# *Complex* EXCITED VAMPIR

## beyond mean-field approach with symmetry projection before variation for nuclear structure

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# *complex* VAMPIR approaches - Framework

- the model space is defined by a finite dimensional set of spherical single particle states
- the effective many-body Hamiltonian is represented as a sum of one- and two-body terms
- the basic buiding blocks are Hartree-Fock-Bogoliubov (HFB) vacua
- the HFB transformations are essentially *complex* and allow for proton-neutron, parity and angular momentum mixing being only restricted by time-reversal and axial symmetry
- the broken symmetries (s=N, Z, I, $\pi$) are restored before variation by projection techniques

# Theoretical tools

Model space

$\{|i\rangle \equiv |\tau n l j m\rangle\}$

$\{c_i^\dagger, c_k^\dagger, \dots\}_M$

$\{c_i, c_k, \dots\}_M$

Effective many-body Hamiltonian

$$\hat{H} = \sum_{i=1}^{M} \varepsilon(i) c_i^\dagger c_i + \frac{1}{4} \sum_{i,k,r,s=1}^{M} v(ikrs) c_i^\dagger c_k^\dagger c_s c_r$$

# Hartree-Fock-Bogoliubov transformation

$$\begin{pmatrix} a^\dagger \\ a \end{pmatrix} = F \begin{pmatrix} c^\dagger \\ c \end{pmatrix} = \begin{pmatrix} A^T & B^T \\ B^\dagger & A^\dagger \end{pmatrix} \begin{pmatrix} c^\dagger \\ c \end{pmatrix}$$

Quasi-particle vacuum

$$|F\rangle = \prod_{\alpha=1}^{M'} a_\alpha|0\rangle \qquad \text{with} \quad \left\{ \begin{array}{lc} a_\alpha|0\rangle \neq 0 & \text{for } \alpha = 1, ..., M' \leq M \\ a_\alpha|0\rangle = 0 & \text{else} \end{array} \right\}$$

$$\hat{\Theta}^s_{MK} \equiv \hat{P}(I;MK)\hat{Q}(N)\hat{Q}(Z)\hat{p}(\pi)$$

$$\hat{p}(\pi) \equiv \frac{1}{2}\left(1 + \pi\hat{\Pi}\right)$$

$$\hat{Q}(N_\tau) \equiv \frac{1}{2\pi}\int_0^{2\pi} d\phi_\tau \exp\{i\phi_\tau(N_\tau - \hat{N}_\tau)\})$$

$$\hat{P}(I;MK) \equiv \frac{2I+1}{8\pi^2}\int d\Omega {D^I_{MK}}^*(\Omega)\hat{R}(\Omega)$$

$$|\psi(F^s); sM\rangle = \sum_{K=-I}^{+I} \hat{\Theta}^s_{MK}|F^s\rangle\, f^s_K$$

$$|\psi(F^s); sM\rangle = \frac{\hat{\Theta}^s_{M0}|F^s\rangle}{\sqrt{\langle F^s|\hat{\Theta}^s_{00}|F^s\rangle}}$$

$$|F> = \{\prod_{m=1/2}^{m_{max}}(\prod_{\alpha}^{(m)}[u_\alpha + v_\alpha b_\alpha^\dagger b_{\bar{\alpha}}^\dagger])\}|0>$$

$$b_\alpha^\dagger = \sum_{\tau_i,n_i,l_i,j_i}^{(m_\alpha>0)} D_{i\alpha}^* c_i^\dagger$$

$$b_\alpha^\dagger b_{\bar{\alpha}}^\dagger = \sum_{\tau=p,n}\sum_{\mathrm{i<k}}^{(m_\alpha\tau)}[1+\delta(\mathbf{i},\underline{\mathrm{k}})]^{-1}\sum_I(-)^{j_k+l_k-m_\alpha}(j_ij_kI|m_\alpha - m_\alpha 0)$$
$$\times\{[Re(D_{i_\tau\alpha}^* D_{k_\tau\alpha})[1+(-)^{l_i+l_k+I}] + iIm(D_{i_\tau\alpha}^* D_{k_\tau\alpha})[1-(-)^{l_i+l_k+I}]][c_{\underline{\mathrm{i}}}^\dagger c_{\underline{\mathrm{k}}}^\dagger]_{12\tau}^{I0}\}$$

$$+\sum_{\underline{\mathrm{i}}}^{(m_\alpha p)}\sum_{\underline{\mathrm{k}}}^{(m_\alpha n)}\sum_{IT}(1/2 1/2 T| - 1/2 1/2 0)(-)^{j_k+l_k-m_\alpha}(j_ij_kI|m_\alpha - m_\alpha 0)$$
$$\times\{[Re(D_{i_p\alpha}^* D_{k_n\alpha})[1+(-)^{l_i+l_k+I}] + iIm(D_{i_p\alpha}^* D_{k_n\alpha})[1-(-)^{l_i+l_k+I}]][c_{\underline{\mathrm{i}}}^\dagger c_{\underline{\mathrm{k}}}^\dagger]_{T0}^{I0}\}$$

$$[c_{\underline{\mathrm{i}}}^\dagger c_{\underline{\mathrm{k}}}^\dagger]_{TT_z}^{IM} \equiv \sum_{m_im_k\tau_i\tau_k}(j_ij_kI|m_im_kM)(\frac{1}{2}\frac{1}{2}T|\tau_i\tau_kT_z)c_i^\dagger c_k^\dagger$$

## Variational strategies

***complex* Vampir approach**

$$E^s[F_1^s] = \frac{\langle F_1^s|\hat{H}\hat{\Theta}^s_{00}|F_1^s\rangle}{\langle F_1^s|\hat{\Theta}^s_{00}|F_1^s\rangle}$$

$$|\psi(F_1^s); sM\rangle = \frac{\hat{\Theta}^s_{M0}|F_1^s\rangle}{\sqrt{\langle F_1^s|\hat{\Theta}^s_{00}|F_1^s\rangle}}$$

## *complex* Excited Vampir approach

$$|\psi(F_2^s); sM\rangle = \hat{\Theta}^s_{M0}\left\{|F_1^s\rangle\alpha_1^2 + |F_2^s\rangle\alpha_2^2\right\}$$

$$|\psi(F_i^s); sM\rangle = \hat{\Theta}^s_{M0}\sum_{j=1}^{i} |F_j^s\rangle\,\alpha_j^i \qquad \text{for} \quad i = 1, \ldots, n$$

$$|\Psi_\alpha^{(n)}; sM> = \sum_{i=1}^{n} |\psi_i; sM> f_{i\alpha}^{(n)}, \qquad \alpha = 1, \ldots, n$$

$$(H - E^{(n)}N)f^n = 0$$

$$(f^{(n)})^+ N f^{(n)} = 1$$

# EXCITED FED VAMPIR approach

$$|\psi_1^{(n_1)}; sM\rangle \equiv \hat{\Theta}^s_{M0} \sum_{k=1}^{n_1} |F^s_k(1)\rangle \, f^{1n_1}_{k;\,1}$$

$$|\psi_i^{(n_i)}; sM\rangle = \hat{\Theta}^s_{M0} \sum_{j=1}^{i} \left\{ \sum_{k=1}^{n_j} |F^s_k(j)\rangle \, f^{jn_j}_{k;\,1} \right\} \alpha^i_j \qquad \text{for} \quad i = 1, ..., m$$

$$|\Psi_\alpha^{(m)}; sM > = \sum_{i=1}^{m} |\psi_i^{(n_i)}; sM > g^{(m)}_{i\alpha}, \qquad \alpha = 1, ..., m$$

$$(H - E^{(m)} N) g^m = 0$$

$$(g^{(m)})^+ N g^{(m)} = 1$$

A= 70 − 90 mass region

$^{40}$Ca - core

model space ( $\pi, \nu$):

$1p_{1/2}\ 1p_{3/2}\ 0f_{5/2}\ 0f_{7/2}\ 1d_{5/2}\ 0g_{9/2}$

***(charge-symmetric basis + Coulomb contributions to the $\pi$-spe from the core)***

renormalized G–matrix (OBEP, Bonn A) (Bonn CD)

- short range Gaussians in the *nn, pp, np channels*
- monopole shifts:

$\langle 0g_{9/2}0f; T=0|\hat{G}|0g_{9/2}0f; T=0\rangle$

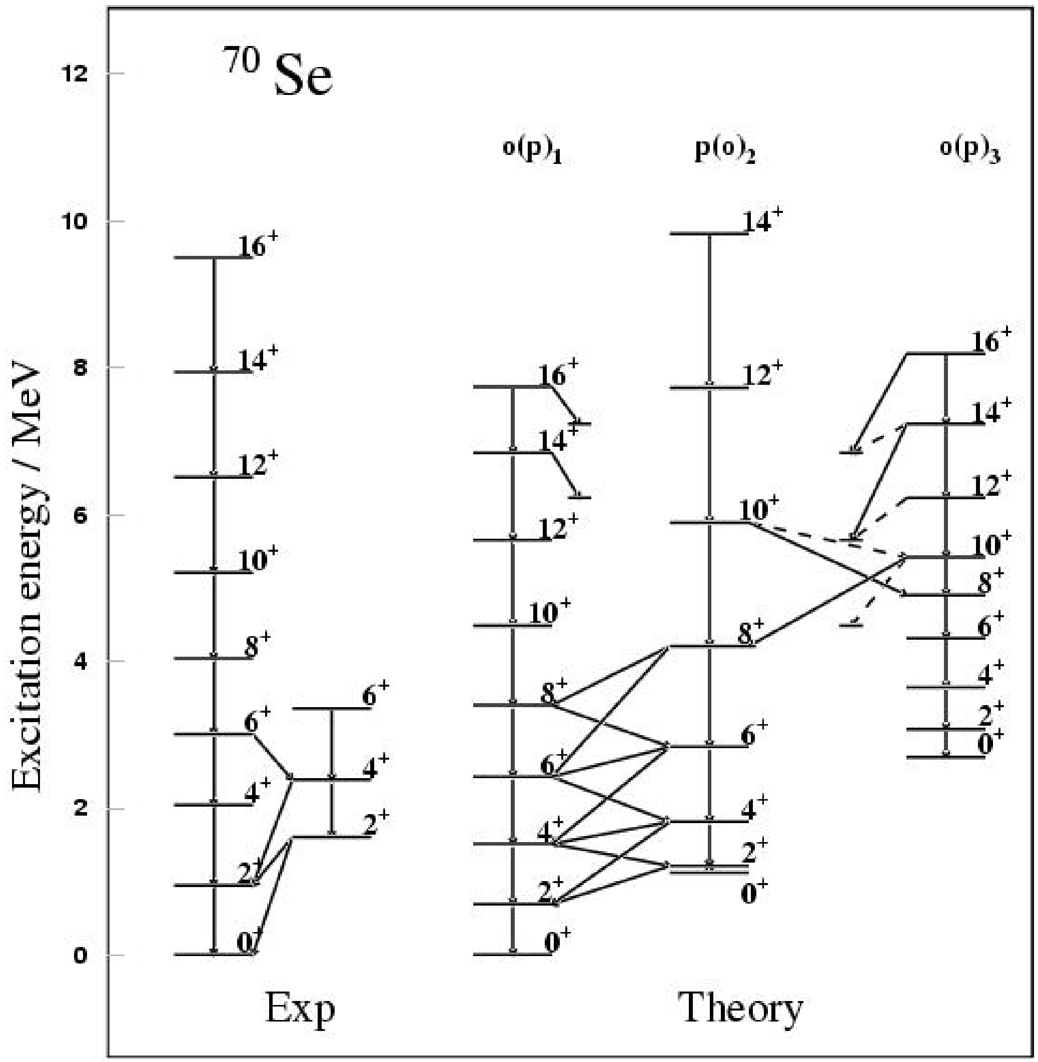
$\langle 1p1d_{5/2}; T=0|\hat{G}|1p1d_{5/2}; T=0\rangle$

| | $f_{5/2}$ | $f_{7/2}$ |
|---|---|---|
| (ms1 ): | -0.590 MeV / | -0.060 MeV |
| (ms2): | -0.500 MeV / | -0.150 MeV |
| * (ms3): | -0.400 MeV / | -0.250 MeV |

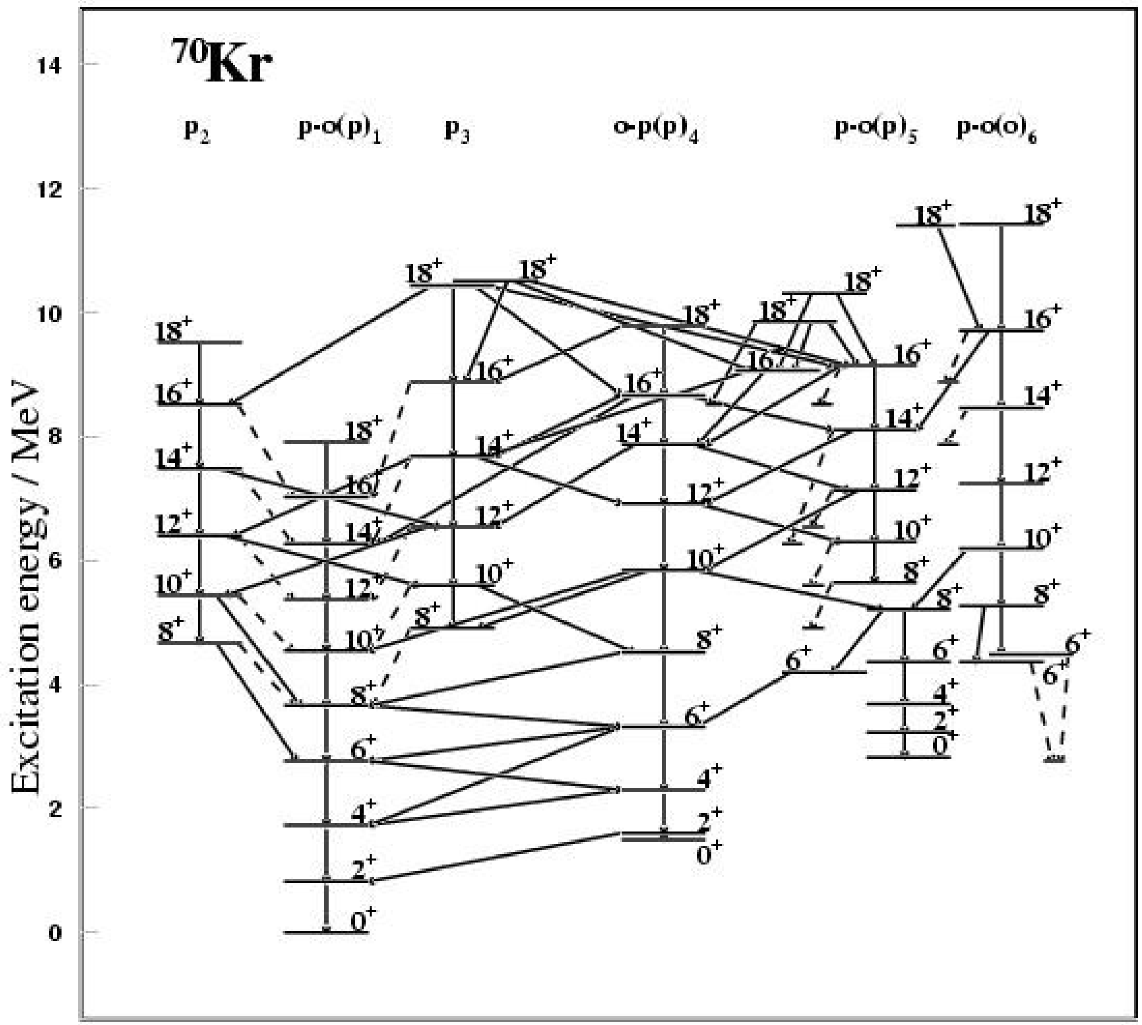
## *Superallowed Fermi β Decay*

| | | | |
|---|---|---|---|
| **A=70** | $_{34}Se_{36}$ | $_{35}Br_{35}$ | $_{36}Kr_{34}$ |
| **A=74** | $_{36}Kr_{38}$ | $_{37}Rb_{37}$ | $_{38}Sr_{36}$ |
| **A=82** | $_{40}Zr_{42}$ | $_{41}Nb_{41}$ | |
| **A=86** | $_{42}Mo_{44}$ | $_{43}Tc_{43}$ | |

