PROGRAM OF THE XVIII WINTER SCHOOL

Bielsko-Biała, Poland 1980

Monday, 11th February   Arrival

19^{00} - Opening

Tuesday, 12th February

Chairman: A. Hrynkiewicz

9^{00} - Z. Szymański
Recent development in high-spin nuclear physics.

16^{00} - P. Taras
Do nuclei near N=82 have an oblate shape at high spin?

17^{00} - W. Enghardt
High spin states in N=80 nuclei.

Seminar

19^{00} - J. Jastrzębski
High spin isomers near N=82.

Wednesday, 13th February

Chairman: H. Morinaga

9^{00} - P. Kleinheinz
^{146}Gd and the Z=64 closure.

16^{00} - S. Lunardi
Structure of the yrast line in the N=84 isotones of Gd, Tb and Dy.

17^{00} - M. Piiparinen
Structure of yrast states of the N=85 isotones.

Thursday, 14th February

Chairman: A. Budzanowski

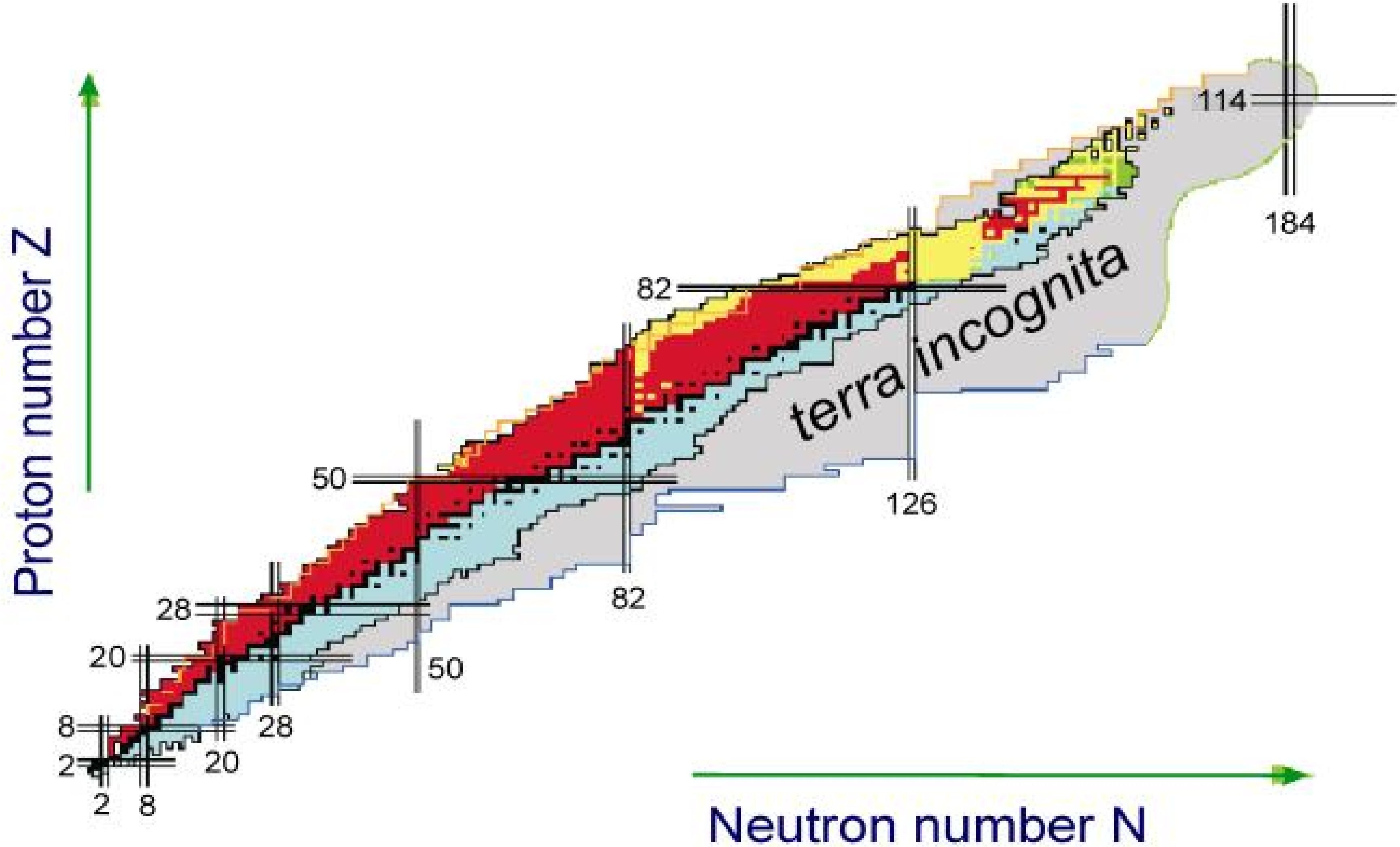
9^{00} - J.P. Wurm
On the experimental assessment of time scales in heavy ion reaction.

16^{00} - H. Machner
Particle decay of unbound states.

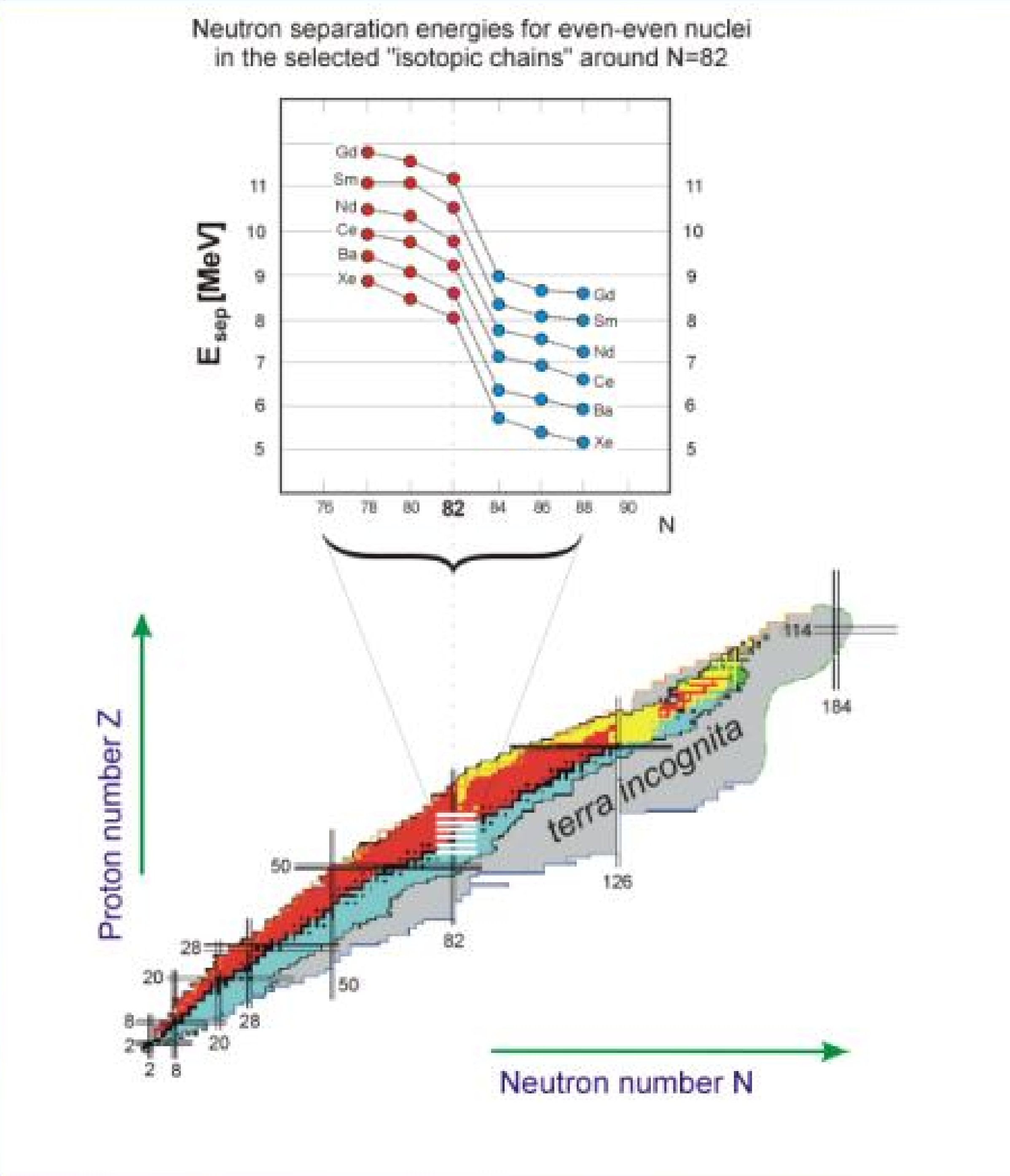
Evolution of Shell Structure in Neutron-Rich Nuclei above ^{48}Ca

Bogdan Fornal

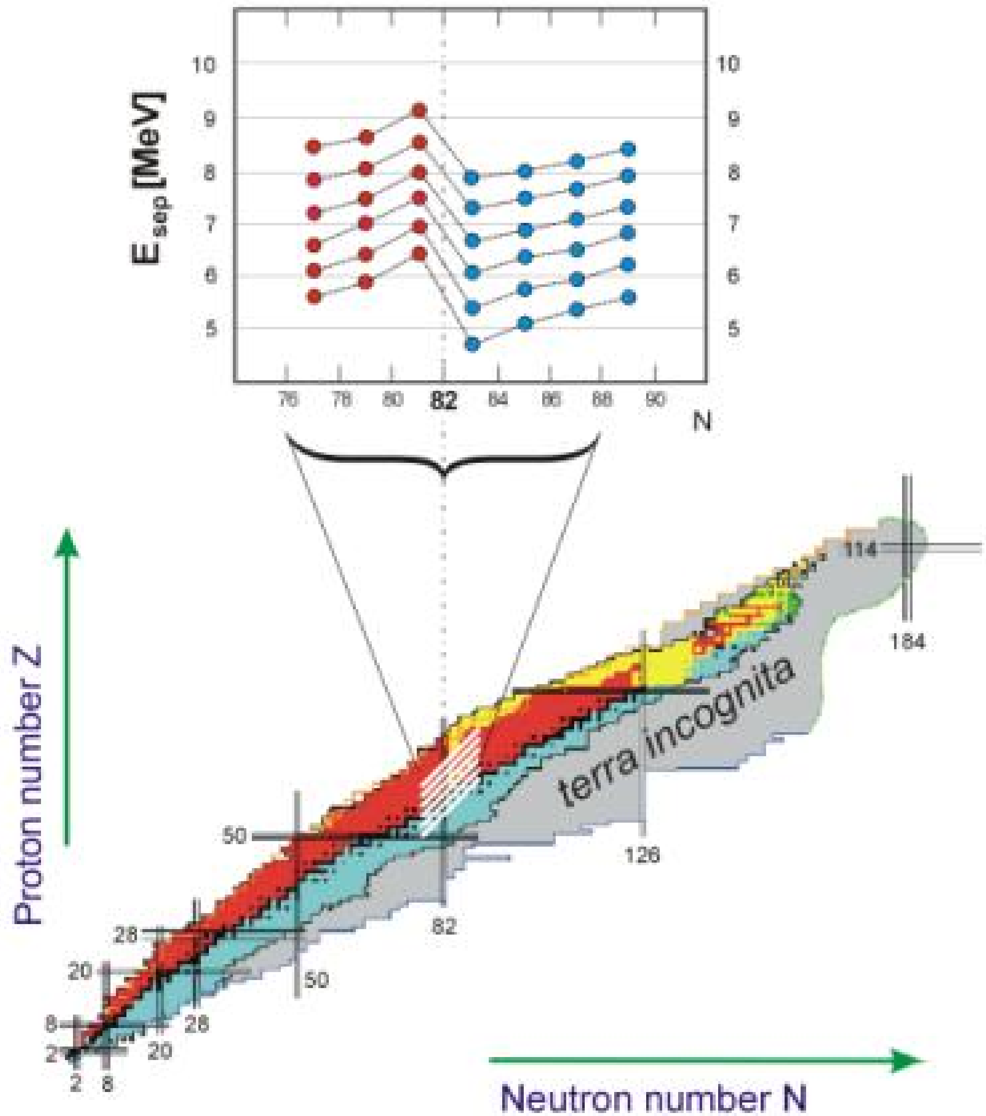
Institute of Nuclear Physics,
Polish Academy of Sciences
Krakow, Poland

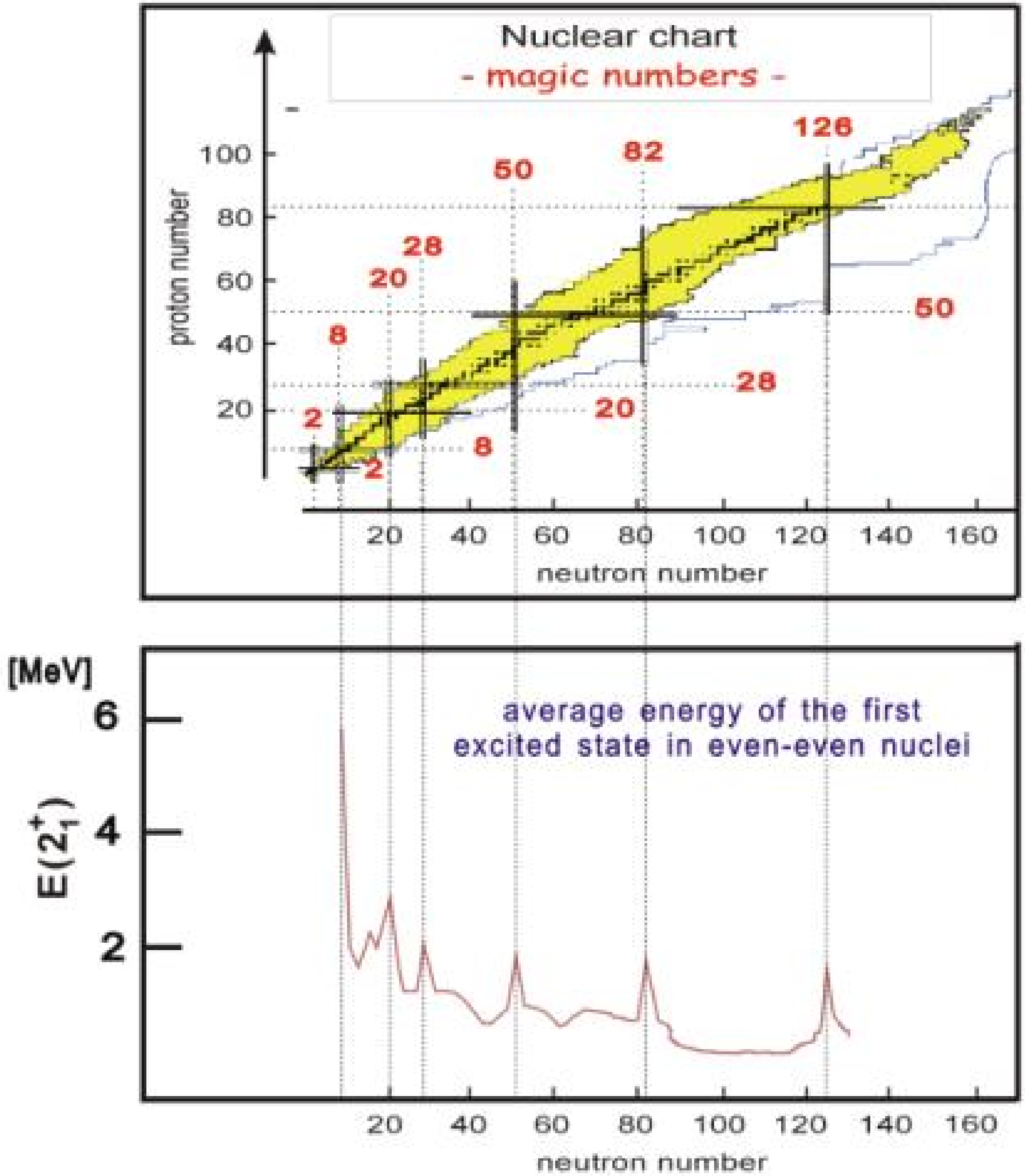


Proton number Z
Neutron number N
terra incognita
114
184
82
126
50
82
28
20
50
8
28
2
20
2
8

