Joint THEIA-STRONG2020 and JAEA/Mainz REIMEI Web-Seminar

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Structures and production cross sections of p-shell Λ-hypernuclei calculated with extended shell model

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collaborated with

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Introduction

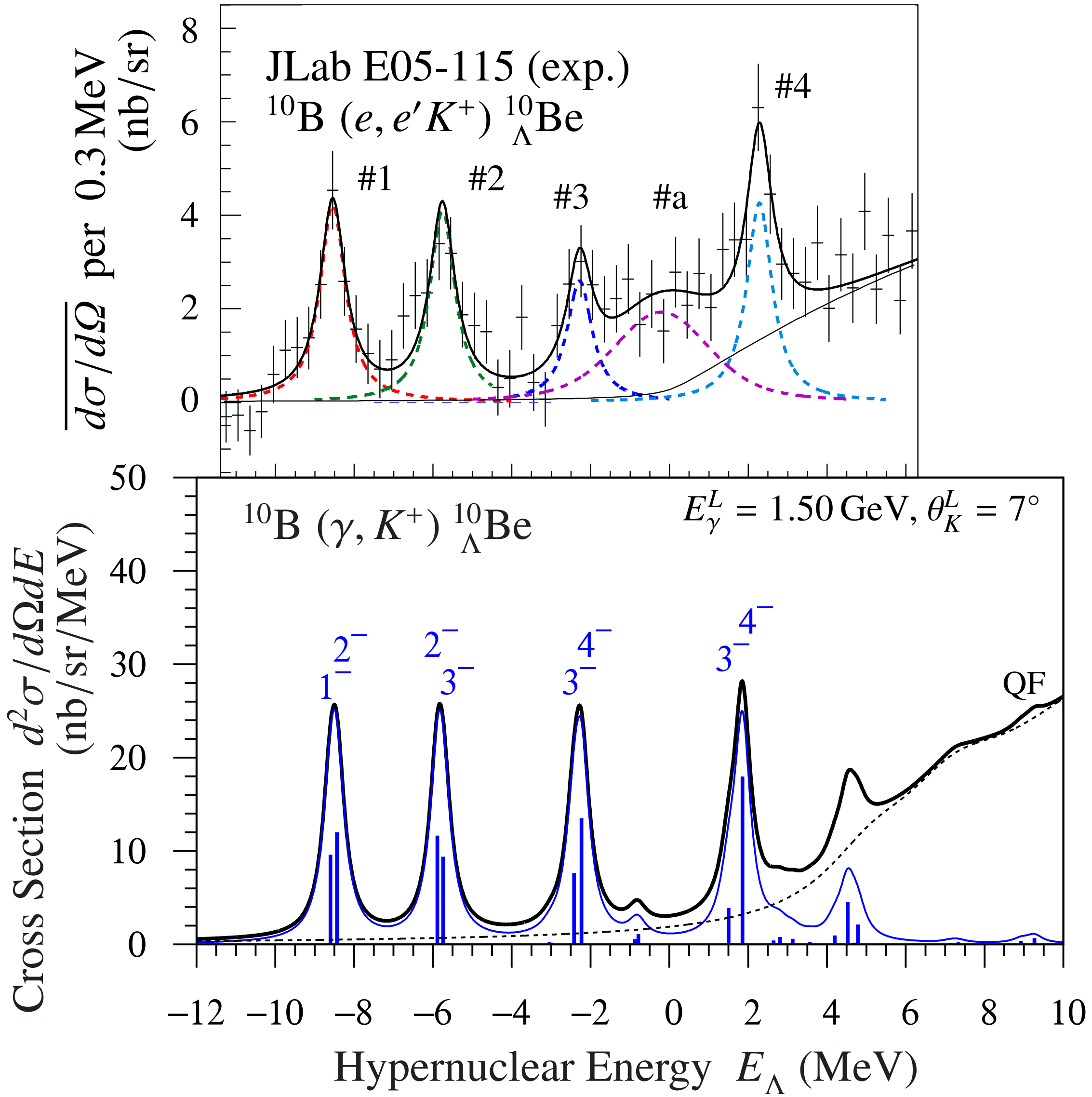
Basic motivations

(1) **p-shell nuclei and hypernuclei provide a variety of interesting phenomena (shell-, cluster-, and coexistent characters), depending on E_x and mass.**

(2) **High-precision experiments in hypernuclear spectroscopy are in progress.**

(3) **Detailed look in Jlab $(e, e'K^+)$ spectroscopic data requires an extended description with multi-configuration parity-mixing mediated by hyperon.**

Recent $(e, e'K^+)$ reaction experiments done at the Jefferson Lab



Recent experimental result

T. Gogami *et al.*, PRC93, 034314 (2016)

Shell-model prediction

T. Motoba *et al.*, PTPS117, 123 (1994)

- Core nucleus calculated with conventional *p*-shell model
- Λ in *s*-orbit

This experiment has confirmed the major peaks (#1, #2, #3, #4) predicted in DWIA by emplying the Λ particle in *s*-orbit coupled with the nuclear core states confined within the *p*-shell configuration.

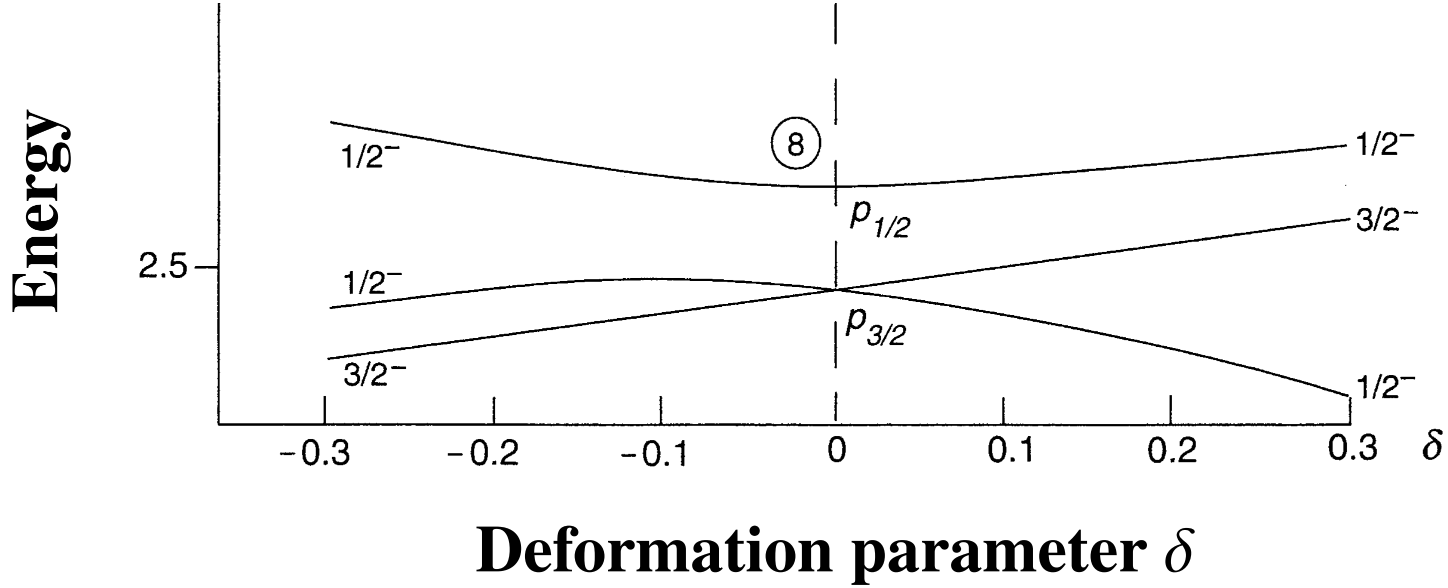
However, it is interesting to observe extra strengths at $E_\Lambda = 0$ MeV excitation (a).

$\Downarrow$

The extension of the model space is necessary and interesting challenge in view of the present hypernuclear spectroscopy.

Splitting of p-state in the deformed nuclei

The bump in the cross sections of $^{10}_{\Lambda}\mathrm{Be}$ will be explained by the splitting of p^{Λ}-state in the deformed core-nucleus.

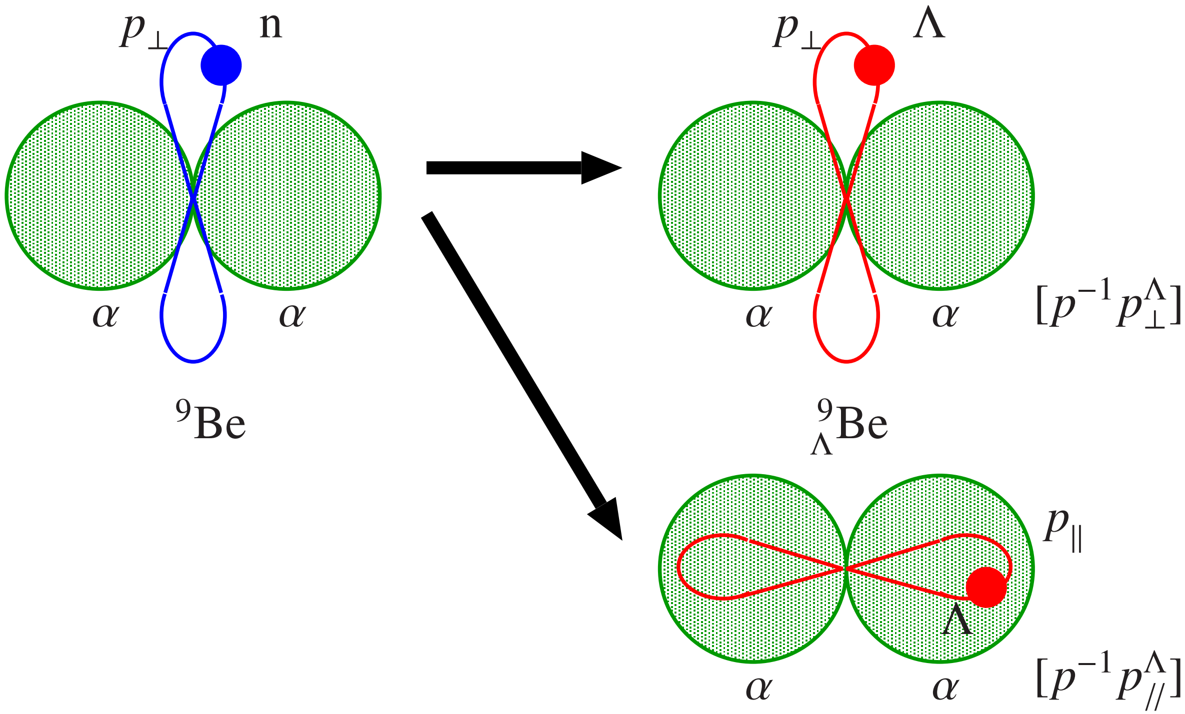


S. G. Nilsson, Mat. Fis. Medd. Dan. Vid. Selsk. 29 (1955) No. 16

Eigenvalues Ω of z-component of angular momentum operator and parities are good quantum numbers in the Nilsson diagram.

$$p_{3/2} \to \Omega^{\pi} = 1/2^{-}, 3/2^{-}$$

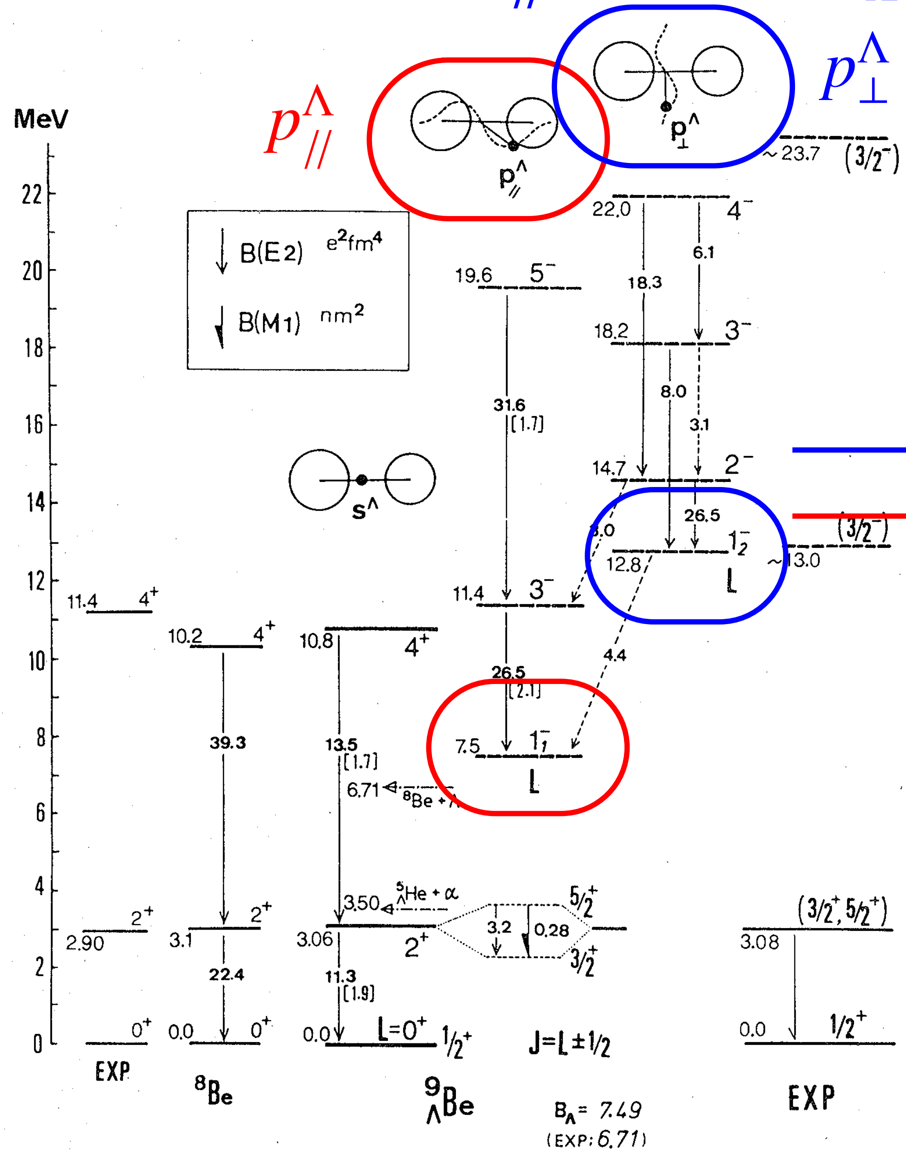
$[p^{-1}p_\perp^\Lambda]$ and $[p^{-1}p_{//}^\Lambda]$ states of ${}^9_\Lambda$Be (1)



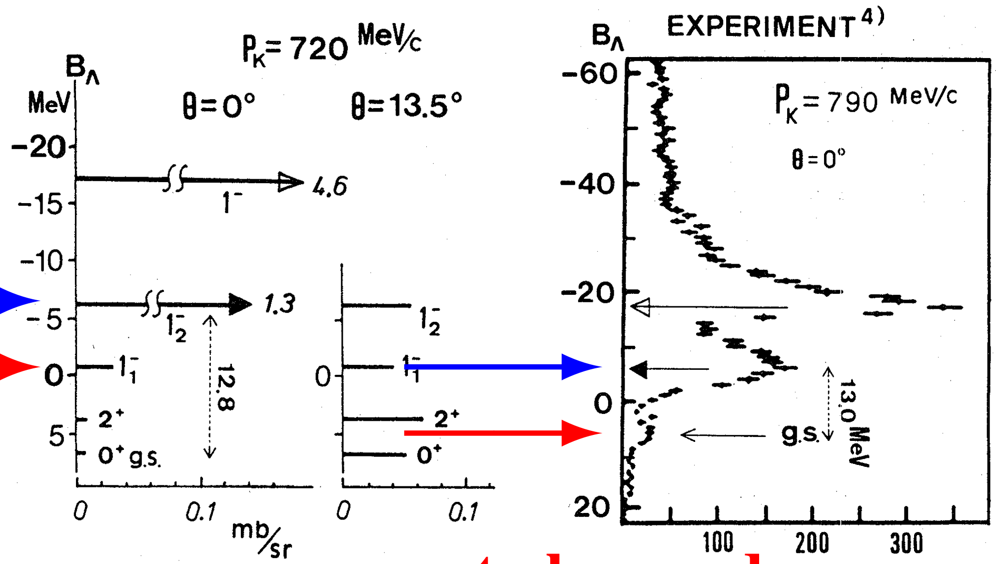
In ${}^9_\Lambda$Be, it is well known that the p_Λ-state splits into two orbital states expressed by $p_\perp$ and $p_{//}$, which is due to the strong coupling with nuclear core deformation having the α-α structure. **T. Motoba *et al.*, PTPS81, 42 (1985)**

The $p_{//}$ state tends to the configuration with an SU(3) classification $[f](\lambda\mu) = [54](50)$ called supersymmetric.
R. H. Dalitz, A. Gal, PRL36, 362 (1976); AP131, 314 (1981)

$[p^{-1}p_{\perp}^{\Lambda}]$ and $[p^{-1}p_{//}^{\Lambda}]$ states of ${}^{9}_{\Lambda}\mathrm{Be}$ (2)



${}^{9}\mathrm{Be}\,(K^{-},\pi^{-})\,{}^{9}_{\Lambda}\mathrm{Be}$



not observed

T. Motoba *et al.*, PTPS81, 42 (1985)

R. Bertini *et al.* (H-S-S Collaboration), NPA368, 365 (1981)

To describe hypernuclei with deformed nuclear core such as $\alpha\alpha$, we need to extend the model space.

This talk

We have calculated the energy levels and the production cross sections for *p*-shell hypernuclei by using the extended shell model.

We focus on the *p*-state Λ hyperon in the *p*-shell Λ hypernuclei.

