Structure of p-shell hypernuclei

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Source	# γ-rays	# doublets
Ge Hyperball	~ 22	9
NaI ${}^{13}_{\Lambda}$C	3	1
NaI ${}^{4}_{\Lambda}$H/${}^{4}_{\Lambda}$He	2	2

Parameters in MeV

	Δ	S_Λ	S_N	T
$A = 7-\ ?$	0.430	-0.015	-0.390	0.030
$A = 11 - 16$	0.330	-0.015	-0.350	0.024

Doublet spacings in p-shell hypernuclei

	J_u^π	J_l^π	$\Lambda\Sigma$	Δ	S_Λ	S_N	T	ΔE^{th}	ΔE^{exp}
$^{7}_{\Lambda}$Li	$3/2^+$	$1/2^+$	72	628	−1	−4	−9	693	692
$^{7}_{\Lambda}$Li	$7/2^+$	$5/2^+$	74	557	−32	−8	−71	494	471
$^{8}_{\Lambda}$Li	2^-	1^-	151	396	−14	−16	−24	450	(442)
$^{9}_{\Lambda}$Li	$5/2^+$	$3/2^+$	116	530	−17	−18	−1	589	
$^{9}_{\Lambda}$Li	$3/2_2^+$	$1/2^+$	−80	231	−13	−13	−93	−9	
$^{9}_{\Lambda}$Be	$3/2^+$	$5/2^+$	−8	−14	37	0	28	44	43
$^{11}_{\Lambda}$B	$7/2^+$	$5/2^+$	56	339	−37	−10	−80	267	264
$^{11}_{\Lambda}$B	$3/2^+$	$1/2^+$	61	424	−3	−44	−10	475	505
$^{12}_{\Lambda}$C	2^-	1^-	61	175	−12	−13	−42	153	161
$^{15}_{\Lambda}$N	$3/2_2^+$	$1/2_2^+$	65	451	−2	−16	−10	507	481
$^{16}_{\Lambda}$O	1^-	0^-	−33	−123	−20	1	188	23	26
$^{16}_{\Lambda}$O	2^-	1_2^-	92	207	−21	1	−41	248	224

Ground-state doublet spacings of ${}^{10}_{\Lambda}$B and ${}^{12}_{\Lambda}$C

KEK E566 Hyperball2

Λ-Σ coupling

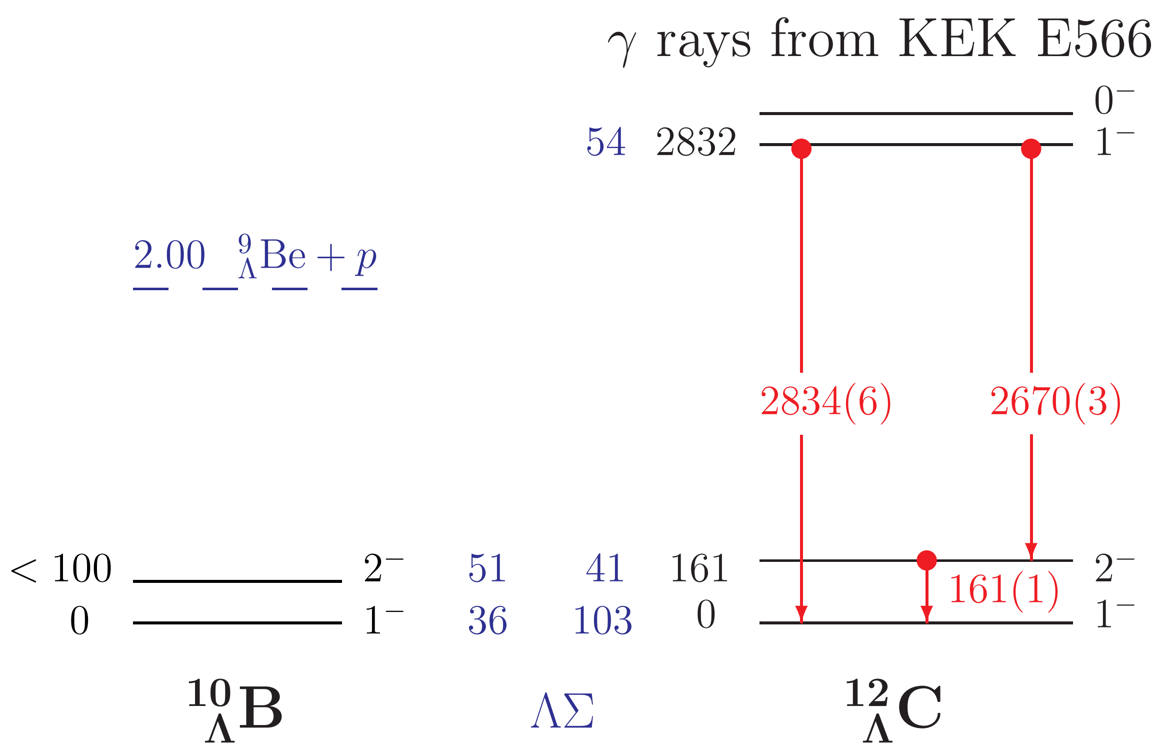
BNL ^{10}B$(3^+)(K^-,\pi^-\gamma){}^{10}_{\Lambda}B(2^-)$

