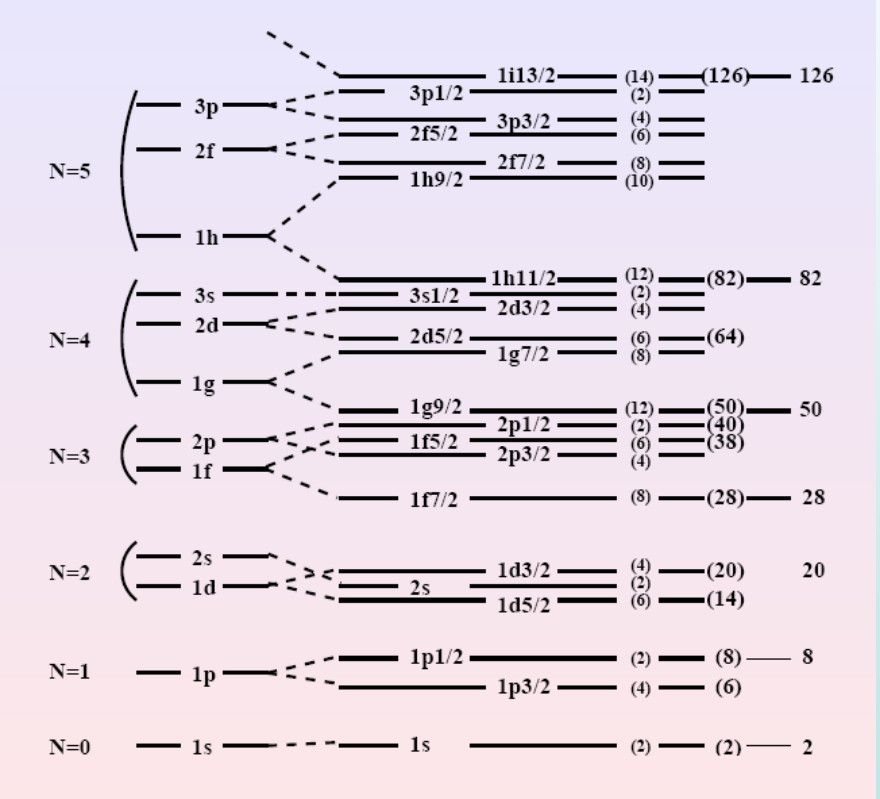
Isomers and intermediate-spin states of ^{93,95,96}Rb

Gary Simpson LPSC Grenoble

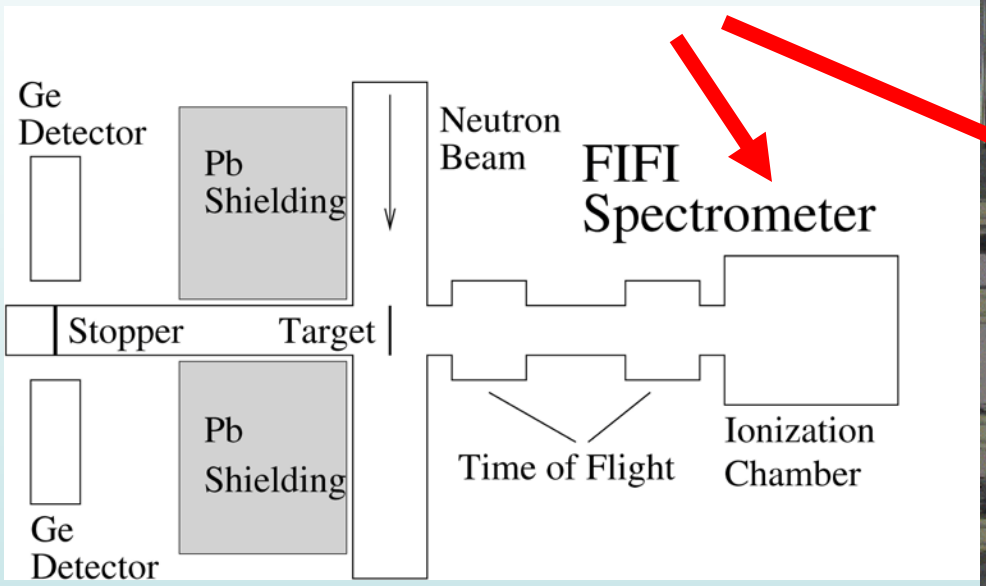
- Experimental techniques
  - Delayed γ-ray spectroscopy at neutron guides
  - Prompt-fission studies with large arrays
- Summary of Recent Results
  - Excited states in ^{93,95,96}Rb
- Future projects at JYFL

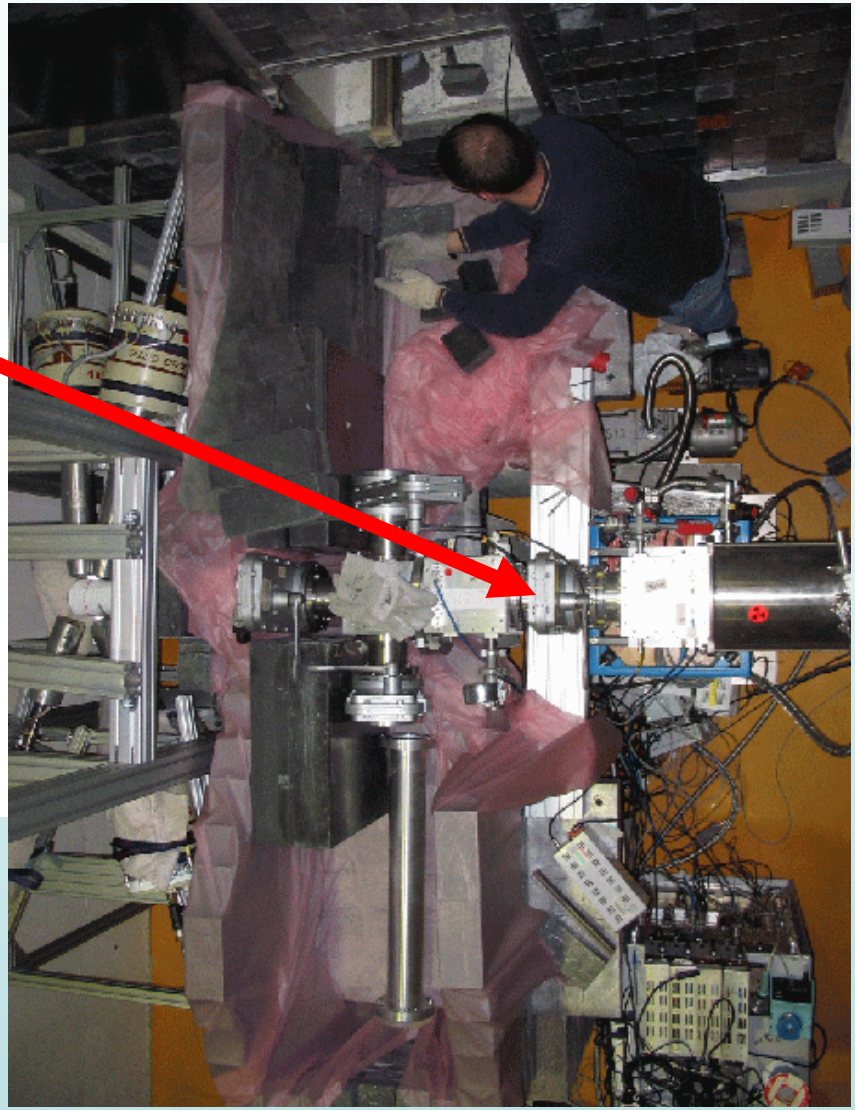
- Lack of data on single-particle orbits outside ^{78}Ni – $\nu h_{11/2}$
- Can extract this information from multi-quasiparticle isomers but expected $T_{1/2}$<500 ns
- Rb nuclei good candidates to search for such isomers
- Can ^{78}Ni be used as a closed core?
- Can the shell-model reproduce the onset of defomation?



Use different instruments

FIFI (FIssion Fragment Indentifier) Spectrometer (Manchester) at PF1B neutron guide





- ToF gives *v*
- Chamber gives *K.E.*

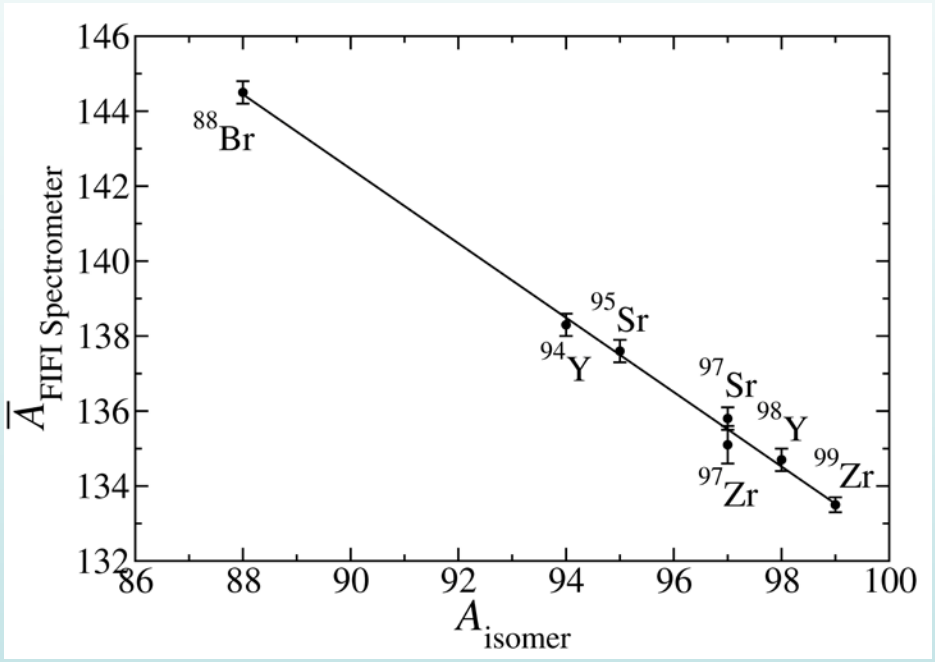
→can get *m*

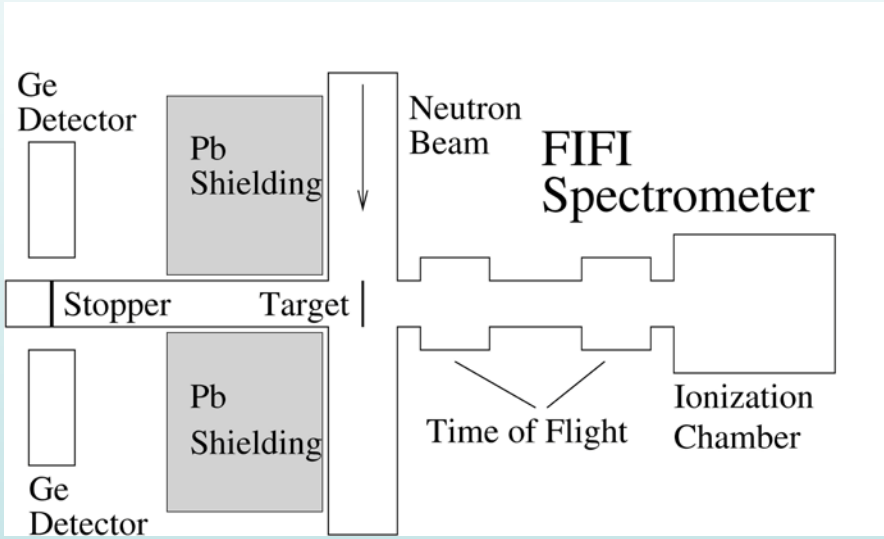
→Observe isomer decays from the mass-identified complementary fragment

Compact array of 15 Ge crystals, each ~60 % rel. eff. (UK-France loan pool + Cologne Cluster)

