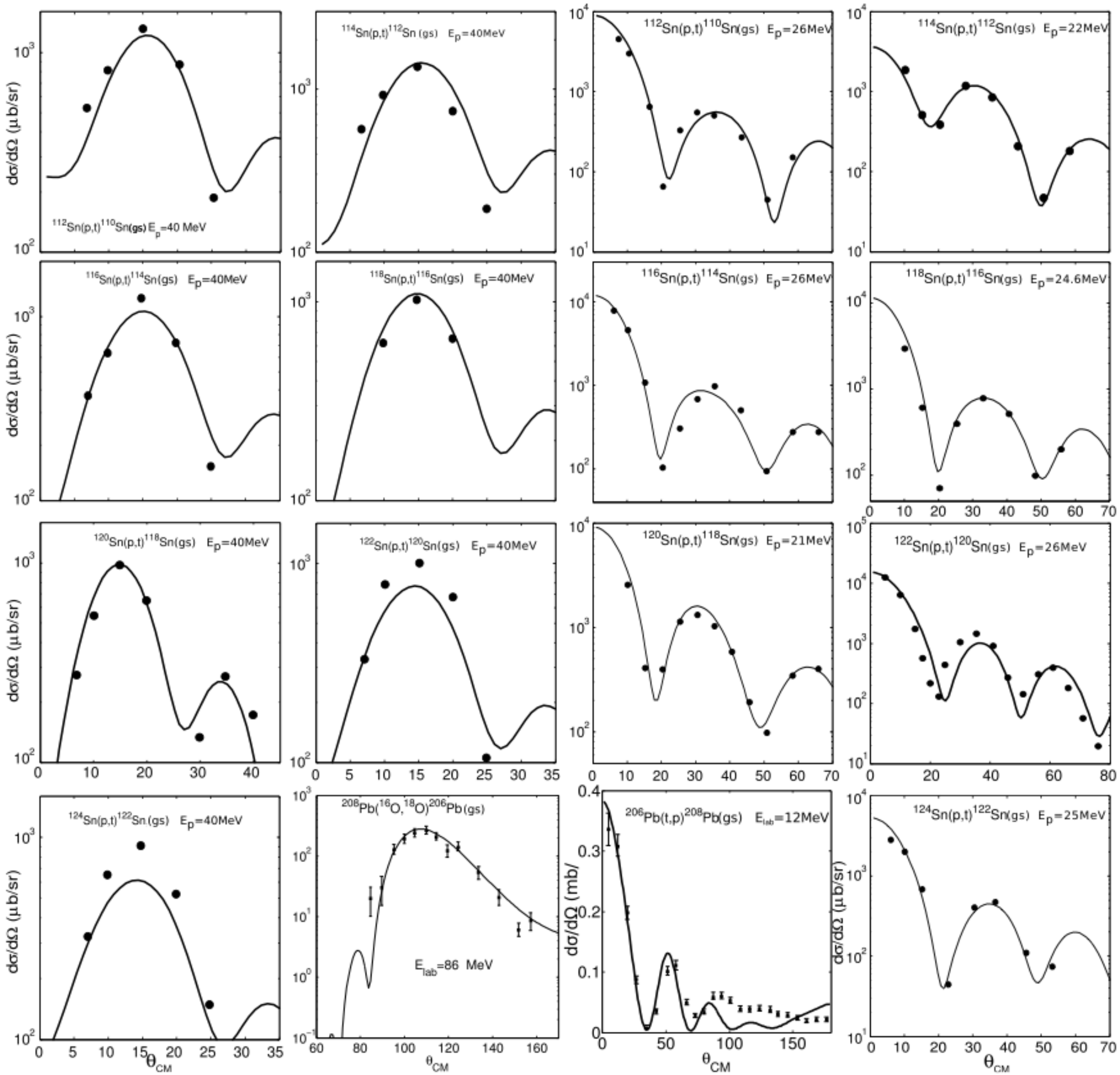
Different behaviour from **even** to **odd** open shell nuclei

__**Fermions pair together**__ in bound states (Cooper pairs): (quasi)bosons

↕



The best probe of pairing correlations: two-particle transfer reactions



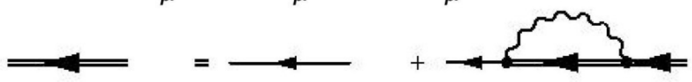
Success of second order DWBA in the calculation of absolute two-neutron transfer cross sections

