Building a coherent physics picture around N=50 towards ^{78}Ni

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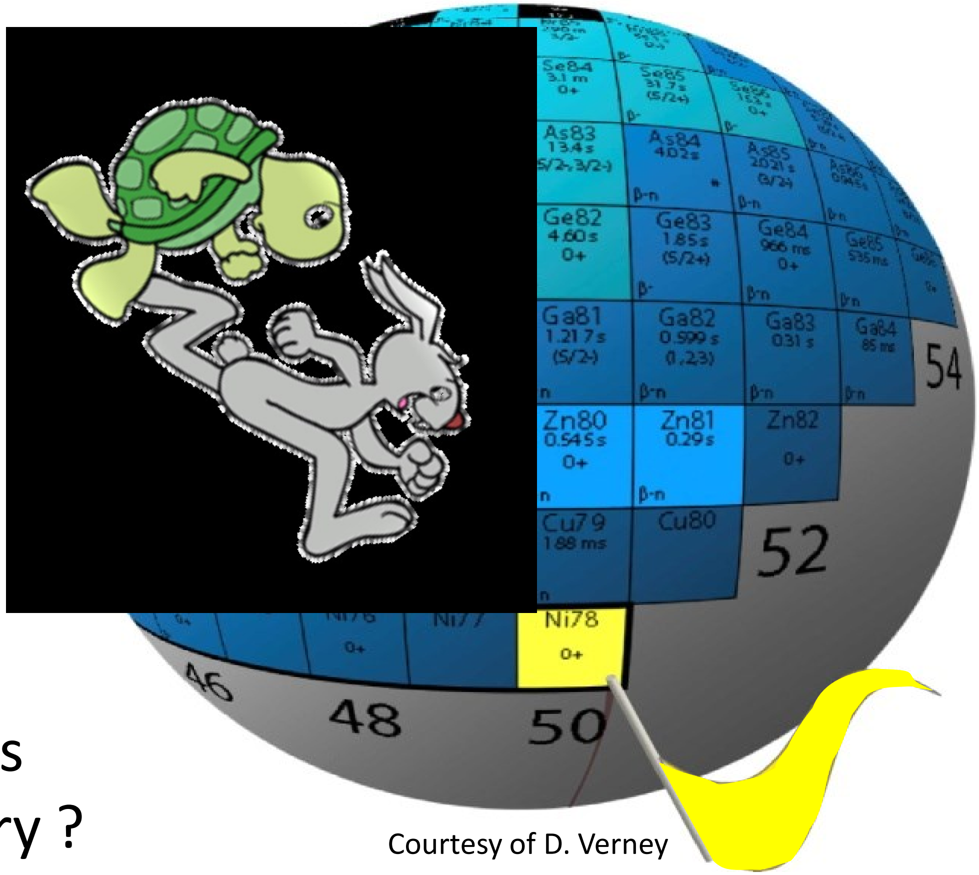
OUTLINE

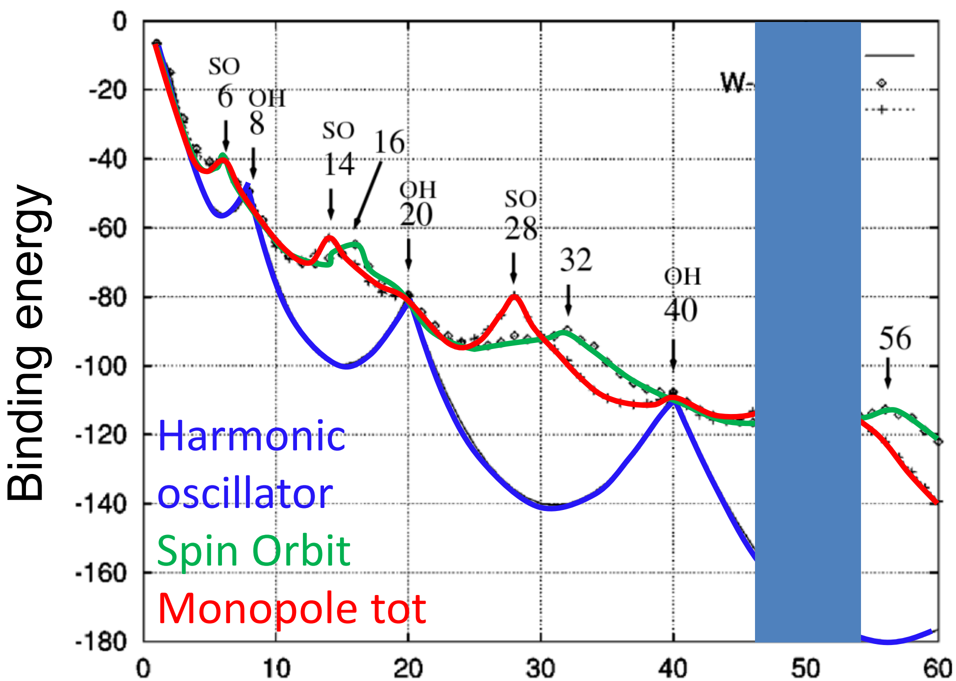
- Which shell gap ? The N=50 case
- N=50 «spectroscopic» gap
- Lifetime measurements around N=50 close to ^{78}Ni
- Intruder configurations as probes of shell structure
- Low-lying $\nu s_{1/2}$ shell and possible consequences
- Perspectives: a common physics driven by pseudo-spin symmetry ?



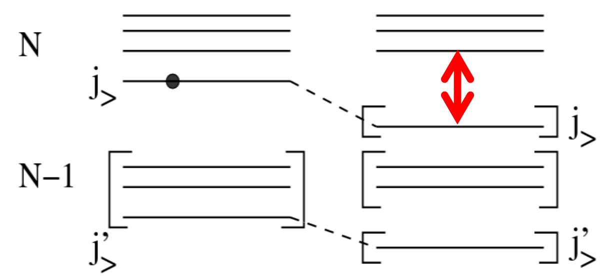
Courtesy of D. Verney

Shell closures: what is their origin ?

J. Duflo et A. P. Zuker, Phys. Rev. C 59, R2347 (1999)

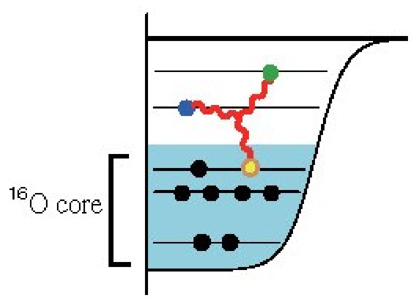


-the true origin of spin-orbit shell closures ?
-the role of the 3-body forces



3-body interactions produce “naturally” this mechanism

A. P. Zuker, Phys. Rev. Lett. 90, 042502 (2003)



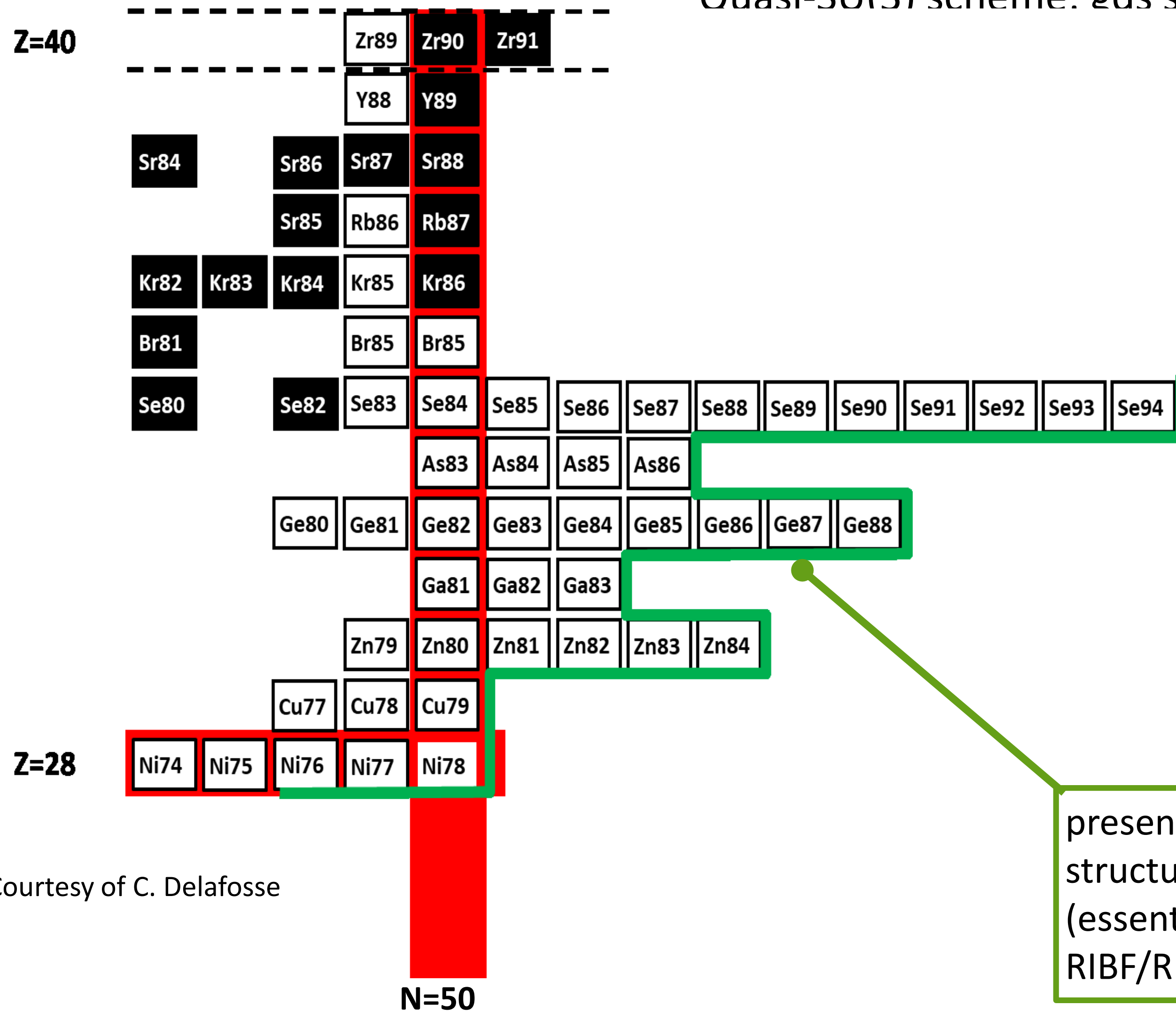
3-body generating SO gaps:

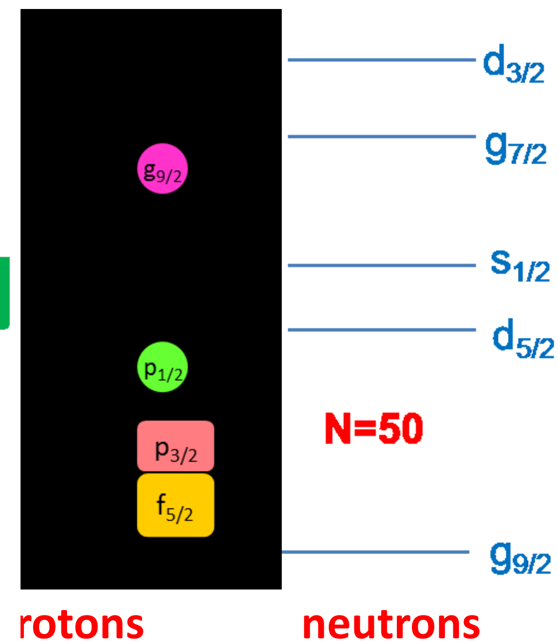
- N=14 in oxygen
- N=28 in calcium

T. Otsuka et al., Phys. Rev. Lett. 104, 012501 (2010),
J. D. Holt et al. arXiv :1009.5984v3 [nucl-th] (2012)

The N=50 region: a testing ground for shell structure

Quasi-SU(3) scheme: gds shells, similar case to

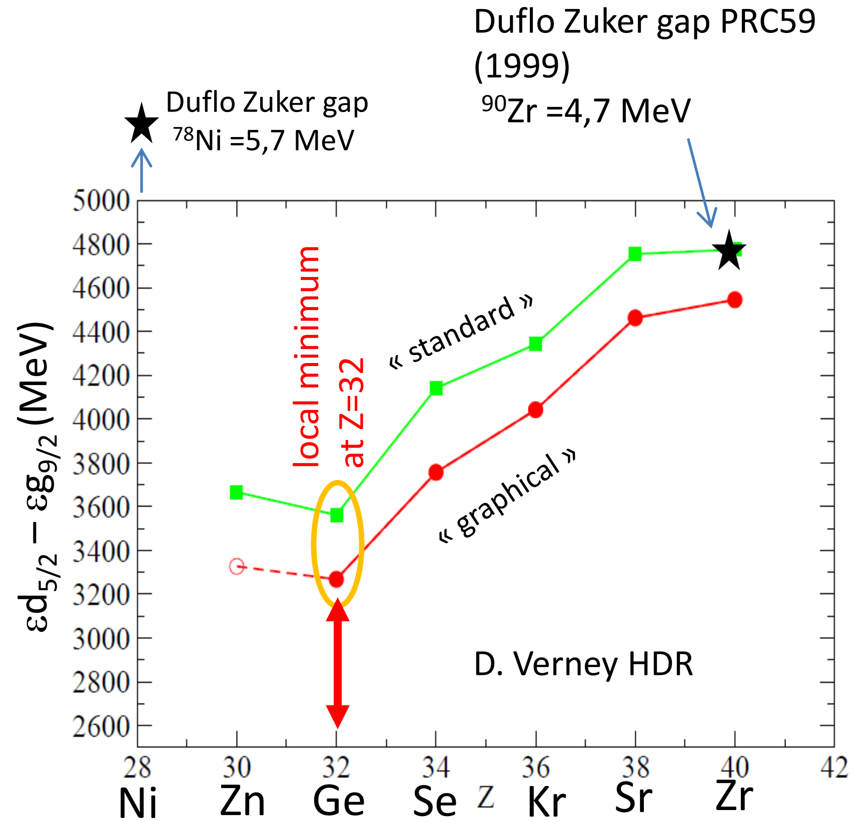




present limit on nuclear structure information (essentially established by RIBF/RIKEN)

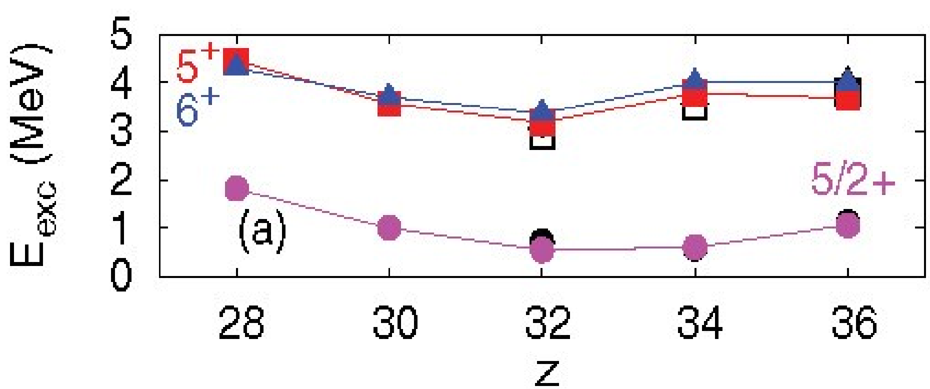
Courtesy of C. Delafosse

The N=50 shell closure: which gap ?



