

Spectroscopy of Heavy Nuclei

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and
Collaborators

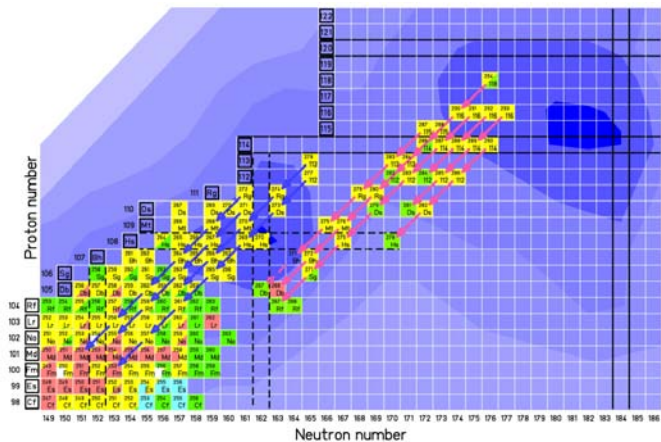
ECT* Gamma-Ray Workshop
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Trento, Italy

Outline

- 1 Introduction
- 2 Studies of Even-Even Nuclei
- 3 In-beam spectroscopy of ^{253}No
- 4 In-beam and decay spectroscopy of ^{255}Lr
- 5 K-Isomerism in ^{254}No
- 6 K-Isomerism in ^{250}Fm
- 7 Future Prospects

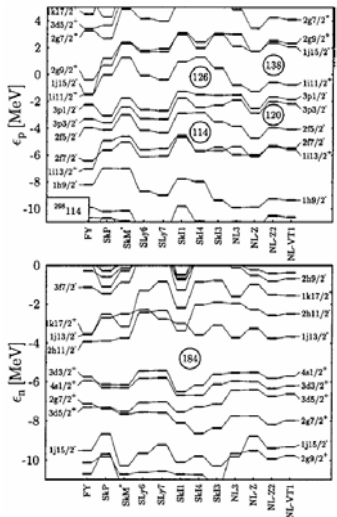


Superheavy Nuclei



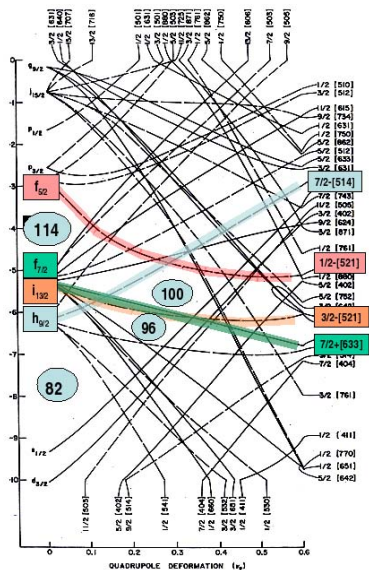
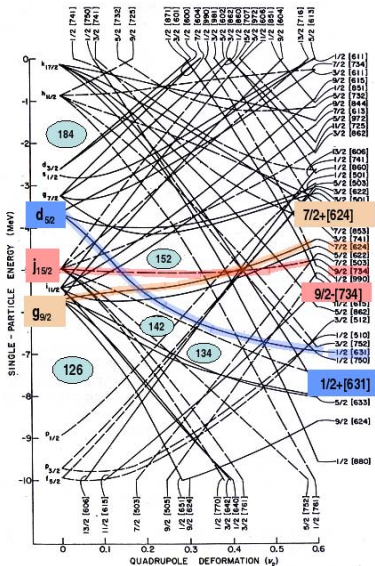
- Low statistics
- Favoured α -decays connect states of similar spin/parity
- Isomers prevalent
- Limit for detailed spectroscopy ≈ 100 pb
- More detailed studies possible in region of ²⁵⁴No

Next Closed Shells?

