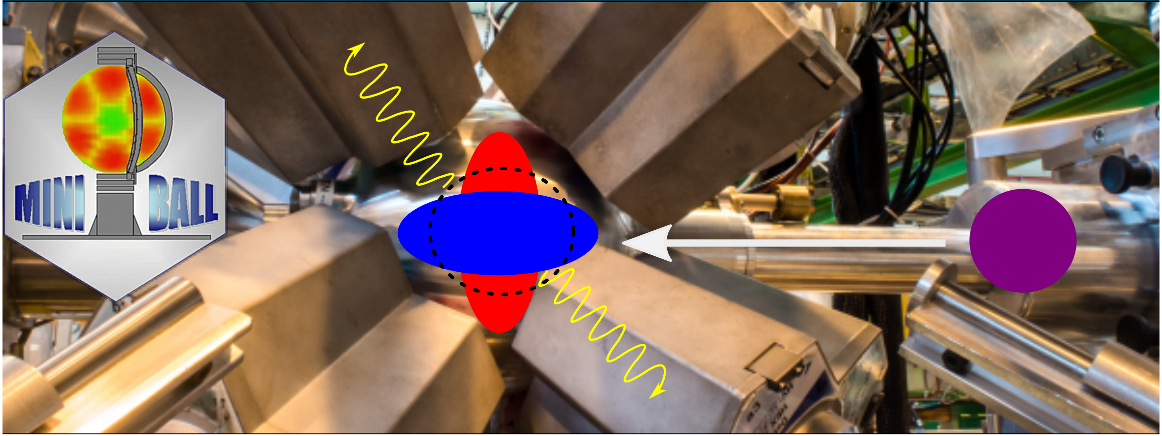
Isovector Valence-Shell Excitation of ^{140}Nd

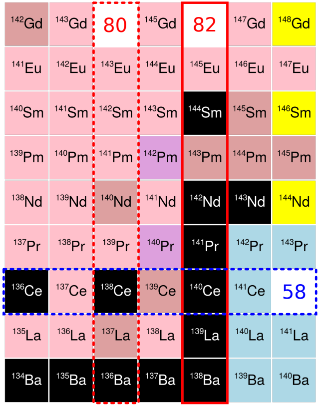
Experiment IS 546



Bundesministerium für Bildung und Forschung

Motivation - $N = 80$ Isotones

- North-west of doubly-magic ^{132}Sn
- Two valence-neutron holes in respect to $N = 82$

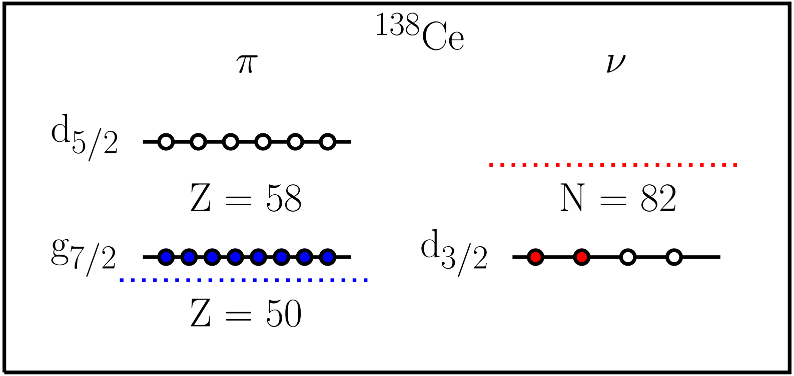


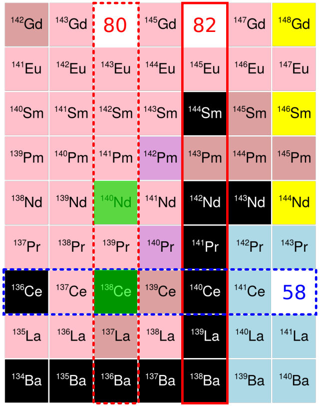
http://people.physics.anu.edu.au/ ecs103/chart/index.php (10.11.2020)

Bundesministerium für Bildung und Forschung

Motivation - $N = 80$ Isotones

- Proposed sub-shell closure at $Z = 58$ (^{138}Ce)
  G. Rainovski et al., Phys. Rev. Lett. **69**, 122501 (2006)