Lots of shielding

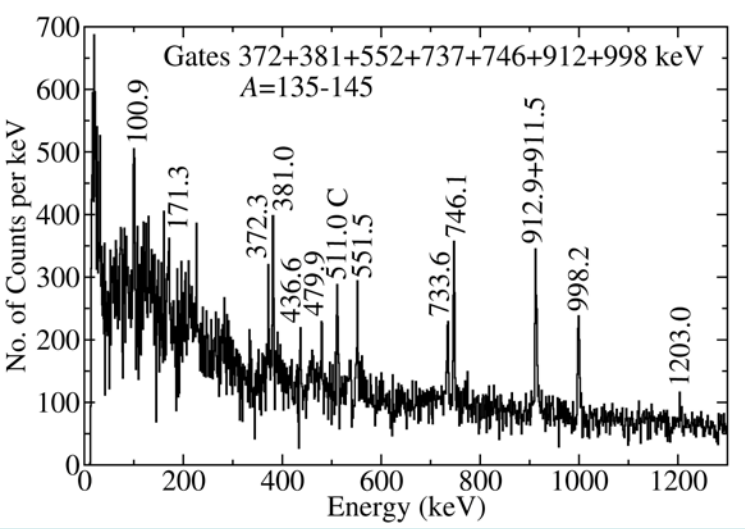
Use known isomers to calibrate mass of complementary fragment measured by FIFI

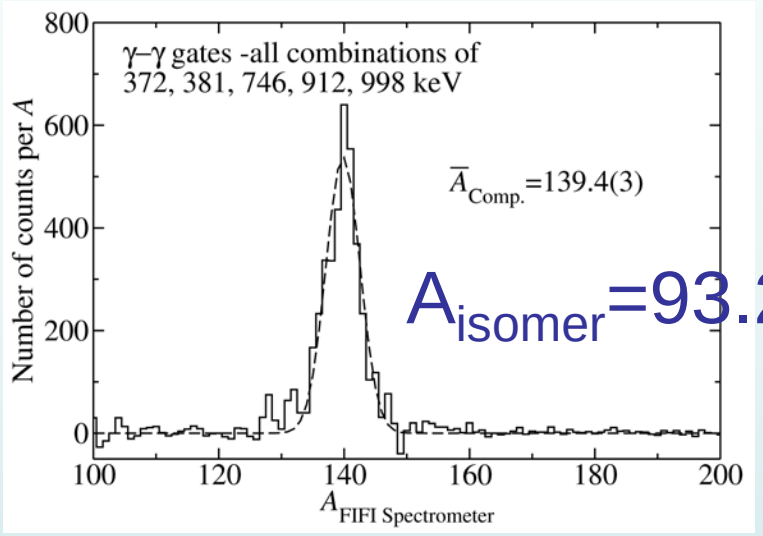




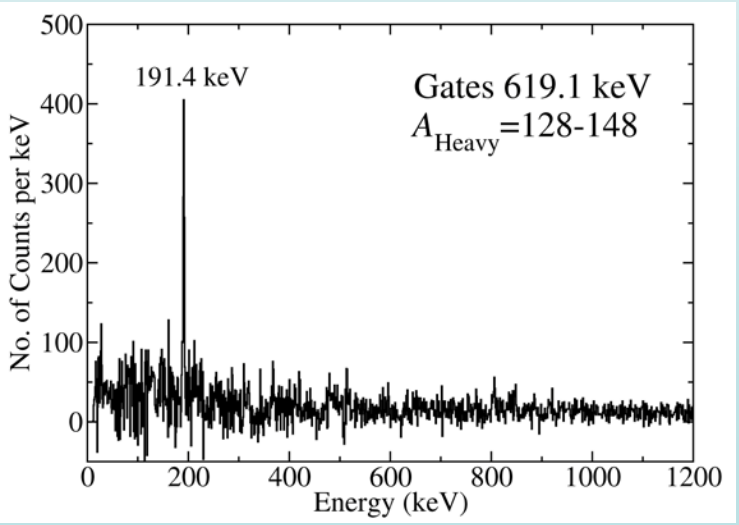
Mean neutron evaporation 2.4 n/fission

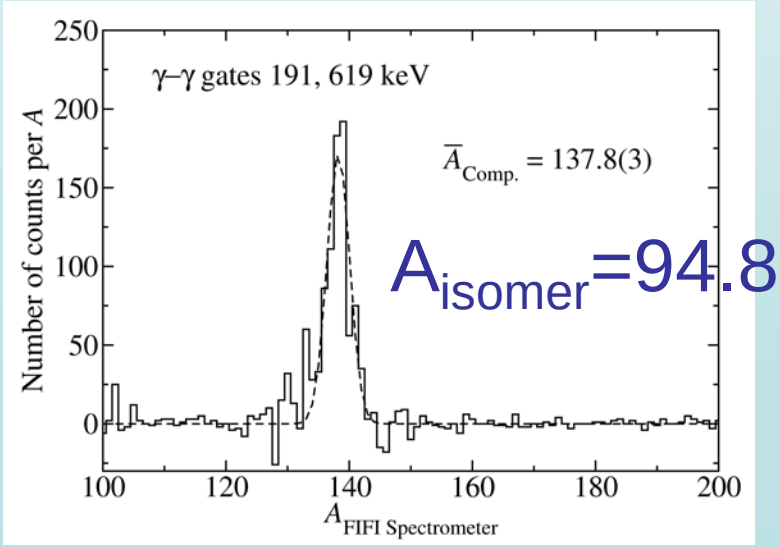
Can see and mass-identify several new isomers





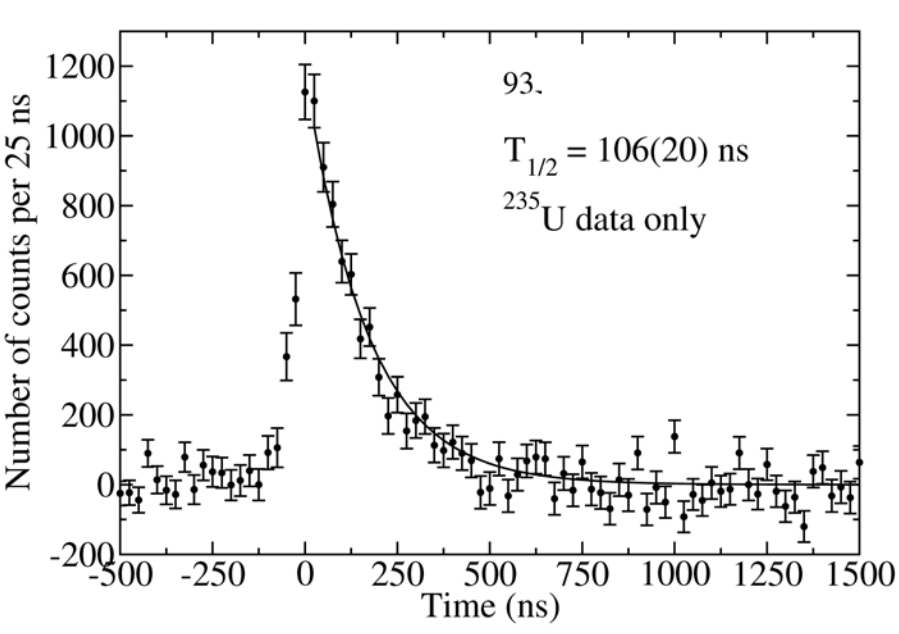
A_{isomer}=93.2(4)

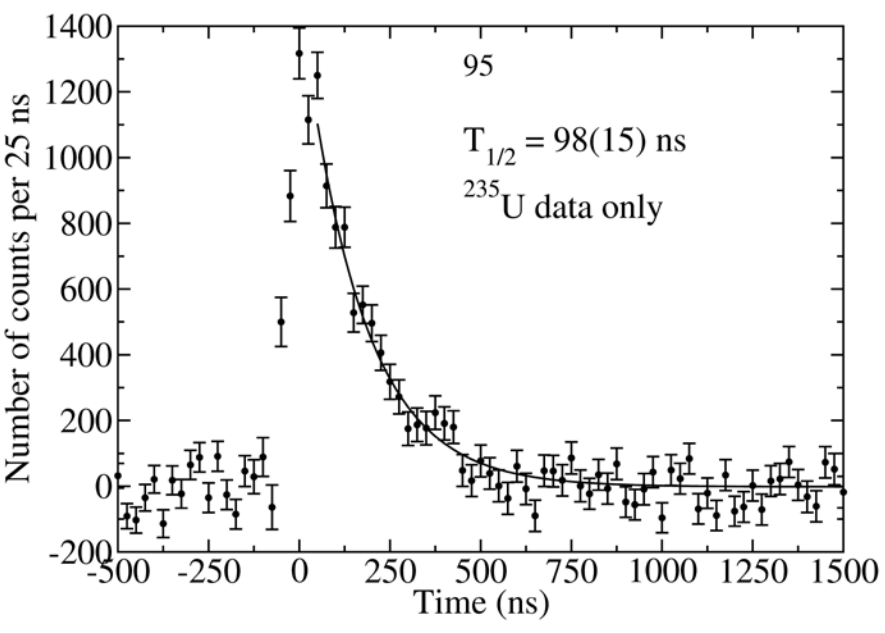




A_{isomer}=94.8(4)

