New Trends in the Nuclear Shell Structure Part 2

O. Sorlin – GANIL Caen

Brief summary on the role of forces at N=20 – Generalization to other shells

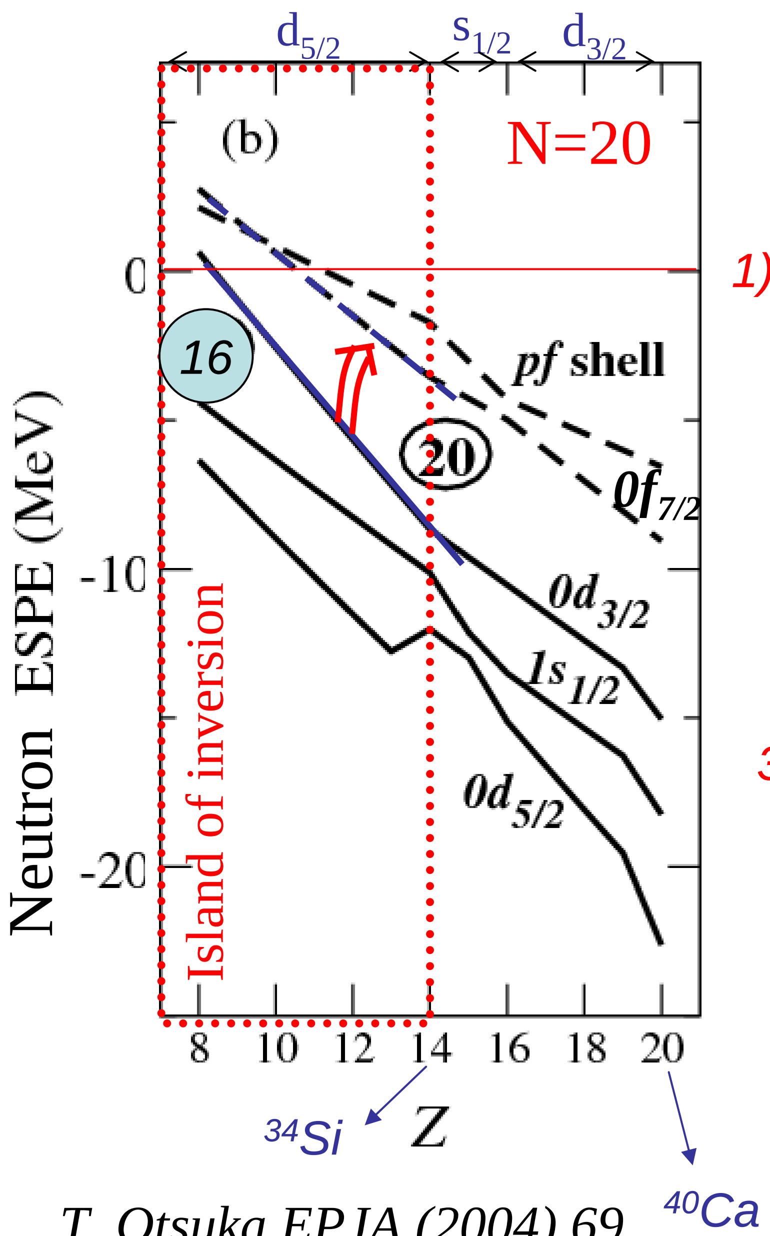
III. Study of the N=28 shell closure
The origin of the N=28 gap, role of nn forces,
From rigid ^{48}Ca to deformed ^{42}Si, the role of tensor force

IV. Nuclear astrophysics: the rapid neutron capture process
Brief introduction, key nuclear parameters
The role of nuclear forces
Impact of nuclear physics on the abundance of r elements

V. Summary

O. Sorlin and M.-G. Porquet Prog. in Part. Nucl. Phys. 61 (2008)

ESPE in N=20 isotones and structural changes



T. Otsuka EPJA (2004) 69

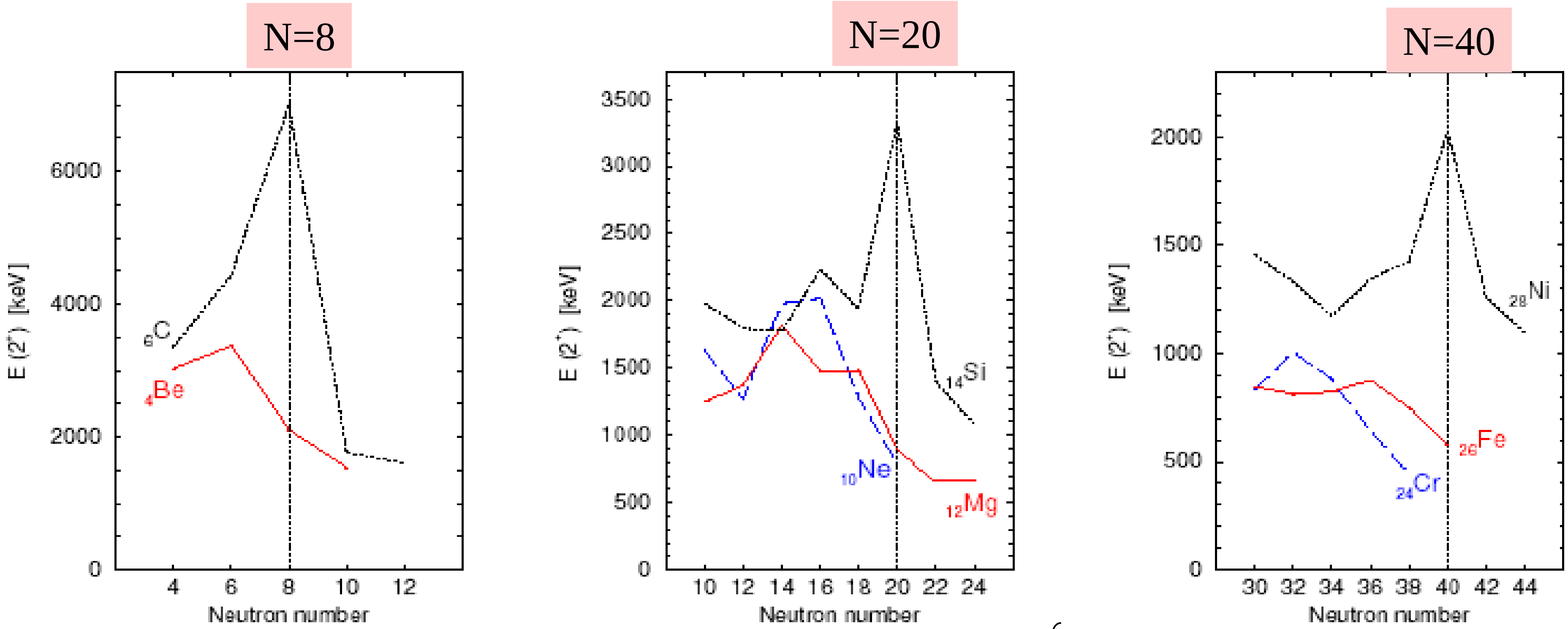
1) ^{28}O unbound ?

2) N=20 disappears :
Enhanced cross shell excitations
Low 2^+, high B(E2)