Reduction of the N=50 spherical **MASS GAP** from N=51 isotones mass

M.-G. Porquet and O. Sorlin, Phys. Rev. C 85, 014307 (2012)

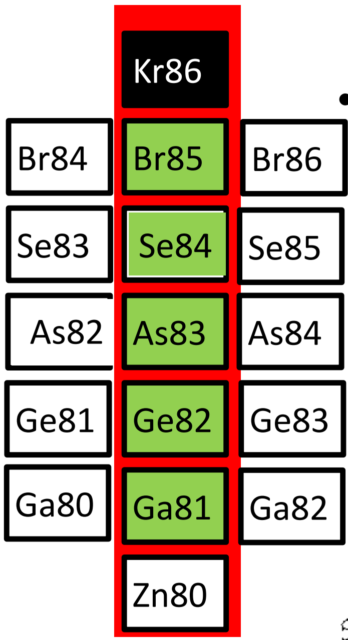


p-h states across N=50 in N=49 and N=50 isotones: minimum at Z=32

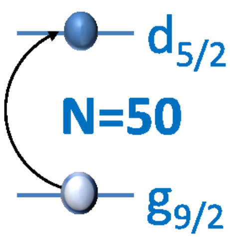
SPECTROSCOPIC GAP

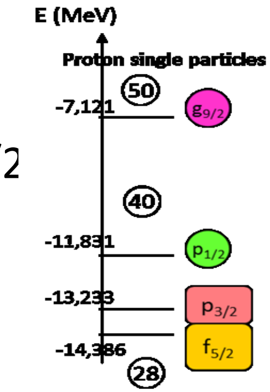
K. Sieja et F. Nowacki, Phys. Rev. C 85, 051301(R) (2012)

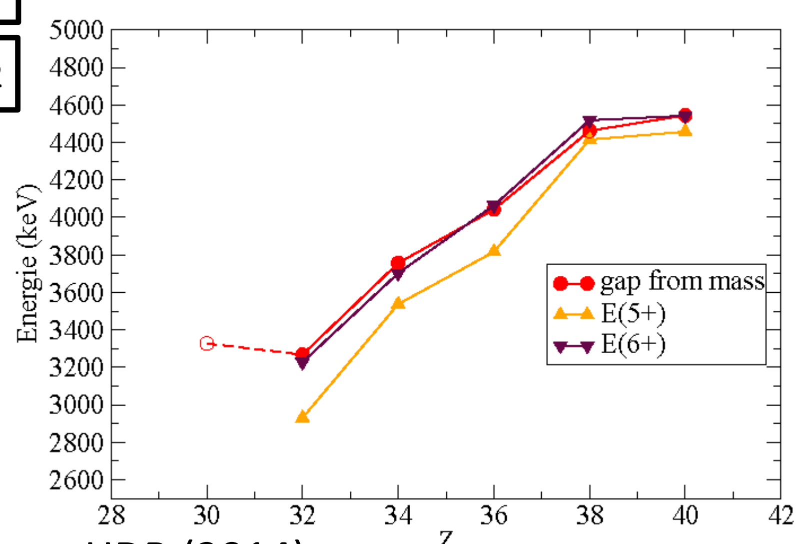
N=50 breaking 5^+ and 6^+ states



- $\pi f_{5/2}p_{3/2}p_{1/2}$: at low energy, maximum spin= even: 4^+
  odd: 11/2
- N=50 core breaking $\nu g_{9/2}^{-1}\ \nu d_{5/2}$= even: 5^+,6^+....
  odd: $13/2^-$...







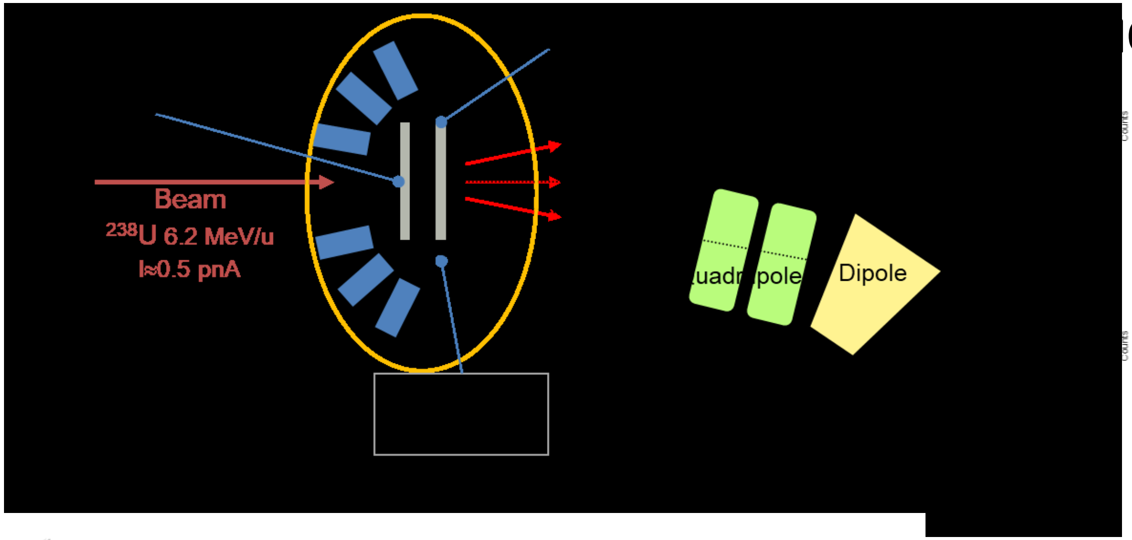
D. Verney HDR (2014)

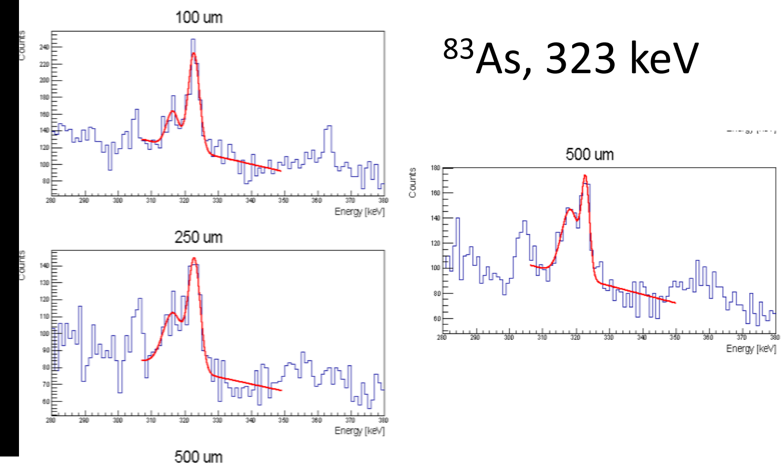
The gap is extracted from the 5^+,6^+ states with shell-model interactions (LNPS,psdg…)

Can they reproduce the wave function ?

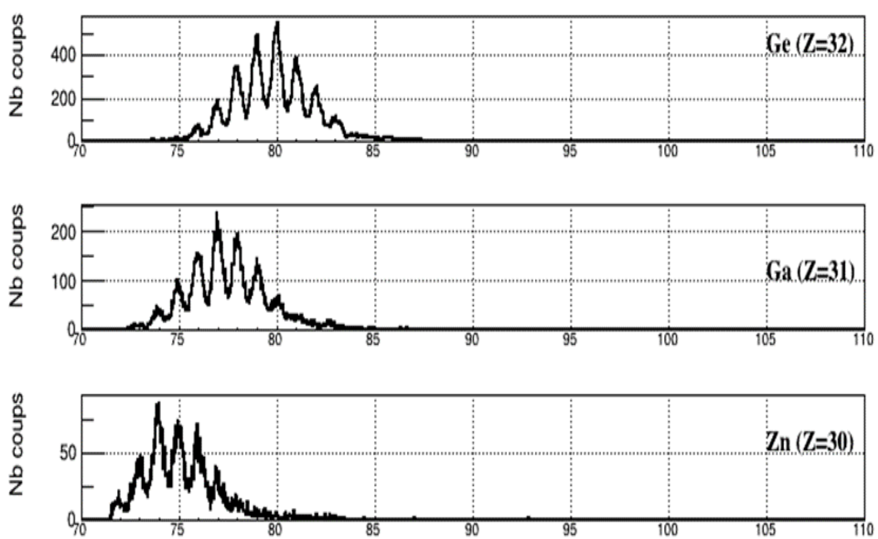
In-beam lifetimes measurements

OS setup @ GANIL





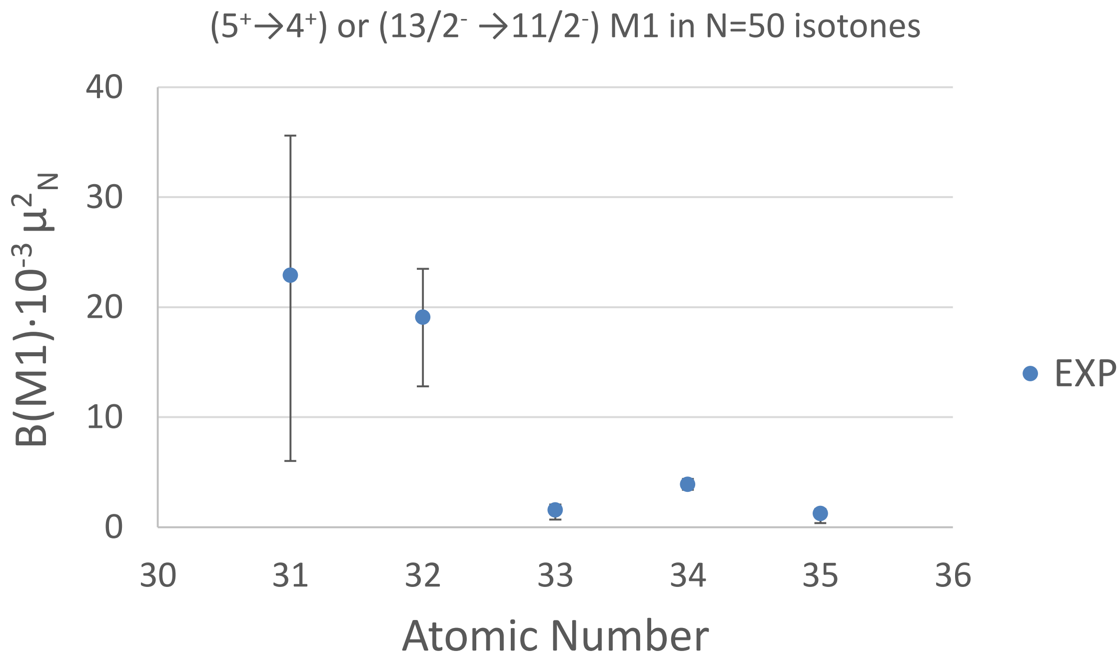
^{83}As, 323 keV



Nuclei	Transition		E_γ (keV)	τ (ps)	
^{81}Ga	$\frac{11}{2}^- \to \frac{9}{2}^-$	(E2/M1)	611.5	5^{+4}_{-3}	
^{82}Ge	$5^+ \to 4^+$	(E2/M1)	647	11^{+4}_{-3}	
^{83}As	$\frac{15}{2}^- \to \frac{13}{2}^-$	(E2/M1)	362.8	9^{+3}_{-2}	
	$\frac{13}{2}^- \to \frac{11}{2}^-$	(E2/M1)	1227.7	20^{+11}_{-6}	
	$? \to \frac{11}{2}^-$		911.1	~ 8	
	$\frac{11}{2}^- \to \frac{9}{2}^-$	(E2/M1)	322.8	10^{+3}_{-2}	(apparent)
	$\frac{9}{2}^- \to \frac{5}{2}^-$	(E2)	1543.3	14^{+19}_{-7}	(apparent)
^{84}Se	$6^+ \to 4^+$	(E2)	1580.2	14^{+7}_{-4}	
^{85}Br	$\frac{13}{2}^- \to \frac{11}{2}^-$	(E2/M1)	1160.5	21^{+11}_{-6}	(lower limit)

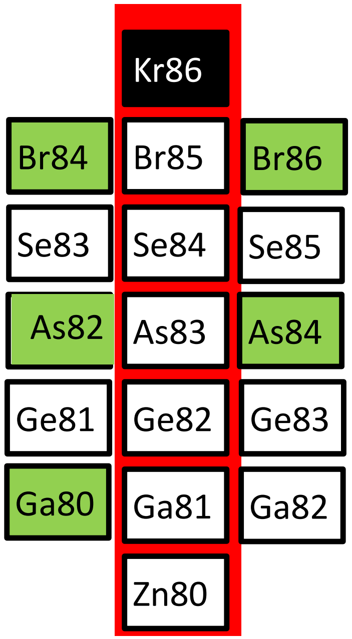
E. Vanzan University of Padova student

Results: suppressed B(M1)



