

Coulomb excitation of Coulomb excitation of doubly magic ^{132}Sn with MINIBALL at HIE-ISOLDE

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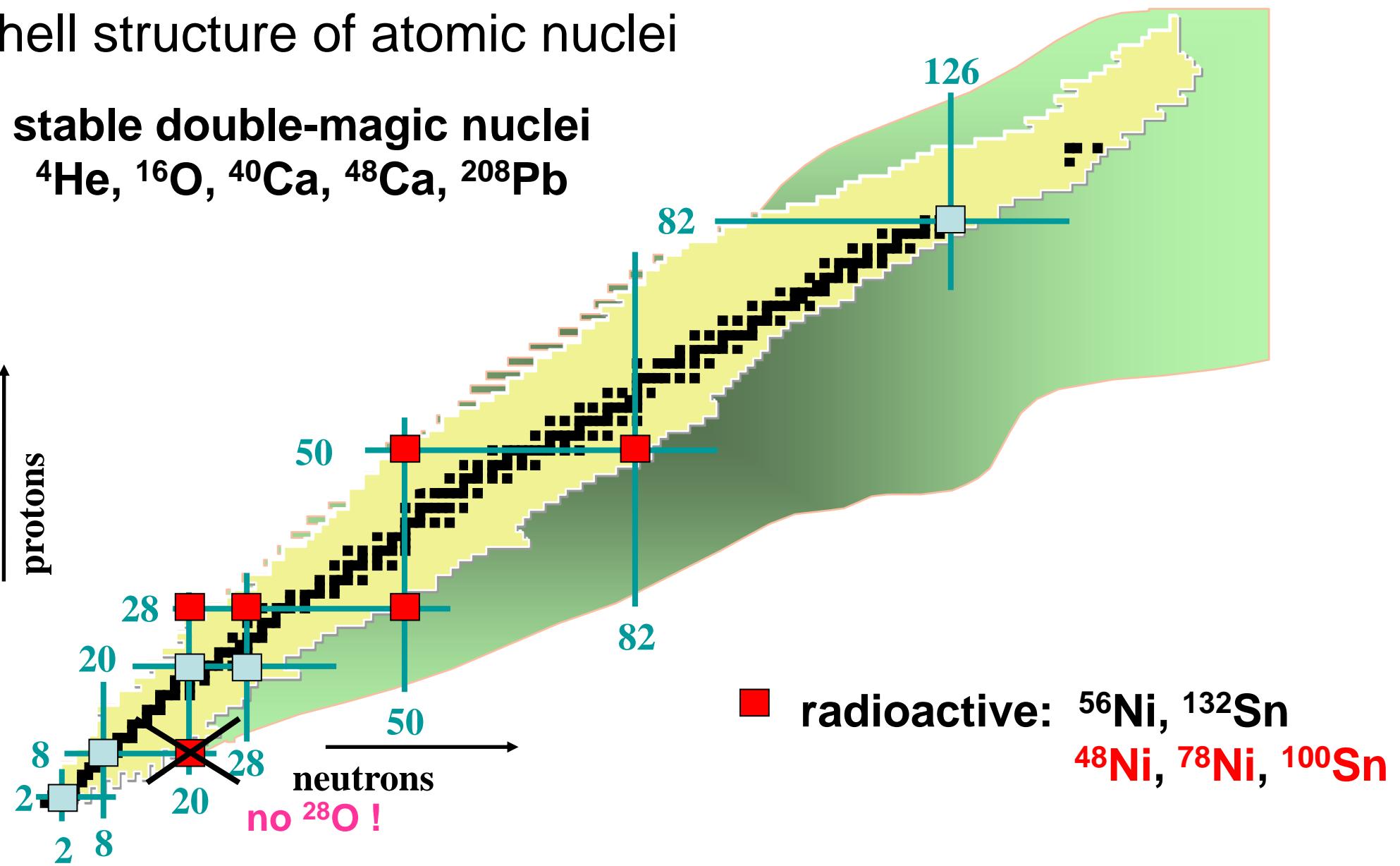
Local contact: Elisa Rapisarda (Elisa.Rapisarda@cern.ch)



