First Identification of Collective Band Structure in Odd-odd ^{166}Re

Hongjie Li

B. Cederwall, T. Bäck, M. Doncel, C. Qi
Royal Institute of Technology, Stockholm, Sweden

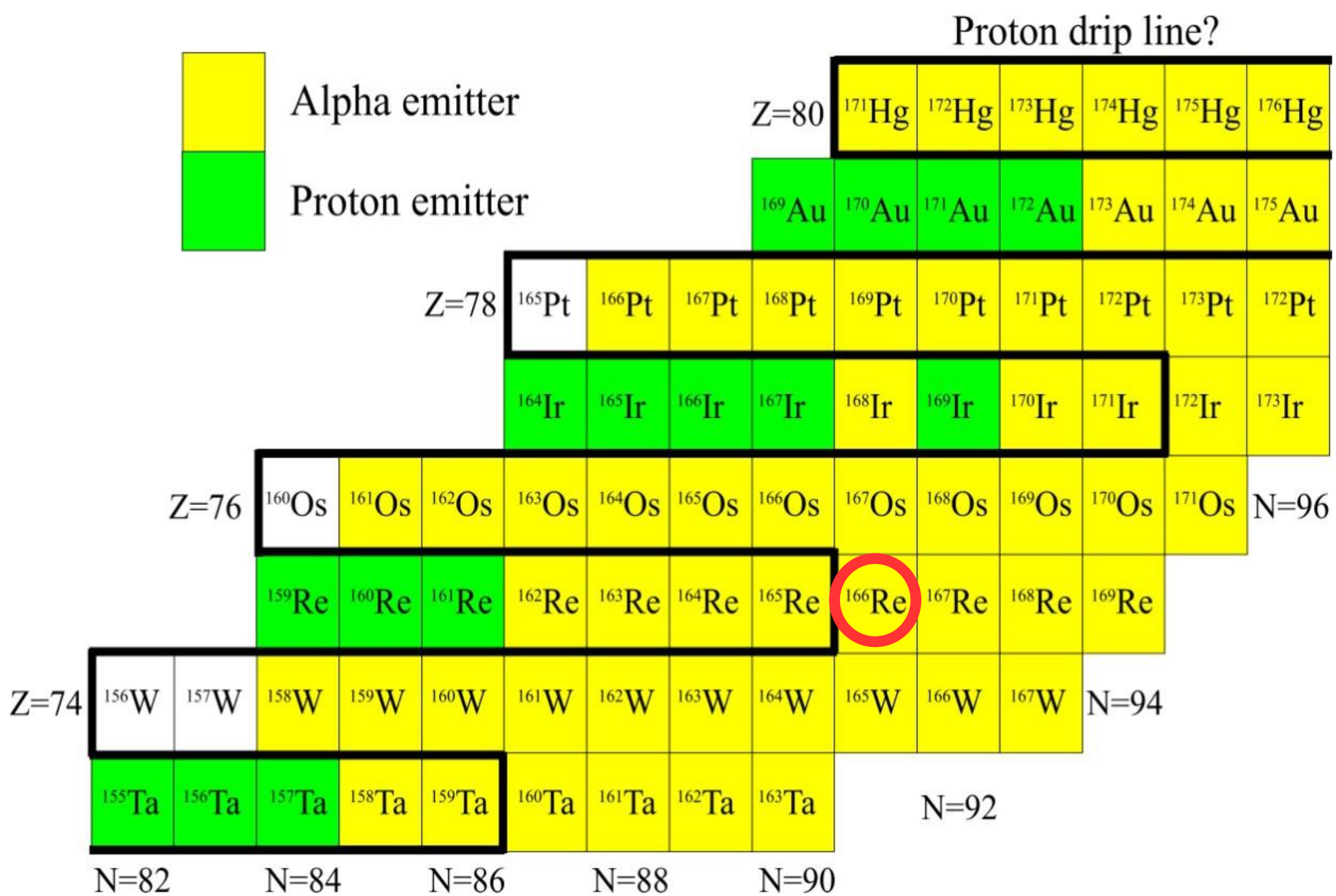
Z. G. Xiao, S. J. Zhu
Tsinghua University, Beijing, China

JUROGAM/GREAT Collaboration

Outline of the Talk

- **Spectroscopy at the Proton Drip Line**
- **Experimental Setup**
- **Preliminary Results**
- **Conclusion**

Proton drip line



courtesy of RD Page, LISA presentation

Identified collective bands

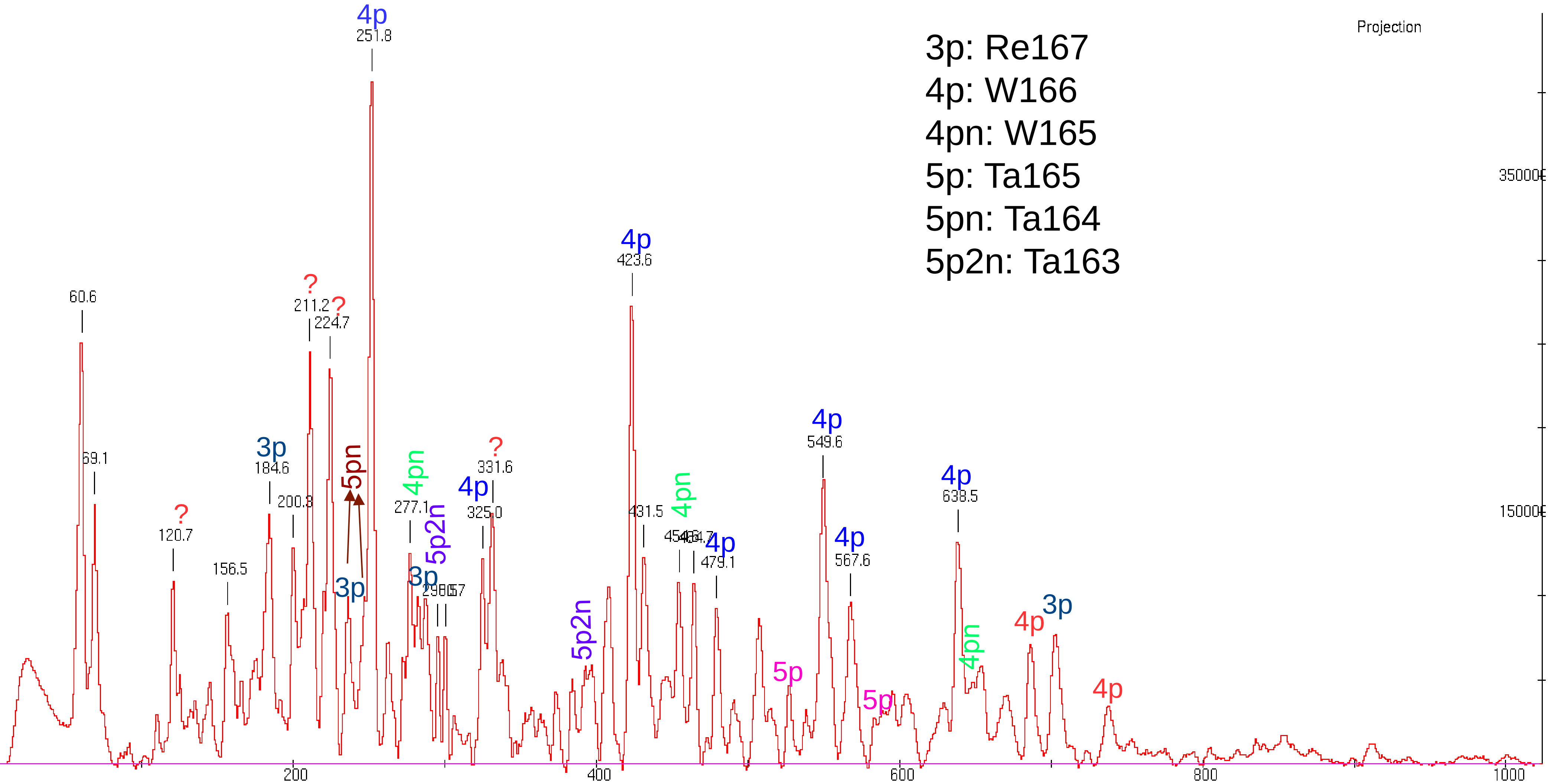
Compound

78	Pt162	Pt163	Pt164	Pt165	Pt166	Pt167	Pt168	Pt169	Pt170	
77	Ir161	Ir162	Ir163	Ir164	Ir165	Ir166	Ir167	Ir168	Ir169	1p
76	Os160	Os161	Os162	Os163	Os164	Os165	Os166	Os167	Os168	2p
75	Re159	Re160	Re161	Re162	Re163	Re164	Re165	Re166	Re167	3p
74	W158	W159	W160	W161	W162	W163	W164	W165	W166	4p
73	Ta157	Ta158	Ta159	Ta160	Ta161	Ta162	Ta163	Ta164	Ta165	5p
72	Hf156	Hf157	Hf158	Hf159	Hf160	Hf161	Hf162	Hf163	Hf164	6p
71	Lu155	Lu156	Lu157	Lu158	Lu159	Lu160	Lu161	Lu162	Lu163	7p
	84		86		88		90		92	

Experimental Setup

- Reaction: $^{92}Mo(^{78}Kr, 3pn)^{166}Re$
- E_{beam}=380 MeV/u
- Accelerator: K130 cyclotron at the University of Jyväskylä
- Target: 0.6-mg/cm^2 ^{92}Mo with 1-mg/cm^2 Ta support
- DPUNS Plunger: 1-mg/cm^2 Mg degrader with the distances of 5, 100, 200, 500, 1000, 2000, 3000, 5000, 8000um
- Setup: JUROGAM II(24 clovers + 15 tapered phase I) Germanium
  RITU(Recoil Ion Transport Unit) gas-filled recoil seperator
  GREAT(Gamma Recoil Electron Alpha Tagging) Spectrometer
    - MWPC
    - Si PIN diode detectors
    - DSSD: 120x + 80y
    - 3 clovers + planar(24x + 12y) in FP
- Total photopeak efficiency: 4.2% at 1.3 MeV

