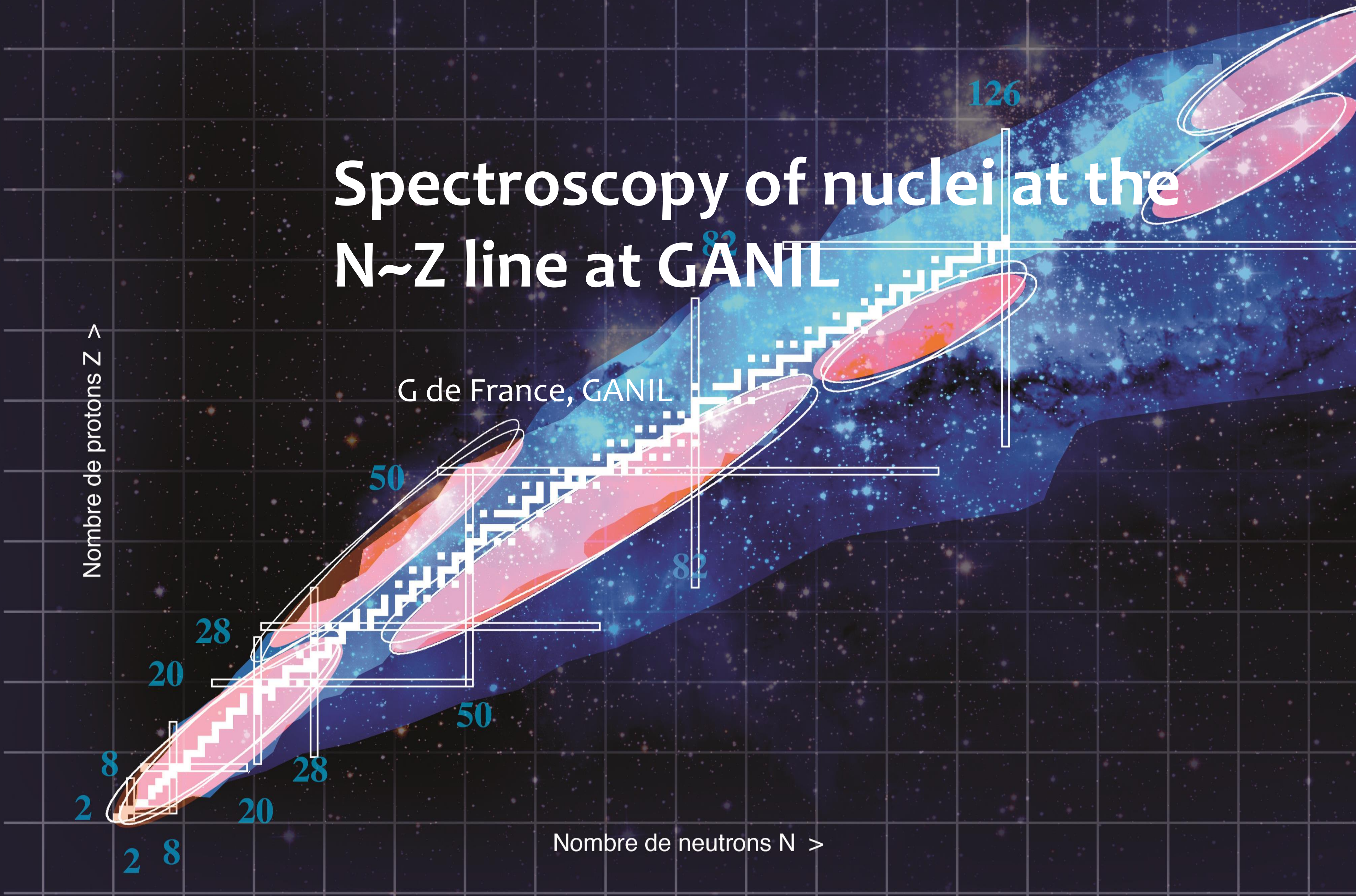
Spectroscopy of nuclei at the N~Z line at GANIL

G de France, GANIL



GANIL colloquium September 9-13, 2019

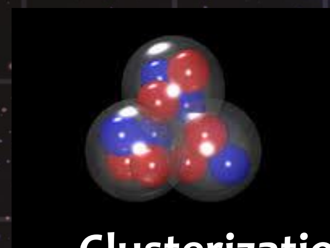
Agenda

- Physics of N~Z nuclei. Experiments.

- Collectivity in Sn isotopes approaching N=50:
  - ^{106,108}Sn with AGATA+VAMOS
- Seniority at N=50:
  - Lifetimes in ^{92}Mo, ^{94}Ru
- Isoscalar pairing:
  - ^{92}Pd with EXOGAM+Nwall+DIAMANT
  - ^{88}Ru with AGATA+NEDA-Nwall+DIAMANT

