



RDT studies of $A \sim 100$ nuclei near the proton dripline

γ - Pool Symposium

ECT*, Trento, May 8-12, 2006

Bo Cederwall

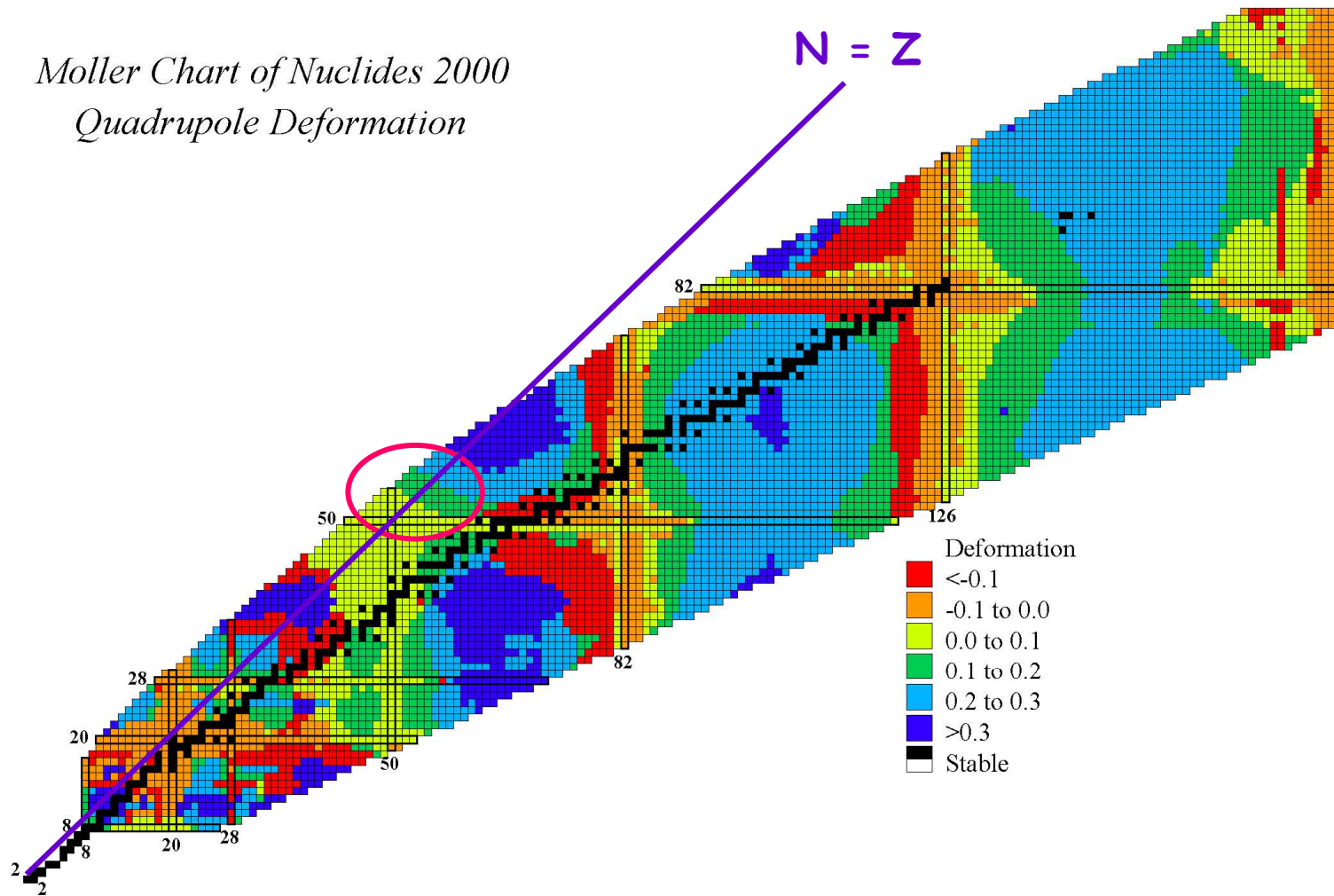
Department of Physics

Royal Institute of Technology (KTH)

Stockholm, Sweden

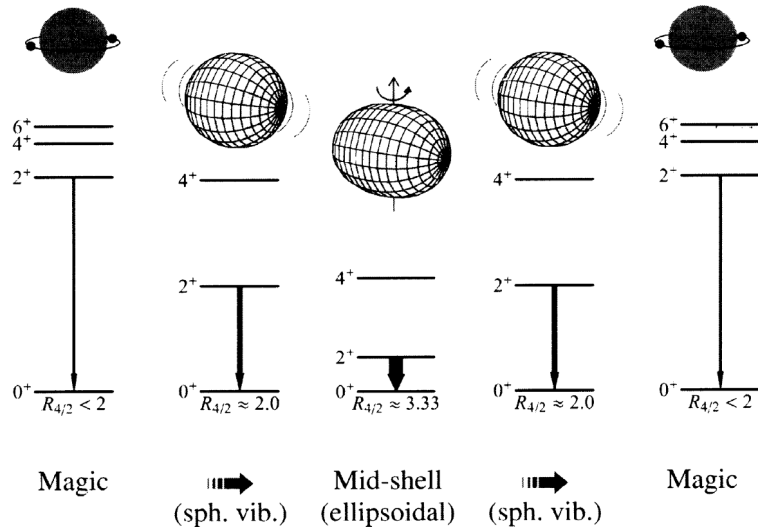


Moller Chart of Nuclides 2000
Quadrupole Deformation



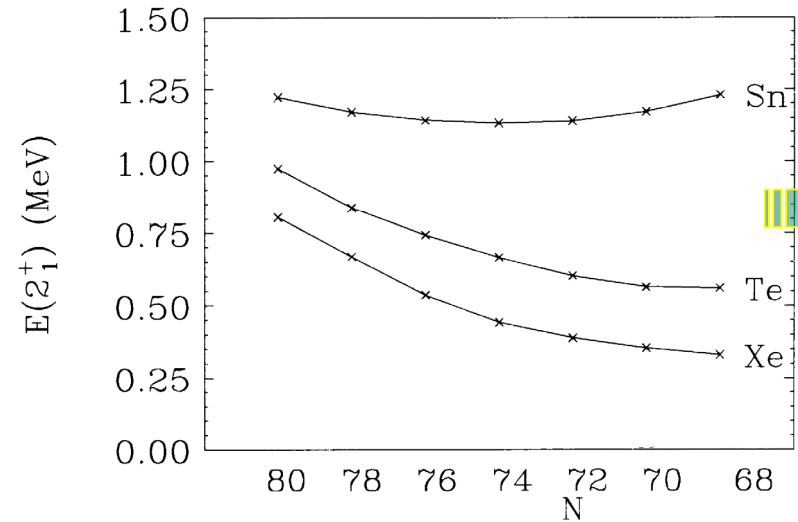
Onset of nuclear collectivity

Evolution of nuclear structure
(as a function of nucleon number)



Taken from R.F. Casten, 2003

THE ORIGIN OF QUADRUPOLE DEFORMATION



Taken from R.F. Casten, 2003

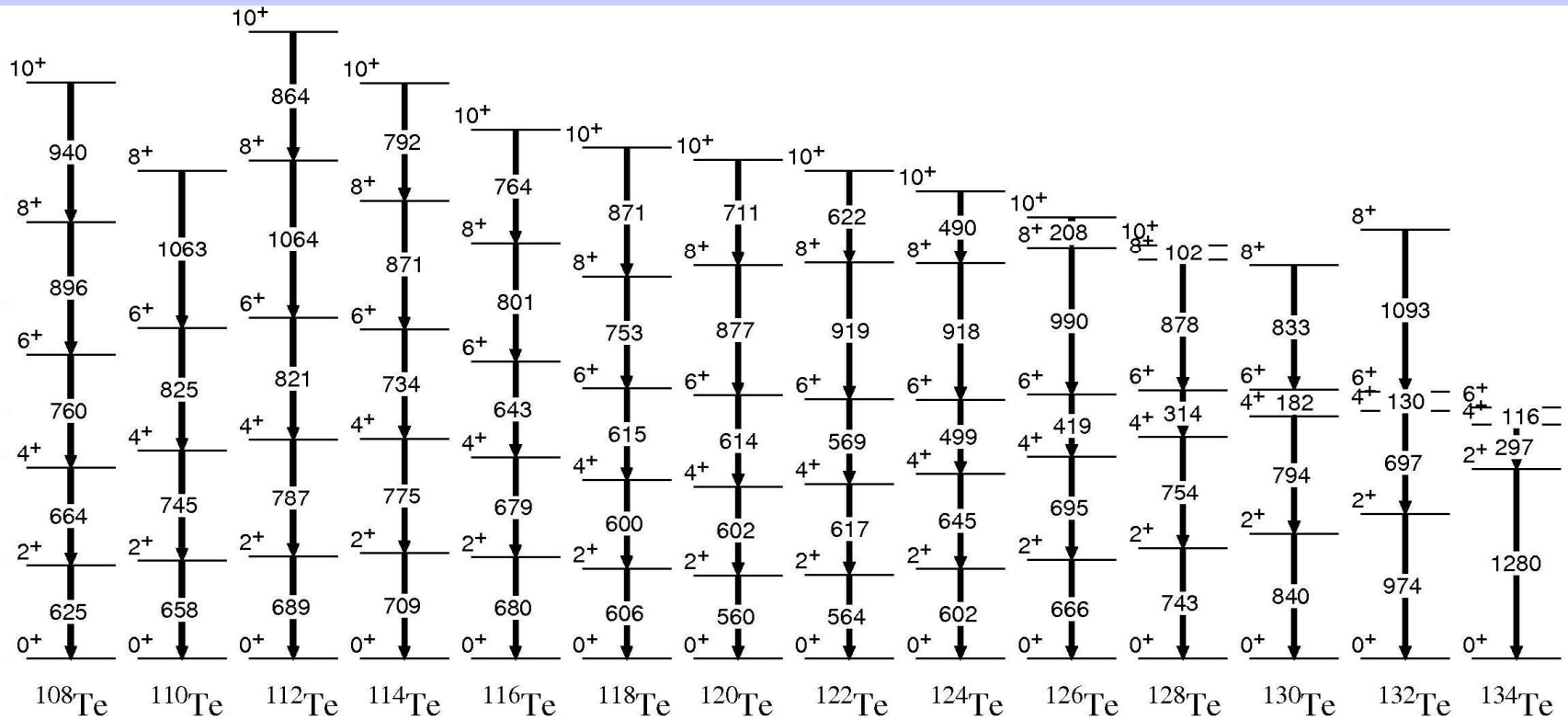
"Magic" nucleus : all occupied j - shells are filled

$$\sum_{i=1}^{2j+1} m_i = 0 \forall \text{ shells} \Rightarrow J^\pi = 0^+ \text{ i.e. no directional preference of w.f.}$$

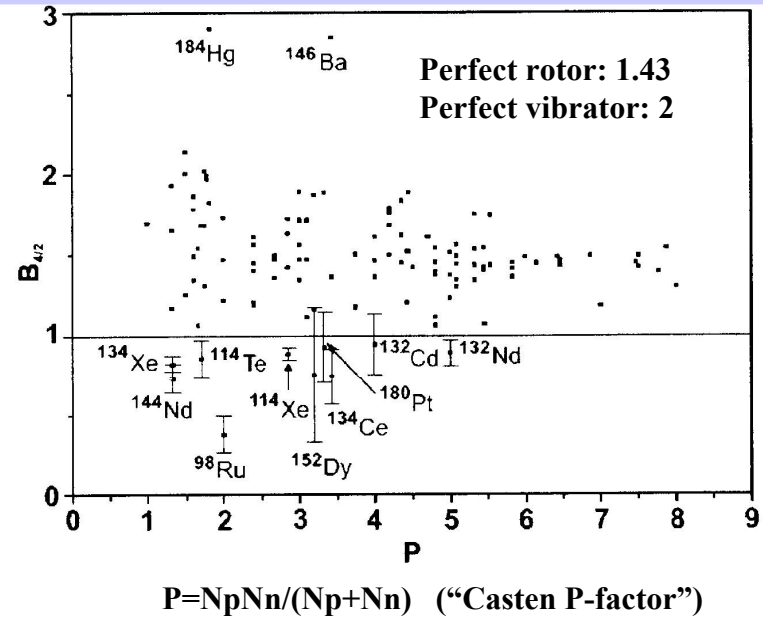
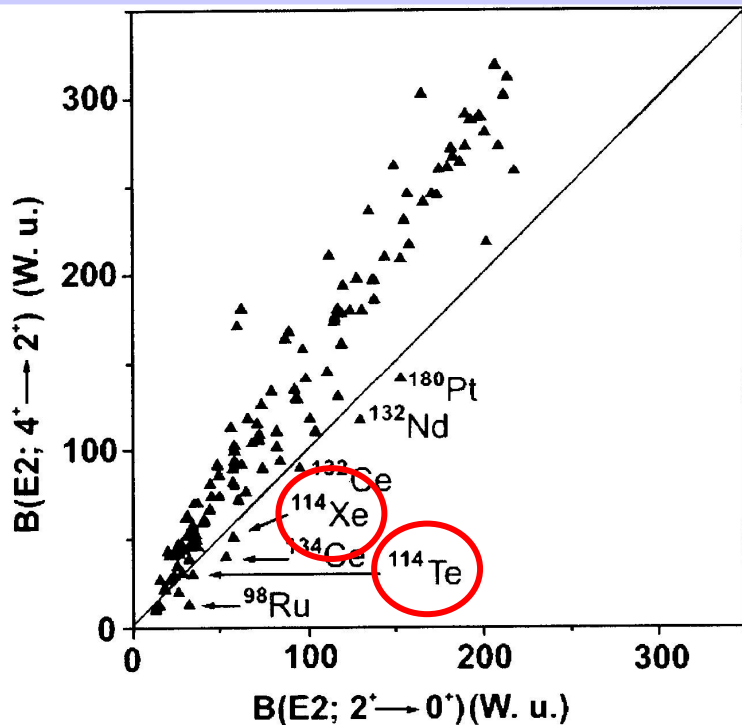
Departing from magicity, residual np interactions play a fundamental role in breaking the spherical symmetry of the nucleus ($N_n N_p$ scheme)

