Clusters accompanying weak decay of light hypernuclei

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Outline

- Non mesonic weak decay of hypernuclei
- Cluster accompanying weak decay
  - "α clusters"
  - "3N clusters"
- Representatives of cluster decay
- Population of resonance states
- Conclusion

The Decay Modes of Λ Hypernuclei

$\Gamma_{tot}(=1/\tau)$

- Γ_m
  - Γ_{π^-} ($\Lambda \rightarrow p\pi^-$)
  - Γ_{π^o} ($\Lambda \rightarrow n\pi^o$)
  - **Mesonic**, q~ 100 MeV/c
- Γ_{nm}
  - Γ_p ($\Lambda p \rightarrow np$)
  - Γ_n ($\Lambda n \rightarrow nn$)
  - Γ_n/Γ_p puzzle
  - **Nonmesonic**, q~ 400 MeV/c

Non mesonic weak decay

- We consider

$$ {}^{A}_{\Lambda}Z \quad \rightarrow \quad \underbrace{(n+N)}_{\approx 176\,MeV} \quad + \quad \underbrace{{}^{A_f}Z^{*}_{f}}_{{}^{A_1}Z_1 \; + \; {}^{A_2}Z_2} \quad (J^{\pi}T) $$

E

decays with <u>α particles</u> (Λ strips the nucleon from <u>*p*-shell</u>)

$$ {}^{A_f}Z^{*}_{f}(J^{\pi}T, E) \quad \rightarrow \quad \alpha \quad + \quad x \qquad (x = n, p, d, t, \tau) $$

<u>three-nucleon clusters</u> (Λ strips the nucleon from <u>*s*-shell</u>)

$$ {}^{A_f}Z^{*}_{f}(J^{\pi}T, E) \quad \rightarrow \quad \tau(t) \quad + \quad x \qquad (E \approx 16 - 20\,MeV\ ) $$

- What are the proper representatives to study such a cluster decay?
- What is the population of such resonance states?
- What will clusters tell us?

