Recent (Exp.) Progresses in the Study of NMWD of Λ Hypernuclei and Japan-Korea Collab.

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(Seoul National University)

JPS_09
Tokyo, Mar. 27-30, 2009

I. Weak Decay Modes of Λ Hypernuclei.
II. Γ_n/Γ_p ratio puzzle and 3-body NMWD process.
III. Partial Decay widths of NMWD.
IV. J-PARC Weak Decay Experiment (E18) on the 3-body NMWD.
V. K-J(J-K) collaboration on the Hypernuclear Physics.

I. Decay Modes of Λ Hypernucleus

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

- Γ_m
  - $\Gamma_{\pi^-}(\Lambda \rightarrow p\pi^-)$
  - $\Gamma_{\pi^0}(\Lambda \rightarrow n\pi^0)$

  } Mesonic, q~ 100 MeV/c

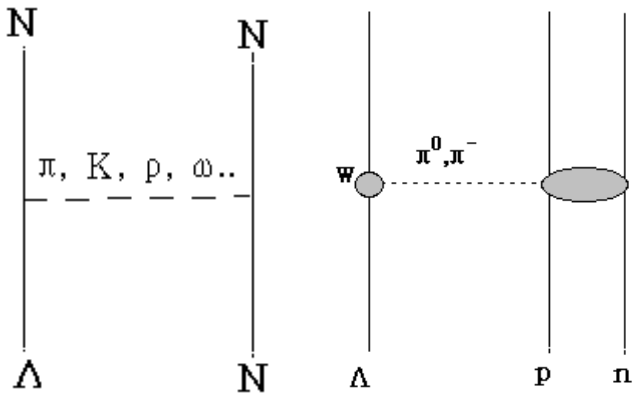
- Γ_{nm}
  - $\Gamma_p(\Lambda p \rightarrow np)$
  - $\Gamma_n(\Lambda n \rightarrow nn)$ — (1N)
  - $\Gamma_{2N}(\Lambda NN \rightarrow nNN)$ — (2N)

  } Nonmesonic, q~ 400 MeV/c

Γ_n/Γ_p puzzle

3-Body Process;

Predicted theoretically



(2N-NMWD)

Status of NMWD of Λ hypernuclei

I. Fundamental Motivation ; to study the elem. B-B Weak Interaction ;

$\Lambda + N \rightarrow N + N$ ($\Delta S=1$ B-B Weak Interaction)

- Γ_n/Γ_p and Ay have been mainly studied so far.

II. Outstanding Issues ;

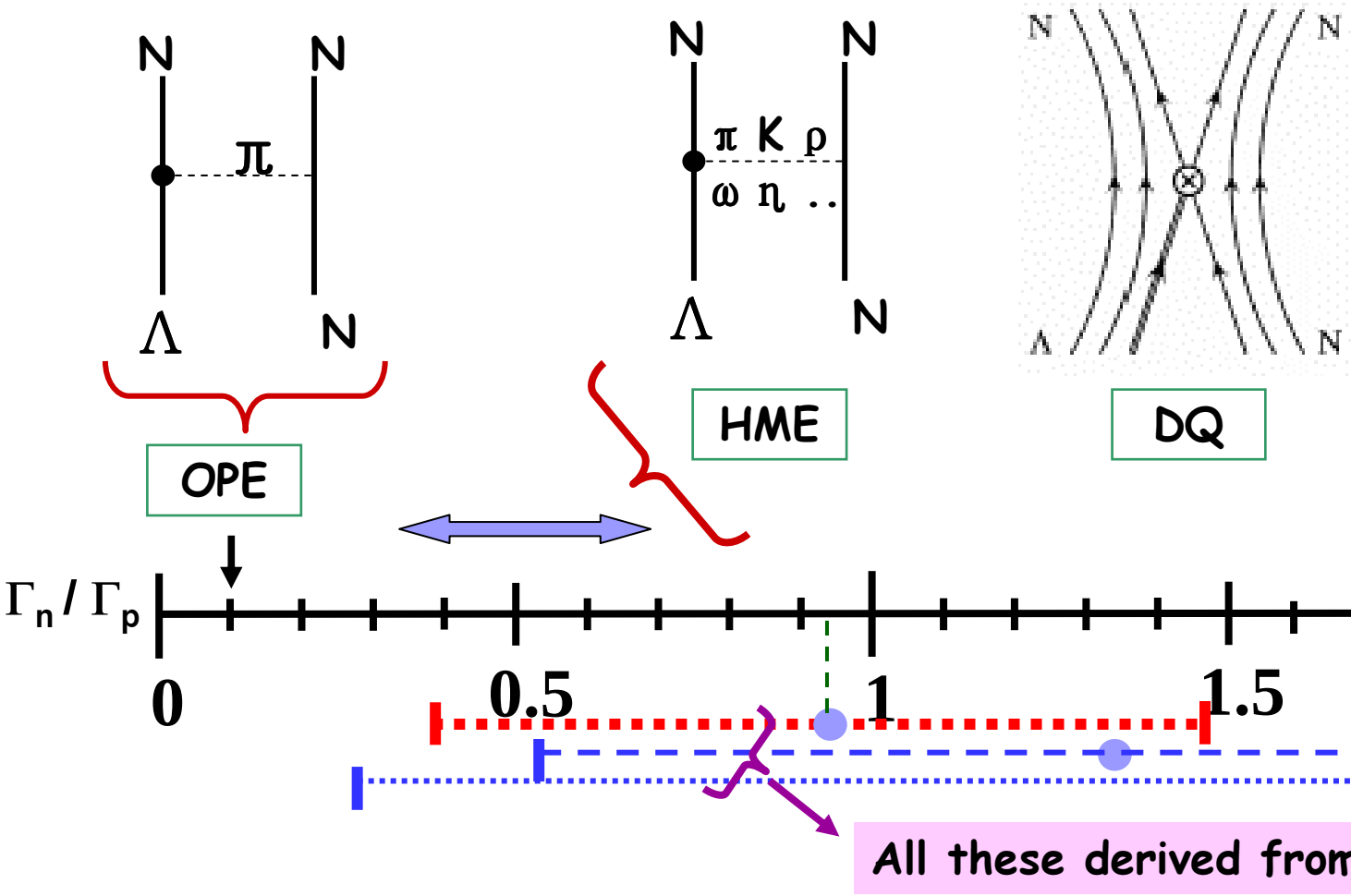
- Decay widths; Γ_n, $\Gamma_p \leftrightarrow \Gamma_{2N}$ (3-body process)
- Asymmetry;
- $\Delta I=1/2$ rule in NMWD ;

Γ_n/Γ_p puzzle and the previous searches

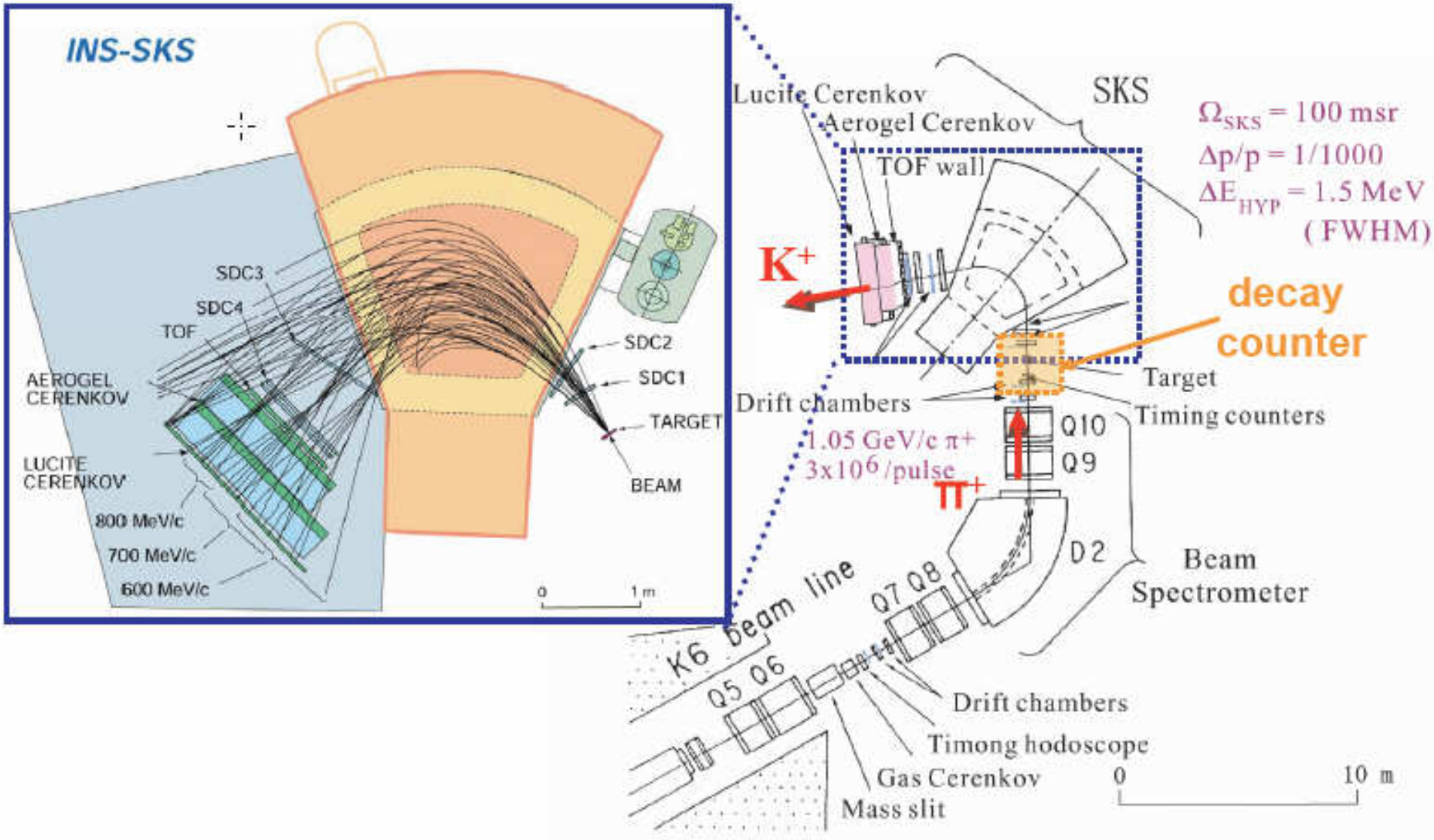
1. Γ_n/Γ_p Puzzle :

$\Gamma_n/\Gamma_p^{exp} \leftrightarrow \Gamma_n/\Gamma_p^{th(OPE)}$

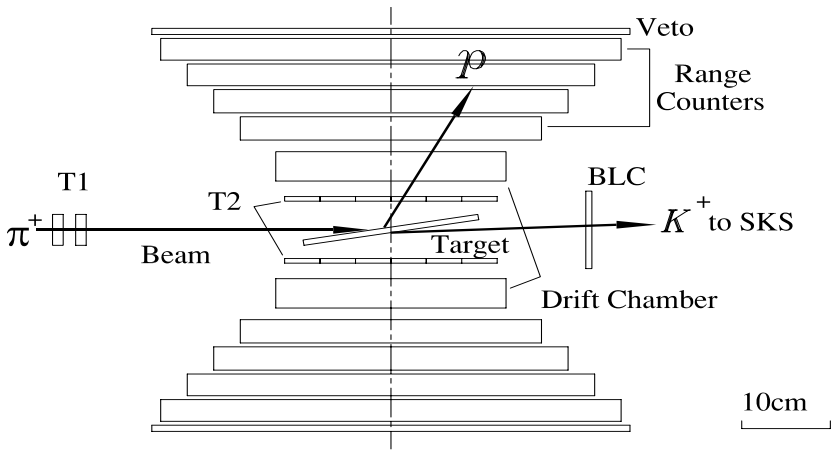
~ 1 ~0.1



KEK-PS K6 beamline and SKS spectrometer



Lifetime and Proton Measurement (E307)

