# Towards $^{78}$Ni: In-beam γ-ray spectroscopy of the exotic nuclei close to N=50

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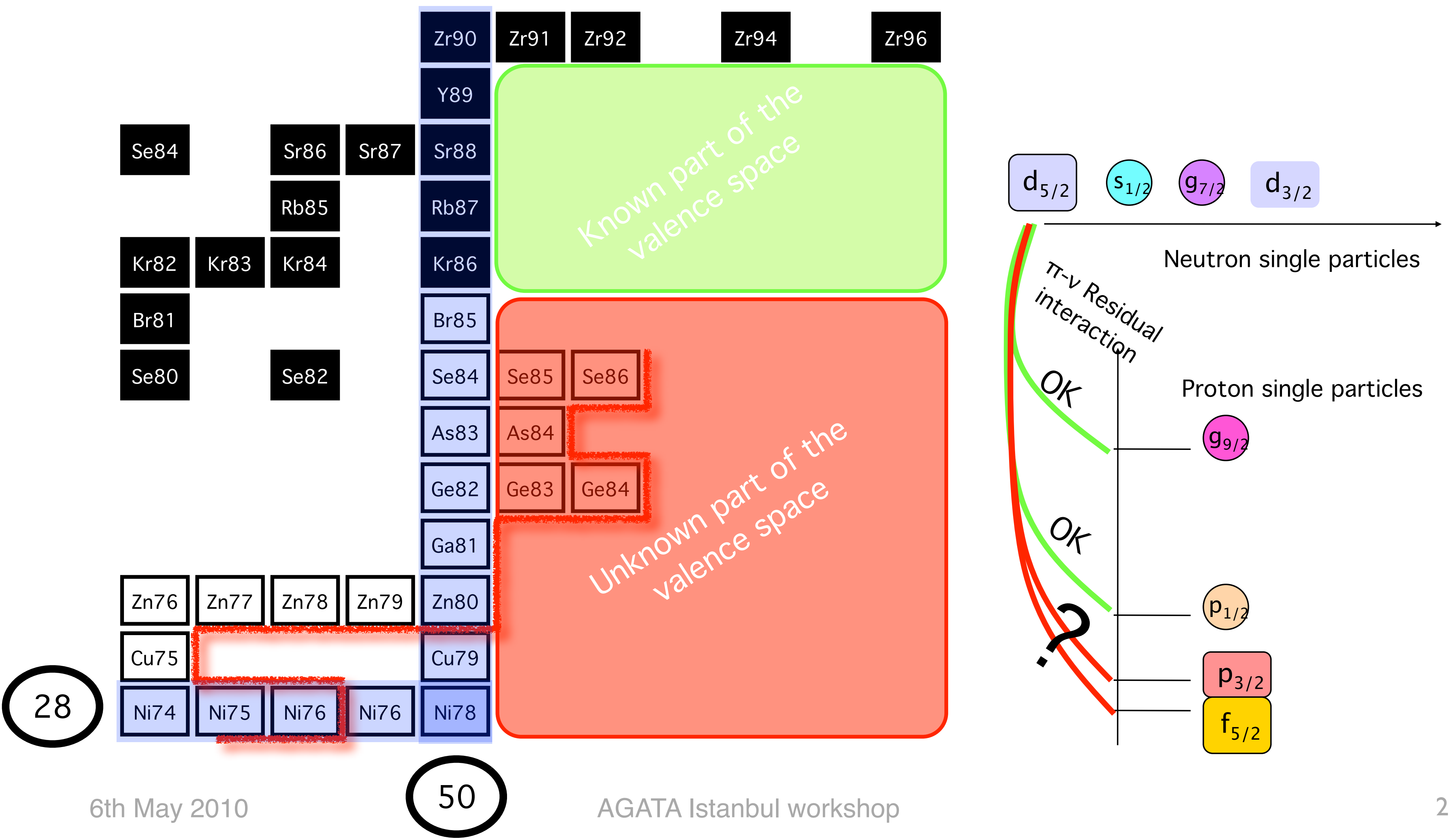
# Physics case: Study of shell structure above $^{78}$Ni

- Is $^{78}$Ni a good core? Persistence of Z=28 and N=50, pair promotions from the lower shells
- What is the nature of valence space which opens up just above ? single particle sequence



# Is $^{78}$Ni good core?

**Probably yes...**

- **from B(E2) measurement in $^{80}$Zn (REX-ISOLDE)**
**J. Van de Walle et al. PRC 79, 014309 (2009)**
«No direct evidence is found for an enhanced Z = 28 core polarization, but the larger proton effective charge needed in the SMI calculations to describe N = 50 isotones with Z < 40 indicate a larger proton core polarization for these isotopes. No evidence is found for breaking of the N = 50 shell gap. »

- **from Yrast structure studies from DIC experiments (Legnaro) down to $^{82}$Ge**
Y. H. Zhang et al. PRC 70, 024301 (2004) and subsequent studies E. Sahin et al.
« The generally good agreement obtained between calculated and measured level energies in all the cases considered is taken as an argument for the proper description of such semi magic nuclei within the shell-model framework and therefore of the persistence of the N=50 closed shell down to Z=32. »

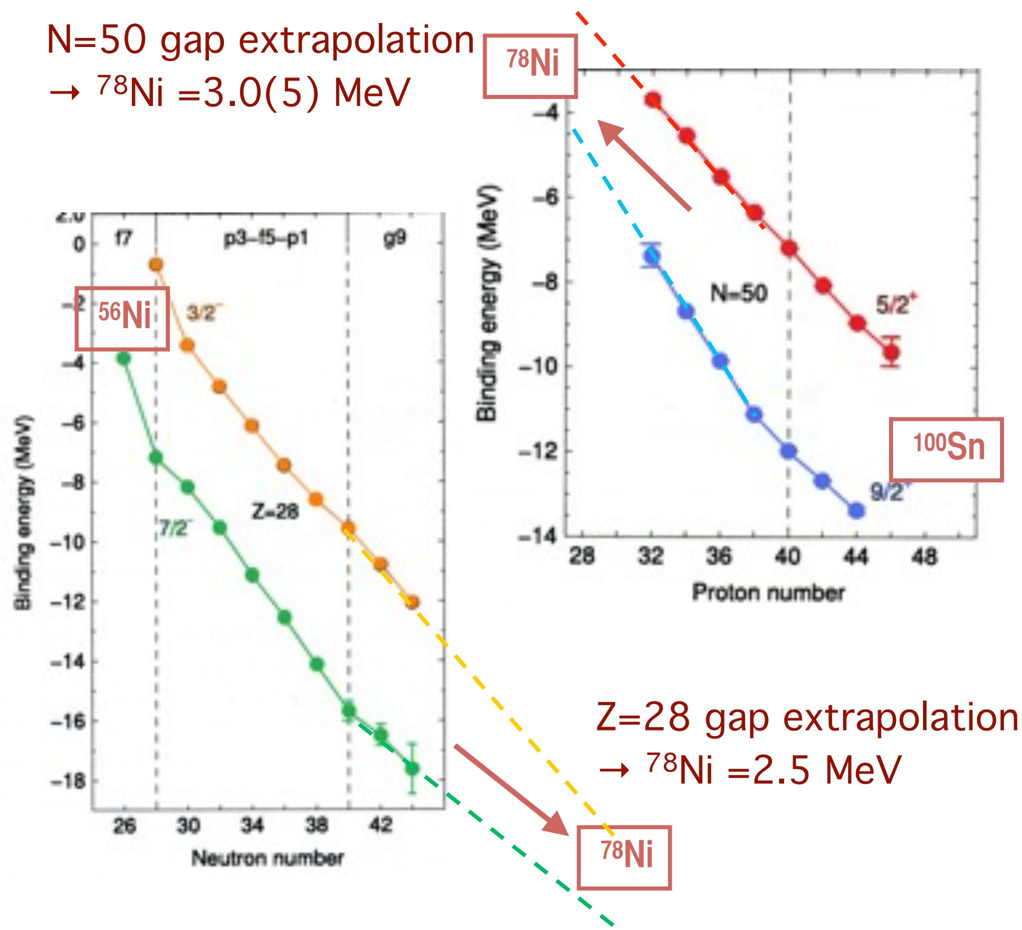
- **from β-decay studies down to $^{81}$Ga (Orsay)**
**O. Perru et al. Eur. Phys. J. A 28, 307 (2006)**
**D. Verney et al. PRC 76, 054312 (2007)**