Te energy systematics

1997

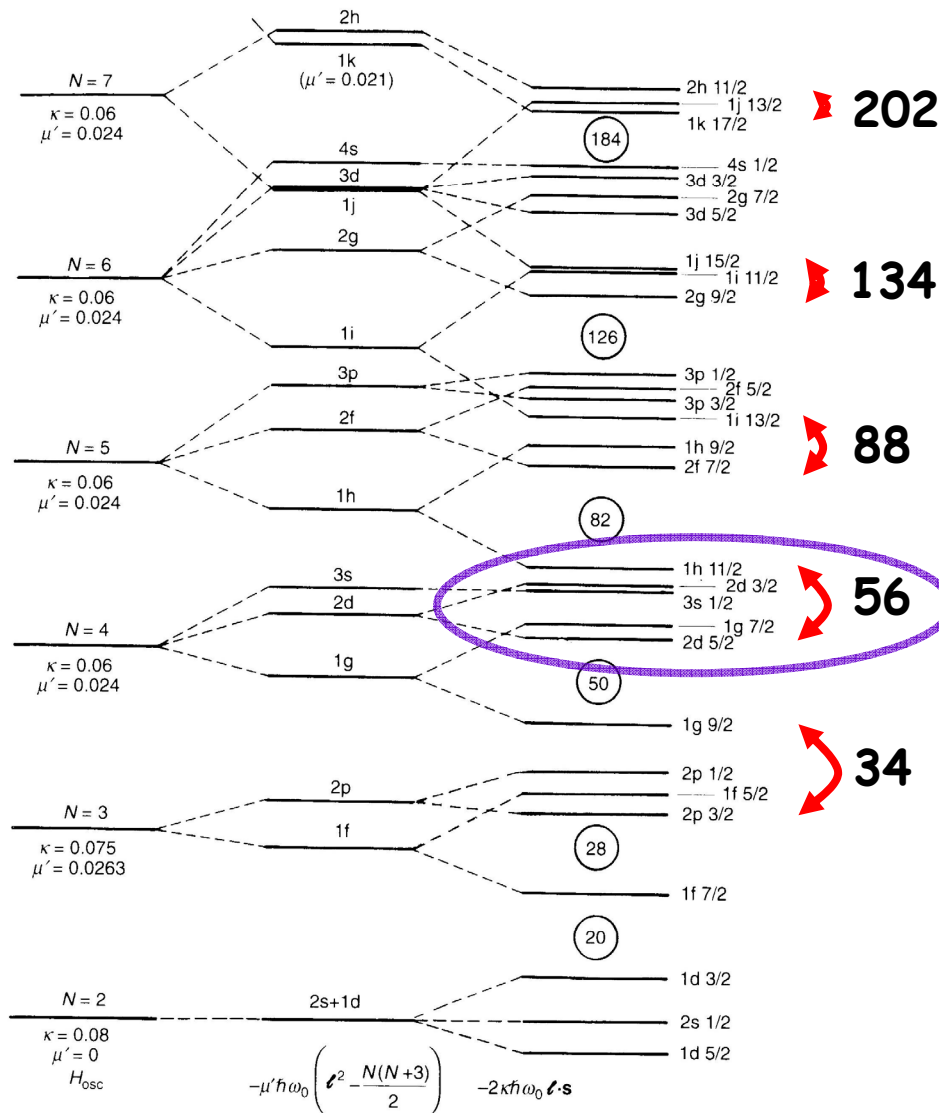


Deviations from "normal" collectivity



All standard collective models $\rightarrow B_{4/2} > 1$

Octupole deformation and correlations near N=Z



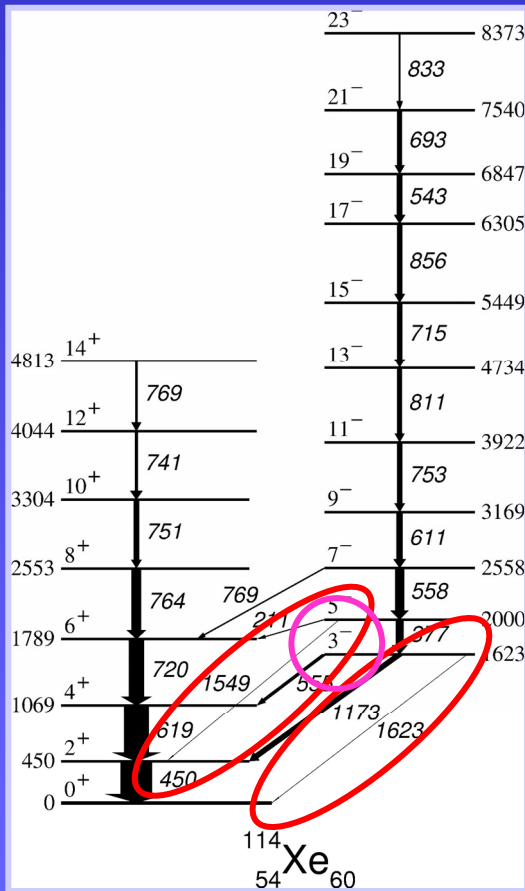
Strong octupole correlations are expected in nuclei where normal-parity single-particle states and intruder states differing by $\Delta l = \Delta j = 3$ are near the Fermi surface.

“Doubly-magic octupole-deformed” Nucleus predicted by theory Next to ^{112}Ba (inaccessible with current technology) $^{110}\text{Xe}_{56}$ is predicted to have the largest octupole stability.

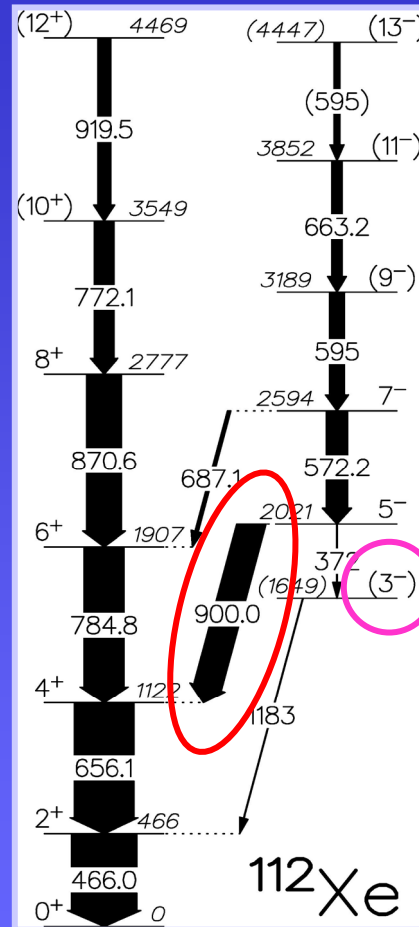
Coherent octupole correlations for neutrons and protons should occur near N=Z.

Can we observe additional enhancement due to np correlations?

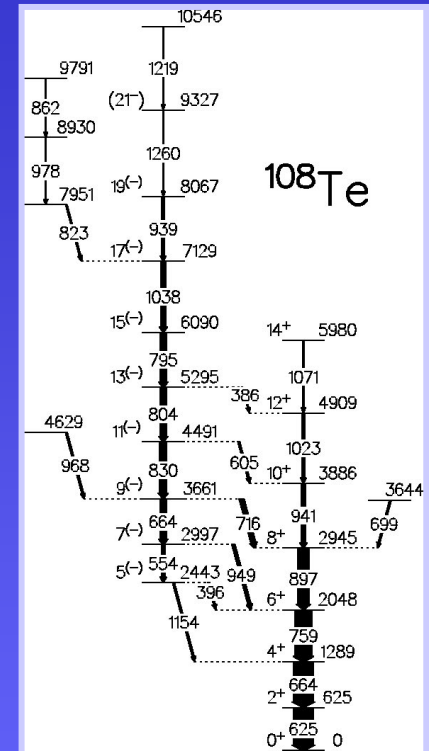
Evidence for enhanced octupole correlations near N=Z



G. de Angelis et al.
 Phys. Lett B535, 153 (2002)
 (Euroball)

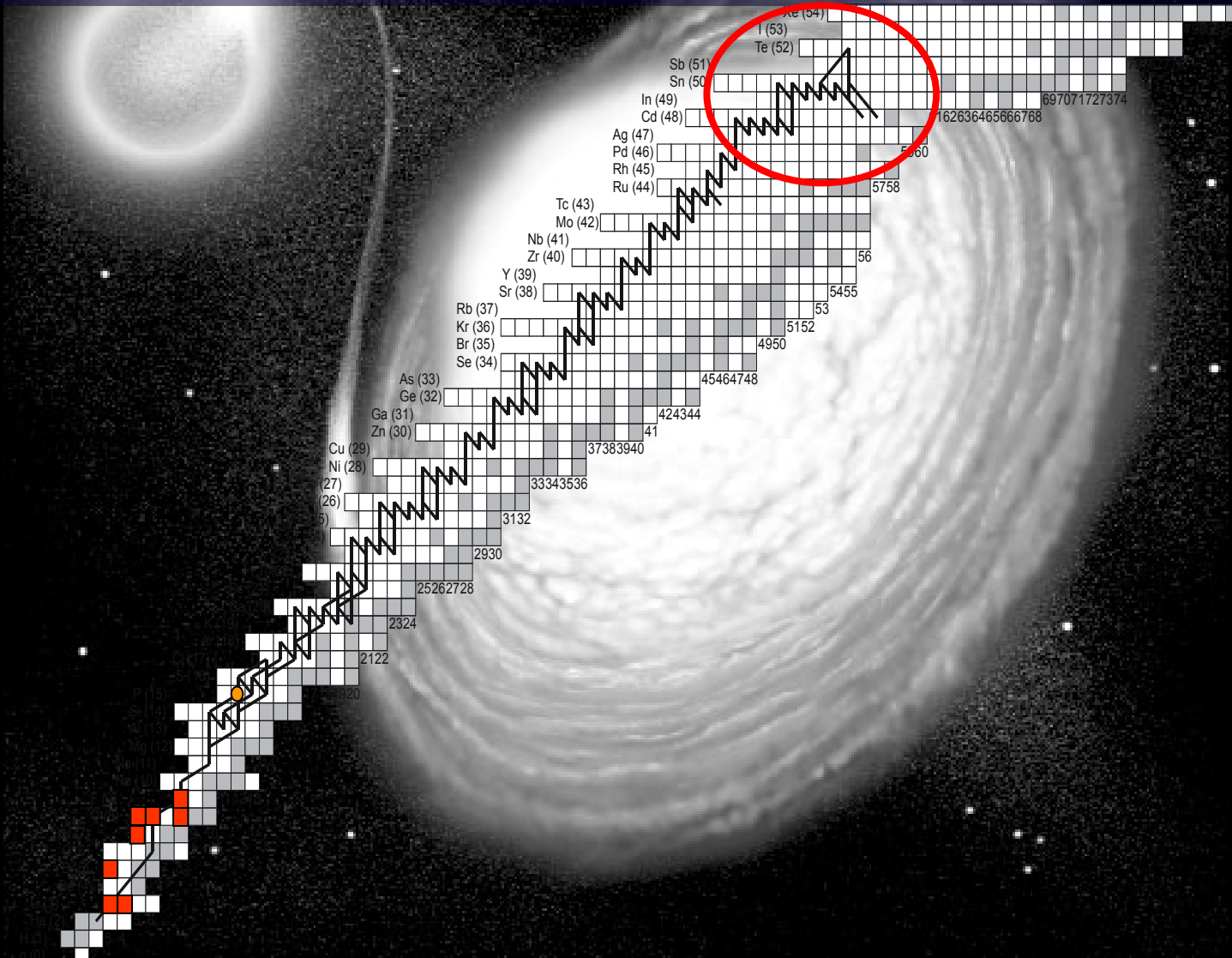


J.F. Smith et al.
 Phys. Lett B523, 13 (2001)
 (Gammasphere)



