Life & Death of Superdeformed Nuclei

A. Lopez-Martens

IJCLab, Orsay

ELSEVIER

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Review

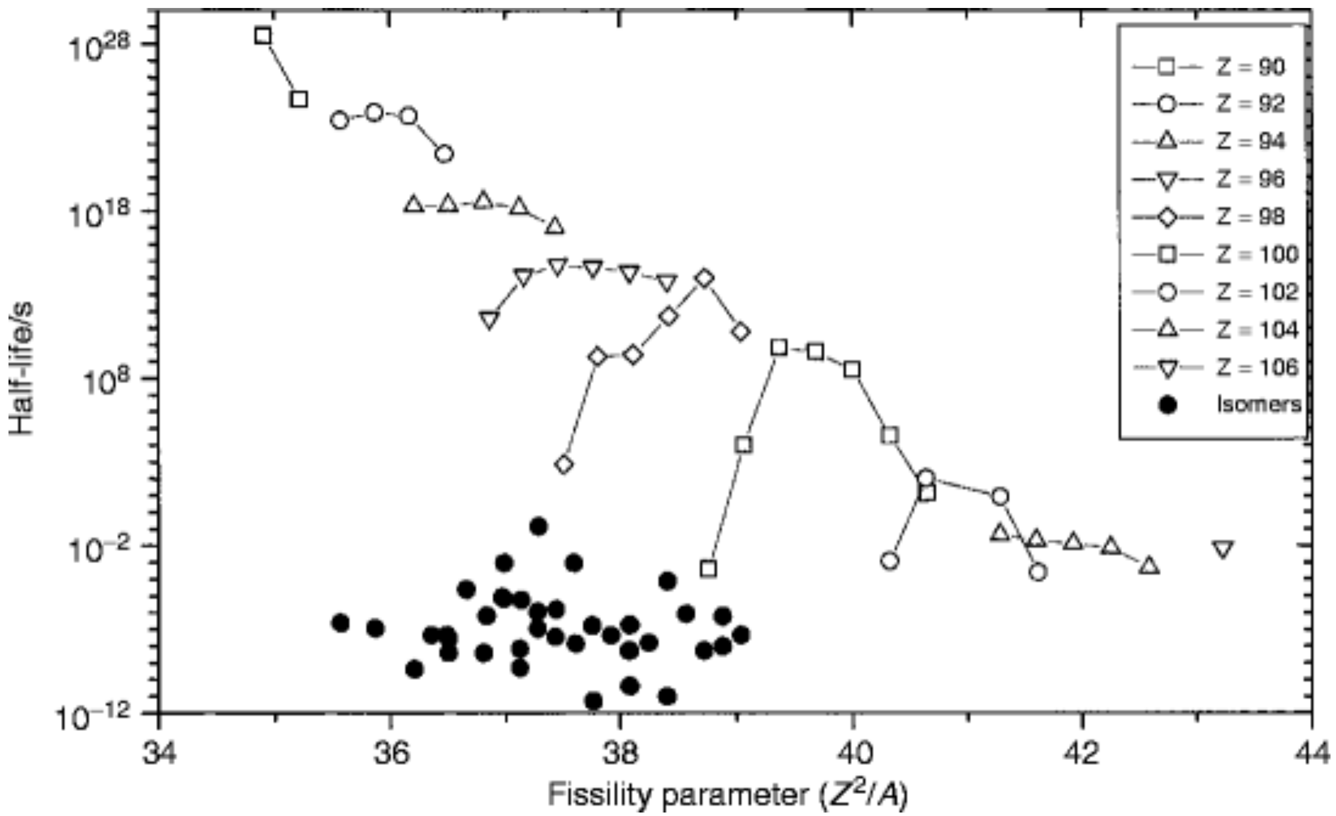
Population and decay of superdeformed nuclei probed by discrete and quasi-continuum γ-ray spectroscopy

A. Lopez-Martens [a], T. Lauritsen [b], S. Leoni [c d], T. Døssing [e], T.L. Khoo [b], S. Siem [f]

Discovery of Superdeformation

First observation of a fission isomer : ^{242}Am

S. Polikanov *et al.* Sov.Phys.JETP **15** (1962)



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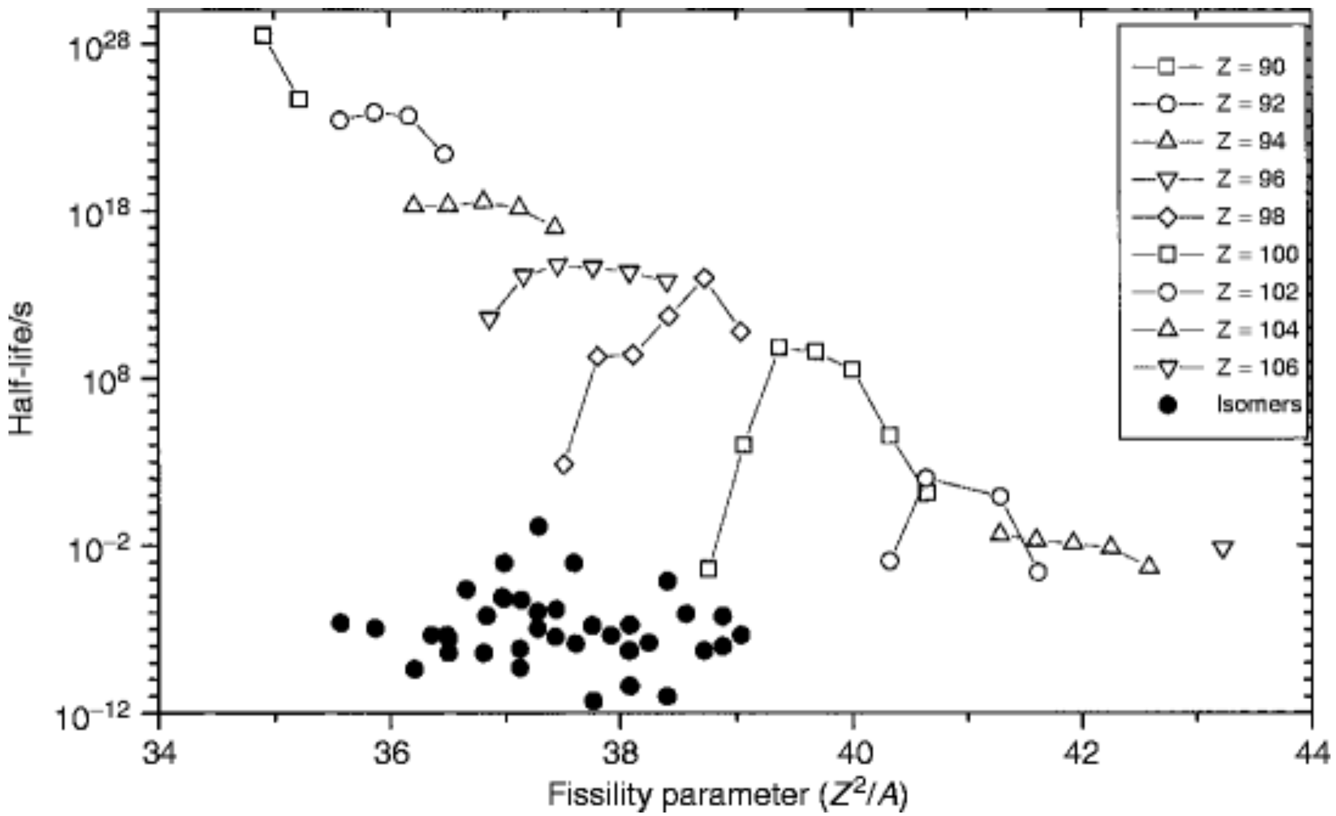

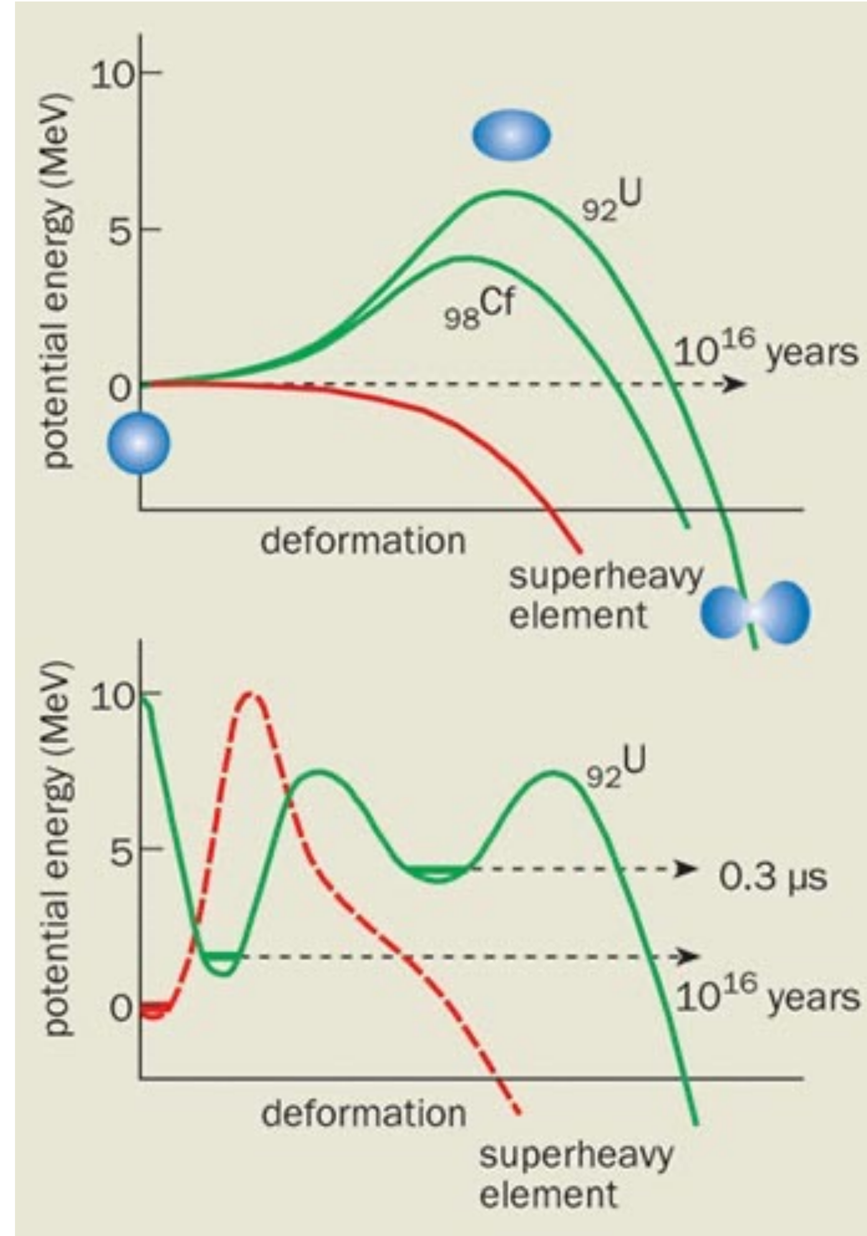

V.M. Strutinski, Nucl. Phys. A **95** (1967) 420

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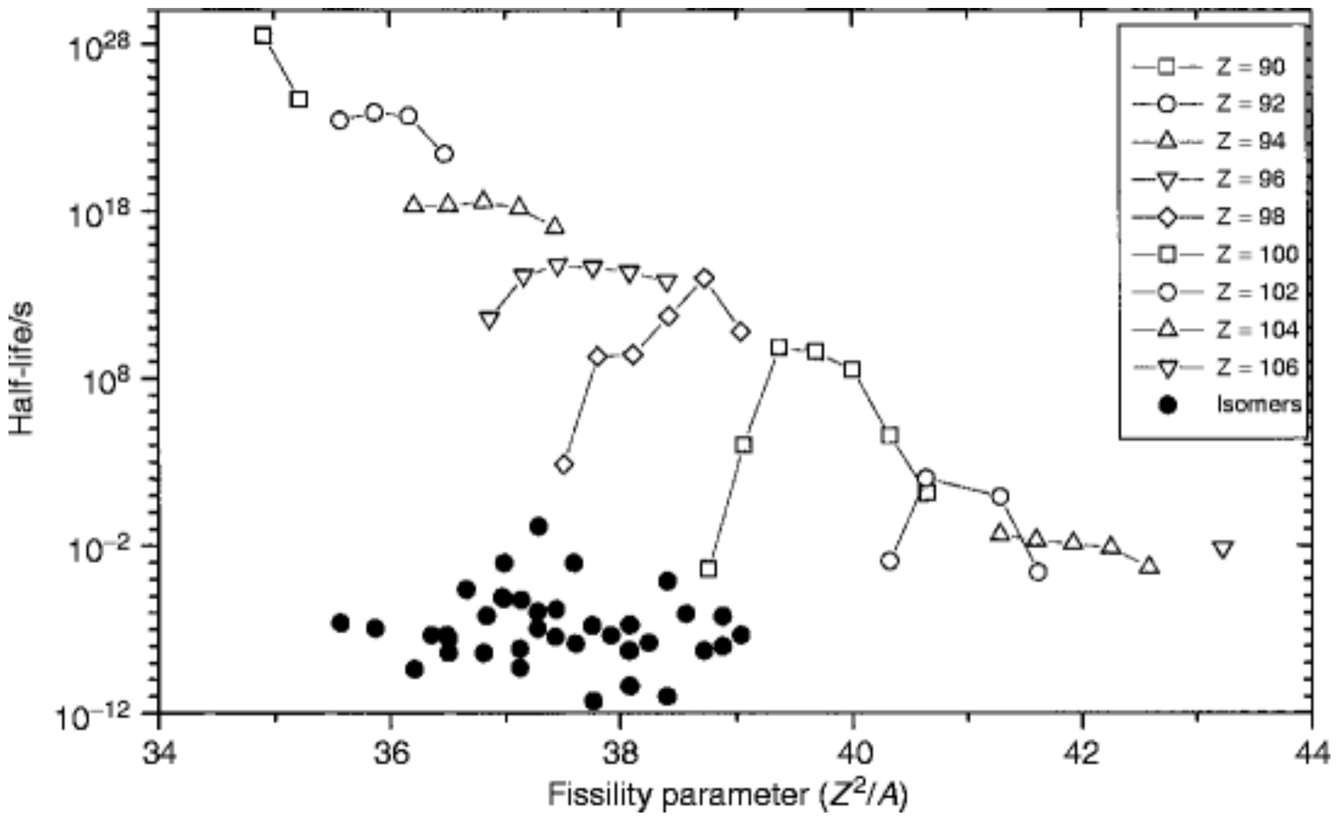
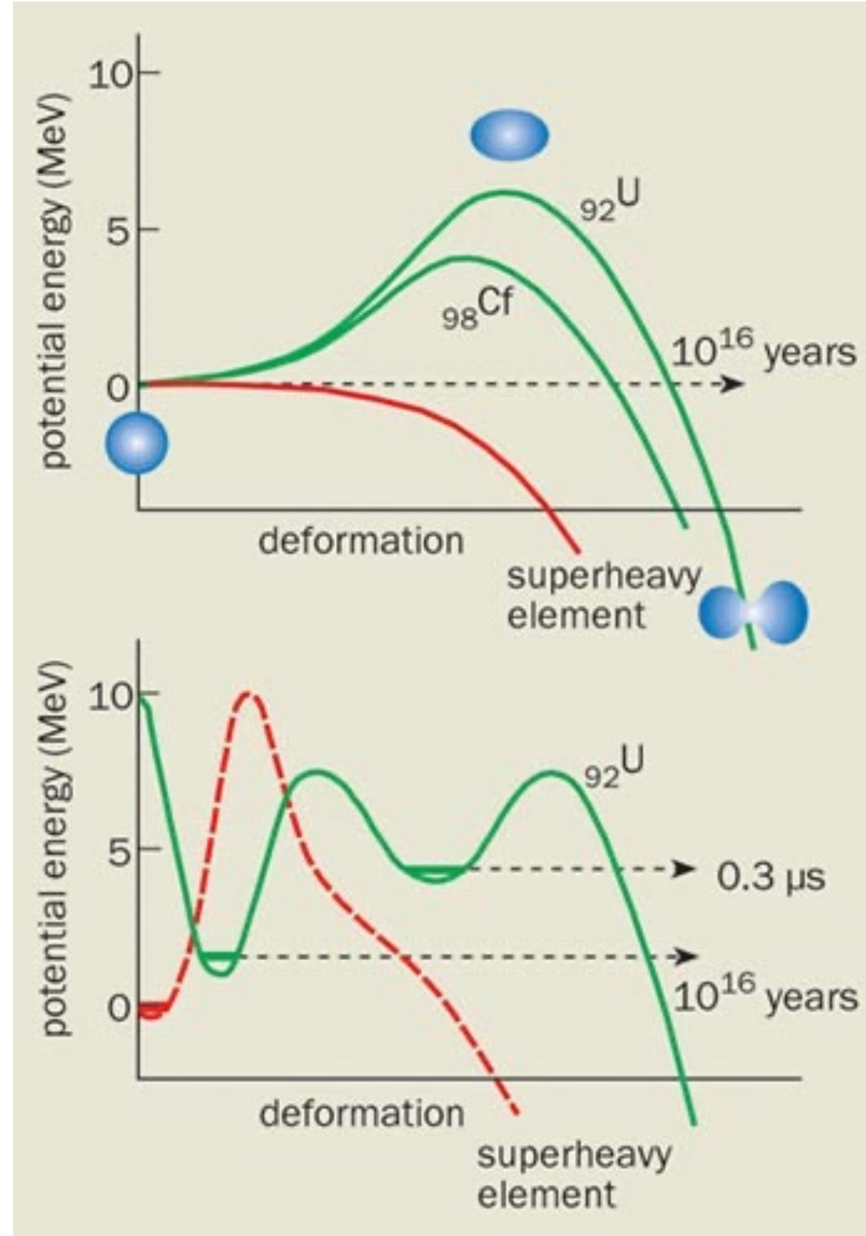


Lifetime measurement of states in the 2nd well of ^{239}Pu (charge plunger)

Q_o: 36 ± 4 eb ⇨ c/a ~ 2

D. Habs, V. Metag, H.J. Specht and G. Ulfert, Phys. Rev. Lett. 38 (1977) 387



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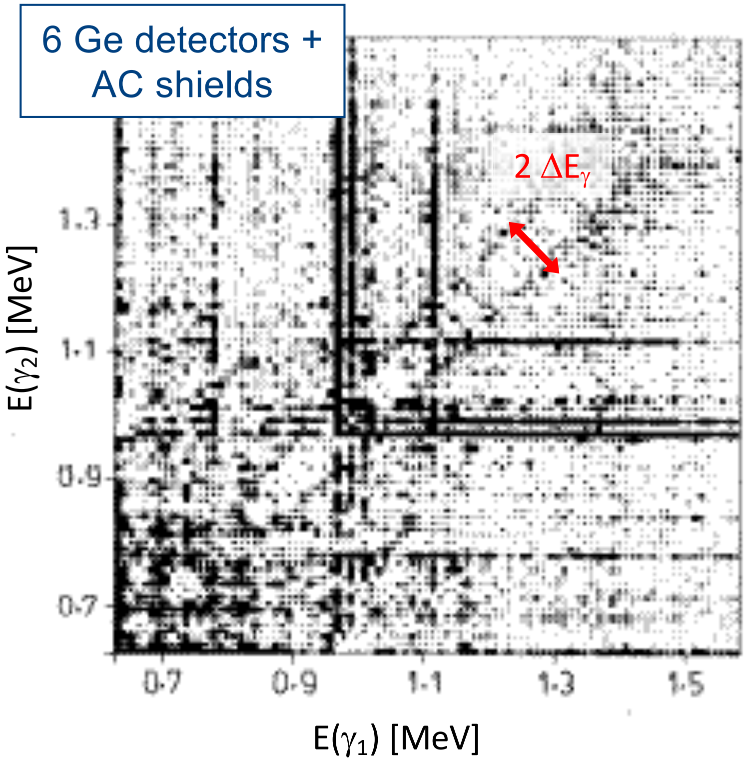
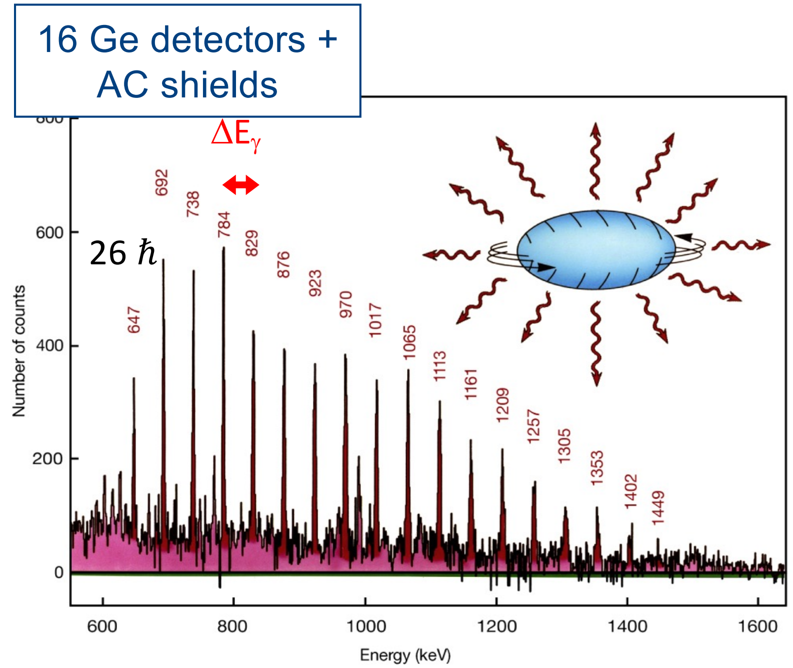
Superdeformation @ high spin



B.M. Nyako et al. Phys. Rev. Lett., 52:507, 1984



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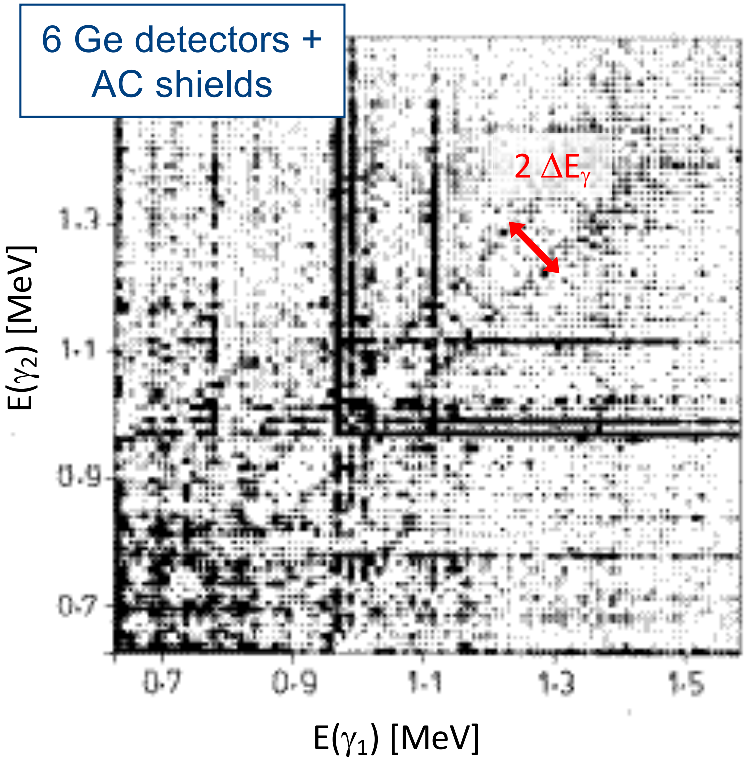

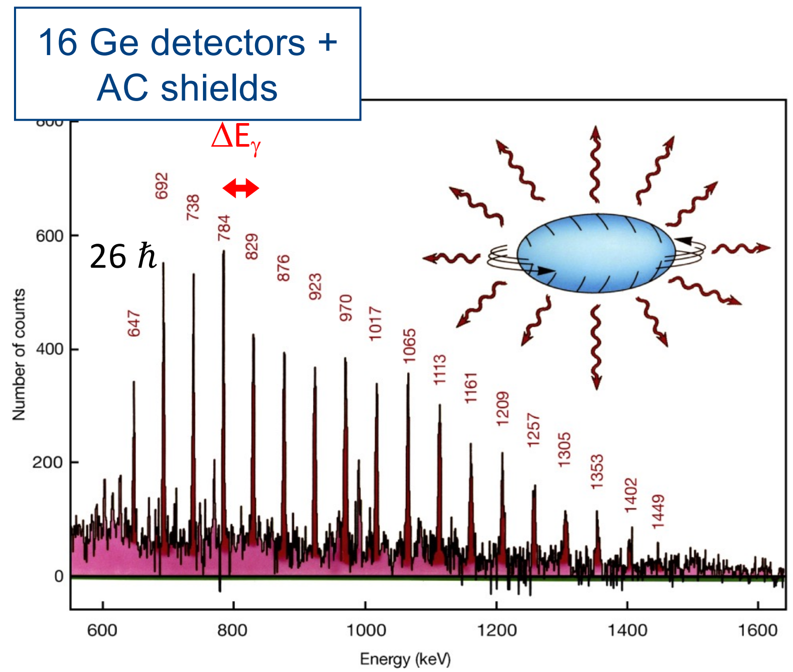

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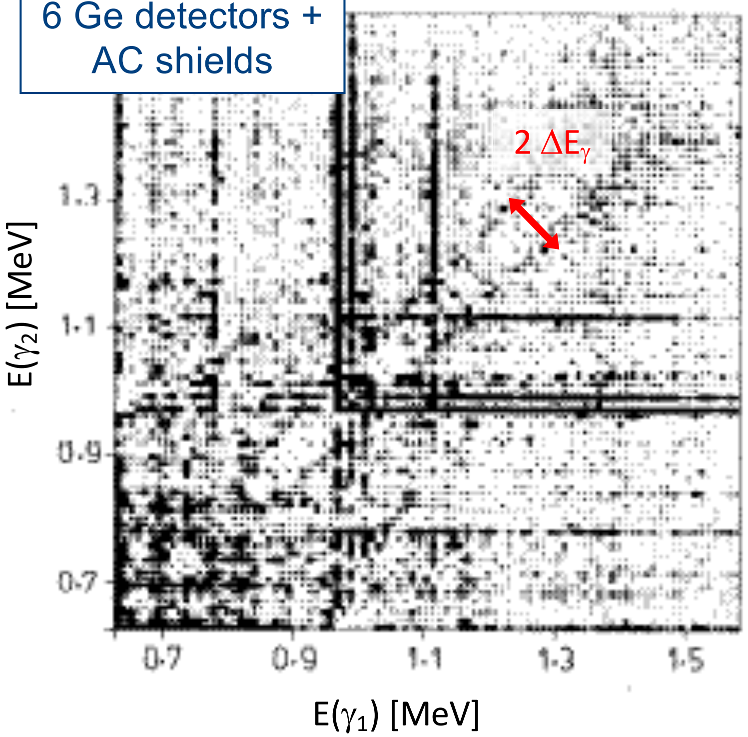
'Top unexpected physics discoveries of the last five years'
(D. Kleppner, Physics Today, 1991)

Superdeformation @ high spin

6 Ge detectors + AC shields



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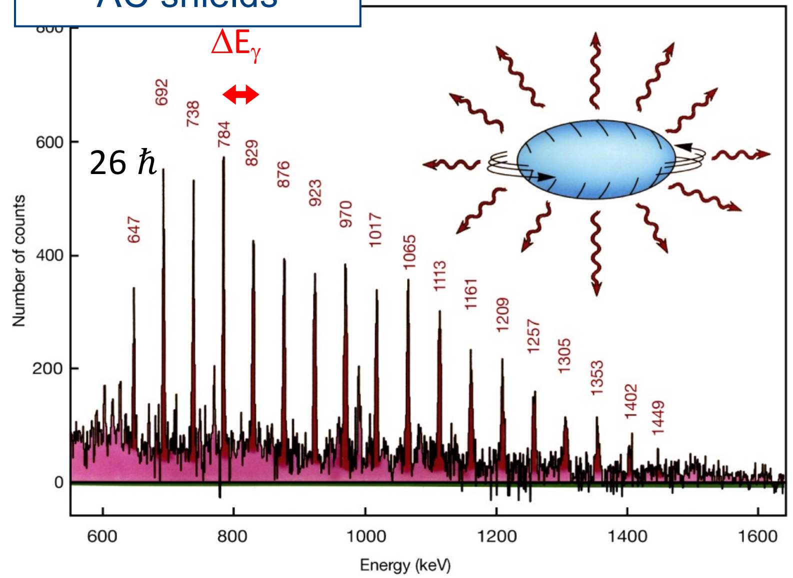
16 Ge detectors + AC shields



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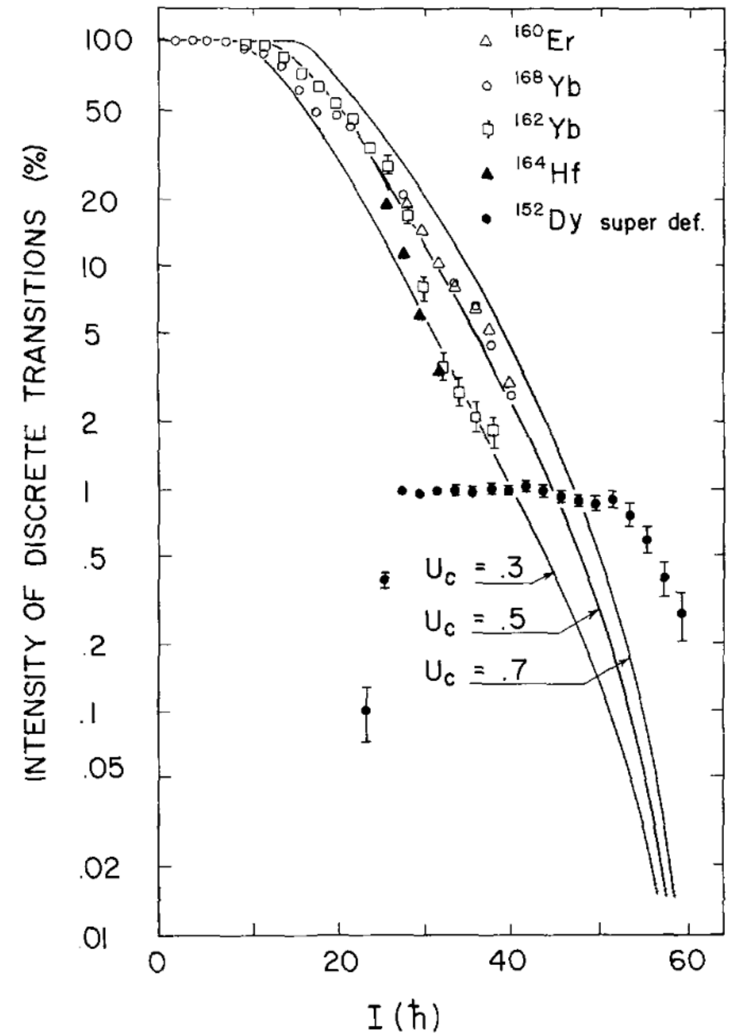

K. Schiffer and B. Hershkind, Phys. Lett. B 255 (1991) 508

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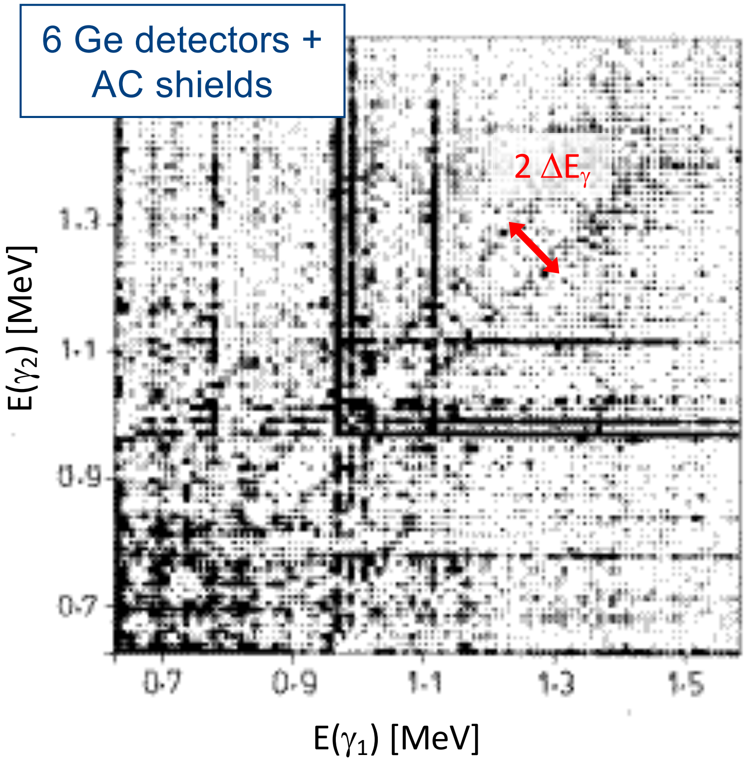