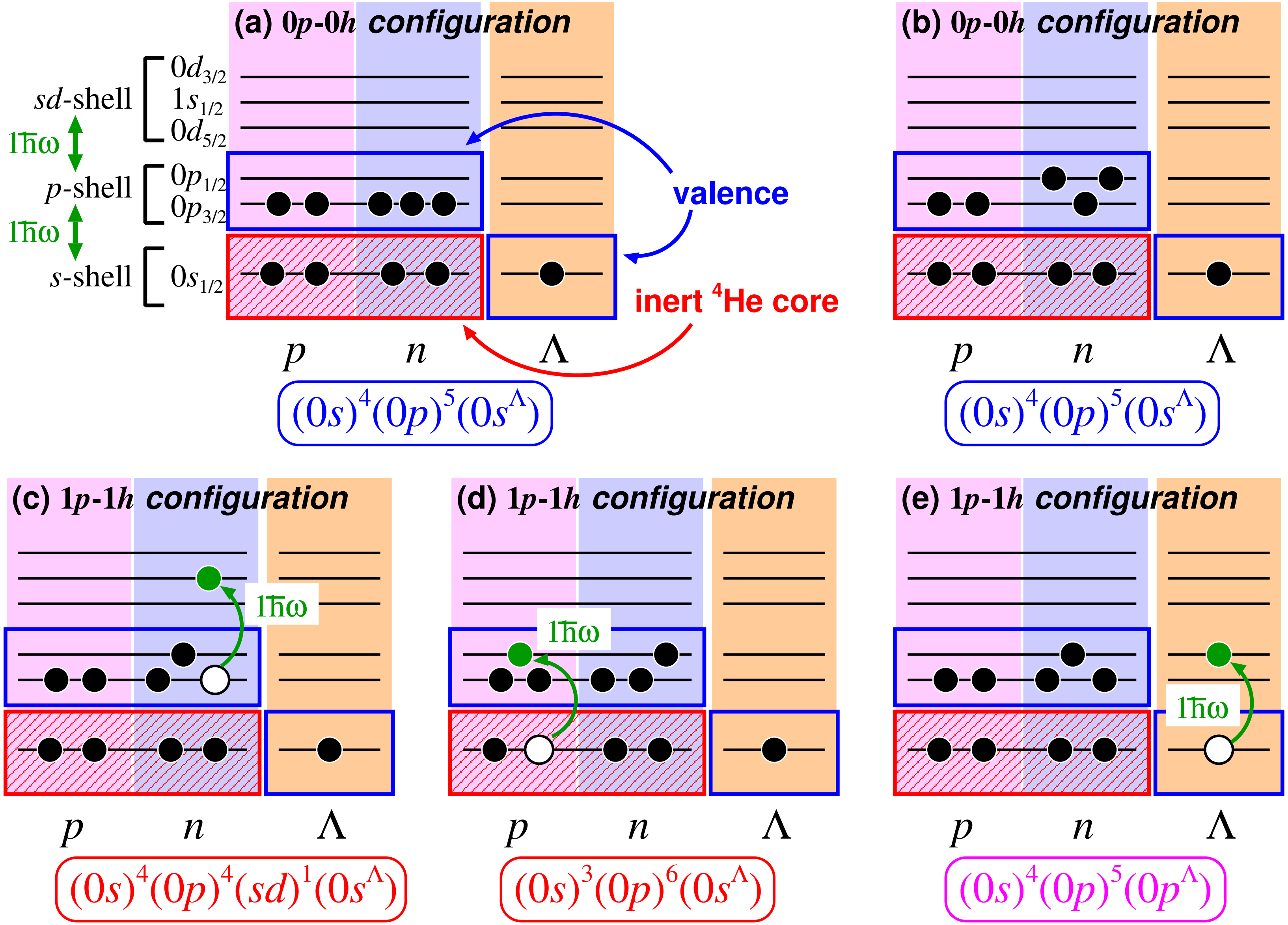
- **Energy levels and cross sections for $^{9}_{\Lambda}$Be, $^{10}_{\Lambda}$Be ($^{10}_{\Lambda}$B), $^{11}_{\Lambda}$B and $^{12}_{\Lambda}$B ($^{12}_{\Lambda}$C)**
- **$p^{\Lambda}_{\perp}$ and $p^{\Lambda}_{//}$ states in hypernuclei with $A = 9$, 10 and 11**
- **Mixing of natural- and unnatural-parity nuclear-core states**

We show the numerical cross sections of (γ, K^{+}) reactions for $^{9}_{\Lambda}$Li and $^{11}_{\Lambda}$Be which have $T = 1$.

- **^{9}Be $(e, e'K^{+})$ experiment has been done at JLab.**
- **^{11}B $(e, e'K^{+})$ experiment may be performed.**

Framework of calculations

Shell-model configurations ($^{10}_{\Lambda}$Be case)



Extension of the model space in the shell model (${}^{10}_{\Lambda}$Be case)

Model space for ^{9}Be core

(A) conventional model space $J^{-}_{\rm core}$ $(0s)^4\,(0p)^5$ $(0p\text{-}0h)$

(B) extended model space $J^{+}_{\rm core}$ $(0s)^3\,(0p)^6$ $\oplus$ $(0s)^4\,(0p)^4\,(sd)^1$ $(1p\text{-}1h)$

Conventional model space for ${}^{10}_{\Lambda}$Be

(I) $J^{-}_{\rm core} \otimes 0s^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{-})$ **(II)** $J^{-}_{\rm core} \otimes 0p^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{+})$

Extension (1) $1p$-$1h$ ($1\hbar\omega$) core excitation is taken into account

(a) $J^{-}_{\rm core} \otimes 0s^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{-})$ **(b)** $J^{-}_{\rm core} \otimes 0p^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{+})$

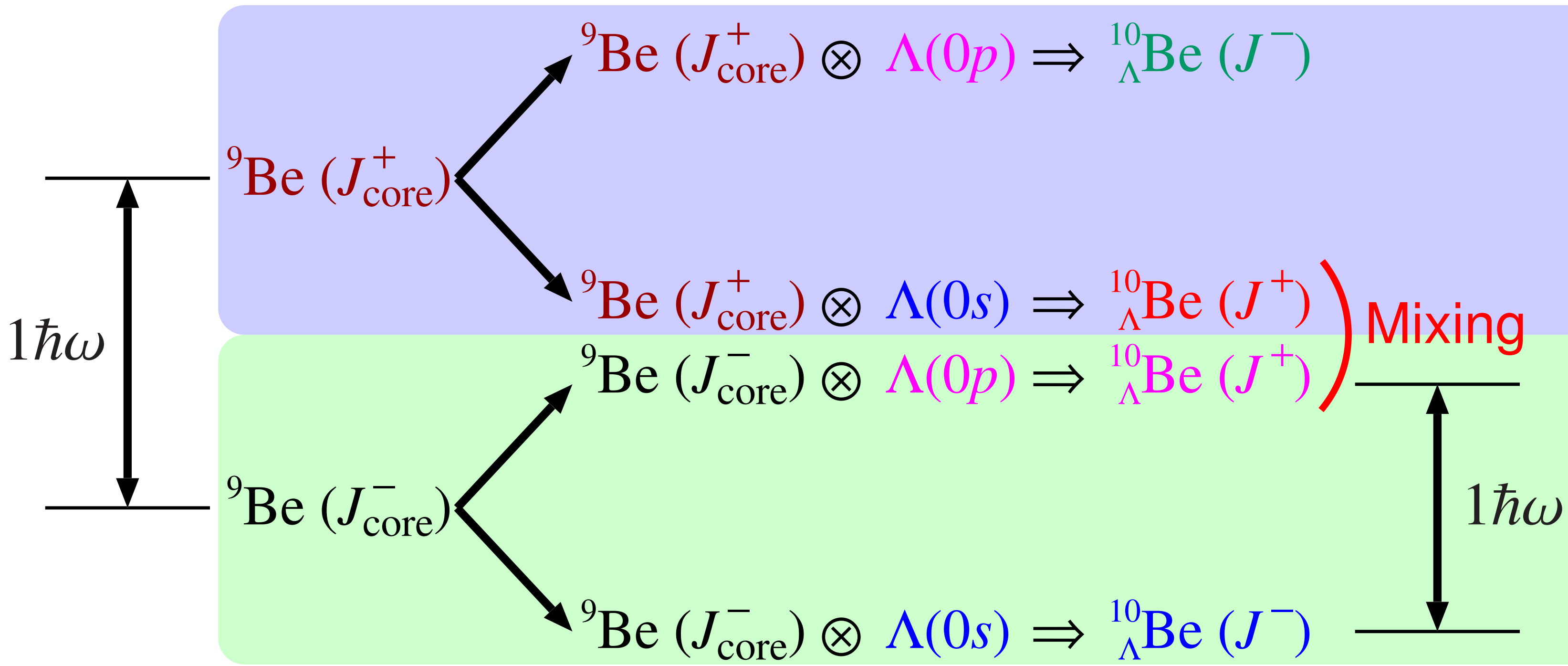
(c) $J^{+}_{\rm core} \otimes 0s^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{+})$ **(d)** $J^{+}_{\rm core} \otimes 0p^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{-})$

Extension (2) Configrations mixed by ΛN interaction

$J^{-}_{\rm core} \otimes 0s^{\Lambda} \oplus J^{+}_{\rm core} \otimes 0p^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{-})$

$J^{-}_{\rm core} \otimes 0p^{\Lambda} \oplus J^{+}_{\rm core} \otimes 0s^{\Lambda} \Rightarrow {}^{10}_{\Lambda}{\rm Be}(J^{+})$

Configration mixing in ${}^{10}_{\Lambda}$Be unnatural parity states

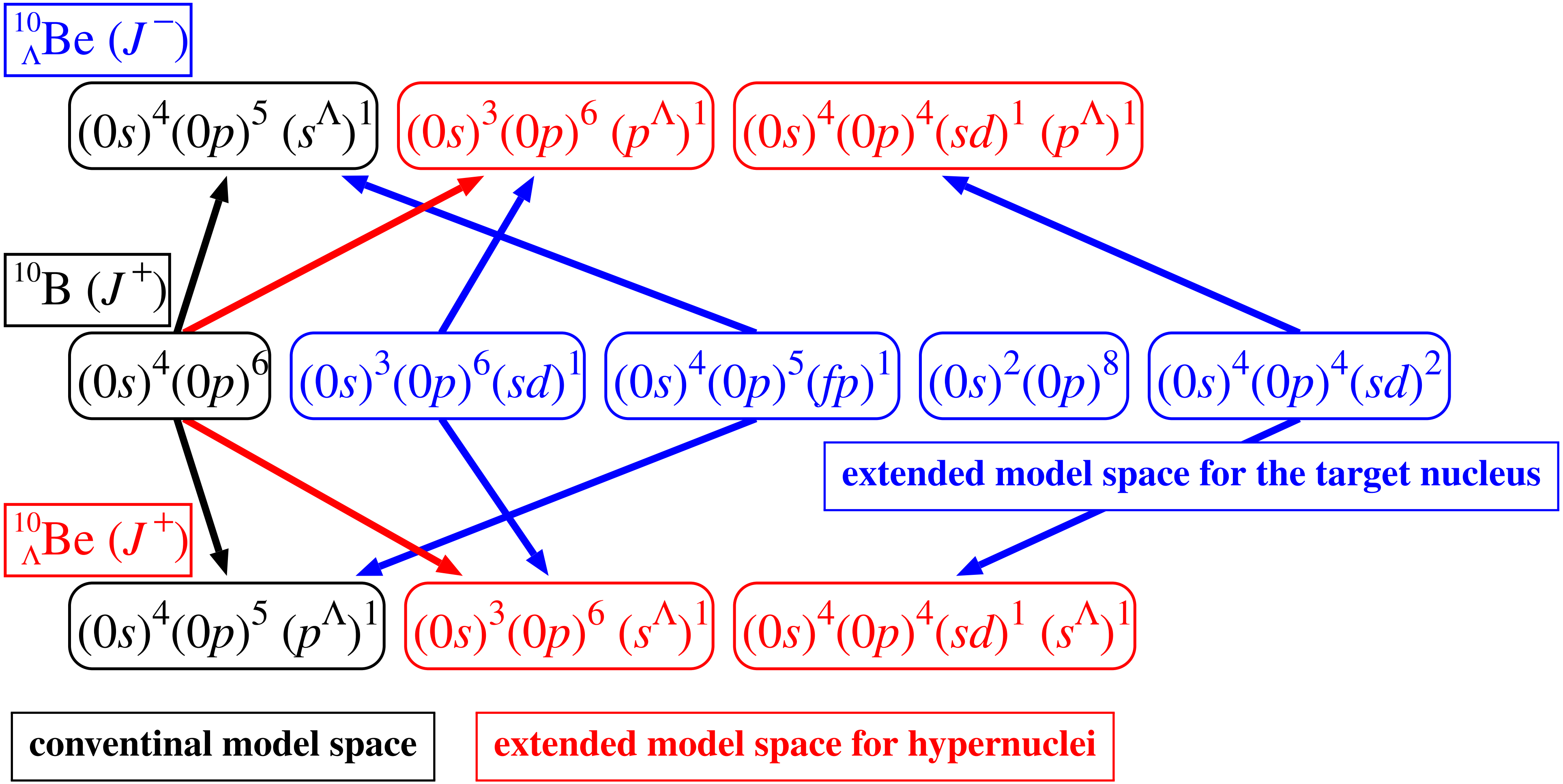


In the conventional shell model, only natural-parity nuclaer-core states (J^{-}_{core}) are taken into account. Λ particle is in the 0s orbit in ${}^{10}_{\Lambda}\mathrm{Be}(J^{-})$.

In ${}^{10}_{\Lambda}\mathrm{Be}(J^{+})$, the energy difference between $\Lambda(0s)$ and $\Lambda(0p)$ is $1\hbar\omega$, and the energy difference between ${}^{9}\mathrm{Be}(J^{-}_{\mathrm{core}})$ and ${}^{9}\mathrm{Be}(J^{+}_{\mathrm{core}})$ is $1\hbar\omega$.

By ΛN interaction, natural-parity nuclaer-core configurations and unnatural-parity nuclaer-core configurations can be mixed.

Extended model space for target nucleus ^{10}B



Extension of model space for target nucleus ^{10}B up to 2*p*-2*h* ($2\hbar\omega$) allows the $^{10}_{\Lambda}$Be production through various configurations.

NN interaction and nucleon single-particle energy

NN effective interactions

$\langle p^2|V|p^2\rangle$ Cohen-Kurath (8–16) TBME
S. Cohen, D. Kurath, NP73, 1 (1965)

$\langle (sd)^2|V|(sd)^2\rangle$ modified Kuo-Brown G-matrix
T. T. S. Kuo, G. E. Brown, NP85, 40 (1966)

$\langle p(sd)|V|p(sd)\rangle$ Millener-Kurath
D. J. Millener, D. Kurath, NPA255, 315 (1975)

$\langle p^2|V|(sd)^2\rangle$ modified Kuo-Brown G-matrix (SFO)
T. Suzuki, R. Fujimoto, T. Otsuka, PRC67, 044302 (2003)

Other part (contains a role of removal of spurious center-of-mass motion effects)

Anantaraman-Toki-Bertsch G-matrix
N. Anantaraman, H. Toki, G. F. Bertsch, NPA398, 269 (1983)

Single-particle energies

adjusting to reproduce the experimental low-lying energy levels

ΛN interaction and Λ single-particle energy

$\langle N\Lambda|V|N\Lambda\rangle$ **Nijmegen NSC97e**

Th. A. Rijken, V. G. J. Stoks, Y. Yamamoto, PRC59, 21 (1999)

ε_s^Λ and ε_p^Λ are determined to reproduce the #1 (2^-) and #6 (3^+) peaks in $^{12}_{\Lambda}$B production cross-section.

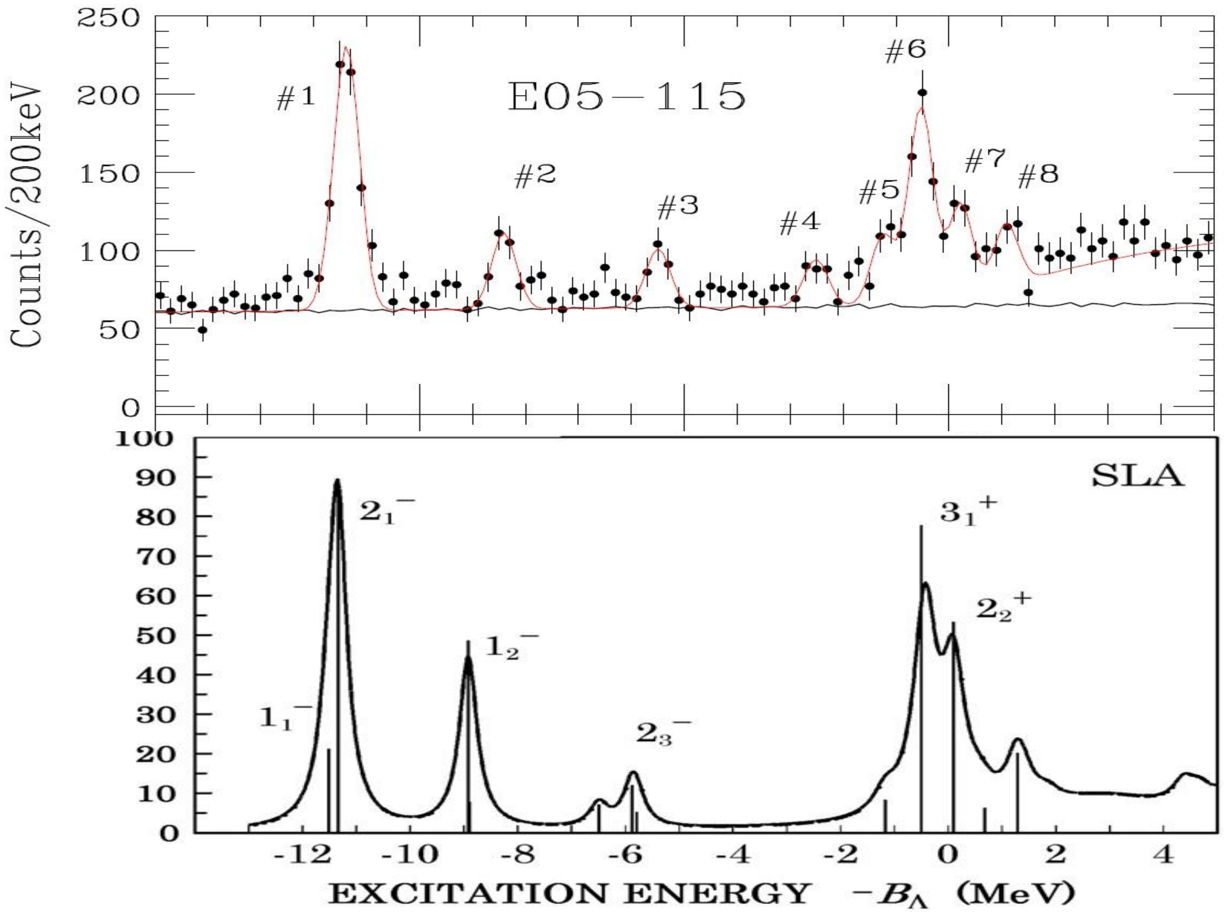
ε_s^Λ and ε_p^Λ are applied to $^{10}_{\Lambda}$Be.