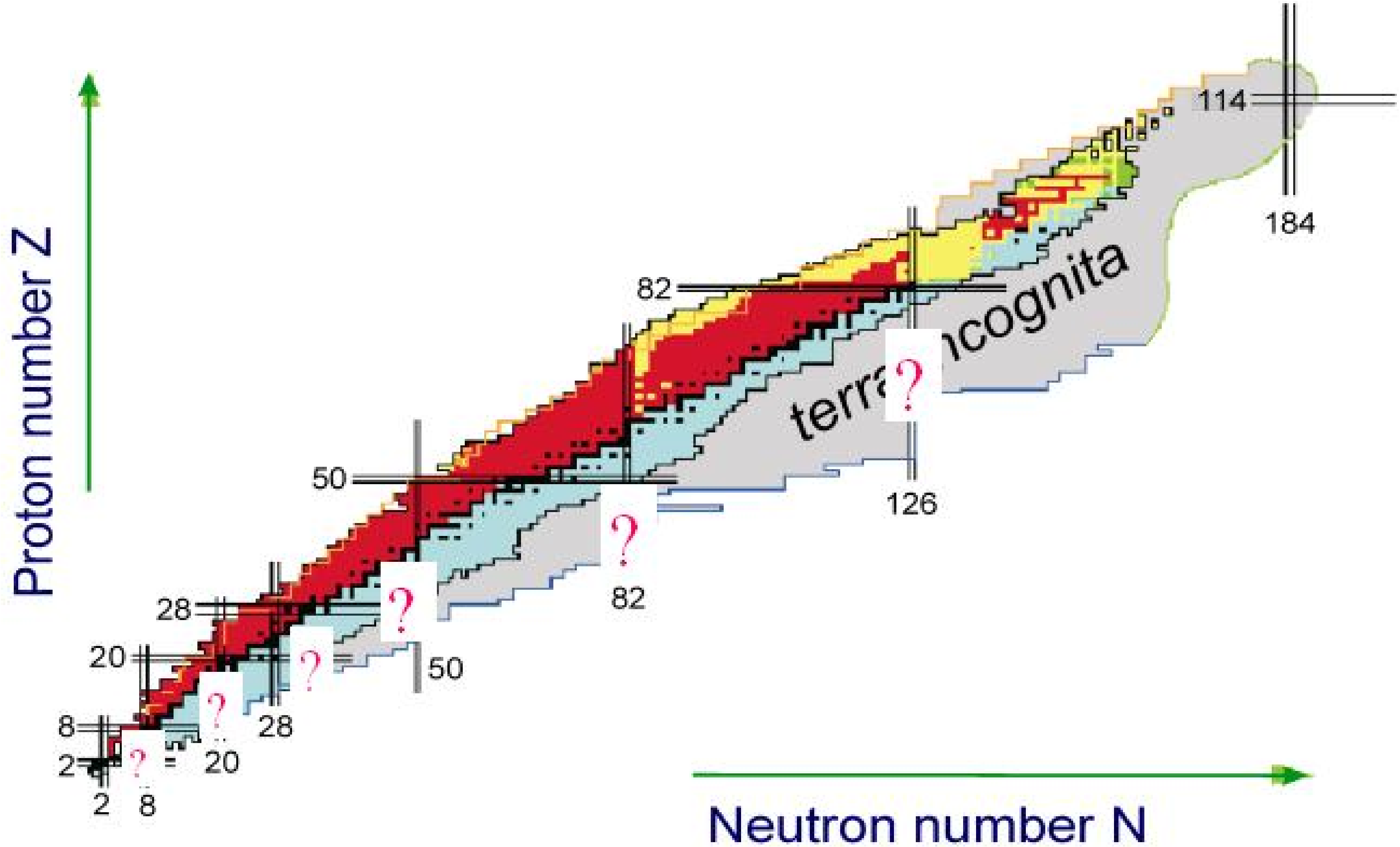

Neutron separation energies for even-even nuclei
in the selected "isotopic chains" around N=82
E_sep [MeV]
Gd
Sm
Nd
Ce
Ba
Xe
5
6
7
8
9
10
11
76
78
80
82
84
86
88
90
N
Proton number Z
Neutron number N
terra incognita
2
8
20
28
50
82
126
114
184

Neutron separation energies for even-even nuclei
in the selected "constant isospin chains" around N=82

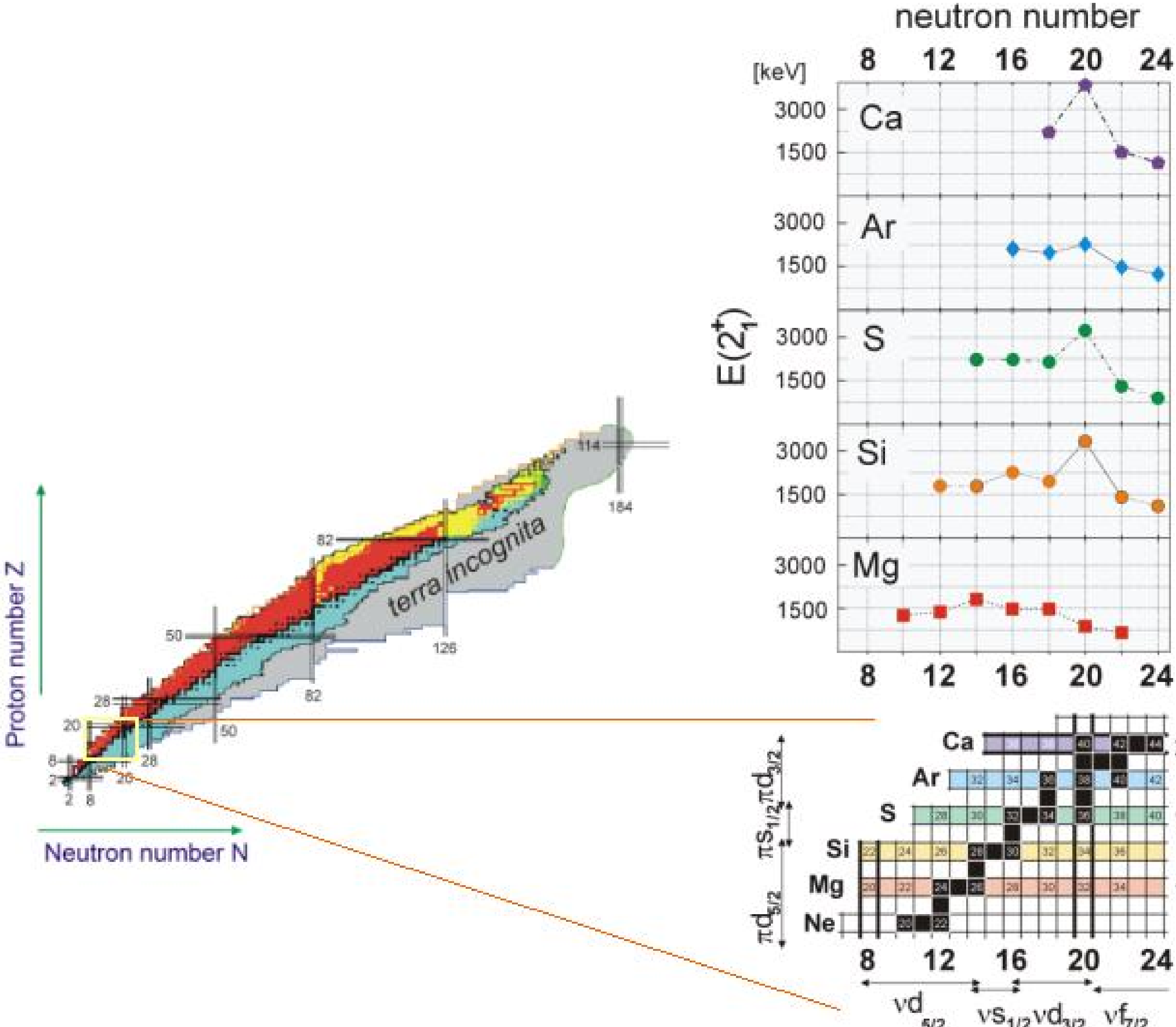




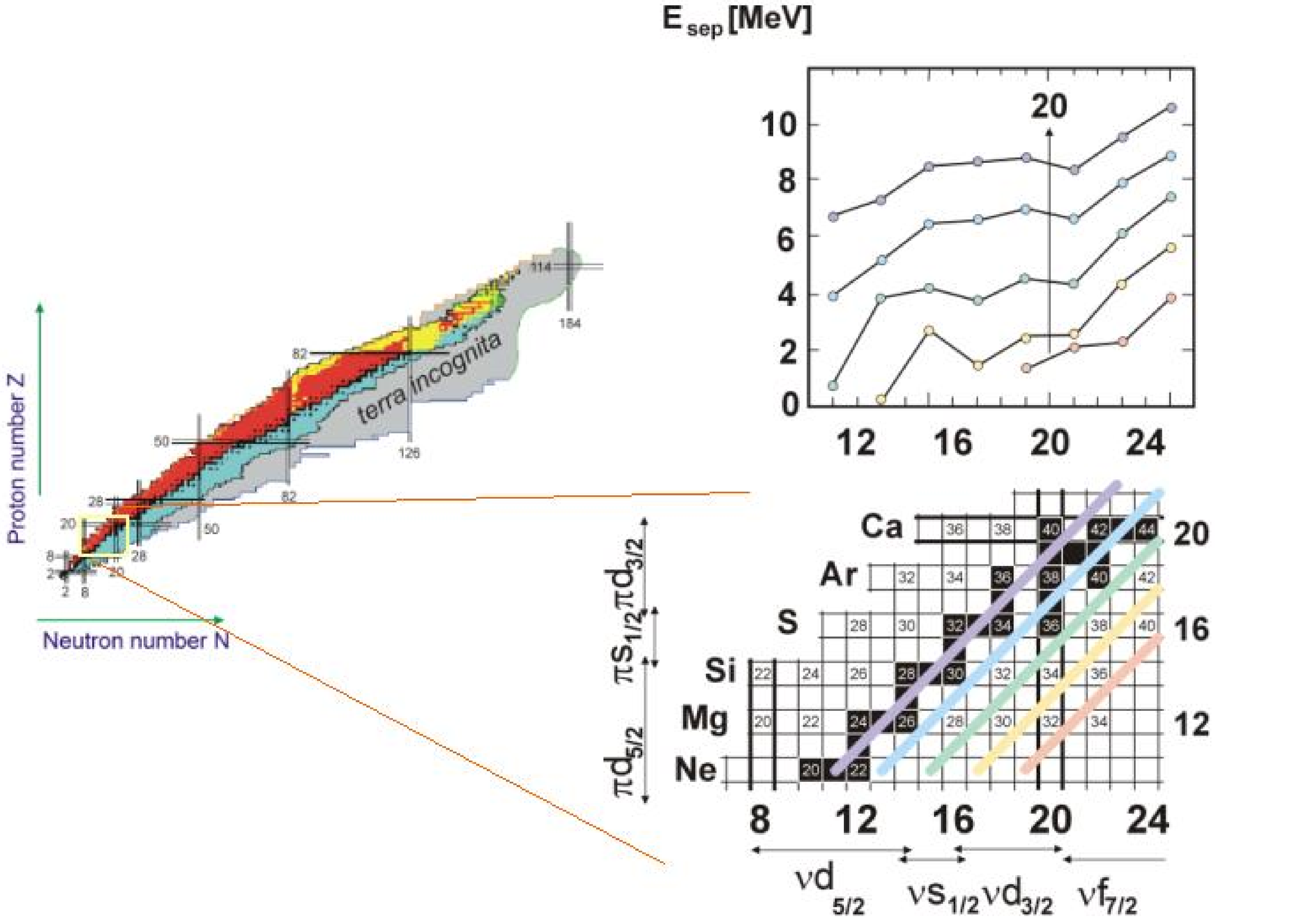
Nuclear chart
- magic numbers -
proton number
neutron number
2
8
20
28
50
82
126
[MeV]
E(2$_1^+$)
average energy of the first
excited state in even-even nuclei
neutron number



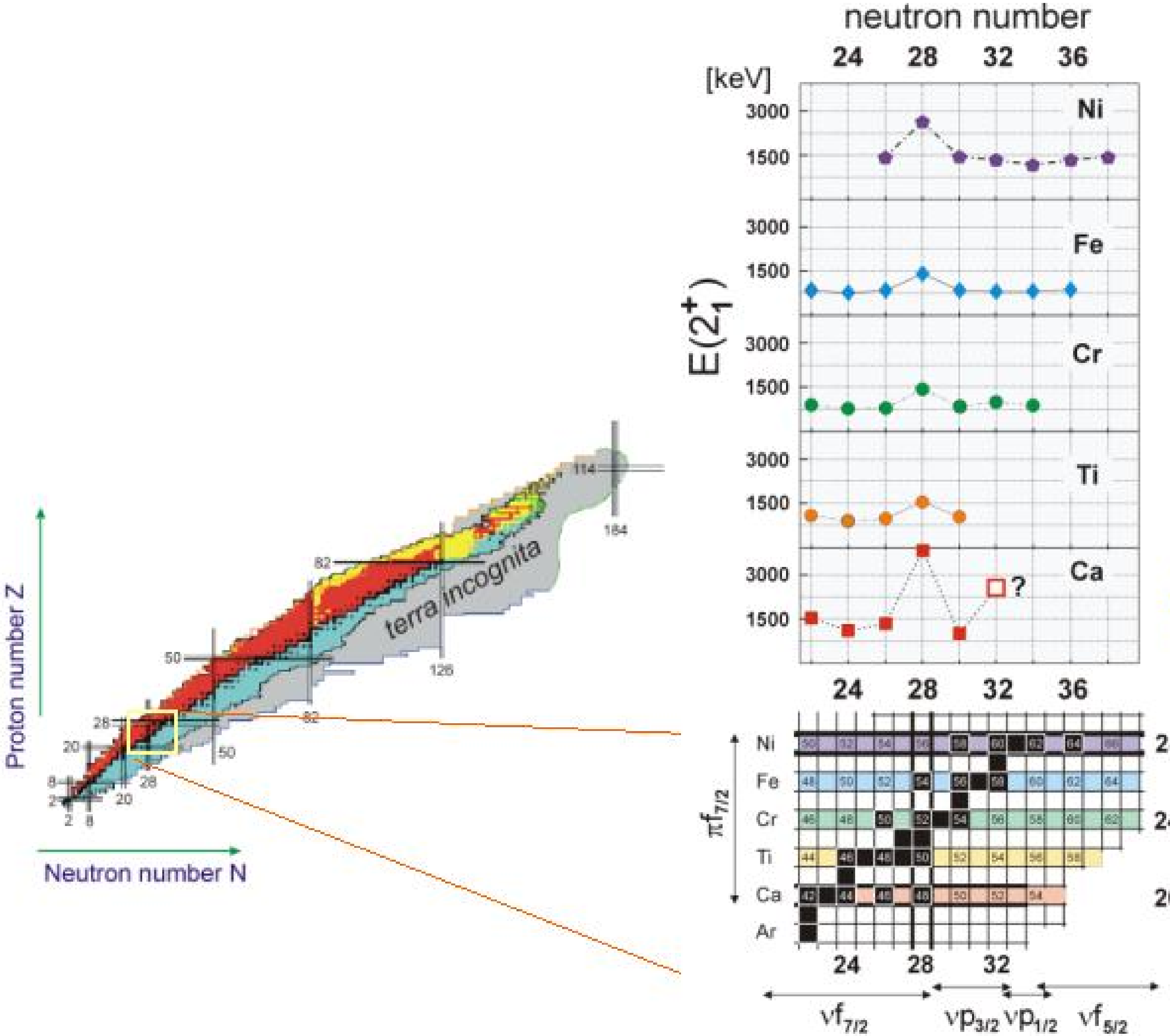
Proton number Z
Neutron number N
terra incognita
114
184
82
126
50
82
28
50
20
28
8
20
2
2
8



