Nuclear structure of ^{132}Sn neighbors across the N=82 shell closure

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Realistic shell-model calculations with two-body forces

$$H = \sum_i \varepsilon_i a_i^+ a_i + \frac{1}{4} \sum_{ijkl} \langle ij | V_{eff} | kl \rangle a_i^+ a_j^+ a_l a_k$$

V_{eff} derived from the free nucleon-nucleon potential

↓

Two main ingredients

- Nucleon-nucleon potential
- Many-body perturbative theory

L. Coraggio, A. Covello, A.Gargano, N.Itaco, T.T.S. Kuo, Prog. Part. Nucl. Phys. 62, 135 (2009)

- **Choice of the nucleon-nucleon potential**

CD-Bonn, Argonne V_{18} , Chiral potentials,…

all modern NN potentials fit equally well the deuteron properties and the NN scattering data up to the inelastic threshold

$\chi^2/N_{data} \sim 1$

these potentials cannot be used directly in the derivation of V_{eff} due to their strong short-range repulsion

⬇

Renormalization procedure is needed

Renormalization of the *NN* potential

V_{low-k} **approach:** **construction of a low-momentum *NN* potential V_{low-k} confined within a momentum-space cutoff $k \leq <$**

V_{low-k} from V_{NN} by integrating out its high-momentum components down to the cutoff momentum Λ

preserves the physics of the original V_{NN}:

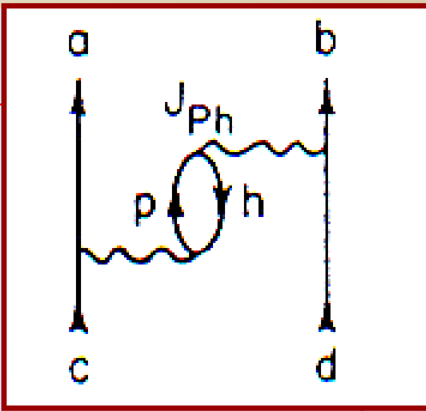
- the deuteron binding energy
- scattering phase-shifts up to the cutoff momentum Λ

S. Bogner,T.T.S. Kuo,L. Coraggio,A. Covello,N. Itaco, Phys. Rev C 65, 051301(R) (2002)
S. Bogner, T.T.S. Kuo, A. Schwenk, Phys. Rep. 386, 1 (2003)
L. Coraggio et al, Prog. Part. Nucl. Phys. 62 (2009) 135

Two-body effective interaction

derived by a many-body perturbation technique: "Q-box folded-diagram method"

In practical applications: diagrams first-, second-,(and third-) order with V_{low-k} in the interaction vertices



"Bubble"

V_{eff} defined

- in the nuclear medium
- in a subspace of the Hilbert space

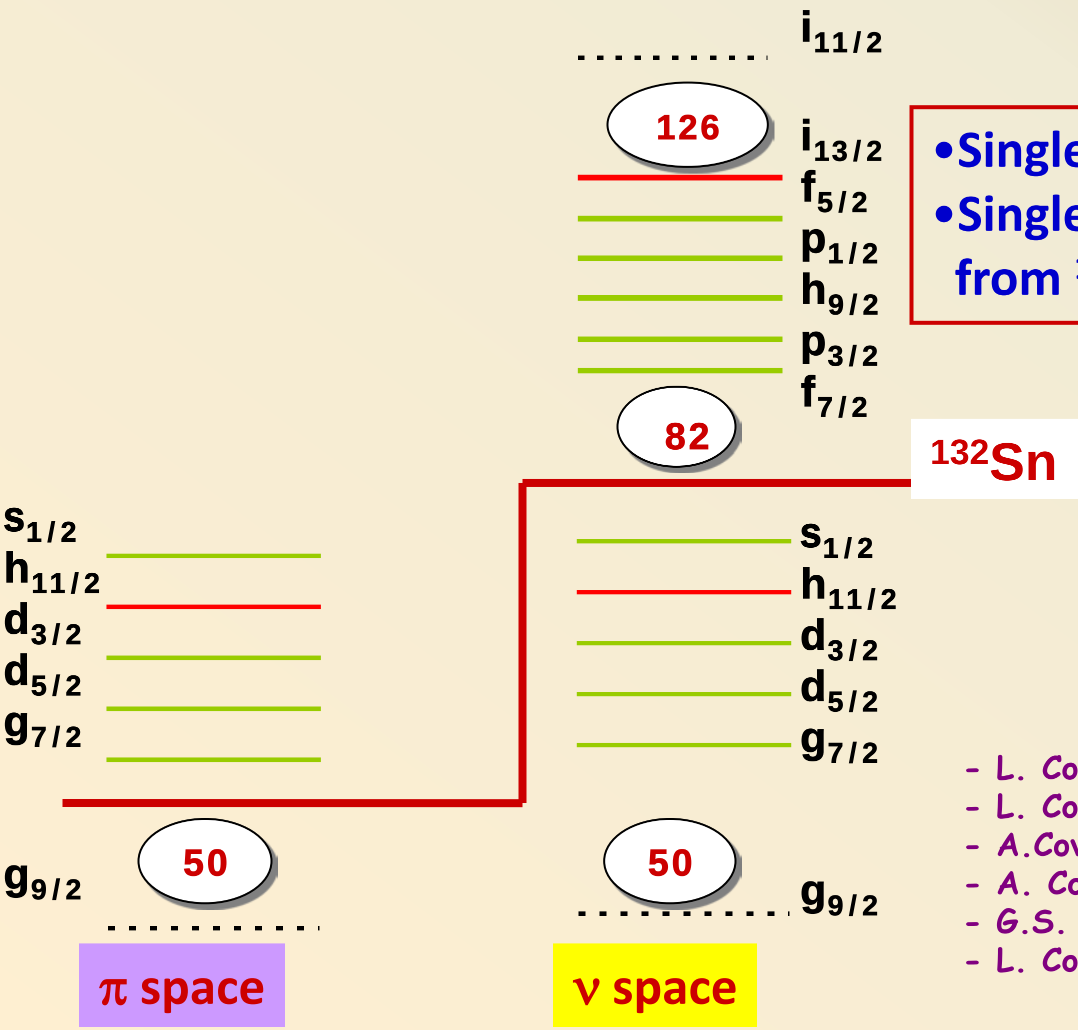
➔ accounts perturbatively for

- configurations beyond the chosen model space
- core polarization effects

^{132}Sn region

Shell-model calculations with two-body effective interaction derived from the CD-Bonn potential through the V_{low-k} approach