Light *p*-shell nuclei – representatives for cluster decay

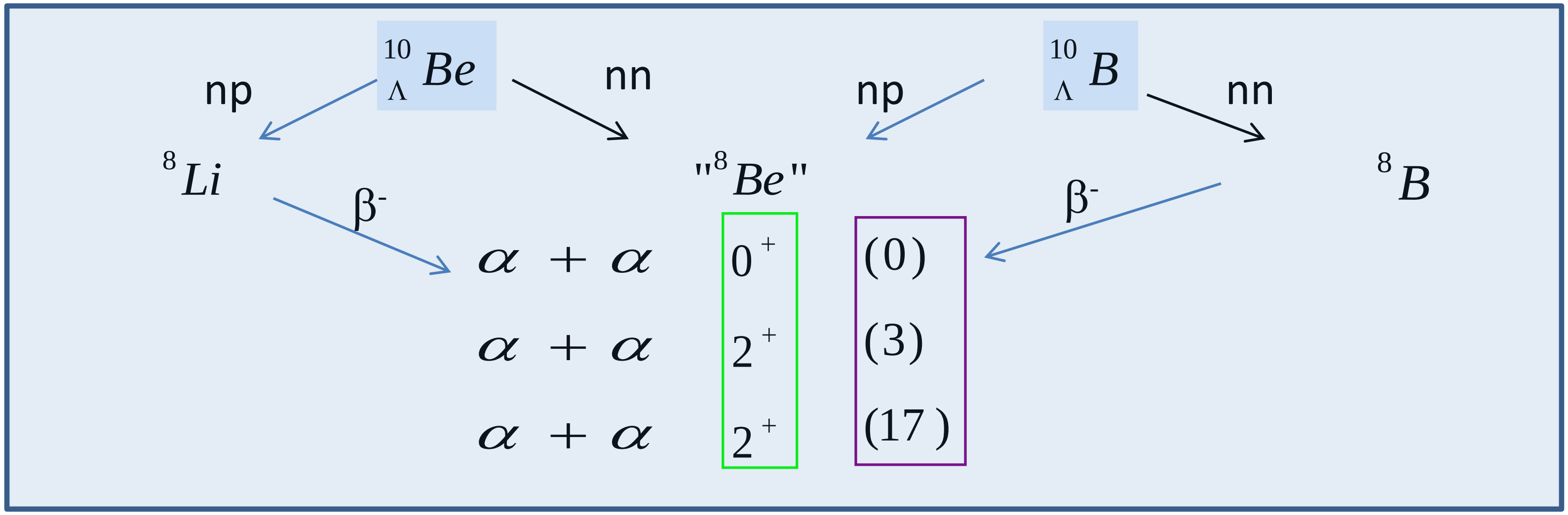
$^{10}_{\Lambda}Be$ $^{10}_{\Lambda}B$

$^{9}_{\Lambda}Li$ $^{9}_{\Lambda}Be$ $^{9}_{\Lambda}B$

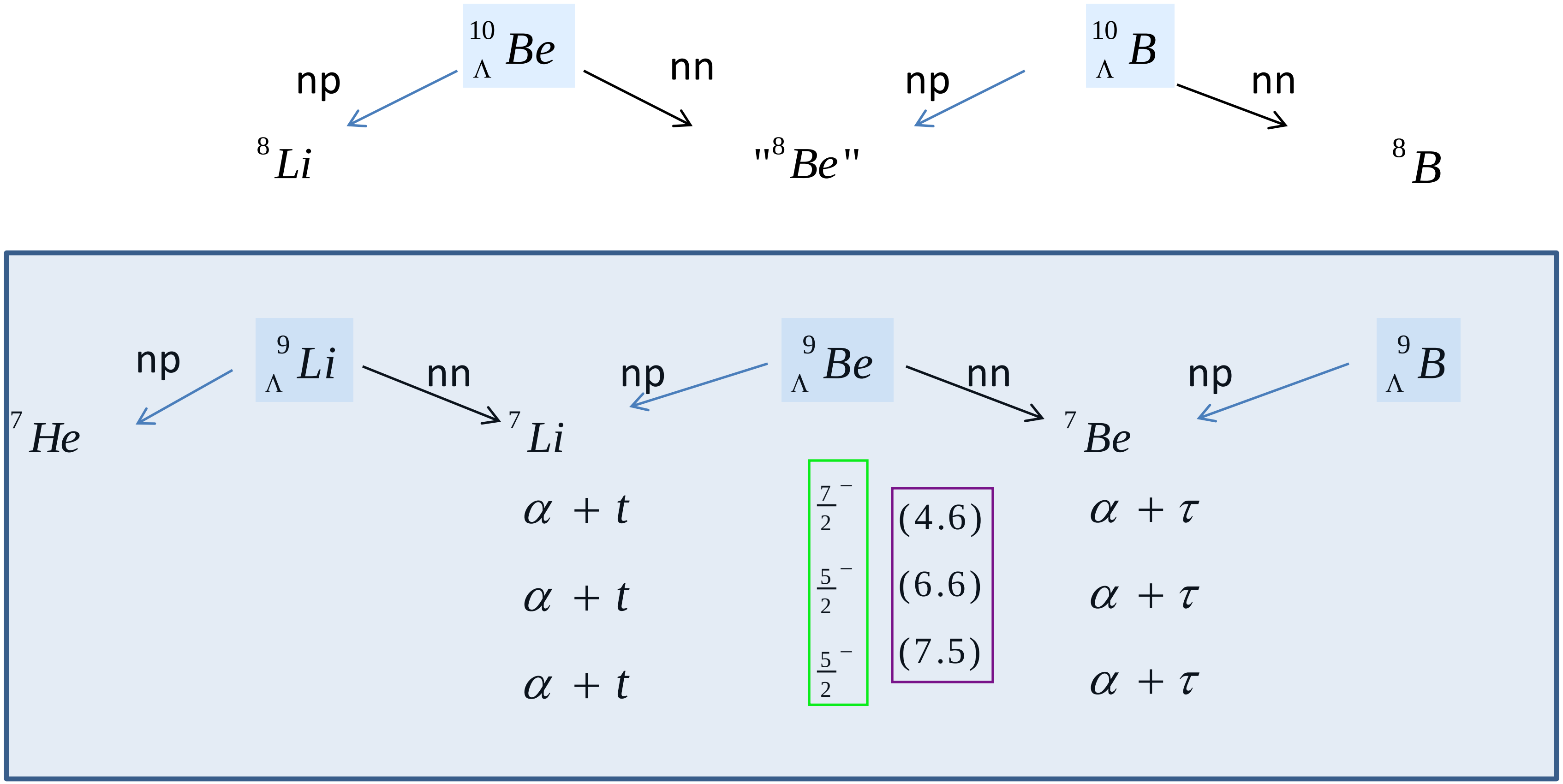
