Study the impact of the microscopic structure on the isovector valence shell excitations in vibrational nuclei

Georgi Rainovski

Physics motivation of the HIE-ISOLDE experiments IS546 and IS596

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University of Sofia: G. Rainovski, D. Kocheva, K. Gladnishki, M. Djongolov

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et al.

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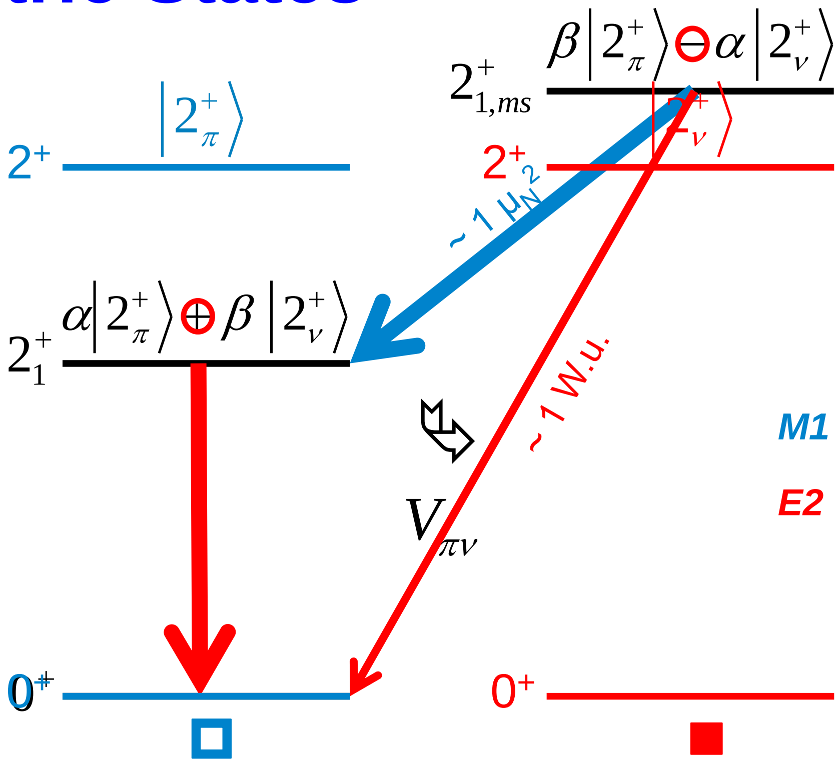
HIE-ISOLDE / MINIBALL-Collaborations

Microscopic origin of One (Quadrupole) Phonon Mixed-Symmetric States

- Nuclei are two-component quantum systems
- Coupling to symmetric and antisymmetric ("mixed-symmetric") state
- Experimental signaturte: **<u>Strong M1 transition</u>** between 2^+ states
- Defined in IBM-2 - MSSs
- Microscopic description by:
  - QPM N. Lo Iudice *et al.*, Phys. Rev. C 77, 044310 (2008)
  - LSSM D. Bianco *et al.*, Phys. Rev. C 85, 034332 (2012)



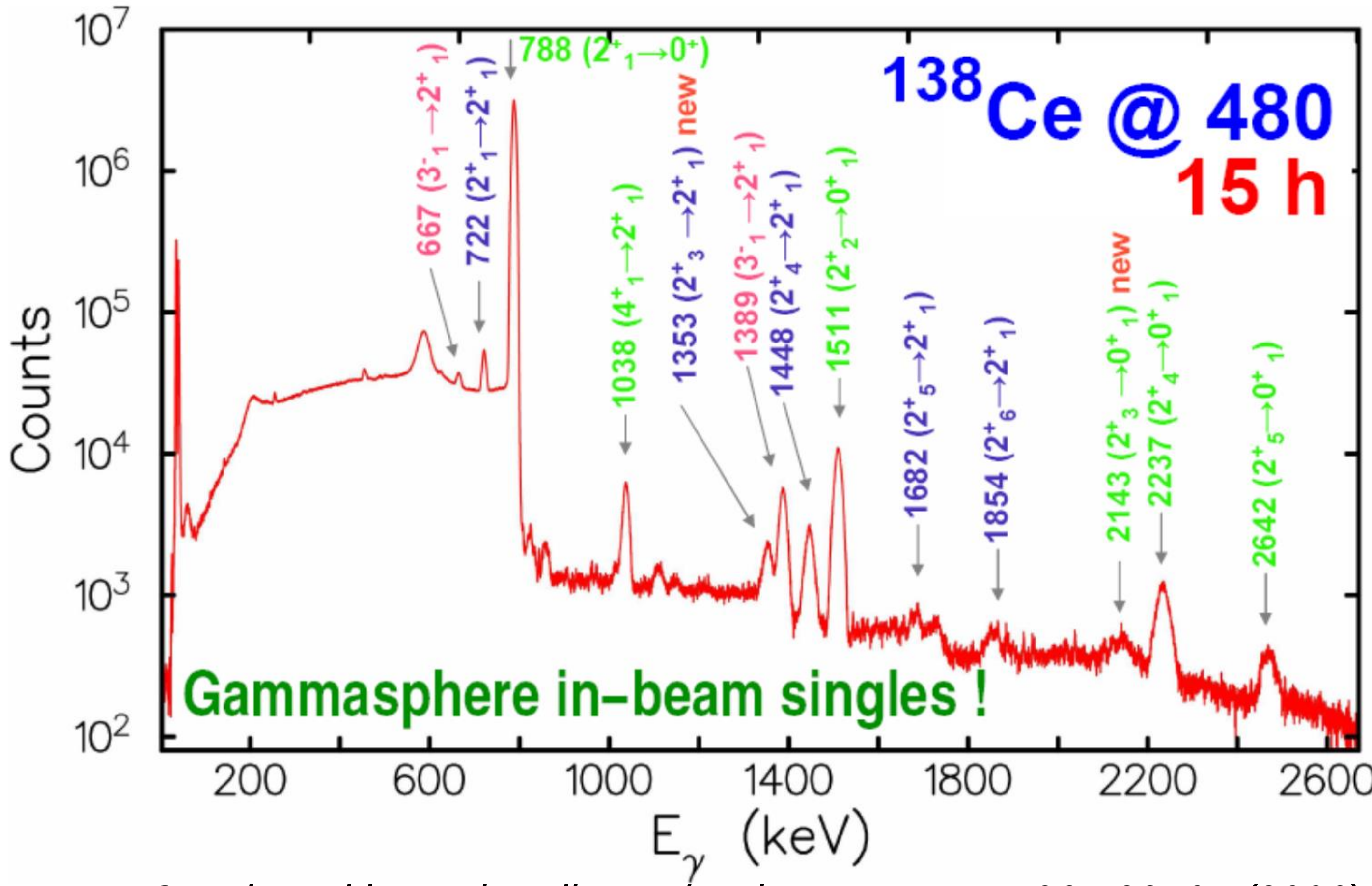
The experimental identification requires full spectroscopy $\Rightarrow$ several experiments

Extremely difficult for rare of radioactive isotopes!