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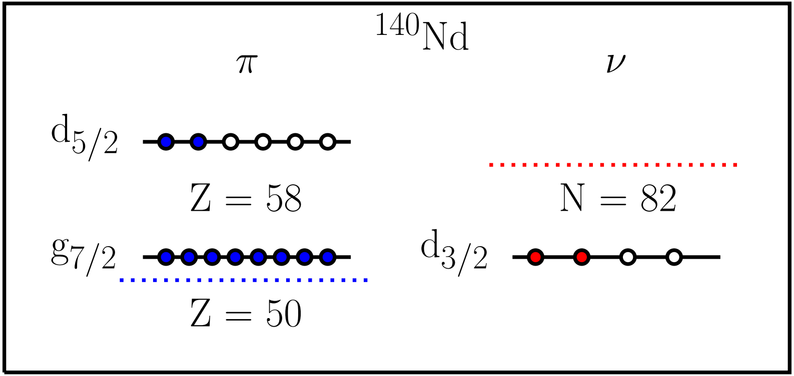

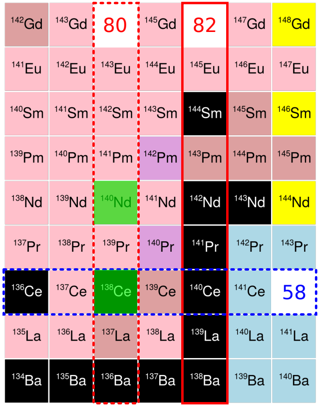

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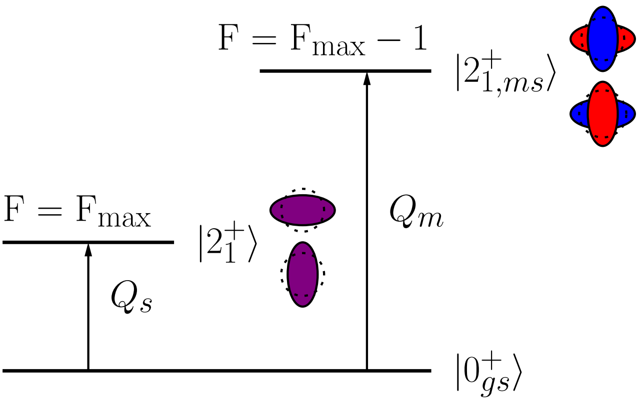
Low-lying Collective Excitations



2^+_1 state (FSS):

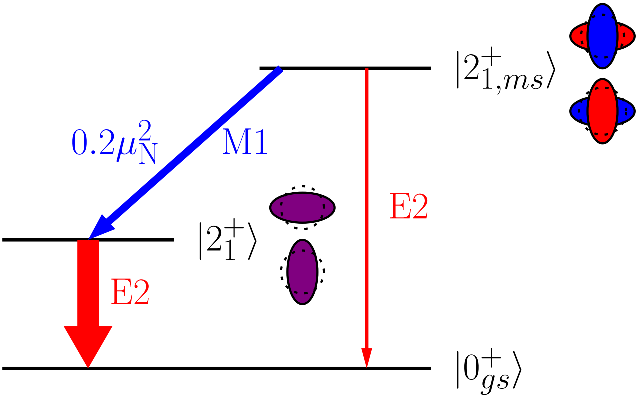
- Symmetrical Q_s ($F = F_{\max}$)
- $2^+_1 \to 0^+_1$ isoscalar ($\Delta F = 0$)

$2^+_{1,\mathrm{ms}}$ state (MSS):

- Mixed-symmetrical Q_m ($F = F_{\max} - 1$)
- $2^+_{1,\mathrm{ms}} \to 2^+_1$ isovector ($\Delta F = 1$)

N. Pietralla et al., Prog. Part. Nucl. Phys. **60**, 225-282 (2008)

Low-lying Collective Excitations



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2^+_1 state (FSS):

- Symmetrical Q_s ($F = F_{\max}$)
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$\rightarrow$ **Strong $E2$ transition**