$^{8}_{\Lambda}Li$ $^{8}_{\Lambda}Be$

$^{7}_{\Lambda}He$ $^{7}_{\Lambda}Li$ $^{7}_{\Lambda}Be$

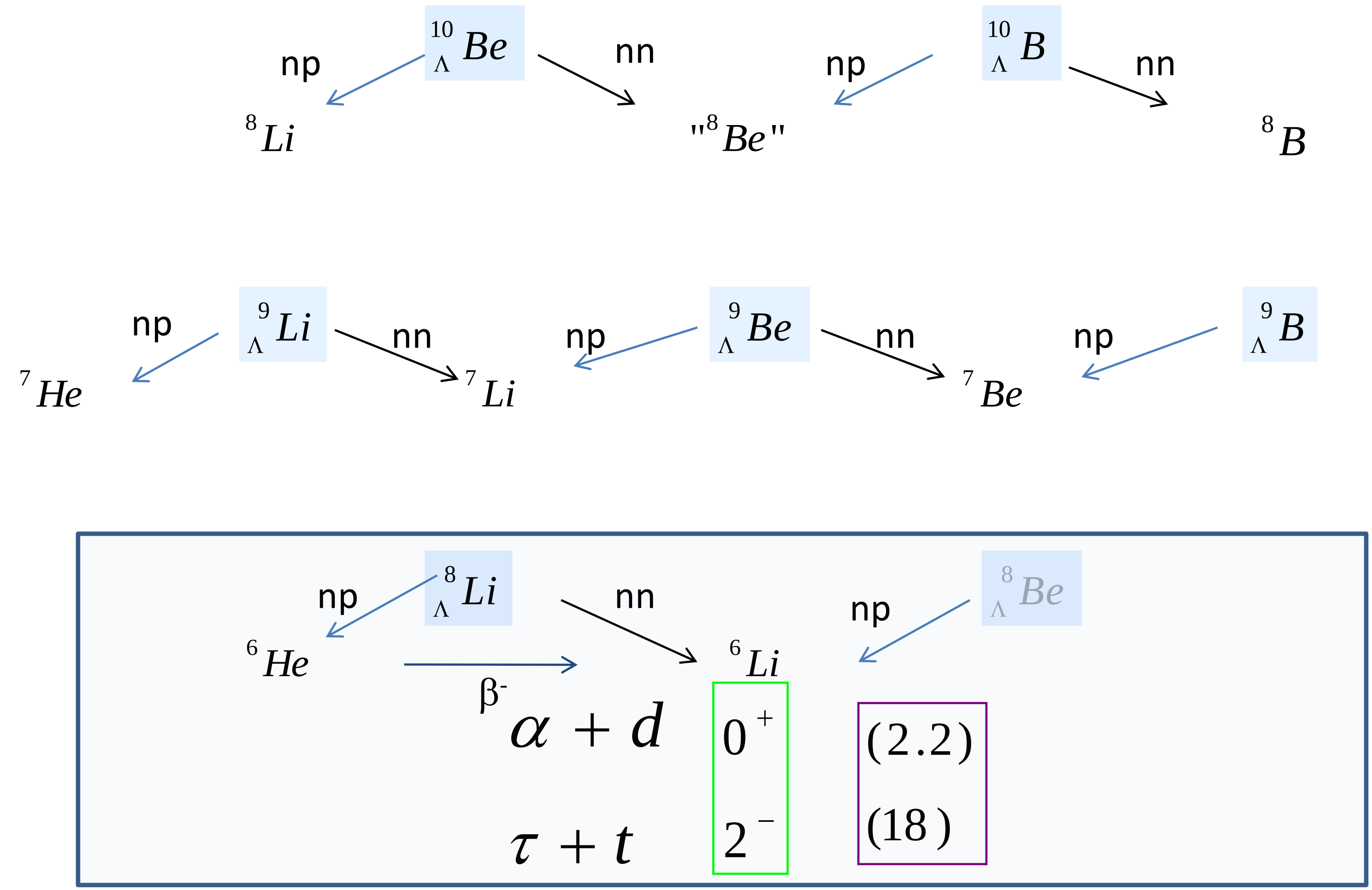
Light *p*-shell nuclei – representatives for cluster decay