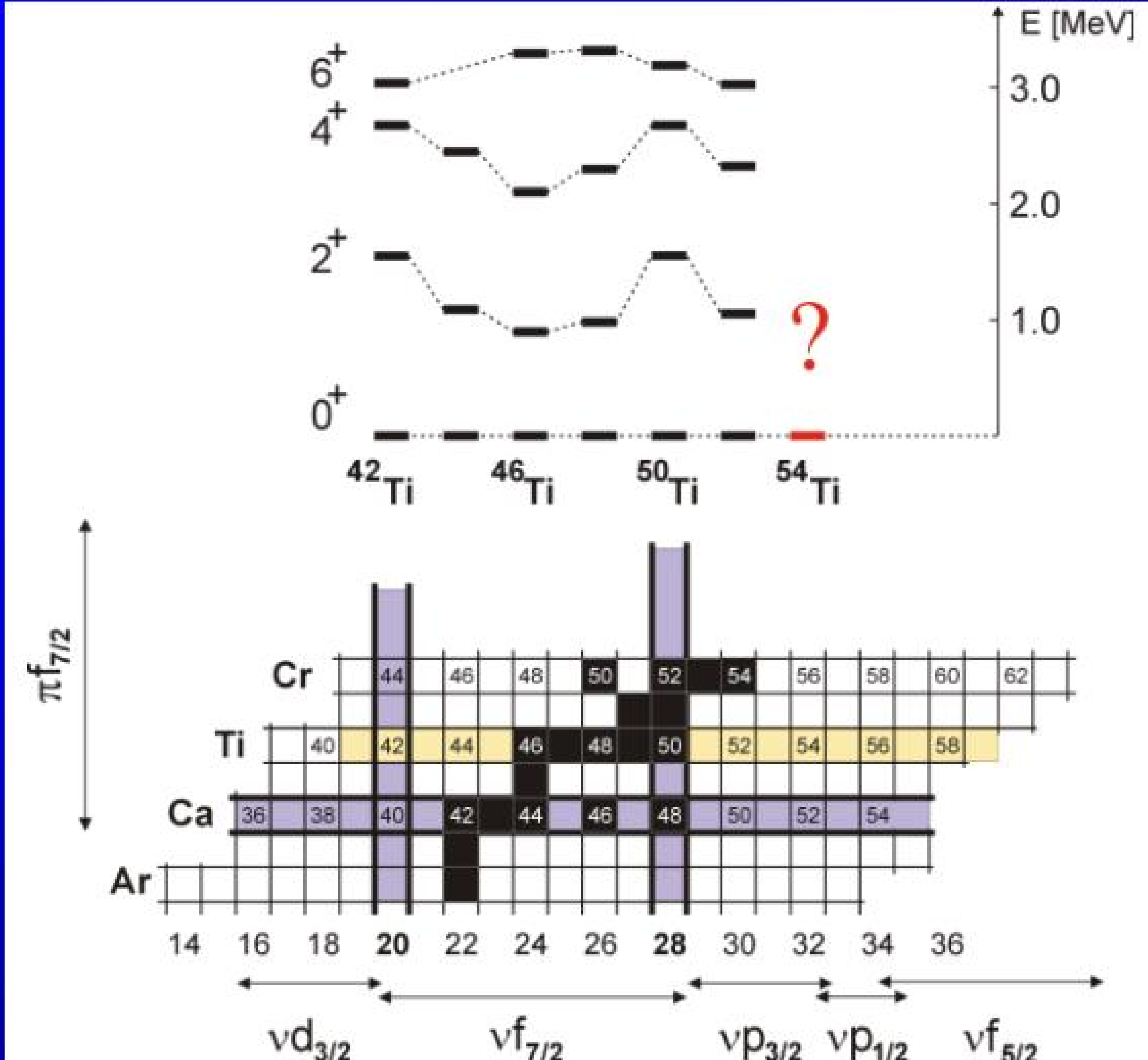
Proton number Z
Neutron number N
terra incognita
neutron number
[keV]
E(2+1)
Ca
Ar
S
Si
Mg
Ne
3000
1500
8
12
16
20
24
114
184
126
82
50
28
νd5/2
νs1/2
νd3/2
νf7/2
πd5/2
πs1/2
πd3/2



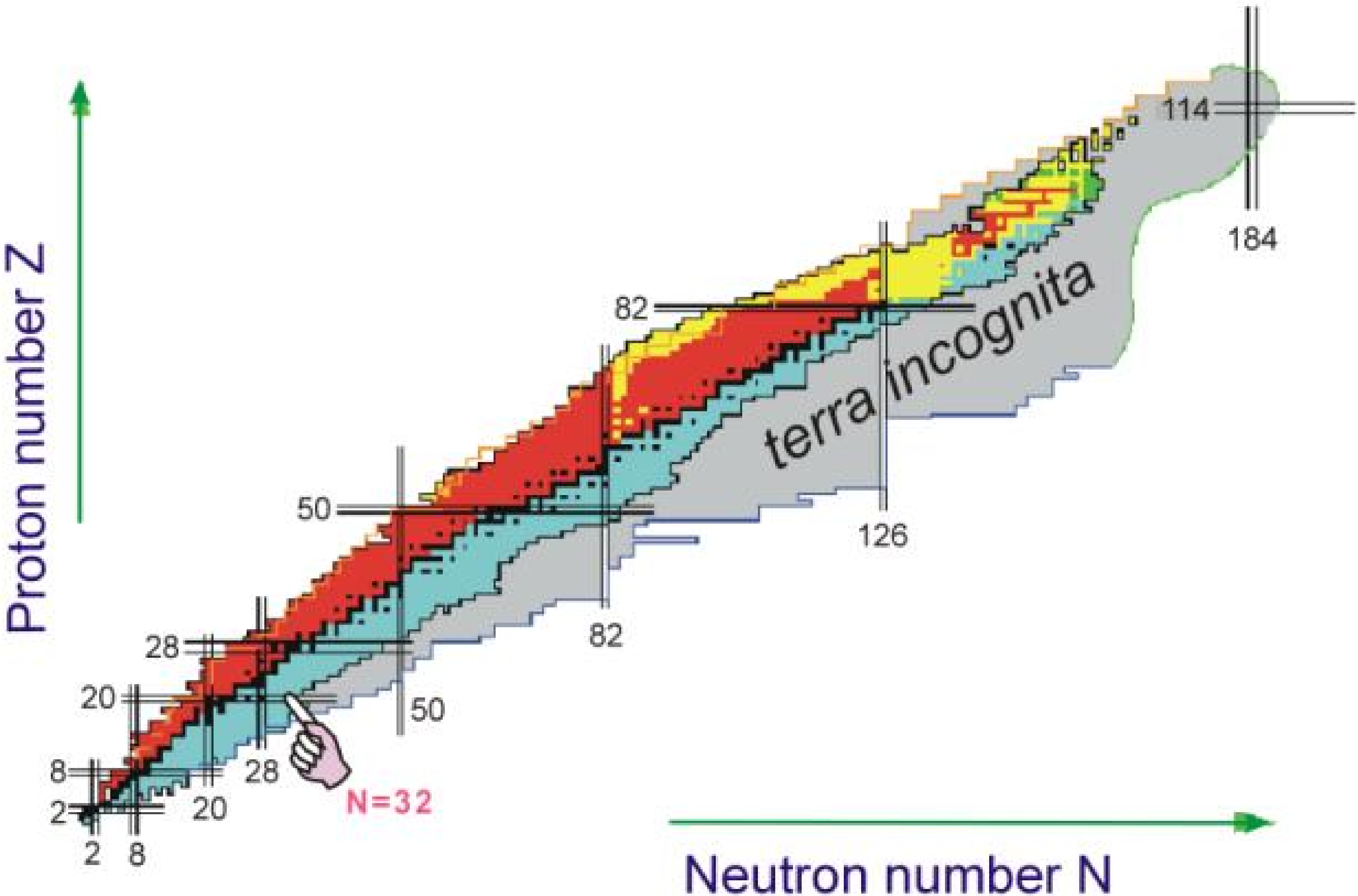
E sep [MeV]
20
terra incognita
Proton number Z
Neutron number N
114
184
82
126
50
28
20
8
2
Ca
Ar
S
Si
Mg
Ne
πd5/2
πs1/2
πd3/2
νd5/2
νs1/2
νd3/2
νf7/2



A. Huck *et al.*, Phys. Rev. C 31, 2226 (1985)



E [MeV]
3.0
2.0
1.0
6+
4+
2+
0+
?
42Ti
46Ti
50Ti
54Ti
πf7/2
Cr
Ti
Ca
Ar
44 46 48 50 52 54 56 58 60 62
40 42 44 46 48 50 52 54 56 58
36 38 40 42 44 46 48 50 52 54
14 16 18 20 22 24 26 28 30 32 34 36
νd3/2
νf7/2
νp3/2
νp1/2
νf5/2



Proton number Z
Neutron number N
terra incognita
114
184
82
126
50
82
28
50
20
28
8
20
2
2
8
N=32

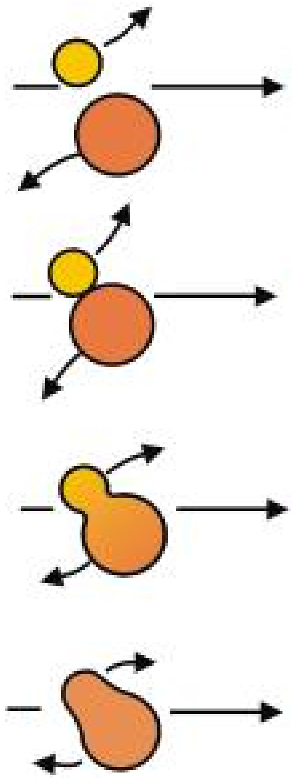
Heavy Ion Reactions

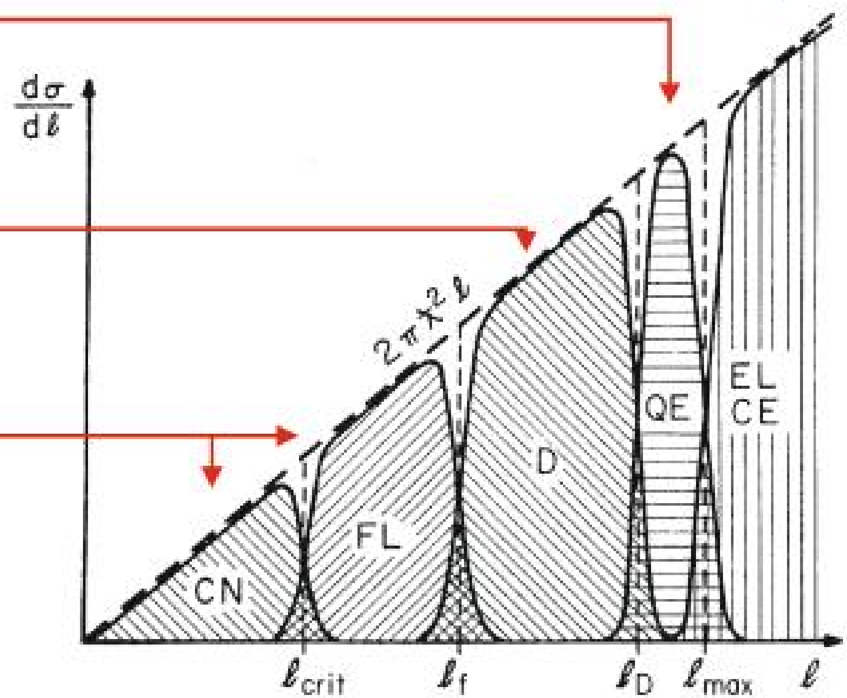
elastic scattering and **Coulomb excitation**

inelastic scattering and onset of nucleon exchange

deep-inelastic or dumped reactions - substantial kinetic energy damping and mass exchange

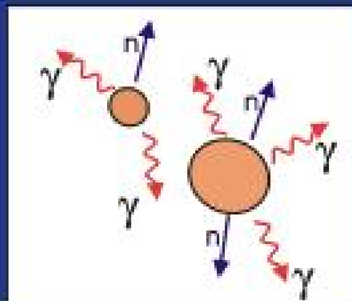
fusion-fission and **fusion-evaporation** reactions

