Nuclear moments and charge radii of the $_{51}$Sb isotopes via collinear laser spectroscopy

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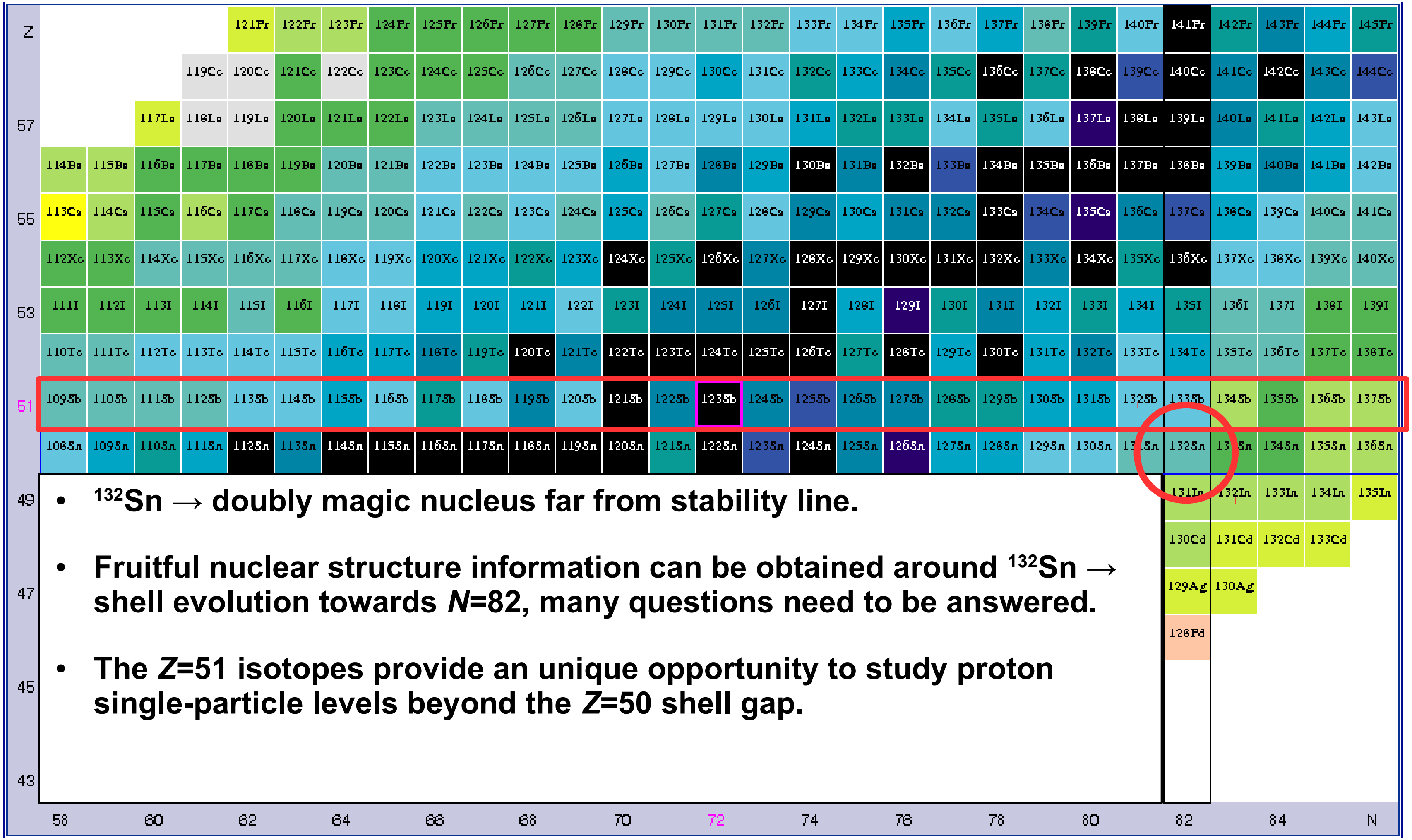
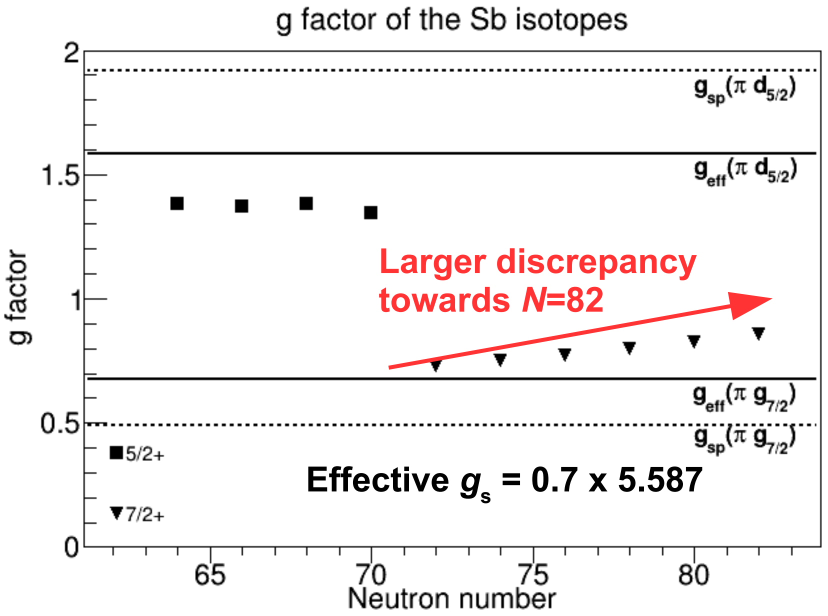
Physics motivation



