THEORETICAL DEVELOPMENTS IN HEAVY NUCLEI

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Warsaw University

International Nuclear Physics Conference
30 July - 3 August 2001
Berkeley, CA

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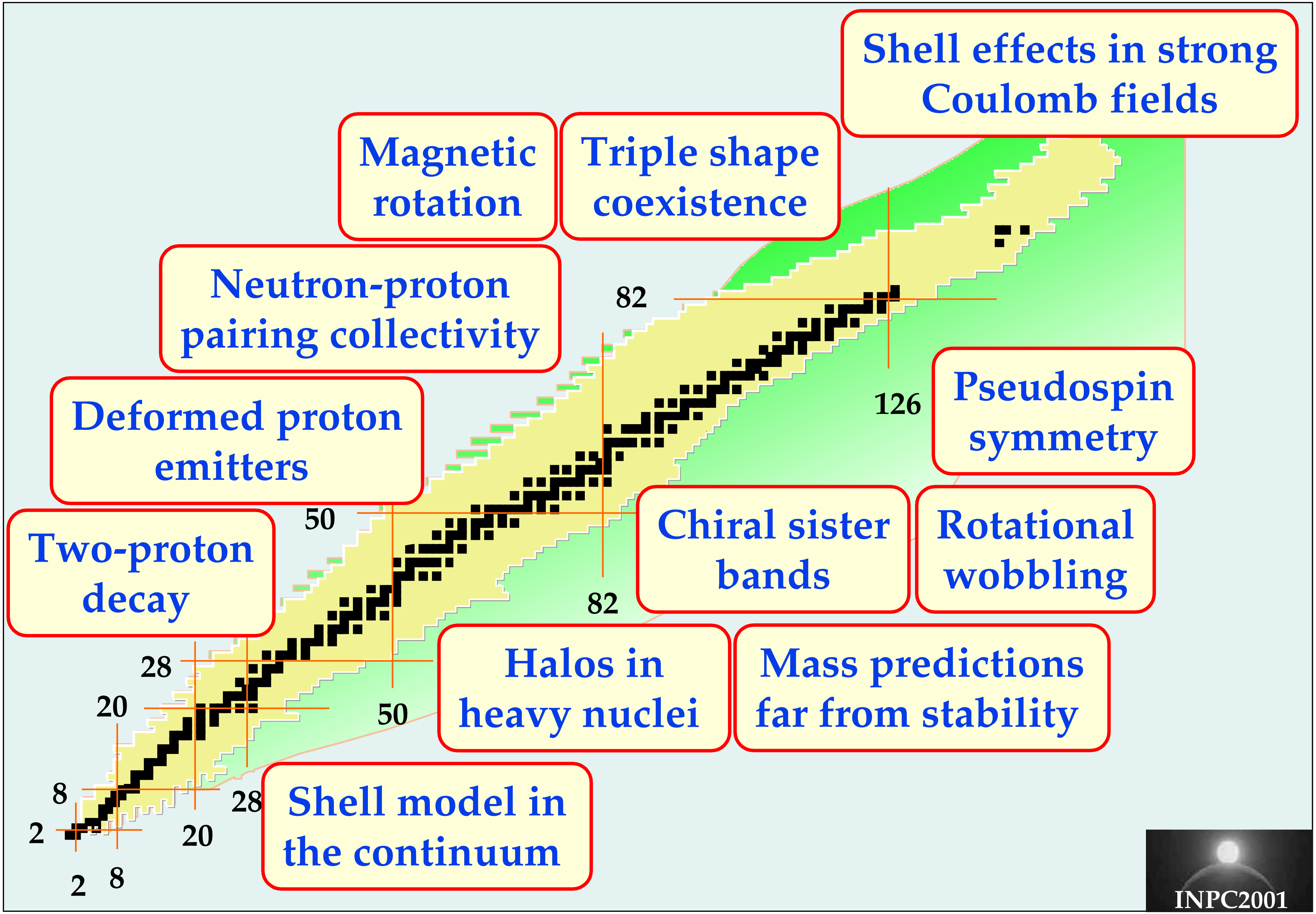

Shell effects in strong Coulomb fields
Magnetic rotation
Triple shape coexistence
Neutron-proton pairing collectivity
Deformed proton emitters
Two-proton decay
Pseudospin symmetry
Chiral sister bands
Rotational wobbling
Halos in heavy nuclei
Mass predictions far from stability
Shell model in the continuum
82
126
50
82
28
20
50
8
2
28
20
2
8
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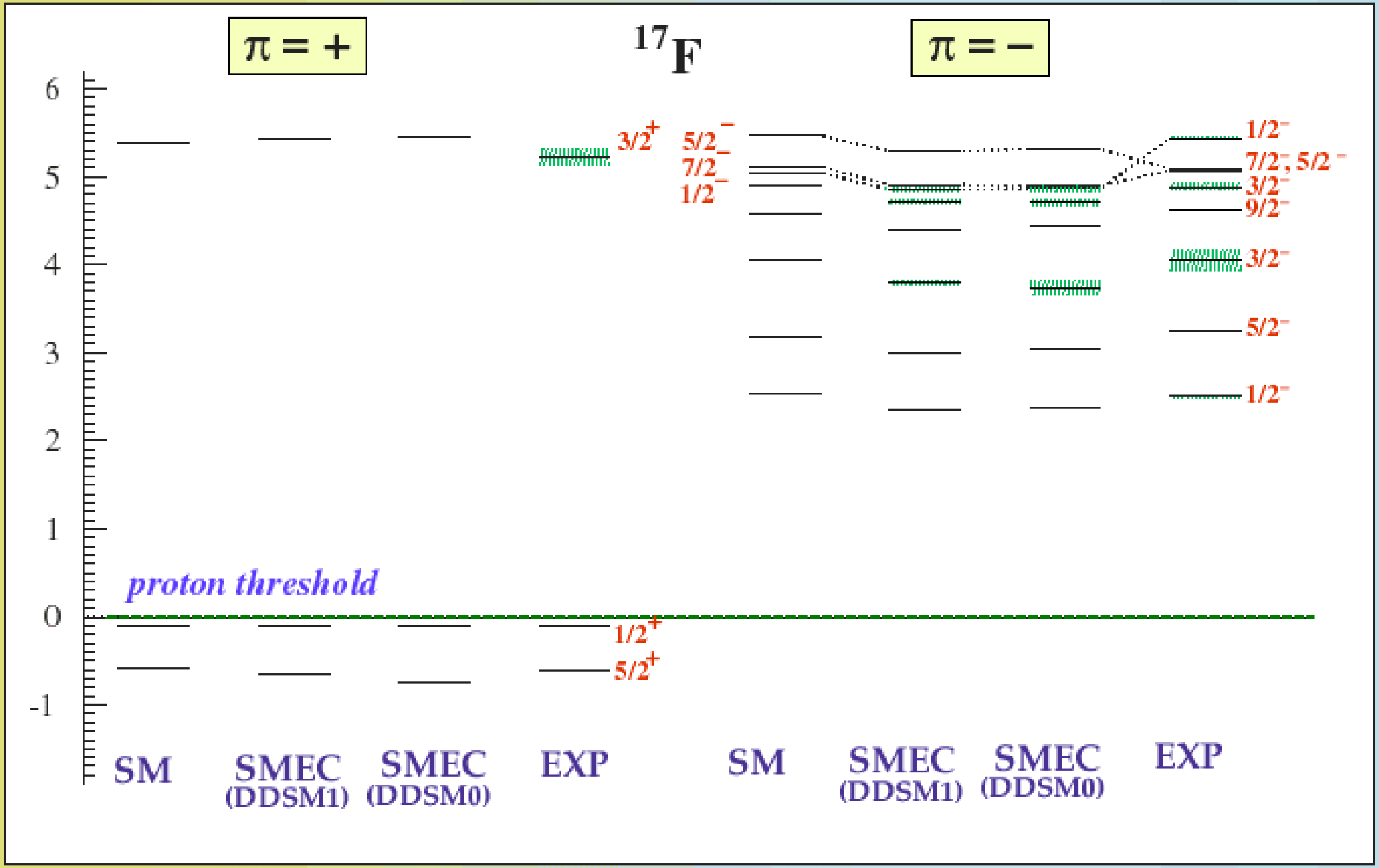
Continuum Shell Model

Q - quasi-bound states P - scattering states

H_{QQ} - shell model Hamiltonian; H_{PQ} - density-dependent



Theory: K. Bennaceur, *et al.*., Nucl. Phys. A651, 289 (1999), Phys.Lett. B488 (2000) 75