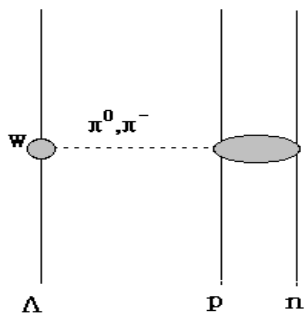


E307 decay counter setup

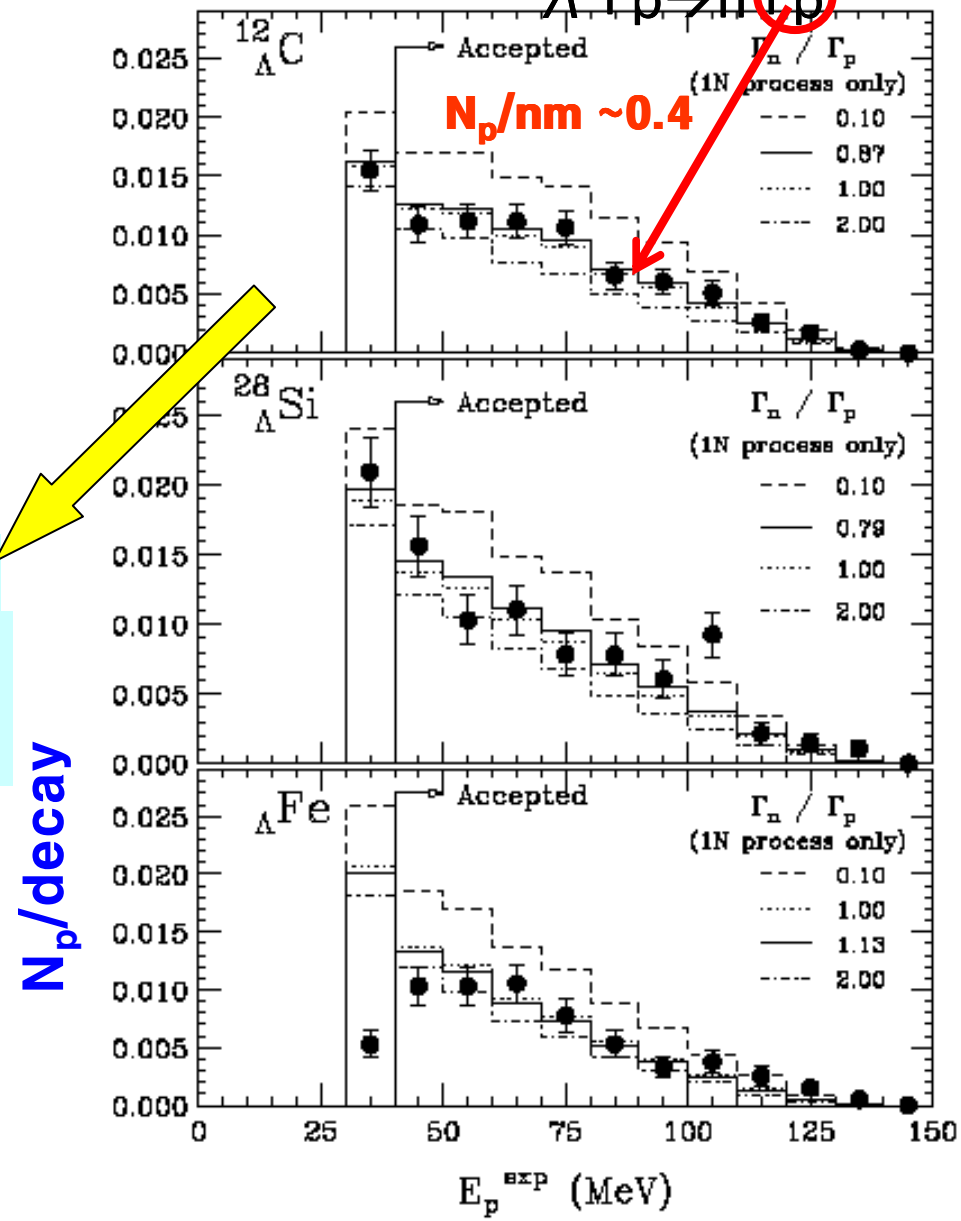
Comparison to INC results gave

$$\frac{\Gamma_n}{\Gamma_p} \rightarrow \begin{pmatrix} 0.87 \pm 0.09 \pm 0.21 \ \ (1N) \\ 0.60 \pm 0.11 \pm 0.23 \ \ (1N+2N) \end{pmatrix}$$

where 2N ; ΛNN → NNN.

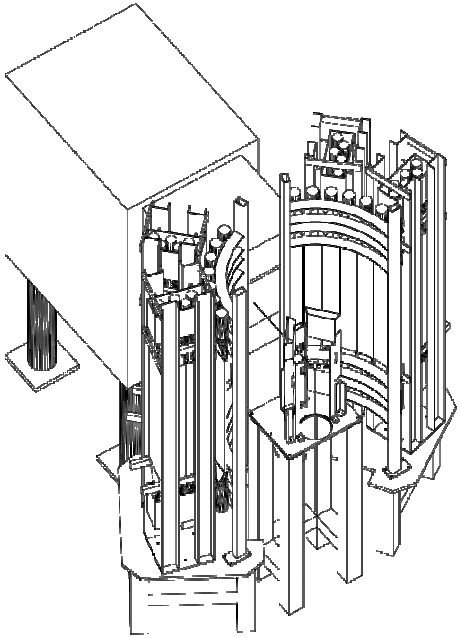


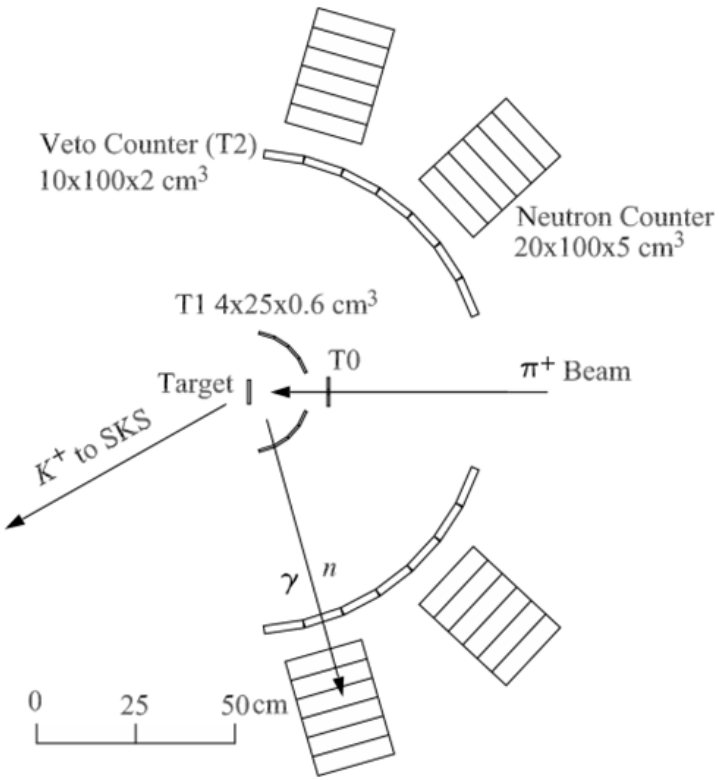
Λ+n→n+n
Λ+p→n+p

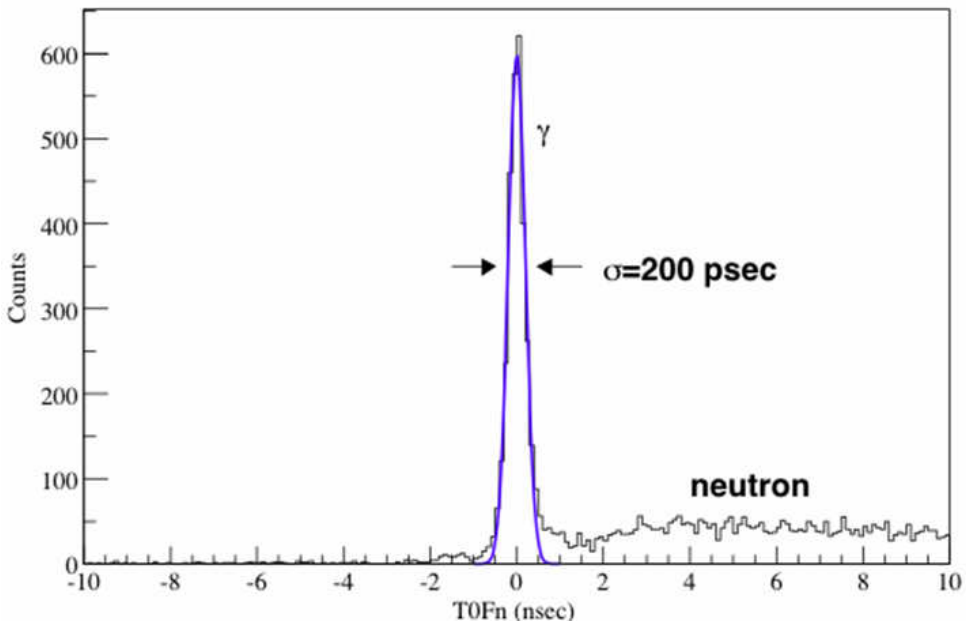


Neutron Measurement (E369)

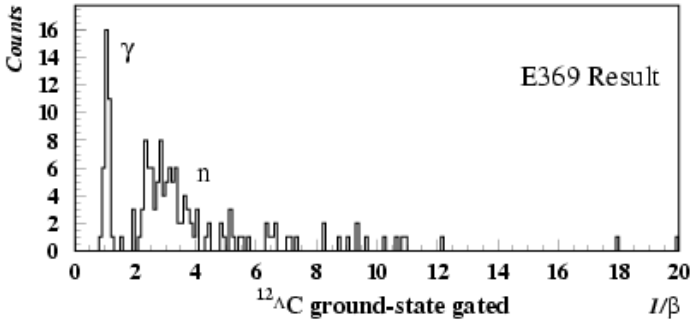
- Neutron spectra measured.
- Target; 12C, 51V and 89Y
- n-γ seperation by TOF

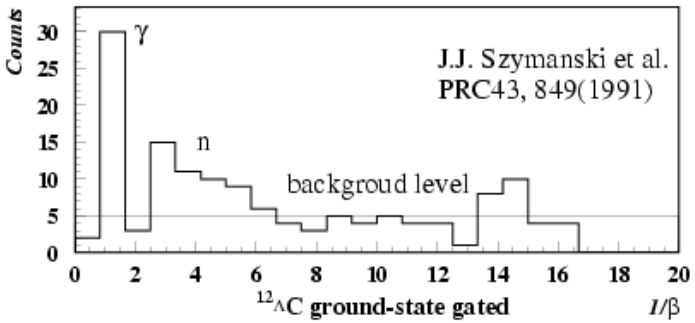


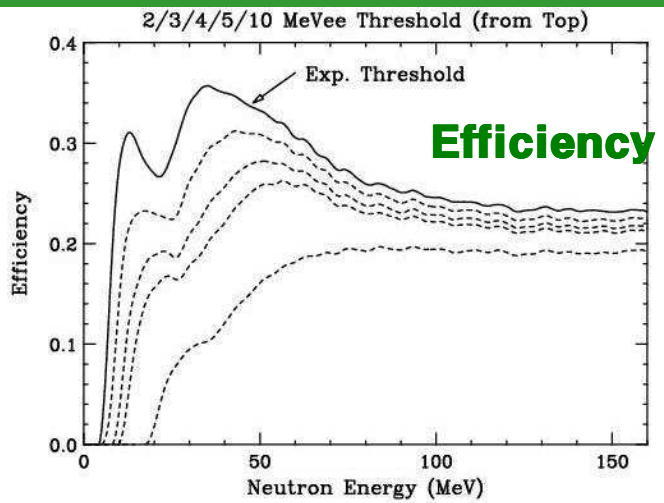


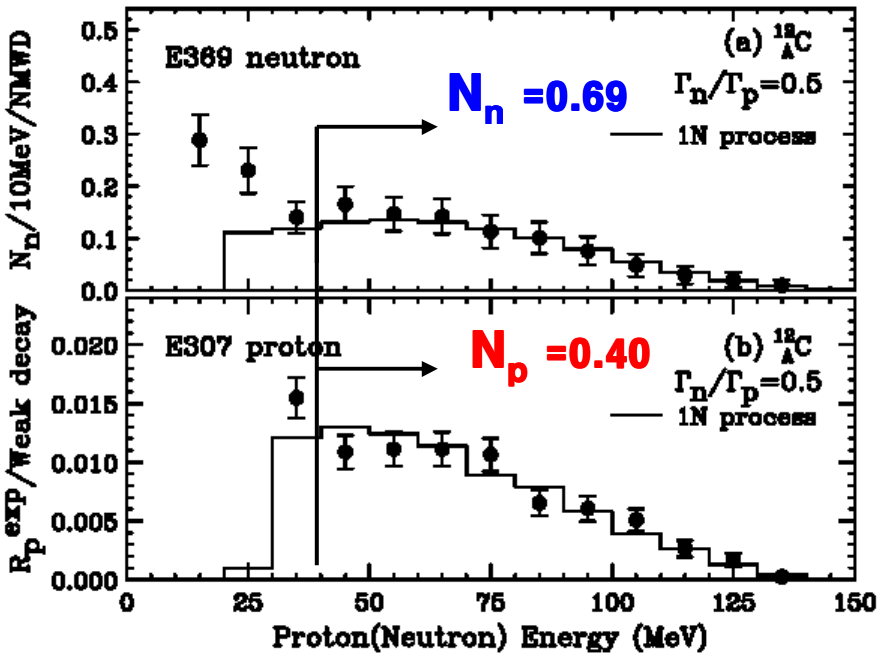


Neutron Spectrum (E369)









- N_n is compared with N_p.
- N_n (> 40 MeV) = 0.69 while N_p = 0.40 (E307)

HYP03 Conf.

Γ_n/Γ_p ratio

E307/E369 Experiment ;

$$\Gamma_n / \Gamma_p\ ({}^{12}{}_{\Lambda}C) = (0.45 \sim 0.51) \pm 0.15 (\text{stat. only})$$

- Obtained almost model independent way
- Large sys. error due to Γ_{nm} is cancelled
- First exp result to show a significantly smaller ratio than unity.