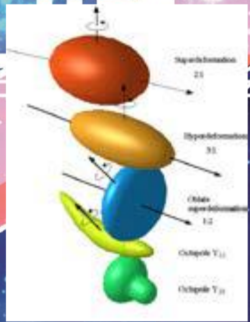
Physics of N~Z nuclei

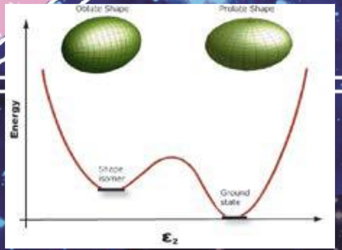
Nuclear astrophysics

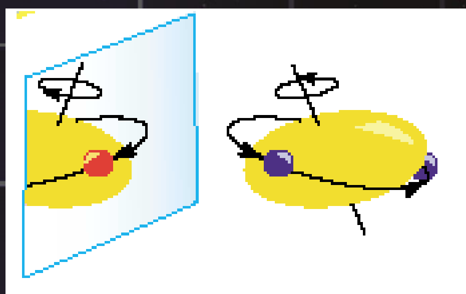


Clusterization

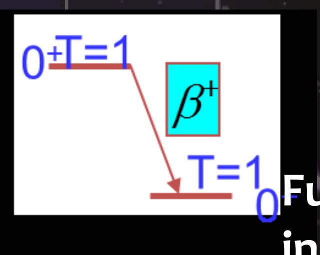
Nuclear shapes
Coexistence



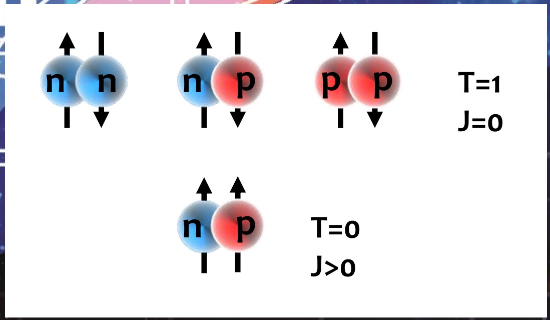




Isospin symmetry breaking

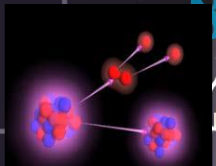


Pairing

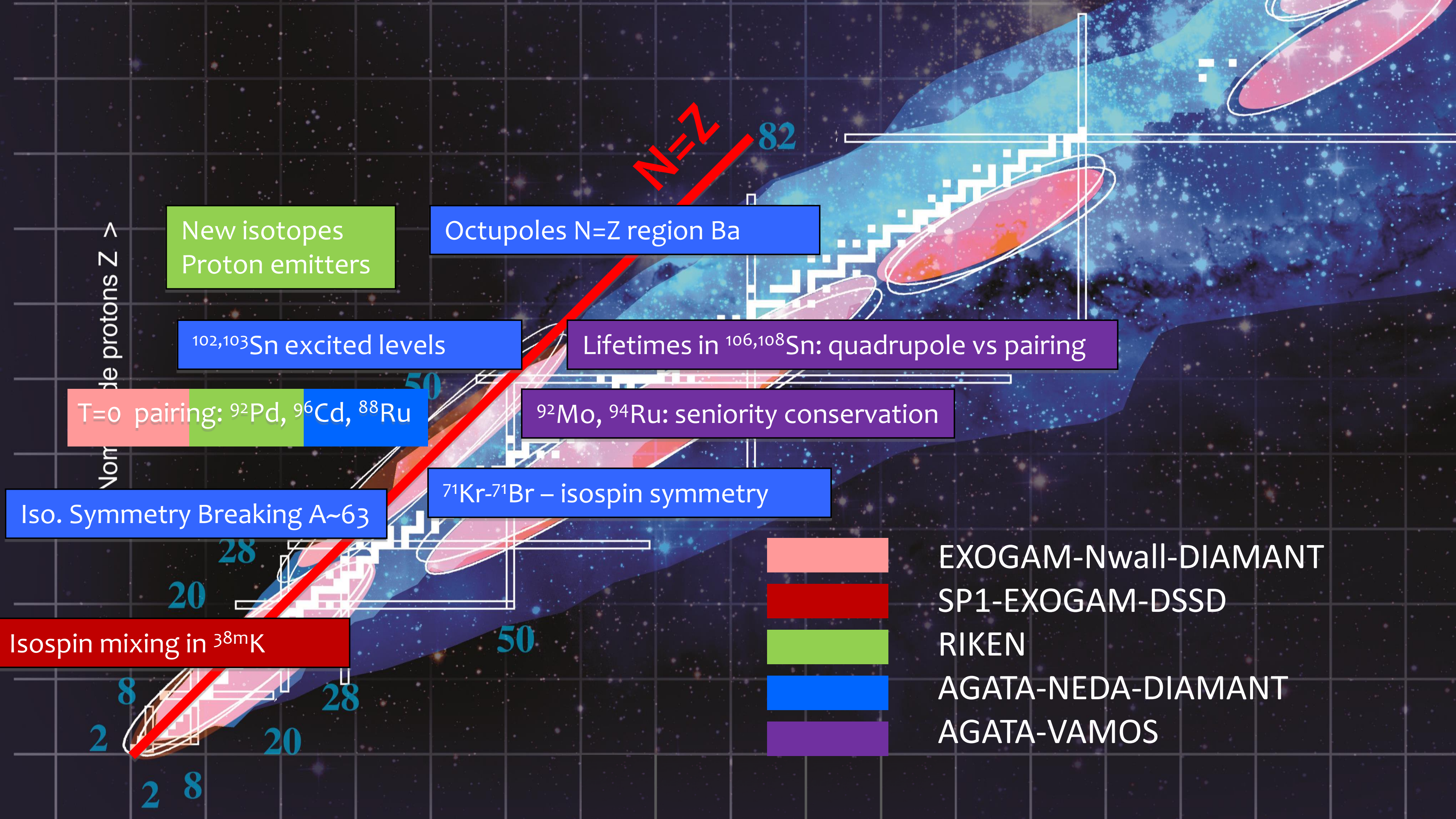


Fundamental interactions

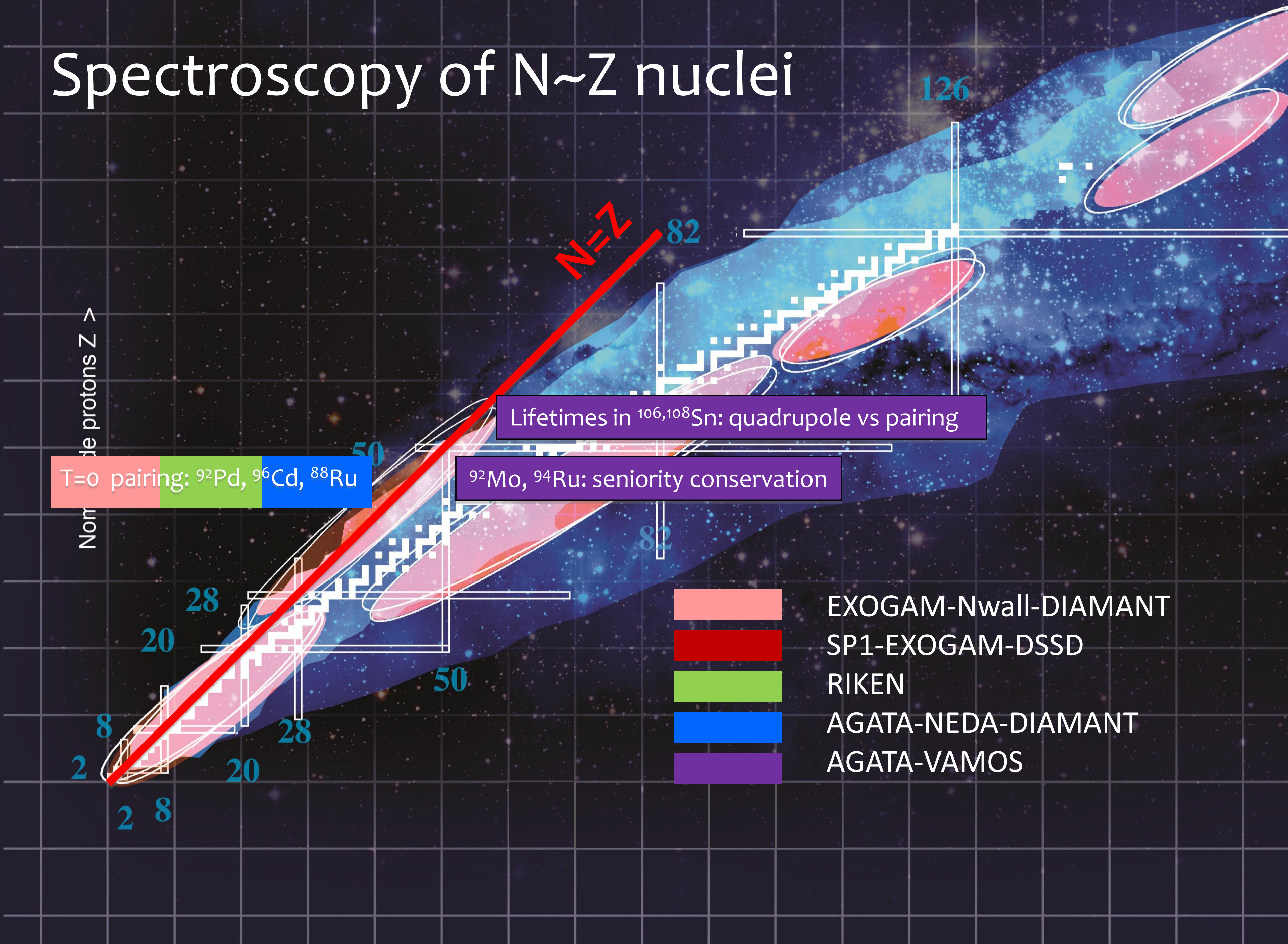
Coupling to continuum
2p



Spectroscopy of N~Z nuclei

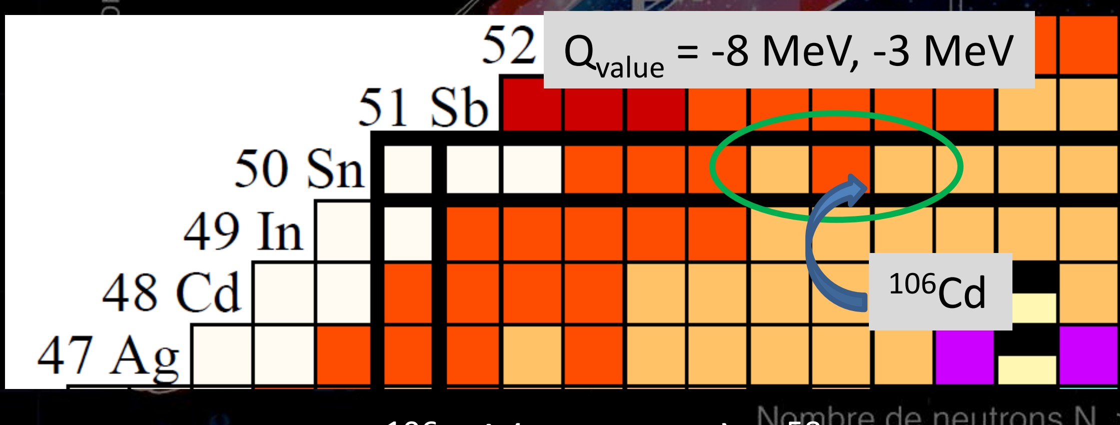


Spectroscopy of N~Z nuclei

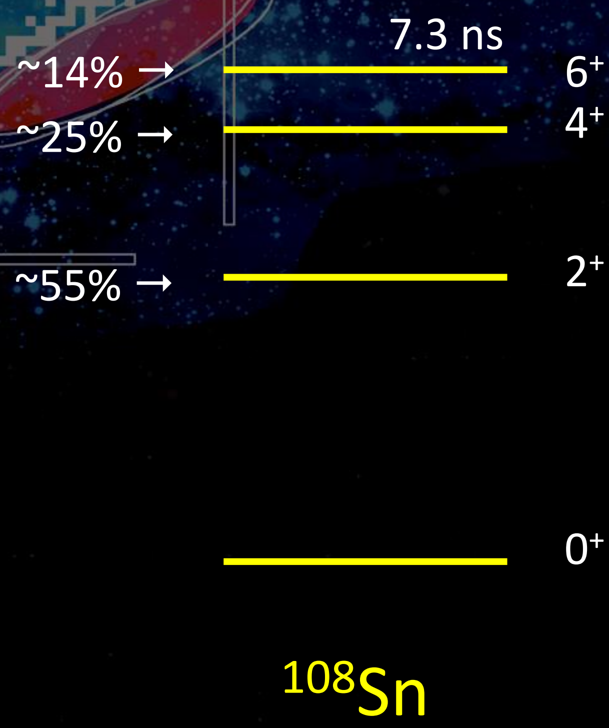


MNT for N~Z nuclei

- ^{106,108}Sn (M Siciliano); ^{90}Zr, ^{92}Mo, ^{94}Ru (RM Perez Vidal)
- Usually f.e. => little feeding below the isomer
- Lifetime below the isomer: use MNT reactions
- Cross sections: ~mbarns



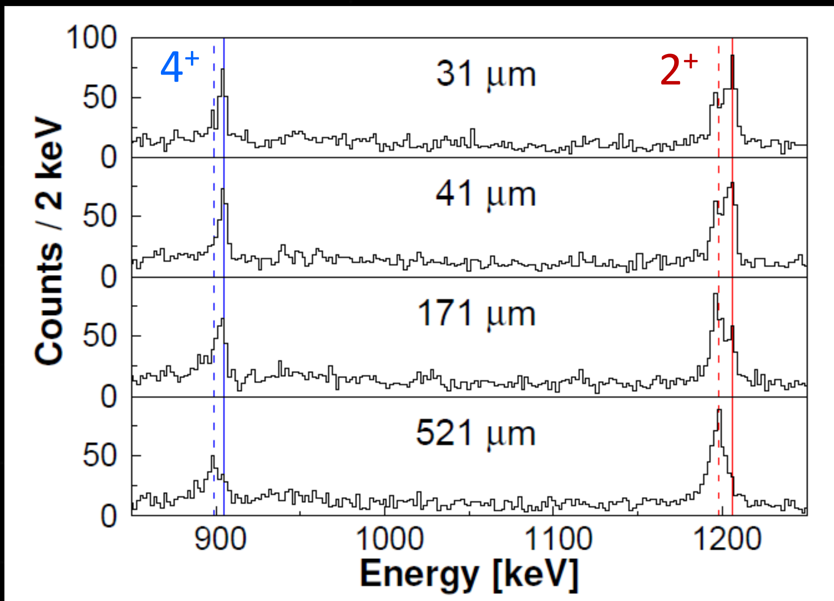
^{106}Cd (680 MeV) + ^{58}Ni

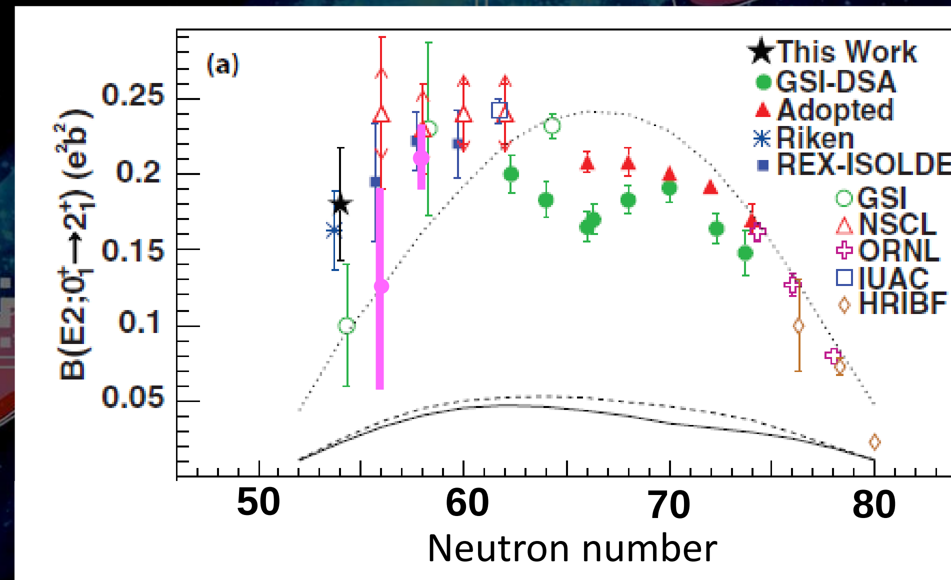


PhD Thesis M. Siciliano

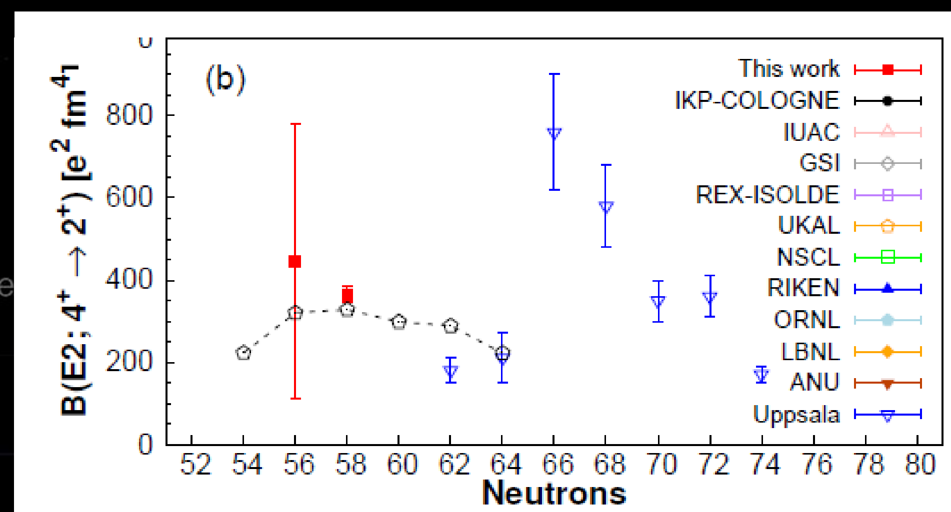
Towards ^{100}Sn: B(E2)'s in ^{106,108}Sn

M Siciliano, GANIL PhD award





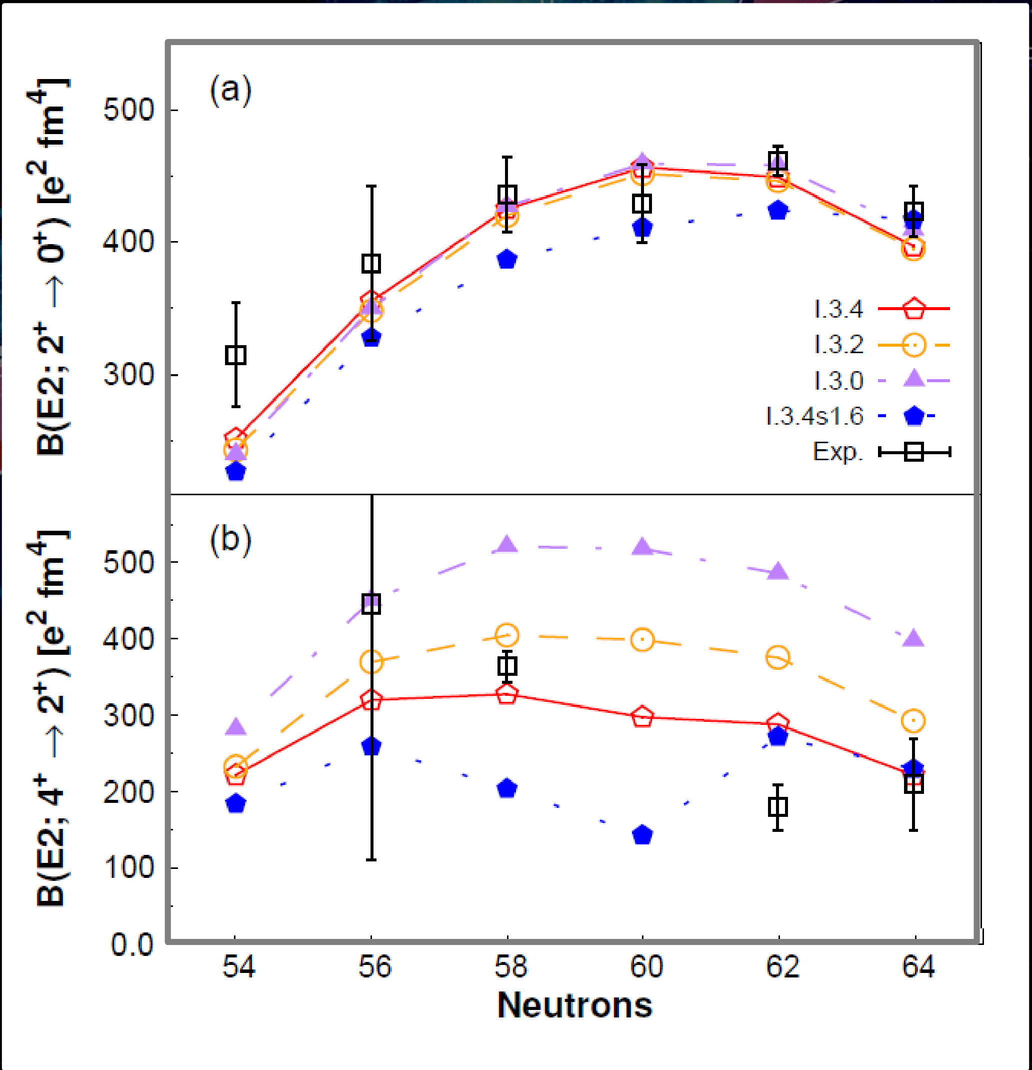
- LSSM Calcs: need core excitations. Up to 4p4h
- B(E2:$0^+ \rightarrow 2^+$) values do not clarify. Large error bars.
- First measurement of B(E2:$4^+ \rightarrow 2^+$) in light tins



PhD Thesis M. Siciliano

Towards ^{100}Sn: B(E2)'s in ^{106,108}Sn

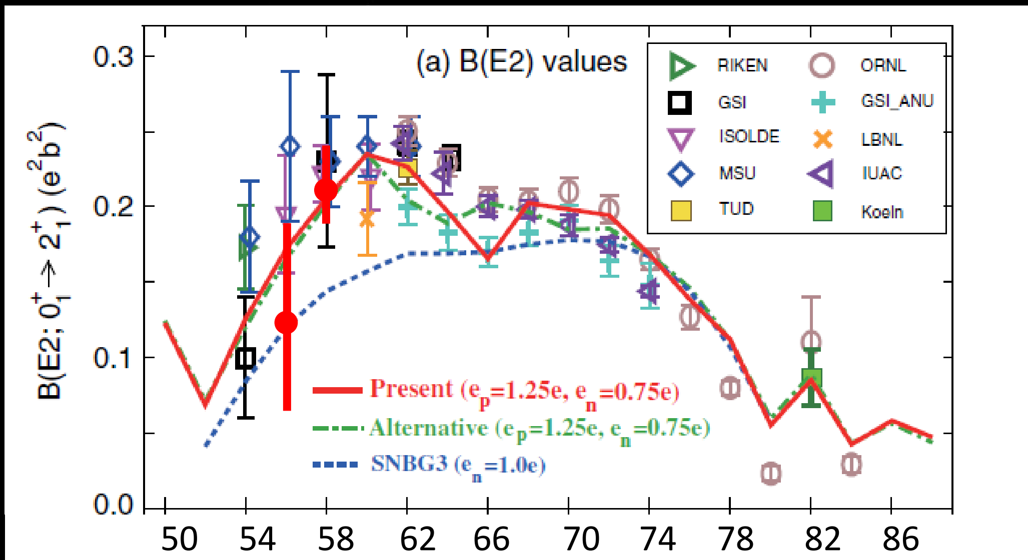
- Zuker SM calcs:
  - Pseudo SU(3) scheme: f (g7/2, d5/2) and p(d3/2, s1/2)-no h11/2
  - Add g9/2
  - N3LO; s.p. energies for ^{100}Sn
  - Scale quadrupole and pairing parts
  - Shift of s1/2
- Probe quadrupole and pairing parts
- Quadrupole dominates B(E2:$2^+ \rightarrow 0^+$)
- Pairing dominates B(E2:$4^+ \rightarrow 2^+$)
- B(E2:$4^+ \rightarrow 2^+$) much more sensitive probe. Constraints on pairing part.