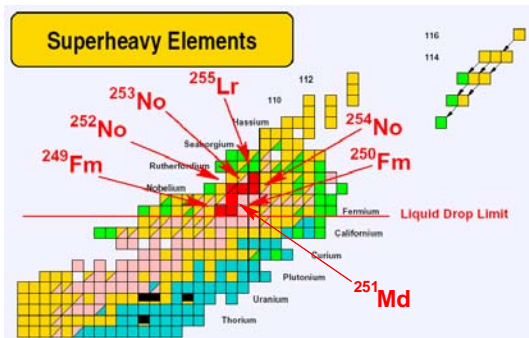


- Various models give different ordering and energies of single-particle states
- Leads to different predictions of next closed shells
- Obtain experimental data to constrain models and determine correct ordering

M. Bender et al., PRC60, 034304 (1999)

Single-Particle Orbitals in Region of ^{254}No 

Heavy Elements Studied at JYFL

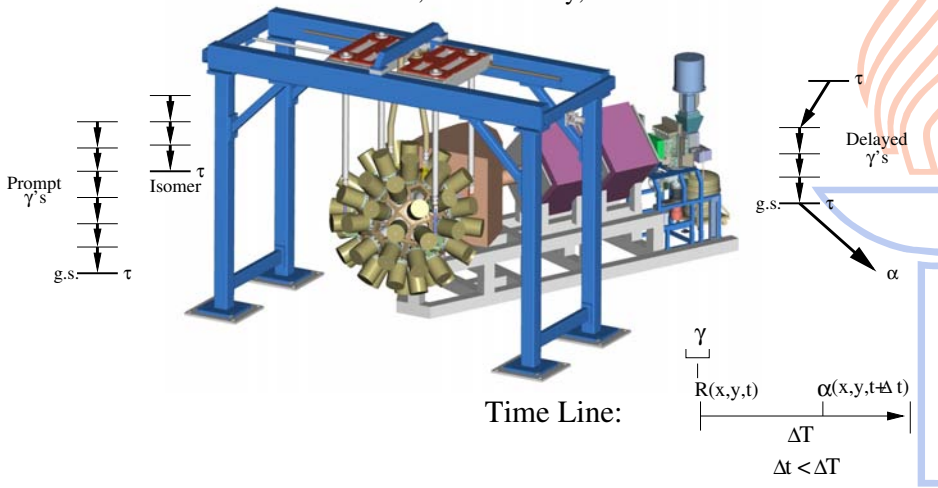


- Reactions of ^{48}Ca on various targets in region of ^{208}Pb
- Initial studies focussed on even-even nuclei
- Progressed to studies of odd-A nuclei
- Also studies of high-K states

Principles of RDT

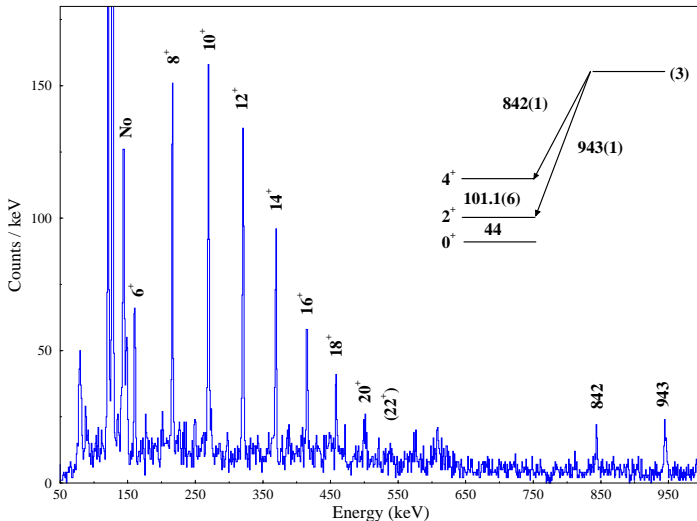
Tagging Techniques

Recoil, Recoil-Decay, Isomer

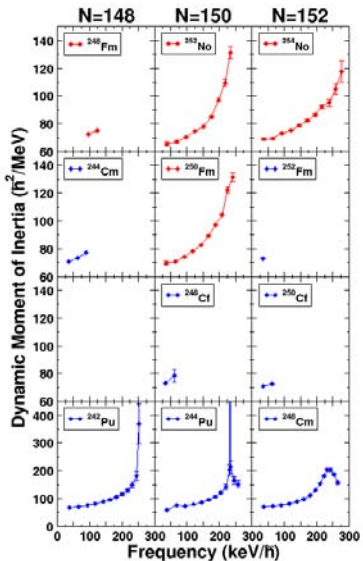


In-beam γ -ray Spectroscopy of ²⁵⁴No

⁴⁸Ca + ²⁰⁸Pb \Rightarrow ²⁵⁴No + 2n, S. Eeckhaudt, P.T. Greenlees et al., EPJA **26**, 227 (2005)



Moment of Inertia Systematics (Even-Even Nuclei)



