Beyond mean-field approach to shape coexistence phenomena in the A=60-90 region

A. PETROVICI

Institute for Physics and Nuclear Engineering, Bucharest, Romania
Institut für Theoretische Physik, Universität Tübingen, Germany

- **Isospin Symmetry Breaking and Coulomb Energy Differences**
- **Shape Isomers and Gamow-Teller β decay of rp-process waiting-point nuclei**

Nuclei near the N = Z line dominated by the interplay of :

- ***shape coexistence and mixing***
- ***competition between T=0 and T=1 pairing correlations***
- ***rapid changes with particle number, angular momentum and excitation energy***

Self-consistent description of coexistence phenomena based on:

- ***realistic effective interactions in large model spaces***
- ***beyond mean-field approaches***

Complex EXCITED VAMPIR approach

- **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 restricted by time-reversal and axial symmetry**
- **the broken symmetries (s=N, Z, I, p) are restored by projection before variation**

Beyond mean field variational procedure

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

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

$$|\psi(F_i^s); sM\rangle = \Sigma_{j=1}^{i}\,|\phi(F_j^s)\rangle\,\alpha_j^i \qquad \text{for} \quad i = 1, ..., n-1$$

$$|\phi(F_i^s); sM\rangle = \hat{\Theta}_{M0}^s|F_i^s\rangle$$

$$|\psi(F_n^s); sM\rangle = \Sigma_{j=1}^{n-1}\,|\phi(F_j^s)\rangle\,\alpha_j^n + |\phi(F_n^s)\rangle\,\alpha_n^n$$

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

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

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

A = 60 – 90 mass region

^{40}Ca - core

model space (π, ν):

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

(charge-symmetric basis + Coulomb contributions to the π-spe from the core)

extended model space { $1d_{3/2}\ 0g_{7/2}\ 2s_{1/2}$ }

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

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

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

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

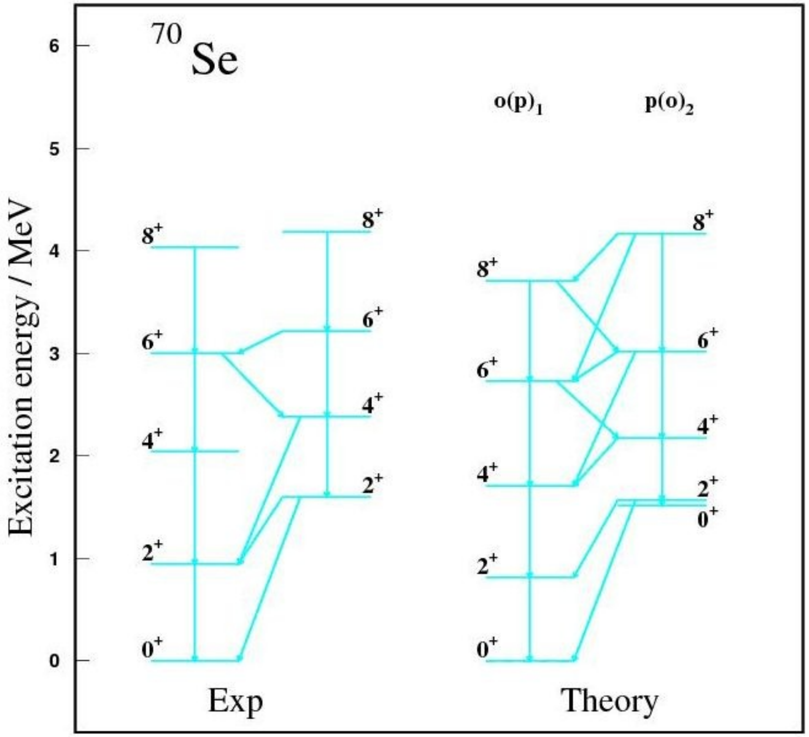
Isospin Mixing and Coulomb Energy Differences (CED)

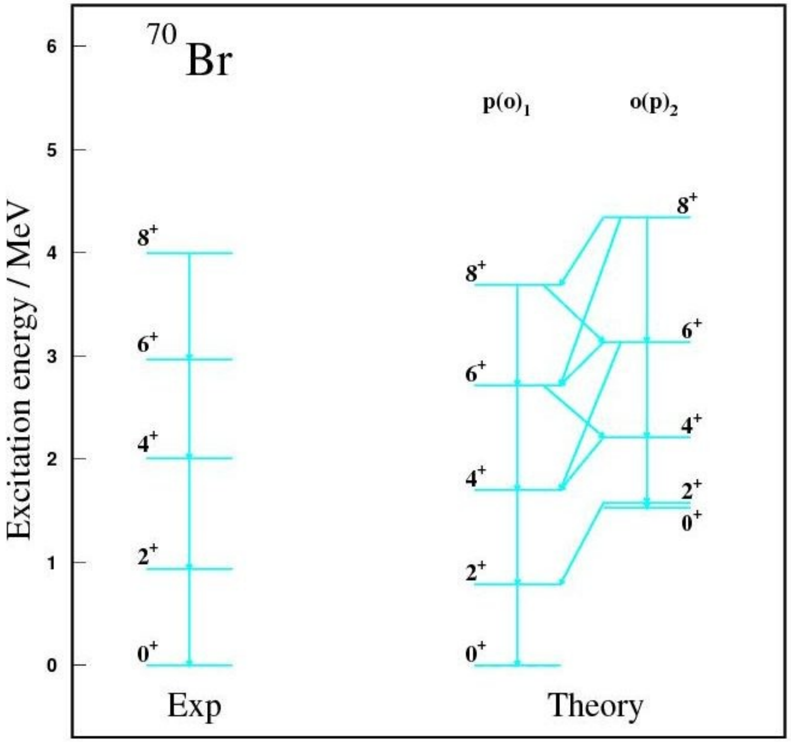
A= 70, 82, 86

A. M. Hurst et al., Phys. Rev. Lett.98 (2007) 072501
(^{70}Se: No evidence for oblate shapes)

J. Ljungvall et al., Phys. Rev. Lett. 100 (2008) 102502
(^{70}Se: Evidence for oblate shapes)

G. de Angelis et al., Eur. Phys. J. A12 (2001) 51 (^{70}Br)





The amount of mixing for the lowest states in ^{70}Se.