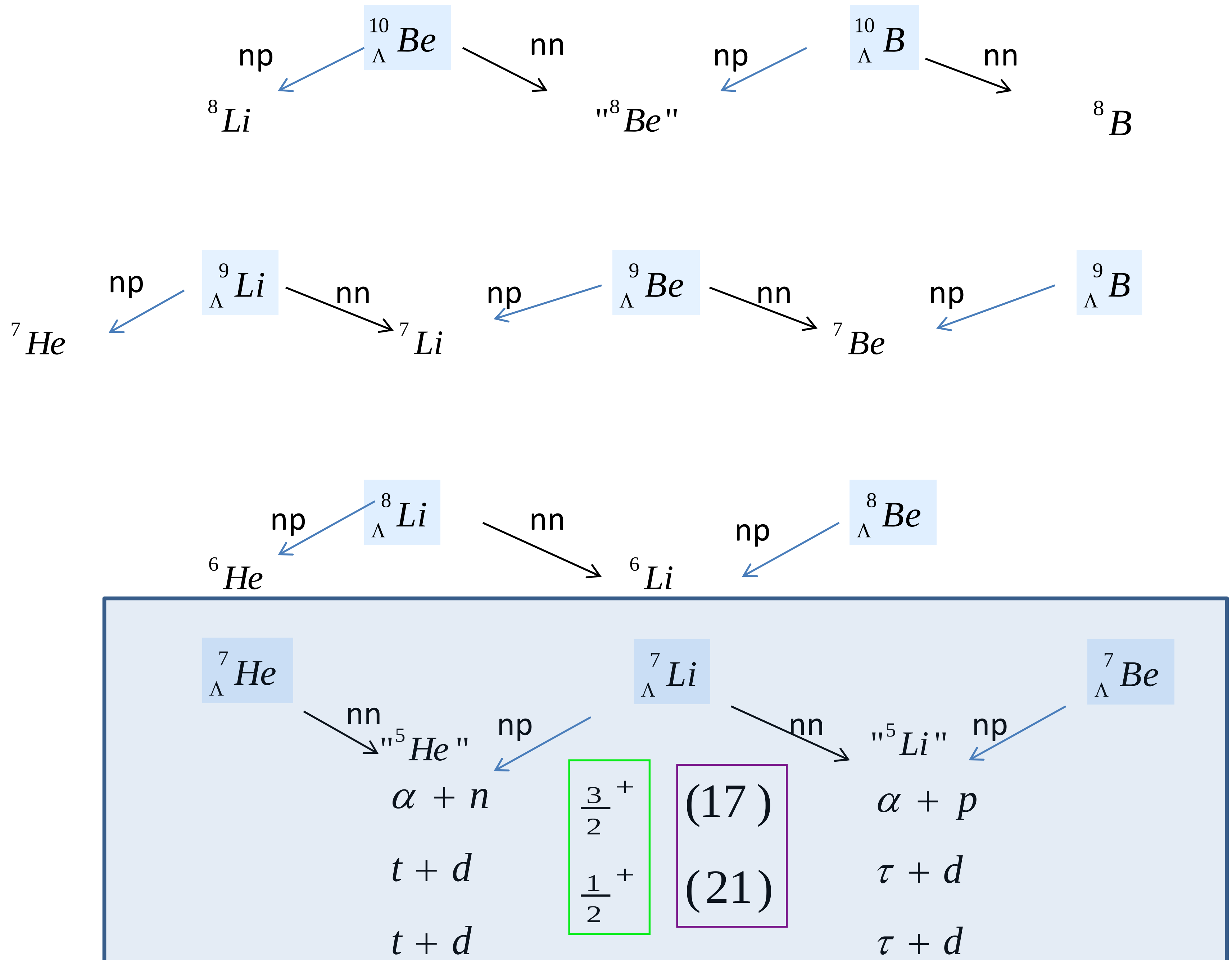
Light *p*-shell nuclei – representatives for cluster decay



