DELAYED CLUSTERS ACCOMPANYING NON-MESONIC WEAK DECAY OF THE HYPERNUCLEI

Lubomír Majling
Nuclear Physics Institute, CAS, Řež, Czech Republic
and
Olga Majlingová
Czech Technical University, Prague, Czech Republic

Outline

1. **Motivation**
2. **Delayed clusters**
3. **Perspective**

This Research is part of the EU Initiative FP7
HadronPhysics $_2$ (Project number 227431)
Study of Strongly Interacting Matter

1 MOTIVATION

“Strictly speaking,
the only observables in hypernuclear weak decay are the lifetime τ
and spectra of the emitted particles.
None of the mesonic and non-mesonic decay rates is
an **observable** from a quantum-mechanical point of view.”

E. Bauer and G. Garbarino :
On the role of g.s. correlations in HN NM WD
`arXiv: 0907.4199 [nucl-th]`

We will try to convinced you
that the **nuclear structure** aspects of the problem,
often an unwelcome part of the theory,
in **some peculiar cases** can be very useful.

2 DELAYED CLUSTERS

in some light p- shell nuclei

stripping of nucleon from the ground state

results in a RESONANCE STATE :

$$^{A}_{\Lambda}Z \longrightarrow (n+N) \;+\; {}^{A_f}Z_f^*(E \;\; J^\pi T)$$

$$\begin{array}{lcl} & & {}^{A_1}Z_1 \\ & \nearrow & \\ {}^{A_f}Z_f^*(E \;\; J^\pi T) & & \qquad E \Rightarrow J^\pi T \\ & \searrow & \\ & & {}^{A_2}Z_2 \end{array}$$

$$\begin{array}{lcll} & & & \alpha + \text{''}(k-1)\text{''} \\ & & & \uparrow \\ & \nearrow & s_\Lambda \; p \;\; + & s^4 \; p^{k-1} \\ s^4 \; p^k \; s_\Lambda & & & \\ & \searrow & s_\Lambda \; s \;\; + & s^3 \; p^k \\ & & & \downarrow \\ & & & 3N + \text{''}k\text{''} \end{array}$$

it is possible to study

EXCLUSIVE CHANNELS

2.1 List of resonance states

D.R. Tilley *et al.,* NP A **708** and **745** :

J^{π} T	E, MeV	decay	E, MeV	decay
	^{8}Be		**^{8}Li / ^{8}B**	
0^{+} 0	0.00	$\alpha+\alpha$		
2^{+} 0	3.03	$\alpha+\alpha$		
4^{+} 0	11.35	$\alpha+\alpha$		
2^{+} 0 }	16.63	$\alpha+\alpha$		
2^{+} 1 }	16.92	$\alpha+\alpha$	0.00	β^{-}/β^{+}
	^{7}Li		**^{7}Be**	
$\frac{3}{2}^{-}$ $\frac{1}{2}$	0.00	stable	0.00	ϵ-capture
$\frac{1}{2}^{-}$ $\frac{1}{2}$	0.48	γ	0.43	γ
$\frac{7}{2}^{-}$ $\frac{1}{2}$	4.65	$\alpha+{}^{3}$H	4.57	$\alpha+{}^{3}$He
$\frac{5}{2}^{-}$ $\frac{1}{2}$	6.60	$\alpha+{}^{3}$H	6.73	$\alpha+{}^{3}$He
	^{6}Li		**^{6}He**	
1^{+} 0	0.00	stable		
3^{+} 0	2.19	$\alpha+d$		
0^{+} 1	3.56	γ	0.00	β^{-}
...				
2^{-} 1	17.99	^{3}H+^{3}He	14.6	^{3}H+^{3}H
	^{5}He		**^{5}Li**	
$\frac{3}{2}^{-}$ $\frac{1}{2}$	0.00	$\alpha+n$	0.00	$\alpha+p$
$\frac{1}{2}^{-}$ $\frac{1}{2}$	6.17	$\alpha+n$	6.18	$\alpha+p$
$\frac{3}{2}^{+}$ $\frac{1}{2}$	16.66	^{3}H+d	16.63	^{3}He+d
$\frac{1}{2}^{+}$ $\frac{1}{2}$	20.32	^{3}H+d	20.30	^{3}He+d

