Investigation of Octupole Correlations in ^{144,145}Ba using the Recoil Distance Doppler-shift Technique

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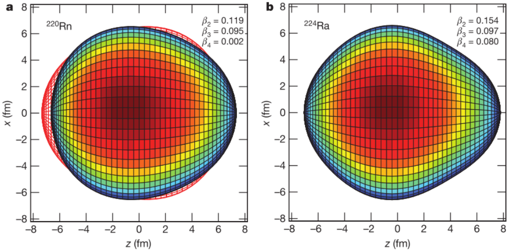
Octupole correlations in the atomic nucleus

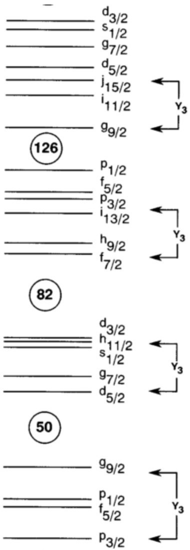
Long-range octupole-octupole interaction, strength depends on:

- $r^3 Y_3 \bullet r^3 Y_3$ ME between SP states with $\Delta j = \Delta l = 3\hbar$
- ΔE between these states

Most pronounced for $A \sim 224$ (Ra, Th)



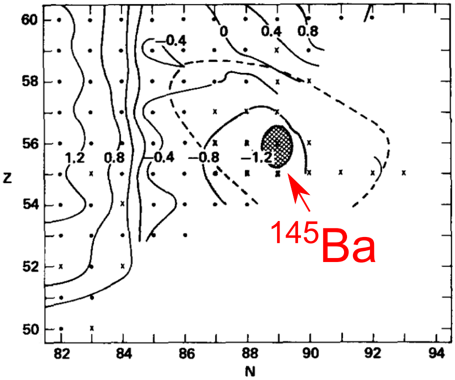
(taken from Gaffney *et al.* Nature **497**, 199 (2013))



Octupole correlations in neutron-rich Ba isotopes

Evidence for octupole correlations around $Z \approx 56$, $N \approx 88, 90$

- **Ground-state masses reveal anomaly around ^{145}Ba**



Mass discrepancy exp-calc (MeV)

(taken from Leander PL B **152**, 284 (1985)).

Octupole correlations in neutron-rich Ba isotopes

Evidence for octupole correlations around $Z \approx 56$, $N \approx 88, 90$

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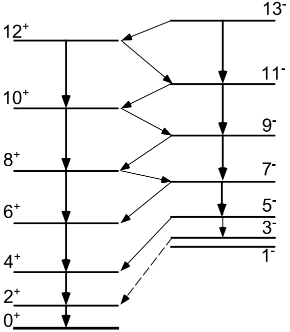
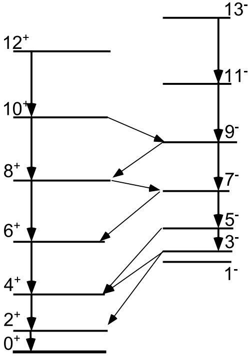
- **Alternating parity sequence above $7\hbar$, e.g. ^{144,146}Ba**



^{144}Ba

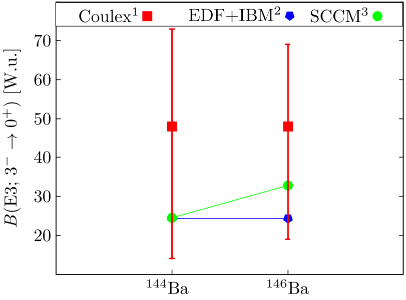


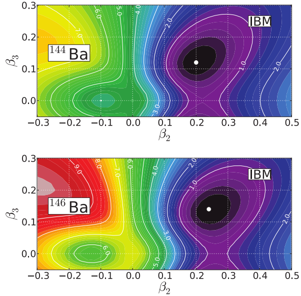
^{146}Ba

Octupole correlations in neutron-rich Ba isotopes

Evidence for octupole correlations around $Z \approx 56$, $N \approx 88, 90$

- Ground-state masses reveal anomaly around ^{145}Ba
- Alternating parity sequence above $7\hbar$, e.g. in ^{144,146}Ba
- **Enhanced B(E3; $3^- \to 0^+$) values in ^{144,146}Ba**





[1] Bucher *et al.* PRL **118**, 1520504 (2017), PRL **116**, 112503 (2016)

