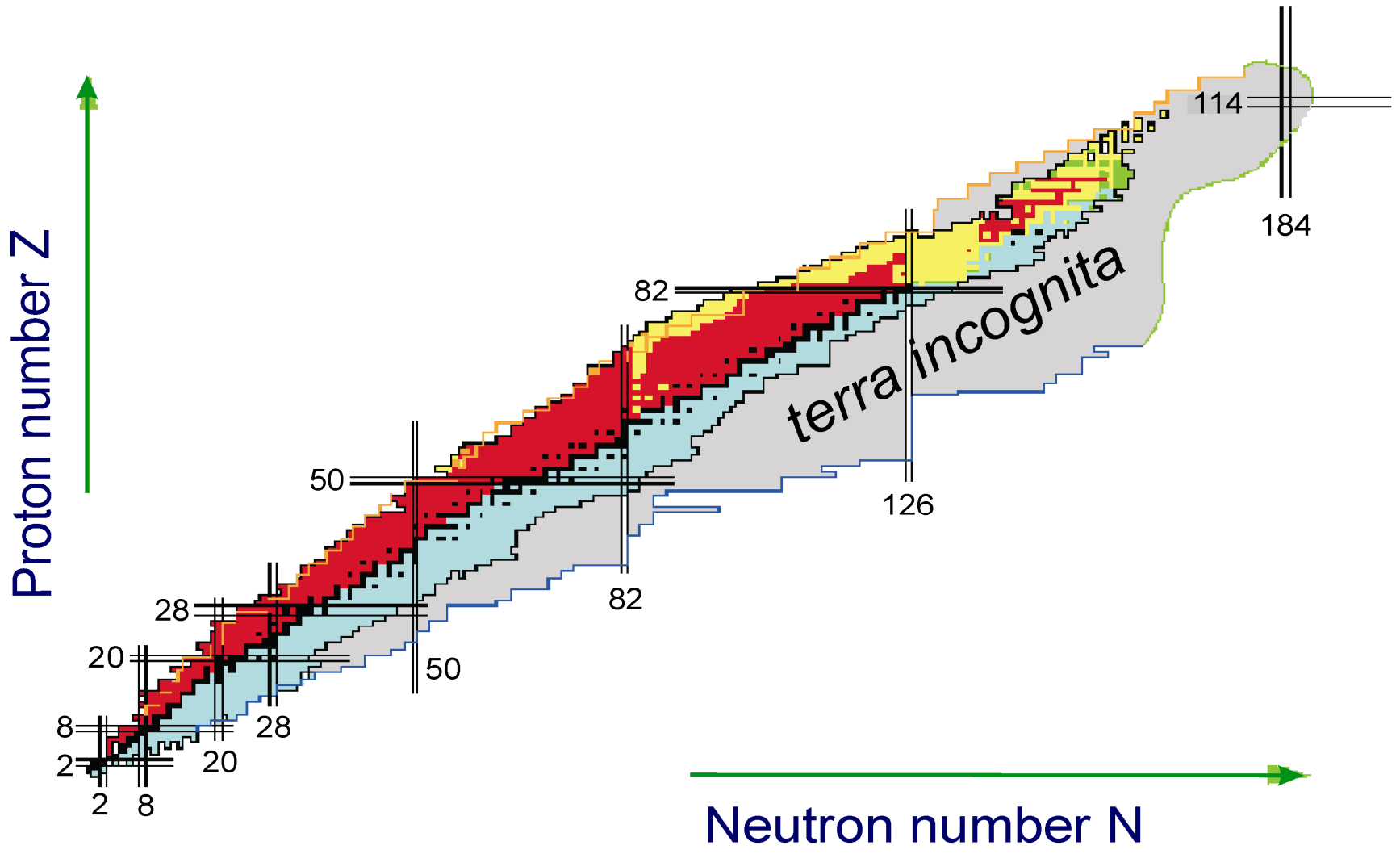
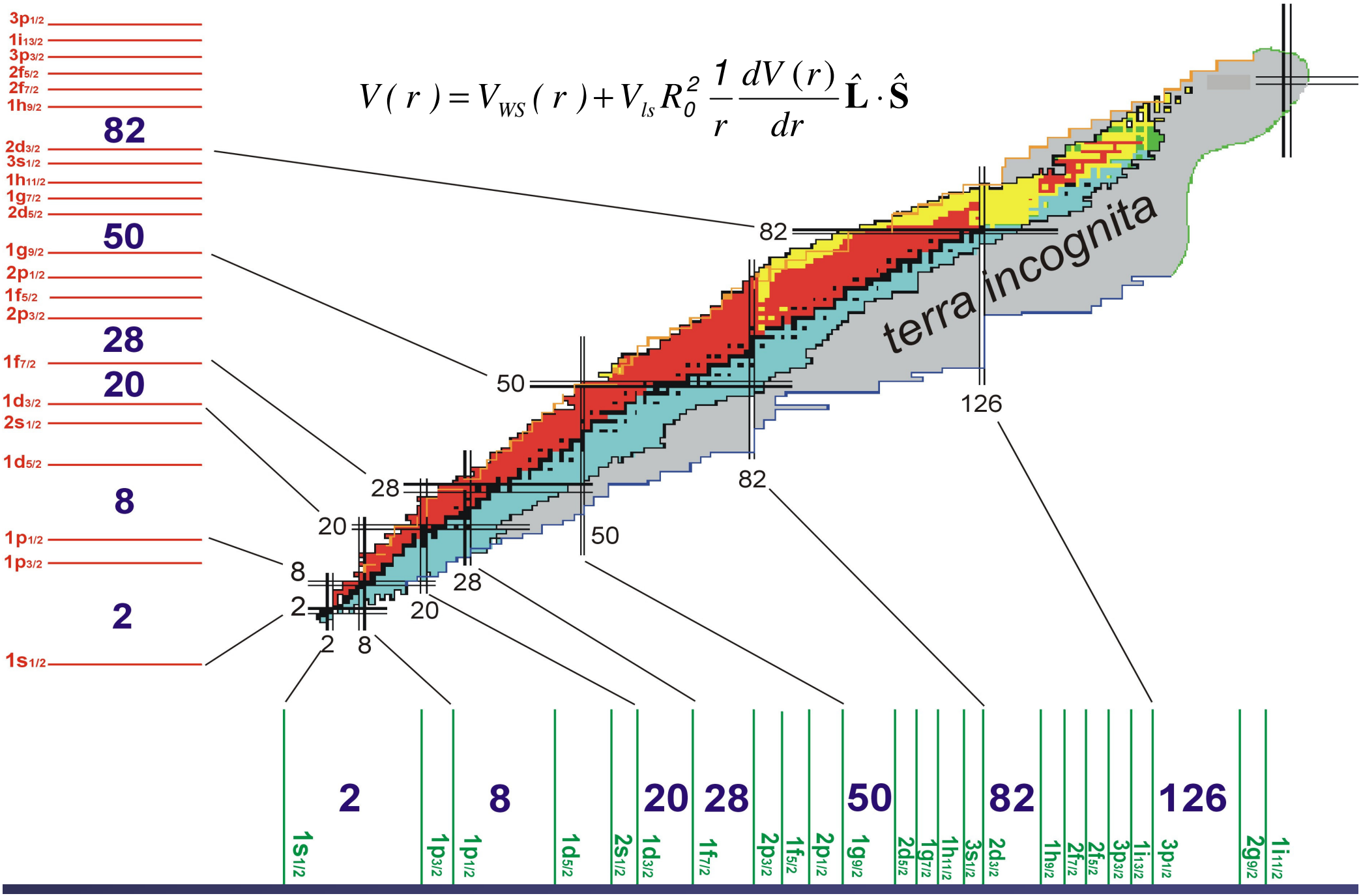
Spectroscopy of neutron-rich nuclei with deep-inelastic reactions - selected cases