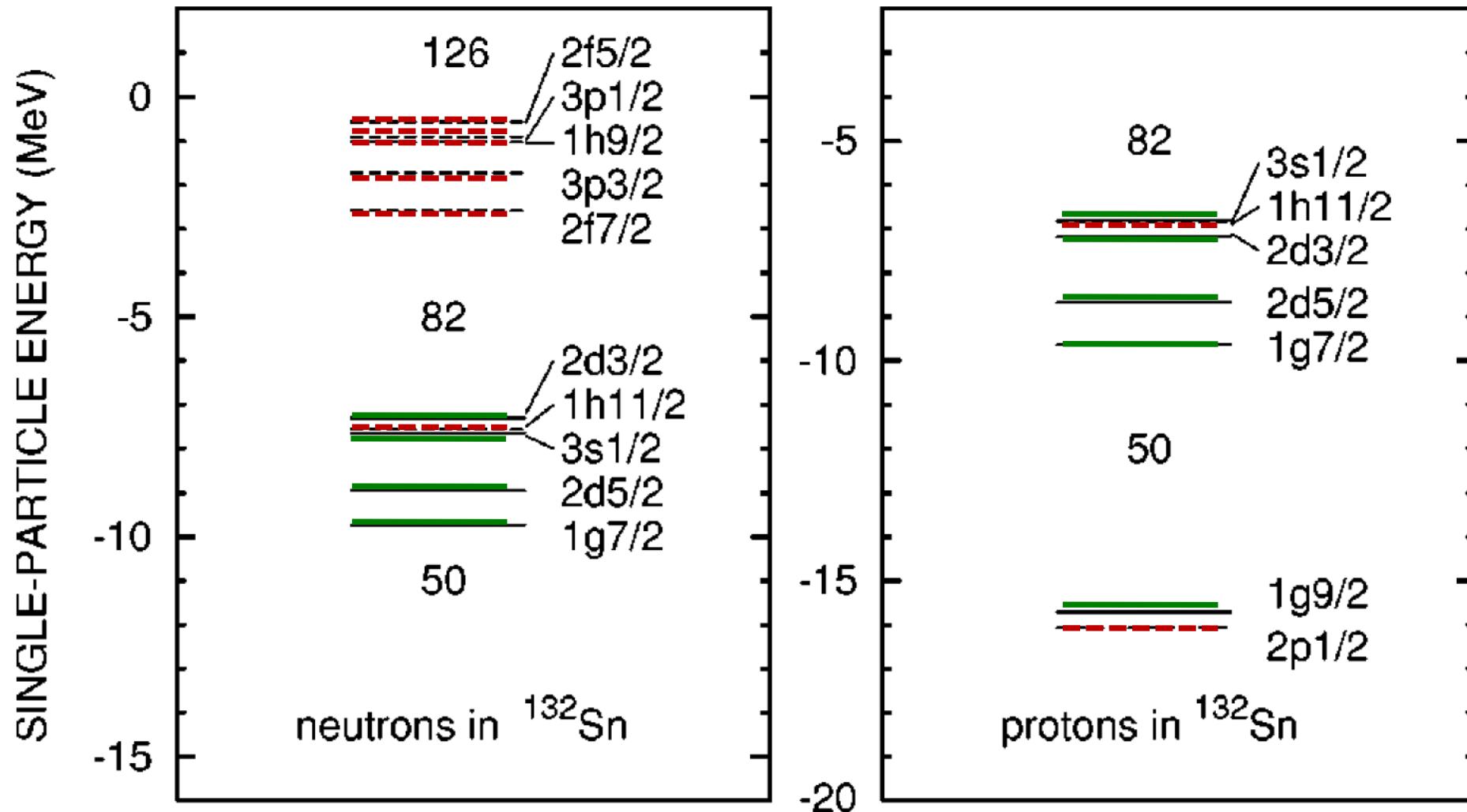
Shell structure of atomic nuclei

- stable double-magic nuclei

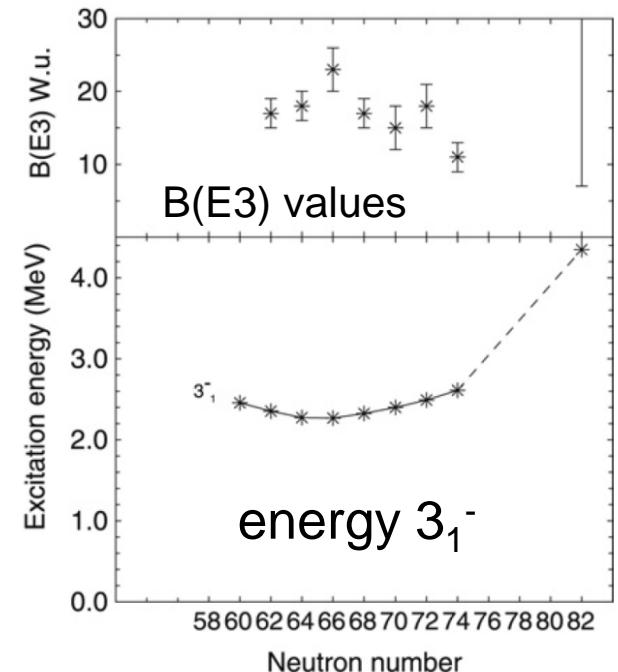
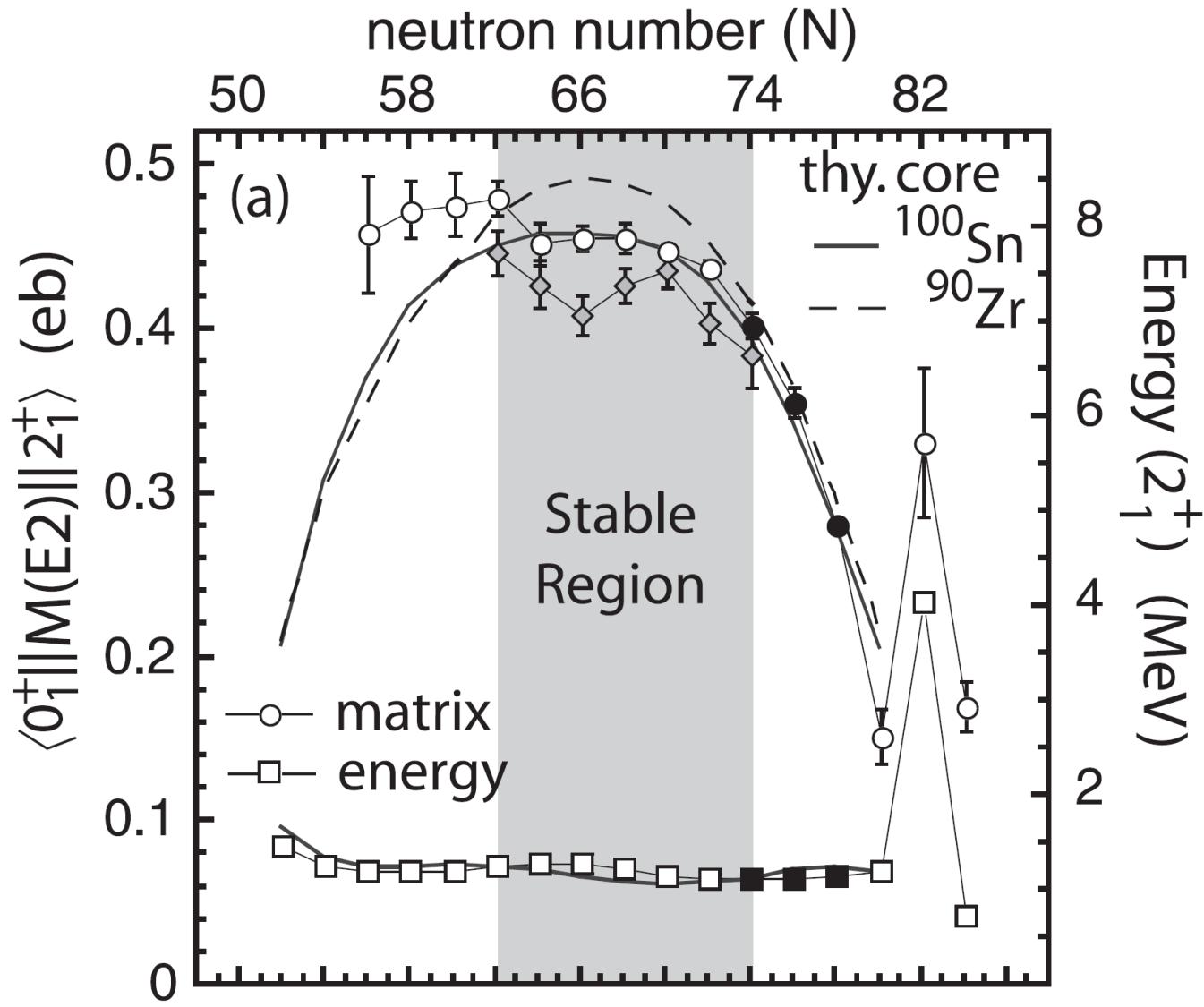
^4He , ^{16}O , ^{40}Ca , ^{48}Ca , ^{208}Pb



Experimental single particle spectrum of ^{132}Sn



The chain of Sn isotopes

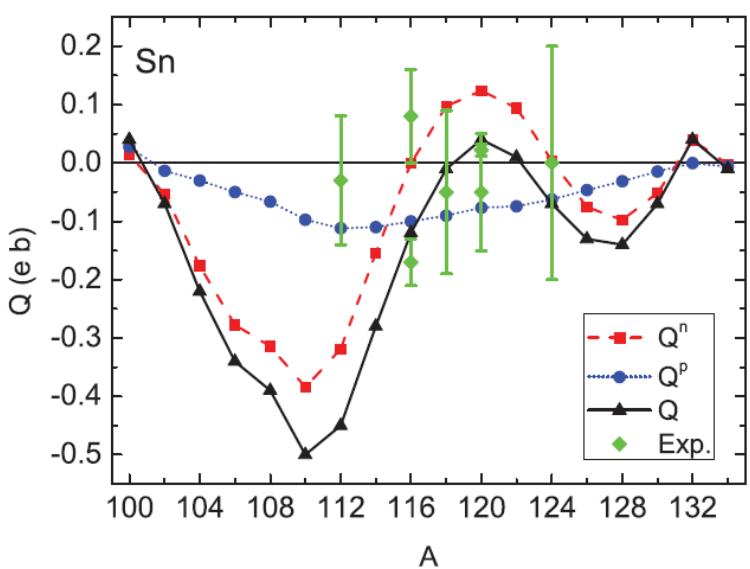
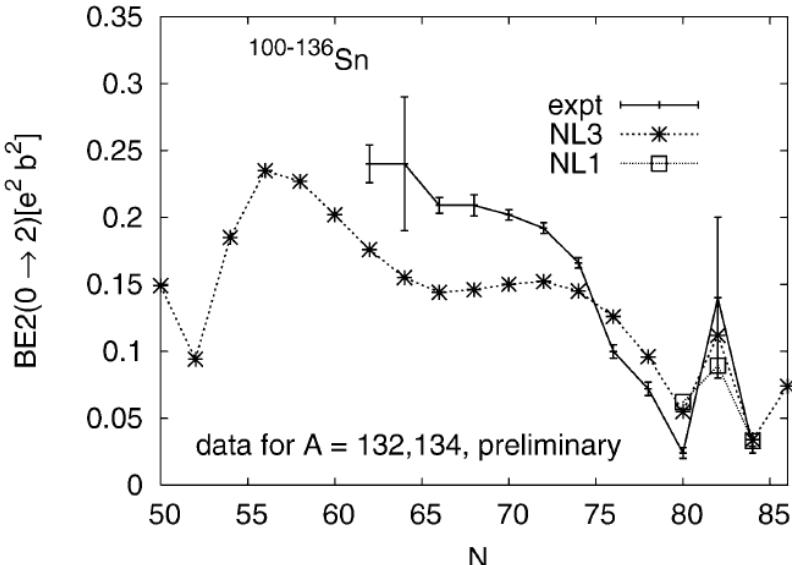


shell-model calculations
 $^{100}\text{Sn}/^{90}\text{Zr}$ core theory curves
 (solid and dashed)
 A.Banu, et al.,
Phys. Rev. C 72 (2005) 061305(R)

gray-filled diamonds
 A.Jungclaus et al.;
Phys. Lett. B 695 (2011) 110

figure taken from
 J.M. Allmond, et al.,
Phys. Rev. C 84 (2011) 061303(R)

