Spectroscopy studies of N≈Z nuclei

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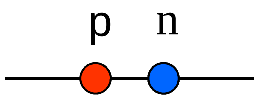
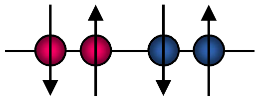
Overview

- Isospin symmetry
- T=0 pn correlations
- Future experimental possibilities

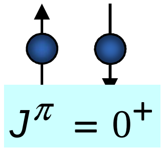
Symmetries in nuclei



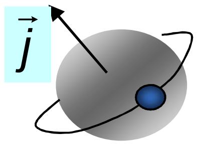
Isospin Symmetry: 1932 Heisenberg SU(2)



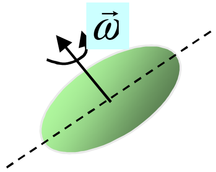
Spin-Isospin Symmetry: 1936 Wigner SU(4)



Seniority Pairing: 1943 Racah



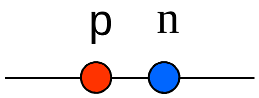
Spherical Symmetry: 1949 Mayer



Nuclear Deformed Field (spontaneous symmetry breaking)
Restore symm. → Rotational spectra: 1952 Bohr-Mottelson
SU(3) Dynamical Symmetry: 1958 Elliott

Courtesy K. Heyde

Violation of the isospin symmetry

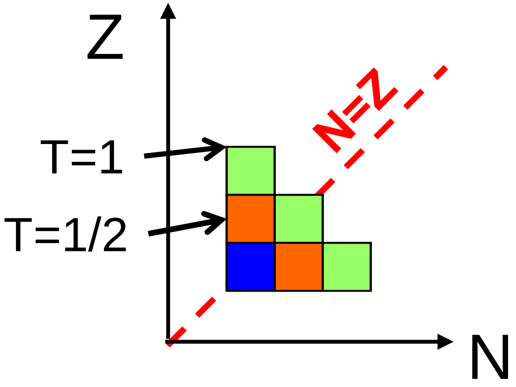


Isospin Symmetry: 1932 Heisenberg SU(2)

- The proton and neutron can be viewed as a two states of the **same particle** nucleon.
- The quantum number that distinguishes both state is the **isospin**
  - $t=1/2$, $t_z= -1/2$ for proton
  - $t=1/2$,$t_z= +1/2$ for neutron
- Isospin symmetry represent a powerful and well recognised tool in the description of nuclei.
- **Coulomb force, nucleonic mass differences and charge dependent nuclear forces** (due to the differences in u and d quark masses and electromagnetic interactions between the quarks) lead to the violation of isospin symmetry.
- The nucleon nucleon scattering data in T=1 channel indicate that pn interaction is 2% stronger then the average of pp and nn interactions.
- Accurate accounting for isospin mixing in nuclear states is crucial in several open problems.

Mirror nuclei

- Isospin symmetry manifest better along the N=Z nuclei
- Coulomb Energy Differences CED, difference in excitation energies between isobaric analog states.
  - The CED will be referred to the ground state, so large Coulomb effect almost vanished
  - Experimentally challenging but reachable at high spins, up to the band termination for medium mass nuclei



$$\boxed{\mathrm{TED}_J = \mathrm{E}^*_{J,T_z=-1} + \mathrm{E}^*_{J,T_z=+1} - 2\mathrm{E}^*_{J,T_z=0}}$$

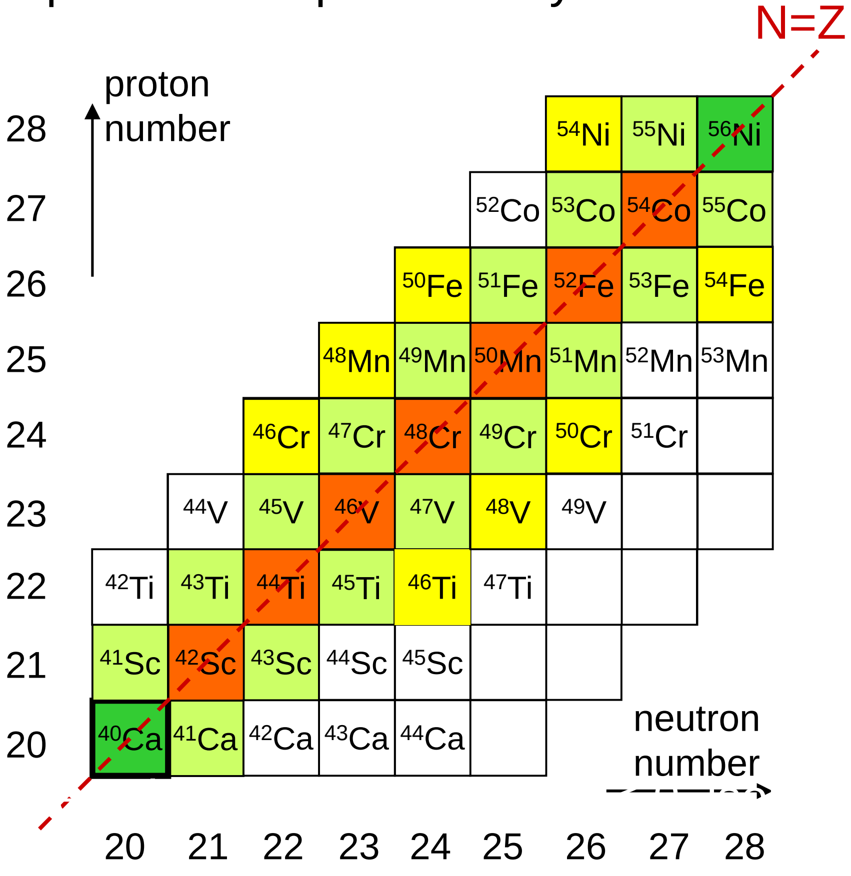
$$\boxed{\mathrm{MED}_J = \mathrm{E}^*_{J,T_z=-1/2} - \mathrm{E}^*_{J,T_z=+1/2}}$$

The isospin symmetry in the $f_{7/2}$

The $1f_{7/2}$ shell is isolated in energy from other major orbits

Wave functions dominated by $(1f_{7/2})^n$ configurations

High-spin states experimentally reachable

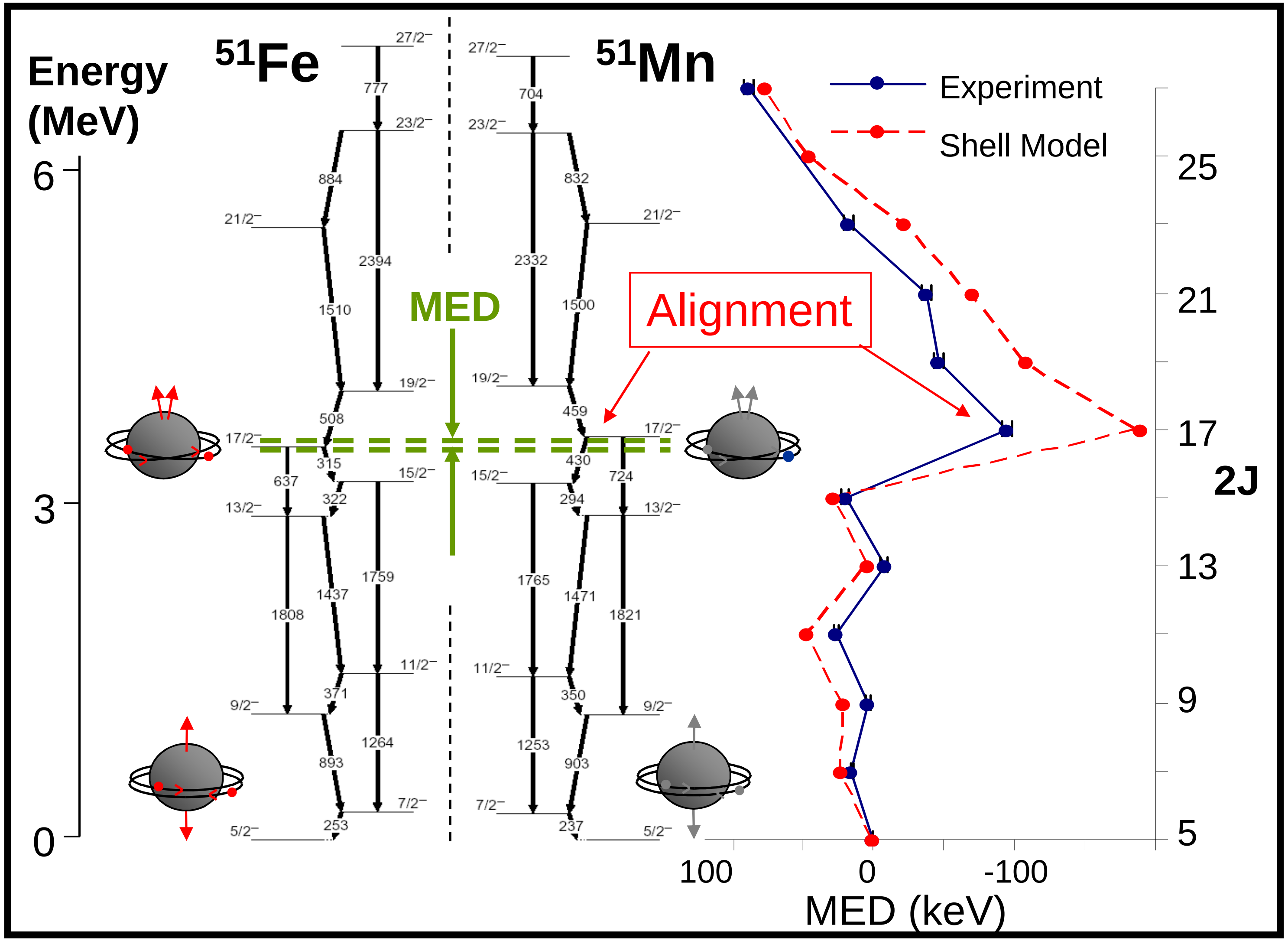


	20	21	22	23	24	25	26	27	28
28							^{54}Ni	^{55}Ni	^{56}Ni
27						^{52}Co	^{53}Co	^{54}Co	^{55}Co
26					^{50}Fe	^{51}Fe	^{52}Fe	^{53}Fe	^{54}Fe
25				^{48}Mn	^{49}Mn	^{50}Mn	^{51}Mn	^{52}Mn	^{53}Mn
24			^{46}Cr	^{47}Cr	^{48}Cr	^{49}Cr	^{50}Cr	^{51}Cr	
23		^{44}V	^{45}V	^{46}V	^{47}V	^{48}V	^{49}V		
22	^{42}Ti	^{43}Ti	^{44}Ti	^{45}Ti	^{46}Ti	^{47}Ti			
21	^{41}Sc	^{42}Sc	^{43}Sc	^{44}Sc	^{45}Sc				
20	^{40}Ca	^{41}Ca	^{42}Ca	^{43}Ca	^{44}Ca				

M.A. Bentley and S.M Lenzi Prog. Part. And Nucl. Phys. 59 (2007) 497

Courtesy S. Lenzi

Isospin symmetry in collective structures



D.D. Warner et al., Nature Physics 2 (2006) 311

Coulomb effects

The description of the Coulomb interaction, taken into parts

$$V_C = V_{CM} + V_{cm}$$

E. Caurier et al., Rev. Mod. Phys. 77 427 (2005)
A.P. Zuker et al., PRL89 142502 (2002)

V_{CM} Multipole term accounts for the interaction between protons in the valence space
V_{cm} monopole term accounts for the single-particle and bulk effects due to the spherical field

- Radial effect $$E_{Cr} = \frac{3}{5}\frac{e^2 Z(Z-1)}{R}$$
- Shell energy $$E_{Cll} = \frac{-4.5 Z_{cs}^{13/12}[2l(l+1) - N(N+3)]}{A^{1/3}(N+3/2)} keV$$

$$E_{Cls} = (g_s - g_l)\frac{1}{4m_N^2 c^2}\left(\frac{1}{r}\frac{dV_C}{dr}\right)\mathbf{l.s}$$

