# RDT studies of A~100 nuclei near the proton dripline

γ- Pool Symposium

ECT*, Trento, May 8-12, 2006

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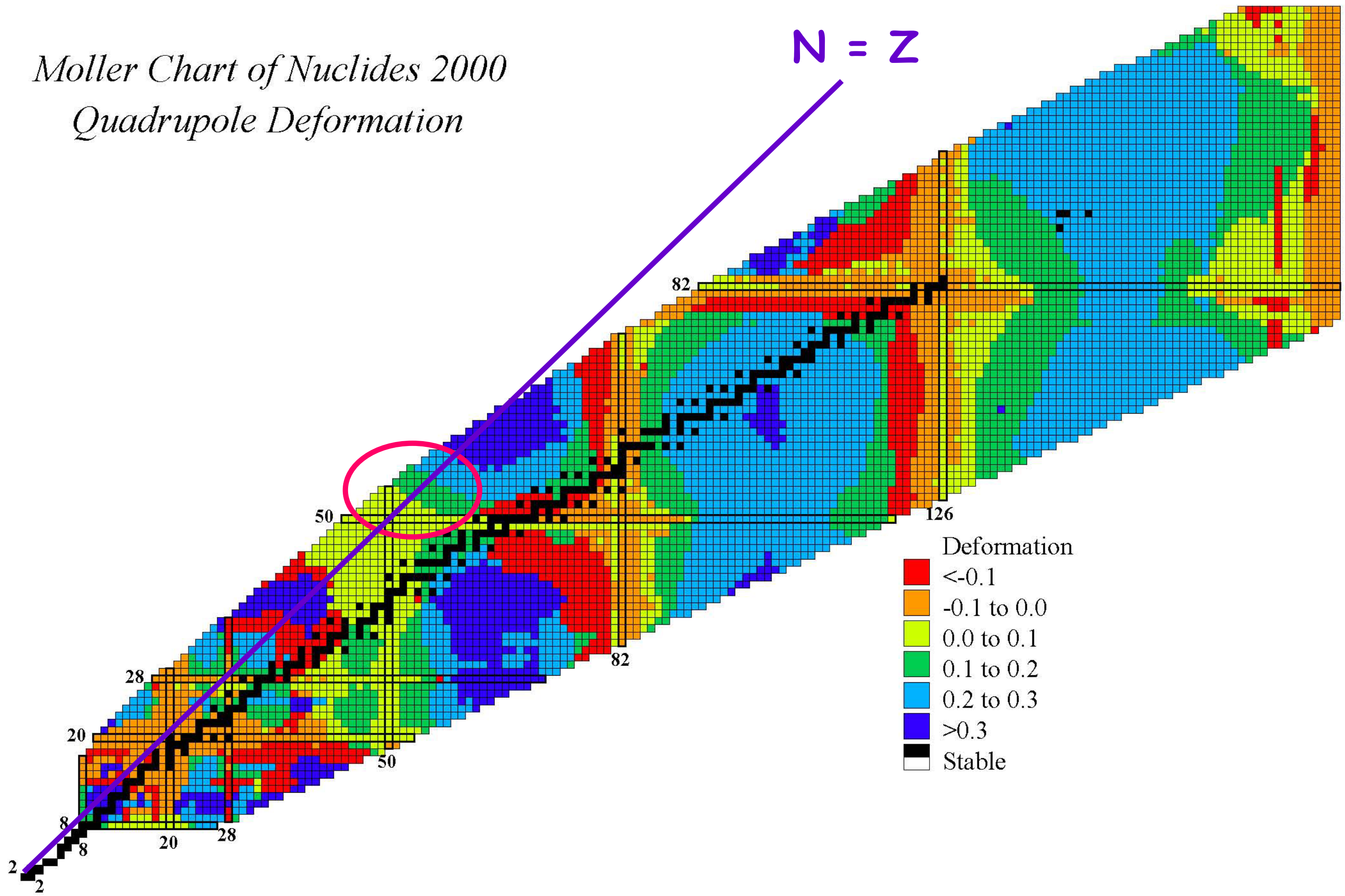
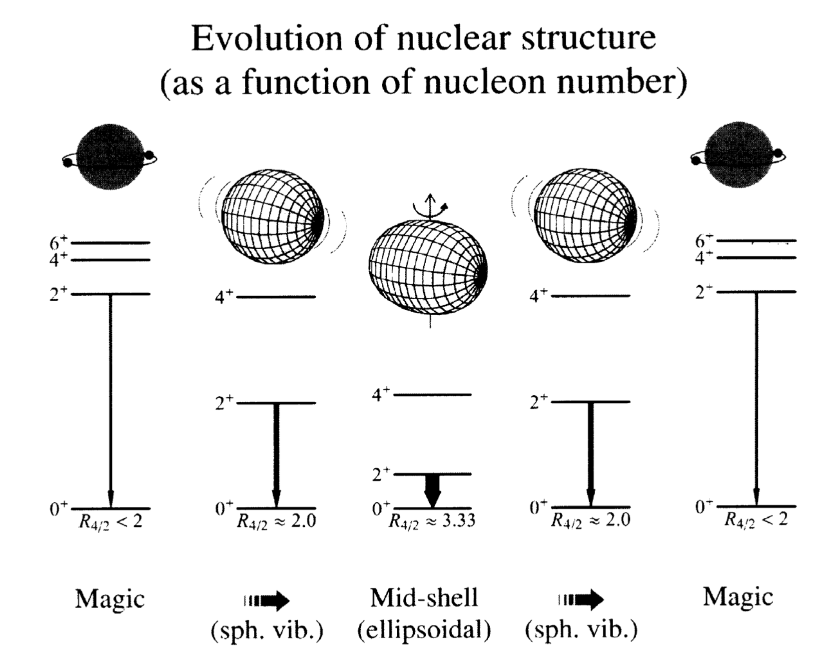
*Royal Institute of Technology (KTH)*
*Stockholm, Sweden*

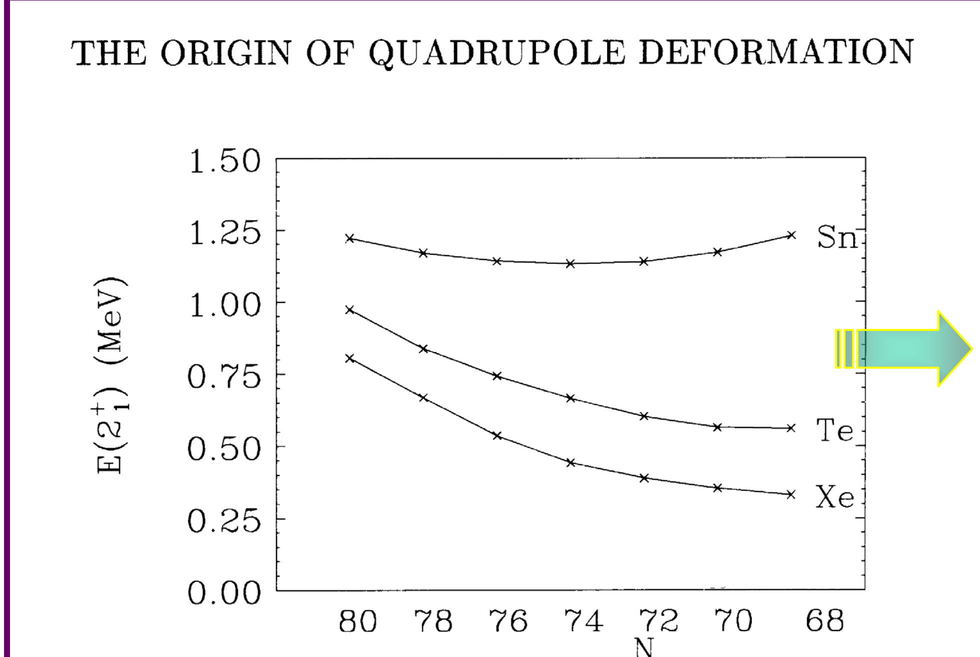
*Moller Chart of Nuclides 2000*
*Quadrupole Deformation*