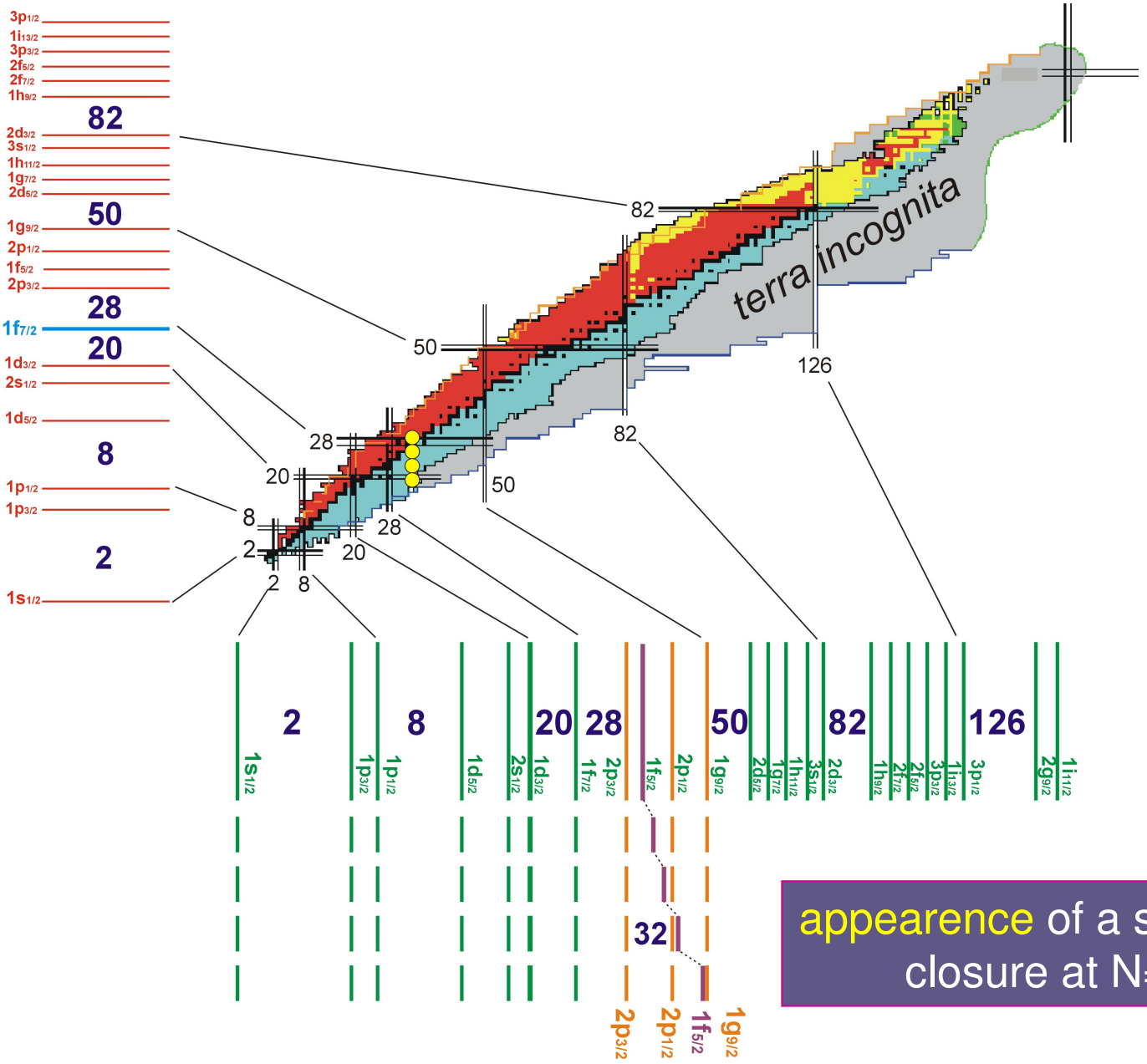
Bogdan Fornal

Institute of Nuclear Physics,
Polish Academy of Sciences
Krakow, Poland

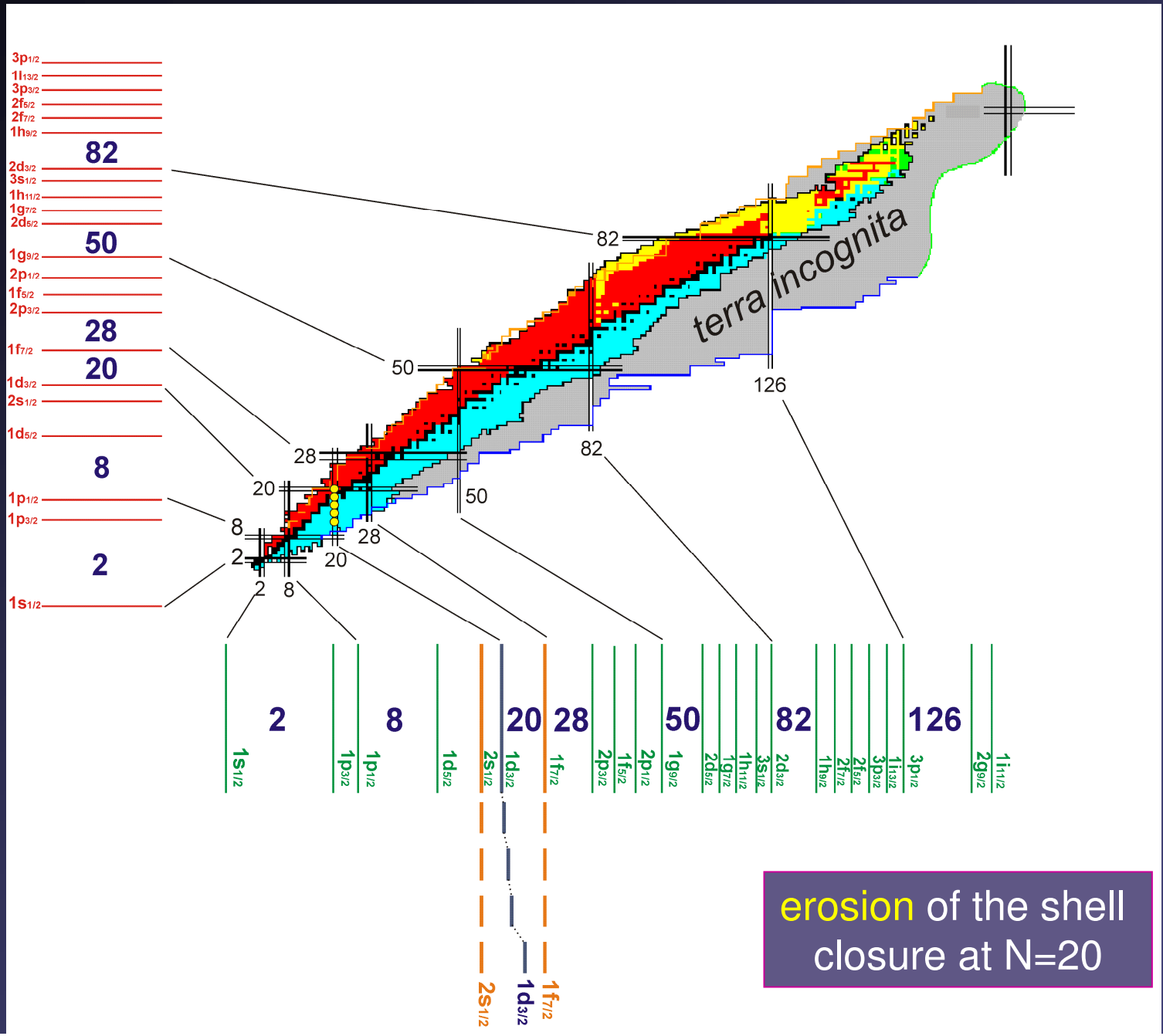
PARIS Workshop, October 14-16, 2009, Kraków, Poland