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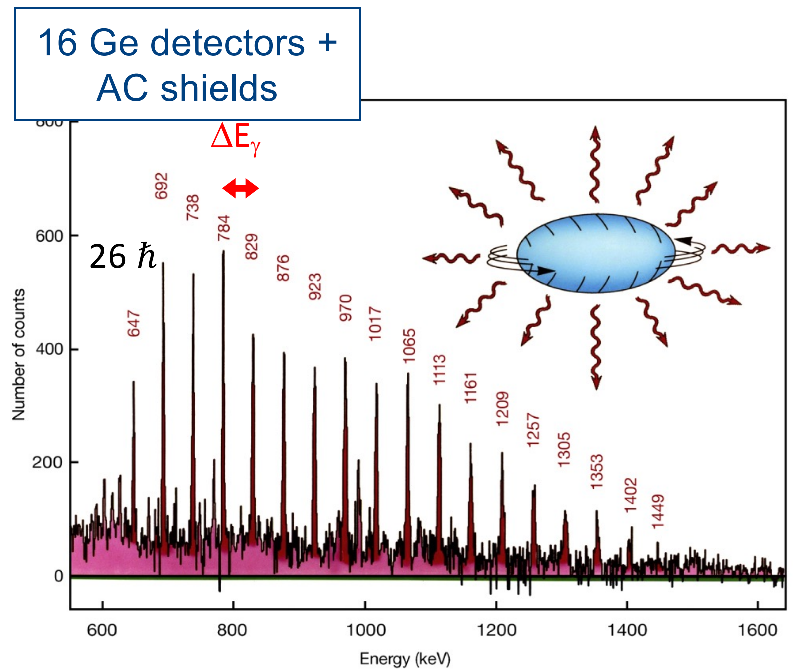

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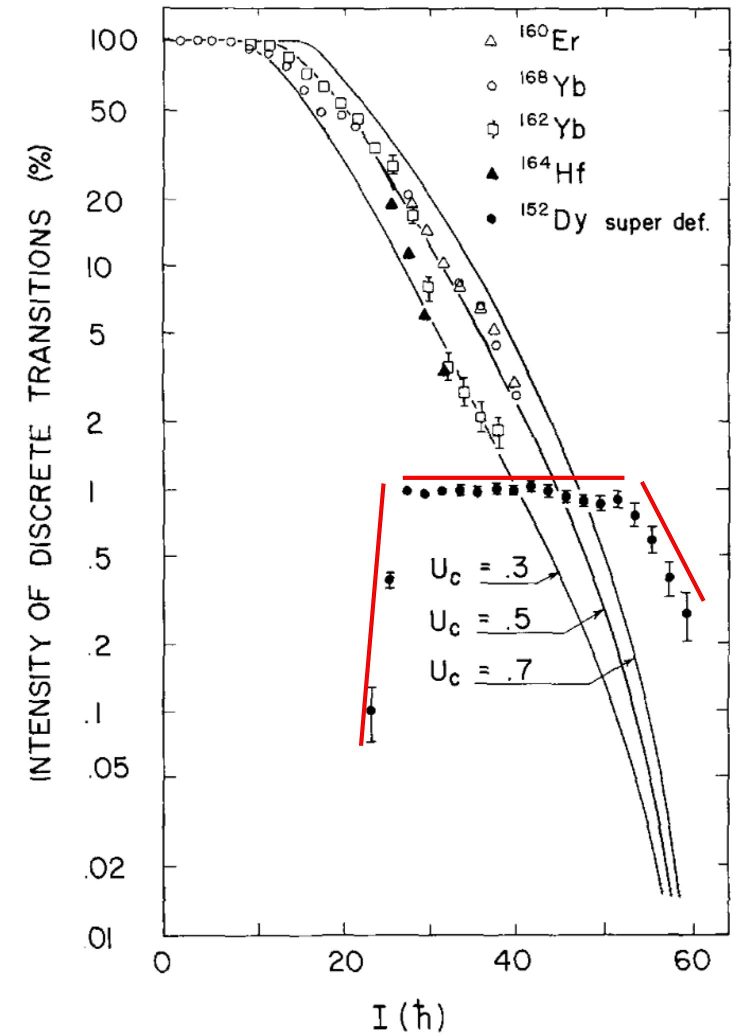

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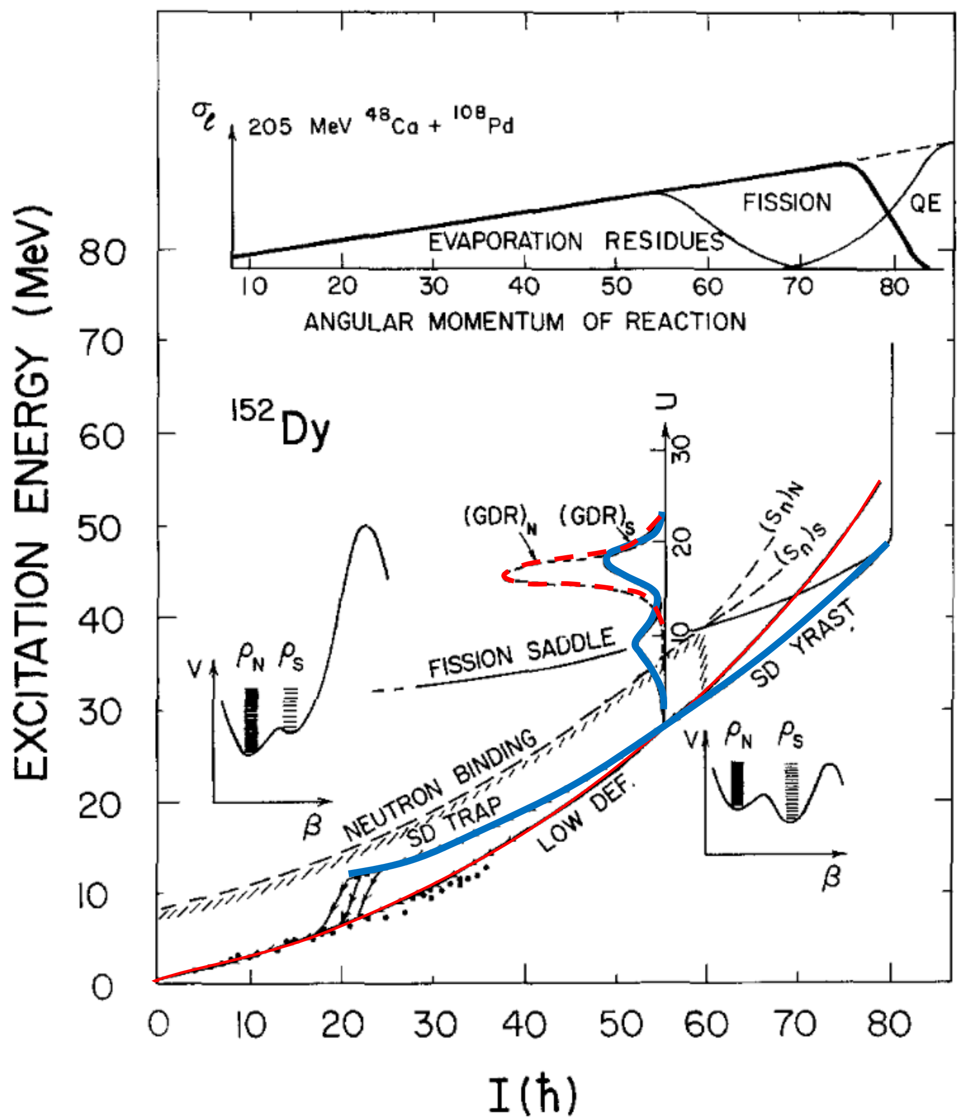
Modelling the population & decay

B. Herskind et al., Phys. Rev. Lett. 59 2416 (1987)



Main ingredients: ND & SD yrast lines, level densities, E1 & E2 decay, strength functions, tunneling & pairing

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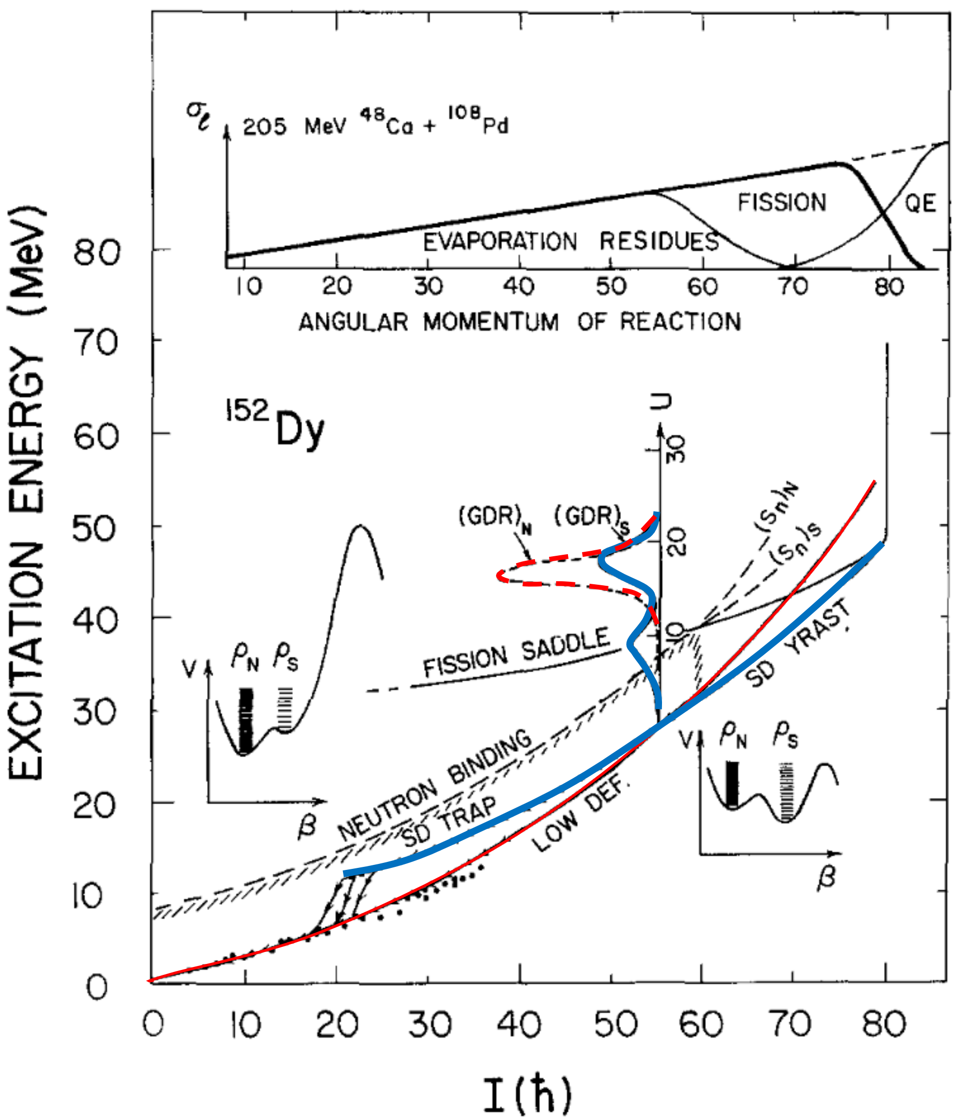

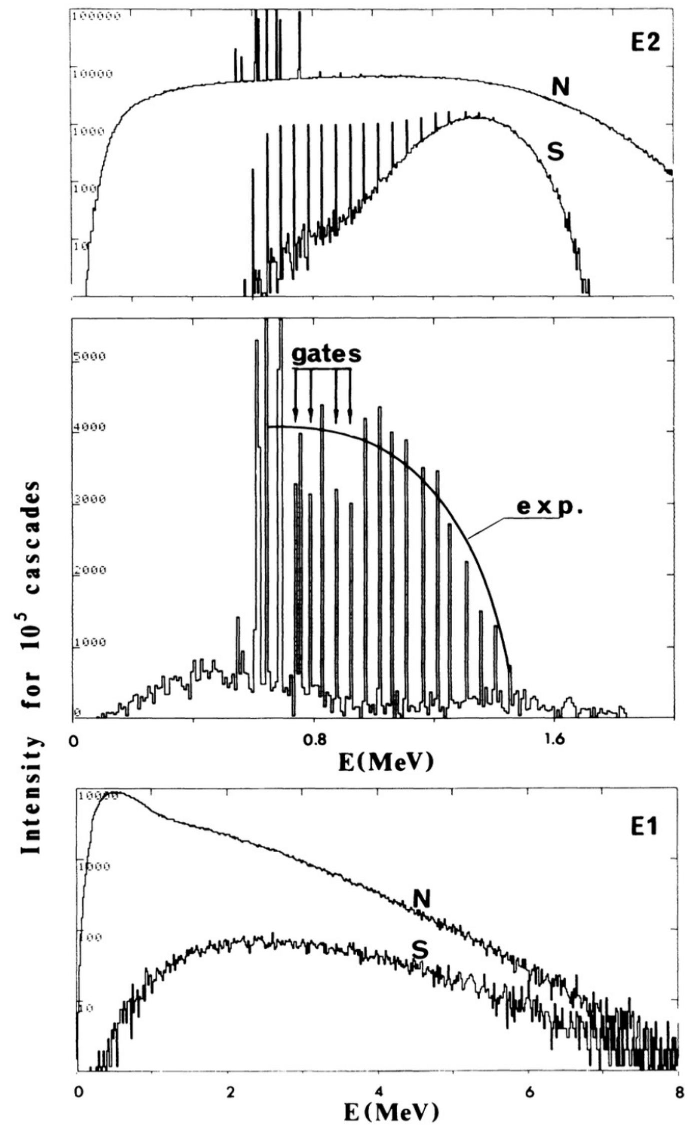

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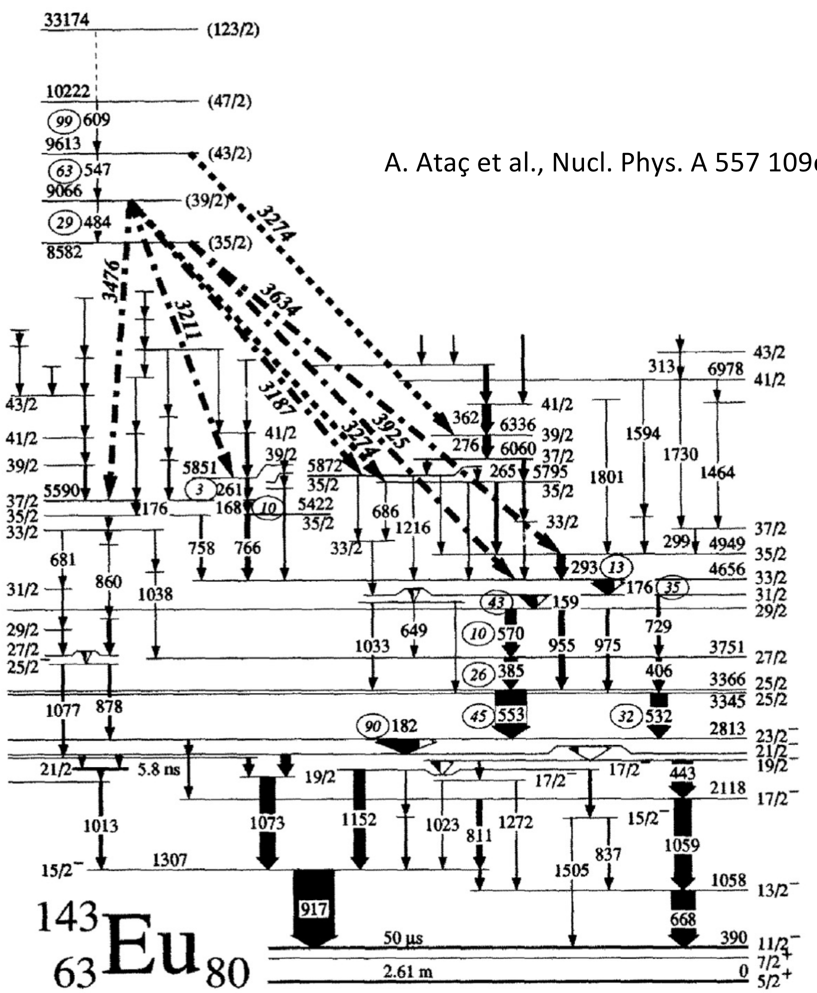
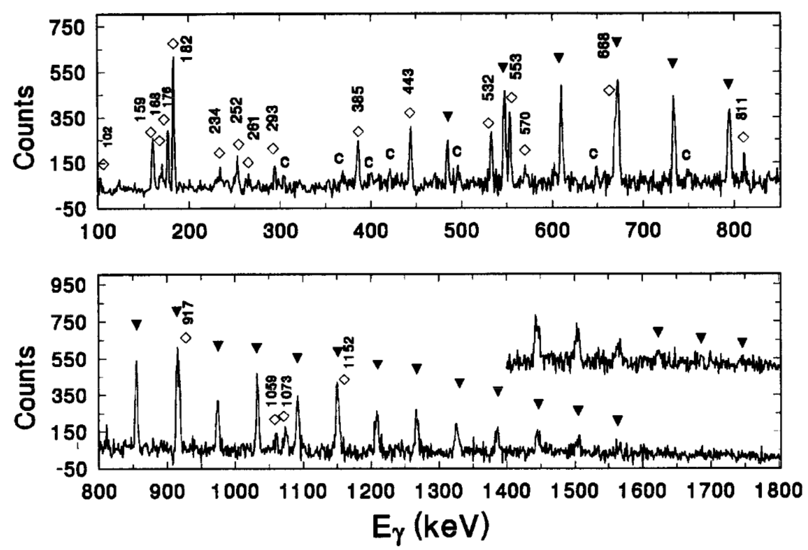
Superdeformed ^{143}Eu



A. Ataç et al., Nucl. Phys. A 557 109c (1993)

NORDBALL
20 Ge detectors + AC shields
+ BaF2 inner ball



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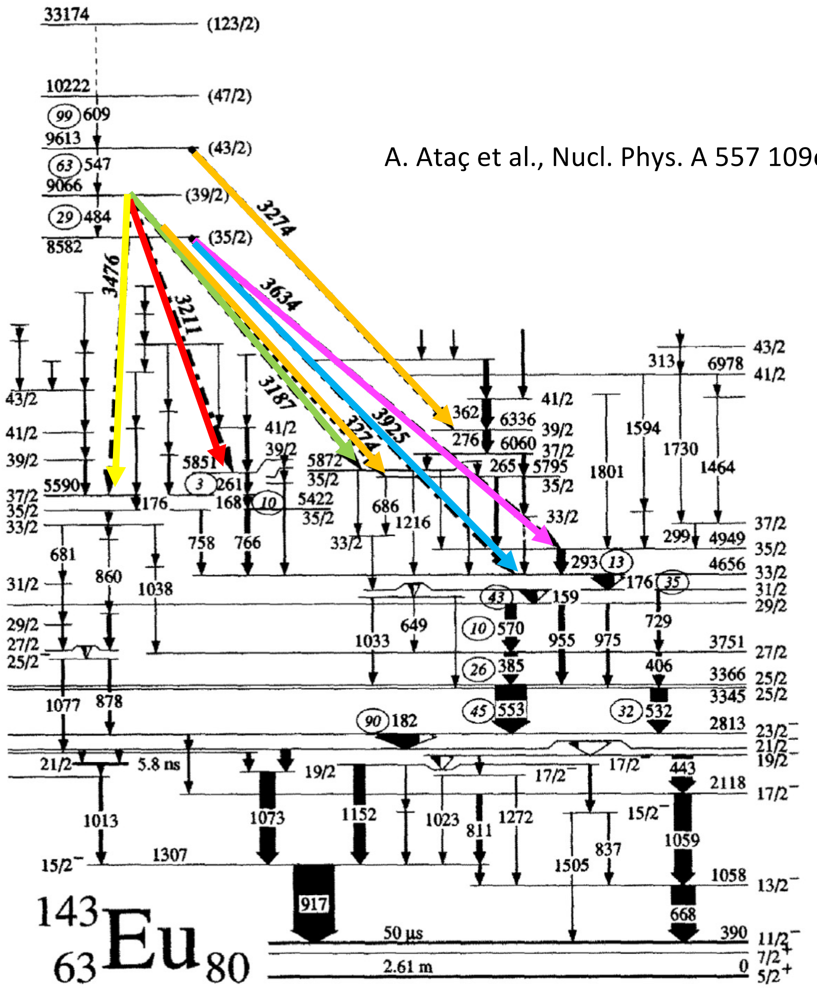

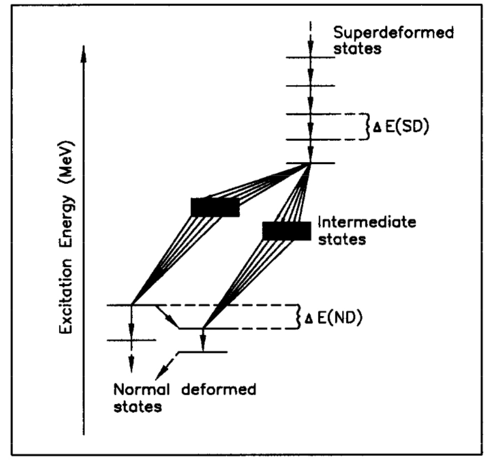

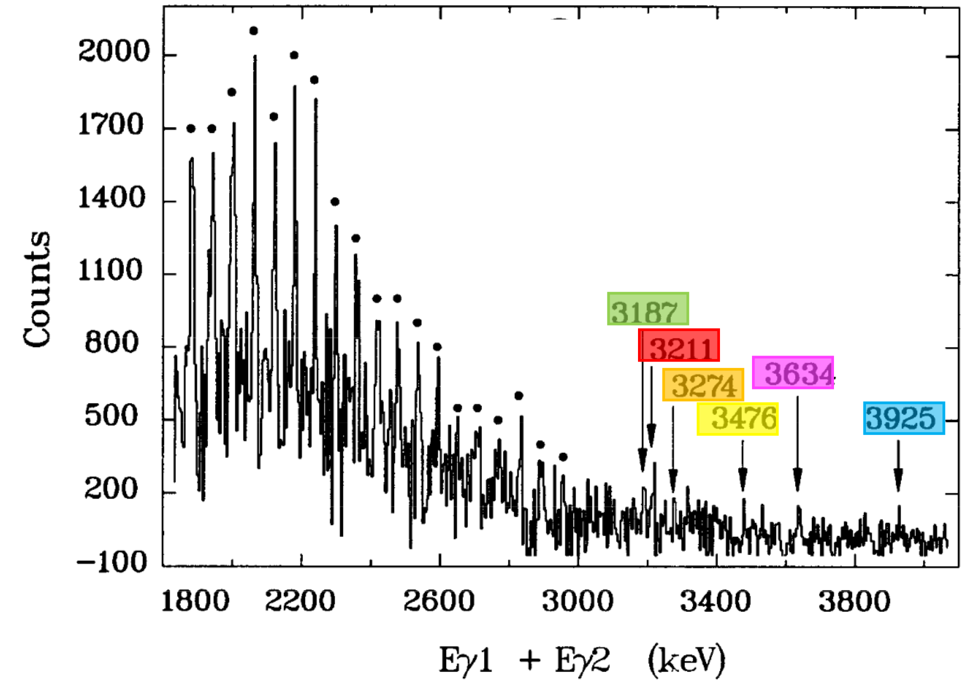

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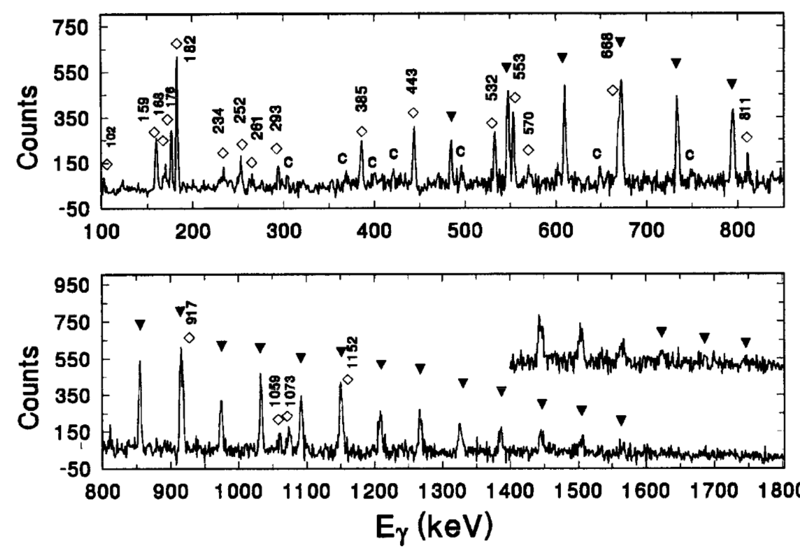

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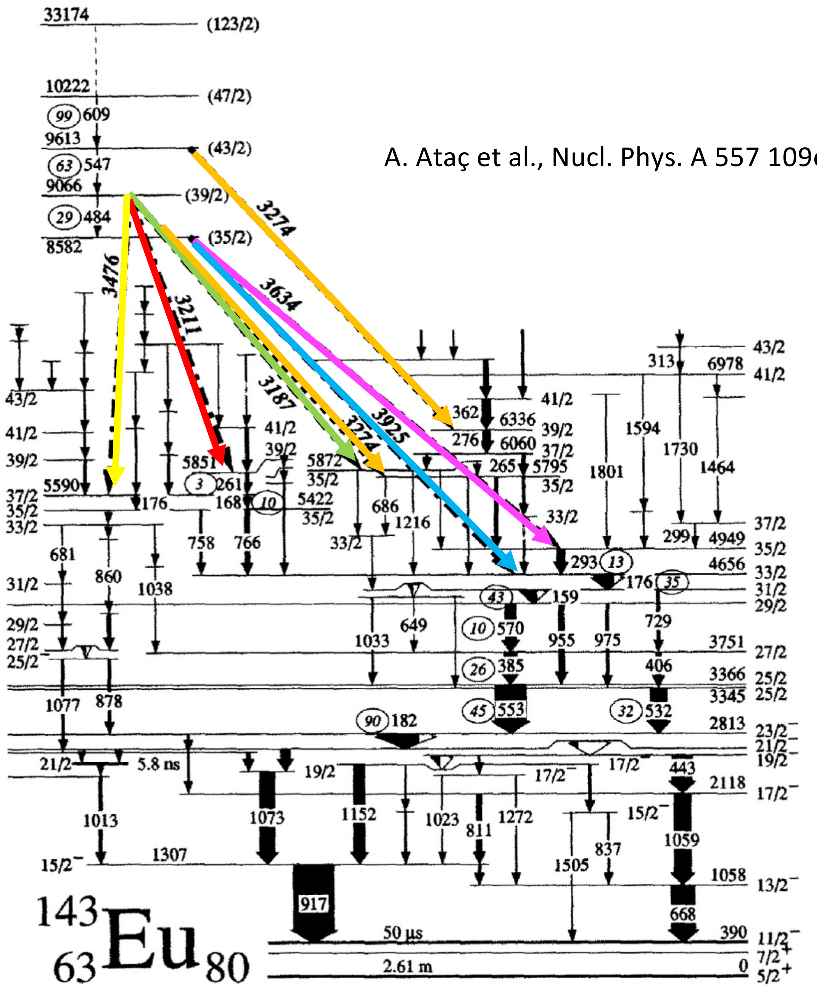

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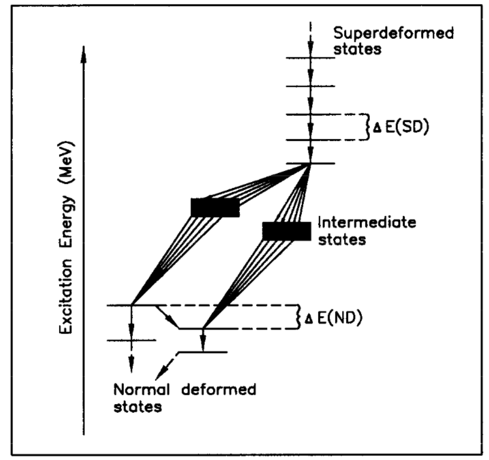

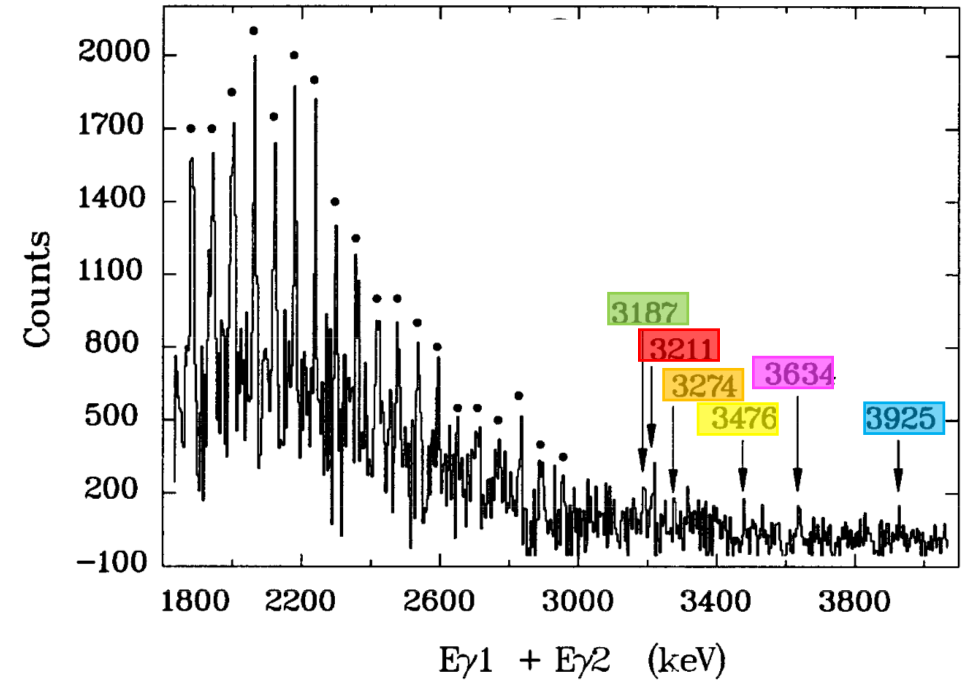

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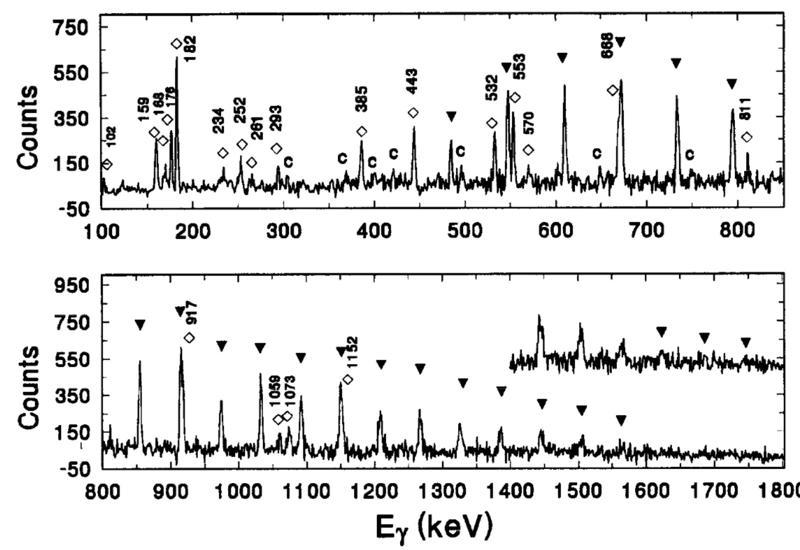

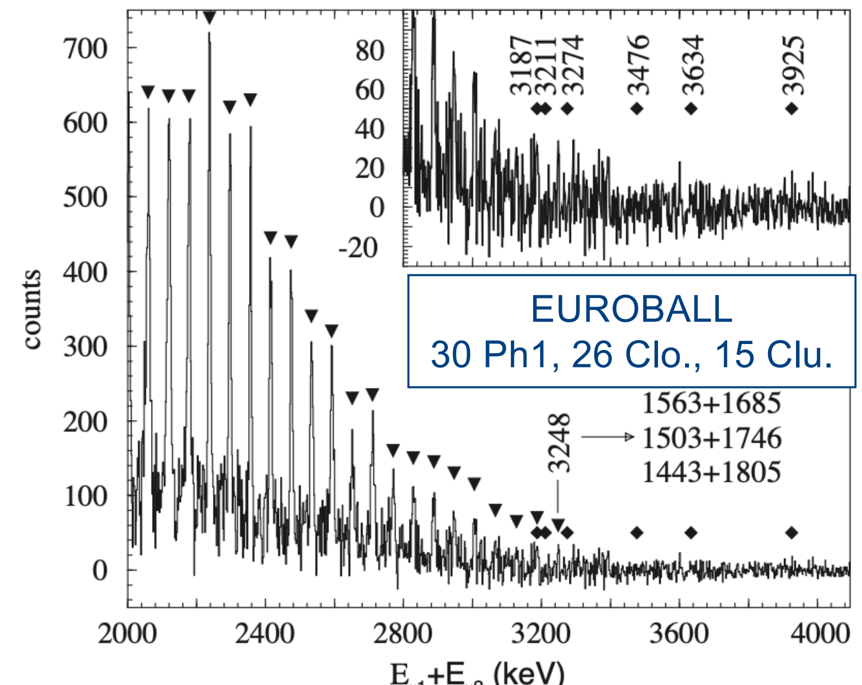

EUROBALL
30 Ph1, 26 Clo., 15 Clu.

