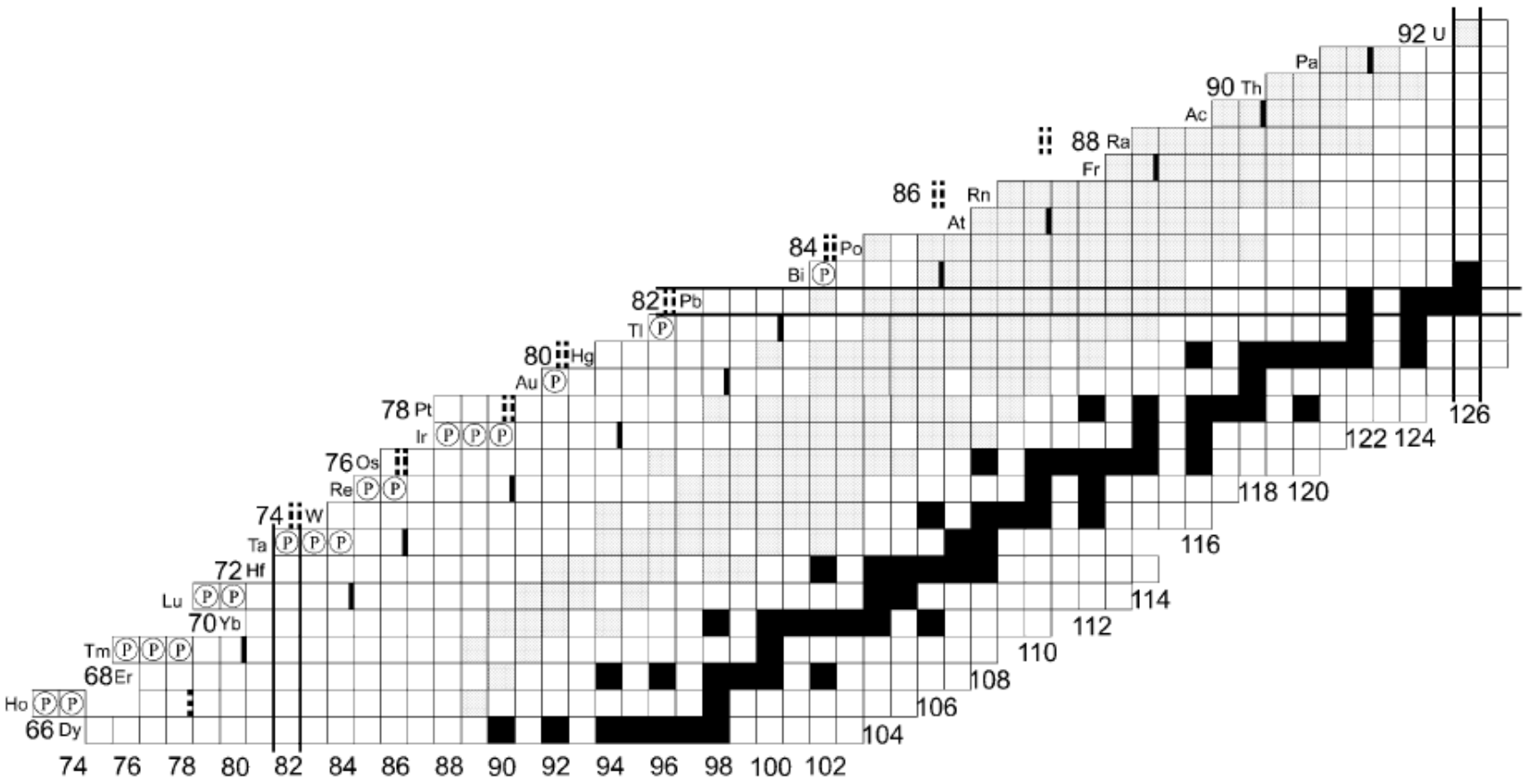
Probing the coexisting shapes at the proton drip line

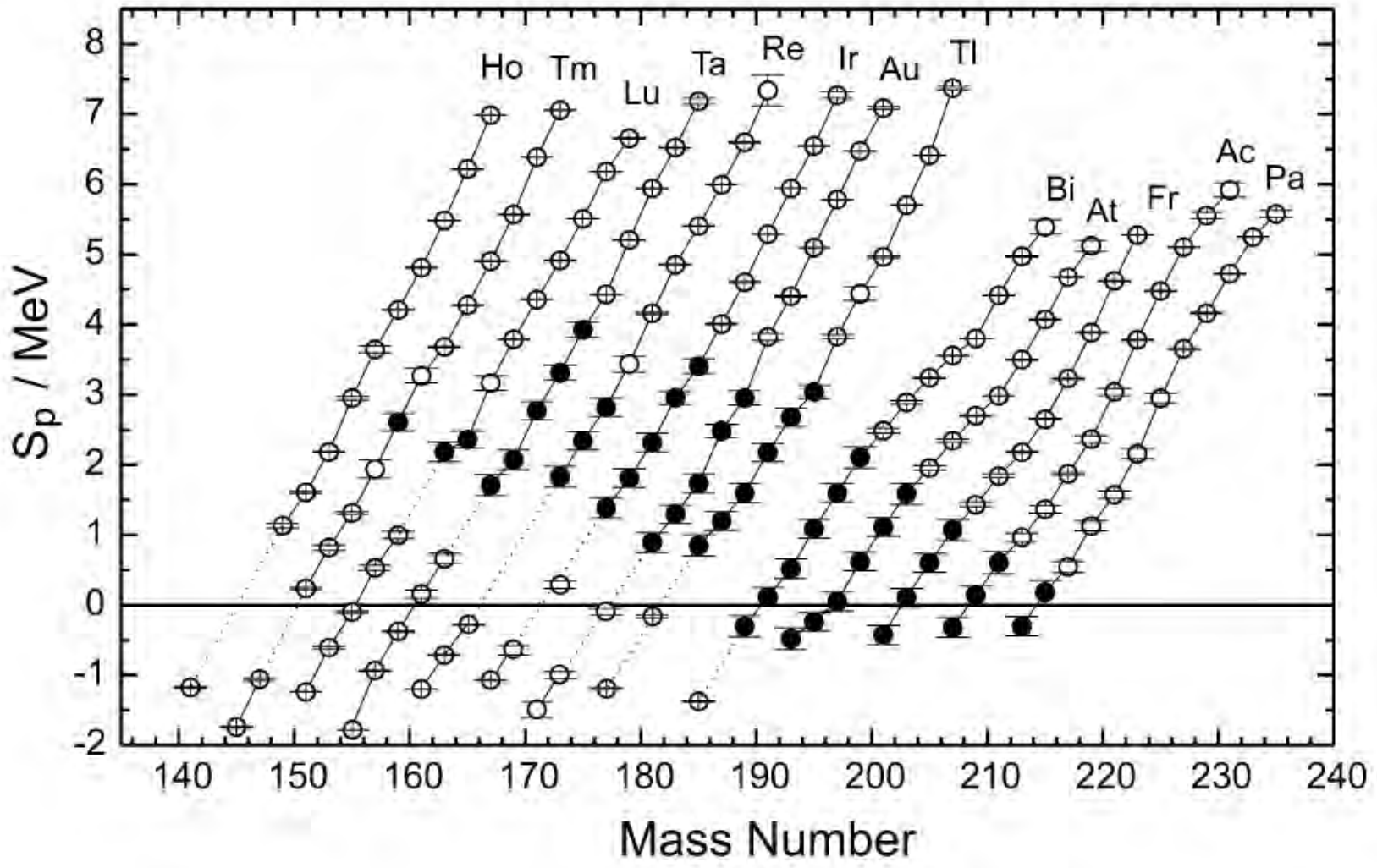
K. Auranen, U. Jakobsson, S. Juutinen, M. Leino, J. Saren, J. Uusitalo
RITU-Gamma collaboration
Department of Physics, University of Jyväskylä, Finland

Motivation
Experimental setup
Some results and conclusions

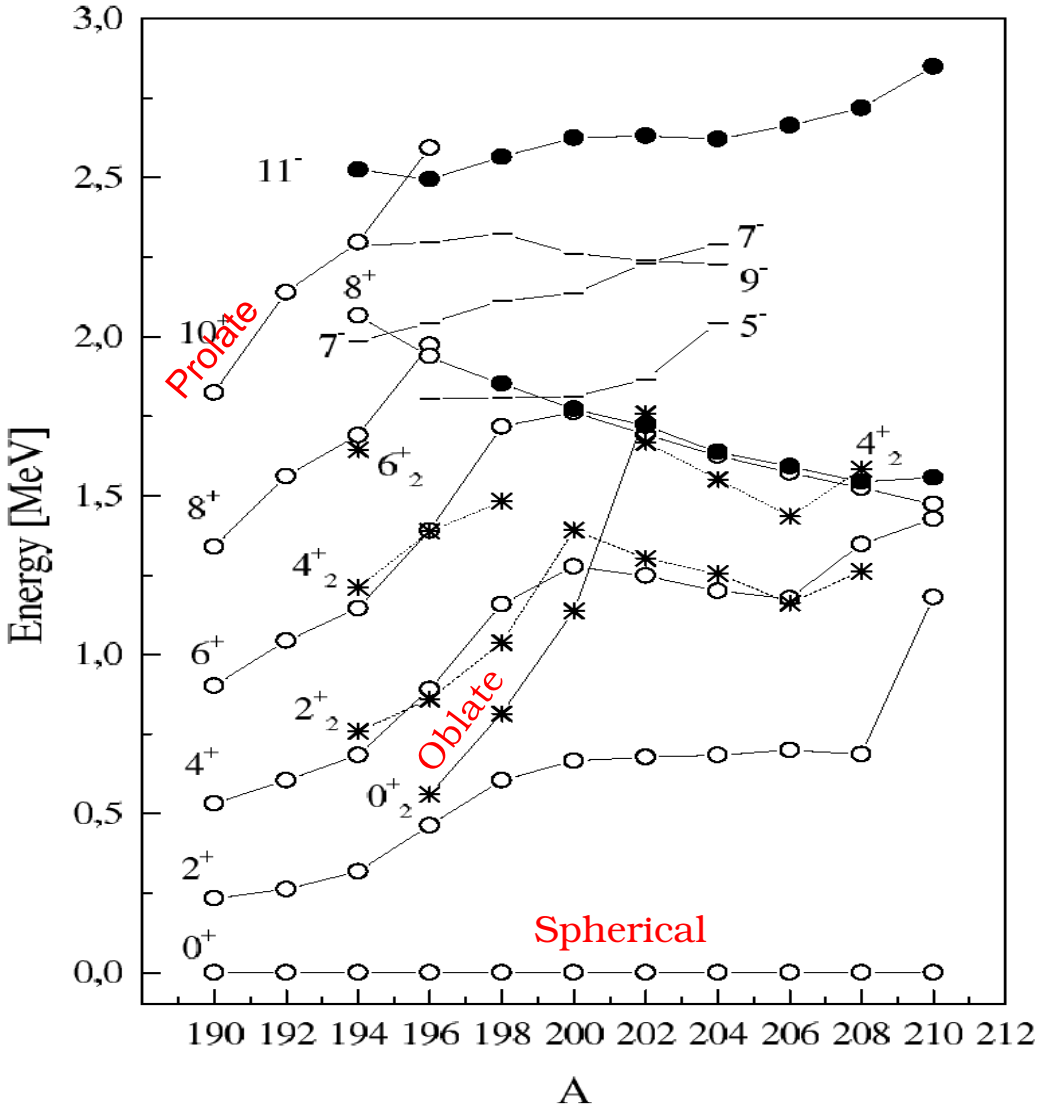
TASCA 14 GSI, Darmstadt, October 21, 2014

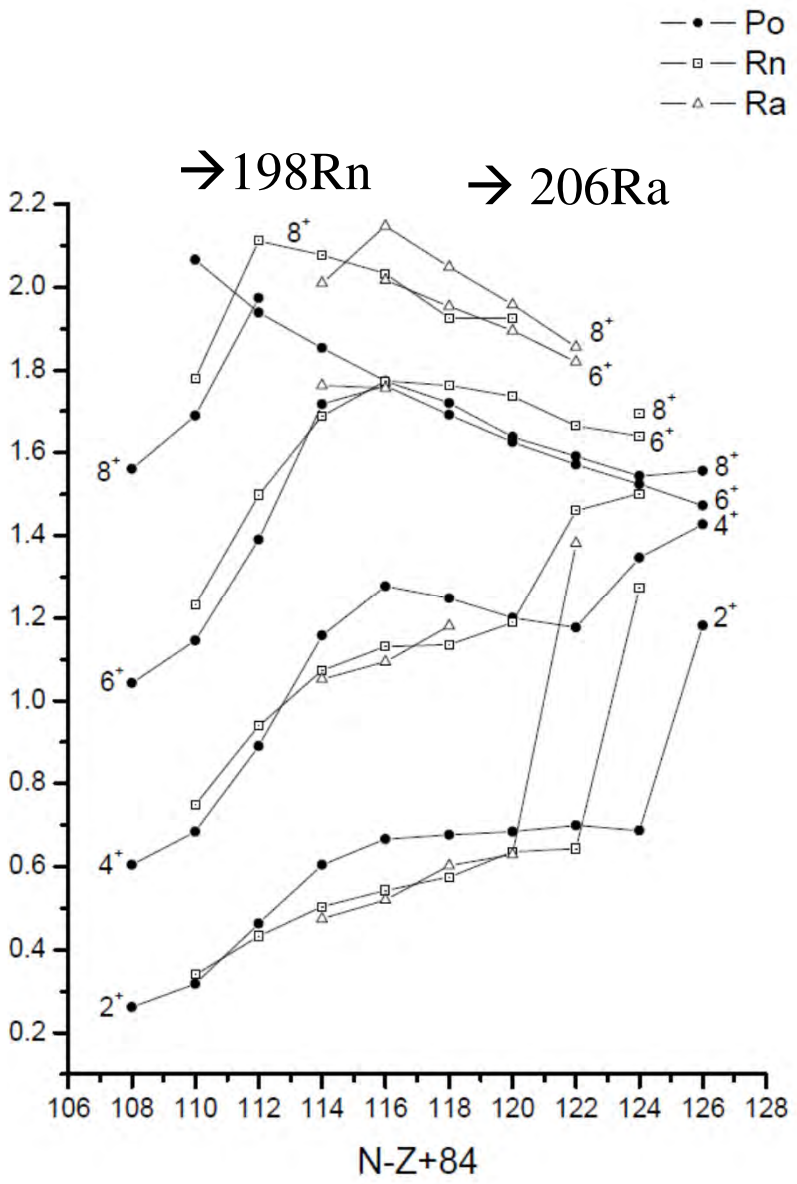


TASCA 14 GSI, Darmstadt, October 21, 2014


Ho
Tm
Lu
Ta
Re
Ir
Au
Tl
Bi
At
Fr
Ac
Pa
S_p / MeV
Mass Number
8
7
6
5
4
3
2
1
0
-1
-2
140
150
160
170
180
190
200
210
220
230
240