JLab Hall C, E05-115

L. Tang *et al.*, PRC90, 034320 (2014)

Theoretical calculation

T. Motoba *et al.*, PTPS185, 224 (2010)



Numerical values of B_Λ for A = 9–12 hypernuclei

unit in MeV

	${}^{9}_{\Lambda}$Li	${}^{9}_{\Lambda}$Be	${}^{10}_{\Lambda}$Be	${}^{11}_{\Lambda}$Be	${}^{11}_{\Lambda}$B	${}^{12}_{\Lambda}$B
J^π	$3/2^+, 5/2^+$	$1/2^+$	$1^-, 2^-$	$1/2^+$	$5/2^+, 7/2^+$	$1^-, 2^-$
$E_{\text{g.s.}}$	−21.87	−37.19	−40.72	−49.49	−51.38	−64.26
$E_{\text{1st ex.}}$	−21.56	—	−40.55	—	−51.09	−64.14
ΔE(cal)	0.31	—	0.17	—	0.29	0.12
ΔE(exp)	0.57	—	0.10	—	0.26	0.16
Core	^{8}Li(2^+)	^{8}Be(0^+)	^{9}Be$(3/2^-)$	^{10}Be(0^+)	^{10}B(3^+)	^{11}B$(3/2^-)$
E_{core}(cal)	−14.50	−30.30	−32.09	−39.47	−41.07	−52.67
E_{core}(exp)		−30.84	−32.50		−41.06	−52.52
B_Λ(cal)	7.37	6.89	8.63	10.02	10.31	11.59
B_Λ(exp)	8.36	6.71	8.55		10.24	11.52

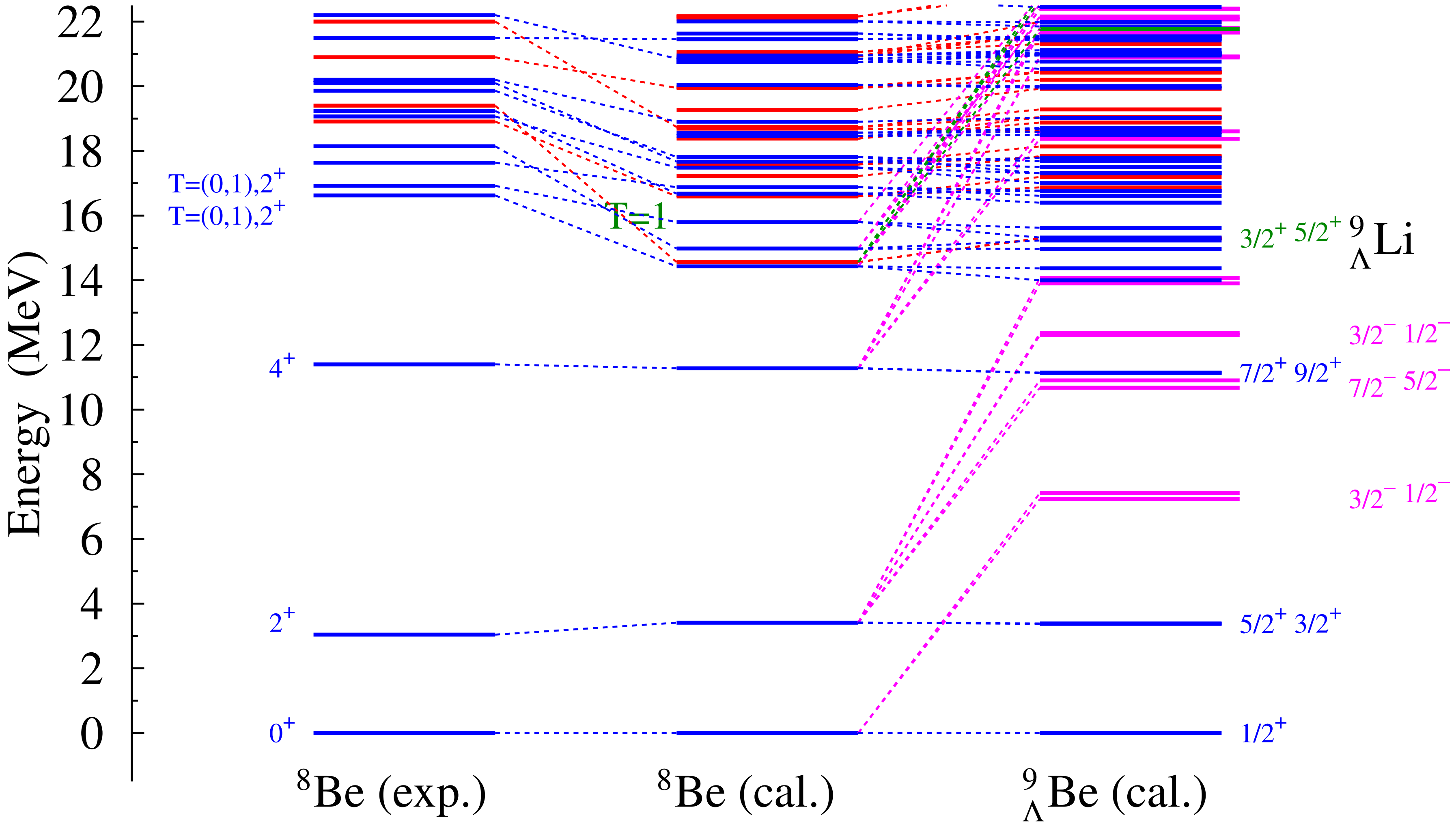
E **denotes the binding energy with respect to the** ^{4}He **core.**

The same two-body matrix elements of the ΛN **interaction are used in the** A = 9–12 **hypernucei.**

Our results of binding energies and doublet spacing are good agreement with the experimental data.

$A = 9$ hypernucleus, ${}^{9}_{\Lambda}\mathrm{Be}$

Results : Energy levels of ^{8}Be and $^{9}_{\Lambda}$Be

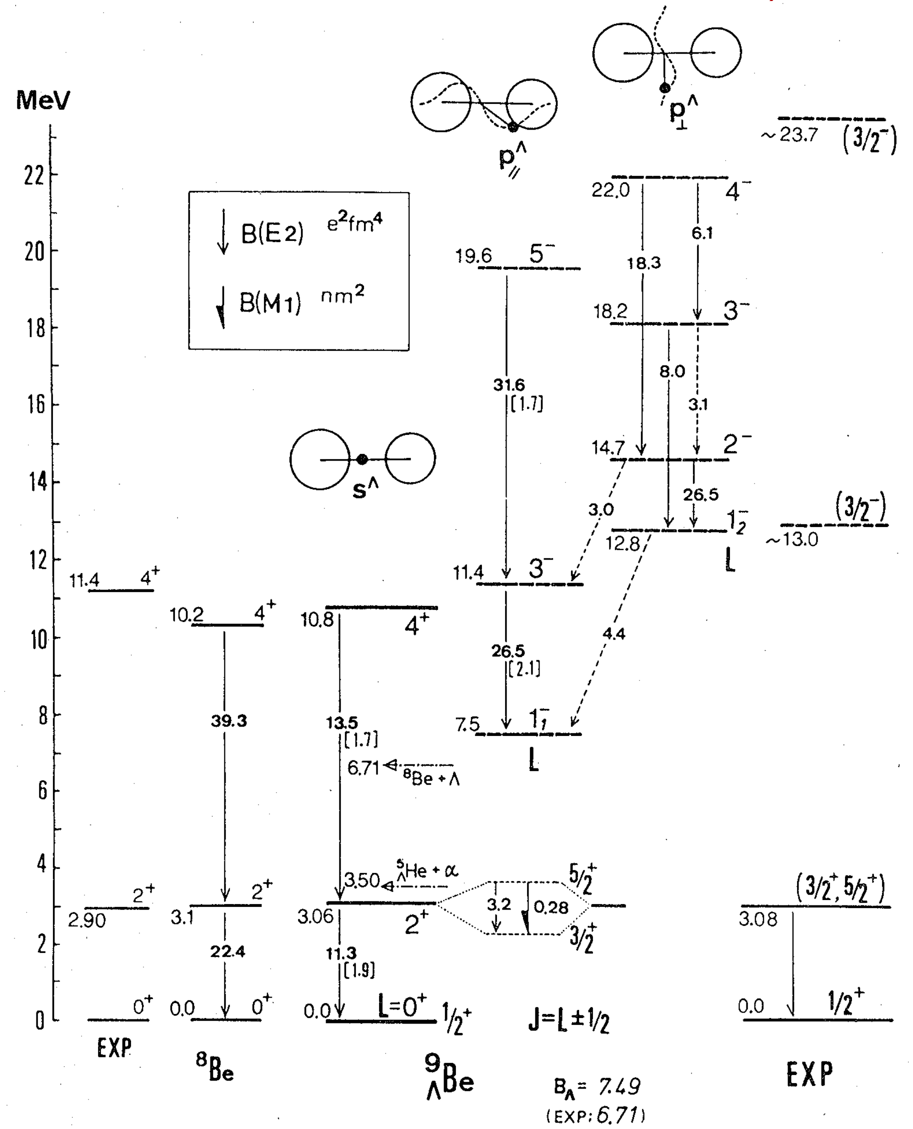


dominant configurations

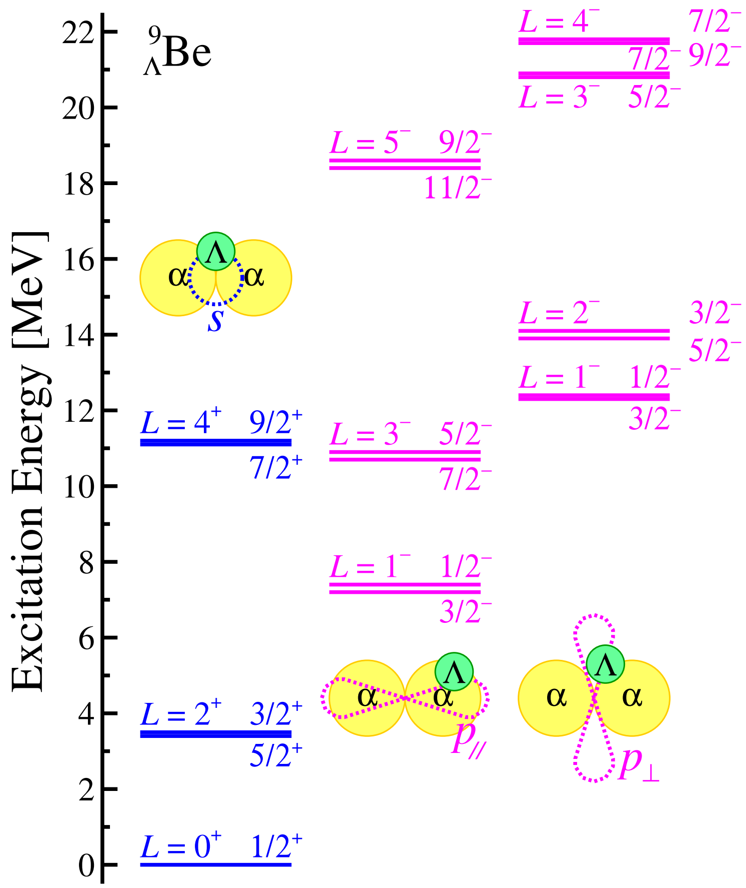
blue	J^{+}; $^{8}\mathrm{Be}(J^{+}_{\mathrm{core}}) \otimes \Lambda(0s)$
magenta	J^{-}; $^{8}\mathrm{Be}(J^{+}_{\mathrm{core}}) \otimes \Lambda(0p)$
red	J^{-}; $^{8}\mathrm{Be}(J^{-}_{\mathrm{core}}) \otimes \Lambda(0s)$

Results : Comparison with the cluster model (1) – Energy level –

Cluster model T. Motoba *et al.*, PTPS81, 42 (1985)

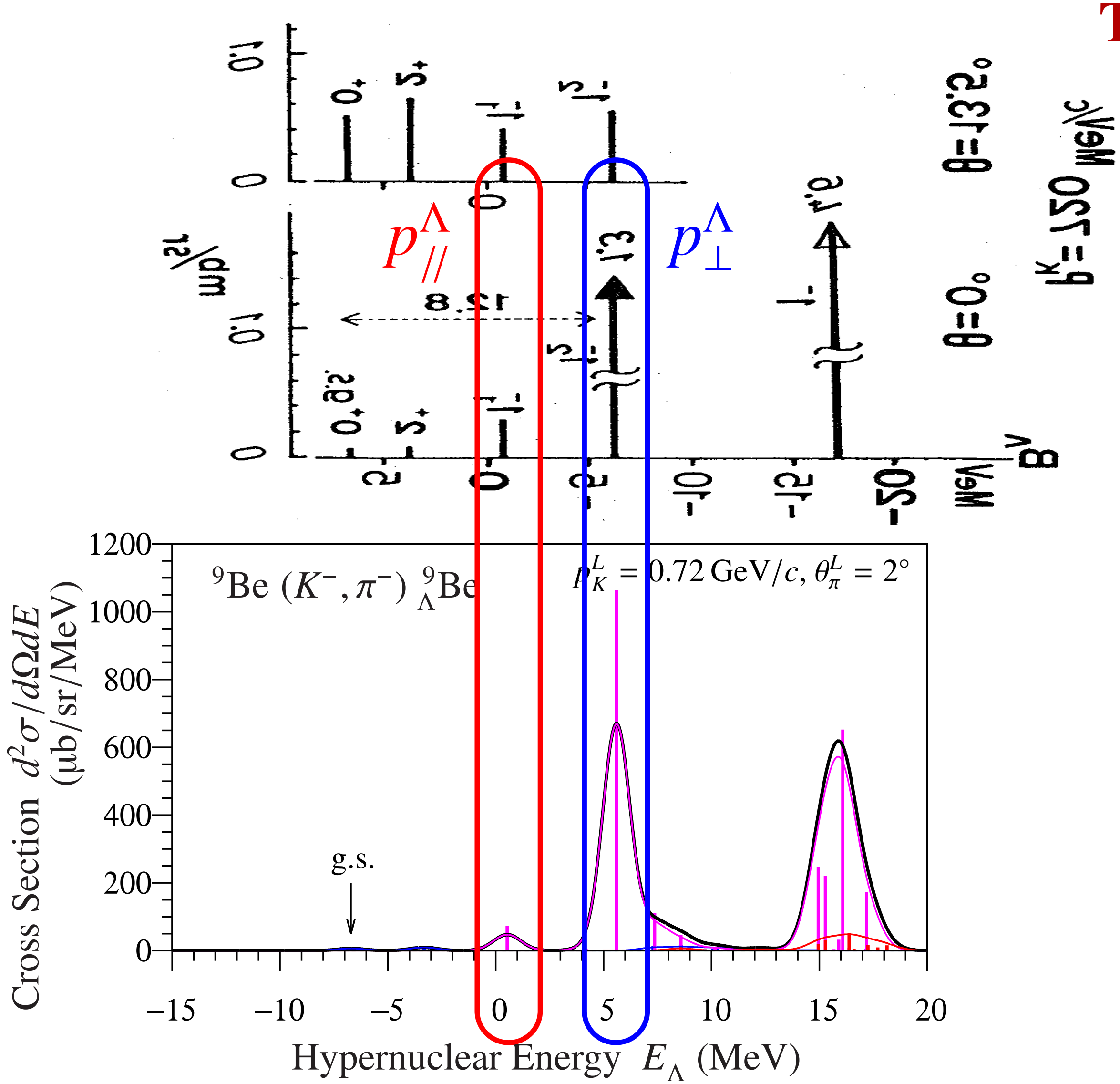


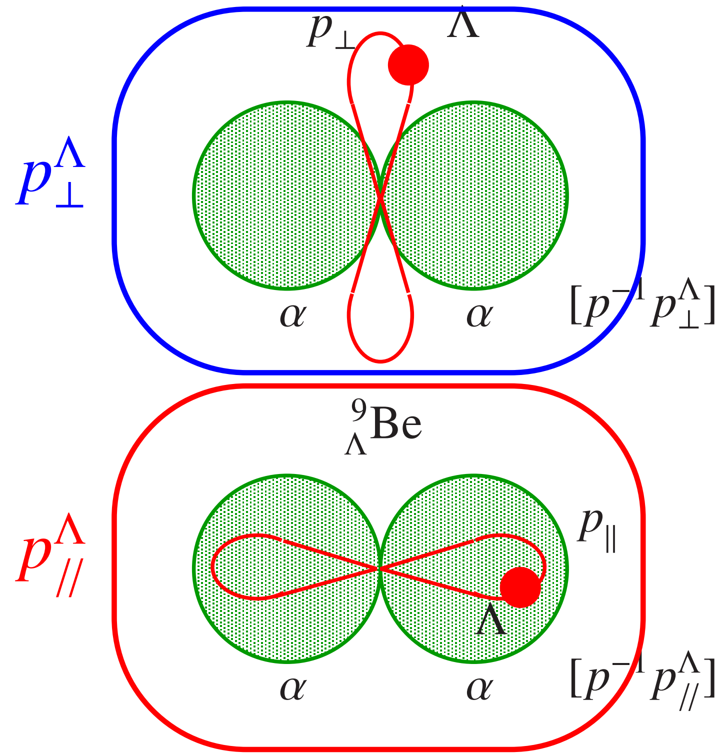
This work



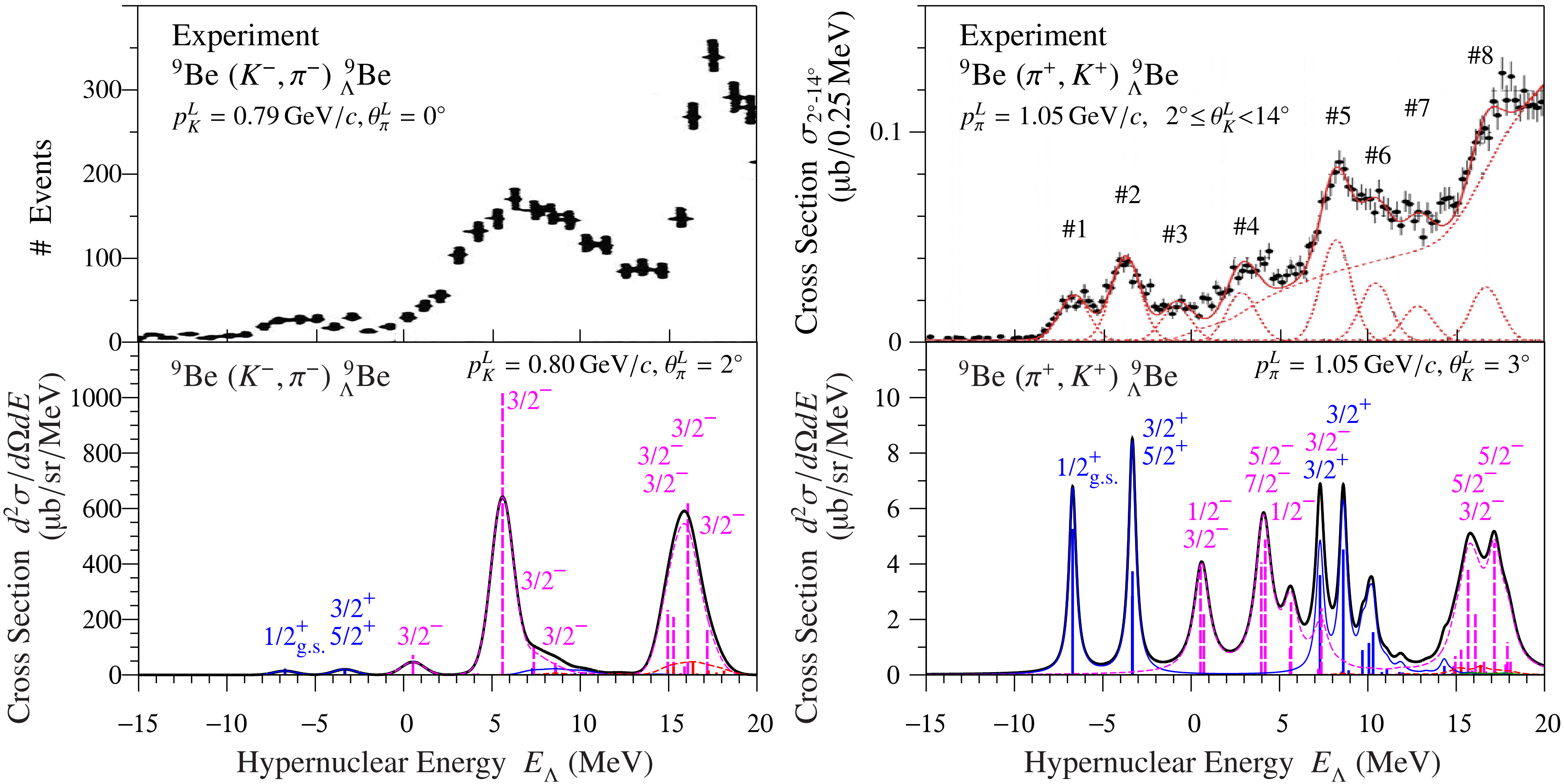
Results : Comparison to the cluster model (2) – Cross section –