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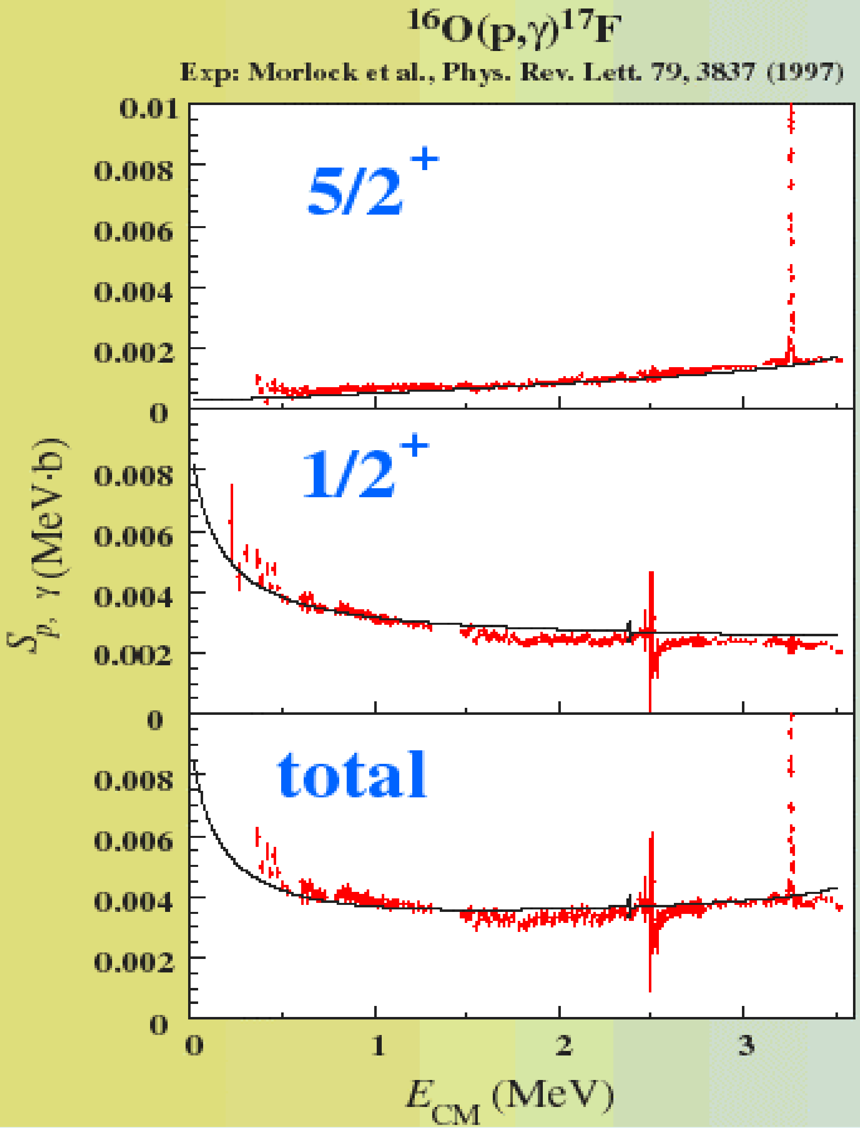
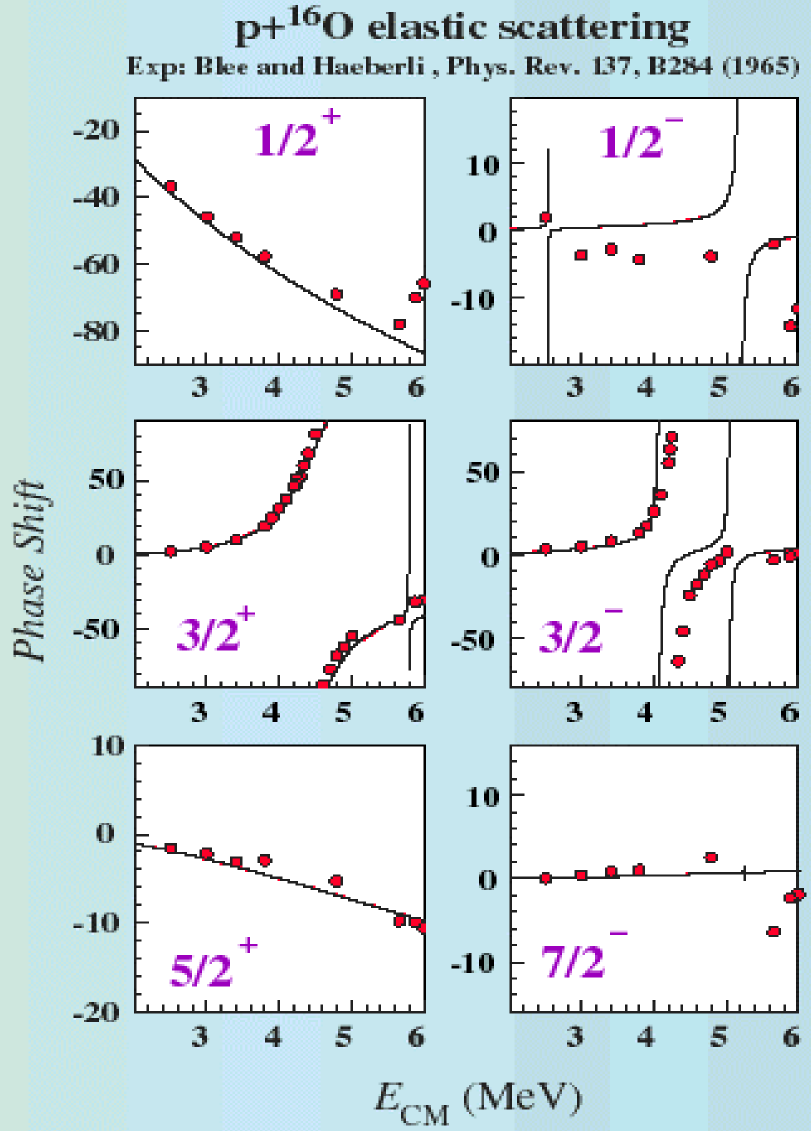
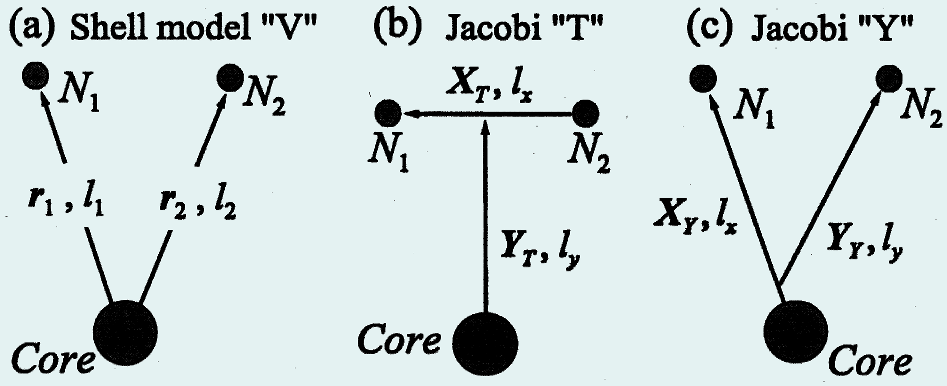
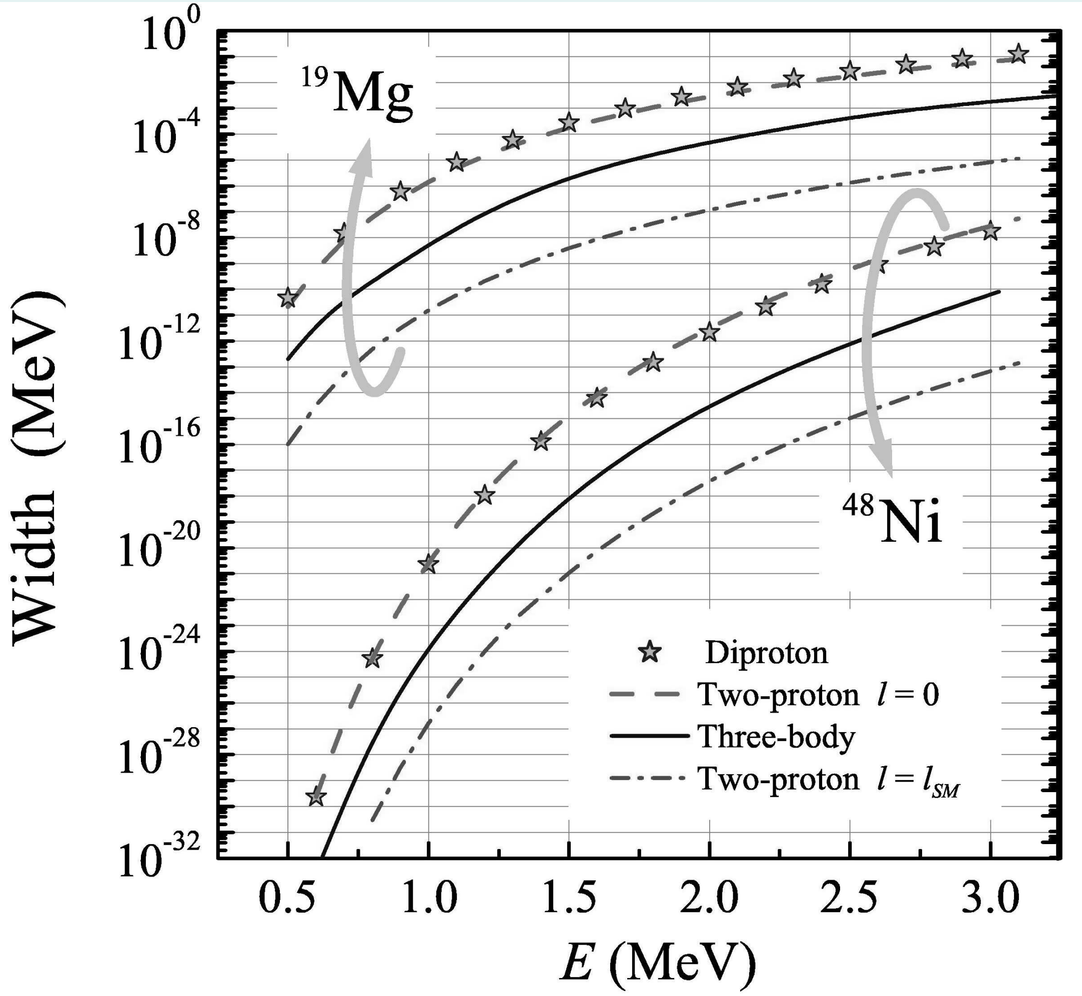
Continuum Shell Model





Theory: K. Bennaceur, *et al.*., Nucl. Phys. A651, 289 (1999), Phys.Lett. B488 (2000) 75





Two-proton decay

- Three-body decay with two protons in the exit channel known for the 0^+ and 2^+ states in ^{6}Be
- Two-proton events in the ^{17}F(p,2p)^{16}O reaction [J. Gomez del Campo, PRL 86. 43 (2001)] tentatively interpreted as a two-proton decay from the 1^- state in ^{18}Ne.
- No ground-state two-proton radioactivity found yet – intense searches currently under way
- Interpretations of decay data in terms of the 2p correlations in the initial state difficult