RDT- experiments 196Po → 190Po





Eur. Phys. J. A **16**, 457–467 (2003)
DOI 10.1140/epja/i2002-10130-9

THE EUROPEAN
PHYSICAL JOURNAL A

Investigations into the alpha-decay of ^{195}At

H. Kettunen[1,a], T. Enqvist[1], M. Leino[1], K. Eskola[2], P.T. Greenlees[1], K. Helariutta[1,b], P. Jones[1], R. Julin[1], S. Juutinen[1], H. Kankaanpää[1], H. Koivisto[1], P. Kuusiniemi[1], M. Muikku[1,c], P. Nieminen[1], P. Rahkila[1], and J. Uusitalo[1]

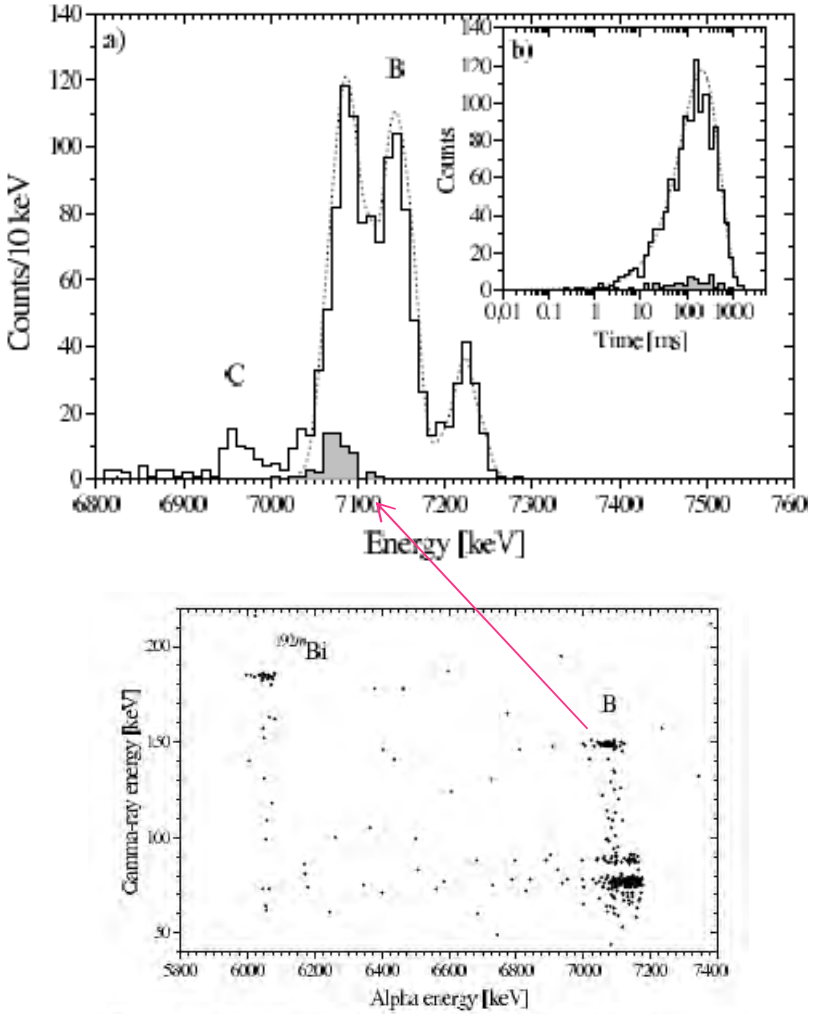
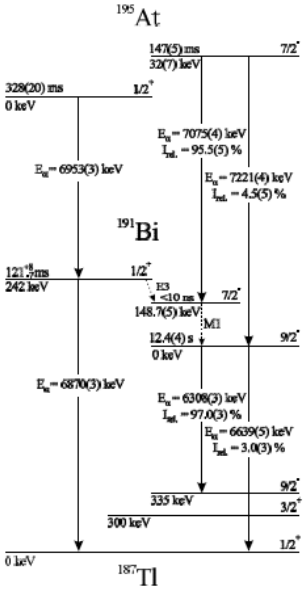
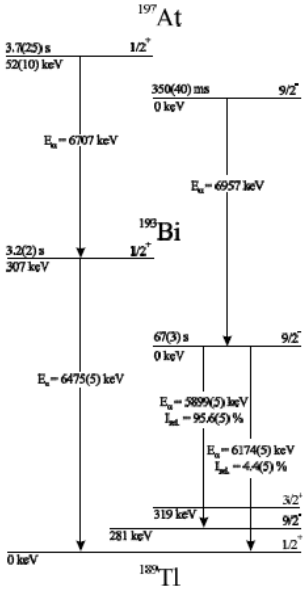


Fig. 4. Two-dimensional display of energies of coincident gamma-ray events and alpha decays in the reaction ^{56}Fe + ^{142}Nd.





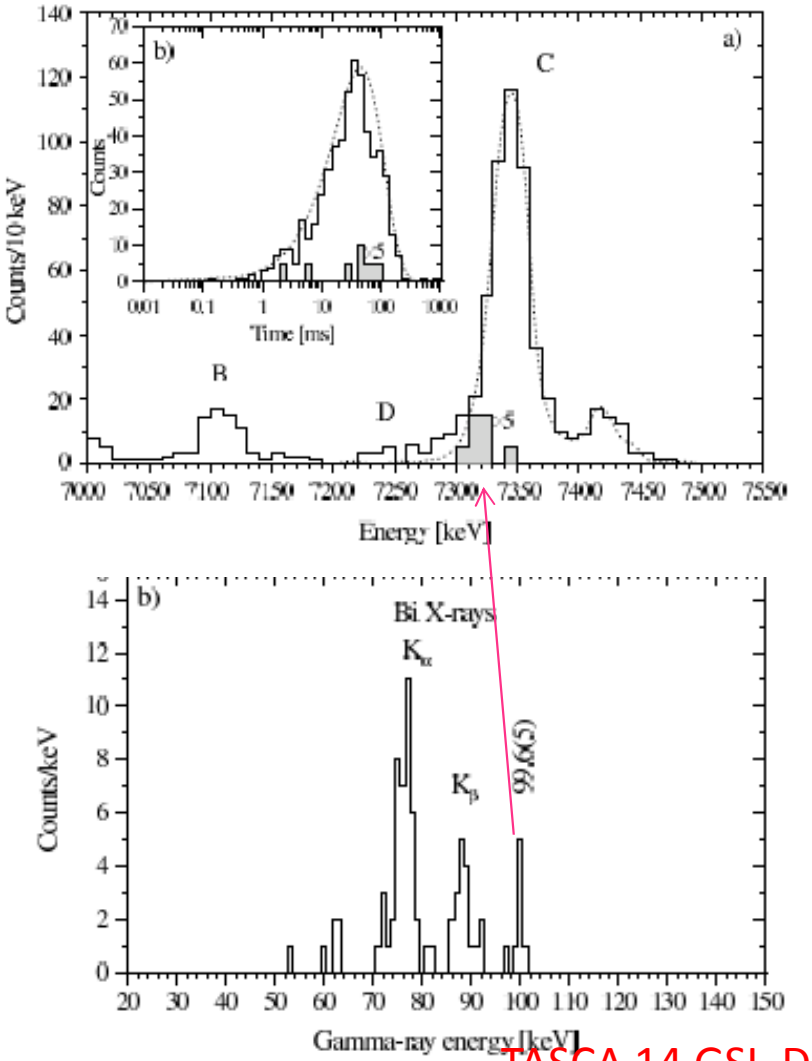
Eur. Phys. J. A **17**, 537–558 (2003)
DOI 10.1140/epja/i2002-10162-1

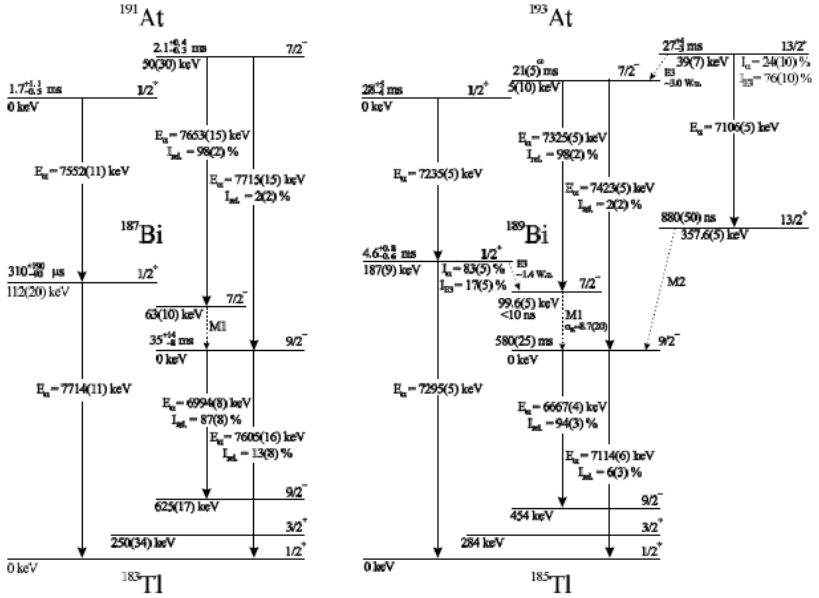
THE EUROPEAN PHYSICAL JOURNAL A

Alpha-decay studies of the new isotopes ^{191}At and ^{193}At

H. Kettunen[a], T. Enqvist, T. Grahn, P.T. Greenlees, P. Jones, R. Julin, S. Juutinen, A. Keenan, P. Kuusiniemi, M. Leino, A.-P. Leppänen, P. Nieminen, J. Pakarinen, P. Rahkila, and J. Uusitalo

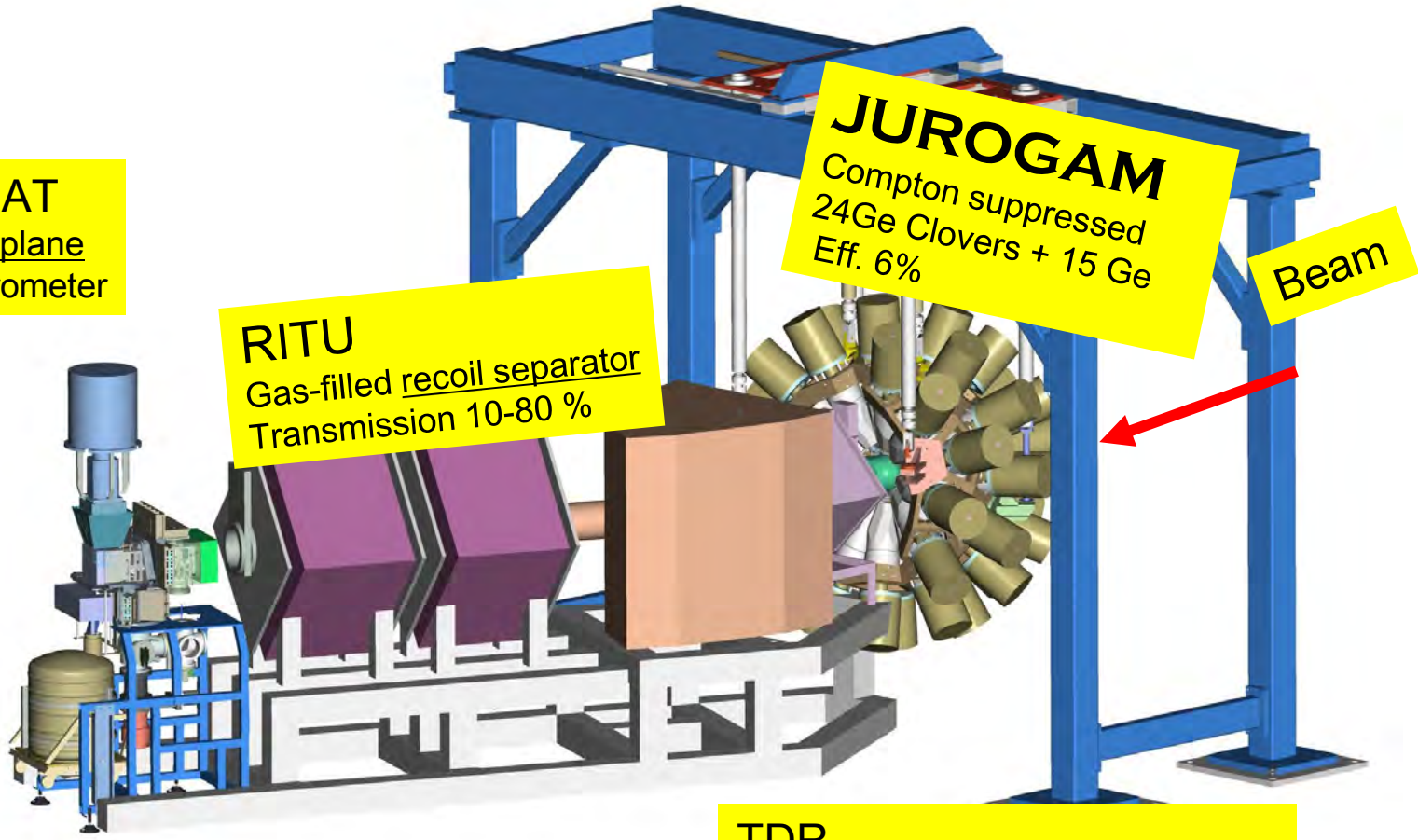
Department of Physics, University of Jyväskylä, P.O. Box 35, FIN-40014 Jyväskylä, Finland