# Onset of nuclear collectivity




Taken from R.F. Casten, 2003



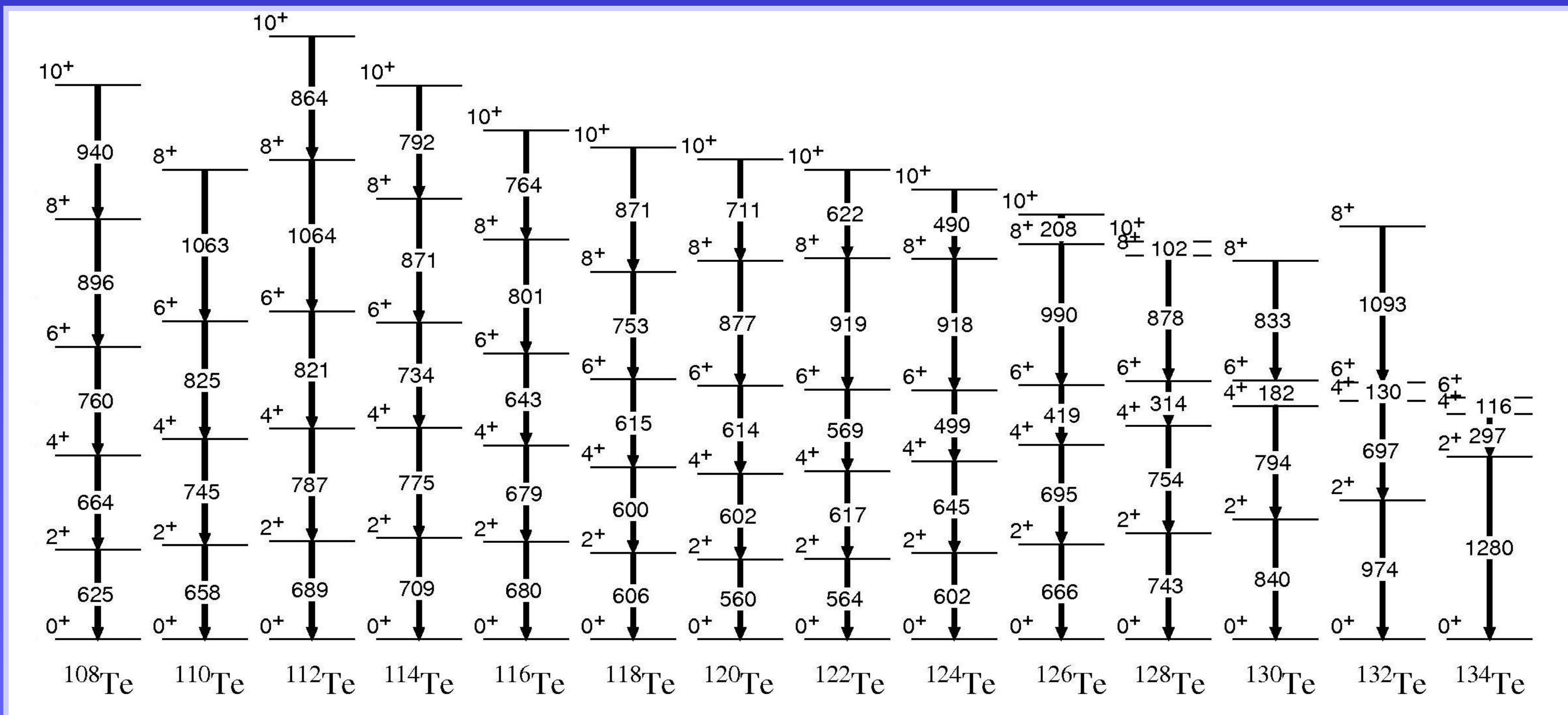

Taken from R.F. Casten, 2003

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

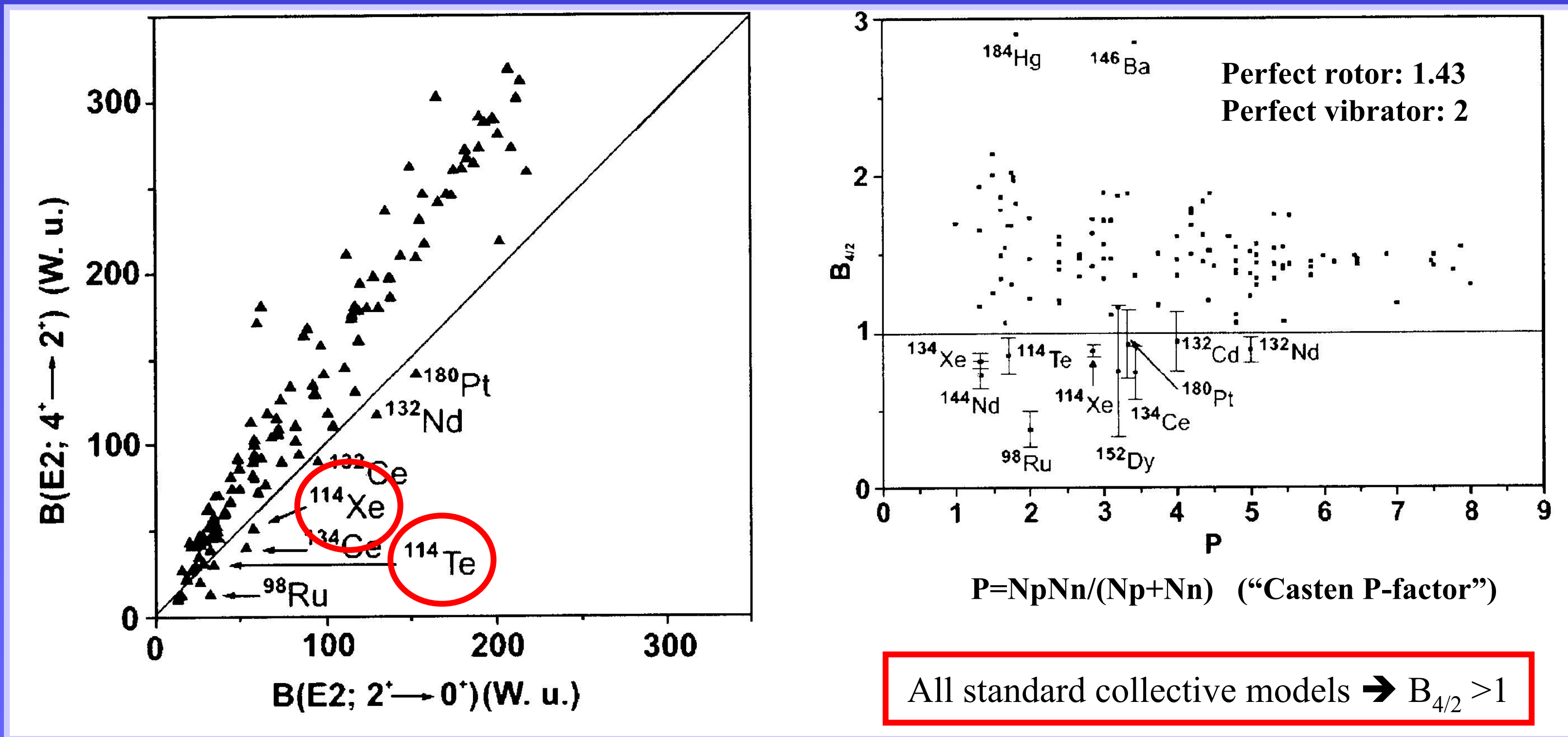
$$\sum_{i=1}^{2j+1} m_i = 0 \ \forall \text{shells} \Rightarrow J^\pi = 0^+ \text{ i.e. no directional preference of w.f.}$$

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

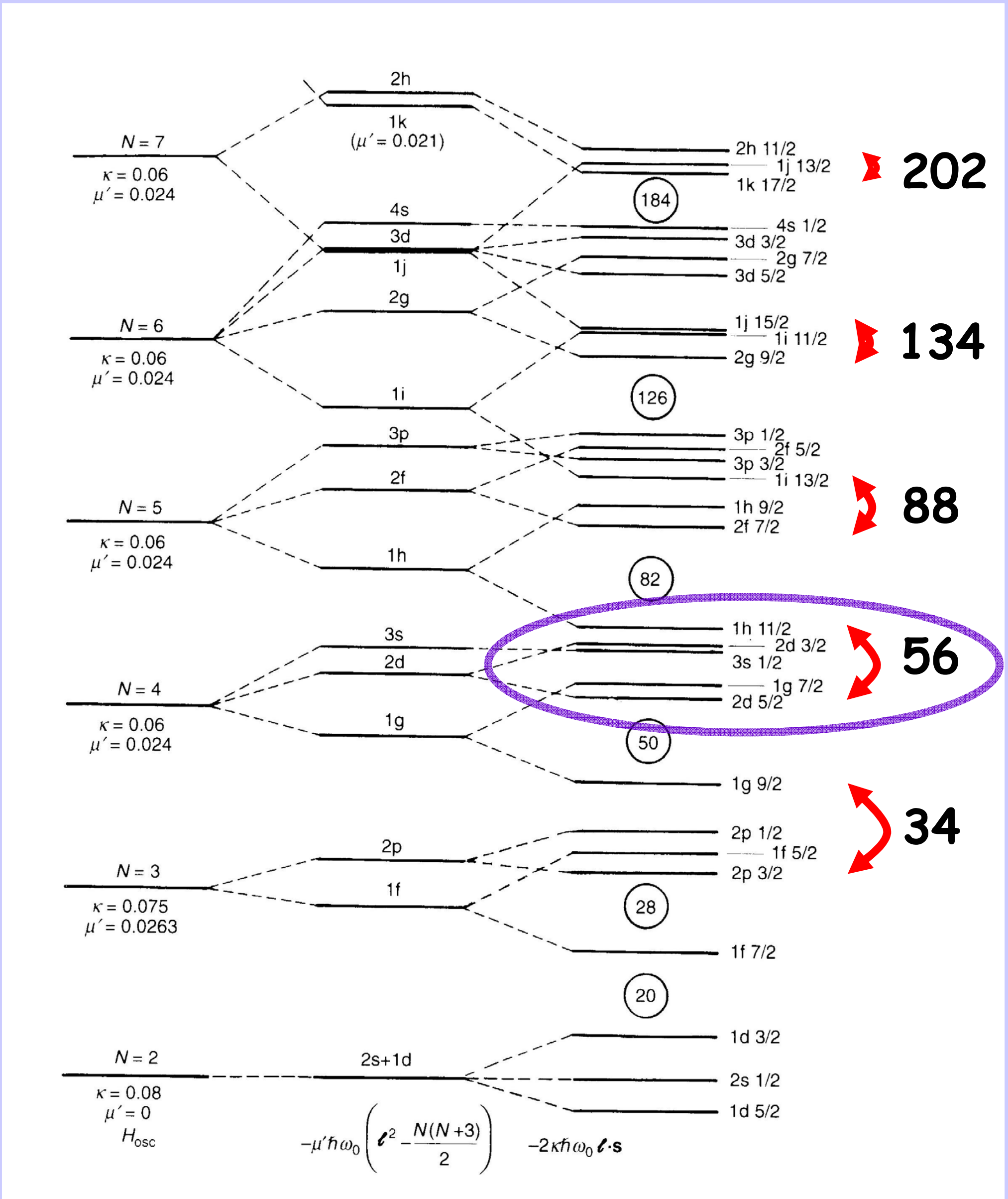


# Deviations from “normal” collectivity




Cakirli, Casten, Jolie and Warr
Phys. Rev. C70, 047302 (2004)

# Octupole deformation and correlations near N=Z



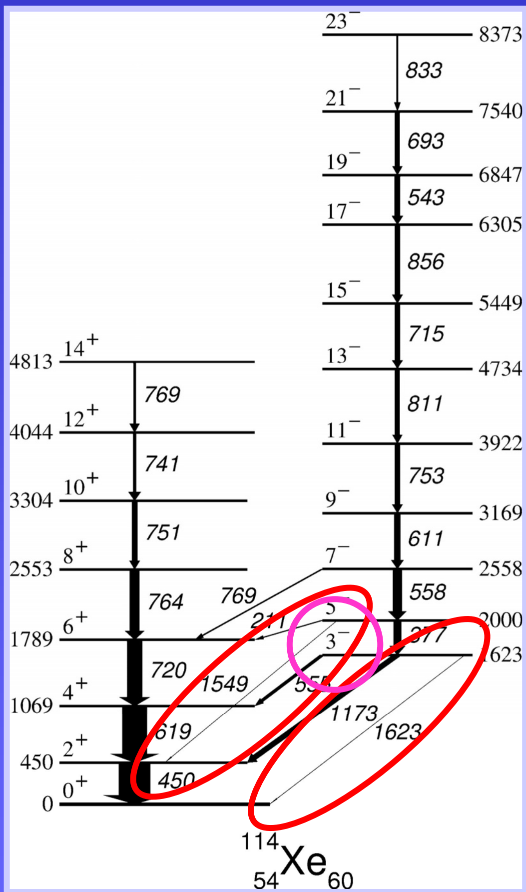

Strong octupole correlations are expected in nuclei where normal-parity single-particle states and intruder states differing by $\Delta l = \Delta j = 3$ are near the Fermi surface.

"Doubly-magic octupole-deformed" Nucleus predicted by theory
Next to $^{112}$Ba
(inaccessible with current technology)
$^{110}Xe_{56}$ is predicted to have the largest octupole stability.

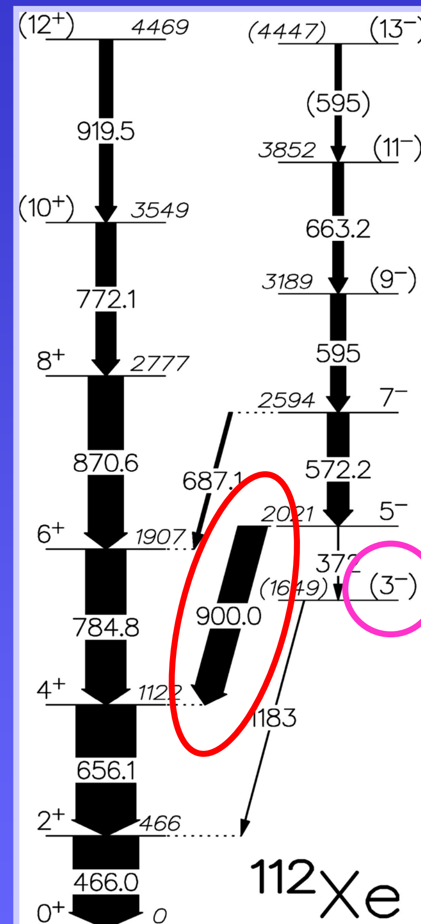
Coherent octupole correlations for neutrons and protons should occur near N=Z.

Can we observe additional enhancement due to np correlations ?

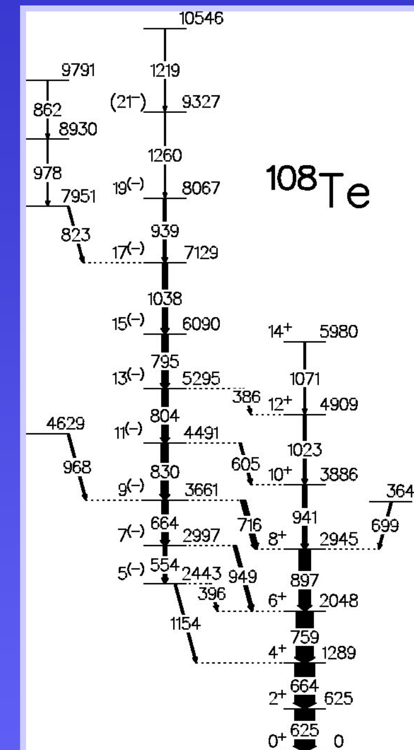
# Evidence for enhanced octupole correlations near N= Z




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

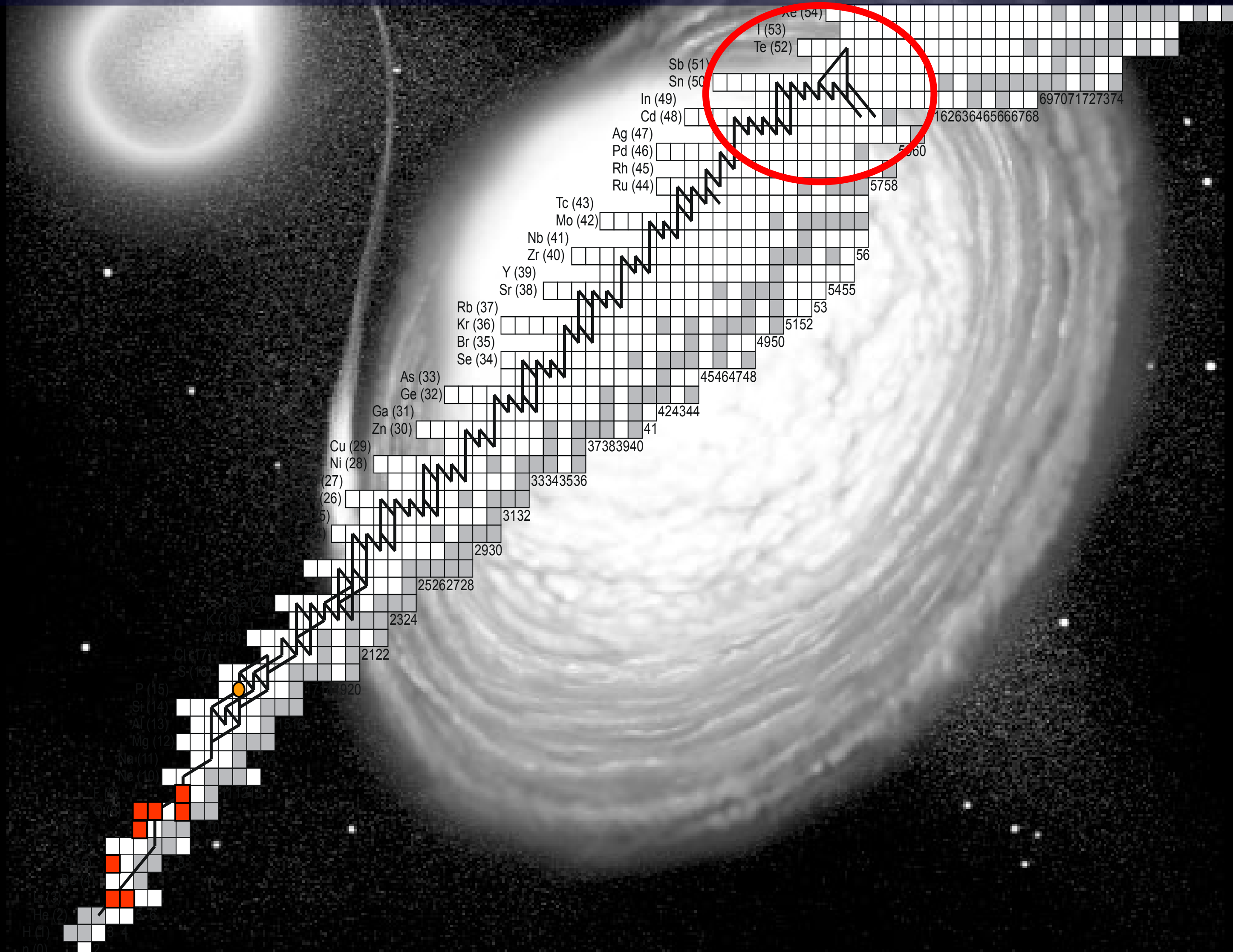



J.F. Smith et al.
Phys. Lett B523, 13 (2001)
(Gammasphere)