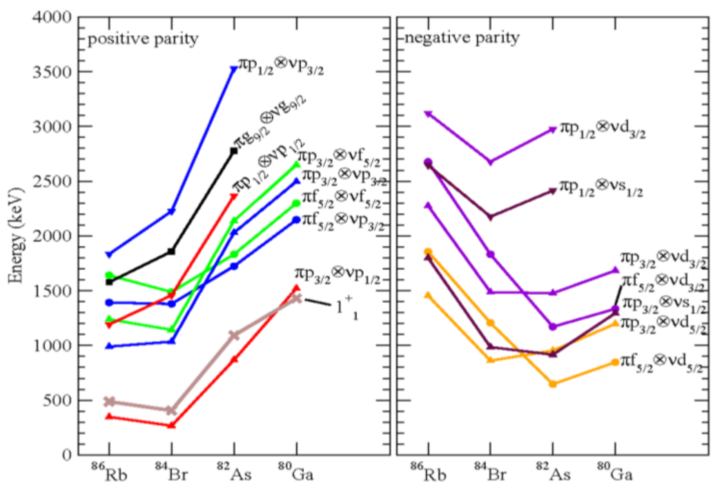
- LSSM calculations with LNPS are ongoing, first results seems not in disagreement with experimental data

In-beam lifetimes measurements: N=49, 51 odd-odd nuclei



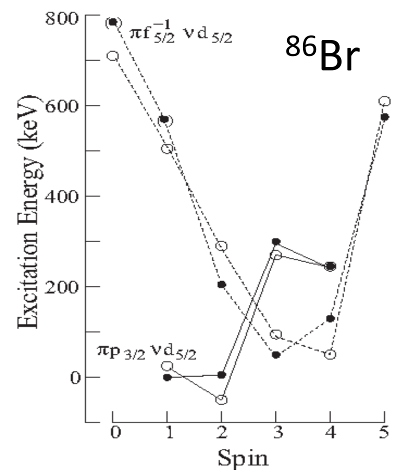
N=49 N=50 N=51

N=49: $\nu g_{9/2}^{-1}$ - $\pi f_{5/2} p_{3/2} p_{1/2}$ coupling
+intruder configurations



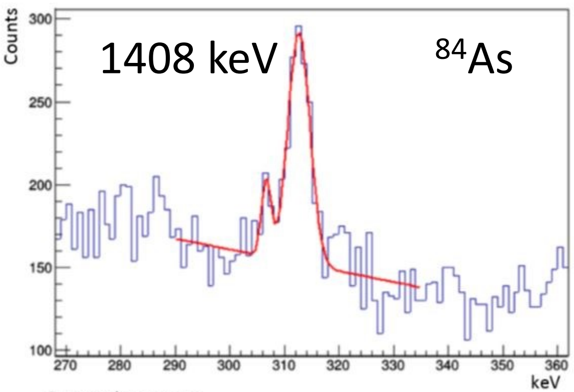
A. Etilè et al., Phys. Rev. C 91, 064317 (2015)

N=51: $\nu d_{5/2} s_{1/2}$- $\pi f_{5/2} p_{3/2} p_{1/2}$ coupling

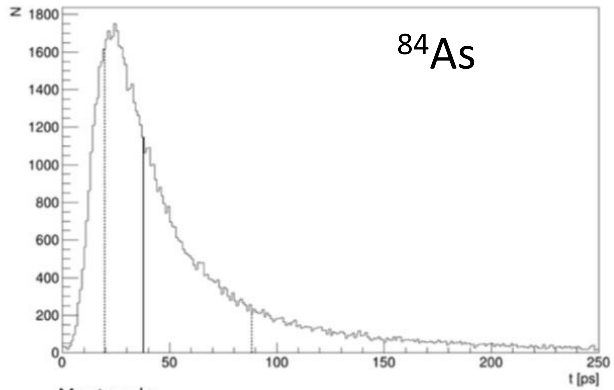


Level	Configuration $\pi p_{3/2}\,\nu d_{5/2}$	$\pi f_{5/2}^{-1}\,\nu d_{5/2}$
0_1		67 %
1_1	74 %	
1_2	8 %	54 %
2_1	66 %	
2_2	5 %	65 %
3_1	37 %	28 %
3_2	41 %	34 %
4_1		61 %
4_2	84 %	
5_1		67 %

N=51 odd-odd nuclei: results



Summed spectrum

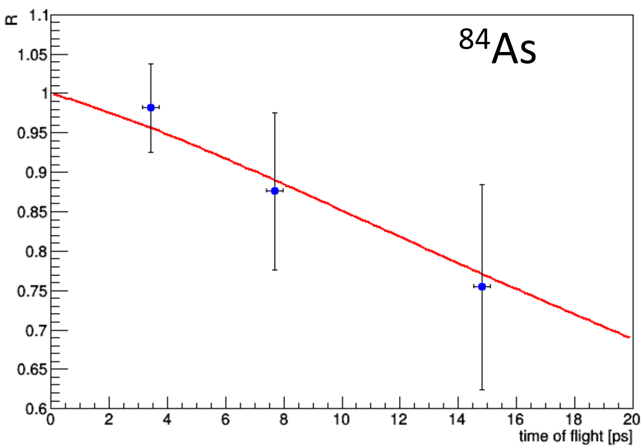


Montecarlo results

1408 keV lifetime determination with sum of three distances

D. Dal Santo, G. Valerin University of Padova students

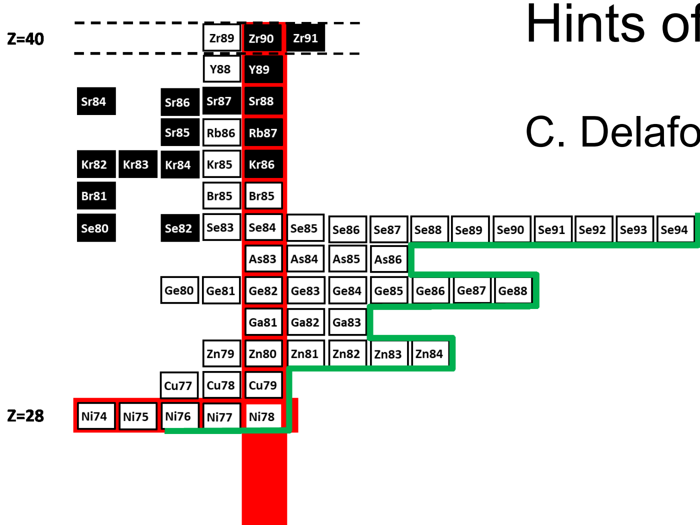
313 keV lifetime fit



^{84}As scheme built based on $\gamma\gamma$ coincidences:

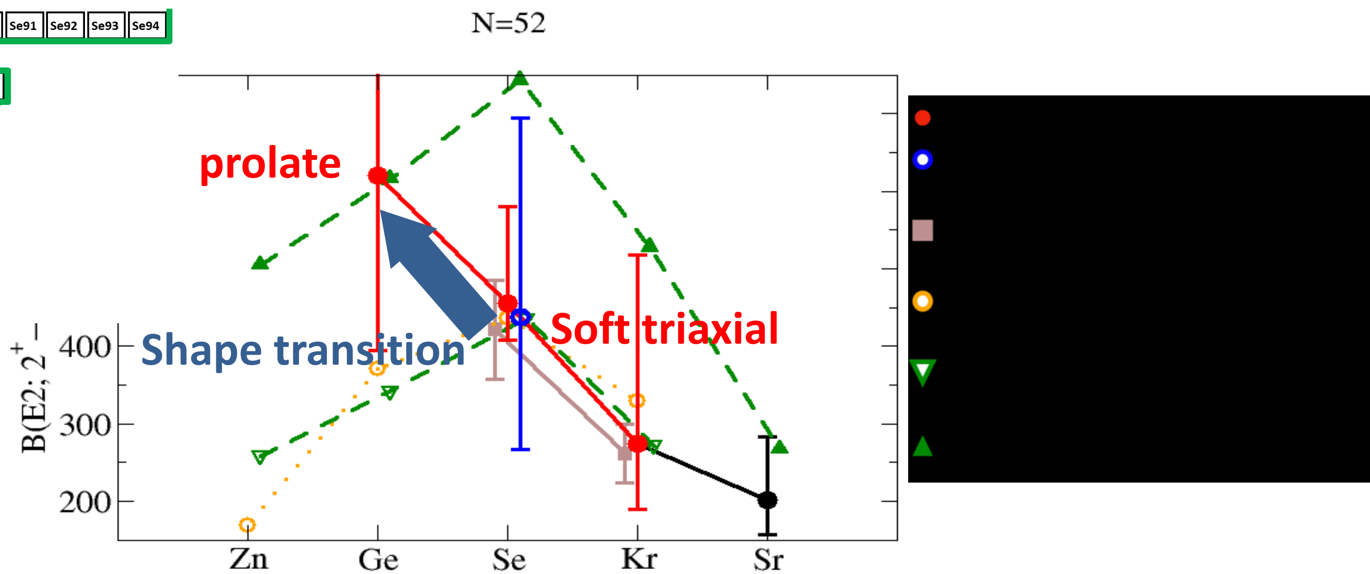
Nuclide	E_γ [keV]	Transition	$\tau[ps]$	$B(E, M\lambda)$ [W.u.]
^{86}Br	331	$5^- \to 4^-$ (M1)	7.4 ± 1.8	$1.2 \pm 0.3 \cdot 10^{-1}$
^{84}Br	194	$8^+ \to 7^+$ (M1)	$12.6^{+8.2}_{-4.5}$	$3.5^{+1.2}_{-2.2} \cdot 10^{-1}$
	972	$7^+ \to 7^-$ (E1)	$4.1^{+5.4}_{-2.8}$	$1.4^{+0.9}_{-1.4} \cdot 10^{-4}$
	530	$7^- \to 6^-$ (M1)	$25.9^{+18.1}_{-8.8}$	$8.2^{+2.8}_{-5.7} \cdot 10^{-3}$
^{84}As	1408	$7^+ \to 5^-$ (M2)	$7.2^{+4.5}_{-3.0}$	$5.9^{+2.4}_{-3.7} \cdot 10^{1}$
	313	$5^- \to 4^-$ (M1)	43 ± 22	$2.4 \pm 1.2 \cdot 10^{-2}$
	1019	$6^- \to 4^-$ (E2)	$3.8^{+2.4}_{-1.7}$	$8.9^{+4.0}_{-5.6} \cdot 10^{0}$
^{82}As	218	unknown	9.0 ± 3.0	
	278	unknown	6.6 ± 2.0	
	656	unknown	$9.8^{+5.5}_{-3.4}$	
	410	unknown	> 40	
^{80}Ga	401	unknown	$12.5^{+9.4}_{-4.7}$	

Large B(E2) value in N=52 ^{84}Ge



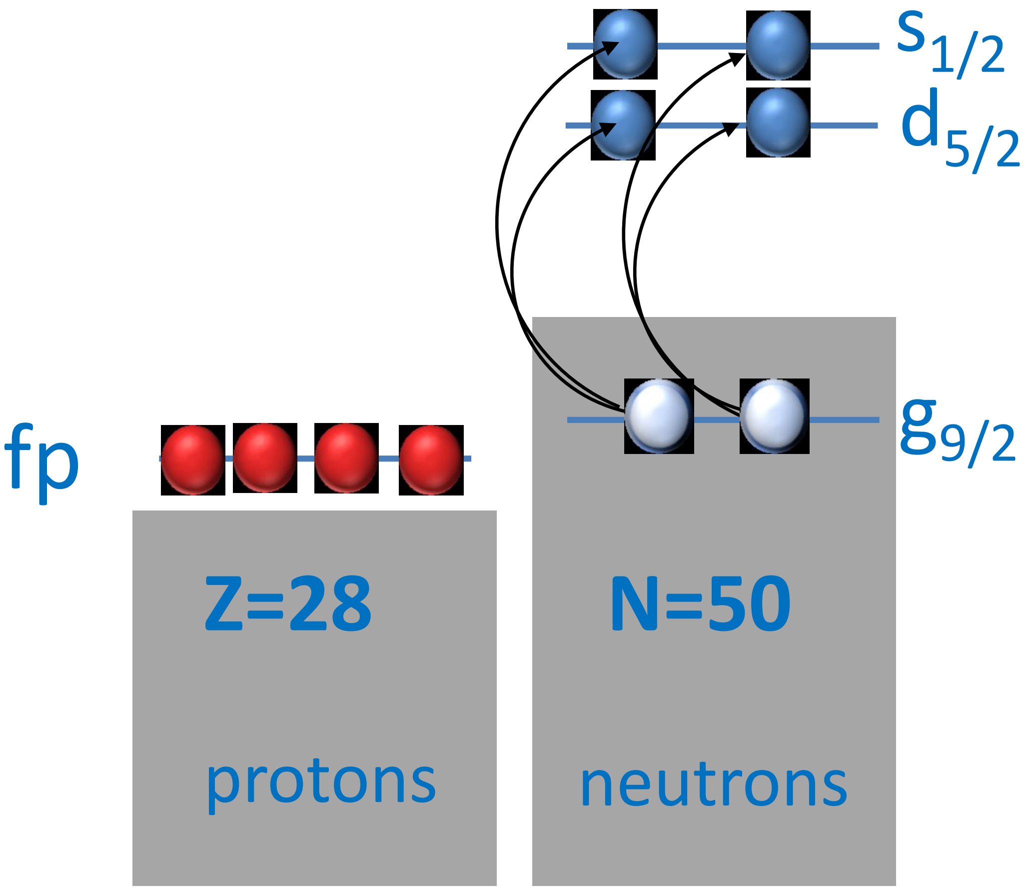
Hints of a shape transition along the N=52 isotonic line

C. Delafosse et al. Phys. Rev. Lett. 121 192502(2018)



- Monotonic increase of the B(E2) along N=52: no midshell maximum ?
- Is the large B(E2) a signature of an intruder configuration in ^{84}Ge ?

