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Interweaving between collective and single-particle excitations in Sn-120

Andrea Idini

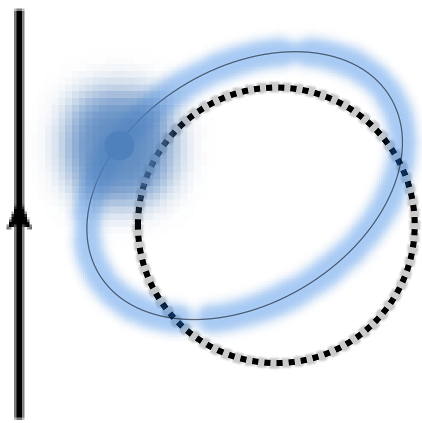
G. Potel, F. Barranco, E. Vigezzi, R.A. Broglia

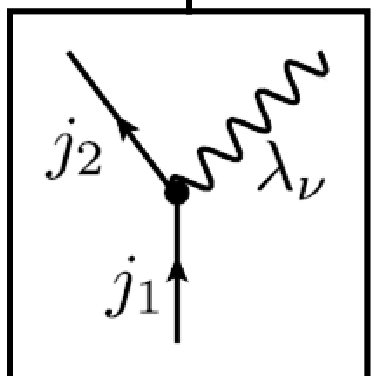
Idini et al., PRC92, *in print*

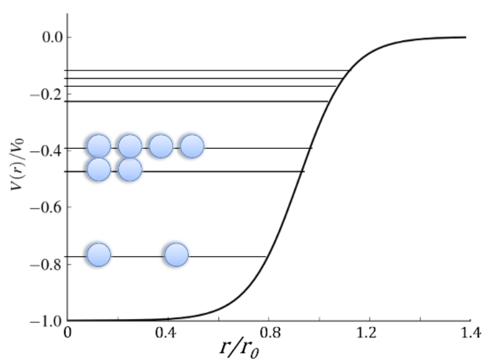
COMEX5, 14-18 September 2015, Krakow

Two Degrees of Freedom

Independent Particle

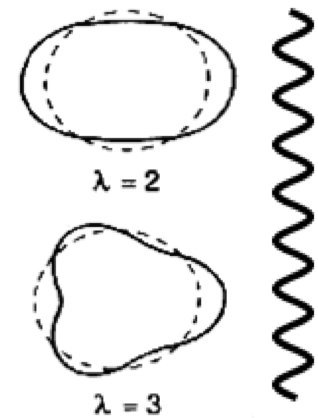


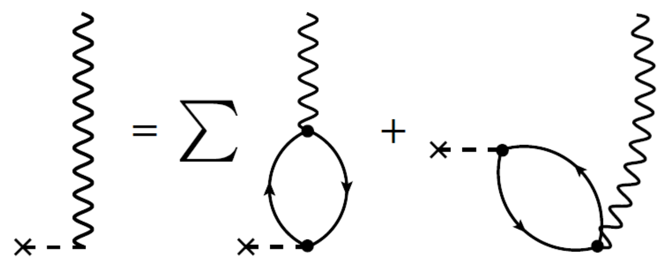




Hartree-Fock mean Field

Collective Phonon

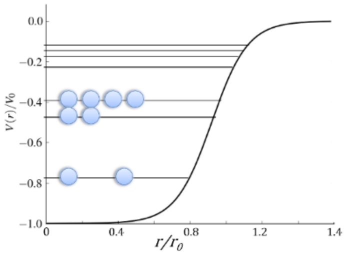




Random Phase Approximation

Three Parameters

Hartree-Fock mean Field

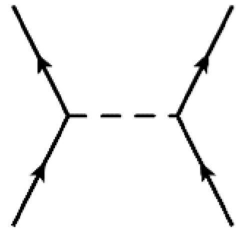


m_k ↓

Skyrme
SLy4

$m_k \approx 0.7m$

Pairing Interaction



G ↓

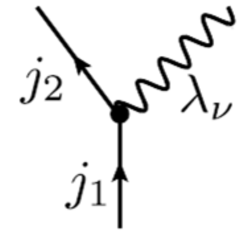
Argonne
v_{14}

In ^{120}Sn with SLy4

$\Delta^{v_{14}} \approx 1.1$ MeV

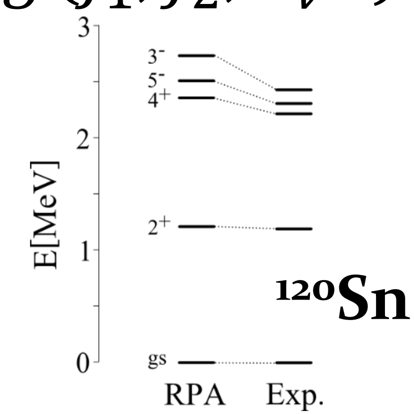
$\Delta^{exp} \approx 1.4\ MeV$

Particle Vibration Coupling Vertex

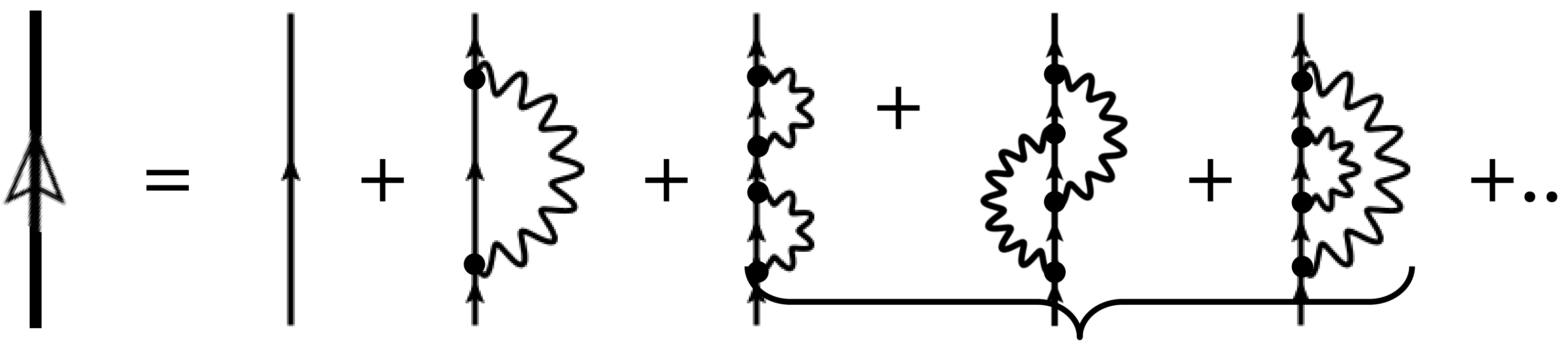


β_λ ↓

$f(j_1, j_2, \lambda_\nu^\pi)$
$g(j_1, j_2, \lambda_\nu^\pi L)$



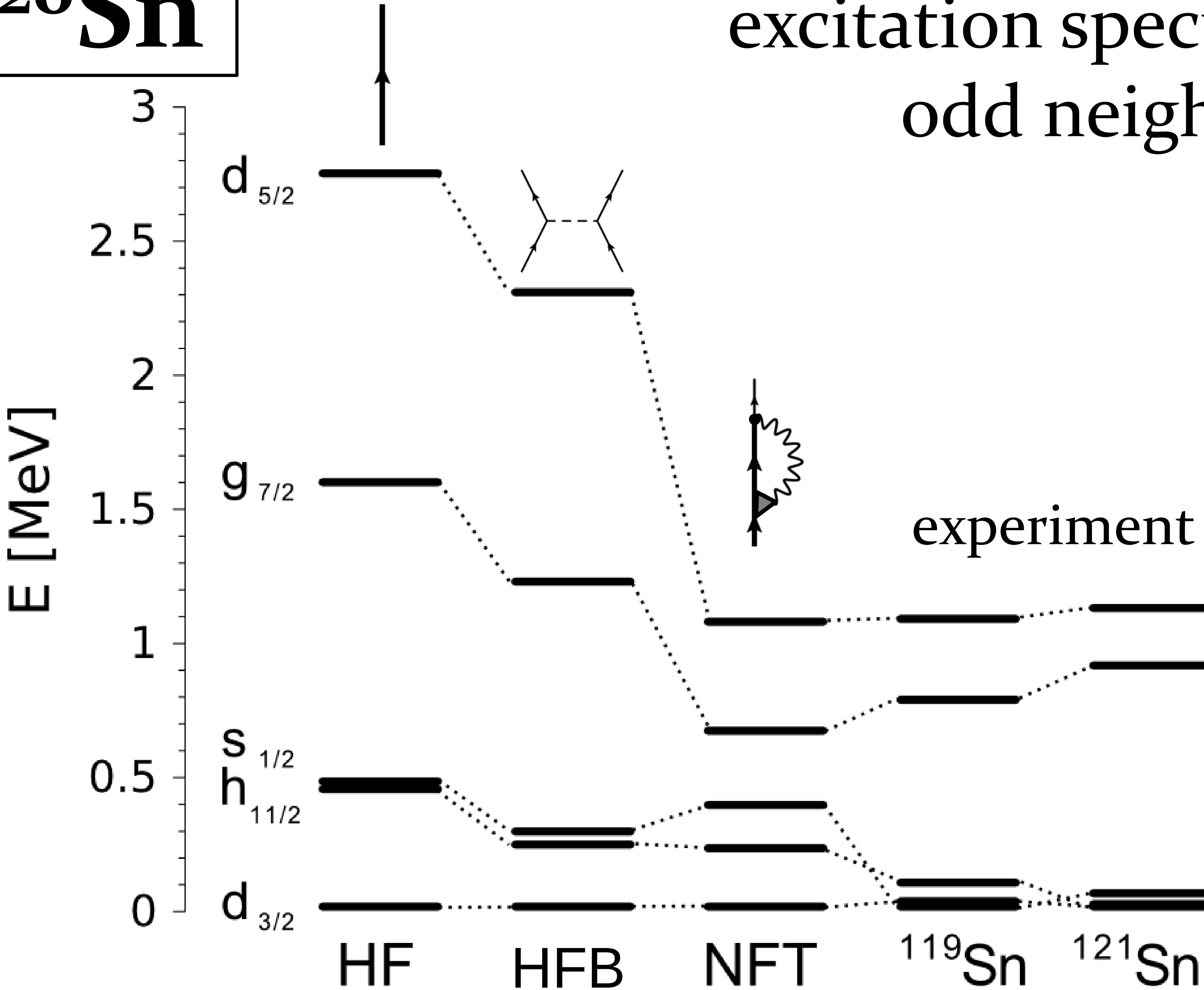
Nuclear Field Theory Approach



Green's function can consistently Particle-Vibration Couplings to the **infinite order**:

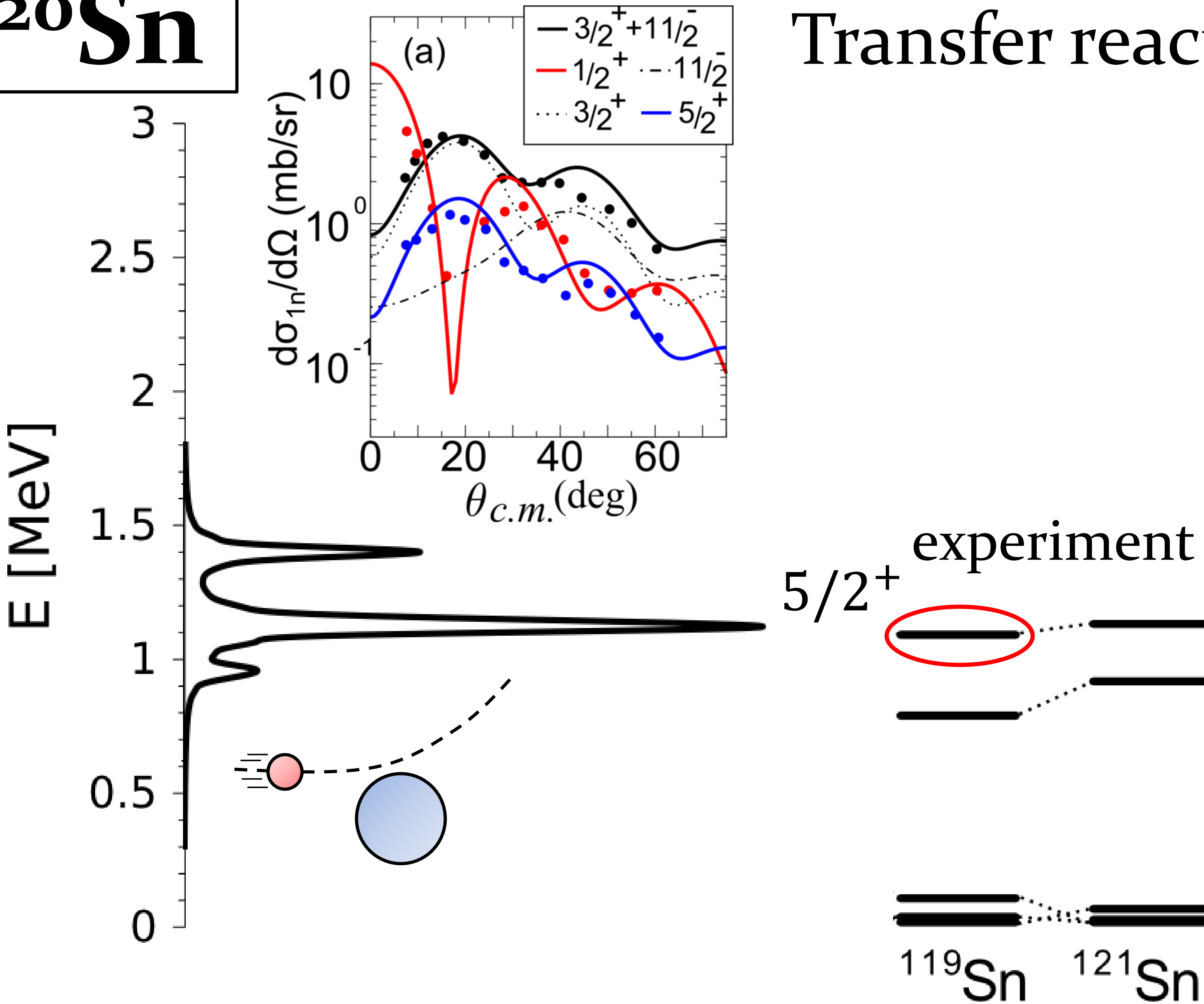
^{120}Sn

excitation spectrum
odd neighbors

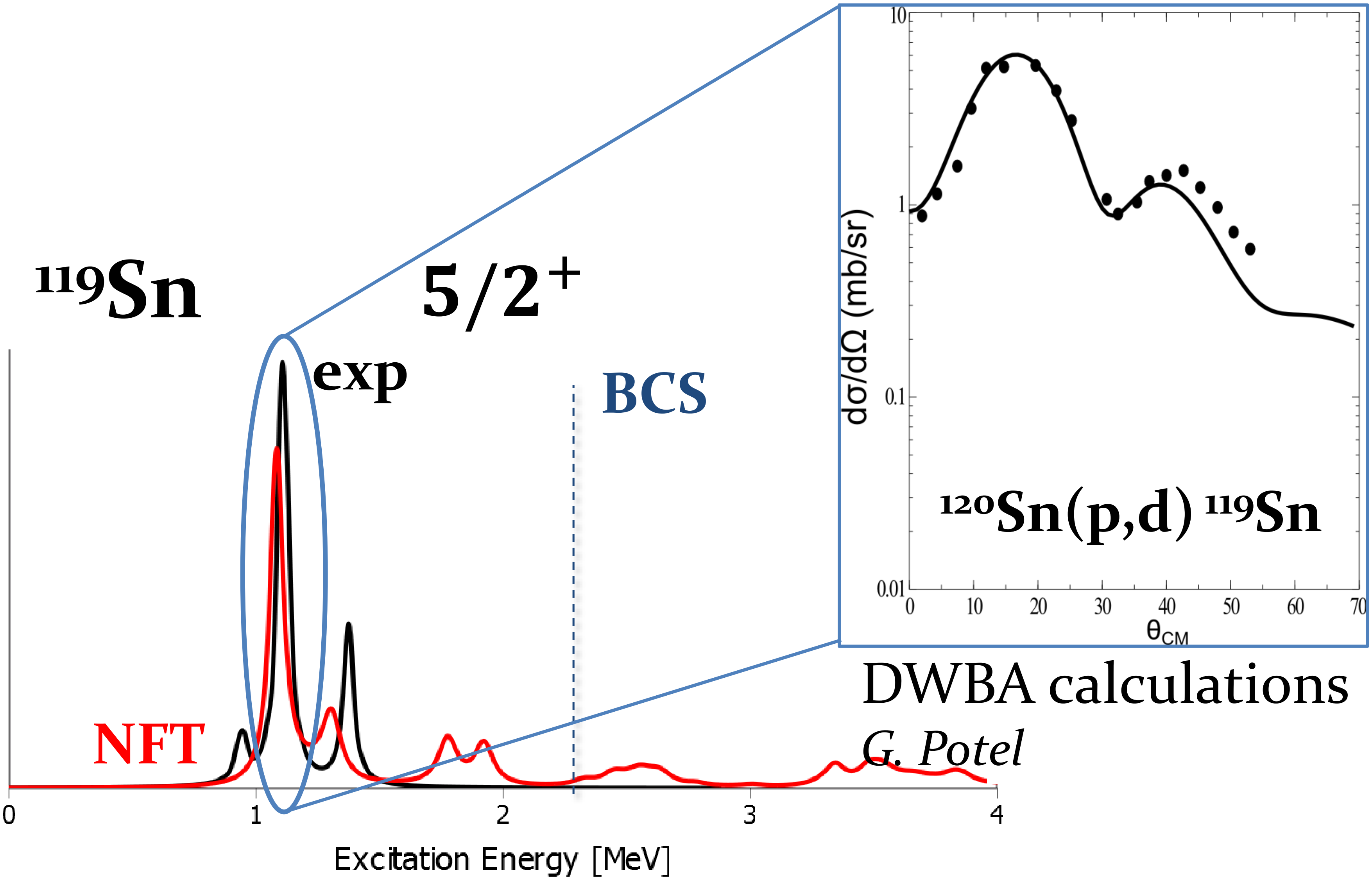


^{120}Sn

Transfer reactions



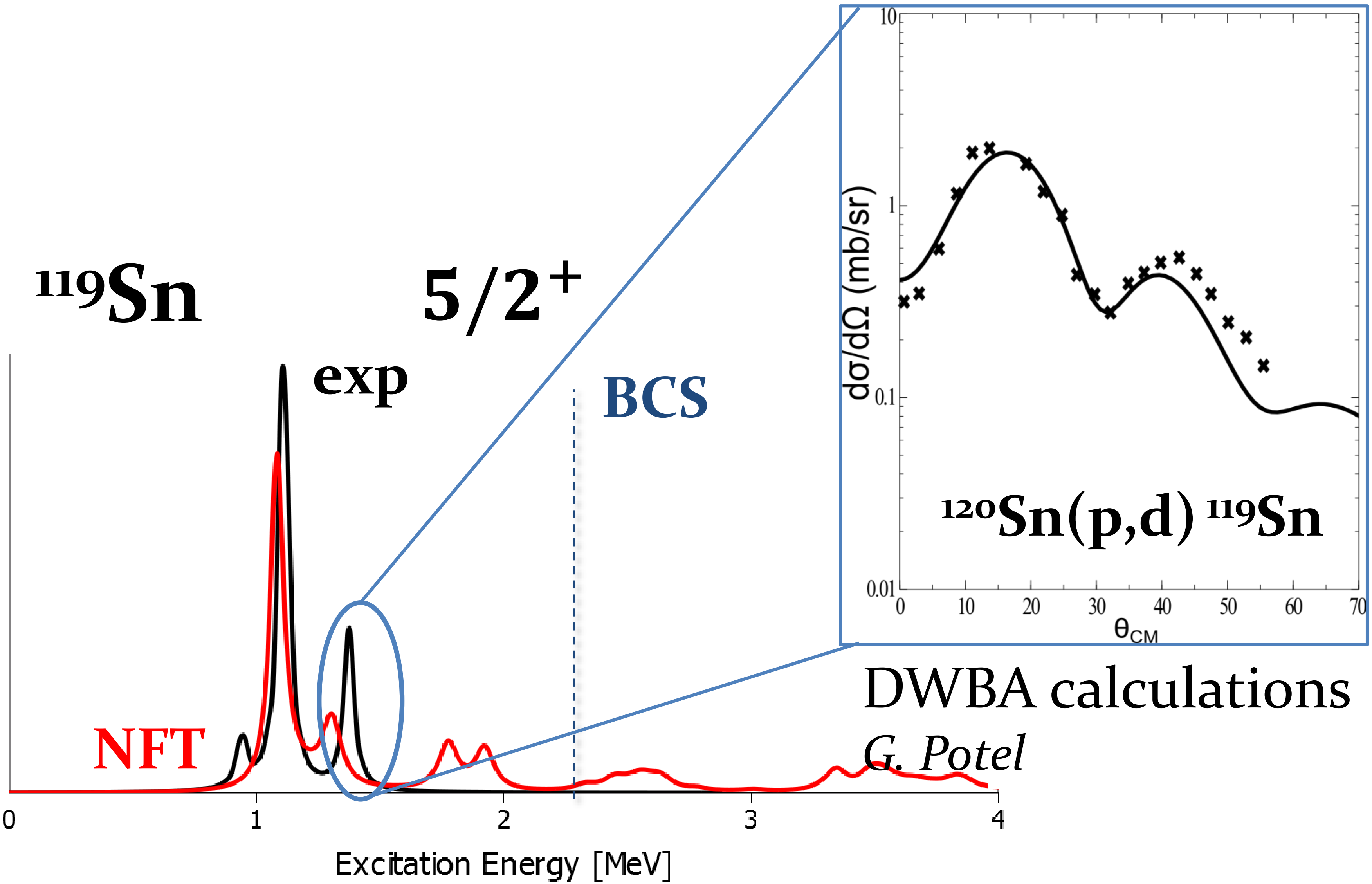
Quasiparticle strength compared with experiment



