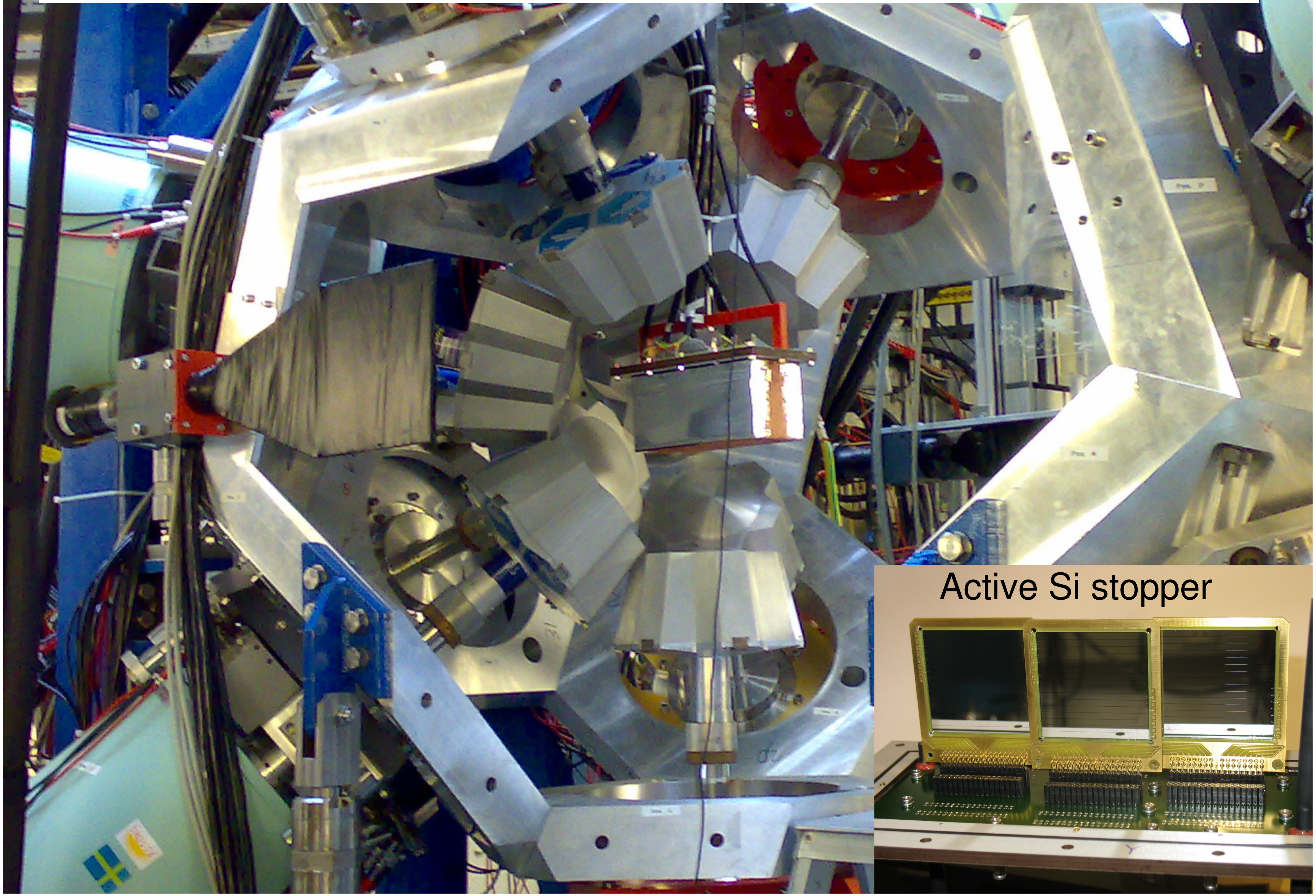
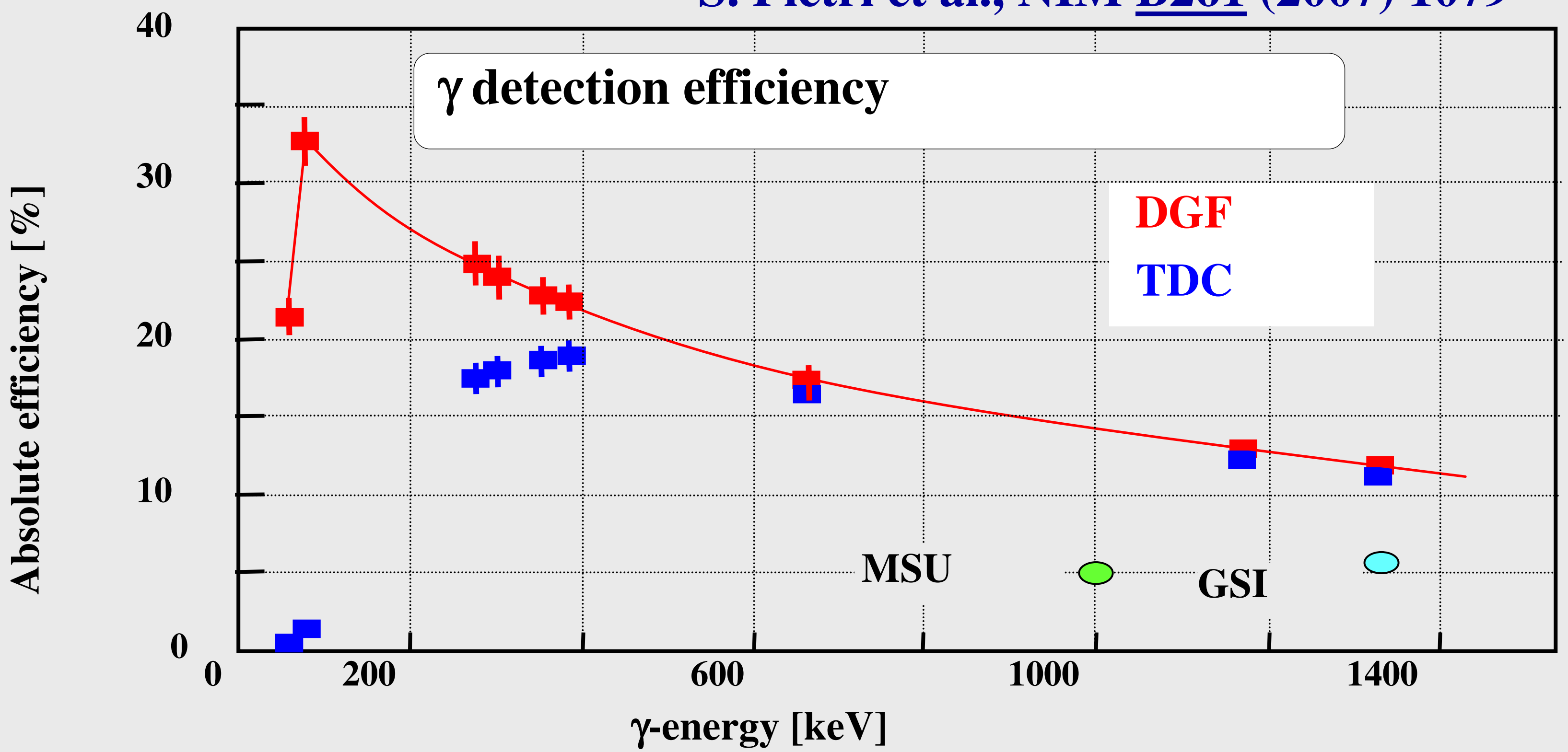
RISING: past results and ***future*** priorities



The RISING γ-ray spectrometer

- 15 EUROBALL Cluster (105 Ge crystals)
- digital signal processing via 30 XIA DGF modules

S. Pietri et al., NIM B261 (2007) 1079



very high γ-ray efficiency
high granularity (prompt flash problem)

FRS + RISING => high sensitivity experiments

Outcome of PAC (EA)

S337 Andres Gadea (Legnaro) 15(+0)

Structure of 132In populated in the beta-decay of 132Cd:

the nf7/2 pg9/2-1 multiplet on the doubly magic 132Sn core

S344 Gary Simpson (Grenoble), R. Lozeva (Leuven) 6+0

Measurements of high-spin microsecond isomers near 132Sn

S347 Zs. Podolyák (Surrey) 18+6(+6)

Along the N=126 closed shell

S350 G. Benzoni, J-J. Valiente-Dobon 18(+6)

Beyond the doubly-magic 208Pb

S352 A. Blazhev (Köln), B.Wadsworth (York) 30(+9)

Study of N>>=Z proton dripline nuclei 96, 97, 98Cd

S353 L.Caceres (Madrid/GSI), P.Regan (Surrey) 21(+6)

Structure of the odd-odd N=Z nuclei in the vicinity of 100Sn:

high spin isomers in 90Rh studied through GT beta-decay

Red: accepted A: must be done

Blue: accepted B: can be done

Fundamental questions in nuclear physics:

Neutron-proton pairing
Isospin symmetry
Shell evolution
Nucleosynthesis (rp- and r-processes)

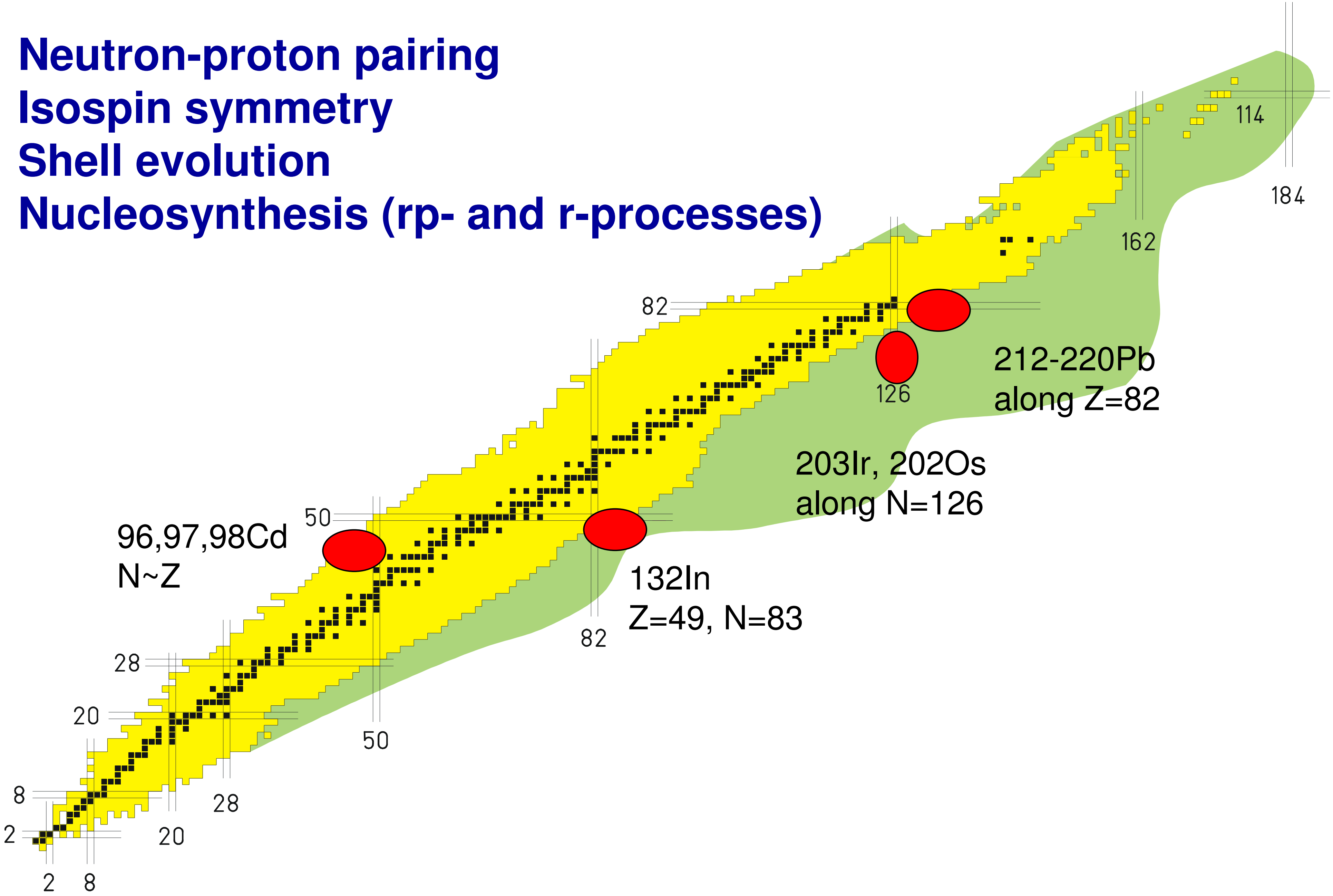


Table 1 -- Nuclear Shell Structure (from *Elementary Theory of Nuclear Shell Structure*, Maria Goeppert Mayer & J. Hans D. Jensen, John Wiley & Sons, Inc., New York, 1955.)

