# The structure of halo nucleus $^{11}$Li and pair transfer reactions

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Advances in Nuclear Many-Body Theory, Primosten, 7-10June 2011

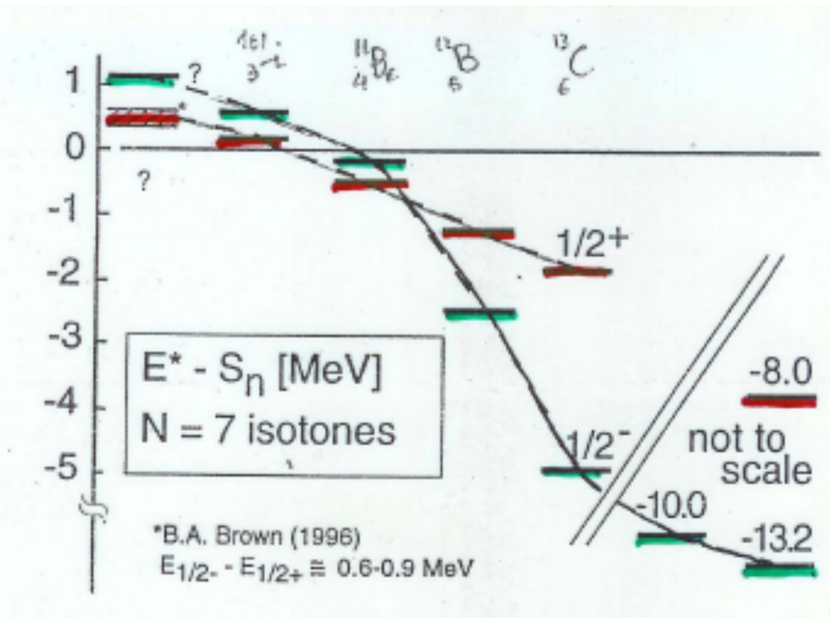
# Outline

-The dynamic halo

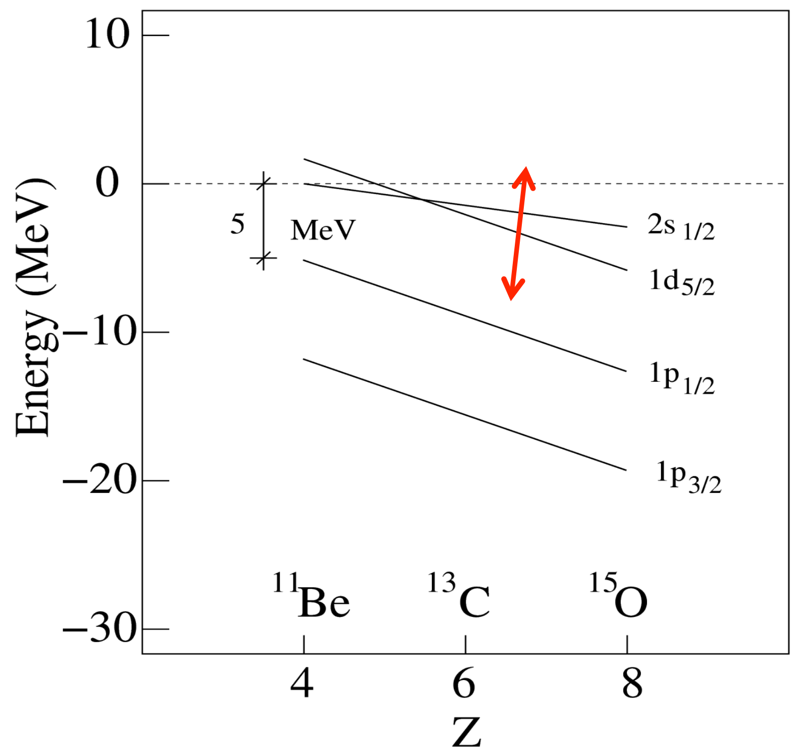
- Microscopic description  of  two nucleon transfer reactions

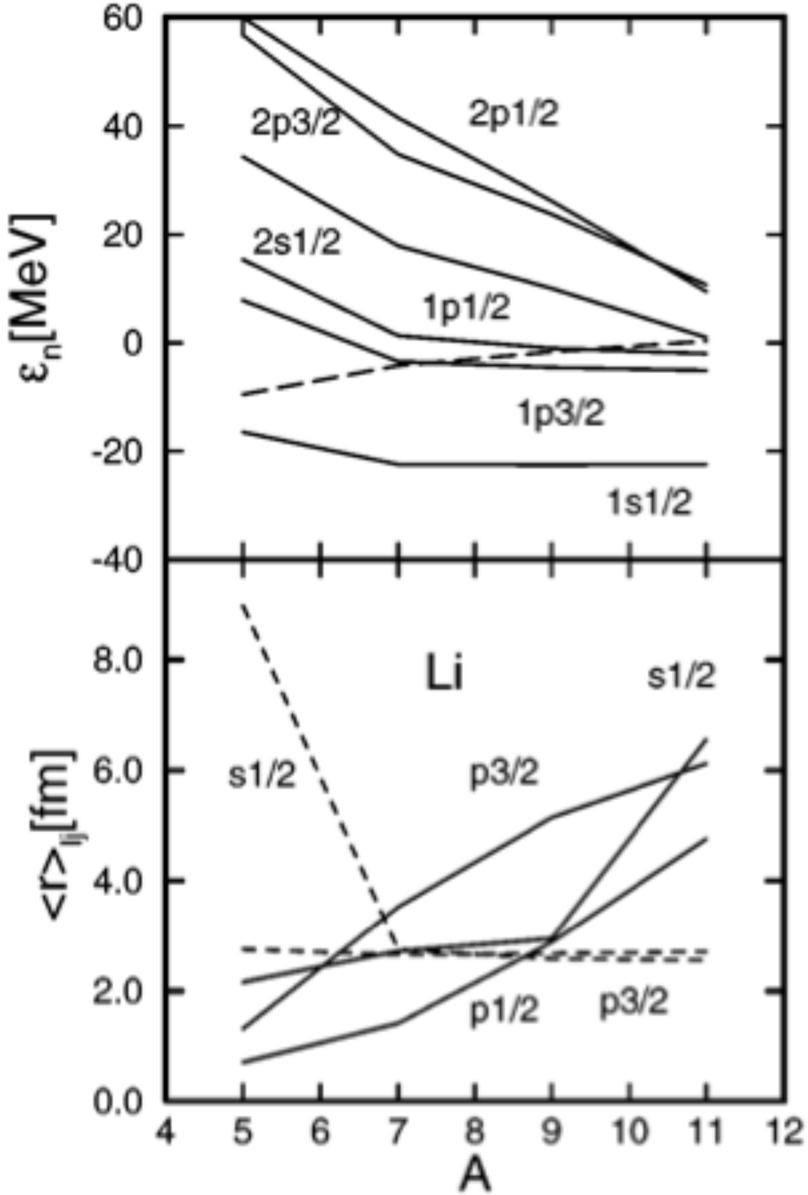
# Parity inversion in N=7 isotones

Experimental systematics



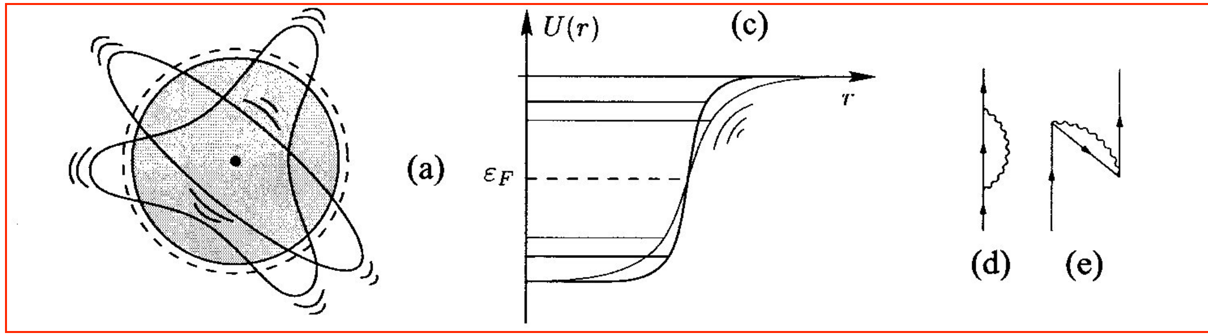

Mean-field results
(Sagawa,Brown,Esbensen PLB 309(93)1)





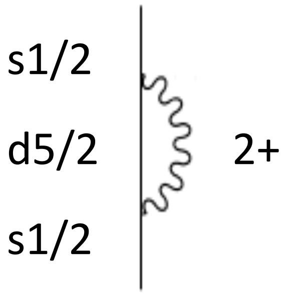

J. Meng and P. Ring, PRL 77(1998)3963

$^{11}$Be




H. Sagawa et al., PLB 309 (1993)1

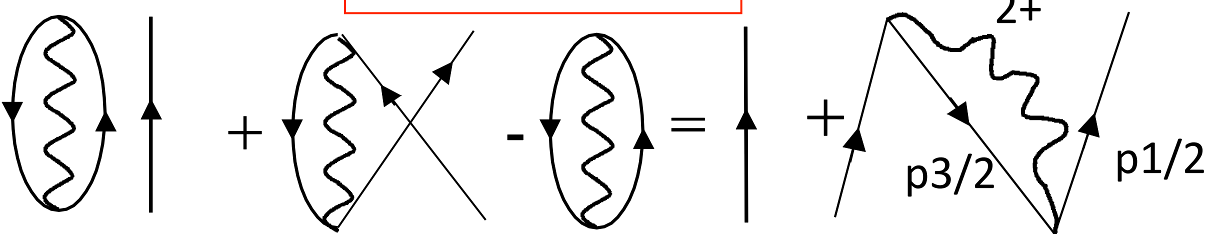
Eshift = - 2.5 MeV




Self-energy

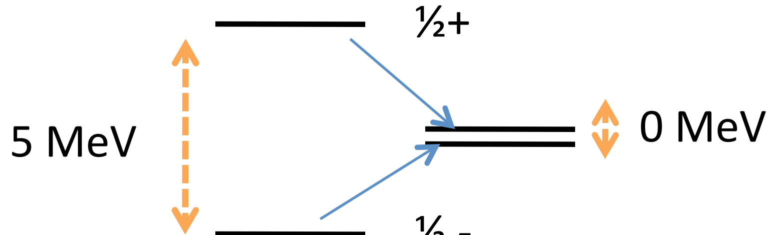
+

Eshift = + 2.5 MeV

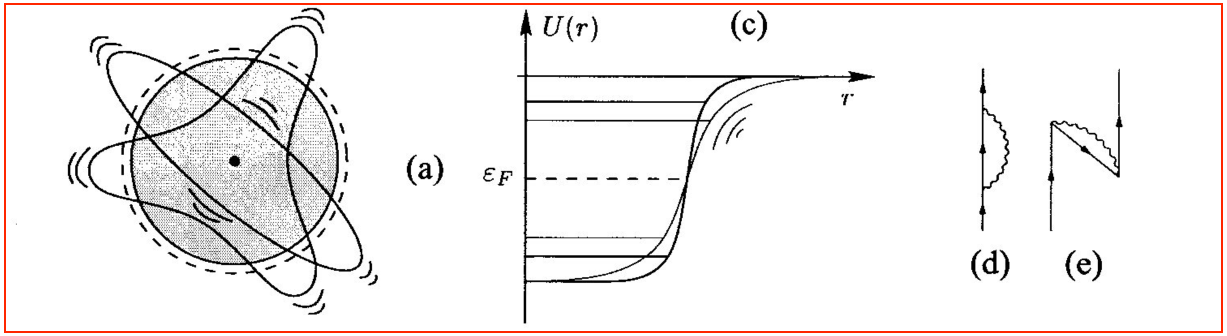


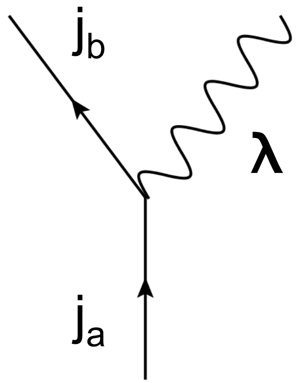

Pauli blocking of core ground state correlations

↓




Level inversion

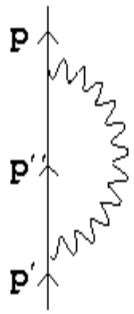


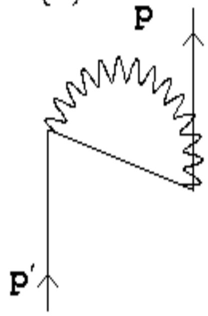

$$= \frac{1}{\sqrt{4\pi}} \langle j_a \lambda | j_b \rangle \beta_\lambda \left\langle j_a \left| \frac{\partial U}{\partial r} \right| j_b \right\rangle = h(a, b\lambda)$$