DWBA calculations

G. Potel

Quasiparticle strength comparison with experiment

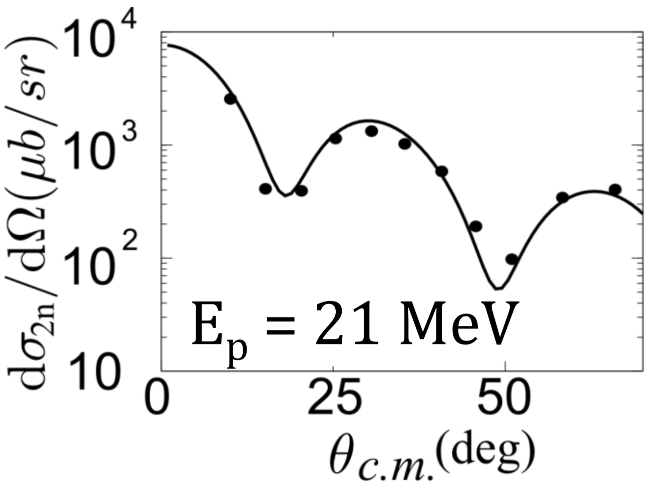


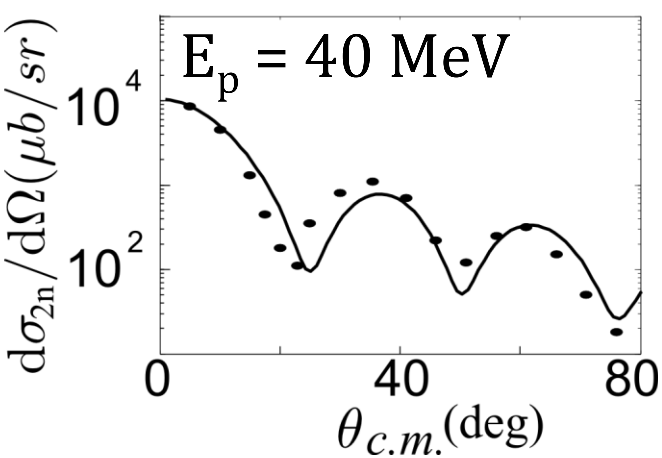
DWBA calculations

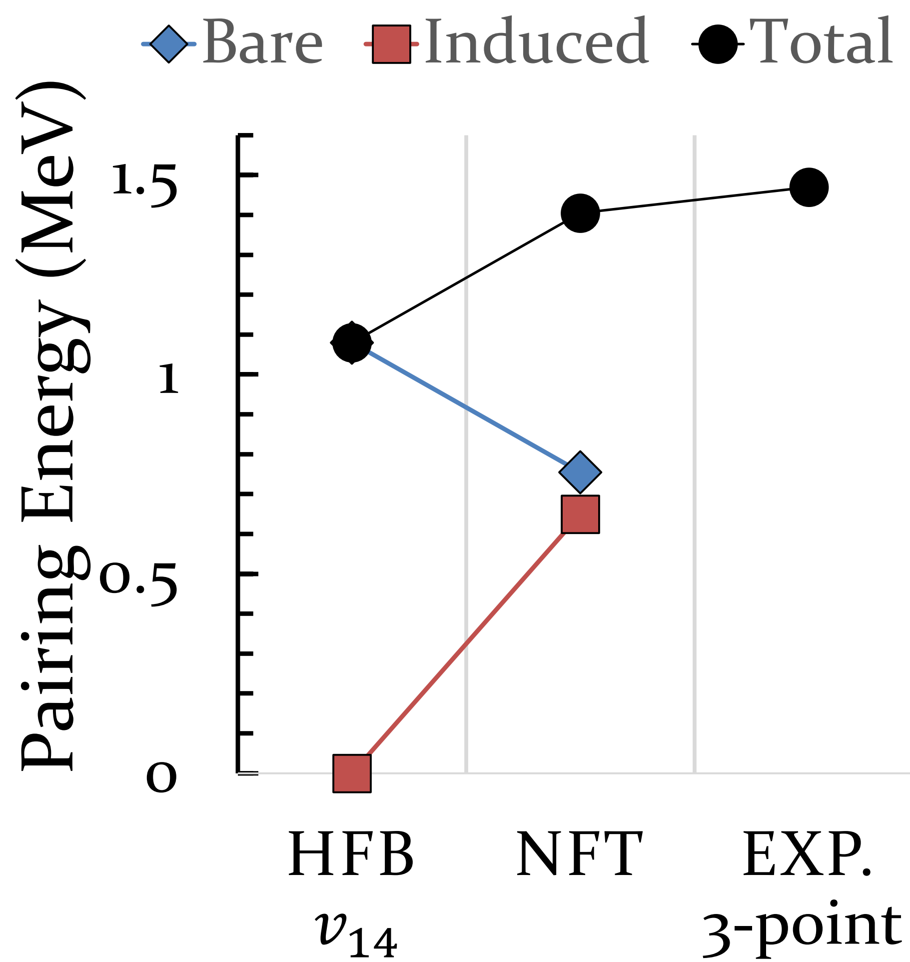
G. Potel

Pairing Properties

Two particle transfer cross section

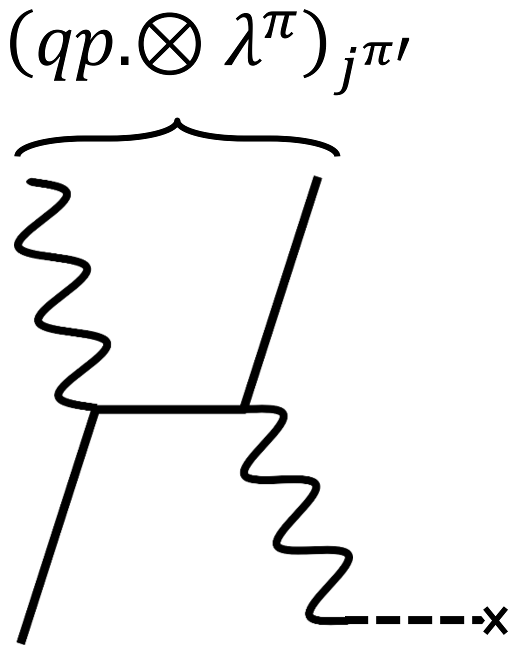


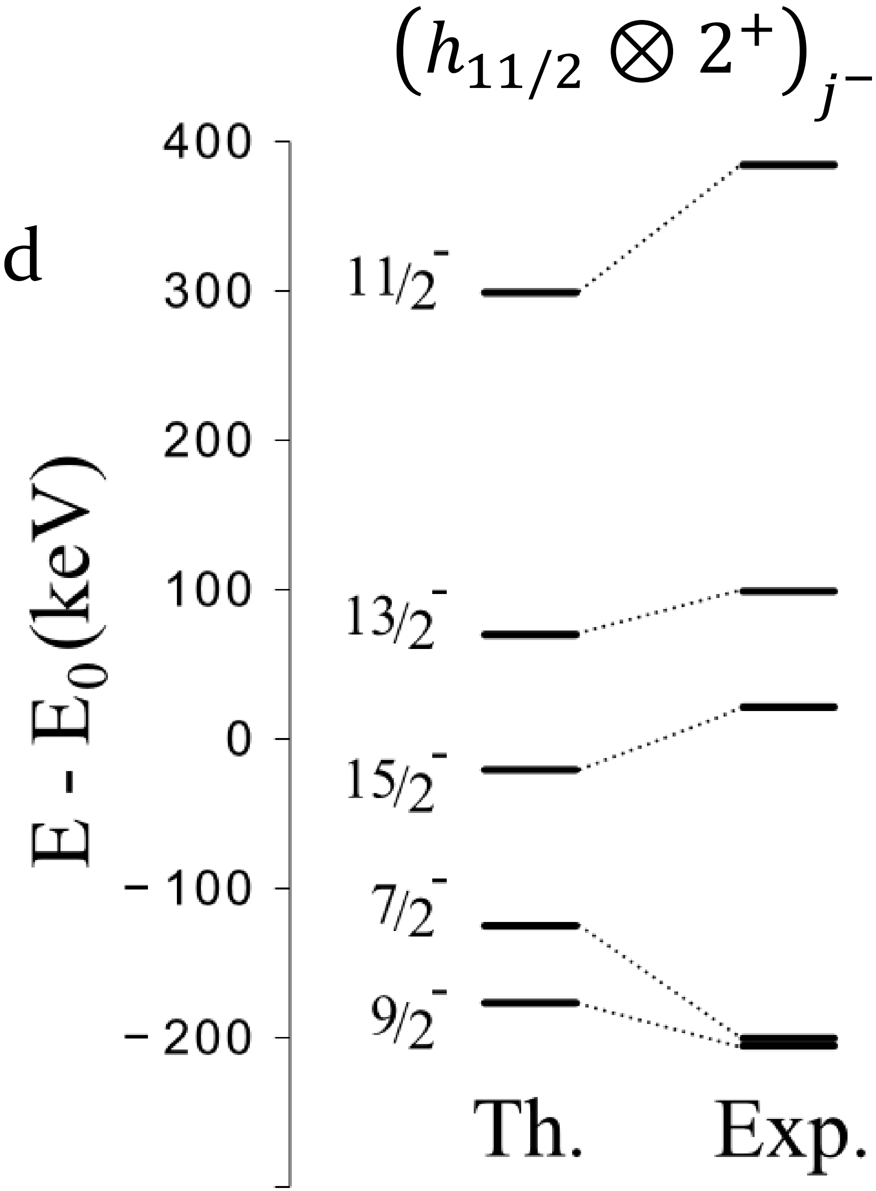




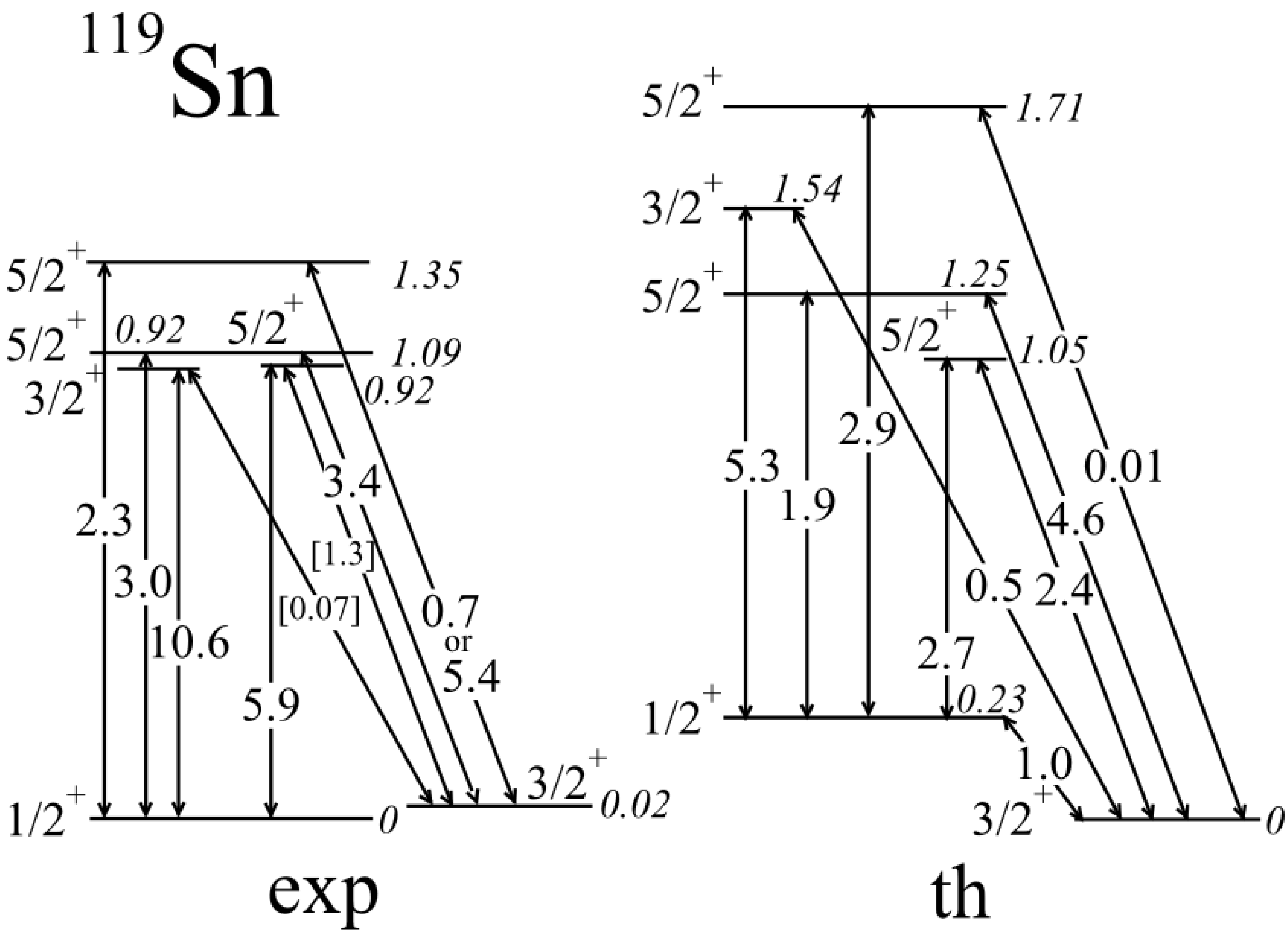
Multiplet Splitting

Elastic excitation of a quasiparticle state coupled to the core vibrations



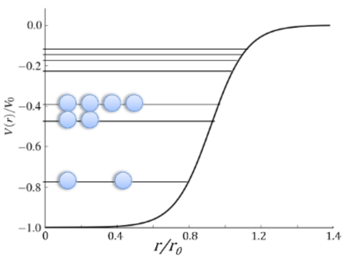


Electromagnetic Transition



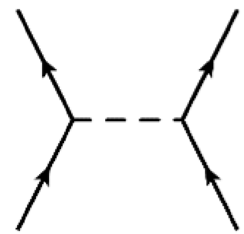
Questioning the assumptions

Hartree-Fock mean Field



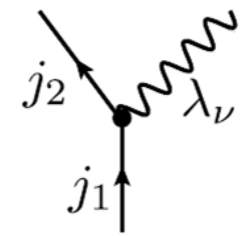
m_k

Pairing Interaction



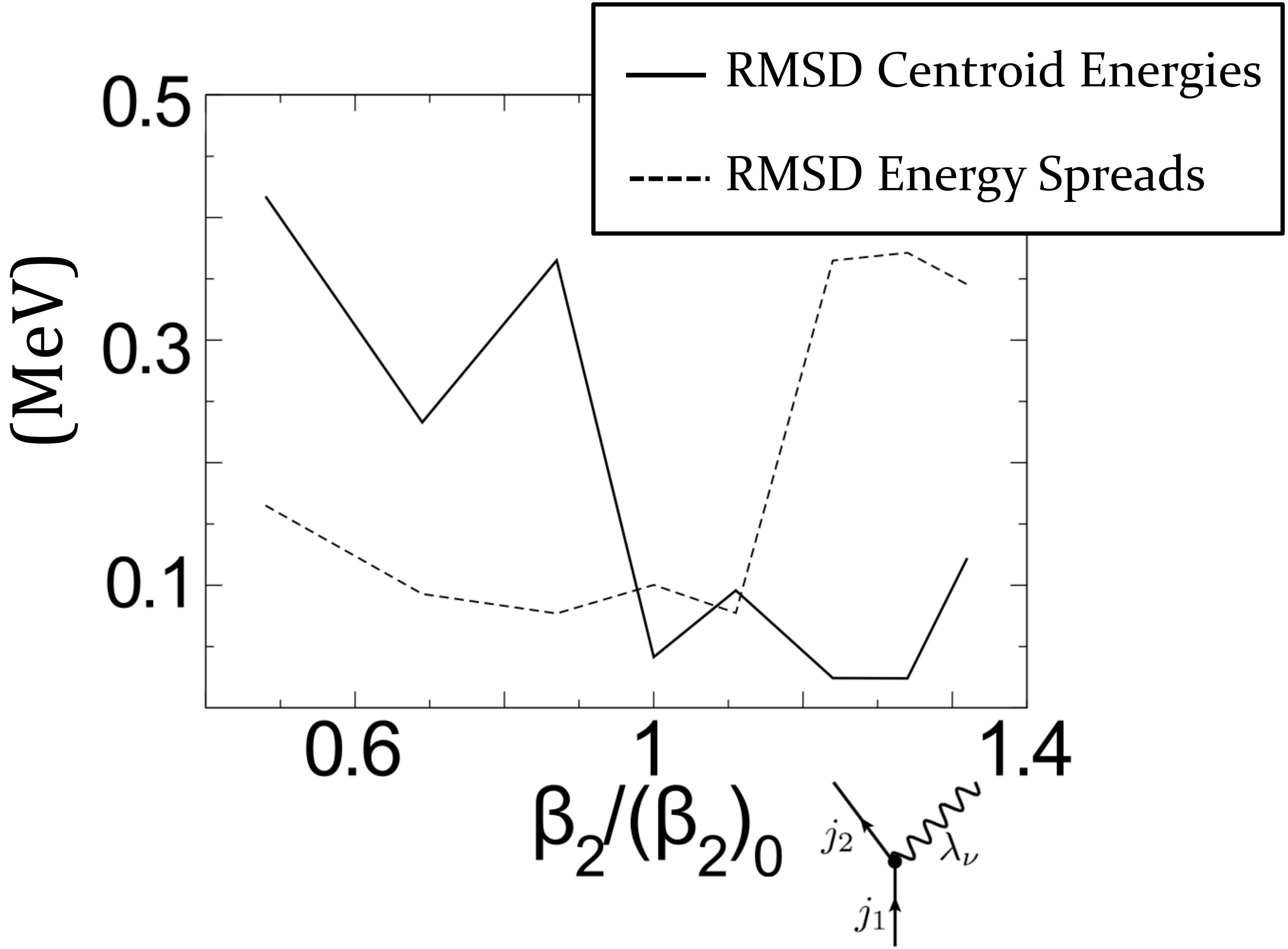
G