- **from mass measurements down to $^{80}$Zn (IGISOL Jyvaskyla)**
**J. Hakala et al. PRL 101, 052502 (2008)**
« The data indicates the persistence of this gap towards Ni (Z =28) with an observed minimum at Z=32. »

**maybe not...**

- **O. Sorlin, M. Porquet Prog. Part. Nucl. Phys. 61 (2008) 602**

from binding energies of the states blow and above Z=28 and N=50



# N=50 shell gap has local minimum at Ge

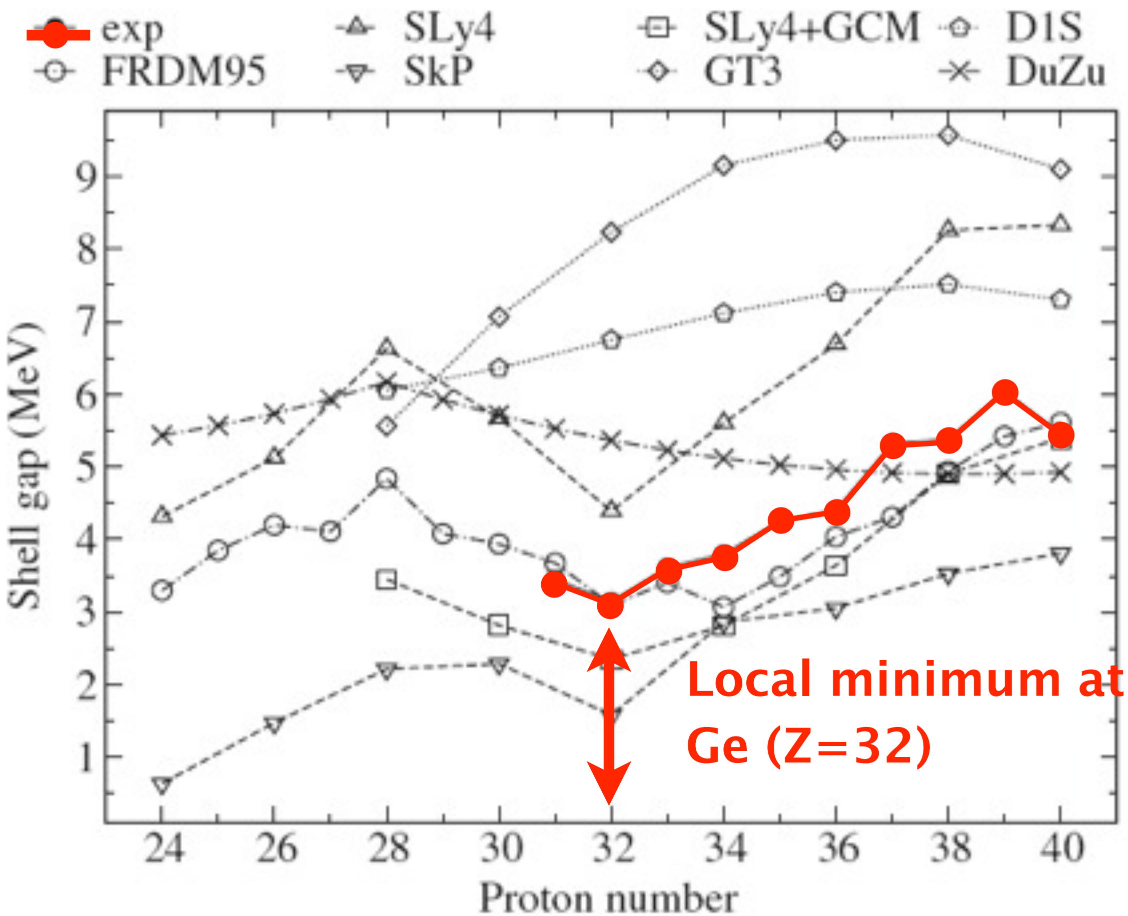
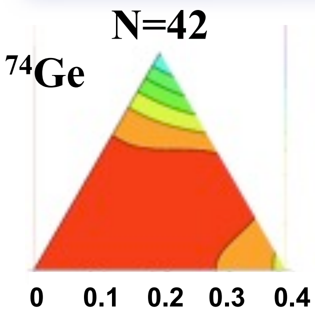


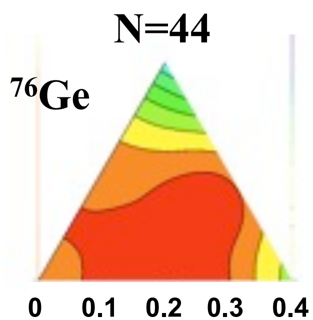

FIG. 4. Evolution of the $N = 50$ shell gap and comparison to theoretical models.

**J. Hakala et al. PRL 101, 052502 (2008)**

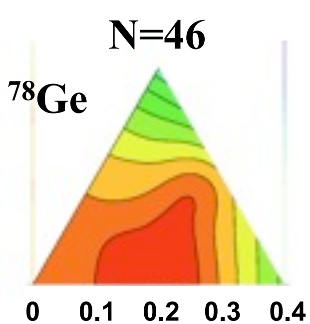
Two neutron separation energy
$\Delta = S_{2n}(52) - S_{2n}(50)$
↓
N=50 shell gap

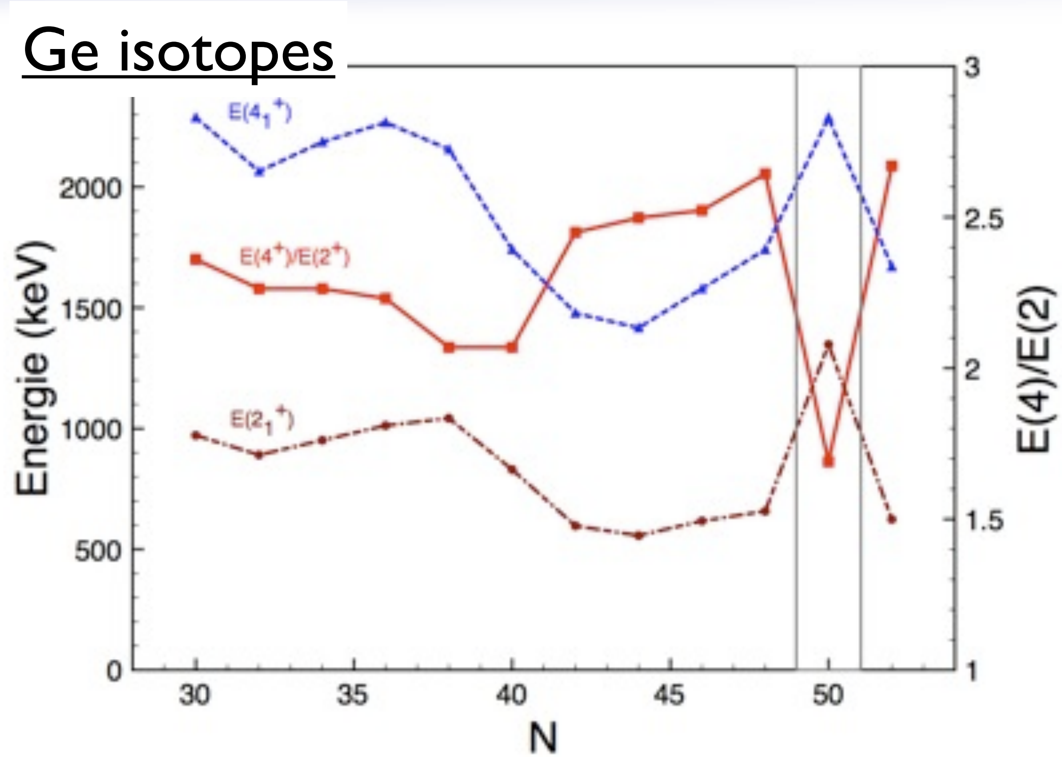
# Increasing collectivity toward N=50 in Ge isotope



