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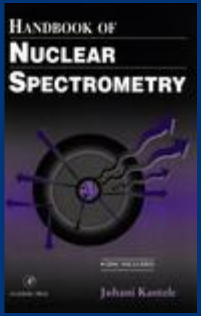
What we can learn from E0 transitions and how?



T. Kibèdi (ANU)

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Outline

Outline

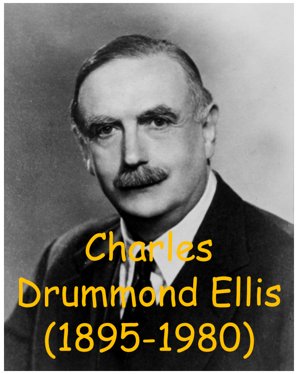
- Emission of E0 transitions
- New tabulation of Ω_{CE}(E0)
- e-γ angular correlations of E0+M1+E2 transitions
- E0 transitions and the evolution of shape co-existence
  - W-Os-Pt-Hg (Z=82, N=126)
  - Fe (Z=N=28)
  - 12C (Z=N=8)
- Monopole transitions in atomic nuclei – new review

E0 transitions - 75 years on

The Absolute Intensities and Internal Conversion Coefficients of the γ-Rays of Radium B and Radium C.

By C. D. Ellis, F.R.S., Fellow of Trinity College, Cambridge, and G. H. Aston, M.A., B.Sc., Trinity Hall, Cambridge.

Proc. Roy. Soc. (London) **129** (1931) 180-207



Charles Drummond Ellis (1895-1980)

Highly converted K, L1, M1 lines corresponding to 1.426 MeV transition

1.4155 MeV E0 in ^{214}Po

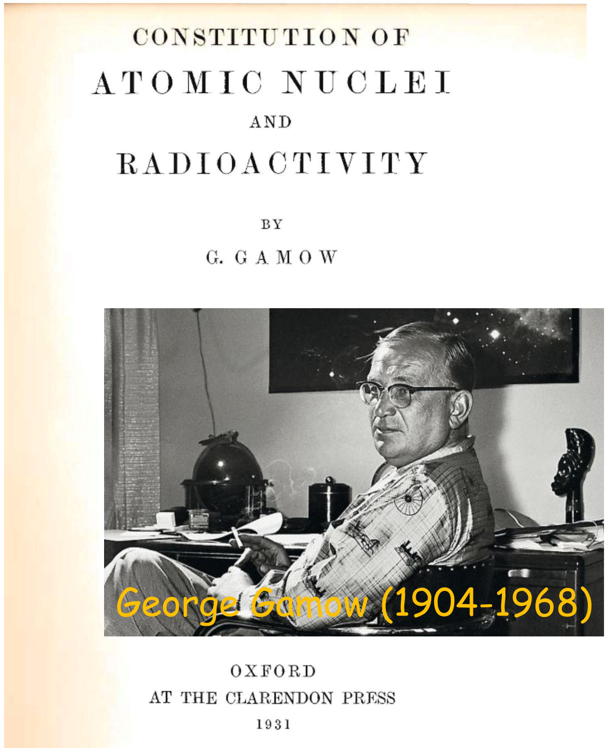
$T_{1/2}$=99(3) ps; ρ^2=0.0013(2)

6.05 MeV E0 pairs in ^{16}O

Fowler & Lauritsen, Phys. Rev. 56 (1939) 840

6.05 MeV E0 (^{16}O) E1+M1 double photon

Gorodetzky et al., Phys. Rev. Lett. 7 (1961) 170



CONSTITUTION OF
ATOMIC NUCLEI
AND
RADIOACTIVITY

BY
G. GAMOW

George Gamow (1904-1968)

OXFORD
AT THE CLARENDON PRESS
1931

1931:
0 → 0 transition:
quantum transition forbidden

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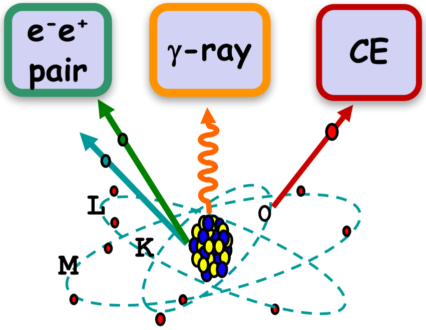
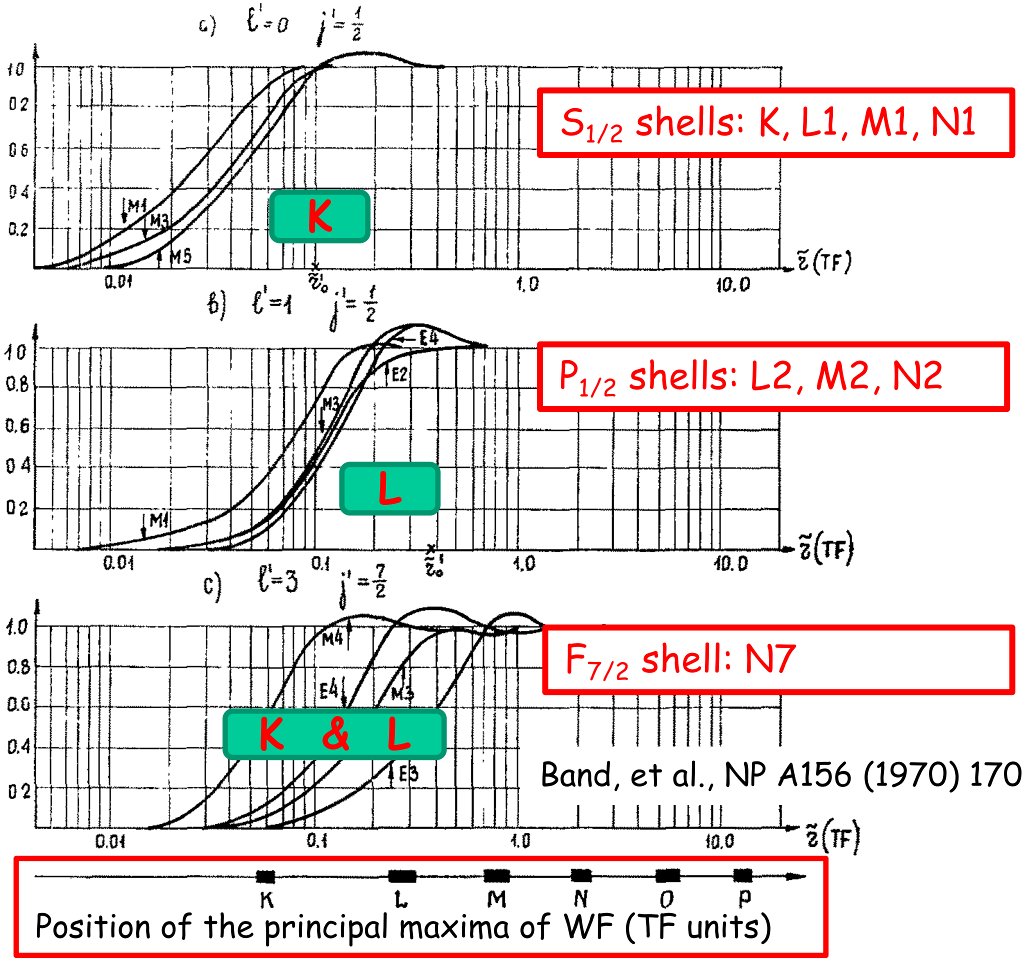
Formation of E0 transitions



- "Normal conversion" (L>0):
  - ☐ Small contribution from inside the nucleus
  - ☐ Inner part of the atom (K-L-M shells)

$\alpha^{\lambda L}(r)/\alpha^{\lambda L}$



$S_{1/2}$ shells: K, L1, M1, N1

$P_{1/2}$ shells: L2, M2, N2

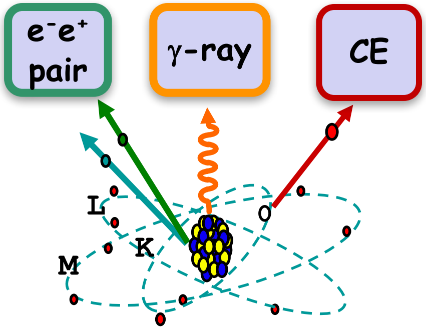
$F_{7/2}$ shell: N7

Band, et al., NP A156 (1970) 170

Position of the principal maxima of WF (TF units)

- E0 conversion electrons:
  - ☐ Monopole potential **localised inside the nucleus**
  - ☐ Point nucleus approx.: $W_{E0} \Rightarrow$ vanishes
  - ☐ Purely penetration effect

E0 transitions



Transition probability

$$W_T = W_\gamma + W_{CE} + W_\pi$$

Conversion coefficient

$$\alpha_{ce,\pi} = W_{ce,\pi} / W_\gamma$$

CE & π

$$W_{ce,\pi} = W_\gamma \times \alpha_{ce,\pi}$$

E0

$$W_{ce,\pi} = \rho^2(0^+ \rightarrow 0^+) \times \Omega_{ce,\pi}(Z,\kappa)$$

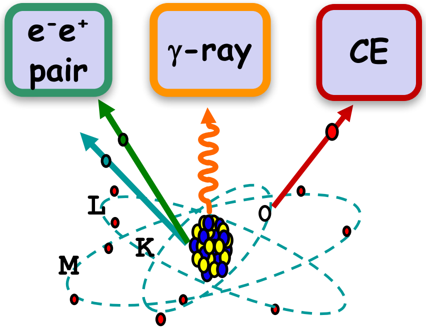
Monopole strength parameter

$$\rho = \frac{\langle 0_f^+ | \sum e_j r_j^2 | 0_i^+ \rangle}{eR^2} = \frac{\langle 0_f^+ | m(E0) | 0_i^+ \rangle}{eR^2}$$

Reduced transition probability

$$B(E0) = e^2 R^4 \rho^2$$

E0 transitions



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E0

$$W_{ce,\pi} = \rho^2(0^+ \rightarrow 0^+) \times \Omega_{ce,\pi}(Z,\kappa)$$

nuclear

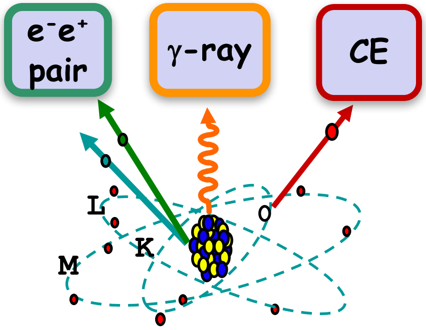
atomic

Separation is less complete!

Piet Van Isacker (GANIL) talk on Monday

$$\rho = \sum_{k\in\text{protons}}^{Z} \langle f | \boxed{\left(\frac{r_k}{R}\right)^2 - \sigma\left(\frac{r_k}{R}\right)^4 + \cdots} | i \rangle \quad \left(R = r_0 A^{1/3}, r_0 = 1.2\ \text{fm}\right)$$

E0 transitions



Transition probability

$$W_T = W_\gamma + W_{CE} + W_\pi$$

Conversion Coefficient

$$\alpha_{ce,\pi} = W_{ce,\pi} / W_\gamma$$

CE & π

$$W_{ce,\pi} = W_\gamma \times \alpha_{ce,\pi}$$

E0

$$W_{ce,\pi} = \rho^2(0^+ \rightarrow 0^+) \times \Omega_{ce,\pi}(Z,\kappa)$$

nuclear

atomic

$L \neq 0$: W_γ and $W_{ce,\pi}$

$L=0$ i.e. E0: only $W_{ce,\pi}$!

Need to measure electrons and/or electron-positron pairs

Ω(E0) - theory

- $\Omega_{\kappa,\pi}(E0) \sim I_{\kappa,\pi}(E0)$
- Only ratios of $\Omega_{\kappa,\pi}(E0)$ could be measured
  - K/π
  - K/L, K/LM, K/MN
  - L/M

New Ω_{CE} calculations

Takahe (Jackson Dowie, ANU)

- Modified version of the CATAR code (Puli & Raff, 1975)
- Relativistic Hartree-Fock-Slater atomic model
- Sliv`s surface current model
- Directional & polarization particle parameters
- Penetration parameters
- Ω_{CE} electronic factors
- Z up to 126

$S_{1/2}$, $P_{1/2}$ and $P_{3/2}$ shells only

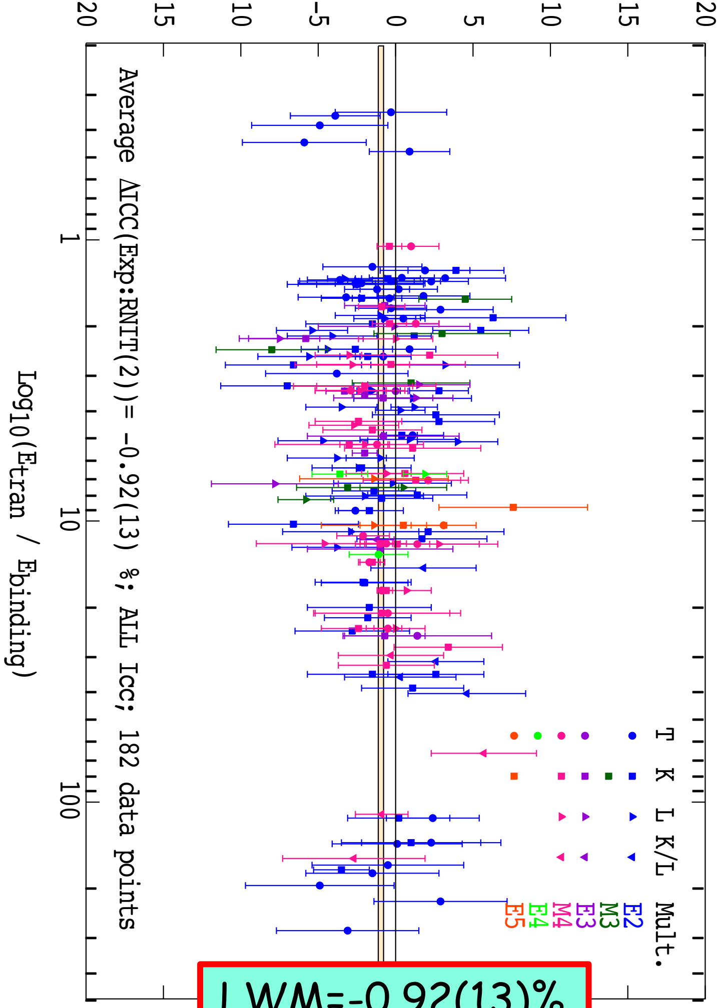
Ω_{CE}(E0), Mo (Z=42) 1000 keV

	Takahe (2017)	**Bell et al. (1972)**	**Hager & Seltzer (1968)**
K	1.454E+9	1.459E+9	1.438E+9
L1	1.629E+8	1.574E+8	1.611E+8
L2	1.358E+6	1.152E+6	1.346E+6
M1	2.913E+7		
M2	2.566E+5		
N1	4.983E+6		
N2	3.788E+4		
O1	3.807E+5		

Ω(E0) - how good are they?