A. Axelsson et al., Eur. Phys. J. A 6 175 (1999)

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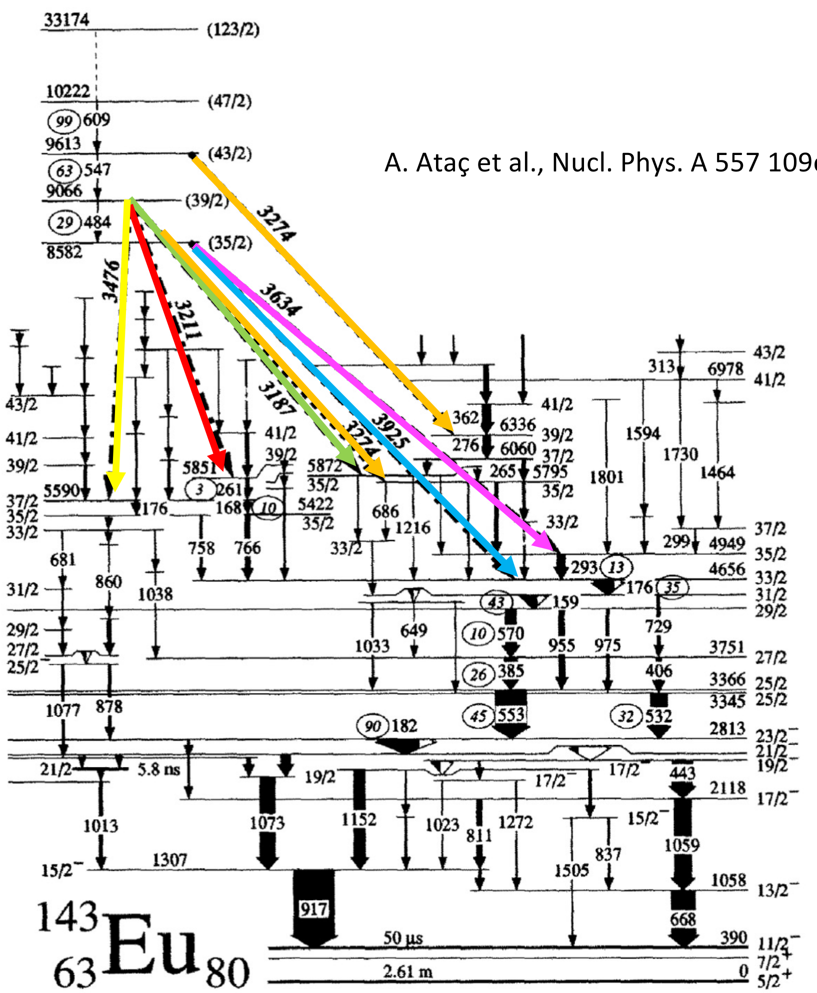

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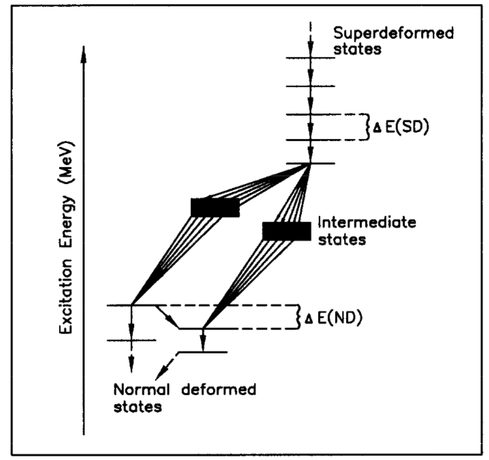

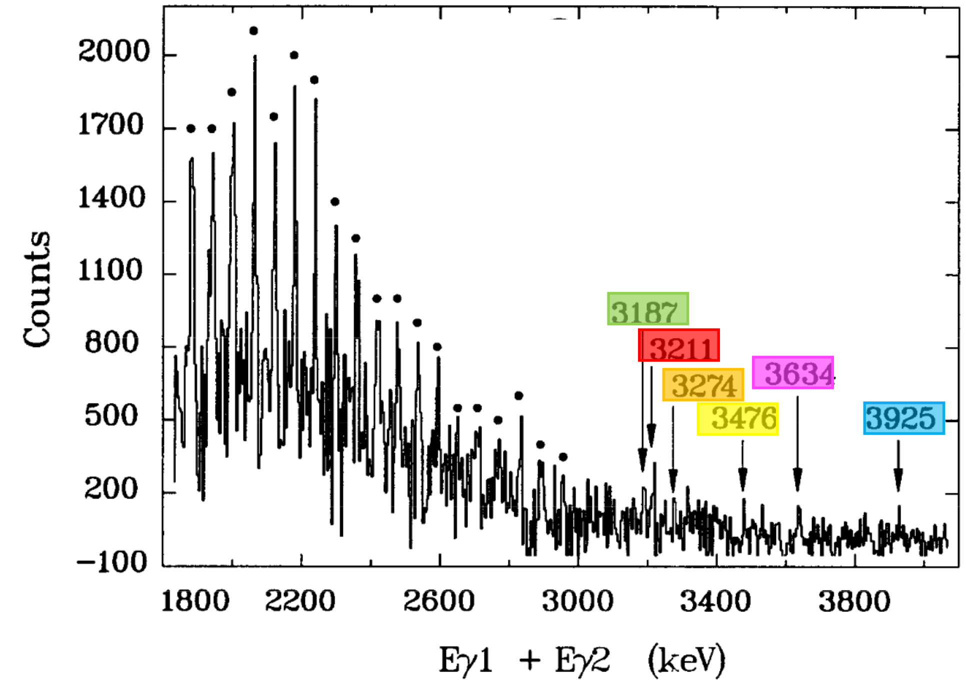

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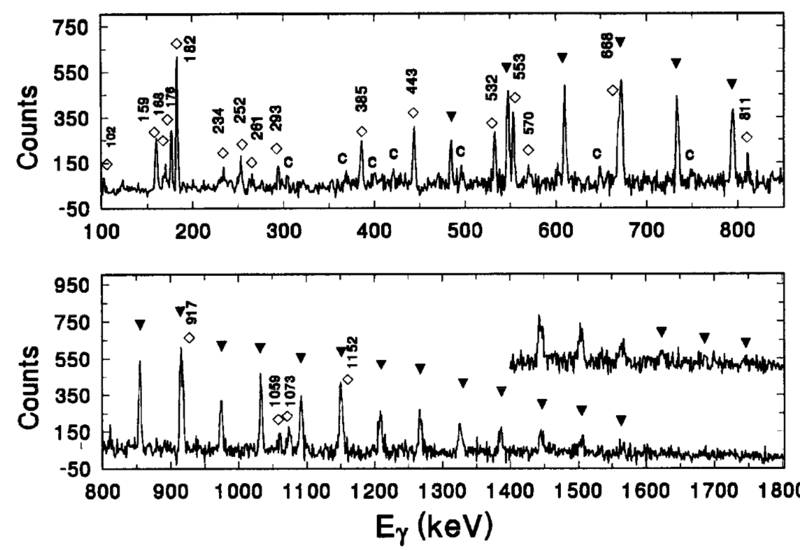

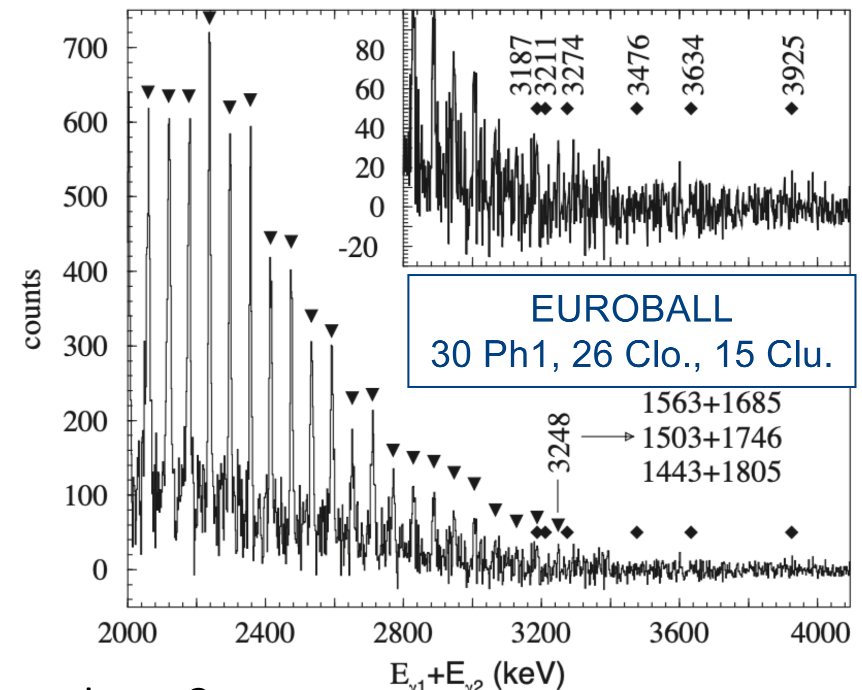

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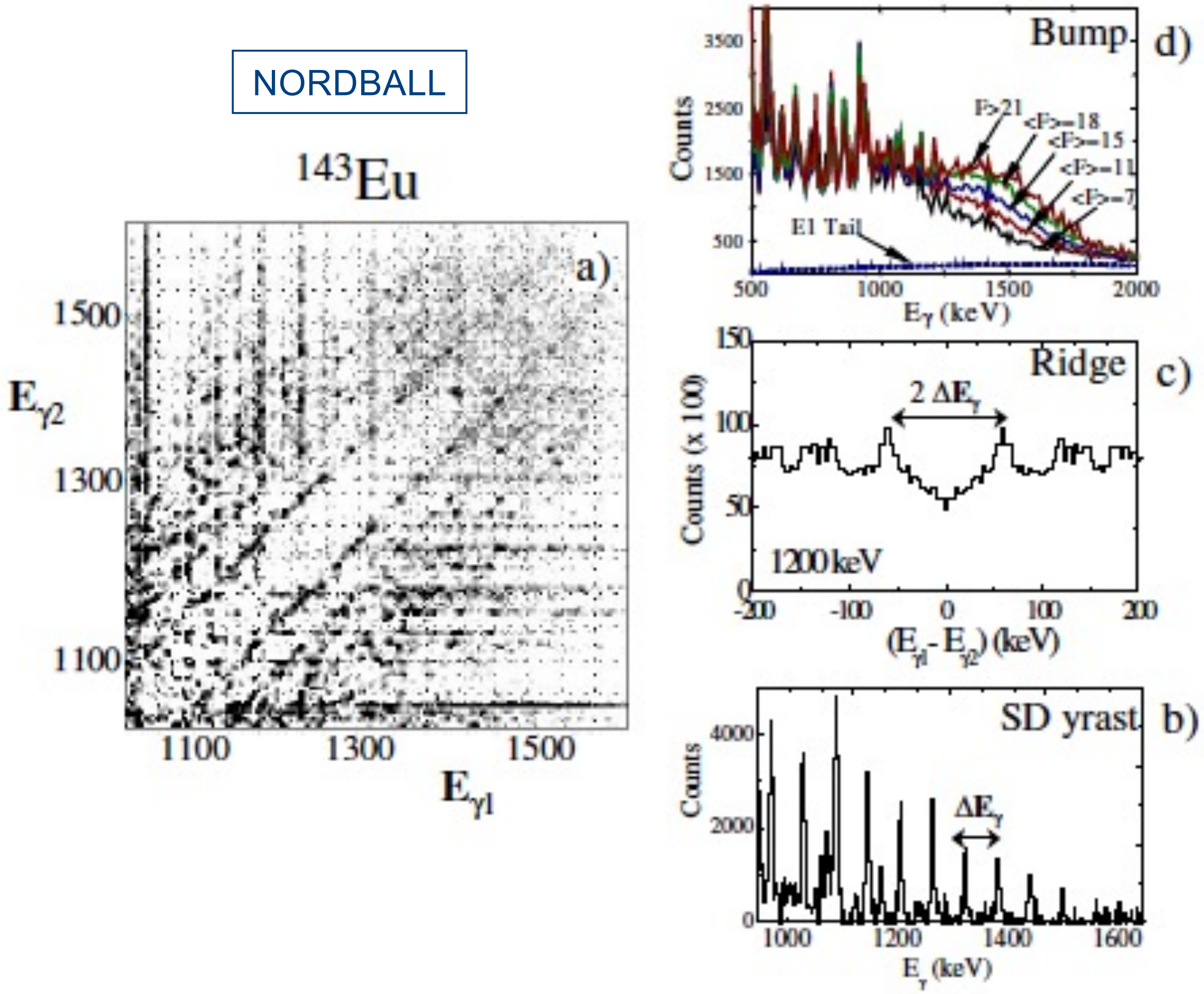
Failure of the sum method: Need to sum more than 2 transitions ? Combinatorial conundrum ?

A. Axelsson et al., Eur. Phys. J. A 6 175 (1999)

Detailed studies of ^{143}Eu

S. Leoni et al., Phys. Rev. Lett 76, 3281 (1996)

NORDBALL



S. Leoni et al., Phys. Lett. B 409 71 (1997)

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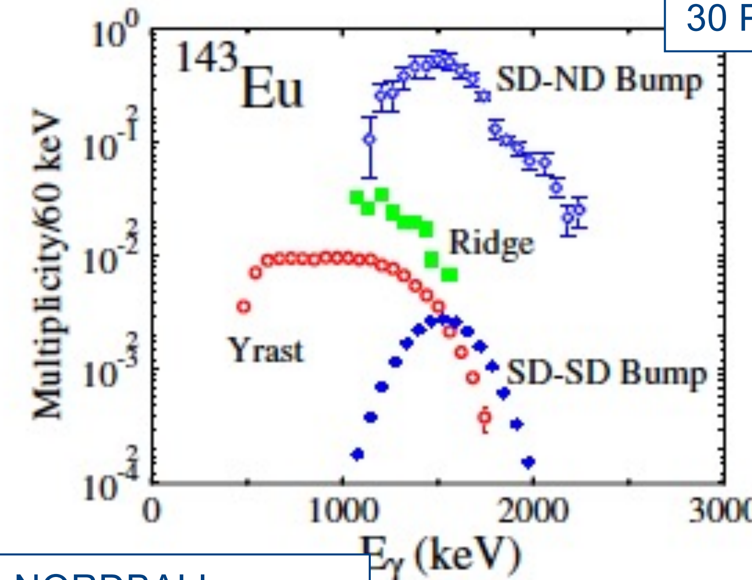
EUROGAM2
30 Ph1. 26 Clo.



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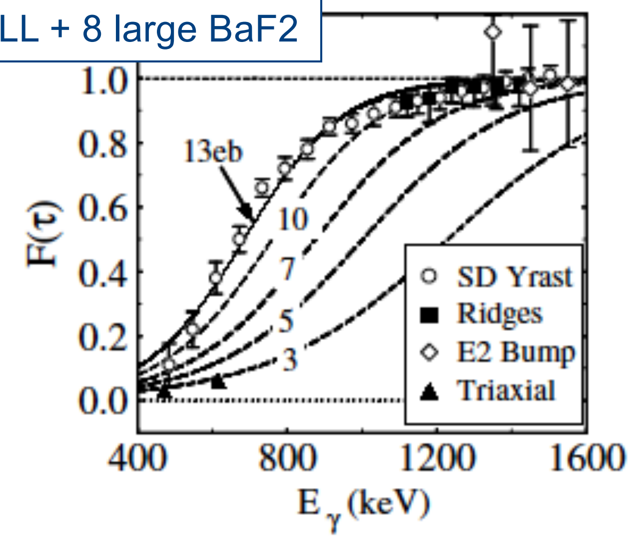
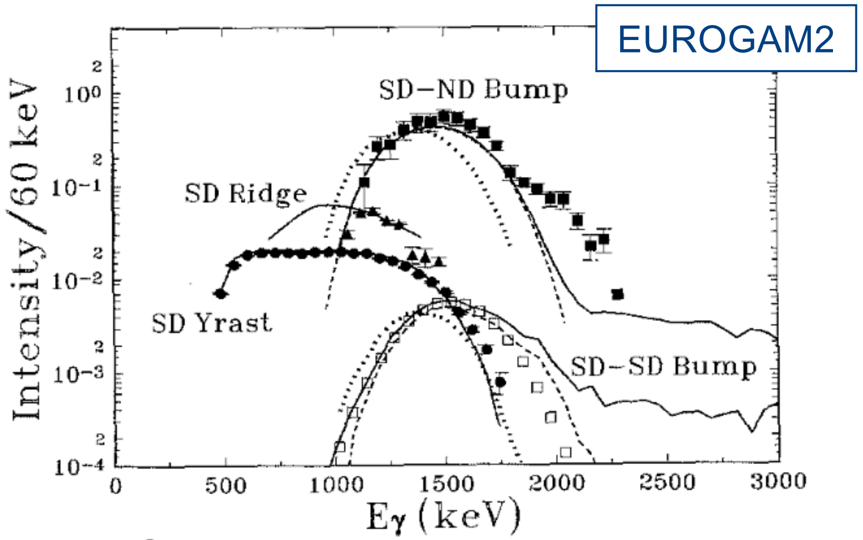
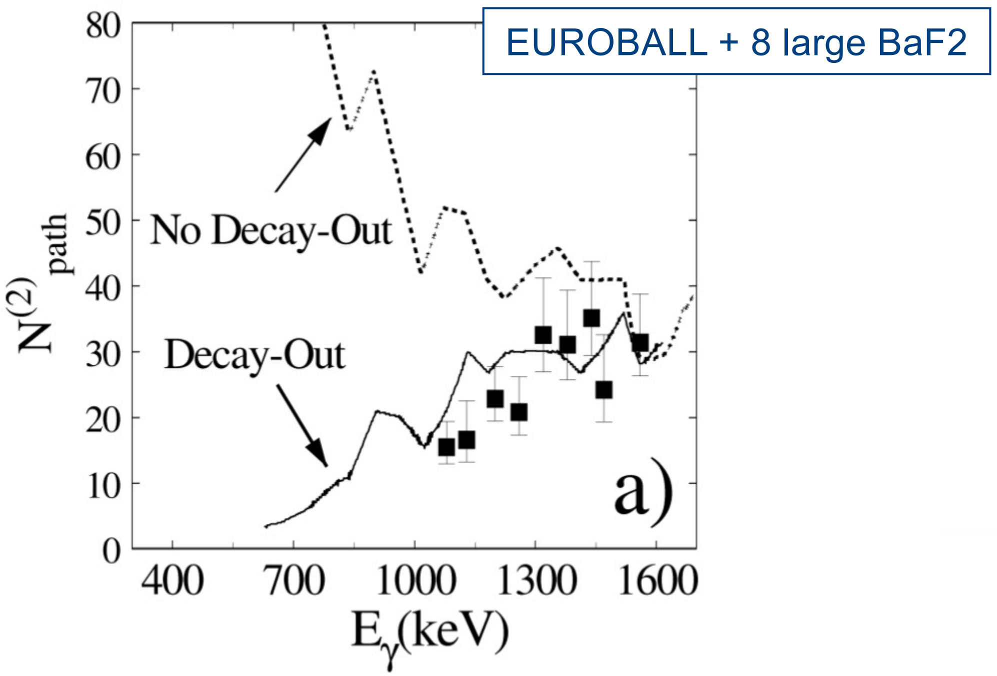
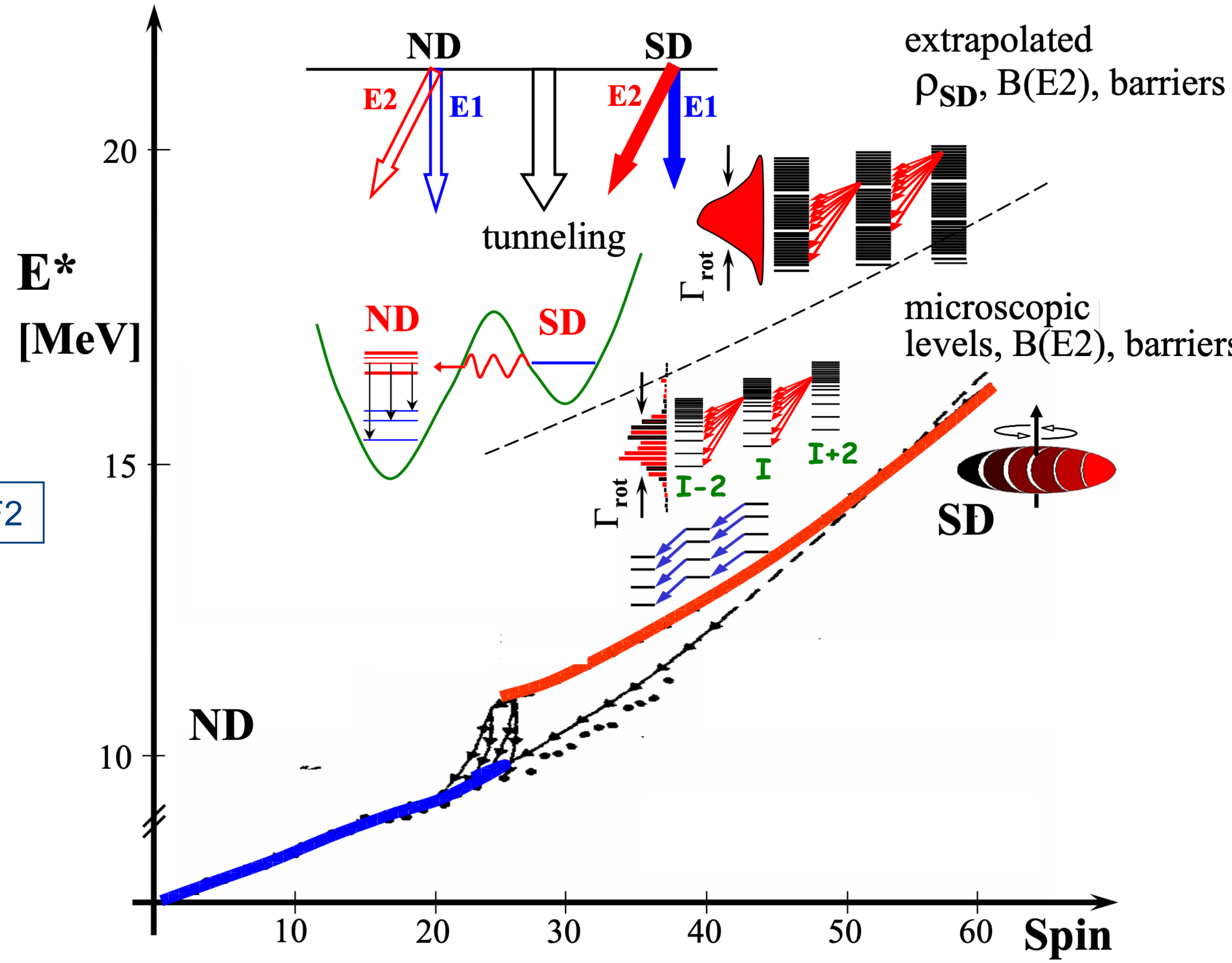


S. Leoni et al., Phys. Lett. B 498 137 (2001)

Detailed modelling of ^{143}Eu







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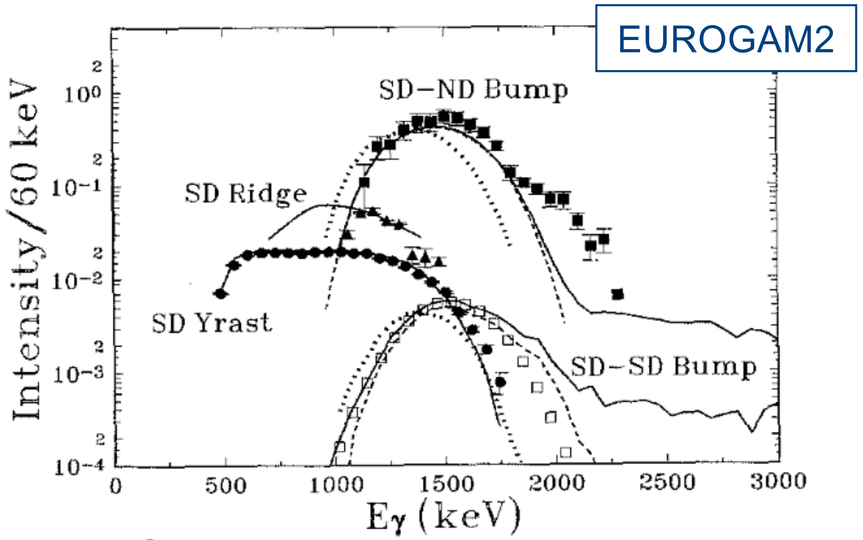
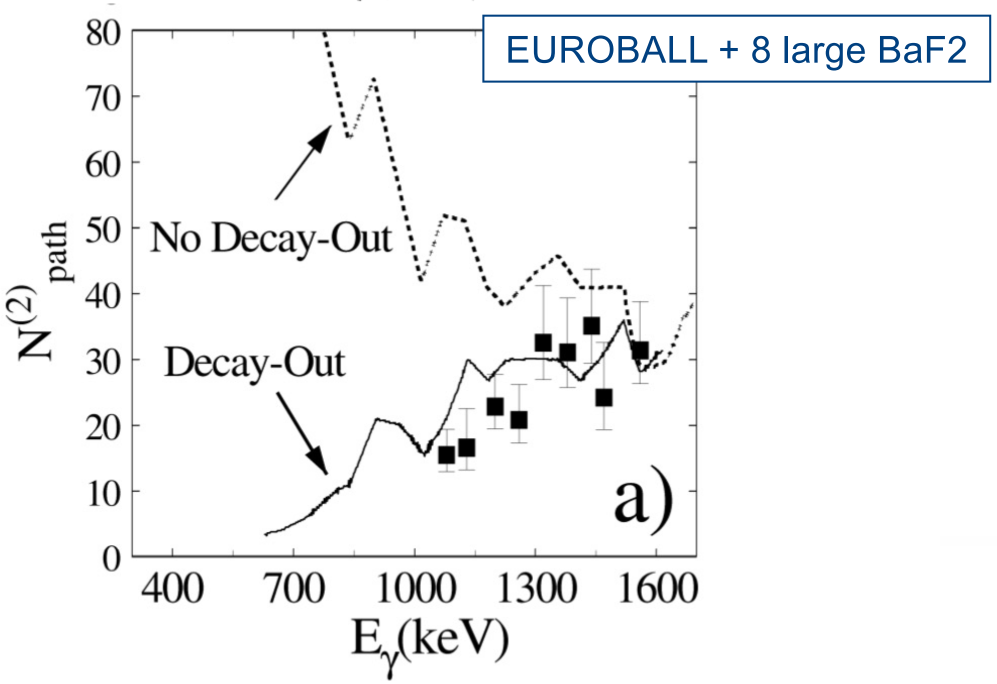
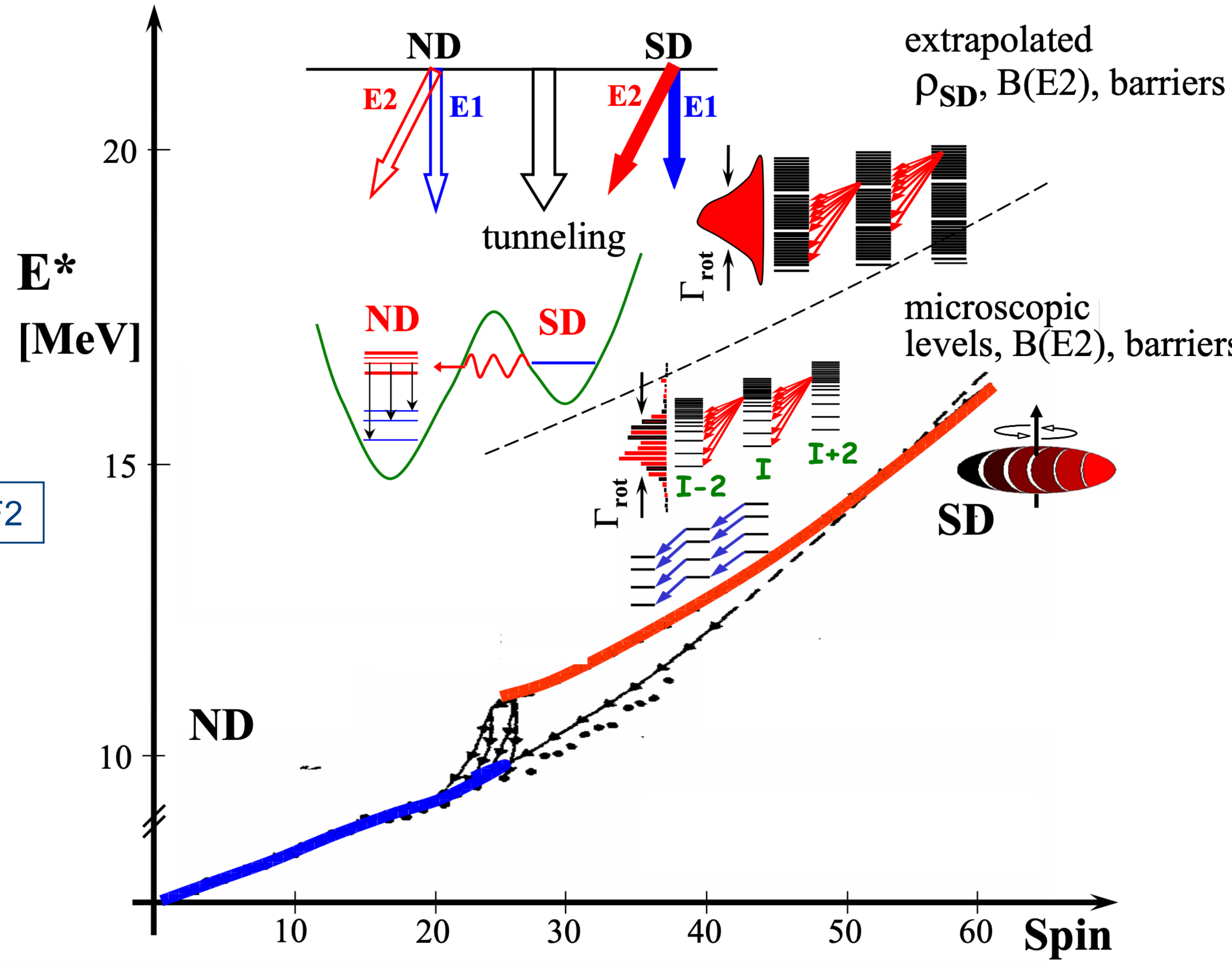
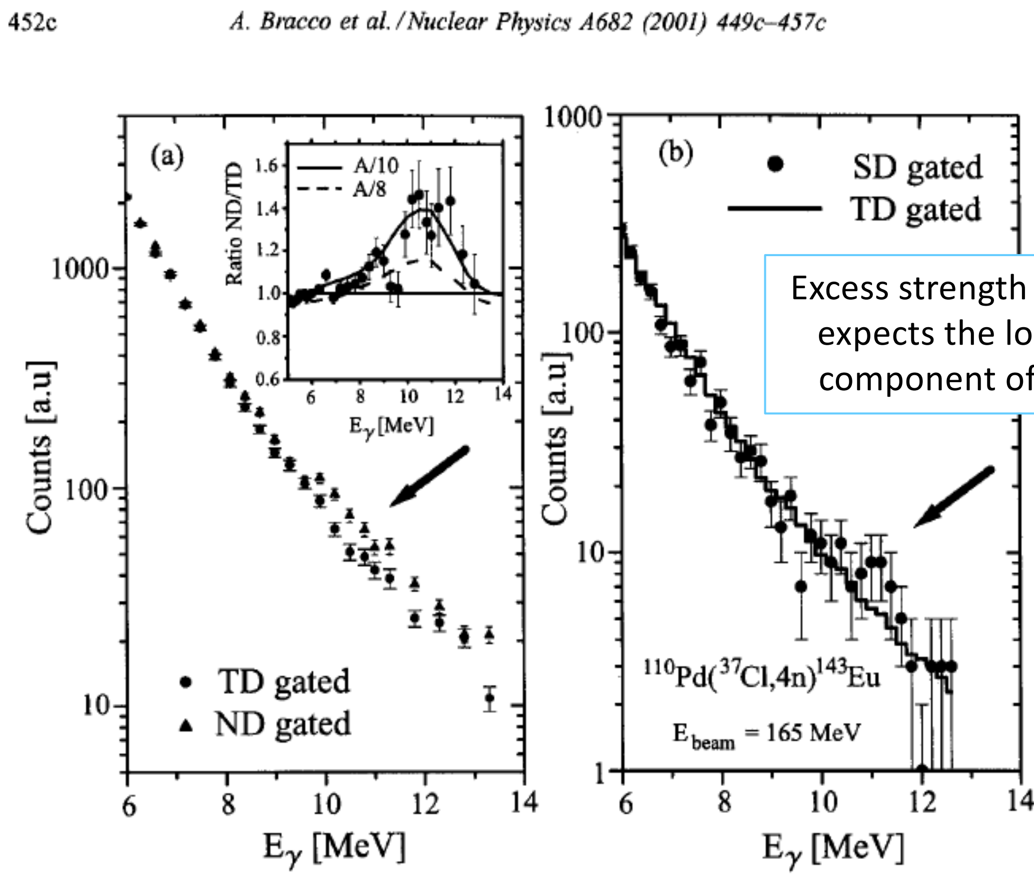