Angular Momentum ($h\Omega/2\pi$)	
7	1j
6	4s
6	3d
6	2g
6	1i
5	3p
5	2f
5	1h
4	3s
4	2d
4	1g
3	2p
3	1f
2	2s
2	1d
1	1p
0	1s

Spin-Orbit Coupling (1/2, 3/2, 5/2, 7/2...)	Number of Nucleons: Shell	Number of Nucleons: Total	Magic Number
1j 15/2	16	[184]	{184}
3d 3/2	4	[168]	
4s 1/2	2	[164]	
2g 7/2	8	[162]	
1i 11/2	12	[154]	
3d 5/2	6	[142]	
2g 9/2	10	[136]	
1i 13/2	14	[126]	{126}
3p 1/2	2	[112]	
3p 3/2	4	[110]	
2f 5/2	6	[106]	
2f 7/2	8	[100]	
1h 9/2	10	[92]	
1h 11/2	12	[82]	{82}
3s 1/2	2	[70]	
2d 3/2	4	[68]	
2d 5/2	6	[64]	
1g 7/2	8	[58]	
1g 9/2	10	[50]	{50}
2p 1/2	2	[40]	{40}
1f 5/2	6	[38]	
2p 3/2	4	[32]	
1f 7/2	8	[28]	{28}
1d 3/2	4	[20]	{20}
2s 1/2	2	[16]	
1d 5/2	6	[14]	
1p 1/2	2	[8]	{8}
1p 3/2	4	[6]	
1s 1/2	2	[2]	{2}

126

82

50

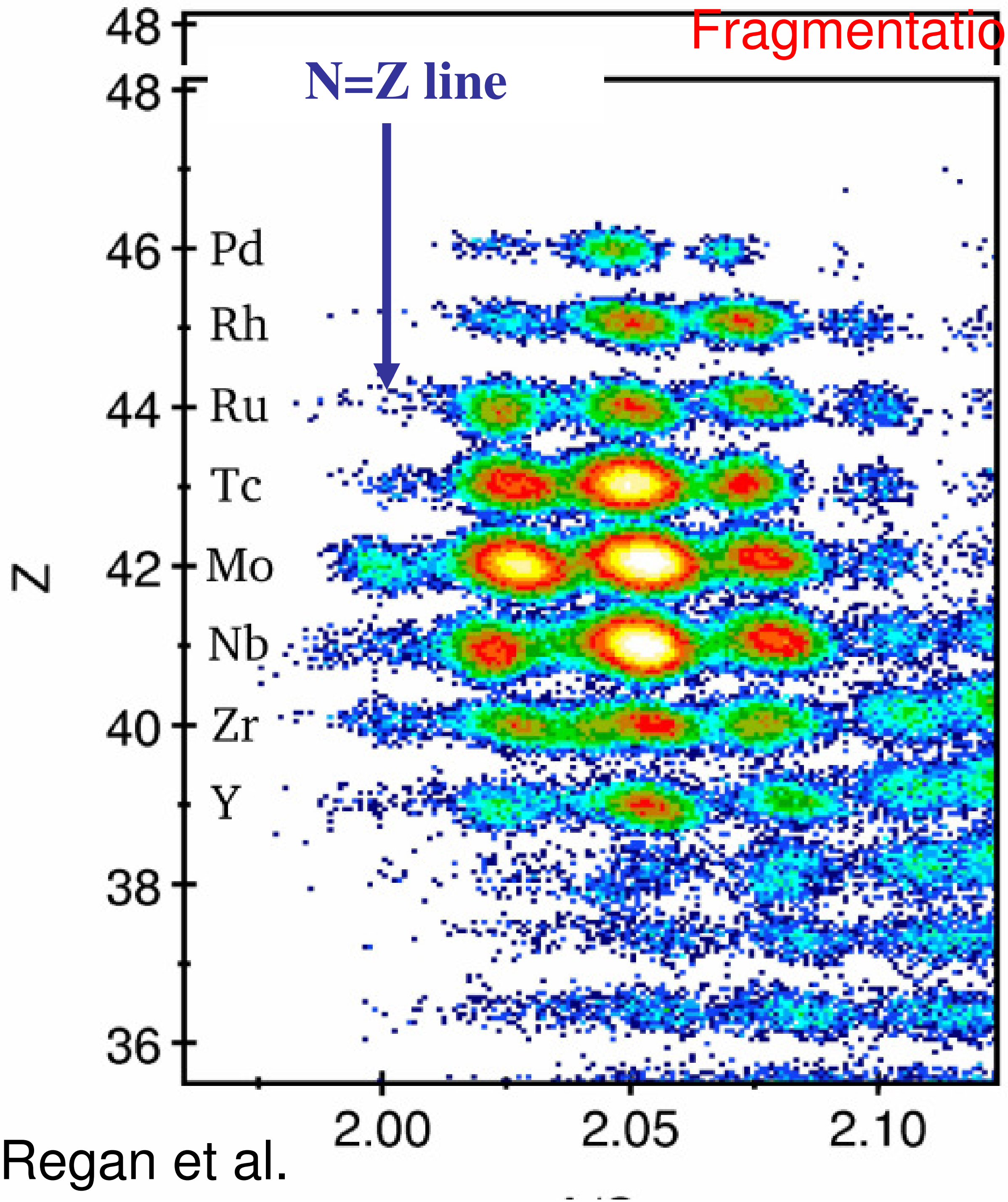
212-220Pb

202Os, 203Ir

132In

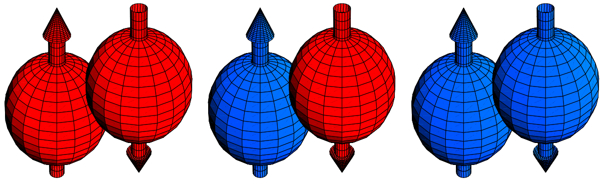
96,97,98Cd

Fragmentation of 107Ag

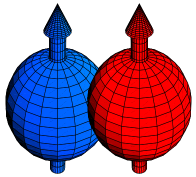


March 2006; Regan et al.

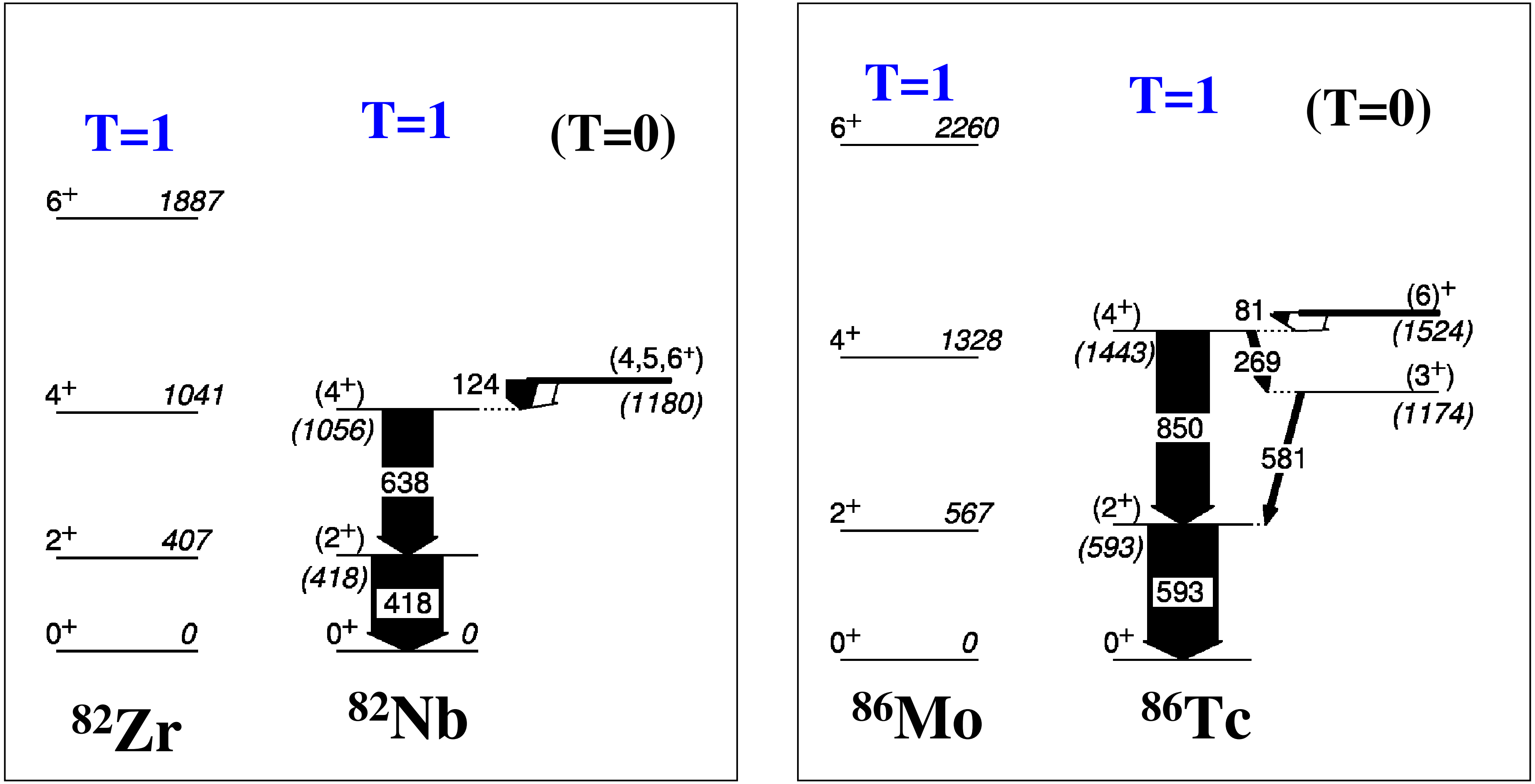
^{82}Nb and ^{86}Tc compared to their $T_Z=+1$ isobars



$T=1$: $I^{\pi}=0^{+}$

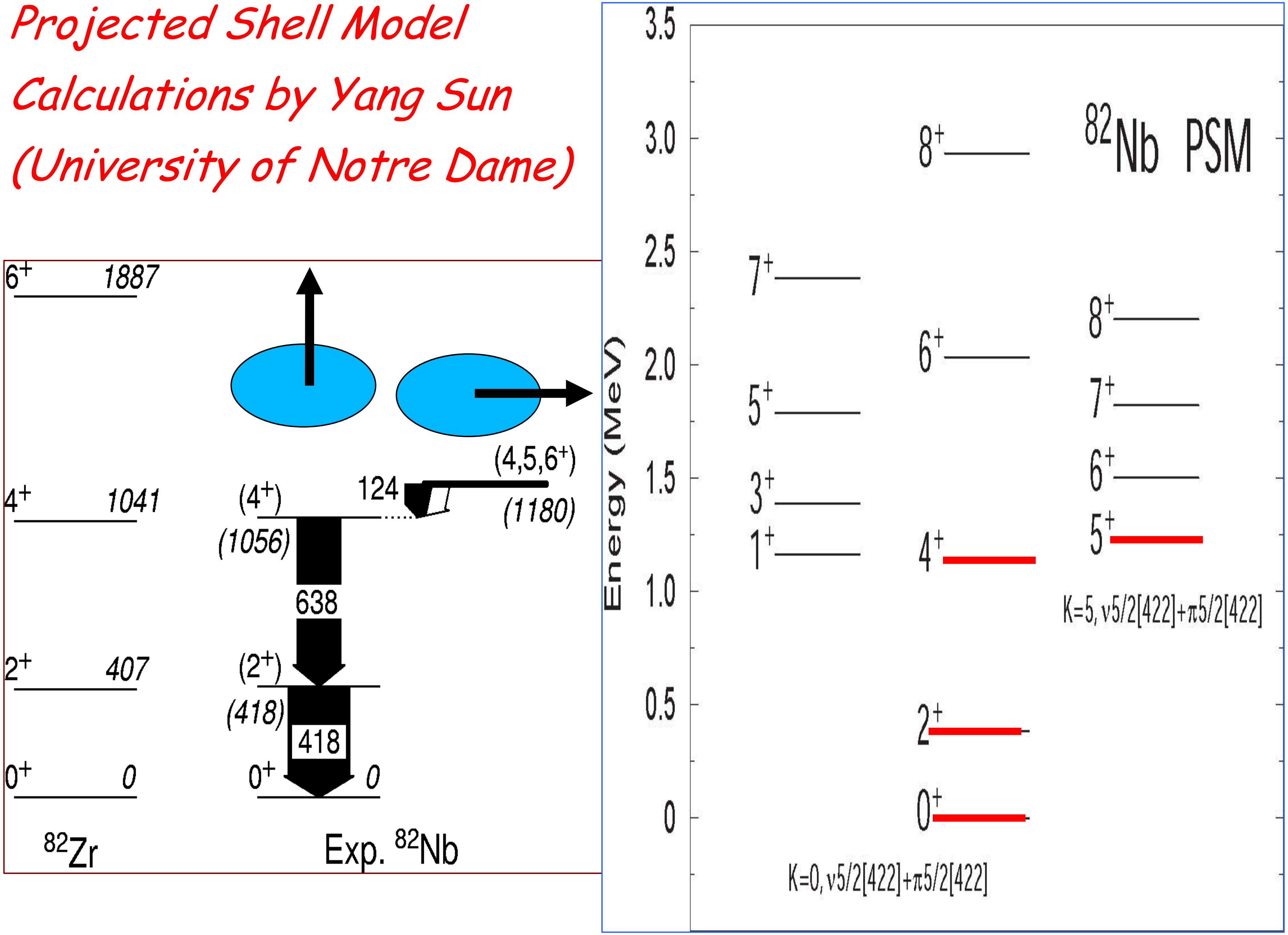


$T=0$: $I^{\pi}=1^{+}$ or $(2j)^{+}$



A. Garnsworthy et al., submitted to Physics Letters B

Projected Shell Model Calculations by Yang Sun (University of Notre Dame)