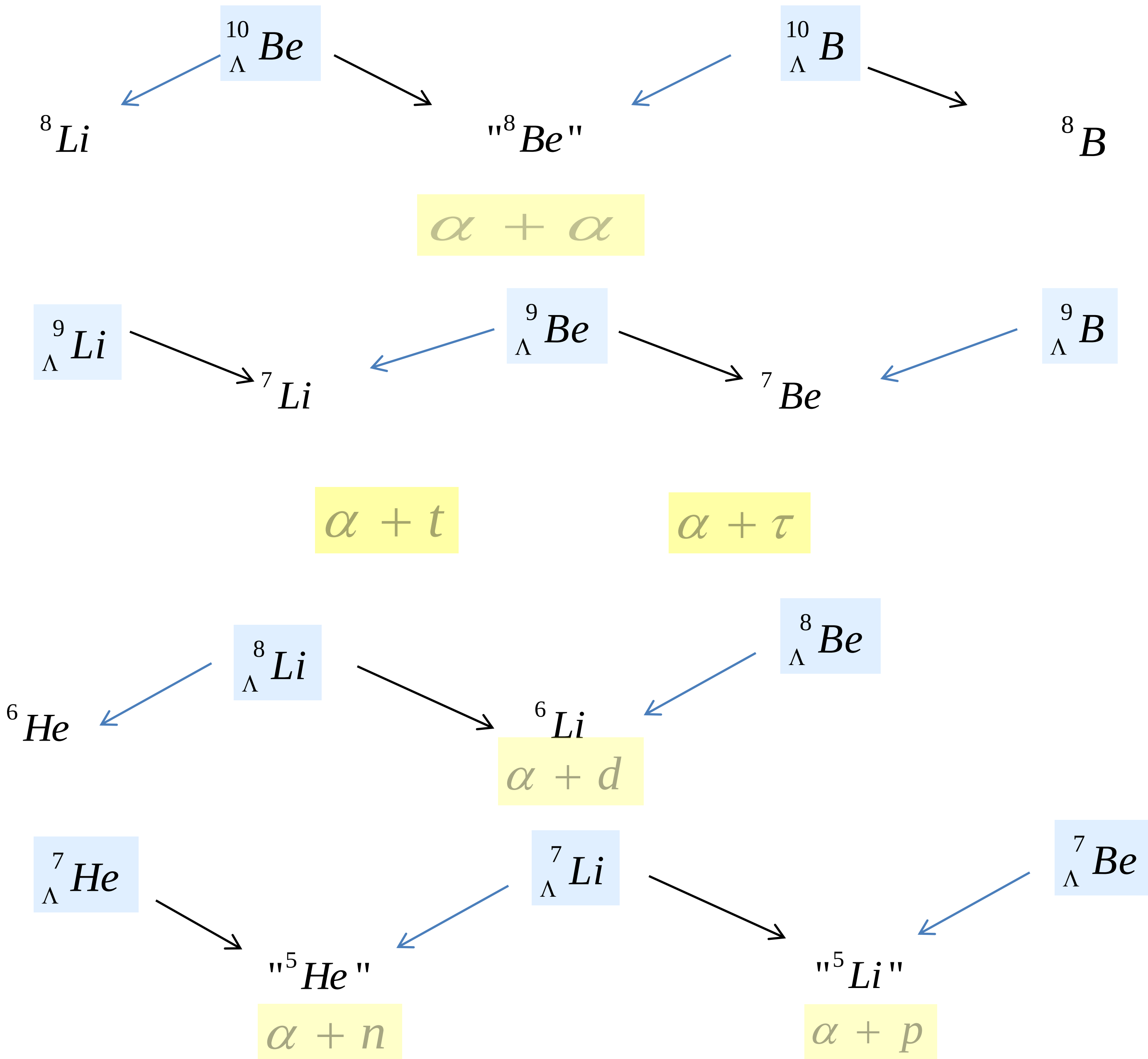
Light *p*-shell nuclei – representatives for cluster decay