Proton number Z
Neutron number N
terra incognita
2
8
20
28
50
82
126
184
114

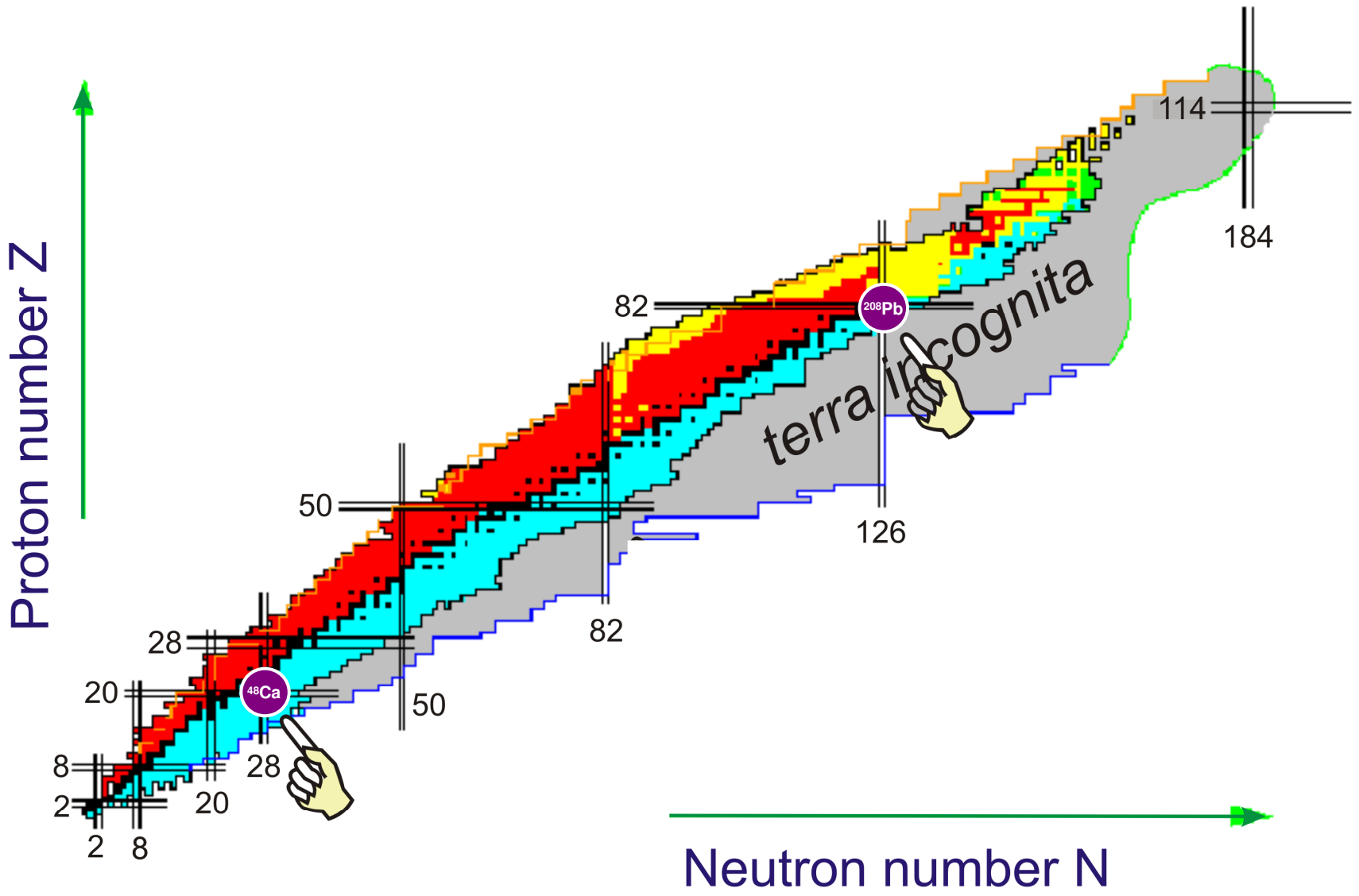

$V(r) = V_{WS}(r) + V_{ls} R_0^2 \frac{1}{r}\frac{dV(r)}{dr}\hat{\mathbf{L}}\cdot\hat{\mathbf{S}}$
3p1/2
1i13/2
3p3/2
2f5/2
2f7/2
1h9/2
82
2d3/2
3s1/2
1h11/2
1g7/2
2d5/2
50
1g9/2
2p1/2
1f5/2
2p3/2
28
1f7/2
20
1d3/2
2s1/2
1d5/2
8
1p1/2
1p3/2
2
1s1/2
terra incognita
82
50
126
28
82
20
50
8
28
2
20
2
8
2
8
20
28
50
82
126
1s1/2
1p3/2
1p1/2
1d5/2
2s1/2
1d3/2
1f7/2
2p3/2
1f5/2
2p1/2
1g9/2
2d5/2
1g7/2
1h11/2
3s1/2
2d3/2
1h9/2
2f7/2
2f5/2
3p3/2
1i13/2
3p1/2
2g9/2
1i11/2



appearence of a sub-shell closure at N=32



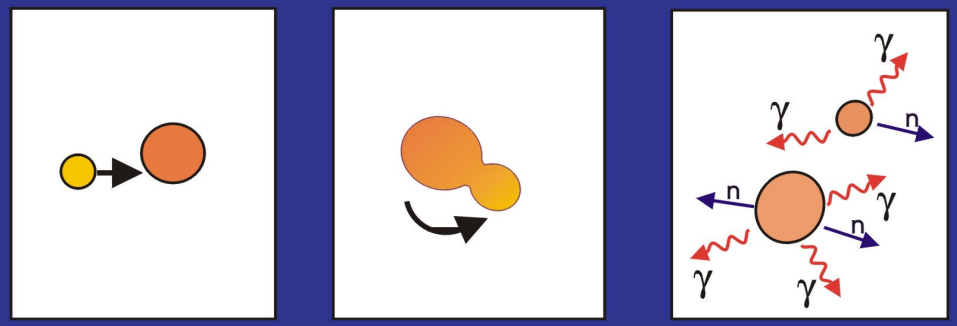
erosion of the shell closure at N=20


Proton number Z
Neutron number N
114
184
82
208Pb
terra incognita
126
50
82
28
20
48Ca
50
8
2
28
20
2
8

Experimental techniques used to access yrast excitations in neutron-rich nuclei

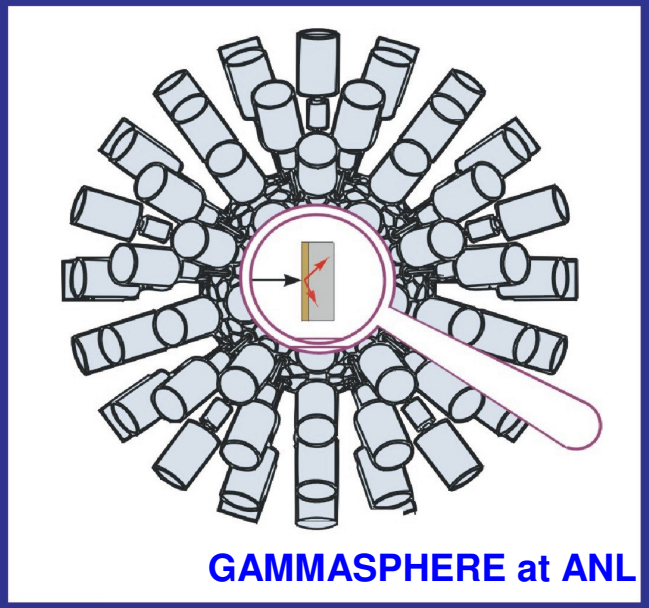
- decay of high-spin isomers populated in fragmentation reactions or projectile fission at intermediate energies
- deep-inelastic processes occurring during heavy-ion reactions
- fission (spontaneous or induced) of uranium and transuranium nuclei