BrIcc

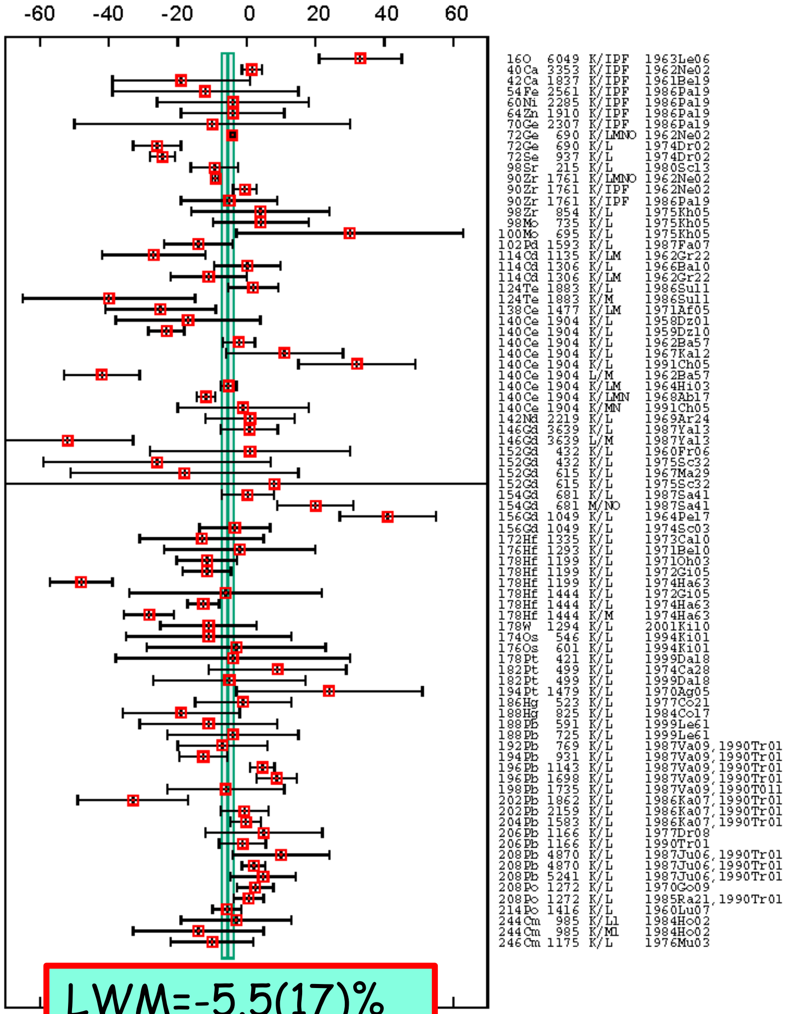
Experiment Vs. Theory
precision ICC



LWM=-0.92(13)%

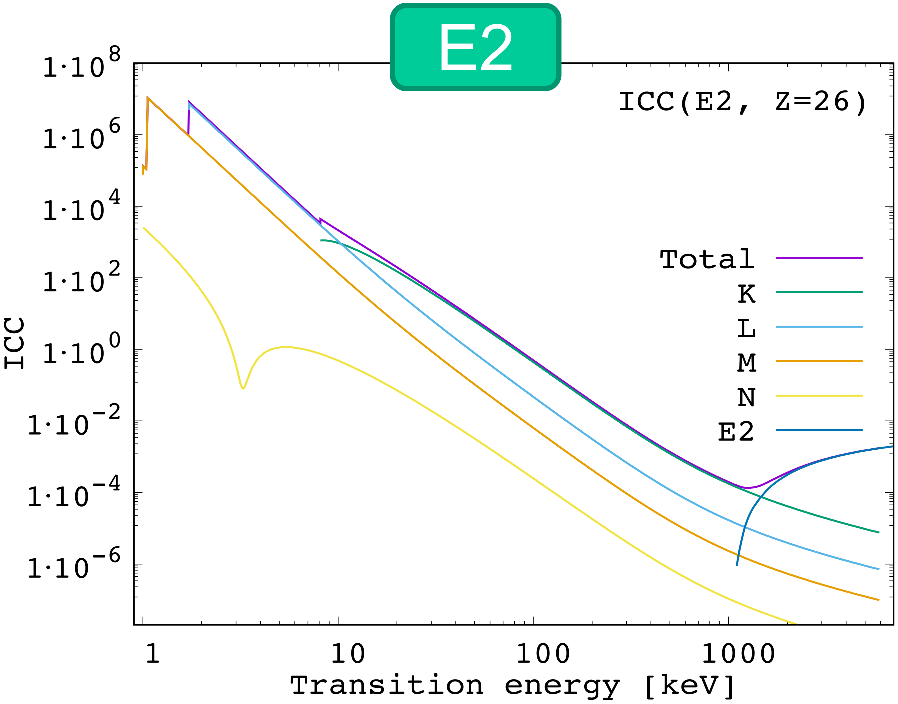
Experiment Vs. Theory
Ratios of Ω_{CE} & Ω_{π}

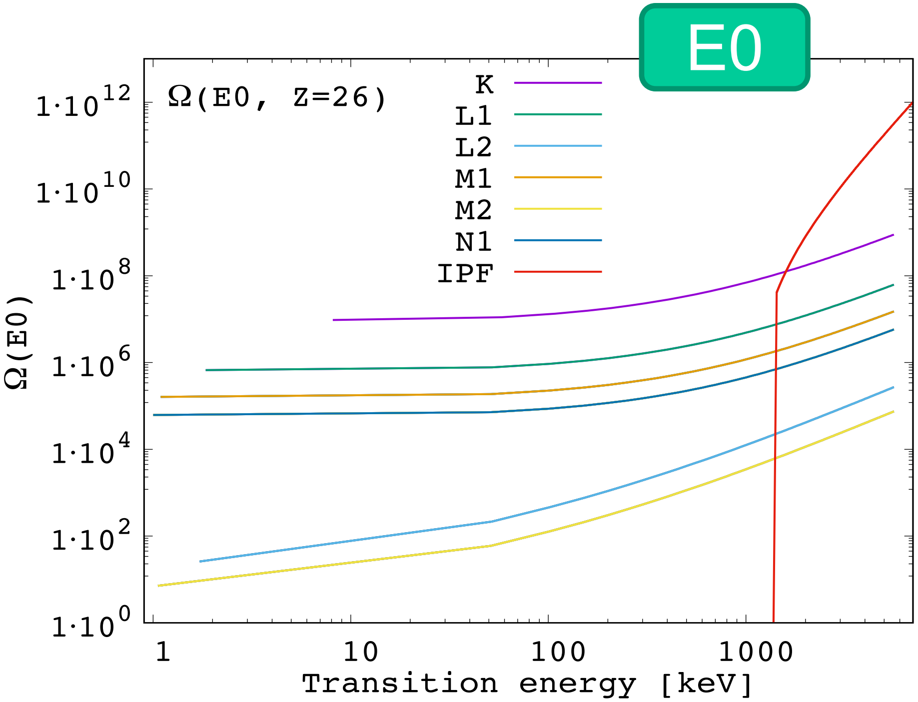
CATAR



LWM=-5.5(17)%

E0 vs E2 transitions





- Z and atomic shell dependent
- Increases with energy
- K/L weak dependence on Z (4 to 9)
- Pair conversion dominant at low Z

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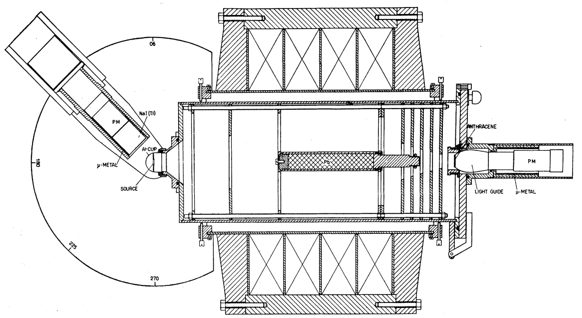
E0+M1+E2 transitions

Church, Rose and Weneser (1958)

- E0 can proceed in competition of E2 & M1
- e-γ angular correlations: a sensitive test
- First observation: 334.0-356.5 cascade in ^{196}Pt (Gerholm & Pettersson 1958)



$$W(\gamma\gamma, M1+E2) = P_0 + \frac{1}{1+\delta^2}[A_2^e + 2\delta A_2 + \delta^2 A_2^m]P_2 + \frac{1}{1+\delta^2}[A_4^e]P_4$$

$$W(e\gamma, M1+E2) = P_0 + \frac{1}{1+p^2}[b_2^e A_2^e + 2p b_2 A_2 + p^2 b_2^m A_2^m]P_2 + \frac{1}{1+p^2}[b_4^e A_4^e]P_4$$

$$W(e\gamma, E0+M1+E2) = \frac{1+p^2}{1+p^2+q^2} W(e\gamma, M1+E2) + \frac{q^2}{1+p^2+q^2}P_0 + \frac{q}{1+p^2+q^2} b_o P_2$$

Mixing ratios:

$$\boxed{\delta^2 = \frac{N_\gamma^{E2}}{N_\gamma^{M1}}}$$

$$\boxed{p^2 = \frac{\alpha_K^{M1}}{\alpha_K^{E2}}\delta^2}$$

$$\boxed{q^2 = \frac{N_K^{E0}}{N_K^{E2}}}$$

Multi-detector electron-γ arrays
Need to evaluate numerically the e-e/e-γ correlation!

E0+M1+E2 transitions

Mixed E0+M1+E2 conversion coefficients

$$\alpha_K^{exp}(E0+M1+E2) = \frac{1}{1+\delta^2}[\delta^2[1+q^2]\alpha_K(E2) + \alpha_K(M1)]$$

Mixing ratios: $\boldsymbol{\delta^2} = \frac{N_\gamma^{E2}}{N_\gamma^{M1}}$ $\boldsymbol{q^2} = \frac{N_K^{E0}}{N_K^{E2}}$

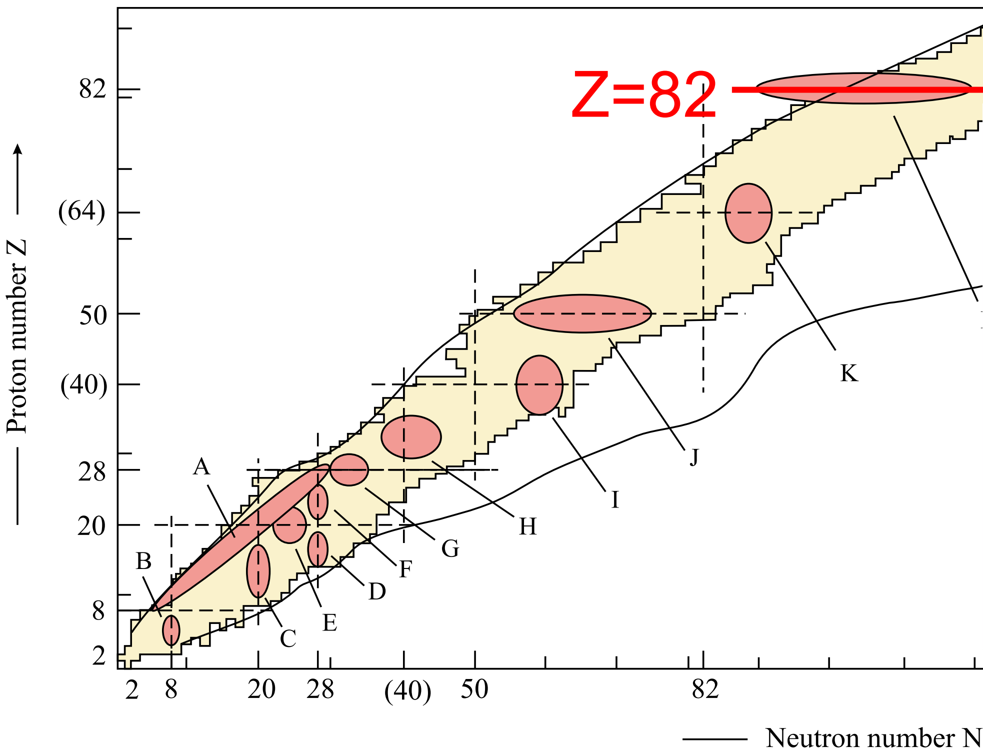
Reduced E0 matrix element

$$\rho^2(E0) = \frac{1}{\tau(E0)\times\Omega(E0)} = \boldsymbol{q^2}\frac{\alpha_K(E2)W_\gamma(E2)}{\Omega(E0)}$$

B(E0)/B(E2) ratio (Rasmussen 1960)

$$X(E0/\mathrm{E2}) = \frac{\rho^2(e0)e^2R_o^4}{B(E2)} = \frac{2.54\times10^9\times A^{4/3}E_\gamma^5 q^2\alpha_K(E2)}{\Omega_K(E0)}$$

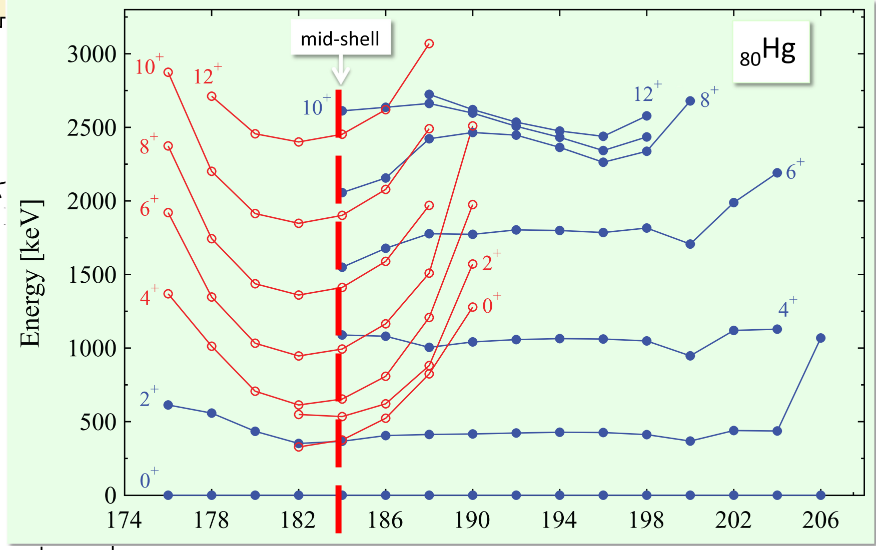
Evolution of shape co-existence

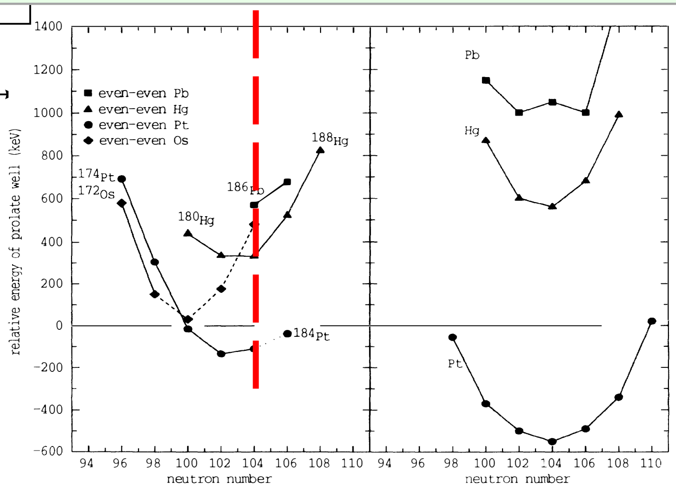


Heyde & Wood, Rev. Mod. Phys. 83 (2011) 1467

Textbook example around Pb(Z=82): Hg(Z=80), Po(Z=84)

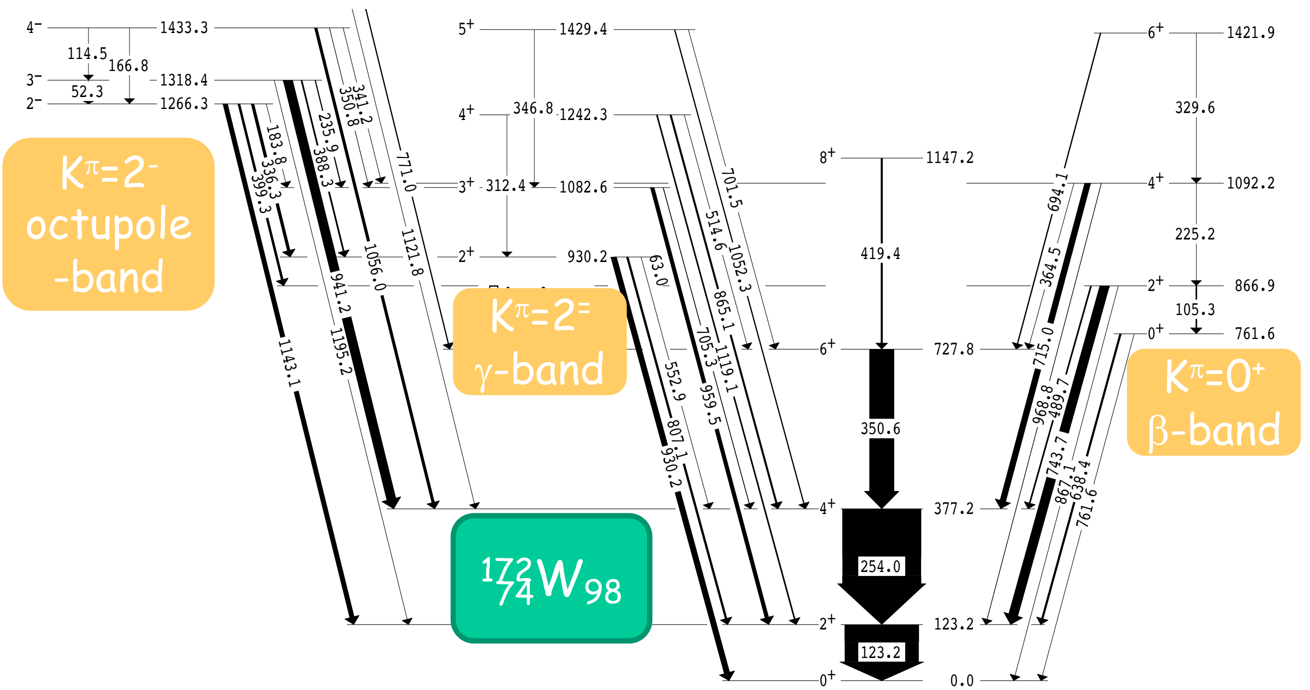
Heyde & Wood, Phys. Scr. 91 (2016) 083008





Dracoulis PRC 49 (1994) 3324

Evolution of shape co-existence W-Os-Pt



From radioactive decay: γ, γ–g, CE

^{174}Pt: Dracoulis, et al., PRC 44, R1246 (1991)
^{176}Pt: Dracoulis, et al., J. Phys. G 12, L97 (1986)
^{172}Os: Davidson, et al., Nucl. Phys. A568, 90 (1994)
$^{174-182}$Os: Kibedi, et al., Nucl. Phys. A567, 183 (1994)
$^{172-178}$W: Kibedi, et al., Nucl. Phys. A 688 669 (2001)

