Medium polarization effects and transfer reactions in halo nuclei

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Outline

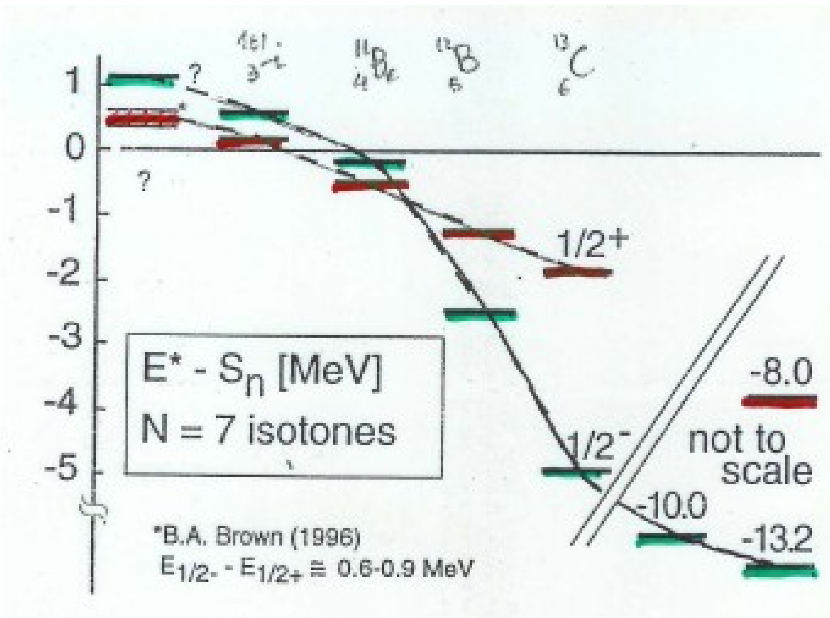
-The dynamic halo

- Microscopic description of two nucleon transfer reactions

- Induced pairing interaction in heavier systems

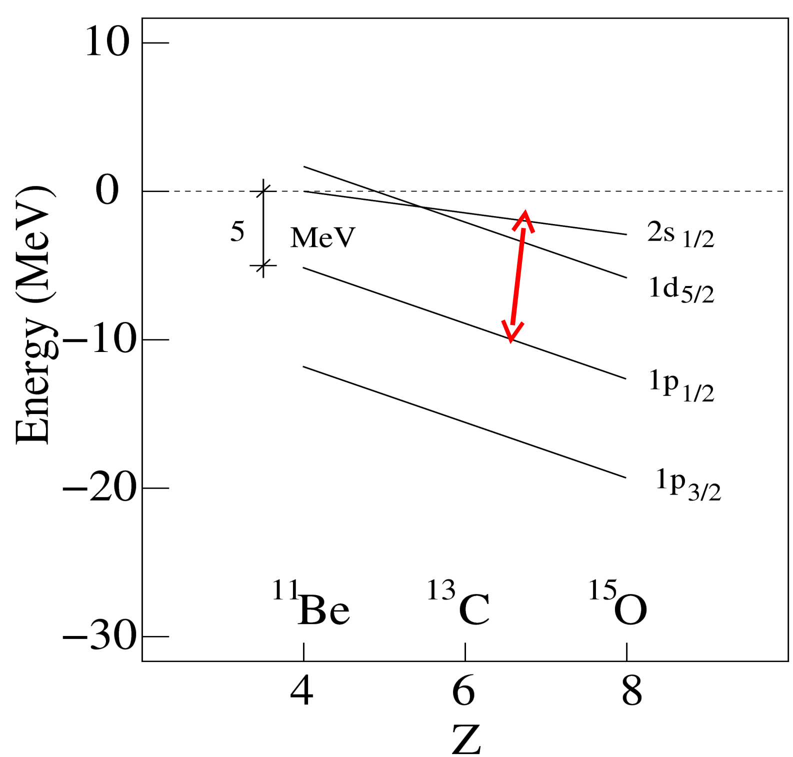
Parity inversion in N=7 isotones

Experimental systematics



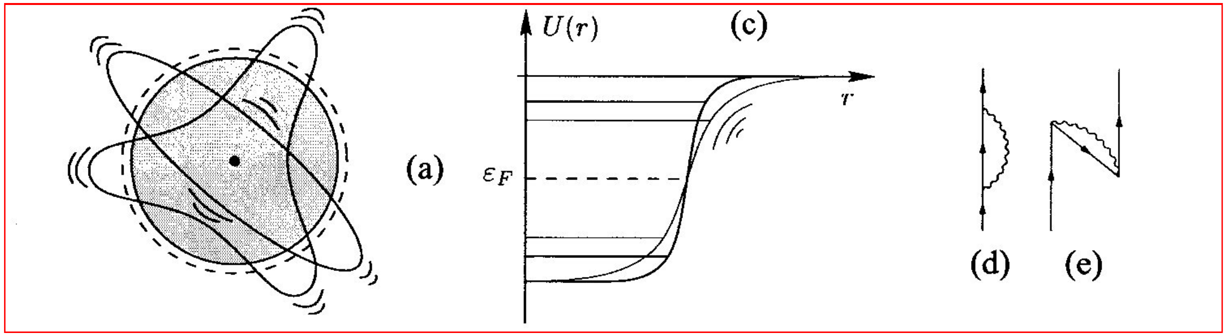
Mean-field results

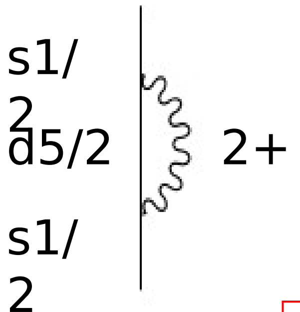
(Sagawa,Brown,Esbensen PLB 309(93)1)



^{11}Be

Eshift = - 2.5 MeV

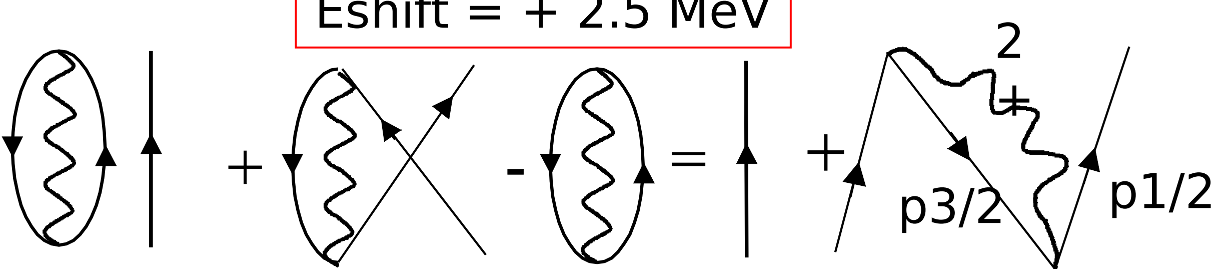




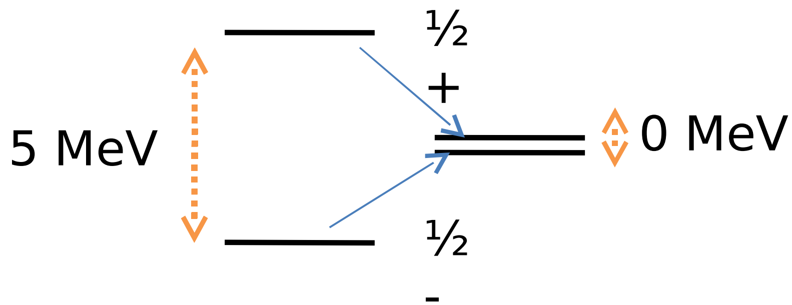
Self-energy

+

Eshift = + 2.5 MeV



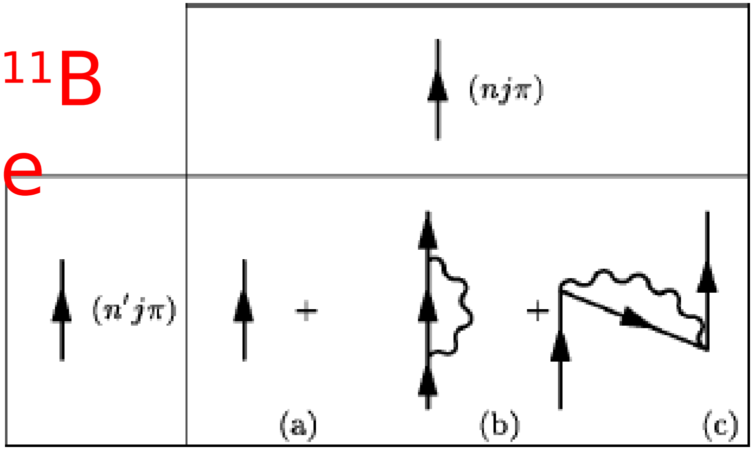
Pauli blocking of core ground state correlations



Level inversion

Effective, energy-dependent matrix (Bloch-Horowitz)

^{11}Be



Main ingredients of our calculation

Fermionic degrees of freedom:

• s1/2, p1/2, d5/2 Wood-Saxon levels up to 150 MeV (discretized continuum) from a standard (Bohr-Mottelson) Woods-Saxon potential

Bosonic degrees of freedom:

• 2+ and 3- QRPA solutions with energy up to 50 MeV; residual interaction: multipole-multipole separable with the coupling constant tuned to reproduce E(2+)=3.36 MeV and $0.6<\beta_2<0.7$

Admixture of $d_{5/2}$ x 2^+ configuration in the $1/2^+$ g.s. of ^{11}Be is about 20%

Calculated ground state

$$|1/2+\rangle = \sqrt{0.87}|s_{1/2}\rangle + \sqrt{0.13}|d_{5/2} \otimes 2+\rangle$$

Exp.:

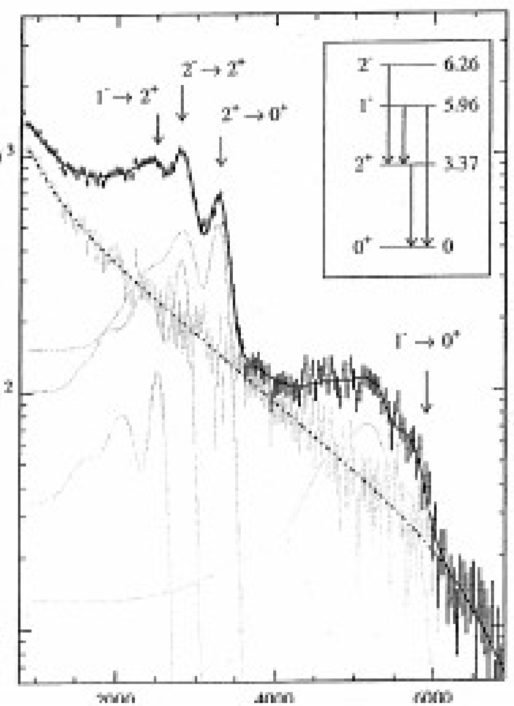
J.S. Winfield et al., Nucl.Phys. **A683** (2001) 48

$$|1/2+\rangle = \sqrt{0.84}|s_{1/2}\rangle + \sqrt{0.16}|d_{5/2} \otimes 2+\rangle$$

^{11}Be(p,d)^{10}Be in inverse kinematic detecting both the ground state and the 2+ excited state of ^{10}Be.