# SELF ENERGY RENORMALIZATION OF SINGLE-PARTICLE STATES: CLOSED SHELL

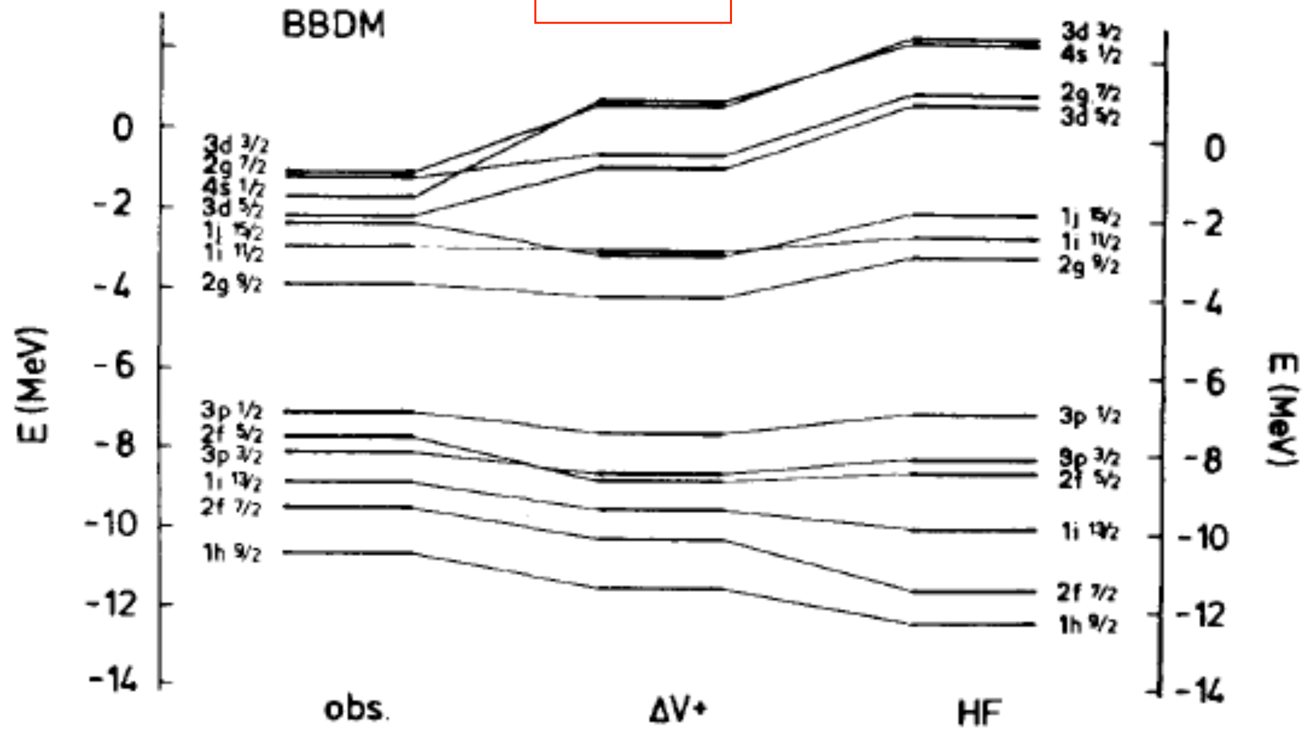
(a)



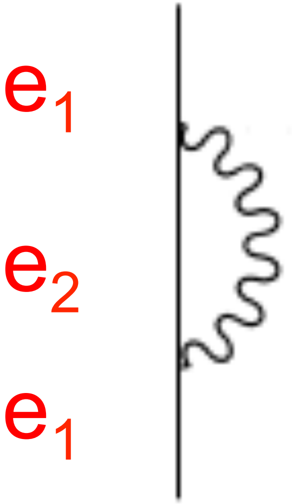

(b)




$^{208}$Pb




C. Mahaux, P.F. Bortignon, R.A. Broglia, C.H. Dasso and Mahaux, Phys. Rep.(1985)1

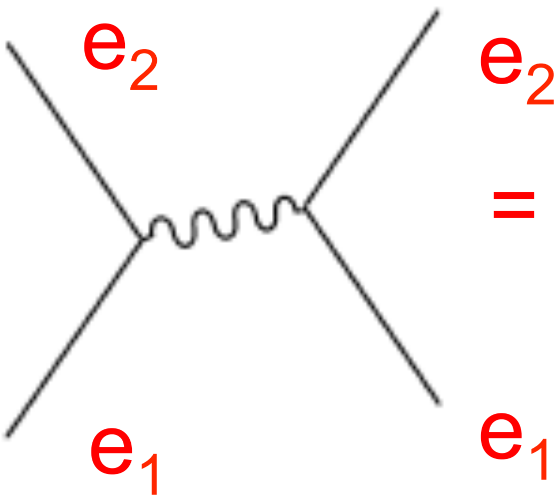



$$= \frac{V^2}{e_1 - (e_2 + \hbar\omega_\lambda)} \approx -\frac{V^2}{\hbar\omega_\lambda}$$

$$m_\omega \approx \left(1 + \frac{2N(0)V^2}{\hbar\omega_\lambda}\right) m$$

$$m_\omega \approx 1.5m$$
$$\hbar\omega_\lambda \approx 1\text{MeV}$$
$$N(0) \approx 3\text{MeV}^{-1}$$

$$\rightarrow \quad V^2 \approx 0.1 \quad \text{MeV}^2$$

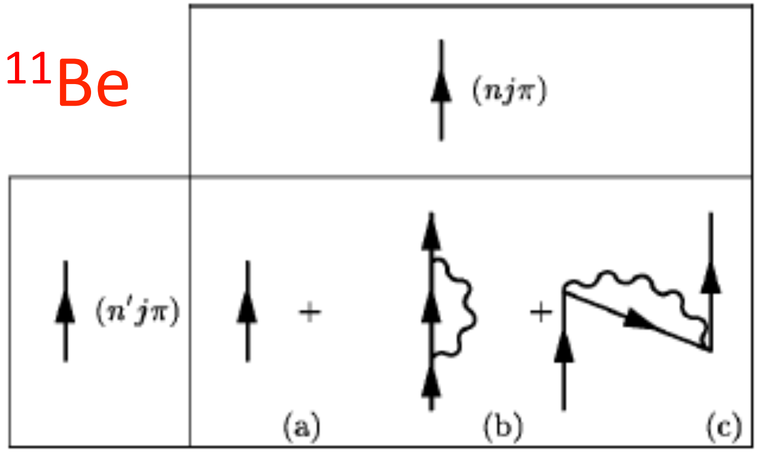



$$= \frac{V^2}{2e_1 - (e_1 + e_2 + \hbar\omega_\lambda)} = \frac{V^2}{e_1 - (e_2 + \hbar\omega_\lambda)} \approx -\frac{V^2}{\hbar\omega_\lambda}$$

$$V_{ind} \approx -0.2\text{MeV}$$

## 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.:

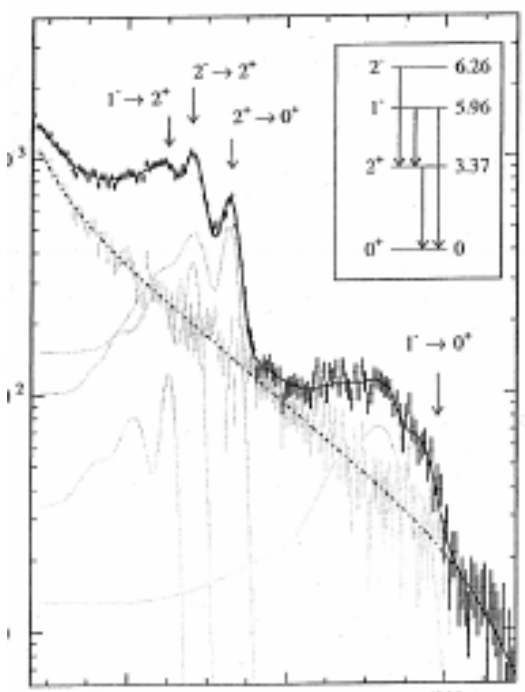
J.S. Winfield et al., Nucl.Phys. **A683** (2001) 48