However, some ambiguities still exist due to

- final state int.
- 2N induced NMWD.

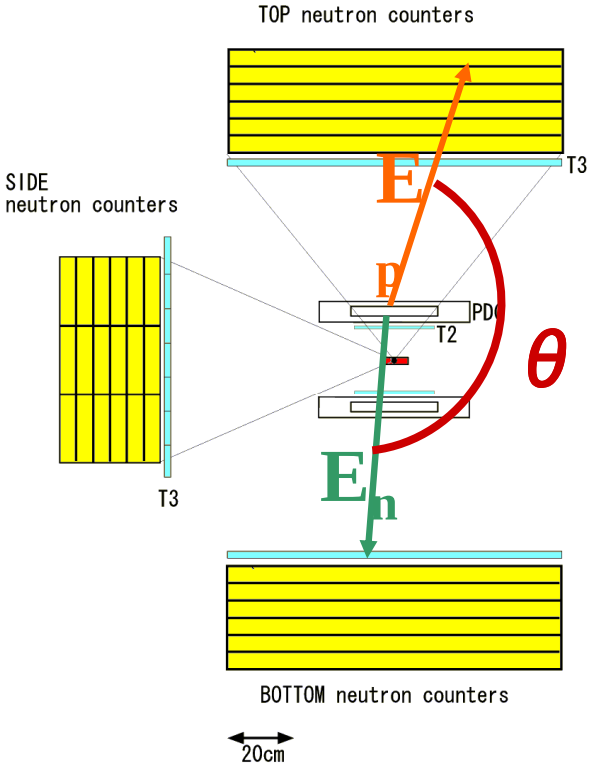
→

- Coincidence measurements
  - ${}^{5}{}_{\Lambda}He$ → E462
  - ${}^{12}{}_{\Lambda}C$ → E508

Asymmetry issue:

Serious inconsistency among α_{nm} for C.

Coincidence Measurement (KEK-PS E462/E508)

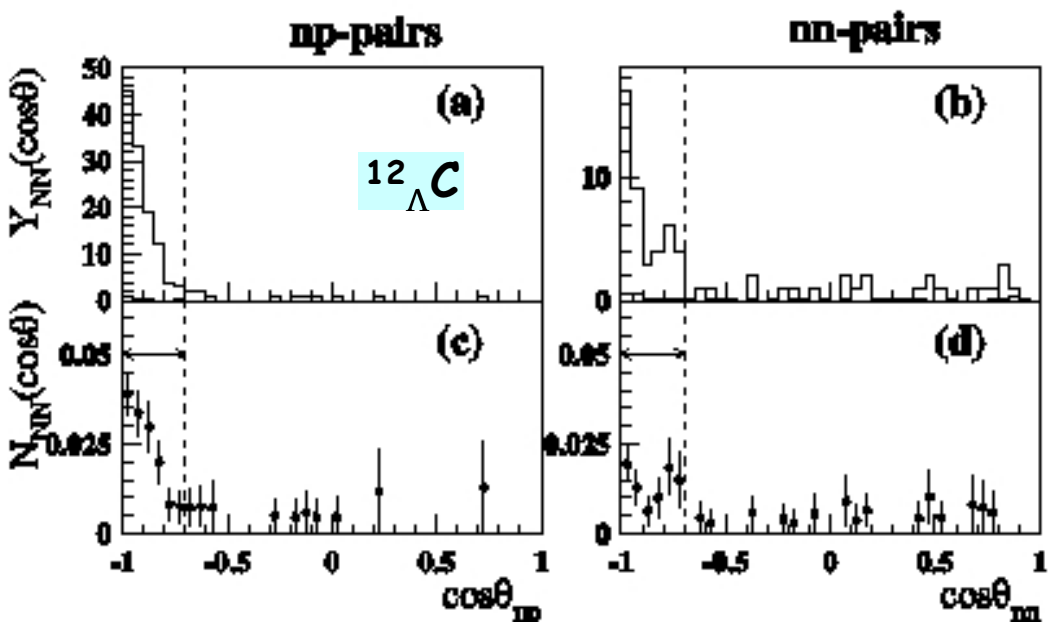


- Pair yields, Y_{np} and $Y_{nn}(\Theta)$ meas.
  $\{Y_{nn}(\Theta),\ Y_{np}(\Theta)\}/N_{nm} \equiv \{N_{nn}(\Theta),\ N_{np}(\Theta)\}$

- Can distinguish back-to-back(bb) and non-bb kinematic events.

- Require back-to-back ($\cos\Theta < -0.7$) condition.
  → can supress FSI and 3-b decay events.

Coincidence Yields (NN correlations)

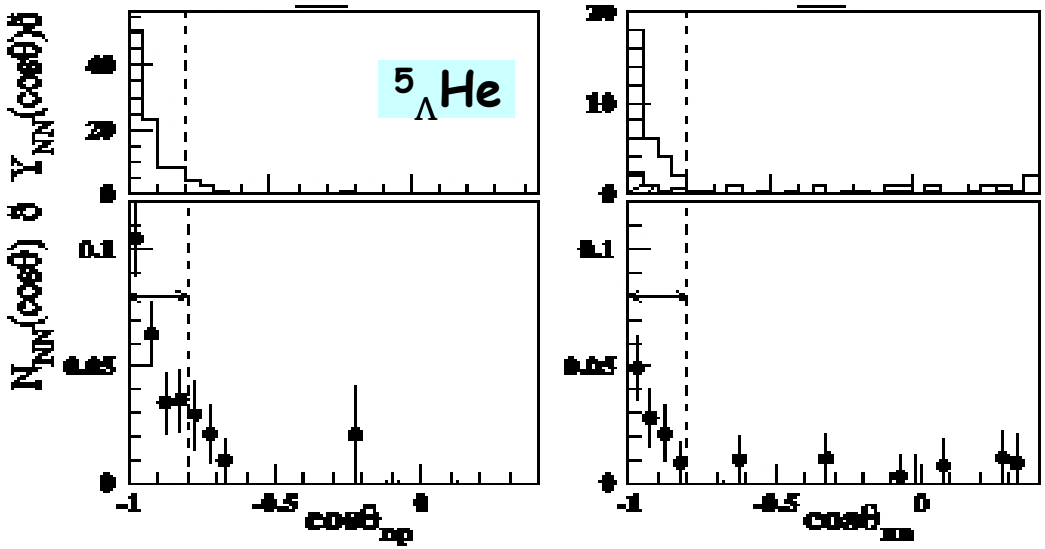


- bb ; $\cos\Theta < -0.7$
- FSI/3-B broaden the angular corr.

$N_{nn}/N_{np} \rightarrow \Gamma_n/\Gamma_p$

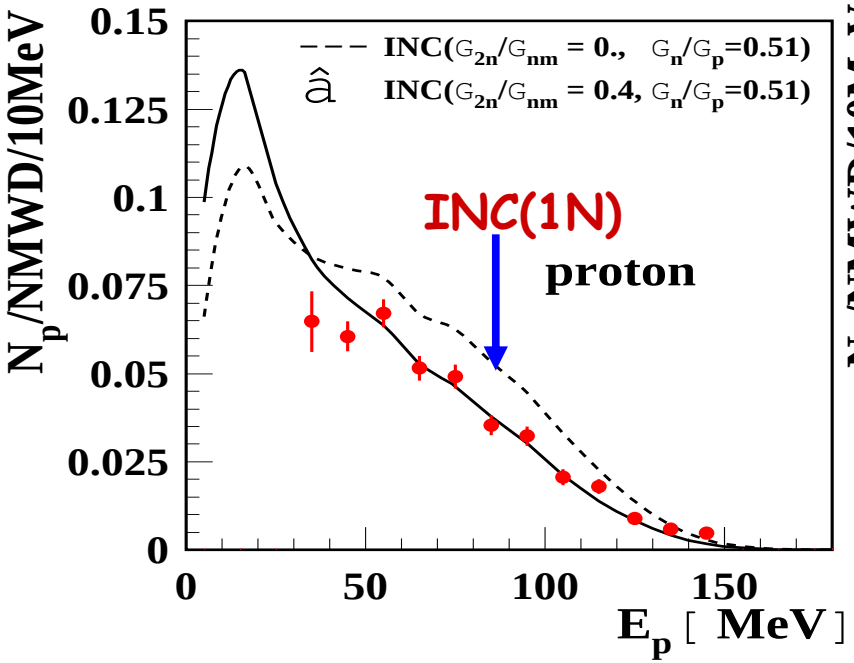
$\Gamma_n/\Gamma_p = 0.51 \pm 0.13 \pm 0.05$
M. Kim et al., PLB ('06)

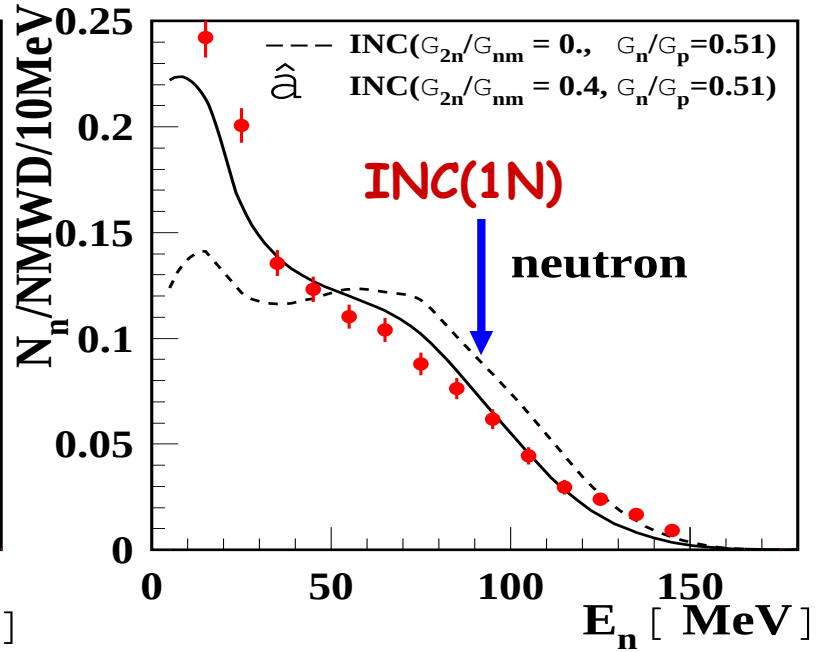
$\Gamma_n/\Gamma_p = 0.45 \pm 0.11 \pm 0.03$
B.Kang et al., PRL 96 ('06)



1. Well agreed with those of Th.
2. Γ_n/Γ_p puzzle finally solved.
3. Why the exp. Γ_n/Γ_p ratio has been so high?

Quenching of Singles Yield





1. Quenching in both p and n spectra from that of INC(1N).
2. What would be the mechanism for the nucleon Quenching?

   → FSI & 3-Body process.

   → Both reduce the energy of emitted nucleons.

Momentum sum distribution.

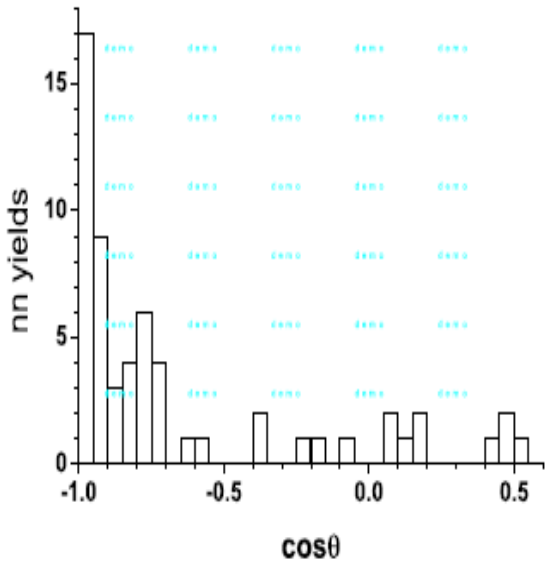
- Missing momentum dist.
  - $|p_1+p_2| \equiv p_{12}$
  - upper fig.; $^{12}{}_{\Lambda}C$
  - lower fig. ; $^{11}{}_{\Lambda}B$

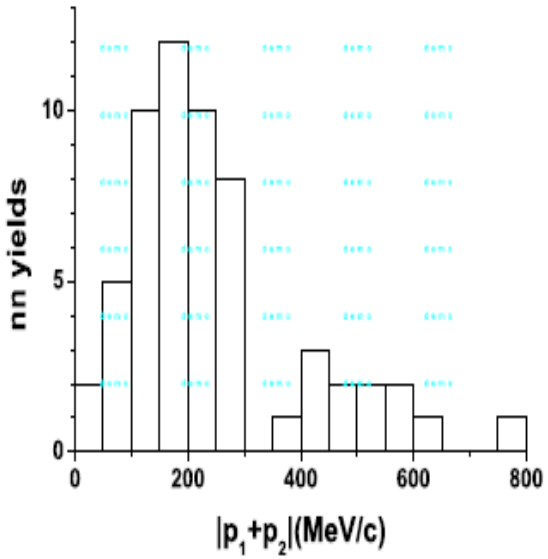
We observe two groups;

- low mom(~150 MeV/c);

  1N NMWD?
- high mom(~500 MeV/c);

What is this high mom group?