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A=51 mirror nuclei

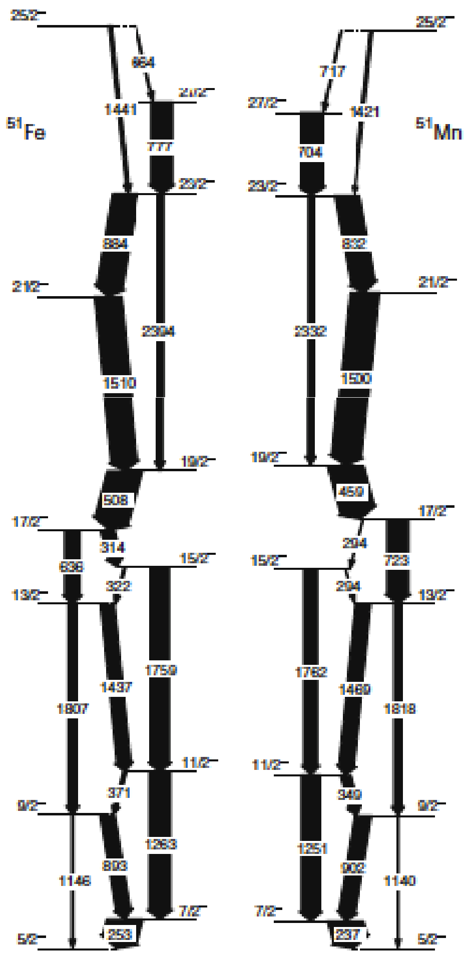
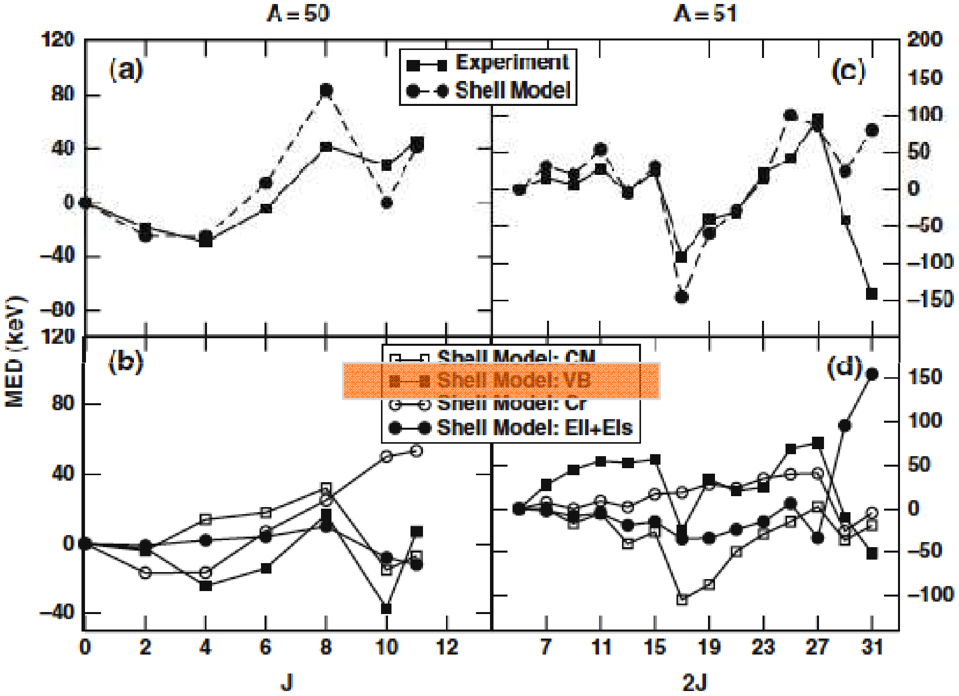


Fig. 11. Partial level schemes of the yrast negative-parity states of ^{51}Fe (data taken from [70]) and of ^{51}Mn (data taken from [72])



The isospin-nonconserving NN interaction –*VB*- is suggested to be as important as the Coulomb part (A.P. Zuker et al., PRL89, 142502(2002).

J. Ekman et al., Eur. Phys. J. A9 13 (2000)
J. Ekman et al., PRC70 0014306 (2004)

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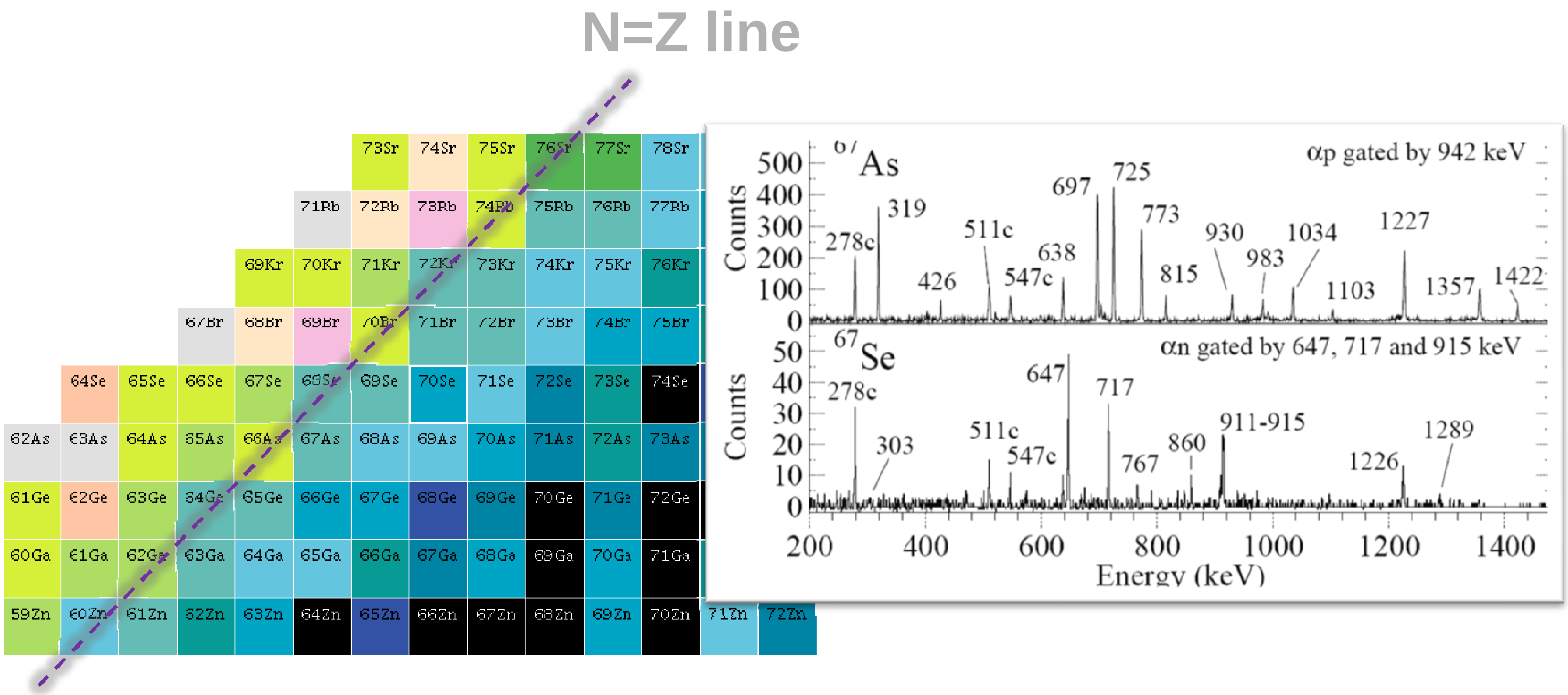
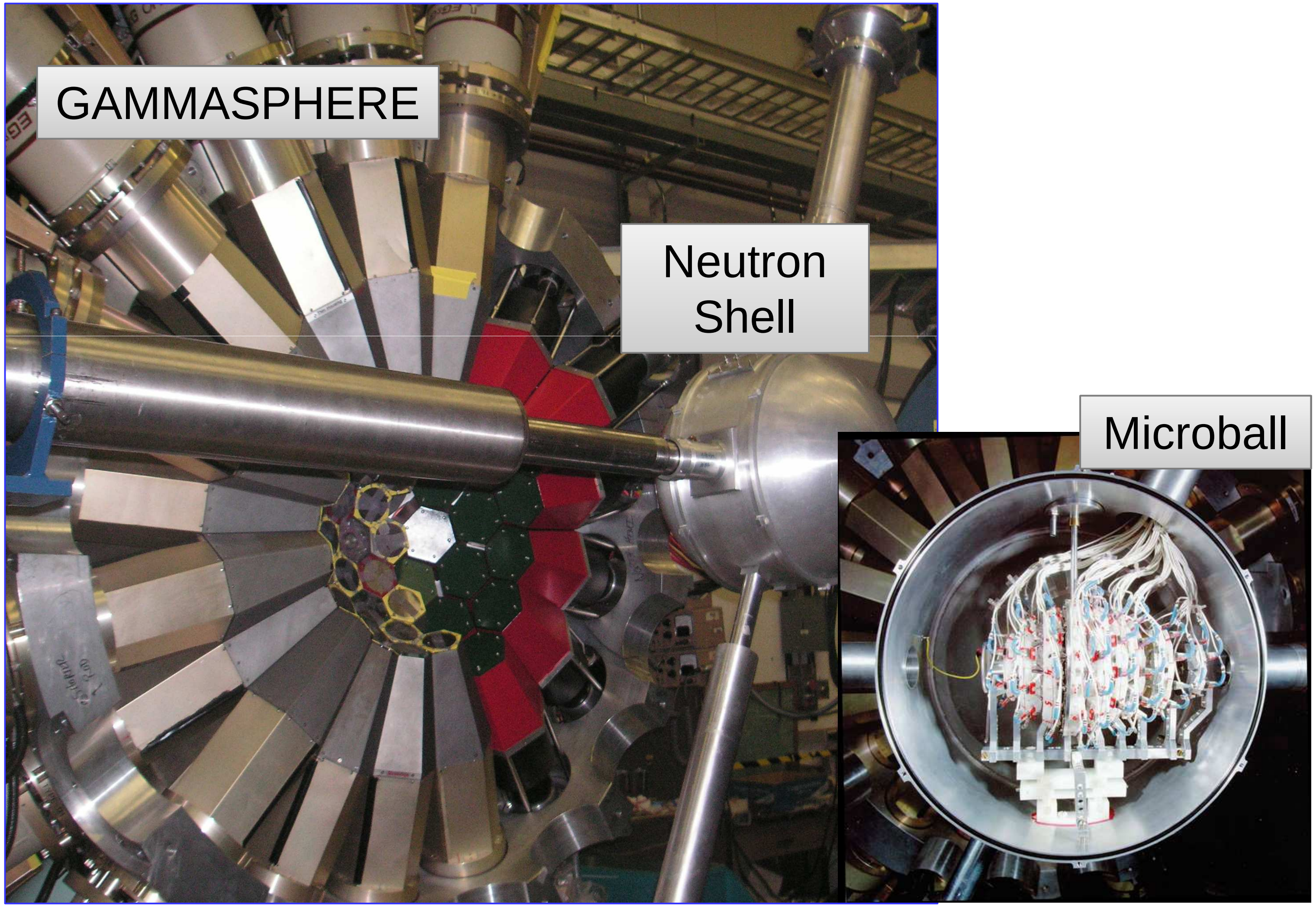
Mirror nuclei in A=70

Existence of E1 transitions fp-$g_{9/2}$



$^{40}Ca(^{32}S,\alpha p)^{67}As$ and $^{40}Ca(^{32}S,\alpha n)^{67}Se$

Experimental approach



Beyond the $f_{7/2}$ shell: ^{67}As – ^{67}Se

PRL **103,** 052501 (2009) PHYSICAL REVIEW LETTERS week ending 31 JULY 2009

Coherent Contributions to Isospin Mixing in the Mirror Pair ^{67}As and ^{67}Se

R. Orlandi,[1,*] G. de Angelis,[1] P. G. Bizzeti,[2] S. Lunardi,[3] A. Gadea,[1,†] A. M. Bizzeti-Sona,[2] A. Bracco,[4] F. Brandolini,[3]
M. P. Carpenter,[5] C. J. Chiara,[6,||] F. Della Vedova,[1] E. Farnea,[3] J. P. Greene,[5] S. M. Lenzi,[3] S. Leoni,[4] C. J. Lister,[5]
N. Mărginean,[3,‡] D. Mengoni,[3] D. R. Napoli,[1] B. S. Nara Singh,[7] O. L. Pechenaya,[6,§] F. Recchia,[1] W. Reviol,[6] E. Sahin,[1]
D. G. Sarantites,[6] D. Seweryniak,[5] D. Tonev,[8] C. A. Ur,[3] J. J. Valiente-Dobón,[1] R. Wadsworth,[7]
Wiedemann,[9] and S. Zhu[5]

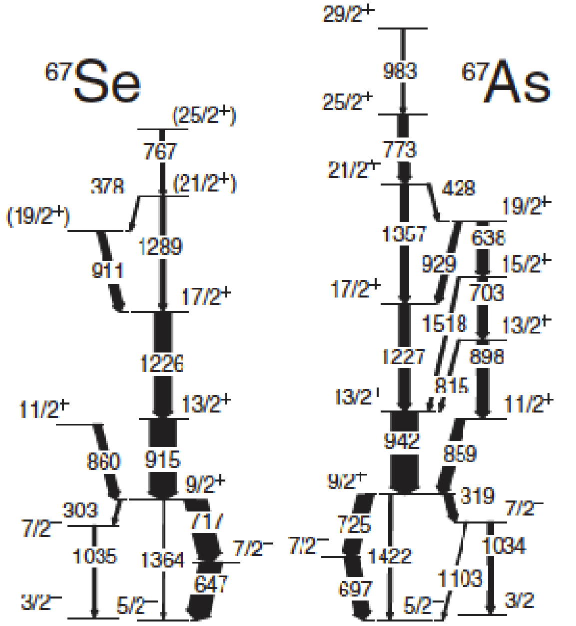


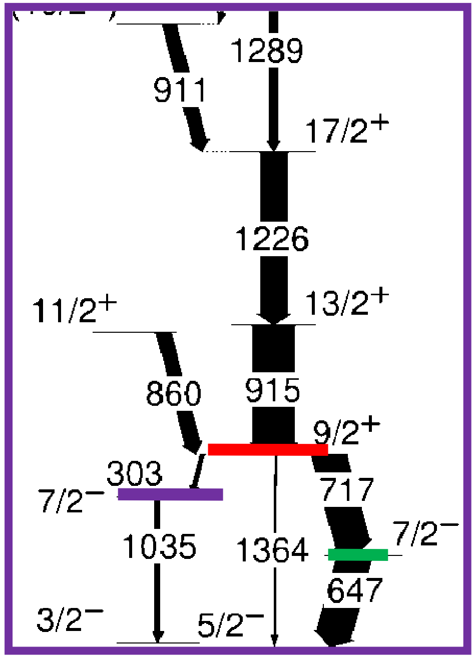
FIG. 1. Proposed partial level schemes for (left) ^{67}Se [16] and (right) ^{67}As determined from the present data. The energy labels are given in keV and the widths of the arrows are proportional to the relative intensities of the γ rays. Spin and parity assignments in ^{67}Se are based on symmetry considerations and on the measured ADO ratios (see text).