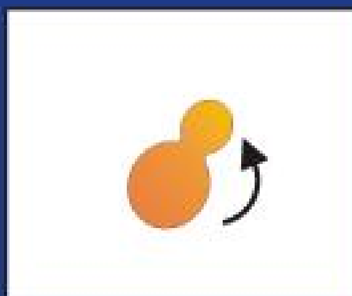


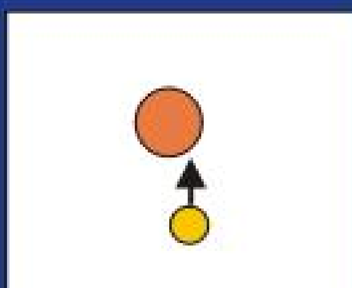


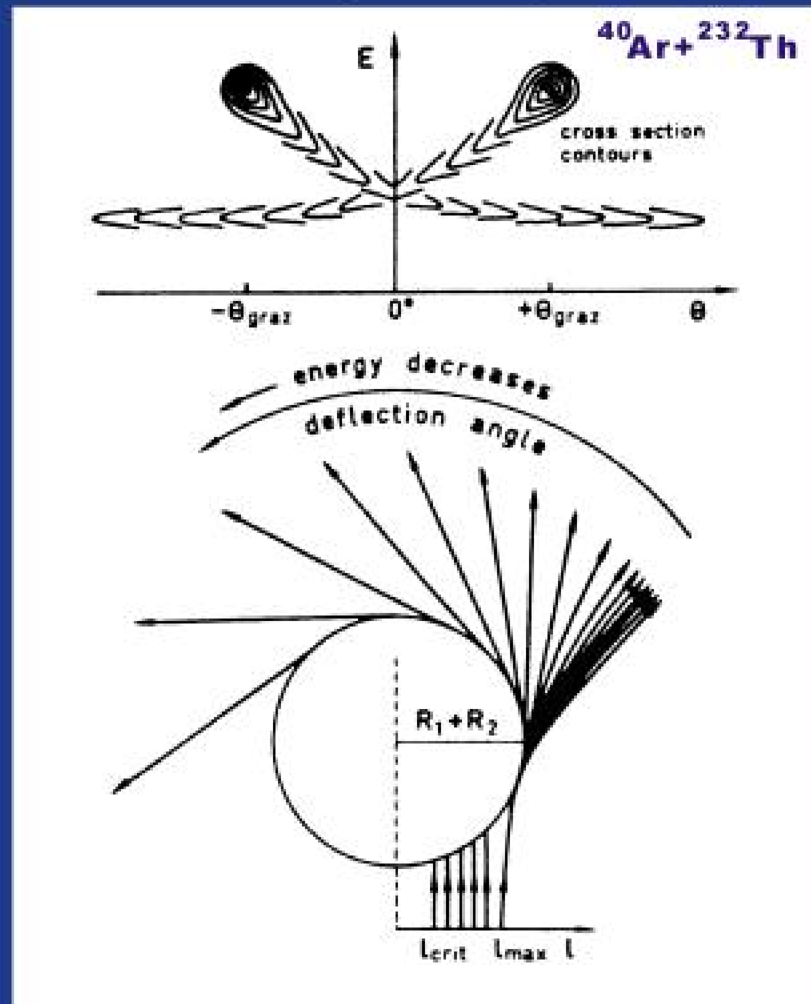
Deep inelastic reactions

Wilczynski plot



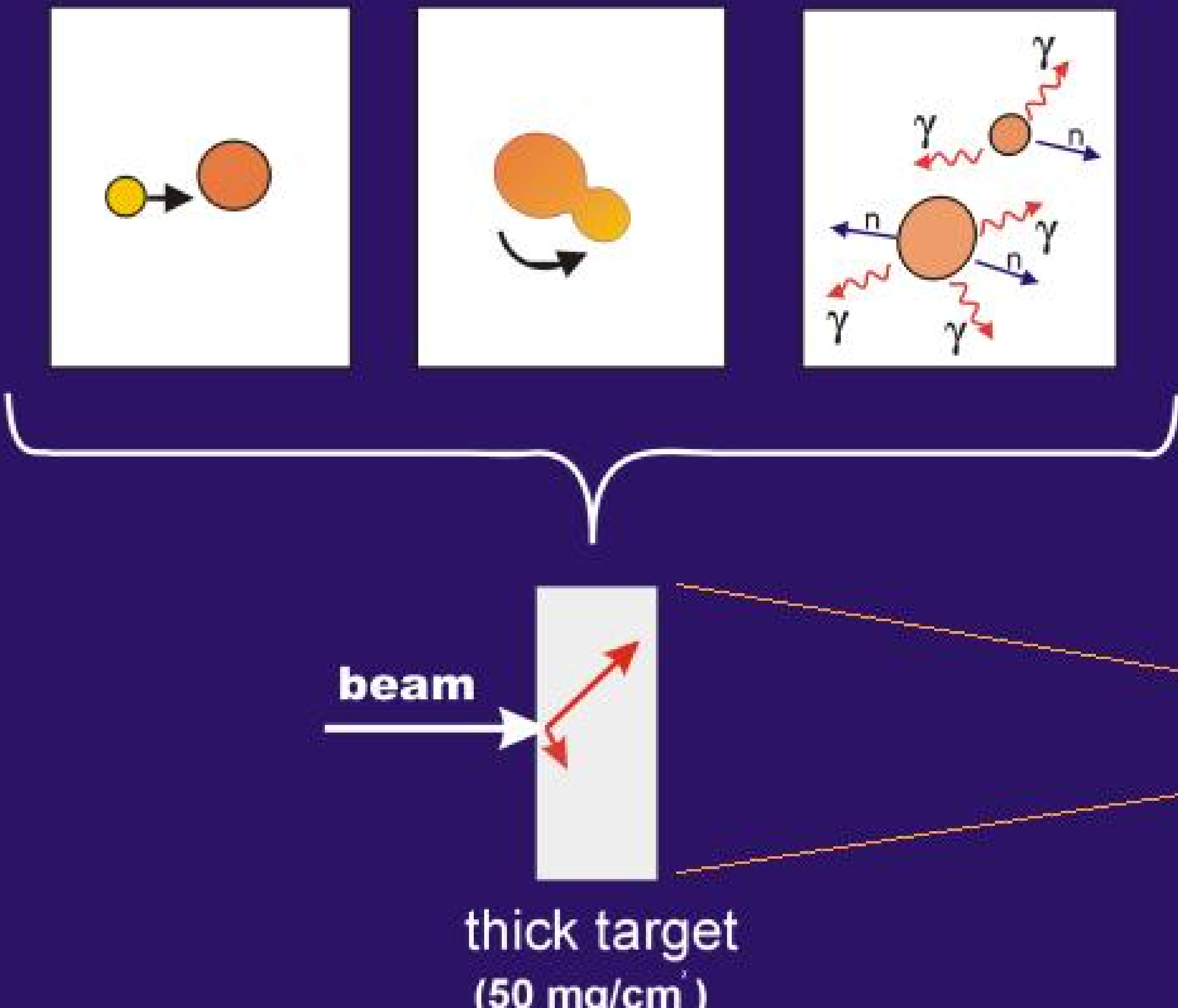




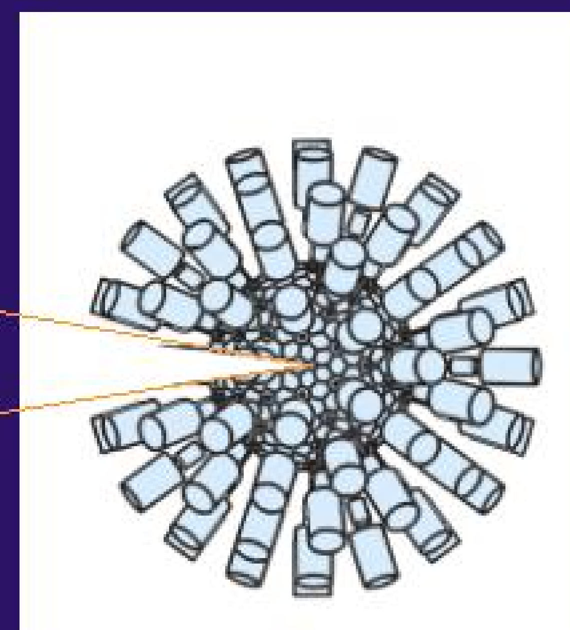


J. Wilczynski, Phys. Lett. B 47, 484 (1973).

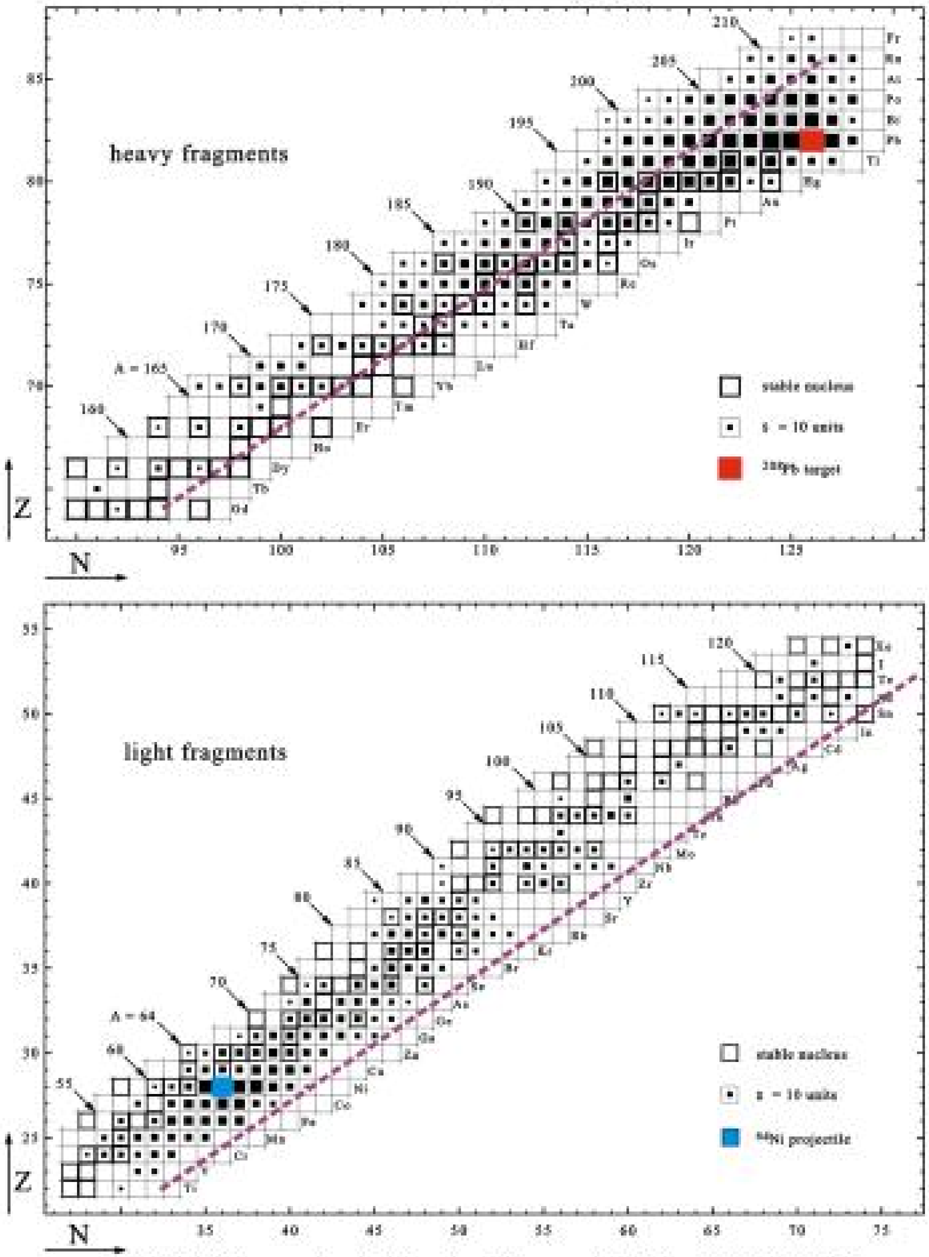
Deep-inelastic reactions as a tool for nuclear spectroscopy



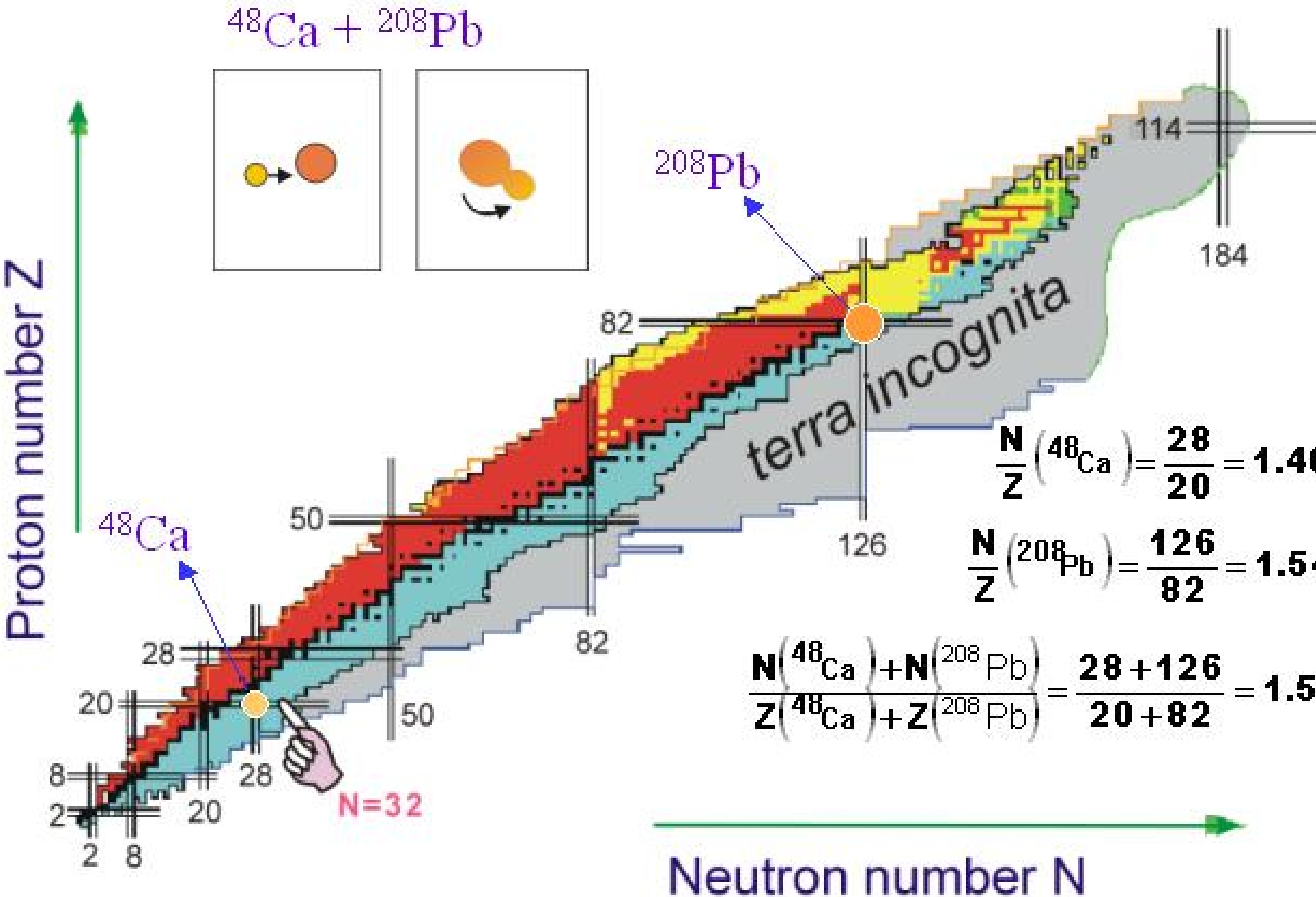
R. Broda *et al.*, Phys.Lett. B 251, 245 (1990)



$^{64}Ni + ^{208}Pb$ E_{beam}=350 MeV



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

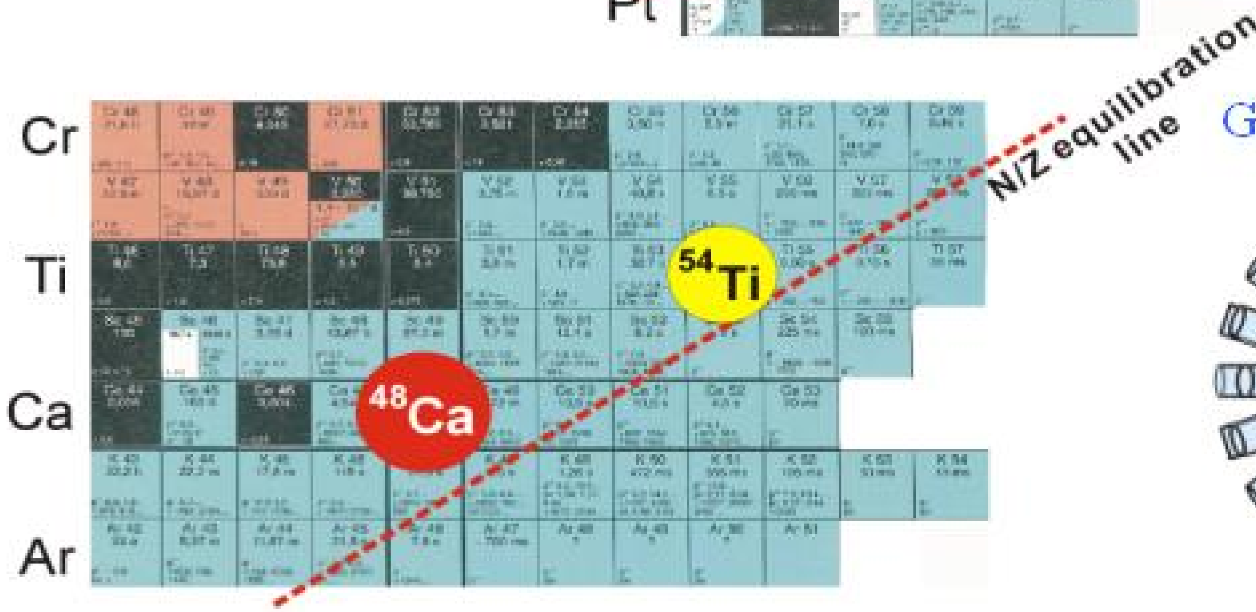


$$\frac{N}{Z}\left(^{48}\mathrm{Ca}\right) = \frac{28}{20} = 1.40$$

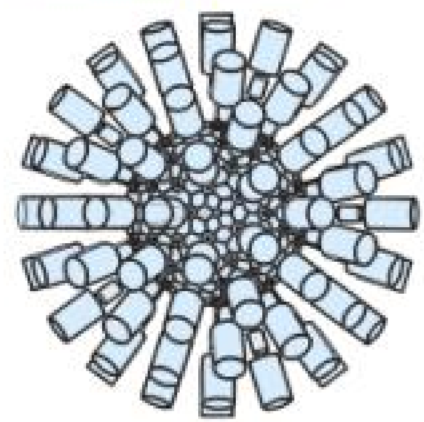
$$\frac{N}{Z}\left(^{208}\mathrm{Pb}\right) = \frac{126}{82} = 1.54$$

$$\frac{N\left(^{48}\mathrm{Ca}\right) + N\left(^{208}\mathrm{Pb}\right)}{Z\left(^{48}\mathrm{Ca}\right) + Z\left(^{208}\mathrm{Pb}\right)} = \frac{28+126}{20+82} = 1.51$$

