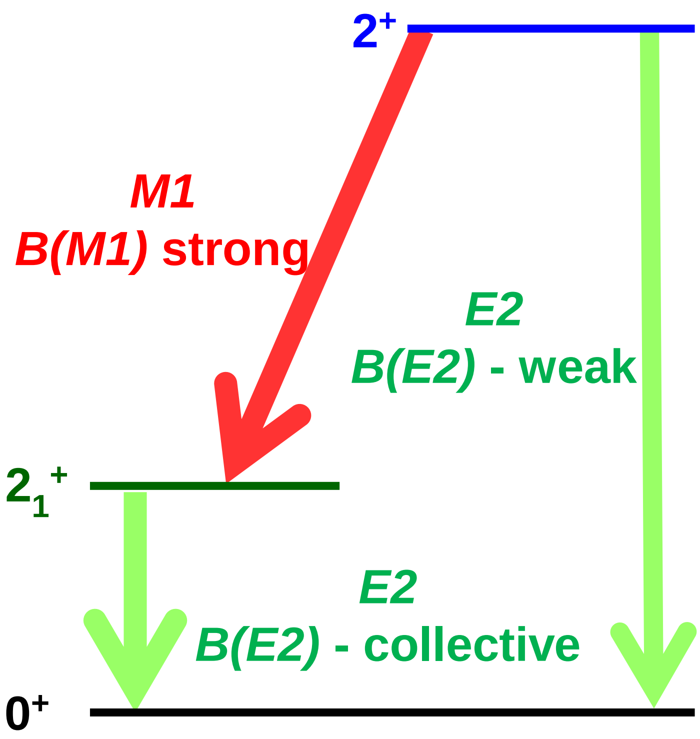
Impact of microscopic structure on isovector valence shell excitations of nuclei near N=82

HIE-ISOLDE experiments IS546 and IS596

Norbert Pietralla, TU Darmstadt



TU Darmstadt: N.Pietralla, R.Stegmann, C.Stahl, V.Werner, S. Ilieva, T.Kröll, M.Lettmann, O.Möller, M.Reese, M.Thürauf

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

University of Cologne: J.Jolie, A.Blahzev, C.Fransen, N.Warr

et al.

&

ISOLDE- / MINIBALL-Collaborations

Microscopic origin of Quadrupole Mixed-Symmetric States

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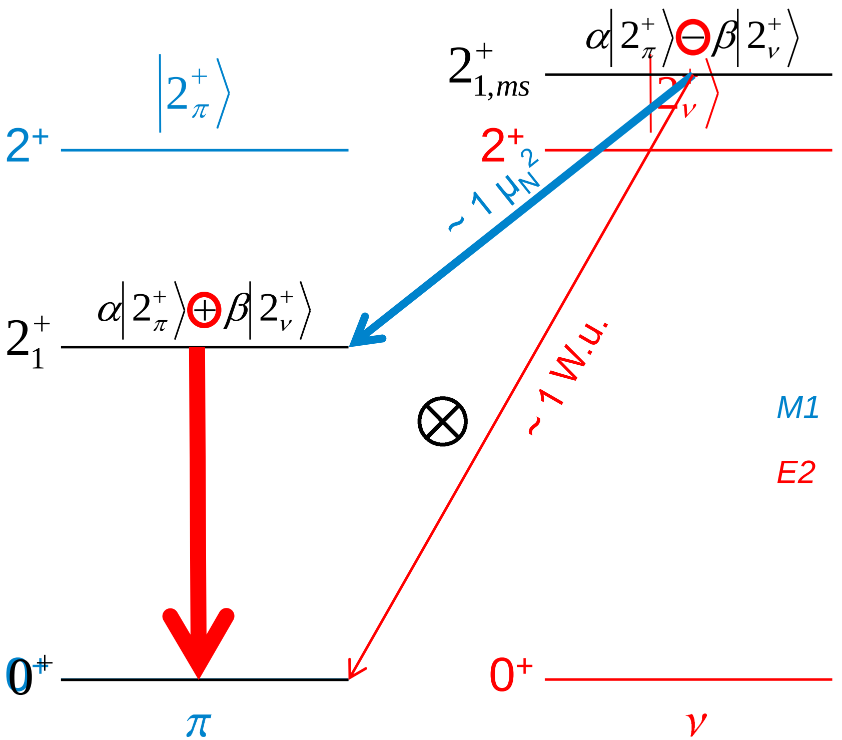
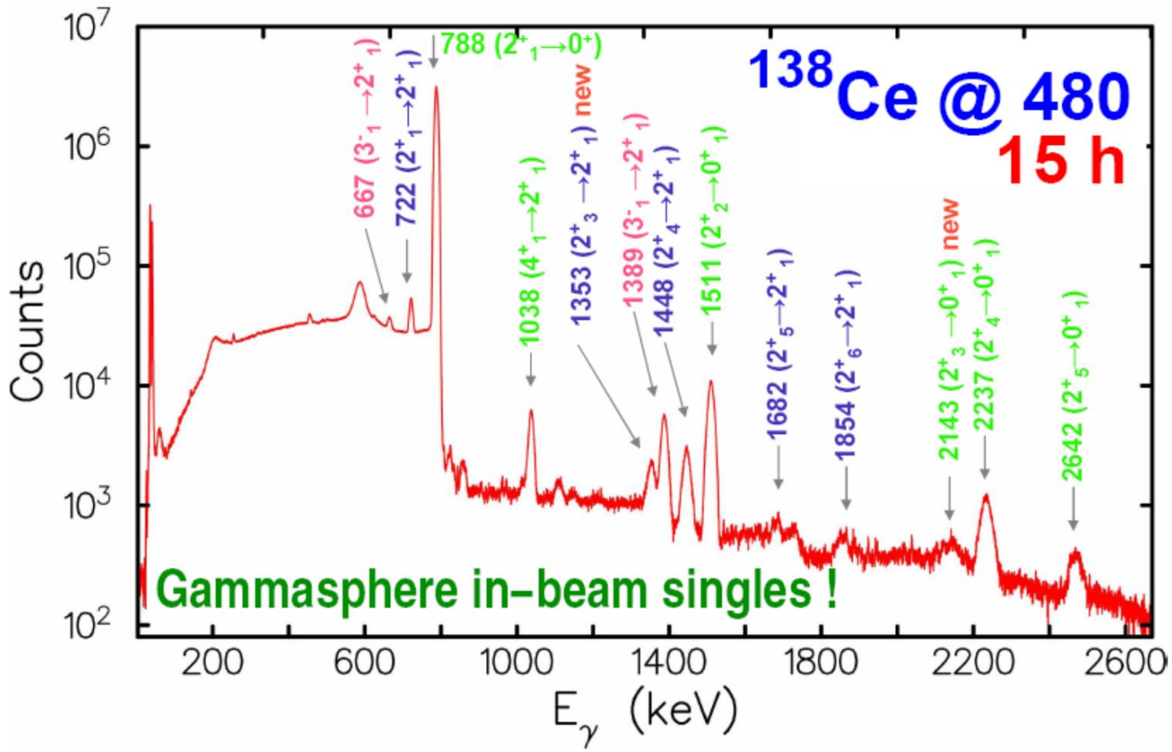
- Nuclei are two-component quantum systems
- Coupling to symmetric and antisymmetric ("mixed-symmetric") state
- Fingerprint: Strong M1 transition between 2^+ states
- Predicted by IBM-2
- Microscopic description by:
  - QPM N. Lo Iudice *et al.*, Phys. Rev. C 77, 044310 (2008)
  - LSSM D. Bianco *et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



Experimental approach – Inverse Kinematics Coulomb excitation reactions ANL program

- Background subtraction
- Doppler shift corrections
- Lorentz boost corrections (v~6%c)
- Angular distributions (Gammasphere=17 rings, 17 θ)
- Coulex analysis: Coulex codes (CLX, Gosia)