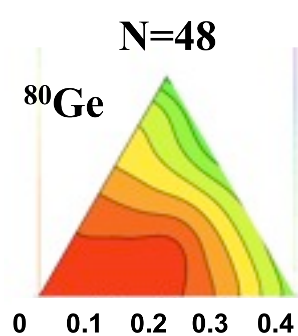




"γ-soft"
nucleus

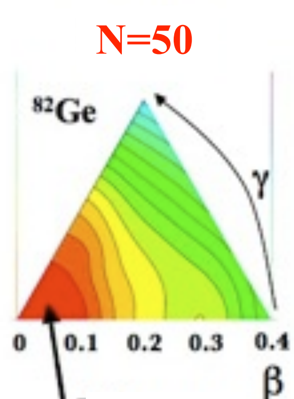


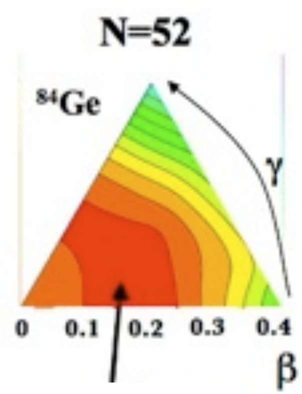

**HFB D1S Gogny + GCM:**
**O. Perru, J. Libert and D. Girod**



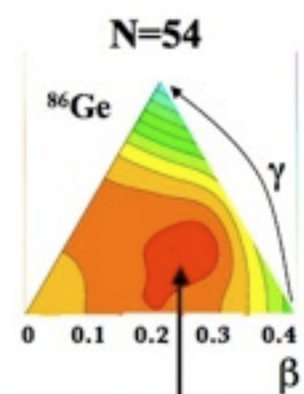

Prolate
vibration




Spherical
vibration




"γ-soft"
nucleus

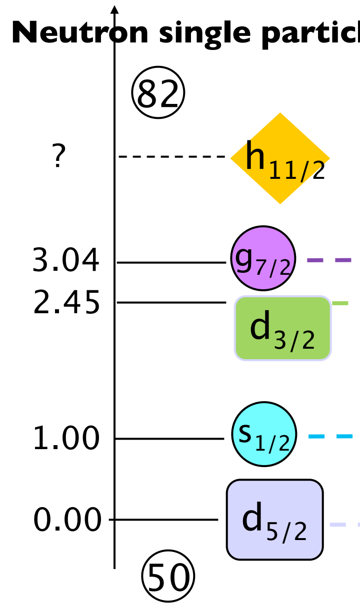


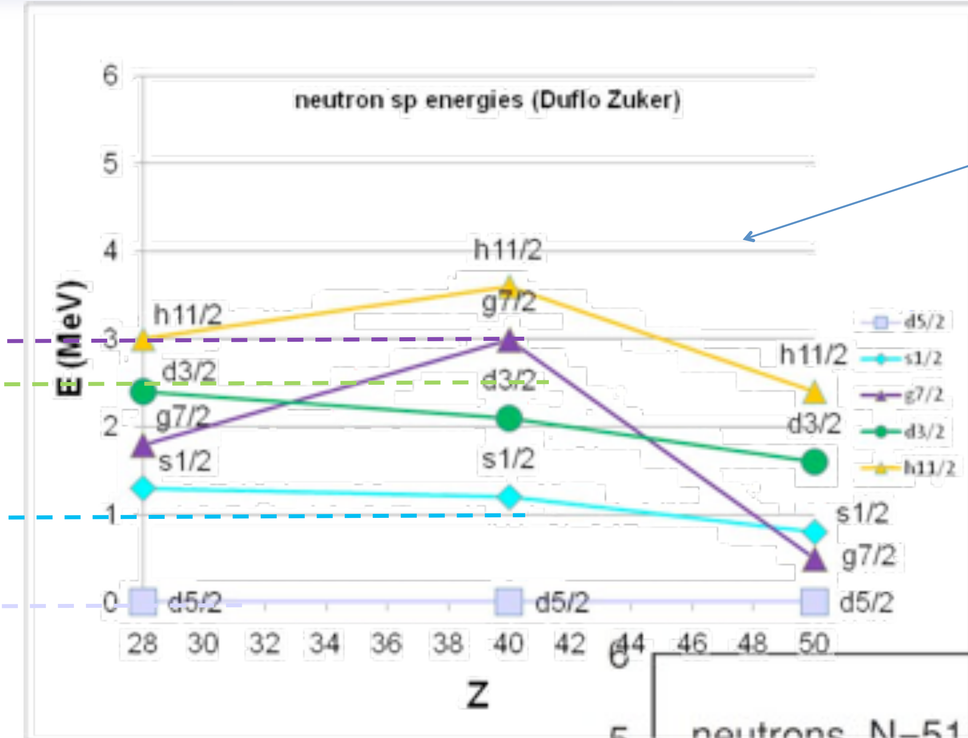

Triaxial rotation

# What is the nature of valence space above $^{78}$Ni?

E (MeV) **in $^{89}$Sr**