T. Motoba *et al.*, PTPS81, 42 (1985)





Results : Cross sections of (K^-, π^-) and (π^+, K^+) reactions

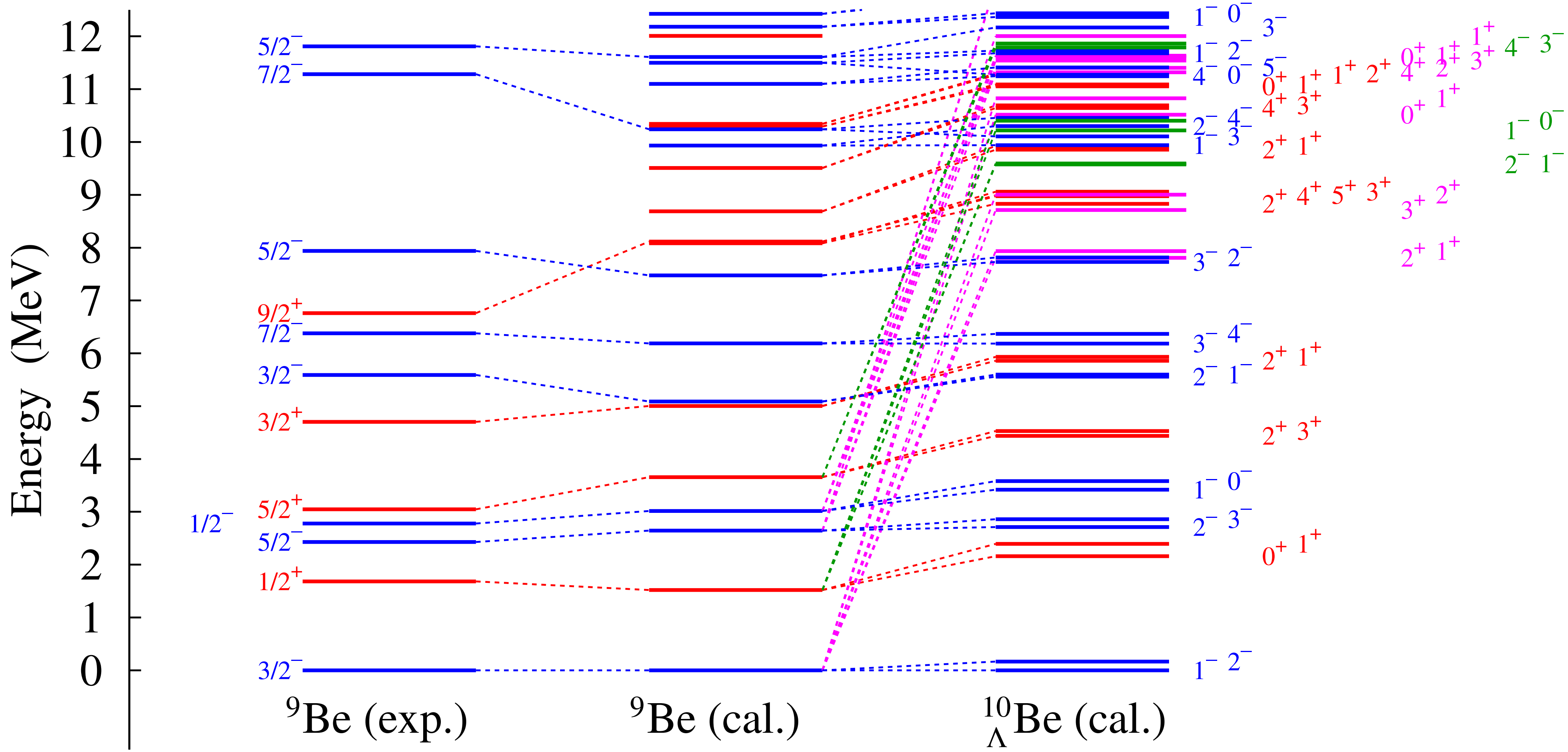


R. Bertini *et al.*, NPA368, 365 (1981)

O. Hashimoto and H. Tamura, PPNP57, 564 (2006)

$A = 10$ **hypernucleus,** $^{10}_{\Lambda}\mathrm{Be}$

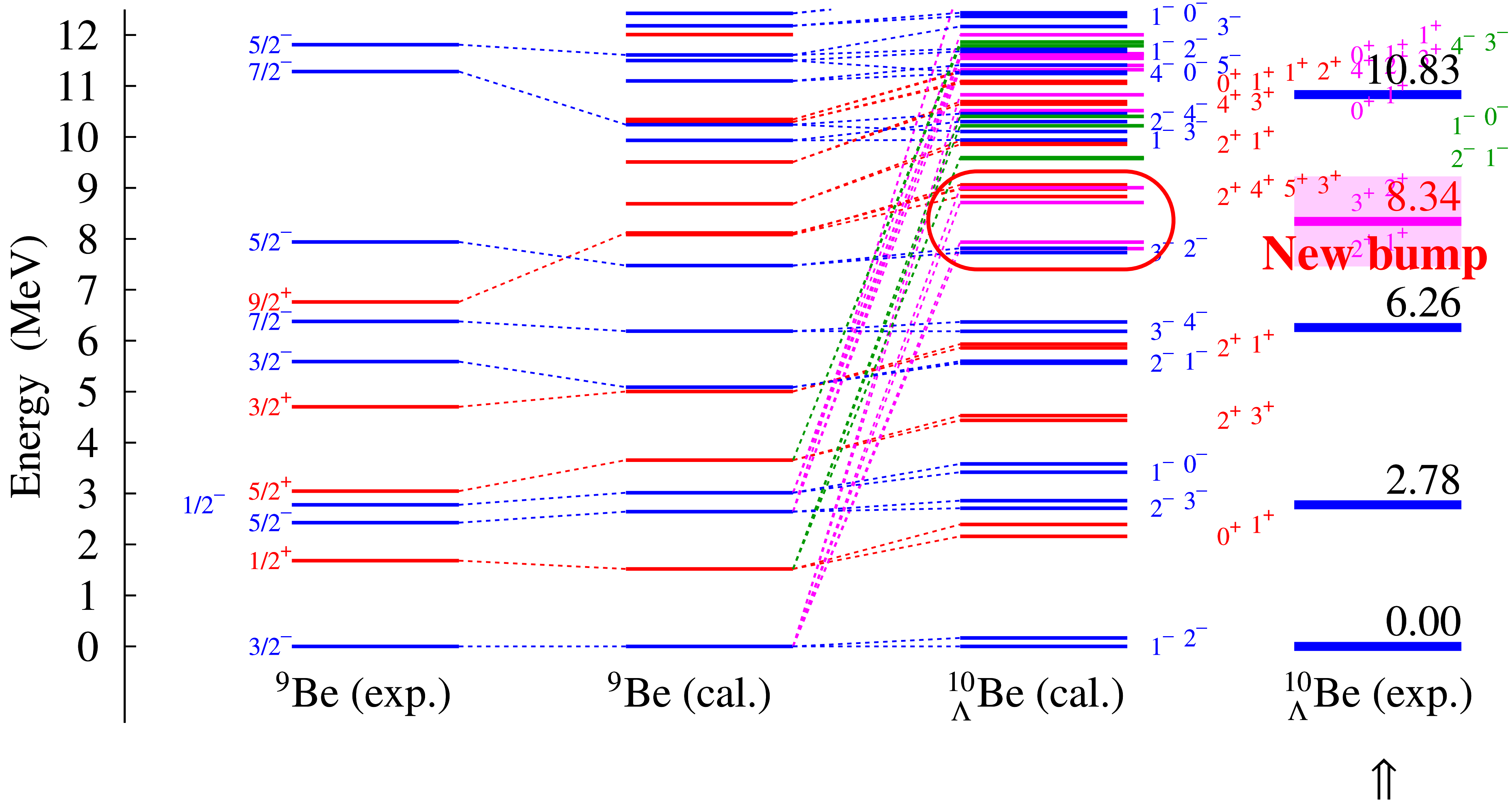
Results : Energy levels of ^{9}Be and $^{10}_{\Lambda}$Be



dominant configurations

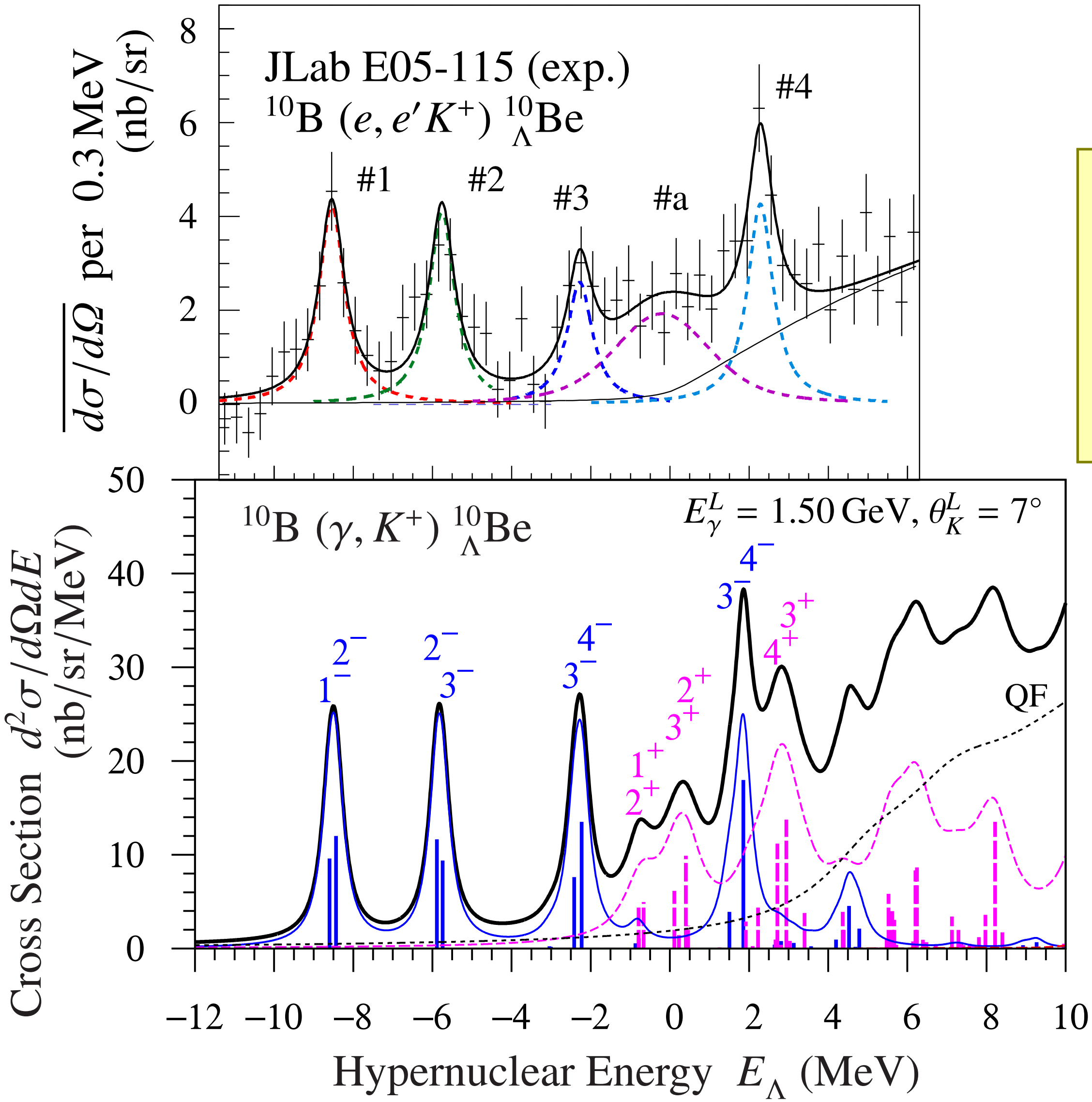
blue	J^-; $^{9}\mathrm{Be}(J^-_{\mathrm{core}}) \otimes \Lambda(0s)$	**green**	J^+; $^{9}\mathrm{Be}(J^+_{\mathrm{core}}) \otimes \Lambda(0p)$
magenta	J^+; $^{9}\mathrm{Be}(J^-_{\mathrm{core}}) \otimes \Lambda(0p)$	**red**	J^+; $^{9}\mathrm{Be}(J^+_{\mathrm{core}}) \otimes \Lambda(0s)$

Results : Energy levels of $^{10}_{\Lambda}$Be (comparison with JLab experiments)



T. Gogami *et al.*, PRC93, 034314 (2016)

Results : Cross sections of the ^{10}B (γ, K^+) $^{10}_{\Lambda}$Be reaction (1)



Recent experimental result

T. Gogami *et al.*, PRC93, 034314 (2016)

For hypernucleus $^{10}_{\Lambda}$Be
(1) 1*p*-1*h* (1$\hbar\omega$) core excitation
(2) Configration mixing by ΛN int.
are taken into account

DWIA calculation by using Saclay-Lyon model A

Our new calculation reproduces the four major peaks (#1, #2, #3, #4).

Our new calculation explains the new bump (a) as a sum of cross sections of some J^+ states.

Results : Cross sections of the $^{10}\mathrm{B}\ (\gamma, K^+)\ ^{10}_{\Lambda}\mathrm{Be}$ reaction (2)

E_γ = 1.5 GeV
θ = 7 deg

EXP = T. Gogami et al, PRC93 (2016)

^{9}Be (J_i)

J_i	E_i (exp) C2S	E_i (cal) C2S
3/2⁻	0.000 / 1.0(rel)	0.000 / 1.0(rel)
5/2⁻	2.429 / 0.958	2.644 / 1.020
7/2⁻	6.380 / 0.668	6.189 / 0.942
7/2⁻	11.283 / 1.299	10.241 / 1.355

$_{\Lambda}^{10}$Be (J_k) CAL

J_k	E_x [MeV]	$-B_\Lambda$ [MeV]	$d\sigma/d\Omega$ [nb/sr]	
1⁻	0.000	−8.600	9.609	21.62
2⁻	0.165	−8.435	12.008	
2⁻	2.712	−5.888	11.654	21.05
3⁻	2.860	−5.740	9.391	
3⁻	6.183	−2.417	7.625	21.13
4⁻	6.370	−2.230	13.505	
2⁺(3)	7.807	−0.793	4.495	9.46
1⁺(3)	7.935	−0.665	4.968	
3⁺(2)	8.712	0.112	6.150	19.91 (29.37)
2⁺(4)	8.828	0.228	1.431	
2⁺(5)	9.002	0.402	9.893	
3⁺(3)	9.059	0.459	2.434	
3⁻	10.105	1.505	3.913	21.90
4⁻	10.455	1.855	17.985	
1⁺(5)	10.828	2.228	4.598	29.54 (51.44)
4⁺(3)	11.318	2.718	11.185	
3⁺(5)	11.543	2.943	13.759	