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

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

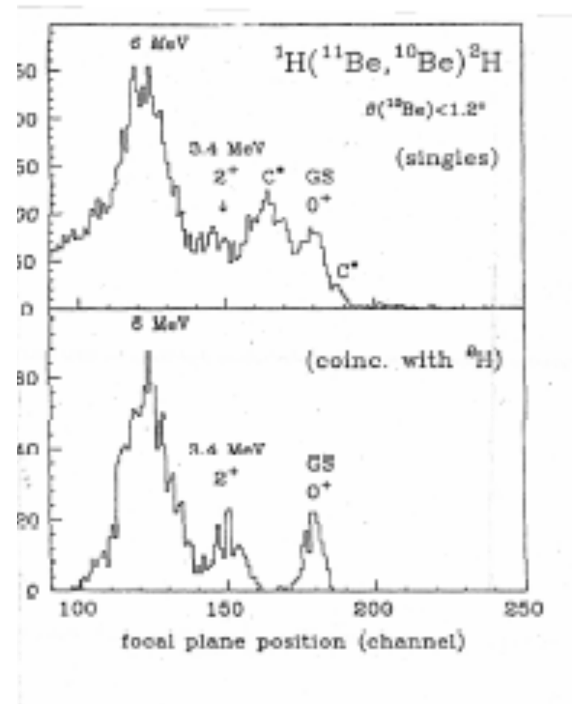
9Be(11Be,10Be+ $\gamma$) X

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




p(11Be,10Be)d

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



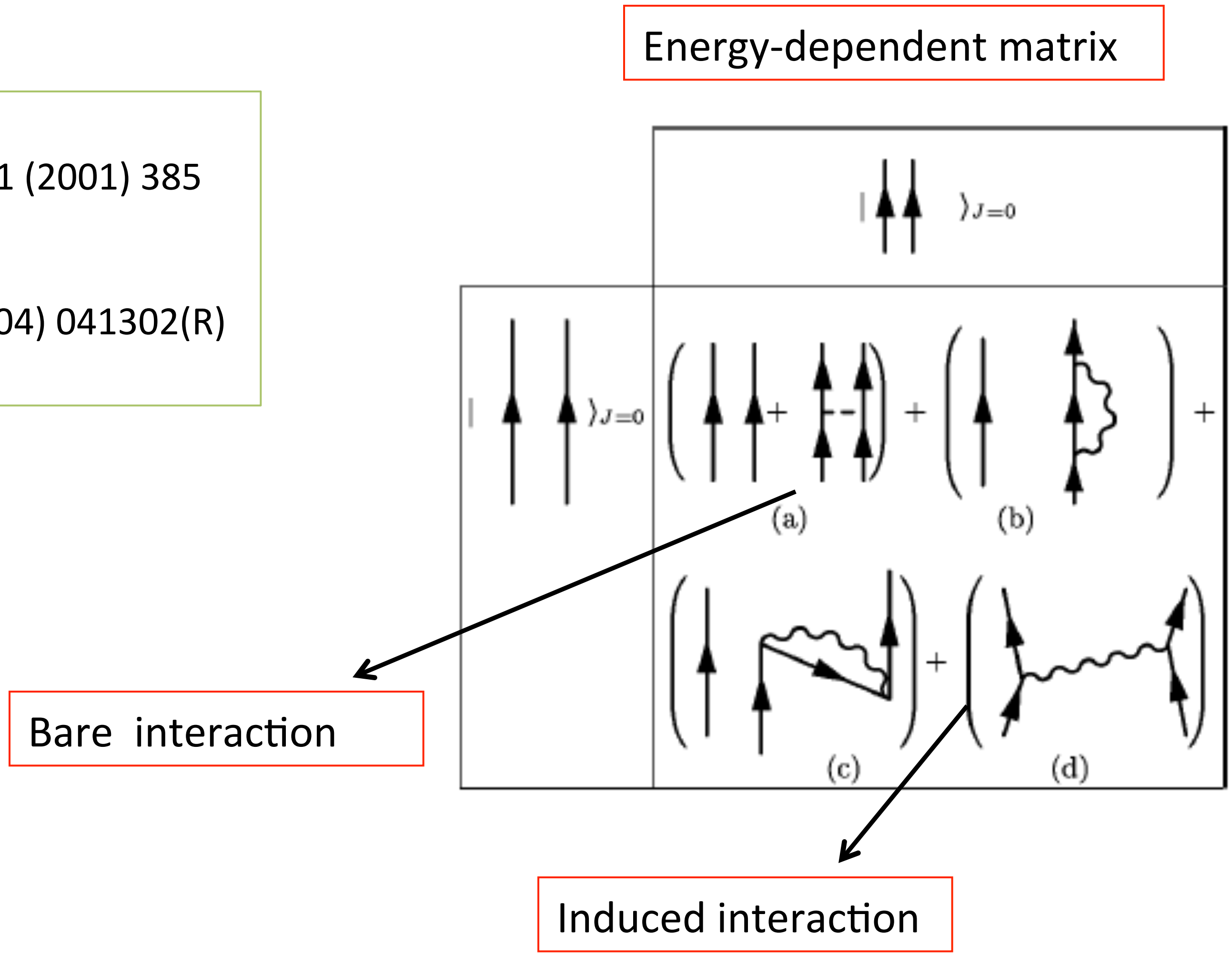
# A dynamical description of two-neutron halos

**$^{11}$Li**

F. Barranco et al. EPJ A11 (2001) 385

**$^{12}$Be**

G. Gori et al. PRC 69 (2004) 041302(R)



Good agreement between theory and experiment concerning energies and spectroscopic factors

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

New result for S[1/2+] from 11Be(d,p)12Be
$0.28^{+0.03}_{-0.07}$

| | | Expt. | Theory | |
|---|---|---|---|---|
| | | | Particle vibration | Mean field |
| $^{11}_{4}\mathrm{Be}_7$ | $E_{s_{1/2}}$ | –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 |
| $^{12}_{4}\mathrm{Be}_8$ | $S_{2n}$ | –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 |

# Theoretical calculation for $^{11}$Li

Low-lying dipole strength

s-p mixing

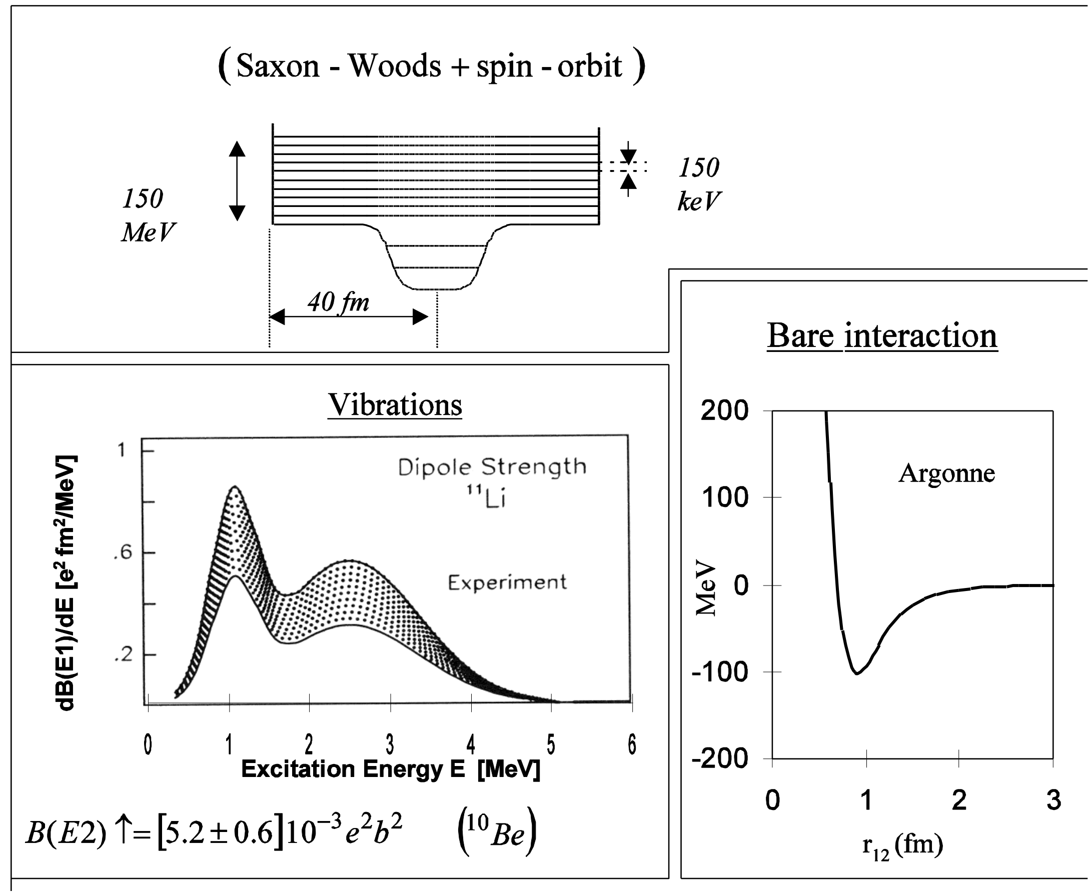


**Table 2.** RPA wave function of the collective low-lying quadrupole phonon in $^{11}$Li, of energy $E_{2^+} = 5.05$ MeV, and leading to the most important contribution to the induced interaction in fig. 1, II. All the listed amplitudes refer to neutron transitions, except for the last column. We have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

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

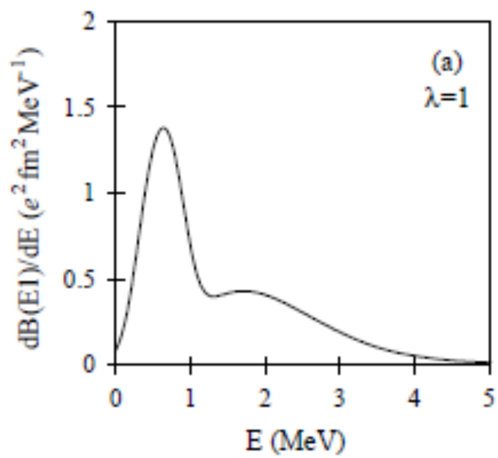
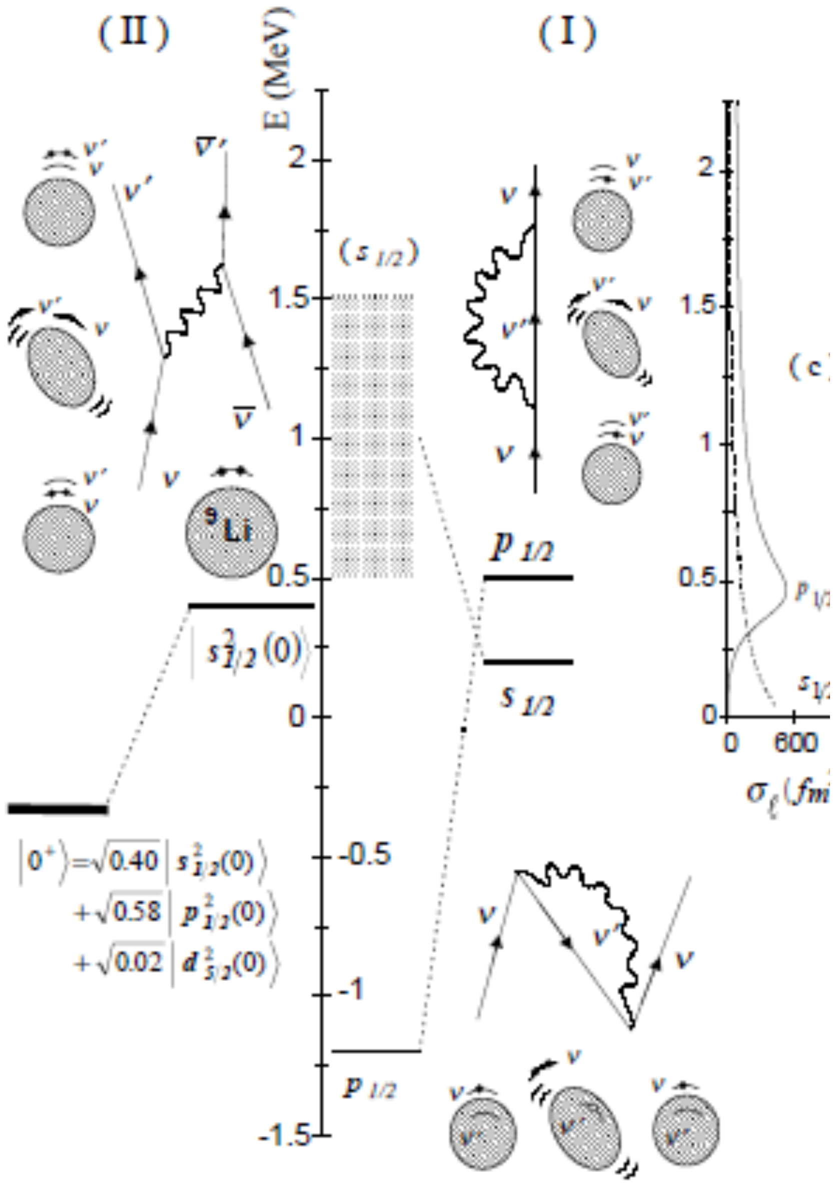