Z					121Pr	122Pr	123Pr	124Pr	125Pr	126Pr	127Pr	128Pr	129Pr	130Pr	131Pr	132Pr	133Pr	134Pr	135Pr	136Pr	137Pr	138Pr	139Pr	140Pr	141Pr	142Pr	143Pr	144Pr	145Pr
				119Ce	120Ce	121Ce	122Ce	123Ce	124Ce	125Ce	126Ce	127Ce	128Ce	129Ce	130Ce	131Ce	132Ce	133Ce	134Ce	135Ce	136Ce	137Ce	138Ce	139Ce	140Ce	141Ce	142Ce	143Ce	144Ce
57			117La	118La	119La	120La	121La	122La	123La	124La	125La	126La	127La	128La	129La	130La	131La	132La	133La	134La	135La	136La	137La	138La	139La	140La	141La	142La	143La
	114Ba	115Ba	116Ba	117Ba	118Ba	119Ba	120Ba	121Ba	122Ba	123Ba	124Ba	125Ba	126Ba	127Ba	128Ba	129Ba	130Ba	131Ba	132Ba	133Ba	134Ba	135Ba	136Ba	137Ba	138Ba	139Ba	140Ba	141Ba	142Ba
55	113Cs	114Cs	115Cs	116Cs	117Cs	118Cs	119Cs	120Cs	121Cs	122Cs	123Cs	124Cs	125Cs	126Cs	127Cs	128Cs	129Cs	130Cs	131Cs	132Cs	133Cs	134Cs	135Cs	136Cs	137Cs	138Cs	139Cs	140Cs	141Cs
	112Xe	113Xe	114Xe	115Xe	116Xe	117Xe	118Xe	119Xe	120Xe	121Xe	122Xe	123Xe	124Xe	125Xe	126Xe	127Xe	128Xe	129Xe	130Xe	131Xe	132Xe	133Xe	134Xe	135Xe	136Xe	137Xe	138Xe	139Xe	140Xe
53	111I	112I	113I	114I	115I	116I	117I	118I	119I	120I	121I	122I	123I	124I	125I	126I	127I	128I	129I	130I	131I	132I	133I	134I	135I	136I	137I	138I	139I
	110Te	111Te	112Te	113Te	114Te	115Te	116Te	117Te	118Te	119Te	120Te	121Te	122Te	123Te	124Te	125Te	126Te	127Te	128Te	129Te	130Te	131Te	132Te	133Te	134Te	135Te	136Te	137Te	138Te
51	109Sb	110Sb	111Sb	112Sb	113Sb	114Sb	115Sb	116Sb	117Sb	118Sb	119Sb	120Sb	121Sb	122Sb	123Sb	124Sb	125Sb	126Sb	127Sb	128Sb	129Sb	130Sb	131Sb	132Sb	133Sb	134Sb	135Sb	136Sb	137Sb
	108Sn	109Sn	110Sn	111Sn	112Sn	113Sn	114Sn	115Sn	116Sn	117Sn	118Sn	119Sn	120Sn	121Sn	122Sn	123Sn	124Sn	125Sn	126Sn	127Sn	128Sn	129Sn	130Sn	13 Sn	132Sn	13 Sn	134Sn	135Sn	136Sn
49																									131In	132In	133In	134In	135In
																									130Cd	131Cd	132Cd	133Cd	
47																									129Ag	130Ag			
																									128Pd				
45																													
43																													
	58		60		62		64		66		68		70		72		74		76		78		80		82		84		N