3) Birth of a new magic number at N=16

Role of $V^{pn}d_{5/2}d_{3/2}$ to break the N=20 shell closure

Great similarity between the three cases of HO shell numbers



Beta decay studies

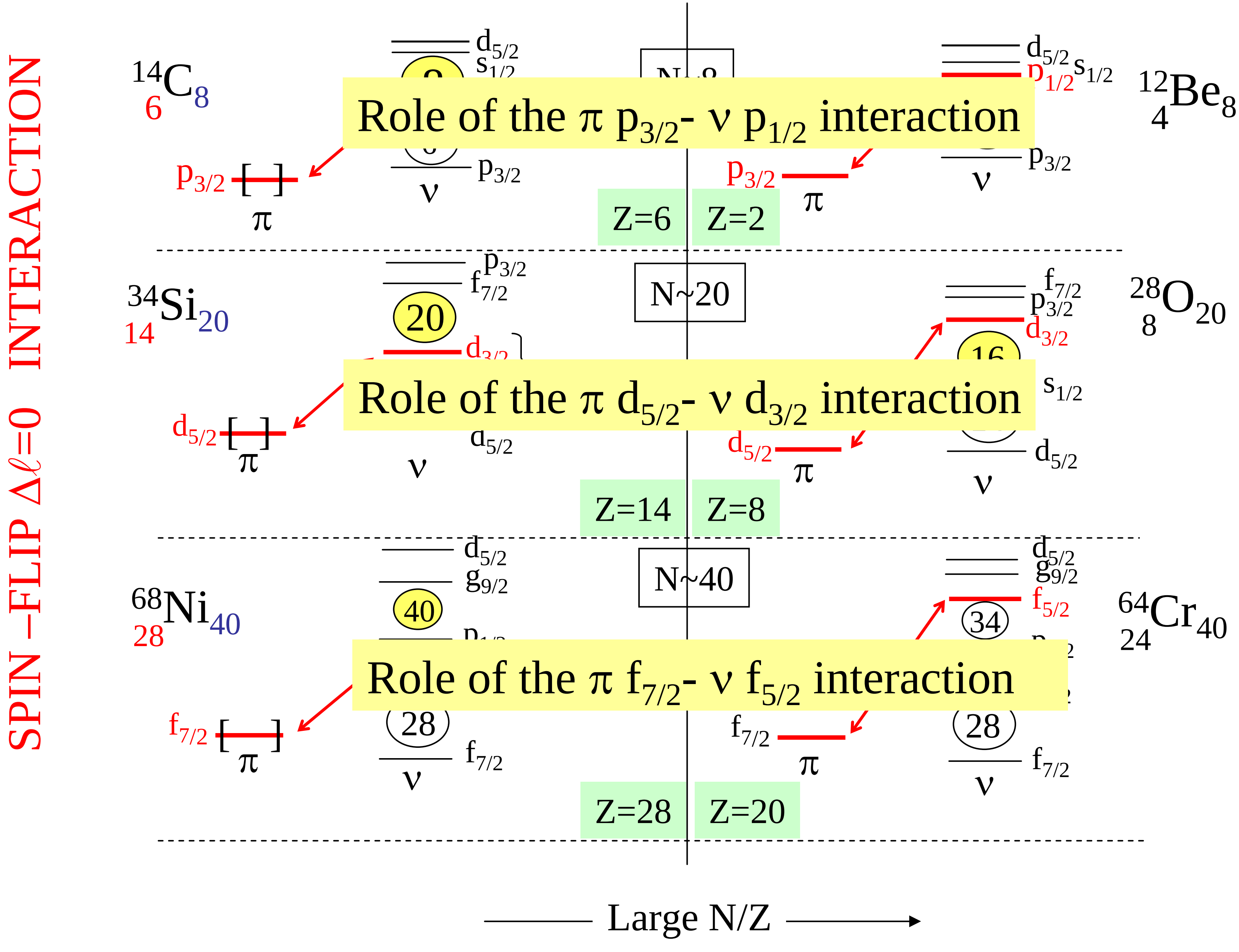
M. Hannawald, PRL 82 (1999) 1391

O. Sorlin et al. EPJA 16 (2003) 55

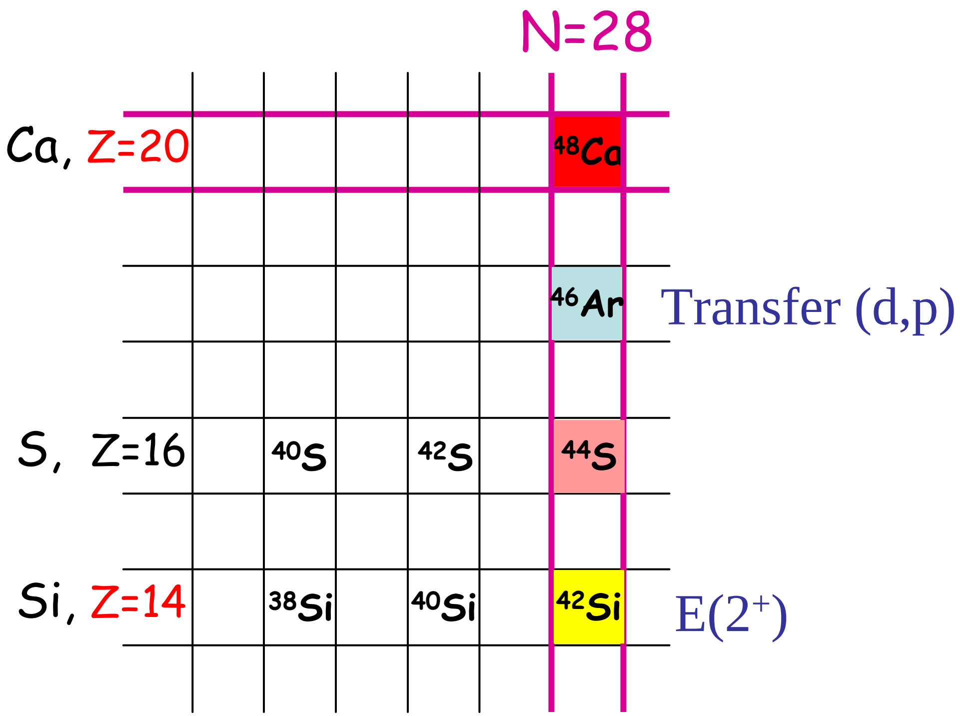
Dramatic change of nuclear structure due to spin-flip pn interaction !

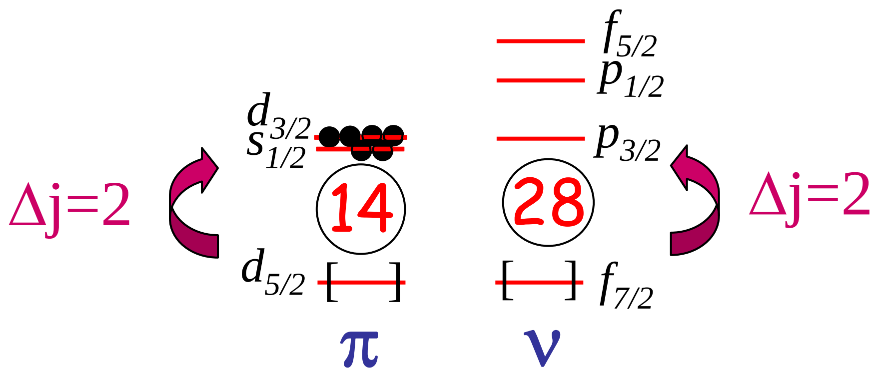
Very robust process…

Evolution of Harmonic Oscillator shell closures



Study of the N=28 shell closure far from stability





$\pi d_{3/2}$-$\nu f_{7/2}$, $\pi d_{3/2}$-$\nu f_{5/2}$ interactions
$\Delta L=1$

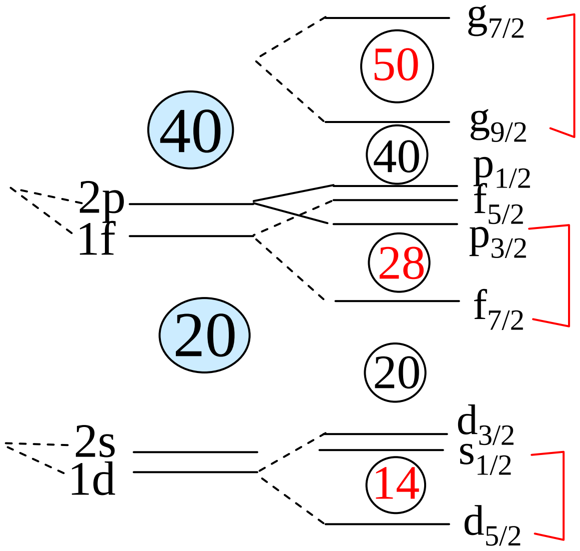
> Role of nuclear forces :
Modification of the N=28 shell gap ?
SO and Tensor interactions

➢Enhanced collectivity due to Δj=2/
reduction of Z=14 at N=28 seen in Part I

The origin of the N=28 shell gap ?

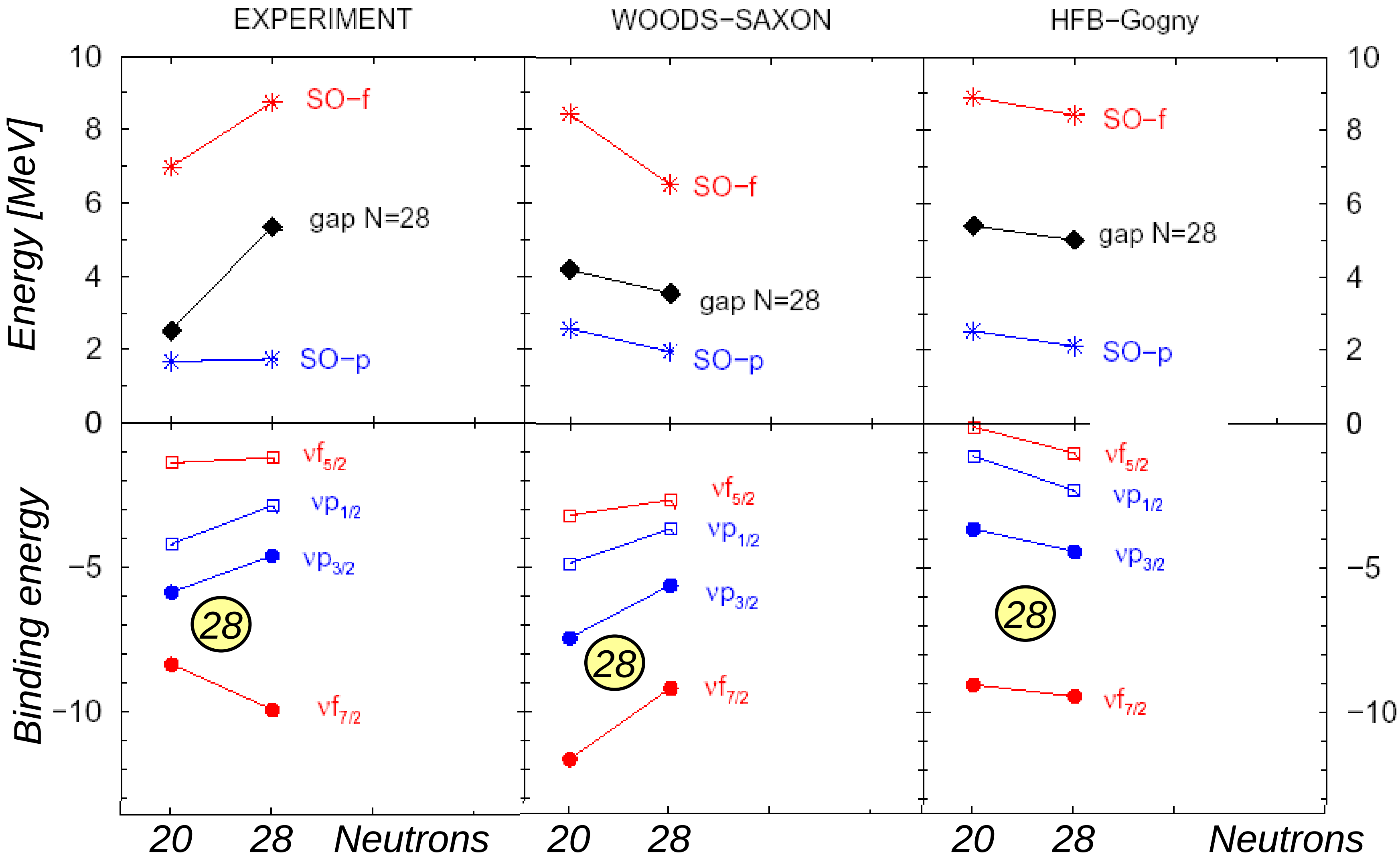
The SO interaction ?

Yes BUT…



$$L^2 + \vec{L}.\vec{S}$$

The origin of the N=28 shell gap viewed in the Ca chain ….

