A Theoretical Determination of N_{nn}/N_{np} in Hypernuclear Non–Mesonic Weak Decay

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Outline of the talk

- Introduction to Λ-Weak Decay in Hypernuclei

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- Theoretical Framework: the Microscopic Model

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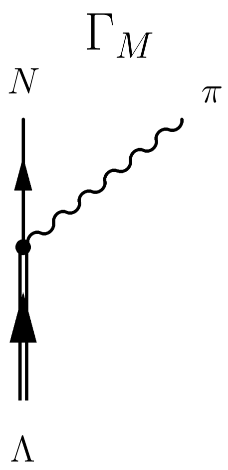
- Conclusions

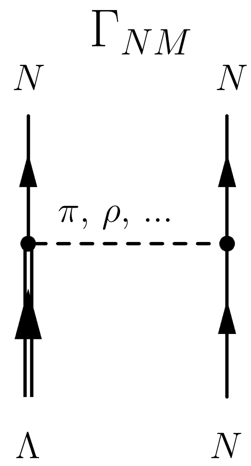
Weak decay modes of Λ-hypernuclei

- Mesonic decay, $\Gamma_M = \Gamma_{\pi^-} + \Gamma_{\pi^0}$,



  - dominant in free space
  - blocked by Pauli Principle

- Non-Mesonic decay, $\Gamma_{NM} = \Gamma_{NM}(\Lambda N ... \rightarrow nN...)$



  - only in hypernuclei
  - dominant for medium and heavy hypernuclei

$$\Gamma_T = \Gamma_M + \Gamma_{NM}$$

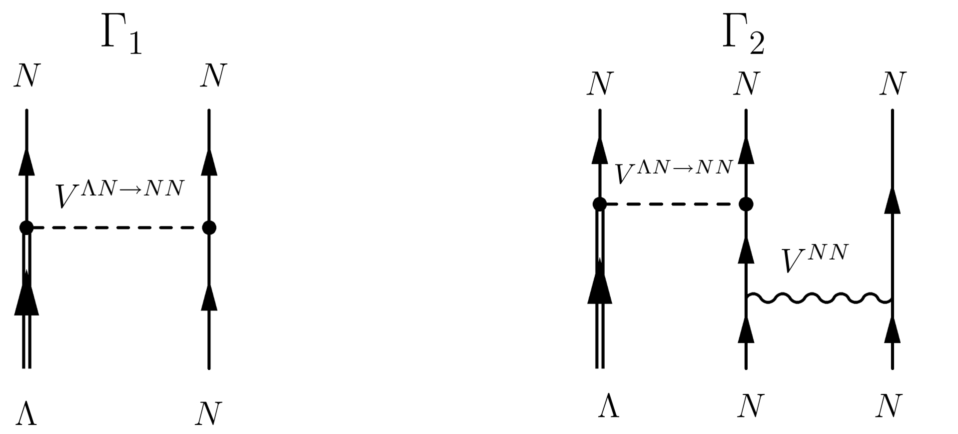
Non-mesonic weak decay

- One-nucleon induced: $\Gamma_1(\Lambda N \to nN)$,

$$\Gamma_1 \equiv \Gamma_n(\Lambda n \to nn) + \Gamma_p(\Lambda p \to np)$$

- Two-nucleon induced: $\Gamma_2(\Lambda NN \to nNN)$,

$$\Gamma_2 \equiv \Gamma_{nn}(\Lambda nn \to nnn) + \Gamma_{np}(\Lambda np \to nnp) + \Gamma_{pp}(\Lambda pp \to npp)$$



$$\boxed{\Gamma_{NM} = \Gamma_1 + \Gamma_2}$$

Some hypernuclear observables

- The hypernuclear lifetime is given in terms of the mesonic ($\Gamma_M = \Gamma_{\pi^-} + \Gamma_{\pi^0}$) and non–mesonic decay widths ($\Gamma_{NM} = \Gamma_1 + \Gamma_2$),

$$\tau = \hbar/\Gamma_T = \hbar/(\Gamma_M + \Gamma_{NM})$$

Almost independent on FSI

- The spectra of the emitted particles (nucleons, pions and photons), *i.e.* N_{nn} and N_{np}, where

$$\frac{\Gamma_n}{\Gamma_p} \equiv \frac{N_{nn}^{\mathrm{wd}}}{N_{np}^{\mathrm{wd}}} \neq \frac{N_{nn}}{N_{np}}$$