- Though the recoil momentum is high, the recoil energy should be small.
- It seems that not only the 3-nucleon-induced, but also many-nucleon induced NMWD exists..

Theo. Prediction of 3-body process (Γ_{2N}) of NMWD.

- Model for 2N-NMWD;

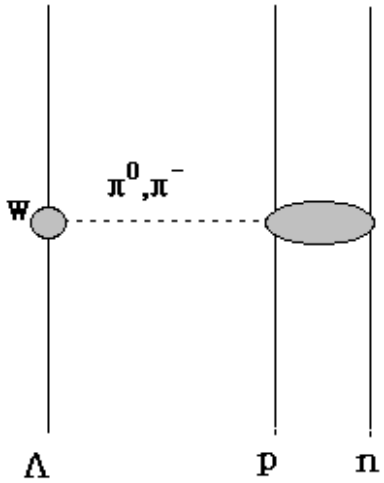
  Alberico-Ericson for Nuc. matter ('91), and
  Ramos-Oset extended to finite nuclei ('94).

- Absorption of virtual pion by 2p-2h states.
  - $\Lambda \rightarrow p\pi^-$ is dominant at the weak vertex and
  - Pions are absorbed dominantly on the pn pair.

  In the process 3 nucleons are emitted;

  1p(LE) + 2n (HE)

- $\Gamma_{2N} = 0.27\ \Gamma_\Lambda\ ({}^{12}{}_{\Lambda}C)$



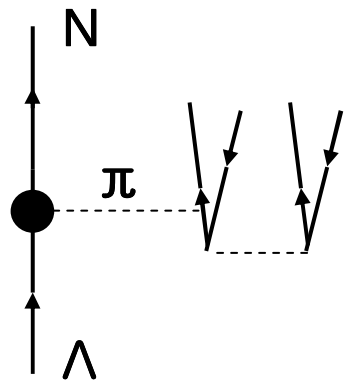


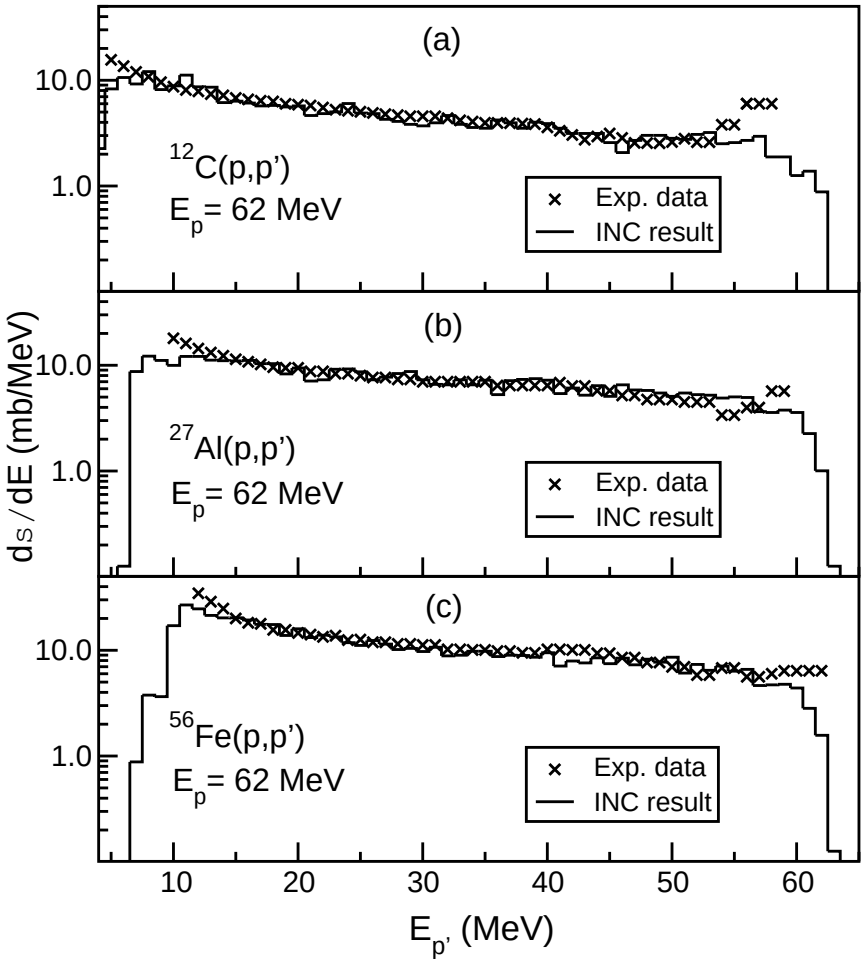
Table 1. The normalized nucleon pair numbers, N_{np} and N_{nn}, to the NMWD of ${}^{12}_{\Lambda}C$ in each kinematics region, back-to-back ($\cos\theta \leq -0.7$;bb) and non-back-to-back ($-0.7 \leq cos\theta \leq 0.6$;nbb), are shown and compared to those of present INC(INC_{1N} and INC_{1N+2N}) and the previous INC [?]. N_{NN} is the sum, $N_{np} + N_{nn}$.

	E508	INC_{1N}	INC_{1N+2N}	INC_{prev}
$N_{np}(bb)$	0.138±0.014	0.231	0.157	0.35
$N_{nn}(bb)$	0.083±0.014	0.118	0.104	0.15
$N_{NN}(bb)$	0.221±0.020	0.349	0.261	0.50
$N_{np}(nbb)$	0.059±0.018	0.089	0.069	0.52
$N_{nn}(nbb)$	0.059±0.017	0.046	0.040	0.18
$N_{NN}(nbb)$	0.118±0.027	0.135	0.109	0.70

INC (IntraNuclear Cascade) calculation

- A nucleus as a local density Fermi gas with Woods-Saxon density dist.
- FSI is simulated as a cascade free NN scattering along with Fermi blocking imposed.
- Density geometry parameters are adopted from (p,p') and (p,n) scattering data.
- These parameters are fixed for the decay INC calc.

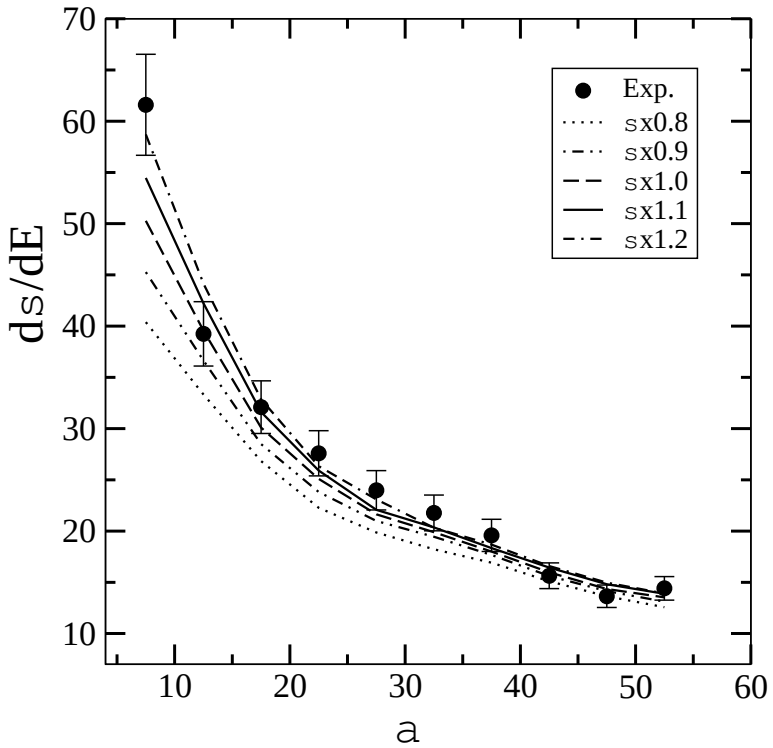
Mass Dependence

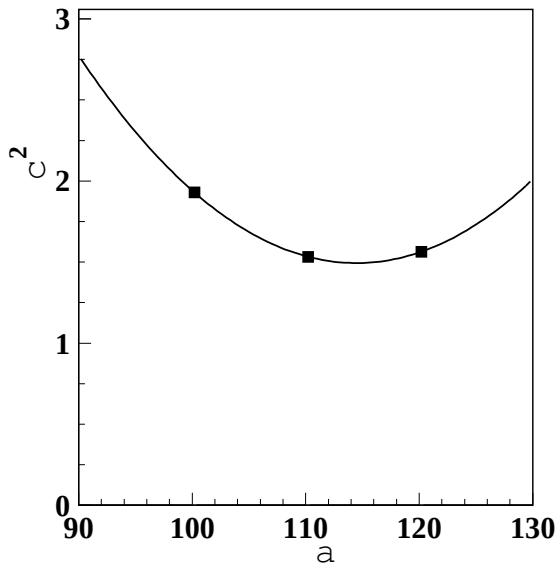


M. Kim, JKPS 46 ('05) 805

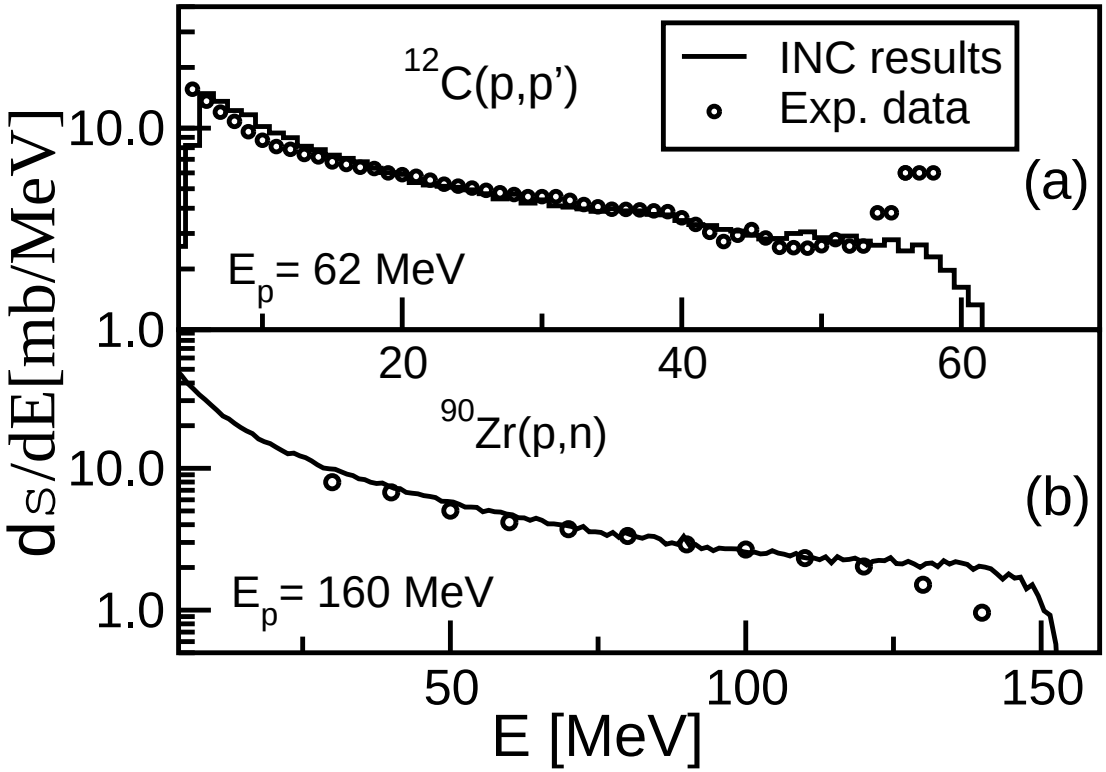
INC and a renormalization parameter

- In principle, INC model does not have fitting parameters.
- However, to reproduce FSI in NMWD, we used INC as a fitting function for scattering data by renormalizing the $\sigma_{NN} \rightarrow \alpha\sigma_{NN}$.
- Renormalization param. ; α~1.15. This α defines the experimental FSI.
- Then INC carry this exp. FSI to the emitted nucleons in NMWD