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 ~ 100 ($^{108,109}$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

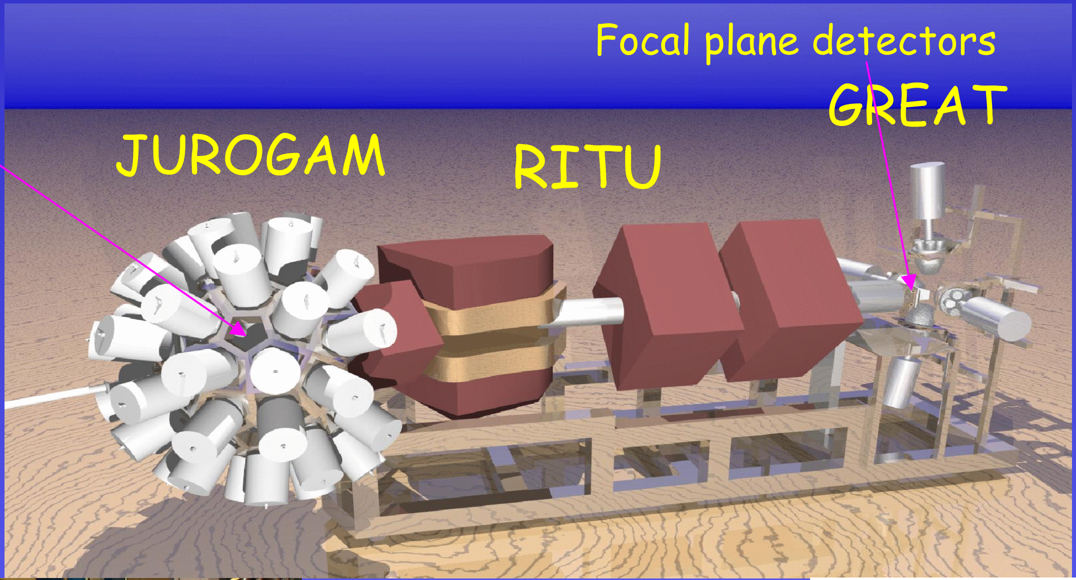
*) **R.S. Simon *et al*., Z.P.A. 325, 197 (1986): NaI + SHIP @ GSI**
**E.S. Paul *et al*., P.R.C. 51, 78 (1995): Eurogam (45 HPGe) + DRS @ Daresbury**

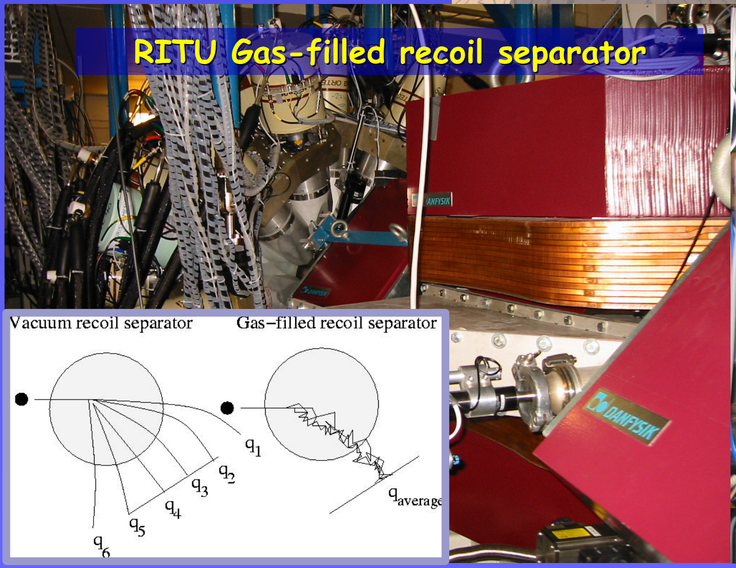
# $^{106,107}$Te - Access to the lightest Te isotopes by means of recoil-decay tagging at JYFL Accelerator Lab.