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

IS546

Coulex of ^{140}Nd, ^{142}Sm

Stabilization of Nuclear Isovector Valence-Shell Excitations

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

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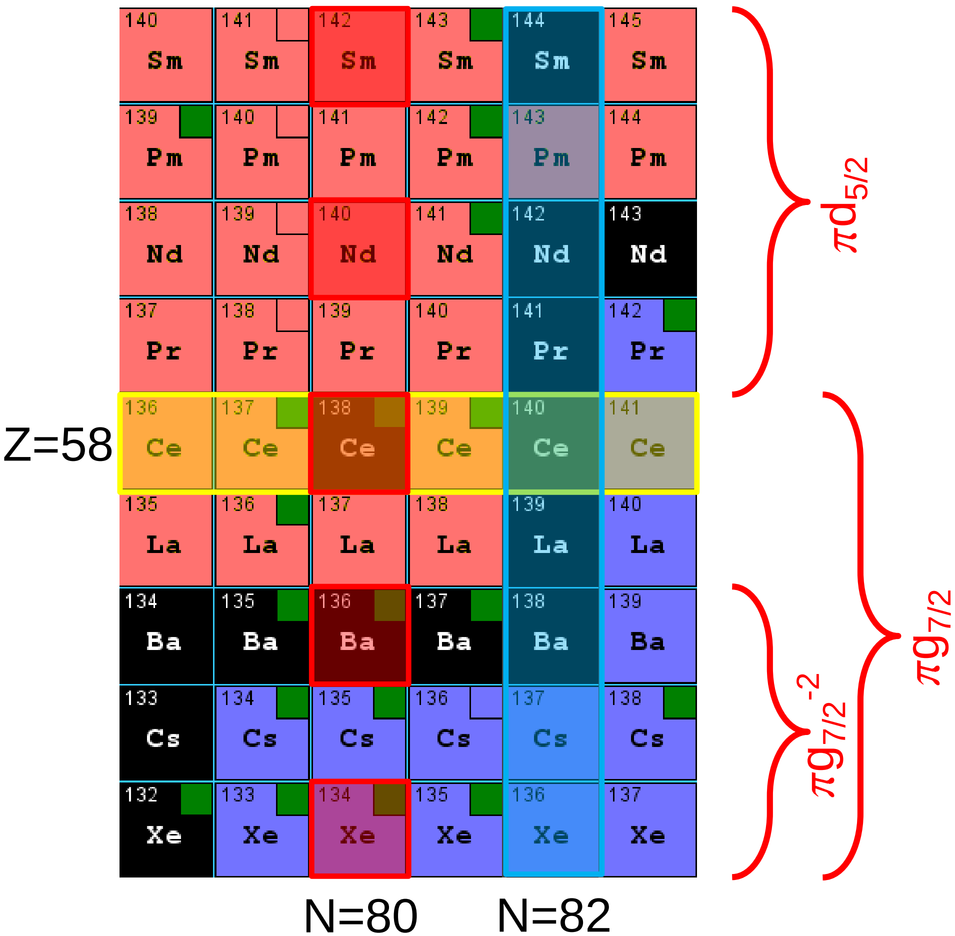
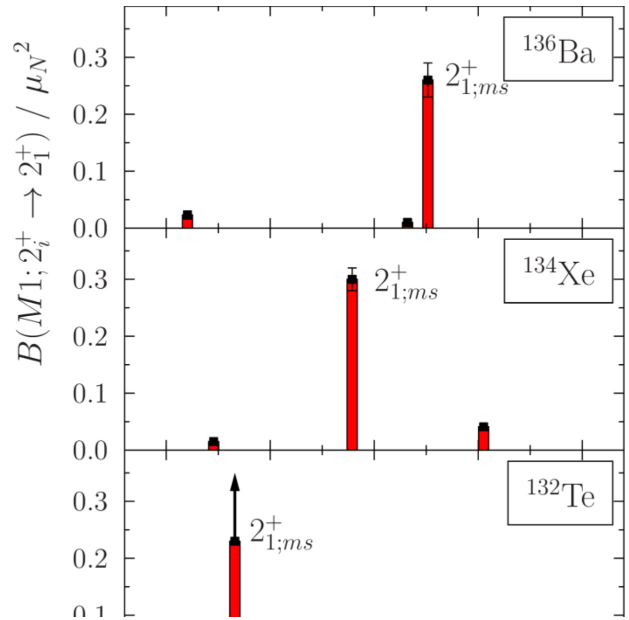


G. Rainovski et al.
PRL 96, 122501 (2006)

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



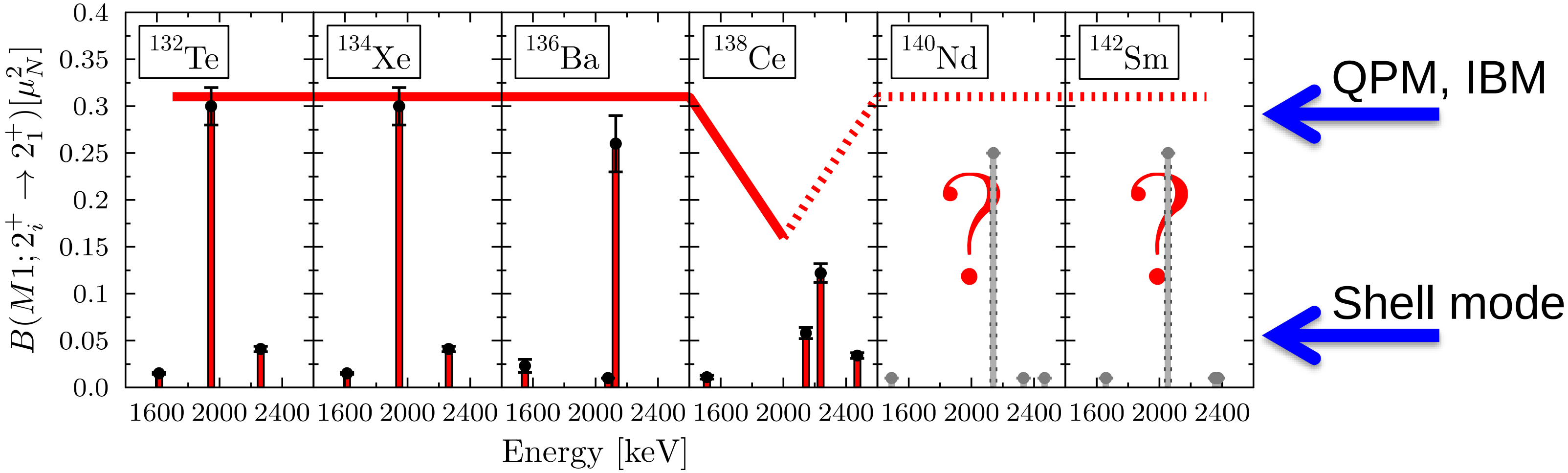
N. Pietralla et al.
PRC 58, 796 (1998)

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!

Motivation: Stabilization of Nuclear Isovector Valence-Shell Excitations – ^{140}Nd and ^{142}Sm



- Single 2^+ MSS of ^{132}Te, ^{134}Xe, ^{136}Ba
- Fragmented 2^+ MSS of ^{138}Ce
- QPM and SM reproduce situation in N=80

What is the predictive power?

- QPM: single 2^+ MSS of ^{140}Nd
- SM: fragmented 2^+ MSS of ^{140}Nd

Need to identify and quantitatively study MSSs of ^{140}Nd and ^{142}Sm

Preparation: REX-ISOLDE experiment IS496

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Hitherto method (*e.g.* ^{138}Ce):

- Coulomb excitation at 80-85% CB
- GAMMASPHERE in singles mode
  → Without particle detector
- Beam intensity ~ 10^9 pps possible
- ^{12}C target → Inverse kinematics
  → No target excitation
  → Normalization to $2_1^+ \rightarrow 0_{1,gs}^+$ transition

But: Stable beams!