L.V.Grigorenko
Phys. Rev. Lett., 85, 22 (2000);
Phys. Rev. C, in press

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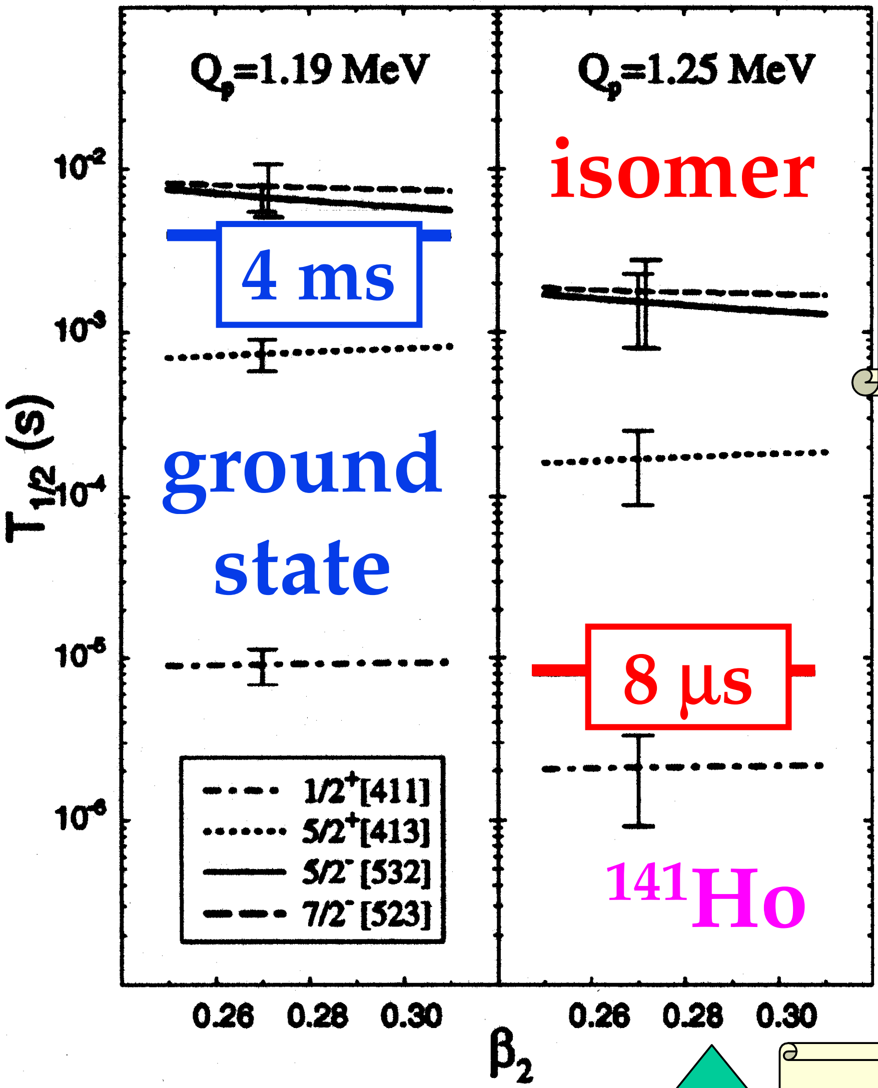
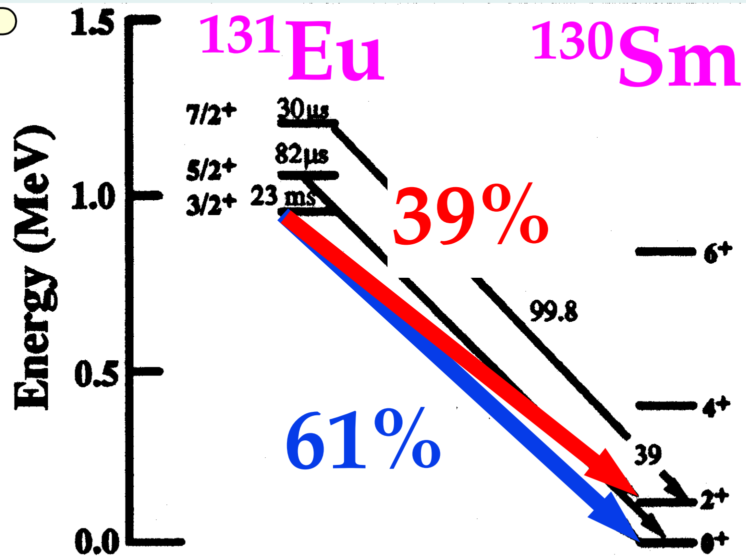
Deformed proton emitters



A.T. Kruppa, *et al.*, Phys. Rev. Lett. 84, 4539 (2000)
B. Barmore, *et al.*, Phys. Rev. C62, 054315 (2000)

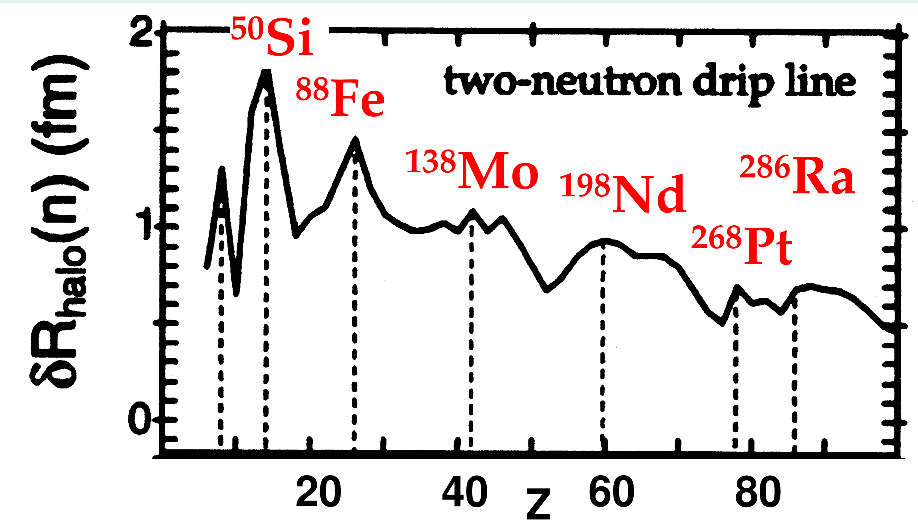


- Precise determination of deformed orbitals in very exotic proton-rich nuclei
- Excited rotational states studied through the fine structure in proton emission
- Coupled-channel calculations of the quantum tunnelling through a deformed Coulomb barrier

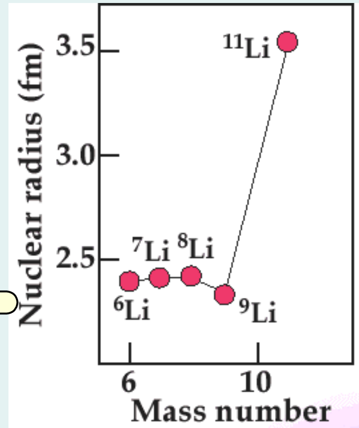
K. Rykaczewski, *et al.*, Phys. Rev. C60, 011301 (1999)

Other groups working in this field:
E. Maglione & L.S. Ferreira, Phys. Rev. C61, 047307 (2000)
H. Esbensen & C.N. Davids, Phys. Rev. C63, 014315 (2000)
P. Talou, *et al.*, Phys. Rev. C58,3280 (1998)

Halos in heavy nuclei



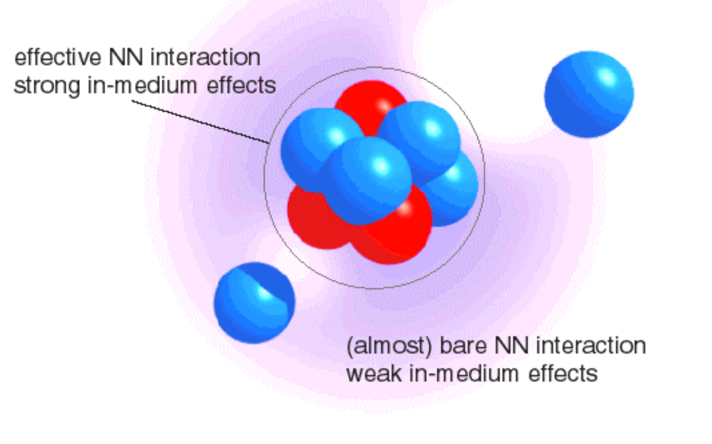
HFB+SLy4
S. Mizutori,
et al.,
Phys.Rev. C61,
044326 (2000)

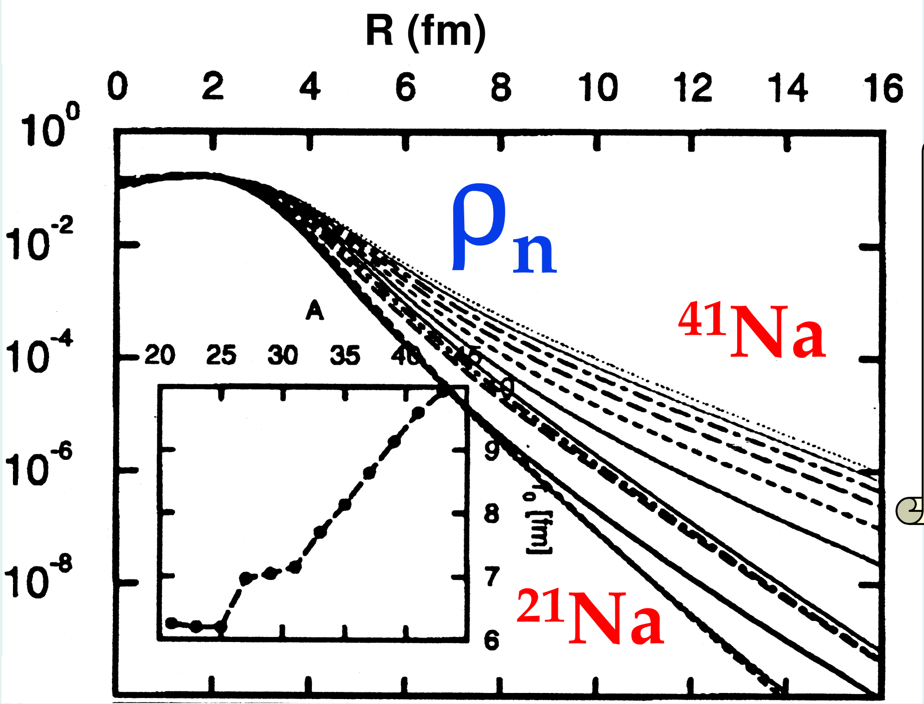


I. Tanihata et al.
Phys. Rev. Lett. 55, 2676 (1985)

Interaction cross section
measurements at Bevalac
(790 MeV/u)

^{11}Li





RMF+ HB
J. Meng, *et al.*,
Phys.Lett.
B419, 1 (1998);
Phys. Rev. Lett.
80, 460 (1998)

Pairing anti-halo effect
(K. Bennaceur, *et al.*.,
Phys. Lett. B406, 154 (2000)
shields the neutron
distributions from
developing singular halos