Theoretical investigations and predictions



Study of the lowest 2^+ excitations and $B(E2)$ transition Strengths in relativistic QRPA for Sn-, and Pb-isotopes

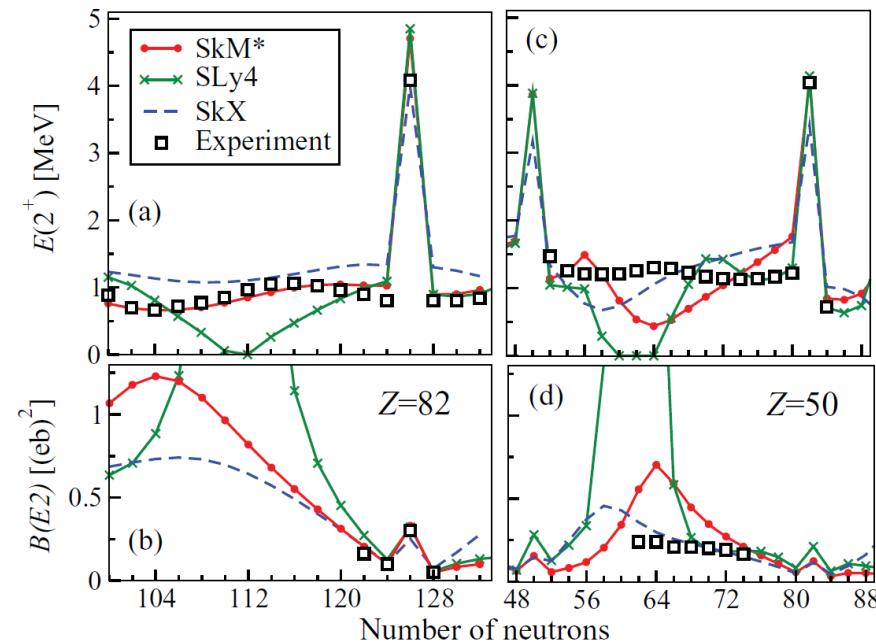
A. Ansari; Phys. Lett. B 623 (2005) 37

Self-consistent calculations of quadrupole moments of the first 2^+ states in Sn and Pb isotopes

D. Voitenkov et al.; Phys. Rev. C 85, 054319 (2012)

Collective vibrational states within the fast iterative quasiparticle random-phase approximation method

B. G. Carlsson, et al.; Phys. Rev. C 86, 014307 (2012)



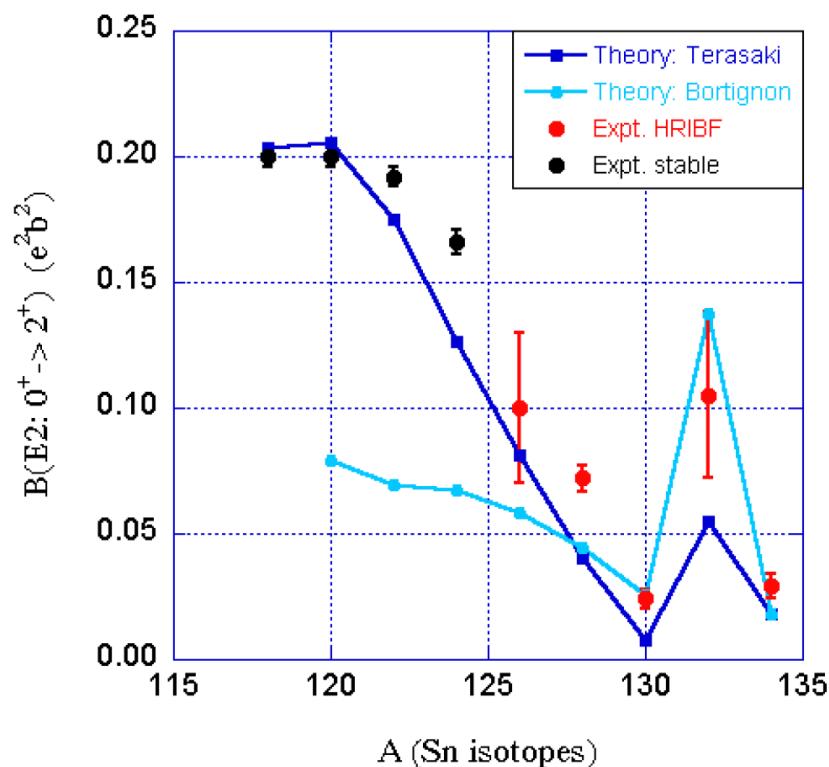
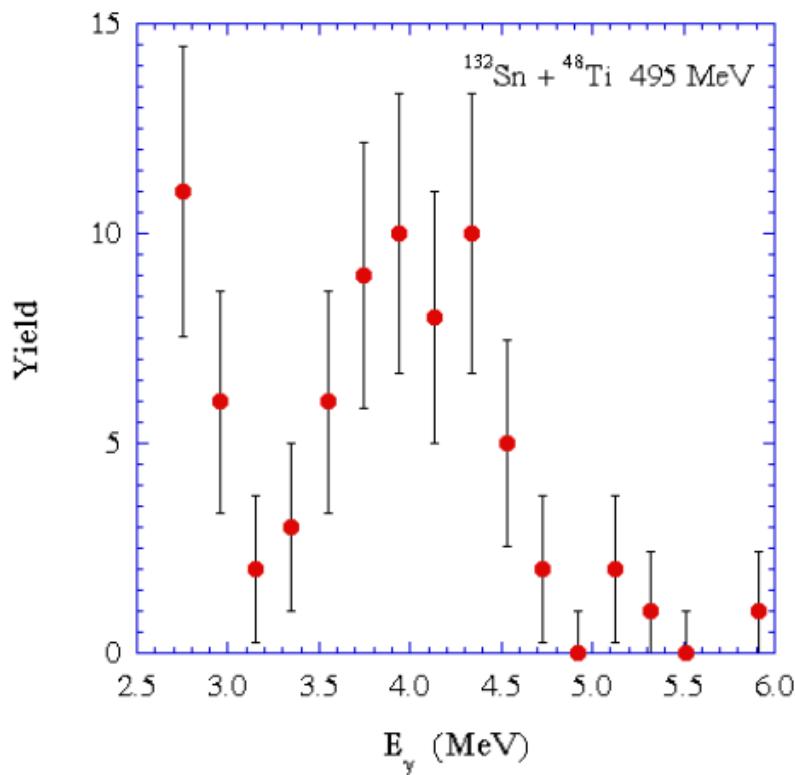
Coulomb excitation of ^{132}Sn at HRIBF

- ^{132}Sn beam
 - 1.3×10^5 ions/s, 96% pure
 - 3.75 MeV/u, 3.56 MeV/u
 - ^{48}Ti target, $Z=22$
- high γ efficiency BaF_2 array ($\sim 30\%$)
- two week experiment
- γ -ion coincidences

^{132}Sn , $E(2^+) = 4041$ keV, $B(E2; 0^+ \rightarrow 2^+) = 0.11(3) e^2 b^2$

D.C. Radford, et al Nucl. Phys. A 752 (2005) 264c–272c
 Proceedings of the 22nd International Nuclear Physics Conference
 Goeteborg, Sweden 27 June–2 July 2004