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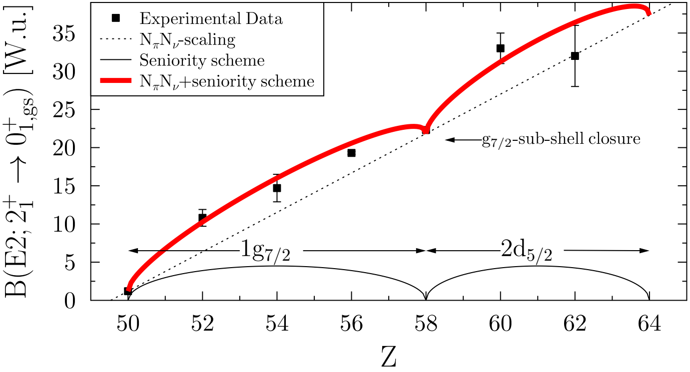
Isoscalar Valence-shell Excitations of the $N = 80$ Isotones



R. Stegmann et al. (2011), M. Danchev et al. (2015), S. Raman et al. (2001), C. Bauer et al. (2013), F. Naqvi et al. (2014), B. Pritychenko et al. (2016), D. Radford et al. (2004), W. Müller et al. (2006)

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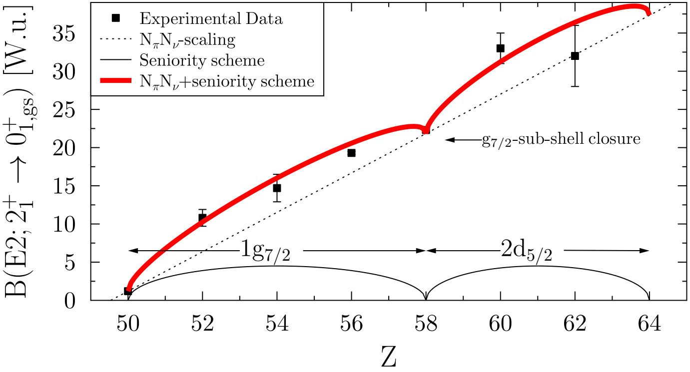

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- Residual π-ν interaction

→ $\propto N_\pi N_\nu$

- Seniority scheme

→ $\propto \sqrt{f(f-1)}$
with f as the fractional filling of an orbital

Casten R.F., Zamfir N.V., J.Phys.G: Nucl.Part.Phys. 22, 1521 (1996)

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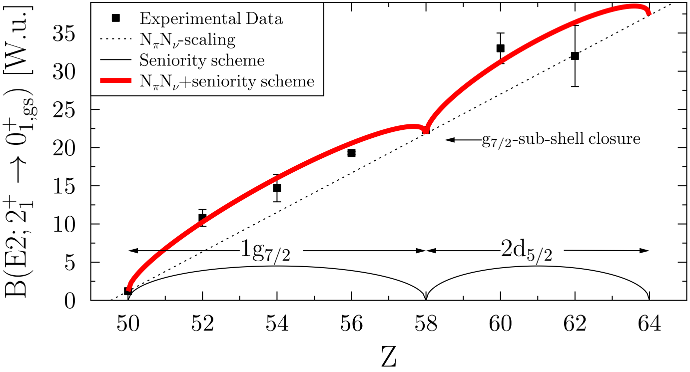

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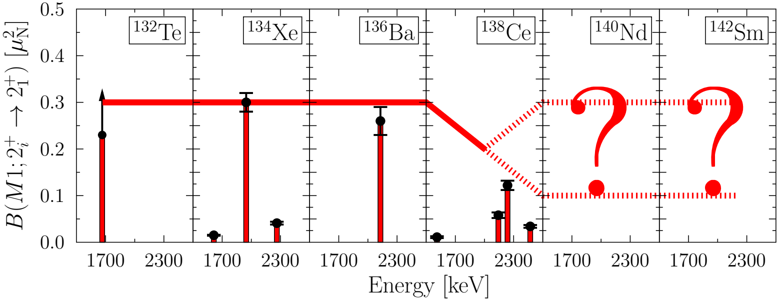
→ Impact of sub-shell structure on collectivity

Isovector Valence-shell Excitations of the $N = 80$ Isotones



^{132}Te M. Danchev et al., Phys. Rev. C **84**, 61306, (2011)