$\Lambda = 2.2\ fm^{-1}$



- Single-particle proton energies from ^{133}Sb
- Single-hole/particle neutron energies from ^{131}Sn/^{133}Sn

- L. Coraggio et al Phys. Rev. C 72, 057302 (2005)
- L. Coraggio et al Phys. Rev. C 73, 031302(R) (2006)
- A.Covello et al Prog. Part. Nucl. Phys. 59, 401 (2007)
- A. Covello et al Eur. Phys. J. ST 150, 93 (2007)
- G.S. Simpson et al Phys. Rev. C 76, 041303(R) (2007).
- L. Coraggio et al Phys. Rev. C 80, 061303(R) (2009).

Results

Quadrupole 2^+ mixed-symmetry states (MSS)

below and above the N=82 shell closure

$^{132}_{52}Te_{80}$ $^{136}_{52}Te_{84}$

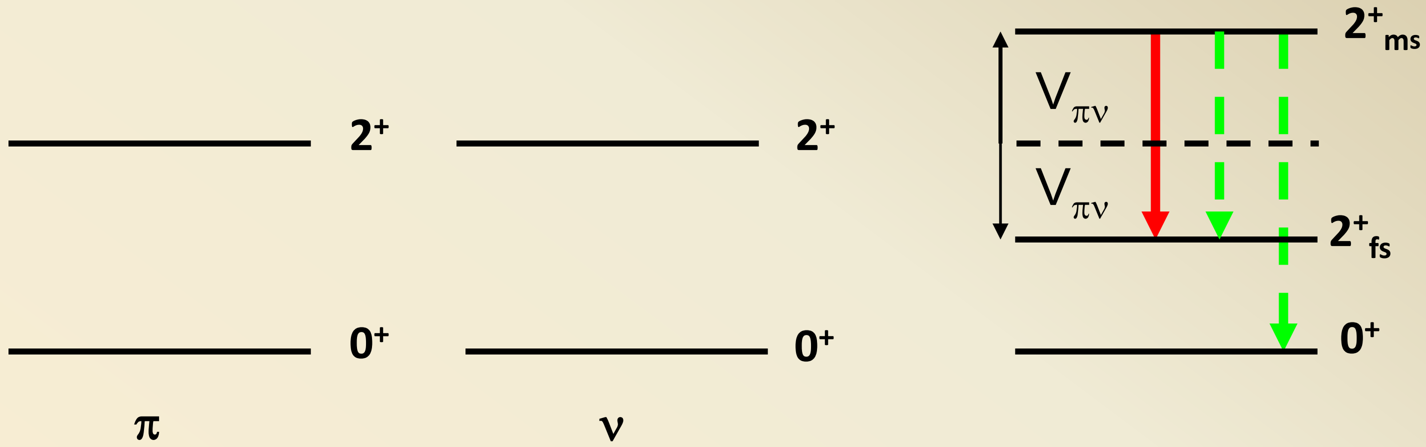
MSSs sensitive to the balance of the neutron and proton contributions