KEK ^{12}C$(0^+)(\pi^+,K^+\gamma){}^{12}_{\Lambda}C(1^-_2)$

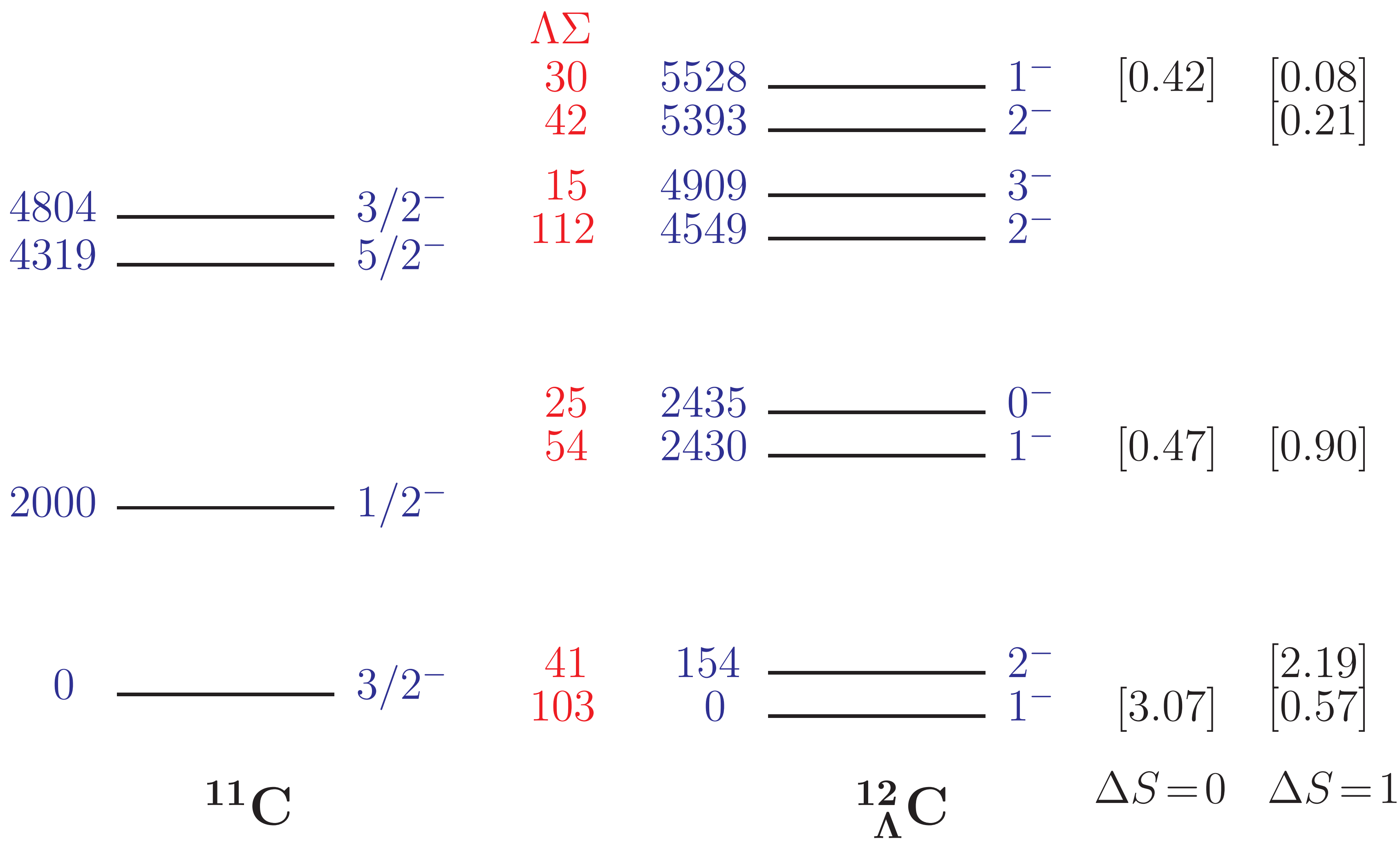
Core nuclei ^{9}B, ^{11}C similar

Particle-hole conjugates in p shell

Spacings of $2^-/1^-$ $(3/2^- \times s_\Lambda)$ doublets should be similar; mainly due to ΛN spin-spin interaction