G.F. Lane et al.
 Phys. Rev. C57, R1022 (1998)
 (Gammasphere)

Astrophysical interest:
End point of the rp process path in X-ray bursts and
steady-state hydrogen burning on accreting neutron stars
Of critical importance for "superbursts"



RDT *) has become a crucial tool for structural studies of heavy, proton rich nuclei

- Recoil-decay tagging spectroscopy started in the $A \sim 100$ ($^{108,109}\text{Te}$) region E.S. Paul et al.
- Extremely low production cross sections prevented further exploration
- Technical advances (RITU + GREAT, TDR ...) were needed to proceed further

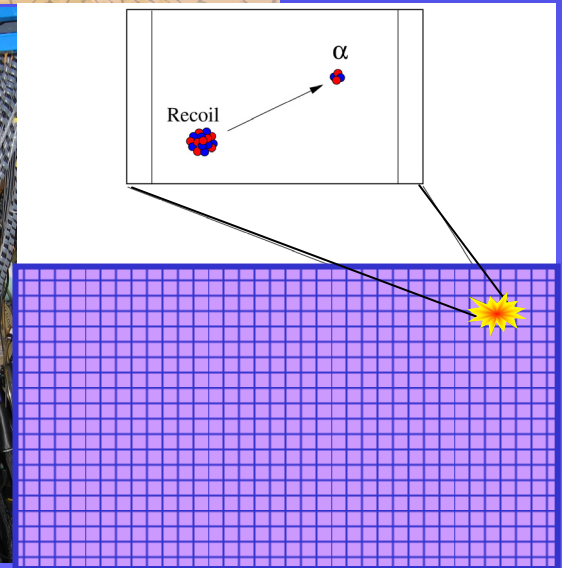
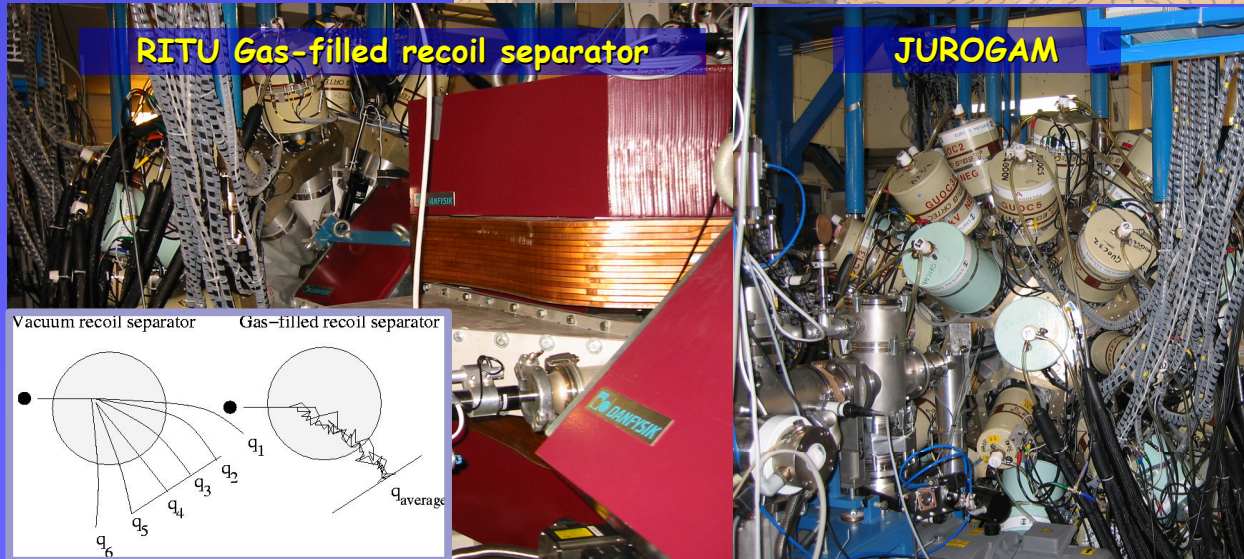
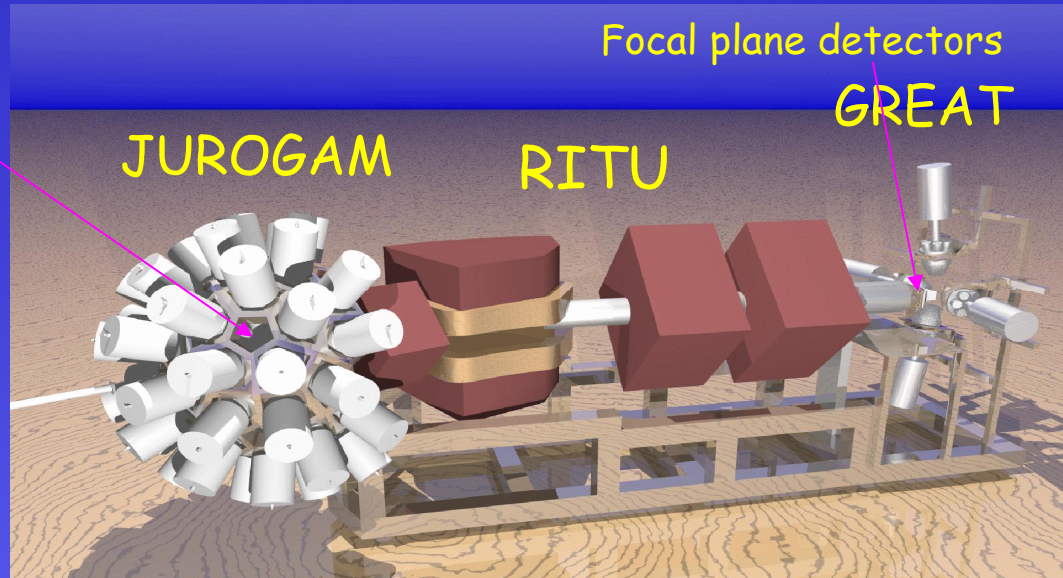
*) R.S. Simon *et al.*, Z.P.A. 325, 197 (1986): NaI + SHIP @ GSI
E.S. Paul *et al.*, P.R.C. 51, 78 (1995): Eurogam (45 HPGe) + DRS @ Daresbury

$^{106,107}\text{Te}$ - Access to the lightest Te isotopes by means of recoil-decay tagging at JYFL Accelerator Lab.

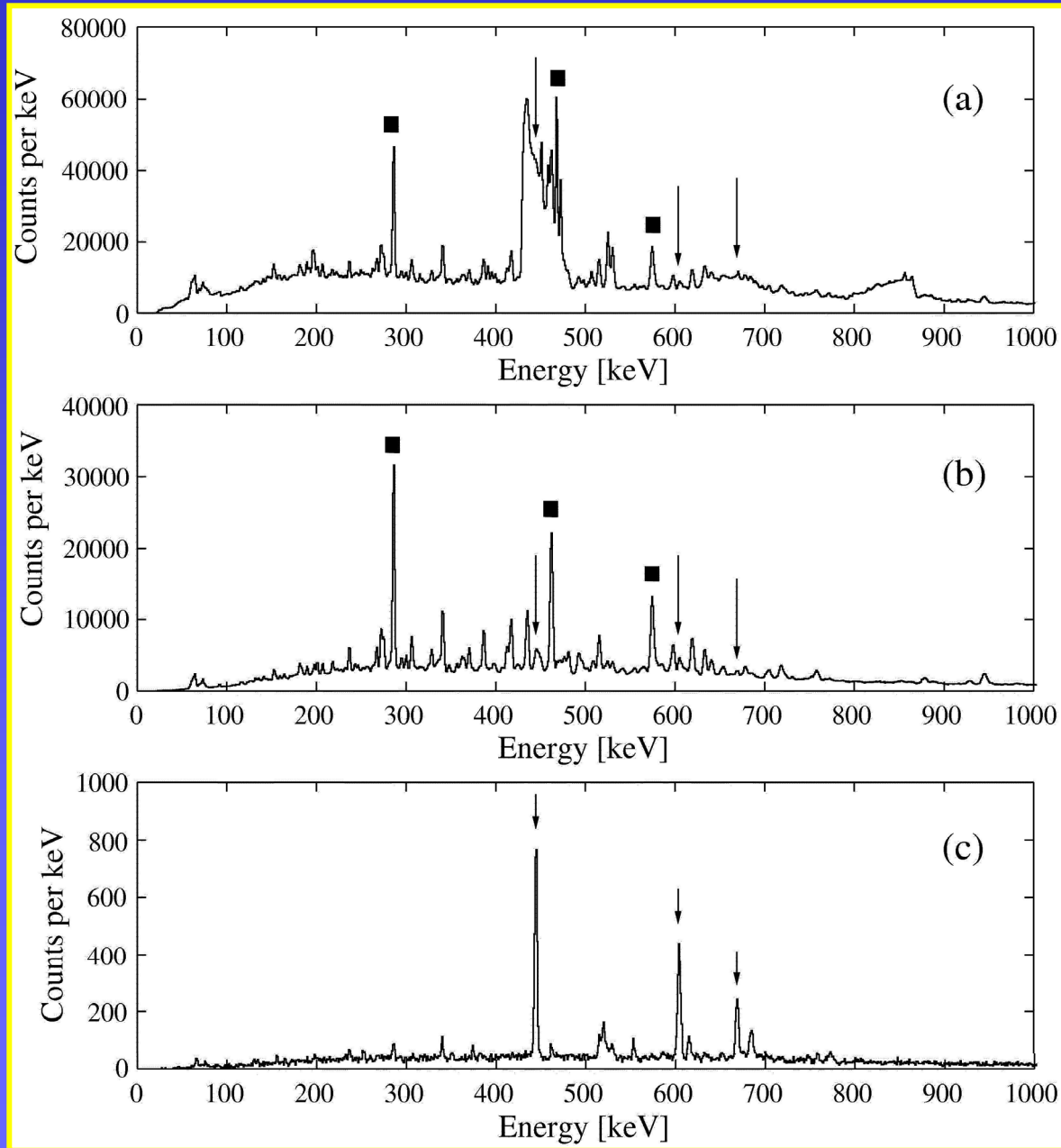
Detection of prompt gamma rays

43 detector HPGe
EUROBALL phase I type

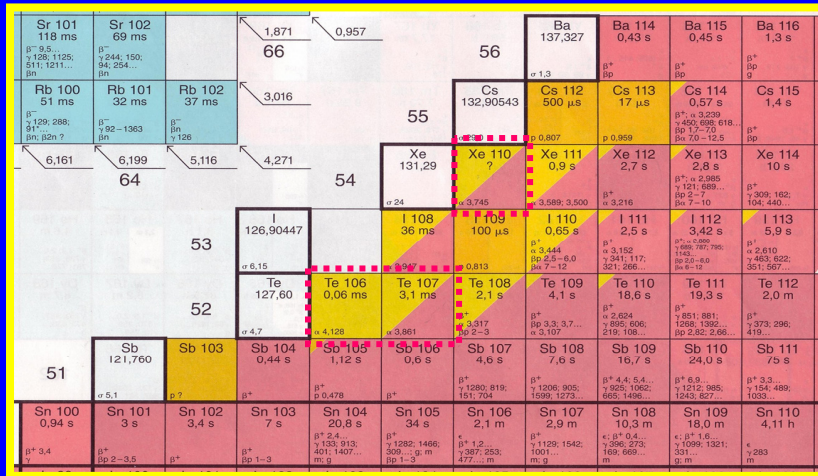
Total photo-peak efficiency
4.2% at 1.3 MeV