Inverse kinematics Coulomb excitation reactions using Gammasphere at ANL (USA)

1) Stable beams (~ 10^9 pps) ⇒ **no need of particle detector**;
2) ^{12}C target ⇒ **no target excitations**, **normalization to $2^+_1 \rightarrow 0^+_{1,gs}$** transition;
3) Beam energy **80-85% CB**;
4) Gammasphere in **singles mode**;

- Background subtraction
- Doppler shift and Lorentz boost corrections (v~6%c)
- Angular distribution (17 rings, 17 θ)
- Coulex analysis: CLX, Gosia normalization to the B(E2; $2^+_1 \rightarrow 0^+_1$)

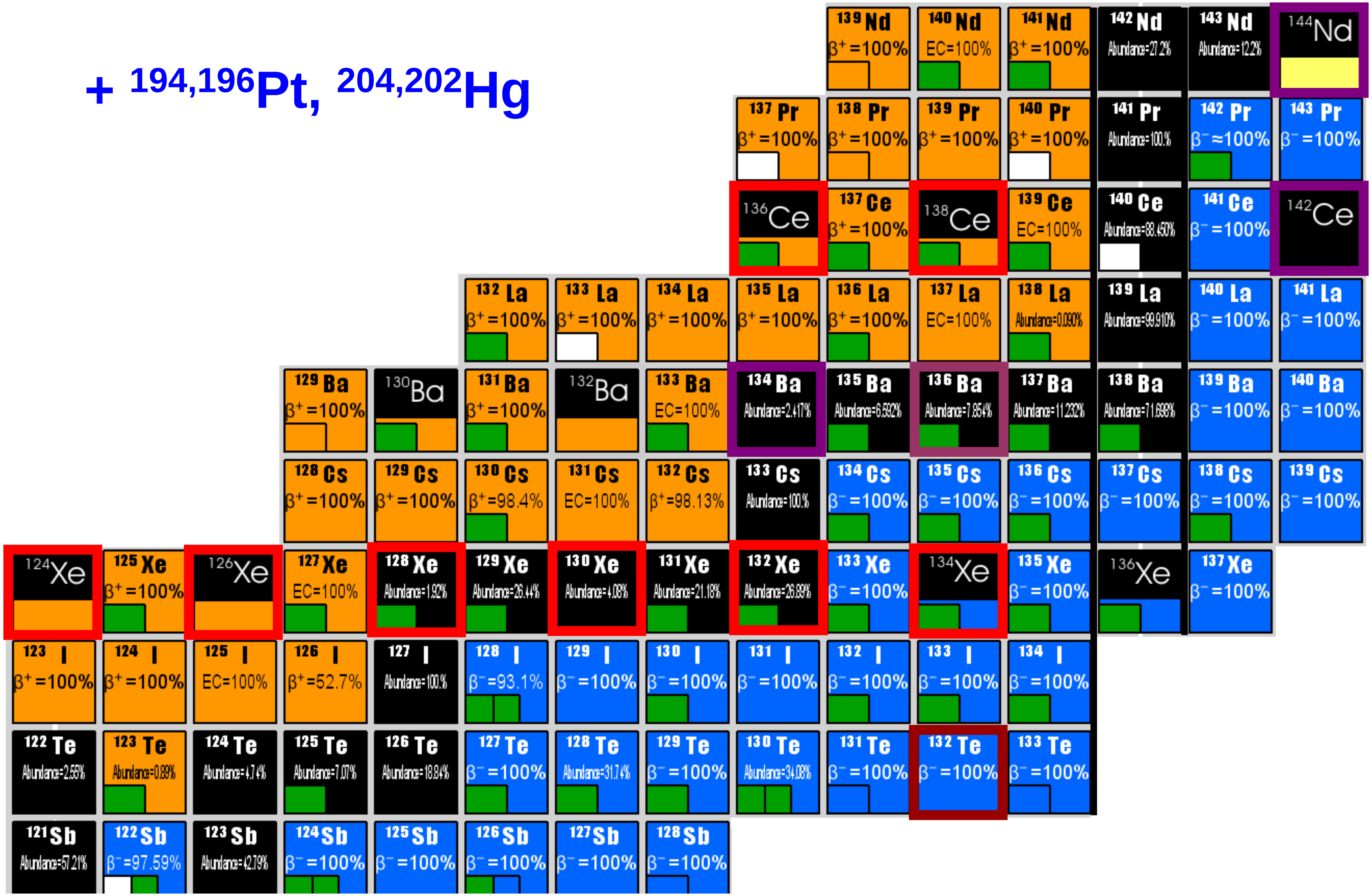


*G.Rainovski, N. Pietralla et al., Phys. Rev. Lett. **96** 122501 (2006).*

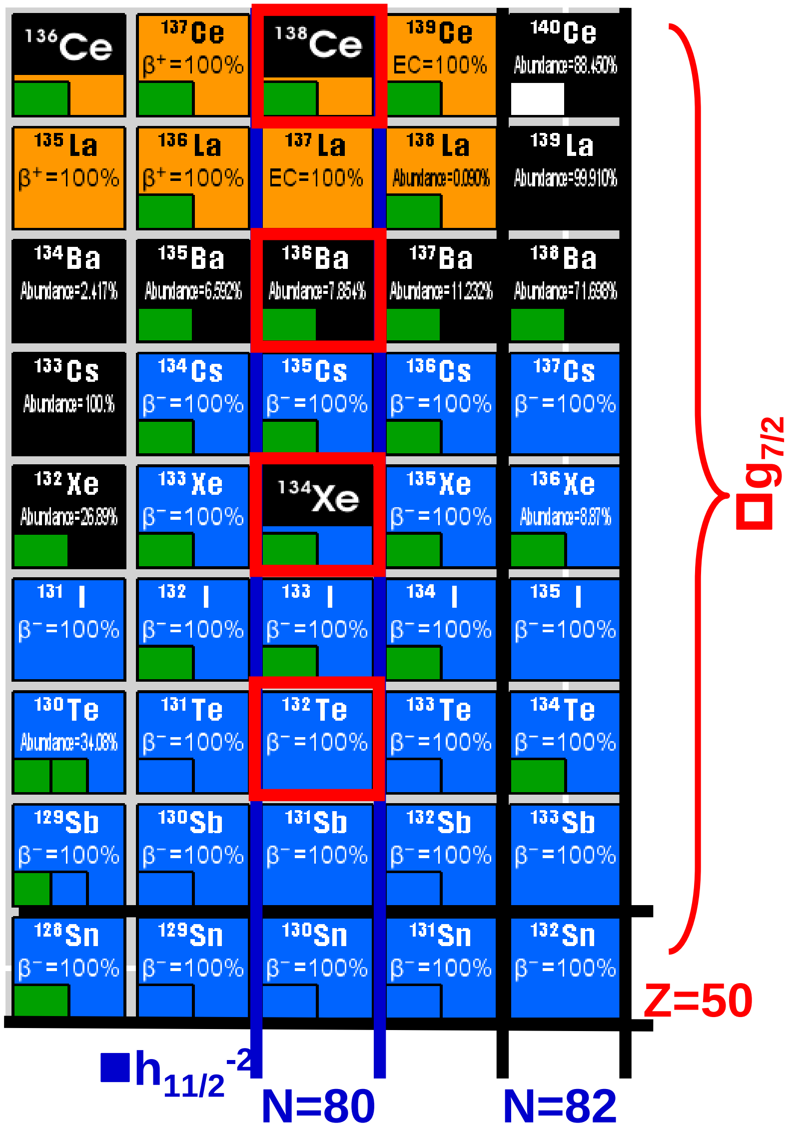
MSSs in the mass A≈130-140 region

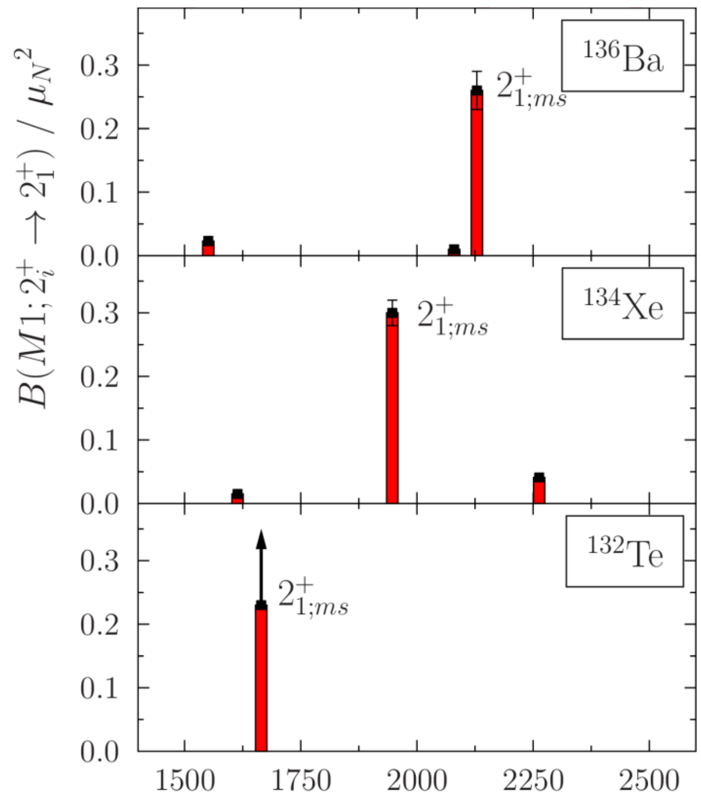
(ANL program 2005 – 2012)

+ ^{194,196}Pt, ^{204,202}Hg



Evolution of nuclear isovector valence-shell excitations in N = 80 isotones





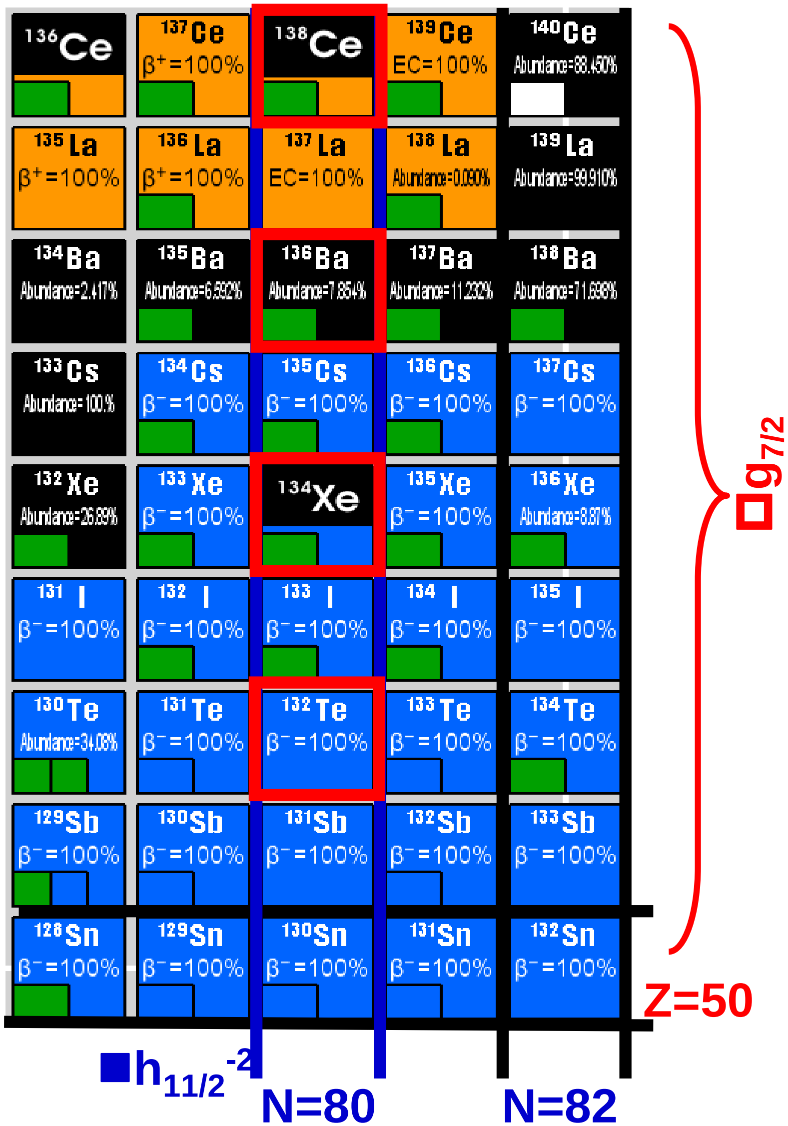
N. Pietralla et al.
PRC 58, 796 (1998)