A Zuker, PRL, accepted

PhD Thesis M. Siciliano

Towards ^{100}Sn: B(E2)'s in ^{106,108}Sn

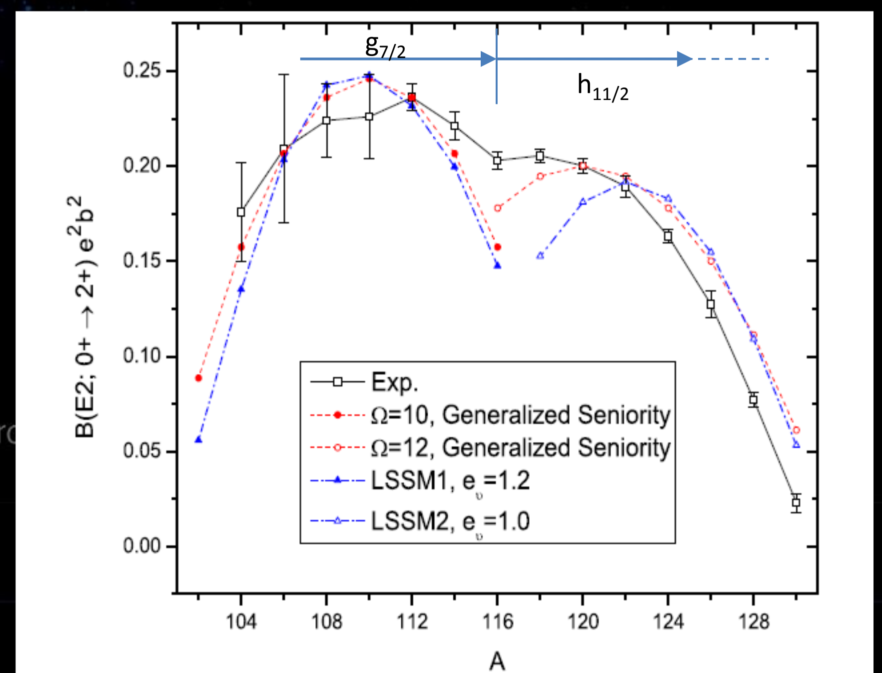


T Togashi et al, PRL 121, 062501

- MCSM calculations
- Bump at N~60 due to large number of $g_{9/2}$ proton holes
- => Z=50 core breaking and deformation

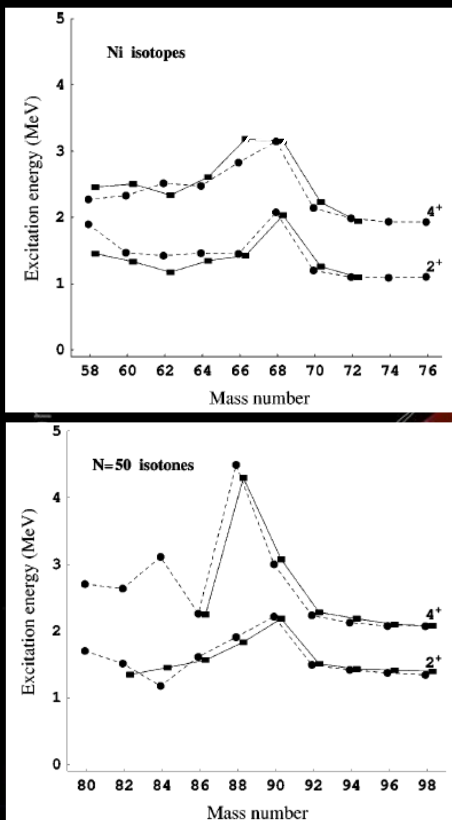
- Generalized seniority
- 2 valence spaces ($g_{7/2}d_{5/2}d_{3/2}s_{1/2}$ ^{100}Sn core and $h_{11/2}d_{5/2}d_{3/2}s_{1/2}$ ^{108}Sn core)
- dip@^{116}Sn: mixing $g_{7/2}$ and $h_{11/2}$; no need to break core

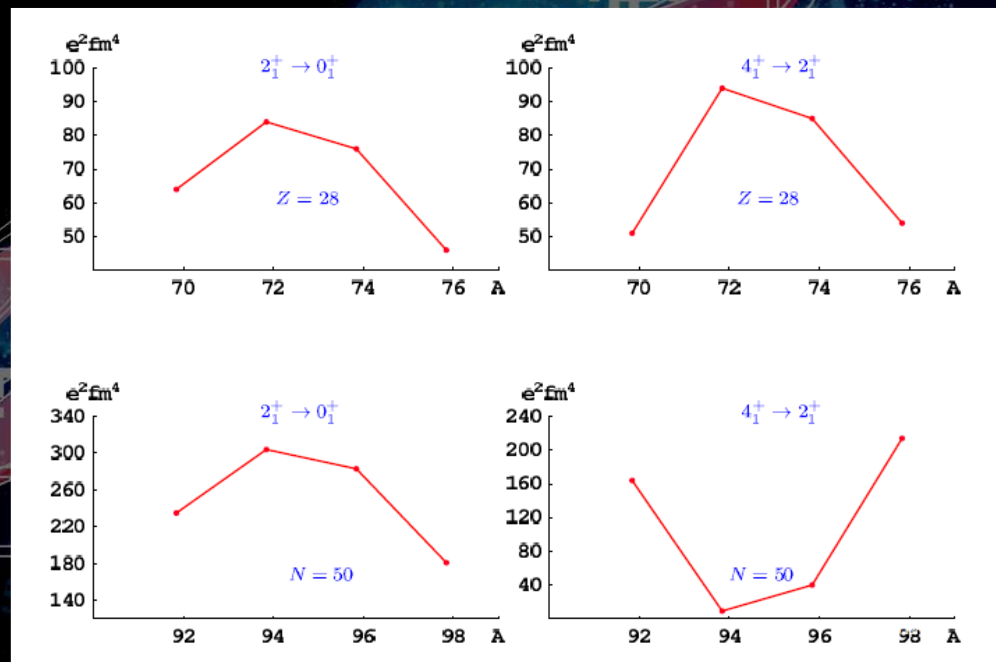
B Maheshwari, AK Jain and B Singh, NPA 952 (2016) 62



Seniority in N=50: ^{92}Mo and ^{94}Ru

measurement of the transition probabilities for N=50 isotones and compare with the Z=28 isotopes *“valence mirror symmetry”*





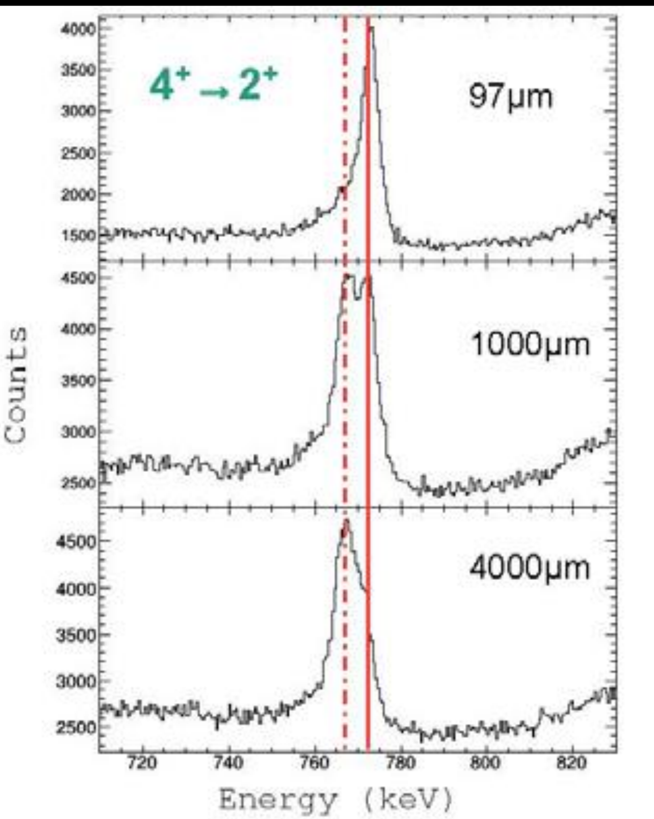
A.F. Lisetskiy et al., EPJ A 25 S01 (2005)

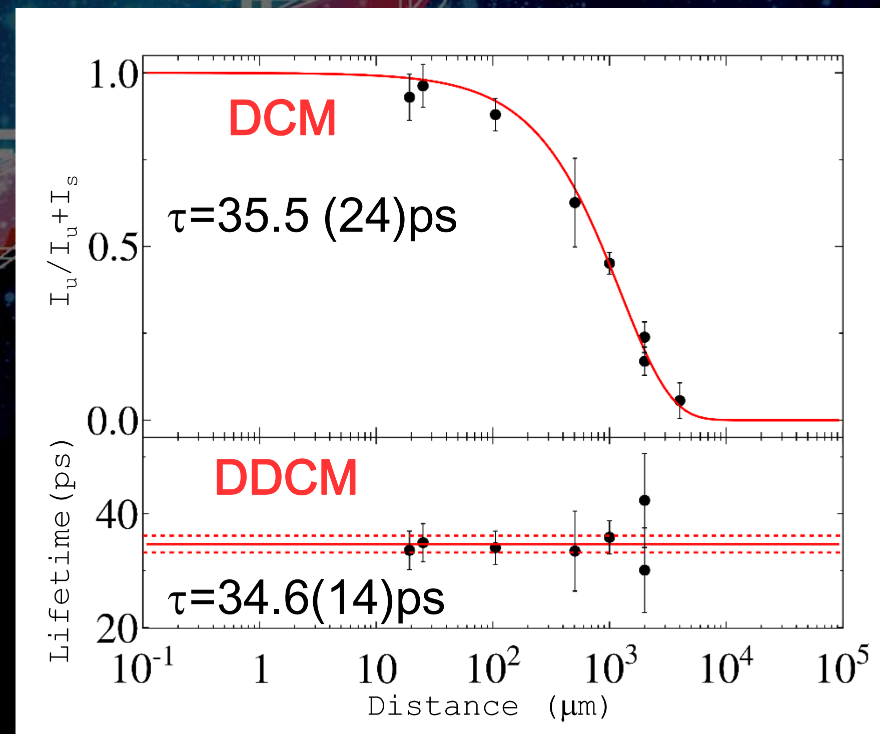
- Effective TBME for $g_{9/2}$ in Z=28 and N=50 different: neutron interaction stronger in $J^{\pi}=2^+$ and 4^+ for Ni compared to N=50
- Yrast 4^+ (seniority v=4) in ^{72,74}Ni where v=2 in ^{94}Ru and ^{96}Pd