$I[\hbar]$	o-mixing	p-mixing
0^+_1	55%	39%
0^+_2	39%	54%
0^+_3		87%
2^+_1	57%	39%
2^+_2	41%	58%
2^+_3		92%
4^+_1	62%	35%
4^+_2	37%	63%
4^+_3		80(13)%
6^+_1	37%	59%
6^+_2	61%	37%
6^+_3	43%	43%
8^+_1		91%
8^+_2	93%	
8^+_3		84(10)%

The amount of mixing for the lowest states in ^{70}Br.

$I[\hbar]$	o-mixing	p-mixing
0^+_1	35%	62%
0^+_2	59%	34%
0^+_3		88%
2^+_1	41%	57%
2^+_2	58%	40%
2^+_3		94%
4^+_1	41%	56%
4^+_2	57%	41%
4^+_3		94%
6^+_1	20%	76%
6^+_2	79%	20%
6^+_3		44(34)(12)%
8^+_1		89%
8^+_2	96%	
8^+_3		71(11)(11)%

Spectroscopic Q_2^{sp} (in $e fm^2$) of the lowest three states of spin I of ^{70}Se (effective charges $e_p = 1.2$, $e_n = 0.2$).

$I[\hbar]$	I_1	I_2	I_3
2^+	4.5	-7.	-43.7
4^+	11.5	-16.8	-54.4
6^+	-17.5	9.5	-54.2
8^+	-64.	52.1	-60.

Spectroscopic Q_2^{sp} (in $e fm^2$) of the lowest three states of spin I of ^{70}Br (effective charges $e_p = 1.2$, $e_n = 0.2$).

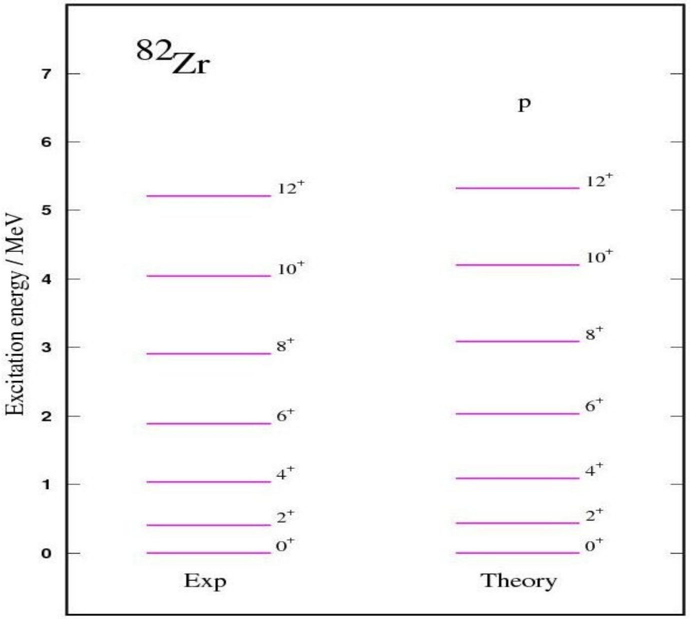
$I[\hbar]$	I_1	I_2	I_3
2^+	-6.4	4.6	-44.6
4^+	-9.8	5.2	-60.8
6^+	-39.7	33.7	-62.2
8^+	-65.5	59.	-71.4

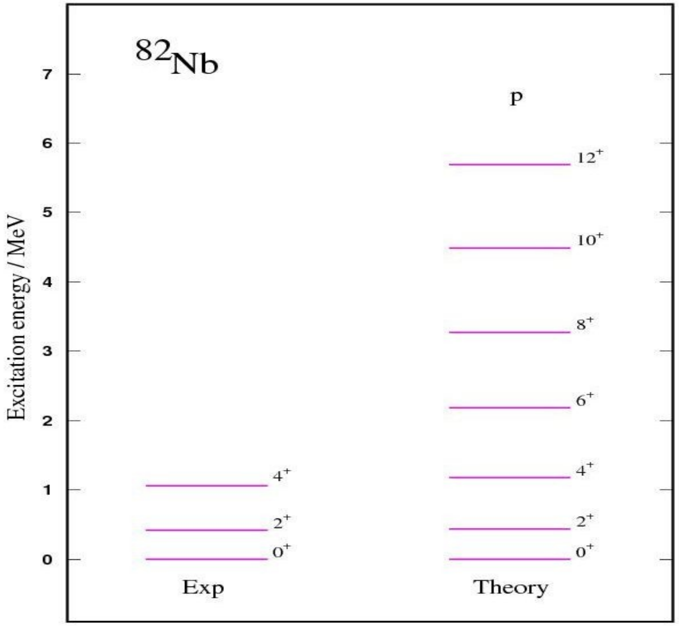
$B(E2; I \rightarrow I-2)$ values (in $e^2 fm^4$) for the lowest two bands of ^{70}Se (EXVAM). Strengths for secondary branches are given in parentheses (effective charges $e_p = 1.2$, $e_n = 0.2$) .

$I[\hbar]$	EXVAM $o(p)_1$	EXVAM $p(o)_2$	Exp.	(HFB-based-config.mix.) (Girod et al.)
2^+	492	501 (5)	342 ± 19	549
4^+	713	761	370 ± 24	955
6^+	779 (62)	792 (33)	530 ± 96	1404
8^+	717 (193)	666 (150)		

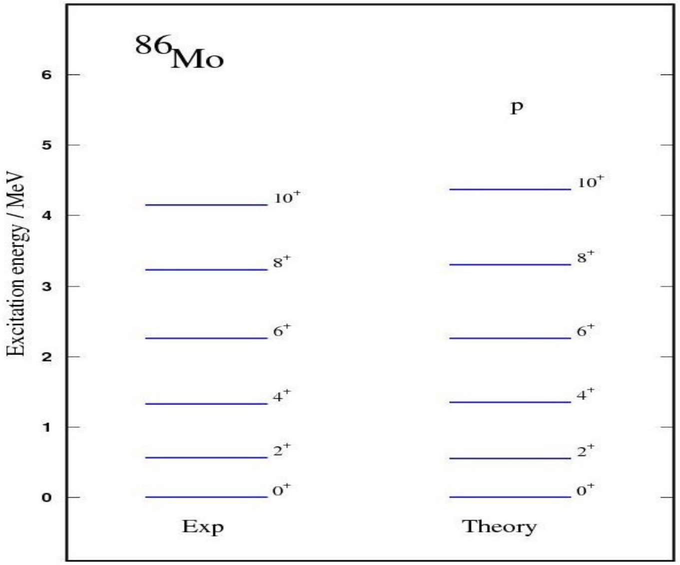
$B(E2; I \rightarrow I-2)$ values (in $e^2 fm^4$) for the lowest two bands of ^{70}Br (EXVAM). Strengths for secondary branches are given in parentheses (effective charges $e_p = 1.2$, $e_n = 0.2$).