**Neutron single particles**

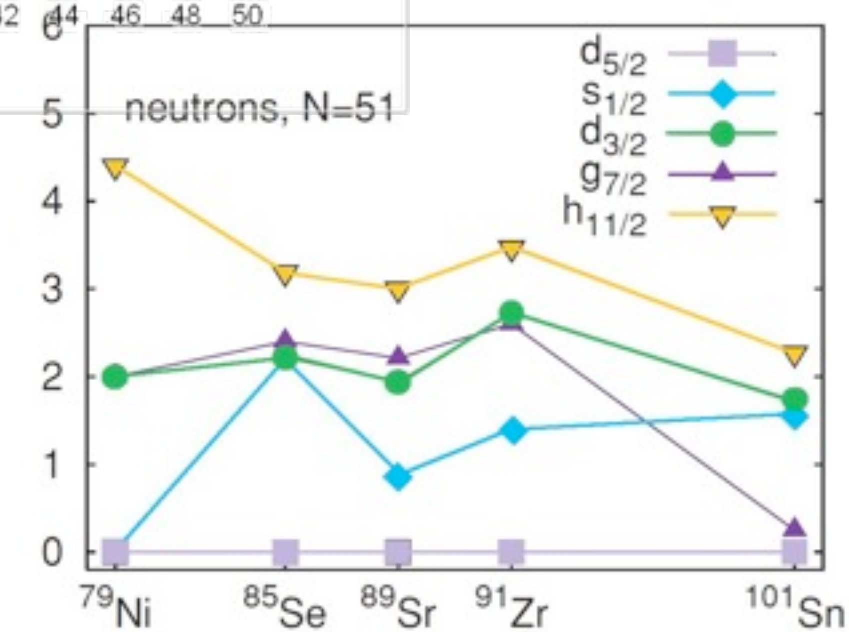



**Duflo Zuker**

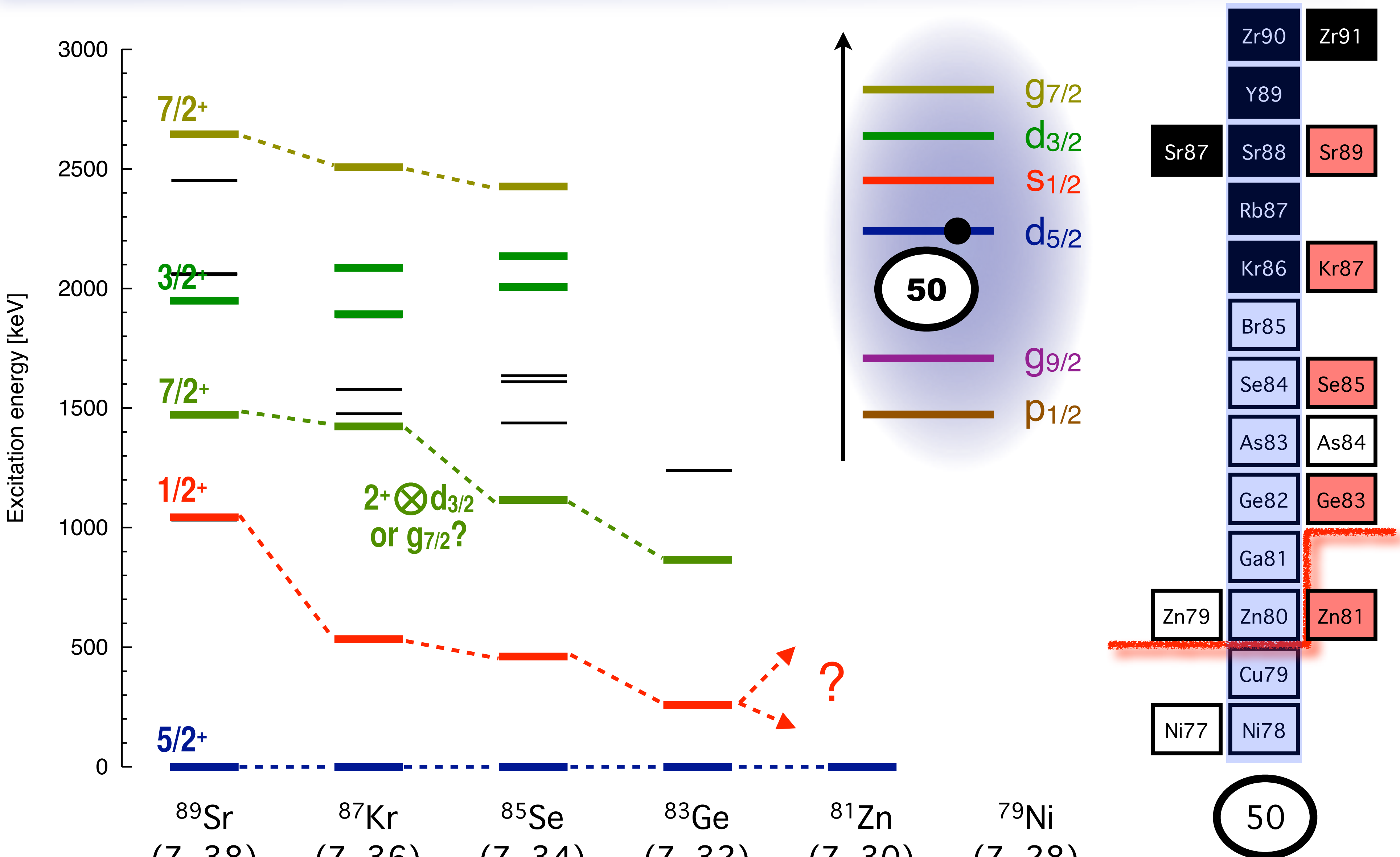
**PRC 59, R2347 (1999)**

**T.A. Hughes, Phys. Rev. 181, 1586 (1969)**

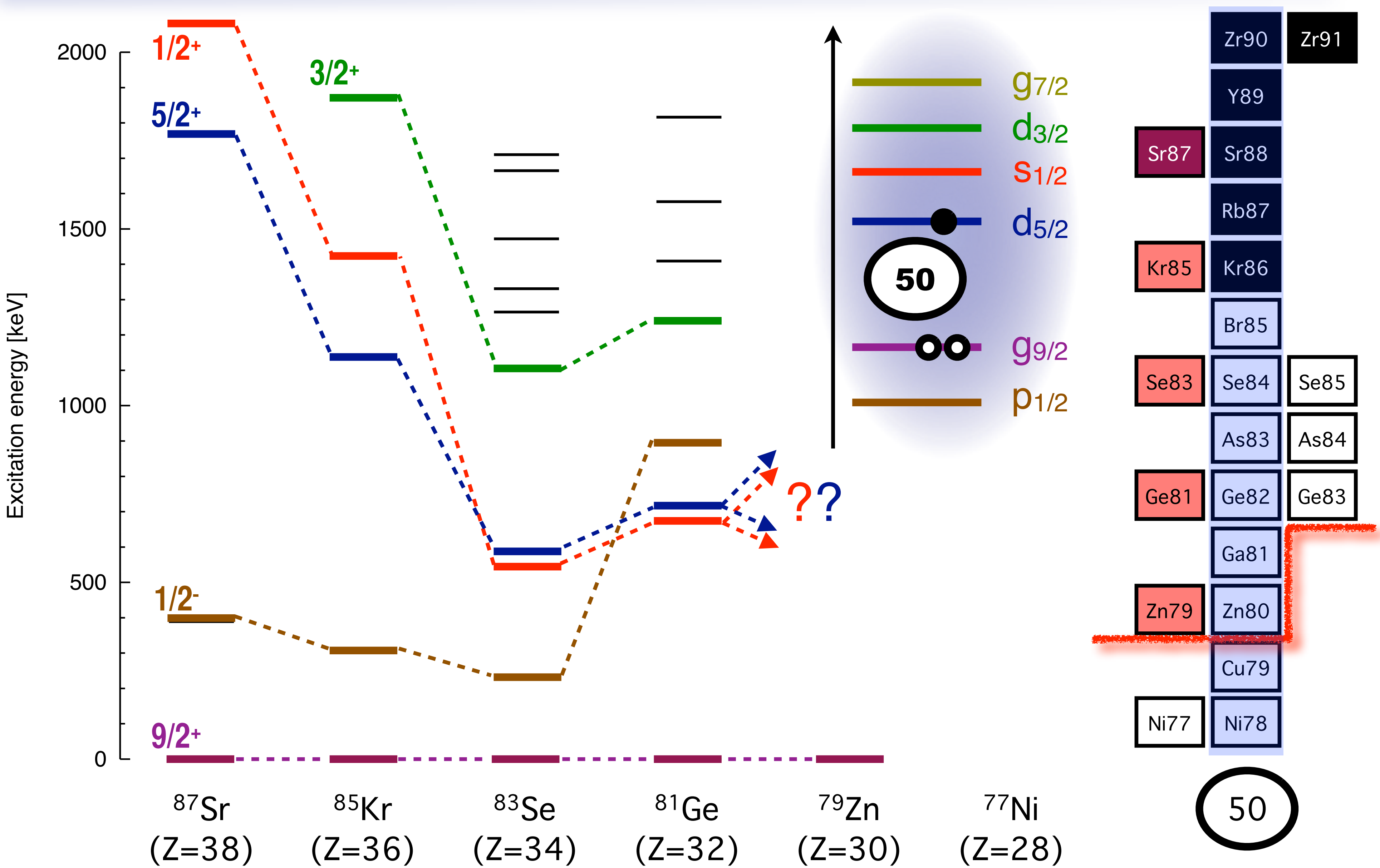



**Shell model calc. with $^{78}$Ni core**
**K. Sieja et al. PRC 79, 064310 (2009)**

# N=51 isotone systematic

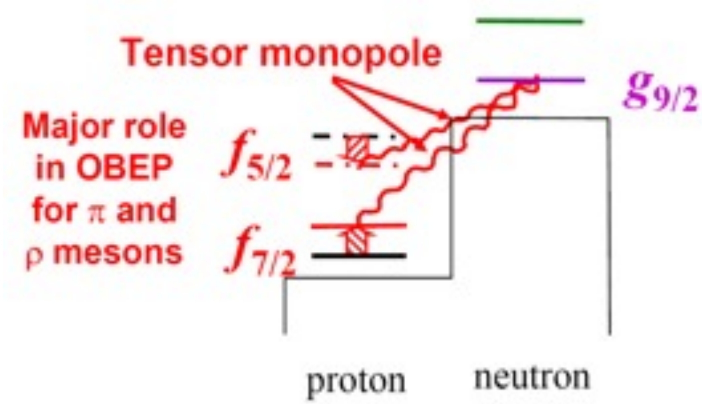


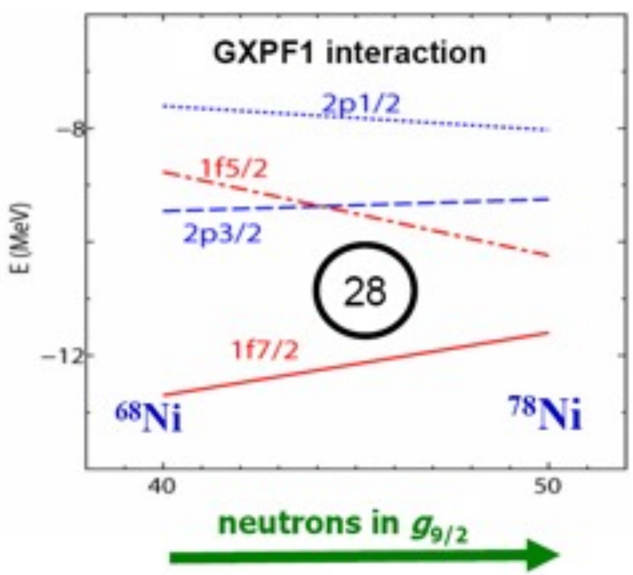
# N=49 isotone systematics



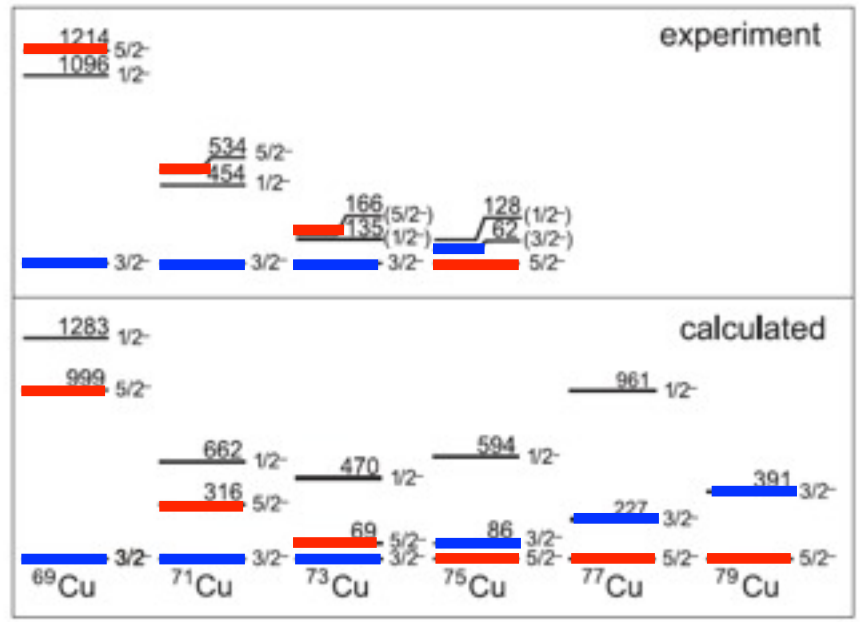

R.A.Meyer et al., PRC 25 (1982) 682