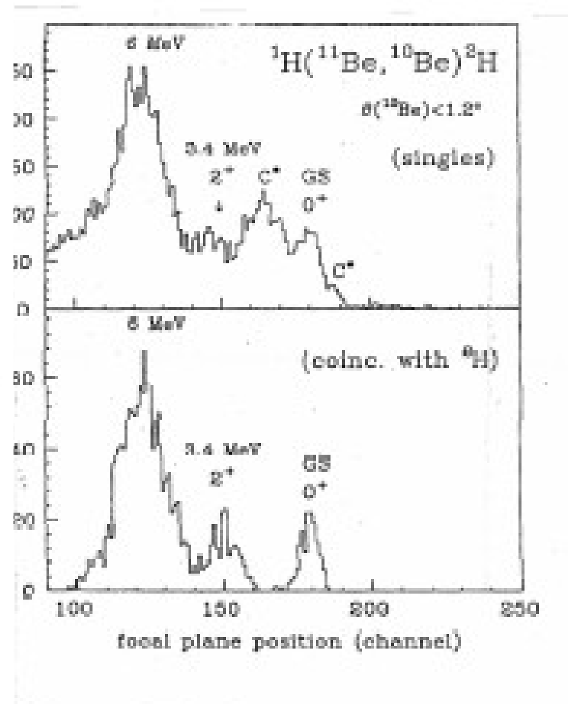
9Be(11Be,10Be+ γ) X

T. Aumann et al.
PRL 84(2000)35



p(11Be,10Be)d

S. Fortier et al.
Phys. Lett.B461(1999)22

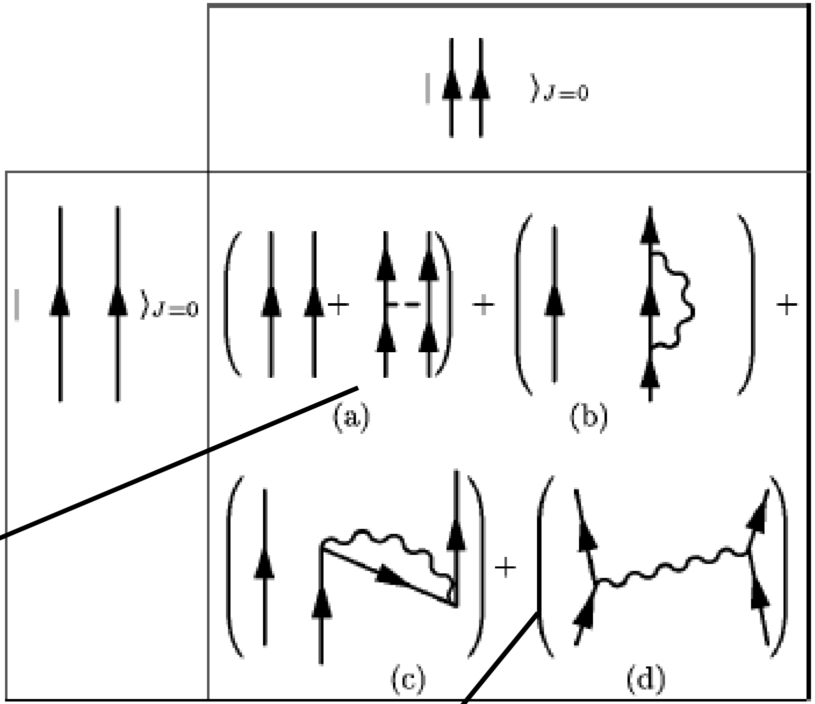


A dynamical description of two-neutron halos

^{1}Li
. Barranco et al. EPJ A11 (2001) 385

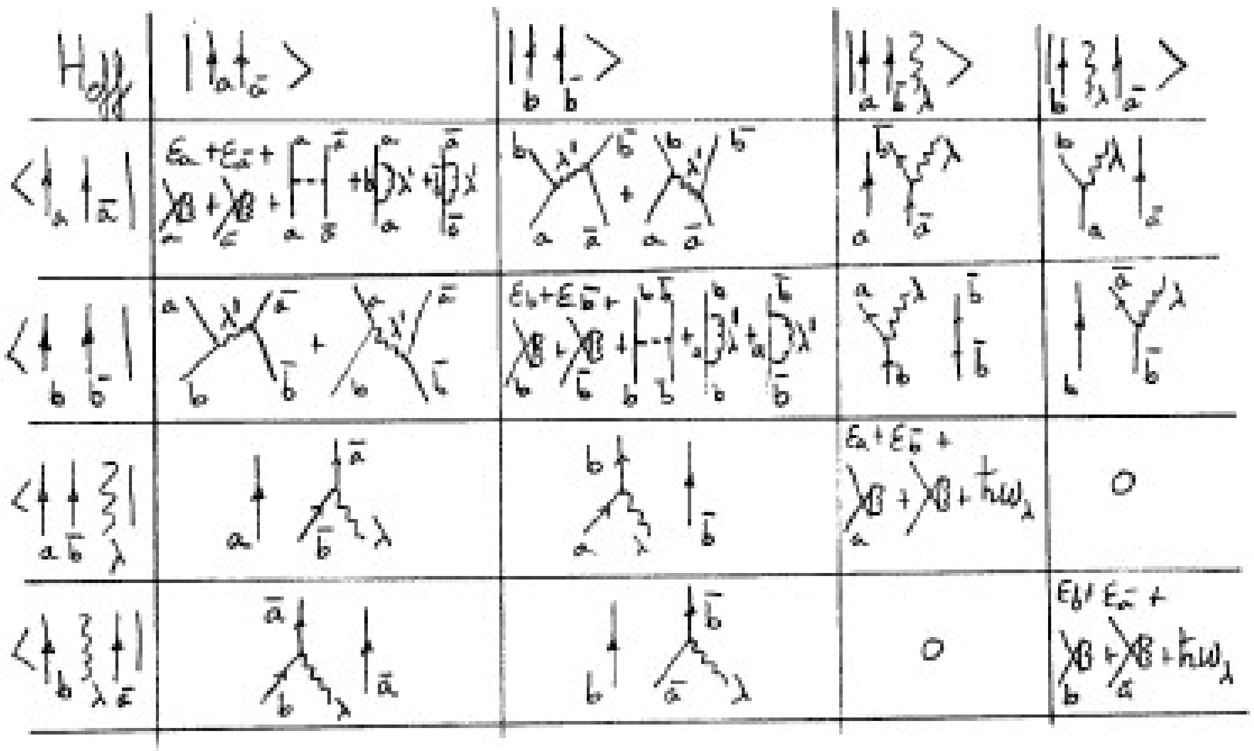
^{2}Be
. Gori et al. PRC 69 (2004) 041302(R)

Energy-dependent matrix



Bare interaction

Induced interaction


Heff
0
0

^{12}Be

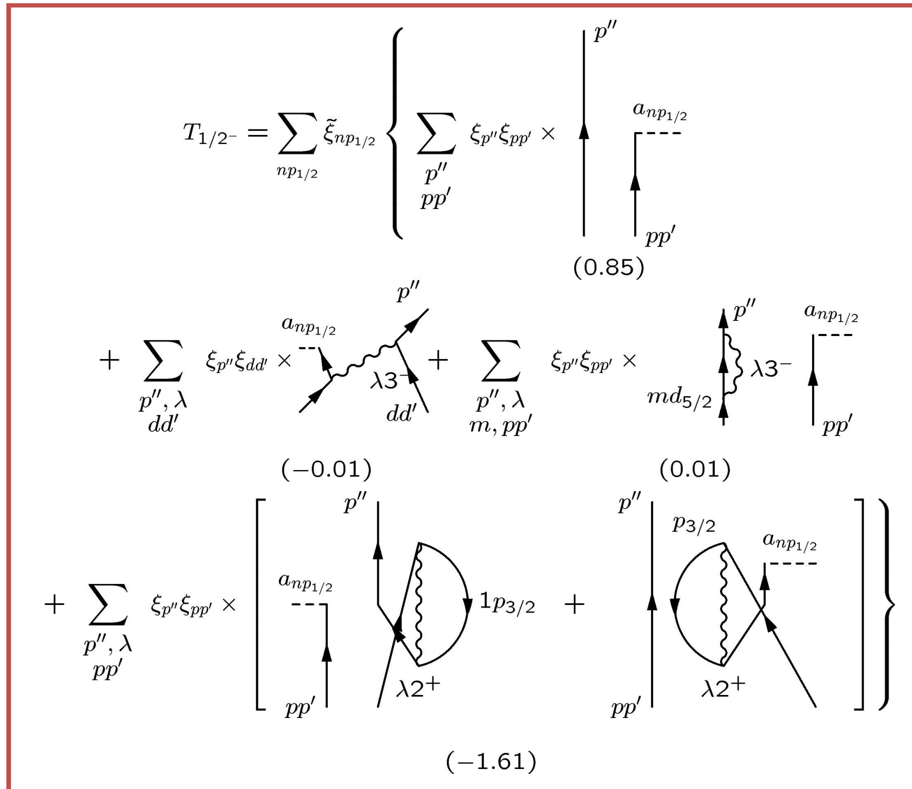
Fermionic degrees of freedom:

• two particle states coupled to zero angular momentum on s1/2, p1/2, d5/2 Woods-Saxon levels up to 150 MeV

Bosonic degrees of freedom:

•1-, 2+ and 3- QRPA solutions up to 50 MeV, associated to a multipole-multipole separable interaction with coupling constant tuned to reproduce E(1-)=2.7 MeV and B(E1)=0.052 e^{2}fm^2 E(2+)=2.1 MeV and 0.6<β_2<0.7

Spectroscopic factors: overlap between ^{11}Be and ^{12}Be



Good agreement between theory and experiment concerning energies and "spectroscopic" factors

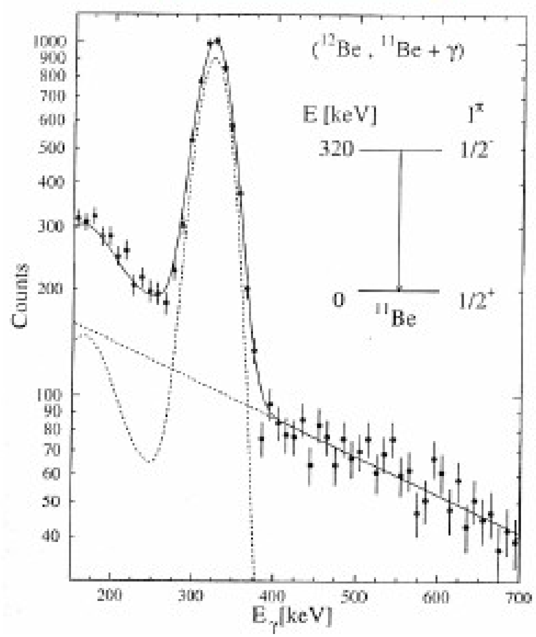
New result for S[1/2+]:
$0.28^{+0.03}_{-0.07}$

Kanungo et al.
PLB 682 (2010) 39

Spectroscopic factors from (12Be,11Be+γ) reaction to ½+ and ½- final states:
S[1/2-]= 0.37±0.10   S[1/2+]= 0.42±0.10

		Expt.	Theory: Particle vibration	Theory: Mean field
$^{11}_{4}Be_7$	$E_{s_{1/2}}$	−0.504 MeV	−0.48 MeV	~0.14 MeV
	$E_{p_{1/2}}$	−0.18 MeV	−0.27 MeV	−3.12 MeV
	$E_{d_{5/2}}$	1.28 MeV	~0 MeV	~2.4 MeV
	$S[1/2^+]$	0.65−0.80 [19]	0.87	1
		0.73±0.06 [20]		
		0.77 [21]		
	$S[1/2^-]$	0.63±0.15 [20]	0.96	1
		0.96 [21]		1
	$S[5/2^+]$		0.72	1
$^{12}_{4}Be_8$	S_{2n}	−3.673 MeV	−3.58 MeV	−6.24 MeV
	s^2, p^2, d^2		23%, 29%, 48%	0%, 100%, 0%
	$S[1/2^+]$	0.42±0.10 [7]	0.31	0
	$S[1/2^-]$	0.37±0.10 [7]	0.57	2

A. Navin et al.,
PRL 85(2000)266



Theoretical calculation for ^{11}Li

Low-lying dipole strength

↓

s-p mixing

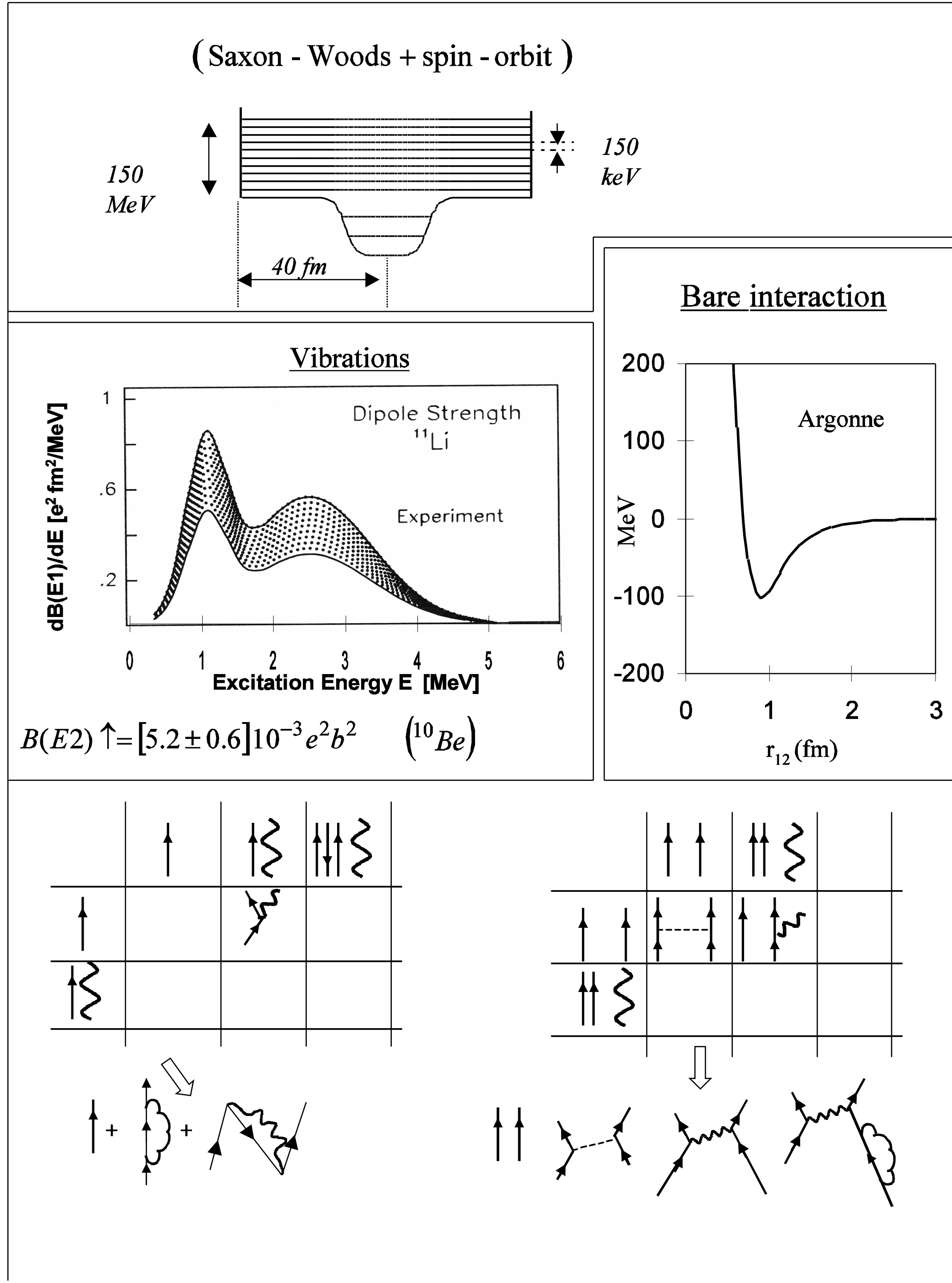


Table 2. RPA wave function of the collective low-lying quadrupole phonon in ^{11}Li, of energy $E_{2^+} = 5.05$ MeV, and leading to the most important contribution to the induced interaction in fig. 1, II. All the listed amplitudes refer to neutron transitions, except for the last column. We have adopted the self-consistent value ($\chi_2 = 0.013\,\mathrm{MeV}^{-1}$) for the coupling constant. The resulting value for the deformation parameter is $\beta_2 = 0.5$.

	$1p_{3/2}^{-1}1p_{1/2}$	$2s_{1/2}^{-1}5d_{3/2}$	$1p_{1/2}^{-1}6p_{3/2}$	$2s_{1/2}^{-1}3d_{5/2}$	$2s_{1/2}^{-1}5d_{5/2}$	$1p_{3/2}^{-1}1p_{1/2}$ (π)
X_{ph}	0.824	0.404	0.151	0.125	0.126	0.16
Y_{ph}	0.119	0.011	−0.002	−0.049	−0.011	0.07