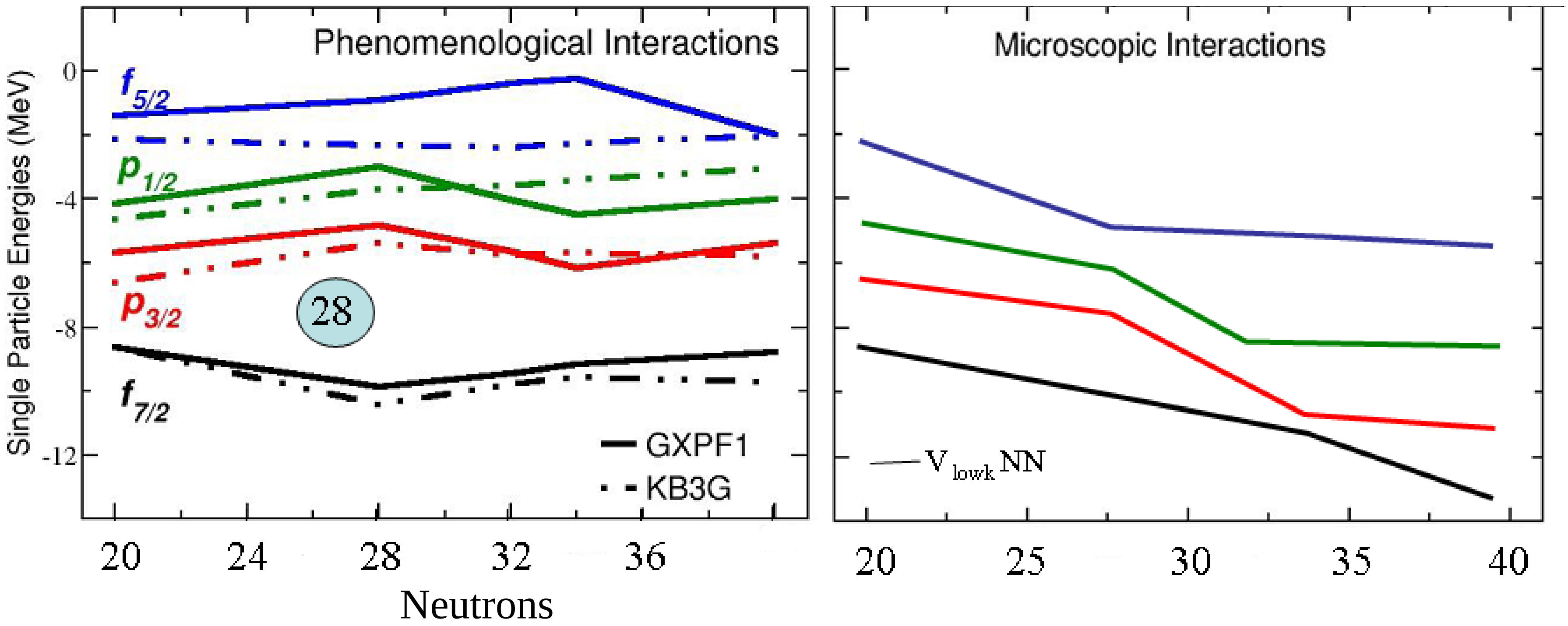


Courtesy M.G Porquet

No increase of the N=28 shell gap when $\nu f_{7/2}$ is filled
Same with realistic V_{lowK} interaction -> 3 body ? -> which experiment ?

The N=28 shell gap and the role of 3 body forces

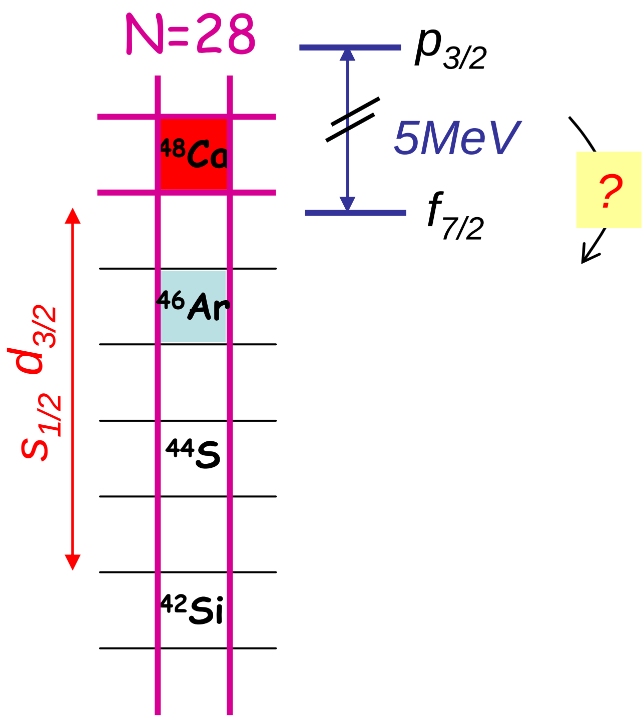
Holt, Otsuka… 3 body forces help

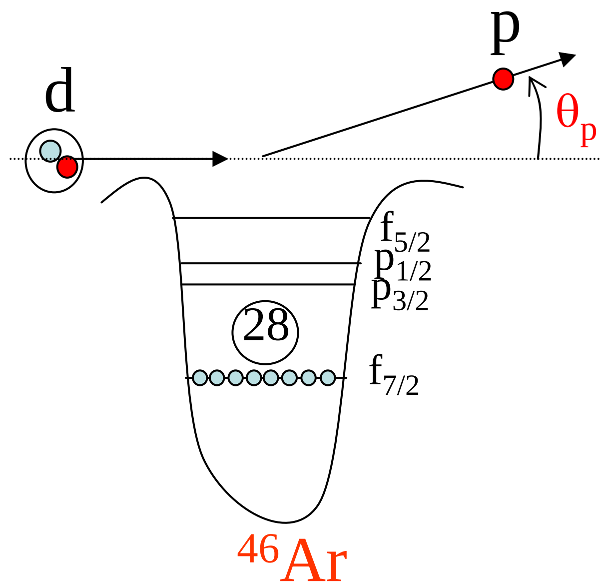


No N=28 shell gap created as well with realistic interactions !

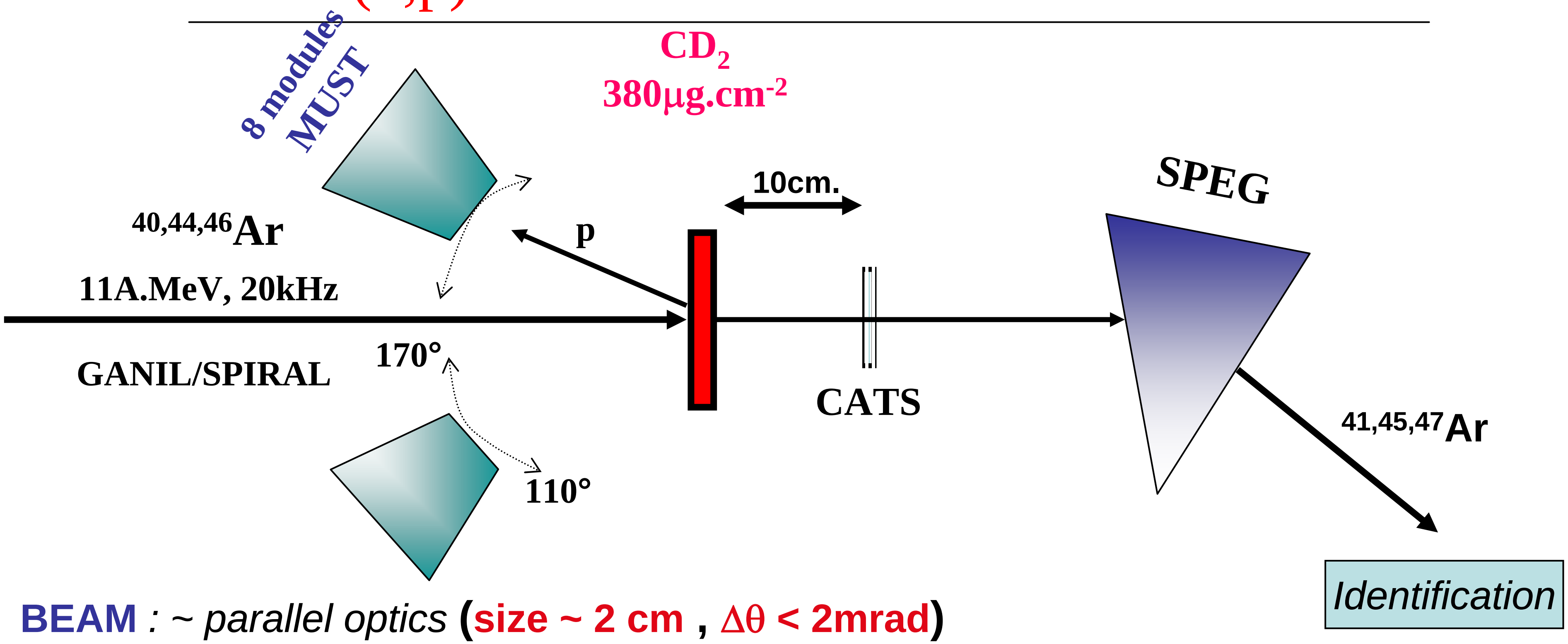
2- Evolution of the N=28 shell gap

➡ *Use of transfer (d,p) reaction with ^{46}Ar beam*





(d,p) reactions with $^{40,44,46}Ar$ beams



BEAM : *~ parallel optics* (**size ~ 2 cm , Δθ < 2mrad**)

CATS : -**beam**-*tracking detector*

- *Proton* **emission point**.