The selective power of recoil-decay tagging spectroscopy



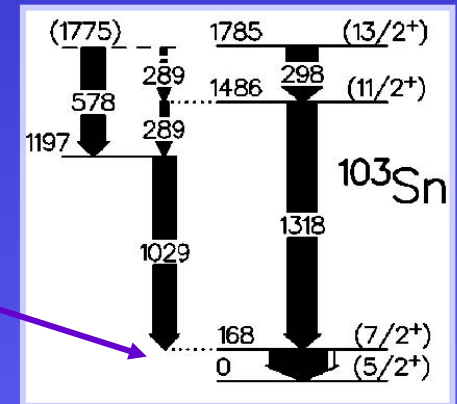
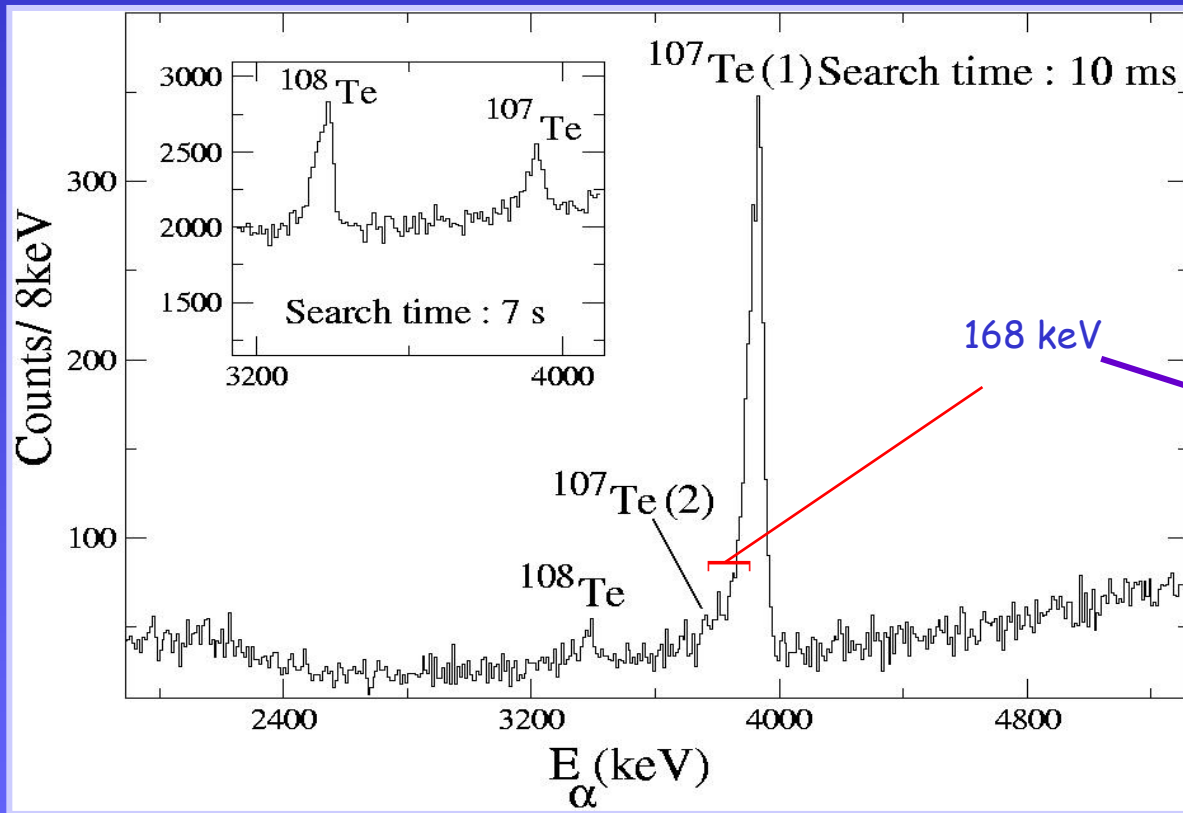
The "island" of alpha radioactivity "NE" of ^{100}Sn - a golden opportunity for RDT



N = Z

Challenge:
Can only be populated in
near-symmetric reactions

$^{58}\text{Ni} (^{52}\text{Cr}, 3n) ^{107}\text{Te}^*$ Recoil-correlated α decays @ RITU focal plane



C. Fahlander et al.
Phys. Rev. C63, 021307 (2001)
(Euroball)

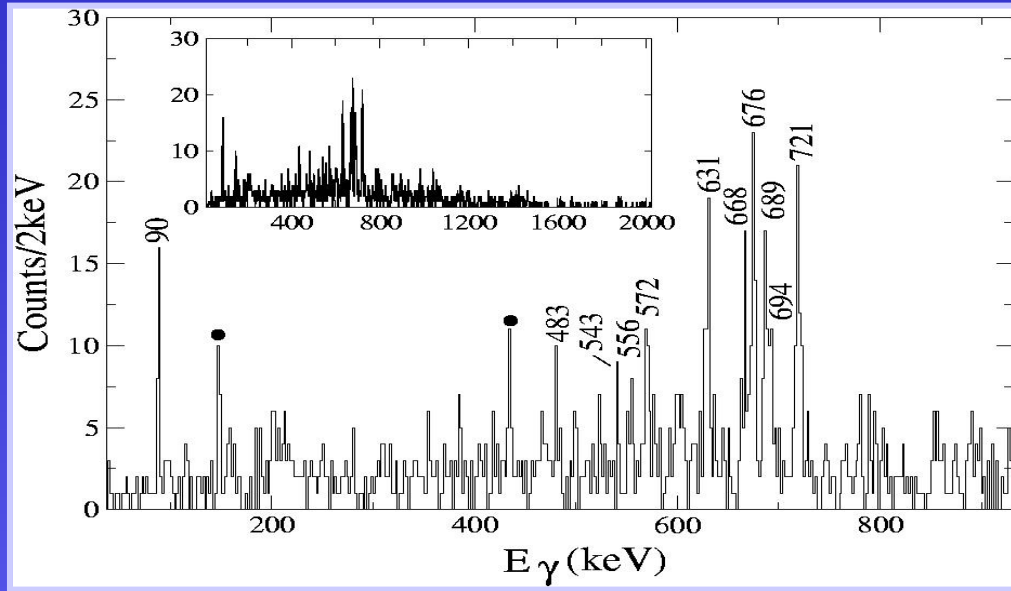
D. Seweryniak et al.
Phys. Rev. C66, 051307 (2002)
(Gammasphere + FMA)

Alpha-decay branching ratio : 70%

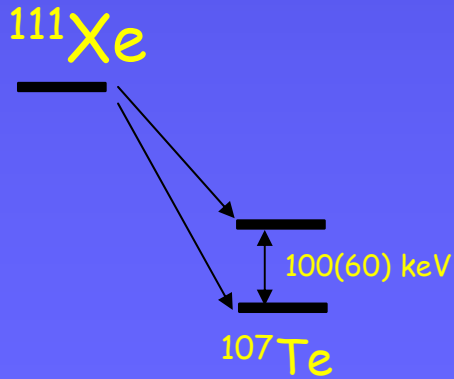
Half life : 3.1ms

$\sigma = 1 \mu\text{b}$

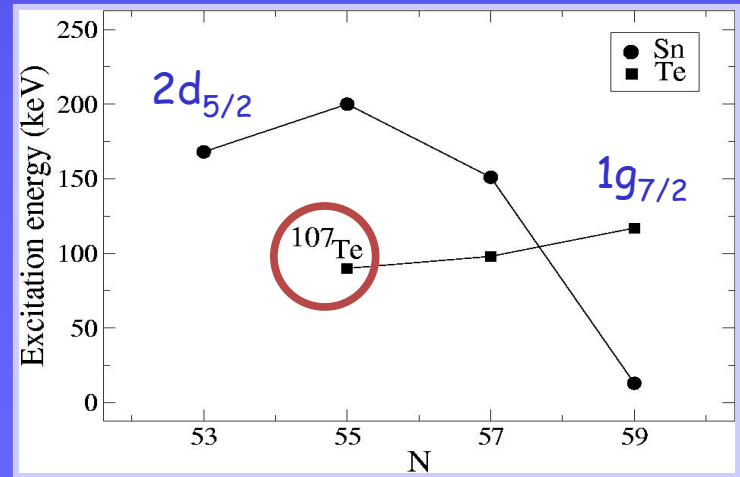
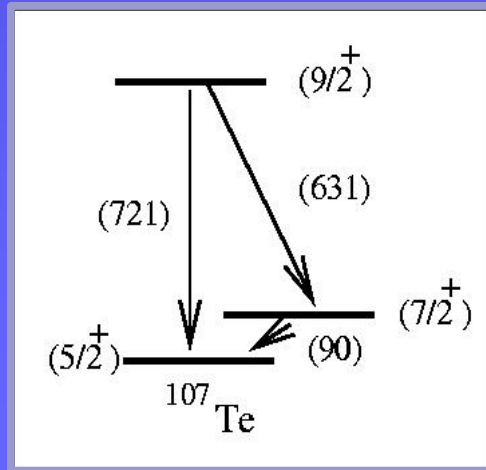
$^{58}\text{Ni} (^{52}\text{Cr}, 3n) ^{107}\text{Te}^*$



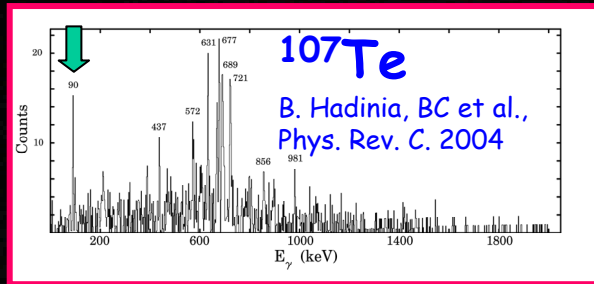
Recoil-decay correlated gamma-ray spectrum
Tentative level scheme



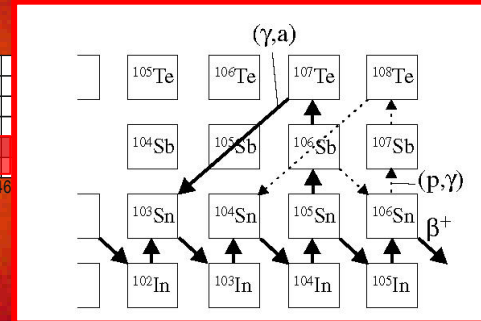
D. Schardt et al.,
Nucl. Phys. A368, 153 (1981)



The predicted rp-process end point in X-ray bursters and accreting neutron stars

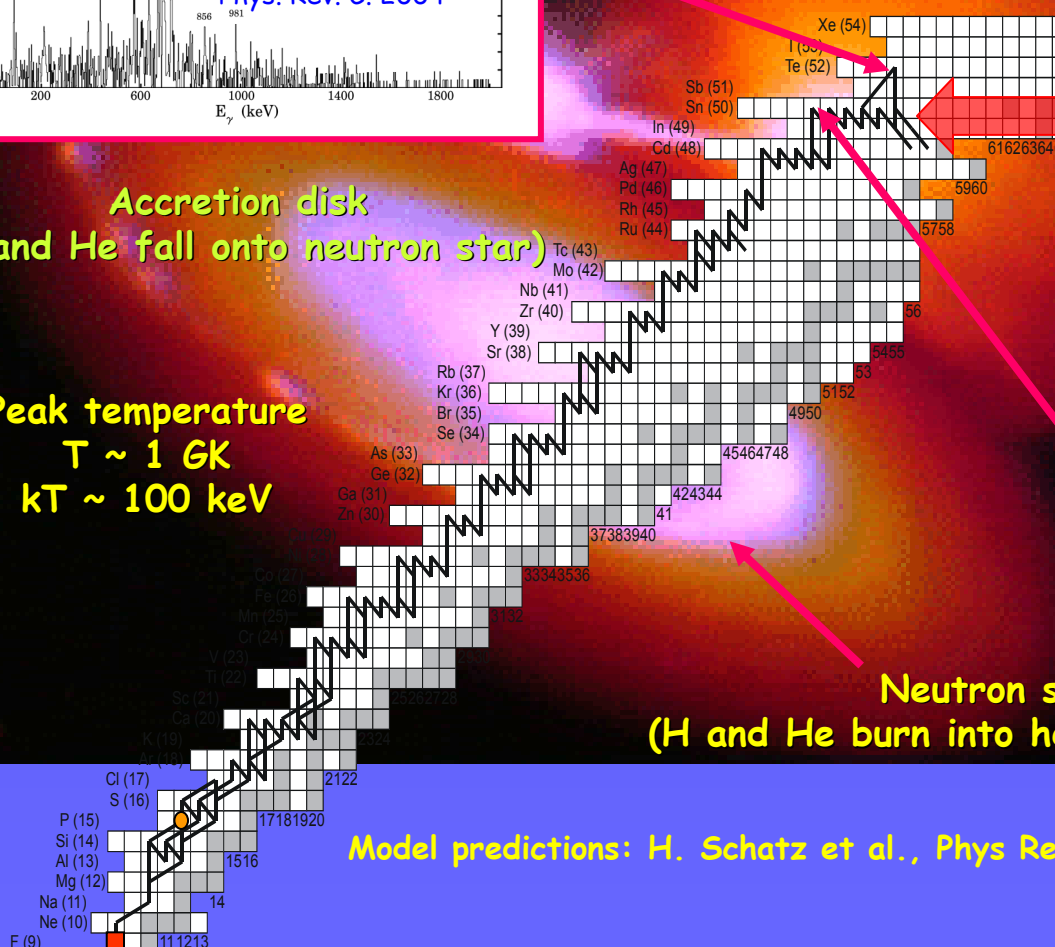


Companion star
 (H and He envelope)



Accretion disk
 (H and He fall onto neutron star)