Studies of neutron-rich nuclei by using deep-inelastic heavy-ion reactions

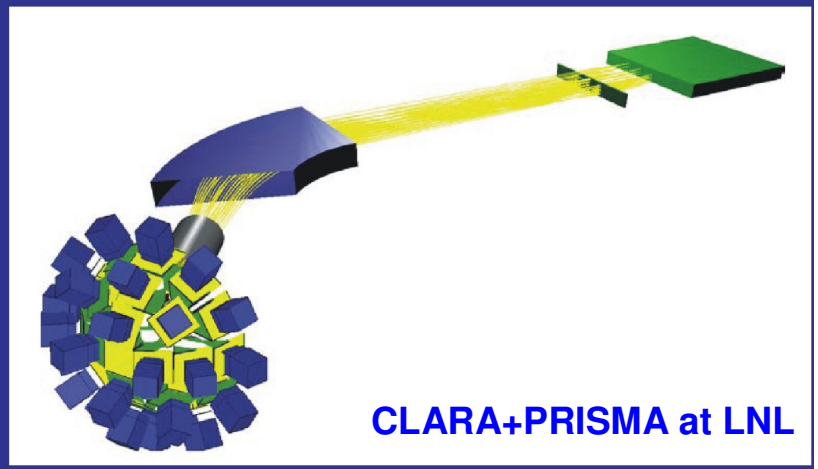


thick target
$\gamma-\gamma$ coincidences

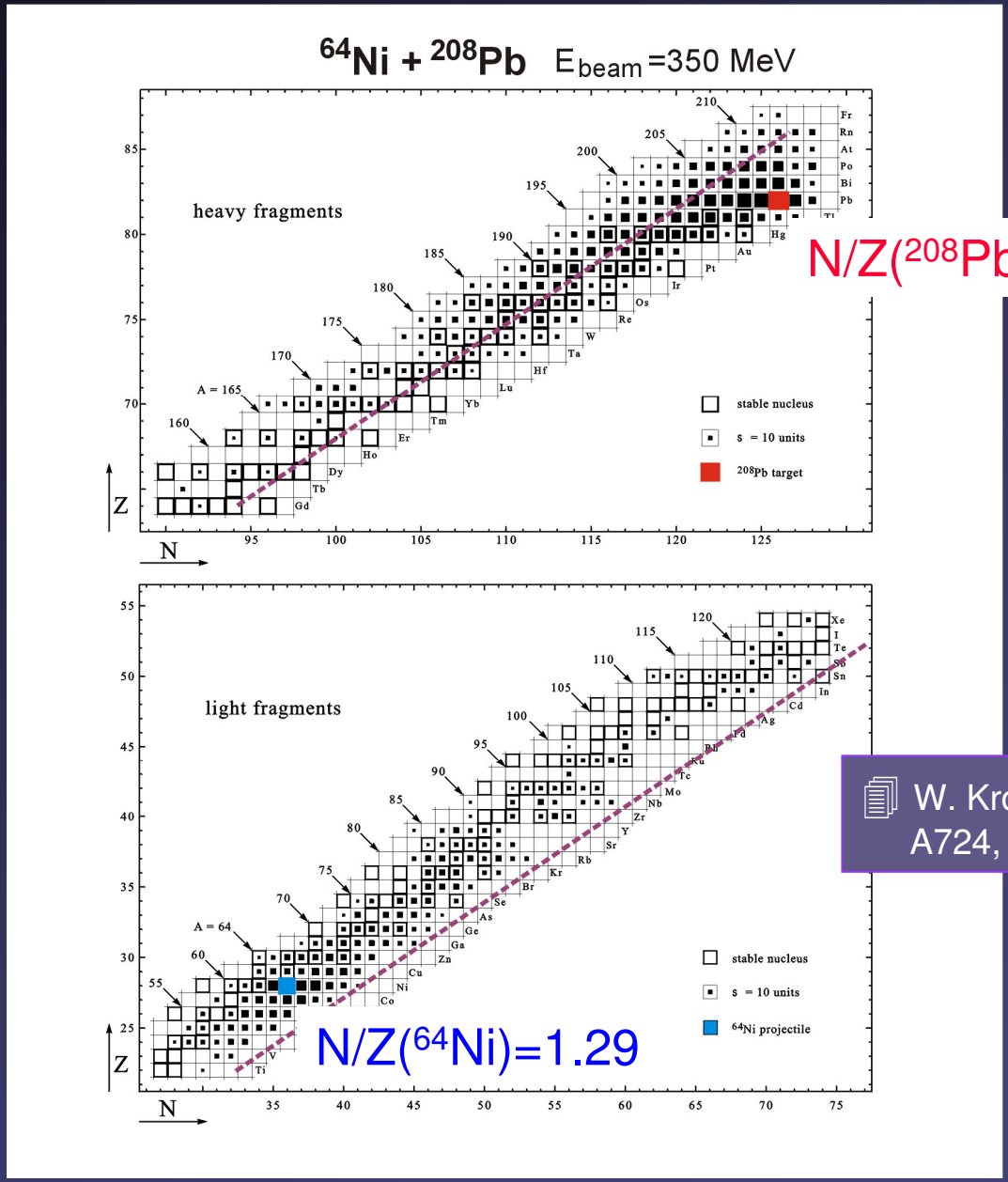
R. Broda *et al.*, Phys.Lett. B (1990)



γ – reaction product coincidences



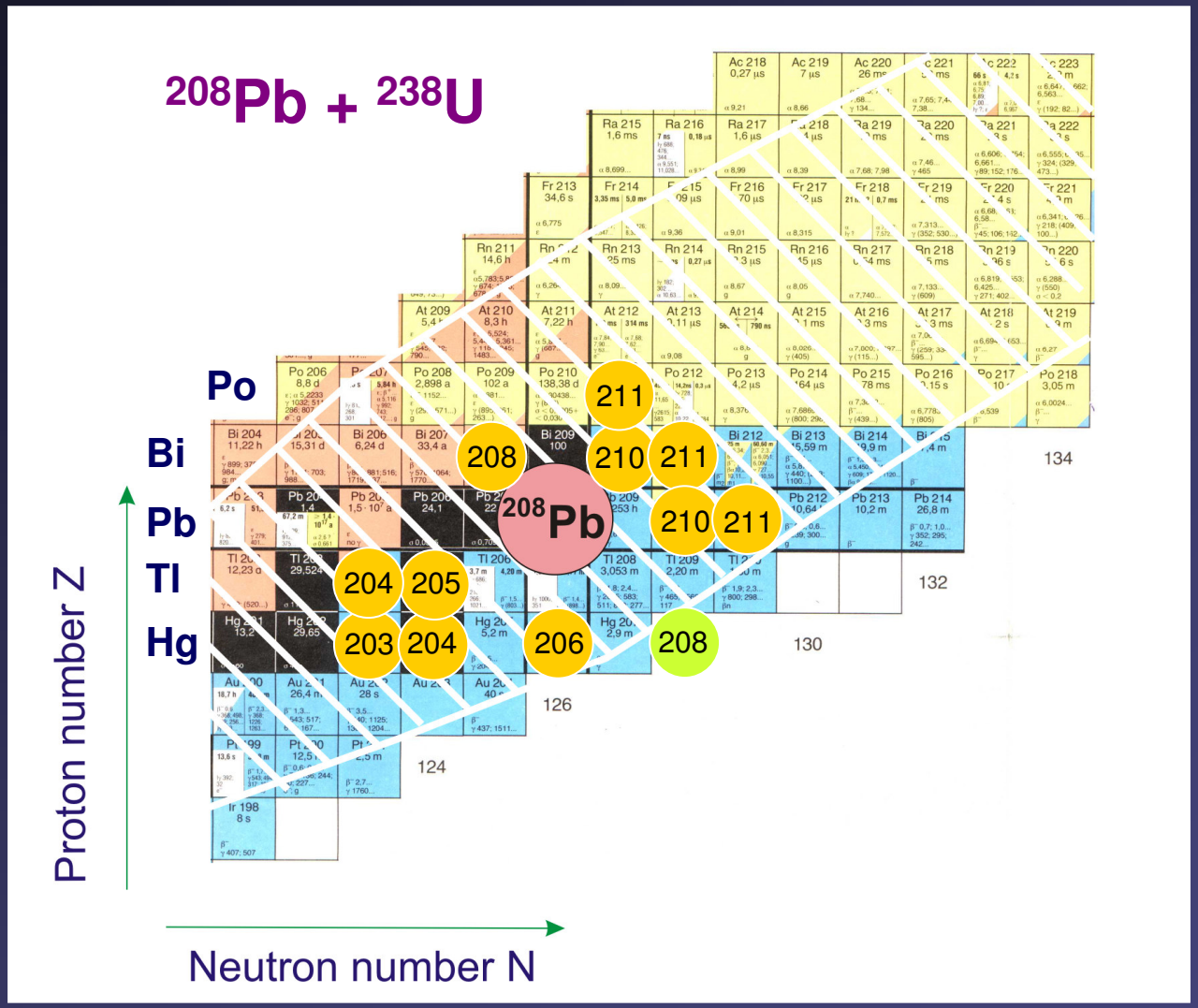
Detailed product yield distribution measured in deep-inelastic reaction of ^{64}Ni (350 MeV) on ^{208}Pb



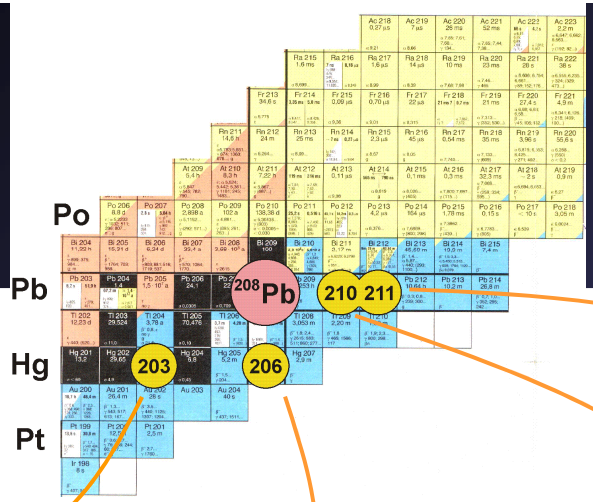
N/Z(^{208}Pb)=1.54

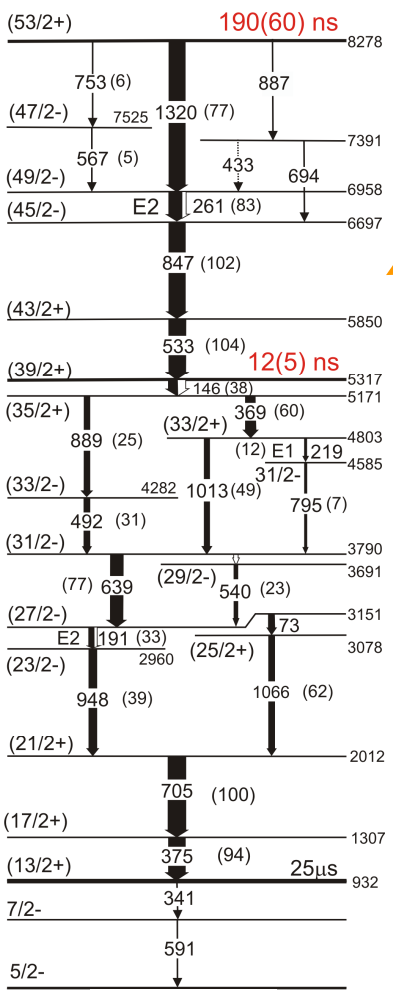
W. Królas et al. Nucl. Phys. A724, 289 (2003)

The nuclei around ^{208}Pb, produced in deep-inelastic reactions, in which we have identified yrast structures using GAMMASPHERE at Argonne Nat. Lab.