  resolution : ~1 mm

MUST : -**Si Strip** *detector*

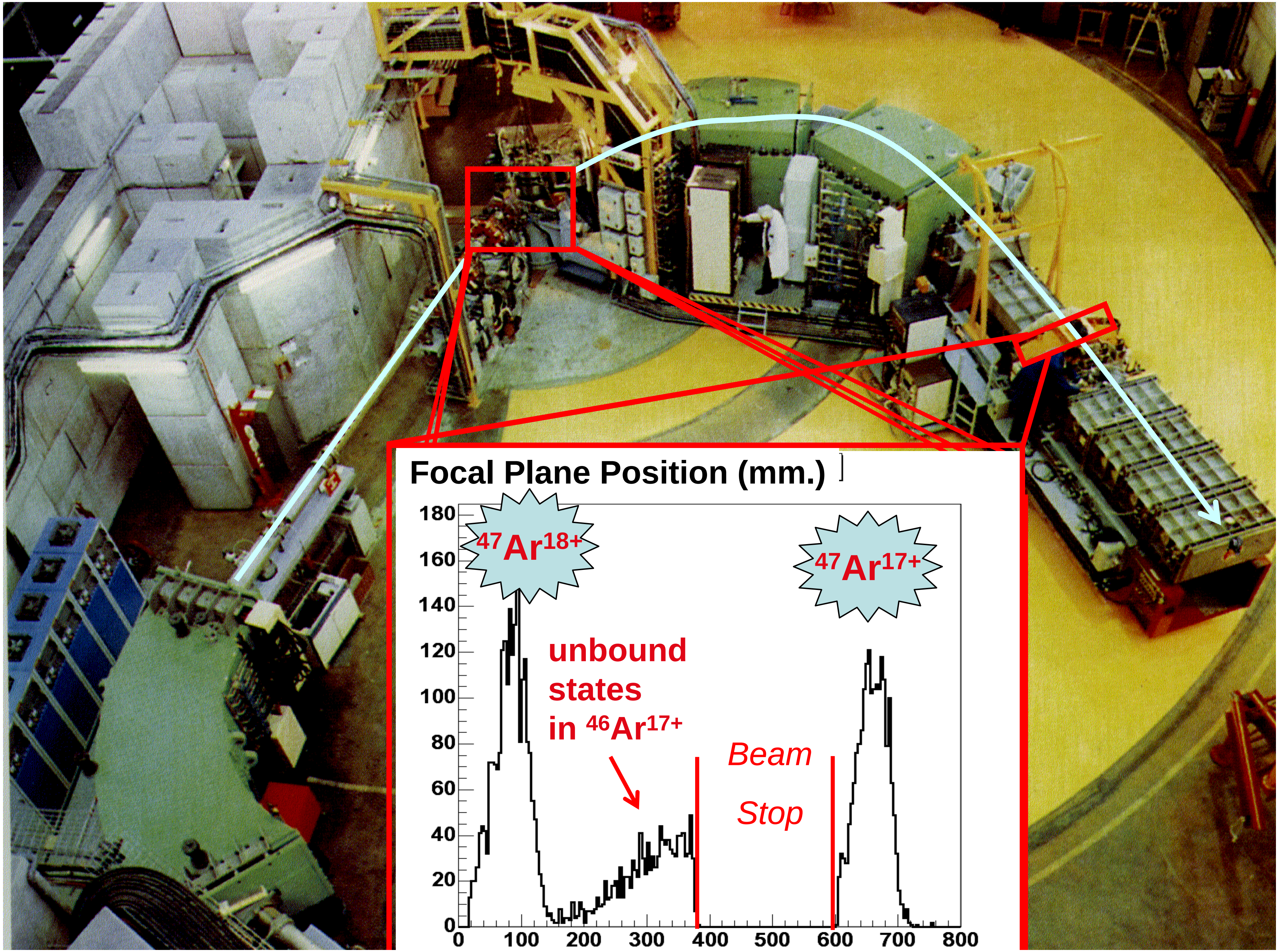
-*Proton* **impact localisation**

resolution : 1 mm; size 6 x 6 cm²

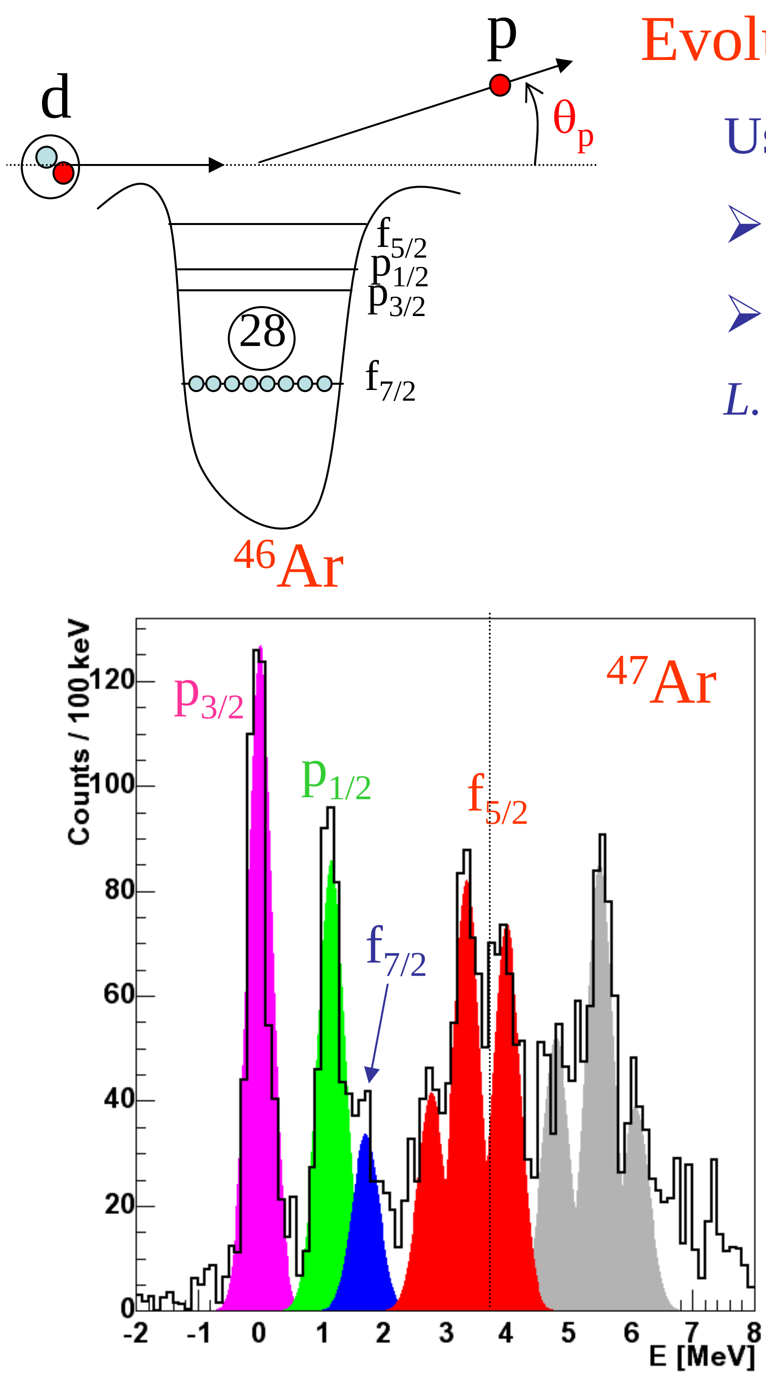
-*Proton* **energy** *measurement.*

resolution : 50 KeV

SPEG : *Energy loss spectrometer :* **recoil ion** *identification→transfert-like products*


Focal Plane Position (mm.)
47Ar18+
47Ar17+
unbound states in 46Ar17+
Beam Stop
0
20
40
60
80
100
120
140
160
180
0 100 200 300 400 500 600 700 800

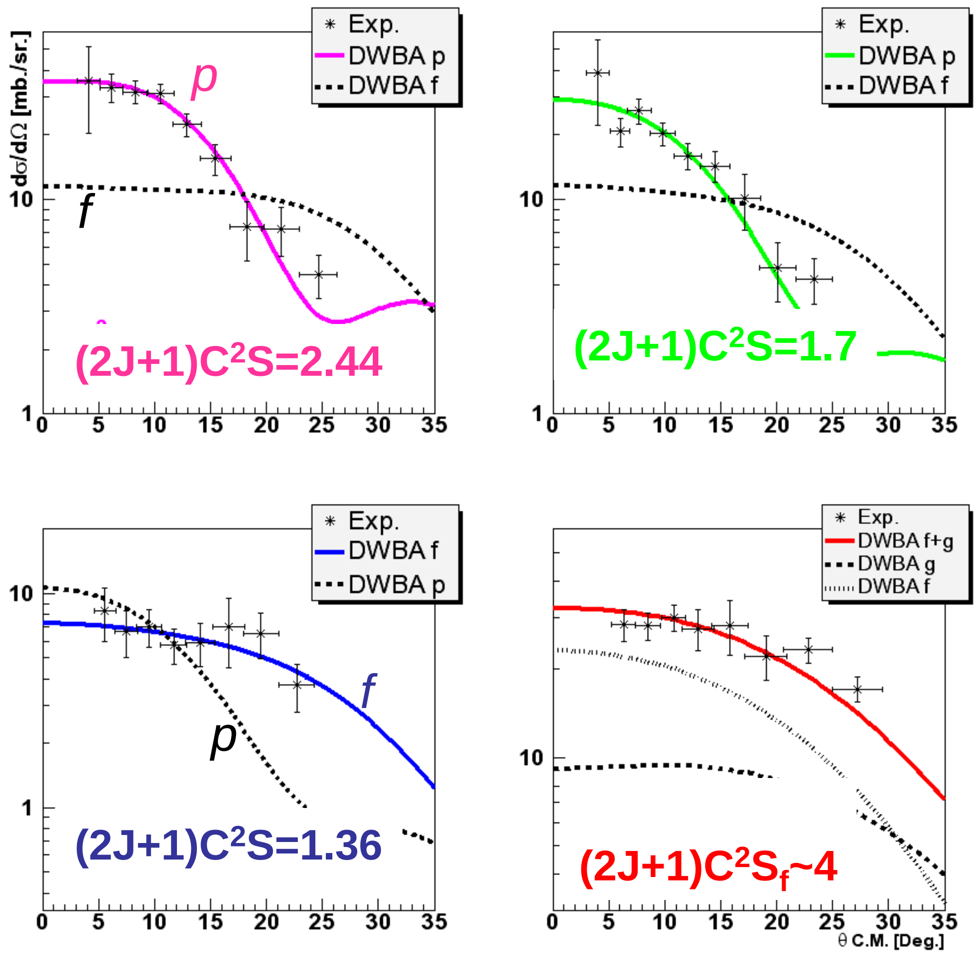
Evolution of the neutron SPE below $^{48}_{20}Ca$



Use of $^{46}_{18}Ar$ (d,p) transfer reaction

- Size of the N=28 shell gap *: reduced by 330keV*
- Reduction of SO splitting

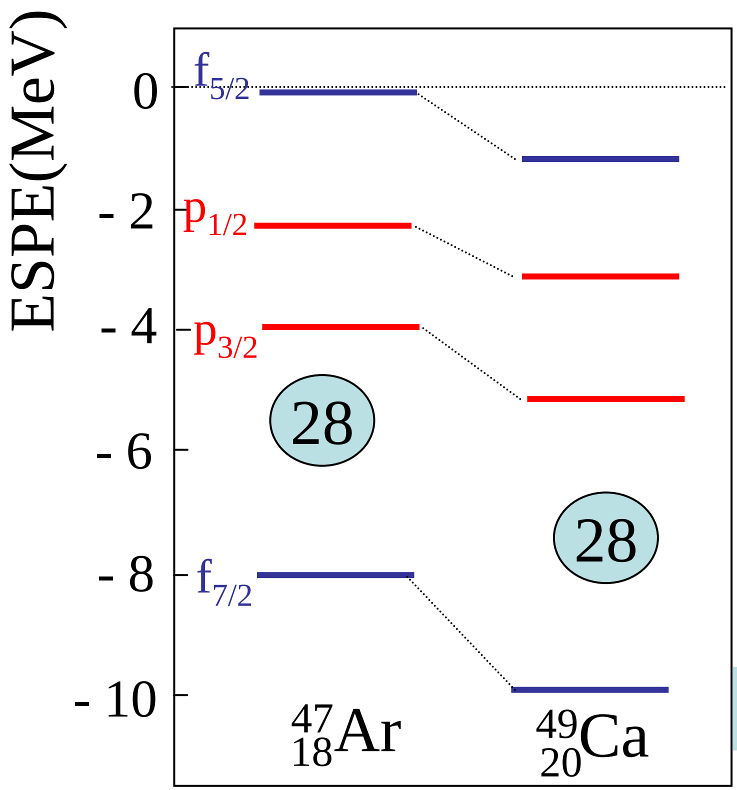
L. Gaudefroy et al. PRL 97 (2006)