- Confirmed deformed nature of nuclei around ^{254}No
- Showed fission barrier robust with spin ($> 20\hbar$)
- Faster alignment at $N=150$ compared to $N=152$ ($\pi i_{13/2}$, $\nu j_{15/2}$)
- Excellent testing ground for theory; e.g.
 - Duguet et al., NPA **679**, 427 (2001),
 - Bender et al., NPA **723**, 354 (2003),
 - Afanasjev et al., PRC **67**, 024309 (2003),
 - Egido and Robledo, PRL **85** 1198 (2000)

Electromagnetic Properties

- Odd-proton orbitals in ²⁵¹Md
- $B(M1)/B(E2)$ depends on $(g_K - g_R / Q_0)$

[514] $\frac{7}{2}^-$

$g_K \sim 0.7$

Mainly E2



[633] $\frac{7}{2}^+$

$g_K \sim 1.3$

Mainly M1



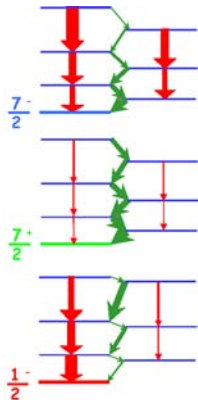
[521] $\frac{1}{2}^-$

$a \sim 0.9$

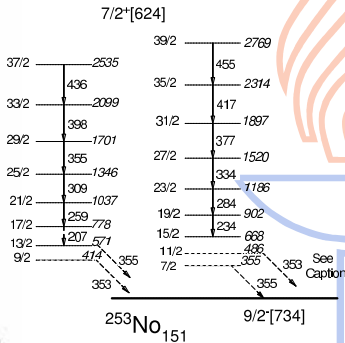
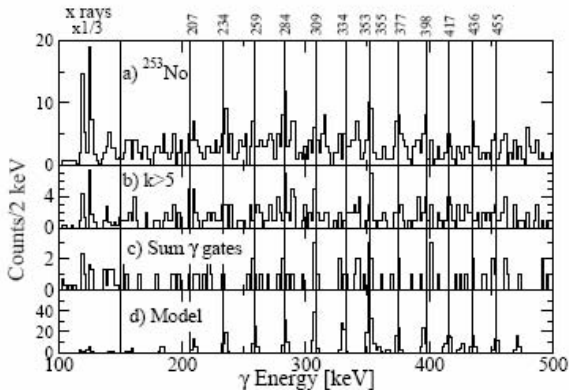
Mainly E2



$g_K \sim -0.55$



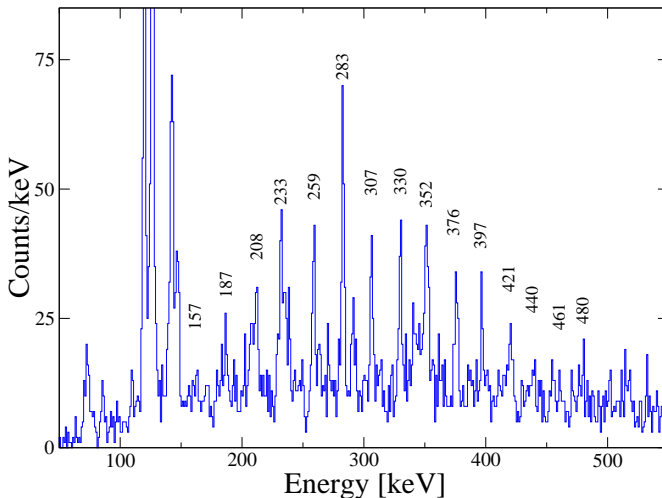
Odd-Mass Transfermium Nuclei - ^{253}No



P. Reiter et al., PRL **95**, 032501 (2005)

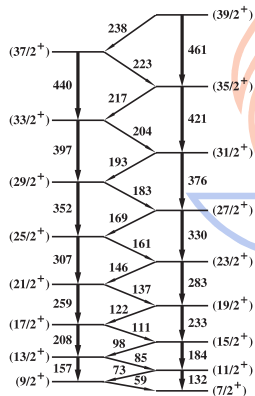
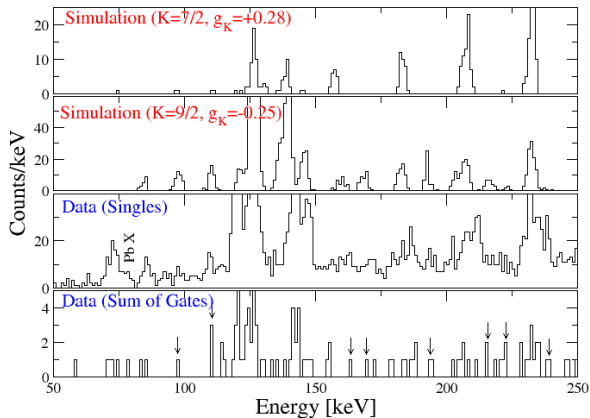
Odd-Mass Transfermium Nuclei - ²⁵³No