S352   30 (+ 9 parasitic) shifts

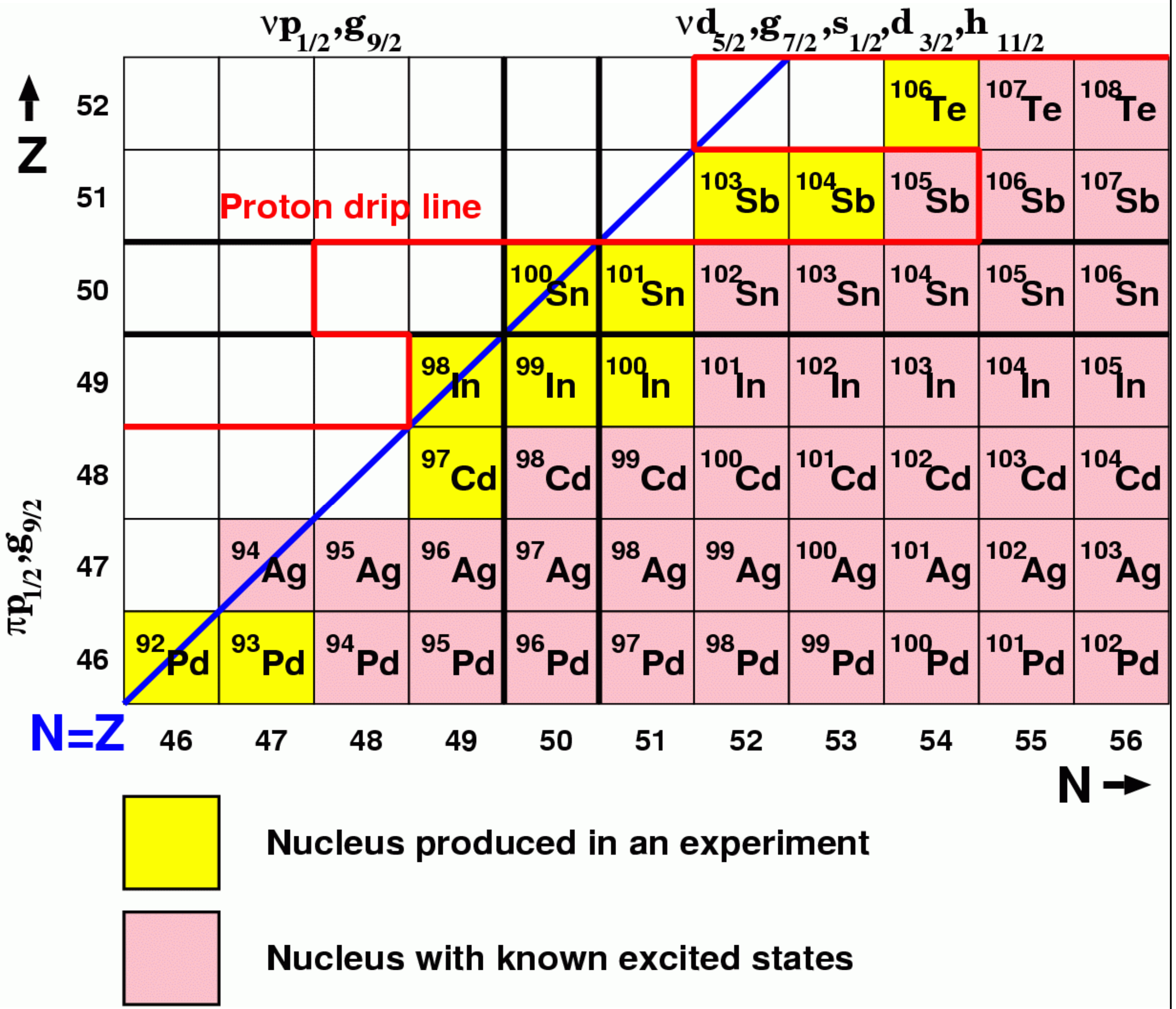
Study of $N \geq Z$ proton drip-line nuclei $^{96,97,98}Cd$ with astrophysical consequences

A. Blazhev[1], R. Wadsworth[2], P. Boutachkov[3], Z. Liu[4] et al.

Abstract

We propose to search for spin-gap 16^+ and $25/2^+$ isomeric states expected in $^{96,97}Cd$ and study in detail the residual interaction between $\pi g_{9/2}$ and $\nu g_{9/2}$, $\nu d_{5/2}$, $\nu g_{7/2}$ shells in $^{96,97,98}Cd$ by measuring the possible isomeric and/or particle decays. We also propose to study the β-decay of ^{96}Cd which is very important for the understanding of the astrophysical *rp*-process. The nuclei of interest will be produced in a fragmentation reaction of ^{112}Sn or ^{124}Xe beam on a ^{9}Be target, separated and identified in the FRS and, stopped in an 'active stopper' surrounded by the RISING stopped-beam high-efficiency Cluster Ge-detector array. Their γ-, β-, $\beta\gamma$- and possibly $\beta p\gamma$- or even $p\gamma$-decay properties will be measured simultaneously in a short (μs) and a long (s) delay window.

The region around ^{100}Sn



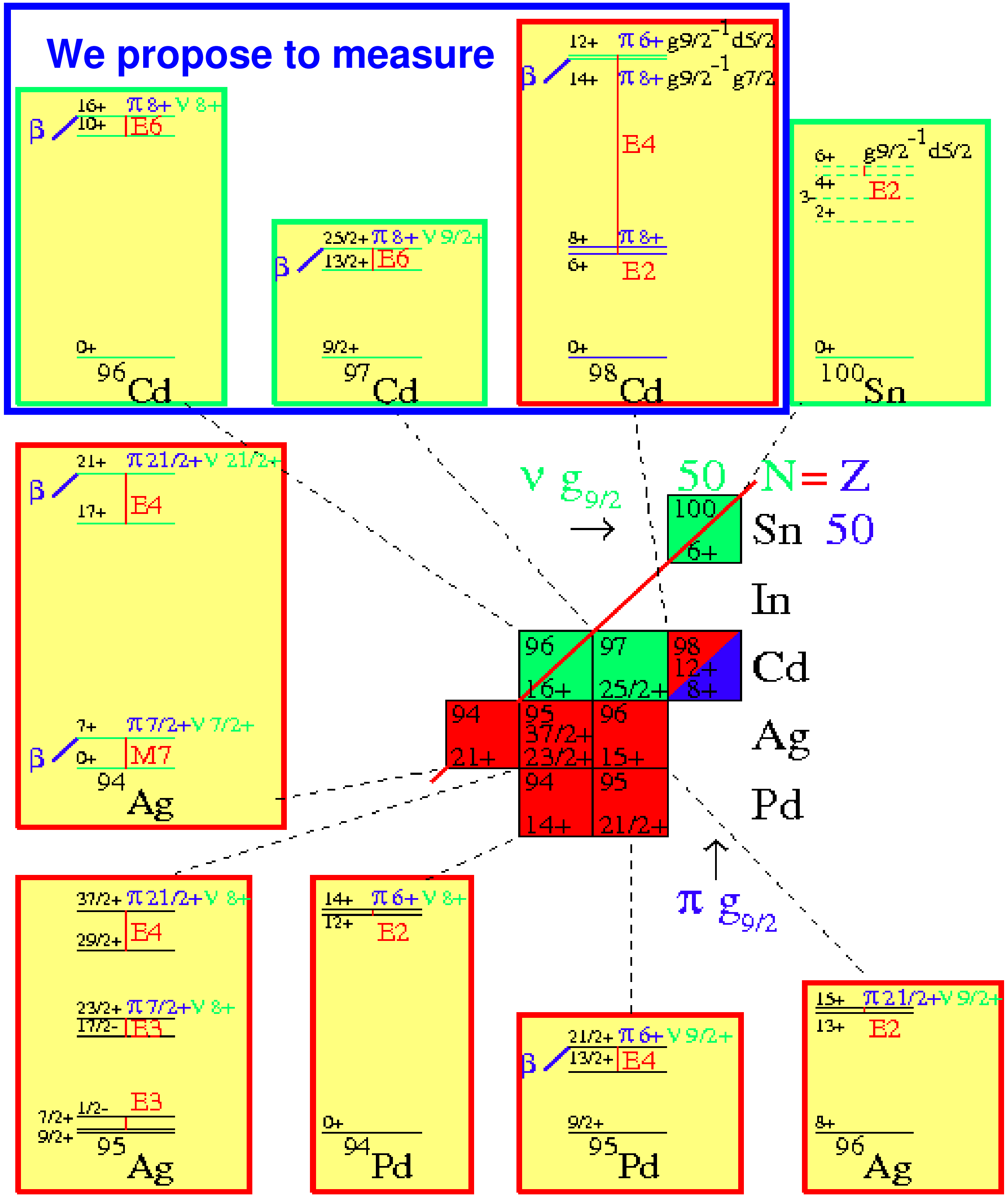
- Fusion-evaporation reaction
  EUROBALL, GASP, GAMMASPHERE
  + Ancillaries
  - -in-beam γ–spectroscopy

  GSI-ISOL
  - particle-decay
  - Isomers

- Spallation
  ISOLDE
  - particle-decay
  - Low-spin isomers

- Fragmentation
  GSI, GANIL
  - Coulex
  - Isomers
  - particle-decay

Spin-gap isomers below N=Z=50



H. Grawe *et al.*, Eur. Phys. J A 27, S01, 257 (2006).

Importance of isomers:

- Test of the Shell-model
- Single-particle structure
- $\pi\nu$ residual interaction
- astrophysics

Properties of isomers:

- Existence
- Excitation energy
- Halflife (transition strength)
- Spin and parity
- γ-decay cascades
- particle decays

Predicted spin-gap isomers

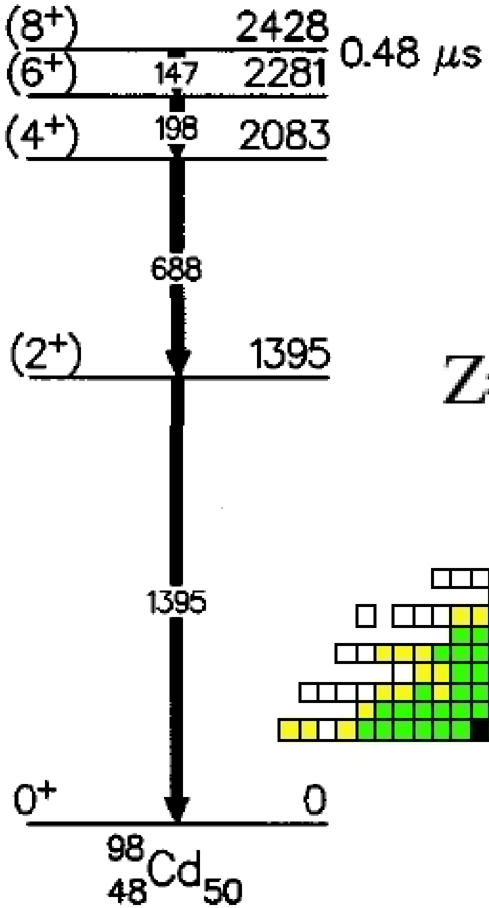
Known spin-gap isomers

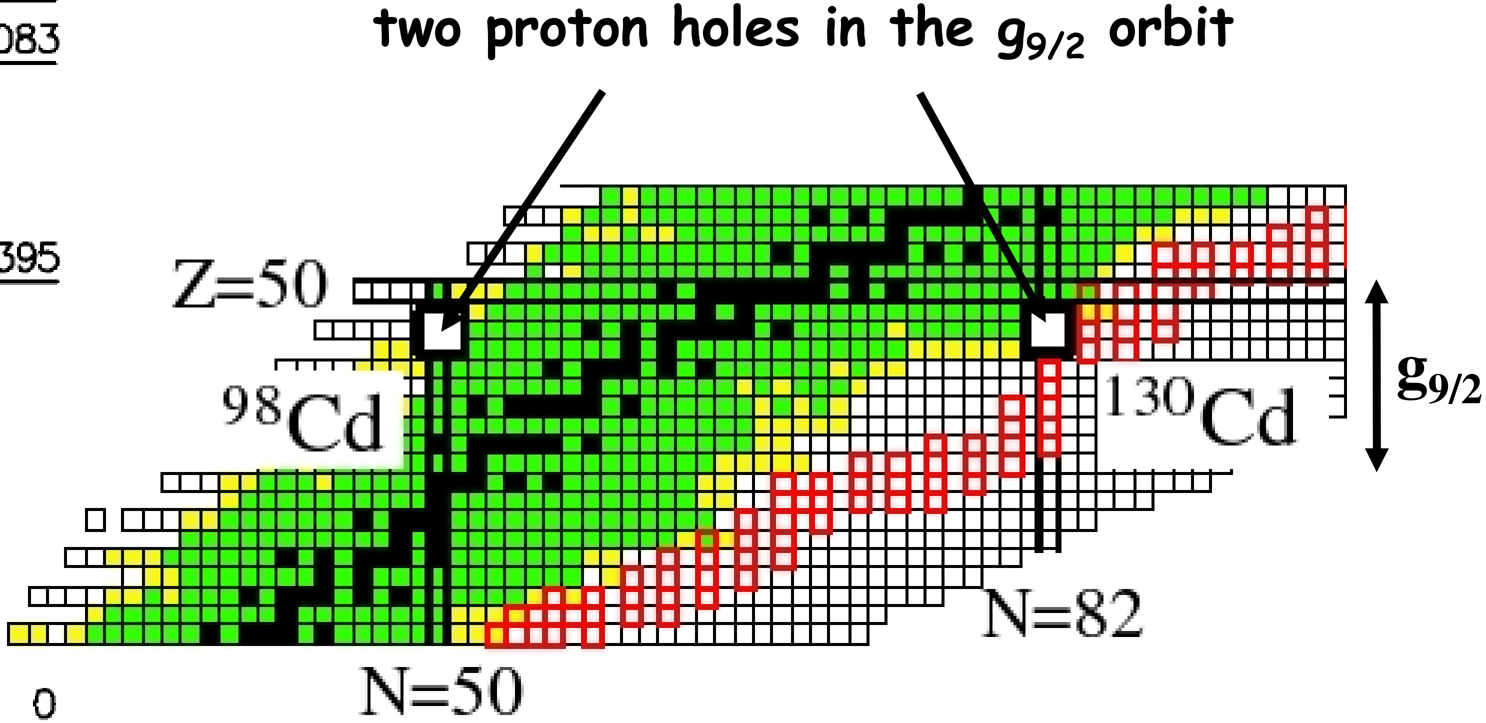
Seniority isomers

8^+ $(g_{9/2})^{-2}$ seniority isomer in ^{130}Cd

6-proton-knockout from ^{136}Xe: A. Jungclaus
fission of ^{238}U: M. Górska, M. Pfützner

