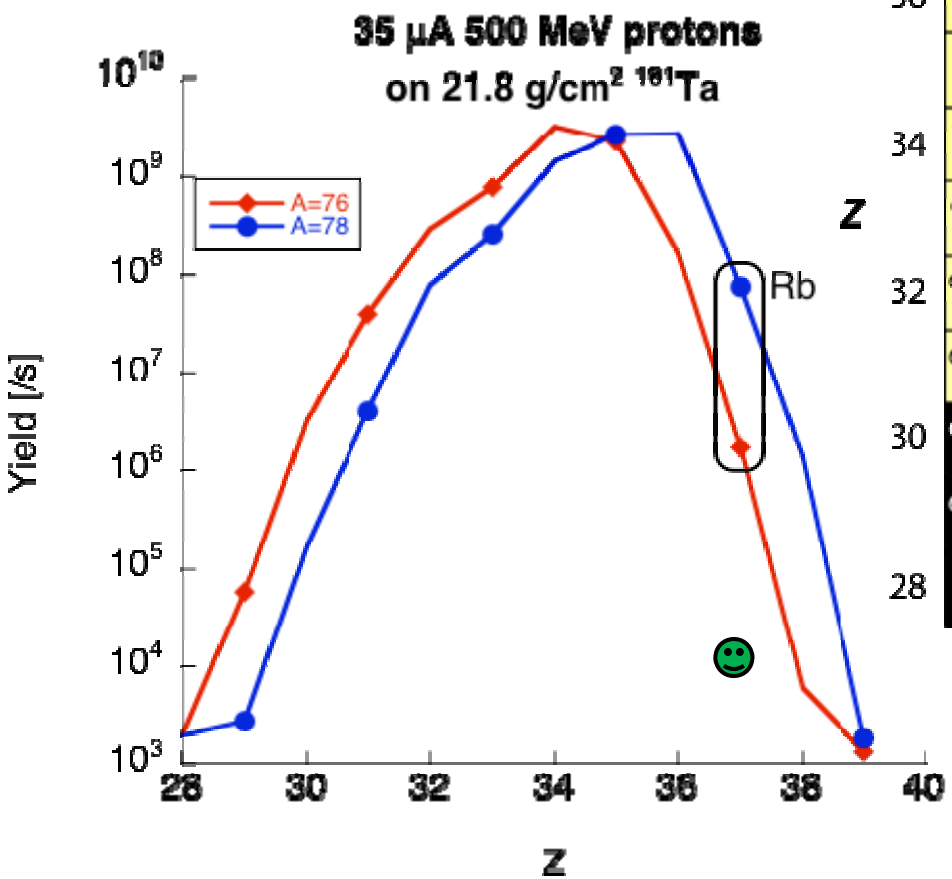
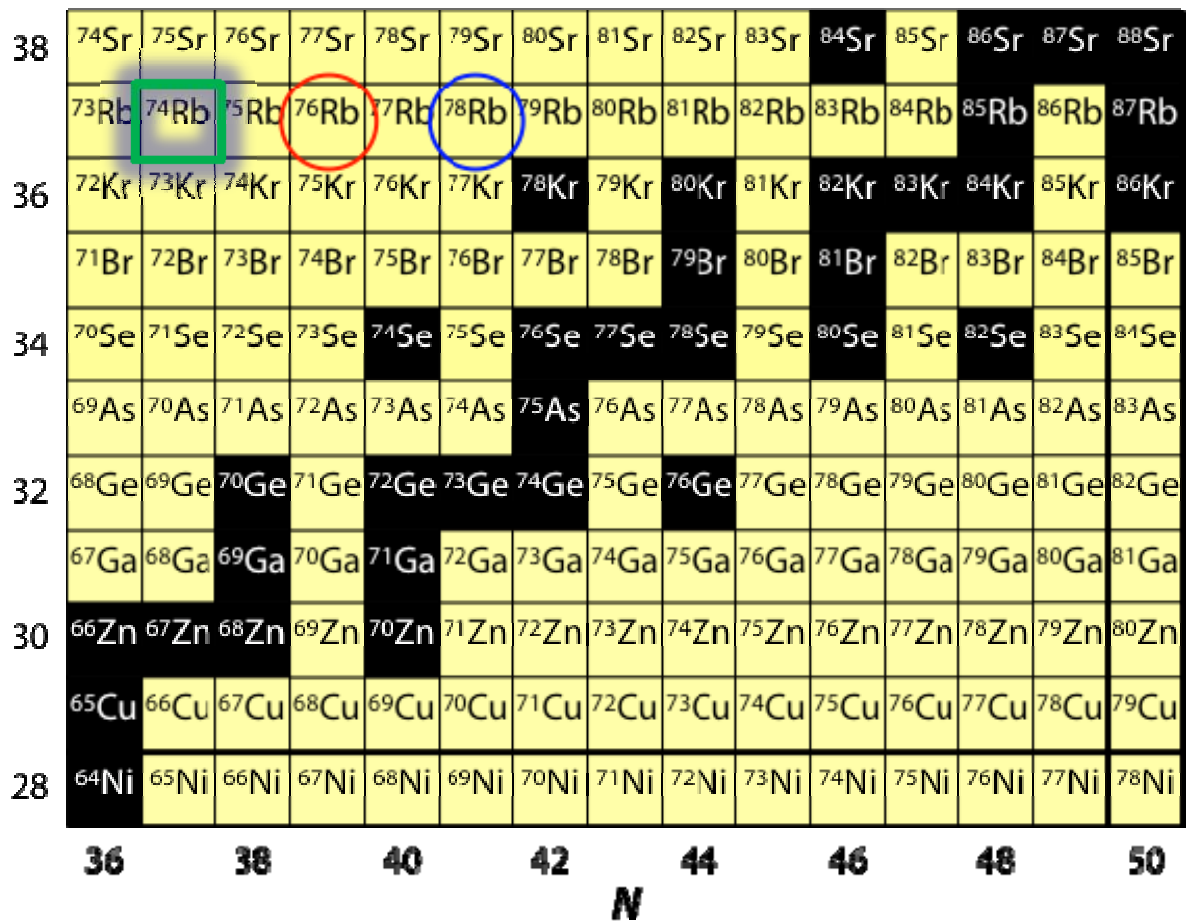
High yields of rubidium isotopes are available with Nb, ZrC, or Ta targets at ISAC.

Nuclide	$T_{\frac{1}{2}}$	Nb (10 μA)	ZrC (35 μA)	Ta (35 μA)
^{74}Rb	65 ms	1.30×10^4	4.20×10^2	
^{76}Rb	37 s	$^*1.60 \times 10^7$	5.30×10^7	4×10^4
^{78}Rb^g	17.5 m	7.00×10^8	2.20×10^9	1×10^7
^{78}Rb^m	5.7 m	4.20×10^9	6.90×10^9	6×10^7
^{80}Rb	33 s	2.60×10^{10}	3.50×10^{10}	1×10^9





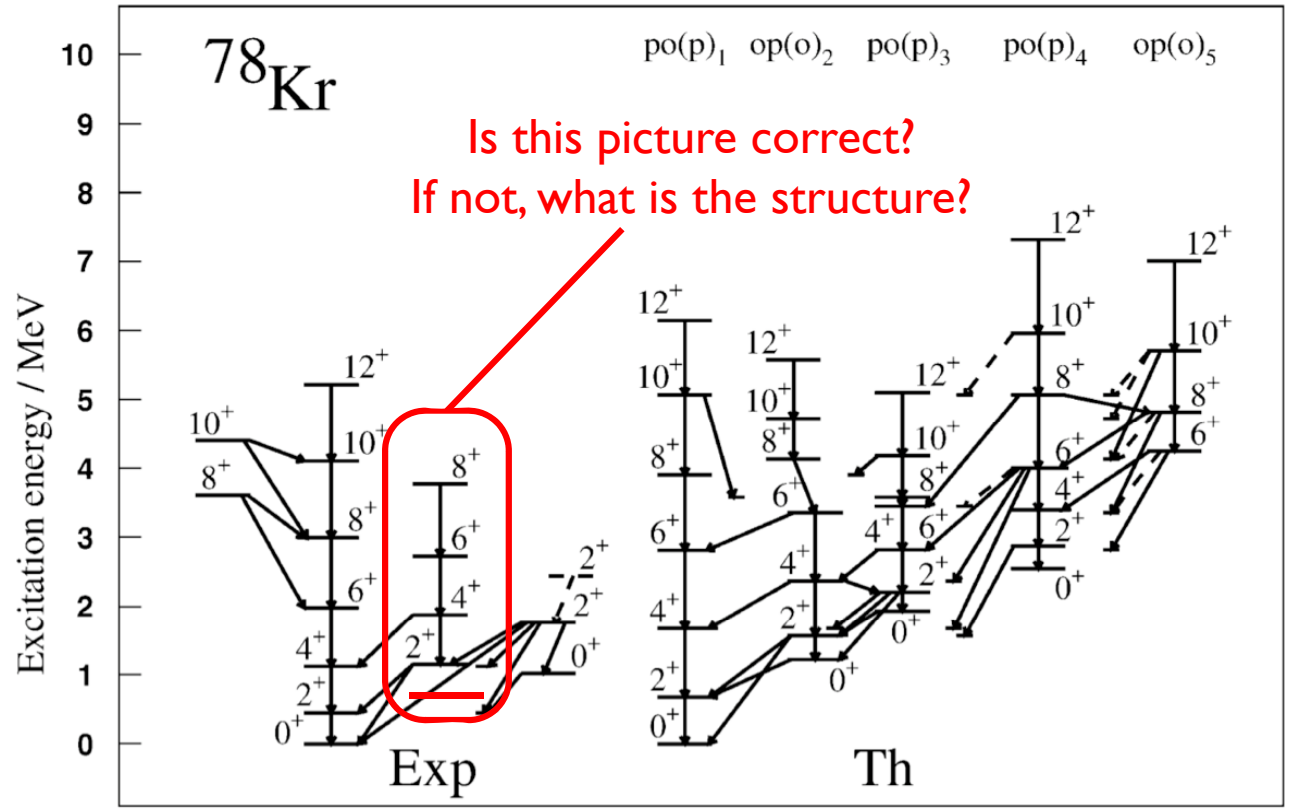
S1215: Characterization of shape coexistence near *N*=40

Steve Yates

Representing **S1215**,
a collaboration including:
Georgia Tech, Guelph, SFU,
TRIUMF, NSCL, and UK
spokesman: W. D. Kulp
(wdkulp@mailaps.org)

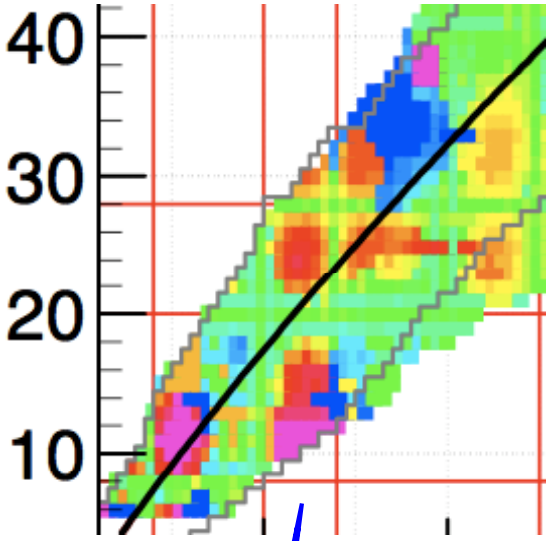
ISAC Forum

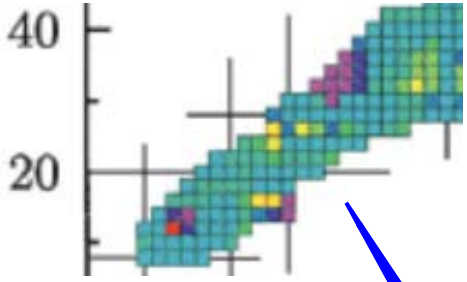
2 Dec 2009

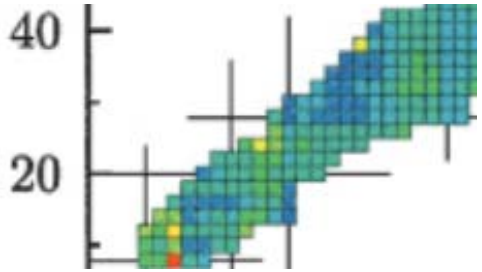


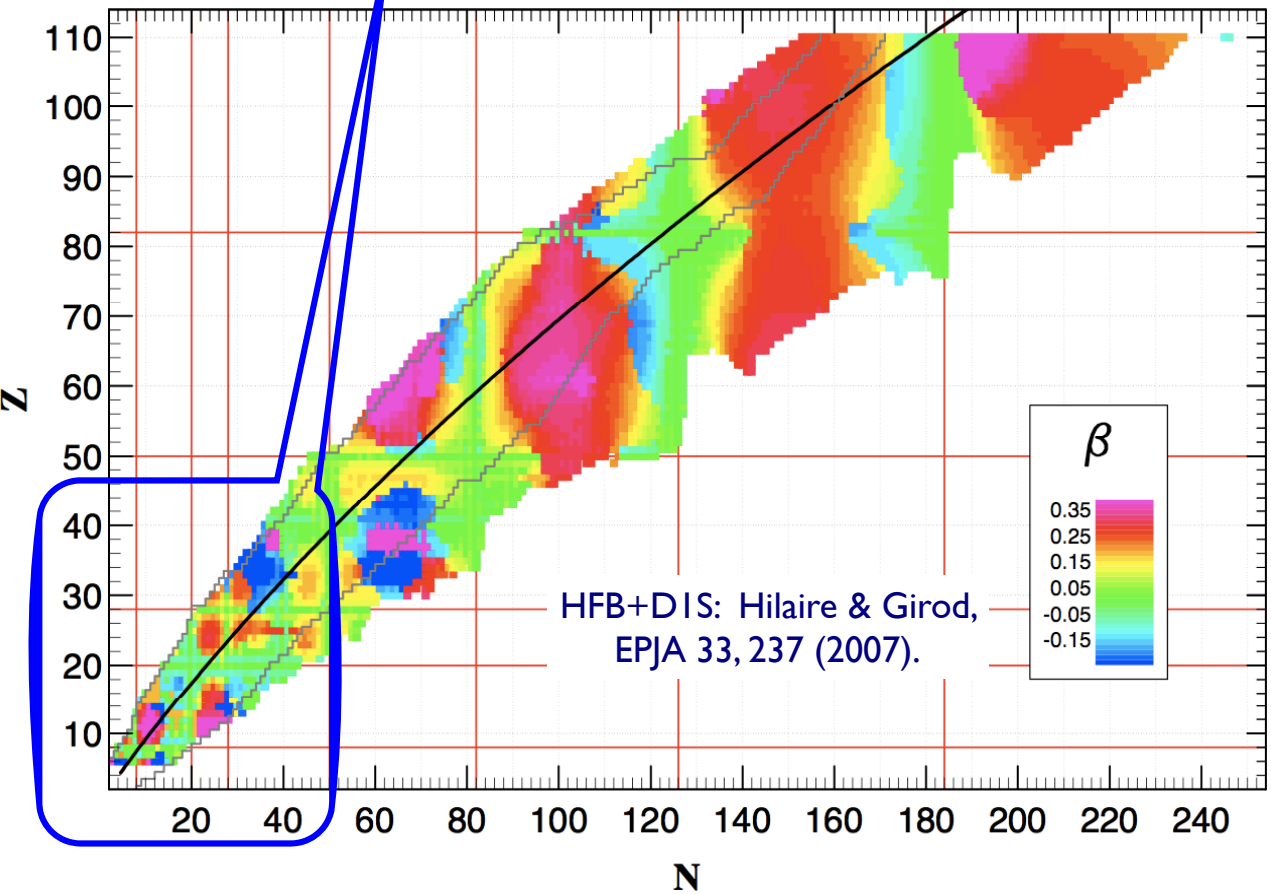
Multi-step Coulomb excitation of ^{78}Kr suggests that the 2^+_2 state belongs to a coexisting *K*=0 oblate band, ***the band-head of which has not yet been observed***.
Becker *et al.*, Nucl. Phys. A770, 107 (2006)

Oblate-deformed shapes are predicted in the *A*~70 region.

