

# Spectroscopy investigation of the $^{78}\text{Ni}$ region: Potential avenues for a joint effort within EURISOL-DF

David Verney, IPN Orsay

- Physics motivations: the N=50 shell effect/evolution towards  $^{78}\text{Ni}$
- What did we learn ?
- Special role of ISOL-based results
- What remains to be done ?
- Towards a “distributed” venture ?



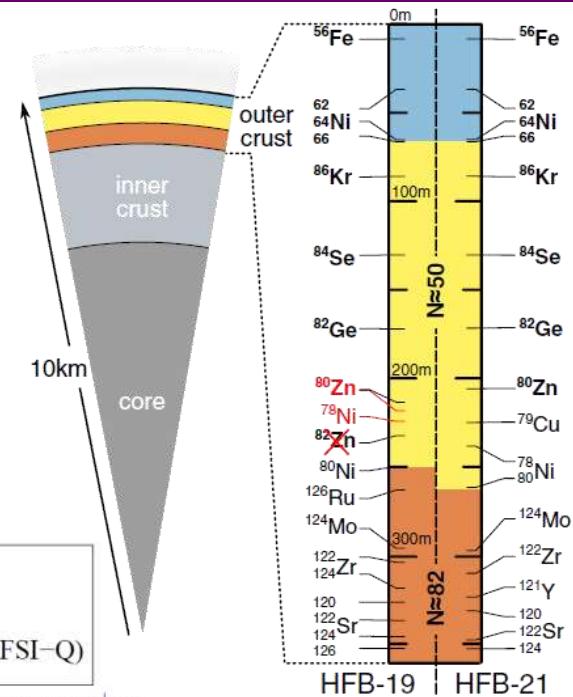
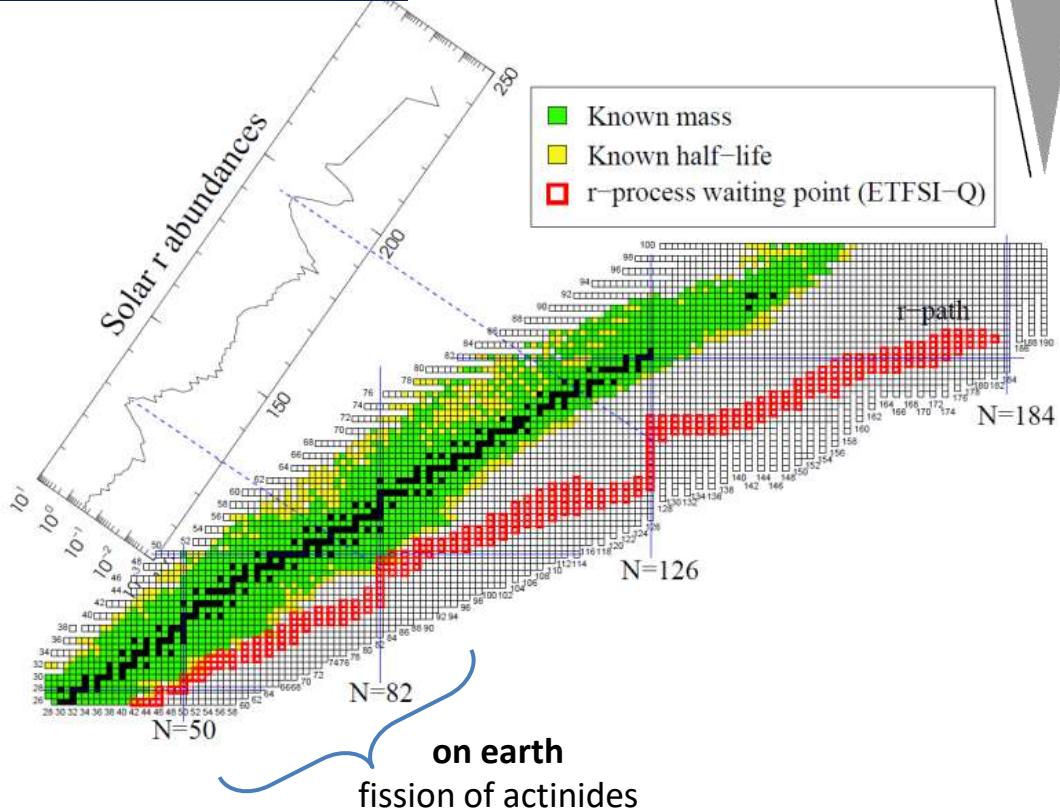
Physics Cases and Instrumentation for the EURISOL-DF, next  
step towards Eurisol

15-16 novembre 2017

Instituto Superior Técnico, Universidade de Lisboa

# SO magic numbers in nature

Neutron stars merging event detected by LIGO-Virgo  
followed quickly by EM emission at all frequencies  
August 17<sup>th</sup> 2017



Wolf et al. PRL 110  
(2013)

# SO magic numbers in historical nuclear physics



## Eugene Paul Wigner (1/2)

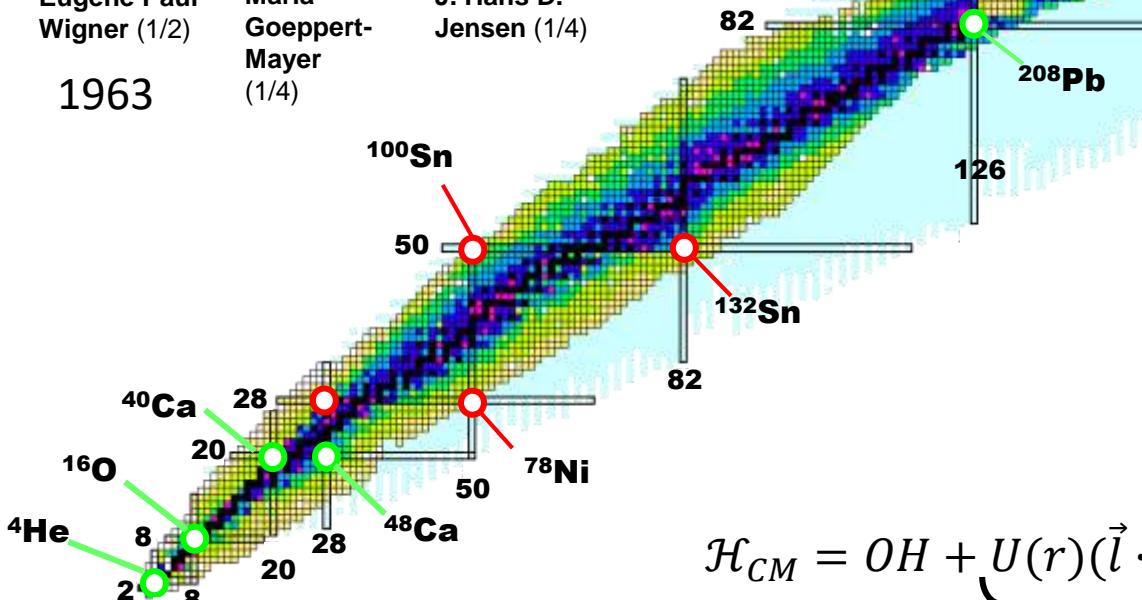
1963



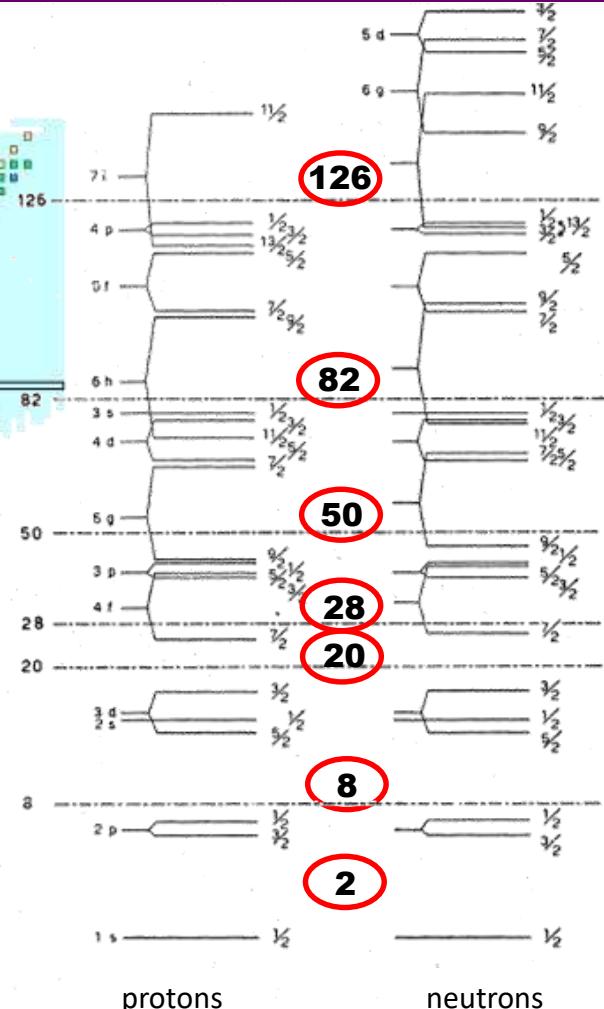
# Maria Goeppert- Mayer (1/4)



J. Hans D.  
Jensen (1/4)



$$\mathcal{H}_{CM} = OH + \underbrace{U(r)(\vec{l} \cdot \vec{s})}_{V^{LS}}$$



## the great surprise: $x \equiv$

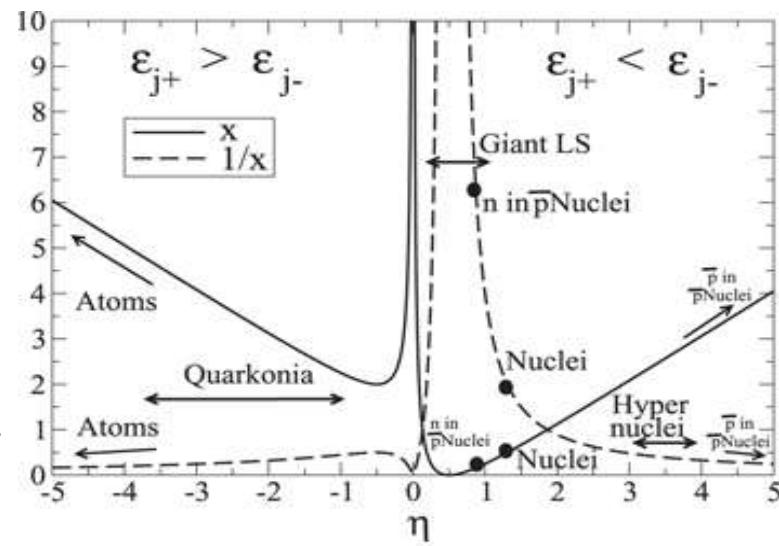
$$\frac{\hbar\omega_0}{|\Delta\langle V^{SL}\rangle|} \approx 1$$

# SO magic numbers in modern RMF

spin-orbit : universal effect for quantum systems made of particles having spin

spin : atoms, nuclei, hyper-nuclei, quarkonia...

important role in condensed matter : cold atoms, spintronics, topological insulators...



$$\eta \equiv \frac{m}{V - S}$$

$$x = \frac{\hbar\omega_0}{|\Delta\langle V^{SL} \rangle|}$$

Dirac equation governing the single particle motion

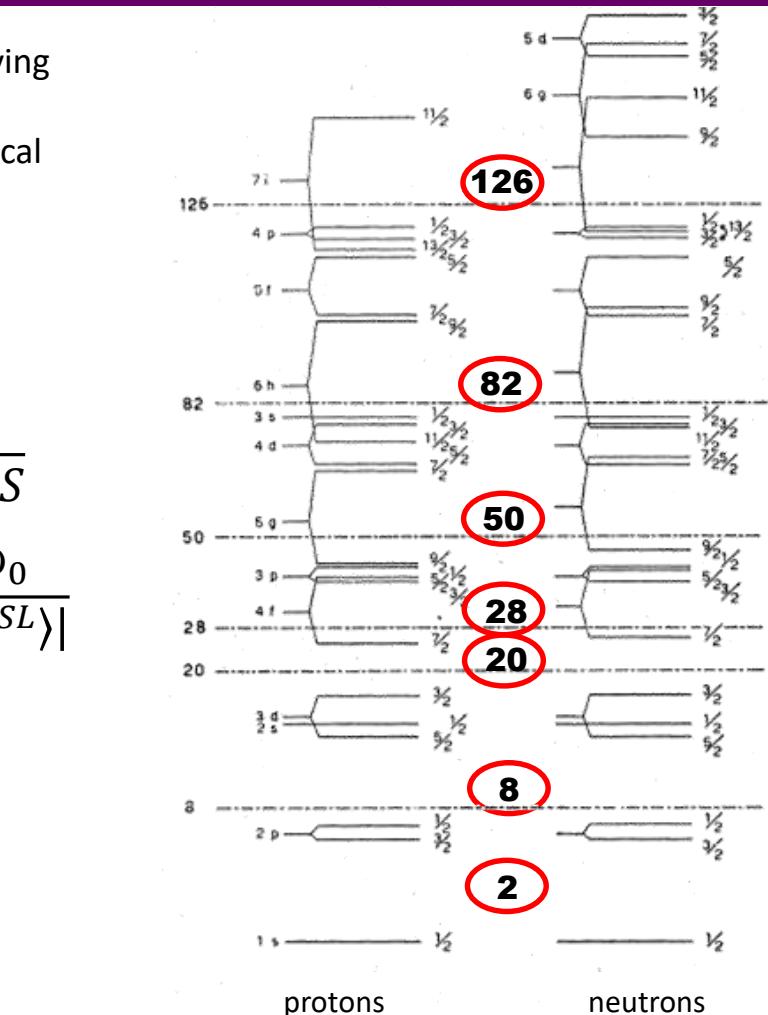
dynamics →

$$V^{LS} = \frac{1}{2M^2(r)} \frac{1}{r} \frac{d}{dr} (V(r) - S(r)) \vec{l} \cdot \vec{s}$$

