A PSDPF interaction to describe negative parity states in sd shell nuclei

- *M. BOUHELAL* — *LPAT, Université de Tébessa, Algérie*
- *F. HAAS* — *IPHC, Strasbourg*
- *E. CAURIER* — *IPHC, Strasbourg*
- *F. NOWACKI* — *IPHC, Strasbourg*

- The S-D shell nuclei
- In the 70ies and 80ies : large number of experimental studies, gamma spectroscopy, gamma decay schemes, J^{π} assignments through angular correlations, lifetime measurements using Doppler methods …
- Detailed spectroscopy for nuclei near the stability line, at low excitation energy

More recently: high spin states and also spectroscopy of neutron rich nuclei

- S-D shell nuclei and the shell model
- Large amount of data not only for the positive parity 0 ħω states but also for the negative parity intruder 1 ħω states.

- For the 0 ħω states: USD

Wildenthal in Prog. Part. Nucl. Phys. 11, 5 (1984).

- For the 1 ħω states: construction of PSDPF in Strasbourg, a long story …

The construction of the PSDPF interaction

- The aim: 0 and 1 ħω of sd shell nuclei
- The model space: ^{4}He core, the 9 p-sd-pf shells
- One jump between major shells

From PSDPF0 to PSDPFB to PSDPF

- *CKI* for the p shell
- *USDB* for the sd shell
- *SDPF-NR* for the pf shell
- *PSDT* for the cross shells p-sd
- *SDPF-NR* for the cross shells sd-pf

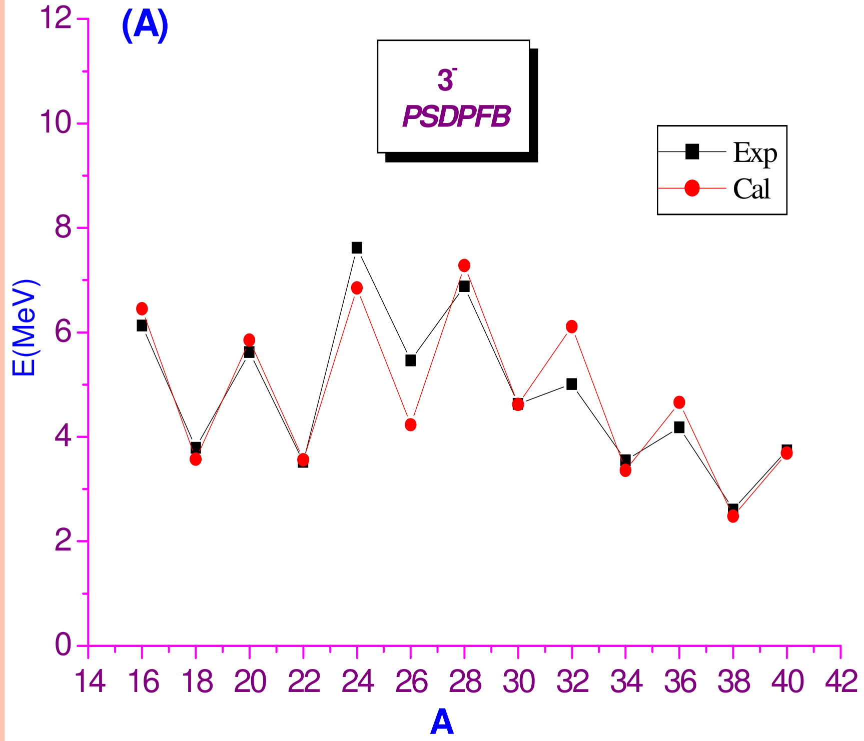
- For the p shell : SPE adopted from CKI
- For the sd and pf shells : SPE were adjusted to reproduce the 0ħω reference states in ^{17}O and ^{41}Ca
- For all TBME, the same mass dependence than in USD :

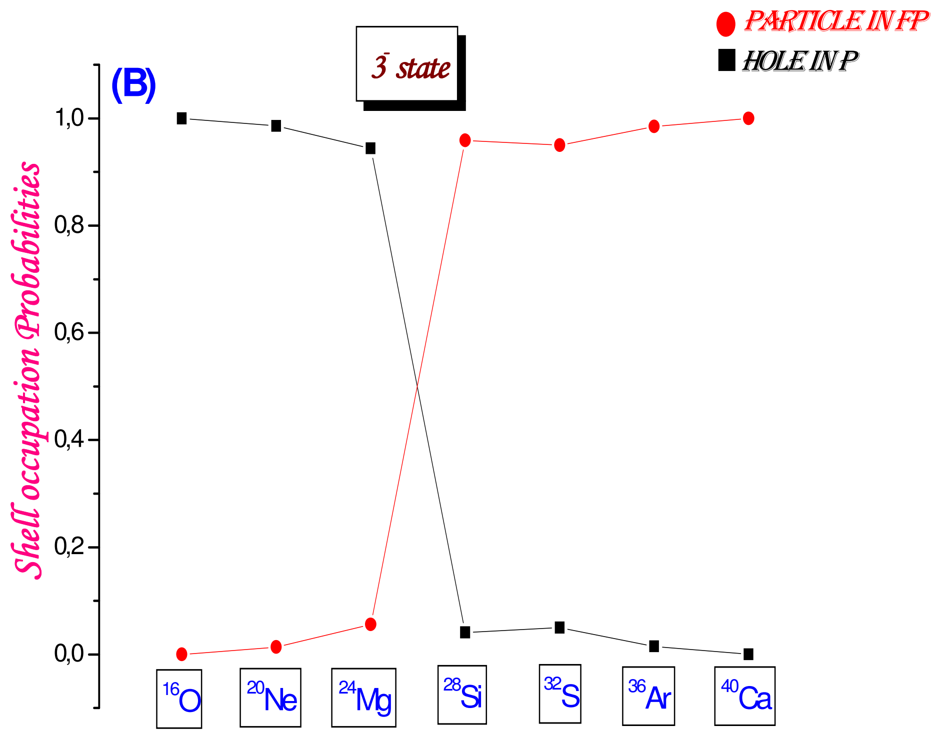
$$<V> (A) = <V> (A=18)\ (A/18)^{-0.3}$$

PSDPF0 to PSDPFB

- Cross-shell monopole parts of PSDPF0 were adjusted by « hand » to reproduce the known experimental intruder "test" levels ($J^{\pi} = 0^-$ à 6^- in N = Z nuclei and $J^{\pi} = 1/2^-$ à $13/2^-$ in N = Z + 1 nuclei)
- During this procedure, we required that the 0ħω states in ^{17}O and ^{41}Ca are unchanged, the energies of all 0ħω states throughout sd are thus kept fixed

Example of results using PSDPFB





PSDPFB to PSDPF

- Fitting procedure of the effective interaction parameters p-sd-pf, cross monopoles and multipoles
- For more details:

- *M. Bouhelal, Ph.D. thesis, University of Batna, Algeria and University of Strasbourg, France (2010).*
- *M. Bouhelal, F. Haas, E. Caurier, F. Nowacki, A. Bouldjedri, Nucl. Phys.* ***A 864****, 113 (2011).*

- In our sd data base: 475 + states; 409 – states
- First fit of the 0ħω states to "readjust" the USDB "parameters"

RMSD for PSDPF : 145 keV

RMSD for USDB : 151 keV

- Fit of the 1ħω states :

Matrices of large dimensions especially in the middle of the shell

^{28}Si with Nathan (J-scheme) : 4^+ : 15089, 4^- : 579120

Impossible to include in the fit the negative parity states of all sd nuclei.

Nuclei between Z = 10, A = 22 and Z = 14, A = 33 could not be included in the fit

Only 220 – states in the fit

Fitting procedure in two steps

- beginning of the shell :

  $p_{1/2} - d_{5/2}, s_{1/2}$ excitations
- end of the shell :

  $s_{1/2}, d_{3/2} - f_{7/2}, p_{1/2}$ excitations

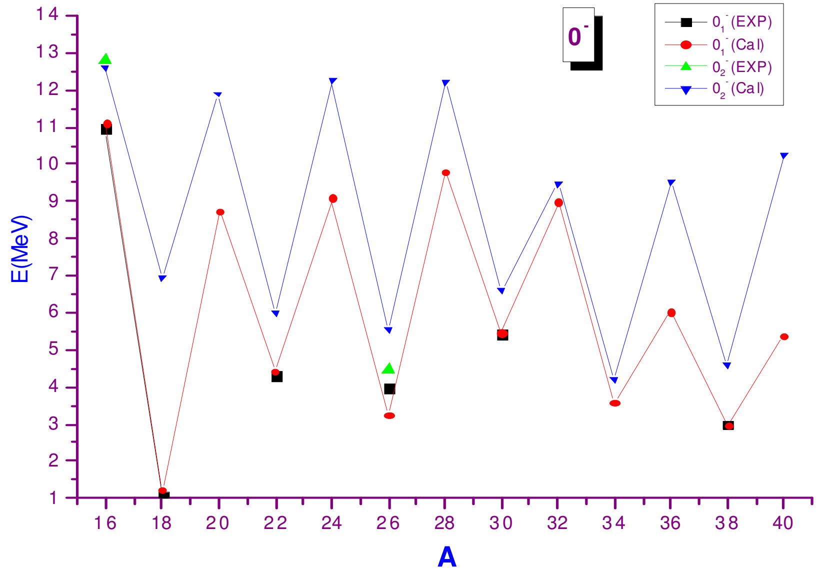
- Results: No "catastrophe" observed ….