Montestella simulation code based on microscopic calculations also applied sucessfully to ^{151}Tb and ^{196}Pb S. Leoni et al., Phys. Rev. C 79, 064307 (2009)

Evidence for the low-energy GDR component



Excess strength where one expects the low energy component of the GDR

EUROBALL + 8 large BaF2

^{143}Eu: Only studied case to date

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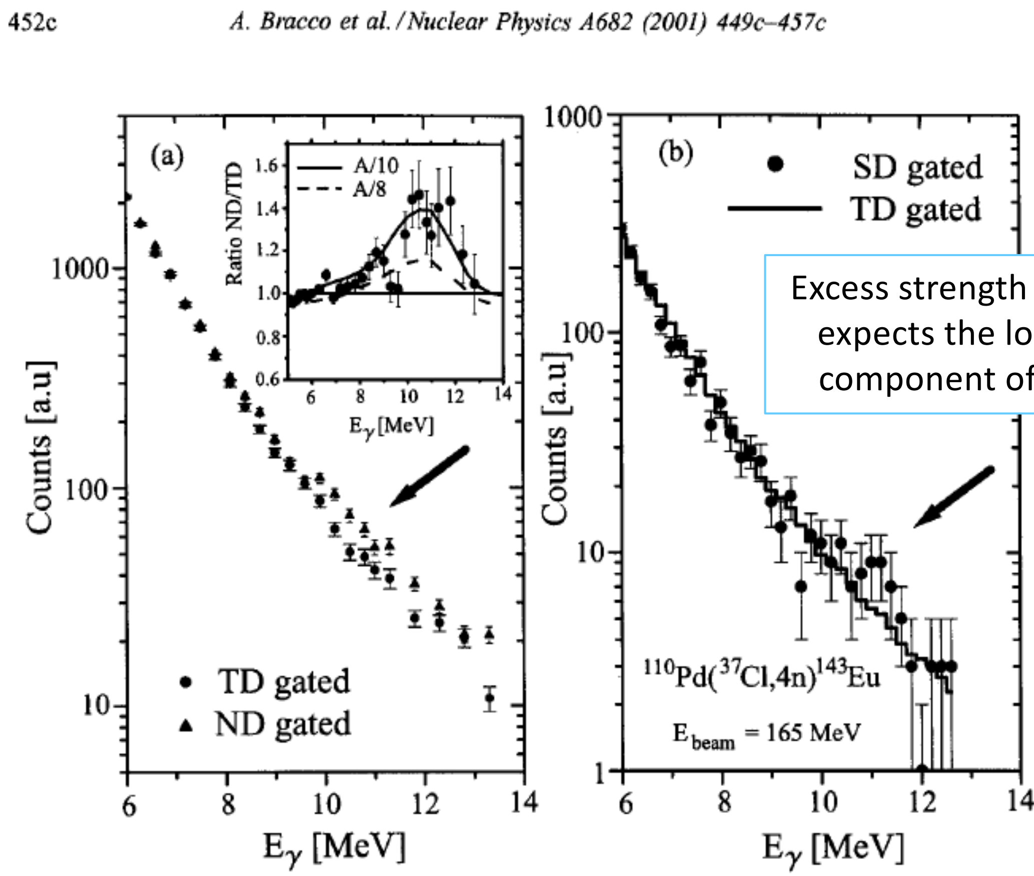

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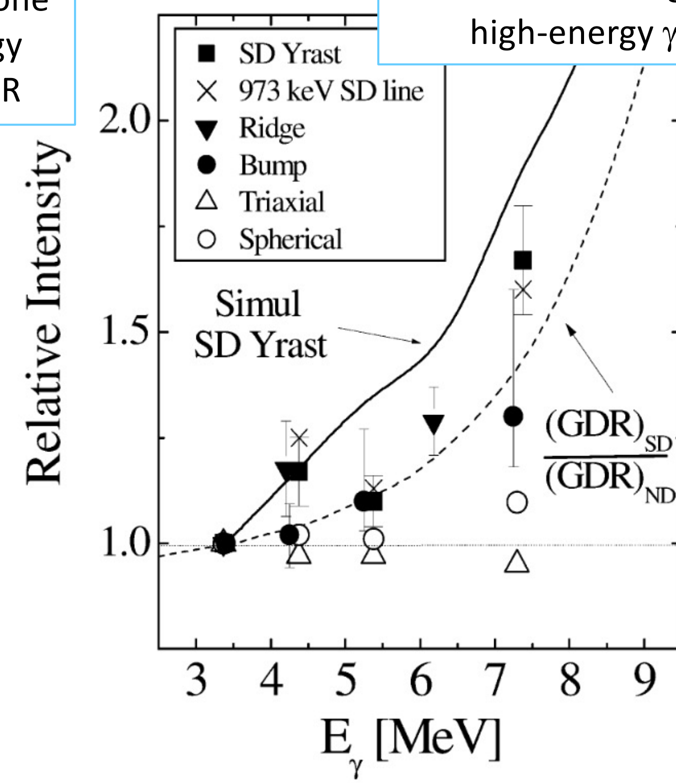
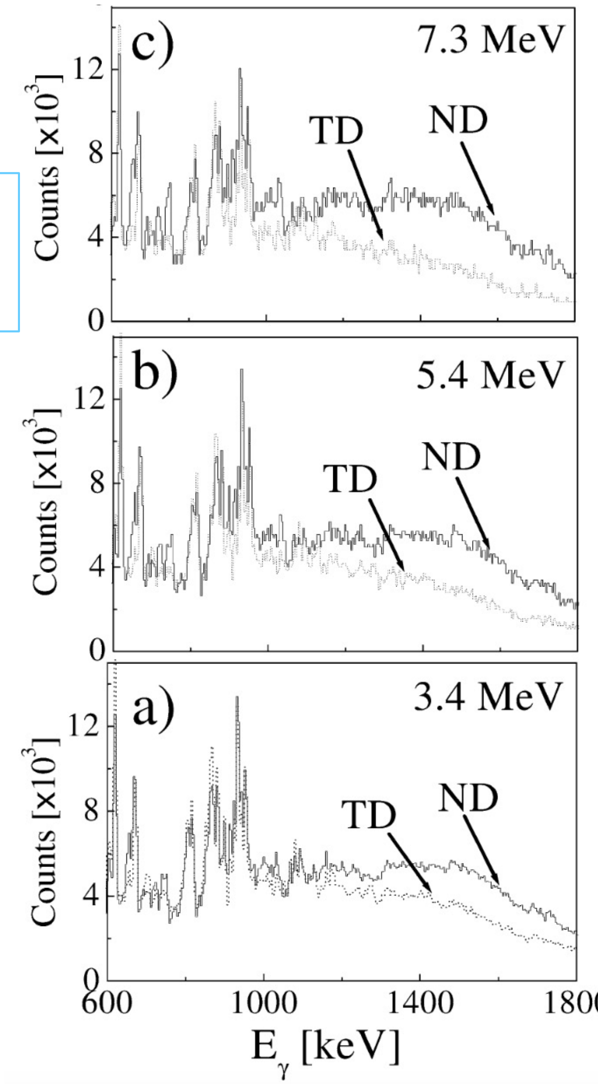
Enhancement of SD structures when gating on high-energy γ rays





G. Benzoni et al., Phys. Lett. B 540 199 (2002)

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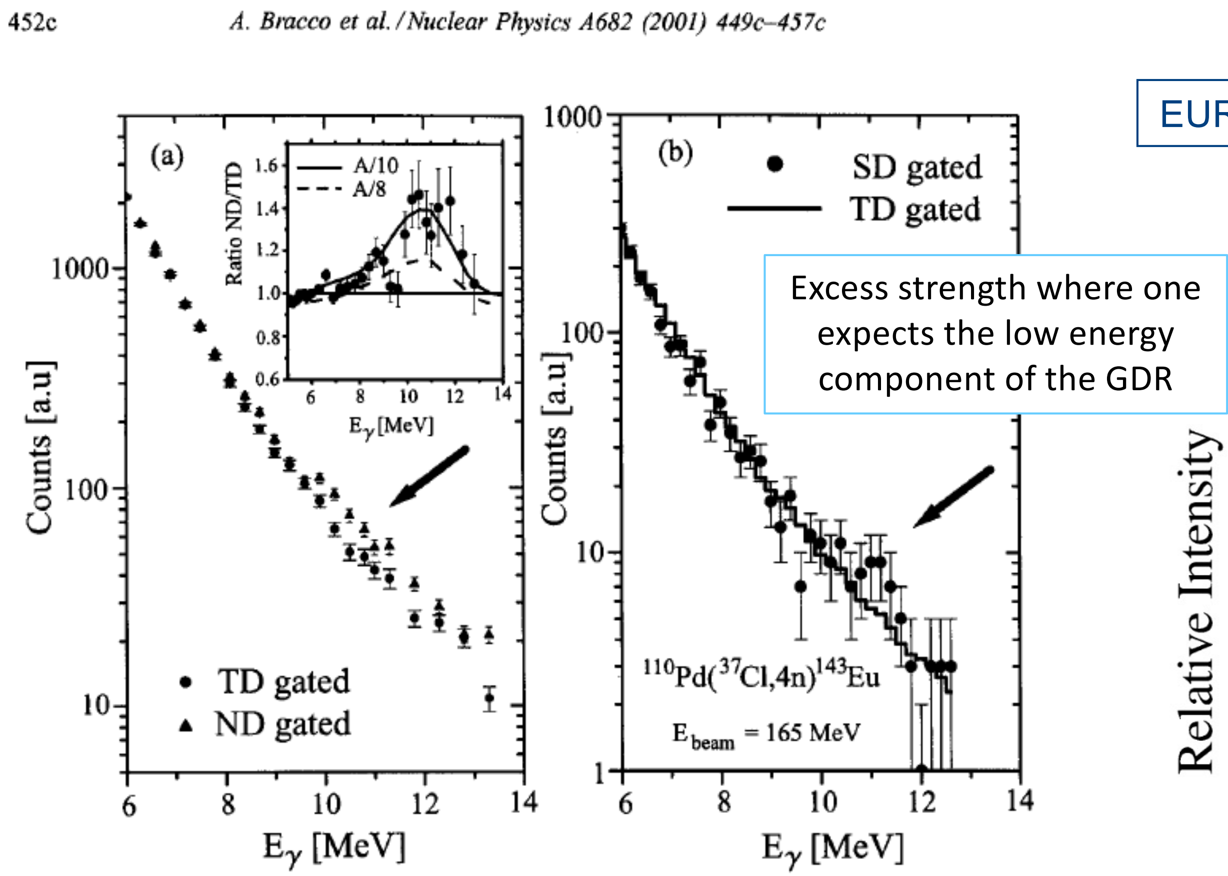

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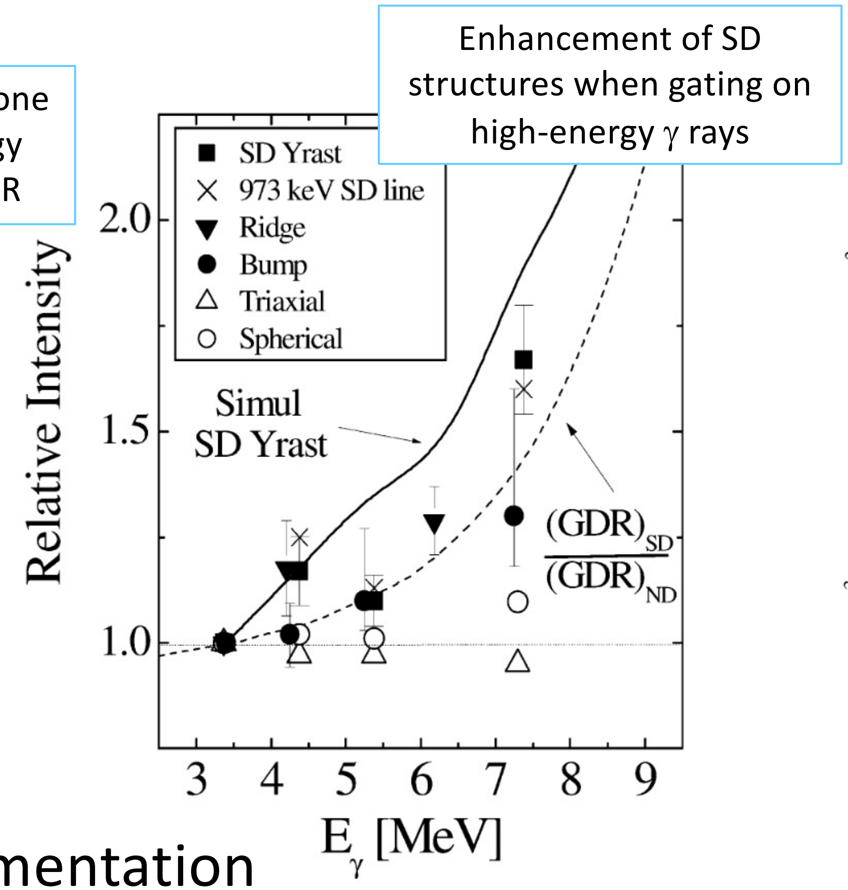

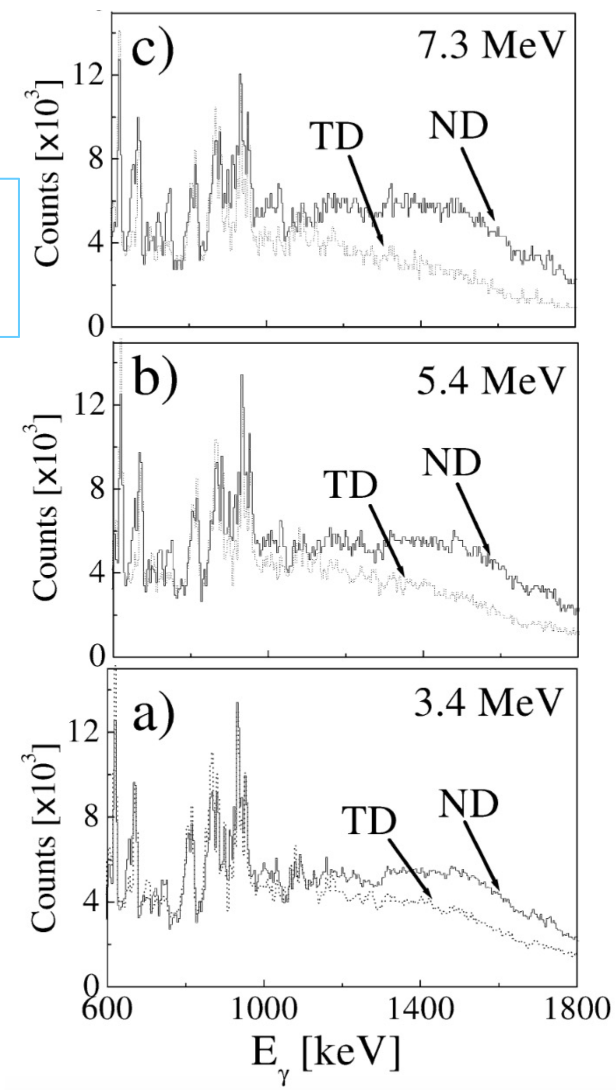

G. Benzoni et al., Phys. Lett. B 540 199 (2002)

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Other experimental evidence of the fragmentation of the GDR strength in highly deformed light nuclei

A. Maj et al. Nuc. Phys. A, 731:319, 2004., M. Kmiecik et al. Acta Phys. Pol. B, 36:1169, 2005.

Elusive linking transitions are finally found !

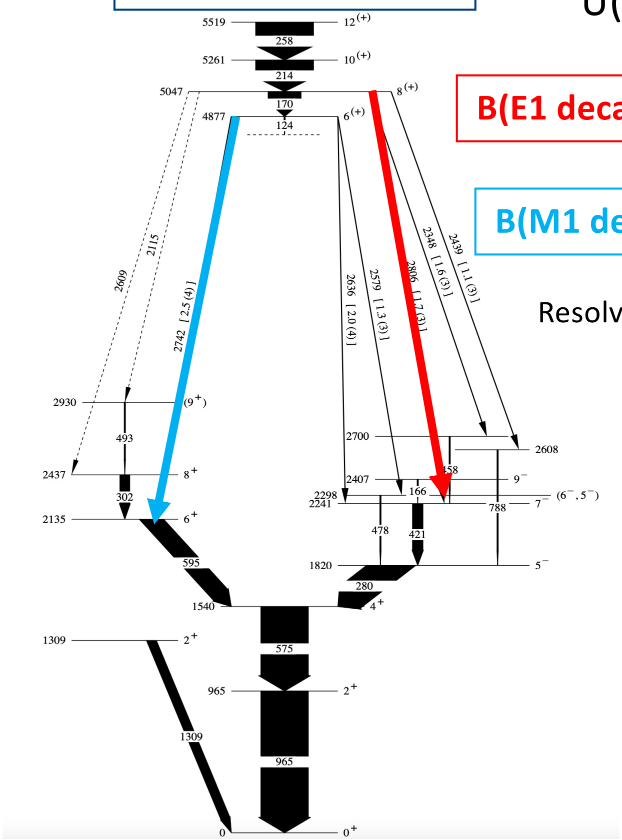
EUROGAM2
GAMMASPHERE
(88 Ge +AC)

U(I=6ℏ)=2.7 MeV

B(E1 decay) =1.5 10^{-8} W.U.

B(M1 decay) = 1.2 10^{-5} W.U.

Resolved primary intensity=21%



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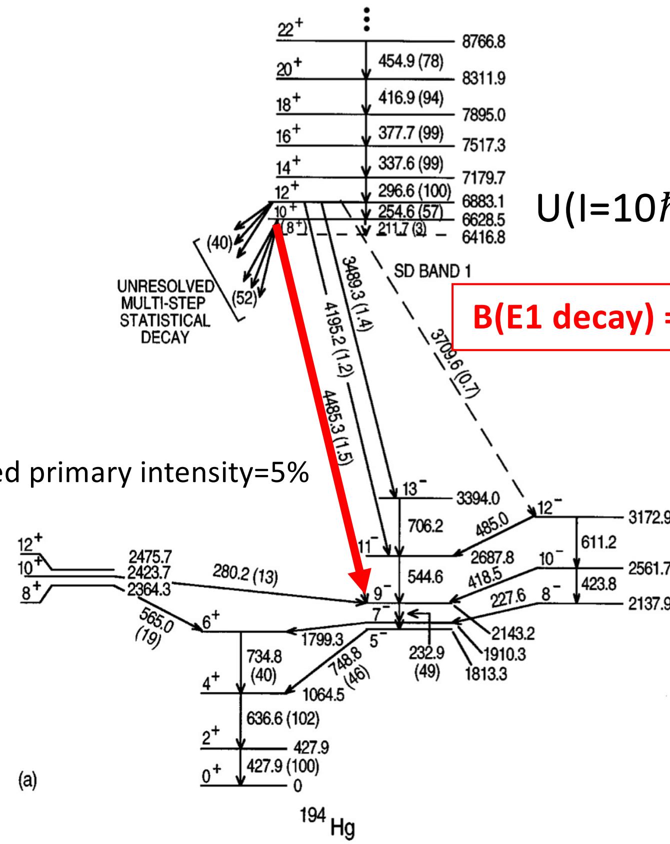

T.L. Khoo et al., Phys. Rev. Lett. 76 1583 (1996)

A. Lopez-Martens et al., Phys. Lett. B 380 18 (1996),
K. Hauschild et al., Phys. Rev. C 55 2819 (1997)

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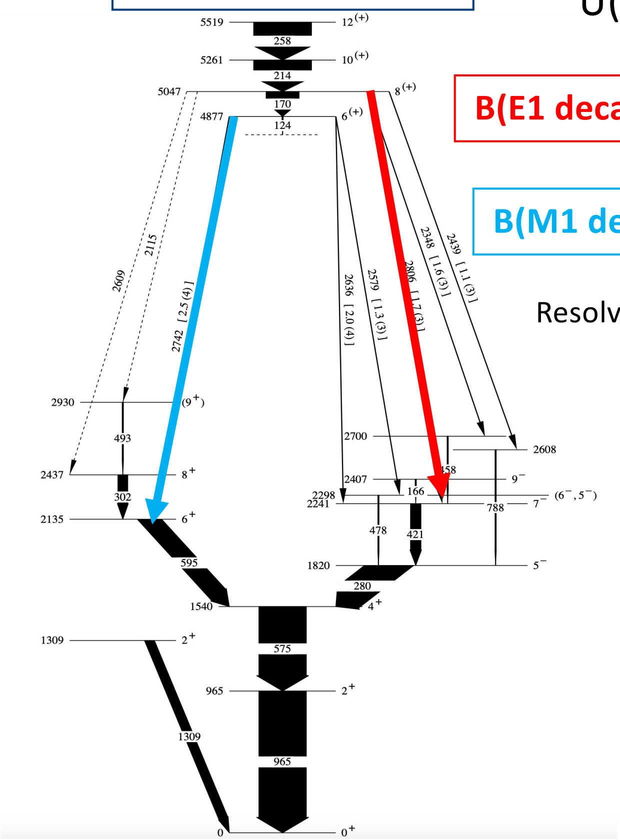

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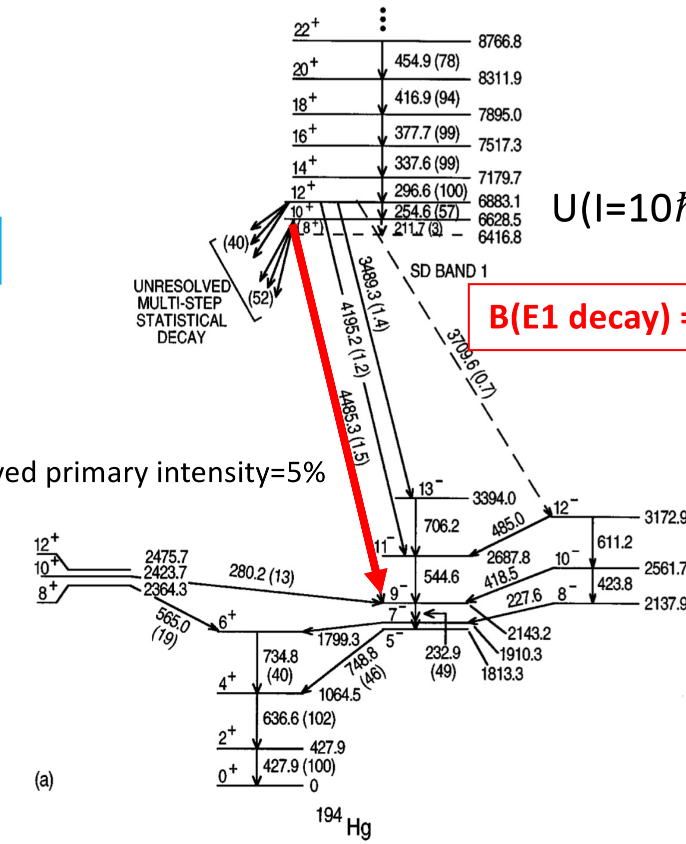


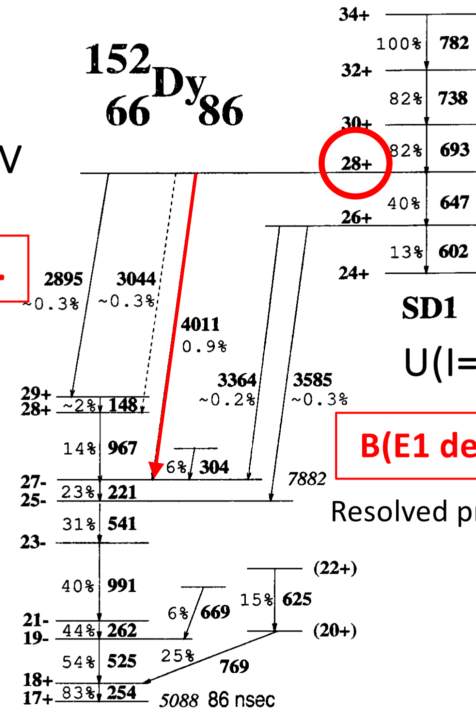
T.L. Khoo et al., Phys. Rev. Lett. 76 1583 (1996)

GAMMASPHERE
(100 Ge + AC)

U(I=28ℏ)=3.7 MeV

B(E1 decay)= 2 10^{-6} W.u.

Resolved primary intensity=5%



T. Lauritsen et al., Phys. Rev. Lett. 88 042501 (2002)

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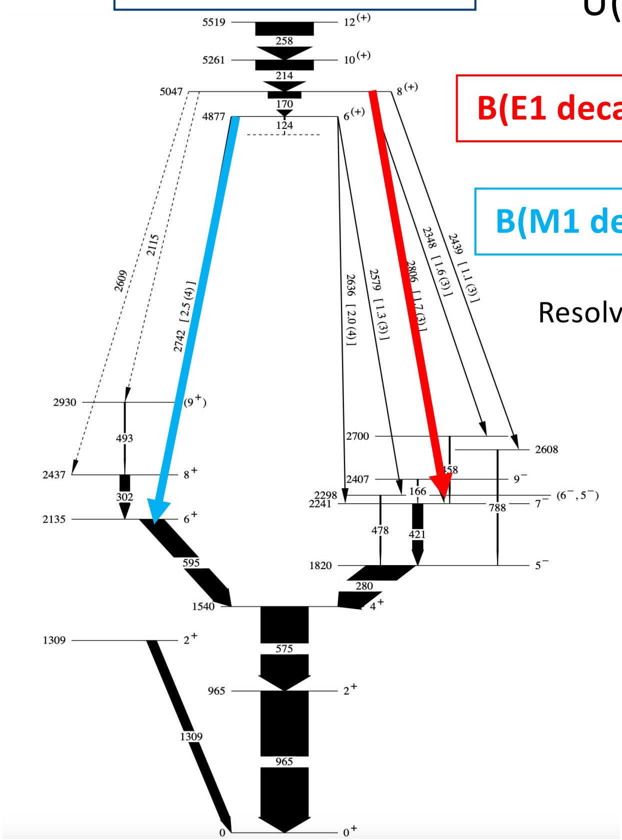

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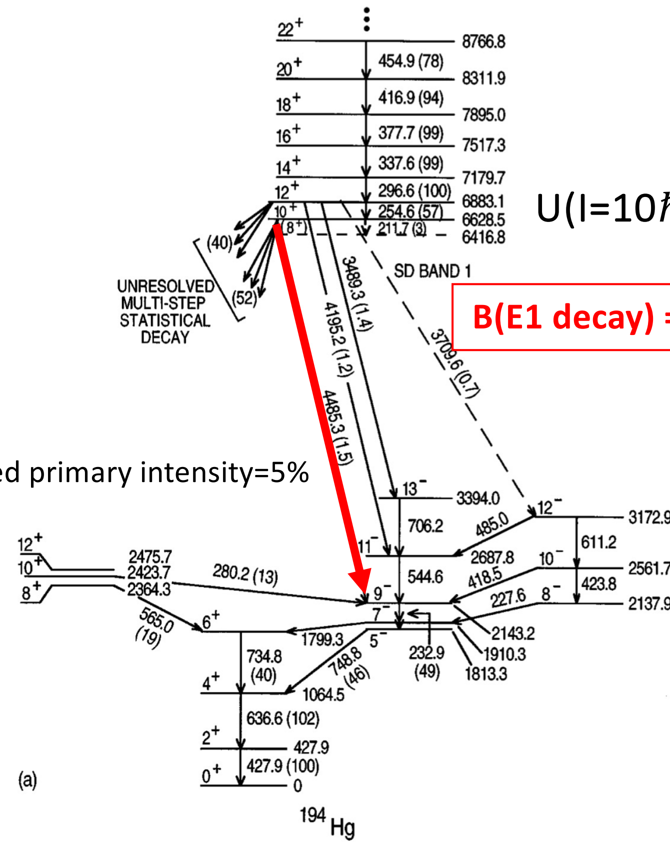
Resolved primary intensity=5%



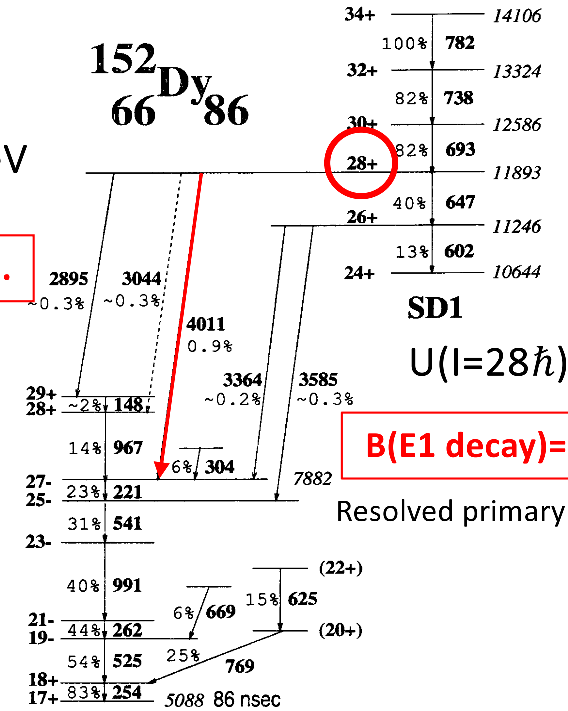
T.L. Khoo et al., Phys. Rev. Lett. 76 1583 (1996)

GAMMASPHERE
(100 Ge + AC)

U(I=28ℏ)=3.7 MeV

B(E1 decay)= 2 10^{-6} W.u.