vector potential (short range repulsion)  $\approx +350$  MeV

scalar potential (medium range attraction)  $\approx -400$  MeV

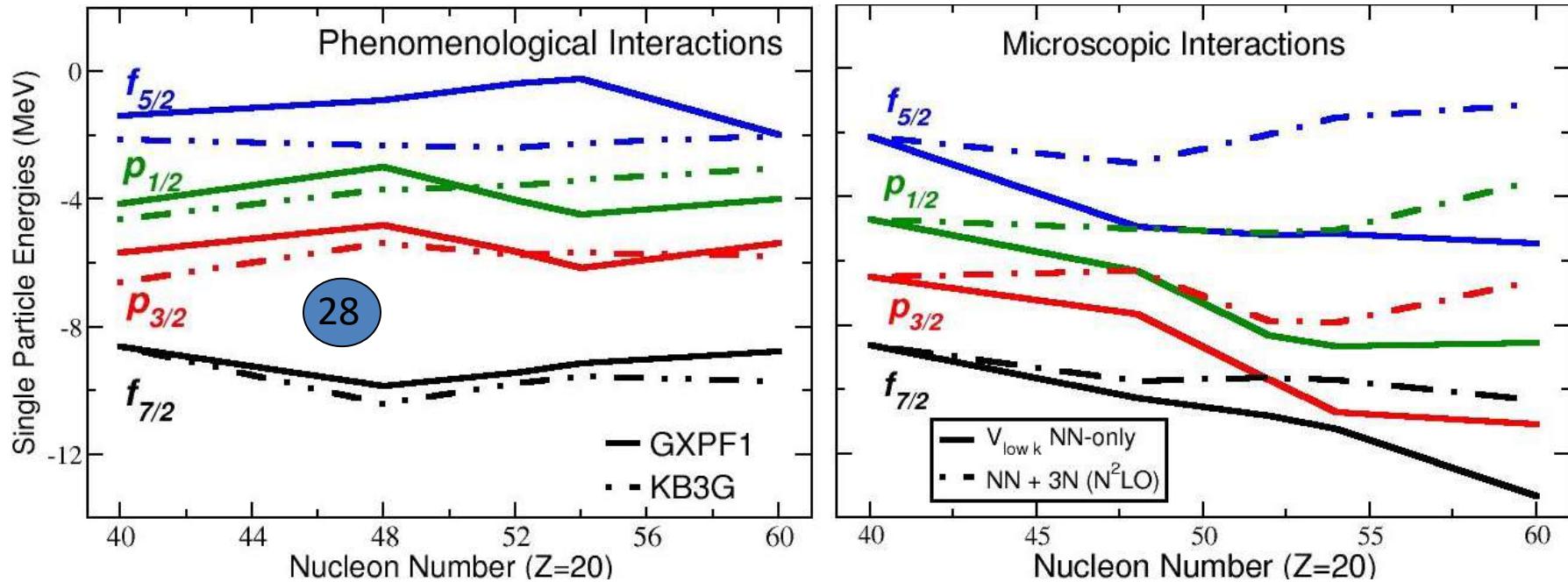
nucleon mass  $\approx 940$  MeV



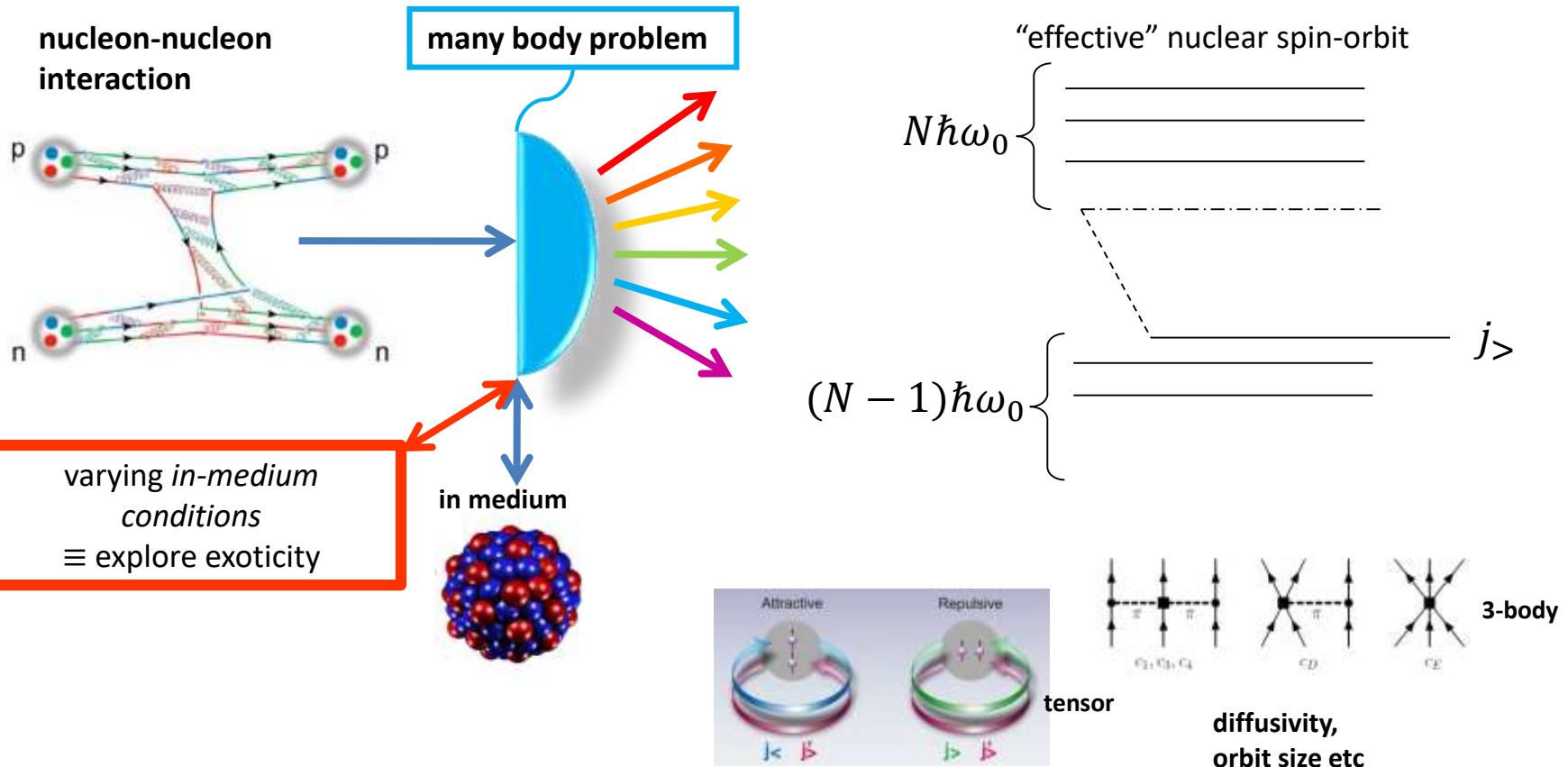
in atomic system:

$$x \sim \frac{1}{\alpha^2} \approx 10^4$$

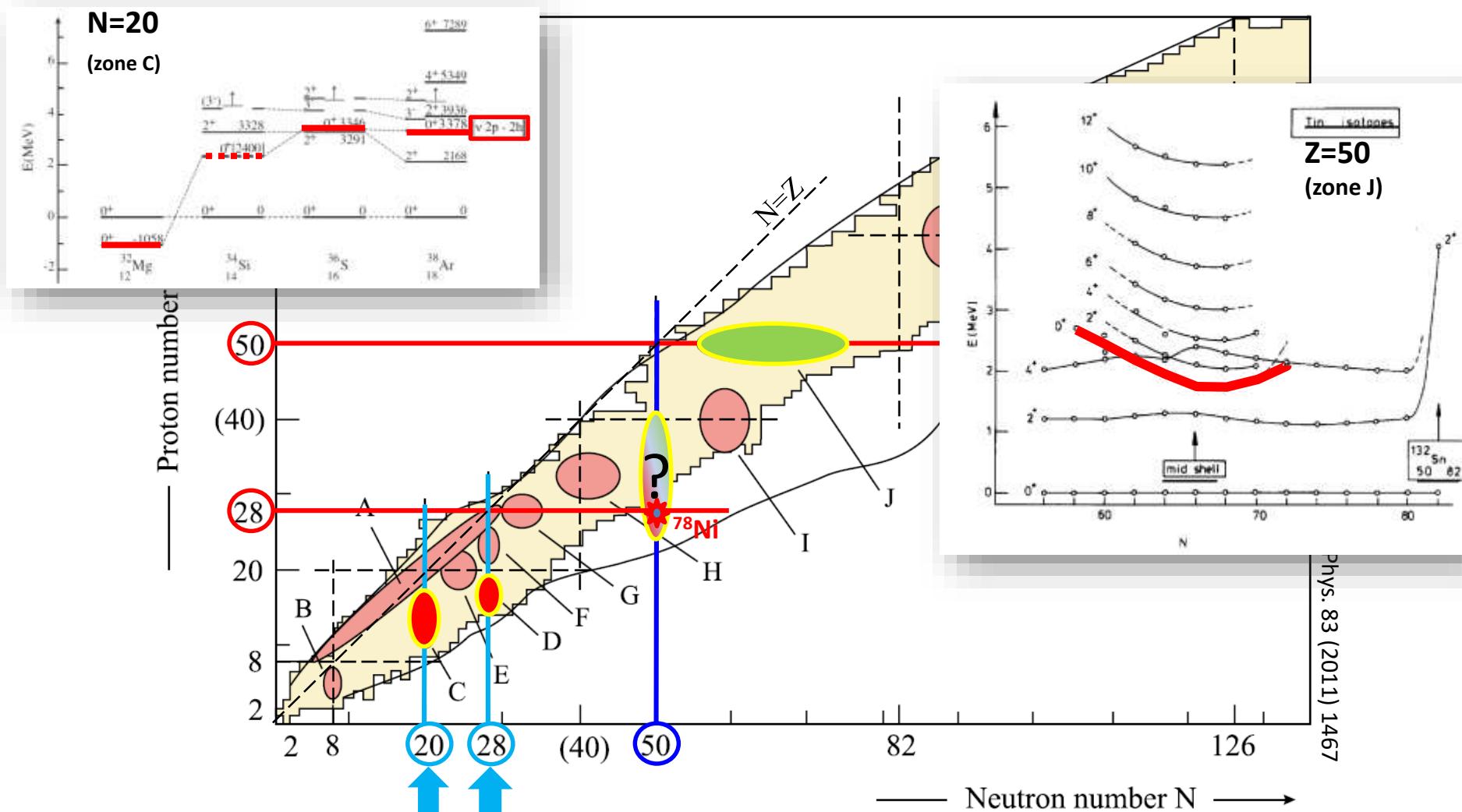
# SO magic numbers : an emerging phenomenon



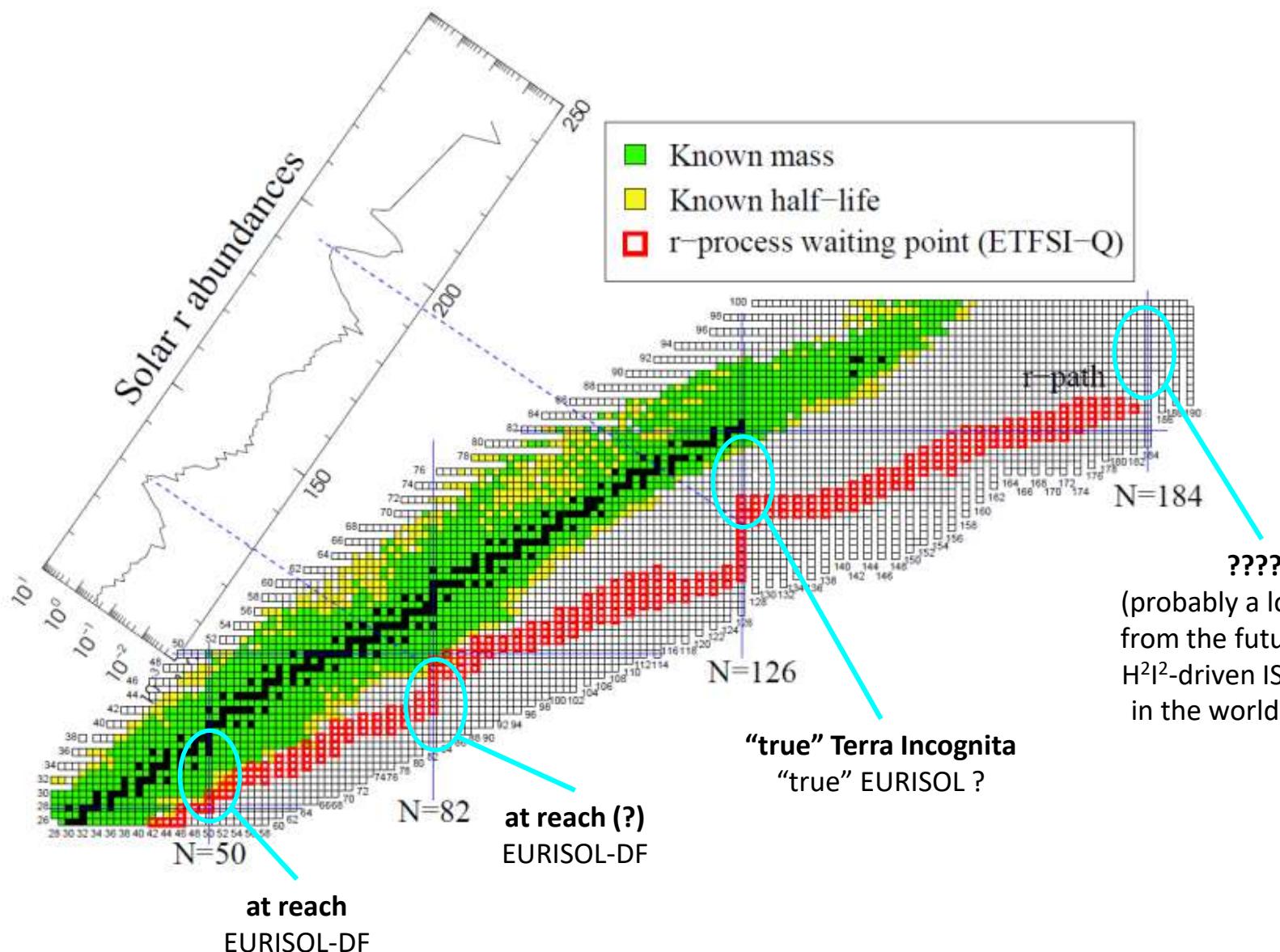
# SO magic numbers : an emerging phenomenon



# SO magic numbers from a shape-coexistence point of view



# SO magic numbers : a long-term roadmap (on earth)



# N=50 shell effect in the $^{78}\text{Ni}$ region : what we have learned

- gap size  $\rightarrow$  Z=32 “singularity”
- shape coexistence
- neutron valence space above  $^{78}\text{Ni}$
- neutron threshold effects and the question of ff transitions in the  $^{78}\text{Ni}$  region

# The Z=32 “singularity”

## Yrast spectroscopy

Zr: H.Fann et. al

Phys. Lett. B 44, 19 (1973)

Sr: P.C.Li et. al.

Nucl. Phys. A 462, 26 (1987)

Kr: G.Winter et. al.

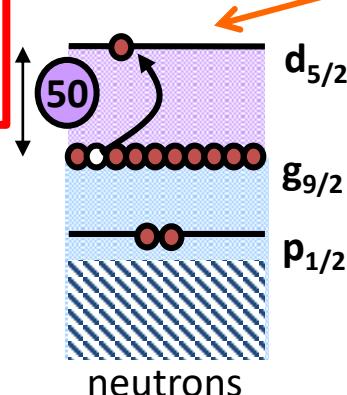
Phys. Rev. C48, 1010 (1993)

Se: Prevost et. al.

Eur. Phys. J. A 22,391-395 (2004)

Ge: T.Rzaca-Urban et. al.

PRC 76, 027302 (2007)



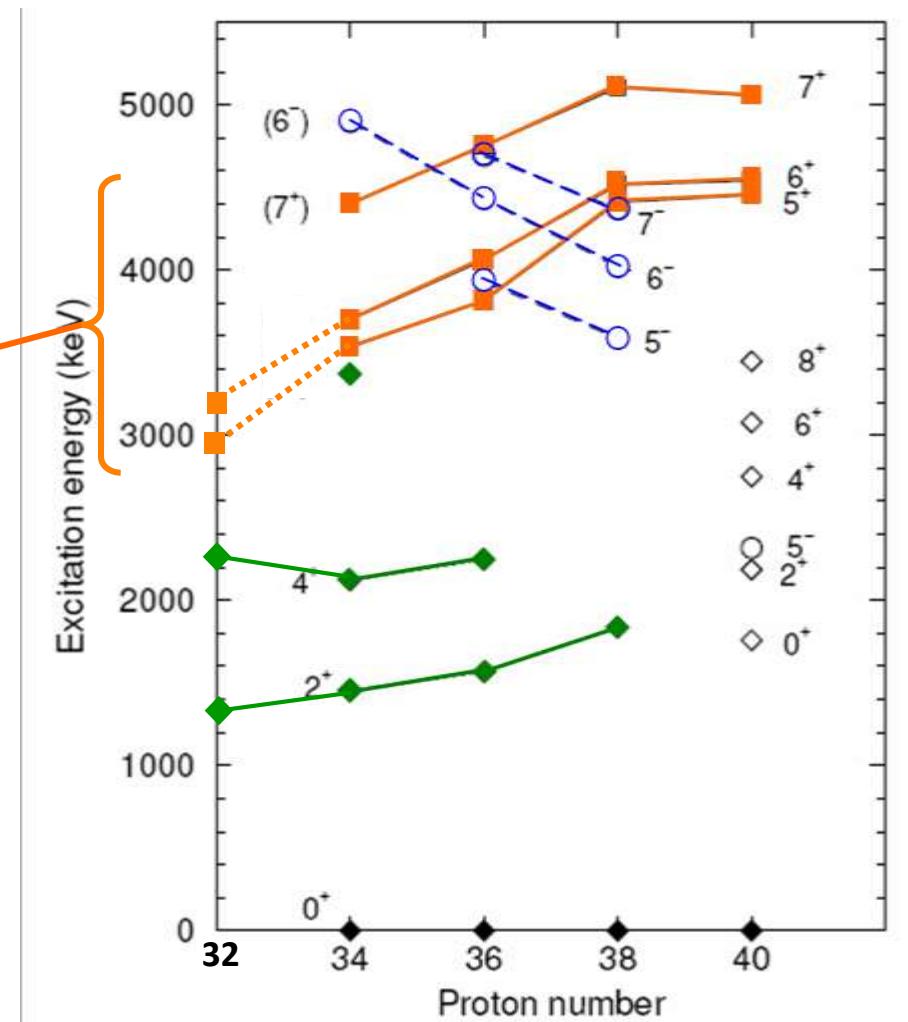
some “shell quenching”

O. Sorlin, M.G. Porquet

Prog. Part. Nucl. Phys. 61 (2008) 602

N=50 gap extrapolation

→  $^{78}\text{Ni}$  =3.0(5) MeV



# The Z=32 “singularity”

## High-precision mass spectrometry (JYFLTRAP and ISOLTRAP)

Hakala et al PRL 101, 052502 (2008); S. Baruah et al PRL 101, 262501 (2008)

later on : up to  $^{82}\text{Zn}$  ISOLTRAP [Wolf et al. PRL 110, 041101 (2013)]

$$\Delta = S_{2n}(52) - S_{2n}(50)$$

(Quantity usually used to extract shell gaps from mass data)