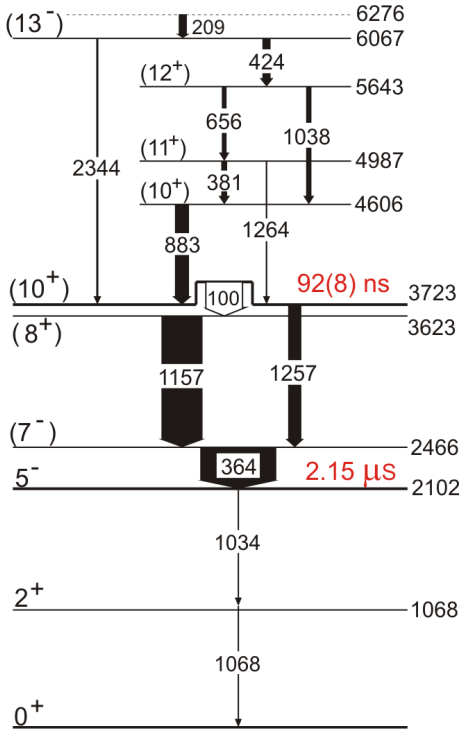


Results on selected neutron-rich nuclei produced in the ^{208}Pb + ^{238}U reaction (from GAMMASPHERE)