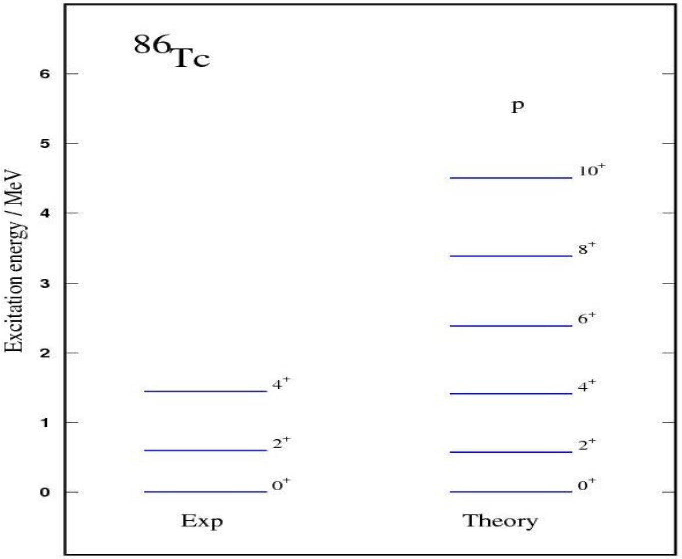
$I[\hbar]$	$p(o)_1$	$o(p)_2$
2^+	541	516
4^+	775	756
6^+	820 (60)	777 (44)
8^+	771 (81)	754 (84)

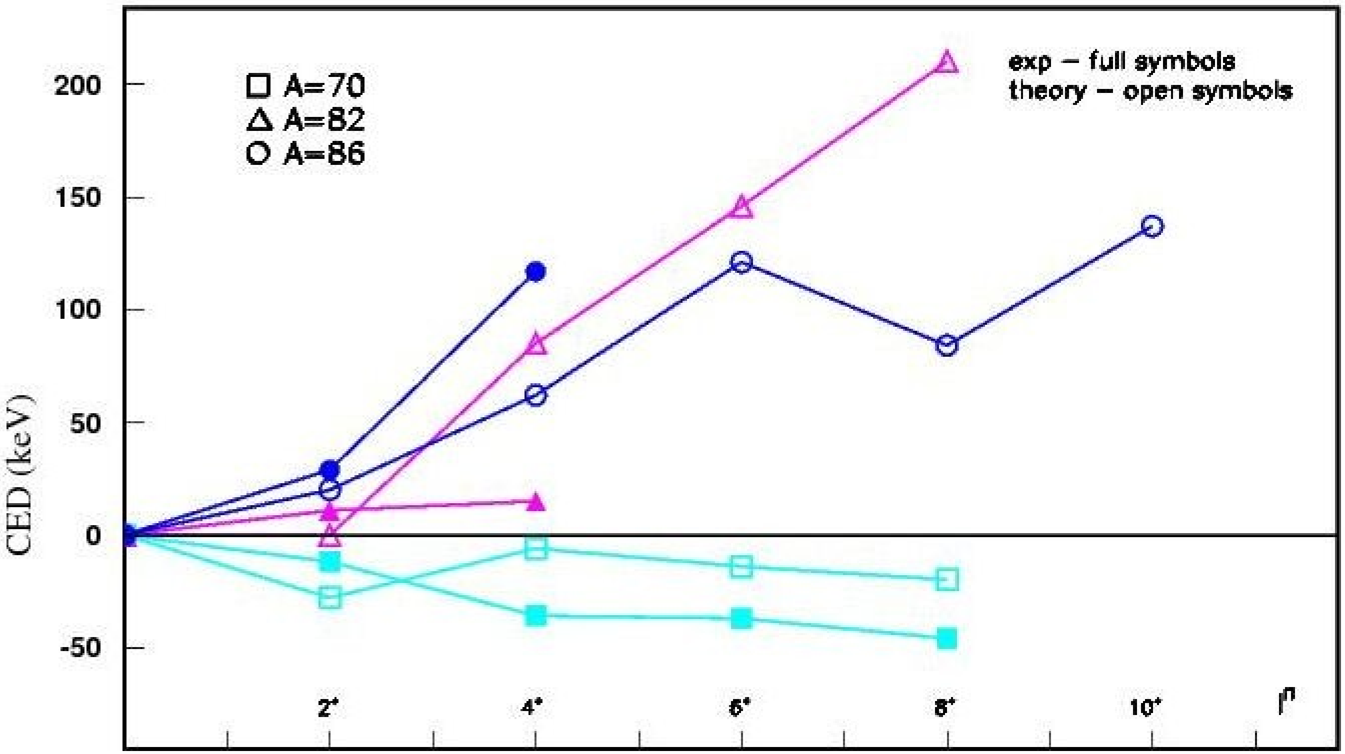




A. Petrovici et al., Phys. Rev. C78 (2008) 064311







A=70
A=82
A=86
exp – full symbols
theory – open symbols
CED (keV)
200
150
100
50
0
-50
2+
4+
6+
8+
10+
I^{π}