R.L. Varner, et al.; Eur. Phys. J. A 25, s01, 391 (2005)
 4th International Conference on Exotic Nuclei and Atomic Masses
 Pine Mountain, Georgia, USA September 12-16, 2004



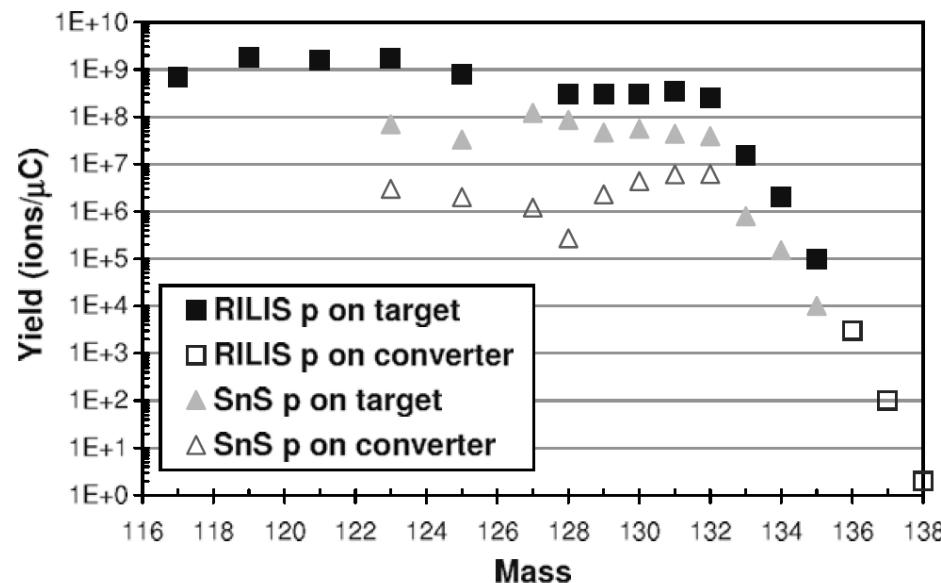
ISOLDE beam intensities

Element	A number	Half life	SC or PSB*	Yield at ISOLDE (ions/ μ C)	Target material
Sn	123 - g	129.2 d	SC	5.0E+08	UC _x
Sn	125 - g	9.64 d	SC	1.3E+08	UC _x
Sn	127 - g	2.10 h	SC	6.0E+07	UC _x
Sn	129 - g	2.23 m	SC	5.0E+07	UC _x
Sn	131 - m	58.4 s	SC	1.5E+07	UC _x
Sn	132 - g	39.7 s	SC	3.0E+07	UC _x

accelerator efficiency of the complete HIE-ISOLDE chain for ^{132}Sn beam 2%

beam intensity at MINIBALL of
 $I(^{132}\text{Sn}) = 8.5 \times 10^5$ ions/s
 PSB proton beam current 1.4 μA

HIE-ISOLDE beam energy: 5.5 MeV/u



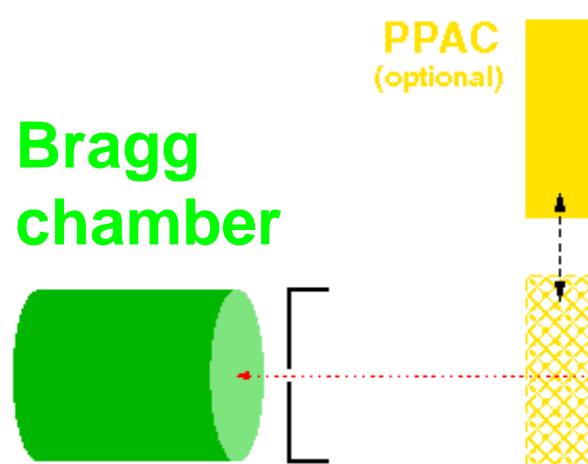
U. Köster et al. Nucl. Instr. and Meth. B 266 (2008) 4229

'safe' Coulex ^{132}Sn (@ 5.5 MeV/u) + ^{206}Pb

Target projectile distance at $\theta_{\text{Lab}} = 77^\circ$
 $d = 39.6$ fm

'safe' criterion $d > R_p + R_t + 5$ fm = 18.8 fm

MINIBALL- setup

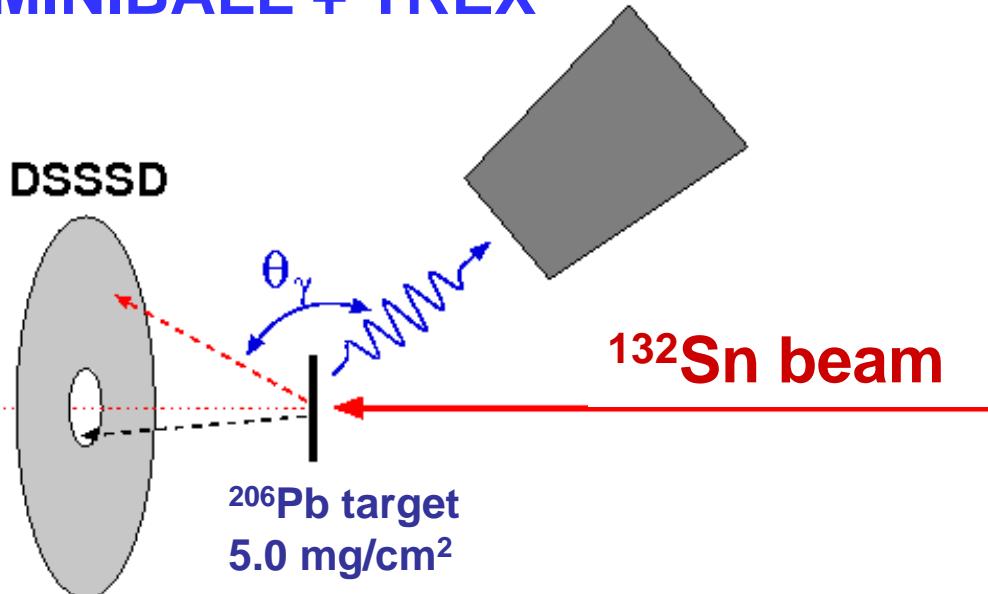


beam
composition
TU München

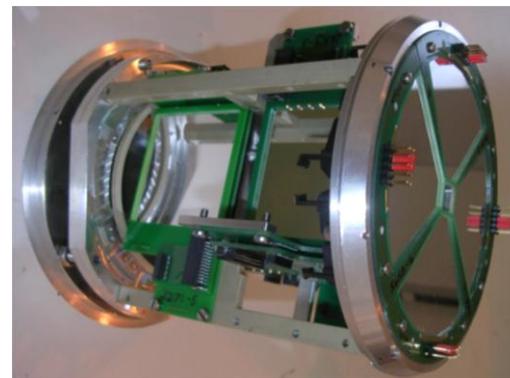
Particle detection
Scat. Angle: $\Delta\theta_{\text{Lab}}=15^\circ\text{-}77^\circ$
 $\Delta\theta_{\text{CM}}=25^\circ\text{-}115^\circ$