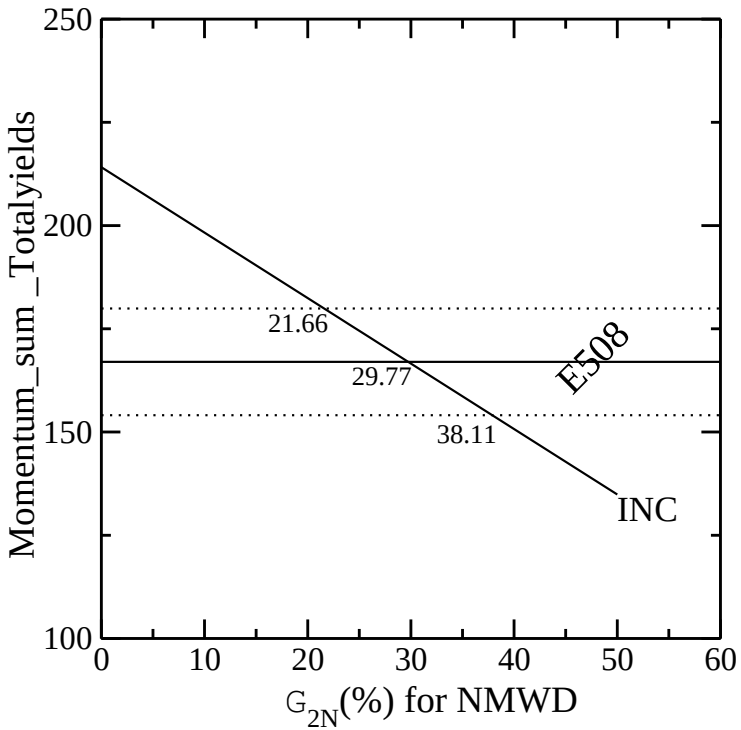


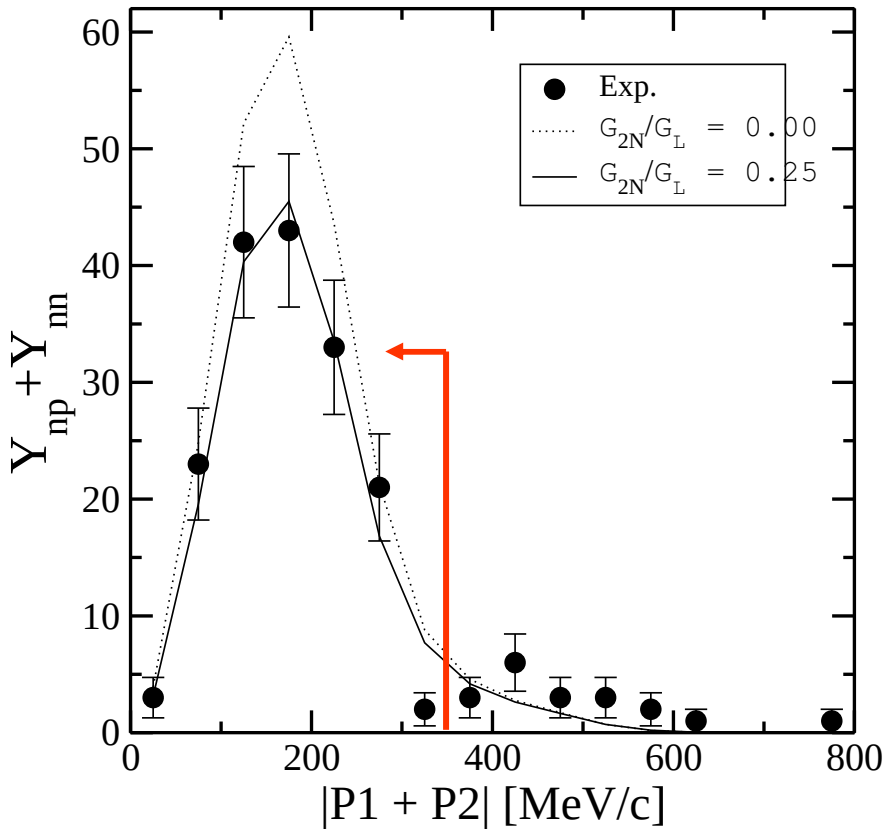


Reproduction of the inelastic scatterings with α =1.20



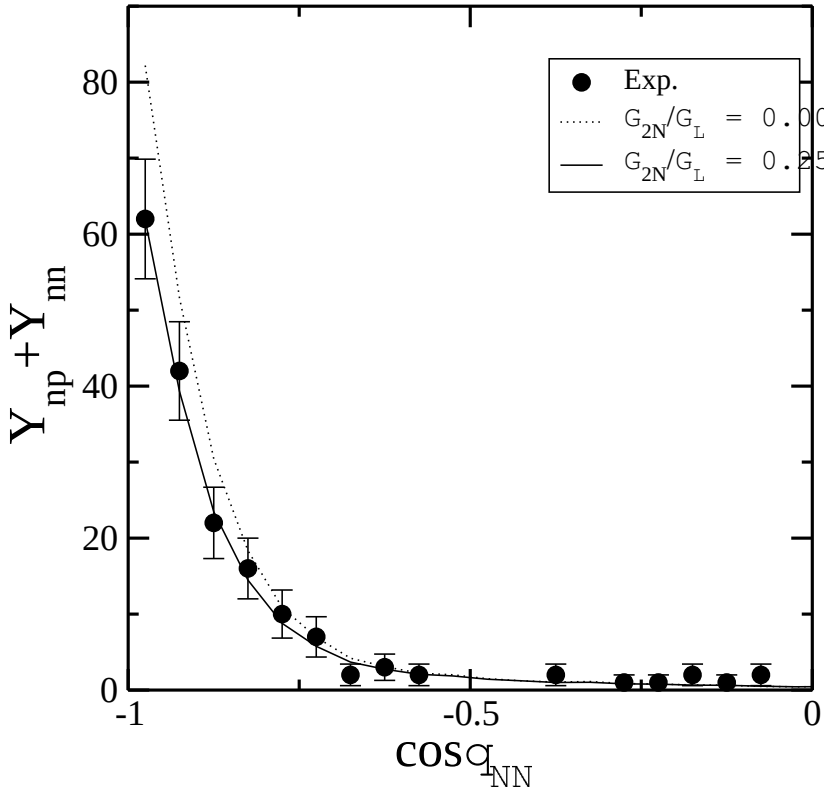
Γ_{2N} and the quenching of yields

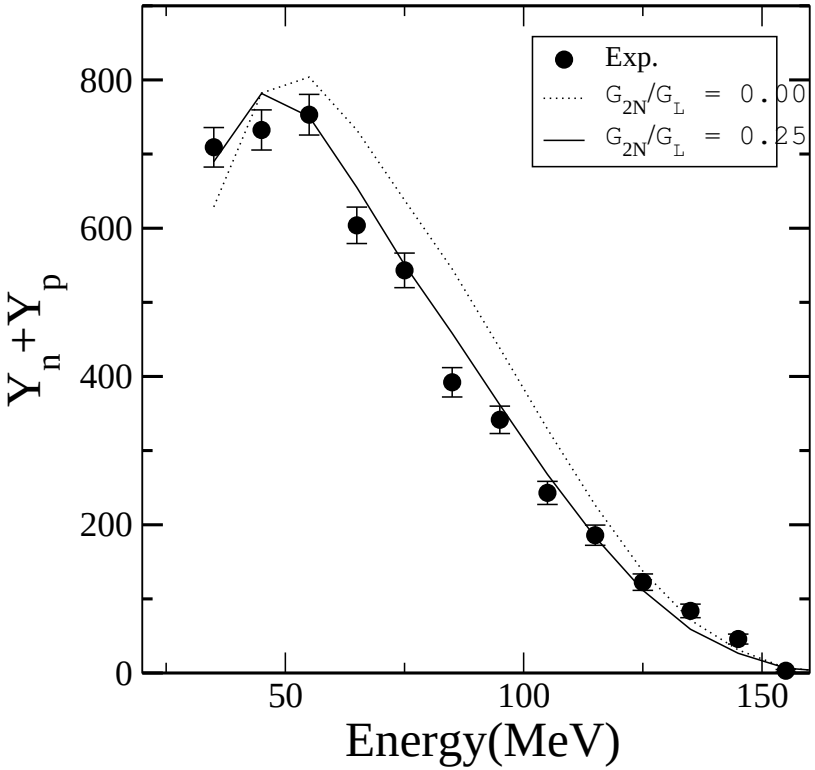




- Total sum of the yields under 350MeV/c is reproduce with the branching ratio 2N-NMWD of 0.298.
- $b_{2N} \equiv \Gamma_{2N}/\Gamma_{nm}$ **=0.298± 0.083**

Reproduction of Angular correlation and singles yields





Partial decay widths of NMWD

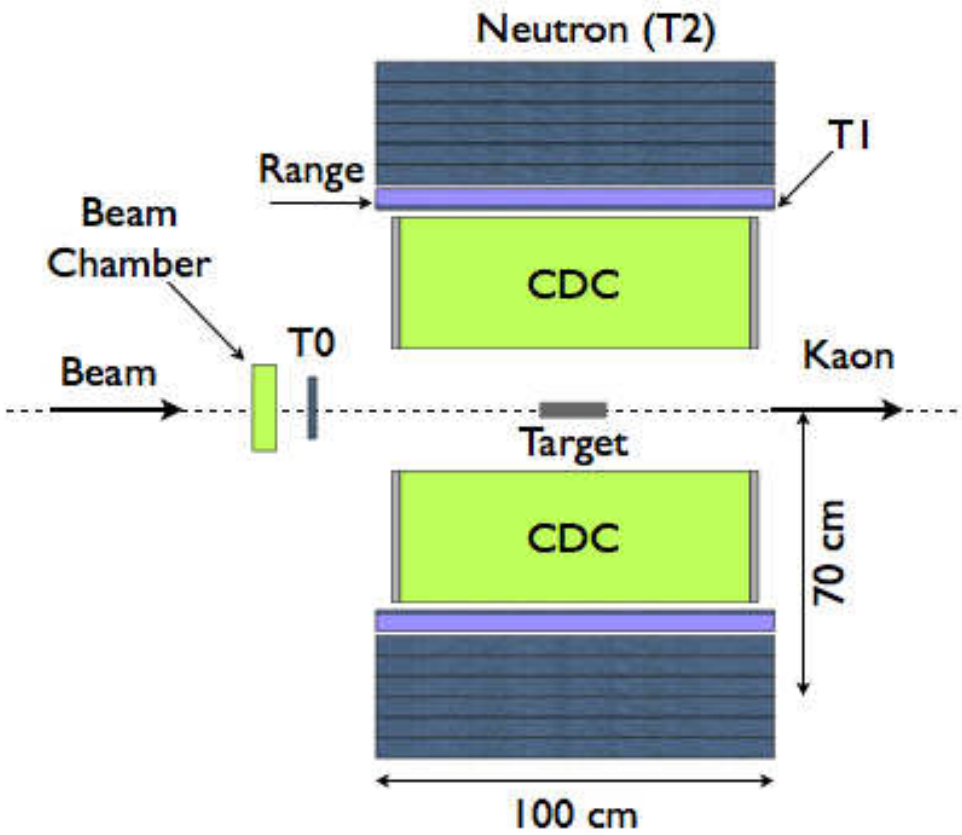
	Present Experiment	Theory		
		Ramos['94]	Jido ['01]	Itonaga ['08]
Γ_n/Γ_p	0.51± 0.13± 0.05		0.53	0.503
Γ_{nm}	0.828± 0.086			
b_{2N}	0.298± .083	0.16		
Γ_{2N}	0.247± .074	0.27		
Γ_n	0.196± 0.048		0.265	0.222
Γ_p	0.385± 0.072		0.504	0.438

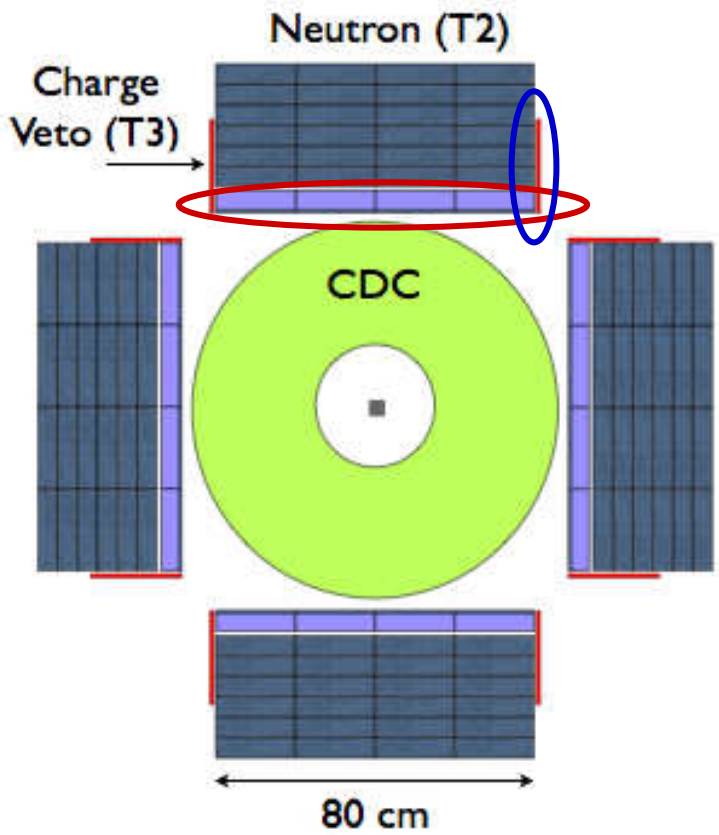
- Units ; Γ_Λ
- Γ_{2N} is derived from the quenching of yields of bb kinematics events which is of low missing momentum.
- Γ_{2N} agrees with the current theo. Prediction.
- Γ_n, Γ_p agree with those of the most extensive recent calculation.
- Errors are still 20-30%. → Experiment(J-PARC E18) ; Extensive study including the non-bb events, namely those of the high missing momentum.

Decay Counter Setup (J-PARC E18)

Basic concepts are based on the setup of E462/E508 expeiments.