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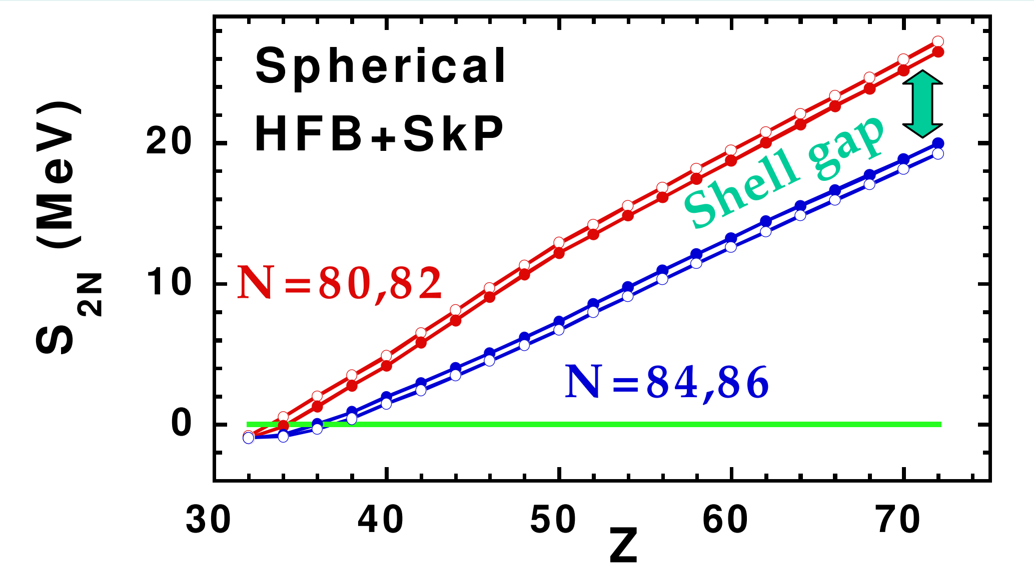
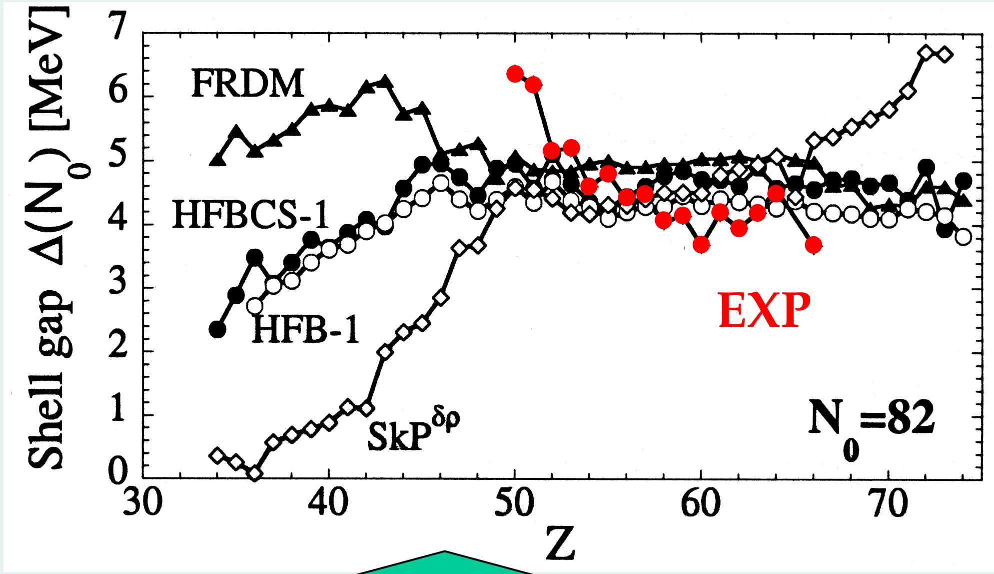
Mass predictions far from stability





- Shell quenching near neutron drip line predicted for some effective interactions
- Shell quenching observed in light nuclei at N=20 and 28
- Mixing with intruder configurations: an origin or a consequence?
- Correlation effects very important

F. Tondeur, *et al.*, Phys. Rev. C62, 024308 (2000)
M. Samyn, *et al.*, Nucl. Phys. A, submitted

Full self-consistent mass predictions from the density functional (Skyrme)
$\chi 2$=0.738 MeV (HF-BCS-1)
$\chi 2$=0.766 MeV (HFB-1)

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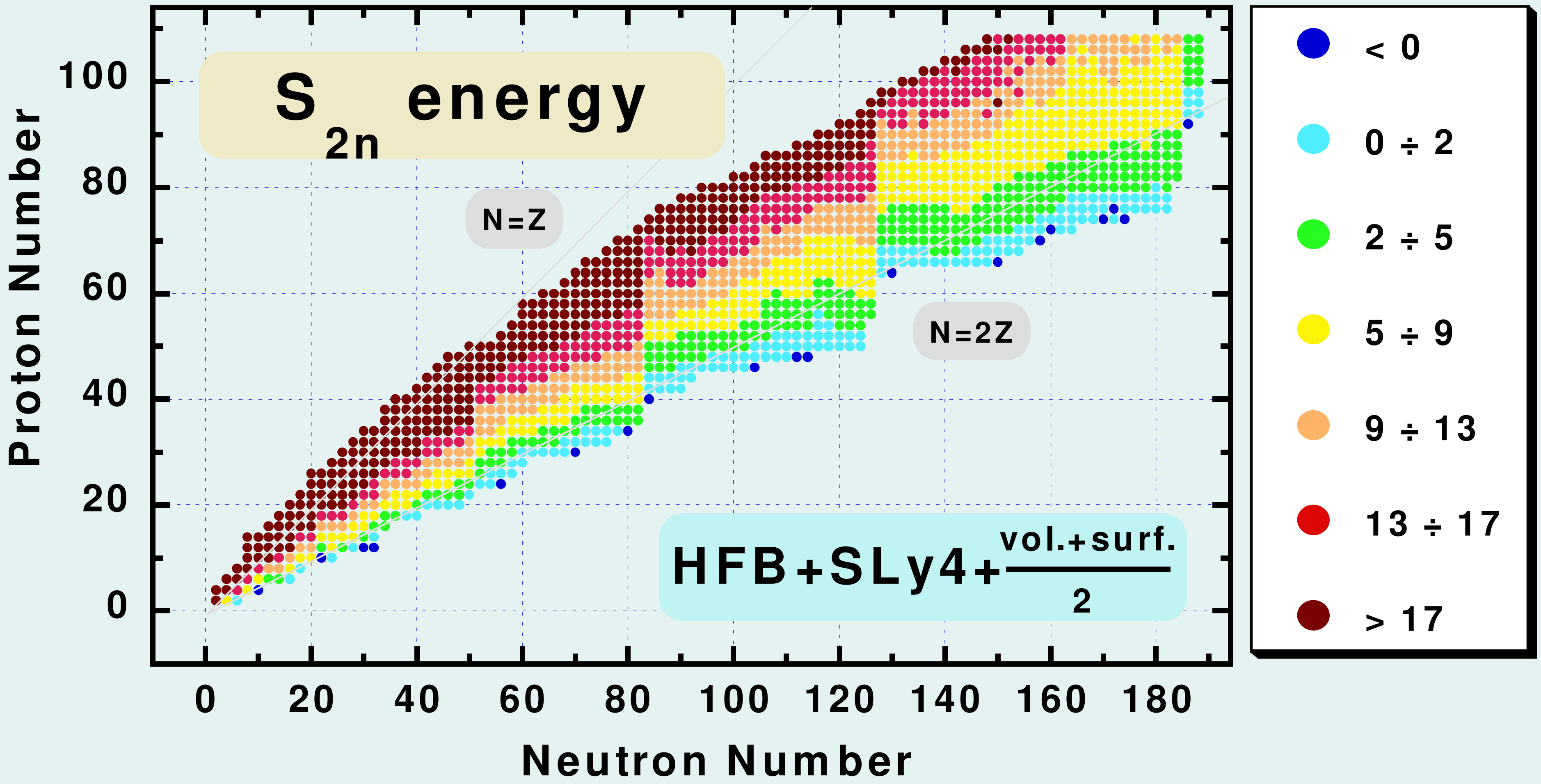
Mass predictions far from stability



- First HFB mass-table calculations with pairing, deformation, and full coupling to continuum possible
- Unbound nuclei beyond drip line with hindered decay predicted

M.V. Stoitsov, *et al.*, Phys. Rev. C58, 2086; C58, 2092 (1998); C61, 034311 (2000); and to be published

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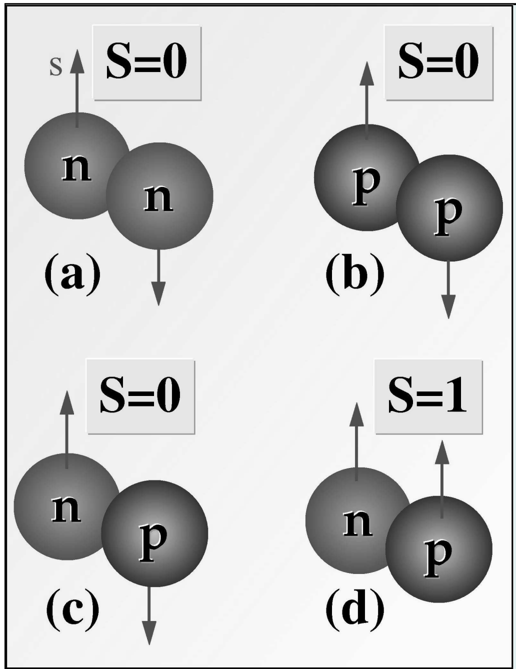
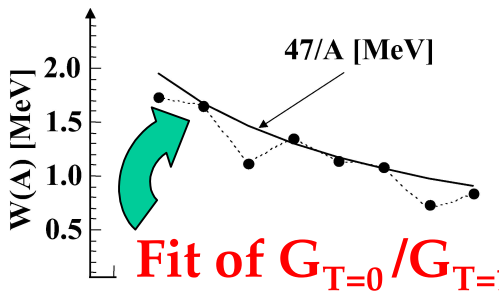
Neutron-proton pairing collectivity

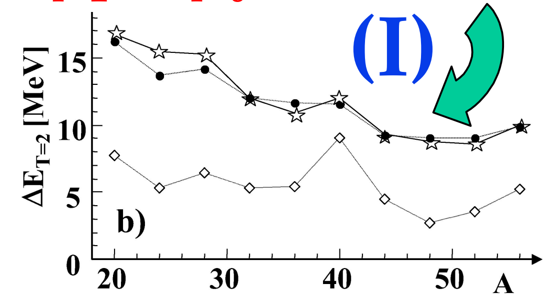
(a fit plus three easy steps)