Situation for ^{140}Nd, ^{142}Sm:

- Radioactive nuclei
  → Beam development
  → Particle detector necessary
- Lower beam energy – 60-65% CB (2.85 Mev/u)
- Lower beam intensity
- $B(E2;2_1^+ \rightarrow 0_{1,gs}^+)$ unknown
  → Necessity to measure B(E2)
- previous REX-ISOLDE IS496

Previous REX-ISOLDE experiment IS496
Experimental runs

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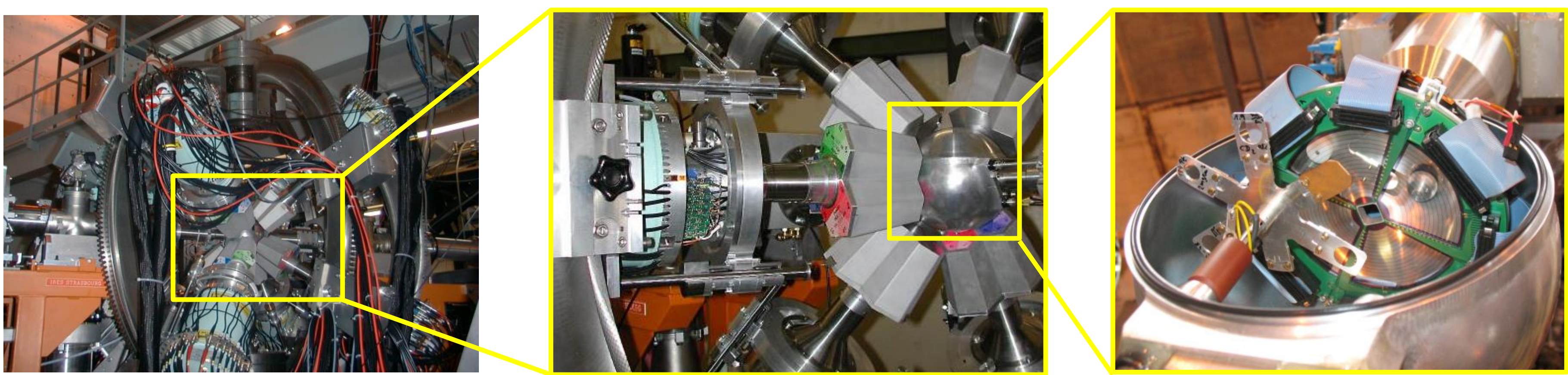
01.07. – 04.07.2011

- Beam: ^{140}Nd
- Contamination: ^{140}Sm
- 2.85 MeV/u (E_{kin} = 399 MeV)
- HRS & RILIS
- Target: ^{48}Ti (1.4 mg/cm^2)
  ^{64}Zn (1.55 mg/cm^2)

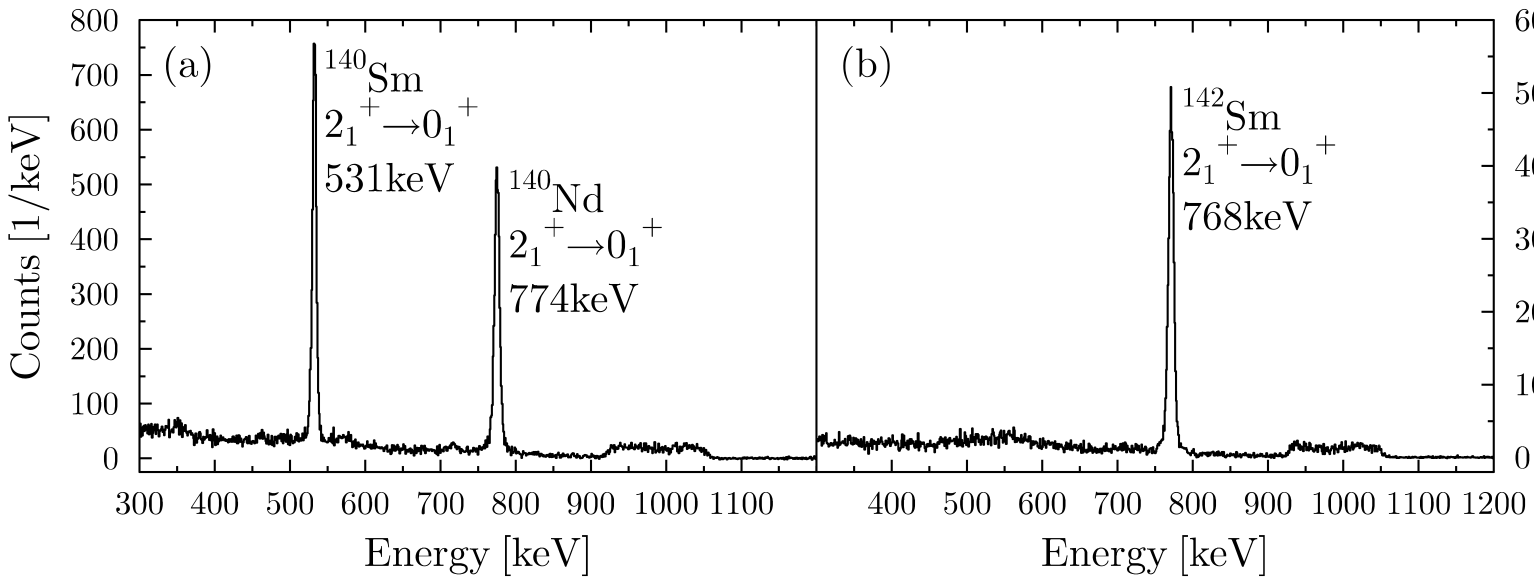
28.06. – 30.06.2012

- Beam: ^{142}Sm
- Contamination: ^{142}Eu, ^{142}Pm
- 2.85 MeV/u (E_{kin} = 405 MeV)
- GPS & RILIS
- Target: ^{48}Ti (1.4 mg/cm^2)
  ^{94}Mo (2 mg/cm^2)



Previous REX-ISOLDE experiment IS496
Results

- Beams for ^{140}Nd, ^{142}Sm (primary target material: Ta) have been developed, tested and used successfully
- Including RILIS ionization scheme
- Beam intensities ~ 10^5 – 10^6 pps