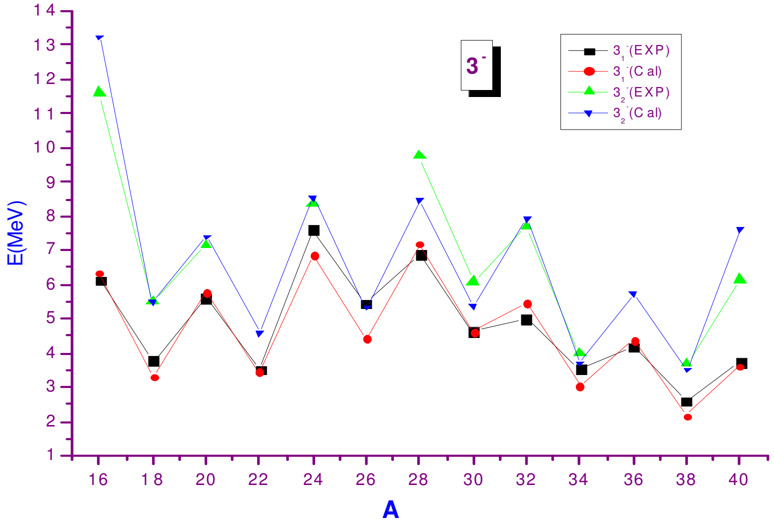
  But RMSD : 407 keV for the – states

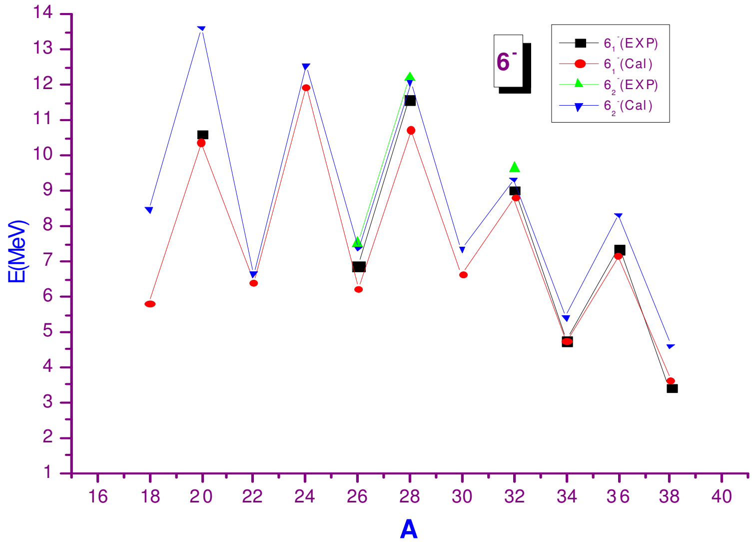
  to be compared to RMSD : 145 keV for the + states

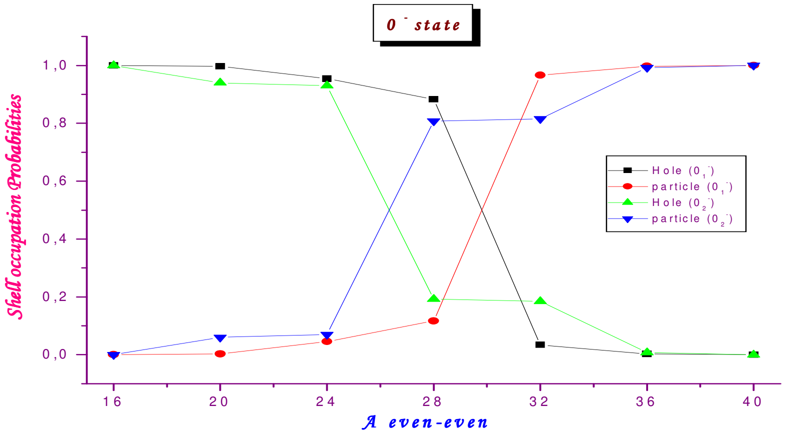
PSDPF versus Experiment

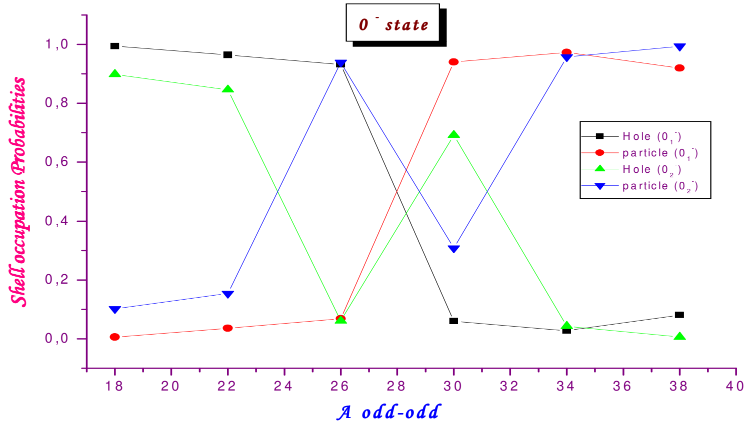
The reference states

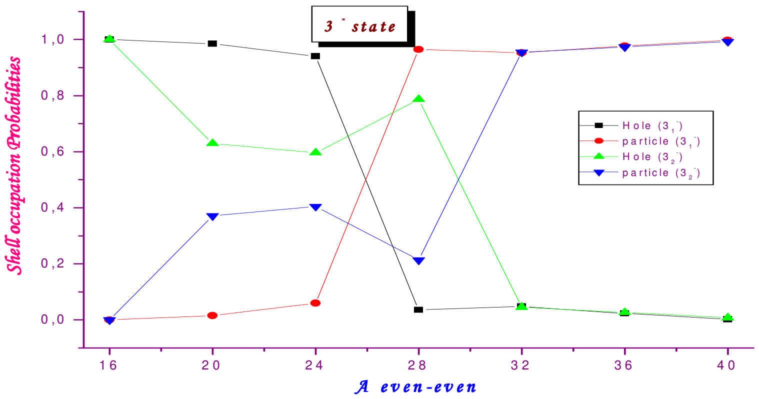


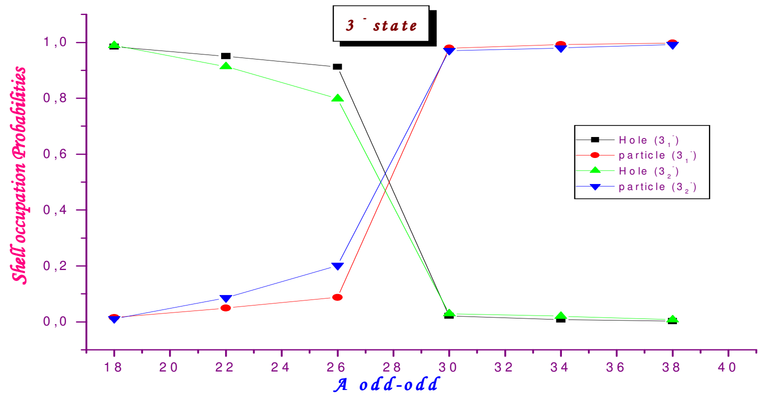


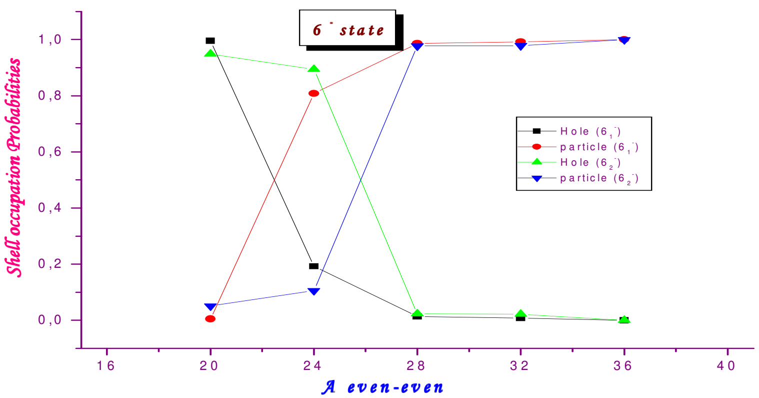


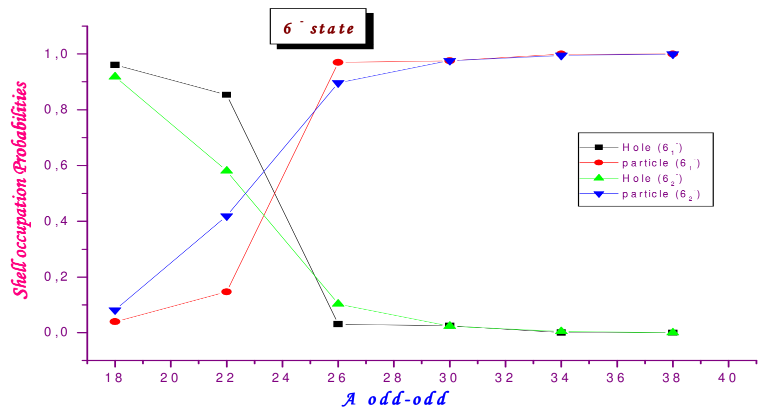

0^- state
Shell occupation Probabilities
A even-even
Hole (0_1^-)
particle (0_1^-)
Hole (0_2^-)
particle (0_2^-)

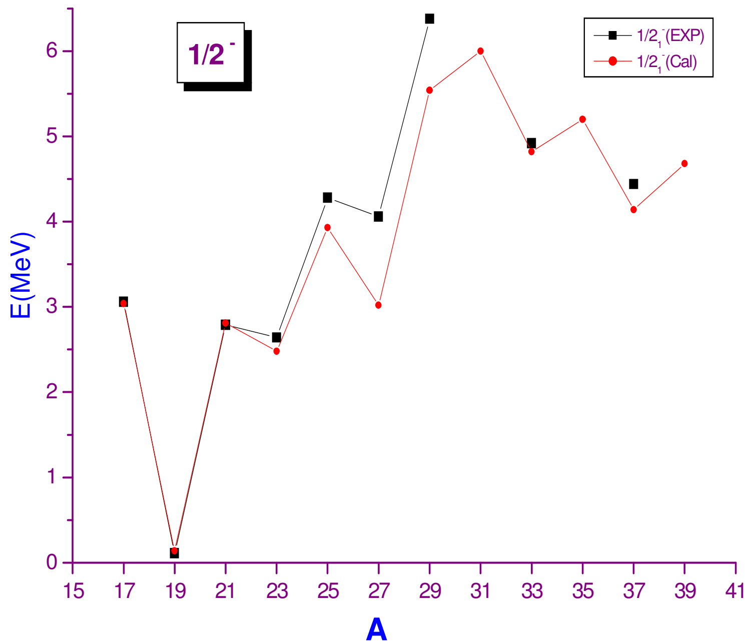

0^- state
Shell occupation Probabilities
A odd-odd
Hole (0_1^-)
particle (0_1^-)
Hole (0_2^-)
particle (0_2^-)

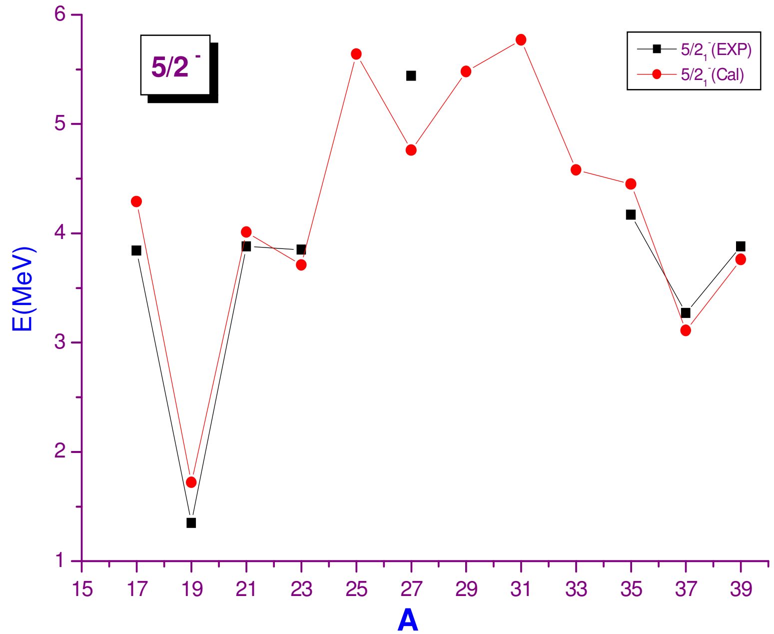

3^- state
Shell occupation Probabilities
A even-even
Hole (3_1^-)
particle (3_1^-)
Hole (3_2^-)
particle (3_2^-)