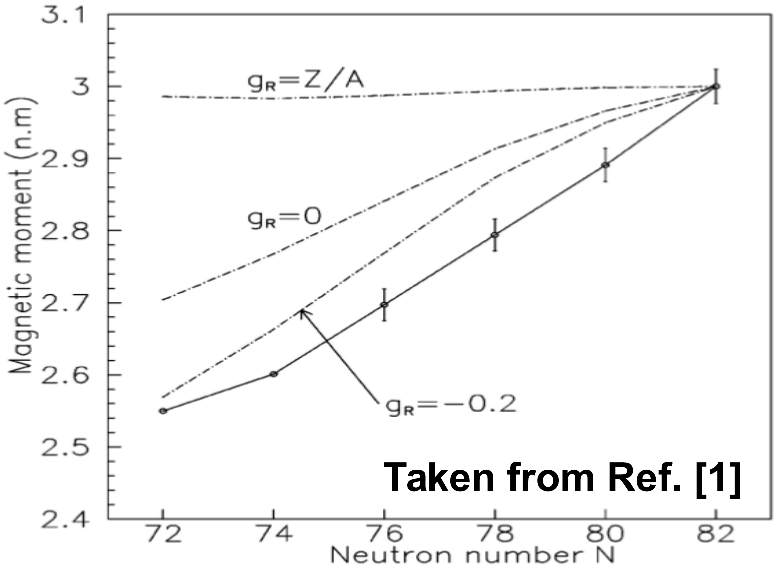
- **^{132}Sn → doubly magic nucleus far from stability line.**
- **Fruitful nuclear structure information can be obtained around ^{132}Sn → shell evolution towards *N*=82, many questions need to be answered.**
- **The *Z*=51 isotopes provide an unique opportunity to study proton single-particle levels beyond the *Z*=50 shell gap.**

Physics motivation



Larger discrepancy towards *N*=82

Effective g_s = 0.7 x 5.587



Taken from Ref. [1]

The magnetic moments are reproduced by introducing negative collective *g* factors g_R [1].