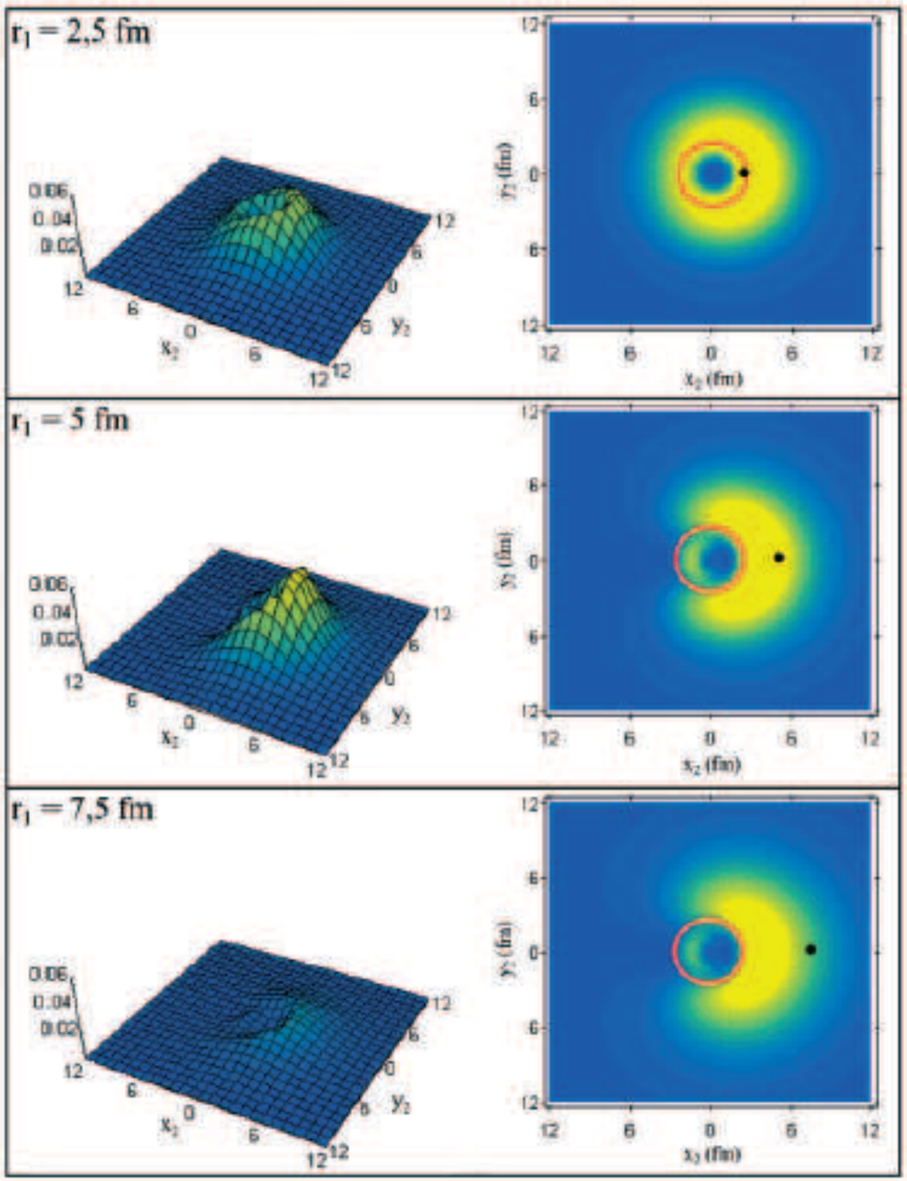

**Table 3.** RPA wave function of the strongest low-lying dipole vibration of $^{11}$Li, ($E_{1^-} = 0.75$ MeV), and contributing most importantly to the pairing induced interaction (fig. 1, II). All the listed amplitudes refer to neutron transitions. We have used the value $\chi_1$= 0.0043 MeV$^{-1}$ 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].

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

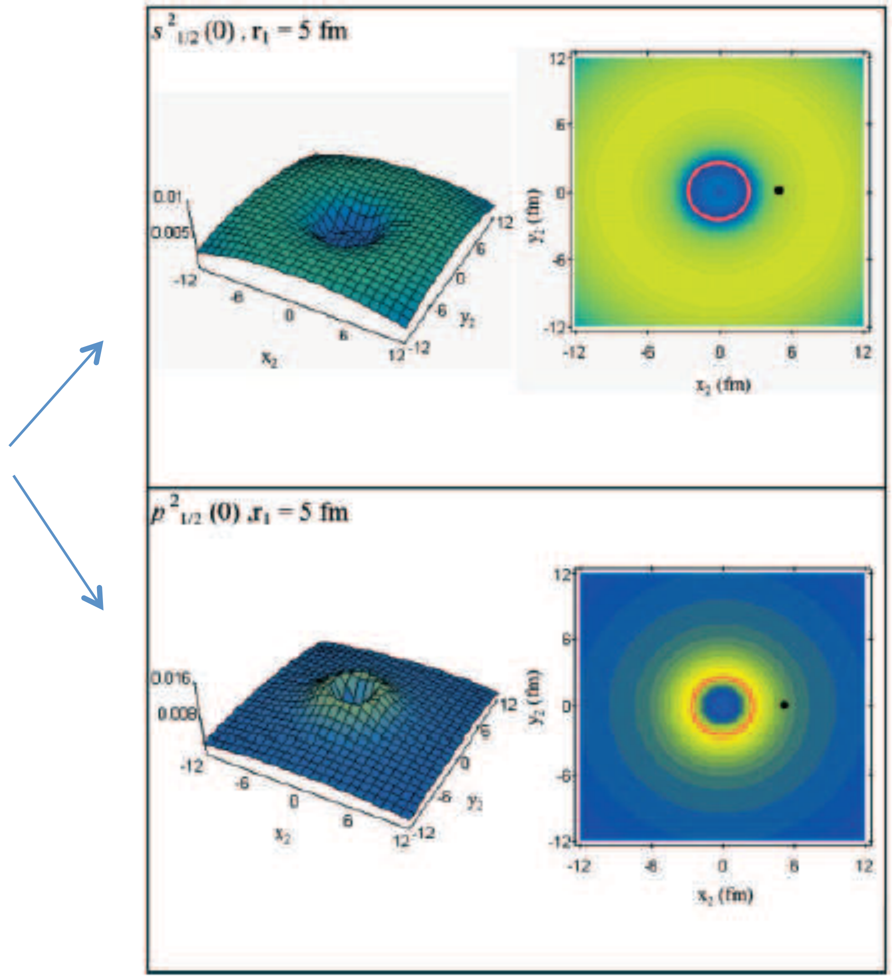



| | | Exp. | Theory | |
|---|---|---|---|---|
| | | | particle-vibration +Argonne | mean field |
| $^{10}_{3}Li_7$ (not bound) | s | 0.1-0.2 MeV | 0.2 MeV (virtual) | ~ 1 MeV (virtual) |
| | p | 0.5-0.6 MeV | 0.5 MeV (res.) | -1.2 MeV (bound) |
| $^{11}_{3}Li_8$ (bound) | $S_{2n}$ | 0.369 MeV | 0.33 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

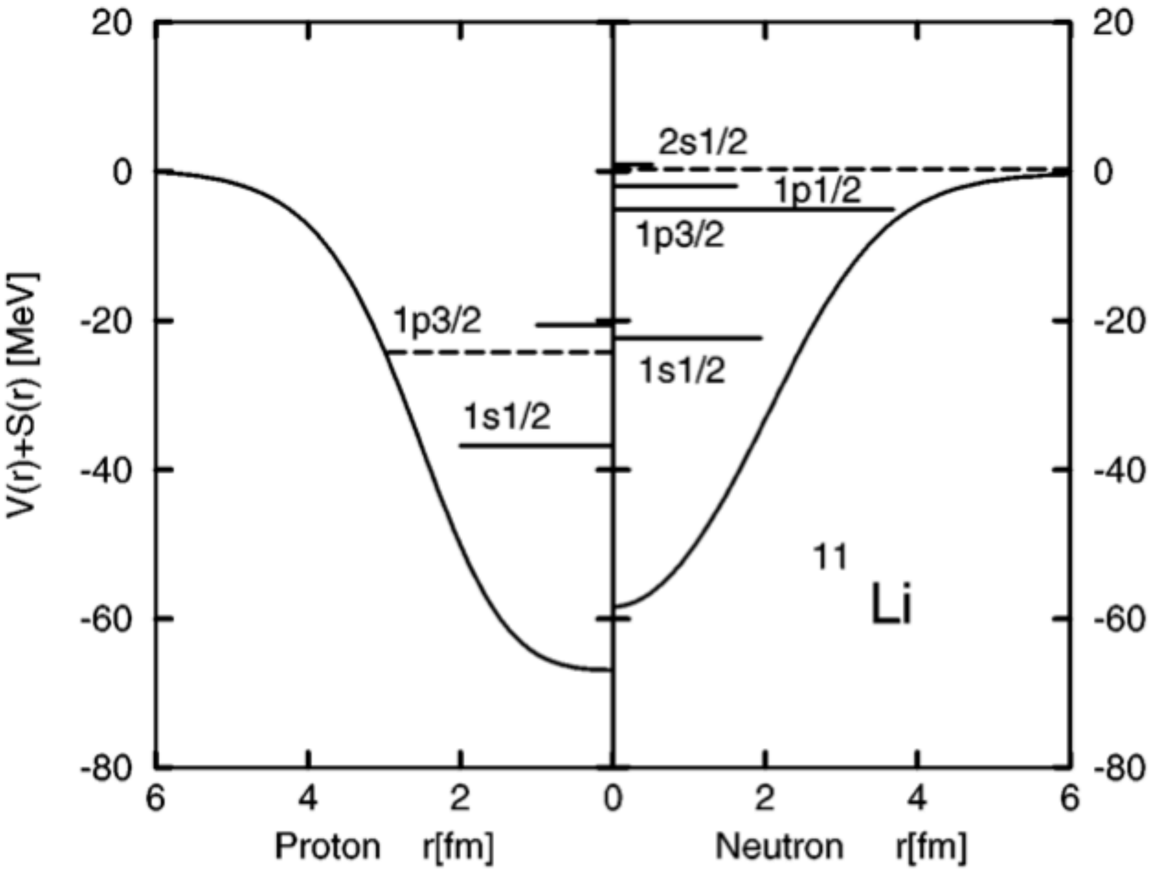
$$v_{\rm eff}(\mathbf{r}_1,\mathbf{r}_2)=\delta(\mathbf{r}_1-\mathbf{r}_2)\left(v_0+v_\rho\left(\frac{\rho_c((\mathbf{r}_1+\mathbf{r}_2)/2)}{\rho_0}\right)^P\right).$$

## Results

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

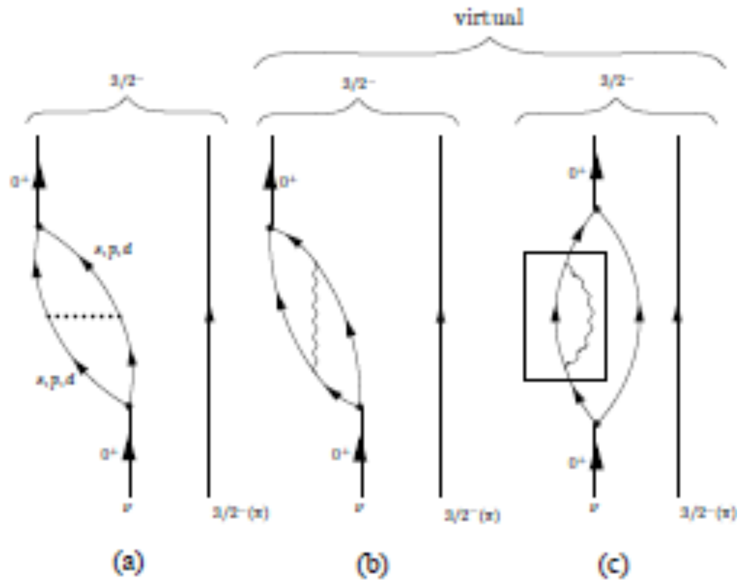
Good reproduction of binding energy
Low $(s_{1/2})^2$ admixture unless two different s.p. potentials are used