^{134}Xe T. Ahn et al., Phys. Lett. B **679**, 19 (2009)

^{136}Ba N. Pietralla et al., Phys. Rev. C **58**, 796 (1998)

^{138}Ce G. Rainovski et al., Phys. Rev. Lett. **69**, 122501 (2006)

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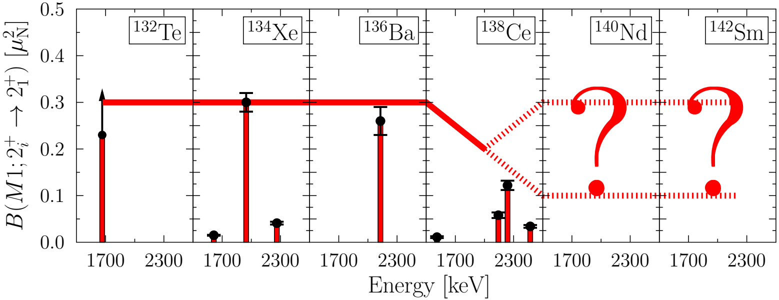
Isovector Valence-shell Excitations of the $N = 80$ Isotones



- $Z < 58$

→ Partly filled $\pi g_{7/2}$ orbital

→ Isolated $2^+_{1,\mathrm{ms}}$ state

- $Z = 58$

→ Fully filled $\pi g_{7/2}$ orbital

→ Fragmented $2^+_{1,\mathrm{ms}}$ state

- $Z > 58$

→ Partly filled $\pi d_{5/2}$ orbital

→ Trend or exception?

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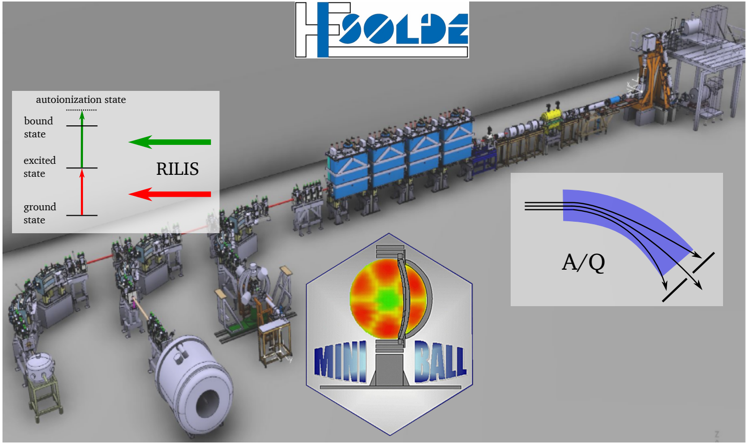
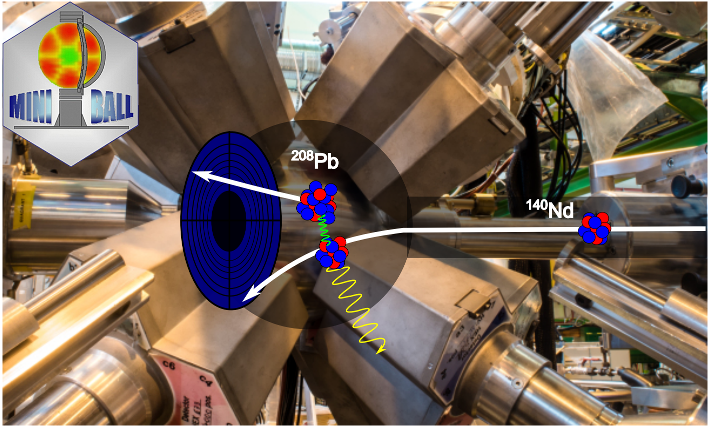
Experimental Setup – HIE-ISOLDE



- Primary target: Tantalum
- Hot surface ion source
- RILIS $\rightarrow$ Nd
- GPS $\rightarrow A = 140$

Experimental Setup – Miniball + DSSD



Nuclear Reaction:

- ^{140}Nd ion current: $\approx 5 \times 10^5$ pps
- Beam energy: 4.62 MeV/u
- Target: ^{208}Pb (1.5 mg/cm^2)