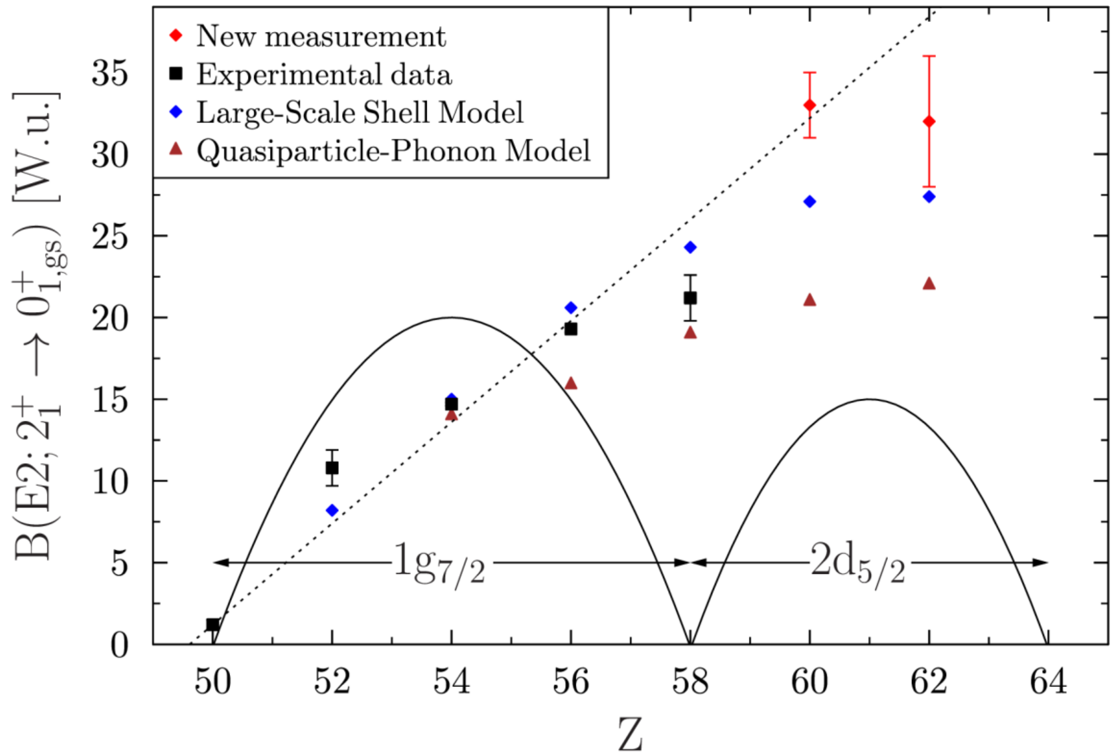
REX-ISOLDE experiment IS496
Results

$$B(E2;2_1^+ \rightarrow 0_{1,gs}^+)$$

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

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

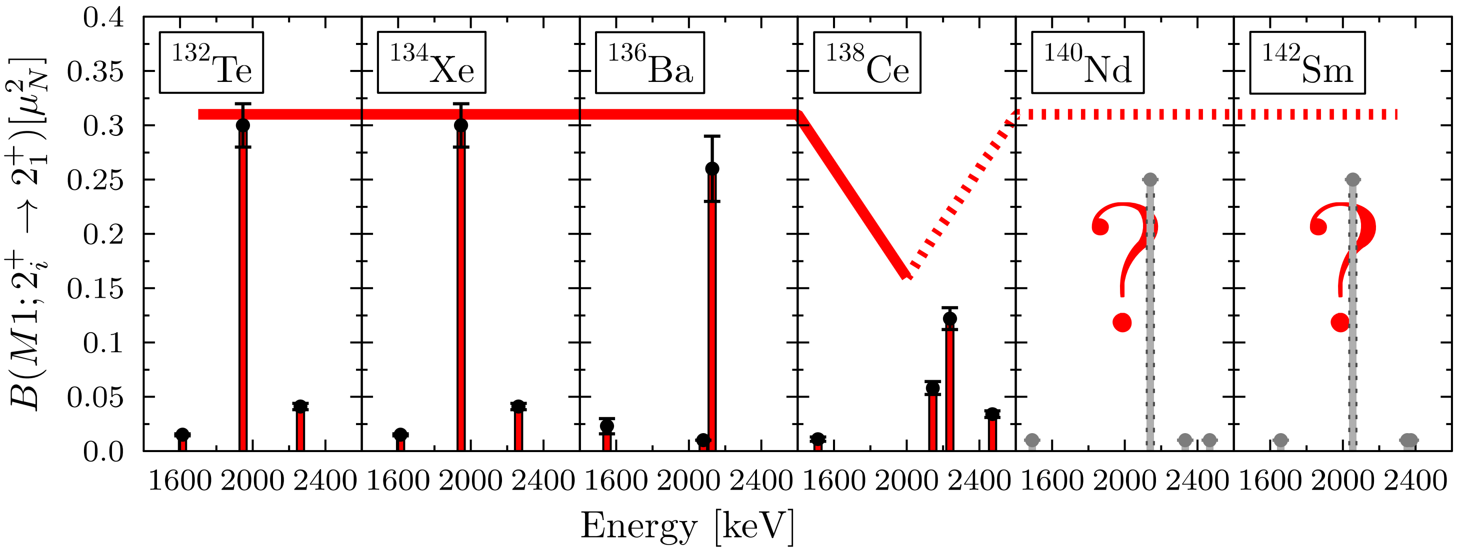
Z=58 sub-shell closure in data



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

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

Preparation done: Proceed to IS546
^{140}Nd and ^{142}Sm @ HIE-ISOLDE



Is sub-shell closure at Z=58 responsible for fragmentation?

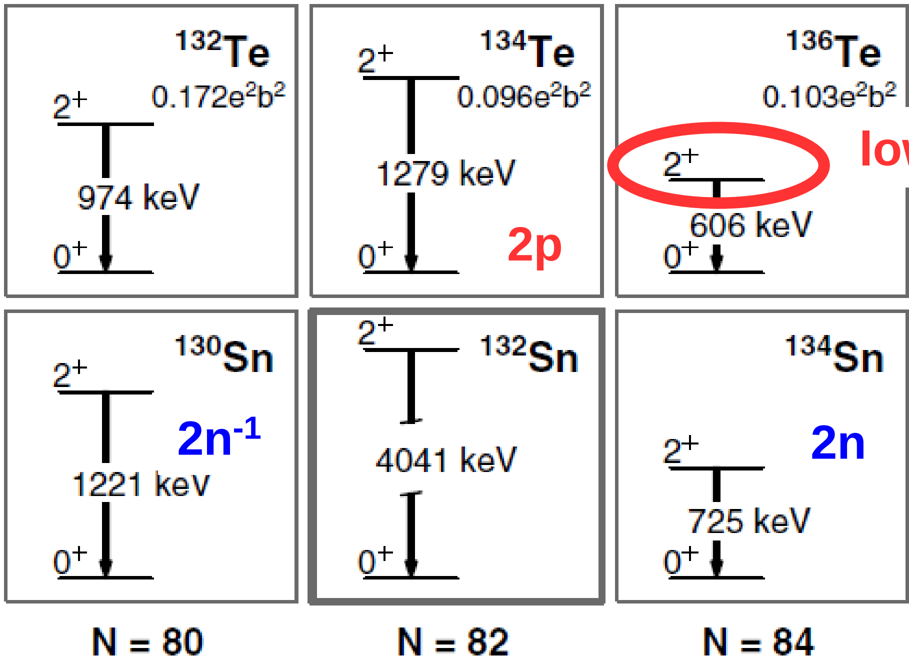
Or does the increasing valence space dissolve the isovector structure?

HIE-ISOLDE (~4 MeV/u) enables us now to identify and quantitatively study MSSs of ^{140}Nd and ^{142}Sm: IS546

IS596

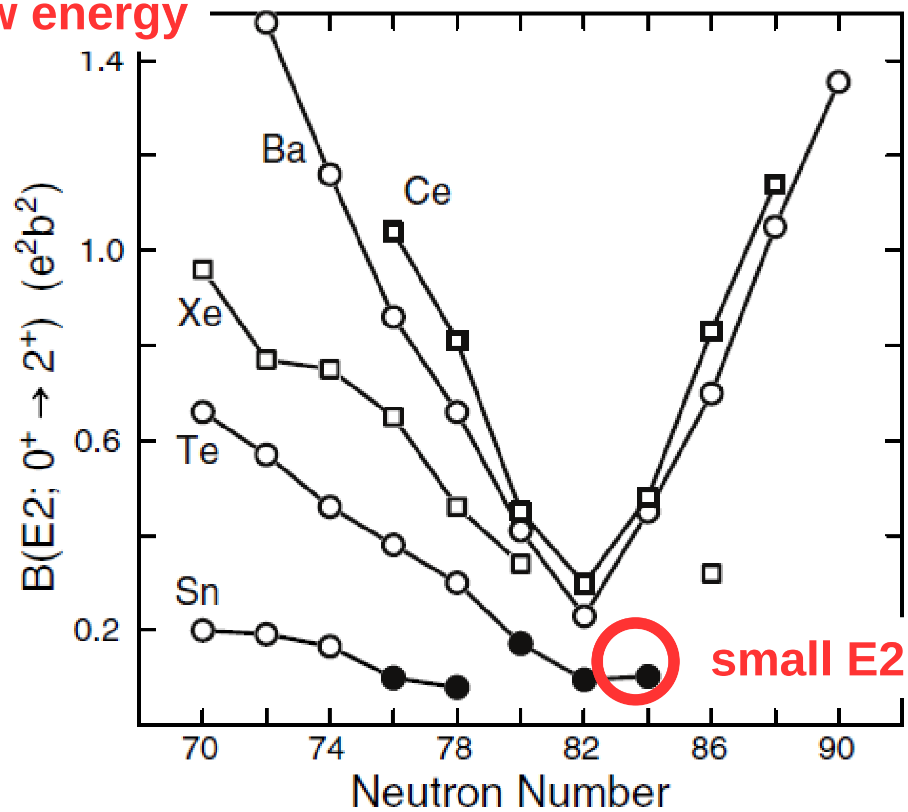
Coulex of ^{136}Te

B(E2) "anomaly" in ^{136}Te



Origin of the anomaly:

Neutron dominance in the 2_1^+ wave function



Shell Model:

N. Shimizu, T. Otsuka, T. Mizusaki, M. Honma, PRC 70, 054313 (2004)

QRPA:

J. Terasaki et al., PRC 66, 054313 (2002)

Configurational Isospin Polarization
^{132}Te – first MS observation with RIB

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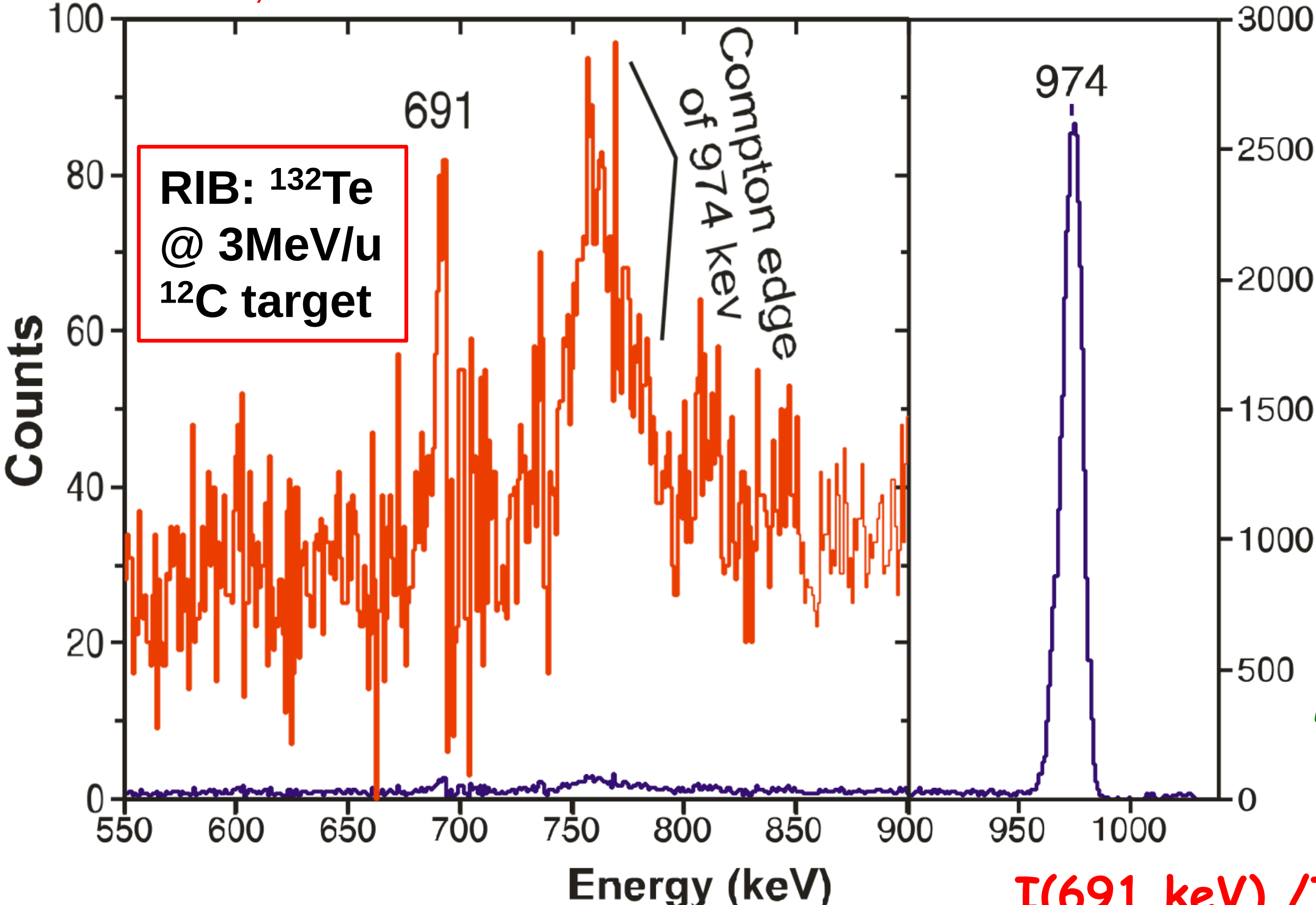
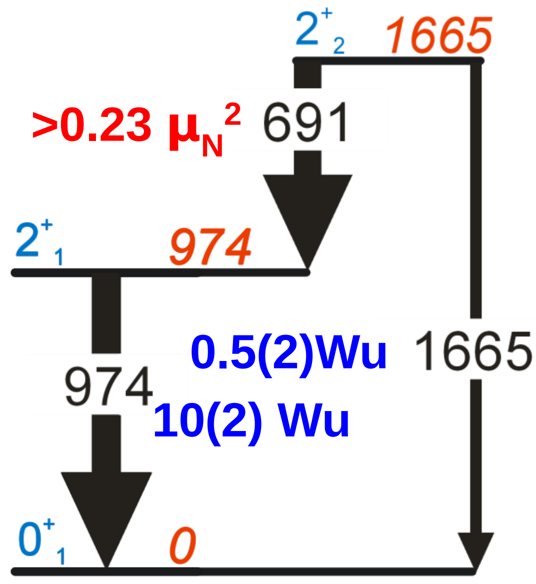
$2^+_{1,MS}$ observed in coincidence with ^{12}C recoils detected in HyBall.





M. Danchev, G. Rainovski, N. Pietralla *et al.*, PRC84 ('11) 061306(R)

I(691 keV) /I(1665 keV) = 100(52)

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

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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

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

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

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

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

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

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

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

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

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Skyrme-QPM: A.Severyukhin, N.Arsenyev, N.Pietralla, V.Werner, PRC 90, 011306(R) (2014)

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

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

	$\lambda_i^\pi = 2_i^+$	Energy (MeV) Expt.	Energy (MeV) Theory	Structure	$B(E2; 0^+_{gs} \to 2^+_i)$ (e^2fm^4) Expt.	$B(E2; 0^+_{gs} \to 2^+_i)$ (e^2fm^4) Theory	$B(E2; 2^+_i \to 2^+_1)$ (e^2fm^4) Expt.	$B(E2; 2^+_i \to 2^+_1)$ (e^2fm^4) Theory	$B(M1; 2^+_i \to 2^+_1)$ (μ_N^2) Expt.	$B(M1; 2^+_i \to 2^+_1)$ (μ_N^2) 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);

Strongly broken *p-n* exchange symmetry

^{136}Te: 2_1^+ neutron dominated
2_2^+ - "MS state", proton domin.
„Smoking gun“ for reduced pn-interaction for cause of Te anomaly