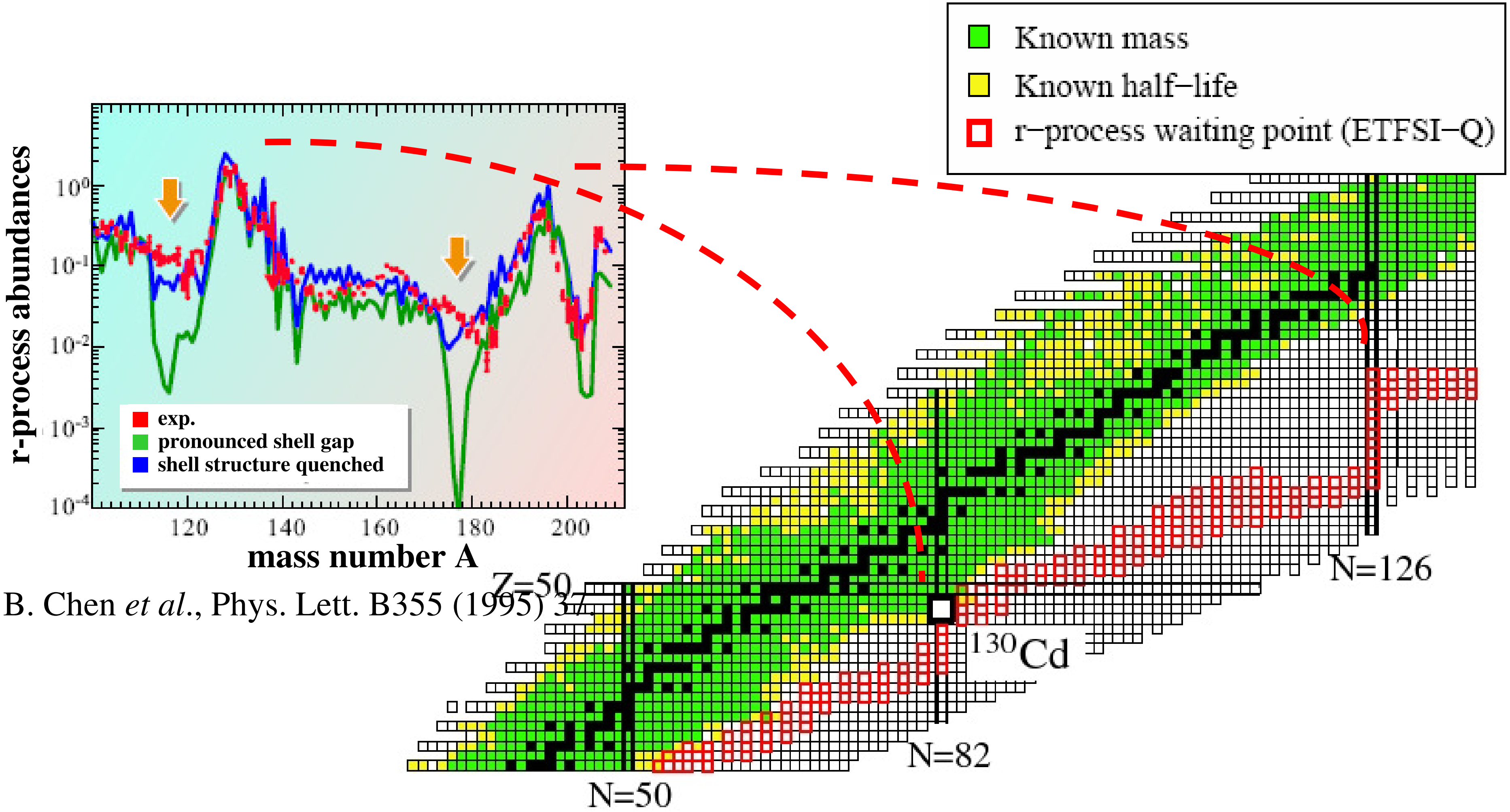
June/July 2006





M. Górska et al., Phys. Rev. Lett. 79 (1997)

Is there evidence for a N=82 shell quenching ?



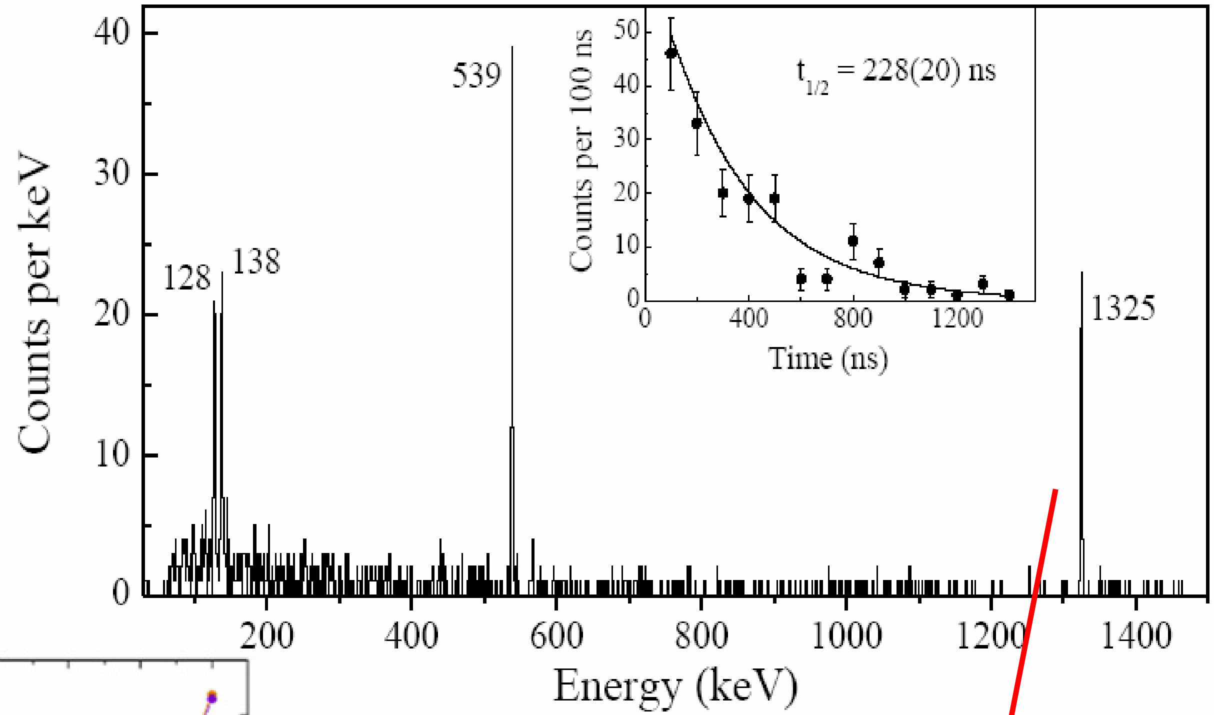
B. Chen *et al.*, Phys. Lett. B355 (1995) 37.

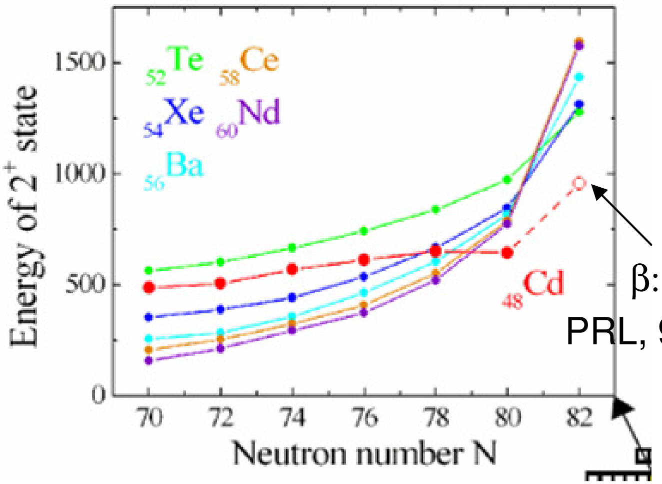
Assumption of a N=82 shell quenching leads to a considerable improvement in the global abundance fit in r-process calculations !

$^{130}Cd_{82}$ r-process waiting point nucleus (from fission and fragmentation)

Lucia Caceres PhD theses

A. Jungclaus et al., PRL 99, 132501 (2007)

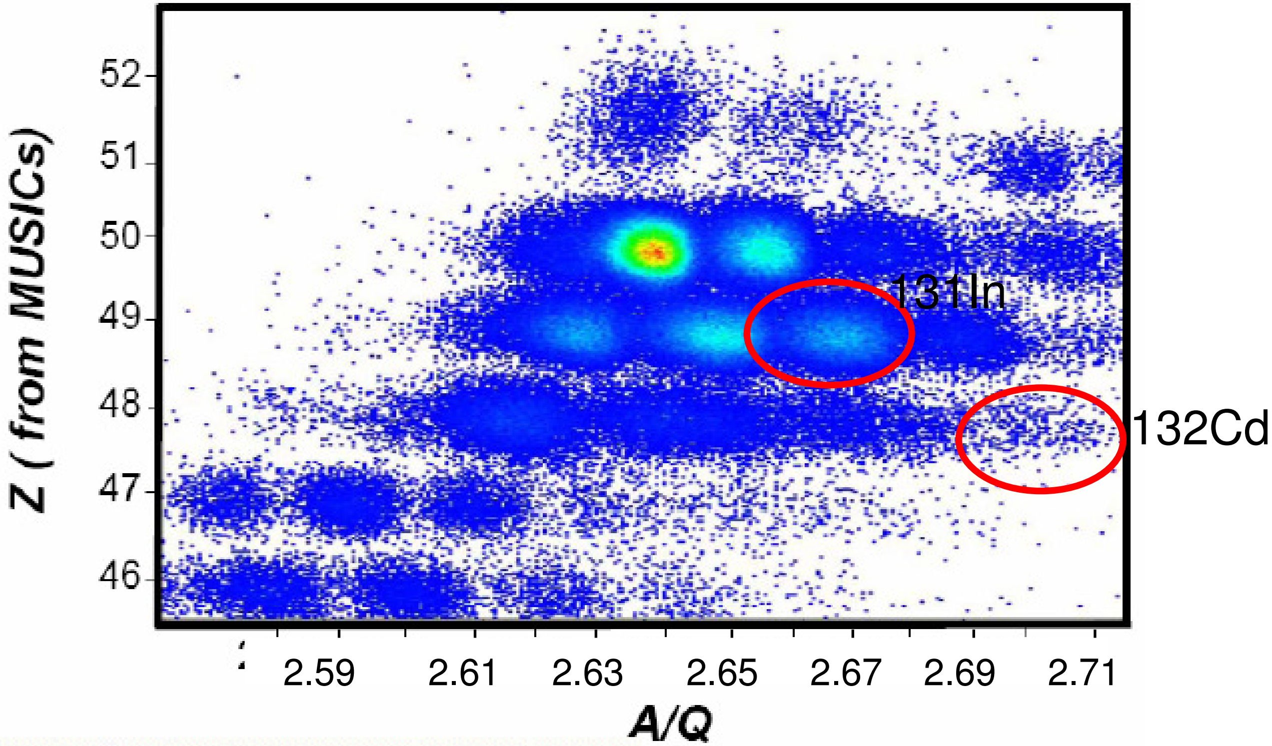


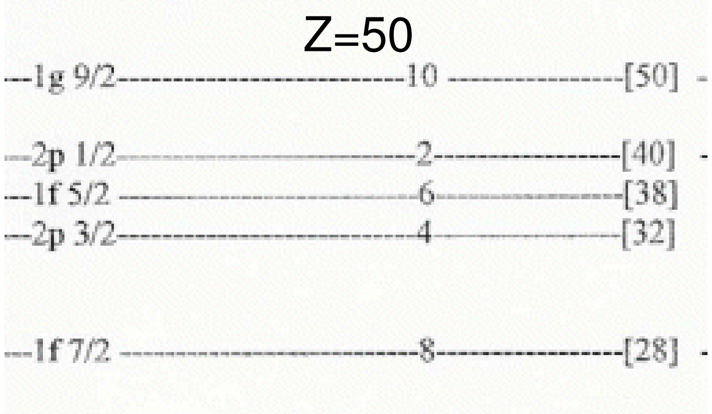


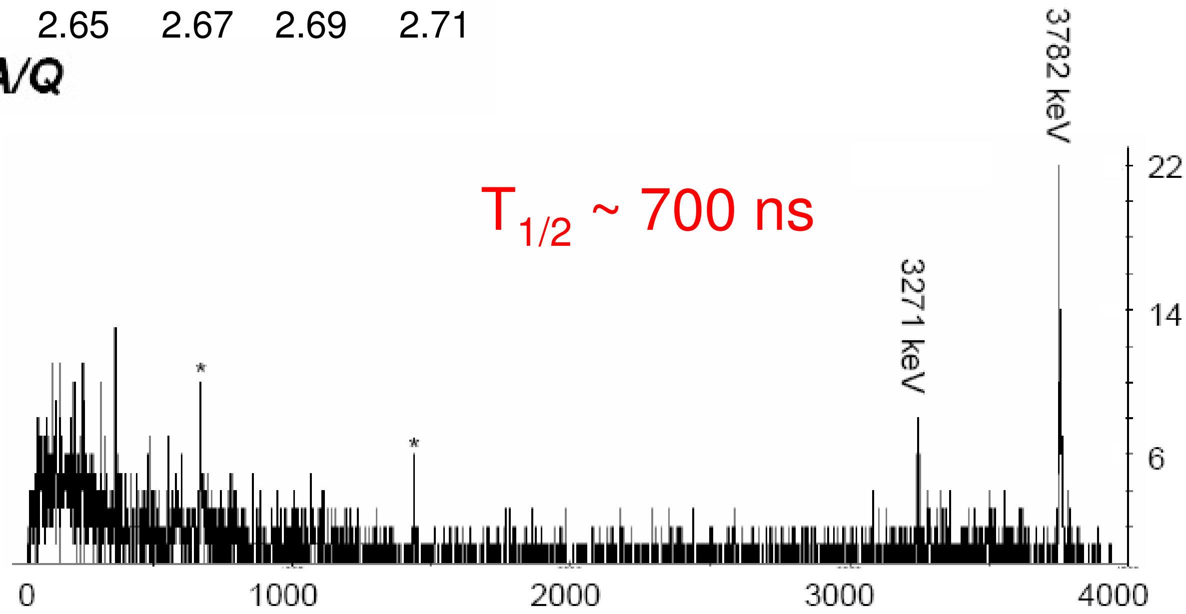
β:Dillman et al., PRL, **91, 162503 (2003)**