Resolved primary intensity=5%



T. Lauritsen et al., Phys. Rev. Lett. 88 042501 (2002)

A. Lopez-Martens et al., Phys. Lett. B 380 18 (1996),
K. Hauschild et al., Phys. Rev. C 55 2819 (1997)

Large hindrance to decay out : Extreme examples of shape coexistence

S. Leoni et al., Eur. Phys. J. Spec. Top. 233 1061 (2024)

Elusive linking transitions are finally found !

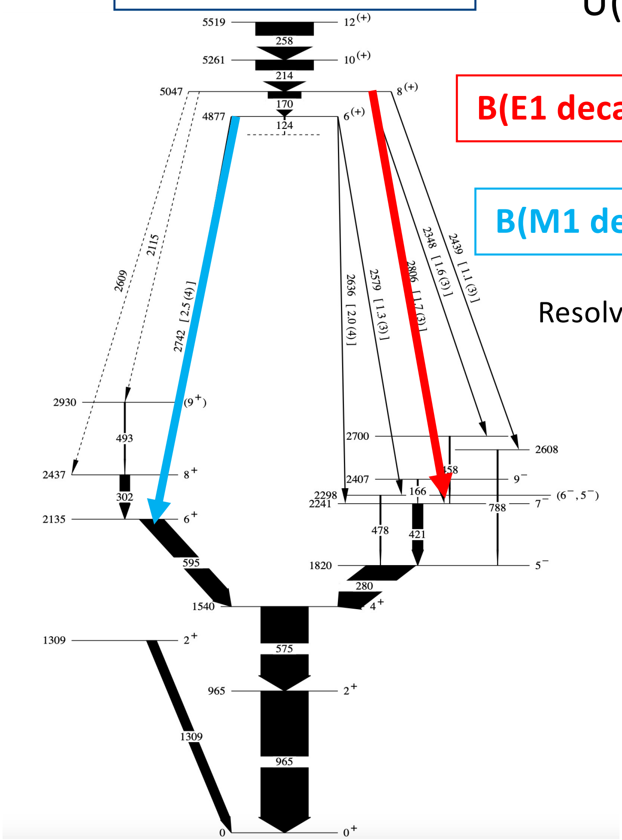
EUROGAM2
GAMMASPHERE
(88 Ge +AC)

U(I=6ℏ)=2.7 MeV

B(E1 decay) =1.5 10^{-8} W.U.

B(M1 decay) = 1.2 10^{-5} W.U.

Resolved primary intensity=21%



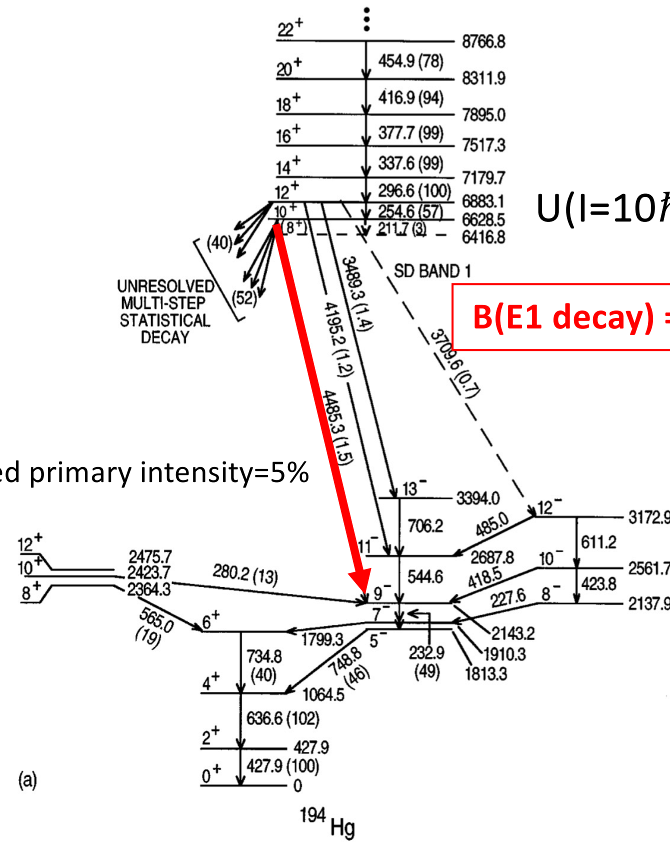
A. Lopez-Martens et al., Phys. Lett. B 380 18 (1996),
K. Hauschild et al., Phys. Rev. C 55 2819 (1997)

GAMMASPHERE
(55 Ge + AC)

U(I=10ℏ)=4.2 MeV

B(E1 decay) =7 10^{-8} W.U.

Resolved primary intensity=5%



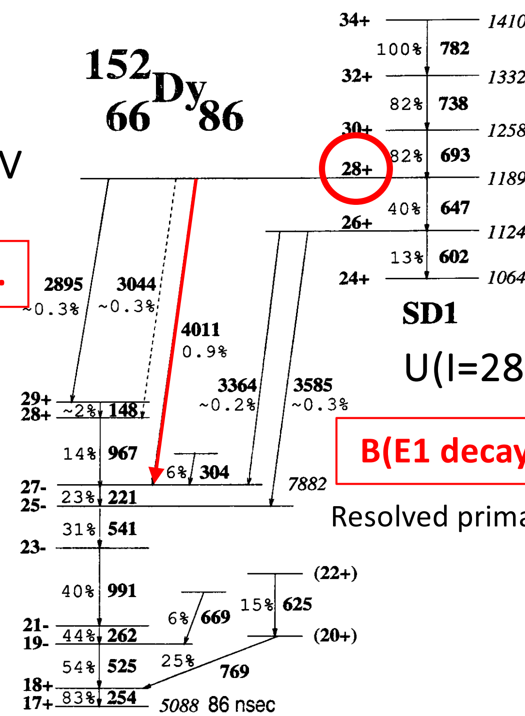
T.L. Khoo et al., Phys. Rev. Lett. 76 1583 (1996)

GAMMASPHERE
(100 Ge + AC)

U(I=28ℏ)=3.7 MeV

B(E1 decay)= 2 10^{-6} W.u.

Resolved primary intensity=5%



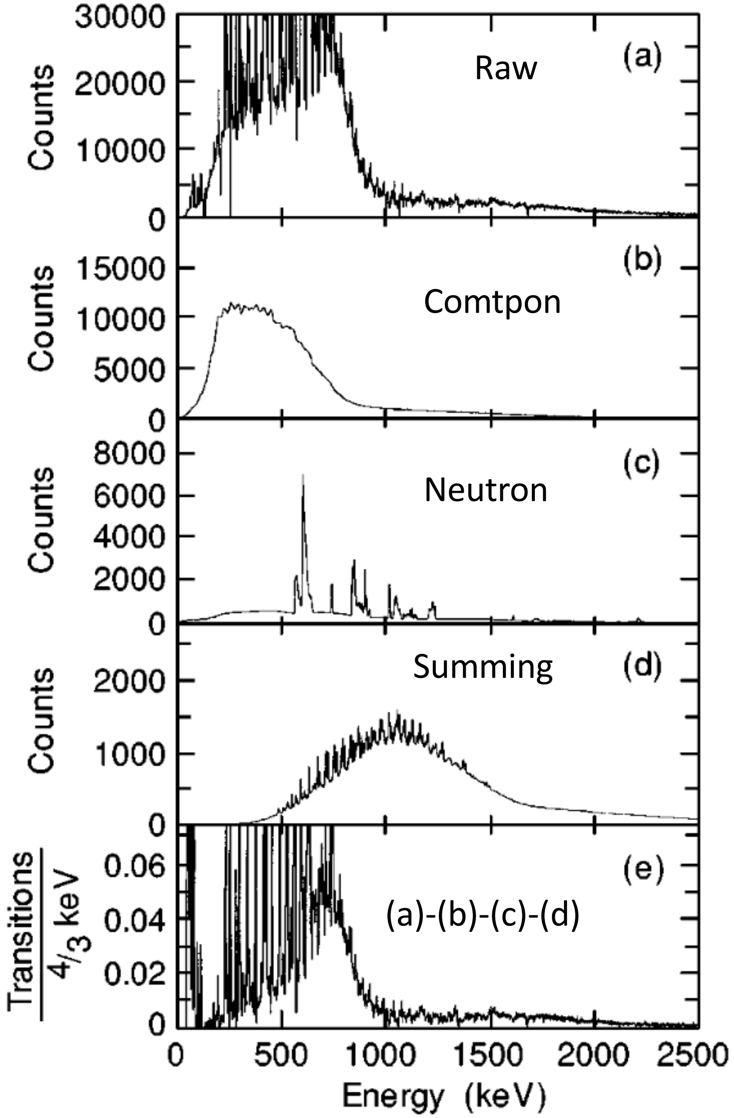
T. Lauritsen et al., Phys. Rev. Lett. 88 042501 (2002)

Large hindrance to decay out : Extreme examples of shape coexistence

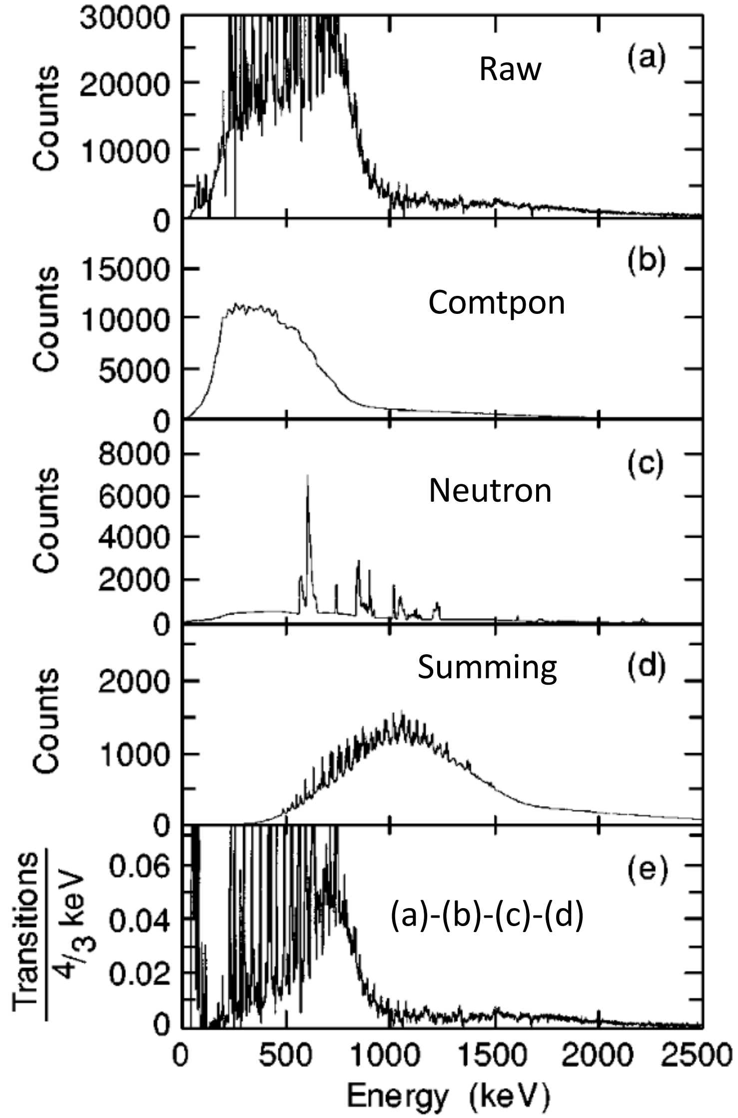
S. Leoni et al., Eur. Phys. J. Spec. Top. 233 1061 (2024)

A large fraction of the decay out transitions are unresolved

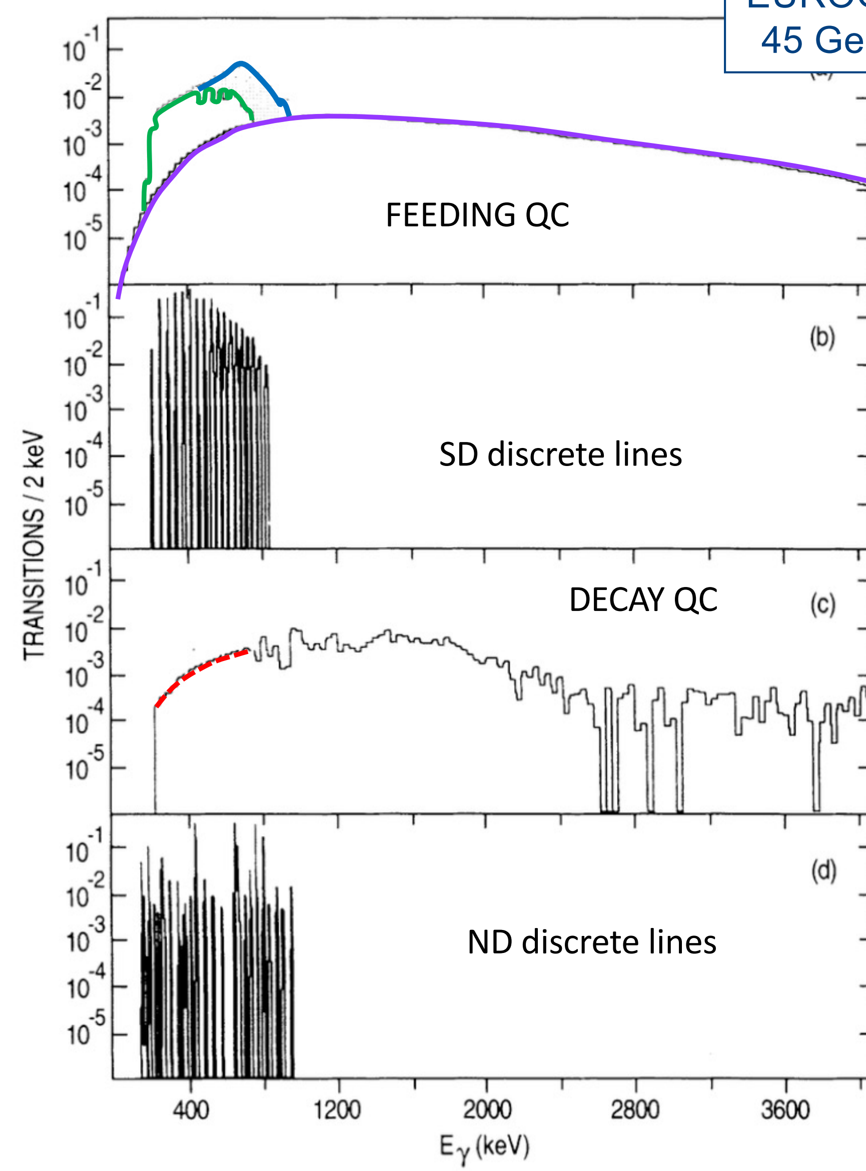
Quasicontinuum extraction & decomposition



Quasicontinuum extraction & decomposition

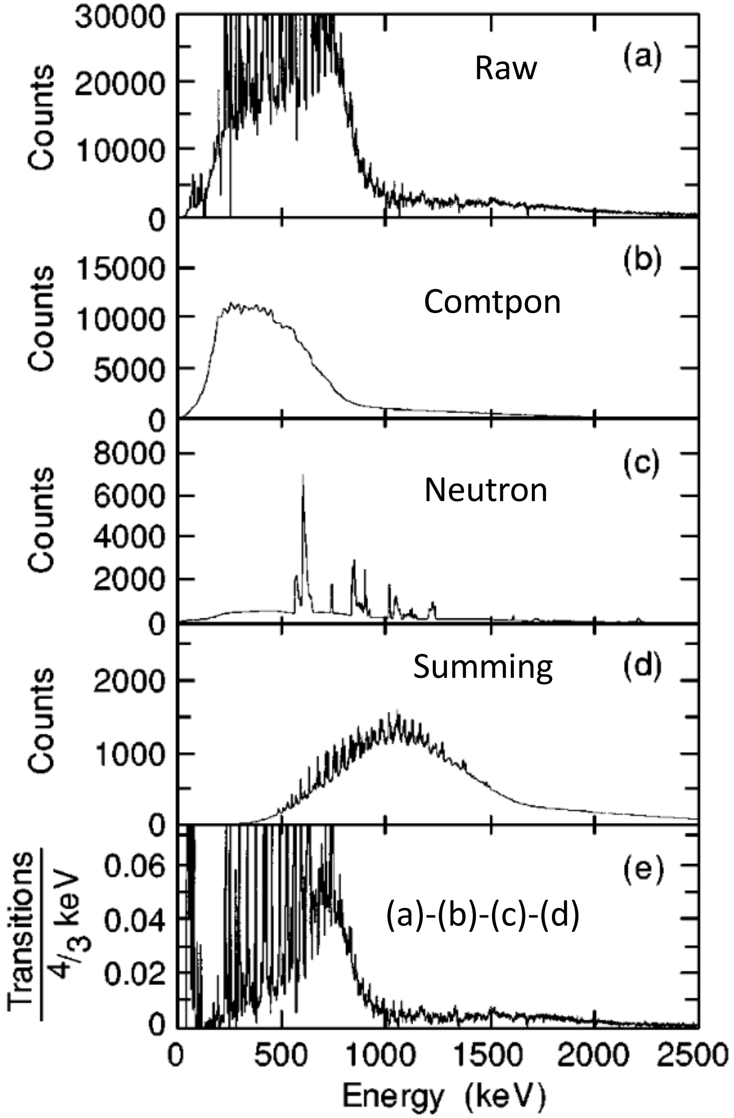


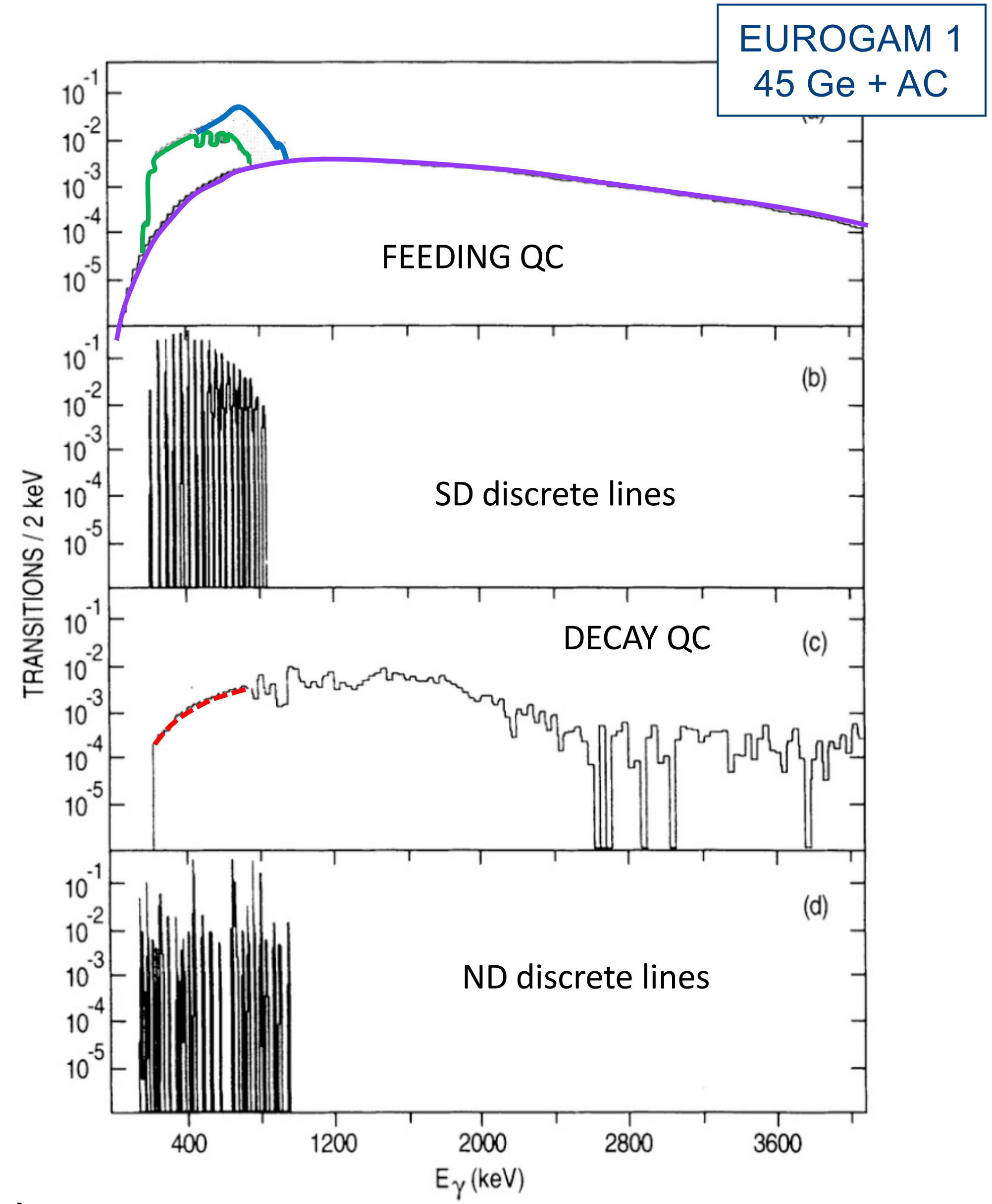
EUROGAM 1
45 Ge + AC



R.G. Henry et al., Phys. Rev. Lett. 73 777 (1992)

Quasicontinuum extraction & decomposition

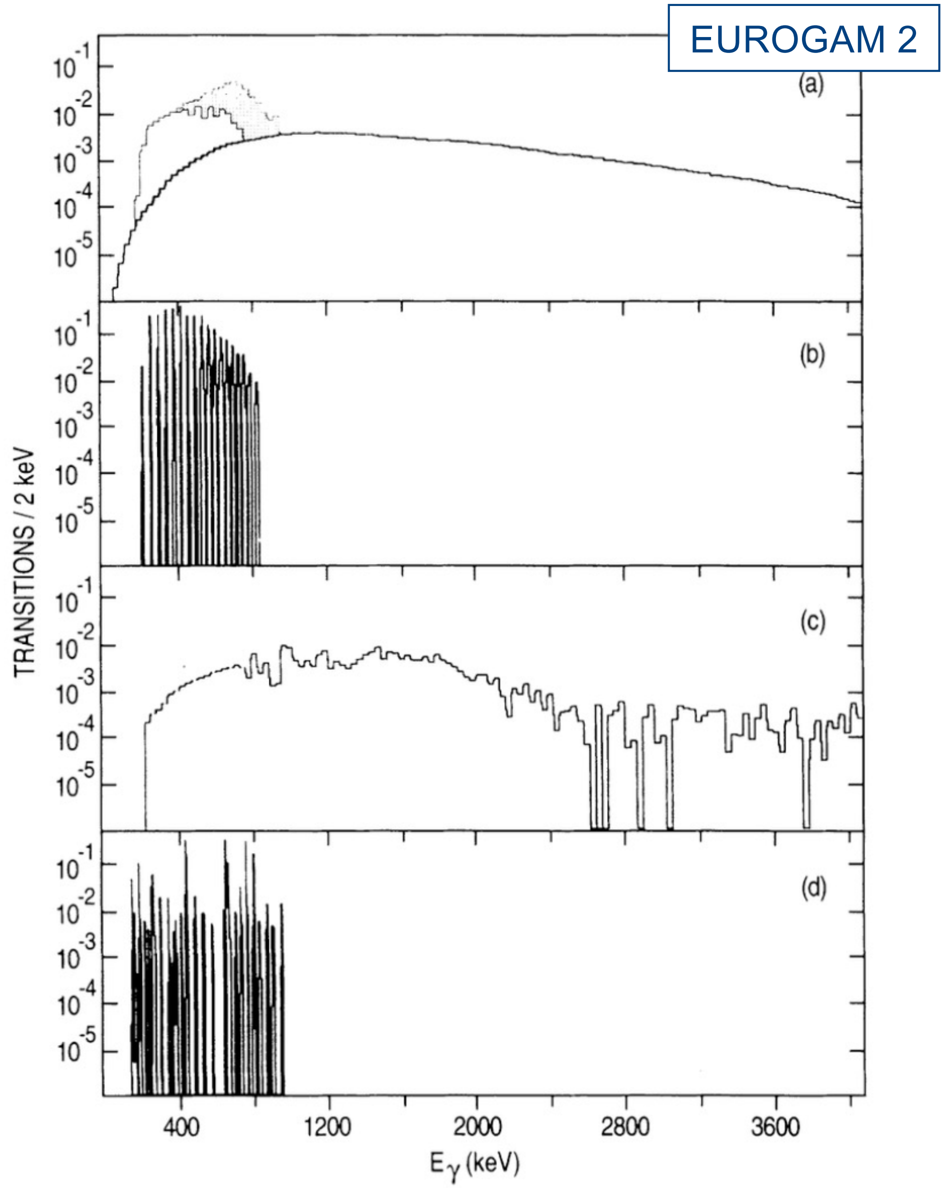




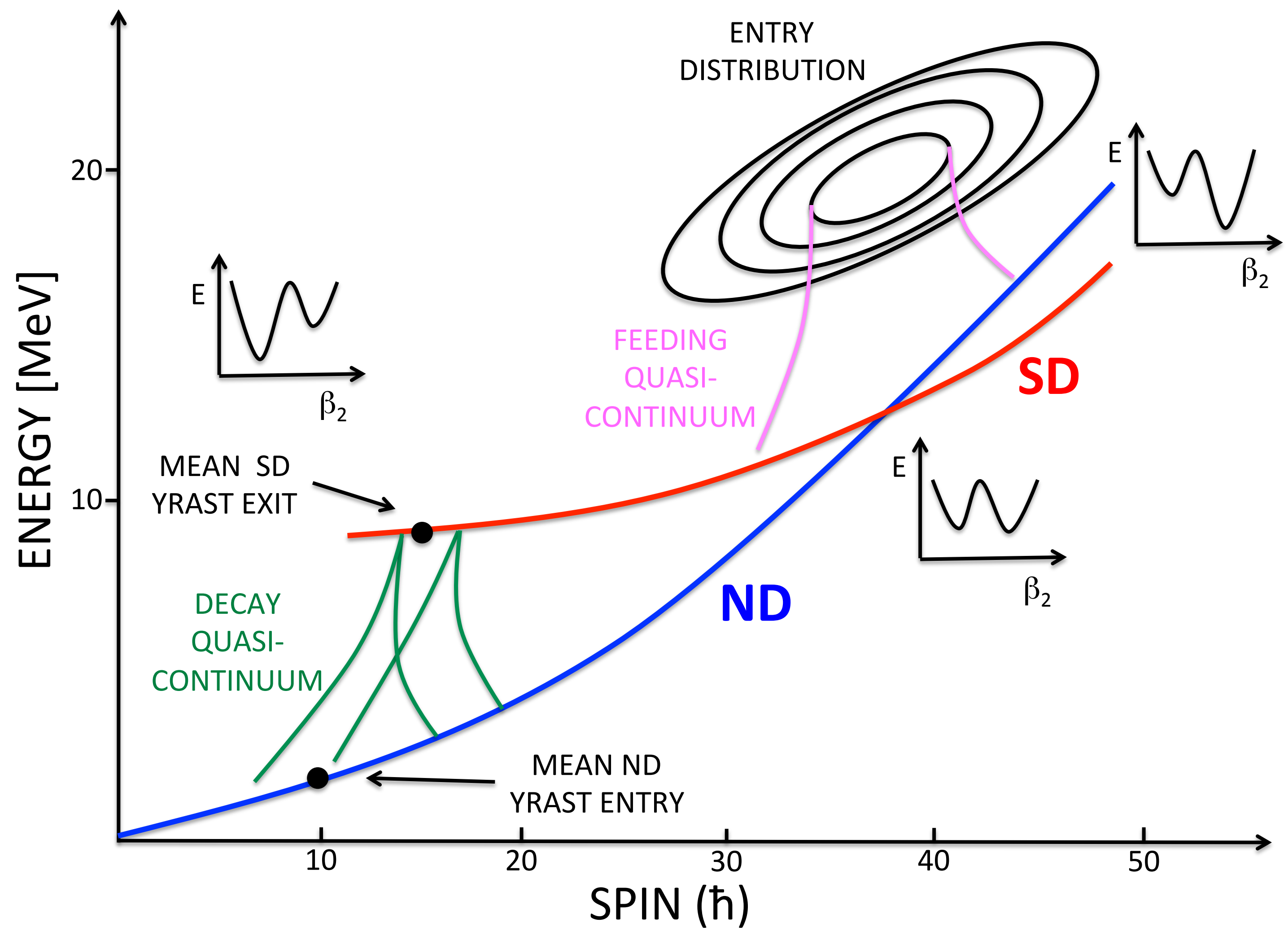
Separation of various components only possible in mass A~190 region

R.G. Henry et al., Phys. Rev. Lett. 73 777 (1992)

Life & death of a superdeformed nucleus

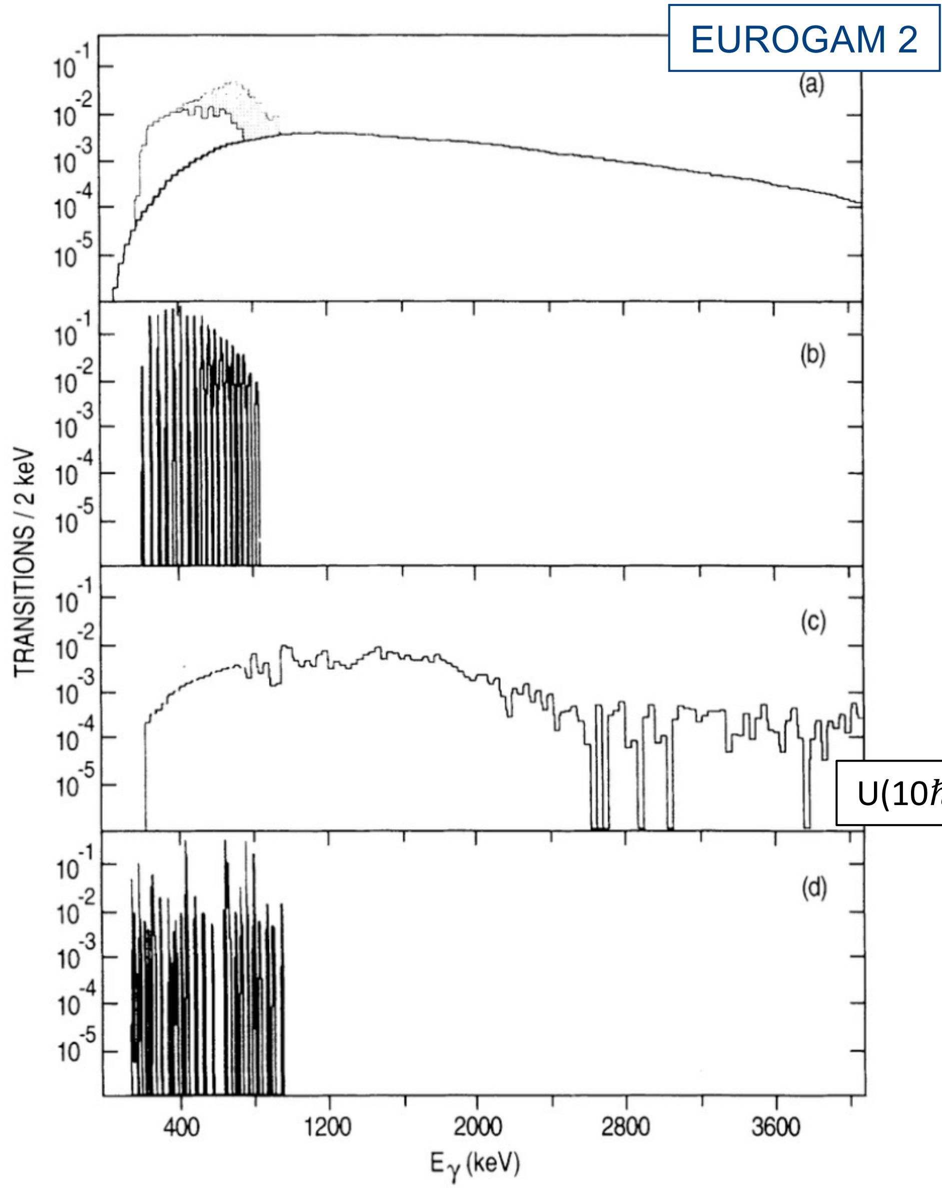


R.G. Henry et al., Phys. Rev. Lett. 73 777 (1992)