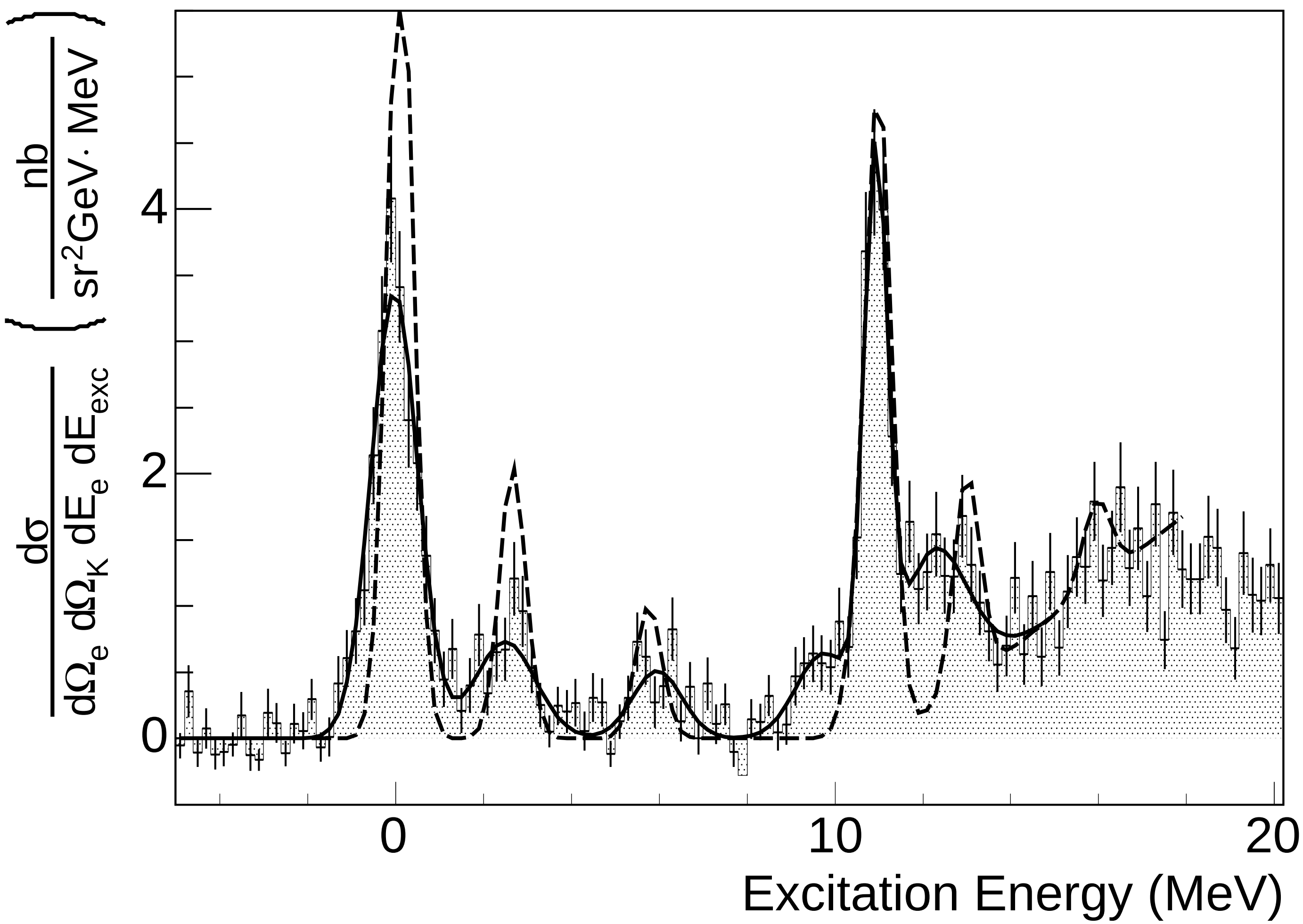
Note: ^{10}B$(K^-,\pi^0\gamma){}^{10}_{\Lambda}$Be would work



$^{12}C(e,e'K^+)^{12}_{\Lambda}$B - can translate energies of 3 peaks into $^{12}_{\Lambda}$C energies

[Hall A/Hall C] $E_x(1^-_2) = [2.65 - 2.80]$ $E_x(1^-_3) = [6.05 - 6.23]$

The excited 1^- states are raised by S_N, but not enough to reproduce the new γ-ray and $(e,e'K^+)$ data.