No evidence for shell quenching

$^{131}In_{82}$ (one proton hole nucleus)

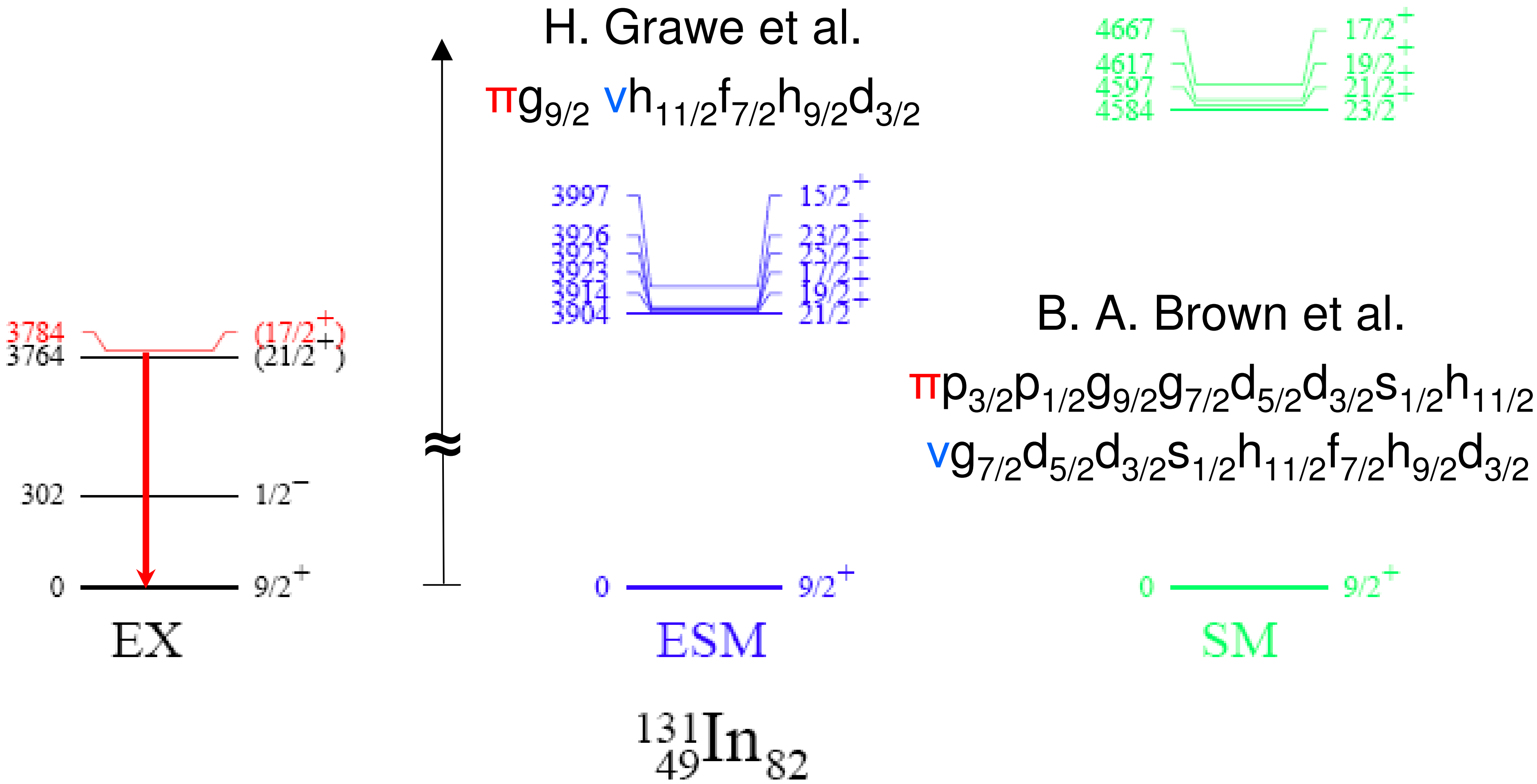






M. Górska et al., to be submitted

SM calculations - shell gap in ^{131}In excitation through the N=82 gap



S337 15(+0) shifts

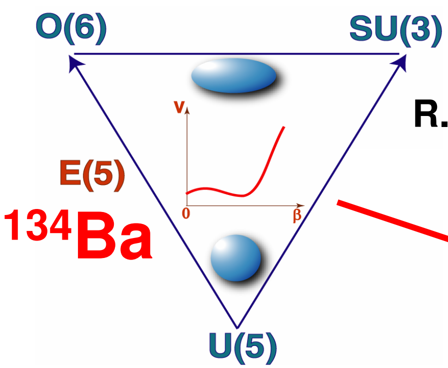
Structure of ^{132}In through the β-decay of ^{132}Cd: the $\nu f_{7/2}\,\pi g_{9/2}^{-1}$ multiplet on the ^{132}Sn core.

A.Gadea (INFN-LNL) et al.

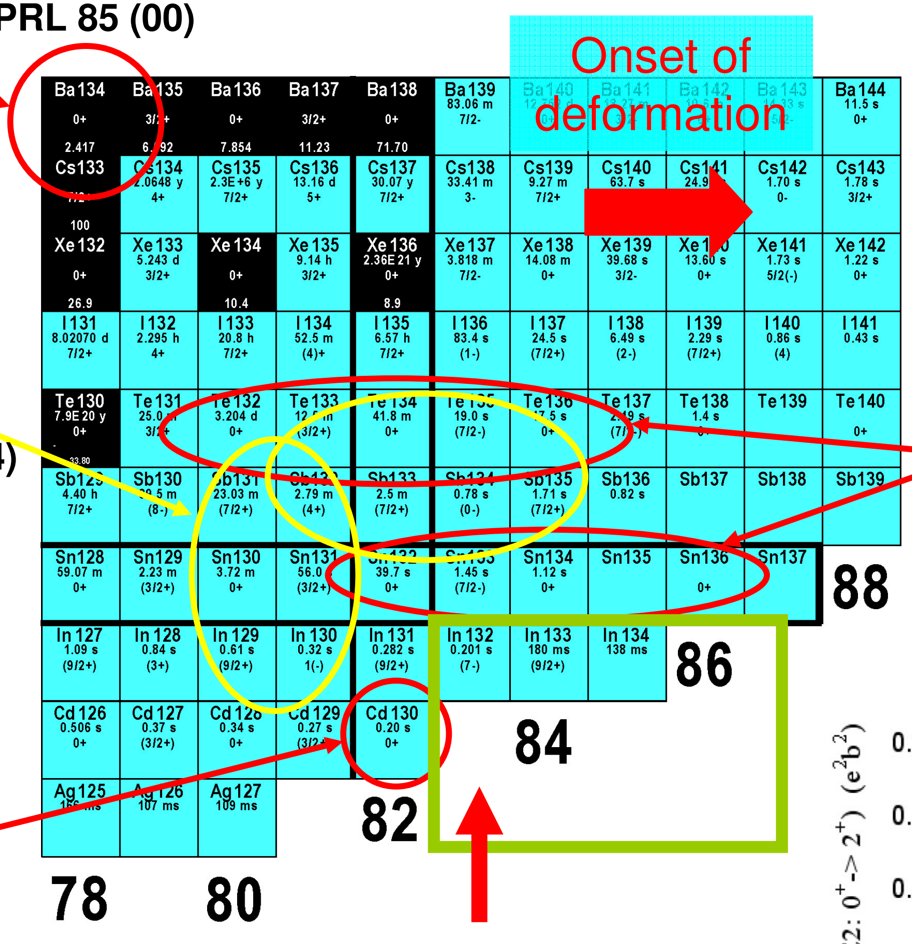
Abstract

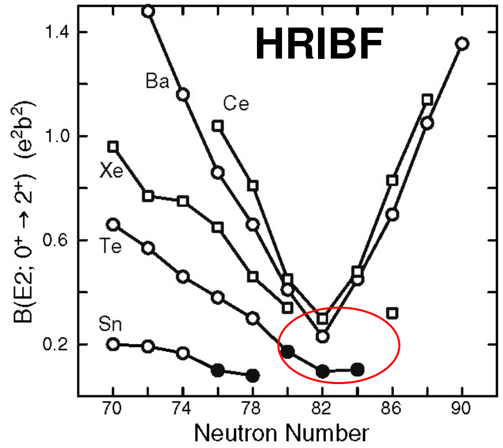
Studies of nuclei around the doubly magic nucleus ^{132}Sn are one of the cornerstones for several new generation RIB facilities, focused on neutron-rich exotic beams originated as fission products or fragmentation. Current experimental and theoretical efforts are ongoing to understand better these nuclei in order to pave the way to the exotic phenomena expected for the very neutron-rich species that will be soon reachable. Present in-flight facilities such as the FRS, equipped with instruments such as the Rising stopped beams setup, can make a large contribution to this endeavour through the study of isomers and β-decay. This is particularly true for those species that are difficult to study in ISOL facilities due to the lack of purity of the beam or the difficulty of extracting some species from the ion-source. This proposal is aimed at the first spectroscopic study of the structure of the one-proton hole, one-neutron particle ^{132}In nucleus. The beta decay of the nucleus ^{132}Cd will be studied following its production with a ^{238}U beam and an induced-fission reaction.

Structure in the ^{132}Sn region



R.F.Casten et al,
PRL 85 (00)



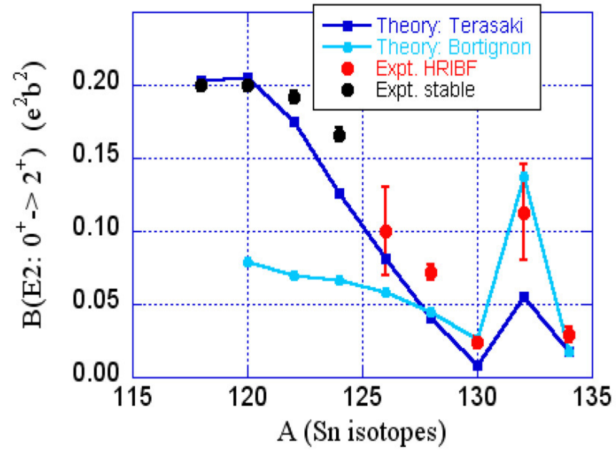


D.C.Radford et al,
PRL 88 (2002)

Shell Model nuclei realistic CD-BONN interaction

A.Sherillo et al, PRC70 (04)

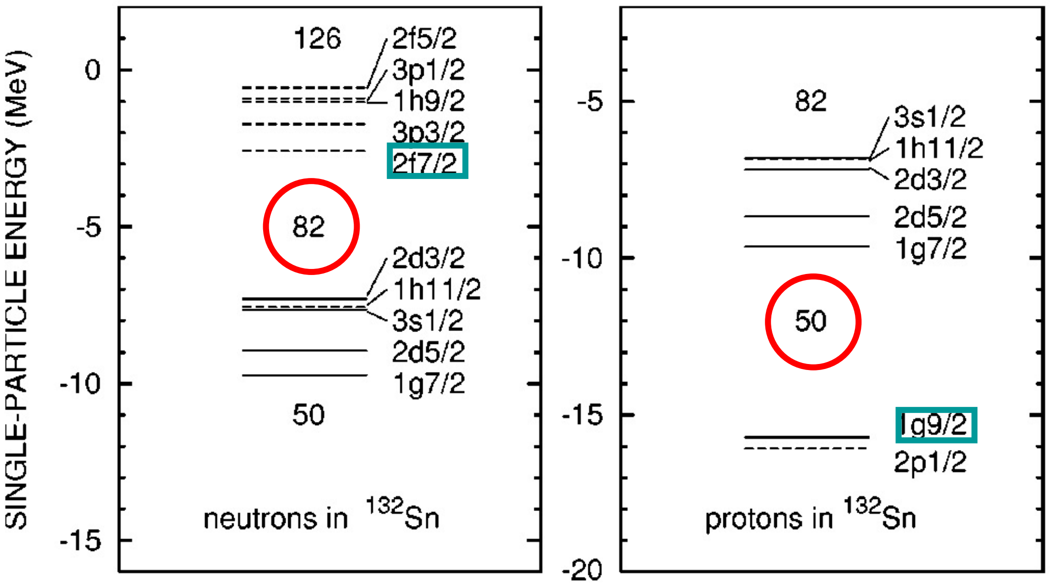
J.Terasaki et al, PRC66 (02)
G.Colo et al., NPA722 (03)
A.Ansari, PLB623 (05)



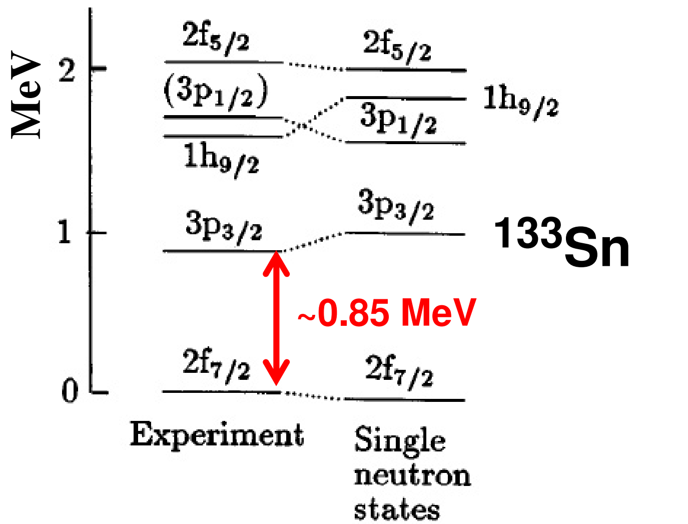
Seniority Isomers
A.Jungclaus / M.Gorska
Rising: PRL