→ test for the different components of the effective interation

Mixed symmetry states

states not fully symmetric with respect the exchange of proton and neutron pairs

A two-state model

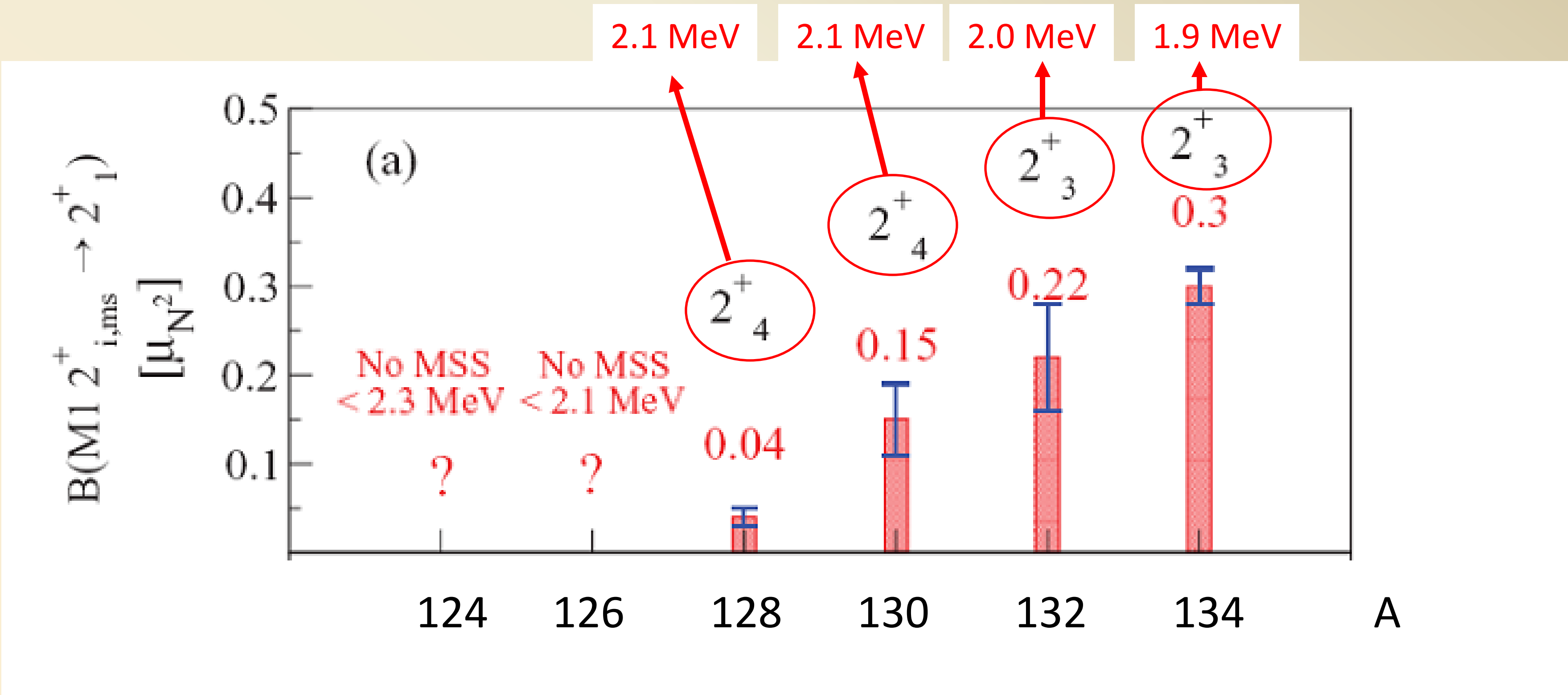


$\left\|2^+_{fs}\right\rangle = \frac{1}{\sqrt{2}}\left[\left\|0^+(\pi)\right\rangle\left\|2^+(\nu)\right\rangle + \left\|0^+(\nu)\right\rangle\left\|2^+(\pi)\right\rangle\right]$	Fully-symmetry state
$\left\|2^+_{ms}\right\rangle = \frac{1}{\sqrt{2}}\left[\left\|0^+(\pi)\right\rangle\left\|2^+(\nu)\right\rangle - \left\|0^+(\nu)\right\rangle\left\|2^+(\pi)\right\rangle\right]$	Mixed-symmetry state

Signatures of the MS 2^+ state:

- ♦ strong M1 to 2^+_{fs} due the strong isovector part of the M1 transition
- ♦ weak E2 to 0^+ and to 2^+_{fs} due to the partial cancellation of the neutron and proton contributions

Xe isotopes

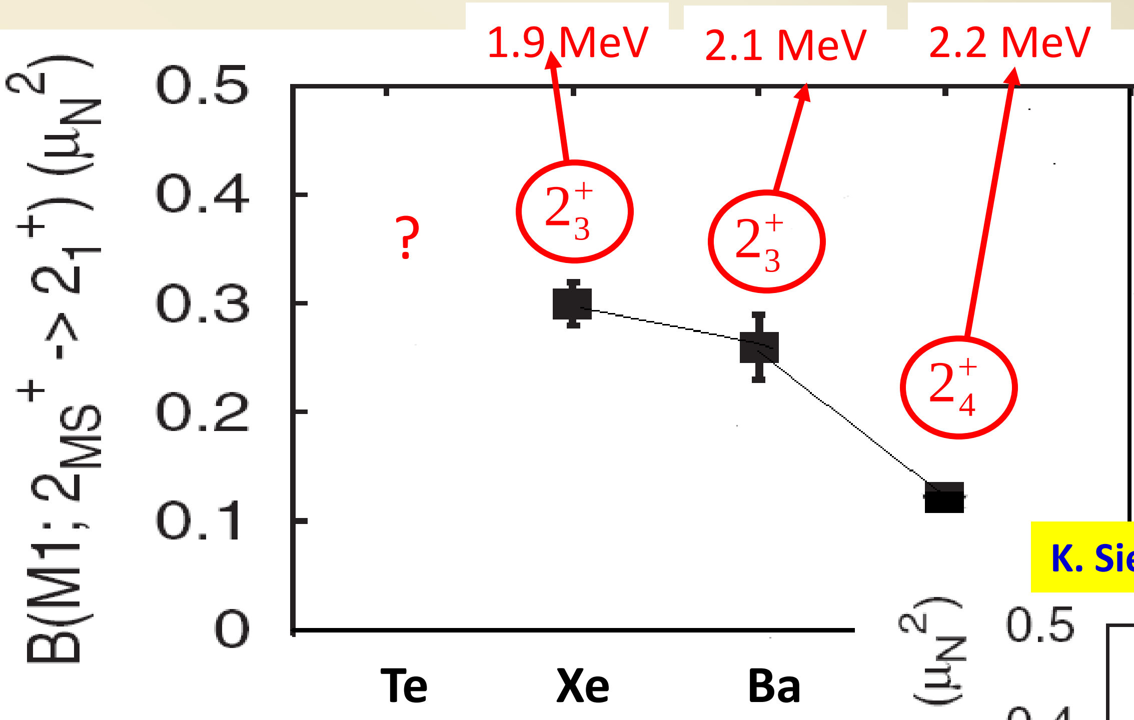


MSSs disappear when moving far from closed shell

… or rise in energy beyond the sensitivity of the experiment?

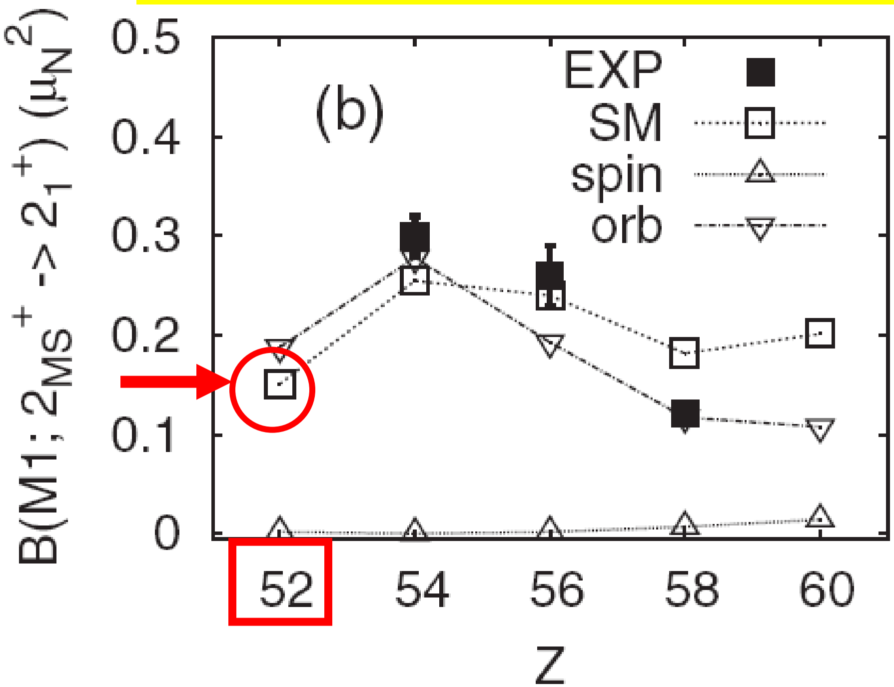
L. Coquard, N. Pietralla et al, Phys. Rev. C 82, 021317 (2010)

N=80 isotones



T. Ahn et al, Phys Lett B 679, 19 (2009)

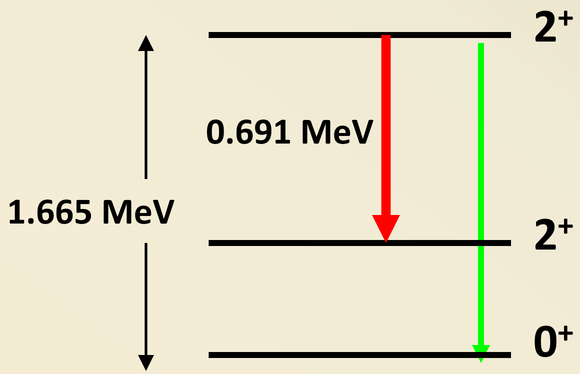
K. Sieja et al, Phys Rev. C 80, 054311 (2009)



^{132}Te

Coulex on carbon target @ ORNL with CLARION+ Hyball

to be published
M. Danchev et al



$$B(M1; 2_2^+ \rightarrow 2_1^+) = 3.8(24)\ \mu_N^2$$

$$B(M1; 2_2^+ \rightarrow 2_1^+) > 0.15\ \mu_N^2$$

$$B(E2;\ 2_2^+ \rightarrow 0_1^+) = 0.35(13)\ \text{W.u.}$$

Shell-model results for ^{132}Te

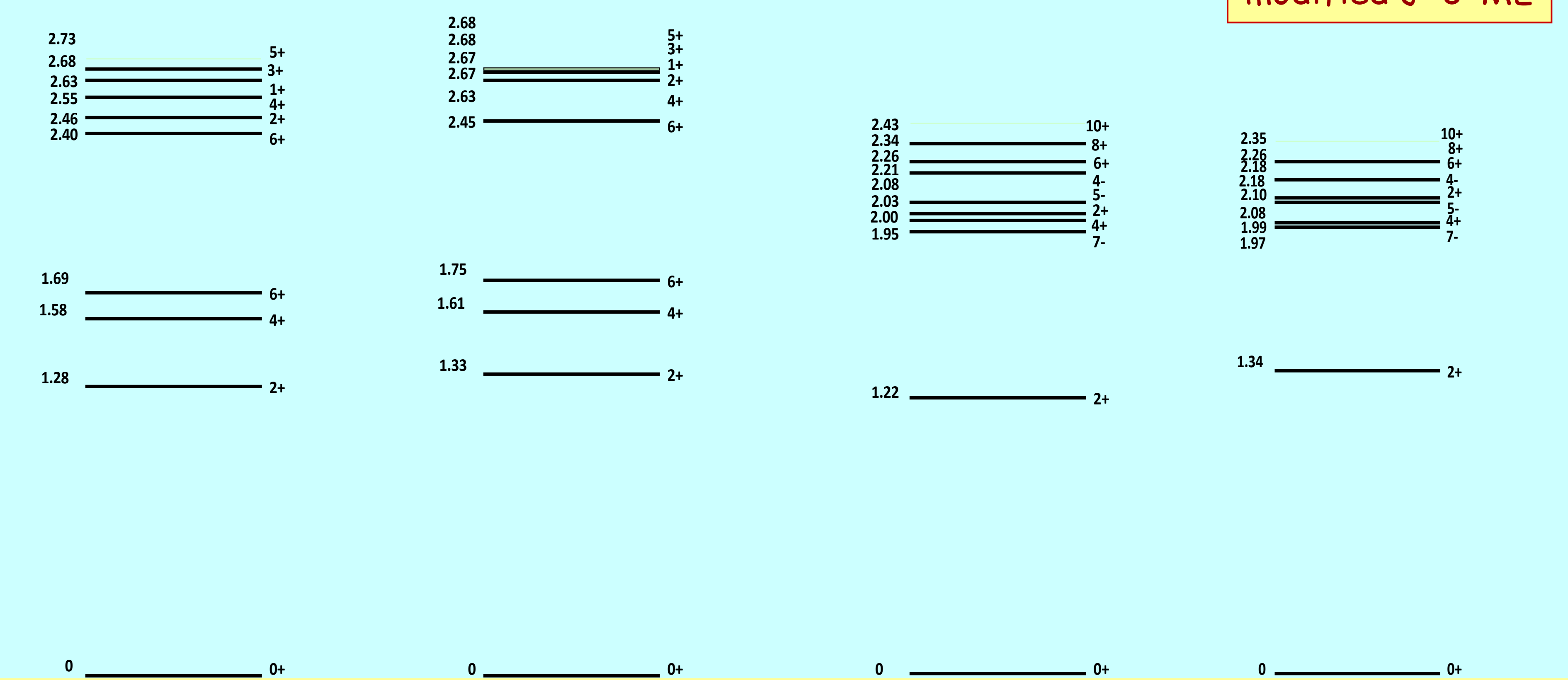
^{132}Te → ^{132}Sn

$+ 2\pi \equiv {}^{134}$Te

$- 2\nu \equiv {}^{130}$Sn

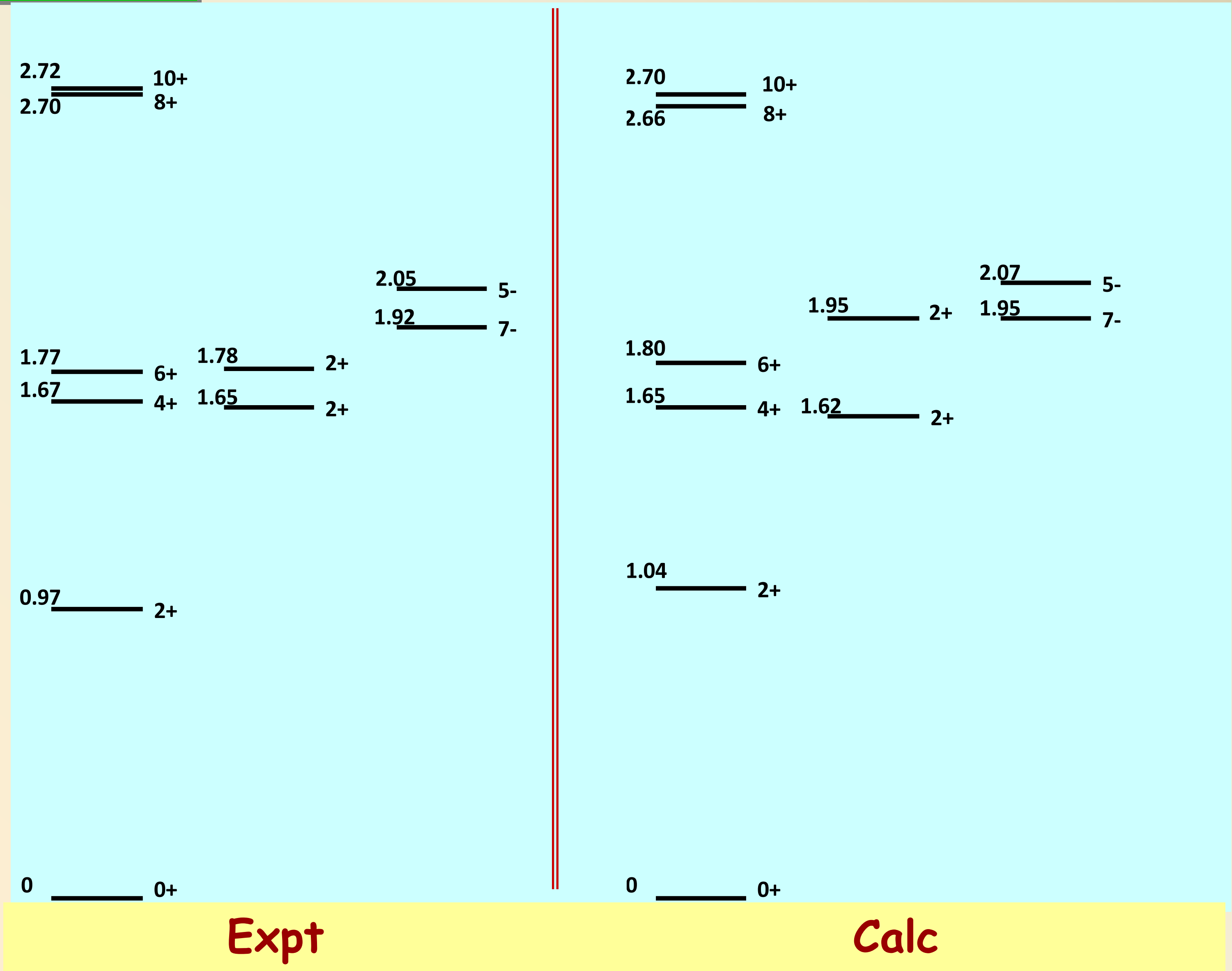
^{134}Te ^{130}Sn

modified J=0$^+$ ME



Expt   Calc   Expt   Calc

132Te



2.72
10+
2.70
8+
2.05
5-
1.92
7-
1.77
6+
1.67
4+
1.78
2+
1.65
2+
0.97
2+
0
0+
2.70
10+
2.66
8+
2.07
5-
1.95
2+
1.95
7-
1.80
6+
1.65
4+
1.62
2+
1.04
2+
0
0+
Expt
Calc

Decay properties for ^{132}Te

	Expt	Calc
B(E2; $2^+_1 \rightarrow 0^+_1$) in W.u.	8.6(9)■	7.8
μ(2^+_1) in μ_N	0.70(10)* 0.56(30)●	0.7
B(E2; $2^+_2 \rightarrow 0^+_1$) in W.u.	0.35(13)	0.21
B(E2; $2^+_2 \rightarrow 2^+_1$) in W.u.	-	0.24
B(M1; $2^+_2 \rightarrow 2^+_1$) in μ^2_N	3.8(24) >0.15	0.20

$e_\pi = 1.7e$; $e_\nu = 0.7e$

by reproducing E2 in ^{134}Te and ^{130}Sn

g_l^π ; g_l^ν free proton and neutron g_l factors

g_s^π ; g_s^ν $0.7 \times$ free proton and neutron g_s factors

from magnetic moments of 6_1^+ states in ^{134}Te

■D.C. Radford et al, Phys Rev. Lett. 88, 222501 (2002)

●N. Benczer-Koller et al, Phys. Lerr. B 664, 241 (2008)

*N.j. Stone et al, Phys Rev. Lett. 94, 192501(2005)

Wave functions ^{132}Te

$$\left|0^+_{gs}\right\rangle = 0.94\left|{}^{134}\mathrm{Te};0^+_{gs}\right\rangle\left|{}^{130}\mathrm{Sn};0^+_{gs}\right\rangle + \cdots$$

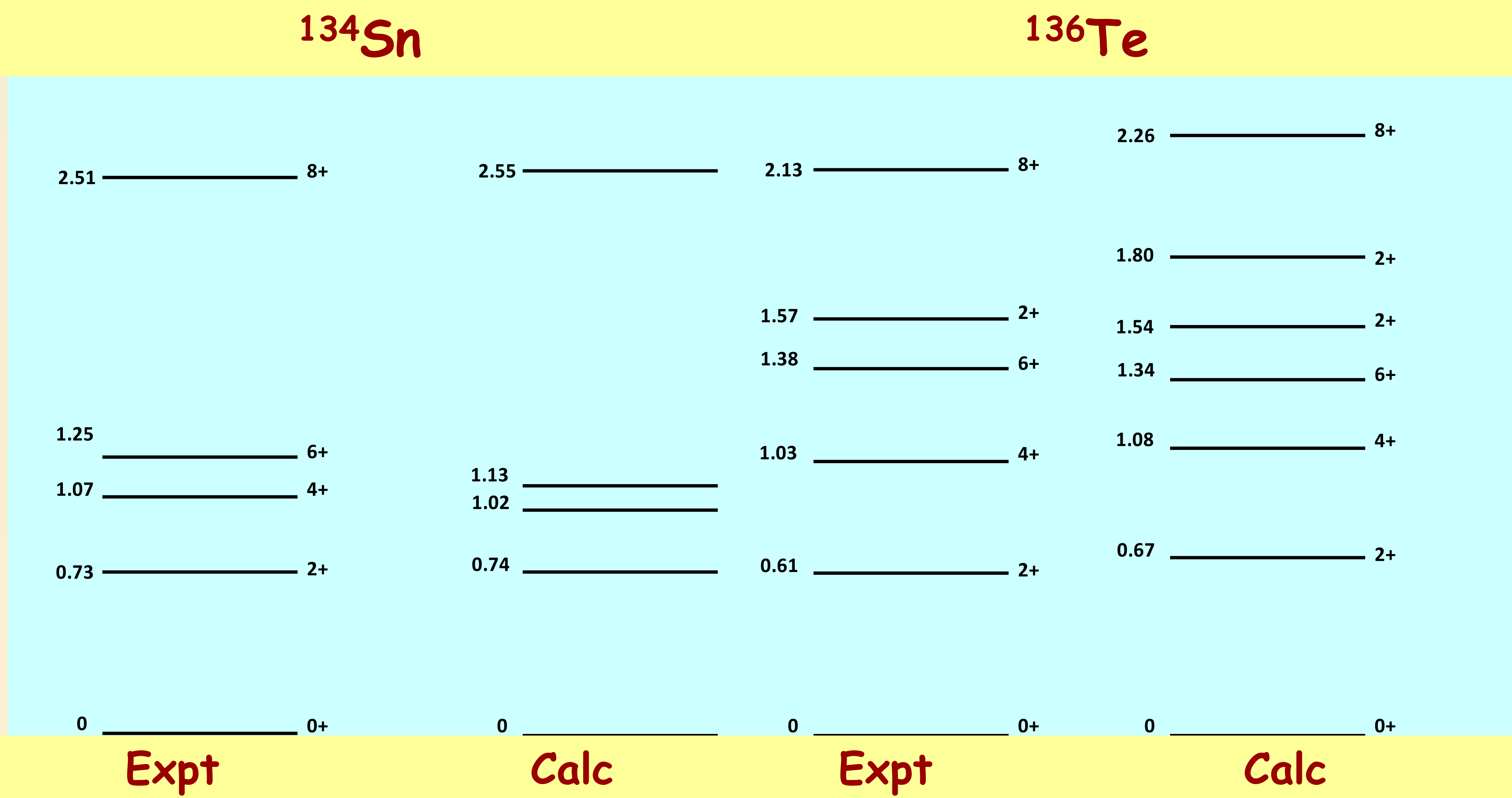
$$\left|2^+_1\right\rangle = 0.66\left|{}^{134}\mathrm{Te};2^+_1\right\rangle\left|{}^{130}\mathrm{Sn};0^+_{gs}\right\rangle + 0.62\left|{}^{134}\mathrm{Te};0^+_{gs}\right\rangle\left|{}^{130}\mathrm{Sn};2^+_1\right\rangle + \cdots$$

$$\left|2^+_2\right\rangle = 0.58\left|{}^{134}\mathrm{Te};2^+_1\right\rangle\left|{}^{130}\mathrm{Sn};0^+_{gs}\right\rangle - 0.63\left|{}^{134}\mathrm{Te};0^+_{gs}\right\rangle\left|{}^{130}\mathrm{Sn};2^+_1\right\rangle + \cdots$$

Shell-model results for ^{136}Te

^{136}Te → ^{132}Sn $+ 2\pi \equiv$ ^{134}Te

$+ 2\nu \equiv$ ^{134}Sn



Decay properties for ^{136}Te

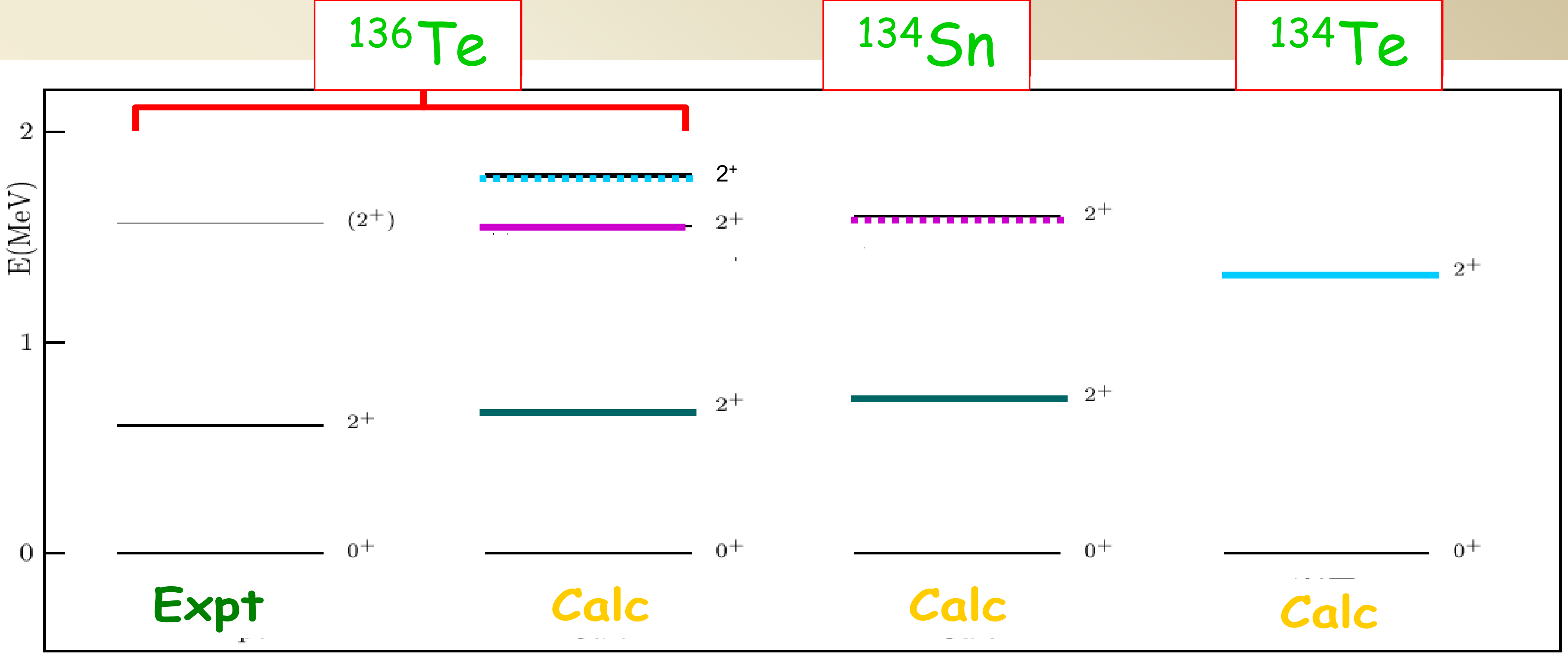
	Expt	Calc
B(E2; $2^+_1 \rightarrow 0^+_{gs}$) in W.u.	5(1) *	9.9
B(E2; $2^+_2 \rightarrow 0^+_{gs}$) in W.u.	-	0.67
B(E2; $2^+_3 \rightarrow 0^+_{gs}$) in W.u.	-	1.04
B(E2; $2^+_2 \rightarrow 2^+_1$) in W.u.	-	9.6
B(E2; $2^+_3 \rightarrow 2^+_1$) in W.u.	-	1.4
B(M1; $2^+_2 \rightarrow 2^+_1$) in μ^2_N	-	0.19
B(M1; $2^+_3 \rightarrow 2^+_1$) in μ^2_N	-	0.18

$e_\pi = 1.7e$; $e_\nu = 0.7e$

g_l^π ; g_l^ν free proton and neutron g_l factors

g_s^π ; g_s^ν 0.7 × free proton and neutron g_s factors

*New preliminary measurement about 50% higher



$$\left|0^+_{gs}\right\rangle = 0.85\left|{}^{134}\mathrm{Te}; 0^+_{gs}\right\rangle\left|{}^{134}\mathrm{Sn}; 0^+_{gs}\right\rangle + \cdots$$

$$\left|2^+_1\right\rangle = 0.72\left|{}^{134}\mathrm{Te}; 0^+_{gs}\right\rangle\left|{}^{134}\mathrm{Sn}; 2^+_1\right\rangle + 0.36\left|{}^{134}\mathrm{Te}; 2^+_1\right\rangle\left|{}^{134}\mathrm{Sn}; 0^+_{gs}\right\rangle + \cdots$$

$$\left|2^+_2\right\rangle = 0.42\left|{}^{134}\mathrm{Te}; 0^+_{gs}\right\rangle\left|{}^{134}\mathrm{Sn}; 2^+_1\right\rangle + 0.60\left|{}^{134}\mathrm{Te}; 0^+_{gs}\right\rangle\left|{}^{134}\mathrm{Sn}; 2^+_2\right\rangle + \cdots$$

$$\left|2^+_3\right\rangle = 0.31\left|{}^{134}\mathrm{Te}; 0^+_{gs}\right\rangle\left|{}^{134}\mathrm{Sn}; 2^+_1\right\rangle - 0.78\left|{}^{134}\mathrm{Te}; 2^+_1\right\rangle\left|{}^{134}\mathrm{Sn}; 0^+_{gs}\right\rangle + \cdots$$

^{132}Te versus ^{136}Te

2 proton particles in the 50-82 shell with $\Delta = E_{exc}(2^+_1) = 1.28$ MeV

2 neutron holes in the 50-82 shell

$\Delta = E_{exc}(2^+_1) = 1.22$ MeV

$< \nu(h_{11/2})^{-2}\, 0^+ \,|V_{eff}|\, \nu(h_{11/2})^{-2}\, 0^+ >= -1.15$ MeV

2 neutron particles in the 82-126 shell

$\Delta = E_{exc}(2^+_1) = 0.73$ MeV

$< \nu(f_{7/2})^{2}\, 0^+ \,|V_{eff}|\, \nu(f_{7/2})^{2}\, 0^+ >= -0.65$ MeV

different contributions of the one particle-one hole excitations ("bubble" diagram) to the effective interaction of two neutrons below and above the *N* = 82 shell,

responsible for the increase/decrease of pairing below /above this shell

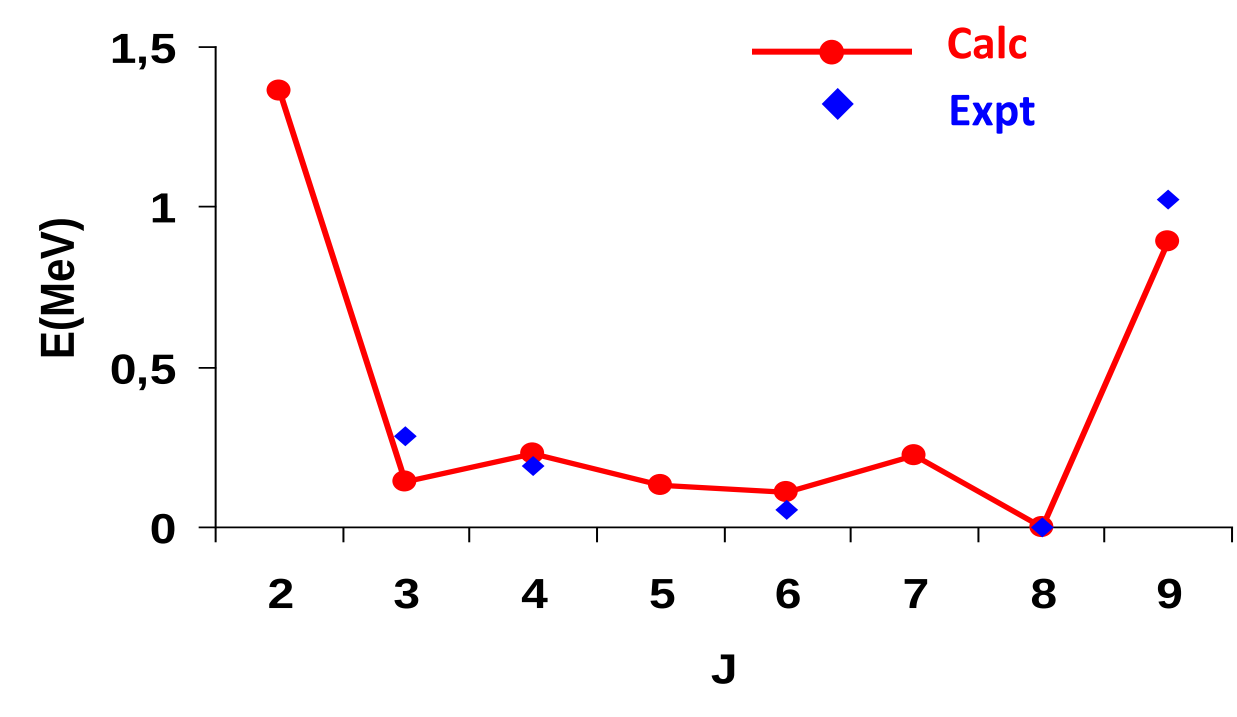
What about neutron-proton interaction ?

$$\overline{V}(\pi g_{7/2} \nu h^{-1}_{11/2}) \approx 0.9 \text{ MeV}$$

$$\overline{V}(\pi g_{7/2} \nu f_{7/2}) \approx -0.2 \text{ MeV}$$

$$\overline{V}(j_1 j_2) = \frac{\sum_J (2J+1) \langle j_1 j_2; J | V_{eff} | j_1 j_2; J \rangle}{\sum_j (2J+1)}$$

Monopole coefficient

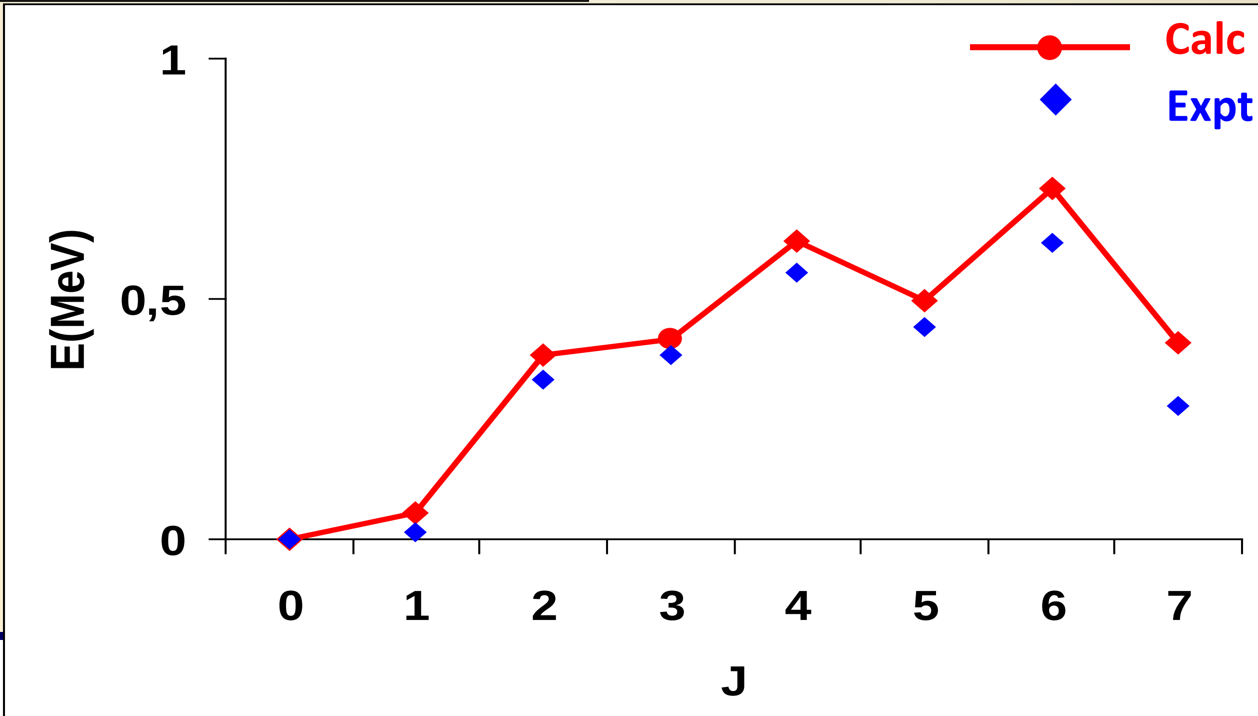


$^{132}_{51}Sb_{81}$

$\pi g_{7/2}\nu(h_{11/2})^{-1}$

$^{134}_{51}Sb_{83}$

$\pi g_{7/2}\nu f_{7/2}$



Summary

- **Mixed-symmetry states** are highly sensitive to the balance between the proton and neutron components ➔ they give specific information on the two-body effective interaction (ππ, νν, πν forces)

➔ **the identification of MSSs in exotic nuclei is of key importance**

- Realistic shell-model calculations are a reliable tool for shell structure studies in ^{132}Sn region, **in particular, they seem to properly describe the changes across the N=82 closure**

➔ **appropriate for the description of MSSs**

- **New and more accurate data as well a futher shell-model studies are needed**