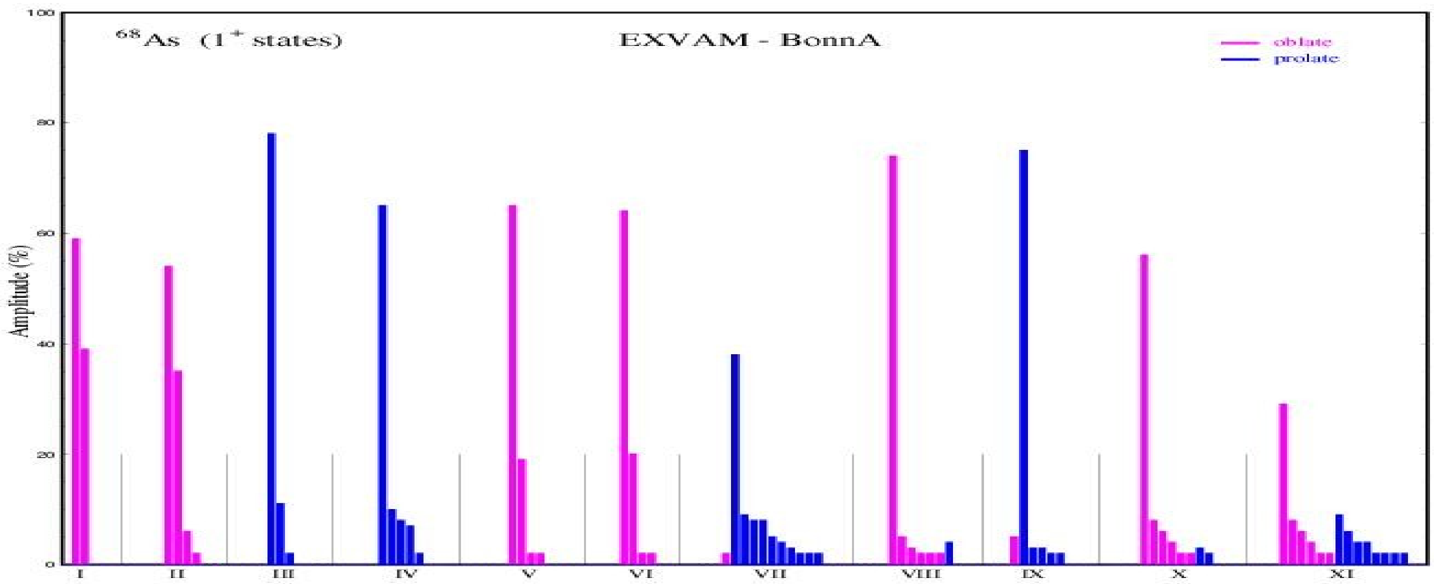
Gamow-Teller β decay of the rp-process waiting point ^{68}Se

CERN/ISOLDE P. Baumann et al., Phys. Rev. C50 (1994) 1180

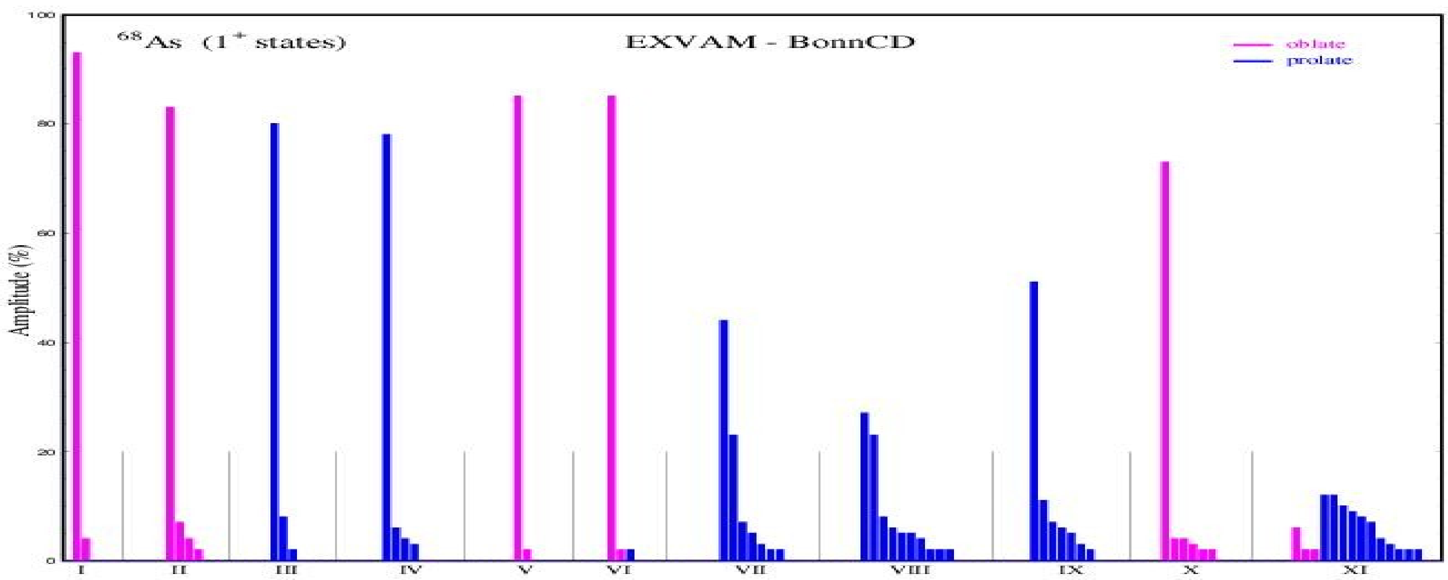
$^{68}Se \rightarrow {}^{68}As$ $\quad 0^+ \rightarrow 1^+$ $\quad Q_{EC} = 4.730 \pm 0.310$ MeV

The amount of mixing for the lowest 0^+ states of the ^{68}Se nucleus (ms3).