A
B
C
12 clovers at 75.5°
12 clovers at 104.5°
10 phase I at 133.6°
5 phase I at 157.6°
A: JUROGAM II
B: RITU
C: GREAT
Planar
MWPC
Si PIN diode
DSSD 200
Clover: 3
Planar: 24x+12y



Identification of ^{166}Re

Total projection in the Cube

Identification of ^{166}Re

The Known Excited States

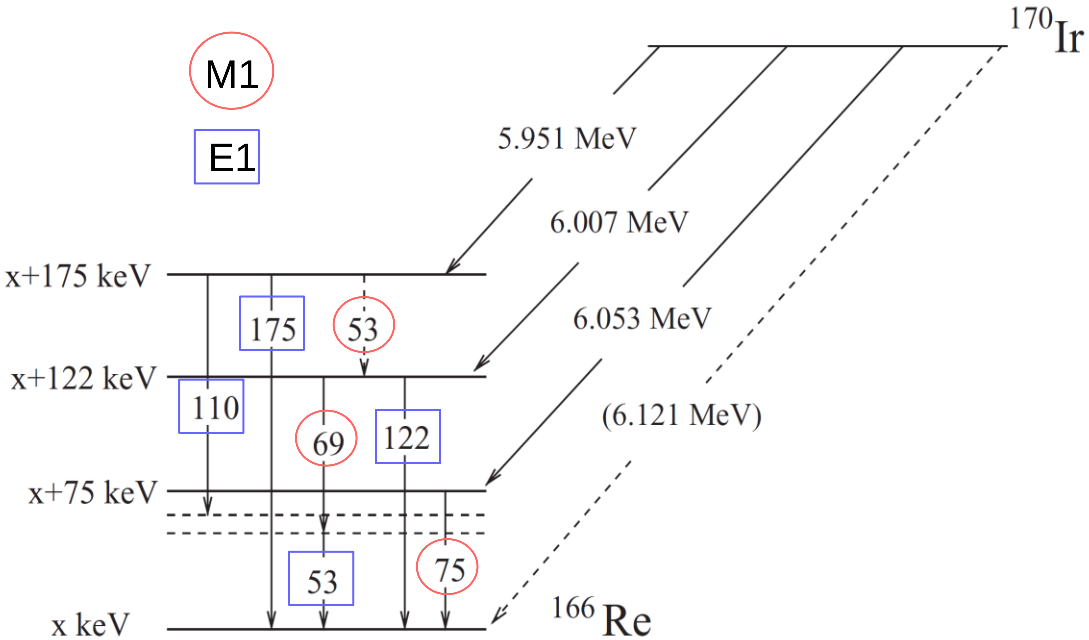