If isospin is conserved, the E1 transitions in mirror nuclei should have the same strength.

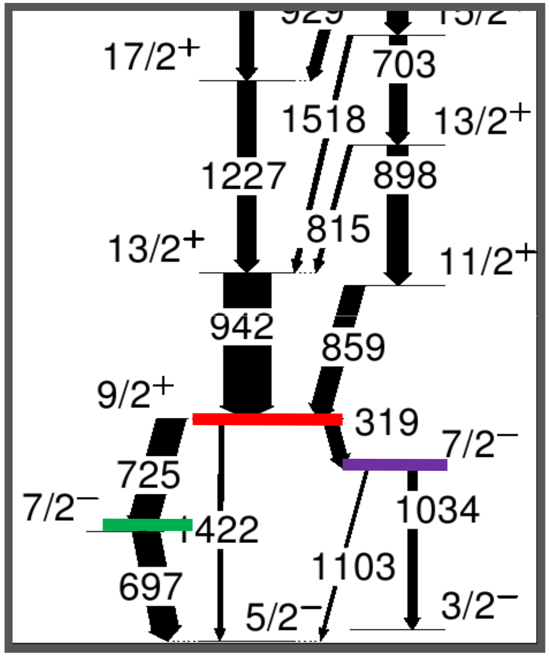
R. Orlandi et al., PRL103, 052501 (2009)

Measured B(E1)

^{67}Se



^{67}As



- Two pairs of $9/2^+ \rightarrow 7/2^-$ analogue transitions
- To determine B(E1)

  - branching ratios

  - lifetime of 9/2+ state

  - multipolarities and mixing ratios

Energy (KeV)	B(E1) (10^{-6} wu)	B(E1) (10^{-6} wu)	Energy (KeV)
717	0.4(4)	1.4(4)	725
303	<1.4(9)	8.3(2.4)	319

The B(E1) isoscalar/isovector

Both transitions consistent with large isoscalar/isovector ratio: IS/IV~ 0.35(20)

$$B(E1)\left(T_z = \pm {}^{1}\!/_{2}\right) \approx \left\langle J_i; T_i T_z \left\| \mathrm{M}(E1)_{IS} \pm \mathrm{M}(E1)_{IV} \right\| J_i; T_i T_z \right\rangle^2$$

- Selection Rules for charge-symmetric nuclear interaction
  - E1 pure isovector (but different sign in mirror nuclei)
  - E1 transitions in $T_z = ½$ nuclei should exhibit same strength
- If differences, may arise from interference between IV and non-zero IS term
  - 10^{-4} in IS/IV for the neglected terms in the long-wave approximation
  - Coulomb mixing with close lying $7/2^-$ levels
  - Mixing via Isovector Giant Monopole Resonance (IVGMR)

Detailed calculations in a forthcoming publication P.G Bizzeti

MED in ^{67}Se and ^{67}As

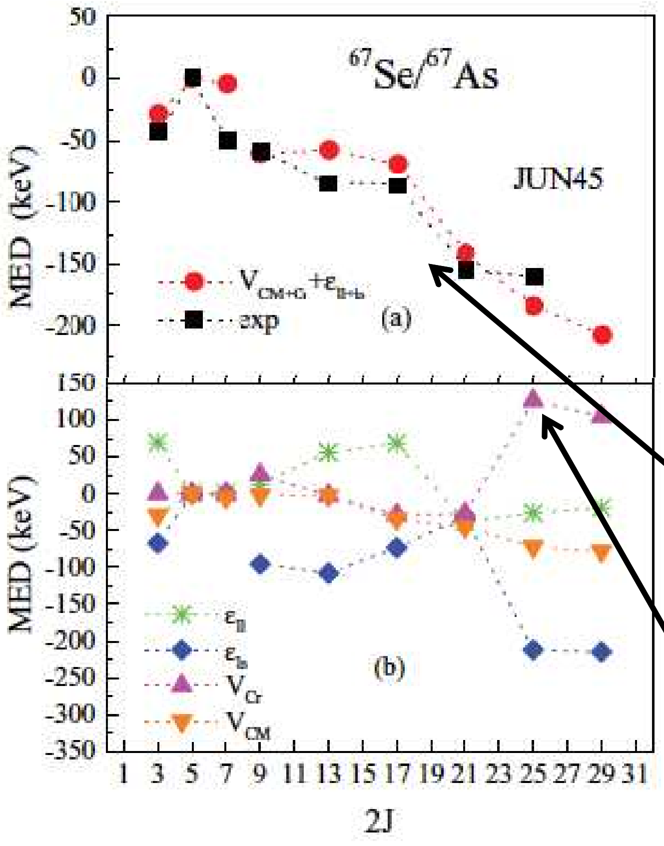


FIG. 2. (Color online) The MED for states shown in Fig. 1. Upper graph: Comparison of calculated MED with available data. Lower graph: Decomposition of theoretical MED into four terms (see text for explanation).

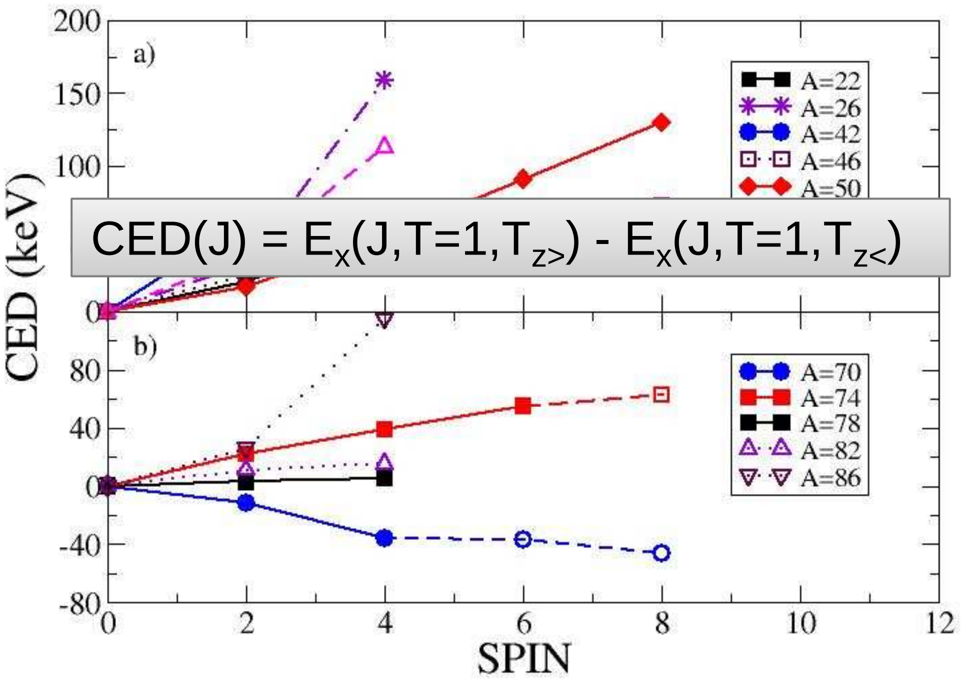
- Need of the $g_{9/2}$ to properly describe the results – Interaction JUN45 ($p_{3/2}$, $f_{5/2}$, $p_{1/2}$, $g_{9/2}$) ^{56}Ni core - M. Honma et al., PRC80, 064323 (2009)

The experimental MED are well described without including an explicit isospin-breaking NN term

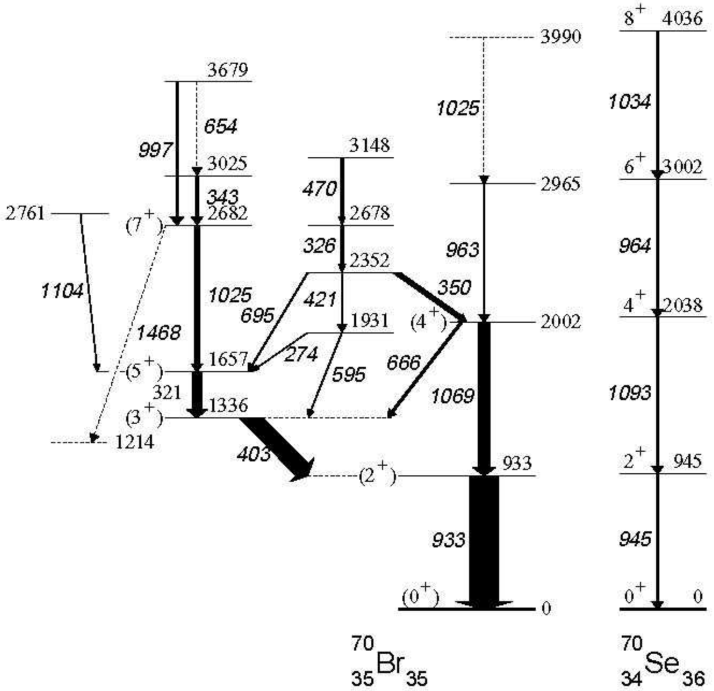
However, the the strength of the V_{Cr} was fitted from data and not determined independently

K. Kaneko et al., PRC82 061301R (2001)

Shape effects in the A=70 mass



$CED(J) = E_x(J,T=1,T_{z>}) - E_x(J,T=1,T_{z<})$

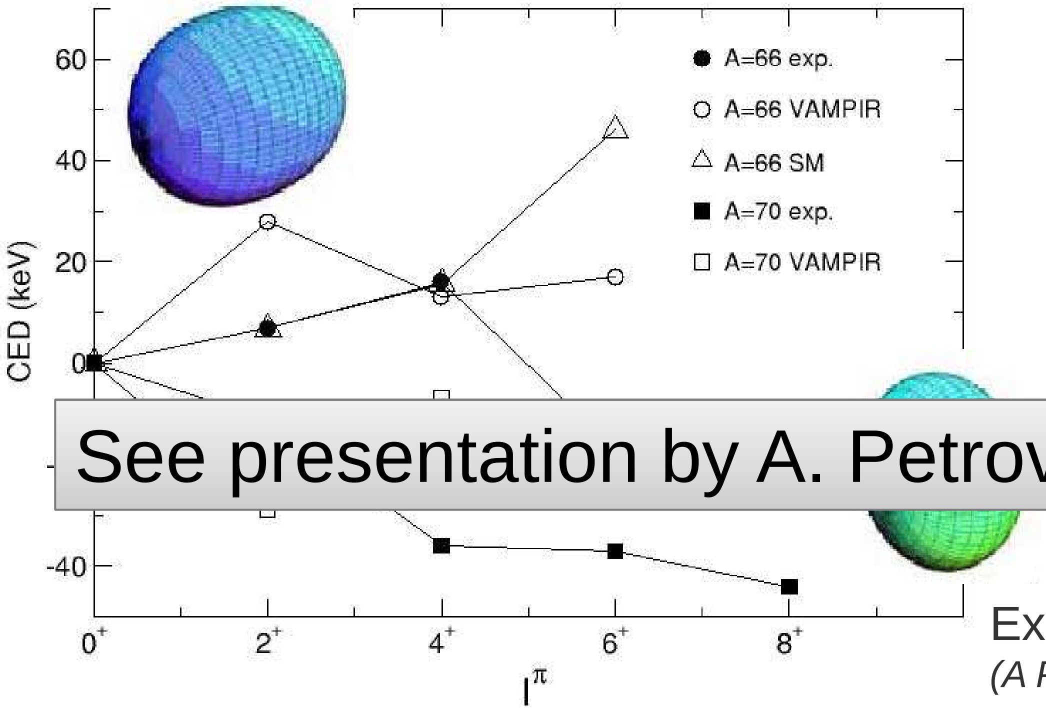


- A=70(^{70}Br/^{70}Se) – large negative CED has been explained as resulting from:

  - Prolate stretching in both nuclei (B S Nara Singh et al., PRC 75,061301(R) (2007))
  - Also speculated that it may be due to diff (obl/ prol) shapes for the two nuclei (R. Wadsworth et al., Act. Pol. B40, 611 (2009), G. de Angelis et al. PRC (R) (to be published))

G. de Angelis et al., EPJ A12, 51 (2001)
D.G. Jenkins et al., PRC 65, 064307 (2002)

Shape effects in CED



See presentation by A. Petrovici

- ^{70}Se is predominantly oblate GS *(J. Ljungvall et al., PRL100 102502 (2008)*

- ^{70}Br is predominantly prolate GS

Excited VAMPIR Model
(A Petrovici et al NPA483, 317 (1988))

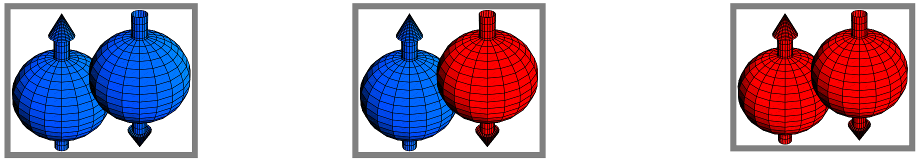
- Beyond mean-field approach with symmetry projection
- Successfully used to describe analogue states in mass 70 region, Petrovici et al., Nucl Phys A728, 396 (2003)
- Takes into account: Oblate/ prolate shape co-existence and n-p pairing correlations in both the T=0 and T=1 channels
- Calculations performed using the isospin symmetric G matrix based on Bonn A potential and Coulomb interaction between the valence protons.