Detection of prompt gamma rays

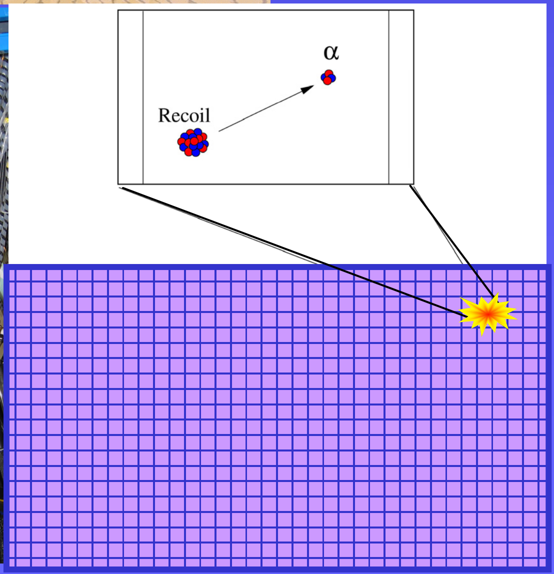
43 detector HPGe EUROBALL phase I type

Total photo-peak efficiency 4.2% at 1.3 MeV

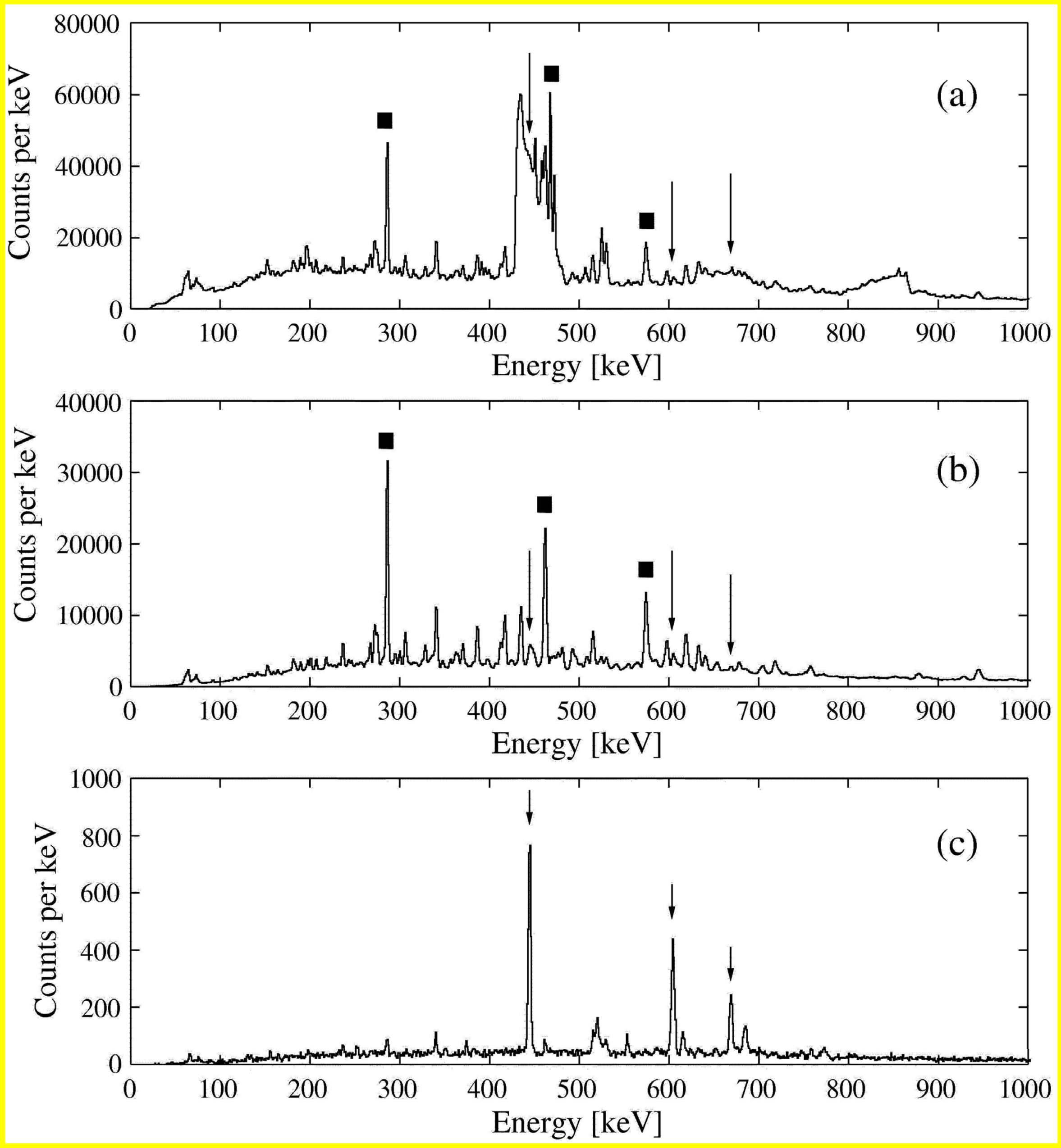


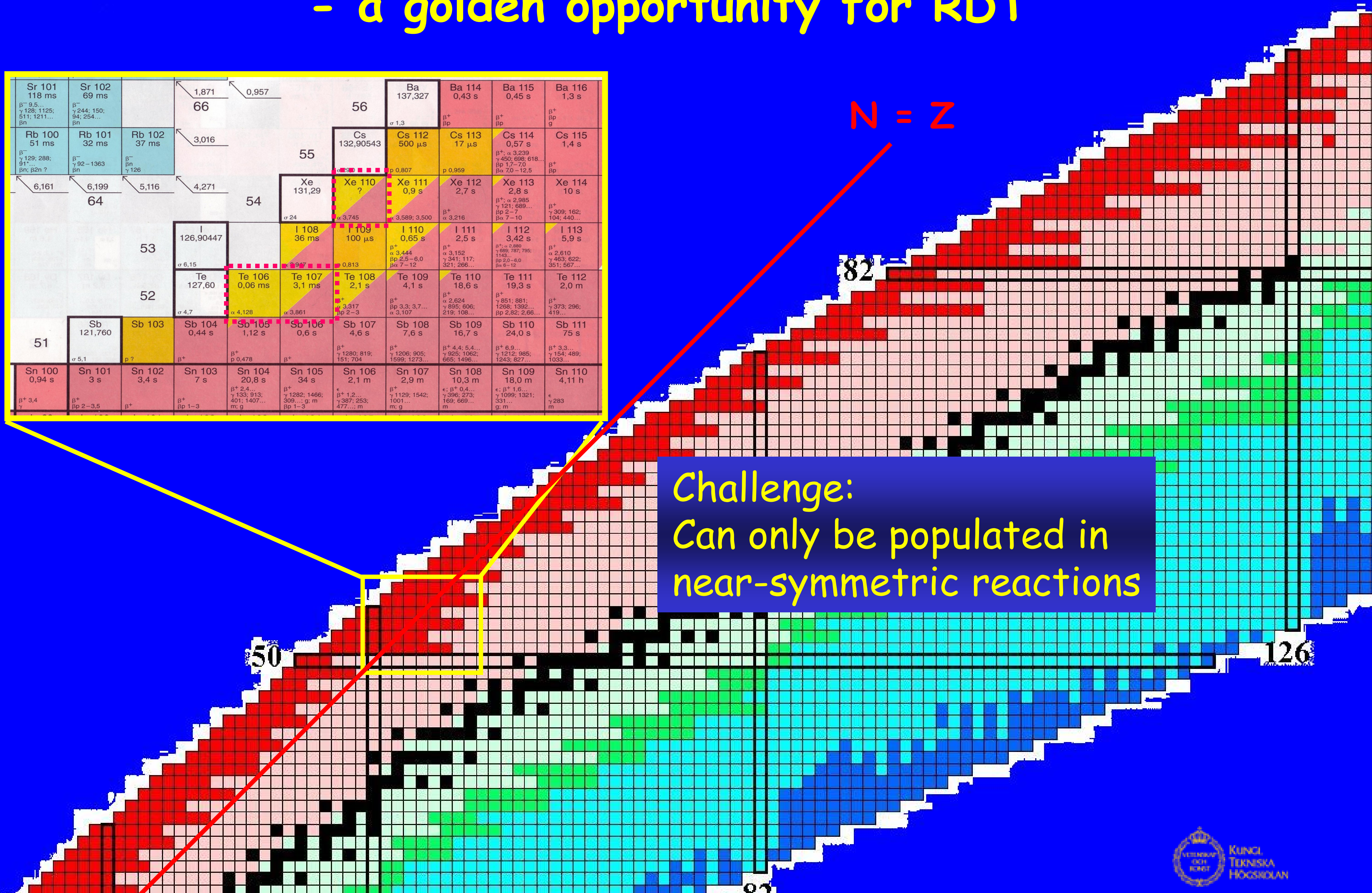




# The selective power of recoil-decay tagging spectroscopy



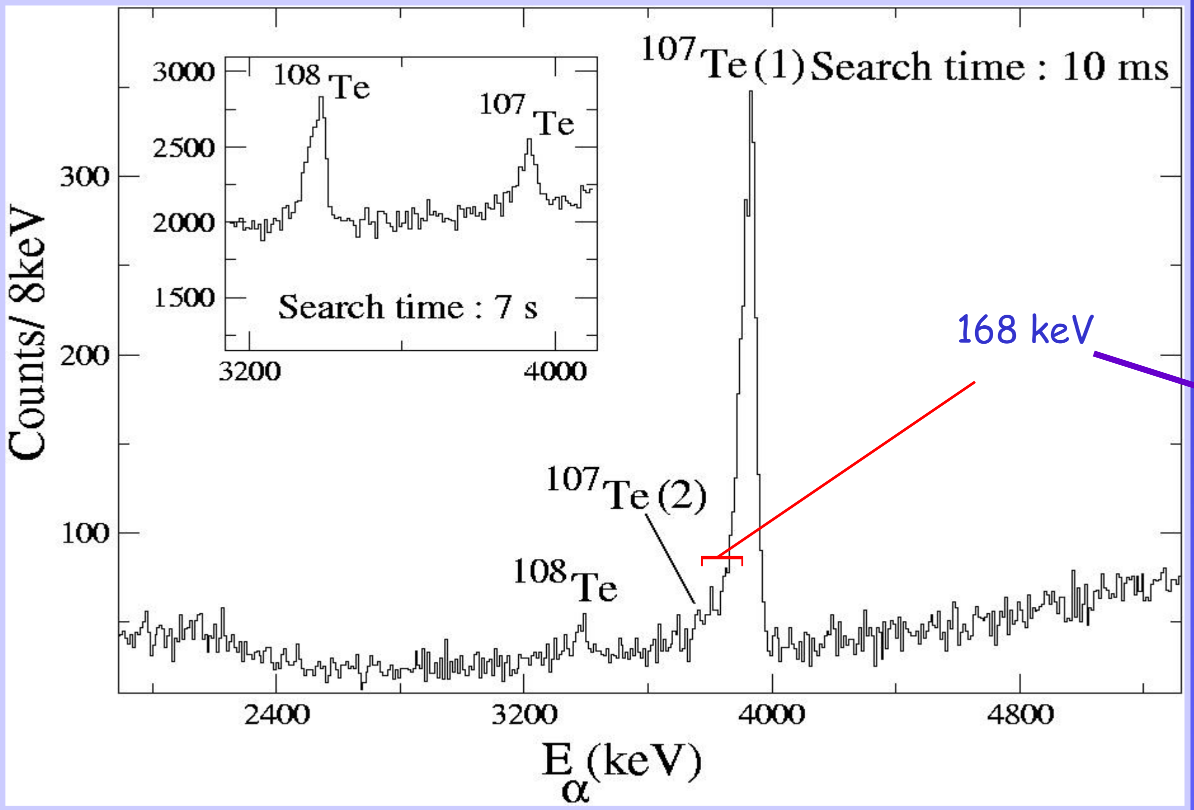
# The "island" of alpha radioactivity "NE" of $^{100}$Sn - a golden opportunity for RDT

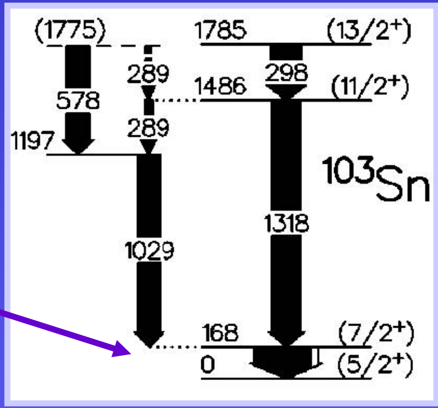



Challenge:
Can only be populated in near-symmetric reactions

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

## Recoil-correlated α decays @ RITU focal plane



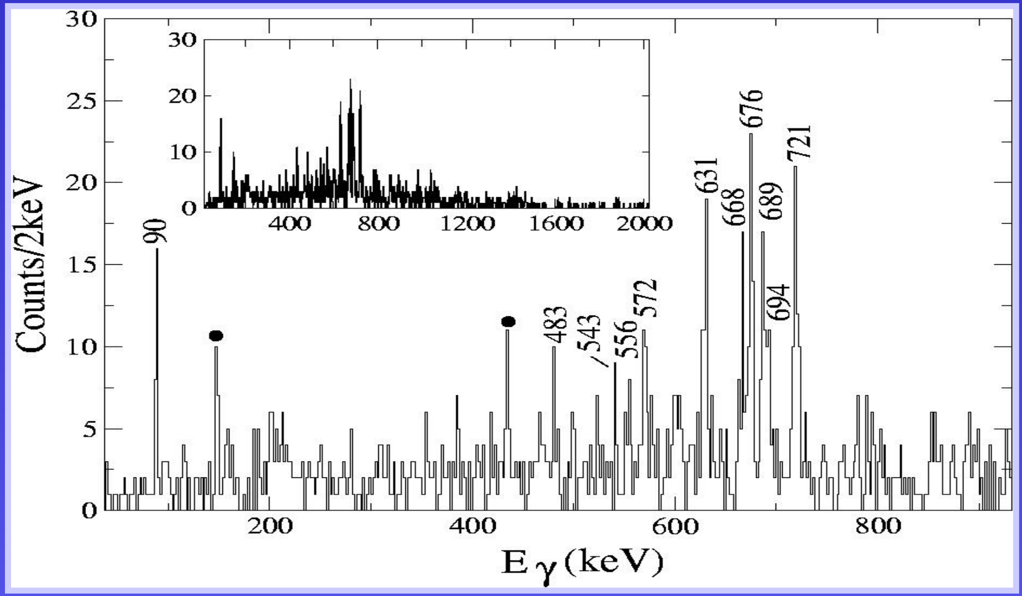




C. Fahlander et al.
Phys. Rev. C63, 021307 (2001)
(Euroball)

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

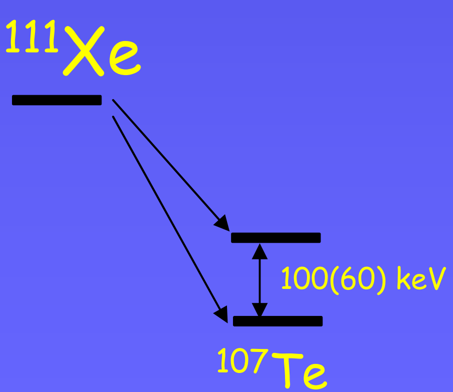
Alpha-decay branching ratio : 70%
Half life : 3.1ms
σ = 1 μb