T. Ahn et al.
PLB 679, 19 (2009)

M. Danchev et al.
PRC 84, 061306 (2011)

The properties of MSSs are sensitive to the sub-shell structure!

Evolution of nuclear isovector valence-shell excitations in N = 80 isotones



The properties of MSSs are sensitive to the sub-shell structure!

Large scale shell model

K. Sieja, G. Martínez-Pinedo, L. Coquard, N. Pietralla, Phys. Rev. C 80, 054311 (2009)

Quasiparticle-phonon model

N. Lo Iudice, Ch. Stoyanov, D. Tarpanov Phys. Rev. C 77, 044310 (2008)

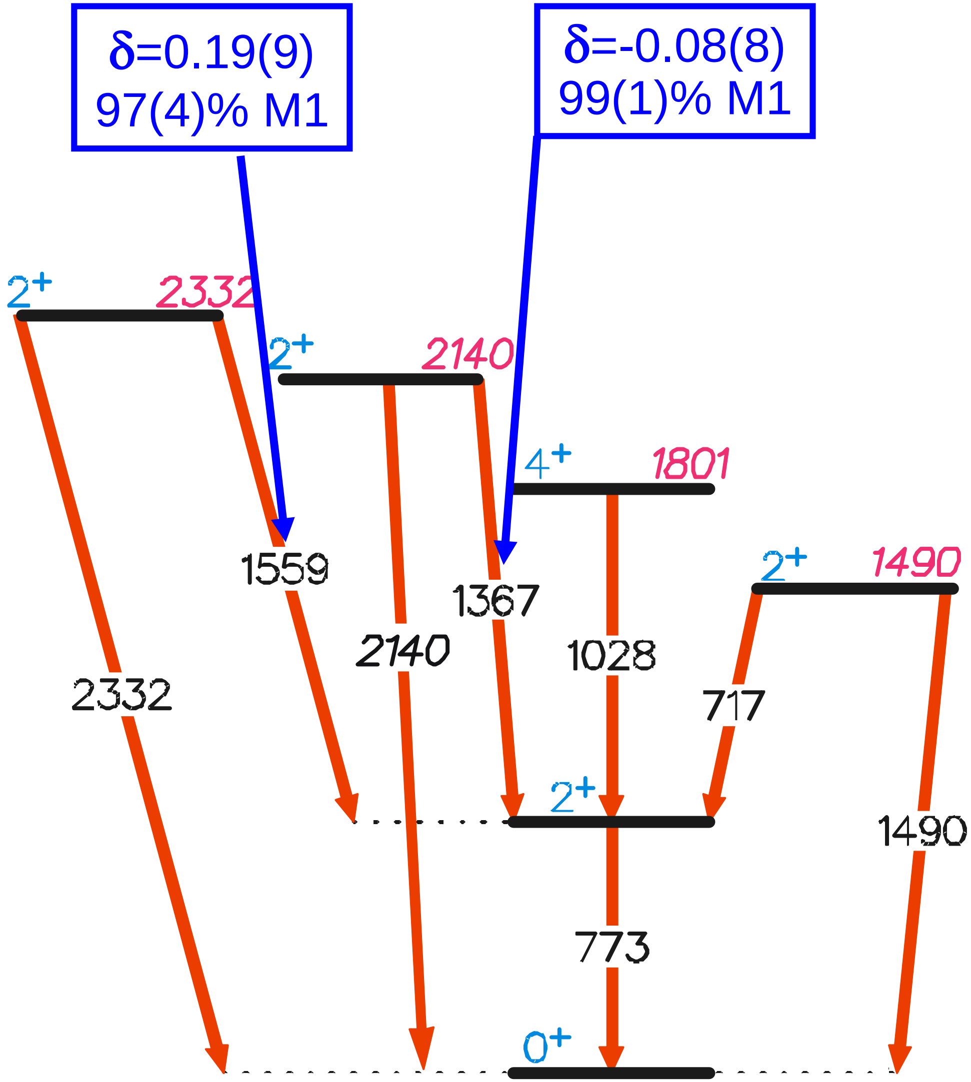
The splitting of the M1 strength in ^{138}Ce is a genuine shell effect caused by the specific shell structure and the pairing correlations!

What are the properties of MSSs of ^{140}Nd and ^{142}Sm?