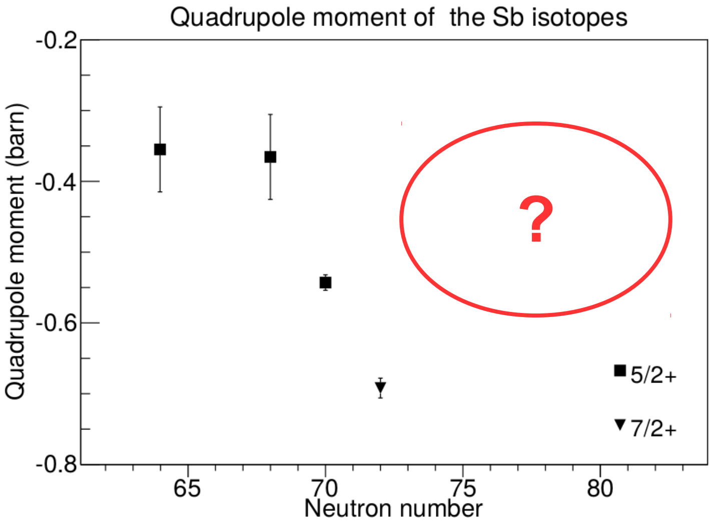
If the states are of pure single-particle character?

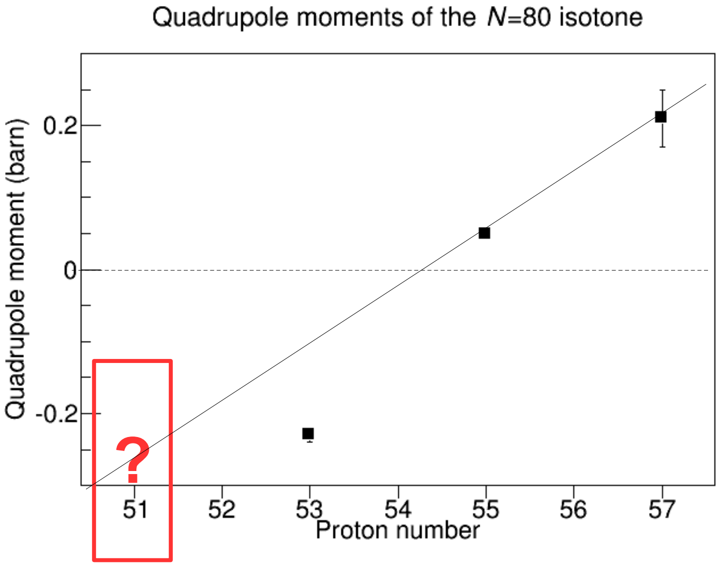
- **spectroscopic factors of the low-lying states via (α,*t*) reaction are close to unity [2].**
- **based on (^{3}He, *d*) reactions, the low-lying 11/2$^-$ states are claimed to be strongly correlated [3].**

The theoretical work in Ref. [4] shows the spectroscopic factors of the ground 7/2$^+$ states ~0.6.
→ Core collectivity can be addressed by nuclear quadrupole moments.

[1] N.J. Stone *et al.*, Phys. Rev. Lett. **78**, 820 (1997).
[2] J.P. Schiffer *et al.*, Phys. Rev. Lett. **92**, 162501 (2004).
[3] O. Sorlin and M. -G. Porquet, Prog. Part. Nucl. Phys. **61**, 602 (2008).
[4] Y. Utsuno *et al.*, EPJ Web of Conferences **66** , 02106 (2014).

Physics motivation





Compared with magnetic moments, the g.s. quadrupole moments are scarce.

→ missing experimental data from *N*=74 to *N*=82!