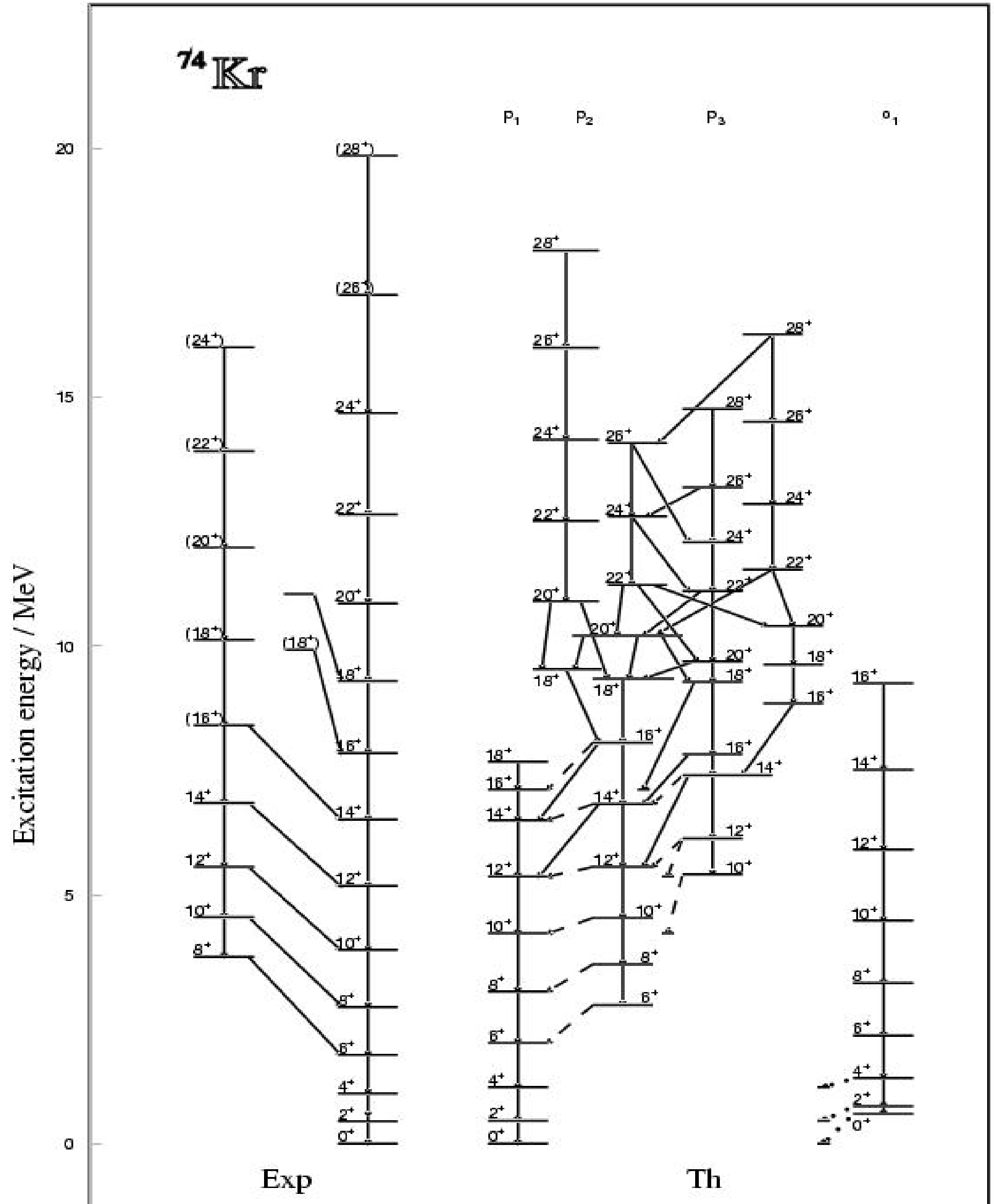
*A.Petrovici et al., Nucl. Phys. A728 (2003) 396*



A. Petrovici et al., Nucl. Phys. A728 (2003) 396



*A. Petrovici et al., Nucl. Phys. A665 (2000) 333*



# Superallowed Fermi $\beta$ decay between analog states

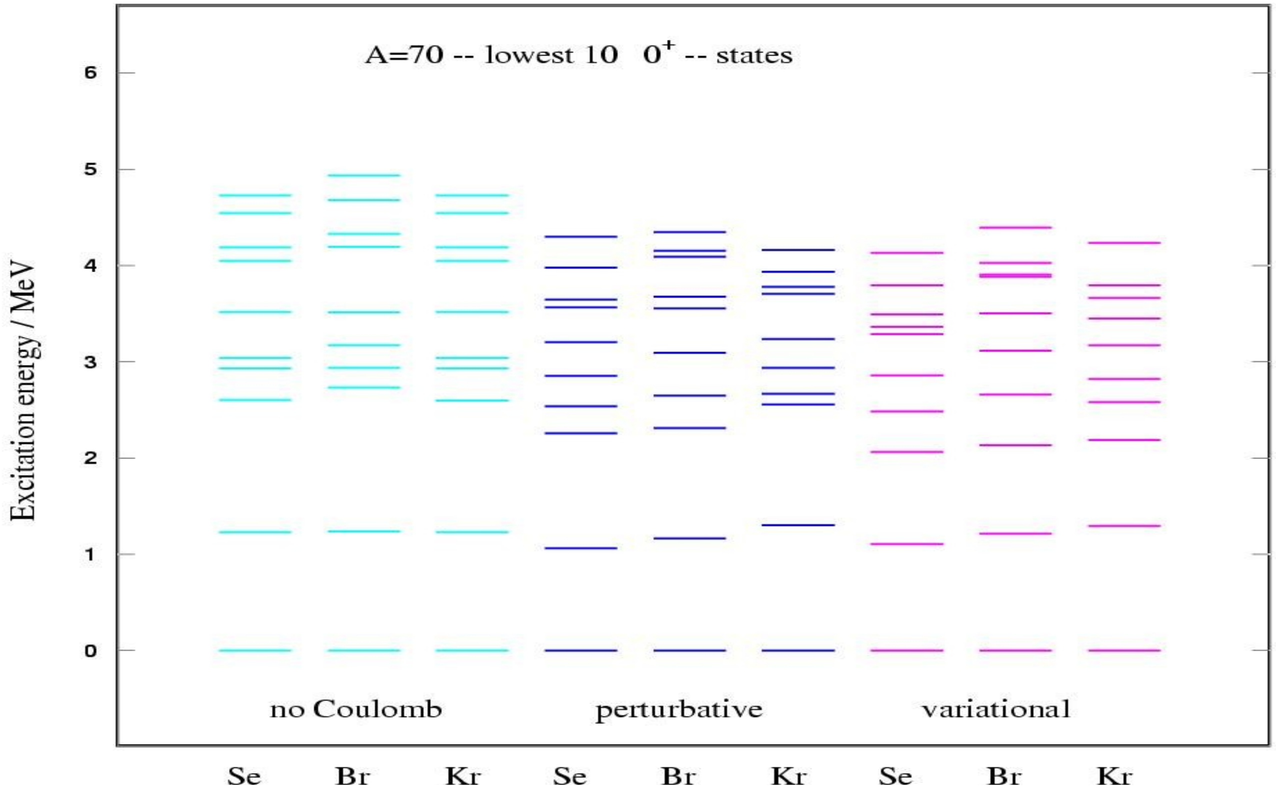
test of the CVC hypothesis

test of the unitarity of the CKM matrix

Two classes of nucleus-dependent corrections applied to the measured $ft$ value of a $0^+ \to 0^+$ $\beta$ transition between T=1 analog states give the coupling constant $G_v$ by

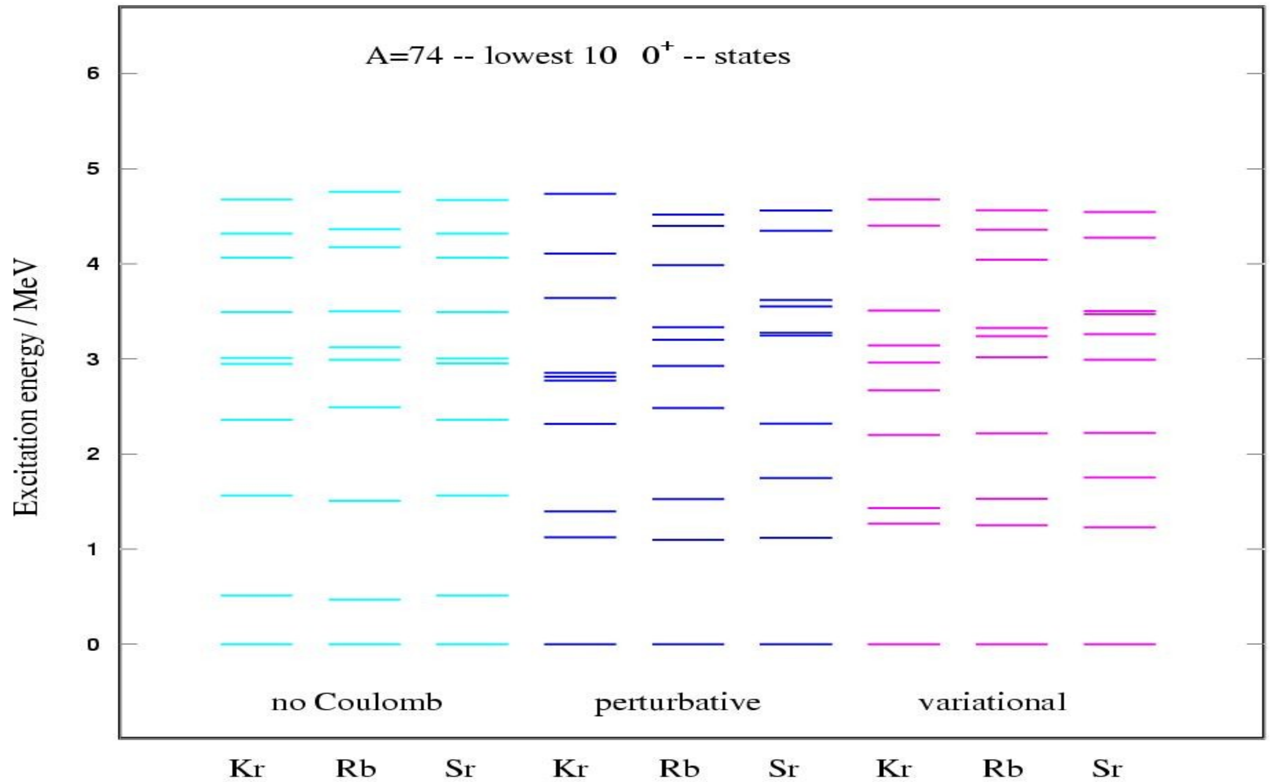
$$ft(1+\delta_R)(1-\delta_c) = \frac{K}{2G_v^2(1+\Delta_R^v)}$$

where f is the statistical rate function, t is the partial half-life for the transition, $\delta_c$ is the isospin-symmetry-breaking correction, $\delta_R$ is the transition-dependent part of the radiative correction, $\Delta_R^v$ is the transition-independent part, K is a constant




The total ($S_T$) and analog ($S_{g-g}$) Fermi $\beta$ decay strengths of selected nuclei for the symmetric ($H_0$) and Coulomb ($H_1$) effective Hamiltonian.The results obtained within the *perturbative* ($H_p^1$) and the *variational* ($H_v^1$) approaches are presented.

| Parent nucleus | $H_0$ |  | $H_1^p$ |  | $H_1^v$ |  |
|---|---|---|---|---|---|---|
|  | $S_T$ | $S_{g-g}$ | $S_T$ | $S_{g-g}$ | $S_T$ | $S_{g-g}$ |
| $^{70}$Kr | 1.975 | 1.967 | 1.970 | 1.935 | 1.946 | 1.917 |
| $^{70}$Br | 1.977 | 1.967 | 1.979 | 1.967 | 1.959 | 1.951 |

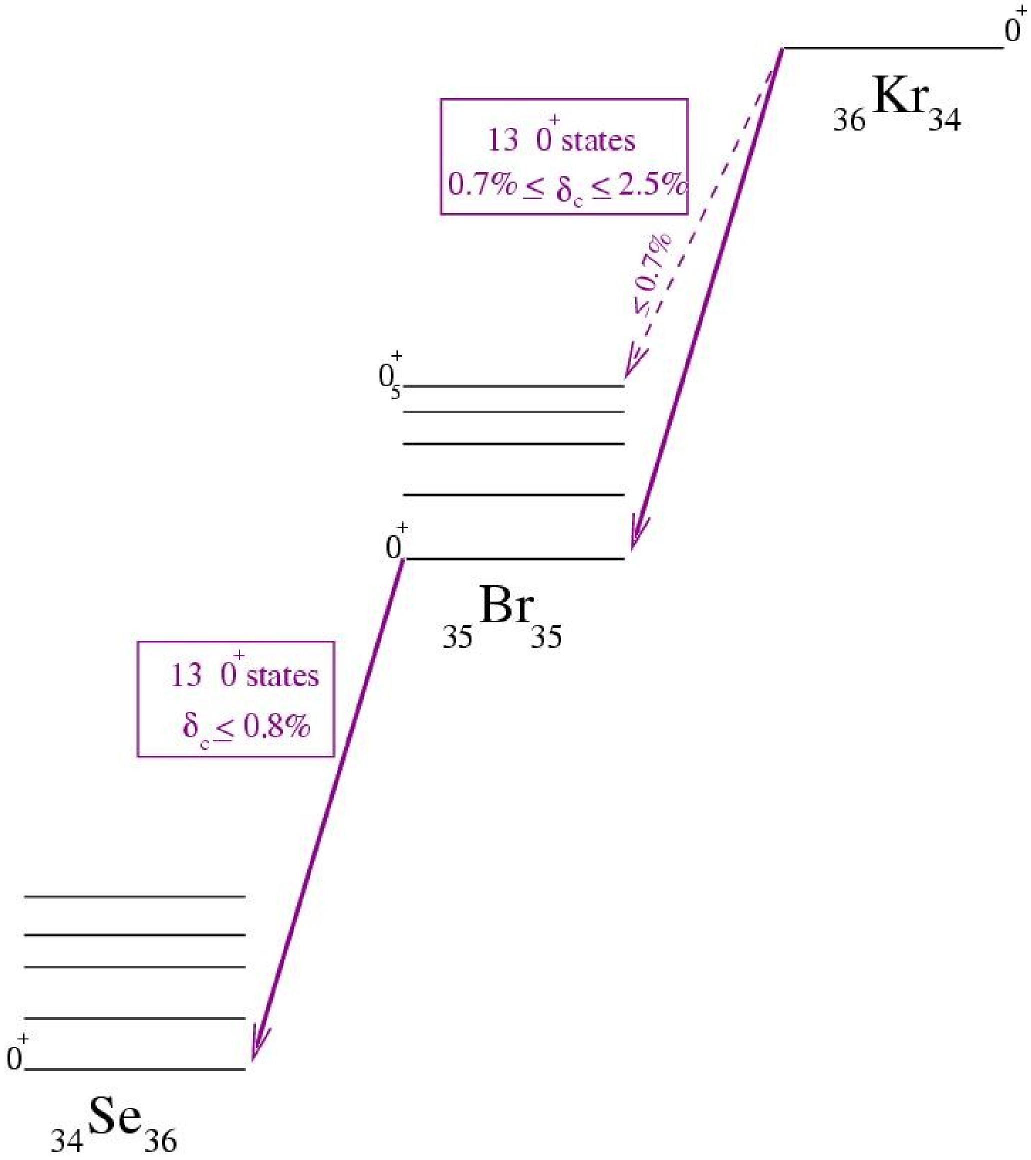



The total ($S_T$) and analog ($S_{g-g}$) Fermi $\beta$ decay strengths of selected nuclei for the symmetric ($H_0$) and Coulomb ($H_1$) effective Hamiltonian.The results obtained within the *perturbative* ($H_p^1$) and the *variational* ($H_v^1$) approaches are presented.