Strongly dependent on FSI

Link between theory and experiment

- When FSI are important, a theoretical model for the FSI is required to connect theory with experiment.
  - Intranuclear Cascade Code (INC)
  - Microscopic Model

  In the present contribution we discuss a microscopic model to describe the observables N_{nn}/N_{np} and the spectra of emitted protons and neutrons
  - Non-relativistic nuclear matter is employed
  - Connection with particular hypernuclei is done by means of the Local Density Approximation (LDA)

The non-mesonic decay width

- Fermi Golden Rule:

$$\Gamma_{NM} = \sum_f |\langle f|V^{\Lambda N \to NN}|0\rangle|^2 \delta(E_f - E_0)$$

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- $V^{\Lambda N \to NN}$: two-body weak transition potential, including the exchange of the complete octets of pseudoscalar and vector mesons (π, η, K, ρ, ω and K^*)
- $|f\rangle$: final state, with energy E_f
  - $|f\rangle = |2p1h\rangle$ for Γ_1
  - $|f\rangle = |3p2h\rangle$ for Γ_2

Microscopic model for N_N and N_{NN}

$$N_n = 2\bar{\Gamma}_n + \bar{\Gamma}_p + 3\bar{\Gamma}_{nn} + 2\bar{\Gamma}_{np} + \bar{\Gamma}_{pp} + \sum_{i,\,i';\,j} N_{j\,(n)}\,\bar{\Gamma}_{i,i'\to j},$$

$$N_p = \bar{\Gamma}_p + \bar{\Gamma}_{np} + 2\bar{\Gamma}_{pp}, + \sum_{i,\,i';\,j} N_{j\,(p)}\,\bar{\Gamma}_{i,i'\to j},$$

$$N_{nn} = \bar{\Gamma}_n + 3\bar{\Gamma}_{nn} + \bar{\Gamma}_{np} + \sum_{i,\,i';\,j} N_{j\,(nn)}\,\bar{\Gamma}_{i,i'\to j},$$

$$N_{np} = \bar{\Gamma}_p + 2\bar{\Gamma}_{np} + 2\bar{\Gamma}_{pp} + \sum_{i,\,i';\,j} N_{j\,(np)}\,\bar{\Gamma}_{i,i'\to j},$$

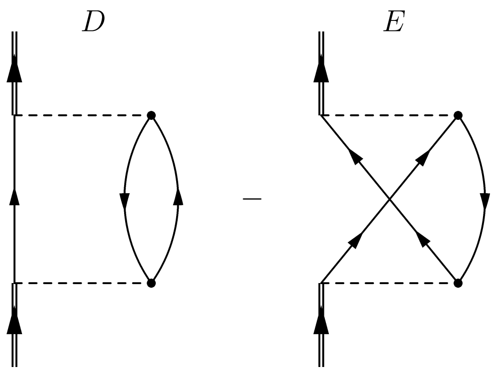
$$N_{pp} = \bar{\Gamma}_{pp} + \sum_{i,\,i';\,j} N_{j\,(pp)}\,\bar{\Gamma}_{i,i'\to j}.$$