p-h intruder states as probes of gap



particle – hole across N=50

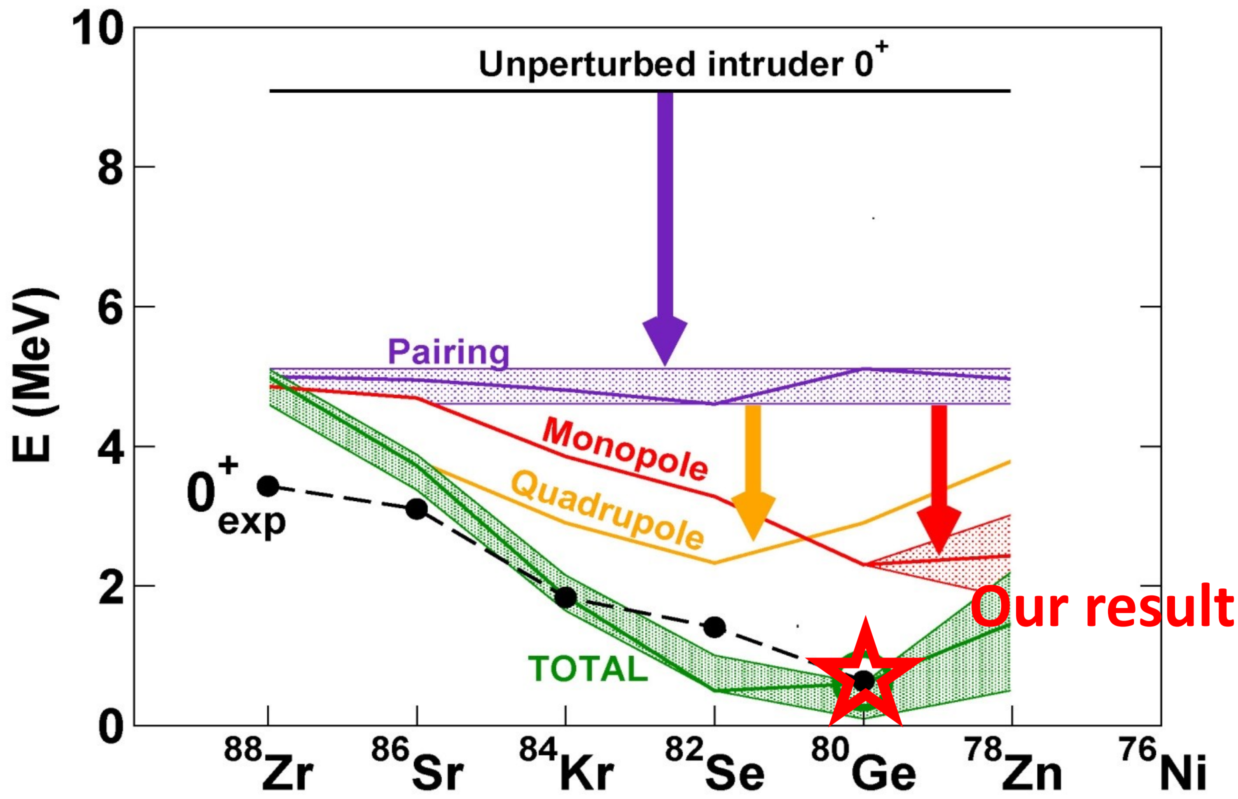
- Spherical gap (p-h):

energy cost

- Correlations by breaking the core:

energy gain

Results on even-even N=48 isotones



Shape coexistence in ^{78}Ni ?

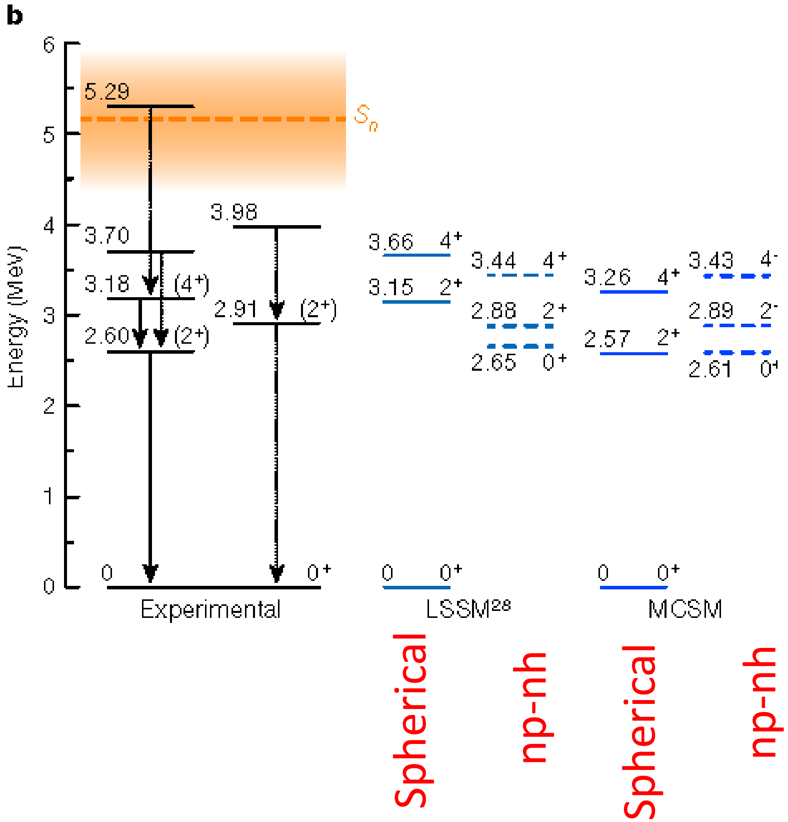
- Monopole evolution towards Z=28: mass measurement in ^{83}Zn
- Reduction the Z=28 gap (increased quadrupole) ?

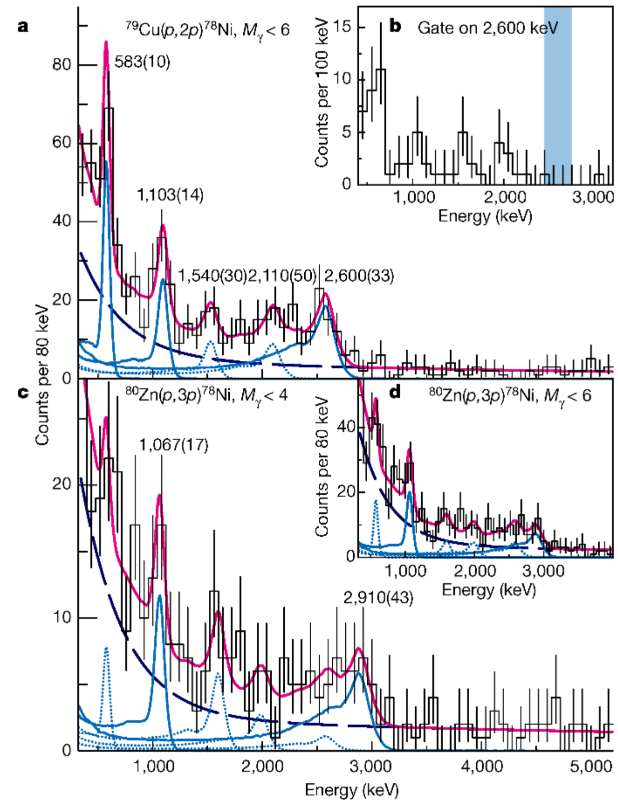
Possibility of finding a (2p-2h) 0^+ state in ^{78}Ni around 2.5 - 3 MeV

A. Gottardo, D.Verney et al.,
Phys. Rev. Lett. 116, 182501 (2016)

First Spectroscopy of ^{78}Ni

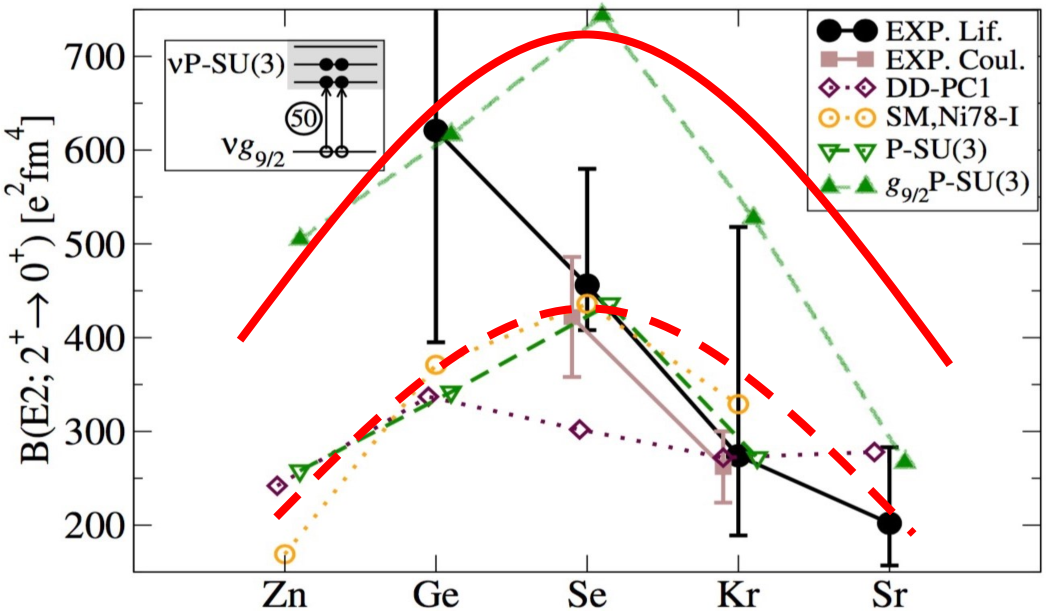
R. Taniuchi et al., Nature **569**, 53–58 (2019)

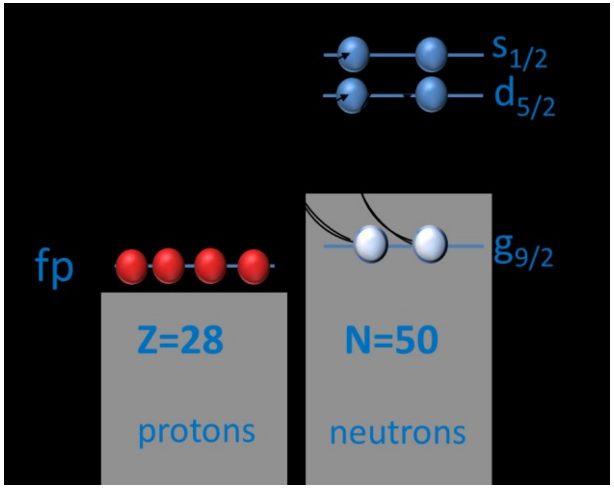




- 2^+ energy at 2.6 MeV
- Intruder configuration (2p-2h, 4p-4h) at low energy, predicted by LSSM

What about the large B(E2) in ^{84}Ge ?

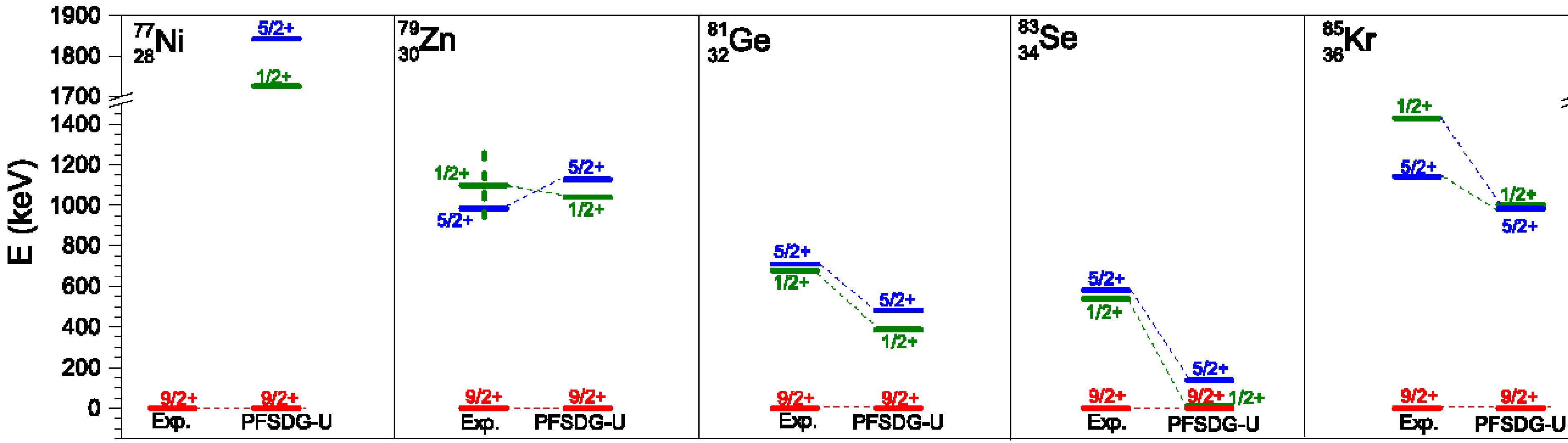




C. Delafosse et al. Phys. Rev. Lett. 121 192502(2018)

T. Nikšić, P. Marević, and D. Vretenar, Phys. Rev. C89, 044325 (2014)

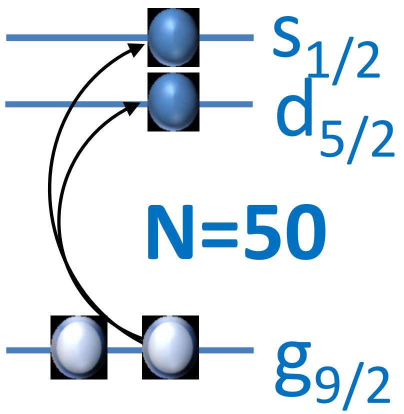
Intruder states in N=49 isotones (1)



C. Wraith et al., Physics Letters B 771 (2017) 385–391

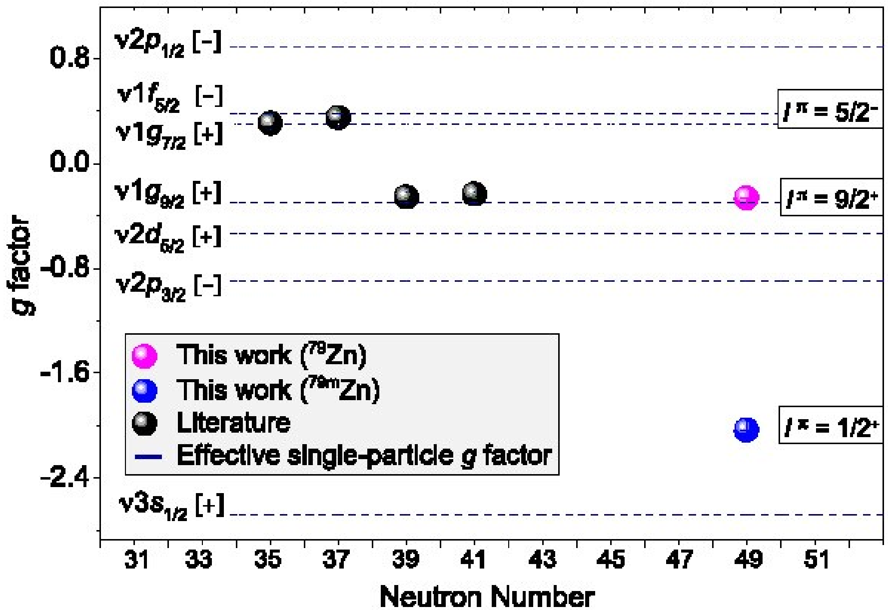
Intruder states (1p-2h) in N=49 states:

- Minimum at Z=34
- Inversion $1/2^+$ - $5/2^+$
- Pure $s_{1/2}$ wave function ? Shape ?