# Valence space for proton in west part of $^{78}$Ni

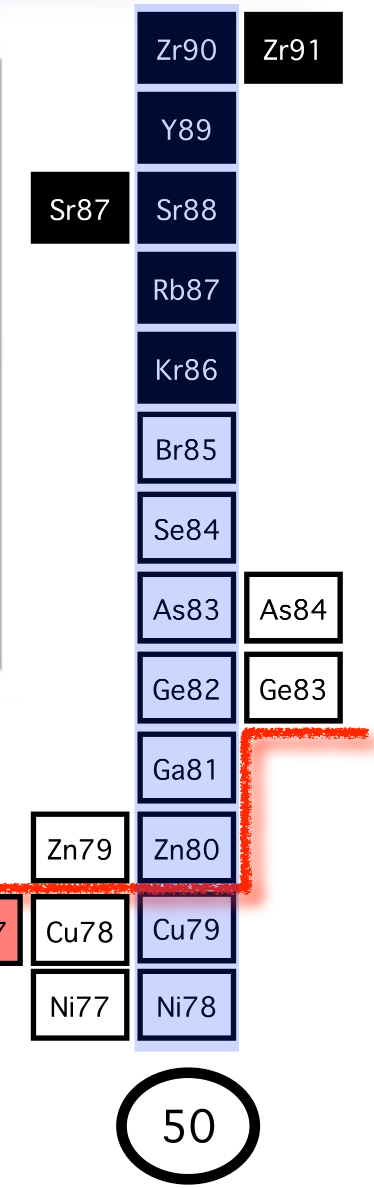


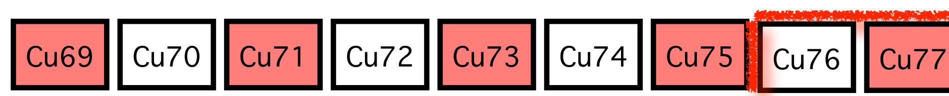




T. Otsuka et al. PRL95, 232502 (2005)

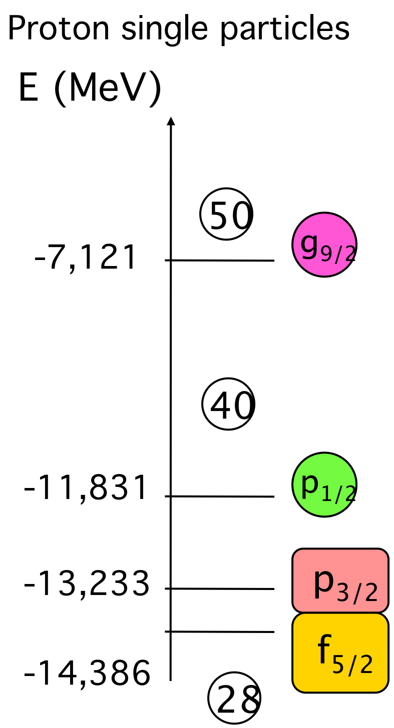



K. Flanagan et al., PRL 103, 142501 (2009)

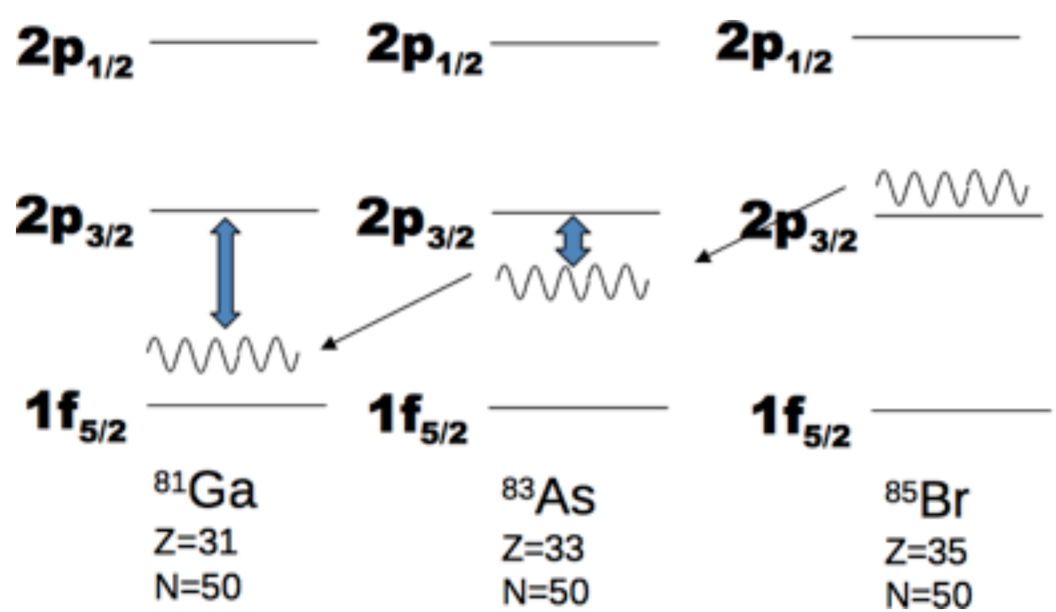


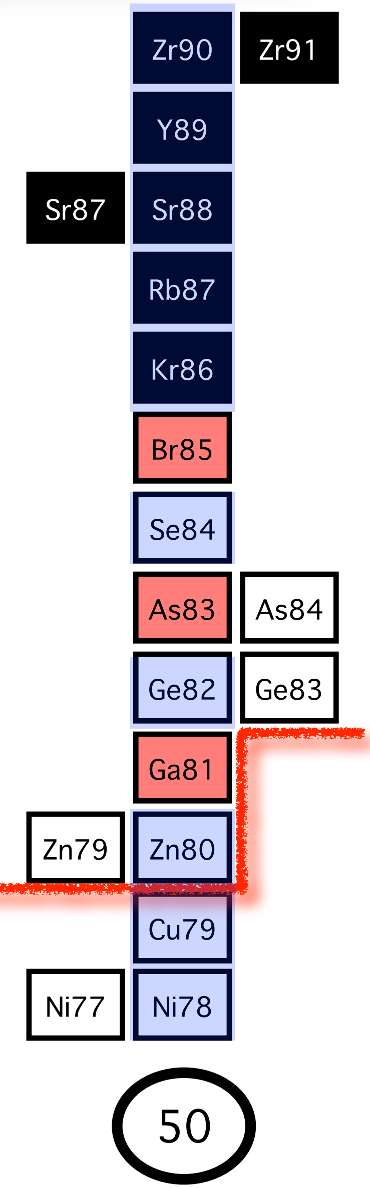



# Valence space for proton in north part of $^{78}$Ni




the observed structure of the odd-proton N=50 isotones should only (and naturally) reflects the change of the Fermi level to be checked experimentally