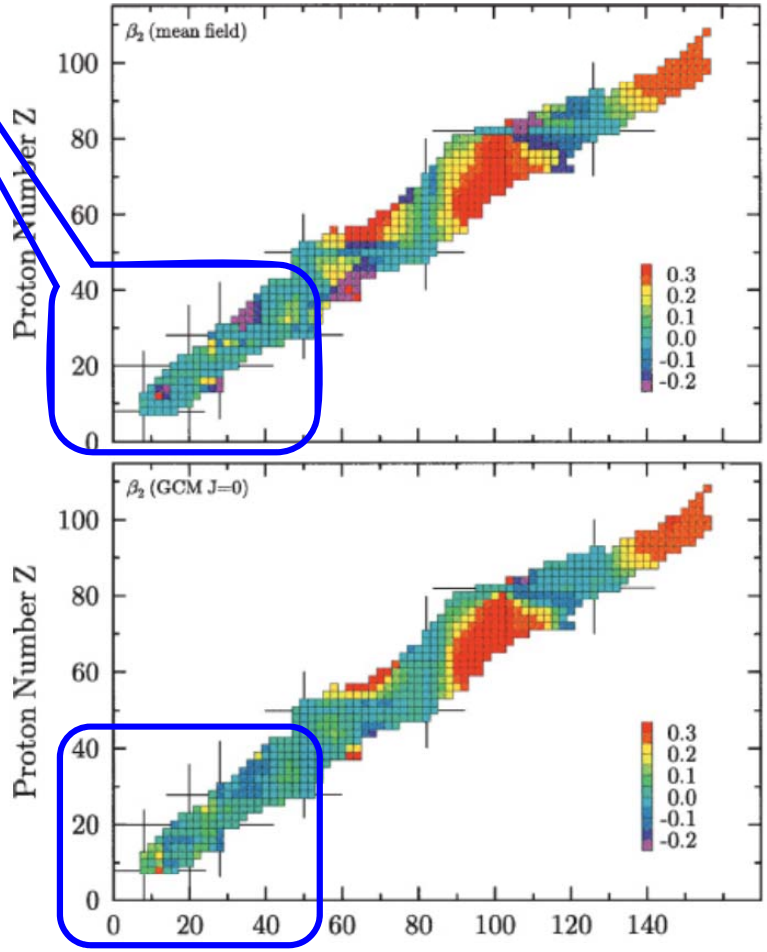






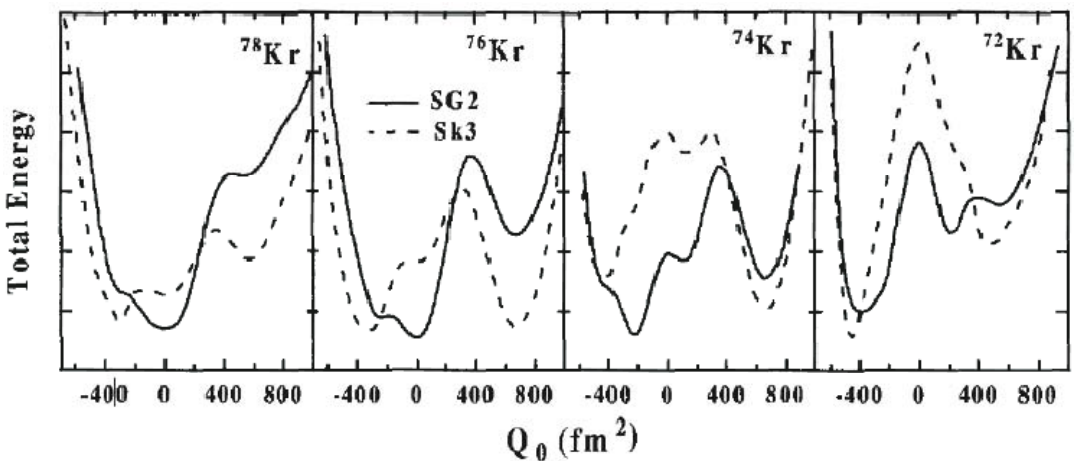


HFB+D1S: Hilaire & Girod, EPJA 33, 237 (2007).

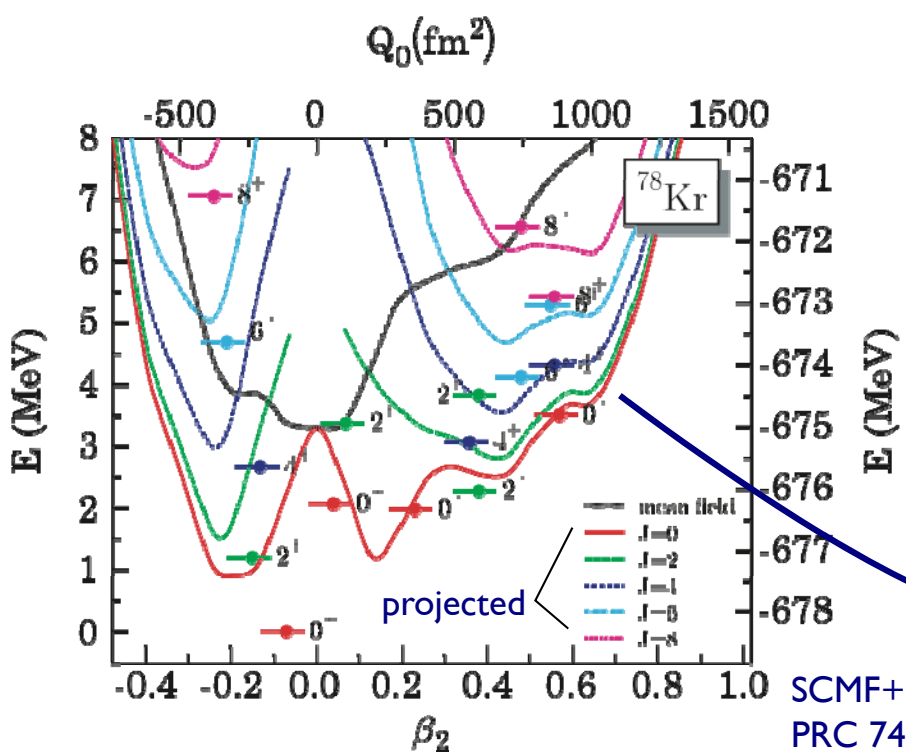


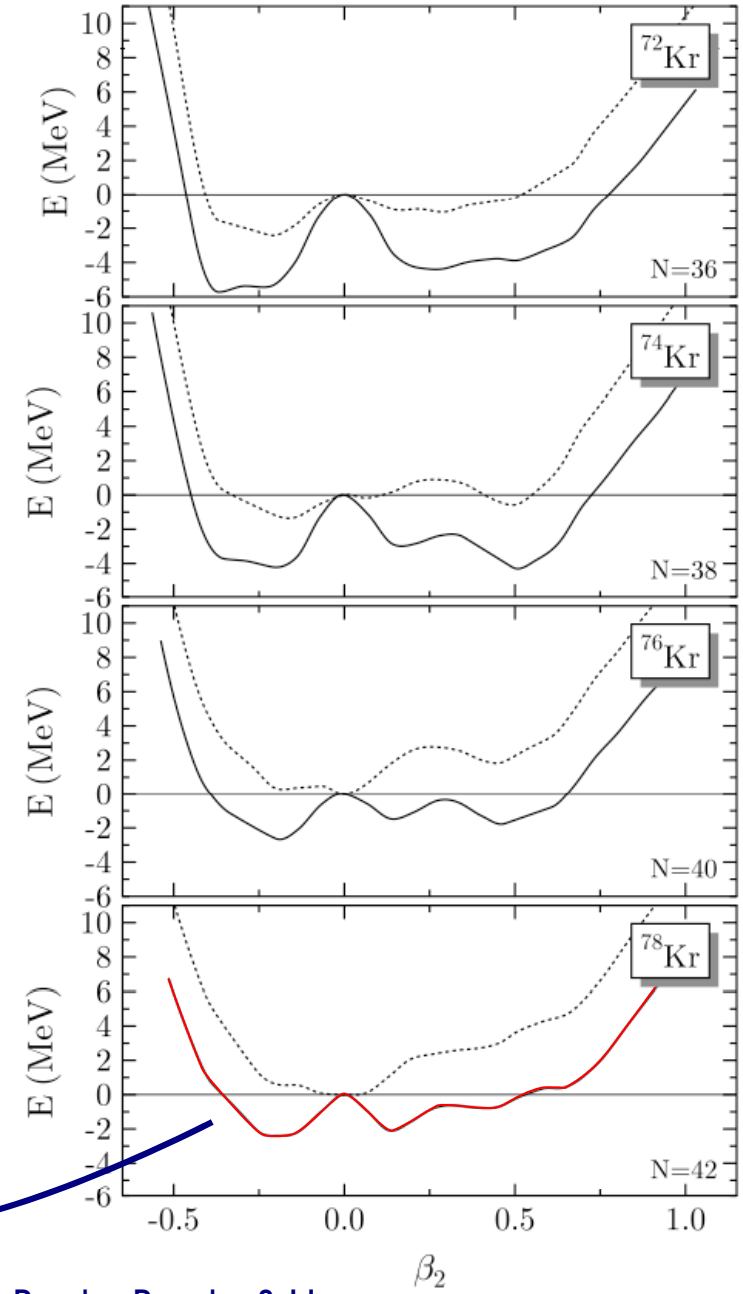
SCMF+SLy4 & GCM: Bender, Bertsch & Heenen, PRC 73, 034322 (2006).

Mean-field calculations indicate coexisting oblate and prolate shapes in the krypton isotopes.



HF+BCS+Skyrme: Sarriguren, Moya de Guerra & Escuderos, NPA 658, 13 (1999).





SCMF+SLy6 & GCM: Bender, Bonche & Heenen, PRC 74, 024312 (2006).

Strong *E0* transitions are evidence of shape coexistence.

Monopole strength parameter

$$\rho_{if}(E0) = \frac{\langle f|\sum_j e_j r_j^2|i\rangle}{eR^2} \equiv \frac{\langle f|m(E0)|i\rangle}{eR^2} \equiv \frac{M_{if}(E0)}{eR^2}$$

Monopole strength from mixing of states with different <r²>

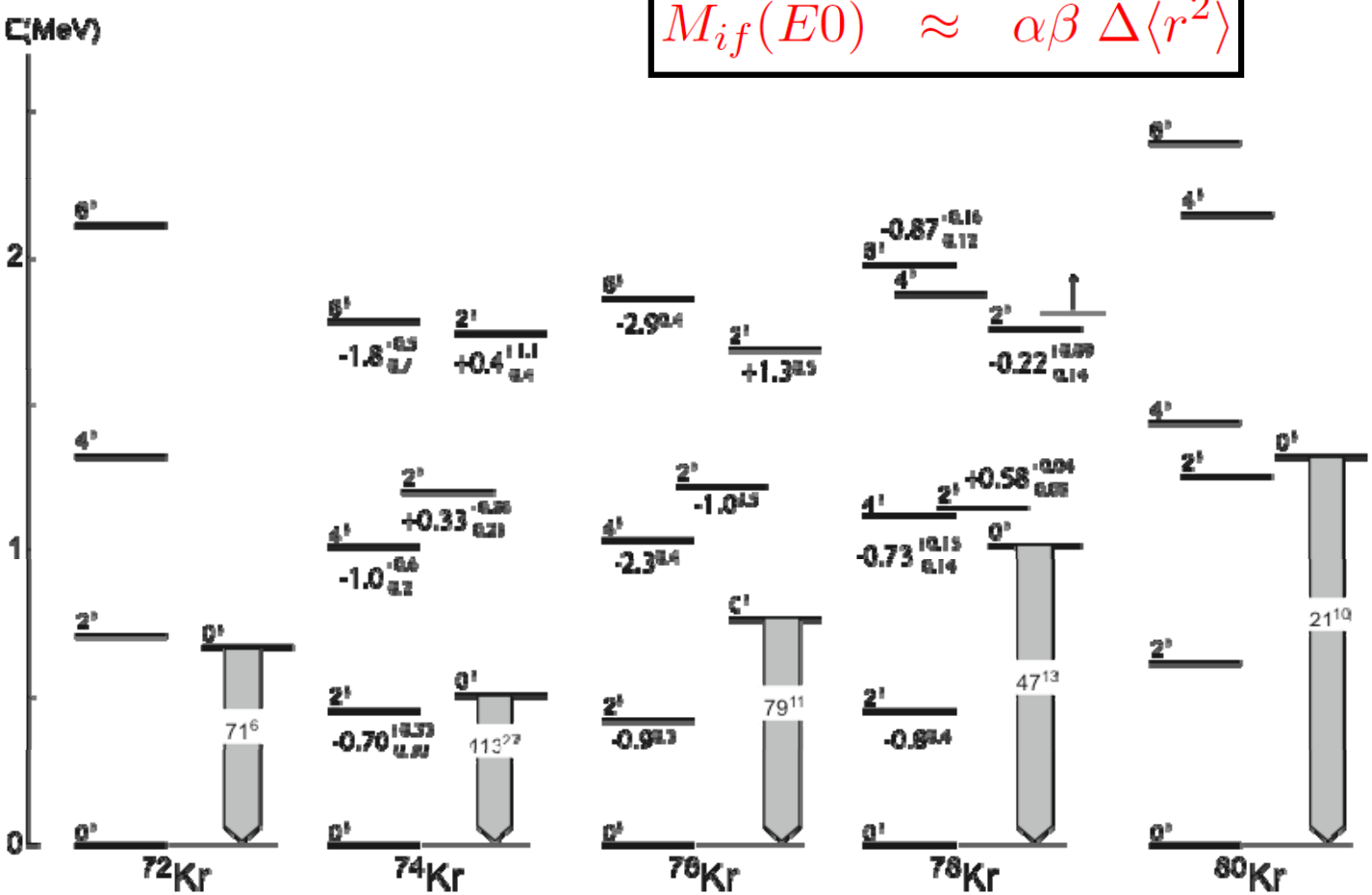
$$|i\rangle = \alpha|1\rangle + \beta|2\rangle, \quad |f\rangle = -\beta|1\rangle + \alpha|2\rangle$$

