NonMesonic Weak Decay of Hypernuclei: Present Status and need for New Experiments

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OUTLINE

- Non–Mesonic Weak Decay of Hypernuclei
- The Ratio Γ_n/Γ_p
- Polarized Hypernuclei: The Decay Asymmetry
- Need for New Experiments
  - s–shell Hypernuclei $\Longleftrightarrow$ $\Delta I = 1/2$ Rule
  - Extraction of $\Gamma_2 = \Gamma(\Lambda NN \to nNN)$ from Data
  - Exotic Hypernuclei $\Longleftrightarrow$ Γ_n/Γ_p
- Conclusions

W. M. Alberico and G. G., Phys. Rep. **369**, 1 (2002);
Hadron Physics, IOS Press, Amsterdam, 2005, p. 125 [nucl-th/0410059].
E. Oset and A. Ramos, Prog. Part. Nucl. Phys. 41, 191 (1998).

NON–MESONIC WEAK DECAY OF HYPERNUCLEI

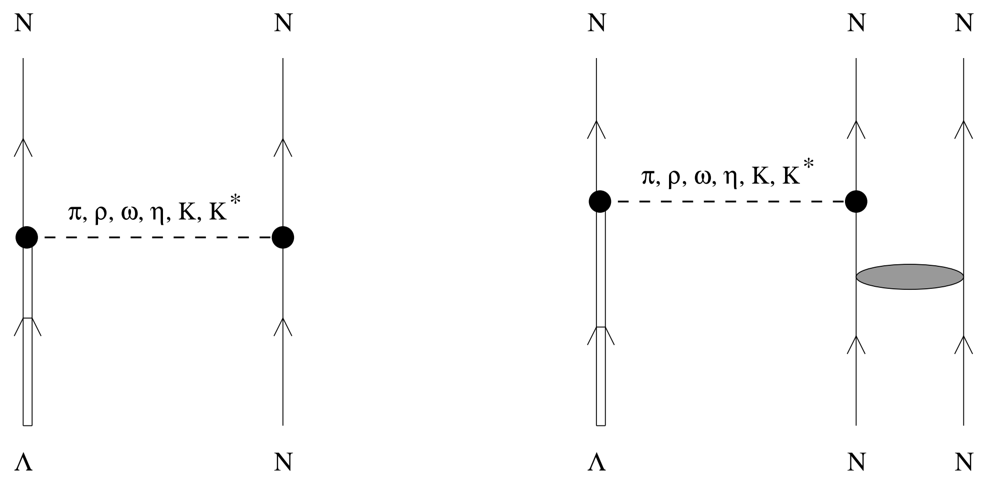
One–nucleon induced

$$\Lambda n \rightarrow nn \qquad \Gamma_n$$

$$\Lambda p \rightarrow np \qquad \Gamma_p$$

Two–nucleon induced

$$\Lambda NN \rightarrow nNN \qquad \Gamma_2$$



$$\Gamma_{\rm T} = \Gamma_{\rm M} + \Gamma_{\rm NM} = \Gamma_{\pi^0} + \Gamma_{\pi^-} + \Gamma_n + \Gamma_p + \Gamma_2$$

- Only possible in nuclei (the only practical way to get information on baryon–baryon weak interactions)

- $Q_{\rm NM} = m_\Lambda - m_N \simeq 176$ MeV $\Longrightarrow$ large p_N ($p_N \simeq 410$ MeV for $1N$–induced)

  – overcoming the Pauli blocking $\Longrightarrow$ the non–mesonic weak decay dominates over the mesonic one for all but the s–shell hypernuclei

  – nuclear structure details do not have substantial influence, but ΛN and NN (strong) Short Range Correlations are very important

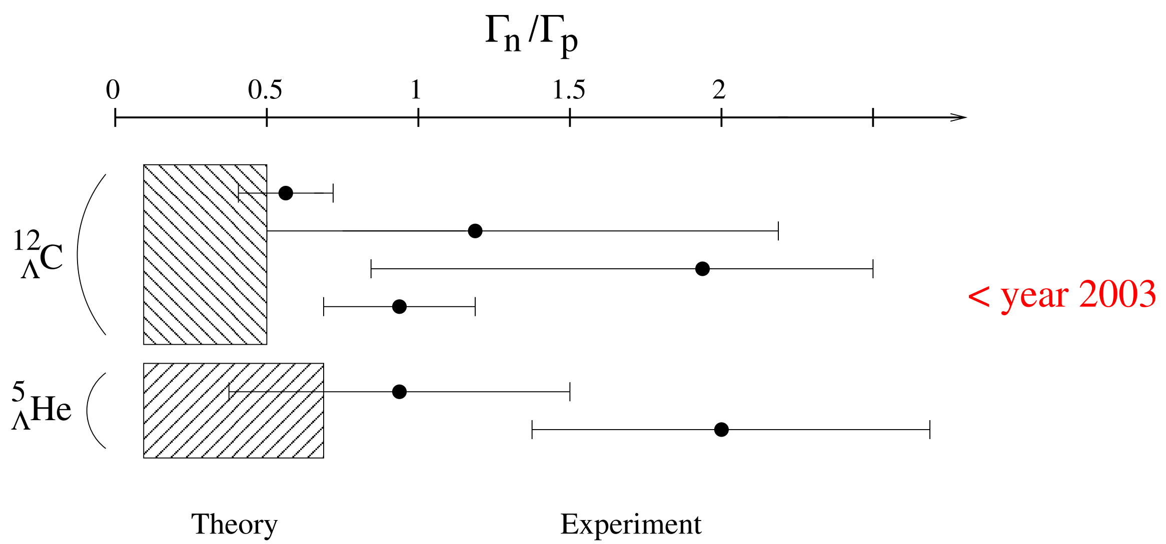
  – non–mesonic channel mediated by Heavy Mesons ($\pi + \rho + K + K^* + \omega + \eta + 2\pi + 2\pi/\rho + 2\pi/\sigma$) and/or Quark Exchange

- Study of $\Gamma_n \equiv \Gamma(\Lambda n \to nn)$ and $\Gamma_p \equiv \Gamma(\Lambda p \to np)$ $\Longleftrightarrow$ Spin– and Isospin–dependence in $\Lambda N \to nN$ (validity of the $\Delta I = 1/2$ rule)

- Anticorrelation between mesonic and non–mesonic decay modes: $\Gamma_{\rm T} = \Gamma_{\rm M} + \Gamma_{\rm NM}$ quite stable from light to heavy hypernuclei

THE RATIO Γ_n/Γ_p

For many years, a sound theoretical explanation of the large experimental values of $\frac{\Gamma_n}{\Gamma_p} \equiv \frac{\Gamma(\Lambda n \to nn)}{\Gamma(\Lambda p \to np)}$ has been missing



Theory strongly underestimated Experiment!

[W. M. Alberico and G. G., Phys. Rep. 369, 1 (2002)]
[E. Oset and A. Ramos, Prog. Part. Nucl. Phys. 41, 191 (1998)]

Experiment

- Large uncertainties in the extraction of Γ_n/Γ_p from "old" data (< year 2002)
  - only Single–Proton Spectra measured
  - very indirect determination of the decay rates, probable overestimation of
    $$\frac{\Gamma_n}{\Gamma_p} = \frac{\Gamma_{\rm T} - \Gamma_{\rm M} - \Gamma_2 - \Gamma_p}{\Gamma_p} \Longleftarrow \Gamma_p \text{ underestimated}, \; \Gamma_2 \text{ neglected}$$
    $$\left(\Gamma_2 = 0\,, \Gamma_p = 0.8[\Gamma_p]^{\rm th} \;:\; \frac{\Gamma_n}{\Gamma_p} = 1 \quad \Longleftrightarrow \quad \left[\frac{\Gamma_n}{\Gamma_p}\right]^{\rm th} = 0.3\right)$$
- KEK–E462/E508: simultaneous measurement of Single–Proton and Single–Neutron Spectra (year 2003) [1]
  - improved determination of $\frac{\Gamma_n}{\Gamma_p}$ from $\frac{N_n}{N_p}$ ratio
- KEK–E462/E508: Nucleon–Nucleon Coincidence Spectra (years 2003–2006) [2]
  - more direct determination of $\frac{\Gamma_n}{\Gamma_p}$ from $\frac{N_{nn}}{N_{np}}$ ratio
- First data from FINUDA@DAΦNE, experiments planned at J–PARC and HypHI@GSI

[1] S. Okada et al., PLB 597, 249 (2004)
[2] B. H. Kang et a., PRL 96, 062301 (2006); M. J. Kim et al., PLB 641, 28 (2006)

Theory

- ✦ The One–Pion–Exchange (OPE) model predicts very small ratios:

$$\left[\frac{\Gamma_n}{\Gamma_p}\right]^{\rm OPE} ({}^{5}_{\Lambda}{\rm He},\ {}^{12}_{\Lambda}{\rm C}) = 0.1 \div 0.2$$

  [$\Delta I = 1/2$ rule + strong tensor component $\Lambda N(^3S_1) \rightarrow nN(^3D_1)$ requiring $I_{nN} = 0 \Longleftrightarrow N = p$]

- ✦ but the OPE reproduces the observed total non–mesonic rates, $\Gamma_{\rm NM} = \Gamma_n + \Gamma_p (+\Gamma_2)$.