G. Potel et al., arXiV 1304.2569

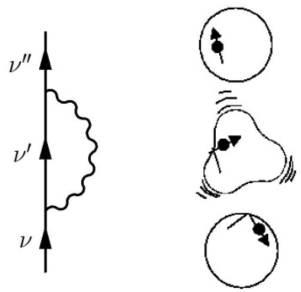
Theoretical progress in the microscopic description of superfluidnuclei beyond mean field: pairing induced interaction

by extending the Dyson equation…

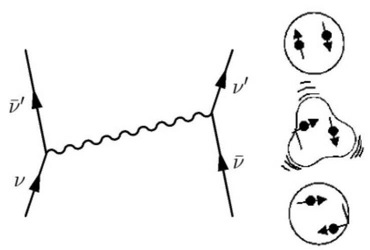
$$G_{\mu}^{-1} = (G_{\mu}^{o})^{-1} - \Sigma_{\mu}(\omega)$$



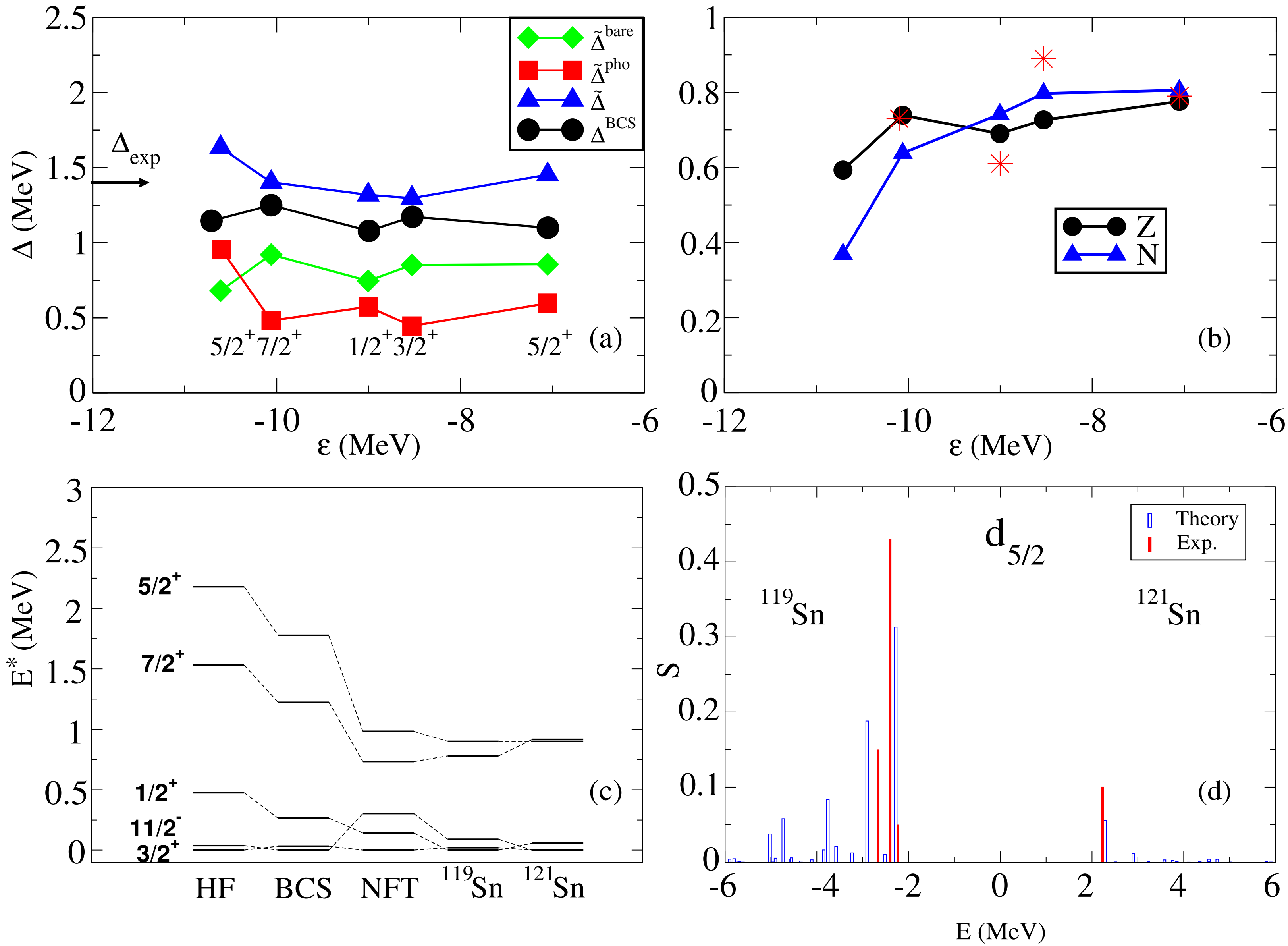
to the case of superfluid nuclei (Nambu-Gor' kov), it is possible to consider both:



and



A. Idini et al., PRC85 (2012) 014331

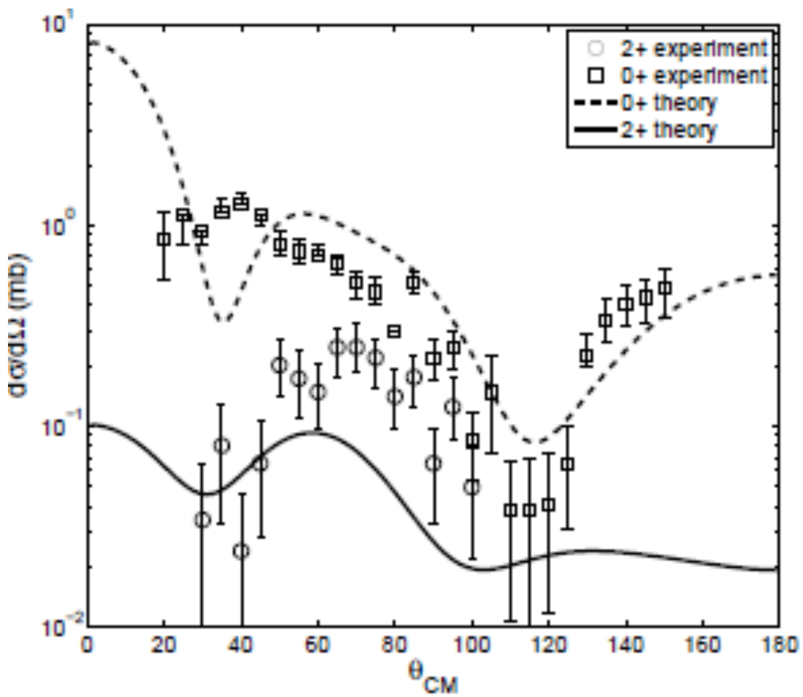


$\tilde{\Delta}^{bare}$
$\tilde{\Delta}^{pho}$
$\tilde{\Delta}$
Δ^{BCS}
Δ_{exp}
Δ (MeV)
ε (MeV)
5/2+ 7/2+ 1/2+ 3/2+ 5/2+
(a)
Z
N
(b)
5/2+
7/2+
1/2+
11/2-
3/2+
E* (MeV)
HF BCS NFT 119Sn 121Sn
(c)
Theory
Exp.
$d_{5/2}$
119Sn
121Sn
S
E (MeV)
(d)

Understanding the physics of halo nuclei

Data	Value	Refs.
S_{2n}	$378 \pm 5,\ 369.15 \pm 0.65$ keV	[7,8]
^{11}Li matter radius	$3.27 \pm 0.24,\ 3.12 \pm 0.16,\ 3.55 \pm 0.10$ fm	[9–11]
^{9}Li matter radius	2.30 ± 0.02 fm	[10,12]
^{11}Li charge radius	2.467(37), 2.423(34), 2.426(34) fm	[13–15]
^{9}Li charge radius	2.217(35), 2.185(33) fm	[13,14]

	$\sigma(^{11}\mathrm{Li(gs)} \to {}^{9}\mathrm{Li\ (i)})$ (mb)		
i	ΔL	Theory	Experiment
gs ($3/2^-$)	0	6.1	5.7 ± 0.9
2.69 MeV ($1/2^-$)	2	0.5	1.0 ± 0.36



G. Potel et al.,
PRL 105 (2010) 172502