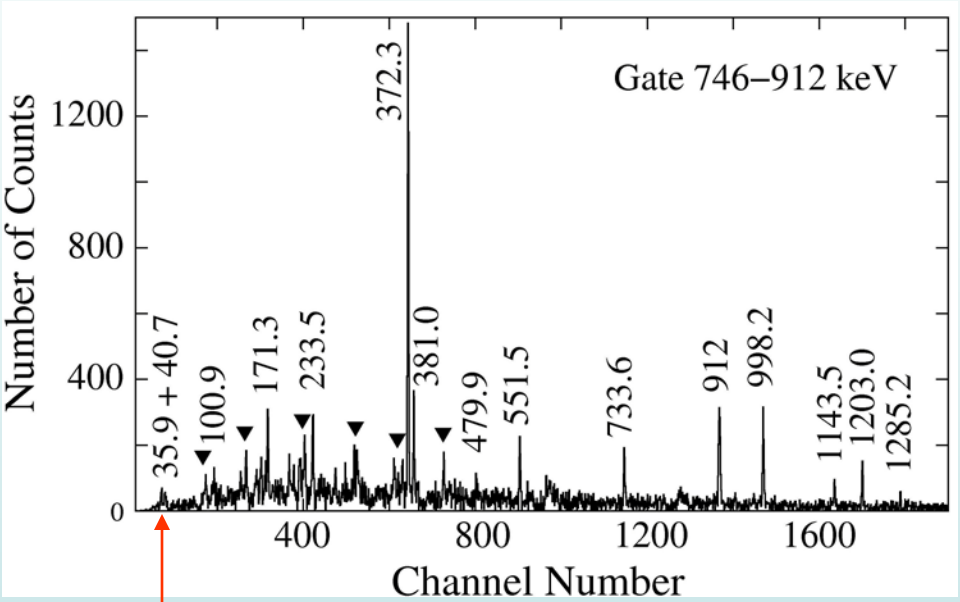
Isomeric half lives obtained



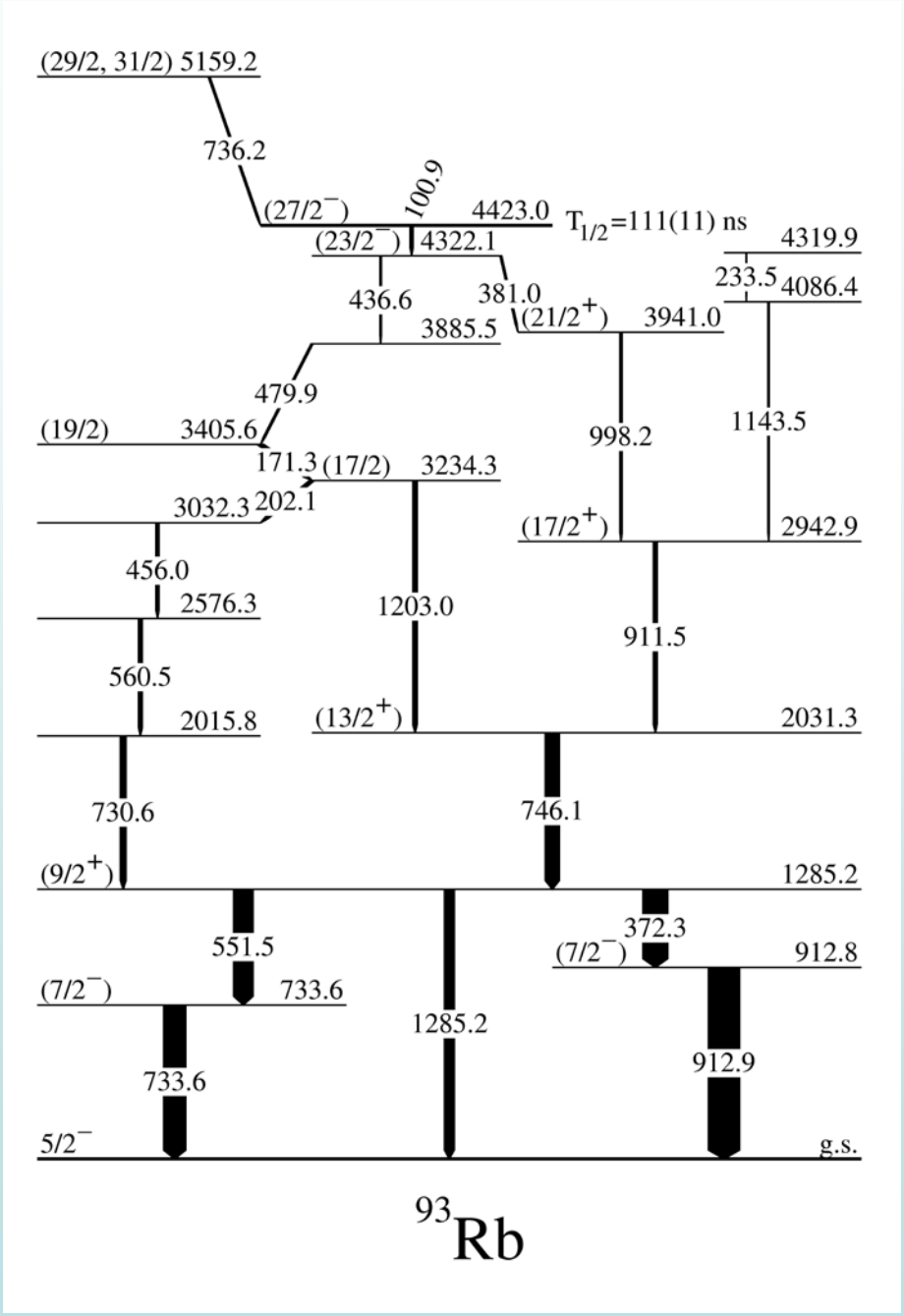


G. Simpson *et al*. Phys. Rev. C 82 (2010) 024302

Gate on strong, delayed lines in ^{248}Cm data
-see same lines as in FIFI data set + new ones

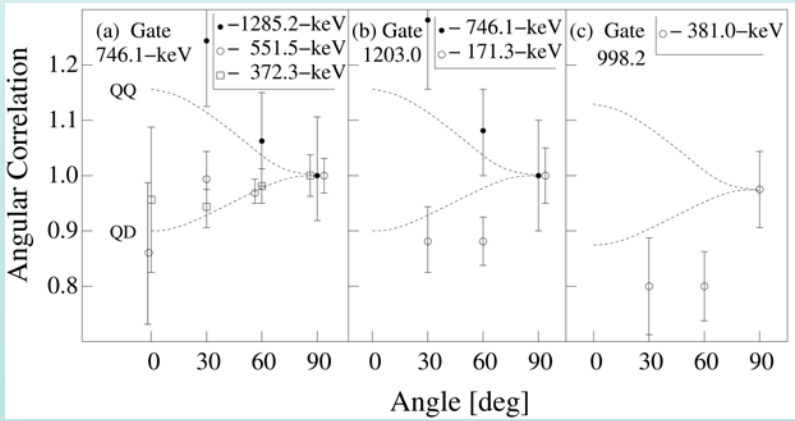


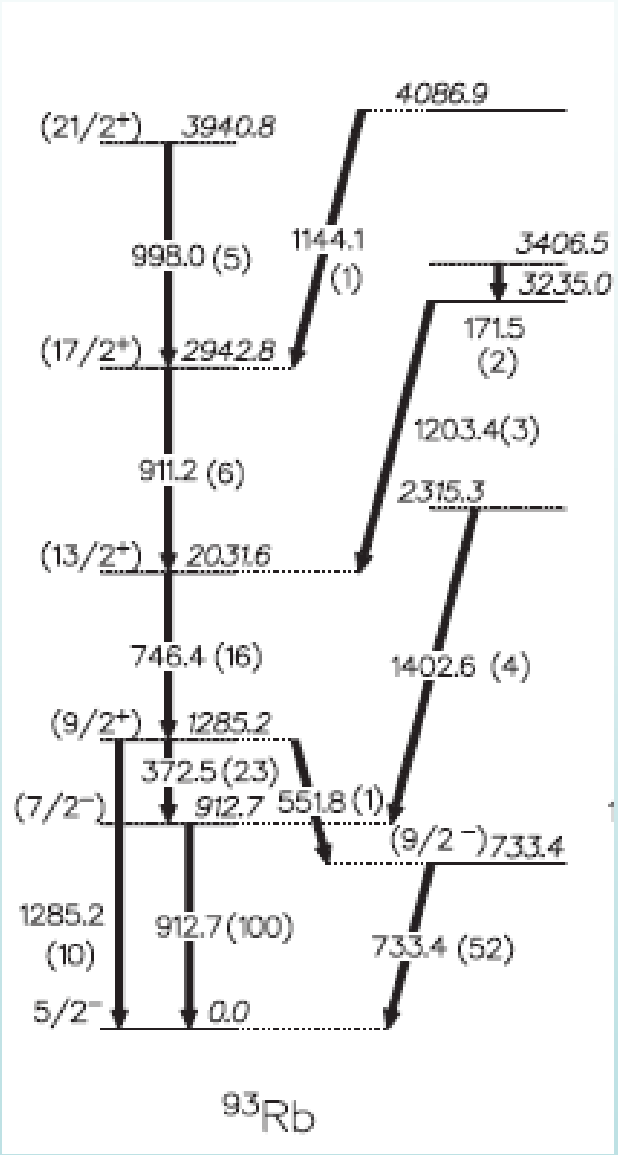
X rays give Z of complementary (Pr) and hence Z of isomeric fragment (Rb)
So isomer belongs to ^{93}Rb



Further gating gives the following level scheme

Can get spins using ang. corr.





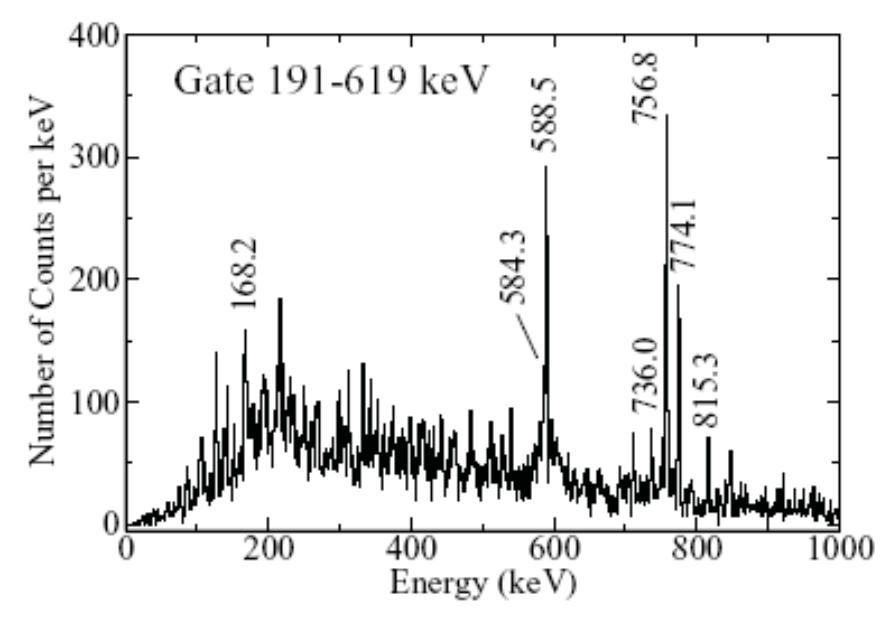
Results in agreement with

PHYSICAL REVIEW C **80**, 037304 (2009)

High-spin states in ^{91,92,93}Rb and ^{155,156}Pm

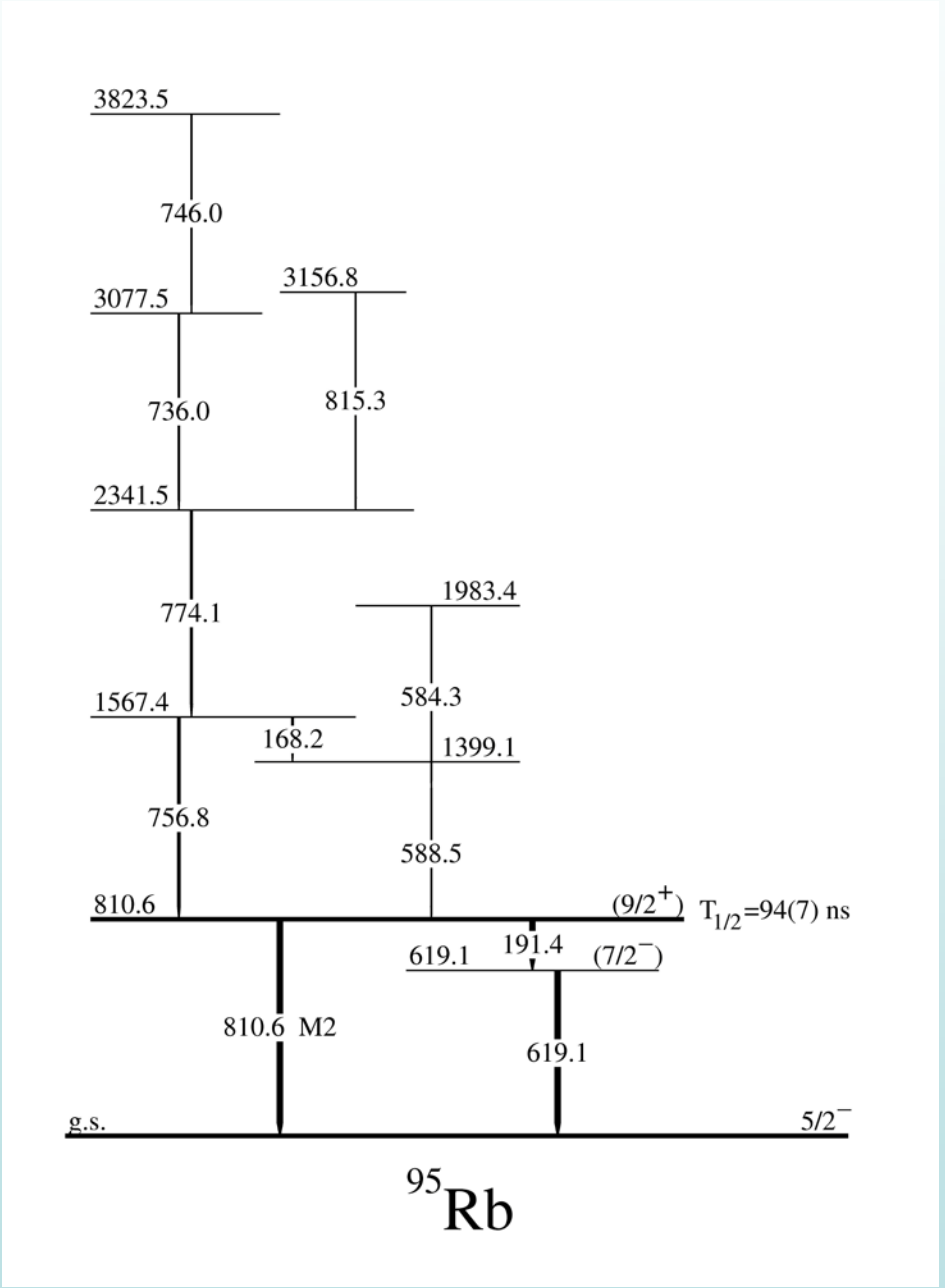
J. K. Hwang,[1] A. V. Ramayya,[1] J. H. Hamilton,[1] S. H. Liu,[1] K. Li,[1] H. L. Crowell,[1] C. Goodin,[1] Y. X. Luo,[1,2] J. O. Rasmussen,[2] and S. J. Zhu[1,3]