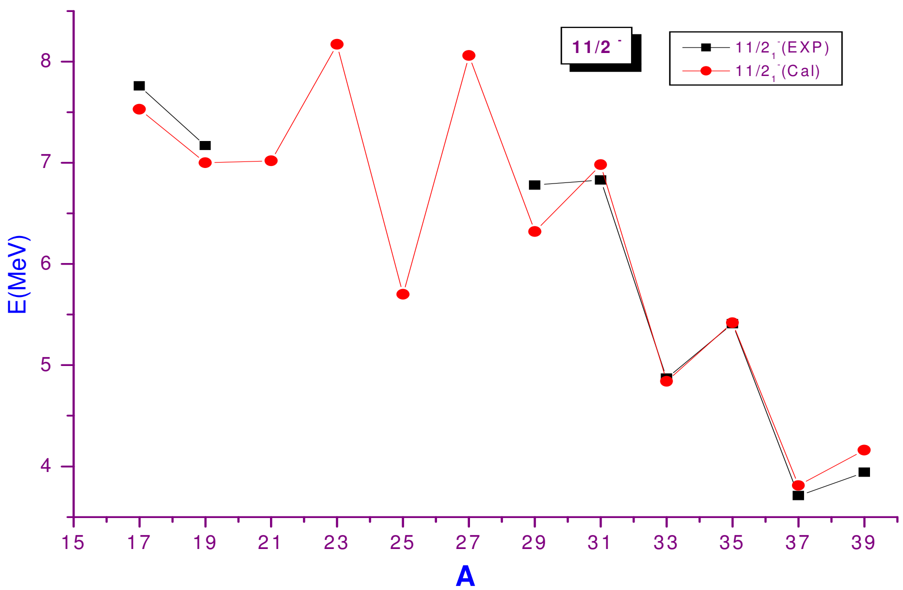

3^- state
Shell occupation Probabilities
A odd-odd
Hole (3_1^-)
particle (3_1^-)
Hole (3_2^-)
particle (3_2^-)

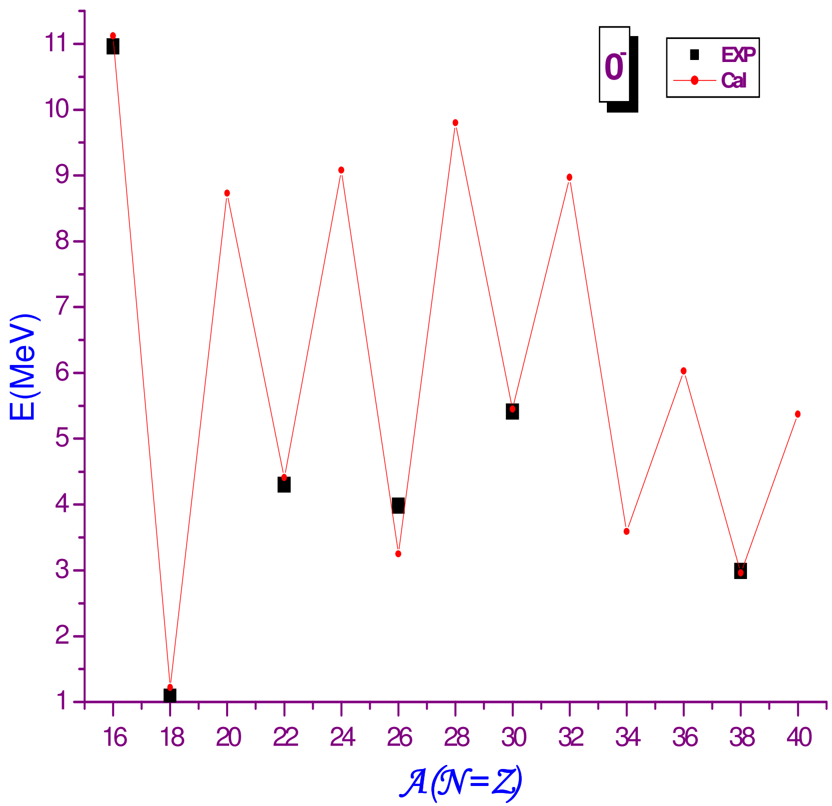

6^- state
Shell occupation Probabilities
A even-even
Hole (6_1^-)
particle (6_1^-)
Hole (6_2^-)
particle (6_2^-)


6^- state
Shell occupation Probabilities
A odd-odd
Hole (6_1^-)
particle (6_1^-)
Hole (6_2^-)
particle (6_2^-)

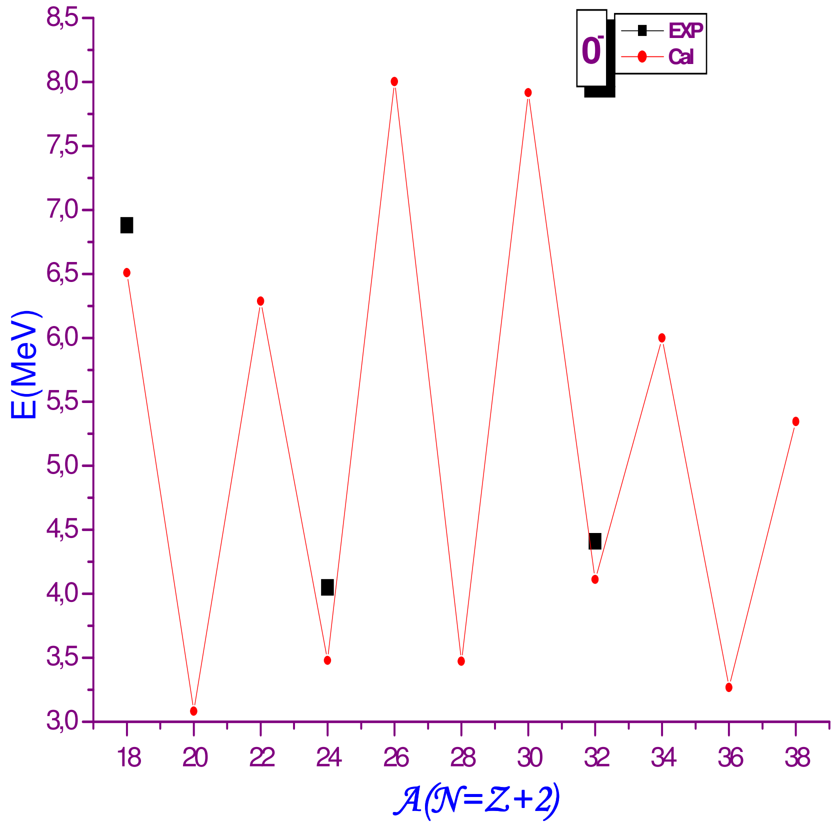

1/2 -
1/2,-(EXP)
1/2,-(Cal)
E(MeV)
A


5/2 -
5/2,-(EXP)
5/2,-(Cal)
E(MeV)
A


11/2 -
11/2,-(EXP)
11/2,-(Cal)
E(MeV)
A

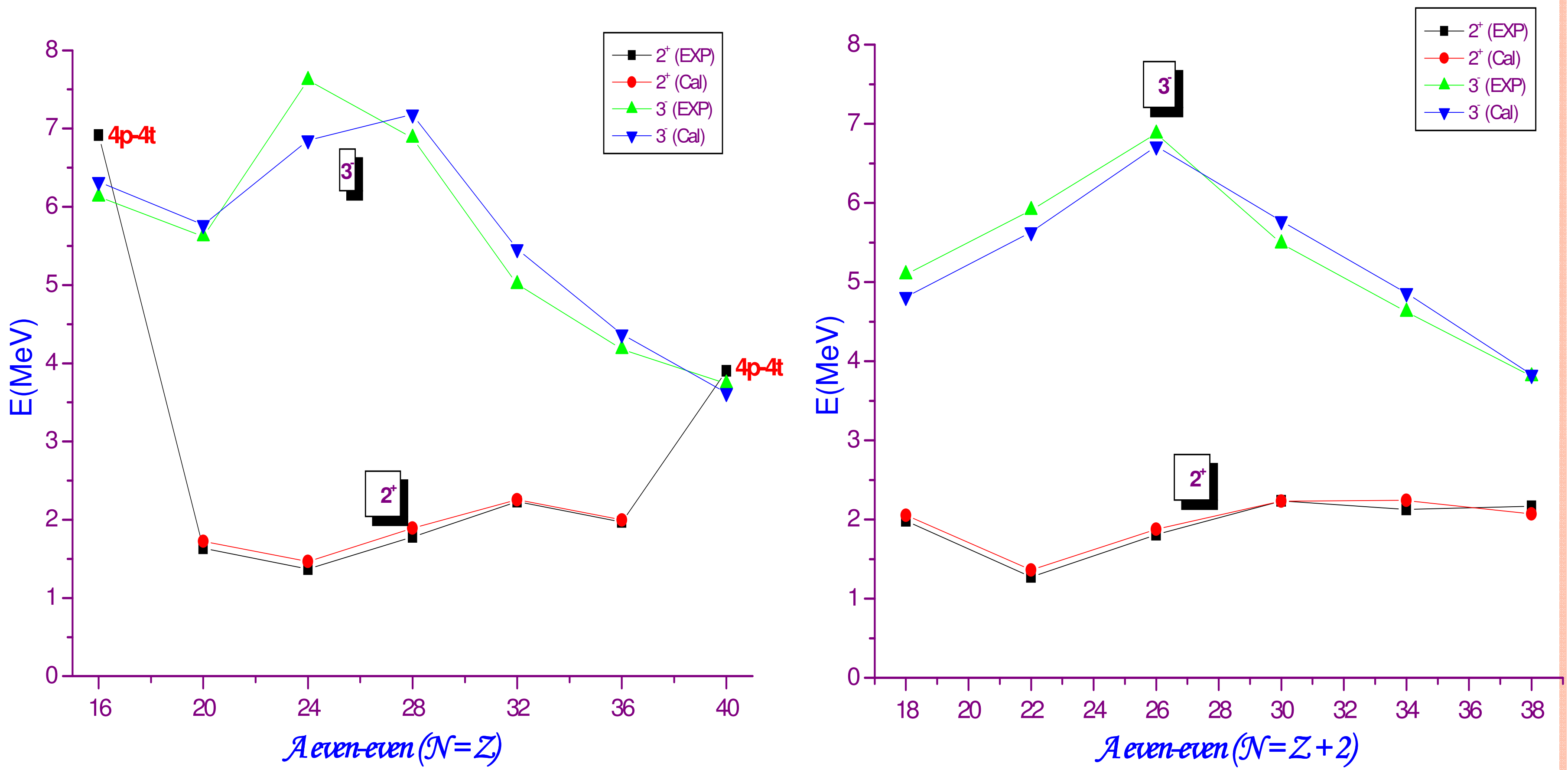


0⁻
EXP
Cal
E(MeV)
A(N=Z)

