# Neutron-proton correlation phenomena in N=Z nuclei around $^{100}Sn$

## - **An experimental perspective**

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NORDITA Conference on Chiral Bands in Nuclei, Stockholm, 20-24 April 2015

# Challenges in Nuclear Structure (selection!)

Shell structure in nuclei (general)
- Structure of doubly magic nuclei
- Changes in the (effective) interactions
- Development of collective excitations

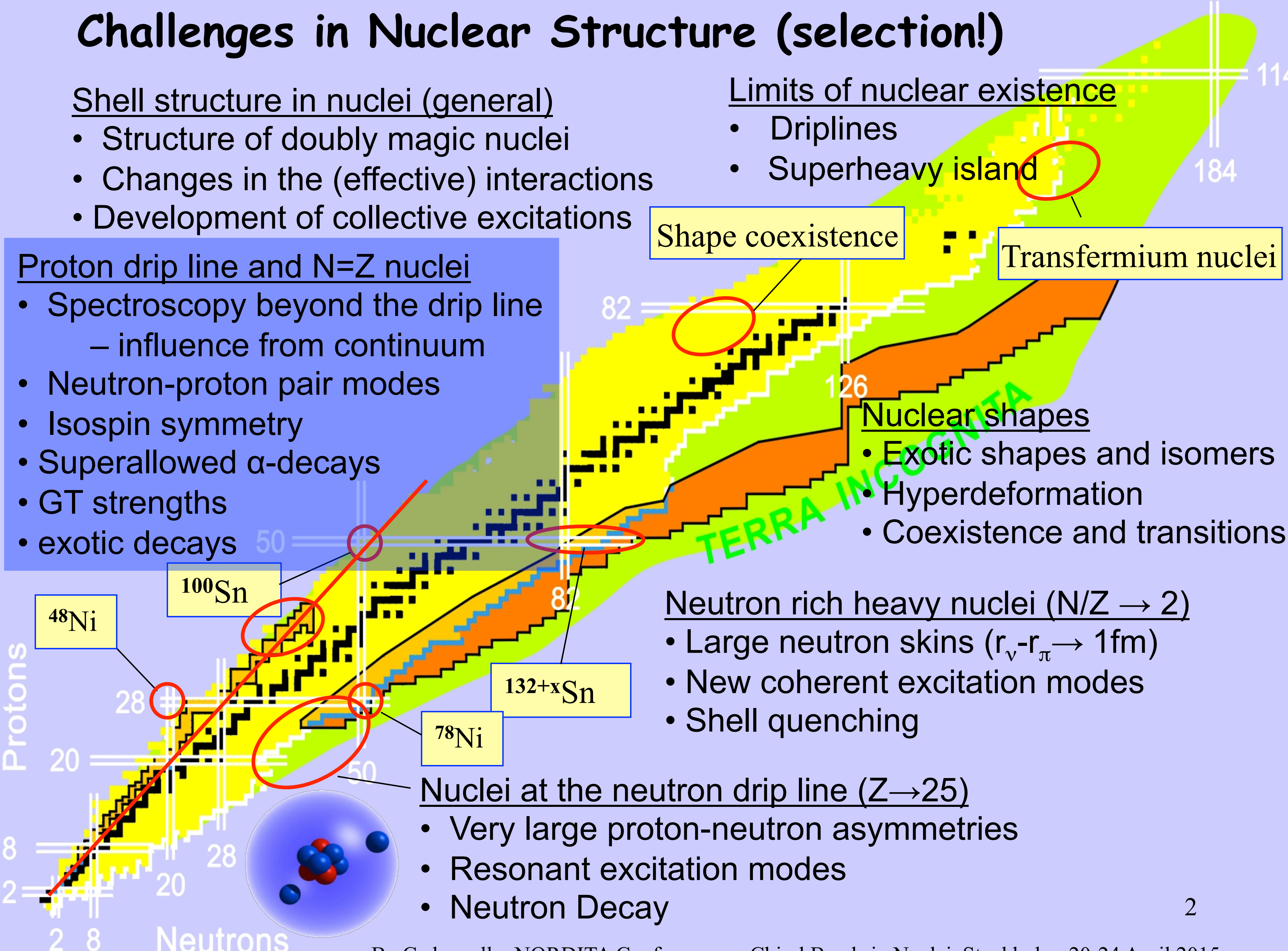
Limits of nuclear existence
- Driplines
- Superheavy island

Proton drip line and N=Z nuclei
- Spectroscopy beyond the drip line
  - influence from continuum
- Neutron-proton pair modes
- Isospin symmetry
- Superallowed α-decays
- GT strengths
- exotic decays

Nuclear shapes
- Exotic shapes and isomers
- Hyperdeformation
- Coexistence and transitions

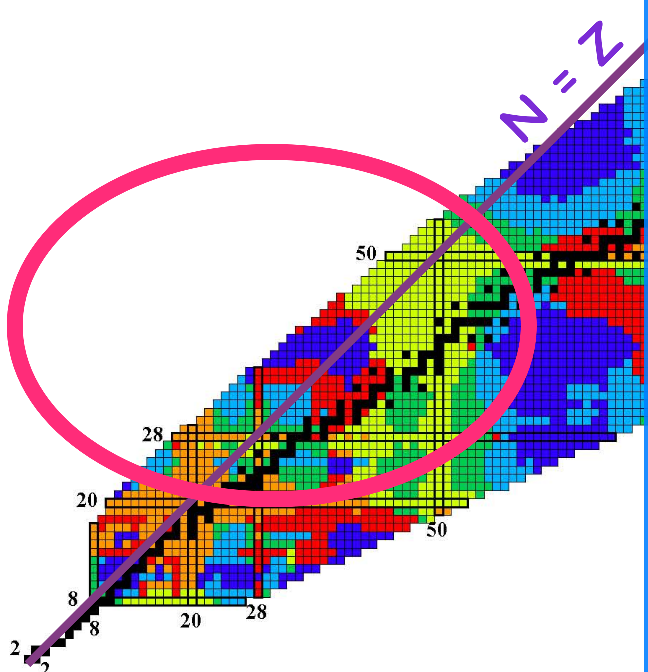
Neutron rich heavy nuclei (N/Z → 2)
- Large neutron skins ($r_\nu$-$r_\pi$ → 1fm)
- New coherent excitation modes
- Shell quenching

Nuclei at the neutron drip line (Z→25)
- Very large proton-neutron asymmetries
- Resonant excitation modes
- Neutron Decay



# Nuclear structure around $^{100}$Sn – near the "top" of the N=Z line

*Moller Chart of Nuclides 2000*
*Quadrupole Deformation*

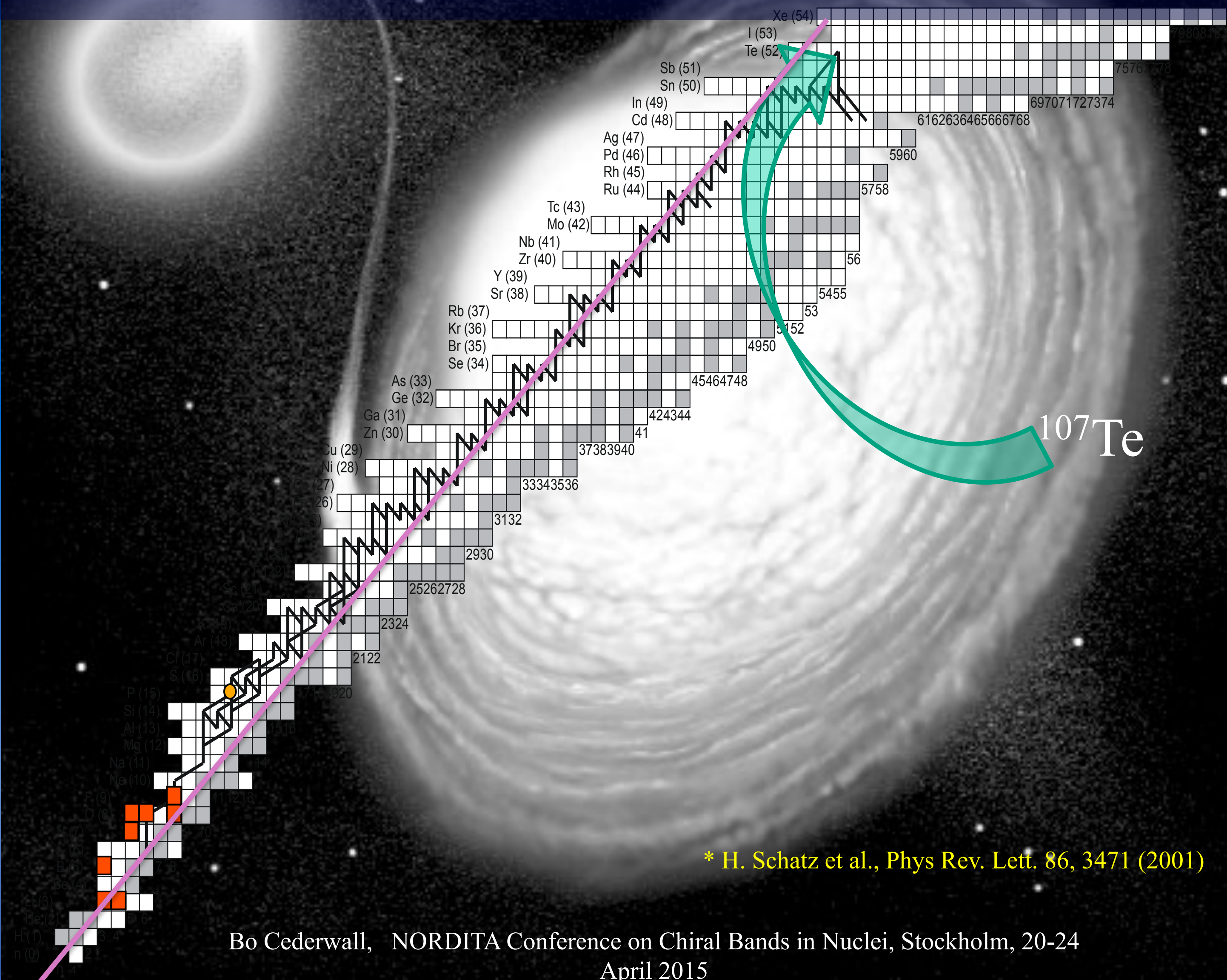



## N=Z line coincides with a doubly-magic system and the proton dripline

- Neutron-proton correlations in identical orbitals
- Neutron-proton (isoscalar) pairing / Spin-aligned np coupling scheme
- Superallowed α-decays
- Emergence of "collectivity"; B(E2), B(E3) strength

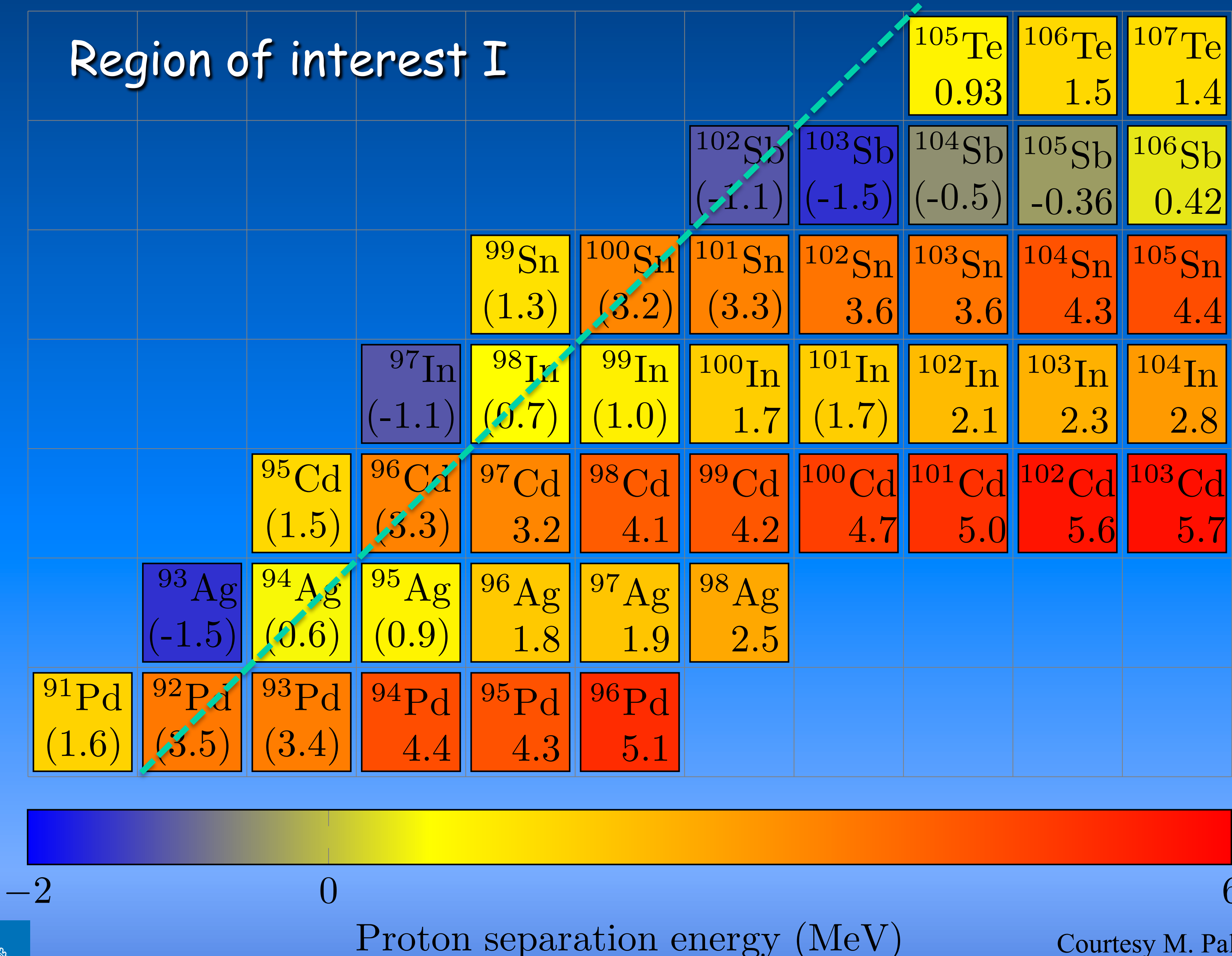
- LSSM calculations (eff. charges, interactions) can be applied and tested

## Astrophysical interest:
## End point of the rp-process path in X-ray bursts and steady-state hydrogen burning on accreting neutron stars*



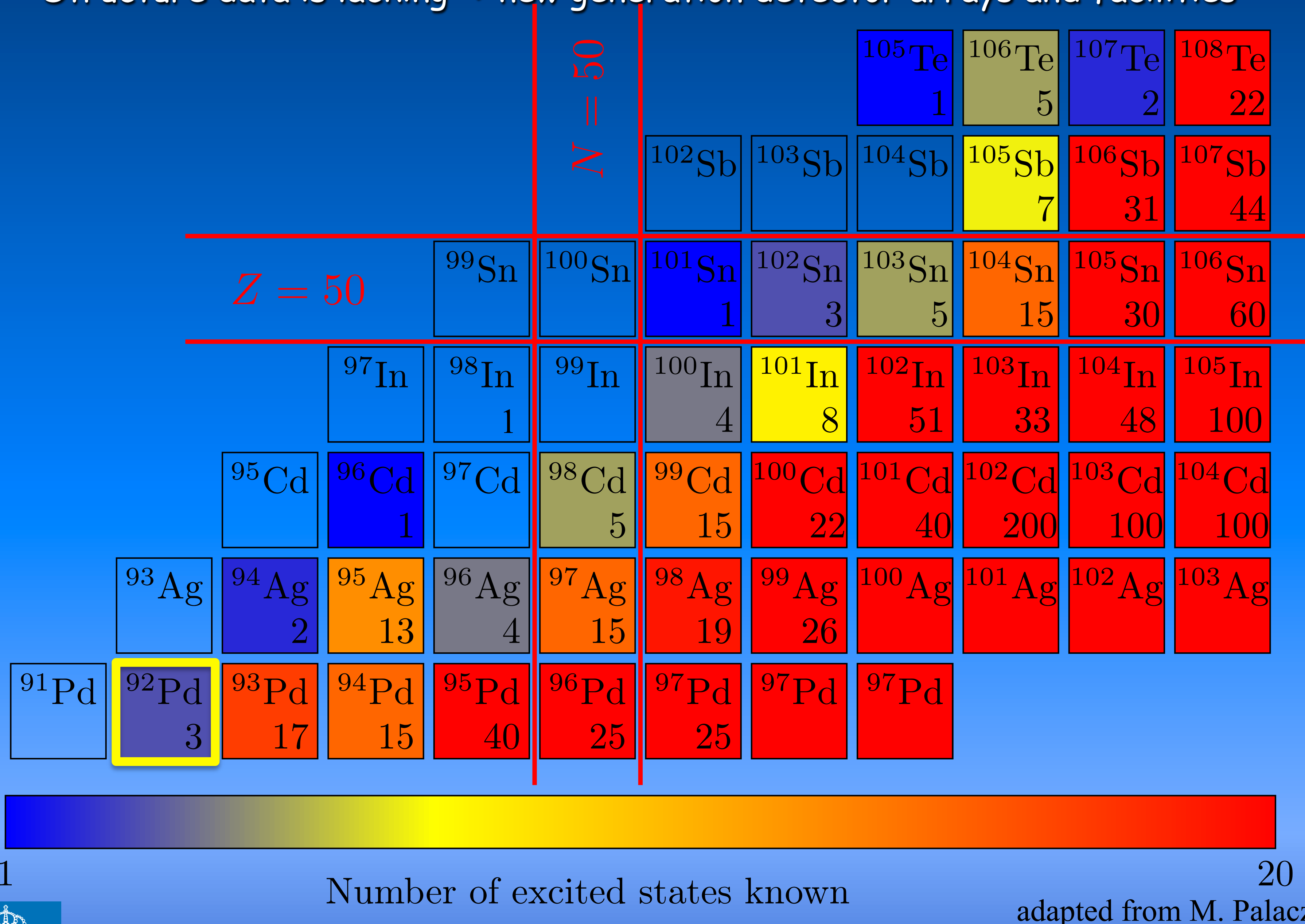

* H. Schatz et al., Phys Rev. Lett. 86, 3471 (2001)

# Region of interest I




Courtesy M. Palacz

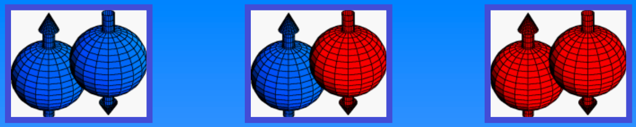
# Structure data is lacking -> new generation detector arrays and facilities



# What is the nature of nuclear pair correlations near N=Z?
# - A long-standing, open question in nuclear structure physics

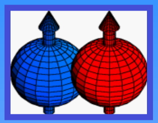
When approaching N=Z, "normal" pair correlations may remain or even be extended as neutrons and protons occupy identical quantum states:

***T*=1, *J*=0 ("isovector") nn, pp**
*as well as* **np** Cooper pairs (neutrons and protons occupy identical orbits)



$T = 1 \quad J = 0$

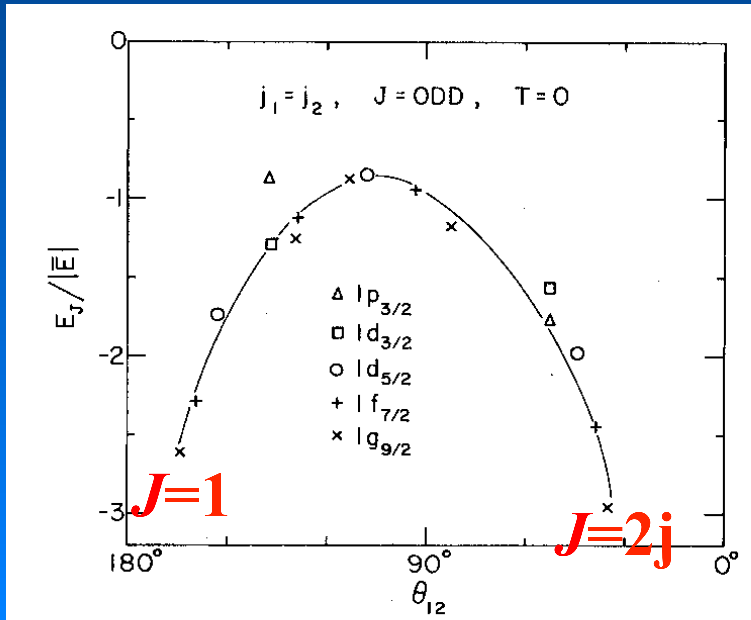
**In addition: *T*=0, *J*=1... ("isoscalar") np pairing?**



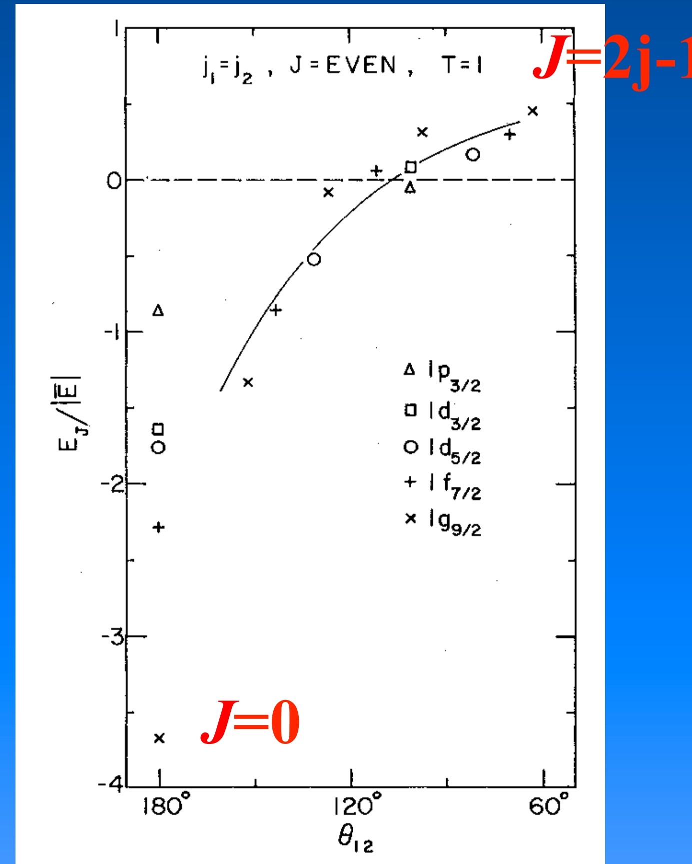
$T = 0 \quad J > 0$

**(We know the isoscalar effective NN interaction is strongly attractive but can it produce a correlated np pairing condensate?)**

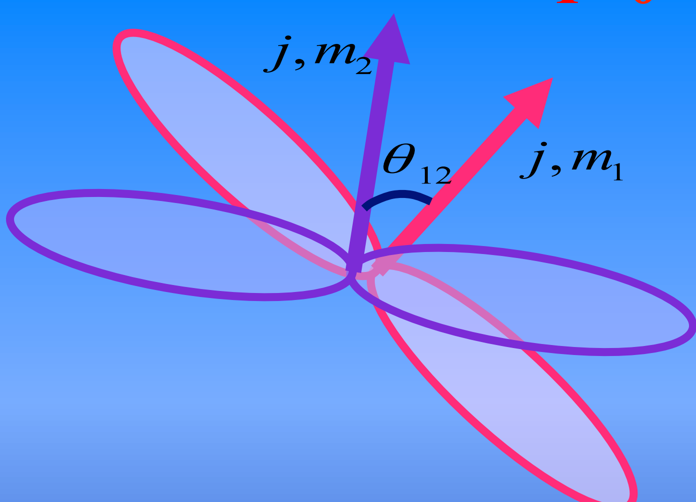
# Effective (residual) interactions between nucleons in a j-shell