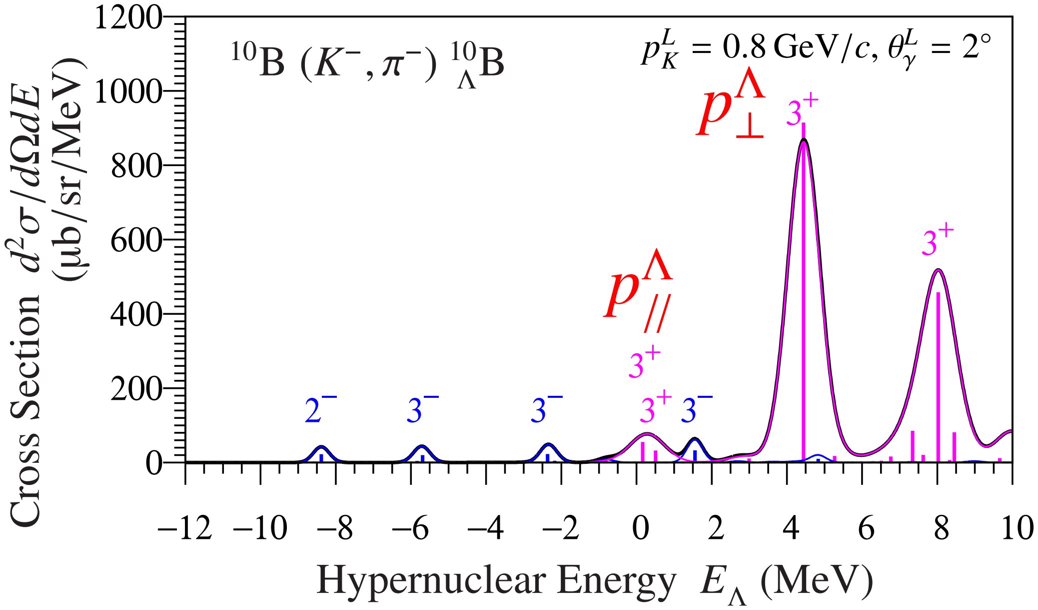
EXP / Fit I

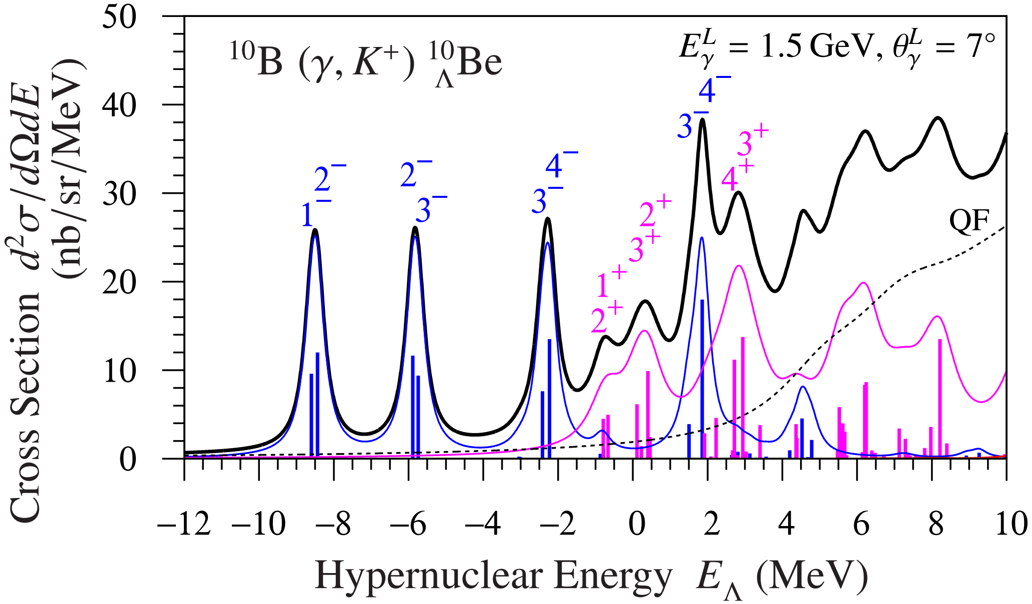
exp peak	E_x [MeV]	$-B_\Lambda$ [MeV]	$d\sigma/d\Omega$ [nb/sr]
#1	0.00	−8.55±0.07	**17.0±0.5**
#2	2.78±0.11	−5.76±0.09	**16.5±0.5**
#3	6.26±0.16	−2.28±0.14	**10.5±0.3**
#a	8.34±0.41	−0.20±0.40	**23.2±0.7**
#4	10.83±0.10	2.28±0.07	**17.2±0.5**

Results : Configrations of J^+ states corresponding to the new bump

$J^\pi_n(-B_\Lambda[\text{MeV}])$ XS [nb/sr]	$[J^\pi_{\text{core}}]j^\Lambda$	$[J^\pi_{\text{core}}]j^\Lambda$	$[J^\pi_{\text{core}}]j^\Lambda$
$2^+_3(-0.739)$ 4.49		$[3/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 82.5%	$[5/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 15.8%
$1^+_3(-0.665)$ 4.97		$[3/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 79.5%	$[5/2^-_1]p^\Lambda_{3/2}$ 17.9%
$2^+_4(0.228)$ 1.43	$[5/2^+_2]s^\Lambda_{1/2}$ 87.5%	$[3/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 9.4%	$[5/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 2.4%
$2^+_5(0.402)$ 9.89	$[5/2^+_2]s^\Lambda_{1/2}$ 11.3%	$[3/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 70.9%	$[5/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 10.8%
$3^+_2(0.112)$ 6.15	$[5/2^+_2]s^\Lambda_{1/2}$ 31.6%	$[3/2^-_1]p^\Lambda_{3/2}$ 55.4%	$[5/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 9.7%
$3^+_3(0.459)$ 2.43	$[5/2^+_2]s^\Lambda_{1/2}$ 67.5%	$[3/2^-_1]p^\Lambda_{3/2}$ 27.1%	$[5/2^-_1](p_{3/2}p_{1/2})^\Lambda$ 2.7%

Results : Cross sections of the $^{10}\mathrm{B}\,(K^-,\pi^-)\,^{10}_{\Lambda}\mathrm{B}$ reaction (1)





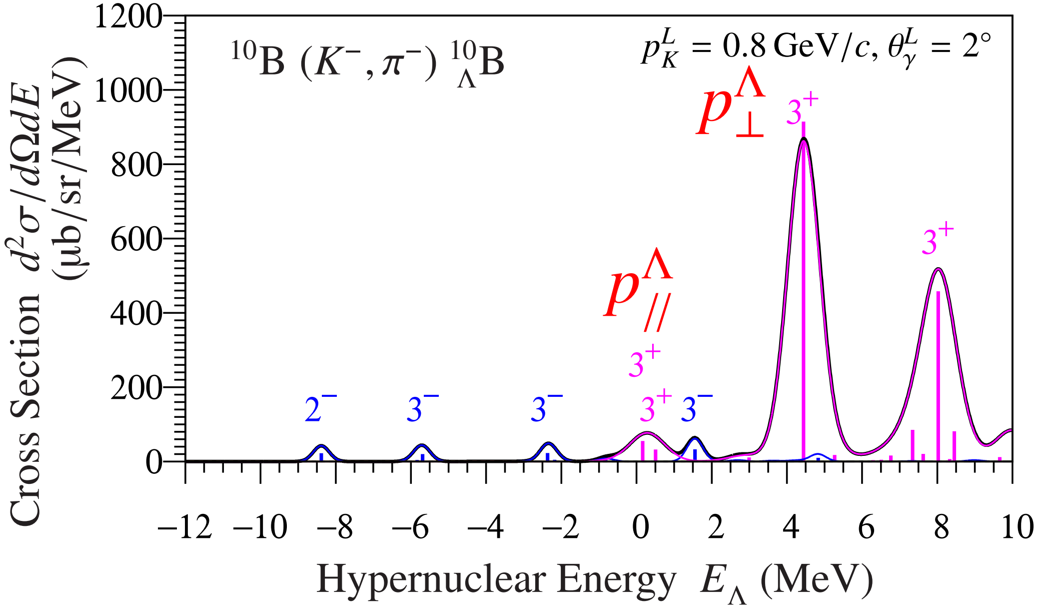
In the (K^-,π^-) reaction, the large peak at $E_\Lambda = 4.4\,\mathrm{MeV}$ is a p-substitutional state via the $p^N_{3/2} \rightarrow p^\Lambda_{3/2}$, which is strongly excited by recoilless reaction.

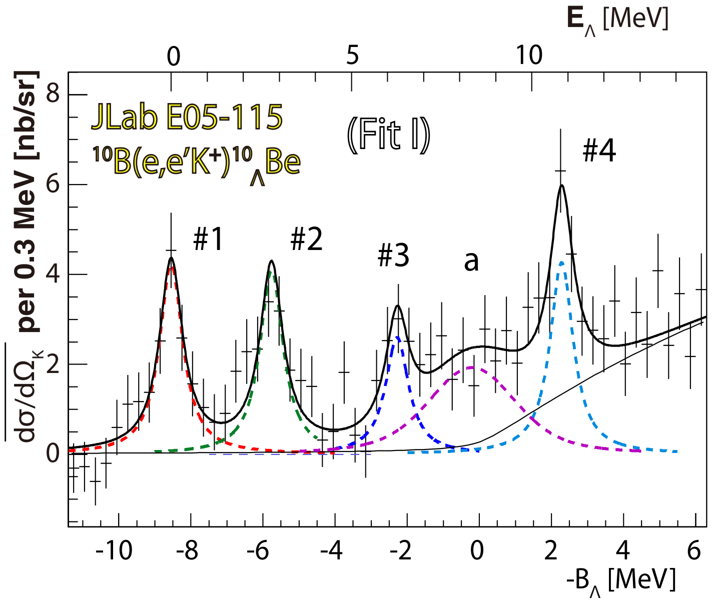
The small peak at $E_\Lambda = 0\,\mathrm{MeV}$ corresponds to the new bump and is explained as a mixture of s^Λ and p^Λ states.

The large peak at $E_\Lambda = 4.4\,\mathrm{MeV}$ in $^{10}_{\Lambda}\mathrm{Be}$ corresponds to the $[p^{-1}p^\Lambda_\perp]$ state in $^{9}_{\Lambda}\mathrm{Be}$ ($^9\mathrm{Be}$ analog state).

The small peak at $E_\Lambda = 0\,\mathrm{MeV}$ in $^{10}_{\Lambda}\mathrm{Be}$ corresponds to the $[p^{-1}p^\Lambda_{//}]$ state in $^{9}_{\Lambda}\mathrm{Be}$.

Results : Cross sections of the $^{10}B\ (K^-, \pi^-)\ ^{10}_{\Lambda}B$ reaction (2)





CONCLUDE:

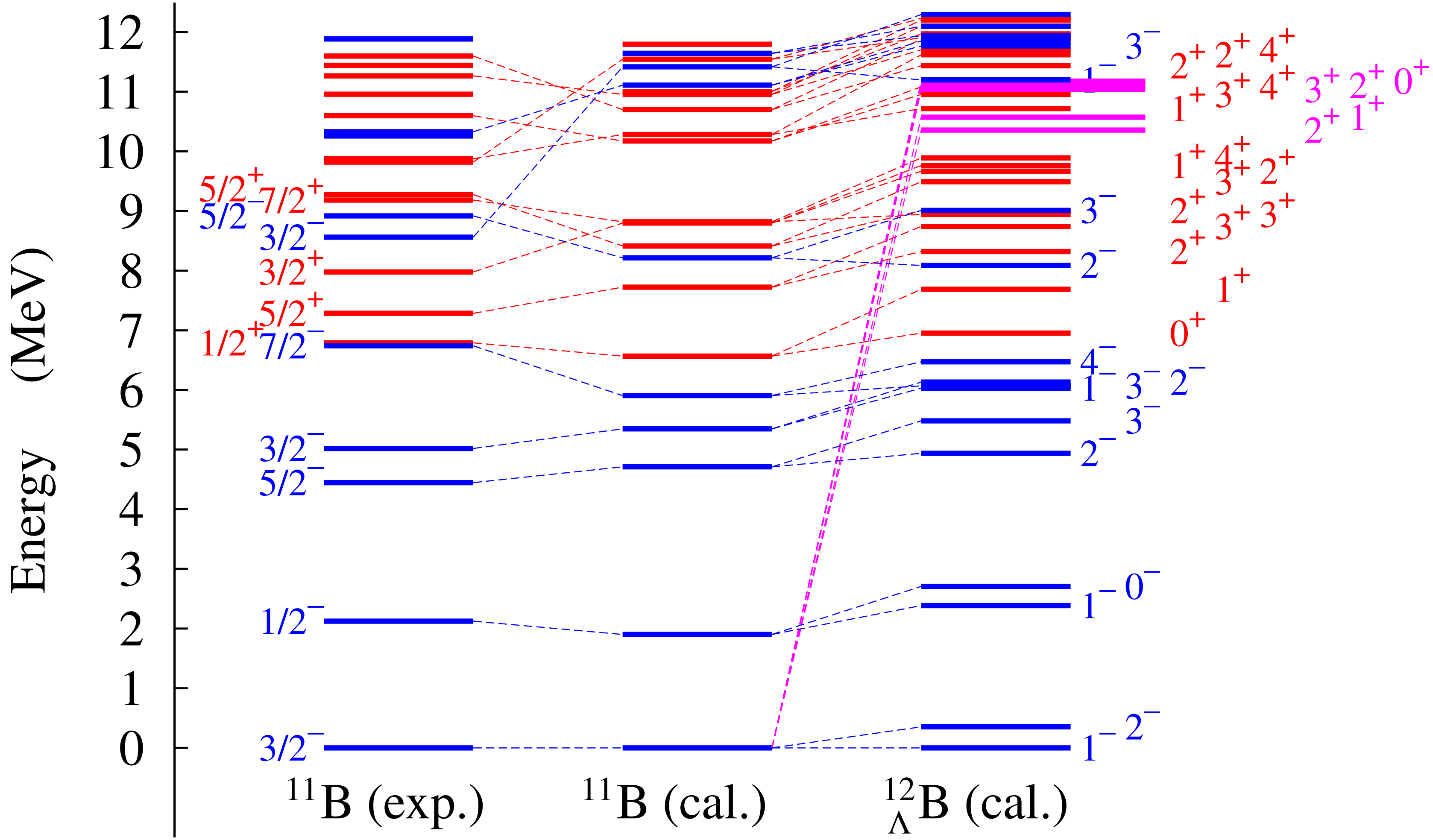
$\alpha\alpha$-like core deformation causes splitting of p^Λ-states, then low-energy $p^\Lambda_{//}$ can mix with s^Λ-states.

$$[^9\mathrm{Be}(J^-) \times \Lambda(p_{//})] + [^9\mathrm{Be}(J^+) \times \Lambda(s)]$$

These parity-mixed wave functions at $E_\Lambda = 0$ MeV can explain the extra peak #a.

$A = 12$ hypernucleus, ${}^{12}_{\Lambda}\mathrm{B}$

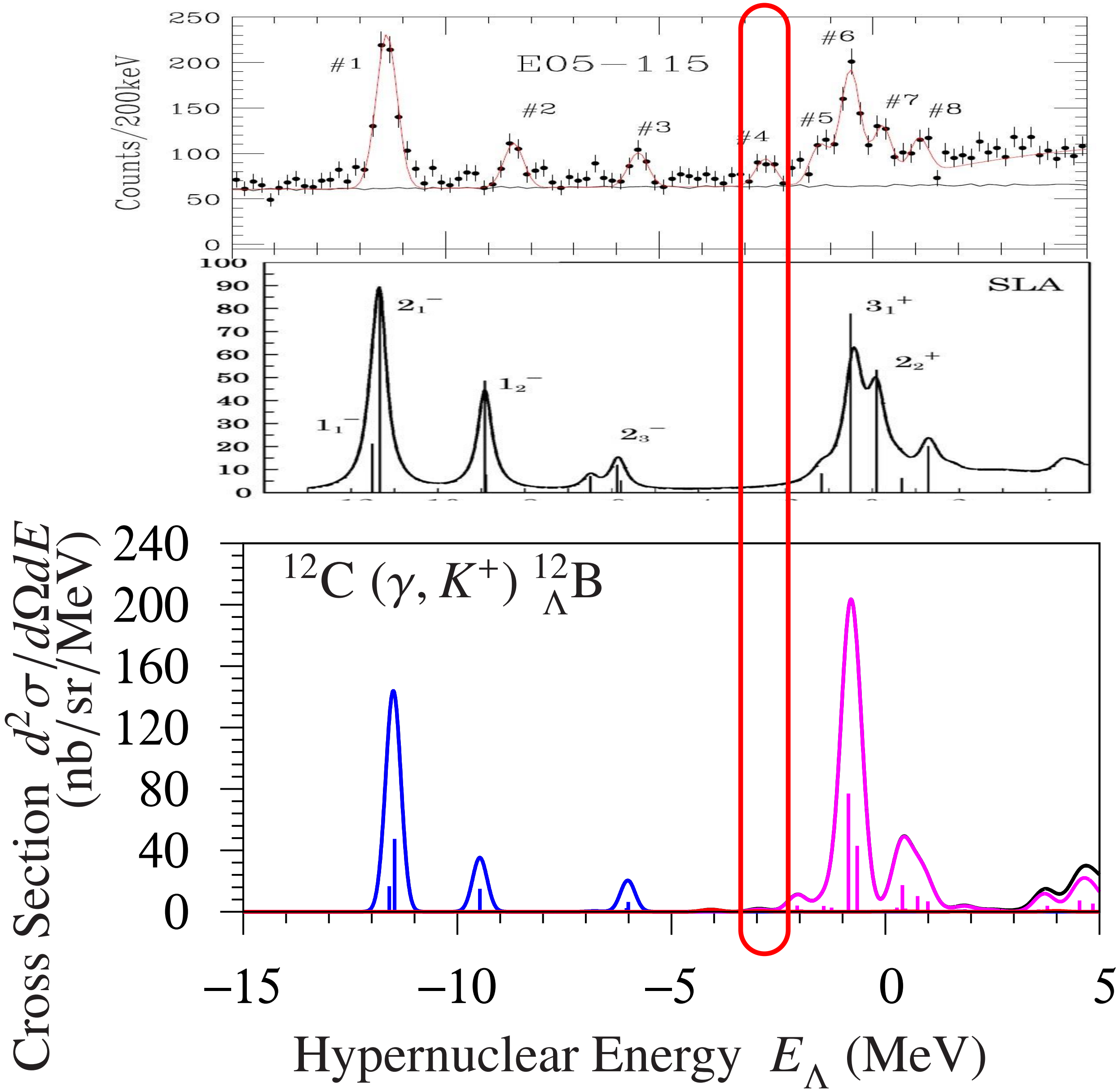
Results : Energy levels of ^{11}B and $^{12}_{\Lambda}$B



dominant configurations

blue	J^-; $^{11}\mathrm{B}(J^-_{\mathrm{core}}) \otimes \Lambda(0s)$
magenta	J^+; $^{11}\mathrm{B}(J^-_{\mathrm{core}}) \otimes \Lambda(0p)$
red	J^+; $^{11}\mathrm{B}(J^+_{\mathrm{core}}) \otimes \Lambda(0s)$

Results : Cross sections of the ^{12}C (γ, K^+) $^{12}_{\Lambda}$B reaction



JLab Hall C, E05-115
L. Tang *et al.*,
PRC90, 034320 (2014)

Theoretical calculation
T. Motoba *et al.*,
PTPS185, 224 (2010)

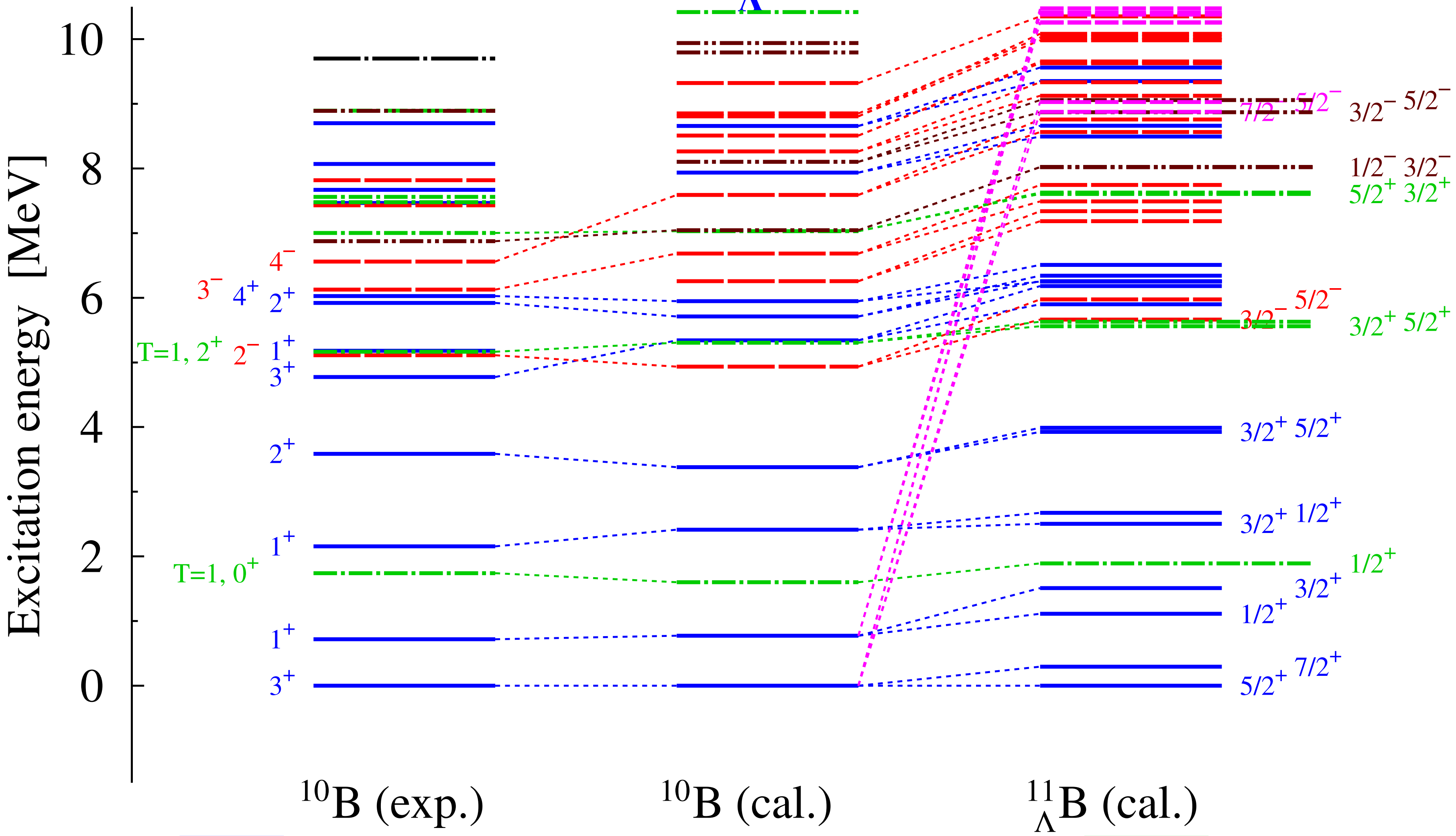
New results show no peak for #4.

p^Λ-state does not split because the core is spherical.