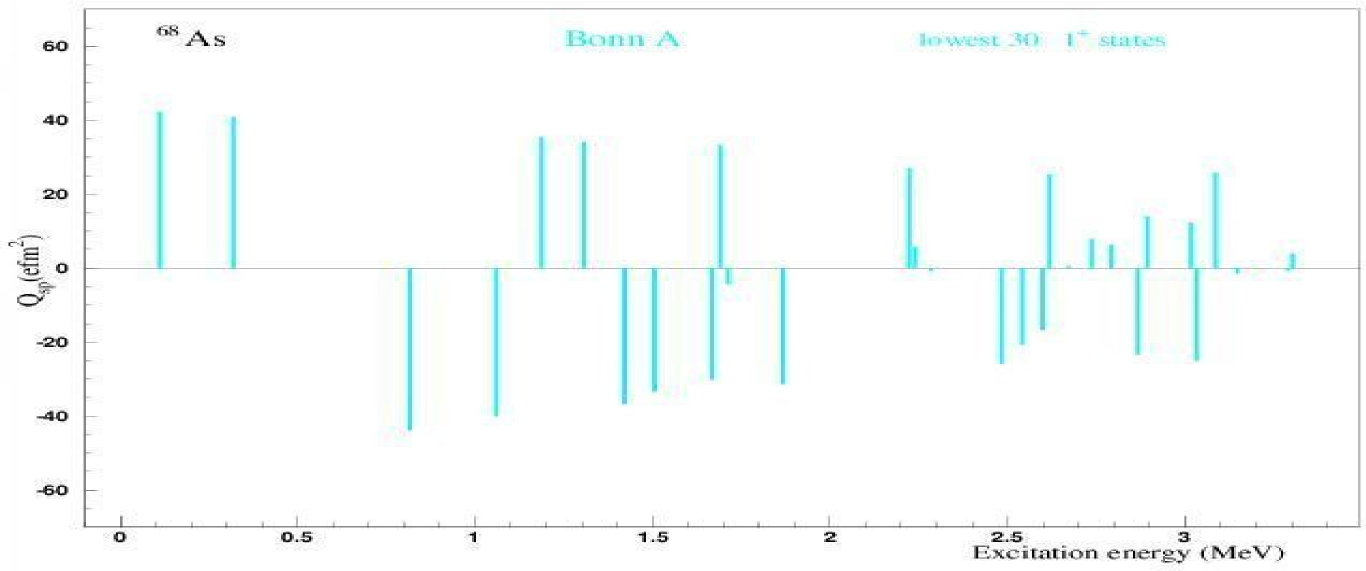
$I[\hbar]$	Bonn A o-mixing	p-mixing	Bonn CD o-mixing	p-mixing
0_1^+	58(2)%	22(10)(4)%	53(2)%	24(11)(4)%
0_2^+	10(6)%	73(5)(3)%	5(5)%	84(3)%
0_3^+	16(7)(3)%	38(20)(10)(2)%	26%	32(16)(11)(10)(2)%



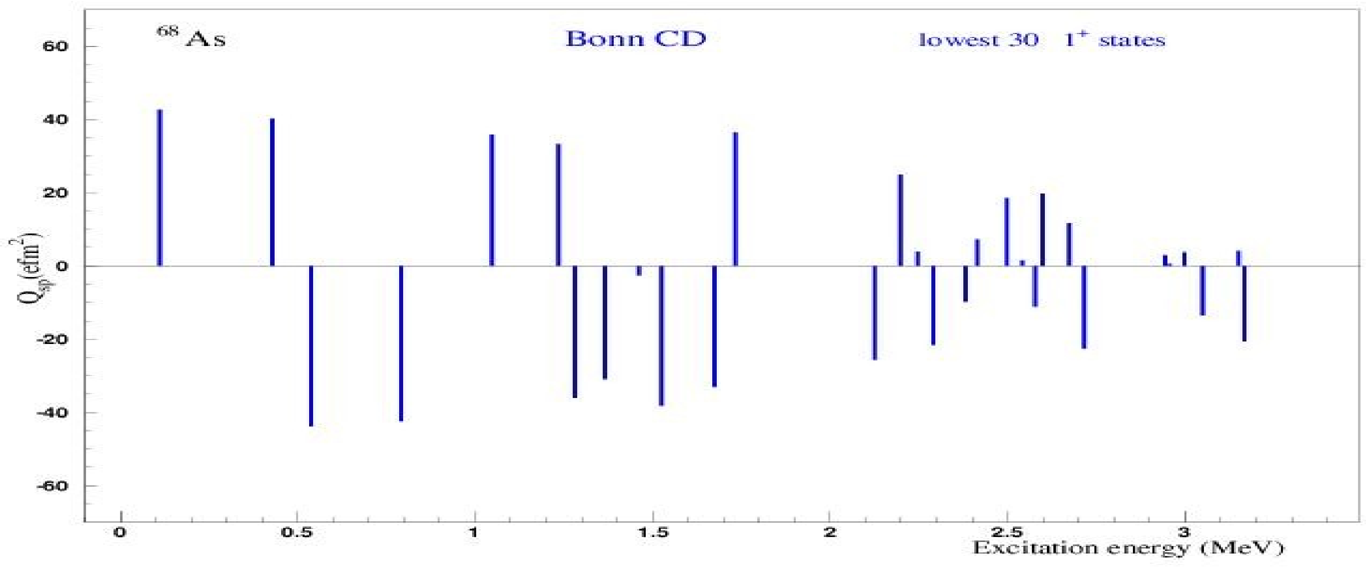
^{68}As (1$^+$ states)
EXVAM - BonnA
oblate
prolate
Amplitude (%)
0
20
40
60
80
100
I
II
III
IV
V
VI
VII
VIII
IX
X
XI