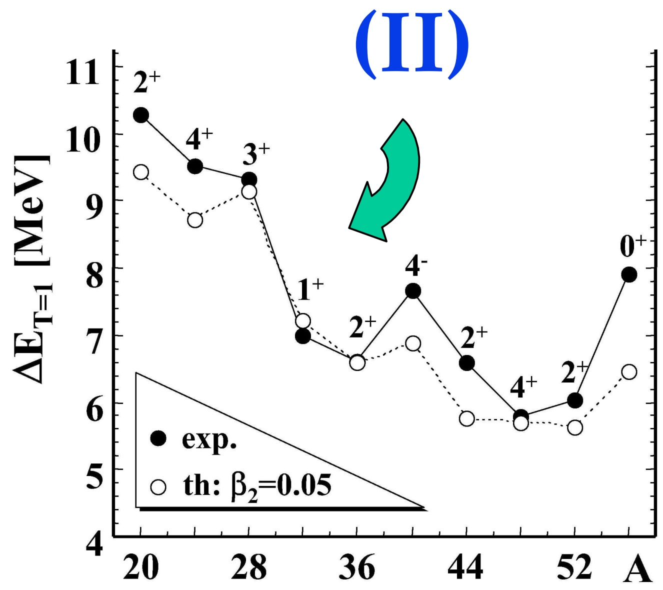


Fit of $G_{T=0}/G_{T=1}$

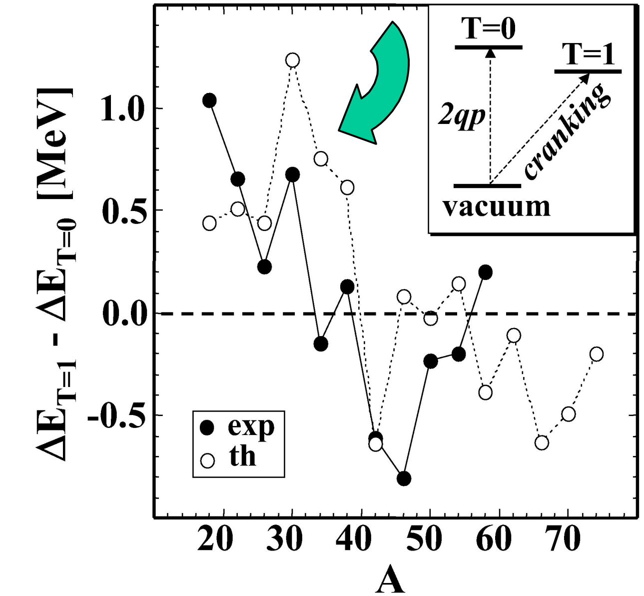
$E_{T=2} - E_{T=0}$ (even-even) (I)



$E_{T=1} - E_{T=0}$ (even-even)



$E_{T=1} - E_{T=0}$ (odd-odd)(III)



- Wigner energy linked to the n-p pairing collectivity
- T=2 states in even-even nuclei obtained from isocranking
- T=1 states in even-even nuclei obtained as 2qp excitations
- T=1 states in odd-odd nuclei obtained from isocranking
- T=0 states in odd-odd nuclei obtained bas 2qp excitations

W. Satuła & R. Wyss Phys. Rev. Lett., 86, 4488 (2001);
Phys. Rev. Lett., 87, 052504 (2001)

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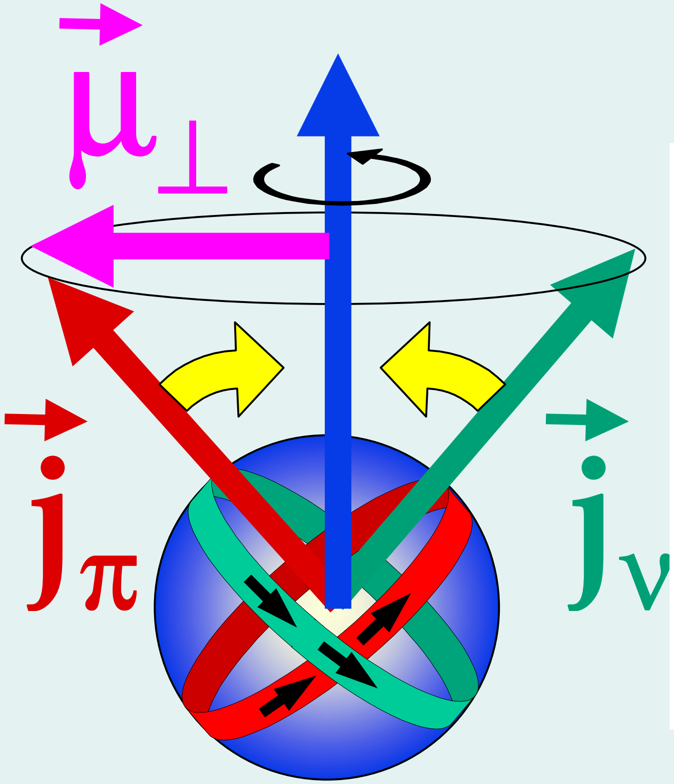
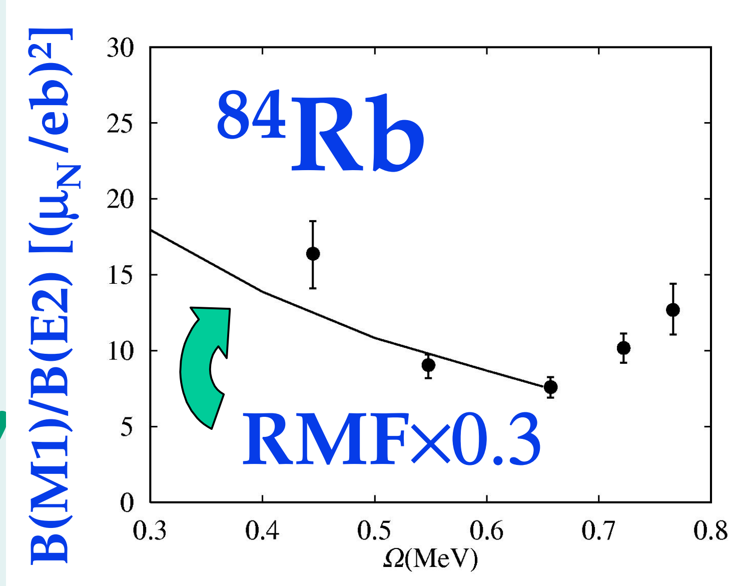
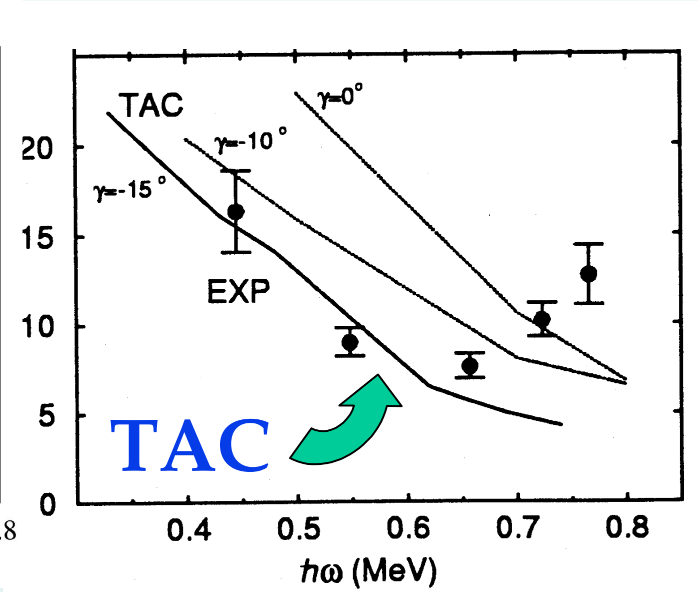
Magnetic rotation

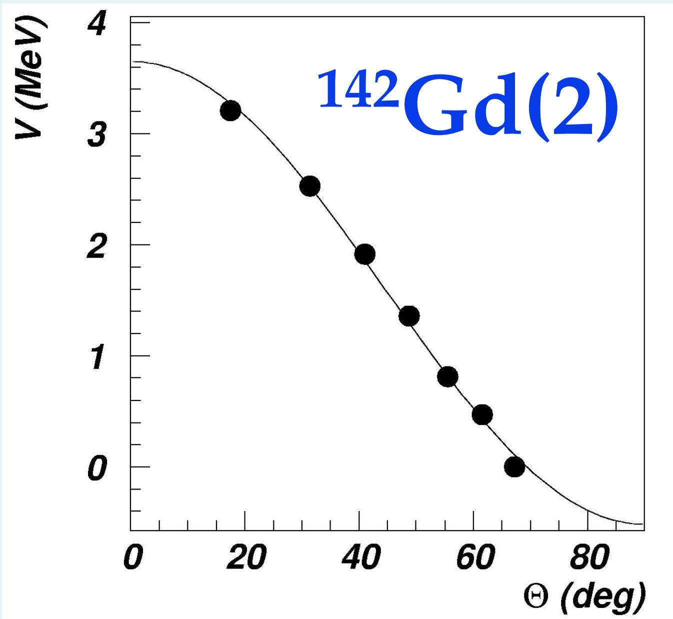






H. Madokoro, *et al.*,
Phys. Rev. C62, 061301 (2000);

H. Schnare, *et al.*,
Phys. Rev. Lett. 82, 4408 (1999);



- Tilted-Axis-Cranking (TAC) calculations reproduce the decrease of B(M1)/B(E2), observed in many rotational bands, within the shears mechanism.
- Simple estimates of V(Θ) reproduce very well E(I)
- First self-consistent (RMF) calculations available

A.O. Macchiavelli, *et al.*, Phys. Rev. C58, 621 (1998)
T. Rząca-Urban, Acta Phys. Pol., in press

