Evidence for enhanced collectivity near N=Z=50

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Outline

- Recoil-Decay-Tagging (RDT) of heavy vs. light nuclei
- RDT study of ¹⁰⁶Te (Z = 52, N = 54)
- RDT study of ¹¹⁰Xe (Z = 54, N = 56) and ¹⁰⁹I (Z = 53, Z = 56)
- Level systematics \rightarrow enhanced collectivity



RDT INSTRUMENTATION AT JYFL



Recoil – Decay – Tagging of Heavy Nuclei vs. Medium-Heavy and Light Nuclei



Heavy nuclei - transfermiums

Produced in <u>asymmetric</u> cold-fusion reaction – $X(^{48}Ca,2n)Y$ \rightarrow ideal for RITU

- → Only <u>one reaction channel</u> open
- \rightarrow Total compound cross-section down to 50 mb
- \rightarrow I_{beam} up to 30pnA on a 0.5mg/cm² target in in-beam runs

Fission dominates: 100000 : 1 \rightarrow I_{beam} limited by the Ge rate \rightarrow Very low focal-plane rate \rightarrow Enables long t_{1/2} – α – tagging



Medium-heavy and light neutron-deficient nuclei

Produced in <u>symmetric</u> fusion-evaporation reactions \rightarrow Difficulties with a gas-filled separator

No fission – <u>large number of fusion ev. reaction channels</u> \rightarrow High recoil rate ~ 1kHz/1pnA on a 0.5mg/cm² target \rightarrow Keep the reaction cold !

 \rightarrow Limited possibilities for short-t_{1/2} p- or α - or β tagging



Reminder:

In-beam gamma-ray experiment \rightarrow 10 pnA on a 0,5 mg/cm² target

10 nanobarn \rightarrow 4 reactions per hour !!



RDT experiments for ¹⁰⁶Te, ¹¹⁰Xe and ¹⁰⁹I

				3		N=Z 56	Ba 137,327 σ 1,3	Ba 114 0,43 s ^{β+}	Ba 115 0,45 s ^{β+} ^{βp}	Ba 116 1,3 s ^{β⁺} ^{βp} g
					55	N=56	Cs 112 500 μs	Cs 113 17 μs p 0,959	Cs 114 0,57 s β ⁺ ; α 3,239 γ 450; 698; 618 βp 1,7-7,0 βα 7,0-12,5	Сз 115 1,4 s ^{β+} _{βp}
				N=54	Xe 131,29 σ 24	Xe 110 ?	Xe 111 0,9 s	Xe 112 2,7 s ^{β⁺} α 3,216	Xe 113 2,8 s β ⁺ ; α 2,985 γ 121; 689 βp 2-7 βα 7-10	Xe 114 10 s ^{β+} γ 309; 162; 104; 440
		53	l 126,90447 _{7 6,15}		I 108 36 ms α 3,947	Ι 109 100 μs p 0,813	1 110 0,65 s 3 ⁺ α 3,444 3p 2,5-6,0 3α 7-12	I 111 2,5 s β ⁺ α 3,152 γ 341; 117; 321; 266 321; 266	$\begin{array}{c} 1 \ 112 \\ 3,42 \ s \\ \beta^{+}; \ \alpha 2,880 \\ \gamma \ 689; \ 787; \ 795; \\ 1143 \\ \beta^{2}, 20-6, 0 \\ \beta\alpha \ 6-12 \end{array}$	$\begin{array}{c} 1 \ 113 \\ 5,9 \ s \\ \beta^+ \\ \alpha \ 2,610 \\ \gamma \ 463; \ 622; \\ 351; \ 567 \end{array}$
		52	Τe 127,60 σ 4,7	Te 106 0,06 ms	Te 107 3,1 ms 3,861	Te 108 2,1 s ^{β⁺} α 3,317 βp 2-3	Te 109 4,1 s ^{β+} βp 3,3; 3,7 α 3,107	Te 110 18,6 s ^{β+} ^{α 2,624} _{γ 895; 606; 219; 108}	$\begin{array}{c} Te \ 111 \\ 19,3 \ s \\ \beta^+ \\ \gamma \ 851; \ 881; \\ 1268; \ 1392 \\ \betap \ 2,82; \ 2,66 \end{array}$	Te 112 2,0 m ^{β+} ^{γ 373; 296;} 419
51	Sb 121,750 9 5,1	Sb 103	Sb 104 0,44 s β ⁺	Sb 105 1,12 s ^{β+} p 0,478	Sb 106 0,6 s β ⁺	Sb 107 4,6 s ^{β+} γ 1280; 819; 151; 704	Sb 108 7,6 s ^{β+} γ 1206; 905; 1599; 1273	Sb 109 16,7 s ^{β+} 4,4; 5,4 γ 925; 1062; 665; 1496	Sb 110 24,0 s ^{β+} 6,9 γ 1212; 985; 1243; 827	Sb 111 75 s ^{β⁺ 3,3 γ 154; 489; 1033}
Sn 100 0,94 s ^{B⁺ 3,4}	Sn 101 3 s ^{β+} βp 2-3,5	Sn 102 3,4 s β ⁺	Sn 103 7 s ^{β+} βp 1-3	Sn 104 20,8 s β ⁺ 2,4 γ 133; 913; 401; 1407 m; g	Sn 105 34 s ^{β+} γ 1282; 1466; 309; g; m βp 1-3	Sn 106 2,1 m [€] β ⁺ 1,2 γ 387; 253; 477; m	$\begin{array}{c} Sn \ 107 \\ 2,9 \ m \\ \beta^+ \\ \gamma \ 1129; \ 1542; \\ 1001 \dots \\ m; \ g \end{array}$	Sn 108 10,3 m ϵ; β ⁺ 0,4 γ 396; 273; 169; 669 m	Sn 109 18,0 m ϵ; β ⁺ 1,6 γ 1099; 1321; 331 g; m	Sn 110 4,11 h [€] γ283 m



