Yrast spectroscopy near doubly magic ^{132}Sn and ^{208}Pb - possibilities with radioactive beams

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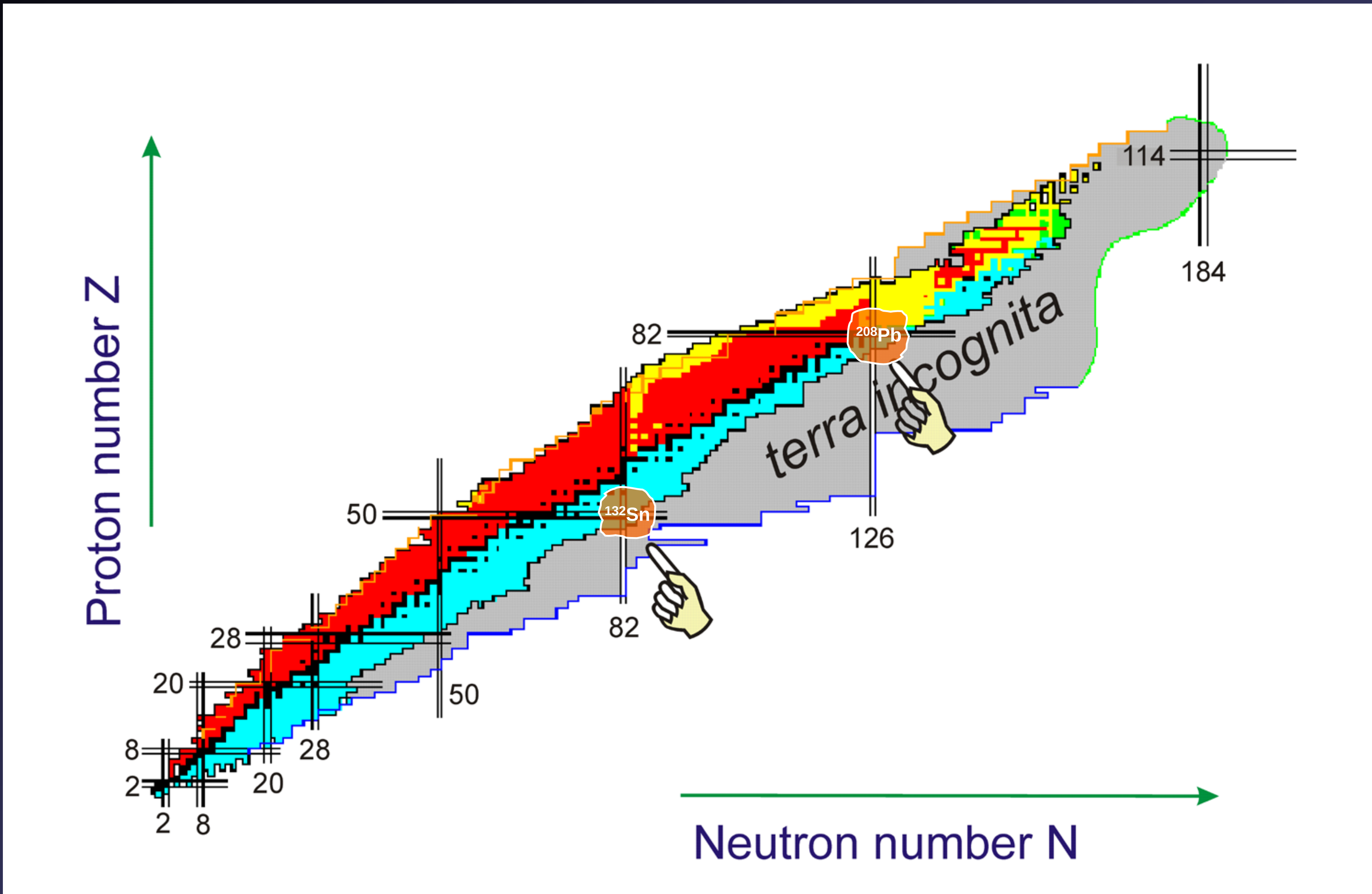
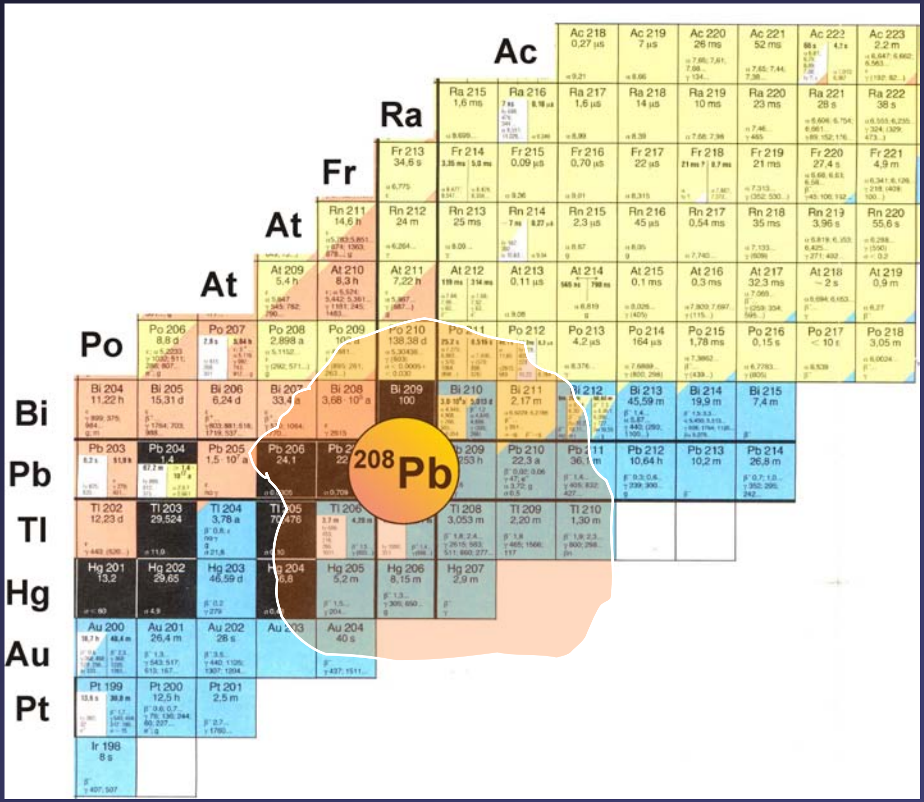
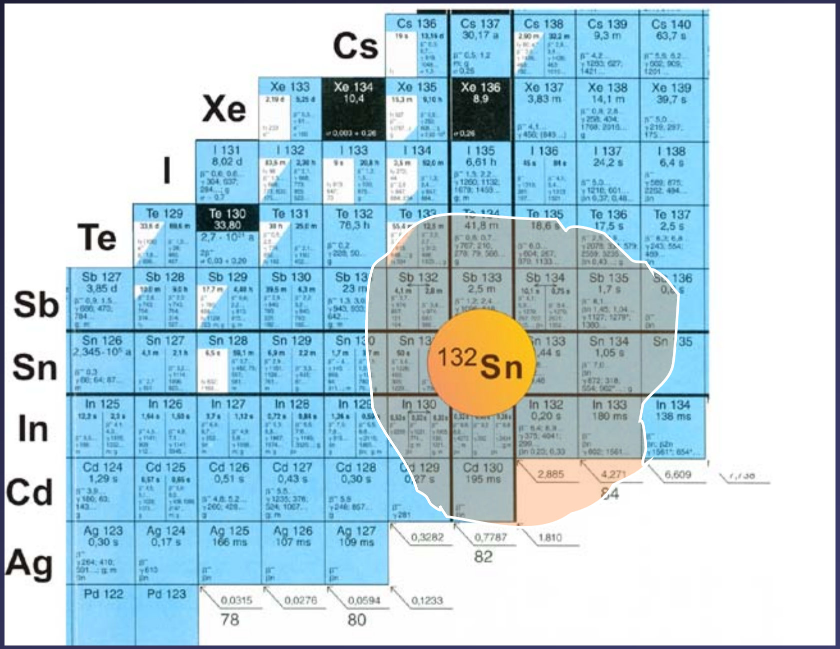

Proton number Z
Neutron number N
terra incognita
^{208}Pb
^{132}Sn
114
184
82
126
50
82
28
50
20
28
8
20
2
2
8

Outline

- **How to access excited structures in the neutron-rich nuclei around ^{132}Sn and ^{208}Pb**
  - **deep-inelastic reactions**
  - **spontaneous or induced fission**
- **Similarities in the yrast structures near ^{132}Sn and ^{208}Pb**
- **Do these similarities emerge from shell model calculations with the „universal” interaction?**
- **Perspectives with radioactive beams**

How to access **YRAST** states in neutron-rich nuclei near ^{132}Sn and ^{208}Pb





Experimental techniques used to access **YRAST** states in neutron-rich nuclei near ^{132}Sn and ^{208}Pb

around ^{132}Sn

- **fission** (spontaneous or induced) of uranium and transuranium nuclei
  - prompt spectroscopy
  - high-spin isomer spectroscopy

- **projectile fission** and **fragmentation reactions** at intermediate energies
  - decay of high-spin isomers

around ^{208}Pb

- **deep-inelastic processes** occurring during heavy-ion reactions
  - prompt spectroscopy
  - high-spin isomer spectroscopy

- **fragmentation reactions** at intermediate energies
  - decay of high-spin isomers