A=95 isomer



Gate on 191 and 619-keV lines in ^{252}Cf data set

New decay scheme

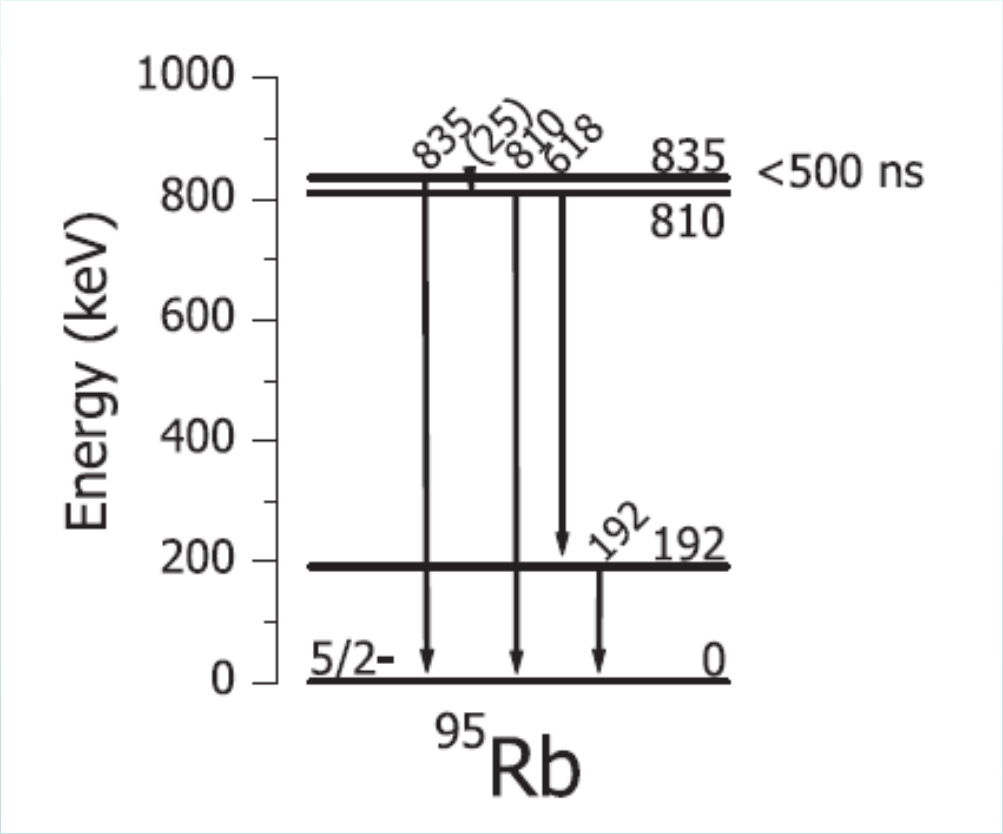


Isomer originates from $\pi g_{9/2}$ orbit

PHYSICAL REVIEW C **79**, 064318 (2009)

New neutron-rich microsecond isomers observed among fission products of ^{238}U at 80 MeV/nucleon

C. M. Folden III,[1,*] A. S. Nettleton,[1,2] A. M. Amthor,[1,2] T. N. Ginter,[1] M. Hausmann,[1] T. Kubo,[3] W. Loveland,[4] S. L. Manikonda,[5] D. J. Morrissey,[1,6] T. Nakao,[3,7] M. Portillo,[1] B. M. Sherrill,[1,2] G. A. Souliotis,[8] B. F. Strong,[6] H. Takeda,[3] and O. B. Tarasov[1,9]



Shell-Model Interpretation by K. Sieja (GSI/Strasbourg)

CD-Bonn potential, G-matrix renormalization

Antoine code (m-scheme)

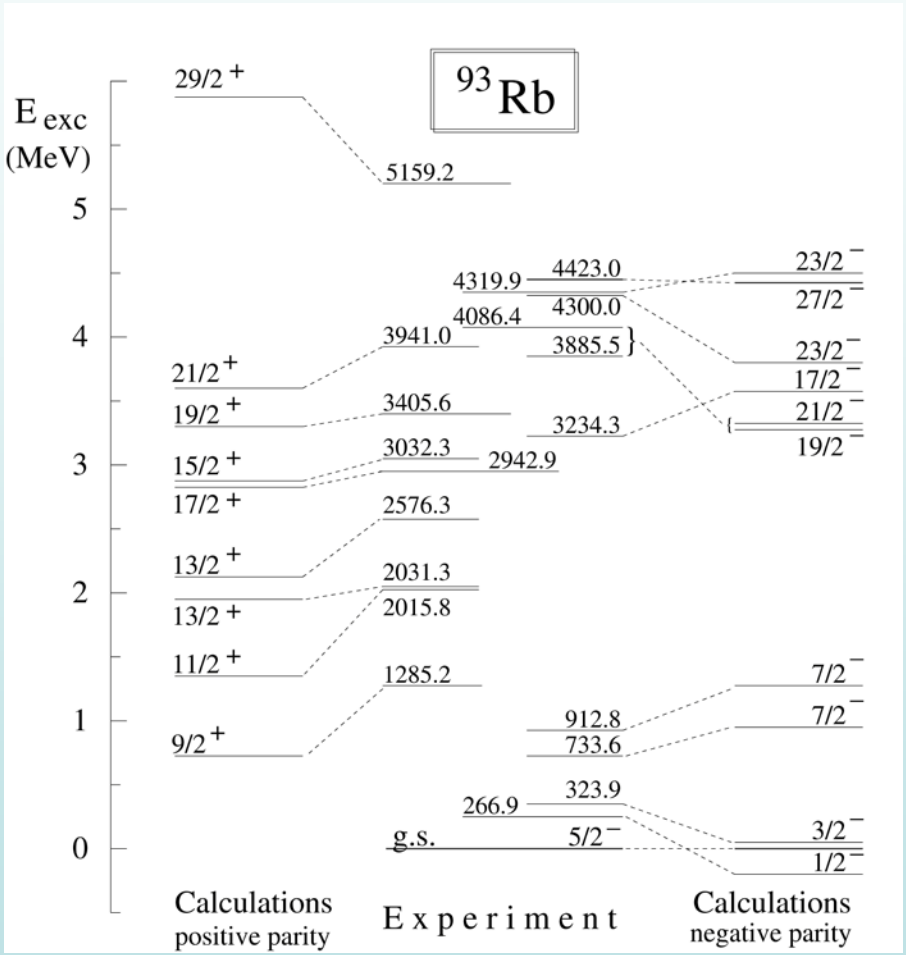
^{78}Ni core

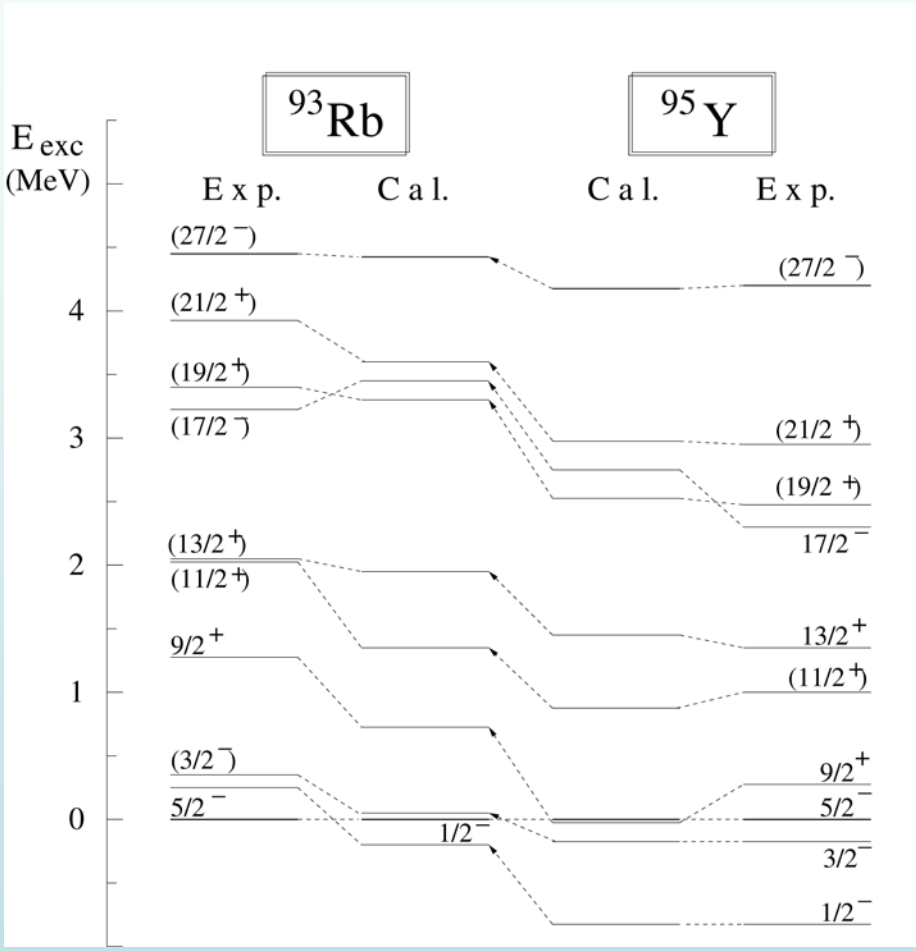
π $1f_{5/2}$, $2p_{1/2}$, $1p_{3/2}$, $1g_{9/2}$