54 Fe+ 54 Fe → 106 Te + 2n (E_b= 182 MeV, I_b= 10 pnA, 5 days)



RITU Focal plane:



B. Hadinia, et al., Phys. Rev. C 72, 041303 (2005)



¹⁰⁶Te gamma rays

 $\sigma = 25 \text{ nb} - (\text{Then})$ a new limit for in-beam γ -ray spectroscopy!





Gamma-gamma coincidences at $\sigma \sim 25$ nb



B. Hadinia, et al., Phys. Rev. C 72, 041303 (2005)



Te energy systematics and S.M. calculations

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B. Hadinia, et al., Phys. Rev. C 72, 041303 (2005)





⁵⁴Fe+ ⁵⁸Ni → ¹¹⁰Xe + 2n ($_{\sigma} \sim 50 \text{ nb}$) ¹⁰⁹T + p2n ($_{\sigma} \sim 10 \text{ µb}$) (E_b= 195 MeV, I_b= <u>10 pnA</u>)

			14	N=Z ·	Ba 137,327	Ba 114 0,43 s	Ba 115 0,45 s	Ba 116 1,3 s
				N=56	σ 1,3	β+ βp	β+ βp	β ⁺ βp g
			1	Cs 132,\$0543	Cs 112 500 μs	Cs 113 17 μs	Cs 114 0,57 s	Cs 115 1,4 s
			55	σ 29,0	p 0,807	p. 0.959	β ⁺ ; α 3,239 γ 450; 698; 618 βρ 1,7–7,0 βα 7,0–12,5	β+ βp
		-1	Xe 131,29	Xe 110 ?	Xe 111 0,9 s	Xe 112 2,7 s	Xe 113 2,8 s	Xe 114 10 s
		54	σ 24	α 3,745	α 3,589; 3,500	β ^β α 3,216	γ 121; 689 βp 2-7 βα 7-10	β ⁺ γ 309; 162; 104; 440
	l 126,90447		l 108 36 ms	l 109 100 μs	l 110 0,65 s	l 111 2,5 s	112 3,42 s	l 113 5,9 s
53	r 6,15		α 3,947	p 0,813	^{β+} α 3,444 βp 2,5-6,0 βα 7-12	β ⁺ α 3,152 γ 341; 117; 321; 266	γ 689; 787; 795; 1143 βp 2,0-6,0 βα 6-12	β ⁺ α 2,610 γ 463; 622; 351; 567
-	Te 127,60	Te 106 0,06 ms	Te 107 3,1 ms	Te 108 2,1 s	Te 109 4,1 s	Te 110 18,6 s	Te 111 19,3 s	Te 112 2,0 m
DZ	σ 4,7	α 4,128	α 3,861	β ⁺ α 3,317 βp 2–3	β ⁺ βp 3,3; 3,7 α 3,107	α 2,624 γ 895; 606; 219; 108	β' γ 851; 881; 1268; 1392 βp 2,82; 2,66	β ⁺ γ 373; 296; 419
Sb Sb 1 121,760	03 Sb 104 0,44 s	Sb 105 1,12 s	Sb 106 0,6 s	Sb 107 4,6 s	Sb 108 7,6 s	Sb 109 16,7 s	Sb 110 24,0 s	Sb 111 75 s
51 σ5,1 p?	β+	β ⁺ p 0,478	β+	β ⁺ γ 1280; 819; 151; 704	β ⁺ γ 1206; 905; 1599; 1273	β ⁺ 4,4; 5,4 γ 925; 1062; 665; 1496	β ⁺ 6,9 γ 1212; 985; 1243; 827	β ⁺ 3,3 γ 154; 489; 1033
Sn 100 Sn 101 Sn 1 0,94 s 3 s 3,4	02 Sn 103 5 7 s	Sn 104 20,8 s	Sn 105 34 s	Sn 106 2,1 m	Sn 107 2,9 m	Sn 108 10,3 m	Sn 109 18,0 m	Sn 110 4,11 h