| Parent nucleus | $H_0$ | | $H_1^p$ | | $H_1^v$ | |
|---|---|---|---|---|---|---|
| | $S_T$ | $S_{g-g}$ | $S_T$ | $S_{g-g}$ | $S_T$ | $S_{g-g}$ |
| $^{74}$Sr | 1.954 | 1.947 | 1.940 | 1.918 | 1.932 | 1.893 |
| $^{74}$Rb | 1.957 | 1.948 | 1.948 | 1.929 | 1.946 | 1.924 |

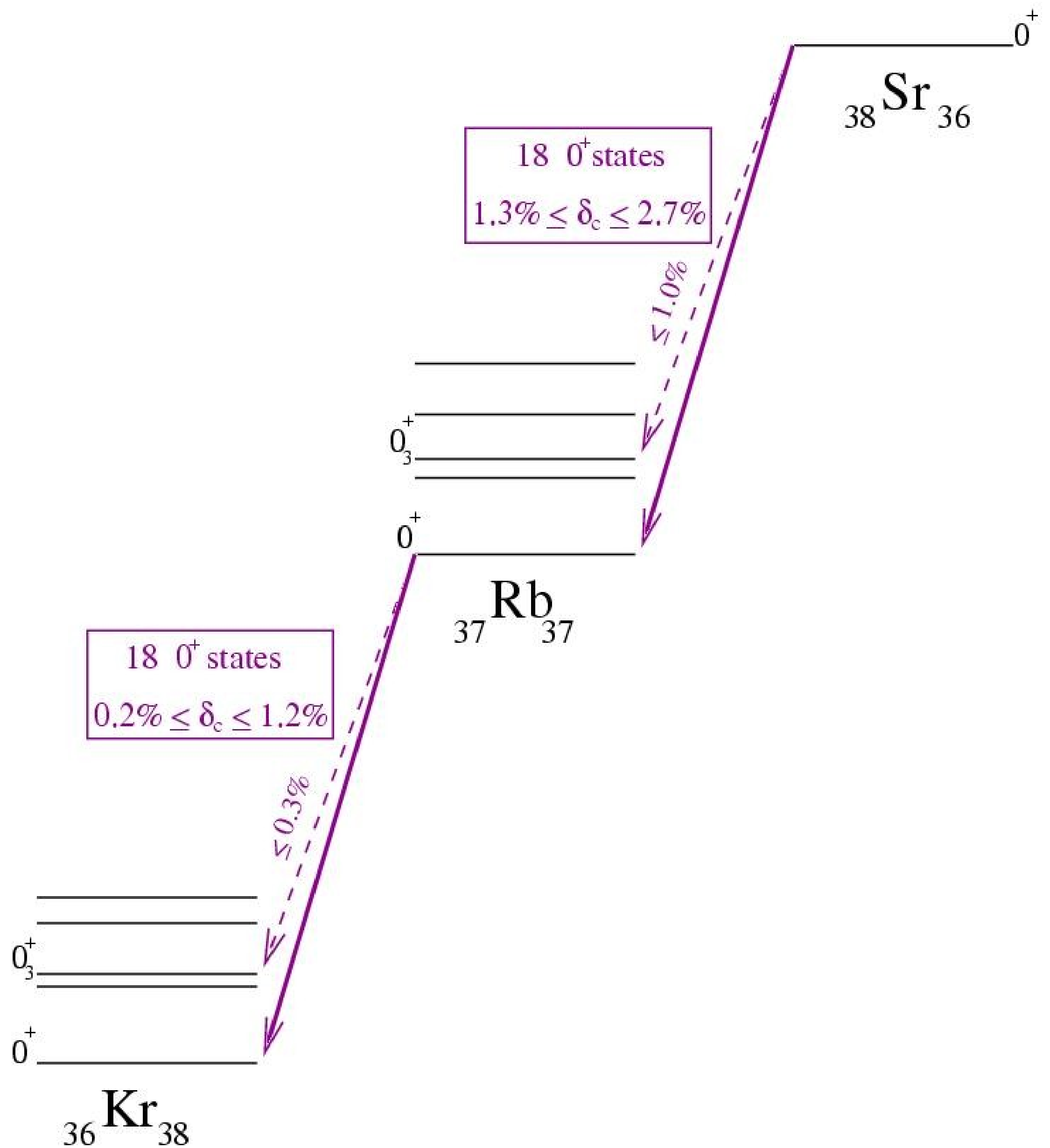
*A. Petrovici et al., Nucl. Phys. A747 (2005) 44*