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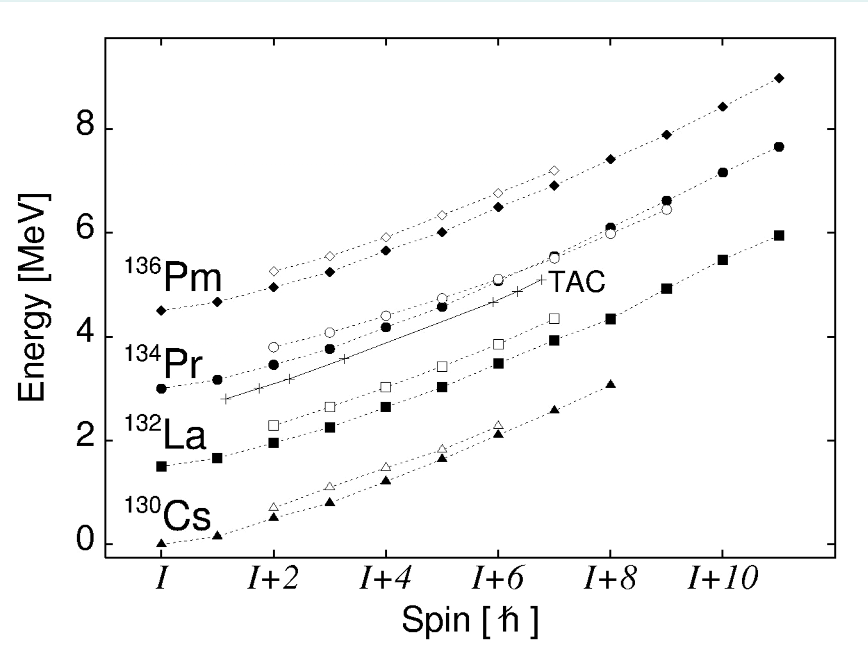
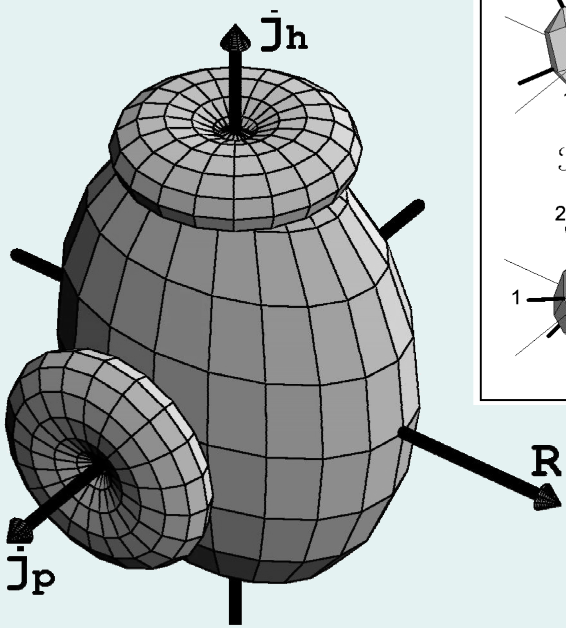
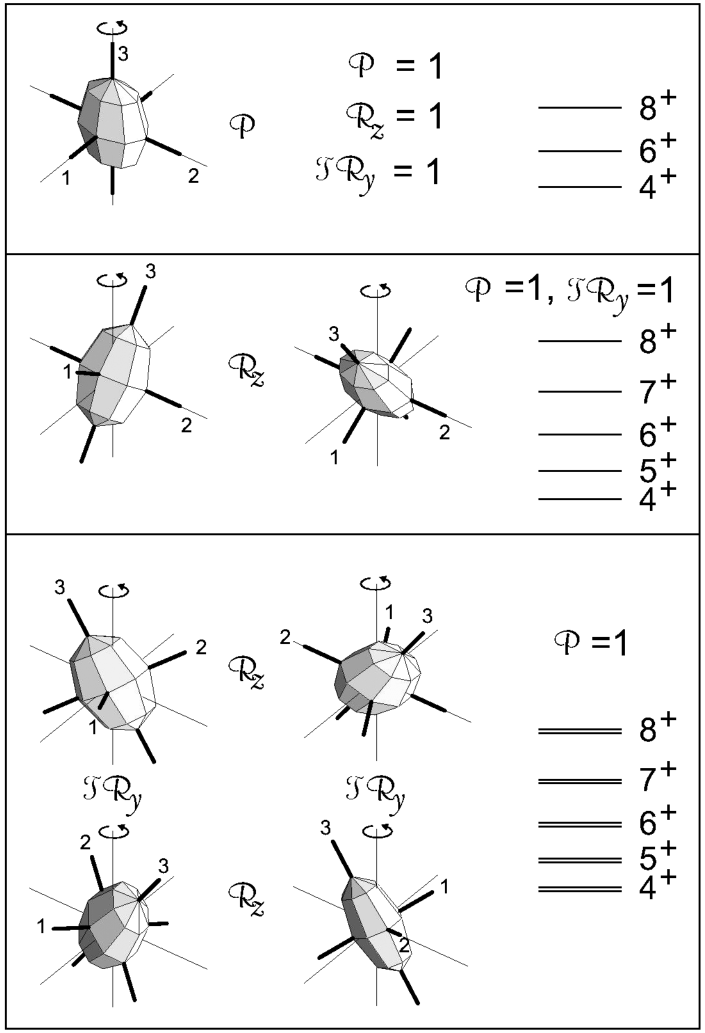
Chiral sister bands

- New symmetry breaking proposed for triaxial nuclei
- Symmetry-breaking for time-odd symmetry operator
- Candidate bands found in N≅75 odd-odd nuclei
- Critical survey of alternative scenarios needed







S. Frauendorf, Rev. Mod. Phys. 73, 463 (2001)

V.I. Dimitrov, *et al.*, Phys. Rev. Lett. 84, 5732 (2000)
K. Starosta, *et al.*, Phys. Rev. Lett. 86, 971 (2001)

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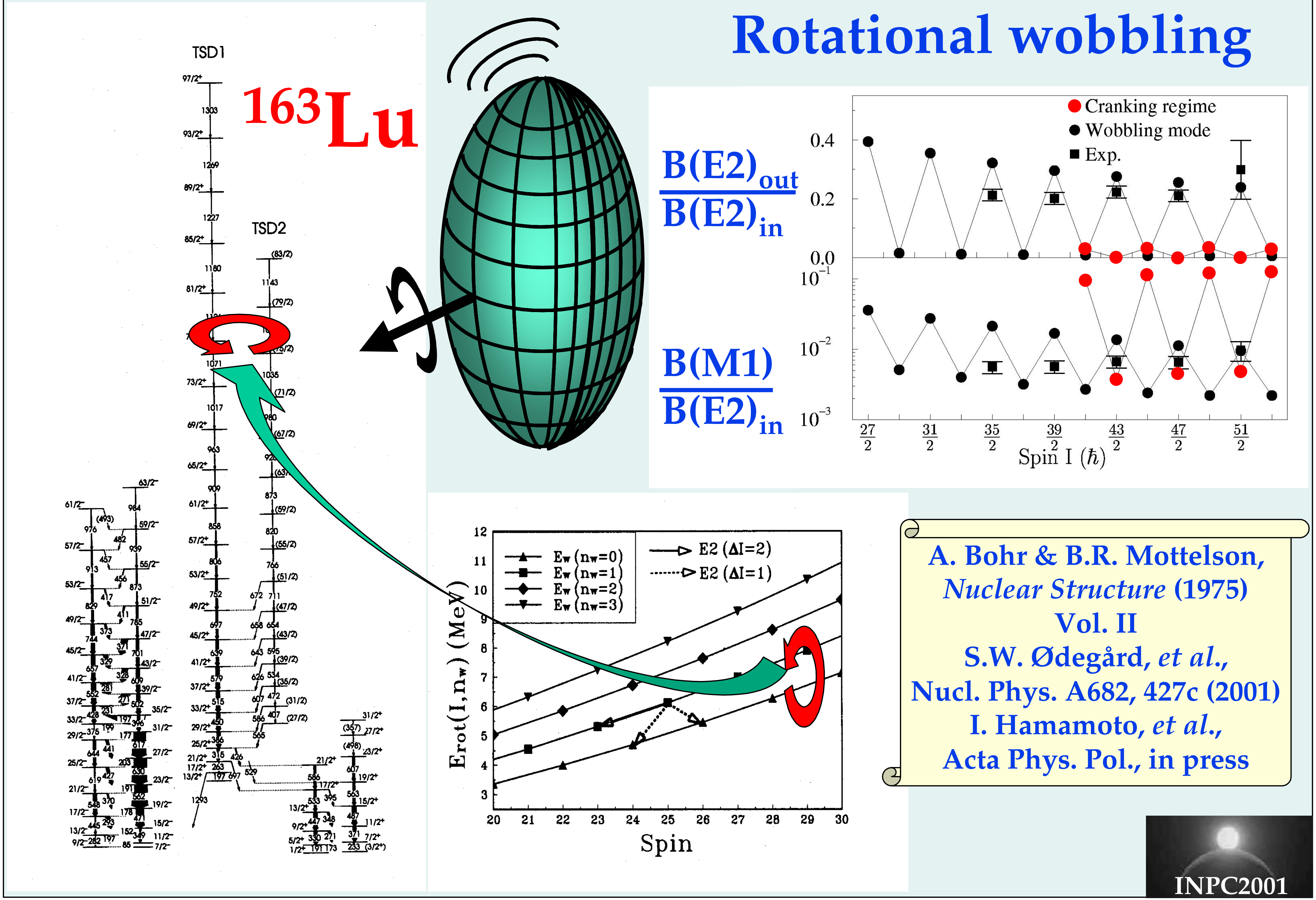
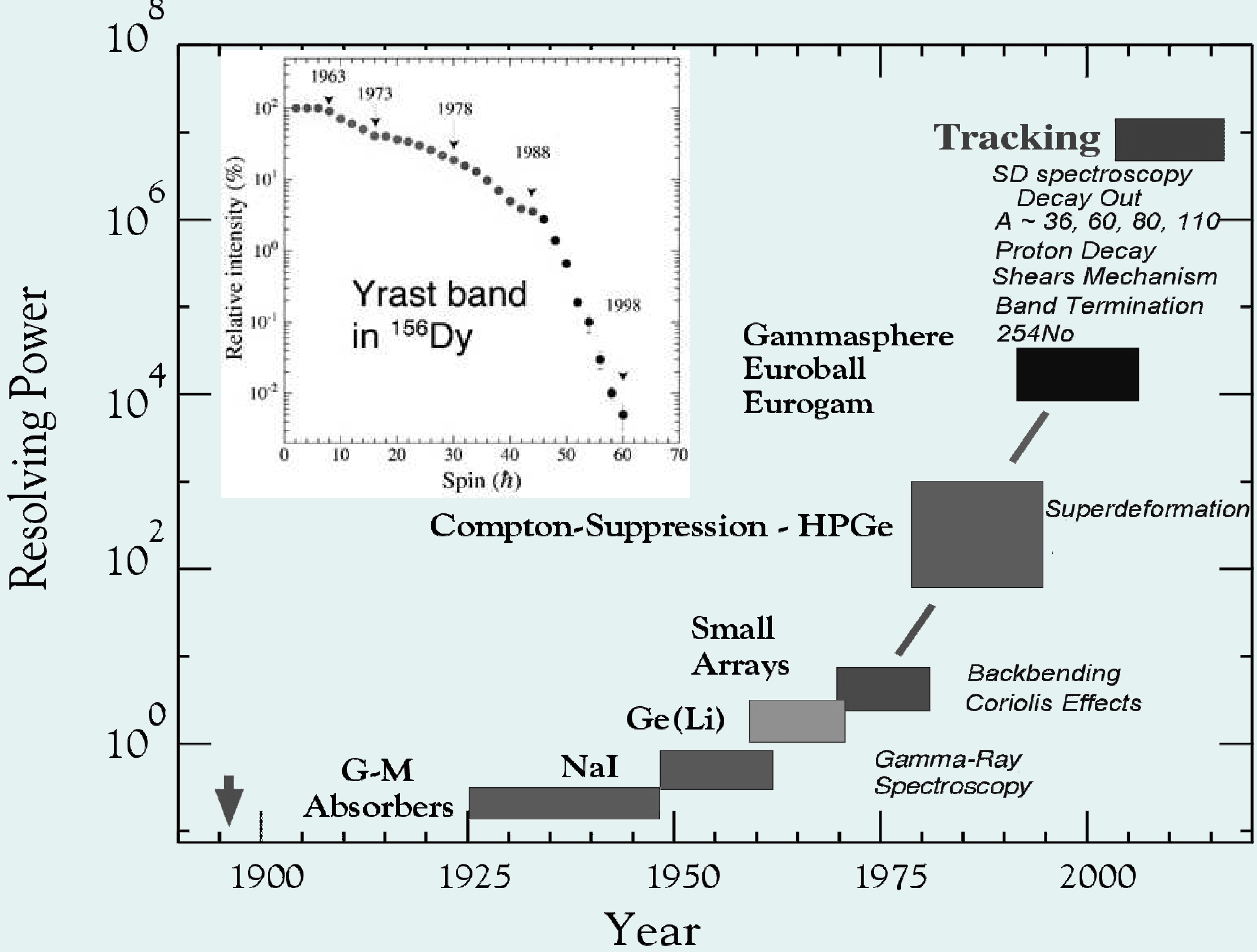
Rotational wobbling