where, $\bar{\Gamma} \equiv \Gamma/\Gamma_{NM}$

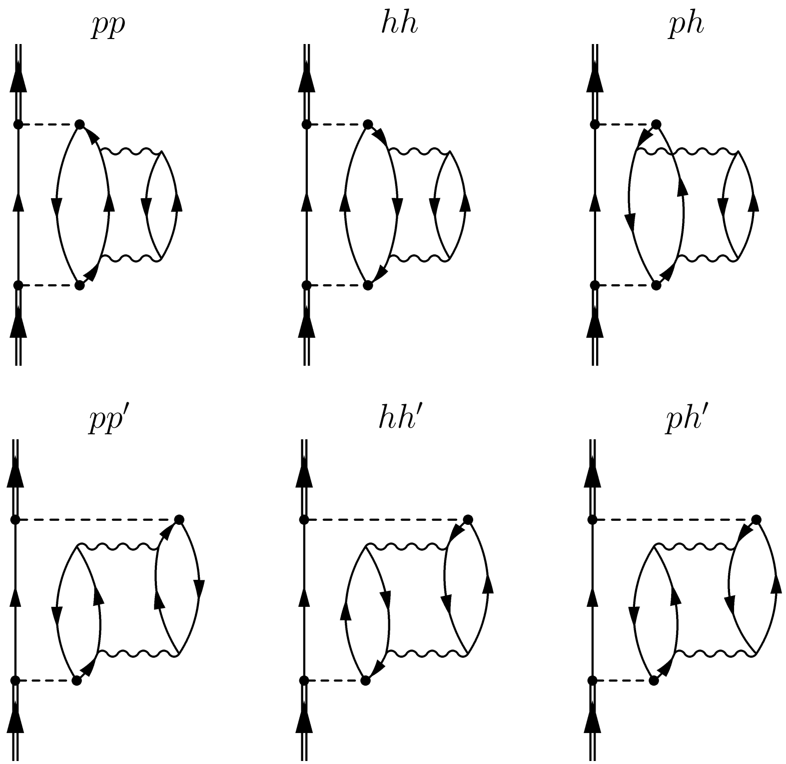
From E.B. Nucl. Phys. A796 (2007) 11

Employed Feynman diagrams

- $\Gamma_1 \rightarrow$ $|f\rangle = |2p1h\rangle$

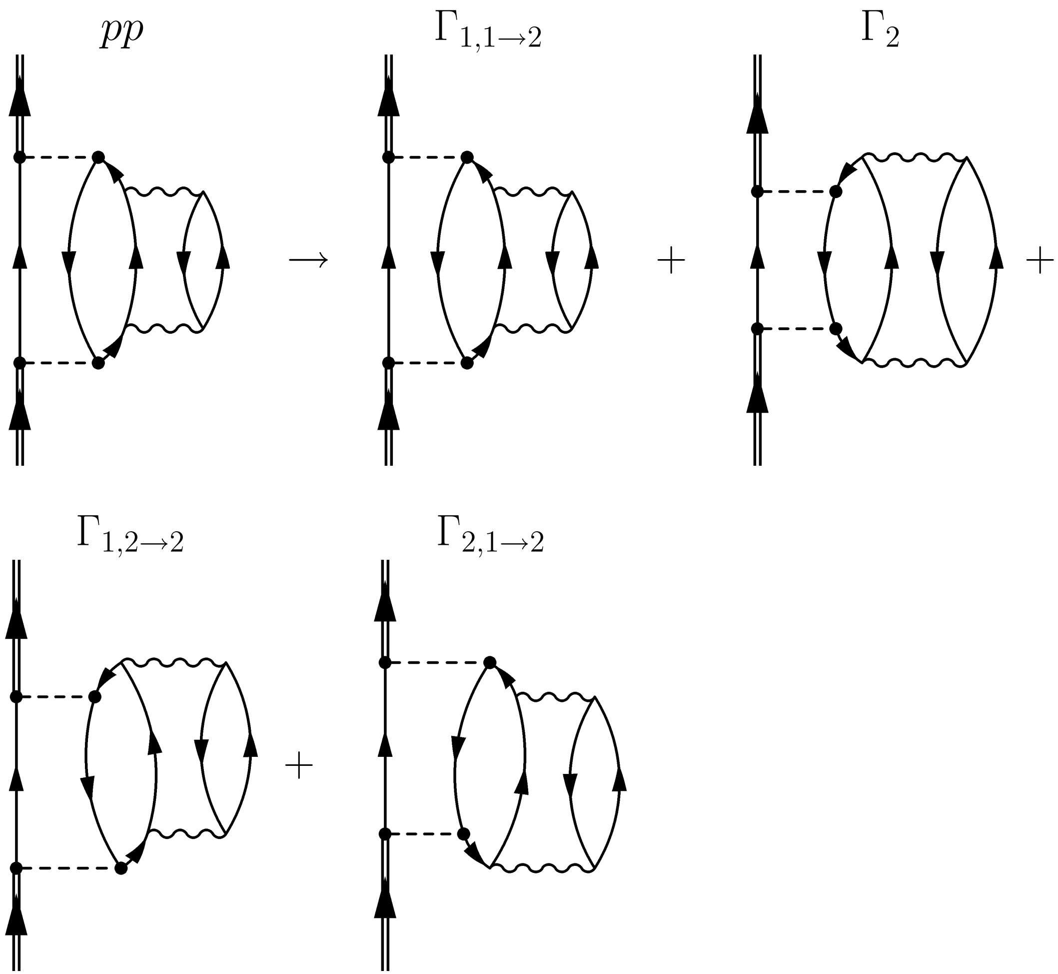


- $\Gamma_2 + \Gamma_{i,i' \rightarrow 2} \rightarrow$ $|f\rangle = |3p2h\rangle$



The pp-Feynman diagram,

expressed in terms of it sum of Goldstone diagrams:



Results & Comparison with Data

- $V^{\Lambda N \to NN}$ is represented by the exchange of the π, η, K, ρ, ω and K^* mesons, with the coupling constants and cut–off parameters deduced from the Nijmegen