FIG. 8. Tentative level structure of ^{166}Re deduced from the α-decay study of ^{170}Ir.

B. Hadinia, *et al*, PRC **76**, 044312 (2007)

Level scheme of ^{166}Re

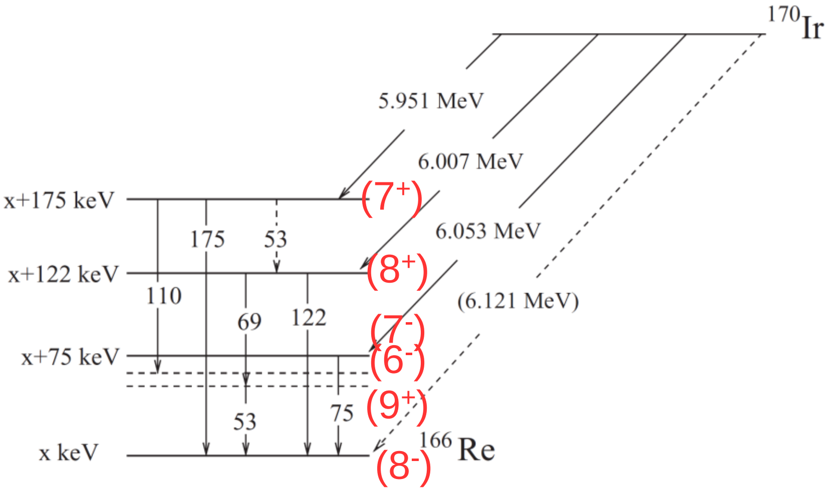
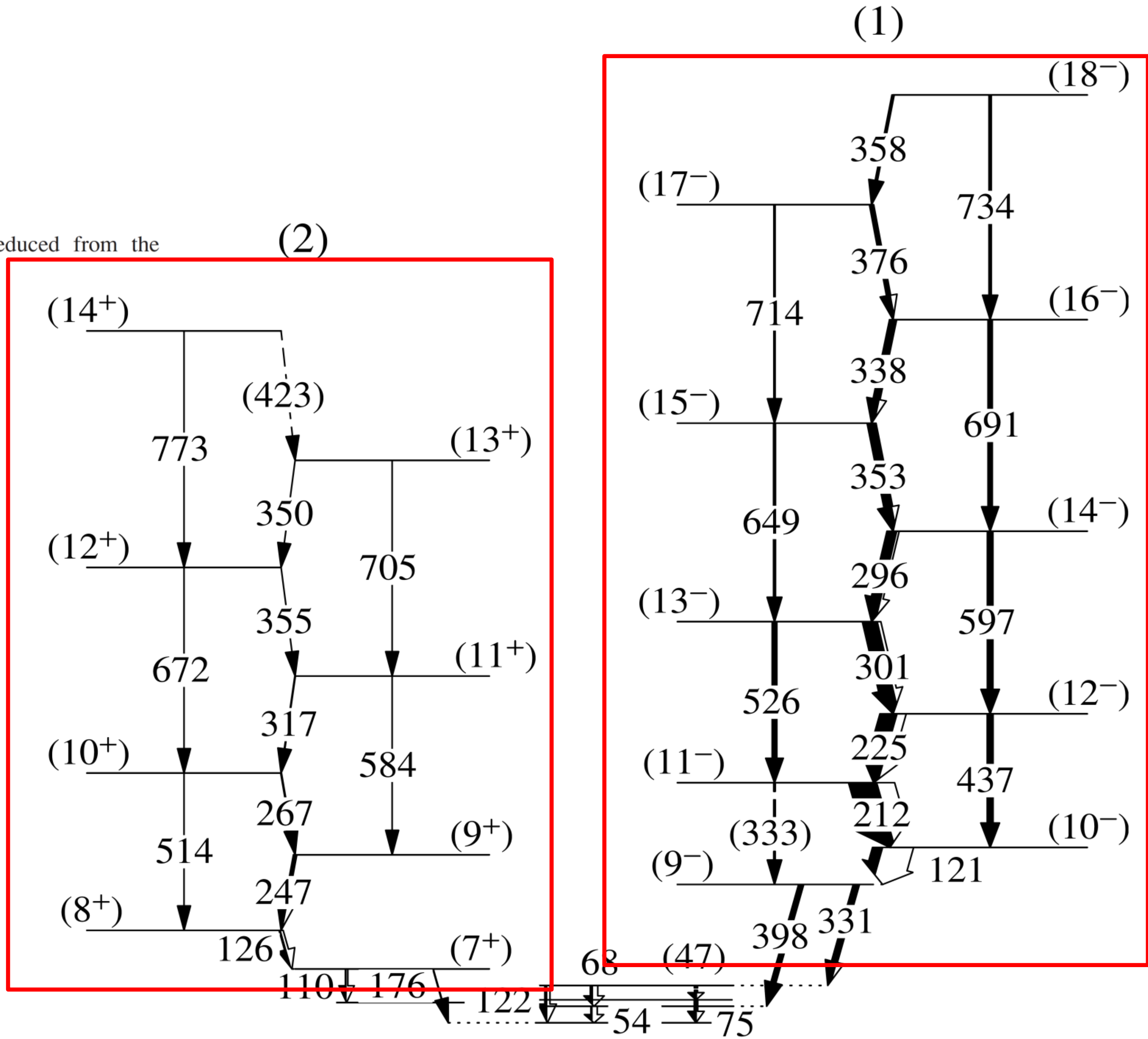
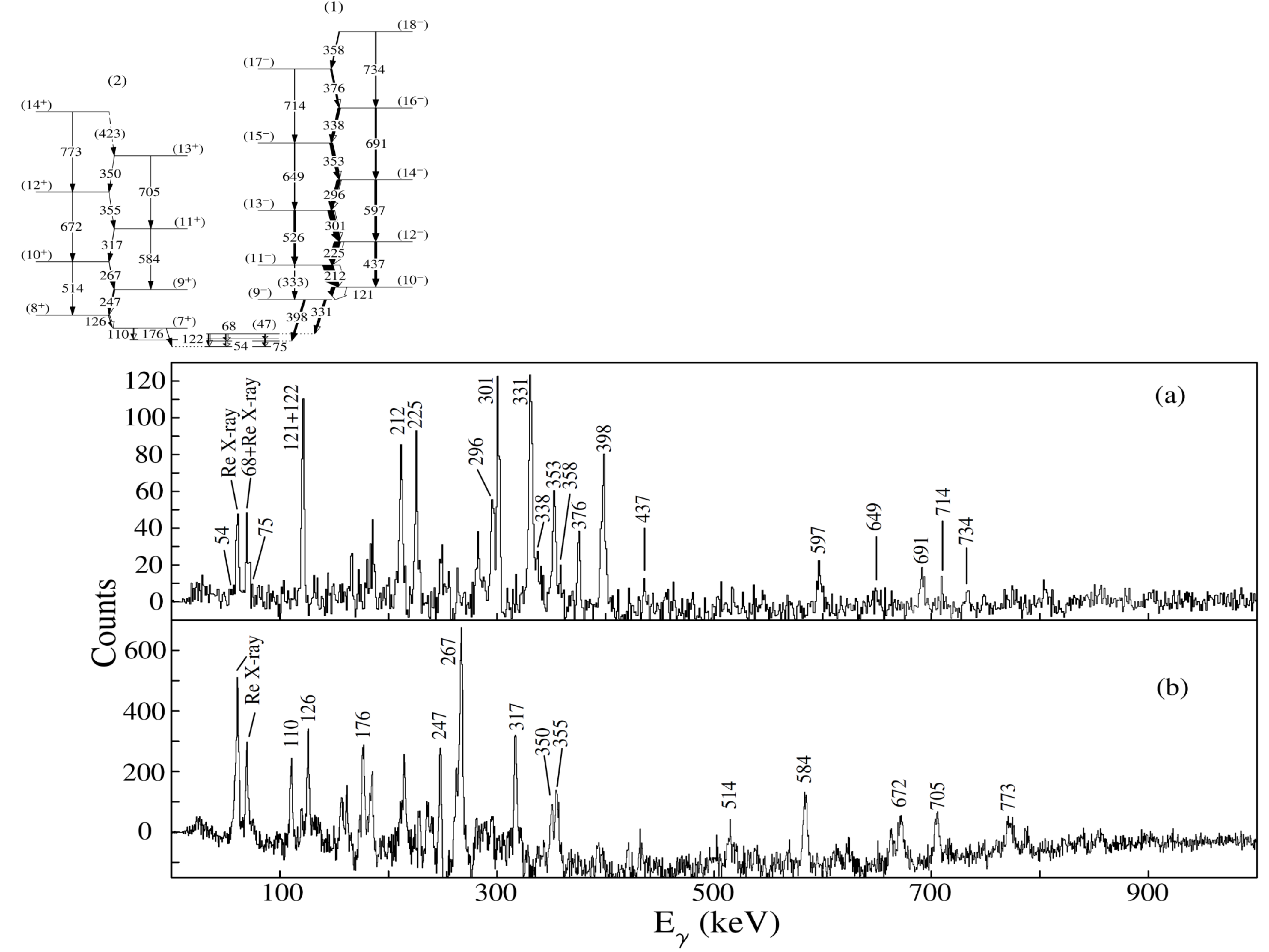
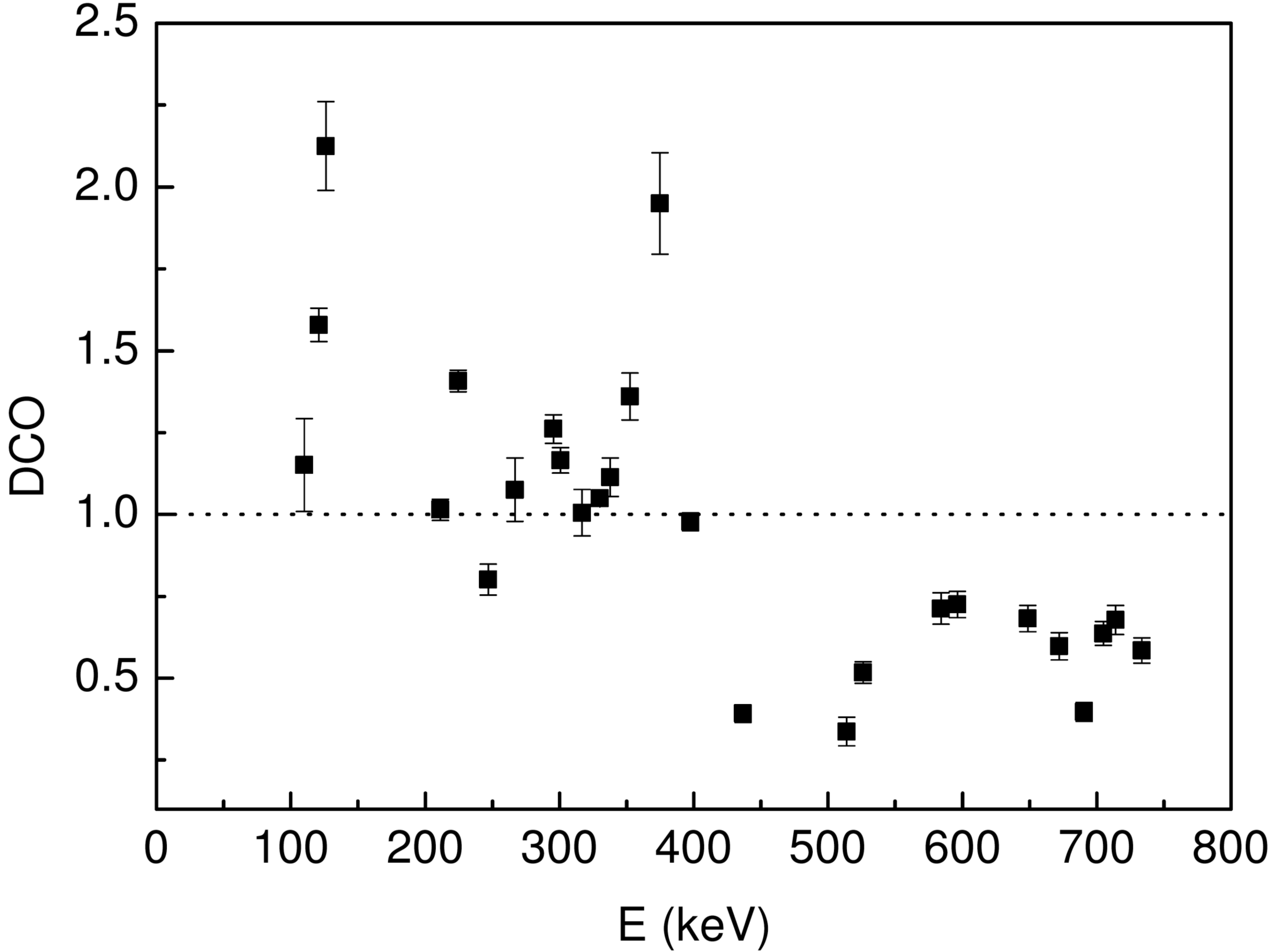