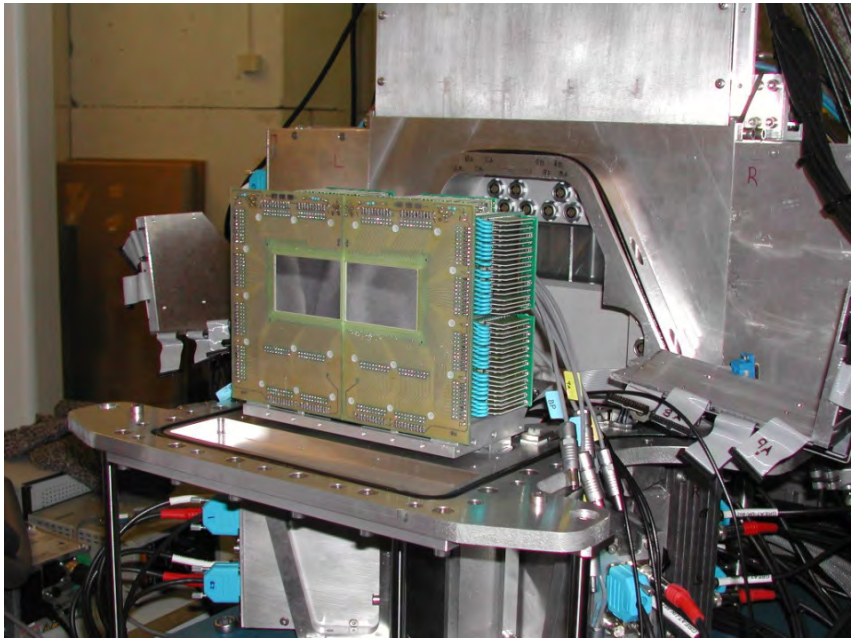


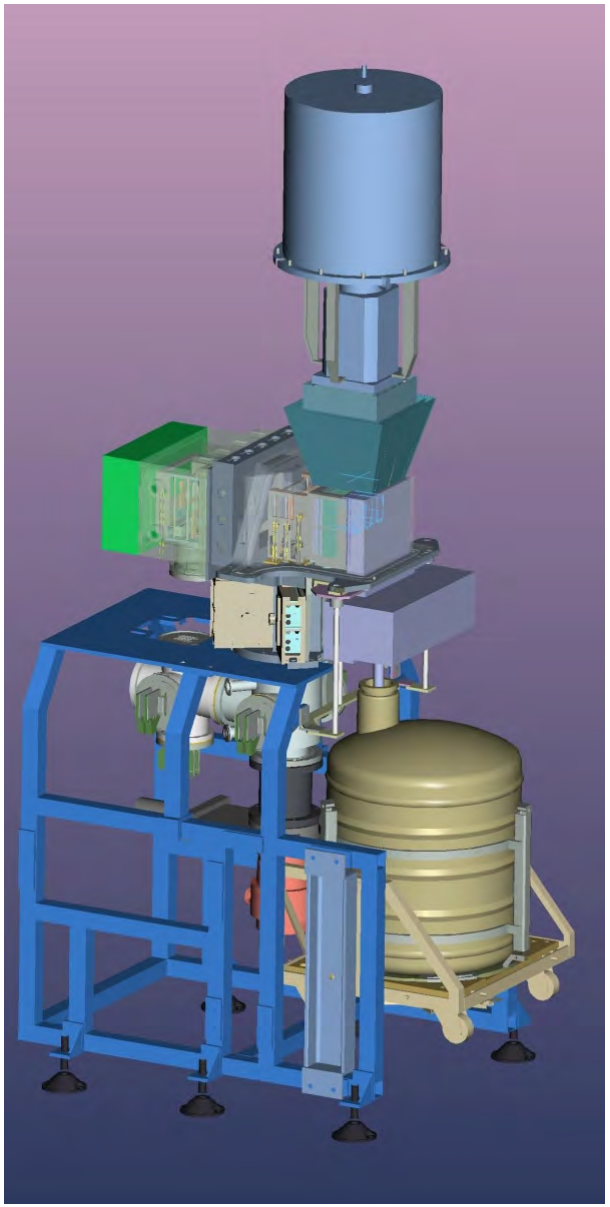


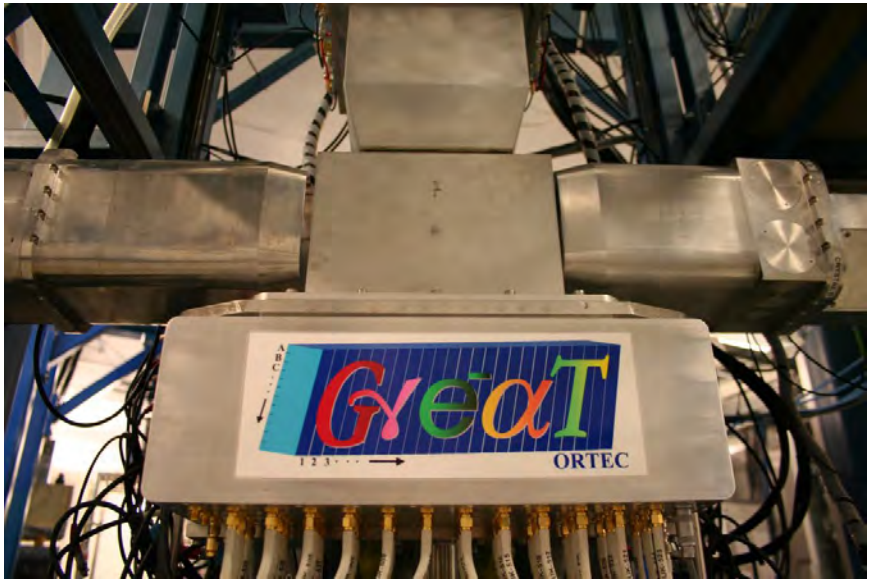
$^{141}Pr(^{63,65}Cu,2n)^{201,203}Fr$	J. Uusitalo et. al., PRC 71, 024306 (2005)
$^{150}Sm(^{52}Cr,p2n)^{199}At$	K. Andgren et. al., PRC 77, 054303 (2008)
$^{120}Sn(^{82}Kr,p2n)^{199}At$	U. Jakobsson et. al., PRC 82, 044302 (2010)
$^{118}Sn(^{82}Kr,p2n)^{197}At$	
$^{169}Tm(^{40}Ar,4n)^{205}Fr$	U. Jakobsson et. al., PRC 85, 014309 (2012)
$^{169}Tm(^{40}Ar,6n)^{203}Fr$	U. Jakobsson et. al., PRC 87, 054320 (2013)
$^{141}Pr(^{60}Ni,2n)^{199}Fr$	J. Uusitalo et. al., PRC 87, 064304 (2013)
$^{147}Sm(^{51}V,3n)^{195}At$	M. Nyman et. al., PRC 88, 054320 (2013)
$^{165}Ho(^{40}Ar,4n(6n))^{199,201}At$	K. Auranen et. al., PRC 90, 024310 (2014)

RDT Instrumentation at JYFL in Jyväskylä, Finland








GeαT
ORTEC

PHYSICAL REVIEW C 82, 044302 (2010)

Prompt and delayed spectroscopy of ^{199}At

U. Jakobsson,[1,*] J. Uusitalo,[1] S. Juutinen,[1] M. Leino,[1] P. Nieminen,[1] K. Andgren,[2] B. Cederwall,[2] P. T. Greenlees,[1] B. Hadinia,[2,†] P. Jones,[1] R. Julin,[1] S. Ketelhut,[1] A. Khaplanov,[2] M. Nyman,[1,‡] P. Peura,[1] P. Rahkila,[1] P. Ruotsalainen,[1] M. Sandzelius,[1] J. Sarén,[1] C. Scholey,[1] and J. Sorri[1]

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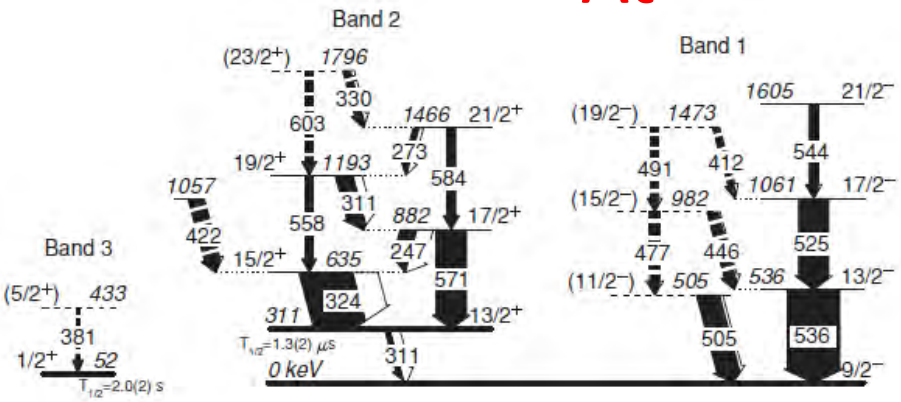
[2]*Department of Physics, Royal Institute of Technology, SE-10691 Stockholm, Sweden*

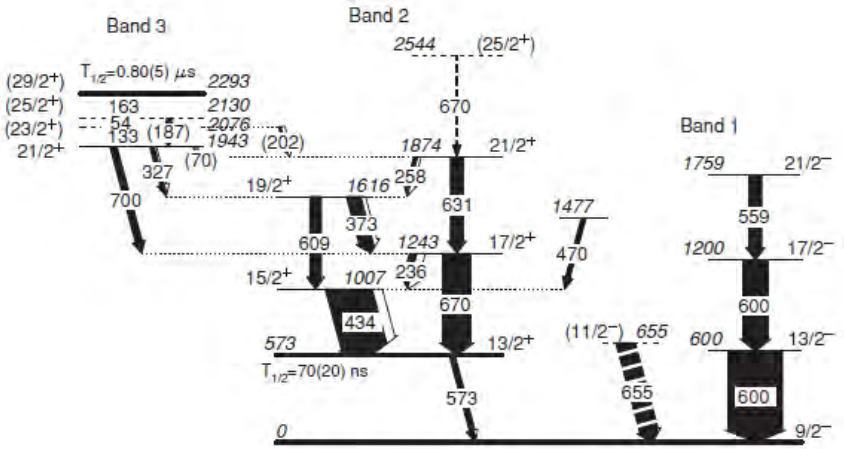
(Received 2 July 2010; published 6 October 2010)

^{197}At



^{199}At

$\pi(h9/2)^{200}Po11^-$



Gamma-ray and decay spectroscopy of ^{194,195,196}At

M. Nyman,[1,*] S. Juutinen,[1] I. Darby,[1,†] S. Eeckhaudt,[1] T. Grahn,[1] P. Greenlees,[1] P. Jones,[1] R. Julin,[1] S. Ketelhut,[1] H. Kettunen,[1] M. Leino,[1] P. Nieminen,[1] P. Rahkila,[1] J. Sarén,[1] C. Scholey,[1] J. Sorri,[1] J. Uusitalo,[1] and T. Enqvist[2]

[1] *Department of Physics, University of Jyväskylä, P.O. Box 35 (YFL), FI-40014 University of Jyväskylä, Finland*

[2] *CUPP, P.O. Box 22, FI-86801 Pyhäsalmi, Finland*

(Dated: May 10, 2011)

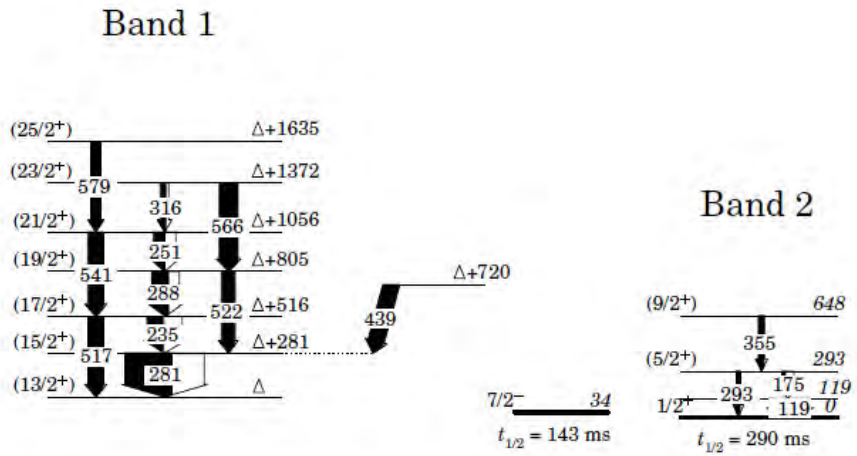
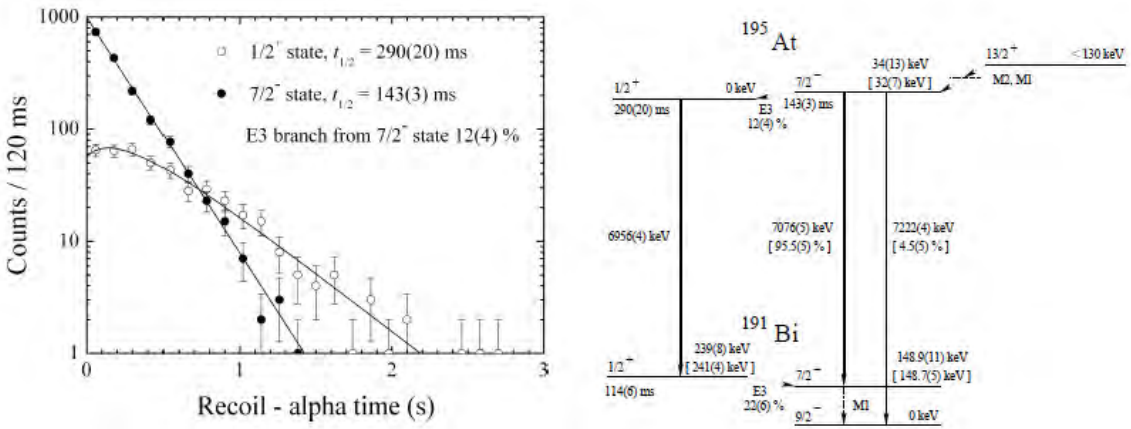


FIG. 5. The level scheme of ^{195}At.