Proton-neutron correlations

n-p spin aligned coupling

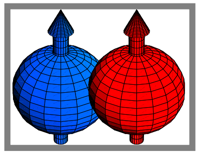
When approaching N=Z, ”normal” pair correlations may remain or even be extended:

Normal T=1, I=0 (isovector”) nn, pp
as well as np Cooper pairs (neutrons and protons occupy identical orbits)



T=1, I=0

In addition: T=0, I=1 ... (”isoscalar”) np pairing



T=0, I>0

So far, the search for T=0 np pairing has focused on special features:

- g.s. binding energies of odd-odd nuclei
- high-spin properties of N=Z nuclei (delayed alignments?)
- deuteron transfer reactions

Delayed alignment: ^{72}Kr

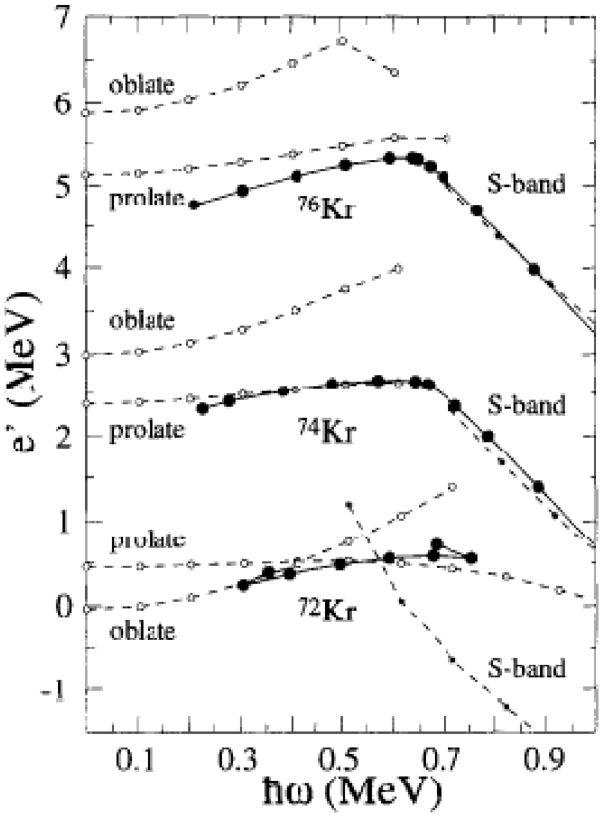
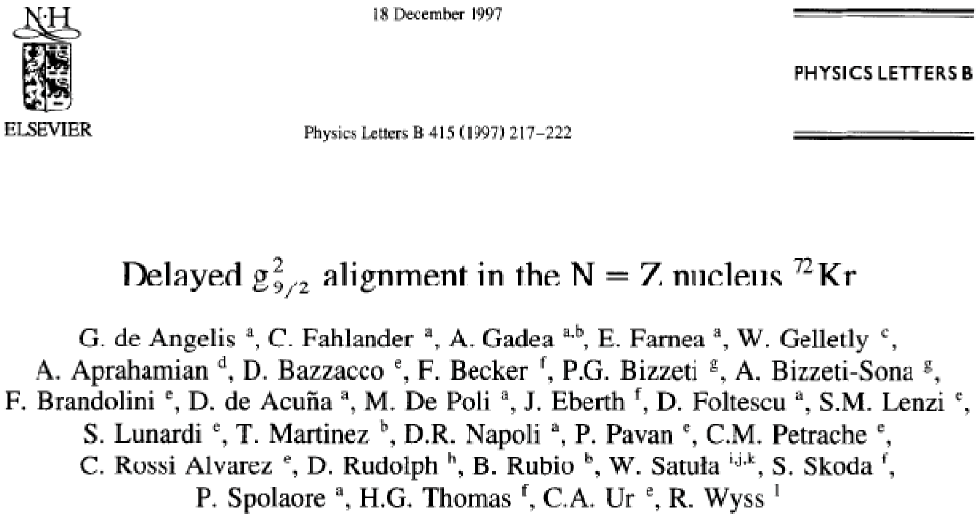


Fig. 4. The experimental (filled circles) and theoretical (small empty symbols) Routhians versus the rotational frequency for the oblate and prolate yrast bands and S-band for ^{72,74,76}Kr. A common reference ($J_0 \omega^2$) with $J_0 = 17.5\hbar^2$ MeV^{-1} has been subtracted. The calculated routhians are reported for oblate ($\beta_2 \approx$ 0.35, 0.35, 0.29, respectively) and prolate ($\beta_2 \approx$ 0.43, 0.39, 0.39, respectively) deformations – empty circles – and for the S-band ($\beta_2 \approx$ 0.30, 0.28, 0.26, respectively) – stars. Note the frequency shift of the crossing of the S-band for the ^{72}Kr nucleus.



ELSEVIER

18 December 1997

Physics Letters B 415 (1997) 217–222

PHYSICS LETTERS B

Delayed $g_{9/2}^2$ alignment in the N = Z nucleus ^{72}Kr

G. de Angelis [a], C. Fahlander [a], A. Gadea [a,b], E. Farnea [a], W. Gelletly [c],
A. Aprahamian [d], D. Bazzacco [e], F. Becker [f], P.G. Bizzeti [g], A. Bizzeti-Sona [g],
F. Brandolini [e], D. de Acuña [a], M. De Poli [a], J. Eberth [f], D. Foltescu [a], S.M. Lenzi [e],
S. Lunardi [e], T. Martinez [b], D.R. Napoli [a], P. Pavan [e], C.M. Petrache [e],
C. Rossi Alvarez [e], D. Rudolph [h], B. Rubio [b], W. Satuła [i,j,k], S. Skoda [f],
P. Spolaore [a], H.G. Thomas [f], C.A. Ur [e], R. Wyss [l]

Delayed alignment in the particle alignmet as a possible signature of T=0 neutron-proton pairing

Delayed backbending

N=Z

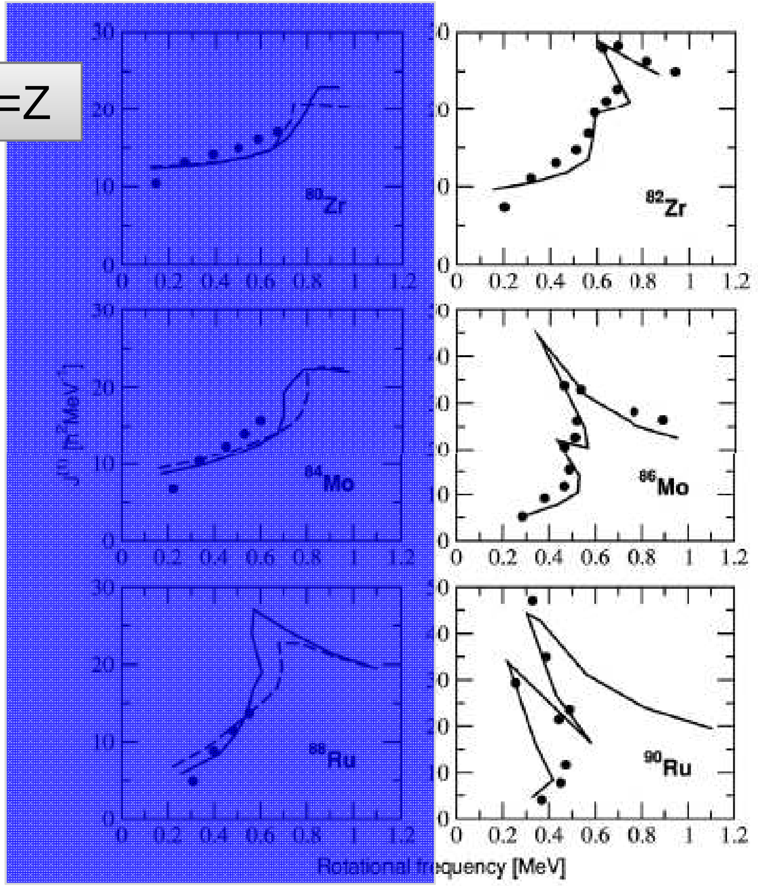
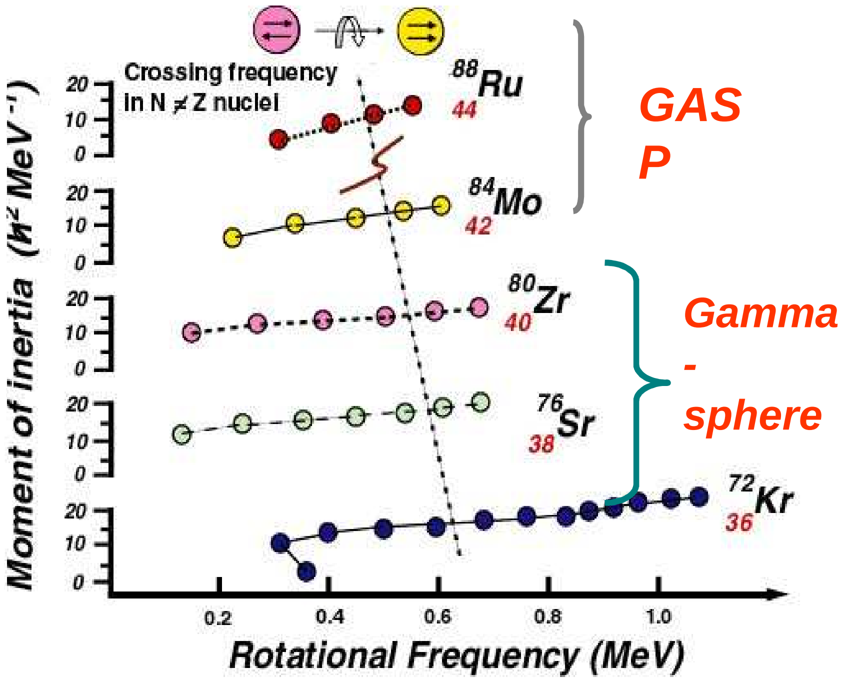


FIG. 3. Comparison of experimental data (dots) and projected shell model calculations. The experimental data are as follows: ^{84}Mo (present data), ^{86}Mo [17], ^{88}Ru [11], ^{90}Ru [20]. For continuity with the study of the $N=Z$ nuclei presented in Ref. [9], ^{80}Zr [2] and ^{82}Zr [21] are also shown. The full lines are the PSM calculations with a standard interaction, the dashed ones with an enhanced neutron-proton residual interaction (see text for details).



GASP

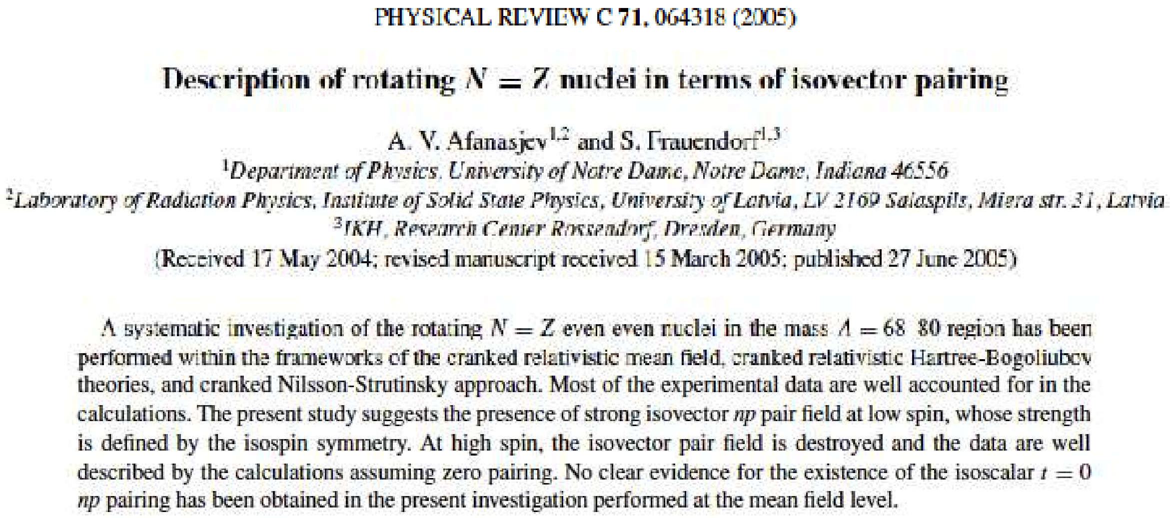
Gamma-sphere

Need of observation of still higher spins in the yrast bands:

- ^{80}Zr above 12ħ
- ^{84}Mo above 10ħ
- ^{88}Ru above 8ħ

N. Marginean et al., PRC65 051303(R) (2002)

N=Z - isovector T=1 pairing



PHYSICAL REVIEW C **71**, 064318 (2005)