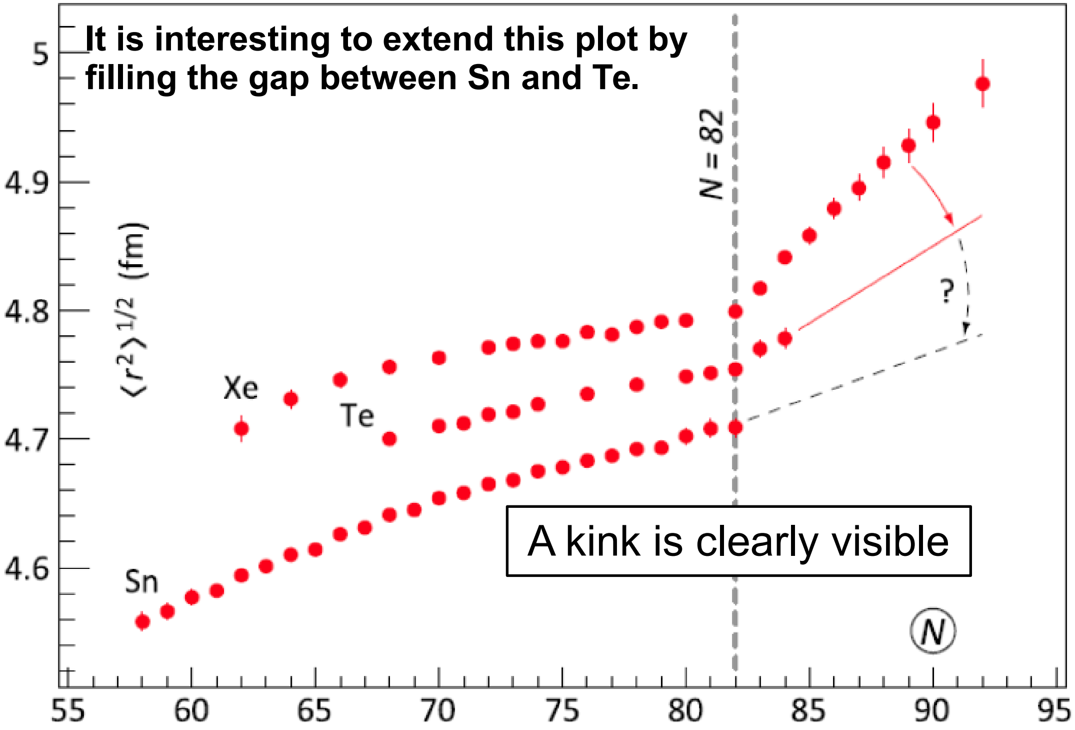
Along the *N*=80 isotonic chain, quadrupole moments can be approximated by the $(\pi g_{7/2})^n$ configurations. According to the seniority scheme, they should follow a linear relationship as a function of proton number *n*, and cross 0 at the mid-shell (*n*=4) [1,2].

What do we expect at *Z*=51?

[1] G. Neyens, Rep. Prog. Phys. **66**, 633 (2003).
[2] D.T. Yordanov *et al.*, Phys. Rev. Lett. **110**, 192501 (2013).

Physics motivation

Nuclear charge radius is another sensitive probe to investigate nuclear shell structure.



It is interesting to extend this plot by filling the gap between Sn and Te.