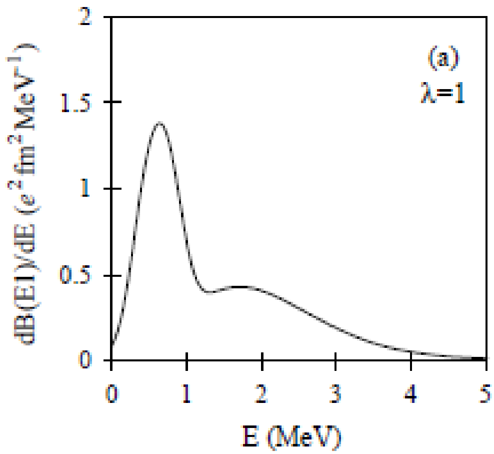
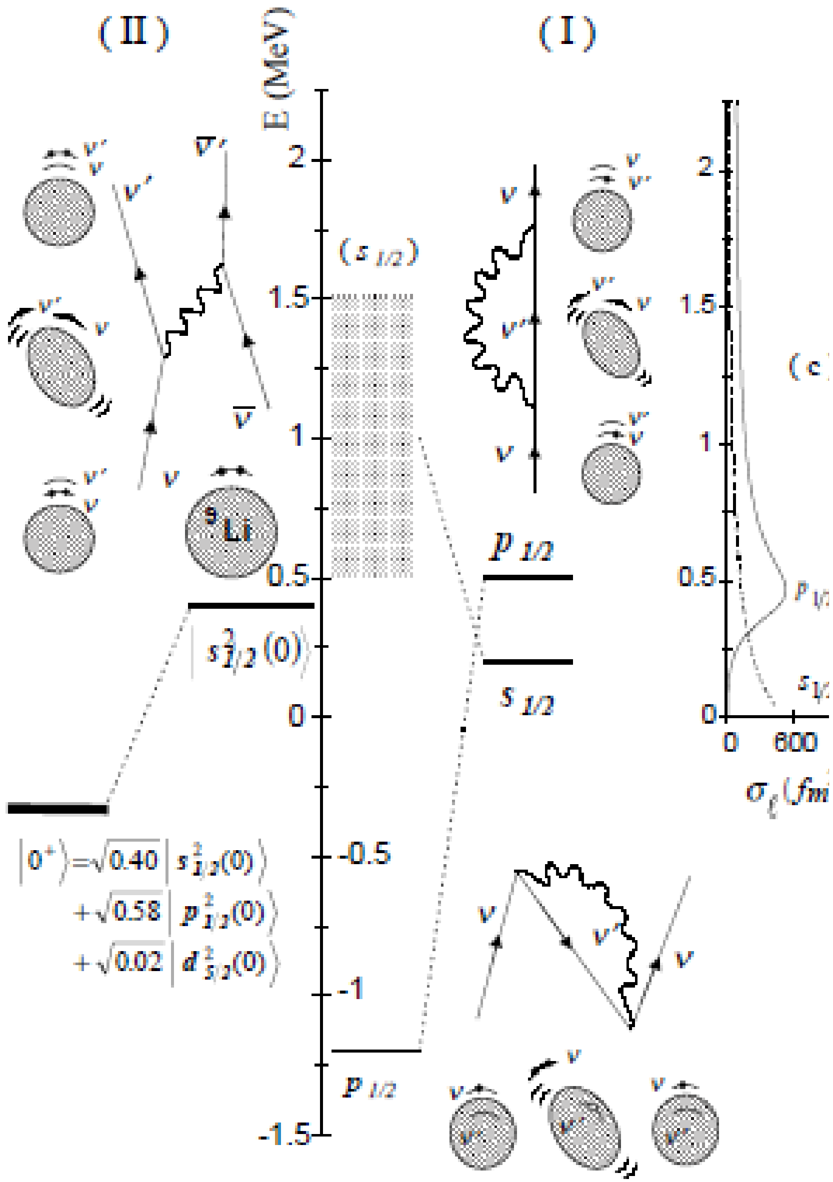


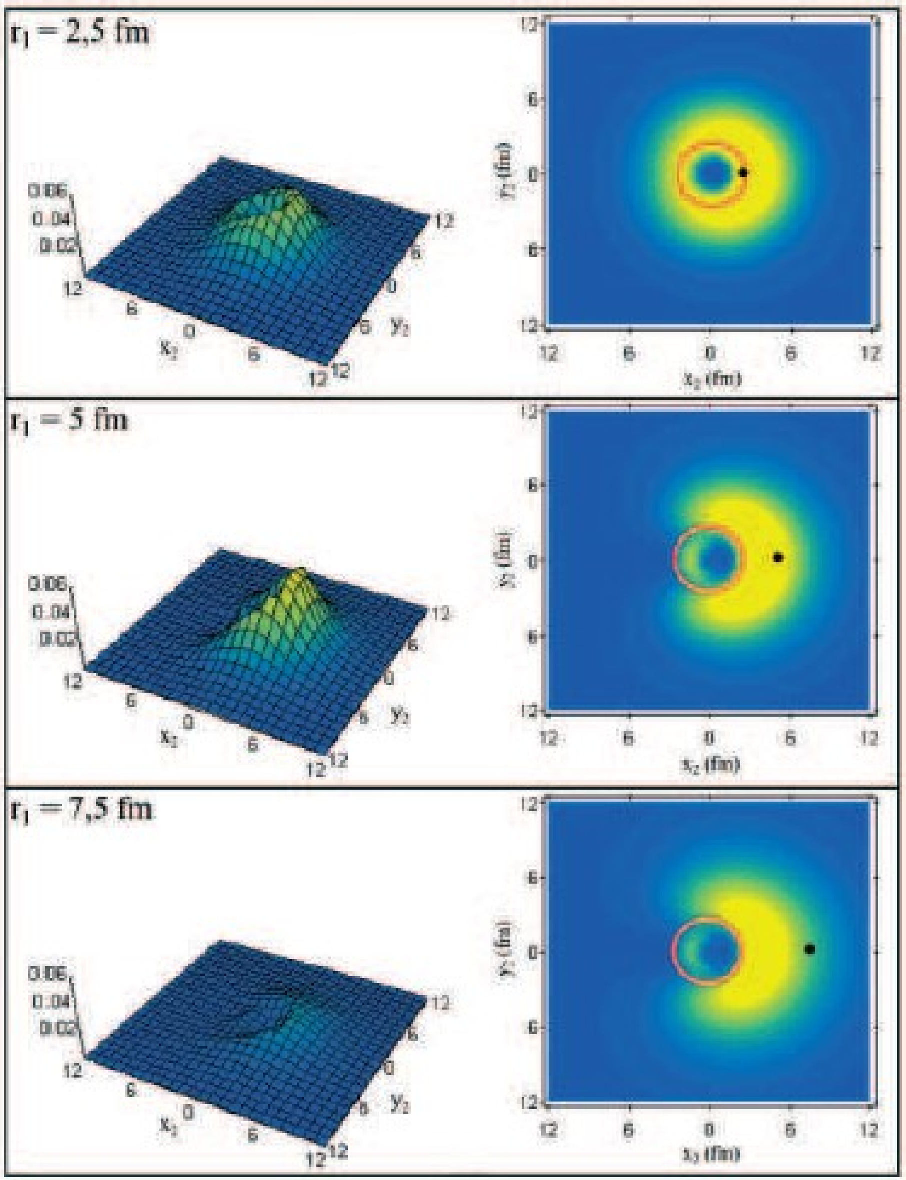
Table 3. RPA wave function of the strongest low-lying dipole vibration of ^{11}Li, ($E_{1^-} = 0.75$ MeV), and contributing most importantly to the pairing induced interaction (fig. 1, II). All the listed amplitudes refer to neutron transitions. We have used the value $\chi_1 = 0.0043$ MeV^{-1} for the isovector coupling constant in order to get a good agreement with the experimental findings. To be noted that this value coincides within 25% close to the selfconsistent value of 0.0032 MeV^{-1}. The resulting strength function (cf. fig. 2(a)) integrated up to 4 MeV gives 7% of the Thomas-Reiche-Kuhn energy weighted sum rule, to be compared to the experimental value of 8% [38].

	$1p_{1/2}^{-1}2s_{1/2}$	$1p_{1/2}^{-1}3s_{1/2}$	$1p_{1/2}^{-1}4s_{1/2}$	$1p_{1/2}^{-1}1d_{3/2}$	$1p_{3/2}^{-1}5d_{5/2}$	$1p_{3/2}^{-1}6d_{5/2}$	$1p_{3/2}^{-1}7d_{5/2}$
X_{ph}	0.847	−0.335	0.244	0.165	0.197	0.201	0.157
Y_{ph}	0.088	0.060	0.088	0.008	0.165	0.173	0.138

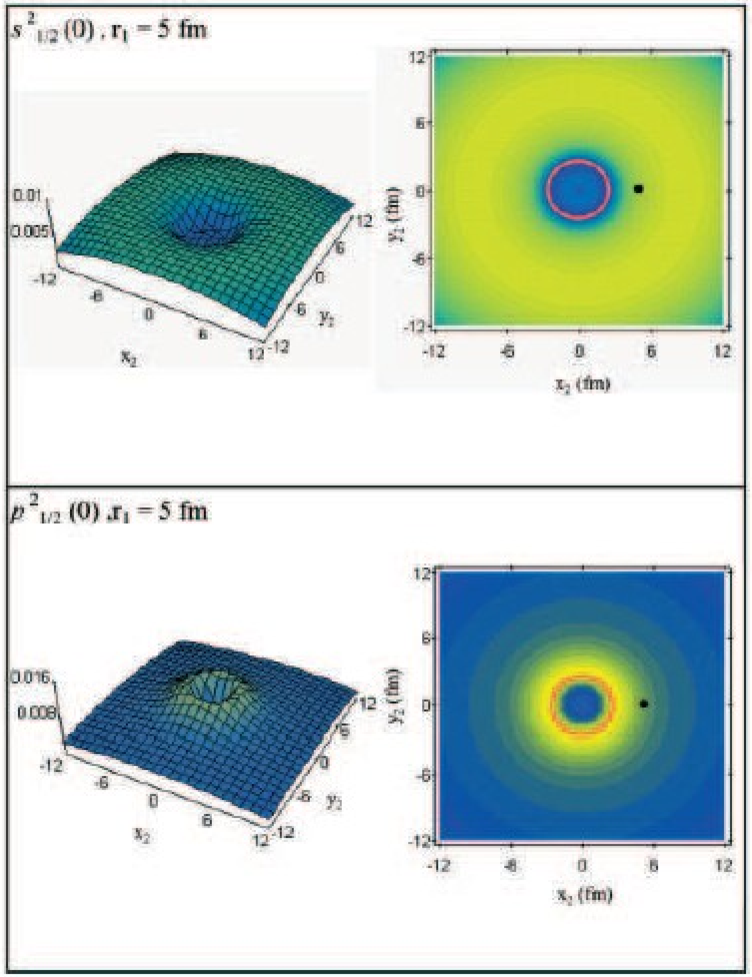


		Exp.	Theory	
			particle-vibration +Argonne	mean field
$^{10}_{3}$Li$_7$ (not bound)	s	0.1-0.2 MeV	0.2 MeV (virtual)	~ 1 MeV (virtual)
	p	0.5-0.6 MeV	0.5 MeV (res.)	-1.2 MeV (bound)
$^{11}_{3}$Li$_8$ (bound)	S_{2n}	0.369 MeV	0.33 MeV	2.4 MeV
	s^2,p^2	50% , 50%	41% , 59%	0% , 100%
	$\langle r^2\rangle^{1/2}$	3.55±0.1 fm	3.9 fm	
	$\Delta p_\perp$	48±10 MeV/c	55 MeV/c	