Description of rotating $N = Z$ nuclei in terms of isovector pairing

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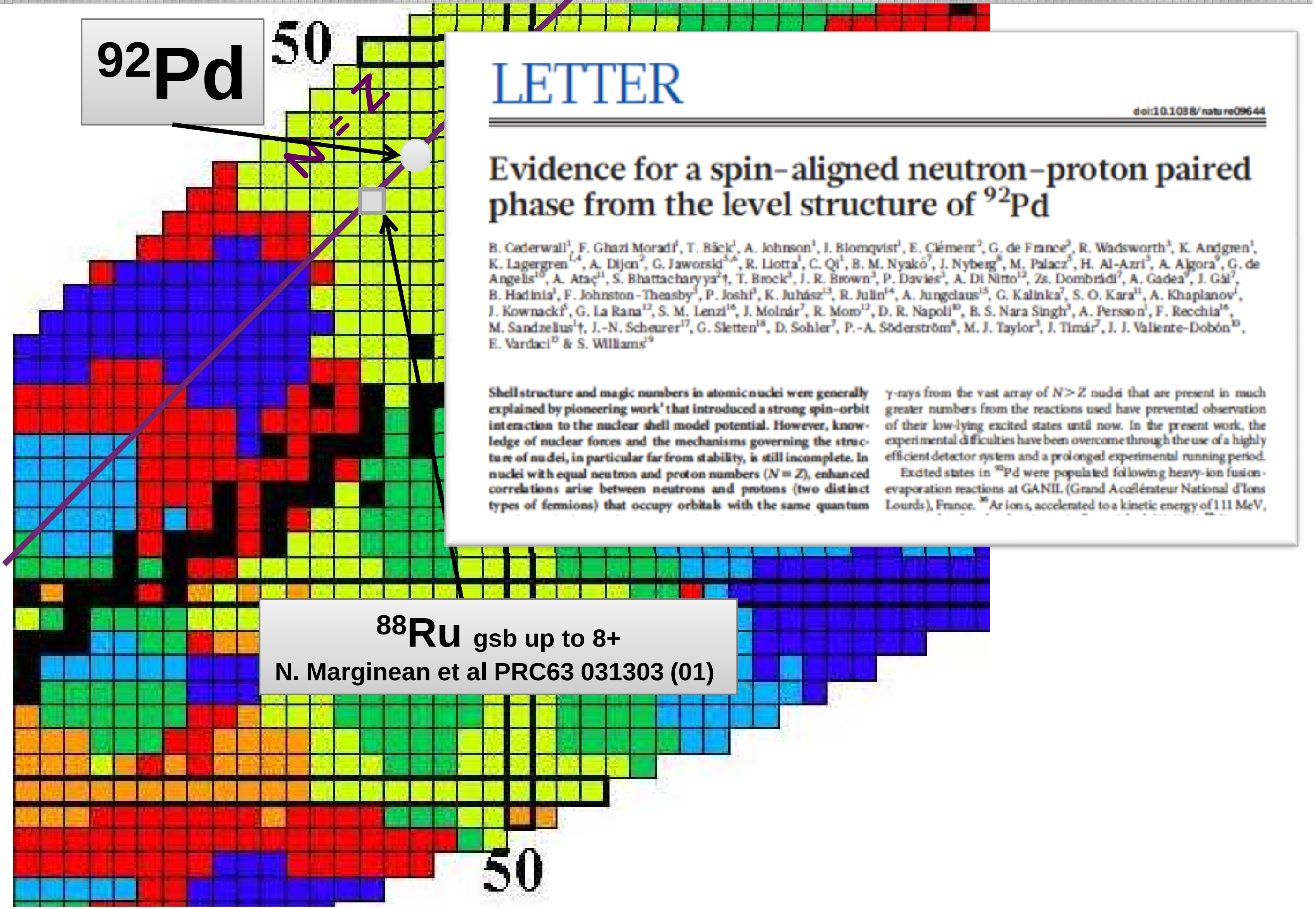
[3]*IKH, Research Center Rossendorf, Dresden, Germany*
(Received 17 May 2004; revised manuscript received 15 March 2005; published 27 June 2005)

A systematic investigation of the rotating $N = Z$ even even nuclei in the mass $A = 68$ 80 region has been performed within the frameworks of the cranked relativistic mean field, cranked relativistic Hartree-Bogoliubov theories, and cranked Nilsson-Strutinsky approach. Most of the experimental data are well accounted for in the calculations. The present study suggests the presence of strong isovector *np* pair field at low spin, whose strength is defined by the isospin symmetry. At high spin, the isovector pair field is destroyed and the data are well described by the calculations assuming zero pairing. No clear evidence for the existence of the isoscalar $t = 0$ *np* pairing has been obtained in the present investigation performed at the mean field level.

•The rotational bands of N≈Z nuclei are well reproduced using Nilsson-Strutinsky or CRMF where only the isovector pair field is considered T=1. No need of the introduction of T=0 np pairing.
•The theoretical approach is based on a strong coupling approximation, therefore can not be concluded the existence of T=0 np pairing
•Can not be excluded that moments of inertia, band crossings, etc are not sensitive to T=0 pairing.

In beam spectroscopy of ^{92}Pd



^{92}Pd

^{88}Ru gsb up to 8+
N. Marginean et al PRC63 031303 (01)

LETTER

doi:10.1038/nature09644

Evidence for a spin-aligned neutron–proton paired phase from the level structure of ^{92}Pd

B. Cederwall[1], F. Ghazi Moradi[1], T. Bäck[1], A. Johnson[1], J. Blomqvist[1], E. Clément[2], G. de France[2], R. Wadsworth[3], K. Andgren[1], K. Lagergren[1,4], A. Dijon[2], G. Jaworski[5,6], R. Liotta[1], C. Qi[1], B. M. Nyakó[7], J. Nyberg[8], M. Palacz[5], H. Al-Azri[3], A. Algora[9], G. de Angelis[10], A. Ataç[11], S. Bhattacharyya[2]†, T. Brock[3], J. R. Brown[3], P. Davies[3], A. Di Nitto[12], Zs. Dombrádi[7], A. Gadea[9], J. Gál[7], B. Hadinia[1], F. Johnston-Theasby[3], P. Joshi[3], K. Juhász[13], R. Julin[14], A. Jungclaus[15], G. Kalinka[7], S. O. Kara[11], A. Khaplanov[1], J. Kownacki[5], G. La Rana[12], S. M. Lenzi[16], J. Molnár[7], R. Moro[12], D. R. Napoli[10], B. S. Nara Singh[3], A. Persson[1], F. Recchia[16], M. Sandzelius[1]†, J.-N. Scheurer[17], G. Sletten[18], D. Sohler[7], P.-A. Söderström[8], M. J. Taylor[3], J. Timár[7], J. J. Valiente-Dobón[10], E. Vardaci[12] & S. Williams[19]

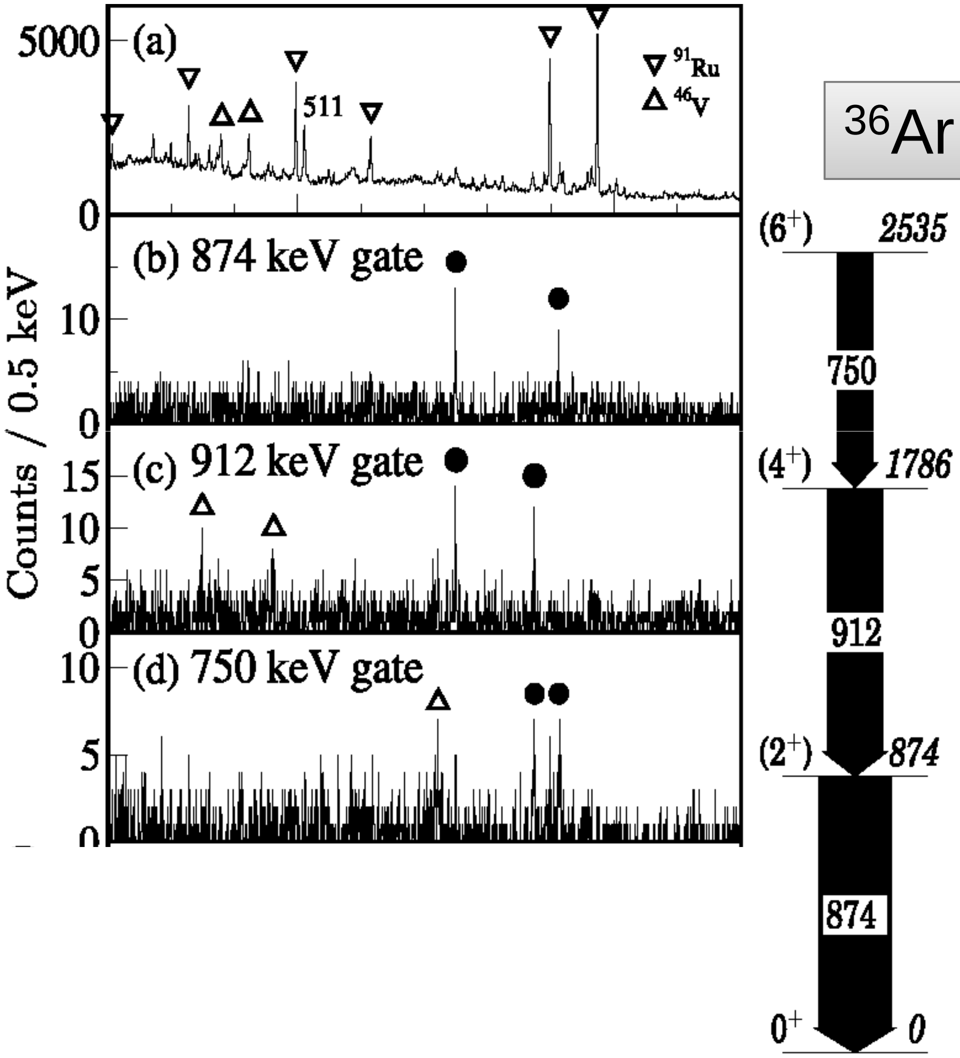
Shell structure and magic numbers in atomic nuclei were generally explained by pioneering work[1] that introduced a strong spin–orbit interaction to the nuclear shell model potential. However, knowledge of nuclear forces and the mechanisms governing the structure of nuclei, in particular far from stability, is still incomplete. In nuclei with equal neutron and proton numbers ($N = Z$), enhanced correlations arise between neutrons and protons (two distinct types of fermions) that occupy orbitals with the same quantum

γ-rays from the vast array of $N > Z$ nuclei that are present in much greater numbers from the reactions used have prevented observation of their low-lying excited states until now. In the present work, the experimental difficulties have been overcome through the use of a highly efficient detector system and a prolonged experimental running period.

Excited states in ^{92}Pd were populated following heavy-ion fusion-evaporation reactions at GANIL (Grand Accélérateur National d'Ions Lourds), France. ^{36}Ar ions, accelerated to a kinetic energy of 111 MeV,

Experimental level scheme

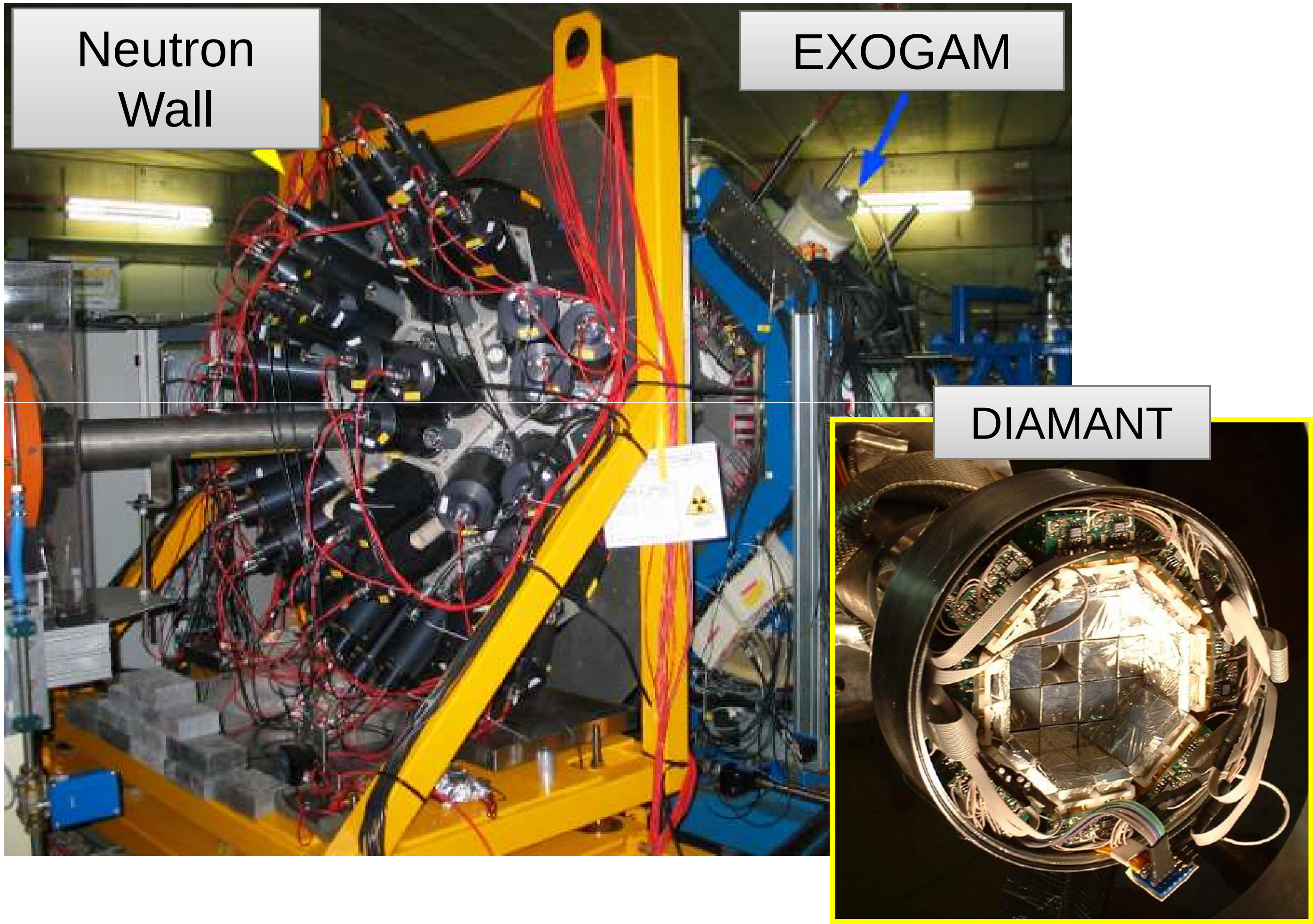
$^{36}Ar + ^{58}Ni \rightarrow ^{94}Pd^* \rightarrow ^{92}Pd + 2n$