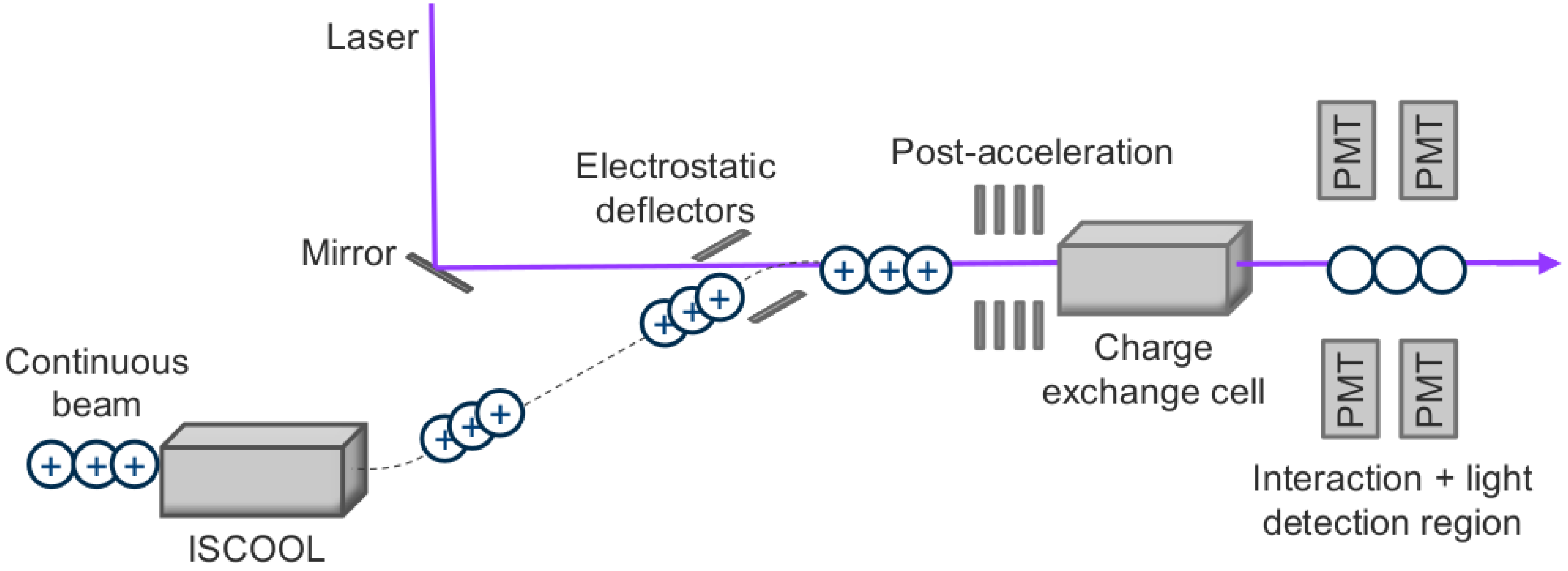
A kink is clearly visible

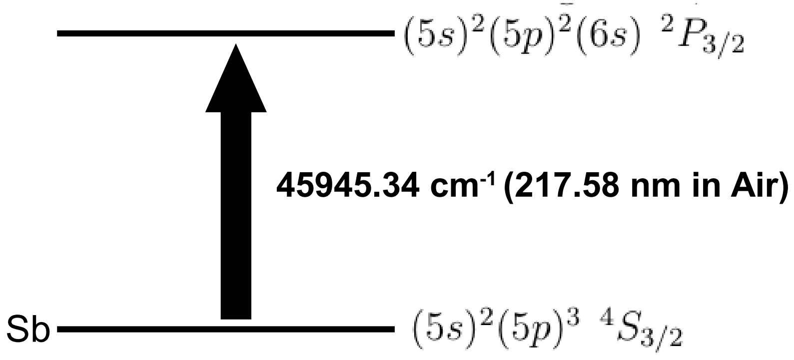
Experimental data is taken from I.Angeli, and K.P.Marinova, At.Data Nucl.Data Tables 99, 69 (2013)

The kink at *N*=82 becomes weaker when Z=54→52.
Similar behavior can be found at *N*=126 in the Pb region [1] but not at *N*=28 towards ^{48}Ca [2].
Only the charge radii of ^{121,123}Sb are known so far.

[1] T.E. Cocolios *et al*., Phys. Rev. Lett. **106**, 052503 (2011).
[2] K. Kreim *et al*., Phys. Lett. B **731**, 97 (2014).

Experimental approach




$(5s)^2(5p)^2(6s)\ ^2P_{3/2}$

45945.34 cm^{-1} (217.58 nm in Air)

Sb $(5s)^2(5p)^3\ ^4S_{3/2}$

The atomic ground state has 19% population in the charge exchange cell

Measure:
Hyperfine structure → *μ*, *Q*, and *I*
Isotope shift → <r^2>

Quadrupling of a Ti:sapphire laser. Close to the laser wavelength in the Cd experiment [1] performed at COLLAPS.