Peak temperature
 $T \sim 1 \text{ GK}$
 $kT \sim 100 \text{ keV}$



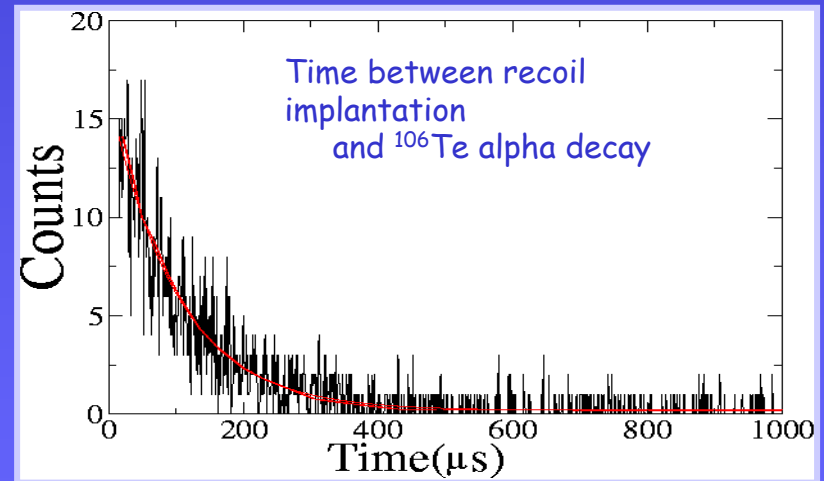
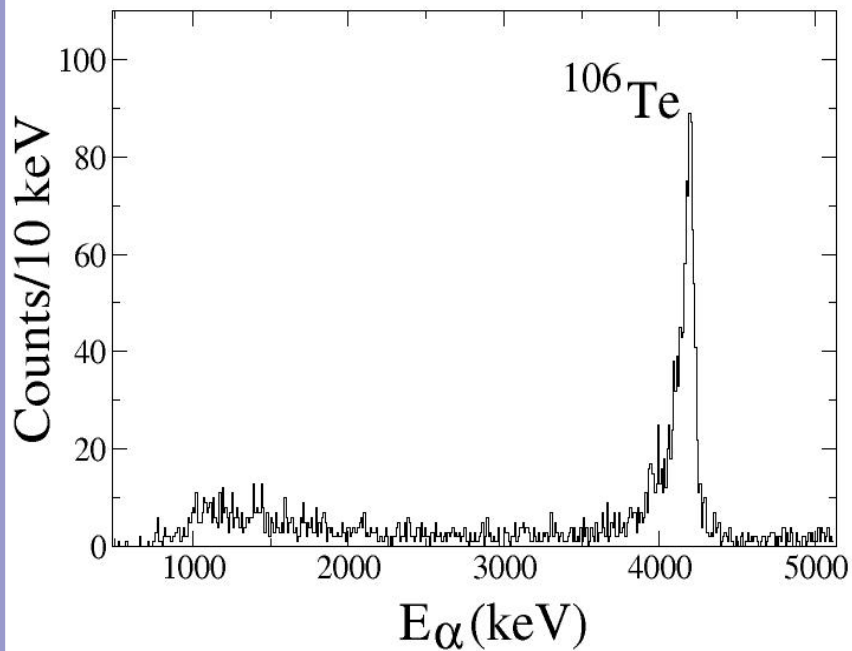
^{100}Sn

Neutron star
 (H and He burn into heavier elements)

Model predictions: H. Schatz et al., Phys. Rev. Lett. 86, 3471 (2001)

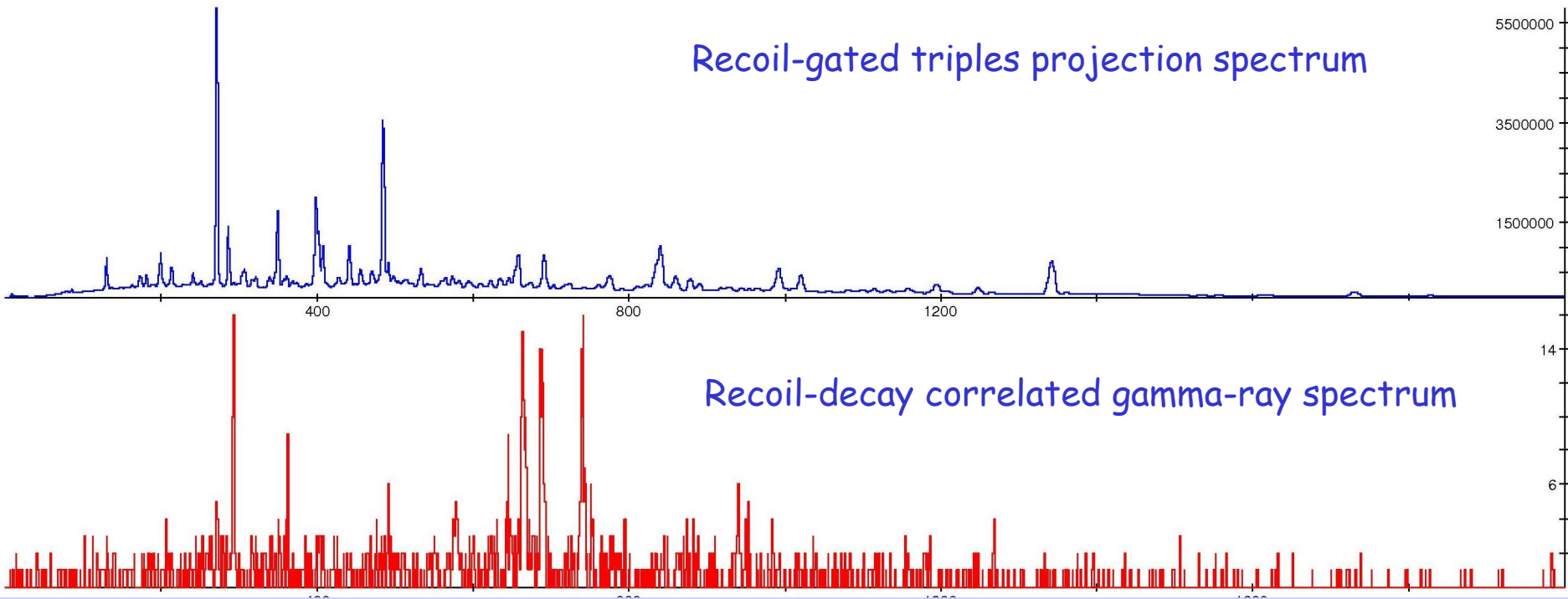


Alpha decay branching ratio : 100%
Halflife : 70ms



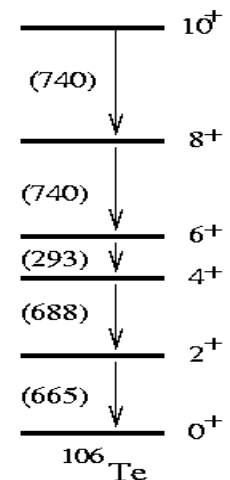
^{106}Te gamma rays

$\sigma = 25 \text{ nb}$ - A new limit for in-beam γ -ray spectroscopy (!)

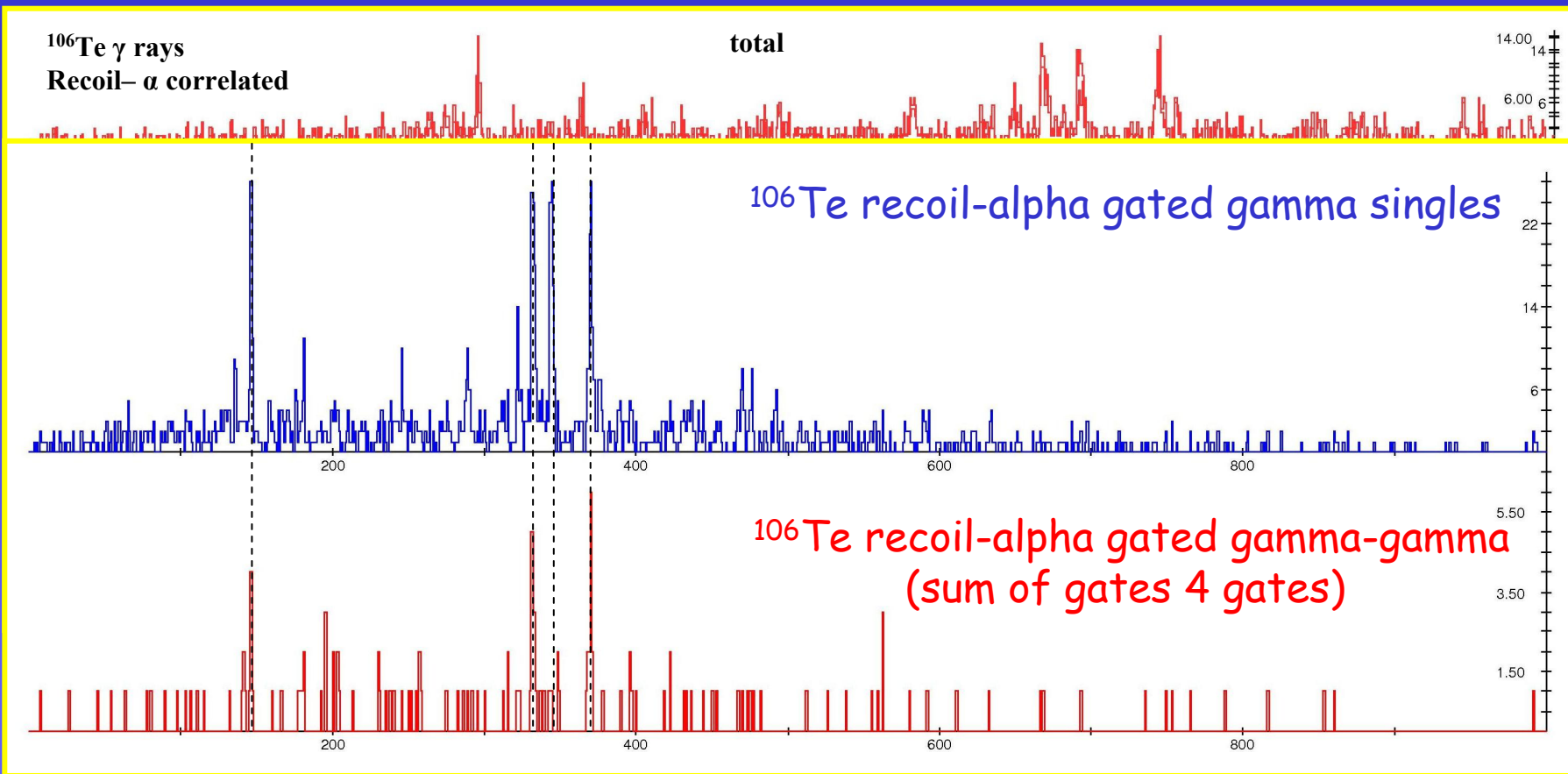


Selectivity: $\sim 10^{-7}$!

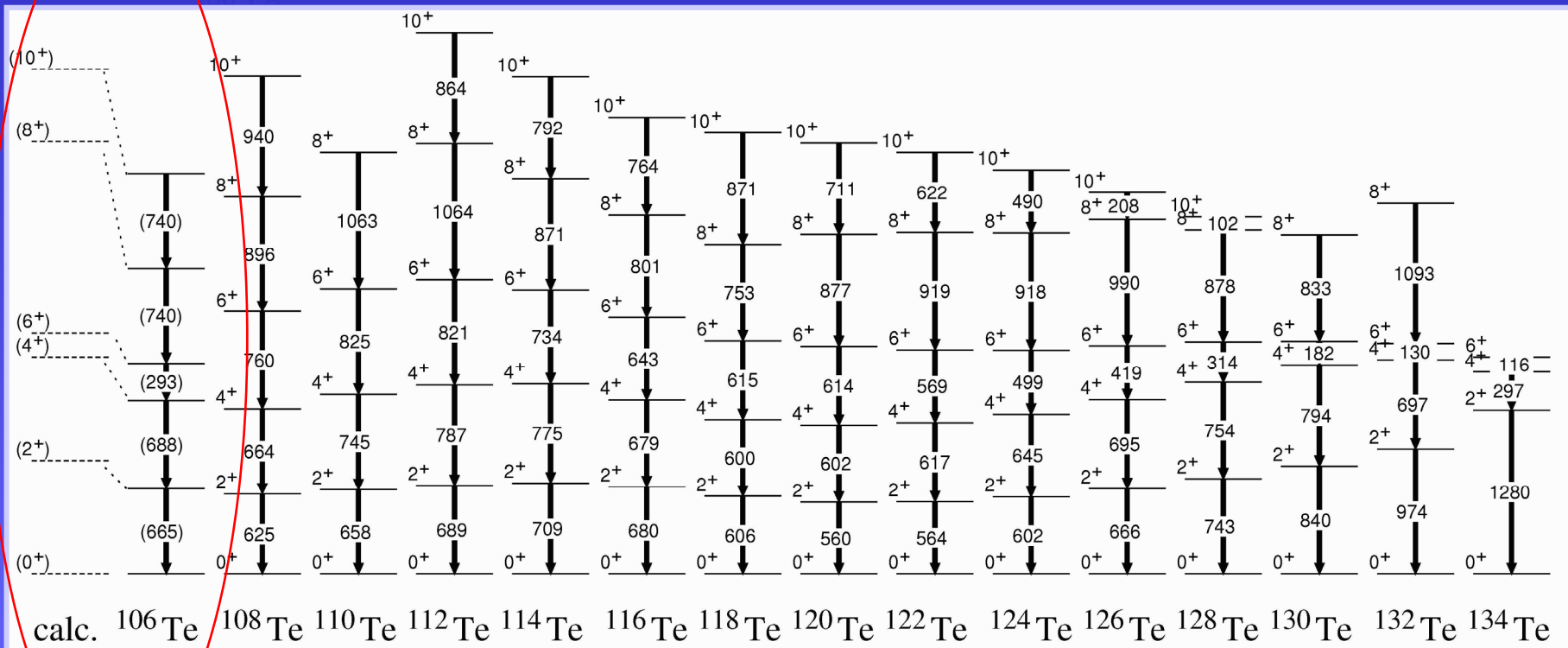
Tentative level structure of ^{106}Te



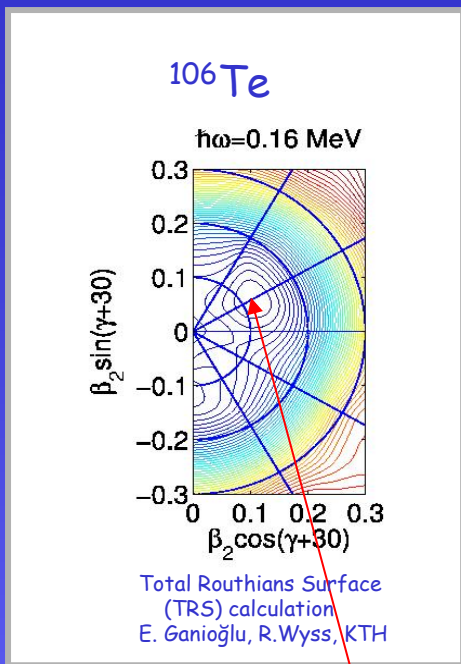
Gamma-gamma coincidences at $\sigma \sim 25$ nb



Te energy systematics and calculations

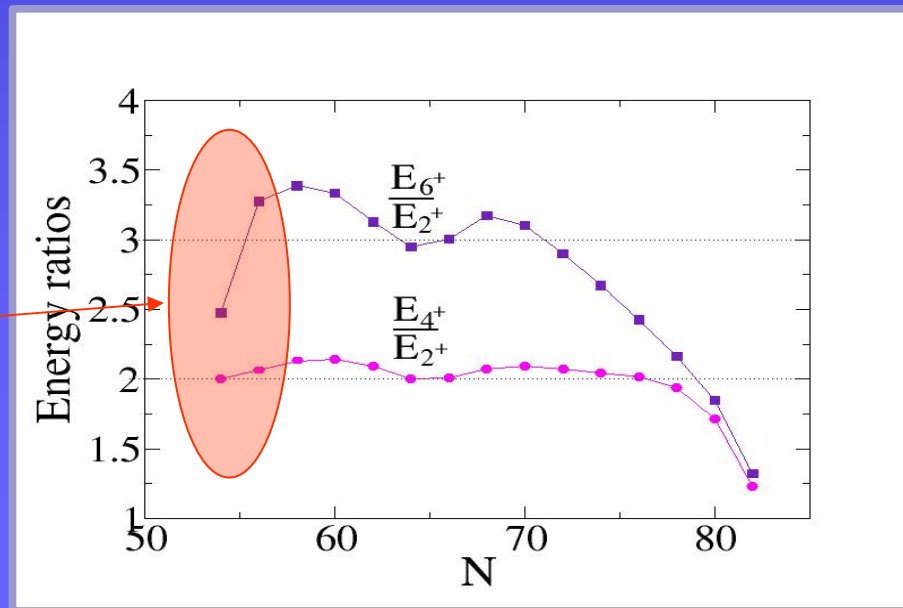


Te energy systematics and calculations ctd'



Shallow minimum consistent with near-spherical shape and susceptibility to beta vibrations

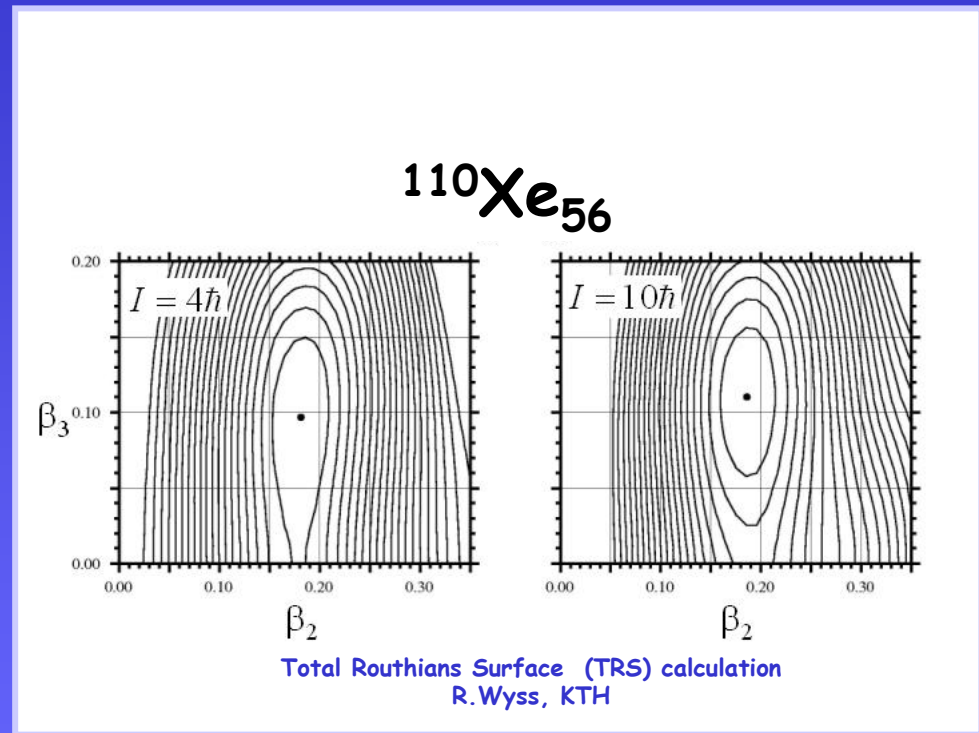
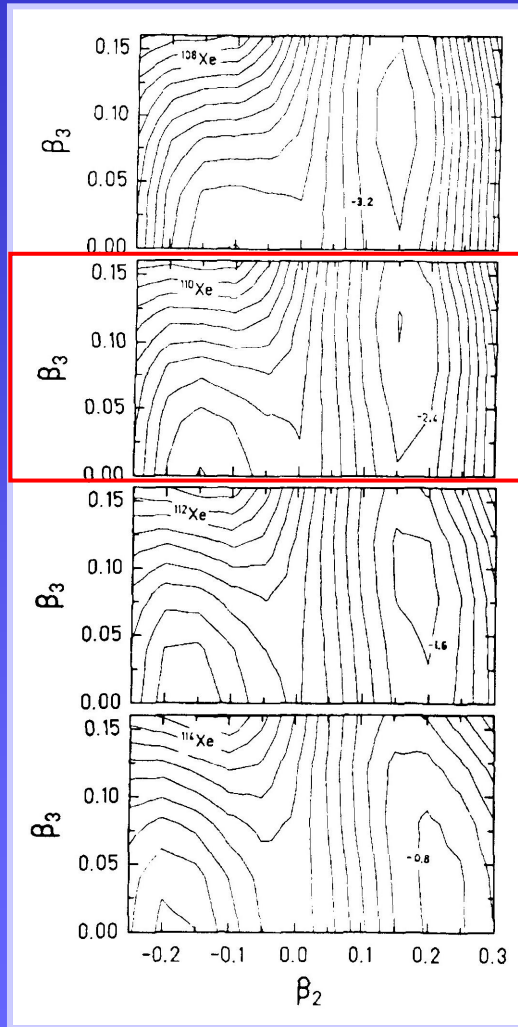
What happens here, and next?

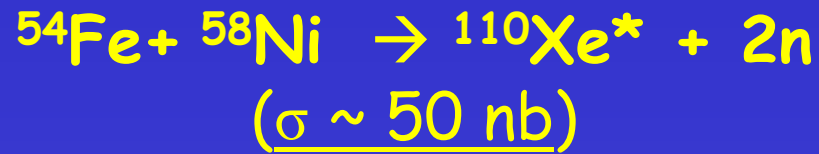


Energy ratios for even Te isotopes, $106 \leq A \leq 134$

Evidence for enhanced collectivity near $N=Z$?

Predicted stable octupole deformation and softness in the Xe isotopes



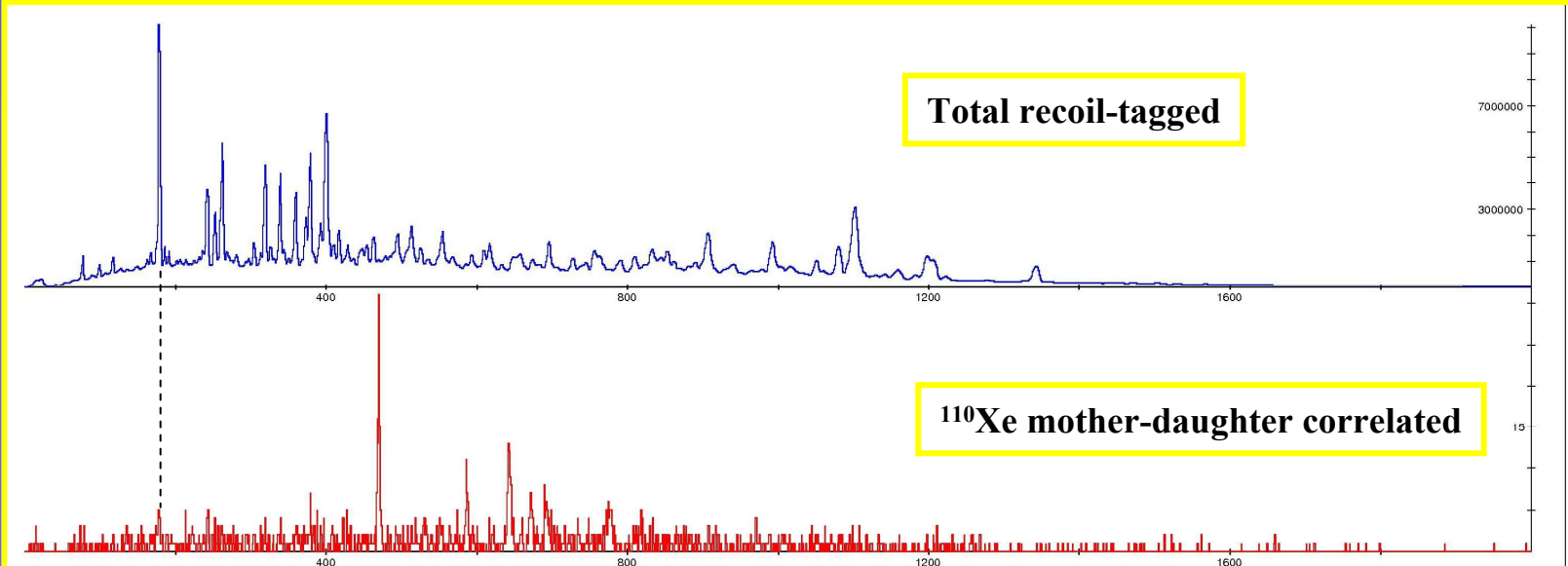
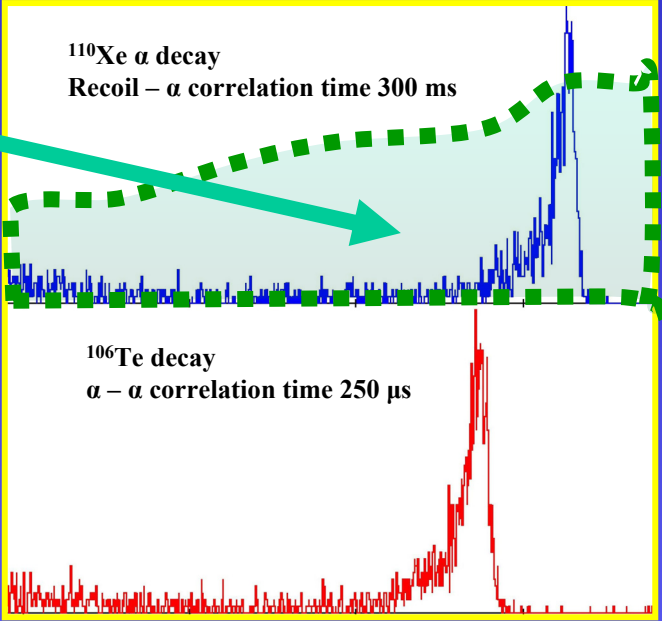


Work in progress!

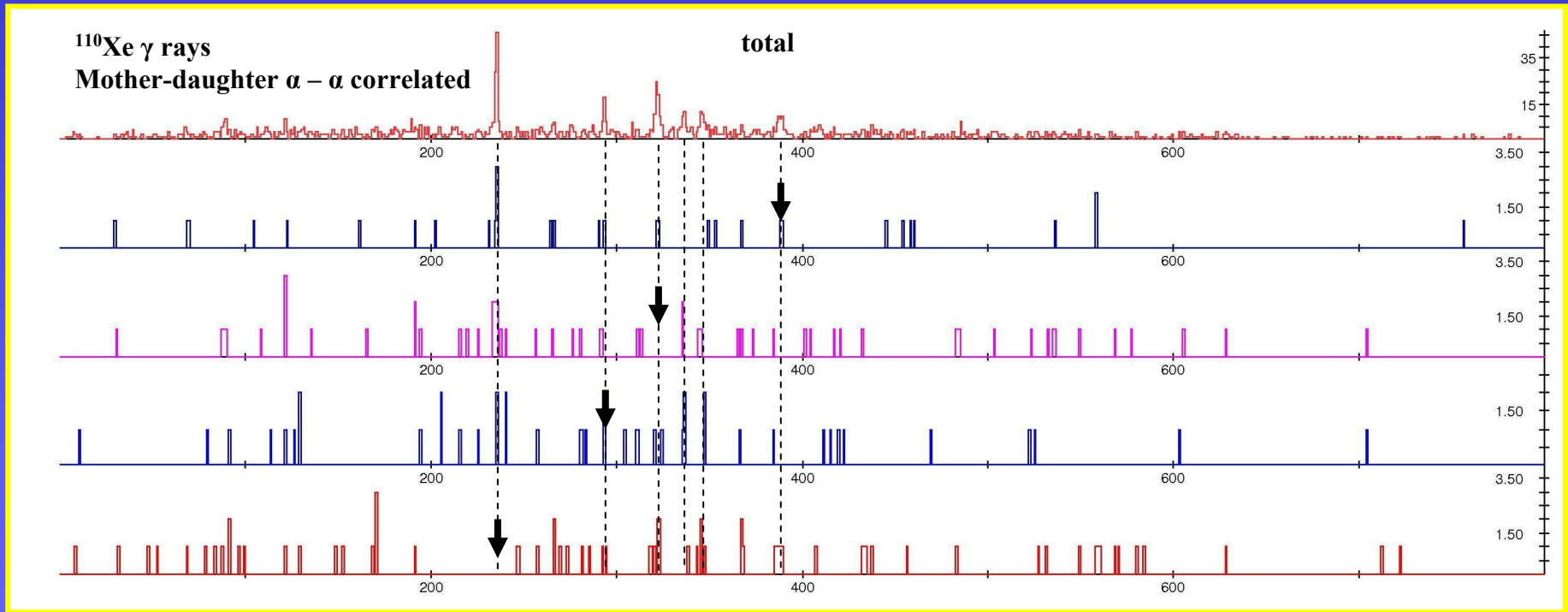
Sr 101 118 ms β^- 9.5... γ 128; 1125; 511; 1211... β_n		Sr 102 69 ms β^- γ 244; 150; 94; 254... β_n		66 1,871 0,957		Ba 137,327 σ 1,3		Ba 114 0,43 s β^+ β_p	Ba 115 0,45 s β^+ β_p	Ba 116 1,3 s β^+ β_p g	
Rb 100 51 ms β^- γ 129; 288; 91*... β_n ; β_2n ?		Rb 101 32 ms β^- γ 92-1363 β_n		Rb 102 37 ms β^- β_n γ 126		Cs 132,90543 σ 29,0		Cs 112 500 μ s p 0,807	Cs 113 17 μ s p 0,959	Cs 114 0,57 s β^+ ; α 3,239 γ 450; 698; 618... β_p 1,7-7,0 $\beta\alpha$ 7,0-12,5	Cs 115 1,4 s β^+ β_p
64 6,161 6,199		Xe 131,29 σ 24		Xe 110 ? α 3,745	Xe 111 0,9 s α 3,589; 3,500	Xe 112 2,7 s β^+ α 3,216	Xe 113 2,8 s β^+ ; α 2,985 γ 121; 689... β_p 2-7 $\beta\alpha$ 7-10	Xe 114 10 s β^+ γ 309; 162; 104; 440...			
53 I 126,90447 σ 6,15		I 108 36 ms α 3,947	I 109 100 μ s p 0,813	I 110 0,65 s β^+ α 3,444 β_p 2,5-6,0 $\beta\alpha$ 7-12	I 111 2,5 s β^+ α 3,152 γ 341; 117; 321; 266...	I 112 3,42 s β^+ ; α 2,880 γ 689; 787; 795; 1143... β_p 2,0-6,0 $\beta\alpha$ 6-12	I 113 5,9 s β^+ α 2,610 γ 463; 622; 351; 567...				
52 Te 127,60 σ 4,7		Te 106 0,06 ms α 4,128	Te 107 3,1 ms α 3,861	Te 108 2,1 s β^+ α 3,917 β_p 2-3	Te 109 4,1 s β^+ α 3,107	Te 110 18,6 s β^+ α 2,624 γ 895; 606; 219; 108...	Te 111 19,3 s β^+ γ 851; 881; 1268; 1392... β_p 2,82; 2,66...	Te 112 2,0 m β^+ γ 373; 296; 419...			
51 Sb 121,760 σ 5,1		Sb 103 p ?	Sb 104 0,44 s β^+	Sb 105 1,12 s β^+ p 0,478	Sb 106 0,6 s β^+	Sb 107 4,6 s β^+ γ 1280; 819; 151; 704	Sb 108 7,6 s β^+ γ 1206; 905; 1599; 1273...	Sb 109 16,7 s β^+ 4,4; 5,4... γ 925; 1062; 665; 1496...	Sb 110 24,0 s β^+ 6,9... γ 1212; 985; 1243; 827...	Sb 111 75 s β^+ 3,3... γ 154; 489; 1033...	
Sn 100 0,94 s β^+ 3,4		Sn 101 3 s β^+ β_p 2-3,5	Sn 102 3,4 s β^+	Sn 103 7 s β^+ β_p 1-3	Sn 104 20,8 s β^+ 2,4... γ 133; 913; 401; 1407... m; g	Sn 105 34 s β^+ γ 1282; 1466; 309...; g; m β_p 1-3	Sn 106 2,1 m ϵ β^+ 1,2... γ 387; 253; 477...; m	Sn 107 2,9 m β^+ γ 1129; 1542; 1001... m; g	Sn 108 10,3 m ϵ ; β^+ 0,4... γ 396; 273; 169; 669... m	Sn 109 18,0 m ϵ ; β^+ 1,6... γ 1099; 1321; 331... g; m	Sn 110 4,11 h ϵ γ 283 m

Good mother - daughter relations are helpful!

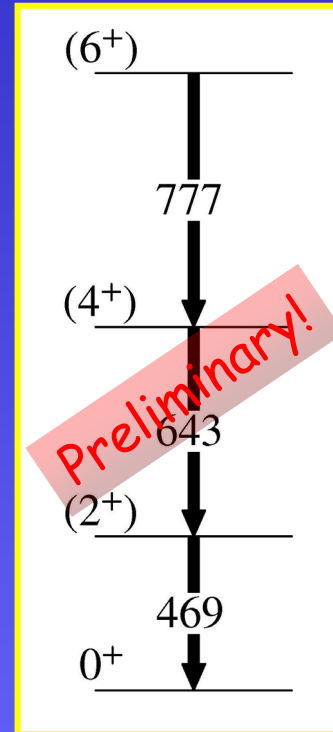
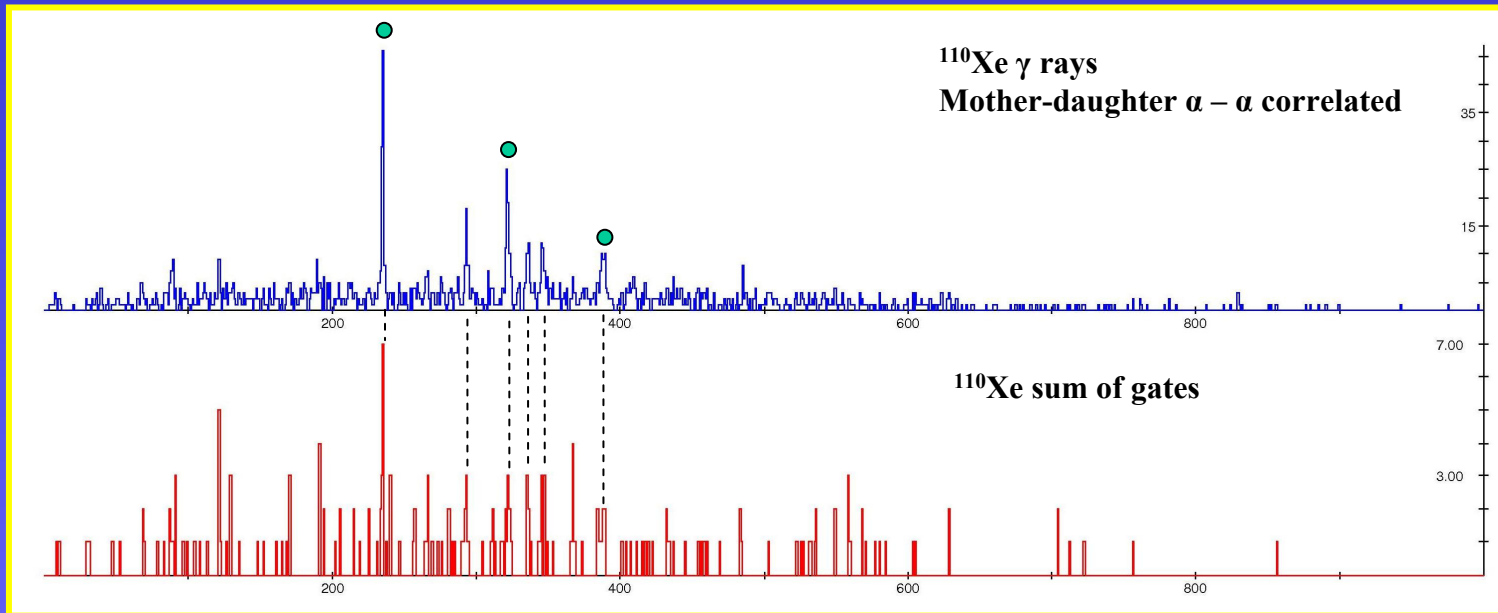
β -delayed protons



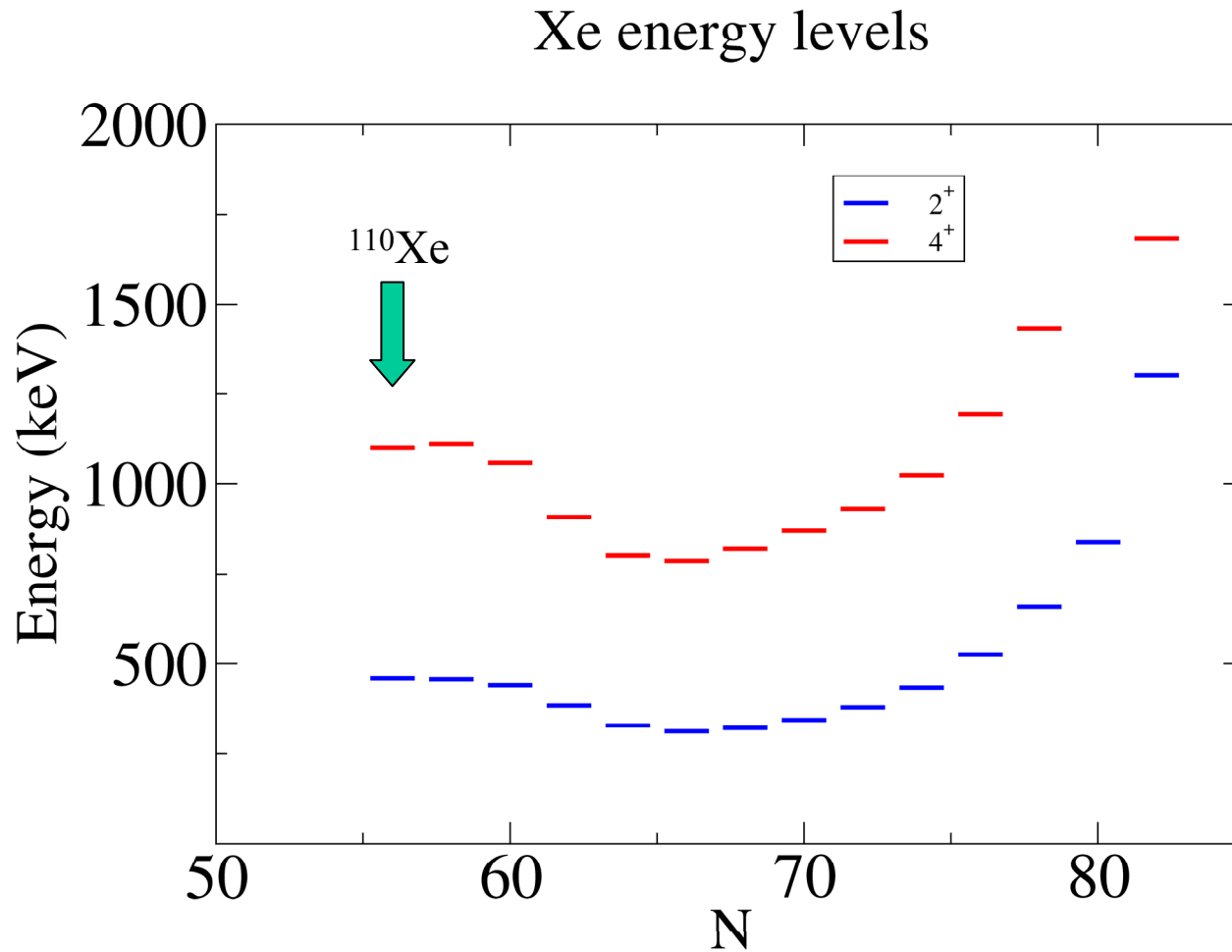
Gamma-gamma coincidences at $\sigma \sim 50$ nb



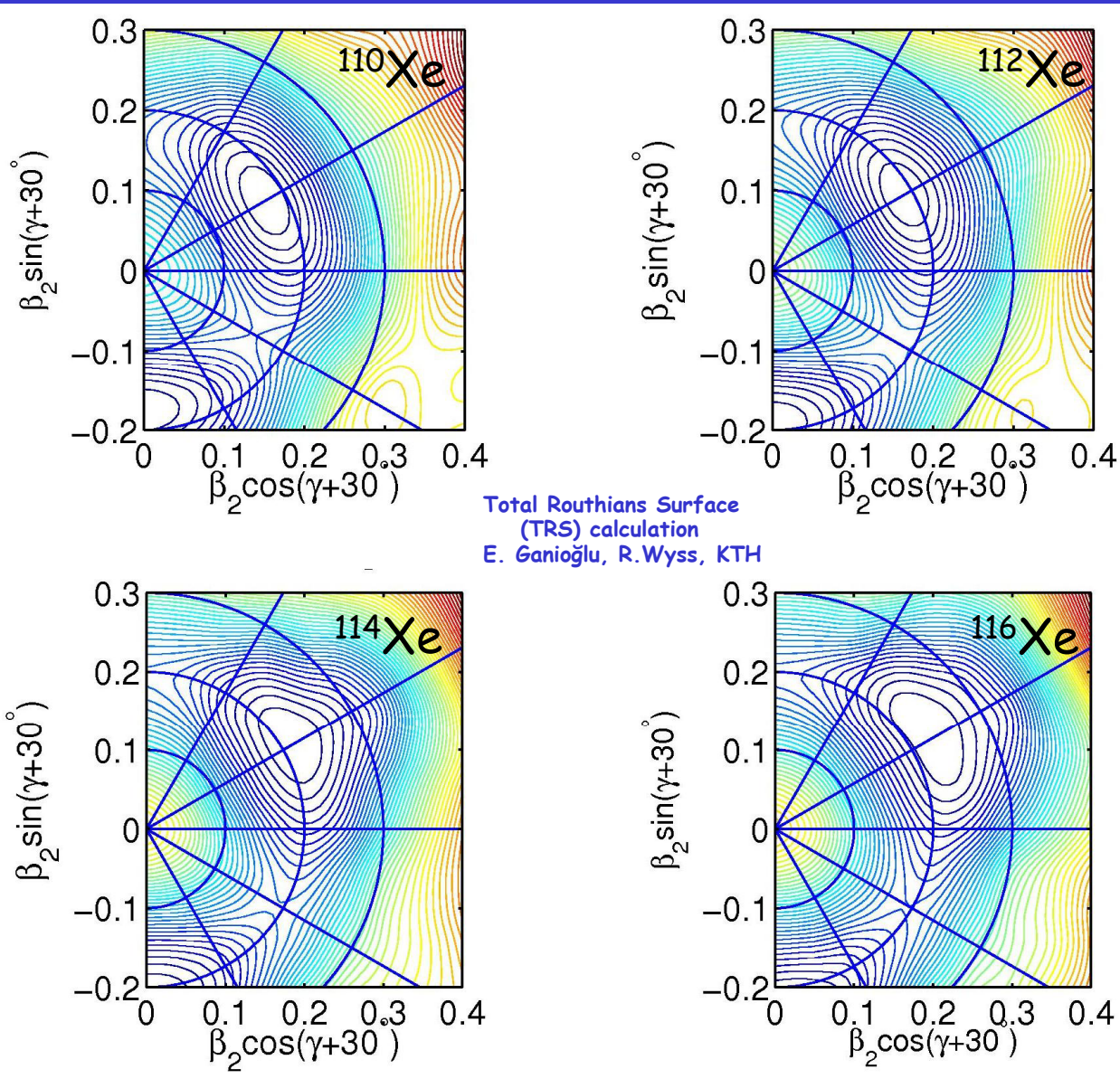
Gamma-gamma coincidences



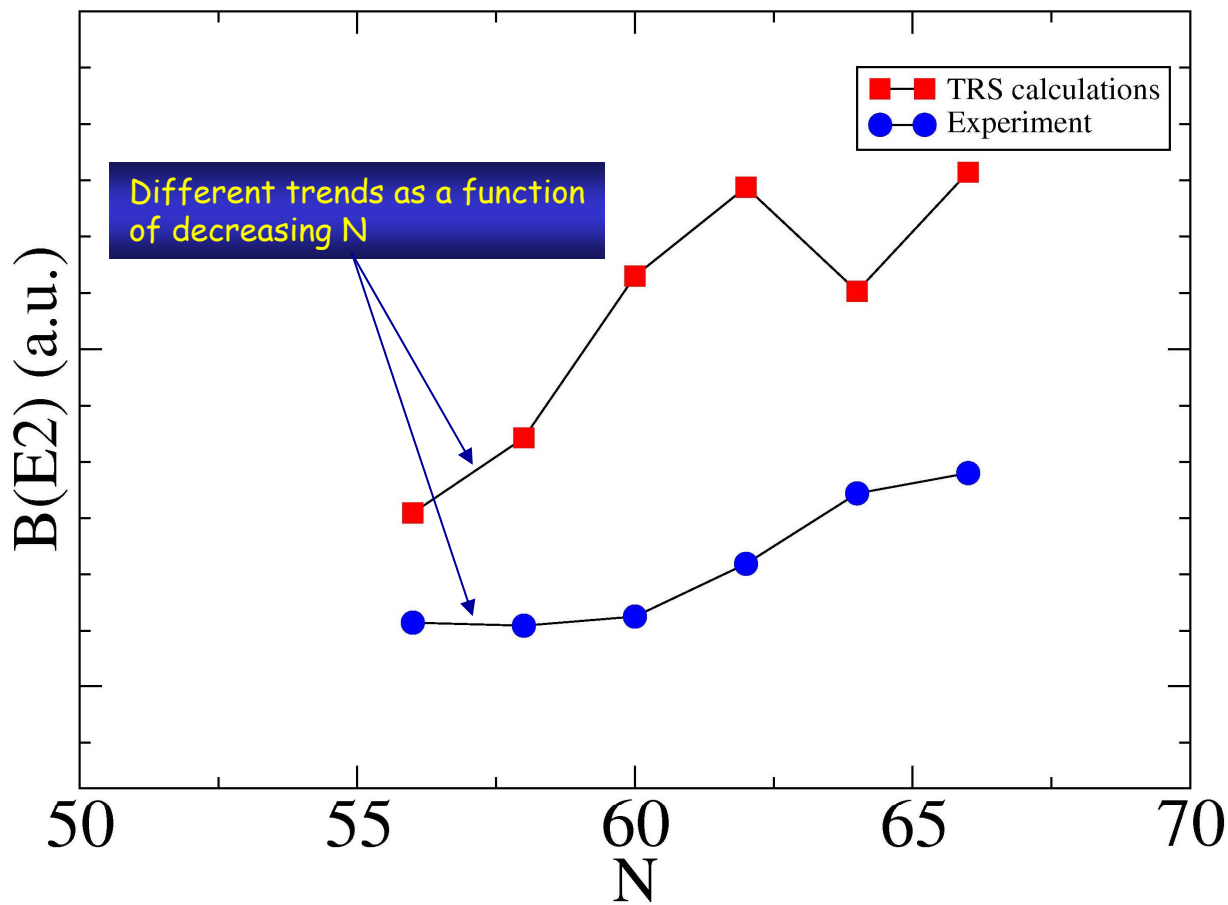
Xe experimental energy systematics



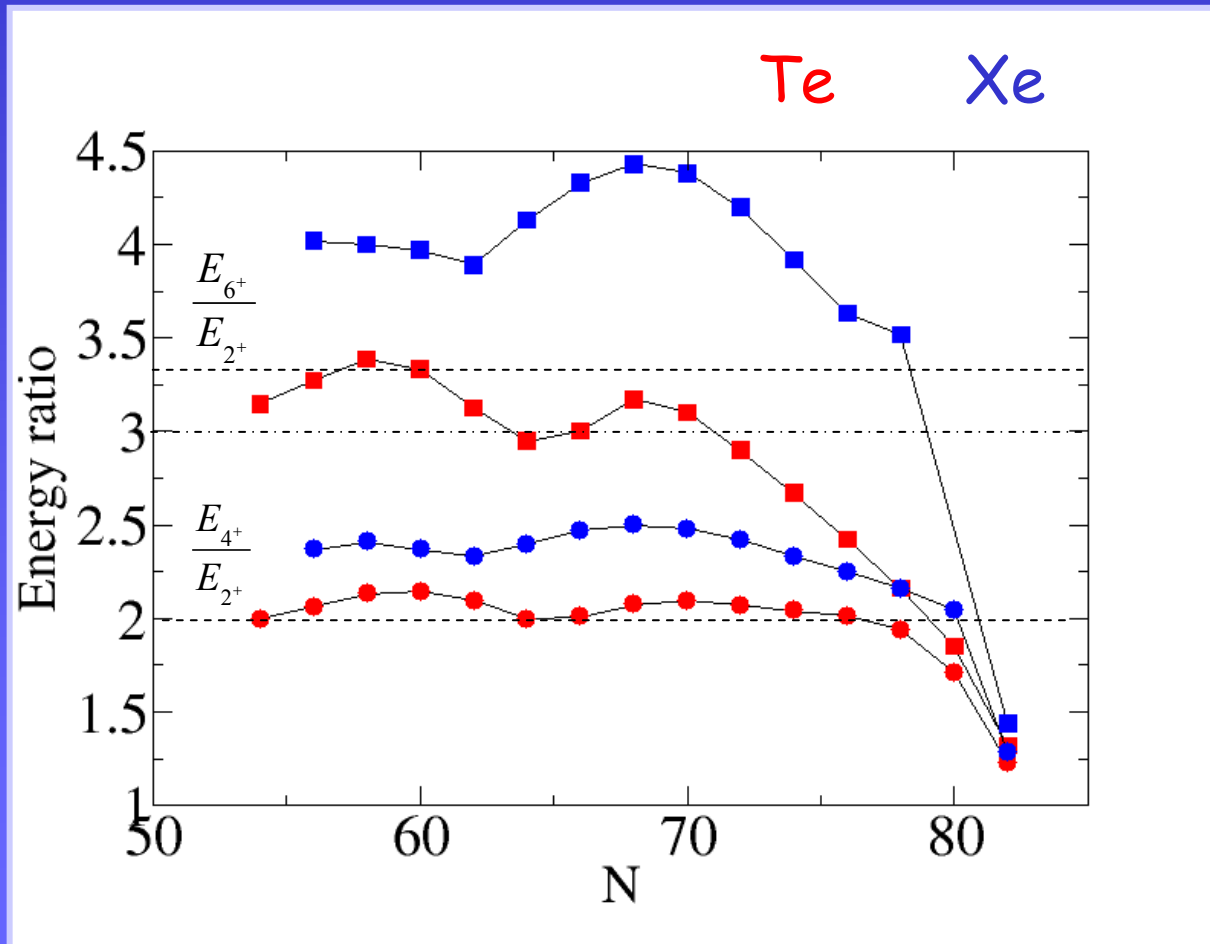
TRS calculations for extremely neutron deficient Xe isotopes predict decreasing collectivity



Comparing theory with experimental B(E2) values (Raman estimates) for extremely neutron deficient Xe isotopes



Xe and Te energy systematics



Conclusions (short version)

- In-beam gamma-ray spectroscopy is possible down to 10s of nb x.s. using RDT and efficient Ge arrays
- Evidence for enhanced collectivity (quadrupole, beta-3 vibrations) in the Te and Xe isotopes as $N \rightarrow Z$
- Possible indication of np correlations
- Need for lifetime data (but a challenge for RDT)
- Need for linear polarization measurements (clovers) at target pos
- Beta-tagging can extend studies to Sn and below
- Mass resolving (vacuum) separator will also be helpful to extend studies around and below ^{100}Sn
- Decay spectroscopy for short half lives (LISA ...)
- ...

Collaborators

Thanks to many collaborators from
JYFL Gamma and RITU groups
KTH Stockholm
Univ. of Liverpool
Univ. of York
Daresbury
RIKEN / Univ. of Tokyo
Istanbul Univ.
NBI