$\rightarrow$ “Safe” Coulomb excitation

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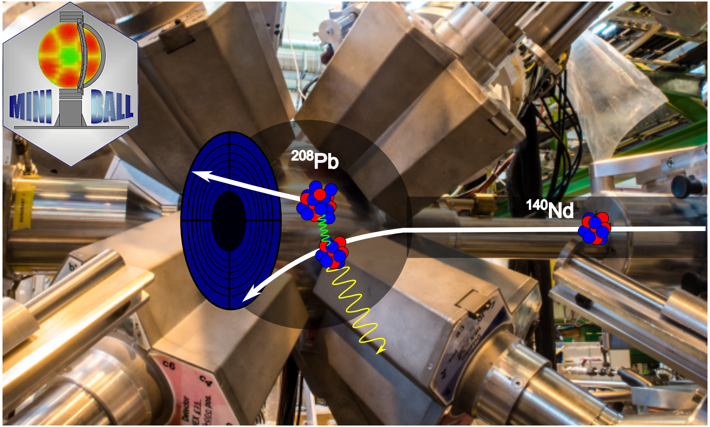

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γ-ray spectroscopy:

- Miniball

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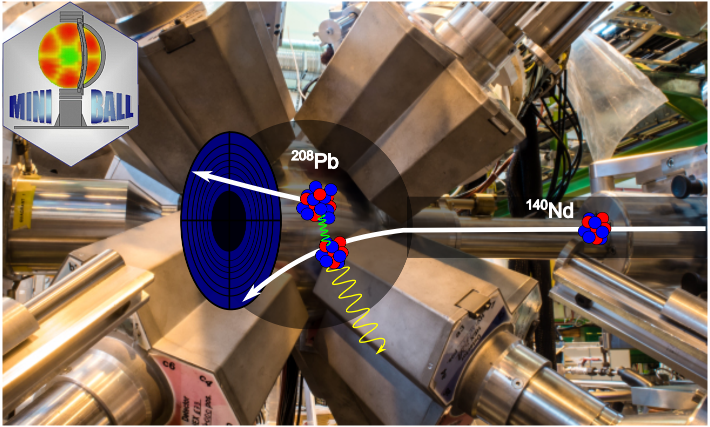

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γ-ray spectroscopy:

- Miniball

Particle detection:

- Double-sided silicon strip detector (DSSD)
- Between 23° and 64°

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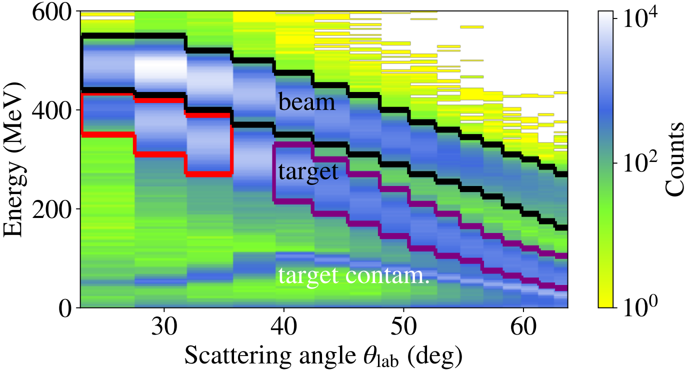
Heavy Particle Detection – DSSD



R. Kern, et al., Phys. Rev. C **102**, 041304(R) (2020)

Particle distinction:

- Beam ^{140}Nd
- Target ^{208}Pb

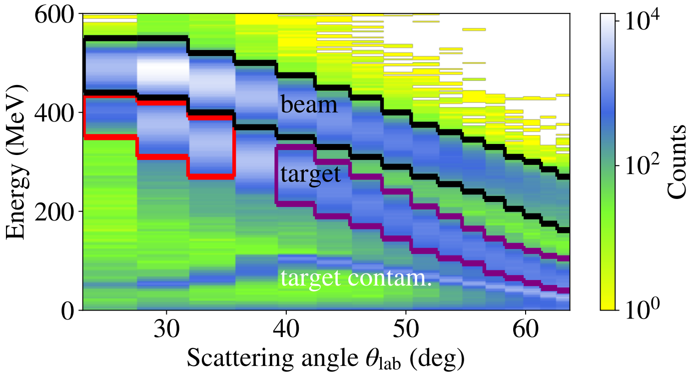
2-particle events:

→ beam-gated spectrum

1-particle events:

- Beam- and target-gated spectrum

Heavy Particle Detection – DSSD



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Particle distinction:

- Beam ^{140}Nd
- Target ^{208}Pb

2-particle events:

$\rightarrow$ beam-gated spectrum

1-particle events:

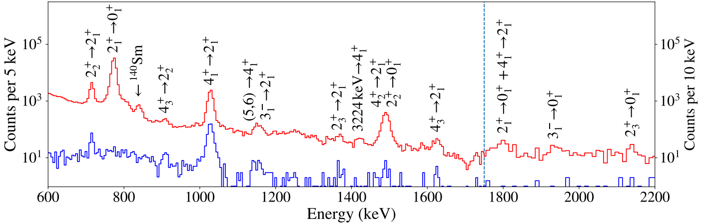
- Beam- and target-gated spectrum

$\rightarrow$ **Coulex calculations**
$\rightarrow$ **Doppler-shift correction**

γ-ray spectroscopy – Miniball

Beam-gated singles and coincidence ($2_1^+ \rightarrow 0_1^+$) spectra:

- 17 transition of ^{140}Nd identified
- Beam contamination ^{140}Sm



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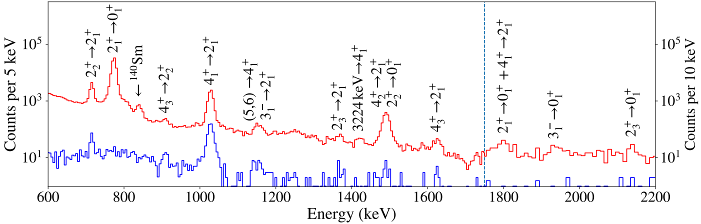
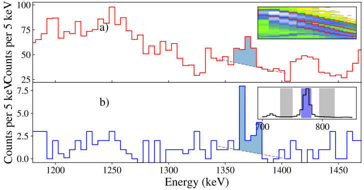
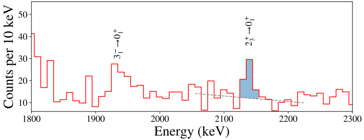


R. Kern, et al., Phys. Rev. C **102**, 041304(R) (2020)

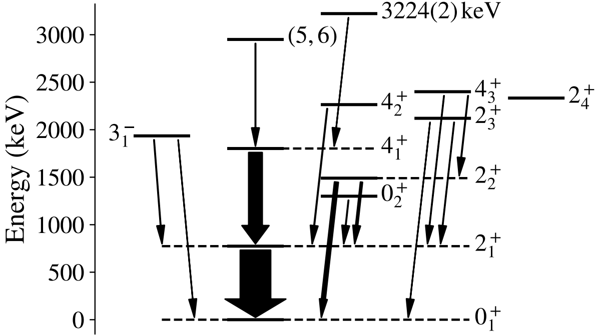
Decays of the 2_3^+ state:





Analysis of Coulex of ^{140}Nd – Level scheme

Partial level scheme of ^{140}Nd:



R. Kern, et al., Phys. Rev. C **102**, 041304(R) (2020)

Identification of $2^+_{1,\mathrm{ms}}$ state:

- Two $2_i^+ \rightarrow 2_1^+$ transitions with $M1$ nature

E. Williams, et al., Phys. Rev. C 80, 054309 (2009)

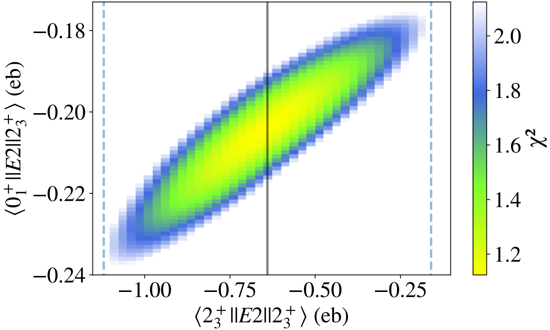
$\rightarrow$ $\delta(2_3^+ \rightarrow 2_1^+) = -0.08(8)$