PHYSICAL REVIEW C 71, 024306 (2005)

α decay studies of very neutron-deficient francium and radium isotopes

J. Uusitalo,[1] M. Leino,[1] T. Enqvist,[1,*] K. Eskola,[2] T. Grahn,[1] P. T. Greenlees,[1] P. Jones,[1] R. Julin,[1] S. Juutinen,[1] A. Keenan,[1] H. Kettunen,[1] H. Koivisto,[1] P. Kuusiniemi,[1,†] A.-P. Leppänen,[1] P. Nieminen,[1,‡] J. Pakarinen,[1] P. Rahkila,[1] and C. Scholey[1]

[1]*Department of Physics, University of Jyväskylä, P.O. Box 35, FI-40014, Jyväskylä, Finland*

[2]*Department of Physics, University of Helsinki, FI-00014, Helsinki, Finland*

(Received 27 October 2004; published 11 February 2005)

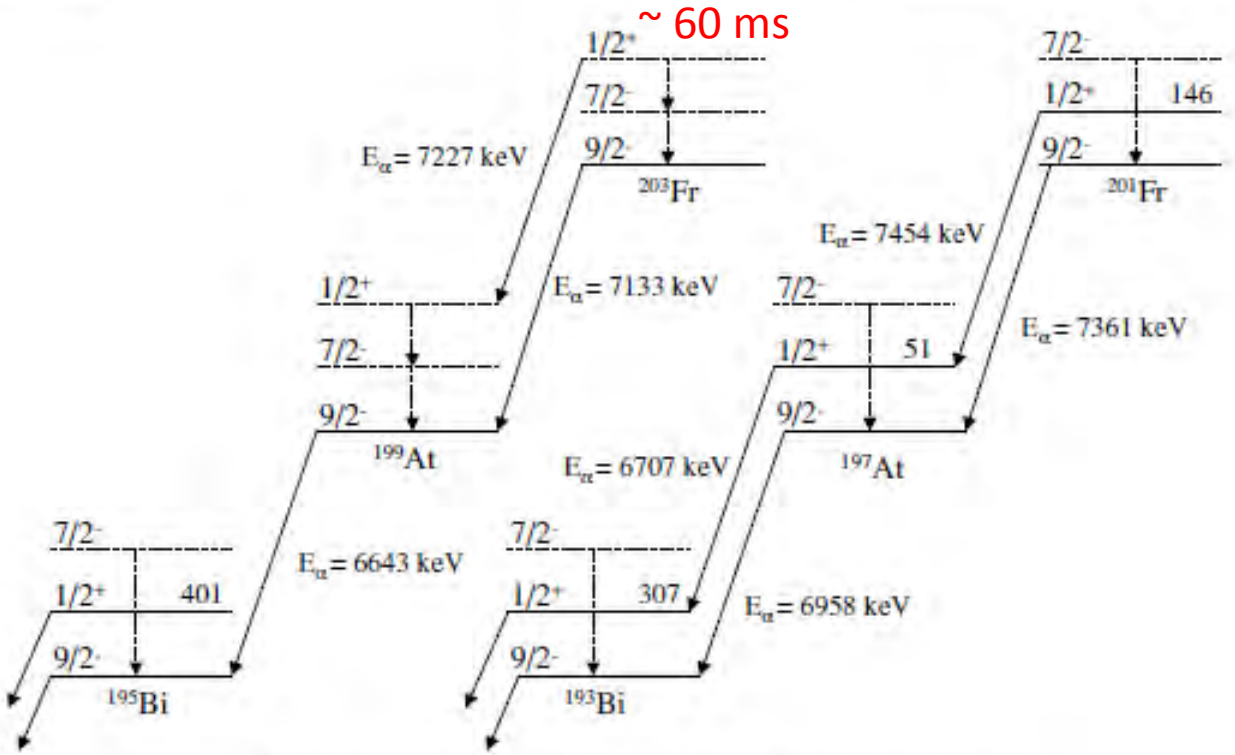
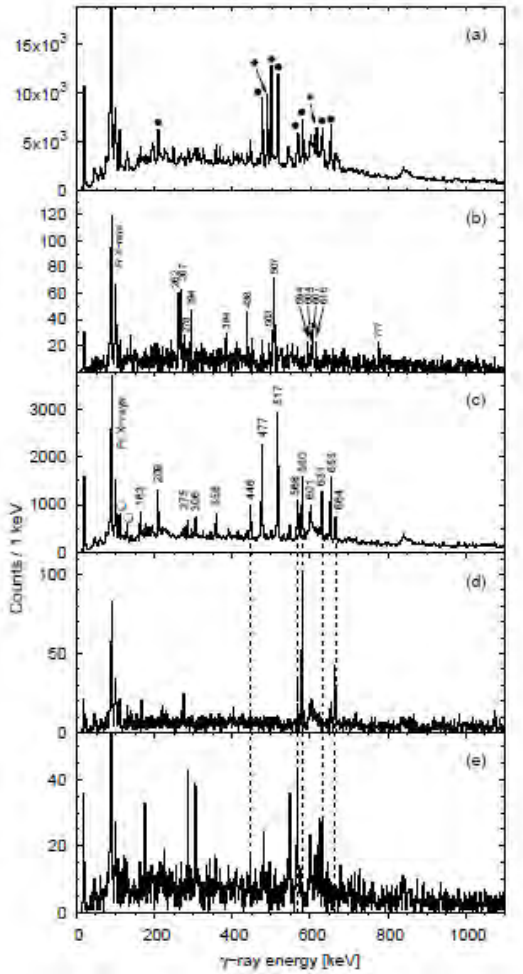
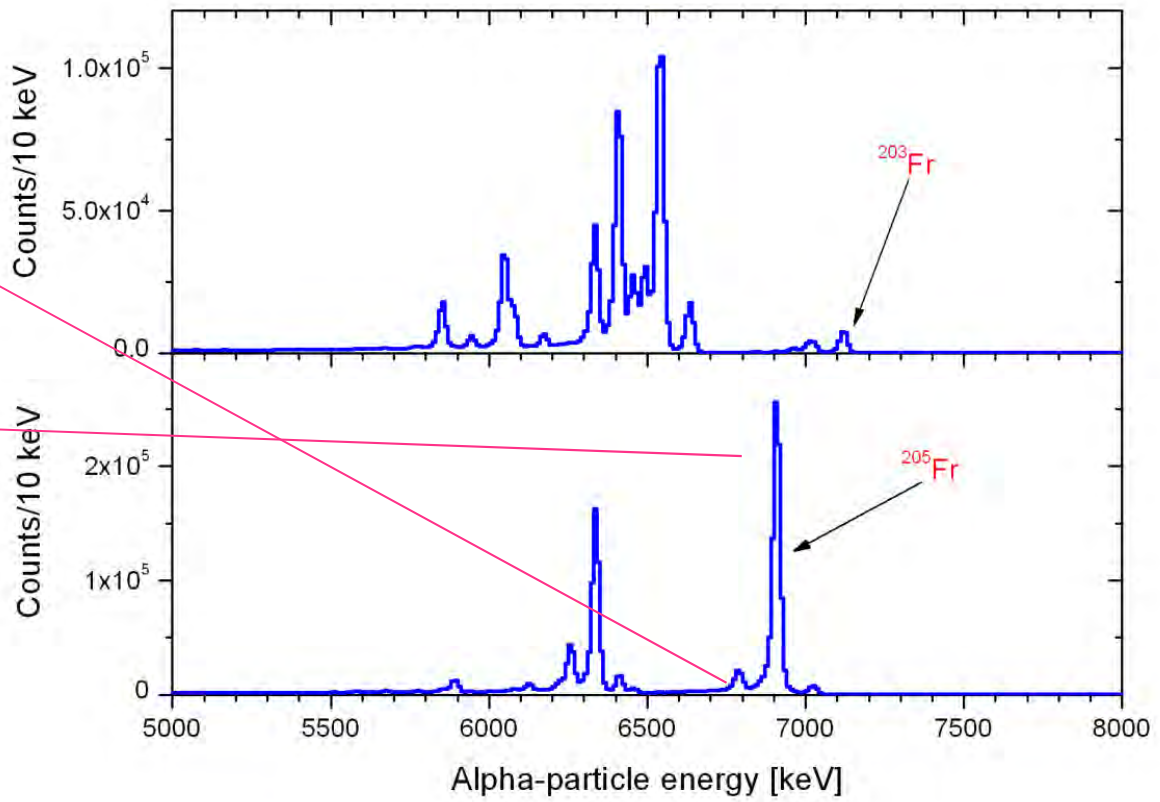


FIG. 8. Suggested α decay schemes belonging to odd-mass francium isotopes are shown.

$^{169}Tm(^{40}Ar,4n)^{205}Fr$ @ 180 MeV

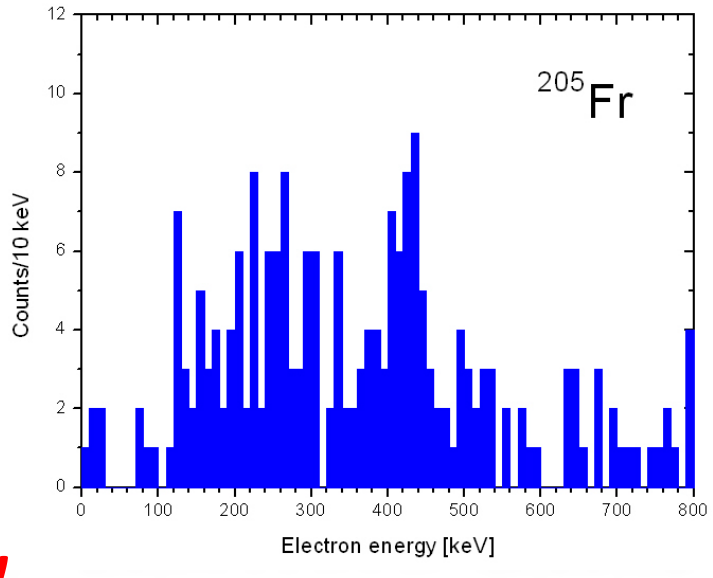
$^{169}Tm(^{40}Ar,6n)^{203}Fr$ @ 210 MeV



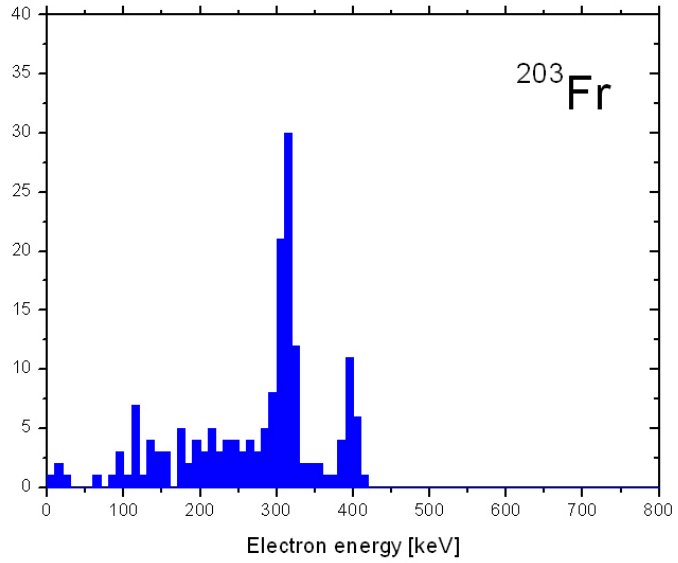


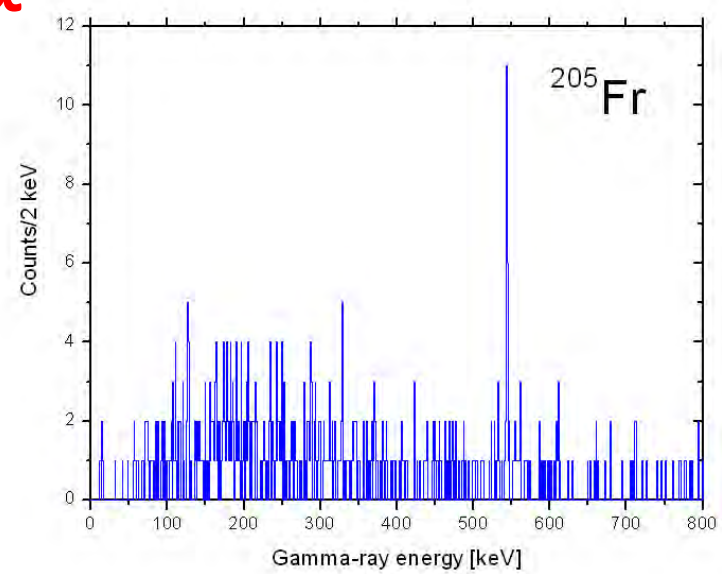
R-e-α

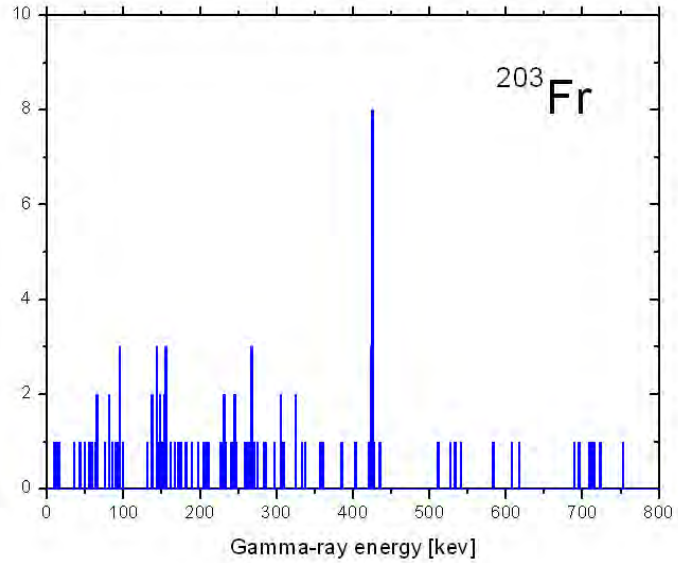
~ 80 ns



~ 200 ns



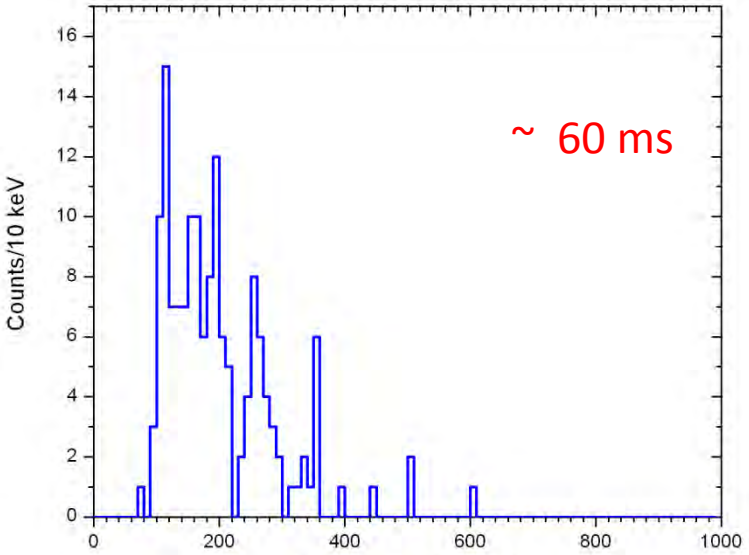




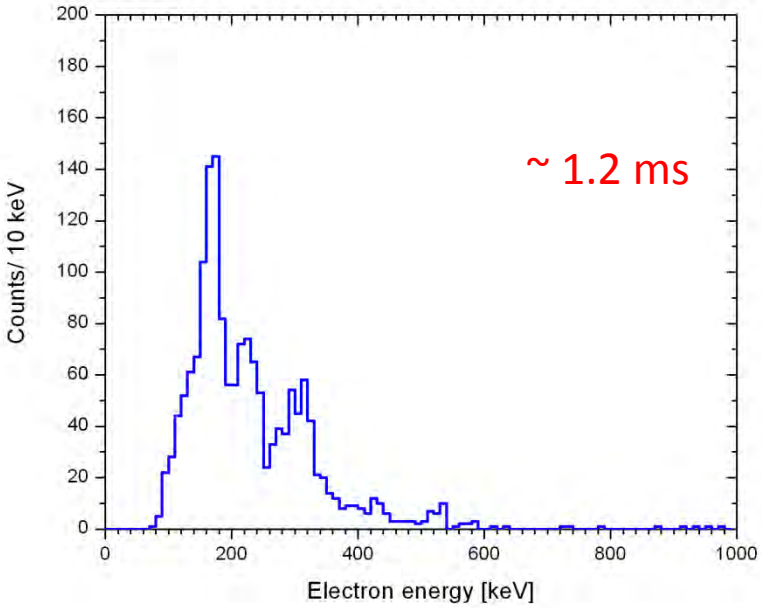
$\alpha_{tot} = 0.36$, $\alpha_k = 0.27$

$\alpha_{tot} = 0.74$, $\alpha_k = 0.56$

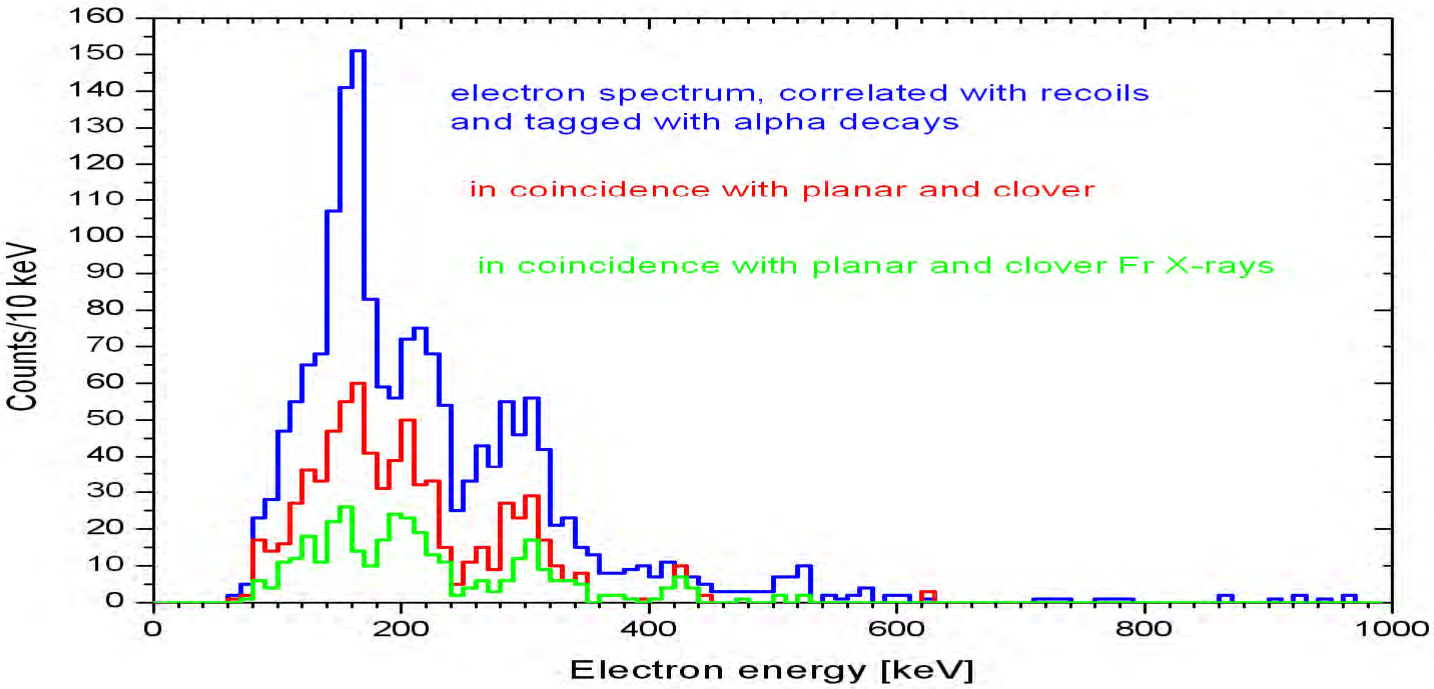
R-e-α

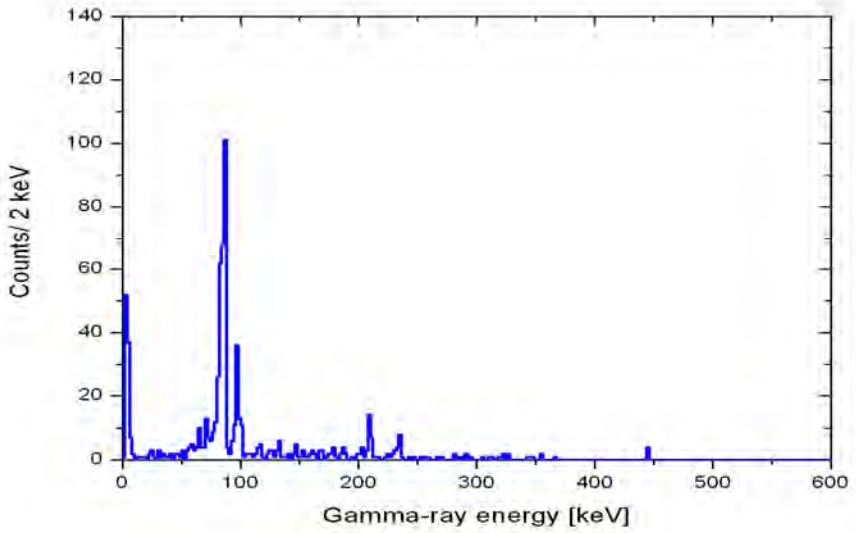


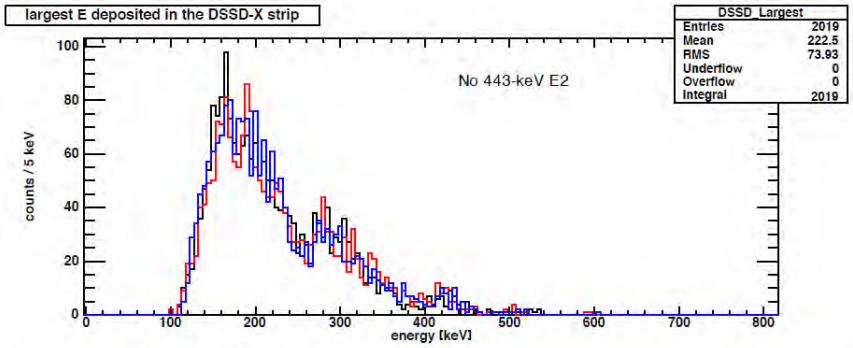
^{203}Fr

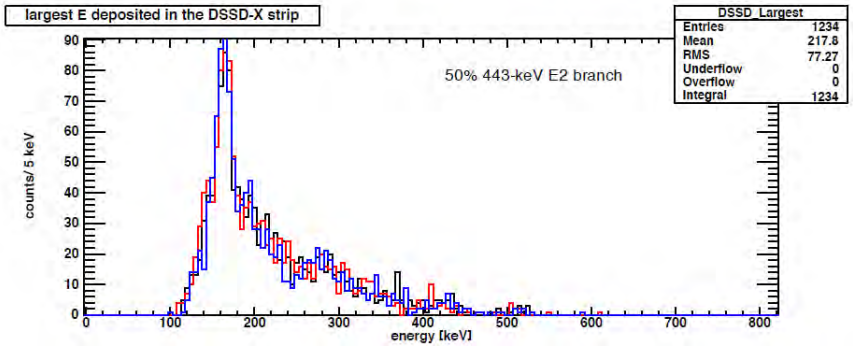


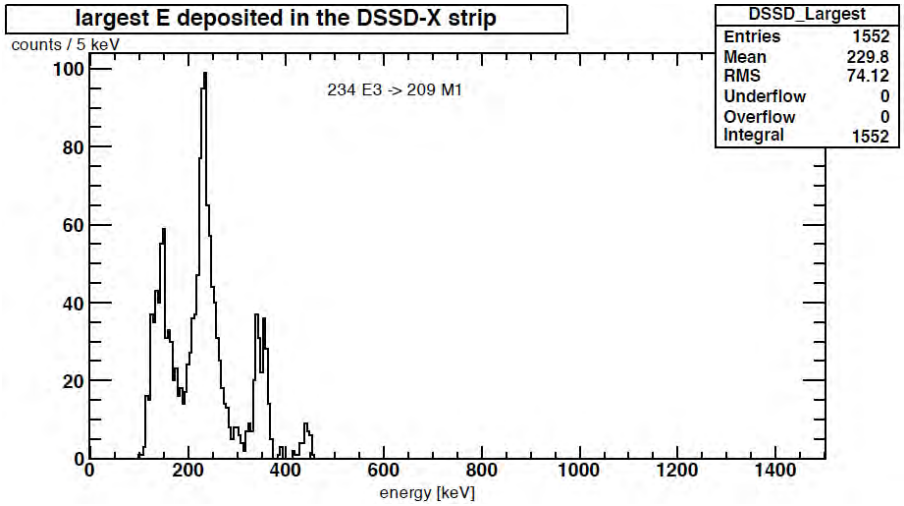
^{205}Fr

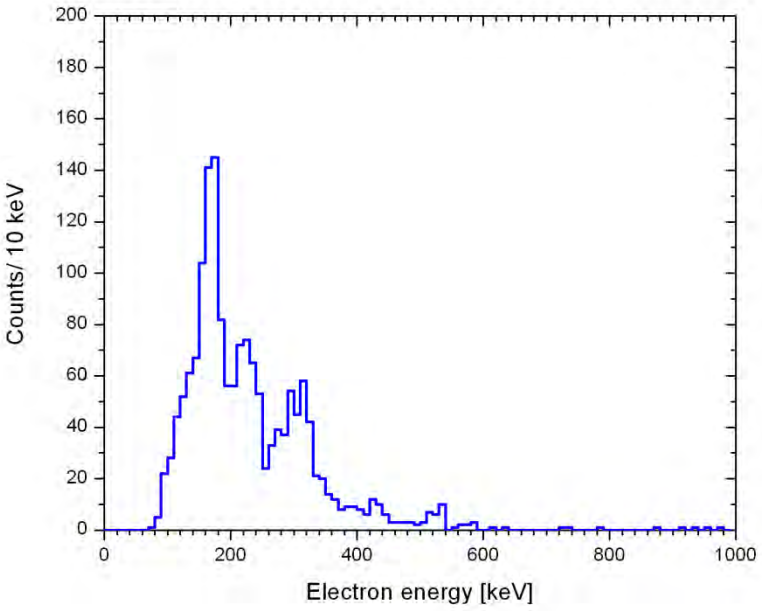

electron spectrum, correlated with recoils
and tagged with alpha decays
in coincidence with planar and clover
in coincidence with planar and clover Fr X-rays
Counts/10 keV
Electron energy [keV]
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
0
200
400
600
800
1000

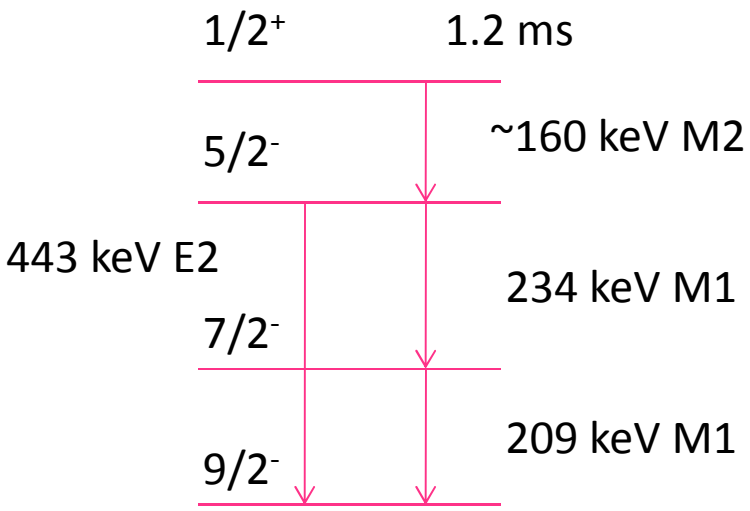

Counts/ 2 keV
Gamma-ray energy [keV]
0
20
40
60
80
100
120
140
0
100
200
300
400
500
600


largest E deposited in the DSSD-X strip
DSSD_Largest
Entries 2019
Mean 222.5
RMS 73.93
Underflow 0
Overflow 0
Integral 2019
No 443-keV E2
counts / 5 keV
energy [keV]


largest E deposited in the DSSD-X strip
DSSD_Largest
Entries 1234
Mean 217.8
RMS 77.27
Underflow 0
Overflow 0
Integral 1234
50% 443-keV E2 branch
counts/ 5 keV
energy [keV]


largest E deposited in the DSSD-X strip
DSSD_Largest
Entries 1552
Mean 229.8
RMS 74.12
Underflow 0
Overflow 0
Integral 1552
234 E3 -> 209 M1
counts / 5 keV
energy [keV]


Counts/ 10 keV
Electron energy [keV]


1/2+
1.2 ms
5/2-
~160 keV M2
443 keV E2
7/2-
234 keV M1
9/2-
209 keV M1

PHYSICAL REVIEW C 87, 054320 (2013)

Spectroscopy of the proton drip-line nucleus ^{203}Fr

U. Jakobsson,[1,*] S. Juutinen,[1] J. Uusitalo,[1] M. Leino,[1] K. Auranen,[1] T. Enqvist,[2] P. T. Greenlees,[1] K. Hauschild,[3] P. Jones,[1,†] R. Julin,[1] S. Ketelhut,[1,‡] P. Kuusiniemi,[2] M. Nyman,[1,§] P. Peura,[1] P. Rahkila,[1] P. Ruotsalainen,[1] J. Sarén,[1] C. Scholey,[1] and J. Sorri[1]

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(Received 21 January 2013; revised manuscript received 12 February 2013; published 17 May 2013)

PHYSICAL REVIEW C 85, 014309 (2012)

Recoil-decay tagging study of ^{205}Fr

U. Jakobsson,[1,*] J. Uusitalo,[1] S. Juutinen,[1] M. Leino,[1] T. Enqvist,[2] P. T. Greenlees,[1] K. Hauschild,[1,3] P. Jones,[1,†] R. Julin,[1] S. Ketelhut,[1,‡] P. Kuusiniemi,[2] M. Nyman,[1] P. Peura,[1] P. Rahkila,[1] P. Ruotsalainen,[1] J. Sarén,[1] C. Scholey,[1] and J. Sorri[1]

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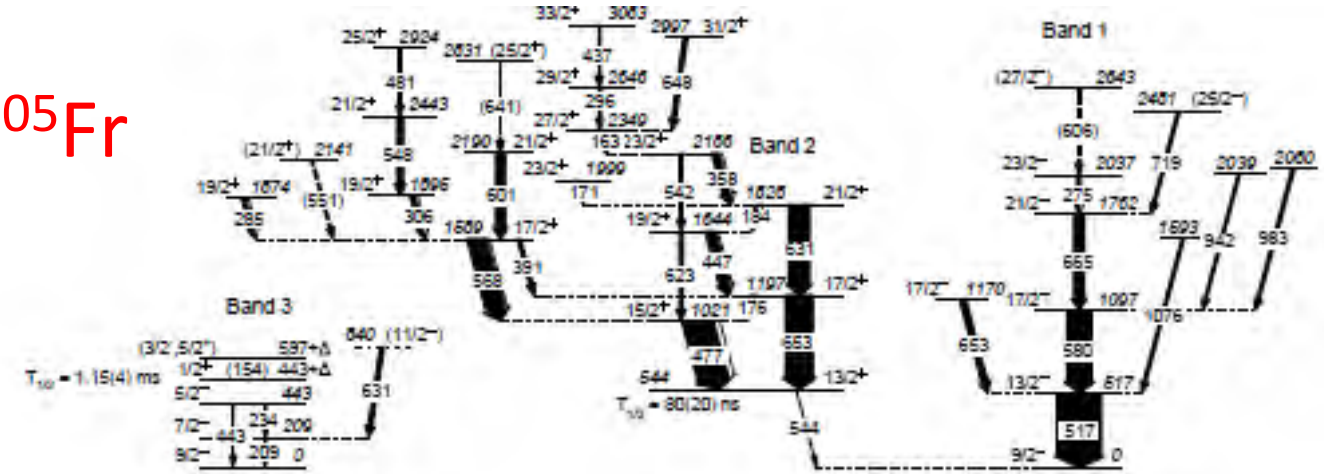
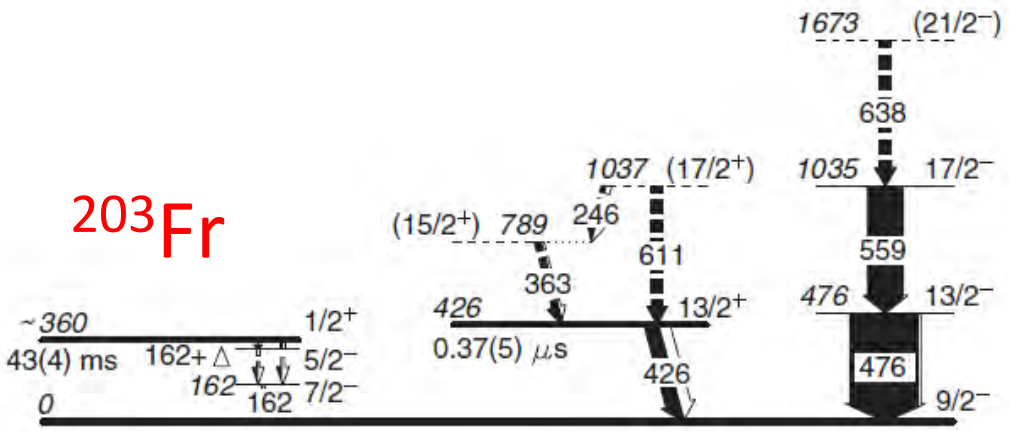
[2]*Oulu Southern Institute and Department of Physics, University of Oulu, FI-90041 Oulu, Finland*
[3]*CSNSM, IN2P3-CNRS, F-91405 Orsay Campus, France*

(Received 1 October 2011; published 12 January 2012)

^{205}Fr



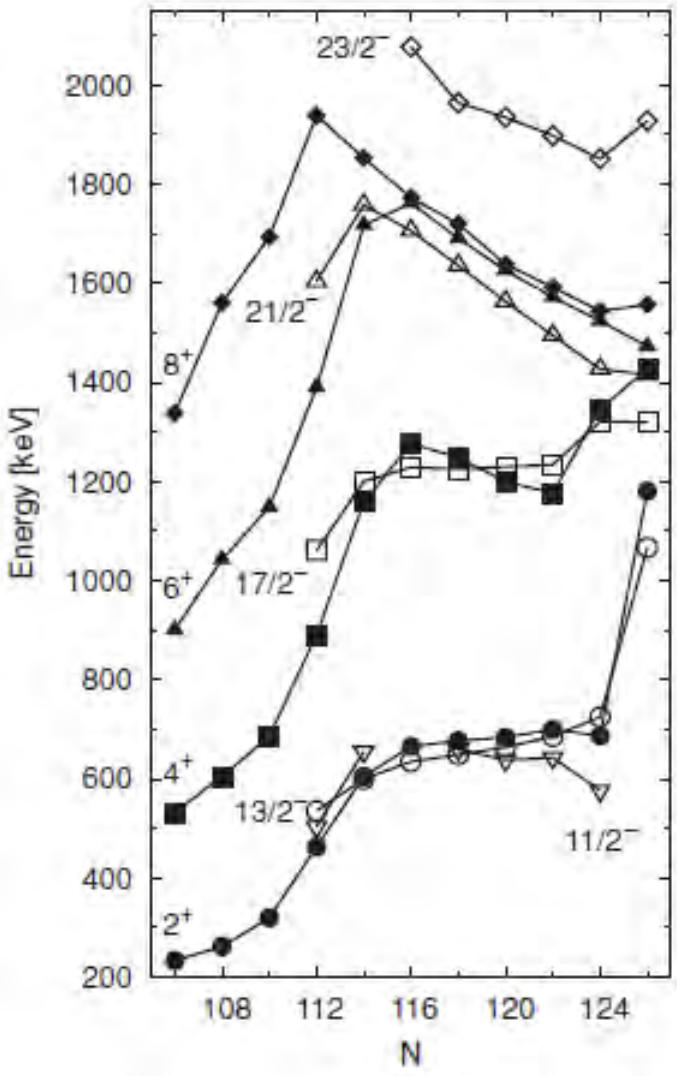
^{203}Fr



TASCA 14 GSI, Darmstadt, October 21, 2014

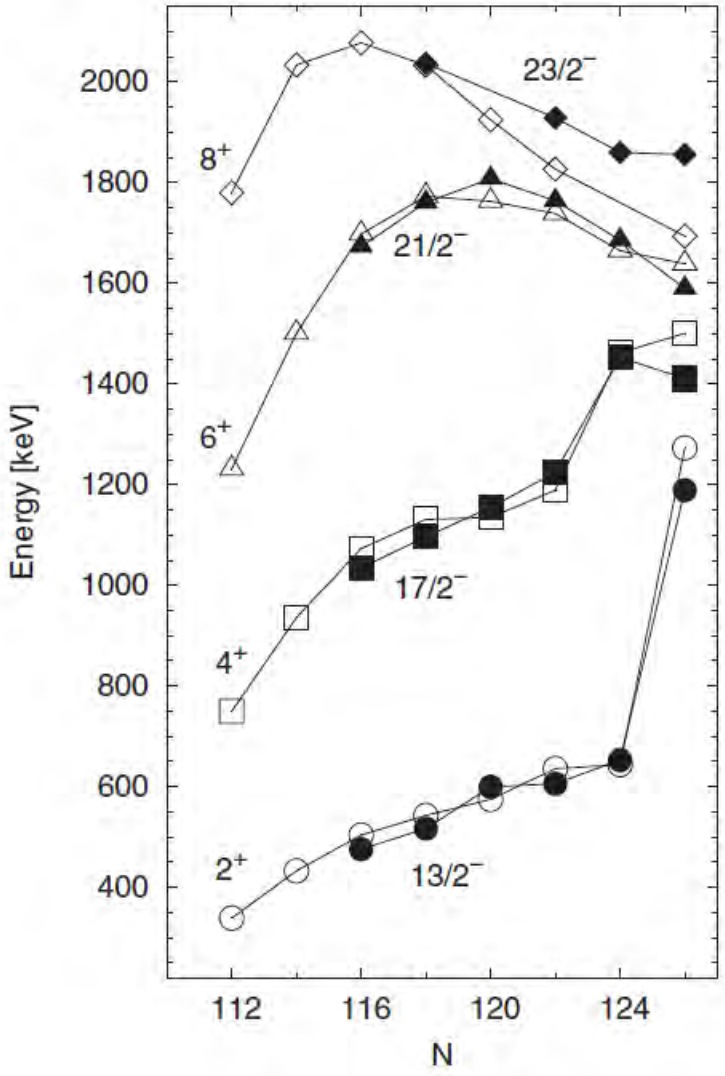
U. Jakobsson et al., PRC 82, 044302 (2010)

Odd-mass At
Even-mass Po



U. Jakobsson et. al., PRC 87, 054320 (2013)

Odd-mass Fr
Even-mass Rn



PHYSICAL REVIEW C **87**, 064304 (2013)

α-decay studies of the francium isotopes ^{198}Fr and ^{199}Fr

J. Uusitalo,[1] J. Sarén,[1] S. Juutinen,[1] M. Leino,[1] S. Eeckhaudt,[1] T. Grahn,[1] P. T. Greenlees,[1] U. Jakobsson,[1] P. Jones,[1] R. Julin,[1] S. Ketelhut,[1,*] A.-P. Leppänen,[1,†] M. Nyman,[1] J. Pakarinen,[1] P. Rahkila,[1] C. Scholey,[1] A. Semchenkov,[2,‡] J. Sorri,[1] A. Steer,[1] and M. Venhart[1,§]

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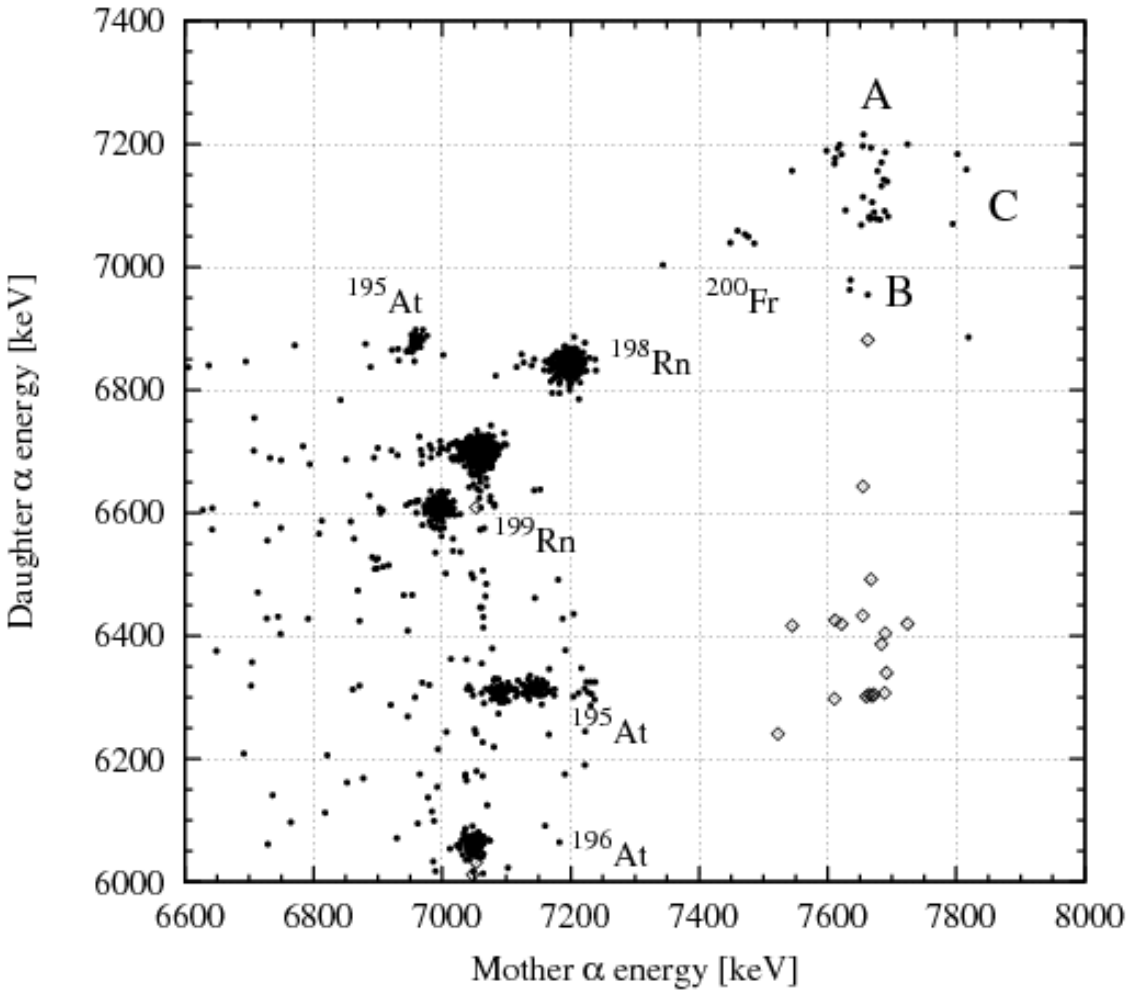
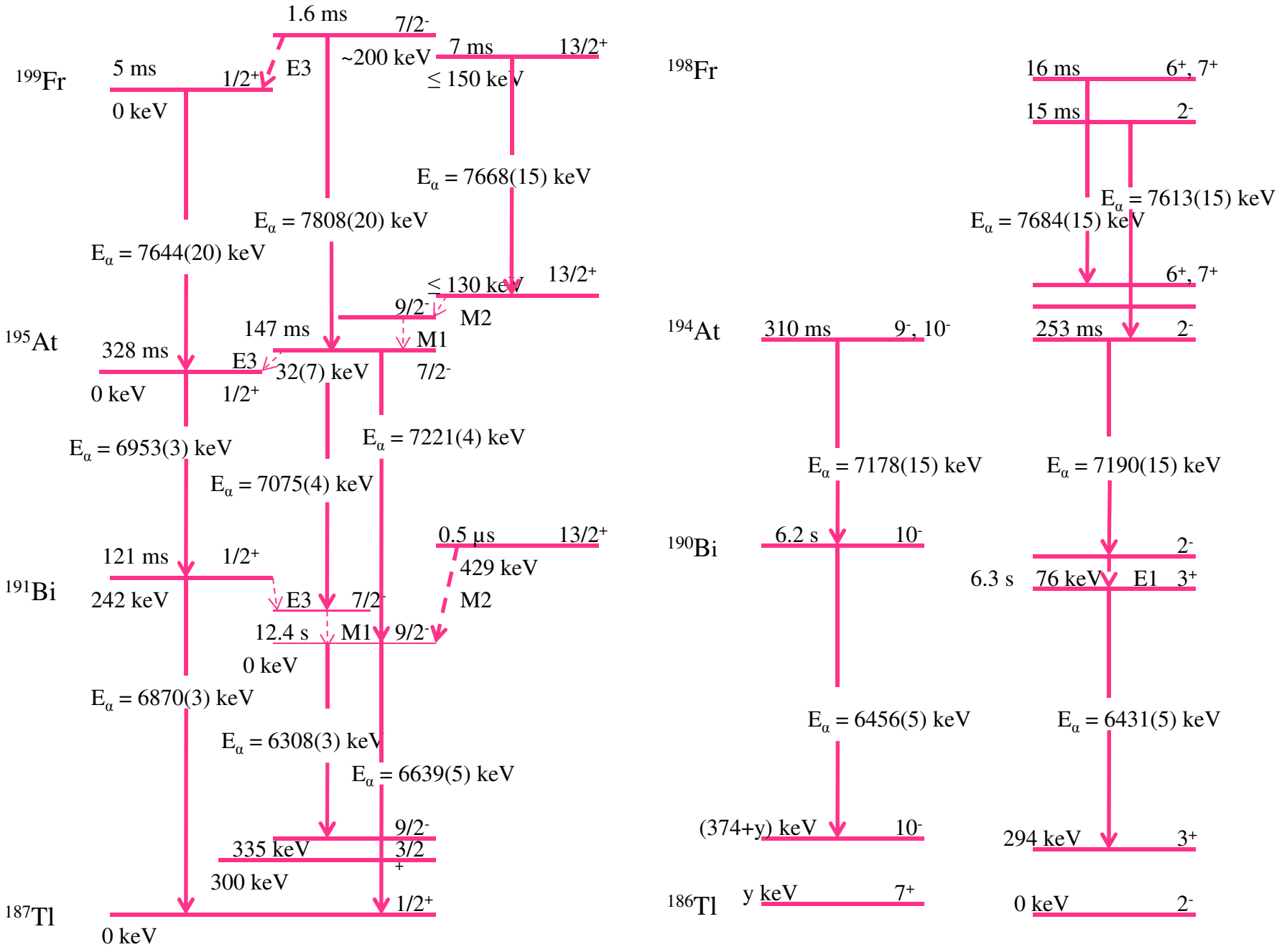
(Received 30 November 2012; revised manuscript received 8 April 2013; published 10 June 2013)



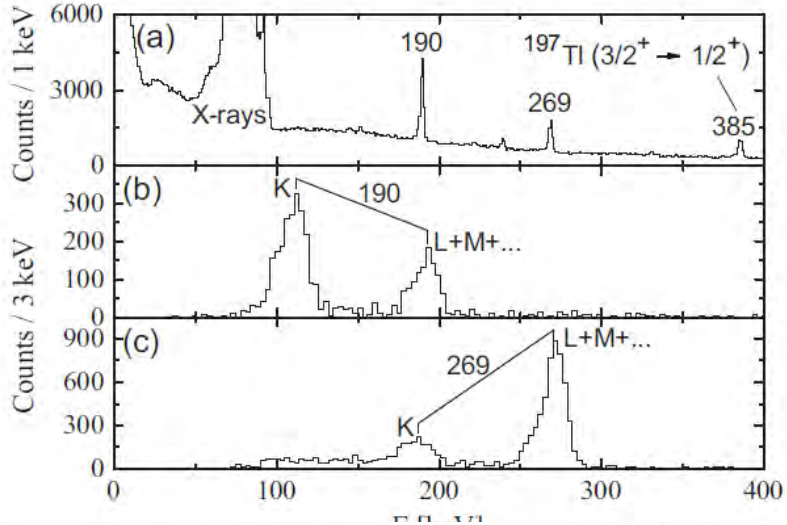
^{198}Fr 120 pb

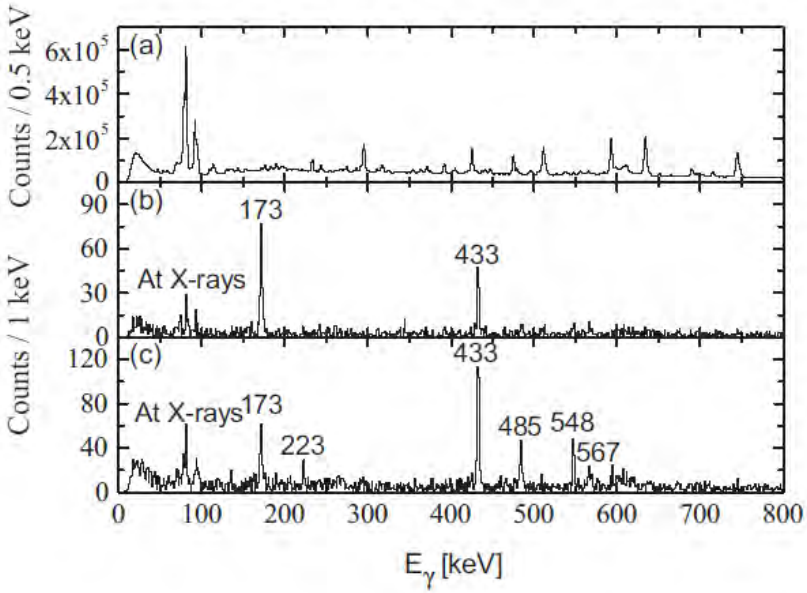
^{199}Fr 240 pb

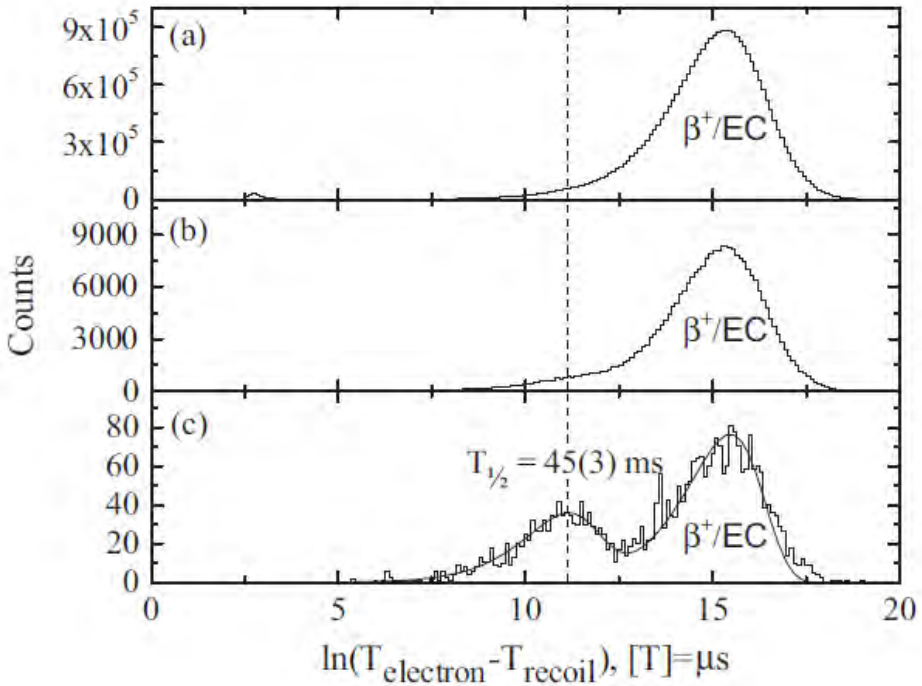
TASCA 14 GSI, Darmstadt, October 21, 2014


1.6 ms
7/2-
199Fr
5 ms
1/2+
E3
~200 keV
7 ms
13/2+
0 keV
≤ 150 keV
Eα = 7668(15) keV
Eα = 7808(20) keV
Eα = 7644(20) keV
≤ 130 keV
13/2+
9/2-
M2
195At
147 ms
M1
328 ms
E3
32(7) keV
7/2-
0 keV
1/2+
Eα = 6953(3) keV
Eα = 7221(4) keV
Eα = 7075(4) keV
0.5 μs
13/2+
121 ms
1/2+
429 keV
191Bi
242 keV
E3
7/2-
M2
12.4 s
M1
9/2-
0 keV
Eα = 6870(3) keV
Eα = 6308(3) keV
Eα = 6639(5) keV
9/2-
335 keV
3/2+
300 keV
187Tl
1/2+
0 keV
198Fr
16 ms
6+, 7+
15 ms
2-
Eα = 7613(15) keV
Eα = 7684(15) keV
6+, 7+
194At
310 ms
9-, 10-
253 ms
2-
Eα = 7178(15) keV
Eα = 7190(15) keV
190Bi
6.2 s
10-
2-
6.3 s
76 keV
E1
3+
Eα = 6456(5) keV
Eα = 6431(5) keV
(374+y) keV
10-
294 keV
3+
186Tl
y keV
7+
0 keV
2-

$^{165}Ho(^{40}Ar,4n)^{201}At$







PHYSICAL REVIEW C **90**, 024310 (2014)

Experimental study of $\frac{1}{2}^+$ isomers in ^{199,201}At

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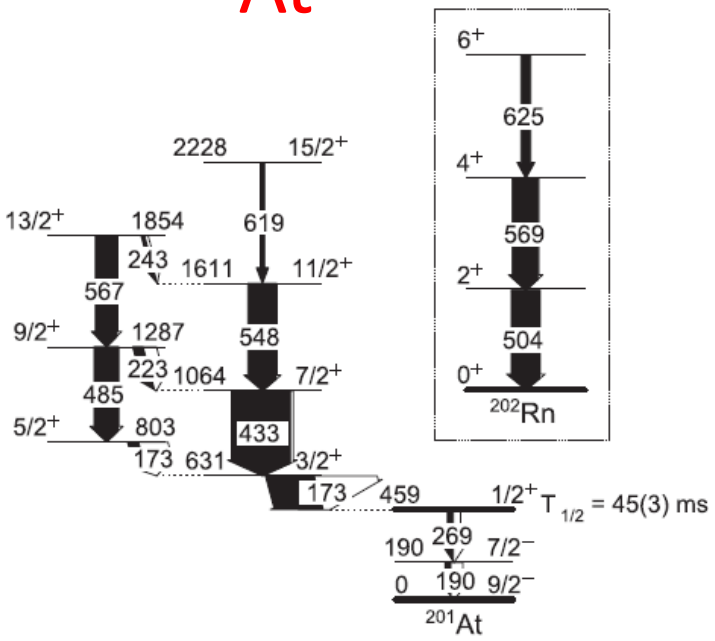
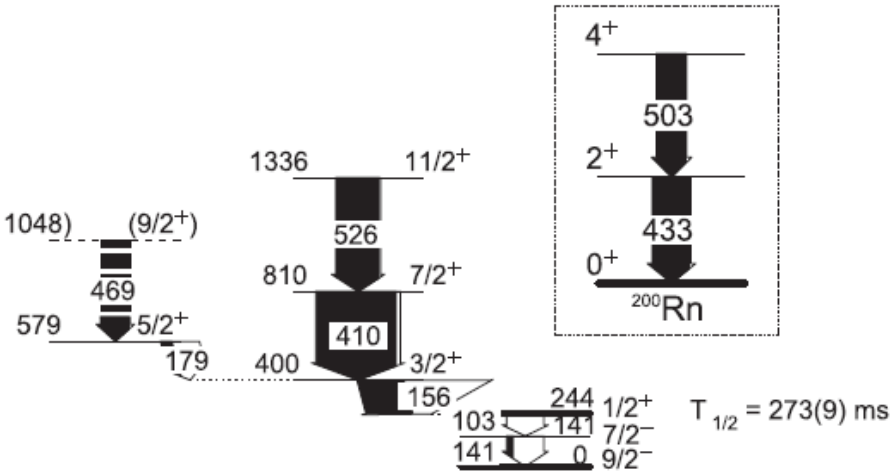
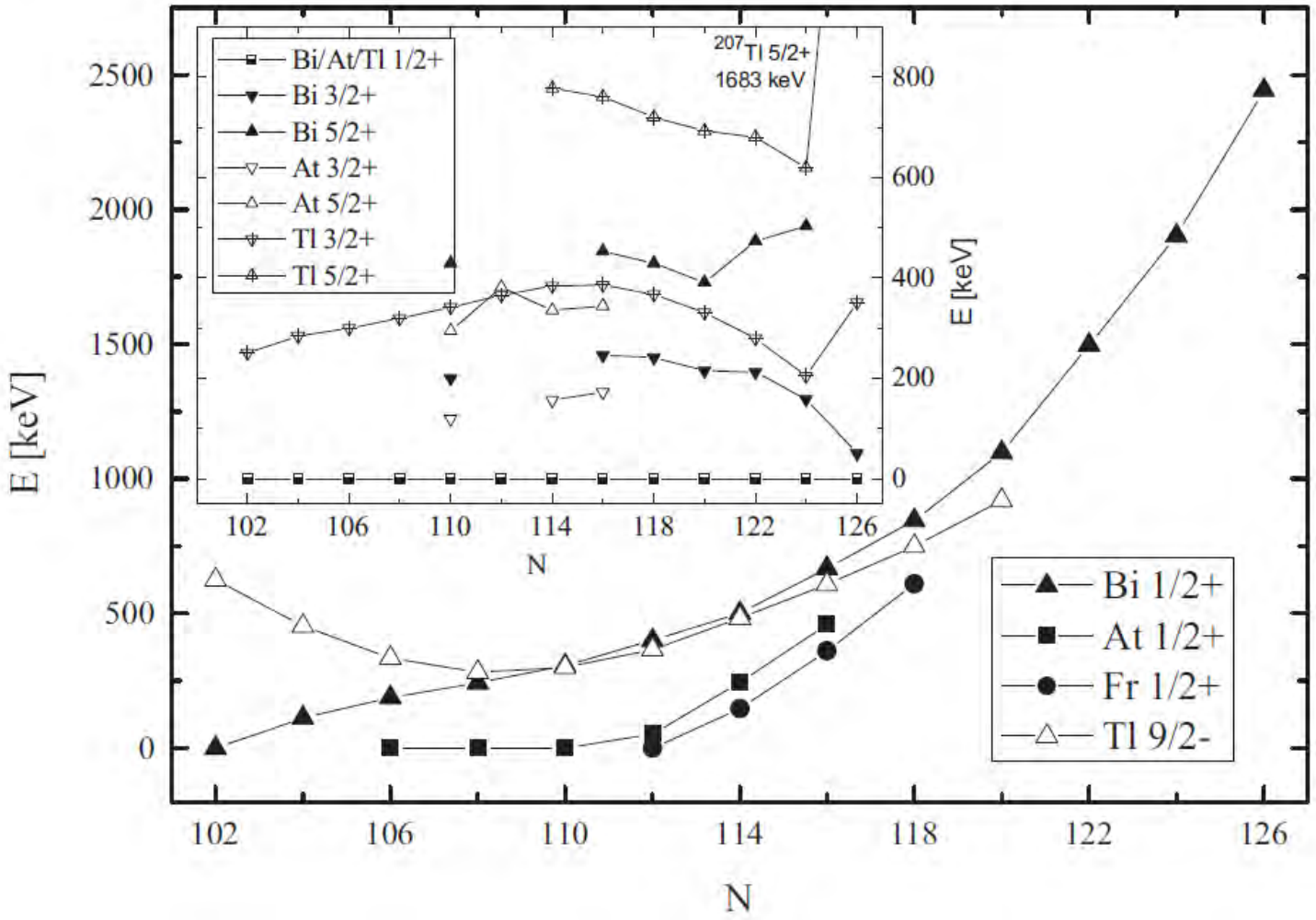
(Received 10 July 2014; published 15 August 2014)

^{201}At



^{199}At




E [keV]
N
Bi 1/2+
At 1/2+
Fr 1/2+
Tl 9/2-
Bi/At/Tl 1/2+
Bi 3/2+
Bi 5/2+
At 3/2+
At 5/2+
Tl 3/2+
Tl 5/2+
207Tl 5/2+
1683 keV
E [keV]

Spring 2014

36Ar + 169Tm → 205Fr* → 201Fr + 4n U. Jakobsson et. al.,

- 13/2+ isomer identified, electron and gamma spectra
- much improved statistics for the alpha decay from the isomeric ½+ state

36Ar + 181Ta → 217Pa* → 211Pa + 6n J. Saren et. al.,
56Fe + 159Tb → 215Pa* → 211Pa + 4n

- one chain of 211Pa identified, cross-section ~ 5 - 10 pb
- evaporation cross section comparison, pxn and alphaxn channels

56Fe: 50-100 pnA on rotating 159Tb target,
36Ar: 100-200 pnA on rotating 169Tm and 181Ta targets,

PHYSICAL REVIEW C VOLUME 28, NUMBER 3 SEPTEMBER 1983

High-spin states in ^{201,203}At and the systematic behavior of $Z = 85$ isotopes

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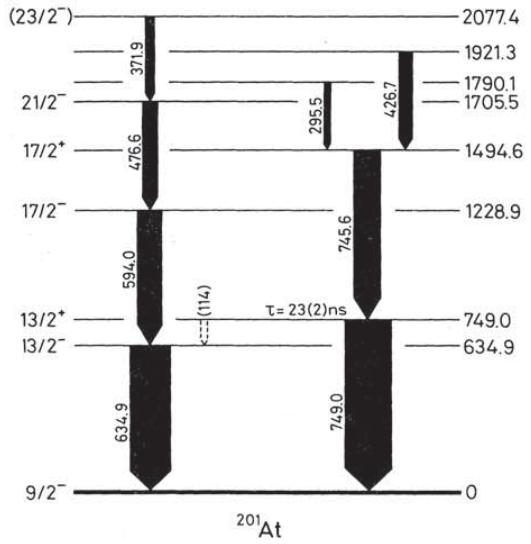
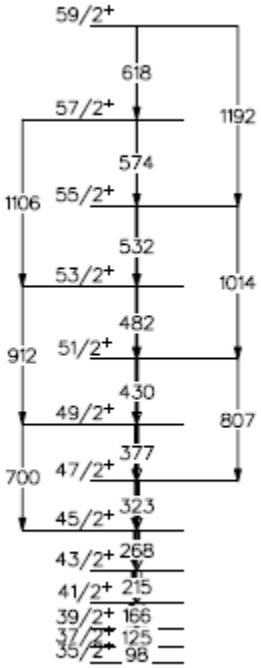
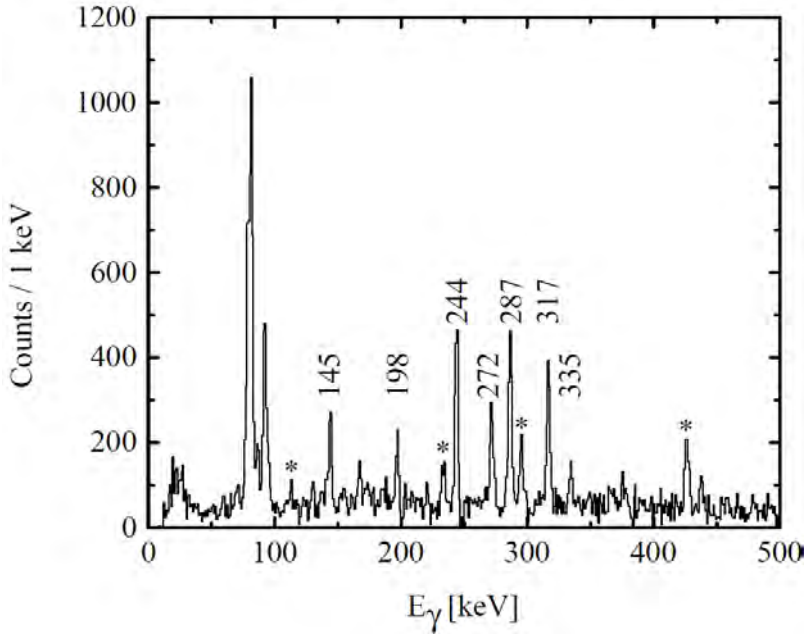




^{199}Pb

K. Auranen et. al.,
(426 tai 746) Ja (145 tai 198 tai 244 tai 272 tai 287 tai 317 tai 335)



Annu. Rev. Nucl. Part. Sci. 2000. 50:1–36

THE SHEARS MECHANISM IN NUCLEI*

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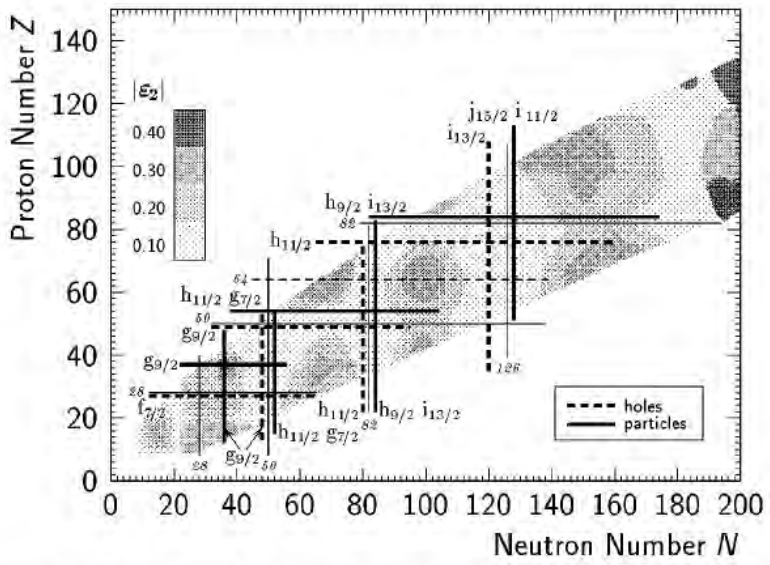

Figure 19 Plot showing likely regions for shears bands. Bold (dashed) lines indicate the location of high-j particles (holes). Where these lines intersect is a particularly favorable region for shears bands. The greyscale indicates the deformation. (Reproduced from Reference 69.)

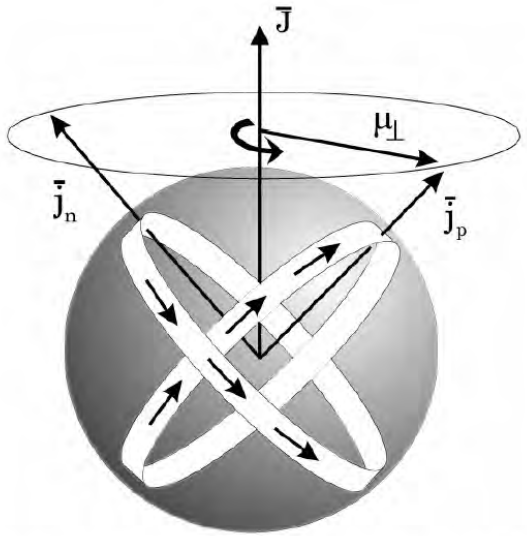

Figure 20 Schematic of the current loops, arising from the nucleons that form the blades of the shears, embedded within the near-spherical mass distribution of the nucleus. The resulting anisotropy breaks the rotational symmetry of the nucleus.