A new question if the extra peak #4 in Hall C experiment can survive in future experiment with better statistics

$A = 11$ hypernucleus, $^{11}_{\Lambda}\mathrm{B}$

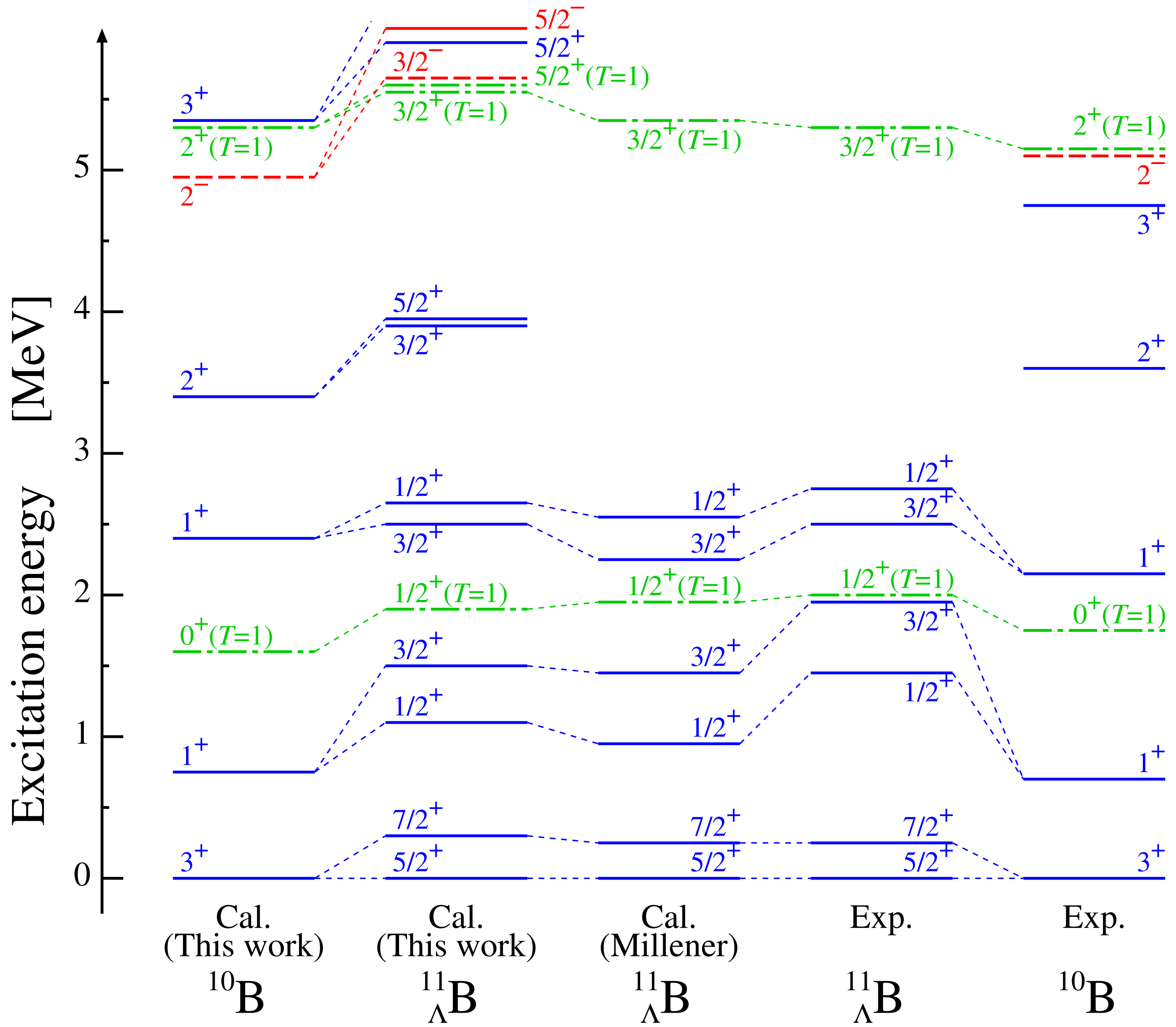
Results : Energy levels of ^{10}B and $^{11}_{\Lambda}$B (1)



dominant configurations

blue	$T\!=\!0, J^+;\ J^+_{\rm core}\otimes s_\Lambda$	**green**	$T\!=\!1, J^+;\ J^+_{\rm core}\otimes s_\Lambda$
red	$T\!=\!0, J^-;\ J^-_{\rm core}\otimes s_\Lambda$	**brown**	$T\!=\!1, J^-;\ J^-_{\rm core}\otimes s_\Lambda$
magenta	$T\!=\!0, J^-;\ J^+_{\rm core}\otimes p_\Lambda$		

Results : Energy levels of ^{10}B and $^{11}_{\Lambda}$B (2)



3rd and 4th column

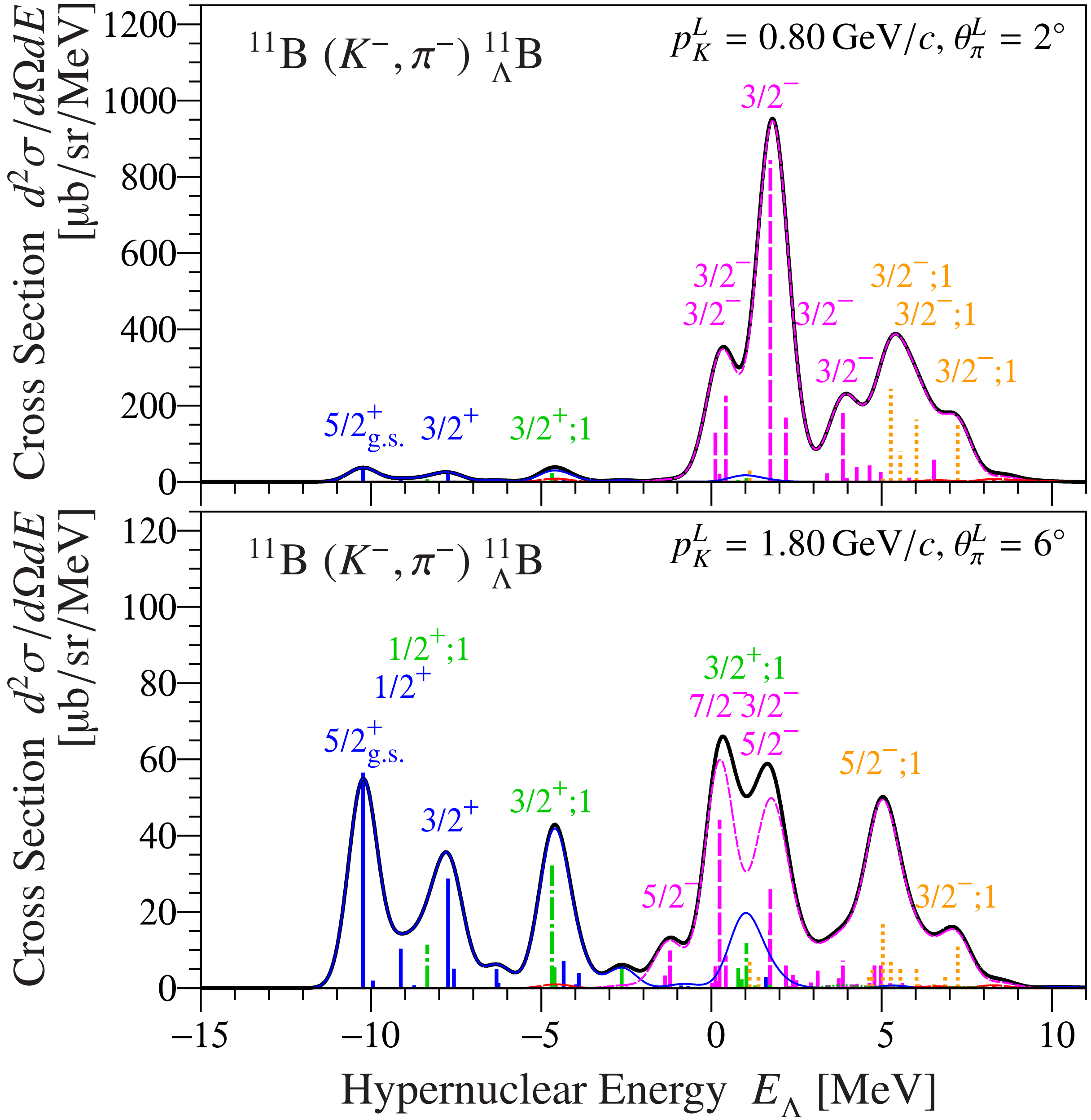
D. J. Millener, NPA804, 84 (2008).

Our result of the energy of the 2nd doublet $(1/2^+, 3/2^+)$ **is almost the same as Millener's result and is** 300 keV **lower than the experimental result.**

For this doublet, effect of the LS **term of the** ΛN **int. is suggested.**

D. J. Millener, NPA804, 84 (2008).

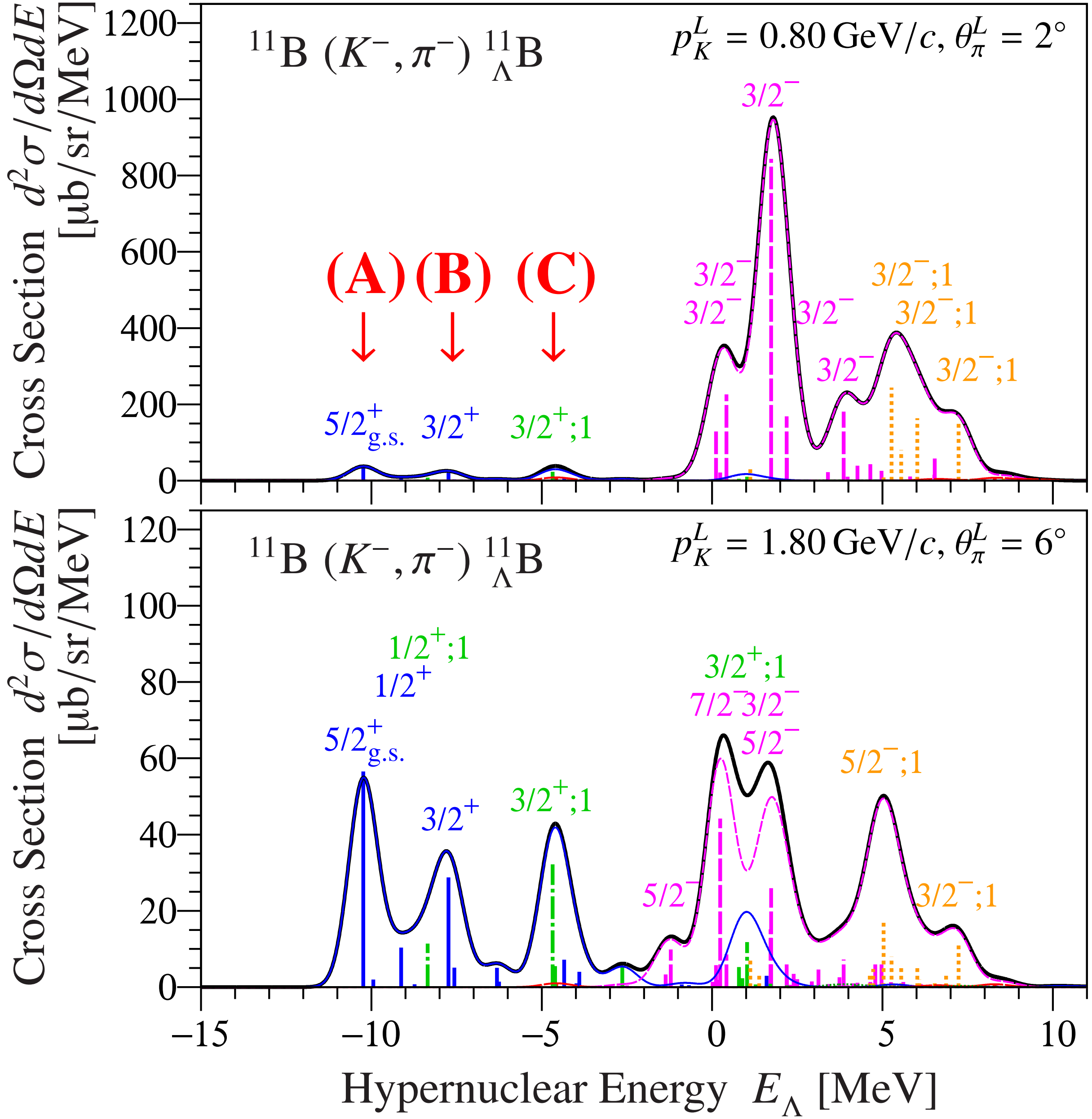
Results : Cross sections of the $^{11}\mathrm{B}\,(K^-,\pi^-)\,^{11}_{\Lambda}\mathrm{B}$ reaction (1)



FWHM = 1.0 MeV

- **blue** $T=0,\ J^+;\ J^+_{\rm core}\otimes s_\Lambda$
- **green** $T=1,\ J^+;\ J^+_{\rm core}\otimes s_\Lambda$
- **magenta** $T=0,\ J^-;\ J^+_{\rm core}\otimes p_\Lambda$
- **orange** $T=1,\ J^-;\ J^+_{\rm core}\otimes p_\Lambda$

Results : Cross sections of the $^{11}\mathrm{B}\,(K^-,\pi^-)\,^{11}_{\Lambda}\mathrm{B}$ reaction (2)



(A) $5/2^+_{\mathrm{g.s.}}$

$^{10}\mathrm{B}(3^+_{\mathrm{g.s.}}) \otimes s^{\Lambda}_{1/2}$ 99.5%

(B) $3/2^+_2$

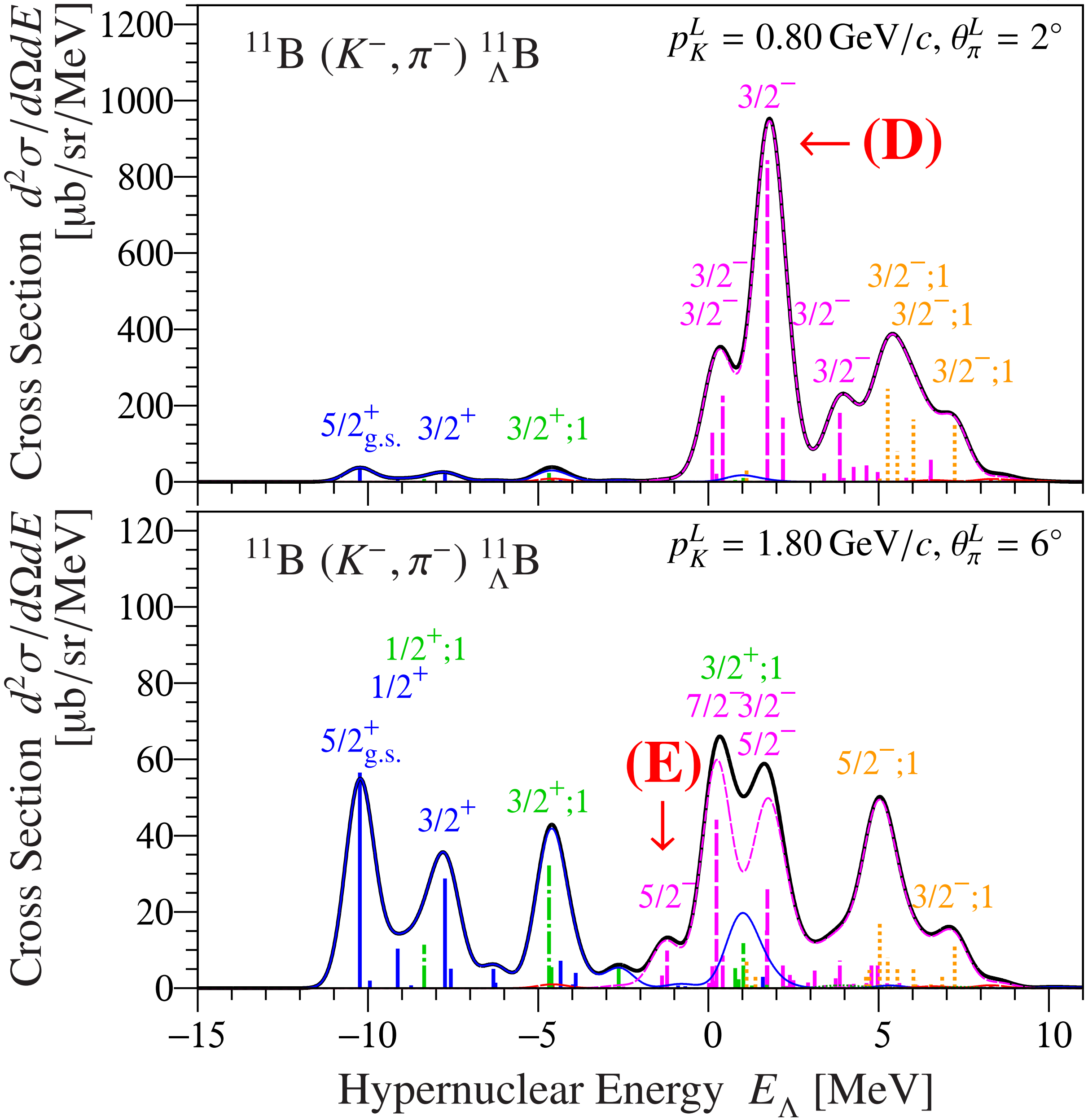
$^{10}\mathrm{B}(1^+_2) \otimes s^{\Lambda}_{1/2}$ 98.0%