- Covers ~50% solid angle; 2(solid angle)x3(beam current)
- CDC+T1(Timing for charged one)+T2(neutron)
- Share most of the detection system with E22





Summary

1. Γ_n/Γ_p values for s- and p-shell hypernuclei were measured accurately in the exclusive measurements and are same to be ~0.5.
2. It turned out that the large values of Γ_n/Γ_p was due to the quenching phenomena of NMWD.
3. It also showed that the quenching is due to the 3-body process of NMWD.
4. Quenching of NMWD yields gives b_{2N}~30%; $\Gamma_{2N} \sim \Gamma_n = \Gamma_p/2$
5. First stage approval for more complete measurement of Γ_{2N}.

J-PARC E18 ; Γ_{2N} (3-body decay process), Γ_n ,Γ_p for $^{12}{}_{\Lambda}C$

KEK-PS E462/508 collaboration

KEK, RIKEN, Seoul N.Univ., GSI,
Tohoku Univ., Osaka Univ., Univ. Tokyo,
Osaka Elec. Comm. Univ., Tokyo Inst. Tech.

S. Ajimura, K. Aoki, A. Banu, H. Bhang, T. Fukuda,
O. Hashimoto, J. I. Hwang, S. Kameoka, B. H. Kang,
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Y. Miyake, T. Nagae, M. Nakamura, S. N. Nakamura,
H. Noumi, S. Okada, Y. Okatasu, H. Outa, H. Park,
P. K. Saha, Y. Sato, M. Sekimoto, T. Takahashi,
H. Tamura, K. Tanida, A. Toyoda, K.Tsukada,
T. Watanabe, H. J. Yim

Korea-Japan Collaboration

- 1990~1991; Prof. Yamazaki and Prof. Nakai visited Korea and introduced N. Physics activity in Japan and the new KEK-PS program.
- 1992 ; started the KOSEF-JSPS international collaboration program and participated the E140a experiment of Prof. Hashimoto.
- 1993 ; proposed the lifetime measurement E307 in collaboration with Prof. Hashimoto. It was the lifetime and proton measurement of Λ hypernuclei and found the saturation of the total decay width at around carbon.
- E369 ; Neutron measurement; Breakthrough of the Γ_n/Γ_p puzzle.
- E462/E508; First coincidence measurement of NMWD and solved the Γ_n/Γ_p puzzle problem.
- 2006 ; JPARC P18; proposal for 3-body NMWD decay.
- 2007; Got 1st stage approval and we are now preparing for it.

- The collaboration was very successful, I consider.
- It was fun and enjoyable, so I would like to thank all the collaborators.
- I am quite sure it to be continued and further blossomed in J-PARC collaboration experiments.

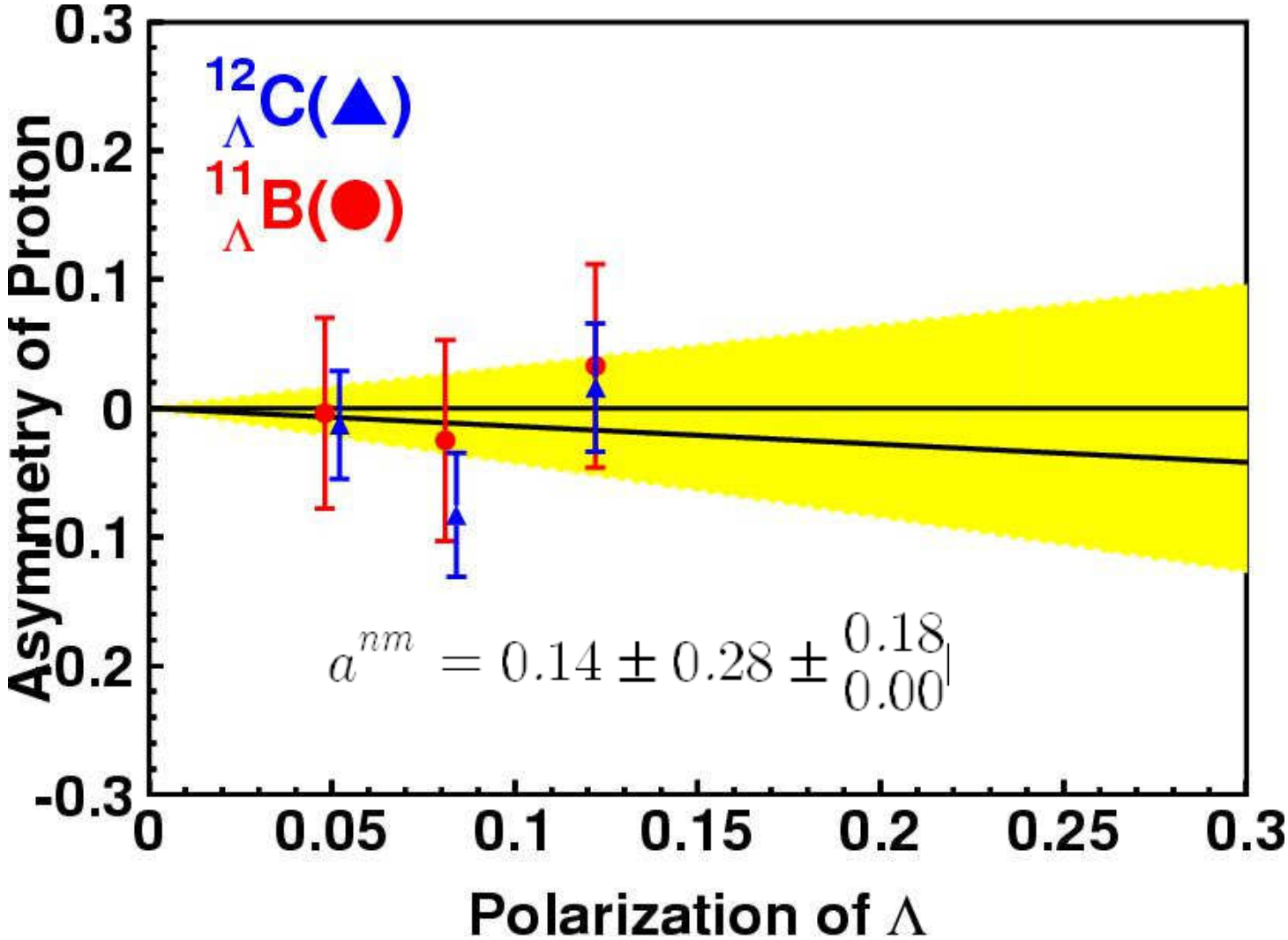
Thank you very much.

Extra

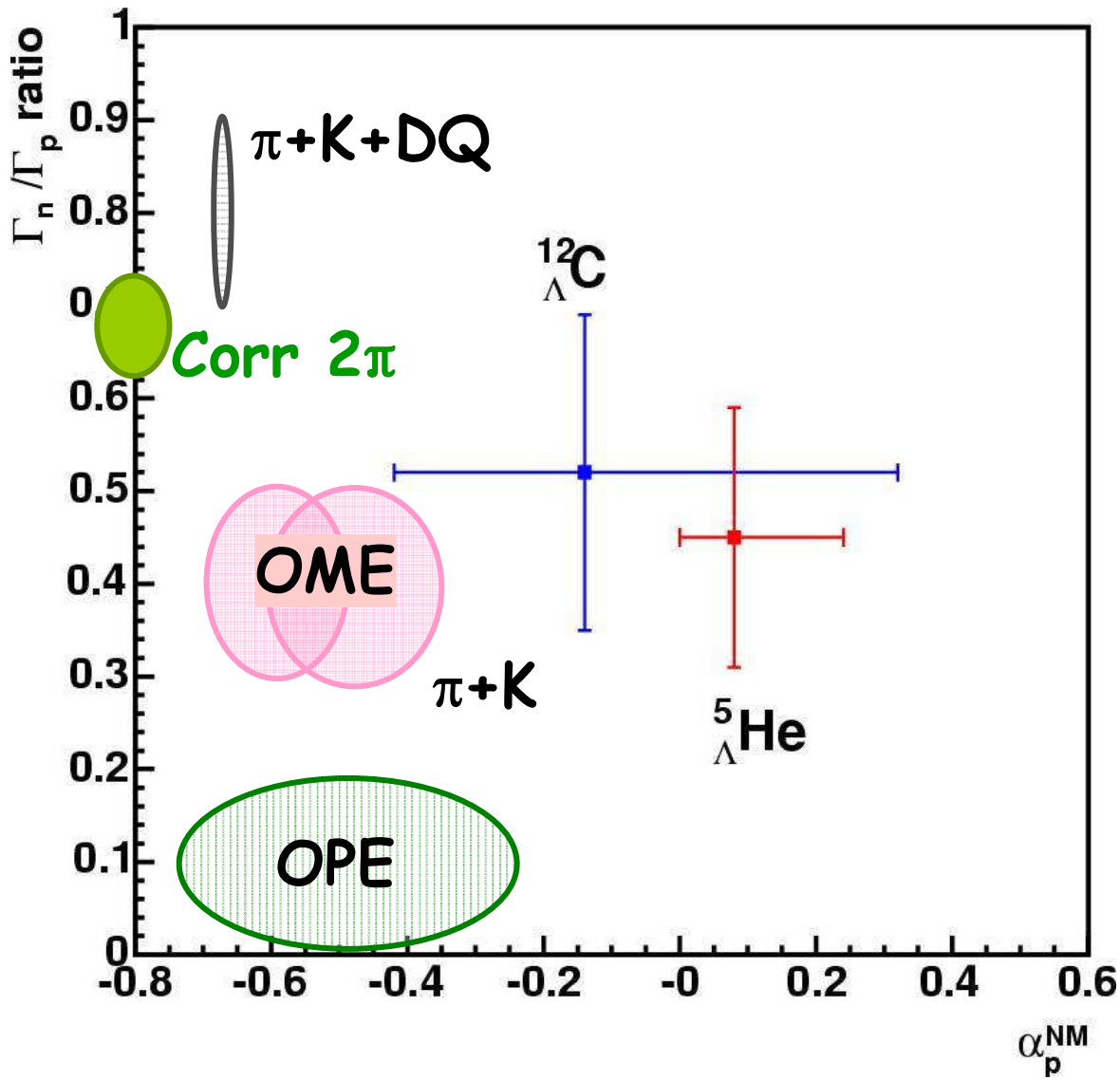
Korea- Japan Collaboration

- In retrospect, for me the collaboration was quite successful and

Asymmetry parameter of $^{11}_{\Lambda}B$, $^{12}_{\Lambda}C$

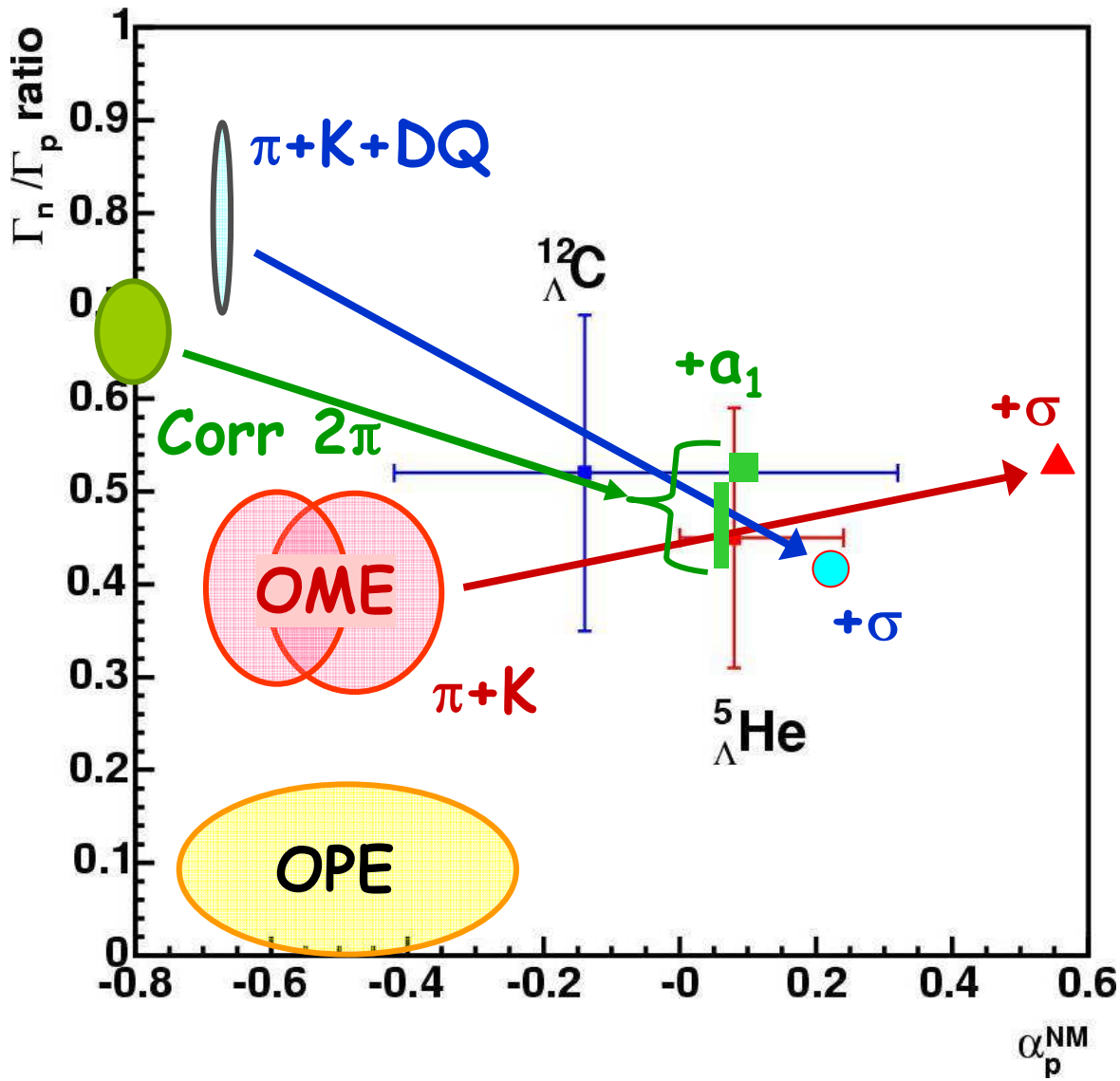


Status of Γ_n/Γ_p and α_p^{nm}



- Models explain Γ_n/Γ_p, but not a_p^{nm} !!
- Serious inconsistency between theo. and exp. α^{nm} values.