[1] D. T. Yordanov *et al.*, Phys. Rev. Lett. **110**, 192501 (2013)

Beam-time request

Production yield from TAC report: UC303/RILIS

^{133}Sb:	4e5/μC	
^{134m}Sb:	2e5/μC	
^{134g}Sb:	4e3/μC	← g.s. spin = 0
^{135}Sb:	5e4/μC	

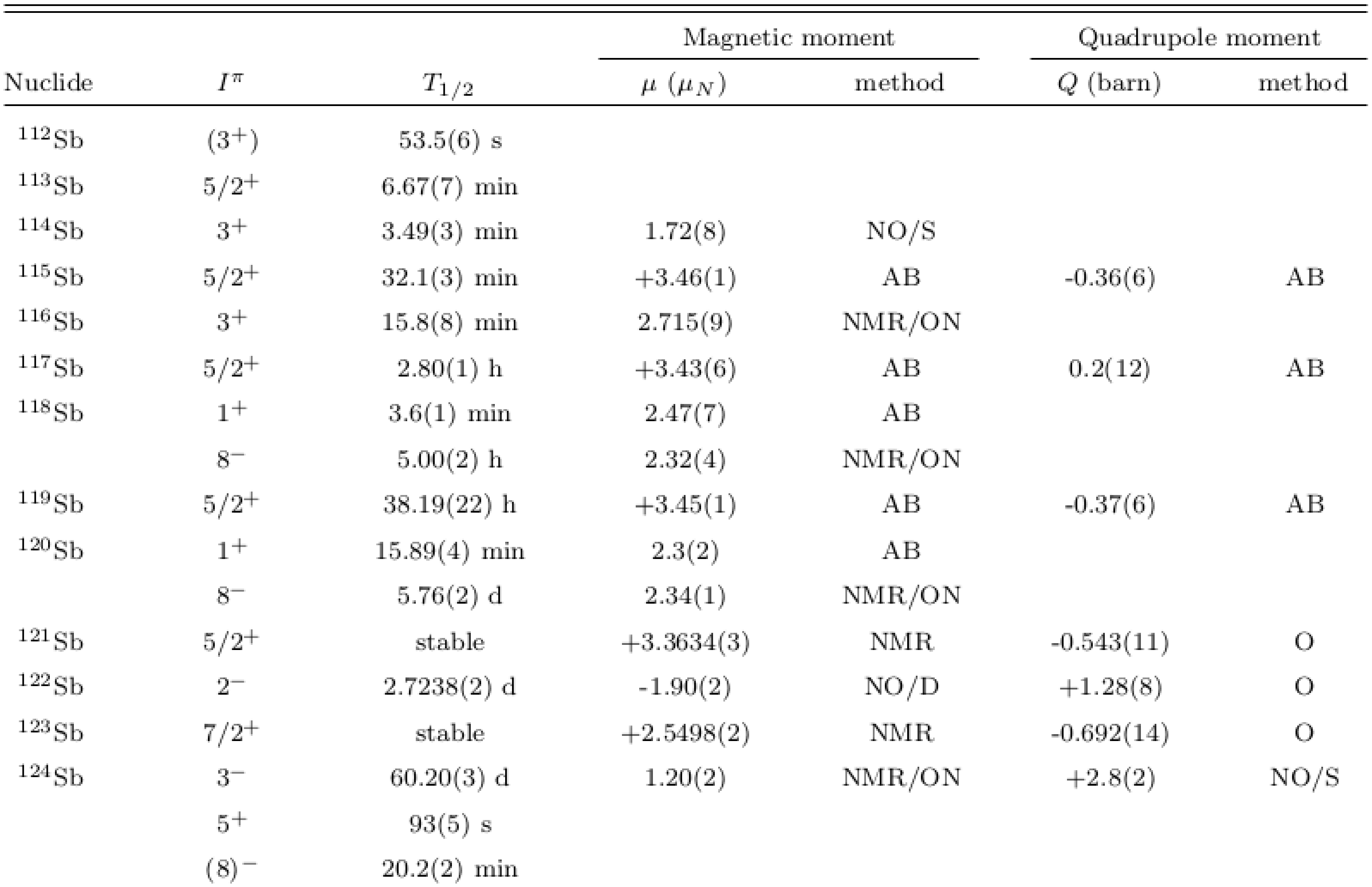
Sensitivity limit of COLLAPS with bunched beam: 10^4 ions/μC
→ $^{112-135}$Sb are accessible