FIG. 8. Tentative level structure of ^{166}Re deduced from the α-decay study of ^{170}Ir.

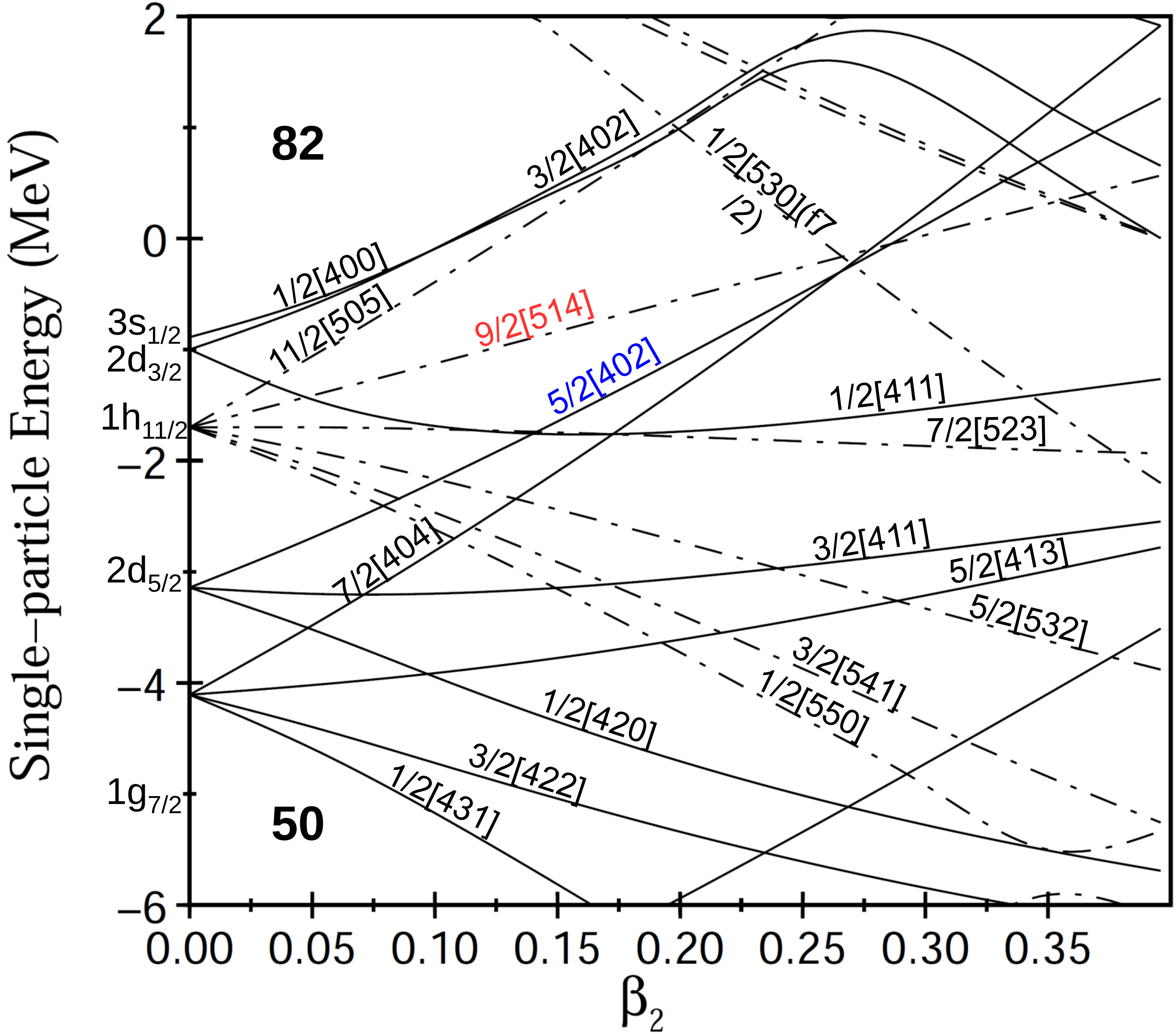


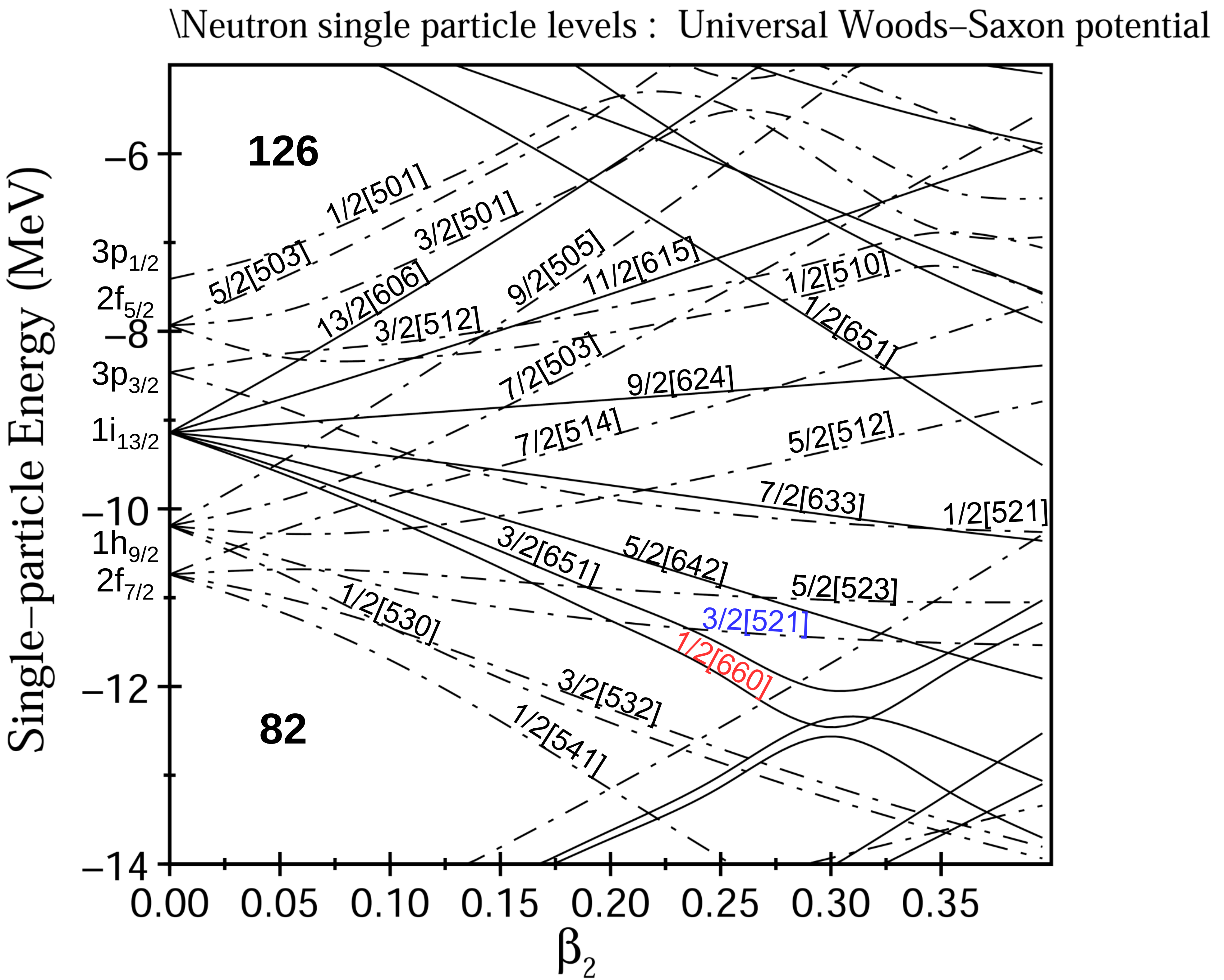


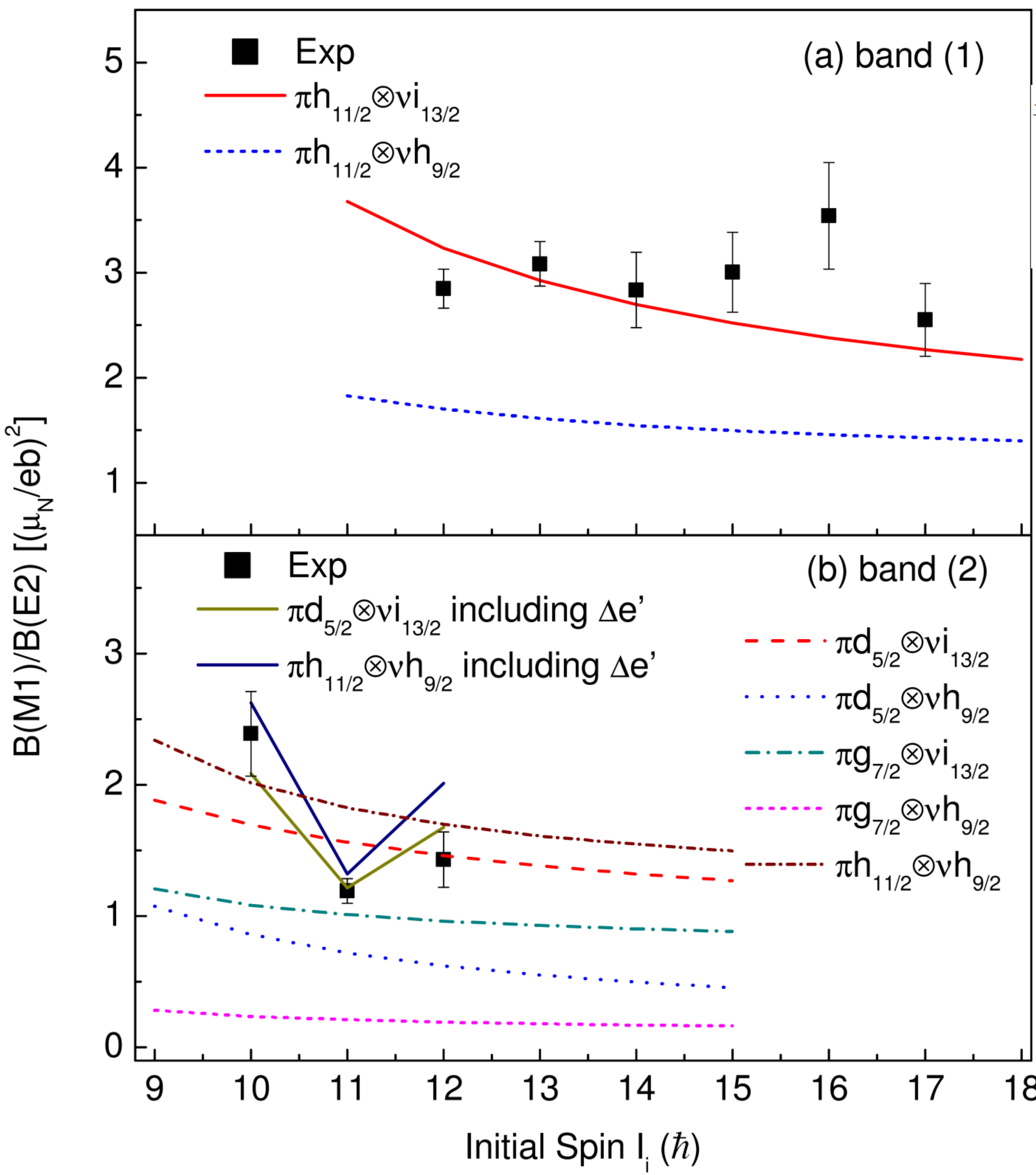
(1)
(2)
(18−)
(17−)
(16−)
(15−)
(14−)
(13−)
(12−)
(11−)
(10−)
(9−)
(14+)
(13+)
(12+)
(11+)
(10+)
(9+)
(8+)
(7+)
358
734
376
714
338
691
353
649
296
597
301
526
225
437
212
(333)
121
398
331
773
(423)
350
705
355
672
317
584
267
514
247
126
110
176
122
68
(47)
54
75
Counts
(a)
(b)
Re X-ray
68+Re X-ray
121+122
E$_\gamma$ (keV)


2.5
2.0
1.5
1.0
0.5
DCO
0
100
200
300
400
500
600
700
800
E (keV)

\Proton single particle levels : Universal Woods–Saxon potential




\Neutron single particle levels : Universal Woods–Saxon potential
Single–particle Energy (MeV)
β2
126
82
3p1/2
2f5/2
3p3/2
1i13/2
1h9/2
2f7/2
1/2[501]
3/2[501]
5/2[503]
13/2[606]
3/2[512]
9/2[505]
11/2[615]
1/2[510]
1/2[651]
7/2[503]
9/2[624]
7/2[514]
5/2[512]
7/2[633]
1/2[521]
3/2[651]
5/2[642]
5/2[523]
3/2[521]
1/2[660]
1/2[530]
3/2[532]
1/2[541]
–6
–8
–10
–12
–14
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35