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

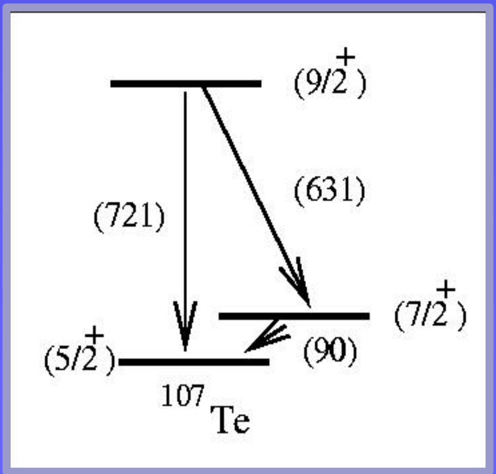


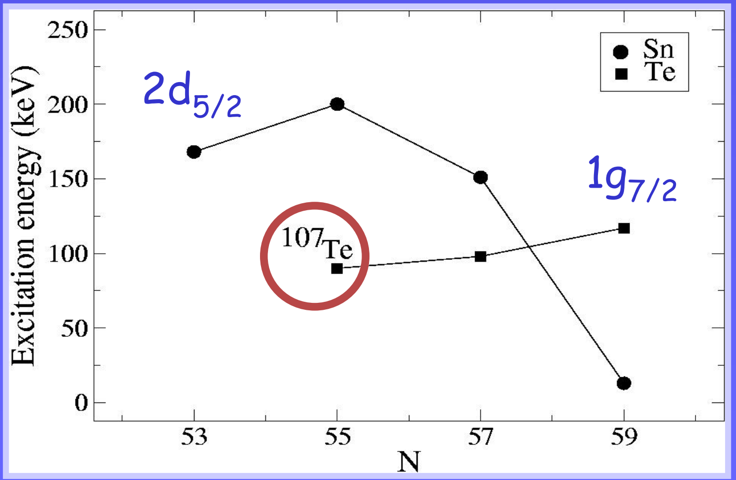

Recoil-decay correlated gamma-ray spectrum

Tentative level scheme



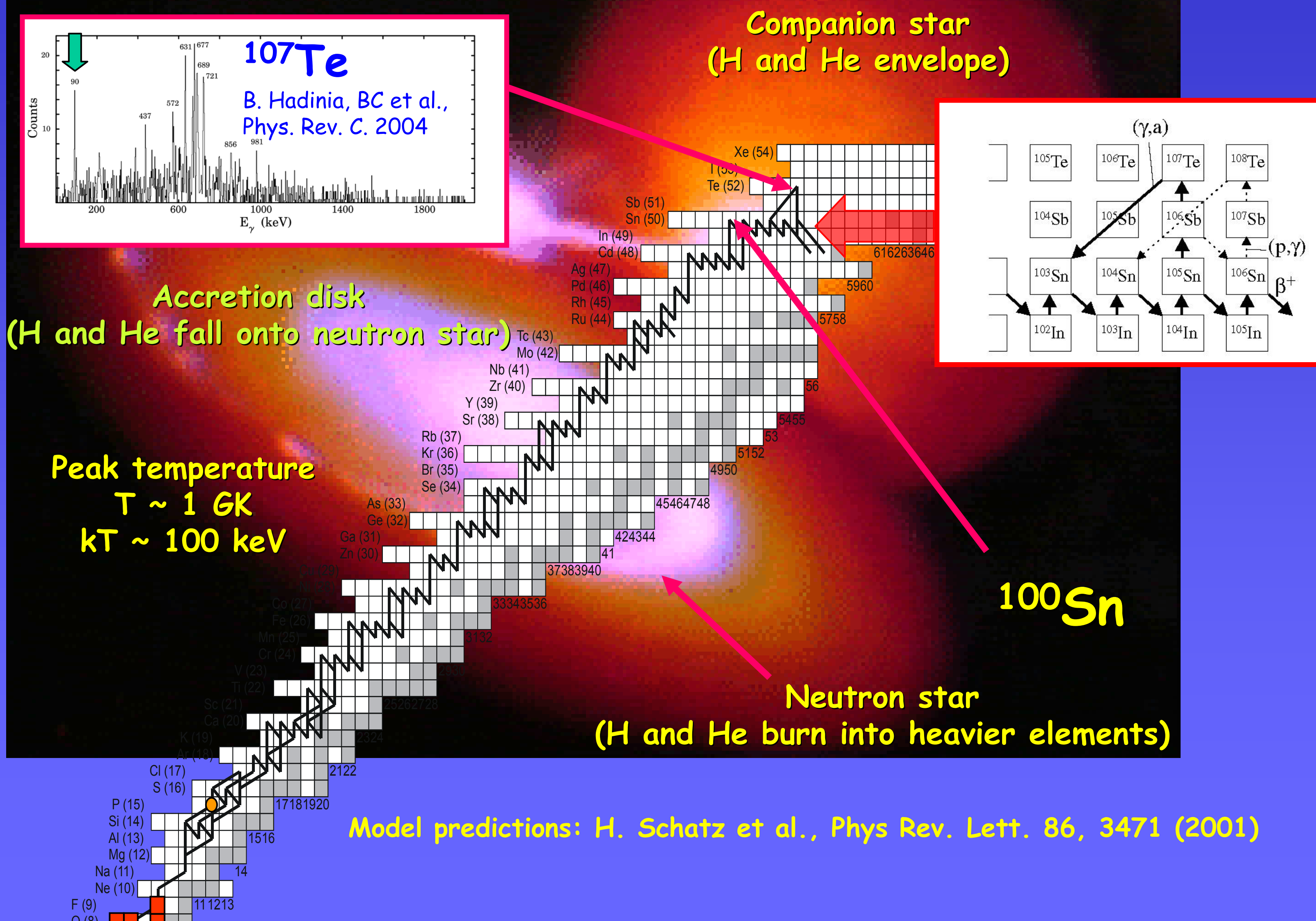

D. Schardt et al.
Nucl. Phys. A368, 153 (1981)



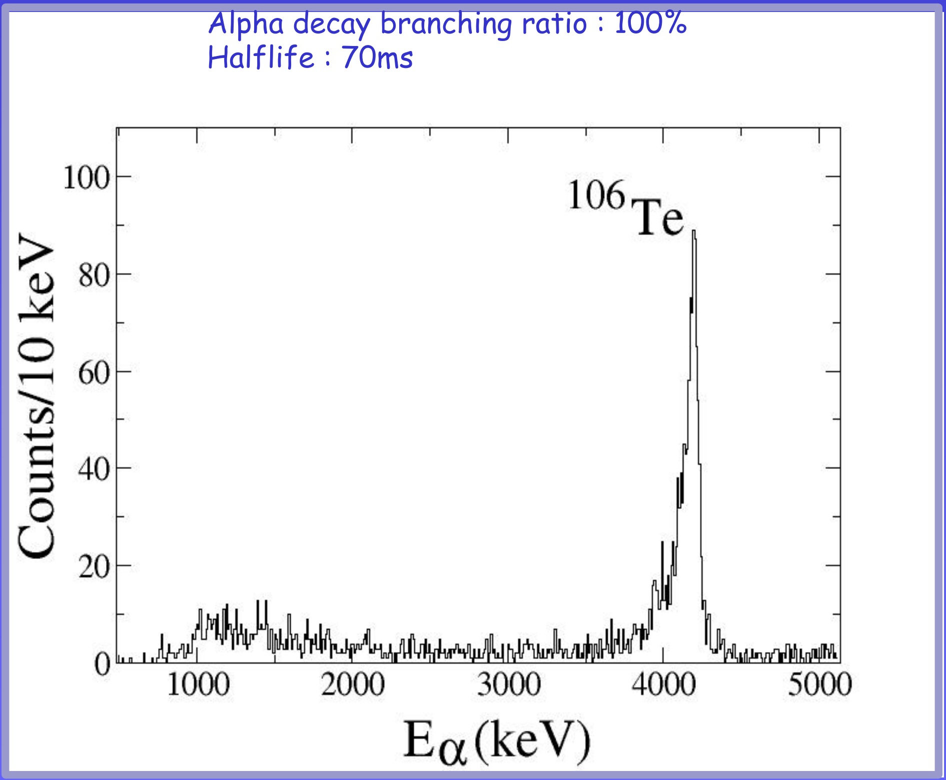

B. Hadinia, B C et al., Phys. Rev. C. 2004

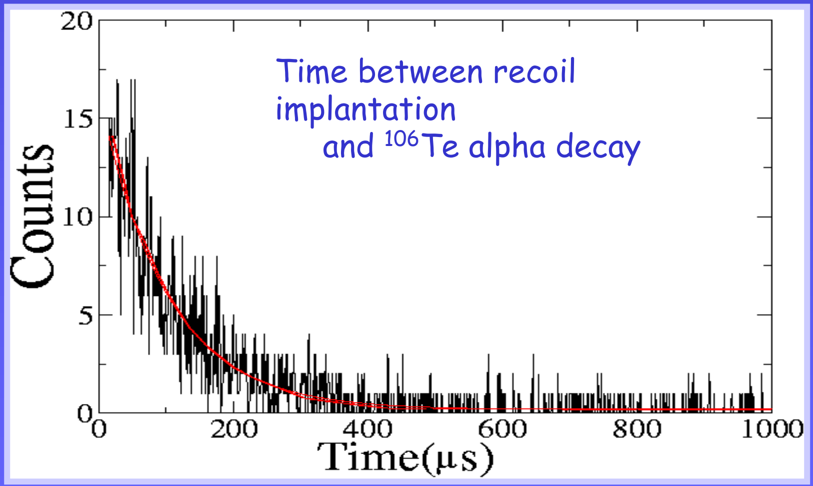
# The predicted rp-process end point in X-ray bursters and accreting neutron stars