ν $2d_{5/2}$, $3s_{1/2}$, $2d_{3/2}$, $1g_{7/2}$, $1h_{11/2}$

Up to 7 p-h excitations from Z=38, N=56

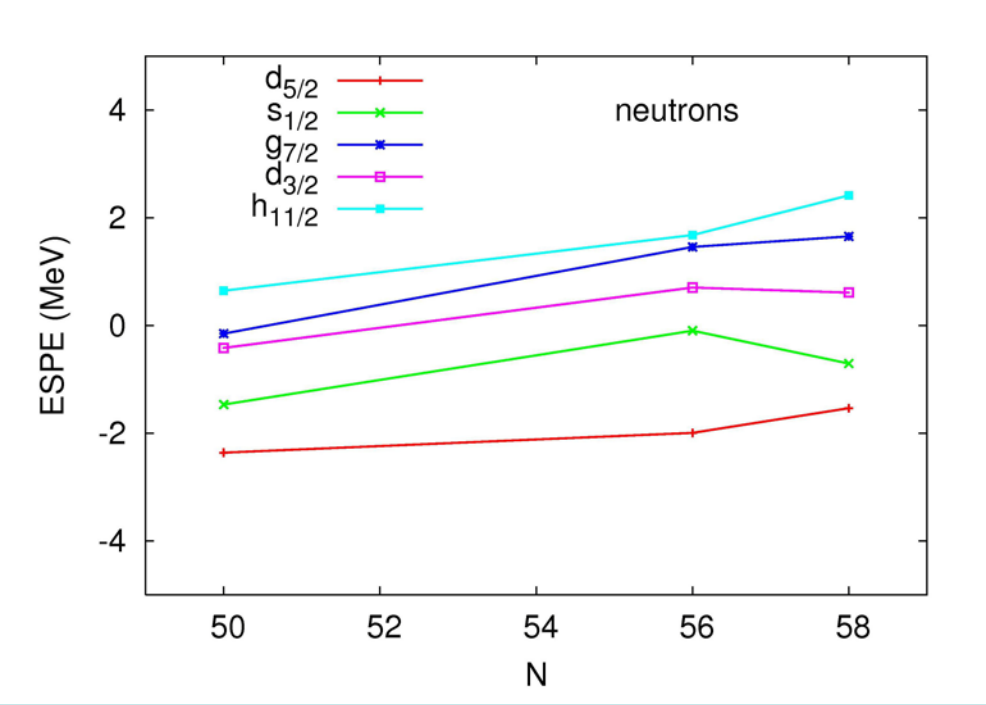
Shell-model Interpretation





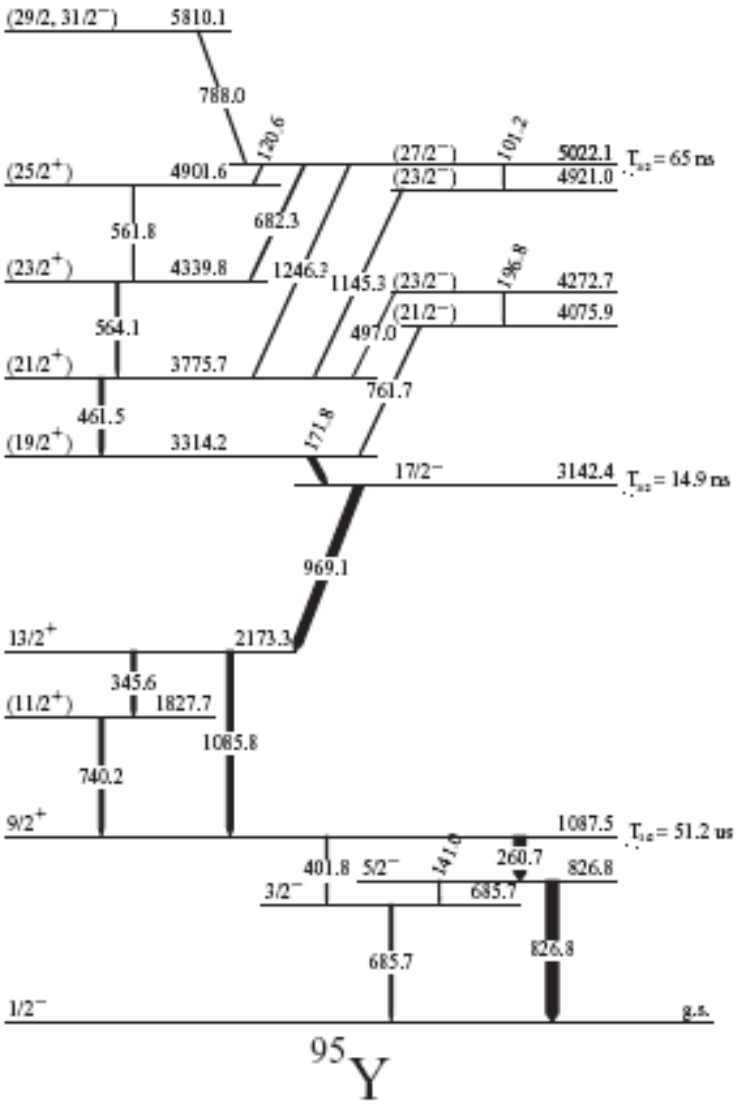
27/2$^-$ isomer has $\pi g_{9/2}\ \nu(g_{7/2}\ \ h_{11/2})$ configuration

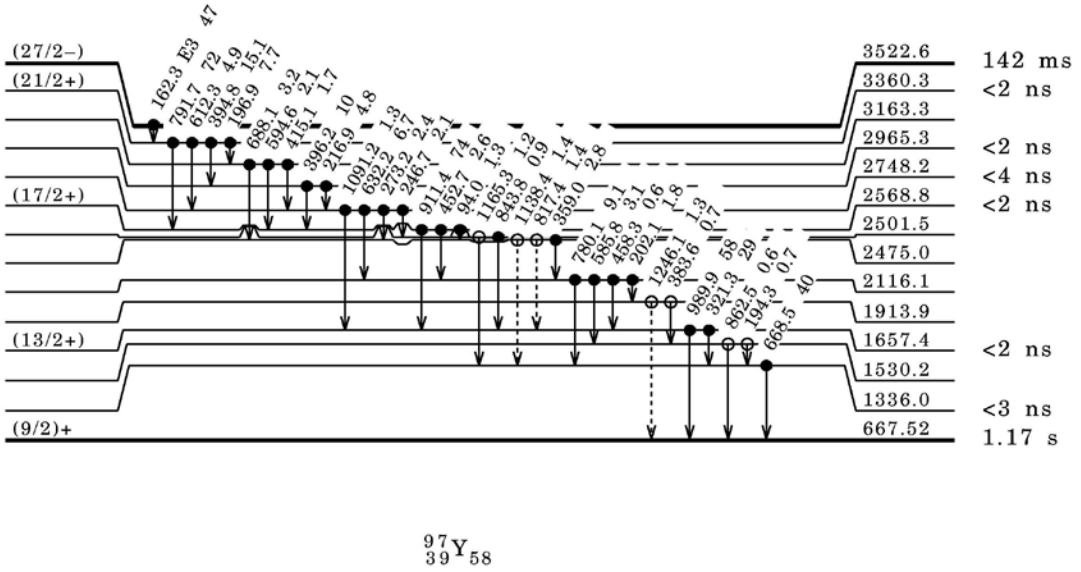
Why does the isomeric lifetime go from 100 ns to 100 ms when going from ^{95}Y to ^{97}Y?



$d_{5/2}$ is full, now filling $s_{1/2}$ → $27/2^-$ isomer ~1 MeV lower in energy and cannot decay to $23/2^-$

Is there an equivalent $27/2^-$ ms isomer in ^{95}Rb?


(29/2, 31/2⁻) 5810.1
788.0
120.6
101.2
(25/2⁺) 4901.6
(27/2⁻) 5022.1
(23/2⁻) 4921.0
T1/2 = 65 ns
561.8
682.3
(23/2⁺) 4339.8
1246.3
1145.3
(23/2⁻) 4272.7
196.8
(21/2⁻) 4075.9
564.1
497.0
(21/2⁺) 3775.7
761.7
461.5
(19/2⁺) 3314.2
171.8
17/2⁻ 3142.4
T1/2 = 14.9 ns
969.1
13/2⁺ 2173.3
345.6
(11/2⁺) 1827.7
1085.8
740.2
9/2⁺ 1087.5
T1/2 = 51.2 us
401.8
5/2⁻
141.0
260.7
826.8
3/2⁻ 685.7
826.8
685.7
1/2⁻ g.s.
95Y


(27/2−) 3522.6 142 ms
(21/2+) 3360.3 <2 ns
3163.3
2965.3 <2 ns
2748.2 <4 ns
(17/2+) 2568.8 <2 ns
2501.5
2475.0
2116.1
1913.9
(13/2+) 1657.4 <2 ns
1530.2
1336.0 <3 ns
(9/2)+ 667.52 1.17 s
162.3 E3 47
791.7 72
612.3 4.9
394.8 15.1
196.9 7.7
688.1 3.2
594.6 2.1
415.1 1.7
396.2 10
216.9 4.8
1091.2 1.3
632.2 6.7
273.2 2.4
246.7 2.1
911.4 2.6
452.7 1.3
94.0 1.2
1165.3 0.9
843.8 1.4
1138.4 1.4
817.4 2.8
359.0
780.1 9.1
585.8 3.1
458.3 0.6
202.1 1.8
1246.1 1.3
383.6 0.7
969.9 58
321.3 29
862.5 0.6
194.3 0.7
668.5 40
97 39Y58

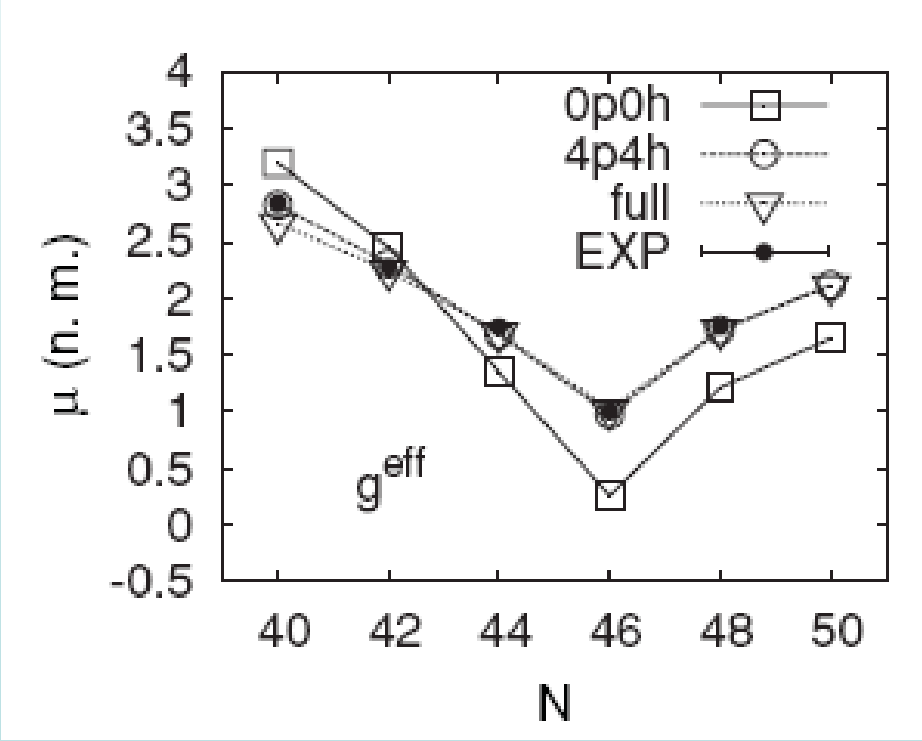
Problems with the interaction

-recently shown that ^{78}Ni is not a good inert core for Cu isotopes

PHYSICAL REVIEW C **81**, 061303(R) (2010)

Shell quenching in ^{78}Ni: A hint from the structure of neutron-rich copper isotopes