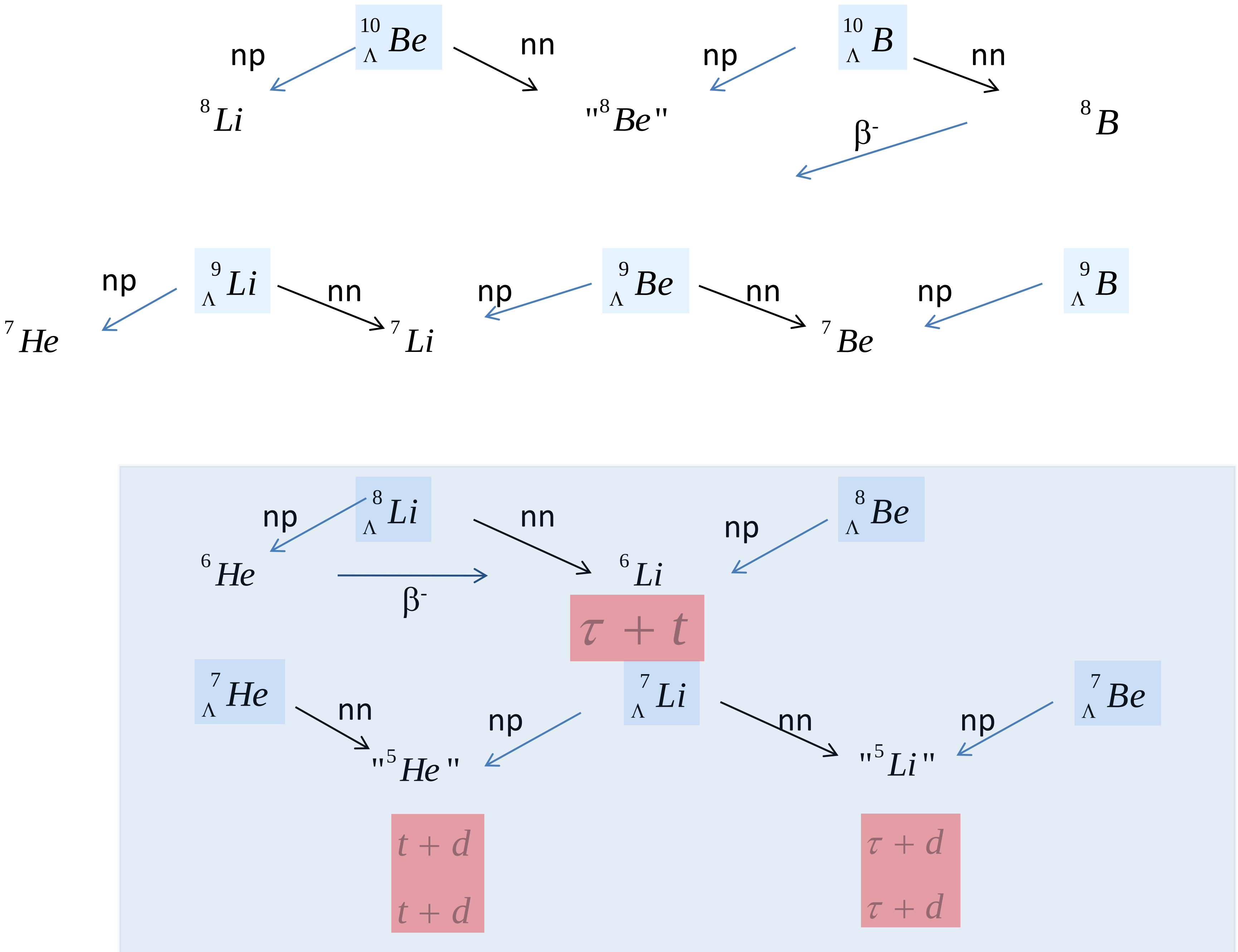
Light *p*-shell nuclei – representatives for cluster decay



Decays with “α clusters”



Decays with “3N” clusters



Decays with "3N" clusters

- Coefficients of fractional parentage – Translation Invariant Shell Model

ℓ / $[f]_i$ / ${}^{2T_i+1,2S_i+1}L_i$	p / $[41]$ / ${}^{22}P$	s / $[32]$ / ${}^{22}S$	s / $[32]$ / ${}^{22}S$	s / $[32]$ / ${}^{24}S$
$s^4p^3[42]^{13}S$	$18/45$	$2/45$	$5/45$	$20/45$

ℓ / $[f]_i$ / ${}^{2T_i+1,2S_i+1}L_i$	p / $[42]$ / ${}^{13}S$	p / $[42]$ / ${}^{31}S$	p / $[42]$ / ${}^{13}D$	p / $[42]$ / ${}^{31}D$	s / $[42]$ / ${}^{13}P$	s / $[42]$ / ${}^{31}P$	s / $[33]$ / ${}^{11}P$	s / $[33]$ / ${}^{33}P$
$s^4p^3[43]^{22}P$	$5/36$	$5/36$	$4/36$	$4/36$	$2/28$	$2/28$	$1/28$	$9/28$