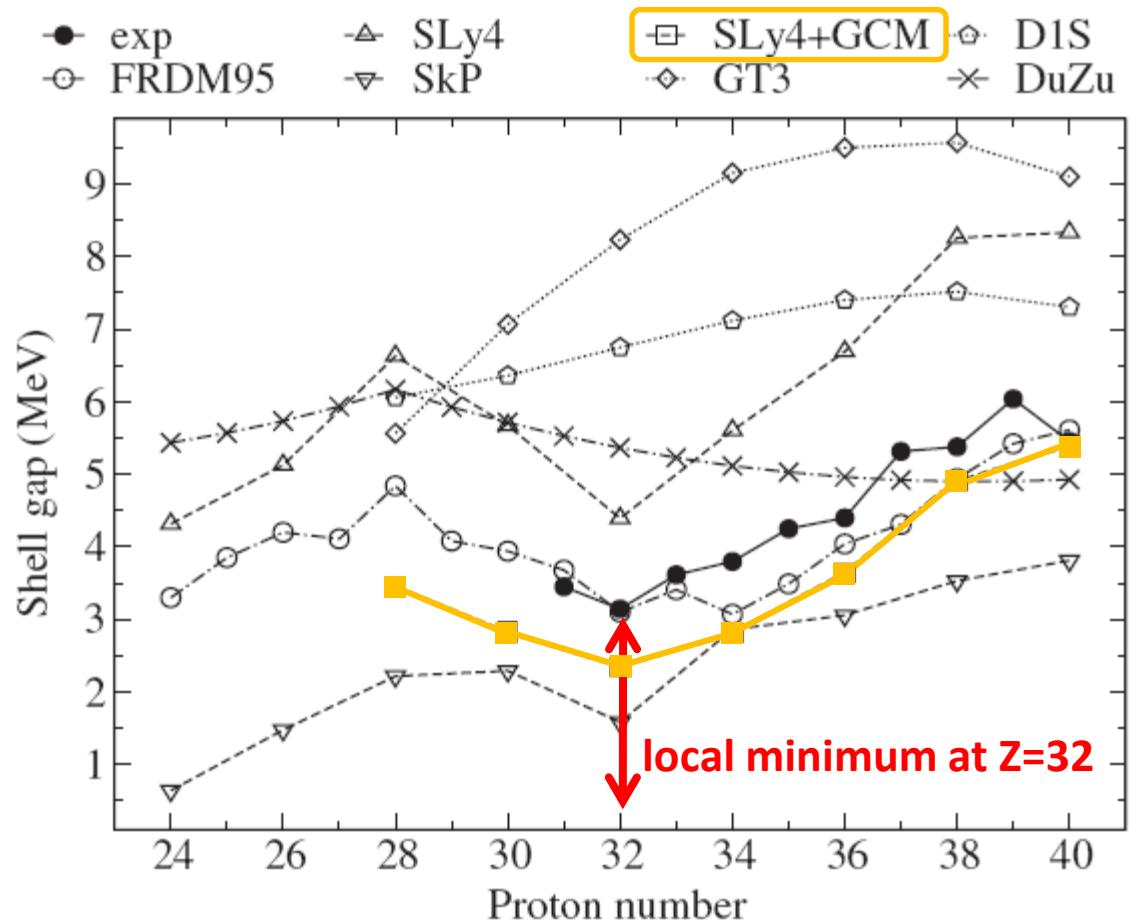
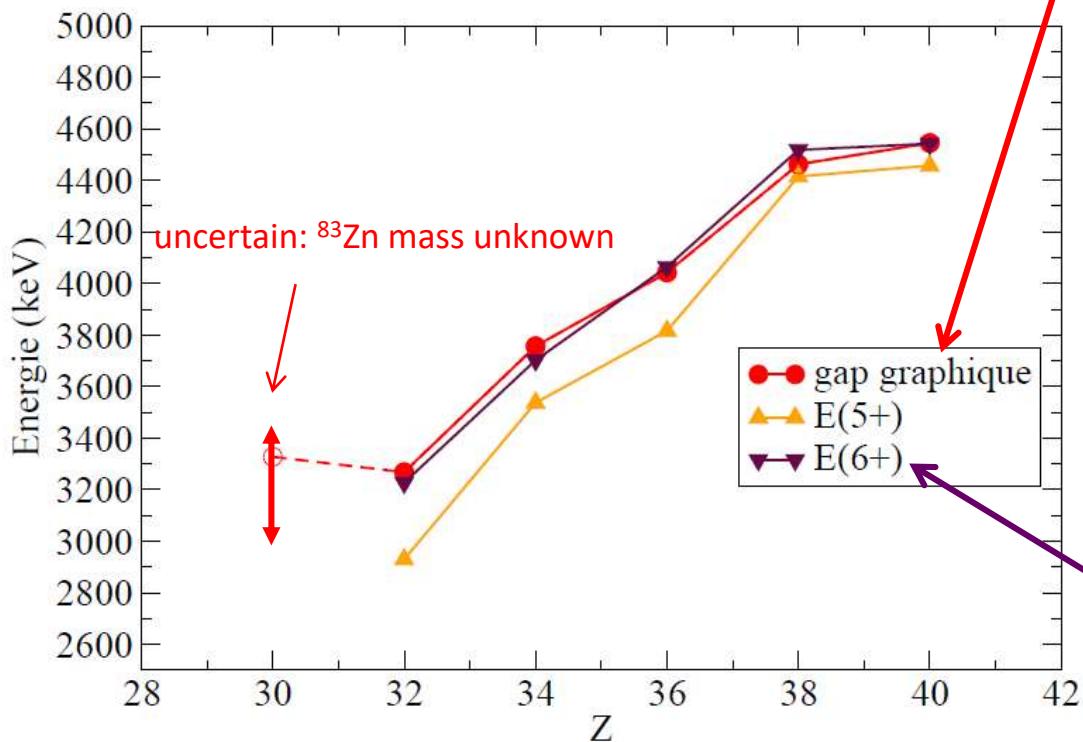


FIG. 4. Evolution of the  $N = 50$  shell gap and comparison to theoretical models.

# The Z=32 “singularity”

Striking similitude

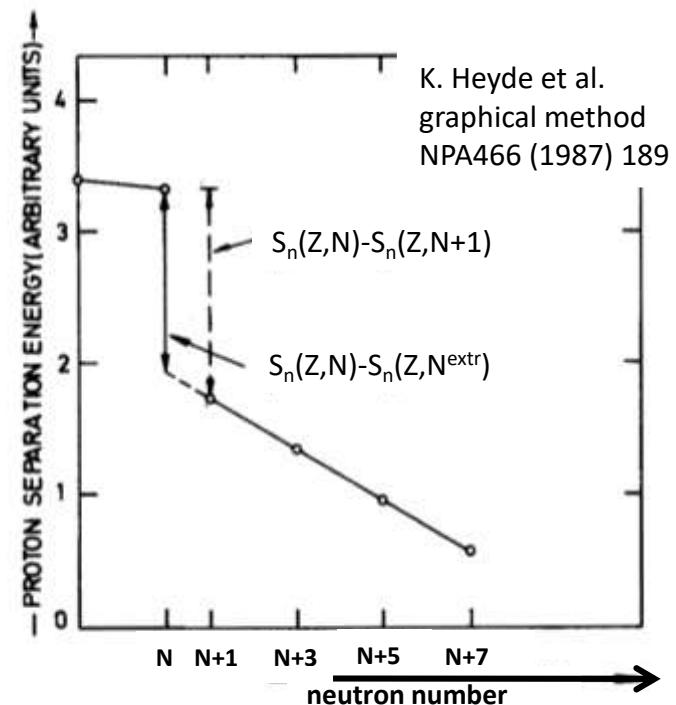
from mass measurement  
(after correction of upper  
shell effects)



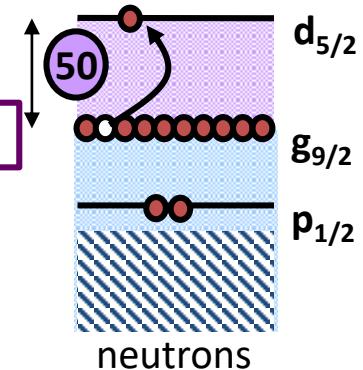
→ pure monopole effect ?

→ how to disentangle spherical mean field from correlation effects ?

→ what correlations ?

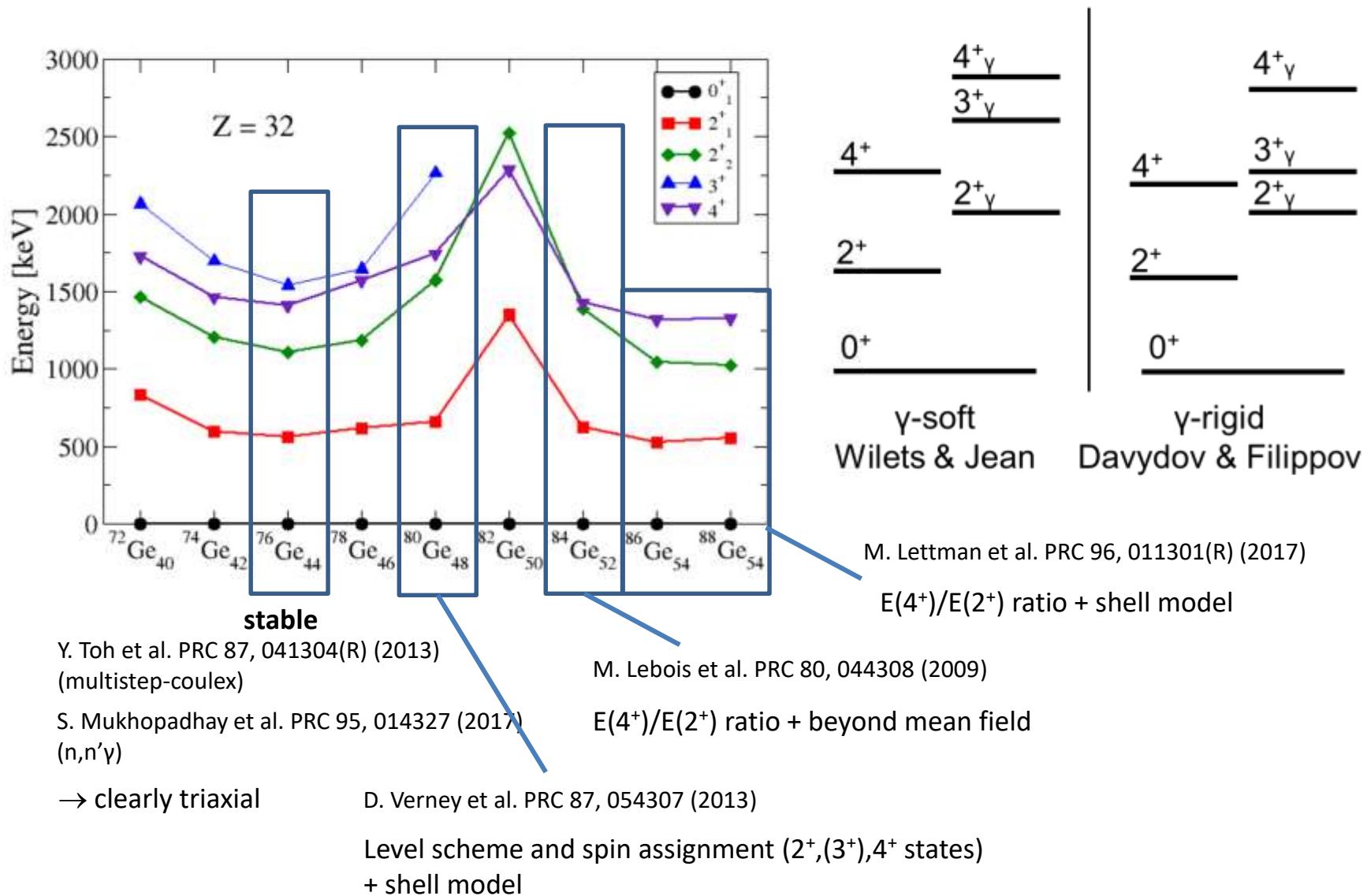


from  $\gamma$ -spectroscopy



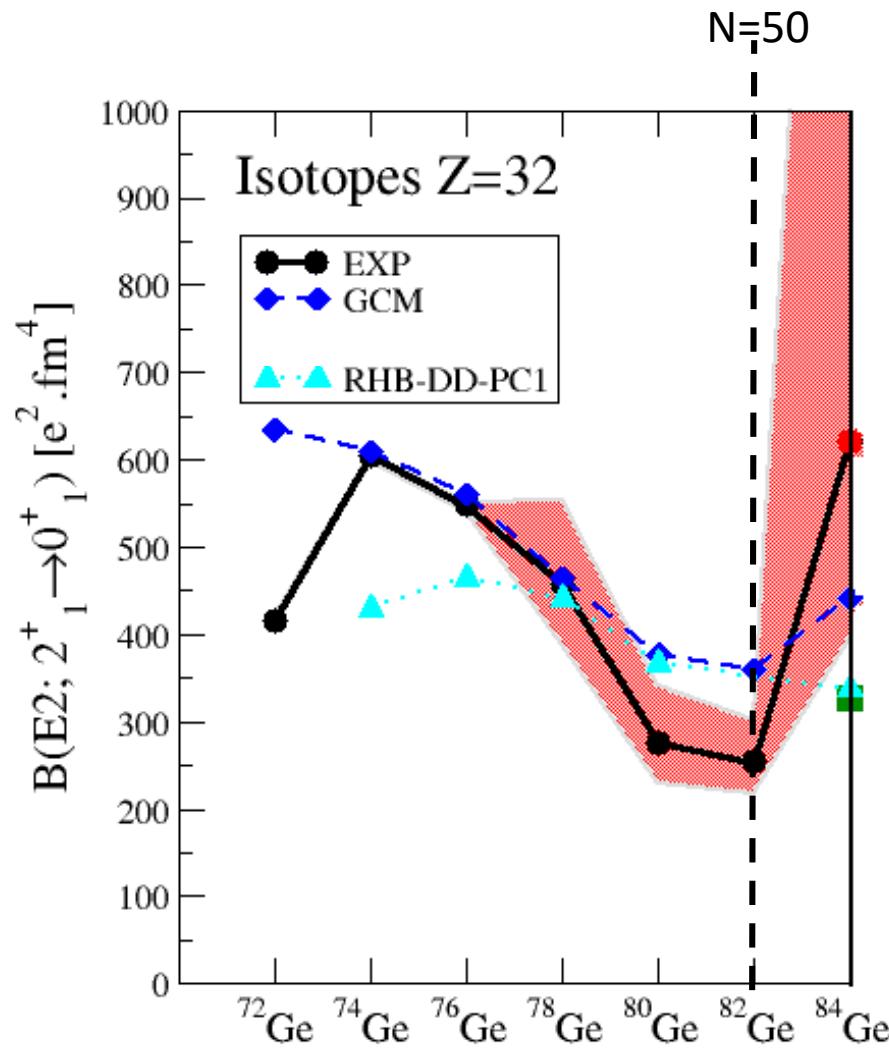
# The Z=32 “singularity”

Z=32 : a triaxiality “corridor” ?



# The Z=32 “singularity”

$^{84}\text{Ge}$  2 $^+$  lifetime measurement : plunger AGATA + VAMOS – Exp. E669 GANIL (C. Delafosse et al. to be published)

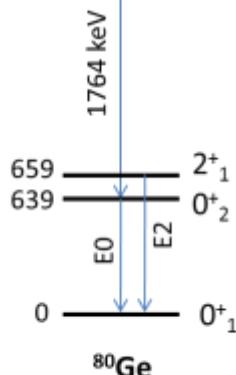
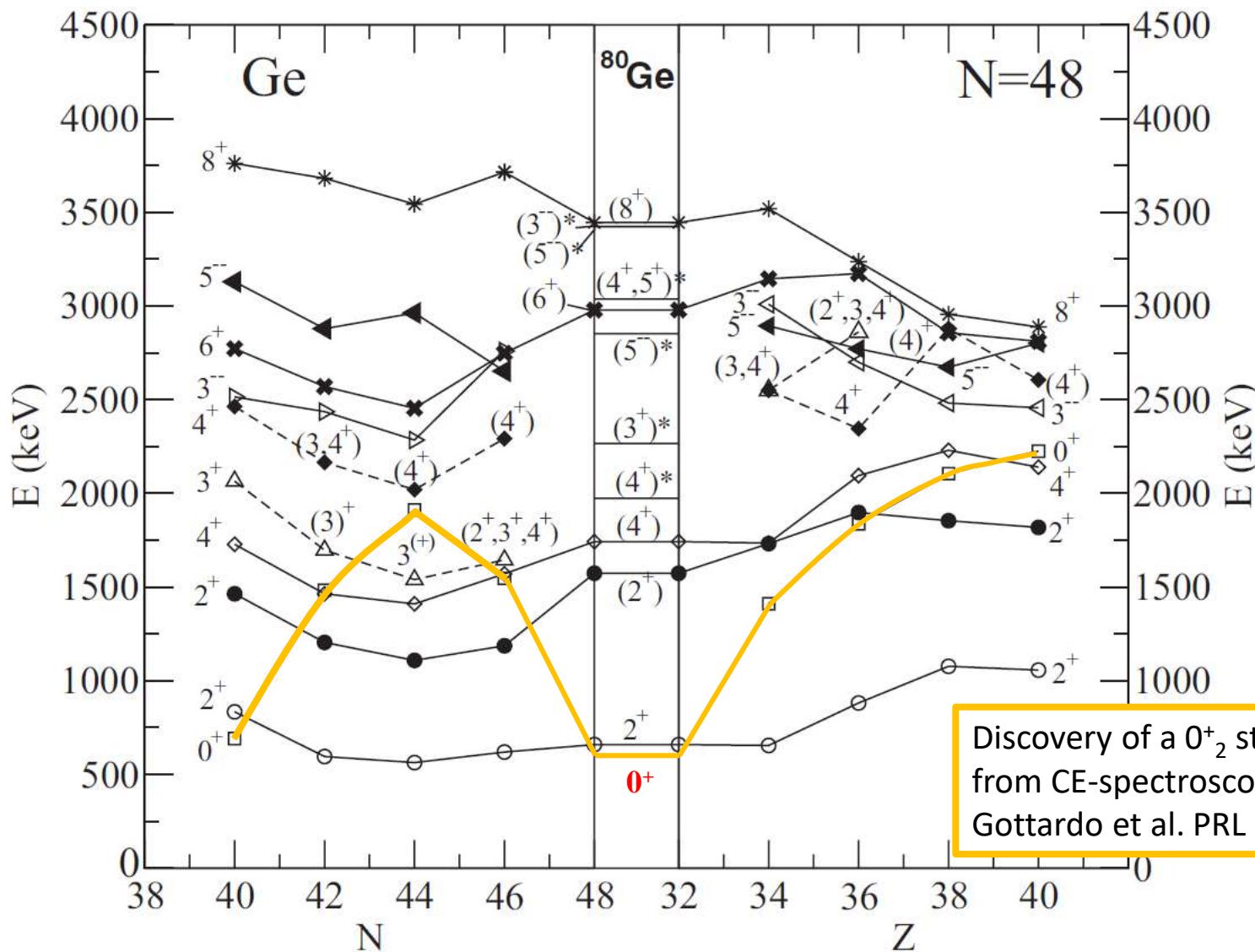


→ what triggers quadrupole correlation / triaxiality at Z=32 ?