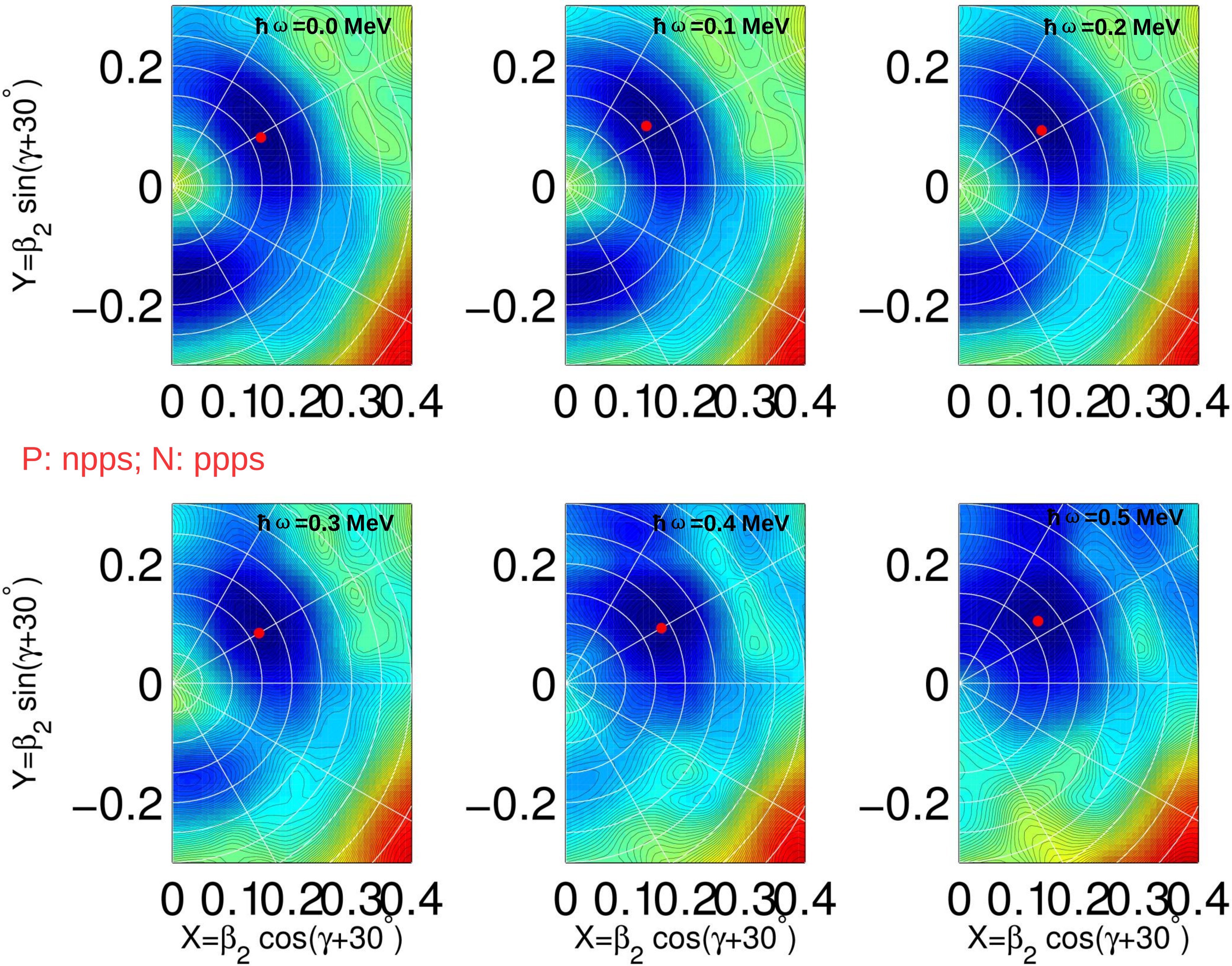
Theo.

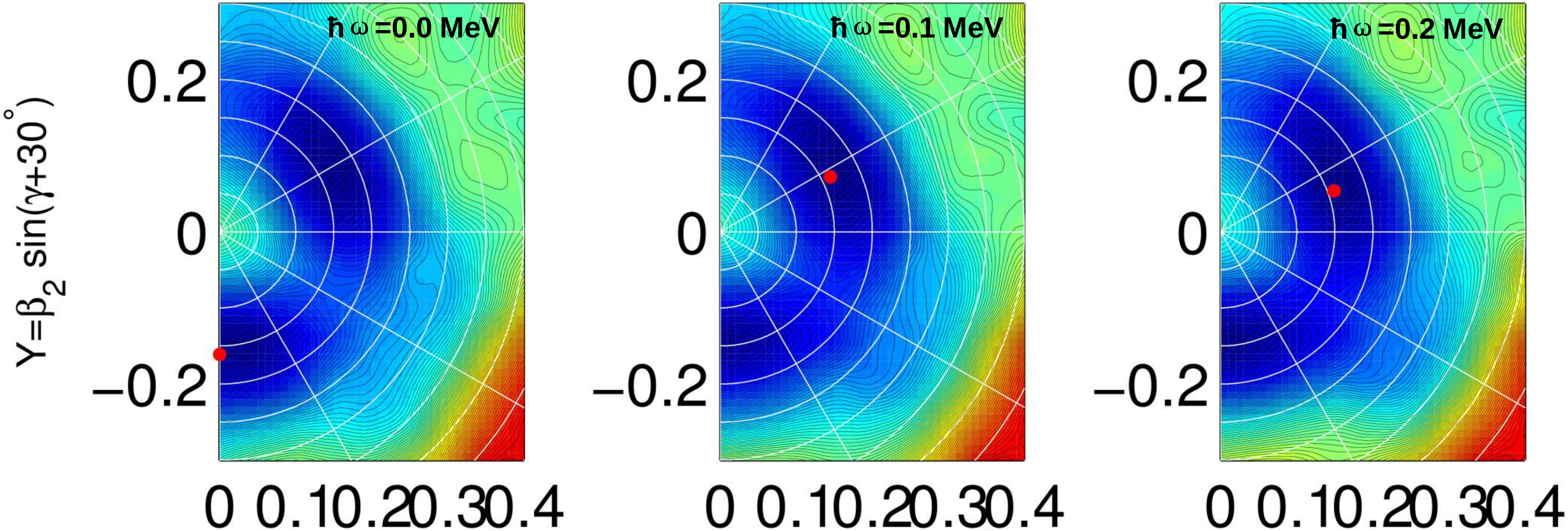
$$\frac{B(M1; I \to I-1)}{B(E2; I \to I-2)} = \frac{12}{5Q_0^2 cos^2(\gamma + 30°)}[1 - \frac{K^2}{(I-1/2)^2}]^{-2}\frac{K^2}{I^2} \times [(g_1 - g_R)(\sqrt{I^2 - K^2} - i_1)(1 \pm \frac{\Delta e'}{\hbar\omega}) - (g_2 - g_R)i_2]^2$$

Semiclassical model of Dönau and Frauendorf

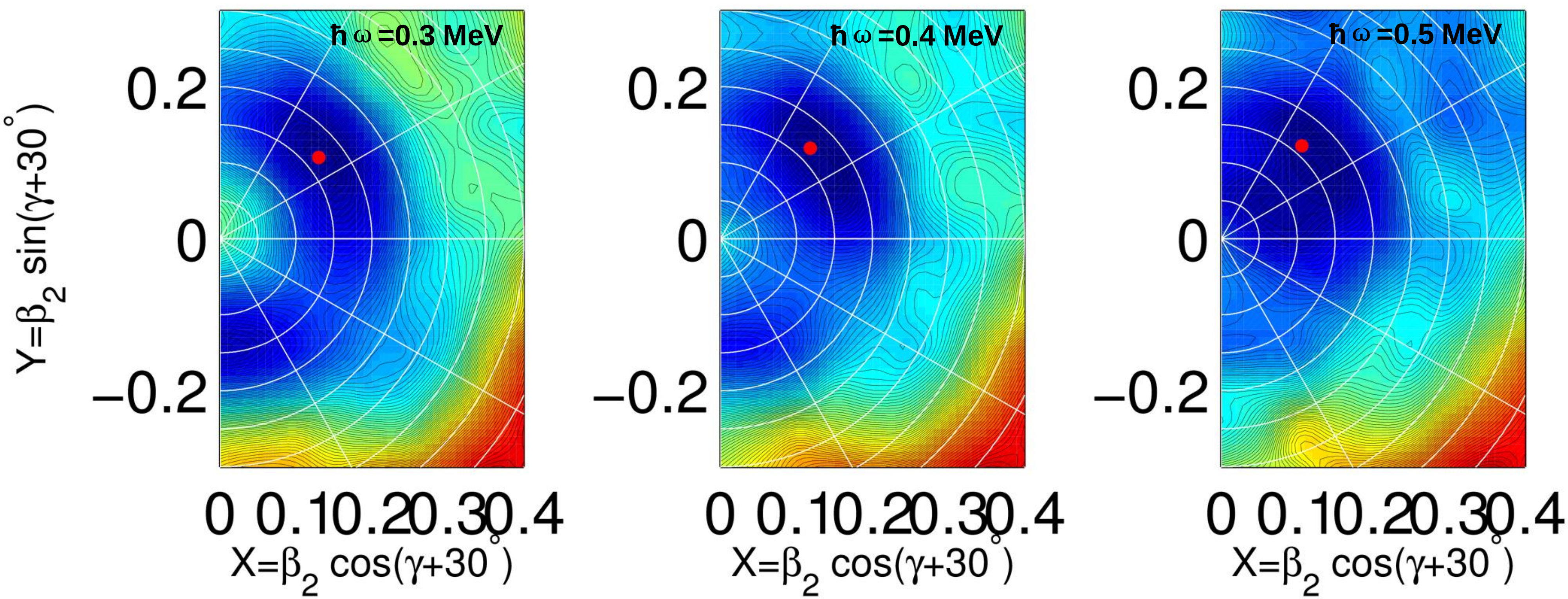
Exp.