Population of excited states in final nuclei decaying by cluster emission

				stable	cluster α+ x	decay τ (t)+x'	total break
${}^{7}_{\Lambda}Li$	$\rightarrow$ n+n	+	^{5}Li	0	0.20	0.28	0.02
	$\rightarrow$ n+p	+	^{5}He	0	0.20	0.28	0.02
${}^{8}_{\Lambda}Li$	$\rightarrow$ n+n	+	^{6}Li	0.19	0.11	0.11	0.16
	$\rightarrow$ n+p	+	^{6}He	0.09	-	0.21	0.13
${}^{9}_{\Lambda}Be$	$\rightarrow$ n+n	+	^{7}Be	0.29	0	0	0.21
	$\rightarrow$ n+p	+	^{7}Li	0.29	0	0	0.21
${}^{10}_{\Lambda}Be$	$\rightarrow$ n+n	+	^{8}Be	0	0.30	0	0.26
	$\rightarrow$ n+p	+	^{8}Li	0	0.17	0	0.27

NMWD s-shell hypernuclei

- Block&Dalitz

$$\Gamma_{nm}\left({}^{3}_{\Lambda}H\right) = \rho_3 \frac{1}{8}\left(3w_0^n + 1w_1^n + 3w_0^p + 1w_1^p\right)$$

$$\Gamma_{nm}\left({}^{4}_{\Lambda}H\right) = \rho_4 \frac{1}{6}\left(1w_0^n + 3w_1^n + 2w_0^p + 0w_1^p\right)$$

$$\Gamma_{nm}\left({}^{4}_{\Lambda}He\right) = \rho_4 \frac{1}{6}\left(2w_0^n + 0w_1^n + 1w_0^p + 3w_1^p\right)$$

$$\Gamma_{nm}\left({}^{5}_{\Lambda}He\right) = \rho_5 \frac{1}{8}\left(1w_0^n + 3w_1^n + 1w_0^p + 3w_1^p\right)$$

Where w_S^{τ} are matrix elements for weak interaction .

Exclusive (cluster) widths

$$ {}^{7}_{\Lambda}Li \longrightarrow (nn) + \tau d \left(\frac{3}{2}^{+}\right) : \frac{4}{18} \rho_7 \; 1w_1^n $$

$$ {}^{7}_{\Lambda}Li \longrightarrow (nn) + \tau d \left(\frac{1}{2}^{+}\right) : \frac{1}{18} \rho_7 \frac{1}{4}(3w_0^n + 1w_1^n) $$

$$ {}^{7}_{\Lambda}Li \longrightarrow (np) + td \left(\frac{3}{2}^{+}\right) : \frac{4}{18} \rho_7 \; 1w_1^p $$

$$ {}^{7}_{\Lambda}Li \longrightarrow (np) + td \left(\frac{1}{2}^{+}\right) : \frac{1}{18} \rho_7 \frac{1}{4}(3w_0^p + 1w_1^p) $$

$$ {}^{8}_{\Lambda}Li \longrightarrow (nn) + \tau t \; (2^-) : \frac{5}{56} \rho_8 \; 1w_1^n $$

$$ {}^{8}_{\Lambda}Li \longrightarrow (np) + tt \; (2^-) : \frac{10}{56} \rho_8 \; 1w_1^p $$

$$ {}^{8}_{\Lambda}Be \longrightarrow (np) + \tau t \; (2^-) : \frac{5}{56} \rho_8 \; 1w_1^p $$

CONCLUSION

- Delayed clusters accompanying weak decay of the light hypernuclei give us a unique information on <u>spin dependence</u> of the non leptonic weak decay <u>matrix elements</u>
- With a <u>set of data</u> on weak decay to several states we can find combinations that carry a bulk information about ΛN interaction , so we can choose an <u>adequate phenomenological model</u> for this interaction
- It could be mentioned that exclusive widths for single hypernucleus ${}^{7}_{\Lambda}Li$ give us <u>four relations for rates</u> w^{τ}_{S} , so the problem of <u>phenomenological weak interaction</u> could be solved.
- If 3N cluster will be registered it means, that Λ hypernucleus strips nucleon <u>from inner shell.</u>