^{48}Ca (305 MeV) + ^{208}Pb (thick)
ATLAS + GAMMASPHERE
at Argonne

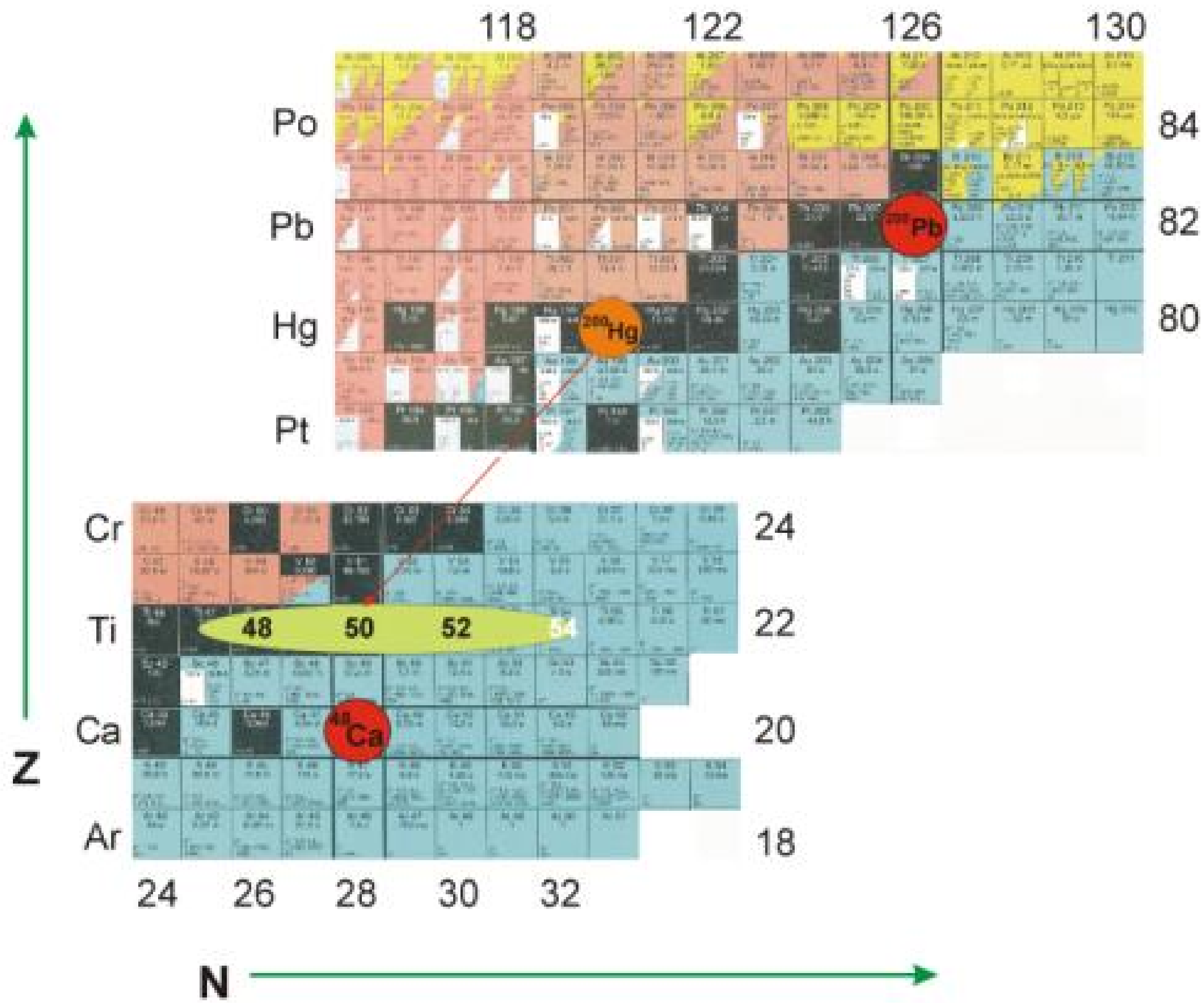


Gammasphere

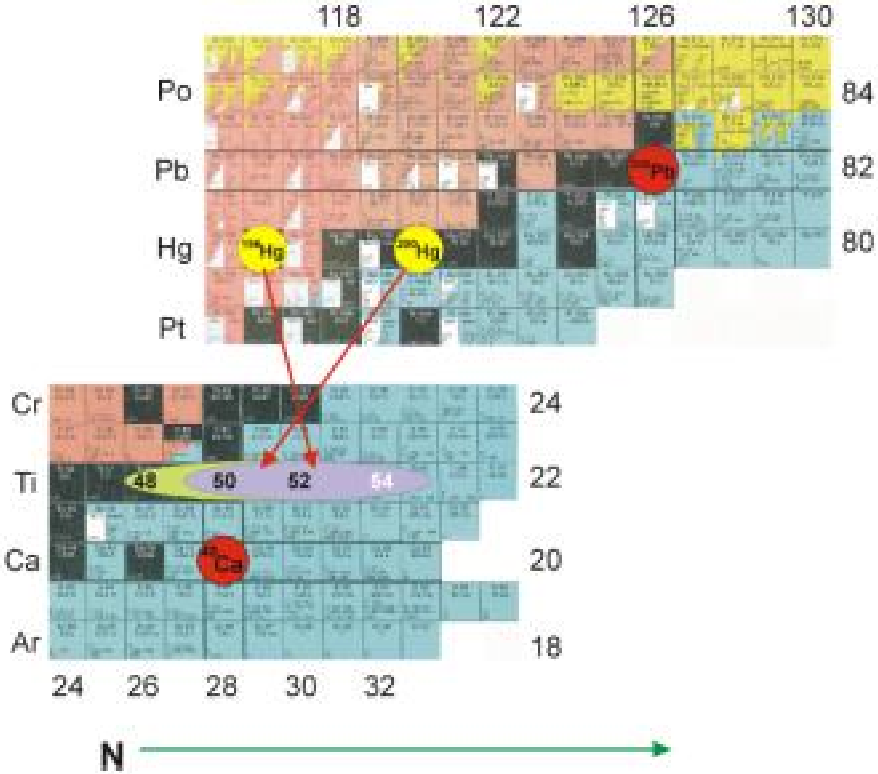


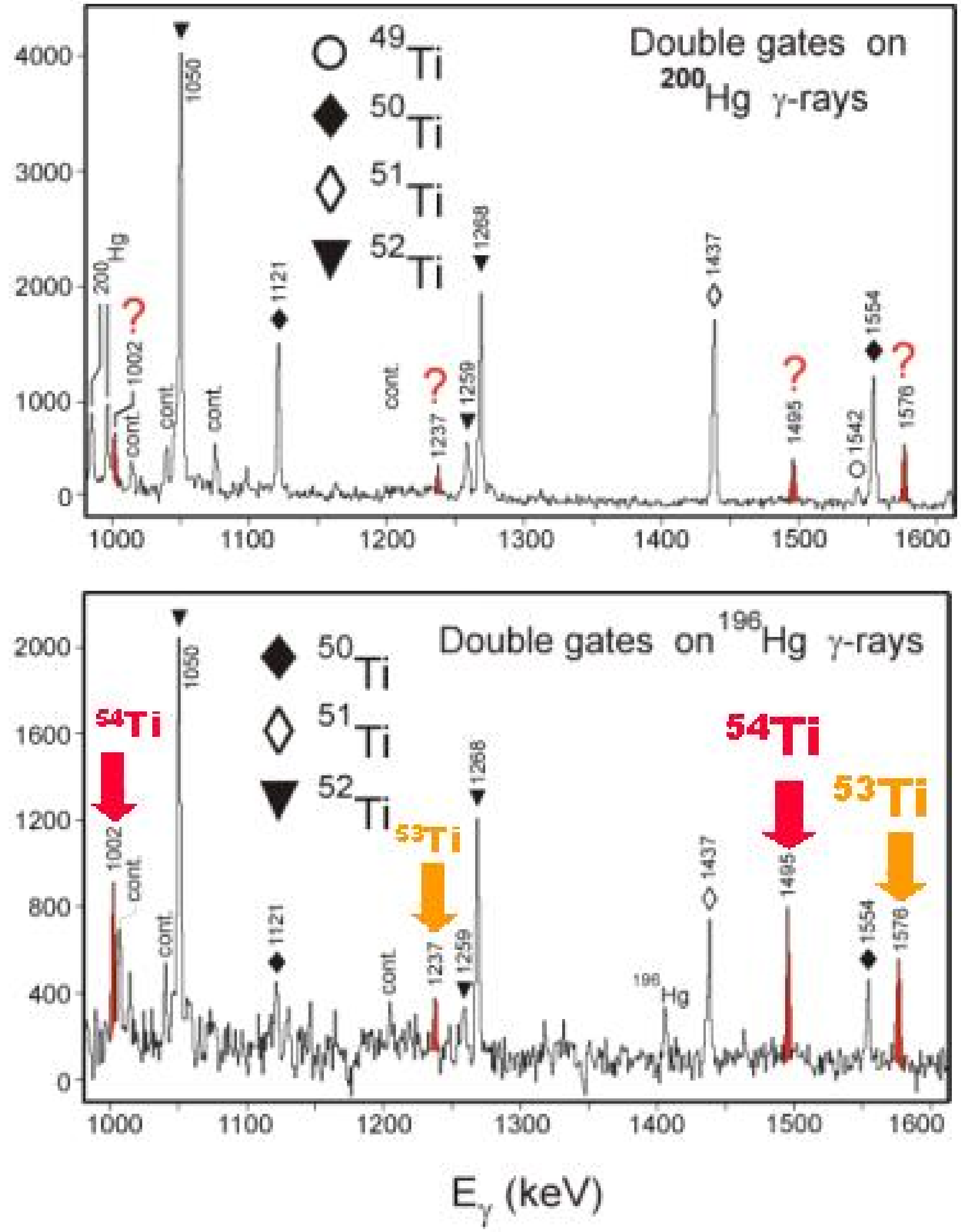
Let's consider a situation in which we have Ti and Hg products

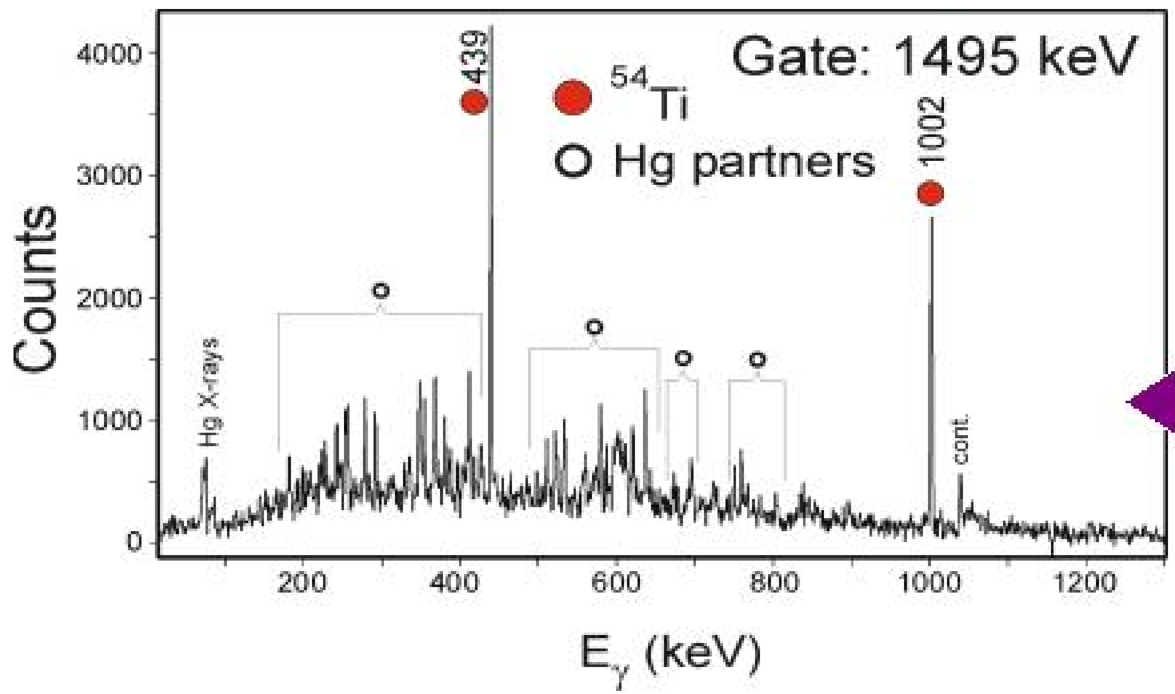
$$^{48}Ca + {}^{208}Pb \longrightarrow \mathbf{Hg} + \mathbf{Ti} + \mathbf{x}\boldsymbol{n}$$



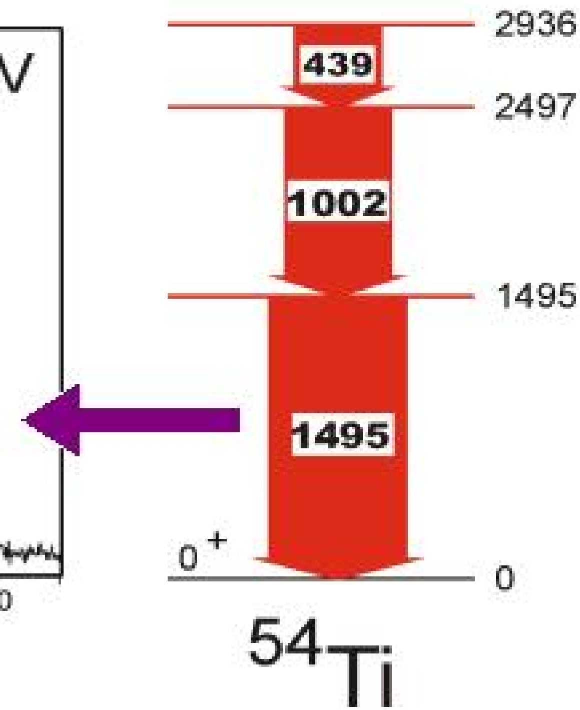
$^{48}Ca + ^{208}Pb \longrightarrow Hg + Ti + xn$



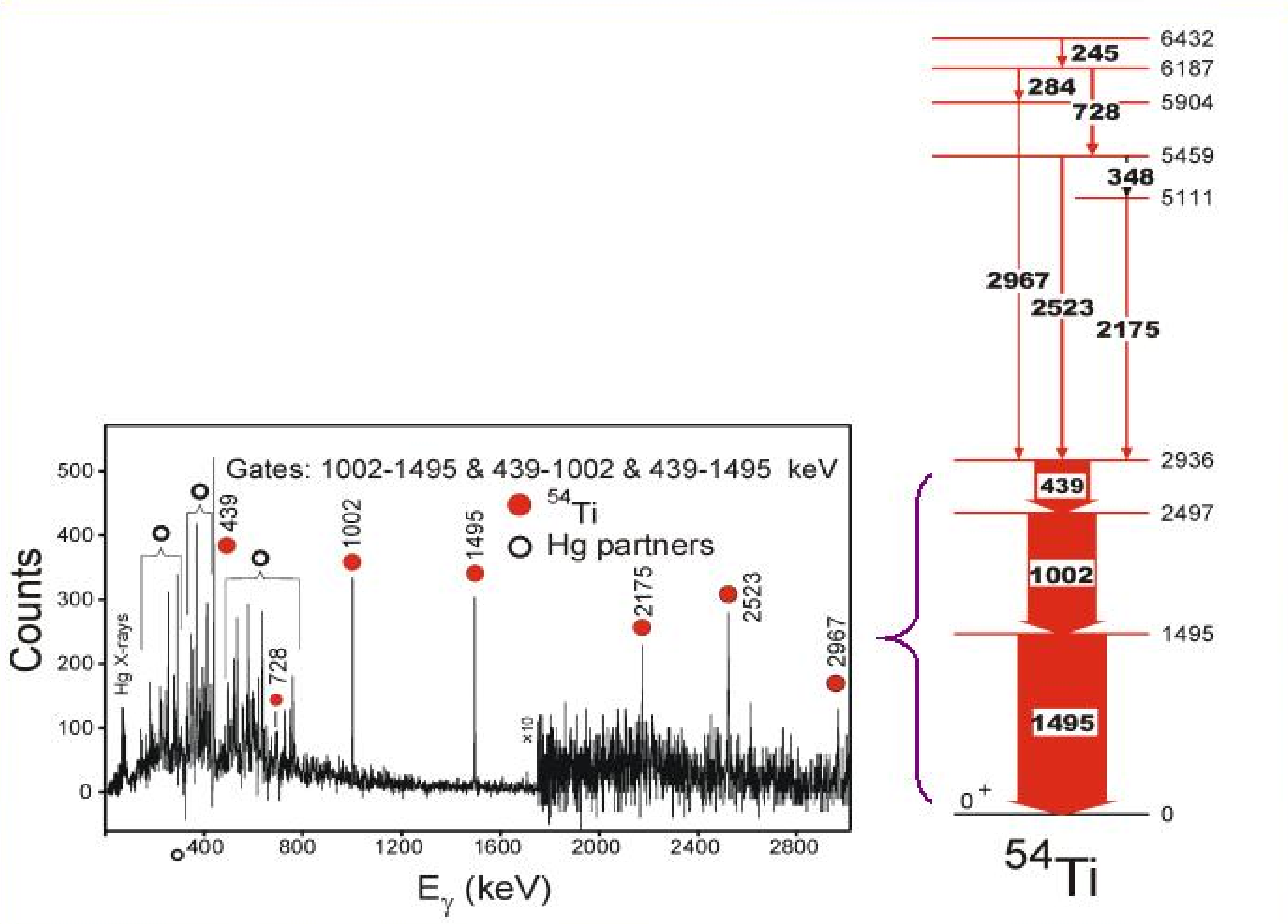




Gate: 1495 keV
54Ti
Hg partners
439
1002
Hg X-rays
cont.
Counts
4000
3000
2000
1000
0
200
400
600
800
1000
1200
Eγ (keV)