$^{48}\text{Ca} + ^{207}\text{Pb} \Rightarrow ^{253}\text{No} + 2n$, JUROGAM+RITU+GREAT, R.-D. Herzberg et al.



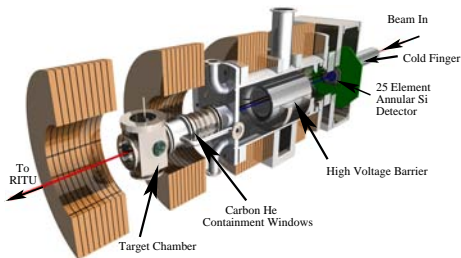
Odd-Mass Transfermium Nuclei - ^{253}No

$^{48}\text{Ca} + ^{207}\text{Pb} \Rightarrow ^{253}\text{No} + 2n$, JUROGAM+RITU+GREAT, R.-D. Herzberg et al. Analysis by S. Eeckhoudt
Configuration of Observed Bands?



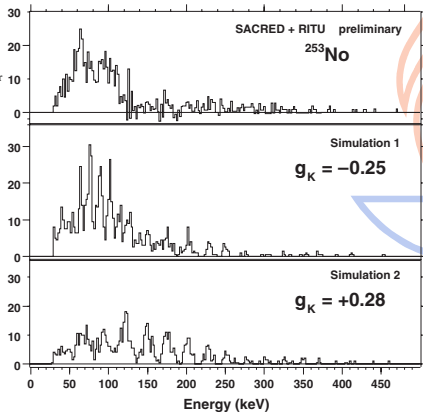
- N.B. Correspondance of structure in experimental spectrum and position of expected M1 transitions

Odd-Mass Transfermium Nuclei - ^{253}No

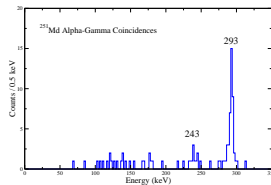
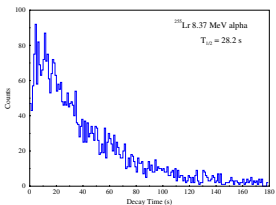
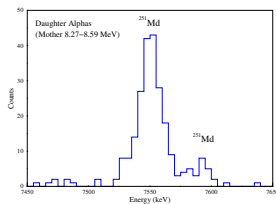
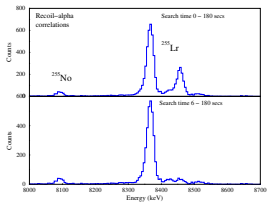