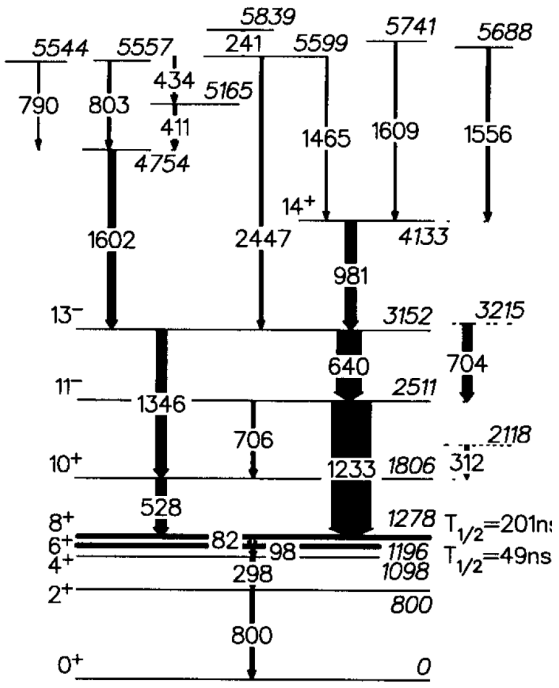


^{203}Hg

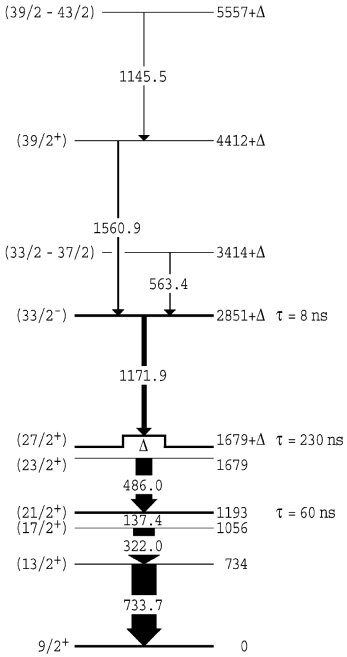


^{206}Hg

B. Fornal et al., Phys. Rev. Lett. 87 (2001)



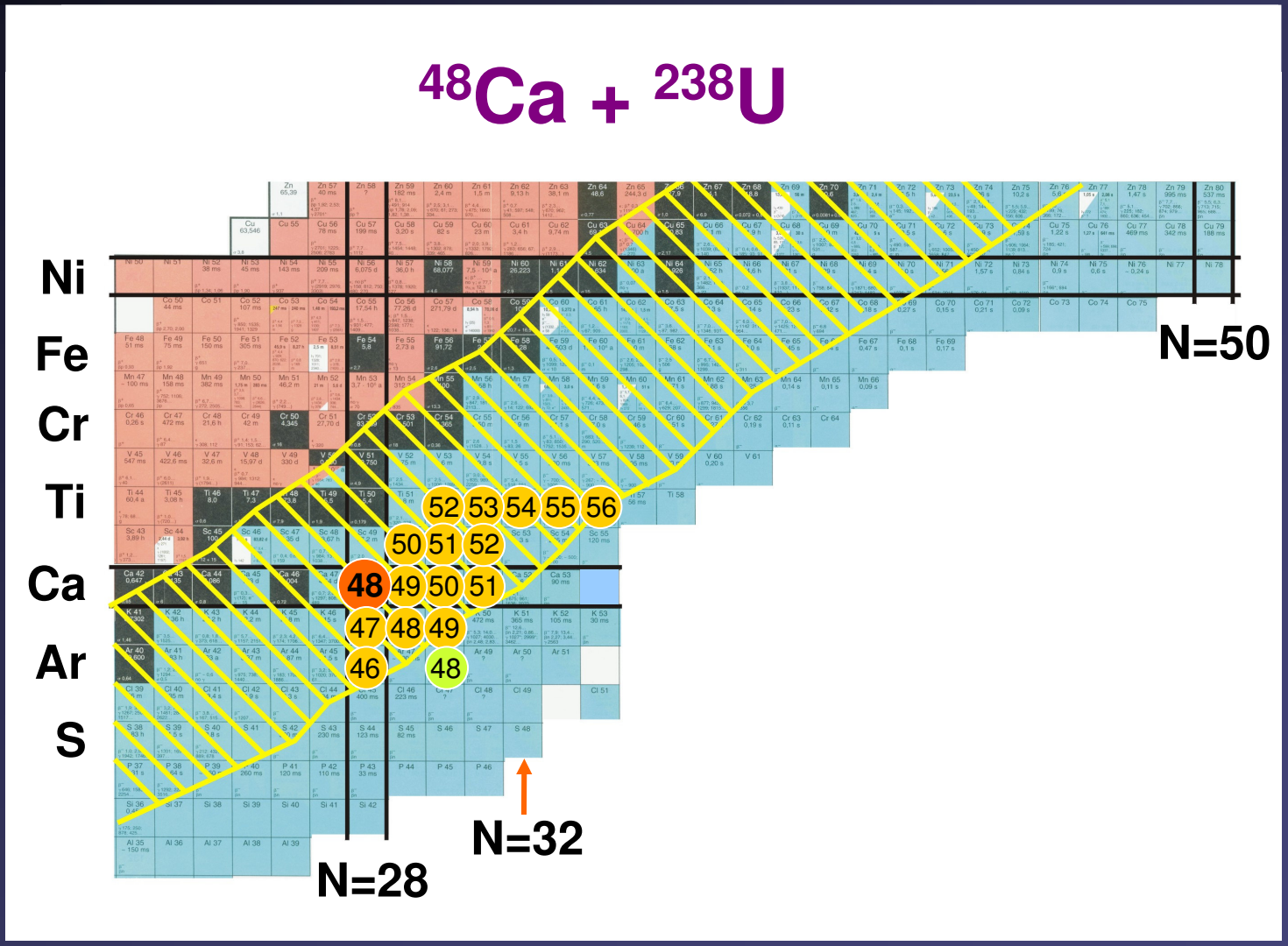
^{210}Pb



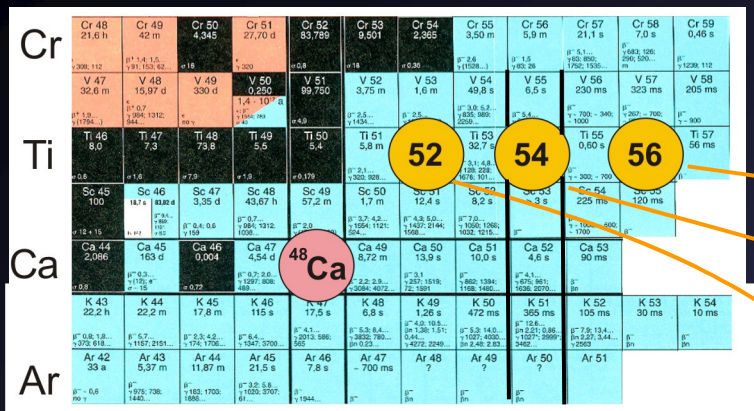
^{211}Pb

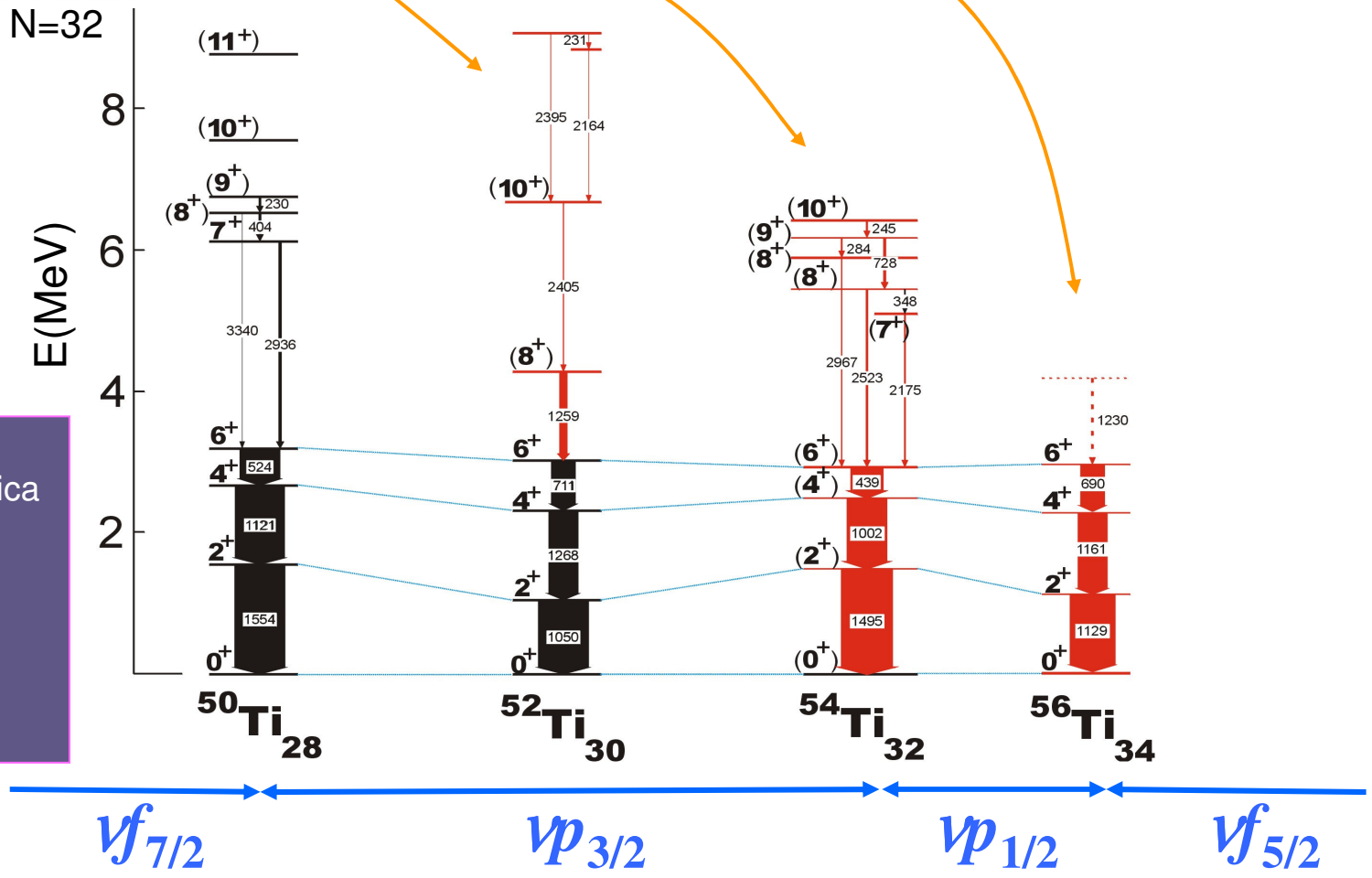
G. Lane et al., Nucl. Phys. A682 (2001), Phys. Lett. B 606 (2005)

The nuclei around ^{48}Ca produced in deep-inelastic reactions of ^{48}Ca (330 MeV) on ^{238}U and investigated with GAMMASPHERE and CLARA+PRISMA



Results on the neutron-rich Ti isotopes from the ^{48}Ca (330 MeV) + ^{238}U reaction studied with GAMMASPHERE

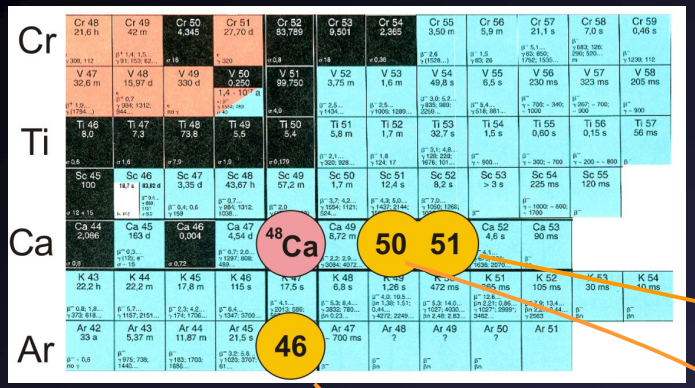


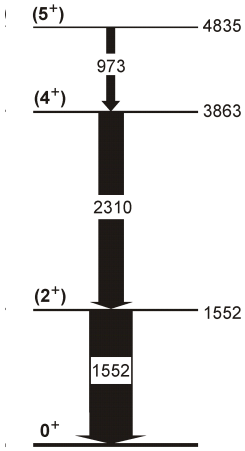


R.V.F. Janssens, B. Fornal, P.F. Mantica et al., Phys. Lett. B 546, 55 (2002).

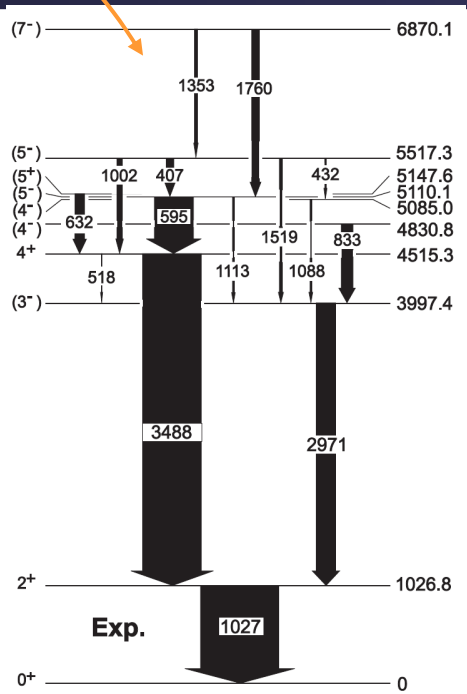
B. Fornal et al., Phys. Rev. C. 70 064304 (2004).

Results on the most neutron-rich nuclei from the ^{48}Ca (330 MeV) + ^{238}U reaction studied with GAMMASPHERE and CLARA+PRISMA