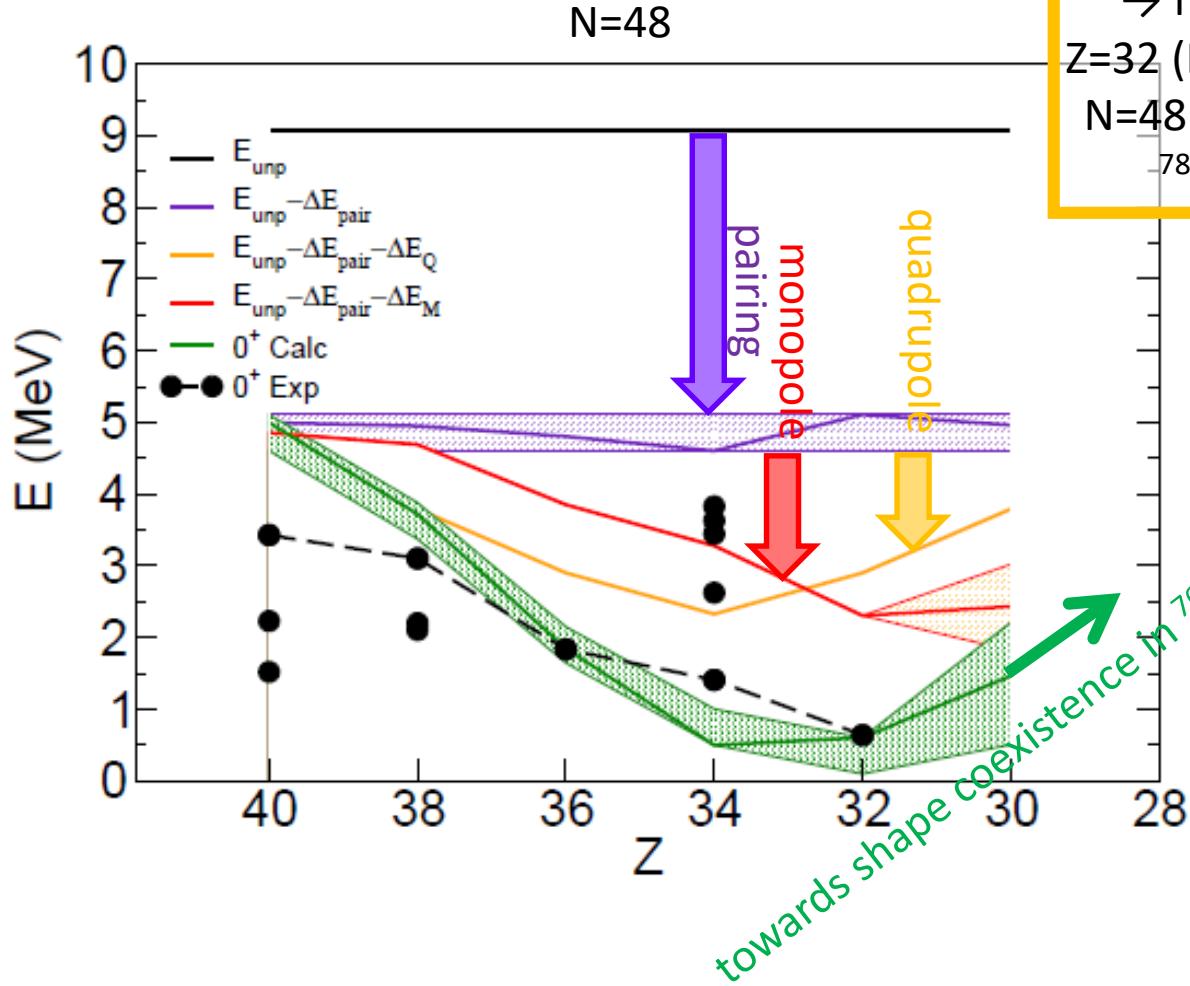
# The Z=32 “singularity”

Z=32 : definitely a “special” proton number

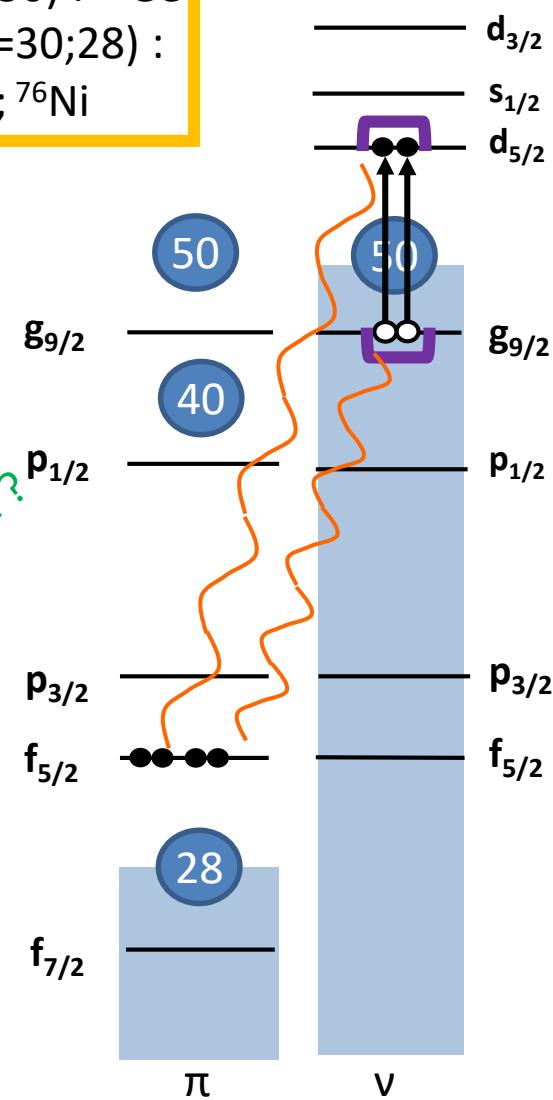
**3<sup>-</sup>** – isomer in  $^{80}\text{Ga}$  —————  $\beta$   
 $[\text{T}_{1/2}(3^-) = 1.3 \pm 0.2 \text{ s};$   
 PRC 87 (2013)]



# Shape coexistence (N=48)



→ next steps  
 $Z=32$  ( $N=50$ ) :  $^{82}\text{Ge}$   
 $N=48$  ( $Z=30;28$ ) :  
 $^{78}\text{Zn}; ^{76}\text{Ni}$



all quantities deduced from most recent **mass data**  
(except quadrupole correlation : IBM estimate)

## Shape Coexistence in $^{78}\text{Ni}$ as the Portal to the Fifth Island of Inversion

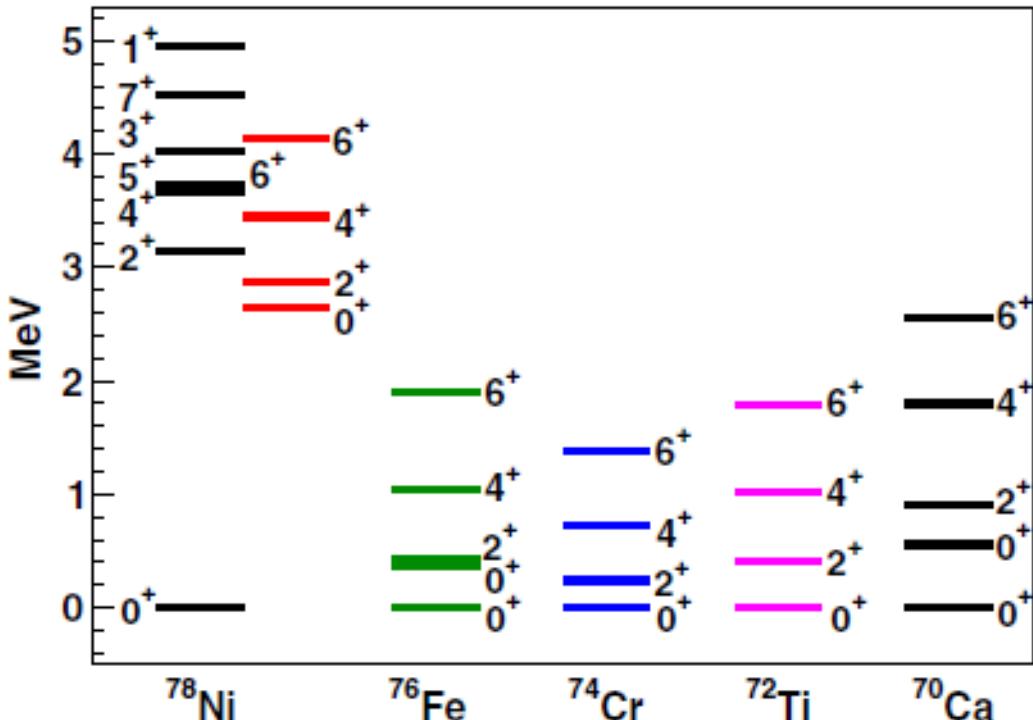
F. Nowacki,<sup>1,2</sup> A. Poves,<sup>3</sup> E. Caurier,<sup>1,2</sup> and B. Bounthong<sup>1,2</sup>

<sup>1</sup>Université de Strasbourg, IPHC, 23 rue du Loess 67037 Strasbourg, France

<sup>2</sup>CNRS, UMR7178, 67037 Strasbourg, France

<sup>3</sup>Departamento de Física Teórica e IFT-UAM/CSIC, Universidad Autónoma de Madrid, E-28049 Madrid, Spain and Institute for Advanced Study, Université de Strasbourg, France

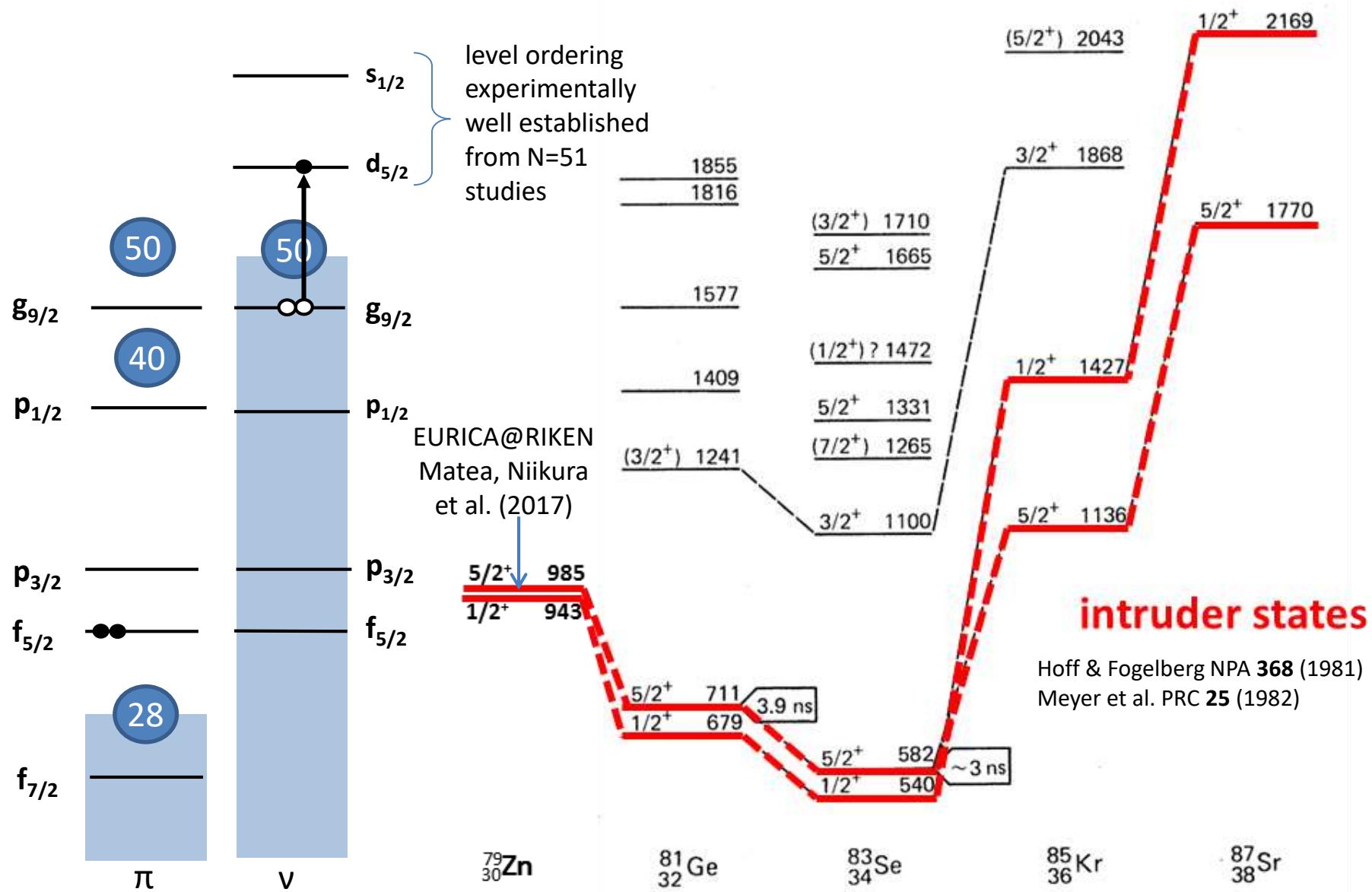
(Received 30 May 2016; revised manuscript received 14 July 2016; published 27 December 2016)



PFSDG-U shell-model calculations reproduce correctly the recently measured mass of  $^{79}\text{Cu}$  PRL 119, 192502 (2017)

... but not the intruder  $0^+_2$  state in  $^{80}\text{Ge}$

# Shape coexistence (N=49)



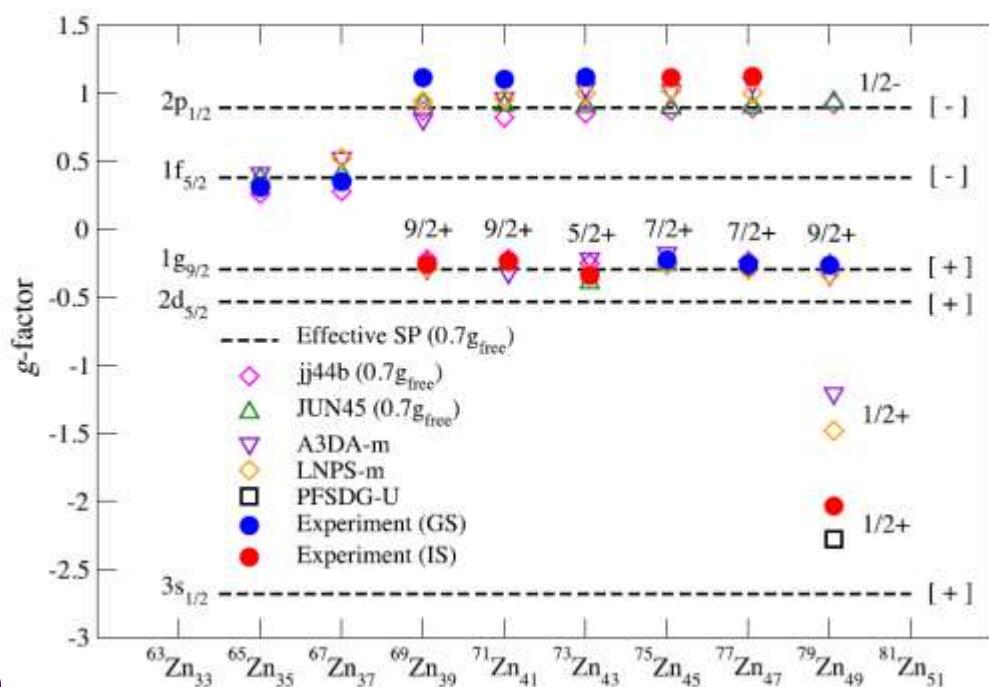
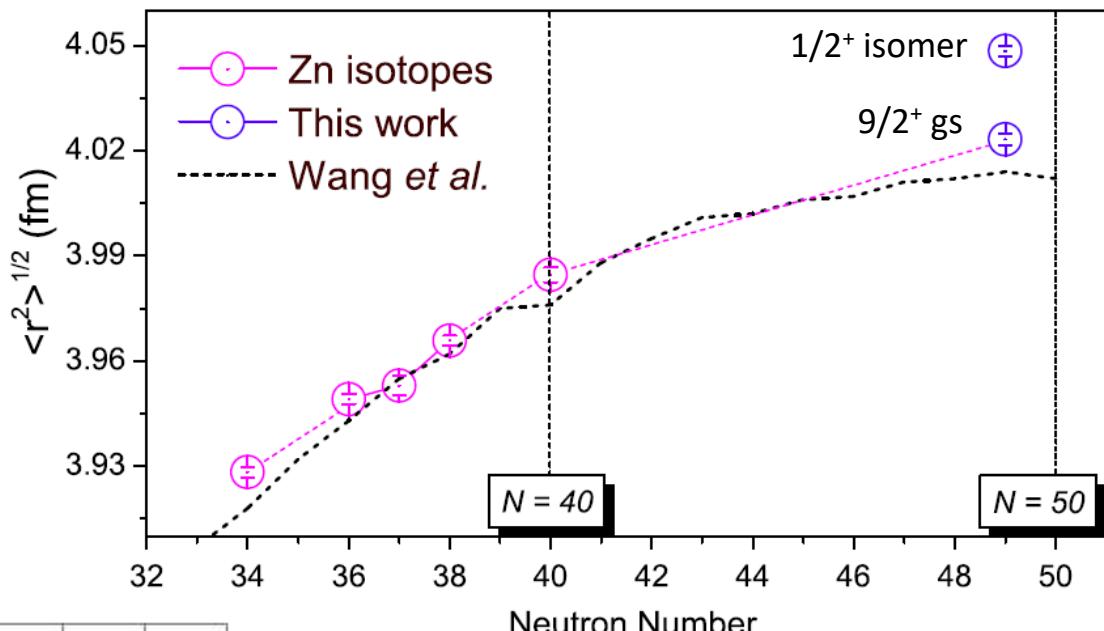
$N=49$