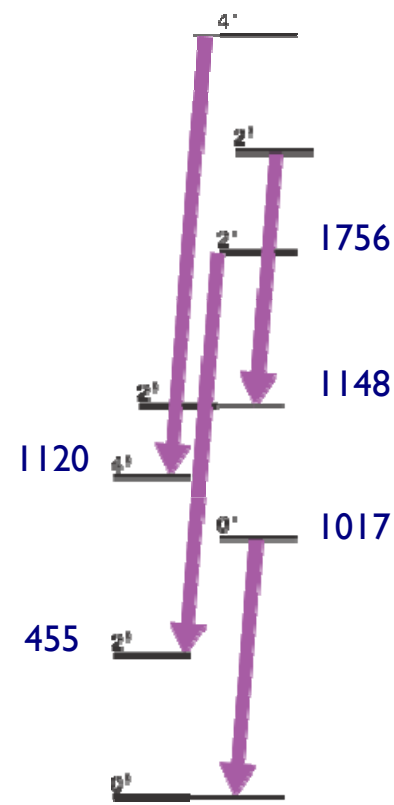
$$M_{if}(E0) = \alpha\beta\{\langle 2|m(E0)|2\rangle - \langle 1|m(E0)|1\rangle\} + (\alpha^2 - \beta^2)\langle 1|m(E0)|2\rangle$$

$$\Delta\langle r^2\rangle \equiv -\langle 1|\sum_j e_j r_j^2|1\rangle + \langle 2|\sum_j e_j r_j^2|2\rangle$$

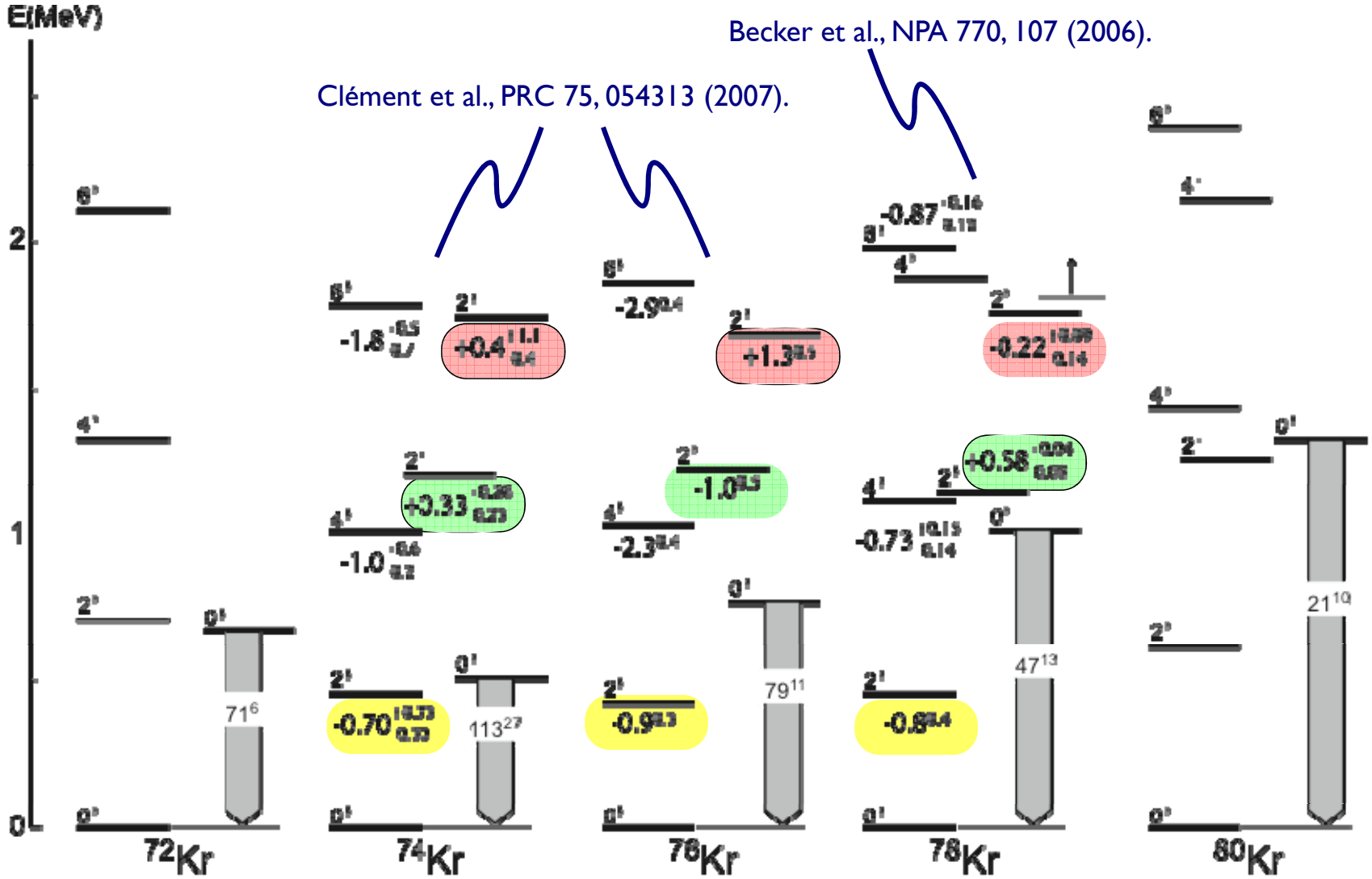
$$\boxed{M_{if}(E0) \approx \alpha\beta\,\Delta\langle r^2\rangle}$$

There should be also be *E0* transitions between $I \neq 0$ states!





Recent multi-step Coulomb excitation studies support oblate and prolate coexistence in the light krypton isotopes.

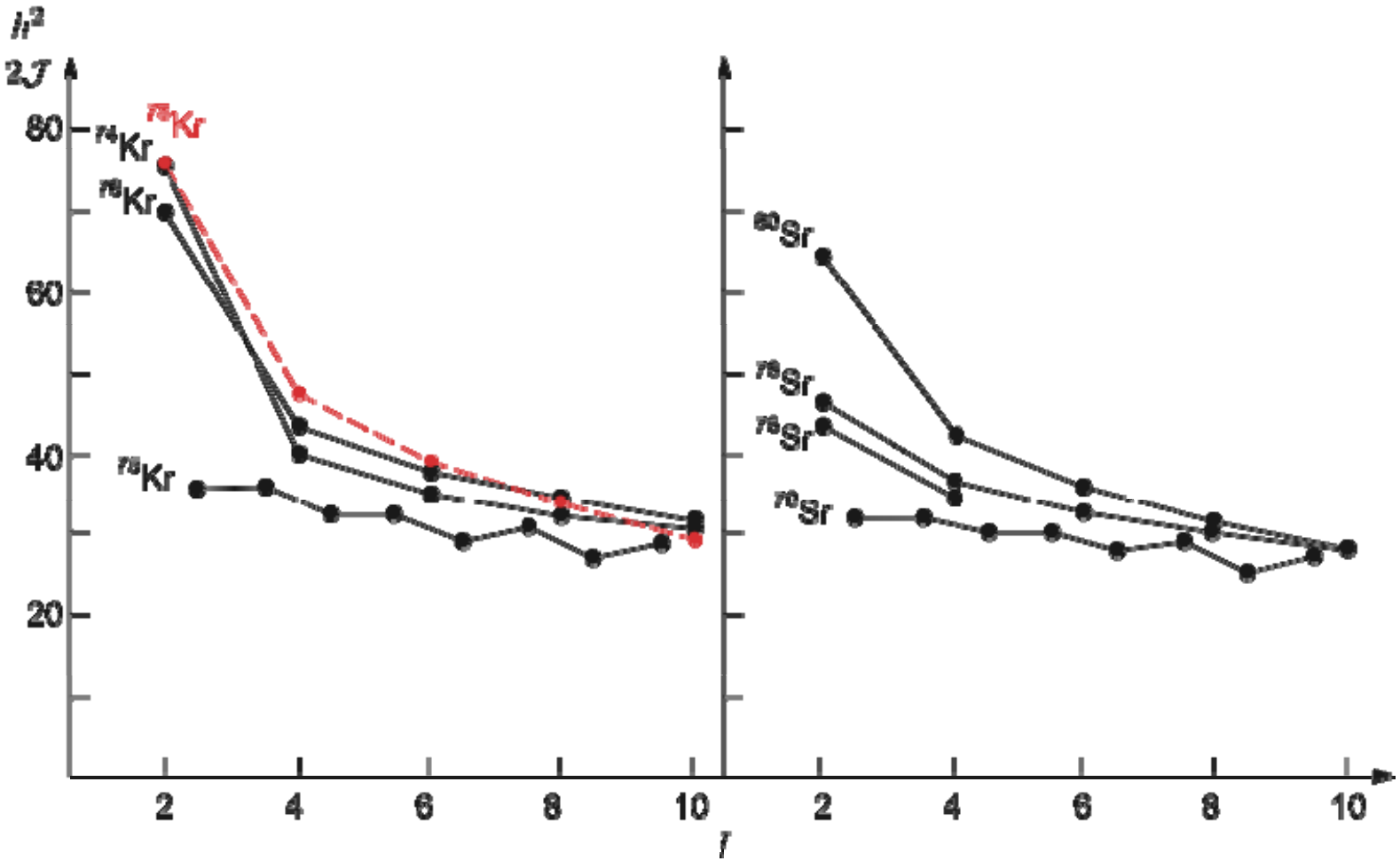


$$\langle K I_i \| \mathcal{M}(E2) \| K I_i \rangle = \sqrt{\frac{5}{16\pi}}\,(2I_i - 1)^{\frac{1}{2}}\,\langle I_i K 20 | I_i K \rangle\, e Q_0$$

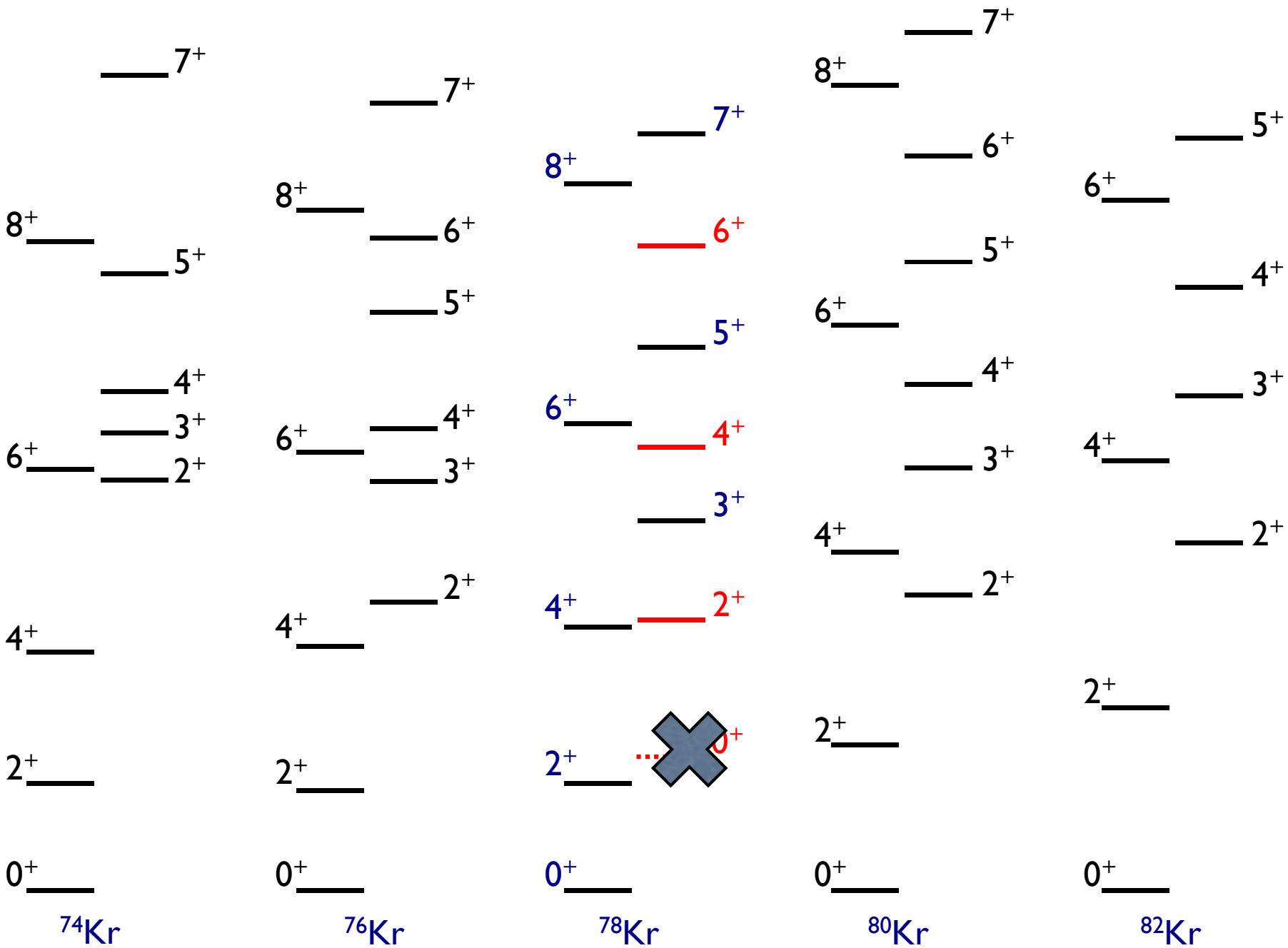
The *K*-quantum number determines sign of the Clebsch-Gordan coefficient:

$3K^2 - I(I+1) \rightarrow$ **+6** for (K=2,I=2), **-6** for (K=0,I=2)

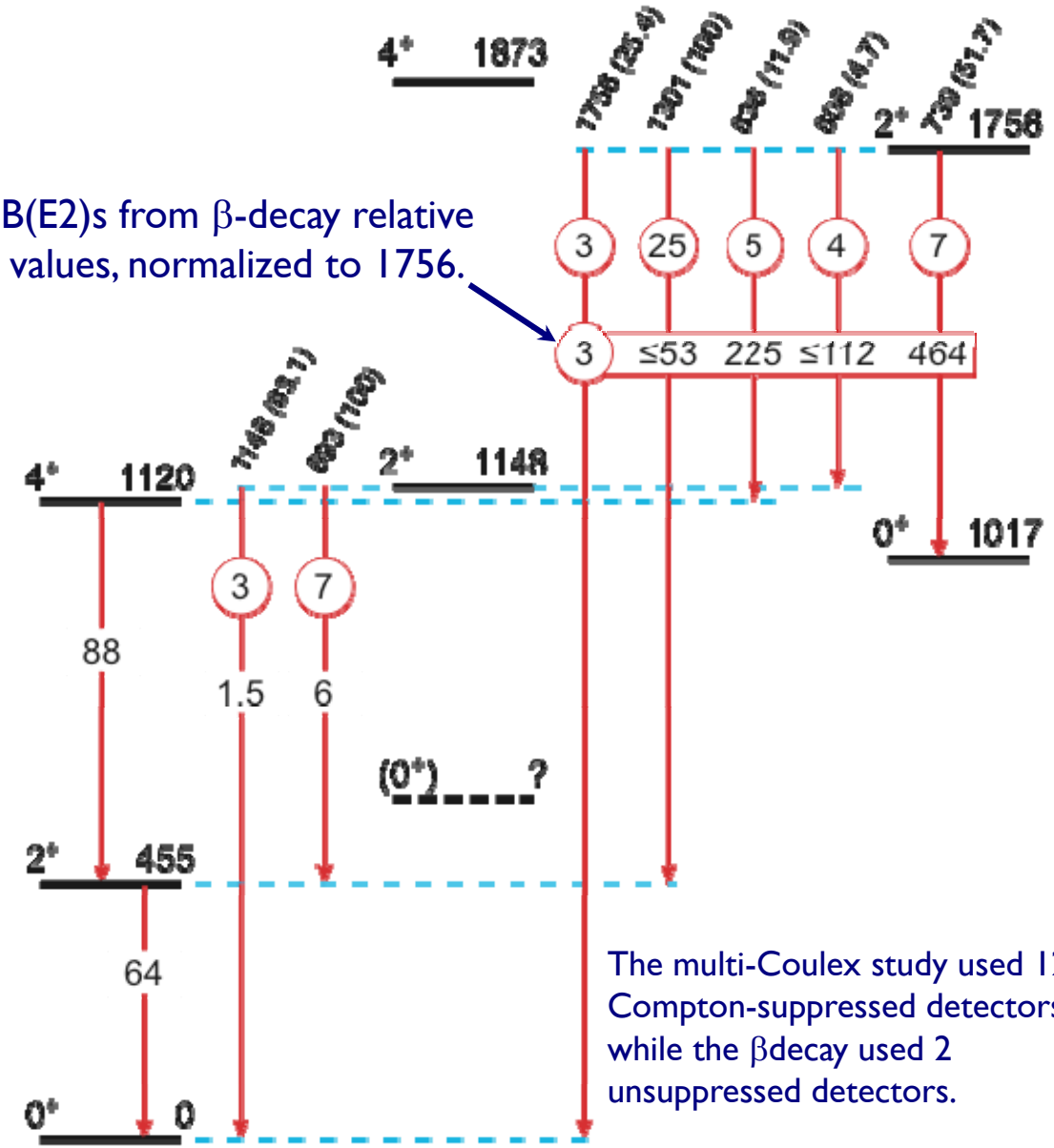
Large deviations from a constant rotational parameter at low spin indicate strong mixing between coexisting shapes.



Systematics indicate that the 1148-keV state is the bandhead of a K=2 band, not the 2^+ member of an oblate K=0 band.

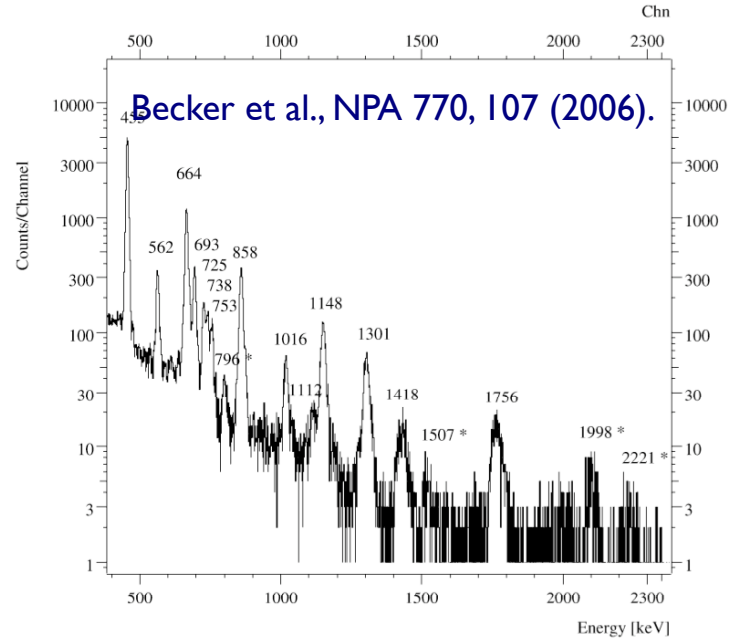


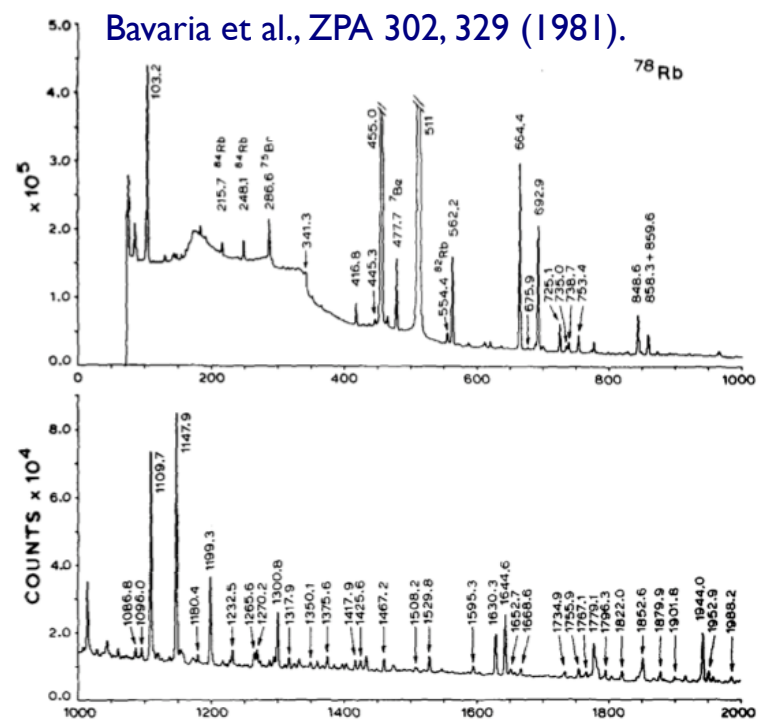
The multi-step Coulex study should provide a much cleaner picture of the structure, but the results do not agree with β decay measurements.



B(E2)s from β-decay relative values, normalized to 1756.

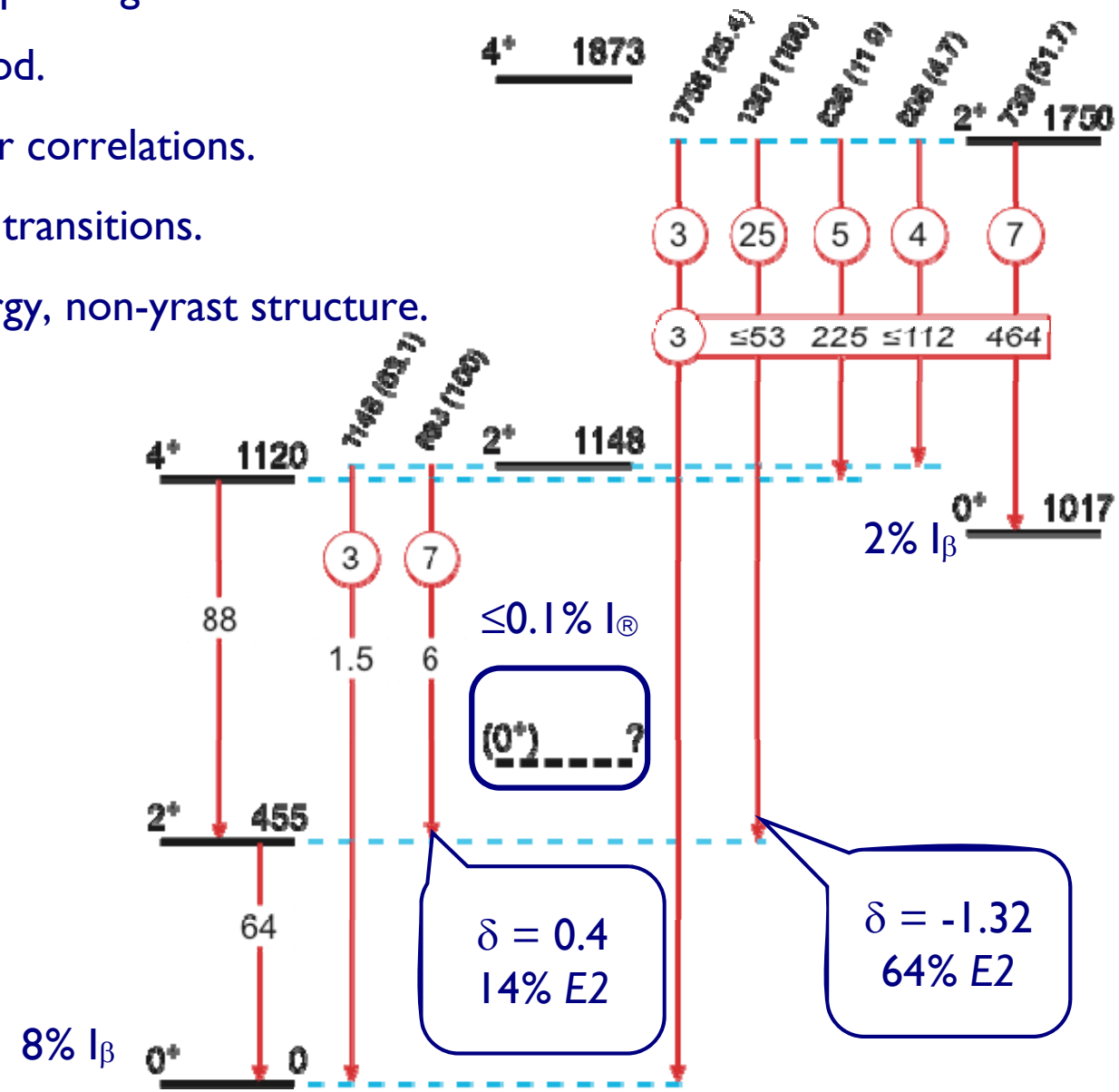
The multi-Coulex study used 12 Compton-suppressed detectors, while the βdecay used 2 unsuppressed detectors.





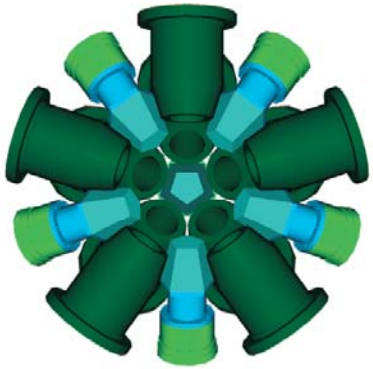
The goal of S1215 was to investigate the nature of the coexisting bands near *N=40*.

- Search for 0^+ oblate bandhead or set a stringent upper limit on its population.
- Measure B(λ) values for transitions depopulating the 1756-keV level.
- Measure α_K with normalized CE/γ method.
- Measure mixing ratios using γγ(θ) angular correlations.
- Determine ***E0* components** for $I^\pi \rightarrow I^\pi$ transitions.
- Obtain detailed information on low-energy, non-yrast structure.
- γ-γ, γ-CE, CE-CE spectroscopy.