Other interaction mechanisms beyond the OPE should then be responsible for the overestimation of Γ_p and the underestimation of Γ_n

- ✦ Heavier Mesons (ρ, K, K^*, ω, η, 2π, $2\pi/\rho$, $2\pi/\sigma$) [Parreño et al., Itonaga et al., Jido et al.]
- ✦ Direct Quark Mechanism [Oka et al.]
- ✦ Two–Nucleon Induced Mechanism [Alberico et al., Ramos et al.]
- ✦ Nucleon Final State Interactions [Ramos et al., Garbarino et al.]

Heavy Meson Exchange (especially Kaons) [1] and Direct Quark contributions [2] improved the situation:

$$\left[\frac{\Gamma_n}{\Gamma_p}\right]^{\rm TH} = 0.3 \div 0.7$$

[1] D. Jido, E. Oset and J. E. Palomar, NPA 694, 525 (2001);
A. Parreño and A. Ramos, PRC 65, 015204 (2002);
K. Itonaga, T. Ueda and T. Motoba, PRC 65, 034617 (2002).

[2] K. Sasaki, T. Inoue and M. Oka, NPA 669, 331 (2000); 678 455E (2000).

The determination of Γ_n/Γ_p from N_{nn}/N_{np} data required theoretical analyses [3]:

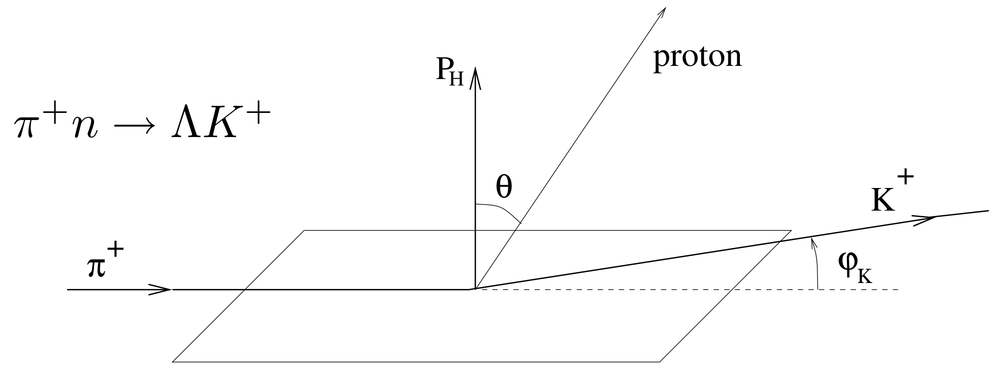
- ✦ inclusion of Two–Nucleon Induced Decays, $\Lambda NN \to nNN$, (experimental identification expected in NNN coincidence measurements, J–PARC)
- ✦ accurate evaluation of the Nucleon FSI inside the residual nucleus

$$\left[\frac{N_{nn}}{N_{np}}\right]^{\rm KEK} \Longrightarrow \left[\frac{\Gamma_n}{\Gamma_p}\right]^{\rm “EXP”} = (0.3 \div 0.4) \pm 0.1$$

convincing evidence for a SOLUTION OF THE PUZZLE

[3] G. G., A. Parreño, A. Ramos, PRL 91, 112501 (2003); PRC 69, 054603 (2004);
E. Bauer, G. G., A. Parreño, A. Ramos, nucl-th/0602066

POLARIZED HYPERNUCLEI: THE DECAY ASYMMETRY



- Weak decay proton intensity from $\vec{\Lambda} p \to np$: $I(\theta) = I_0 \left[1 + p_\Lambda \, a_\Lambda \cos\theta\right]$

$$p_\Lambda = \Lambda \text{ polarization}$$
$$a_\Lambda = \text{intrinsic } \Lambda \text{ asymmetry parameter}$$

$a_\Lambda \iff$ interference among PC and PV $\vec{\Lambda} p \to np$ channels

$\Longrightarrow$ information on strengths and relative phases of the decay amplitudes

- Nucleon FSI modify the weak decay proton intensity $I(\theta)$

Experimentally one measures $I^{\rm M}(\theta) = I_0^{\rm M} \left[1 + p_\Lambda \, a_\Lambda^{\rm M} \cos\theta\right]$

$\Longrightarrow$ *observable* Λ asymmetry parameter $a_\Lambda^{\rm M} = \dfrac{1}{p_\Lambda} \dfrac{I^{\rm M}(0^\circ) - I^{\rm M}(180^\circ)}{I^{\rm M}(0^\circ) + I^{\rm M}(180^\circ)}$

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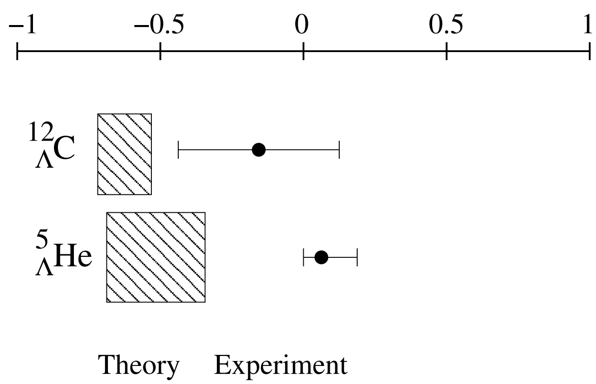
	$^{5}_{\Lambda}$He	$^{12}_{\Lambda}$C
Sasaki et al. a_Λ		
$\pi + K + \mathrm{DQ}$	-0.68	
Parreño et al.		
$\pi + \rho + K + K^* + \omega + \eta$	-0.68	-0.73
Itonaga et al.		
$\pi + K + \omega + 2\pi/\rho + 2\pi/\sigma$	-0.33	
Barbero et al.		
$\pi + \rho + K + K^* + \omega + \eta$	-0.54	-0.53
KEK–E508 a_Λ^{M}		$-0.16 \pm 0.28^{+0.18}_{-0.00}$
KEK–E462	$+0.07 \pm 0.08^{+0.08}_{-0.00}$	

KEK–E508/E462: T. Maruta et al., EPJA 33, 255 (2007)



FSI prevent establishing direct comparisons between a_Λ and a_Λ^{M}

$\Longrightarrow$ a theoretical evaluation of a_Λ^{M} is required

OME + Nucleon FSI

[W. M. Alberico, G.G., A. Parreño and A. Ramos, PRL 94, 082501 (2005)]

$$\text{OME} = \pi + \rho + K + K^* + \eta + \omega$$

$$I(\theta) = I_0 \left[1 + p_\Lambda \, a_\Lambda \cos\theta\right] \qquad I^{\rm M}(\theta) = I_0^{\rm M} \left[1 + p_\Lambda \, a_\Lambda^{\rm M} \cos\theta\right]$$

	${}^{5}_{\Lambda}$He	${}^{11}_{\Lambda}$B	${}^{12}_{\Lambda}$C
a_Λ	-0.68	-0.81	-0.73
$a_\Lambda^{\rm M}$ ($T_p \geq 30$ MeV)	-0.46	-0.39	-0.37
$a_\Lambda^{\rm M}$ ($T_p \geq 50$ MeV)	-0.52	-0.55	-0.51
$a_\Lambda^{\rm M}$ ($T_p \geq 70$ MeV)	-0.55	-0.70	-0.65
KEK–E462	$0.07 \pm 0.08^{+0.08}_{-0.00}$		
KEK–E508		$-0.16 \pm 0.28^{+0.18}_{-0.00}$	

Data from [T. Maruta et al., EPJA 33, 255 (2007)]

- Effective Field Theory: $\pi + K +$ Leading–Order Contact Interactions

  [A. Parreño, C. Bennhold and B. R. Holstein, PRC 70, 051601 (2004)]

  – LOCI coefficients fixed to reproduce experimental $\Gamma_{\rm NM}$ and Γ_n/Γ_p for ${}^{5}_{\Lambda}$He, ${}^{11}_{\Lambda}$B and ${}^{12}_{\Lambda}$C and $a_\Lambda({}^{5}_{\Lambda}{\rm He})$

  – Predicted a dominating central, spin– and isospin–independent contact term

- $\pi + K + \sigma +$ Direct Quark

  [K. Sasaki, M. Izaki, M. Oka, PRC 71, 035502 (2005)]

  – Decay data for s-shell hypernuclei fitted to obtain the weak couplings of the scalar–isoscalar σ–meson, $\mathcal{H}^{\rm W}_{\Lambda\sigma N} = g_W \bar{\psi}_N (A_\sigma + B_\sigma \gamma_5)\phi_\sigma \psi_\Lambda$

  – All ${}^{5}_{\Lambda}$He decay observables reasonably reproduced. No calculation for ${}^{12}_{\Lambda}$C

- OME $+ \sigma$, OME$= \pi + \rho + K + K^* + \eta + \omega$

  [C. Barbero and A. Mariano, PRC 73, 024309 (2006)]

  – Unknown σ couplings fixed to reproduce measured $\Gamma_{\rm NM}({}^{5}_{\Lambda}{\rm He})$ and $\Gamma_n/\Gamma_p({}^{5}_{\Lambda}{\rm He})$

  – Improved overall agreement with experiment for ${}^{12}_{\Lambda}$C and ${}^{5}_{\Lambda}$He but data for $a_\Lambda({}^{5}_{\Lambda}{\rm He})$ could not be reproduced

- $\Longrightarrow$ Importance of the Scalar–Isoscalar channel in Asymmetry calculations

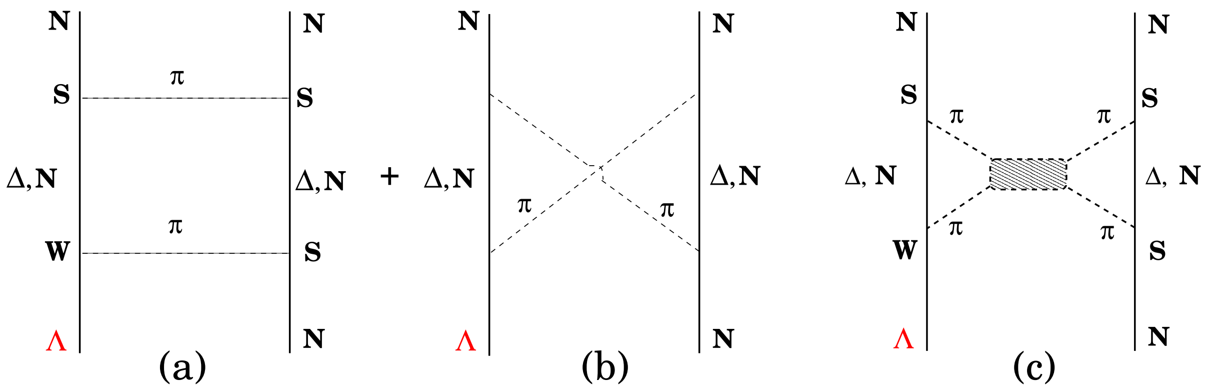
One–Meson–Exchange + Two–Pion–Exchange

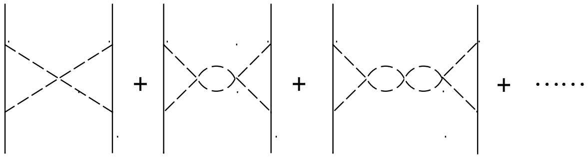
[C. Chumillas, G. G, A. Parreño and A. Ramos, PLB 657, 180 (2007)]

- Uncorrelated (2π) and Correlated ($2\pi/\sigma$) Two–Pion–Exchange (TPE)

  [D. Jido, E. Oset and J.E. Palomar, NPA 694, 525 (2001)]

- $2\pi/\sigma$ motivated by Chiral Unitary Theory





- 2π: dominated by the isoscalar channel
- $2\pi/\sigma$ reproduces $\pi\pi$ scattering data in the scalar sector
- No free parameter: couplings determined from chiral meson–meson and meson–baryon Lagrangians

Model	$\Gamma_{\rm NM} = \Gamma_n + \Gamma_p$	${}^{5}_{\Lambda}$He Γ_n/Γ_p	a_Λ
OME	0.379	0.474	-0.590
OME+TPE	0.388	0.415	$+0.041$
OME+TPE+FSI			$+0.028$
KEK–E462	0.424 ± 0.024	0.40 ± 0.11 $(1N)$ 0.27 ± 0.11 $(1N + 2N)$	$+0.07 \pm 0.08^{+0.08}_{-0.00}$

Model	$\Gamma_{\rm NM} = \Gamma_n + \Gamma_p$	${}^{12}_{\Lambda}$C Γ_n/Γ_p	a_Λ
OME	0.667	0.357	-0.698
OME+TPE	0.722	0.366	-0.207
OME+TPE+FSI			-0.126
KEK–E508	0.940 ± 0.035	0.38 ± 0.14 $(1N)$ 0.29 ± 0.14 $(1N + 2N)$	$-0.16 \pm 0.28^{+0.18}_{-0.00}$
KEK–E307	0.828 ± 0.087		

- ✦ Moderate change of the Decay Rates, huge influence on the Asymmetries!
- ✦ Agreement with Asymmetry data for *both* ${}^{5}_{\Lambda}$He and ${}^{12}_{\Lambda}$C !

${}^5_\Lambda$He	OME	OME + TPE		OME	OME + TPE
$A:\ {}^1S_0 \to {}^1S_0$	-0.1044	$+0.0835$	AE	-0.2854	$+0.2112$
$B:\ {}^1S_0 \to {}^3P_0$	$+0.0057$	$+0.0057$	BC	$+0.0027$	-0.0033
$C:\ {}^3S_1 \to {}^3S_1$	-0.1399	$+0.1480$	BD	-0.0029	-0.0027
$D:\ {}^3S_1 \to {}^3D_1$	-0.1814	-0.1814	CF	-0.0856	$+0.0405$
$E:\ {}^3S_1 \to {}^1P_1$	$+0.3833$	$+0.3833$	DF	-0.2186	-0.2046
$F:\ {}^3S_1 \to {}^3P_1$	$+0.2234$	$+0.2234$			
$\Gamma_p = \sum_{\alpha=A\ldots F} \lvert\alpha\rvert^2$	0.257	0.275	a_Λ	-0.590	$+0.041$

- Spectroscopic notation: $\Lambda p\,({}^{2S+1}L_J) \to np\,({}^{2S'+1}L'_J)$
- OME → OME + TPE:
  - Drastic change of the Scalar–Isoscalar amplitudes A and C
  - AE interference changes sign and cancels the DF contribution

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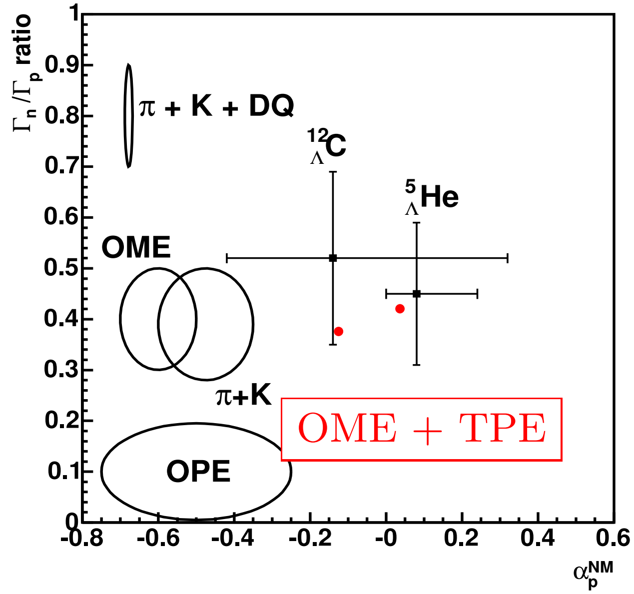
NEED FOR NEW EXPERIMENTS

- Experiment and Theory have reached an advanced degree of development: solution of the long–standing puzzles on Γ_n/Γ_p and Decay Asymmetry



OME + TPE reproduces all data without $\Delta I = 3/2$ contributions

- Nevertheless, new experiments are necessary to achieve a detailed theoretical understanding of the reaction mechanism of Non–Mesonic Weak Decay
  - Precise determination of Partial Decay Rates and Asymmetries
  - Still model–dependendent results in OME and DQ model calculations (unknown weak meson–baryon–baryon couplings, validity of $\Delta I = 1/2$ rule)

s–shell Hypernuclei $\Longleftrightarrow$ $\Delta I = 1/2$ Rule

- Block–Dalitz Phenomenological Model $\Longrightarrow$ Spin–Isospin structure of $\Lambda N \to nN$

- Introducing the rates R_{NJ} for the spin–singlet (R_{n0}, R_{p0}) and spin–triplet (R_{n1}, R_{p1}) elementary $\Lambda N \to nN$ interactions:

$$\begin{aligned}
\Gamma_{\rm NM}({}^{3}_{\Lambda}{\rm H}) &= (3R_{n0} + R_{n1} + 3R_{p0} + R_{p1})\,\frac{\rho_2}{8} \\
\Gamma_{\rm NM}({}^{4}_{\Lambda}{\rm H}) &= (R_{n0} + 3R_{n1} + 2R_{p0})\,\frac{\rho_3}{6} \\
\Gamma_{\rm NM}({}^{4}_{\Lambda}{\rm He}) &= (2R_{n0} + R_{p0} + 3R_{p1})\,\frac{\rho_3}{6} \\
\Gamma_{\rm NM}({}^{5}_{\Lambda}{\rm He}) &= (R_{n0} + 3R_{n1} + R_{p0} + 3R_{p1})\,\frac{\rho_4}{8}
\end{aligned}$$

- Relations which test the $\Delta I = 1/2$ Rule

$$\frac{\Gamma_n({}^{4}_{\Lambda}{\rm He})}{\Gamma_p({}^{4}_{\Lambda}{\rm H})} = \frac{\frac{\Gamma_n}{\Gamma_p}({}^{4}_{\Lambda}{\rm H})\,\frac{\Gamma_n}{\Gamma_p}({}^{4}_{\Lambda}{\rm He})}{\frac{\Gamma_n}{\Gamma_p}({}^{5}_{\Lambda}{\rm He})} = \frac{R_{n0}}{R_{p0}} \quad \Longleftrightarrow \quad \Delta I = 1/2 \text{ Rule}: \quad \frac{R_{n1}}{R_{p1}} \leq \frac{R_{n0}}{R_{p0}} = 2$$

✦ $\Gamma_{\rm NM}({}^5_\Lambda{\rm He}) = 0.411 \pm 0.024 \quad \dfrac{\Gamma_n}{\Gamma_p}({}^5_\Lambda{\rm He}) = 0.3 \pm 0.1$ (KEK):

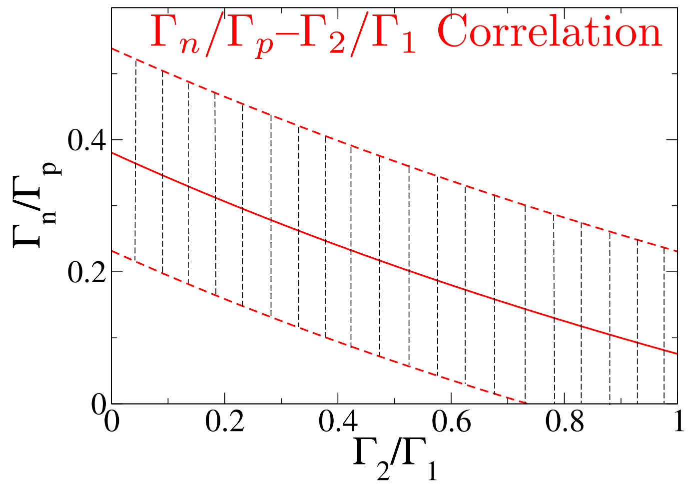
$\Delta I = 1/2$ rule				Experiment	
$\Gamma_{\rm NM}({}^4_\Lambda{\rm He})$	$=$	$0.25^{+0.04}_{-0.01}$	$\Longleftrightarrow$	0.177 ± 0.028	(BNL−E788)
$\Gamma_{\rm NM}({}^4_\Lambda{\rm H})$	$=$	$0.08^{+0.03}_{-0.02}$	$\Longleftrightarrow$	0.17 ± 0.11	(KEK)

$\Longrightarrow$ violation of the $\Delta I = 1/2$ rule? Too early to conclude!

✦ P22@J–PARC: precise measurement of Γ_n and Γ_p for ${}^4_\Lambda{\rm H}$ and ${}^4_\Lambda{\rm He}$ [Ajimura's Talk]

Extraction of $\Gamma_2 = \Gamma(\Lambda NN \to nNN)$ from Data

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



Theoretical analysis of present Data
[G. G., A. Parreño, A. Ramos, PRL 91, 112501 (2003); PRC 69, 054603 (2004)]

KEK–E462 ${}^{12}_{\Lambda}$C:

$$\frac{N_{nn}}{N_{np}} = 0.4 \pm 0.1 \ (T_N > 30 \text{ MeV}, \cos\theta_{NN} \le -0.8)$$

- Theory: $\Gamma_2/\Gamma_1 = 0.26$ $\quad \Gamma_{np}/\Gamma_1 = 0.20$ $\quad \Gamma_{pp}/\Gamma_1 = 0.05$ $\quad \Gamma_{nn}/\Gamma_1 = 0.01$
  [E. Bauer, G. G., A. Parreño and A. Ramos, nucl-th/0602066]
- KEK Data + simplistic Assumptions: $\Gamma_2/\Gamma_1 \simeq 0.7$
  [H. Bhang et al., EPJA 33, 259 (2007)]
- BNL–E788 ${}^{4}_{\Lambda}$He Data: $\Gamma_2/\Gamma_1 \le 0.32$ (95% CL)
  [J. D. Parker et al., PRC 76, 035501 (2007)]
- P18@J–PARC: extraction of Γ_n, Γ_p and Γ_2 for ${}^{12}_{\Lambda}$C with a 10% error level via Double– and Triple–Nucleon Coincidence [Bhang's Talk]

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Exotic Hypernuclei $\Longleftrightarrow \Gamma_n/\Gamma_p$

- ✦ Neutron– and Proton–Rich (${}^{6}_{\Lambda}$H, ${}^{9}_{\Lambda}$He; ${}^{7}_{\Lambda}$Be, ${}^{8}_{\Lambda}$C)
  - Γ_n/Γ_p for extreme N/Z
  - Effects of (low–density) Neutron and Proton Halos on NMWD
  - Present and Future searches:

    KEK and FINUDA: formation probability studies (upper limits)

    HypHI@GSI: in–flight decays, no surrounding target ($T_N^{\rm th} \to 0$) [Saito's Talk]

    J–PARC: future extension of E10 Proposal? [Sakaguchi's Talk]

    Nuclotron@JINR (Dubna): relativistic hypernuclei

- ✦ Medium and Heavy: $A > 11$ (saturation property of $\Gamma_{\rm NM}$)
  - KEK: saturation at $\Gamma_{\rm NM}({}^{28}_{\Lambda}{\rm Si} - {}^{56}_{\Lambda}{\rm Fe}) \simeq 1.2$, in agreement with Theory
  - COSY–13@Juelich: $p + A$, $A =$ Au, Bi and U targets, measurement of fragments from fission induced by NMWD, no direct identification of hypernuclear formation $\Gamma_{\rm NM}(A \simeq 180 - 225) = 1.81 \pm 0.14$
  - CEBAF@JLAB: proposal for high–precision measurement of lifetime of heavy hypernuclei?

CONCLUSIONS

- A reasonable agreement has been obtained between Experiment and Theory on the Γ_n/Γ_p Ratio and the Decay Asymmetries: the Scalar–Isoscalar mechanism is essential in Asymmetry calculations

- Nevertheless, new precise measurements are necessary to achieve a detailed understanding of the reaction mechanism for the Non–Mesonic Weak Decay
  - s–shell Hypernuclei *vs* $\Delta I = 1/2$ rule
  - Extraction of $\Gamma_2 = \Gamma(\Lambda NN \to nNN)$ from Data
  - Exotic hypernuclei *vs* Γ_n/Γ_p

- J–PARC could give an important contribution

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ADDITIONAL SLIDES

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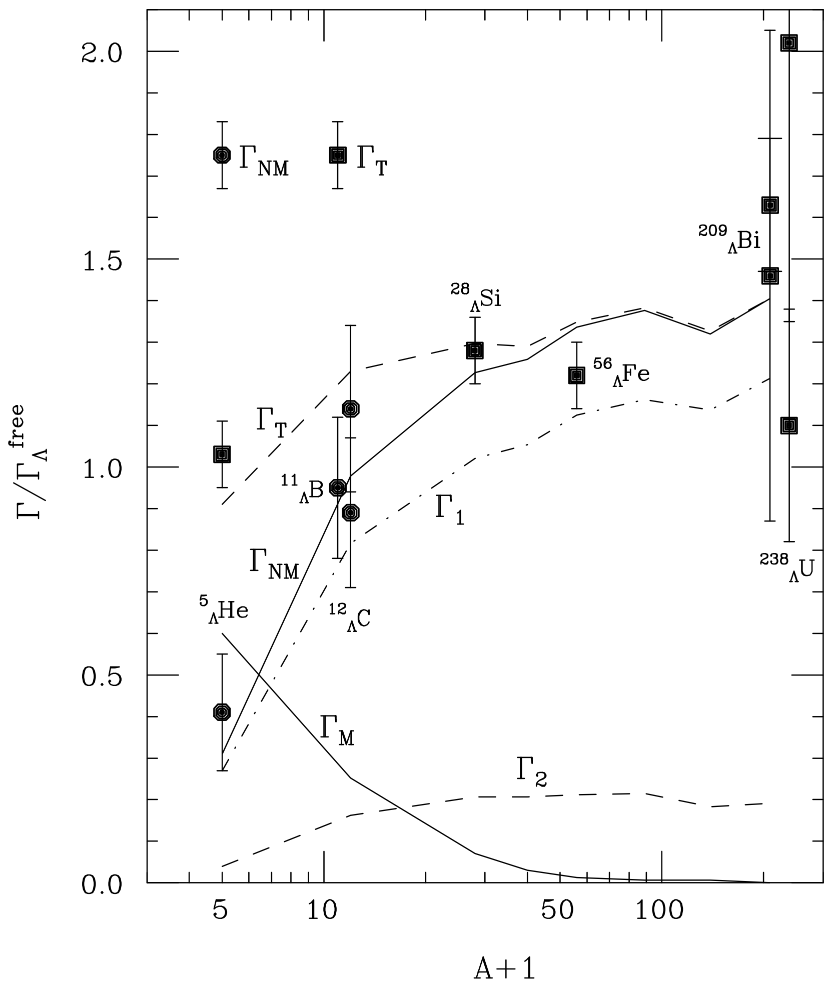
RESULTS



[W. M. Alberico and G. G., Phys. Rep. **369**, 1 (2002)]

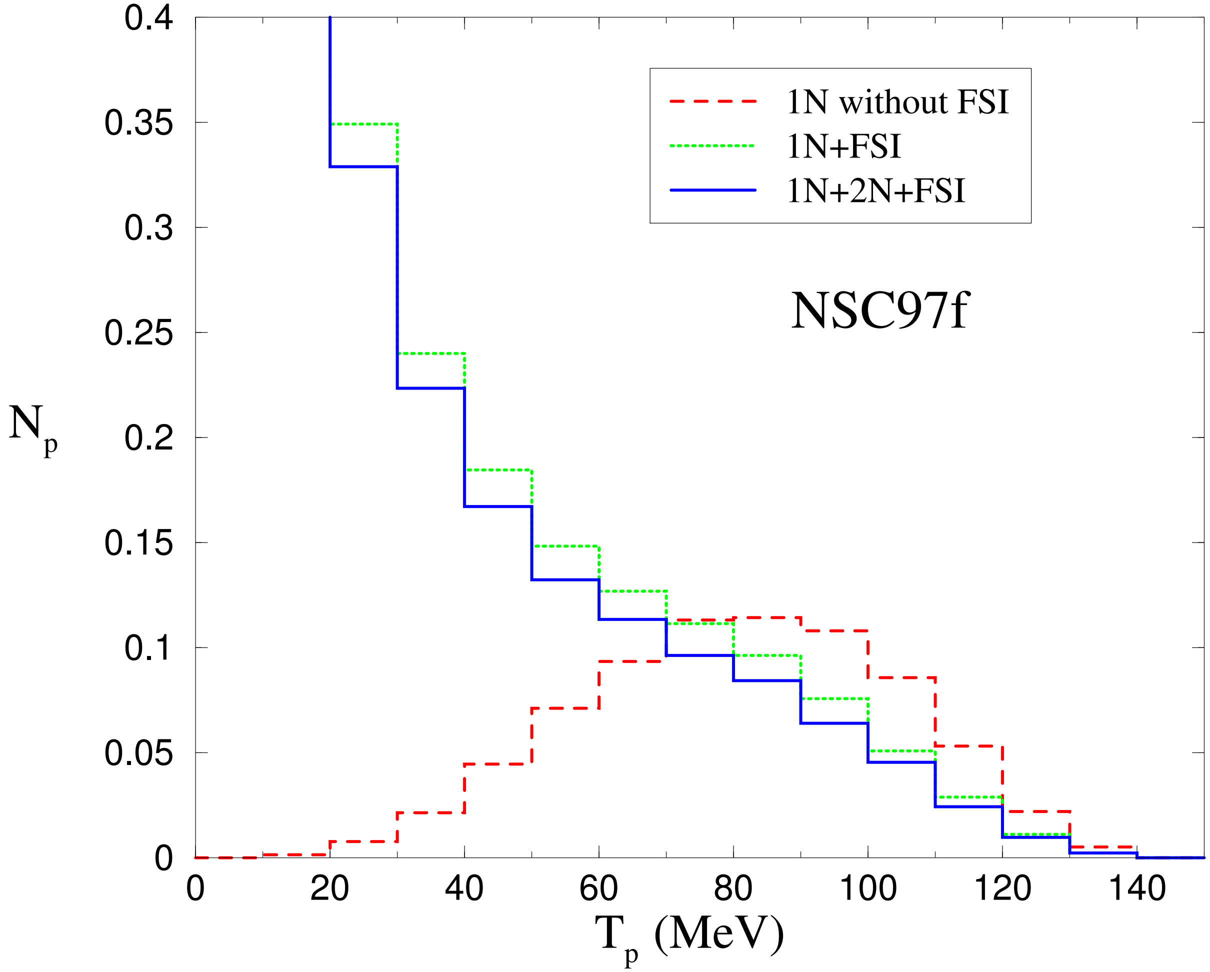


Figure 1: Single–proton kinetic energy spectra per NMWD of ${}^{12}_{\Lambda}C$.

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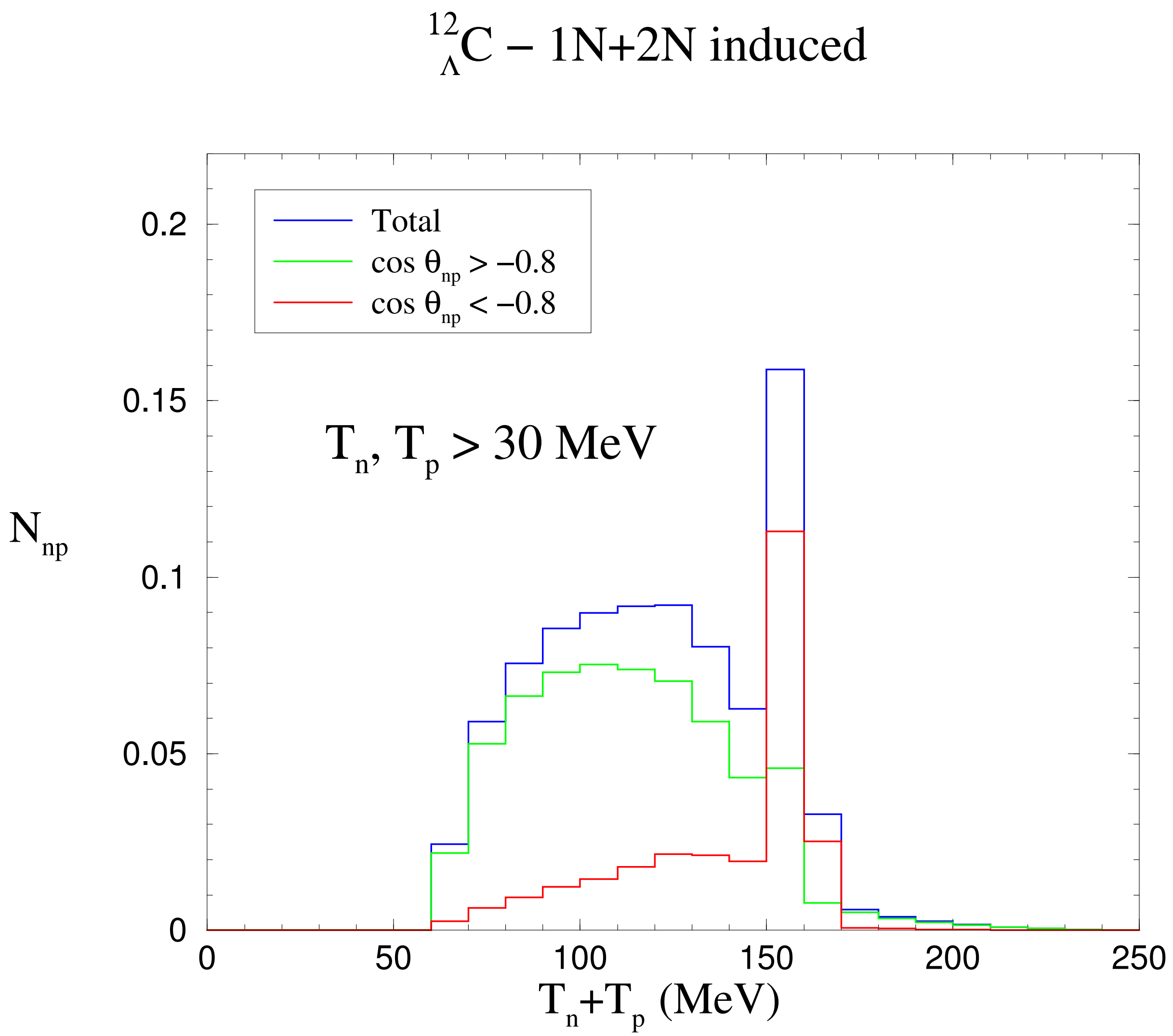


Figure 2: Kinetic energy correlations of *np* pairs emitted per NMWD of $^{12}_{\Lambda}C$

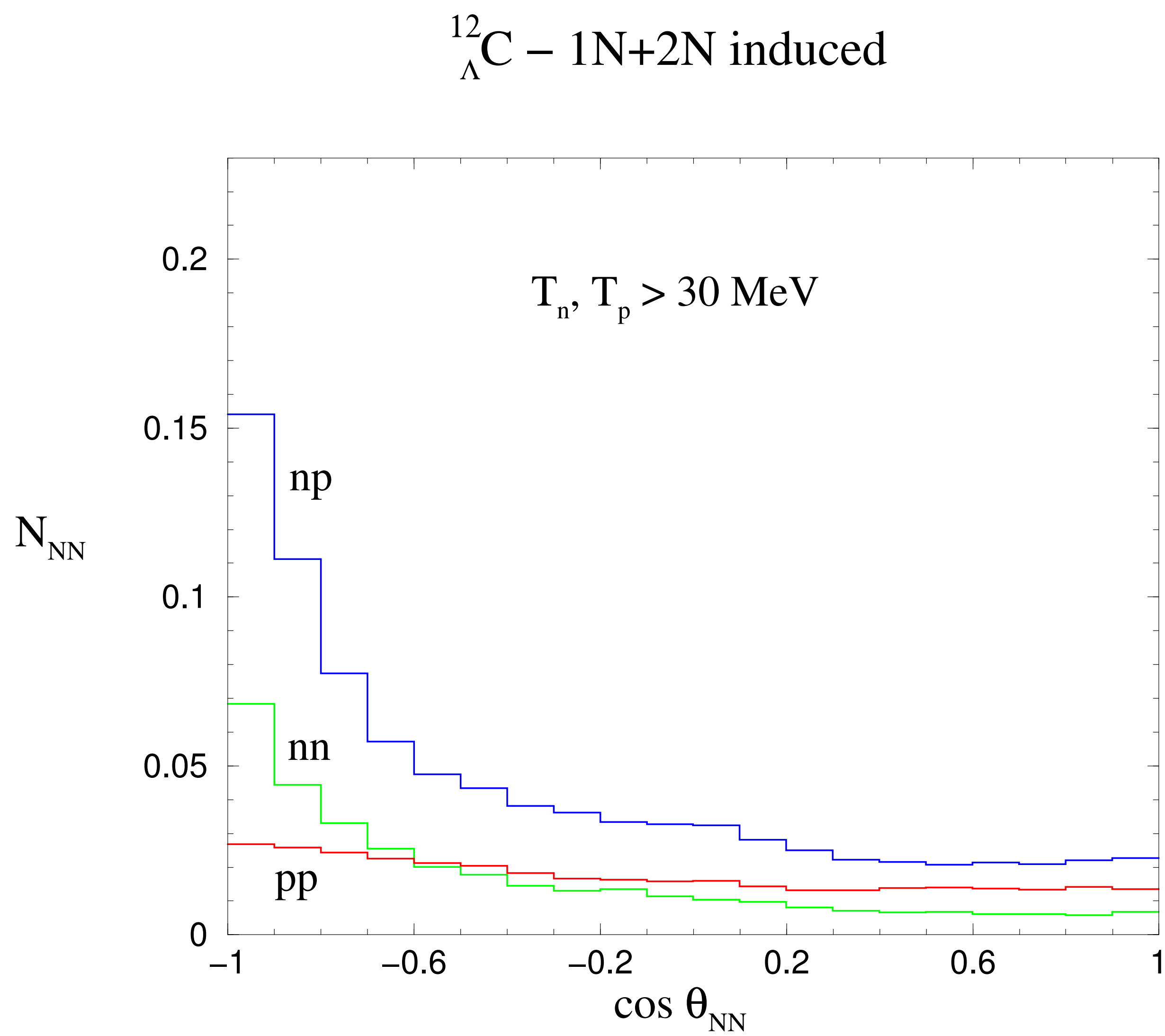


Figure 3: Angular distribution of *nn*, *np* and *pp* pairs emitted per NMWD of $^{12}_{\Lambda}C$

Γ_n/Γ_p

Number of primary nn and np pairs:

$$N_{nn}^{\rm wd} \propto \Gamma_n \qquad N_{np}^{\rm wd} \propto \Gamma_p$$

Denoting with N_{nn} and N_{np} the number of nucleons emitted by the nucleus:

$$\frac{\Gamma_n}{\Gamma_p} \equiv \frac{\Gamma(\Lambda n \to nn)}{\Gamma(\Lambda p \to np)} \equiv \frac{N_{nn}^{\rm wd}}{N_{np}^{\rm wd}} \neq \frac{N_{nn}}{N_{np}} = R_2\,(\Gamma_2, {\rm FSI})$$

Table 1: N_{nn}/N_{np} for ${}^5_\Lambda$He and ${}^{12}_\Lambda$C ($\cos\theta_{NN} \leq -0.8$ and $T_N^{\rm th} = 30$ MeV)

	${}^5_\Lambda$He N_{nn}/N_{np}	${}^5_\Lambda$He Γ_n/Γ_p	${}^{12}_\Lambda$C N_{nn}/N_{np}	${}^{12}_\Lambda$C Γ_n/Γ_p
OPE	0.25	0.09	0.24	0.08
OME	0.51	0.34	0.39	0.29
KEK–E462	$0.45 \pm 0.11 \pm 0.03$			
KEK–E508			0.40 ± 0.10	

Data from B. H. Kang et al., PRL 96, 062301 (2006); M. J. Kim et al., PLB 641, 28 (2006); H. Outa, NPA 754, 157c (2005)

A weak–decay–model independent analysis of Γ_n/Γ_p

- Total number of NN pairs emitted per NMWD:

$$N_{nn} = \frac{N_{nn}^{\rm 1Bn}\,\Gamma_n + N_{nn}^{\rm 1Bp}\,\Gamma_p + N_{nn}^{\rm 2B}\,\Gamma_2}{\Gamma_n + \Gamma_p + \Gamma_2}$$

$$N_{np} = \frac{N_{np}^{\rm 1Bn}\,\Gamma_n + N_{np}^{\rm 1Bp}\,\Gamma_p + N_{np}^{\rm 2B}\,\Gamma_2}{\Gamma_n + \Gamma_p + \Gamma_2}$$

which define the six weak–decay–model independent quantities: $N_{nn}^{\rm 1Bn}$ (the number of nn pairs emitted per neutron–induced NMWD), etc.

- From a measurement of N_{nn}/N_{np} and appropriate values for Γ_2/Γ_1:

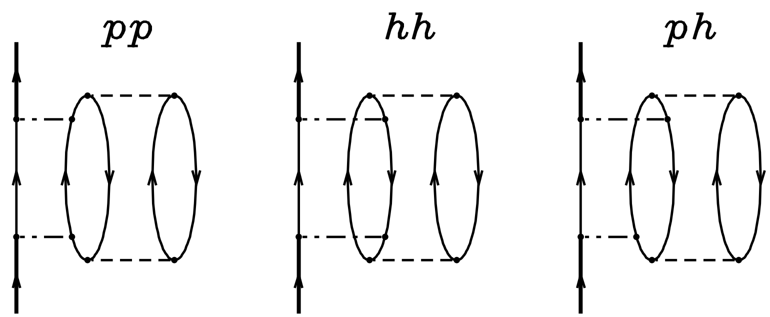
$$\frac{\Gamma_n}{\Gamma_p} = \frac{N_{nn}^{\rm 1Bp} + N_{nn}^{\rm 2B}\frac{\Gamma_2}{\Gamma_1} - \left(N_{np}^{\rm 1Bp} + N_{np}^{\rm 2B}\frac{\Gamma_2}{\Gamma_1}\right)\frac{N_{nn}}{N_{np}}}{\left(N_{np}^{\rm 1Bn} + N_{np}^{\rm 2B}\frac{\Gamma_2}{\Gamma_1}\right)\frac{N_{nn}}{N_{np}} - N_{nn}^{\rm 1Bn} - N_{nn}^{\rm 2B}\frac{\Gamma_2}{\Gamma_1}}$$

- From KEK data we obtained:

${}^{5}_{\Lambda}$He	$\Gamma_n/\Gamma_p = 0.26 \pm 0.11$	$\Gamma_2 = 0.20\,\Gamma_1$	$(\Gamma_n/\Gamma_p = 0.39 \pm 0.11 \quad \Gamma_2 = 0)$
${}^{12}_{\Lambda}$C	$\Gamma_n/\Gamma_p = 0.29 \pm 0.14$	$\Gamma_2 = 0.25\,\Gamma_1$	$(\Gamma_n/\Gamma_p = 0.38 \pm 0.14 \quad \Gamma_2 = 0)$

A recent and more detailed study of the **Two–Nucleon Induced decay channel**

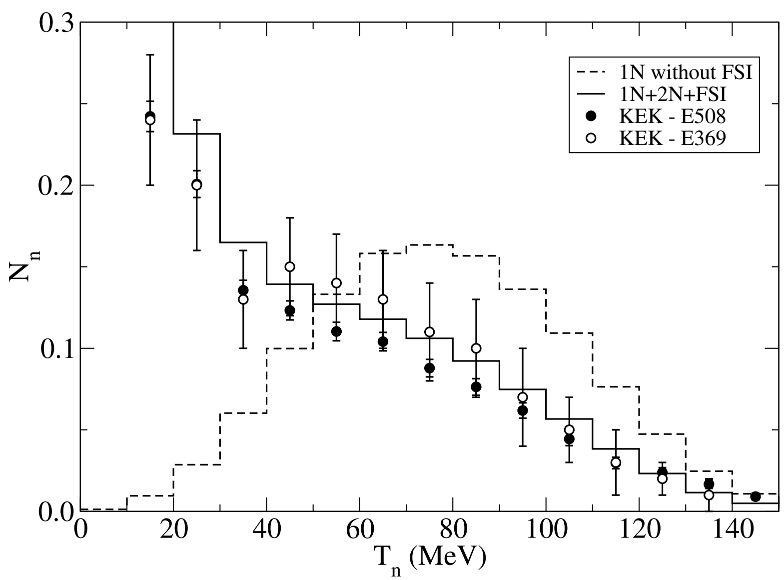
[E. Bauer, G. G., A. Parreño and A. Ramos, nucl-th/0602066]
[E. Bauer and F. Krmpotic, NPA 739, 109 (2004)]

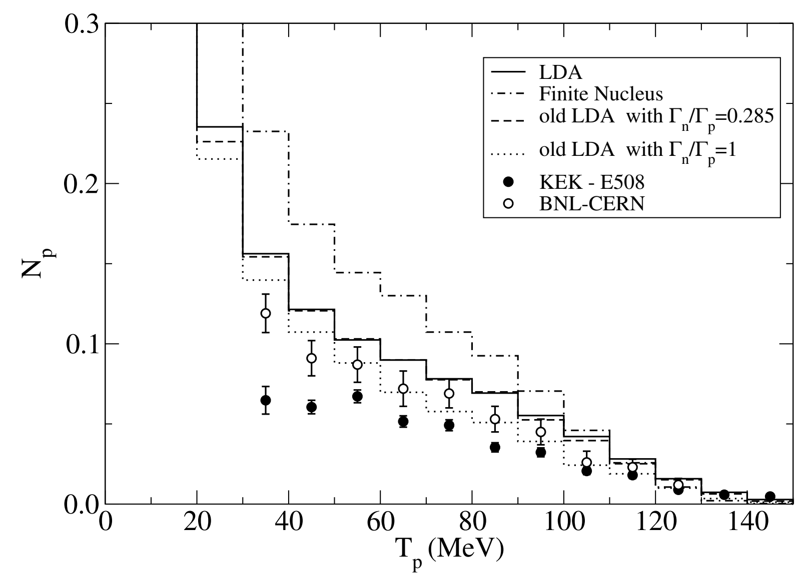


- Microscopic approach, Nuclear Matter + LDA with full OME (previous approach: Phenomenological, Finite Nucleus with OPE)
- $\Lambda nn \to nnn$ and $\Lambda pp \to npp$ also included in addition to $\Lambda np \to nnp$
- $\Gamma_{nn} = \Gamma(\Lambda nn \to nnn)$ $\quad \Gamma_{np} = \Gamma(\Lambda np \to nnp)$ $\quad \Gamma_{pp} = \Gamma(\Lambda pp \to npp)$
- $\Gamma_2 = \Gamma_{nn} + \Gamma_{np} + \Gamma_{pp}$
- For ${}^{12}_{\Lambda}$C: $\Gamma_2/\Gamma_1 = 0.26$ $\quad \Gamma_{np}/\Gamma_1 = 0.20$ $\quad \Gamma_{pp}/\Gamma_1 = 0.05$ $\quad \Gamma_{nn}/\Gamma_1 = 0.01$
- An analysis of KEK nucleon–nucleon correlation spectra confirms the previous determination: $\dfrac{\Gamma_n}{\Gamma_p}({}^{12}_{\Lambda}\mathrm{C}) = 0.34 \pm 0.15$

Disagreement on Proton Spectra

Agreement for Neutrons $^{12}_{\Lambda}$C Disagreement for Protons



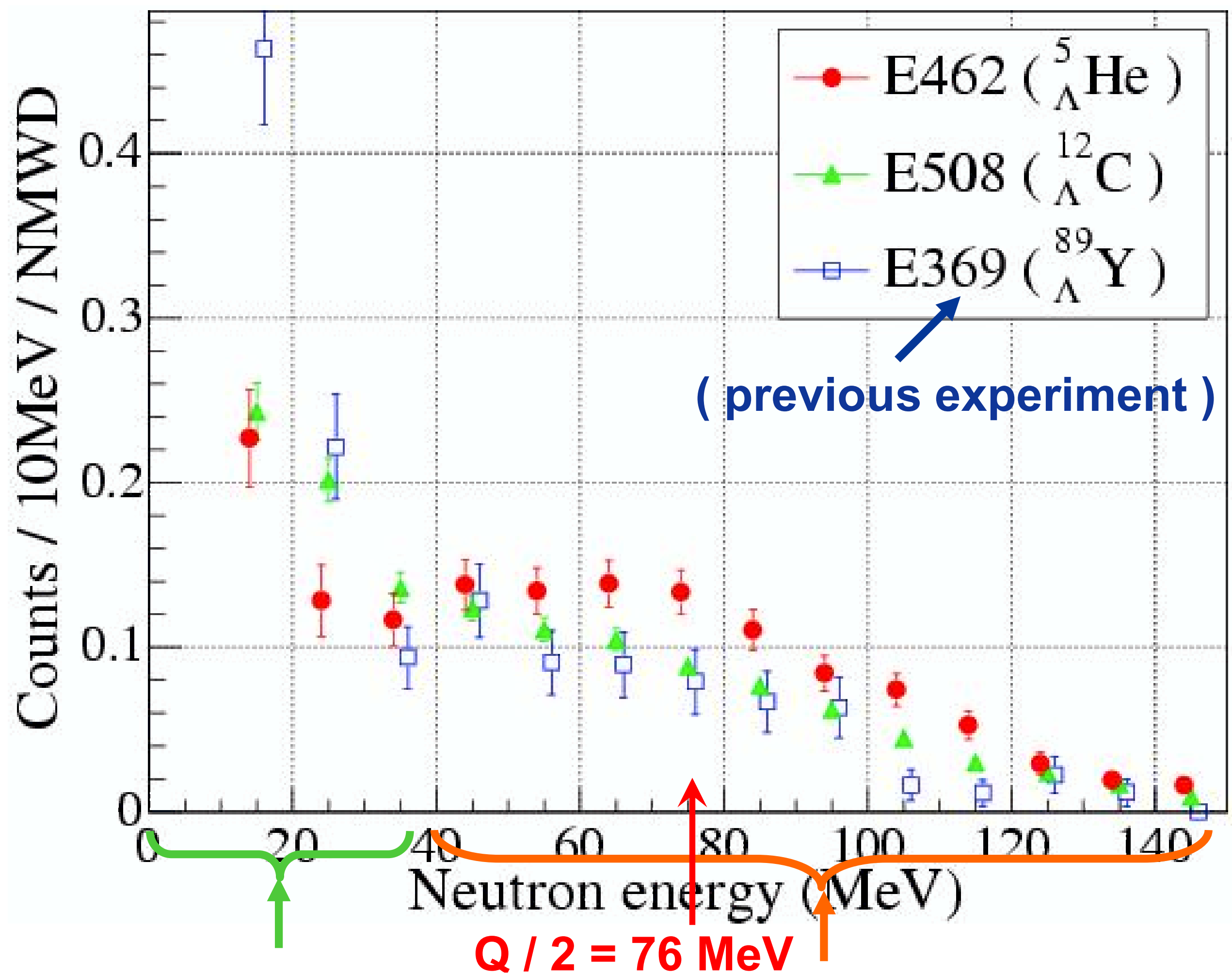


- BNL–E788: Neutron and Proton Spectra for $^{4}_{\Lambda}$He

  [J. D. Parker at al., PRC 76, 035501 (2007)]

- FINUDA: Proton Spectra for $^{5}_{\Lambda}$He, $^{7}_{\Lambda}$Li and $^{12}_{\Lambda}$C:
  peaking structure at $\simeq$ 80 MeV also for $^{12}_{\Lambda}$C, no mass–dependence

  [M. Agnello et al., EPJA 33, 251 (2007); NPA, Special Issue, in press (2008)]

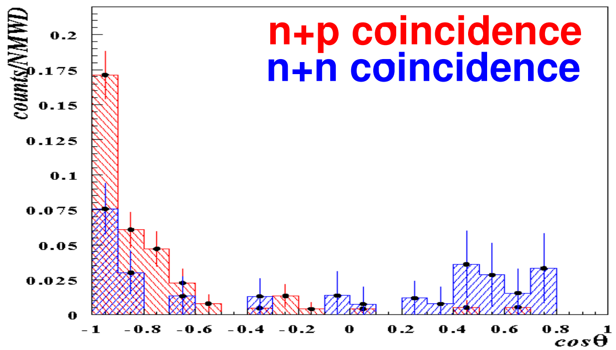


✦ New data needed: FINUDA, J–PARC and HypHI@GSI

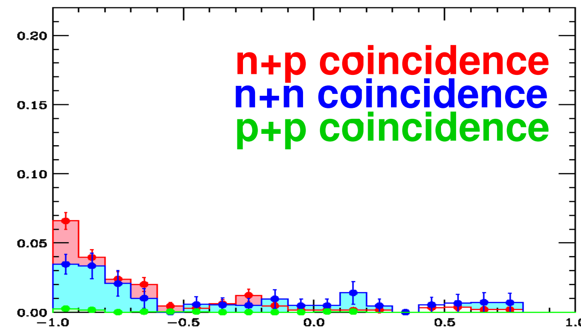
Comparison with theoretical calc. for angular correlation

experimental data

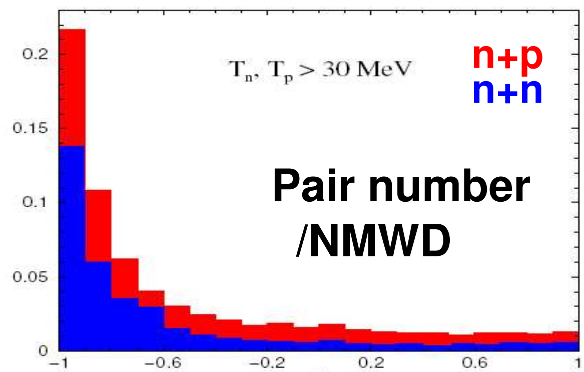
$^{5}_{\Lambda}$He (E462)

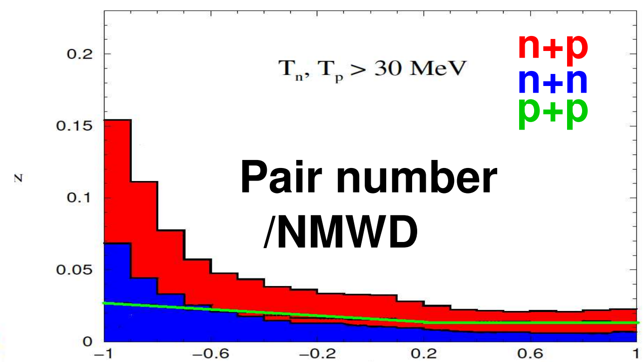


$^{12}_{\Lambda}$C (E508)



theoretical calc.





Garbarino's calc.

assuming Gn/Gp = 0.46 (for $^{5}_{\Lambda}$He), 0.34 (for $^{12}_{\Lambda}$C)

considered 2N-induced(□20%), FSI

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