^{140}Nd status

Experiment

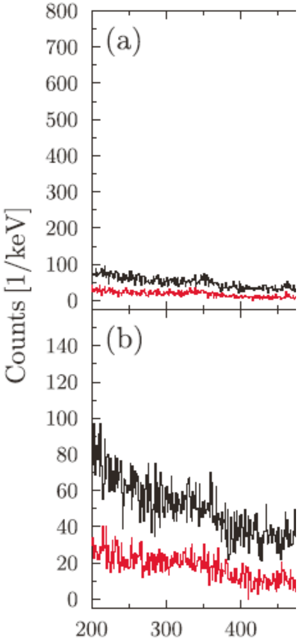
E. Williams et al., PRC 80, (2009) 054309
K. Gladnishki et al., PRC 82, (2010) 037302

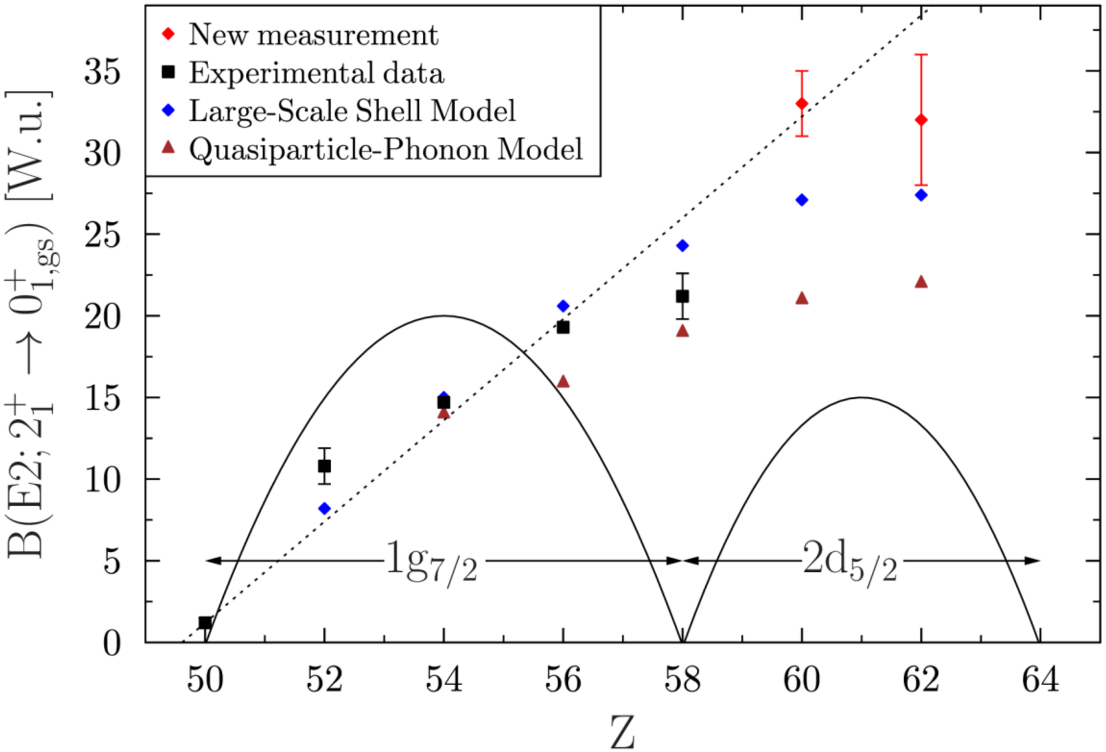


REX-ISOLDE experiment IS496

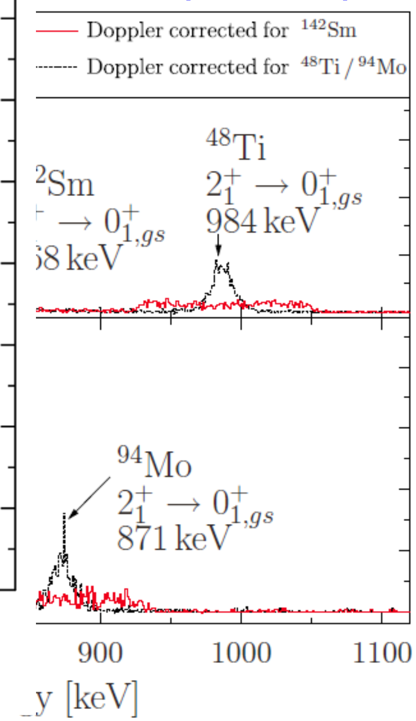
- Beams for ^{140}Nd, ^{142}Sm (primary target material: Ta) have been developed, tested and used successfully, including RILIS ionization scheme
- Beam intensities: ^{140}Nd - **5×10⁵ pps** (contaminations ^{140}Sm, laser on/off), ^{142}Sm - **10⁵ pps** (contaminations ^{142}Eu, ^{142}Pm, decay spectroscopy 8.8(62)%)
- Beam energy 2.85 MeV/u

^{140}Nd: 07.2011





.2012 (5 shifts)



^{140}Nd: 33 (2) W.u.

^{142}Sm: 32 (4) W.u.

C. Bauer et al., Phys. Rev. C 88, 021302 (2013)

R. Stegmann et al., Phys. Rev. C 91, 054326 (2015)

HIE-ISOLDE experiment IS546

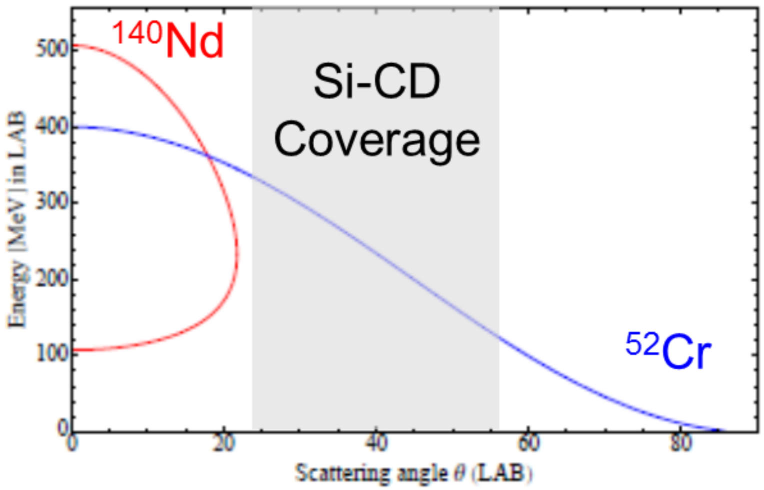
42 shifts recommended by INTC (18 for ^{140}Nd, 24 for ^{142}Sm)

Measure E/M matrix elements from Coulex yields using **MINIBALL + C-REX(DSSD)** ⇒
Quantitative identification of 2^+ MSSs of ^{140}Nd and ^{142}Sm via measurement of B(M1) strength