Correlated halo wavefunction



Uncorrelated



Comparison with the model by Bertsch and Esbensen

OUR MODEL

Ann. Phys.209(1991)327
PRC56(1997)3054

Single-particle potential

Standard Bohr-Mottelson

Depth adjusted to experimental $p_{1/2}$ single particle energy

2-body interaction

Bare Argonne interaction+ particle-vibration coupling with phenomenological parameters (low-lying vibrations)

Strength fitted to S_{2n} in ^{12}Be

$$v_{\rm eff}(\mathbf{r}_1,\mathbf{r}_2)=\delta(\mathbf{r}_1-\mathbf{r}_2)\left(v_0+v_\rho\left(\frac{\rho_c((\mathbf{r}_1+\mathbf{r}_2)/2)}{\rho_0}\right)^P\right).$$

Results

Good reproduction of binding energies in ^{12}Be and ^{11}Li
50% $(s_{1/2})^2$

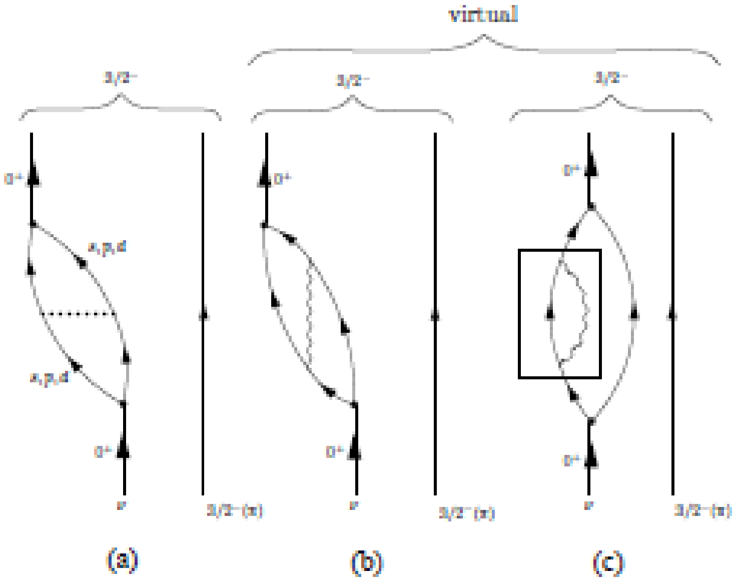
Good reproduction of binding energy
Low $(s_{1/2})^2$ admixture unless two different s.p. potentials are used

Vibrational vs. deformed core

Shell-model calculations [21] indicate that ^{10}Be is not a perfect rotor: the calculated quadrupole moment of the lowest 2^+ state is only 34% of the value predicted from the β_2 value, assuming a static deformation. We have

H. Esbensen, B.A. Brown, H. Sagawa, PRC 51 (1995) 1274

How to probe the particle-phonon coupling?
Test the microscopic correlated wavefunction with phonon admixture



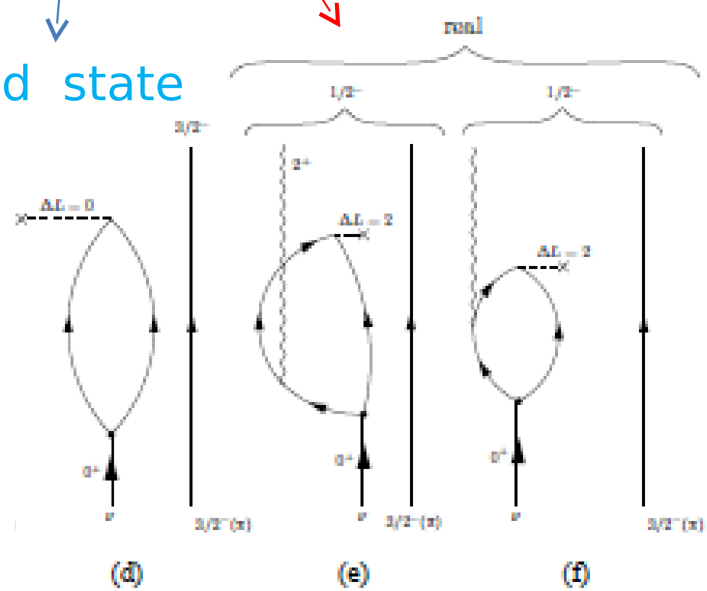
$$|\tilde{0}\rangle = |0\rangle + 0.7|(ps)_{1^-} \otimes 1^-; 0\rangle + 0.1|(sd)_{2^+} \otimes 2^+; 0\rangle$$

$$|0\rangle = 0.45|s^2_{1/2}(0)\rangle + 0.55|p^2_{1/2}(0)\rangle + 0.04|d^2_{5/2}(0)\rangle$$

Two-neutron transfer to

ground state

exc. state



Probing ^{11}Li halo-neutrons correlations via (p,t) reaction

PRL **100,** 192502 (2008) PHYSICAL REVIEW LETTERS week ending 16 MAY 200

Measurement of the Two-Halo Neutron Transfer Reaction ^{1}H(^{11}Li, ^{9}Li)^{3}H at 3*A* MeV

I. Tanihata,* M. Alcorta,† D. Bandyopadhyay, R. Bieri, L. Buchmann, B. Davids, N. Galinski, D. Howell, W. Mills, S. Mythili, R. Openshaw, E. Padilla-Rodal, G. Ruprecht, G. Sheffer, A. C. Shotter, M. Trinczek, and P. Walden
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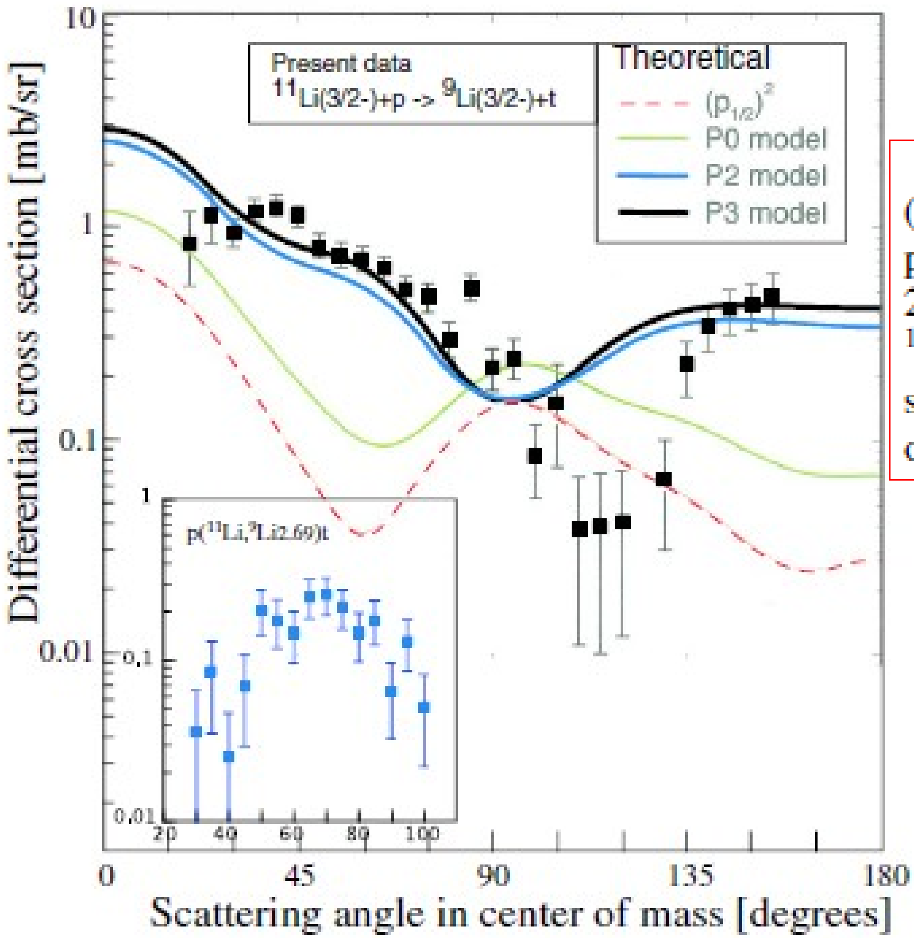
(Received 22 January 2008; published 14 May 2008)

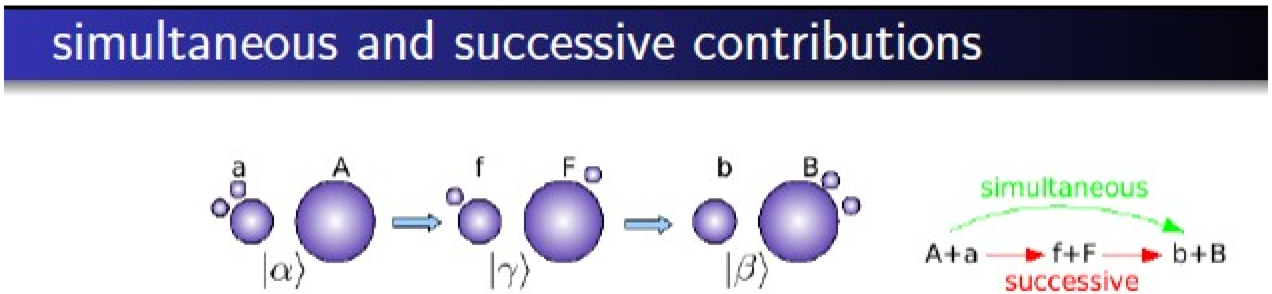


The cross section for transitions to the first excited state (Ex = 2.69 MeV) is shown also in Fig. 3. If this state were populated by a direct transfer, it would indicate that a 1^+ or 2^+ halo component is present in the ground state of ^{11}Li($\frac{3}{2}^-$), because the spin-parity of the ^{9}Li first excited state is $\frac{1}{2}^-$. This is new information that has not yet been observed in any of previous investigations. A compound

TABLE I. Optical potential parameters used for the present calculations.