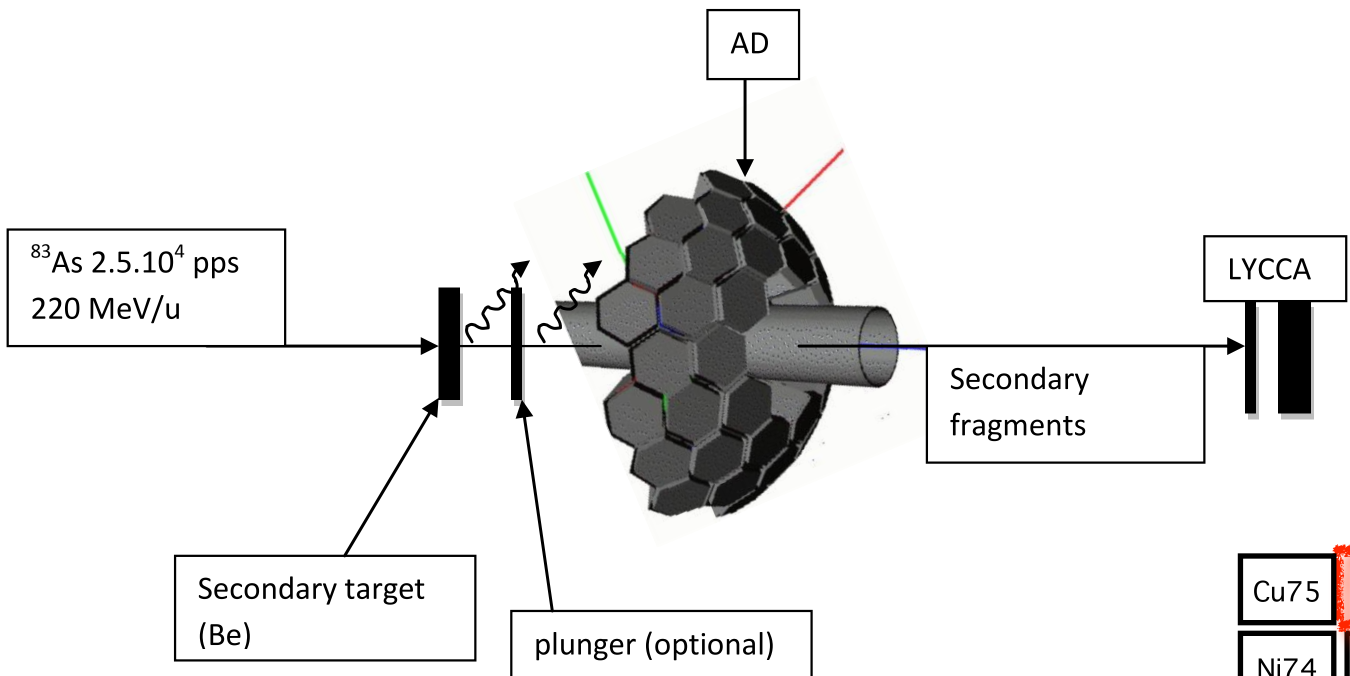


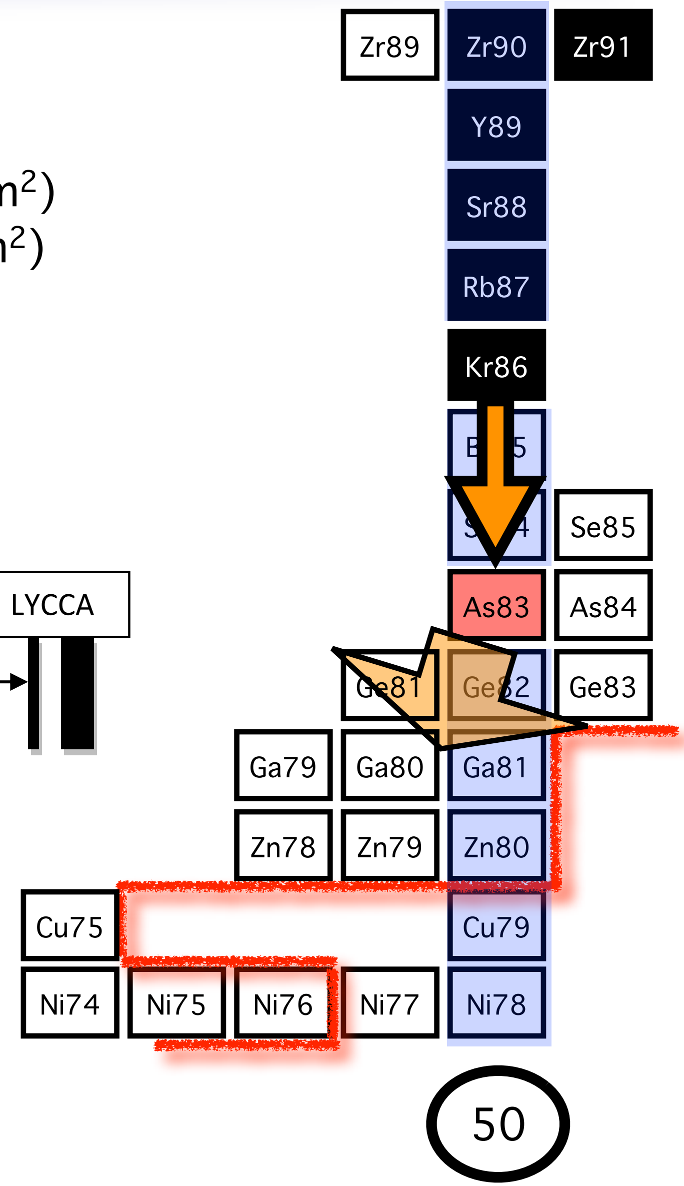




**From Ji et Wildenthal**
**Phys. Rev. C 38, 2849 (1988)**

# Proposed experimental setup

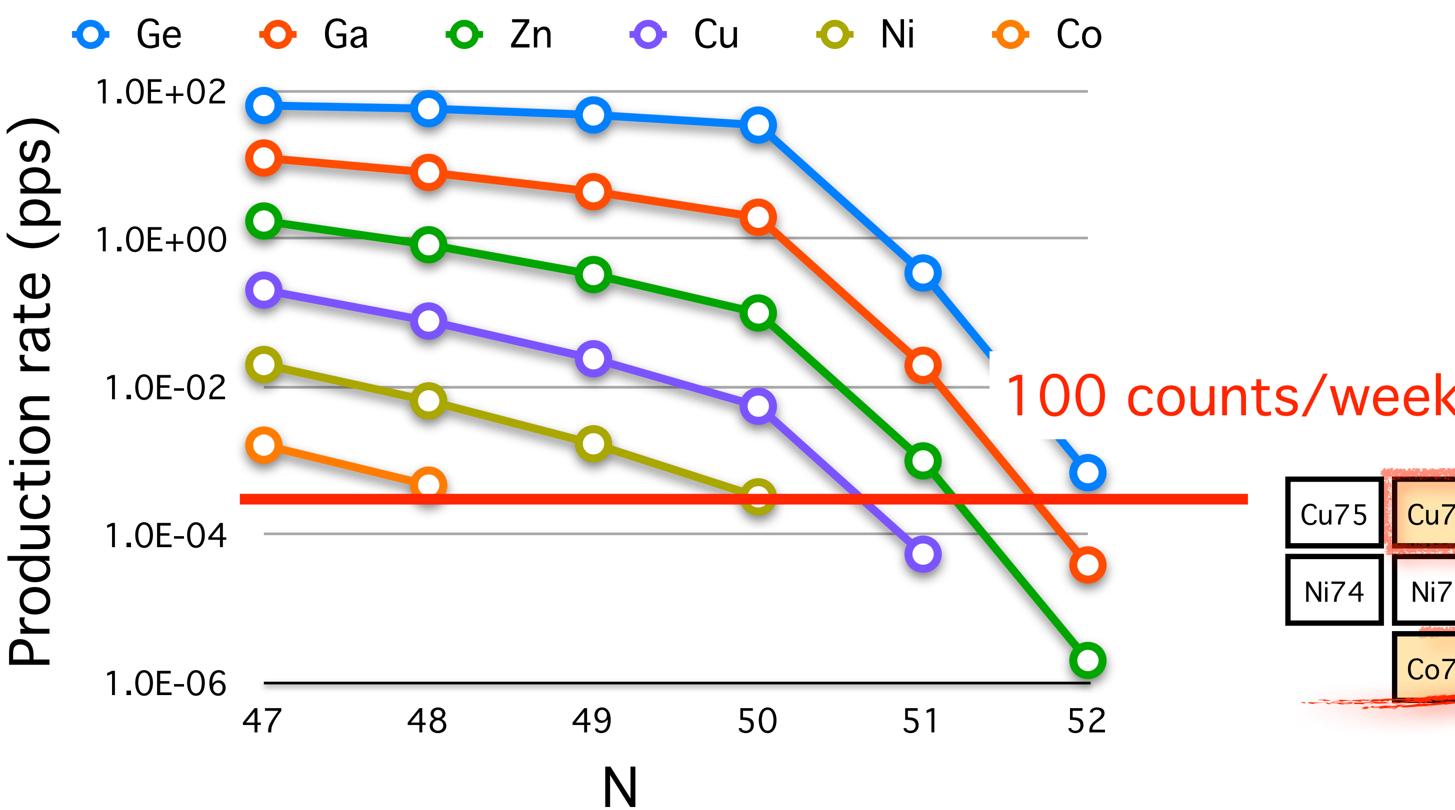
FRS + AGATA + LYCCA
secondary fragmentation reaction
$^{86}$Kr (550 MeV/u, 1.0x10$^{10}$ pps) on $^{9}$Be target (4011 mg/cm$^{2}$)