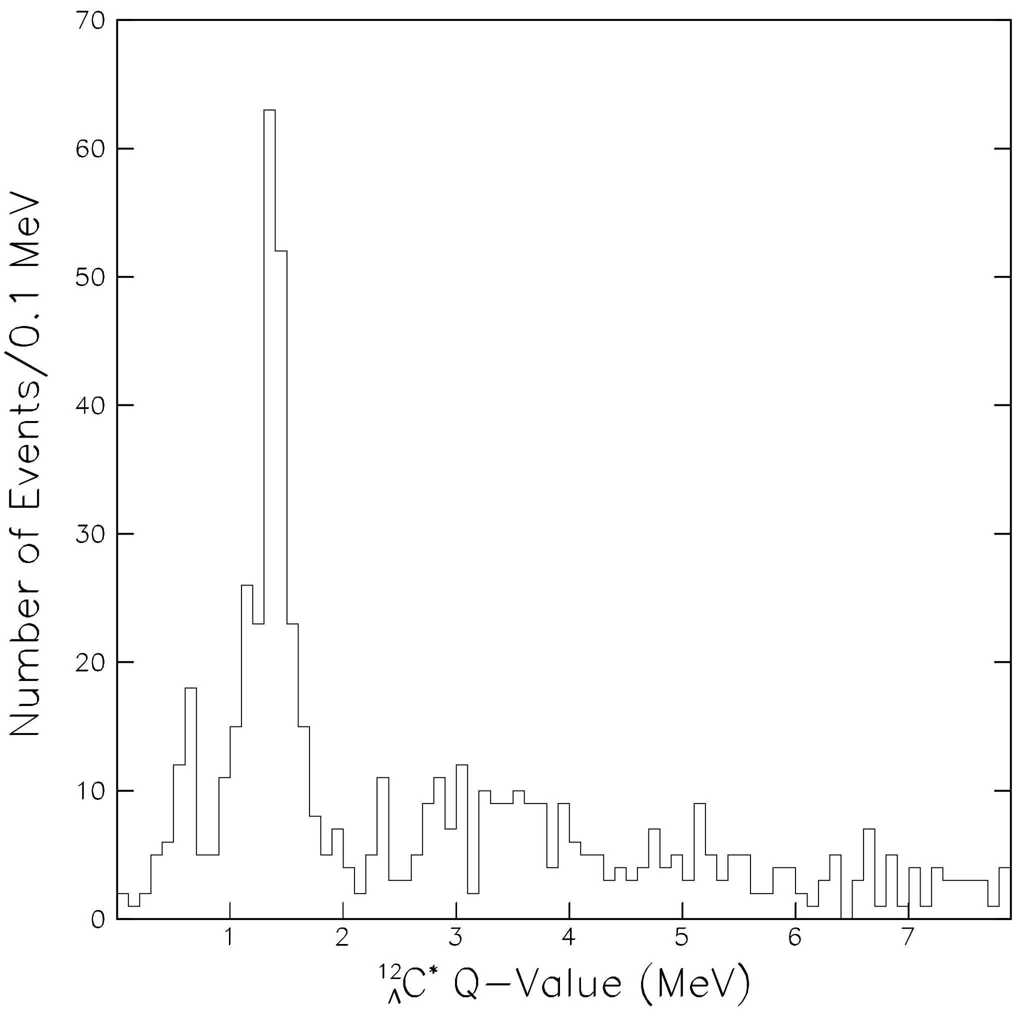
Iodice et al., PRL 99 (2007) 052501

J^π	# events	Γ keV	B_Λ MeV
0^+	64	< 100	0.14(5)
2^+	193	~ 600	0.20(5)
2^+	48	~ 150	0.95(5)

Upper 2^+ strong in $(e, e'K^+)$; 3^+ predicted 0.07 MeV higher $\Rightarrow B_\Lambda$ for p_Λ peak is 0.16 MeV

Iodice PRL 99, 052501 (2007) $\Rightarrow$ 10.93 MeV between s_Λ and p_Λ peaks; centroid of gs doublet at 0.13 MeV $\Rightarrow B_\Lambda$ for $^{12}_{\Lambda}$C = 11.22 MeV