# A = 70

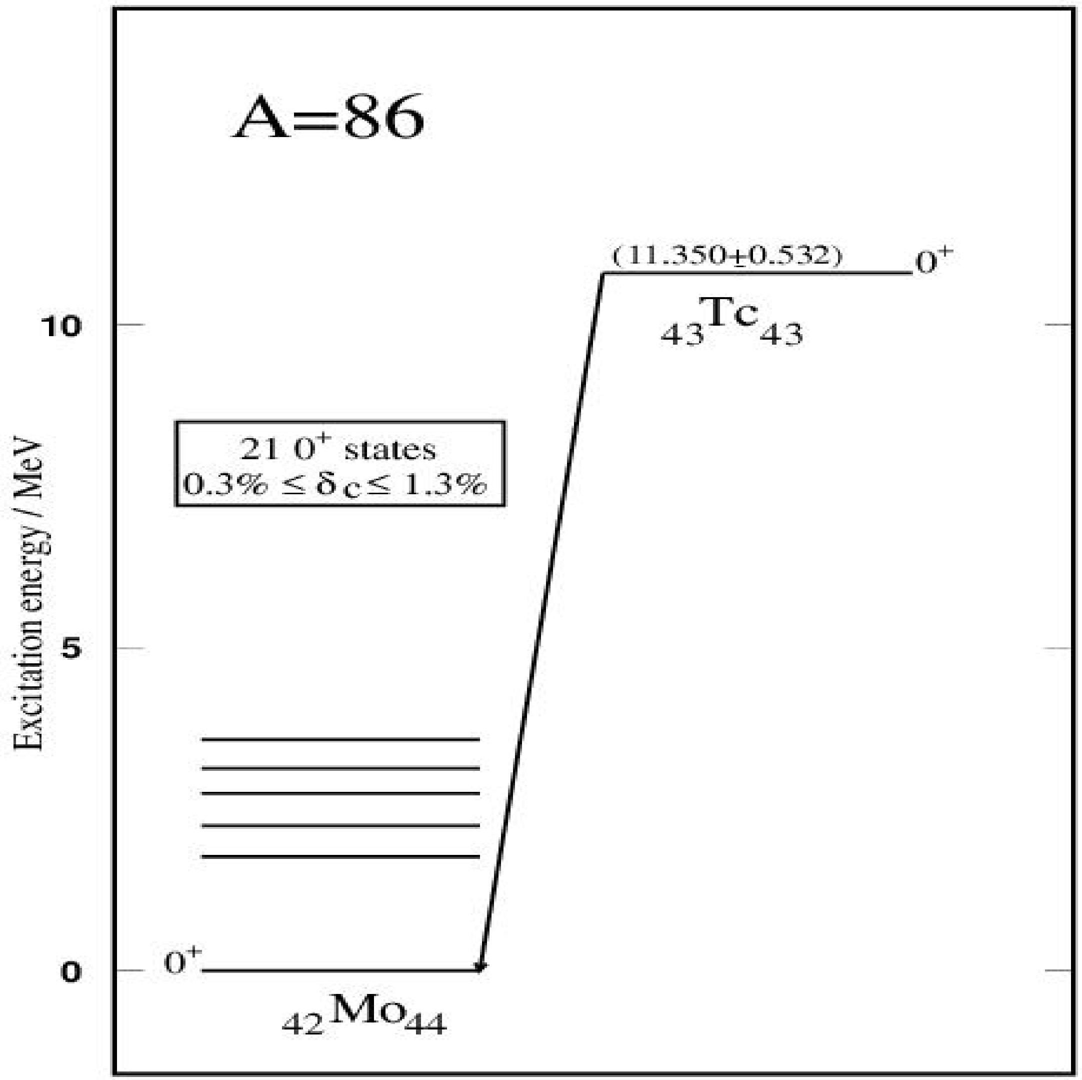


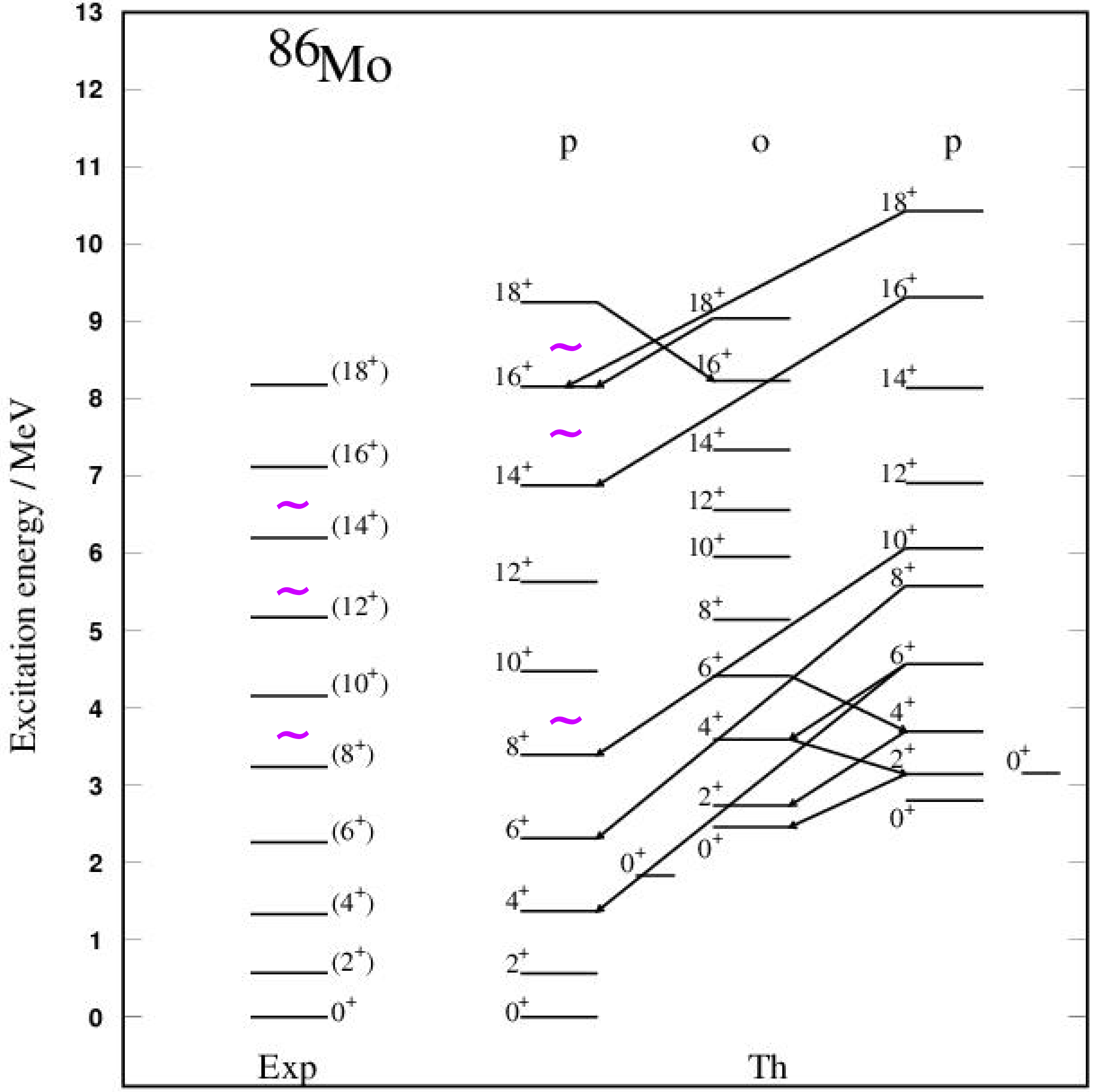
# A = 74

*A. Petrovici et al., Nucl. Phys. A747 (2005) 44*

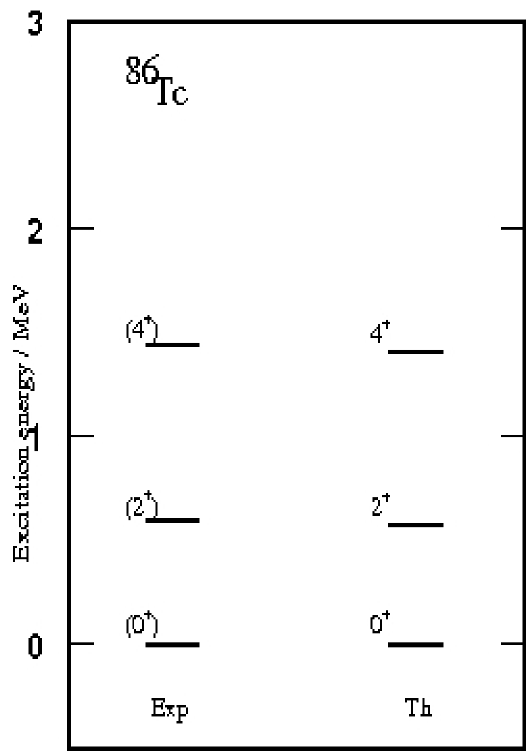


*Preliminary results*

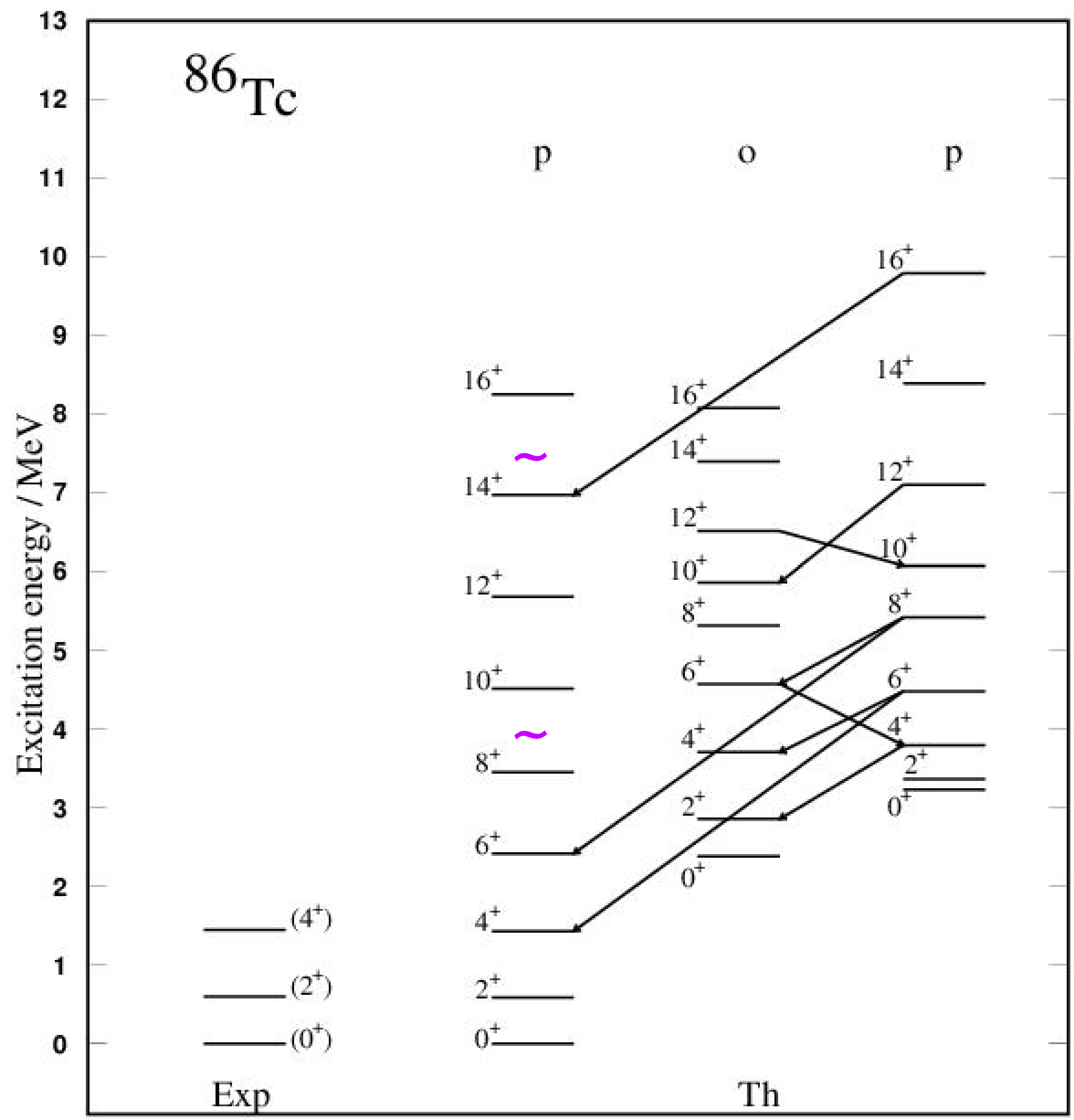




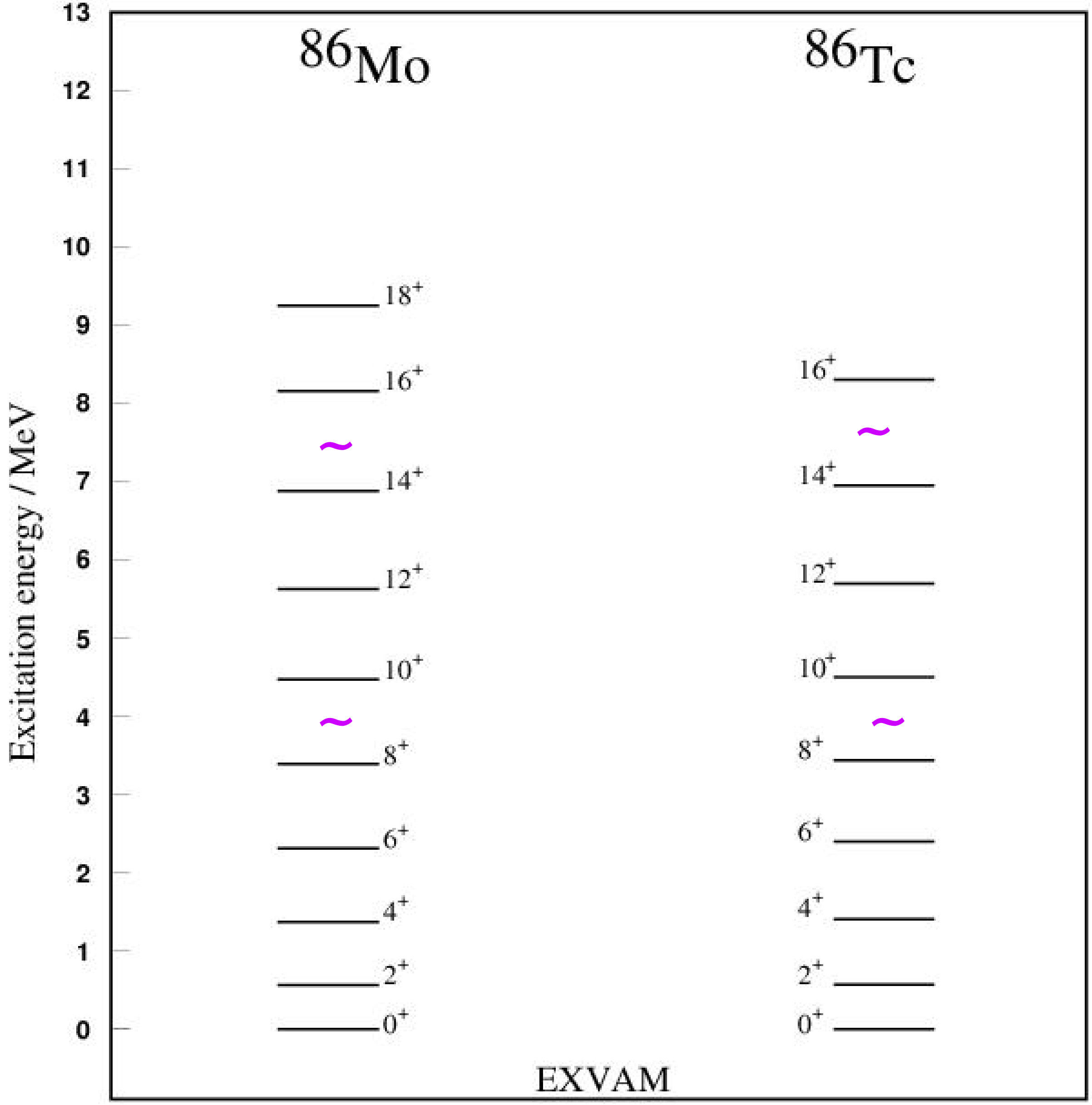
$^{86}$Mo
Excitation energy / MeV
0
1
2
3
4
5
6
7
8
9
10
11
12
13
Exp
Th
p
o
p
$0^+$
$(2^+)$
$(4^+)$
$(6^+)$
$(8^+)$
$(10^+)$
$(12^+)$
$(14^+)$
$(16^+)$
$(18^+)$
$0^+$
$2^+$
$4^+$
$6^+$
$8^+$
$10^+$
$12^+$
$14^+$
$16^+$
$18^+$



86Tc
Excitation energy / MeV
(0+)
(2+)
(4+)
0+
2+
4+
Exp
Th

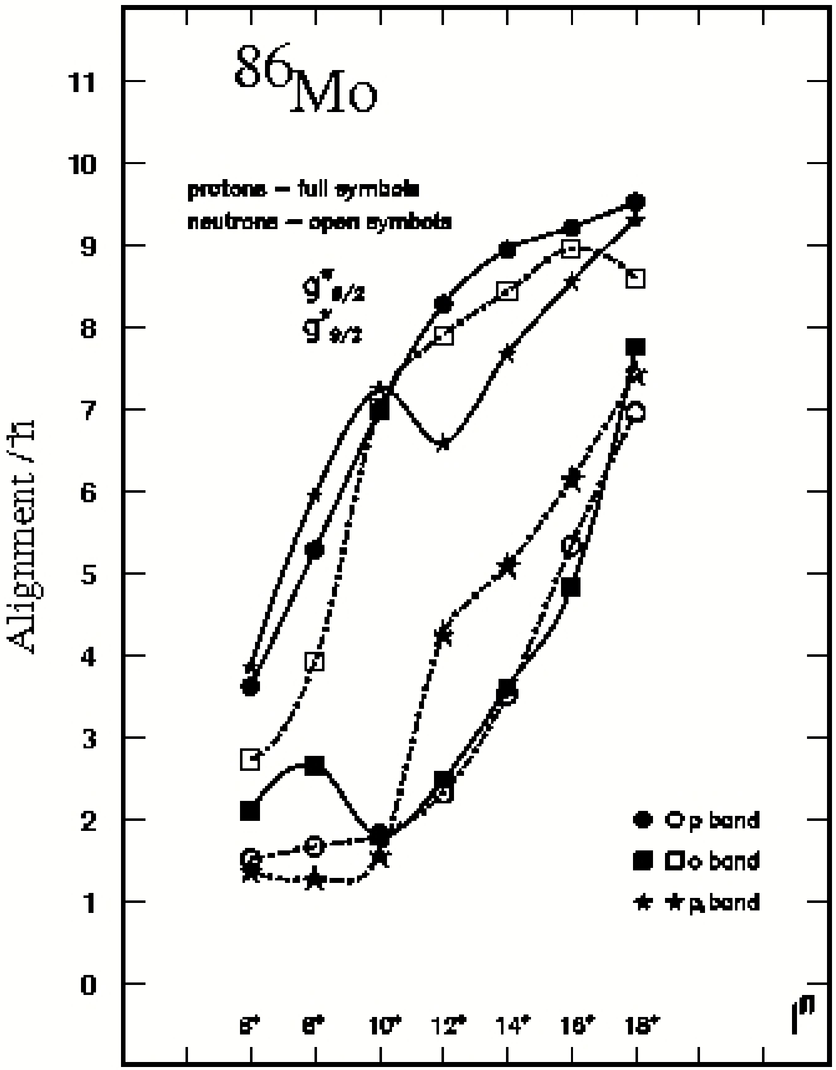
86Tc
p
o
p
Excitation energy / MeV
(0+)
(2+)
(4+)
0+
2+
4+
6+
8+
10+
12+
14+
16+
Exp
Th



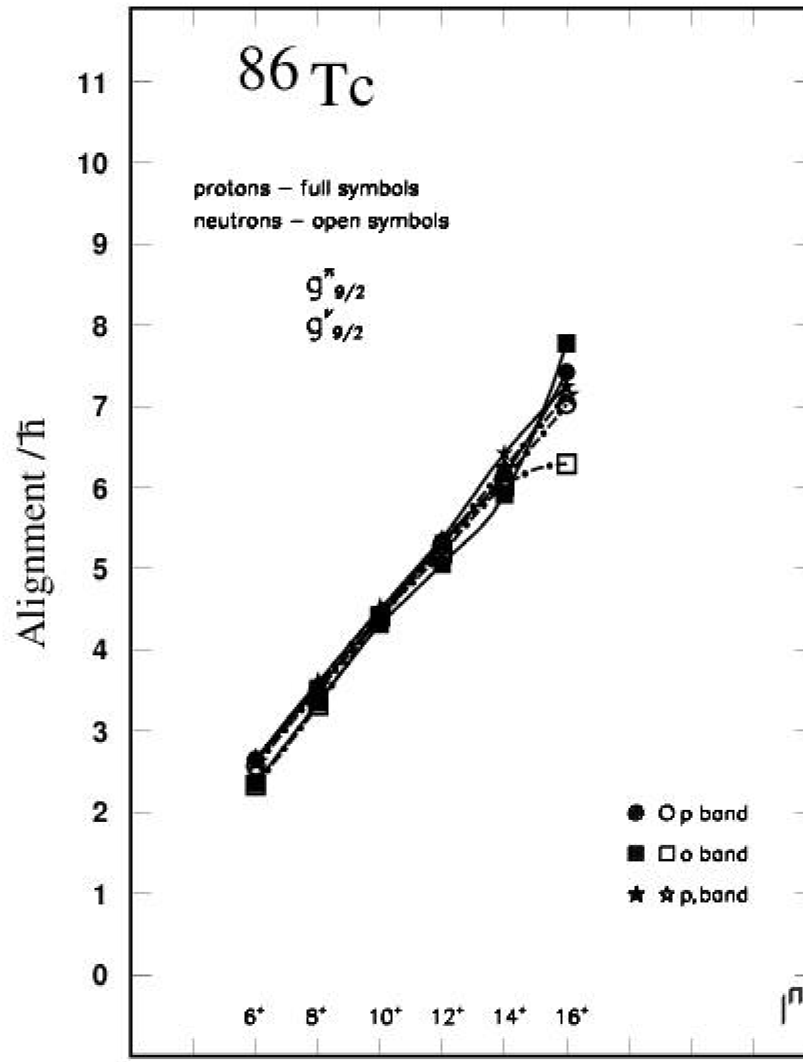
86Mo
86Tc
Excitation energy / MeV
0
1
2
3
4
5
6
7
8
9
10
11
12
13
18+
16+
14+
12+
10+
8+
6+
4+
2+
0+
EXVAM

Table 2.
$B(E2; I \rightarrow I-2)$ values (in $e^2fm^4$) for the yrast states of the nucleus $^{82}$Zr and $^{86}$Mo