soft–core interaction NSC97f of V. G. J. Stoks and Th. A. Rijken, Phys. Rev. **C 59** (1999) 3009; Th. A. Rijken, V. G. J. Stoks and Y. Yamamoto, *ibid.* 59 (1999) 21.

- For V^{NN} we have used a $V_{\pi+\rho}$-potential with the addition of a g'-Landau-Migdal parameter. (See for instance, E. Oset, H. Toki and W. Weise, Phys. Rept. **83** (1982) 281). We have used, $g' = 0.7$.

Results & Comparison with Data

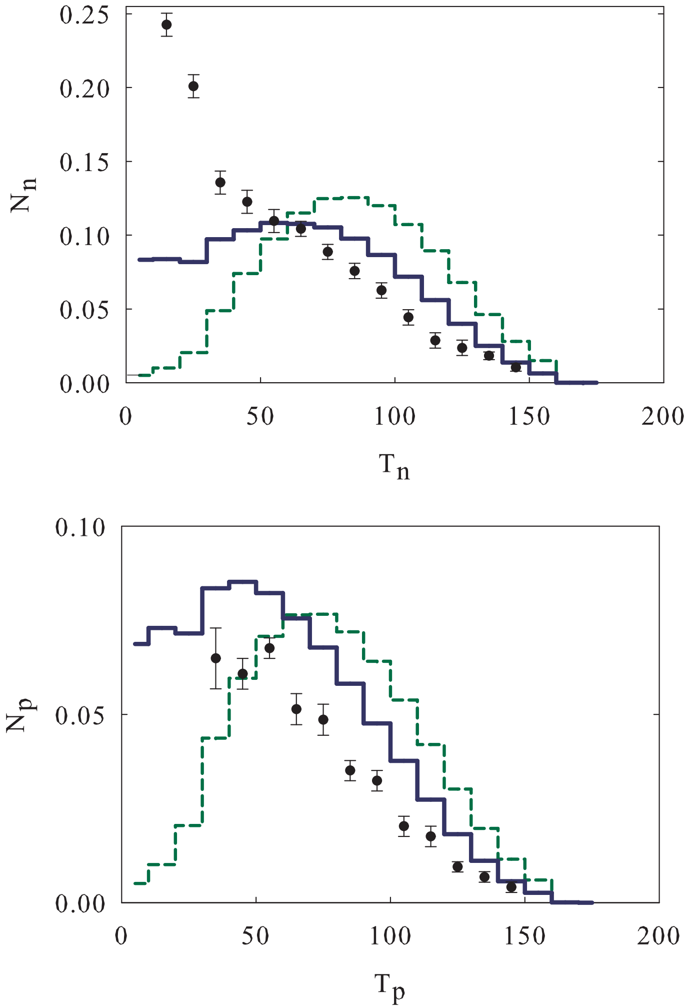
Table 1
KEK data from M. J. Kim et al., Phys. Lett. **B 641**, 28 (2006), where $T_N^{\rm th} = 30$ and $\cos(\theta_{NN}) \leqslant -0.8$ $T_N^{\rm th}$ is given in MeV.