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

# $^{54}Fe + ^{54}Fe \rightarrow ^{106}Te^{*} + 2n$

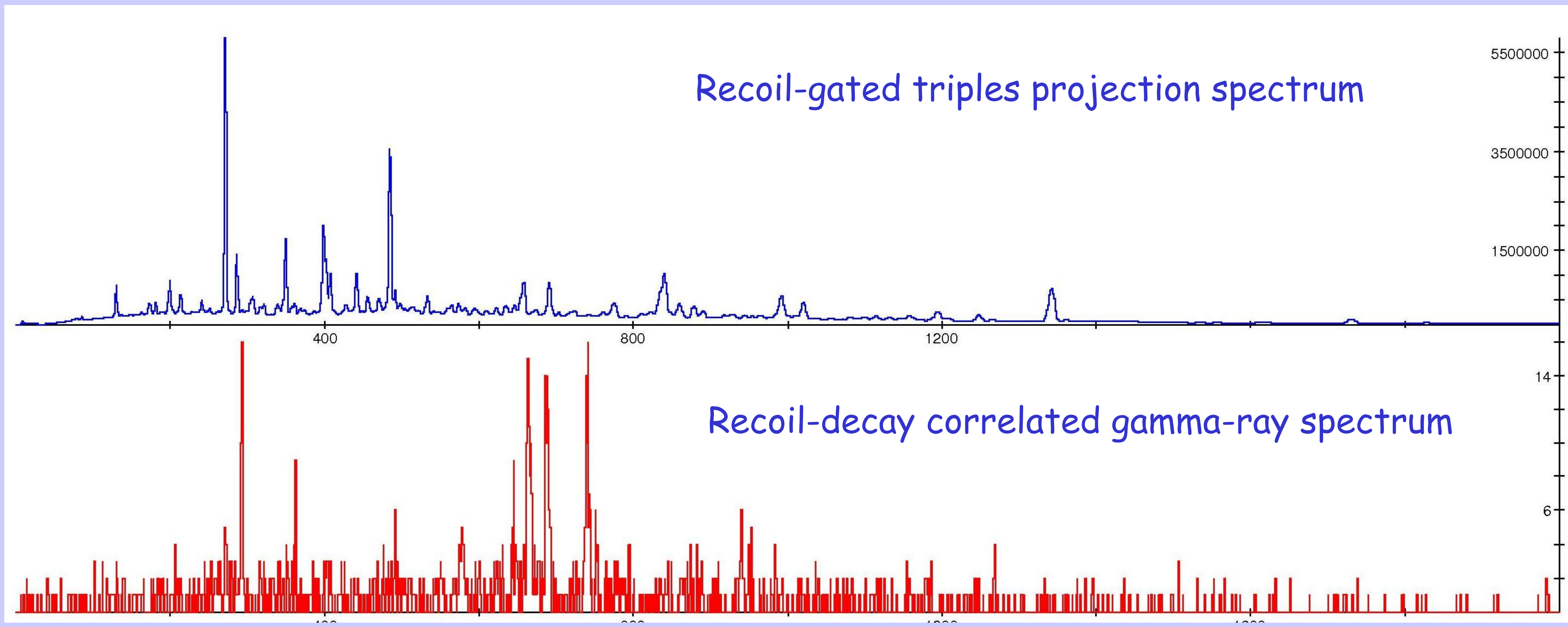



B. Hadinia, BC *et al.*, Phys. Rev. C 72, 041303 (2005)

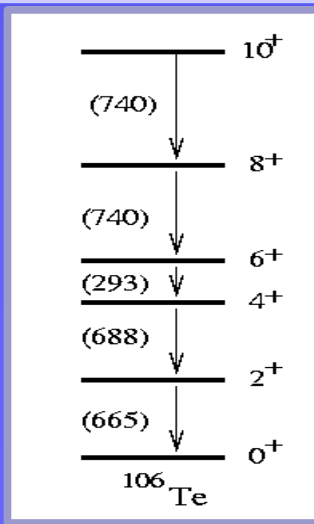
# $^{106}$Te gamma rays

## $\sigma$ = 25 nb – A new limit for in-beam $\gamma$-ray spectroscopy (?)!




**Selectivity: ~$10^{-7}$ !**

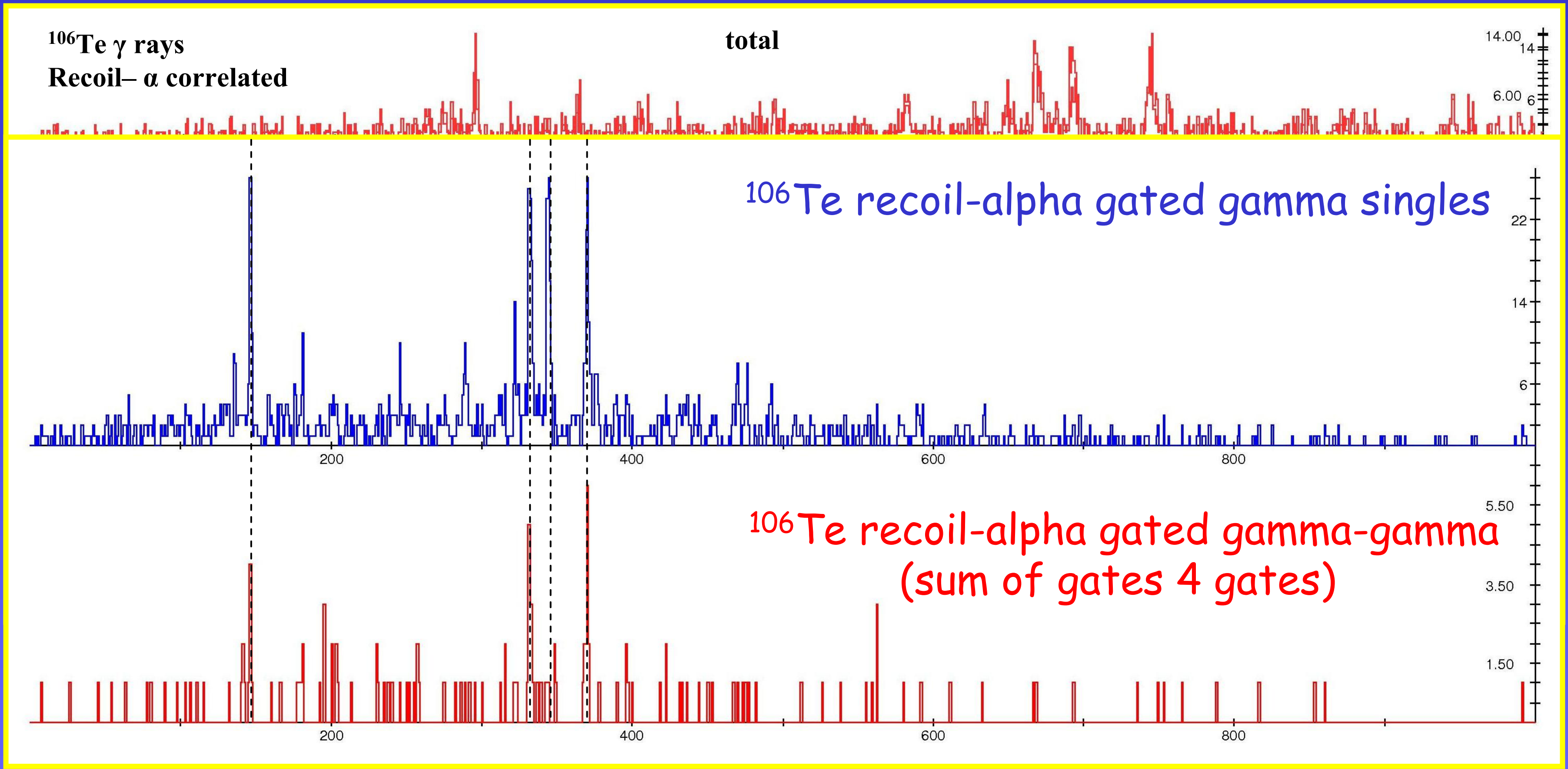
Tentative level structure of $^{106}$Te



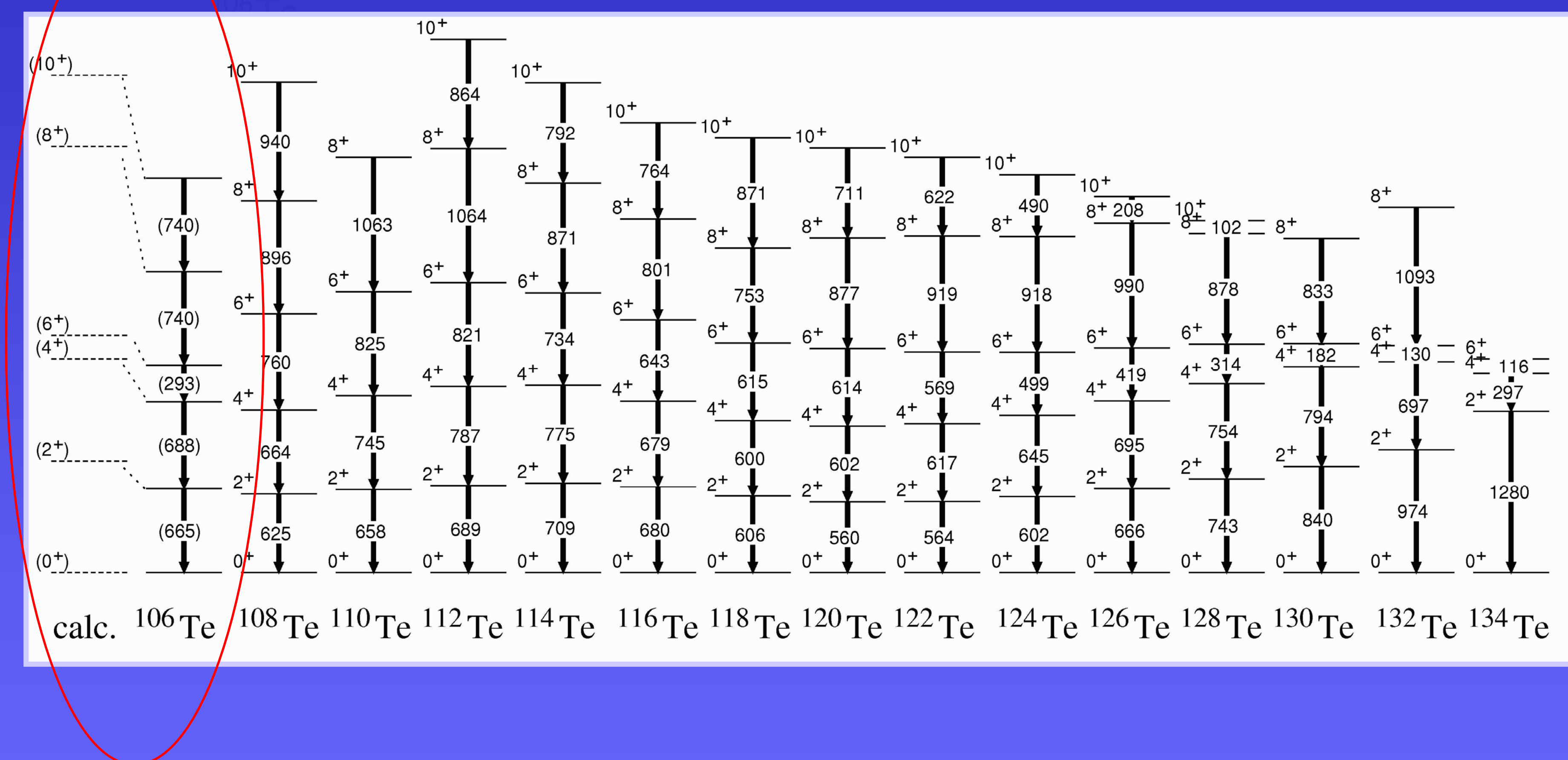

B. Hadinia, BC *et al.*, Phys. Rev. C 72, 041303 (2005)

KUNGL. TEKNISKA HÖGSKOLAN

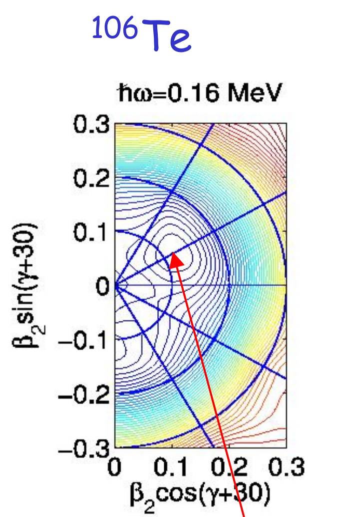
# Gamma-gamma coincidences at $\sigma \sim 25$ nb



# Te energy systematics and calculations



# Te energy systematics and calculations ctd'

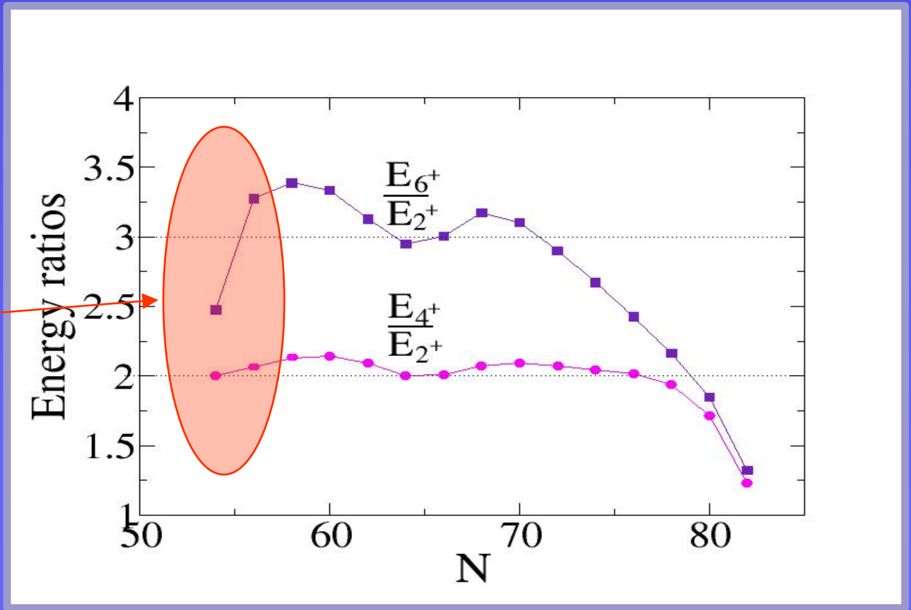



Total Routhians Surface (TRS) calculation
E. Ganioğlu, R.Wyss, KTH

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

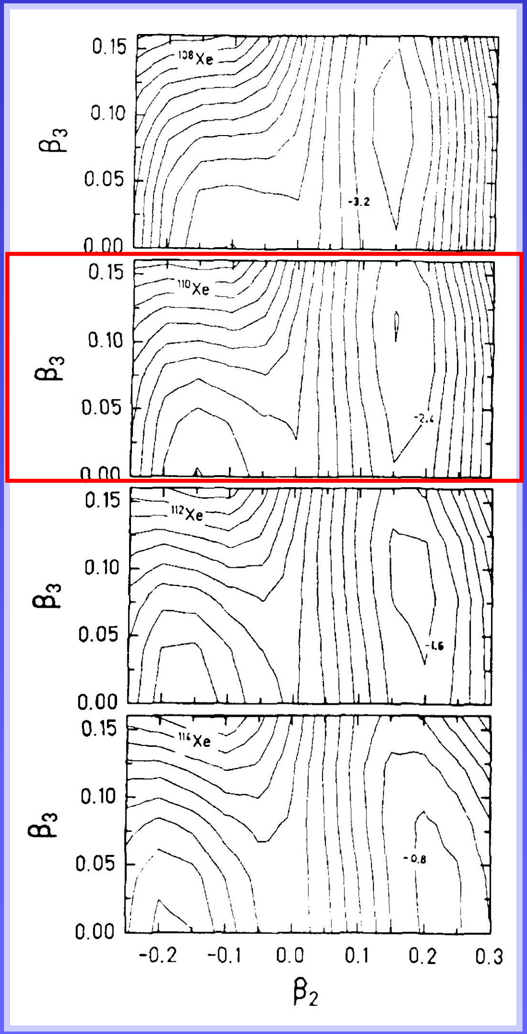
What happens here, and next?

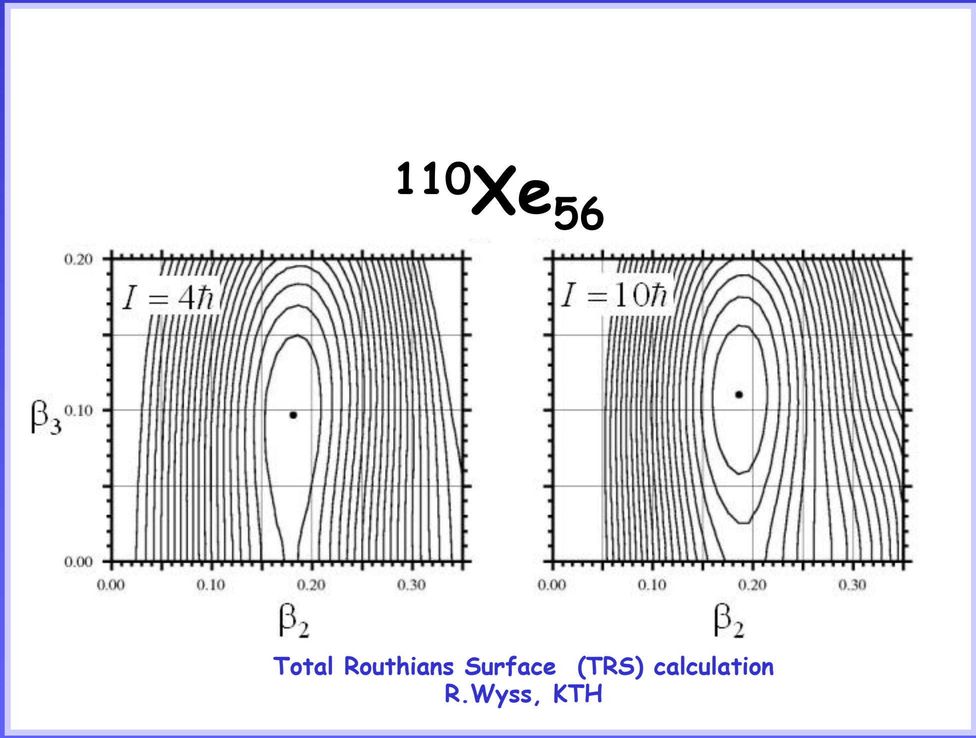
Evidence for enhanced collectivity near N=Z ?




Energy ratios for even Te isotopes, 106 ≤ A ≤ 134

# Predicted stable octupole deformation and softness in the Xe isotopes



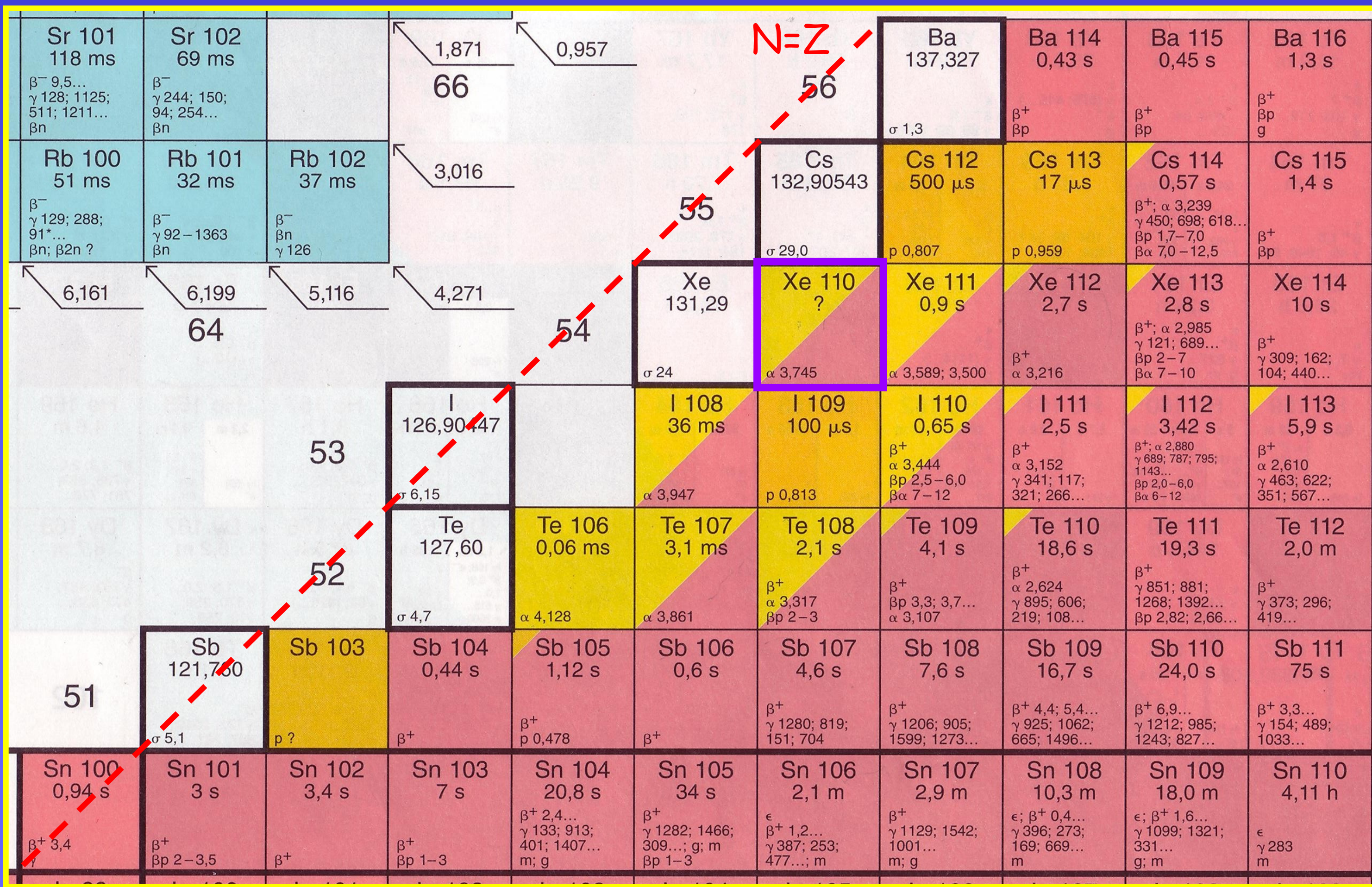




J. Skalski, Phys. Lett. B239, 6 (1990)

# $^{54}Fe + ^{58}Ni \rightarrow ^{110}Xe^{*} + 2n$

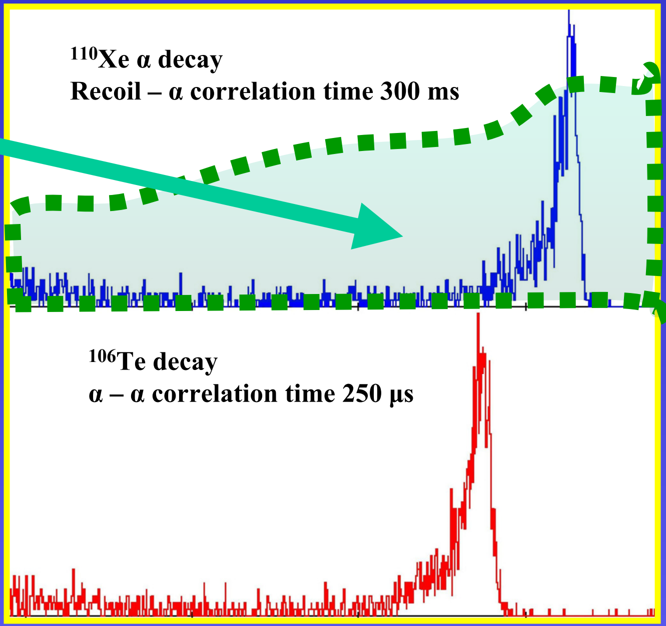
(σ ~ 50 nb)