# Shape coexistence (N=49)

X. Yang et al. PRL 116 (2016)

$^{79}\text{Zn}$  : isomer shift measured  
COLLAPS collaboration

$$\langle r_c^2 \rangle ({}^{79m}\text{Zn}) - \langle r_c^2 \rangle ({}^{79g}\text{Zn}) = 0.204(6)[36] \text{ fm}^2$$

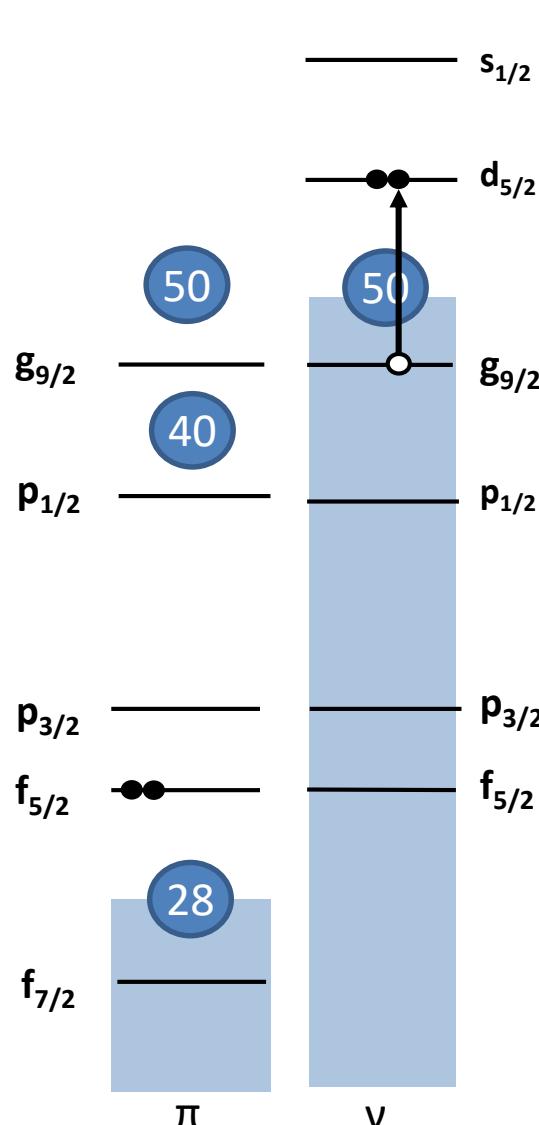


C. Wraith et al. PLB 771 385 (2017)

PFSDG-U based shell model calculations  
→  $s_{1/2} d_{5/2} (d_{3/2} g_{7/2})$  composition  
of the  $1/2^+$  intruder state seems under control (?)

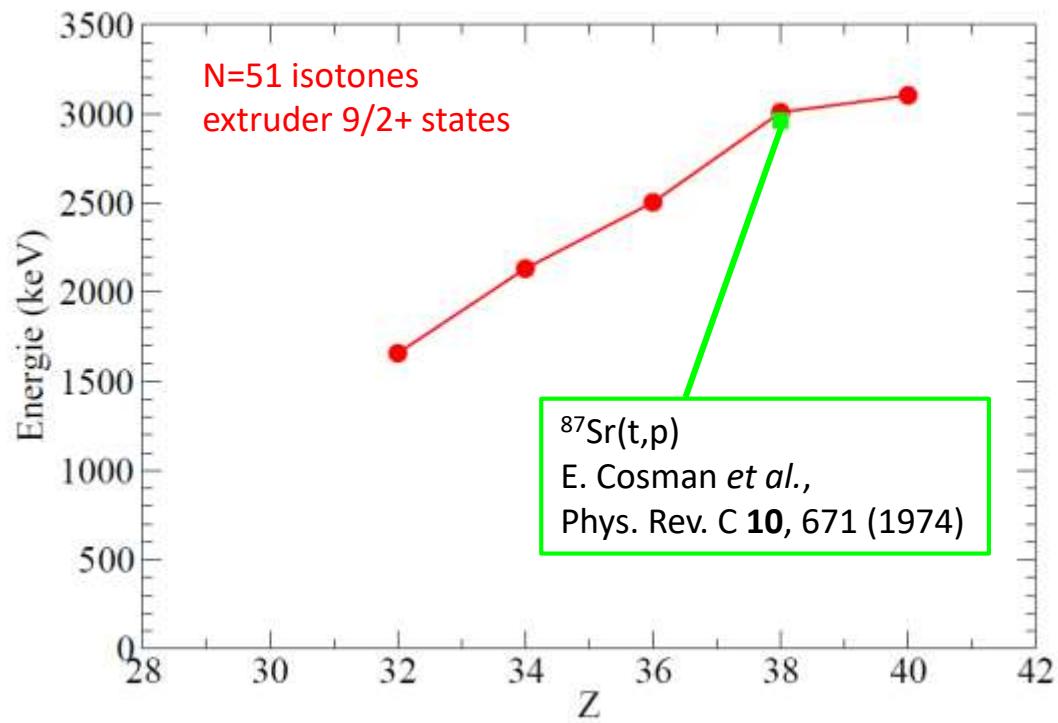
# Shape coexistence (N=51)

Extruder counterparts identified at N=51 : none identified so far



using the same mass ingredients as for the evaluation of the  $0^+_2$  intruder energy in  $^{80}\text{Ge}$  →

$$E_{d_{5/2}^2 g_{9/2}^{-1}}^{\text{unp}} = \tilde{\epsilon}_{d_{5/2}} - \tilde{\epsilon}_{g_{9/2}} + \Delta E_{\text{pairing}}(p)$$

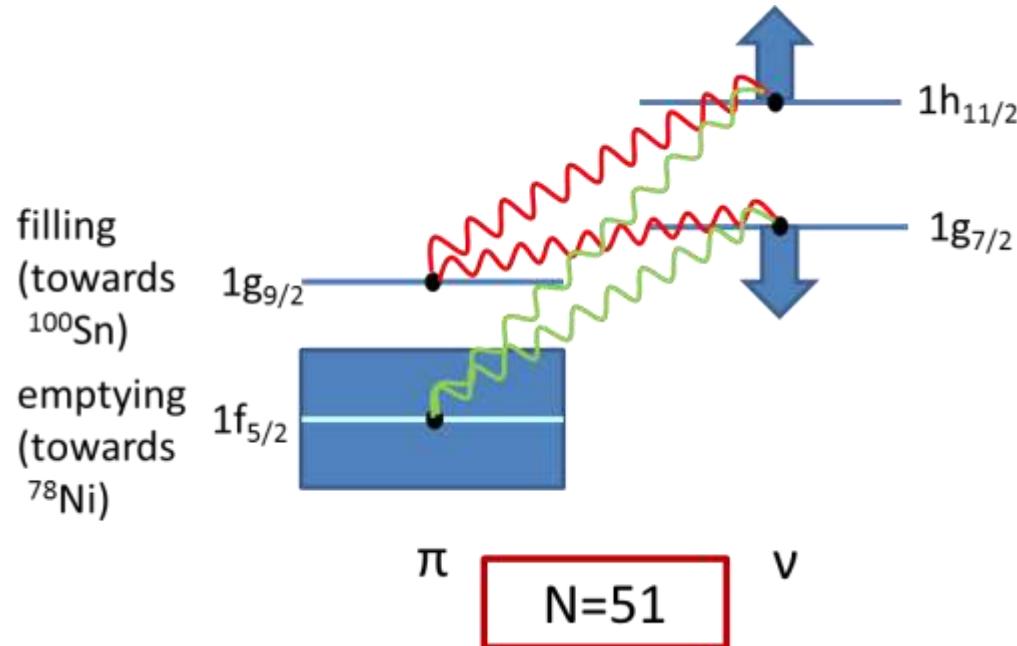


# neutron valence space above $^{78}\text{Ni}$ ?

## Energy location of high- $\ell$ orbitals

Tensor (Otsuka) mechanism: a robust feature of the physics of the  $^{100}\text{Sn}$  region which brings the  $v1g_{7/2}$  close to the g.s.

should be true also for the  $^{78}\text{Ni}$  region  
⇒ the  $7/2^+$  state stemming from  $v g_{7/2}$  should become Yrast along the N=51 line towards  $^{79}\text{Ni}$

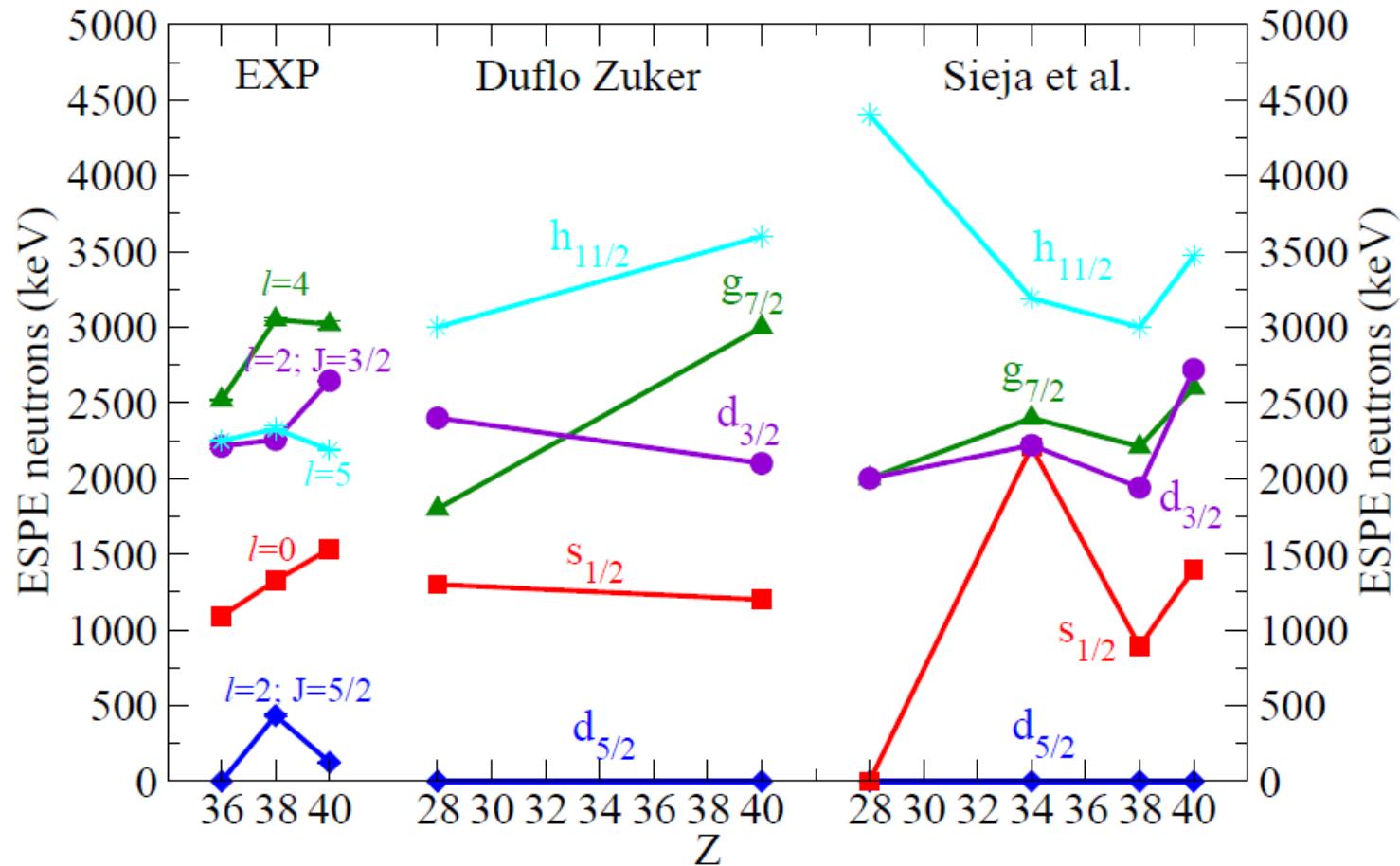


# neutron valence space above $^{78}\text{Ni}$ ?

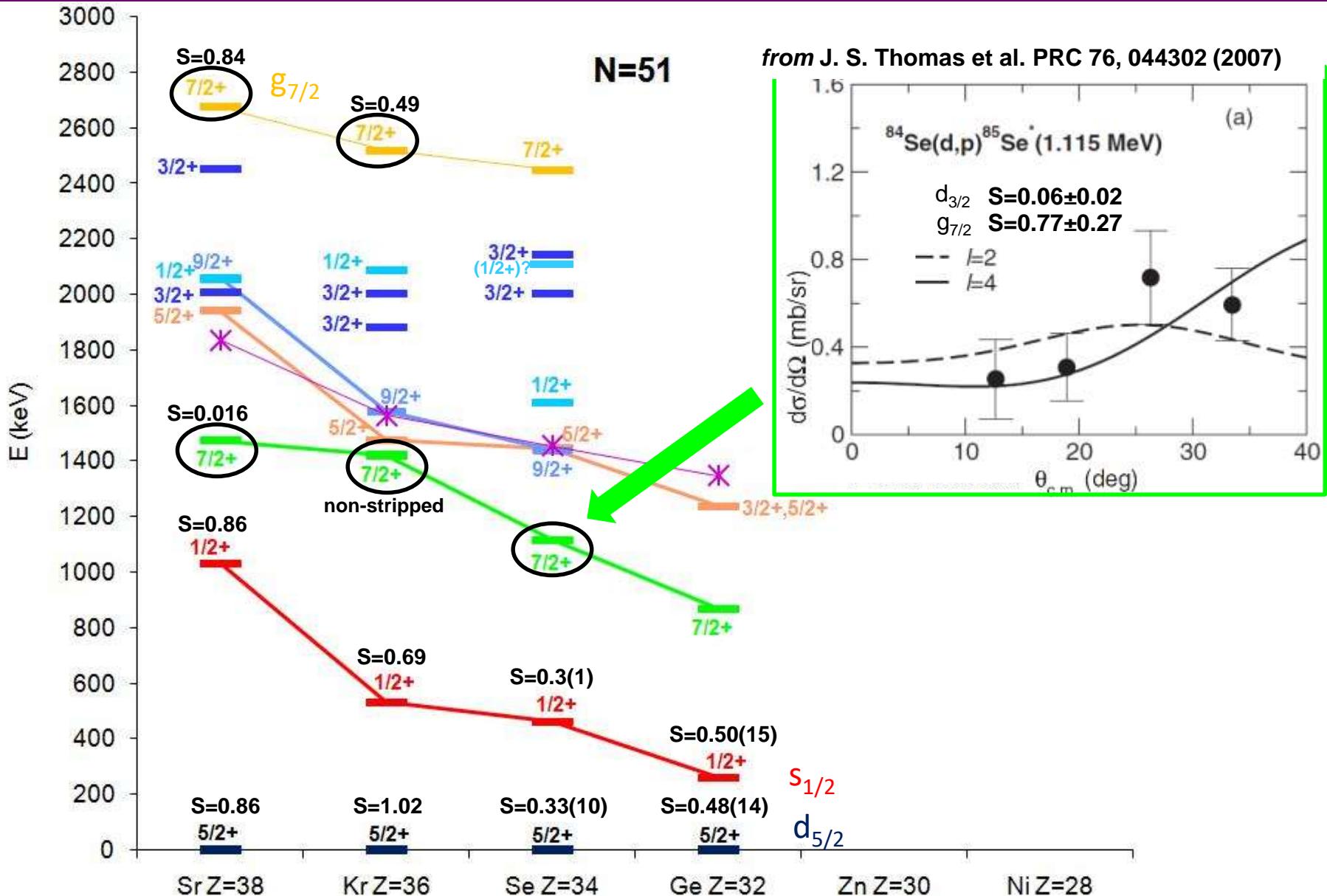
D. K. Sharp et al., PRC **87**,  
014312 (2013)

From Duflo Zuker  
PRC **59**, R2347 (1999)