T=0




T=1



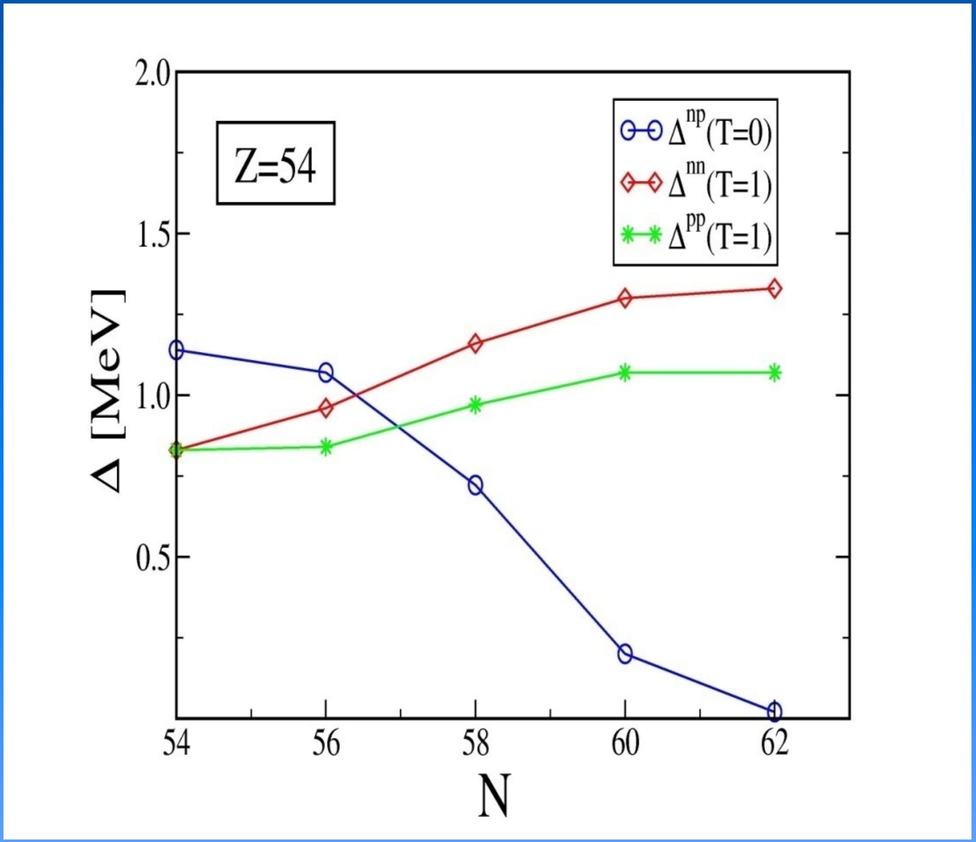

$$\cos\theta_{12} = \frac{J(J+1)}{2j(j+1)} - 1$$

J. P. Schiffer and W. W. True

Rev. Mod. Phys., Vol. 48, No. 2, Part I, April 1976

- **effective force between particles, <u>orbital overlap</u>**
- **Pauli principle**

# The isoscalar (np) pair gap is predicted to increase sharply as N→Z

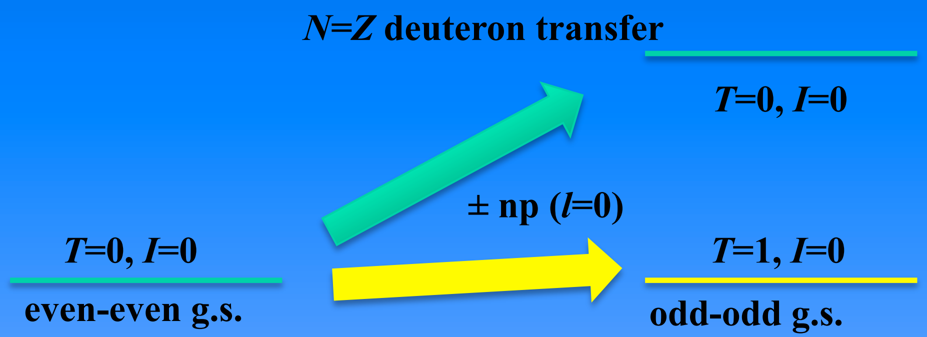



"Isospin-generalized" BCS-type calculation by W. Satula, R. Wyss
Phys. Rev. Lett. Vol. 86, 4488 (2001)

# Does isoscalar (np) pairing *in the BCS sense* exist in Nature?
## (i.e. can we find an isoscalar pairing "deuteron" condensate somewhere?)

The experimental search for *T*=0 np pairing has focused on special features:

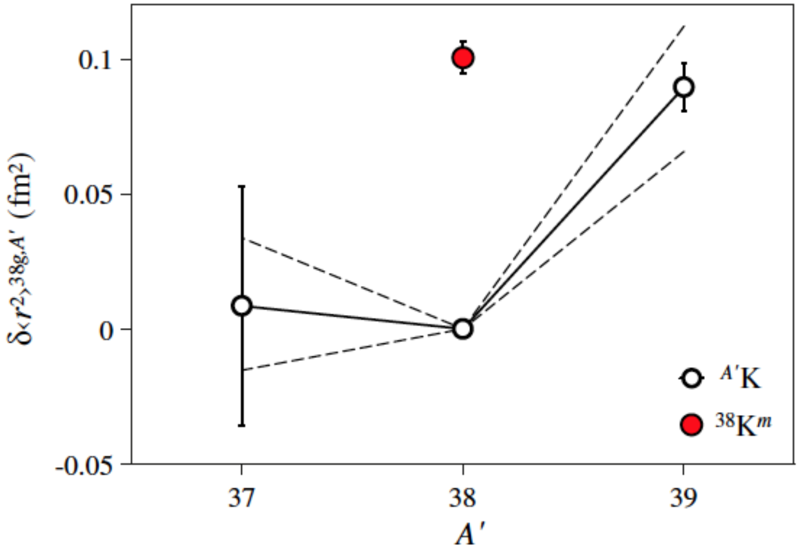
- g.s. binding energies of N=Z (even-even vs odd-odd) nuclei
- high-spin properties of deformed N=Z nuclei (reduced CAP, delayed alignments?)
- deuteron transfer reactions in inverse kinematics
  (e.g. measure branching to T=1 and T=0 states in odd-odd N=Z nuclei)



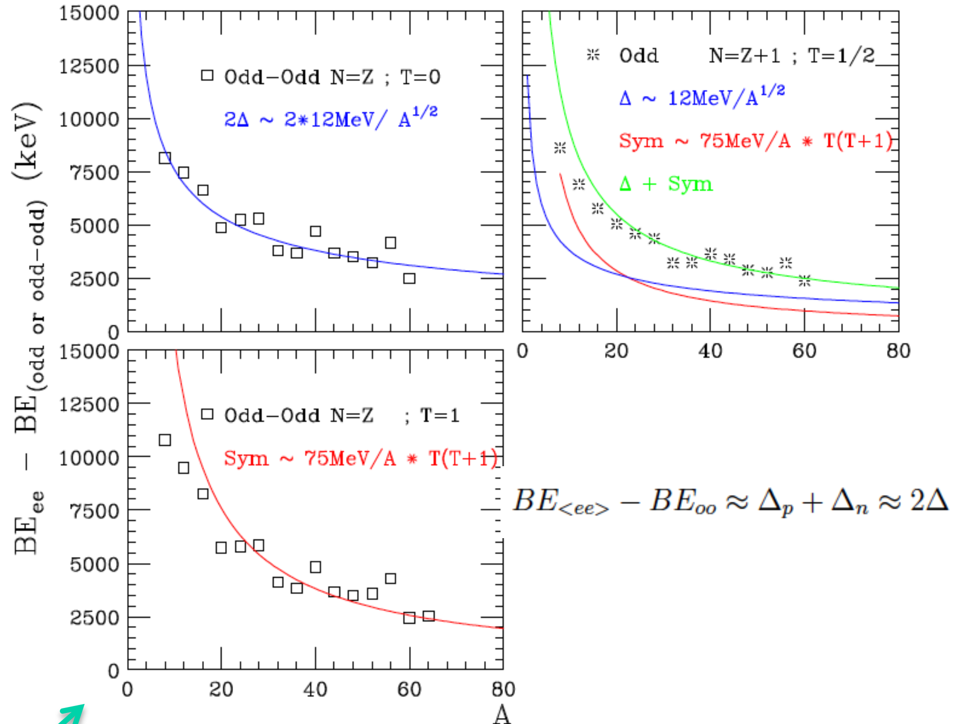

<u>Need for (reaction) theory to develop sharp predictions</u>

**Status: No convincing evidence for so far**
**But much more to be done …**

# Evidence for *isovector* np pairing is claimed from nuclear binding energies, rotational alignments, charge radii etc




"Proton-Neutron Pairing Correlations in the Self-Conjugate Nucleus $^{38}K$ Probed via a Direct Measurement of the Isomer Shift", Bissell et al., PRL 113, 052502 (2014)



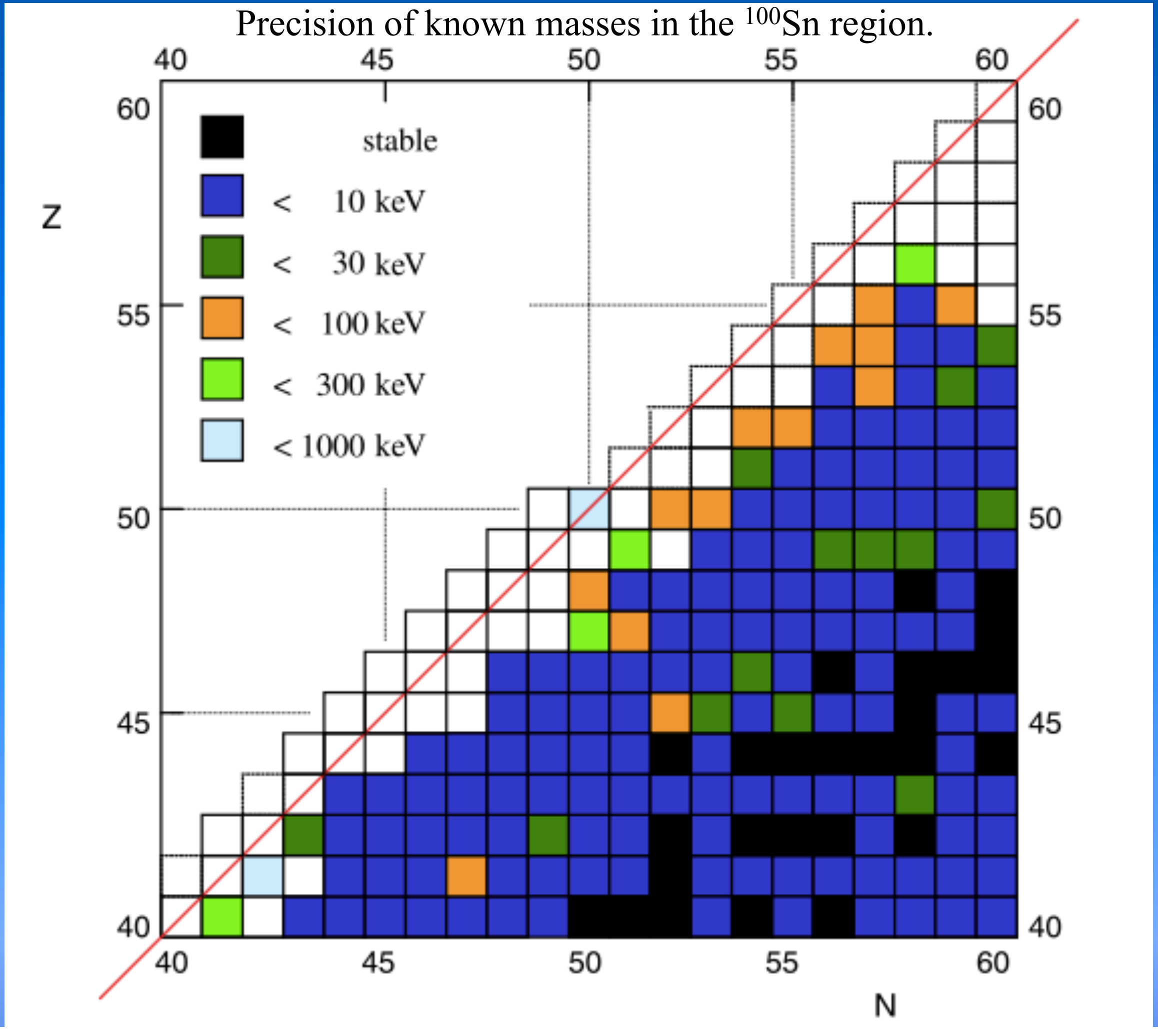

$$BE_{<ee>} - BE_{oo} \approx \Delta_p + \Delta_n \approx 2\Delta$$

Figure 25: Summary of binding energy differences for nuclei along the $N = Z$ line.

"Overview of neutron-proton pairing"
Frauendorf, S., Macchiavelli, A.O.
Progress in Particle and Nuclear Physics volume 78, 2014, pp. 24 - 90

"Excludes" $T$=0 pairing in g.s
Note: Data end at $N$=$Z$≈30!
Symmetry energy?

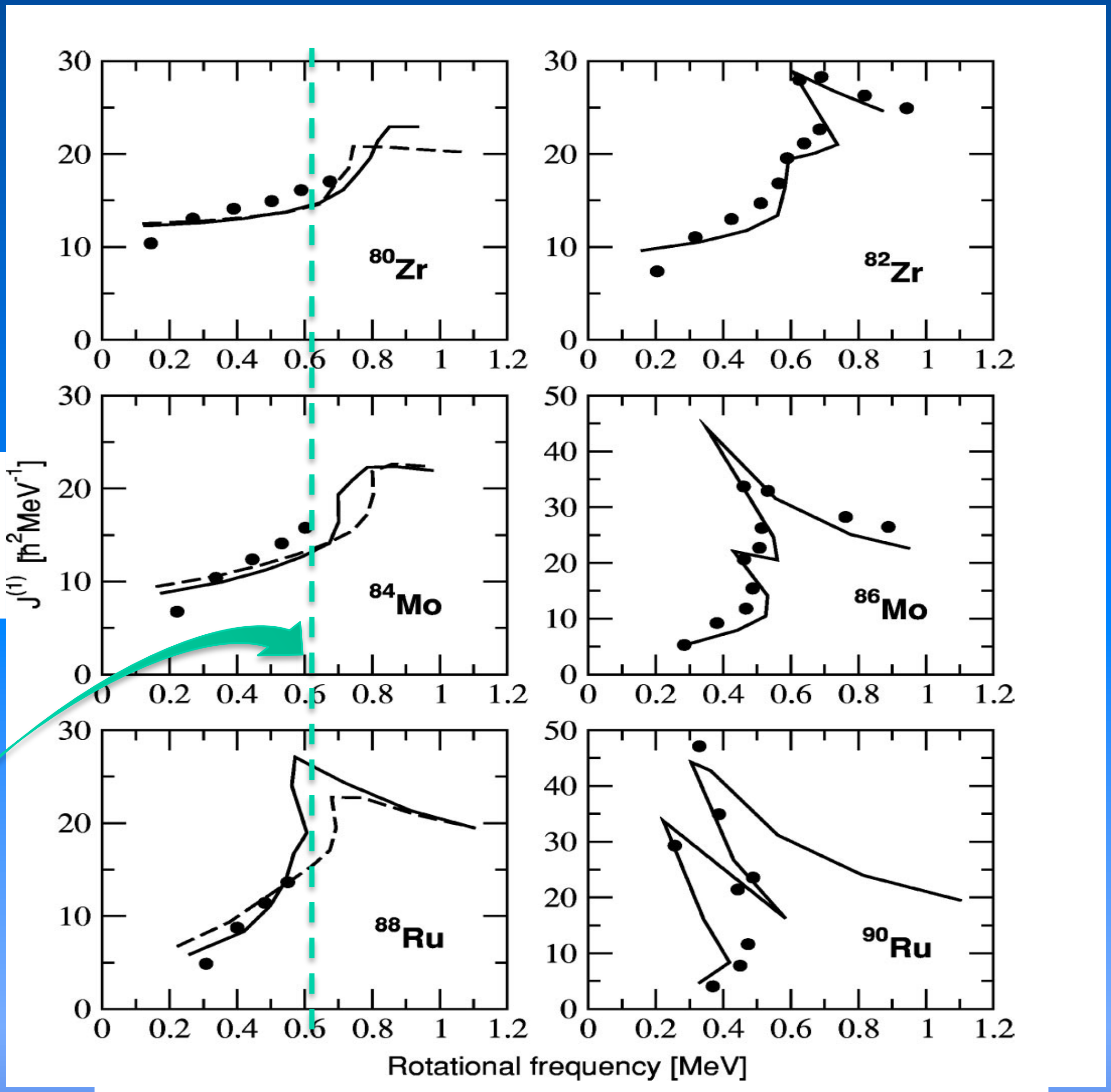
# Precison mass data is crucially lacking for N=Z!




T. Faestermann, M. Górska, and H. Grawe, Prog. Part. Nucl.Phys. 69, 85 (2013)

# Delayed (or absent) paired (T=1) bandcrossings in deformed N=Z nuclei?

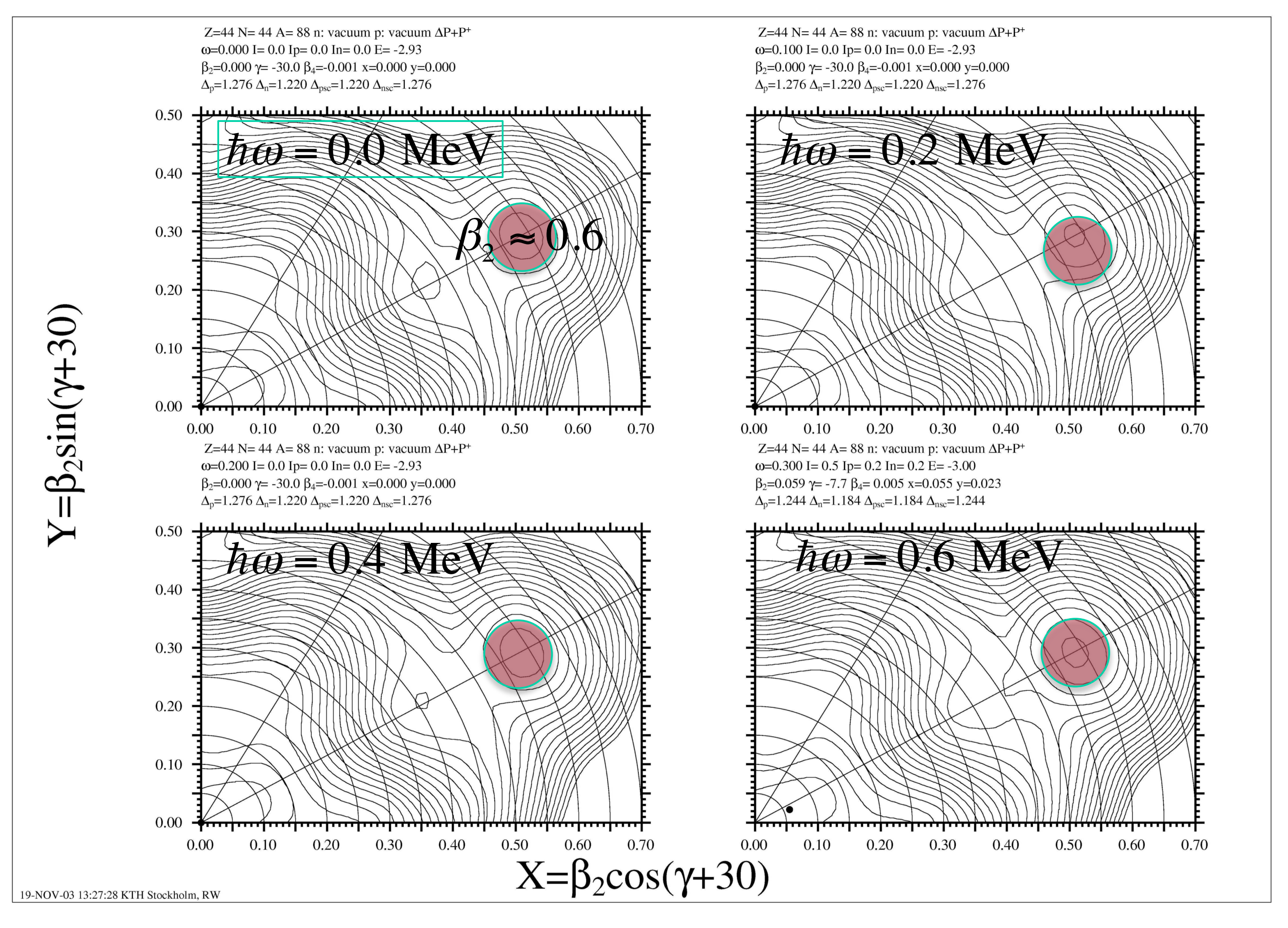
PSM ____________
PSM with enhanced np res. int._ _ _ _ _ _




Data end crucially here!

N. Marginenan *et al.,* Phys. Rev. C 65, 051303R (2002)

# $^{88}$Ru – a superdeformed self-conjugate system? The perfect "laboratory" for investigating nuclear pairing effects? Deep SD minumum persists down to zero rot frequency, low excitation energy




TRS calculation by R. Wyss

Strong T=0 neutron-proton (np) pair correlations may lead to something different from a BCS-type of pairing condensate:

"Isoscalar spin-aligned coupling scheme" *

predicted for N=Z nuclei close below $^{100}Sn$.