The 8π spectrometer

8π Spectrometer at ISAC



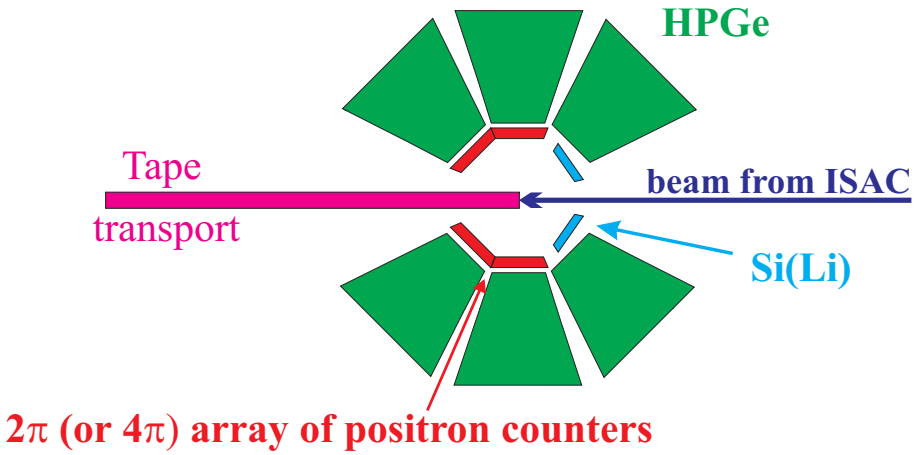
20 Compton-Suppressed HPGe detectors

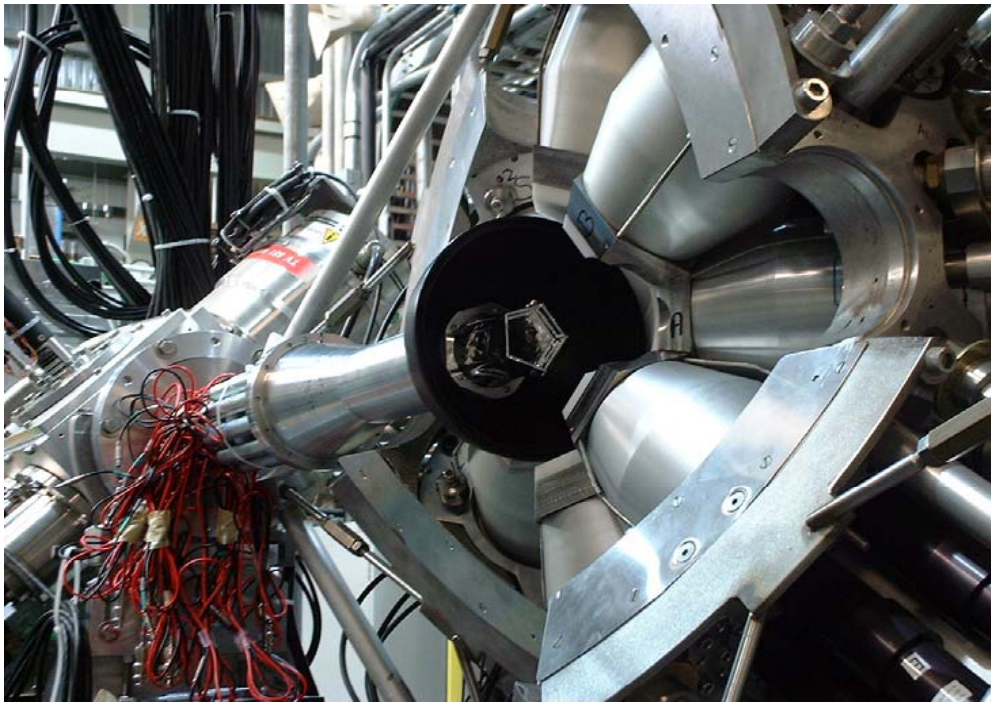
and 10 BaF2 detectors for γ-ray detection

20 plastic scintillators for β detection

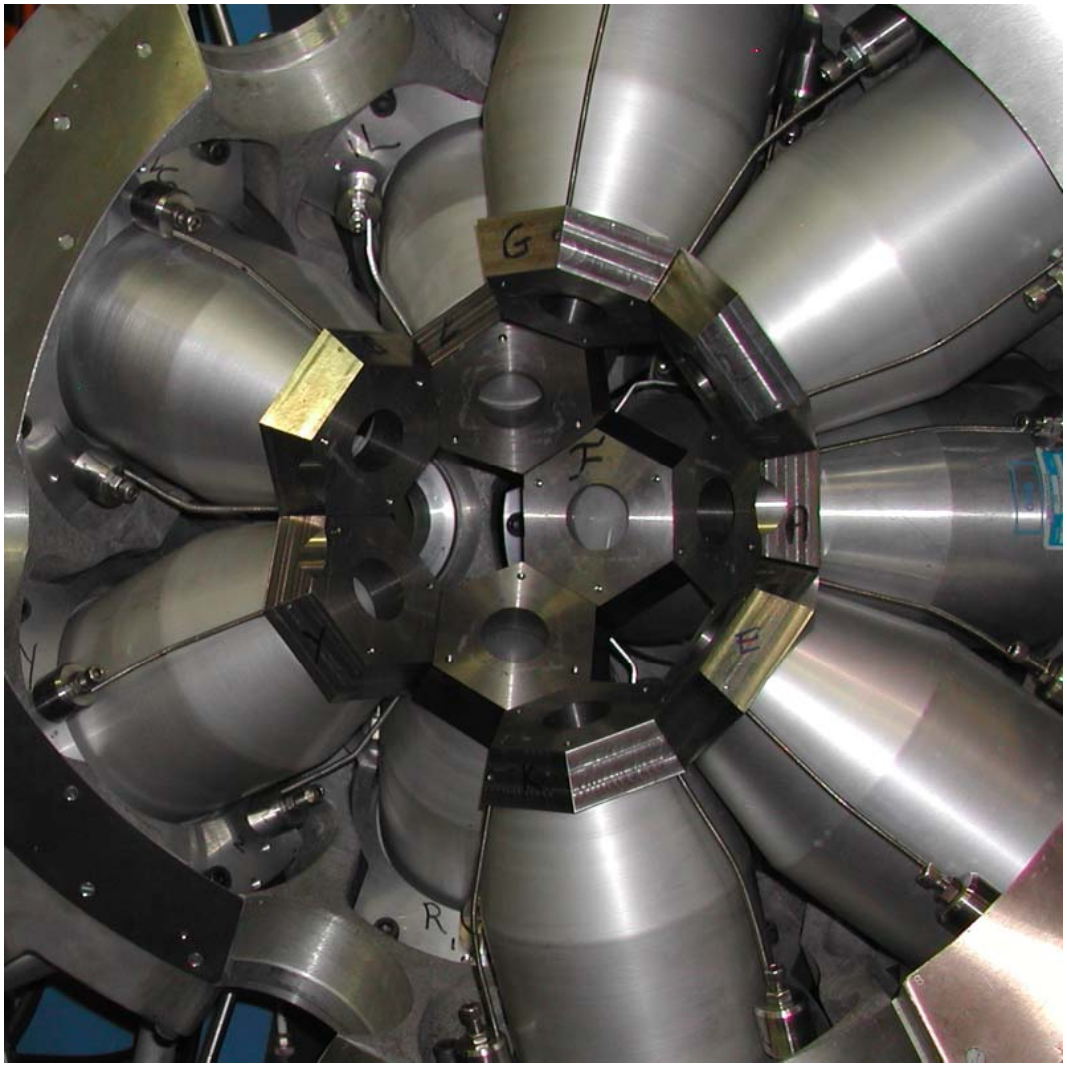
5 Si(Li) detectors for conversion electron spectroscopy

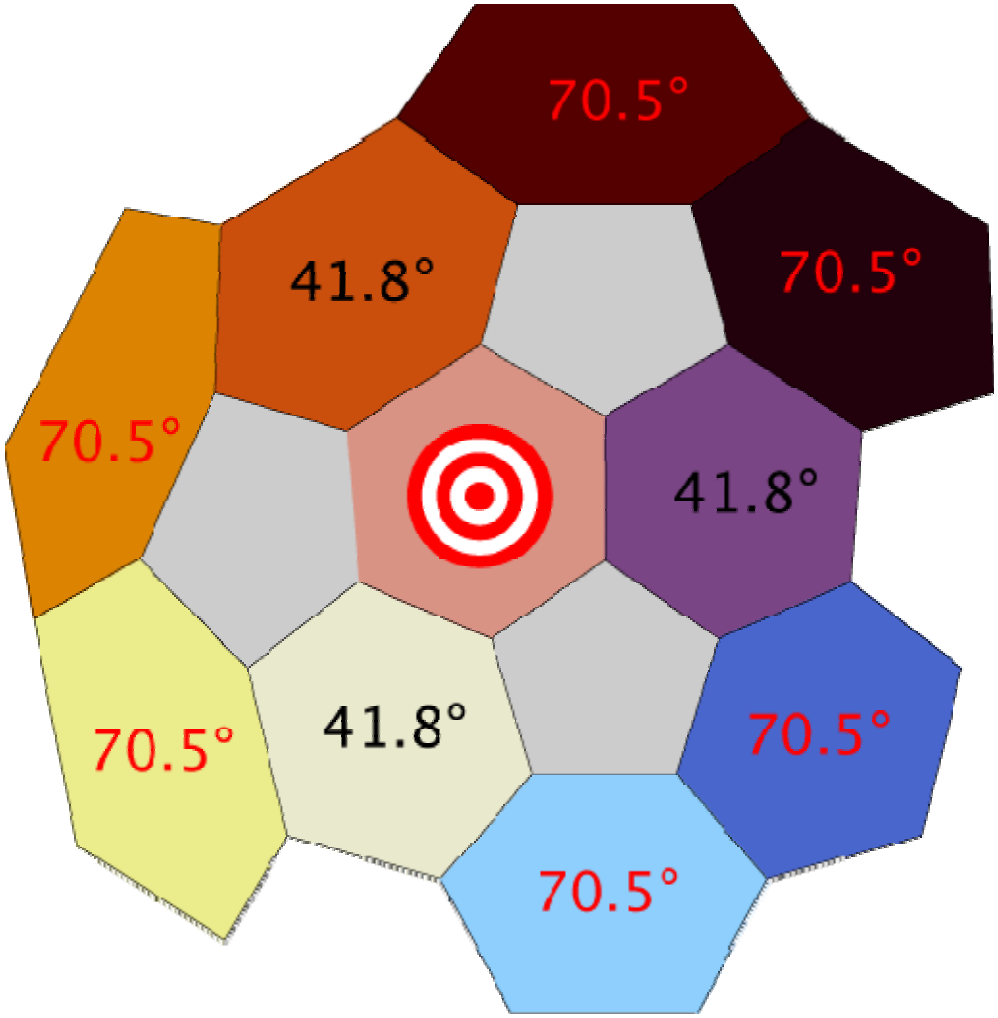
Fast, in-vacuum tape transport system





8π Spectrometer





Precision γ-γ angular correlation measurements

$W(\theta) = N[1+A_2P_2(\theta) + A_4P_4(\theta)]$

$P_2(\theta)$, $P_4(\theta)$ - Legendre polynomials

5 angles between detector pairs

41.8° (60 pairs)

70.5° (120 pairs)

109.5° (120 pairs)

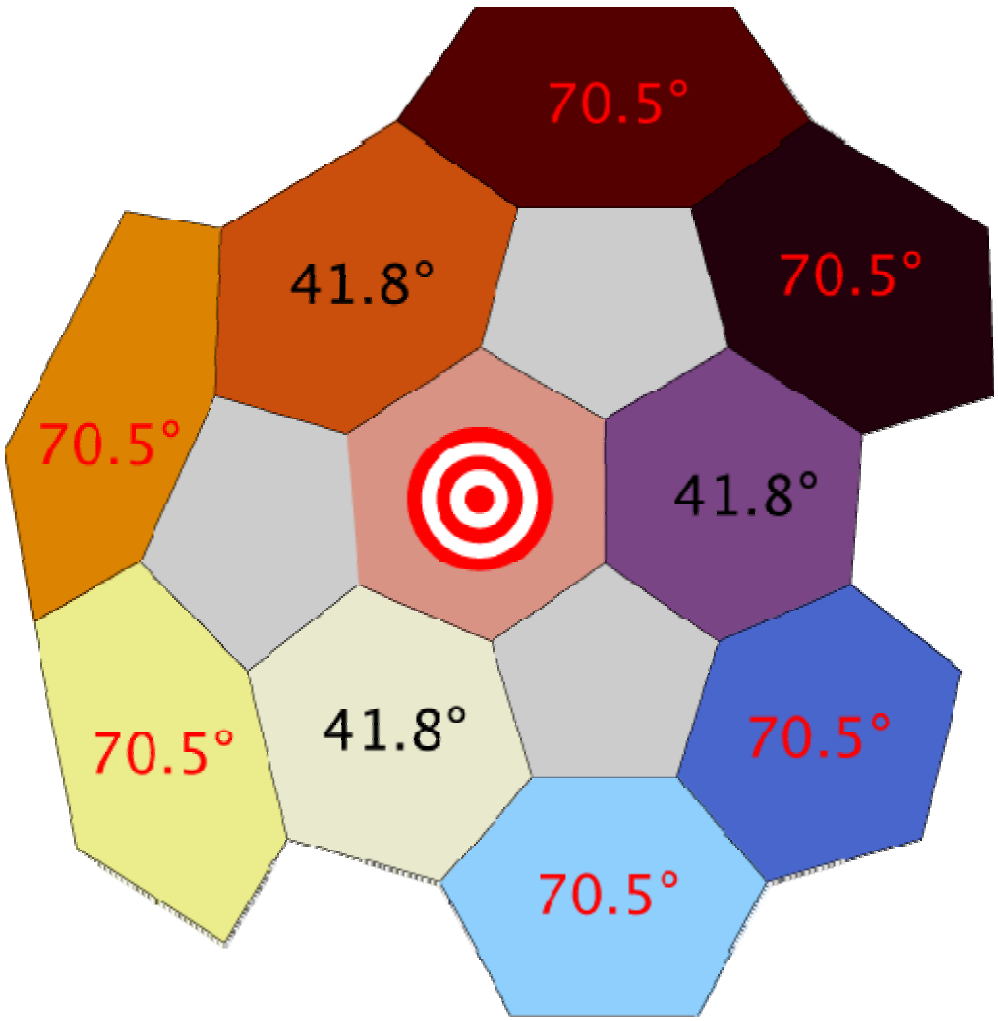
138.2° (60 pairs)

180° (20 pairs)