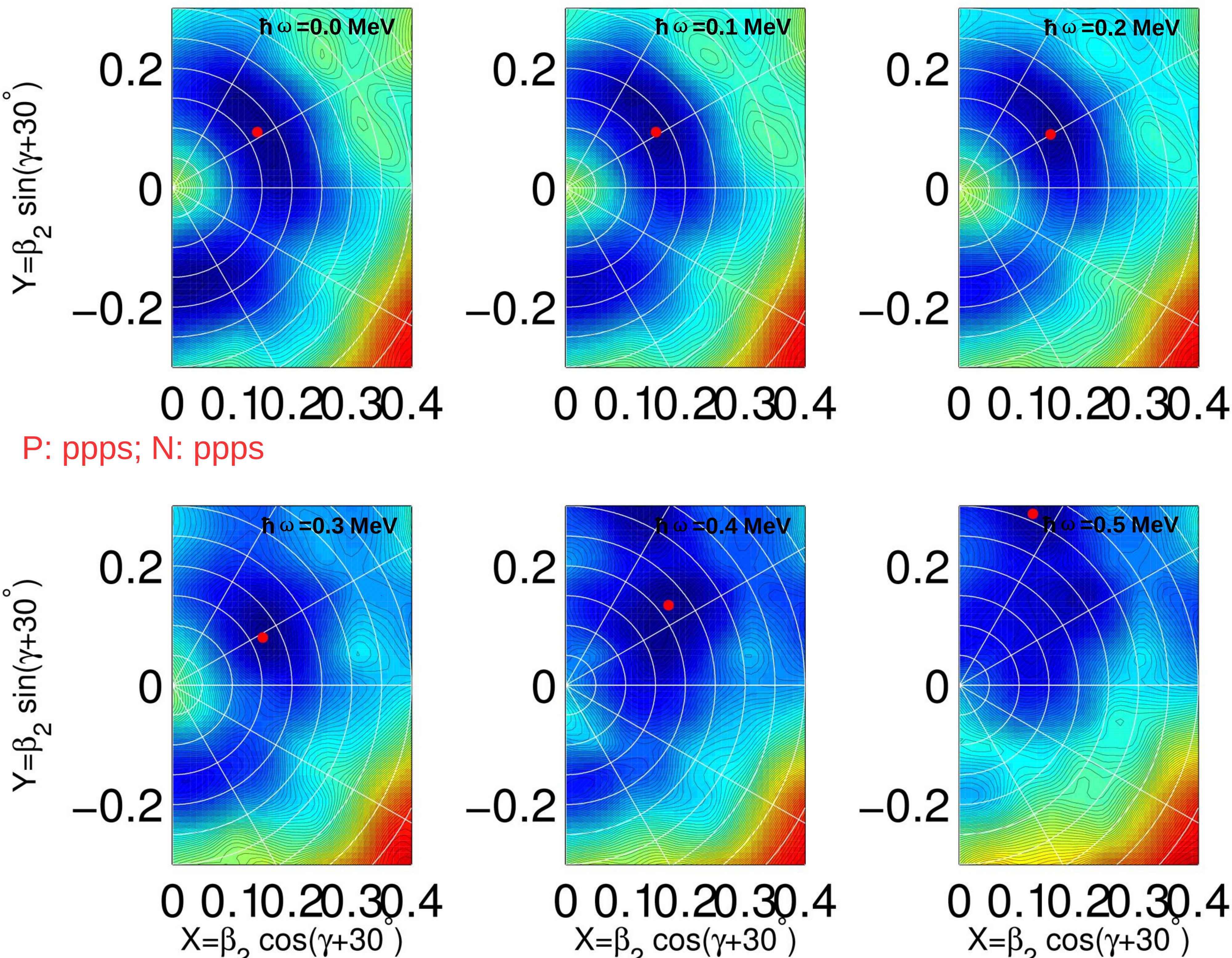
$$\frac{B(M1; I \to I-1)}{B(E2 : I \to I-2)} = 0.697\frac{1}{\lambda}\frac{E_\gamma^5(E2)}{E_\gamma^3(M1)}\frac{1}{1+\delta^2}[\frac{\mu_N^2}{e^2b^2}]$$

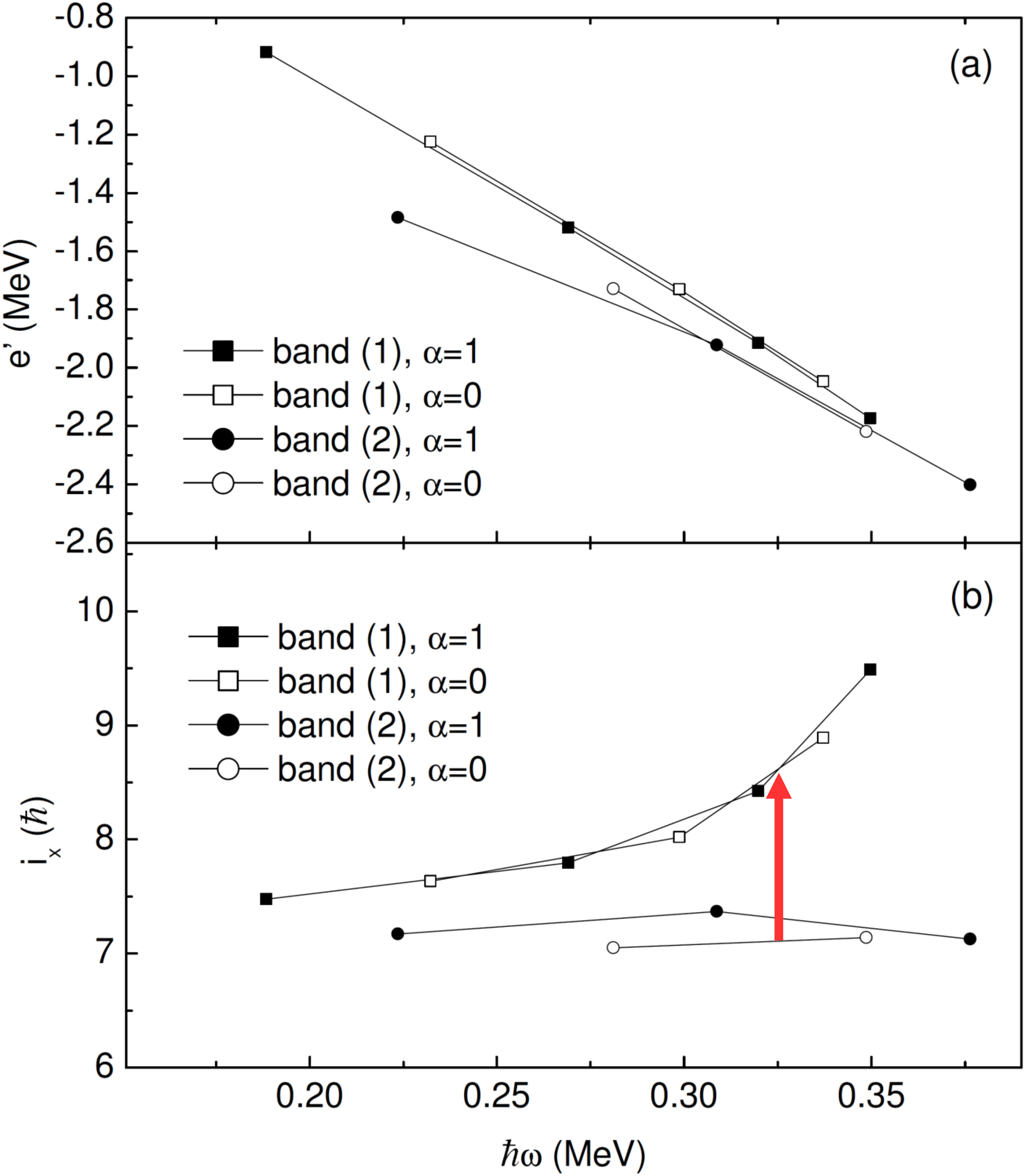

ħω =0.0 MeV
ħω =0.1 MeV
ħω =0.2 MeV
P: npps; N: ppps
ħω =0.3 MeV
ħω =0.4 MeV
ħω =0.5 MeV
Y=β2 sin(γ+30°)
X=β2 cos(γ+30°)
0.2
0
−0.2
0 0.1 0.2 0.3 0.4


ħω =0.0 MeV
ħω =0.1 MeV
ħω =0.2 MeV
Y=β2 sin(γ+30°)
0.2
0
−0.2
0 0.10.20.30.4

P: npns; N: npps


ħω =0.3 MeV
ħω =0.4 MeV
ħω =0.5 MeV
Y=β2 sin(γ+30°)
0.2
0
−0.2
0 0.10.20.30.4
X=β2 cos(γ+30°)


ħω =0.0 MeV
ħω =0.1 MeV
ħω =0.2 MeV
ħω =0.3 MeV
ħω =0.4 MeV
ħω =0.5 MeV
Y=β2 sin(γ+30°)
X=β2 cos(γ+30°)
0.2
0
−0.2
0 0.1 0.2 0.3 0.4
P: ppps; N: ppps



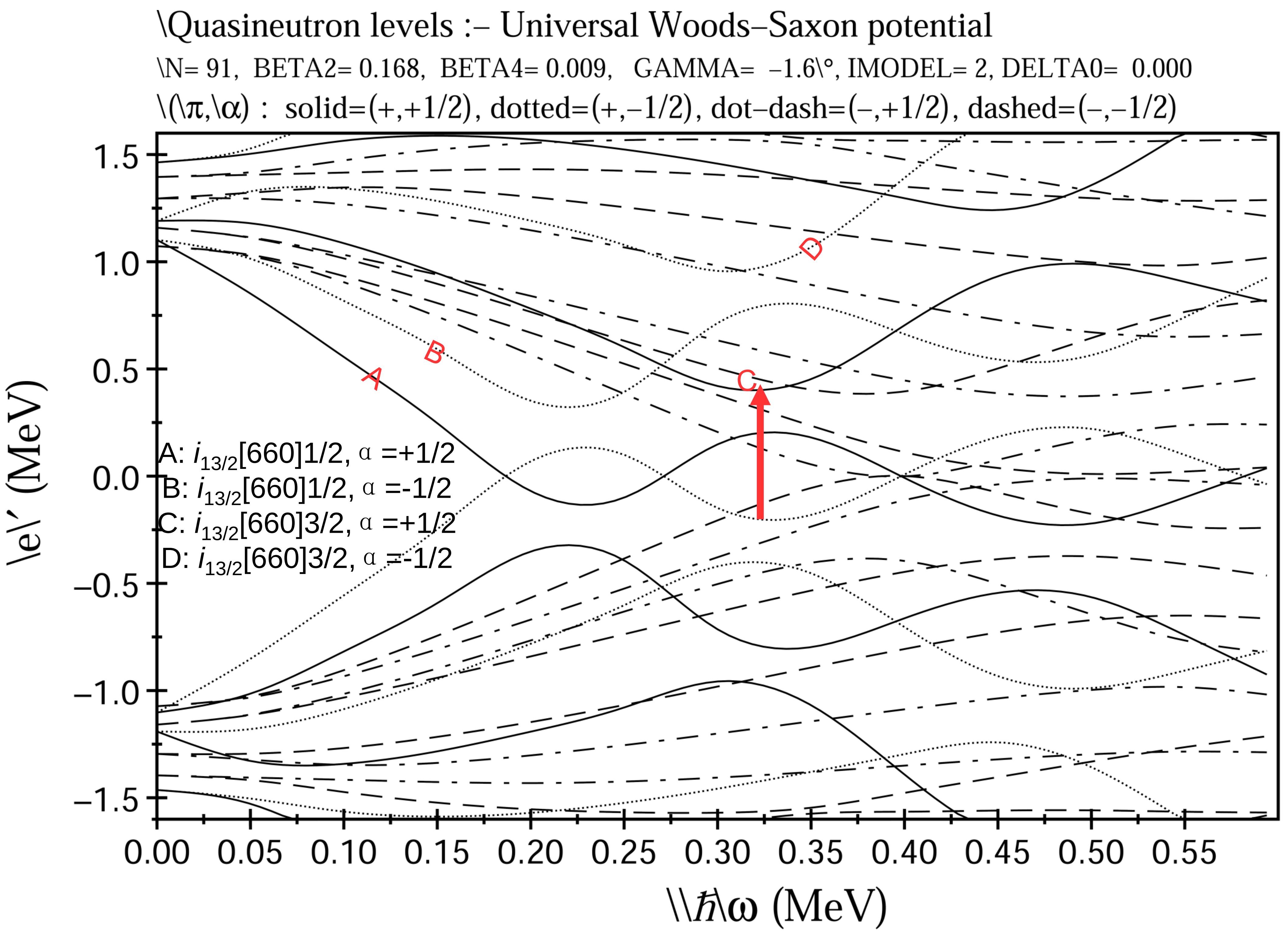
Harris Parameters:

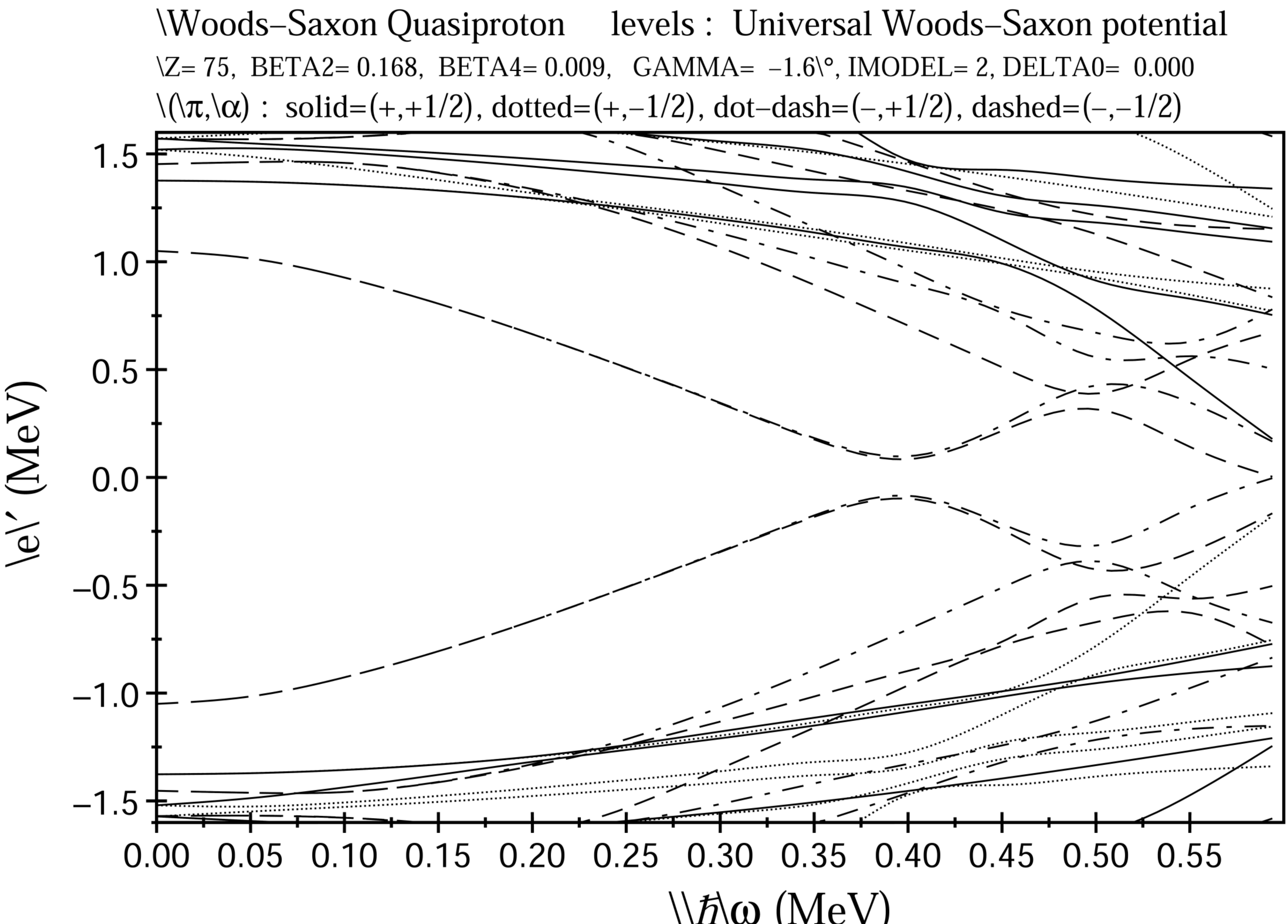
Band 1

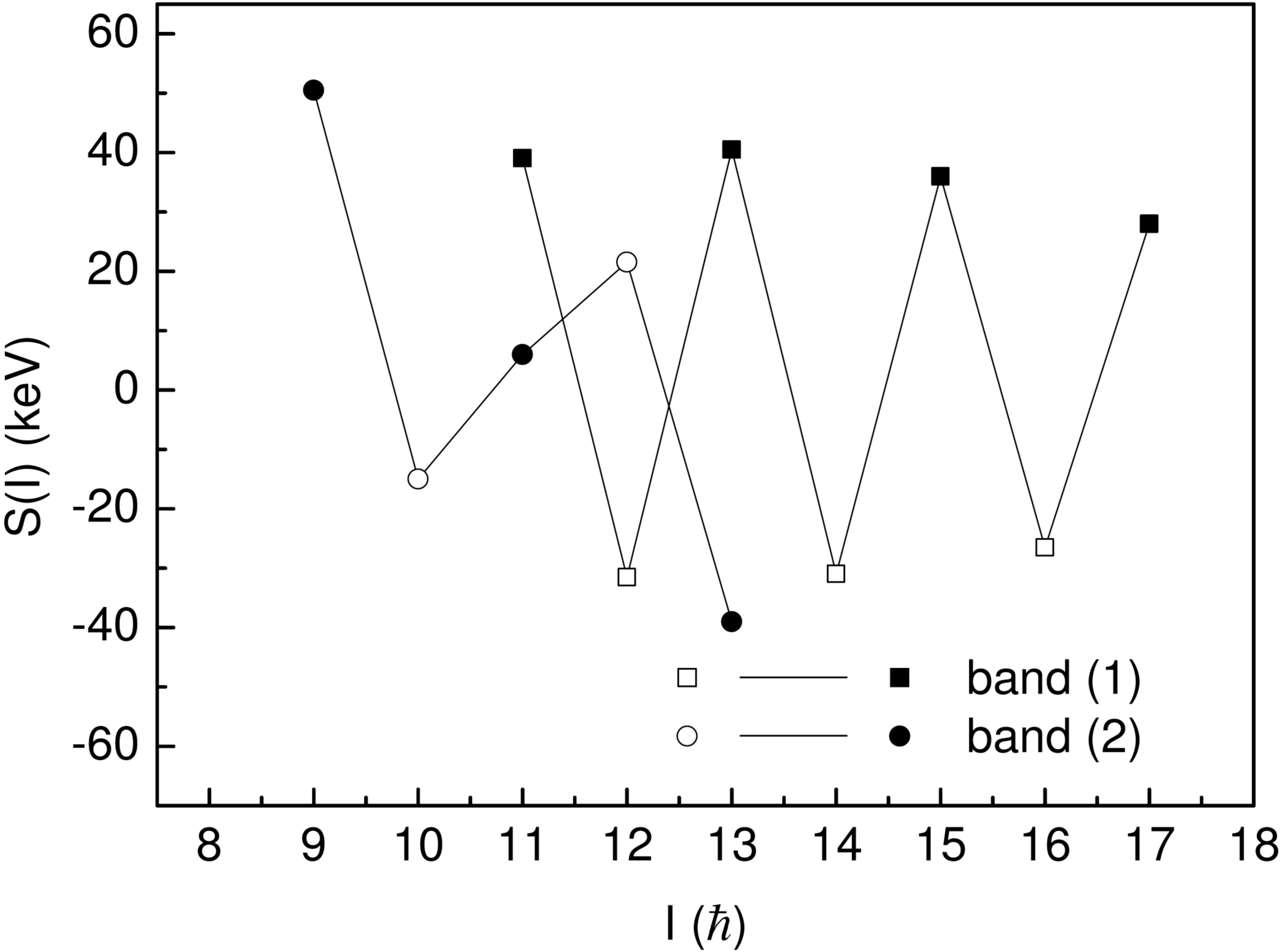
J_0=13 $\hbar^2$MeV^{-1},
J_1=64 $\hbar^4$MeV^{-3}

Band 2

J_0=4 $\hbar^2$MeV^{-1},
J_1=85 $\hbar^4$MeV^{-3}


\Quasineutron levels :– Universal Woods–Saxon potential
\N= 91, BETA2= 0.168, BETA4= 0.009, GAMMA= –1.6\°, IMODEL= 2, DELTA0= 0.000
\(\π,\α) : solid=(+,+1/2), dotted=(+,–1/2), dot–dash=(–,+1/2), dashed=(–,–1/2)
A: $i_{13/2}$[660]1/2, α =+1/2
B: $i_{13/2}$[660]1/2, α =-1/2
C: $i_{13/2}$[660]3/2, α =+1/2
D: $i_{13/2}$[660]3/2, α =-1/2
A
B
C
D
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
\e\′ (MeV)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
\\ℏ\ω (MeV)


\Woods–Saxon Quasiproton levels : Universal Woods–Saxon potential
\Z= 75, BETA2= 0.168, BETA4= 0.009, GAMMA= –1.6\°, IMODEL= 2, DELTA0= 0.000
\(\π,\α) : solid=(+,+1/2), dotted=(+,–1/2), dot–dash=(–,+1/2), dashed=(–,–1/2)
\e\′ (MeV)
1.5
1.0
0.5
0.0
–0.5
–1.0
–1.5
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
0.50
0.55
\\ℏ\ω (MeV)