${}^{12}_{\Lambda}$C					
$T_N^{\rm th}$	$\cos(\theta_{NN})$	Γ_n/Γ_p	$(N_{nn}/N_{np})^0$	$(N_{nn}/N_{np})^{no-int}$	N_{nn}/N_{np}
0.	$\leqslant 1.$	0.321	0.321	0.392	0.372
30.	$\leqslant -0.8$		0.336	0.376	0.374
	KEK-E508				0.40 ± 0.10

Table 2
Results are given in units of $\Gamma^0 = 2.52 \cdot 10^{-6}$ eV.

${}^{12}_{\Lambda}$C									
	$T_N^{\rm th}$	$\cos(\theta_{NN})$	1N-ind	pp	ph	hh	pp'	ph'	hh'
N_{nn}	0.	$\leqslant 1.$	0.18	0.32	-0.05	0.31	0.14	-0.12	0.14
	30.	$\leqslant -0.8$	0.17	0.04	-0.01	0.05	0.02	-0.01	0.02
N_{np}	0.	$\leqslant 1.$	0.57	0.94	-0.04	0.61	0.32	-0.15	0.27
	30.	$\leqslant -0.8$	0.50	0.10	-0.01	0.09	0.04	-0.02	0.04

Single nucleon spectra



Data have been taken from S. Okada et al., Phys. Lett. **B 597**, 249 (2004).

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- Our results suggest that quantum-interference terms are not important
- The next steps: the microscopic model requires improvements and further studies:
  - a more realistic nuclear residual interaction,
  - the inclusion of the Pauli exchange terms in 2N-ind,
  - the study of the effect of the $\Delta(1232)$ over the spectra,
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  - a more realistic nuclear residual interaction,
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  - the study of the effect of the $\Delta(1232)$ over the spectra,
  - the evaluation of the double coincidence emission spectra.
- Finally, the microscopic model allows to study not only $V^{\Lambda N \rightarrow NN}$ but also V^{NN}.

Arigatou Gozaimashita!

(Thank you!)

The Γ_1 and Γ_2-decay widths

$$\Gamma_1(\boldsymbol{k},k_F) = \mathcal{N}^2(k_F)\sum_f \left|\langle f|V^{\Lambda N\to NN}|p_\Lambda\rangle\right|^2 \delta(E_f - E_0)\ ,$$

$$\Gamma_2(\boldsymbol{k},k_F) = \mathcal{N}^2(k_F)\sum_f \left|\sum_{p_2' h_2 p_3 h_3} \langle f|V^{\Lambda N\to NN}|p_2' h_2 p_3 h_3;\, p_\Lambda\rangle \times \frac{\langle p_2' h_2 p_3 h_3;\, p_\Lambda|V^{NN}|p_\Lambda\rangle}{\varepsilon_{p_2'} - \varepsilon_{h_2} + \varepsilon_{p_3} - \varepsilon_{h_3}}\right|^2 \delta(E_f - E_0)\ ,$$

$$\mathcal{N}(k_F) = \left(1 + \sum_{p_2' h_2 p_3 h_3}\left|\frac{\langle p_2' h_2 p_3 h_3|V^{NN}|\ \rangle}{\varepsilon_{p_2'} - \varepsilon_{h_2} + \varepsilon_{p_3} - \varepsilon_{h_3}}\right|^2\right)^{-1/2}$$

$$\Gamma_{1\ (2)} = \int d\boldsymbol{k}\,|\widetilde{\psi}_\Lambda(\boldsymbol{k})|^2 \int d\boldsymbol{r}\,|\psi_\Lambda(\boldsymbol{r})|^2 \Gamma_{1\ (2)}(\boldsymbol{k},k_F(r))\ ,$$

A $\Delta(1232)$-contribution: