Coulomb excitation of nuclei around ^{132}Sn

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Second SPES One-day Workshop: Coulomb excitation with RiBs

Firenze, September 27-28, 2012

Outline

- Physics cases
- Theoretical framework
- Results
- Conclusions

Region of interest

Z\N	76	78	80	82	84	86
50	^{126}Sn	^{128}Sn	^{130}Sn	^{132}Sn	^{134}Sn	^{136}Sn
51	^{127}Sb	^{129}Sb	^{131}Sb	^{133}Sb	^{135}Sb	^{137}Sb
52	^{128}Te	^{130}Te	^{132}Te	^{134}Te	^{136}Te	^{138}Te

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Data from CE experiments @HRIBF

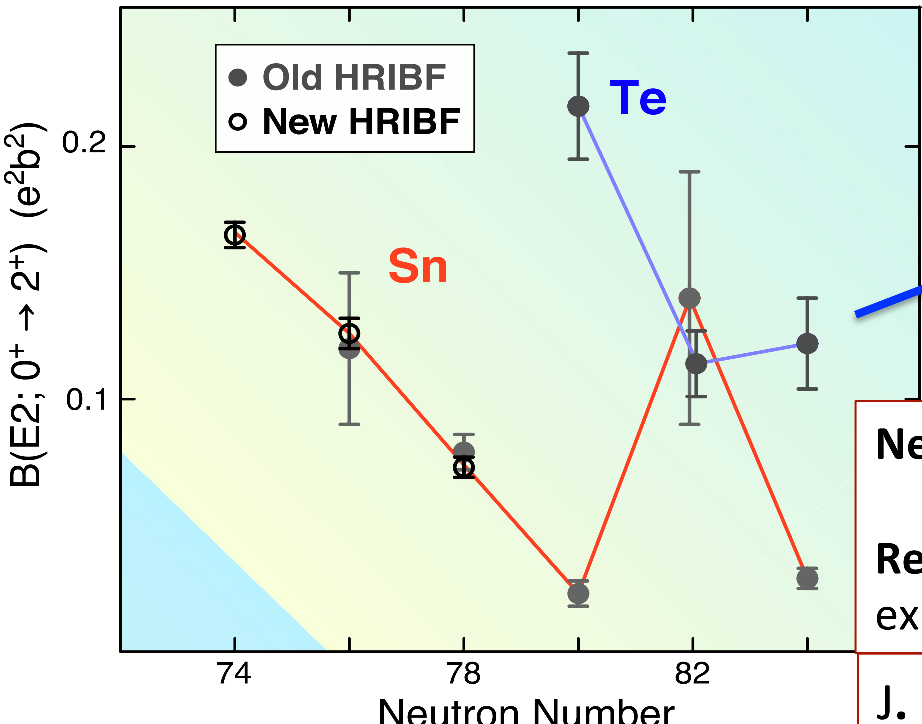
Pioneering CE experiments with RIBs in inverse kinematics @ HRIBF

VOLUME 88, NUMBER 22 PHYSICAL REVIEW LETTERS 3 JUNE 2002

Coulomb Excitation of Radioactive ^{132,134,136}Te Beams and the Low $B(E2)$ of ^{136}Te

D. C. Radford,[1] C. Baktash,[1] J. R. Beene,[1] B. Fuentes,[1,2] A. Galindo-Uribarri,[1] C. J. Gross,[1,3] P. A. Hausladen,[1] T. A. Lewis,[1] P. E. Mueller,[1] E. Padilla,[1,4] D. Shapira,[1] D. W. Stracener,[1] C.-H. Yu,[1] C. J. Barton,[5] M. A. Caprio,[5] L. Coraggio,[6] A. Covello,[6] A. Gargano,[6] D. J. Hartley,[7] and N. V. Zamfir[5,8]

E(2$^+$) and B(E2; 2$^+$→0$^+$) for ^{124,126,128,130,132,134}Sn & ^{132,134,136}Te



puzzling result for ^{136}Te B(E2) and E(2$^+$) decrease by about 40% across N=82

New HRIBF for Sn: new measurements with improved statistics

Results for Te: from a reanalysis of previous experiments

J. R. Beene et al, J. P. G 38, 024002 (2011)

Quadrupole moments in ^{124,126,128}Sn by CE

PHYSICAL REVIEW C **84**, 061303(R) (2011)

Coulomb excitation of ^{124,126,128}Sn

J. M. Allmond,[1] D. C. Radford,[2] C. Baktash,[2,*] J. C. Batchelder,[3] A. Galindo-Uribarri,[2,4] C. J. Gross,[2] P. A. Hausladen,[1] K. Lagergren,[1] Y. Larochelle,[4] E. Padilla-Rodal,[1,†] and C.-H. Yu[2]

High-precision measurements of $\langle 0_1||M(E2)||2_1\rangle$ matrix elements from the Coulomb excitation of ^{124,126,128}Sn on a ^{12}C target are presented. The extracted $B(E2)$ values decrease monotonically from the neutron midshell toward the ^{132}Sn double-shell closure, despite a near constancy in the first 2^+ level energy. Furthermore, Coulomb excitation of ^{124,126,128}Sn on an enriched ^{50}Ti target, combined with the results from the ^{12}C target, provide a measure of the static quadrupole moments, $Q(2_1{}^+)$ (expected to be zero for a spherical shape). These new results confirm that the unstable neutron-rich ^{126,128}Sn isotopes have deformations consistent with zero. The present study marks the first report on measured $2_1{}^+$ static quadrupole moments for unstable closed-shell nuclei.

$Z = 50$	N	$B(E2; 0_1^+ \rightarrow 2_1^+)$[b] [in e^2b^2]	$Q(2_1^+)$[c] [in eb] without high-lying	P_3	$Q(2_1^+)$[a,c] with high-lying
^{124}Sn	74	0.162(6)	+0.03(7)	+	−0.06(8)
				−	−0.04(8)
^{126}Sn	76	0.127(8)	+0.08(11)	+	−0.02(11)
				−	+0.01(11)
^{128}Sn	78	0.080(5)	−0.02(18)	+	−0.13(19)
				−	−0.08(19)

Experimental identification of the 2^+ MSS in ^{132}Te

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **84**, 061306(R) (2011)

One-phonon isovector $2^+_{1,MS}$ state in the neutron-rich nucleus ^{132}Te

M. Danchev,[1] G. Rainovski,[1,2] N. Pietralla,[2,3] A. Gargano,[4] A. Covello,[4,5] C. Baktash,[6] J. R. Beene,[6] C. R. Bingham,[7] A. Galindo-Uribarri,[6] K. A. Gladnishki,[1] C. J. Gross,[6] V. Yu. Ponomarev,[2] D. C. Radford,[6] L. L. Riedinger,[7] M. Scheck,[2] A. E. Stuchbery,[8] J. Wambach,[2] C.-H. Yu,[6] and N. V. Zamfir[9]

The 2^+_2 state in ^{132}Te is identified as the one-phonon mixed-symmetry state in a projectile Coulomb excitation experiment presenting a firm example of a mixed-symmetry state in unstable, neutron-rich nuclei. The results of shell-model calculations based on the low-momentum interaction V_{low-k} are in good agreement with experiment demonstrating the ability of the effective shell-model interaction to produce states of mixed-symmetry character.

Signatures of the MS 2^+ state:

- ♦ strong M1 and weak E2 transition rates to the 2^+_{FS} state
- ♦ weak E2 transition rate to the 0^+ ground state

Experimental identification of the 2^+ MSS in ^{132}Te

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **84**, 061306(R) (2011)

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Sig

- strong M1 and wea
- weak E2 transition

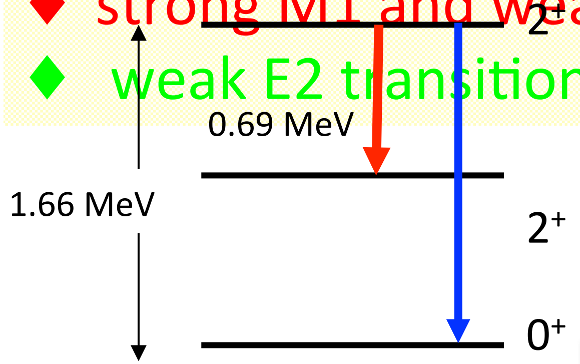


TABLE I. Comparison of the available experimental data on the electromagnetic properties of the 2^+_1 and the 2^+_2 states in ^{132}Te with results of the shell-model calculations.

Observable	Unit	Experiment	Shell Model
$B(E2;2^+_1 \to 0^+_1)$	W.u.	10(1)[a]	7.8
$\mu(2^+_1)$	μ_N	+0.92(10)[b]	0.68
$B(E2;2^+_2 \to 0^+_1)$	W.u.	0.5(1)[c]	0.21
$B(E2;2^+_2 \to 2^+_1)$	W.u.	0–20[c]	0.24
$B(M1;2^+_2 \to 2^+_1)$	μ_N^2	5.4(3.5)[c] (>0.23[d])	0.20
$\mu(2^+_2)$			0.69

Shell model calculations

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

Main steps

1. Model space
2. Single-particle energies
3. Two-body matrix elements
4. Construction and diagonalization of the energy matrices

Realistic effective interaction

Realistic shell-model effective interaction

$\langle ij | V_{eff} | kl \rangle$ from the free nucleon-nucleon potential

- Understand the properties of nuclei starting from the forces between nucleons

- No adjustable parameter in the calculation of two-body matrix elements

Derivation of V_{eff}

Two main ingredients

- Nucleon-nucleon potential

- Many-body theory

L. Coraggio et al, Prog. Part. Nucl. Phys. 62, 135 (2009)
L. Coraggio et al, Annals of Phys. 327, 2061 (2012)

Nucleon-nucleon potential

Potentials which reproduce the two-body data (deuteron properties and the NN scattering data up to the inelastic threshold) with

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

- Nijmegen II
- CD-Bonn
- Argonne V_{18}
- N^3LO Chiral potential

Problem:

these potentials have a strongly repulsive short-range component

↓

cannot be used directly in nucler structure perturbative calculations

Remedy:

V_{low-k} approach

construction of an *NN* potential confined within a low-momentum space (defined by a cutoff Λ)

Realistic shell-model effective interaction

Schrödinger equation for A nucleons

$$H\psi_i = (H_0 + H_1)\psi_i = E_i\psi_i$$

$$\begin{cases} H_0 = T + U \\ H_1 = V_{NN} - U \end{cases}$$

Shell-model equation for N-valence nucleons

$$PH_{eff}P\psi_i = P(H_0 + V_{eff})P\psi_i = E_i P\psi_i$$

P **projection operator onto the chosen model space**

V_{eff} different from V_{NN}

Defined

- in the nuclear medium
- in a subspace of the Hilbert space
- accounts perturbatively
  - for configurations beyond the chosen model space
  - for core polarization effects

Many body theory

$\hat{Q}$ - box folded-diagram method

V_{eff} is written as a perturbative expansion in terms of the

$\hat{Q}$-box

→ collection of diagrams with V_{low-k} in the interaction vertices

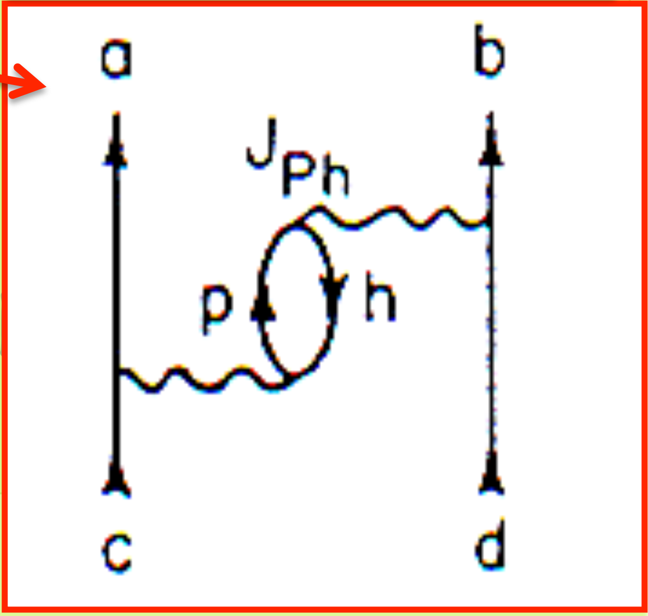
Many body theory

$\hat{Q}$ - box folded-diagram method

V_{eff} is written as a perturbative expansion in terms of the

$\hat{Q}$-box

"bubble" =1p-1h diagram



➔ collection of diagrams wit
the interaction vertices

OUTLINE OF CALCULATION

^{132}Sn core

Single proton energies from 133Sb

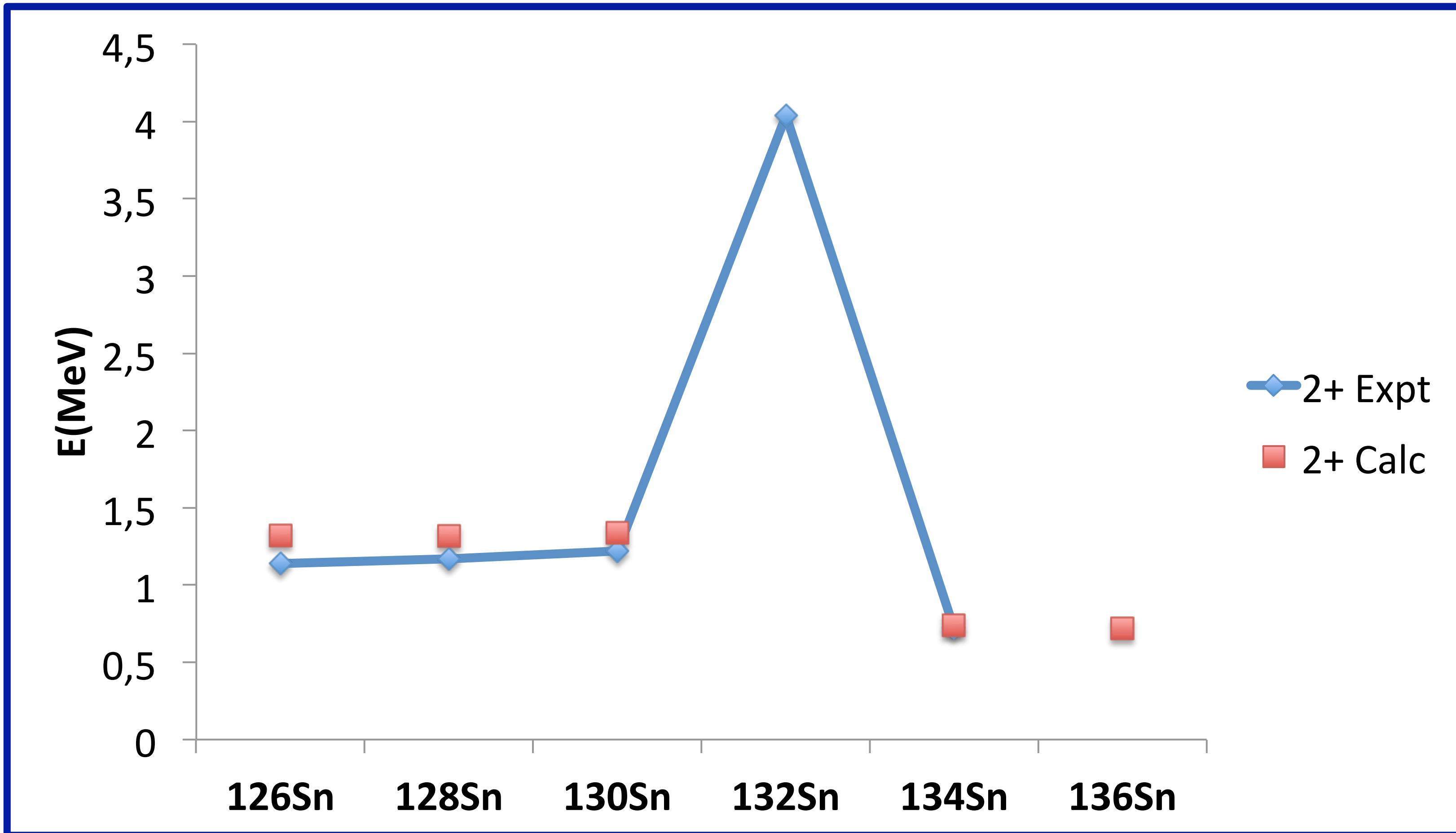
Single neutron energies from 133Sn

Single neutron-hole energies from 131Sn

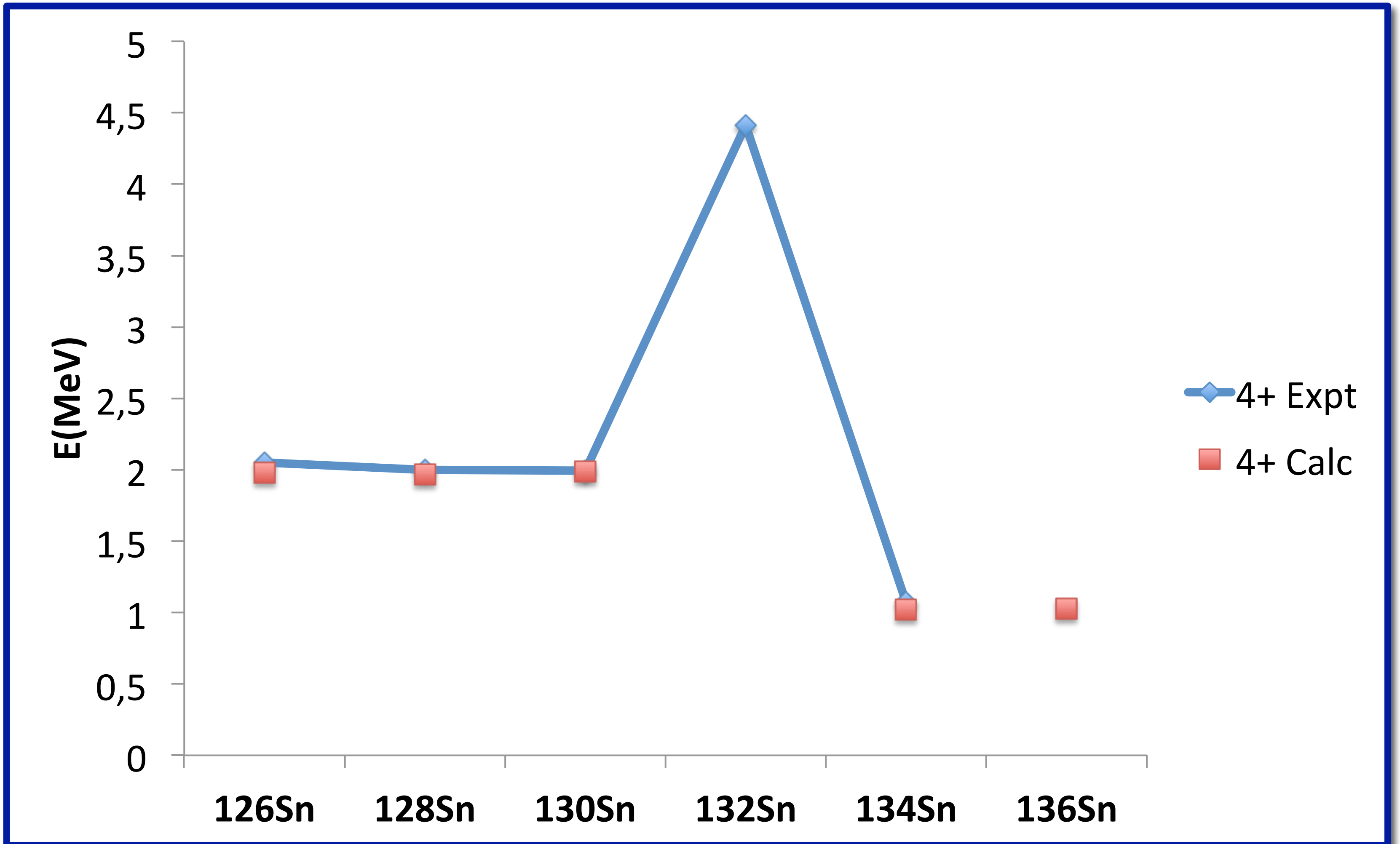
V_{NN} CD Bonn potential + Coulomb force for protons

V_{low-k} with Λ=2.2 fm^{-1}

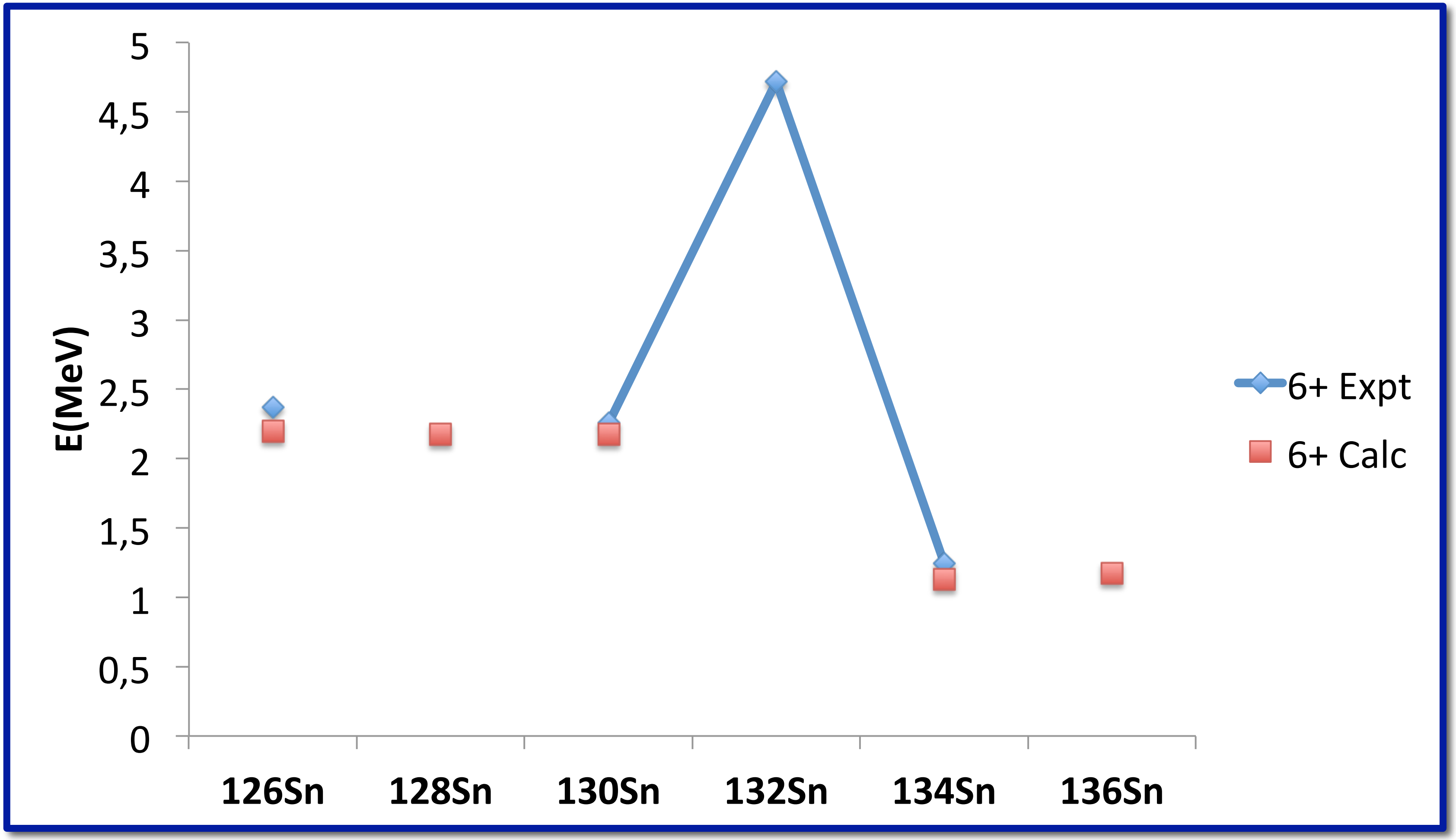
2^+ yrast state in Sn isotopes



4^+ yrast state in Sn isotopes

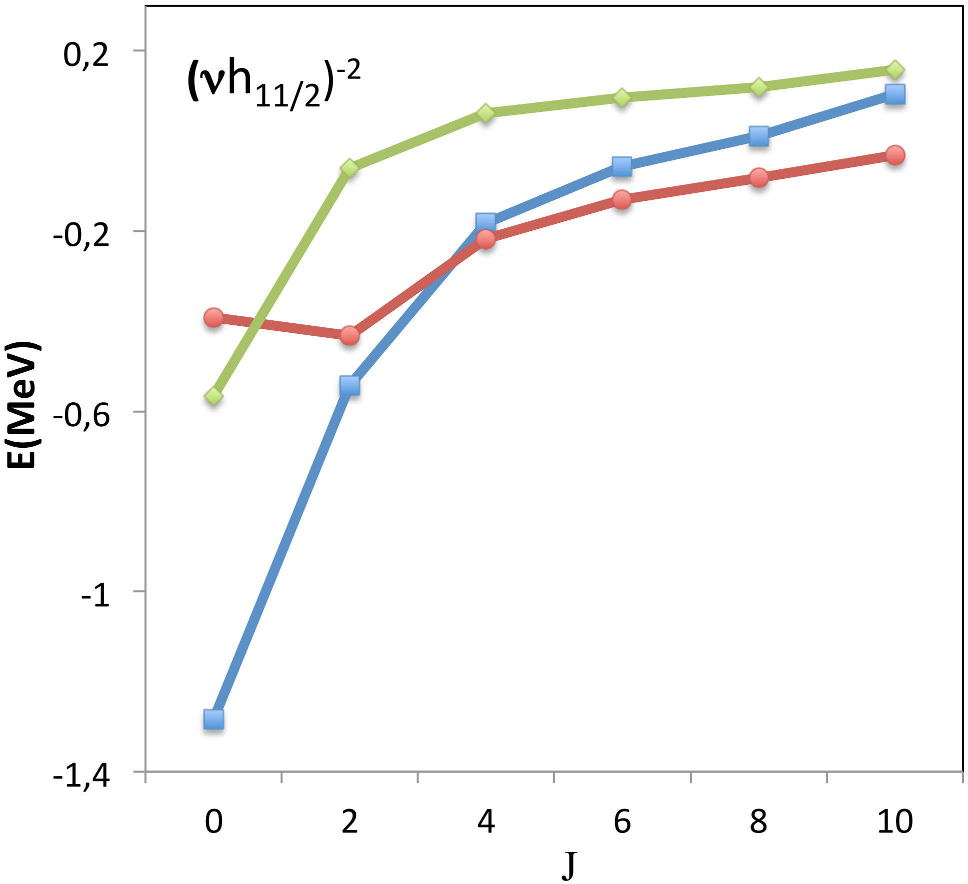


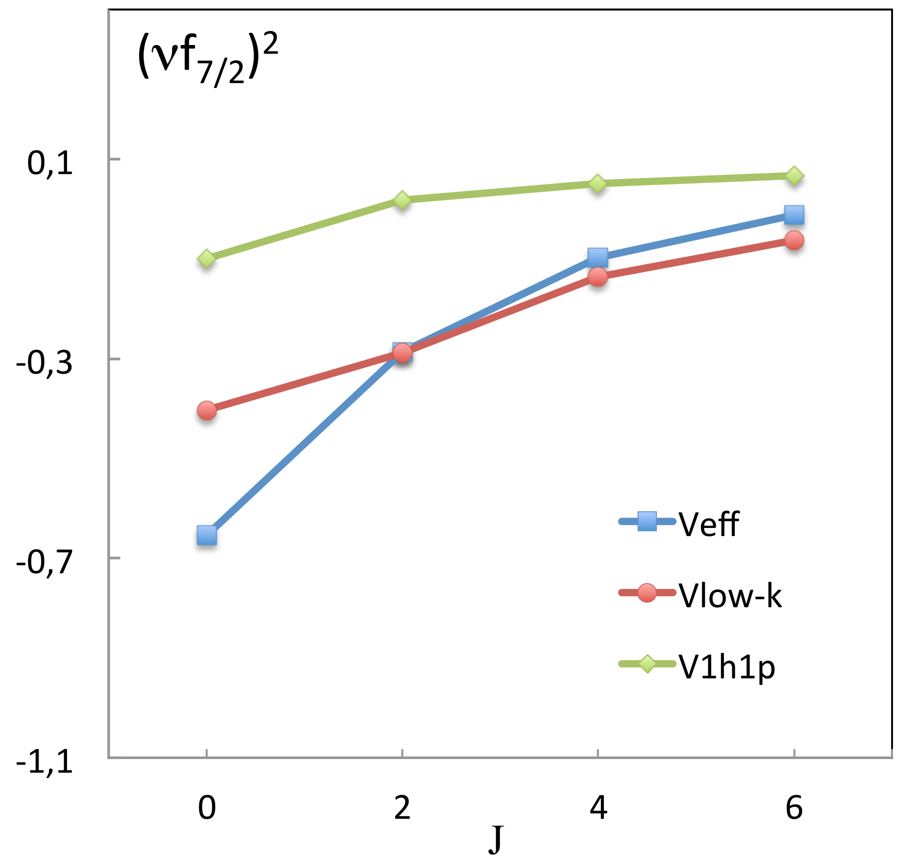
6^+ yrast state in Sn isotopes



6^+ in ^{126}Sn Phys. Rev.C 85, 054316 (2012)

Diagonal matrix elements of the interaction for the $(\nu h_{11/2})^{-2}$ and $(\nu f_{7/2})^2$ configurations





e_n=0.7 e	B(E2; $2^+ \rightarrow 0^+$) in W.u.		
	Expt[1]	Expt[2]	Calc
^{126}Sn	6.8(4)	5.3(16)	3.6
^{128}Sn	4.2(3)	3.8(3)	2.6
^{130}Sn		1.2(3)	1.4
^{134}Sn		1.4(2)	1.6
^{136}Sn			2.8

[1] Phys.Rev. C **84**, 061303 (2011) [2] Nucl.Phys. A **746**, 83c (2004); Nucl.Phys. A **752**, 264c (2005)

Q(2^+) for Sn isotopes [in eb]

	Expt		Calc
	Without high lying states	With high lying states	
^{126}Sn	+0.08(11)	-0.02(11) +0.01(11)	+0.02
^{128}Sn	-0.02(18)	-0.13(19) -0.08(19)	-0.005
^{130}Sn			-0.02
^{134}Sn			-0.02
^{136}Sn			-0.13

Expt from Phys.Rev. C **84**, 061303 (2011)

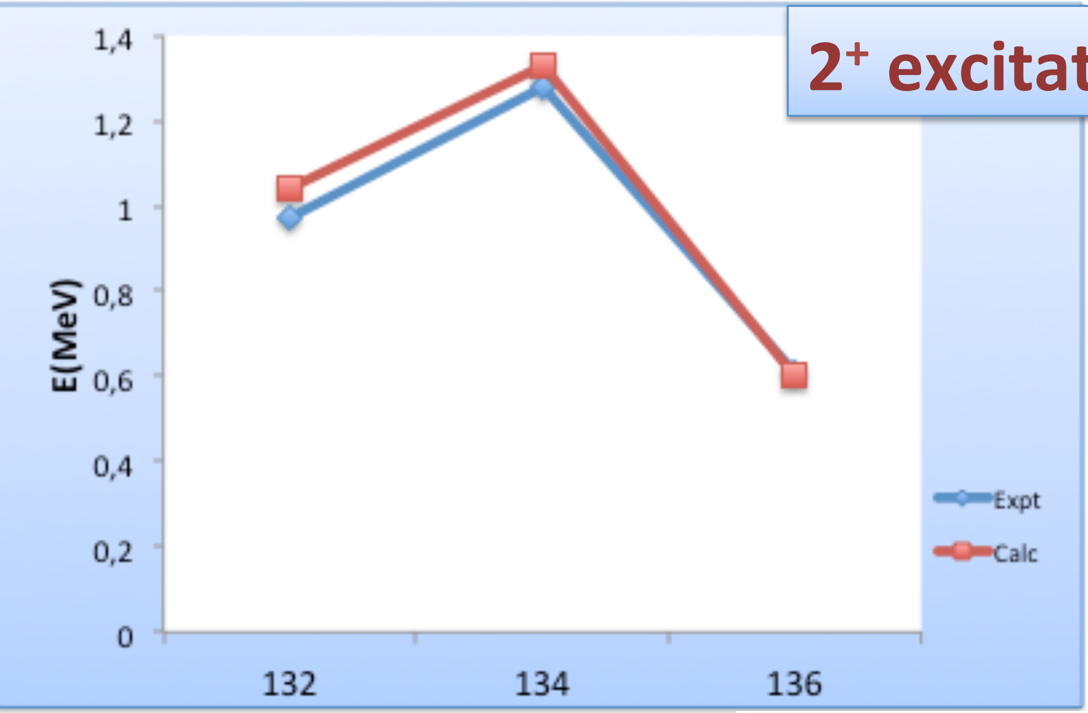
Some predictions for ^{134}Sn & ^{136}Sn

	^{134}Sn		^{136}Sn
	Expt	Calc	Calc
$B(E2:2_1^+ \to 0^+)$ [in W.u.]	1.4(2)	1.6	2.8
$B(E2:4^+ \to 2^+)$		1.7	0.83
$B(E2:6^+ \to 4^+)$	0.89(17)	0.82	0.12
$B(E2:2_2^+ \to 0^+)$		0.35	0.06
$B(E2:2_2^+ \to 2_1^+)$		2.93	1.8
$B(E2:2_2^+ \to 4^+)$		0.23	1.0
$B(M1:2_2^+ \to 2_1^+)$		0.02	0.09 x
$Q(2_1^+)$ [in eb]		-0.02	-0.13
$Q(2_2^+)$		-0.03	+0.06
$\mu(2_1^+)$ [in nm]		-0.57	+0.46
$\mu(2_2^+)$		-0.25	+0.54