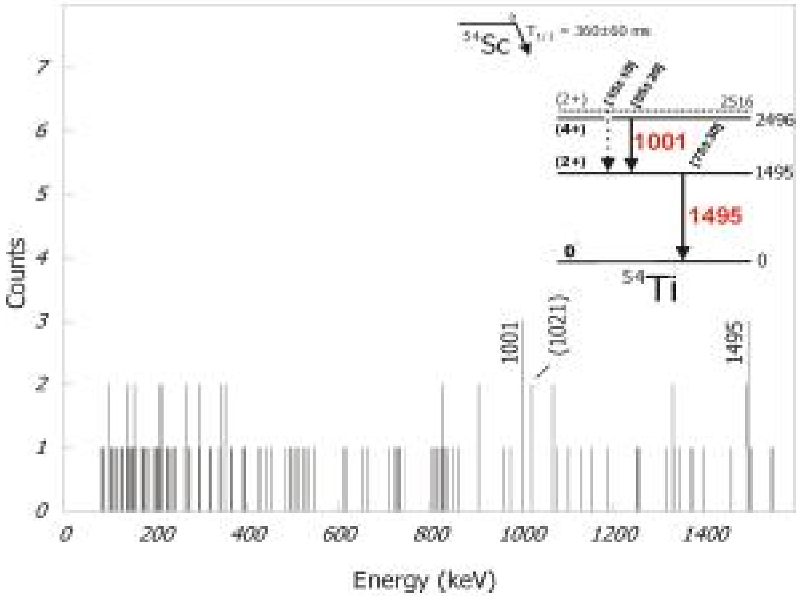


2936
2497
1495
0
439
1002
1495
0+
54Ti

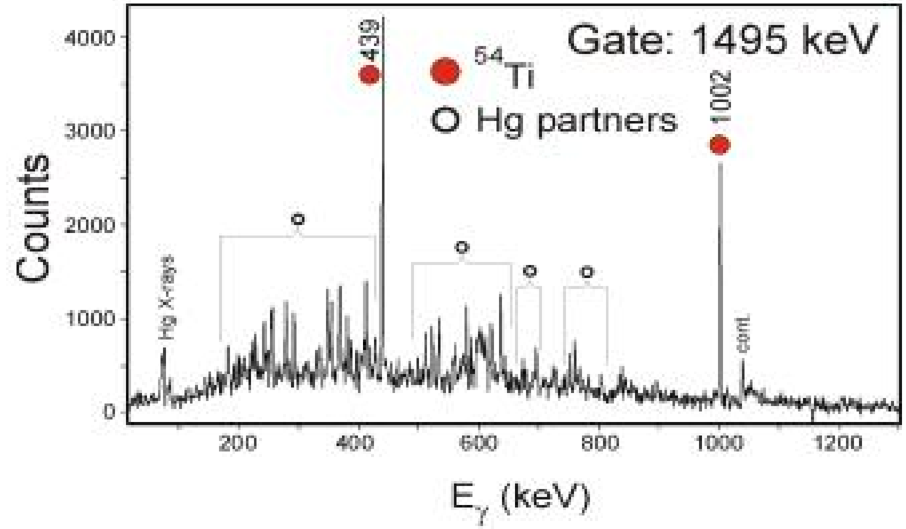


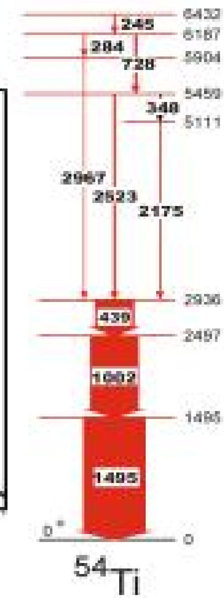
Gates: 1002-1495 & 439-1002 & 439-1495 keV
^{54}Ti
Hg partners
Hg X-rays
439
728
1002
1495
2175
2523
2967
x10
Counts
E_γ (keV)
6432
6187
5904
5459
5111
2936
2497
1495
0
245
284
728
348
2967
2523
2175
439
1002
1495
0^+
^{54}Ti

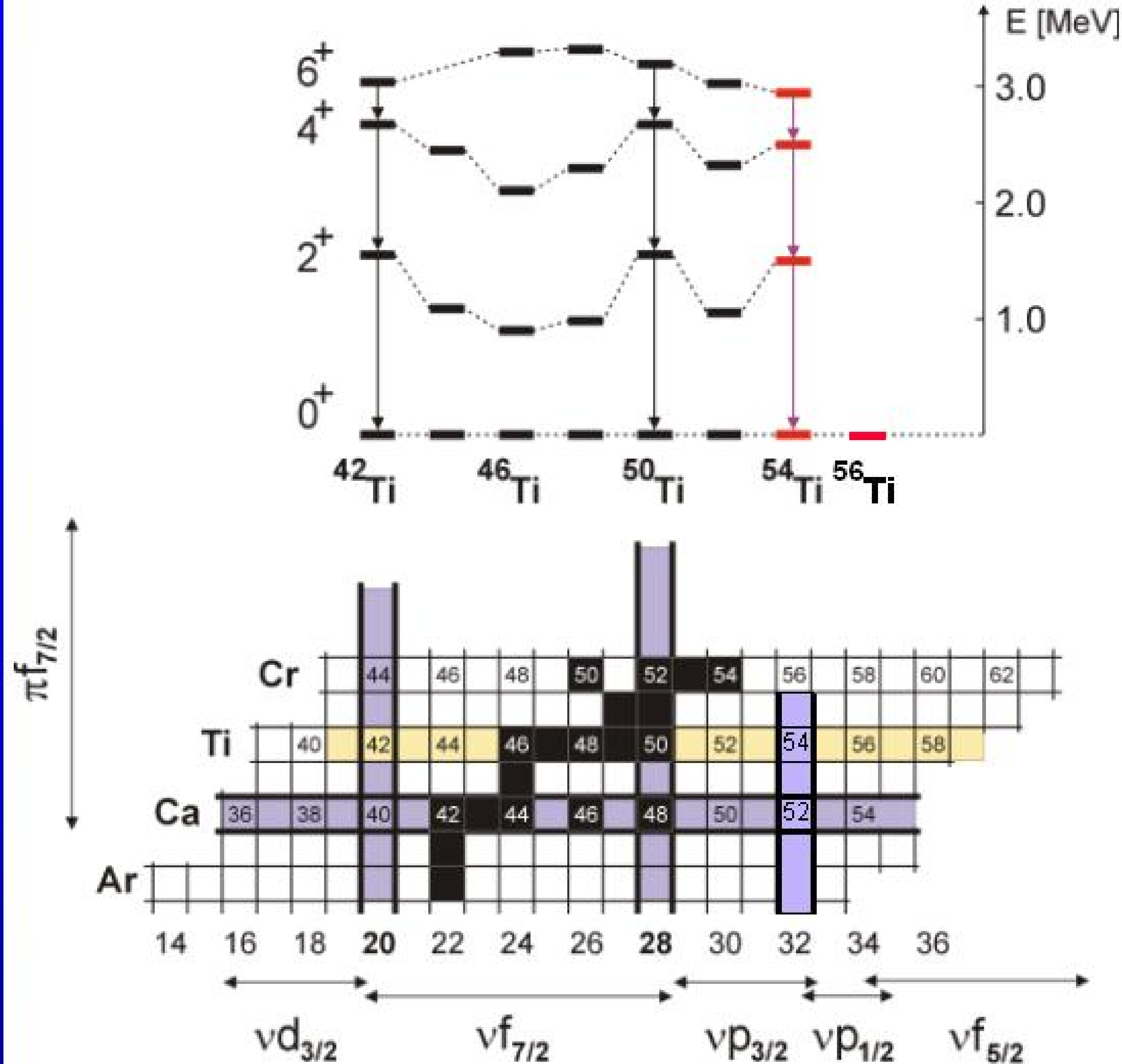
Beta-decay of the ^{54}Sc parent measured at MSU following fragmentation of a Kr beam



Deep-inelastic reaction data
^{48}Ca + ^{208}Pb, Gammasphere, Argonne







E [MeV]
3.0
2.0
1.0
6+
4+
2+
0+
42Ti
46Ti
50Ti
54Ti
56Ti
πf7/2
Cr
44 46 48 50 52 54 56 58 60 62
Ti
40 42 44 46 48 50 52 54 56 58
Ca
36 38 40 42 44 46 48 50 52 54
Ar
14 16 18 20 22 24 26 28 30 32 34 36
νd3/2
νf7/2
νp3/2
νp1/2
νf5/2

Search for ^{56}Ti

Combining the two techniques:

β decay and Deep Inelastic reactions

MSU: ^{86}Kr fragmentation

A1900 fragment separator

$1.3 \cdot 10^4$ ^{56}Sc implants

Argonne: ATLAS & Gammasphere

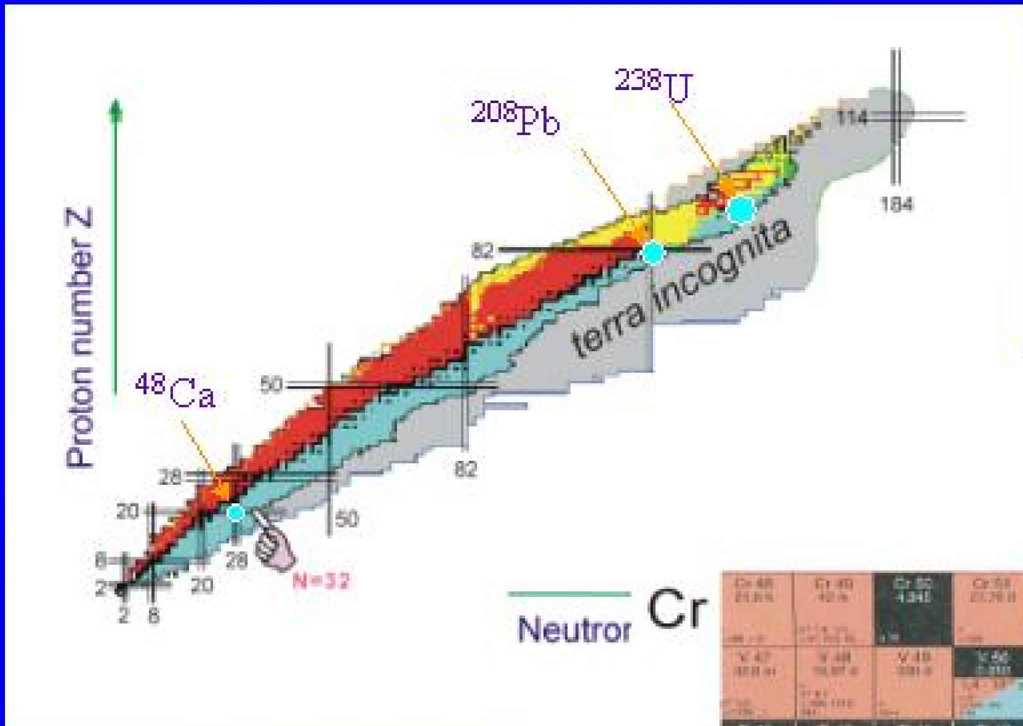
^{48}Ca (330 MeV) + ^{238}U (thick)

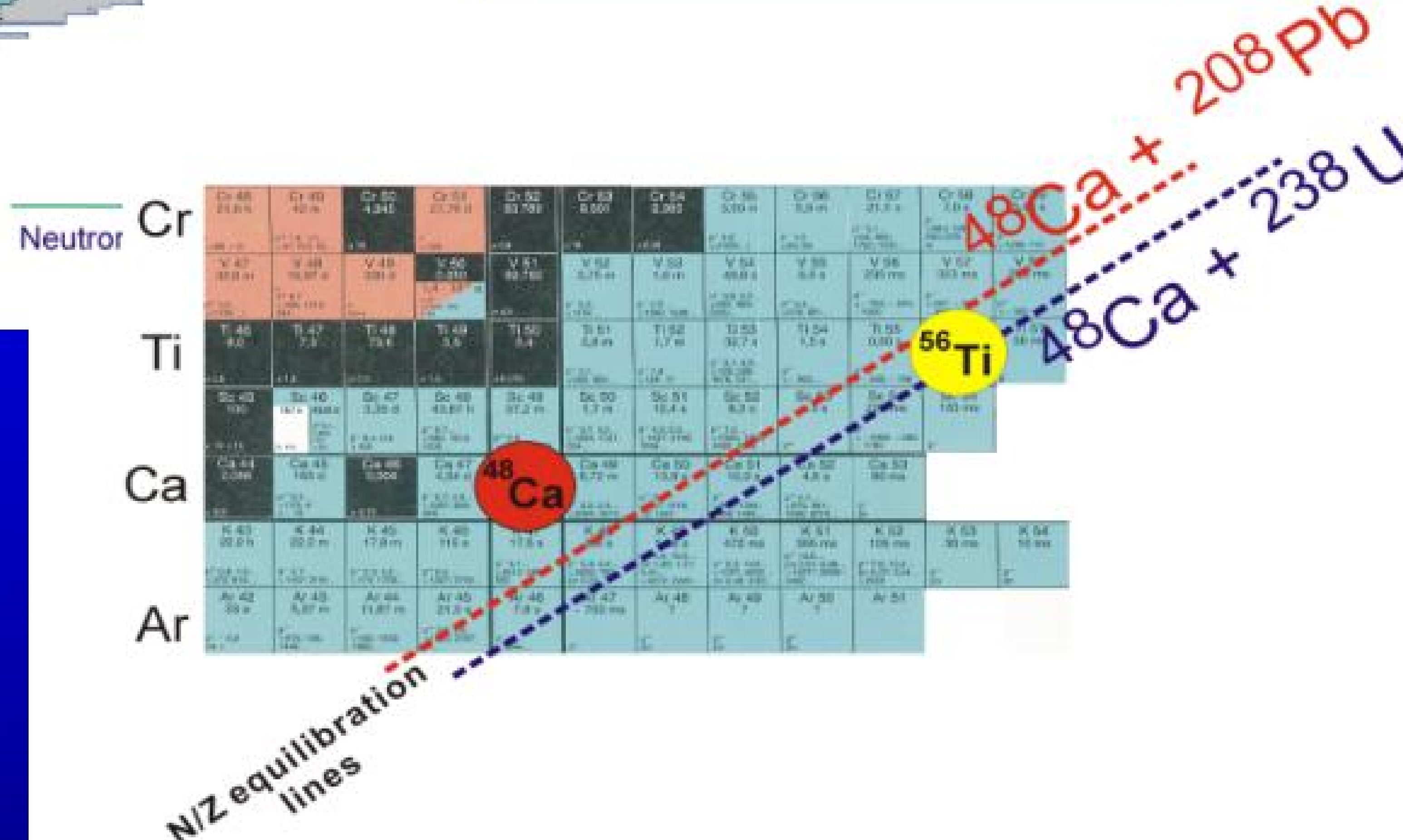
Use ^{238}U as the most neutron-rich stable nucleus

GAMMASPHERE at Argonne

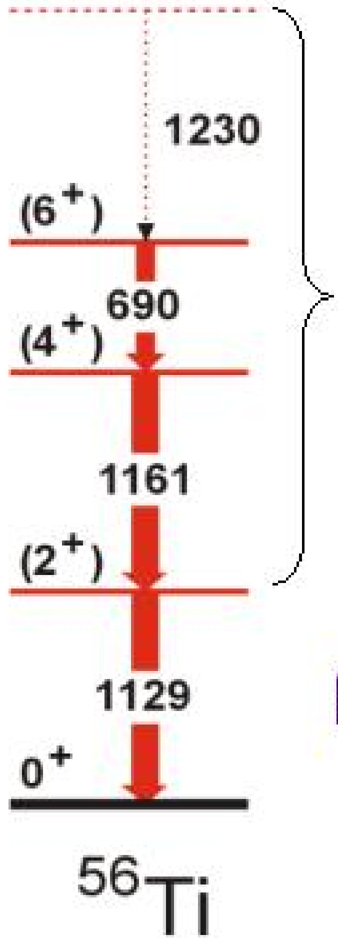
^{48}Ca (330 MeV) + ^{238}U (thick target)