Shell structure evolution

The Shell Structure in ^{132}Cd and ^{132}In

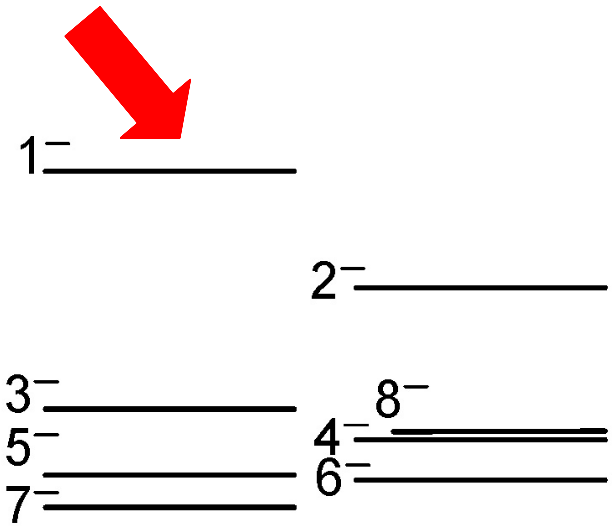


J.Terasaki et al, PRC66 (02), V.I.Isakov at al, nucl-th/0202044

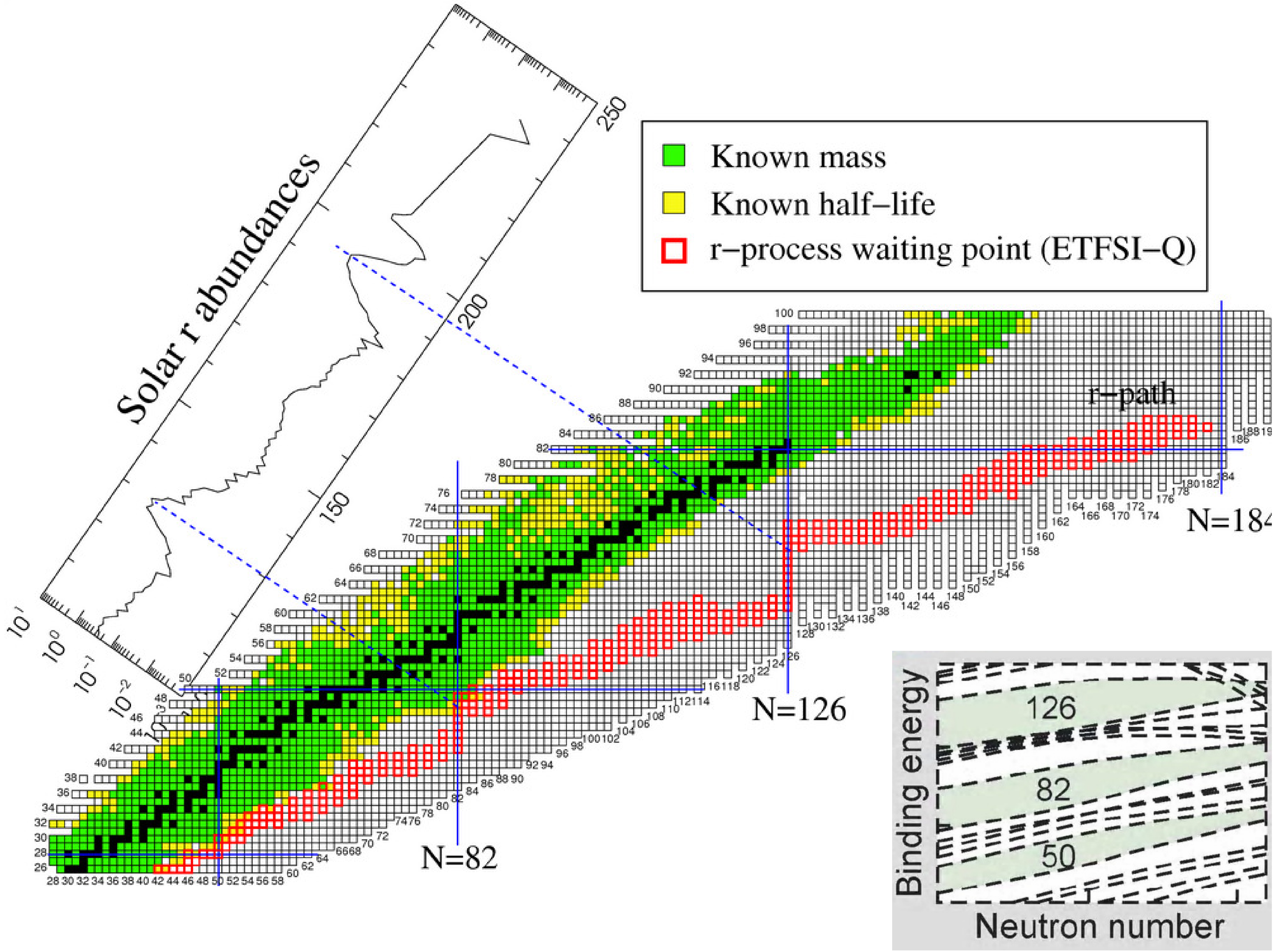


Low excitation energy $\nu p_{3/2}$

P.Hoff et al, PRL77 (96)



S.M. estimates of the 132In $f_{7/2}\, g_{9/2}^{-1}$ multiplet



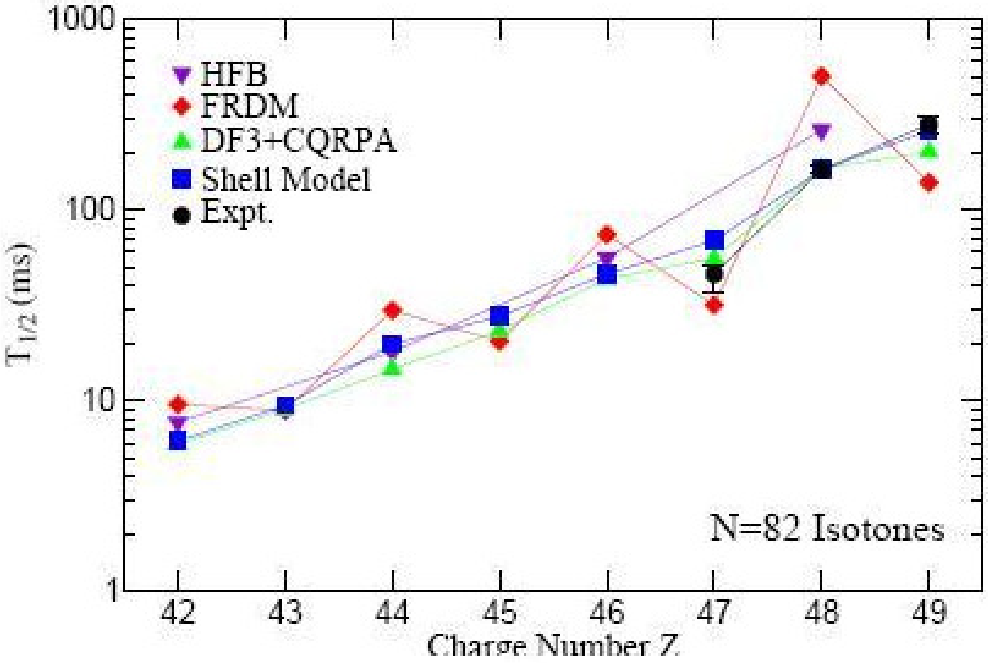
Solar r abundances
Known mass
Known half−life
r−process waiting point (ETFSI−Q)
r−path
N=82
N=126
N=184
Binding energy
Neutron number
126
82
50

S347 18(+6) shifts

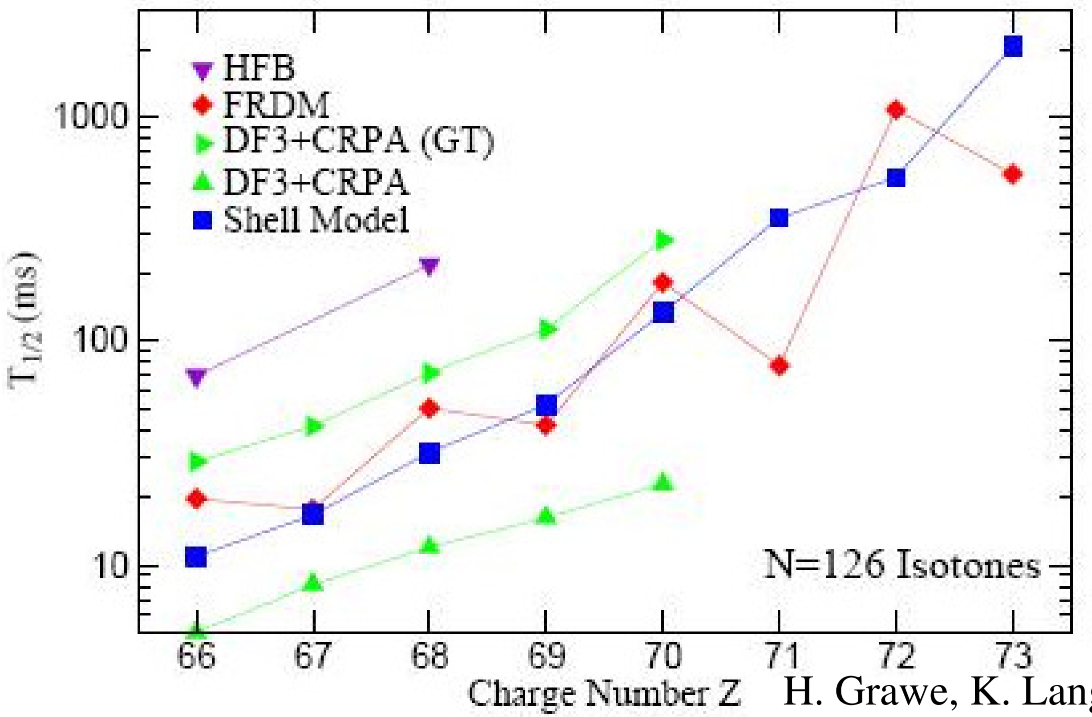
Along the N=126 closed shell

Zs.Podolyák et al.

Abstract: The main aim of the experiment is to extend our knowledge of the neutron-rich N=126 nuclei. It will be done by observing isomeric decays in ^{202}Os, as well as observation of beta decays from the N=127 isotones into the ^{202}Os, ^{203}Ir, ^{205}Au N=126 nuclei. It is expected that the following yrast isomeric states in ^{202}Os are populated in the fragmentation of ^{238}U with sufficient cross section to be observed: 5^- $(\pi s_{1/2}^{-1} h_{11/2}^{-1})$ and/or 7^- $(\pi d_{3/2}^{-1} h_{11/2}^{-1})$, and 10^+ $(\pi h_{11/2}^{-2})$. The beta decay into ^{203}Ir and ^{205}Au will fix the proton single particle energies. The gained information is important both for our understanding of the possible shell evolution at N=126 and to provide better theoretical predictions for the properties of the r-process path N∼126 nuclei. In addition, the reaction mechanism of the projectile fragmentation will be studied by measuring the population of states with high angular momenta (I≈30$\hbar$) in the neutron-deficient N∼126 nuclei.