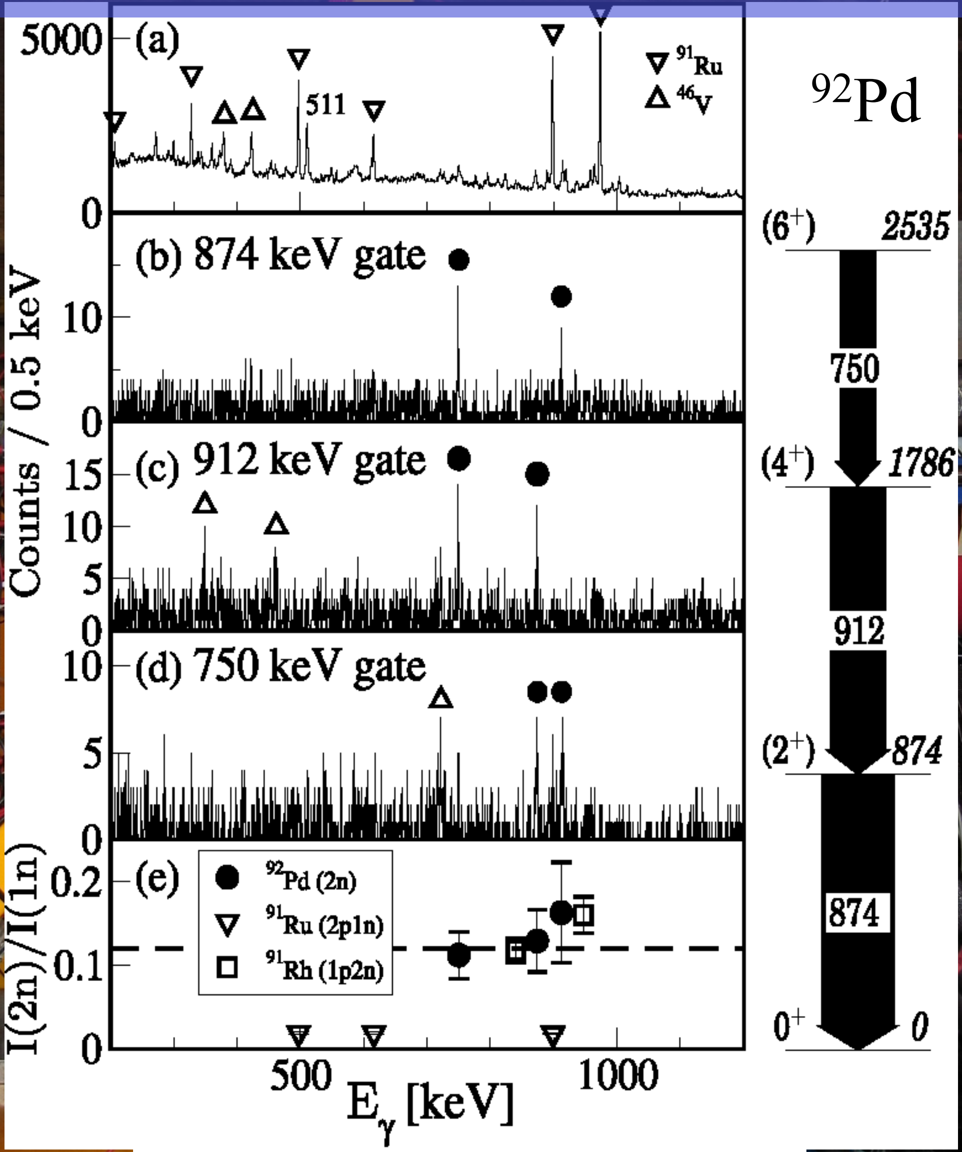
- Unique signature of "vibrational-like" yrast energies and "rotational-like" B(E2) strengths. B(E2;$0^+ \rightarrow 2^+$)s develop differently compared with standard seniority scheme along isotopic chain as N→ Z
- A new manifestation of strong np-pair correlations

* 'Evidence for a spin-aligned neutron-proton paired phase from the level structure of $^{92}Pd$'
B. Cederwall et al., Nature **469**, 68 (2011)

'Spin-aligned neutron-proton pair mode in atomic nuclei'
C. Qi, **J. Blomqvist**, T. Bäck, B. Cederwall, A. Johnson, R. J. Liotta, and R. Wyss
Phys. Rev. C 84, 021301 (2011)

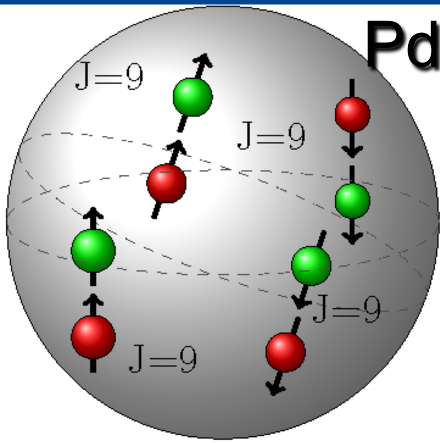
# Observation of excited states in the N=Z=46 nucleus $^{92}$Pd

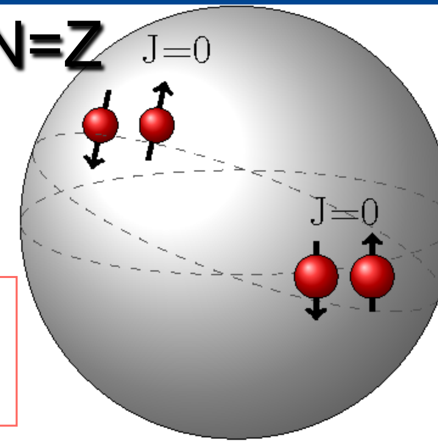
## EXOGAM + Neutron Wall + Diamant experiment



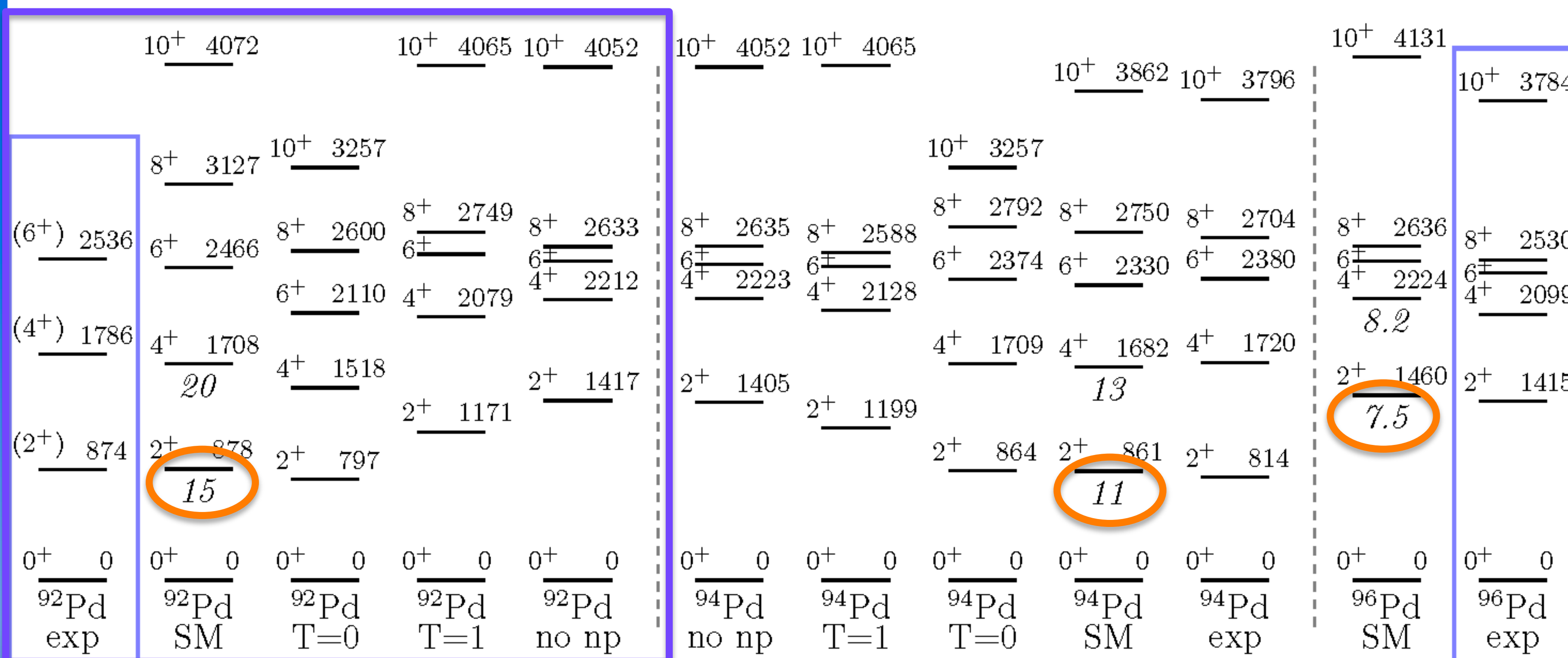

B. Cederwall et al., Nature **469**, 68 (2011)

# Pd energy level systematics near N=Z - effects of np interactions



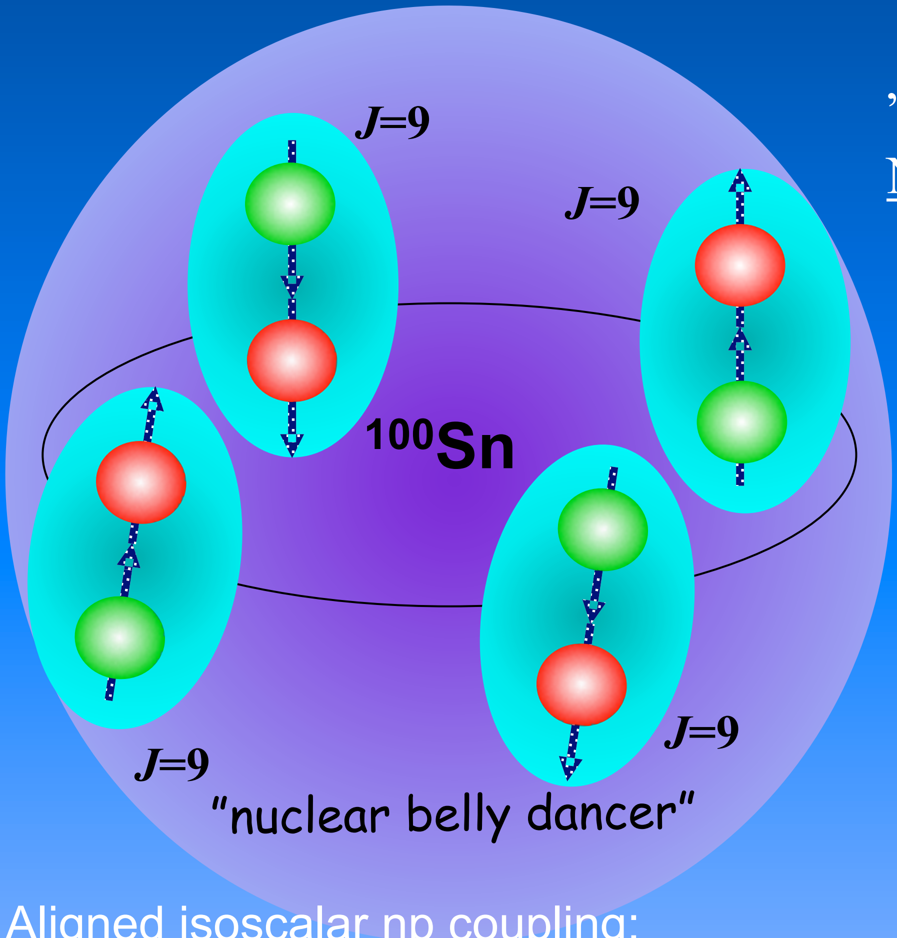




*Calculations performed in several model spaces,*
*i.e., 0g9/2, 0g9/2-1p1/2 and 0g9/2-1p1/2-0f5/2-1p3/2*
*which all give very similar results .*
*Int. parameters determined to reproduce exp energies in* $^{94,95}$*Pd,* $^{93,94}$*Rh*




B. Cederwall et al., Nature **469**, 68 (2011)

# Strong residual np interactions → Spin-aligned T=0 np coupling scheme for N=Z nuclei below $^{100}$Sn




"Spin-aligned $T$=0 np paired phase"

Not pairing as a BCS condensate

The diagonal SM interaction matrix element that corresponds to the isoscalar $\nu\pi(g_{9/2})^2$ aligned np pair ($J^\pi = 9^+$), $V_9 = \langle g^2_{9/2}; J=9 | V | g^2 9/2; J=9 \rangle$, is strongly attractive, with $V_9 \sim -2$ MeV

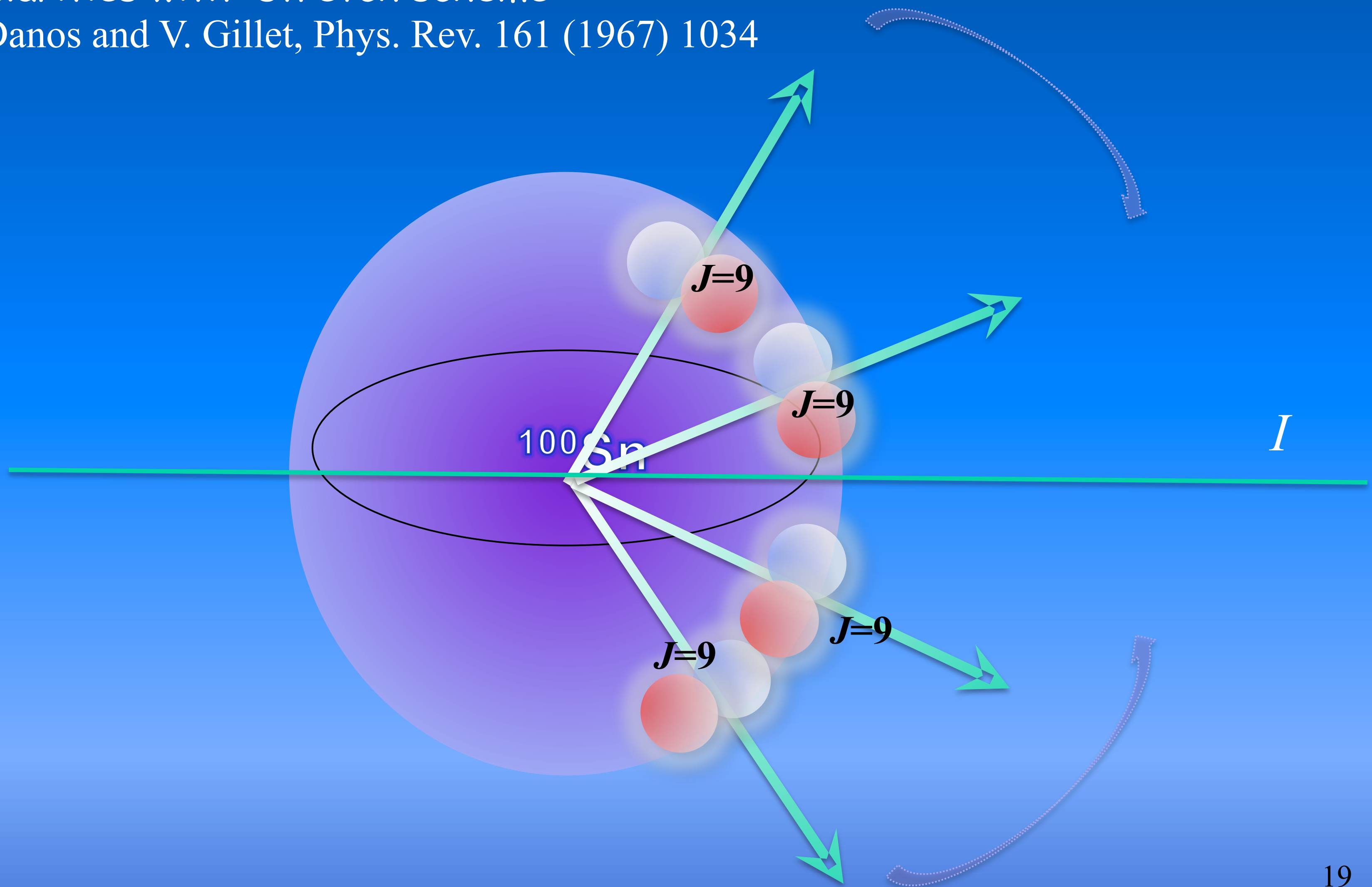
Aligned isoscalar np coupling:

$$\Psi_{G.S.} = [(\{\nu g_{9/2}^{-1} \times \pi g_{9/2}^{-1}\}_{9+})^2]_{0+} \times [(\{\nu g_{9/2}^{-1} \times \pi g_{9/2}^{-1}\}_{7+})^2]_{0+}$$

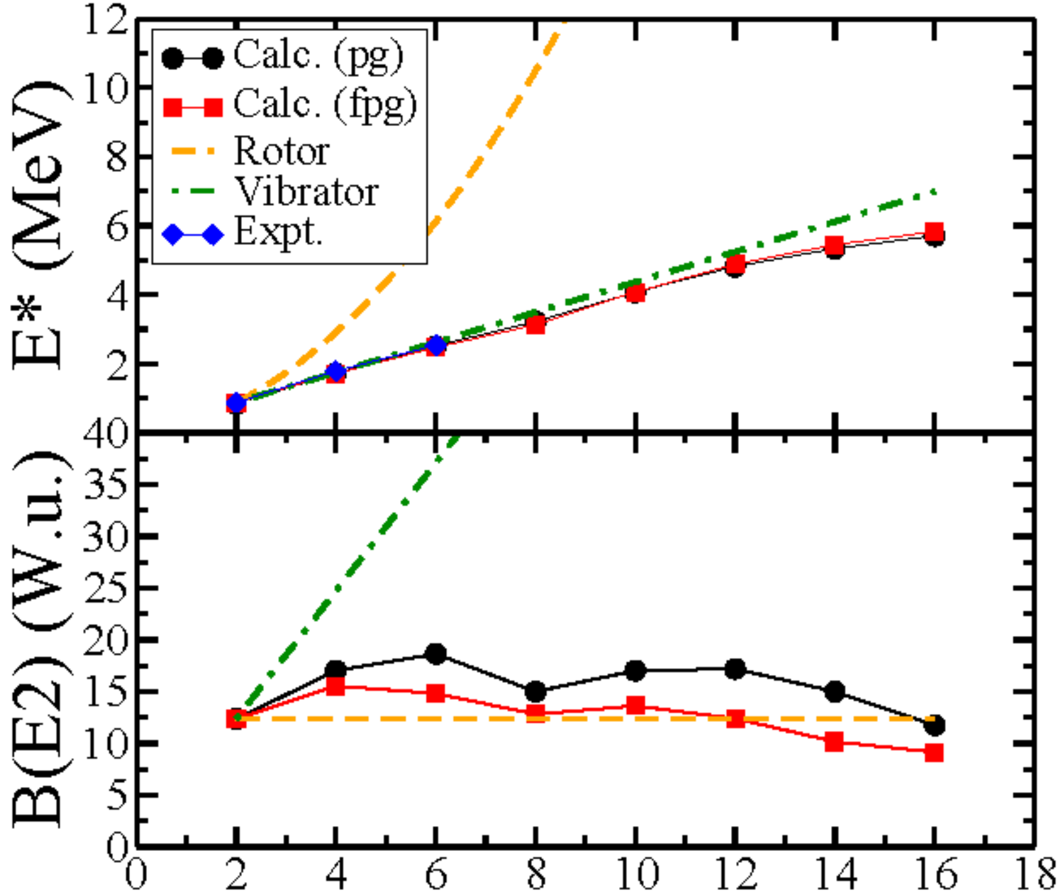
Different from the standard textbook description of the ground states in even-even nuclei!

# Generation of angular momentum in the isoscalar spin-aligned coupling scheme ($^{92}$Pd)

Similarities with "stretch scheme"
M. Danos and V. Gillet, Phys. Rev. 161 (1967) 1034



## "Unique" signature of spin-aligned T=0 coupling scheme

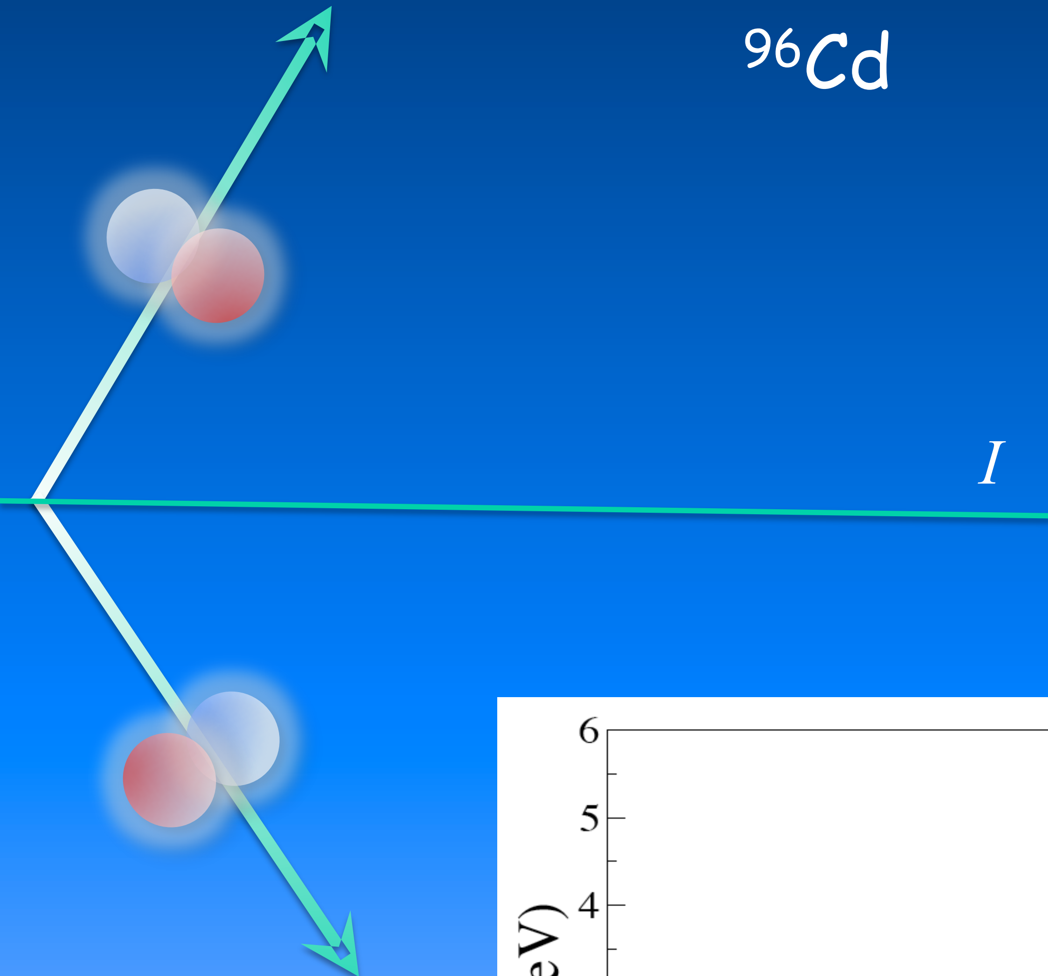


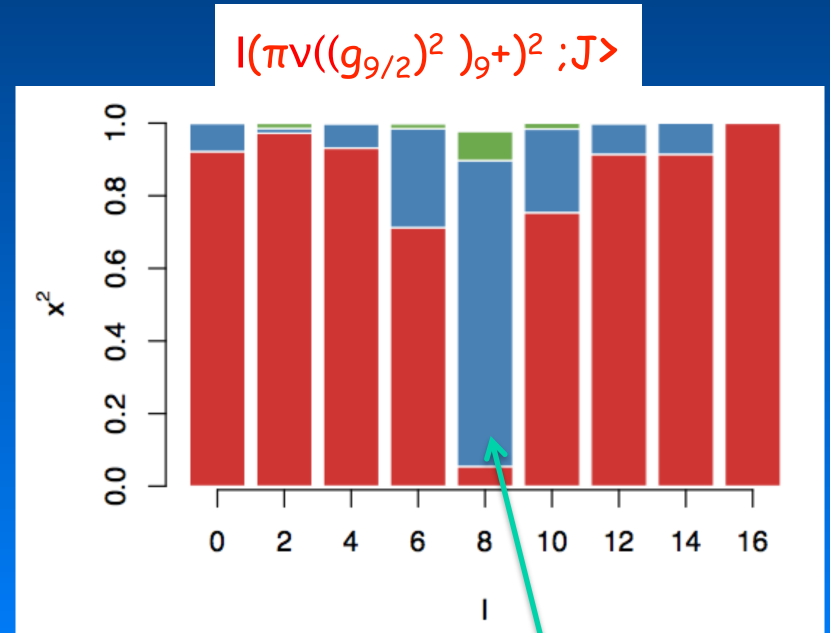

Upper: Shell model spectra of $^{92}$Pd
calculated within the $1p_{3/2}0f_{5/2}1p_{1/2}0g_{9/2}$ space [10] (fpg) and the $1p_{1/2}0g_{9/2}$ space (pg).
Lower: B(E2; I → I − 2) values in $^{92}$Pd calculated within the fpg and pg spaces. The two dashed lines show the predictions of the geometric collective model normalized to the $2^+_1$ state
C.Qi, J.Blomqvist, T.Bäck, B. Cederwall, A. Johnson, R. J. Liotta, and R. Wyss,
PRC 84, 021301(R) (2011)