γ -spectroscopy
Efficiency @ 4 MeV $\sim 3\%$

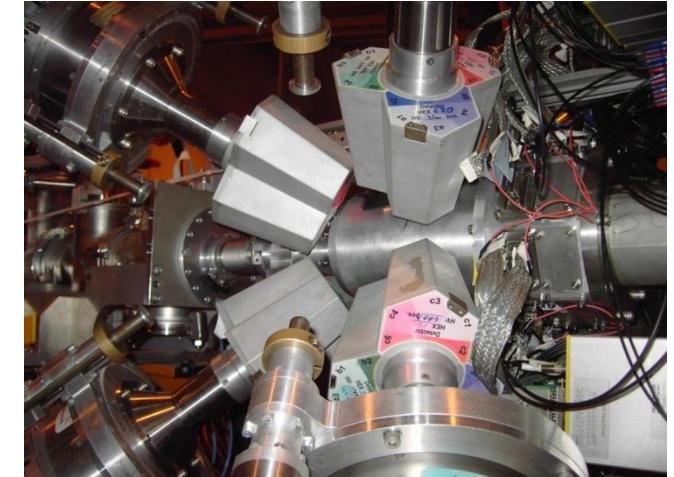
MINIBALL + TREX



beam
monitor
Particle detection
Scat. angle, energy



TU München, K.U. Leuven



Uni Köln, K.U. Leuven

Count rate estimate & beam time request

Primary ISOLDE yield (ions/ μ C) ^{132}Sn	beam intensity at MINIBALL (ions/s)	Transition energy	Transition strength	Integr. Coulex cross- section (mb)	Events in photo peak	
					Count rate Cts/h	Count rate Cts/120h
3×10^7	8×10^5	$0_1^+ \rightarrow 2_1^+$ 4041 keV	$B(E2, 2_1^+ \rightarrow 0^+)$ 7(3) W.u. [1,2]	$\sigma(2_1^+)$ 13 mb	17	2040
3×10^7	8×10^5	$0_1^+ \rightarrow 3_1^-$ 4352 keV	$B(E3, 3_1^- \rightarrow 0^+)$ >7.1 W.u. [3] $B(E1, 3_1^- \rightarrow 2^+)$ >0.00017W.u. [3]	$\sigma(3_1^-)$ 1.7 mb	2 1	240 120
3×10^7	8×10^5	$0_1^+ \rightarrow 4_1^+$ 4416 keV	$B(E2, 4_1^+ \rightarrow 2_1^+)$ 0.4 W.u. [3]	$\sigma(4_1^+)$ 0.1 mb	0.5	60

[1] D.C. Radford, et al., Nucl. Phys. A752 (2005) 264c.

[2] R.L. Varner, et al.; Eur. Phys. J. A 25, s01, 391 (2005)

[3] S. Raman, C.W. Nestor Jr., P. Tikkanen, At. Data Nucl. Data Tables 78, 1 (2000).

Summary

Coulomb excitation of the first 2^+ and 3^- states of the doubly magic nucleus ^{132}Sn .

$B(E2)$ and $B(E3)$ values and collectivity of states in ^{132}Sn will provide information on cross shell configurations which are expected to be dominated by a strong proton contribution.

Test of theoretical predictions:

- (i) large scale shell model calculations
- (ii) mean field calculations (RPA and QRPA)

Main advantages of the HIE-ISOLDE-MINIBALL experiment

- (i) intense ^{132}Sn beam at ISOLDE
- (ii) high beam energy of HIE-ISOLDE
 - allows high Z target for safe Coulomb excitation with high cross section
- (iii) high energy resolution and good efficiency of the 8 MINIBALL HPGe detectors

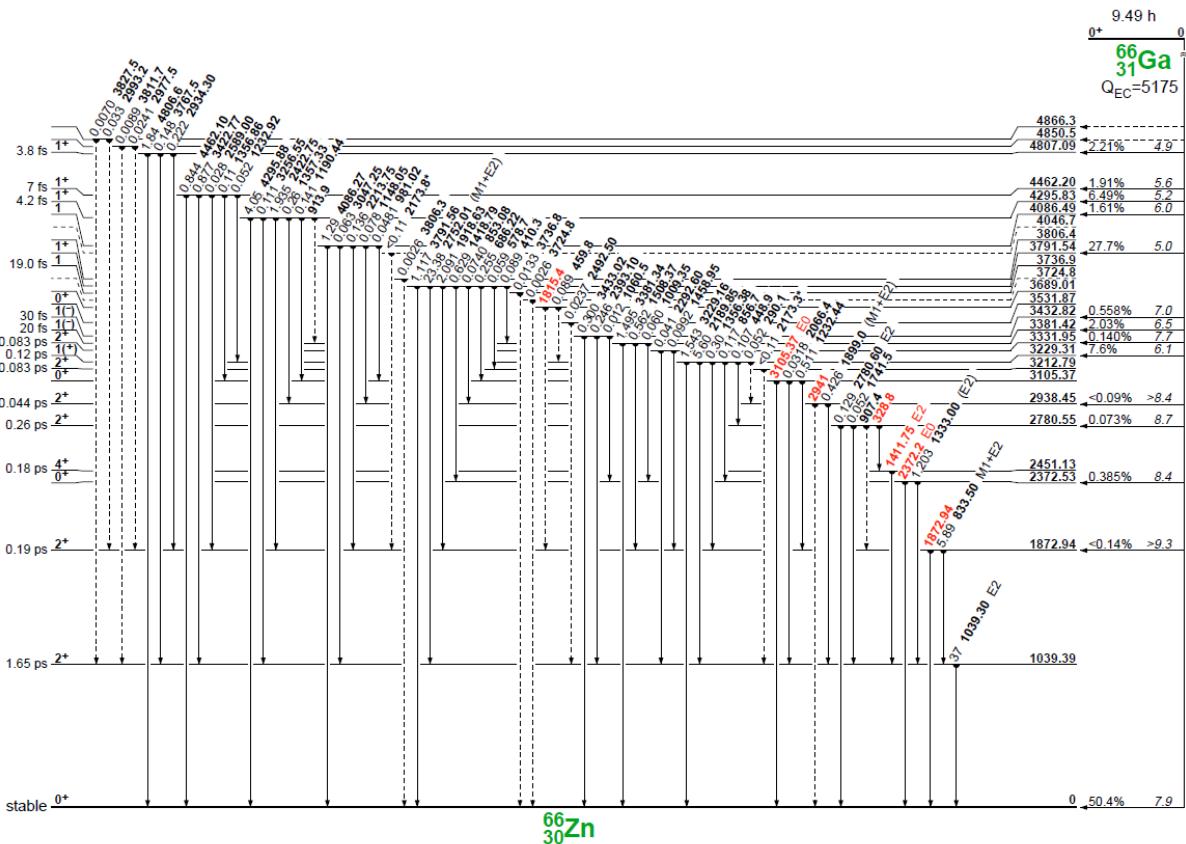
Beam time request: 15x8 hours shifts for ^{132}Sn

high energy γ -ray calibration, HIE-ISOLDE set-up 3x8 hours shifts

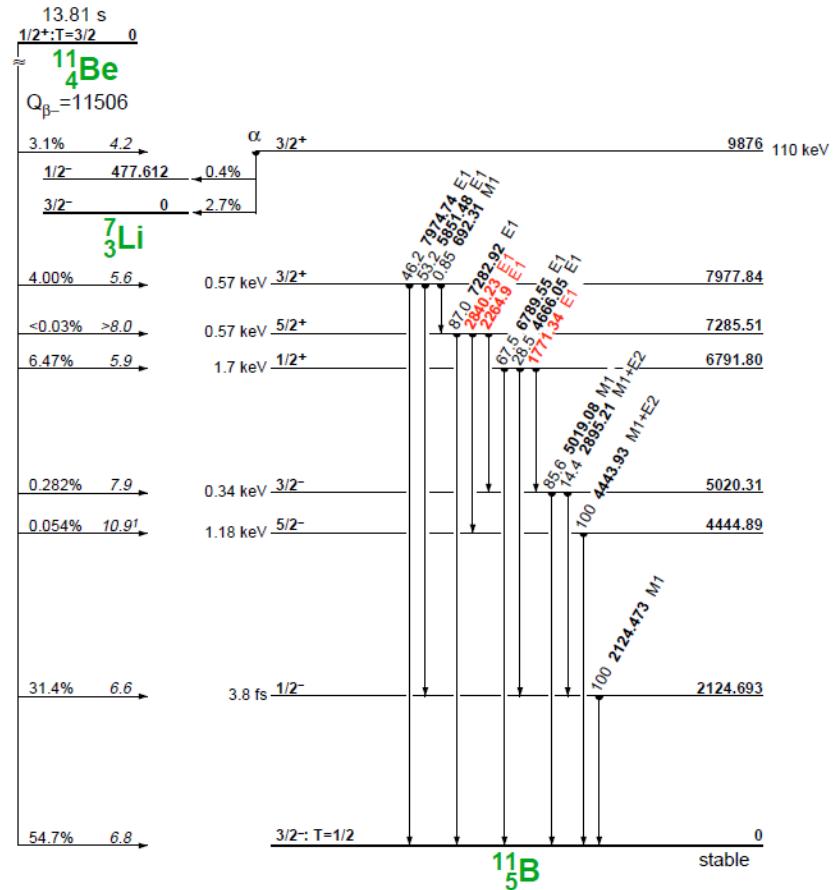
18 shifts are requested for this proposal