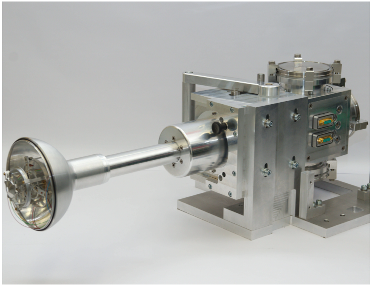
[2] Nomura *et al.* PRC **89**, 024312 (2012)

[3] Bucher *et al.* PRC **89**, 024312 (2012) and Bernard *et al.* PRC **93**, 061302(R) (2016)

PRC **89**, 024312 (2012)

Proposed experiment

Determination of level lifetimes in ^{144,145}Ba using the RDDS technique

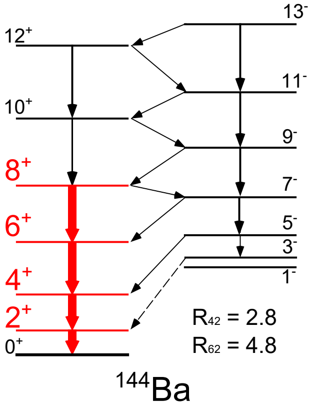


- Sensitivity to $\tau \approx 0.5 - 500\,\text{ps}$
- Establish plunger measurements at ISOLDE
- Population by ^{7}Li induced ICF[1] (Fusion of ^{144}Cs + t)

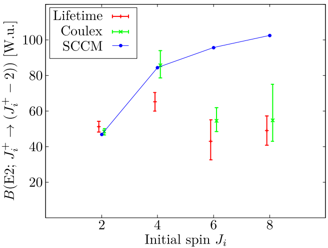
Which Quantities are proposed to be measured?

[1] Bottoni *et al.* PRC **92**, 024322 (2015)

Transition strengths in ^{144}Ba



- ▶ **B(E2)'s in yrast band (parity +)**
  - ▶ Coulomb excitation[1]
  - ▶ RDDS (fission source)[2]



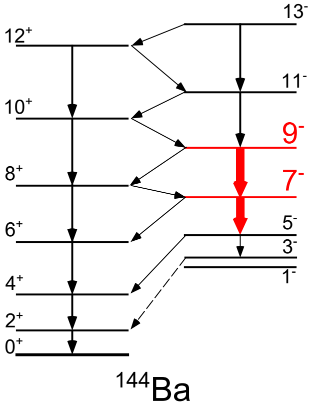
Aim:

- ▷ Classify collective pattern
- ▷ Reduce uncertainties

[1] Bucher PRL **116**, 112503 (2016)

[2] Biswas PRC **71**, 011301 (2005)

Transition strengths in ^{144}Ba



- B(E2)'s in yrast band (parity +)
- **B(E2)'s in yrast band (parity -)**
  - RDDS[1] + branching ratios

Results:

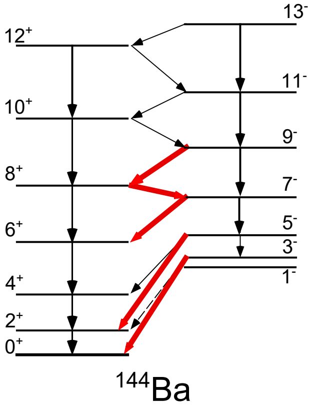
- $B(\mathrm{E2};\, 9^- \rightarrow 7^-) = 39(12)$ W.u
- $B(\mathrm{E2};\, 7^- \rightarrow 5^-) = 195(47)$ W.u.

Aim:

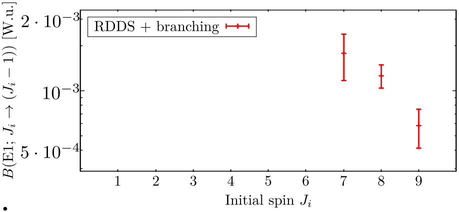
- Quantify collectivity in $\pi = -$ band
- Evaluate $B(\mathrm{E2};\, 5^- \rightarrow 3^-)$

[1] Biswas PRC **71**, 011301 (2005)

Transition strengths in ^{144}Ba



- B(E2)'s in yrast band (parity +)
- B(E2)'s in yrast band (parity -)
- **B(E1)'s and B(E3)'s**

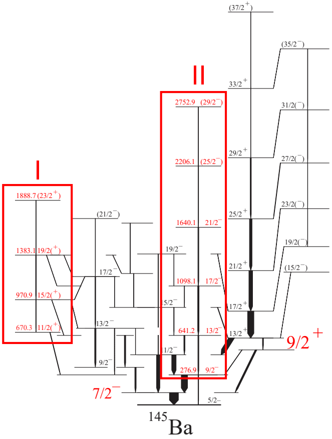


Aim:

- Limits for B(E3) (branching)
- $\tau(5^-)$, $\tau(3^-)$ and $\tau(1^-)$ (?)