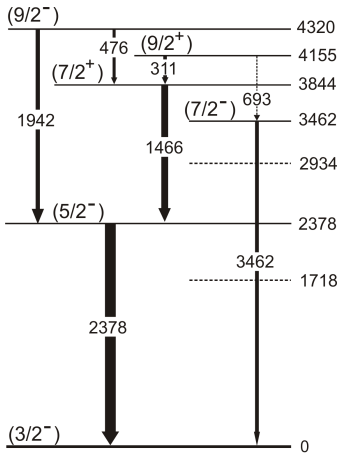




^{46}Ar



^{50}Ca



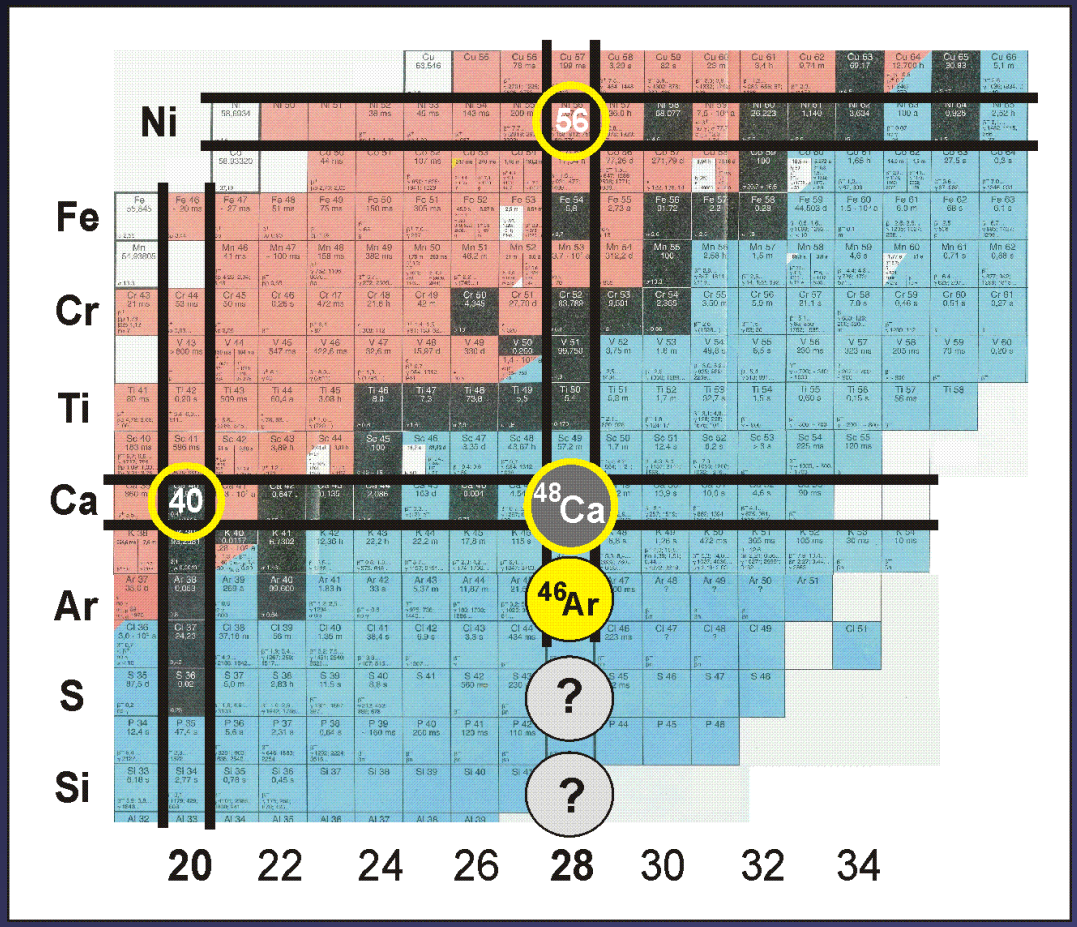
^{51}Ca

B. Fornal et al., Proc. of the 9th Spring Seminar on Nuclear Structure, Vico Equense, 2007

R. Broda et al., Acta Phys. Pol. B 36, 1343 (2005)

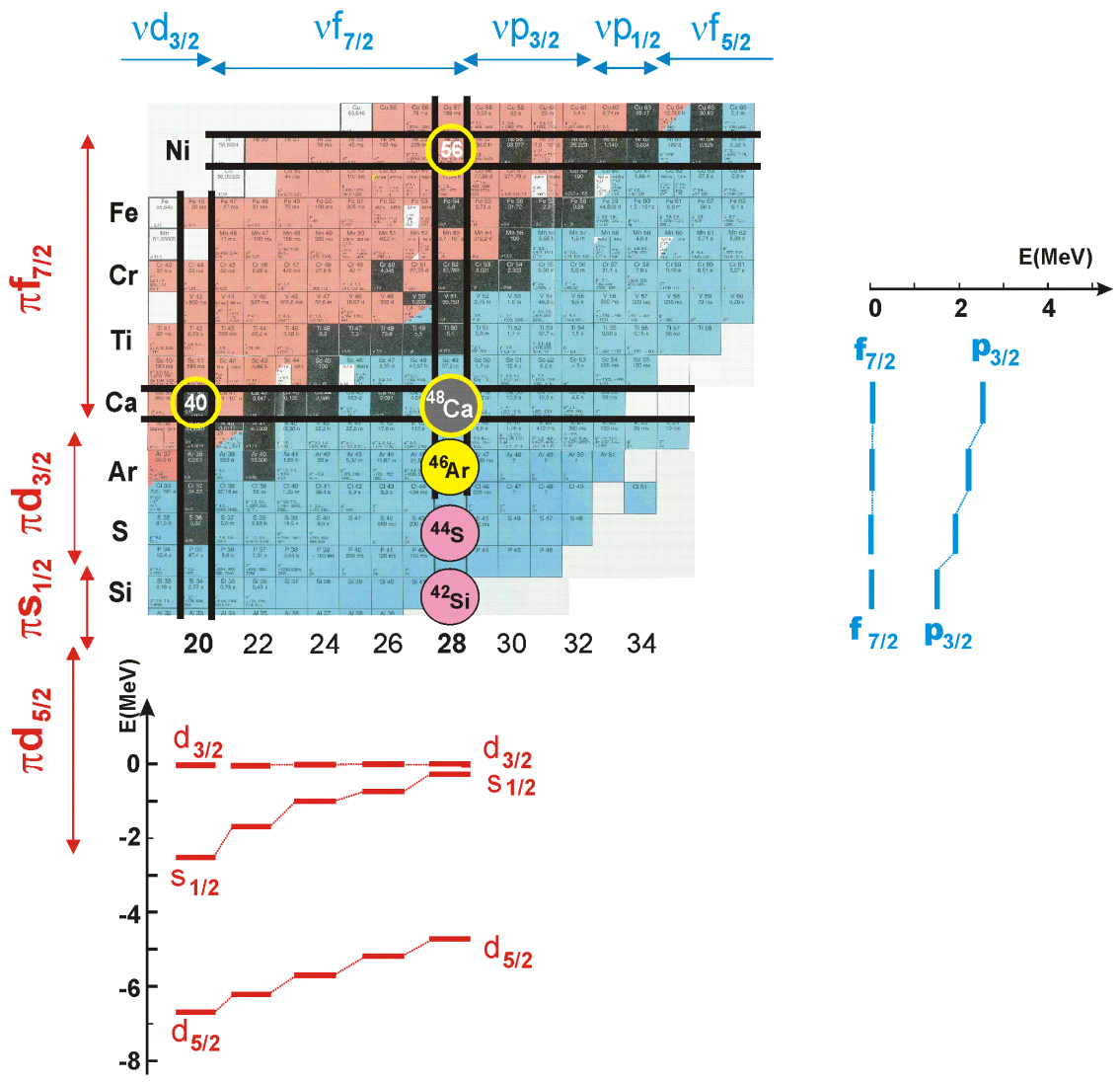
B. Fornal et al., Phys. Rev. C (2008)

How to get to even more neutron-rich nuclei?

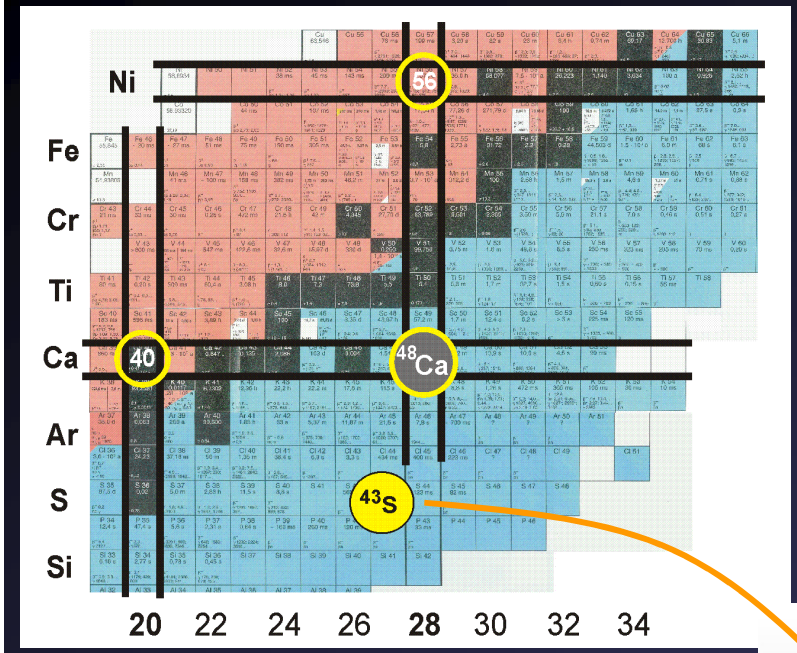


In-beam γ-ray spectroscopy of the fragmentation products at GANIL

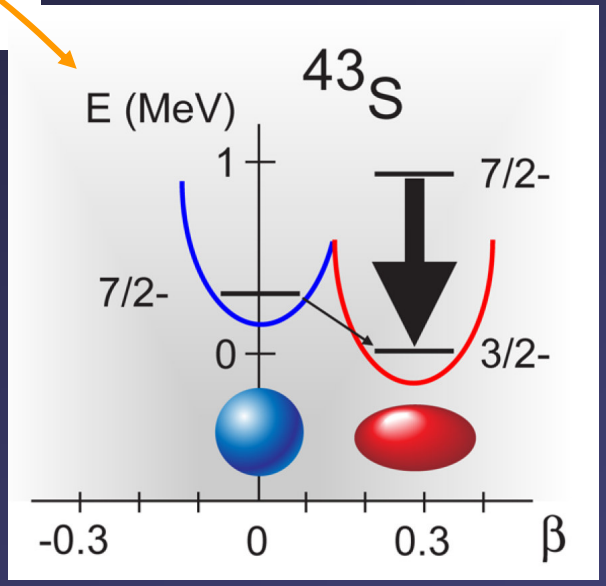
„N=28 shell erosion”



- L. Gaudefroy et al., Phys. Rev. Lett 97, 092501 (2006).
- L. Gaudefroy et al., Phys. Rev. Lett. 102, 092501 (2009).
- B. Bastin et al., Phys. Rev Lett. 99, 022503 (2007).