Z. Phys. A – Atomic Nuclei 324, 161–171 (1986)

Zeitschrift für Physik A
Atomic Nuclei

Discrete γ-Rays in the Reactions of 143 MeV ^{32}S with ^{58}Ni

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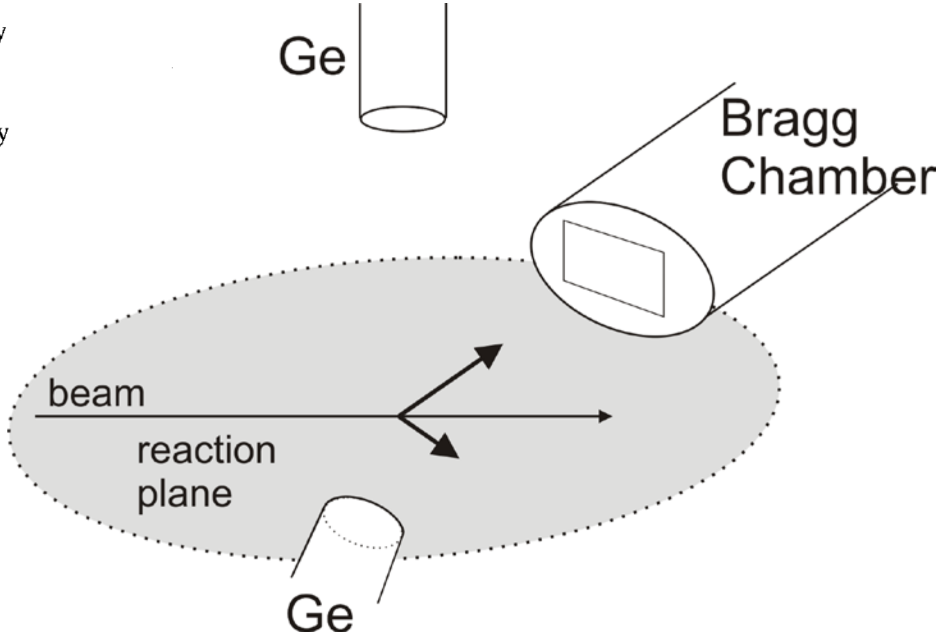
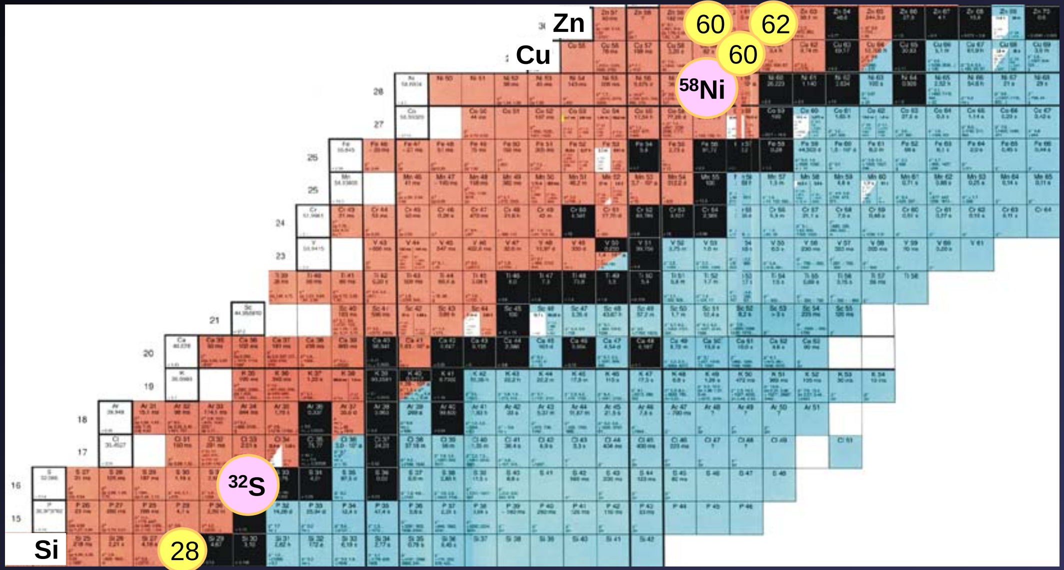
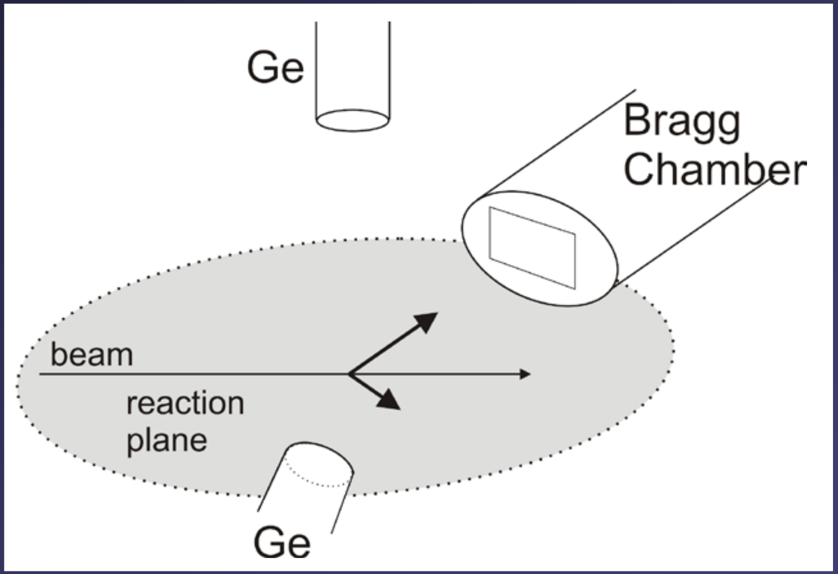
Received February 18, 1986

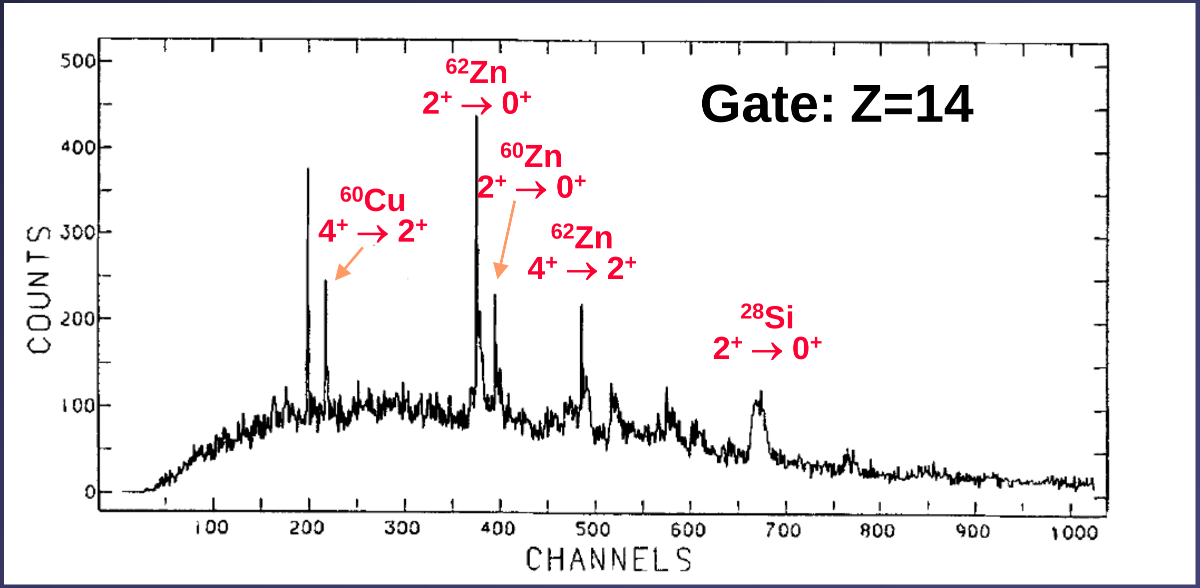
Deep-inelastic reactions
studied by means
of the discrete γ-ray spectroscopy
at LNL di Legnaro in the 1980's



^{32}S + ^{58}Ni, E_{beam}= 143 MeV, XTU Tandem at LNL Legnaro







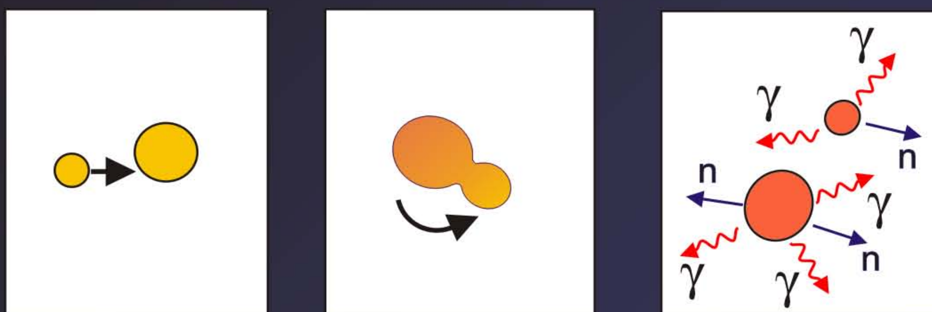
Gamma rays from the deep-inelastic reaction products

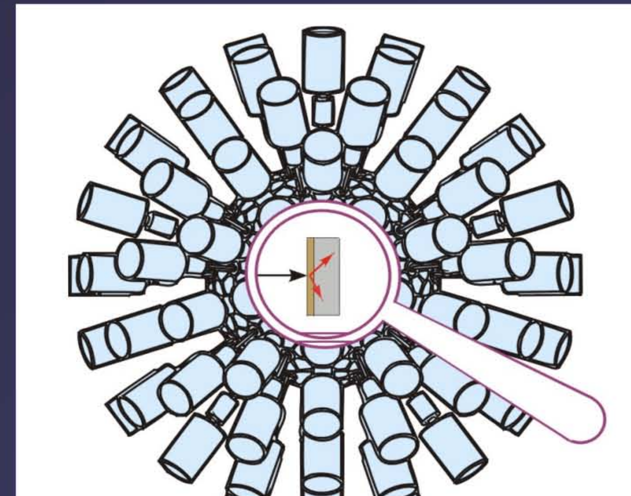
Deep-inelastic heavy-ion reactions – a tool for gamma-ray spectroscopy of neutron-rich nuclei

thick target

$\gamma-\gamma$ coincidences

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



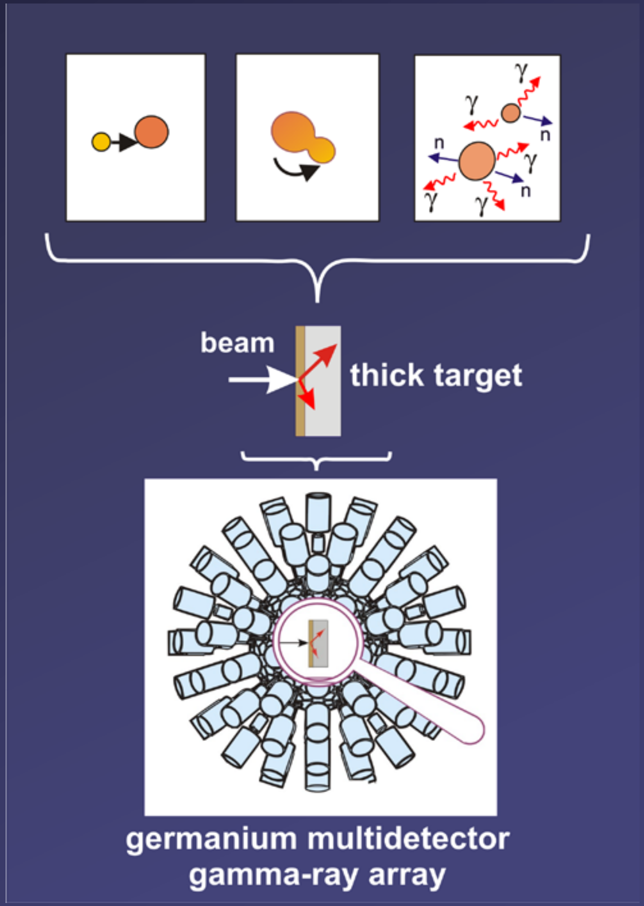


γ-ray array
(e.g.,GS, GASP, EUROB.,AGATA)