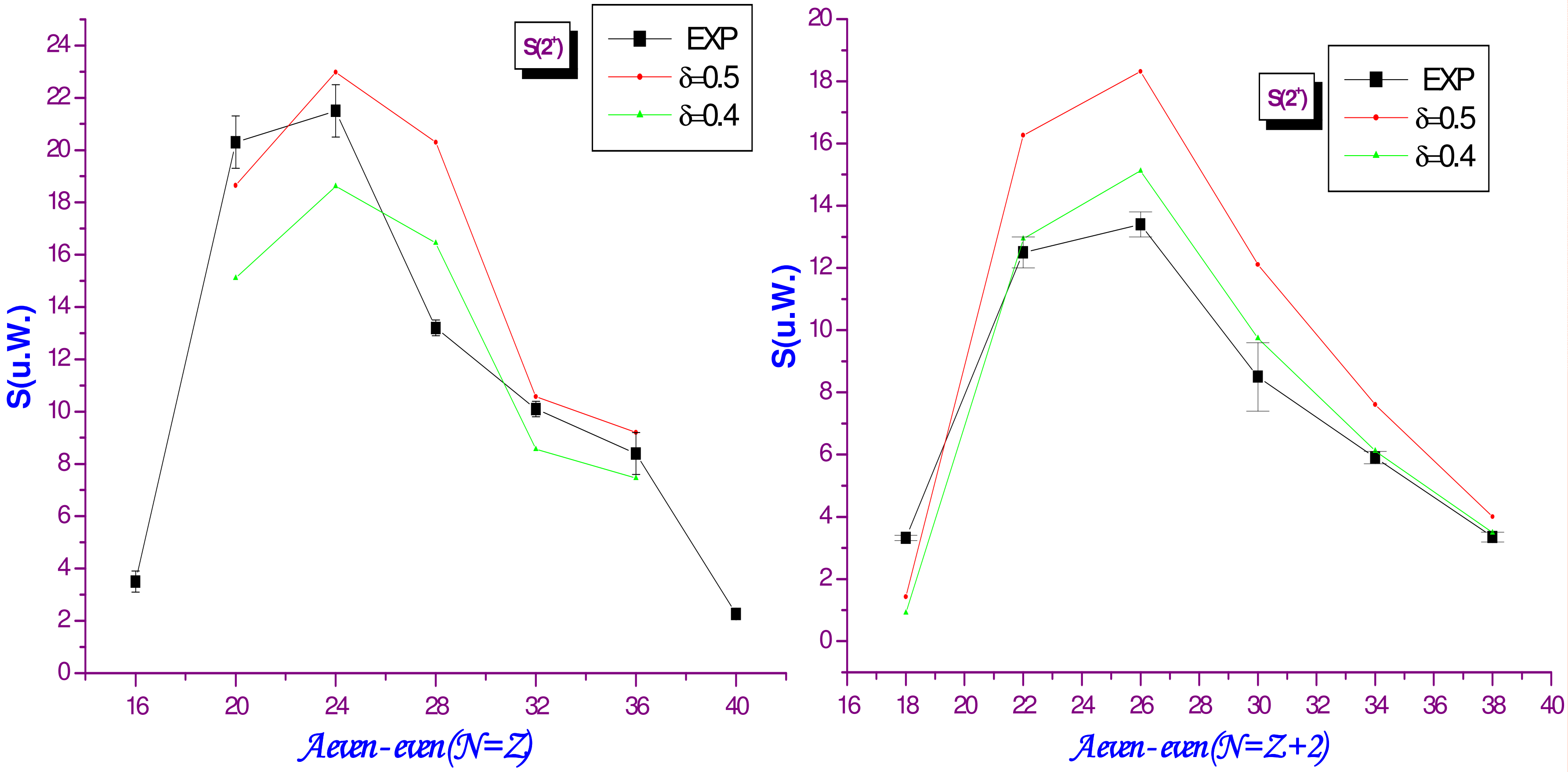


0⁻
EXP
Cal
E(MeV)
A(N=Z+2)

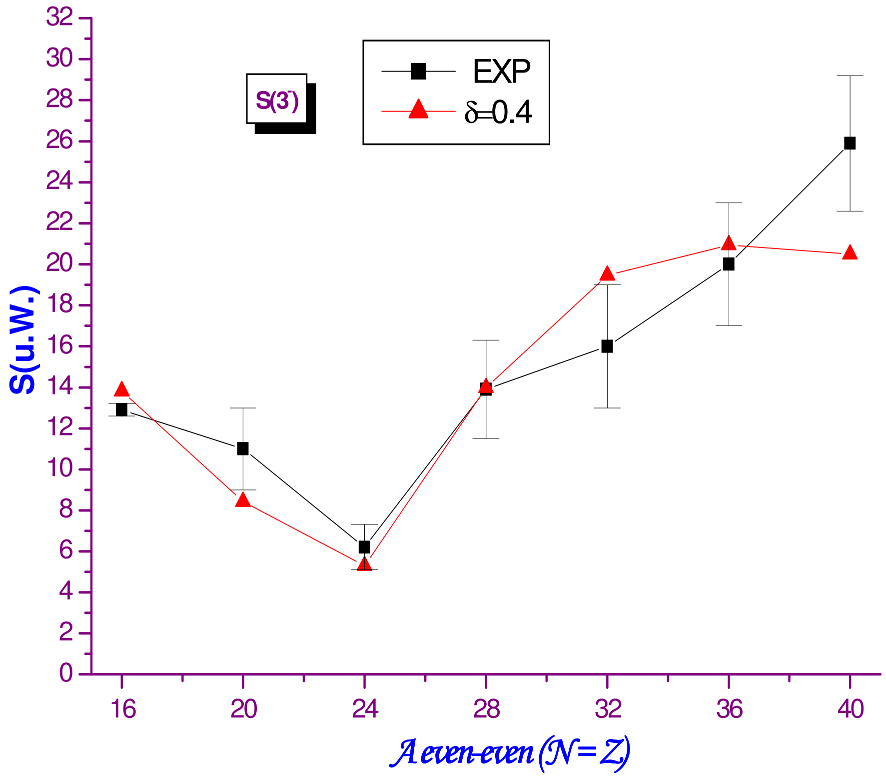
2^+ and 3^- states in sd even-even nuclei

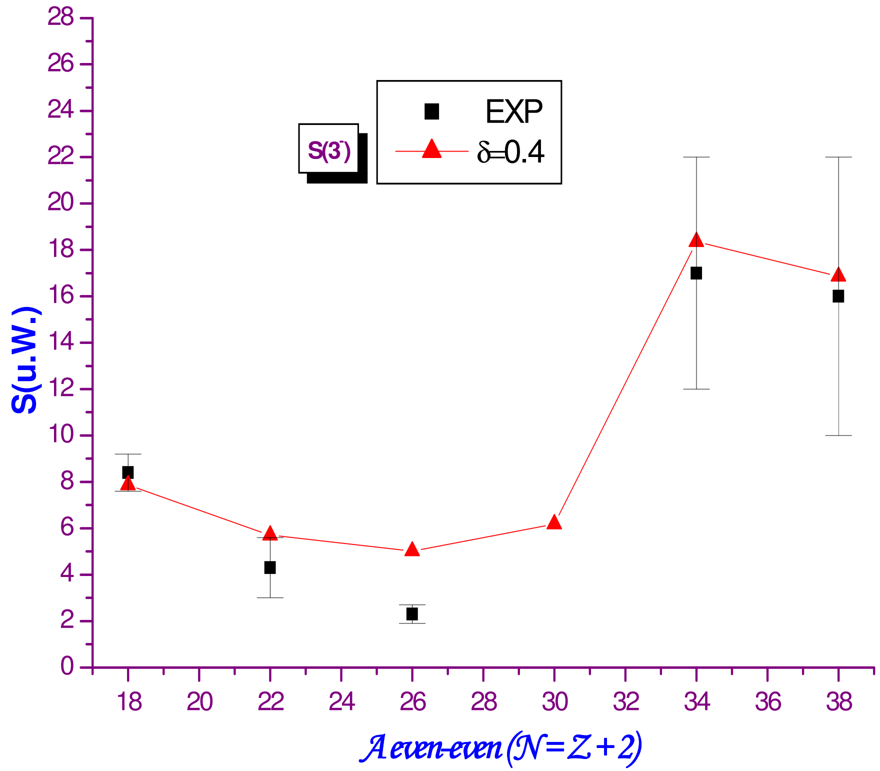


E2 transition strength $2_1^+ \rightarrow 0^+$



E3 transition strength $3_1^- \to 0^+$





- **PSDPF has been used to describe :**

❖ The N = 20 nuclei with Z = 14-16

(*M. BOUHELAL et al, Eur. Phys. J.* **A 42**, (2009) 529)

❖ ^{36}S Spectrum

(*M.BOUHELAL et al, AIP Conf.Proc.1165 (2009) 61)*

❖ ^{22}Na and ^{23}Na Spectra and EMT properties

(*M. BOUHELAL et al, AIP Conf.Proc.1444 (2012) 375)*

- **PSDPF calculations have been compared to new experimental data obtained for :**

❖ ^{33}Si Spectroscopy

(*Z. M. Wang et al., Phys. Rev.* ***C 81****, (2010) 064301*)

❖ ^{24}Mg Spectroscopy

(*P. Marley et al., Phys. Rev.* ***C 84****, (2011) 044332*)