High energy γ -ray calibration

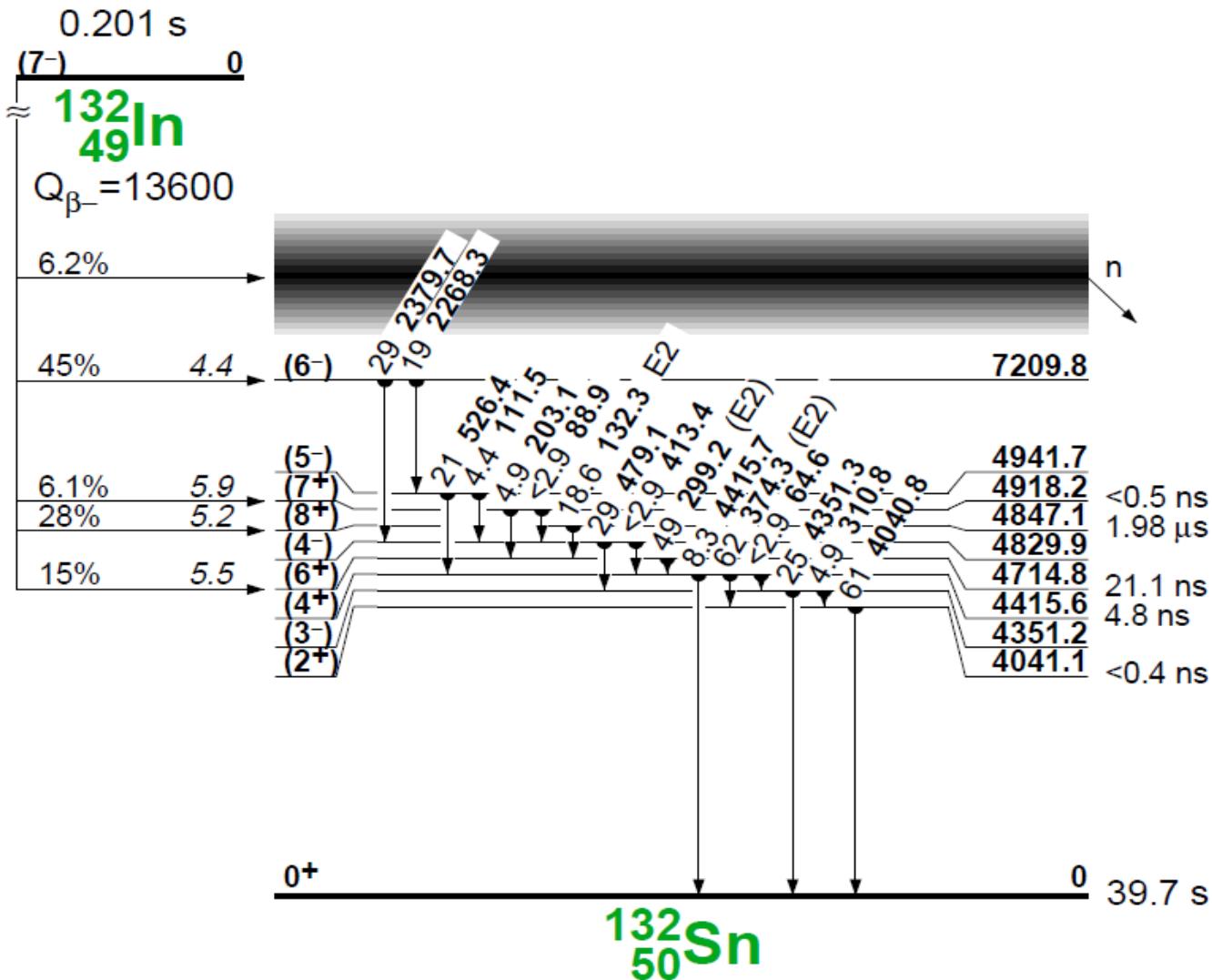
^{66}Ga β -decay

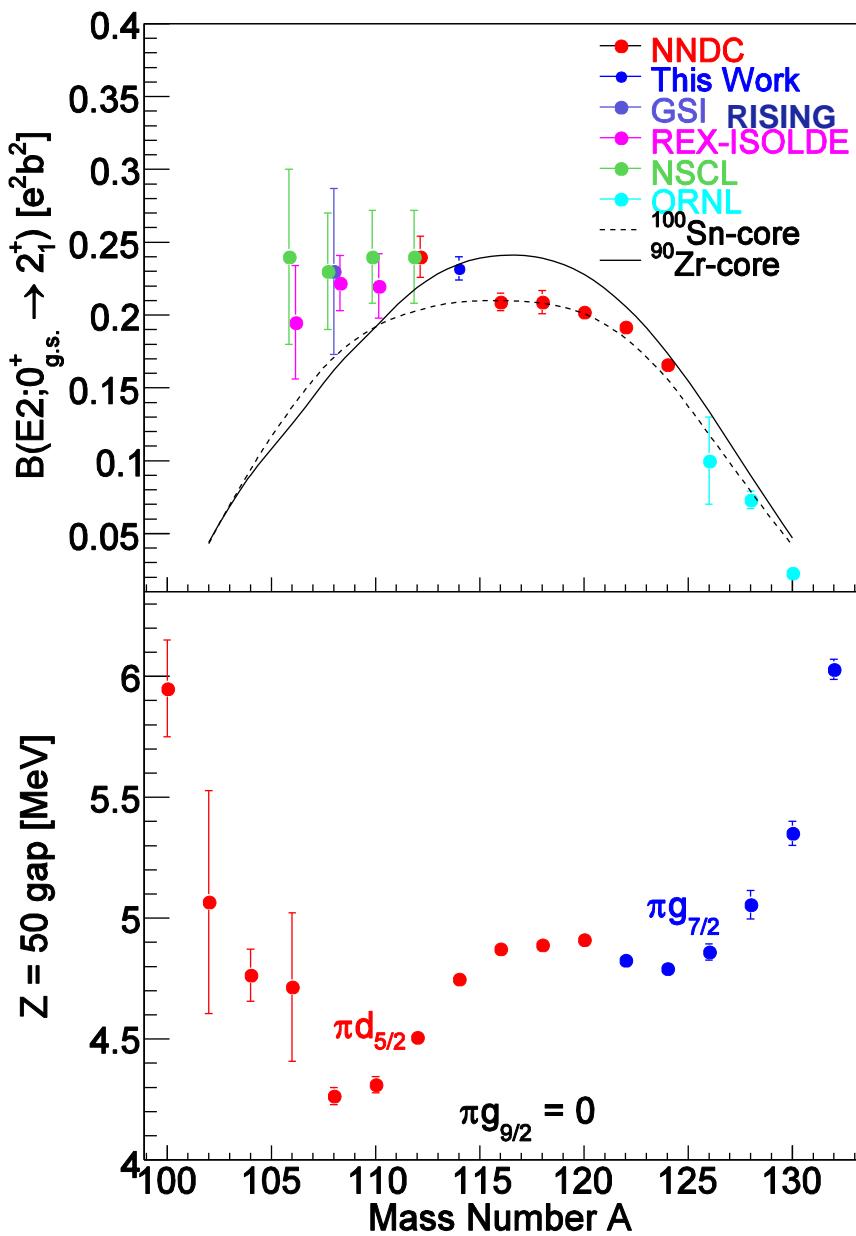


^{11}Be β -decay



^{132}Sn level scheme





- relativistic energy Coulex RISING

$$^{108}\text{Sn} B(E2) = 0.230(57) e^2 b^2$$

A. Banu et al, Phys. Rev. C 72 061305(R) (2005)

- sub-barrier Coulex REX-ISOLDE

$$^{110}\text{Sn} B(E2) = 0.220(22) e^2 b^2$$

J. Cederkäll et al., Phys. Rev. Lett. 98, 172501 (2007)

- intermediate energy Coulex NSCL

$$^{106,108,110,112}\text{Sn} B(E2) > 0.22 e^2 b^2$$

C. Vaman et al., Phys. Rev. Lett. 99, 162501 (2007)

- sub-barrier Coulex REX-ISOLDE

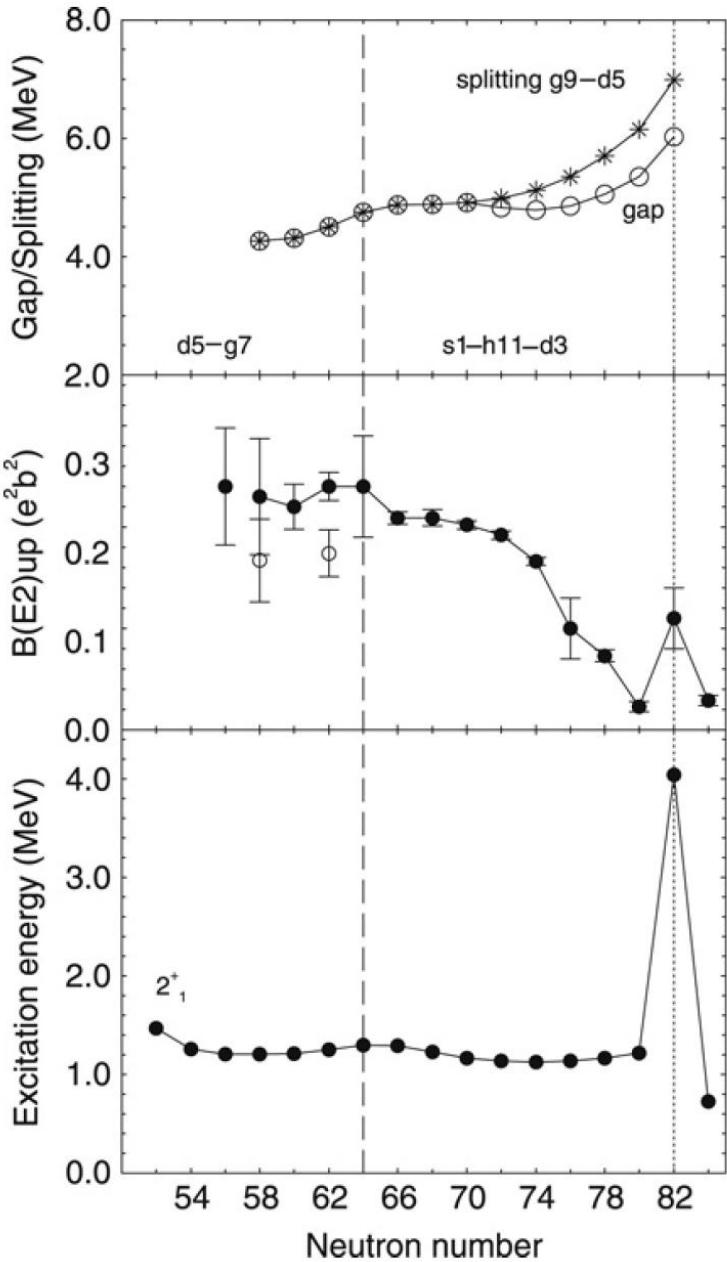
$$^{106,108}\text{Sn}$$

A. Ekström et al., Phys. Rev. Lett. 101, 012502 (2008)

- sub-barrier, stable Coulex GSI