# Relativistic HB calculation




J. Meng and P. Ring,
PRL 77(1998)3963

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




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

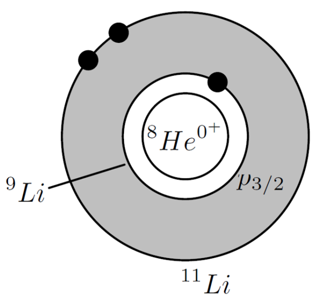
$$|0\rangle = 0.45|s^2_{1/2}(0)\rangle + 0.55|p^2_{1/2}(0)\rangle + 0.04|d^2_{5/2}(0)\rangle$$

**Two-neutron transfer to**

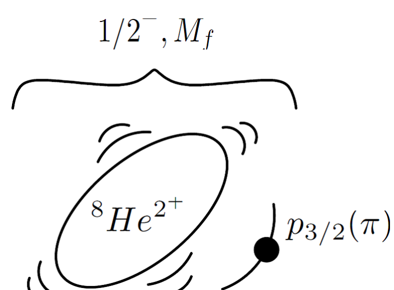
exc. state

ground state

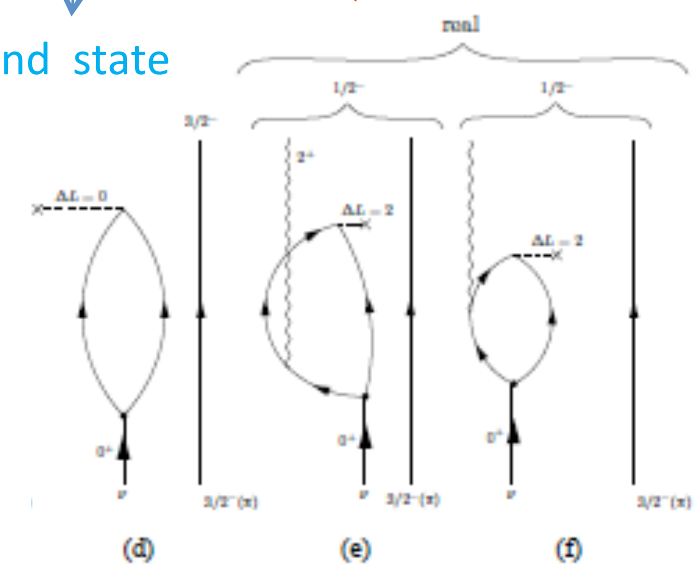
We will try to draw information about the halo structure of $^{11}$Li from the reactions $^1$H($^{11}$Li,$^9$Li)$^3$H and $^1$H($^{11}$Li,$^9$Li*(2.69 MeV))$^3$H (I. Tanihata *et al.*, Phys. Rev. Lett. **100**, 192502 (2008))




Schematic depiction of $^{11}$Li




First excited state of $^9$Li



# 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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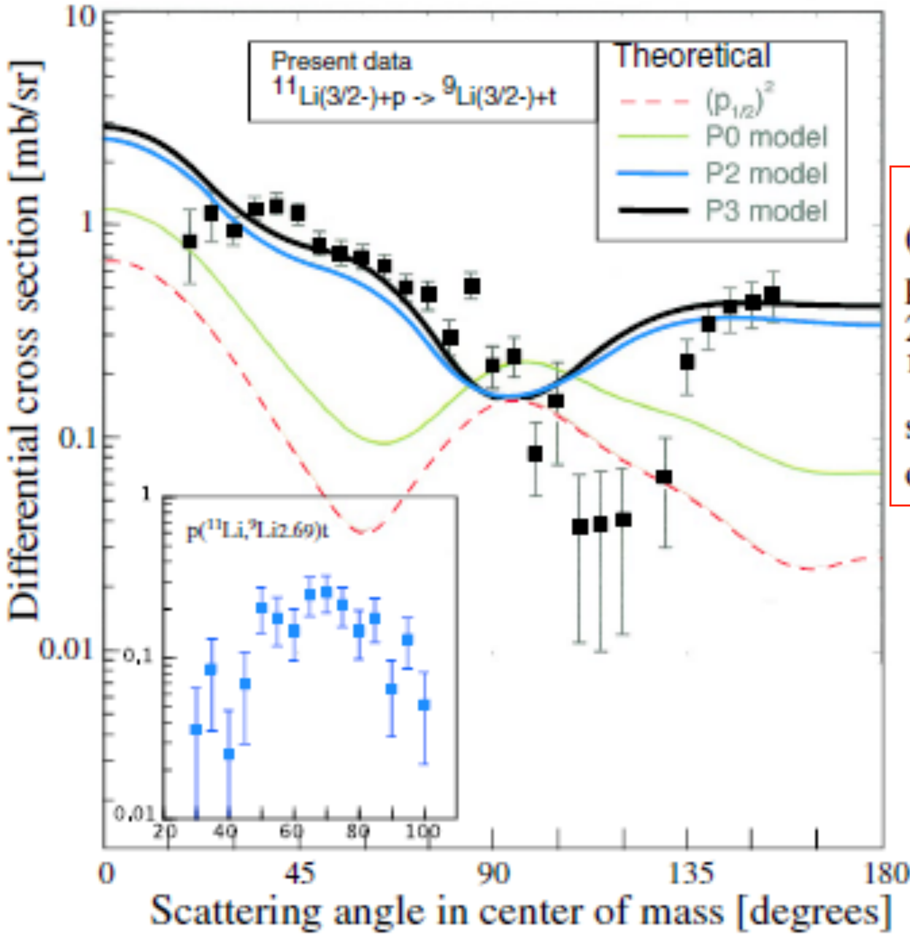
(Received 22 January 2008; published 14 May 2008)



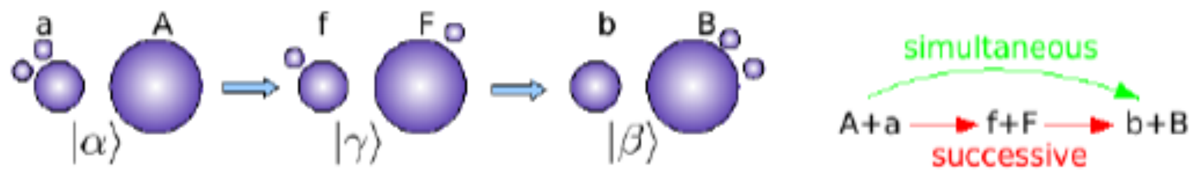

The cross section for transitions to the first excited state (Ex = 2.69 MeV) is shown also in Fig. 3. If this state were populated by a direct transfer, it would indicate that a $1^+$ or $2^+$ halo component is present in the ground state of $^{11}Li(\frac{3}{2}^-)$, because the spin-parity of the $^9Li$ 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

## simultaneous and successive contributions




the initial and final channel wave functions are

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

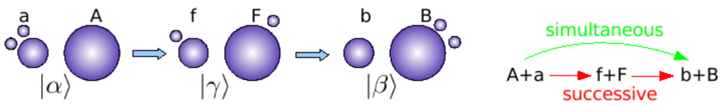
very schematically, the first order (*simultaneous*) contribution is

$$T^{(1)} = \langle\beta|V|\alpha\rangle,$$

while the second order contribution can be separated in a *successive* and a *non-orthogonality* term

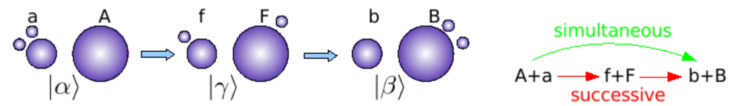
$$T^{(2)} = T^{(2)}_{succ} + T^{(2)}_{NO}$$
$$= \sum_\gamma \langle\beta|V|\gamma\rangle G\langle\gamma|V|\alpha\rangle - \sum_\gamma \langle\beta|\gamma\rangle\langle\gamma|V|\alpha\rangle.$$

B.F. Bayman and J. Chen, Phys. Rev. C 26 (1982) 150
M. Igarashi, K. Kubo and K. Yagi, Phys. Rep. 199 (1991) 1
G. Potel et al., arXiv: 0906.4298



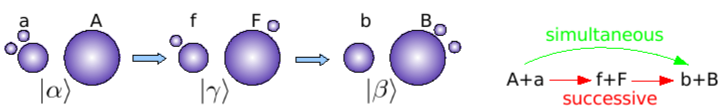

**Simultaneous transfer**

$$T^{(1)}(j_i,j_f) = 2\sum_{\sigma_1\sigma_2}\int d\mathbf{r}_{fF}\,d\mathbf{r}_{b1}\,d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}\chi_{bB}^{(-)*}(\mathbf{r}_{bl}$$
$$\times\, v(\mathbf{r}_{b1})[\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)\Psi^{j_i}(\mathbf{r}_{b2},\sigma_2)]_0^0\chi_{aA}^{(+)}(\mathbf{r}_{aA})$$




**Successive transfer**

$$T^{(2)}_{succ}(j_i,j_f) = 2\sum_{K,M}\sum_{\substack{\sigma_1\sigma_2\\ \sigma_1'\sigma_2'}}\int d\mathbf{r}_{fF}\,d\mathbf{r}_{b1}\,d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}$$
$$\times\, \chi_{bB}^{(-)*}(\mathbf{r}_{bB})v(\mathbf{r}_{b1})[\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)]_M^K$$
$$\times \int d\mathbf{r}'_{fF}\,d\mathbf{r}'_{b1}\,d\mathbf{r}'_{A2}\,G(\mathbf{r}_{fF},\mathbf{r}'_{fF})[\Psi^{j_f}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_M^K$$
$$\times\, \frac{2\mu_{fF}}{\hbar^2}v(\mathbf{r}'_{f2})[\Psi^{j_i}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_0^0\chi_{aA}^{(+)}(\mathbf{r}'_{aA})$$




**Non–orthogonality term**

$$T^{(2)}_{NO}(j_i,j_f) = 2\sum_{K,M}\sum_{\substack{\sigma_1\sigma_2\\ \sigma_1'\sigma_2'}}\int d\mathbf{r}_{fF}\,d\mathbf{r}_{b1}\,d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}$$
$$\times\, \chi_{bB}^{(-)*}(\mathbf{r}_{bB})v(\mathbf{r}_{b1})[\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)]_M^K$$
$$\times \int d\mathbf{r}'_{b1}\,d\mathbf{r}'_{A2}[\Psi^{j_f}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_M^K$$
$$\times\, [\Psi^{j_i}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_0^0\chi_{aA}^{(+)}(\mathbf{r}'_{aA})$$

$$T^{(1)}(j_i, j_f) = 2\sum_{\sigma_1\sigma_2}\int d\mathbf{r}_{fF}d\mathbf{r}_{b1}d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}\chi_{bB}^{(-)*}(\mathbf{r}_{bB})$$
$$\times\, v(\mathbf{r}_{b1})[\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)\Psi^{j_i}(\mathbf{r}_{b2},\sigma_2)]_0^0\chi_{aA}^{(+)}(\mathbf{r}_{aA}),$$