HIE-ISOLDE experiment IS546

42 shifts recommended by INTC

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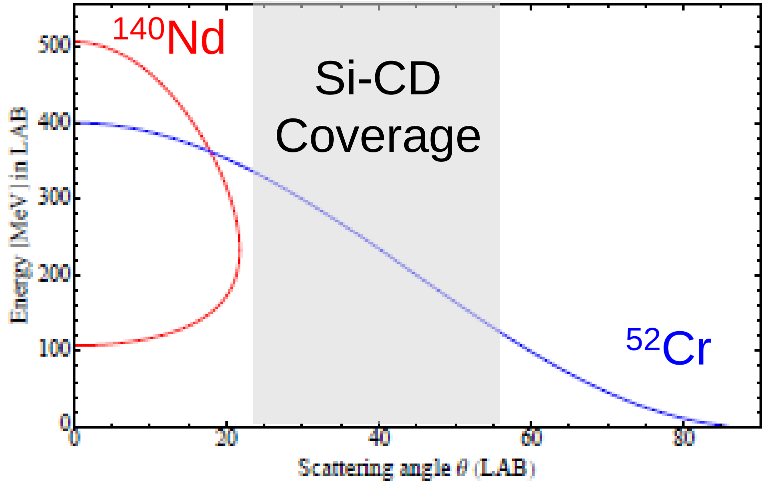
Measure E/M matrix elements from Coulex yields using **MINIBALL + DSSD** ⇒
Quantitative identification of 2^+ MSSs of ^{140}Nd and ^{142}Sm via measurement of B(M1) strength

- 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)

Can run immediately!



HIE-ISOLDE experiment IS596

9 shifts recommended by INTC

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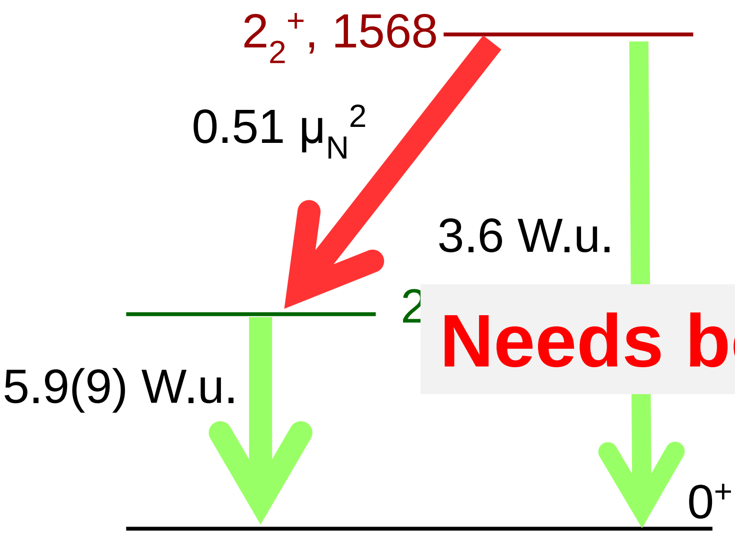
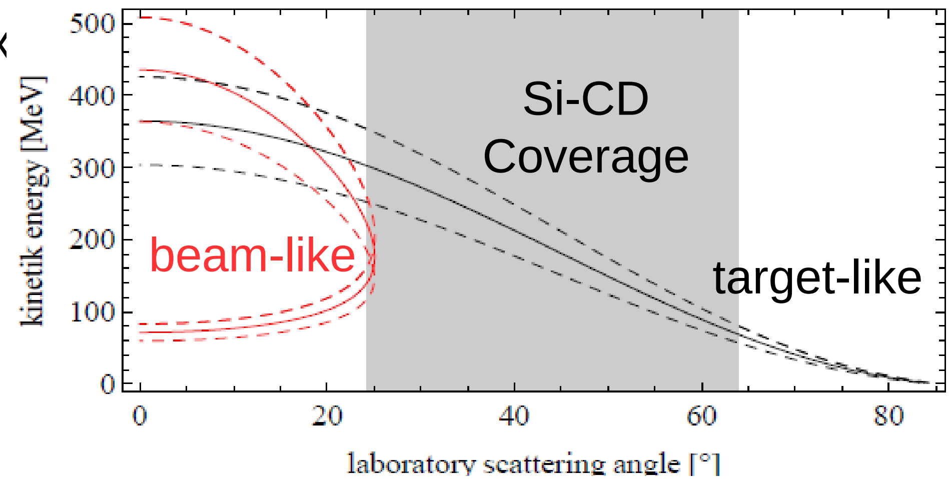
Measure E/M matrix elements from Coulex yields using MINIBALL + DSSD

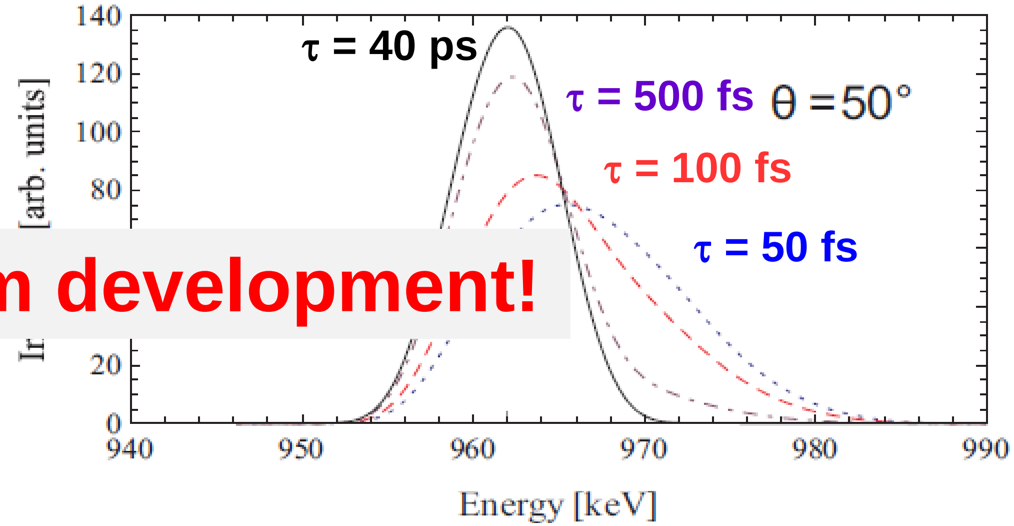
Primary target UC_x/graphene, RILIS beam

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

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







Needs beam development!

Scheduling

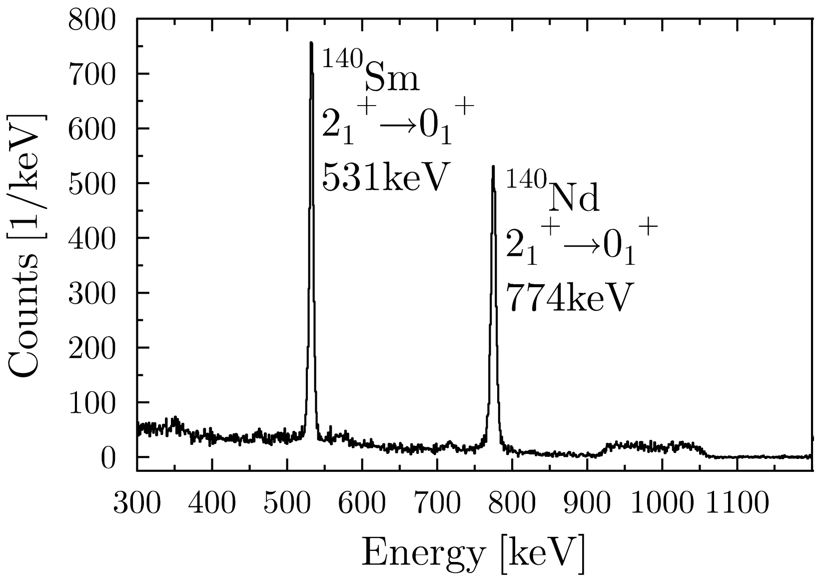
- G. Rainovski is CERN fellow in fall 2016
- Ideally, we would like to run both experiments a.s.a.p.
- ^{140}Nd, ^{142}Sm is straight forward (42 shifts)
- ^{136}Te is scientifically more urgent (9 sh.; 3 sh. beam + 6 sh. production)
- Te beam needs further development
- status of HIE-ISOLDE accelerator module?
- Thank you!