60
40
20
0
-20
-40
-60
S(I) (keV)
8
9
10
11
12
13
14
15
16
17
18
I (ħ)
band (1)
band (2)

Zhang Y. H, *et al*, CPL 22, (2005) 2788

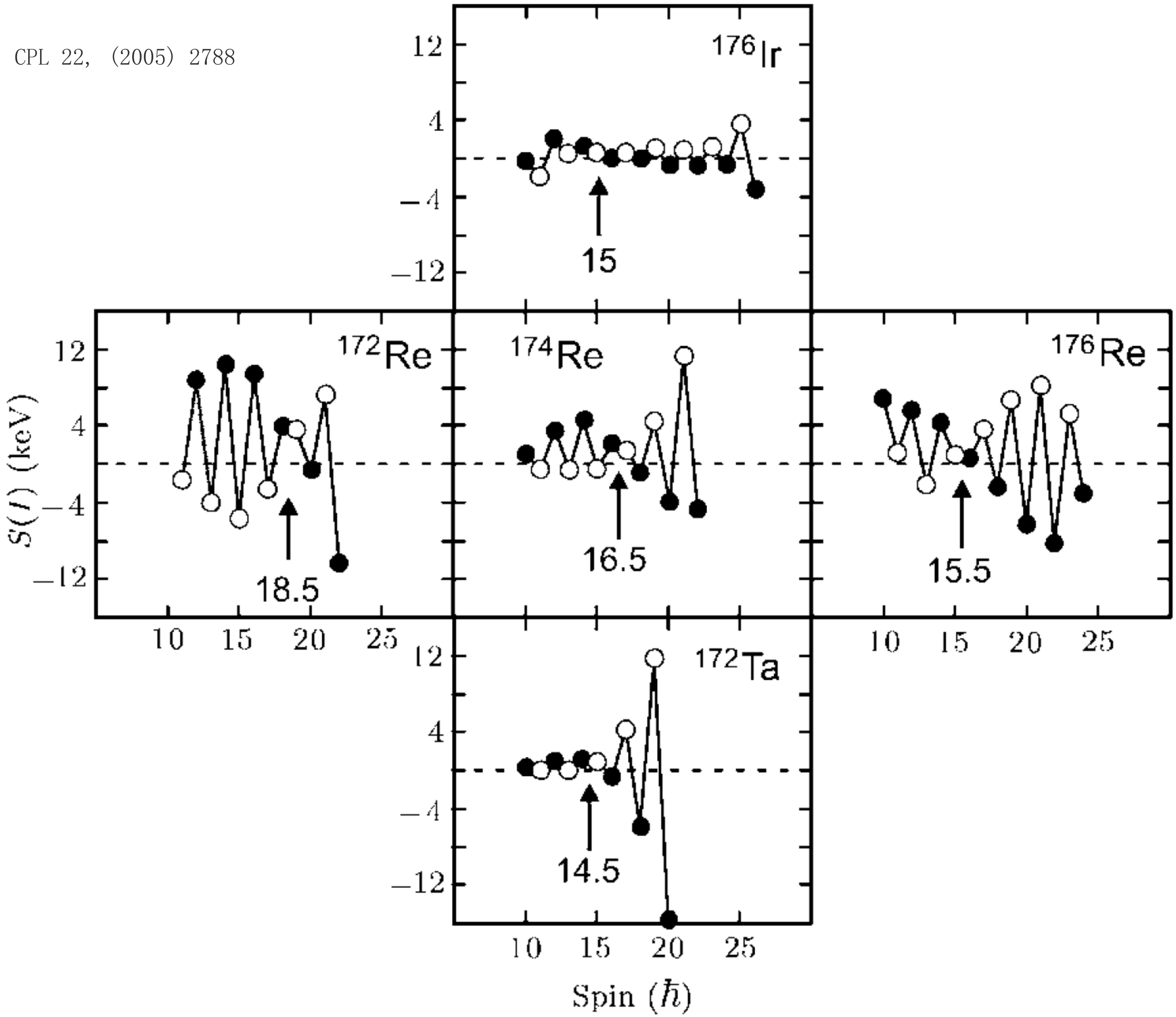


Fig. 4. Behaviour of signature splitting $S(I)$ versus I for band 1 and the $\pi h_{11/2} \otimes i_{13/2}$ bands in adjacent odd–odd nuclei. The arrow indicates the signature inversion spin.

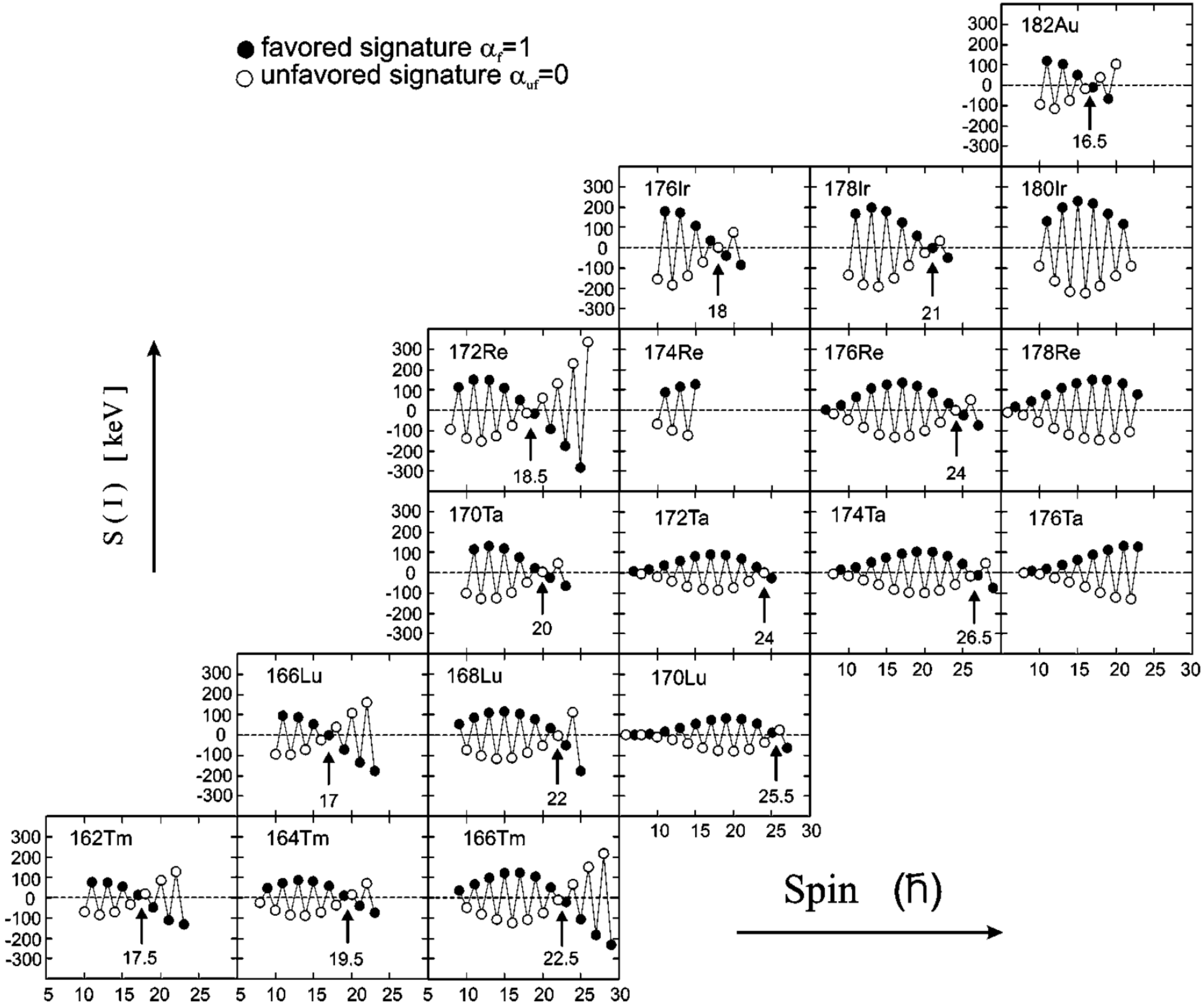


FIG. 9. A compilation of signature inversion for the $\pi h_{9/2} \otimes \nu i_{13/2}$ bands in A=160~180 mass region. The filled (opened) symbols correspond to the levels with favored signature α_f=1 (unfavored signature α_{uf}=0). The arrows indicate the signature crossing spins. The data sources are ^{182}Au [11], ^{176}Ir [10,49], ^{178}Ir [5,50], ^{180}Ir [32], ^{172}Re [this work], ^{174}Re [24], ^{176}Re [4], ^{178}Re [4,25], ^{170}Ta [41,44], ^{172}Ta [51], ^{174}Ta [13], ^{176}Ta [34], ^{166}Lu [52], ^{168}Lu [53,54], ^{170}Lu [43], ^{162,164}Tm [13], ^{166}Tm [55].

Y. H. Zhang *et al*, PRC 68, 054313 (2003)

Conclusion

- ✓ First identification of two collective bands in odd-odd ^{166}Re
- ✓ The configurations for the two bands have been tentatively assigned and the deformation has been predicted by TRS calculations
- ✓ The backbending for band (1) may originate from the $i_{13/2}$ BC crossing
- ✓ Signature splitting and inversion was found in band (1), abnormal signature splitting was found in band (2).

Conclusion

- ✓ First identification of two collective bands in odd-odd ^{166}Re
- ✓ The configurations for the two bands have been tentatively assigned and the deformation has been predicted by TRS calculations
- ✓ The backbending for band (1) may originate from the $i_{13/2}$ BC crossing
- ✓ Signature splitting observed in bands (1) and (2) in agreement with TRS calc. (small triaxial deformation)
- ✓ Signature inversion observed in band (2). This phenomenon lacks consistent theoretical interpretation!!!

Thank you !