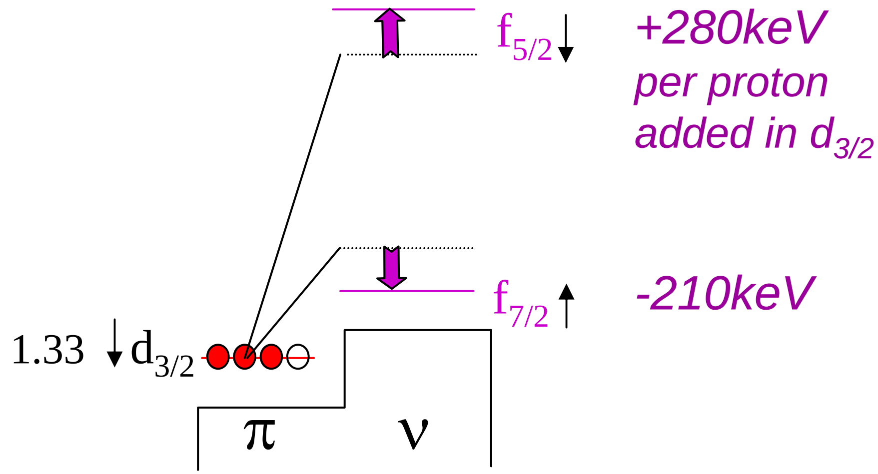


Variation of single particle energies (SPE)

-From ^{47}Ar to ^{49}Ca, 2 protons added to $d_{3/2}$ and $s_{1/2}$ equiprobably, i.e. 1.33 ($d_{3/2}$), 0.66 ($s_{1/2}$)

-The $\pi d_{3/2}$ acts differently on $\nu f_{5/2}$ and $\nu f_{7/2}$ orbits $\rightarrow$ tensor forces ?





Tensor interaction (*Otsuka*)

$\pi d_{3/2} - \nu(f_{7/2} - f_{5/2})$

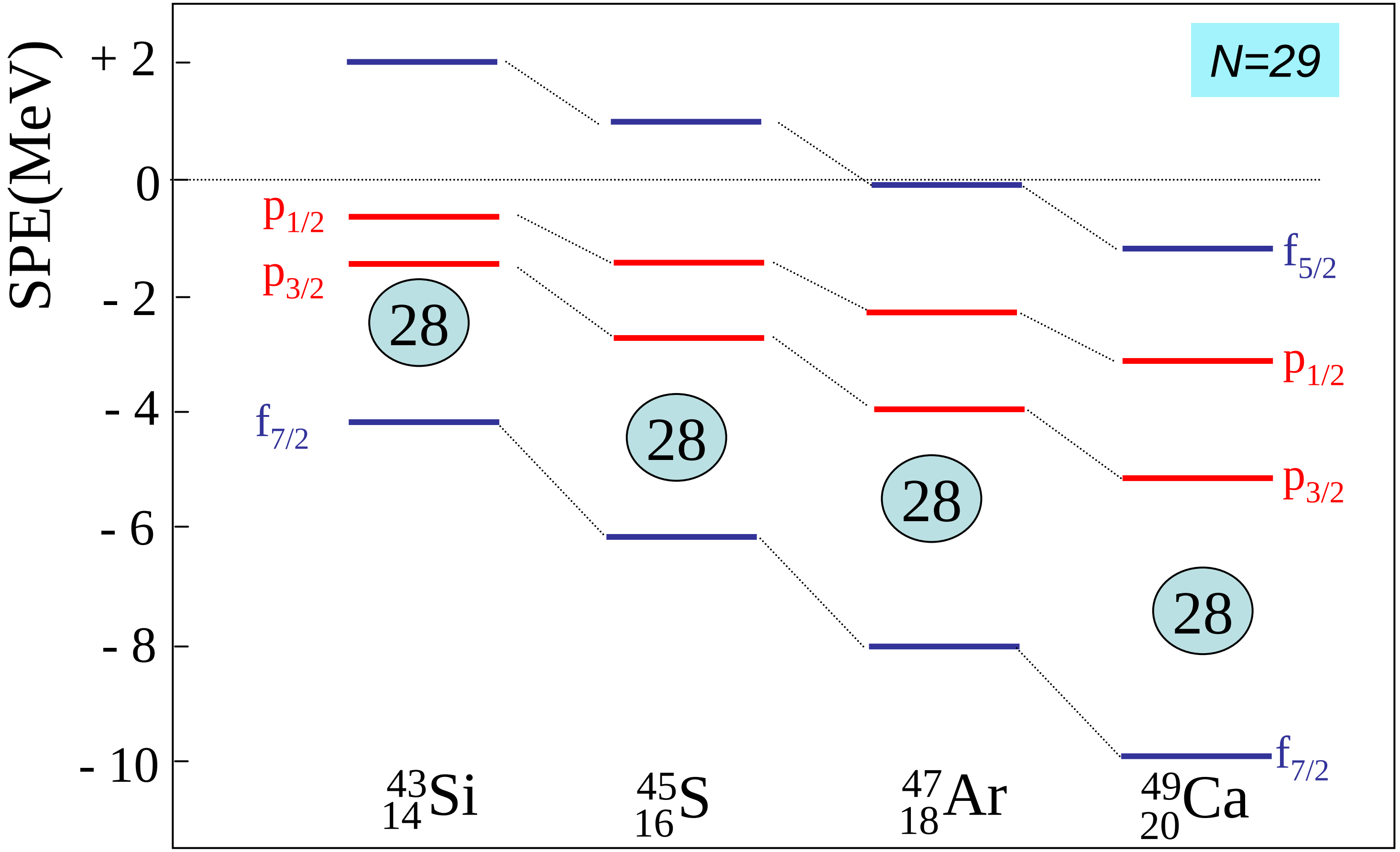
Tensor sum rule : $8 (V^T d_{3/2} f_{7/2}) + 6 (V^T d_{3/2} f_{5/2}) = 0$

-> Tensor term ~ 20% of total monopole

-> Relative intensity between ↓↓ and ↓↑ looks similar in Vlow k interactions !

Global trend of single particle energies between ^{49}Ca and ^{43}Si

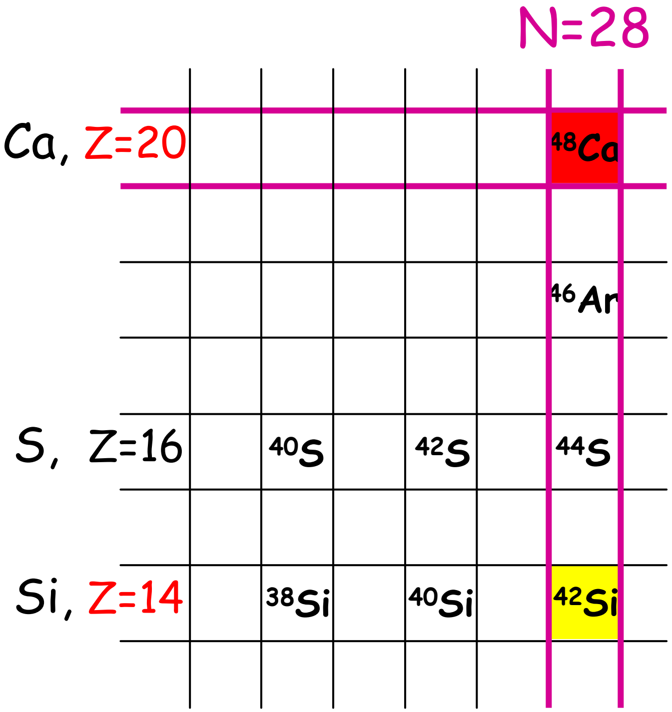
derived from experimentally-constrained monopole variations