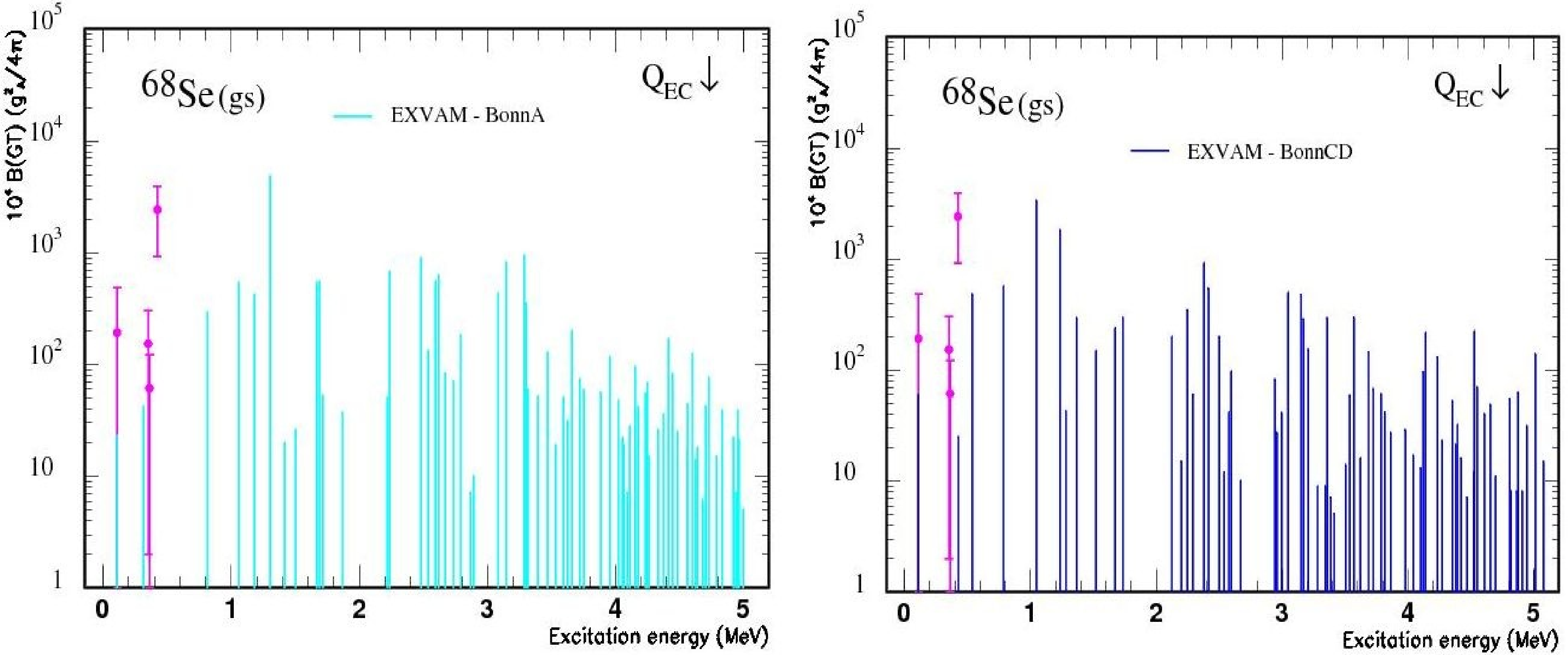
^{68}As (1$^+$ states)
EXVAM - BonnCD
oblate
prolate
Amplitude (%)
0
20
40
60
80
100
I
II
III
IV
V
VI
VII
VIII
IX
X
XI



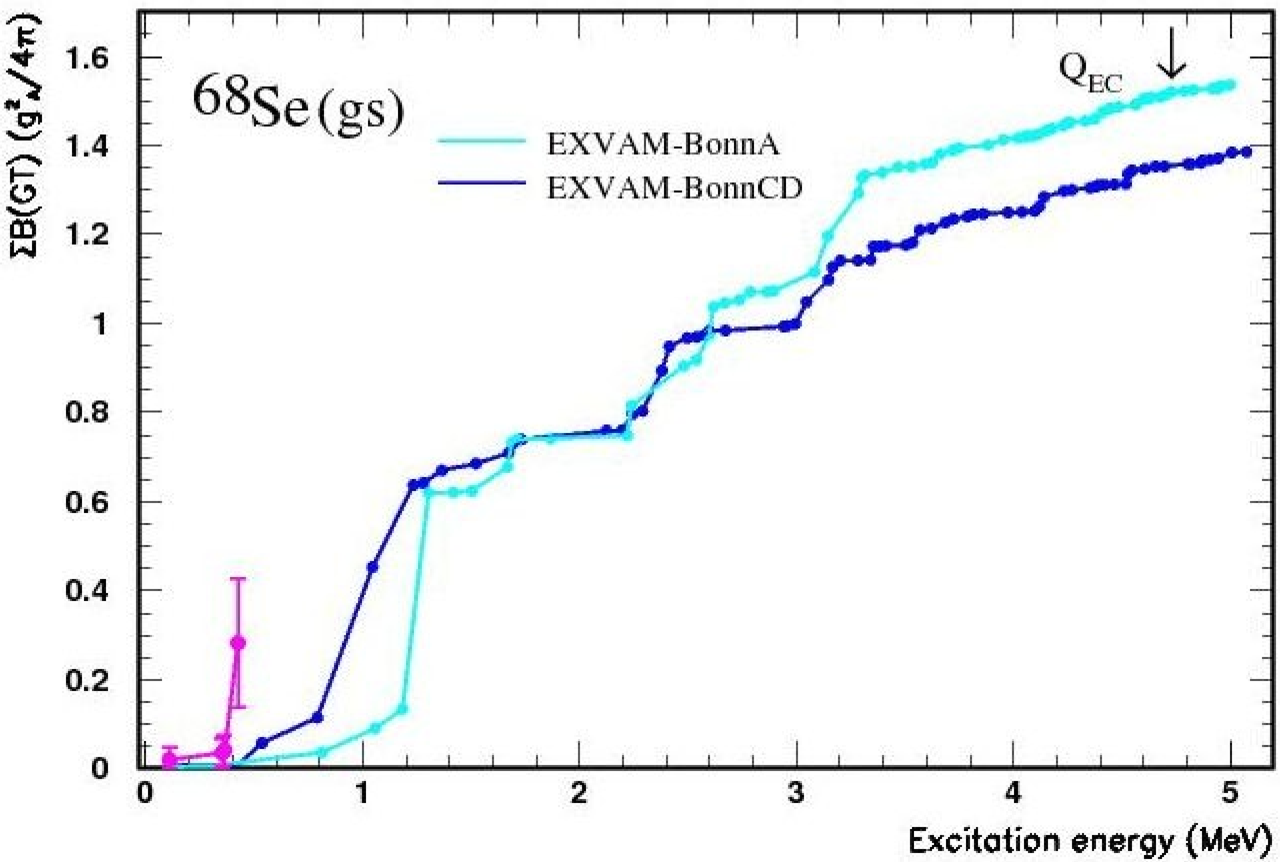
68 As
Bonn A
lowest 30 1+ states
Qsp(efm2)
60
40
20
0
-20
-40
-60
0
0.5
1
1.5
2
2.5
3
Excitation energy (MeV)



