A quantitative account of the variety of nuclear structure observables in superfluid nuclei

A. Idini

Surrey University

G. Potel

Michigan State University

R.A. Broglia

Milano University and

The Niels Bohr Institute, Copenhagen

F. Barranco

Sevilla University

E. Vigezzi

INFN Milano

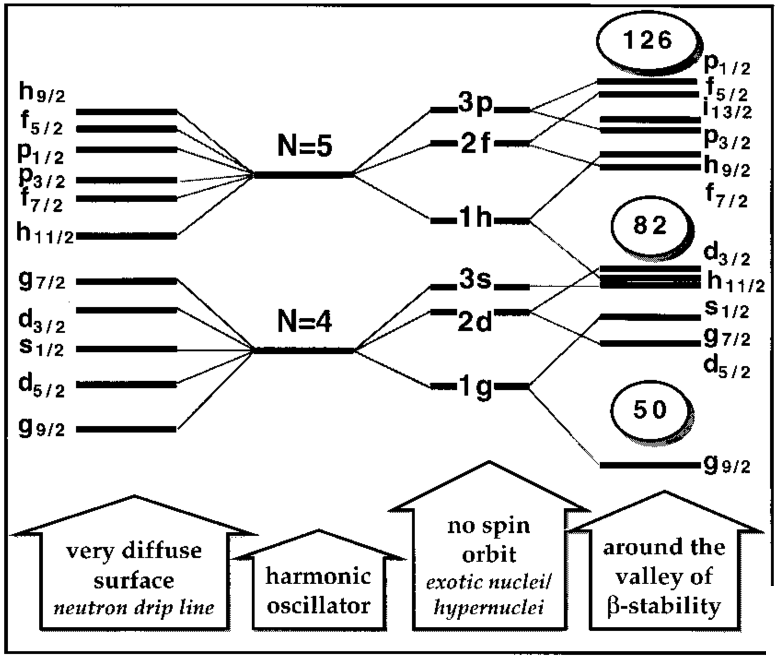
A. Idini et al., PRC92 031304(2015)

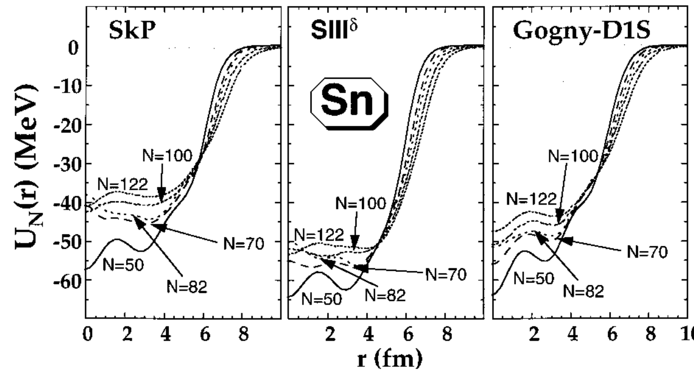
Open-shell nuclei around $_{50}Sn_{70}$

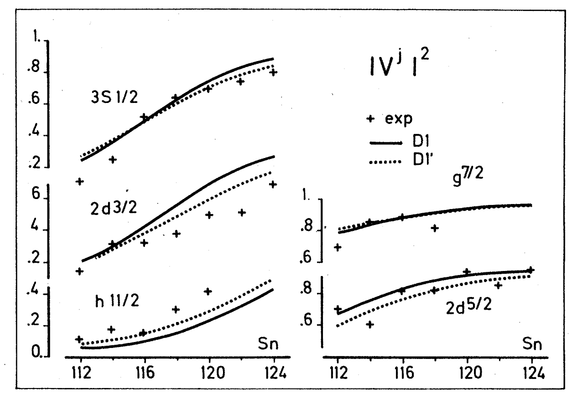
Observables:

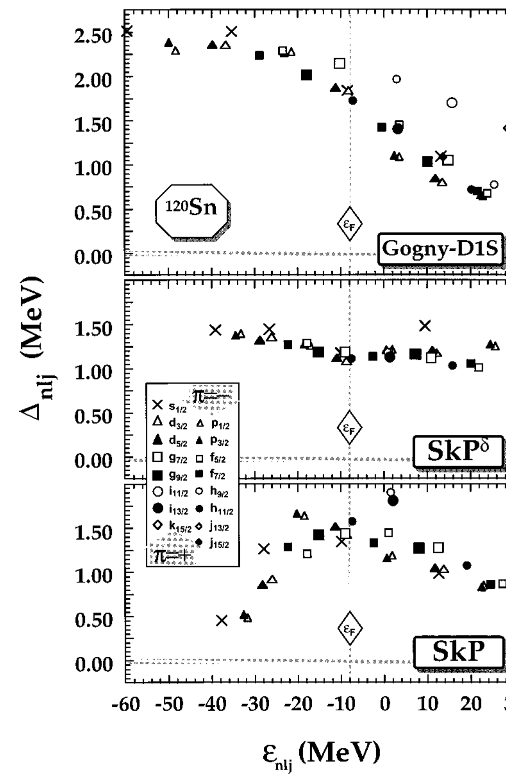
- Low-energy quasiparticle spectrum
- Multiplet splitting
- Electromagnetic transition strength
- One-neutron transfer reactions
- Two-nucleon transfer cross sections
- Pairing gaps

Mean field description: HFB





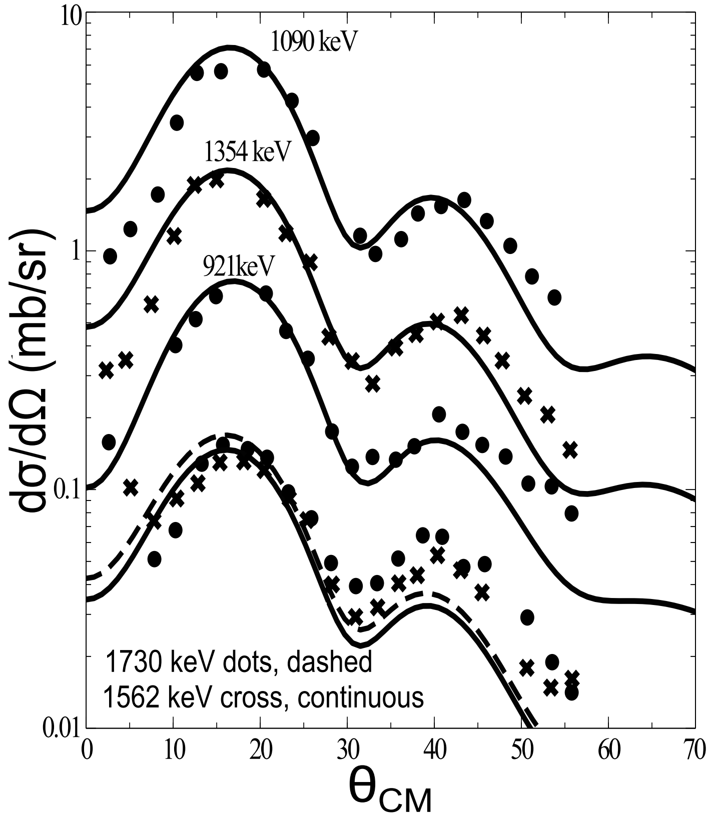




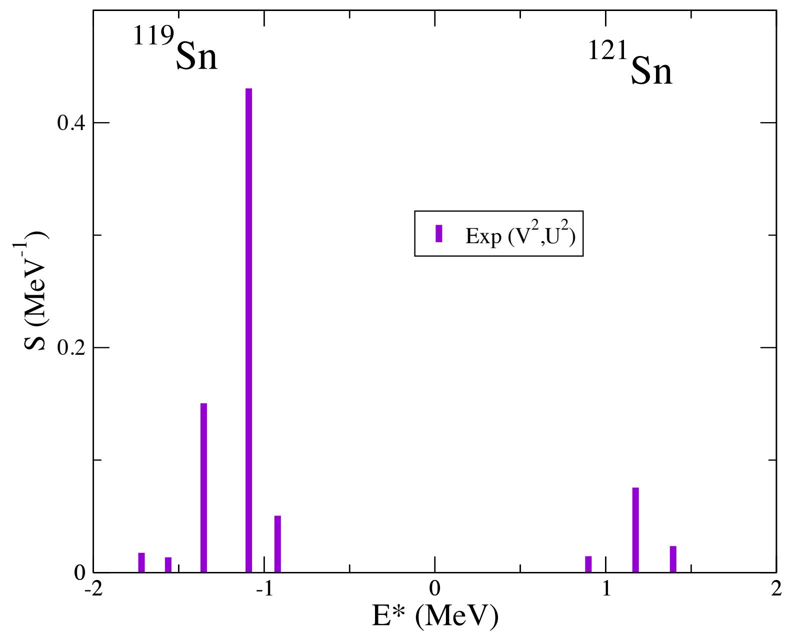
J. Dechargé and D. Gogny, PRC 21(1980)1568
J. Dobaczewski et al., PRC 53(1996)2809

Fragmented $d_{5/2}$ strength

^{120}Sn(p,d)^{119}Sn



Spectroscopic factors (DBWA)

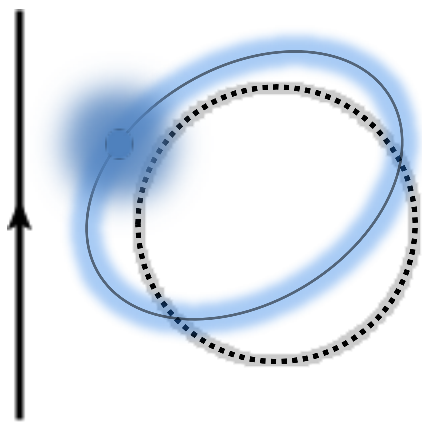


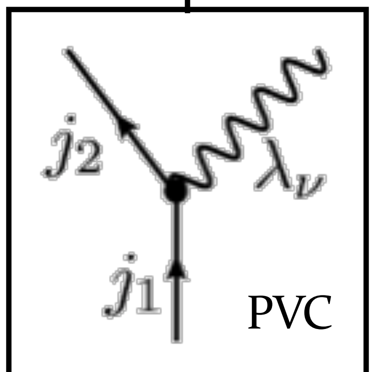
Elementary modes of excitation

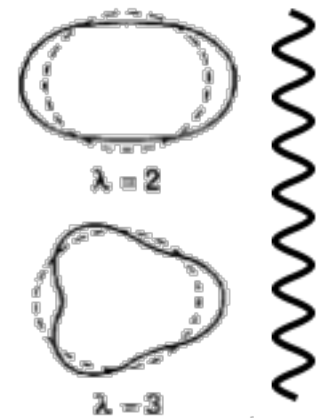
Independent Particle

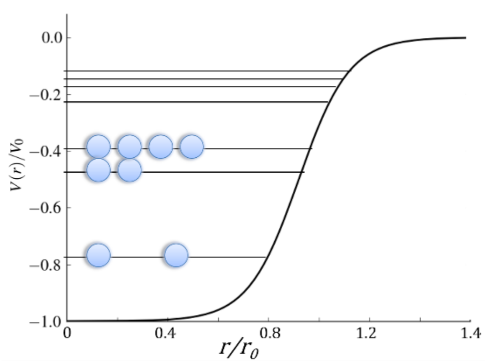
Collective Phonon

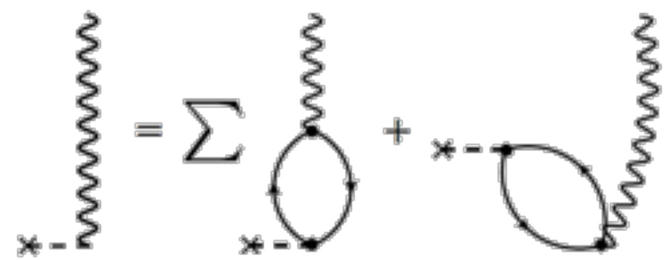
Particle-vibration coupling







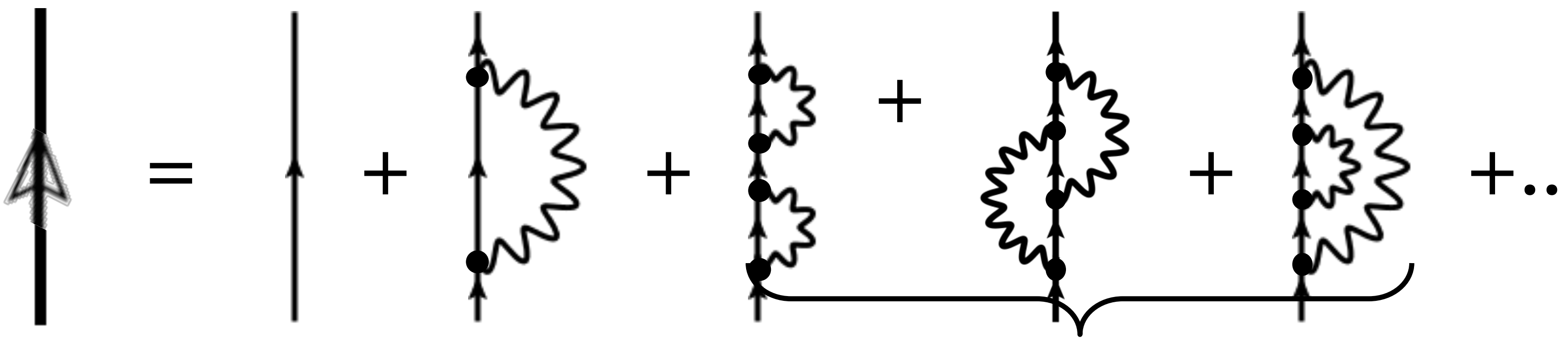




Hartree-Fock mean Field

Random Phase Approximation

Nuclear Field Theory Approach



I^{st} order II^{nd} order

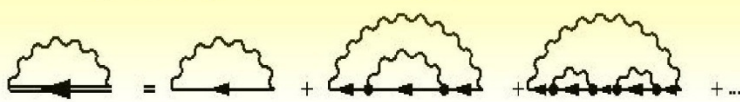
Green's function can consistently Particle-Vibration Couplings to the **infinite order**:

Microscopic description of superfluid nuclei beyond mean field: iterating the PVC with Nambu-Gor'kov formalism

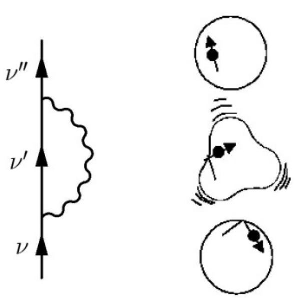
by extending the Dyson equation…

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

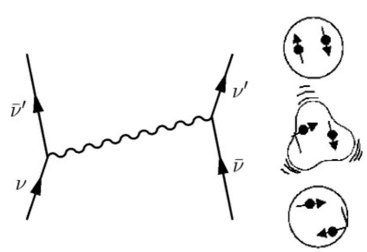
$$\Sigma_\mu(\omega)=\int_{-\infty}^{+\infty}\frac{d\omega'}{2\pi}\sum_{\mu'}\frac{1}{\hbar}G_{\mu'}(\omega')\sum_{\alpha}\frac{1}{\hbar}D^o_\alpha(\omega-\omega')*V^2_{\mu\mu',\alpha}$$



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



and



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

F. Barranco et al, EPJ A21 (2004) 57

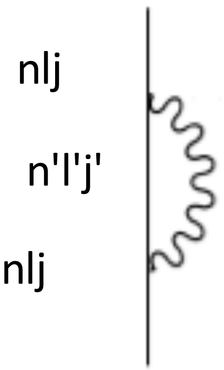
A. Idini et al. PRC 85 (2012) 014

cf. V. Soma' , C. Barbieri, T. Duguet,

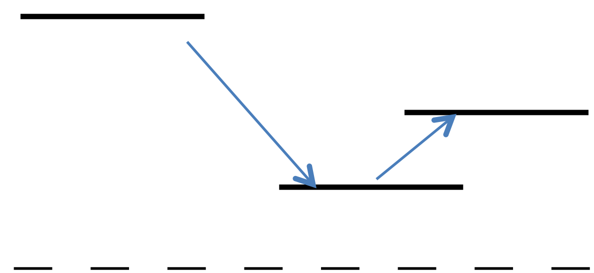
PRC **84** (2011) 064317 ;PRC87 (2013) 011303

Resume of s-p Self-energy

(A)

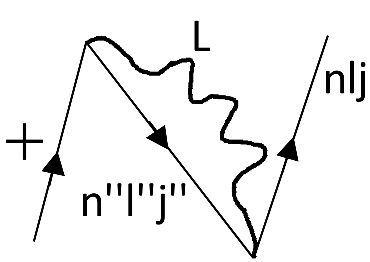


$$L = \frac{h^2(j,j',L)}{e_j - (e_{j'} + \hbar\omega_\lambda)} < 0$$



$+$

(B)



$$= \frac{h^2(j,j',L)}{(e_j - e_{j''} + \hbar\omega_\lambda)} > 0$$

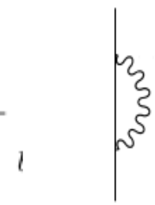
This is a kind of UNIVERSAL RESULT: Green Functions, Equations of Motion, in general
any many body theory based on sp picture

Renormalization of BCS quasiparticle energies and pairing gap

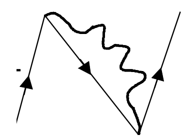
Van der Sluys et al., NPA551(1993)210
A. Idini et al., PRC 85 (2012) 014331

$$\begin{pmatrix} E_a + \Sigma_{11}(\tilde{E}_{a(n)}) & \Sigma_{12}(\tilde{E}_{a(n)}) \\ \Sigma_{12}(\tilde{E}_{a(n)}) & -E_a + \Sigma_{22}(\tilde{E}_{a(n)}) \end{pmatrix} \begin{pmatrix} x_{a(n)} \\ y_{a(n)} \end{pmatrix} = \tilde{E}_{a(n)} \begin{pmatrix} x_{a(n)} \\ y_{a(n)} \end{pmatrix}$$

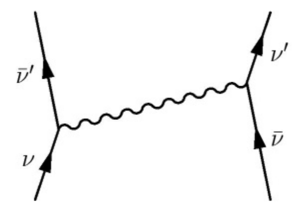
$$\Sigma_{11} = \sum_{b,m,J,\nu} \frac{V^2(a(n)b(m)J\nu)}{\tilde{E}_{a(n)} - \tilde{E}_{b(m)} - \hbar\omega_{J\nu}} +$$



$$\sum_{b,m,J,\nu} \frac{W^2(a(n)b(m)J\nu)}{\tilde{E}_{a(n)} + \tilde{E}_{b(m)} + \hbar\omega_{J\nu}}$$



$$\Sigma_{12}(\tilde{E}_{a(n)}) = -\sum_{b,m,J,\nu} V(a(n), b(m), J, \nu) W(a(n), b(m), J, \nu)$$
$$\left[\frac{1}{\tilde{E}_a(n) - \tilde{E}_b(m) - \hbar\omega_{J,\nu}} - \frac{1}{E_a(n) + \tilde{E}_b(m) + \hbar\omega_{J,\nu}} \right].$$

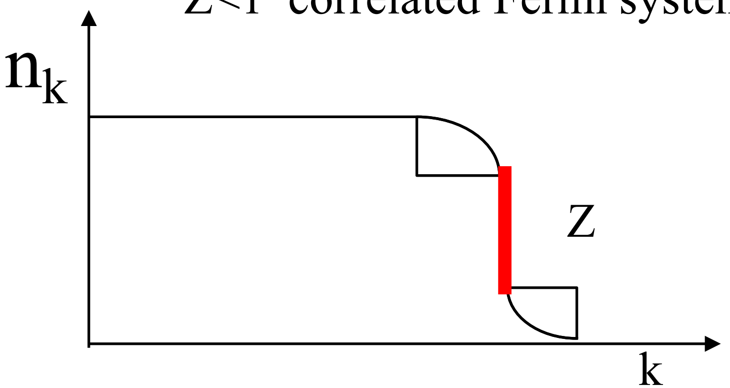


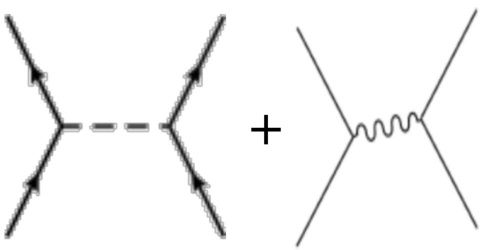
$$\begin{aligned} V(ab(m)\lambda\nu) &= \quad h(ab\lambda\nu)(u_a^{BCS}\tilde{u}_{b(m)} - v_a^{BCS}\tilde{v}_{b(m)}) \qquad \tilde{u}_{a(n)} = x_{a(n)}u_a^{BCS} - y_{a(n)}v_a^{BCS} \\ W(ab(m)\lambda\nu) &= \quad h(ab\lambda\nu)(u_a^{BCS}\tilde{v}_{b(m)} + v_a^{BCS}\tilde{u}_{b(m)}) \qquad \tilde{v}_{a(n)} = x_{a(n)}v_a^{BCS} + y_{a(n)}u_a^{BCS}, \end{aligned}$$

Generalized Gap Equation (schematic)

Z=1 free Fermi gas

Z<1 correlated Fermi system





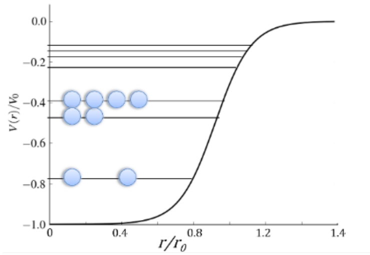
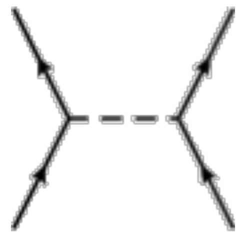
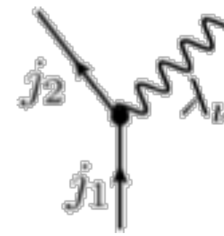
Quasiparticle strength <1

Bare+Induced interaction

$$\Delta_p = -\frac{1}{2}\int d^3p' \frac{Z_p V_{pp'} Z_{p'}}{\sqrt{(\tilde{\varepsilon}_{p'} - \varepsilon_F)^2 + \Delta_{p'}^2}} \Delta_{p'}$$

Renormalized s.p. energy

Three Parameters

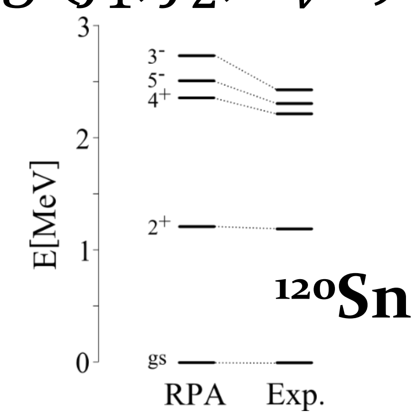
Hartree-Fock mean Field	Pairing Interaction	Particle Vibration Coupling Vertex
		
m_k	G	β_λ
Skyrme SLy4	Argonne v_{14}	$f(j_1, j_2, \lambda_\nu^\pi)$ $g(j_1, j_2, \lambda_\nu^\pi L)$

$m_k \approx 0.7m$

In ^{120}Sn with SLy4

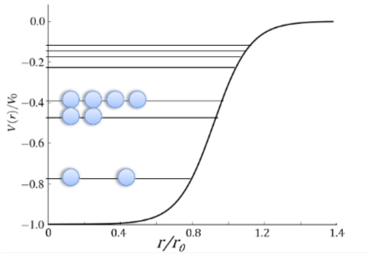
$\Delta^{v_{14}} \approx 1.1$ MeV

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

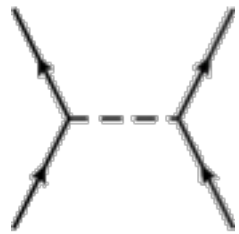


Tuning the parameters

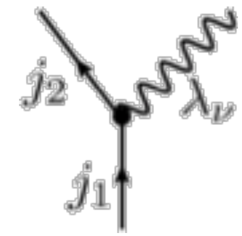
Hartree-Fock mean Field



Pairing Interaction



Particle Vibration Coupling Vertex

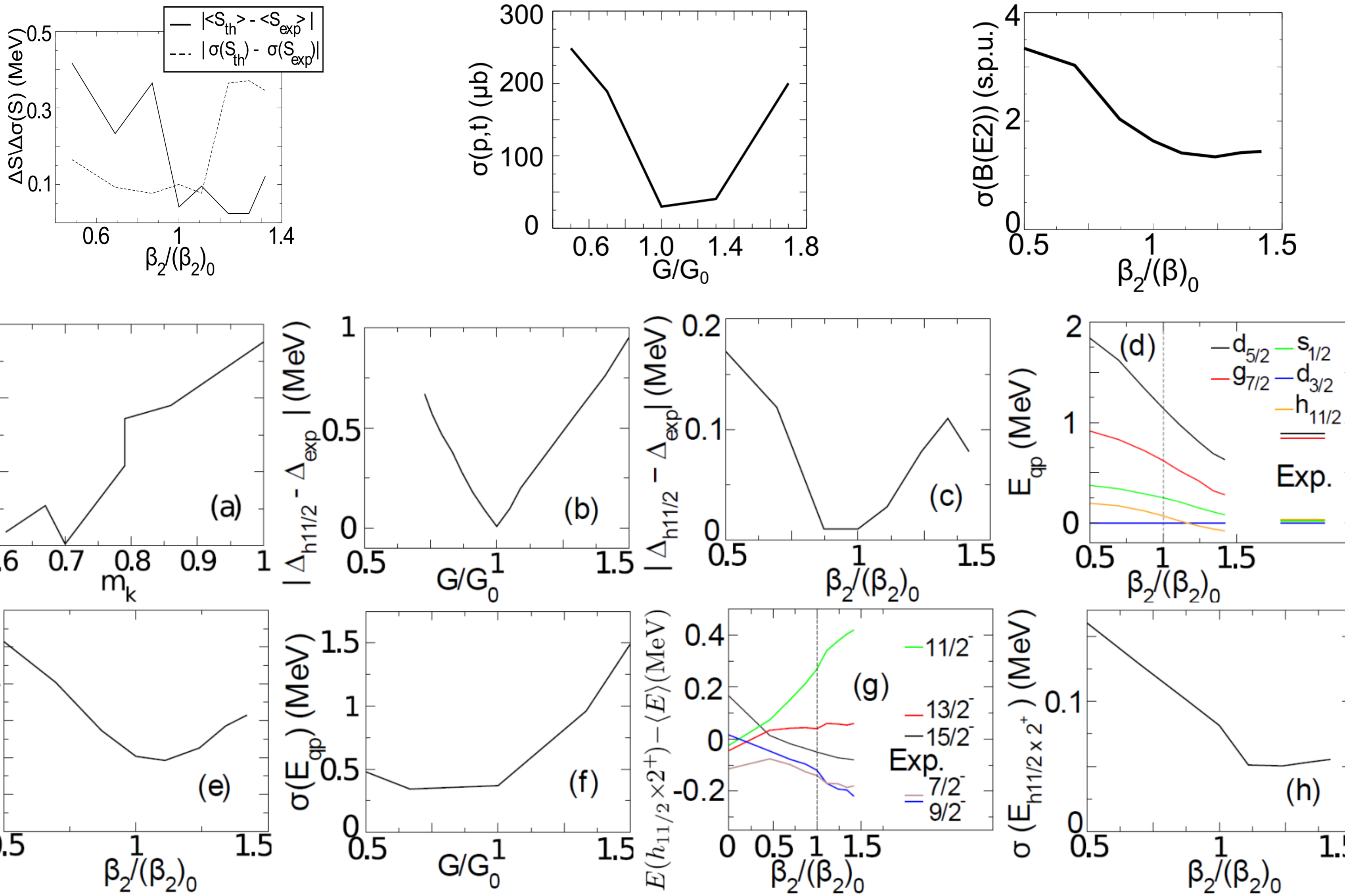


m_k

G

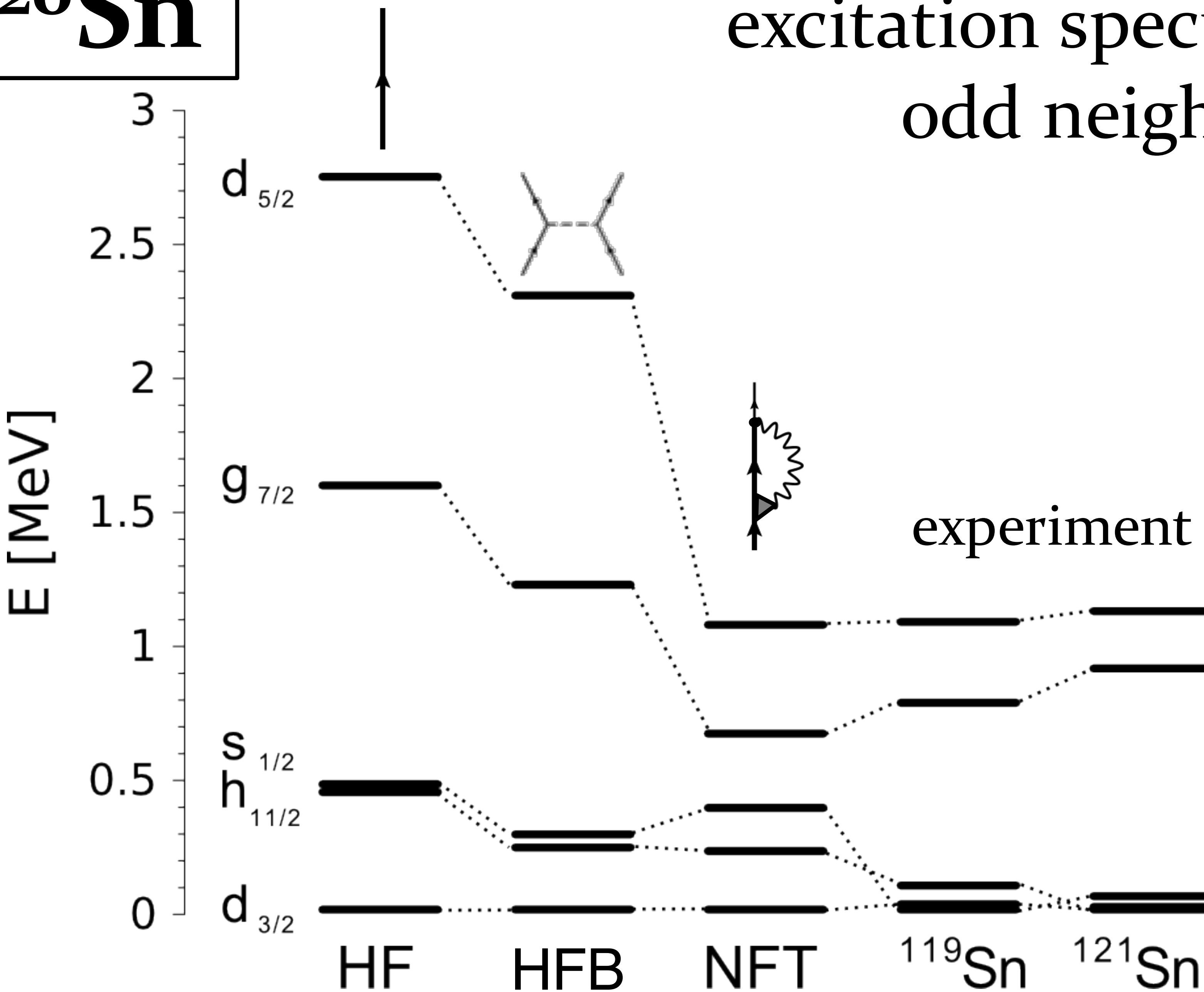
β_λ

$(\beta_2)_0 = 0.12 \quad G_0 = 0.22$ MeV $\quad m_k = 0.7$

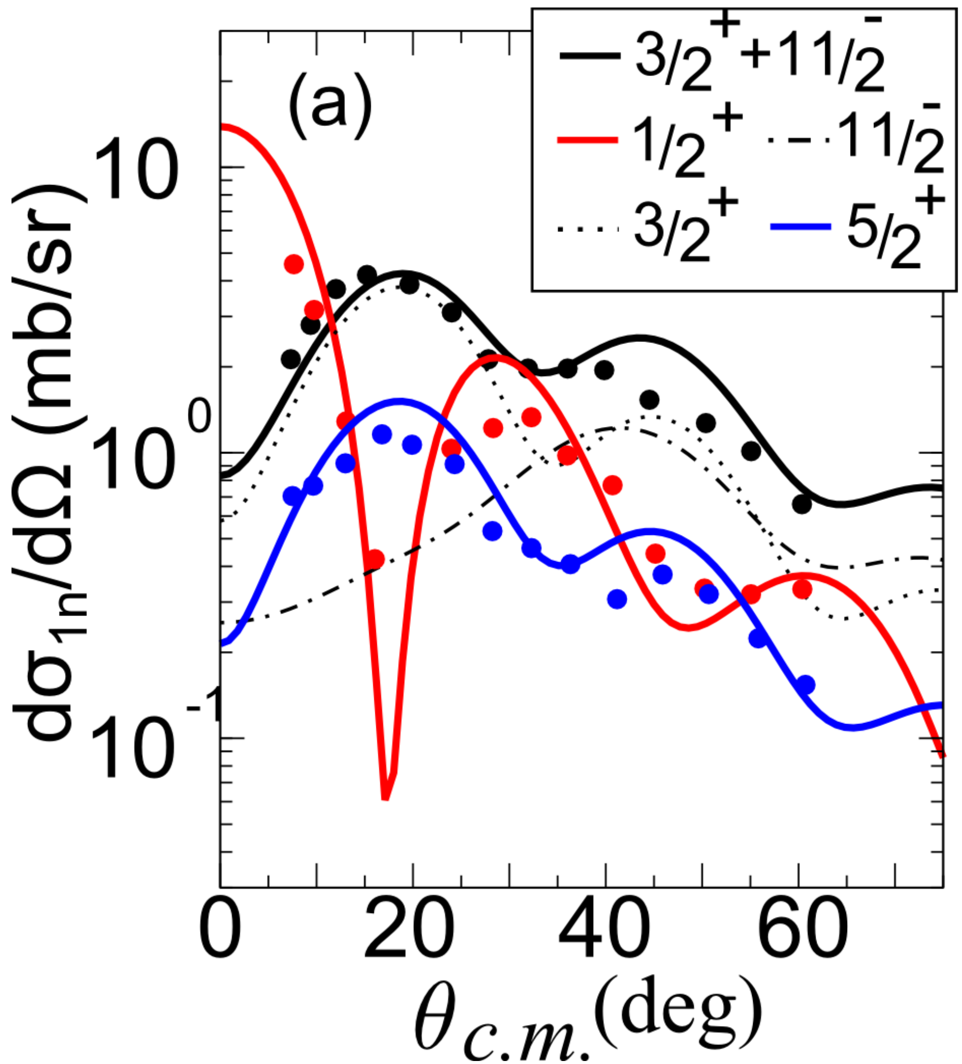


^{120}Sn

excitation spectrum odd neighbors

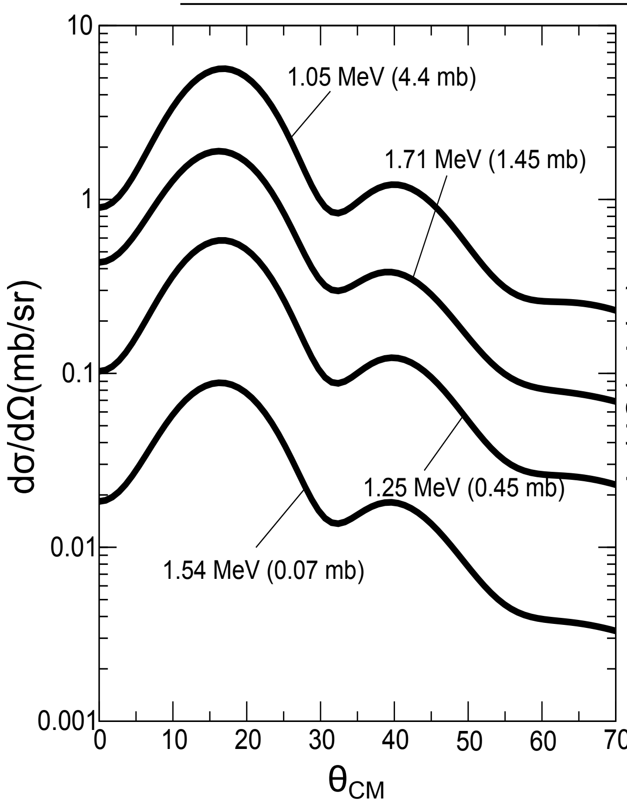


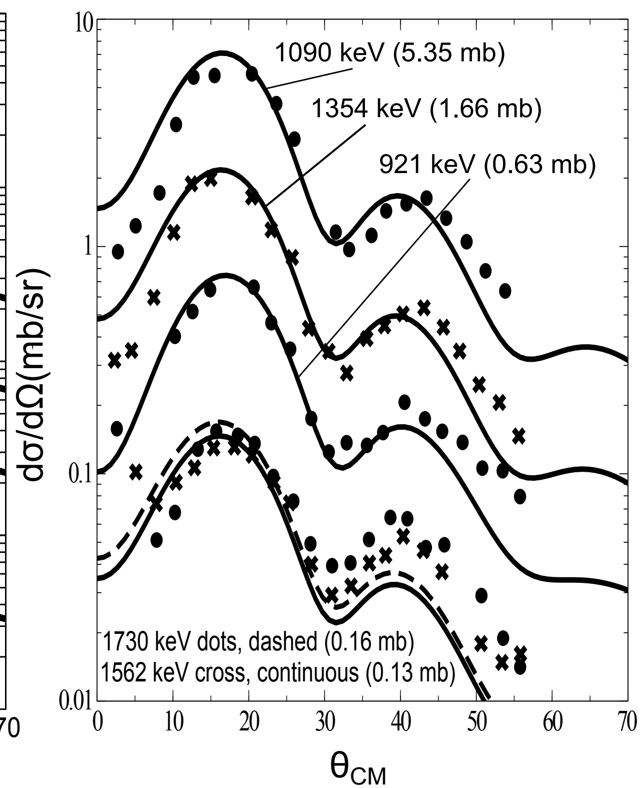
Transfer reactions: $^{120}Sn(d,p)^{121}Sn$



Transfer reactions: $^{120}Sn(p,d)^{119}Sn$ $(5/2^+)$

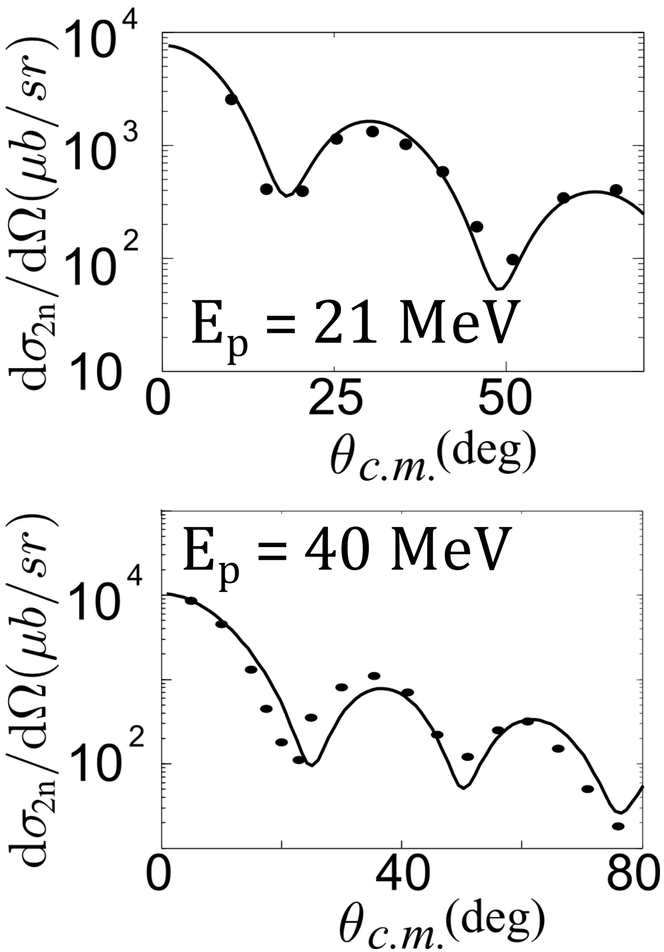
ϵ_i	Expt.		SLy4			SLy4 ($d_{5/2}$ shift)		
	σ	$d\sigma/d\Omega$	ϵ_i	σ	$d\sigma/d\Omega$	ϵ_i	σ	$d\sigma/d\Omega$
921	0.63	0.75						
1090	5.35	7.0	1150	1.80	2.3	1050	4.40	5.60
1354	1.66	2.3	1290	1.20	1.7	1250	0.45	0.58
1562	0.13	0.16	1710	0.25	0.32	1540	0.07	0.09
1730	0.16	0.18	1910	2.90	4.0	1710	1.45	1.90
	7.93 ± 2	10.39		6.15	8.32		6.37	8.17

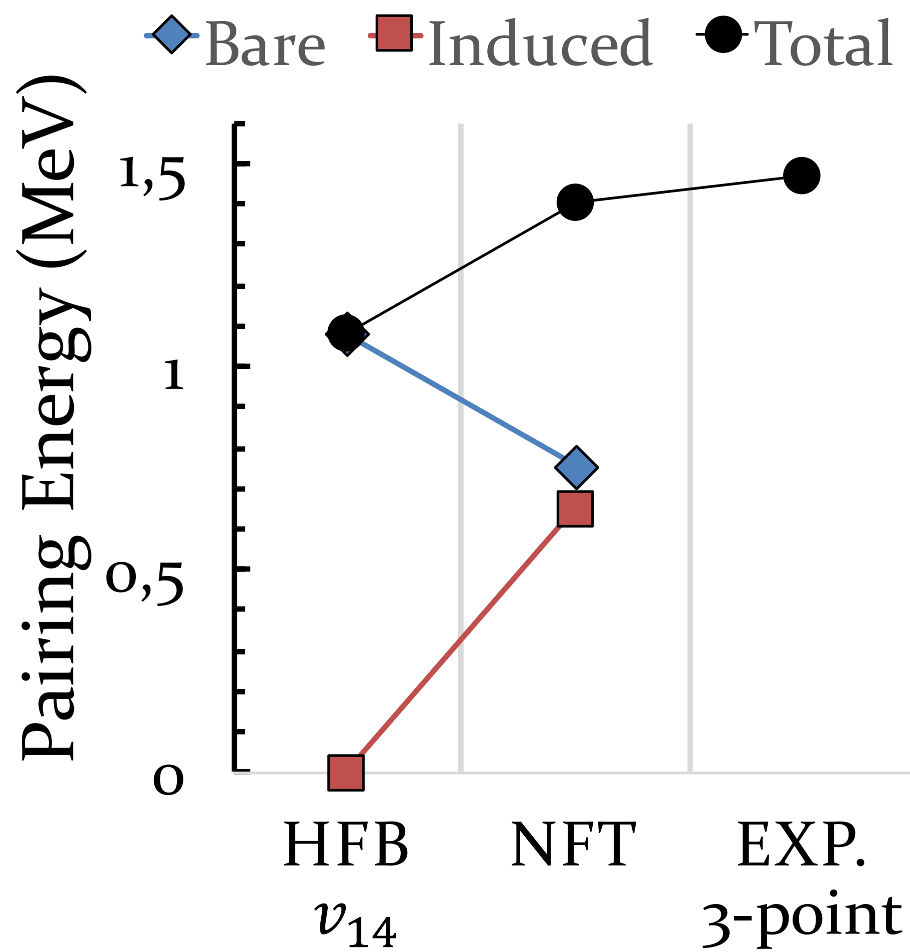




Pairing Properties

Two particle transfer cross section

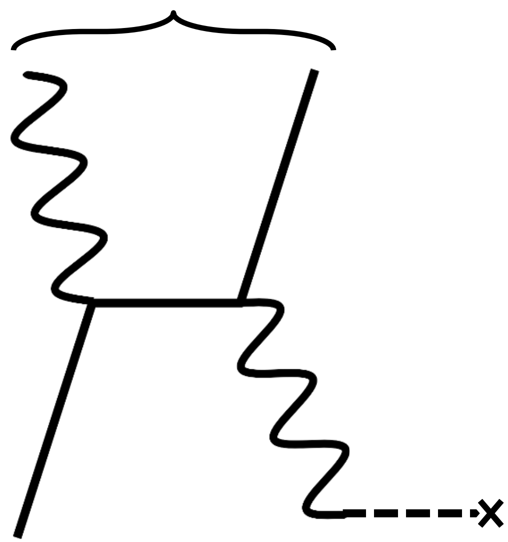




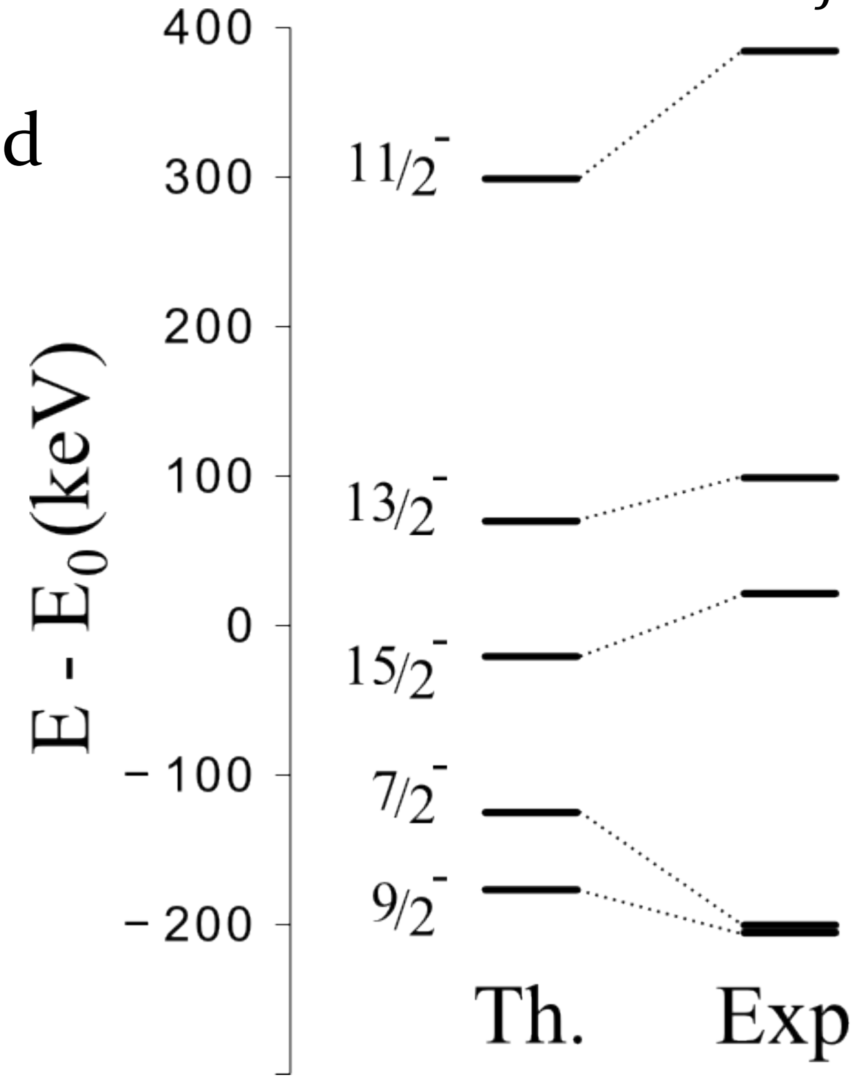
Multiplet Splitting

Elastic excitation of a quasiparticle state coupled to the core vibrations

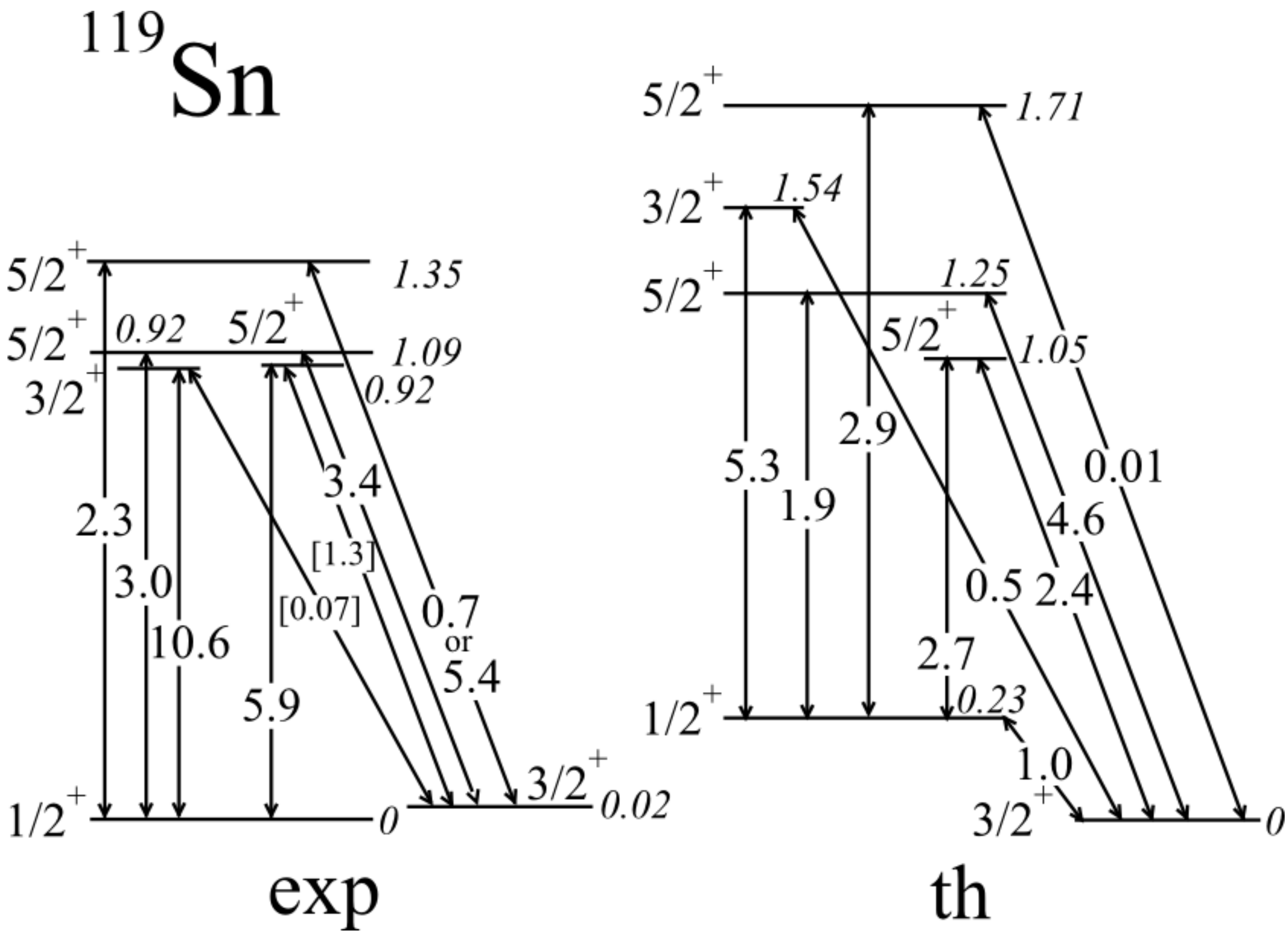
$(qp.\otimes \lambda^{\pi})_{j^{\pi'}}$



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



Electromagnetic Transitions



- 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 **within 10% error**.

Observables	SLy4	$d_{5/2}$ shifted	Opt. levels
Δ (keV)	10 (0.7%)	10 (0.7 %)	50 (3.5 %)
E_{qp} (keV)	190 (19%)	160 (16%)	45 (4.5 %)
Mult. splitt. (keV)	50 (7%)	70 (10%)	59 (8.4 %)
$d_{5/2}$ (centr.) (keV)	200 (20%)	40 (4%)	40 (4%)
$d_{5/2}$ (width) (keV)	160 (20%)	75 (9.3%)	8 (1%)
$B(E2)/B_{sp}$	1.4 (14%)	1.34 (13%)	1.43 (14%)
$\sigma_{2n}(p,t)$ (mb)	40 (2%)	40 (2%)	40 (2%)