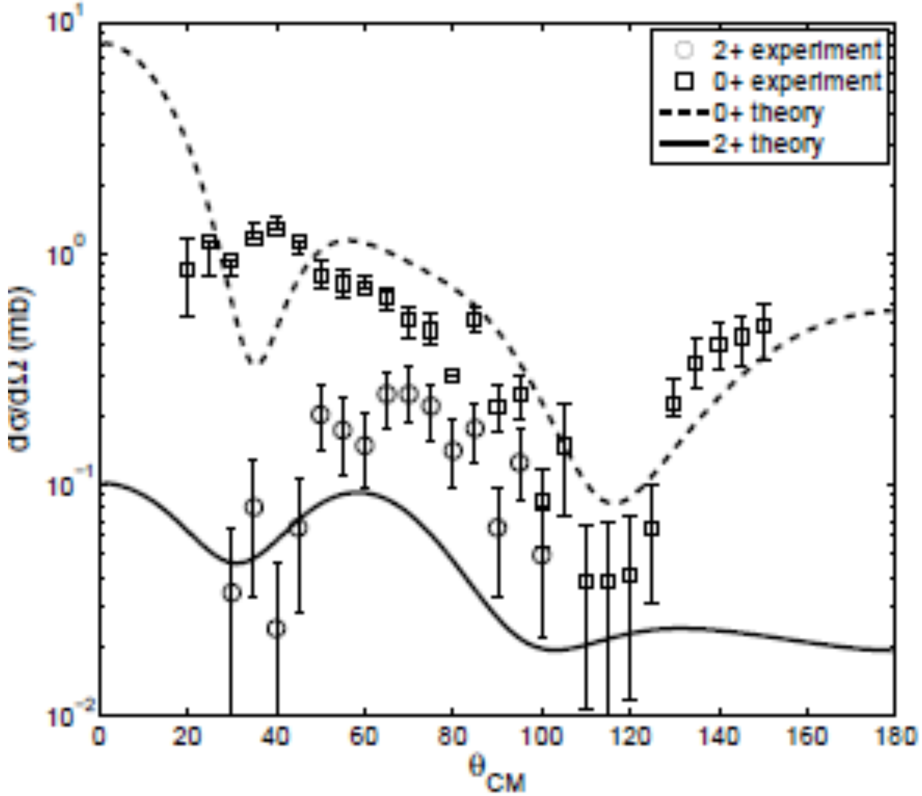
Simultaneous

$$T^{(2)}_{succ}(j_i, j_f) = 2\sum_{K,M}\sum_{\substack{\sigma_1\sigma_2\\ \sigma_1'\sigma_2'}}\int d\mathbf{r}_{fF}d\mathbf{r}_{b1}d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}$$
$$\times\,\chi_{bB}^{(-)*}(\mathbf{r}_{bB})v(\mathbf{r}_{b1})[\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)]_M^K$$
$$\times\int d\mathbf{r}'_{fF}d\mathbf{r}'_{b1}d\mathbf{r}'_{A2}G(\mathbf{r}_{fF},\mathbf{r}'_{fF})[\Psi^{j_f}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_M^K$$
$$\times\,\frac{2\mu_{fF}}{\hbar^2}v(\mathbf{r}'_{f2})[\Psi^{j_i}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_0^0\chi_{aA}^{(+)}(\mathbf{r}'_{aA}),$$

Successive

$$T^{(2)}_{NO}(j_i, j_f) = 2\sum_{K,M}\sum_{\substack{\sigma_1\sigma_2\\ \sigma_1'\sigma_2'}}\int d\mathbf{r}_{fF}d\mathbf{r}_{b1}d\mathbf{r}_{A2}[\Psi^{j_f}(\mathbf{r}_{A1},\sigma_1)\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)]_0^{0*}$$
$$\times\,\chi_{bB}^{(-)*}(\mathbf{r}_{bB})v(\mathbf{r}_{b1})[\Psi^{j_f}(\mathbf{r}_{A2},\sigma_2)\Psi^{j_i}(\mathbf{r}_{b1},\sigma_1)]_M^K$$
$$\times\int d\mathbf{r}'_{b1}d\mathbf{r}'_{A2}[\Psi^{j_f}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_M^K$$
$$\times\,[\Psi^{j_i}(\mathbf{r}'_{A2},\sigma'_2)\Psi^{j_i}(\mathbf{r}'_{b1},\sigma'_1)]_0^0\chi_{aA}^{(+)}(\mathbf{r}'_{aA}).$$

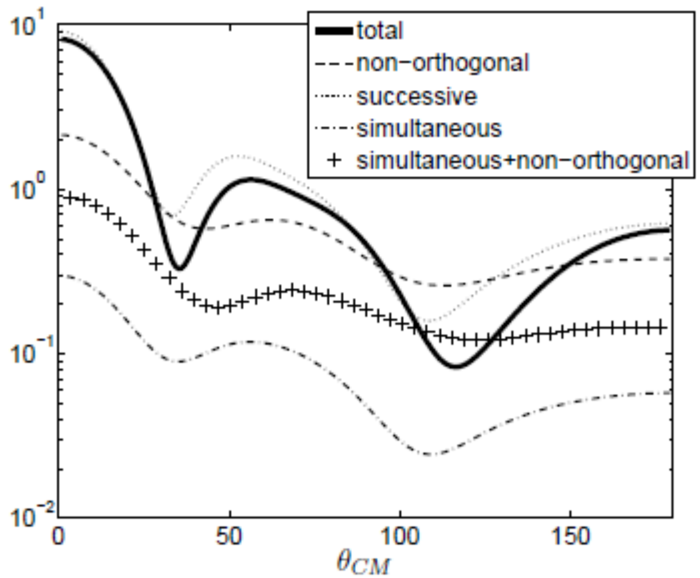
Non orthogona

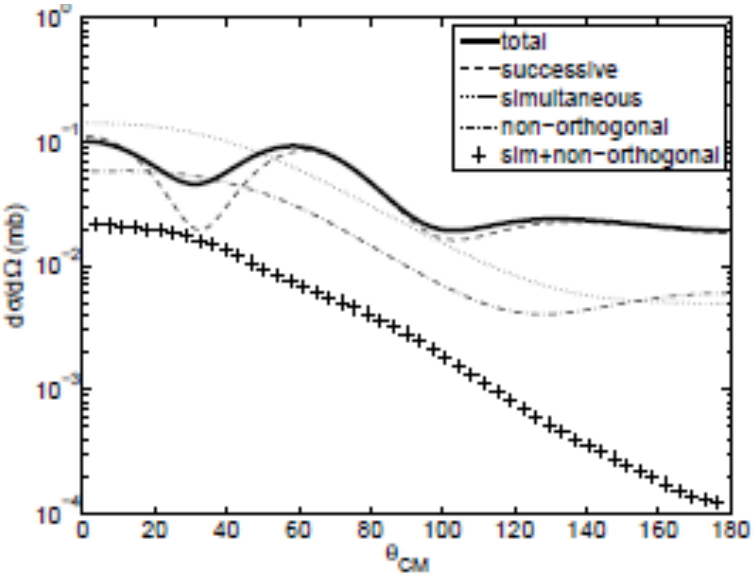



| | $\sigma(^{11}Li(gs) \rightarrow {}^{9}Li\ (i))$ (mb) | | |
|---|---|---|---|
| i | $\Delta L$ | Theory | Experiment |
| gs ($3/2^-$) | 0 | 6.1 | $5.7 \pm 0.9$ |
| 2.69 MeV ($1/2^-$) | 2 | 0.5 | $1.0 \pm 0.36$ |

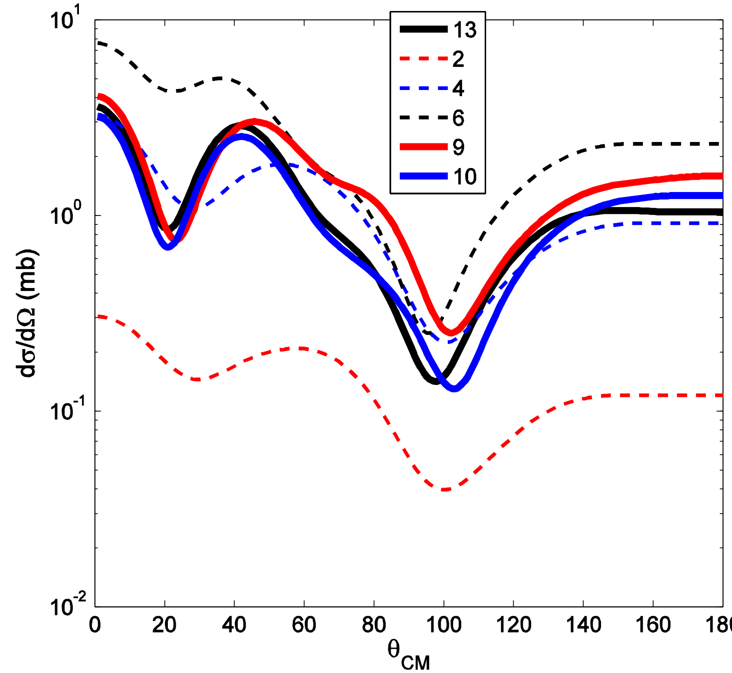
G. Potel et al., PRL 105 (2010) 172502

Decomposition into successive and simultaneous contributions




Convergence of the calculation of successive transfer

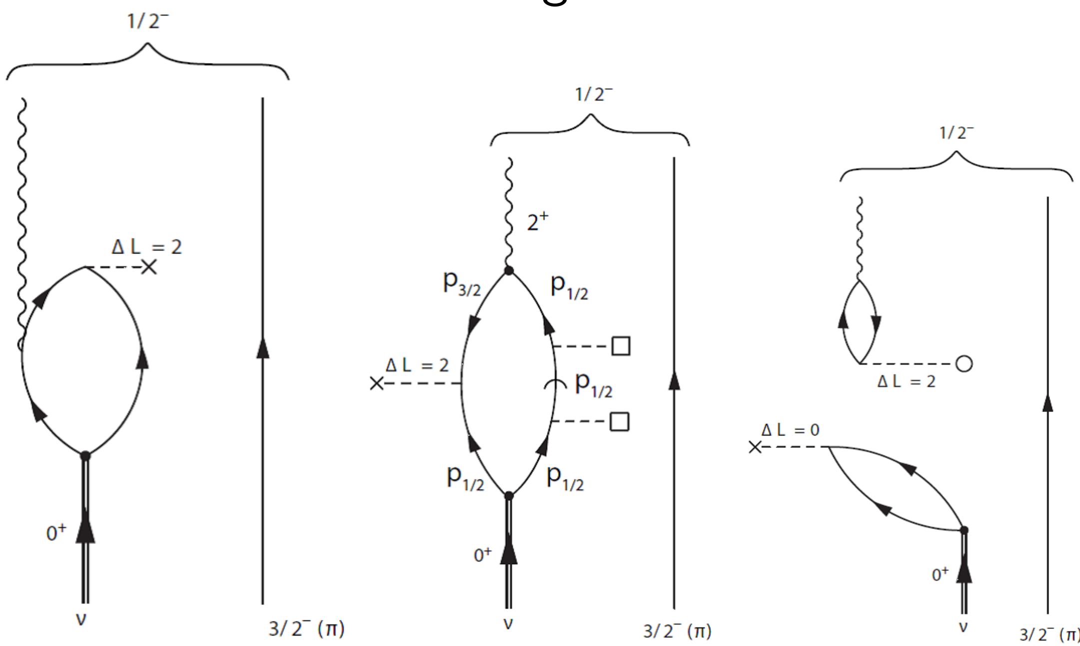


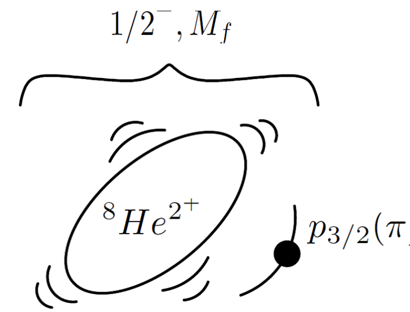
# Channels $c$ leading to the first $1/2^-$ excited state of $^9$Li