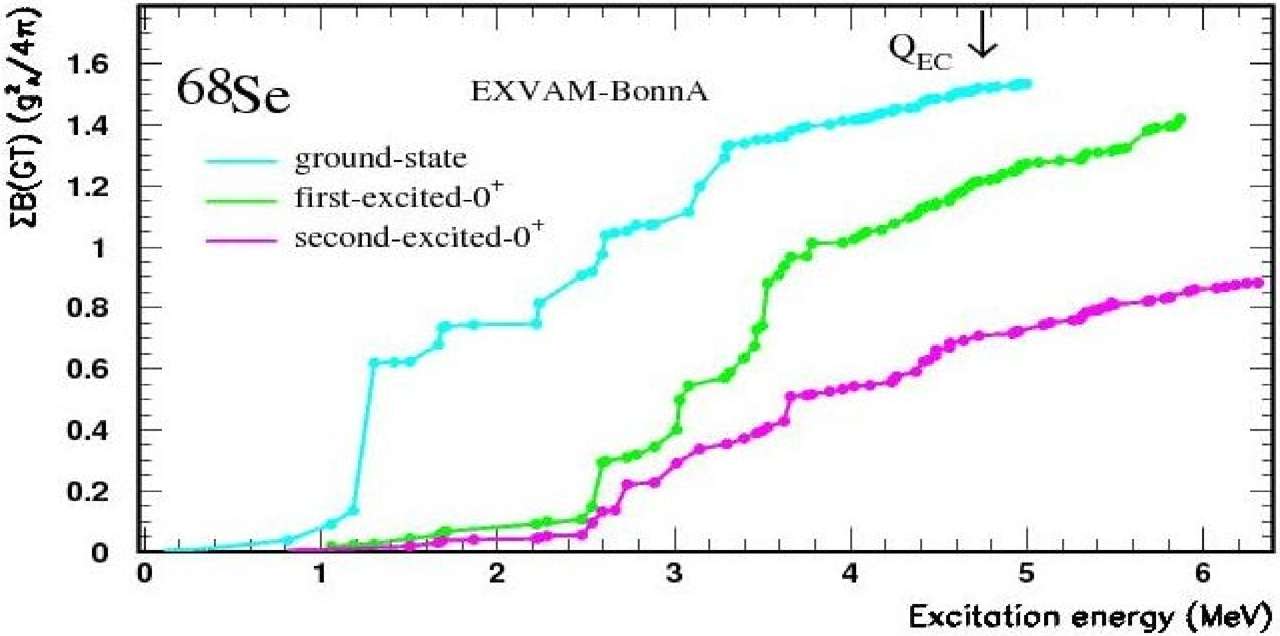
68 As
Bonn CD
lowest 30 1+ states
Qsp(efm2)
60
40
20
0
-20
-40
-60
0
0.5
1
1.5
2
2.5
3
Excitation energy (MeV)



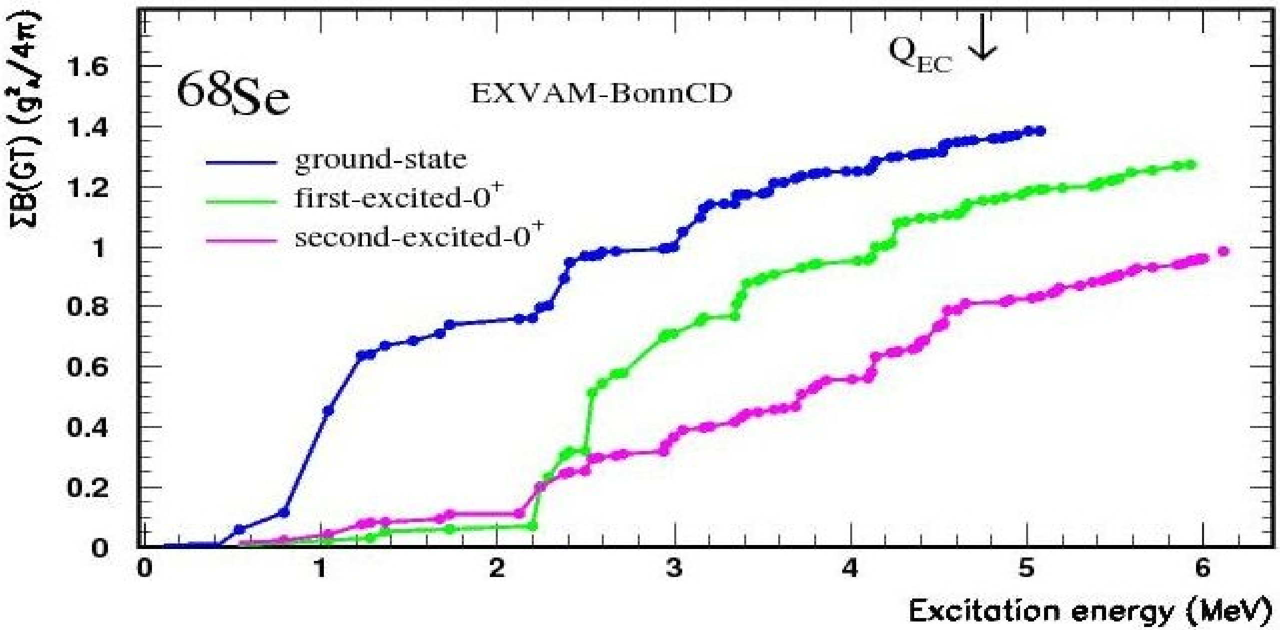
^{68}Se(gs)
Q_{EC} ↓
EXVAM - BonnA
10^4 B(GT) ($g_A^2/4\pi$)
Excitation energy (MeV)
^{68}Se(gs)
Q_{EC} ↓
EXVAM - BonnCD
10^4 B(GT) ($g_A^2/4\pi$)
Excitation energy (MeV)