27.07.-01.08: ISOLDE exp by M. Scheck et al. $\rightarrow B$(E3)

Octupole correlations in ^{145}Ba



[1]PRC **86**, 044324 (2012)

- No parity doublet to the gs ($5/2^-$)
- Level scheme explainable[1] by symmetric gs shape
  - Octupole vibrations (coupled to reflection symmetric gs?)
- So far:
  - Only $\tau(7/2^{(-)})$
  - $B(\text{E1})/B(\text{E2})$ from branching

Aim:

- Extend knowledge on level lifetimes (transition strength)

Central experimental aims

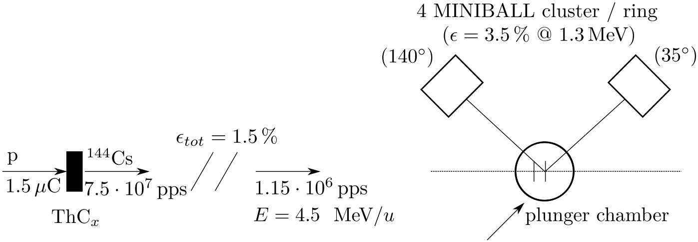
^{144}Ba

- Clarify nature of yrast structure
- Enable a comparison of $\pi = +$ and $\pi = -$ bands
- Evaluate B(E1) strength
- General: Reduction of uncertainties

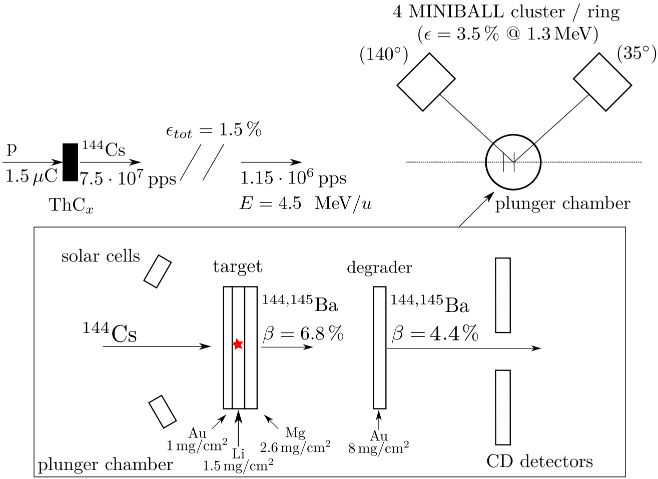
^{145}Ba

- First systematic lifetime measurement

Experimental setup

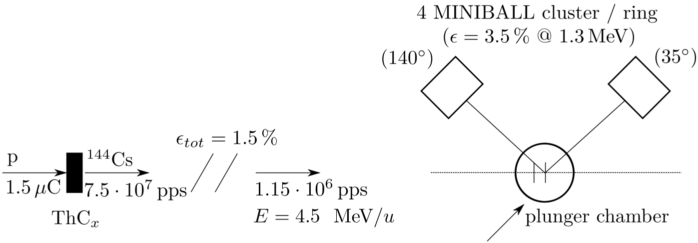


Experimental setup



(Modified secondary beam energy compared to proposal)