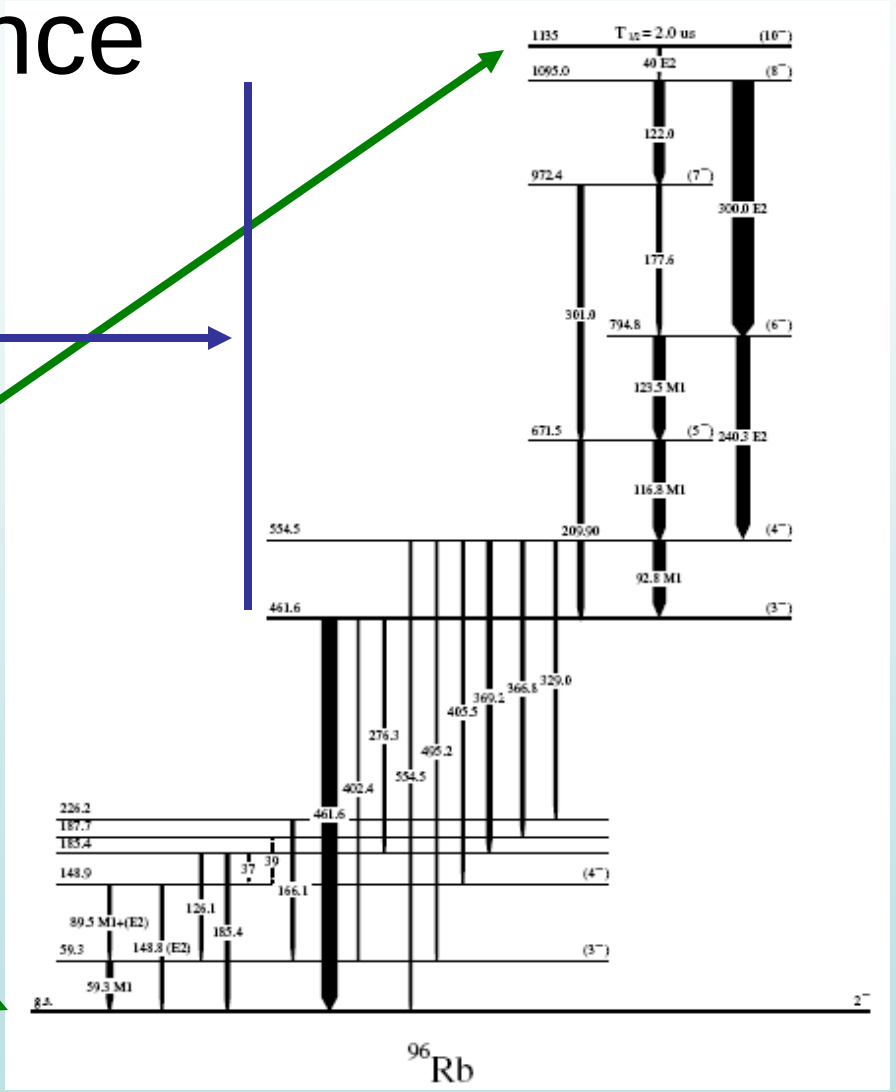
K. Sieja and F. Nowacki



Challenge for the shell model -shape coexistence

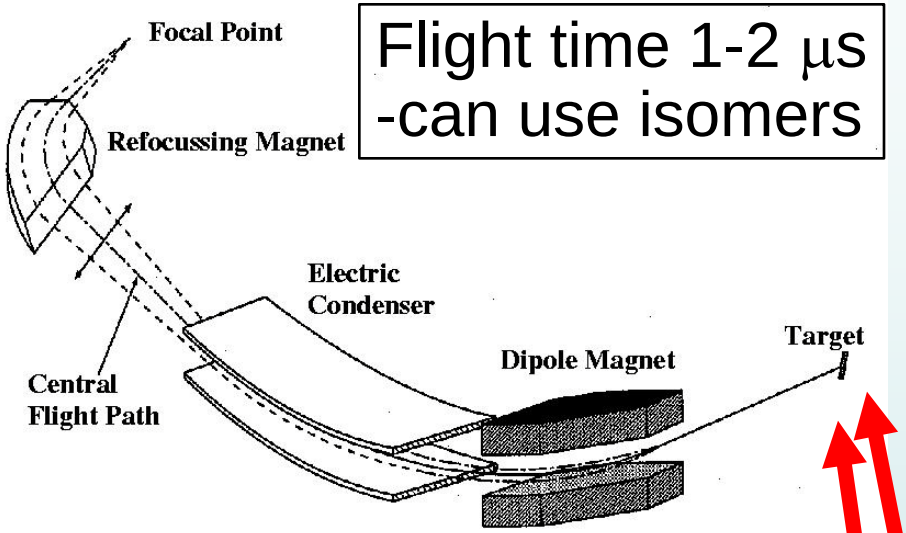
Deformed

Spherical

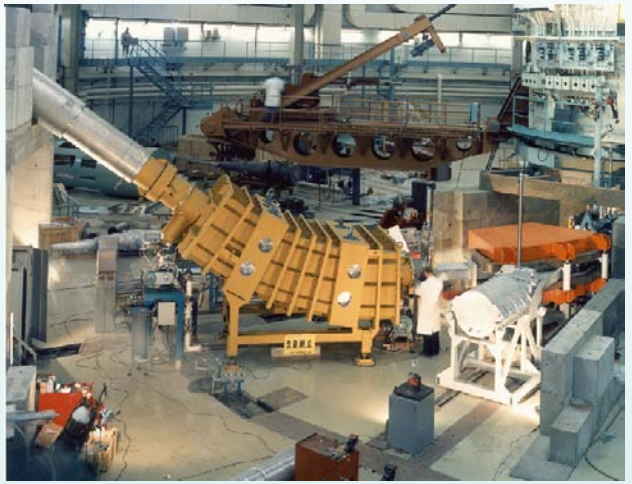


J. A. Pinston *et al*. Phys. Rev. C 71 (2005) 064327

The Lohengrin Fission-Product Spectrometer



Flight time 1-2 μs
-can use isomers



Separates according to A/q and E/q

A/δA~250

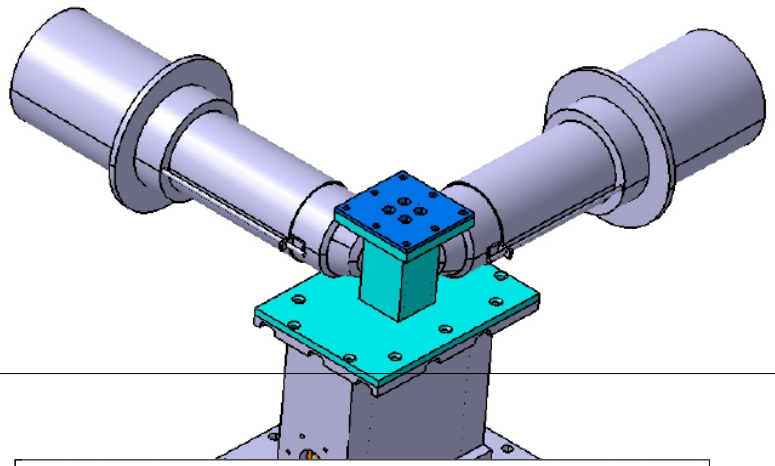
Solid angle < 2 x 10^{-5}

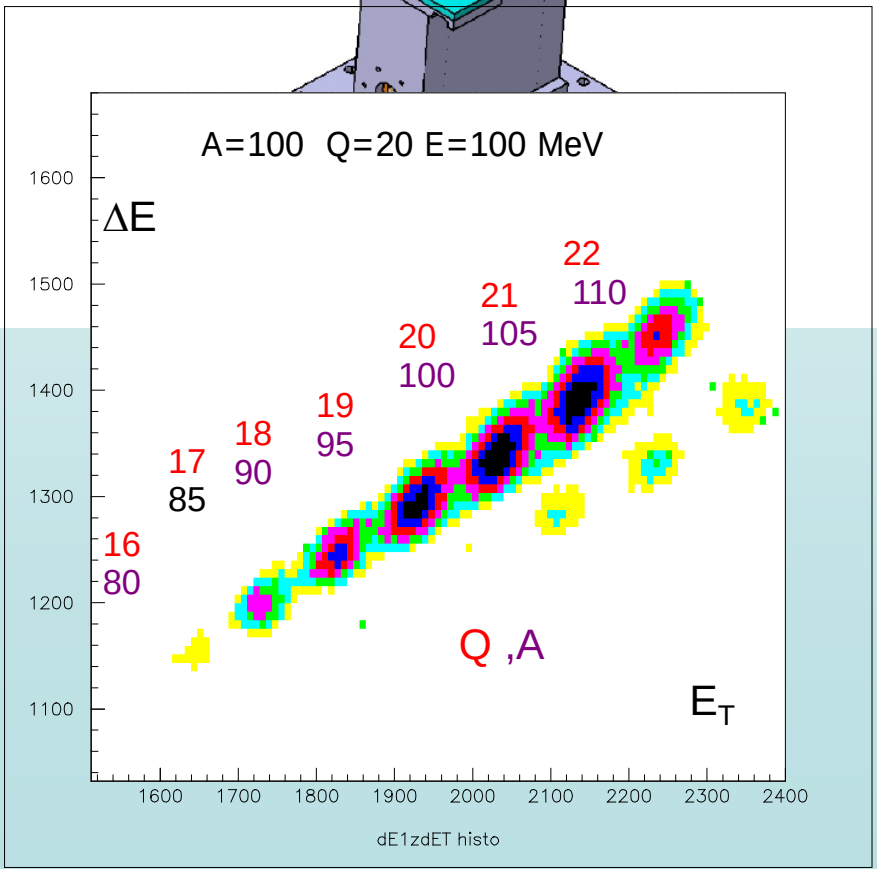
Rates at focal point
~ 3000 ions of ^{132}Sn /s

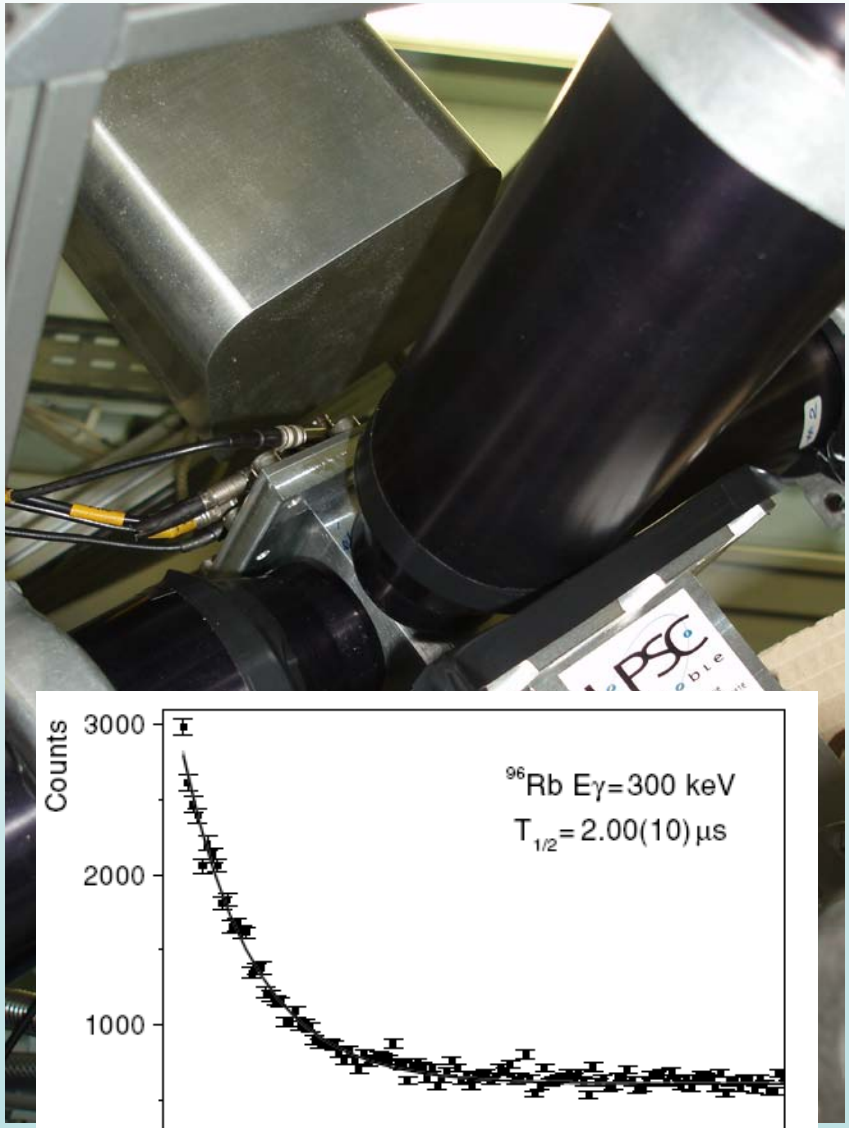
No ion source - no chemical selectivity

Neutron flux 5×10^{14} n/s/cm^2

~2×10^{12} fissions/s
(3.5 mg of ^{239}Pu 742 b)