RM Perez Vidal PhD thesis

4^+ states in ^{92}Mo

^{92}Mo



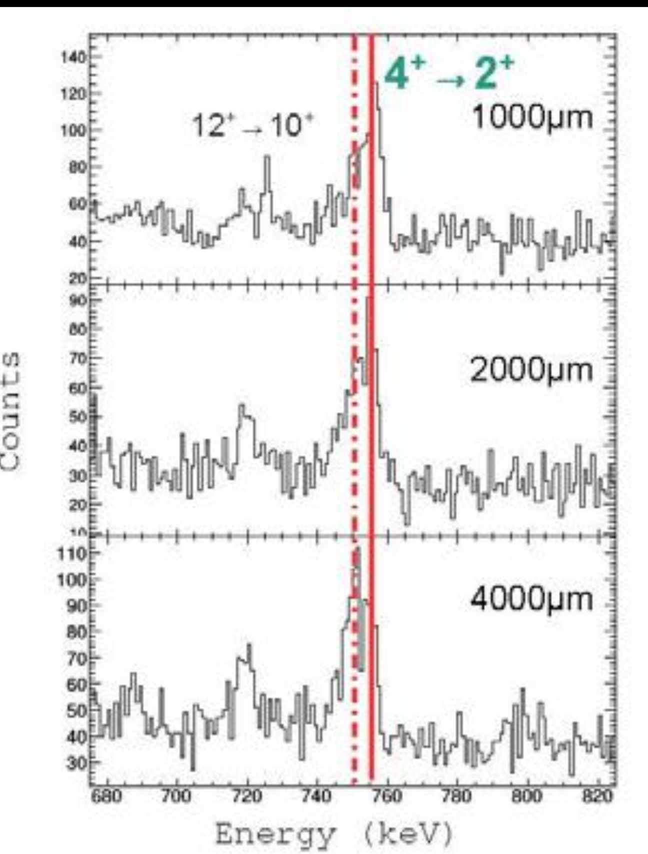


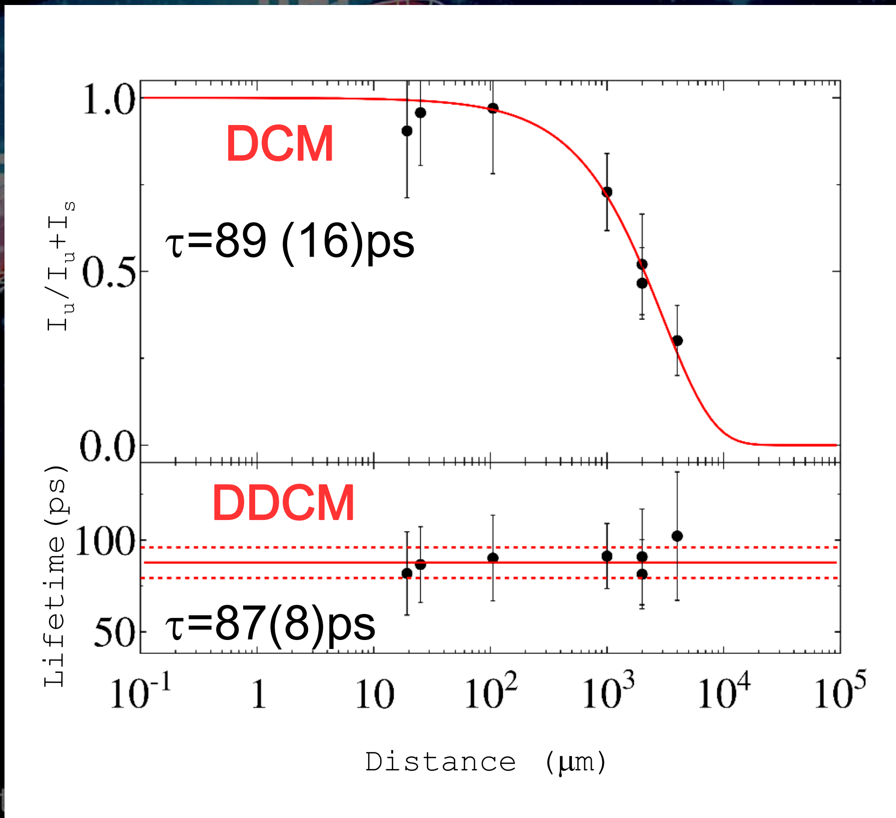
7 distances measured

R. Perez et al, in preparation

4^+ states in ^{94}Ru

^{94}Ru

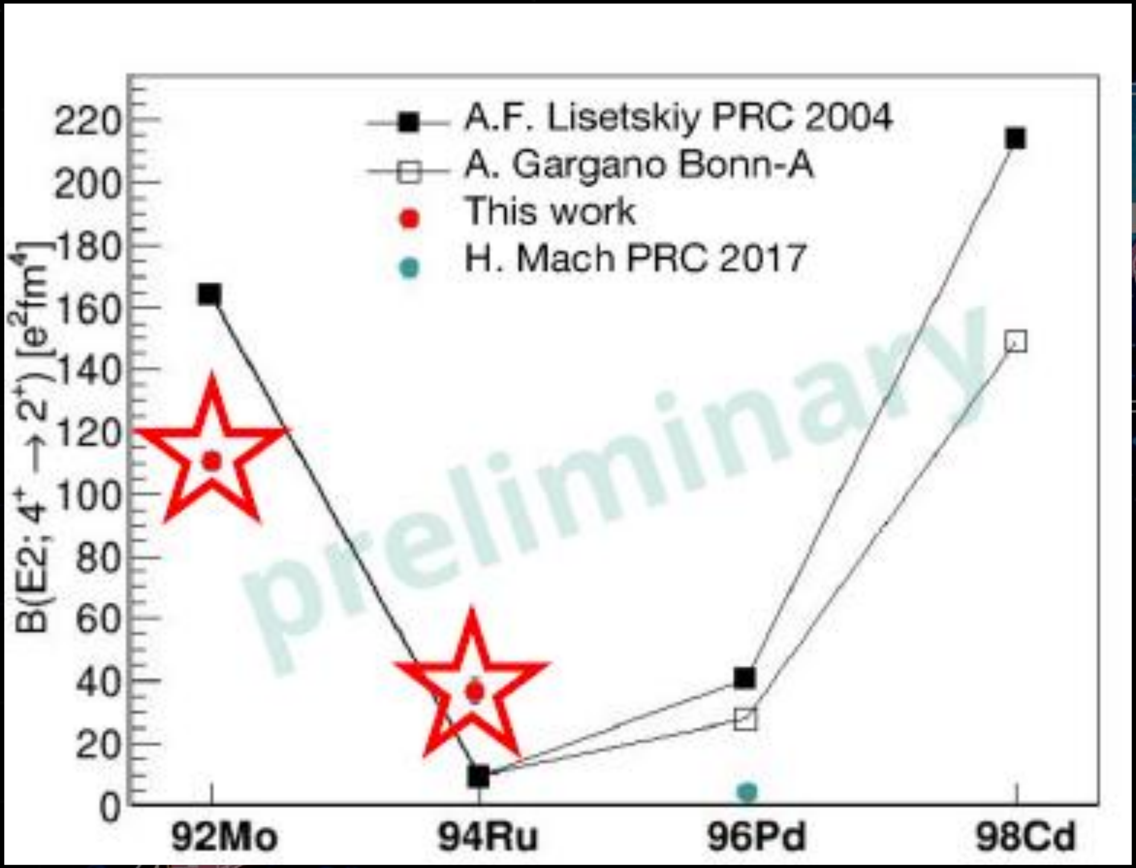




7 distances measured

R. Perez et al, in preparation

4^+ states in ^{92}Mo and ^{94}Ru



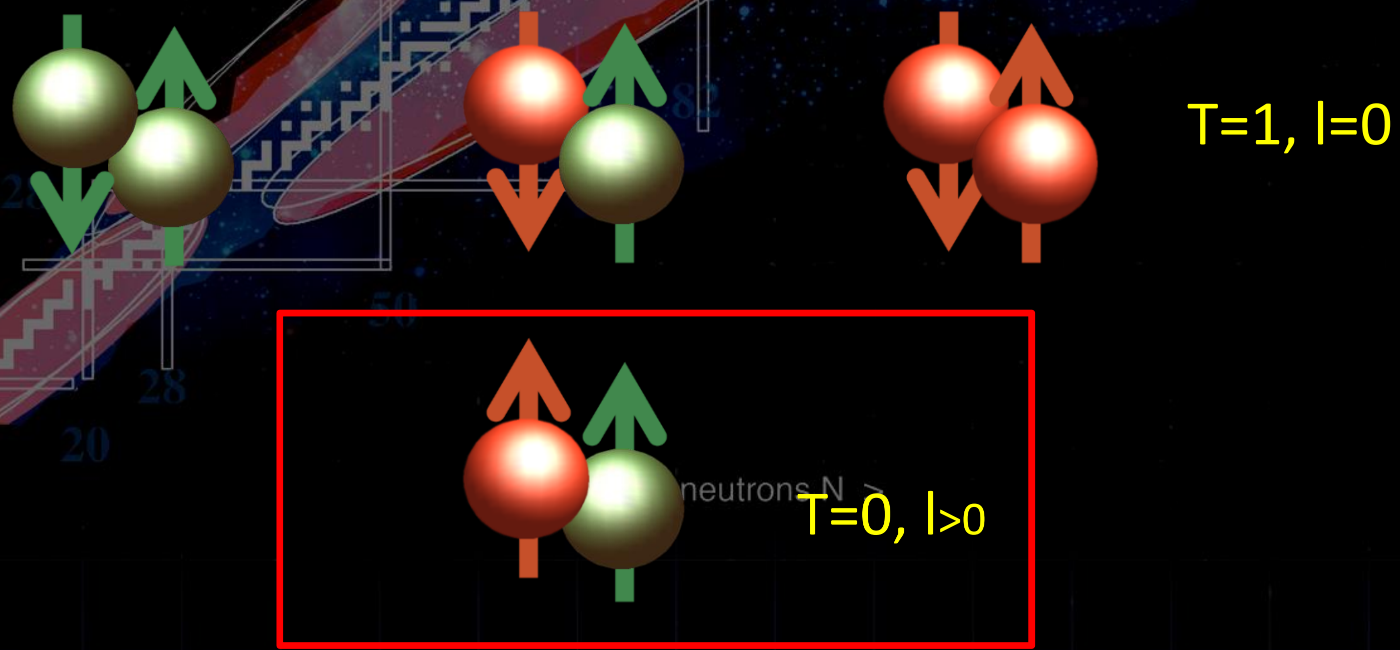
SM Calcs in *f5pg9* valence space:
AF Lisetskiy: Bonn-C int
A Gargano: Bonna-A int

Nombre de neutrons N >

⇒Measurements confirm conservation of seniority
⇒Good probe to tune the TBME in $g_{9/2}$

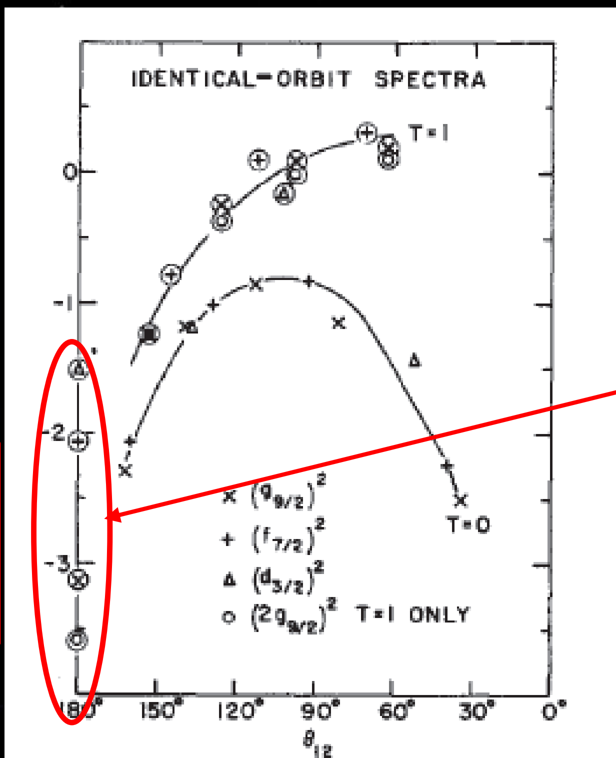
T=0 pairing: ^{92}Pd, ^{96}Cd, ^{88}Ru

- « Standard » pairing: like-nucleon coupled to l=0 in time reversed orbits (isovector)
- in N~Z: np pairing T=1, l=0 (isovector) + T=0, l=1 (isoscalar)



T=0 vs T=1 strength

Particle-particle matrix elements of magic nuclei+2 nucleons in the same orbit (from E*) as a function of coupling angle (➔ independent of the considered orbit)



J=0, T=1

- **2 « universal » curves** for all the orbits: one for T=1 and one for T=0 (except for J=0, T=1)
- For T=1, strength concentrates in **J=0** i.e. (j,m)(j,-m)
- When spin increases:
  - T=1 pairs are less bound; and less and less
    T=0 dominates T=1 => rotational properties

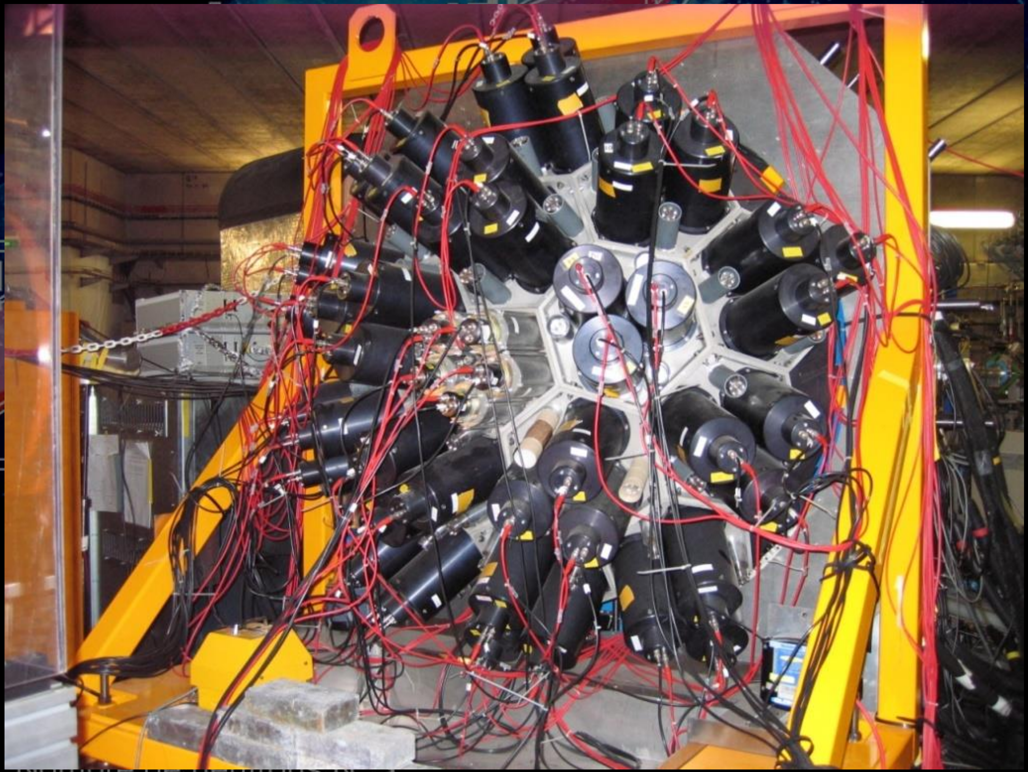
Nombre de neutrons N >

N. Anantaraman and J.P. Schiffer PLB37 (1971) 229

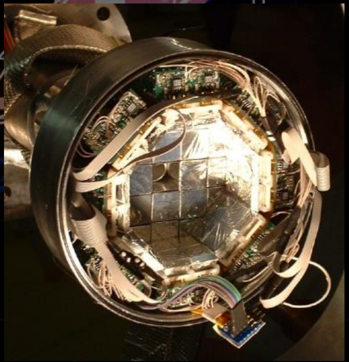
EXOGAM-NWall-DIAMANT:

The power of the coupling

- EXOGAM: 11 Clovers with partial shield. $\varepsilon_p\omega$ ~ 10% for E_γ=1.3 MeV

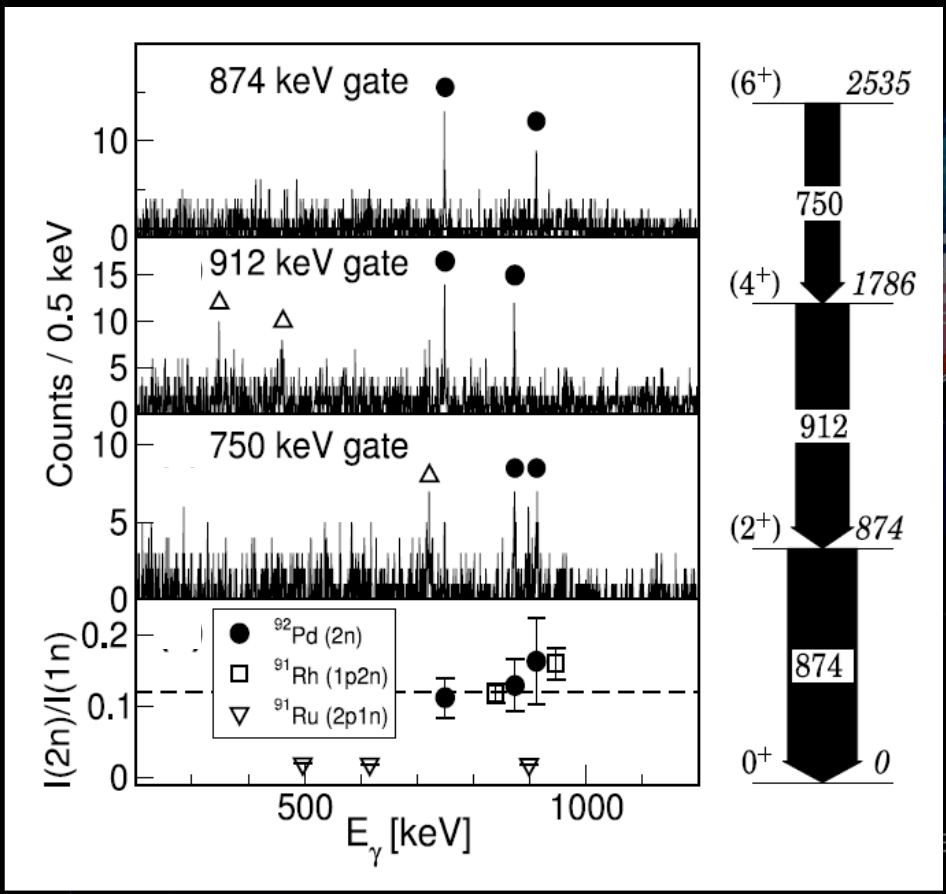


- DIAMANT: 80 CsI(Tl) dets. $\varepsilon_{p\ or\ \alpha}$ ~ 66%



- The Neutron Wall: 50 liquid scintillator detectors. ε_{1n} ~ 23%

EXOGAM:
First identification of γ-rays in ^{92}Pd



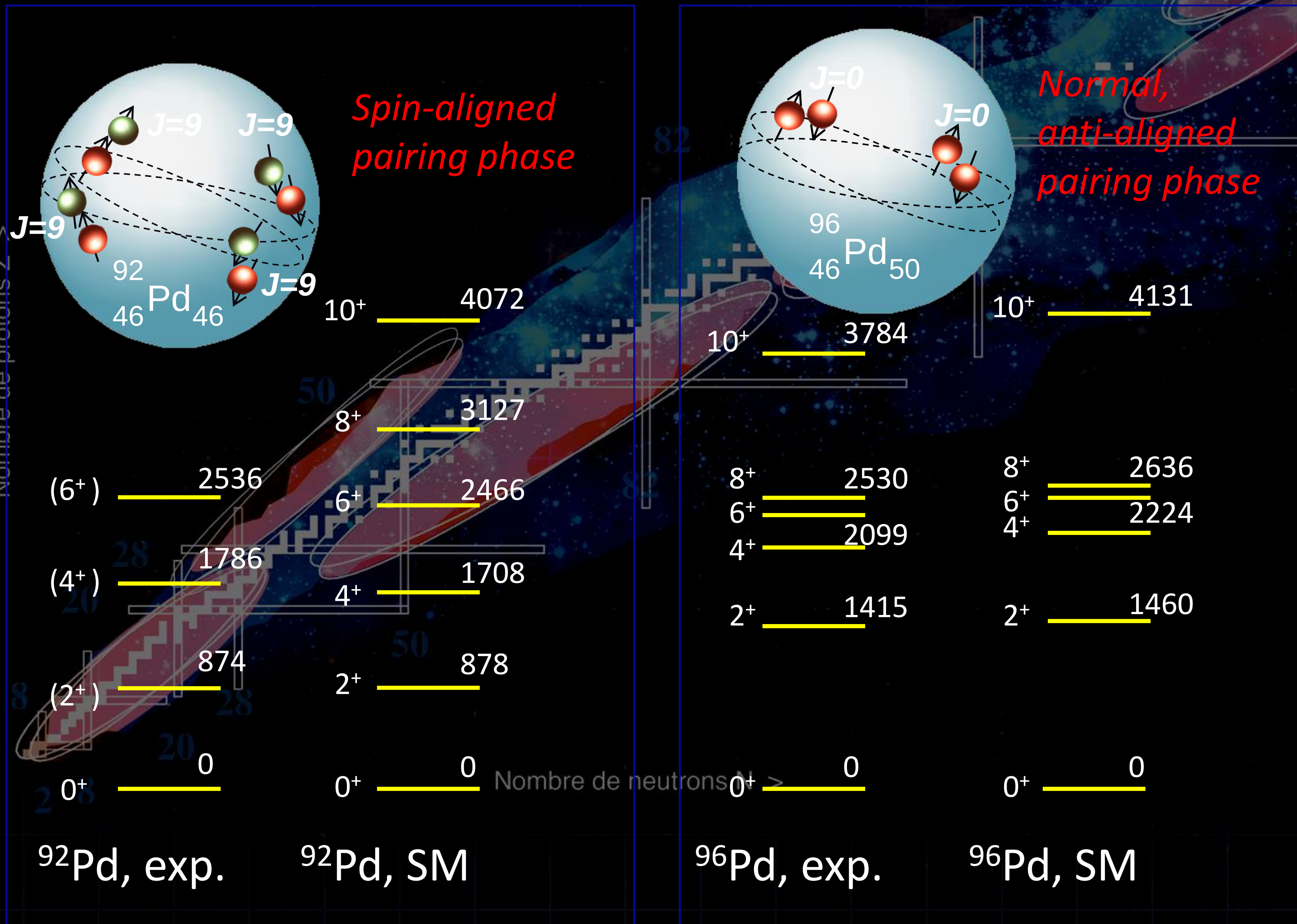
- Three γ-rays firmly identified
- In coincidence with 2n
- Not in coincidence with charged particles
- Mutually coincident
- All possible contaminants excluded
- → Unambiguously assigned to ^{92}Pd

Production cross section ~ 0.5 μb

B Cederwall, F. Ghazi-Moradi, T Back, A Johnson, J. Blomqvist, E Clément, G. de France, R Wadsworth et al,

Nature 469, 68-71 (2011)

^{92}Pd: A new spin aligned np coupling scheme

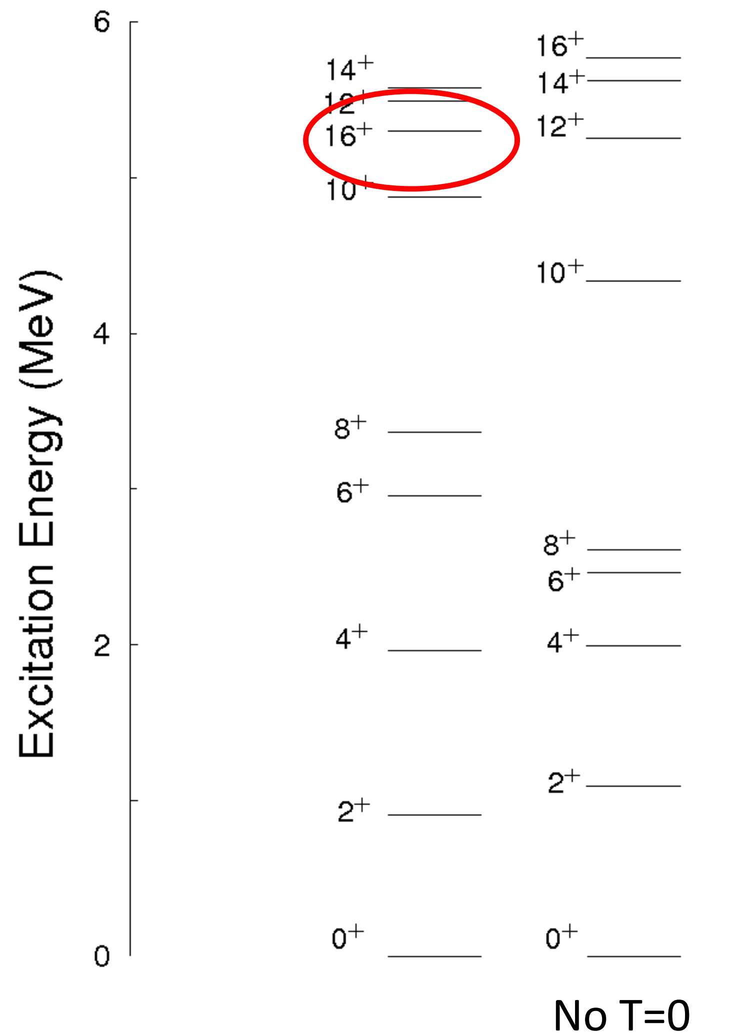


SM expectations for ^{96}Cd

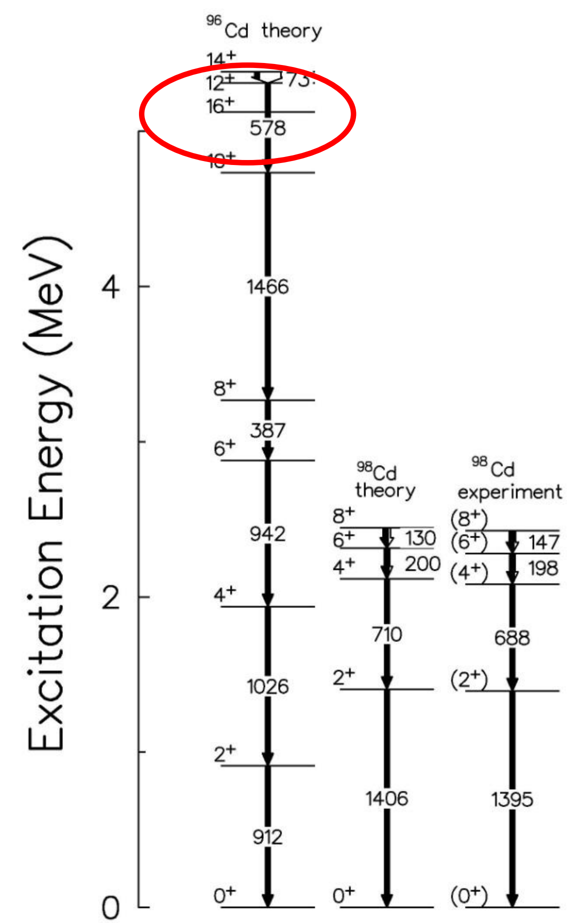
Spin-gap isomer: arising from strong attraction between n and p in $g_{9/2}$

Probe T=0

Lifetime long enough to give β-decay branches

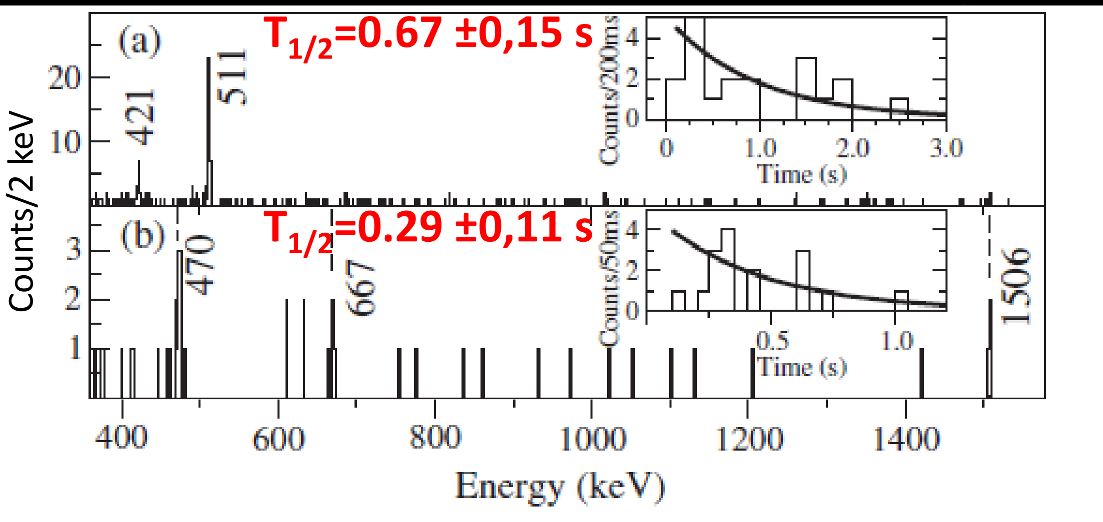


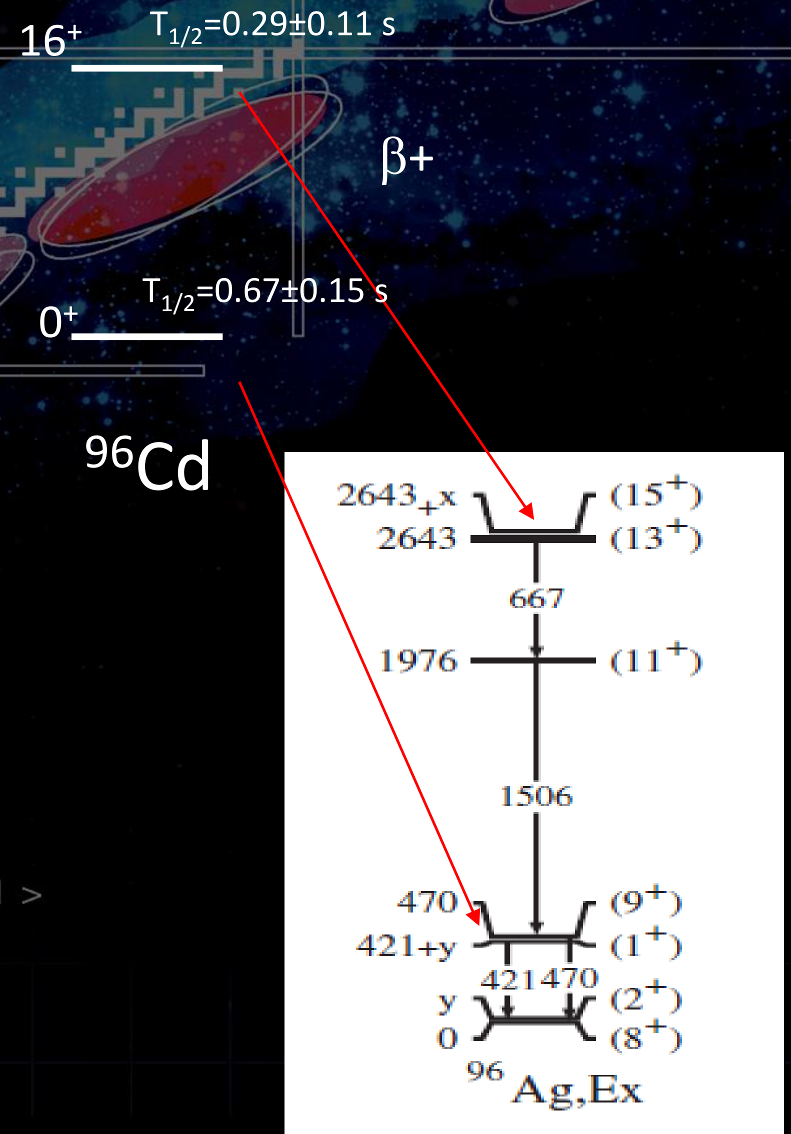
H. Grawe



J. Blomqvist (2007)

Decay of ^{96}Cd/GSI: the 16^{+} spin gap isomer



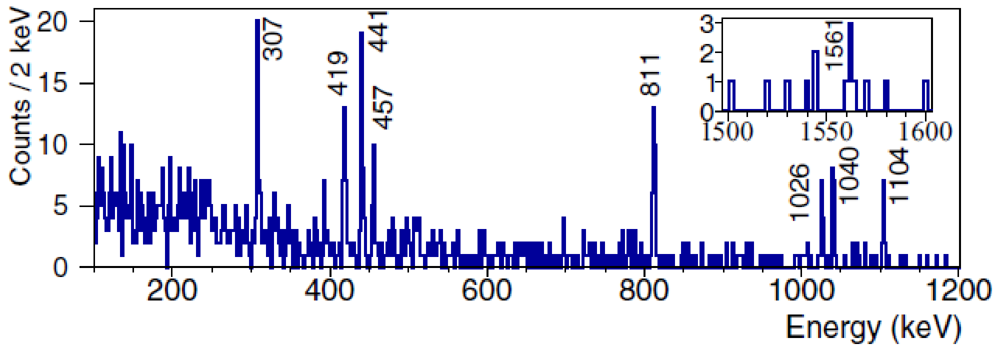


- Fragmentation of ^{124}Xe at GSI
- Observe the decay of identified ^{96}Cd to an 15^{+} isomer in ^{96}Ag
- Time after ^{96}Cd implantation => $T_{1/2}$
- No prompt γ in ^{96}Cd

Nombre de neutrons N >

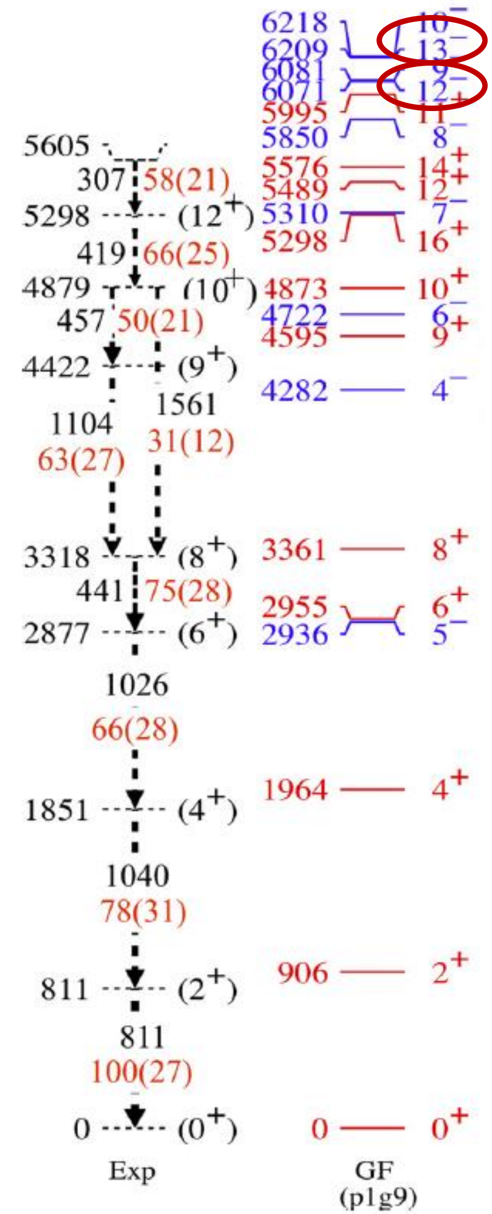
BS Nara Singh PRL 107, 172501 (2011)
PJ Davies et al, PLB 767, 474 (2017)

Decay of ^{96}Cd/RIKEN: decay of isomer



Delayed γ-ray (50-1200 ns after ^{96}Cd implantation)

- Tentative level scheme
- Ordering based on SM calcs
- New isomer with $T_{1/2}=197^{+19}_{-17}$ ns
- Likely retarded E1
- 12^- or 13^- possible assignment

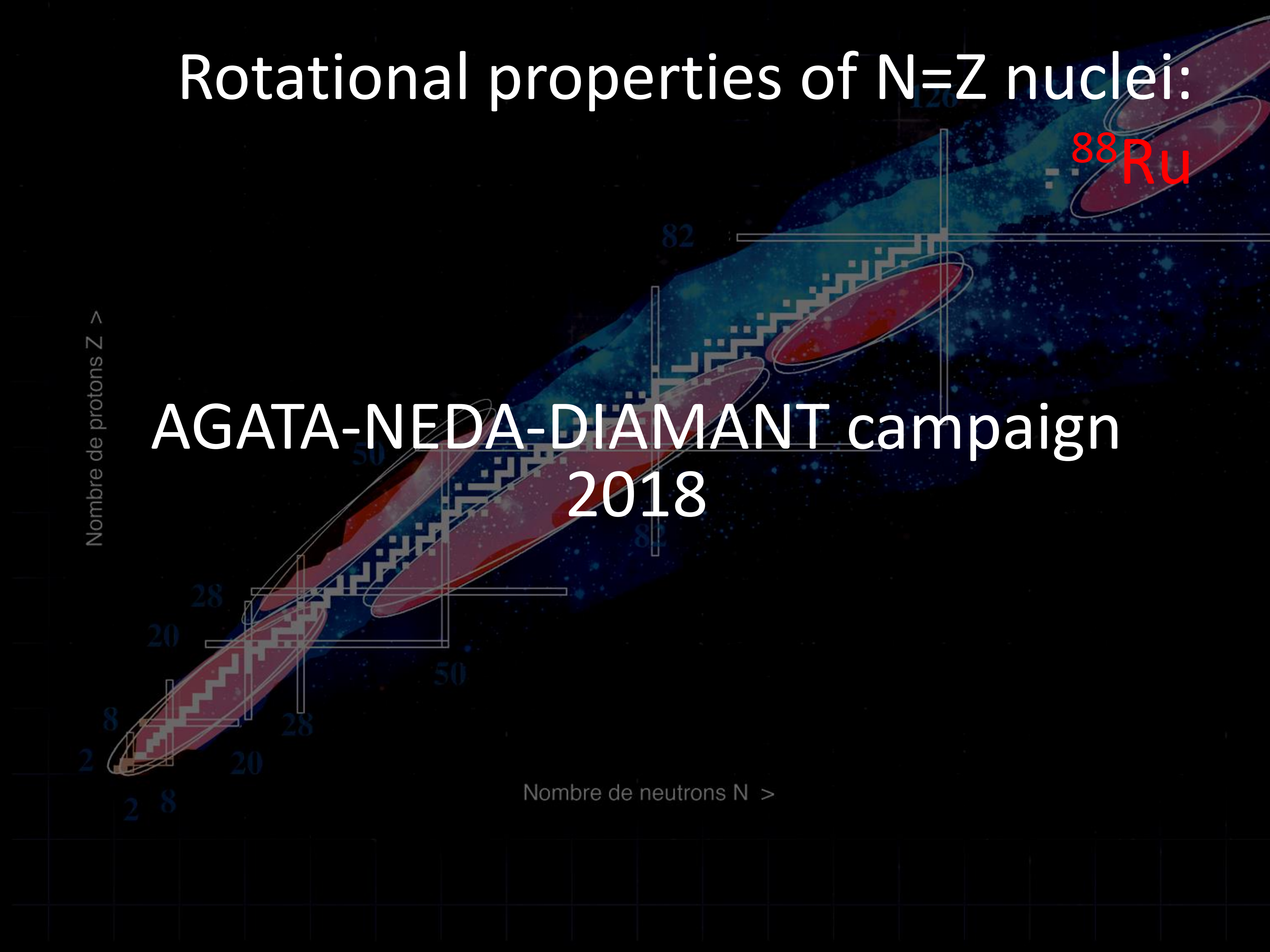


PJ Davies et al, PRC99 021302(R) (2019)

Rotational properties of N=Z nuclei:

^{88}Ru

AGATA-NEDA-DIAMANT campaign 2018



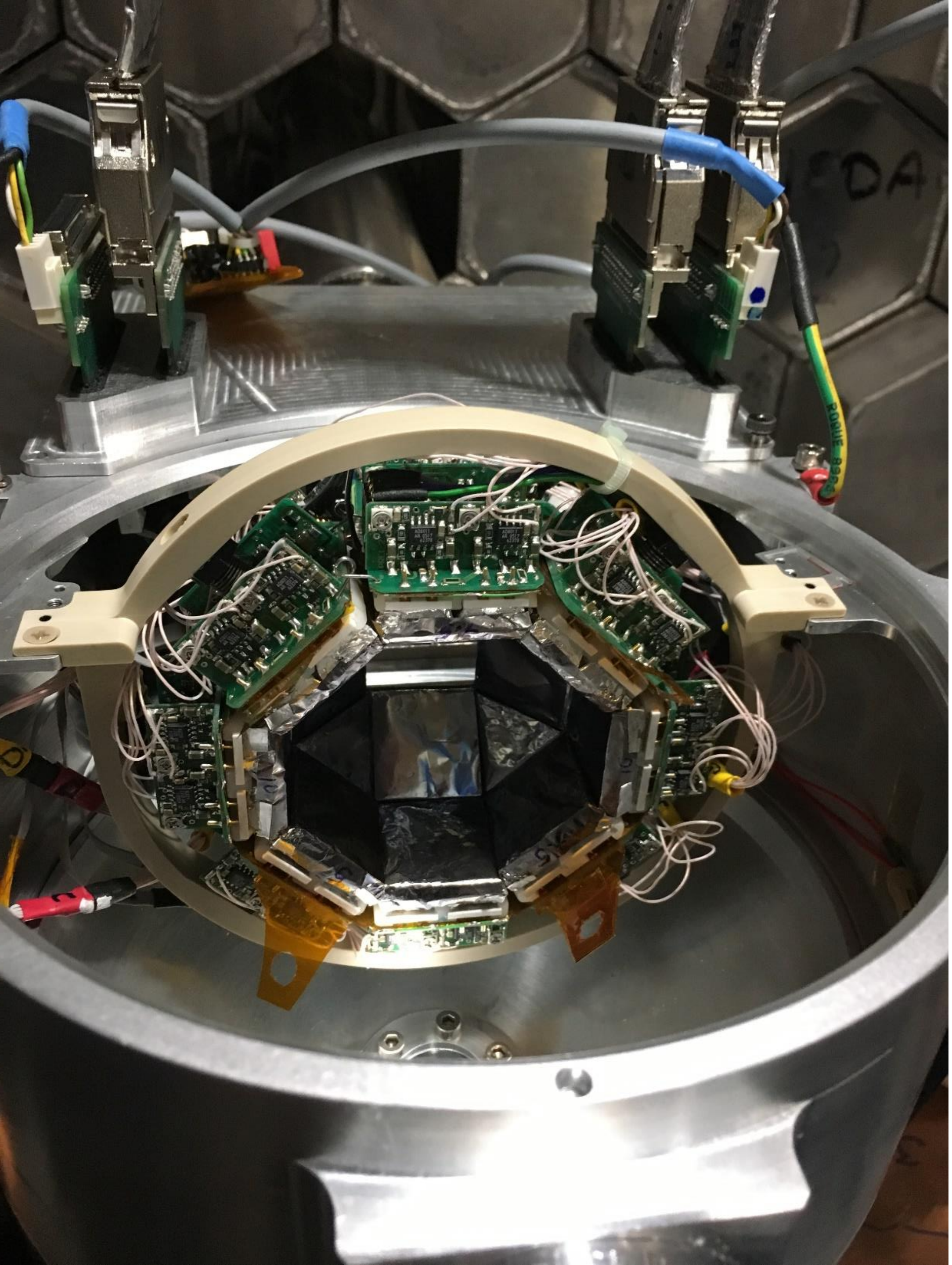
NEDA (+Nwall)

- 54 +42 BC501 scintillators
- NUMEXO2

Efficiencies (Ni+Fe):

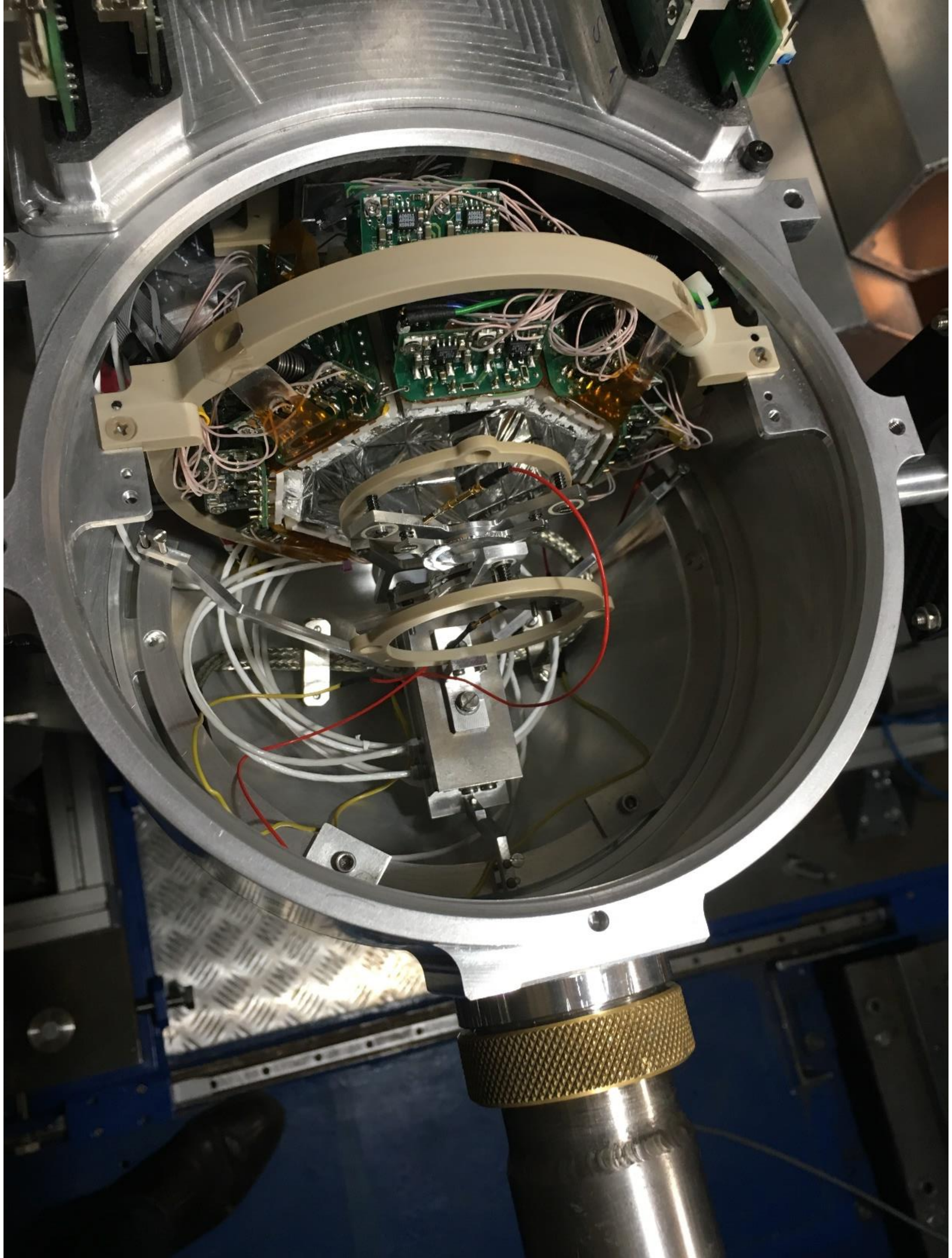
- $\varepsilon_{1n} \sim 0.30$
- $\varepsilon_{2n} \sim 0.07$

T. Huyuk et al., Eur. Phys. J. A (2016) 52



DIAMANT

- 64 (80) CsI
- NUMEXO2
- $\varepsilon_{\pi \text{ or } \alpha}$~0.4-0.5
- New target chamber
- Compatible plunger, target loader



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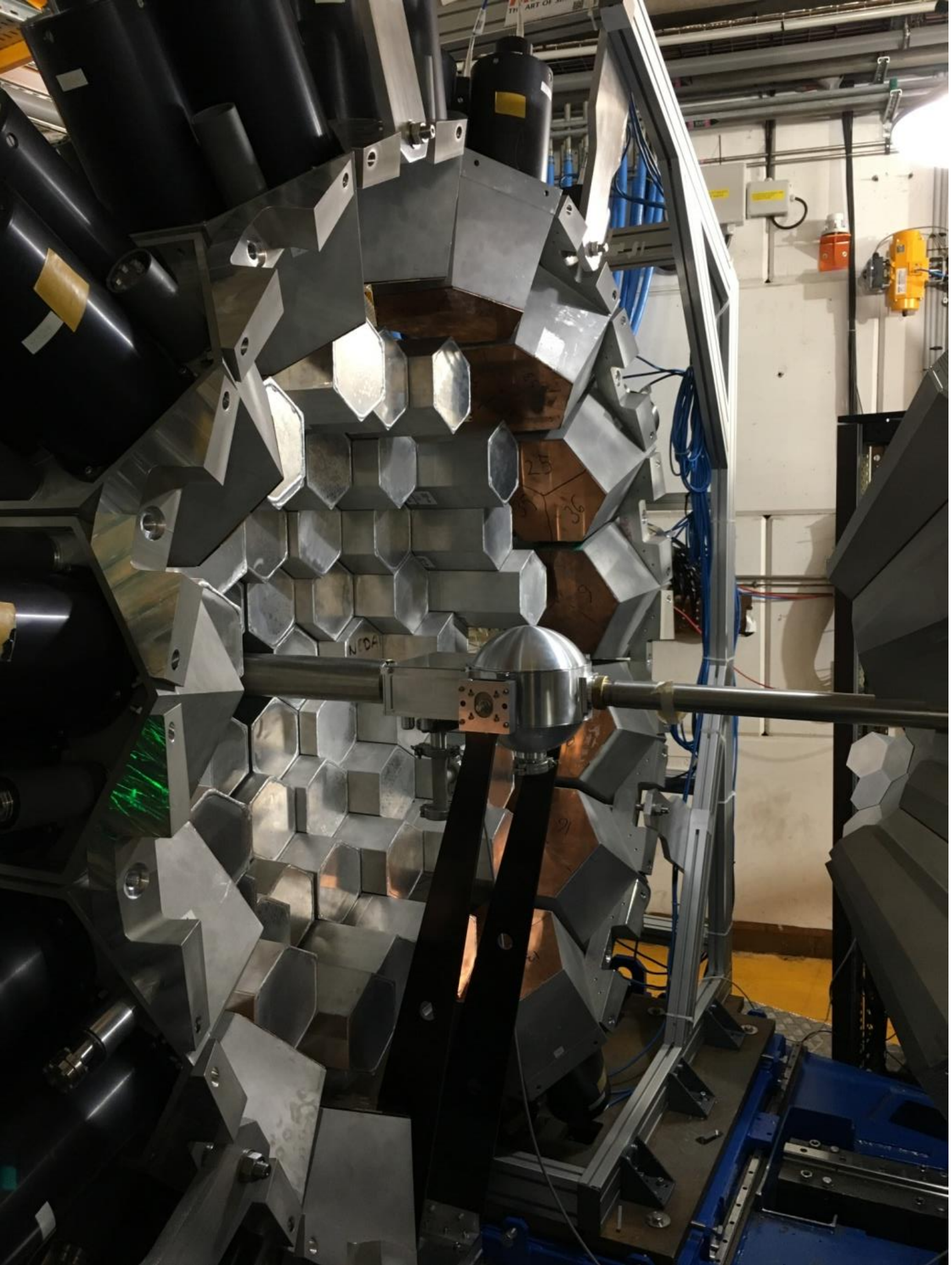


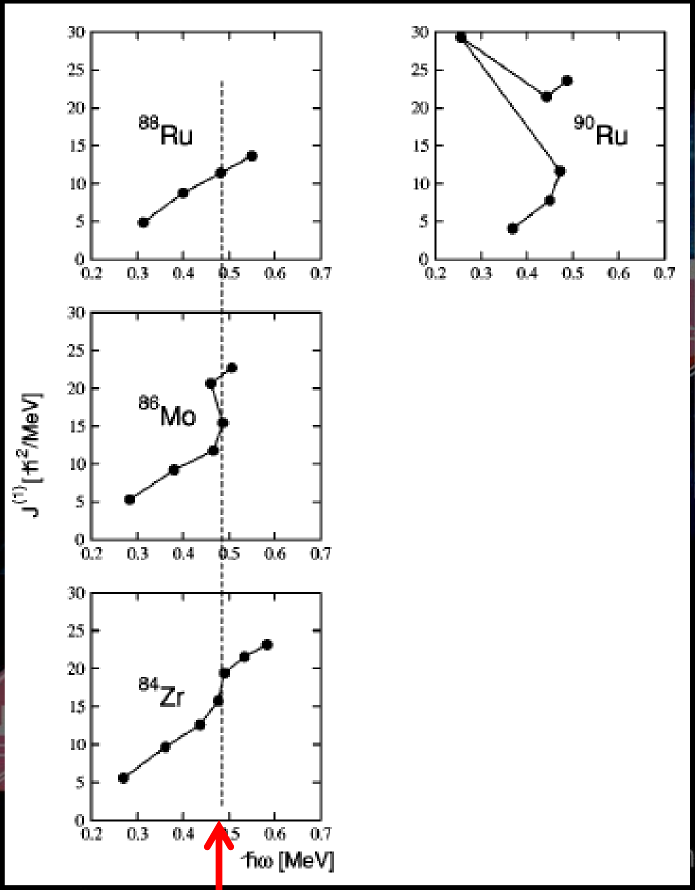
AGATA NEDA DIAMANT

35 AGATA Capsules
54 NEDA detectors
42 Nwall detectors
60 DIAMANT CsI in a newly designed target chamber

Rotational properties in ^{88}Ru:
a probe for T=0 pairing ?

N = 44

Z = 44



N Marginean et al, PRC 63, 031303(R), 2001

At J>0, T=0 pairs more bound than T=1?

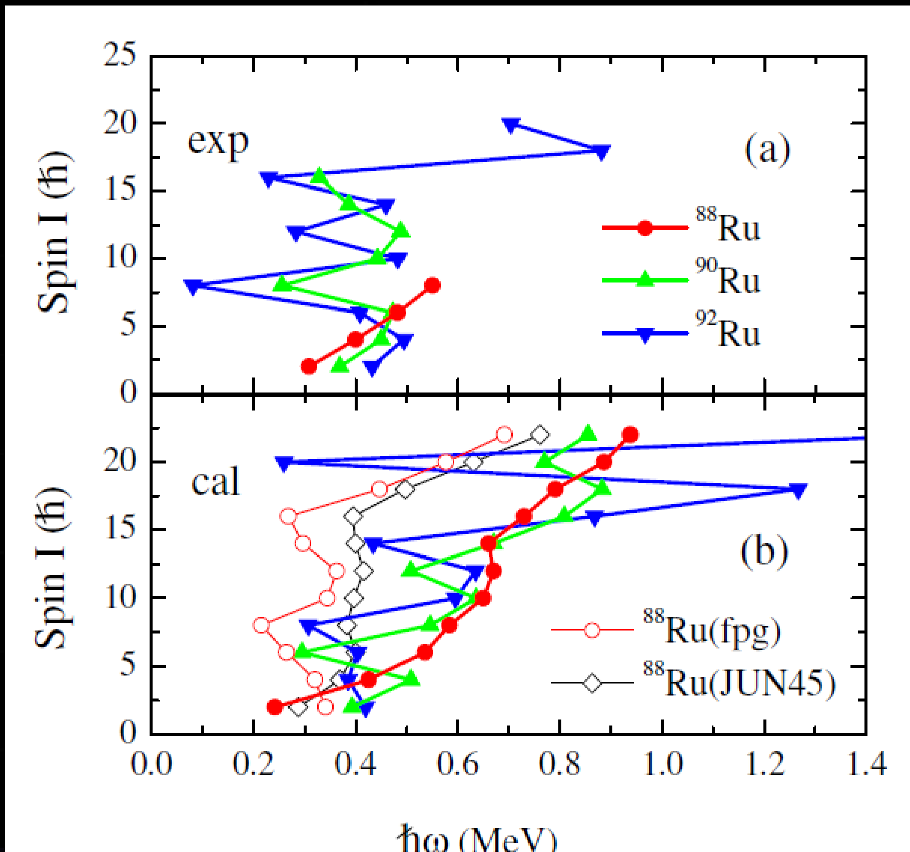
Delayed alignment?