- •Three γ rays firmly identified
- •In coincidence with 2 neutrons and not charged particles
- •Mutually coincident
- •All possible “contaminants” excluded
- •Production cross section ~0.5μb

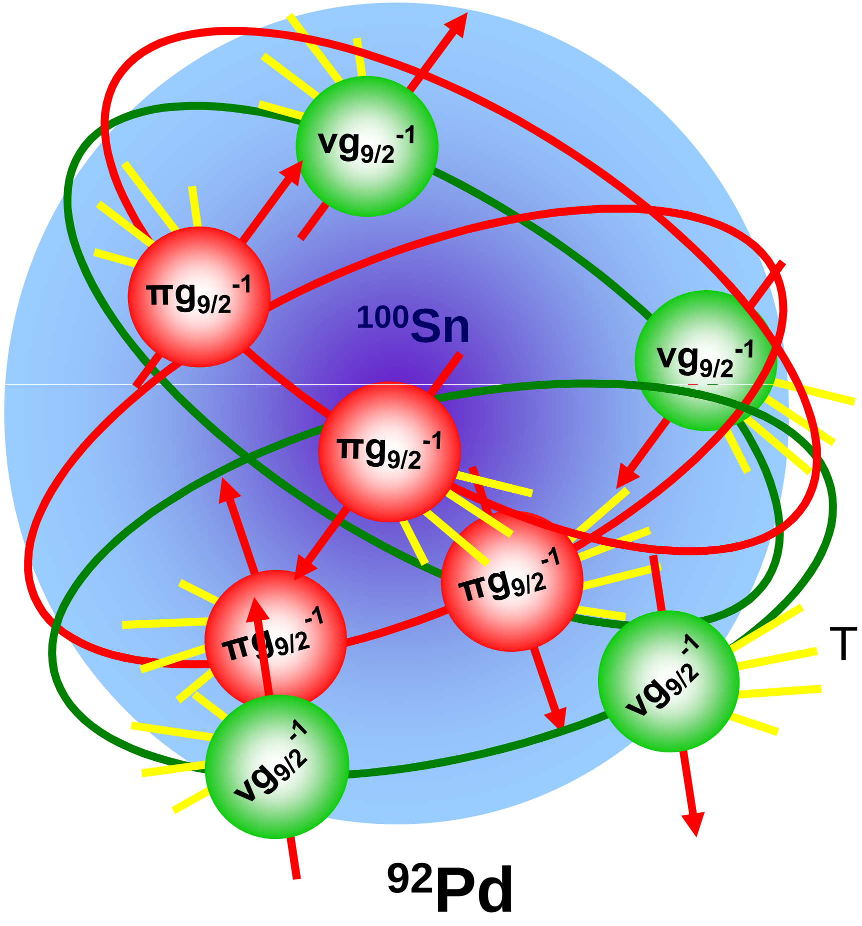
B. Cederwall et al., Nature 469 (2011)

Experimental approach



$^{40}Ca + ^{58}Ni \rightarrow ^{98}Cd^{*} \rightarrow ^{96}Cd + 2n$

Normal T=1 pairing



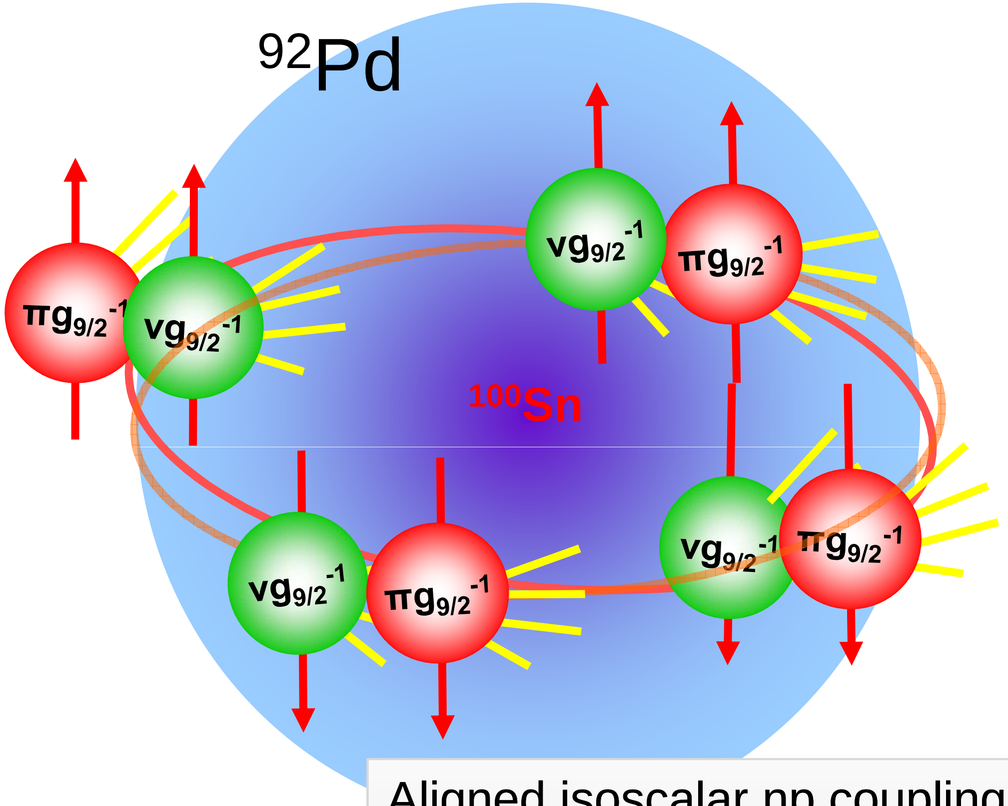
For ^{92}Pd, neutrons and protons mainly occupy the g $_{9/2}$ subshell

The conventional pairing picture:
$\Psi_{G.S}=(\{\nu g_{9/2}^{-2}\}_{0+})^n \text{ x } (\{\pi g_{9/2}^{-2}\}_{0+})^n$

This would lead to a seniority type spectrum of low-lying excited states.
Larger energy of the 2+, smaller 4+, …

Courtesy B. Cederwall

Manifestation of T=0 pairing



The np-paired ground-state configuration is given by the strong attractive interaction between $g_{9/2}$ neutrons and protons in aligned angular momentum J=9.

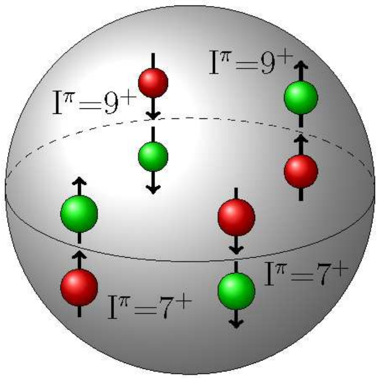
Aligned isoscalar np coupling:

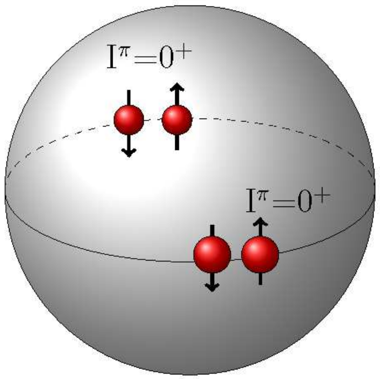
$$\Psi_{G.S.}=[(\{\nu g_{9/2}^{-1} \times \pi g_{9/2}^{-1}\}_{9+})^2]_{0+} \times [(\{\nu g_{9/2}^{-1} \times \pi g_{9/2}^{-1}\}_{7+})^2]_{0+}$$

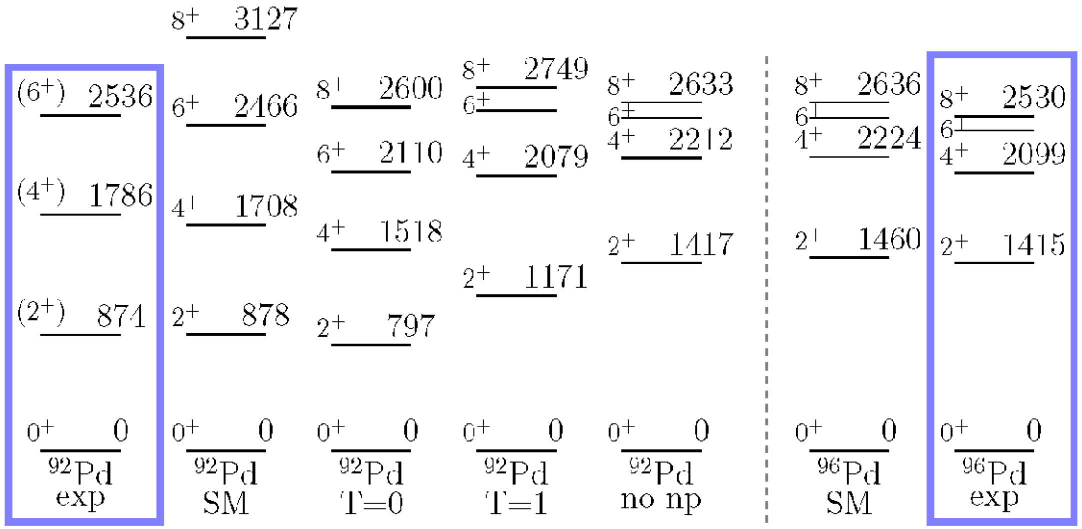
- 4-deuteron hole-like pairs coupled to J=9, each with a different angular momentum projection M = +9, -9, +7, -7 to satisfy the Pauli Principle.

Courtesy B. Cederwall

^{92}Pb vs. ^{96}Pd







Shell model calculations by J. Blomqvist et al.

Calculations done in several model spaces,:i.e., 0g9/2, 0g9/2-1p1/2 and 0g9/2-1p1/2-0f5/2-1p3/2 which all give similar results . Int. parameters determined to reproduce exp energies in ^{94,95}*Pd,* ^{93,94}*Rh*

Experimental challenges

Some initial considerations

We know

- Stable beams have been used in the past to populate N=Z nuclei with fusion evaporation reactions.
- The higher in mass we go the smaller is the cross section for N≈Z nuclei
- In fusion-evaporation reactions, many channels opened → High selectivity is needed

We need

- Measurement of transition energies, γ-γ coincidences and τ (electromagnetic transition probabilities)
- Highly selective and efficient detectors are needed with the capability of Doppler correction.