$$^{114}\text{Sn}$$

P. Doornenbal et al., Phys. Rev. C 78, 031303(R) (2008)



constant, large energy gap at $Z=50$
proton excitations require high excitation energy
first excited 2^+ levels of Sn ~ 1.2 MeV neutron states

around $N = 64$ weak subshell closure

drastic increase of the 2^+ state for $^{132}\text{Sn}_{82}$ nucleus
both neutron and proton excitations across
 $Z = 50$ and $N = 82$ shell gaps require large energies

2^+ state may not be of pure neutron origin anymore
but contains proton excitations

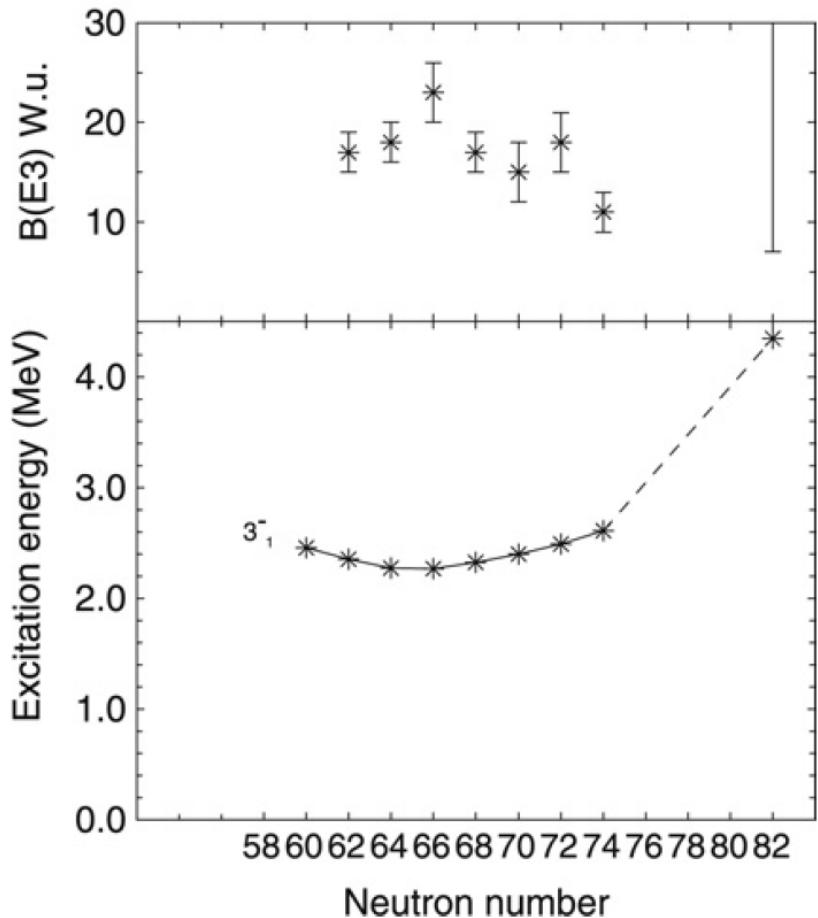
wave function has mixed components from neutron
and proton local increase of the $B(E2)$ value

For $N > 64$ $B(E2)$ value follows parabolic trend of
generalized seniority scheme exception $^{132}\text{Sn}_{82}$