Can play similar games with FINUDA, KEK E336, and Hall C data



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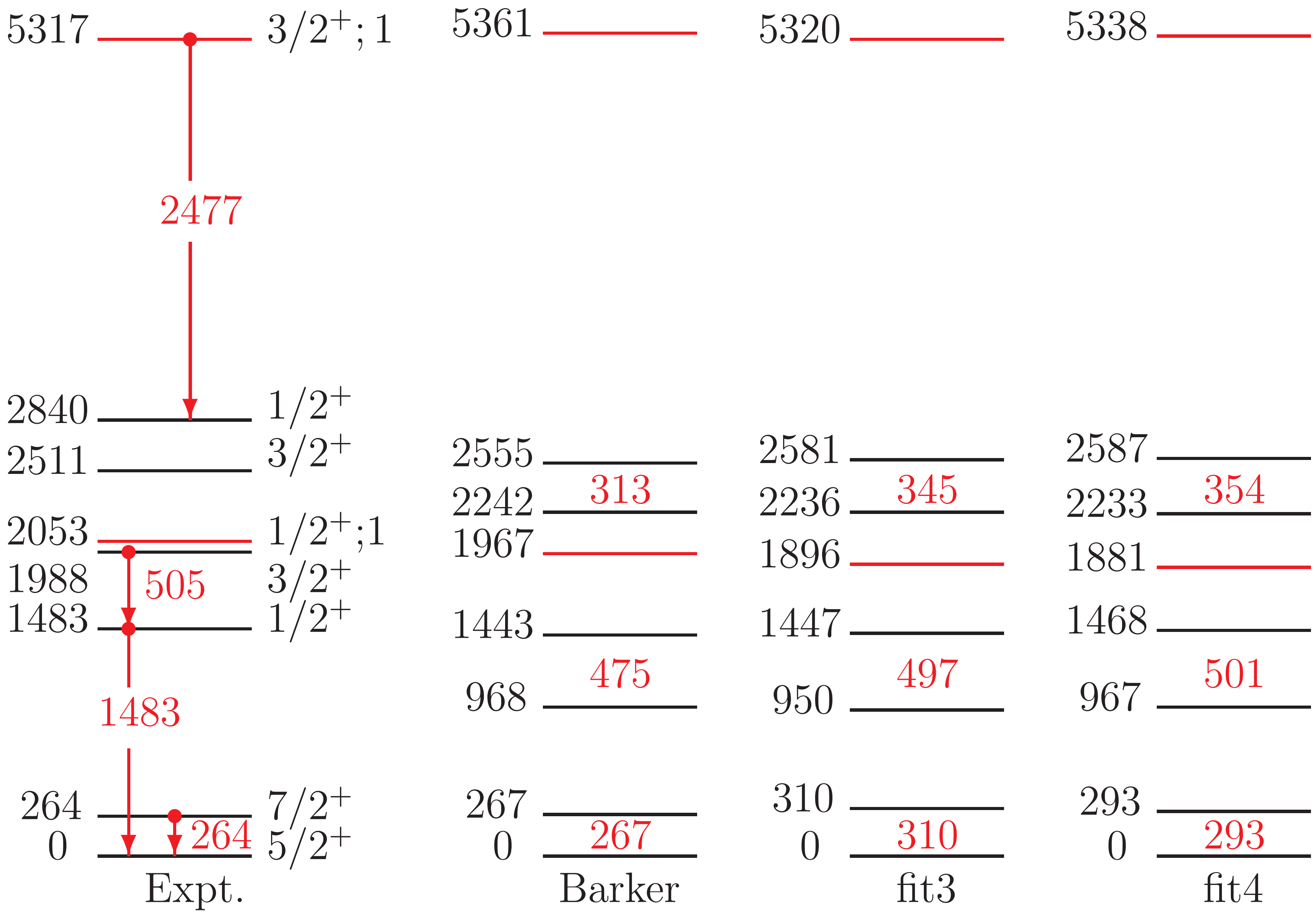
Shell-model calculations for ${}^{11}_{\Lambda}$B



Double one-pion exchange ΛNN interaction

Gal, Soper, and Dalitz: Ann. Phys. (N.Y.) 63, 53 (1971)