^{238}U - most neutron-rich stable target



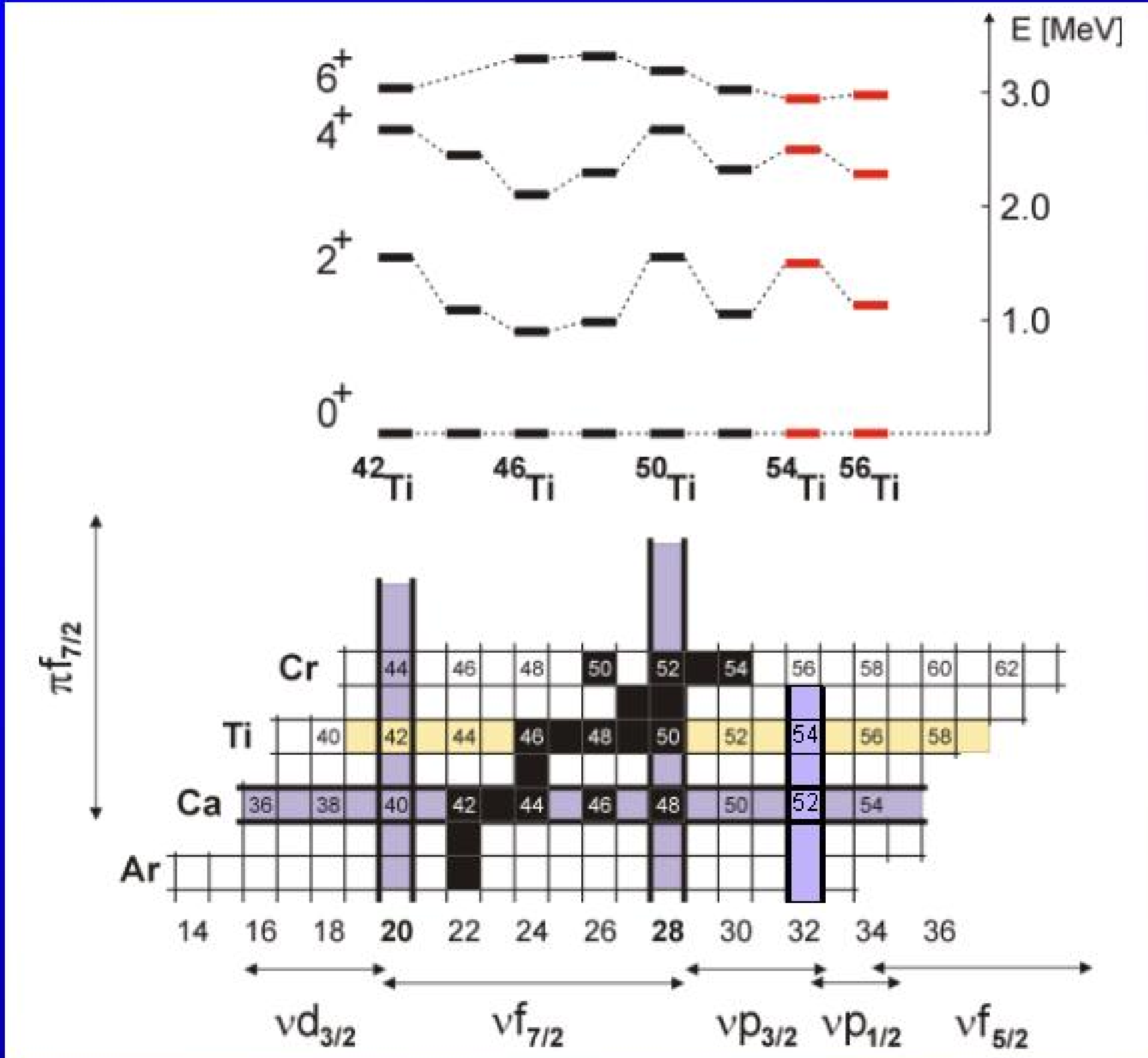


Findings in ^{56}Ti

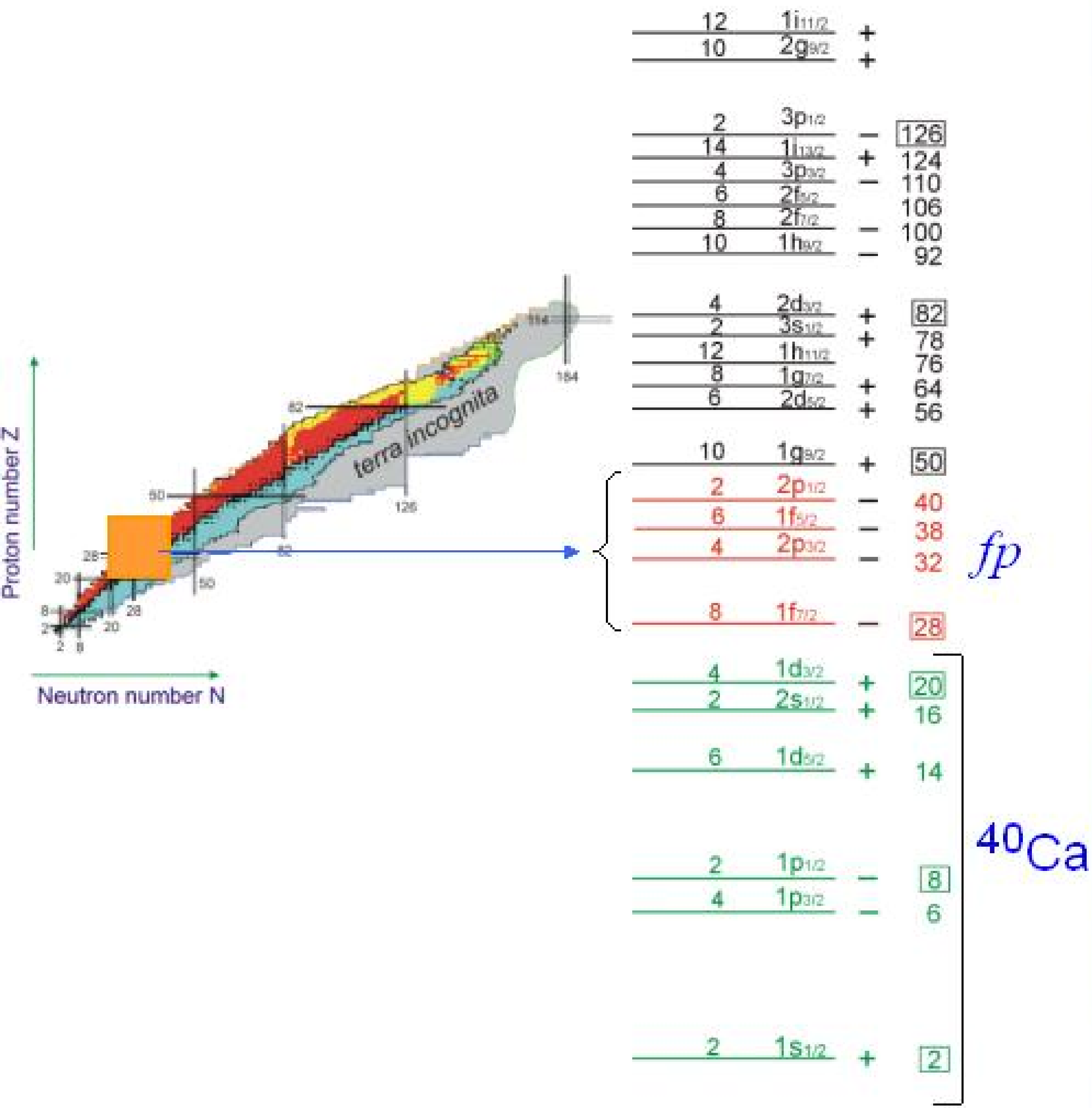


γ – ray spectroscopy of deep-inelastic reaction products (^{48}Ca+^{238}U)

β-decay of fragmentation product ^{56}Sc



E [MeV]
3.0
2.0
1.0
6+
4+
2+
0+
42Ti
46Ti
50Ti
54Ti
56Ti
πf7/2
Cr
44 46 48 50 52 54 56 58 60 62
Ti
40 42 44 46 48 50 52 54 56 58
Ca
36 38 40 42 44 46 48 50 52 54
Ar
14 16 18 20 22 24 26 28 30 32 34 36
νd3/2
νf7/2
νp3/2
νp1/2
νf5/2



fp shell

4 single-particle energies

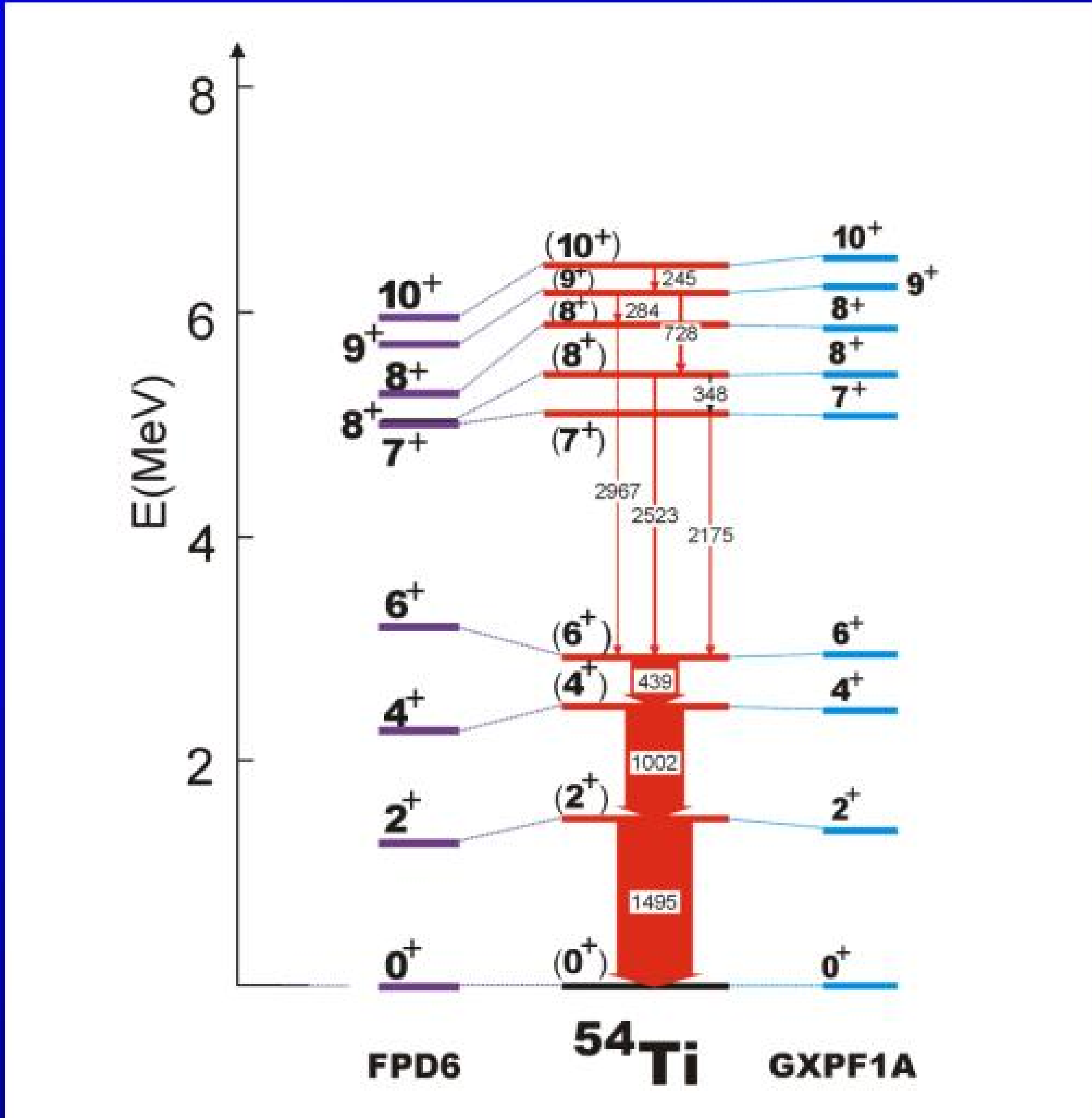
195 two-body matrix elements (TBME)

FPD6 interaction:

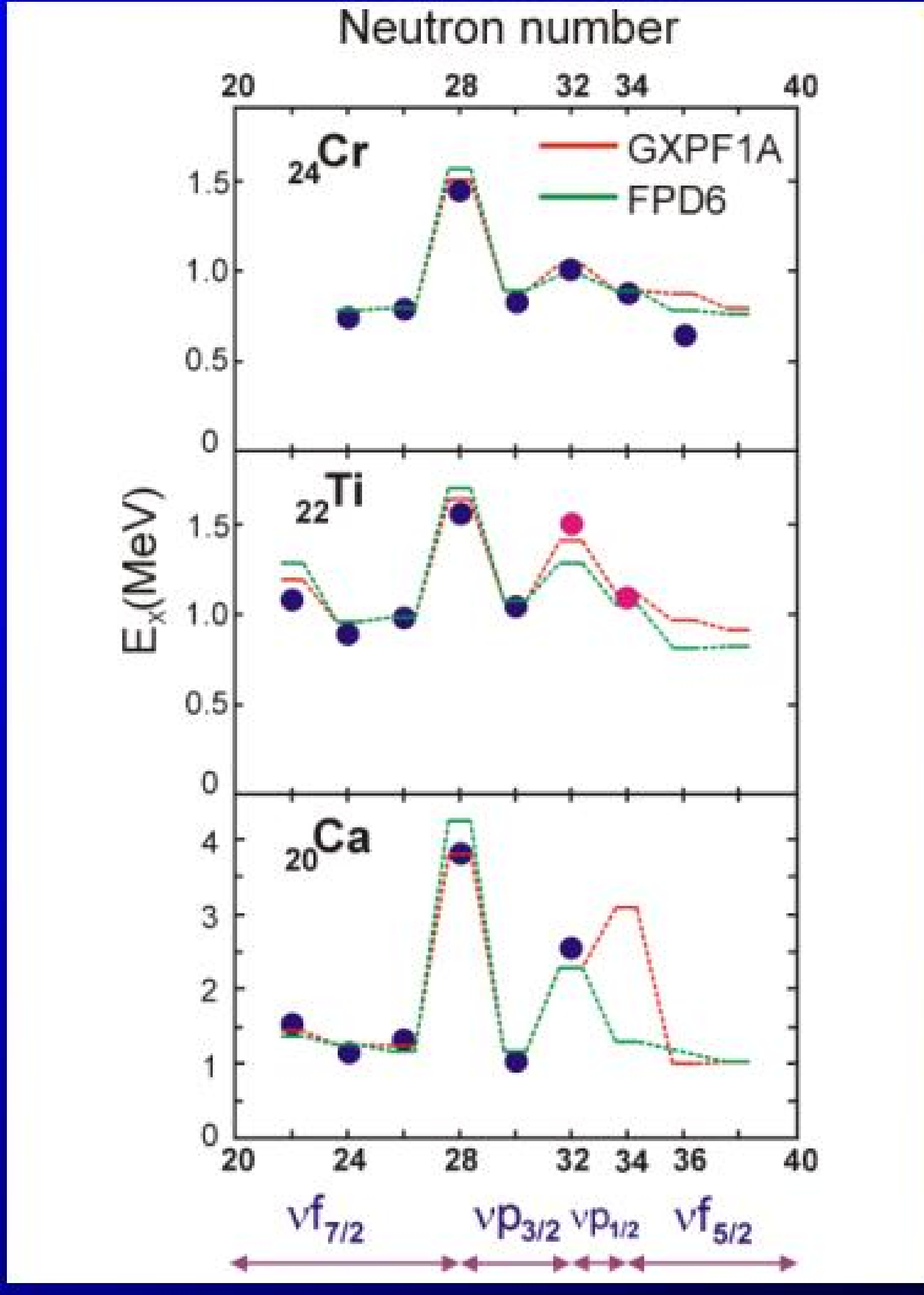
W.A. Richter, M.G. van der Merwe, R.E. Julies, B.A. Brown,
Nucl. Phys. A523, 325 (1991).

GXPF1A interaction:

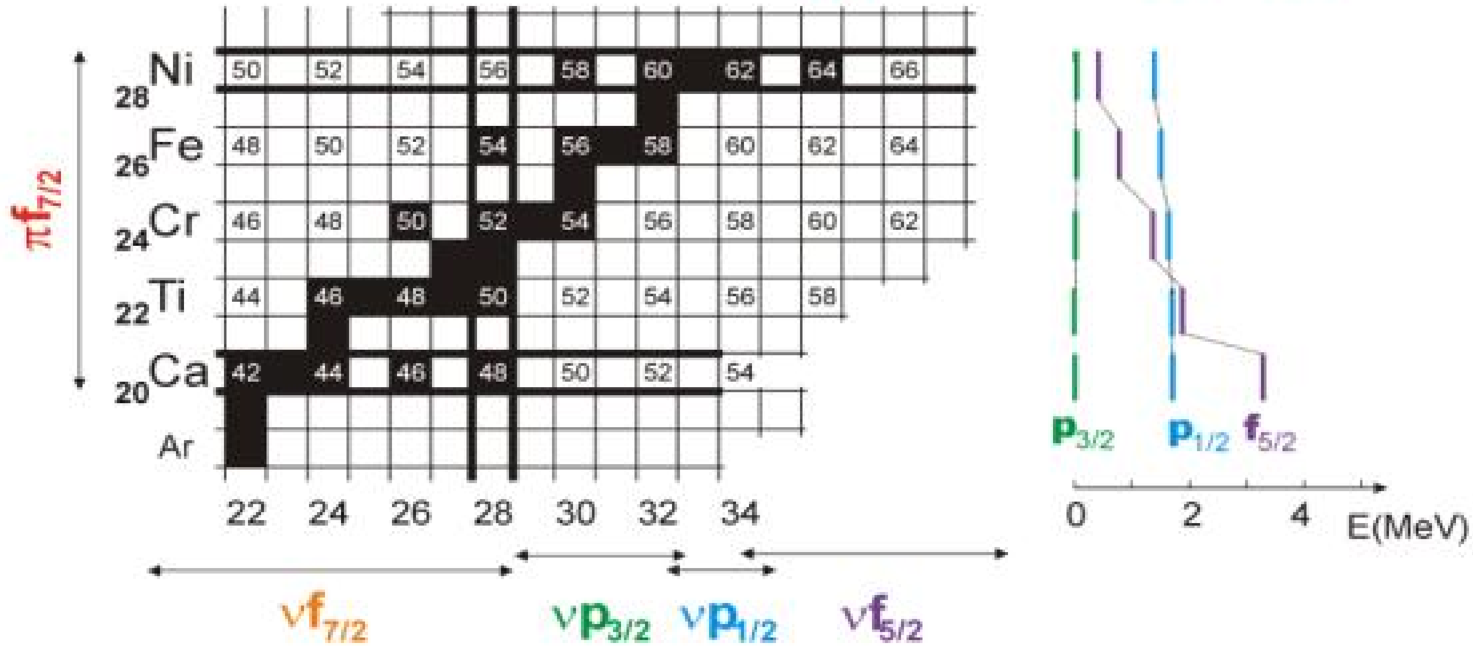
M. Honma, T. Otsuka, B.A. Brown, T. Mizusaki,
Phys. Rev. C 65, 061301(R.) (2002).
and
M. Honma, T. Otsuka, B.A. Brown, T. Mizusaki,
Proc. of ENAM'04, Eur. Phys. J. (to be published).