Most recent status of Γ_n/Γ_p and α_p^{nm}



- +σ meson; Sasaki et al., PRC 71 035502 ('05)
- +a_1 meson; Itonaga et al PRC 77 044605 ('08)

Summarising on the decay widths of NMWD

1. NN Correlation data show two groups of missing momentum, low and high mom groups. The HM group tells the existence of many-body process.
2. FSI calculation strongly indicates that the reason behind the Γ_n/Γ_p puzzle was the quenching of the nucleon yields in NMWD.
3. The degree of the quenching is well explained simply by adopting the uniform phase space distribution of the 3-body process, but of the significant fraction of NMWD.
4. In order to extract the most fundamental decay observables, Γ_n, Γ_p accurately, one has to determine Γ_{2N} first. → J-PARC (E18).
5. The Γ2N is

Status of NMWD of Λ hypernuclei

Urgent problems to be solved ;

- **$\Delta I=1/2$ rule (I: $^{4}_{\Lambda}He$)** → **J-PARC E22**
- **3-body process of Weak Decay;**

  Is there really such processes?

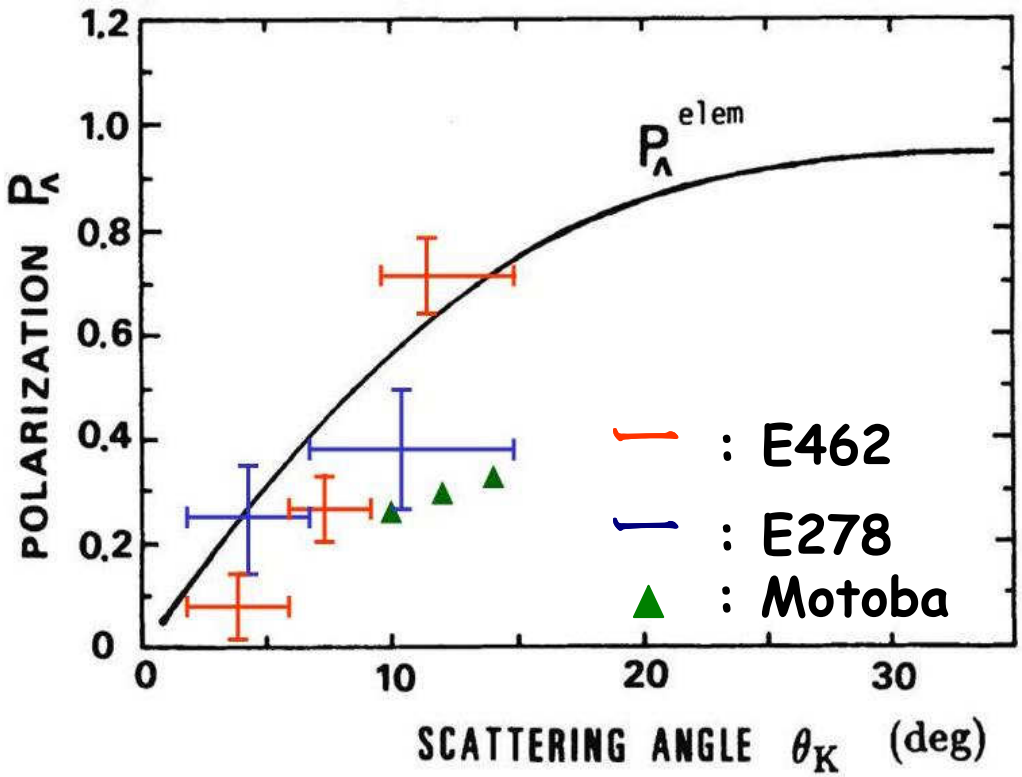
  How much contribution?

  Why 3-body effect is so strong that it is comparabe to 2-body effect?

  → **J-PARC E18**
- **Branching ratios of NMWD;** It has been so long, but accurate branching ratios are not available yet.

→ **Since the contribution of 3-body process seems significant, we have to measure first of all.**

Asymmetry measurement of decay proton

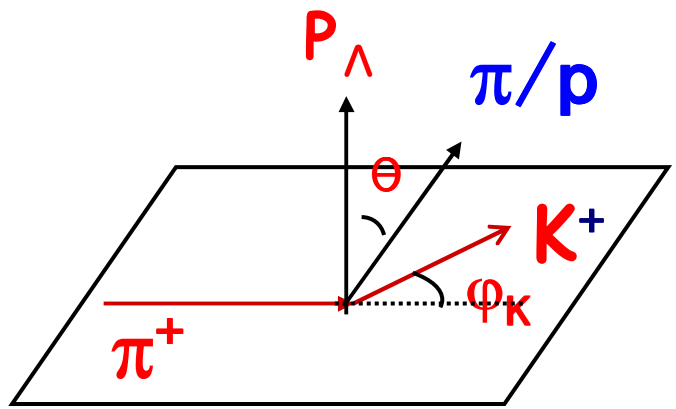


$$N(\theta) = N_0 \, (1 + Ay \cos\theta)$$

$$= N_0 \, (1 + \alpha_p P_\Lambda \cos\theta)$$

(α_p: Asymmetry parameter)

$$Ay = \frac{N(0) - N(180)}{N(0) + N(180)}$$



Previous situation of Asymmetry Parameter

Asymmetry Parameter

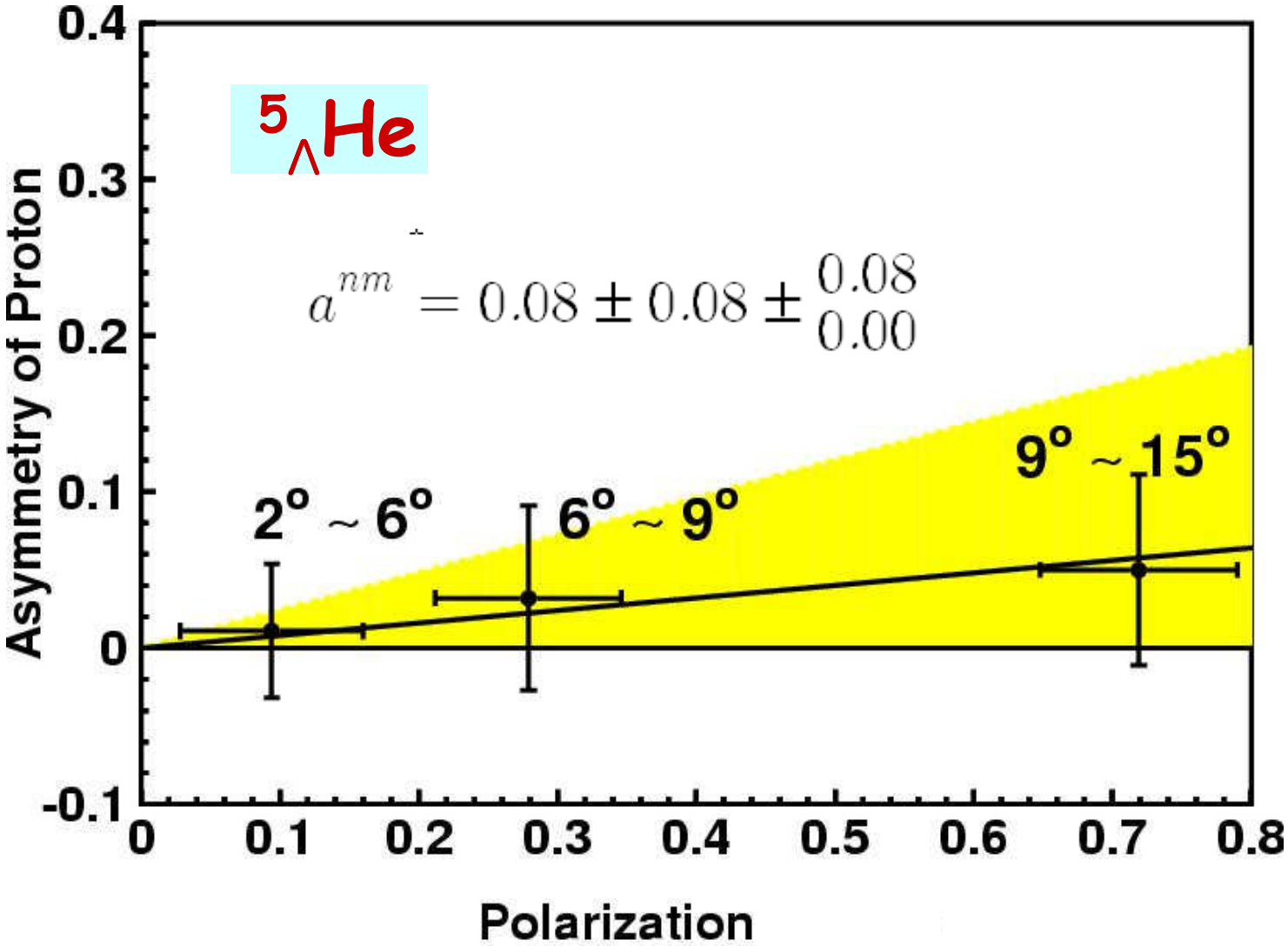
Previous experiments		Theoretical prediction
$^{5}{}_{\Lambda}He$: 0.24 ± 0.22	⟷	$-0.6 \sim -0.8$
$^{12}{}_{\Lambda}C, ^{11}{}_{\Lambda}B$: -1.3 ± 0.4		OME Ex.
Ajimura *et al.*		π+K+DQ Ex. etc.

- High Statistics
- Exclusive identification of $\Lambda p \rightarrow np$ channel

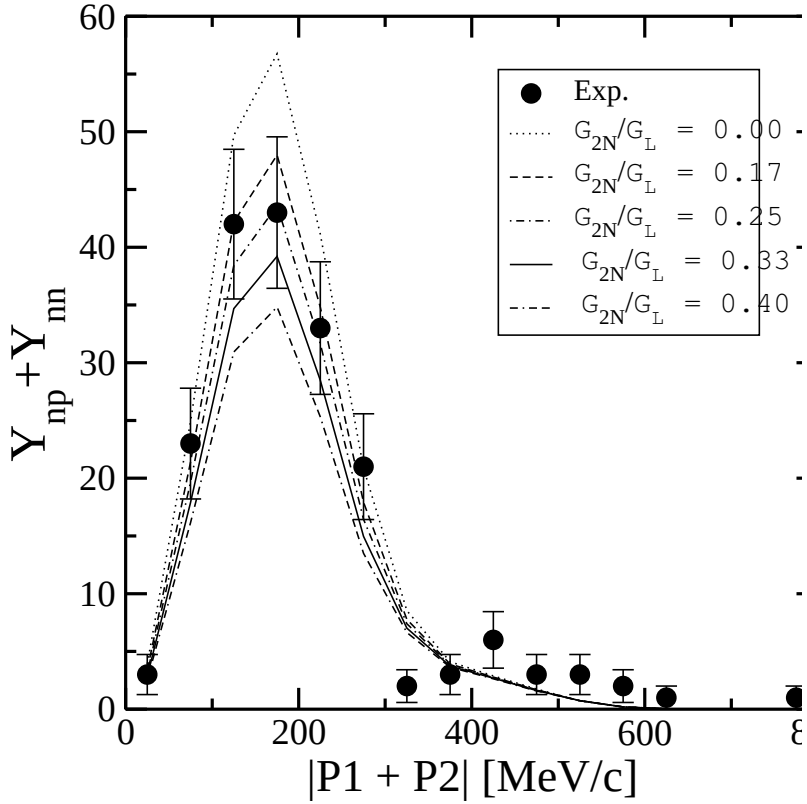
Exclusive Coin. Exp.