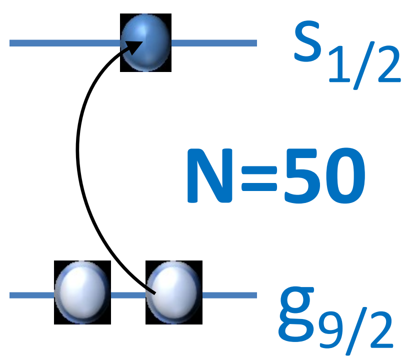
Intruder states in N=49 isotones (2)

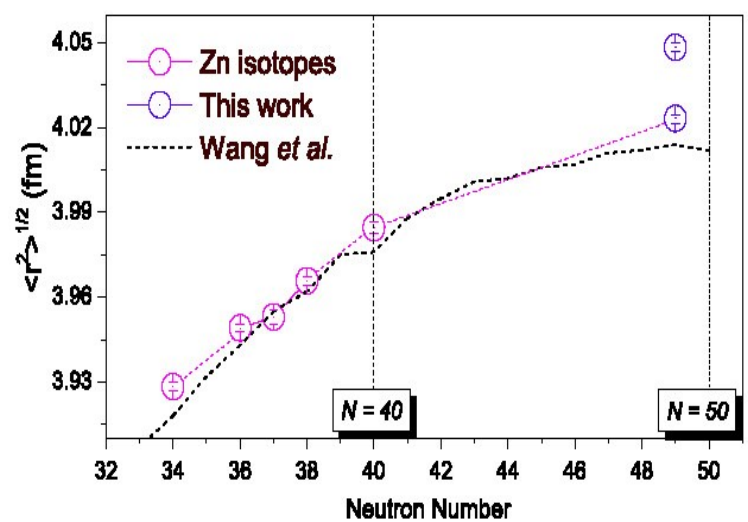
X. F. Yang et al. Phys. Rev. Lett. 116, 182502 (2016)



1. The $1/2^+$ state in ^{79}Zn has a dominant $\nu(g_{9/2}^{-2}\, s_{1/2})$ character

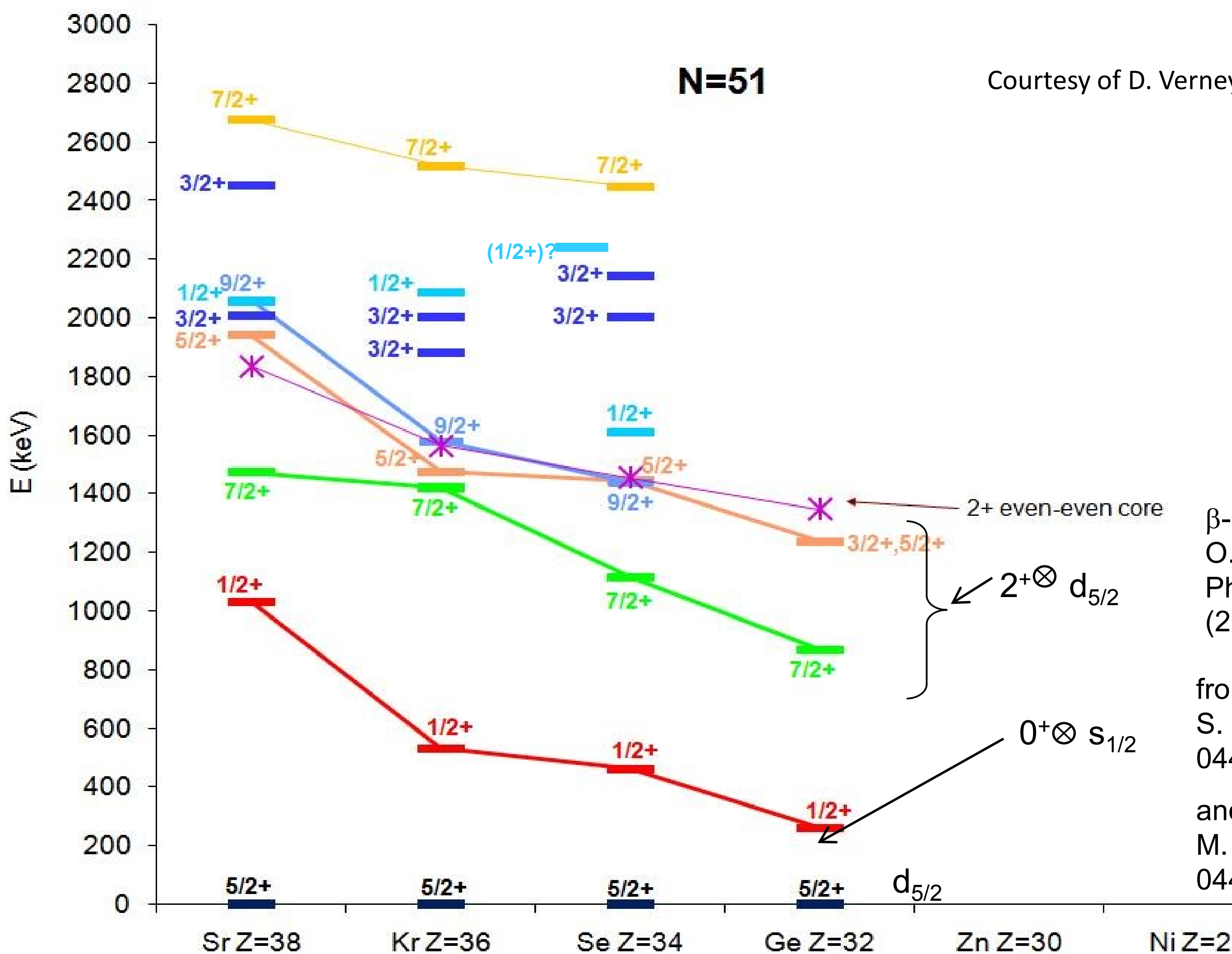
2. Large isomer shift. Interpreted as large intrinsic deformation (β ~0.22) of the intruder state, but the observable is <Q>





Lowering of the $s_{1/2}$ shell

Coupling to continuum: G. Hagen, Phys. Rev. Lett. 117, 172501 (2016)

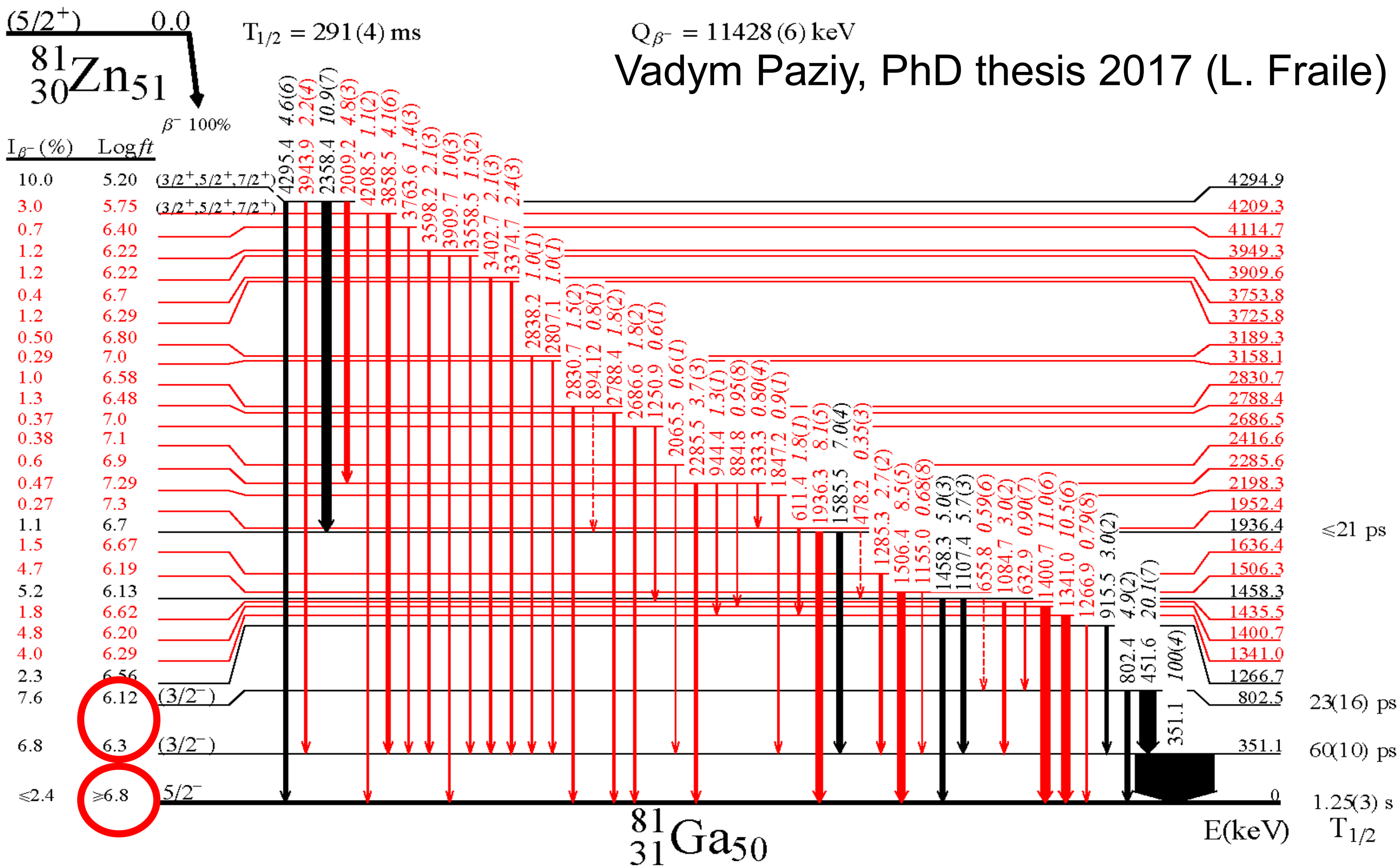


β-decay at Orsay O. Perru et al. Eur. Phys. J. A 28, 307 (2006)

from (d,p) Oak Ridge : J. S. Thomas et al. PRC **76**, 044302 (2007)

and βn-decay at Orsay : M. Lebois PRC **80**, 044308 (2009)

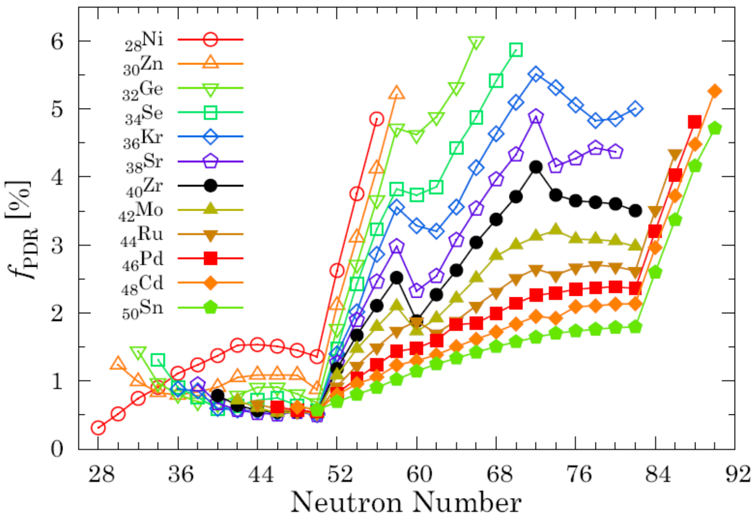
Is $s_{1/2}$ the ground state in ^{81}Zn ?



Low β feeding of the 5/2- ground state in ^{81}Ga: a unique FF transition ?

$\nu s_{1/2}$ shell and β decay ? Study at BEDO

Strong increase of PDR after N=50 in Ge, Zn, Ni linked to an increased skin thickness



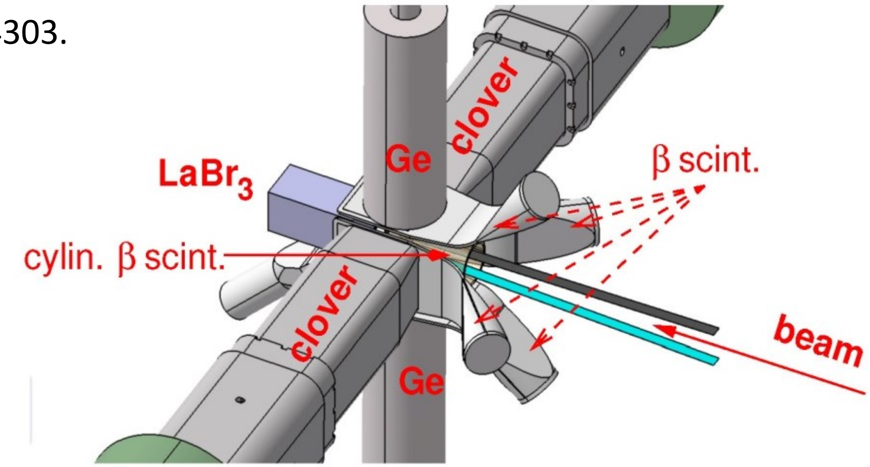
S. Ebata, T. Nakatsukasa, T. Inakura, Phys. Rev. C 90 (2013) 024303.