$^{83}$As (220 MeV/u, 2.5x10$^{4}$ pps) on $^{9}$Be target (2650 mg/cm$^{2}$)

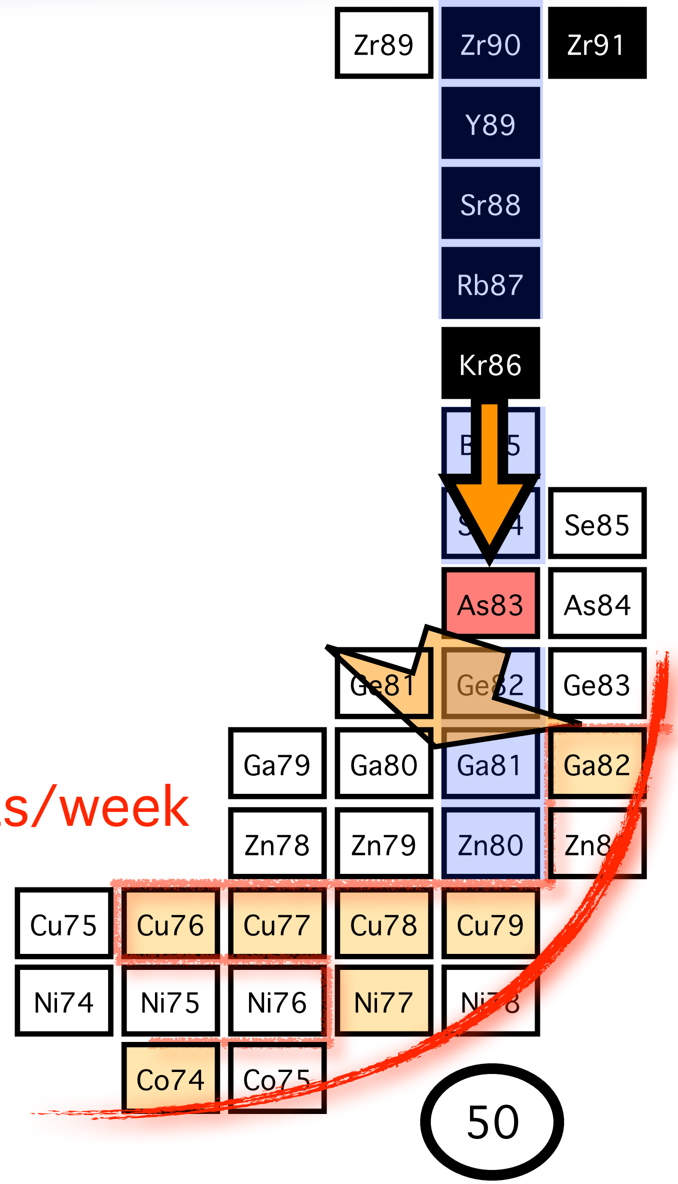


# Yield estimation (preliminary)

- $^{83}$As beam (220 MeV/u, 2.5x10$^4$ pps)
- Be target (2650 mg/cm$^2$)
- 15% efficiency for AGATA
- all products through 1st to g.s. transition