Particle Vibration Coupling Vertex

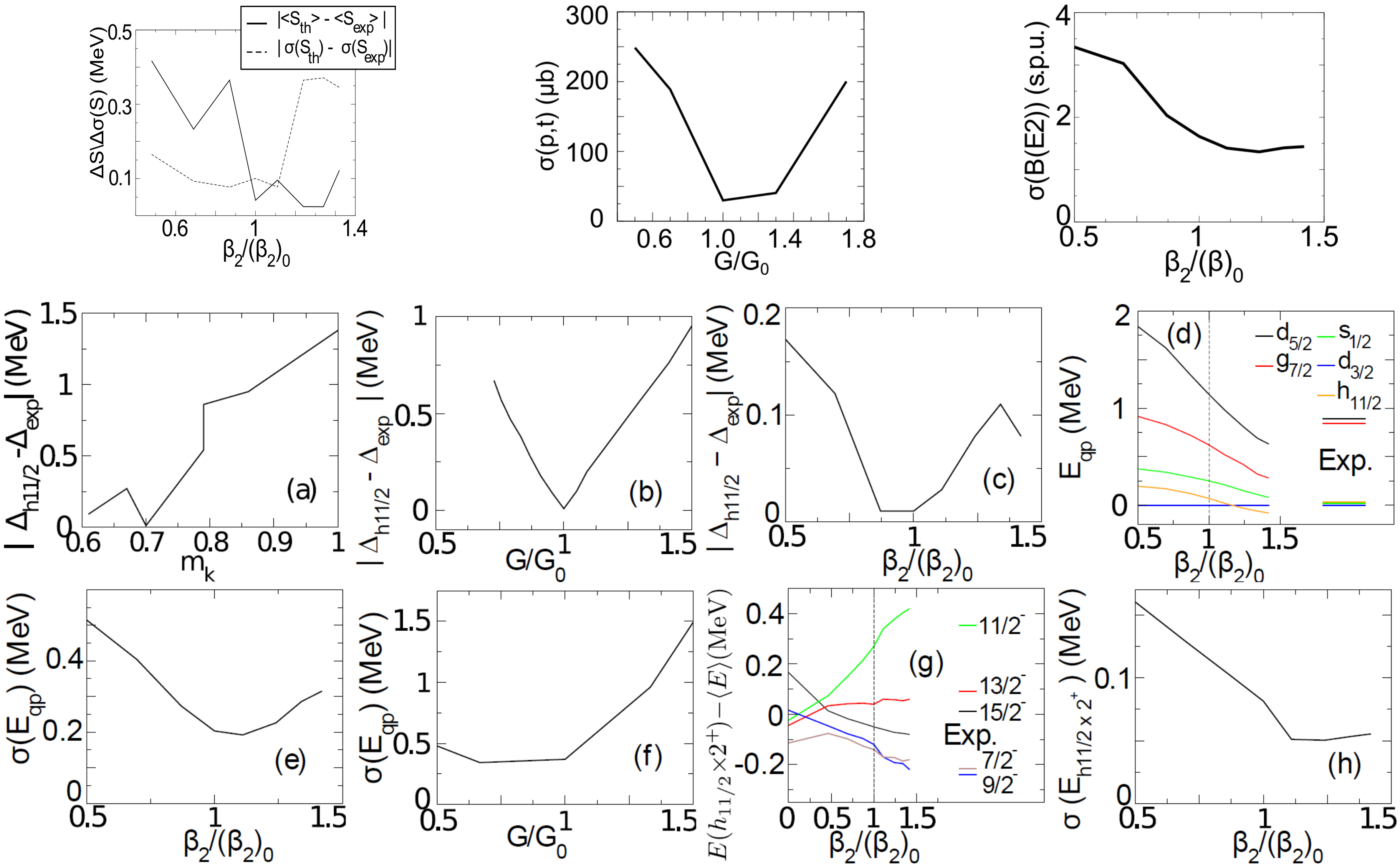


β_λ

Questioning the assumptions



Questioning the assumptions



A neat description of Nuclear Structure

- Interweaving single-particle ($m_k \approx 0.7m$) and collective (*tuned to experiment*) degrees of freedom, we can calculate **several nuclear structure observables** in open shell nuclei (*pairing from realistic interactions*) **within 10% error**.

Idini et al., PRC92, *in print*

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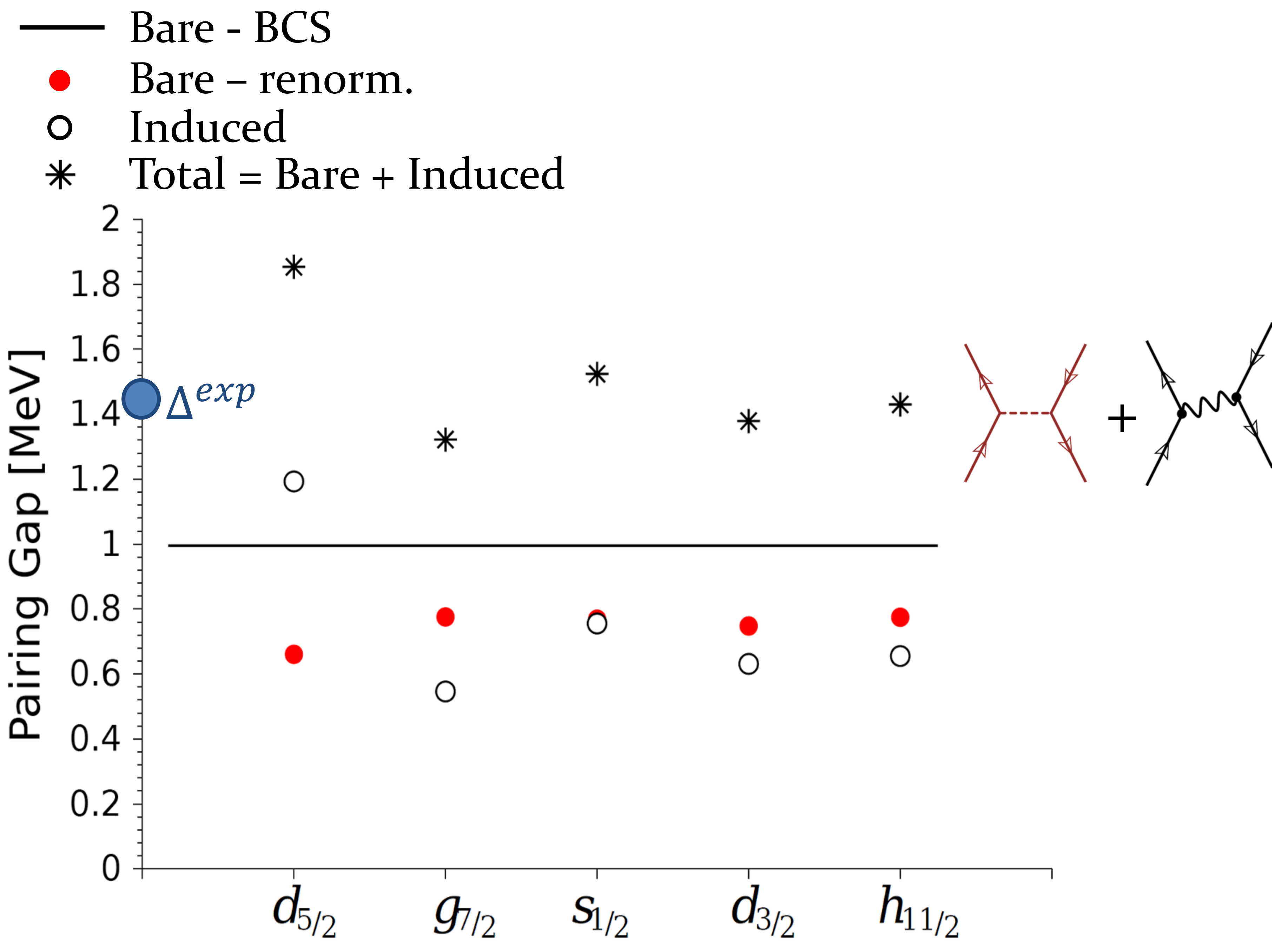
- Interweaving single-particle ($m_k \approx 0.7m$) and collective (*tuned to experiment*) degrees of freedom, we can calculate **several nuclear structure observables** in open shell nuclei (*pairing from realistic interactions*) **within 10% error**.

Interweaving of elementary modes of excitation in superfluid nuclei through particle-vibration coupling: Quantitative account of the variety of nuclear structure observables

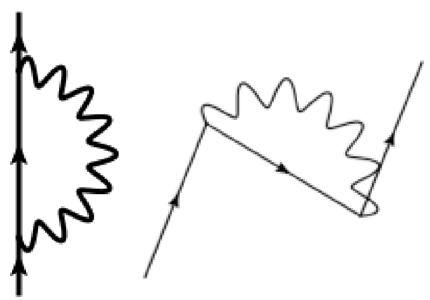
Idini et al., PRC92, *in print*

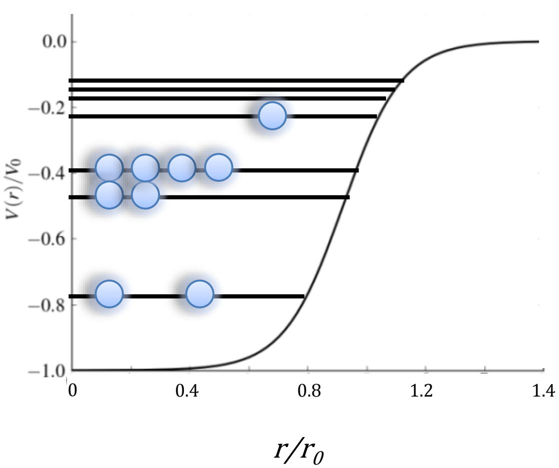


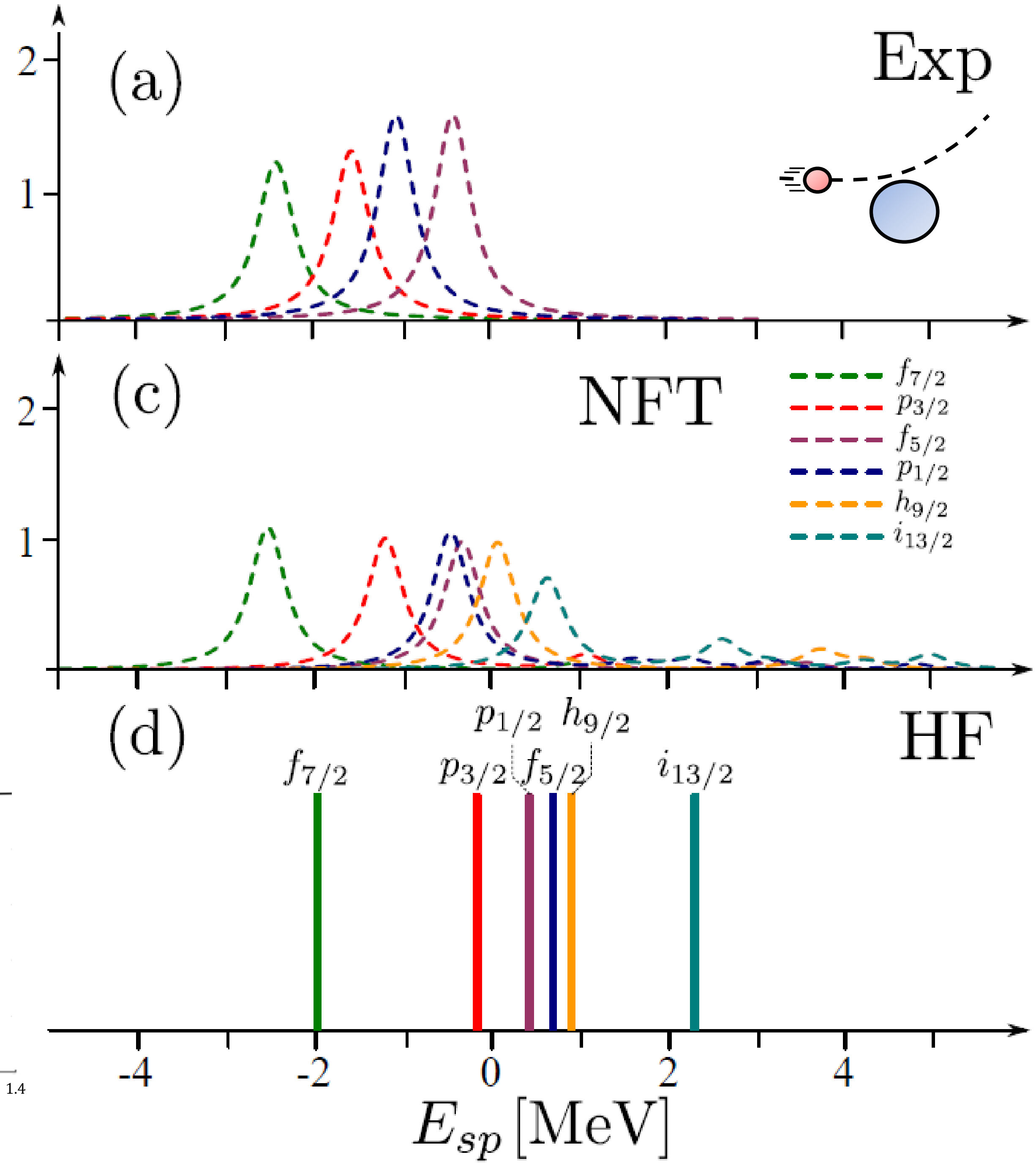
Bare - BCS
Bare – renorm.
Induced
Total = Bare + Induced
Pairing Gap [MeV]
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
Δ^{exp}
$d_{5/2}$
$g_{7/2}$
$s_{1/2}$
$d_{3/2}$
$h_{11/2}$
+

^{133}Sn

Particle Channel

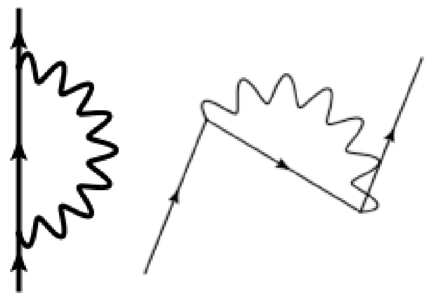


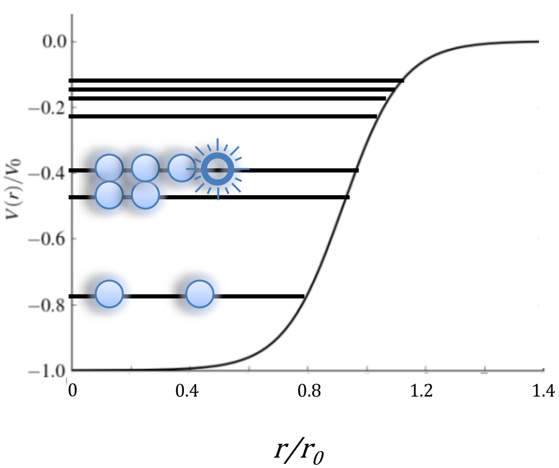


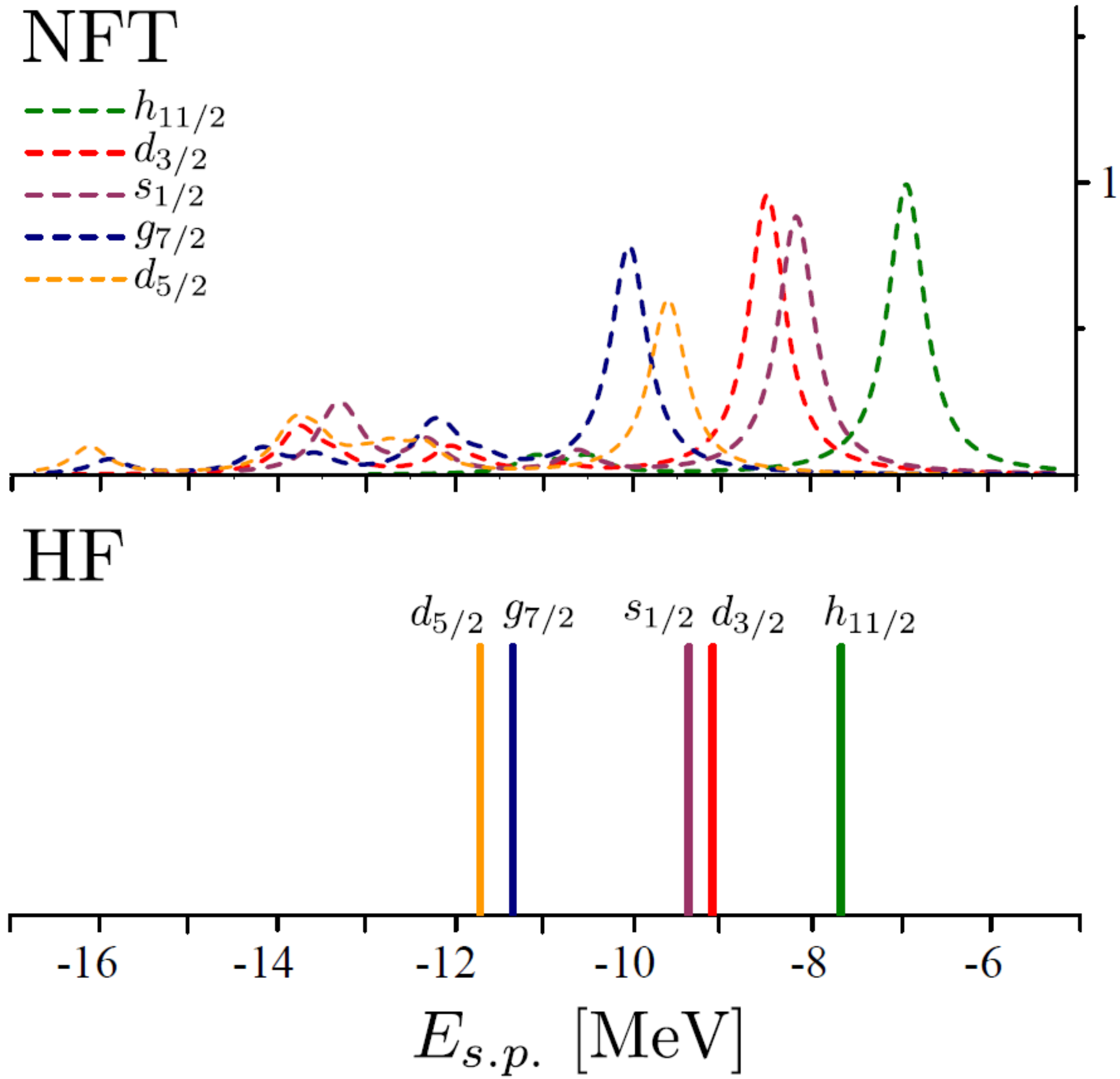


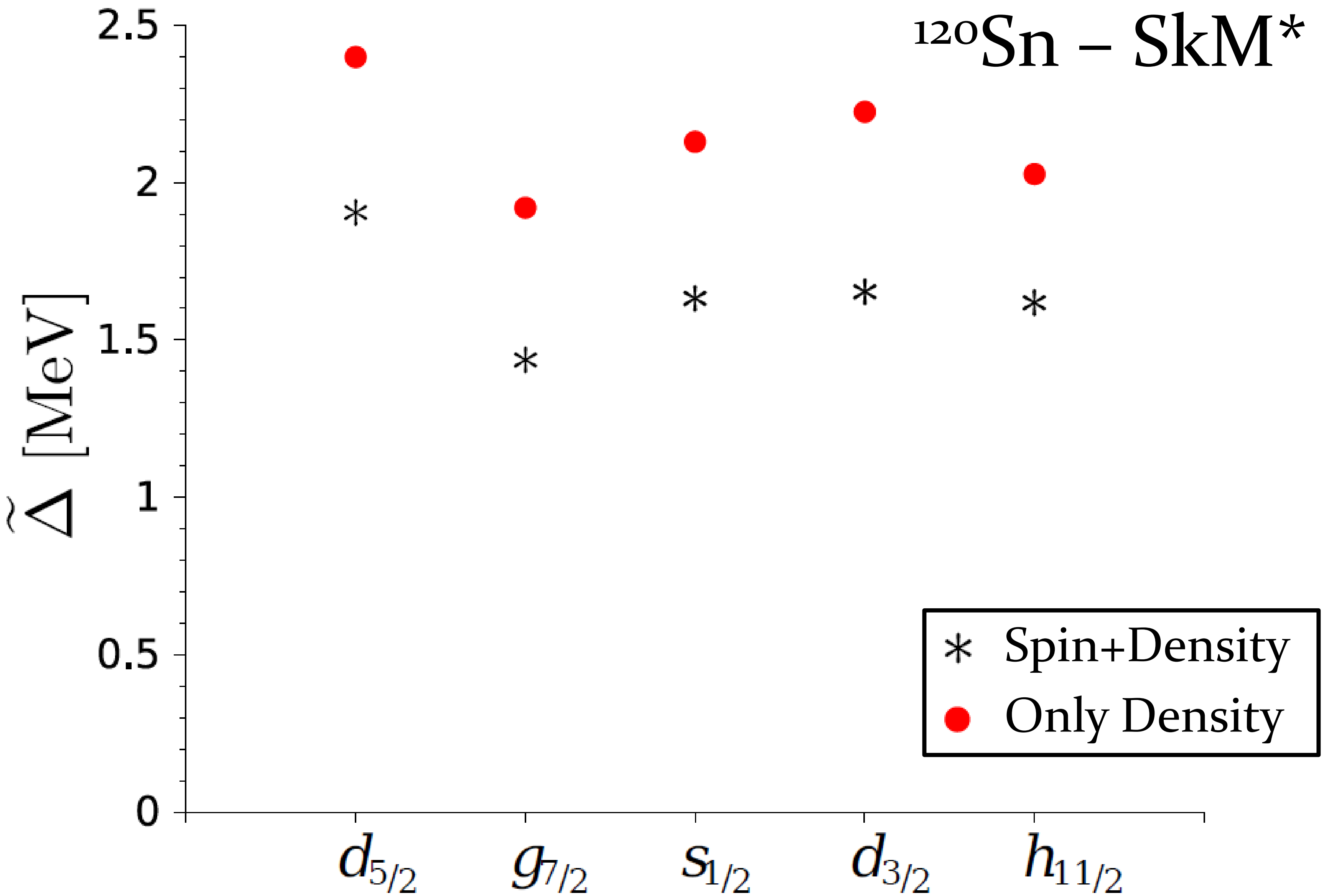
^{131}Sn

Hole Channel









$$\tilde{\Delta}(a,\omega) = Z(a,\omega)\left(\Delta_a^{BCS} + \tilde{\Sigma}^{12}(a,\omega)\right) \equiv \tilde{\Delta}^{bare}(a,\omega) + \tilde{\Delta}^{ind}(a,\omega), \quad (1.19)$$

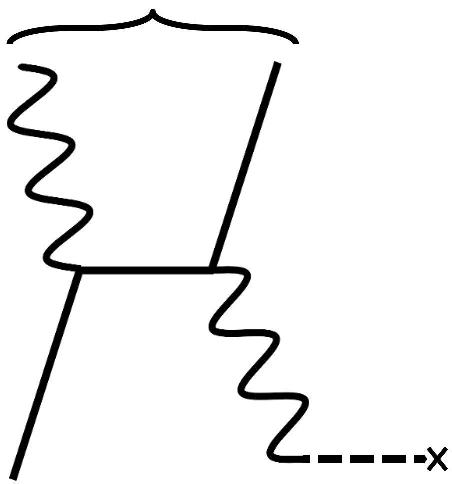
Multiplet Splitting

$$\Delta E(j,\lambda^\pi) =$$

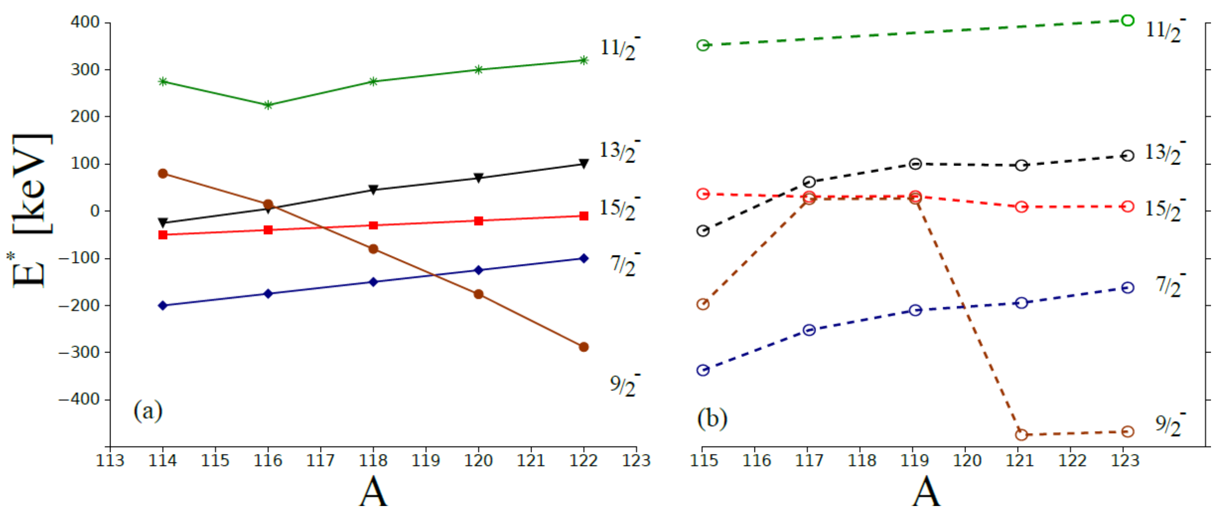
$$= \sum_{j'} \left(\delta_{J,\lambda} \frac{V^2(j,j',\lambda^\pi)}{E_j - E_{j'} + \hbar\omega_{\lambda^\pi}} + (2j+1) \begin{Bmatrix} \lambda & j & j' \\ \lambda & j & J \end{Bmatrix} \frac{W^2(j,j',\lambda^\pi)}{E_j + E_{j'} - \hbar\omega_{\lambda^\pi}} \right)$$

$$\left(h_{11/2} \otimes 2^+\right)_{j^-}$$

$$\left(j \otimes \lambda^\pi\right)_{J^{\pi'}}$$



Theory experiment

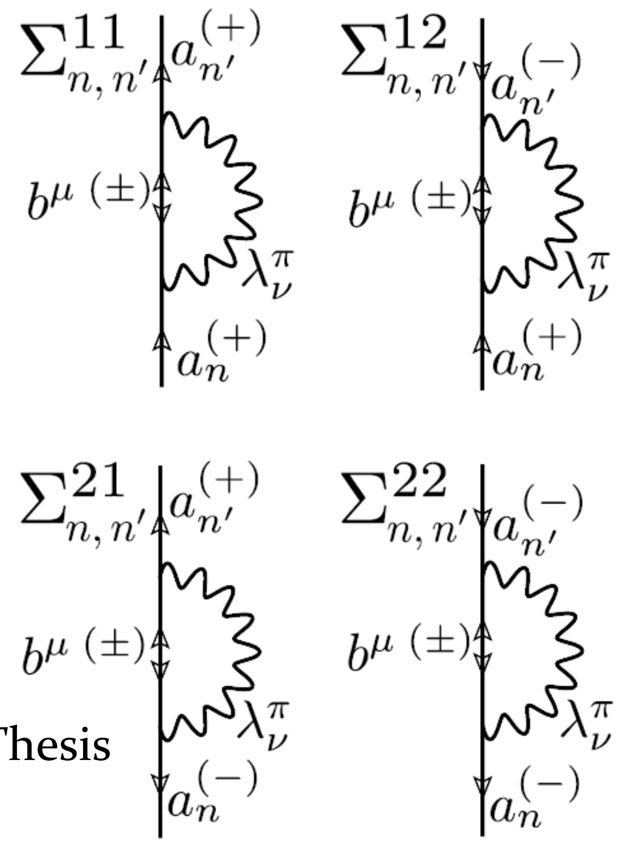


$$\Sigma^{11}(a,\omega) = \sum_{b,\lambda_\nu^\pi} \int_0^{+\infty} \mathrm{d}\omega' \frac{V^2(a,b,\lambda_\nu^\pi,\omega')}{\omega - \omega' - \hbar\omega_{\lambda_\nu^\pi}} + \frac{W^2(a,b,\lambda_\nu^\pi,\omega')}{\omega + \omega' + \hbar\omega_{\lambda_\nu^\pi}}, \tag{1.9}$$

$$\Sigma^{22}(a,\omega) = \sum_{b,\lambda_\nu^\pi} \int_0^{+\infty} \mathrm{d}\omega' \frac{V^2(a,b,\lambda_\nu^\pi,\omega')}{\omega + \omega' + \hbar\omega_{\lambda_\nu^\pi}} + \frac{W^2(a,b,\lambda_\nu^\pi,\omega')}{\omega - \omega' - \hbar\omega_{\lambda_\nu^\pi}}, \tag{1.10}$$

$$\Sigma^{12}(a,\omega) = \sum_{b,\lambda_\nu^\pi} \int_0^{+\infty} \mathrm{d}\omega' VW(a,b,\lambda_\nu^\pi,\omega') \left[\frac{1}{\omega + \omega' + \hbar\omega_{\lambda_\nu^\pi}} - \frac{1}{\omega - \omega' - \hbar\omega_{\lambda_\nu^\pi}} \right]. \tag{1.11}$$

$$\left(\begin{array}{c|c||c|c} \Sigma^{11}_{hh} & \Sigma^{11}_{hp} & \Sigma^{12}_{hh} & \Sigma^{12}_{hp} \\ \hline \Sigma^{11}_{ph} & \Sigma^{11}_{pp} & \Sigma^{12}_{ph} & \Sigma^{12}_{pp} \\ \hline\hline \Sigma^{21}_{hh} & \Sigma^{21}_{hp} & \Sigma^{22}_{hh} & \Sigma^{22}_{hp} \\ \hline \Sigma^{21}_{ph} & \Sigma^{21}_{pp} & \Sigma^{22}_{ph} & \Sigma^{22}_{pp} \end{array} \right)$$



A. Idini, Renormalization Effects in Nuclei, PhD Thesis
http://hdl.handle.net/2434/216315

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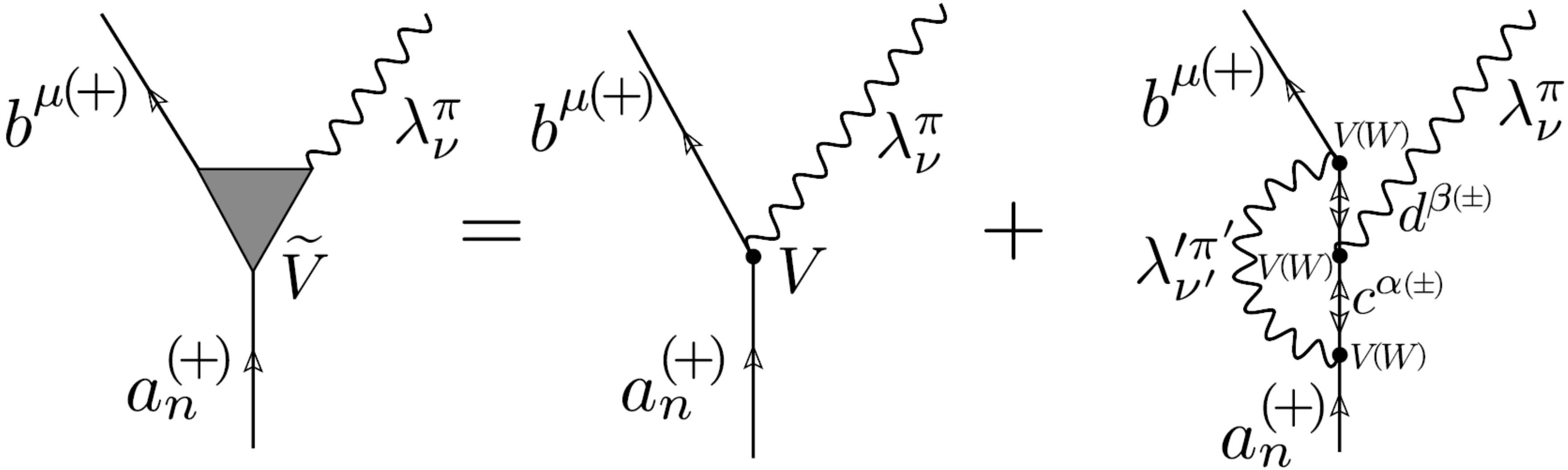
$$\begin{aligned} V^2(a,b,\lambda_\nu^\pi,\omega) = {} & (f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi))^2 u^2 a S^+(b,\omega) \\ & + (f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi))^2 v_a^2 S^-(b,\omega) \\ & - 2(f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi))(f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi)) u_a v_a \widetilde{S}(b,\omega) \end{aligned} \tag{1.12}$$

$$\tag{1.13}$$

$$\begin{aligned} W^2(a,b,\lambda_\nu^\pi,\omega) = {} & (f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi))^2 u_a^2 S^-(b,\omega) \\ & + (f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi))^2 v_a^2 S^+(b,\omega) \\ & - 2(f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi))(f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi)) u_a v_a \widetilde{S}(b,\omega) \end{aligned} \tag{1.14}$$