$T_{1/2}^{exp} = 35.5(7)$ s $T_{1/2}^{BonnCD} = 33.9$ s $T_{1/2}^{BonnA} = 48.5$ s



68Se
EXVAM-BonnA
Q_{EC}
ground-state
first-excited-0^+
second-excited-0^+
$\Sigma B(GT)$ $(g_A^2/4\pi)$
Excitation energy (MeV)



68Se
EXVAM-BonnCD
Q_{EC}
ground-state
first-excited-0^+
second-excited-0^+
$\Sigma B(GT)$ $(g_A^2/4\pi)$
Excitation energy (MeV)

$$\lambda = \ln 2/K \sum_i [(2J_i+1)\, e^{-E_i/(kT)}]/\, G(Z,A,T) \sum_j B_{ij} \Phi_{ij}$$

i – parent states *j – daughter states*

$$G(Z,A,T) = \sum_i e^{-E_i/(\kappa T)}$$ *(partition function of the parent nucleus)*

Bij = Bij (GT)

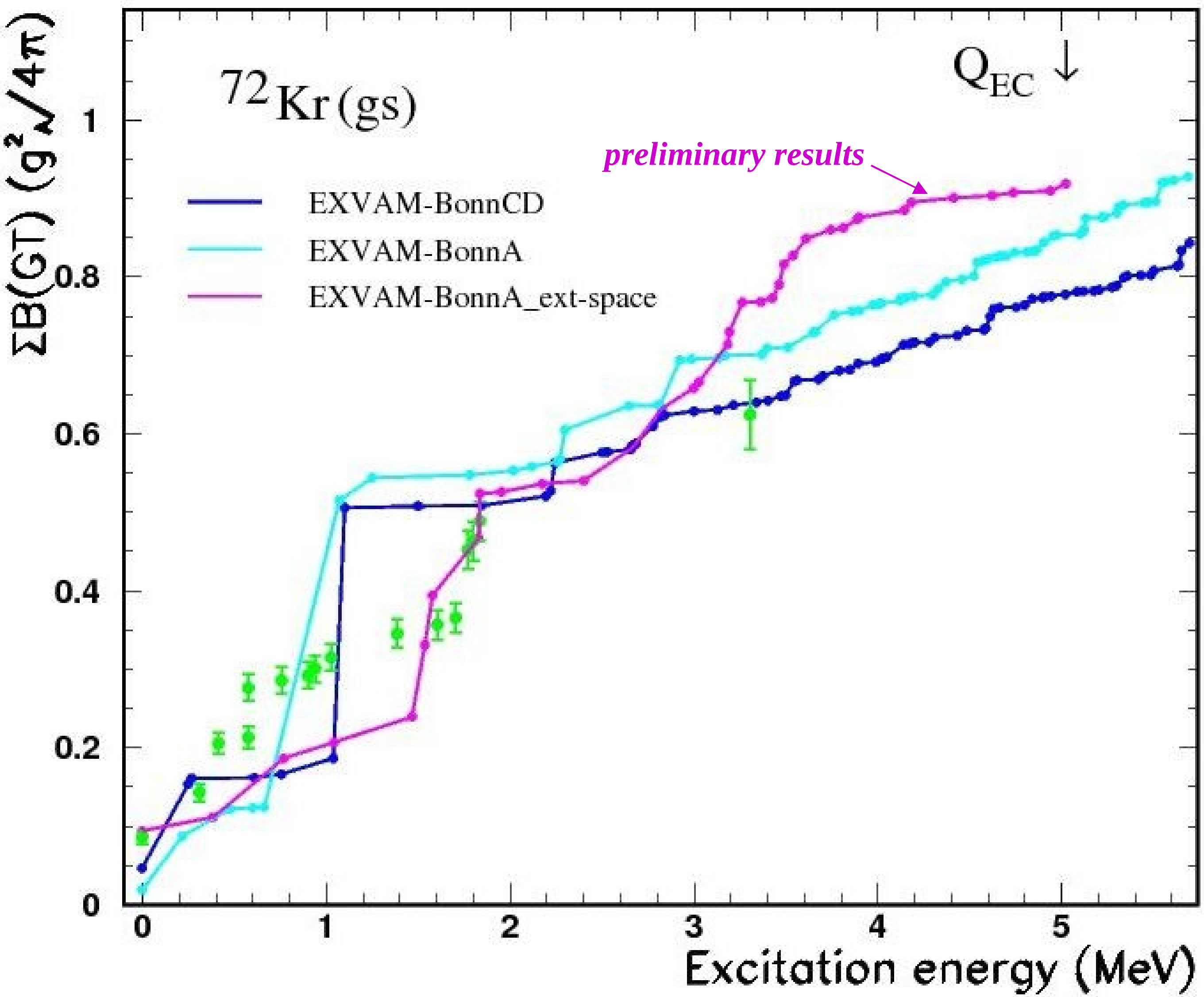
Φ_{ij} *– phase space integral*

$T < 2$ *GK X-ray bursts*

In the astrophysical environment of the X-ray bursts the decay of the isomeric 0^+ *states of* ^{68}Se *will not influence the effective half-life*

A. Petrovici et al., Phys. Rev. C80 (2009) 044319

different dimensional model spaces - no quenching



A. Petrovici et al. Phys. Rev. C78 (2008) 044315

Summary and outlook

- shape mixing and isospin symmetry breaking Coulomb interaction could explain the trends in CED

- self-consistent approach to the Gamow-Teller β decay of the ground state and the lowest shape isomers 0^+ of ^{68}Se to ^{68}As gives good agreement with the available data
- at the temperatures of the X-ray bursts the effect of the decay of the lowest isomeric states of ^{68}Se will not influence the effective half-life

- quenching is not needed in a beyond mean field description of the influence of shape coexistence and mixing on the Gamow-Teller β decay using a model space with all spin-isospin partners in $0\hbar\omega$ spaces

- in progress: construction of a realistic effective interaction in a larger model space

In collaboration with:

K. W. Schmid, Amand Faessler

Tuebingen University, Germany

O. Andrei

National Institute for Physics and Nuclear Engineering,
Bucharest, Romania