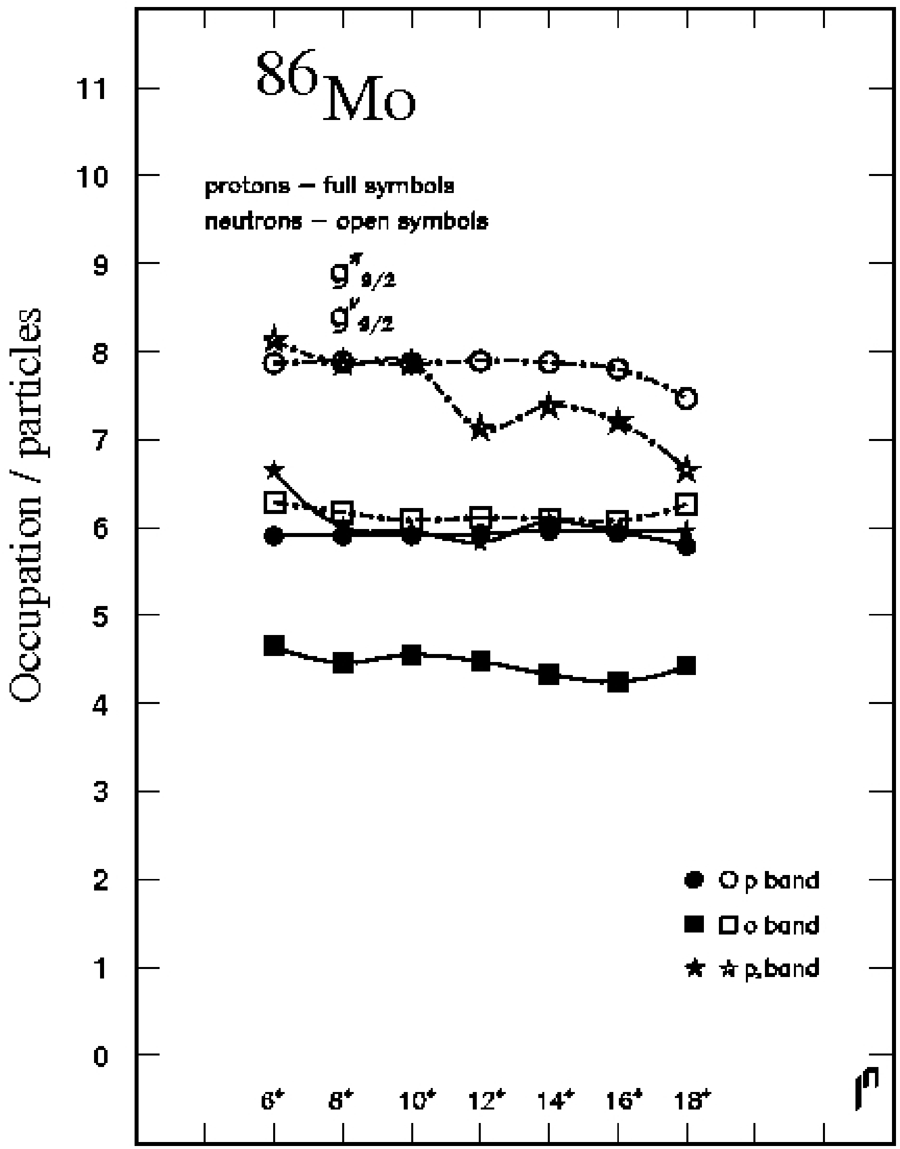
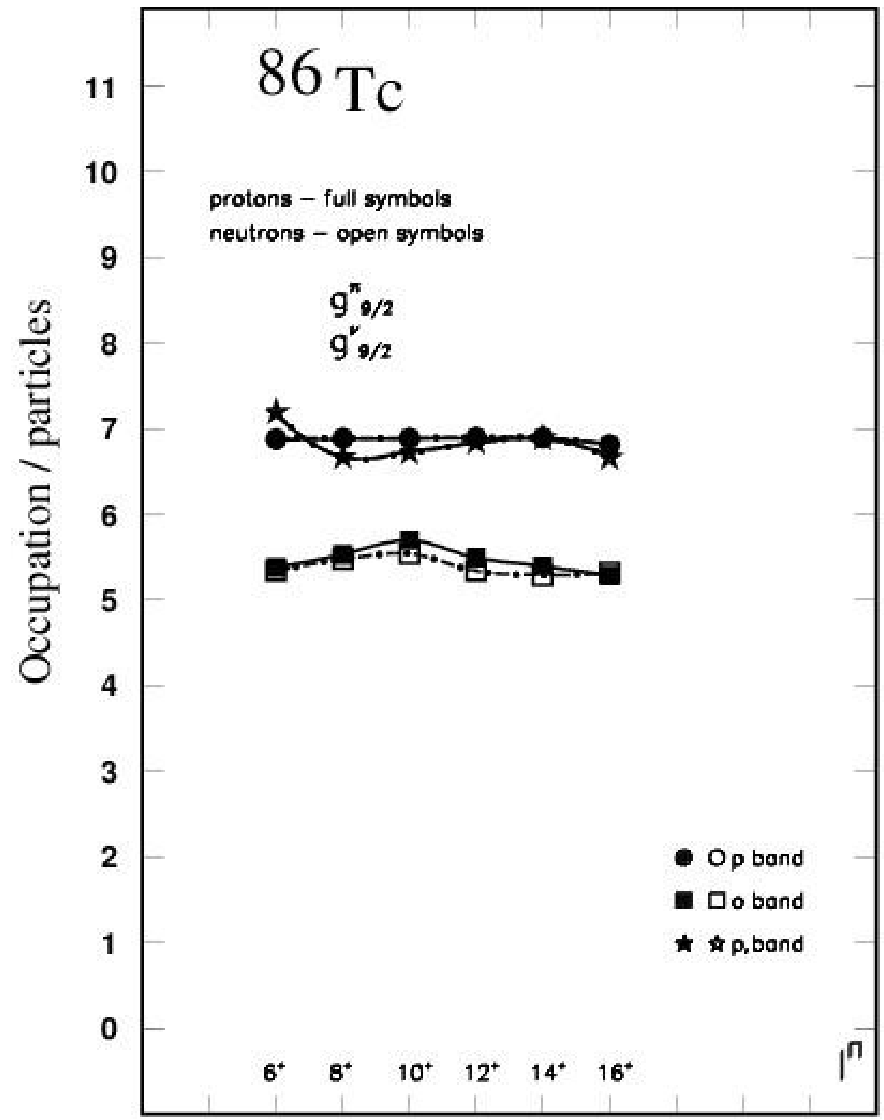
| $I^{\pi}[\hbar]$ | $^{82}$Zr Experiment | Theory | $^{86}$Mo Theory |
|---|---|---|---|
| $2^+$ | $2328^{+1058}_{-1058}$ | 1351 | 875 |
| $4^+$ | $2328^{+1058}_{-1058}$ | 1992 | 1277 |
| $6^+$ | $1672^{+395}_{-395}$ | 2166 | 1298 |
| $8^+$ | $2539^{+1058}_{-1058}$ | 2174 | 1288 |
| $10^+$ | $2328^{+635}_{-635}$ | 2129 | 1176 |
| $12^+$ | $1926^{+486}_{-486}$ | 1974 | 1053 |
| $14^+$ | $1904^{+634}_{-634}$ | 1733 | 908 |
| $16^+$ | $> 621$ | 1472 | 692 |
| $18^+$ | | 809 | 492 |
| $20^+$ | | 808 | |



86Mo
protons – full symbols
neutrons – open symbols
Alignment /ħ
p band
o band
p₁ band
6⁺
8⁺
10⁺
12⁺
14⁺
16⁺
18⁺
I^π

86 Tc
protons – full symbols
neutrons – open symbols
Alignment /ħ
p band
o band
p₁ band
6⁺
8⁺
10⁺
12⁺
14⁺
16⁺
I^π


86Mo
protons – full symbols
neutrons – open symbols
g^π 9/2
g^ν 9/2
Occupation / particles
p band
o band
p, band
6+ 8+ 10+ 12+ 14+ 16+ 18+
I^π
0 1 2 3 4 5 6 7 8 9 10 11

86Tc
protons – full symbols
neutrons – open symbols
g^π 9/2
g^ν 9/2
Occupation / particles
p band
o band
p, band
6+ 8+ 10+ 12+ 14+ 16+
I^π
0 1 2 3 4 5 6 7 8 9 10 11

# *Gamow-Teller β Decay of $^{74}$Kr*

*CERN/ISOLDE E. Poirier et al., Phys.Rev. C69(2004)034307*

$$^{74}\mathrm{Kr} \rightarrow {}^{74}\mathrm{Br}$$

$$Q_{EC} = 3.140 \pm 0.060\ MeV$$

$$0^+_{ground-state} \rightarrow 1^+$$

The amount of mixing for the ground-state of $^{74}$Kr.

| | o-mixing | p-mixing |
|---|---|---|
| ms1 | 56(2)(1)(1)% | 35(3)(1)(1)% |
| ms2 | 39(2)(1)(1)% | 51(3)(1)(1)% |
| ms3 | 28(1)(1)% | 65(3)(2)% |

The amount of mixing for the lowest calculated $1^+$ states of $^{74}$Br (ms1).

| o-mixing /p-mixing |
|---|
| 94(3)(3)% |
| 61(35)(2)(1)% |
| 89(3)(2)(2)(1)(1)(1)% |
| 44(28)(19)(4)(1)(1)(1)% |
| 97% |
| 69(19)(5)(2)(2)% |
| 70(7)(3)(2)(1)(1)(1)%4(3)(2)(2)% |
| 9(3)% 25(24)(11)(10)(3)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 7(1)(1)% 71(8)(5)(1)(1)(1)(1)(1)% |
| 43(12)(9)(7)(7)(3)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 57(3)(2)(1)(1)(1)(1)%13(5)(4)(2)(2)(1)(1)(1)(1)% |
| 26(1)(1)% 36(20)(4)(3)(2)(1)(1)(1)% |
| 21(21)(14)(14)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 1%26(20)(8)(7)(6)(5)(4)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 2(1)(1)(1)% 36(14)(12)(6)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 10(2)(2)(1)(1)% 27(13)(11)(9)(3)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 50(16)(9)(5)(3)(3)(2)(2)(2)(1)(1)(1)% 2(2)% |
| 33(21)(12)(8)(5)(5)(3)(3)(2)(2)(1)(1)% 1(1)(1)% |
| 1(1)%34(18)(13)(9)(4)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |

The amount of mixing for the lowest calculated $1^+$ states of $^{74}$Br (ms1).

| o-mixing /p-mixing |
|---|
| 94(3)(3)% |
| 61(35)(2)(1)% |
| 89(3)(2)(2)(1)(1)(1)% |
| 44(28)(19)(4)(1)(1)(1)% |
| 97% |
| 69(19)(5)(2)(2)% |
| 70(7)(3)(2)(1)(1)(1)%4(3)(2)(2)% |
| 9(3)% 25(24)(11)(10)(3)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 7(1)(1)% 71(8)(5)(1)(1)(1)(1)(1)% |
| 43(12)(9)(7)(7)(3)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 57(3)(2)(1)(1)(1)(1)%13(5)(4)(2)(2)(1)(1)(1)(1)% |
| 26(1)(1)% 36(20)(4)(3)(2)(1)(1)(1)% |
| 21(21)(14)(14)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 1%26(20)(8)(7)(6)(5)(4)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 2(1)(1)(1)% 36(14)(12)(6)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 10(2)(2)(1)(1)% 27(13)(11)(9)(3)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 50(16)(9)(5)(3)(3)(2)(2)(2)(1)(1)(1)% 2(2)% |
| 33(21)(12)(8)(5)(5)(3)(3)(2)(2)(1)(1)% 1(1)(1)% |
| 1(1)%34(18)(13)(9)(4)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |

The amount of mixing for the lowest calculated $1^+$ states of $^{74}$Br (ms2).

| o-mixing /p-mixing |
|---|
| 94(3)(1)% |
| 61(35)(2)% |
| 46(29)(17)(3)(1)(1)% |
| 91(2)(2)(1)(1)(1)(1)% |
| 97(1)% |
| 40(37)(14)(4)(1)% |
| 69(28)(1)(1)% |
| 54(20)(11)(6)(1)(1)%2% |
| 46(27)(9)(6)(2)(2)(1)(1)(1)(1)(1)% |
| 5% 65(16)(4)(1)(1)(1)(1)% |
| 49(8)(8)(5)(5)(4)(4)(3)(2)(2)(2)(1)(1)(1)% |
| 29(14)(11)(10)(9)(7)(7)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 1% 61(19)(7)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 57(11)(8)(5)(3)(3)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 78(6)(2)(1)(1)(1)(1)(1)(1)% 1(1)(1)(1)% |
| 3% 33(23)(10)(7)(6)(5)(3)(2)(2)(1)(1)% |
| 31(10)(10)(6)(6)(5)(3)(3)(3)(2)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| (1)1% 25(19)(14)(7)(6)(5)(4)(4)(2)(2)(2)(2)(1)(1)% |
| 2% 42(10)(9)(6)(5)(4)(4)(3)(3)(3)(1)(1)(1)(1)(1)(1)% |
| 28(19)(13)(10)(7)(4)(3)(1)(1)(1)% 3(1)(1)(1)(1)(1)(1)% |
| 23(16)(14)(6)(5)(4)(2)(1)(1)(1)(1)% 12(3)(2)(1)(1)(1)(1)% |
| (1)1% 28(13)(12)(10)(6)(5)(3)(3)(3)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 51(16)(11)(3)(3)(3)(2)(2)(2)(1)(1)% 1(1)(1)% |
| 25(19)(11)(10)(8)(8)(3)(3)(2)(2)(1)(1)(1)(1)% 2(1)% |

The amount of mixing for the lowest calculated $1^+$ states of $^{74}$Br (ms1).

| o-mixing /p-mixing |
|---|
| 94(3)(3)% |
| 61(35)(2)(1)% |
| 89(3)(2)(2)(1)(1)(1)% |
| 44(28)(19)(4)(1)(1)(1)% |
| 97% |
| 69(19)(5)(2)(2)% |
| 70(7)(3)(2)(1)(1)(1)%4(3)(2)(2)% |
| 9(3)% 25(24)(11)(10)(3)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 7(1)(1)% 71(8)(5)(1)(1)(1)(1)(1)% |
| 43(12)(9)(7)(7)(3)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 57(3)(2)(1)(1)(1)(1)%13(5)(4)(2)(2)(1)(1)(1)(1)% |
| 26(1)(1)% 36(20)(4)(3)(2)(1)(1)(1)% |
| 21(21)(14)(14)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 1%26(20)(8)(7)(6)(5)(4)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 2(1)(1)(1)% 36(14)(12)(6)(6)(5)(4)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 10(2)(2)(1)(1)% 27(13)(11)(9)(3)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 50(16)(9)(5)(3)(3)(2)(2)(2)(1)(1)(1)% 2(2)% |
| 33(21)(12)(8)(5)(5)(3)(3)(2)(2)(1)(1)% 1(1)(1)% |
| 1(1)%34(18)(13)(9)(4)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |

The amount of mixing for the lowest calculated $1^+$ states of $^{74}$Br (ms3).

| o-mixing /p-mixing |
|---|
| 61(35)(2)% |
| 94(4)(1)% |
| 48(31)(15)(2)(2)(1)% |
| 92(3)(1)(1)(1)(1)(1)% |
| 94(2)(2)% |
| 76(16)(3)(2)(1)% |
| 2(2)%63(10)(10)(3)(3)(1)(1)(1)(1)(1)% |
| 45(42)(5)(1)% 2(1)(1)% |
| 2(1)(1)% 64(15)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 45(19)(15)(13)(1)(1)(1)%1% |
| 67(21)(3)(2)(2)(1)(1)(1)% |
| 2% 54(16)(12)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 53(12)(5)(4)(4)(3)(2)(2)(2)(2)(2)(2)(2)(1)(1)(1)(1)% |
| 41(26)(7)(7)(3)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 32(26)(16)(5)(5)(3)(2)(2)(2)(1)(1)(1)% |
| 20(19)(10)(8)(7)(6)(4)(4)(3)(2)(2)(2)(2)(2)(2)(1)(1)(1)(1)(1)% |
| 52(24)(11)(4)(1)(1)(1)(1)%1% |
| 36(10)(8)% 16(13)(3)(2)(2)(2)(1)(1)(1)% |
| 31(18)(9)(8)(6)(6)(3)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 41(11)(8)(7)(6)(5)(4)(3)(2)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 1%33(13)(7)(7)(6)(5)(4)(4)(4)(3)(2)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 61(7)(7)(6)(3)(2)(1)(1)(1)(1)(1)% 2(1)(1)(1)(1)% |
| 42(9)(7)(4)(2)(2)(1)(1)(1)% 4(4)(3)(2)(2)(2)(1)(1)(1)(1)(1)(1)(1)% |
| 25(20)(13)(12)(8)(5)(3)(3)(2)(1)(1)(1)(1)(1)% 3(1)(1)% |
| 57(12)(10)(2)(2)(1)% 11% |
| 3(1)% 25(19)(14)(6)(6)(5)(4)(3)(2)(1)(1)(1)(1)(1)(1)(1)(1)(1)(1)% |
| 1(1)(1)(1)% 38(9)(8)(7)(5)(5)(5)(4)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |
| 1%23(16)(9)(7)(5)(4)(4)(4)(3)(3)(2)(2)(2)(2)(2)(1)(1)(1)(1)(1)(1)% |

Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$ ) for the lowest calculated $1^+$ states of the $^{74}$Br nucleus (ms1).

| $1_I^+$ | $1_{II}^+$ | $1_{III}^+$ | ......... | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48.6 | -49.4 | 46.6 | -46.7 | -47.7 | 45.1 | 45.3 | 47.7 | -56.6 | 33.2 | -38.2 |
| -40.1 | 42.0 | -50.7 | -58.1 | -52.4 | -51.0 | 16.7 | -22.0 | -50.9 | -50.5 | -48.5 |
| -43.4 | 37.2 | 45.0 | -40.3 | -34.3 | 26.2 | 39.2 | 41.0 | -44.5 | -49.0 | 40.9 |
| -51.3 | -39.8 | -42.3 | 14.4 | 18.4 | 37.9 | 41.0 | -37.4 | 15.0 | -40.4 | 29.3 |
| -39.3 | 41.5 | -54.2 | -52.3 | 38.4 | -47.6 | -45.3 | -8.4 | -1.4 | -41.4 | -48.2 |
| 40.3 | 48.7 | -40.6 | 43.1 | -24.0 | 46.0 | -45.3 | -61.4 | -54.8 | -55.0 | -16.1 |

Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$ ) for the lowest calculated $1^+$ states of the $^{74}$Br nucleus (ms1).

| $1^+_I$ | $1^+_{II}$ | $1^+_{III}$ | ......... | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48.6 | -49.4 | 46.6 | -46.7 | -47.7 | 45.1 | 45.3 | 47.7 | -56.6 | 33.2 | -38.2 |
| -40.1 | 42.0 | -50.7 | -58.1 | -52.4 | -51.0 | 16.7 | -22.0 | -50.9 | -50.5 | -48.5 |
| -43.4 | 37.2 | 45.0 | -40.3 | -34.3 | 26.2 | 39.2 | 41.0 | -44.5 | -49.0 | 40.9 |
| -51.3 | -39.8 | -42.3 | 14.4 | 18.4 | 37.9 | 41.0 | -37.4 | 15.0 | -40.4 | 29.3 |
| -39.3 | 41.5 | -54.2 | -52.3 | 38.4 | -47.6 | -45.3 | -8.4 | -1.4 | -41.4 | -48.2 |
| 40.3 | 48.7 | -40.6 | 43.1 | -24.0 | 46.0 | -45.3 | -61.4 | -54.8 | -55.0 | -16.1 |

Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$ ) for the lowest calculated $1^+$ states of the $^{74}$Br nucleus (ms2).