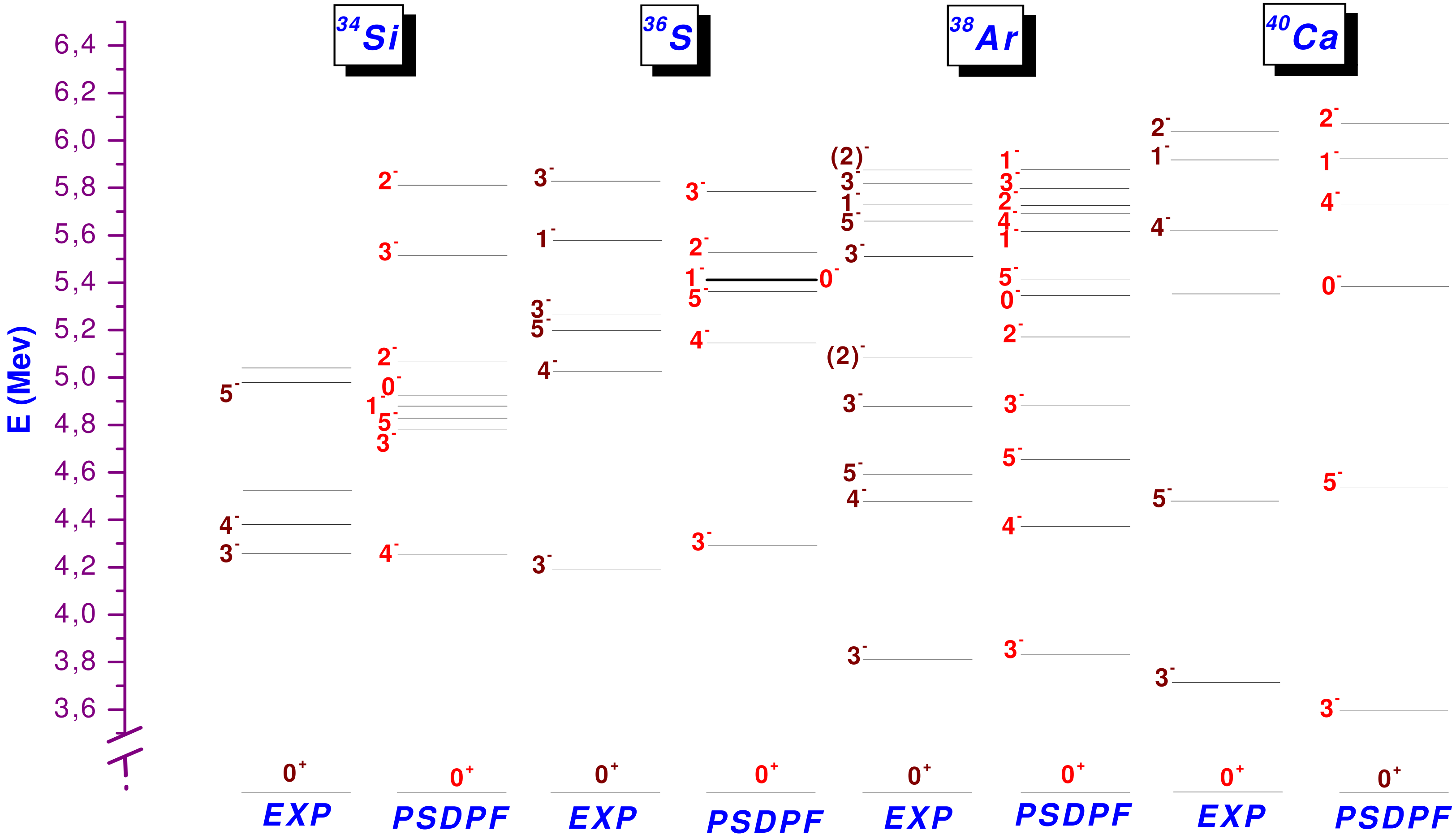
❖ ^{36}Cl Spectroscopy

(*S. Aydin et al., Phys. Rev.* ***C 86,*** *(2012) 024320)*

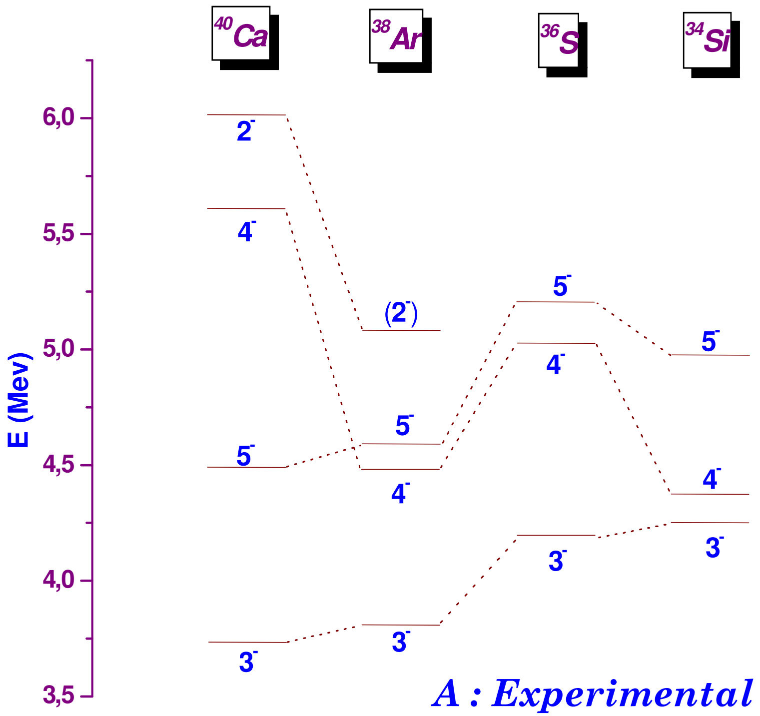
❖ ^{22}Ne and ^{22}Mg mirror nuclei

(*M.BOUHELAL et al, Next presentation)*

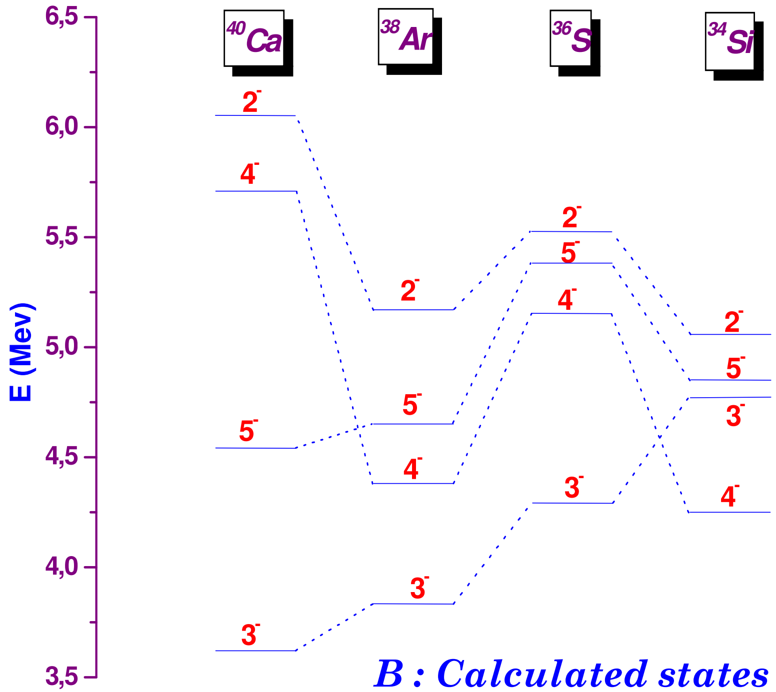
N = 20 isotones



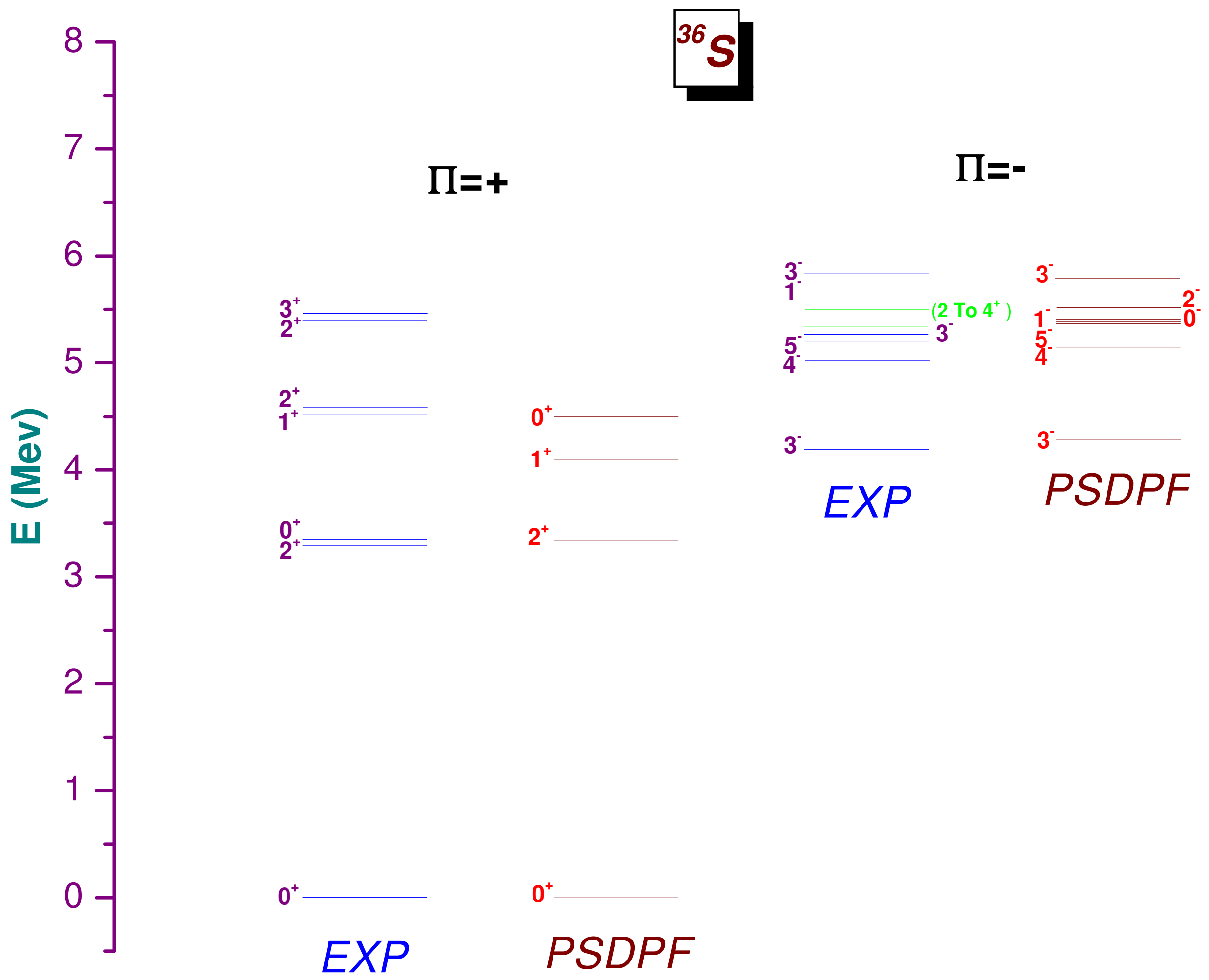
3^-_1, 4^-_1 and 5^-_1 states membres of the $\upsilon(d_{3/2}^{-1}f_{7/2}^{1})$ multiplet