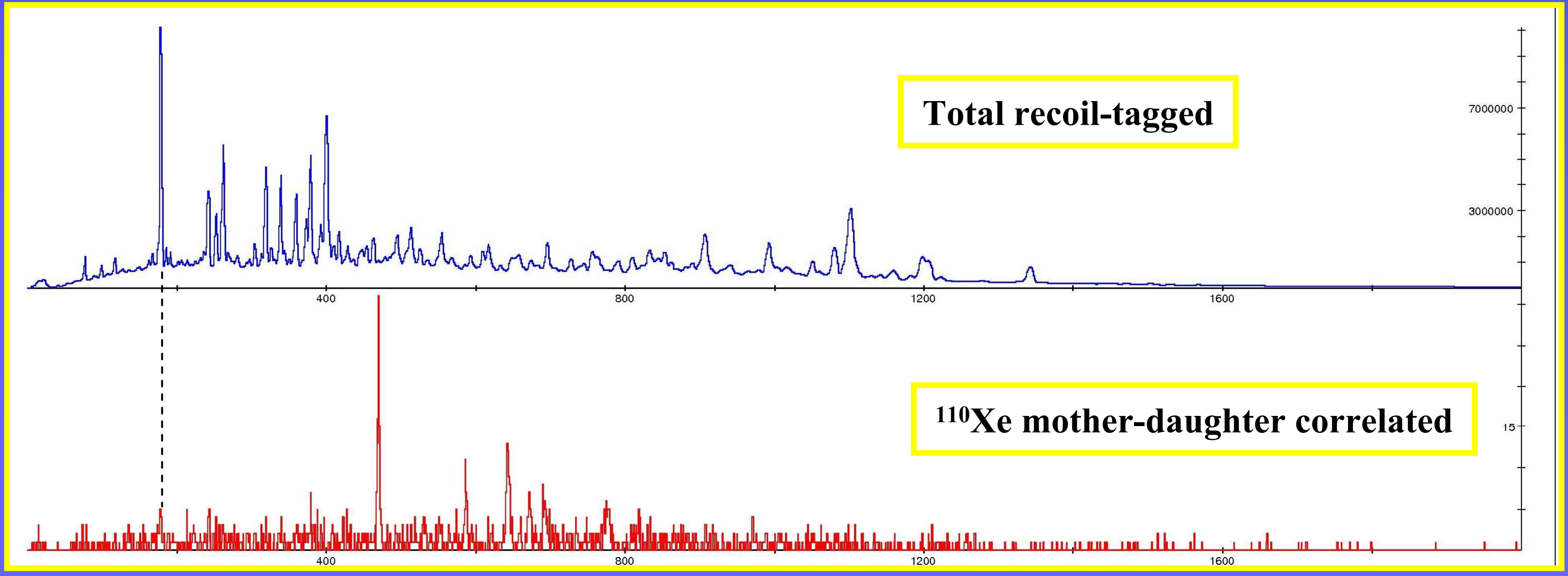
## Work in progress!



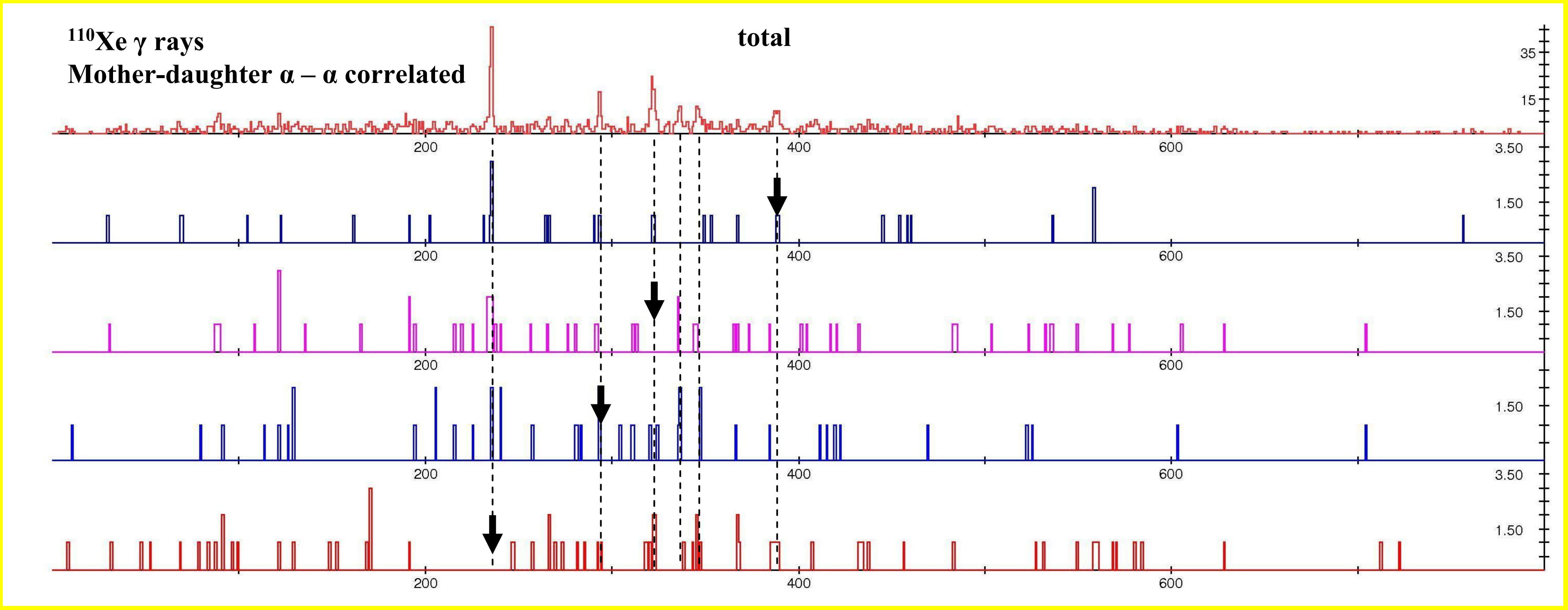
# Good mother - daughter relations are helpful!