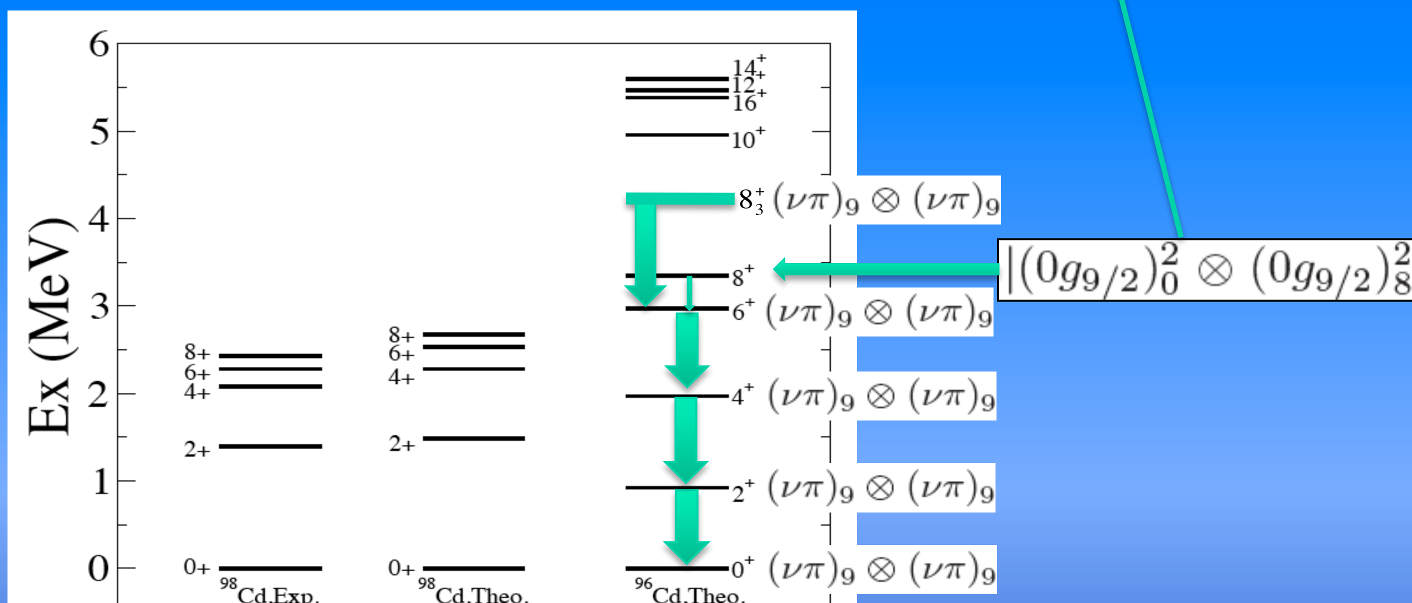
# LSSM calculation, fpg (f5/2, p3/2,p1/2, g9/2) (all shells between 28 and 50) C. Qi


* 1 W.U. ~ 25 $e^2fm^4$ here

# $^{96}$Cd

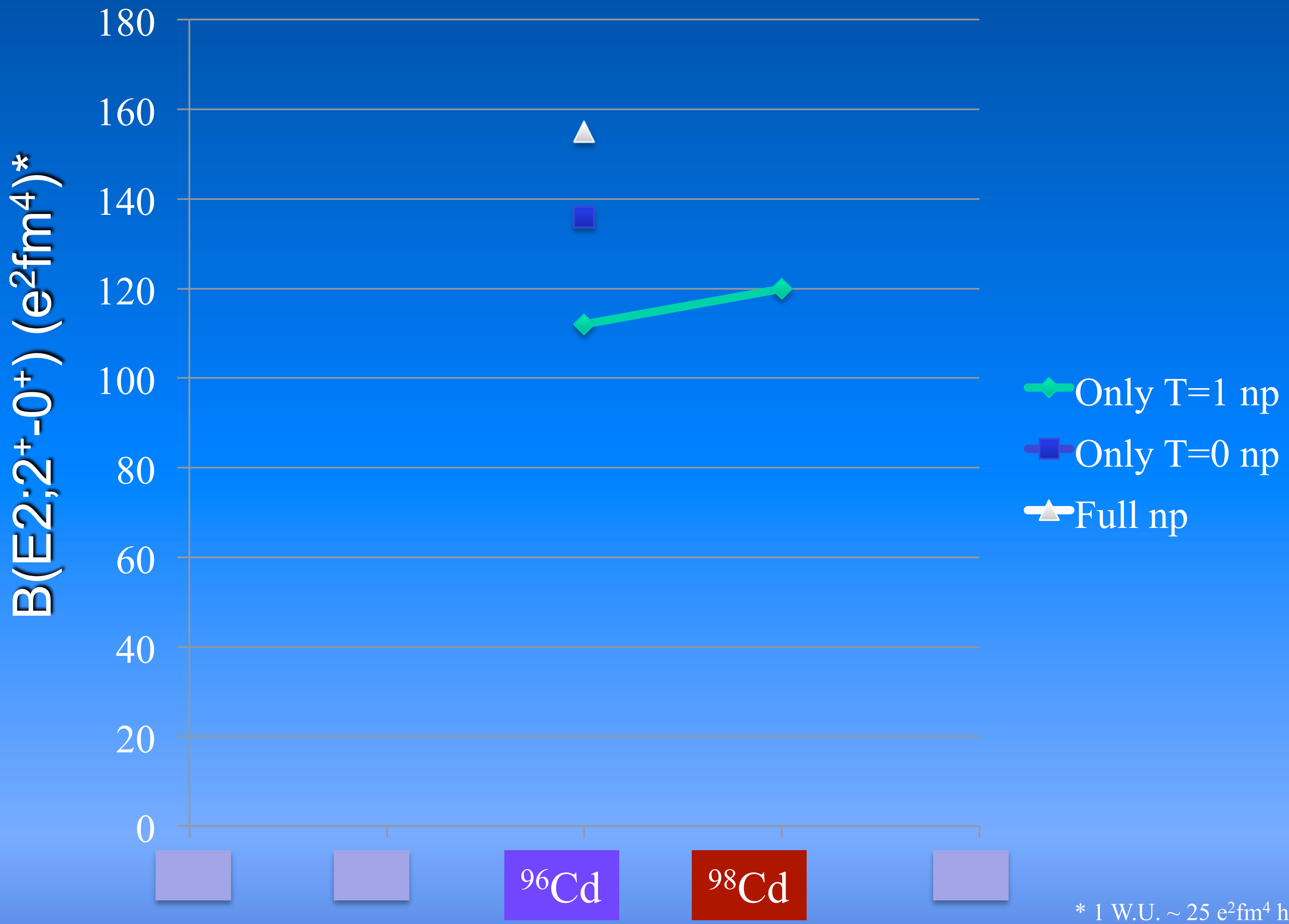



C. Qi, priv. comm., Z.X. Xu et al., Nuclear Physics A 877 (2012) 51–58

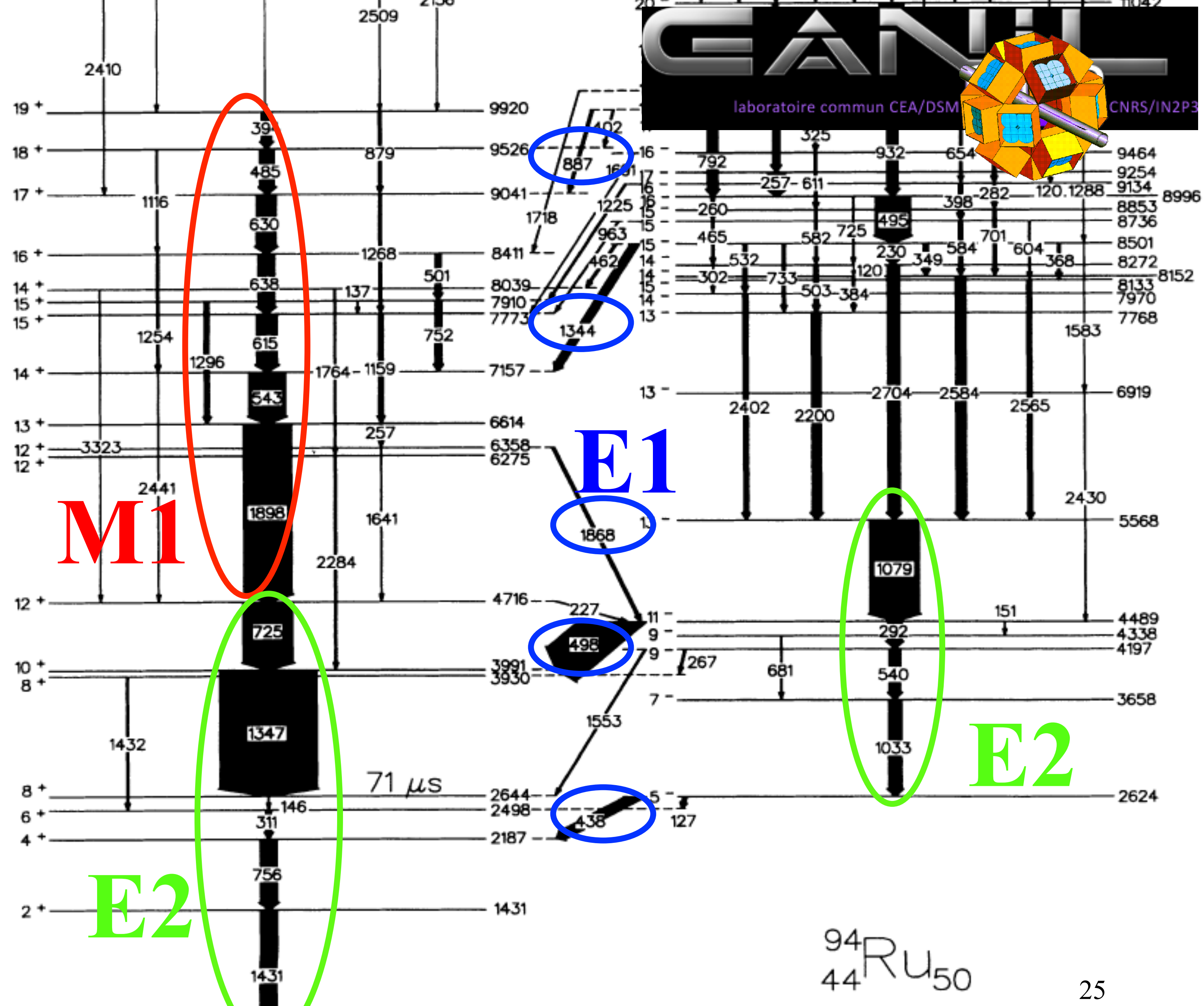
# LSSM calculation, fpg (f5/2, p3/2,p1/2, g9/2) (all shells between 28 and 50) C. Qi




* 1 W.U. ~ 25 $e^2fm^4$ here

# Critical test of LSSM interactions: Precision spectroscopy of E1 transitions in semimagic nuclei

- All low-lying states in this region are well described within the $f_{5/2}$, $p_{3/2}$, $p_{1/2}$ and $g_{9/2}$ model space.
- *E*1 transitions are "forbidden" within this space since the matrix elements $\langle f|E1|i\rangle$ vanish for all possible combinations of initial states i and final states f.
- Presence of E1 transitions → other (higher or deeper lying) single-particle states are active.
- A sensitive probe of SM parameters: Even a minute admixture of such configurations in the wave function may greatly increase the probability of *E*1 decay since the *E*1 single-particle matrix element is very large in comparison with any other multipole mode.
- The observed *E*1 transition strengths serve as a critical test of the shell-model wave function with respect to the model subspace from which it is constructed. In particular for core excited states.


M1
E1
E2
E2
71 μs
$^{94}_{44}Ru_{50}$
laboratoire commun CEA/DSM
CNRS/IN2P3
9920
9526
9041
8411
8039
7910
7773
7157
6614
6358
6275
4716
3991
3930
2644
2498
2187
1431
0
1898
1347
725
1431
756
1079
1033
1868
1344
498
438

# E1 hindrance factors in N=50 nucleus $^{94}$Ru

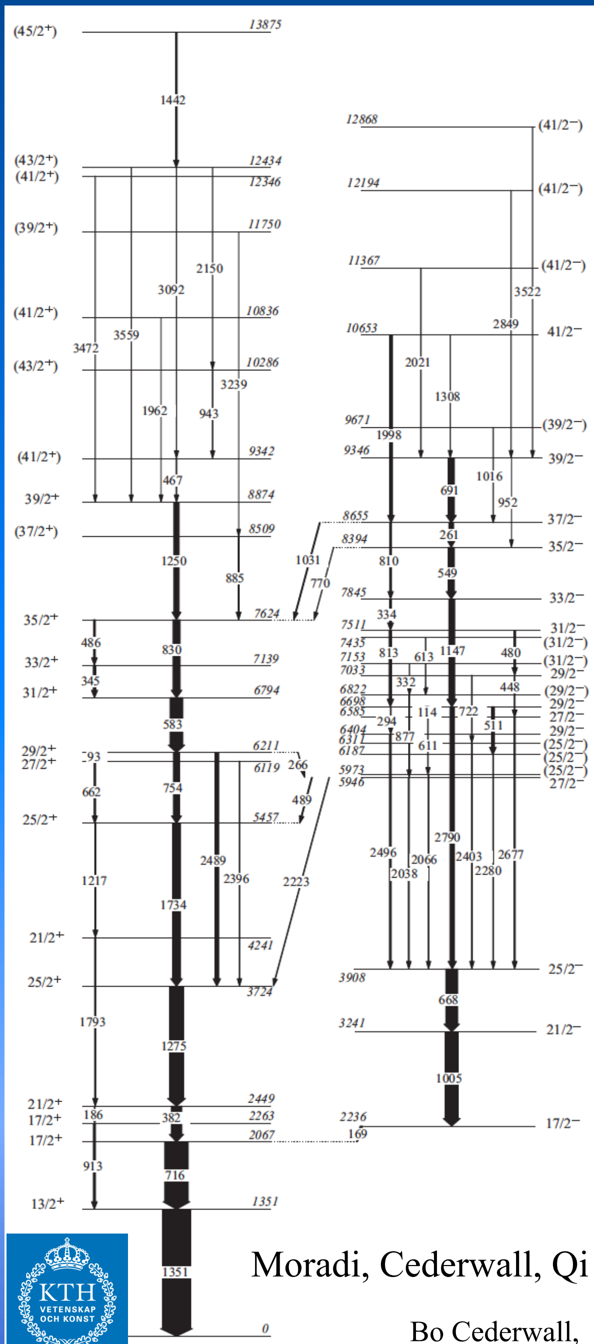
TABLE II. The hindrance factors[a] $H$ for the observed $E1$ $\gamma$-ray transitions as deduced from the branching ratios and lifetimes [30] of the initial states. Uncertainties are given in parentheses. $\Delta E_\gamma = \pm 0.5$ keV.

| $E_\gamma$ (keV) | $J_i^\pi \rightarrow J_f^\pi$ | $H \times 10^5$ (W.u.)$^{-1}$ |
|---|---|---|
| 257 | $13^+ \rightarrow 12_1^-$ | 0.006 (1) |
| 462 | $15_2^- \rightarrow 14_2^+$ | 0.051 (5) |
| 402 | $18_1^- \rightarrow 18^+$ | 0.188 (25) |
| 1344 | $15_2^- \rightarrow 14_1^+$ | 0.451 (32) |
| 227 | $12_1^+ \rightarrow 11^-$ | 0.57 (27) |
| 887 | $18_1^- \rightarrow 17^+$ | 1.09 (12) |
| 438 | $5^- \rightarrow 4^+$ | 1.90 (17) |
| 498 | $11^- \rightarrow 10^+$ | 4.27 (19) |

[a] $H = \frac{A^{2/3}}{15.5 \times B(E1)}$.

Moradi, Qi, Cederwall et al., PRC, 014301 (2014)

# E1 hindrance in $^{95}Rh_{50}$



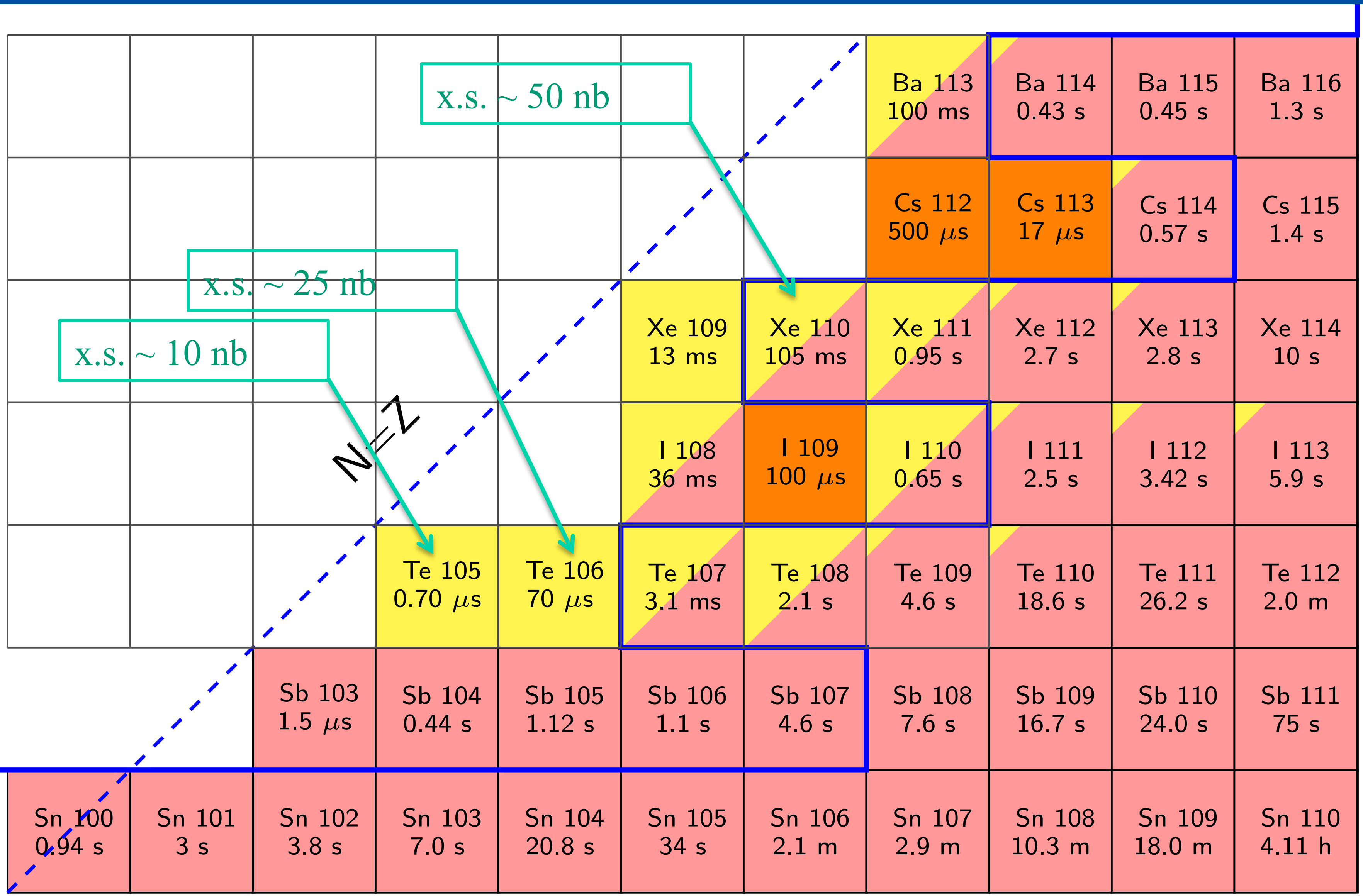
| $E_\gamma$ (keV) | $J_i^\pi \rightarrow J_f^\pi$ | $H \times 10^5$ (W.u.)$^{-1}$ |
|---|---|---|
| 266 | $29/2^+ \rightarrow 27/2^-$ | 0.11(1) |
| 1031 | $37/2^- \rightarrow 35/2^+$ | 0.29(1) |
| 770 | $35/2^- \rightarrow 35/2^+$ | 0.35(1) |
| 169 | $17/2^- \rightarrow 17/2_1^+$ | 2.8(2) |

[a] $H = \frac{A^{2/3}}{15.5 \times B(E1)}$

Table II of this work, there are a number of weak $E1$ transitions present, even at low excitation energies (below 5 MeV). We evaluated all possible $E1$ transitions among states within the expanded shell model space. Considering first the $E1$ decay from the first $17/2^-$ state to the yrast $17/2_1^+$ state, these states are predominantly of $\pi(1p_{1/2}^{-1}0g_{9/2}^{-4})$ and $\pi(0g_{9/2}^{-5})$ character, respectively, as discussed above; i.e., without possibility of $E1$ decay. This transition has the largest hindrance, $2.8 \times 10^5$ W.u.$^{-1}$ among the $E1$ decays observed in $^{95}$Rh which is reflected by the long (∼19 ns) half-life of the $17/2^-$ state [2]. The core-excitation components in these two states are mainly of a one-neutron character. In our calculation the contribution to the transition in terms of occupation probability from the high lying shells $1d_{5/2}$ and $0g_{7/2}$ is 0.02, while the corresponding contribution from the deep-lying shells $1p_{3/2}$ and $0f_{5/2}$ is approximately $10^{-4}$. Therefore the $E1$ hindrance factor is of the order $5 \times 10^5$ W.u.$^{-1}$, which is consistent with the value given in Table II. The absence of $E1$ transitions depopulating the following negative-parity states up to $25/2^-$ indicates that the influence of the core excited configurations is limited in these states as predicted in Ref. [8]. $E1$ decays observed from the higher-lying negative-parity states as well as from the $29/2_1^+$ state signal significant contributions from core-excited configurations with one neutron being excited from below the $N = 50$ shell closure to the $1d_{5/2}$ or $0g_{7/2}$ orbits, in agreement with the calculations presented in Ref. [20].