H. Kankaanpää et al., NIM A534, 503 (2004)

P. A. Butler et al., NIM A381, 433 (1996)



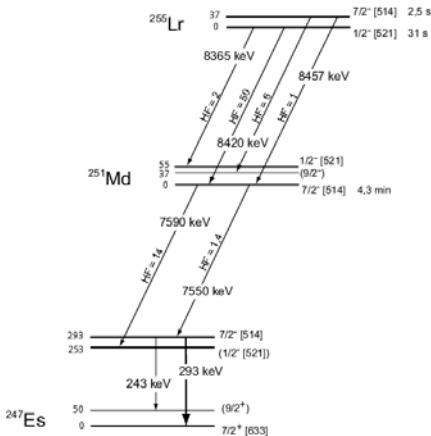
Decay spectroscopy of ^{255}Lr



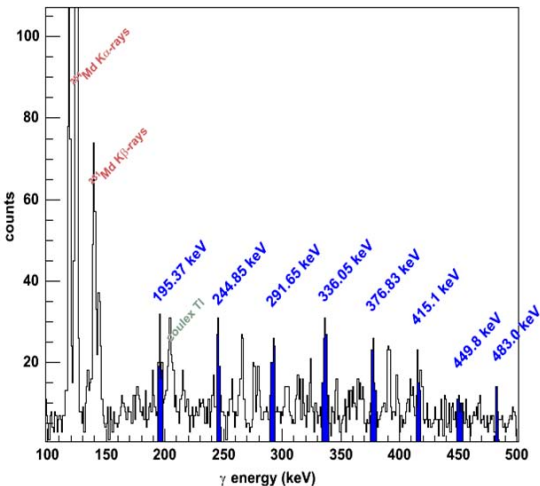
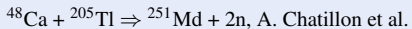
$^{48}\text{Ca} + ^{209}\text{Bi} \Rightarrow ^{255}\text{Lr} + 2n$, $\sigma \simeq 300$ nb, A.Chatillon, Ch.Theisen, P.T.Greenlees et al., To be published
Experiments carried out at both JYFL and GANIL

Decay spectroscopy - ²⁵⁵Lr

$^{48}\text{Ca} + ^{209}\text{Bi} \Rightarrow ^{255}\text{Lr} + 2\text{n}$, $\sigma \simeq 300 \text{ nb}$, GANIL and JYFL data
 A.Chatillon, Ch.Theisen,P.T.Greenlees et al., Coming soon...

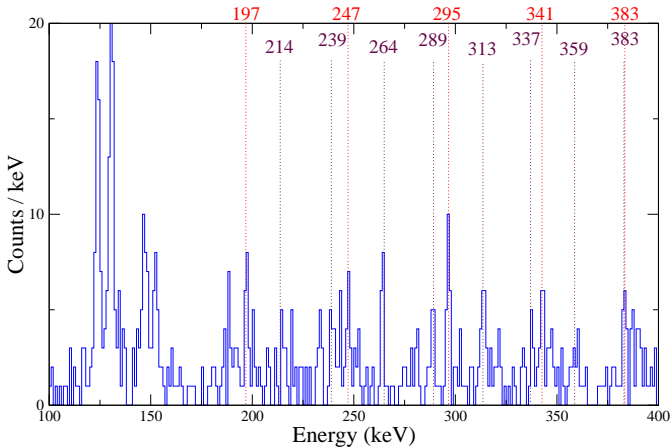


Odd-Mass Transfermium Nuclei - ²⁵¹Md



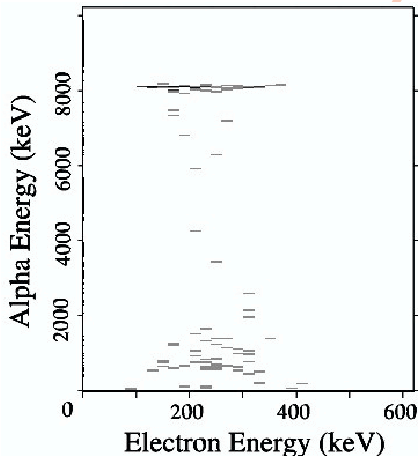
Heaviest Nucleus Studied In-Beam - ²⁵⁵Lr

$^{48}\text{Ca} + ^{209}\text{Bi} \Rightarrow ^{255}\text{Lr} + 2n$, $\sigma \simeq 300$ nb, P.T. Greenlees, S. Ketelhut et al.



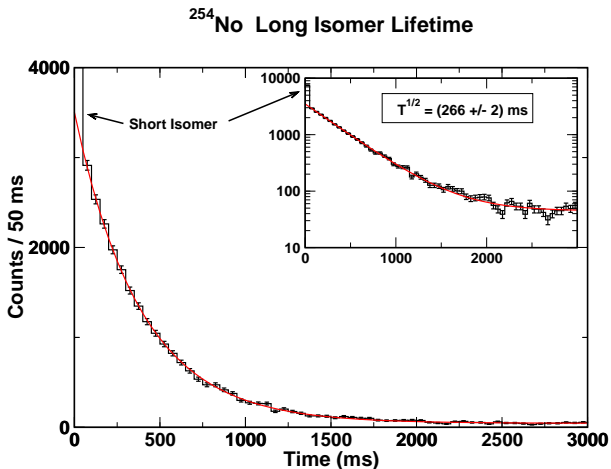
K-Isomerism in ²⁵⁴No

- Isomeric state with half-life 280 ms first postulated by Ghiorso et al., PRC7 (1973) 2032
- Powerful method proposed by Jones, NIM A488 (2002) 471
- Low-energy transitions highly converted, look for Recoil-electron- α correlated chains in DSSSD
- Isomer confirmed in several experiments: Butler et al., Acta. Pol. B34 (2003) 2107, Mukherjee et al., AIP Conf. Proc 764 (2005) 243
- Recent experiments carried out at ANL and JYFL