β ⁺ 3,4 β ⁺ βp 2-3,5 β ⁺	β ⁺ βp 1–3	β' 2,4 γ 133; 913; 401; 1407 m; g	β' γ 1282; 1466; 309; g; m βp 1–3	ε β ⁺ 1,2 γ 387; 253; 477; m	γ 1129; 1542; 1001 m; g	ε; β ⁺ 0,4 γ 396; 273; 169; 669 m	ε; β* 1,6 γ 1099; 1321; 331 g; m	ε γ 283 m



M. Sandzelius *et al.,* Phys. Rev. Lett. 99, 022501 (2007) M. Perti et al. Phys.Rev. C 76, 054301 (2007)



Identification of excited states in ¹¹⁰Xe







Clean mother-daughter correlations essential for selecting the ¹¹⁰Xe nuclei



Xe experimental energy systematics

110



Evidence for enhanced collectivity near N=Z!

Xe and Te energy ratios





Comparing theory with experimental B(E2) values for Xe - Ba isotopes Raman *et al.*, PRC '95





TRS calculations for neutron deficient Xe isotopes predict decreasing collectivity with decreasing N





Iodine energy systematics

109 2.0 23/2 Energy (MeV) 1.0 15/2-11/2-0.0 -1.07/2 5/2+ 7/2+ 127 129 131 125 A: 109 113 115 117 119 121 123

Suggest a larger quadrupole deformation as the N=50 shell closure is approached





Conclusions and outlook

- In-beam gamma-ray spectroscopy is possible down to 10's of nb x.s. using RDT and efficient Ge arrays
- Evidence for enhanced quadrupole collectivity in the Te, I and Xe isotopes as N → Z, against "common wisdom"
- np correlations (np pairing) driving the collectivity? (New effect, not considered earlier in quest for np pairing)
- Recent QRPA calculations (Delion, Liotta, Wyss et al.) confirm isoscalar pairing scenario for enhanced collectivity
- Theoretical models accounting for detailed dynamic coupling of protons and neutrons are needed.





Comparing theory with experimental B(E2) values (Raman estimates) for extremely neutron deficient Xe isotopes



- B(E2) values are a measure of nuclear collectivity
- Theoretical models predict a decrease in B(E2) values for decreasing N

 $B(E2; 2_1^+ \to 0_1^+) \approx 0.66E(2_1^+)^{-1}Z^2A$

The empirically deduced values^{*} reveal a leveling off and a even a small *increase* of the B(E2) value for ¹¹⁰Xe



Light Xe isotope pairing gap systematics



D. Delion, R. Liotta, R. Wyss et al. (in preparation)