Backup slides

REX-ISOLDE experiment IS496
Contamination analysis

^{140}Nd

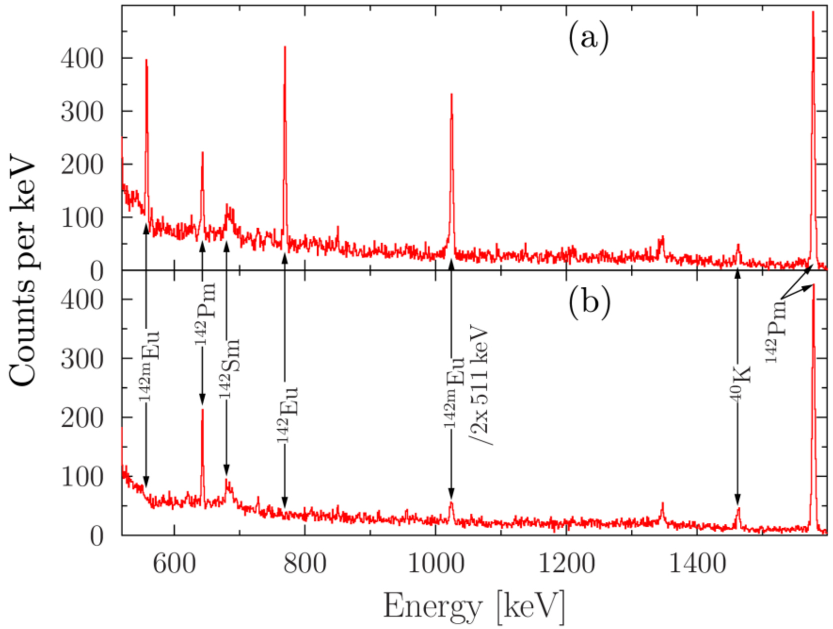
- Beam contamination of ^{140}Sm



- Treatment via comparison of laser on / laser off run

^{142}Sm

- Contamination of ^{142}Eu and ^{142}Pm



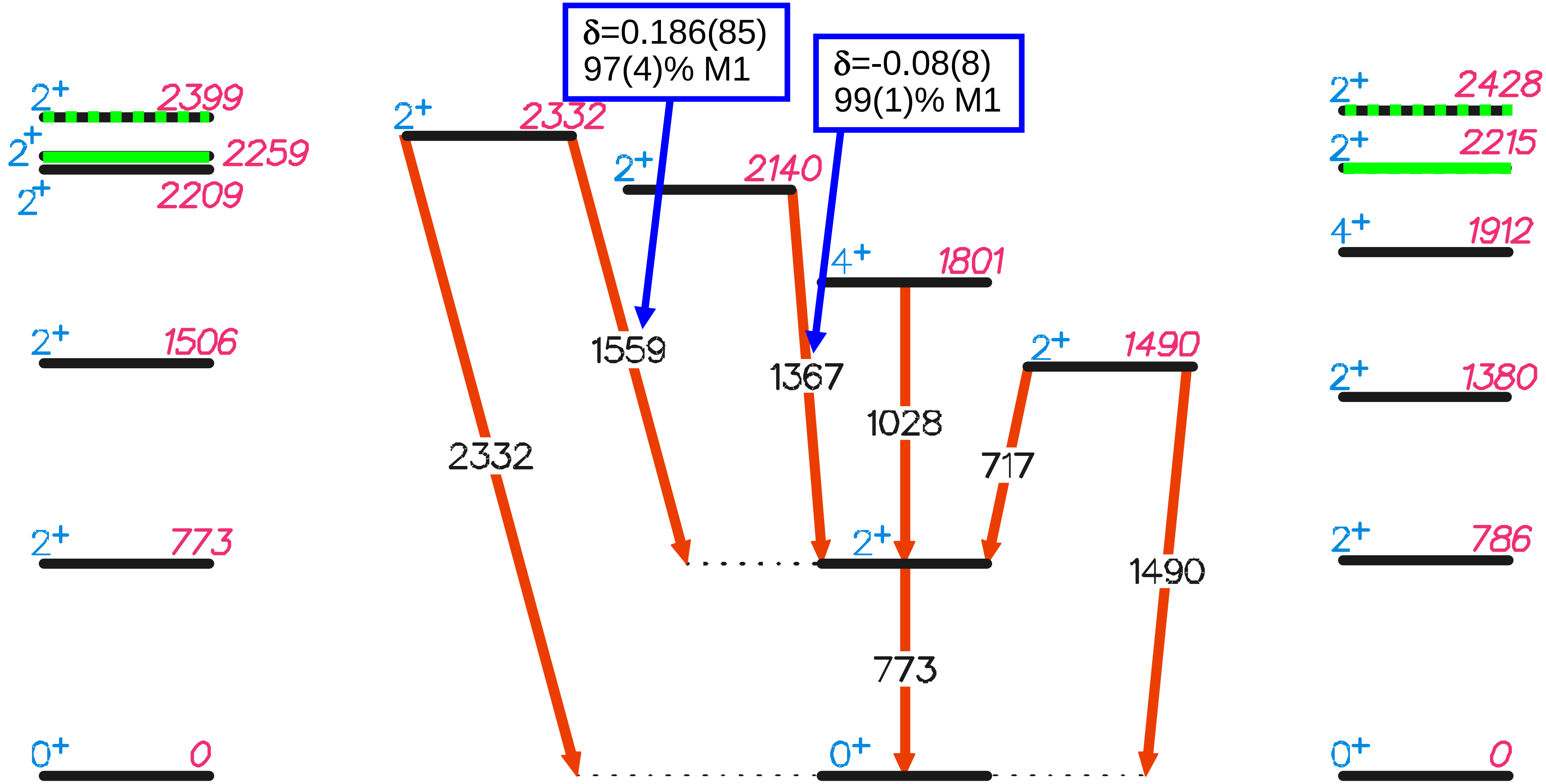
- Treatment via decay analysis at beginning and end of experiment

^{140}Nd status

QPM predictions
Ch. Stoyanov, private communication

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

SM predictions
K. Sieja et al.,
PRC 80, (2009) 054311



Evolution of the one-phonon $2^+_{1,ms}$ in N=80 isotones

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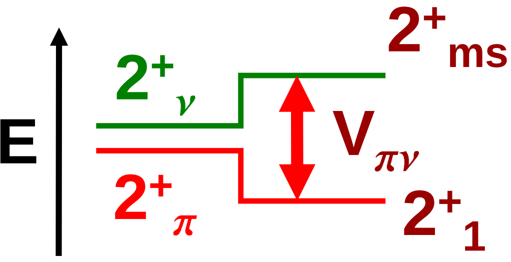


$$H = \begin{pmatrix} \varepsilon_\pi & V_{\pi\nu} \\ V_{\pi\nu} & \varepsilon_\nu \end{pmatrix}$$