Moradi, Cederwall, Qi et al., PRC, 044310 (2014)

# Region of interest II: Island of α and p radioactivity "NE" of $^{100}$Sn

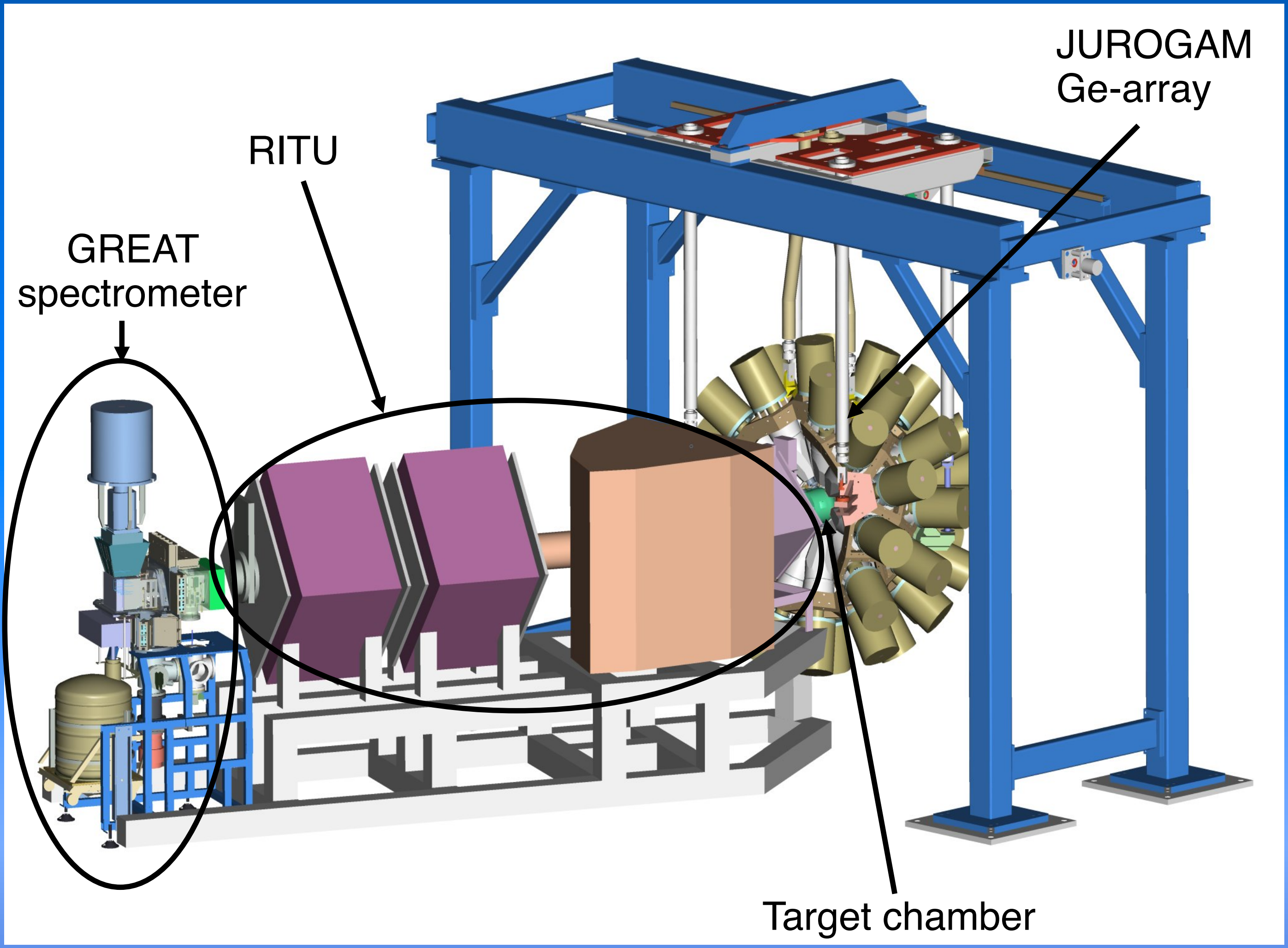


# Recoil-decay tagging (RDT) *) has become a crucial tool for structural studies of heavy, proton rich nuclei

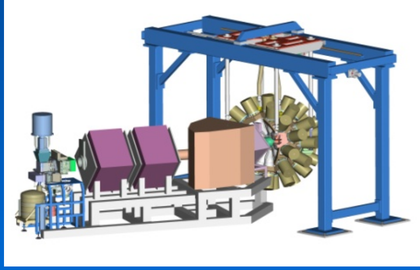
- Recoil-decay tagging spectroscopy (as we know it nowadays) started in the A ~ 100 ($^{108,109}$Te) region E.S. Paul et al.
- Extremely low production cross sections prevented further exploration
- Technical advances (RITU + GREAT, TDR ...) were needed to proceed further
- Technique now getting ready for high-intensity beams

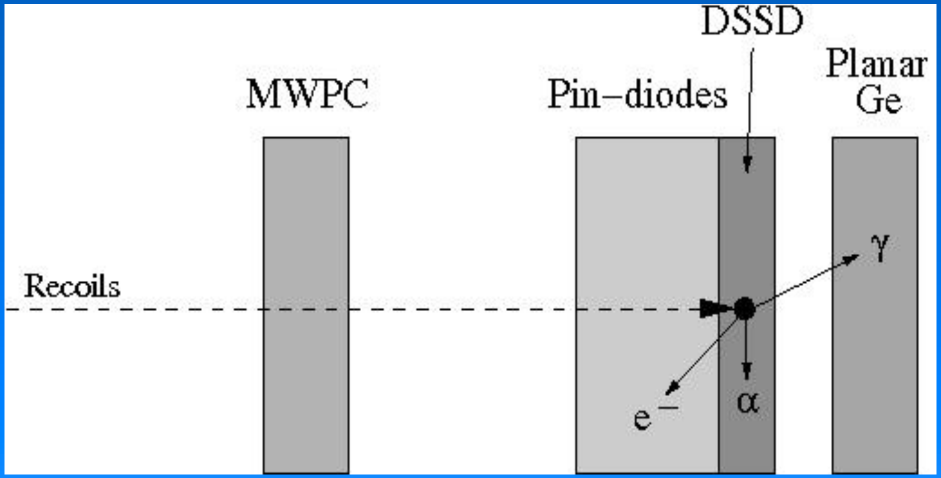
*) R.S. Simon *et al*., Z.P.A. 325, 197 (1986): NaI + SHIP @ GSI
E.S. Paul *et al*., P.R.C. 51, 78 (1995): Eurogam (45 HPGe) + DRS @ Daresbury

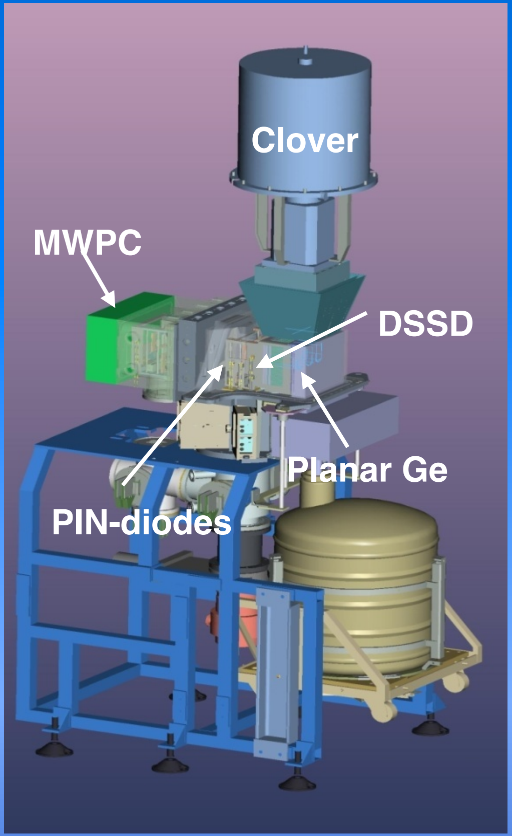
# Experimental set-up at JYFL; Univ. of Jyväskylä Cyclotron Laboratory



# Gamma Recoil Electron Alpha Tagging - GREAT

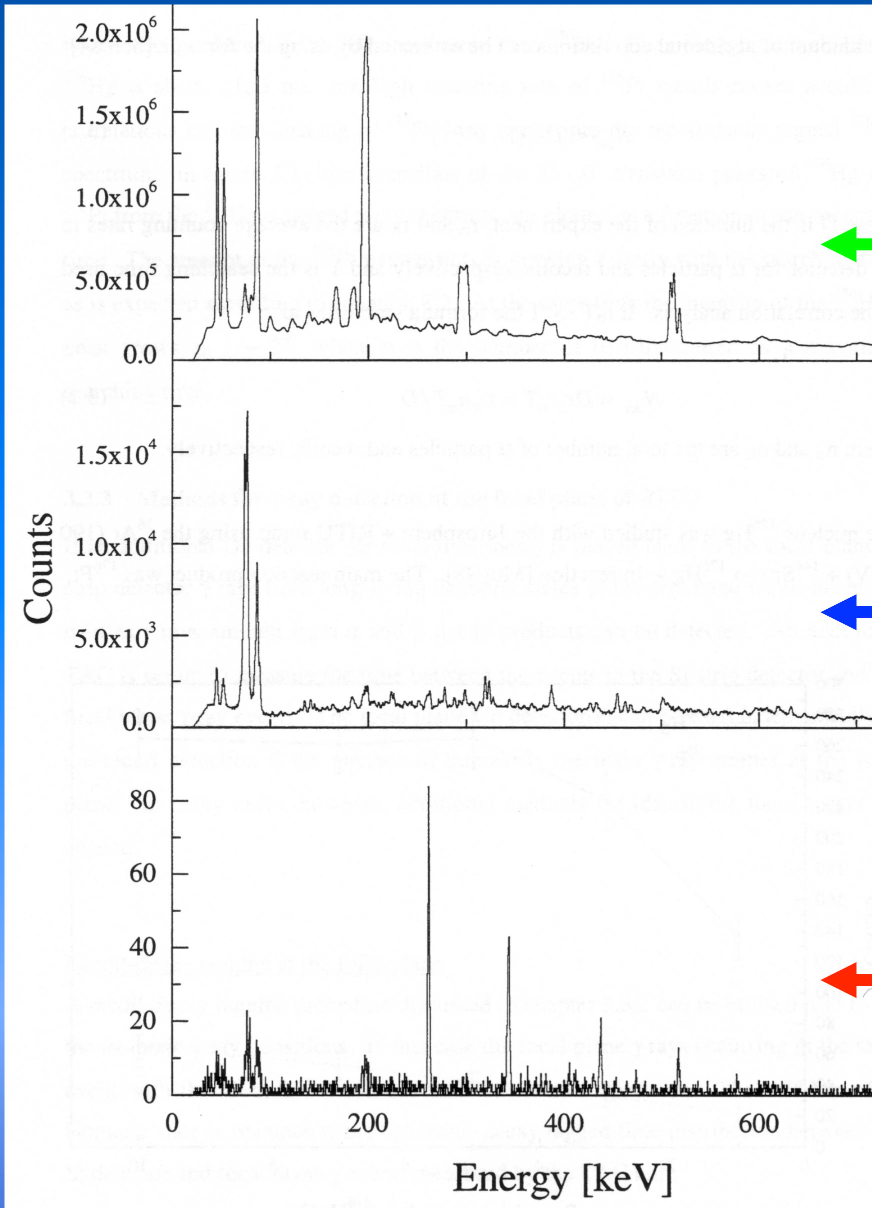


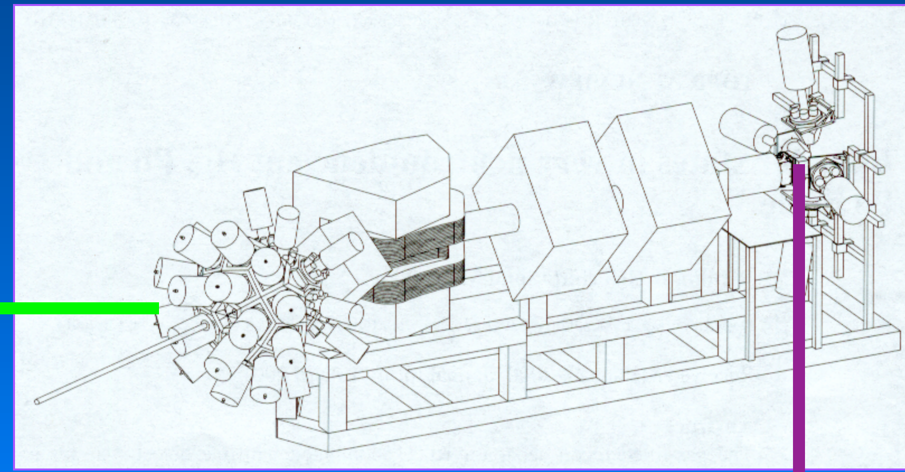



**MWPC - Multi Wire Proportional Counter:** Recoil discriminator
**PIN-diodes:** Detection of β-particles and conversion $e^-$
**DSSD - Double-sided Silicon Strip Detector:**
Charged particle detection (alpha, proton)
**Planar Ge and Clover:** Detection of delayed gamma rays following radioactive decays or from isomeric states

# RDT selectivity



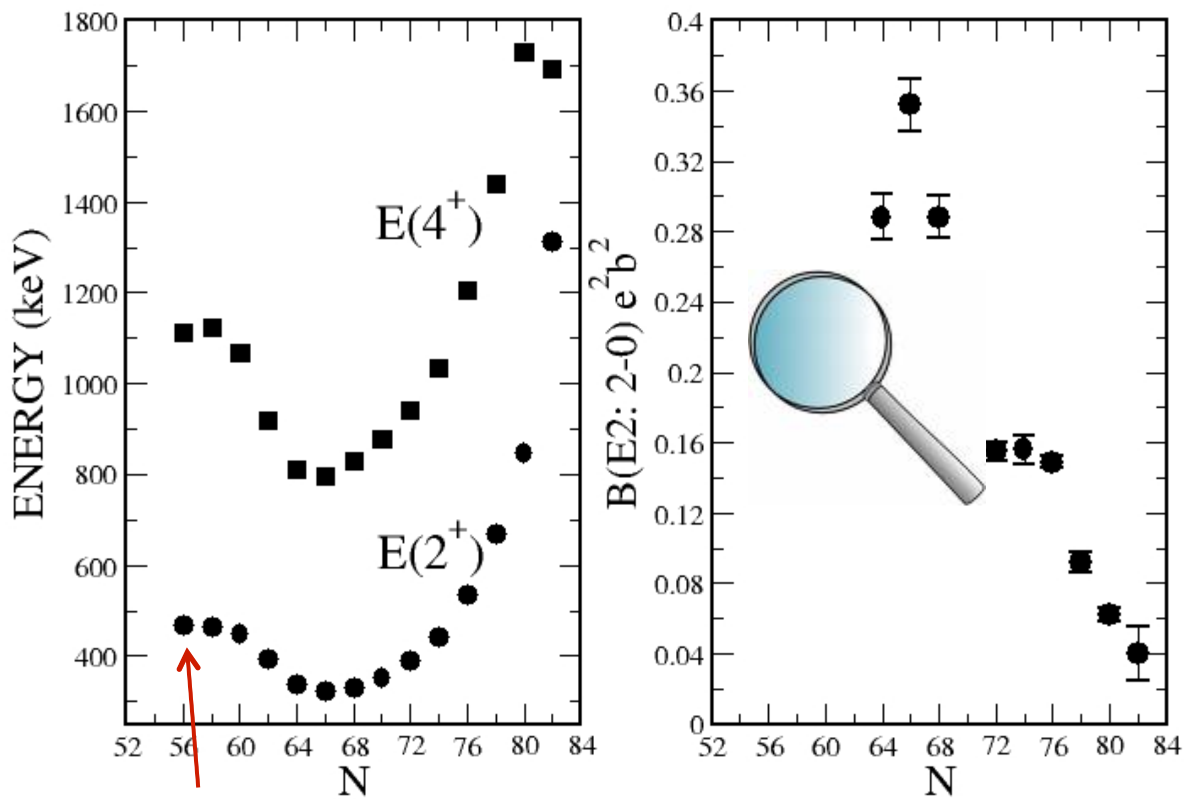
$\gamma$

$\gamma - recoil$

$\gamma - recoil - \alpha$

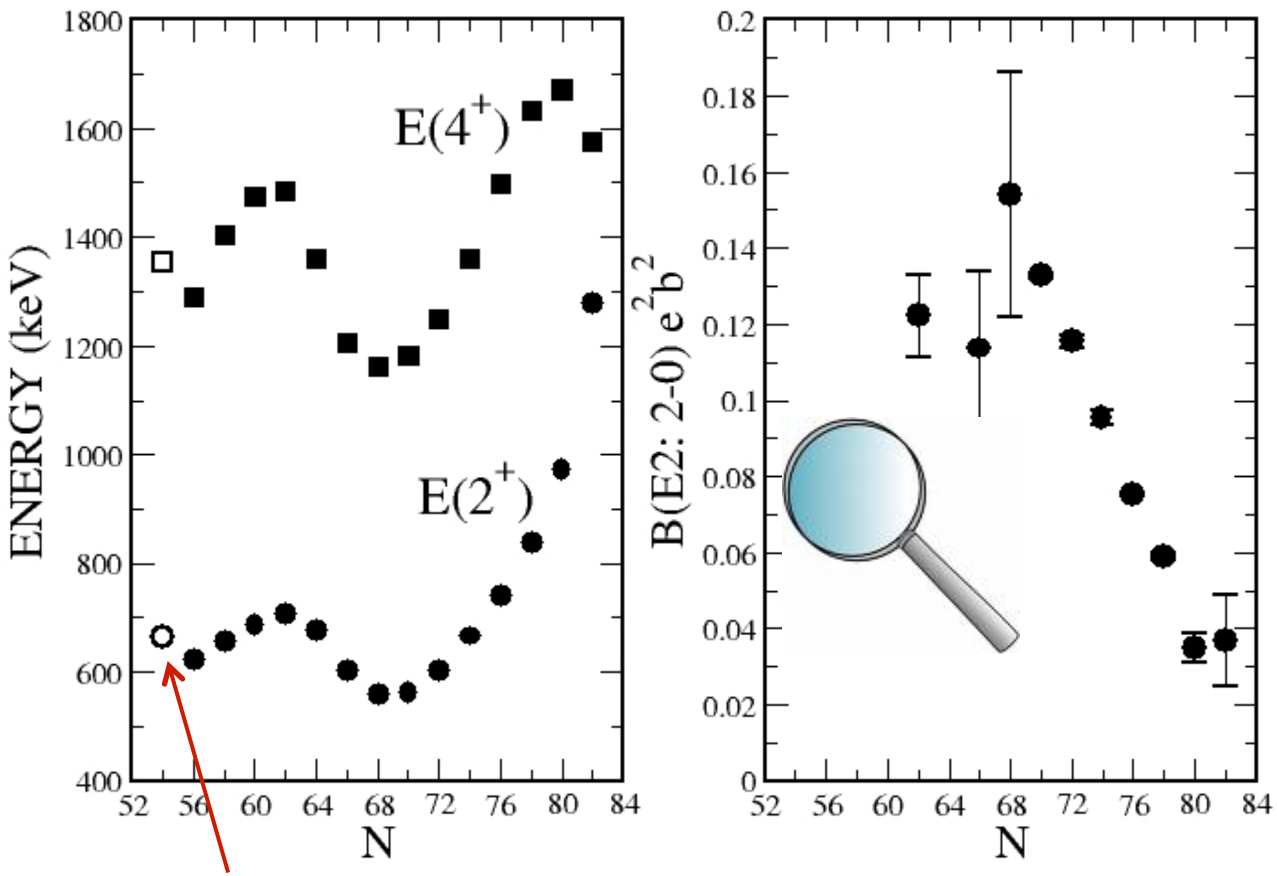
# Evidence for enhanced collective strength in Te and Xe nuclei approaching N=Z?