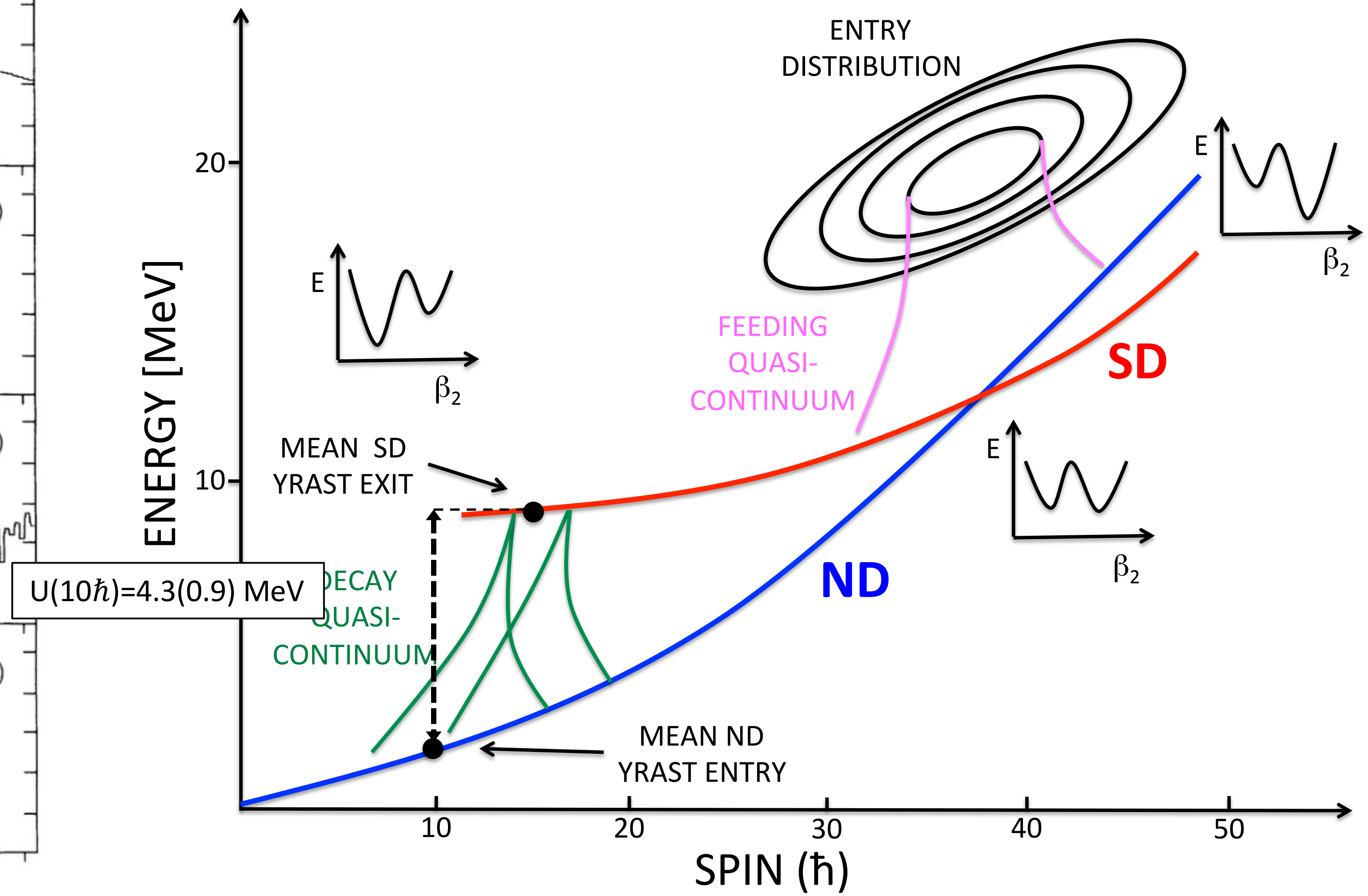


Double cycle of Hot & Cold motion

Life & death of a superdeformed nucleus



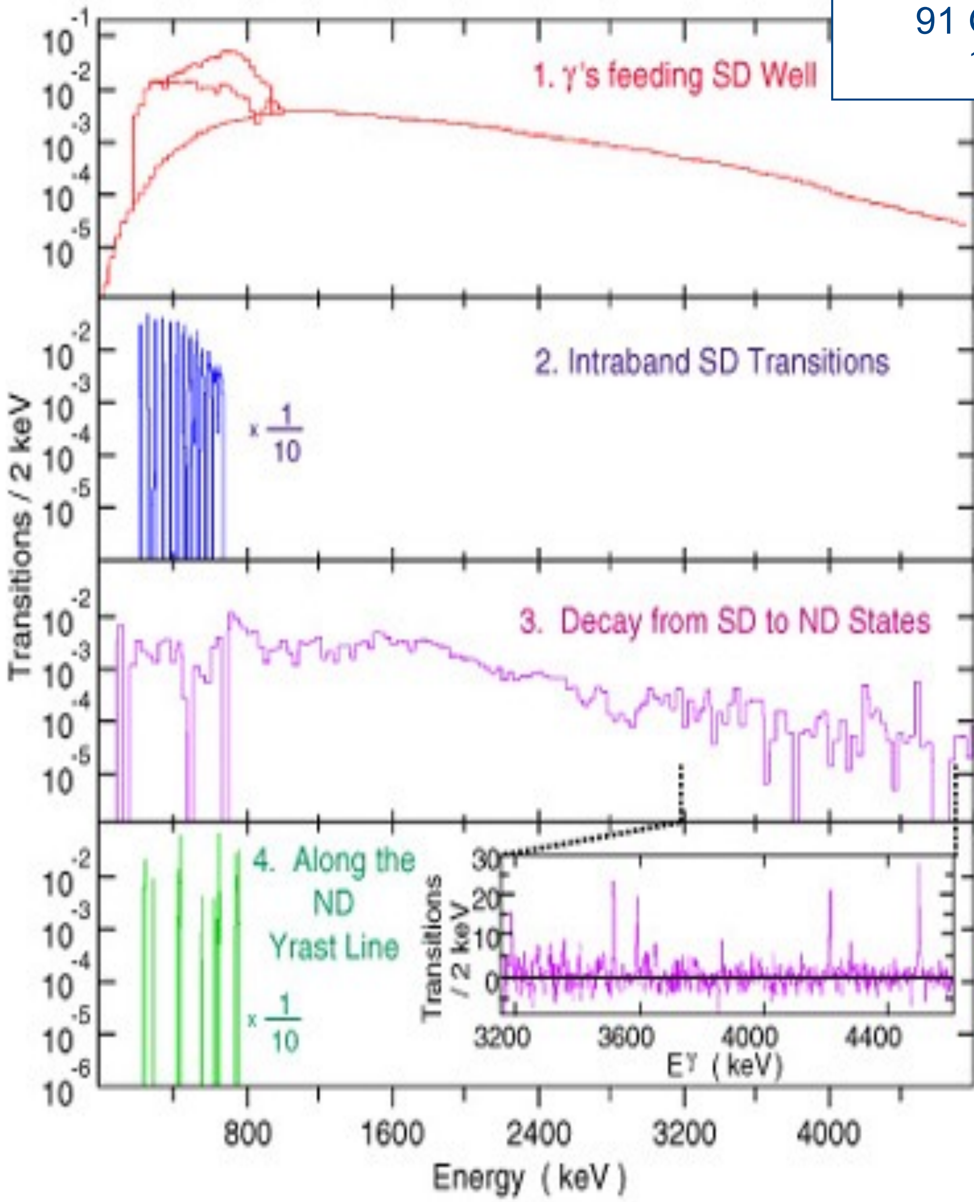
R.G. Henry et al., Phys. Rev. Lett. 73 777 (1992)



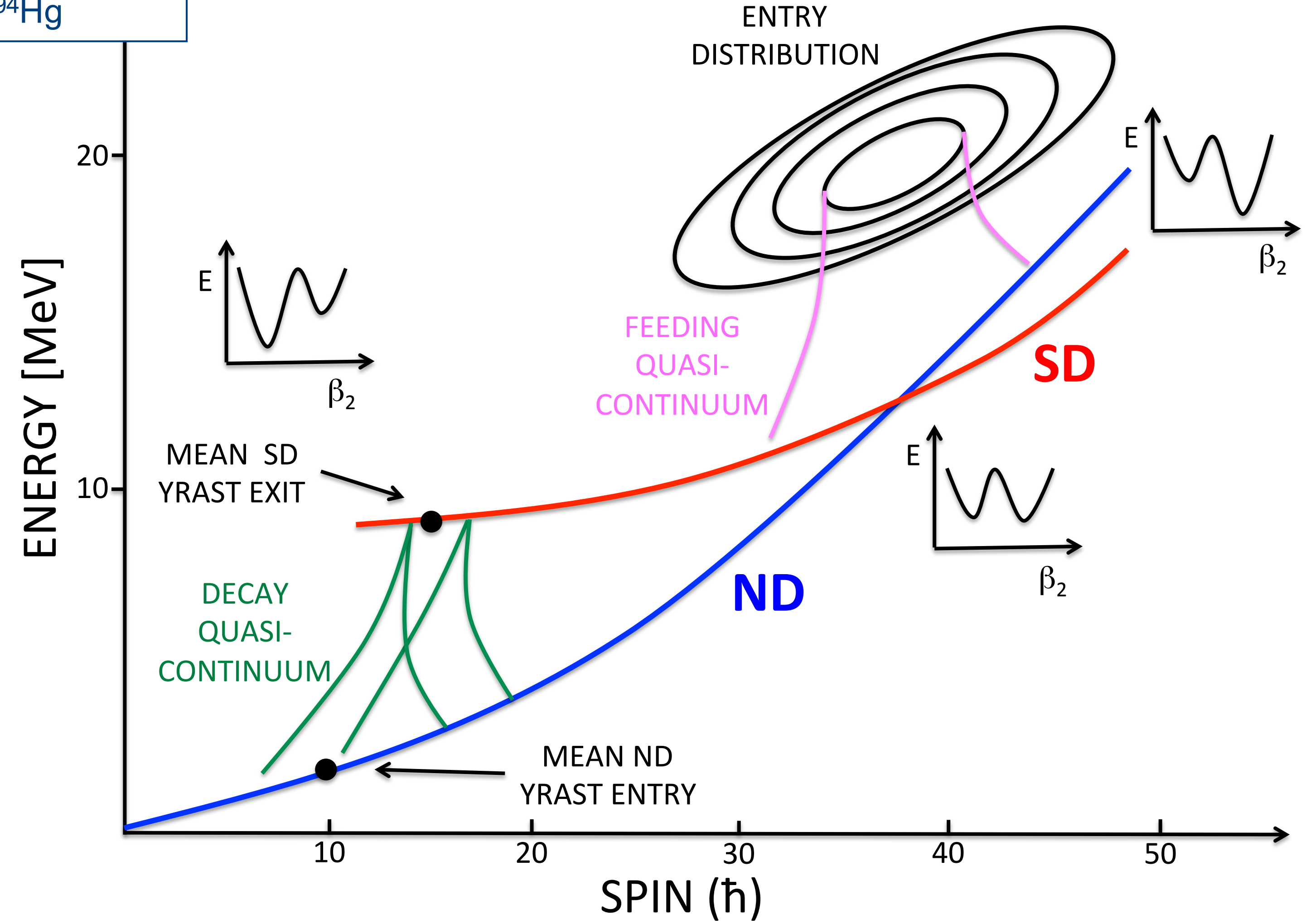
Double cycle of Hot & Cold motion

Life & death of a superdeformed nucleus

T. Lauritsen et al., Phys. Rev. C 62 044316 (2000)



GAMMASPHERE
91 Ge + AC
^{194}Hg



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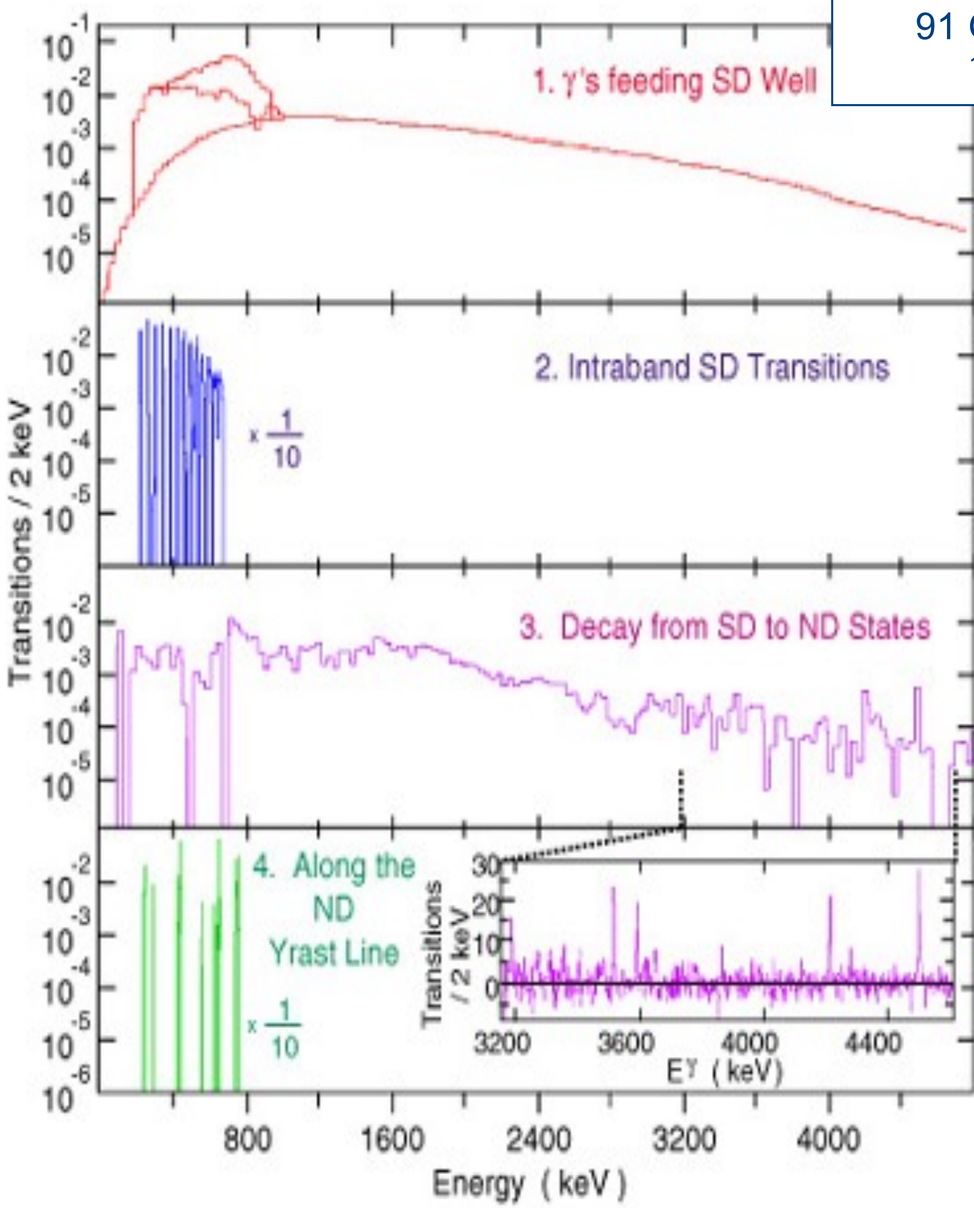
T. Lauritsen et al., Phys. Rev. C 62 044316 (2000)



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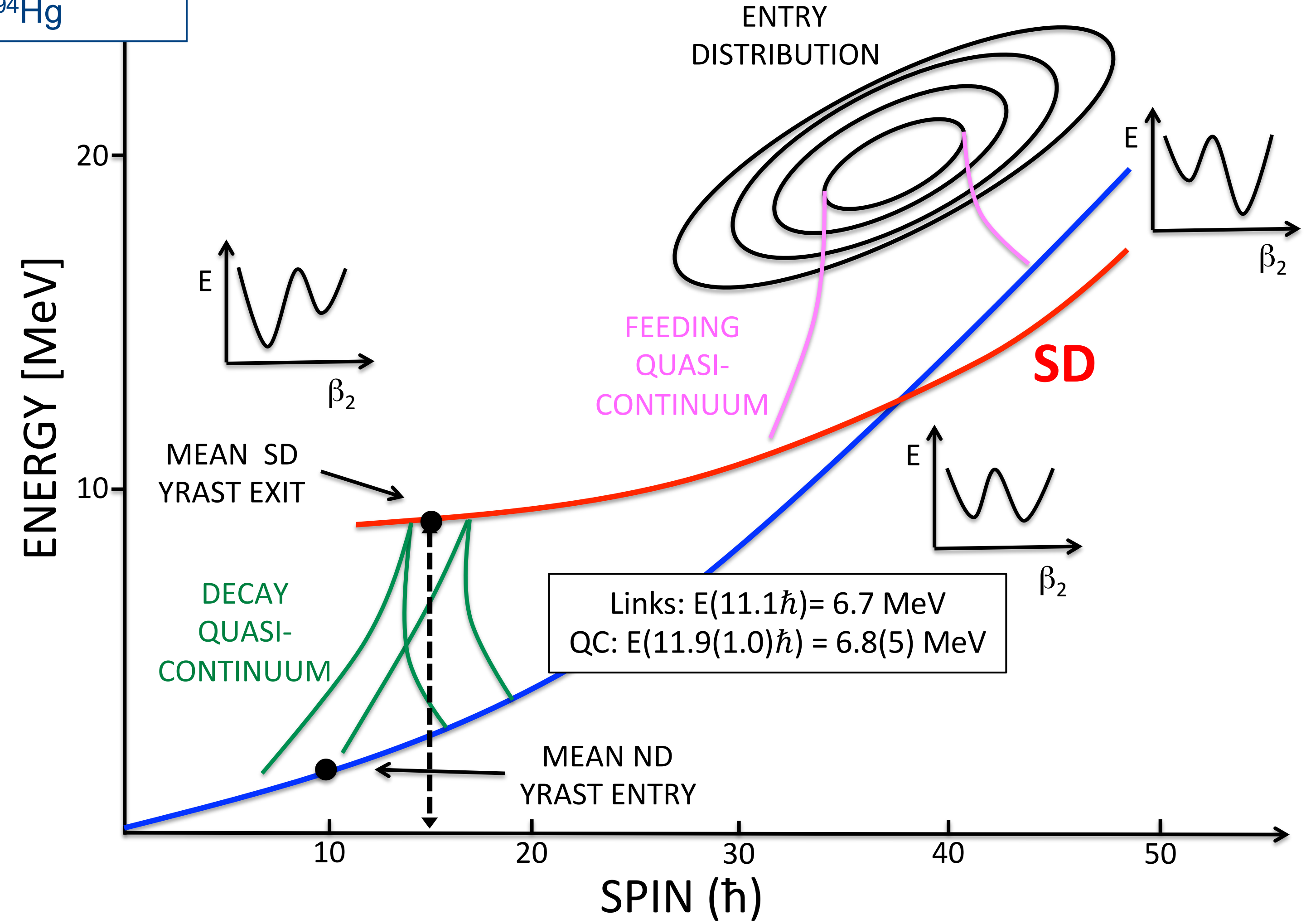
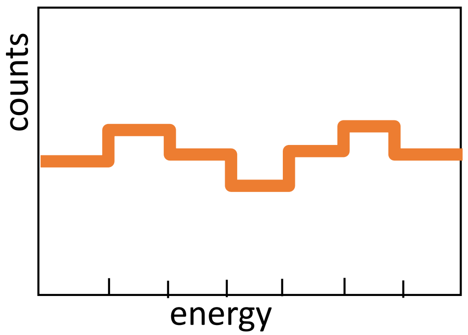


Double cycle of Hot & Cold motion

How many decay out cascades ?

FLUCTUATION ANALYSIS METHOD (FAM)

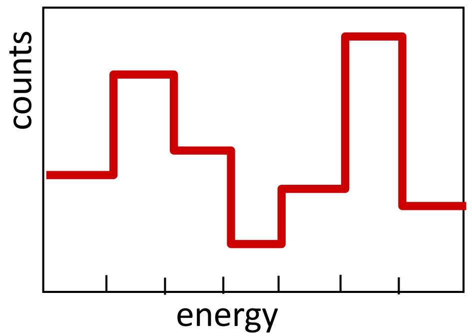
N transitions sampled from an infinite number



$\mu_2/\mu_1 \sim 1$

Purely statistical fluctuations

N transitions sampled from a finite number N_t ($N>N_t$)



$\mu_2/\mu_1 = N/N_t + 1$

Enhancement of the fluctuations

T. Døssing , B. Herskind, S. Leoni *et al.* Phys. Rep. **268** (1996)

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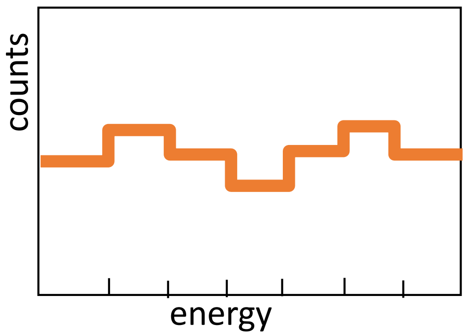

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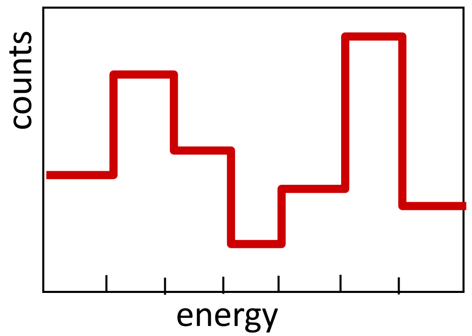

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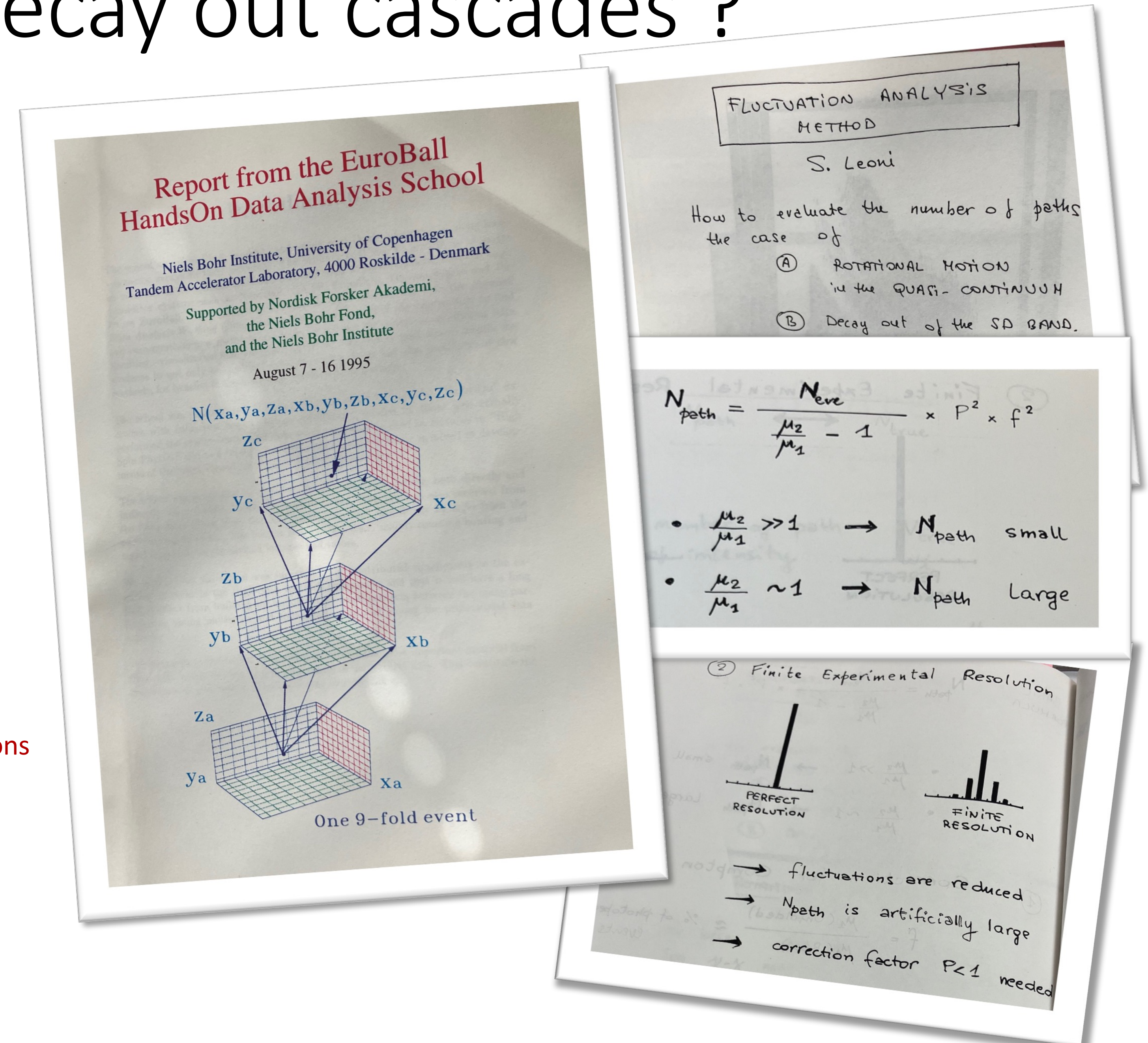
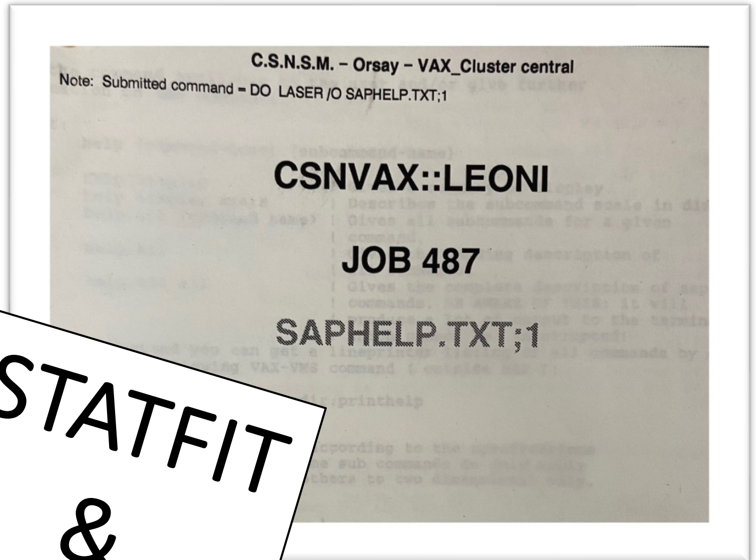


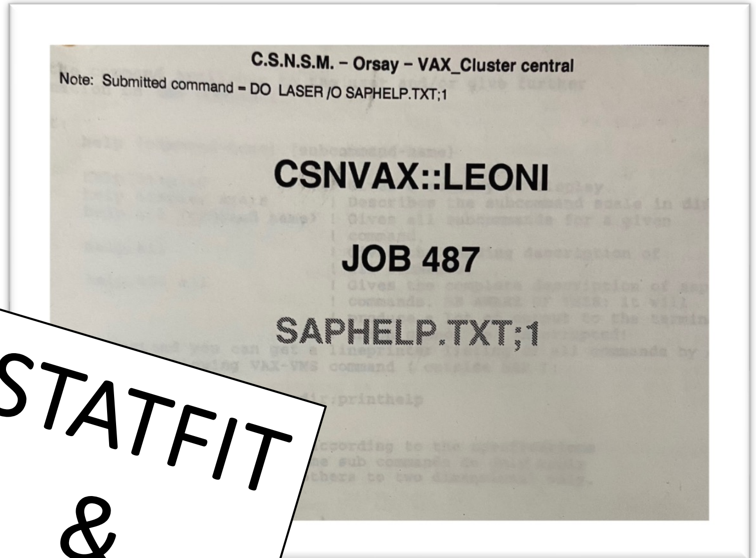
Fluctuation Analysis applied to decay-out spectra



STATFIT
&
SAP

Preliminary analyses on
EUROGAM1 data at CSNSM:
^{192}Hg: $\langle N_t \rangle$ ~5000
^{194}Pb: $\langle N_t \rangle$ ~1500

Fluctuation Analysis applied to decay-out spectra


C.S.N.S.M. – Orsay – VAX_Cluster central
Note: Submitted command – DO LASER /O SAPHELP.TXT;1
CSNVAX::LEONI
JOB 487
SAPHELP.TXT;1

STATFIT
&
SAP

Preliminary analyses on
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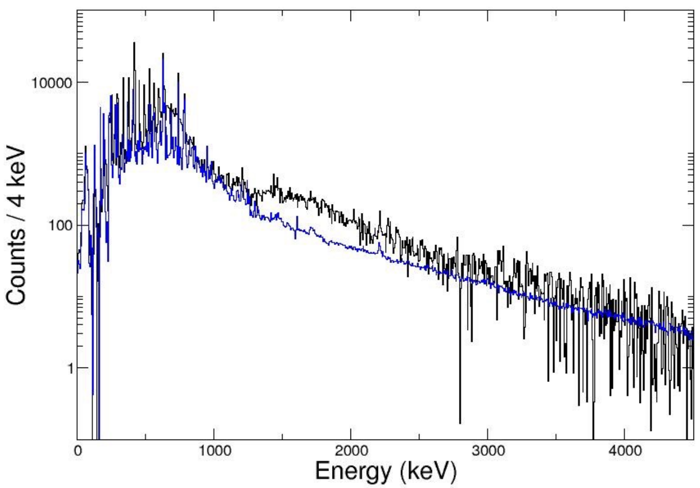
^{192}Hg: <N_t> ~5000
^{194}Pb:<N_t>~1500

EUROGAM2 experiment

F. Hannachi, S. Leoni, N. Redon, A. Korichi, A. Bracco, A. Wilson
A. Lopez-Martens, C. Schuck, I. Deloncle

FAM applied to ^{192}Hg



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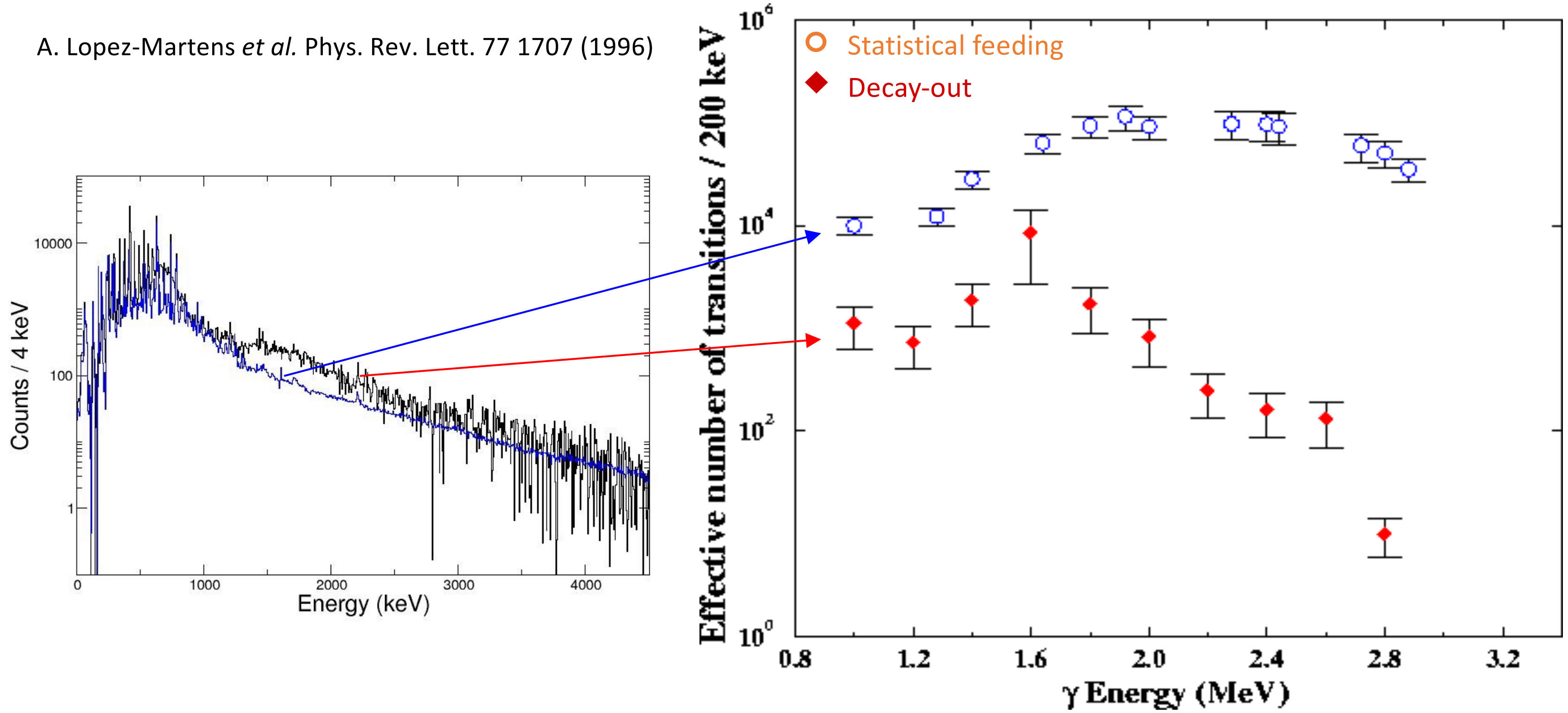
A. Lopez-Martens *et al.* Phys. Rev. Lett. 77 1707 (1996)