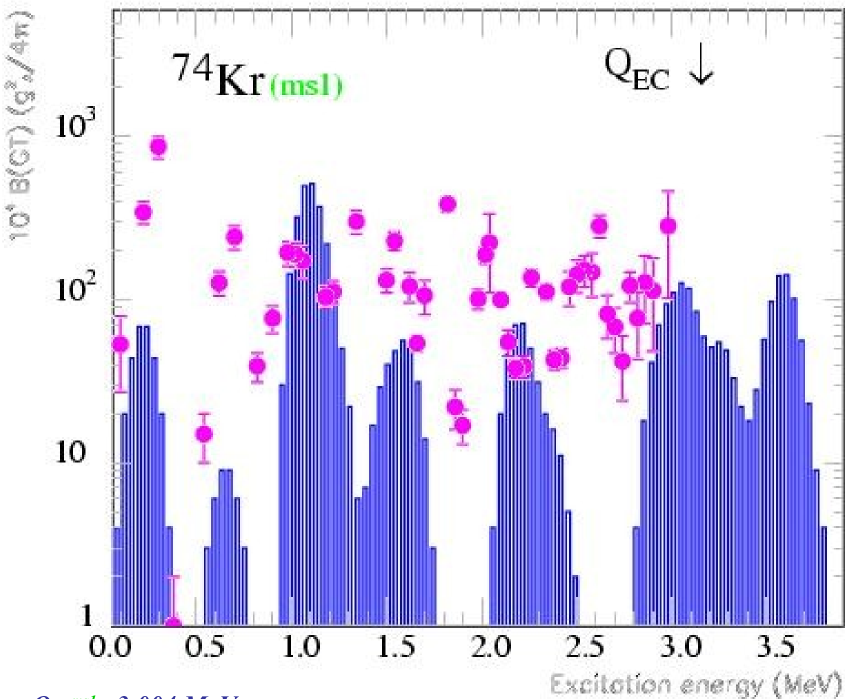
| $1^+_I$ | $1^+_{II}$ | $1^+_{III}$ | ......... | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48.5 | -49.0 | -47.6 | 47.0 | -48.5 | 48.2 | 44.1 | 45.4 | -51.7 | -53.1 | 42.5 |
| -43.3 | -50.8 | 40.0 | -50.2 | -52.5 | -55.0 | -50.8 | -50.5 | 42.4 | -49.1 | -46.1 |
| 47.6 | -44.1 | -44.2 | -43.7 | 40.9 | 35.6 | 34.3 | -31.5 | -47.3 | -45.3 | 39.5 |
| -51.4 | 42.4 | -53.4 | -47.3 | -44.0 | 35.9 | -46.5 | 39.9 | -44.1 | -59.6 | -48.5 |
| 33.8 | 38.4 | -44.4 | 40.8 | -43.4 | 7.6 | -3.8 | 33.0 | -51.7 | -46.1 | -45.2 |
| 33.3 | -34.7 | -14.7 | 5.6 | 44.4 | 14.6 | -12.2 | -62.2 | 44.9 | -44.2 | -52.2 |
| 40.3 | -55.1 | -52.2 | 46.6 | 33.3 | -15.5 | | | | | |

Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$ ) for the lowest calculated $1^+$ states of the $^{74}$Br nucleus (ms1).

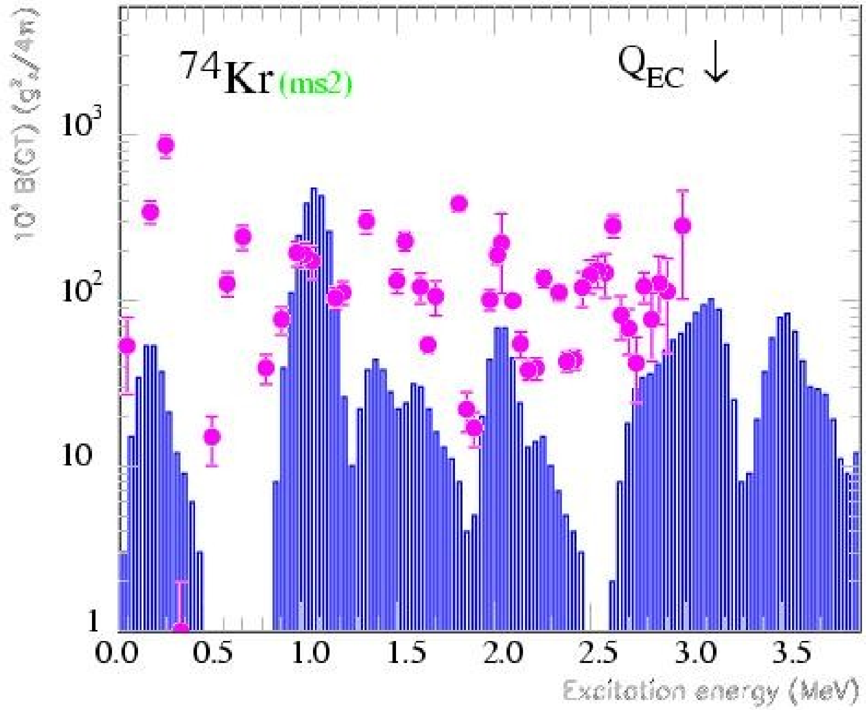
| $1^+_I$ | $1^+_{II}$ | $1^+_{III}$ | ......... | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 48.6 | -49.4 | 46.6 | -46.7 | -47.7 | 45.1 | 45.3 | 47.7 | -56.6 | 33.2 | -38.2 |
| -40.1 | 42.0 | -50.7 | -58.1 | -52.4 | -51.0 | 16.7 | -22.0 | -50.9 | -50.5 | -48.5 |
| -43.4 | 37.2 | 45.0 | -40.3 | -34.3 | 26.2 | 39.2 | 41.0 | -44.5 | -49.0 | 40.9 |
| -51.3 | -39.8 | -42.3 | 14.4 | 18.4 | 37.9 | 41.0 | -37.4 | 15.0 | -40.4 | 29.3 |
| -39.3 | 41.5 | -54.2 | -52.3 | 38.4 | -47.6 | -45.3 | -8.4 | -1.4 | -41.4 | -48.2 |
| 40.3 | 48.7 | -40.6 | 43.1 | -24.0 | 46.0 | -45.3 | -61.4 | -54.8 | -55.0 | -16.1 |

Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$ ) for the lowest calculated $1^+$ states of the $^{74}$Br nucleus (ms3).

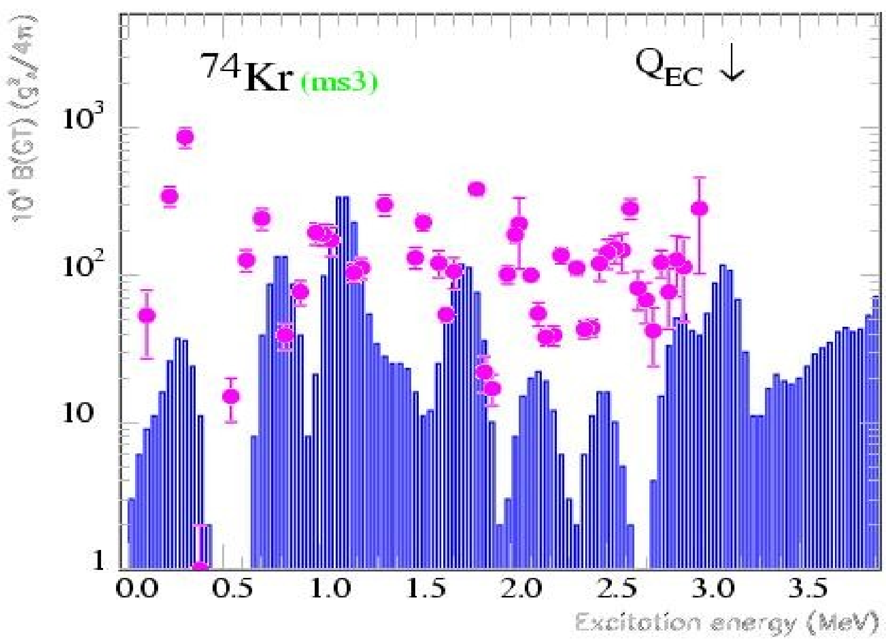
| $1^+_I$ | $1^+_{II}$ | $1^+_{III}$ | ......... | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| -49.3 | 48.4 | -48.7 | 47.1 | -49.5 | 47.8 | -48.0 | 40.9 | -51.3 | 45.5 | -49.8 |
| -51.3 | 45.0 | -50.1 | -51.4 | -44.9 | 38.1 | -53.7 | -49.6 | -50.9 | 44.7 | 6.6 |
| -3.4 | -47.3 | -52.1 | -46.2 | -52.0 | 4.9 | -11.9 | -43.4 | -45.4 | 38.9 | -27.5 |
| 16.7 | 39.2 | -44.9 | 30.9 | -42.0 | -42.5 | -45.3 | -52.9 | -44.2 | -27.3 | 28.1 |
| -0.1 | -4.7 | -45.8 | 39.4 | -37.3 | -45.4 | 32.0 | 39.6 | -40.3 | -41.4 | 30.4 |
| -43.5 | -24.2 | 20.6 | 41.9 | 13.0 | -16.0 | 38.4 | -34.4 | 25.8 | -55.7 | -15.5 |
| 14.5 | -52.2 | 40.9 | 35.2 | 29.1 | 2.7 | -15.9 | 4.7 | | | |