	V MeV	r_V fm	a_V fm	W MeV	W_D MeV	r_W fm	a_W fm	V_{so} MeV	r_{so} fm	a_{so} fm
$p + {}^{11}$Li [10]	54.06	1.17	0.75	2.37	16.87	1.32	0.82	6.2	1.01	0.75
$d + {}^{10}$Li [11]	85.8	1.17	0.76	1.117	11.863	1.325	0.731	0		
$t + {}^{9}$Li [12]	1.42	1.16	0.78	28.2	0	1.88	0.61	0		

Calculation of absolute two-nucleon transfer cross section by finite-range DWBA calculation

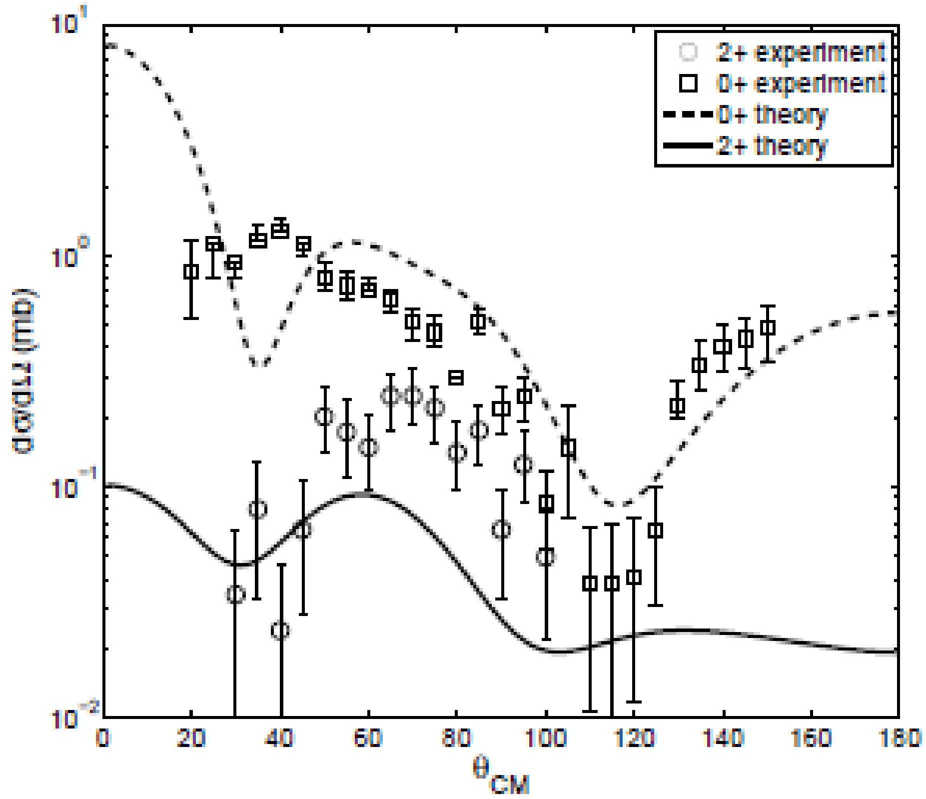


$$|\alpha\rangle = \phi_a(\xi_b, \mathbf{r}_1, \mathbf{r}_2)\times \phi_A(\xi_A)\chi_{aA}(\mathbf{r}_{aA})$$

$$|\beta\rangle = \phi_b(\xi_b)\phi_B(\xi_A, \mathbf{r}_1, \mathbf{r}_2)\times \chi_{bB}(\mathbf{r}_{bB})$$

Optical potentials from global systematics in the various channels

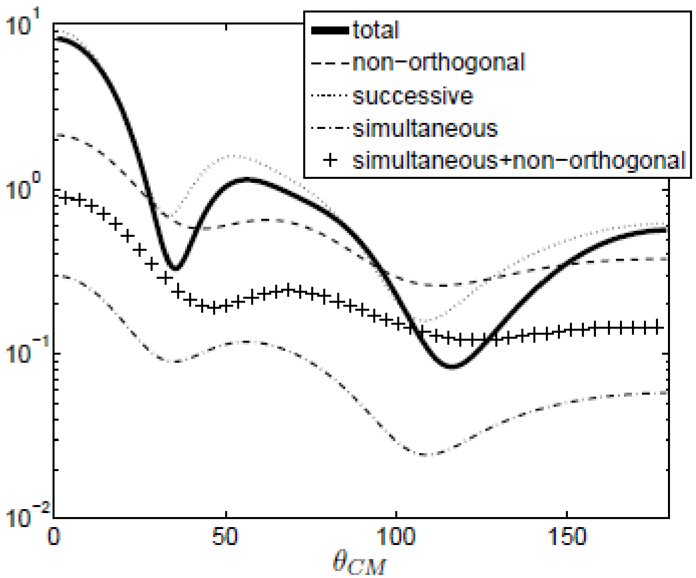
B.F. Bayman and J. Chen, Phys. Rev. C 26 (1982) 1509
G. Potel et al., arXiv:0906.4298

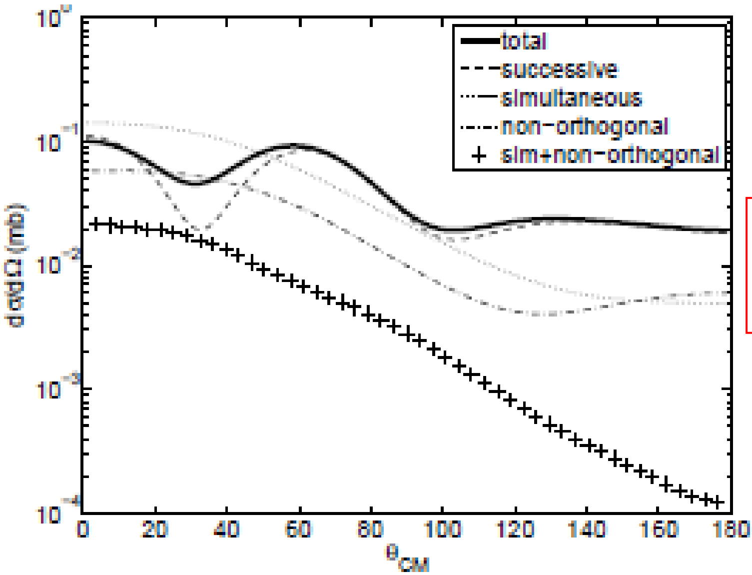


	$\sigma(^{11}\mathrm{Li(gs)} \rightarrow {}^{9}\mathrm{Li\ (i)})$ (mb)		
i	ΔL	Theory	Experiment
gs ($3/2^-$)	0	6.1	5.7 ± 0.9
2.69 MeV ($1/2^-$)	2	0.5	1.0 ± 0.36

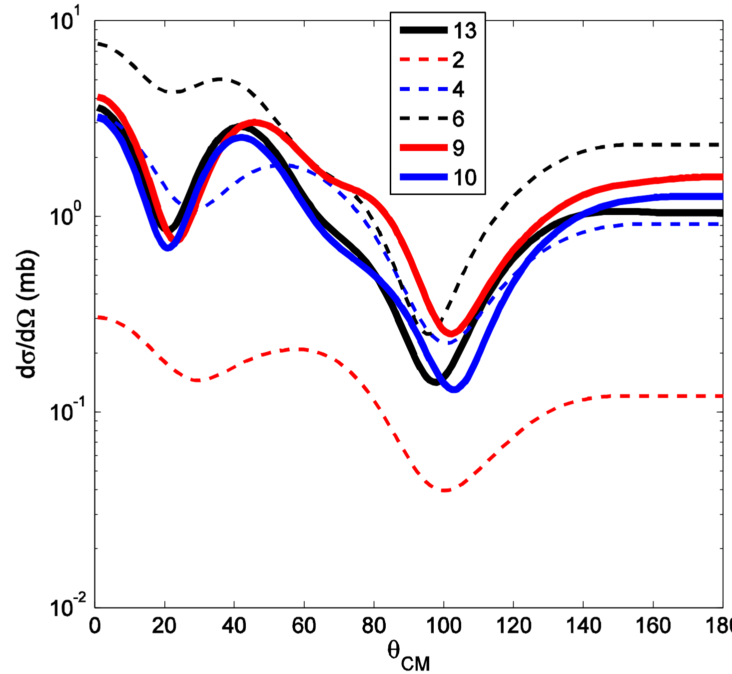
G. Potel et al., arXiv:0912.0847

Decomposition into successive and simultaneous contributions





Convergence of the calculation of successive transfer



Excitation of ½- state following transfer:
10-100 times smaller than direct population

Setting these findings in a broader context – pairing in heavy nuclei

Various effective forces in the pairing
channel have been proposed, with different features
(finite/zero range, density dependence…)
Unfortunately it is difficult to discriminate
among them comparing with available data.

We want to follow a different strategy:

- Start from an Hartree-Fock calculation with a 'reasonable' interaction. Then solve the pairing problem with a bare interaction in the $^1S_0$ channel. And finally add correlations beyond mean field.

We know that these correlations strongly renormalize the density of single-particle levels (effective mass) and their occupation factors (fragmentation), and we expect that they can have a large effect on pairing properties.