$c = 1$: Transfer of the two halo neutrons

$c = 2$: Transfer of a $p_{1/2}$ halo neutron and a $p_{3/2}$ core neutron

$c = 3$: Transfer to the ground state + inelastic excitation



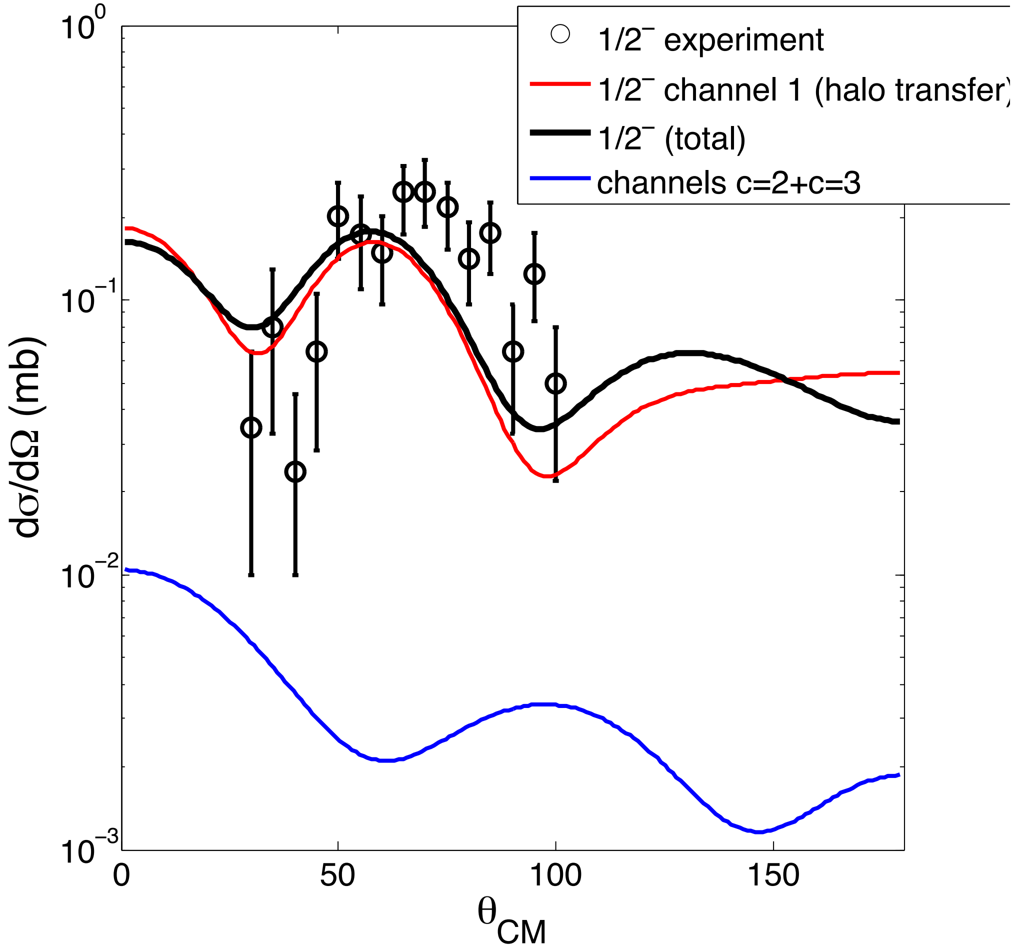

$P^{(1)} = 1.3 \times 10^{-3}$

$P^{(2)} = 4.6 \times 10^{-5}$

$P^{(3)} = 2.6 \times 10^{-6}$

$\sigma_c = \frac{\pi}{k^2} \sum_l (2l+1)|S_l^{(c)}|^2, \; P^{(c)} = \sum_l |S_l^{(c)}|^2 \; (c = 1, 2, 3).$

Small probabilities $\Rightarrow$ use of second order perturbation theory.



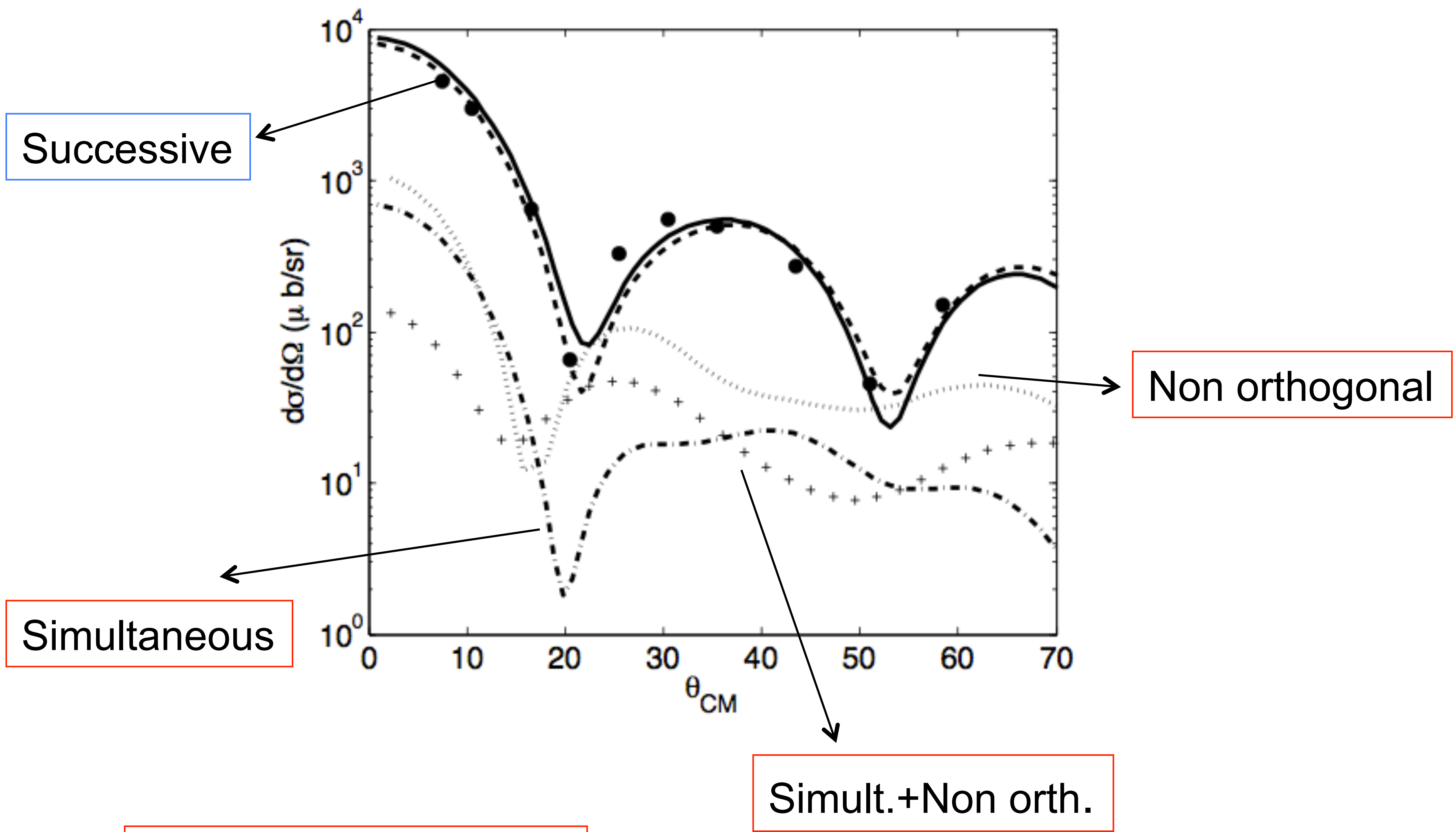
$10^0$
$10^{-1}$
$10^{-2}$
$10^{-3}$
$d\sigma/d\Omega$ (mb)
0
50
100
150
$\theta_{CM}$
$1/2^-$ experiment
$1/2^-$ channel 1 (halo transfer)
$1/2^-$ (total)
channels c=2+c=3

## summary and conclusions

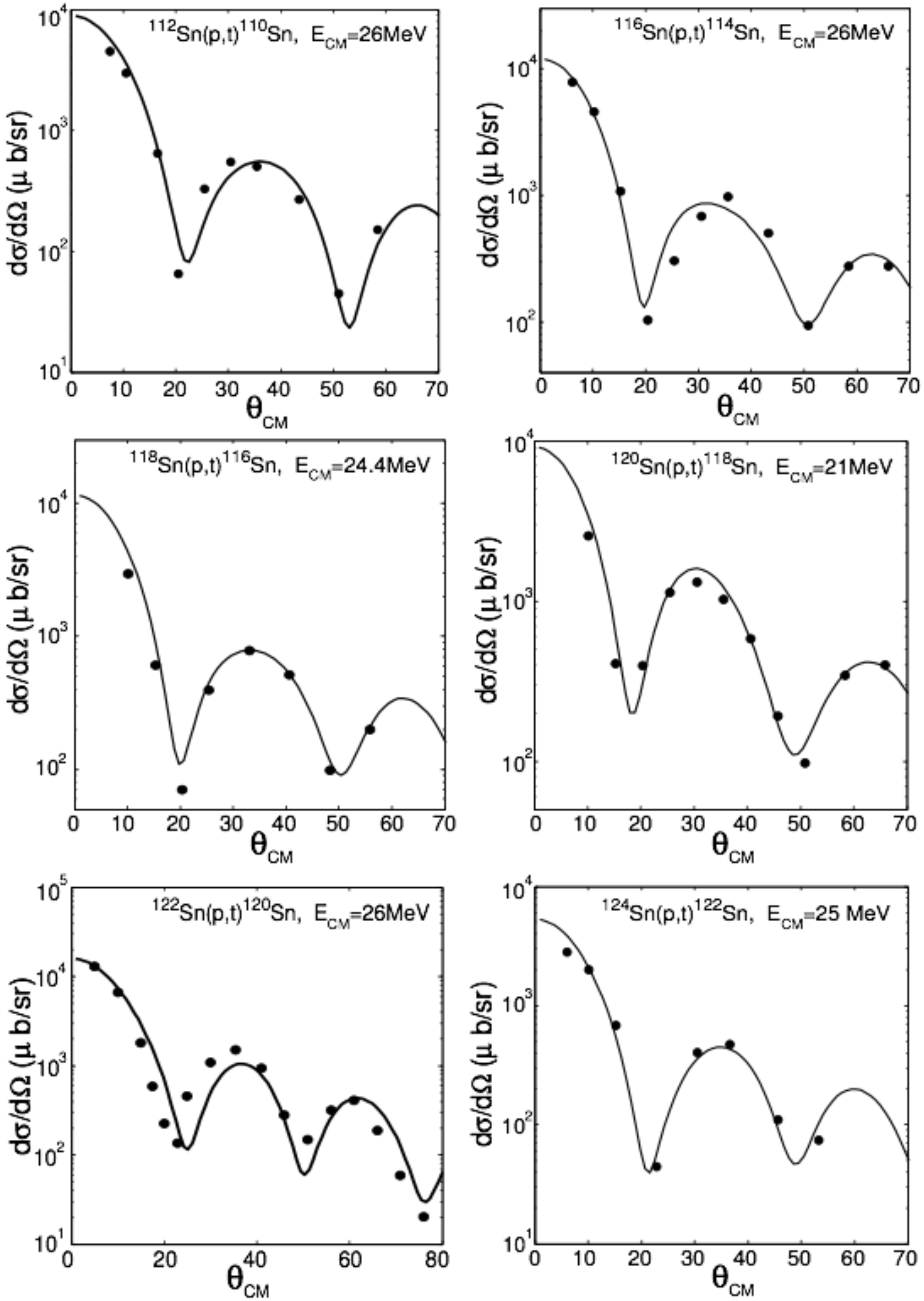
- A recent two–neutron transfer experiment ($^{1}$H($^{11}$Li,$^{9}$Li)$^{3}$H, Tanihata *et al.*, 2008) provided new insight in the structure of $^{11}$Li.
- We show that the differential cross section is quantitatively consistent with the *s*–*p* mixing in the ground state of $^{11}$Li already predicted (see e.g. Barranco *et al.* 2001).