$\rightarrow$ $\delta(2_4^+ \rightarrow 2_1^+) = -0.19(9)$

Analysis of Coulex of ^{140}Nd – GOSIA

χ^2 distribution of $\langle 2_3^+||E2||0_1^+\rangle$ and $\langle 2_3^+||E2||2_3^+\rangle$:

- $\langle 2_3^+||E2||2_3^+\rangle = \langle 2_1^+||E2||2_1^+\rangle$



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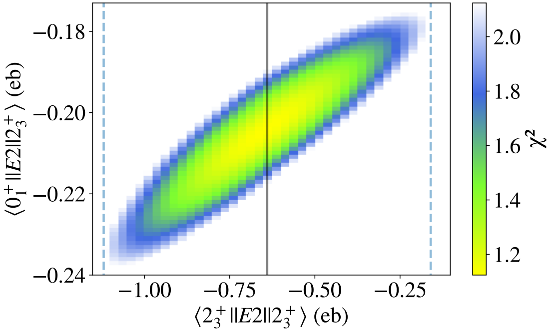

Identification of $2^+_{1,\mathrm{ms}}$ state:

- $\langle 2_3^+||E2||0_1^+\rangle = 0.204(34)\mathrm{eb}$

$\rightarrow B(M1; 2_3^+ \rightarrow 2_1^+) = 0.26^{+0.11}_{-0.10}\mu_N^2$

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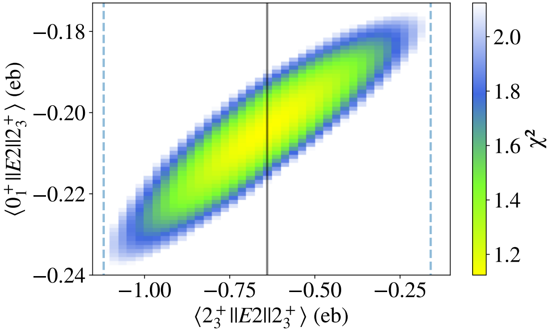

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- $\langle 2_3^+||E2||0_1^+\rangle = 0.204(34)$eb

→ $B(M1; 2_3^+ \to 2_1^+) = 0.26^{+0.11}_{-0.10}\mu_N^2$

- $2_4^+ \to 2_1^+$ transition was not observed

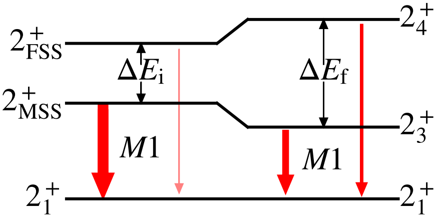
→ $B(M1; 2_4^+ \to 2_1^+) < 0.04\mu_N^2$

R. Kern, et al., Phys. Rev. C **102**, 041304(R) (2020)

Analysis of Coulex of ^{140}Nd – *F*-Spin Mixing

Two-state mixing scenario:

R. Casten, Nuclear Structure from a simple perspective, Oxford University Press, 2000.



Assumptions:

- $2^+_{MSS} \rightarrow 2^+_1$: strong *M*1
- $2^+_{FSS} \rightarrow 2^+_1$: no/low *M*1 (IBM-2/reality)

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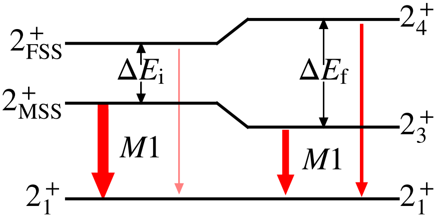

Application:

- Fragments of $2^+_{1,ms}$ state: 2^+_3, 2^+_4 states
- FSS→FSS: $B(M1; 2^+_2 \rightarrow 2^+_1) = 0.033(8)\mu_N^2$
- MSS→FSS: $\sum_i^{3,4} B(M1; 2^+_i \rightarrow 2^+_1) - B(M1; 2^+_2 \rightarrow 2^+_1)$