and

$$\begin{aligned} VW(a,b,\lambda_\nu^\pi,\omega) = {} & (f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi))^2 u_a v_a S^+(b,\omega) \\ & - (f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi))^2 u_a v_a S^-(b,\omega) \\ & + (f(a,b,\lambda_\nu^\pi) + g(a,b,\lambda_\nu^\pi))(f(a,b,\lambda_\nu^\pi) - g(a,b,\lambda_\nu^\pi))(u_a^2 - u_a^2) \widetilde{S}(b,\omega) \end{aligned} \tag{1.15}$$



$$\widetilde{V}(a_n, b^{\mu}, \lambda^{\pi}_{\nu}, \omega) \;=\; V(a_n, b^{\mu}, \lambda^{\pi}_{\nu}) \;+\; \delta V(a_n, b^{\mu}, \lambda^{\pi}_{\nu}, \omega)$$

$$\begin{aligned}
\delta Vertex_i(a_n, b^{\mu}, \lambda^{\pi}_{\nu}, \omega) = &\sum_{c,d,\lambda'^{\pi'}_{\nu'}} \frac{(-1)^{j_c+\lambda'-j_a}(-1)^{j_d+\lambda'-j_b}}{1+\delta_{\lambda^{\pi}_{\nu},\lambda'^{\pi'}_{\nu'}}} \langle (\lambda' j_d) j_b \lambda; j_a | \lambda' (j_d \lambda) j_c; j_a \rangle \\
&\sum_{\alpha,\beta} Vertex(a_n, c^{\alpha}, \lambda'^{\pi'}_{\nu'}) Vertex(c^{\alpha}, d^{\beta}, \lambda^{\pi}_{\nu}) Vertex(d^{\beta}, b^{\mu}, \lambda'^{\pi'}_{\nu'}) \\
&\frac{1}{\omega \mp (E_{c^{\alpha}} + \hbar\omega_{\lambda'^{\pi'}_{\nu'}})} \frac{1}{\omega \mp (E_{d^{\beta}} + \hbar\omega_{\lambda'^{\pi'}_{\nu'}} + \hbar\omega_{\lambda^{\pi}_{\nu}})}
\end{aligned} \tag{B.0.1}$$

DWBA

Entrance Channel **Exit Channel**

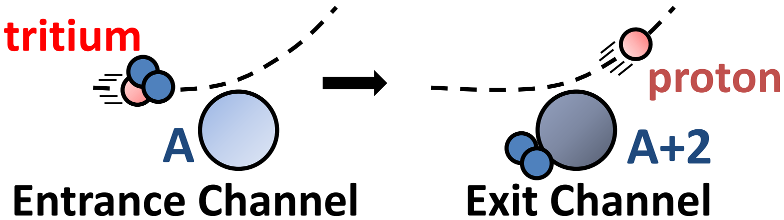
$$\frac{d\sigma}{d\Omega} \sim \left| \left\langle \phi_\alpha(\xi_\alpha)\, \chi_\alpha(r_\alpha) \middle| V_{int} \middle| \phi_\beta(\xi_\beta)\chi_\beta(r_\beta) \right\rangle \right|^2$$

Internal Structure Wavefunction

Relative Motion: Distorted Wave

DWBA approximate the entrance channel as a factorization of internal and relative coordinates, consider relative motion as Distorted Plain Wave, and calculate matrix element between this approximated ***<intial| and |final>*** state.

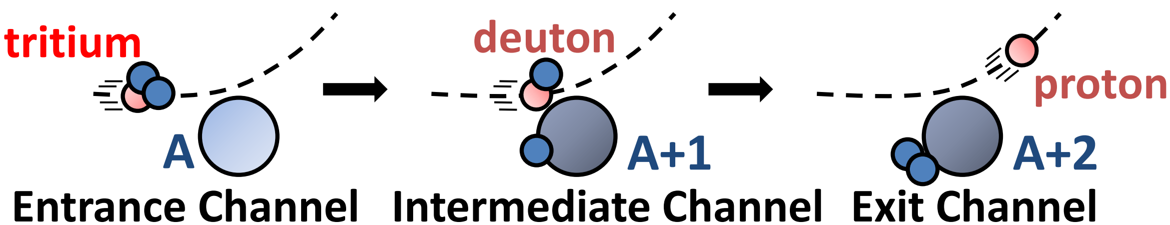
2-particle transfer DWBA



Ist order DWBA:

Simultaneus transfer

$$\langle (A,t)|V_{int}|(A+2,p)\rangle$$

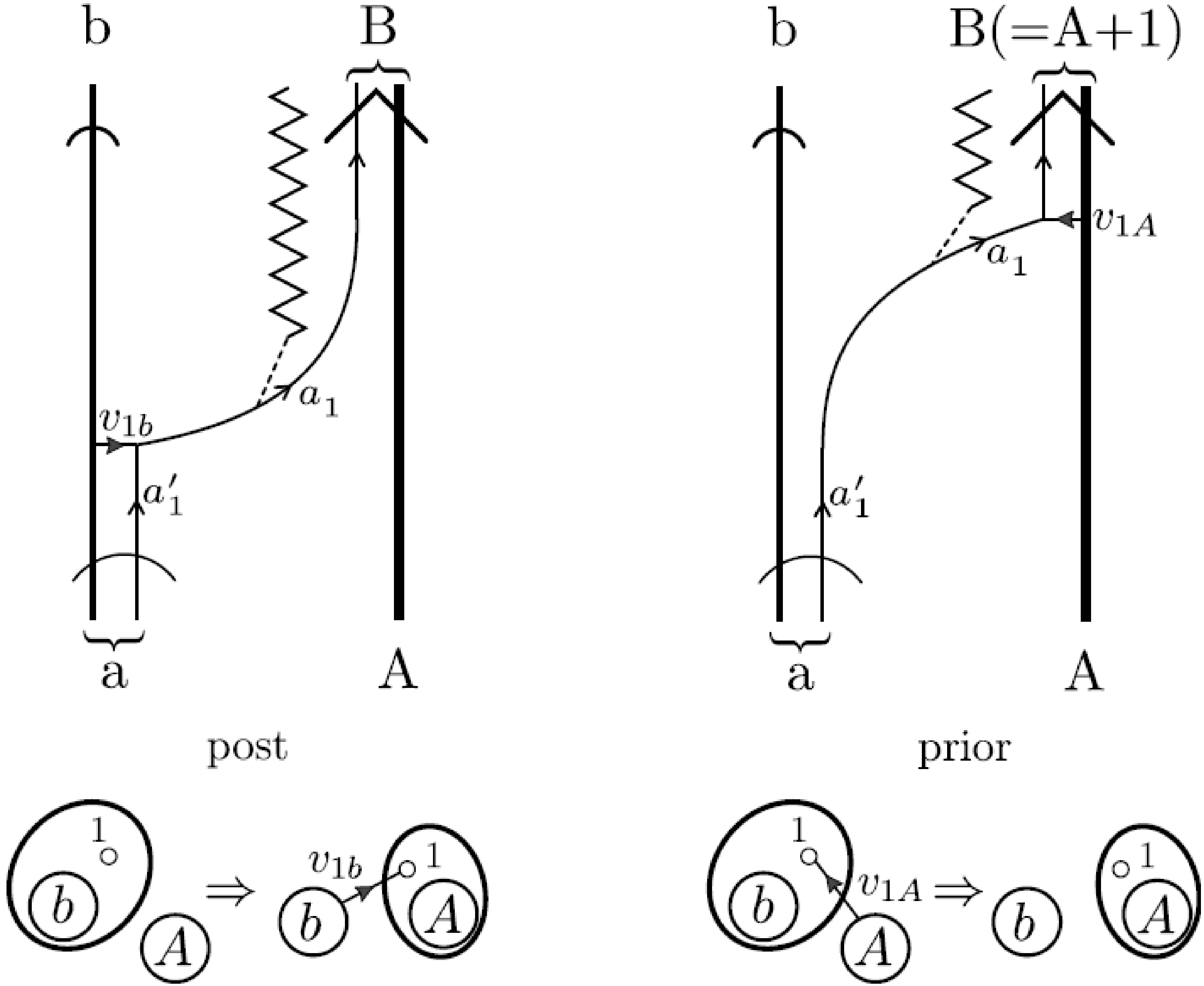


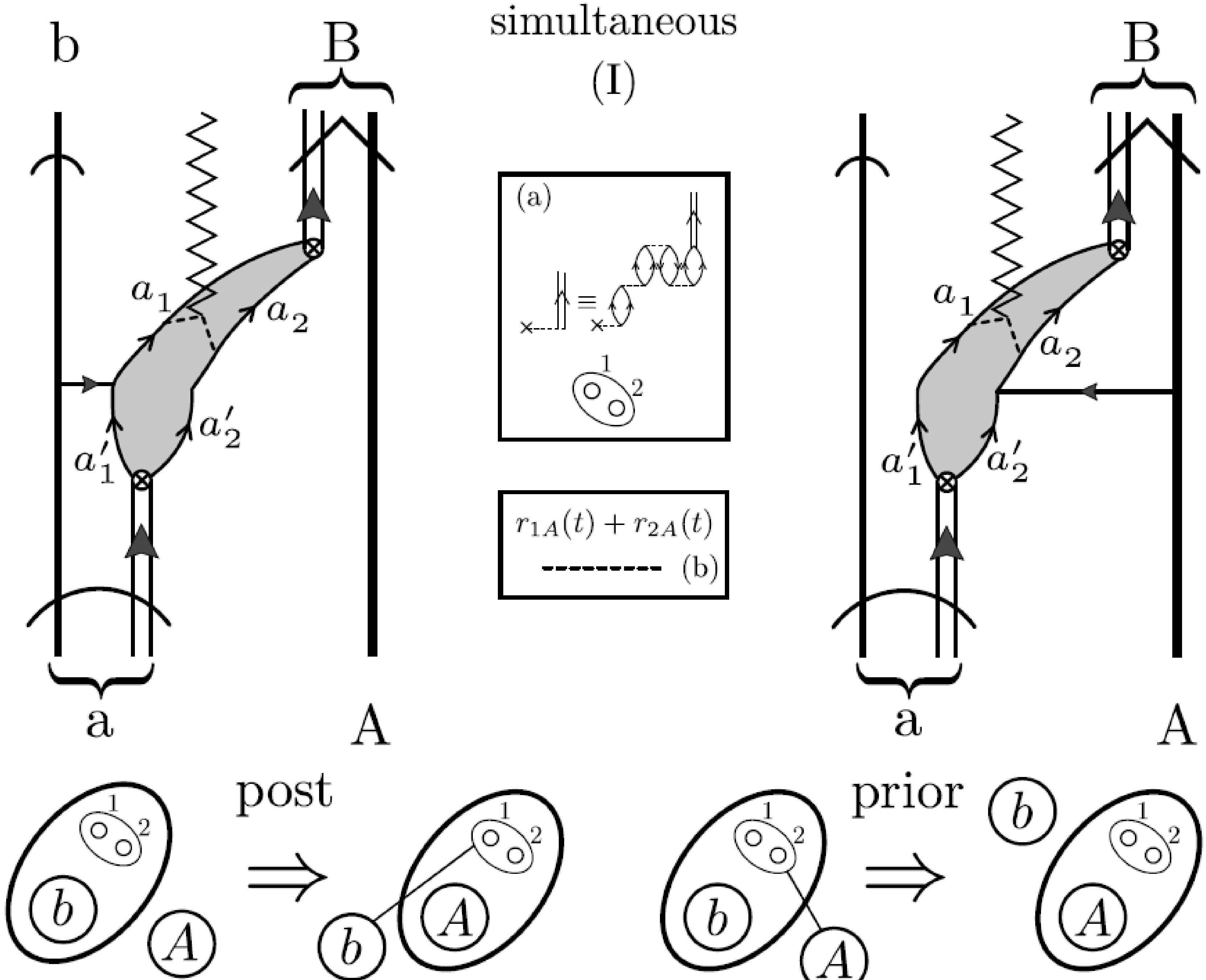
IInd order DWBA:

Successive transfer

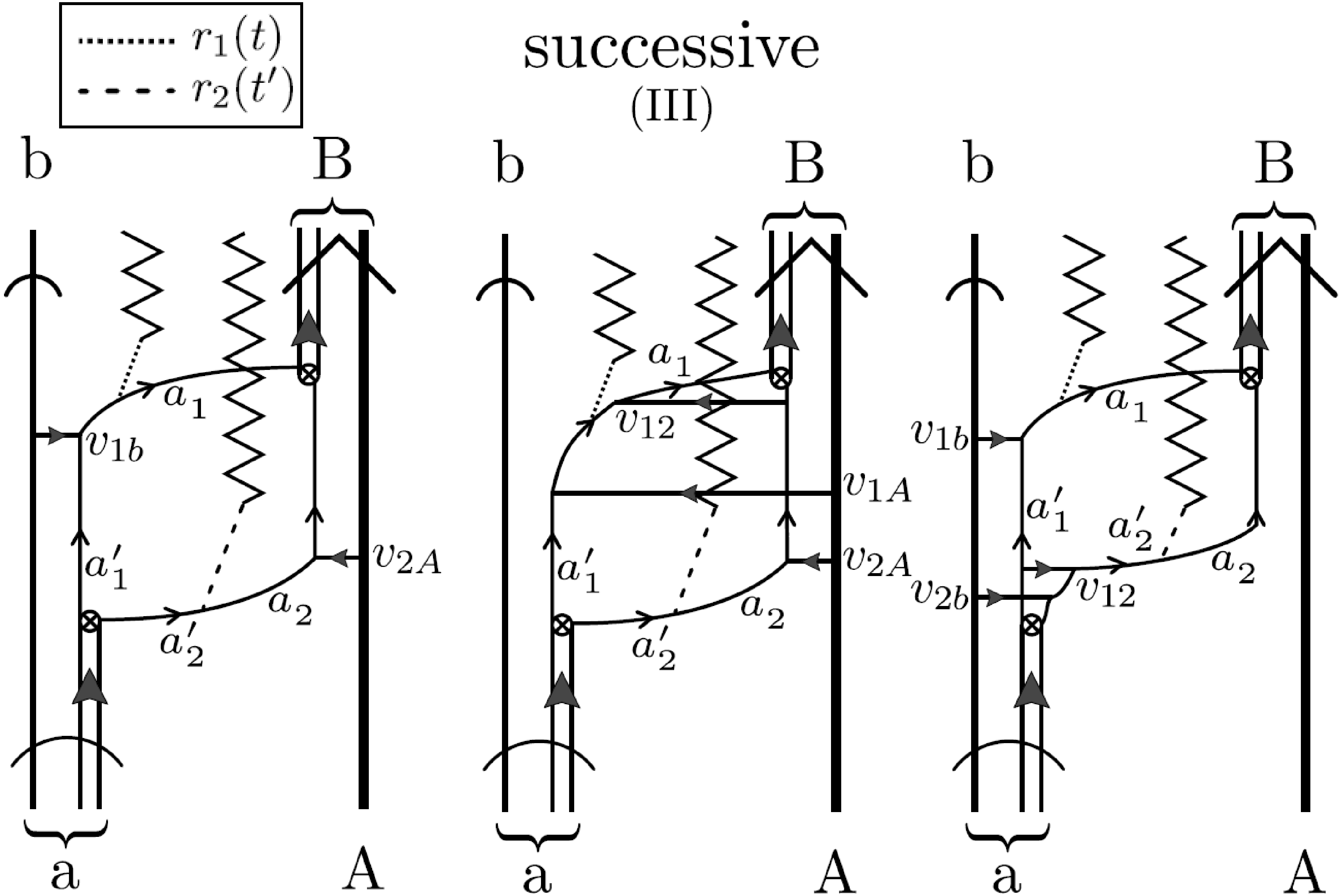
We need the structure information to calculate the correlation between the two transferred neucleons, so the probability of 1 neutron in the target and 1 in the ejectile, in the intermediate state

See G. Potel, A. Idini et al. Rep. Prog. Phys. 76 (106301) one-particle transfer

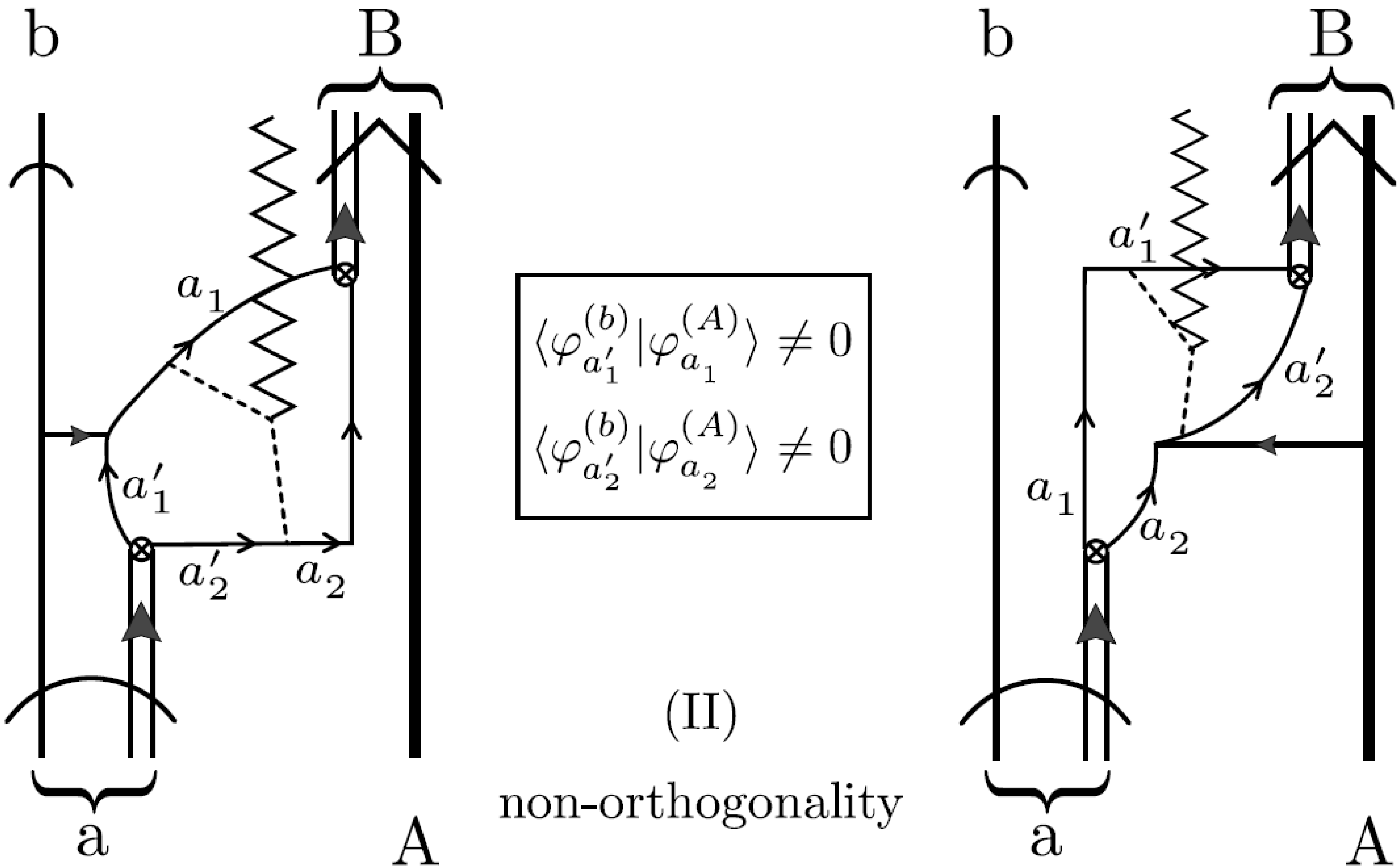




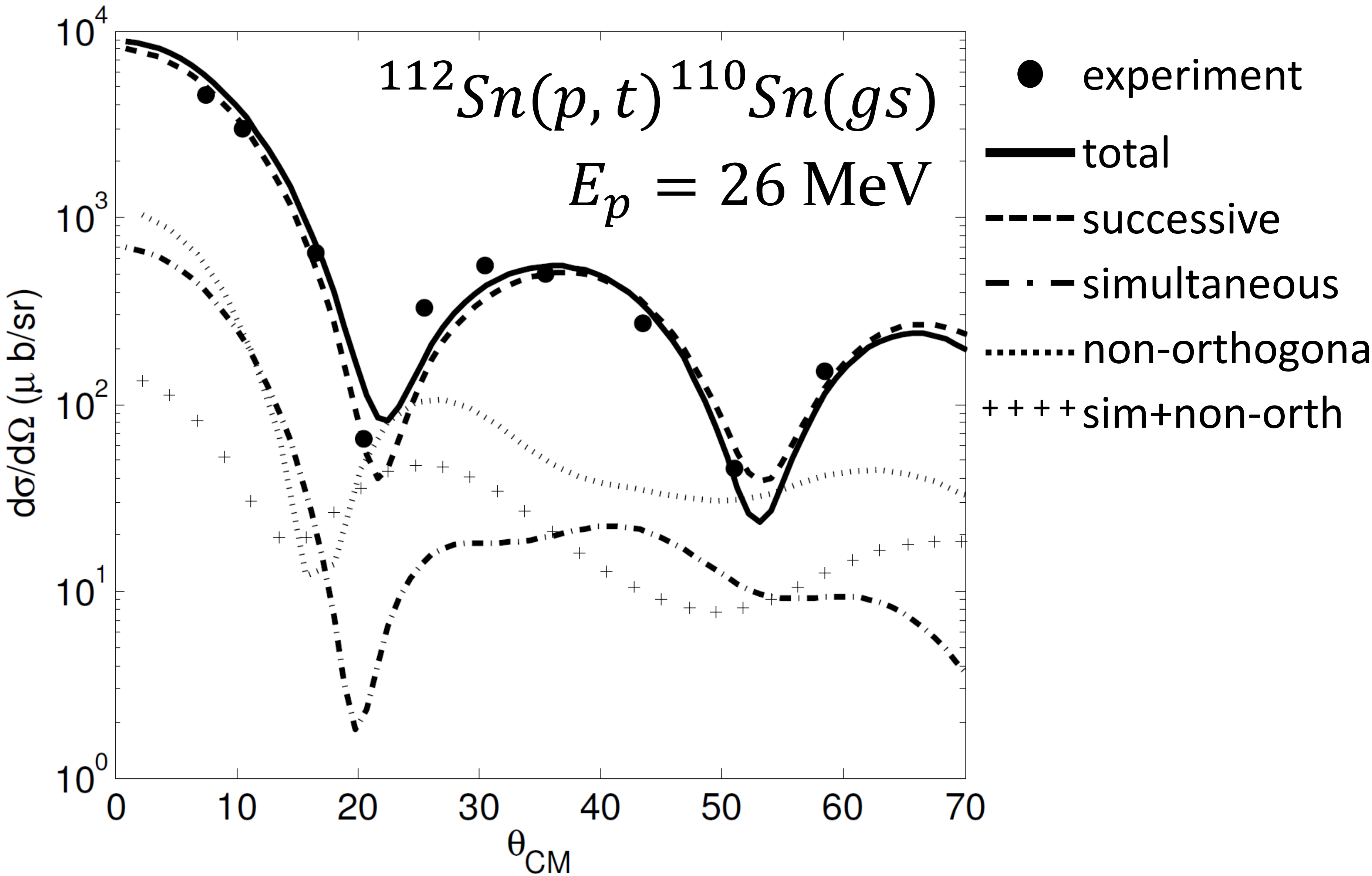
simultaneous
(I)
b
B
a
A
a_1
a_2
a'_1
a'_2
(a)
$\equiv$
1
2
$r_{1A}(t) + r_{2A}(t)$
(b)
post
prior
b
A



$r_1(t)$
$r_2(t')$
successive
(III)
b
B
a
A
a_1
a_1'
a_2
a_2'
v_{1b}
v_{2A}
v_{12}
v_{1A}
v_{2b}



b
B
a
A
a_1
a'_1
a'_2
a_2
$\langle \varphi^{(b)}_{a'_1} | \varphi^{(A)}_{a_1} \rangle \neq 0$
$\langle \varphi^{(b)}_{a'_2} | \varphi^{(A)}_{a_2} \rangle \neq 0$
(II)
non-orthogonality



$^{112}Sn(p,t)^{110}Sn(gs)$
$E_p = 26$ MeV
experiment
total
successive
simultaneous
non-orthogonal
sim+non-orth
dσ/dΩ (μ b/sr)
θ_CM
10^0
10^1
10^2
10^3
10^4
0
10
20
30
40
50
60
70