(C) $3/2^+_1(T{=}1)$

$^{10}\mathrm{B}(2^+_1;T{=}1) \otimes s^{\Lambda}_{1/2}$ 99.3%

ΛN int. is weak coupling for s^Λ

Results : Cross sections of the ^{11}B (K^-, π^-) $^{11}_{\Lambda}$B reaction (3)



(D) $3/2^-$

$^{10}\mathrm{B}(3^+_{\mathrm{g.s.}}) \otimes p^\Lambda_{3/2}$ 51.4%

$^{10}\mathrm{B}(1^+_2) \otimes p^\Lambda_{1/2}$ 23.0%

$^{10}\mathrm{B}(3^+_2) \otimes p^\Lambda_{3/2}$ 9.4%

→ **substitutional state**

(E) $5/2^-$

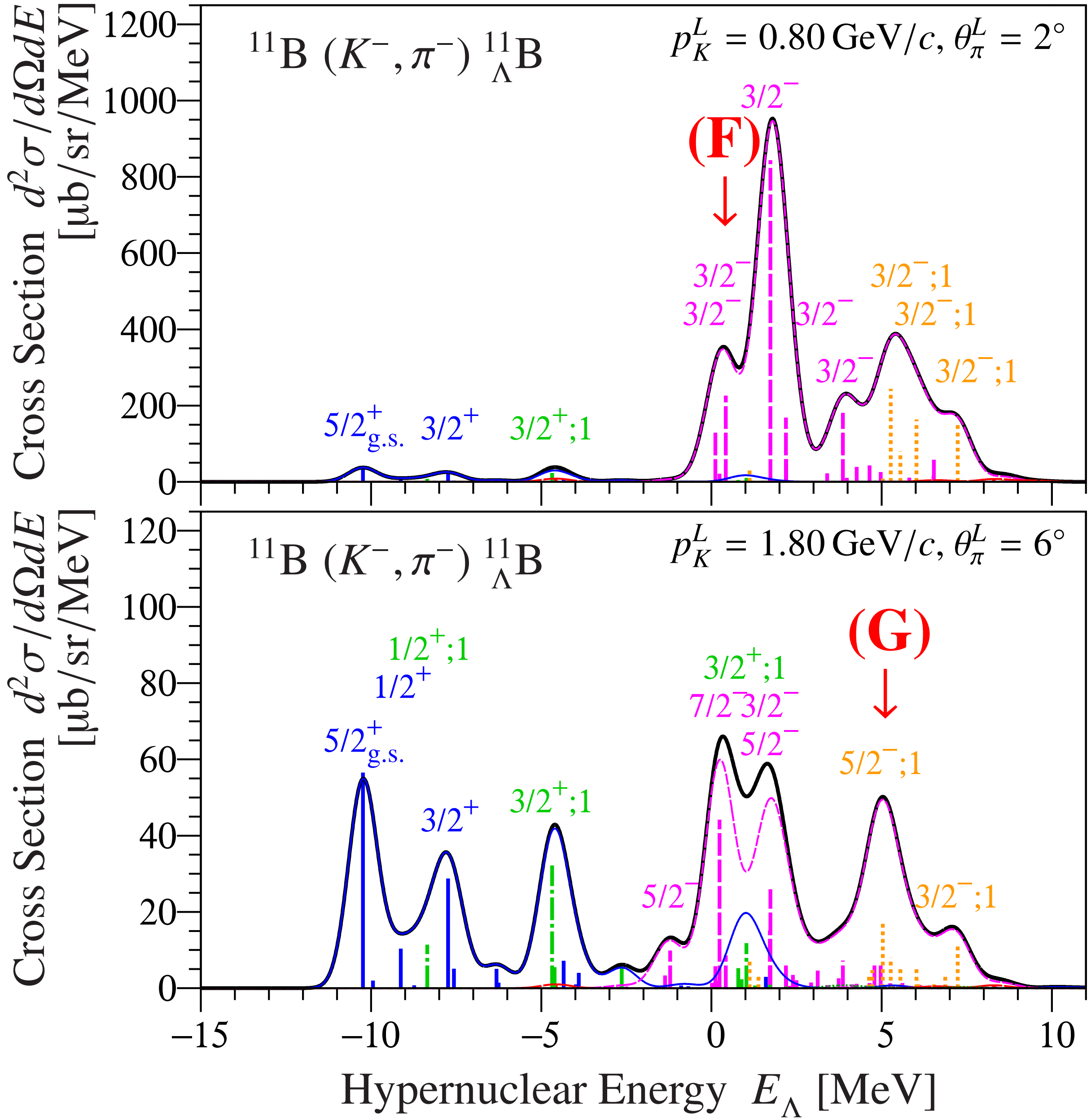
$^{10}\mathrm{B}(3^+_{\mathrm{g.s.}}) \otimes p^\Lambda_{3/2}$ 56.1%

$^{10}\mathrm{B}(3^+_{\mathrm{g.s.}}) \otimes p^\Lambda_{1/2}$ 35.7%

→ $p_{//}$ **state**

ΛN int. is strong coupling for p^Λ as in the case of $^{9}_{\Lambda}$Be

Results : Cross sections of the $^{11}B\,(K^-,\pi^-)\,^{11}_{\Lambda}B$ reaction (4)



(F) $3/2^-$

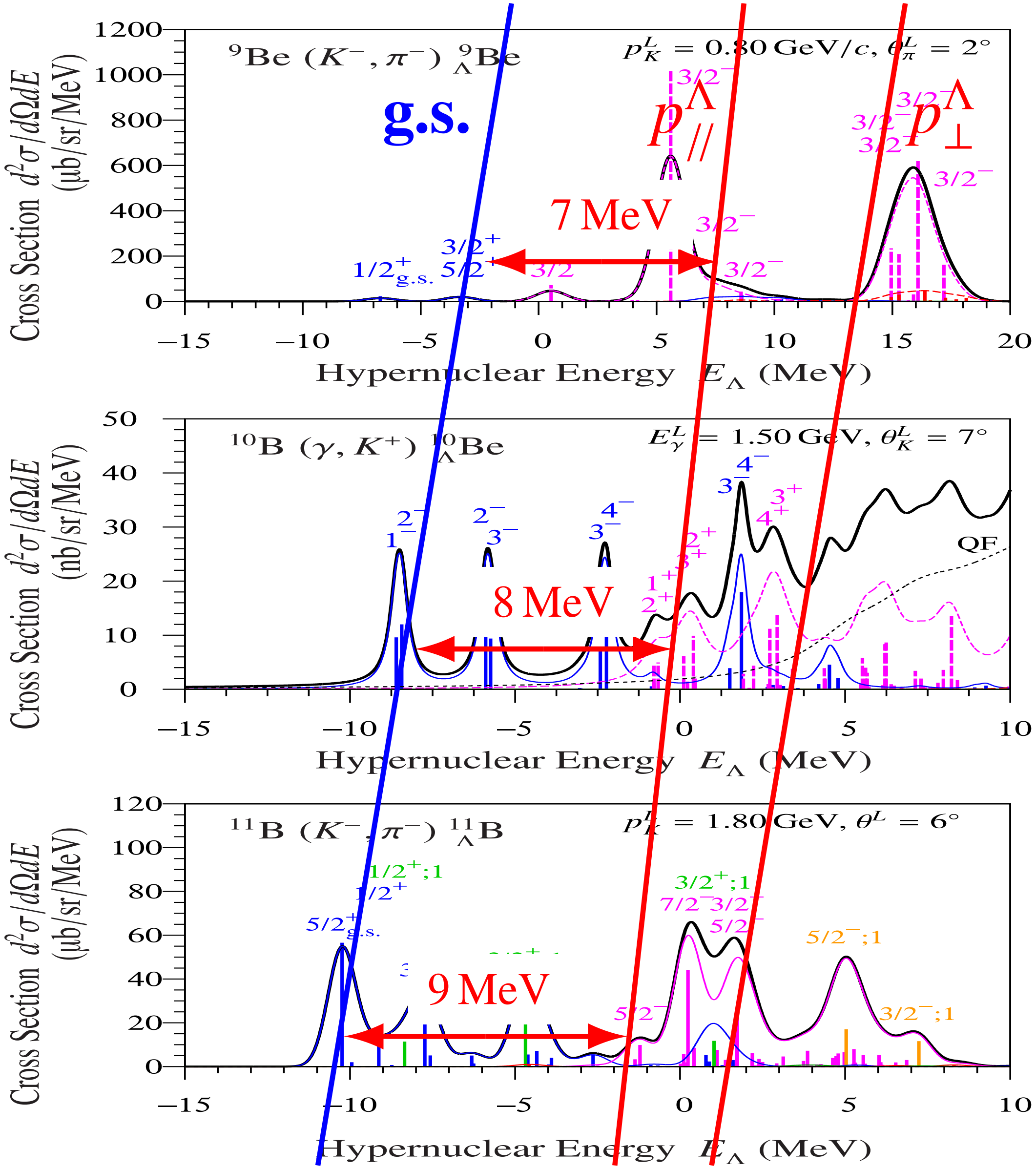
$^{10}B(2^-_3)\otimes s^\Lambda_{1/2}$	31.6%
$^{10}B(3^+_{g.s.})\otimes p^\Lambda_{3/2}$	11.1%
$^{10}B(1^+_1)\otimes p^\Lambda_{1/2}$	46.9%

(G) $5/2^-(T=1)$

$^{10}B(3^-_3;T=1)\otimes s^\Lambda_{1/2}$	21.2%
$^{10}B(2^+_1;T=1)\otimes p^\Lambda_{3/2}$	29.3%
$^{10}B(2^+_1;T=1)\otimes p^\Lambda_{1/2}$	42.0%

large parity mixing in the core nucleus

Results : Energy of $p_{//}$-state



The p^Λ-state splits into $p_\perp$- and $p_{//}$-states due to the strong coupling with nuclear core deformation.

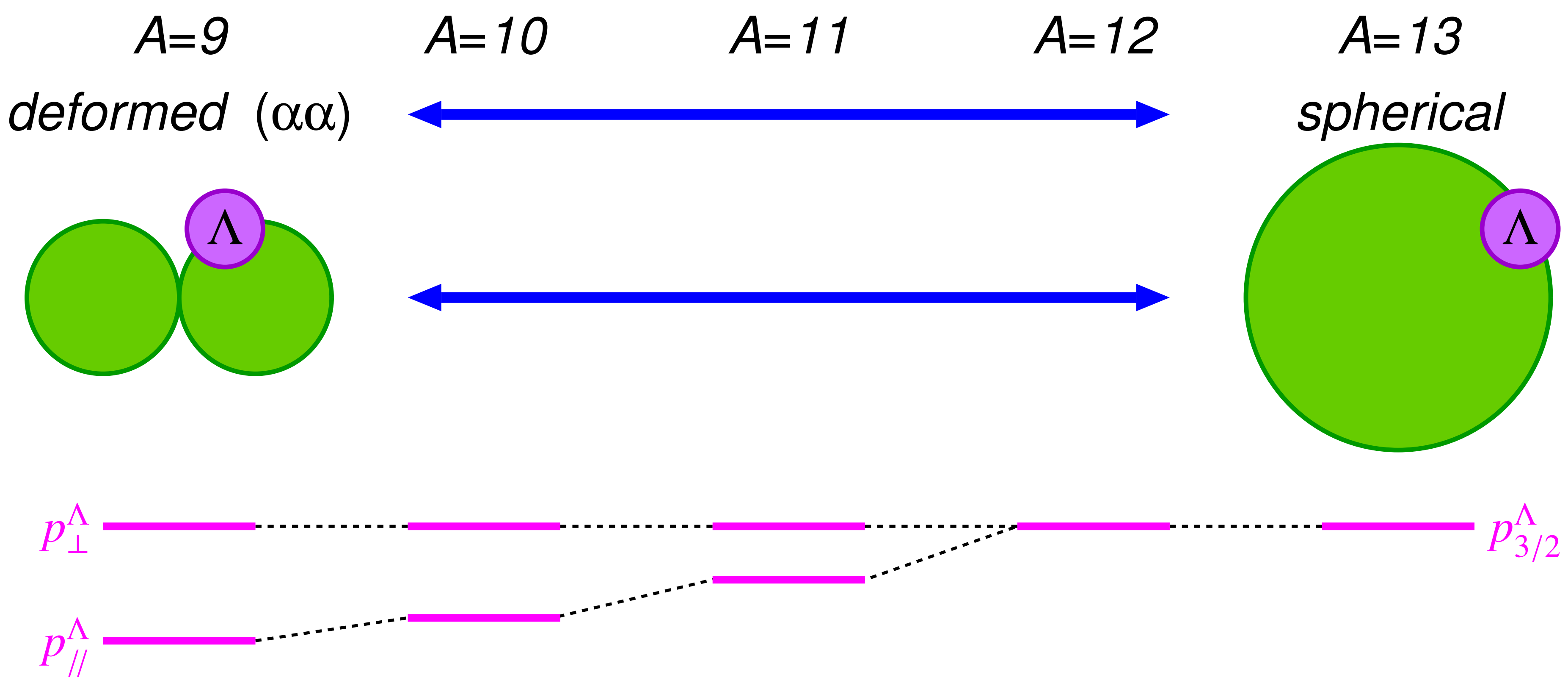
In $^9_\Lambda$Be, the enregy of $p^\Lambda_{//}$-state comes down to $E_x \approx 7\,$MeV from the Λ single-particle energy difference $\varepsilon^\Lambda_p - \varepsilon^\Lambda_s \approx 11\,$MeV.

The bump at $E_x \approx 8\,$MeV in the cross sections of $^{10}_\Lambda$Be corresponds to the $p^\Lambda_{//}$-state.

In the cross sections of $^{11}_\Lambda$B, the small $5/2^-$ peak at $E_x \approx 9\,$MeV corresponds to the $p^\Lambda_{//}$-state.

The energy splitting between $p_\perp$- and $p_{//}$-states in $^{11}_\Lambda$B is smaller than that in $^9_\Lambda$Be, which is due to the small deformation of the nuclear core in $^{11}_\Lambda$B.

p^Λ state in the sperical nuclear core

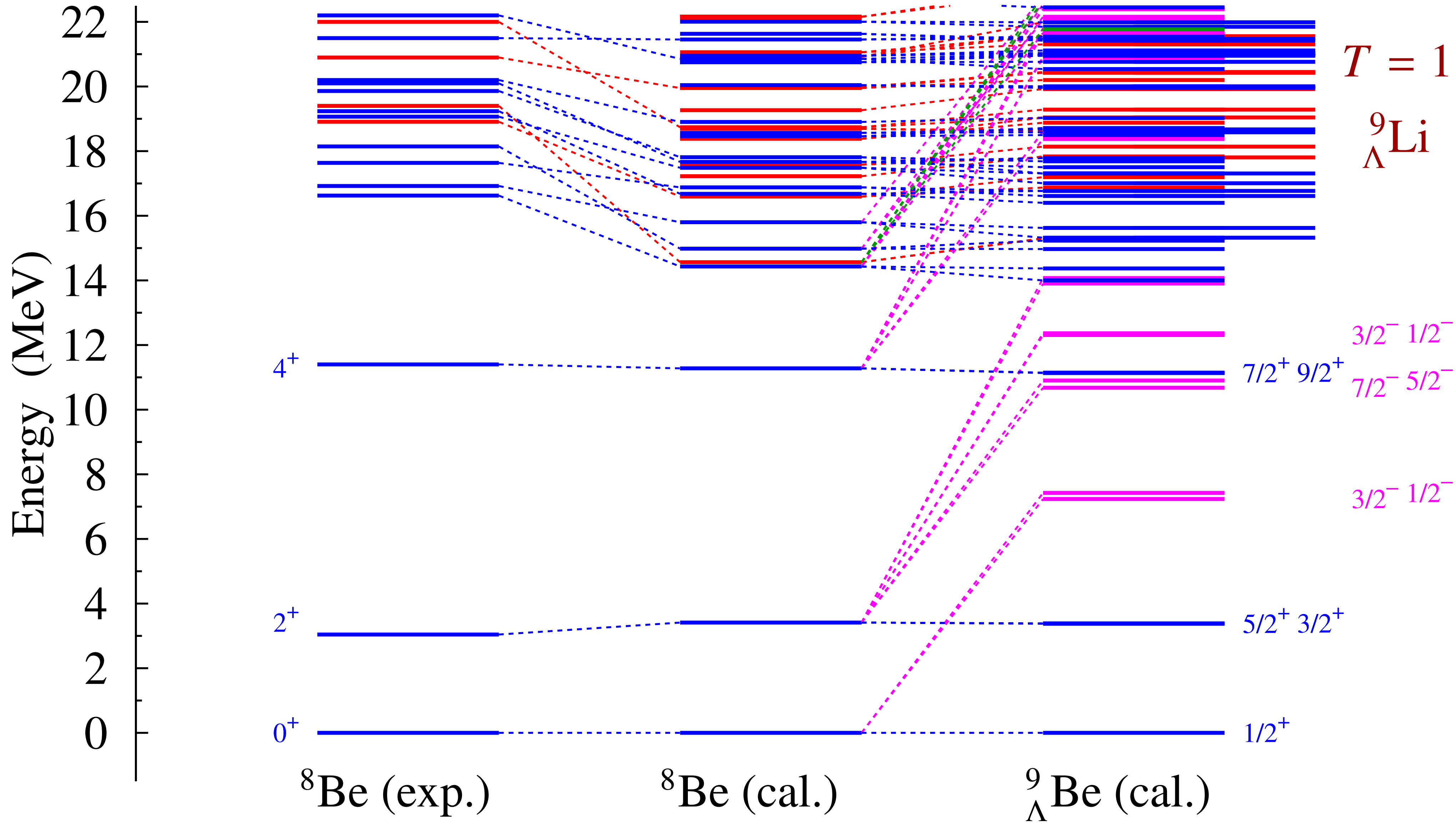


In the spherical nuclear core, p^Λ-state does not split into $p^\Lambda_{//}$ and $p^\Lambda_\perp$.