γ - reaction product coincidences

Experimental technique that we used to access **YRAST** states in neutron-rich nuclei **around ^{208}Pb:**

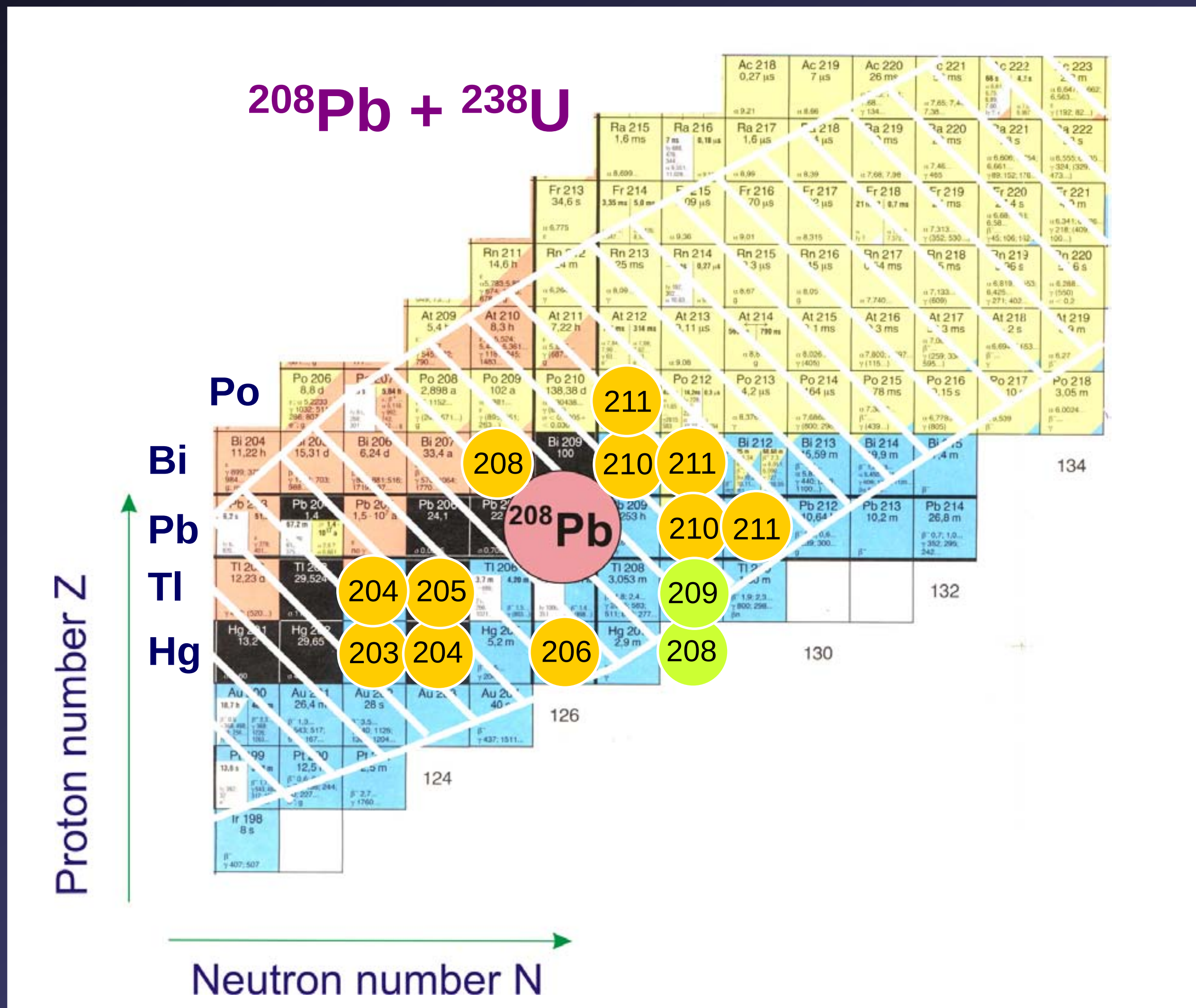
prompt γ-ray spectroscopy of deep-inelastic reaction products following the reaction ^{208}Pb+^{238}U



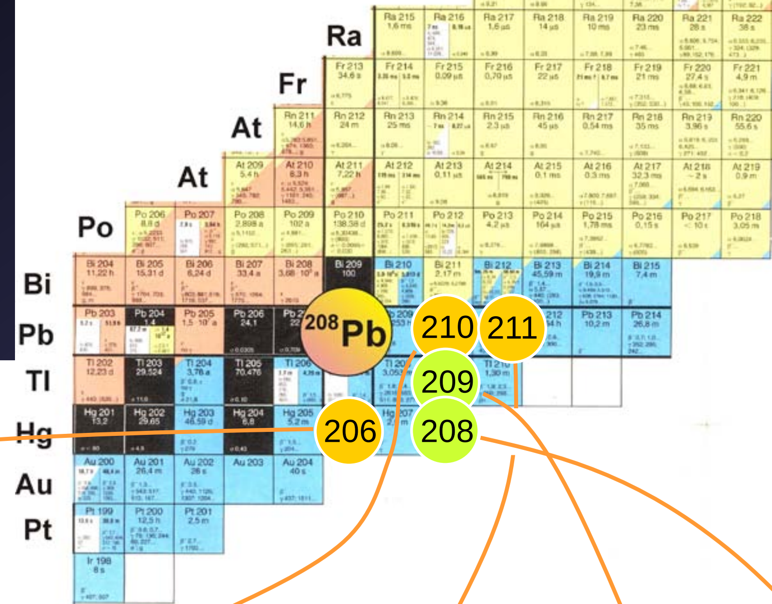
Product distribution in deep-inelastic reaction of ^{208}Pb (1360 MeV) on ^{238}U

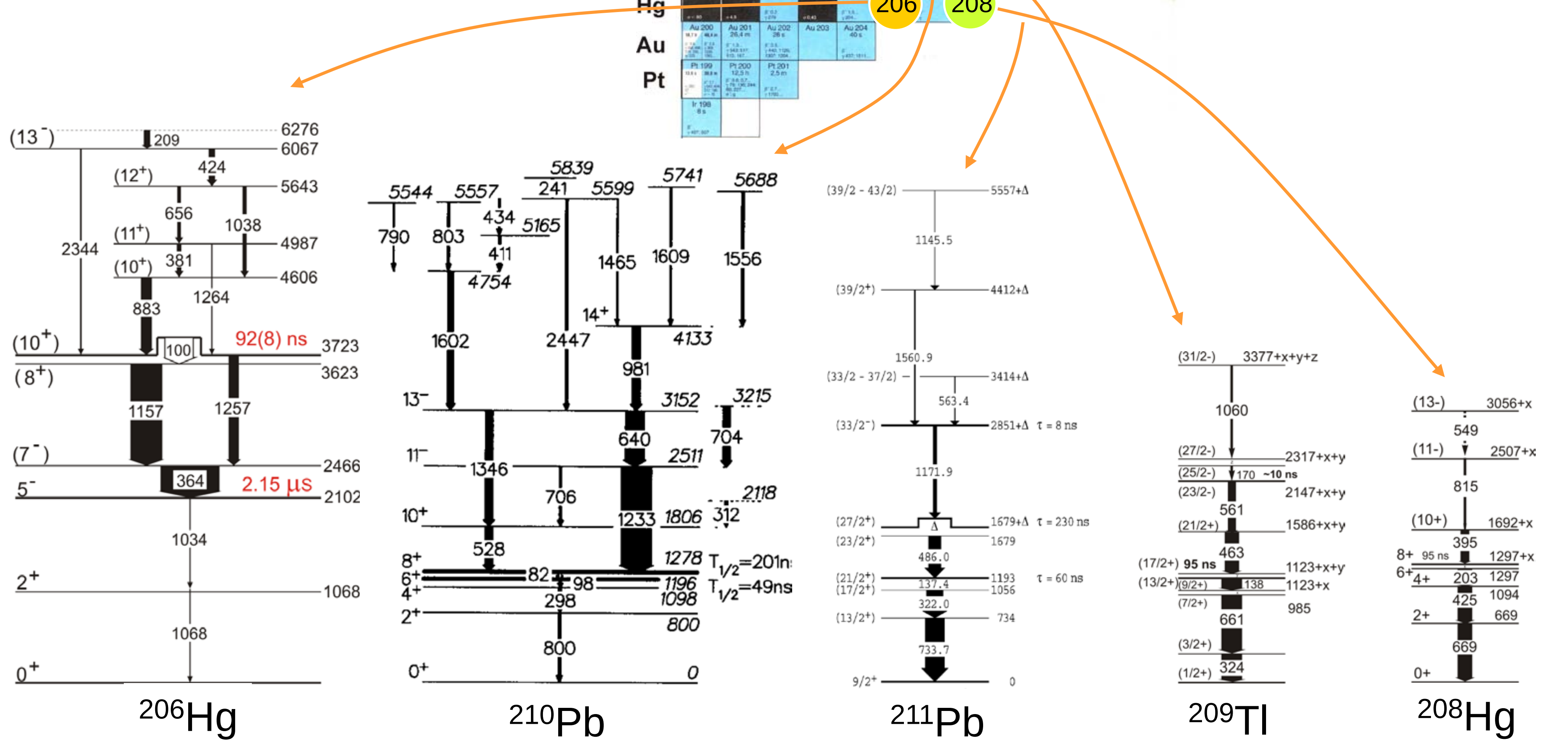
$^{208}Pb + ^{238}U$

The nuclei around ^{208}Pb, produced in deep-inelastic reactions of ^{208}Pb on ^{238}U, in which we have identified yrast structures by using γ–γ–γ coincidence thick-target technique with GAMMASPHERE



Results on the most neutron-rich nuclei around ^{208}Pb produced in the ^{208}Pb + ^{238}U reaction and studied by using γ–γ–γ coincidence thick-target technique with GAMMASPHERE