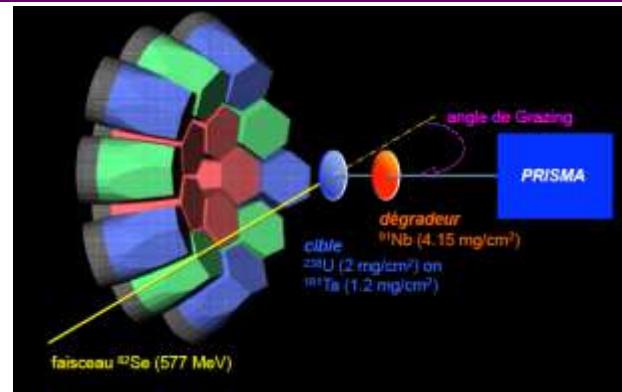
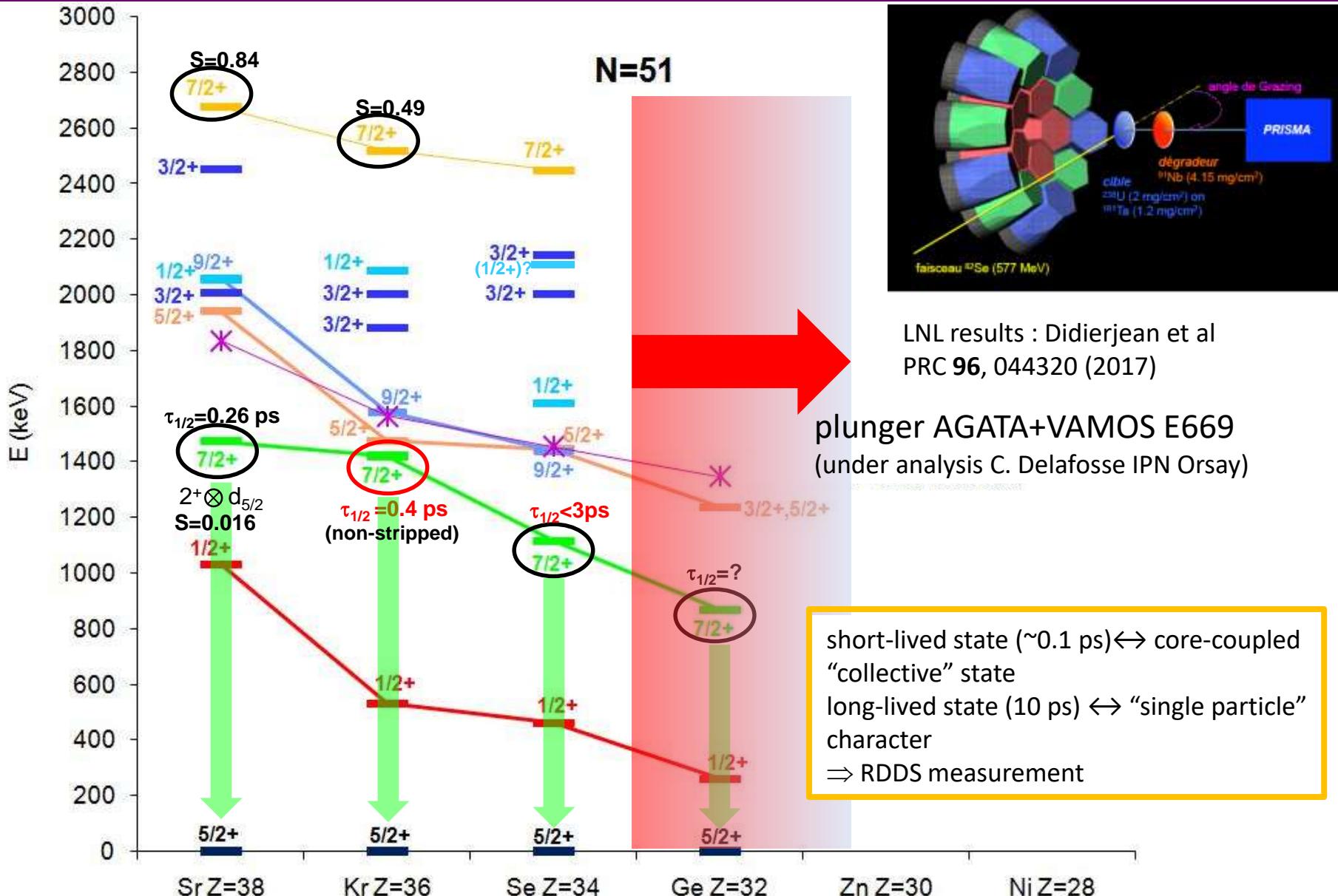
SM calculations in valence space  
above  $^{78}\text{Ni}$   
K. Sieja et al. PRC **79**, 064310 (2009)



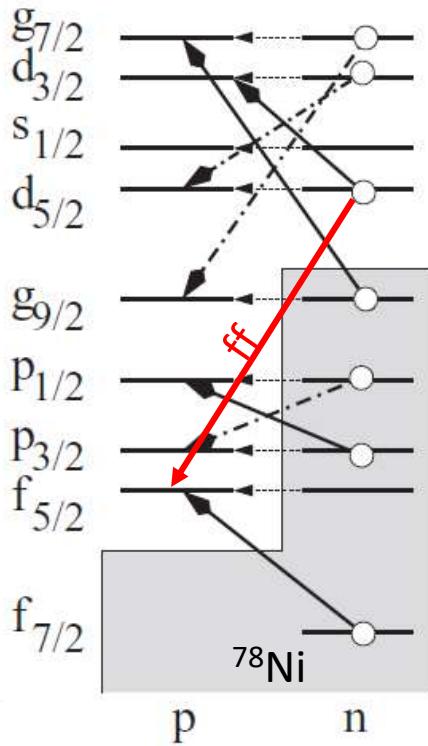
## neutron valence space above $^{78}\text{Ni}$ ?



# neutron valence space above $^{78}\text{Ni}$ ?

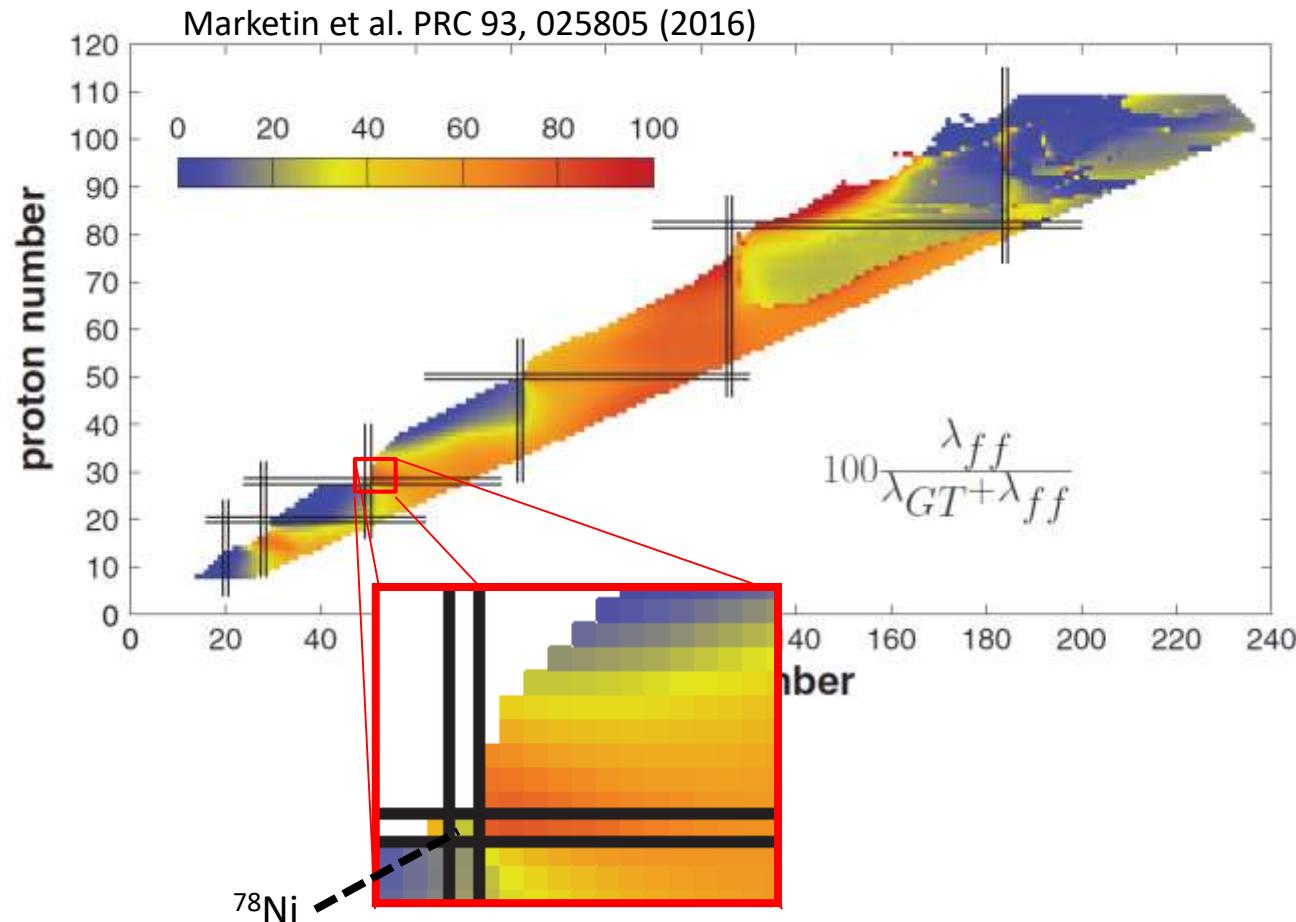


# The question of ff-transitions in the $^{78}\text{Ni}$ region



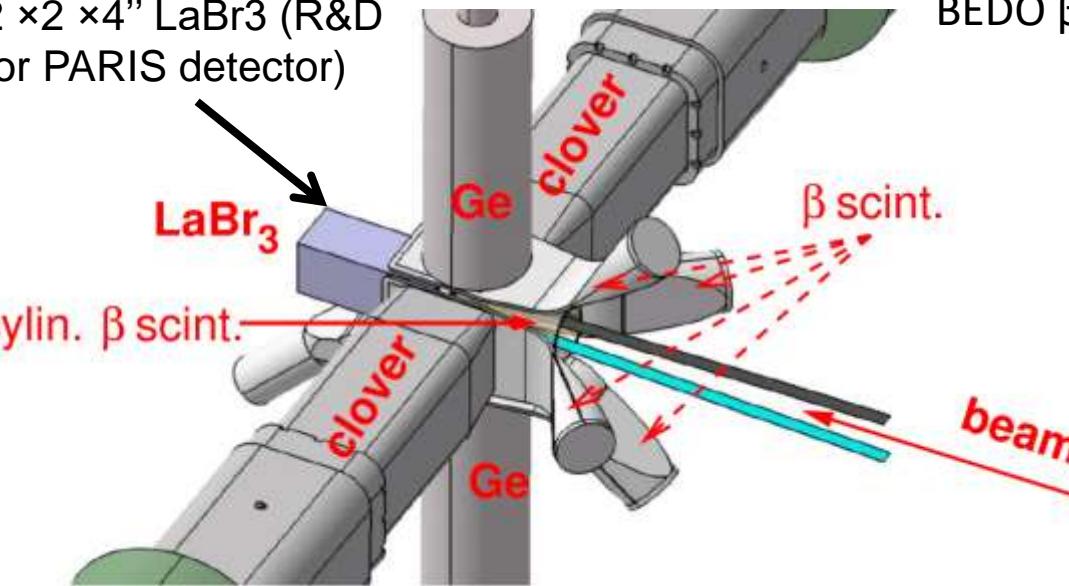
Because of the structure of the valence space in very N/Z asymmetric nuclei first-forbidden transition are believed to play a major role just after closed neutron shell

→ consequences for r-process modeling



# The question of ff-transitions in the $^{78}\text{Ni}$ region

$2 \times 2 \times 4"$  LaBr<sub>3</sub> (R&D  
for PARIS detector)