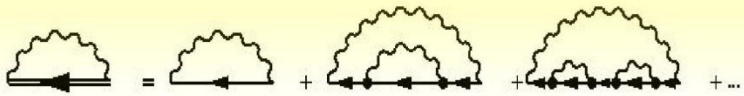
Going beyond the quasi-particle approximation

J. Terasaki et al., Nucl.Phys. **A697**(2002)126

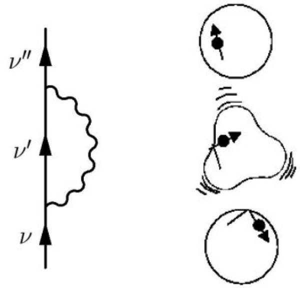
by extending the Dyson equation…

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

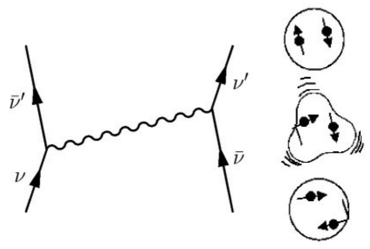
$$\Sigma_\mu(\omega) = \int_{-\infty}^{+\infty} \frac{d\omega'}{2\pi} \sum_{\mu'} \frac{1}{\hbar} G_{\mu'}(\omega') \sum_\alpha \frac{1}{\hbar} D_\alpha^o(\omega-\omega') * V^2_{\mu\mu',\alpha}$$



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

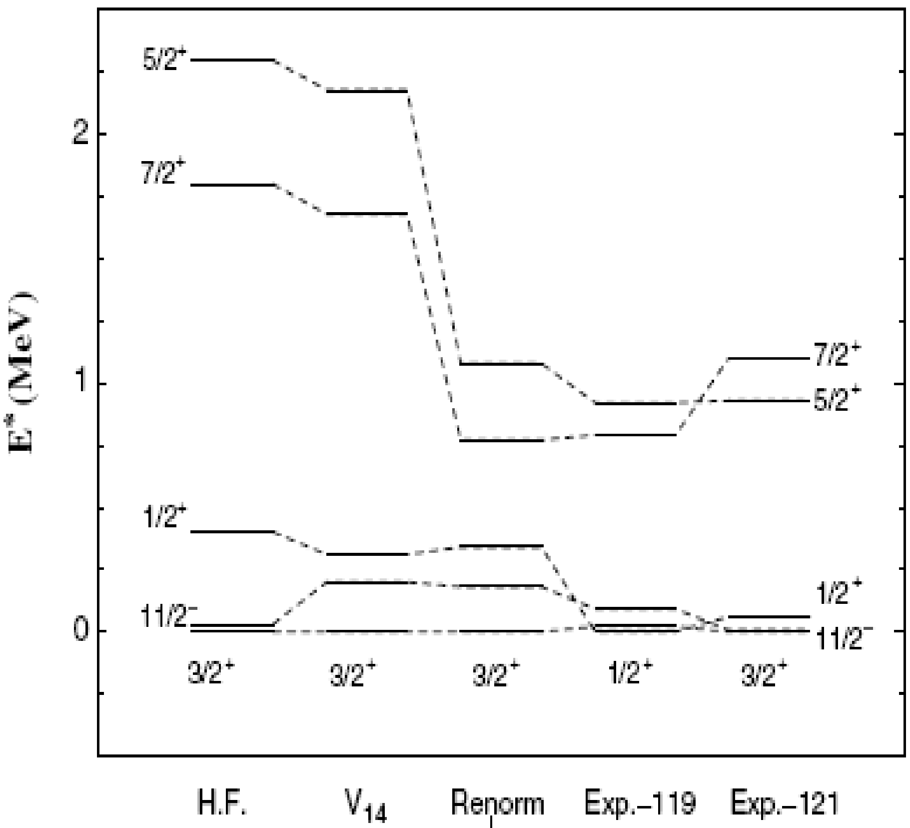


and



Renormalization of quasiparticles

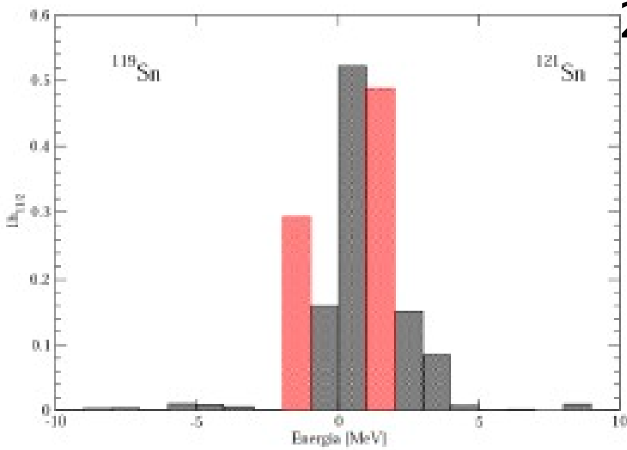
120Sn



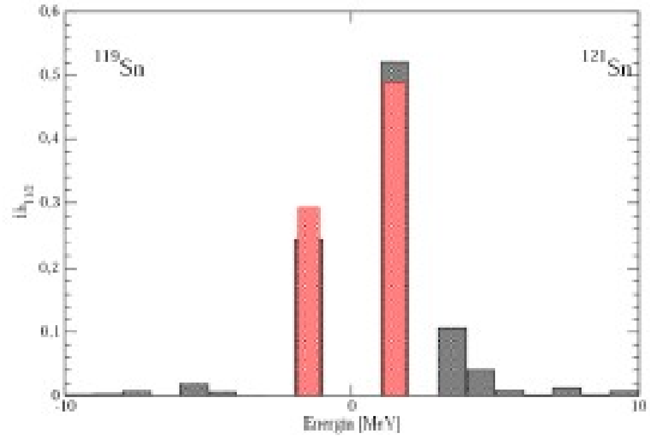
Argonne

Argonne + induced interaction

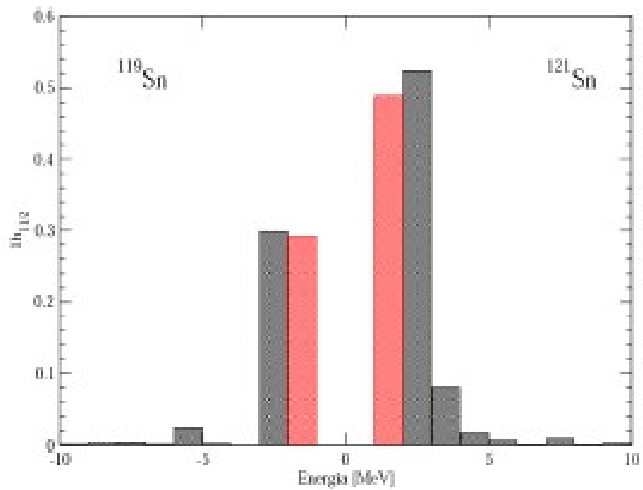
$h_{11/2}$



SII



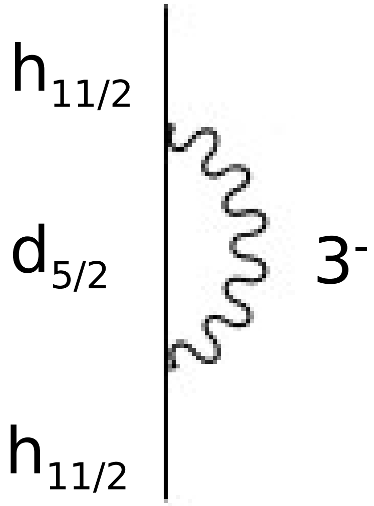
SLy4



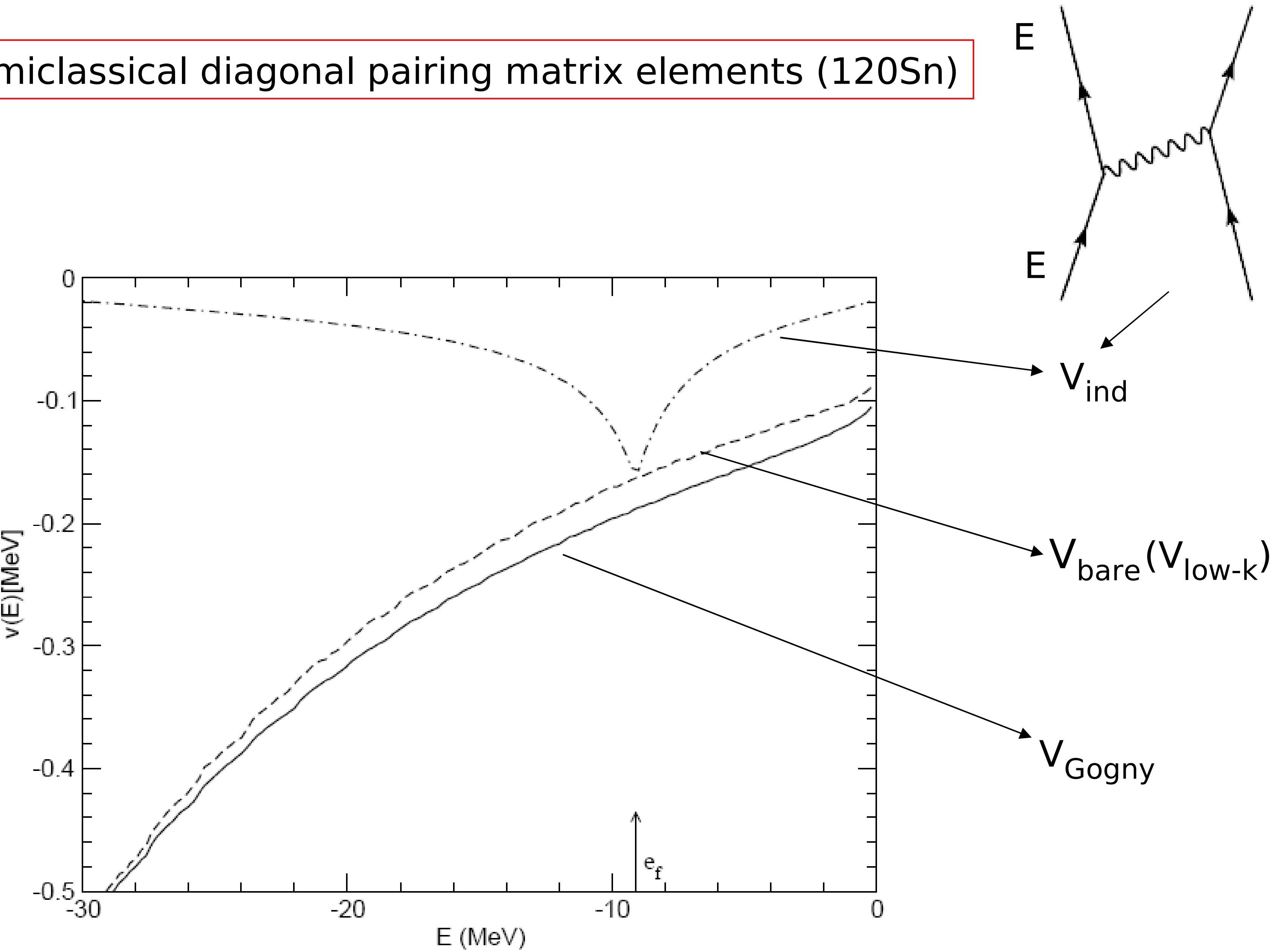
SGII

Exp.