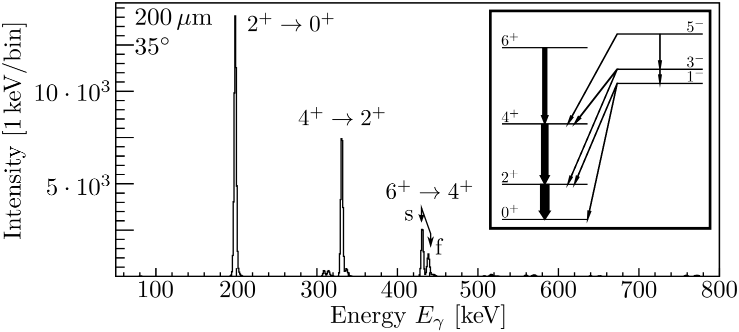
Yield estimate



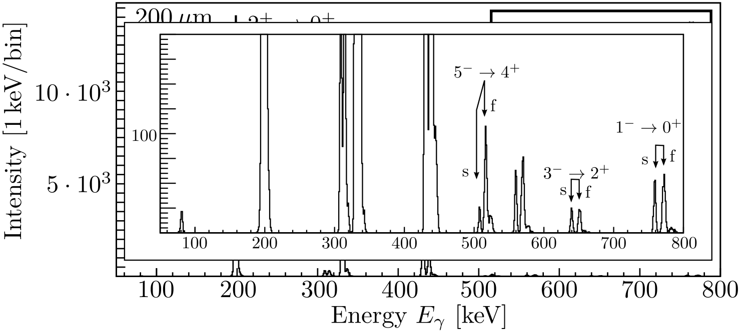
Estimates:

- Incomplete ^{144}Cs-t fusion cross section: $\sim$70 mb
- γ-ray yield for $2^+ \rightarrow 0^+$ in ^{144}Ba: $4.5 \cdot 10^4$ γ's in 8hrs
- In total: 15 shifts
  - Target-only data: 24 hrs (Three shifts)
  - Measurement of eight foil separations à 12 hrs $\rightarrow$ 12 shifts

Final remarks



Final remarks



Aim: Measurement of level lifetimes in ^{144,145}Ba with high precision within 15 shifts

Backup - Intensity of ^{144}Cs

Comment by TAC: Overestimated beam intensity in proposal

Yield database (ThC target): $^{142(143)}$Cs: $3.4(1.5) \cdot 10^{9}$ions/μC

TAC reference (UC target): ^{145}Cs: $2.5 \cdot 10^{7}$ions/μC

Experimental options:

- Increase of target thickness (factor 1.5)
- Fourth cluster / ring (factor 1.3)
- Increase time per foil separation (factor 2)
- Conservative estimates

Backup - β-decay of ^{144}Ce

Problematic: ^{144}Ce ($T_{1/2} = 289\,\text{days}$)
Note: It will be implanted somewhere (CD, shielding foil, beam dump)
Bright side:

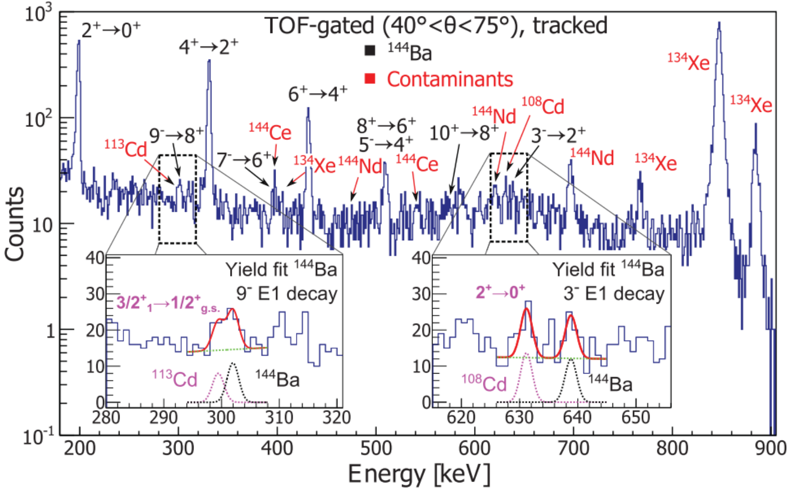
- Low specific activity
- Low Q-value for β^- (319keV)
- Highest γ-ray with $E = 133\,\text{keV}$ ($11\,\%$), all others at lower energies (or converted)

General approach: use shielding foils

Backup - Additional aspects

- FE with ^{7}Li populates ^{146,147,148}Ce (only τ of lowest states are known)
- ICF with α populates ^{145,146}La
- Reaction study (see PRC 92, 024322 (2015))

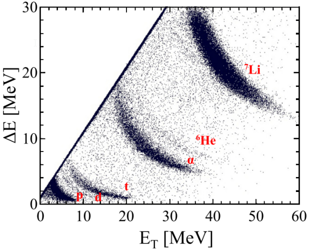
Backup - Recent B(E3) measurement in ^{144}Ba