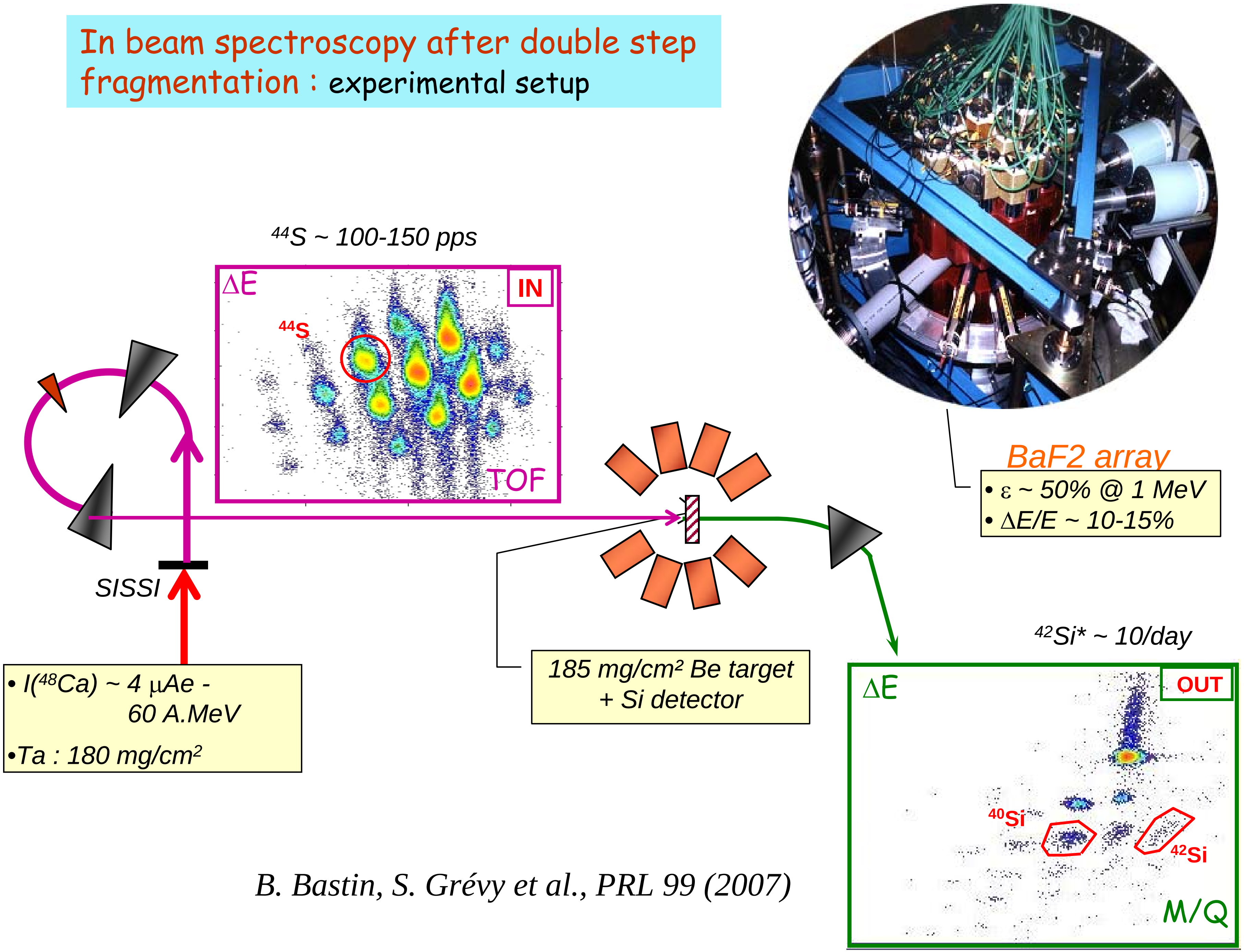
-A shrink of SPE's is occurring gradually when N>>Z due to two-body p-n interactions…

- Favor particle-hole excitations and E2 collectivity

Deformation at N=28 in ^{42}Si ?
Measurement of 2^+ energy



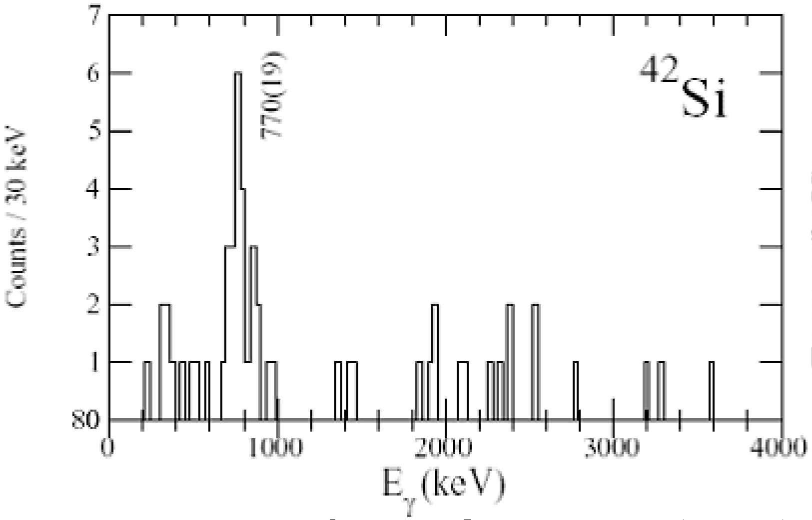
In beam spectroscopy after double step fragmentation : experimental setup



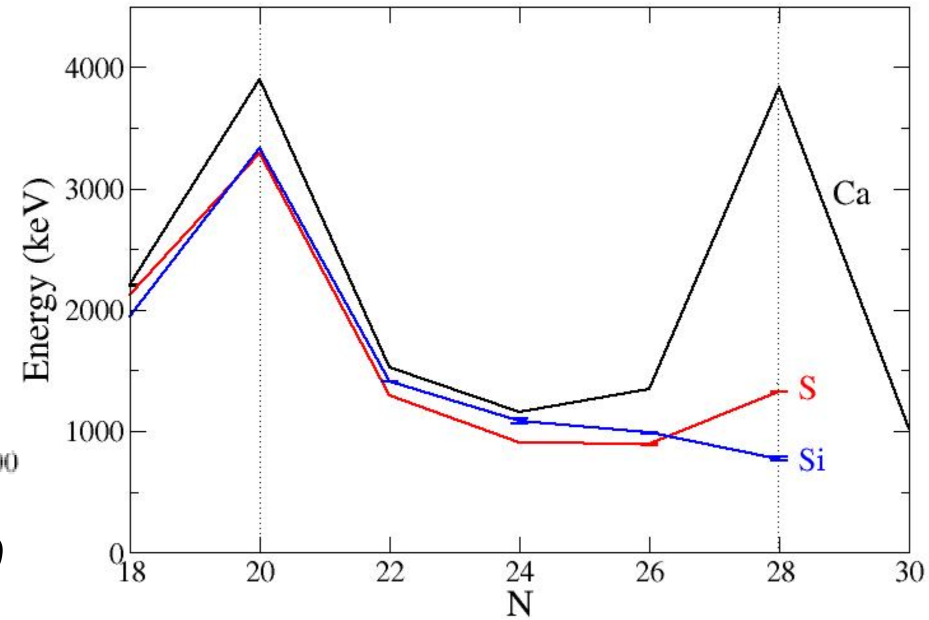
B. Bastin, S. Grévy et al., PRL 99 (2007)

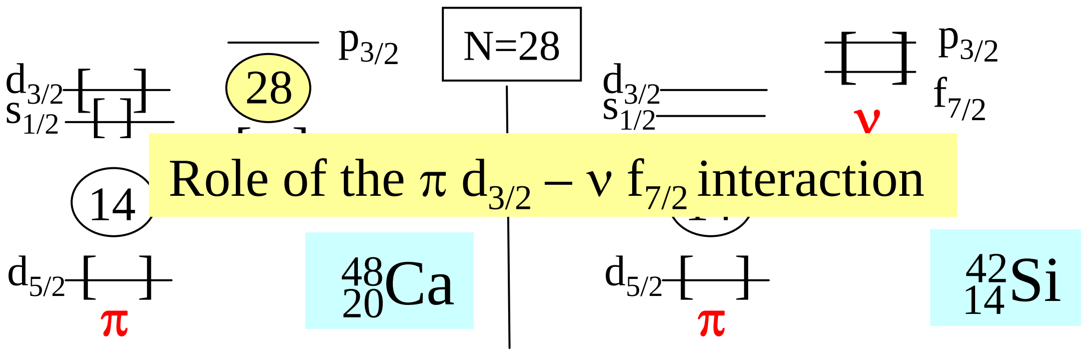
SPIN-FLIP $\Delta\ell=1$ INTERACTION

Collapse of the N=28 shell closure in ^{42}Si



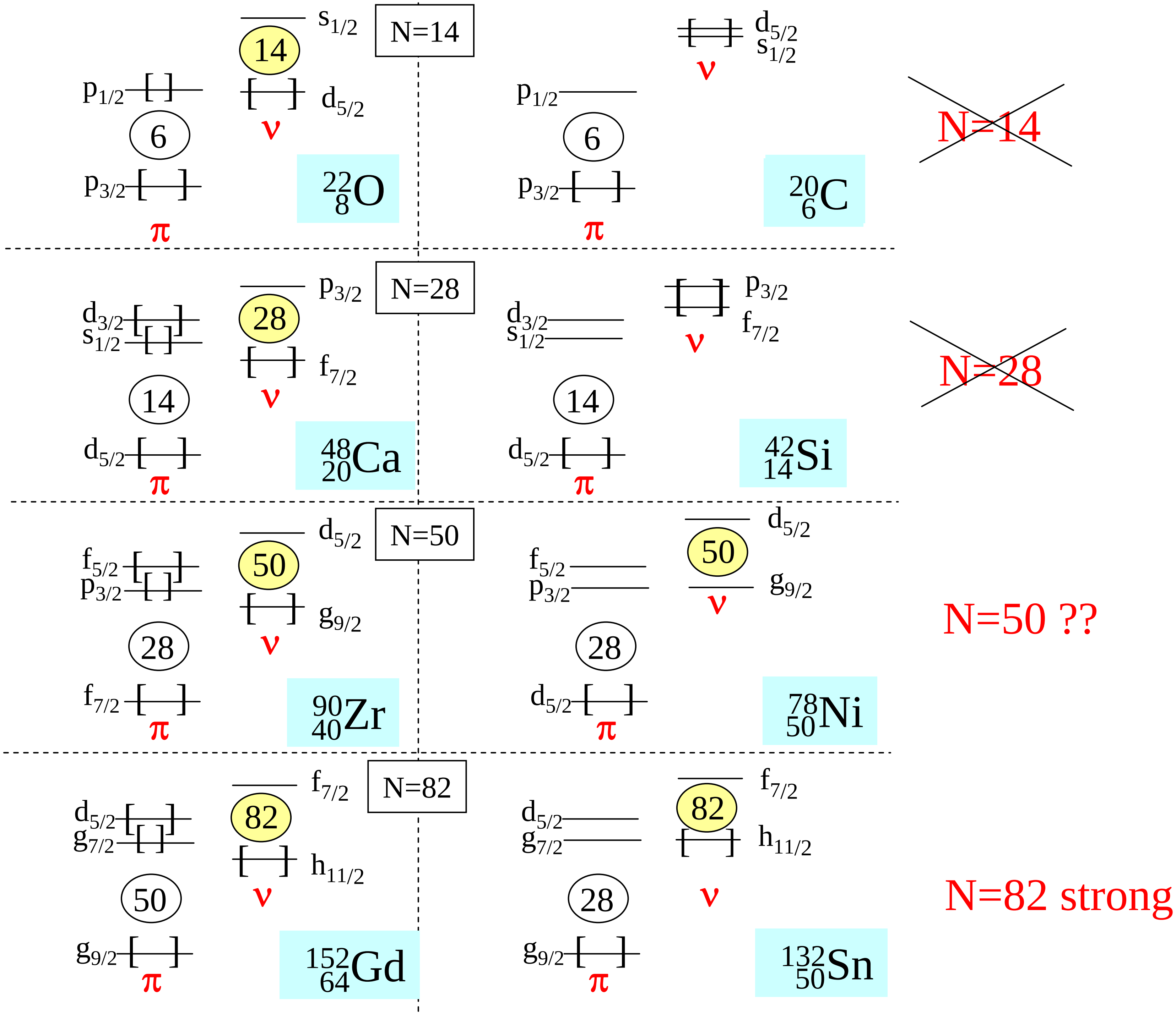
B. Bastin, S. Grévy et al., PRL 99 (2007)