Experimental needs for Stable Beams

- **Stable beams**
  - High efficiency & high granularity gamma-ray spectrometer (e.g. GASP, Euroball, Gammasphere) - high fold γ^n ($n \geq 3$) coincidence spectroscopy
  - *0^o recoil mass spectrometer* + focal plane detectors - identify A,Z of the recoil
  - Identify cleanly all emitted particles from reaction - needs a *charged-particle detector* (p, α) + high-efficiency & high granularity *neutron detector array*
  - Recoil-decay tagging for nuclei emitting charged particles α, β

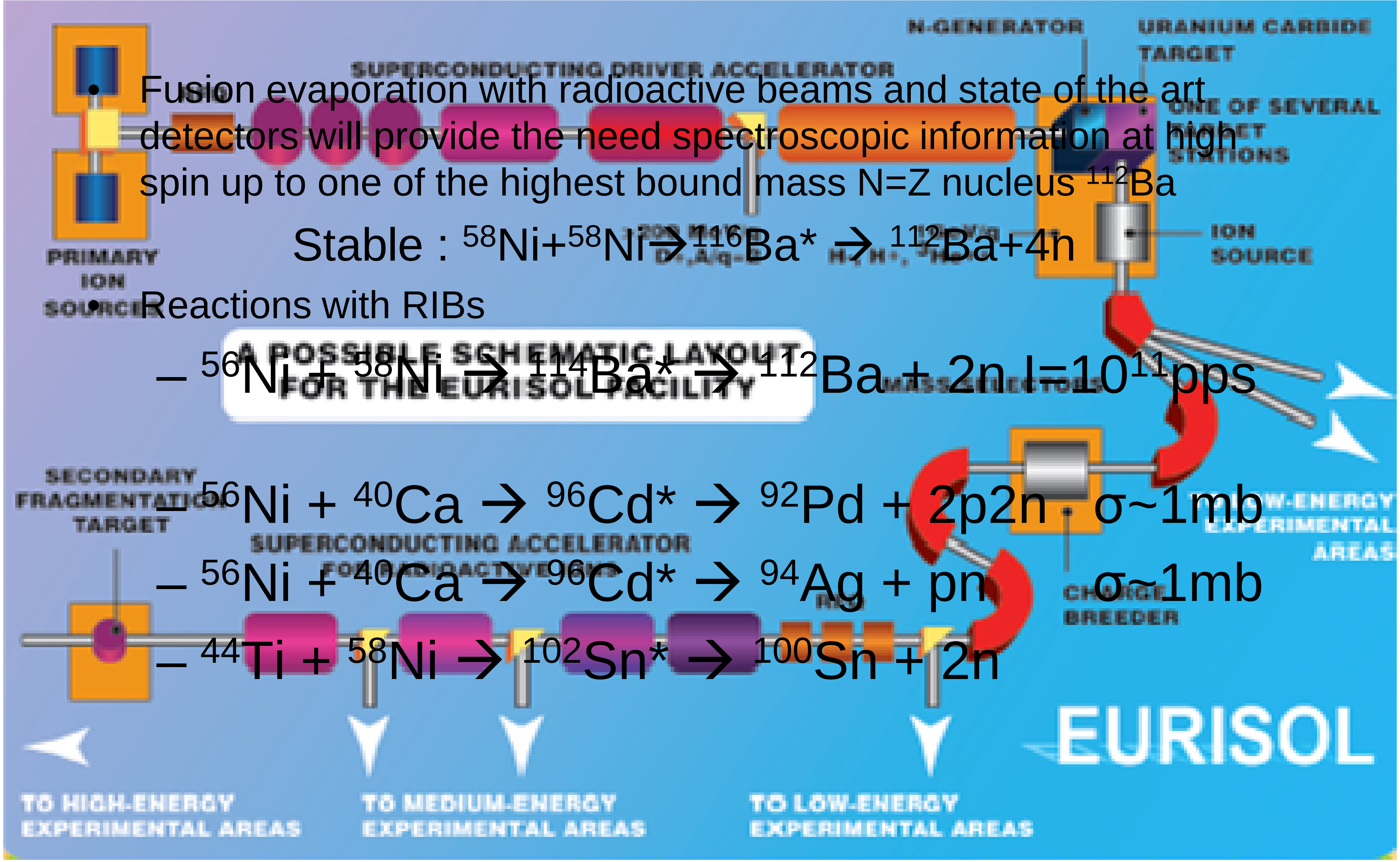
<u>Pros and cons:</u> more flexible than a mass spectrometer and more channels can be studied but if neutrons are to be measured, specially 2n, the setup becomes less efficient.

Experimental needs for RIB

- **Radioactive beams**
  - High efficiency & high granularity gamma-ray spectrometer (e.g. AGATA)
  - ISOL beams (e.g. Coulomb excitation, direct reactions)
  - Fragment separator with a secondary target for Coulomb excitation (Au) or knockout (Be). Identify cleanly the reaction after the secondary target (e.g. LYCAA, spectrometer like S800, Zerodegrees)

<u>Pros and cons: </u>one can go further away from stability, low gamma multiplicities but electromagnetic transitions probabilities can be measured. However still low RIB currents.

Reactions with RIB



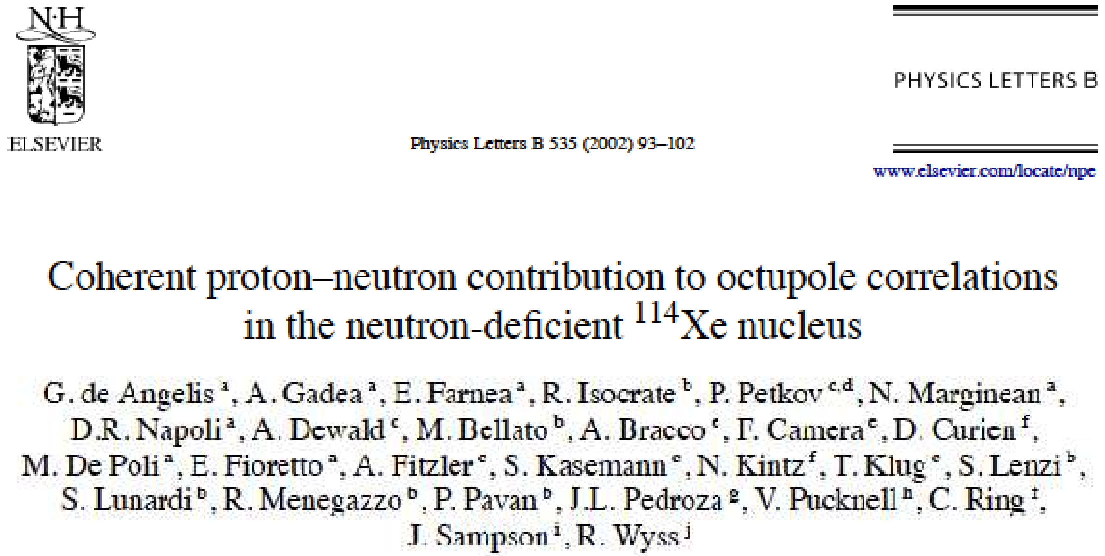
- Fusion evaporation with radioactive beams and state of the art detectors will provide the need spectroscopic information at high spin up to one of the highest bound mass N=Z nucleus ^{112}Ba

  Stable : $^{58}\mathrm{Ni}+^{58}\mathrm{Ni} \rightarrow ^{116}\mathrm{Ba}^* \rightarrow ^{112}\mathrm{Ba}+4n$

- Reactions with RIBs
  - $^{56}\mathrm{Ni} + ^{58}\mathrm{Ni} \rightarrow ^{114}\mathrm{Ba}^* \rightarrow ^{112}\mathrm{Ba} + 2n$ $I=10^{11}$pps
  - $^{56}\mathrm{Ni} + ^{40}\mathrm{Ca} \rightarrow ^{96}\mathrm{Cd}^* \rightarrow ^{92}\mathrm{Pd} + 2p2n$ $\sigma\sim1$mb
  - $^{56}\mathrm{Ni} + ^{40}\mathrm{Ca} \rightarrow ^{96}\mathrm{Cd}^* \rightarrow ^{94}\mathrm{Ag} + pn$ $\sigma\sim1$mb
  - $^{44}\mathrm{Ti} + ^{58}\mathrm{Ni} \rightarrow ^{102}\mathrm{Sn}^* \rightarrow ^{100}\mathrm{Sn} + 2n$

Octupole deformations

$^{56}Ni + ^{58}Ni \rightarrow ^{114}Ba^* \rightarrow ^{112}Ba + 2n$ I=10^{11}pps



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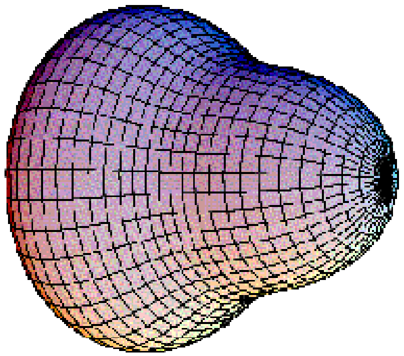
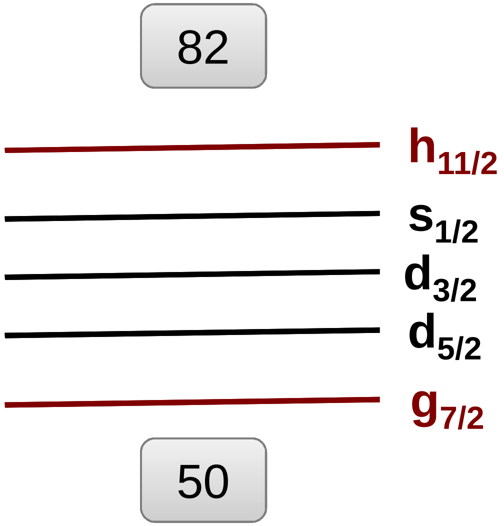
Coherent proton–neutron contribution to octupole correlations in the neutron-deficient ^{114}Xe nucleus

G. de Angelis [a], A. Gadea [a], E. Farnea [a], R. Isocrate [b], P. Petkov [c,d], N. Marginean [a], D.R. Napoli [a], A. Dewald [c], M. Bellato [b], A. Bracco [e], F. Camera [e], D. Curien [f], M. De Poli [a], E. Fioretto [a], A. Fitzler [c], S. Kasemann [c], N. Kintz [f], T. Klug [c], S. Lenzi [b], S. Lunardi [b], R. Menegazzo [b], P. Pavan [b], J.L. Pedroza [g], V. Pucknell [h], C. Ring [i], J. Sampson [i], R. Wyss [j]

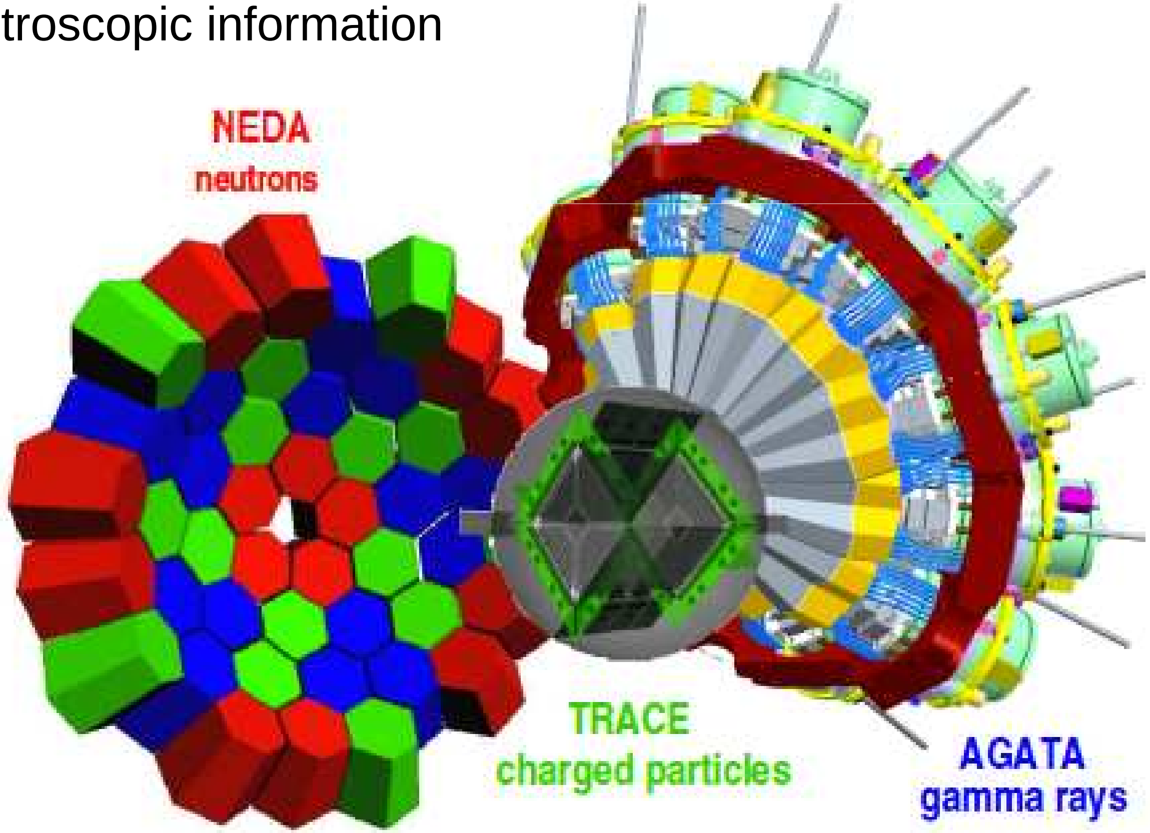




- There have been observed already in nuclei around ^{112}Ba enhanced E3 transitions
- ^{112}Ba will correspond to the best octupole N=Z=56 for p and n→ Enhanced octupole due to the interaction of $d_{5/2}$ and $h_{11/2}$ ΔL=3, ΔJ=3, inverse parity