A : Experimental states

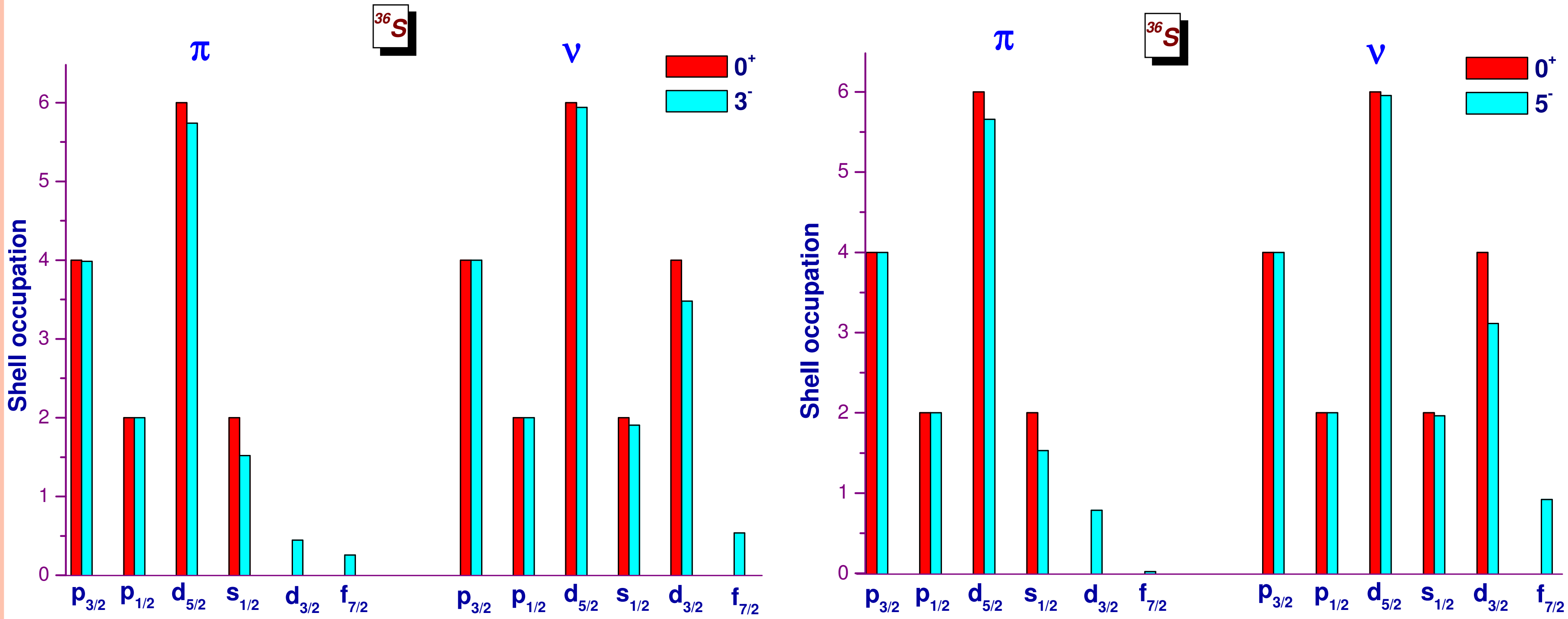


B : Calculated states

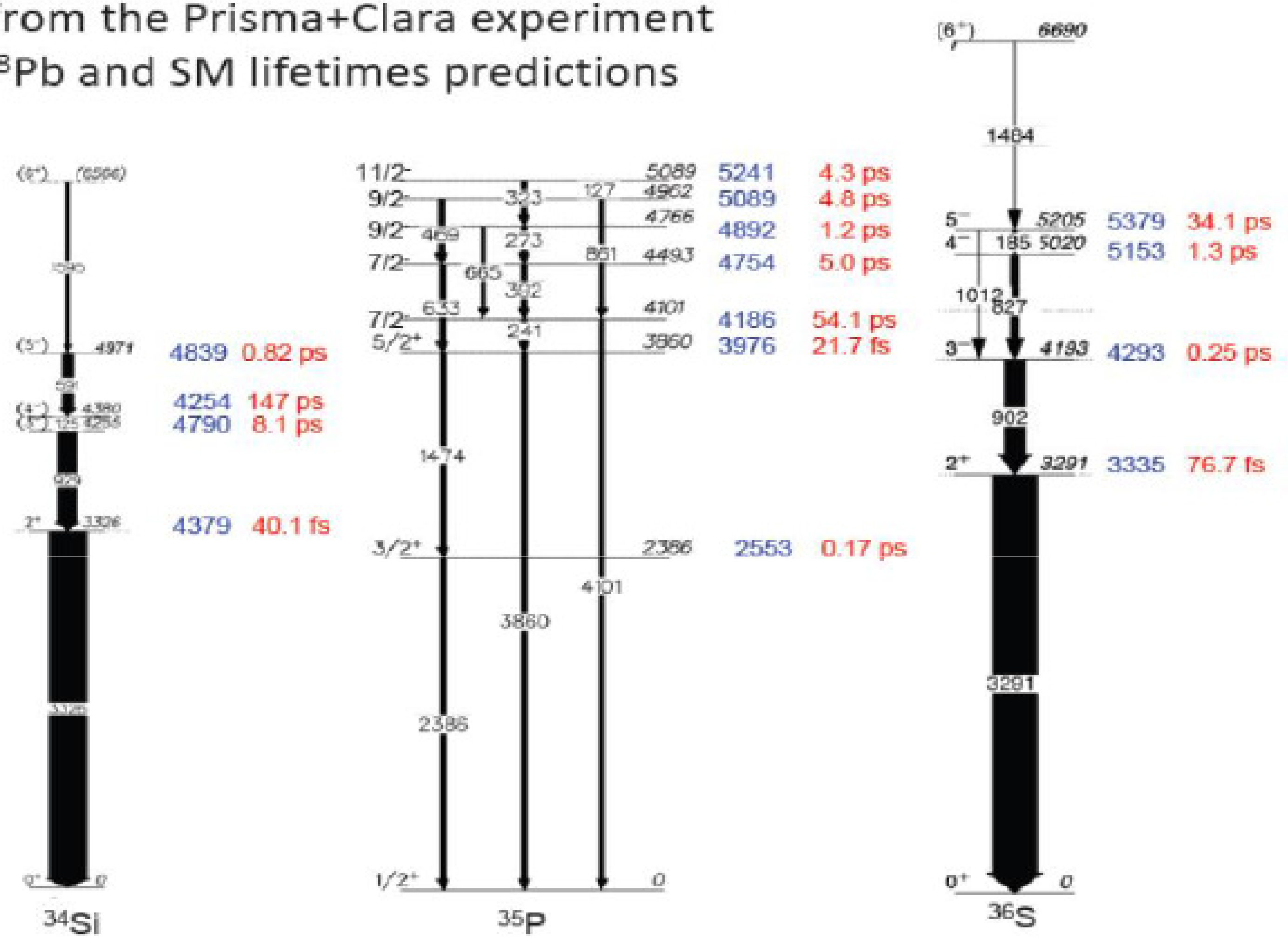


36S
Π=+
Π=-
E (Mev)
0
1
2
3
4
5
6
7
8
EXP
PSDPF
EXP
PSDPF
(2 To 4+)

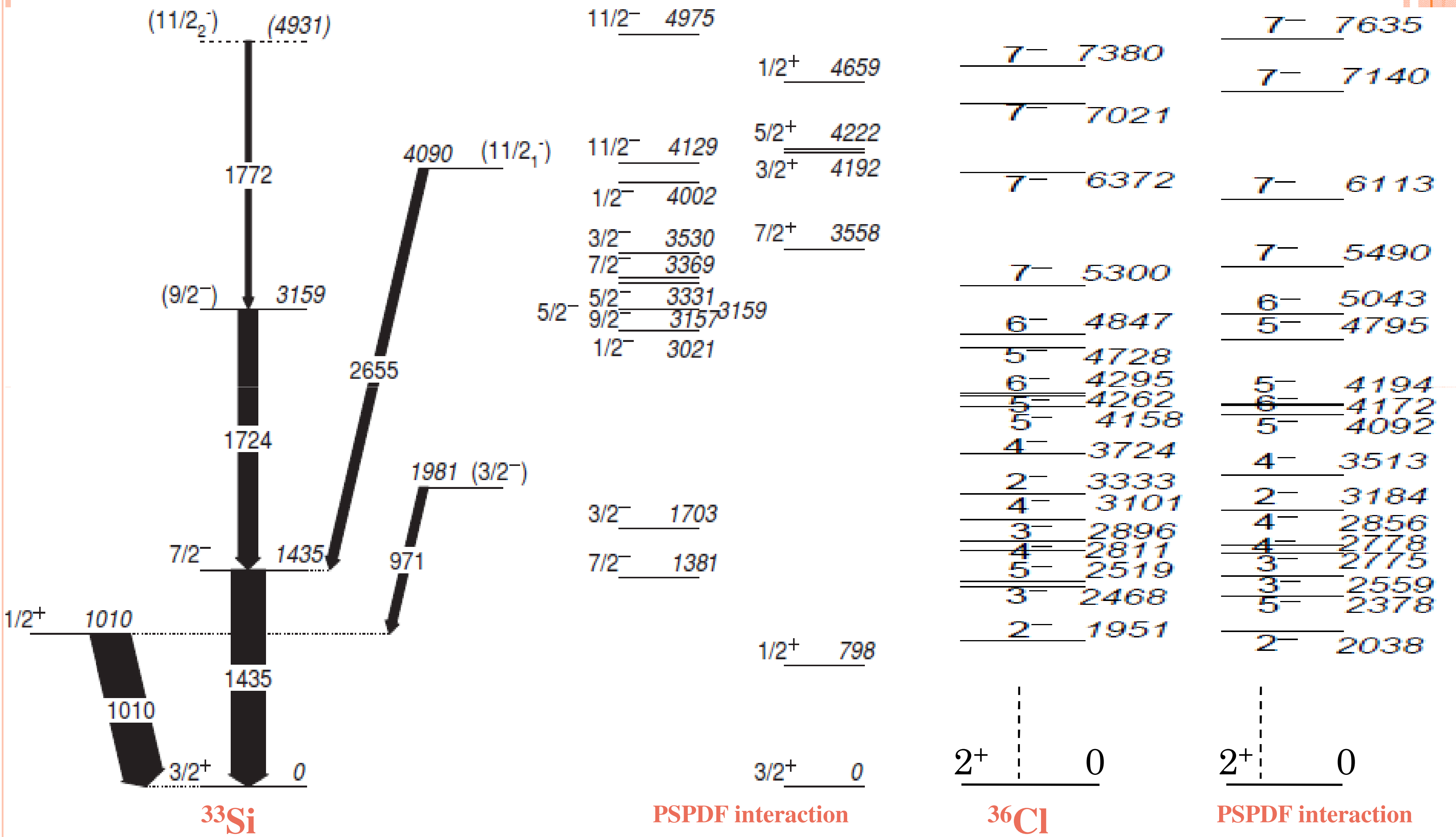
3^-_1, 4^-_1 and 5^-_1 states membres of the $\upsilon(d_{3/2}^{-1}f_{7/2}^{1})$ multiplet