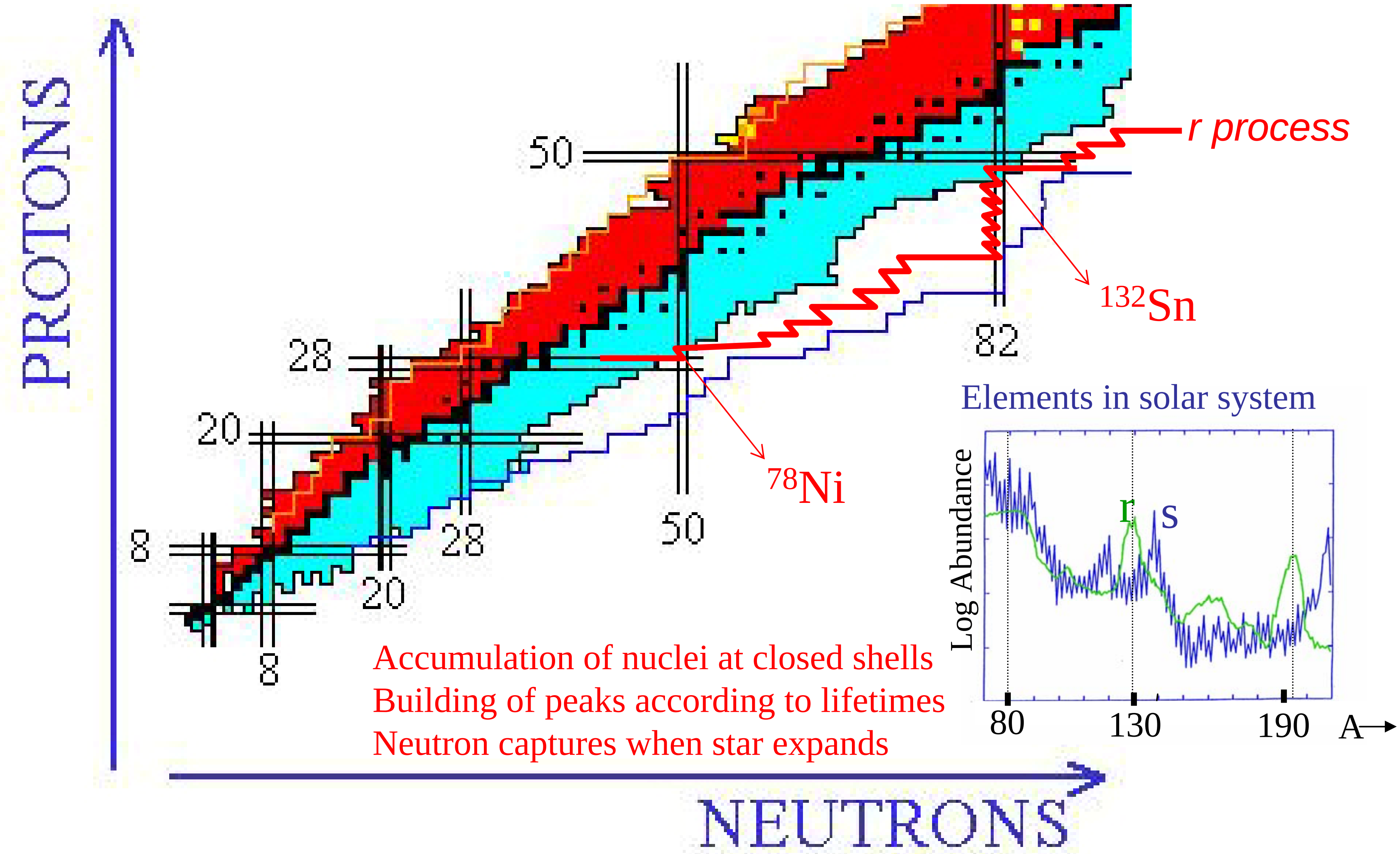


Role of the $\pi\ d_{3/2} - \nu\ f_{7/2}$ interaction

SPIN-FLIP $\Delta\ell=1$ INTERACTION



Nuclear forces and astrophysics



Accumulation of nuclei at closed shells
Building of peaks according to lifetimes
Neutron captures when star expands

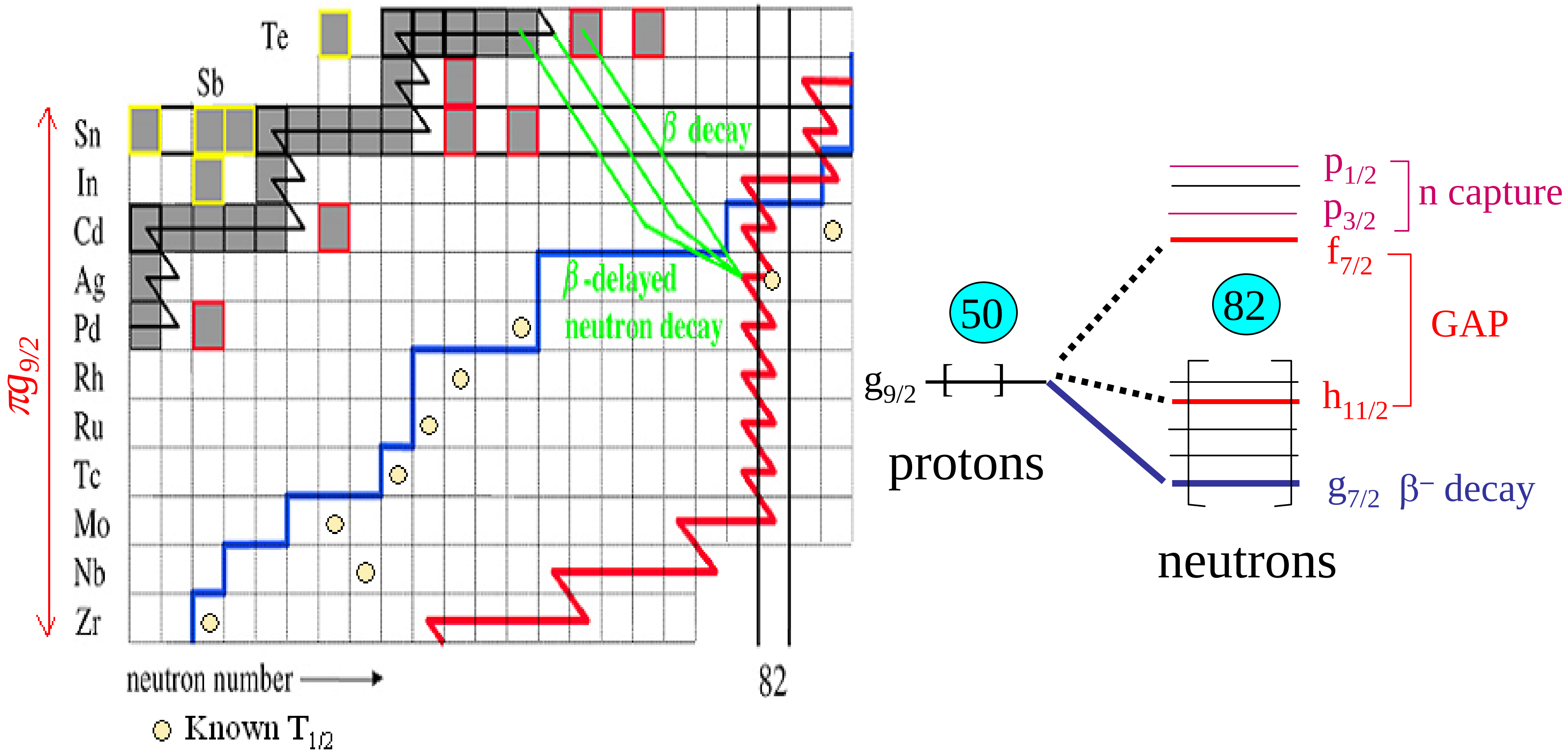
Astrophysical r-process around N=82

Evolution of N=82 shell gap -> location of waiting points

Beta-decay lifetimes (GT decay $\nu g_{7/2}$-> $\pi g_{9/2}$) -> building of r process peaks

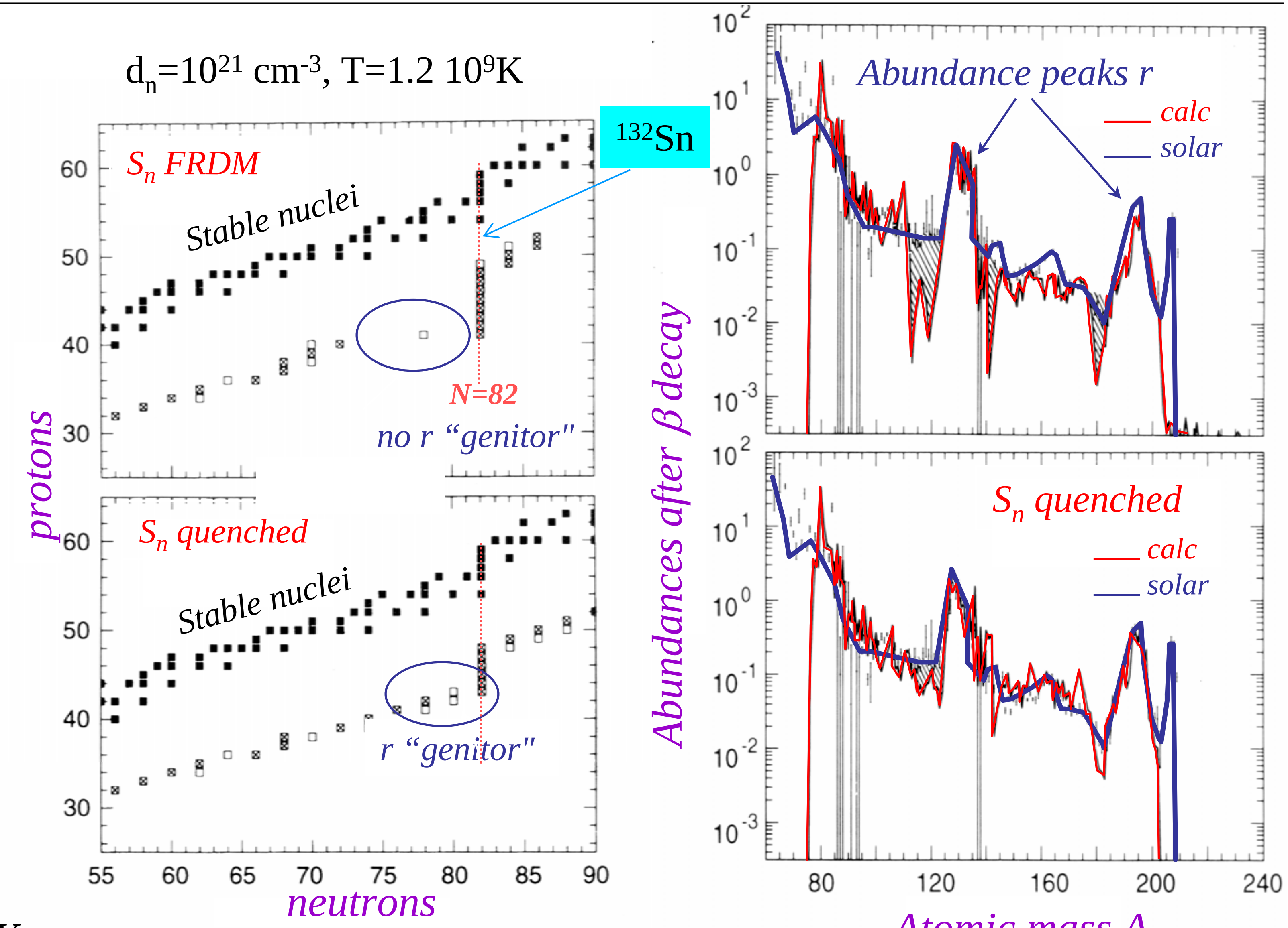
$$1/T_{1/2} \approx S_{GT} (Q_\beta\text{-}E^*)5$$