Evolution of shape co-existence W-Os-Pt

$^{172-178}$W: Kibedi, et al.,

Nucl. Phys. A 688 669 (2001)

- 0+ - 0+ E0 transitions (4)
- J+ - J+ (J=2,4,6) E0+M1+E2 transitions (19)
- No T1/2 – only X=B(E0)/B(E2)

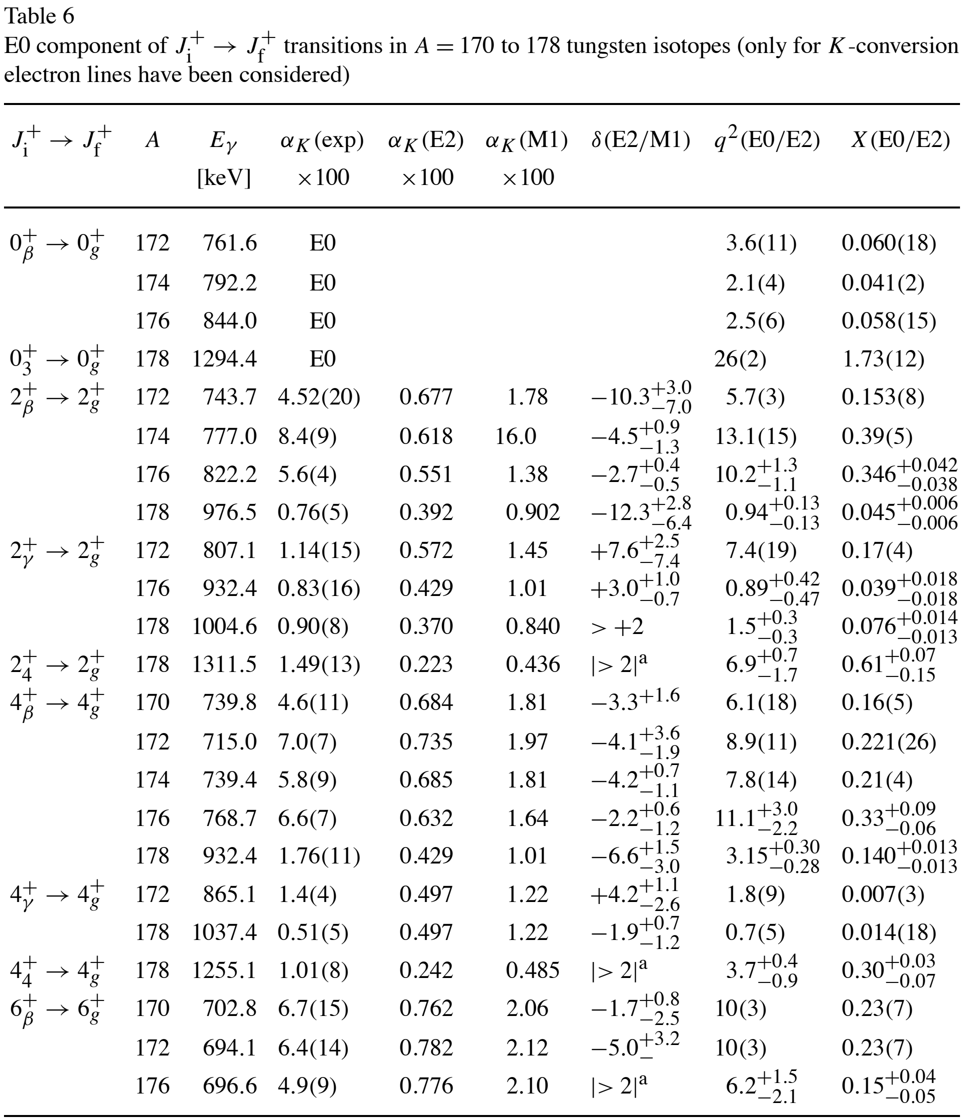
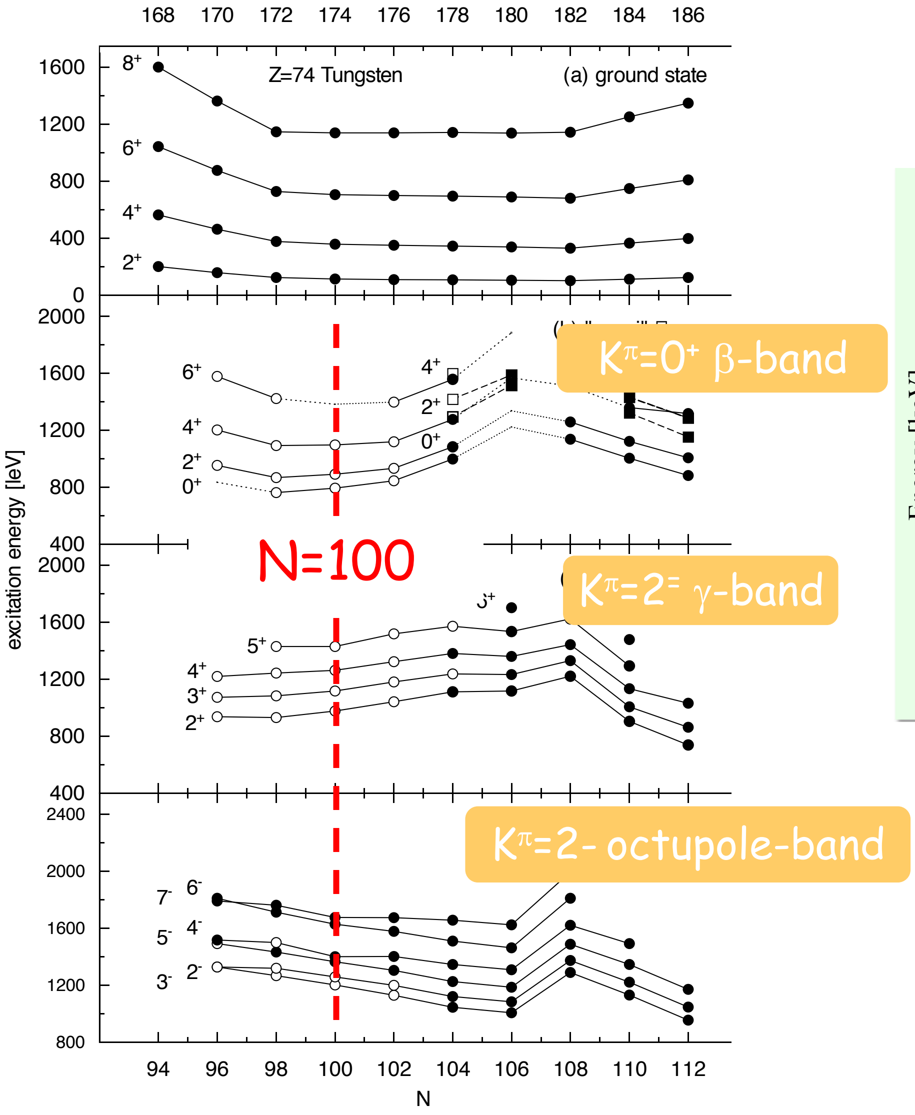


Table 6
E0 component of $J_i^+ \rightarrow J_f^+$ transitions in $A = 170$ to 178 tungsten isotopes (only for K-conversion electron lines have been considered)

$J_i^+ \rightarrow J_f^+$	A	E_γ [keV]	α_K(exp) ×100	α_K(E2) ×100	α_K(M1) ×100	δ(E2/M1)	q^2(E0/E2)	X(E0/E2)
$0_\beta^+ \rightarrow 0_g^+$	172	761.6	E0				3.6(11)	0.060(18)
	174	792.2	E0				2.1(4)	0.041(2)
	176	844.0	E0				2.5(6)	0.058(15)
$0_3^+ \rightarrow 0_g^+$	178	1294.4	E0				26(2)	1.73(12)
$2_\beta^+ \rightarrow 2_g^+$	172	743.7	4.52(20)	0.677	1.78	$-10.3^{+3.0}_{-7.0}$	5.7(3)	0.153(8)
	174	777.0	8.4(9)	0.618	16.0	$-4.5^{+0.9}_{-1.3}$	13.1(15)	0.39(5)
	176	822.2	5.6(4)	0.551	1.38	$-2.7^{+0.4}_{-0.5}$	$10.2^{+1.3}_{-1.1}$	$0.346^{+0.042}_{-0.038}$
	178	976.5	0.76(5)	0.392	0.902	$-12.3^{+2.8}_{-6.4}$	$0.94^{+0.13}_{-0.13}$	$0.045^{+0.006}_{-0.006}$
$2_\gamma^+ \rightarrow 2_g^+$	172	807.1	1.14(15)	0.572	1.45	$+7.6^{+2.5}_{-7.4}$	7.4(19)	0.17(4)
	176	932.4	0.83(16)	0.429	1.01	$+3.0^{+1.0}_{-0.7}$	$0.89^{+0.42}_{-0.47}$	$0.039^{+0.018}_{-0.018}$
	178	1004.6	0.90(8)	0.370	0.840	$> +2$	$1.5^{+0.3}_{-0.3}$	$0.076^{+0.014}_{-0.013}$
$2_4^+ \rightarrow 2_g^+$	178	1311.5	1.49(13)	0.223	0.436	$\|> 2\|$[a]	$6.9^{+0.7}_{-1.7}$	$0.61^{+0.07}_{-0.15}$
$4_\beta^+ \rightarrow 4_g^+$	170	739.8	4.6(11)	0.684	1.81	$-3.3^{+1.6}$	6.1(18)	0.16(5)
	172	715.0	7.0(7)	0.735	1.97	$-4.1^{+3.6}_{-1.9}$	8.9(11)	0.221(26)
	174	739.4	5.8(9)	0.685	1.81	$-4.2^{+0.7}_{-1.1}$	7.8(14)	0.21(4)
	176	768.7	6.6(7)	0.632	1.64	$-2.2^{+0.6}_{-1.2}$	$11.1^{+3.0}_{-2.2}$	$0.33^{+0.09}_{-0.06}$
	178	932.4	1.76(11)	0.429	1.01	$-6.6^{+1.5}_{-3.0}$	$3.15^{+0.30}_{-0.28}$	$0.140^{+0.013}_{-0.013}$
$4_\gamma^+ \rightarrow 4_g^+$	172	865.1	1.4(4)	0.497	1.22	$+4.2^{+1.1}_{-2.6}$	1.8(9)	0.007(3)
	178	1037.4	0.51(5)	0.497	1.22	$-1.9^{+0.7}_{-1.2}$	0.7(5)	0.014(18)
$4_4^+ \rightarrow 4_g^+$	178	1255.1	1.01(8)	0.242	0.485	$\|> 2\|$[a]	$3.7^{+0.4}_{-0.9}$	$0.30^{+0.03}_{-0.07}$
$6_\beta^+ \rightarrow 6_g^+$	170	702.8	6.7(15)	0.762	2.06	$-1.7^{+0.8}_{-2.5}$	10(3)	0.23(7)
	172	694.1	6.4(14)	0.782	2.12	$-5.0^{+3.2}_{-}$	10(3)	0.23(7)
	176	696.6	4.9(9)	0.776	2.10	$\|> 2\|$[a]	$6.2^{+1.5}_{-2.1}$	$0.15^{+0.04}_{-0.05}$

Evolution of shape co-existence W-Os-Pt



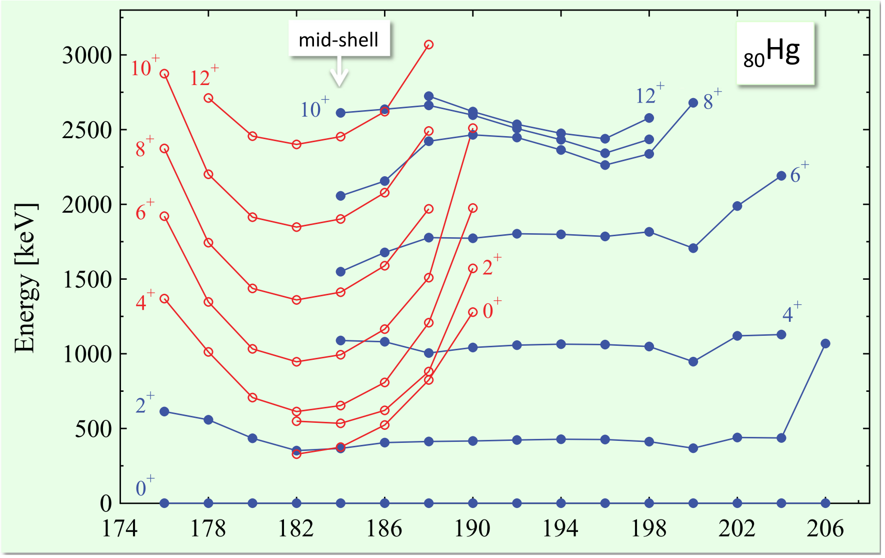
$K^{\pi}=0^{+}$ β-band

N=100

$K^{\pi}=2^{+}$ γ-band

$K^{\pi}=2^{-}$ octupole-band

Level systematics



Kibedi, et al., Nucl. Phys. A 688 669 (2001)

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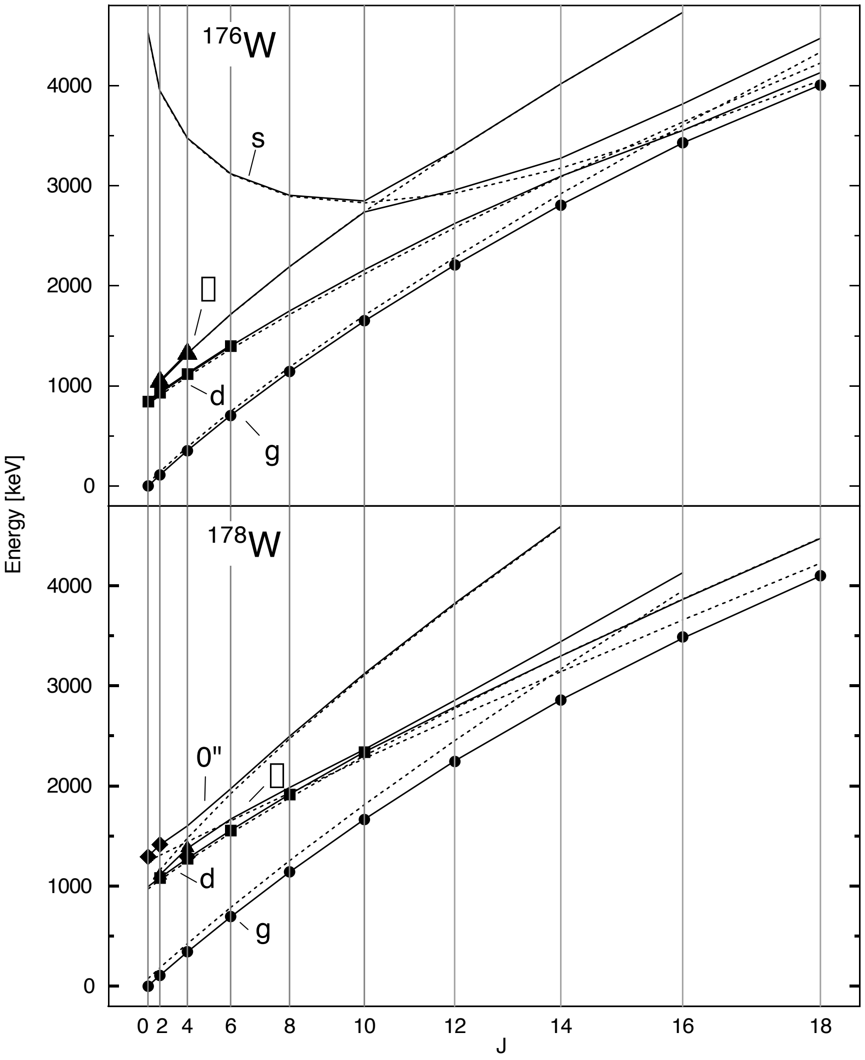
Evolution of shape co-existence W-Os-Pt