Results from the Prisma+Clara experiment
^{36}S on ^{208}Pb and SM lifetimes predictions



N = 19 isotones



$^{30}P_{15}$

RMSD = 146 keV

^{30}P Ex	^{30}P J^{π}	PSDPF Ex	PSDPF J^{π}	^{30}Si Ex	^{30}Si J^{π}
0	1^+	0	1^+_1		
677	0^+	721	0^+_1	677	0^+
709	1^+	713	1^+_2		
1454	2^+	1766	2^+_1		
1973	3^+	2012	3^+_1		
2539	(3^+)	2351	3^+_2		
2724	2^+	2570	2^+_2		
2839	(3^+)	3030	3^+_3		
2937	2^+	2955	2^+_3	2912	2^+
3019	1^+	3085	1^+_3		
3304	(1^+)				
3734	(1^+)	3782	1^+_4		
3836	2^+	3734	2^+_4		
3929	3^+	4091	3^+_4		
4144	2^-	4228	2^-_1		

^{30}P Ex	^{30}P J^{π}	PSDPF Ex	PSDPF J^{π}	^{30}Si Ex	^{30}Si J^{π}
4183	2^+	4177	2^+_5	4176	2^+
4232	4^-	4144	4^-_1		
4299	4^+	4445	4^+_1		
4344	5^+	4337	5^+_1		
4423	2^+	4542	2^+_6		
4468	0^+	4781	0^+_2	4465	0^+
4502	1^+	4765	1^+_5	4447	1^+
4626	3^-	4619	3^-_1		
4736	3^+	4941	3^+_5		
4926	$(3^-,5^-)$	5143	5^-_1		
4937	1	4984	1^-_1		
4941	(1^+)	4896	1^+_6		
4951					
		6449	6^-_1		
		7142	6^+_1		
		8255	7^-_1		
		8500	7^+_1		

$^{31}P_{16}$

RMSD = 181 keV

^{31}P Ex	^{31}P $2J^{\pi}$	PSDPF Ex	PSDPF $2J^{\pi}_{n}$	^{31}P Ex	^{31}P $2J^{\pi}$	PSDPF Ex	PSDPF $2J^{\pi}_{n}$
0	1^+	0	1^+_1	5256	1^+	5567	1^+_4
1265	3^+	1199	3^+_1	5343	9^+	5345	9^+_1
2234	5^+	2212	5^+_1	5529	7^+ (5^+)	5471	7^+_3
3134	1^+	3260	1^+_2	5559	3^+	5814	3^+_5
3295	5^+	3303	5^+_2	5672	5	5771	5^-_1
3415	7^+	3438	7^+_1	5773	$(5,7^+)$	5778	7^+_4
3506	3^+	3429	3^+_2	5892	9^+	5778	9^+_2
4190	5^+	4081	5^+_3	5988	$(3,5)^+$	5804	5^+_6
4261	3^+	4335	3^+_3	6048	7^+	6014	7^+_5
4431	7^-	4786	7^-_1	6080	9^+	6060	9^+_3
4594	3^+	4846	3^+_4			6333	9^-_1
4634	7^+	4791	7^+_2			6439	11^+_1
4783	5^+	4718	5^+_4			6980	11^-_1
5015	3	5604	3^-_1			8709	13^-_1
5015	1	5090	1^+_3			8925	13^+_1
5115	5^+	5213	5^+_5			10015	15^-_1
						11424	15^+_1

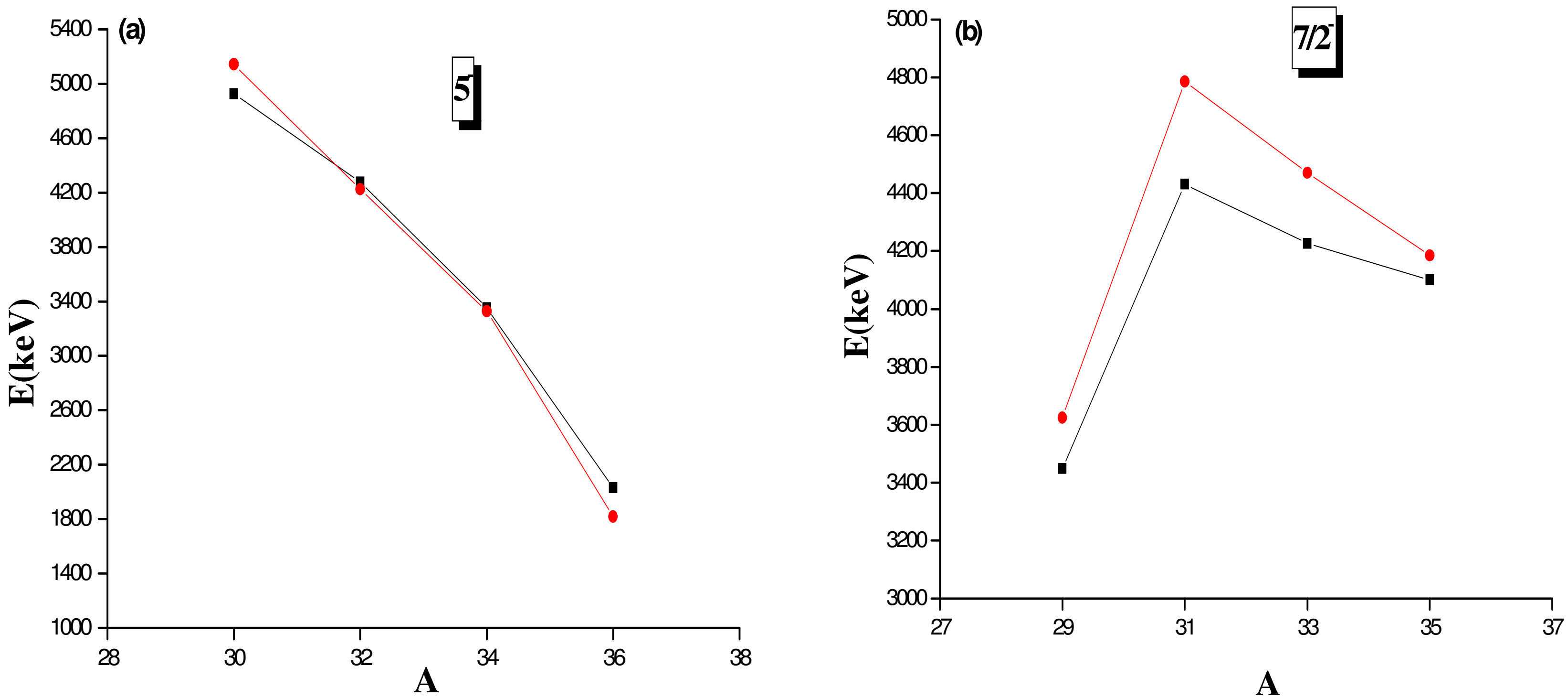
❖ $^{32}P_{17}$

RMSD = 222 keV

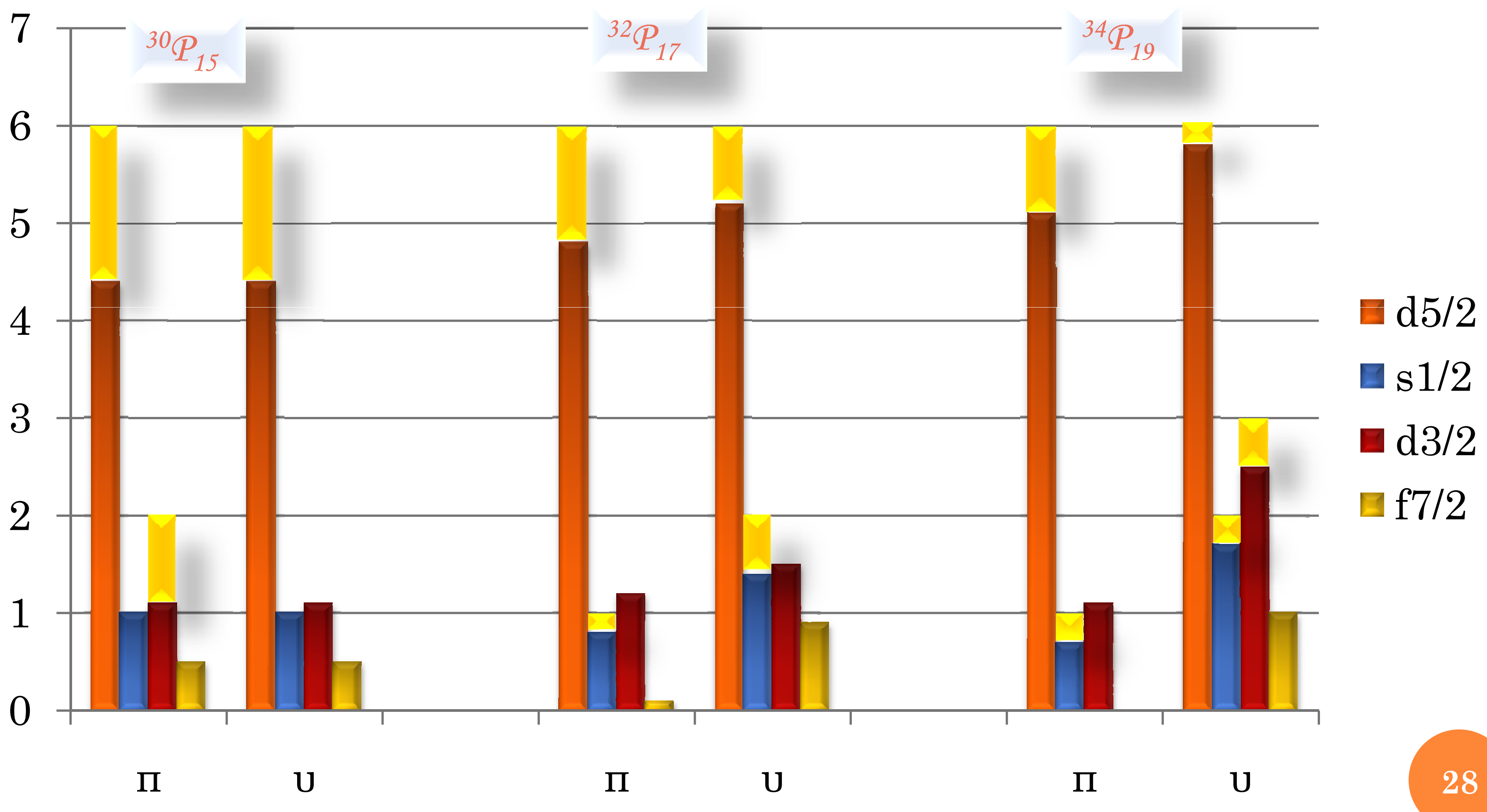
^{32}P Ex	^{32}P J^{π}	PSDPF Ex	PSDPF J^{π}_{n}
0	1^+	0	1^+_1
78	2^+	168	2^+_1
513	0^+	663	0^+_1
1149	1^+	1059	1^+_2
1323	2^+	1258	2^+_2
1755	3^+	1675	3^+_1
2177	3^+	2153	3^+_2
2218	2^+	2267	2^+_3
2230	1^+	2043	1^+_3
2658	2^+	2580	2^+_4
2740	1^+	2837	1^+_4
3005	3^+	2826	3^+_3
3149	4^+	3146	4^+_1
3264	2^-	2909	2^-_1
3320	3^-	3283	3^-_1
3443	4^-	3181	4^-_1
3444	$(1, 2^+)$	3464	1^-_1
3796	1^+	3765	1^+_5
3880	2^+	3311	2^+_5
3990	3^+	3632	3^+_4
4009	2^-	4052	2^-_2
4035	4^+	3565	4^+_2
4036	1^-	4395	1^-_2