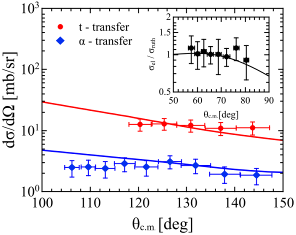


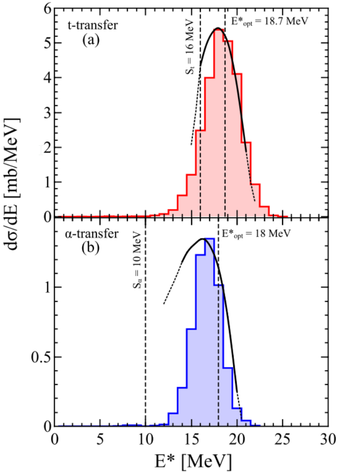
Backup - Li induced breakup

	This proposal	INTC-P-419	PRC 92, 0244322
Beam ^{A}Z	^{144}Cs	^{132}Sn	^{98}Rb
Compound	^{147}Ba	^{135}Sb	^{101}Sr
Mid-target E [MeV/u]	3.9	3.5	2.48
Intensity	$7.8 \cdot 10^{6}$	$8.5 \cdot 10^{5}$	$2 \cdot 10^{4}$
Q_{gs} value $^{A}Z + t$	9.5	5.6	13.6
Q_{op} value	-7.7	-5.3	-5.1
Excitation E E_{op} [MeV]	17.2	10.9	18.9
S_n [MeV]	5.5	3.7	3.8
S_{2n} [MeV]	9.3	6.8	9.2
S_{3n} [MeV]	15.2	12.5	13.4

Backup - Li induced breakup







Source: Bottoni et al., PRC 92, 024322 (2015)

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Local contact: J.Pakarinen (janne.pakarinen@cern.ch)

Abstract

We propose to exploit the unique capability of ISOLDE to provide intense post-accelerated ^{144}Ba ion beams from the REX facility to enable the Coulomb excitation of the first 3^- state in this nucleus. By measuring the γ-ray yields of the E1 decay connecting the 3^- and 2^+ states using the MINIBALL array, we can obtain the interesting $<3^-|E3|0^+>$ transition matrix element. The result will give quantitative information about octupole correlations in this nucleus. We require **27 shifts** to fulfil the aims of the experiment.

Backup - Expected γ-ray yield (simulation)

Transition	E_γ [keV]	Rel. intensity [%]	yield per day
$2^+ \to 0^+$	199	100	$\sim 9.3 \cdot 10^4$
$4^+ \to 2^+$	331	76	$\sim 5.4 \cdot 10^4$
$6^+ \to 4^+$	431	48	$\sim 2.8 \cdot 10^4$
$5^- \to 4^+$	509	2.4	$\sim 1.2 \cdot 10^3$
$5^- \to 3^-$	200	2.7	$\sim 2.4 \cdot 10^3$
$3^- \to 4^+$	309	6.4	$\sim 4.6 \cdot 10^3$
$3^- \to 1^-$	80	0.14	$\sim 1.5 \cdot 10^2$
$3^- \to 2^+$	640	0.93	$\sim 4.2 \cdot 102$
$1^- \to 2^+$	560	2.5	$\sim 1.2 \cdot 10^3$
$1^- \to 0^+$	759	2.6	$\sim 1.1 \cdot 10^3$

Experimental transition strengths in ^{144}Ba

	Biswas PRC 71, 011301	Mach PRC 41, R2469	Krücken PRC 64, 017305	Bucher PRL 116, 112503
$B(E2; 2^+ \to 0^+)$	51(3)	48.2(20)	-	$48.4^{+1.6}_{-2.0}$
$B(E2; 4^+ \to 2^+)$	65.1(52)	54.9(70)	-	$85.7^{+8.2}_{-7.3}$
$B(E2; 6^+ \to 4^+)$	56.1(71)	-	$42.9^{+12}_{-10.4}$	$54.4^{+7.5}_{-6.0}$
$B(E2; 8^+ \to 6^+)$	48.9(82)	-	-	$54.8^{+20.1}_{-11.8}$
$B(E2; 9^- \to 7^-)$	39(12)	-	-	-
$B(E2; 7^- \to 5^-)$	384(141)	-	195(47)	-
$B(E1; 7^- \to 6^+)$	$1.77(61) \cdot 10^{-3}$	-	$9.0(19) \cdot 10^{-4}$	-
$B(E1; 9^- \to 8^+)$	$5.8(17) \cdot 10^{-4}$			
$B(E1; 1^- \to 0^+)$	$> 2.9 \cdot 10^{-5}$			
$B(E3; 3^- \to 0^+)$	-	-	-	48^{+25}_{-34}
$B(E3; 5^- \to 2^+)$	-	-	-	< 106
$B(E3; 7^- \to 4^+)$	-	-	-	< 189