Small pairwise γ-γ angular distortions

4 - 2 - 0 cascade: 0.57%

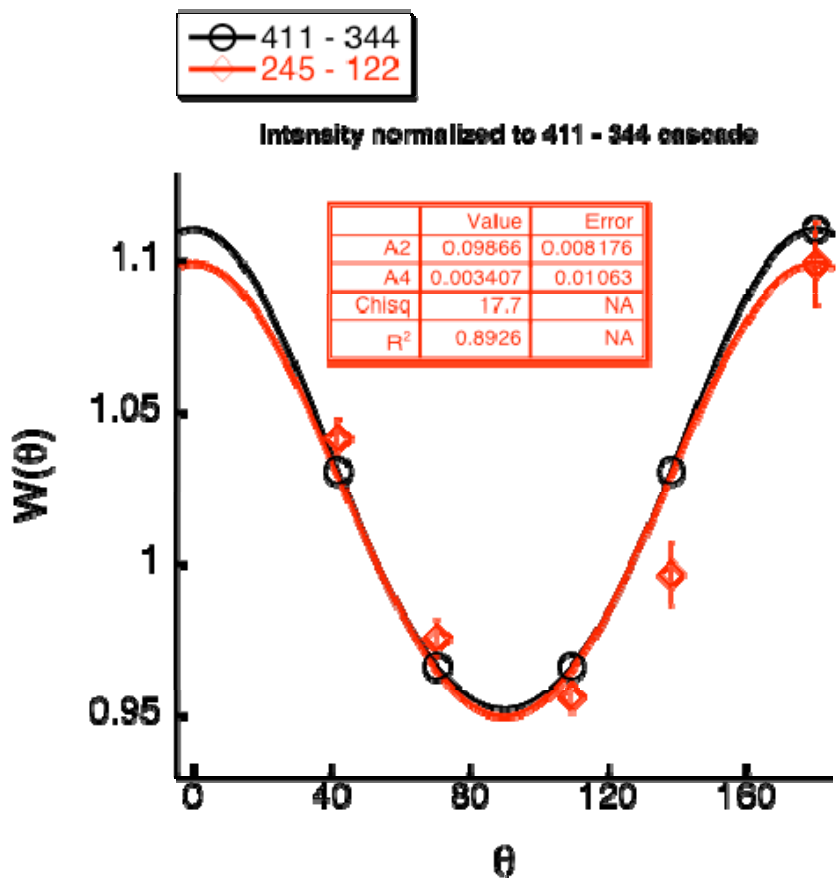
2 - 4 - 2 cascade: 1.50%



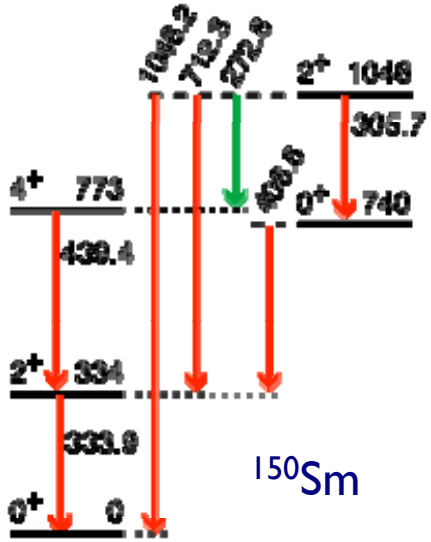
An internal normalization can be used to determine the multipolarity.

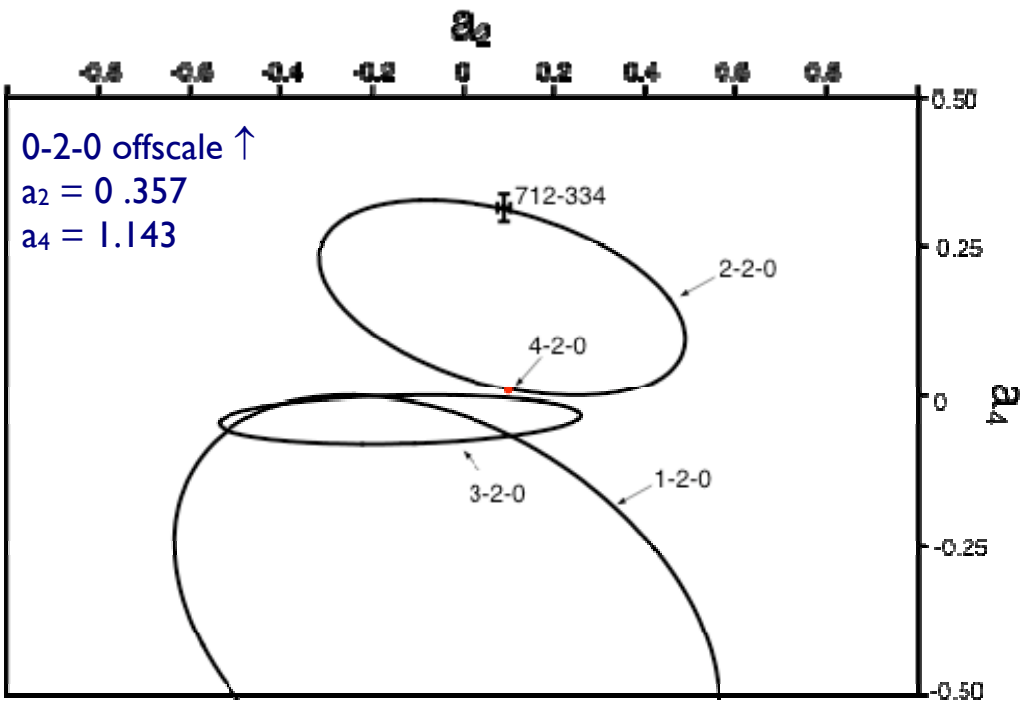
Correction factors for each angle are extracted using transitions of known multipolarity, e.g., a cascade of E2 transitions from levels of spin $4^+ \rightarrow 2^+ \rightarrow 0^+$.

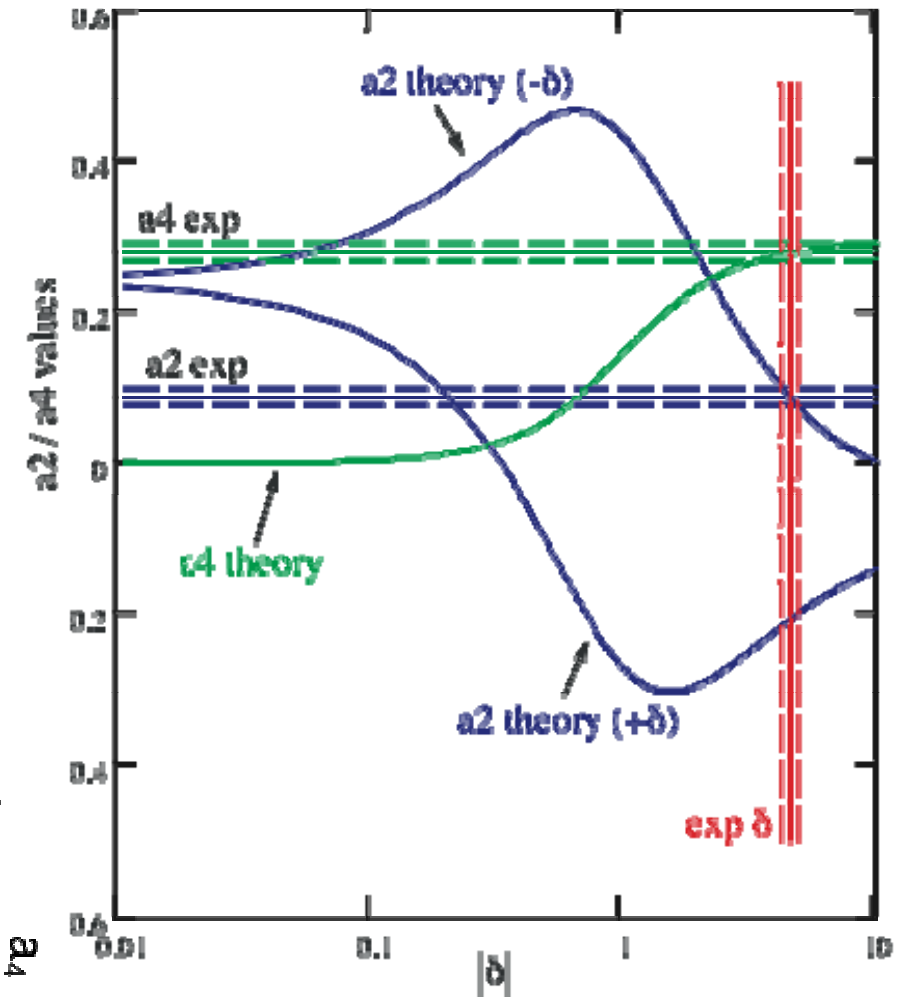
Normalized in this way, the data from ^{152}Sm closely fits the theoretical curve.



Precision γγ(θ) measurements can yield the sign of the multipole mixing ratio, δ.

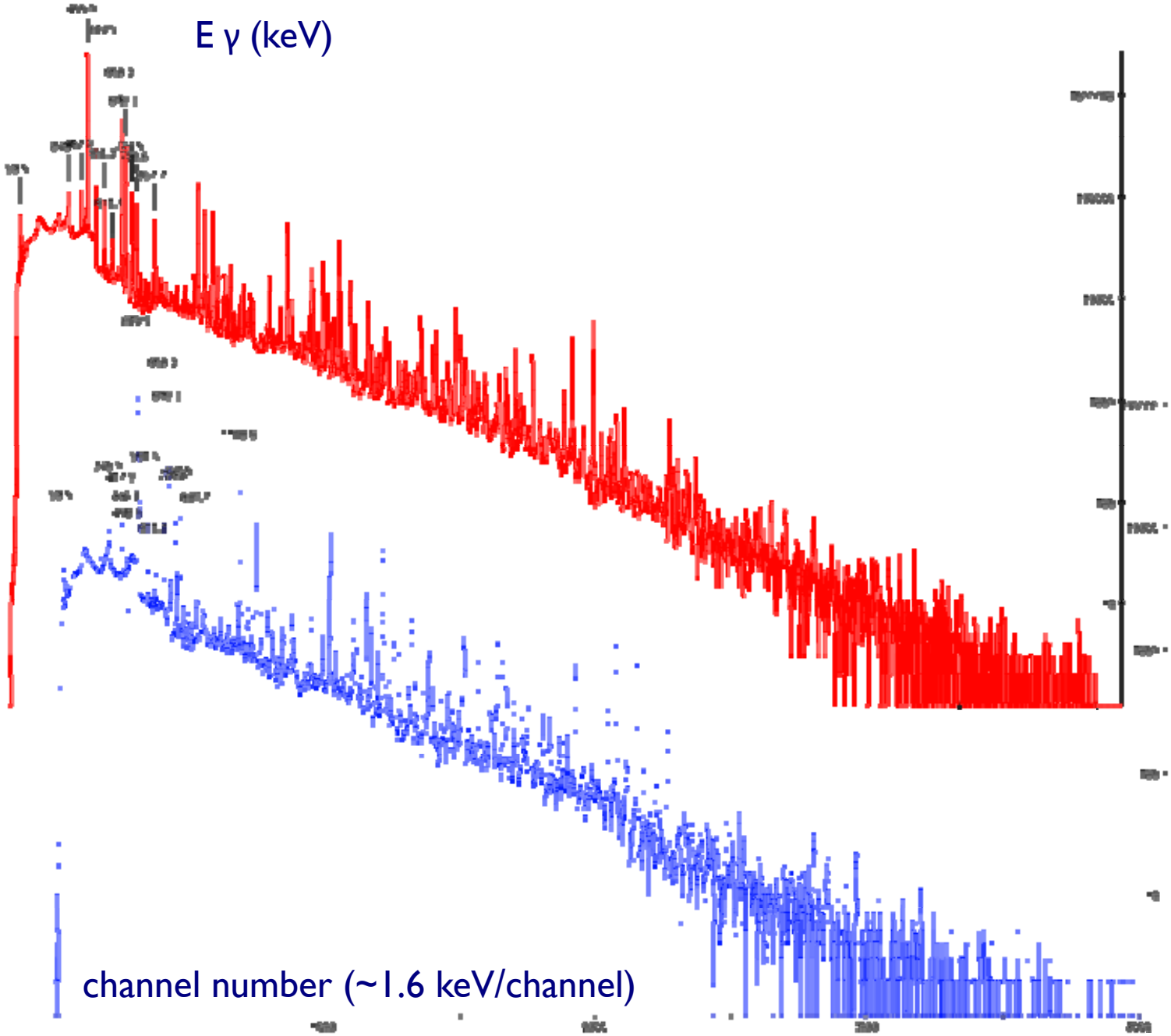






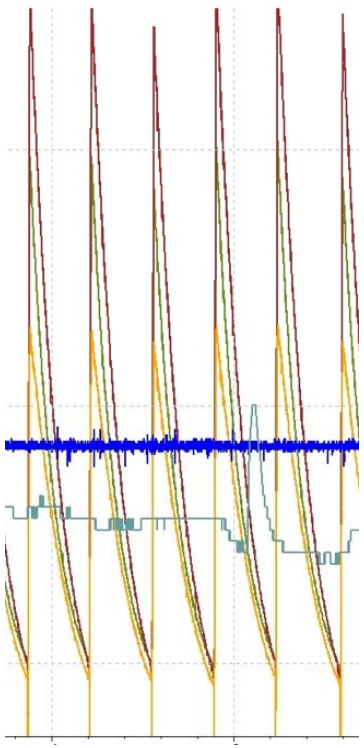
Ph. D. thesis work of P. Schmelzenbach, OSU.

The high β–decay Q value (7243 keV) leads to complex γ-ray spectra (a sign of things to come further from stability).