K-Isomerism in ^{254}No

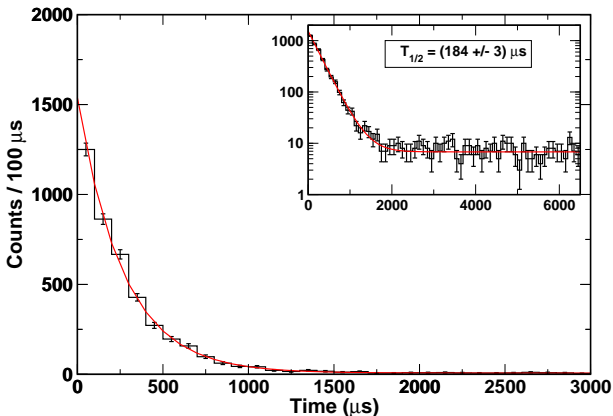
$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron time differences



K-Isomerism in ^{254}No

$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron time differences

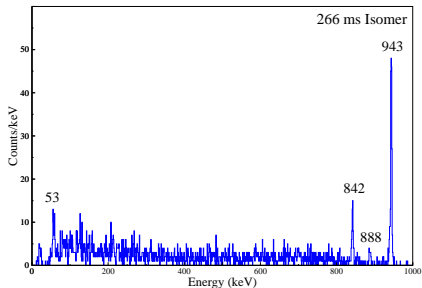
^{254}No Short Isomer Lifetime



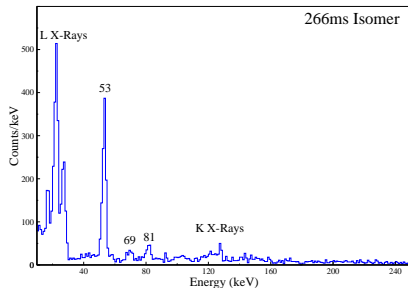
K-Isomerism in ^{254}No - 266ms Isomer

$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron γ coincidences

Clover Ge Spectra



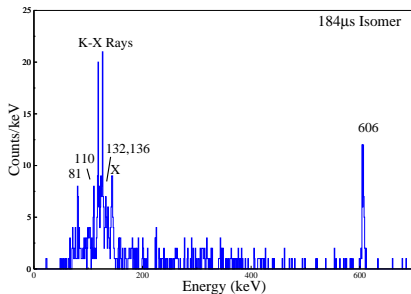
Planar Ge Spectra



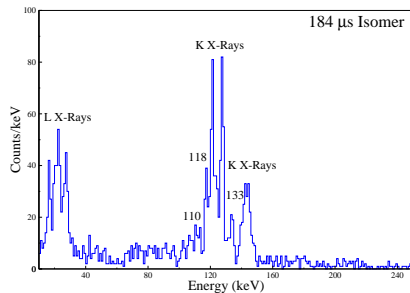
K-Isomerism in ²⁵⁴No - 184 μ s Isomer

$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron γ coincidences

Clover Ge Spectra



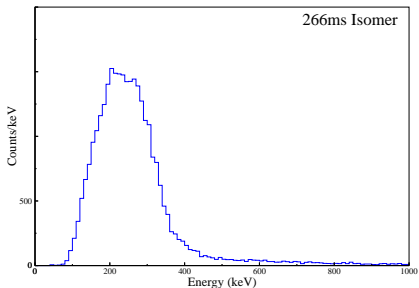
Planar Ge Spectra



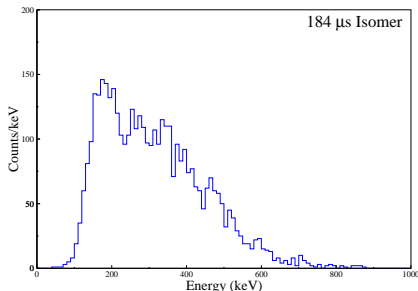
K-Isomerism in ^{254}No

$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron spectra

Slow Isomer

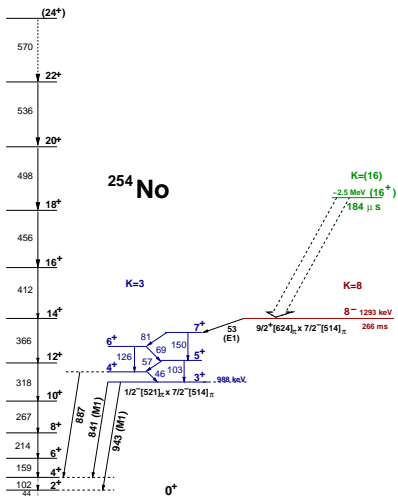


Fast Isomer