Xe experimental $E(2^+)$ and $B(E2; 2^+ \rightarrow 0^+)$ systematics



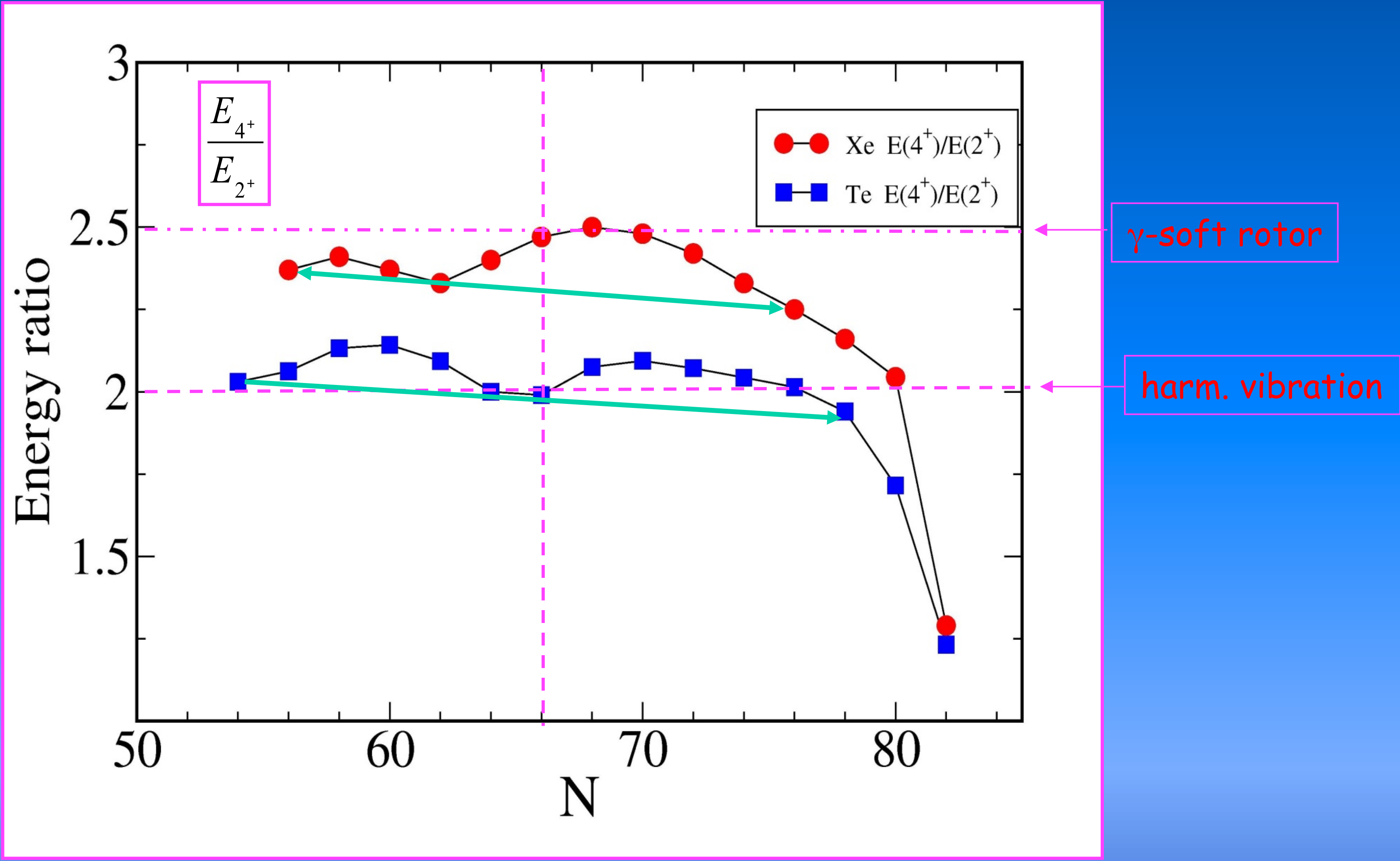

**$T_Z$=1 nucleus $^{110}$Xe;** M. Sandzelius, B. Hadinia,, B. Cederwall *et al.*, Phys. Rev. Lett. 99, 022501 (2007)

# Te experimental E($2^+$) and B(E2; $2^+ \rightarrow 0^+$) systematics




**$T_Z$=1 nucleus $^{106}$Te :** B. Hadinia, B. Cederwall *et al.,* Phys. Rev. C 72, 041303 (2005)

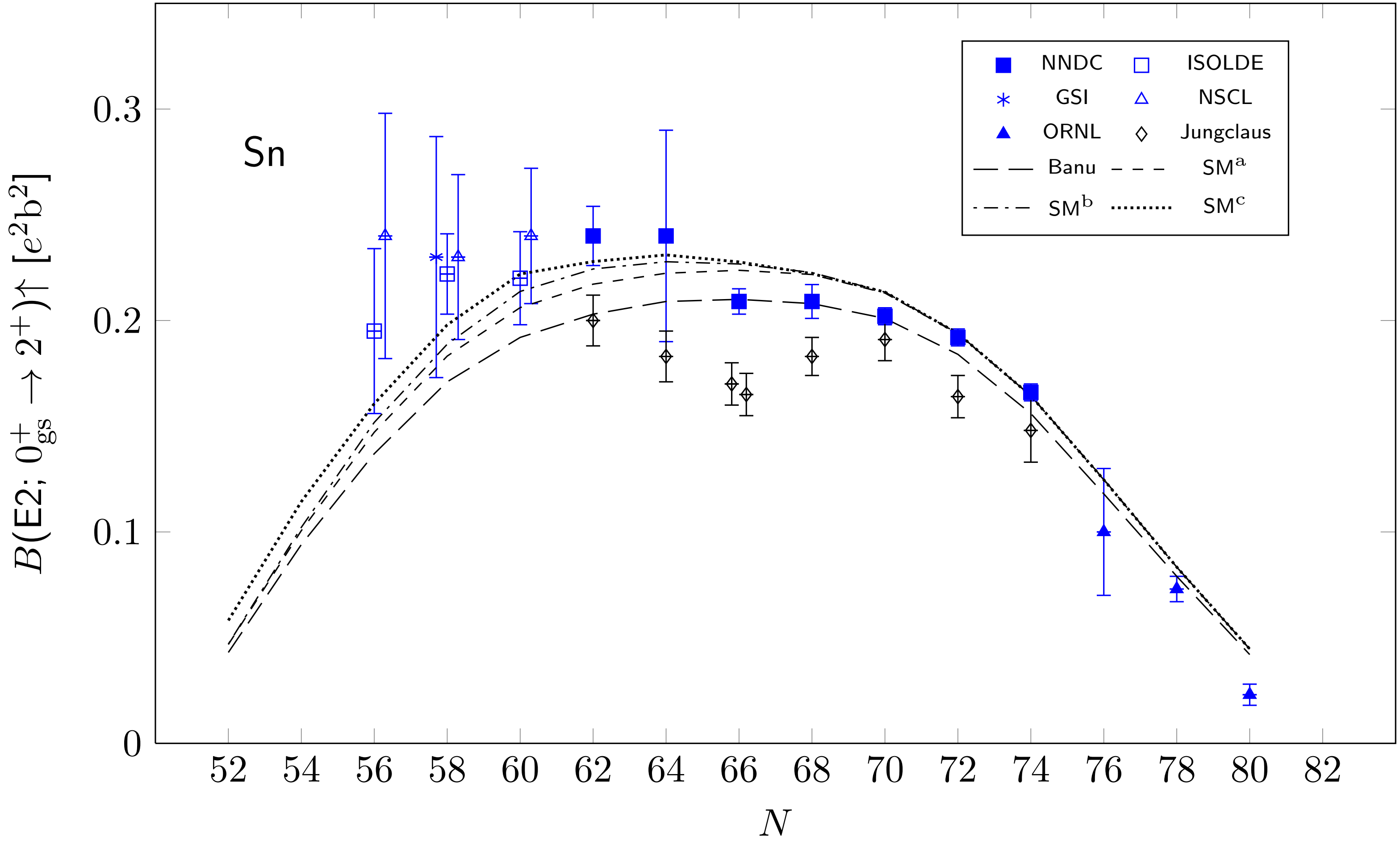
# Xe and Te energy ratios



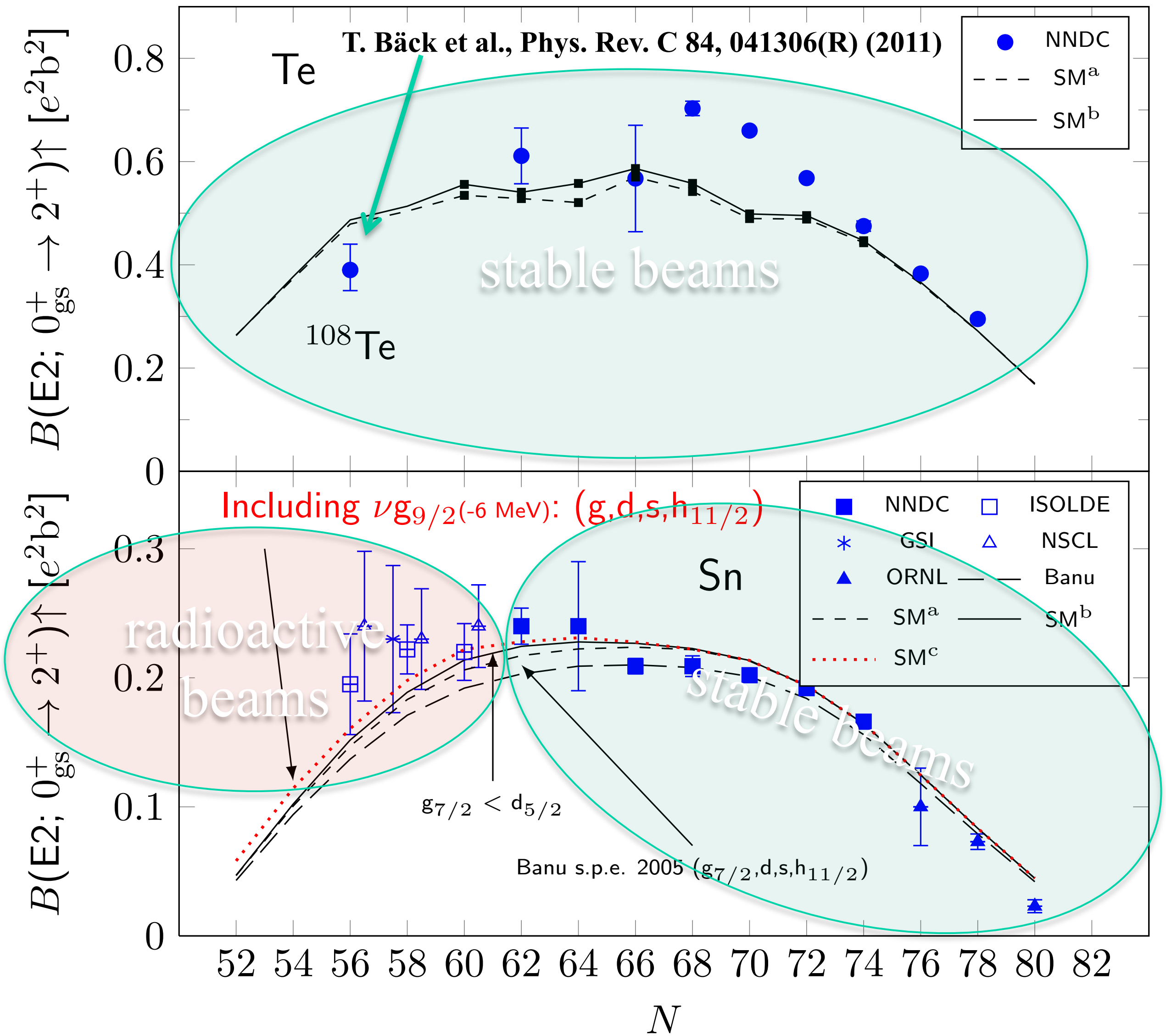
# Evidence for weakening of the N=Z=50 shell closure??

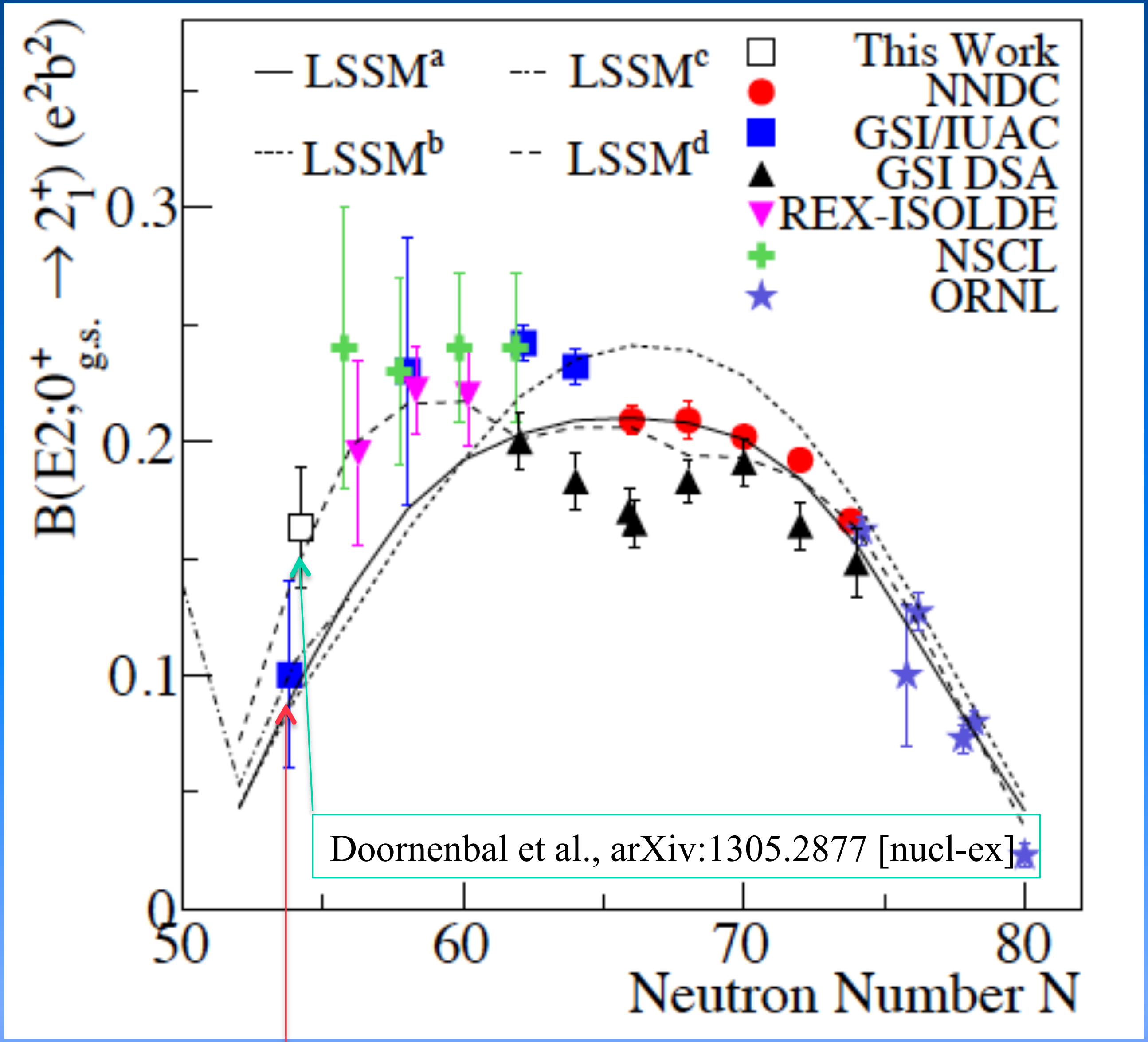
## Systematics of B(E2)↑ for Sn isotopes

Status pre 2013



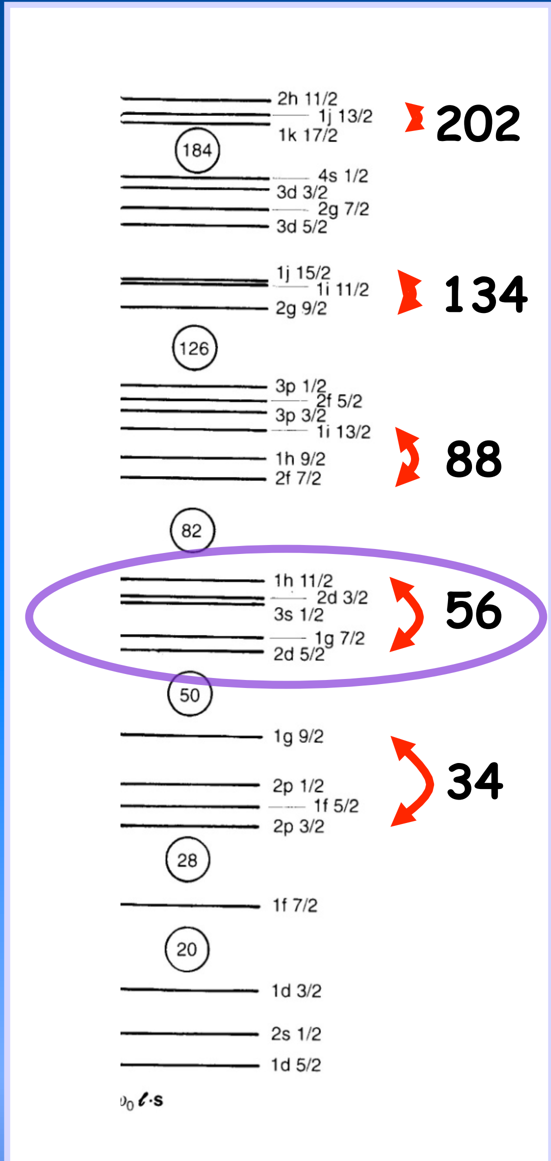
# Systematics of B(E2)↑ for Te and Sn isotopes






$^{104}$Sn, PRESPEC, Guastalla et al., PRL 110, 172501 (2013)

# Enhanced octupole deformation and correlations near N=Z



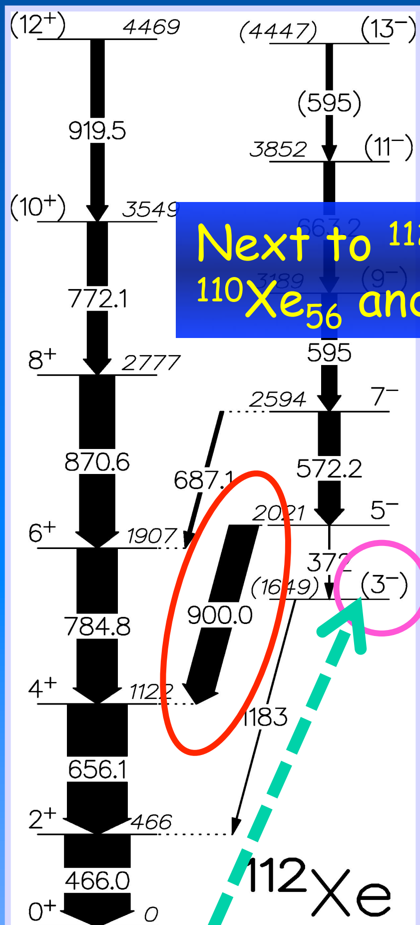

Strong octupole correlations are expected in nuclei where normal-parity single-particle states and intruder states differing by $\Delta l = \Delta j = 3$ are near the Fermi surface.

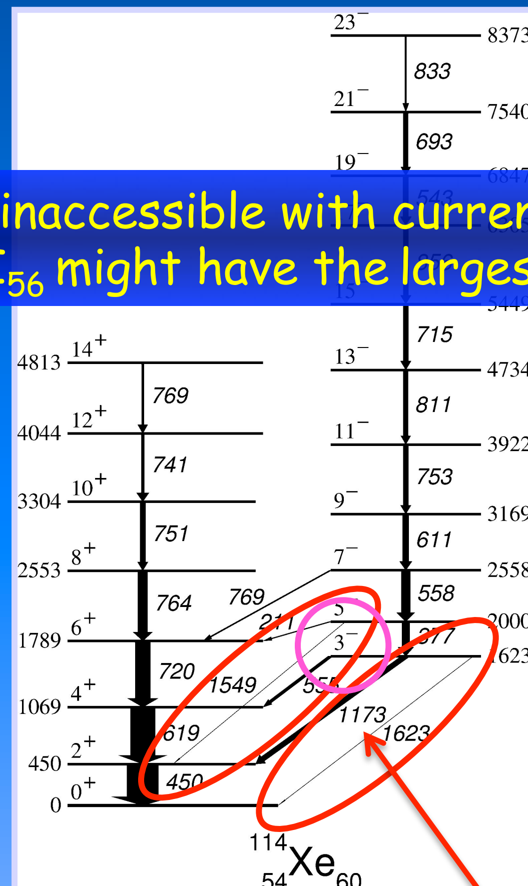
"Doubly-magic octupole-deformed" nucleus predicted by theory (J. Skalski, Phys Lett. **B,** 1990)

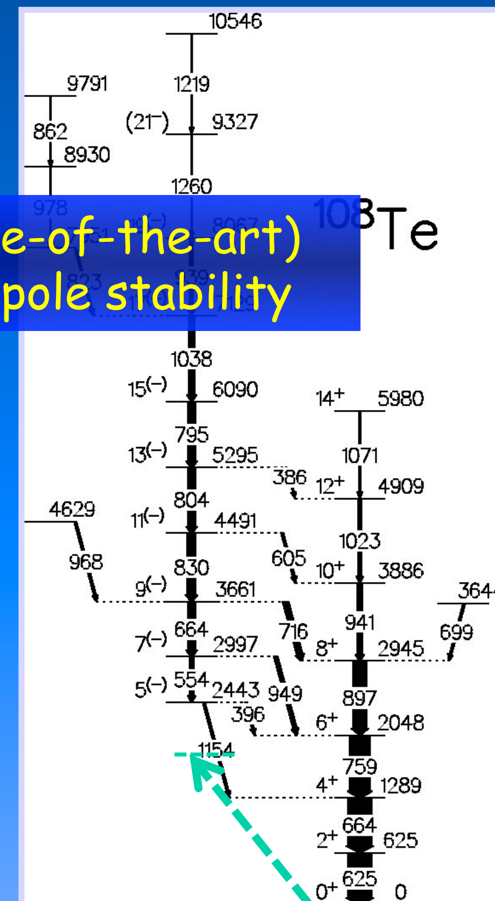
$^{112}_{56}\mathrm{Ba}_{56}$

Coherent octupole correlations for neutrons and protons should occur near N=Z.
Can we observe additional enhancement due to dynamic np correlations ?

# Enhanced octupole correlations in light Te-Xe nuclei due to dynamical np coupling ($\pi(\nu)d_{5/2}$- $\nu(\pi)h_{11/2}$) ?




Next to $^{112}$Ba (inaccessible with current state-of-the-art)
$^{110}$Xe$_{56}$ and $^{109}$I$_{56}$ might have the largest octupole stability

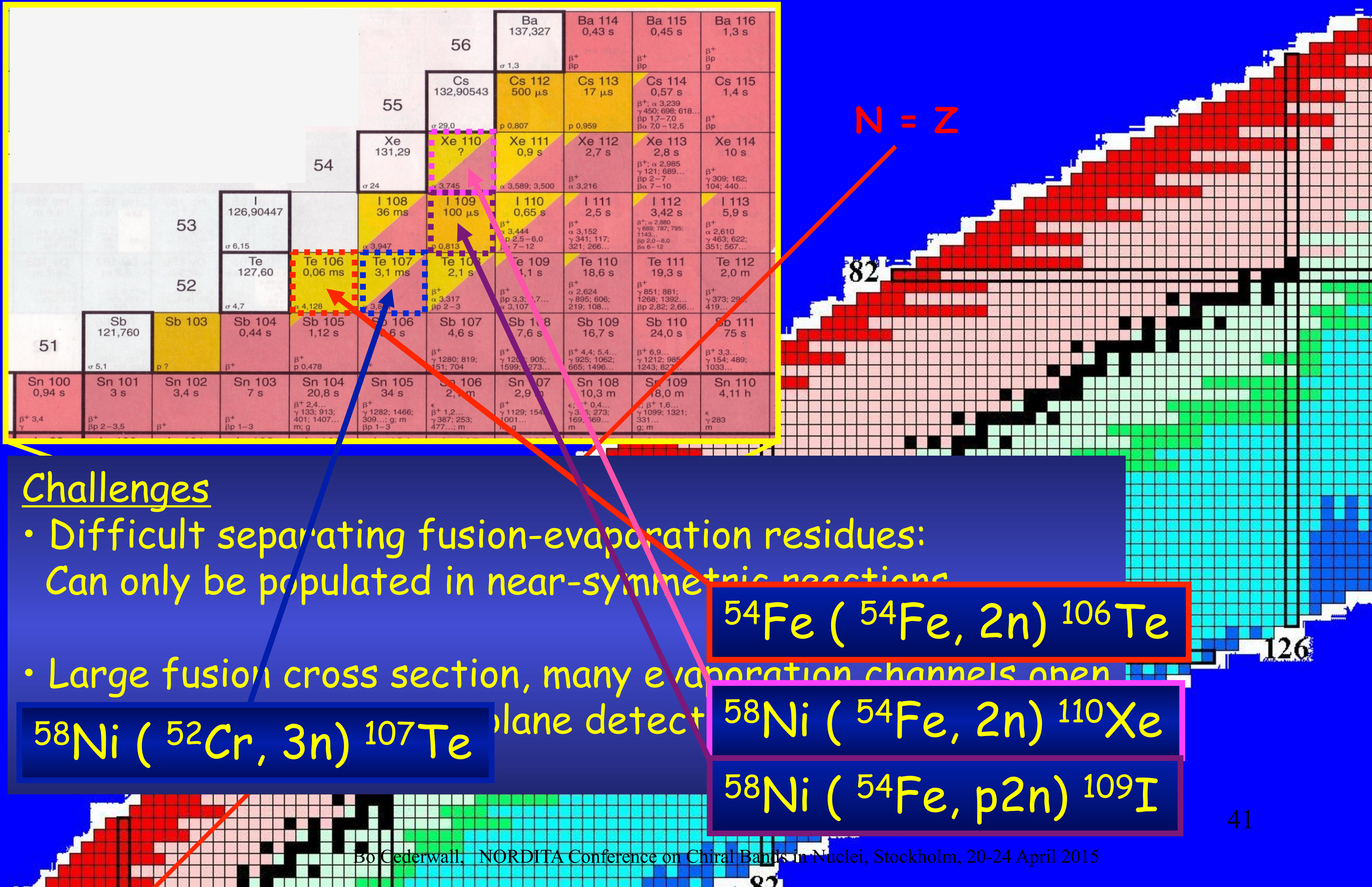
B(E3) ≈ 80 W.u. !