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

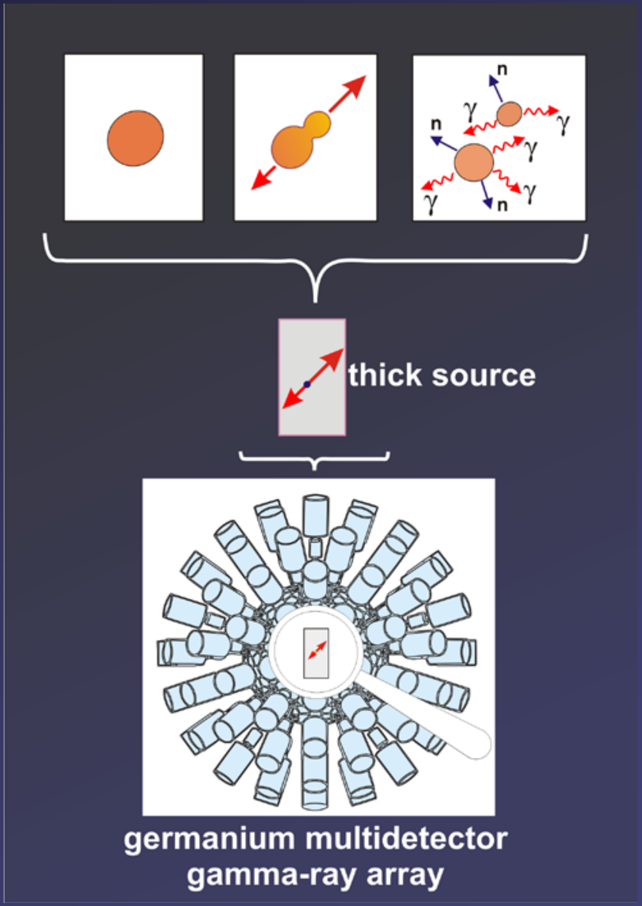
G. Lane et al., Nucl. Phys. A682 (2001)

G. Lane et al., Phys. Lett. B (2005)

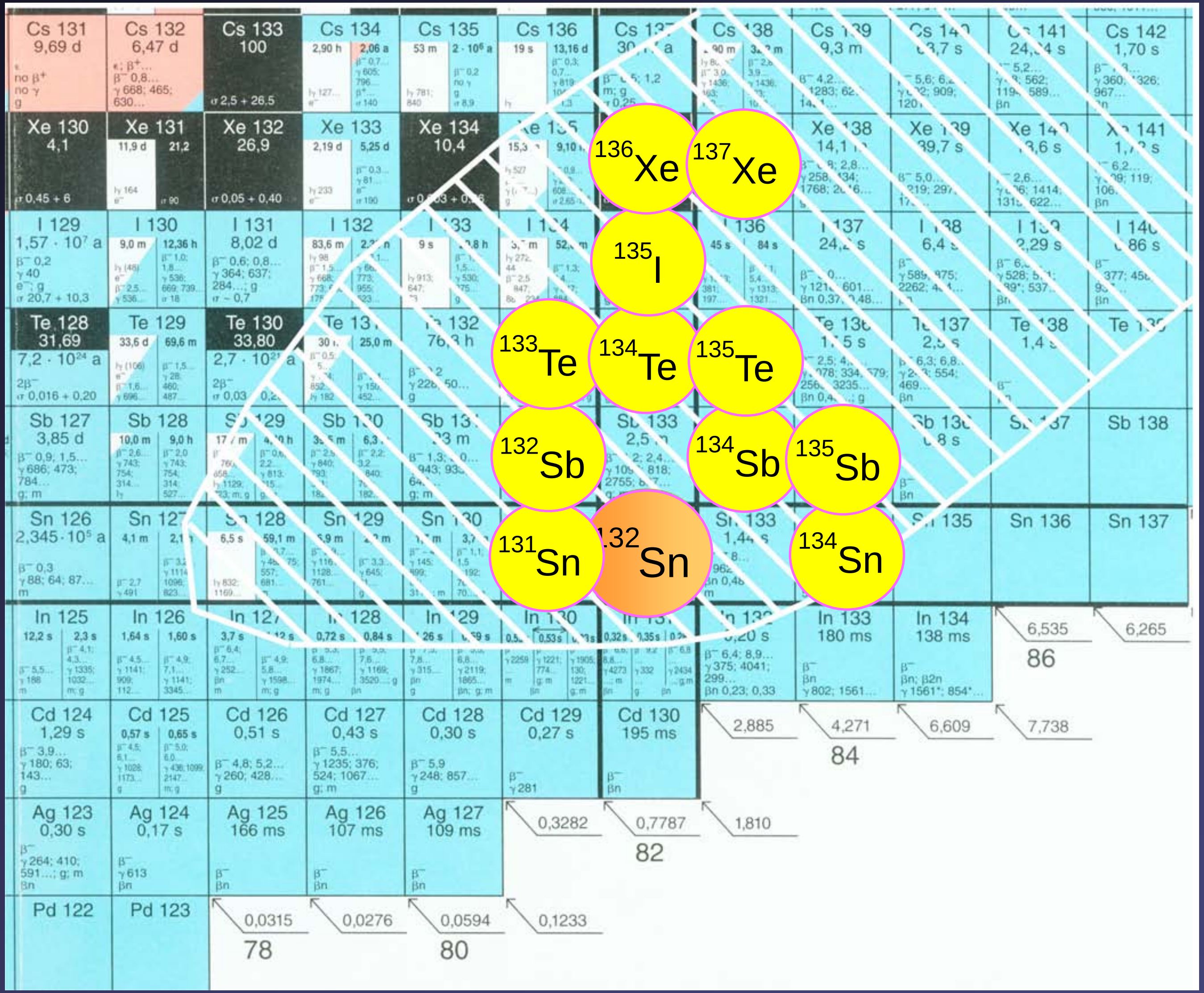
B. Fornal et al., Proc. Vietri Conf. (2010)

Experimental technique that we used to access **YRAST** states in neutron-rich nuclei **around ^{132}Sn:**

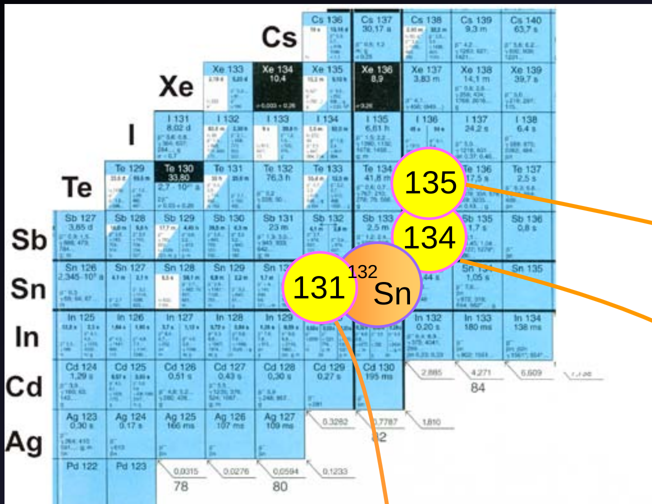
prompt γ-ray spectroscopy of fission products following spontaneous fission of ^{248}Cm

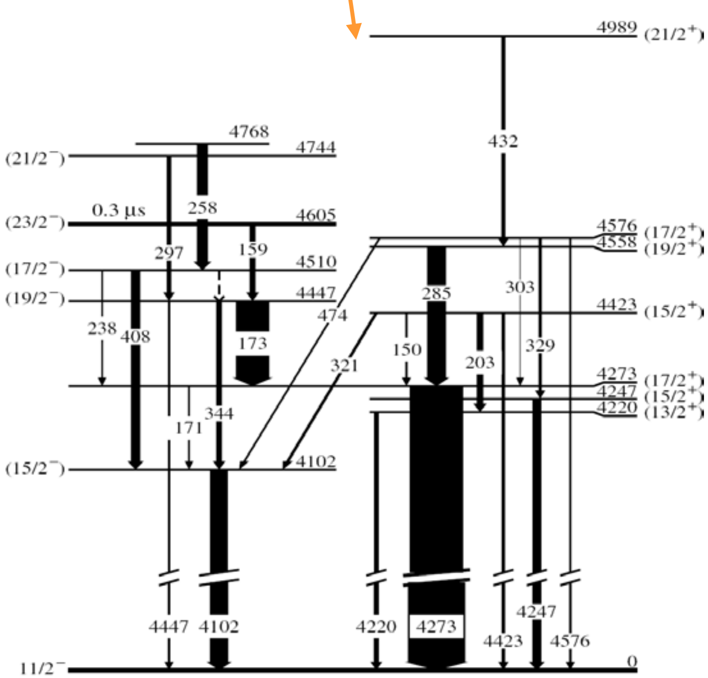


The nuclei around ^{132}Sn produced in spontaneous fission of ^{248}Cm in which we have identified yrast structures by using γ–γ–γ coincidence thick-target technique with GAMMASPHERE

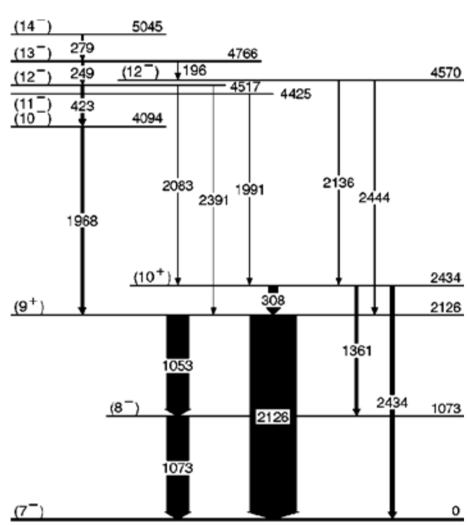


Results on the <u>most neutron-rich</u> nuclei around ^{132}Sn produced in spontaneous fission of ^{248}Cm that we studied by using γ–γ–γ coincidence thick-target technique with GAMMASPHERE