K-Isomerism in ²⁵⁴No

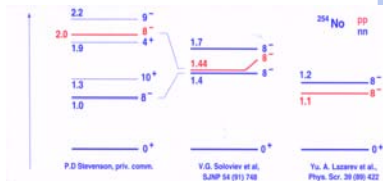
R.-D. Herzberg, P.T. Greenlees et al., Submitted to Nature



Possible Configurations:

- 3⁺ - p[514]7/2⁻ ⊗ p[521]1/2⁻
- 3⁺ - n[624]7/2⁺ ⊗ n[631]1/2⁺
- 8⁻ - n[734]9/2⁻ ⊗ n[613]7/2⁺
- 8⁻ - p[514]7/2⁻ ⊗ p[624]9/2⁺
- 8⁻ - n[624]7/2⁺ ⊗ n[734]9/2⁻

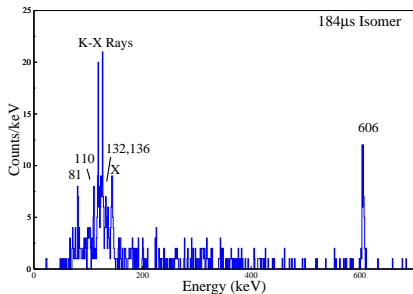
Dominant M1 decay suggests proton configurations



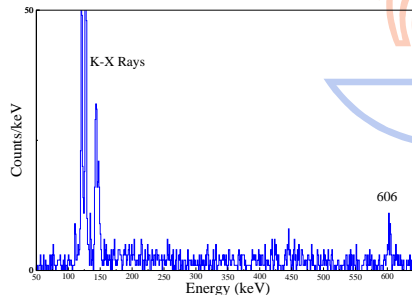
K-Isomerism in ^{254}No - JUROGAM

$^{48}\text{Ca} + ^{208}\text{Pb} \Rightarrow ^{254}\text{No} + 2n$, RITU+GREAT, R.-D. Herzberg, P.T. Greenlees et al.,
Correlated recoil-electron γ coincidences

Clover Ge Spectra

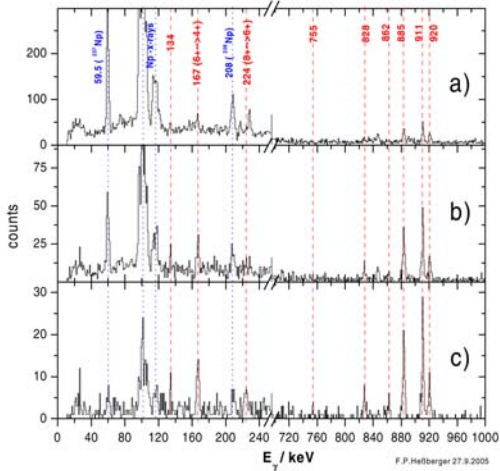


Recoil-Electron Tagged Jurogam Singles



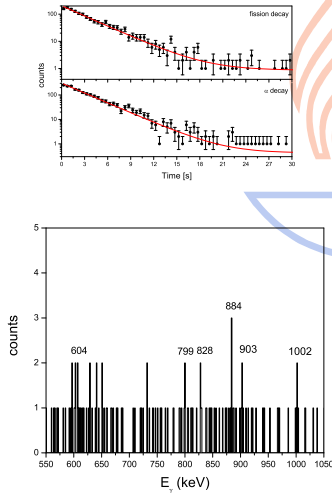
K-Isomerism in ^{252}No

GSI Focal Plane Data



Strongest γ rays confirmed in recent experiment at ANL

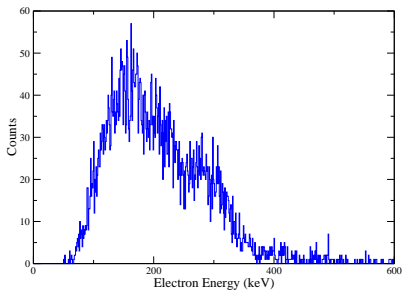
JYFL Fission Tagging of ^{252}No
A.-P. Leppänen et al., Submitted to EPJA