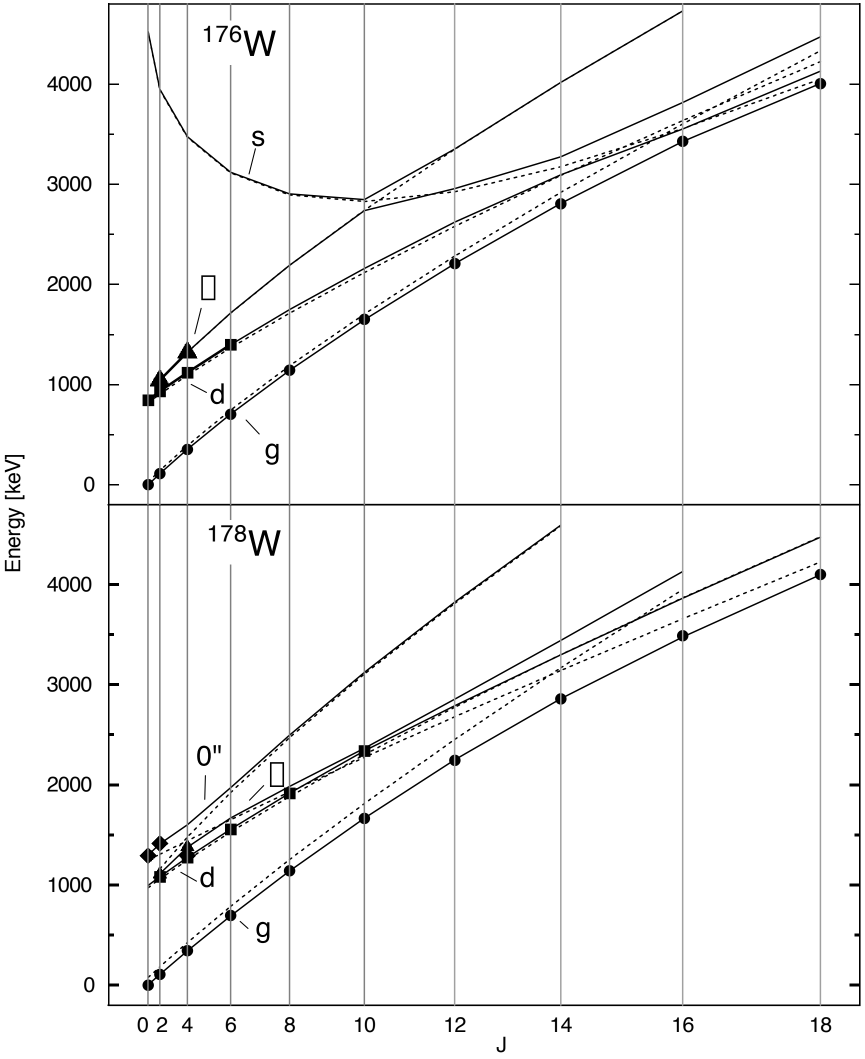
Kibedi, et al., Nucl. Phys. A 688 669 (2001)

4-band mixing calculations

- K=0 g.s. unperturbed ground-state rotation
- K=0 "deformed" band
- K=2 g-band
- K=0 "s"-band, unperturbed rotation-aligned band, back banding observed in (HI,xn)

- <u>Parameters to fit excitation energies:</u>
  - ☐ Moment of inertia (VMI)
  - ☐ Unperturbed band-head energies
  - ☐ Spin-independent interactions
  - ☐ aligned angular momentum of the s-band

Evolution of shape co-existence W-Os-Pt



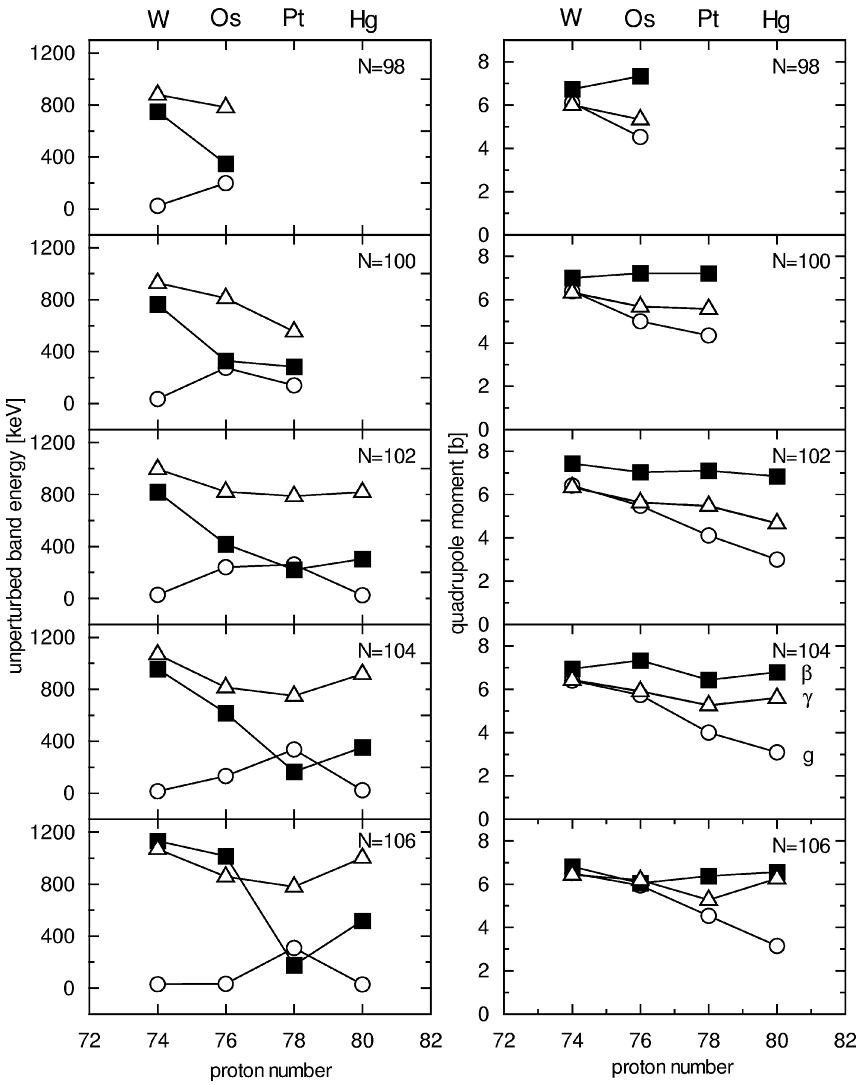
Kibedi, et al., Nucl. Phys. A 688 669 (2001)

4-band mixing calculations

- K=0 g.s. unperturbed ground-state rotation
- K=0 "deformed" band
- K=2 g-band
- K=0 "s"-band, unperturbed rotation-aligned band, back banding observed in (HI,xn)

- Interactions:
    - 150 keV (g-d)
    - 30 keV (g-γ)
    - 5 keV (d-γ)

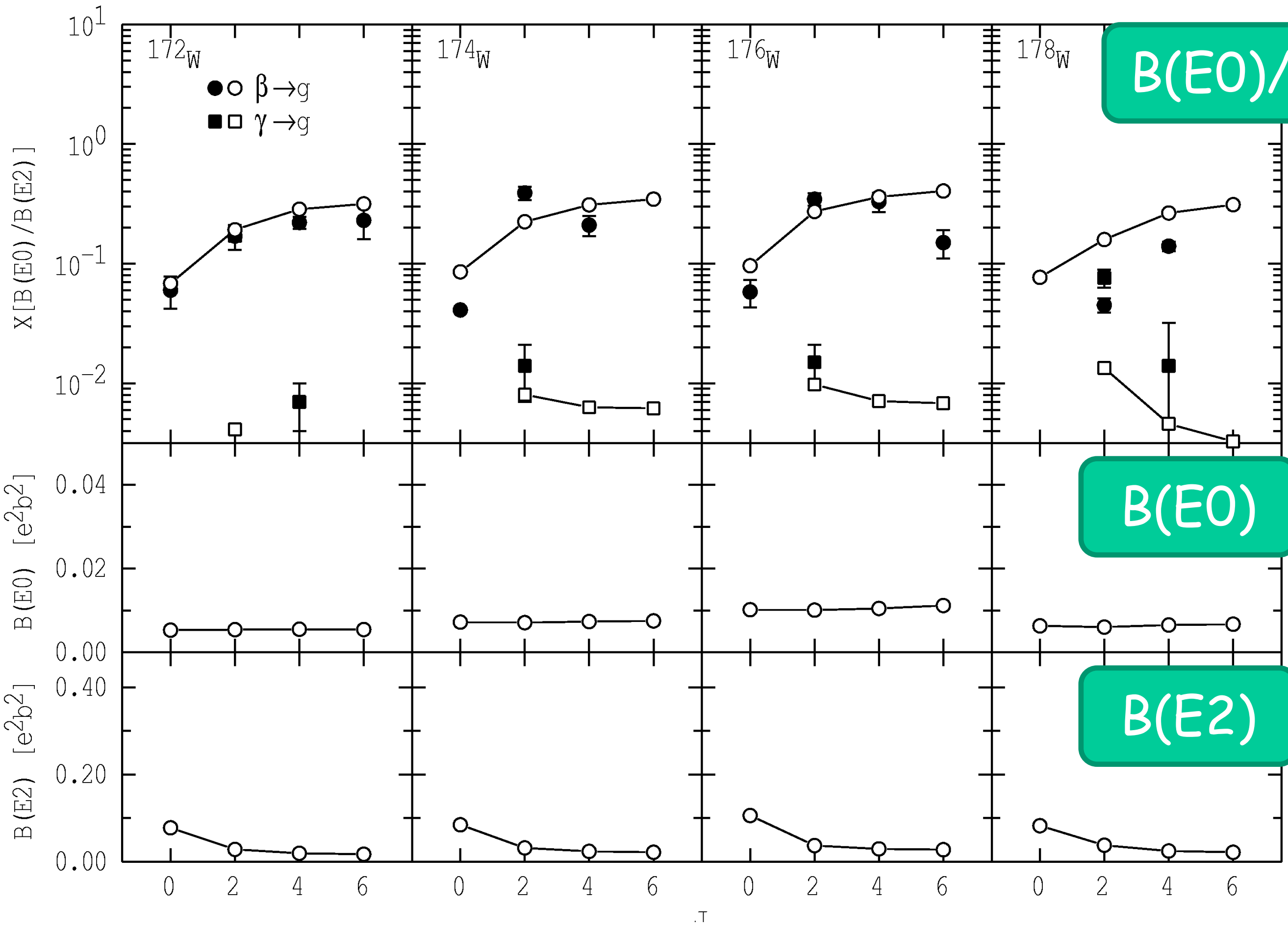
Evolution of shape co-existence W-Os-Pt



Kibedi, et al., Nucl. Phys. A 688 669 (2001)

- Smooth evolution across Z=80 to 74 and N=98 to 106
- Differences in deformation
- Unperturbed γ and d bands shifted down in energy as Z >> 82

Evolution of shape co-existence W-Os-Pt



B(E0)/B(E2)

- ➢ J-dependence
- ➢ E0 component of J_γ - J_g transitions

B(E0)

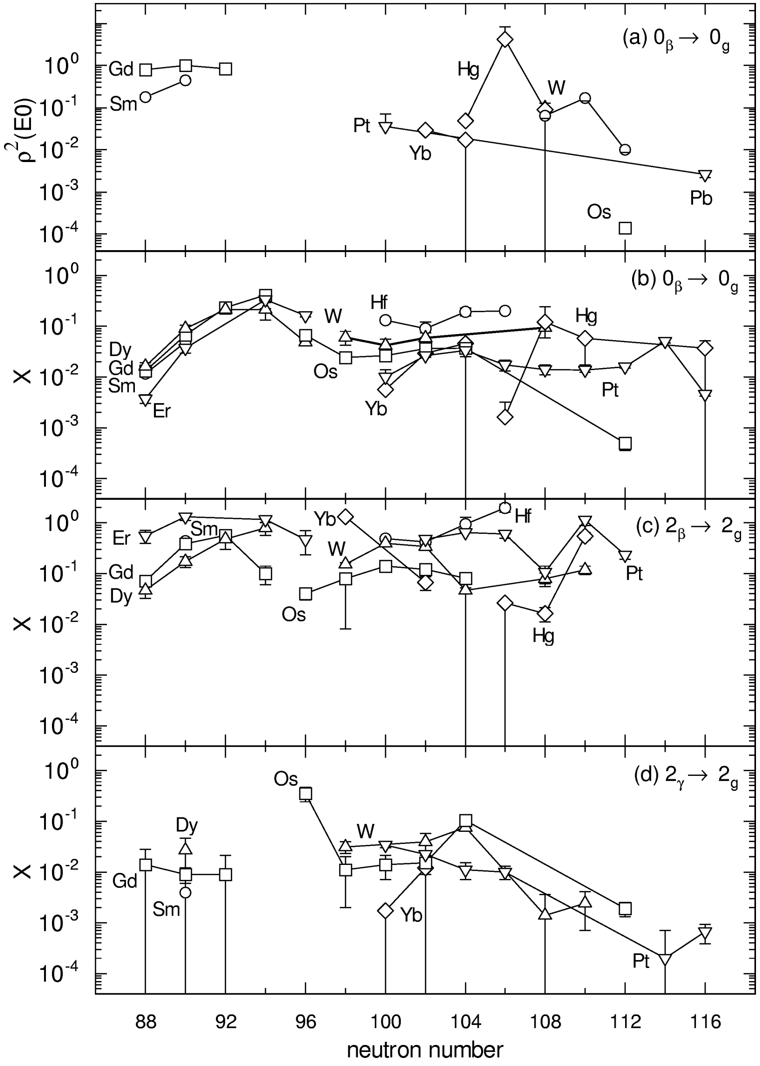
- ➢ B(E0) J-independent

B(E2)

- ➢ J-dependence from B(E2)

Kibedi, et al., Nucl. Phys. A 688 669 (2001)

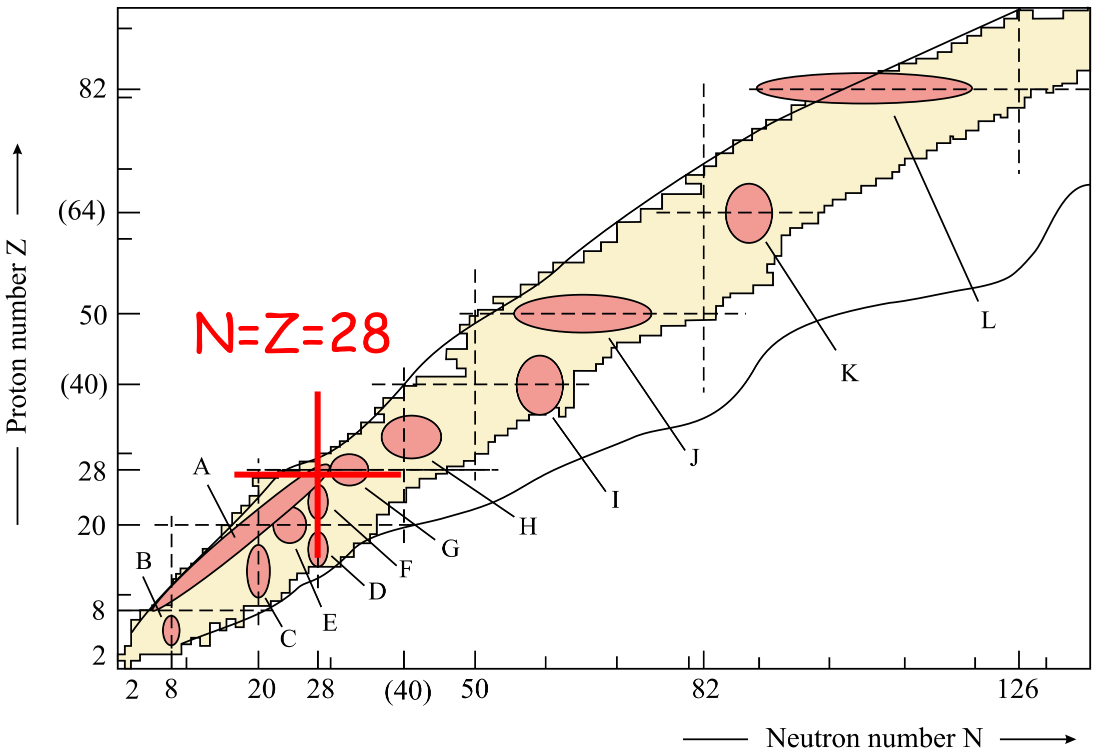
Evolution of shape co-existence x(E0/E2) systematics



$\rho^2(E0)$ $0_2 - 0_1$	15 data
B(E0)/B(E2) $0_2 - 0_1$	42 data
B(E0)/B(E2) $2_2 - 2_1$	39 data
B(E0)/B(E2) $2_\gamma - 2_1$	24 data

Kibedi, et al., Nucl. Phys. A 688 669 (2001)