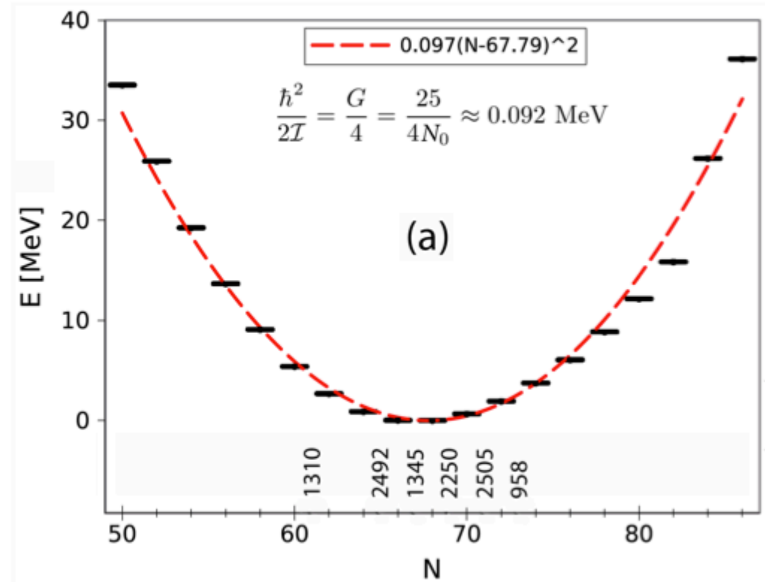
- We found hat the differential cross section for the excitation of the first $1/2^{-}$ (2.69 MeV) provides evidence of phonon–mediated pairing between the two halo neutrons of $^{11}$Li.

$^{122}Sn(p,t)^{120}Sn$  $E_{lab}$= 26 MeV

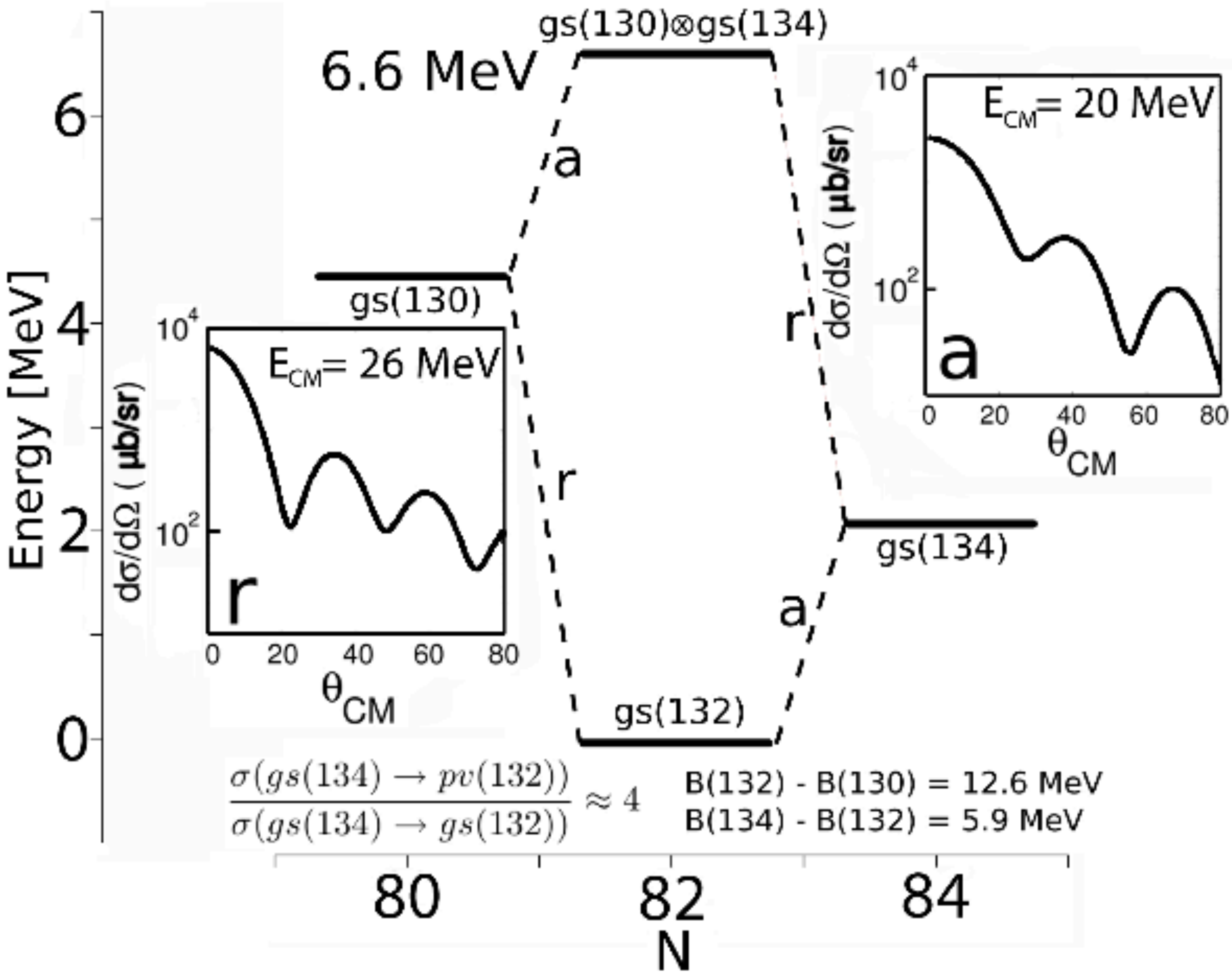



$B_j = \sqrt{(j+1/2)}\ U_j V_j$

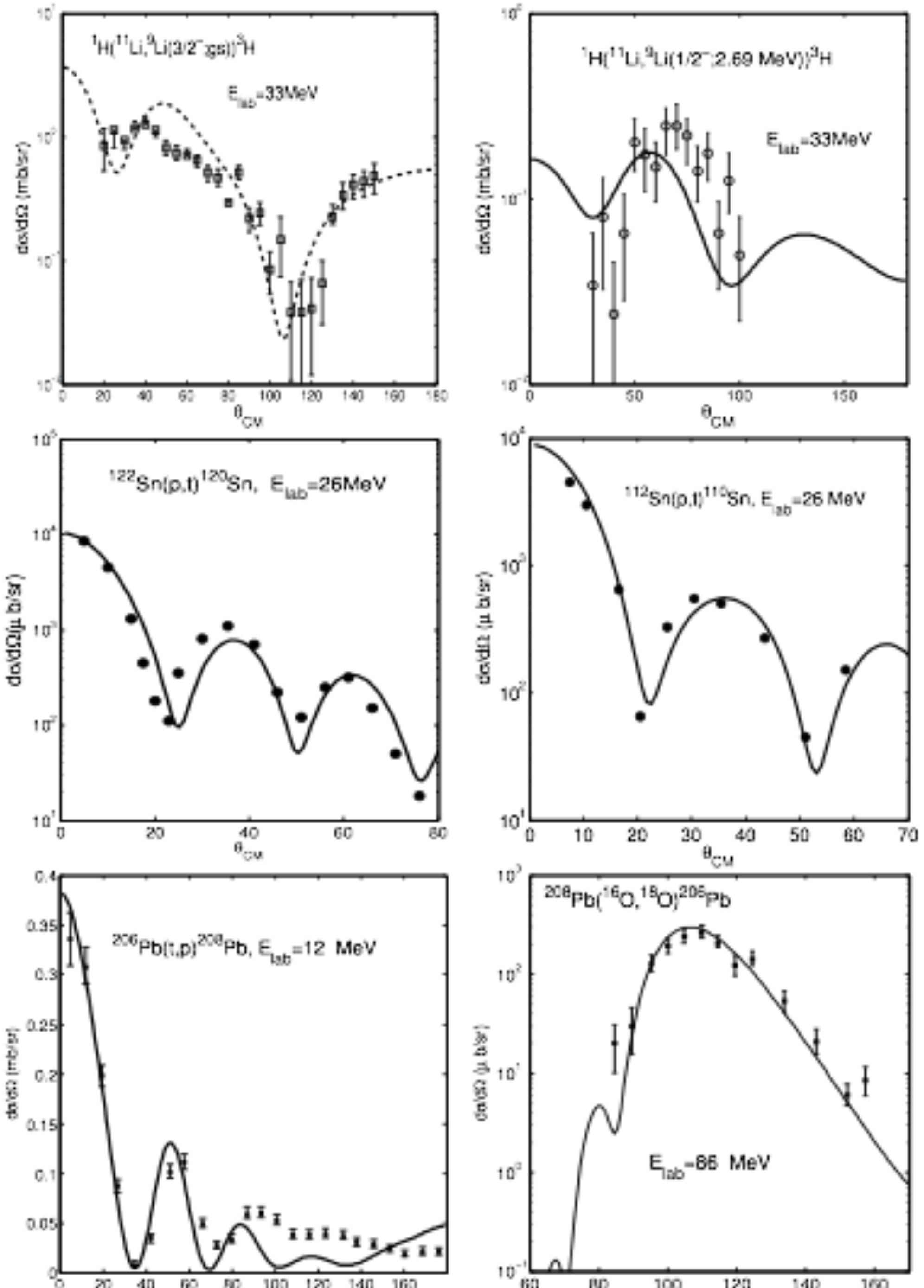



G. Potel et al.,
nucl-th/1105.6250



gs(130)⊗gs(134)
6.6 MeV
a
r
gs(130)
r
a
gs(134)
gs(132)
Energy [MeV]
N
E_CM= 26 MeV
dσ/dΩ ( μb/sr)
θ_CM
E_CM= 20 MeV
$\frac{\sigma(gs(134) \to pv(132))}{\sigma(gs(134) \to gs(132))} \approx 4$
B(132) - B(130) = 12.6 MeV
B(134) - B(132) = 5.9 MeV




A recent analysis of various two-neutron transfer reactions Based on second order DWBA reproduces absolute cross sections

G. Potel et al., nucl_th/ 0906.4298