^{43}S produced in fragmentation of a ^{48}Ca beam on a ^{9}Be target at GANIL



- L. Gaudefroy et al., Phys. Rev. Lett. 102, 092501 (2009).
- F. Sarazin et al., Phys. Rev. Lett. 84, 5062 (2000).

Is there a method of studying higher yrast states?

The figure from the VIEWPOINT article
by P.F. Mantica, Physics 2, 18 (2009)
based on L. Gaudefroy et al., PRL. (2009)

The idea presented by Faizal Azaies at the COPIGAL Workshop (November 2008):
relies on employing „two-step DI reaction"

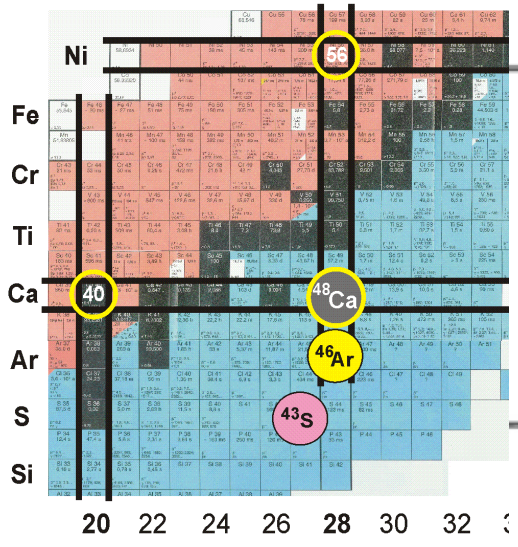
^{48}Ca + ^{238}U → (primary DI reaction) X (e.g. ^{46}Ar) + ^{238}U → (secondary DI reaction) Y (e.g. ^{43}S) + U-like partner

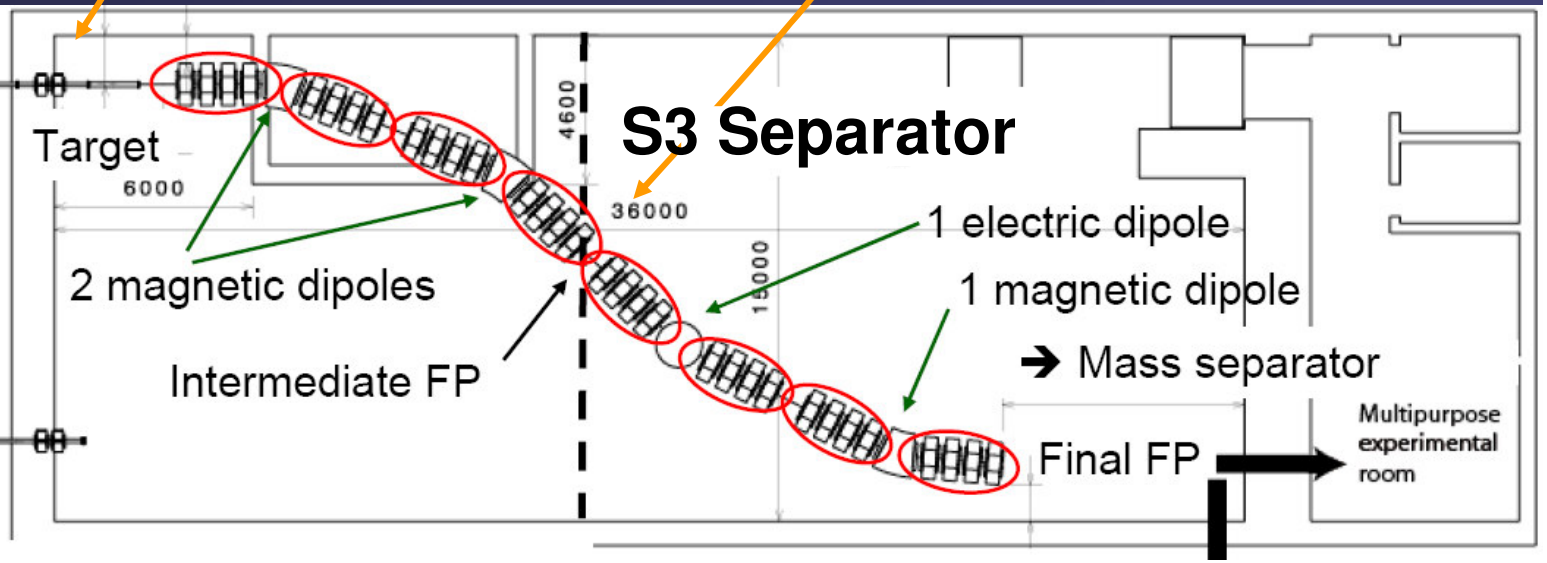
high intensity beam (~10 AMeV, ~ 1 pmA) from LINAG

high power rotating target

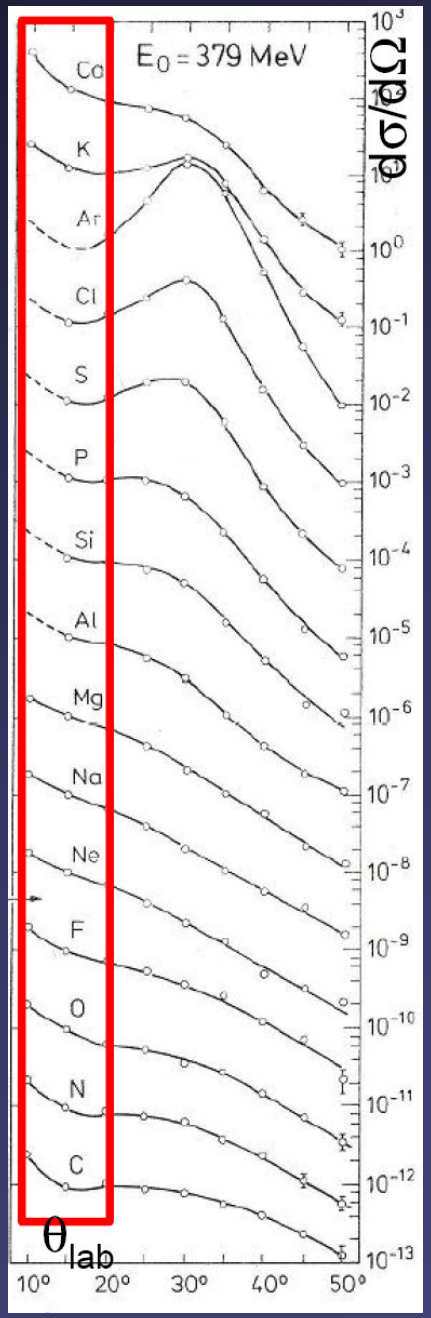
separation of deep-inelastic secondary beams

in-beam gamma spectroscopy of Y (PARIS, EXOGAM)





Angular distributions
of DI reaction products
for the system
^{40}Ar (388 MeV) + ^{232}Th



Artukh et al,
NPA215 (1973)

LoI - Day 1 experiments

In-beam gamma spectroscopy of neutron-rich nuclei studied with PARIS at the intermediate focal plane of S3

F. Azaiez, A. Maj, I. Stefan, B. Fornal et al.

Conclusions and Outlook

- **Gamma-ray spectroscopic studies with deep-inelastic reactions turned out to be extremely efficient in elucidating yrast structures in many neutron-rich nuclei.**

- **With high-intensity stable beams (LINAG at GANIL), magnetic separators of new generation (S3 at GANIL) and high efficiency gamma-ray arrays (PARIS, EXOGAM, AGATA Demo), a new tachnique based on „two-step DI reaction" may allow the access to yrast structures in yet harder-to-rich exotic species.**

R. Broda, W. Krolas, K-H. Maier, T. Pawlat, B. Szpak, J. Wrzesinski, B.F.	*IFJ PAN Krakow, Poland*
R.V.F. Janssens, S. Zhu, M.P. Carpenter, D. Seweryniak et al.	*ANL Argonne, USA*
G. Lane, G. Dracoulis et al.	*ANU Canberra, Australia*
P. Mantica, A. Gade, D.-C. Dinca, B.A. Brown et al.	*MSU East Lensing, USA*
M. Honma	*University of Aizu, Japan*
T. Otsuka	*University of Tokyo, Japan*
L. Corradi, A. Gadea, E. Farnea, S.Lunardi, N. Marginean, et al.	*PRISMA-CLARA group, Legnaro-Padova*