Shape co-existence around N=Z=28



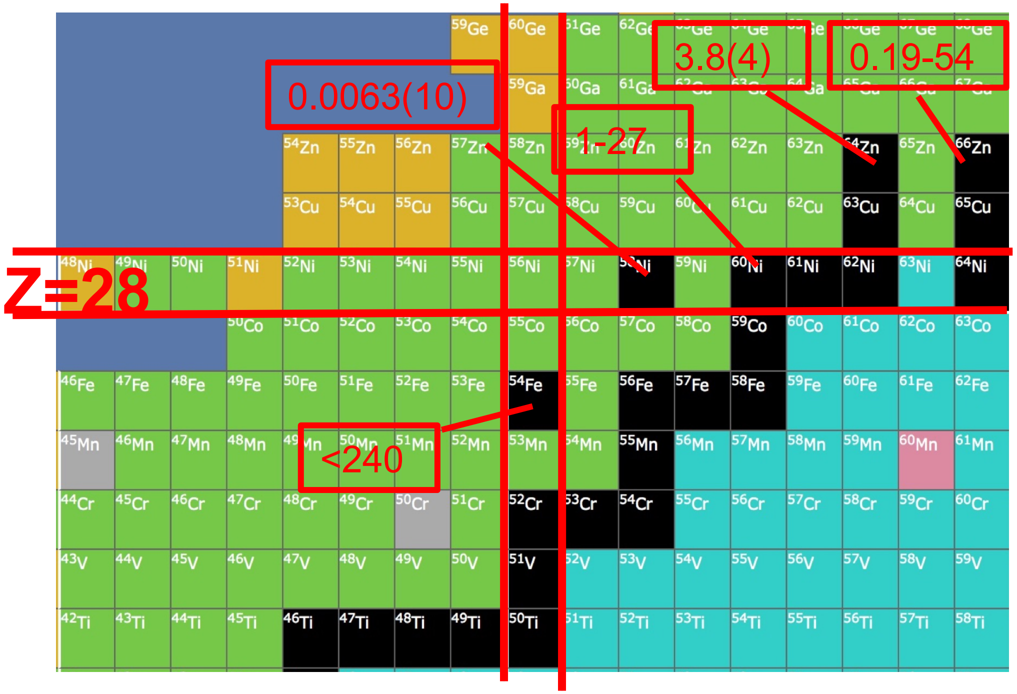
Heyde & Wood, Rev. Mod. Phys. 83 (2011) 1467

N=Z=28 double magic
Shape co-existence *"could emerge"*

Dracoulis PRC 49 (1994) 3324

Motivation

- Excited 0^+ around N=Z=28: from mp-mh excitations from the $1f_{7/2}$ to the $1f_{5/2}$, $2p_{1/2}$ and $2p_{3/2}$ orbits
- E0 transitions: not very well known
- **<u>Aim:</u>** Characterise E0 transitions in Z=26, N=28,30,32
- E0\`s in Ni isotopes talk by <u>Adam Garnsworthy</u>

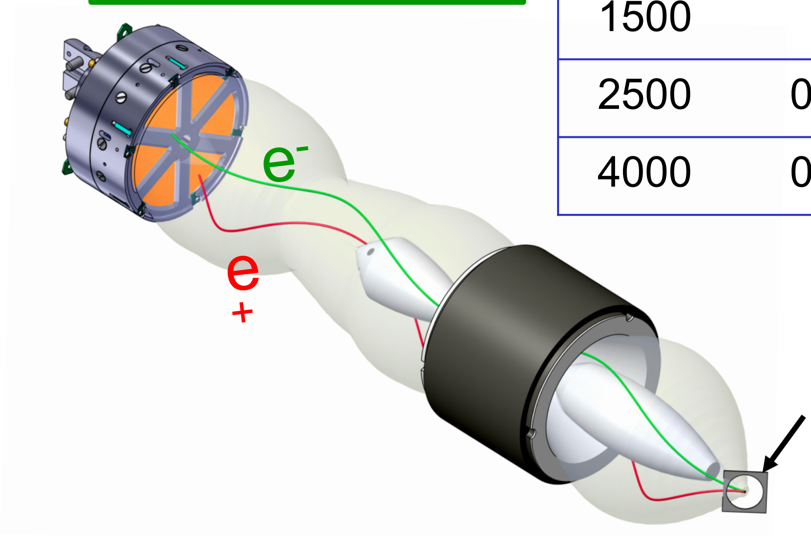


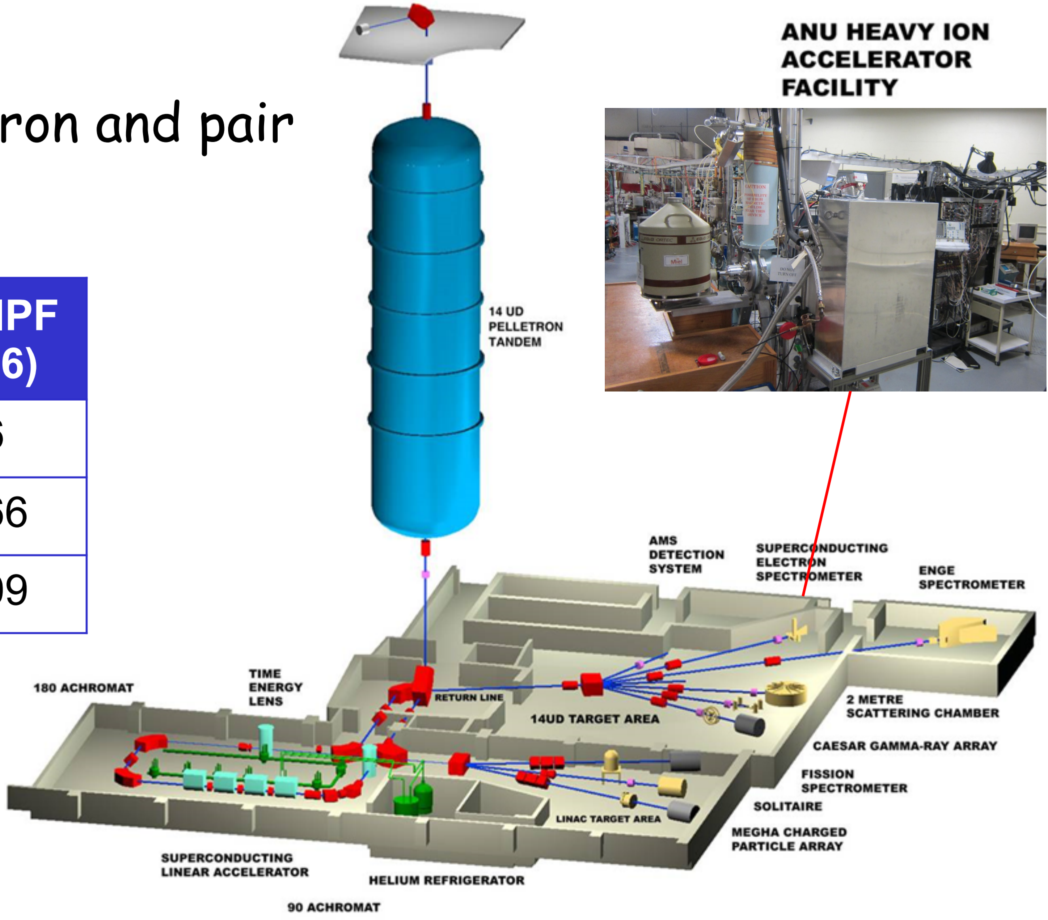
Experiments

- (p,p') reaction, E_p=6.7-7 MeV DC beam
- 1-2 mg/cm^2 ^{54,56,58}Fe targets
- Singles gamma, conversion electron and pair conversion (Super-e)

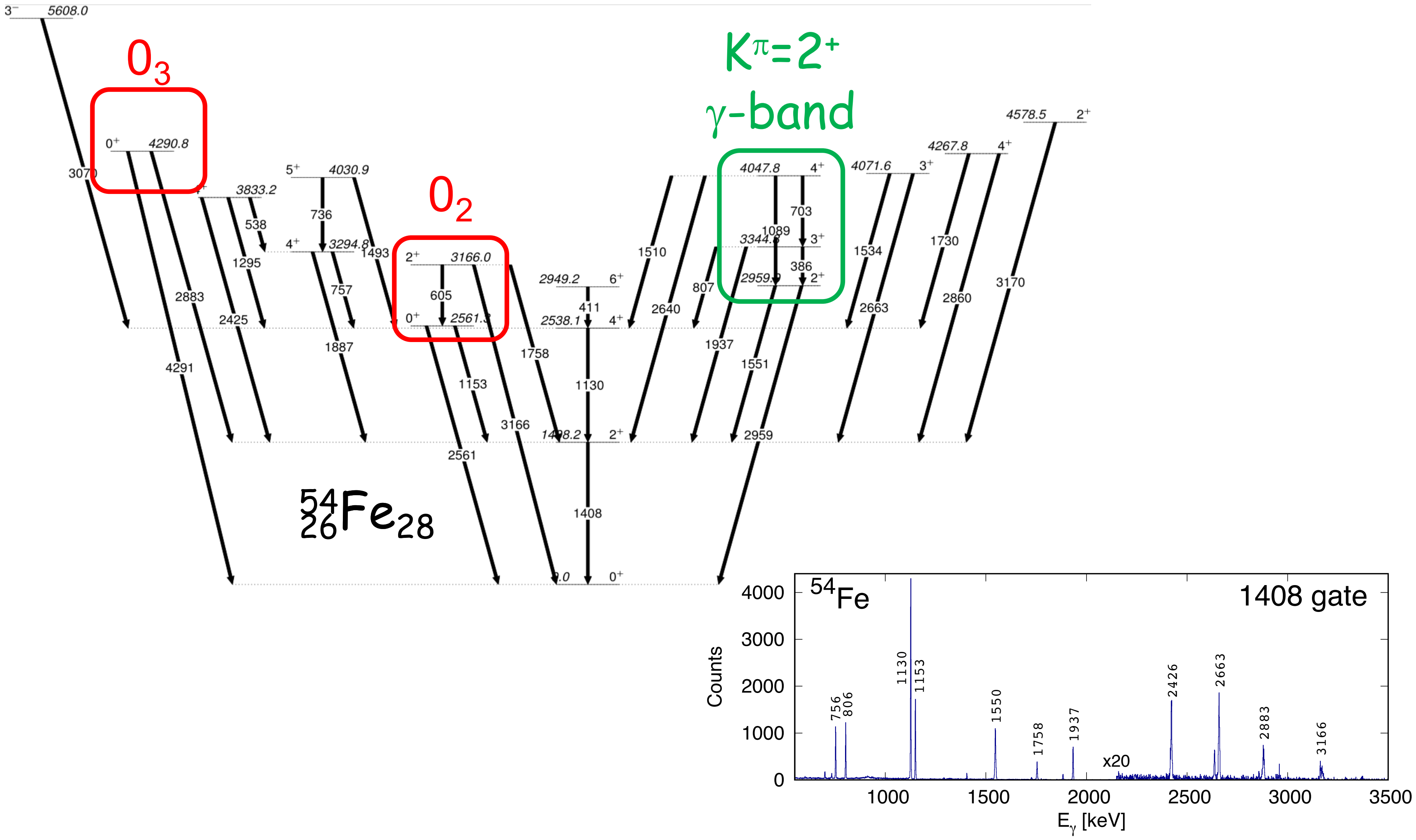
ε_{CE}=0.1-0.5%
ε_{IPF}=0.01%

E [keV]	CEK/IPF (Z=26)
1500	1.6
2500	0.066
4000	0.009

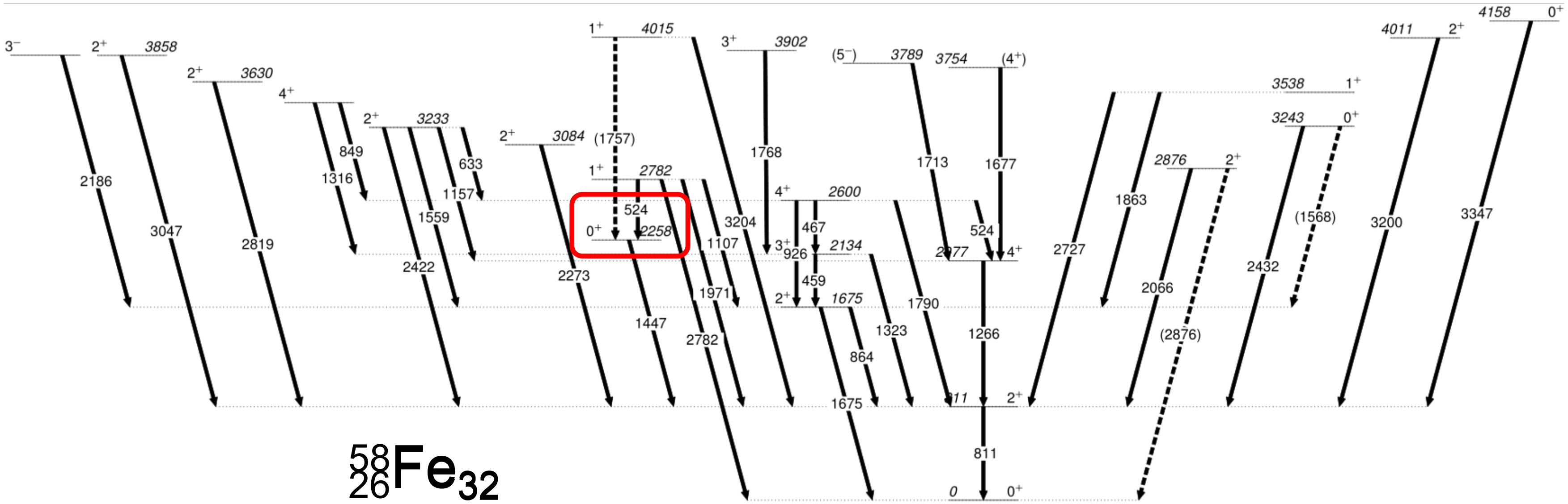




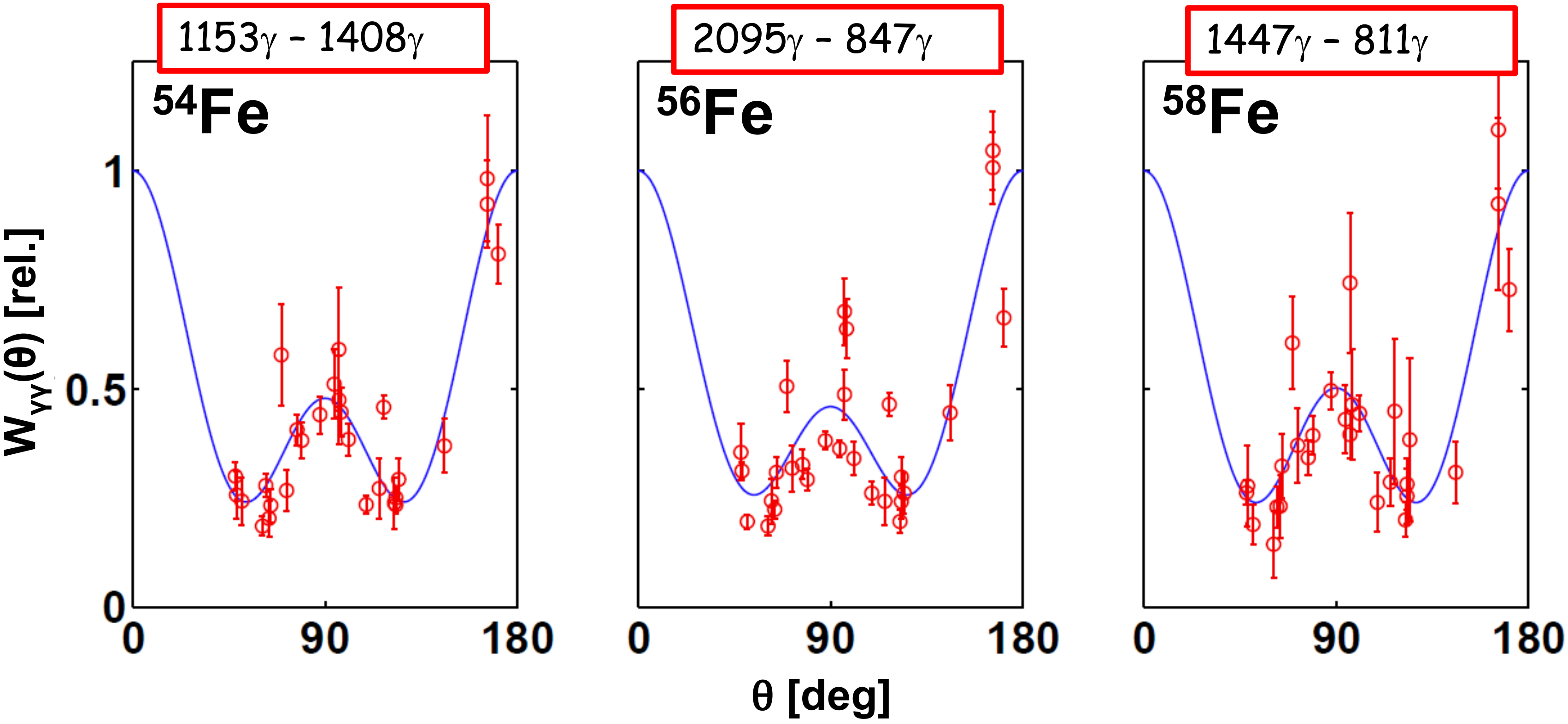
Extended level schemes



Extended level schemes



Angular correlation of 0-2-0 cascades



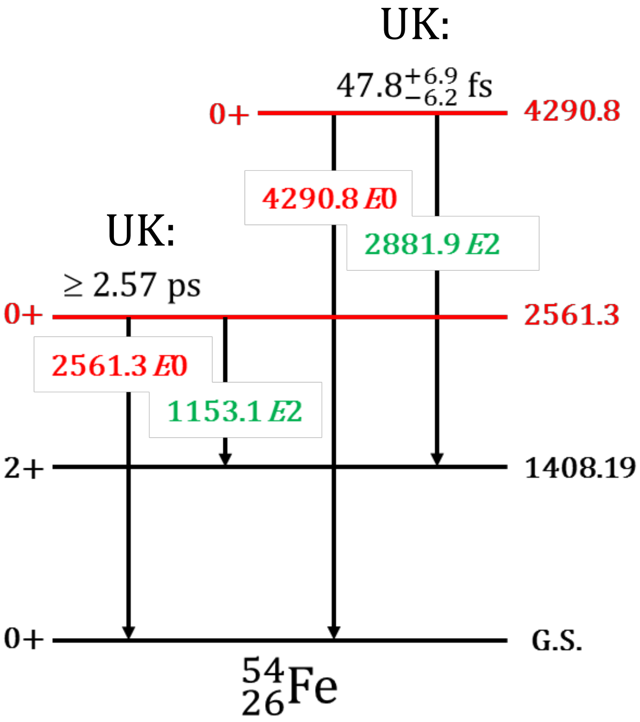
$$W_{\gamma\gamma}(\theta) = N(1 + a_2\cos^2(\theta) + a_4\cos^4(\theta))$$