- Model predictions for ^{140}Nd: SM - Fragmented MSS
  QPM: Single isolated MSS
  } Shell stabilization of MSSs?
- Beam: ^{140}Nd and ^{142}Sm RILIS beams – **developed and tested!**
- Beam energy 3.62 MeV/u for ^{52}Cr target or 4.5 MeV/u for ^{208}Pb target (85% CB)

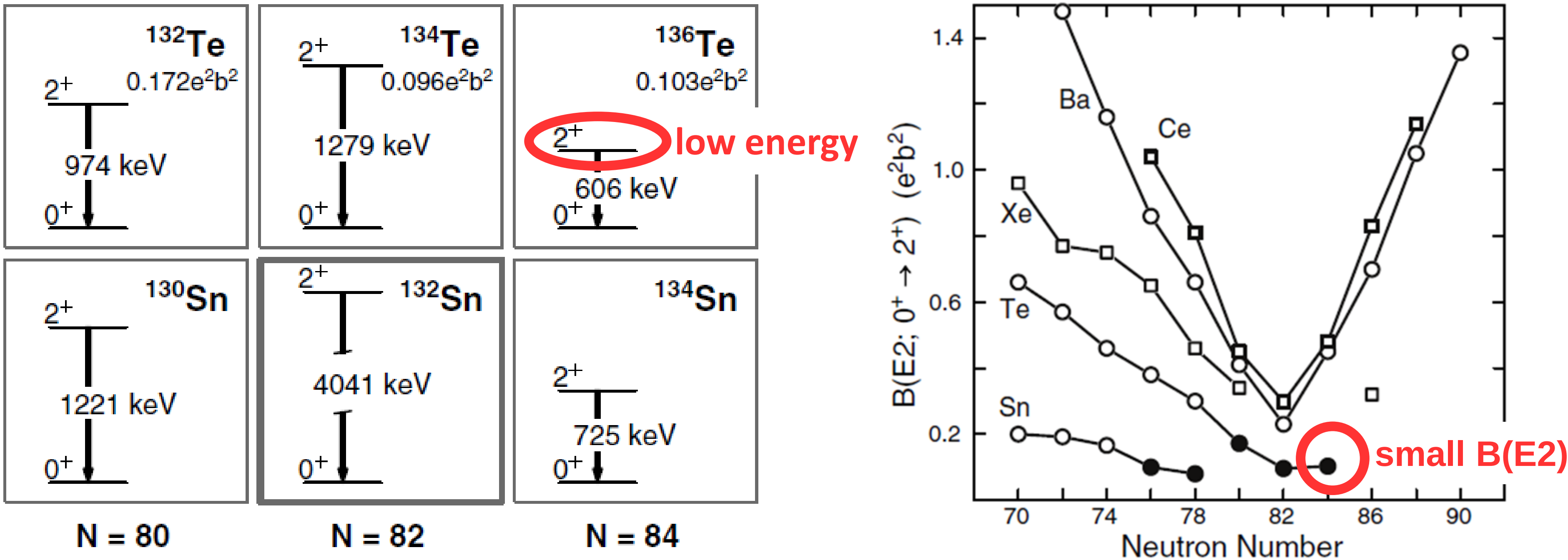
E_{level}(keV)	J^{π}	γ's/day 2 mg/cm² ^{52}Cr	γ's/day 2 mg/cm² ^{208}Pb
774	2^+_1	17228	54114
1490	2^+_2	328	2421
2267	2^+_4	**147**	**196**
2468	2^+_5	8.6	72

↑ 6 days ↑ 4.5 days



Can be run immediately!

B(E2) “anomaly" in ^{136}Te



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

Shell Model:
N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)
QRPA:
J. Terasaki et al., PRC 66, 054313 (2002)

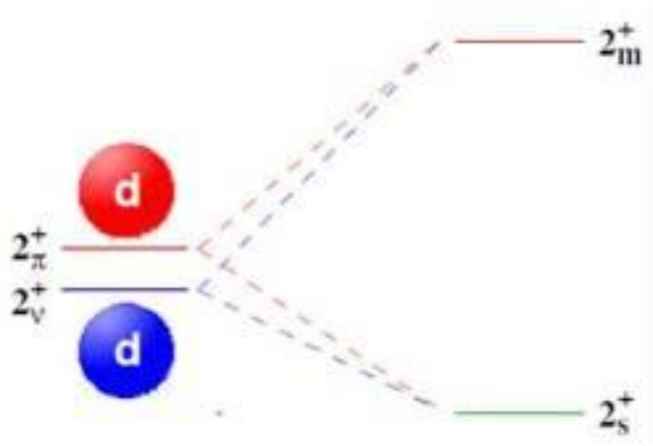
Origin of the anomaly:

Neutron dominance in the 2_1^+ wave function, resulting as a combined effect of:

- the asymmetry in the excitation energies of the basic 2^+ proton and neutron configurations;
- week proton-neutron interaction;

Configurational Isospin Polarization (CIP)

J.D. Holt *et al.*, PRC 76, 034325 (2007)



$$2^+_{ms} = a_2 2^+_n - b_2 2^+_p$$

$$2^+_{sym} = a_1 2^+_n + b_1 2^+_p$$

$| a_i | \approx | b_i |$ protons and neutrons contribute about equally: strong mixing (no CIP)

$| a_i | \neq | b_i |$ imbalance in proton and neutron contributions: week mixing (CIP)

Observables which are sensitive to p/n content:

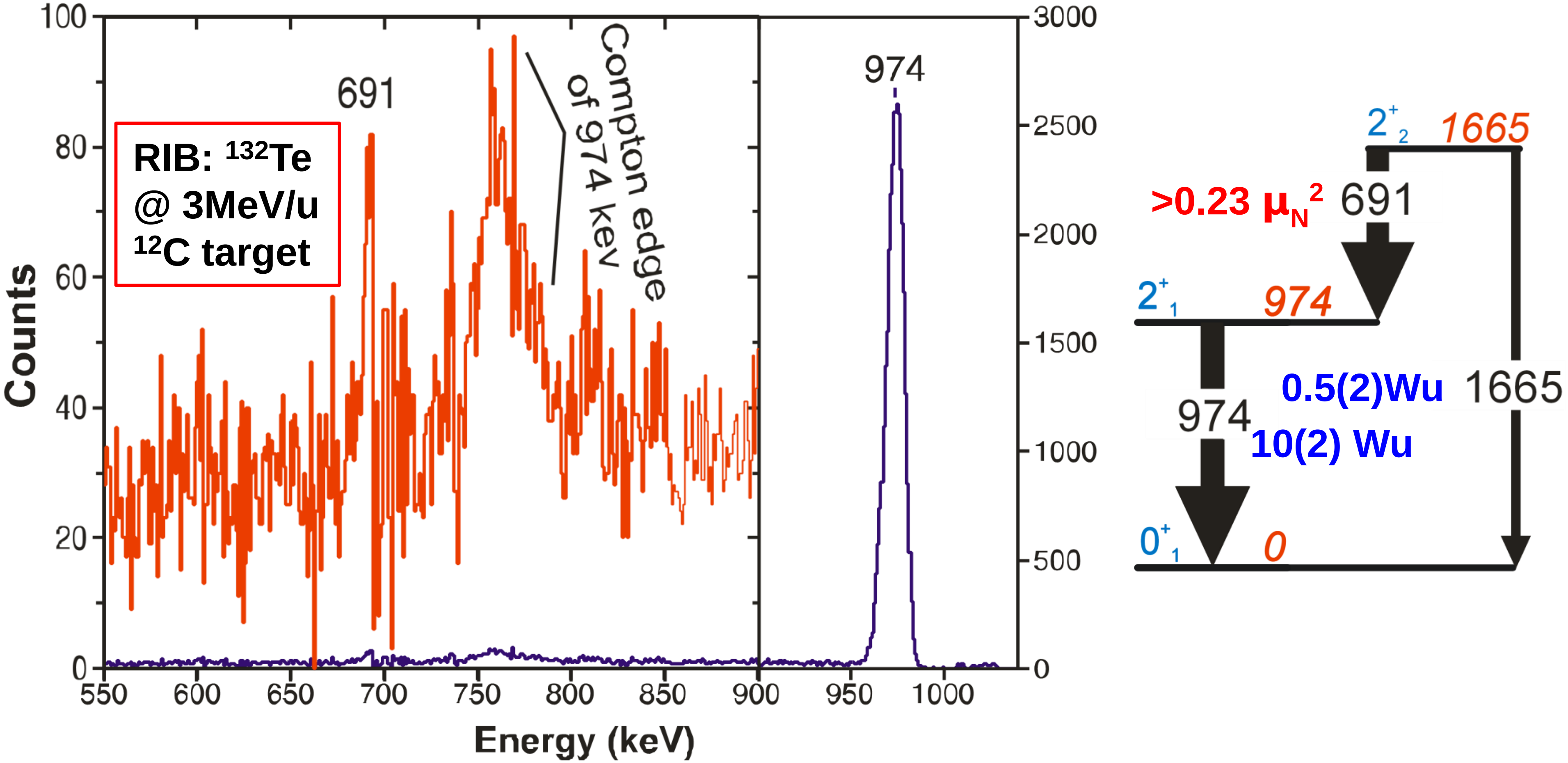
B(E2)'s and M1

^{132}Te(No CIP)
strong M1 $2^+_{ms} \rightarrow 2^+_1$
week E2 $2^+_{ms} \rightarrow 0^+_1$

^{136}Te(CIP)
week M1 $2^+_{ms} \rightarrow 2^+_1$
strong E2 $2^+_{ms} \rightarrow 0^+_1$

^{132}Te – first MS observation with RIB

$2^+_{1,MS}$ observed in coincidence with ^{12}C recoils detected in HyBall.



M. Danchev, G. Rainovski, N. Pietralla *et al.*, Phys. Rev. C 84 (2011) 061306(R)

Configurational Isospin Polarization
the case of ^{132}Te – no CIP

Shell model calculations
(A. Gargano, A. Covello)

Interaction:
$V_{low\text{-}k}$ from the CD-Bonn potential, core – ^{132}Sn;

Space:
$\{0g_{7/2}, 1d_{5/2}, 1d_{3/2}, 2s_{1/2}, 0h_{11/2}\}$
for both protons and neutrons;

Observable	Experiment	Shell Model
$B(E2; 2^+_1 \rightarrow 0^+_1)$ [Wu]	10(1)	7.8
$\mu(2^+_1)$ [μ_N]	+0.92(10)	+0.68
$B(E2; 2^+_2 \rightarrow 0^+_1)$ [Wu]	0.5(1)	0.21
$B(E2; 2^+_2 \rightarrow 2^+_1)$ [Wu]	0 ÷ 20	0.24
$B(M1; 2^+_2 \rightarrow 2^+_1)$ [μ_N^2]	>0.23	0.20

$|0^+_1\rangle = 0.94\, |0^+_1\rangle_\nu |0^+_1\rangle_\pi + \ldots$

$|2^+_1\rangle = 0.66\, |0^+_1\rangle_\nu |2^+_1\rangle_\pi + 0.62\, |2^+_1\rangle_\nu |0^+_1\rangle_\pi + \ldots$

$|2^+_2\rangle = 0.58\, |0^+_1\rangle_\nu |2^+_1\rangle_\pi - 0.63\, |2^+_1\rangle_\nu |0^+_1\rangle_\pi + \ldots$

$|0^+_1\rangle_\nu = |0^+_1;\, ^{130}\mathrm{Sn}\rangle$

$|2^+_1\rangle_\nu = |2^+_1;\, ^{130}\mathrm{Sn}\rangle$

$|0^+_1\rangle_\pi = |0^+_1;\, ^{134}\mathrm{Te}\rangle$

$|2^+_1\rangle_\pi = |2^+_1;\, ^{134}\mathrm{Te}\rangle$

Almost balanced proton-neutron characters, i.e. no **CIP**
(J. D. Holt *et al*., Phys. Rev. C **76,** 034325 (2007))

CIP case predicted: ^{136}Te

QPM: A.P. Severyukhin, N.N. Arsenyev, N. Pietralla, Volker Werner, PRC 90, 011306(R) (2014)

2^+_1 and 2^+_2 have significant E2 $\rightarrow$ 1-phonon states
Strong M1 between them $\rightarrow$ $2^+_2 = 2^+_{1,MS}$

$[2_1^+]_{QRPA}$ = ~86% Neutron, $[2_2^+]_{QRPA}$ ~68% Proton (opposite phase)