- β-decay populates part of the pygmy dipole resonance

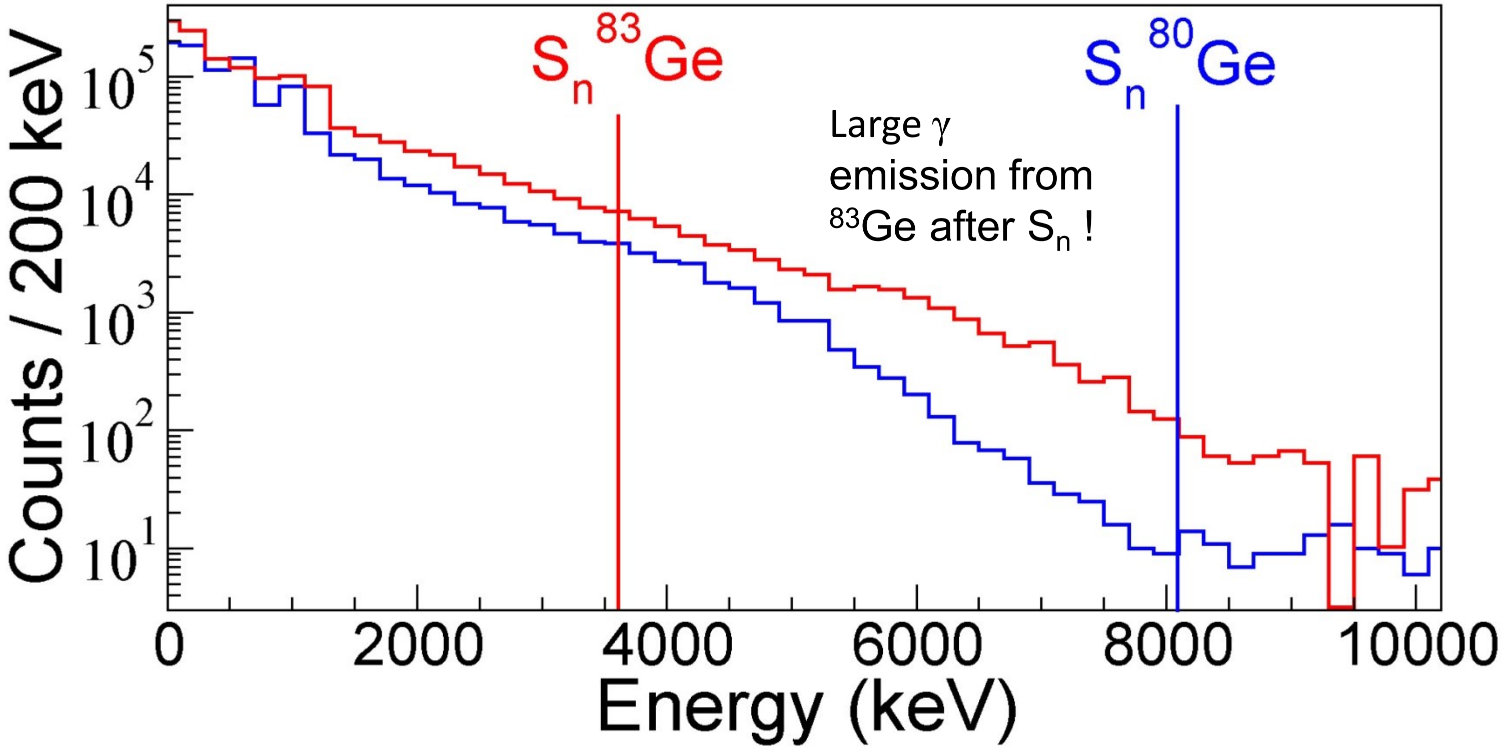
M. Sheck et al. : PRL 116, 132501 (2016)

BEDO setup @ ALTO (IPNO) with large $LaBr_3$

- ^{80,83}Ga beams from ISOL ALTO
- Large $LaBr_3$, 2 clovers, 2 coaxial Ge



^{83}Ga - ^{80}Ga β decay: high energy



After N=50

^{83}Ga → ^{83}Ge (15%), ^{82}Ge (85%)

Before N=50

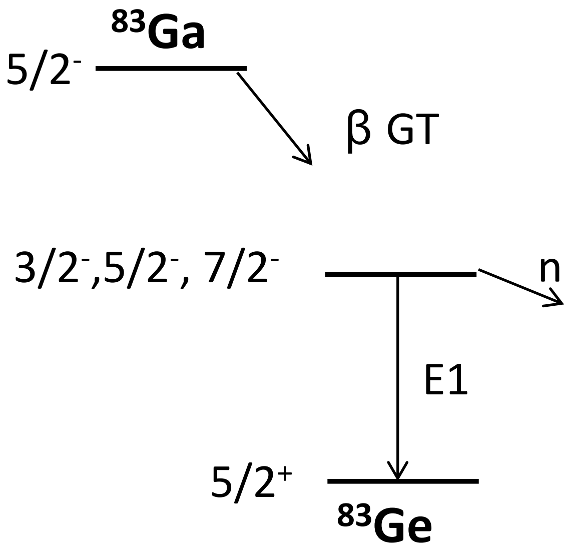
^{80}Ga → ^{80}Ge (98%), ^{79}Ge (2%)

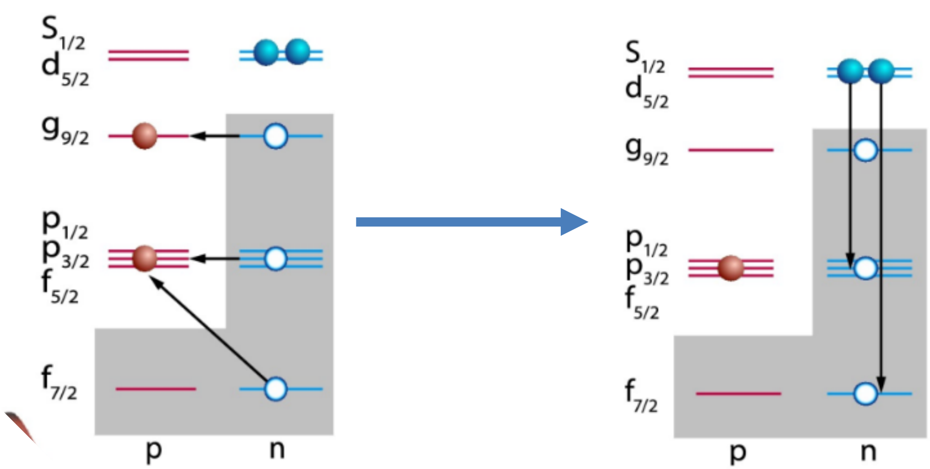
A. Gottardo et al, Phys. Lett. B 772 (2017) 359–362

In total 16(4)% of absolute γ strength beyond S_n in ^{83}Ge

3.5% $I_{\beta\gamma}$ in J.L. Tain et al. Phys. Rev. Lett., 115, 062502 (2015)

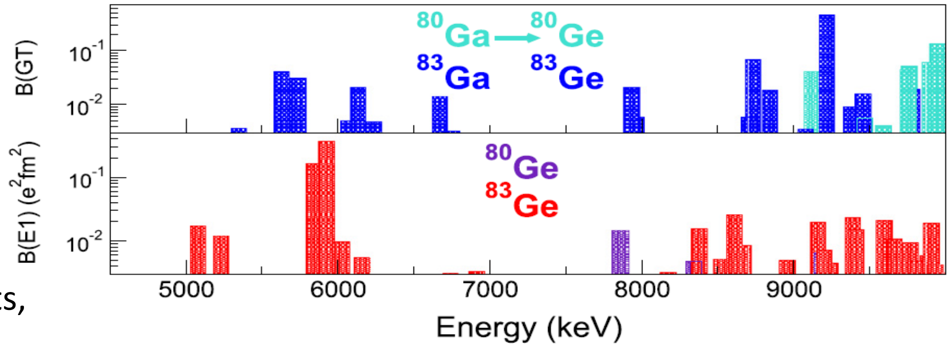
^{83}Ge: theoretical calculations of strengths

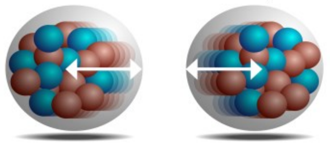




E1 γ strength to compete with neutron emission: 0.01-0.1 W.u.

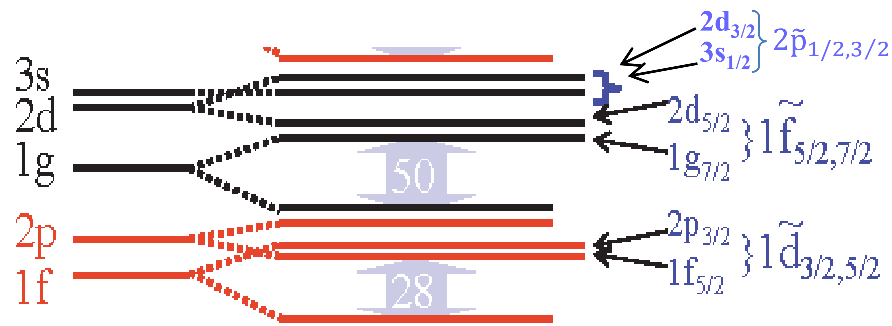
^{80,83}Ga: PDR and GT from Gogny D1M – QRPA (DAM - CEA)





I. Deloncle, Sophie Peru-Desenfants, Marco Martini DAM -CEA

Nuclear Pseudo-Spin Symmetry (PSS)

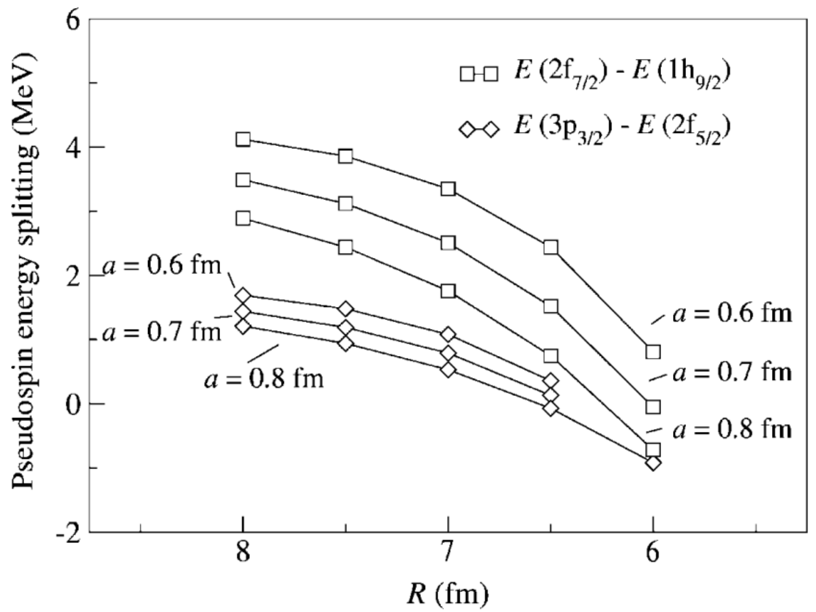


- Quasidegeneracy between
(*n*, ℓ, *j*= ℓ +1/2) and (*n-1*, ℓ-2, *j*= ℓ+3/2) orbitals

- Dynamical symmetry in a relativistic mean field

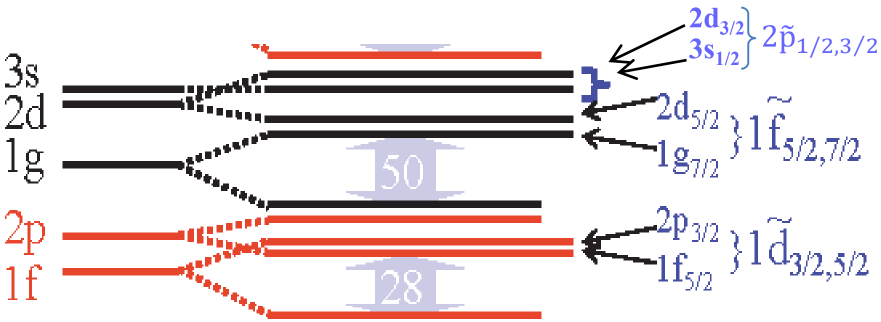
- repulsive vector potential (350 MeV) cancels with medium-range attractive scalar potential (−400 MeV)

P. Alberto et al., Phys. Rev. Lett. 86, 5015 (2001)

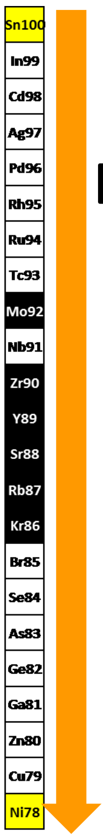


A PSS doublet becomes inverted as a result of INCREASING diffusivity and DECREASING mass

Nuclear PSS along N=50



proton 5/2 - 3/2 inversion in Cu:
restauration of PSS



T=1/2

Binding Σ_n ↘

R ↘

neutron diffusivity ↗

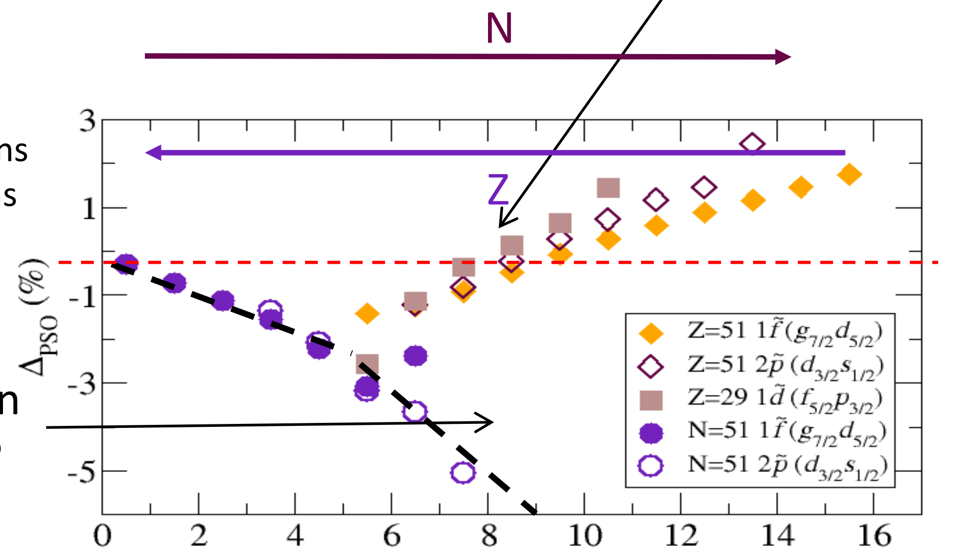
T=23/2

ρ meson interaction,
in neutron rich nuclei :

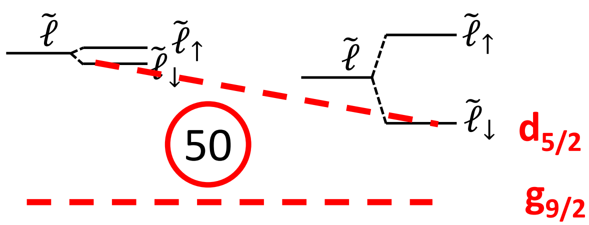
- repulsive for the neutrons
- attractive for the protons

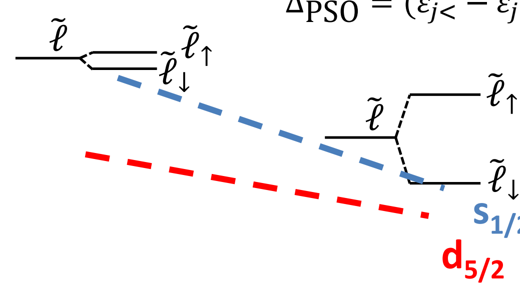
$$V = V_\omega + V_\rho = V_\omega \pm \frac{g_\rho}{2}\rho_0$$

neutron skin formation ?



$$\Delta_{PSO} = (\varepsilon_{j<} - \varepsilon_{j>})/[\hbar\omega(2\tilde{l}+1)]$$





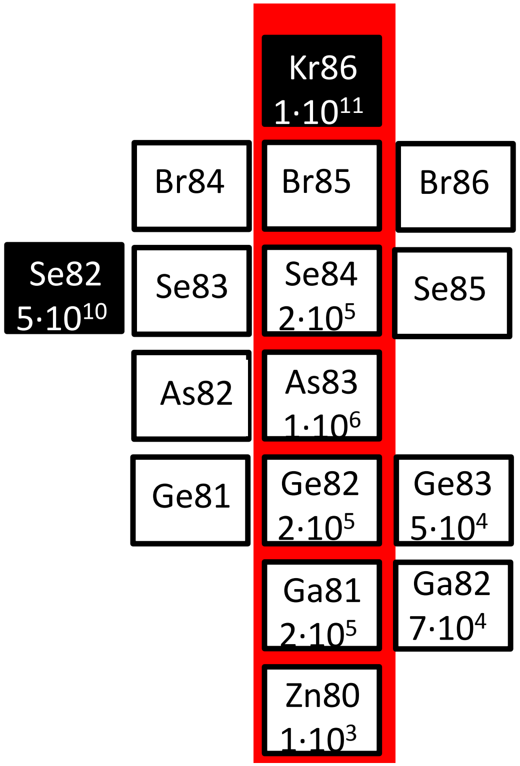
Conclusions

- Rich phenomenology around the N=50 shell closure: gap size behaviour, shape coexistence and collectivity, possible low-lying large E1
- Shell-model calculations help to extract N=50 gap size from p-h states: test on lifetimes of p-h states
- Odd-odd nuclei convey further information
- Lifetimes measurements on open-shell N=52 isotones point out increase of collectivity at Z=32
- Rapid lowering of the $\nu s_{1/2}$ shell, maybe g.s. at Z=30 already ?

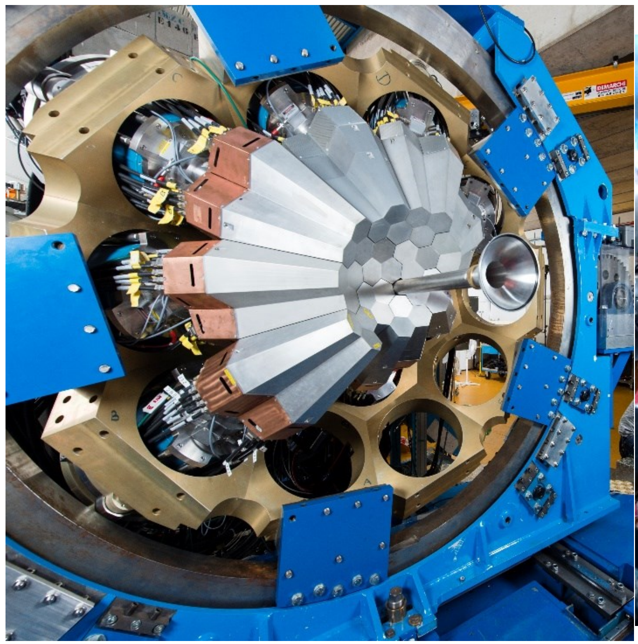
Pseudo-spin symmetry could be the driving mechanism behind this phenomena

In the future: - probe of the s.p. space beyond N=50
- further investigation of shape coexistence and collectivity
- large radius of the $\nu s_{1/2}$ orbit ?

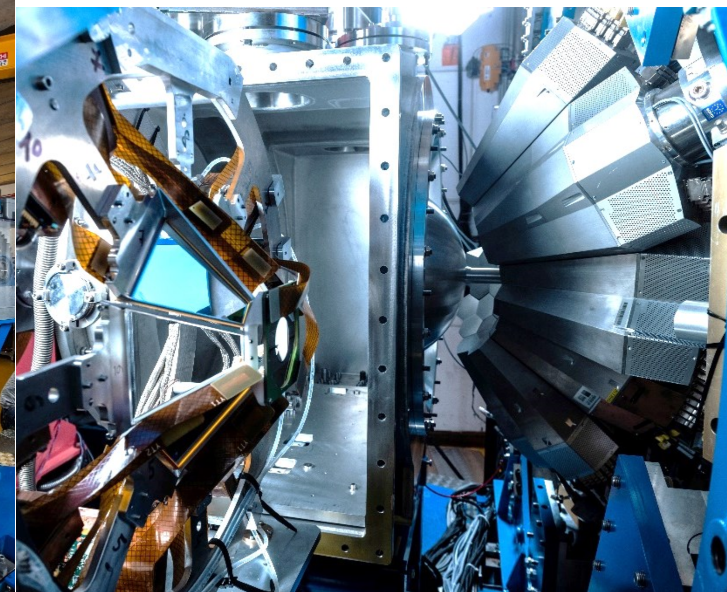
Perspectives for N=50 studies at LNL



ALPI-SPES yields (pps)
Stable and exotic beams
@ 10-15 MeV/u



γ-ray spectroscopy with AGATA and GALILEO (+ LaBr, plunger…)

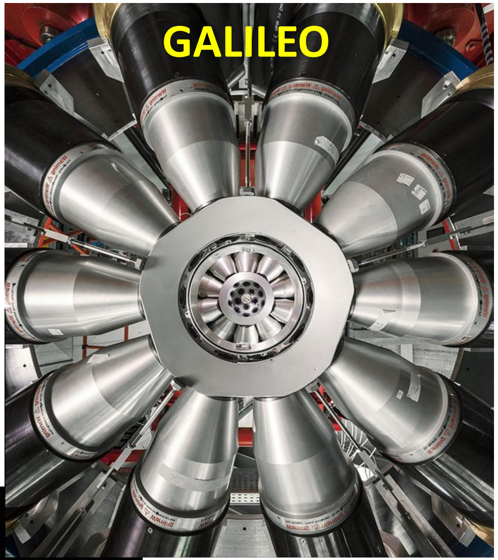


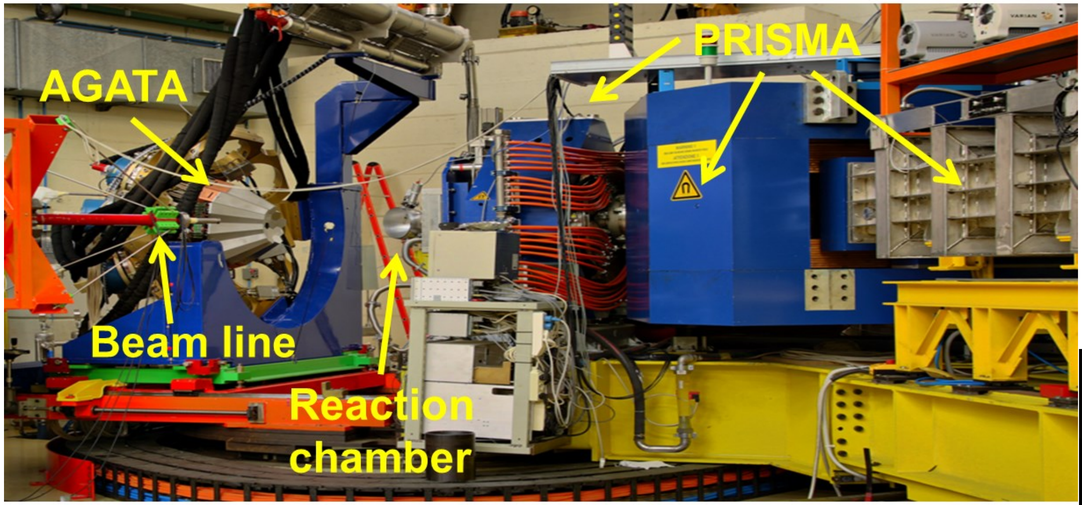
Heavy-ion and light particles detectors: PRISMA, GRIT, TRACE, Euclides…

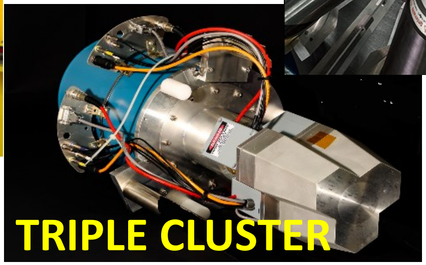
- Cryogenic targets: solid $^{1,2}H$, high density/liquid $^{3,4}He$

Perspectives at LNL

- Stable and reaccelerated (10-15 MeV/u) radioactive beams from SPES (2023)
- γ-ray spectroscopy with AGATA and GALILEO (+ LaBr, plunger…)
- Heavy-ion and light particles detectors: PRISMA, GRIT, TRACE, Euclides…
- Cryogenic targets: solid ^{1,2}H , high density/liquid ^{3,4}He







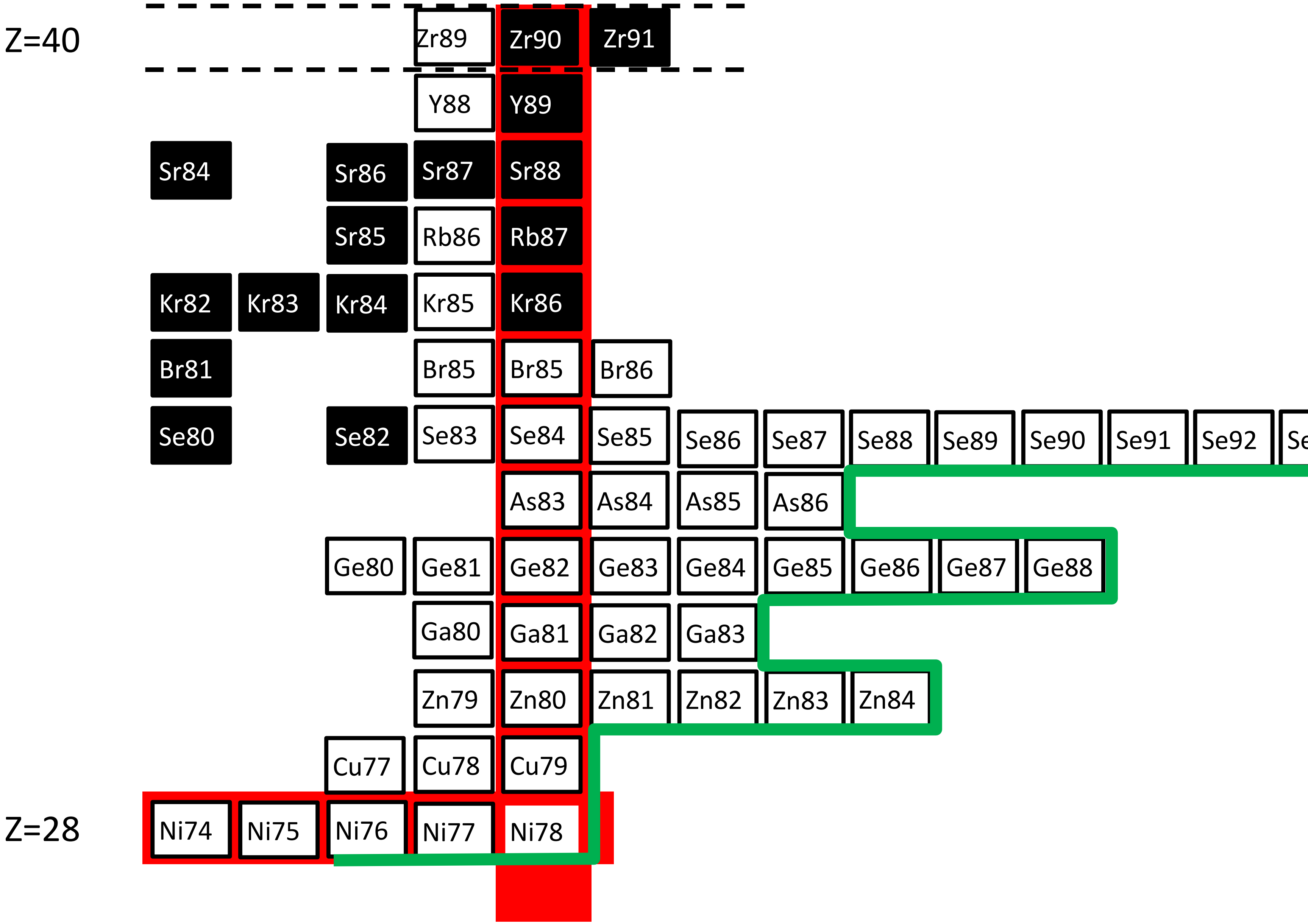
In beam lifetimes measurements: N=51 odd-odd nuclei

Nuclide	E_γ [keV]	Transition	$\tau[ps]$	$B(E, M\lambda)$ [W.u.]
^{86}Br	331	$5^- \to 4^-$ (M1)	7.4 ± 1.8	$1.2 \pm 0.3 \cdot 10^{-1}$
^{84}Br	194	$8^+ \to 7^+$ (M1)	$12.6^{+8.2}_{-4.5}$	$3.5^{+1.2}_{-2.2} \cdot 10^{-1}$
	972	$7^+ \to 7^-$ (E1)	$4.1^{+5.4}_{-2.8}$	$1.4^{+0.9}_{-1.4} \cdot 10^{-4}$
	530	$7^- \to 6^-$ (M1)	$25.9^{+18.1}_{-8.8}$	$8.2^{+2.8}_{-5.7} \cdot 10^{-[illegible]}$
^{84}As	1408	$7^+ \to 5^-$ (M2)	$7.2^{+[illegible]}_{-3.0}$	$5.9^{+[illegible]}_{-3.7} \cdot 10^{[illegible]}$
	313	$5^- \to 4^-$ (M1)	43 ± 22	$2.4 \pm 1.2 \cdot 10^{-2}$
	1019	$6^- \to 4^-$ (E2)	$3.8^{+2.4}_{-1.7}$	$8.9^{+4.0}_{-5.6} \cdot 10^{0}$
^{82}As	218	unknown	9.0 ± 3.0	
	278	unknown	6.6 ± 2.0	
	656	unknown	$9.8^{+5.5}_{-3.4}$	
	410	unknown	> 40	
^{80}Ga	401	unknown	$12.5^{+9.4}_{-4.7}$	

https://www.facebook.com/318650778688911/videos/268152114112879/

^{84}As built based on coincidences:

D. Dal Santo, G. Valerin University of Padova students


Z=40
Zr89
Zr90
Zr91
Y88
Y89
Sr84
Sr86
Sr87
Sr88
Sr85
Rb86
Rb87
Kr82
Kr83
Kr84
Kr85
Kr86
Br81
Br85
Br85
Br86
Se80
Se82
Se83
Se84
Se85
Se86
Se87
Se88
Se89
Se90
Se91
Se92
As83
As84
As85
As86
Ge80
Ge81
Ge82
Ge83
Ge84
Ge85
Ge86
Ge87
Ge88
Ga80
Ga81
Ga82
Ga83
Zn79
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Zn83
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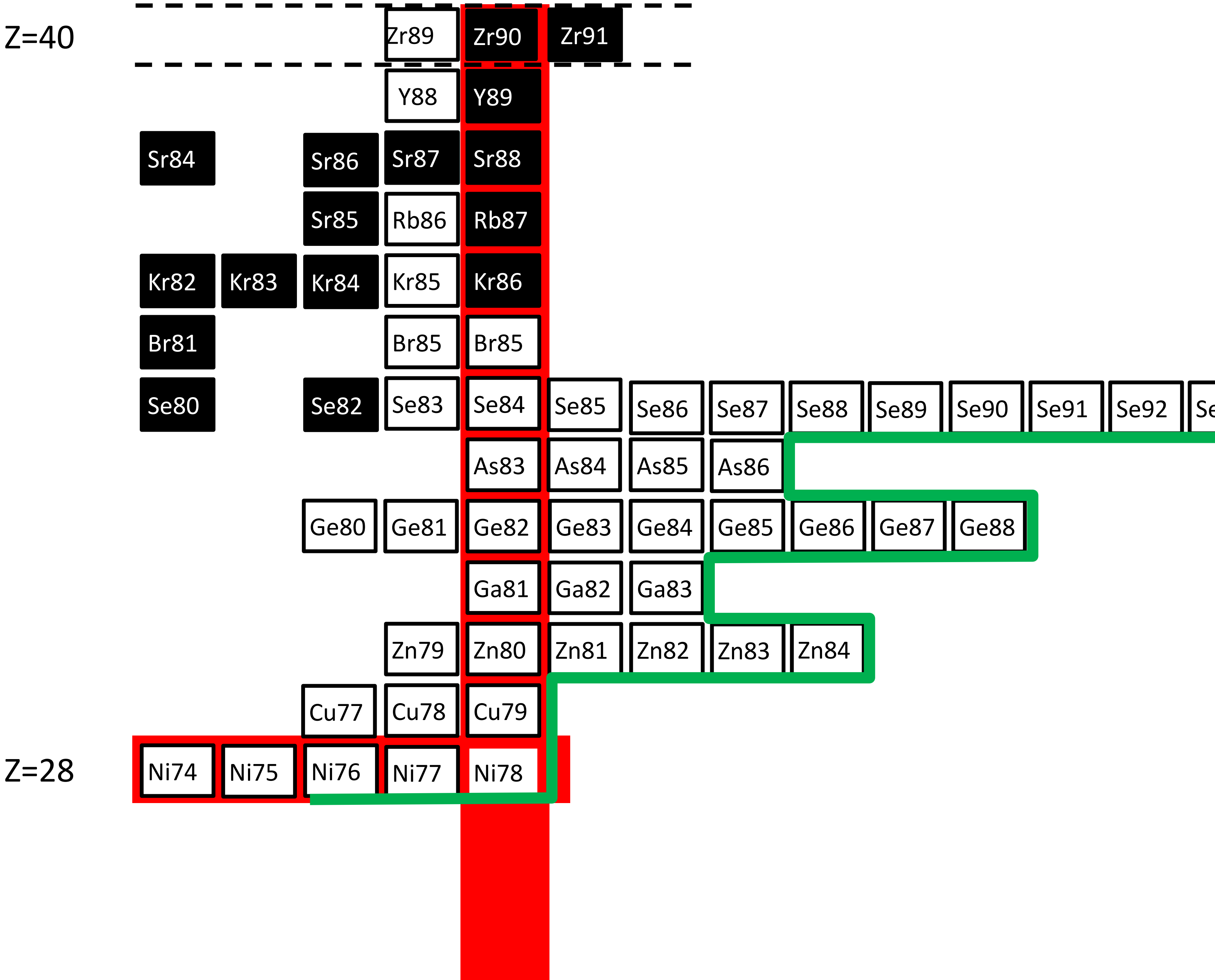
Cu77
Cu78
Cu79
Z=28
Ni74
Ni75
Ni76
Ni77
Ni78



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Kr82
Kr83
Kr84
Kr85
Kr86
Br81
Br85
Br85
Se80
Se82
Se83
Se84
Se85
Se86
Se87
Se88
Se89
Se90
Se91
Se92
As83
As84
As85
As86
Ge80
Ge81
Ge82
Ge83
Ge84
Ge85
Ge86
Ge87
Ge88
Ga81
Ga82
Ga83
Zn79
Zn80
Zn81
Zn82
Zn83
Zn84
Cu77
Cu78
Cu79
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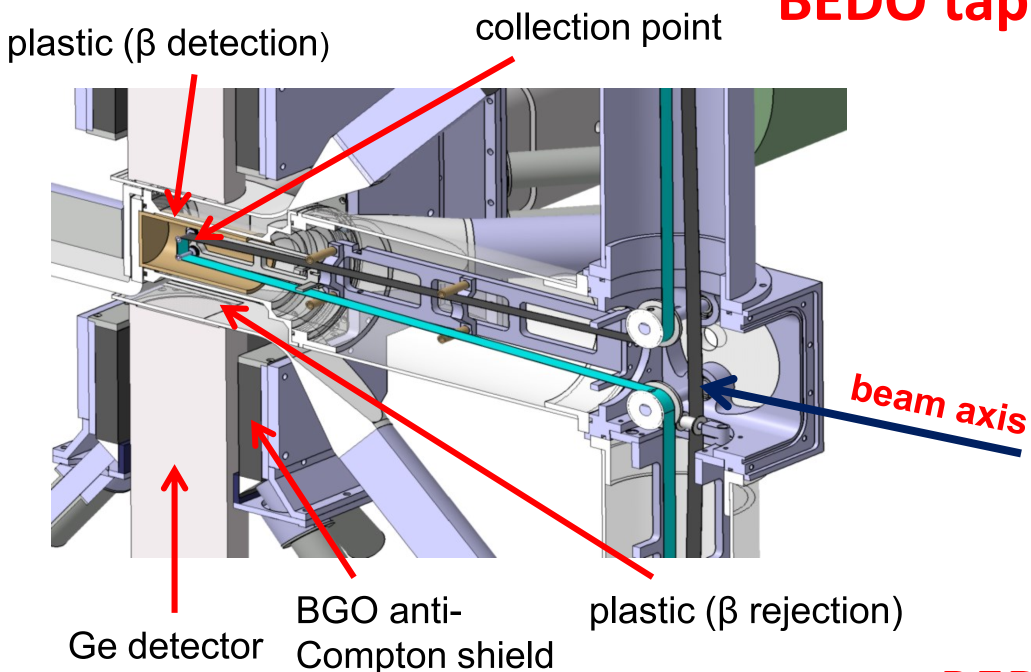
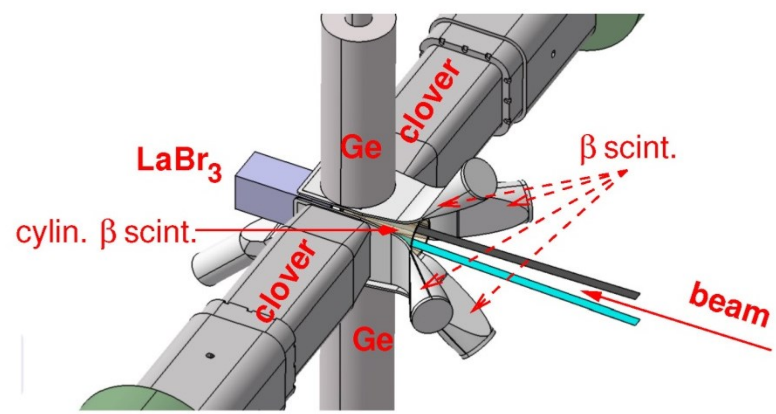
Ni74
Ni75
Ni76
Ni77
Ni78



BEDO tape station

- Up to 5 Ge detectors
- Compton BGO shielding
- Plastic veto detector
- > 50 % β efficiency

BEDO setup with large $LaBr_3$



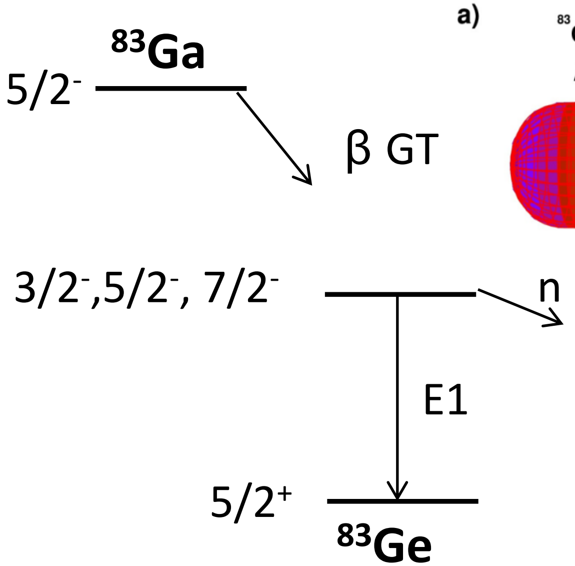
Optimal configurations:

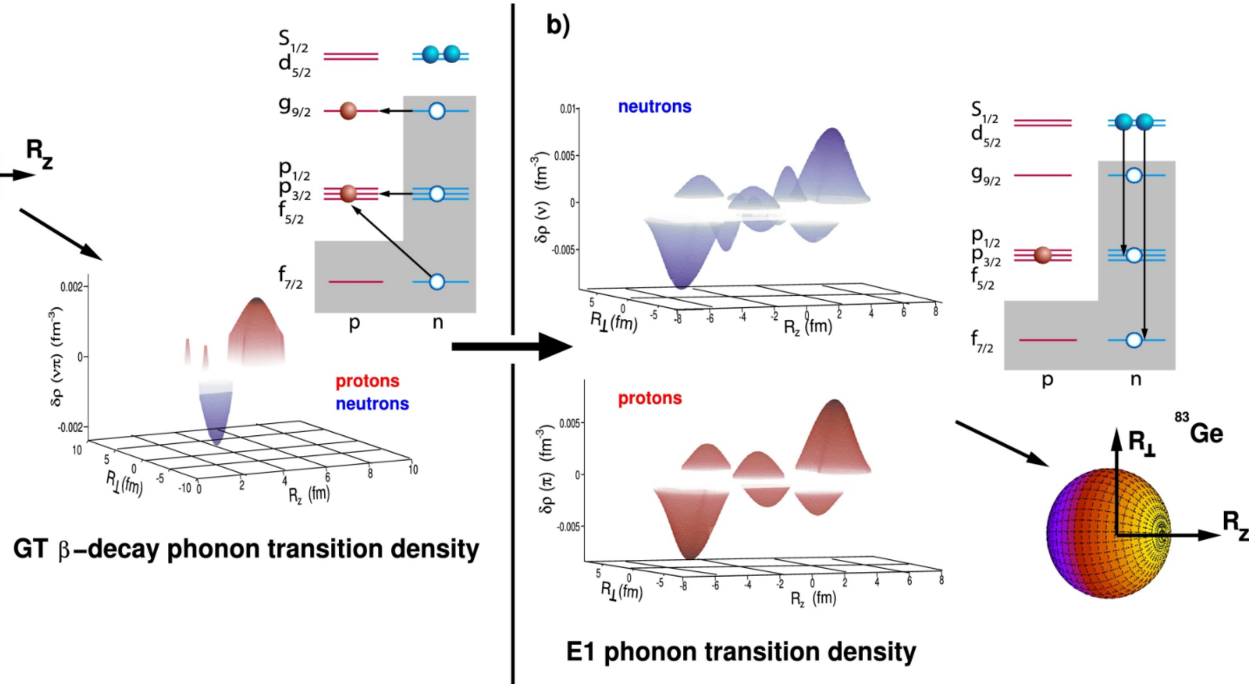
- 4 clovers (~ 3.5 - 4% eff. @ 1 MeV)
- 1 planar Ge for X rays

OR

- FAST timing configuration (2 LaBr + 2 Ge)

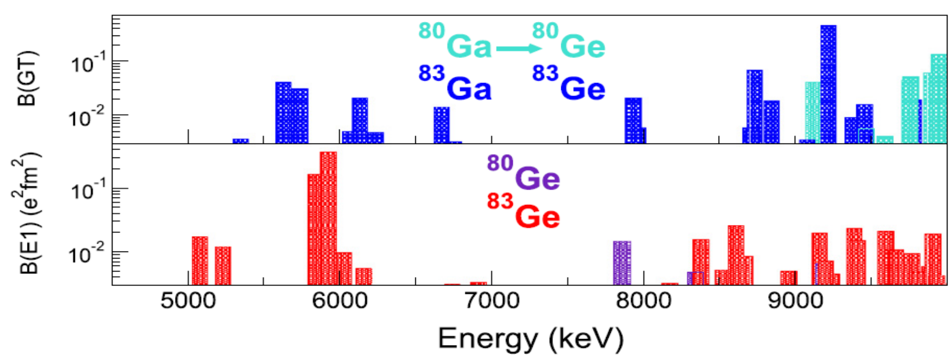
^{83}Ge: Theoretical Calculations of Strengths

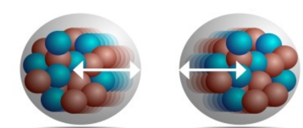




E1 γ strength to compete with neutron emission: 0.01-0.1 W.u.

^{80,83}Ga: PDR and GT from Gogny D1M – QRPA (DAM - CEA)





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