$$0^+ \rightarrow 2^+ \rightarrow 0^+$$

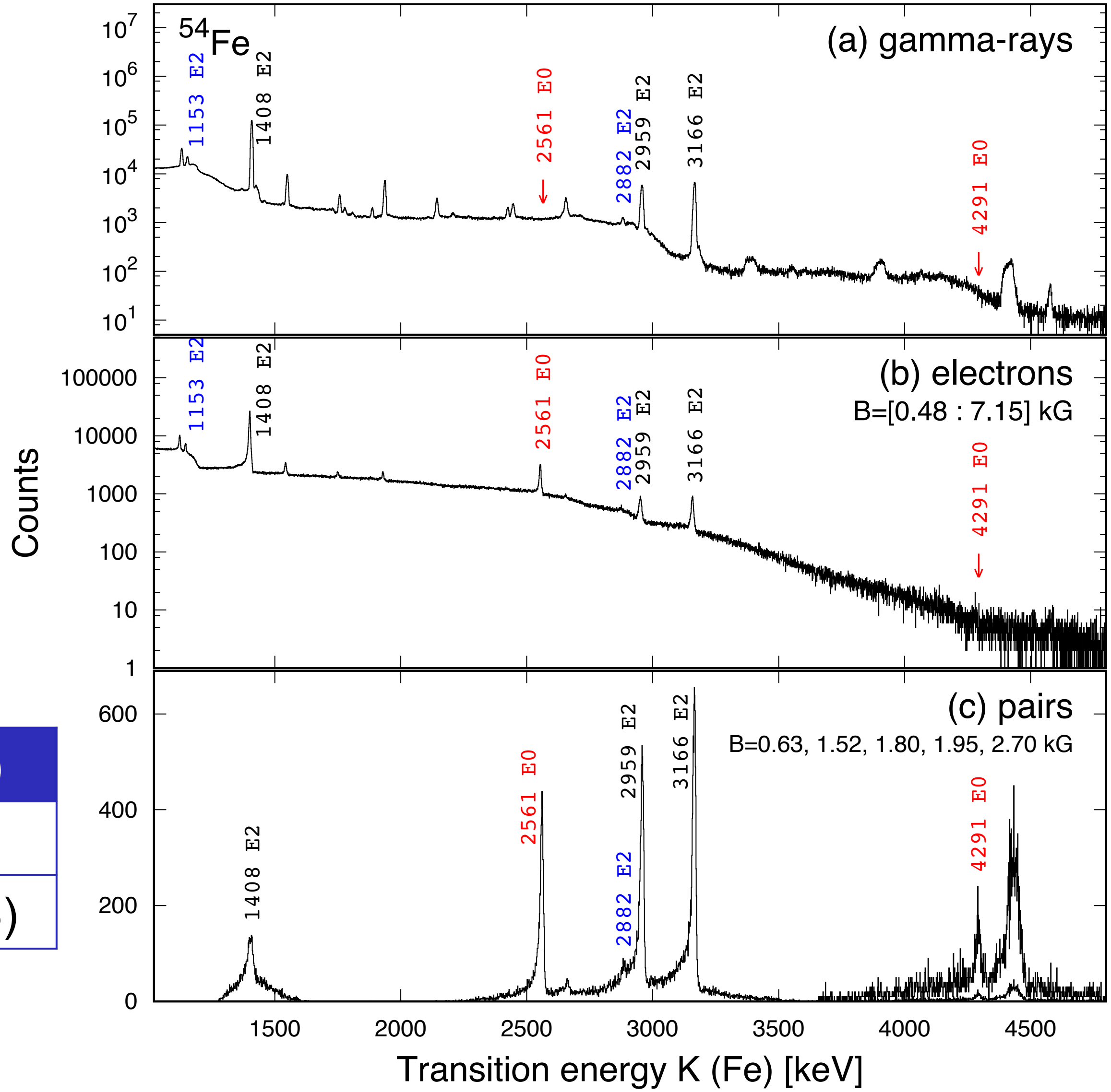
$$a_2 = -3, a_4 = 4$$

	a_2	a_4
^{54}Fe	−2.8(6)	3.9(7)
^{56}Fe	−2.6(9)	3.7(10)
^{58}Fe	−2.8(8)	3.8(9)

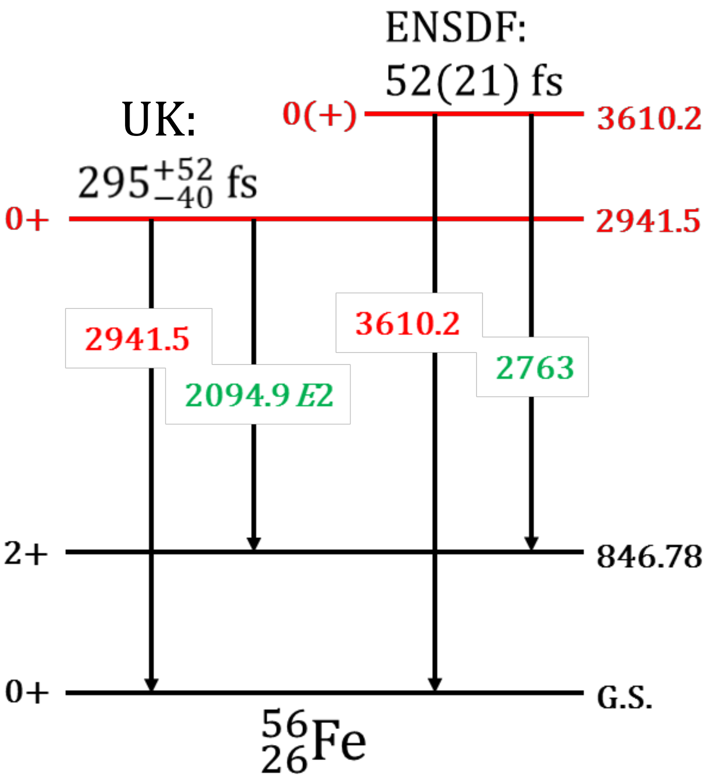
E0 transitions – ^{54}Fe



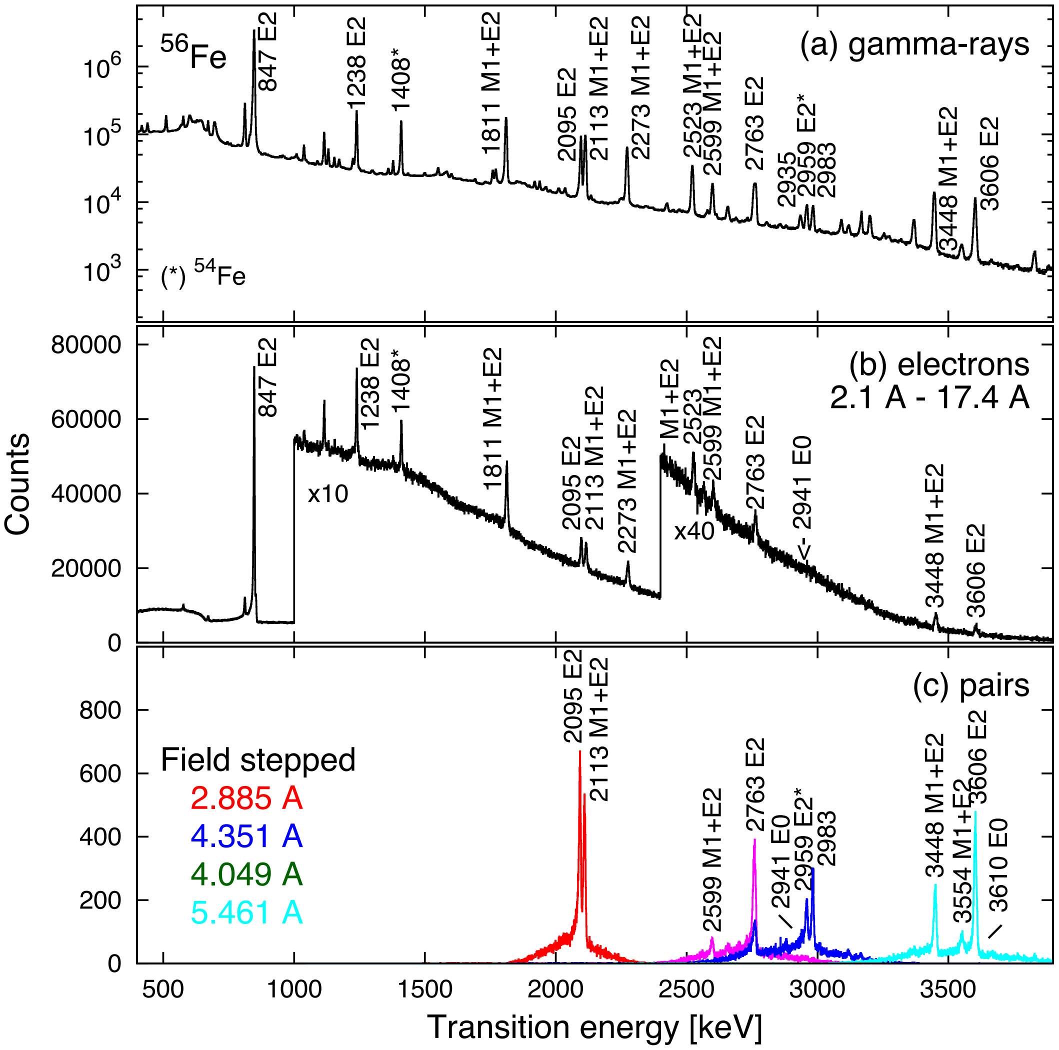
	$10^3\rho^2(E0)$
2561.0 E0	<80
4290.8 E0	92(+22-23)



E0 transitions - ^{56}Fe



	$10^3\rho^2(E0)$
2941.5 E0	3.2(11)
3610.2 E0	?



E0 transitions in ^{54,56,58}Fe

Experimental monopole strength

$$\rho^2(E0) = \frac{1}{\Omega(E0)\times\tau(E0)}$$

Monopole strength and band mixing

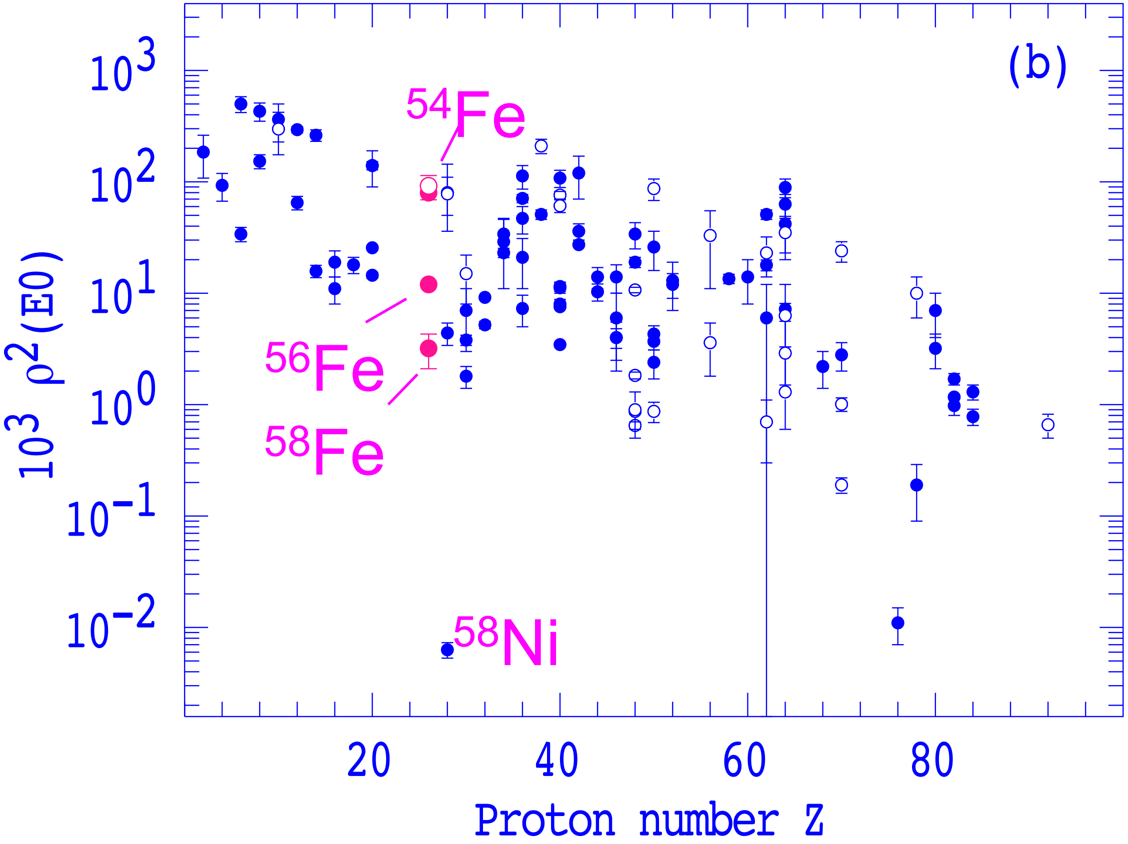
$$\varrho^2(E0) = \frac{Z^2}{R_0^4} a^2(1-a^2)\,[\Delta\langle r^2\rangle]^2$$

		$10^3 r^2$(E0)
^{54}Fe	2561 (0_2-0_1)	<80
	4291 (0_3-0_1)	92(+22-23)
^{56}Fe	2942 (0_2-0_1)	3.2(11)
^{58}Fe	2258 (0_2-0_1)	<12

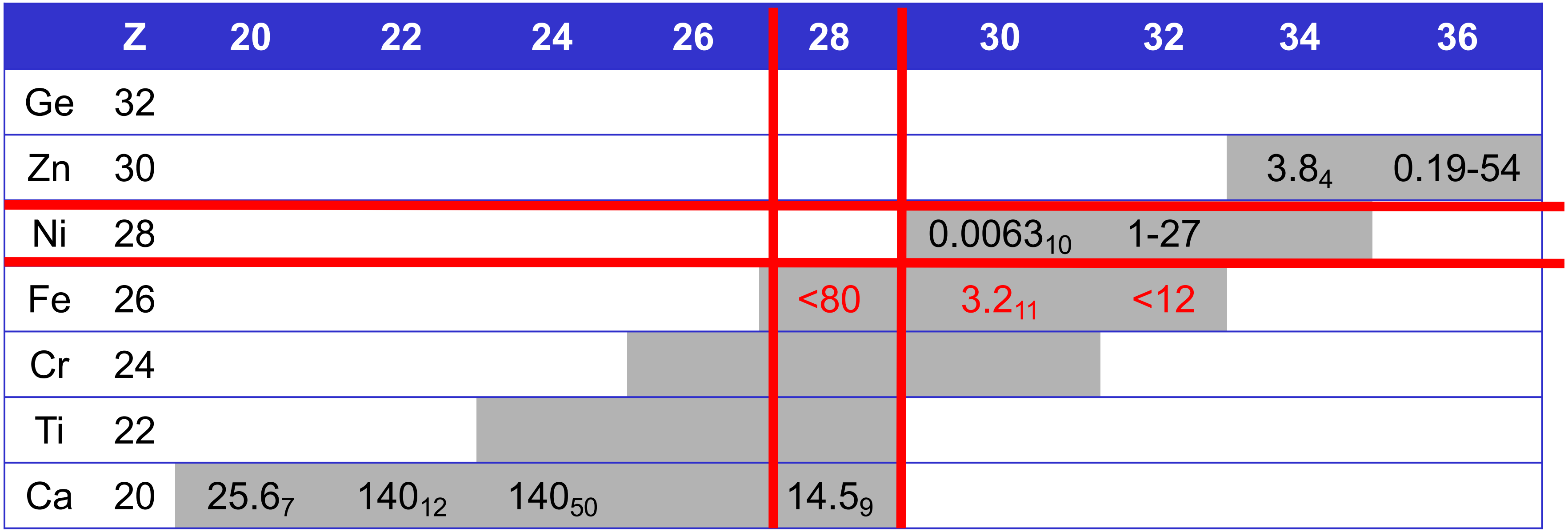
^{54}Fe 1758 (2_2-2_1)