A. Bohr & B.R. Mottelson,
Nuclear Structure (1975)
Vol. II
S.W. Ødegård, *et al.*,
Nucl. Phys. A682, 427c (2001)
I. Hamamoto, *et al.*,
Acta Phys. Pol., in press

Novel detector technology yields discovery potential

©M. Riley



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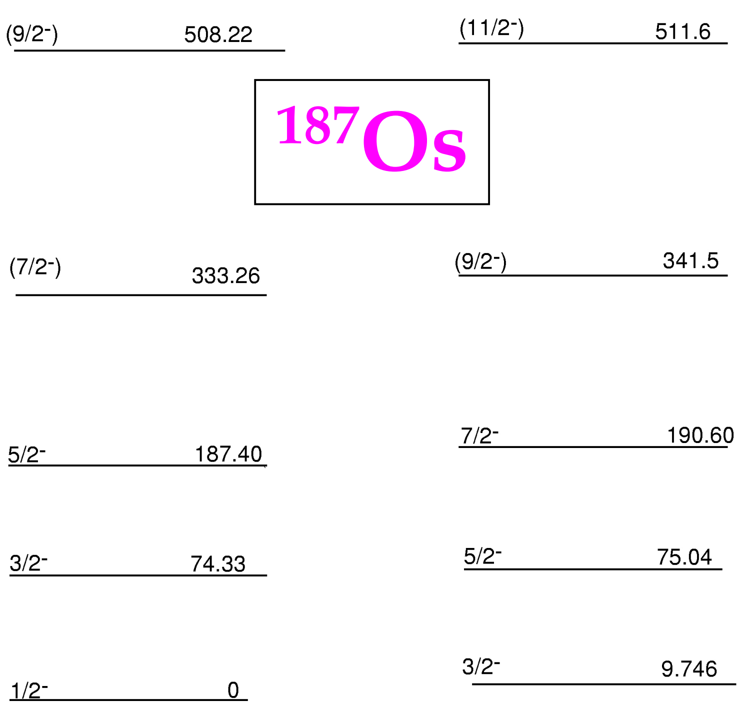
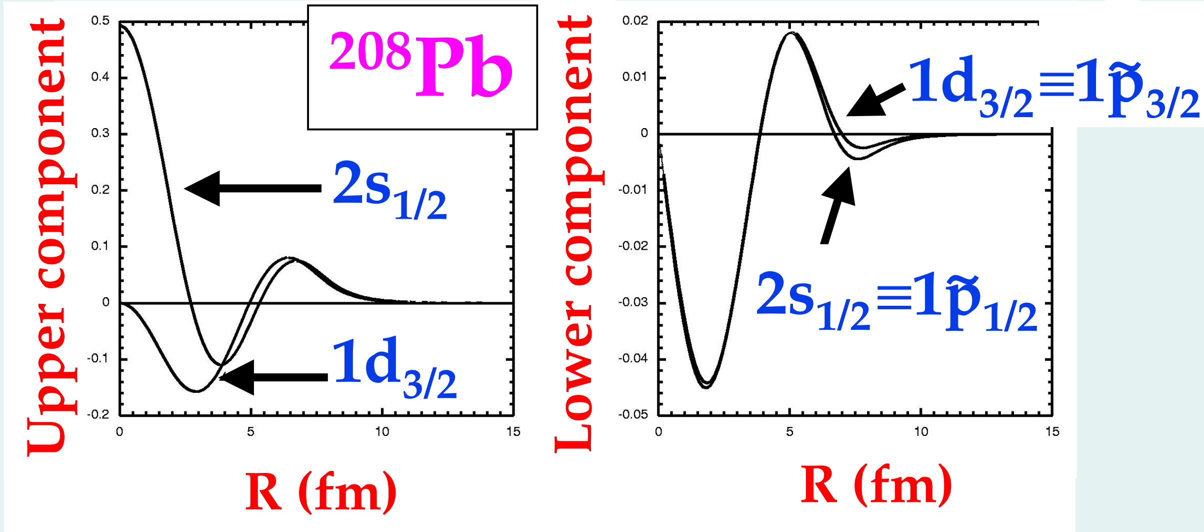
Understanding the pseudospin symmetry



[510]1/2 — **pseudospin down**

[512]3/2 — **pseudospin up**



$$H=\vec{\alpha}\bullet\vec{p}+\beta(M+V_S)+V_V$$

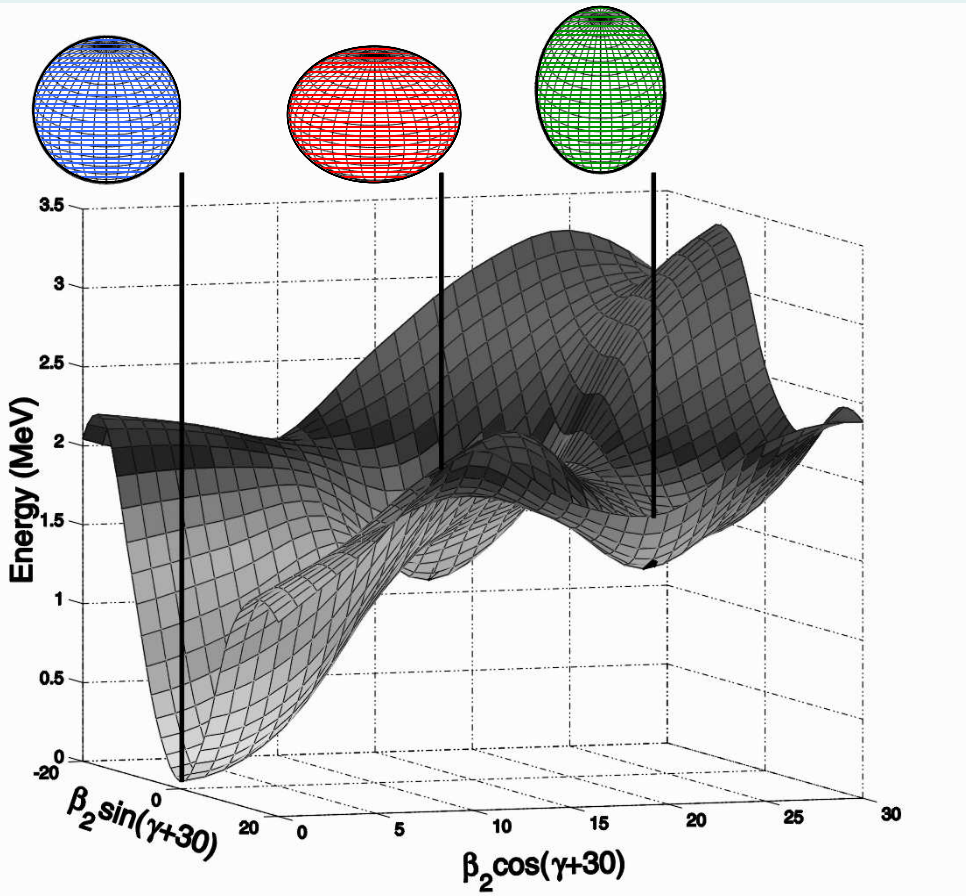
J.N. Ginocchio, Phys. Rev. Lett. 78, 436 (1997)
J.N. Ginocchio & D.G. Madland, Phys. Rev. C57, 1167 (1998)

A. Arima, *et al.*,
Phys. Lett. B30, 517 (1969)
K.T. Hecht & A. Adler,
Nucl. Phys. A137, 129 (1969)
F.S. Stephens, *et al.*,
Phys. Rev. C57, 1565 (1998)

- „Strange” degeneracies in nuclear spectra have been since long ago interpreted in terms of the pseudospin symmetry
- Recently the pseudospin symmetry has been linked to properties of relativistic single-particle Dirac equation
- Analysis of the symmetry-breaking pattern needed