K. Heyde and J. Sau
Phys. Rev. C, 33, 1050(1986)

$$\varepsilon_\nu (N = 80) = const = E(2^+_1, {}^{130}Sn) = 1221 \;\; keV$$

$$V_{\pi\nu} = \beta \sqrt{N_\pi N_\nu}$$

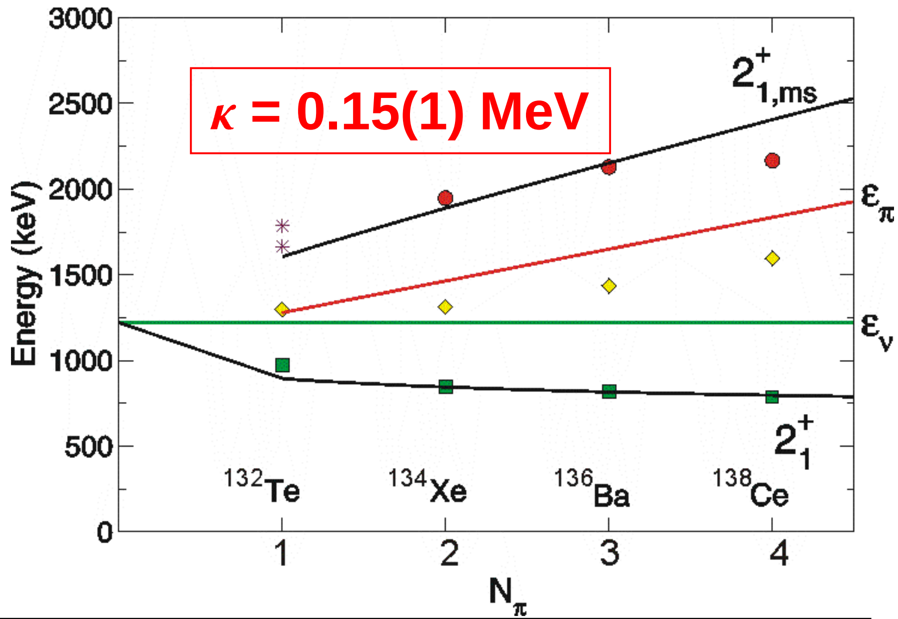
$$\varepsilon_\pi = a + b(N_\pi - 1) \;\; a = \varepsilon_\pi (N_\pi = 1) = E_{2^+_1}({}^{134}Te) = 1279 \; keV$$

$$E(2^+_{1,ms}) = E_{AV} + \sqrt{\frac{1}{4}(\varepsilon_\pi - \varepsilon_\nu)^2 + \beta^2 N_\pi}$$

$$E(2^+_1) \;\; = \;\; E_{AV} - \sqrt{\frac{1}{4}(\varepsilon_\pi - \varepsilon_\nu)^2 + \beta^2 N_\pi}$$

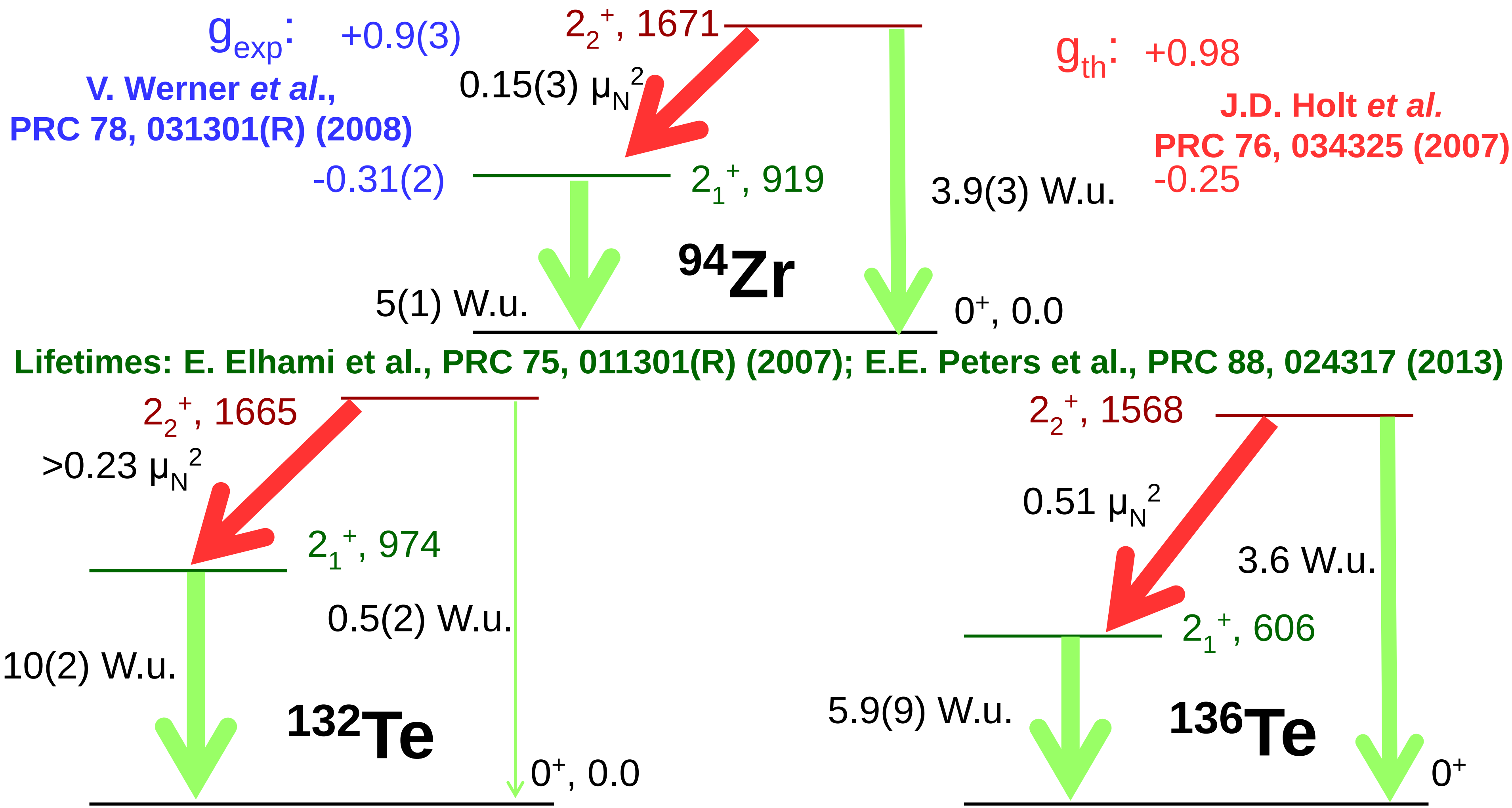
$\beta = 0.35(1)$ MeV   b=0.23(4) MeV

$$V_{\pi\nu} = \langle 2^+_\pi \,| -\kappa Q_\pi Q_\nu \,| 2^+_\nu \rangle \xrightarrow[j\to\infty]{} (12/5)\kappa$$



T. Ahn, L. Coquard, N. Pietralla *et al.*,
Phys. Lett. B 679, 19 (2010)

CIP in ^{94}Zr vs. ^{132,136}Te



Configurational Isospin Polarization

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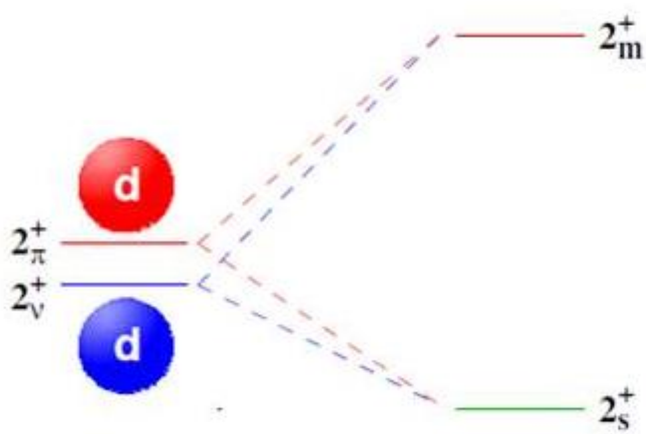

$$2^+_{ms} = a_2 \cdot 2^+_n - b_2 2^+_p$$

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

protons and neutrons contribute about equally: large mixing

$$| a_i | \approx | b_i |$$

imbalance in proton and neutron contributions: small mixing

$$| a_i | \neq | b_i |$$

observables which are sensitive to p/n content:
B(E2)'s and M1