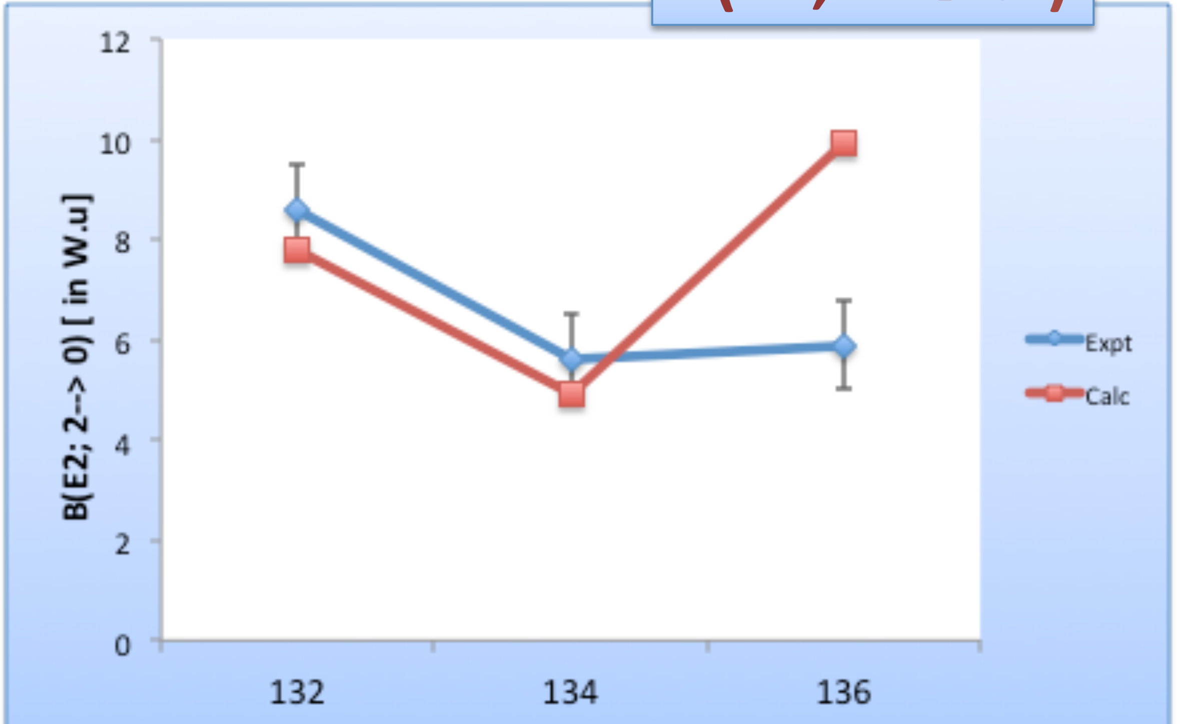
	^{134}Sn	^{136}Sn
0^+	80% $(f_{7/2})^2$	64% $(f_{7/2})^4$
2^+	85% $(f_{7/2})^2$	66% $(f_{7/2})^4$
4^+	94% $(f_{7/2})^2$	75% $(f_{7/2})^4$
6^+	98% $(f_{7/2})^2$	83% $(f_{7/2})^4$
2_2^+	80% $f_{7/2}p_{3/2}$	64% $(f_{7/2})^4$

Te isotopes

2^+ excitation energy



B(E2; $2^+ \rightarrow 0^+$)



e_n=0.7 e e_p=1.7 e

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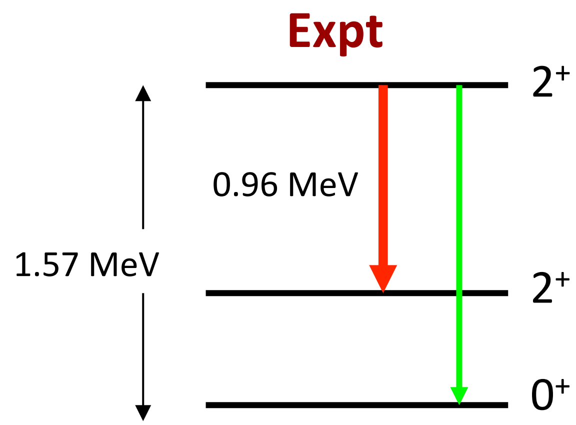
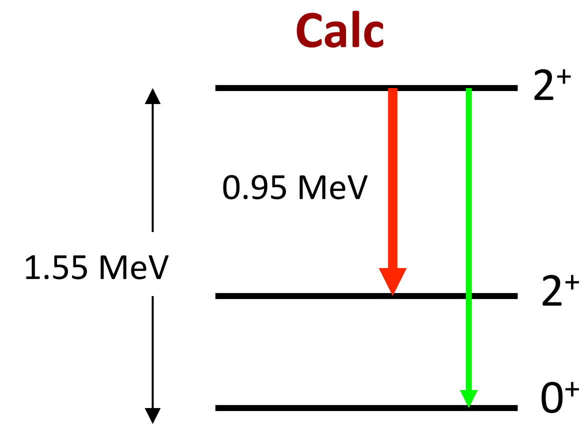
2^+ MSS in ^{136}Te





$$B(E2;\ 2^+_2 \rightarrow 0^+_1) = 0.67\ \text{W.u.}$$

$$B(E2;\ 2^+_2 \rightarrow 2^+_1) = 9.6\ \text{W.u.}$$

$$B(M1;\ 2^+_2 \rightarrow 2^+_1) = 0.19\ \mu_N^2$$

2^+_3 1.88 MeV

$$B(E2;\ 2^+_3 \rightarrow 2^+_1) = 1.4\ \text{W.u.}$$

$$B(E2;\ 2^+_3 \rightarrow 0^+_1) = 1.04\ \text{W.u.}$$

$$B(M1;\ 2^+_3 \rightarrow 2^+_1) = 0.18\ \mu_N^2$$

Wave functions of ^{136}Te

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

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

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

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

Conclusions

- ^{132}Sn region is a quite interesting region to test the shell structure

- CE in inverse kinematics is a proper technique to study the properties of these nuclei

- Future experiments
  - Missing data
  - Higher-precision measurements
  - Multipole Coulomb excitations

Naples group

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Thanks for your attention