E(MeV)
8
6
4
2
10+
9+
8+
8+
7+
6+
4+
2+
0+
(10+)
(9+)
(8+)
(8+)
(7+)
(6+)
(4+)
(2+)
(0+)
245
284
728
348
2967
2523
2175
439
1002
1495
10+
9+
8+
8+
7+
6+
4+
2+
0+
FPD6
54Ti
GXPF1A


Neutron number
20
28
32
34
40
$_{24}$Cr
GXPF1A
FPD6
1.5
1.0
0.5
0
$_{22}$Ti
E_x(MeV)
1.5
1.0
0.5
0
$_{20}$Ca
4
3
2
1
0
20
24
28
32
34
36
40
$\nu f_{7/2}$
$\nu p_{3/2}$
$\nu p_{1/2}$
$\nu f_{5/2}$

Evolution of the single particle orbitals with Z going from 28 to 20

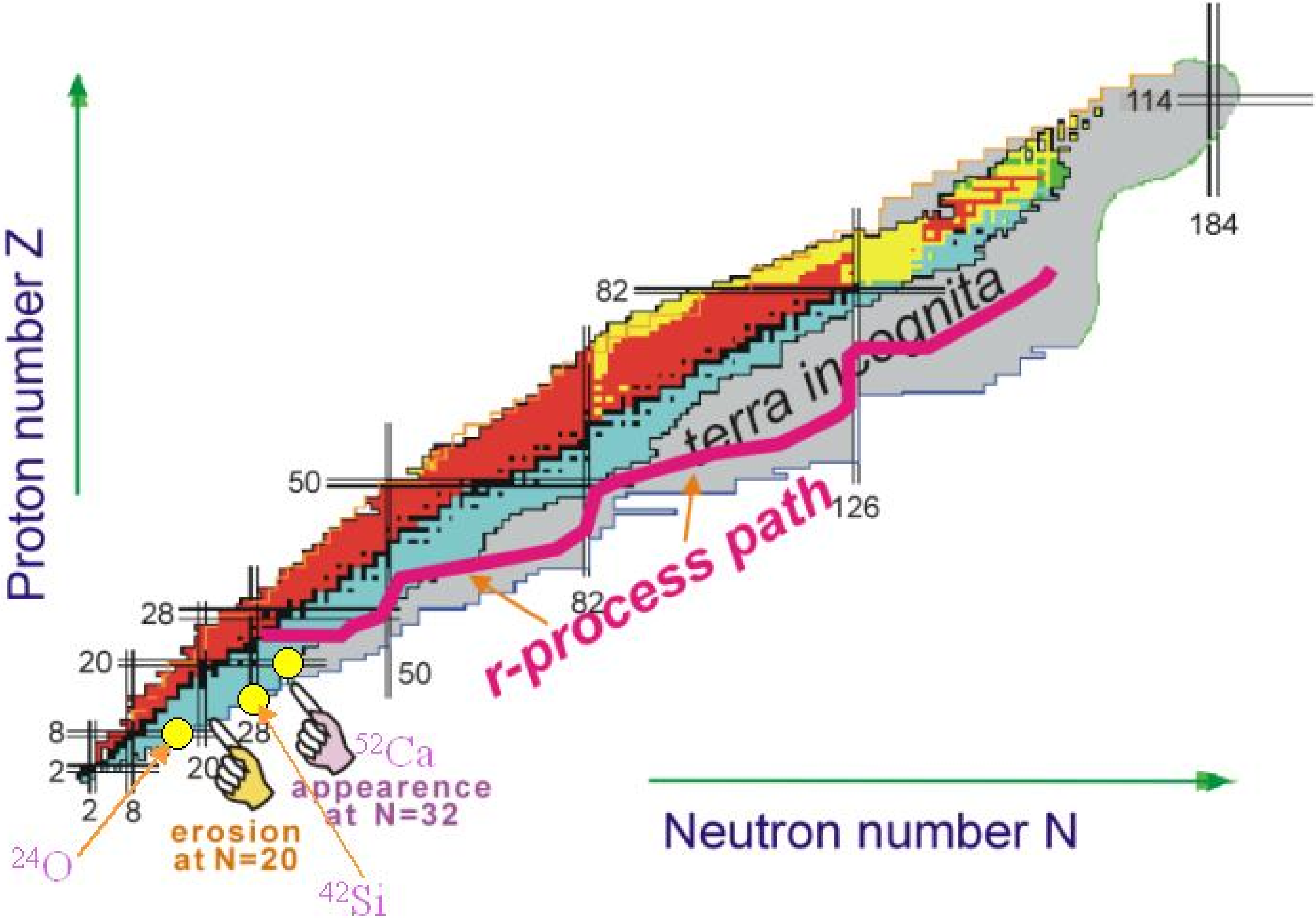


$$V_{\sigma\tau} = f_{\sigma\tau}(r)(\hat{\sigma}_1 \cdot \hat{\sigma}_2)(\hat{\tau}_1 \cdot \hat{\tau}_2)$$

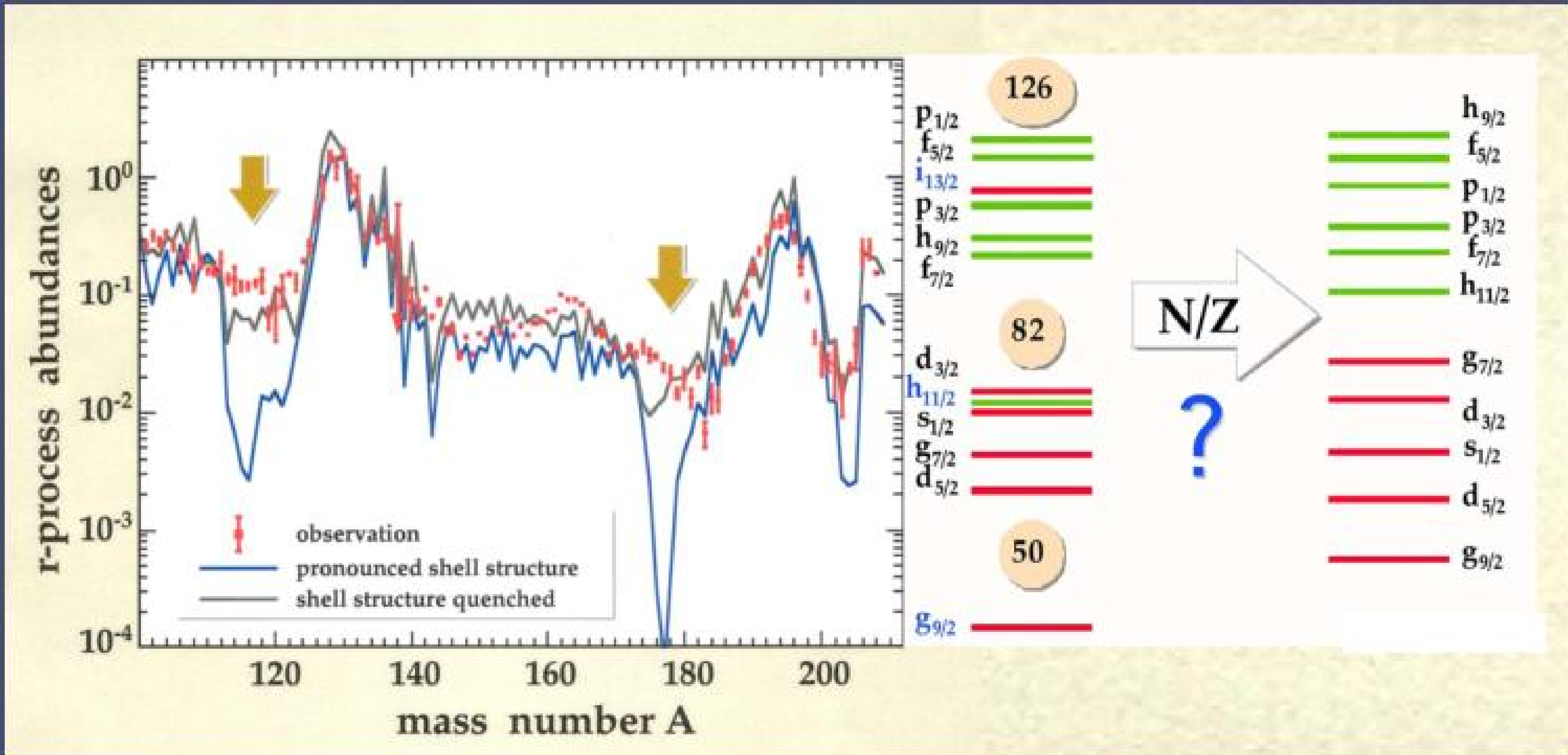
$V_{\sigma\tau}$ couples $j_>$ and $j_<$ orbitals and favors charge exchange processes

$$\pi f_{7/2} \leftrightarrow \nu f_{5/2}$$

T. Otsuka *et al.* Phys. Rev. Lett 87, 082502 (2001)



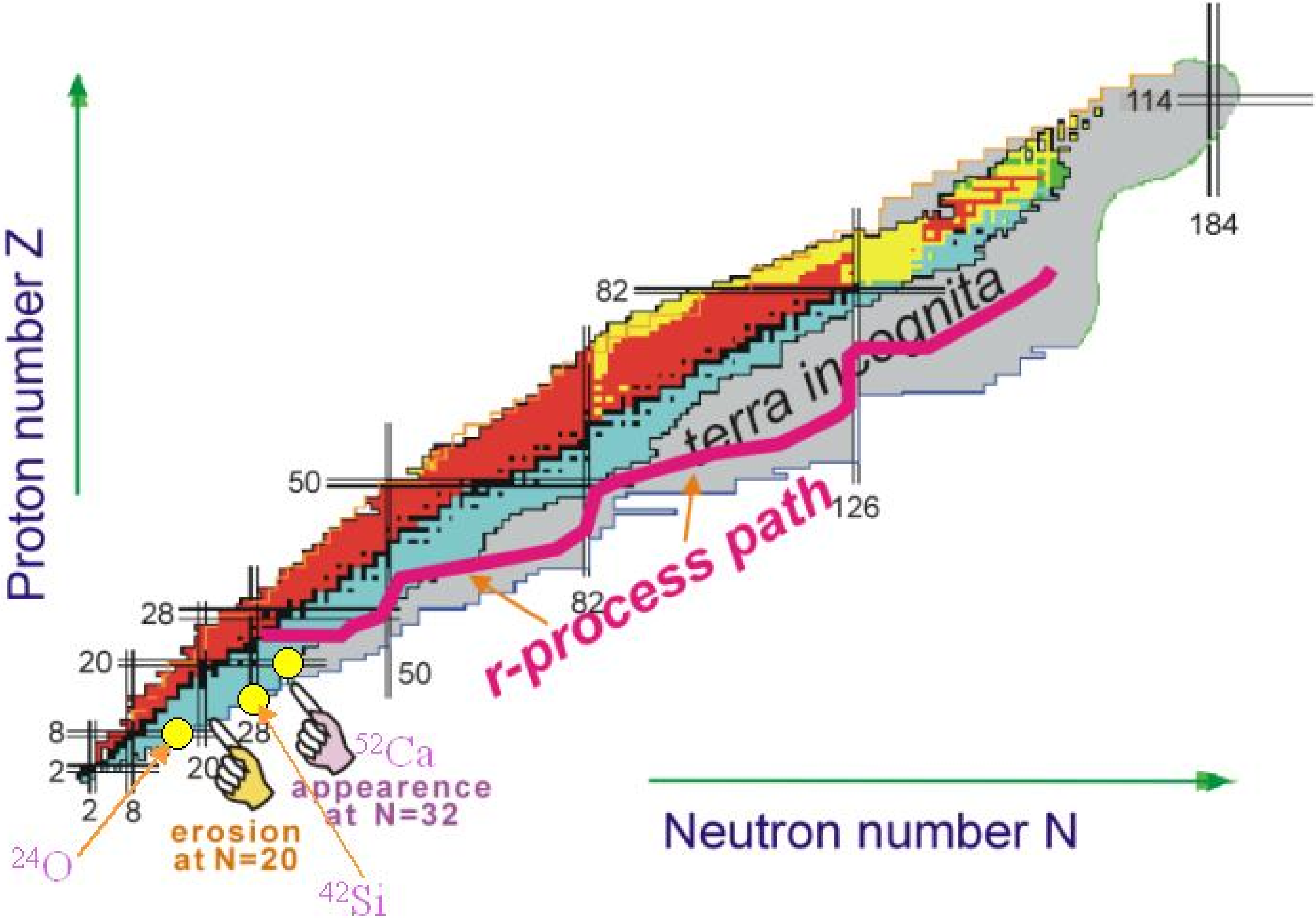
Proton number Z
Neutron number N
114
184
82
126
50
28
20
8
2
terra incognita
r-process path
52Ca
appearence at N=32
erosion at N=20
24O
42Si



K.-L. Kratz, J.-P. Bitouzet, F.-K. Thielemann, P. Moller, B. Pfeiffer , Astrophys. J. 403, 216 (1993) .

J. Dobaczewski, I Hamamoto, W. Nazarewicz, J.A. Sheikh, Phys. Rev. Lett. 72, 981 (1994) .

B. Pfeiffer, K.-L. Kratz, J. Dobaczewski, P. Moller, Acta Phys. Pol. B, 27, 475 (1996).


Proton number Z
Neutron number N
114
184
82
126
50
28
20
8
2
terra incognita
r-process path
52Ca
appearence at N=32
erosion at N=20
24O
42Si

Summary

- Using the γ–γ coincidence measurements of deep inelastic reaction products (^{48}Ca + ^{208}Pb, ^{48}Ca + ^{238}U), complemented by β-decay measurements following fragmentation of a ^{86}Kr beam,
  yrast structures of neutron-rich Ti isotopes were identified, including **^{54}Ti and ^{56}Ti.**

- These structures point to the existence of the sub-shell closure at ***N*=32** in neutron-rich nuclei.

- New sub-shell closures seem to be associated with the monopole migration of single particle orbitals in exotic nuclei.

- Deep-inelastic reactions are well suited for gamma-ray spectroscopic Investigations of very neutron-rich nuclei with radioactive beams.

EXPERIMENT:

R. Broda, W. Krolas, T. Pawlat, J. Wrzesinski, B. F.	*IFJ PAN Krakow, Poland*
R.V.F. Janssens, S. Zhu, M.P. Carpenter, N. Hammond, F.G. Kondev, T. Lauritsen, C.J. Lister, E. F. Moore, D. Seweryniak	*ANL Argonne, USA*
P. Mantica, S. Liddick, A.D. Davies, T. Glasmacher, D.E. Groh, D.J. Morrissey, A.C. Morton, W.F. Mueller, H. Schatz, A. Stolz, B. Tomlin	*MSU East Lensing, USA*
S.L. Tabor, I. Wiedenhoever	*Florida State Univ., USA*
P.J. Daly, Z.W. Grabowski	*Purdue University, USA*
S.J. Freeman,	*University of Manchester, UK*
S. Lunardi, N. Marginean, C.A. Ur, M. Cinausero, G. Viesti	*Padova Univ.* *LNL INFN, Legnaro, Italy*

THEORY:

M. Honma	*University of Aizu, Japan*
T. Otsuka	*University of Tokyo, Japan*
B.A. Brown	*Michigan State University, USA*
T. Mizusaki	*Senshu University, Japan*

XXI Winter
School on Physics,
Zakopane, Poland
1986