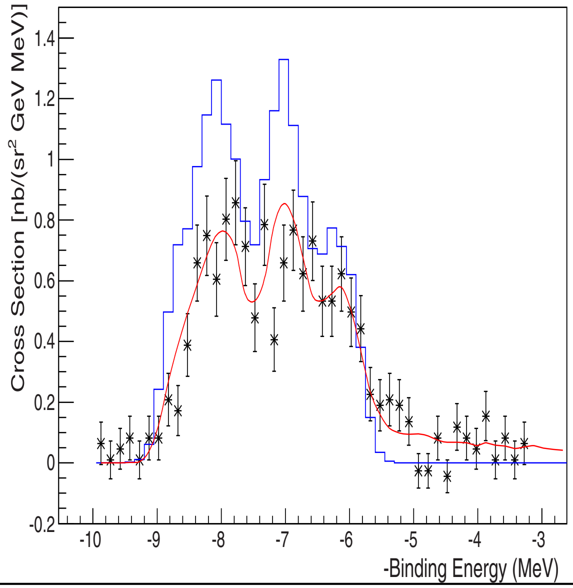
The new type wave function should appear in $^{9,10}_{\Lambda}$Be and $^{10,11}_{\Lambda}$B due to the core deformation, but "not" in spherical systems without enough deformation.

$A = 9$ and $T = 1$ hypernucleus, ${}^{9}_{\Lambda}\mathrm{Li}$

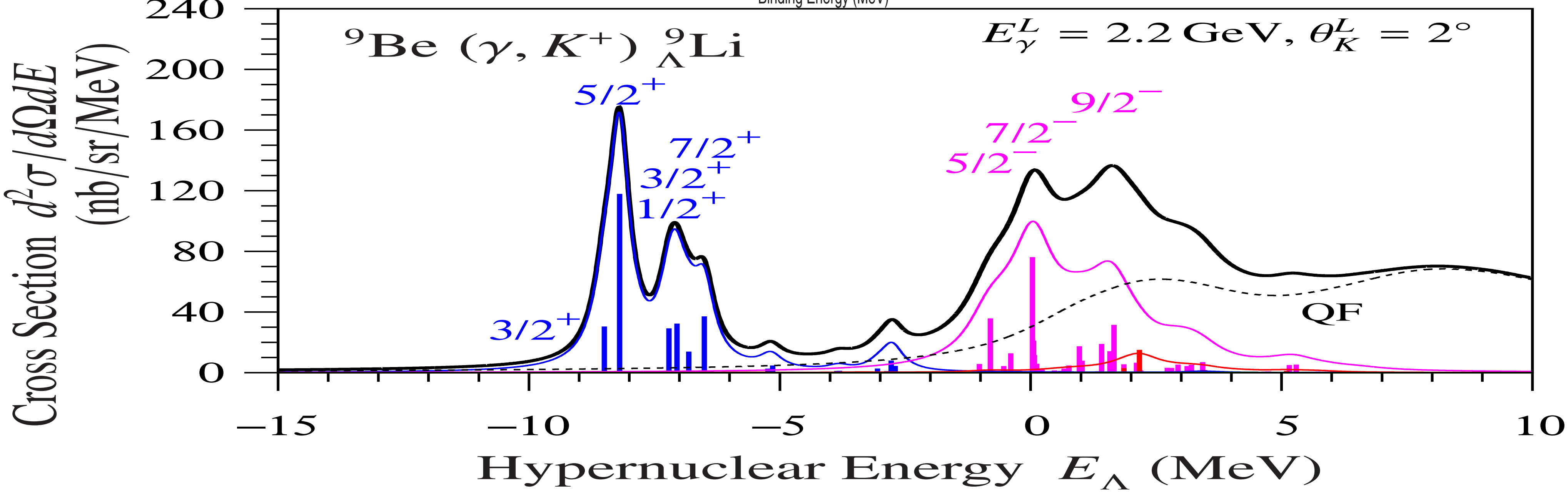
Results : Energy levels of ^{8}Be (^{8}Li) and $^{9}_{\Lambda}$Be ($^{9}_{\Lambda}$Li)



Results : Cross sections of the ^{9}Be (γ, K^{+}) $^{9}_{\Lambda}$Li reaction

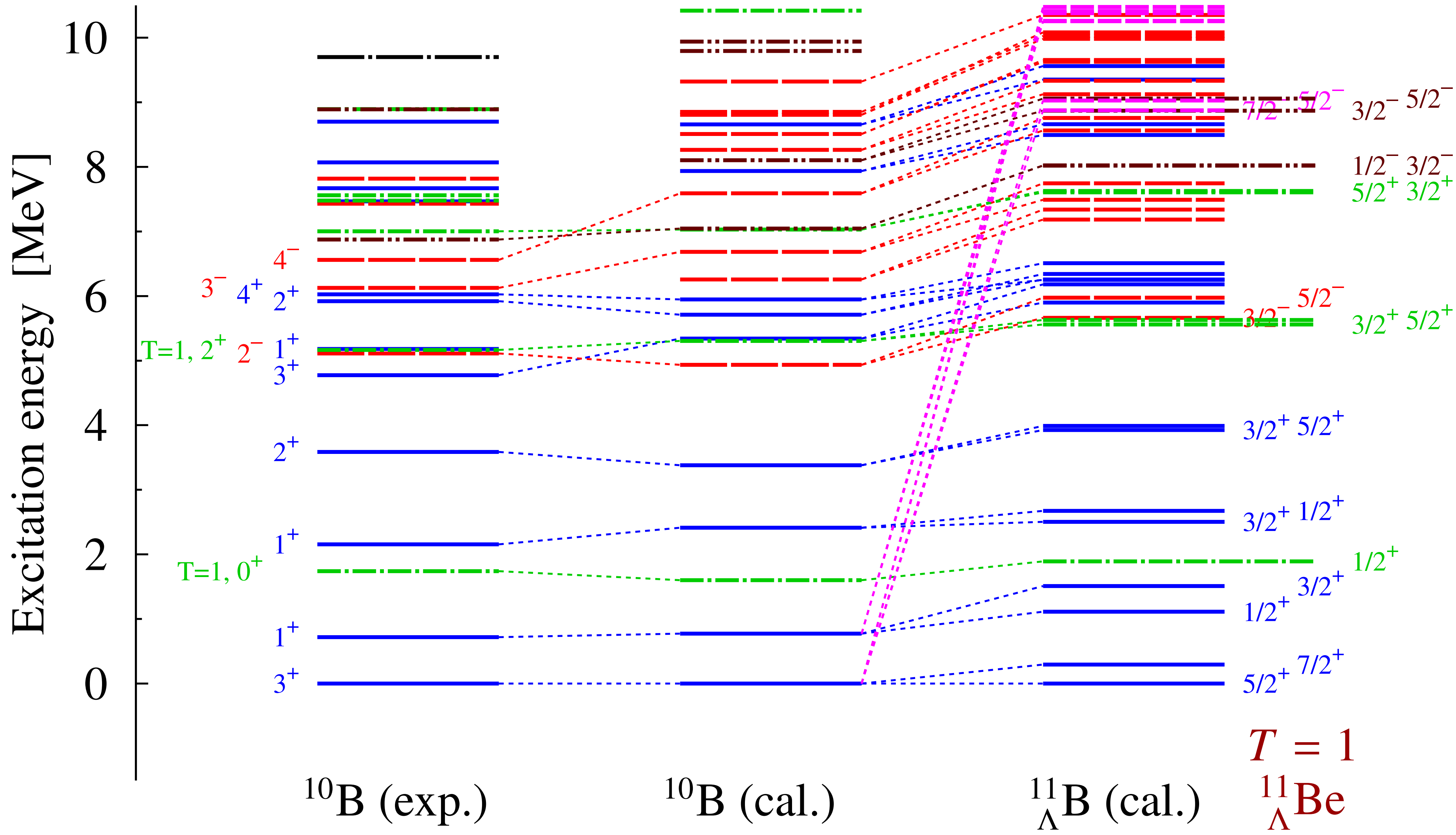


G. M. Urciuoli *et al.*, PRC91, 034308 (2015)

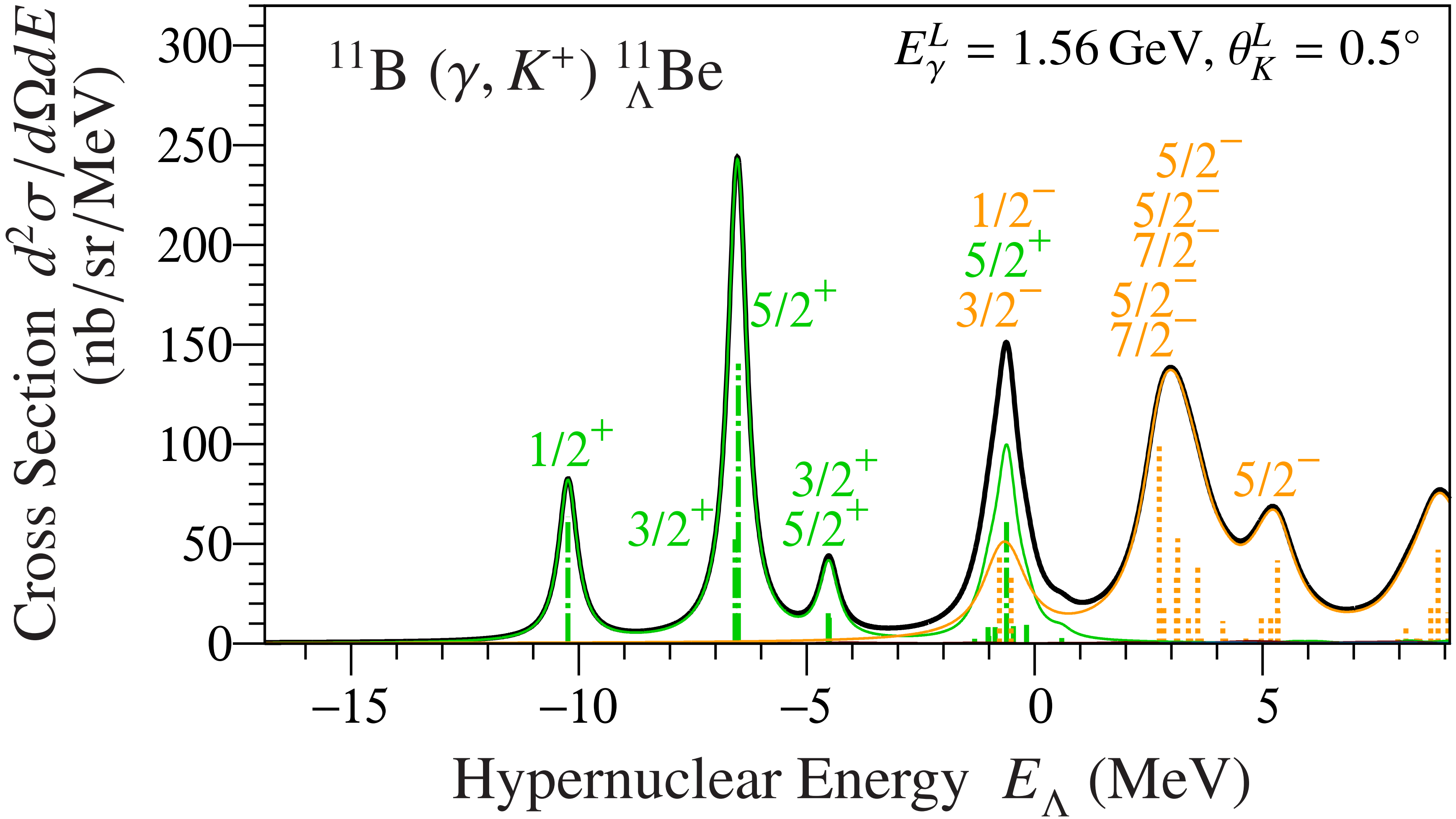


$A = 11$ and $T = 1$ hypernucleus, $^{11}_{\Lambda}\mathrm{Be}$

Results : Energy levels of ^{10}B (^{10}Be) and $^{11}_{\Lambda}$B ($^{11}_{\Lambda}$Be)



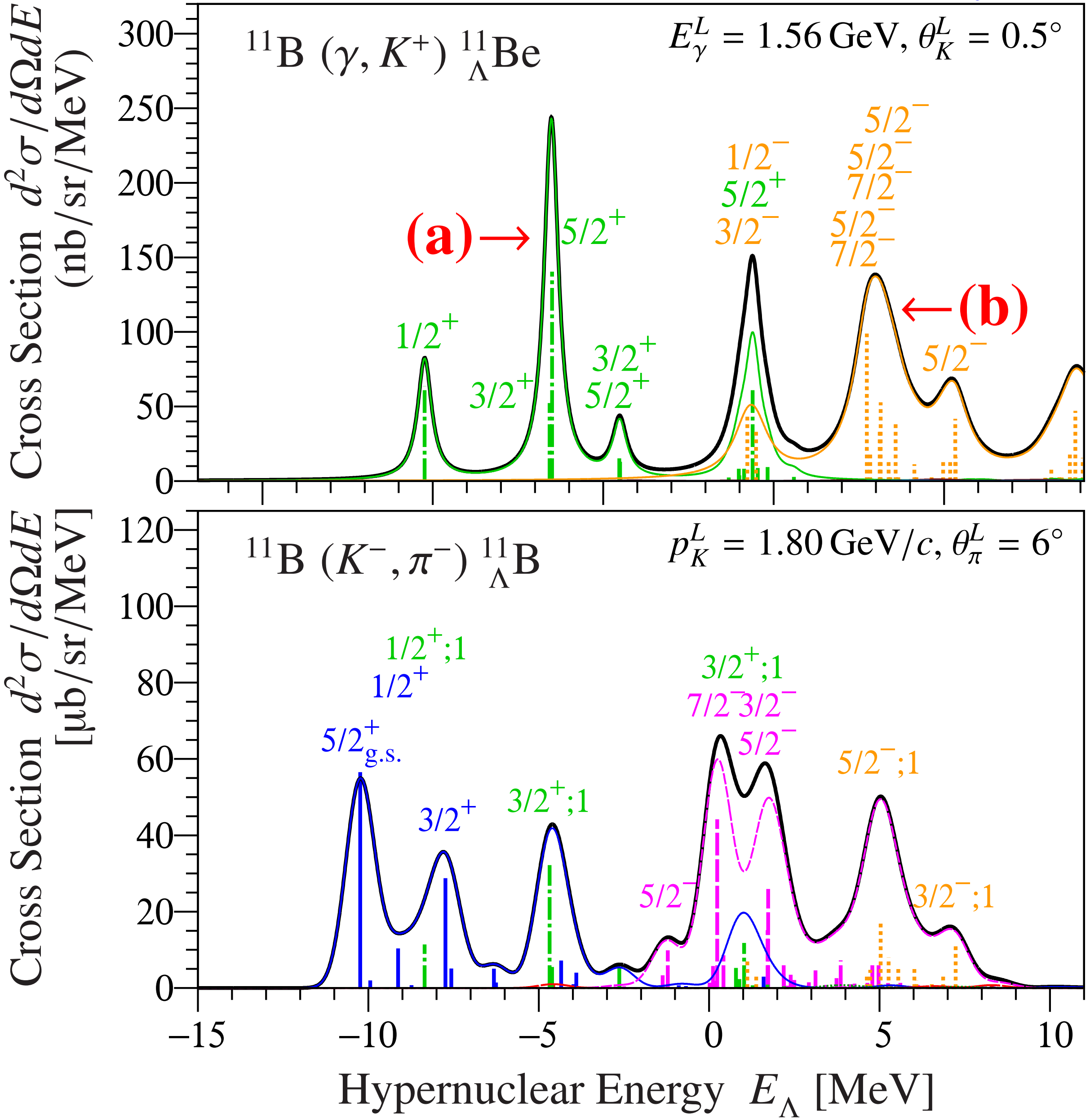
Results : Cross sections of the $^{11}B\ (\gamma, K^+)\ ^{11}_{\Lambda}Be$ reaction (1)



without QF, FWHM = 1.0 MeV

dominant configurations **green** $T=1, J^+;\ J^+_{core} \otimes s_\Lambda$ **orange** $T=1, J^-;\ J^+_{core} \otimes p_\Lambda$

Results : Cross sections of the ^{11}B (γ, K^+) $^{11}_{\Lambda}$Be reaction (2)



(a) $5/2^+(T=1)$

^{10}Be$(2^+_1) \otimes s^\Lambda_{1/2}$ 99.5%

(b-1) $5/2^-(T=1)$

^{10}Be$(3^-_3) \otimes s^\Lambda_{1/2}$ 73.7%

^{10}Be$(2^+_1) \otimes p^\Lambda_{3/2}$ 4.2%

^{10}Be$(2^+_1) \otimes p^\Lambda_{1/2}$ 17.9%

(b-2) $5/2^-(T=1)$

^{10}Be$(3^-_3) \otimes s^\Lambda_{1/2}$ 21.2%

^{10}Be$(2^+_1) \otimes p^\Lambda_{3/2}$ 29.3%

^{10}Be$(2^+_1) \otimes p^\Lambda_{1/2}$ 42.0%

large parity mixing in the core nucleus

Summary

Summary

We have calculated the energy levels and the production cross sections for *p*-shell hypernuclei by using the extended shell model.

- **Strong coupling between *p*-state Λ and core deformation is realized in $^{9,10,11}_{\Lambda}\mathrm{Be}$ and $^{10,11}_{\Lambda}\mathrm{B}$.**
- **In these nuclei, p^{Λ}-state splits into $p^{\Lambda}_{//}$ and $p^{\Lambda}_{\perp}$.**
- **In $^{10}_{\Lambda}\mathrm{Be}$, the lower $p^{\Lambda}_{//}$ comes down in energy and $[^{9}\mathrm{Be}(J^{-})\times\Lambda(p_{//})]$ couples easily with $[^{9}\mathrm{Be}(J^{+})\times\Lambda(s)]$.**
- **Such new type wave function should appear in $^{9,10,11}_{\Lambda}\mathrm{Be}$ and $^{10,11}_{\Lambda}\mathrm{B}$ due to the core deformation.**

The finding of peak #a in $^{10}\mathrm{B}\ (e,e'K^{+})\ ^{10}_{\Lambda}\mathrm{Be}$ is a novel evidence for genuine hyper-nuclear wave function with parity-mixing realized in "deformed" hypernuclei.

Detailed analysis for $^{9}_{\Lambda}\mathrm{Li}$ and $^{11}_{\Lambda}\mathrm{Be}$ with $T=1$ are now in progress.