$Q_{EC}^{ms1}$ =3.004 MeV

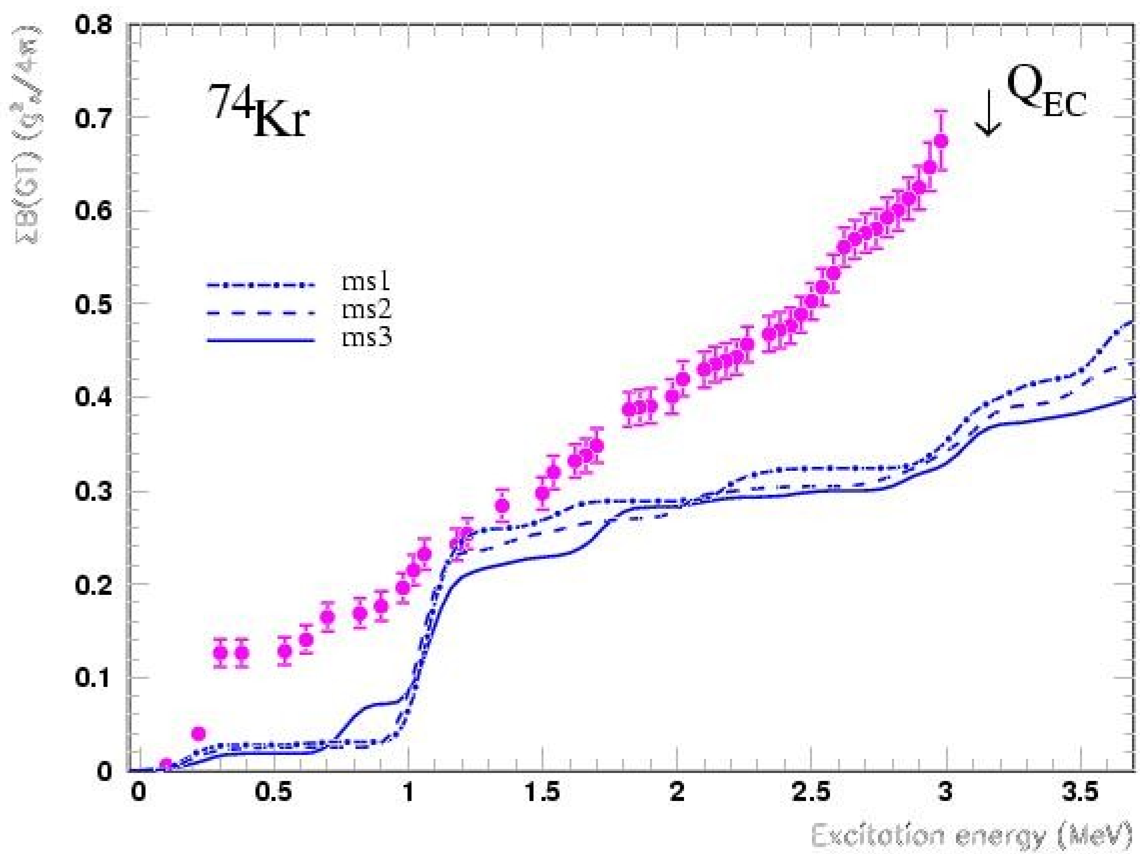



$Q_{EC}^{ms2}$ =2.945 MeV

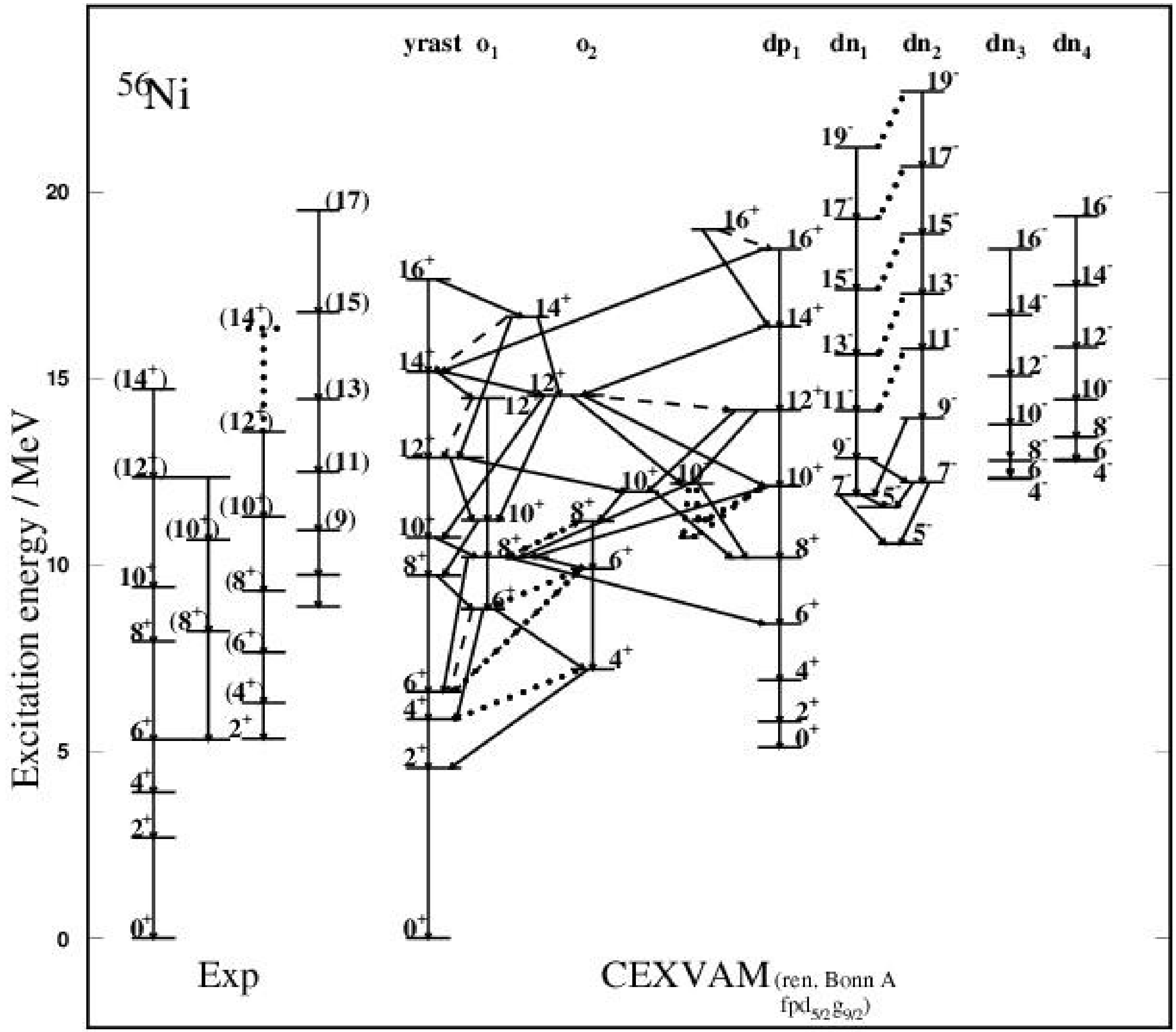



$Q_{EC}^{ms3}$ =2.912 MeV

*A. Petrovici et al., Nucl. Phys. A 799 (2008) 94*



# *Cross-fertilization between Shell Model and complex Excited Vampir Model*




*A. Petrovici et al.Nucl. Phys. A689 (2001) 707*

$^{56}$Ni

Mizusaki et al., NPA704 (2002) 190c

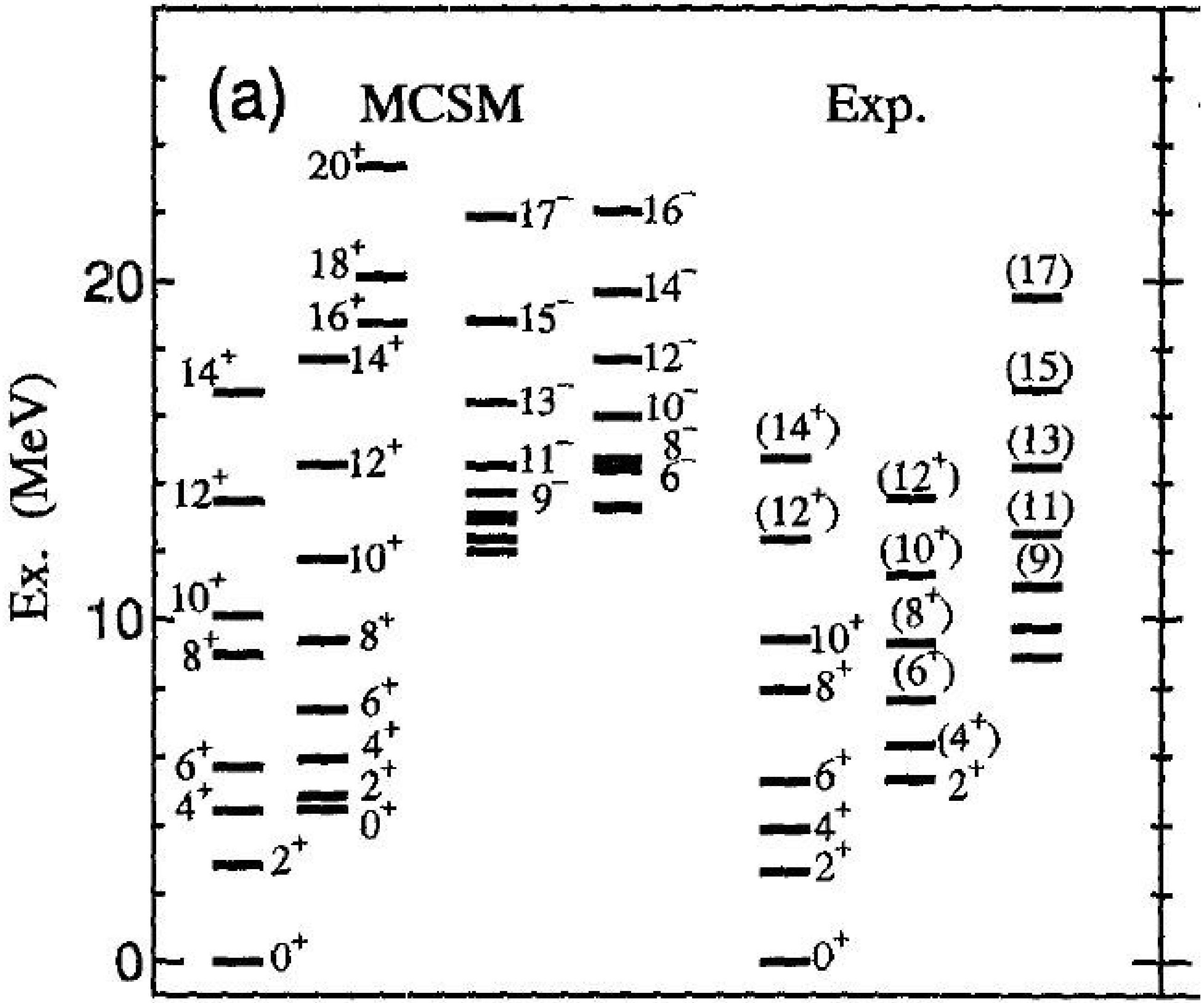


Table 2. $B(E2; I \to I-2)$ values (in $e^2 fm^4$) for some states of the nucleus $^{56}$Ni presented in Fig. 1. The strengths for the secondary branches are given in parentheses and the labels indicate the end point of the transition. In Fig. 1 the transitions corresponding to the strengths given in brackets are not shown. As effective charges $e_p = 1.5$ and $e_n = 0.5$ have been used.

| $I[\hbar]$ | $yrast$ | $o_1$ | $o_2$ | $deformed$ |
|---|---|---|---|---|
| $2^+$ | 115<br>[10][34][20][14] | | | 348<br>[81] |
| $4^+$ | 94<br>[18] | | 56<br>[50] | 615<br>[11] |
| $6^+$ | 44<br>[30] | 86<br>(33)$o_2$[17][22][79] | 57<br>[32] | 673<br>[24] |
| $8^+$ | 3<br>(39)$o_1$ | 163<br>(38)$yrast$<br>(134)$deformed$(41)$o_2$ | 59<br><br>[12][28] | 563<br><br>[10][30][13][29] |
| $10^+$ | 2<br>(36)$o_1$[11] | 29<br>(25)$yrast$[10] | | 315<br>(89)$o_1$ |
| $12^+$ | 3<br>(12)$o_1$(76) | 19<br>[10][19] | | 360<br>(46)(209) |
| $14^+$ | 68<br>(7)$o_1$(8) | | | 520<br>(27) |
| $16^+$ | 33<br>(24) | | | 222<br>(22)$yrast$ |

Table 1. $B(E2; I \rightarrow I-2)$ values (in $e^2 fm^4$) for some negative-parity states of the nucleus $^{56}$Ni presented in Fig. 1. The strengths for the secondary branches are given in parentheses. In Fig. 1 the transitions corresponding to the strengths given in brackets are not shown. As effective charges $e_p = 1.5$ and $e_n = 0.5$ have been used.

| $I[\hbar]$ | $dn_1$ | $dn_2$ | $I[\hbar]$ | $dn_3$ | $dn_4$ |
|---|---|---|---|---|---|
| | | | $6^-$ | 823 | 746 |
| $7^-$ | 477 | 361 | | | |
| | (362) | (312) | | | |
| | | | $8^-$ | 825 | 767 |
| $9^-$ | 806 | 612 | | | |
| | (65) | (67) | | | |
| | | | $10^-$ | 797 | 769 |
| $11^-$ | 875 | 366 | | | |
| | | [402] | | | |
| | | | $12^-$ | 770 | 742 |
| $13^-$ | 836 | 503 | | | |
| | | [315] | | | |
| | | | $14^-$ | 706 | 699 |
| $15^-$ | 757 | 746 | | | |
| | | | $16^-$ | 626 | 617 |
| $17^-$ | 635 | 651 | | | |
| $19^-$ | 373 | 529 | | | |

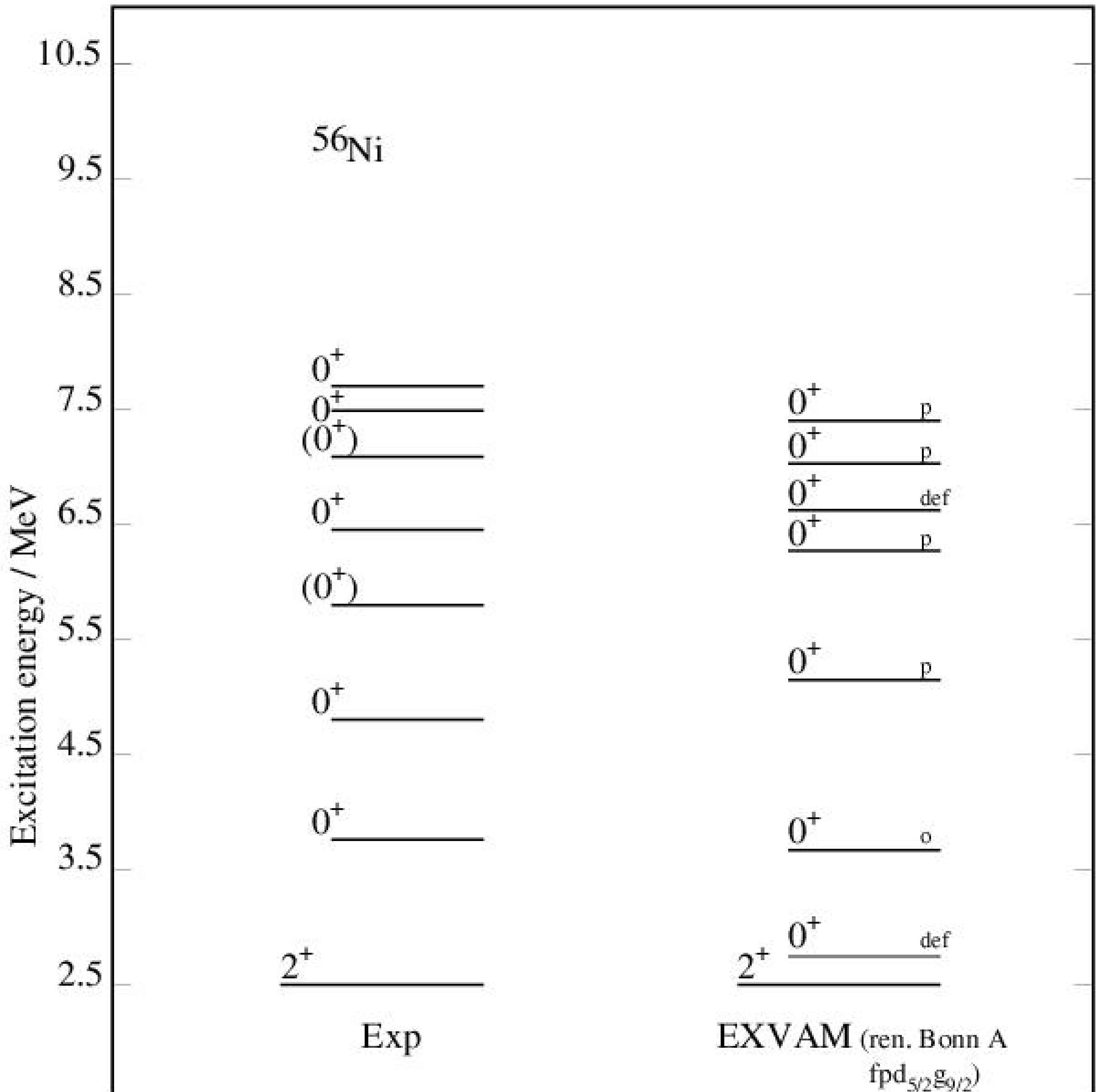
Table 4. Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$) of selected positive-parity states in $^{56}$Ni. As effective charges $e_p = 1.5$ and $e_n = 0.5$ have been used.

| $I[\hbar]$ | $yrast$ | $o_1$ | $o_2$ | $deformed$ |
|---|---|---|---|---|
| $2^+$ | 16.8 | | | -42.4 |
| $4^+$ | 17.5 | | 28.3 | -54.1 |
| $6^+$ | 4.3 | 39.3 | 39.2 | -60.3 |
| $8^+$ | 40.9 | 21.2 | 23.2 | -42.1 |
| $10^+$ | 19.2 | 18.3 | | -37.2 |
| $12^+$ | 48.2 | 32.1 | | -55.6 |
| $14^+$ | 19.3 | | | -58.8 |
| $16^+$ | 36.6 | | | -17.5 |