Detector system

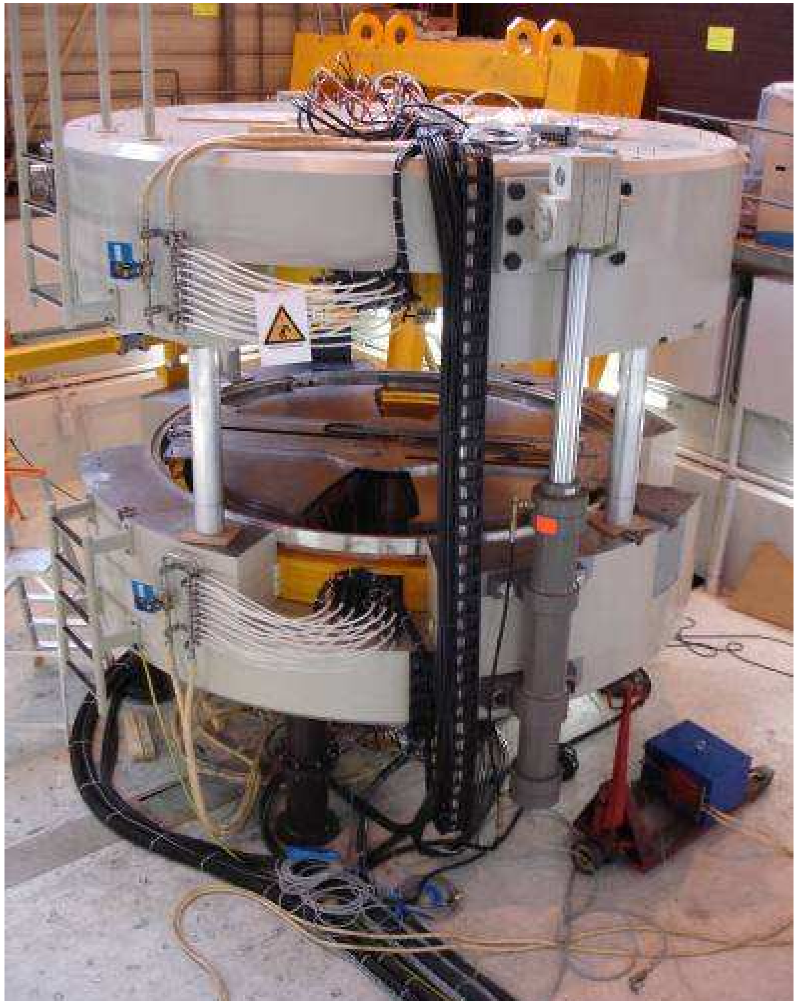
- In addition to an intense radioactive beam, highly detector performances are essential:
  - Channel selection
  - Sensitivity enhancement and
  - Spectroscopic information



RIB in batch mode at LNL

Radioactive beams of species with lifetimes in excess of several days can be efficiently generated by **irradiating target materials with a 40-50 MeV proton** beam for a time sufficiently long for secular equilibrium to transpire followed by a transfer of the target to the ion source (Batch Mode) to be **reaccelerated** in a TANDEM.

- Irradiation(15-35µA of p)
- Transport
- Re-acceleration

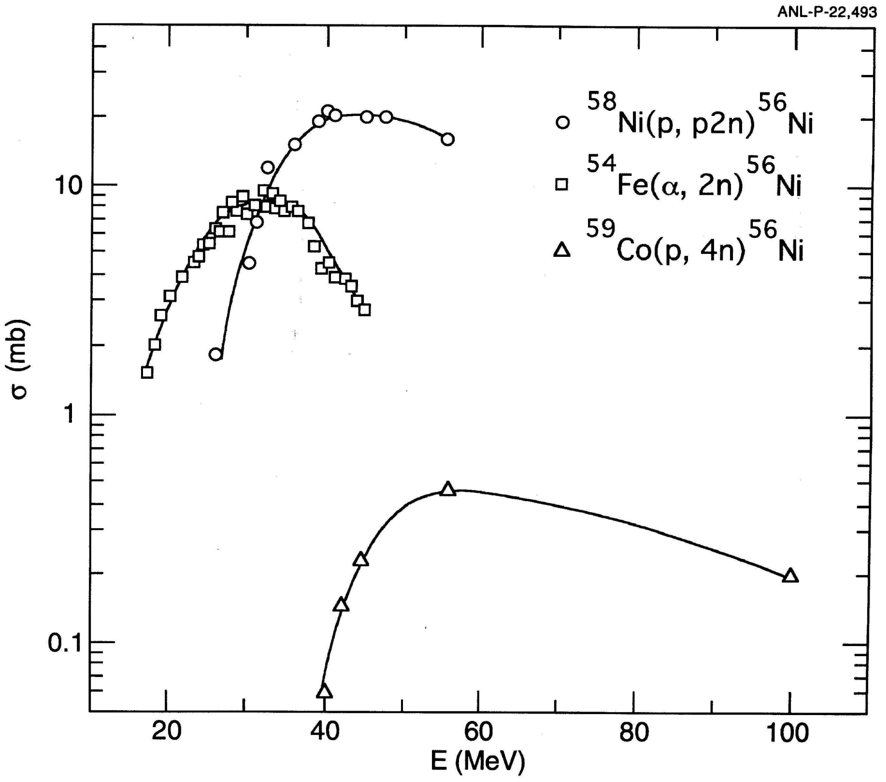


Reactions batch mode

- ^{9}Be(p,p2n)^{7}Be (53.2 d)
- ^{46}Ti(p,p2n)^{44}Ti (47.3 a)
- ^{58}Ni(p,p2n)^{56}Ni (6.1d)
- ^{70}Ge(p,p2n)^{68}Ge (288 d)
- ^{74}Se(p,p2n)^{72}Se (8.5 d)
- ^{84}Sr(p,p2n)^{82}Sr (25.5 d)
- ^{90}Zr(p,p2n)^{88}Zr (83.4 d)

After power disipation, lifetime, etc considerations a final intensity

^{56}Ni → 3 10^{7} pps
^{44}Ti → 2 10^{7} pps



D. Schwalm et al., NPA192 449 (1972)

Summary

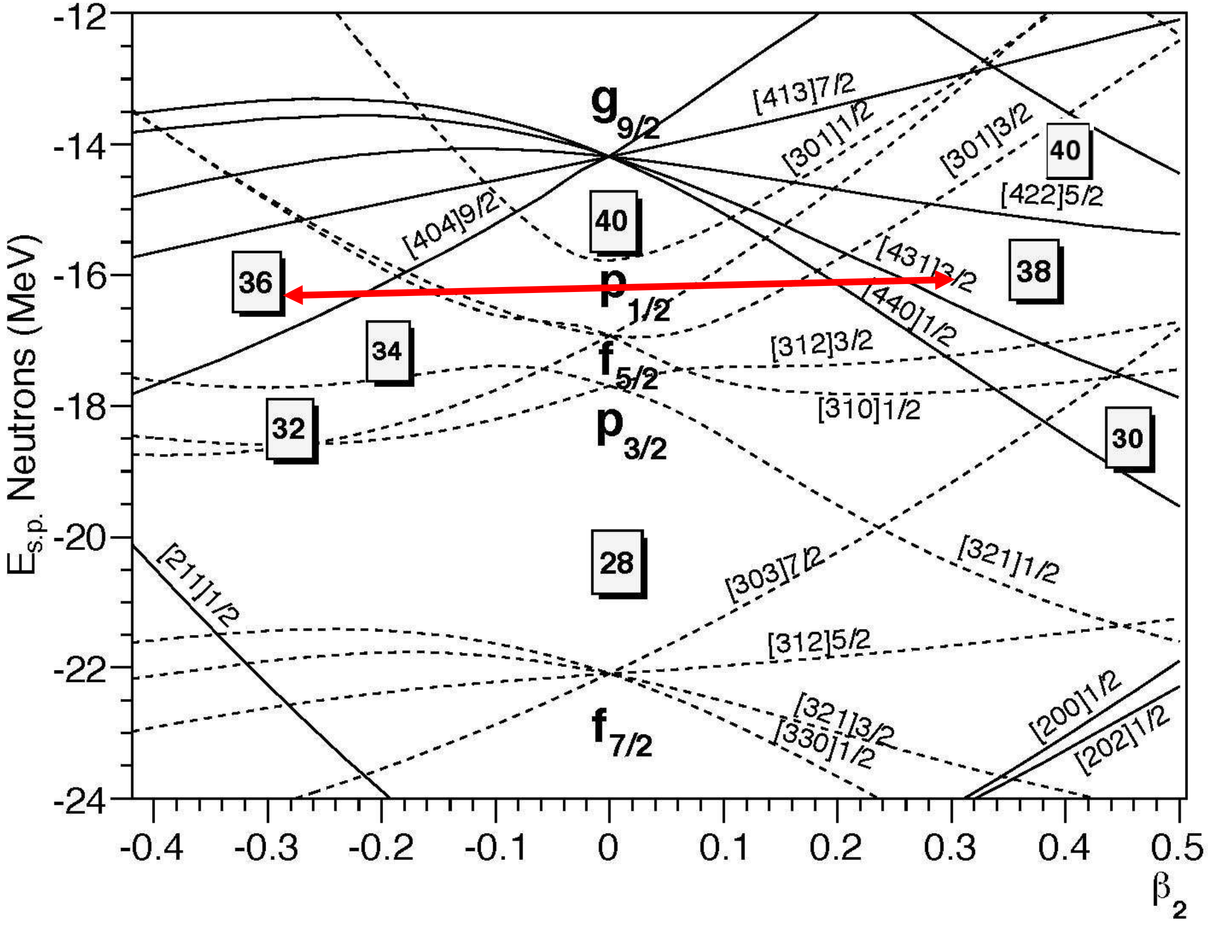
- Study of isospin symmetry beyond the $f_{7/2}$ with in beam gamma spectroscopy might help to understand the degree of isospin breaking in NN interaction. Recent examples in the A=70 show the importance of shape mixing. ^{70}Kr will be essential to fully understand the issue. $^{34}\text{Ar} + {}^{40}\text{Ca} \rightarrow {}^{74}\text{Sr}^{*} \rightarrow {}^{70}\text{Kr} + 2p2n$ (in beam).

EURISOL

- Study of N=Z nuclei in beam up to ^{112}Ba (possibly the best octupole) is a job that probably can only be done by EURISOL.
- Necessity of state-of-the-art detectors highly efficient and selective to pin down the most exotic channels.
- Road paved for EURISOL with near future facilities: SPES, SPIRAL2, HIE-ISOLDE, etc

Shape effects in the A=70 mass

It is commonly assumed that Mirror nuclei have identical shape. Is it true?



Expect shape co-existence in Se, Kr, Sr, Zr nuclei with N~Z

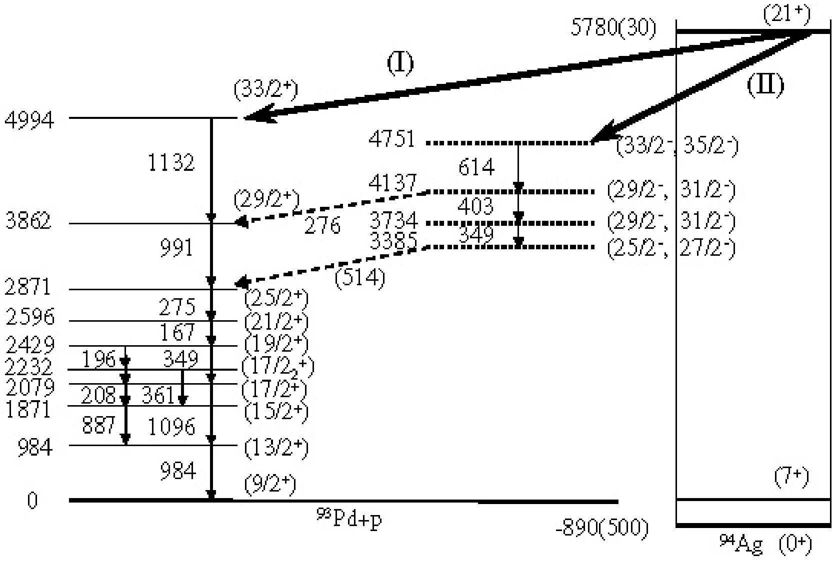
The ^{94}Ag

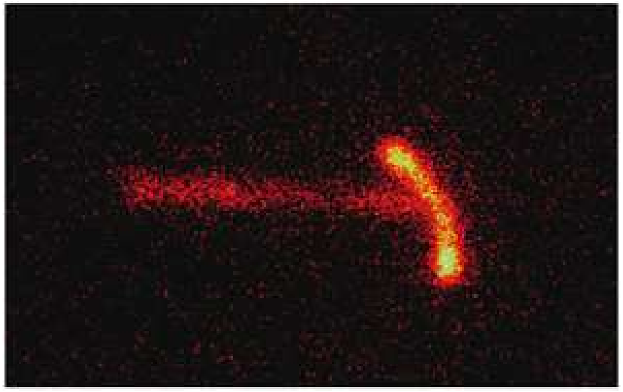
^{56}Ni + ^{40}Ca → ^{96}Cd* → ^{94}Ag + pn σ~1mb

This N = Z nucleus has two isomers (7^+, 21^+, $t_{1/2}$ ~ 0.5 s), with the highest one decaying via one and two-proton emission

Nature, 439, 298 (2006)

The 2p radioactivity strength suggest a very deformed (3:1) 21^+ isomer





The 21^+ isomer also decays by two different 1p emission

PRL 95, 022501 (2005)

In the road to Eurisol

- In the road to EURISOL: there are near future facilities SPES, SPIRAL2, HIE-ISOLDE, etc

- Example: SPIRAL2: LoI proposes to use the high intensity LINAG beams (ex. ^{58}Ni) to produce separated beams of the nuclei with N~*Z* , which can then be Coulomb excited at the focal plane of the S3 separator, following *A* and, possibly, *Z* identification.
    - Coulomb excitation of T=1 states in isobaric triplets ^{62}Ga-^{62}Zn, ^{66}As-^{66}Ge and ^{70}Br-^{70}Se produced by fusion reactions (^{58}Ni on ^{6}Li (liquid) 210-170 MeV)

estimated rates	^{62}Ga	15 10^6 pps
	^{66}As	3 10^6 pps
	^{70}Br	17 10^5 pps