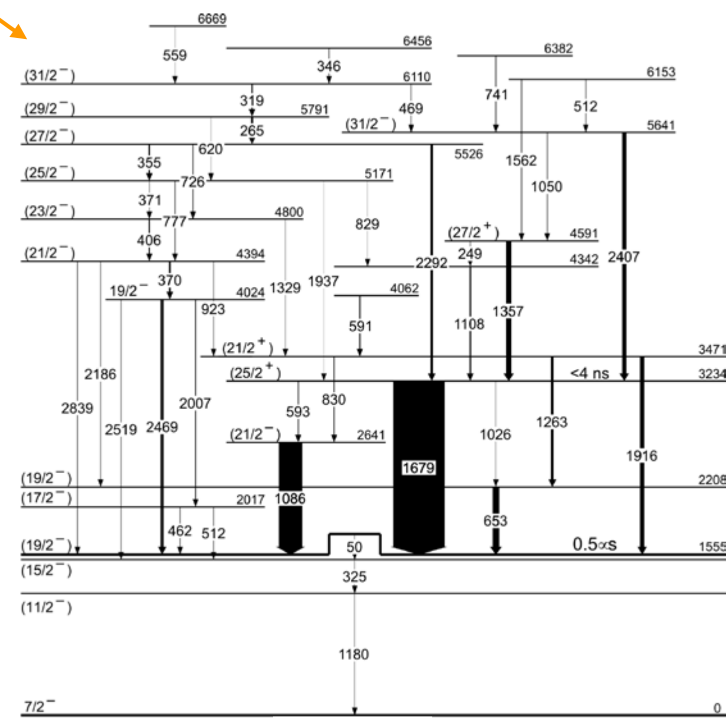




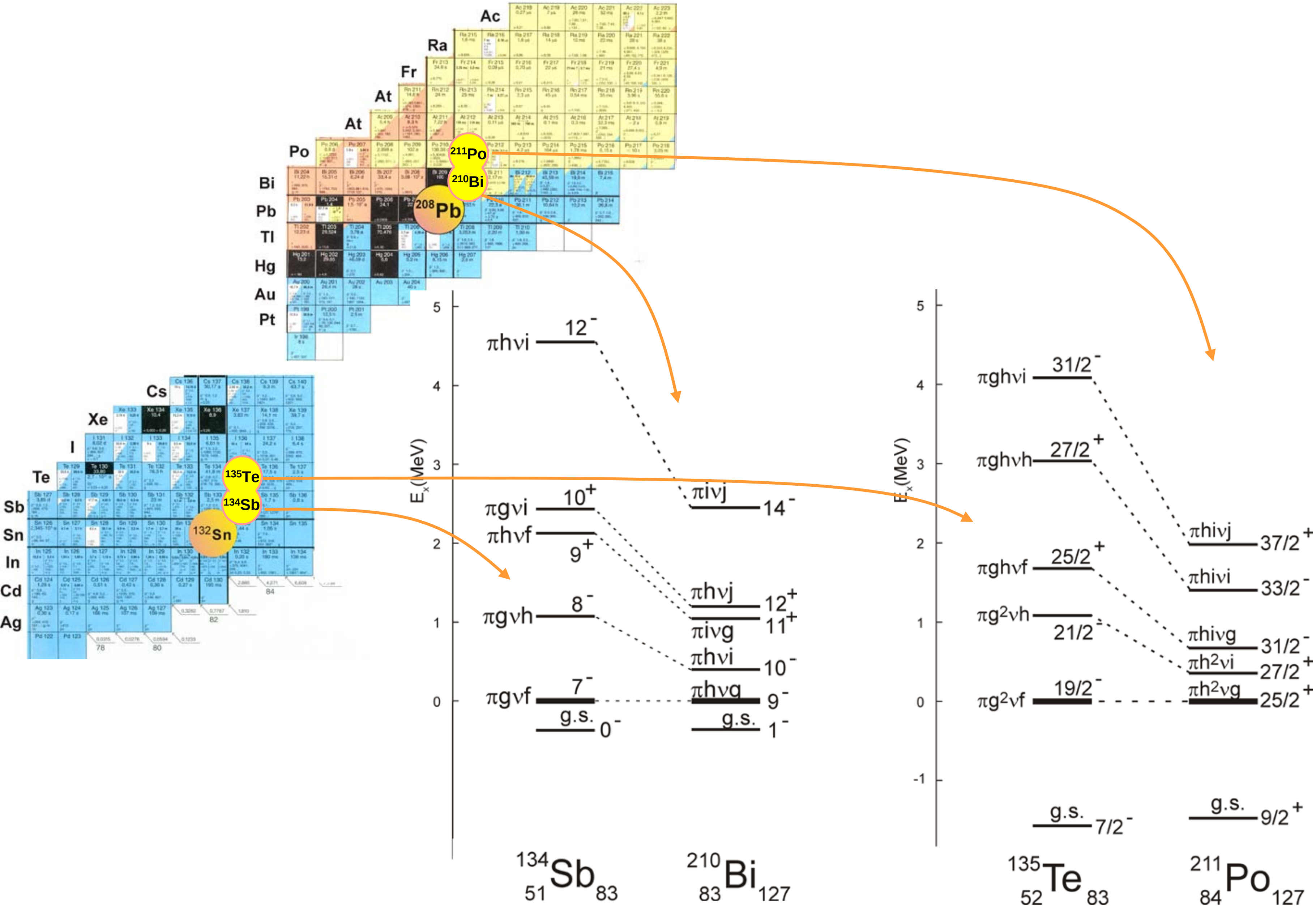
^{131}Sn



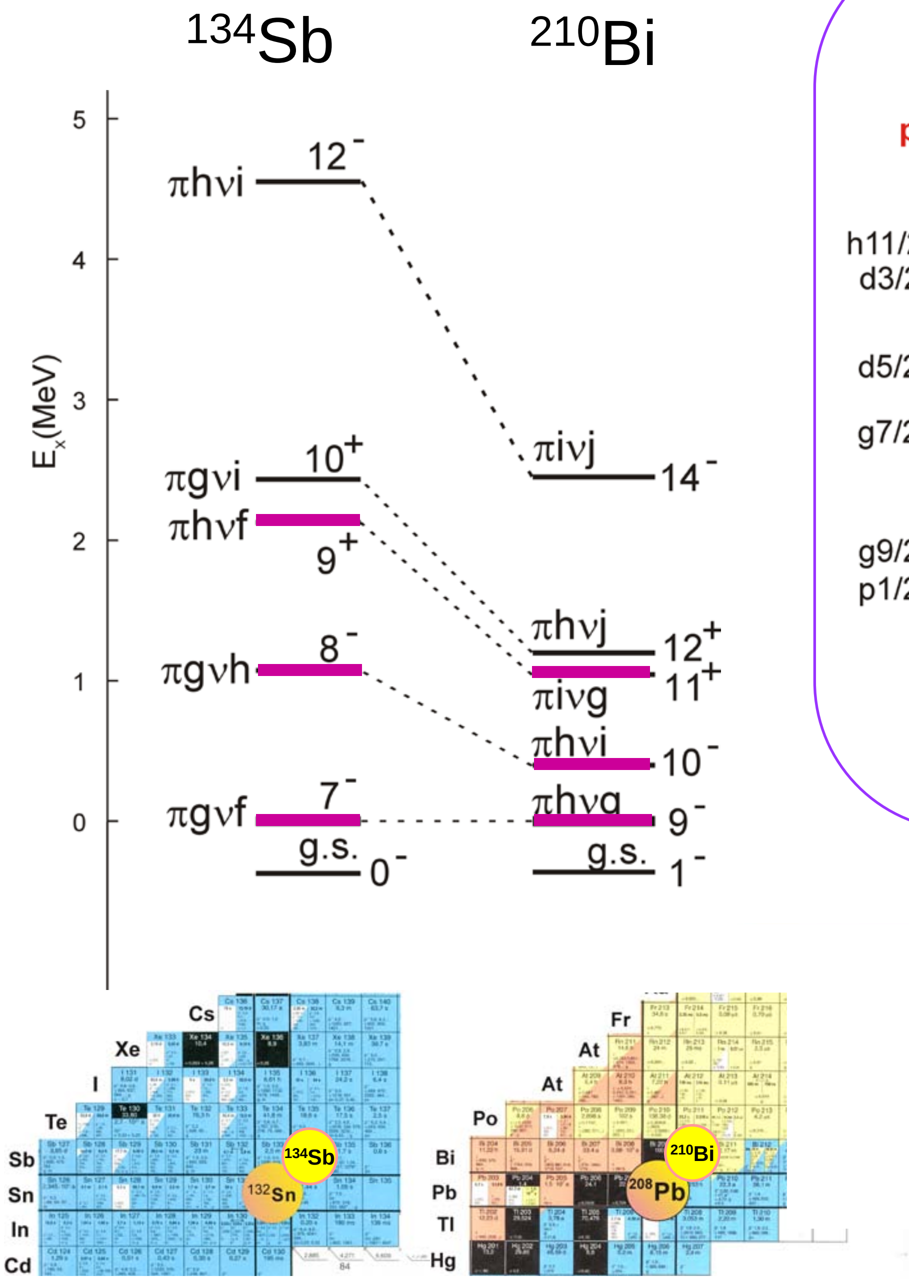
^{134}Sb



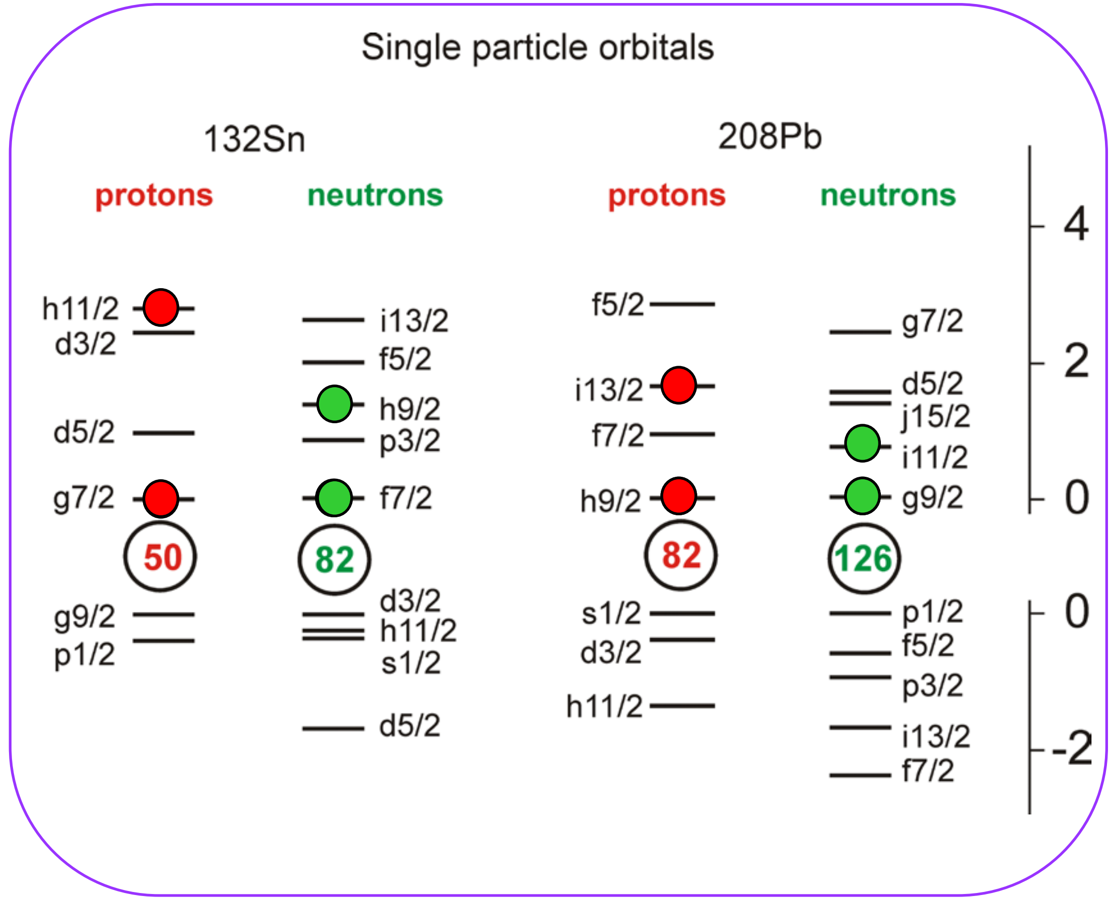
^{135}Te



Ac
Ra
Fr
At
At
Po
Bi
Pb
Tl
Hg
Au
Pt
211Po
210Bi
208Pb
Cs
Xe
I
Te
Sb
Sn
In
Cd
Ag
135Te
134Sb
132Sn
E_x (MeV)
πhνi 12⁻
πgνi 10⁺
πhνf 9⁺
πgνh 8⁻
πgνf 7⁻
g.s. 0⁻
πiνj 14⁻
πhνj 12⁺
πiνg 11⁺
πhνi 10⁻
πhνg 9⁻
g.s. 1⁻
134 51 Sb 83
210 83 Bi 127
πghνi 31/2⁻
πghνh 27/2⁺
πghνf 25/2⁺
πg2νh 21/2⁻
πg2νf 19/2⁻
g.s. 7/2⁻
πhiνj 37/2⁺
πhiνi 33/2⁻
πhiνg 31/2⁻
πh2νi 27/2⁺
πh2νg 25/2⁺
g.s. 9/2⁺
135 52 Te 83
211 84 Po 127



^{134}Sb
^{210}Bi
E_x(MeV)
5
4
3
2
1
0
πhνi
12^-
πgνi
10^+
πhνf
9^+
πgνh
8^-
πgνf
7^-
g.s.
0^-
πiνj
14^-
πhνj
12^+
πiνg
11^+
πhνi
10^-
πhνg
9^-
g.s.
1^-
Cs
Xe
I
Te
Sb
Sn
In
Cd
^{134}Sb
^{132}Sn
Fr
At
At
Po
Bi
Pb
Tl
Hg
^{210}Bi
^{208}Pb



Single particle orbitals
132Sn
208Pb
protons
neutrons
protons
neutrons
h11/2
d3/2
d5/2
g7/2
50
g9/2
p1/2
i13/2
f5/2
h9/2
p3/2
f7/2
82
d3/2
h11/2
s1/2
d5/2
f5/2
i13/2
f7/2
h9/2
82
s1/2
d3/2
h11/2
g7/2
d5/2