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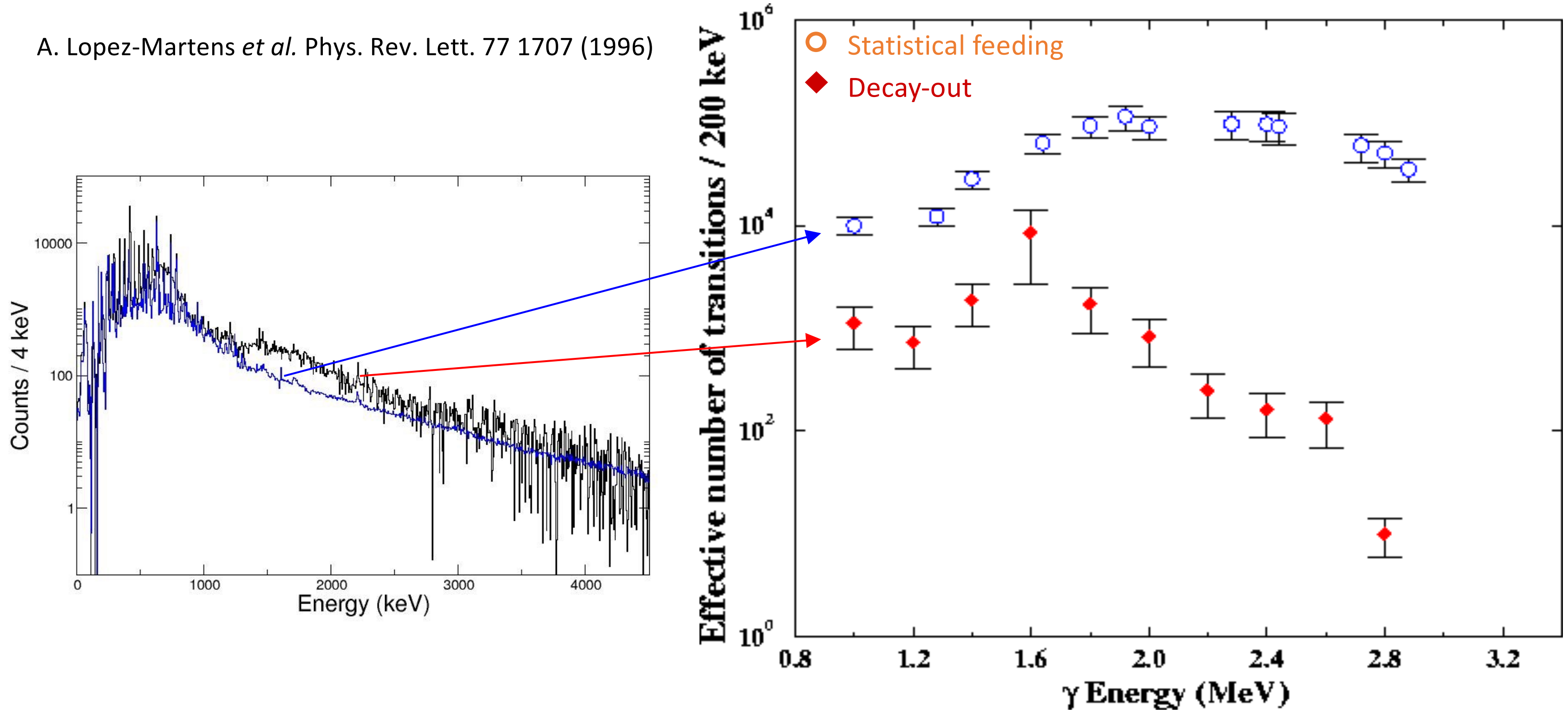

- large fragmentation ~ 10^4 decay paths

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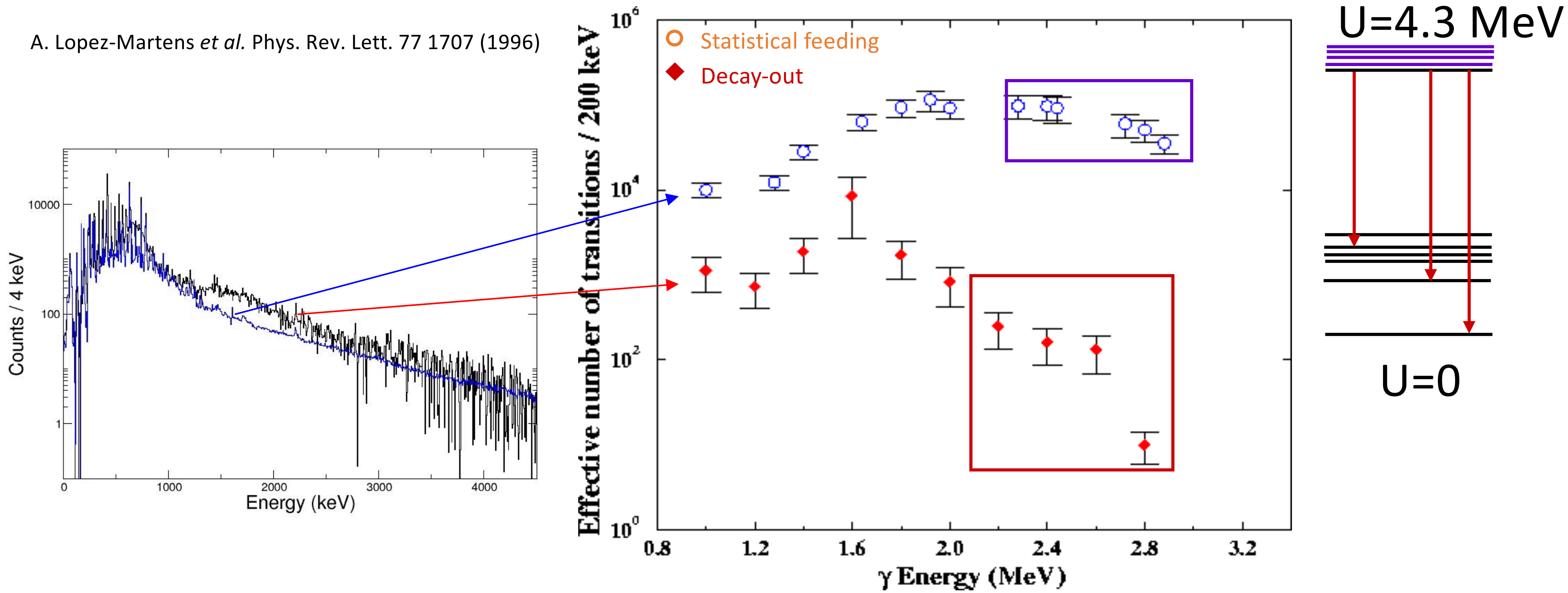

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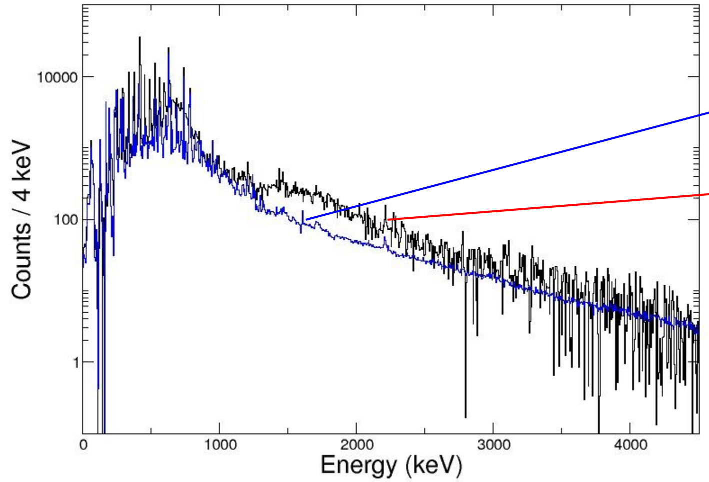

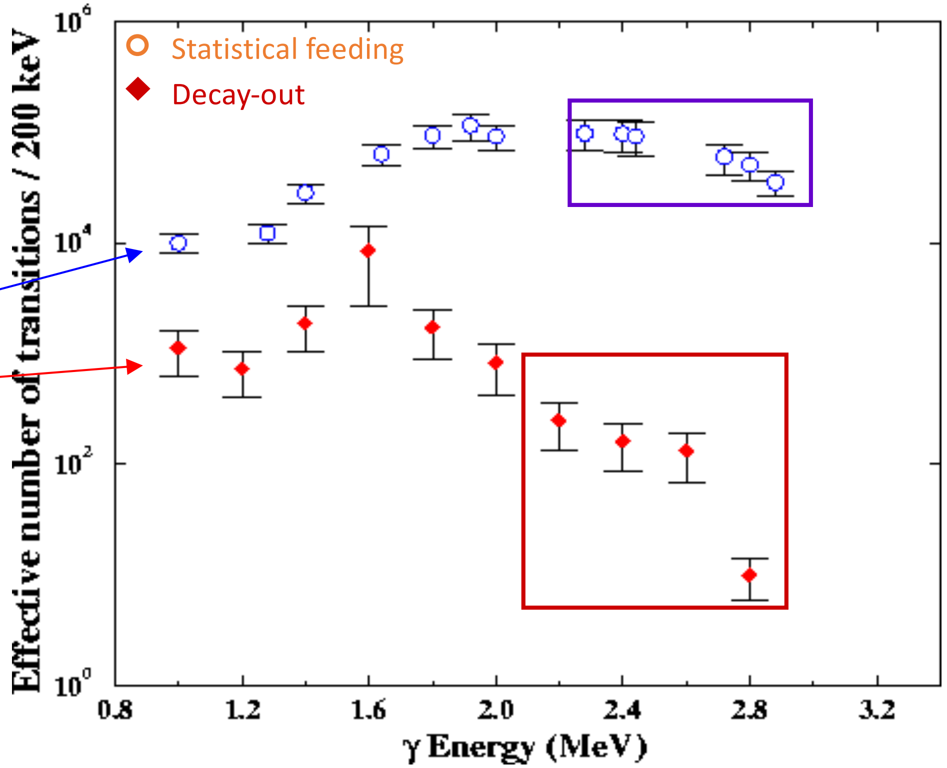

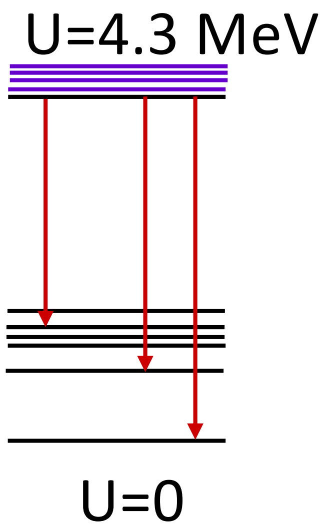

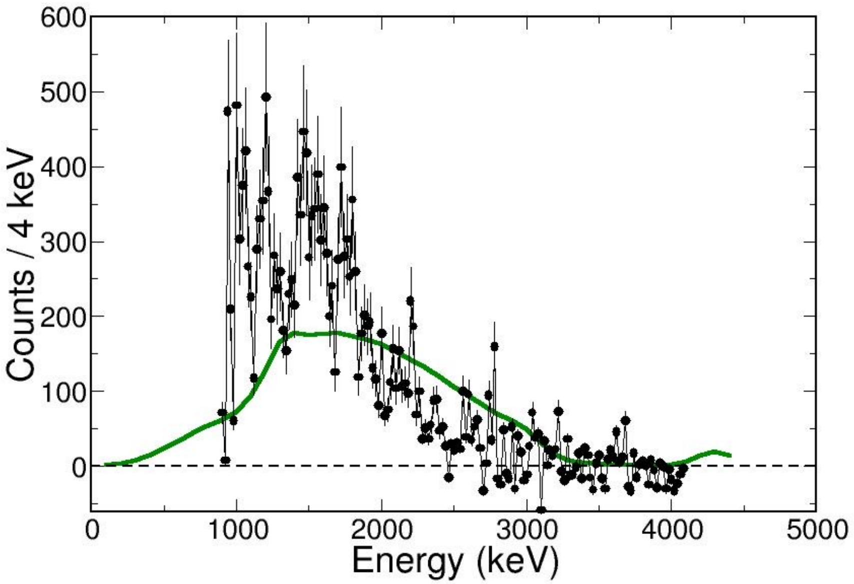

- large fragmentation ~ 10^4 decay paths
- 1-2 initial states ⇨ weak coupling to neighbouring ND states
- The shape of the decay-out spectrum reflects the density of ND states and the effects due to pairing

T. Døssing *et al.* Phys. Rev. Lett. 75 1276 (1995)

FAM applied to ^{192}Hg

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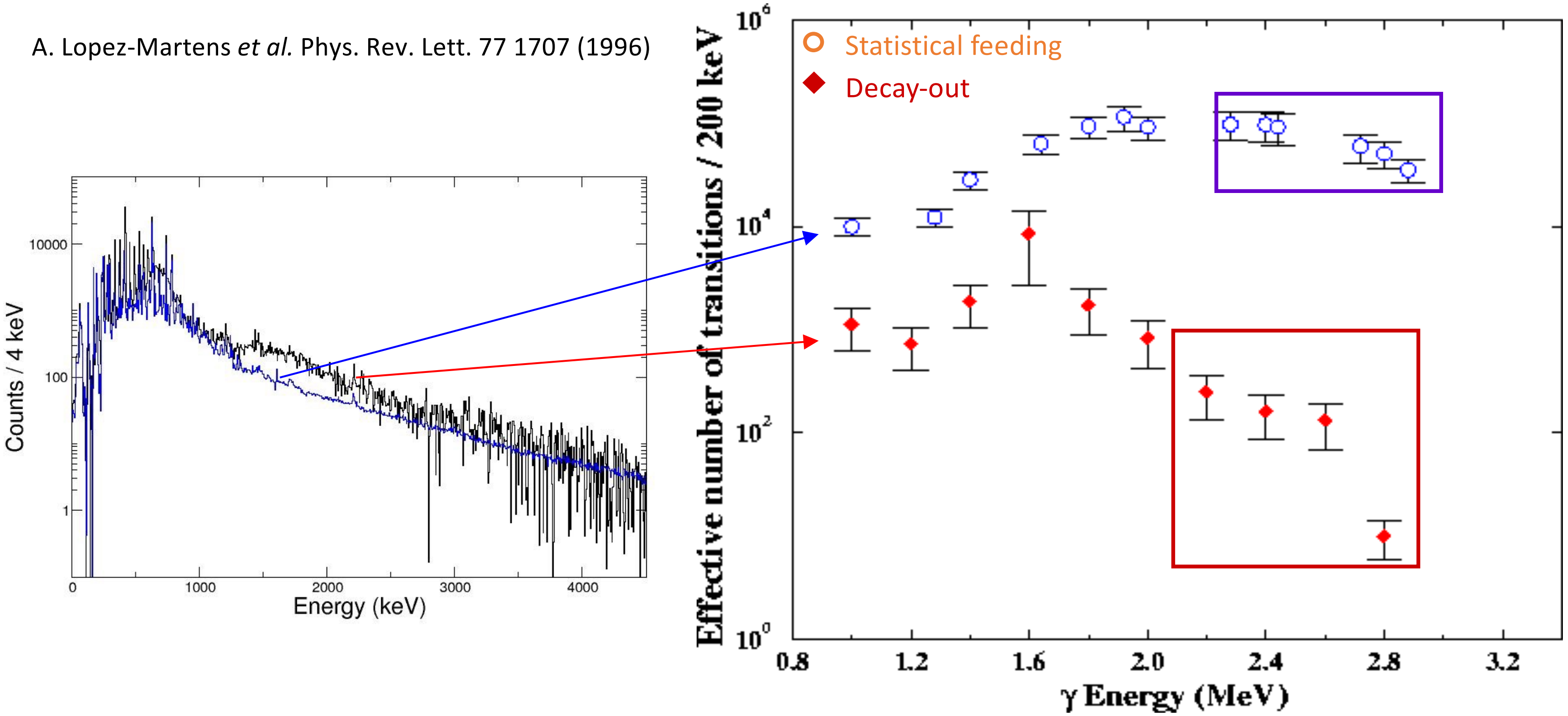
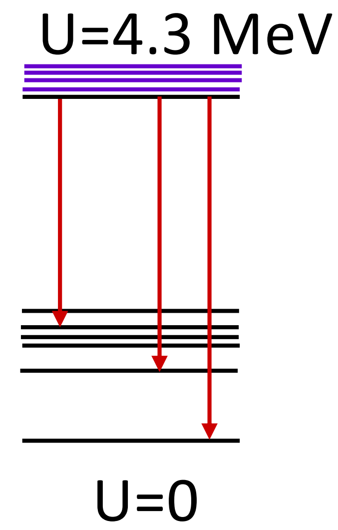
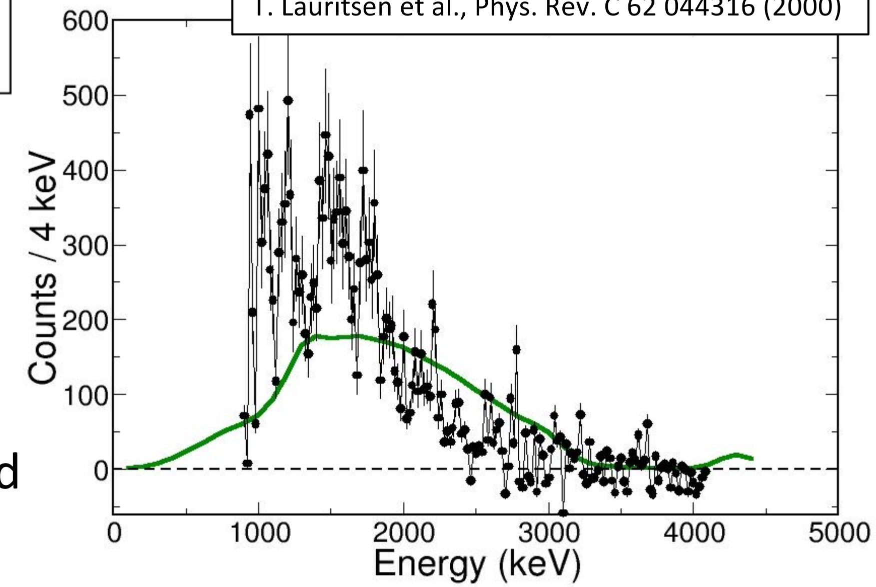




U(10ℏ)=3.3(0.5) MeV

T. Lauritsen et al., Phys. Rev. C 62 044316 (2000)



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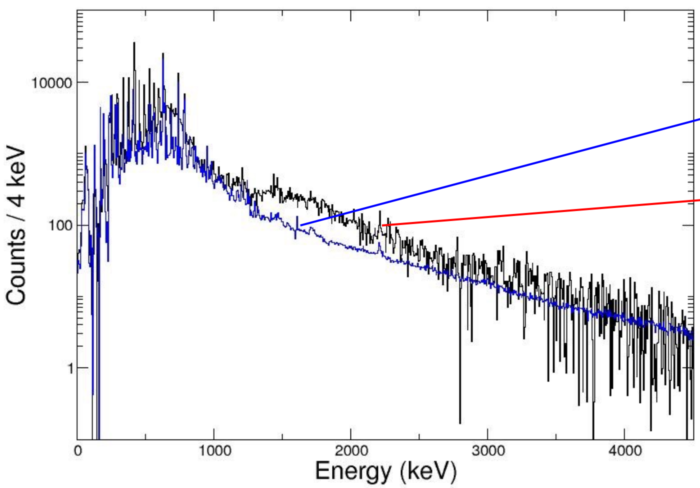

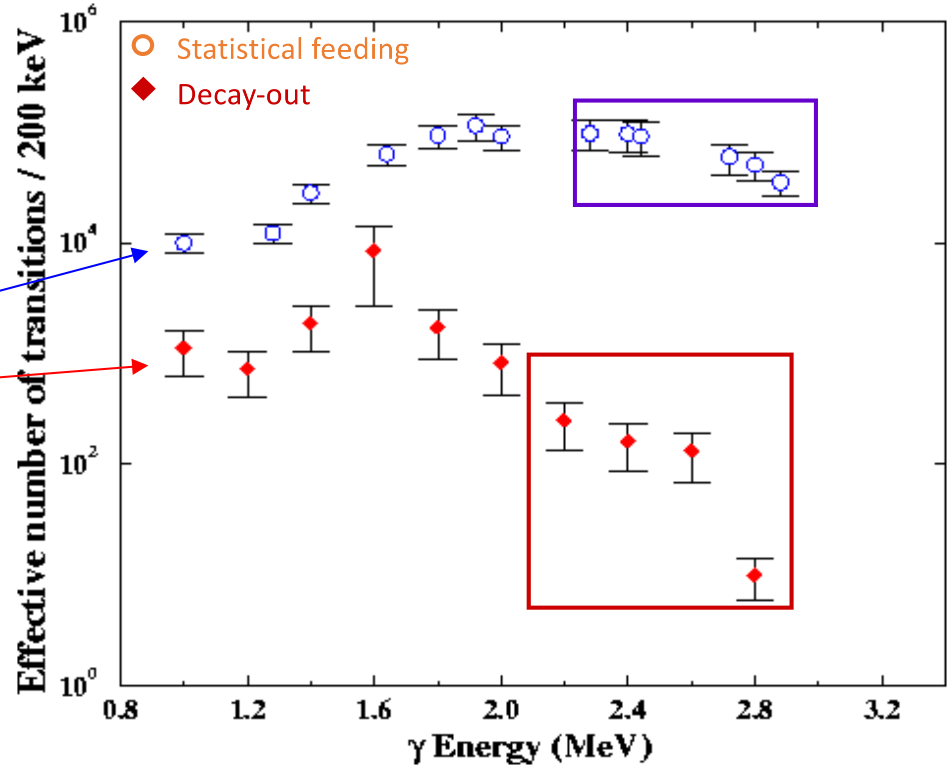

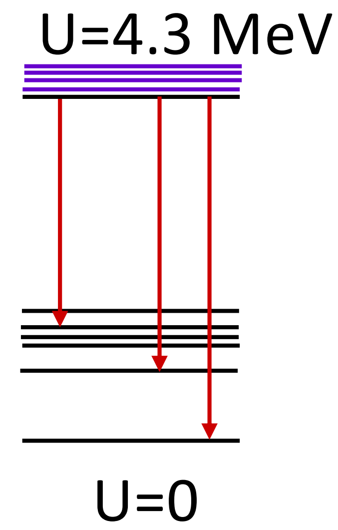

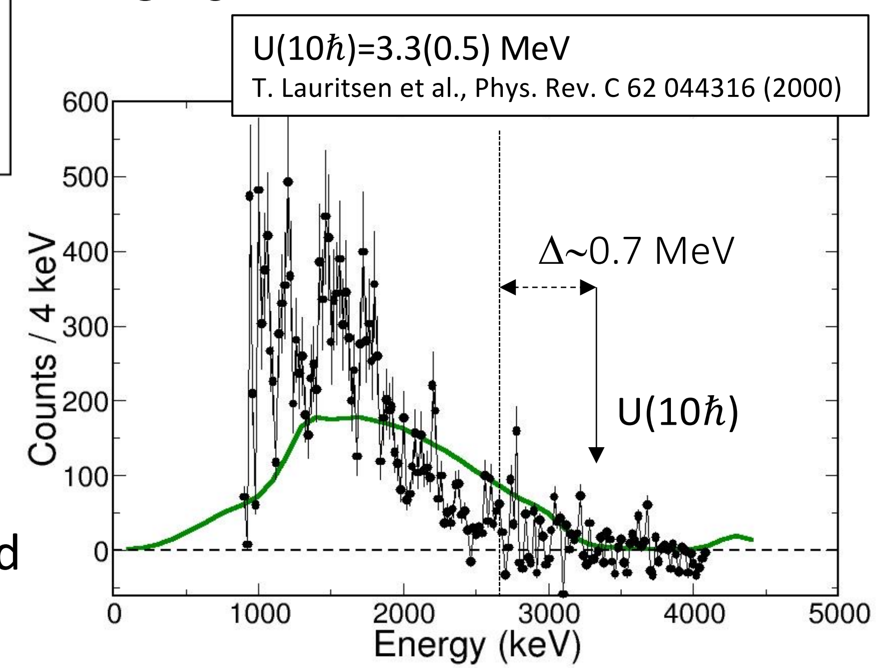

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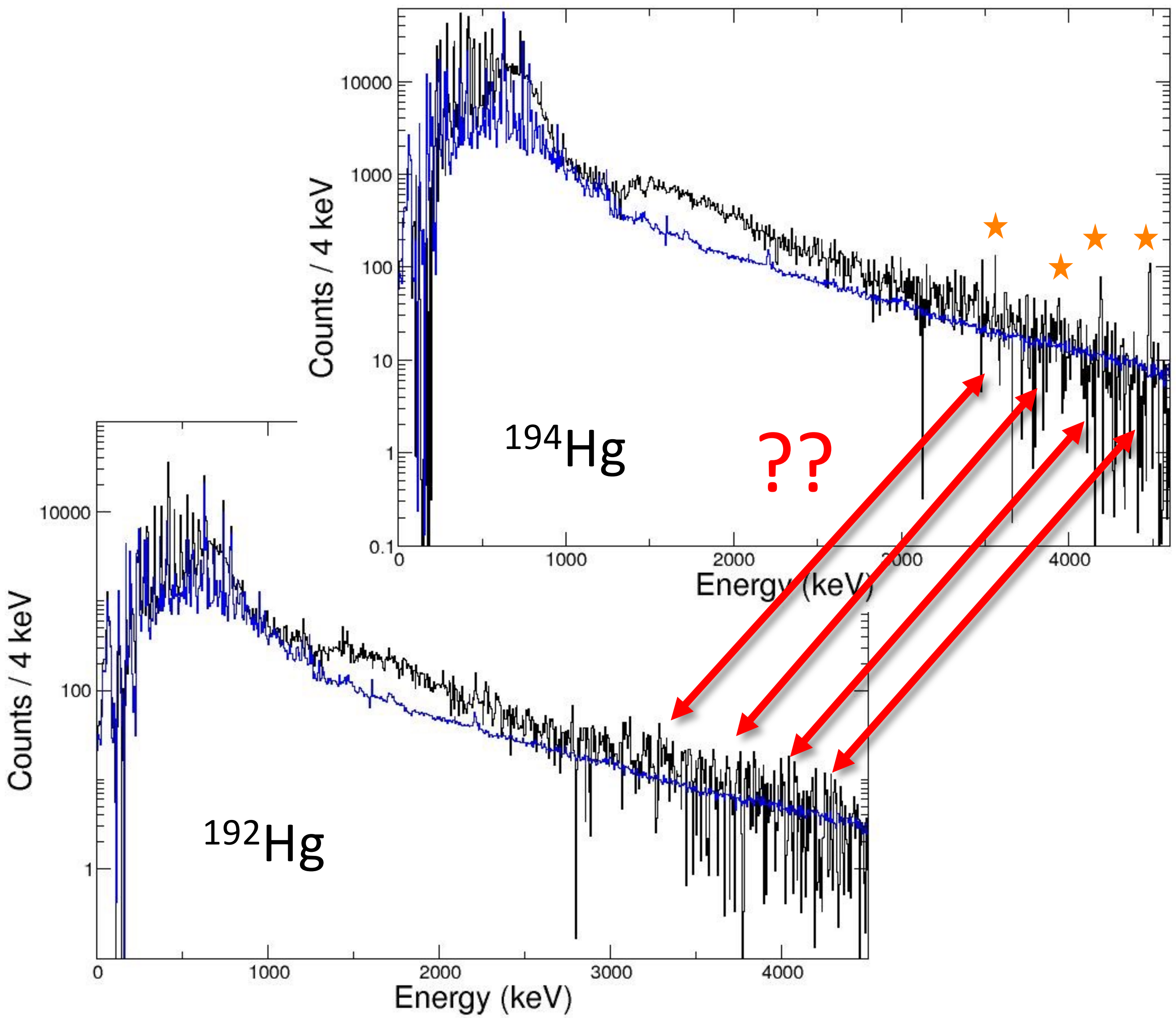
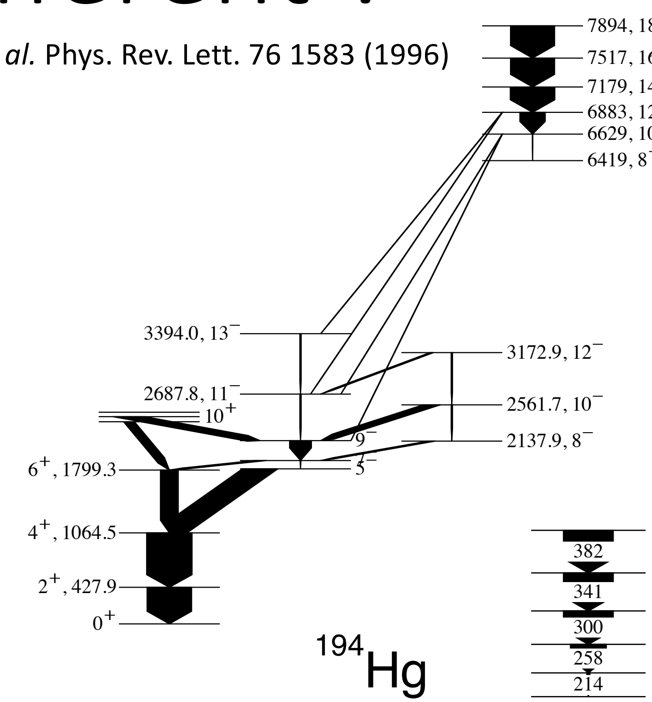
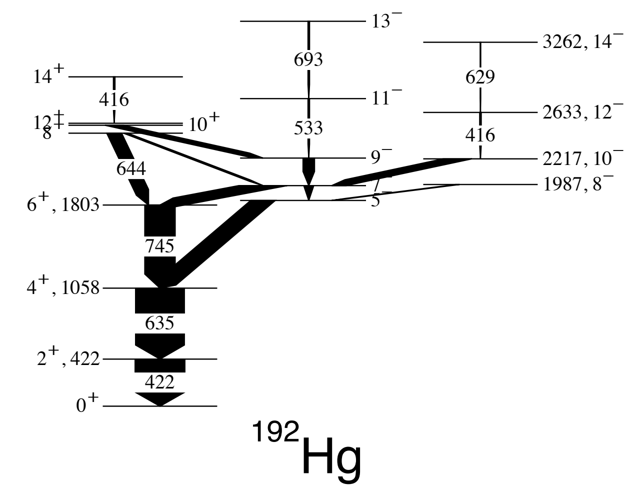
Why are ^{192}Hg and ^{194}Hg so different ?