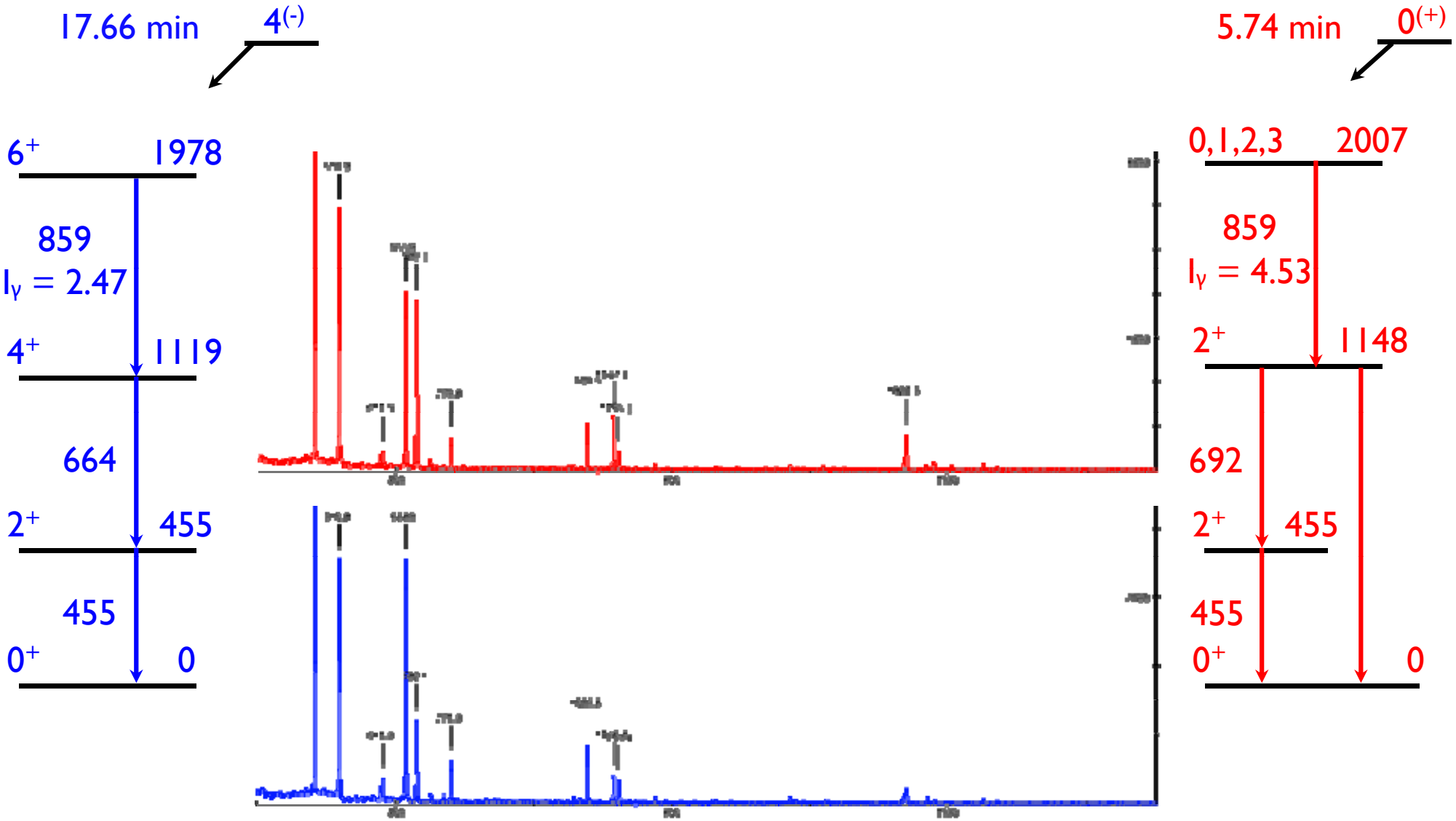


The projection of the γ-γ coincidence matrix for 12 runs (~4 hours counting) and the 455-keV γ-gated spectrum.

Sources were collected at the center of the 8π for 40 seconds and counted for 20 minutes.

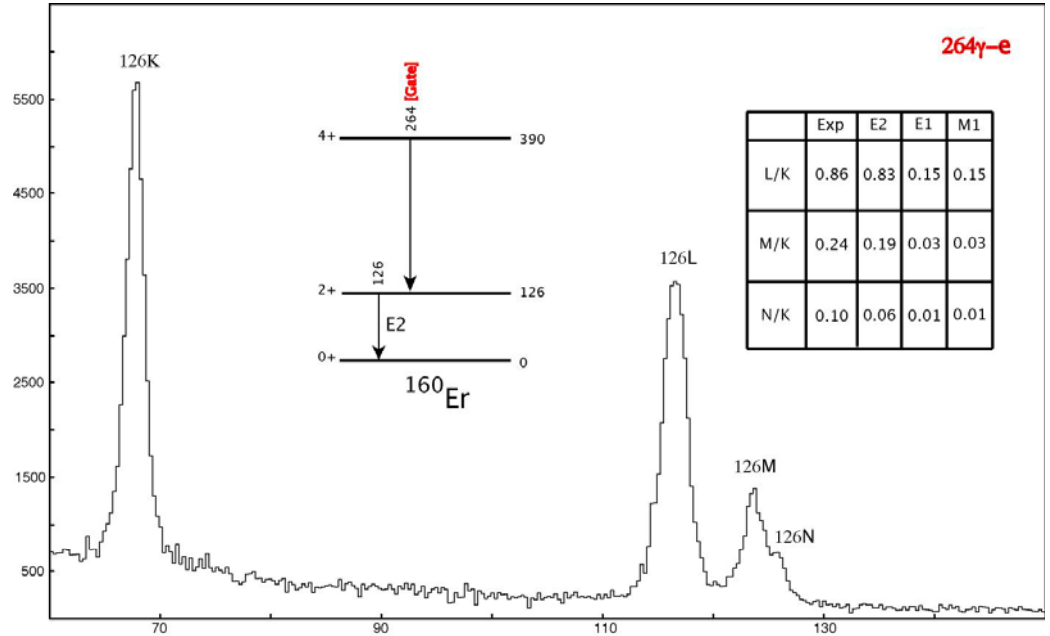


Isomer and ground-state decays were identified using the moving tape collector and varying the counting program.

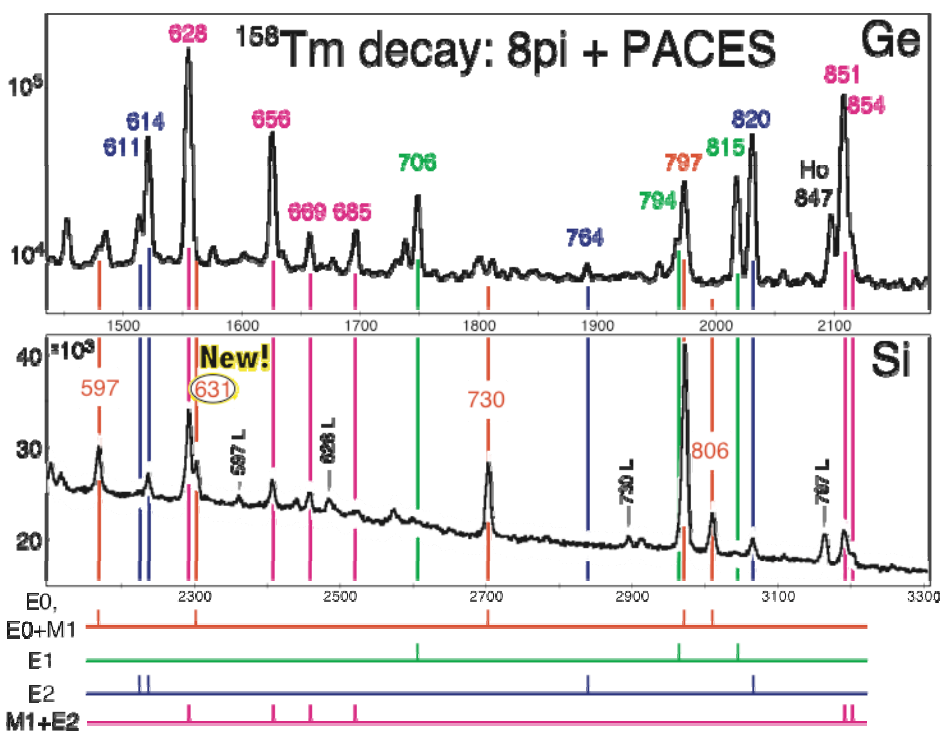


Multipolarity information is extracted from PACES and 8π spectra.

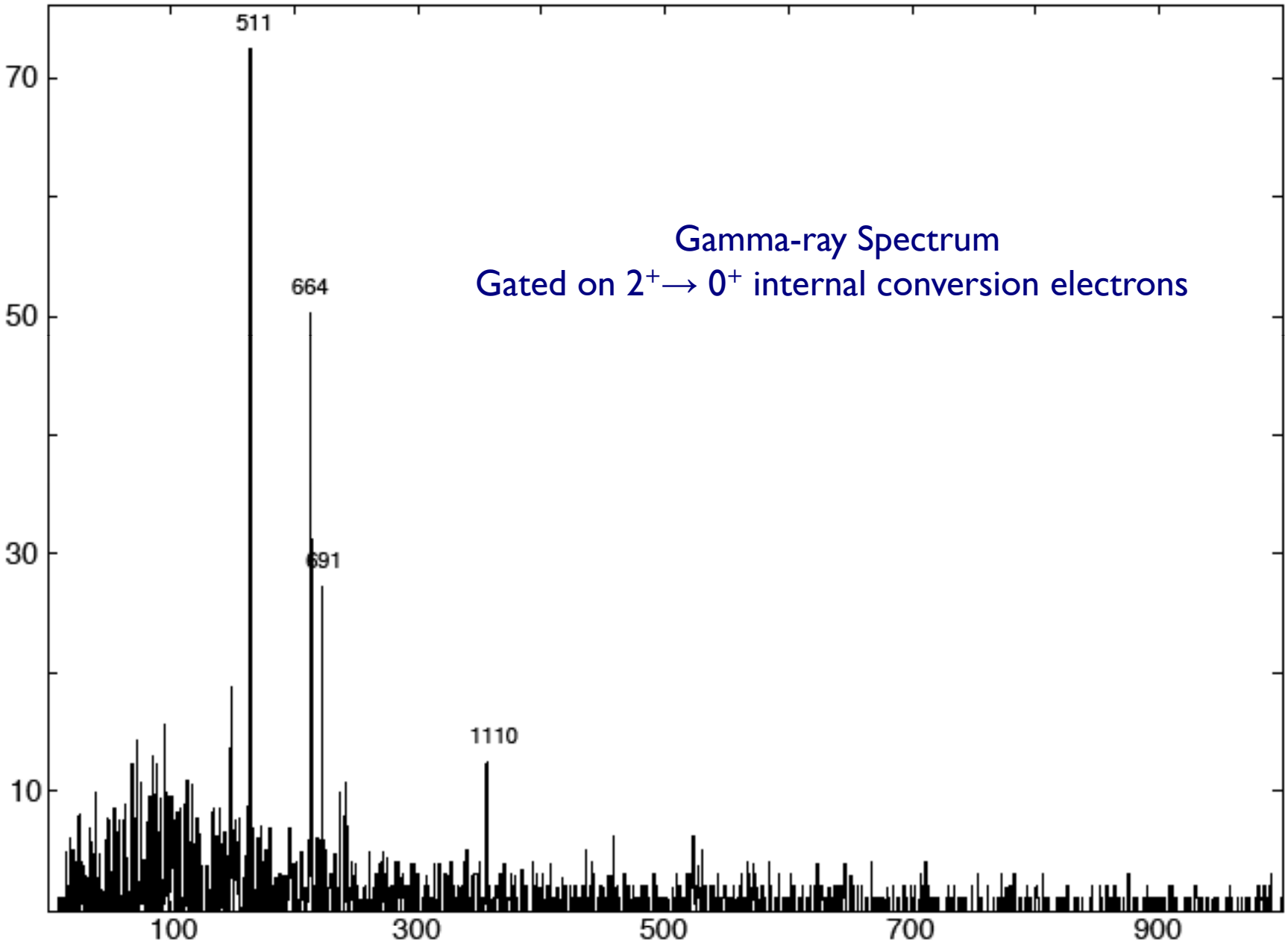
PACES, built by
E. F. Zganjar
(LSU)



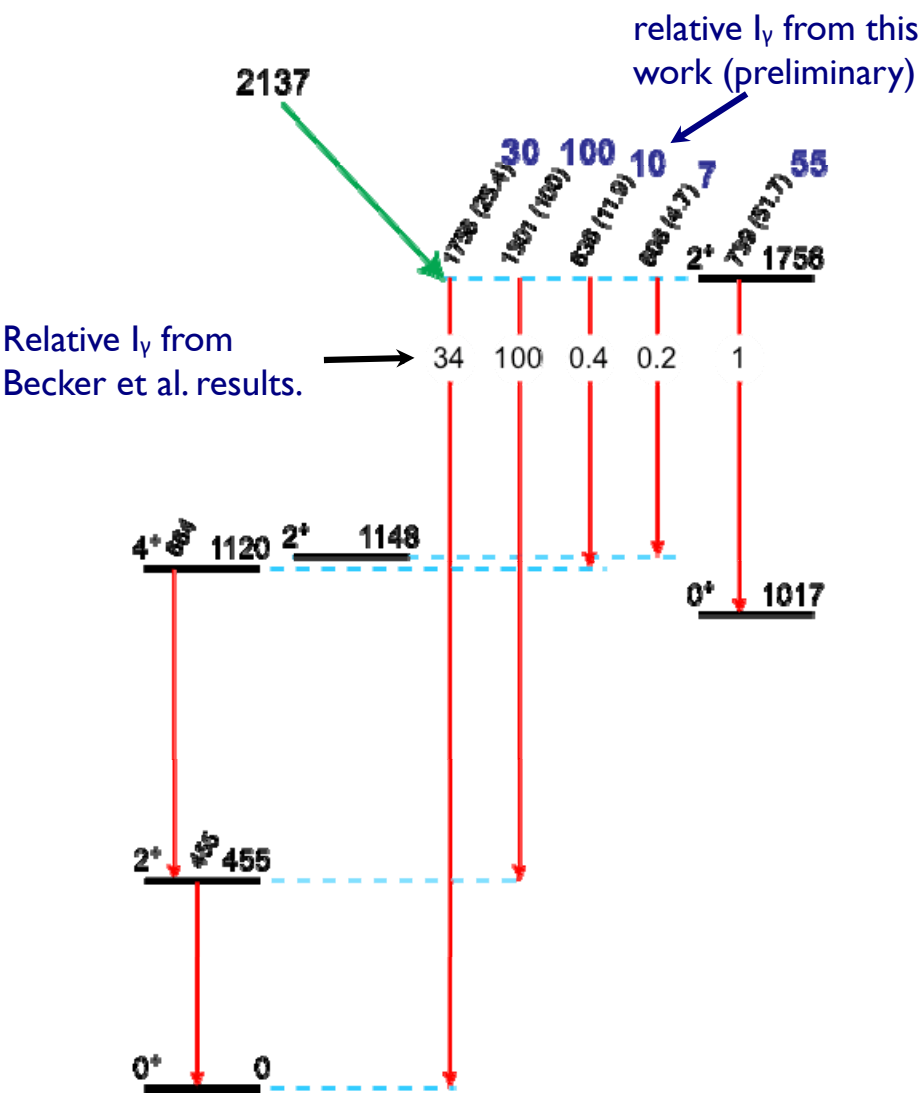
Comparing EC/γ intensity provides α_K.