j15/2
i11/2
g9/2
126
p1/2
f5/2
p3/2
i13/2
f7/2
4
2
0
0
-2

Realistic shell model calculations using a $V_{low\text{-}k}$ approach –

a theoretical framework for microscopic shell-model calculations starting from the free nucleon–nucleon potential

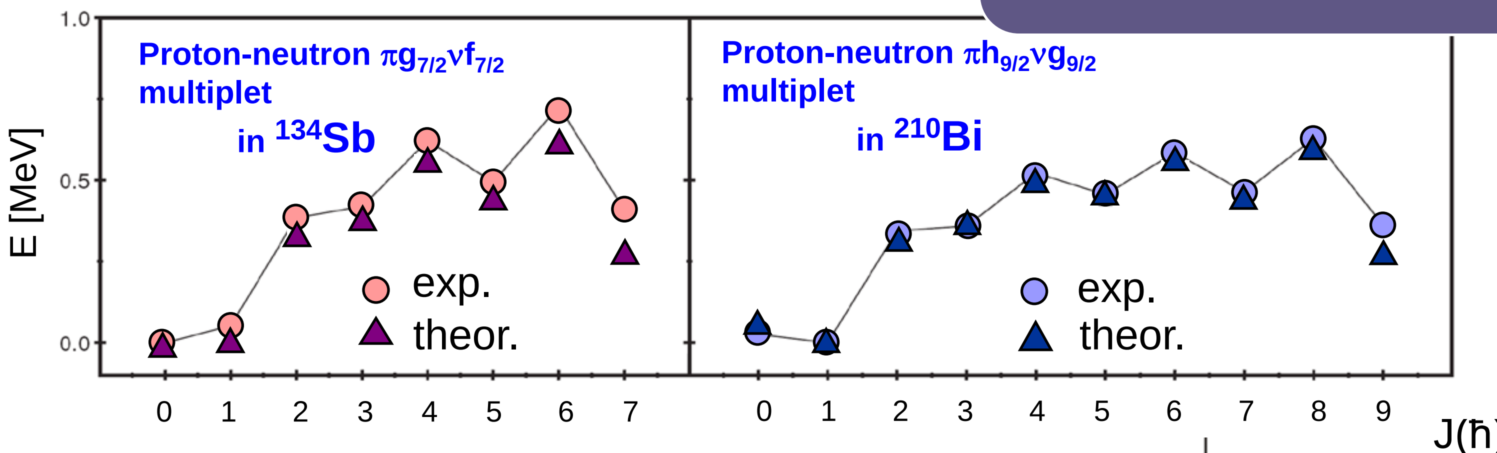
and its application to exotic nuclei around doubly magic ^{132}Sn.

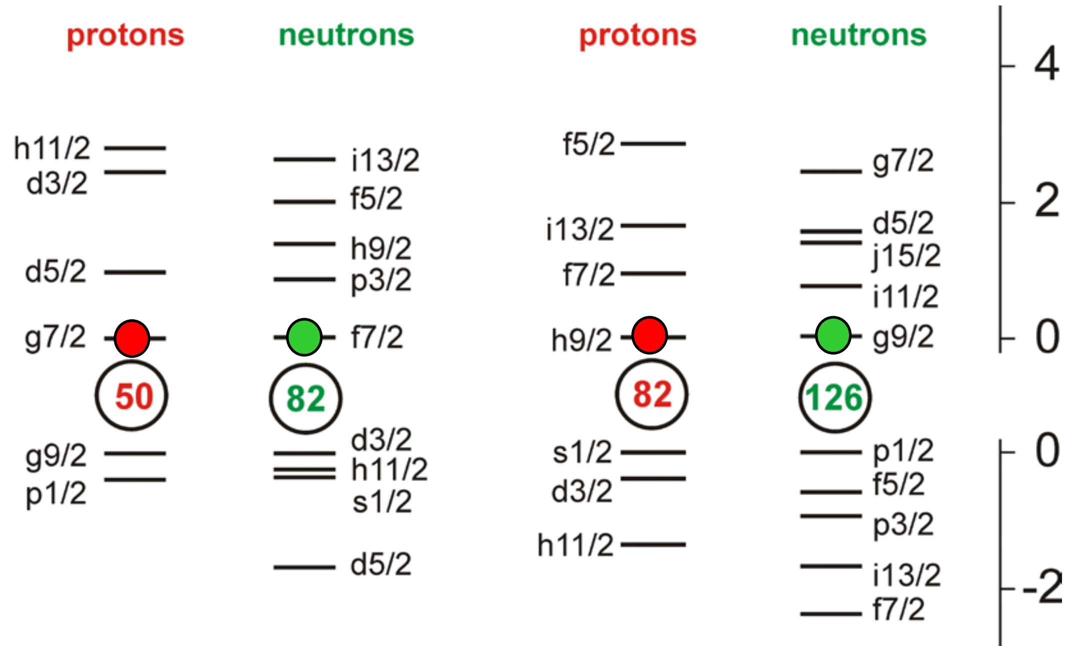
A.Covello, L.Coraggio,A.Gargano, N.Itaco,
Prog. Part. Nucl. Phys. 59, 404 (2007).

Similarity of proton-neutron multiplets in ^{134}Sb and ^{210}Bi

L.Coraggio, A.Covello, A.Gargano, N.Itaco, T.T.S. Kuo, Phys. Rev. C 80, 44320 (2009).

Vlow-k realistic shell model calculations





Yrast states - comparison with results of the realistic shell model calculations using a $V_{low\text{-}k}$ approach

To get $V_{low\text{-}k}$ effective interaction we used:

Computational Environment for Nuclear Structure (CENS)

Authors: T. Engeland, M.Hjorth-Jensen and G.R. Jansen

Reference article: M.Hjorth-Jensen, T.T.S.Kuo, E.Osnes,
Physics Reports 261, 125-270 (1995)