α_K=4.9E-5(3) M1+E2

Small/negligible E0



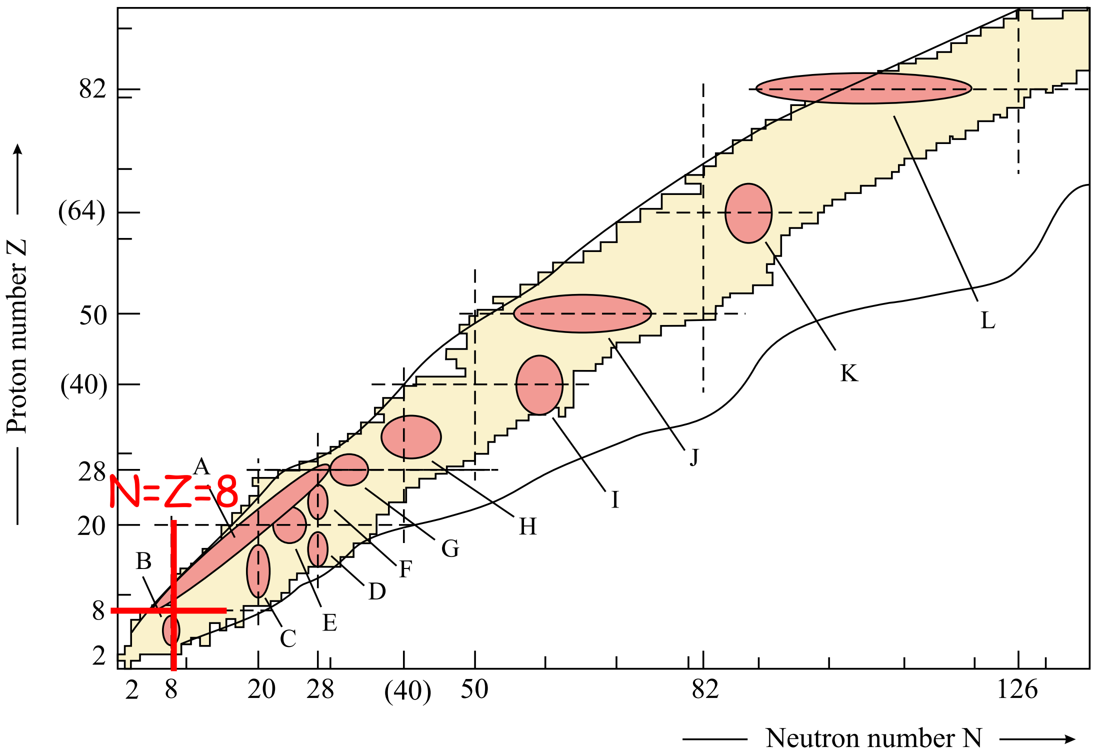
Shape co-existence around N=Z=28
Summary



	Z	20	22	24	26	28	30	32	34	36
Ge	32									
Zn	30								3.8_4	0.19-54
Ni	28						0.0063_{10}	1-27	▨	
Fe	26					<80	3.2_{11}	<12		
Cr	24				▨	▨	▨			
Ti	22			▨	▨	▨				
Ca	20	25.6_7	140_{12}	140_{50}	▨	14.5_9				

- ☐ New results in ^{54,56,58}Fe: extended level schemes, new T1/2, δ(E2/M1), E0 transitions, ρ^2(E0)
- ☐ Future: look for E0s between J>0 states to characterise bands built on excited 0^+ states
- ☐ Interpretation within the bandmixing approach
- ☐ E0s in Cr (Z=24) and Ti(Z=22) to explore N=28 isotones

The Hoyle state

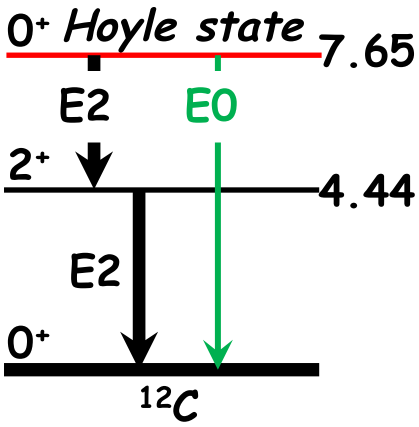


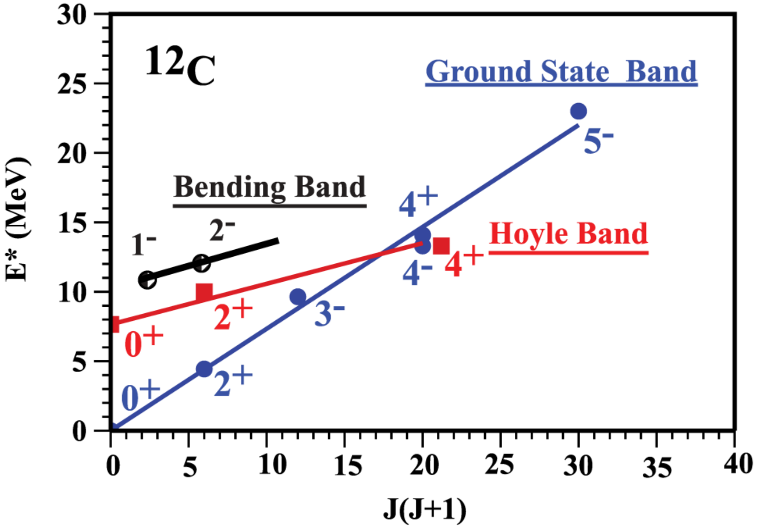
Heyde & Wood, Rev. Mod. Phys. 83 (2011) 1467

Hoyle state: not a typical excited 0^+ at south-west from the double magic ^{16}O

Dracoulis PRC 49 (1994) 3324

The Hoyle state



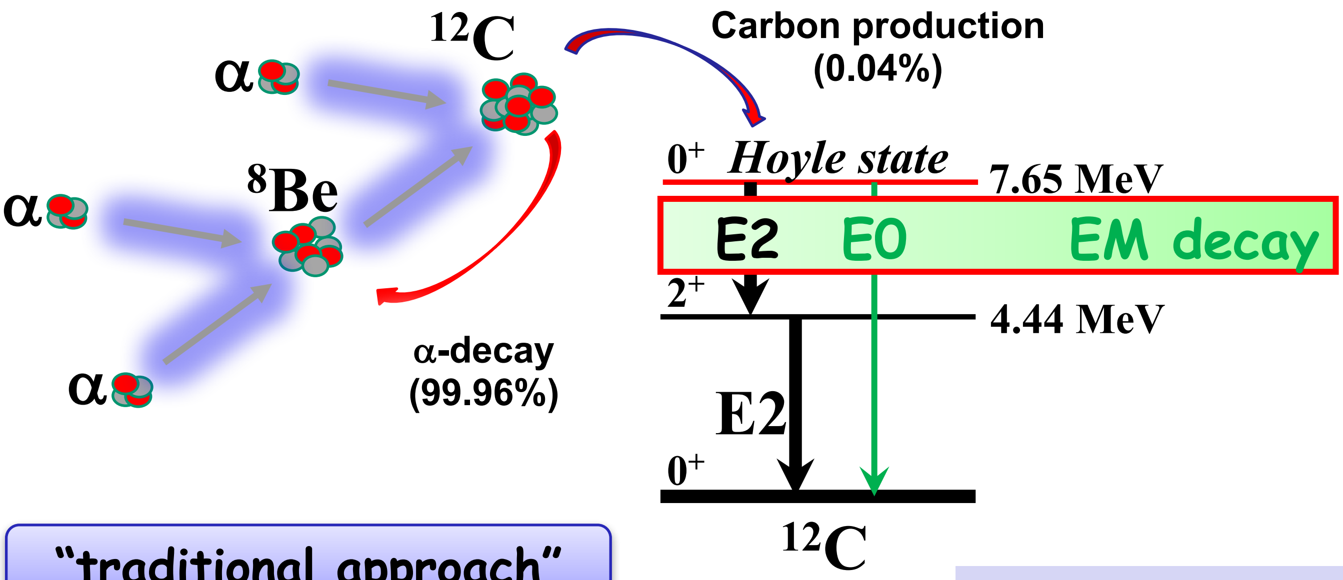


D.J. Marín-Lámbarri, et al., *PRL* ***113*** *(2014) 012502*

- $\Gamma(0_2)$=9.3(9) eV; $T_{1/2}(0_2)$=3.5(3) $\times 10^{-17}$ s
- "Extended object" (Brink 1966)
  RMS=2.89(4) fm = 1.2* RMS(g.s.)
  PRC ***80*** *(2009) 054603*
- ρ^2(E0)=500(81) ADNDT **89** (2005) 77
- 2^+ at 9.8 MeV
  Nucl. Phys. **A738**, (2004) 268; Phys. Rev. **C 84** (2011) 054308; **80** (2009) 041303(R); **84** (2011) 027304; **86** (2012) 034320;
  PRL ***113*** *(2014) 012502*
- 4^+ at 13.3 MeV
  Phys. Rev. **C83** (2011) 034314
- 0_3^+ at 10.3 MeV; $\Gamma(0_3)$=2.7 MeV
  Nucl. Phys. **A738**, (2004) 268
- Microscopic α-cluster model /exp
  $E(0_2)-E_{3\alpha}$=0.23 / 0.38 MeV
  $\Gamma(0_2)$=7.6 / 9.3(9) μeV
  M(E0)= 6.3 / 5.4(2) fm^2
  Yasuro Funaki, Phys. Rev. **C 94 (2016) 024344**

Dracoulis PRC 49 (1994) 3324

The radiative width of the Hoyle state



"traditional approach"

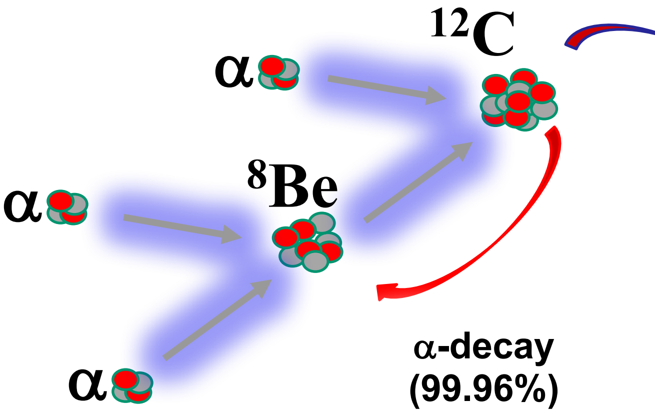
$$r_{3\alpha} \propto [\Gamma_{rad}]\exp(-[Q_{3\alpha}]/kT)$$

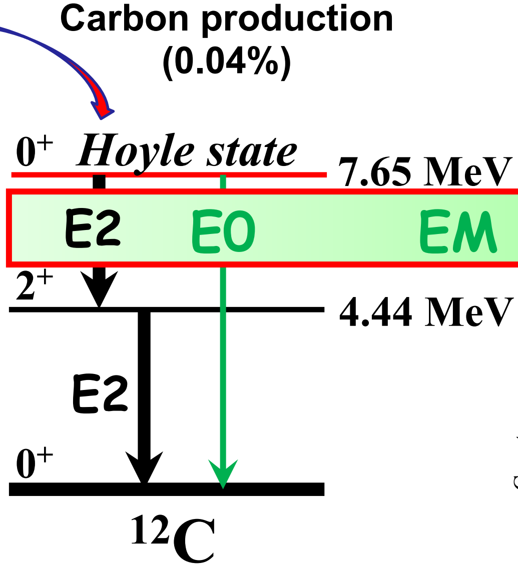
$$\Gamma_{rad} = \boxed{\left[\frac{\Gamma_{rad}}{\Gamma}\right]} \times \boxed{\left[\frac{\Gamma}{\Gamma_{\pi}(E0)}\right]} \times \boxed{[\Gamma_{\pi}(E0)]}$$

		Unc. [%]	# exp
Γ_{rad}/Γ ($\times 10^{-4}$)	4.19(11)	2.7	8
$\Gamma_{\pi}(E0)/\Gamma$ ($\times 10^{-6}$)	6.7(6)	8.9	4
$\Gamma_{\pi}(E0)$ (μeV)	62.3(20)	3.2	8

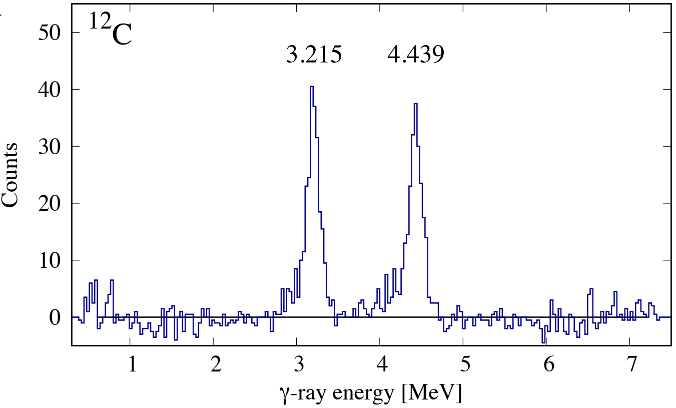
Γ_{rad}=3.9(4) ×10^{-3} eV EM branching: 0.042%

The radiative width from p-γ–γ





Univ. Oslo Cyclotron
CACTUS + SiRi



"traditional approach"

$$r_{3\alpha} \propto [\Gamma_{rad}] \exp(-[Q_{3\alpha}]/kT)$$

$$\Gamma_{rad} = \boxed{\left[\frac{\Gamma_{rad}}{\Gamma}\right]} \times \left[\frac{\Gamma}{\Gamma_{\pi}(E0)}\right] \times [\Gamma_{\pi}(E0)]$$

Events in 12 days:

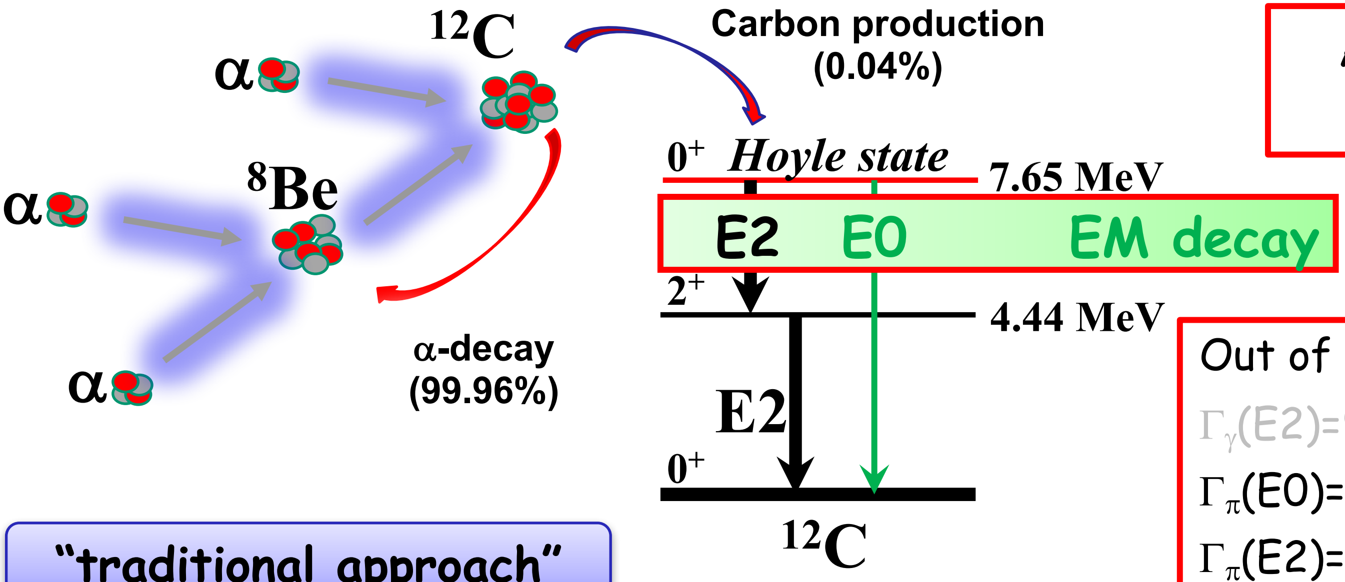
☐ Total: 6.0E+9

☐ p-singles (7.65): 2.72E+8

☐ p-γ–γ (7.65): 260(16)

$\left[\frac{\Gamma_{rad}}{\Gamma}\right] =$ 2.76(21)E-4

The radiative width from pair conversion measurements



Carbon production (0.04%)