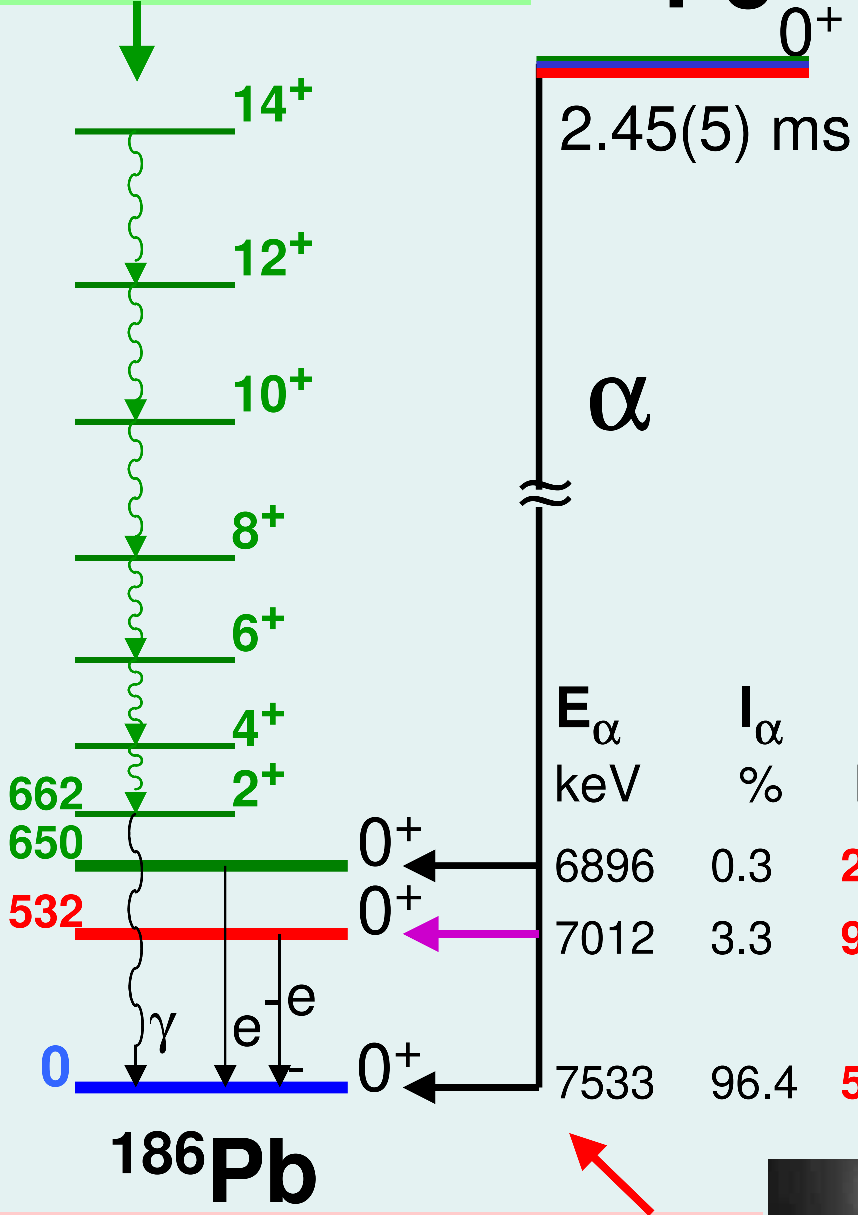
Different shapes, co-existing at low excitation energy

©M. Huyse



Potential Energy Surface for ^{186}Pb

J. Heese et al., Phys. Lett. B302 (1993) 390



E_α keV	I_α %	δ^2 keV
6896	0.3	**21(8)**
7012	3.3	**90(18)**
7533	96.4	**51(4)**

A. Andreyev et al., Nature 405 (2000) 430

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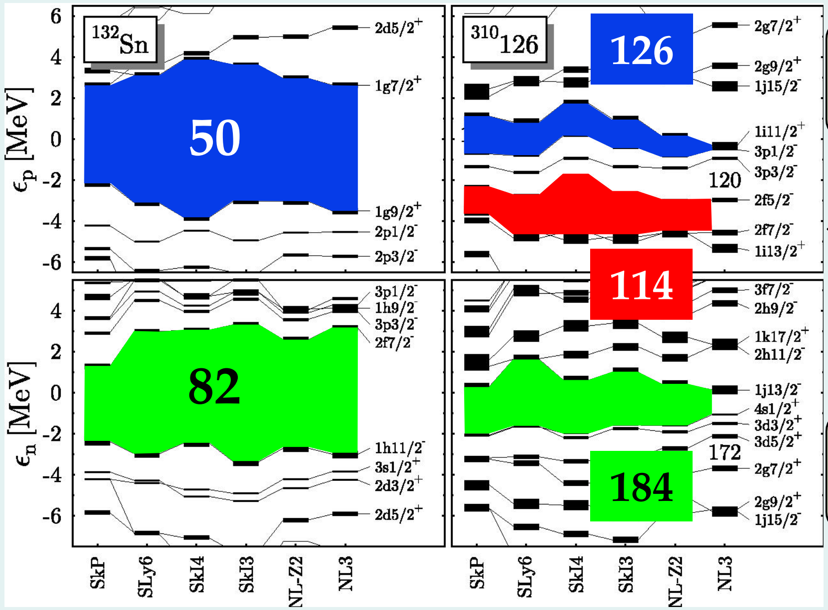
Shell effects in strong Coulomb fields

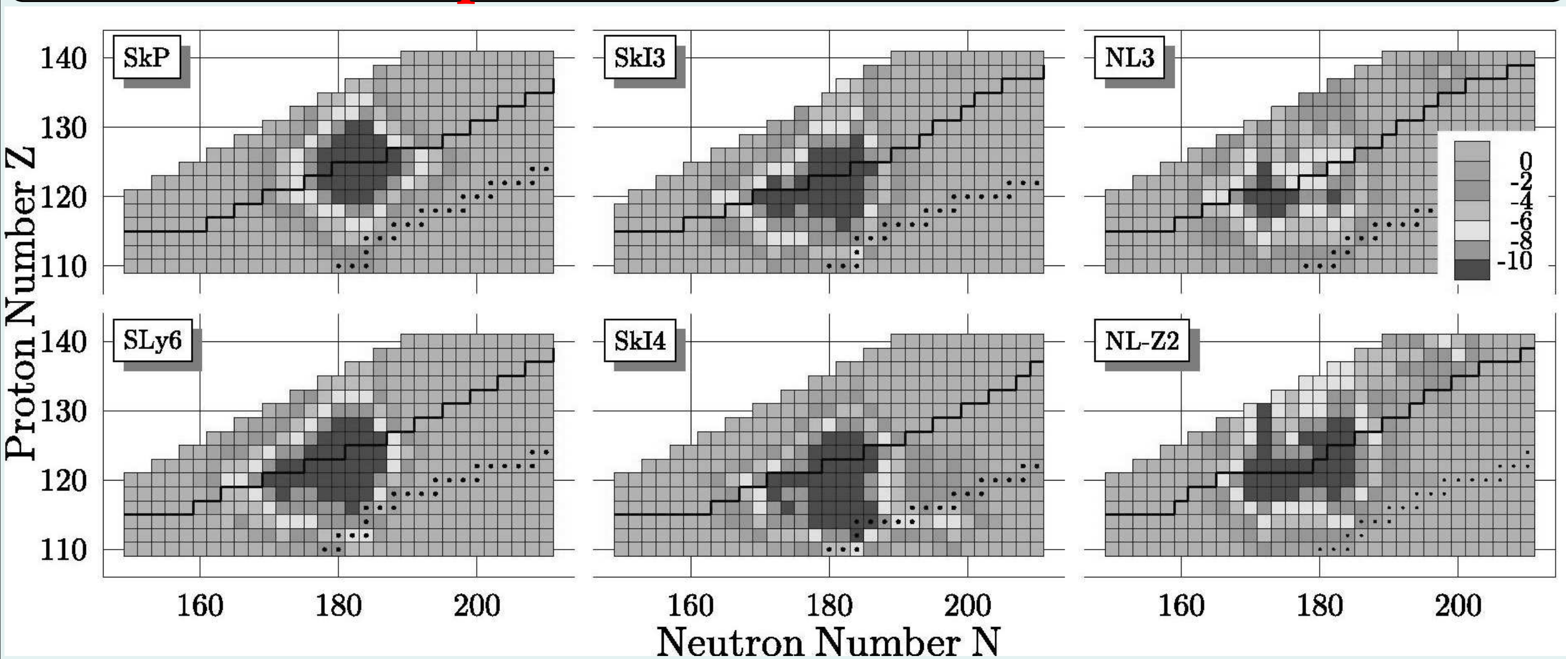
- Proton shell gaps in super-heavy nuclei strongly influenced by the Coulomb force
- Shell effects hindered by a large density of states
- Shell stabilisation occurs in a large range of nuclides around Z=114-126 and N=172-184



protons

neutrons

Spherical shell correction



A.T. Kruppa, *et al.*, Phys. Rev. C61, 034313 (2000)
M. Bender , *et al.*, nucl-th/0103065

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Summary, conclusions, and outlook

Theory:

- **Derivations** of effective interactions and/or density functionals from „first principles" (NN and NNN interactions, meson fields, chiral perturbation...)
- **Adjustments** of effective interactions and/or density functionals to experimental data at extreme N/Z ratios and angular momenta.

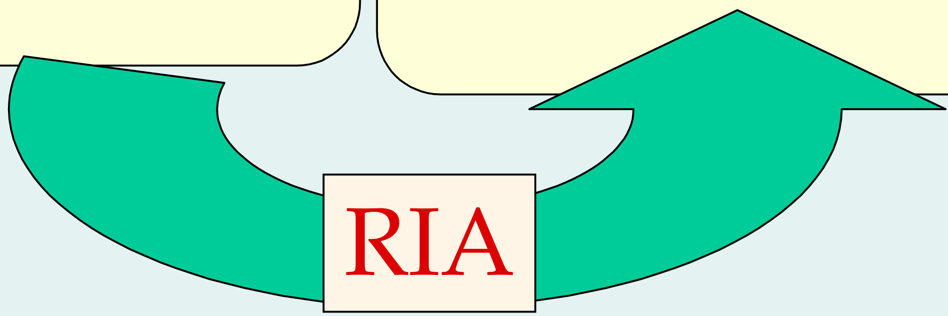
Experiment:

- Production!
- Selectivity!
- Sensitivity!

Recommendation #1

The highest priority for the nuclear structure and nuclear astrophysics communities is the construction of Rare Isotope Accelerator (RIA) as the world's premier facility for the study of exotic nuclei and the pursuit of the associated exciting physics opportunities. These encompass the understanding of nucleonic matter – from the nucleus to neutron stars, – the origin of elements, the quest for the nature of stellar explosions, and tests of fundamental interactions and conservation laws in nature.

Nuclear Structure and Astrophysics Town Meeting



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