CD-Bonn potential, $\Lambda = 2.2\ fm^{-1}$,

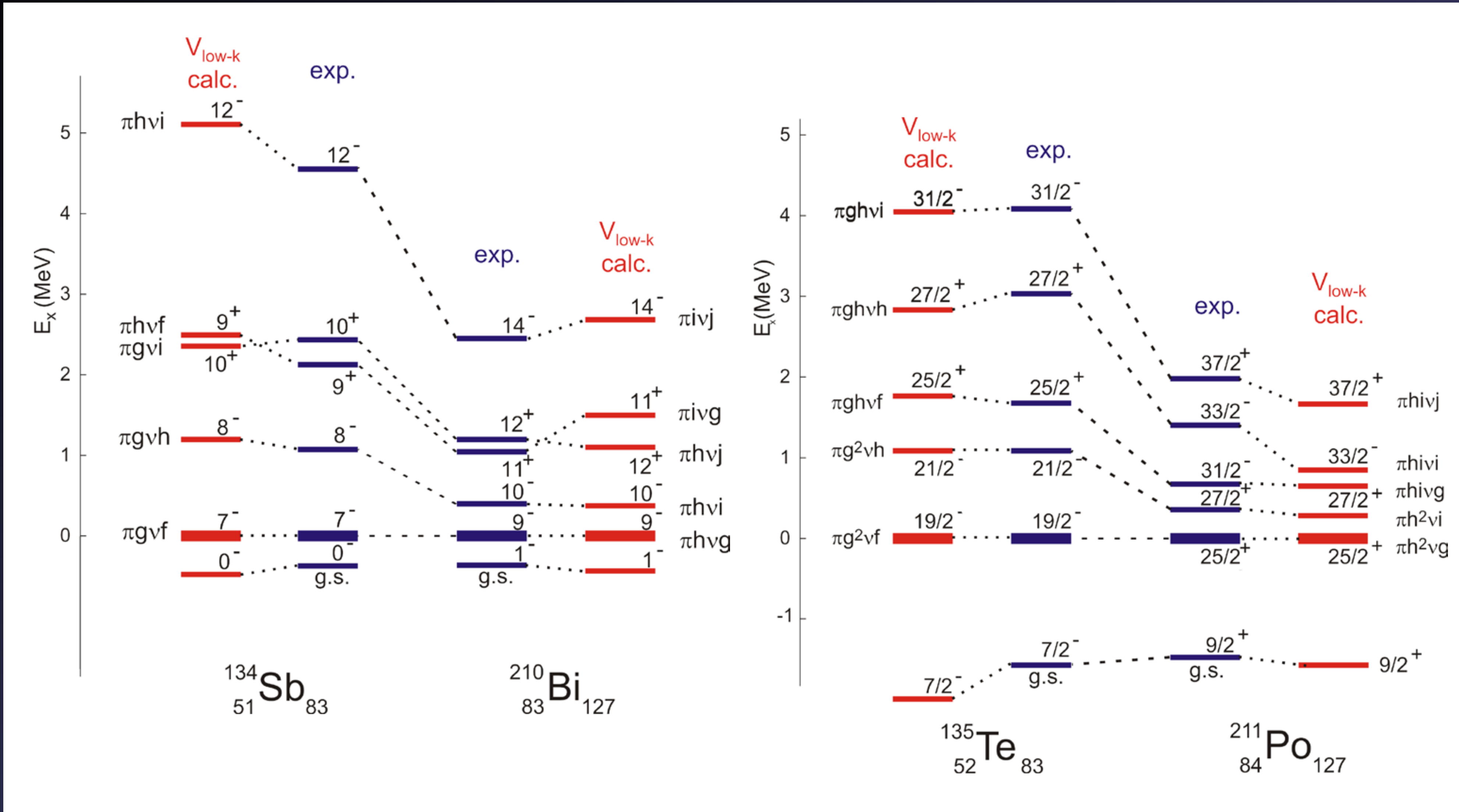
model spaces: (Z=50-82, N=82-126) , (Z=82-126, N=126-184)

For shell-model calculations we used:

computer code **OXBASH,**

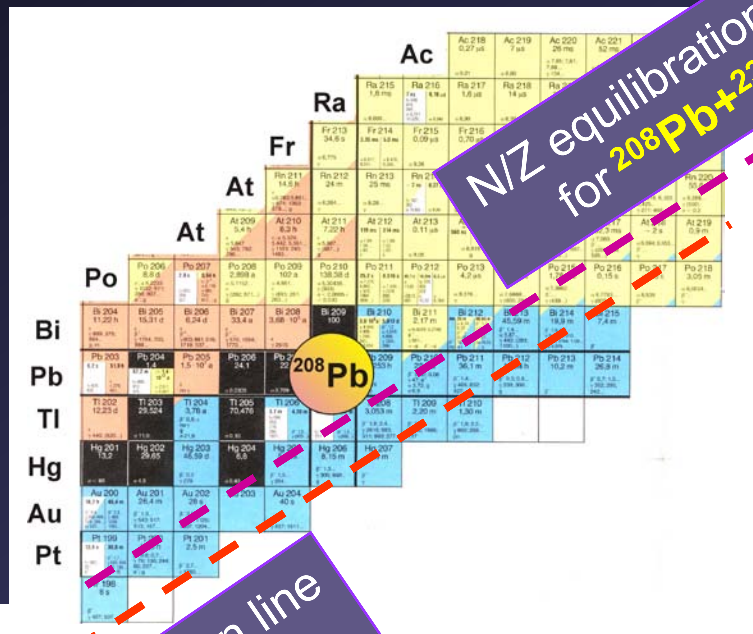
B. A. Brown, A. Etchegoyen, W. D. M. Rae, N. S. Goldwin, W. A. Richter,
C. H. Zimmerman, W. E. Ormand, and J. S. Winfield,
MSU-NSCL Report No. 524, 1985.

s.p.s. energies from experiment



CONCLUSION: **similarity** between the yrast states in nuclei near **^{132}Sn and ^{208}Pb emerges** from the shell-model interactions that are derived from a realistic nucleon-nucleon potential without any adjustable parameters.

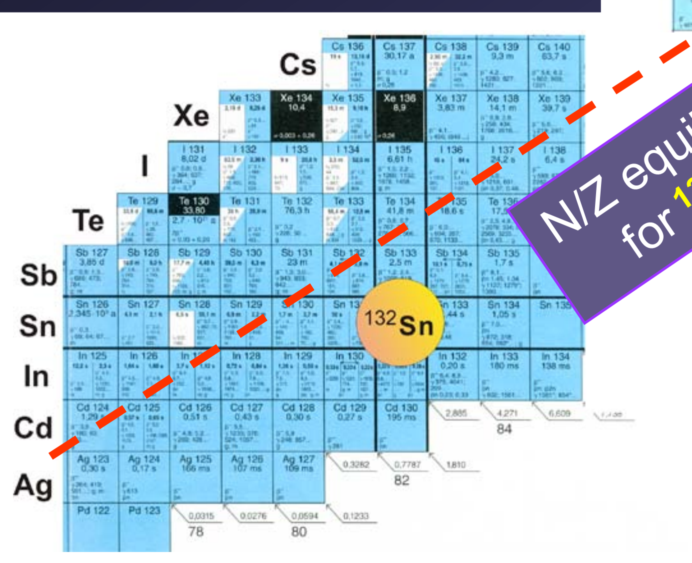
Perspectives for accessing neutron-rich nuclei near ^{208}Pb by using a beam of ^{132}Sn



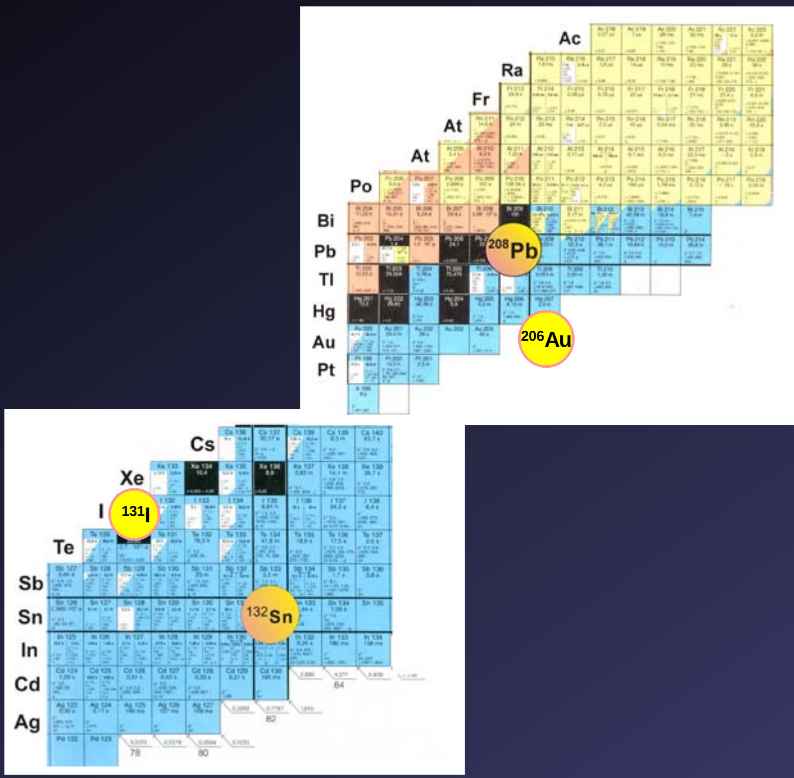
Let's consider reactions:

^{208}Pb + ^{238}U

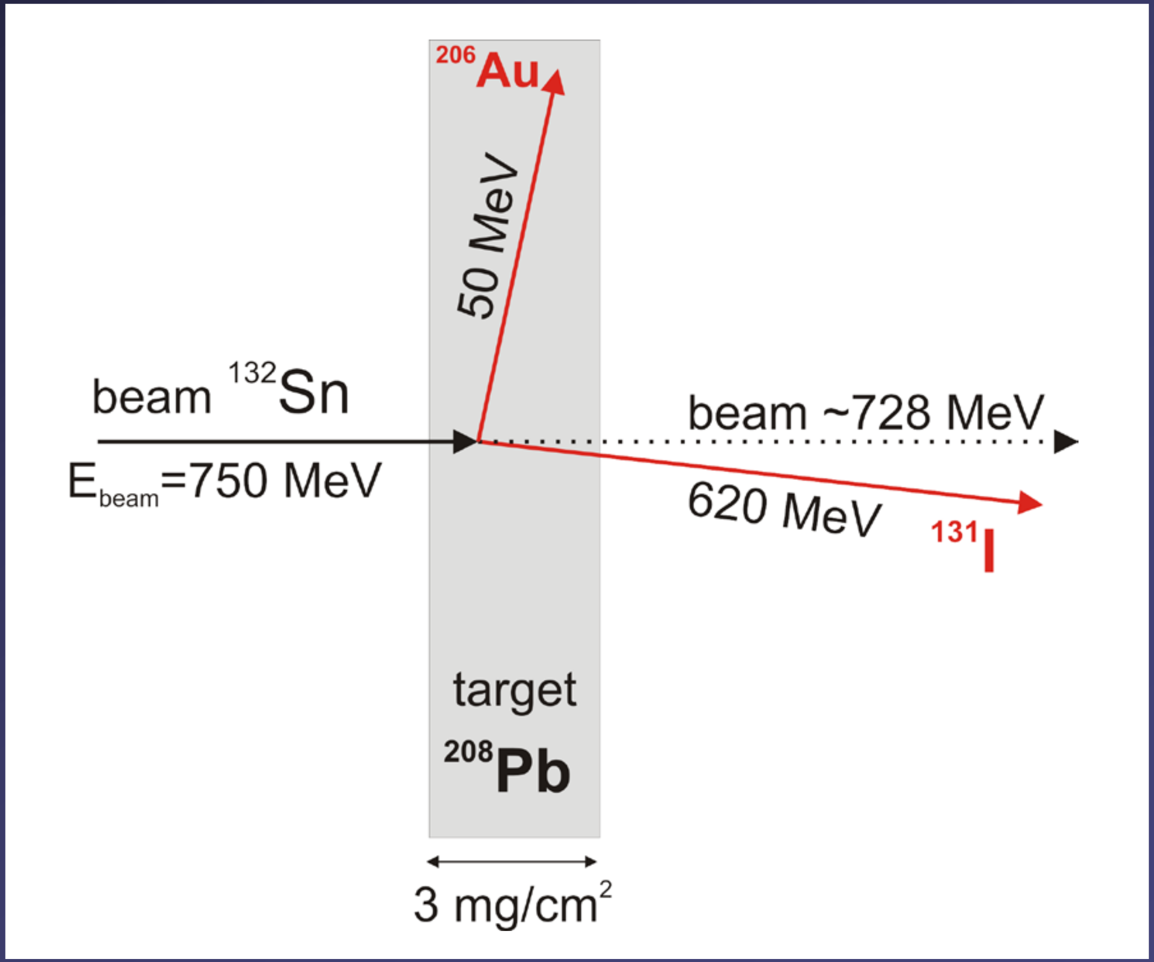
^{132}Sn + ^{208}Pb



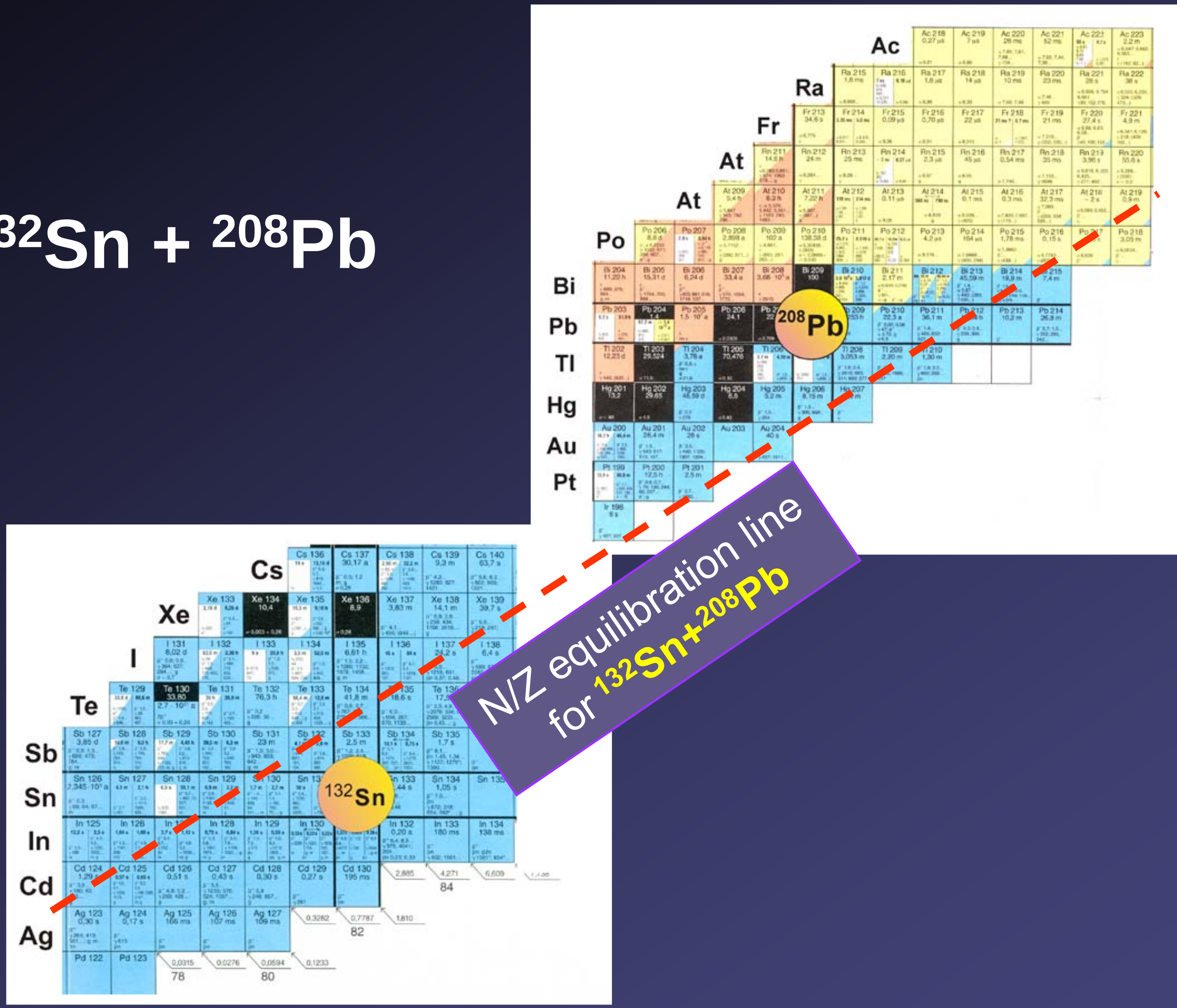
Deep-inelastic reaction ^{132}Sn + ^{208}Pb at E_{beam}=750 MeV with an intermediate-thick target



The kinematics is favorable for stopping Pb-like neutron-rich nuclei in the target



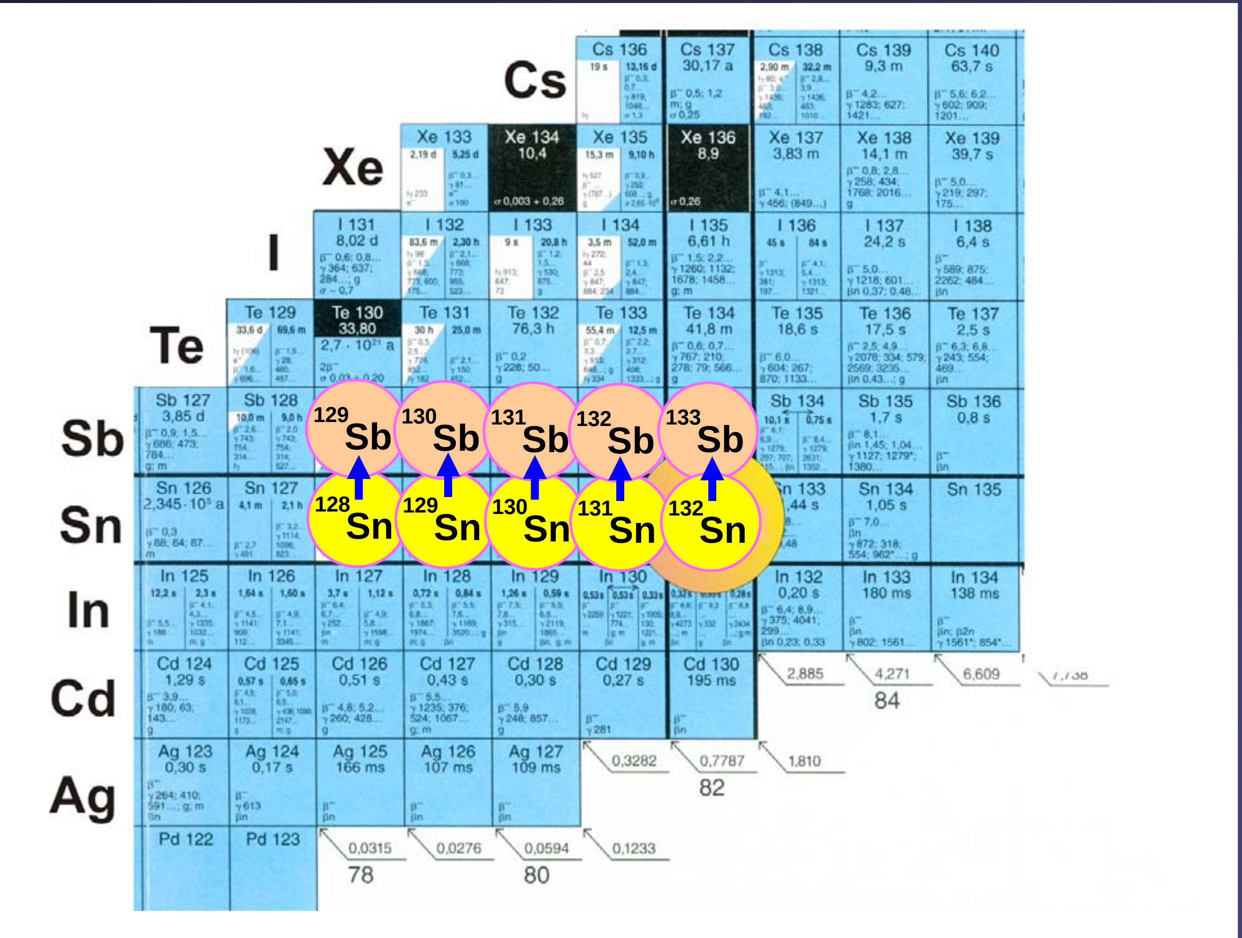
$^{132}Sn + ^{208}Pb$



Ac
Ra
Fr
At
At
Po
Bi
Pb
Tl
Hg
Au
Pt
208Pb
Cs
Xe
I
Te
Sb
Sn
In
Cd
Ag
132Sn
N/Z equilibration line
for 132Sn+208Pb

Perspectives for reaching yrast states in neutron-rich Sb isotopes by employing radioactive ^{A}Sn beams on a ^{7}Li target

$$^{7}\mathrm{Li}(^{A}\mathrm{Sn},\alpha 2n)^{A+1}\mathrm{Sb}$$



Conclusions and Outlook

- Deep-inelastic reactions and spontaneous fission of transuranium nuclei - extremely efficient in elucidating yrast structures near ^{132}Sn and ^{208}Pb.

- Similarity between yrast states in nuclei near ^{132}Sn and ^{208}Pb that was observed experimentally, also emerges from the shell-model calculations with Vlow-k realistic interactions.

- Discrete gamma-ray yrast spectroscopy of very neutron-rich nuclei located south-east of ^{208}Pb might be possible with deep-inelastic reactions induced by Sn-like radioactive beams.

- For gamma-ray spectroscopic studies of neutron-rich isotopes near ^{132}Sn one may use other methods: for example, radioactive beams of heavy Sn isotopes on a thin ^{7}Li target.

Collaborators

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G. Lane, G. Dracoulis et al. — *ANU Canberra, Australia*

P. Daly, P. Bhattacharyya , Z. Grabowski
C.T. Zhu — *Purdue University, USA*