2.2 Population of the excited states in final nuclei

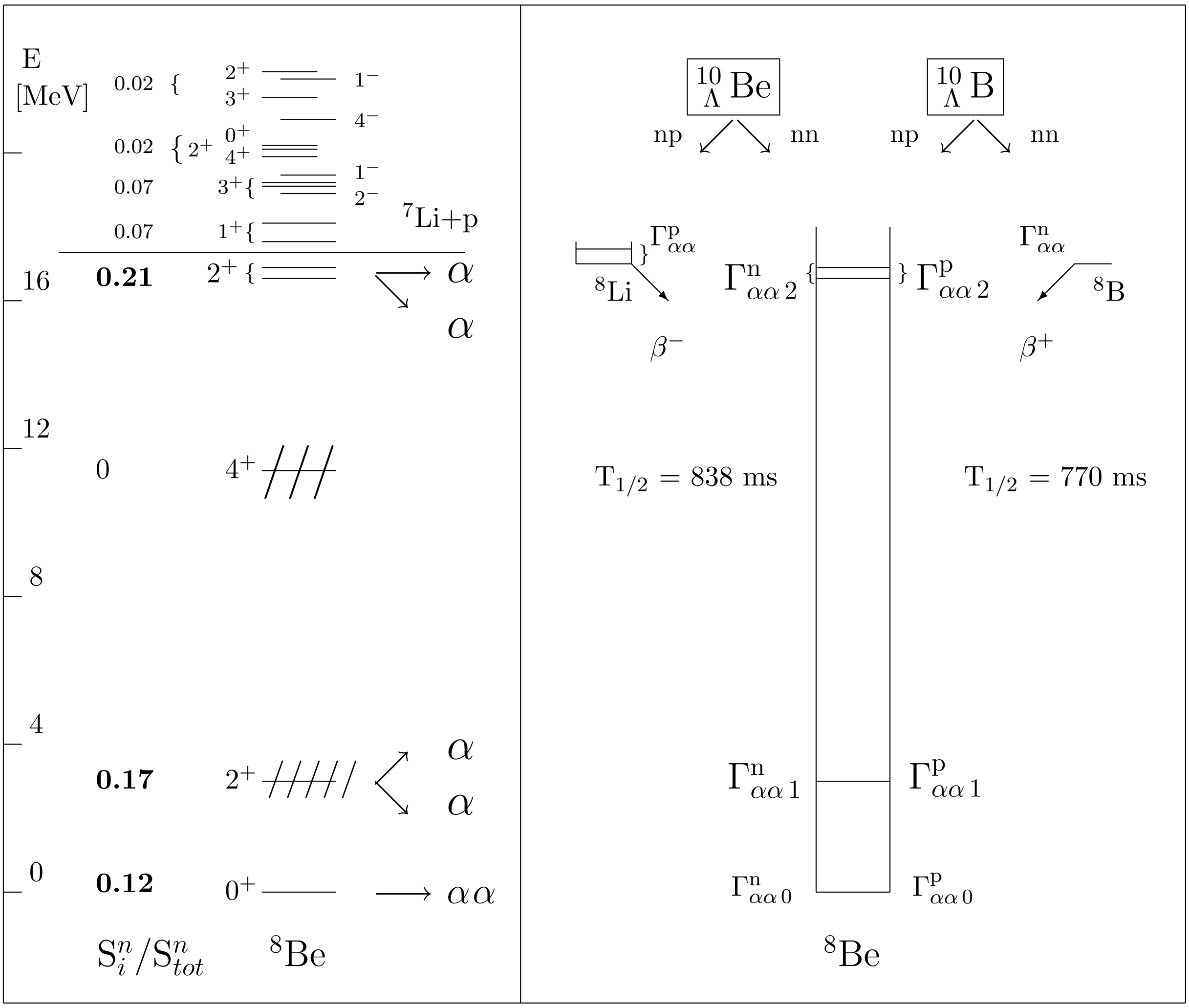
$^{A}_{\Lambda}$Z				^{A_f}Z$_f$	stable	cluster α	cluster ^{3}H (^{3}He)	total break
$^{7}_{\Lambda}$Li	↗	n+p	+	^{5}He	0	0.20	**0.28**	0.02
	↘	n+n	+	^{5}Li	0	0.20	**0.28**	0.02
$^{8}_{\Lambda}$Li	↗	n+p	+	^{6}He	0.09	-	0.21	0.13
	↘	n+n	+	^{6}Li	0.19	0.11	0.11	0.16
$^{8}_{\Lambda}$Be	→	n+p	+	^{6}Li	0.19	0.11	0.11	0.16
$^{9}_{\Lambda}$Li	→	n+n	+	^{7}Li	0.29	0	0	0.21
$^{9}_{\Lambda}$Be	↗	n+p	+	^{7}Li	0.29	0	0	0.21
	↘	n+n	+	^{7}Be	0.29	0	0	0.21
$^{9}_{\Lambda}$B	→	n+p	+	^{7}Be	0.29	0	0	0.21
$^{10}_{\Lambda}$Be	↗	n+p	+	^{8}Li (β^-)	0	**0.17**	0	0.27
	↘	n+n	+	^{8}Be	0	**0.30**	0	0.26
$^{10}_{\Lambda}$B	↗	n+p	+	^{8}Be	0	**0.30**	0	0.26
	↘	n+n	+	^{8}B (β^+)	0	**0.17**	0	0.27

2.3 alpha clusters

LM, Batusov, HYP VII, NP A **691** (2001)

LM, Batusov, Lukstins, Parfenov, HYP VIII, NP A **754** (2005)

Batusov, Lukstins, LM, Parfenov, Phys. Particles & Nuclei, **36** (2005)



^{9}Be spectroscopic factors

Notation of the partial widths. Note the similarity of the structure of $\Gamma^n_{\alpha\alpha}$ $^{10}_{\Lambda}$Be and $\Gamma^p_{\alpha\alpha}$ $^{10}_{\Lambda}$B.

2.4 Delayed d + t clusters

^{6}Li 1^+ 0, g.s. $s^4\ p^2$

model		$^{2T+1,2S+1}L_J$ [f]	$^{13}S_1$ [42]	$^{13}D_1$ [42]	$^{11}P_1$ [411]
SM	Barker	'66	0.992	-0.028	0.120
GFMC	Pudliner	'97	0.987	0.117	0.111

Energy levels of ^{5}He and ^{5}Li

[f]		J$^\pi$	E(He)	E(Li)
$s^4\ p$				
[41]	^{22}P	$\frac{3}{2}^-$	g.s.	g.s.
[41]	^{22}P	$\frac{1}{2}^-$	6.17	6.18
$s^3\ p^2$				
[32]	^{24}S	$\frac{3}{2}^+$	16.84	16.87
[32]	^{22}S	$\frac{1}{2}^+$	21.64	20.63

fpc		[42] $^{13}\Gamma$
[32]	$^{24}\Gamma$	$-\sqrt{\frac{4}{5}}$
[32]	$^{22}\Gamma$	$\sqrt{\frac{1}{5}}$

thresholds :	α	-0.80	-1.69
	d	16.79	16.66

2.5 $^{7}_{\Lambda}$Li Block & Dalitz Phys.Rev.Lett. **11**, 96 (1963)

$$\Gamma_{\rm nm}(^4_\Lambda{\rm H}) \equiv \Gamma^n_{\rm H} + \Gamma^p_{\rm H} = \varrho_4/6 \cdot (1\ {\rm R}_{n0} + 3\ {\rm R}_{n1} + 2\ {\rm R}_{p0} + 0\ {\rm R}_{p1})$$
$$\Gamma_{\rm nm}(^4_\Lambda{\rm He}) \equiv \Gamma^n_{\rm He} + \Gamma^p_{\rm He} = \varrho_4/6 \cdot (2\ {\rm R}_{n0} + 0\ {\rm R}_{n1} + 1\ {\rm R}_{p0} + 3\ {\rm R}_{p1})$$

$^{7}_{\Lambda}$**Li**

$$nn + {}^5{\rm Li}\ (\tfrac{3}{2}^+\tfrac{1}{2};\ 16.6):\quad \tfrac{5}{9}\cdot\tfrac{1}{2}\cdot\tfrac{4}{5}\times\quad 1\ w^{0n}_{11}$$
$$nn + {}^5{\rm Li}\ (\tfrac{1}{2}^+\tfrac{1}{2};\ 20.3):\quad \tfrac{5}{9}\cdot\tfrac{1}{2}\cdot\tfrac{1}{5}\times\quad \tfrac{1}{4}\ (1\ w^{0n}_{11} + 3\ w^{0n}_{00})$$
$$np + {}^5{\rm He}\ (\tfrac{3}{2}^+\tfrac{1}{2};\ 16.7):\quad \tfrac{5}{9}\cdot\tfrac{1}{2}\cdot\tfrac{4}{5}\times\quad 1\ w^{0p}_{11}$$
$$np + {}^5{\rm He}\ (\tfrac{1}{2}^+\tfrac{1}{2};\ 20.3):\quad \tfrac{5}{9}\cdot\tfrac{1}{2}\cdot\tfrac{1}{5}\times\quad \tfrac{1}{4}\ (1\ w^{0p}_{11} + 3\ w^{0p}_{00})$$

$$\mathcal{R}_1 \equiv \frac{5{\rm Li}(1/2^+)}{5{\rm Li}(3/2^+)} \qquad \mathcal{R}_2 \equiv \frac{5{\rm He}(1/2^+)}{5{\rm He}(3/2^+)} \qquad \mathcal{R}_3 \equiv \frac{5{\rm Li}(3/2^+)}{5{\rm He}(3/2^+)}$$

		$^4_\Lambda$**H**		$^4_\Lambda$**He**		$^7_\Lambda$**Li**		
Ref.	model	$\Gamma_{\rm nm}$	Γ_n/Γ_p	$\Gamma_{\rm nm}$	Γ_n/Γ_p	$\kappa\mathcal{R}_1$	$\kappa\mathcal{R}_2$	$\mathcal{R}_3$
[1]	π	0.02482	4.1192	0.2141	0.0475	3.890	1.108	<u>0.075</u>
	$+2\pi/\rho$	0.02418	9.2497	0.1094	0.0452	2.090	<u>1.102</u>	0.188
	$+2\pi/\sigma+\omega$	0.08700	2.7243	0.4065	0.1302	6.238	1.302	0.116
	$+\rho$	0.1278	2.1709	0.3034	0.3631	<u>8.719</u>	1.896	0.233
[2]	ME	0.128	2.705	0.235	0.417	6.308	2.068	0.397
	DQ+	0.204	0.693	0.229	0.269	4.600	<u>5.500</u>	<u>0.500</u>
[3]	PSVE	0.159	9.98	0.492	0.062	2.007	1.138	0.284
	PKE	0.149	27.9	0.368	0.031	<u>1.360</u>	1.063	0.372
	SPKE	0.076	2.70	0.191	0.068	1.831	1.127	0.368
[4]	Exp.			0.177	$\leq$0.19			

[1] K. Itonaga *et al.*, Phys. Rev. **C 65** (2002) 034617.
[2] K. Sasaki *et al.*, Phys. Rev. **C 71** (2005) 035502.
[3] E. Bauer *et al.*, Phys. Lett. **B 674** (2009) 103.
[4] J.D. Parker *et al.*, Phys. Rev. **C 76** (2007) 035501.

3 PERSPECTIVE

3.1 Experiment

Kinematics for hypernuclear production

Beam		Target		Secondaries		
				SLOW		FAST
K^-	+	^{A}Z	$\rightarrow$	$^{A}_{\Lambda}Z$	+	π^-
^{A}Z	+	p	$\rightarrow$	K^+	+	n + $^{A}_{\Lambda}Z$

Relativistic hypernuclei

Yu. Batusov, J. Lukstins, LM, A. Parfenov,
"Alpha decays" of $^{10}_{\Lambda}Be$ and $^{10}_{\Lambda}B$ hypernuclei on a Nuclotron:
A clue to some puzzles in nonleptonic processes"
Physics of Particles and Nuclei, **36** (2005) 169 – 190.

Status and last news: Juris LUKSTINS, this session

another possibility :

HypHI at GSI T.R. Saito, Monday

3.2 Theory

The role of s^{-1}- hole states in p- shell hypernuclei

- E. Hiyama, T. Yamada:
  Structure of light hypernuclei
  to appear in Progress in Particle and Nuclear Physics

- Bertini *et. al.* : $^{6}_{\Lambda}$Li, $^{7}_{\Lambda}$Li, $^{9}_{\Lambda}$Be, $^{12}_{\Lambda}$C, $^{13}_{\Lambda}$C,
- feeding of the $^{7}_{\Lambda}$Li ($\frac{7}{2}^{+}$) from $^{10}_{\Lambda}$B
- new proposal - L.Tang, A. Margaryan, S.N. Nakamura, J.Reinhold :
  Study of light hypernuclei by pionic decay at JLab

- C. Barbero, A.P. Galeão, M.S. Hussein, F. Krmpotič:
  Kinetic energy sum spectra in nonmesonic weak decay of hypernuclei
  Phys. Rev. C **78,** 044312 (2008)

- R.A. Eramzhyan, B.S. Ishkhanov, I.M. Kapitonov, V.G. Neudatchin:
  The GDR in light nuclei and related phenomena
  Phys. Reports **136,** 229 (1986)

Problems:

Spurious states of Center-of Mass
Continuum
Channel coupling
Kinematics

3.3 Expectations

p - shell hypernuclei

STRONG interaction	WEAK interaction
gamma transitions	delayed clusters
doublet splitting	Γ_i^N
$\Updownarrow$	$\Updownarrow$
Δ, S_Λ, S_N, T	R_{NS}
$\Updownarrow$	$\Updownarrow$
Nijmegen Julich'04 QQ	OBE TPE DQ