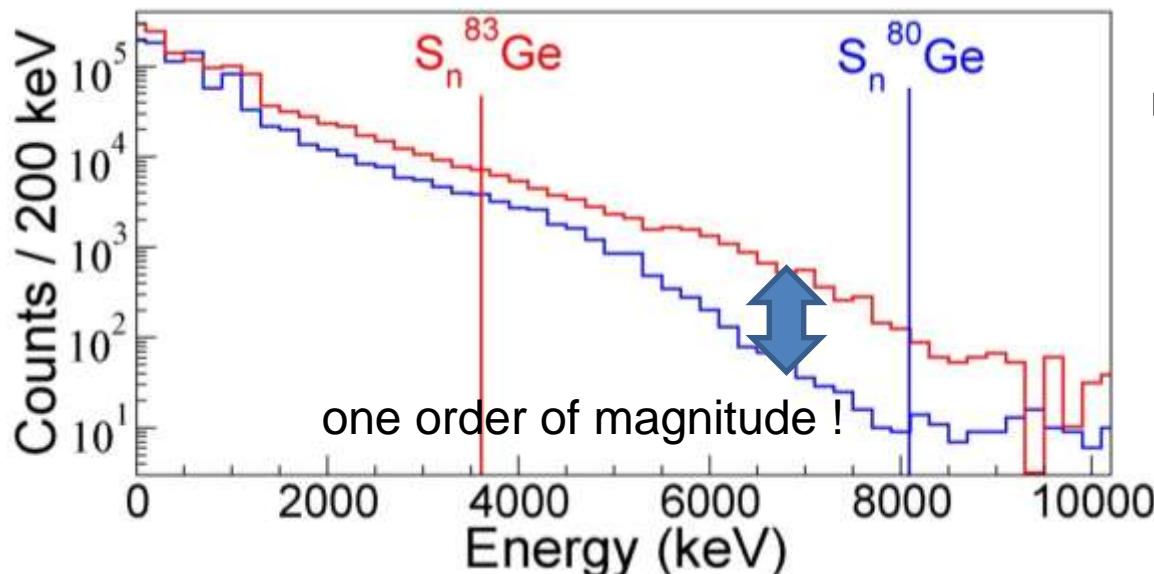


BEDO  $\beta$ -decay station at ALTO

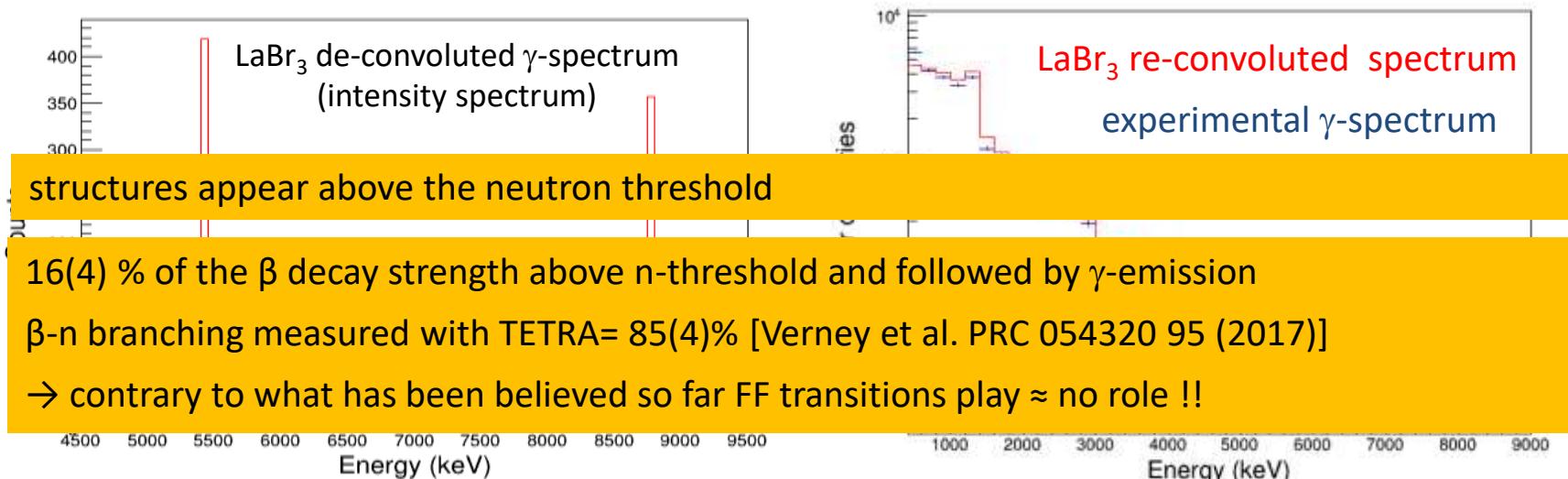
	Zr90	Zr91	Zr92	Zr93	Zr94	Zr95	Zr96
0+	*	5/2+	6+	1.53E+0.5	0+	64.03 d	0+
51.45	11.21	17.15	9	17.38	9	17.38	9
Y89	Y <sup>90</sup> 44.19 h	Y <sup>91</sup> 58.51 d	Y <sup>92</sup> 3.54 h	Y <sup>93</sup> 10.18 h	Y <sup>94</sup> 11.7 m	Y <sup>95</sup> 10.3 m	Y <sup>96</sup> 1.2- 1m
10-	*	1/2-	*	1/2-	*	1/2-	*
100	p	p	p	p	p	p	p
Sr88	Sr <sup>89</sup> 86.53 d	Sr <sup>90</sup> 52.1 h	Sr <sup>91</sup> 9.83 h	Sr <sup>92</sup> 7.1 h	Sr <sup>93</sup> 7.423 m	Sr <sup>94</sup> 55.3 s	Sr <sup>95</sup> 0+
82.58	p	p	p	p	p	p	p
Rb87	Rb <sup>88</sup> 4.75E10 y	Rb <sup>89</sup> 17.78 m	Rb <sup>90</sup> 15.15 m	Rb <sup>91</sup> 58.4 s	Rb <sup>92</sup> 4.091 s	Rb <sup>93</sup> 5.84 s	Rb <sup>94</sup> 5.2-
3/2-	*	3/2-	3/2-	3/2-	3/2-	3/2-	3/2-
p	p	p	p	p	p	p	p
Kr84	Kr <sup>85</sup> 10.756 y	Kr <sup>86</sup> 9.2+	Kr <sup>87</sup> 7.43 m	Kr <sup>88</sup> 3.15 m	Kr <sup>89</sup> 32.32 s	Kr <sup>90</sup> 8.57 s	Kr <sup>91</sup> 1.340 s
0+	*	0+	0+	0+	0+	0+	0+
57.0	p	p	p	p	p	p	p
Kr86	Kr <sup>85</sup> 2.46 h	Kr <sup>84</sup> 31.89 m	Kr <sup>85</sup> 2.99 m	Kr <sup>86</sup> 55.1 s	Kr <sup>87</sup> 55.69 s	Kr <sup>88</sup> 16.34 s	Kr <sup>89</sup> 4.348 s
17.3	*	*	*	(2)	*	(2)	*
p	p	p	p	p	p	p	p
Br85	Br <sup>86</sup> 2.46 h	Br <sup>87</sup> 55.69 s	Br <sup>88</sup> 16.34 s	Br <sup>89</sup> 4.348 s	Br <sup>90</sup> 1.910 s	Br <sup>91</sup> 0.541 s	Br <sup>92</sup> 0 n
2.99 m	3/2-	3/2-	3/2-	3/2-	3/2-	3/2-	0 n
3/2-	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Br86	Br <sup>87</sup> 55.69 s	Br <sup>88</sup> 16.34 s	Br <sup>89</sup> 4.348 s	Br <sup>90</sup> 1.910 s	Br <sup>91</sup> 0.541 s	Br <sup>92</sup> 0 n	Br <sup>93</sup> 0 n
55.1 s	(2)	(2)	(2)	(2)	(2)	(2)	(2)
As84	As <sup>85</sup> 22.3 m	As <sup>86</sup> 15.3 s	As <sup>87</sup> 5.29 s	As <sup>88</sup> 1.53 s	As <sup>89</sup> 0.41 s	As <sup>90</sup> 0 n	As <sup>91</sup> 0 n
3/2+	*	0+	(5/2+)	(5/2+)	(5/2+)	(5/2+)	(5/2+)
p	p	p	p	p	p	p	p
As85	As <sup>86</sup> 22.3 m	As <sup>87</sup> 15.3 s	As <sup>88</sup> 5.29 s	As <sup>89</sup> 1.53 s	As <sup>90</sup> 0.41 s	As <sup>91</sup> 0 n	As <sup>92</sup> 0 n
22.3 m	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Se84	Se <sup>85</sup> 22.3 m	Se <sup>86</sup> 15.3 s	Se <sup>87</sup> 5.29 s	Se <sup>88</sup> 1.53 s	Se <sup>89</sup> 0.41 s	Se <sup>90</sup> 0 n	Se <sup>91</sup> 0 n
3/2+	*	0+	(5/2+)	(5/2+)	(5/2+)	(5/2+)	(5/2+)
p	p	p	p	p	p	p	p
Se85	Se <sup>86</sup> 22.3 m	Se <sup>87</sup> 15.3 s	Se <sup>88</sup> 5.29 s	Se <sup>89</sup> 1.53 s	Se <sup>90</sup> 0.41 s	Se <sup>91</sup> 0 n	Se <sup>92</sup> 0 n
22.3 m	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
As83	As <sup>84</sup> 13.4 s	As <sup>85</sup> 2.021 s	As <sup>86</sup> 0.845 s	As <sup>87</sup> 0.48 s	As <sup>88</sup> 0.24 s	As <sup>89</sup> 0.12 s	As <sup>90</sup> 0 n
13.4 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
As84	As <sup>85</sup> 13.4 s	As <sup>86</sup> 2.021 s	As <sup>87</sup> 0.845 s	As <sup>88</sup> 0.48 s	As <sup>89</sup> 0.24 s	As <sup>90</sup> 0.12 s	As <sup>91</sup> 0 n
13.4 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge82	Ge <sup>83</sup> 1.85 s	Ge <sup>84</sup> 96.0 m	Ge <sup>85</sup> 335 m	Ge <sup>86</sup> 0+	Ge <sup>87</sup> 83 m	Ge <sup>88</sup> 85 m	Ge <sup>89</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge83	Ge <sup>84</sup> 1.85 s	Ge <sup>85</sup> 96.0 m	Ge <sup>86</sup> 335 m	Ge <sup>87</sup> 83 m	Ge <sup>88</sup> 85 m	Ge <sup>89</sup> 0 n	Ge <sup>90</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge84	Ge <sup>85</sup> 1.85 s	Ge <sup>86</sup> 96.0 m	Ge <sup>87</sup> 335 m	Ge <sup>88</sup> 83 m	Ge <sup>89</sup> 85 m	Ge <sup>90</sup> 0 n	Ge <sup>91</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge85	Ge <sup>86</sup> 1.85 s	Ge <sup>87</sup> 96.0 m	Ge <sup>88</sup> 335 m	Ge <sup>89</sup> 83 m	Ge <sup>90</sup> 85 m	Ge <sup>91</sup> 0 n	Ge <sup>92</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge86	Ge <sup>87</sup> 1.85 s	Ge <sup>88</sup> 96.0 m	Ge <sup>89</sup> 335 m	Ge <sup>90</sup> 83 m	Ge <sup>91</sup> 85 m	Ge <sup>92</sup> 0 n	Ge <sup>93</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge87	Ge <sup>88</sup> 1.85 s	Ge <sup>89</sup> 96.0 m	Ge <sup>90</sup> 335 m	Ge <sup>91</sup> 83 m	Ge <sup>92</sup> 85 m	Ge <sup>93</sup> 0 n	Ge <sup>94</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge88	Ge <sup>89</sup> 1.85 s	Ge <sup>90</sup> 96.0 m	Ge <sup>91</sup> 335 m	Ge <sup>92</sup> 83 m	Ge <sup>93</sup> 85 m	Ge <sup>94</sup> 0 n	Ge <sup>95</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge89	Ge <sup>90</sup> 1.85 s	Ge <sup>91</sup> 96.0 m	Ge <sup>92</sup> 335 m	Ge <sup>93</sup> 83 m	Ge <sup>94</sup> 85 m	Ge <sup>95</sup> 0 n	Ge <sup>96</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge90	Ge <sup>91</sup> 1.85 s	Ge <sup>92</sup> 96.0 m	Ge <sup>93</sup> 335 m	Ge <sup>94</sup> 83 m	Ge <sup>95</sup> 85 m	Ge <sup>96</sup> 0 n	Ge <sup>97</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge91	Ge <sup>92</sup> 1.85 s	Ge <sup>93</sup> 96.0 m	Ge <sup>94</sup> 335 m	Ge <sup>95</sup> 83 m	Ge <sup>96</sup> 85 m	Ge <sup>97</sup> 0 n	Ge <sup>98</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge92	Ge <sup>93</sup> 1.85 s	Ge <sup>94</sup> 96.0 m	Ge <sup>95</sup> 335 m	Ge <sup>96</sup> 83 m	Ge <sup>97</sup> 85 m	Ge <sup>98</sup> 0 n	Ge <sup>99</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge93	Ge <sup>94</sup> 1.85 s	Ge <sup>95</sup> 96.0 m	Ge <sup>96</sup> 335 m	Ge <sup>97</sup> 83 m	Ge <sup>98</sup> 85 m	Ge <sup>99</sup> 0 n	Ge <sup>100</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge94	Ge <sup>95</sup> 1.85 s	Ge <sup>96</sup> 96.0 m	Ge <sup>97</sup> 335 m	Ge <sup>98</sup> 83 m	Ge <sup>99</sup> 85 m	Ge <sup>100</sup> 0 n	Ge <sup>101</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge95	Ge <sup>96</sup> 1.85 s	Ge <sup>97</sup> 96.0 m	Ge <sup>98</sup> 335 m	Ge <sup>99</sup> 83 m	Ge <sup>100</sup> 85 m	Ge <sup>101</sup> 0 n	Ge <sup>102</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge96	Ge <sup>97</sup> 1.85 s	Ge <sup>98</sup> 96.0 m	Ge <sup>99</sup> 335 m	Ge <sup>100</sup> 83 m	Ge <sup>101</sup> 85 m	Ge <sup>102</sup> 0 n	Ge <sup>103</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge97	Ge <sup>98</sup> 1.85 s	Ge <sup>99</sup> 96.0 m	Ge <sup>100</sup> 335 m	Ge <sup>101</sup> 83 m	Ge <sup>102</sup> 85 m	Ge <sup>103</sup> 0 n	Ge <sup>104</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge98	Ge <sup>99</sup> 1.85 s	Ge <sup>100</sup> 96.0 m	Ge <sup>101</sup> 335 m	Ge <sup>102</sup> 83 m	Ge <sup>103</sup> 85 m	Ge <sup>104</sup> 0 n	Ge <sup>105</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge99	Ge <sup>100</sup> 1.85 s	Ge <sup>101</sup> 96.0 m	Ge <sup>102</sup> 335 m	Ge <sup>103</sup> 83 m	Ge <sup>104</sup> 85 m	Ge <sup>105</sup> 0 n	Ge <sup>106</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge100	Ge <sup>101</sup> 1.85 s	Ge <sup>102</sup> 96.0 m	Ge <sup>103</sup> 335 m	Ge <sup>104</sup> 83 m	Ge <sup>105</sup> 85 m	Ge <sup>106</sup> 0 n	Ge <sup>107</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge101	Ge <sup>102</sup> 1.85 s	Ge <sup>103</sup> 96.0 m	Ge <sup>104</sup> 335 m	Ge <sup>105</sup> 83 m	Ge <sup>106</sup> 85 m	Ge <sup>107</sup> 0 n	Ge <sup>108</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge102	Ge <sup>103</sup> 1.85 s	Ge <sup>104</sup> 96.0 m	Ge <sup>105</sup> 335 m	Ge <sup>106</sup> 83 m	Ge <sup>107</sup> 85 m	Ge <sup>108</sup> 0 n	Ge <sup>109</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge103	Ge <sup>104</sup> 1.85 s	Ge <sup>105</sup> 96.0 m	Ge <sup>106</sup> 335 m	Ge <sup>107</sup> 83 m	Ge <sup>108</sup> 85 m	Ge <sup>109</sup> 0 n	Ge <sup>110</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge104	Ge <sup>105</sup> 1.85 s	Ge <sup>106</sup> 96.0 m	Ge <sup>107</sup> 335 m	Ge <sup>108</sup> 83 m	Ge <sup>109</sup> 85 m	Ge <sup>110</sup> 0 n	Ge <sup>111</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge105	Ge <sup>106</sup> 1.85 s	Ge <sup>107</sup> 96.0 m	Ge <sup>108</sup> 335 m	Ge <sup>109</sup> 83 m	Ge <sup>110</sup> 85 m	Ge <sup>111</sup> 0 n	Ge <sup>112</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge106	Ge <sup>107</sup> 1.85 s	Ge <sup>108</sup> 96.0 m	Ge <sup>109</sup> 335 m	Ge <sup>110</sup> 83 m	Ge <sup>111</sup> 85 m	Ge <sup>112</sup> 0 n	Ge <sup>113</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge107	Ge <sup>108</sup> 1.85 s	Ge <sup>109</sup> 96.0 m	Ge <sup>110</sup> 335 m	Ge <sup>111</sup> 83 m	Ge <sup>112</sup> 85 m	Ge <sup>113</sup> 0 n	Ge <sup>114</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge108	Ge <sup>109</sup> 1.85 s	Ge <sup>110</sup> 96.0 m	Ge <sup>111</sup> 335 m	Ge <sup>112</sup> 83 m	Ge <sup>113</sup> 85 m	Ge <sup>114</sup> 0 n	Ge <sup>115</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge109	Ge <sup>110</sup> 1.85 s	Ge <sup>111</sup> 96.0 m	Ge <sup>112</sup> 335 m	Ge <sup>113</sup> 83 m	Ge <sup>114</sup> 85 m	Ge <sup>115</sup> 0 n	Ge <sup>116</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge110	Ge <sup>111</sup> 1.85 s	Ge <sup>112</sup> 96.0 m	Ge <sup>113</sup> 335 m	Ge <sup>114</sup> 83 m	Ge <sup>115</sup> 85 m	Ge <sup>116</sup> 0 n	Ge <sup>117</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge111	Ge <sup>112</sup> 1.85 s	Ge <sup>113</sup> 96.0 m	Ge <sup>114</sup> 335 m	Ge <sup>115</sup> 83 m	Ge <sup>116</sup> 85 m	Ge <sup>117</sup> 0 n	Ge <sup>118</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge112	Ge <sup>113</sup> 1.85 s	Ge <sup>114</sup> 96.0 m	Ge <sup>115</sup> 335 m	Ge <sup>116</sup> 83 m	Ge <sup>117</sup> 85 m	Ge <sup>118</sup> 0 n	Ge <sup>119</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge113	Ge <sup>114</sup> 1.85 s	Ge <sup>115</sup> 96.0 m	Ge <sup>116</sup> 335 m	Ge <sup>117</sup> 83 m	Ge <sup>118</sup> 85 m	Ge <sup>119</sup> 0 n	Ge <sup>120</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge114	Ge <sup>115</sup> 1.85 s	Ge <sup>116</sup> 96.0 m	Ge <sup>117</sup> 335 m	Ge <sup>118</sup> 83 m	Ge <sup>119</sup> 85 m	Ge <sup>120</sup> 0 n	Ge <sup>121</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge115	Ge <sup>116</sup> 1.85 s	Ge <sup>117</sup> 96.0 m	Ge <sup>118</sup> 335 m	Ge <sup>119</sup> 83 m	Ge <sup>120</sup> 85 m	Ge <sup>121</sup> 0 n	Ge <sup>122</sup> 0 n
1.85 s	*	*	*	*	*	*	*
p	p	p	p	p	p	p	p
Ge116	Ge <sup>117</sup> 1.85 s	Ge <sup>118</sup> 96.0 m	Ge <sup>119</sup> 335 m	Ge <sup>120</sup> 83 m	Ge <sup>121</sup> 85 m	Ge <sup>1</sup>	

# The question of ff-transitions in the $^{78}\text{Ni}$ region

comparison of  $^{80}\text{Ge}$  vs  $^{83}\text{Ge}$  spectra (below vs above N=50) up to  $\approx Q_\beta$



Response function + energy linearity of LaBr<sub>3</sub> detector fully characterized up to 11 MeV using  $^{27}\text{Al}(p,\gamma)^{28}\text{Si}$  reaction at the ARAMIS accelerator (CSNSM in Orsay)



Gottardo et al. Phys. Lett. B 772 359 (2017)

# N=50 shell effect in the $^{78}\text{Ni}$ region : open questions

- gap size  $\rightarrow Z=32$  “singularity”
  - { monopole effect ? (quadratic ??)  $\longrightarrow$  mass measurements
  - { dynamical effect ? (triaxiality corridor ??)  $\longrightarrow$  (multi-step) coulex
- shape coexistence
  - {  $0^+_2$  states  $\longrightarrow$   $\beta$ -delayed e- spectroscopy
  - { extruder states at N=51  $\longrightarrow$  direct nucleon exchange (t,p)
- neutron valence space above  $^{78}\text{Ni}$  : high  $\ell$   $\longrightarrow$  direct nucleon exchange (d,p) and ( $\alpha$ , ${}^3\text{He}$ )
- first-forbidden transitions in the  $^{78}\text{Ni}$  region  $\longrightarrow$   $\beta$ -delayed neutron and high-energy  $\gamma$  spectroscopy

conclusions and outlook:

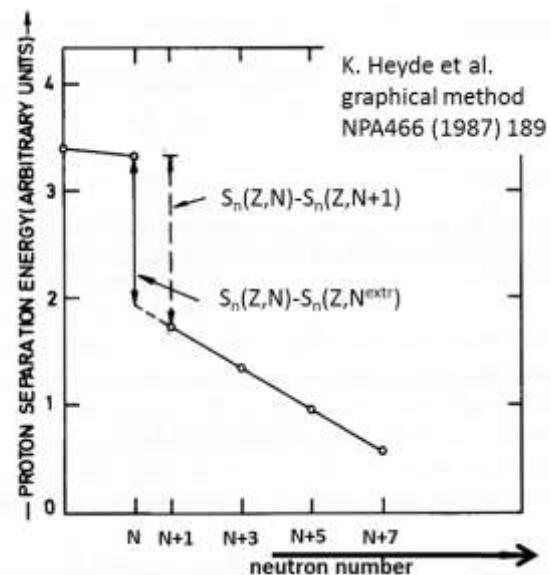
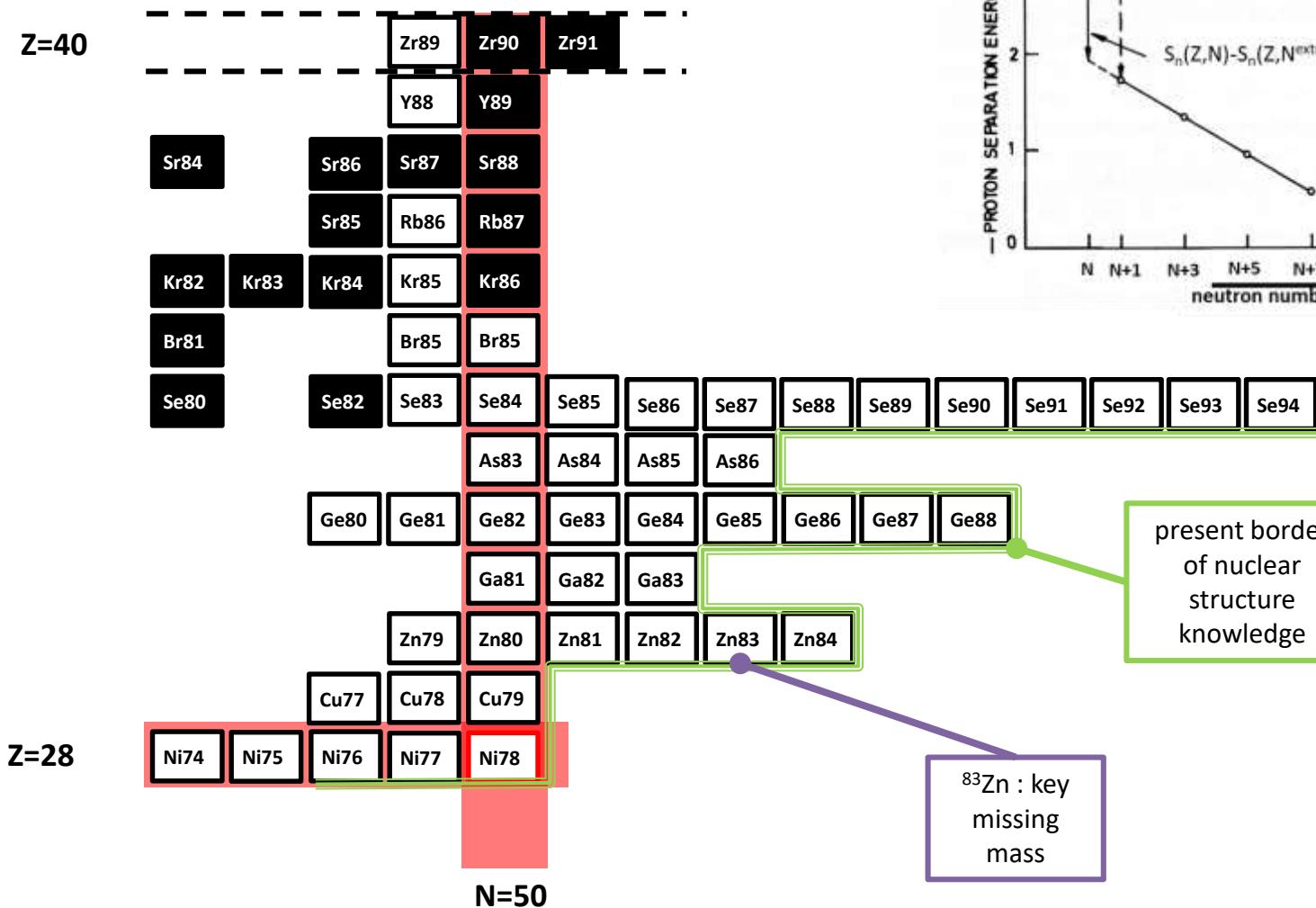
some suggestions for a possible joint N=50/<sup>78</sup>Ni program within EURISOL-DF