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

G. de Angelis et al.
Phys. Lett B535, 93 (2002)
(Euroball)

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

# The "island" of alpha and proton radioactivity "NE" of $^{100}$Sn → opportunity for RDT spectroscopy of exotic N~Z nuclei




<u>Challenges</u>

- Difficult separating fusion-evaporation residues:
  Can only be populated in near-symmetric reactions
- Large fusion cross section, many evaporation channels open
  plane detect

$^{54}$Fe ( $^{54}$Fe, 2n) $^{106}$Te

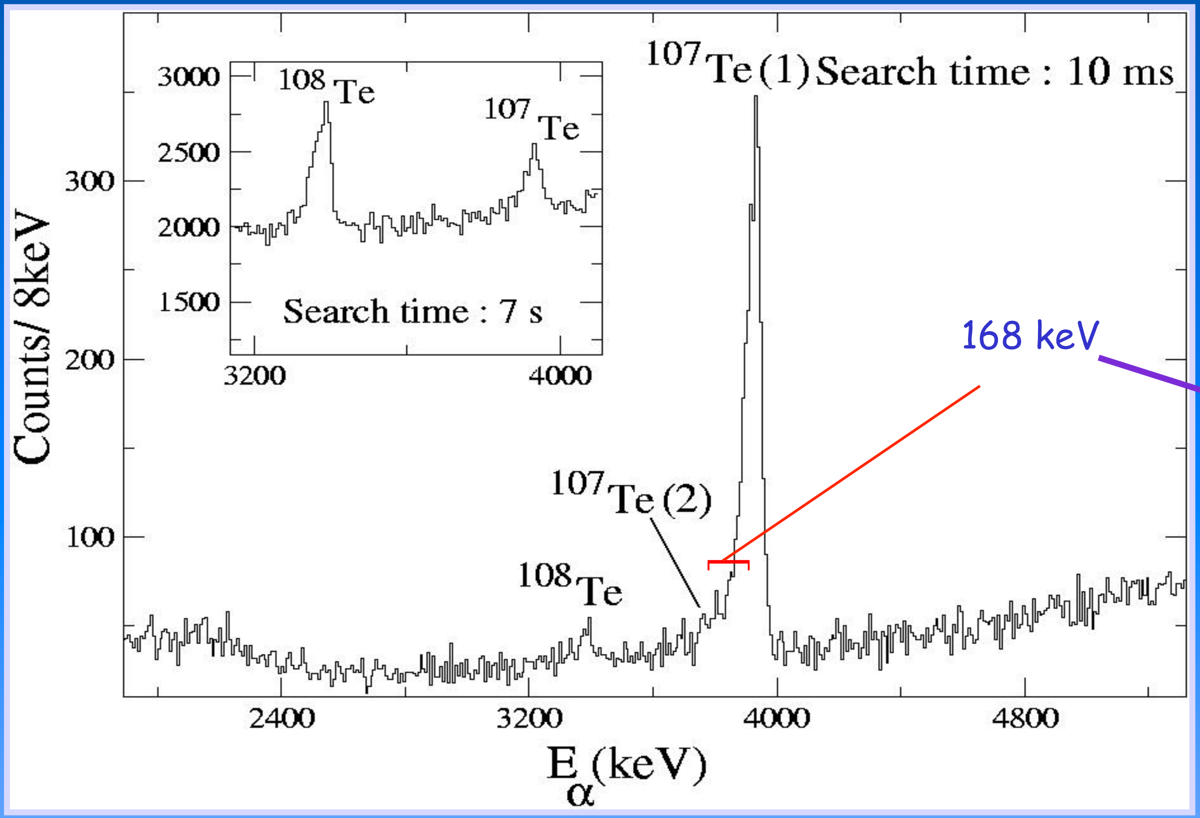
$^{58}$Ni ( $^{54}$Fe, 2n) $^{110}$Xe

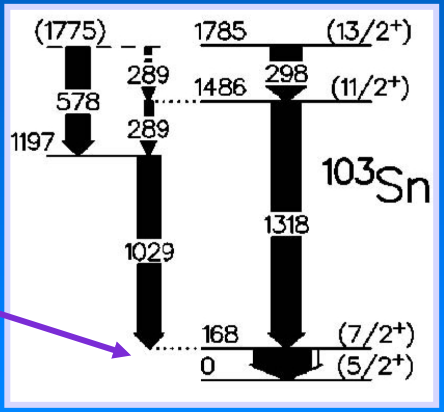
$^{58}$Ni ( $^{54}$Fe, p2n) $^{109}$I

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

# $^{58}$Ni ( $^{52}$Cr, 3n) $^{107}$Te* @ 187MeV

## Recoil-correlated α decays @ RITU focal plane
## 4pnA, ~5 days



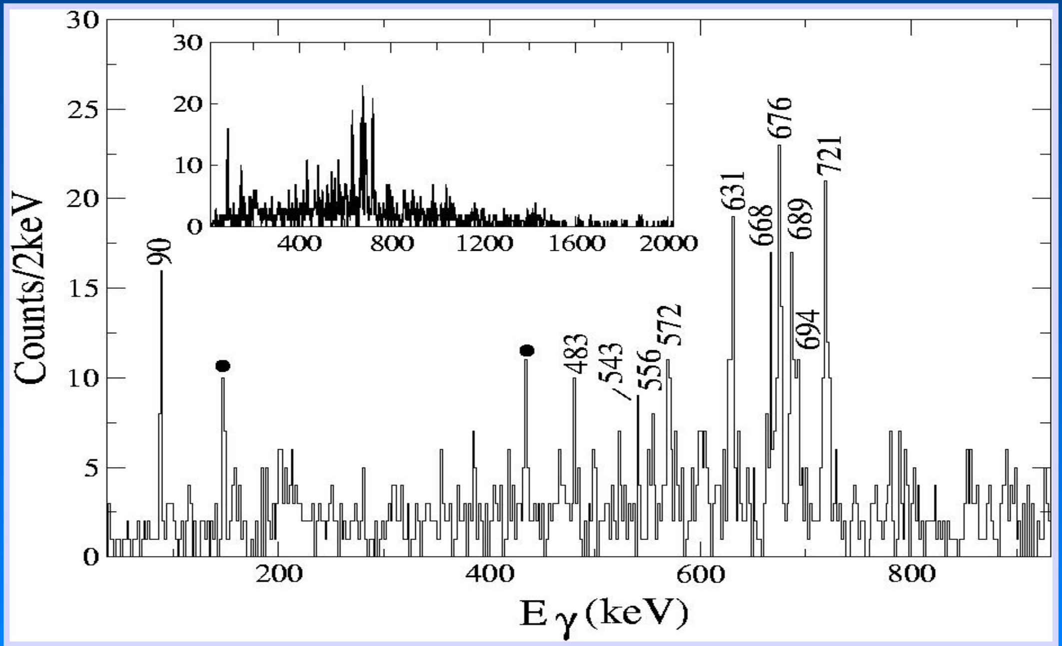




C. Fahlander et al.
Phys. Rev. C63, 021307 (2001)
(Euroball)

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

Alpha-decay branching ratio : 70%
Half life : 3.1ms
$\sigma$ = 1 μb

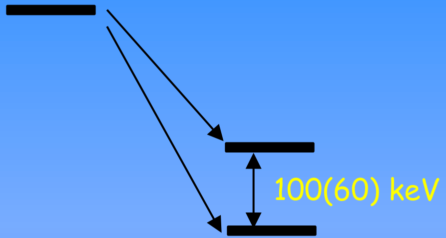
# $^{58}$Ni ( $^{52}$Cr,3n) $^{107}$Te*




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

Recoil-decay correlated gamma-ray spectrum

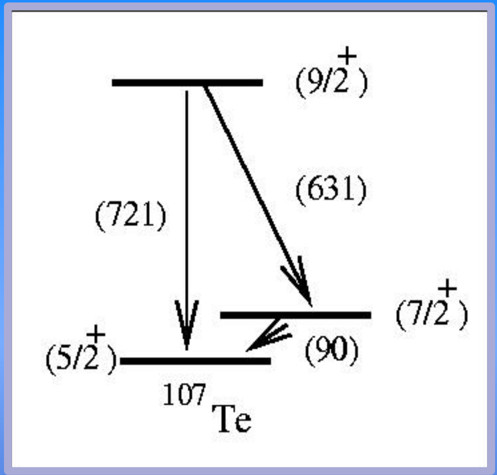
$^{111}$Xe

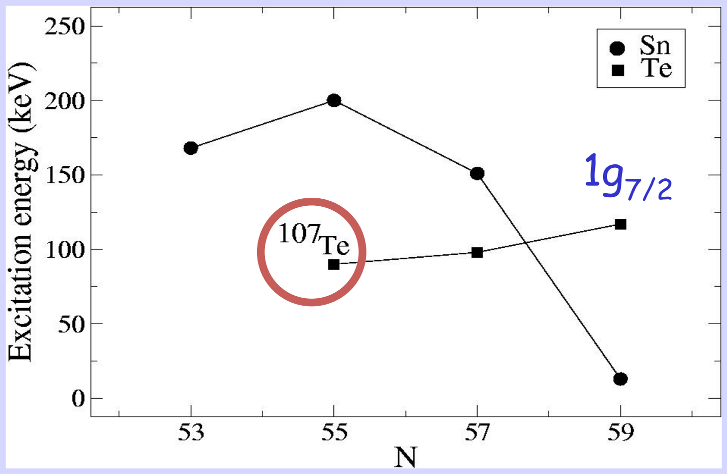


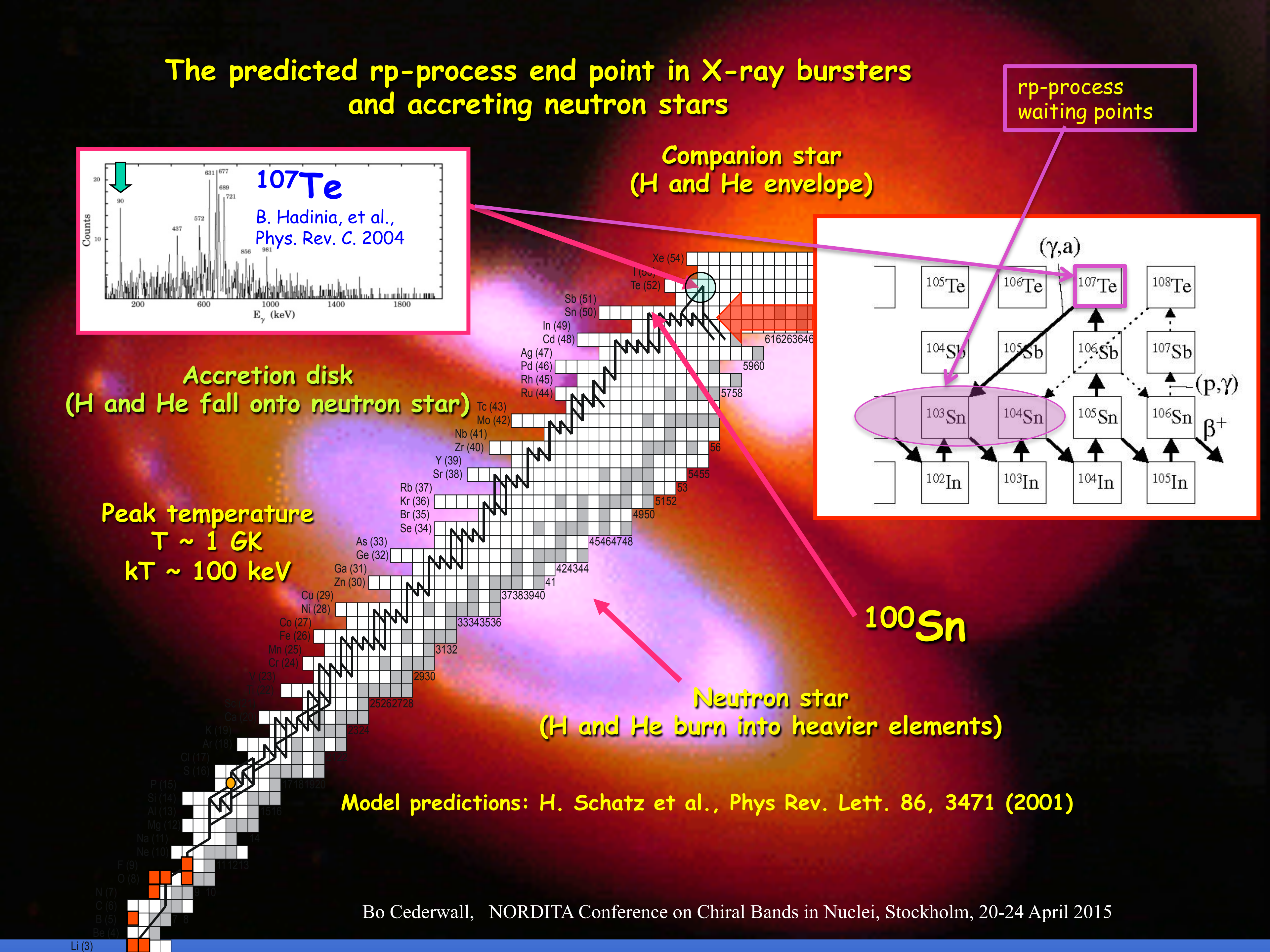

$^{107}$Te

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

Tentative level scheme

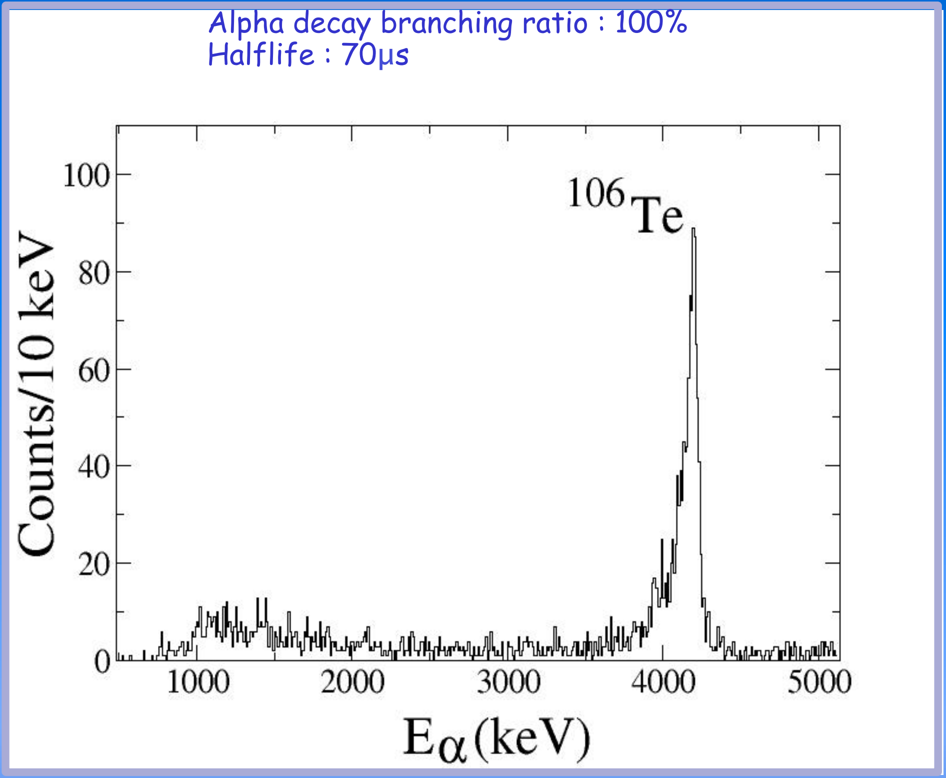


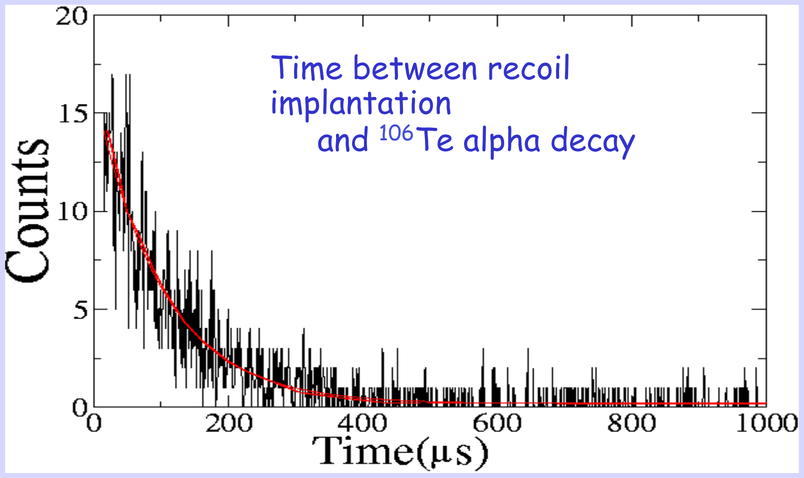




The predicted rp-process end point in X-ray bursters
and accreting neutron stars
rp-process
waiting points
Companion star
(H and He envelope)
107Te
B. Hadinia, et al.,
Phys. Rev. C. 2004
Counts
E$_\gamma$ (keV)
(γ,a)
105Te
106Te
107Te
108Te
104Sb
105Sb
106Sb
107Sb
(p,γ)
103Sn
104Sn
105Sn
106Sn
β+
102In
103In
104In
105In
Accretion disk
(H and He fall onto neutron star)
Peak temperature
T ~ 1 GK
kT ~ 100 keV
100Sn
Neutron star
(H and He burn into heavier elements)
Model predictions: H. Schatz et al., Phys Rev. Lett. 86, 3471 (2001)
Bo Cederwall, NORDITA Conference on Chiral Bands in Nuclei, Stockholm, 20-24 April 2015