Independent of Λ spin. Averaged over s_Λ wave function gives

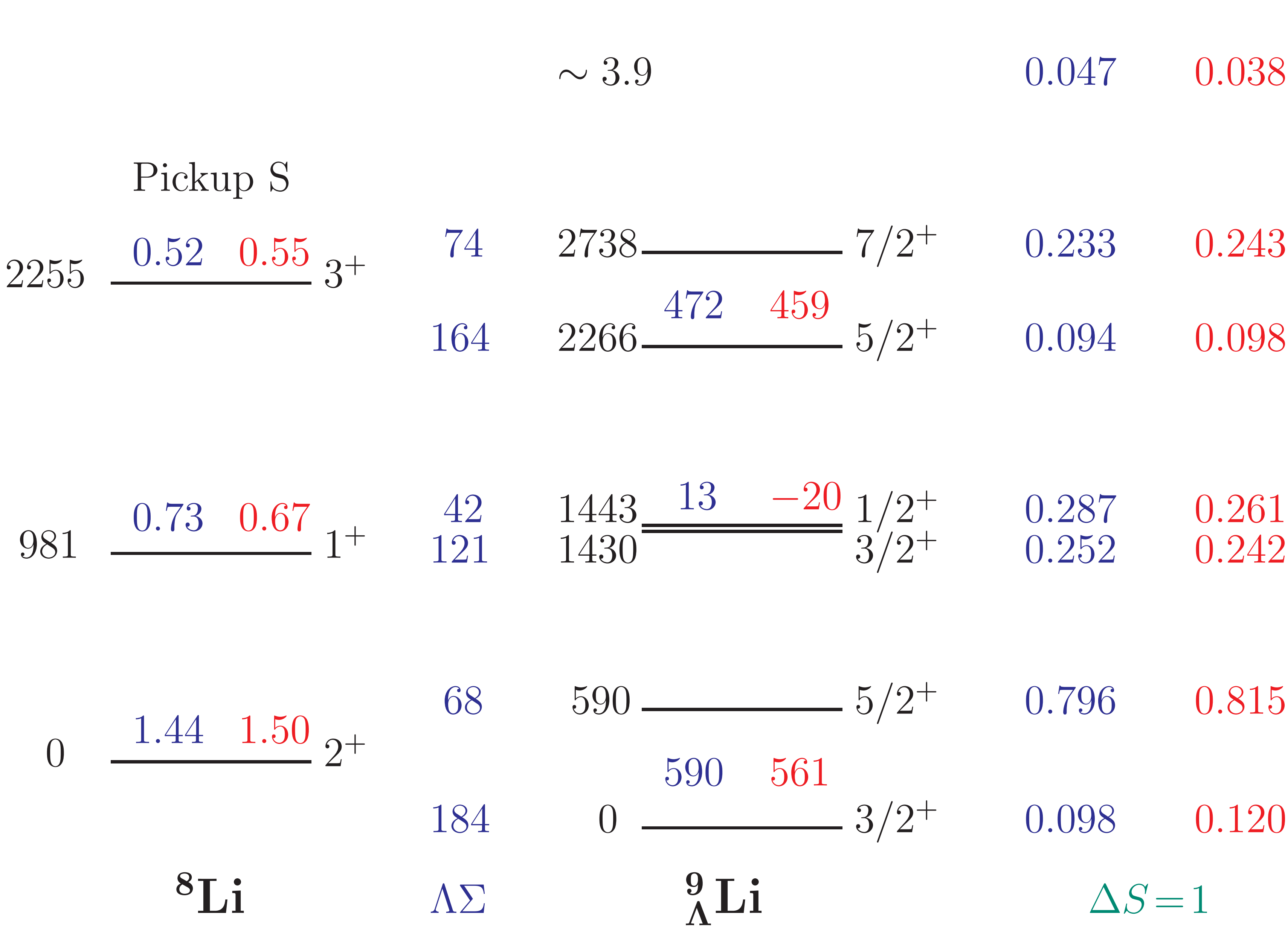
$$V_{NN}^{eff} = \sum_{klm} Q_{lm}^{k}(r_1, r_2)\,[\sigma_1, \sigma_2]^k \cdot [C_l(\hat{r_1}), C_m(\hat{r_2})]^k \;\; \tau_1 \cdot \tau_2$$

Parameters in MeV

Q_{00}^0	Q_{22}^0	Q_{22}^1	$Q_{02}^2 = Q_{20}^2$	Q_{22}^2
0.026	1.037	−0.531	−0.049	0.245

- Q_{00}^0 and Q_{22}^0 give repulsive contributions to B_Λ that depend quadratically on the number of p-shell nucleons in the core.
- Q_{22}^1 represents an anti-symmetric spin-orbit interaction that behaves rather like S_N