^{32}P Ex	^{32}P J^{π}	PSDPF Ex	PSDPF J^{π}_{n}
4149	3^-	4381	3^-_2
4205	1^+	4077	1^+_6
4275	5^-	4225	5^-_1
4313	3^+	4008	3^+_5
4409	0^-	4113	0^-_1
4548	1^+	4692	1^+_7
4555	2^+	3543	2^+_6
4611	3^+	4205	3^+_6
4661	2^-	4425	2^-_3
4697	$(3, 5)^+$	4495	3^+_7
4711	1^+	5403	1^+_8
4743	5^+	4713	5^+_1
4849	$(3^+, 4^-, 5^+)$	4615	4^-_2
4877	1^-	4822	1^-_3
		5682	6^-_1
		6966	7^-_1
		7148	6^+_1
		8502	7^+_1

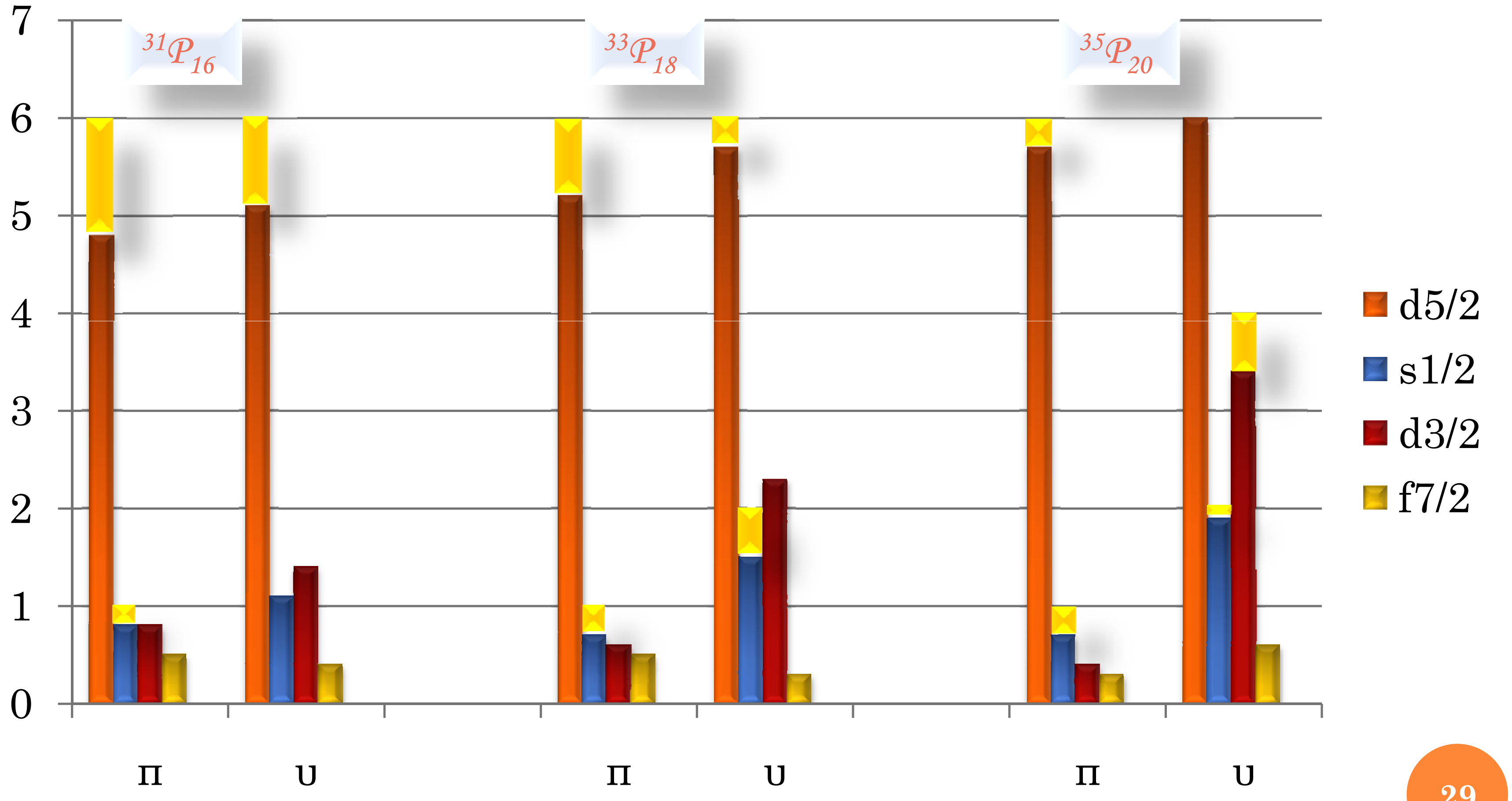
Energy of the 5^- and $7/2^-$ states in Phosphorous isotopes with A = 30 – 35



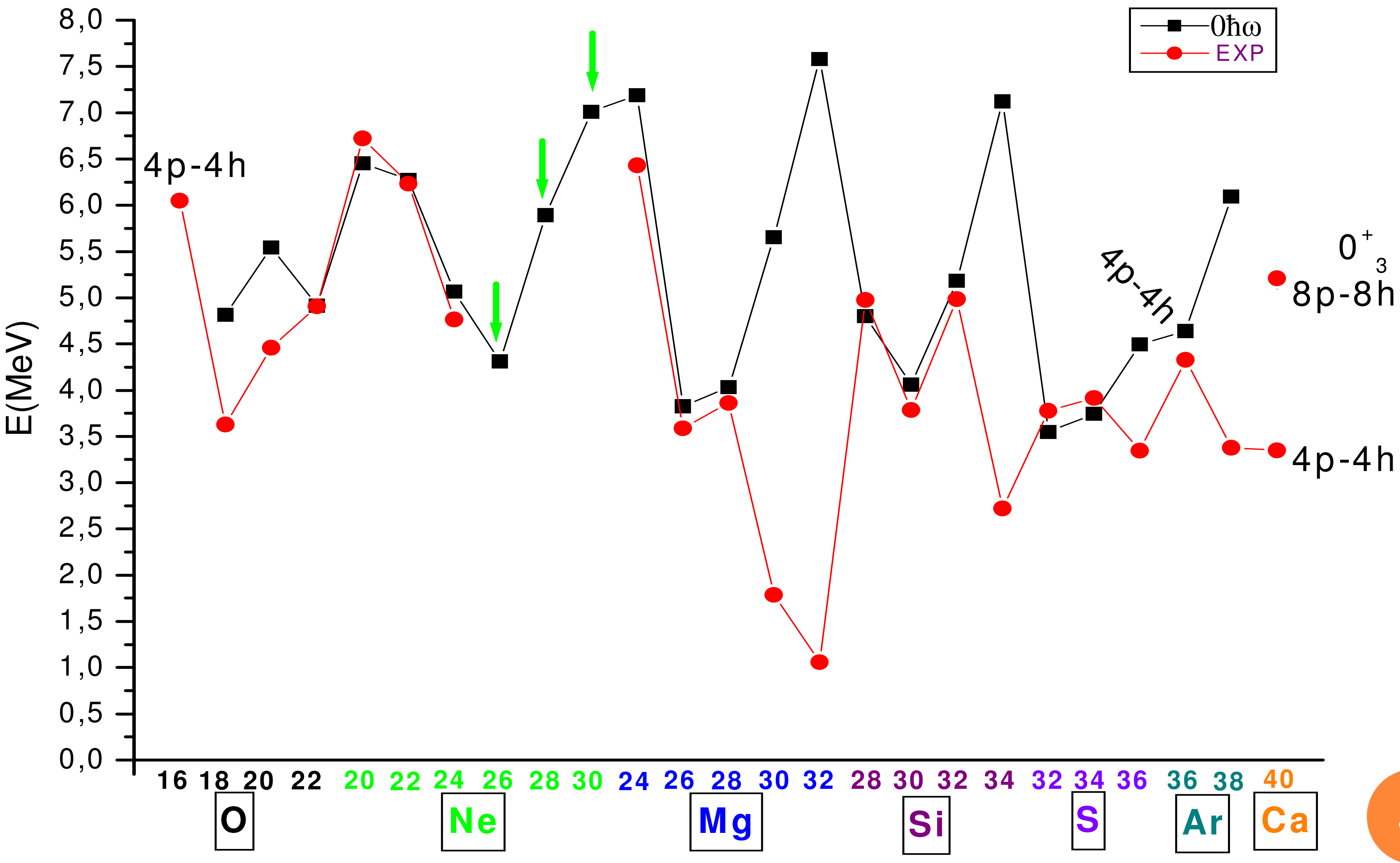
Shell occupations of the 5^- state



Shell occupations of the 7/2$^-$ state



First excited 0^+ state in even-even sd nuclei



Conclusion

- PSDPF : a $1\hbar\omega$ interaction for the negative parity states <u>throughout</u> the sd shell
- What are the limits of PSDPF as a function of A, J and Ex ?
- Study "chains" ⟹ underway: Na, P and Cl
- PSDPF over 3 major shells (9 subshells) ⟹

  RMSD ~ 400 keV compared to ~ 150 keV for USD

  (1 major shell, 3 subshells)
- Very good description of the negative parity states in the isotones N = 20 from Si to Ca. Works better at the end of the shell!
- Room for improvement : the new fitting code of Etienne…