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

## ($E_b$= 182 MeV, $I_b$= 10 pnA, 5 days)

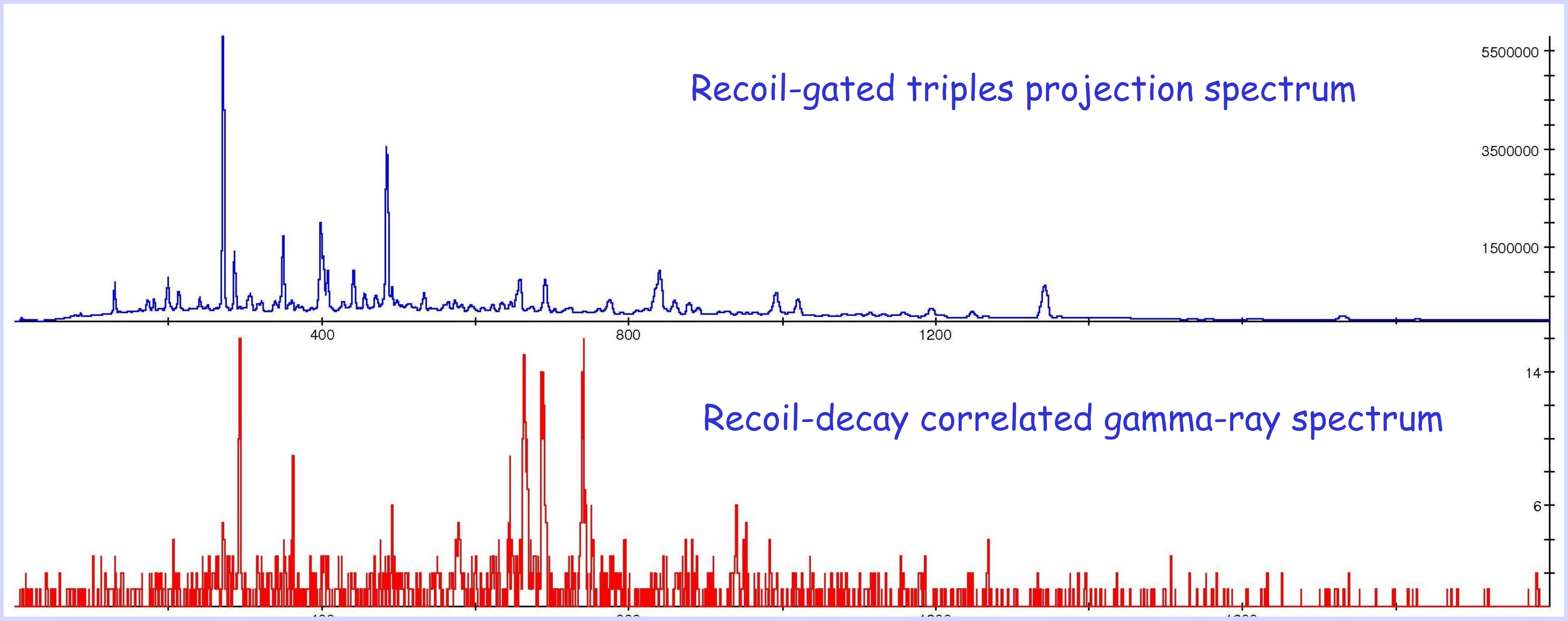



B. Hadinia, *et al.*, Phys. Rev. C 72, 041303 (2005)

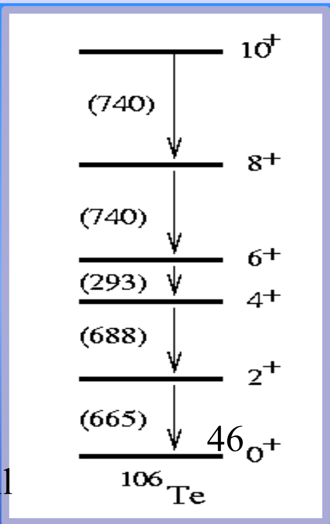
# $^{106}$Te gamma rays

## σ = 25 nb – (Then) a new limit for in-beam γ-ray spectroscopy!



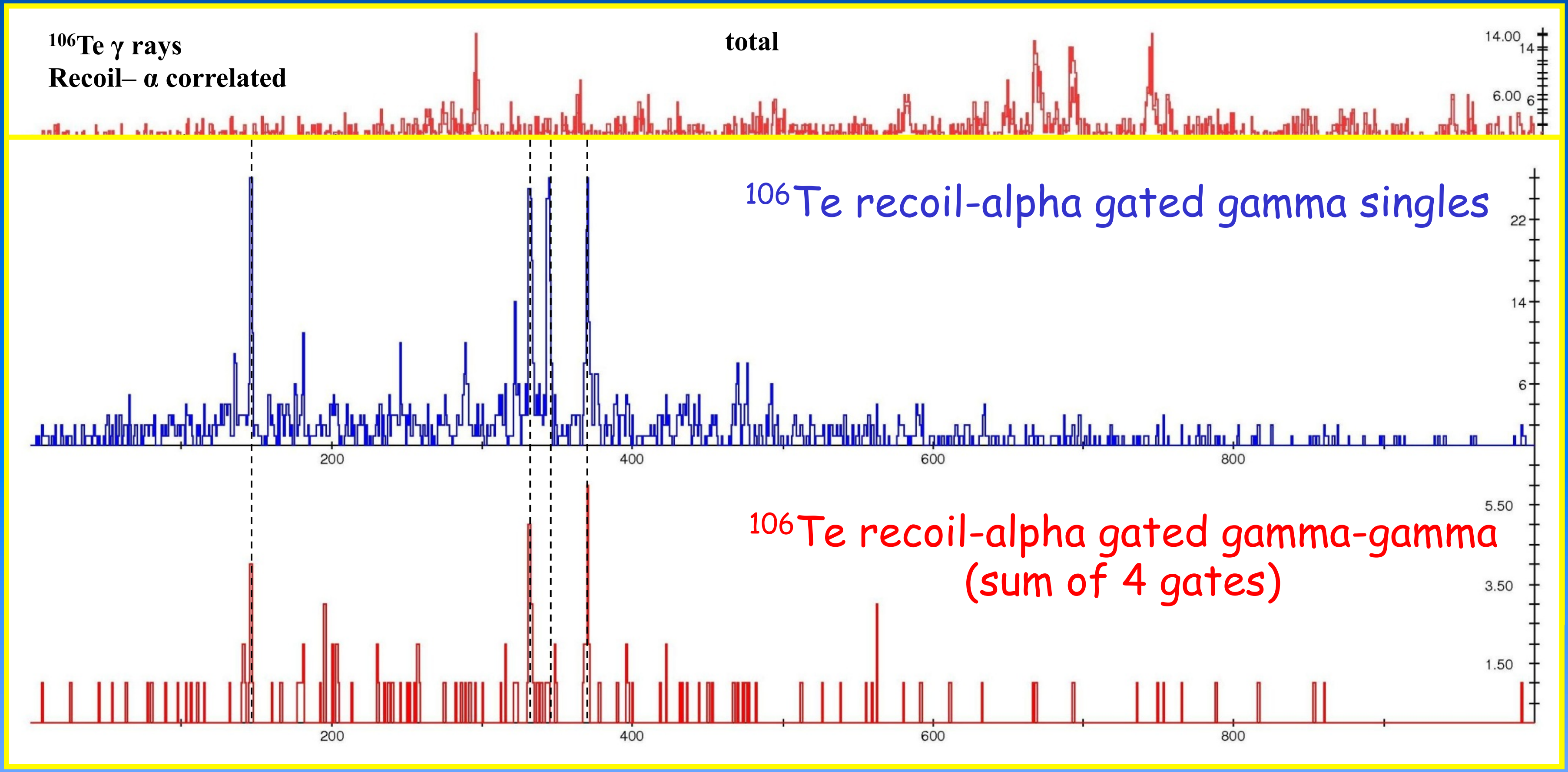

**Selectivity: ~$10^{-7}$**

Tentative level structure of $^{106}$Te




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

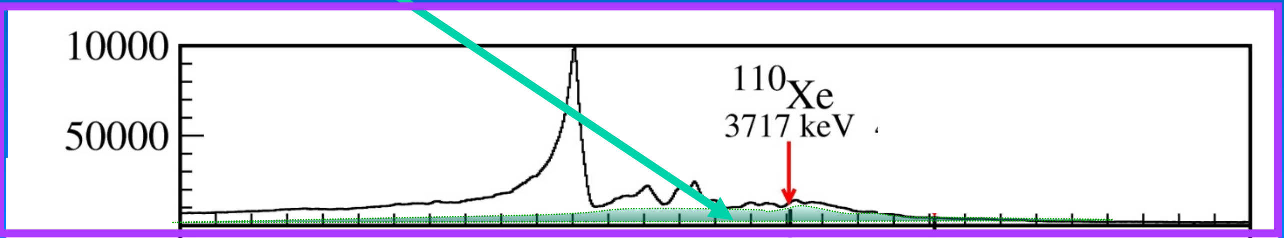
# Gamma-gamma coincidences at σ ~ 25 nb

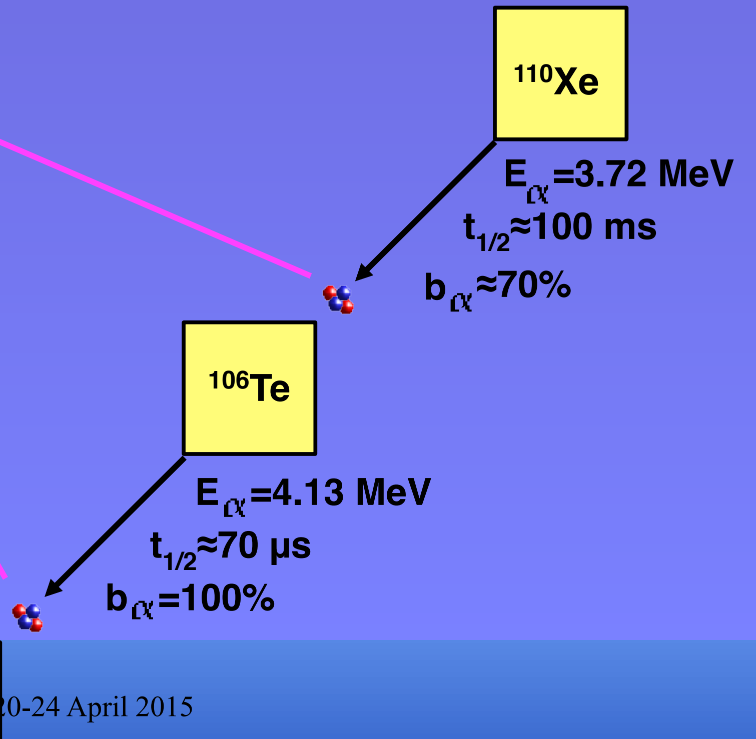


# Identification of excited states in $^{110}$Xe

*M. Sandzelius, et al. Phys. Rev. Lett 2007*

β-delayed protons



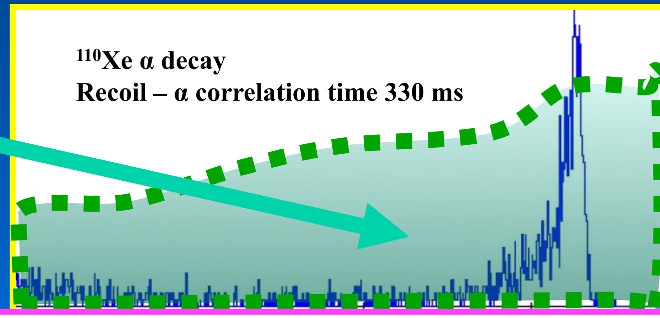



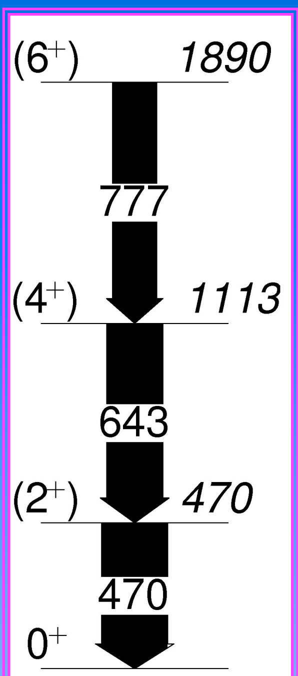

First evidence for superallowed α–decay at $T_z$=1

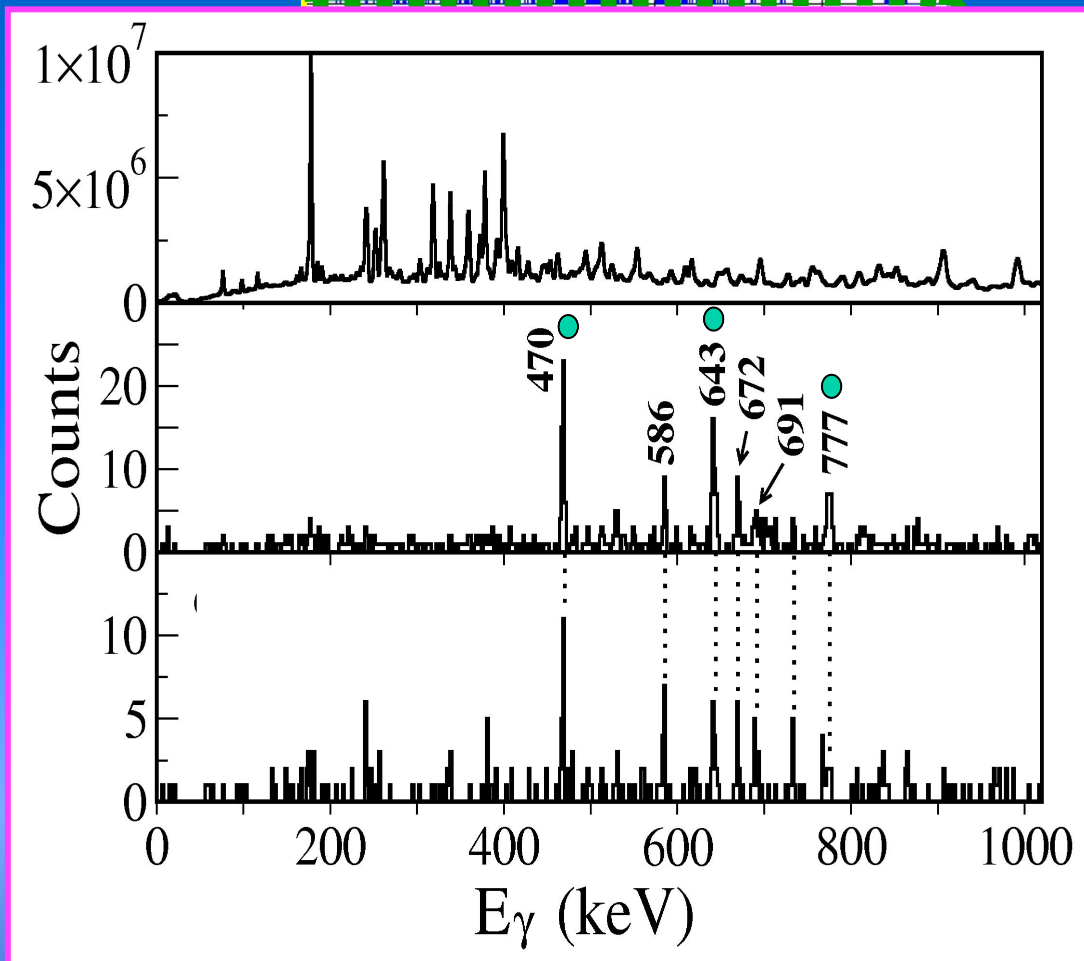
# Clean mother-daughter correlations essential for selecting the $^{110}$Xe nuclei

*M. Sandzelius, et al. Phys. Rev. Lett 2007*

β-delayed protons



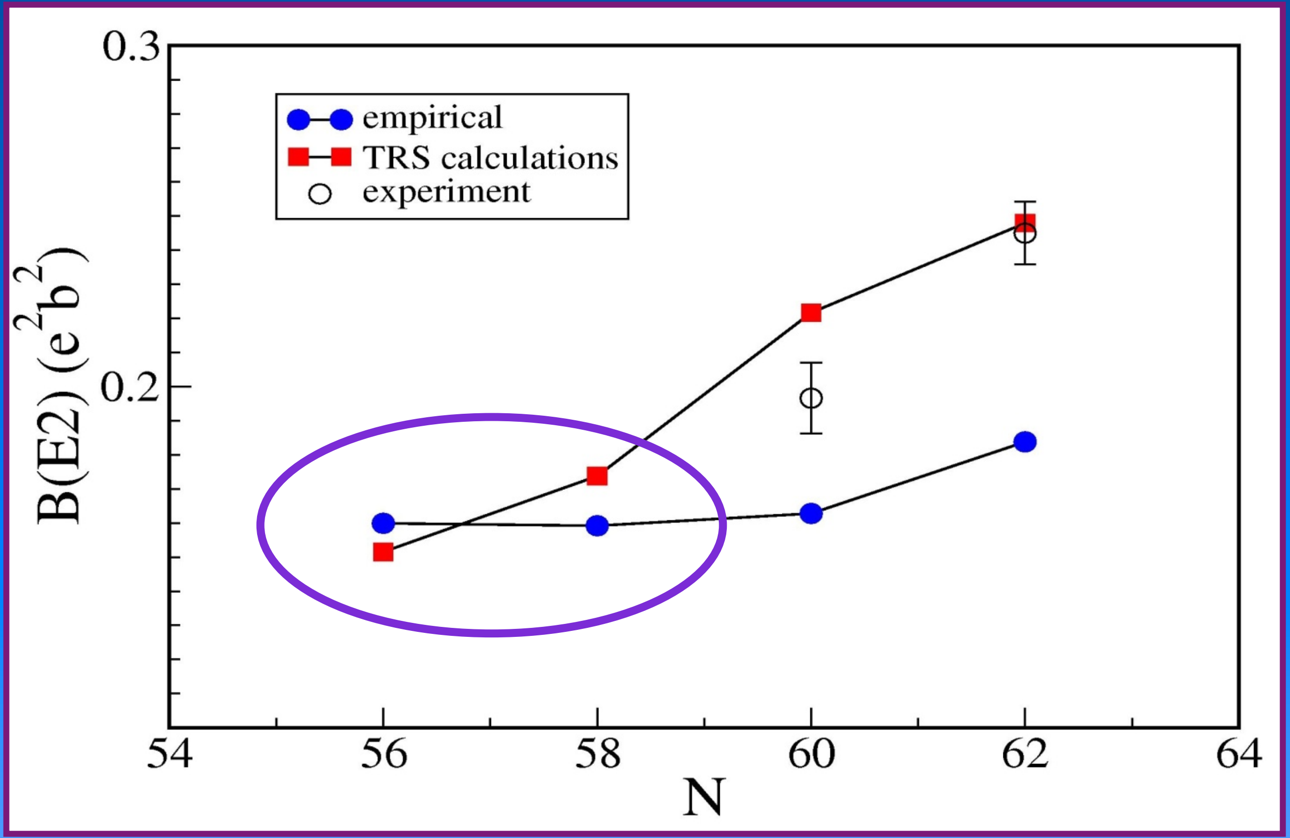




Total recoil-tagged

$^{110}$Xe mother-daughter correlated

$^{110}$Xe mother-daughter correlated, sum γγ

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




- *B*(E2) values are a measure of nuclear collectivity
- Theoretical models predict a *decrease* in *B*(E2) values for decreasing *N*
- The empirically deduced values*) reveal a leveling off and a even a small *increase* of the *B*(E2) value for $^{110}$Xe





*) $B(E2; 2_1^+ \rightarrow 0_1^+) \approx 0.66 E(2_1^+)^{-1} Z^2 A^{-0.69}$

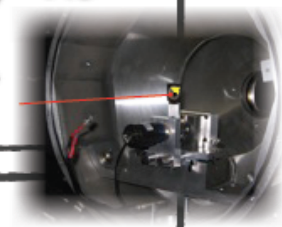
# Decay spectroscopy:
# "High-intensity" stable beams and new detection schemes

$^{109}Xe \to ^{105}Te \to ^{101}Sn$
**Exp I**
Liddick et al., PRL97 082501 (2006)

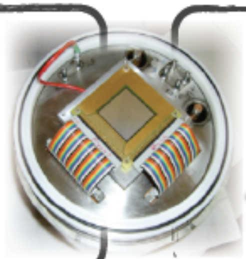
$^{109}Xe \to ^{105}Te \to ^{101}Sn$
**Exp II**
I.G. Darby et al, Phys. Rev. Lett. **105**, 2010

$^{54}Fe + ^{58}Ni \to ^{112}Xe^{*}(3n)^{109}Xe$
~8 part. nA
standard target

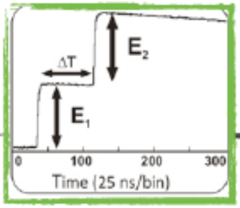
$^{54}Fe + ^{58}Ni \to ^{112}Xe^{*}(3n)^{109}Xe$
~50 part. nA
rotating target



DSSD (40x40, 65 μm)
+ veto detectors



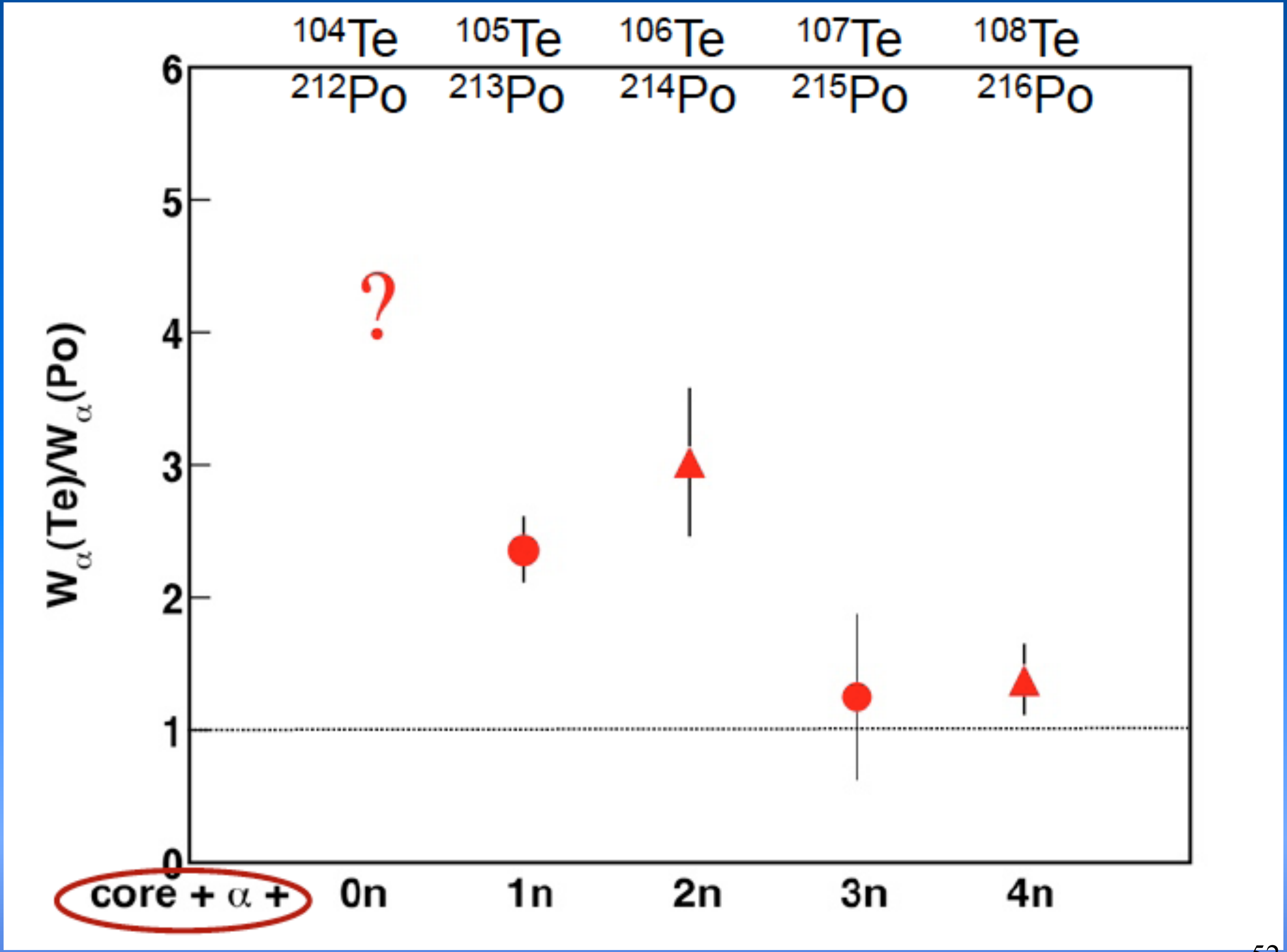
DSSD (40x40, 65 μm)
+ veto detectors
+ HPGe (11.2% @ 123 keV)



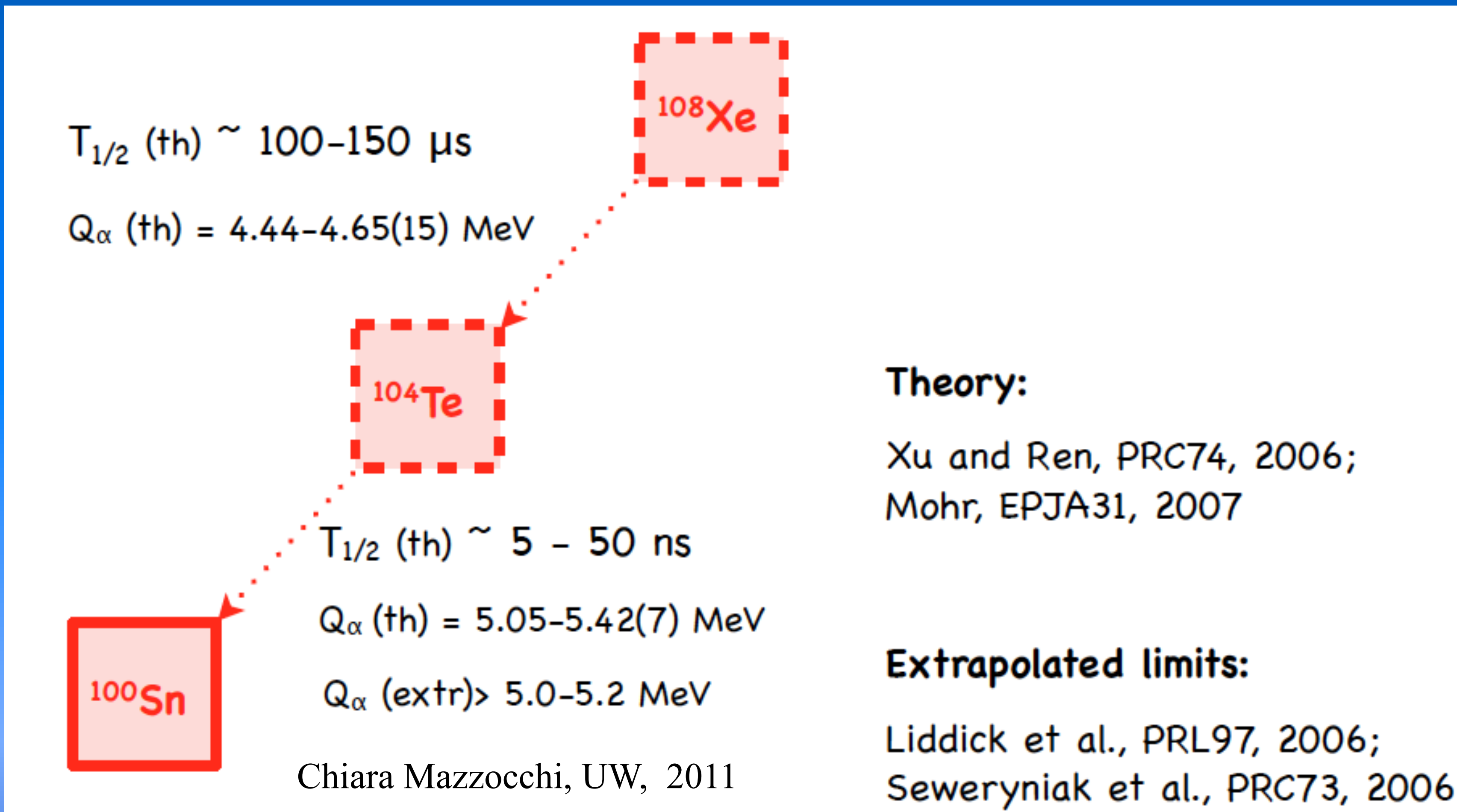

Digital DAQ: alpha catcher mode

Chiara Mazzocchi, UW, 2011

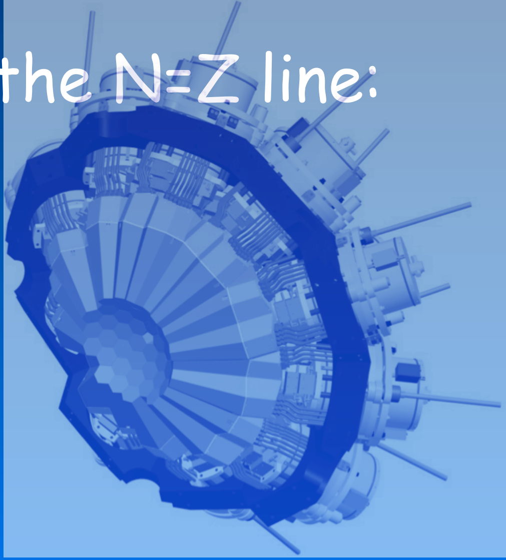
# Superallowed alpha decay: enhanced preformation
# - Strongly connected to np correlations in N=Z systems




Chiara Mazzocchi, UW, 2011

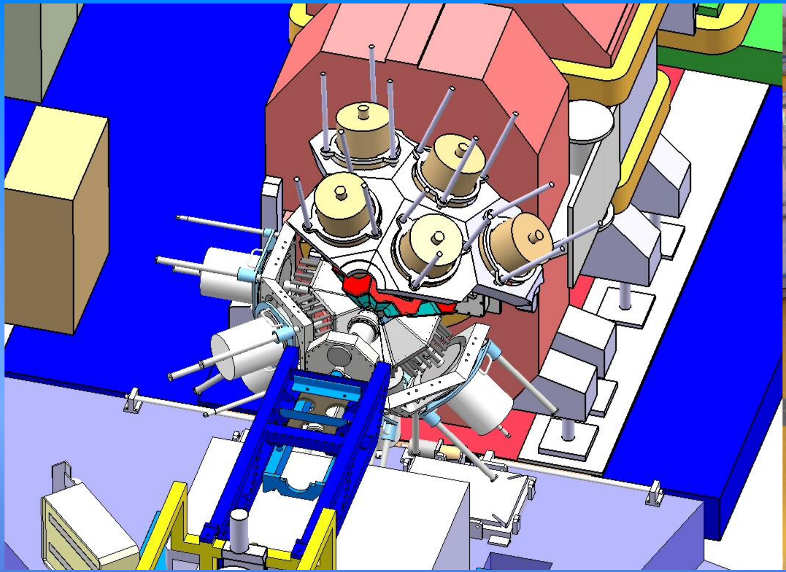

108Xe
T1/2 (th) ~ 100-150 μs
Qα (th) = 4.44-4.65(15) MeV
104Te
T1/2 (th) ~ 5 - 50 ns
Qα (th) = 5.05-5.42(7) MeV
Qα (extr)> 5.0-5.2 MeV
100Sn
Chiara Mazzocchi, UW, 2011
Theory:
Xu and Ren, PRC74, 2006;
Mohr, EPJA31, 2007
Extrapolated limits:
Liddick et al., PRL97, 2006;
Seweryniak et al., PRC73, 2006

# Experimental opportunities at the end of the N=Z line:



AGATA @ GANIL → SPIRAL2
- RDT/RDDS using VAMOS in gas-filled mode
- L.E. Coulex
- Spectroscopy
- np-transfer

RIKEN (DALI2+ZDS) ?
AGATA-HISPEC @ FAIR
- H.E. Coulex, knockout



# "Conclusions"

**Proton rich and N=Z nuclei – major potential for important discoveries**

- Neutron-proton correlation effects
  - isoscalar pair modes
  - superallowed alpha decays
  - development of collective excitations
- GT strengths — Not discussed here
- Isospin symmetry — Not discussed here
- Exotic particle decay modes (2p, … ) — Not discussed here
- Influence from proton state continuum on structure and correlations — Not discussed here
- High-spin physics — Discussed only briefly here
- …

"High-intensity" stable beams coupled to improved detector instrumentation one important route forward!

# np pair modes - outlook

- $^{100}Sn$ region a prime "laboratory" for investigating effects of strong residual neutron-proton correlations including T=0 pairing
- Strong need for mass measurements in N=Z nuclei beyond A≈60 to pin down ground-state isoscalar pairing issue
- Deuteron transfer reactions with RIBs (inverse kinematics) another promising route
- Angular momentum response in (super) deformed N=Z systems
- Isoscalar spin-aligned coupling scheme is a possible, different "paired phase" with characteristic features that need further experimental verification at the new facilities
- Need sharper theoretical predictions for reactions & structure

# Thank You