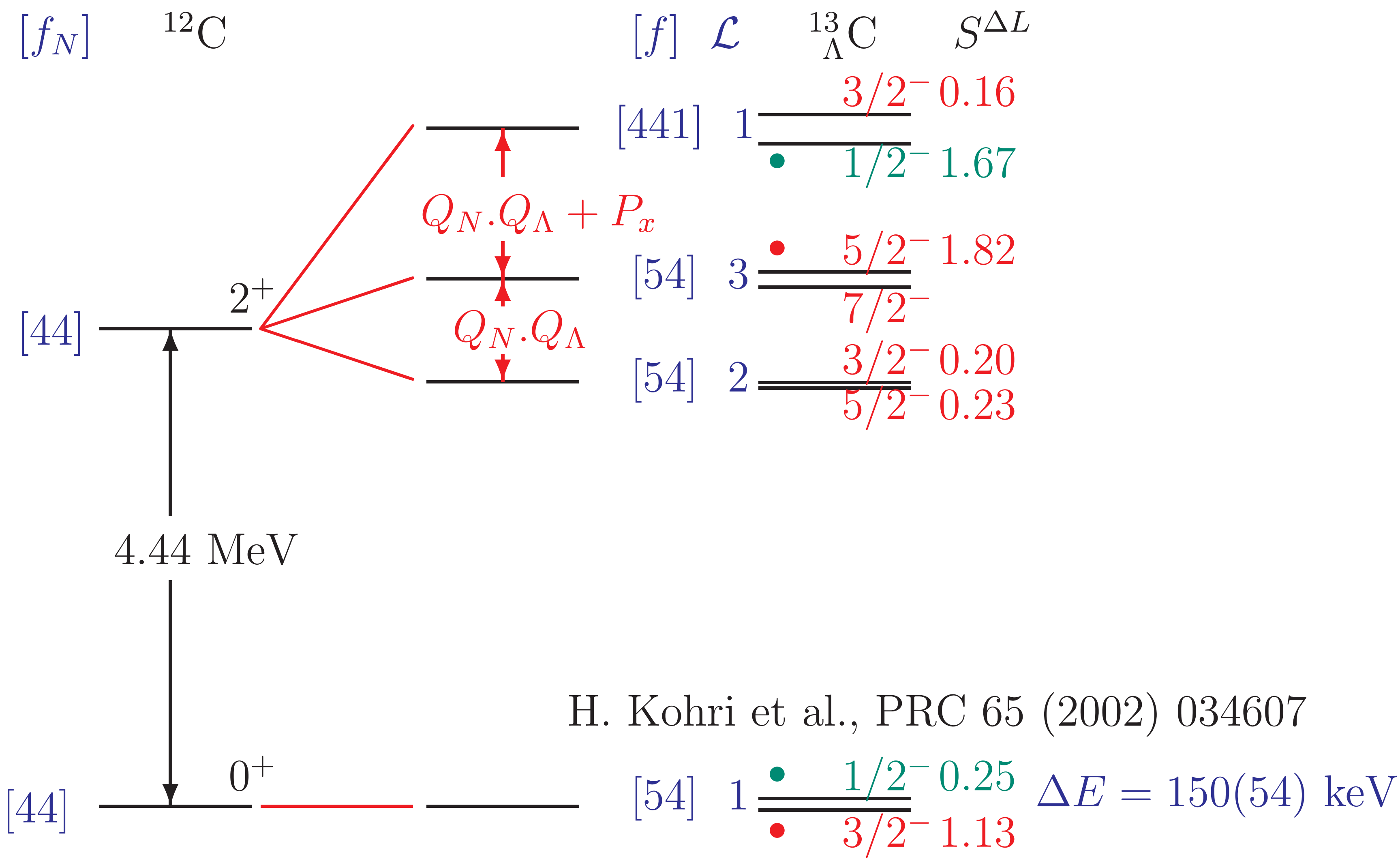
$^{9}\mathrm{Be}(e,e'K^{+})^{9}_{\Lambda}\mathrm{Li}$



		singlet even	triplet even	singlet odd	triplet odd	even	odd	in odd states
nsc97f	$\overline{V}$	−0.421	−0.834	0.070	0.102	−1.255	0.172	repulsive
	Δ					0.571	−0.148	
esc04a	$\overline{V}$	−0.421	−0.791	0.029	−0.100	−1.212	−0.072	strong spin
	Δ					0.632	−0.248	dependence
fit-djm	$\overline{V}$	−0.331	−0.701	−0.036	−0.069	−1.032	−0.105	attractive
	Δ					0.387	0.051	

- Most new YN models use some constraint to ensure a more attractive s-wave interaction than triplet to bind hypertriton, fit A=4 $0^+/1^+$ doublet, and Δ for p-shell hypernuclei.
- The p-wave central interaction is not constrained, but may be important - along with Λ-Σ coupling - to simultaneously fit data on s-shell and p-shell hypernuclei.
- Next two slides show an old example that puts some constraint on the exchange character of the central interaction.

$^{12}\mathrm{C}(0^+, 2^+) \times p_\Lambda$ states of $^{13}_{\Lambda}\mathrm{C}$



$B_\Lambda = 11.69 \pm 0.12$ MeV $\quad 3/2^-/1/2^- \quad E_x = 10.83/10.98$ MeV

$^{13}C(K^-, \pi^-)^{13}_{\Lambda}C$ M. May et al., PRL 47, 1106 (1981)