$\lambda_i^\pi = 2_i^+$	Energy (MeV)		Structure	$B(E2; 0^+_{gs} \to 2^+_i)$ (e^2fm^4)		$B(E2; 2^+_i \to 2^+_1)$ (e^2fm^4)		$B(M1; 2^+_i \to 2^+_1)$ (μ_N^2)	
	Expt.	Theory		Expt.	Theory	Expt.	Theory	Expt.	Theory
^{136}Te 2_1^+	0.606	0.92	$97\%[2_1^+]_{QRPA}$	1220 ± 180	1120				
2_2^+	1.568	2.01	$94\%[2_2^+]_{QRPA}$		740		20		0.51

Shell Model:

- **N. Shimizu *et al.*, PRC 70, 054313 (2004);**
- **N. Lo Iudice *et al.*, Phys. Rev. C 77, 044310 (2008);**
- **D. Bianco *et al.*, Phys. Rev. C 84, 024310 (2011);**
- **D. Bianco *et al.*, Phys. Rev. C 85, 034332 (2012);**
- **D. Bianco *et al.*, Phys. Rev. C 86, 044325 (2012);**
- **D. Bianco *et al.*, Phys. Rev. C 88, 024303 (2013);**

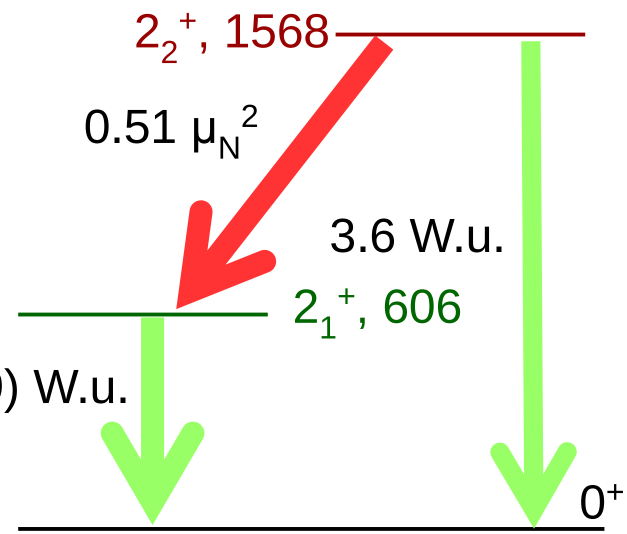
^{136}Te: 2_1^+ neutron dominated
2_2^+ - MS state,
proton dominated

Needs to be experimentally proven!
B(E2) and B(M1) strengths of the lowest 2^+ states.

HIE-ISOLDE experiment IS596

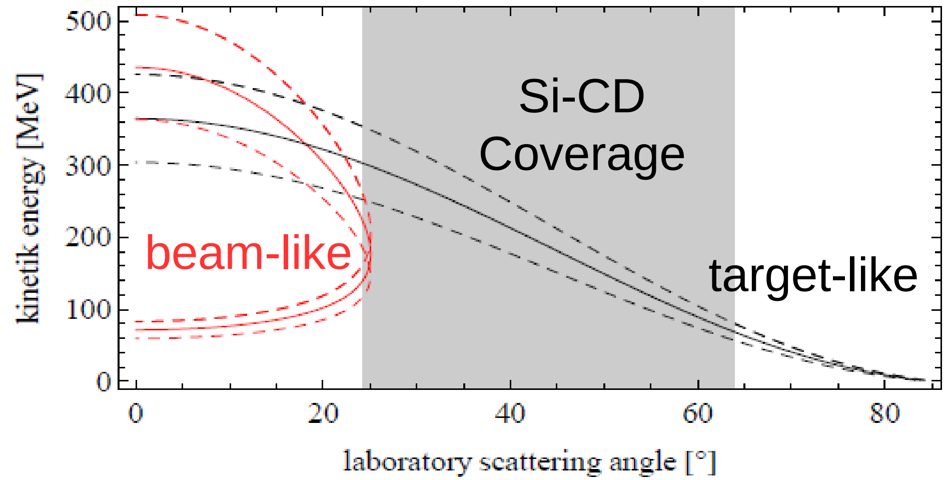
9 shifts recommended by INTC

Measure E/M matrix elements from Coulex yields using MINIBALL + C-REX(DSSD)

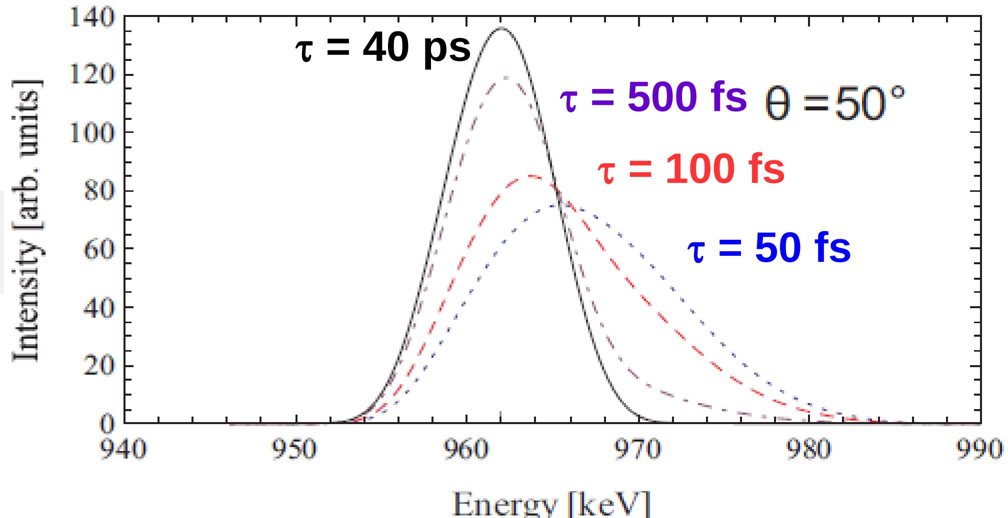


Needs beam development!

Primary target UC_x/graphene, RILIS beam
E_{beam}= 510 MeV, target 3 mg/cm^2 ^{58}Ni



In addition, measure ~100 fs 2_2^+ lifetime through differential DSAM



Thank you for your attention!