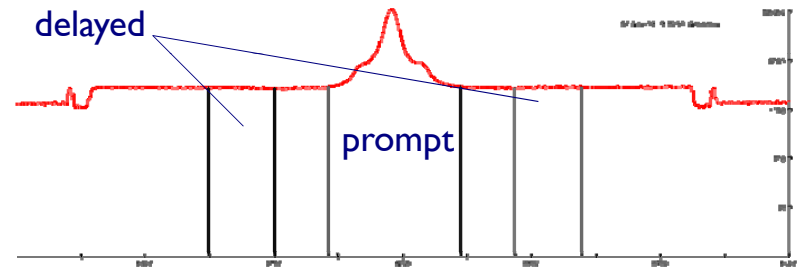


Subshell ratios provide multipolarity.
Thesis work of N. Brown, Georgia Tech


Gamma-ray Spectrum
Gated on 2+→ 0+ internal conversion electrons
511
664
691
1110
70
50
30
10
100
300
500
700
900

Coincidence spectroscopy allows us to take clean cuts on the data for very specific interests.





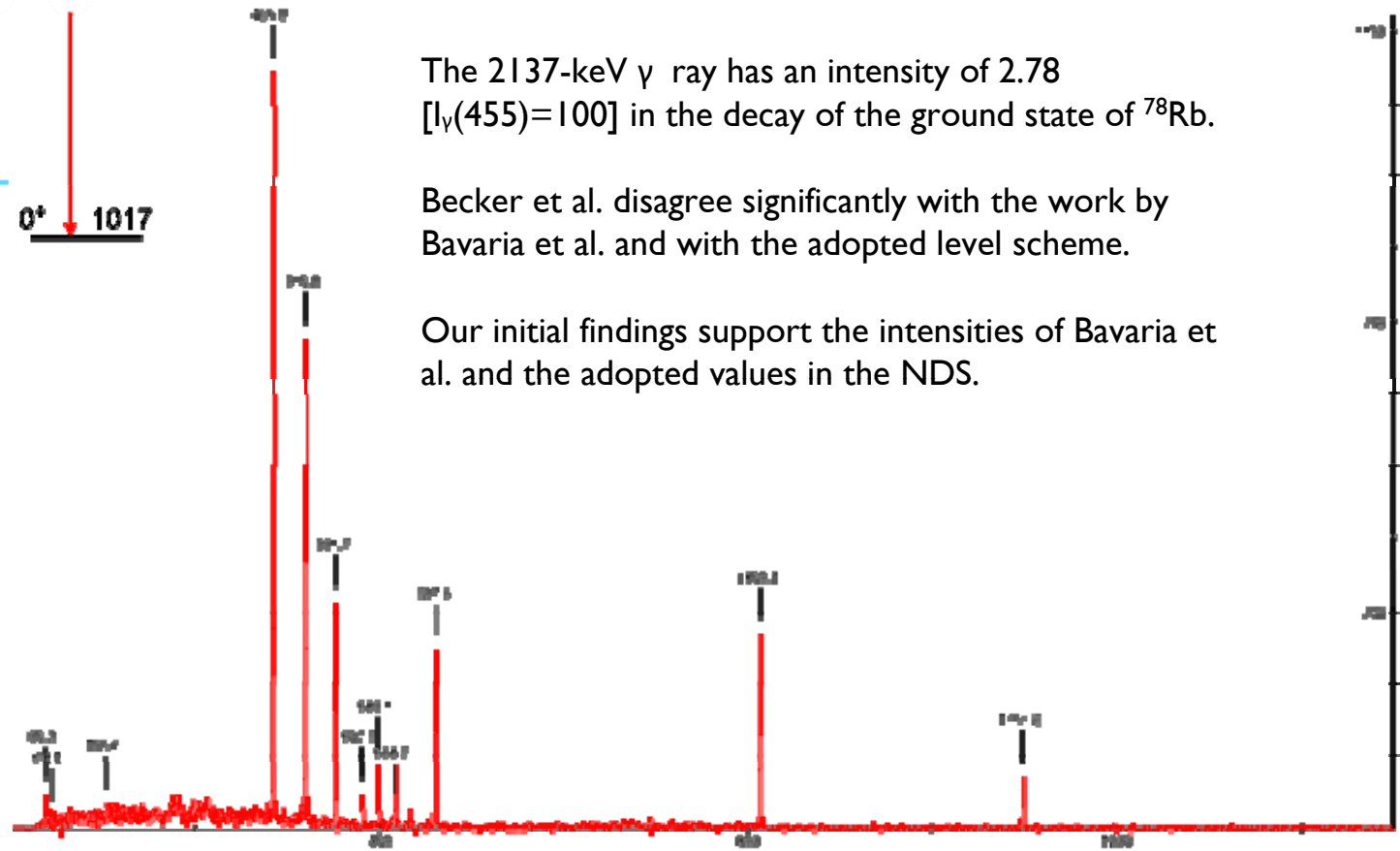
TDC time difference

Key requirements are Compton suppression and removal of random coincidences.

The 2137-keV γ ray has an intensity of 2.78 [I_γ(455)=100] in the decay of the ground state of ^{78}Rb.

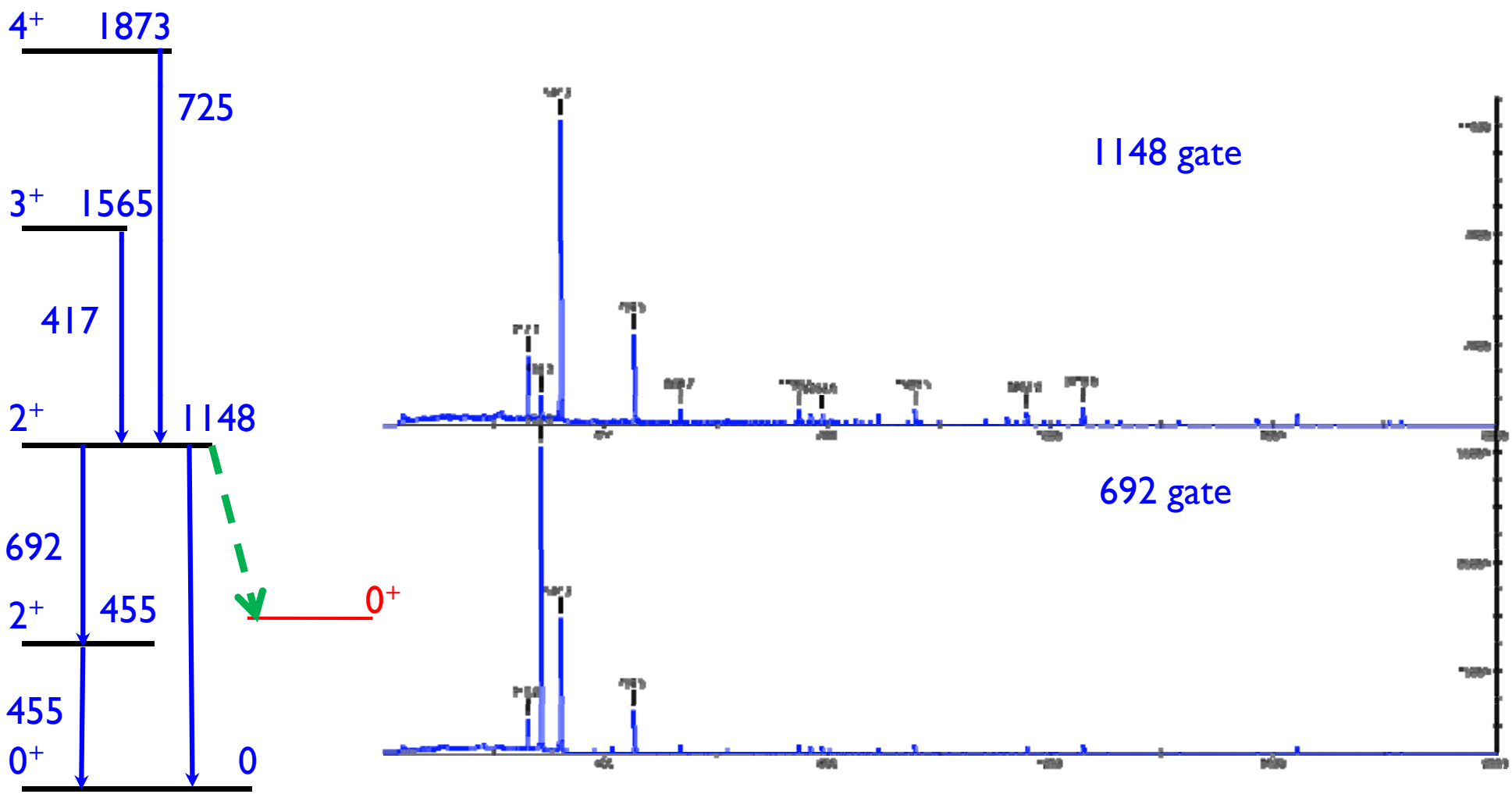
Becker et al. disagree significantly with the work by Bavaria et al. and with the adopted level scheme.

Our initial findings support the intensities of Bavaria et al. and the adopted values in the NDS.

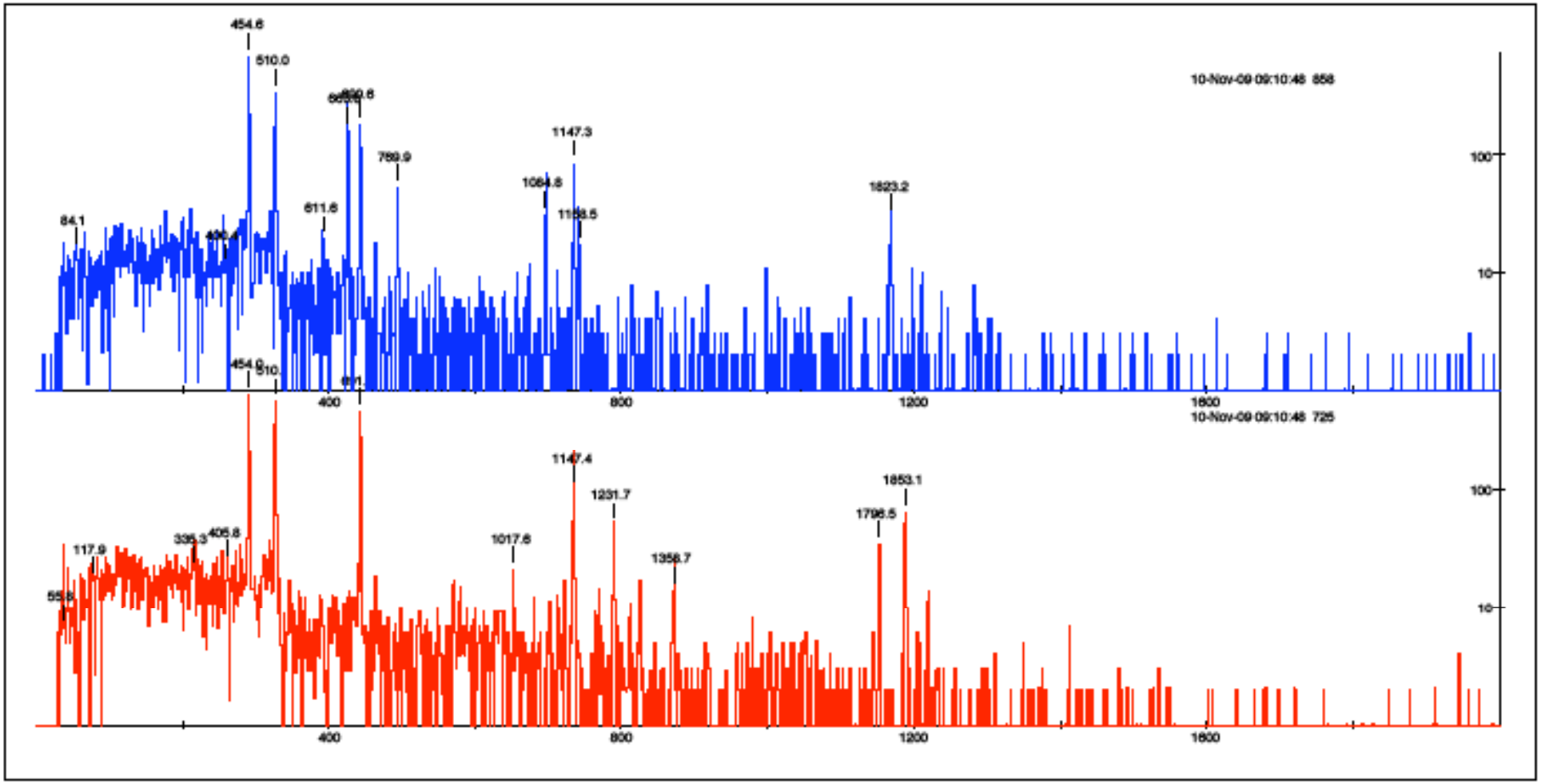


2137-keV γ-gated γ-ray spectrum

The nature of the 1148-keV state (K=0 or K=2) will be determined from its band properties and detailed decay branching measurements.



Gates on gamma-rays feeding the 1148-keV 2^+ level



Summary

- High-statistics data (~1 TB total) were collected for the decay of ^{78g,m}Rb into ^{78}Kr.
- Data analysis is underway on γ-γ, γ-e, e-e coincidence spectra (sorting continues).
- From these detailed spectroscopic measurements, we should:

  identify the suggested, but yet to be identified 0^+ oblate bandhead (or set a stringent upper limit on its population).

  determine B(λ) values for many transitions.

  determine E0 components for $I^\pi \rightarrow I^\pi$ transitions.

  perform detailed spectroscopy of the low-energy, non-yrast structure of ^{78}Kr.