➔ Higher spin

$g_{9/2}$ pair alignment in nuclei with A=80-90

Predictions for ^{88}Ru

New shell model (PMMU) interaction developed for $fpg_{9/2}d_{5/2}$ model space:
K Kaneko et al., Phys. Rev. C 89, 011302 (2014)



K. Kaneko et al NPA957 (2017) 144

PMMU: $H = H_o + H_P + H_M + H_m$

H_o = s.p,

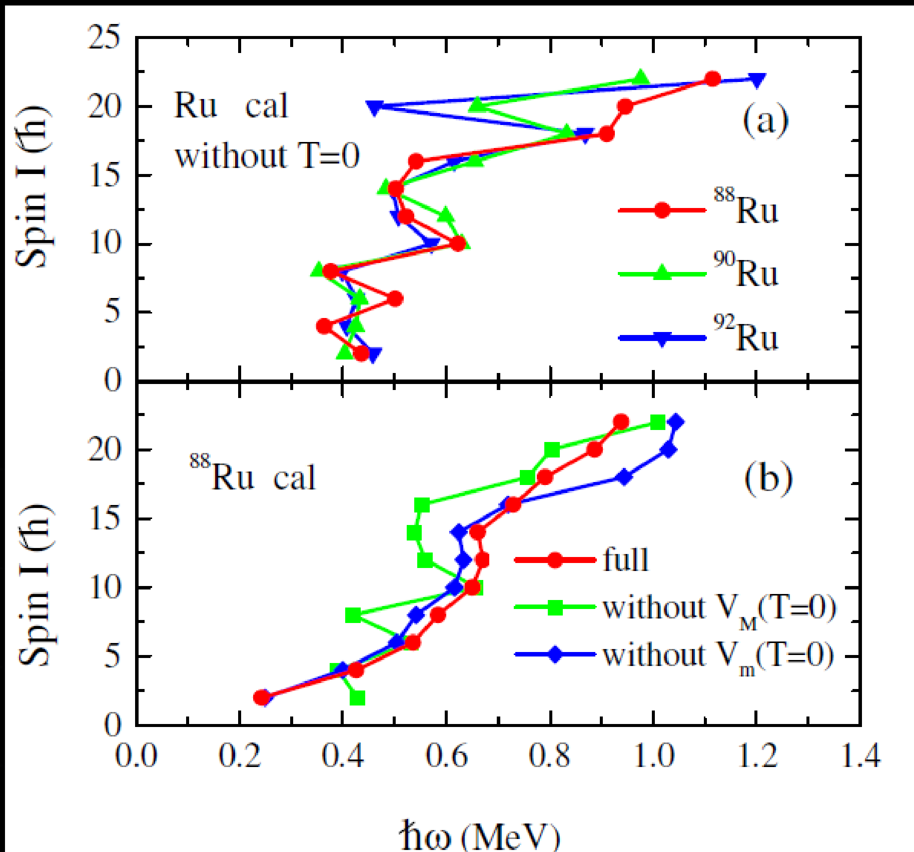
H_P = pairing,

H_M = multipole, contains QQ + OO components

H_m = monopole term

- New calcs reproduce (qualitatively) strong “zigzags” observed in ^{90,92}Ru
- Smooth evolution of I vs ħω in ^{88}Ru
- Delayed alignment

Predictions for ^{88}Ru



Kaneko et al NPA957 (2017) 144

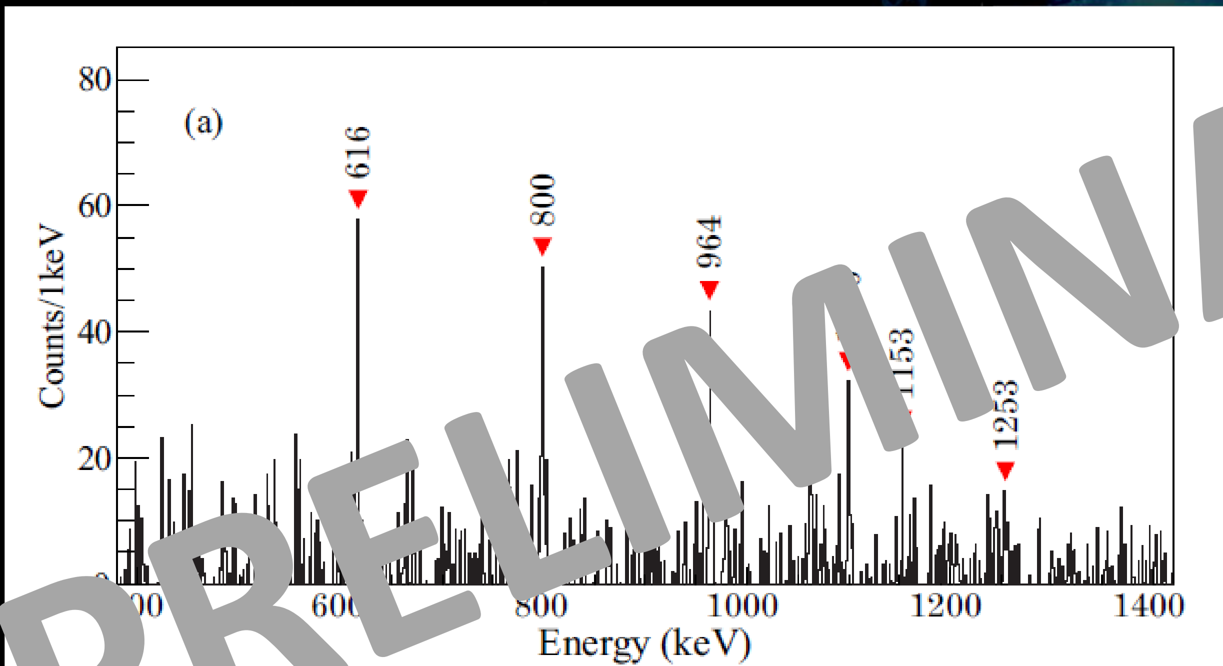
- Removing the isoscalar monopole (V_m, T=0) in the T=0, np interaction has no effect

- Strong deviation appears when removing the multipole part (V_M, T=0)

- loose the smooth behaviour experimentally observed which becomes similar to that in ^{90,92}Ru

QQ np T=0 is most important in ^{88}Ru

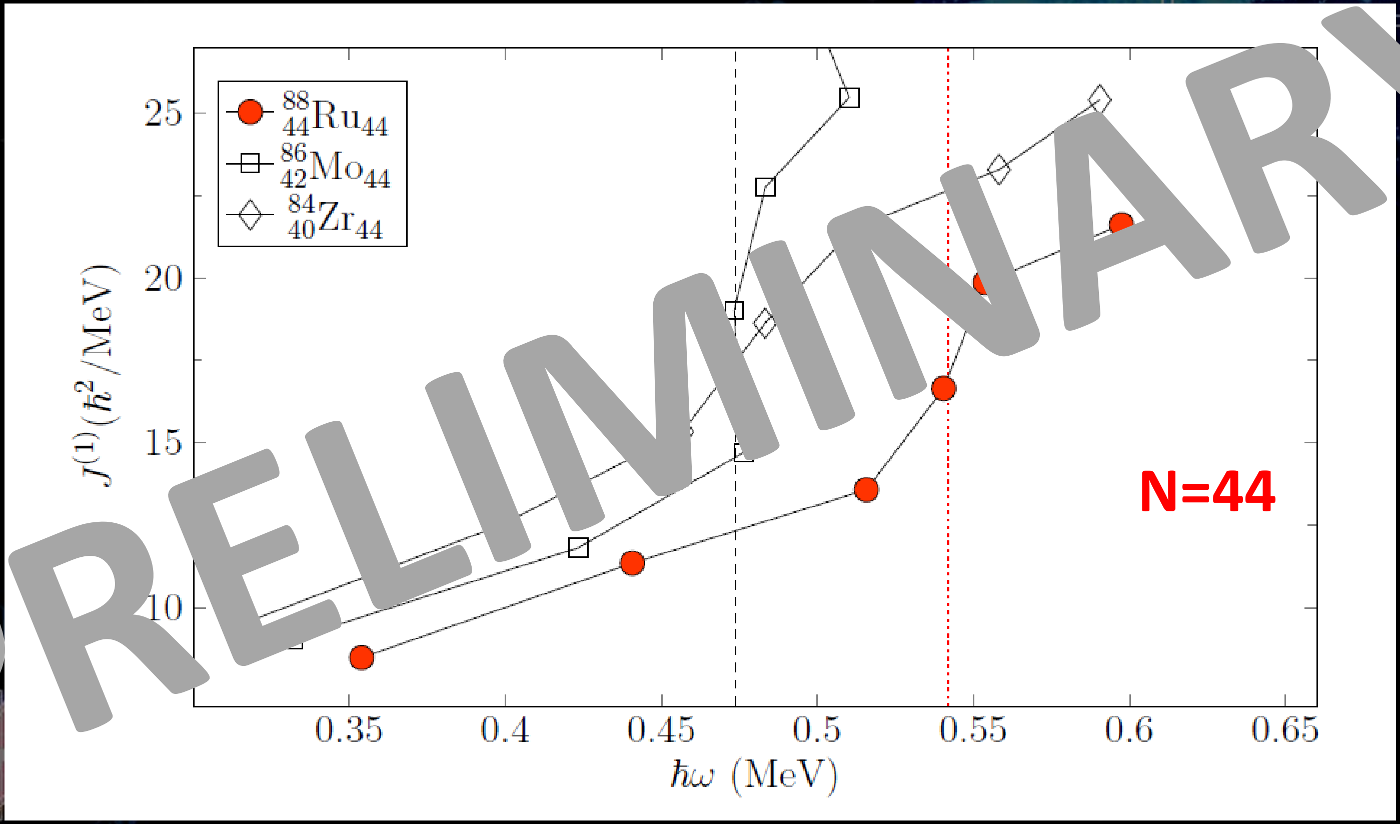
Rotational properties of N=Z nuclei: ^{88}Ru



B Cederwall et al

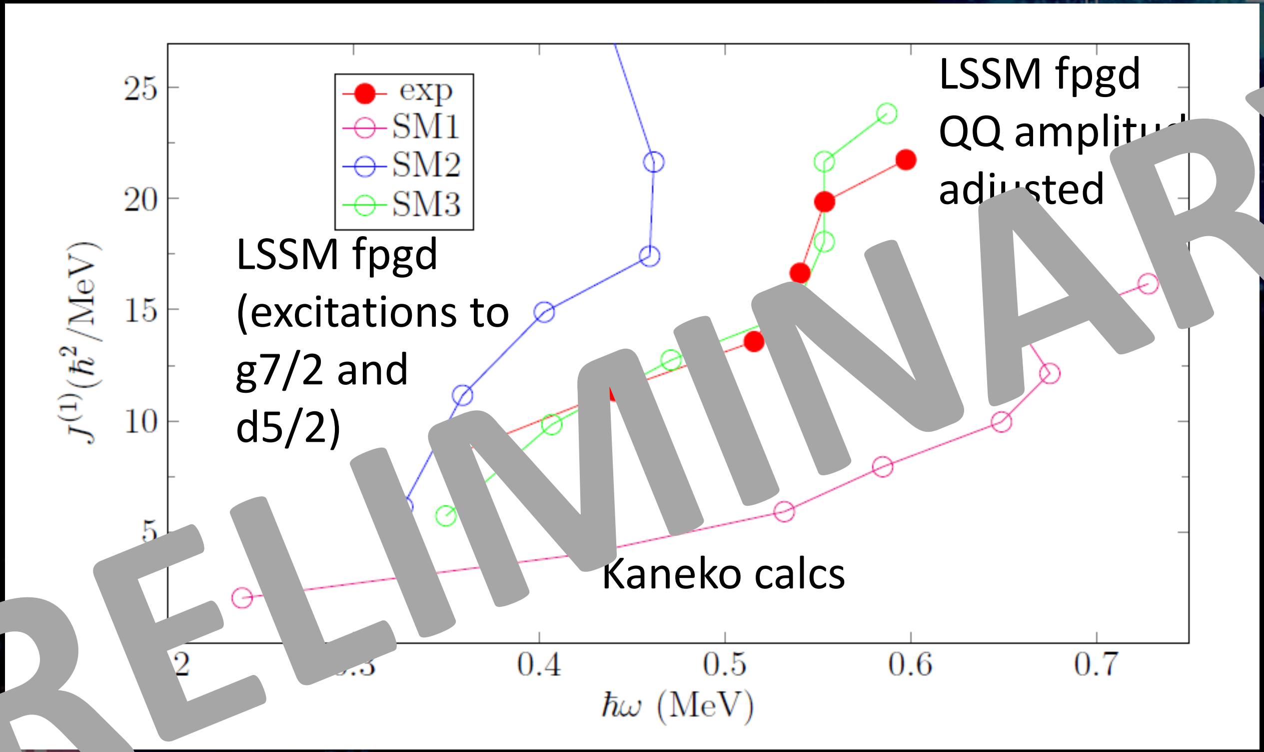
- Projection of Eγ-Eγ, 2n selected, CP veto
- Eγ in coincidence with 616, 800, 964 and 1100 keV transitions (known in ^{88}Ru)
- New transitions observed

Rotational properties of N=Z nuclei: ^{88}Ru



Delayed alignment confirmed in 88Ru

Rotational properties of N=Z nuclei: ^{88}Ru



PRELIMINARY

- Different SM hamiltonians (Moradi et al, Kaneko et al)
- Confirms the importance of excitations to g7/2 and d5/2 to describe the collective rotational behaviour of the band
- Need to increase the QQ amplitude by 9% to reproduce the data
- Number of np pairs; overlap with SM w.f. and that of the different pair coupling schemes => dominated by isoscalar np pair coupling

Summary

- Very rich physics program
- Several successful campaigns at GANIL
- MNT might an efficient mechanism to study N~Z nuclei
- The importance to measure states beyond just the 2+ (eg ^{108}Sn)
- Theoretical challenges
- Confirmation of seniority conservation at N=50
- Not a smoking gun proof but another piece of evidence of the role of T=0

Thank you

Special thanks to: M Palacz, E Clément, J Nyberg, S Lenzi, JJ Valiente Dobon, M Siciliano, A Gadea, R Perez, C Domingo-Pardo, X Egea, A Goasduff, G Jaworski, D Ralet, I Kuti
and the AGATA, NEDA, DIAMANT collaborations