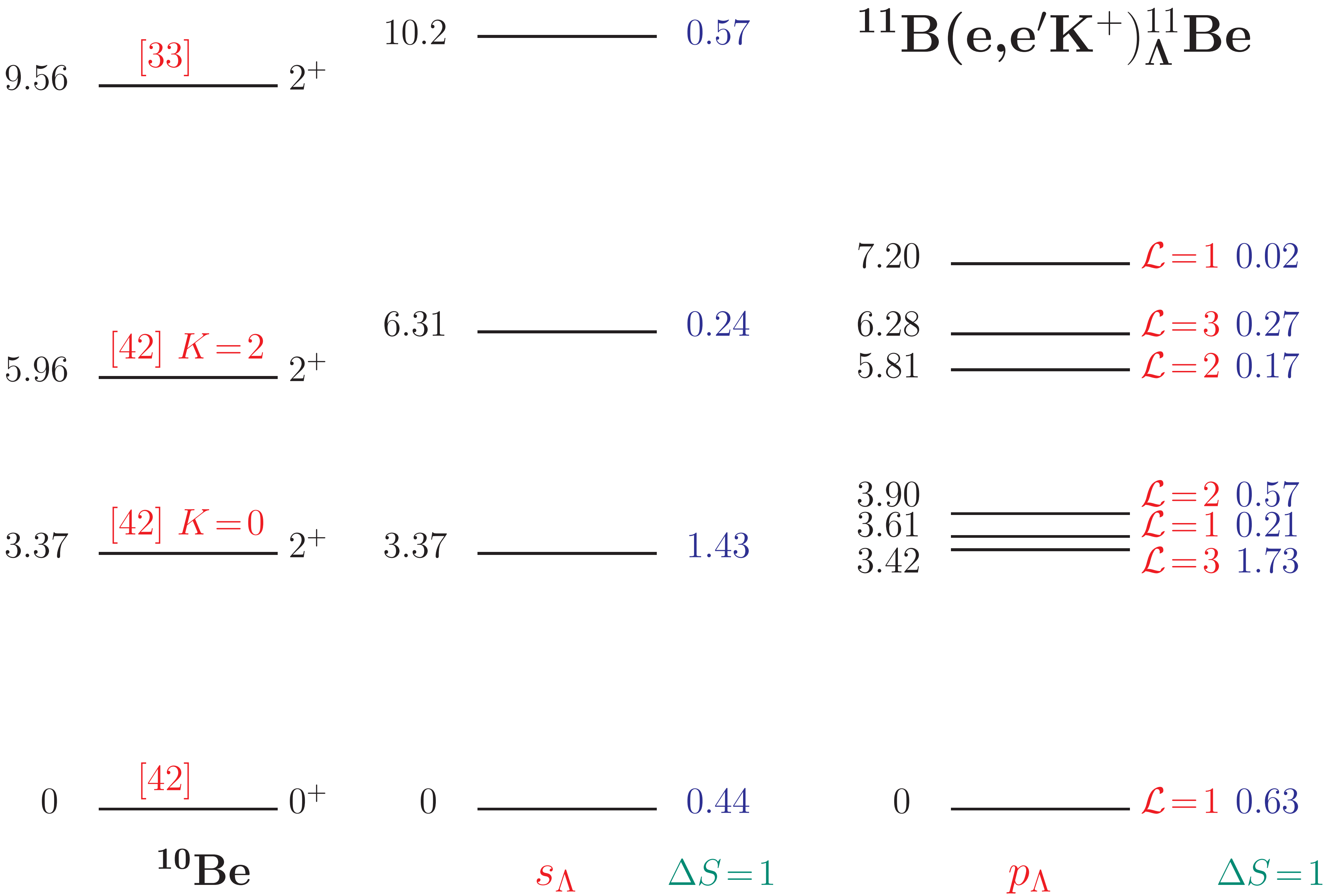
Theory: E.H. Auerbach et al., PRL 47, 1110 (1981); Ann. Phys. 148, 381 (1983)

Basic data: Separation between 10.4 and 16.4 MeV peaks at 0° and shift in position of upper peak at 15°.

Woods-Saxon: p_Λ bound at 0.8 MeV

$^{13}_{\Lambda}C$	nsc97f	esc04a	djm	Experiment
$1/2^-_2 - 1/2^-_1$	6.94	6.05	6.18	6.0 ± 0.4
$1/2^-_2 - 5/2^-_1$	2.18	1.23	1.37	1.7 ± 0.4

Odd-state tensor, even-state tensor, and Λ-Σ mixing work against one-body and two-body spin-orbit interactions in the "single-particle" p_Λ splitting. Mixing of $2^+ \times p_\Lambda$ into $0^+ \times p_\Lambda$ (typically 5%) also contributes to the spacing.



^{11}B(e,e′K$^+$)$^{11}_{\Lambda}$Be
9.56 [33] 2$^+$
5.96 [42] K=2 2$^+$
3.37 [42] K=0 2$^+$
0 [42] 0$^+$
^{10}Be
10.2 0.57
6.31 0.24
3.37 1.43
0 0.44
s_Λ ΔS=1
7.20 ℒ=1 0.02
6.28 ℒ=3 0.27
5.81 ℒ=2 0.17
3.90 ℒ=2 0.57
3.61 ℒ=1 0.21
3.42 ℒ=3 1.73
0 ℒ=1 0.63
p_Λ ΔS=1