N=82

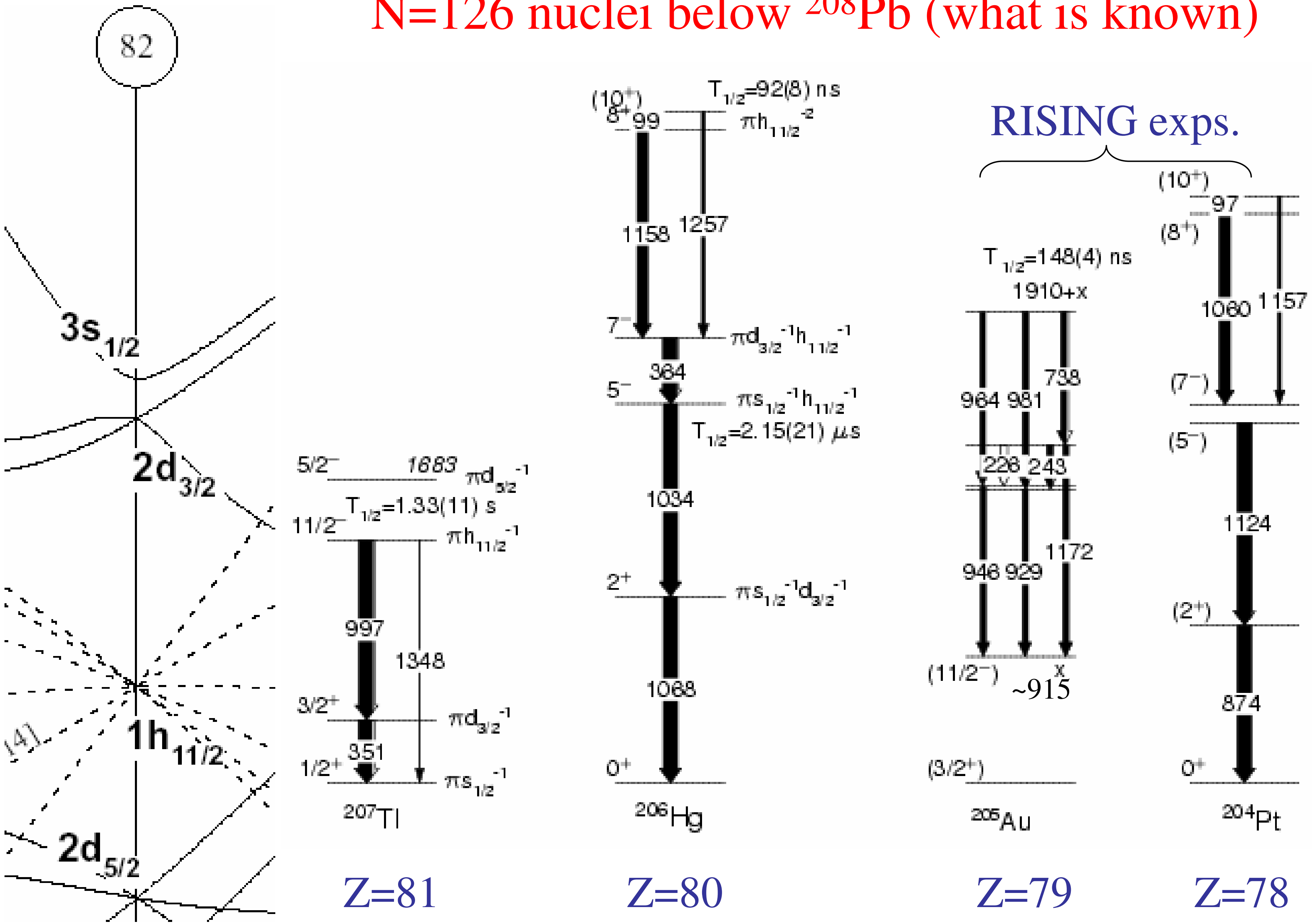


N=126

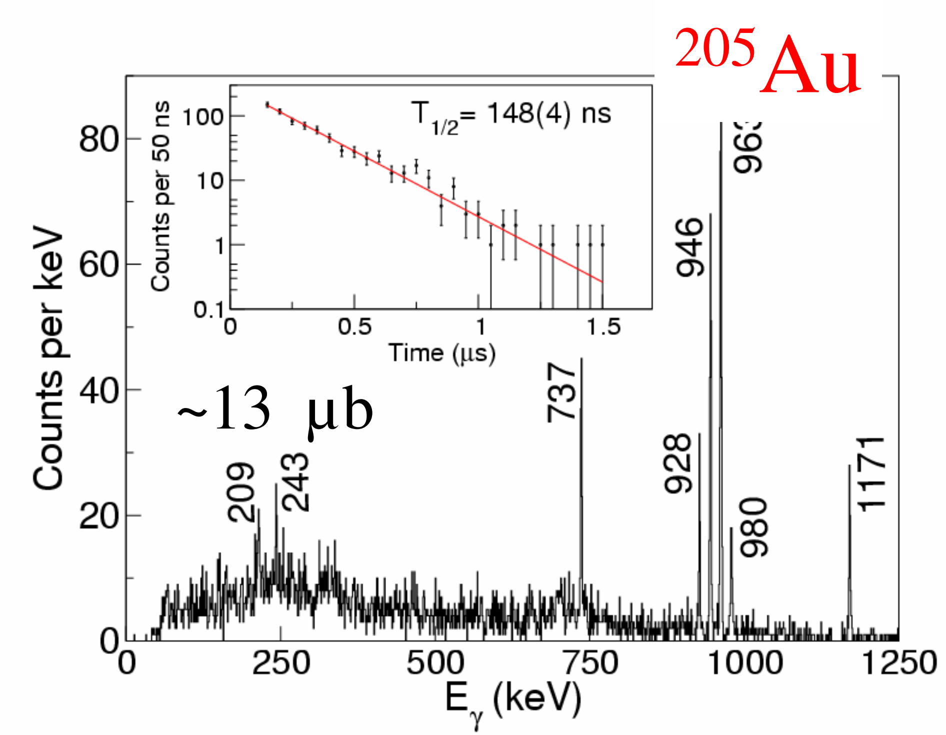
Larger differences
(lack of experimental data)

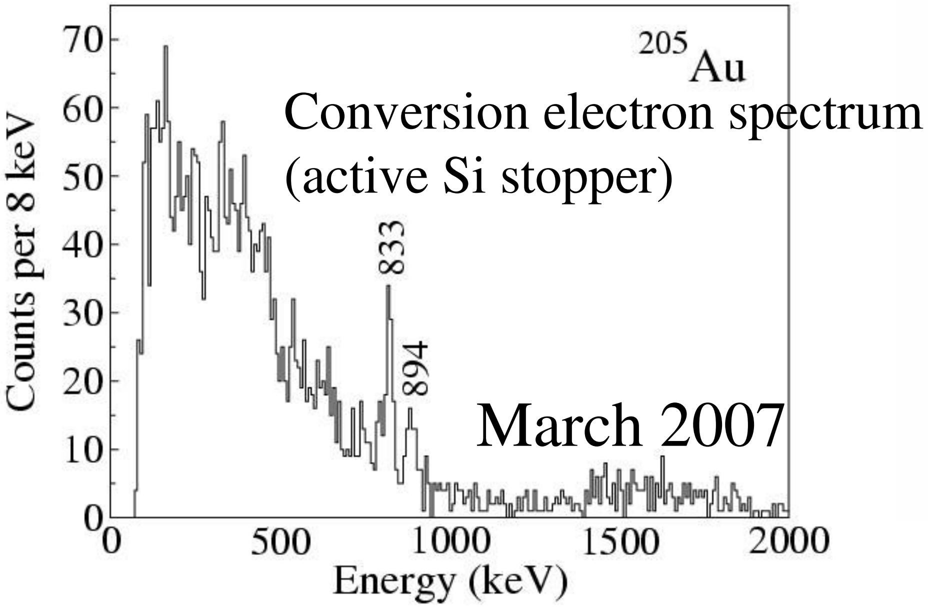
H. Grawe, K. Langanke, G. Martinez-Pinedo, to be published.

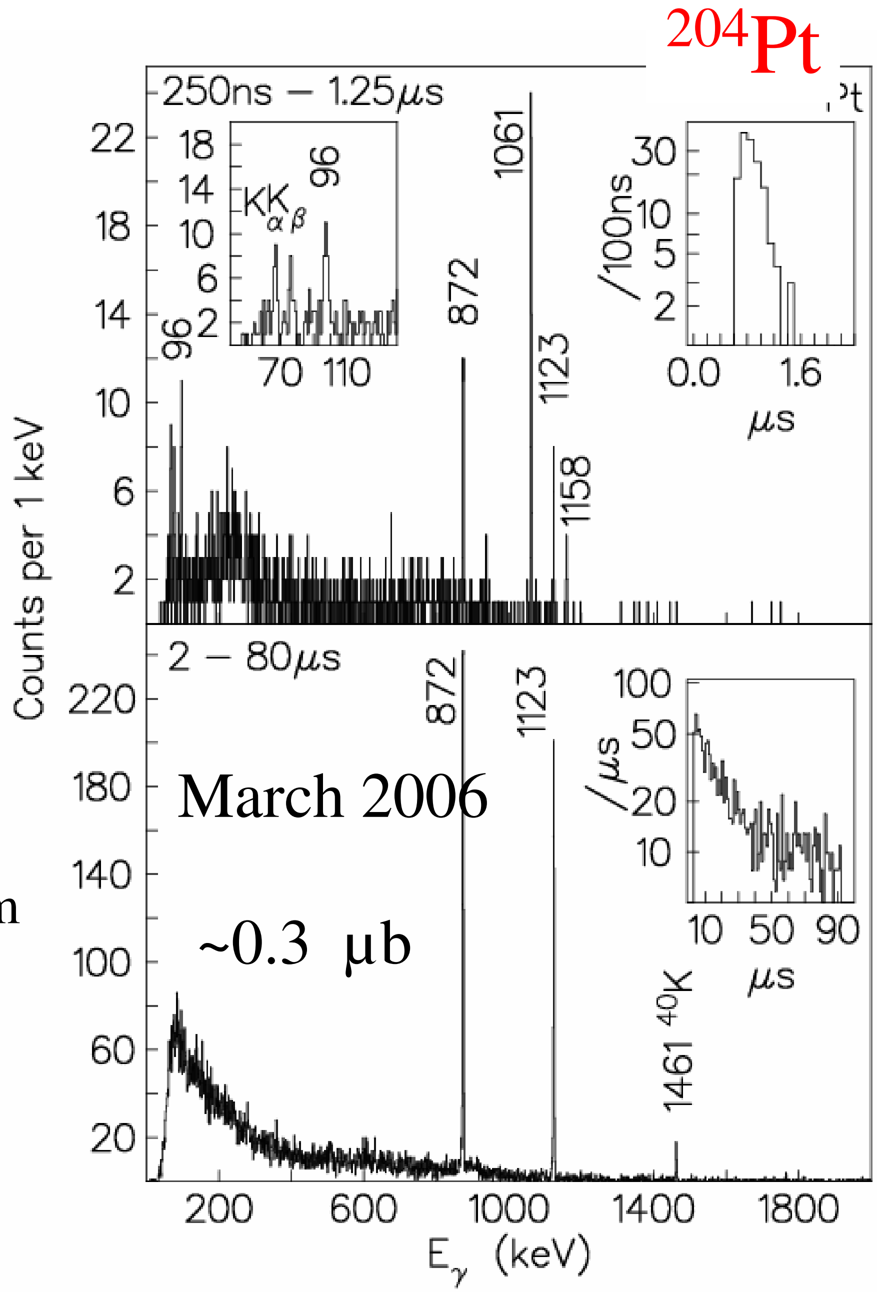
N=126 nuclei below ^{208}Pb (what is known)



S.Steer et al., PRL in prep.







^{208}Pb beam was used

Further ‘down’ along the N=126 line: ^{238}***U beam***

^{205}**Au**: beta decay from ^{205}Pt

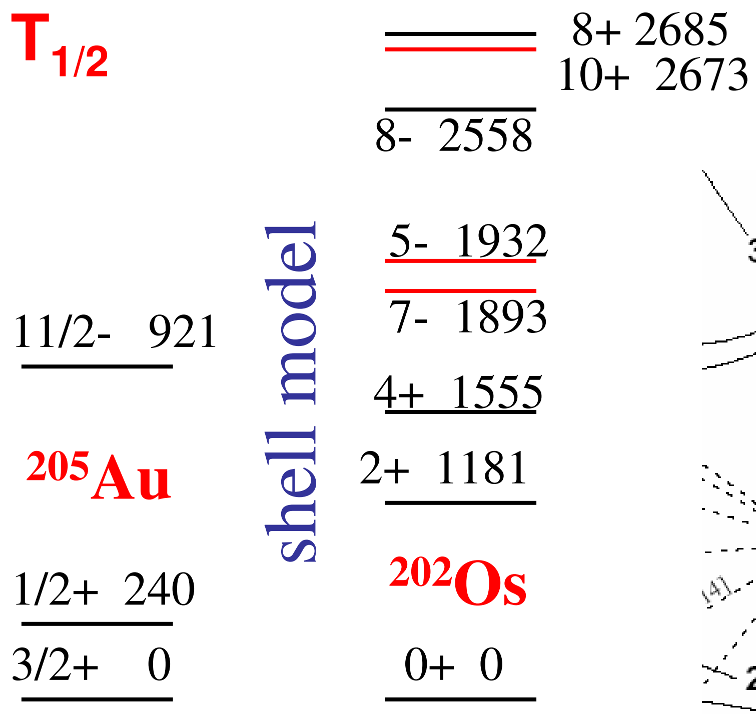
=> will fix the $\pi s_{1/2}$ orbital

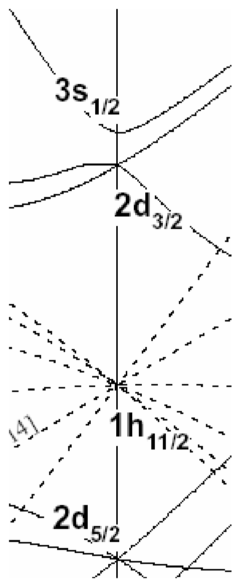
^{203}**Ir**: beta decay from ^{203}Os ($\nu g_{9/2}$)

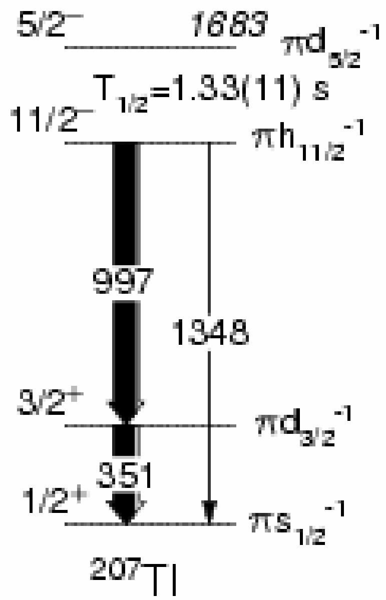
=> will fix the $\pi d_{3/2}$,$\pi s_{1/2}$,$\pi h_{11/2}$

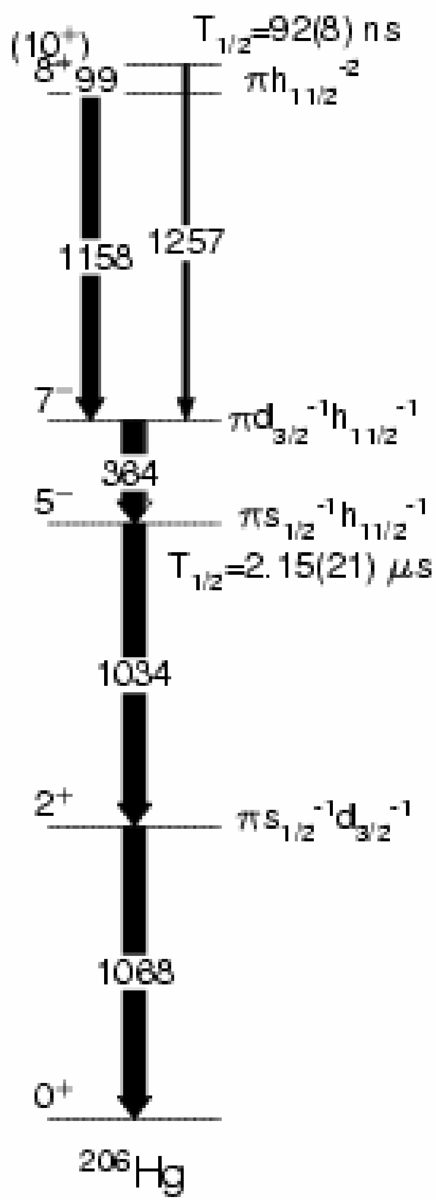
^{202}**Os**: isomeric decay I=(5),(7),(10)