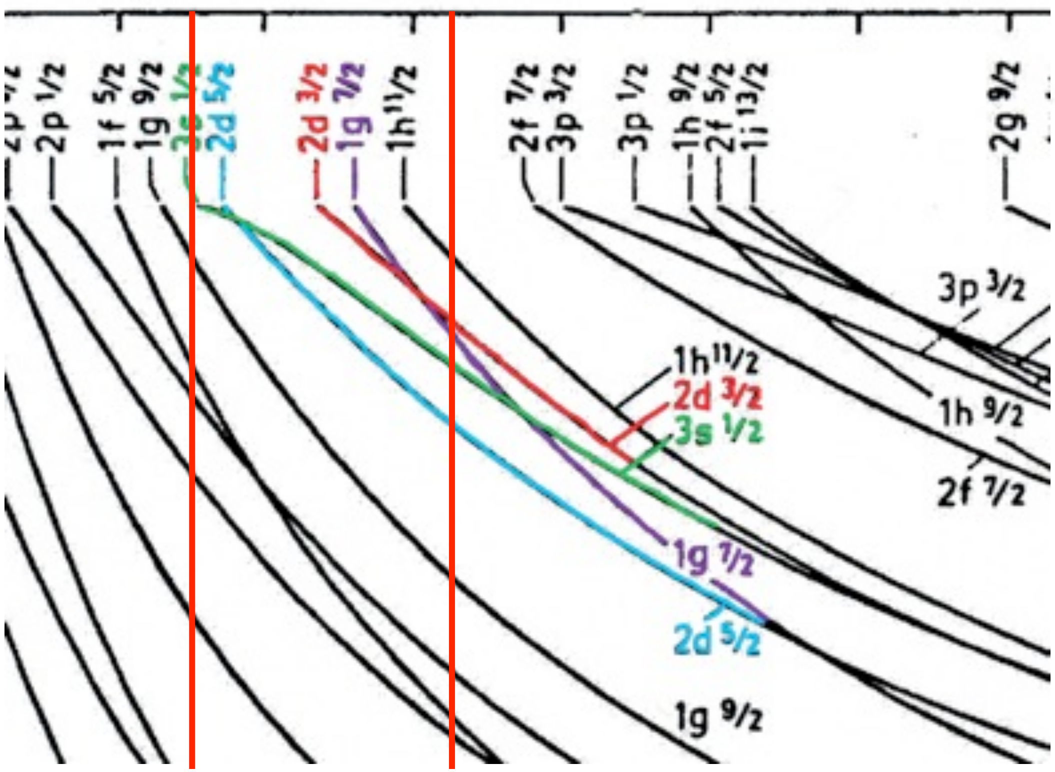
# Summary

We propose to perform the in-beam gamma-ray spectroscopy of very neutron-rich nuclei around N=50 towards $^{78}$Ni using the secondary fragmentation reaction of a $^{83}$As (Z=33, N=50) beam with FRS + AGATA + LYCCA.

Physics interest

- $^{78}$Ni can be considered as a good core for shell model?
  - increasing collectivity across N=50 ($2^+$, $4^+$ sequence)
- shell structure, order of orbit, π-ν interaction
  - proton shell seems to be understood by tenser interaction (cf. Cu isotope)
  - inversion of g.s. spin from $5/2^-$ to $3/2^-$ between $^{85}$Ba and $^{83}$As
  - decreasing single-particle energy space between $\nu s_{1/2}$ and $\nu d_{5/2}$
  - mysterious of $1/2^-$ state in N=49

# Down sloping of $s_{1/2}$ states



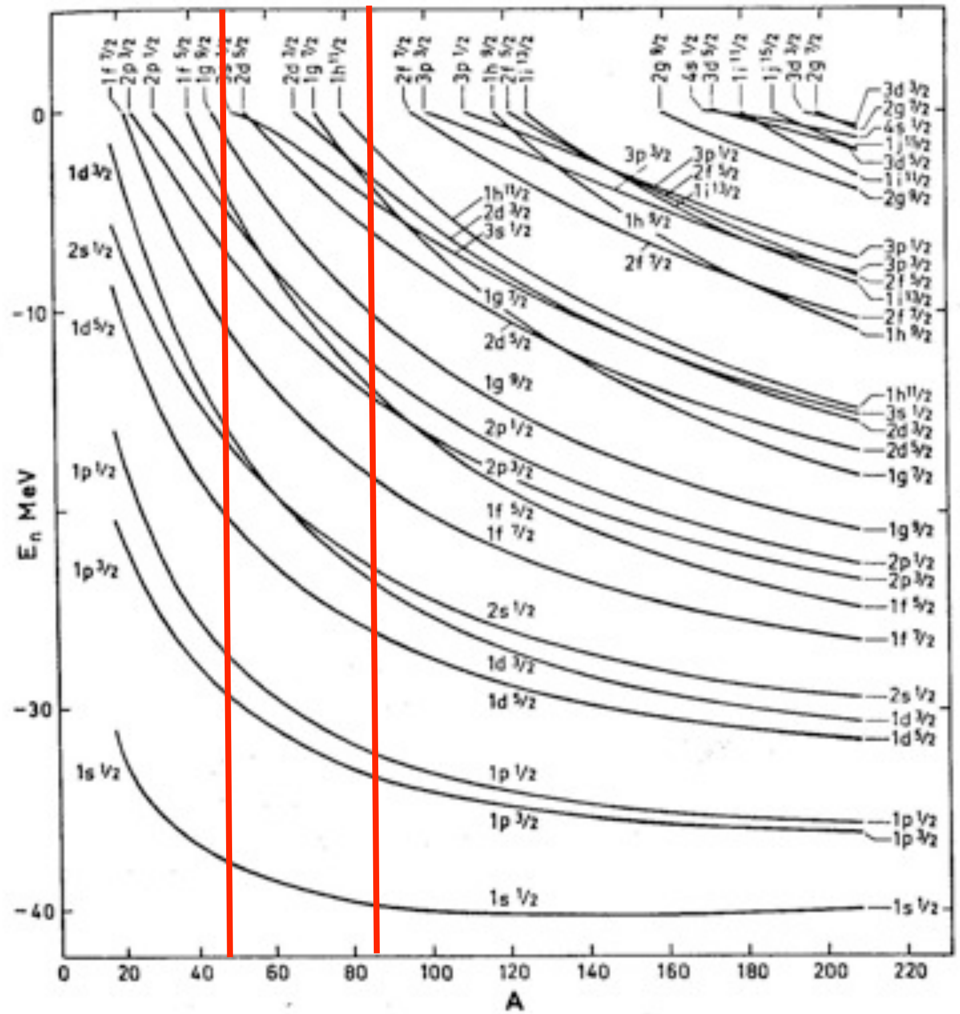




Fig. 3.15. Energies of neutron orbitals, calculated by C.J. Veje as quoted in (Bohr 1969). Use has been made of a Woods-Saxon potential $U = Vf(r) + V_{ls}(l \cdot s)r_0^2(1/r)(d/dr)f(r)$, with $f(r)$ having a Woods-Saxon shape $[1 + \exp(r - R_0/a)]^{-1}$, and $R_0 = r_0 A^{1/3}$ ($r_0 = 1.27\ fm$) and $a = 0.67\ fm$. The potentials $V$ and $V_{ls}$ are given as $V = (-51 + 33((N - Z)/A))$ MeV, $V_{ls} = -0.44$ V, [taken from (Bohr, Mottelson 1969)]