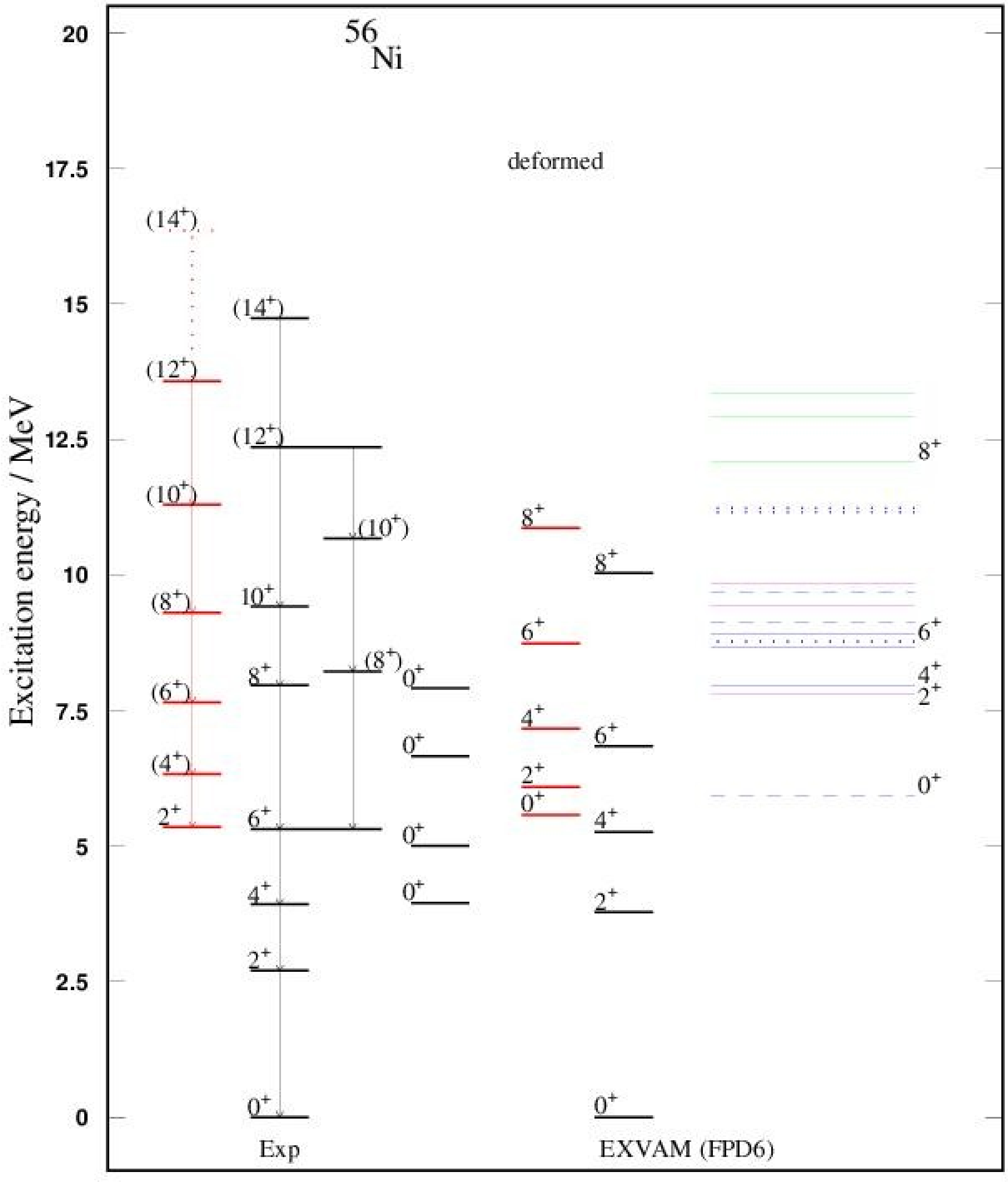
Table 3. Spectroscopic quadrupole moments $Q_2^{sp}$ (in $efm^2$) of selected negative-parity states in $^{56}$Ni. As effective charges $e_p = 1.5$ and $e_n = 0.5$ have been used.

| $I[\hbar]$ | $dn_1$ | $dn_2$ | $I[\hbar]$ | $dn_3$ | $dn_4$ |
|---|---|---|---|---|---|
| | | | $4^-$ | -62.9 | -57.8 |
| $5^-$ | -63.3.8 | -59.9 | | | |
| | | | $6^-$ | -70.3 | -63.8 |
| $7^-$ | -71.0 | -62.1 | | | |
| | | | $8^-$ | -74.8 | -67.5 |
| $9^-$ | -75.2 | -65.1 | | | |
| | | | $10^-$ | -77.7 | -69.6 |
| $11^-$ | -77.1 | -72.1 | | | |
| | | | $12^-$ | -78.1 | -70.8 |
| $13^-$ | -77.5 | -78.0 | | | |
| | | | $14^-$ | -77.2 | -69.9 |
| $15^-$ | -76.0 | -77.7 | | | |
| | | | $16^-$ | -74.7 | -67.0 |
| $17^-$ | -71.4 | -74.5 | | | |
| $19^-$ | -49.6 | -71.8 | | | |

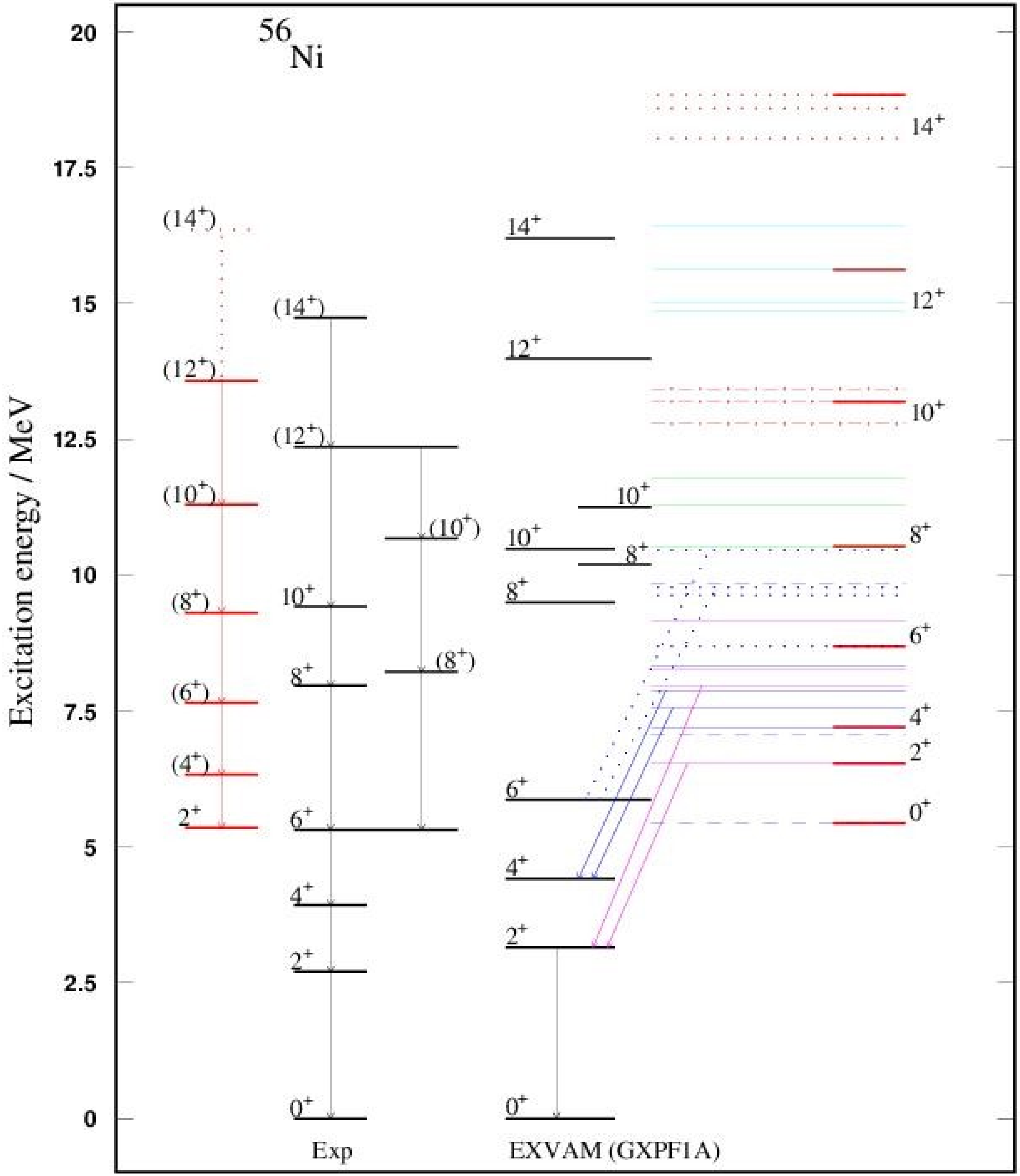
***CEXVAM***



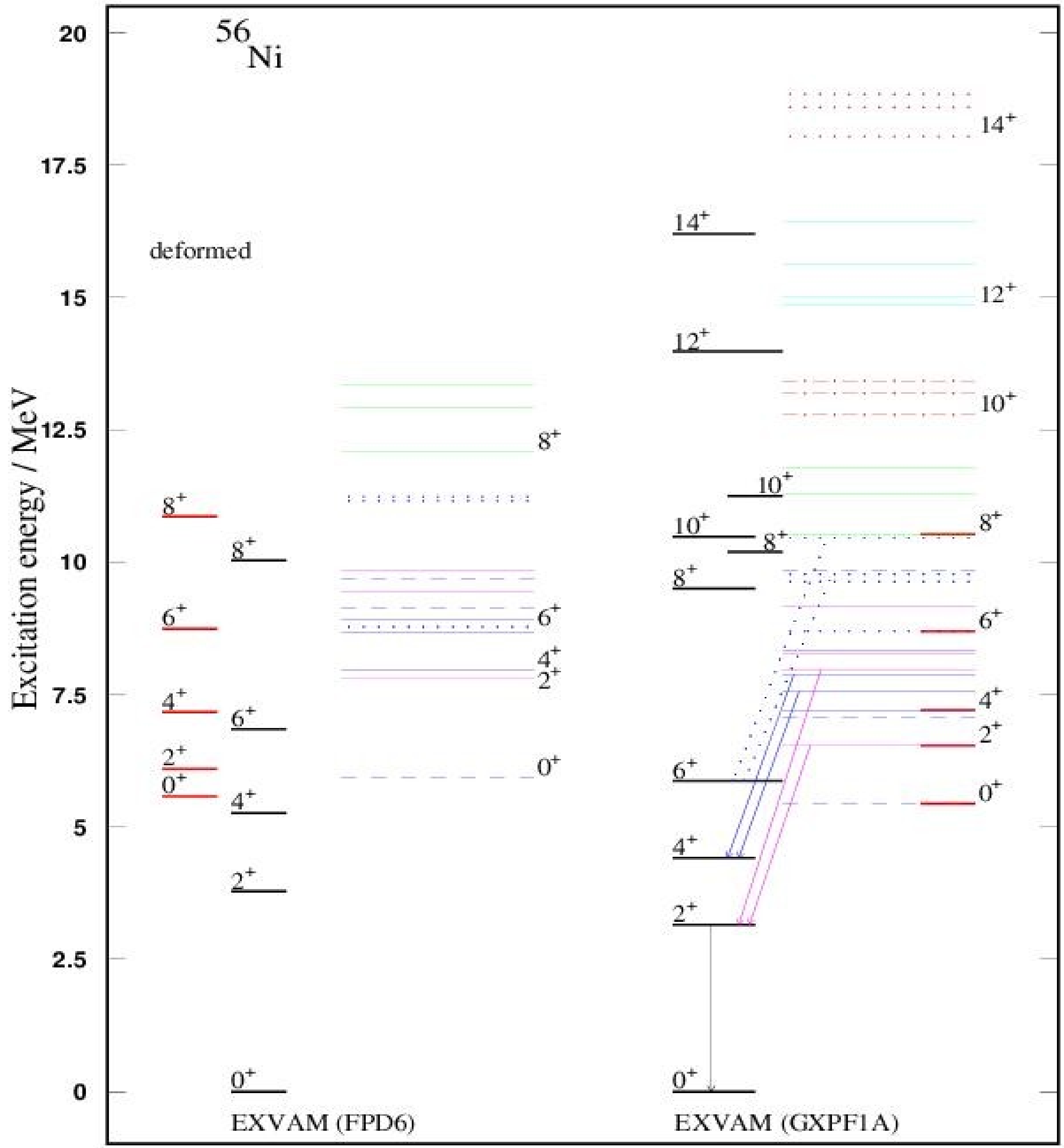
10.5
9.5
8.5
7.5
6.5
5.5
4.5
3.5
2.5
Excitation energy / MeV
56Ni
0+
0+
(0+)
0+
(0+)
0+
0+
2+
0+ p
0+ p
0+ def
0+ p
0+ p
0+ o
0+ def
2+
Exp
EXVAM (ren. Bonn A
fpd5/2g9/2)



56 Ni
deformed
Excitation energy / MeV
20
17.5
15
12.5
10
7.5
5
2.5
0
(14+)
(12+)
(10+)
(8+)
(6+)
(4+)
2+
(14+)
(12+)
(10+)
10+
(8+)
8+
6+
4+
2+
0+
0+
0+
0+
0+
8+
6+
4+
2+
0+
8+
6+
4+
2+
0+
8+
6+
4+
2+
0+
Exp
EXVAM (FPD6)

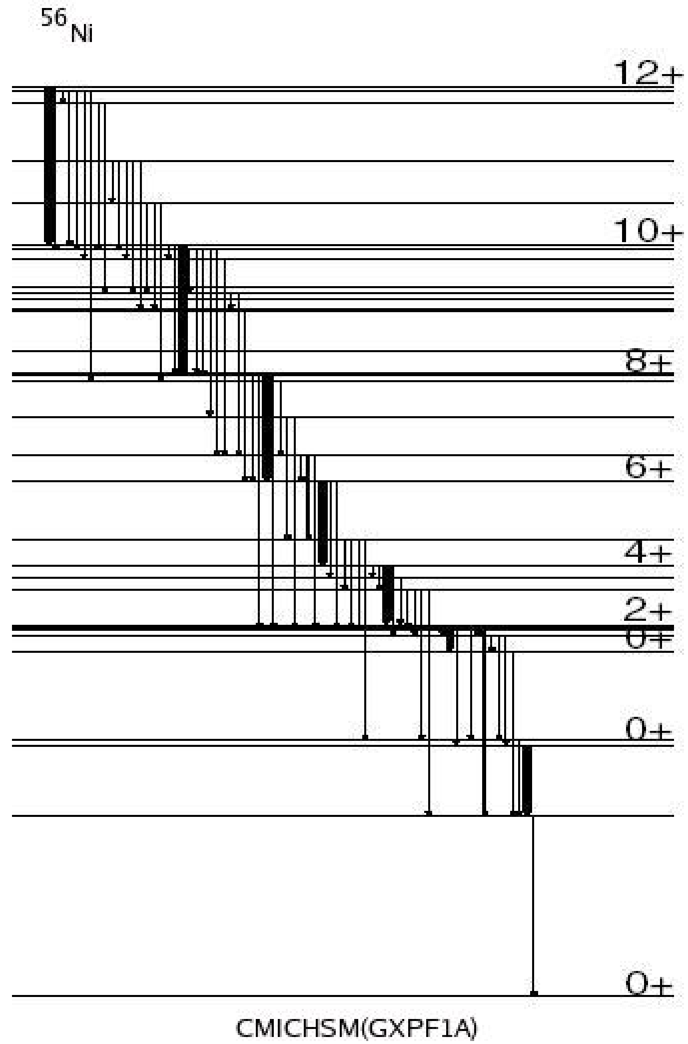


56Ni
Excitation energy / MeV
0
2.5
5
7.5
10
12.5
15
17.5
20
(14+)
(12+)
(10+)
(8+)
(6+)
(4+)
2+
(14+)
(12+)
10+
8+
6+
4+
2+
0+
(10+)
(8+)
14+
12+
10+
10+
8+
8+
6+
4+
2+
0+
14+
12+
10+
8+
6+
4+
2+
0+
Exp
EXVAM (GXPF1A)



56 Ni
deformed
Excitation energy / MeV
20
17.5
15
12.5
10
7.5
5
2.5
0
8+
6+
4+
2+
0+
14+
12+
10+
EXVAM (FPD6)
EXVAM (GXPF1A)

Horoi et al. PRC73 (2006) R061305



# Summary and outlook

***The complex Excited (Fed) Vampir model --- beyond mean-field variational approach to the nuclear many-body problem**

***able to describe exotic structure and decay***

***Illustrative results***

- the Coulomb-induced isospin-mixing effect on the superallowed Fermi β decay was investigated for the first time within the complex Excited Vampir approach describing self-consistently both the analog and non-analog Fermi branches for the A=70, 74 and 86 T=1 nuclei
- the *complex* Excited Vampir description of the properties at low and high spins in even-even and odd-odd members of the T=1 multiplet for the A=70, 74, 86 nuclei is in very good agreement with the available data
- the Gamow-Teller β decay of $^{74}$Kr was investigated for the first time within the complex Excited Vampir variational approach, describing self-consistently the shape-coexistence and –mixing in both parent and daughter nucleus

***Required improvements***

- the uncertainties in the effective interaction require systematic investigations, ***but*** the effective Hamiltonian is strongly connected with the nuclear many-body model used for the renormalization

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