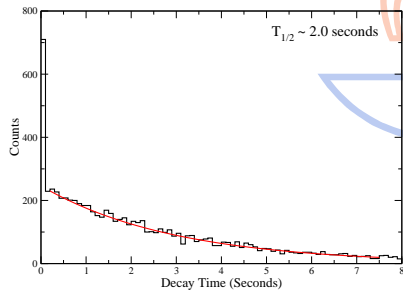
K-Isomerism in ²⁵⁰Fm

$^{48}\text{Ca} + ^{204}\text{HgS} \Rightarrow ^{250}\text{Fm} + 2n$, JUROGAM+RITU+GREAT, P.T. Greenlees, R.-D. Herzberg et al.

Correlated Electron Energy



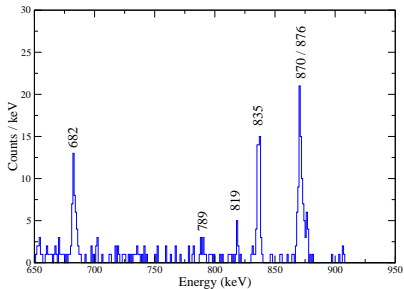
Electron Decay Curve



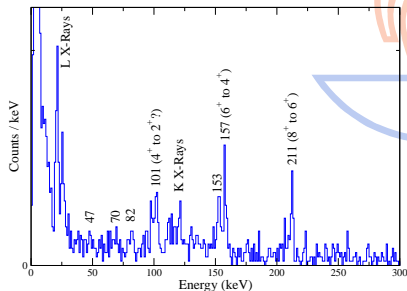
K-Isomerism in ²⁵⁰Fm

$^{48}\text{Ca} + ^{204}\text{HgS} \Rightarrow ^{250}\text{Fm} + 2n$, JUROGAM+RITU+GREAT, P.T. Greenlees, R.-D. Herzberg et al.

Electron-Clover Coincidences



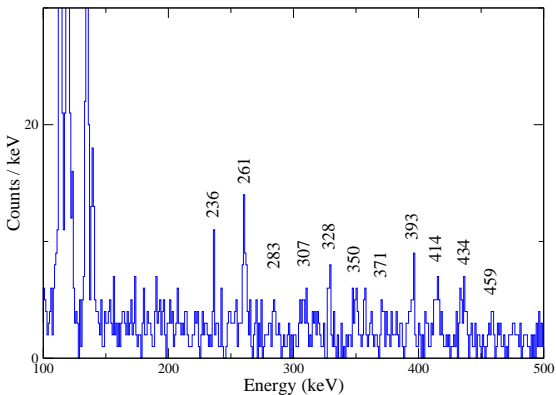
Electron-Planar Coincidences



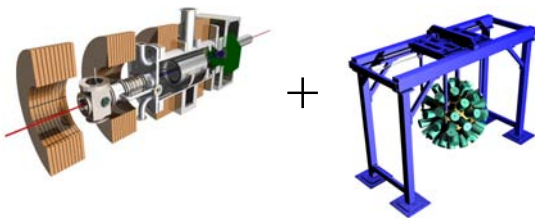
K-Isomerism in ^{250}Fm

$^{48}\text{Ca} + ^{204}\text{HgS} \Rightarrow ^{250}\text{Fm} + 2n$, JUROGAM+RITU+GREAT, P.T. Greenlees, R.-D. Herzberg et al.

Recoil-Electron Tagged Jurogam Singles



The Future....



\Rightarrow SAGE



- Simultaneous Electron-Gamma Measurements
- Combine Digital Electronics with TDR
- Unique and Powerful Device for Spectroscopy of Heavy Nuclei
- Progress to $Z=104$ - ^{256}Rf @ 12 nb!
- Lighter beams / Radioactive Targets e.g. ^{256}No
- Still many cases to be studied e.g. ^{255}No , ^{248}Fm , ^{249}Md

Collaborating Institutes

Institutes Collaborating in the Experiments Presented:



UNIVERSITY OF JYVÄSKYLÄ



THE UNIVERSITY
of LIVERPOOL



CCLRC



HELSINGIN YLIOPISTO



ISOLDE
CERN