Th.

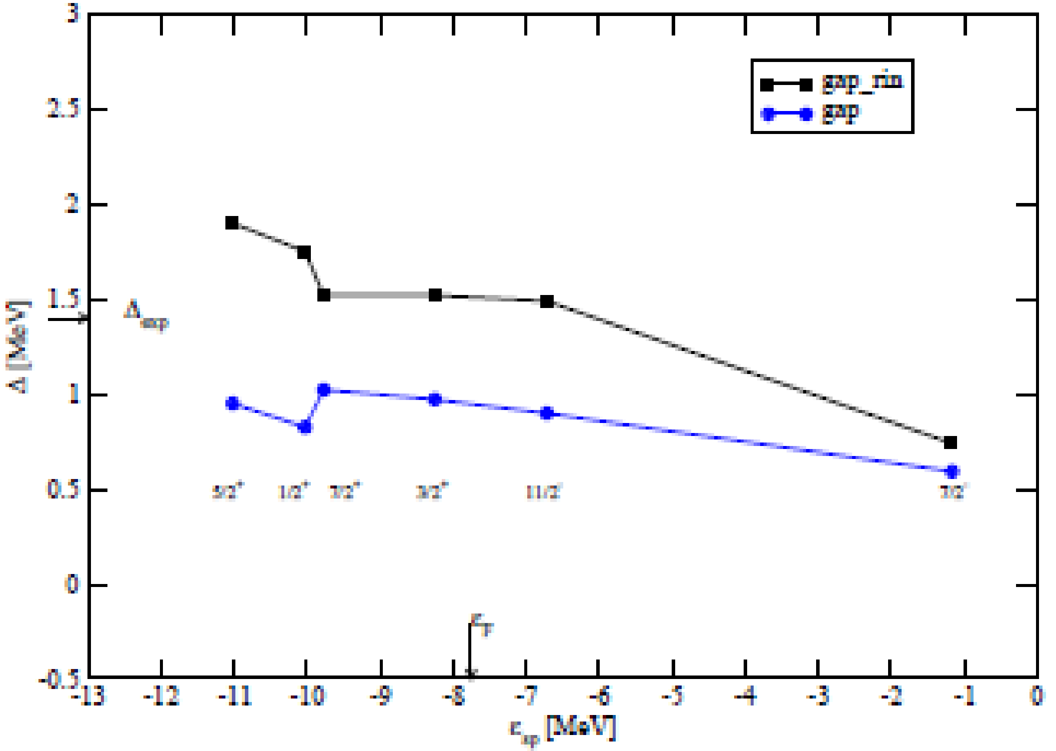


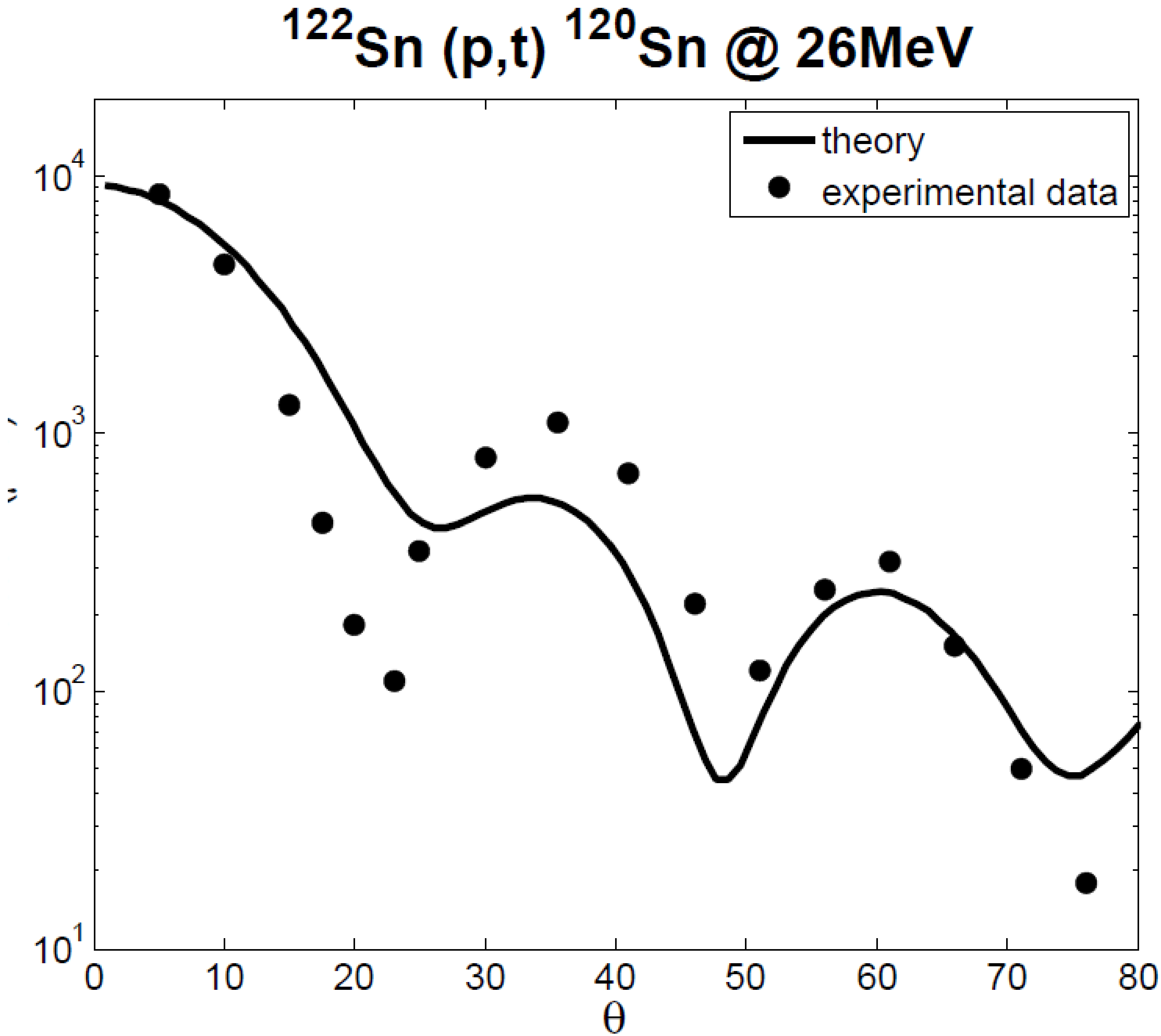
Semiclassical diagonal pairing matrix elements (120Sn)



F. Barranco et al., Phys. Rev. 72(2005)054314

Renormalized pairing gaps

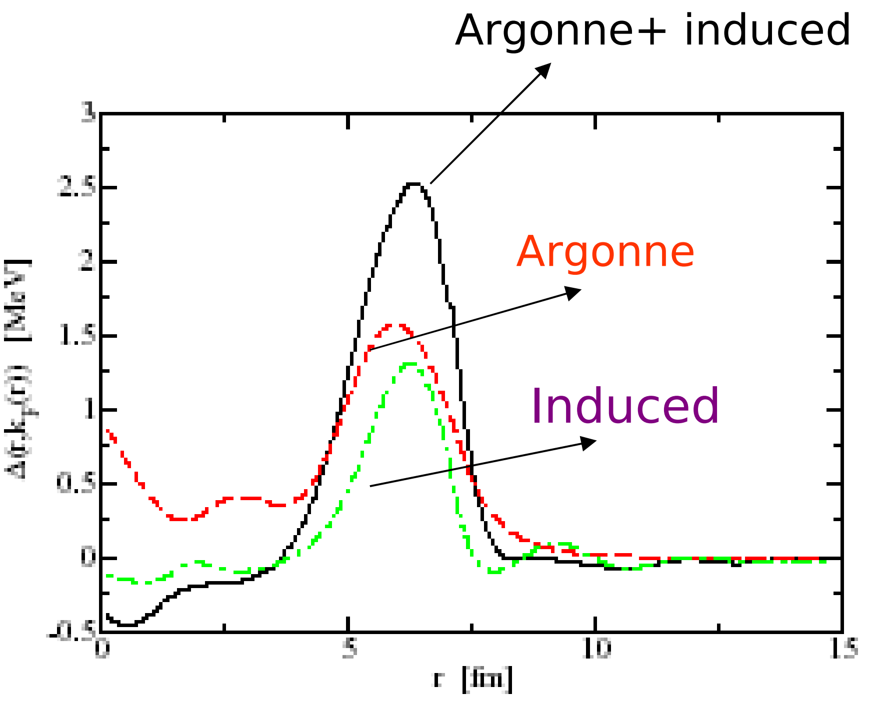




122Sn (p,t) 120Sn @ 26MeV
theory
experimental data
10^4
10^3
10^2
10^1
0
10
20
30
40
50
60
70
80
θ

Local approximation

The pairing gap associated with the bare interaction is surface peaked; the induced interaction reinforces this feature



Microscopic justification of surface peaked, density-dependent pairing force

A. Pastore et al., Phys. Rev. C78 (2008) 024315

According to a dynamical model of the halo nucleus 11Li,
a key role is played by the coupling of the valence nucleons
with the vibrations of the system.
The structure model has been tested with a detailed reaction calculation, comparing with data obtained in a recent (t,p) experiment.
Theoretical and experimental cross section are in reasonable agreement.

The exchange of collective vibrations represents a source of pairing also in heavy nuclei. The quantitative assessment of this contribution is an open problem.