Isotopes	target	# of shifts
$^{113-131}$Sb (odd mass)	UCx	6 shifts
$^{112-132}$Sb (even mass)	UCx	7 shifts
^{134}Sb	UCx	2 shifts
^{133,135}Sb	UCx	3 shifts

→ 20 shifts (18 radioactive beam and 2 stable beam) are requested to measure

- **the ground- and isomeric state spins of the odd-odd and a few odd-even neutron-rich Sb isotopes, and confirm earlier measured spins;**
- **the quadrupole moments for the neutron-rich isotopes (odd-even and odd-odd);**
- **the charge radii, with the aim to go beyond *N*=82 to investigate the slope of the kink.**

Thanks for your attention



			Magnetic moment		Quadrupole moment	
Nuclide	I^π	$T_{1/2}$	μ (μ_N)	method	Q (barn)	method
^{112}Sb	(3$^+$)	53.5(6) s				
^{113}Sb	5/2$^+$	6.67(7) min				
^{114}Sb	3$^+$	3.49(3) min	1.72(8)	NO/S		
^{115}Sb	5/2$^+$	32.1(3) min	+3.46(1)	AB	-0.36(6)	AB
^{116}Sb	3$^+$	15.8(8) min	2.715(9)	NMR/ON		
^{117}Sb	5/2$^+$	2.80(1) h	+3.43(6)	AB	0.2(12)	AB
^{118}Sb	1$^+$	3.6(1) min	2.47(7)	AB		
	8$^-$	5.00(2) h	2.32(4)	NMR/ON		
^{119}Sb	5/2$^+$	38.19(22) h	+3.45(1)	AB	-0.37(6)	AB
^{120}Sb	1$^+$	15.89(4) min	2.3(2)	AB		
	8$^-$	5.76(2) d	2.34(1)	NMR/ON		
^{121}Sb	5/2$^+$	stable	+3.3634(3)	NMR	-0.543(11)	O
^{122}Sb	2$^-$	2.7238(2) d	-1.90(2)	NO/D	+1.28(8)	O
^{123}Sb	7/2$^+$	stable	+2.5498(2)	NMR	-0.692(14)	O
^{124}Sb	3$^-$	60.20(3) d	1.20(2)	NMR/ON	+2.8(2)	NO/S
	5$^+$	93(5) s				
	(8)$^-$	20.2(2) min				

			Magnetic moment		Quadrupole moment	
Nuclide	I^π	$T_{1/2}$	μ (μ_N)	method	Q (barn)	method
^{125}Sb	$7/2^+$	2.75856(25) y	+2.63(4)	NMR		
^{126}Sb	(8^-)	12.35(6) d	1.28(7)	NO/S		
	(5^+)	19.15(8) min				
	(3^-)	about 11 s				
^{127}Sb	$7/2^+$	3.85(5) d	2.697(6)	NMR/ON		
^{128}Sb	8^-	9.05(4) h	1.3(2)	NO/S		
	5^+					
^{129}Sb	$7/2^+$	4.366(26) h	2.79(2)	NMR/ON		
	$(19/2^-)$	17.7(1) min				
^{130}Sb	(8^-)	39.5(8) min				
	$(4,5)^+$	6.3(2) min				
^{131}Sb	$(7/2^+)$	23.03(4) min	2.89(1)	NMR/ON		
^{132}Sb	$(4)^+$	2.79(7) min				
	(8^-)	4.10(5) min				
^{133}Sb	$(7/2^+)$	2.34(5) min	3.00(1)	NMR/ON		
^{134}Sb	(0^-)	0.78(6) s				
	(7^-)	10.07(5) s				
^{135}Sb	$(7/2^+)$	1.679(15) s				