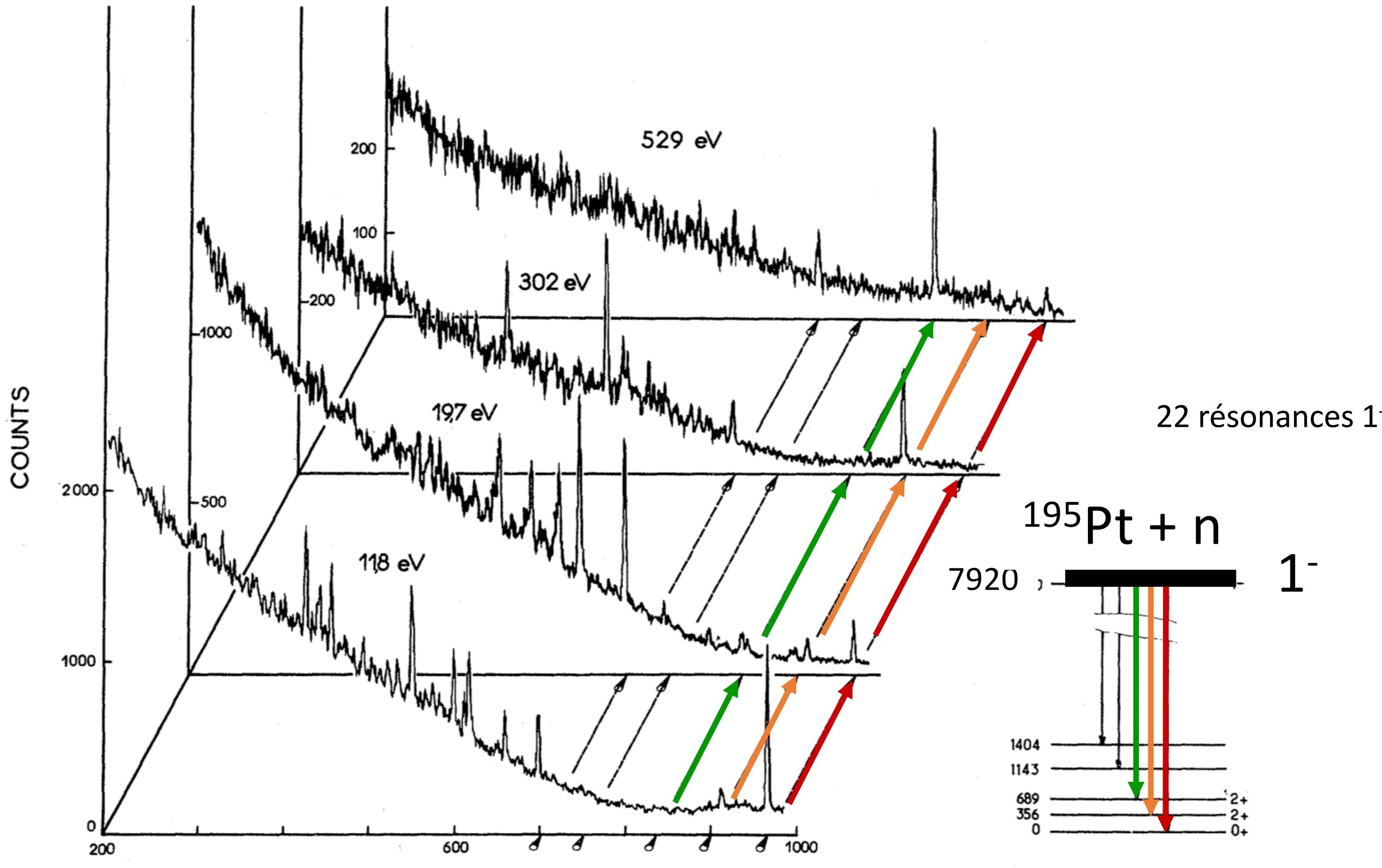
T.L. Khoo *et al.* Phys. Rev. Lett. 76 1583 (1996)







Similarity to γ-ray spectra following resonant neutron capture



H. Jackson *et al.* Phys. Rev. Lett. 17 656 (1966)

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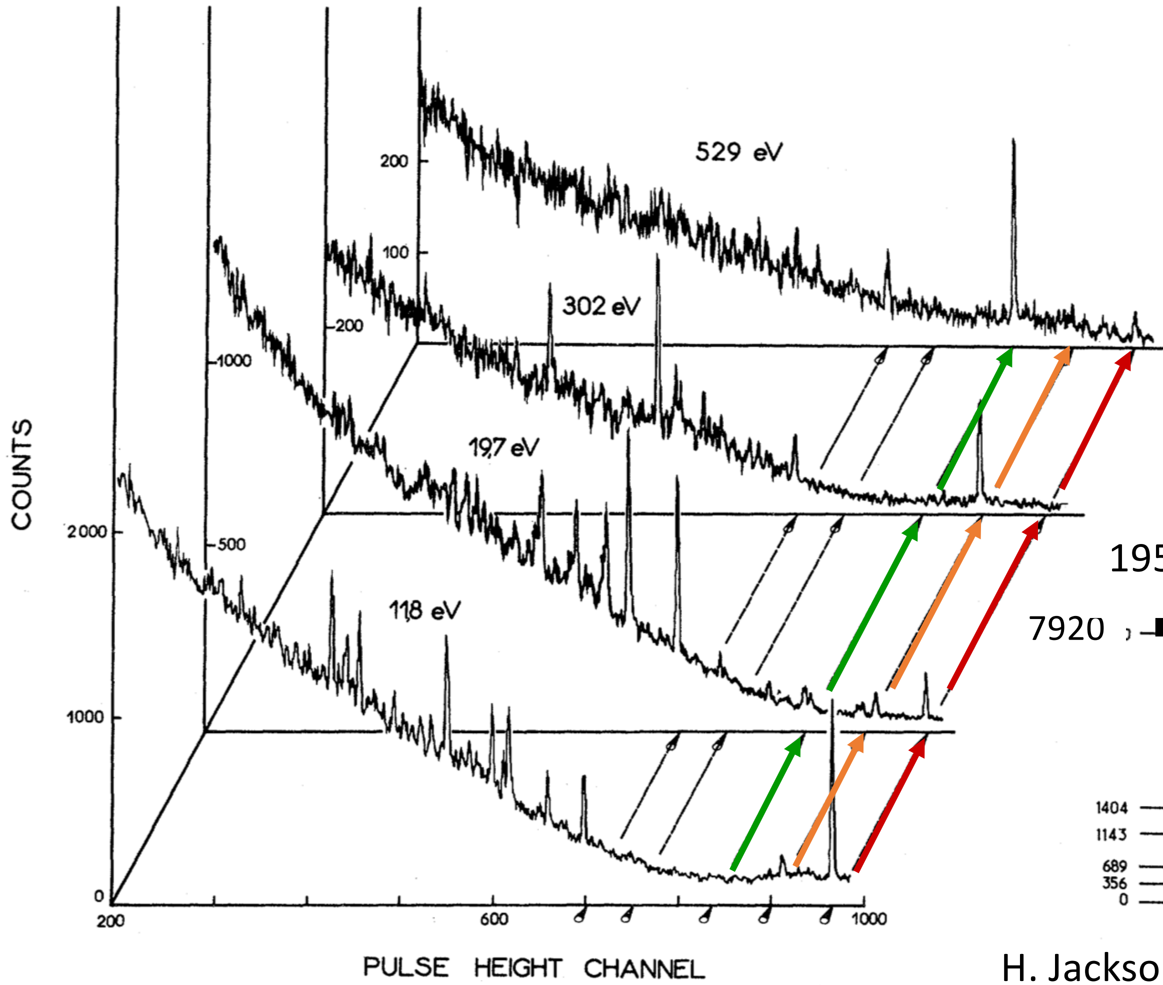

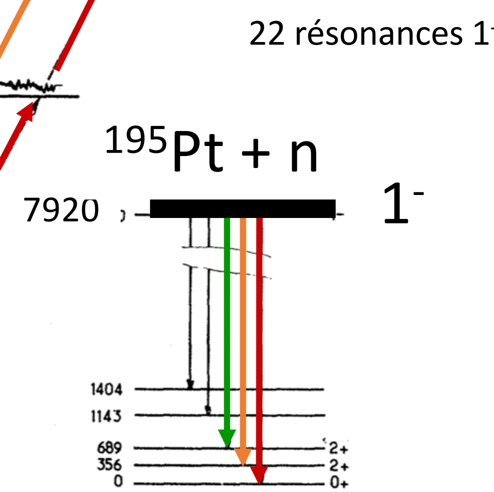

H. Jackson *et al.* Phys. Rev. Lett. 17 656 (1966)

The strength distribution follows a χ^2 distribution with ν=1 degree of freedom = Porter-Thomas distribution

Does the primary decay-out strength in ^{194}Hg follow a Porter Thomas distribution ?

$\nu=1^{+20}_{-1}$, $\theta=0.00062^{+0.00021}_{-0.00044}$

A. Lopez-Martens *et al.* Nucl. Phys. A 647 217 (1999)

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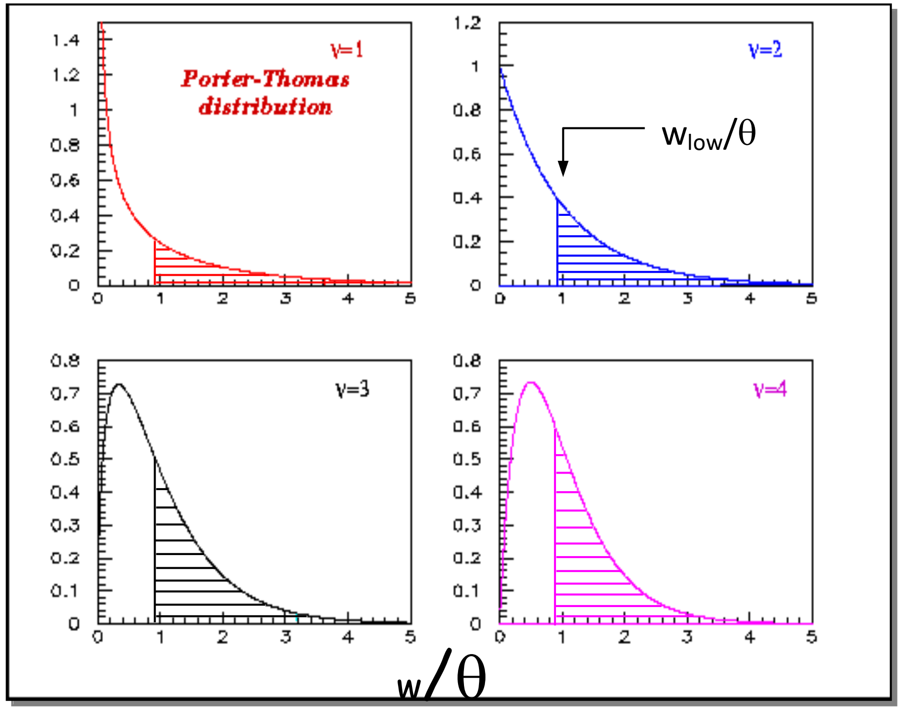

$w_{low}/\theta=3.8$! ⇔ 19 lines observed out of 600 !

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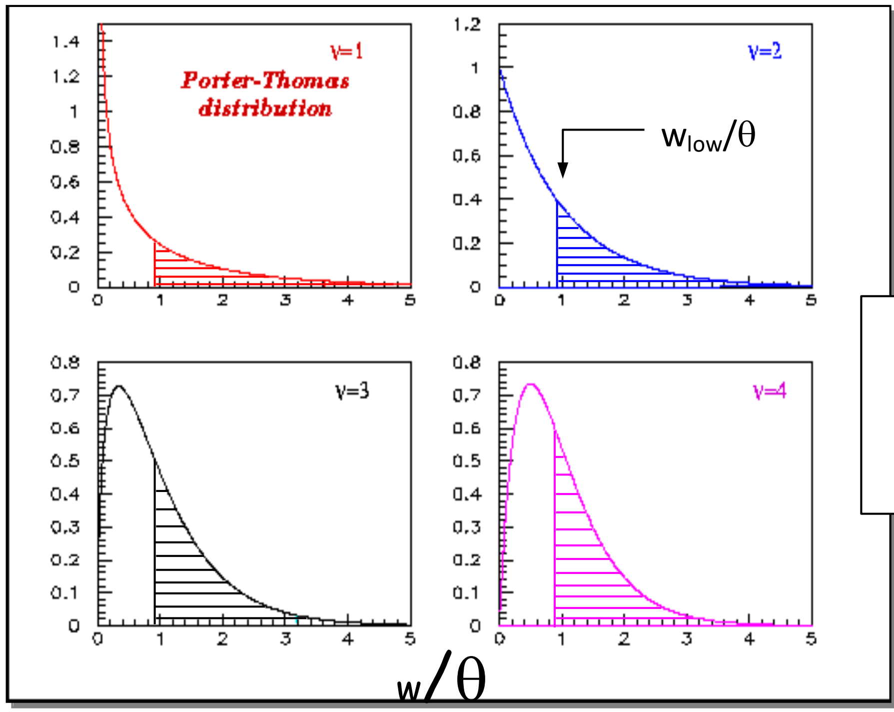

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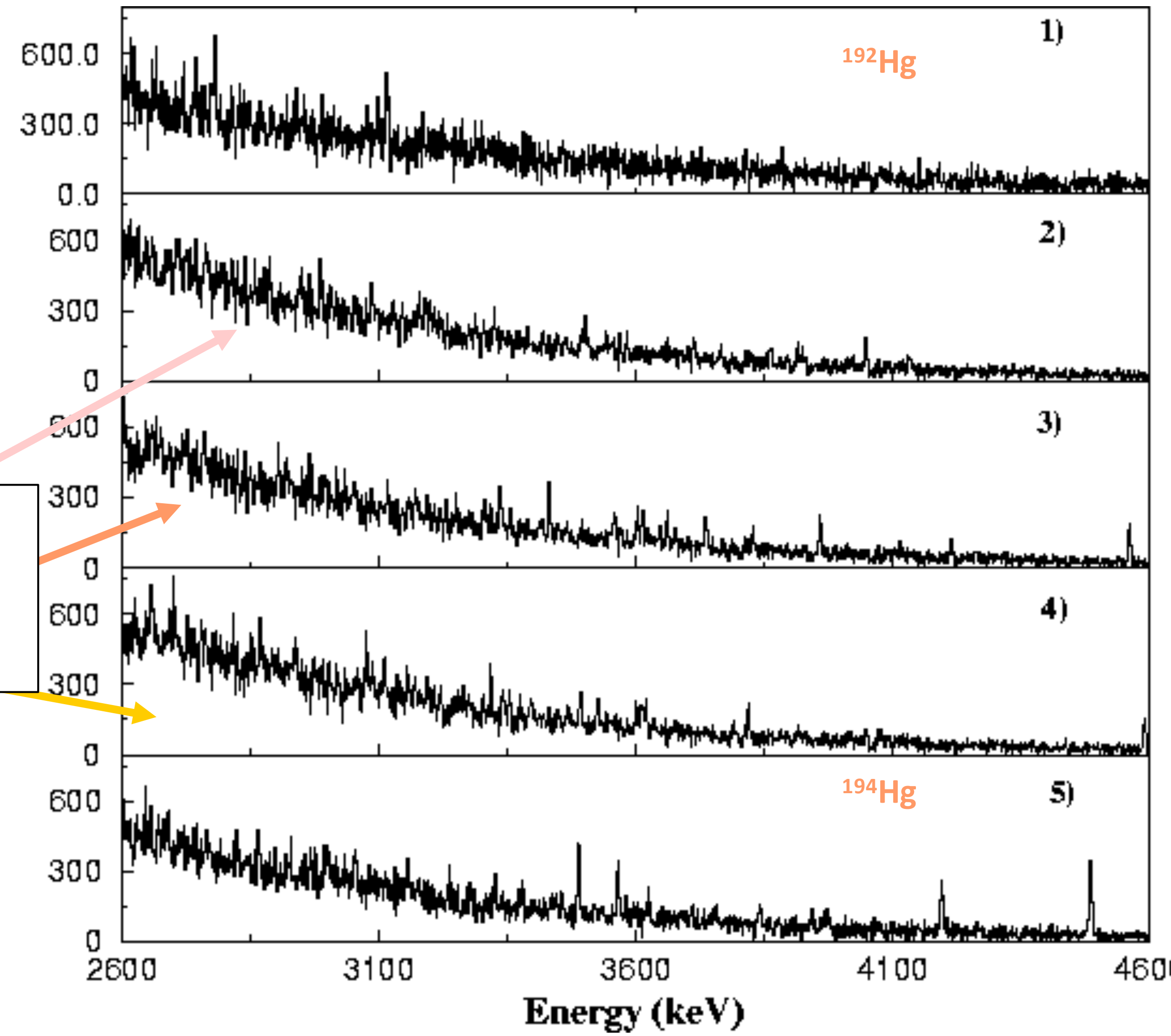
3 simulations of 600 primary Transitions



Conclusion & perspectives

Qualitative & quantitative understanding of the underlying mechanisms involved the population and decay of superdeformed states

Many experimental & data-analysis methods have been developped to study the different aspects related to the population & decay of superdeformed states

Still many open questions & lots to investigate:

- Excitation energy, spin & parity of most superdeformed states?
- Mixing and damping properties as a function of E, I (and K) and A ?
- Competition with M1 and M1/E2 decays ?
- Enhanced cooling mechanism of SD nuclei in other mass regions ?
- Shape and nature of the decay out spectrum for A≉190 ?
- …

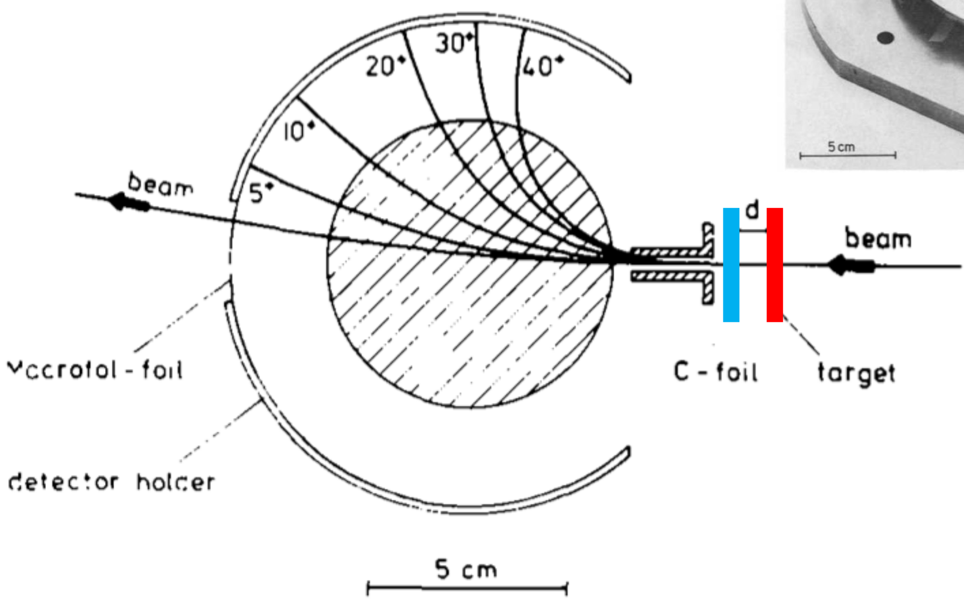
⇨ Clear physics cases for the next generation γ-ray arrays such as AGATA & GRETA

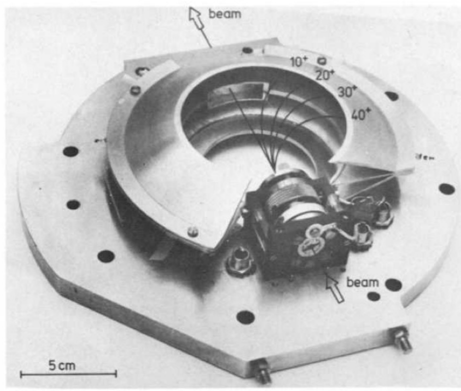
Backup

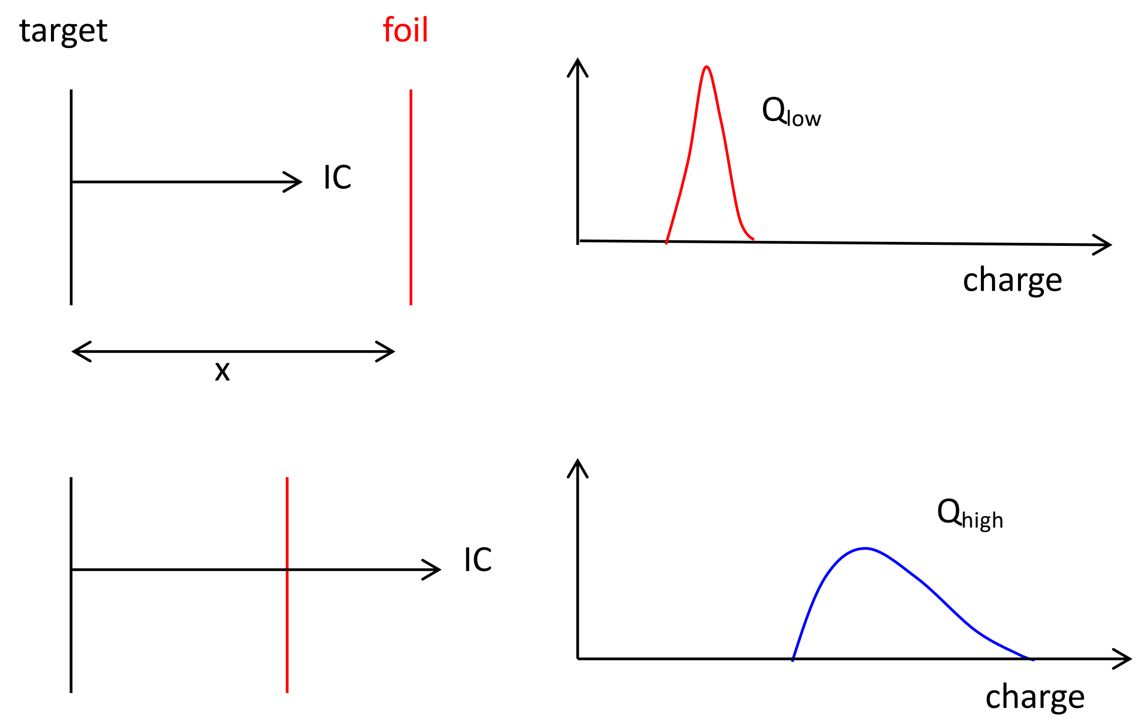
Magnitude of superdeformation first measured

Charge plunger technique

G. Ulfert et al., Nucl. Instr. Meth. 148 (1978) 369







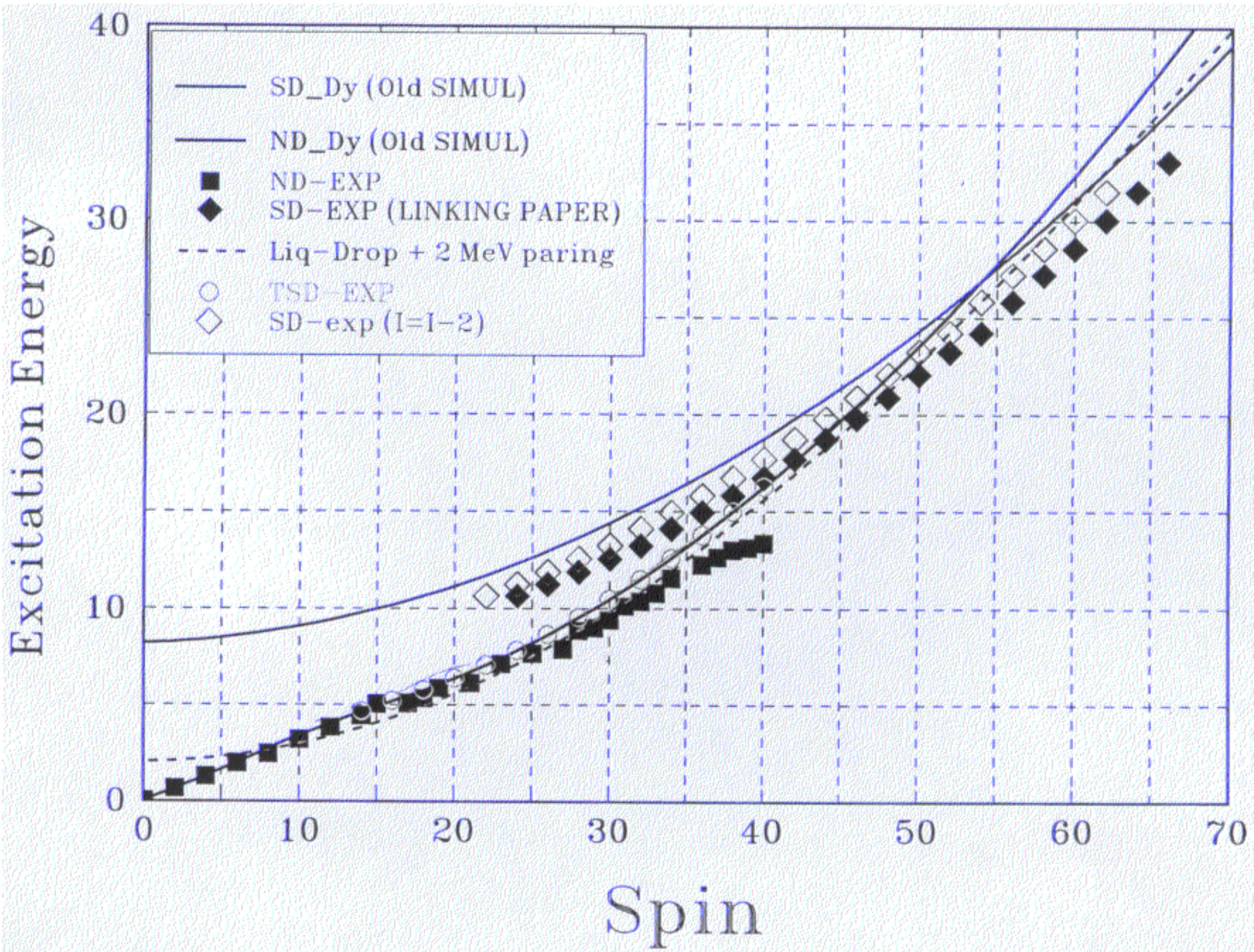
Measurement of lifetimes in the 2nd well of ^{239}Pu produced in the ^{238}U(α,3n) reaction

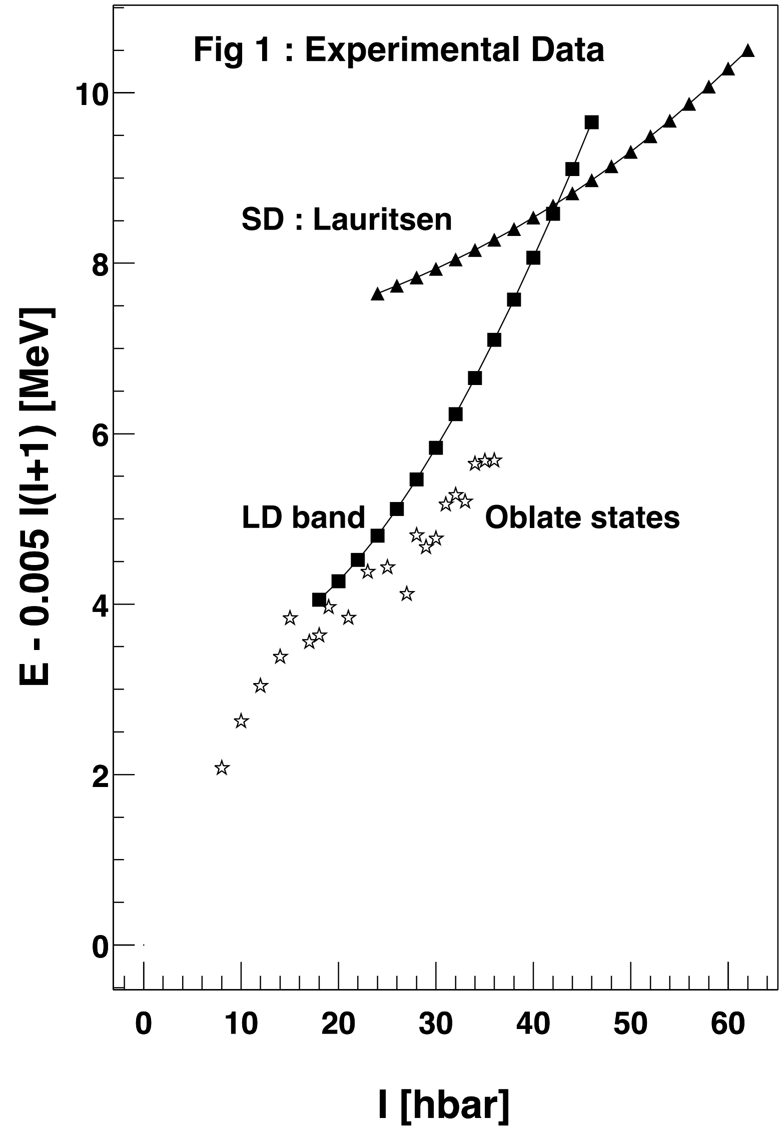
⇨ first proof of shape isomerism: Q_o: 36 ± 4 eb ⇔ c/a ~ 2

D. Habs, V. Metag, H.J. Specht and G. Ulfert, Phys. Rev. Lett. 38 (1977) 387

Linking transitions in ^{152}Dy: implications for SD-ND crossing

~1 MeV lower in E* and ~10ℏ lower ?

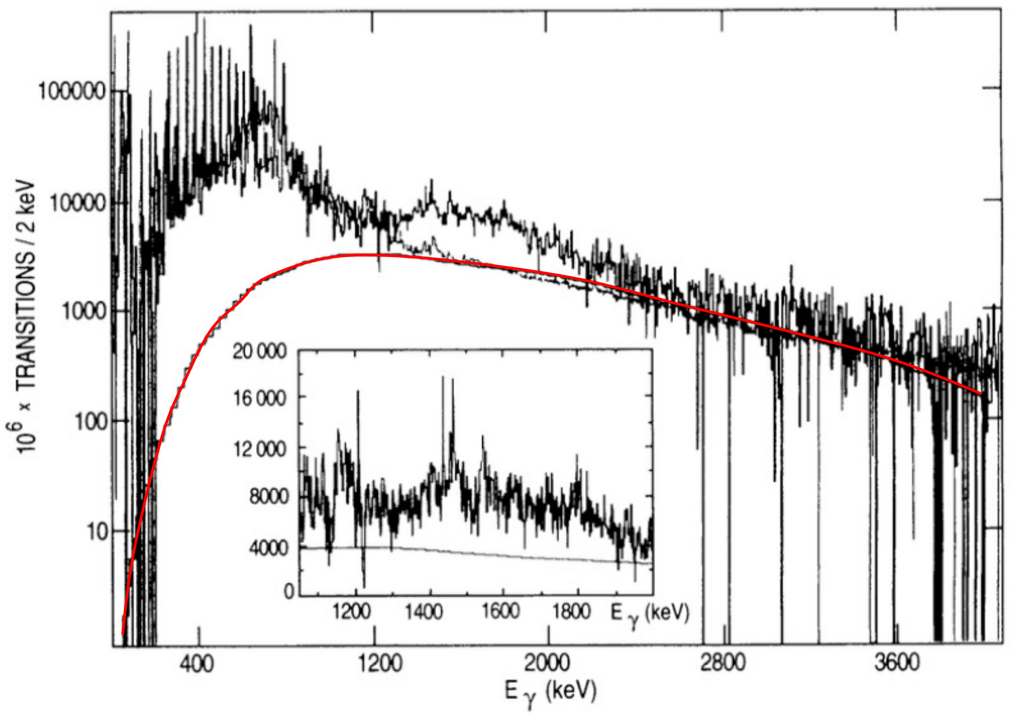




Crossing 10ℏ and 1 MeV lower than previosuly thought

QC decomposition

Simulation & removal of E1 spectrum



Angular distribution of remaining QC