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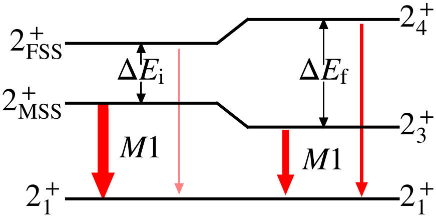

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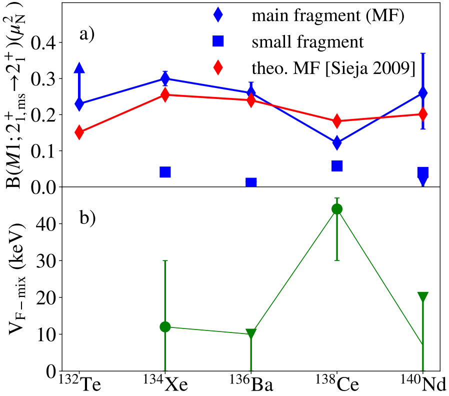
Result:

- $V_{F-mix} = 7^{+13}_{-7}\mathrm{keV}$

→ Measure of strength of *F*-spin mixing

Results in Context

Results in context with $N = 80$ isotones:



R. Kern, et al., Phys. Rev. C **102**, 041304(R) (2020)

Evolution of the *F*-spin mixing:

- Increase of $B(M1)$ for ^{140}Nd

→ $B(M1)$ by LSSM of Sieja et al., 2009

- V_{F-mix} outstanding at $Z = 58$

→ Fragmentation of the $2^+_{1,ms}$ state at $Z = 58$

Summary

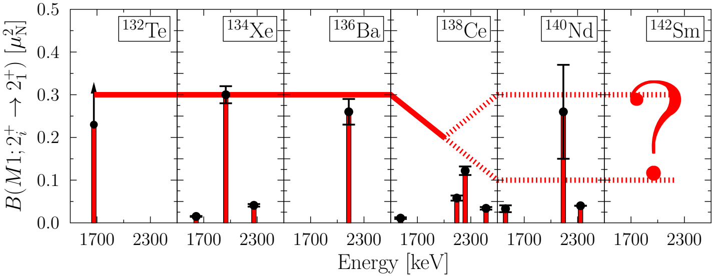
Summary of the ^{140}Nd Coulex experiment:

- Identification of the $2^+_{1,\mathrm{ms}}$ state

$\rightarrow$ $B(M1; 2^+_3 \rightarrow 2^+_1) = 0.26^{+0.11}_{-0.10}\mu_N^2$

- Determination of the *F*-spin mixing

$\rightarrow$ $V_{\mathrm{F-mix}} = 7^{+13}_{-7}$ keV



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Outlook

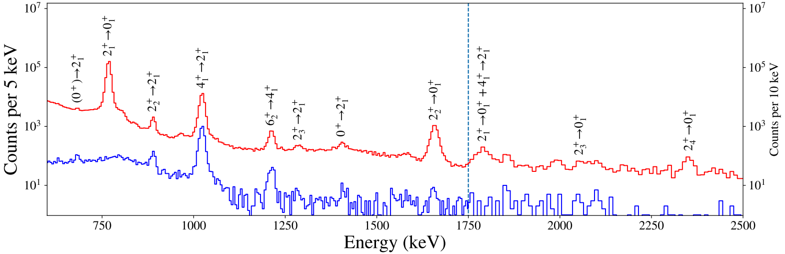
MSSs of $N = 80$ isotones:

- Analog experiment of ^{142}Sm (IS 546)

→ Determination of $\delta(2_i^+ \rightarrow 2_1^+)$ (accepted experiment at HIL)

MSSs around ^{132}Sn at HIE-ISOLDE:

- Reproposal of ^{136}Te (IS 596) via Coulex and DSAM



Thank you!

Thanks to the Miniball and ISOLDE collaboration and especially to:

R. Zidarova, G. Rainovski, N. Pietralla, L. P. Gaffney, A. Blazhev, K. Gladnishki, J. Jolie, V. Karayonchev, T. Kröll, P. Reiter, M. Scheck, P.-A. Söderström, P. Spagnoletti, R. Stegmann, A. Vogt, N. Warr, A. Welker, V. Werner, J. Wiederhold

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