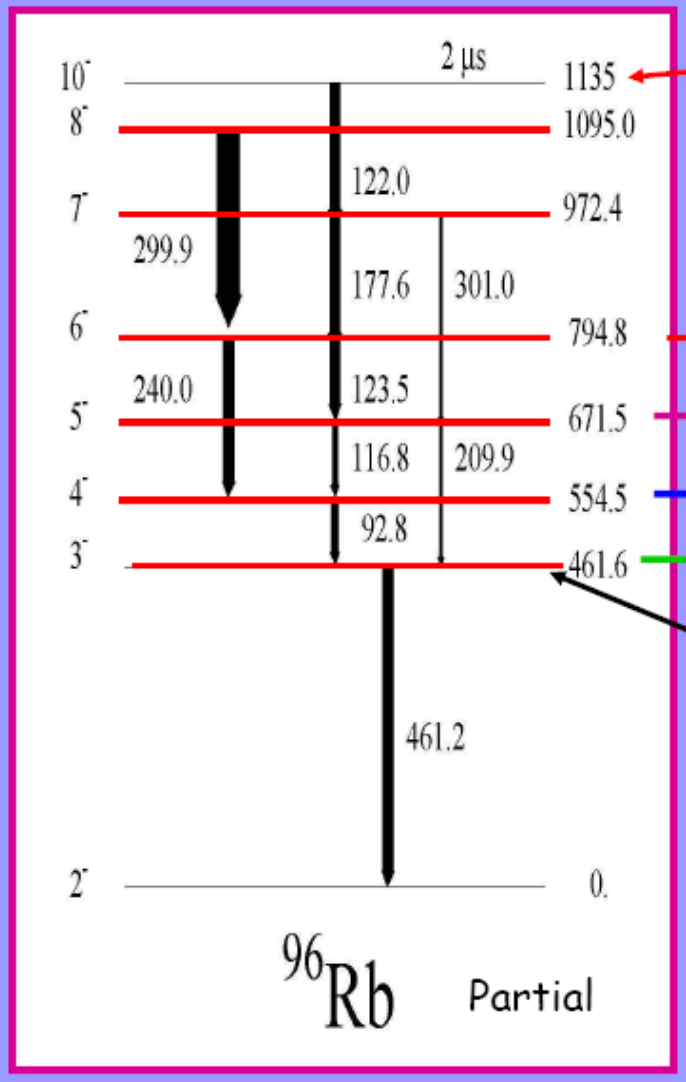



A=100 Q=20 E=100 MeV
ΔE
1600
1500
1400
1300
1200
1100
16
80
17
85
18
90
19
95
20
100
21
105
22
110
Q ,A
E_T
1600
1700
1800
1900
2000
2100
2200
2300
2400
dE1zdET histo



Counts
3000
2000
1000
^{96}Rb Eγ=300 keV
$T_{1/2}$= 2.00(10) μs
0
5
10
15
20
25
Time (μs)

^{96}Rb ion of interest



Preliminary Results

$\pi(g_{9/2})\ \nu(h_{11/2})$

Experiment	Theory (*)
	180 ps
	418 ps
1100 ± 200 ps	700 ps
2200 ± 300 ps	

$\pi[431]3/2\ \nu[541]3/2$

(*) Quasiparticle-rotor-model

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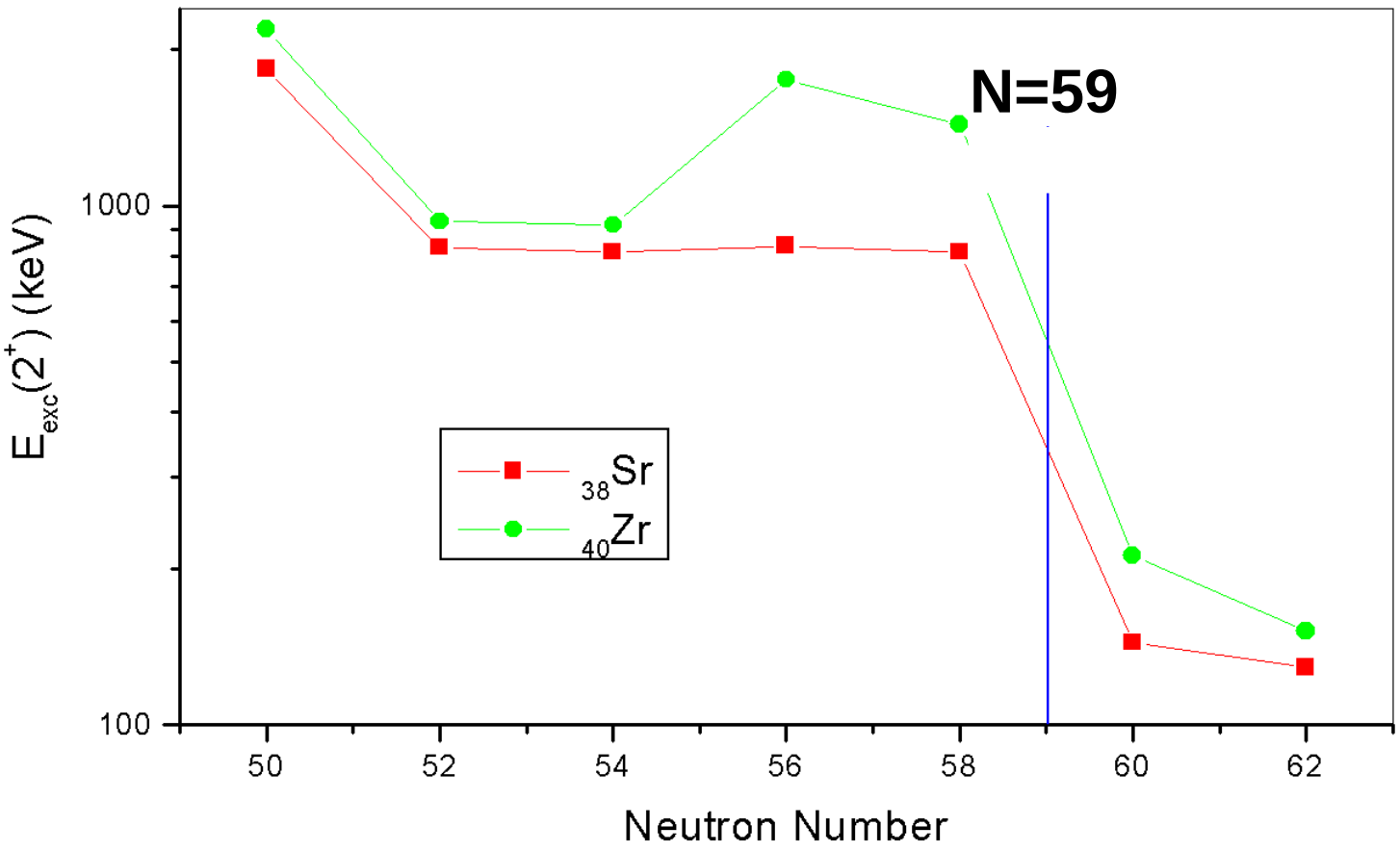
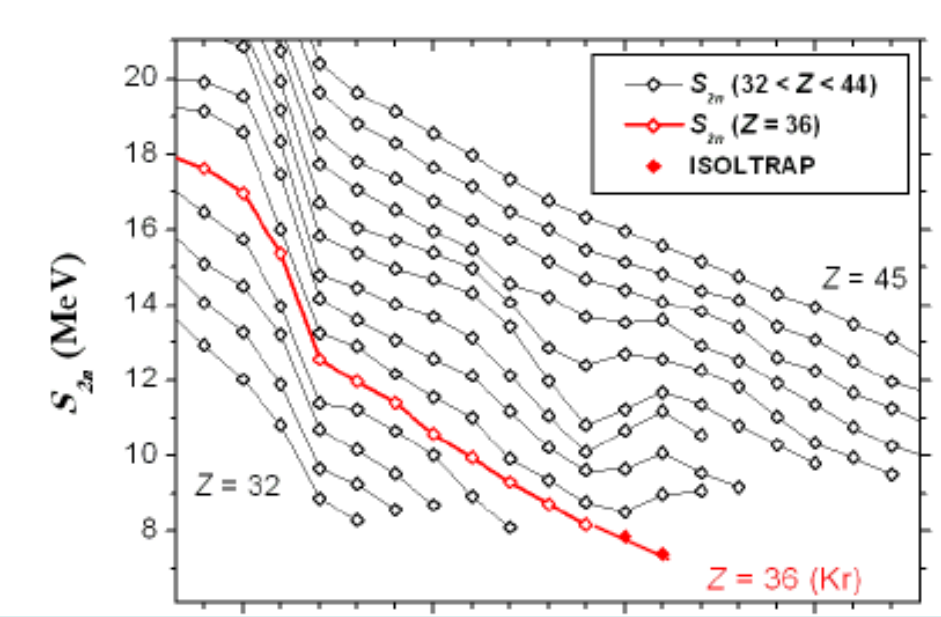
Laboratoire de Physique Subatomique et de Cosmologie

A = 100 region

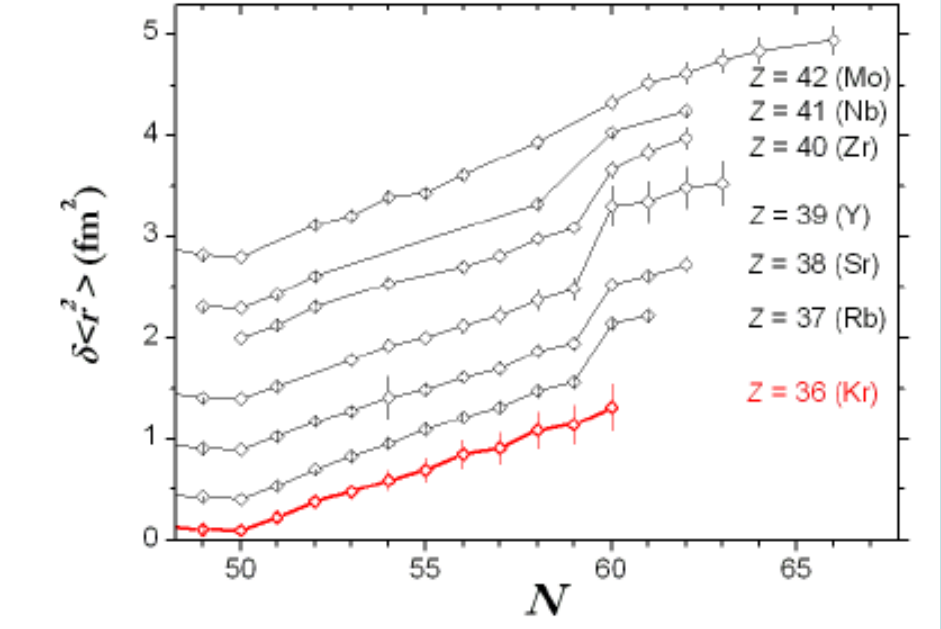


Previous studies in this area used beta-decay which could only populate spherical $s_{1/2}$, $d_{3/2}$ and $g_{7/2}$