# Some suggestions for a “EURISOL-DF joint N=50 program”

- gap size → Z=32 “singularity”

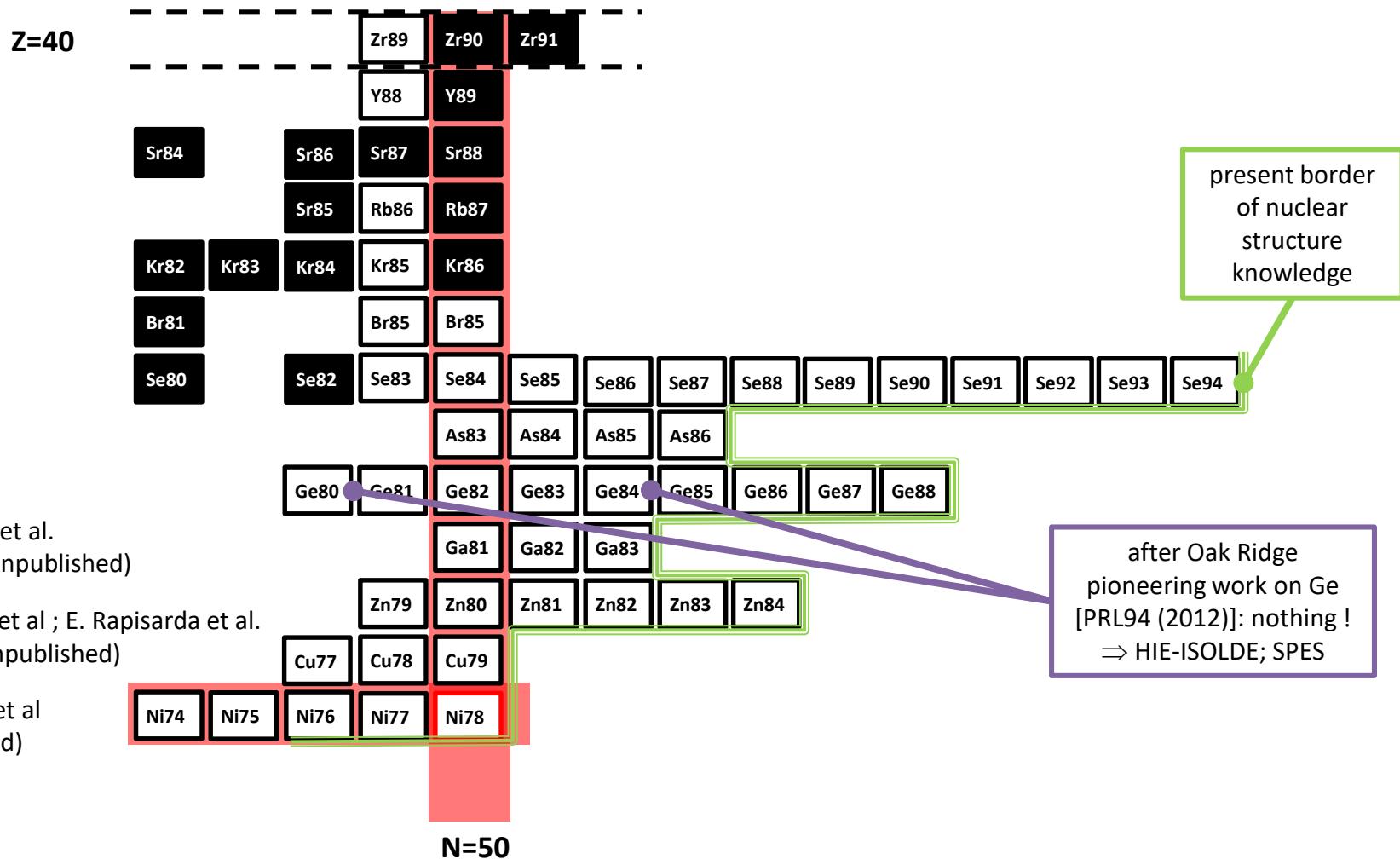
## mass measurements

monopole effect ? (quadratic ??)



# Some suggestions for a “EURISOL-DF joint N=50 program”

- gap size → Z=32 “singularity”
- (multistep) coulex
- dynamical effect ? (triaxiality ??)

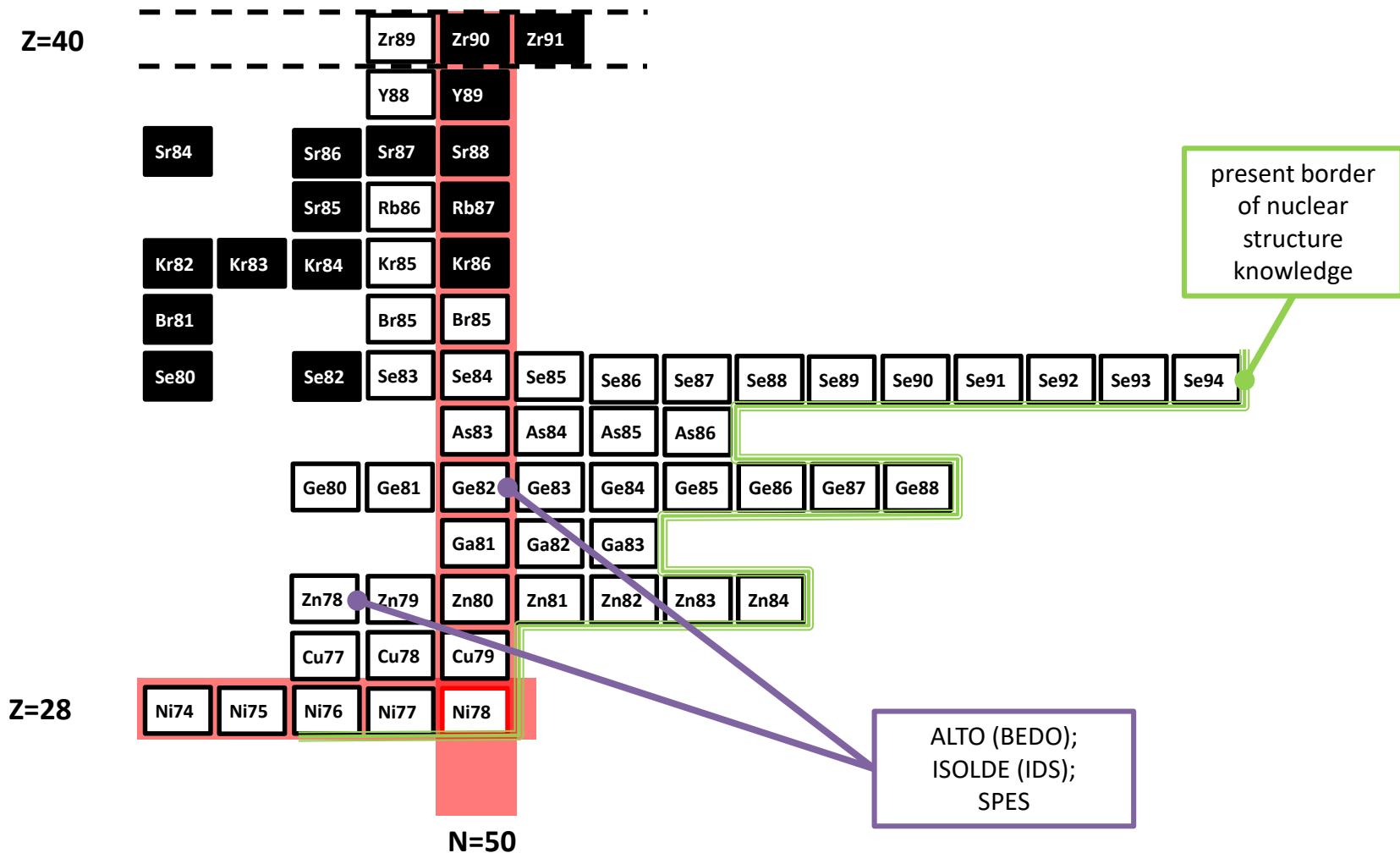


# Some suggestions for a “EURISOL-DF joint N=50 program”

- shape coexistence

## $\beta$ -delayed e- spectroscopy

$0^+_2$  states



# Some suggestions for a “EURISOL-DF joint N=50 program”

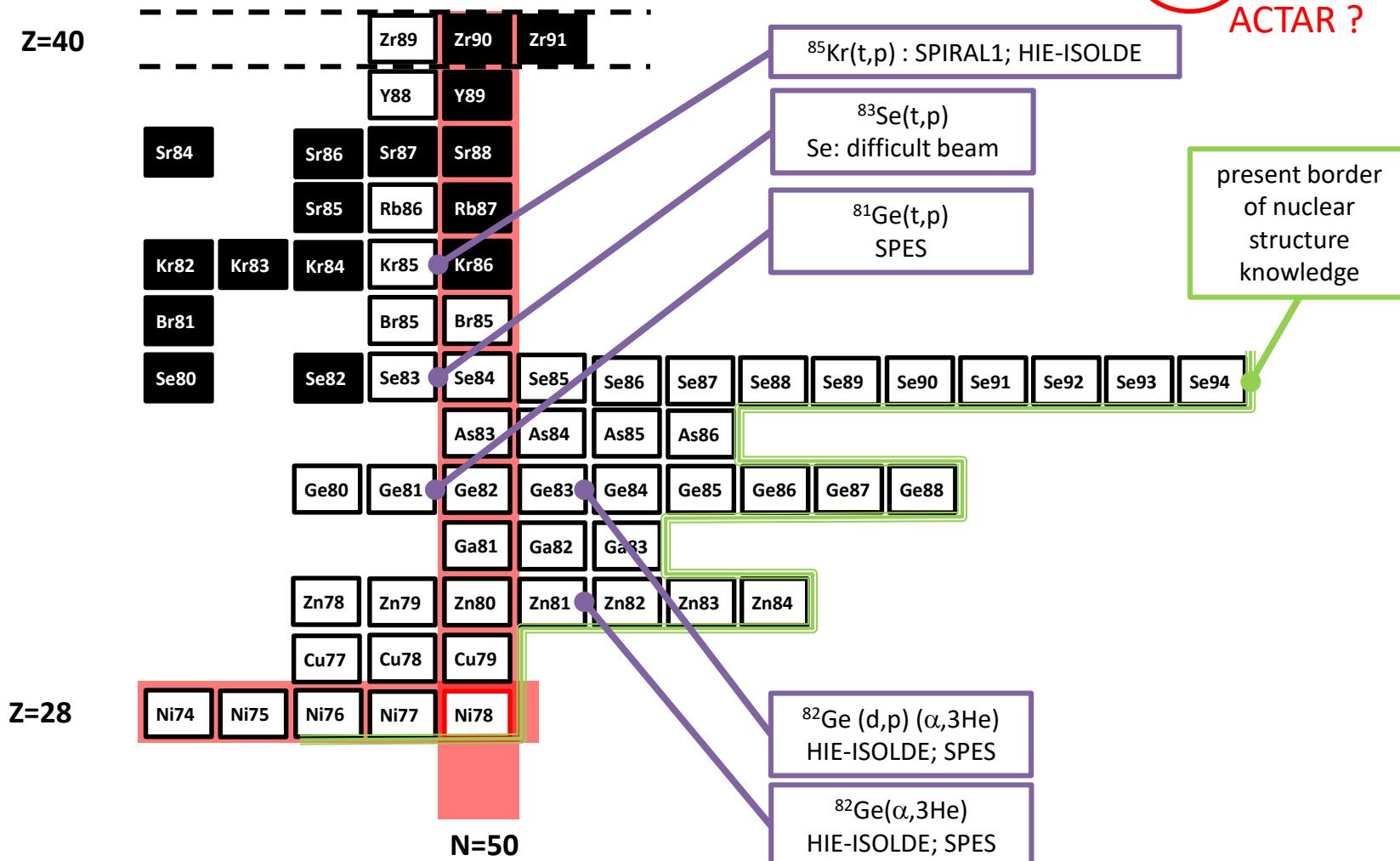
## direct nucleon exchange

- shape coexistence

extruder states at N=51 : (t,p) reaction

- neutron valence space above  $^{78}\text{Ni}$  : high  $\ell$

direct nucleon exchange (d,p) and  $(\alpha, {}^3\text{He})$



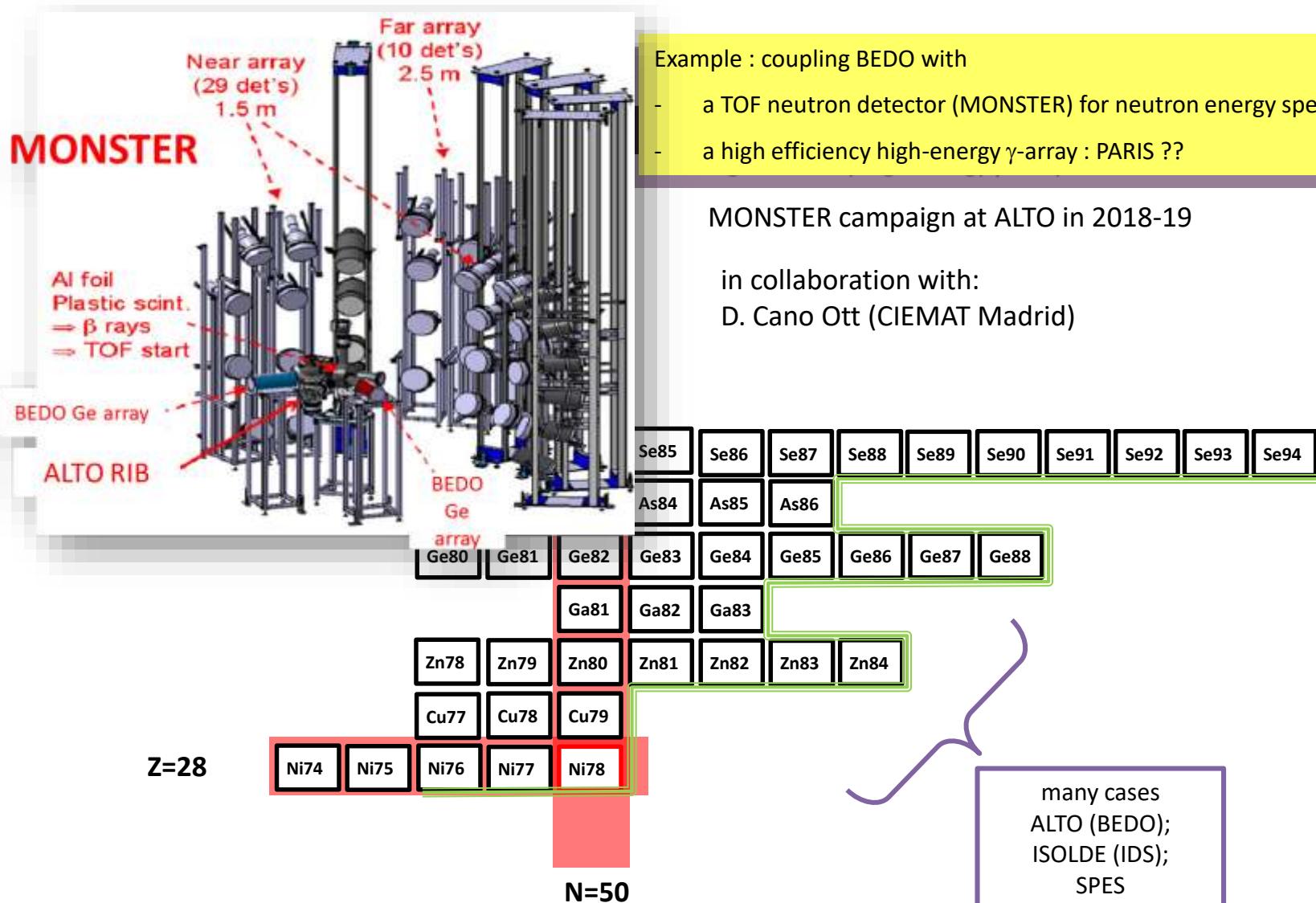
ACTAR ?

present border  
of nuclear  
structure  
knowledge

# Some suggestions for a “EURISOL-DF joint N=50 program”

- first-forbidden transitions in the  $^{78}\text{Ni}$  region

## $\beta$ -delayed neutron and high-energy $\gamma$ spectroscopy



Thank you !