β-delayed protons

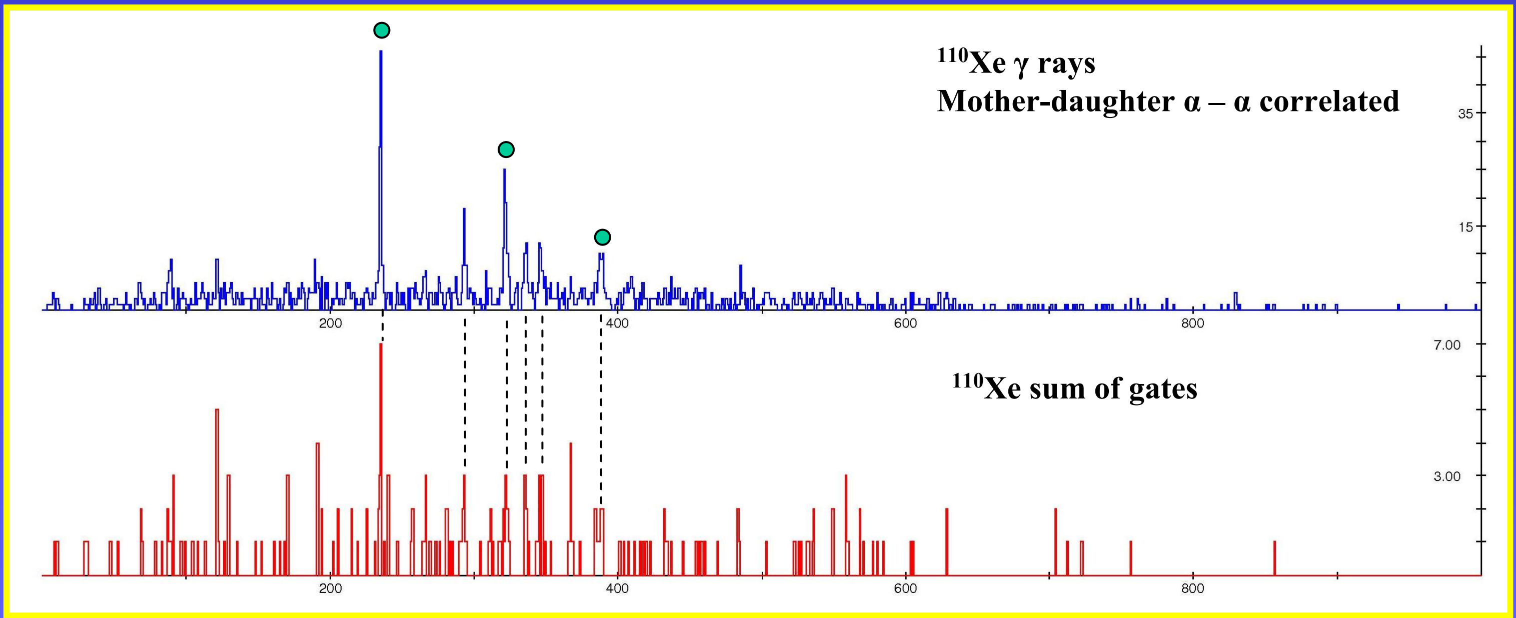


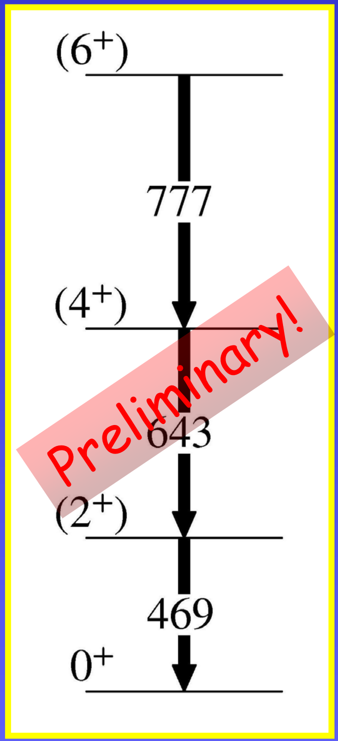



# Gamma-gamma coincidences at σ ~ 50 nb

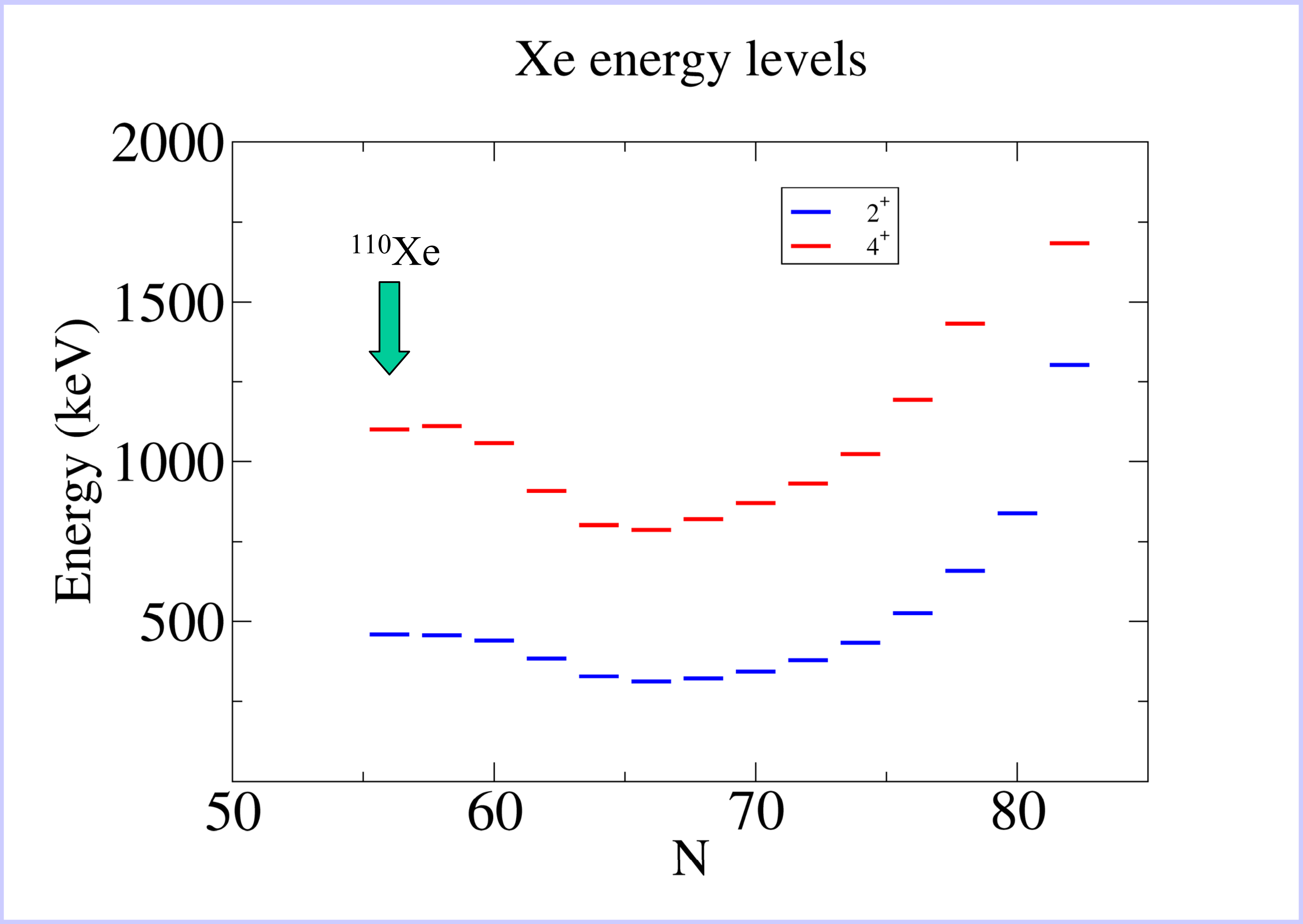


# Gamma-gamma coincidences

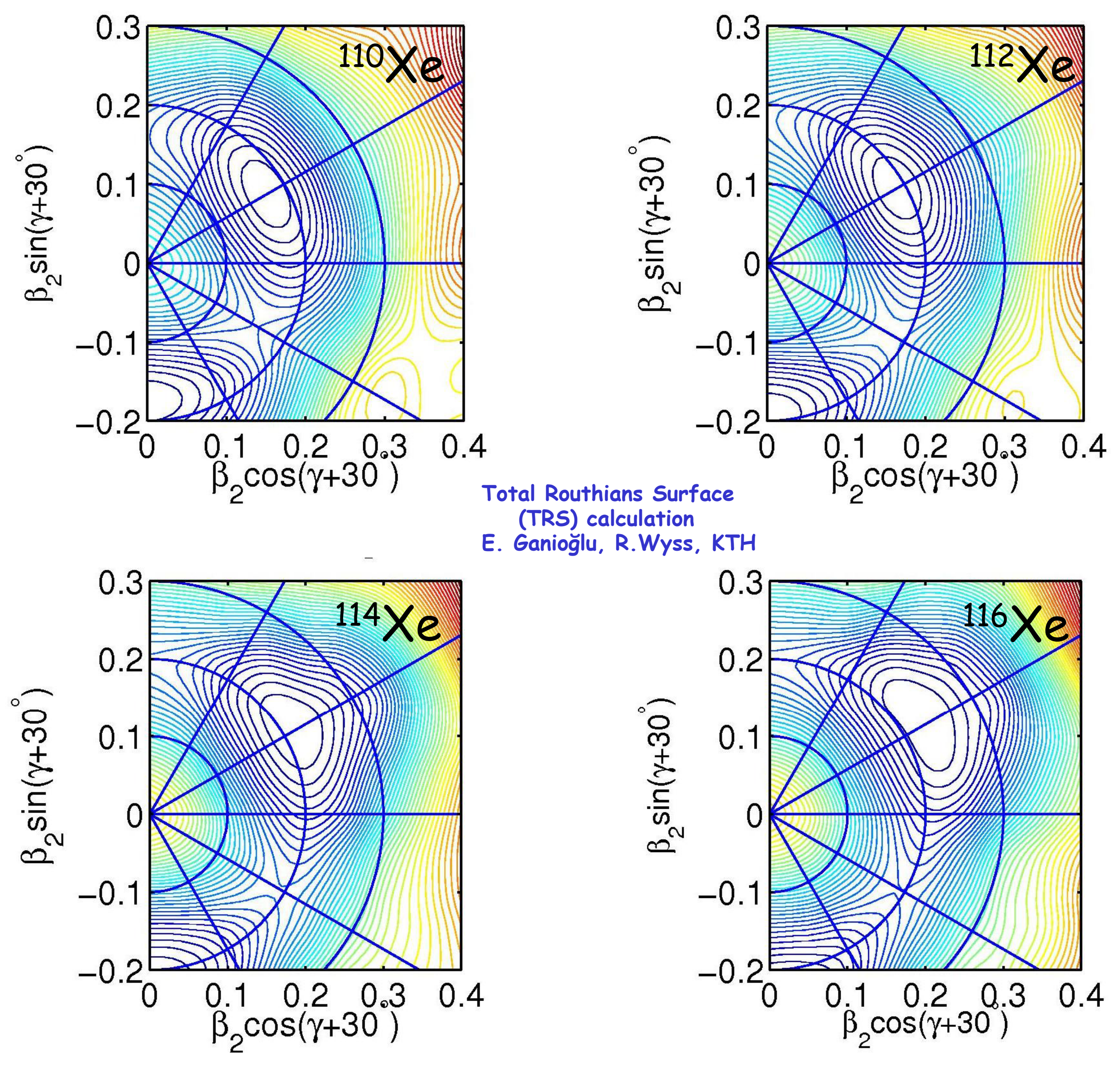


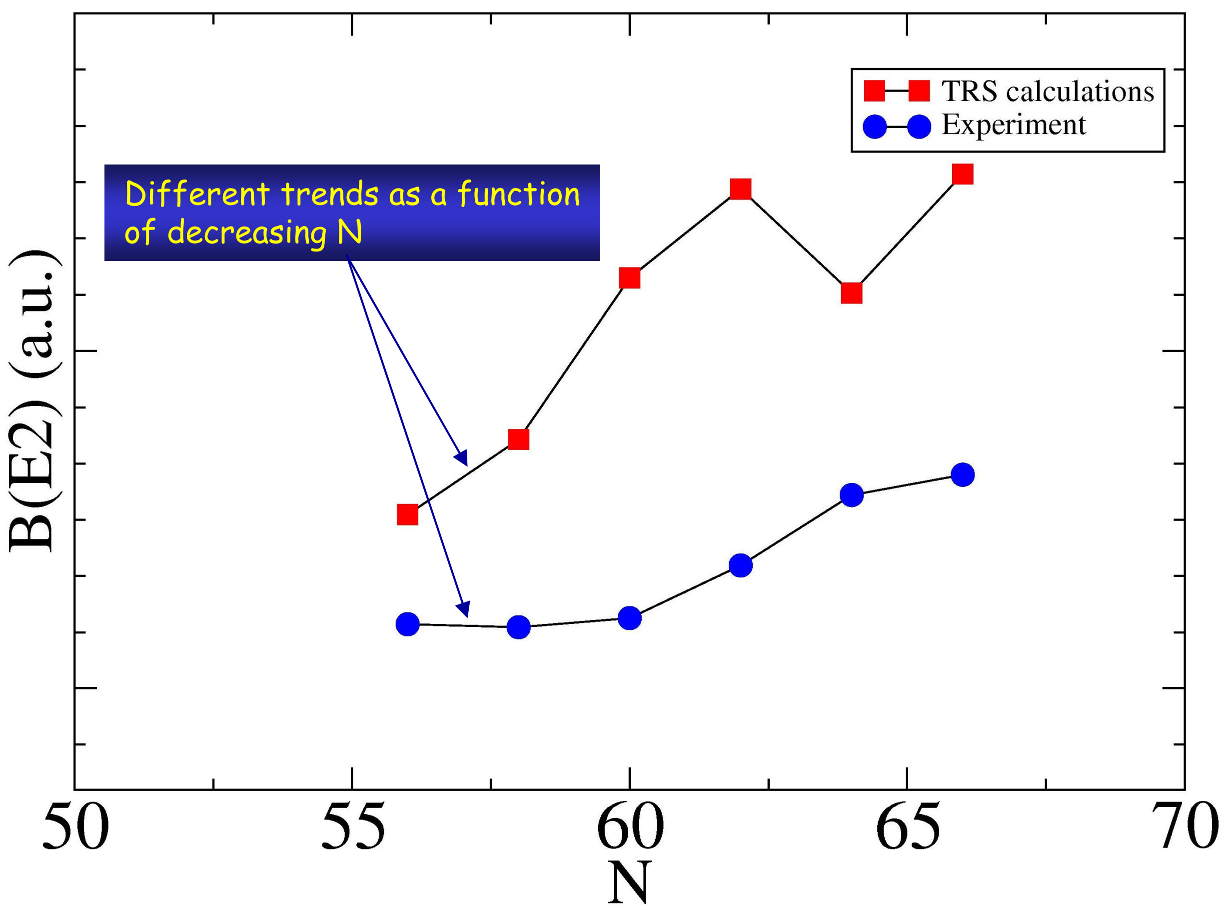
# Xe experimental energy systematics



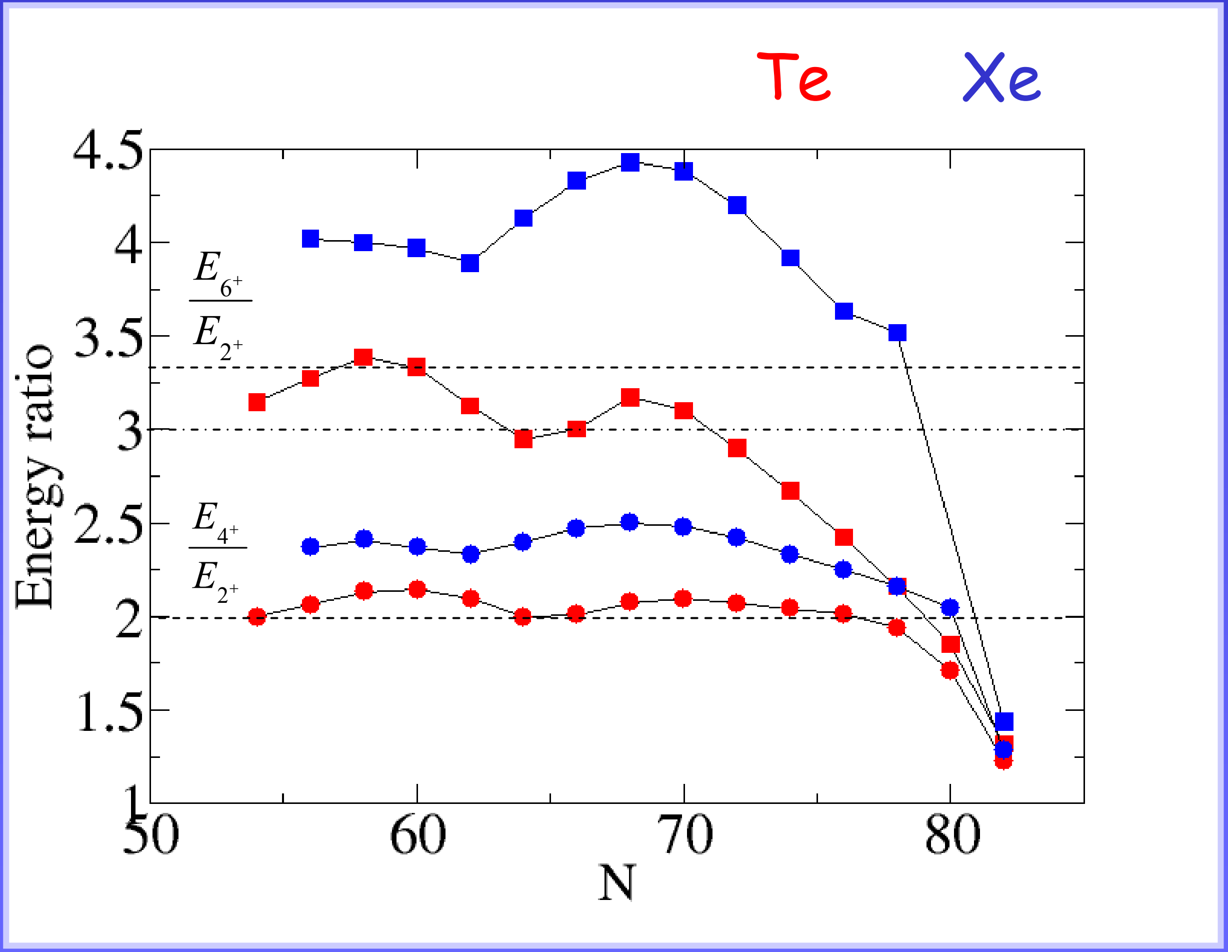
# TRS calculations for extremely neutron deficient Xe isotopes predict decreasing collectivity



# 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 downs 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 → 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