Kr nuclei

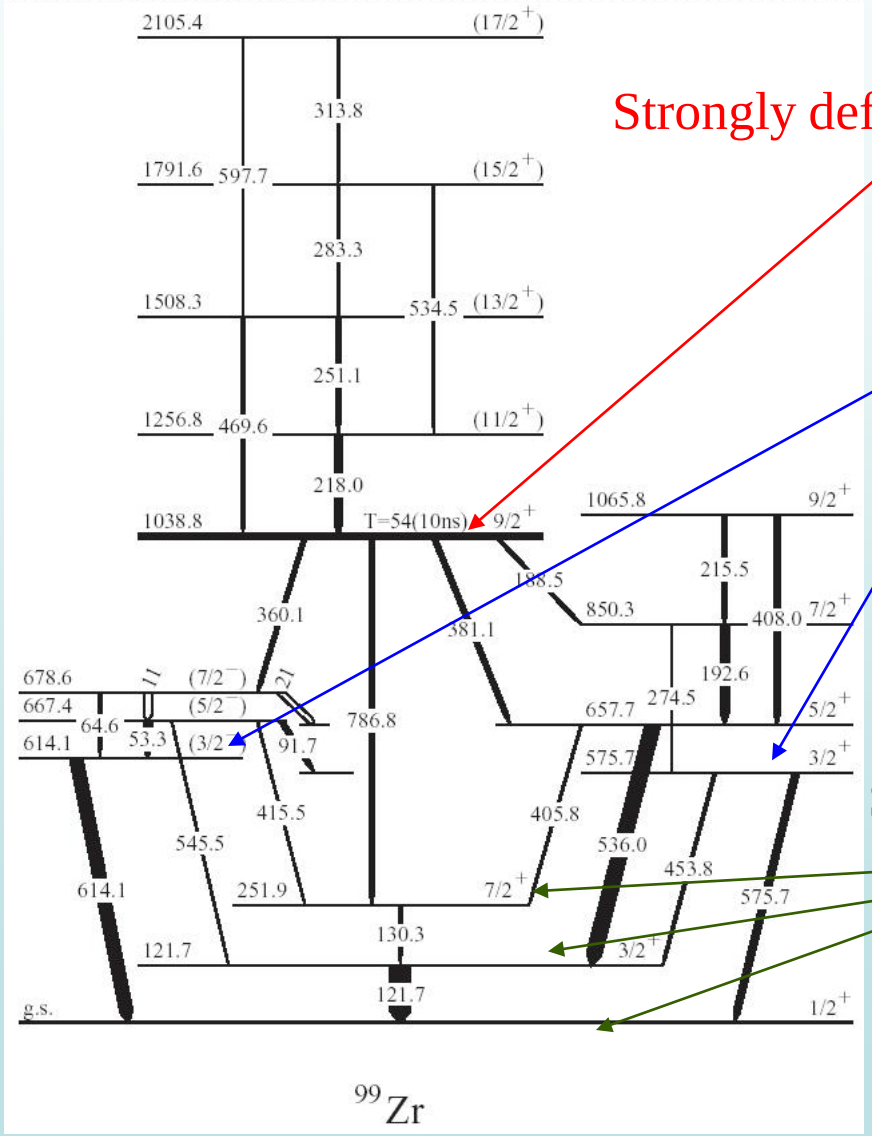


S. Naimi *et al*. Phys. Rev. Lett. 105 (2010) 032502



M. Keim *et al*. Nucl. Phys. A586 (1995) 219

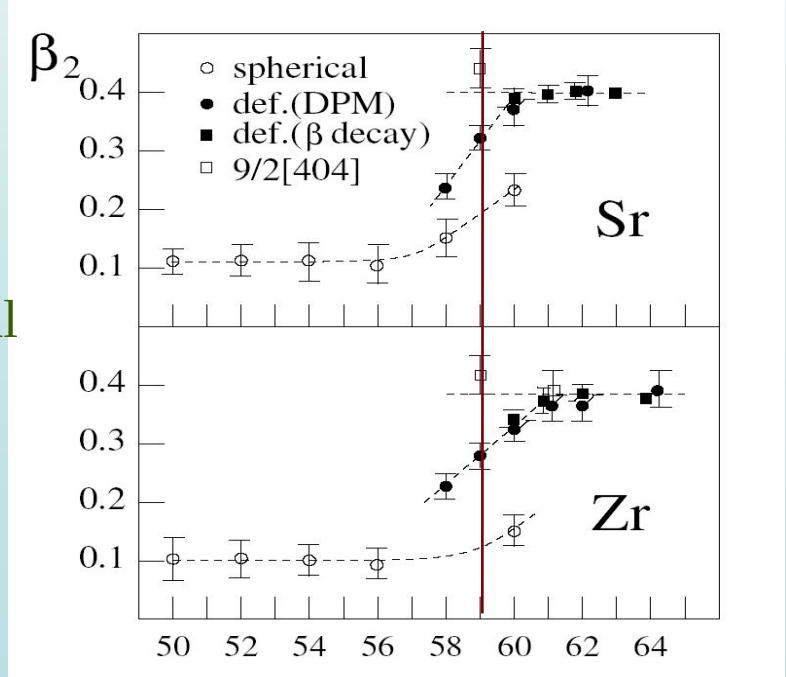
Combination of Eurogam II and Lohengrin data
Observation of 3 different shapes in ^{99,101}Zr and ^{97}Sr

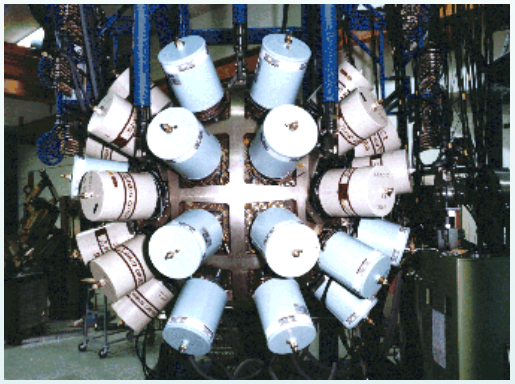


Strongly deformed $\beta_2 = 0.41$

Intermediate deformation $\beta_2 = 0.32$

Spherical





W. Urban, J.A. Pinston *et al.* Eur. Phys. J. A **16**, 11 (2003)

ν9/2[404] was assigned to these states from

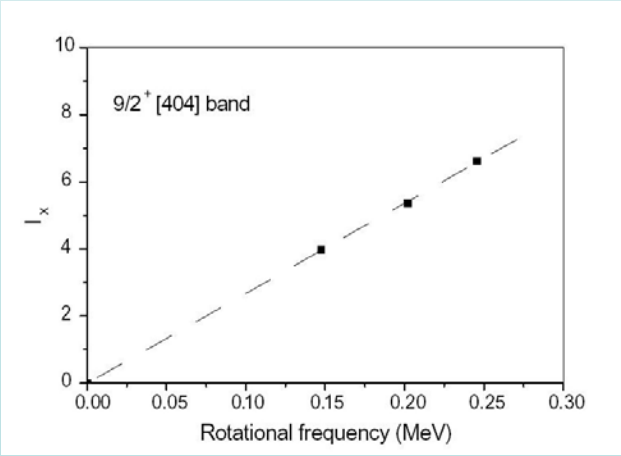
Partial half-lives of decays to known states -gives spin 9/2

Angular correlations between states of known spin.

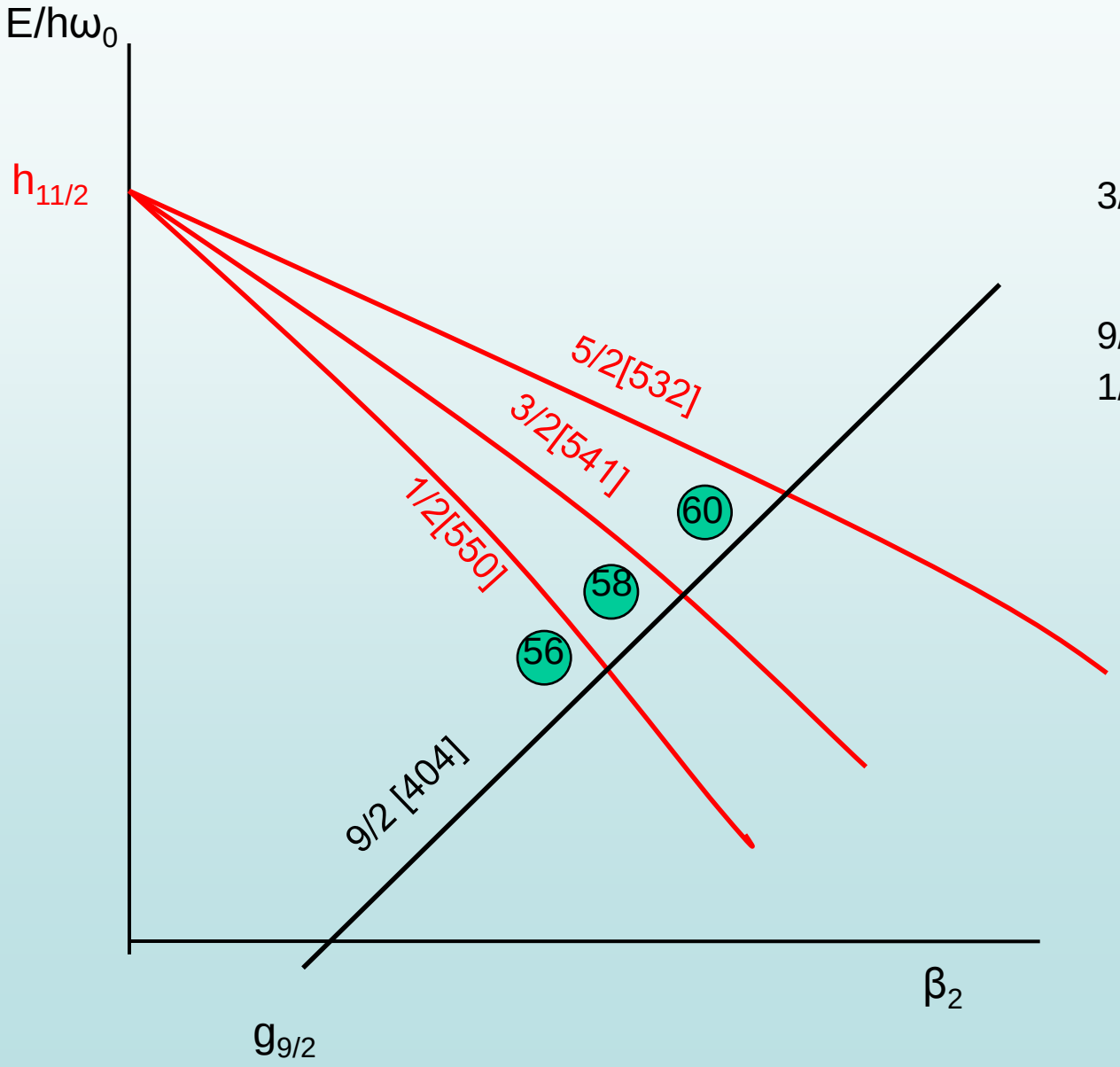
An assignment of 7/2 was rejected from branching ratios of transitions decaying out of isomeric states (Alaga rules)

ν9/2[404] orbital should show little alignment (spin is along symmetry axis)

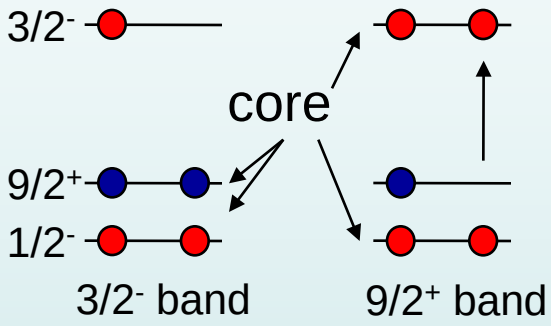
$I_x=\sqrt{(I+1/2)^2-K^2}$ where I_x is spin proj. on symmetry axis



Schematic representations of deformed configurations of odd-mass Sr and Zr isotones



N=59



Kleinheinz *et al.*
P.R.L. **32**, 68 (1974)
Similarity to lanthanides
11/2[505] n-hole states

Conclusions

- First delayed spectroscopy of fission products at a neutron-guide
- New isomers found and identified with $T_{1/2}$~100 ns in Rb isotopes
- Shell-model interpretation works reasonably well – but can be improved
- $27/2^-$ isomer of ^{93}Rb has $\pi g_{9/2}\ \nu(g_{7/2}\ \ h_{11/2})$ configuration
- $9/2^+$ isomer of ^{95}Rb has a $\pi g_{9/2}$ configuration
- If ^{96}Kr is not strongly deformed, a new or improved explanation must be found for shape changes in the A=100 region