^{202}**Os**: beta decay of ^{203}Ir ($\nu g_{9/2}$)









S350 18(+6) shifts

Moving along Z=82, beyond the doubly-magic ^{208}Pb nucleus

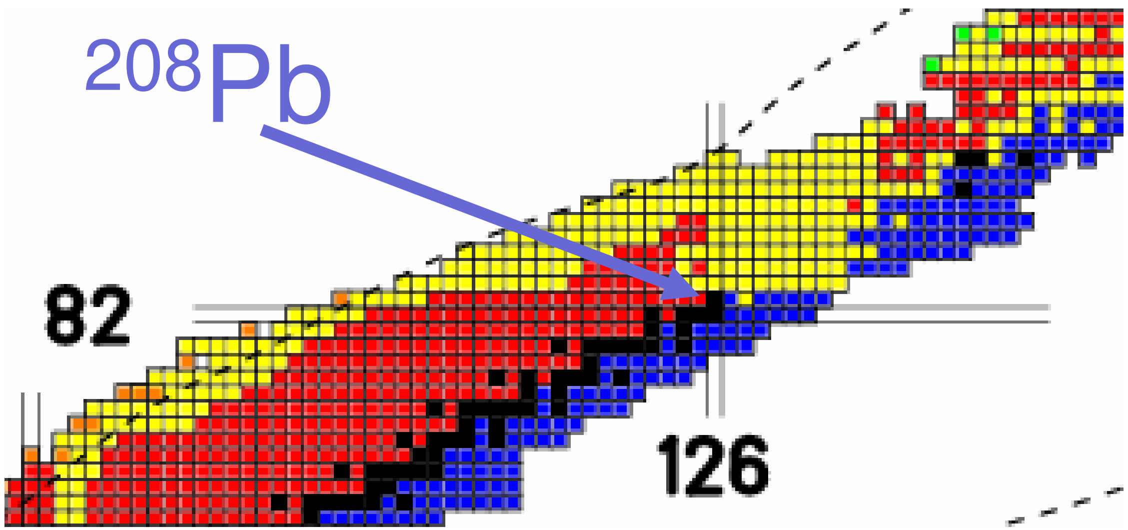
G. Benzoni (Milano), J-J. Valiente Dobón (Legnaro) et al.

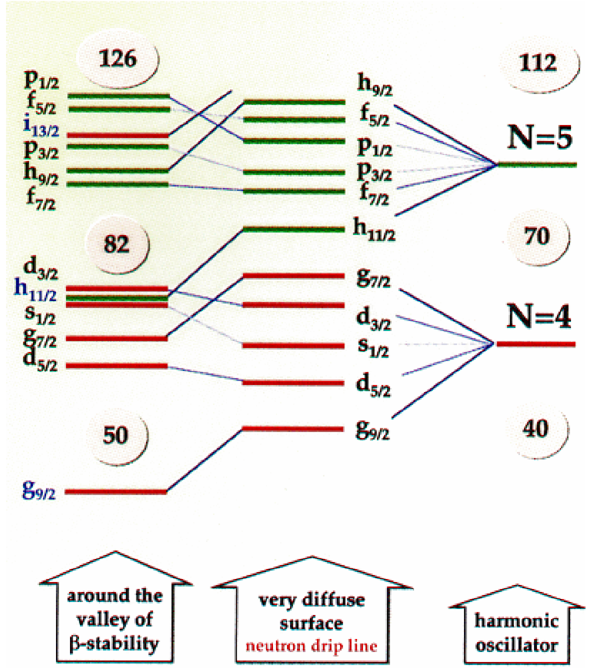
Abstract: This proposal is aimed at the study of the nuclear structure of neutron-rich Z=82 nuclei, ranging from ^{212}Pb to ^{220}Pb, taking advantage of the long-lived high-spin isomers expected for these nuclei. These nuclei will be produced in a cold fragmentation reaction at relativistic energies, using a ^{238}U beam at 1GeV/u. The study of the isomeric γ-decay of long lived states will provide a detailed insight on the nuclear structure of the neutron-rich lead nuclei and an efficient probe of the Z=82 shell evolution at large isospin values. The study of the isomers will be complemented by the measurement of the half-lives of the β decay from the exotic lead isotopes, by means of an active stopper array.

Physics Motivation

Shell Evolution

Study shell structure along Z=82



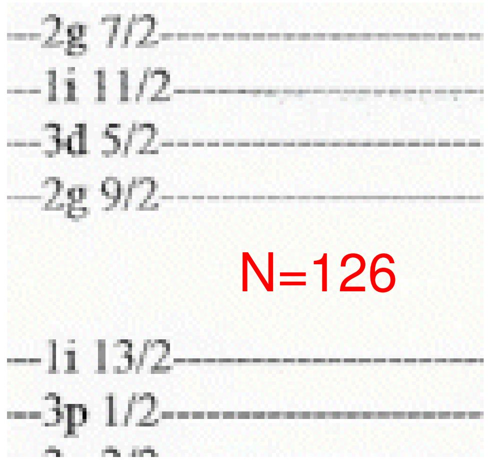


N/Z~1.0– 1.6 N/Z~3.0

Evolution of shell structure: Measurement of the $E(2^+)$, $E(4^+)$ and $B(E2)$

What is the shell structure of neutron-rich Pb nuclei?

Physics Motivation



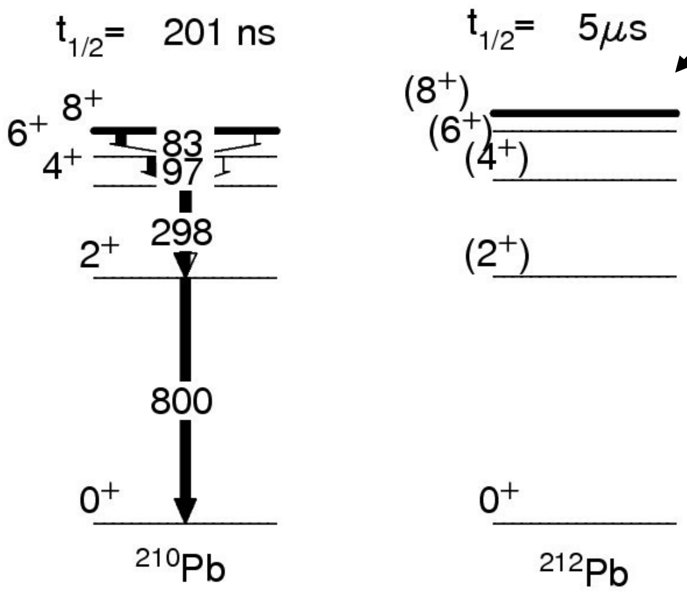
Presence of isomers involving high-j orbita:

$vg_{9/2}$, $vi_{11/2}$, $vj_{15/2}$

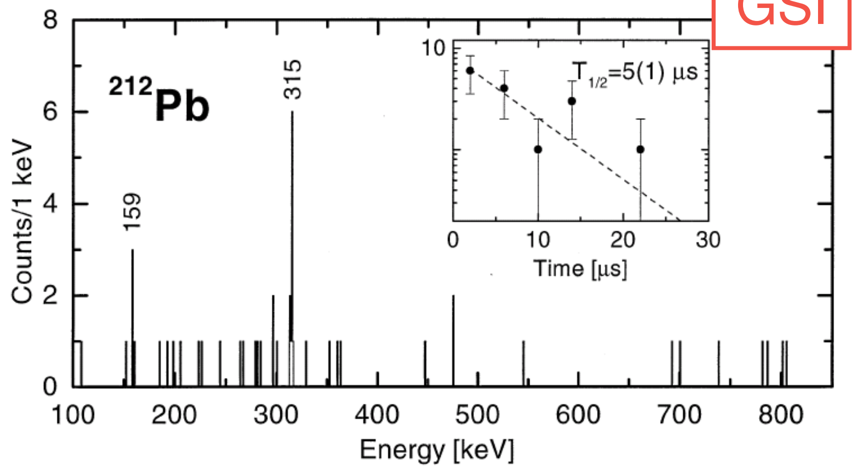
we want to study the developmet of

nuclear structure from ^{212}Pb up to ^{220}Pb

Configuration $(vg_{9/2})^4$



GSI



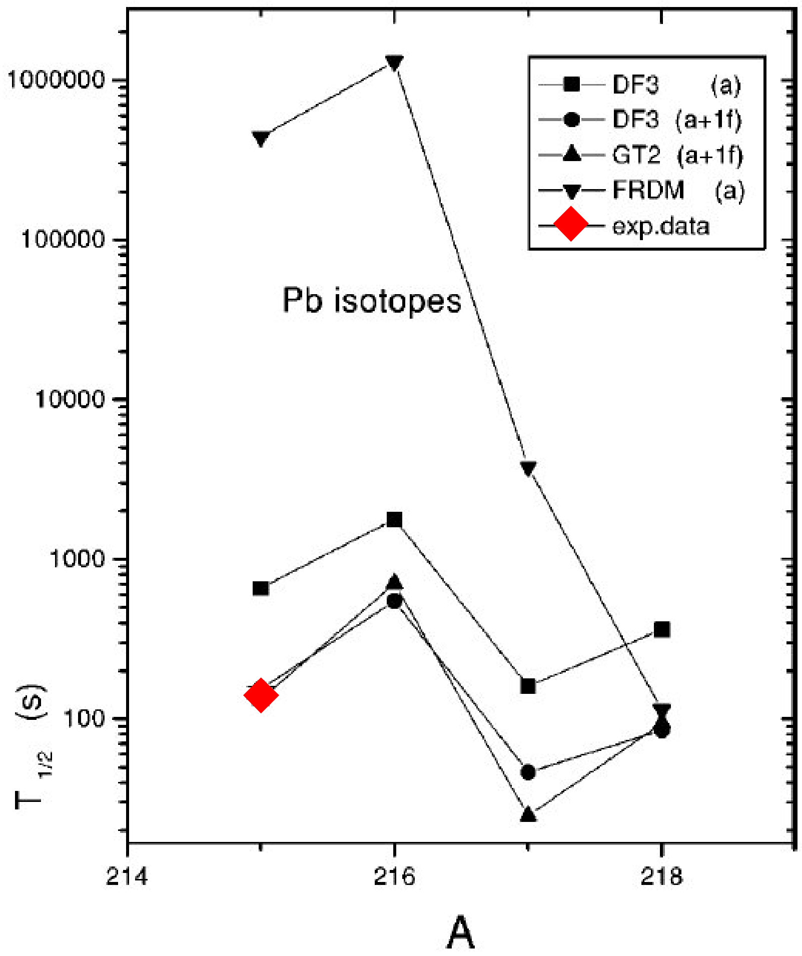
- $5x10^6$ pps
- 2 HPGe detectors (Eff_γ=1%)
- 350 ions implanted

Neutron-rich lead isotopes known up to ^{212}Pb

M. Pfutzner PLB444 (1998) 32.

Physics Motivation

Beta-decay lifetimes



- Experimental β-decay data needed around ^{208}Pb to validate theoretical models.
- Models might differ by orders of magnitude to reproduce the lifetimes.
- β-lifetimes needed for r-process calculations.
- Last lifetime measured for ^{215}Pb

I.N. Borzov PRC67, 025802 (2003)

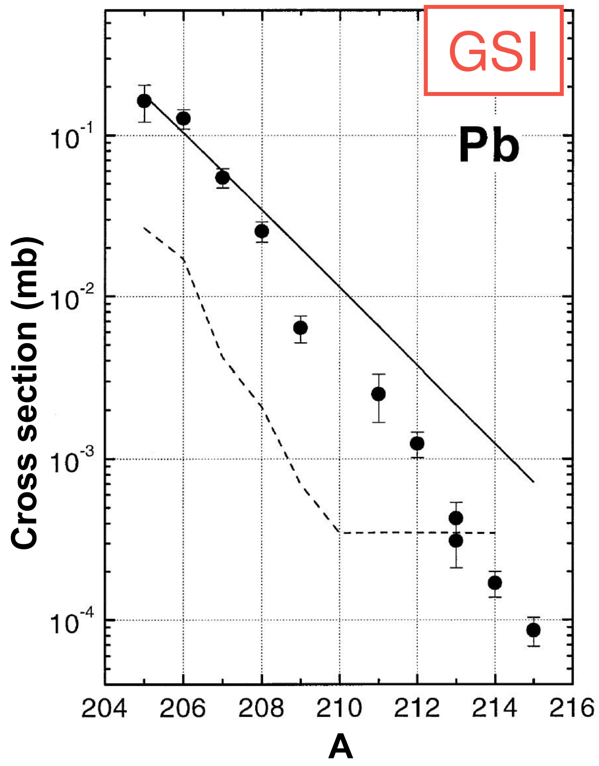
Experimental approach

Deep inelastic | ^{238}U fragmentation

^{208}Pb	^{209}Pb	^{210}Pb 210ns	^{211}Pb	^{212}Pb 5μs	^{213}Pb	^{214}Pb	…

^{238}U fragmentation at 1 GeV/u allows to reach heavy Pb isotopes with a reasonable cross section (^{212}Pb up to ^{220}Pb).

The GSI UNILAC-SIS accelerator system combined with the FRS and RISING setup provide a UNIQUE worldwide facility to populate and study the neutron-rich lead isotopes.



M. Pfutzner PLB444 (1998) 32.

Fundamental questions in nuclear physics:

Neutron-proton pairing
Isospin symmetry
Shell evolution
Nucleosynthesis (rp- and r-processes)