Neutron capture rates (p states)-> smearing of r abundance peaks while freeze-out



Sensitivity of nuclear structure at N=82 on the r abondance curve

$d_n = 10^{21}$ cm^{-3}, T=1.2 10^9K

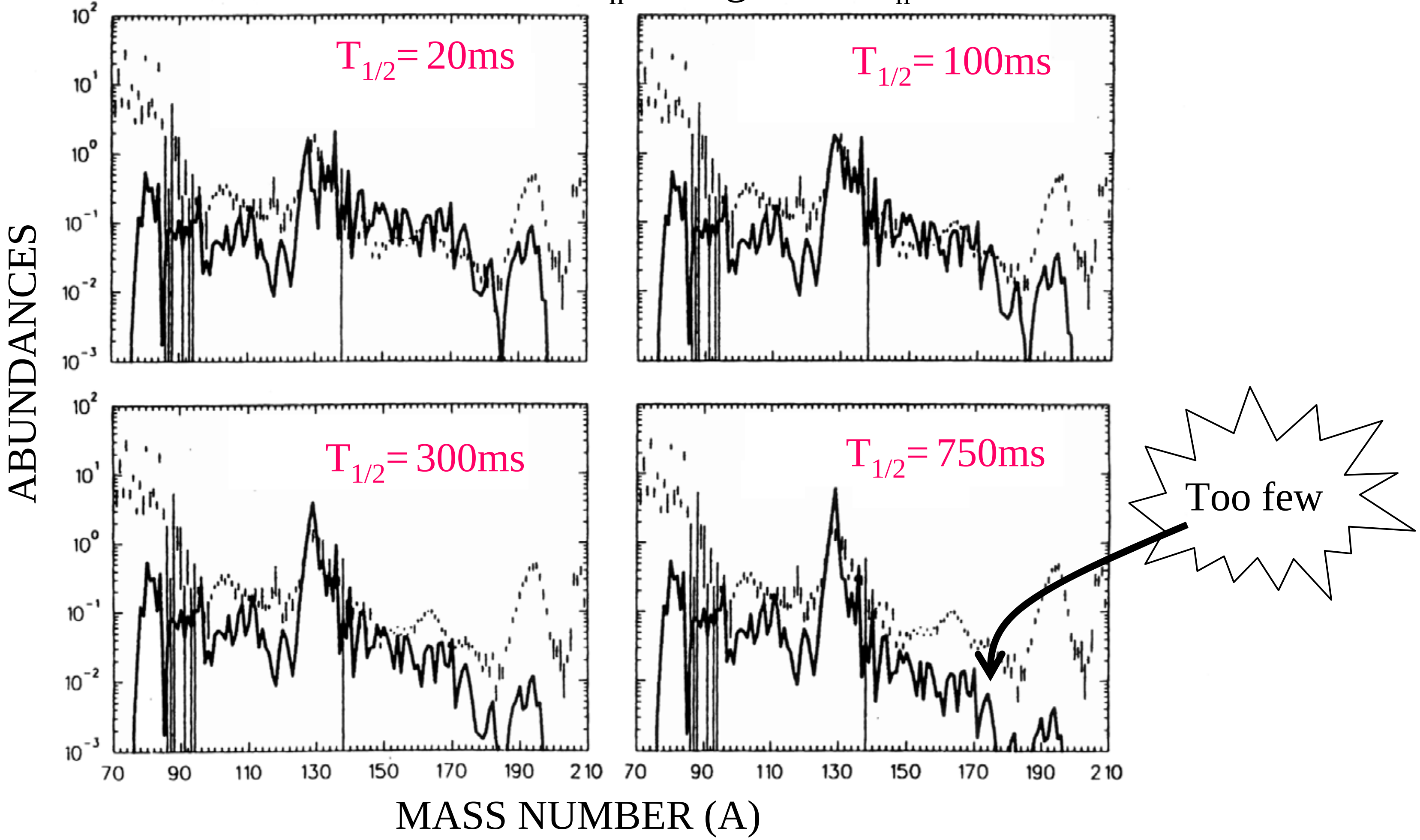


K.-L. Kratz

Shape of the abundance peak depends strongly on the behaviour of the N=82 shell

Influence of the N≈82 Cd, Ag lifetimes on the A=130 peak

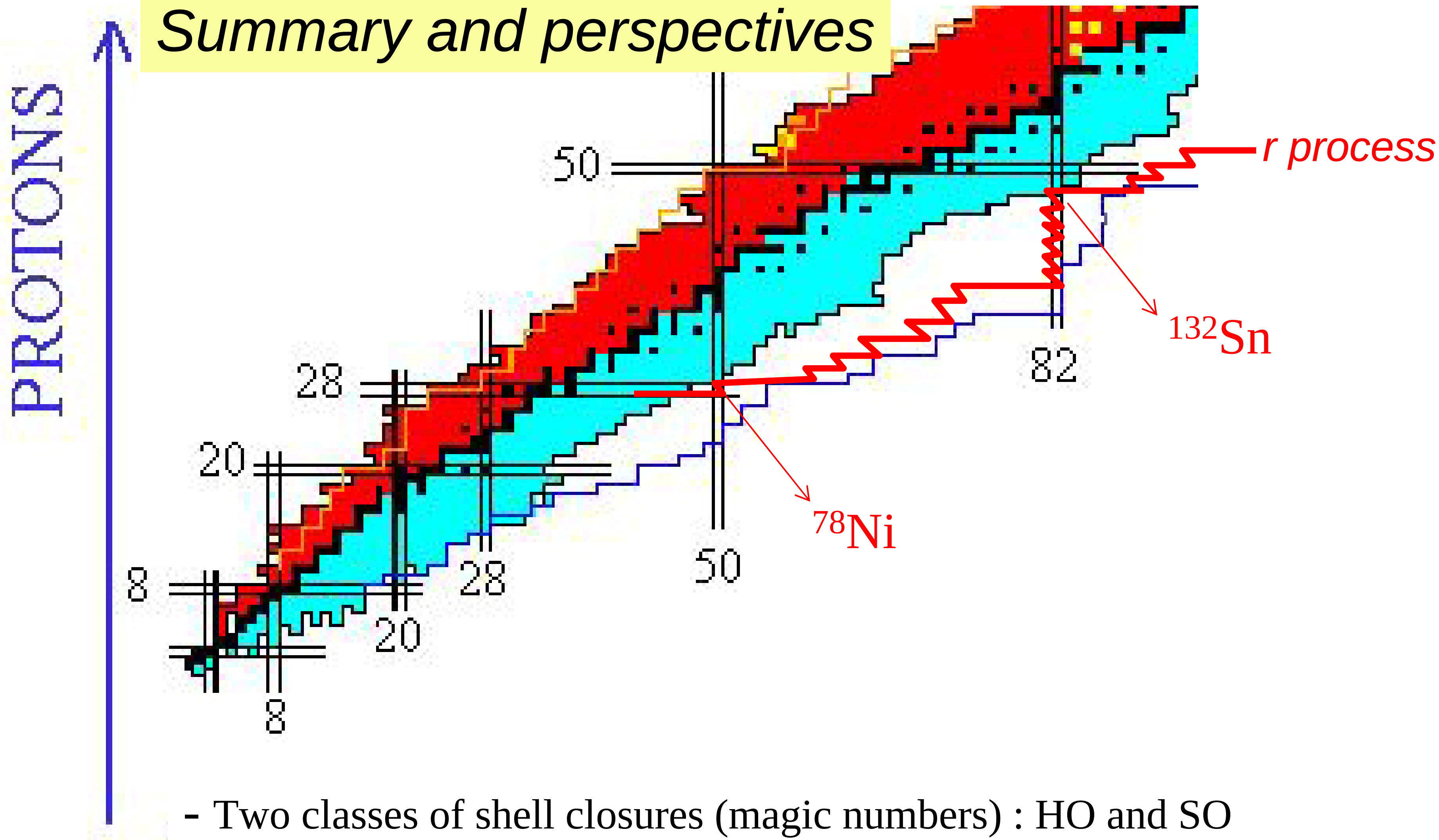
$T=1.35\ 10^9$ K, $n_n=10^{23}$g.cm^{-3} ; $\tau_n=1.86$s



Shape of r peak at A=130; constraint to produce heavier A>130 elements

K. L. Kratz, Nucl. Phys. A 630(98)352c

Summary and perspectives



- Two classes of shell closures (magic numbers) : HO and SO
- Proton-neutron interactions usually act to modify them !!!
- Takes root in NN bare forces – link with in-medium forces in progress
-Link between astrophysical r process and nuclear forces
- Are extrapolation to superheavies or unknown regions reliable ?