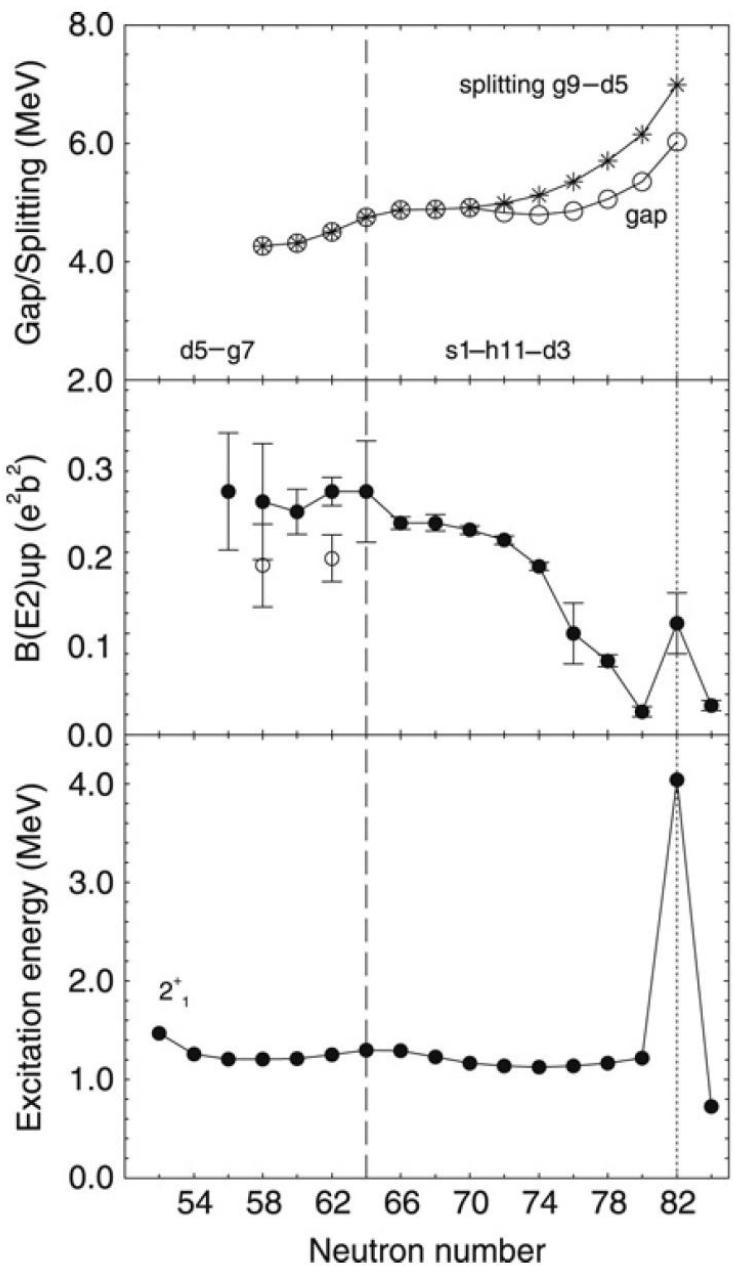
the first 2^+ state in $^{132}\text{Sn}_{82}$ contains more proton
excitations, enhances $B(E2)$ significantly

local increase of $B(E2)$ at ^{132}Sn predicted by QRPA

The chain of Sn isotopes



First 3⁻ state around 2.5 MeV excitation energy throughout the Sn isotopic chain
collective states large B(E3) values 10–20 W.u.
neutron excitations with negative-parity intruder $h_{11/2}$ orbit and positive-parity orbits $d_{5/2}$ and $g_{7/2}$.
proximity of $\Delta l=2$ and $\Delta l=3$ neutron orbits cause E2 and E3 collective excitations



energy gap at $Z=50$ constant and large
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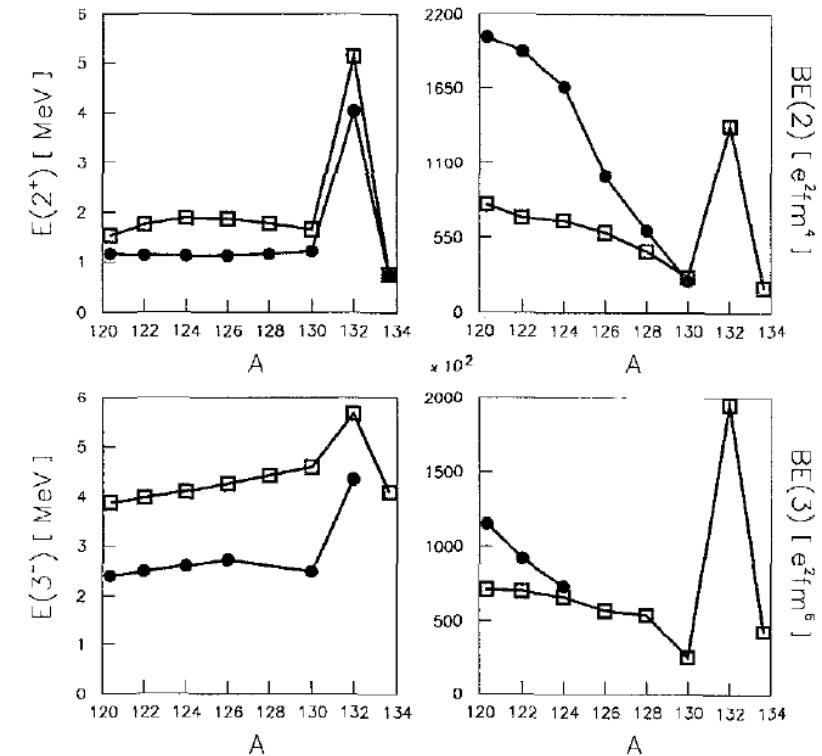
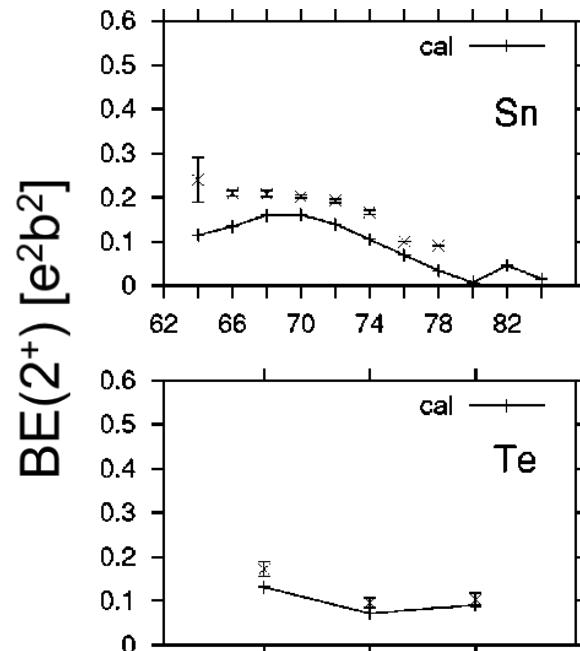
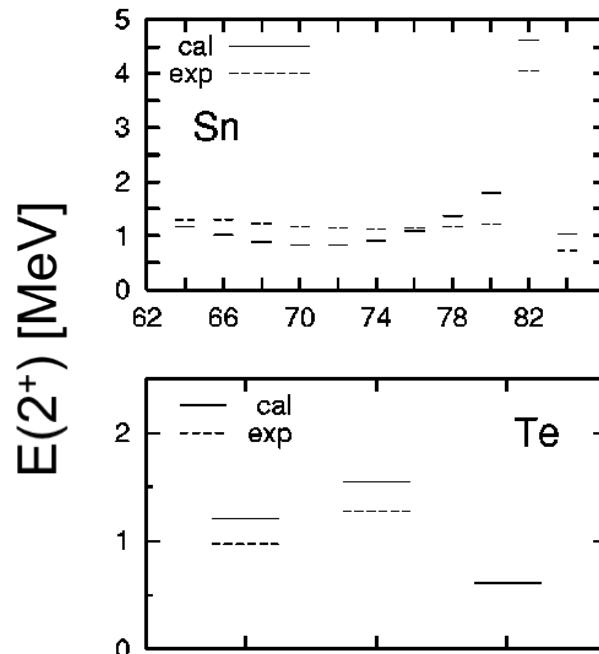
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local increase of $B(E2)$ at ^{132}Sn predicted by QRPA

Theoretical investigations and predictions



Anomalous behavior of 2^+ excitations around ^{132}Sn
 J. Terasaki, et al.; Phys. Rev. C 66, 054313 (2002)

Excited states of neutron rich nuclei:
 Mean field theory and beyond
 G. Colo, et al.; Nucl. Phys. A722 (2003) 111c