THANK YOU FOR ATTENTION

Weak decay

The nonmesonic decay rate Γ_{nm} can be written as $\Gamma_{nm} = \sum_{\tau=n,p} \Gamma^{\tau} = \sum_{\tau} \sum_{i} \Gamma_i^{\tau}$,

where the partial decay width, Γ_i^{τ}, is

$$\Gamma_i^{\tau} = |\langle \Psi^{A-2}(\{i\}) \otimes \psi^{NN}(JT) \mid V_{weak} \mid [\Psi^{A-1}(\{c\}) \otimes \psi^{\Lambda}(\tfrac{1}{2})\,]^{\mathcal{J}} \rangle|^2.$$

(We use the shorthand notation $\{i\} \equiv E_i, J_i, T_i, \tau_i$ and $\{c\} \equiv E_c, J_c, T_c, \tau_c$ for quantum numbers of the excited states of the residual nucleus and the ground state core nucleus, respectively.)
It is possible to factorize this expression as

$$\Gamma_i^{\tau} = \sum_{SJ} \; G_{\mathcal{J}}^2(\{c\},\{i\},\tau LSJ\,) \cdot w_{SJ}^{\ell\tau},$$

with

$$w_{SJ}^{\ell\tau} = \Big| \sum_{L'S'} \langle l_1 l_2 : L'S'J\,T \mid V_{weak} \mid \tau\ell\; s_{\Lambda} : L = \ell\, S\, J \rangle \Big|^2, \qquad (1)$$

for matrix elements of the "weak interaction" and $G_{\mathcal{J}}$ for $N\Lambda$-pair fractional parentage coefficient

$$G_{\mathcal{J}}(\{c\},\{i\},\tau\ell SJ\,) = \sum_{j} U(J_i j \mathcal{J} \tfrac{1}{2} : J_c J)\, U(\ell \tfrac{1}{2} J \tfrac{1}{2} : jS)\, \mathcal{S}_i(\tau\ell j).$$

U are Racah coefficients for three angular momenta recoupling:

$$\overbrace{J_i + j}^{J_c} + \tfrac{1}{2}\,(s_\Lambda) = \mathcal{J} \rightarrow J_i + \overbrace{j + \tfrac{1}{2}\,(s_\Lambda)}^{J} = \mathcal{J}; \quad \overbrace{\ell + \tfrac{1}{2}\,(s_N)}^{j} + \tfrac{1}{2}\,(s_\Lambda) = J \rightarrow \ell + \overbrace{\tfrac{1}{2} + \tfrac{1}{2}}^{S} = J;$$

and $\mathcal{S}_i(\tau\ell j)$ are spectroscopic amplitudes to separate the nucleon participating in the weak decay from the ground state of the nucleus:

$$\mathcal{S}_i(\tau\ell j) = \sqrt{k} \cdot (T_i \tau_i\, \tfrac{1}{2}\tau \mid T_c \tau_c) \cdot g\,^{E_c\, J_c\, T_c}_{E_i\, J_i\, T_i}(\ell j). \qquad (2)$$

The $g\,^c_i(\ell j)$ is a one-nucleon fractional parentage coefficient in the intermediate coupling:

$$g\,^c_i(\ell j) = \sum_{f_c L_c S_c} \sum_{f_i L_i S_i} a^{E_c\, J_c\, T_c}_{f_c L_c S_c}\; a^{E_i\, J_i\, T_i}_{f_i L_i S_i} \begin{pmatrix} L_i & S_i & J_i \\ \ell & \frac{1}{2} & j \\ L_c & S_c & J_c \end{pmatrix} \langle \ell^k [f_c] L_c S_c T_c \,\{|\, \ell^{k-1}[f_i] L_i S_i T_i \rangle. \qquad (3)$$

The coefficients $a^{E_c\, J_c\, T_c}_{f_c L_c S_c}$, $a^{E_i\, J_i\, T_i}_{f_i L_i S_i}$ results from the shell model Hamiltonian diagonalization, 9j-symbol is used to transform the wave function from jj- to LS-coupling and $\langle \ell^k \{c\} \,\{|\, \ell^{k-1}\{i\}\, \rangle$ is a standard fractional parentage coefficient in the LS-coupling [4].