α-decay (99.96%)

E2 E0 EM decay

ANU Super-e pair spectrometer

Out of the ~0.04%

Γ_{γ}(E2)=98.5%

Γ_{π}(E0)=1.5%

Γ_{π}(E2)=0.088%

Γ_{CE}(E2), Γ_{CE}(E0) ~0

Internal pair conversion

"traditional approach"

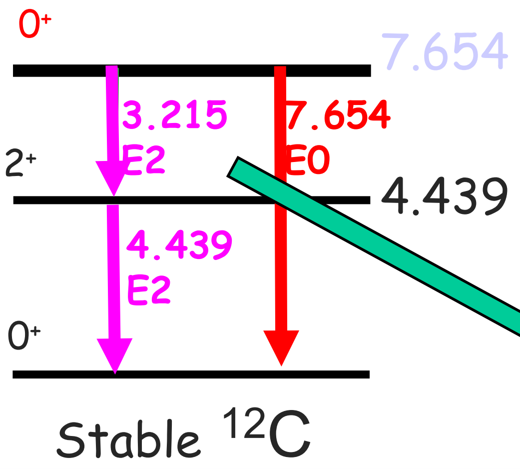
$$r_{3\alpha} \propto [\Gamma_{rad}]\exp(-[Q_{3\alpha}]/kT)$$

$$\Gamma_{rad} = \left[\frac{\Gamma_{rad}}{\Gamma}\right]\times\left[\frac{\Gamma}{\Gamma_{\pi}(E0)}\right]\times[\Gamma_{\pi}(E0)]$$

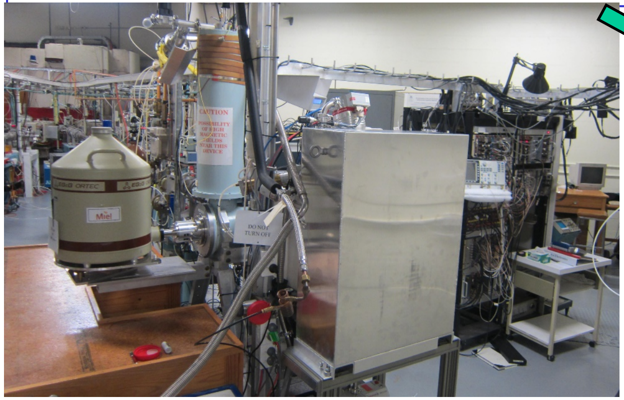
$$\Gamma_{rad} = \left(\boxed{\left[\frac{\Gamma_{\pi}(E2)}{\Gamma_{\pi}(E0)}\right]}\times\left(1+\frac{1}{[\alpha_{\pi}(E2)]}\right)+1\right)\times\boxed{[\Gamma_{\pi}(E0)]}$$

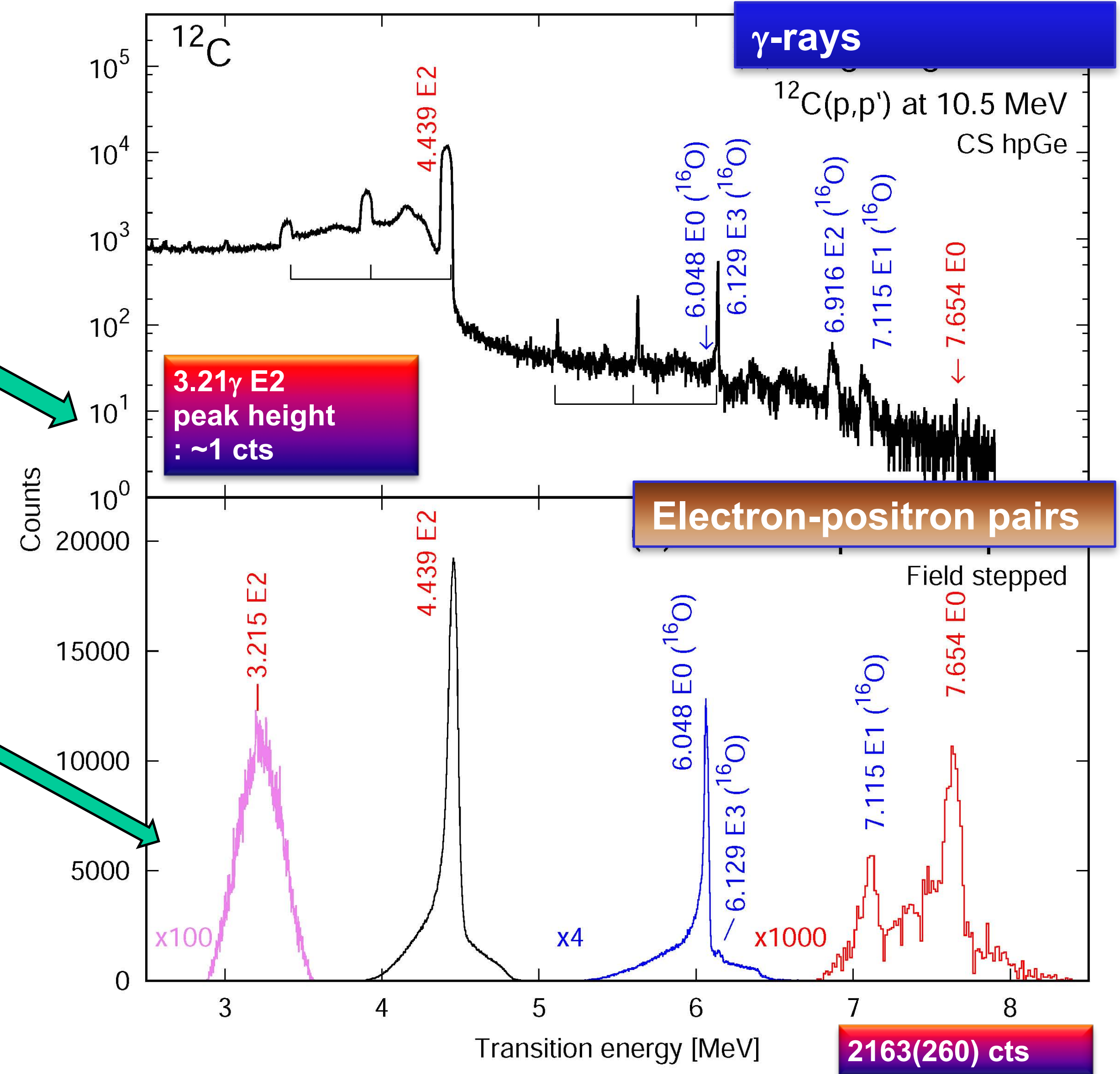
α_{π}(E2)=8.765E-4

The radiative width from pair conversion measurements



	gamma	pairs
4.439 E2	= 1	1.32E-3
3.215 E2	1.1E-4	9.2E-8
7.654 E0	--	1.6E-6



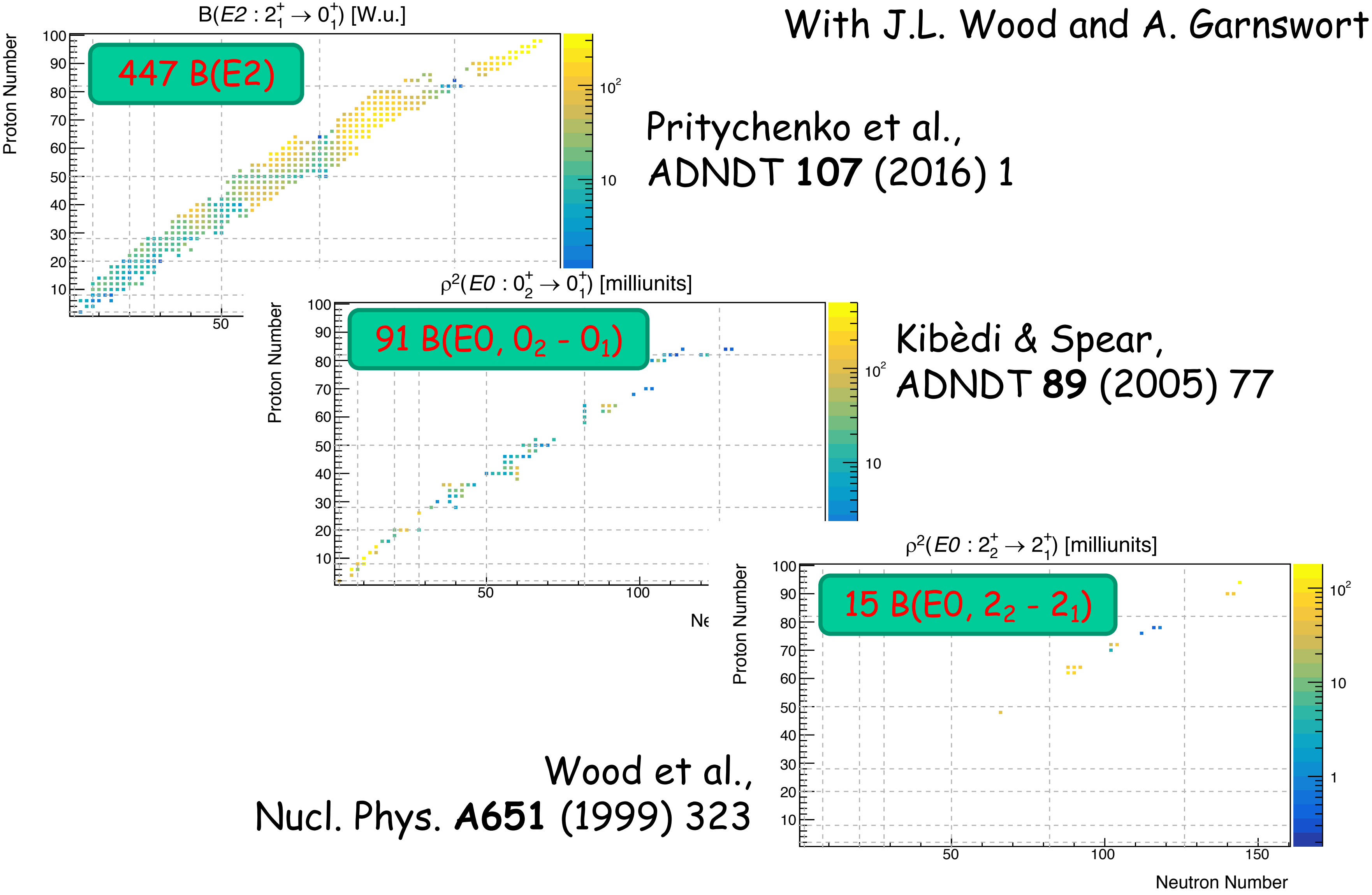


3.21γ E2 peak height : ~1 cts

2163(260) cts

Properties of Monopole transitions in atomic nuclei

With J.L. Wood and A. Garnsworthy



447 B(E2)

Pritychenko et al.,
ADNDT **107** (2016) 1

91 B(E0, 0_2 - 0_1)

Kibèdi & Spear,
ADNDT **89** (2005) 77

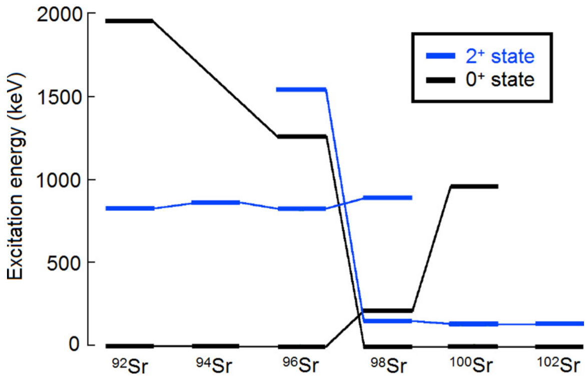
15 B(E0, 2_2 - 2_1)

Wood et al.,
Nucl. Phys. **A651** (1999) 323

Properties of Monopole transitions in atomic nuclei

Motivation:

With J.L. Wood and A. Garnsworthy

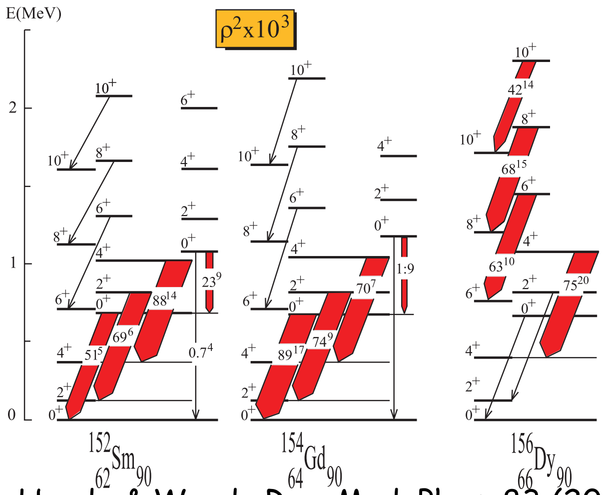


- New data since the last evaluations

First pass of ENSDF: 174 j-j (j>0) transitions

Eg=[41.9:1877] keV

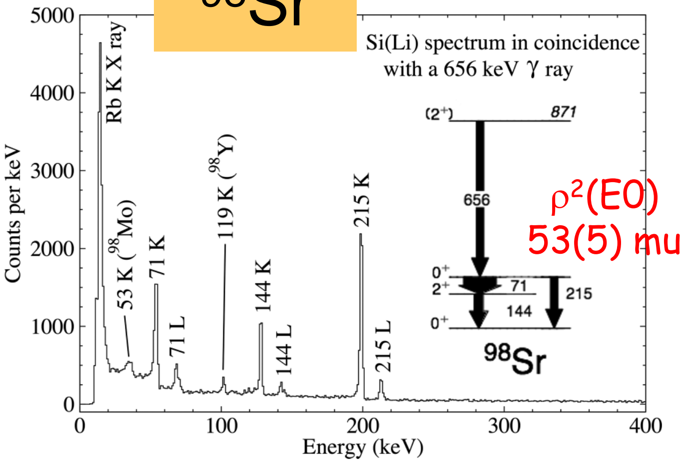
J_i=1[8], 2[109], 3[4], 4[32], 5[3], 6[6], 8[2], 9[1], 10[1], 16[1]



Heyde & Wood., Rev. Mod. Phys. 83 (2011) 1467

E0 strength model independent probe of co-existing structures –spin dependence

^{98}Sr



Si(Li) spectrum in coincidence with a 656 keV γ ray

ρ^2(E0) 53(5) mu

Park et al., PRC 93, 014315 (2016)

Strongly deformed g.s., weakly deformed 0^+ at 215 keV

Properties of Monopole transitions in atomic nuclei

With J.L. Wood and A. Garnsworthy

Approach

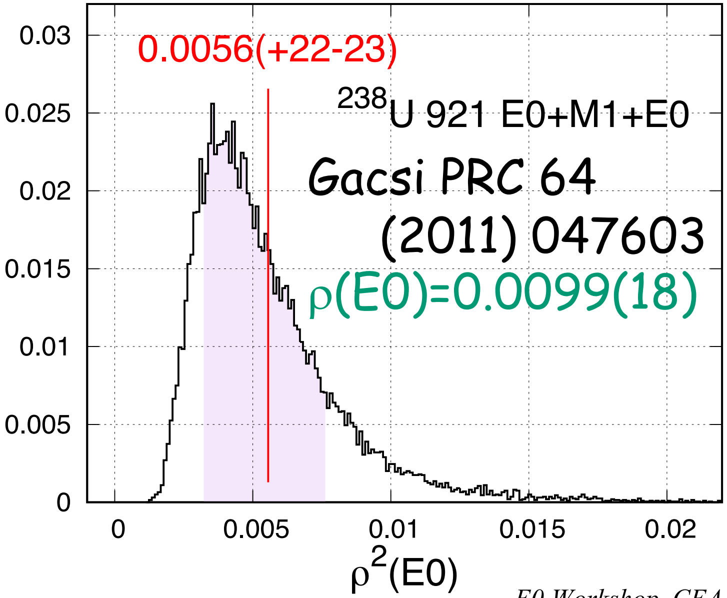
- Consistent treatment of the data known
  - ☐ Combine data on $0^+ \rightarrow 0^+$ and $J^+ \rightarrow J^+$ (J>0) transitions
  - ☐ Collect and adopt T1/2, EM branching ratios, multipolarities, mixing ratios, experimental conversion coefficients <u>from original references</u>
  - ☐ Accept data if: T1/2, ICC and mixing ratio are known
- New conversion coefficients, Ω(E0) electronic factors

^{238}U 966.1 keV 2^+

$T_{1/2}$=2.4(+17-7) ps

921.2 keV E0+M1+E2

α_K = 0.191(30)
α_K(M1)= 0.0390
α_K(E2)= 0.00966



Gacsi PRC 64 (2011) 047603

ρ(E0)=0.0099(18)

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- T.G. Tornyi

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- A. Akber
- J. Dowie (Ω_{CE} calculations)
- M. Gerathy
- B.Q. Lee
- M. de Vries
- T. Palazzo

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