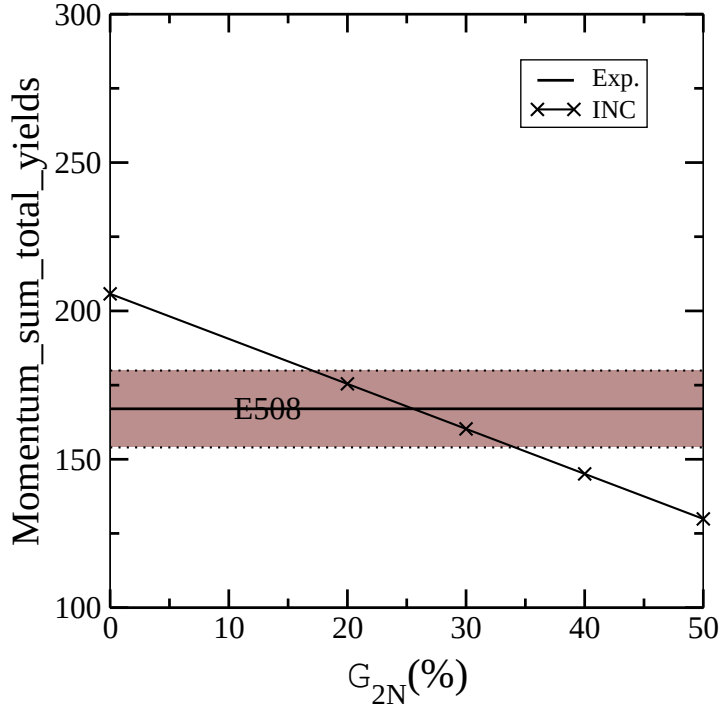
E462/E508

Asymmetry parameter of $^{5}_{\Lambda}He$



⟺ **Theory: - 0.6 ~ - 0.8**



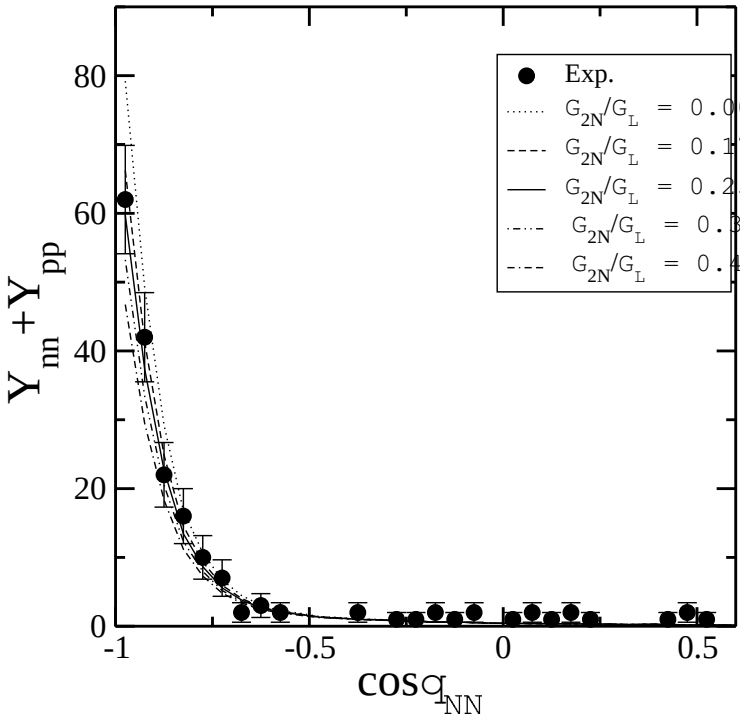


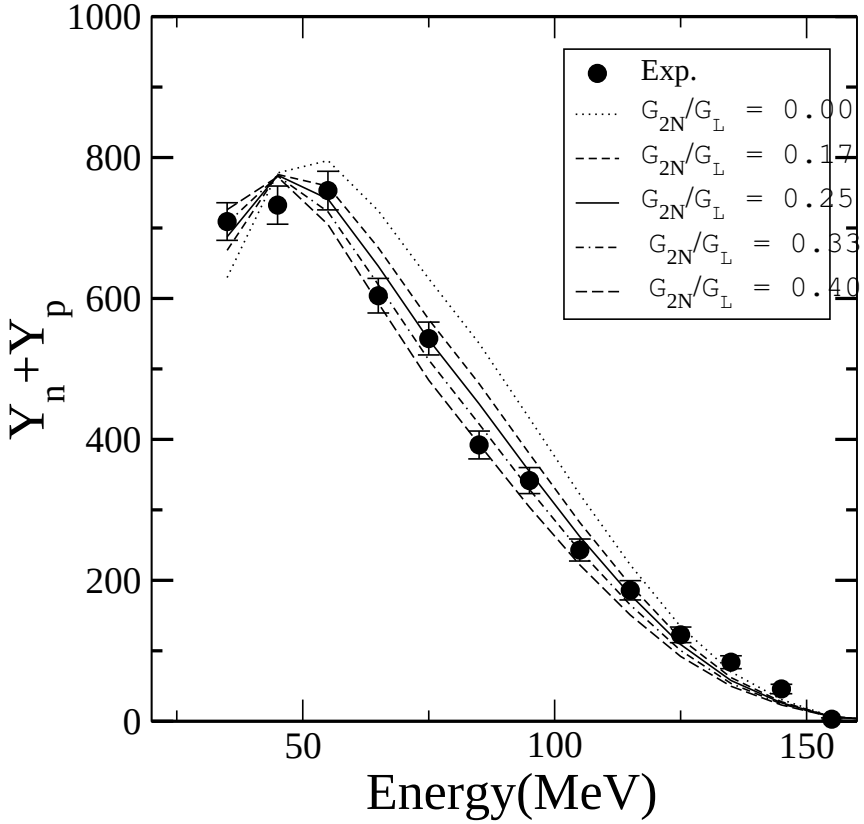
- **For 2N-NMWD, we adopted t kinematics of uniform phase space sharing of 3 nucleons.**
-

- Total yields in LM region is produced with

$$b_{2N} = \Gamma_{2N}/\Gamma_{nm}$$

$$= 0.261 \pm 0.086.$$


Exp.
G2N/GL = 0.0
G2N/GL = 0.1
G2N/GL = 0.2
G2N/GL = 0.3
G2N/GL = 0.4
Ynn+Ypp
cosθNN
80
60
40
20
0
-1
-0.5
0
0.5


Exp.
G2N/GL = 0.00
G2N/GL = 0.17
G2N/GL = 0.25
G2N/GL = 0.33
G2N/GL = 0.40
Yn+Yp
Energy(MeV)
1000
800
600
400
200
0
50
100
150

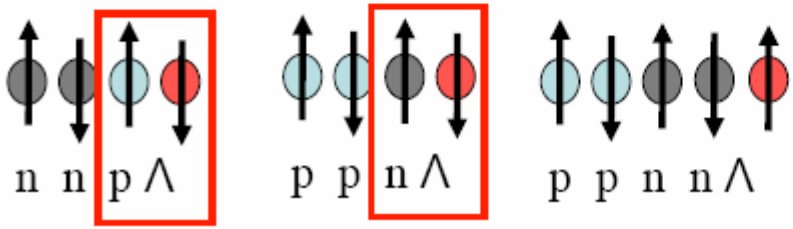
$\Delta I=1/2$ rule and Nonmesonic Weak Decay of ${}^{4}_{\Lambda}H$ and ${}^{4}_{\Lambda}He$.

Spin / isospin dependence

$$\Gamma_{nm}({}^{4}_{\Lambda}H) = (3R_{n1} + R_{n0} + \boxed{2R_{p0}}) \times \rho_4 / 6$$
$$\Gamma_{nm}({}^{4}_{\Lambda}He) = (\boxed{2R_{n0}} + 3R_{p1} + R_{p0}) \times \rho_4 / 6$$
$$\Gamma_{nm}({}^{5}_{\Lambda}He) = (3R_{n1} + R_{n0} + 3R_{p1} + R_{p0}) \times \rho_5 / 8$$

R_{NS} … N : $\Lambda n \rightarrow nn$, $\Lambda p \rightarrow np$
S : spin = 0 or 1

${}^{4}_{\Lambda}H$ ${}^{4}_{\Lambda}He$ ${}^{5}_{\Lambda}He$

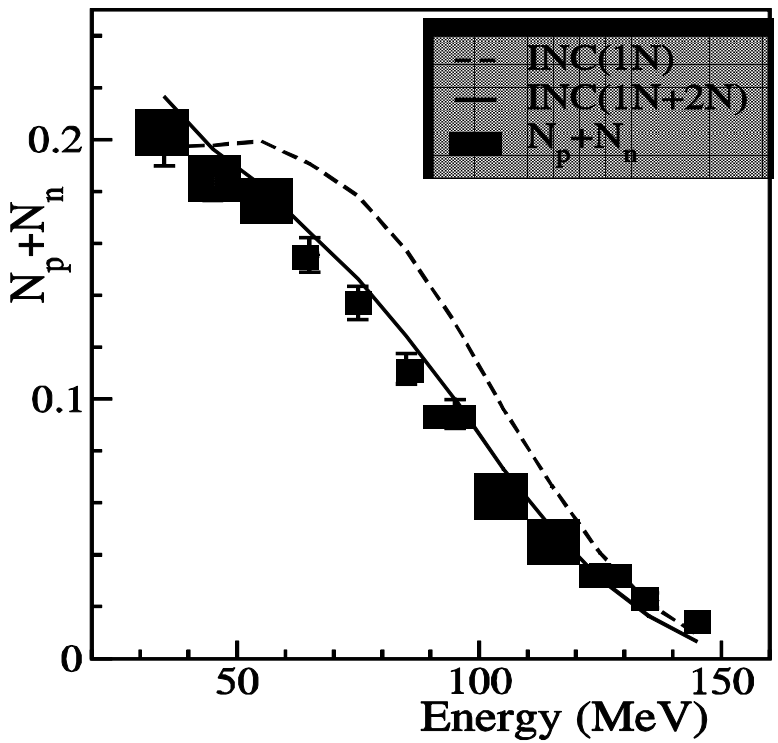


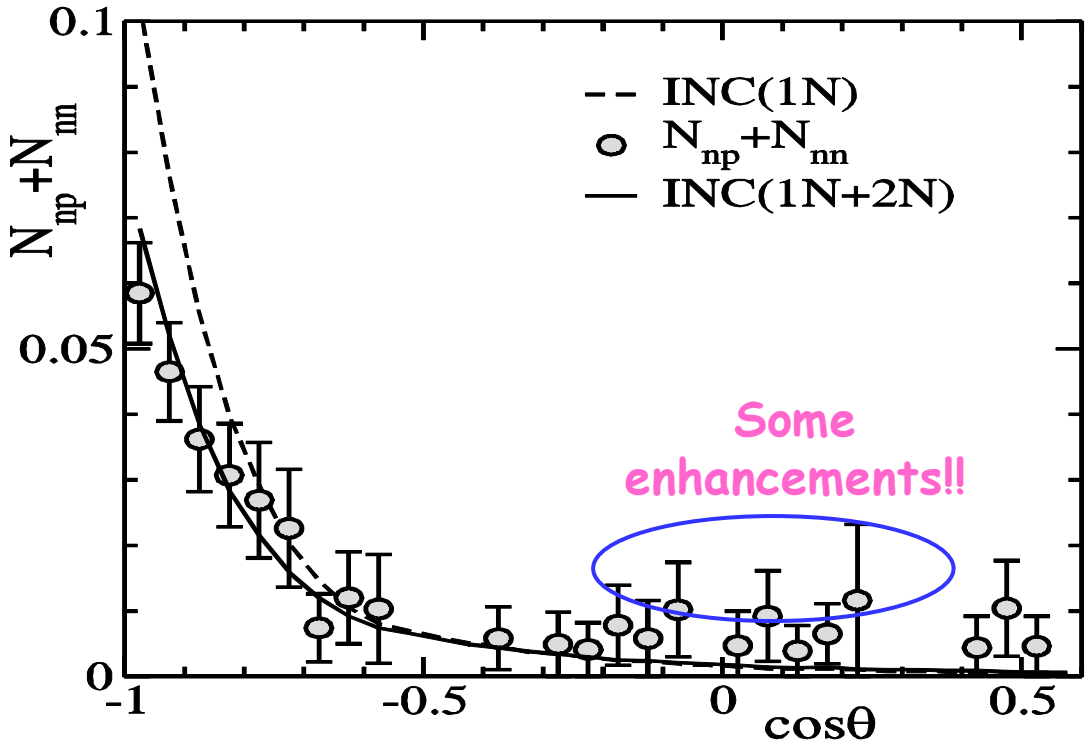
${}^{4}He$ (K^-,π^-) ${}^{4}_{\Lambda}He$ or
${}^{4}He$ (π^+,K^+) ${}^{4}_{\Lambda}He$
→ n+n back-to-back

${}^{4}He$ (K^-,π^0) ${}^{4}_{\Lambda}H$
→ p+n back-to-back
(π^0 spectrometer)

→ *Need one-order higher statistics.* → *J-PARC*

Extraction of Γ_{2N}.





For 2N-NMWD, we adopted the kinematics of uniform phase space sharing of 3 nucleons.

Γ_{2N} is extracted by fitting the N_p+N_n, $N_{pn}+N_{nn}$ (cosΘ).

In order to explain the quenching,

→ $\Gamma_{2N}\sim 0.4\Gamma_{nm}$

Momentum sum distribution.

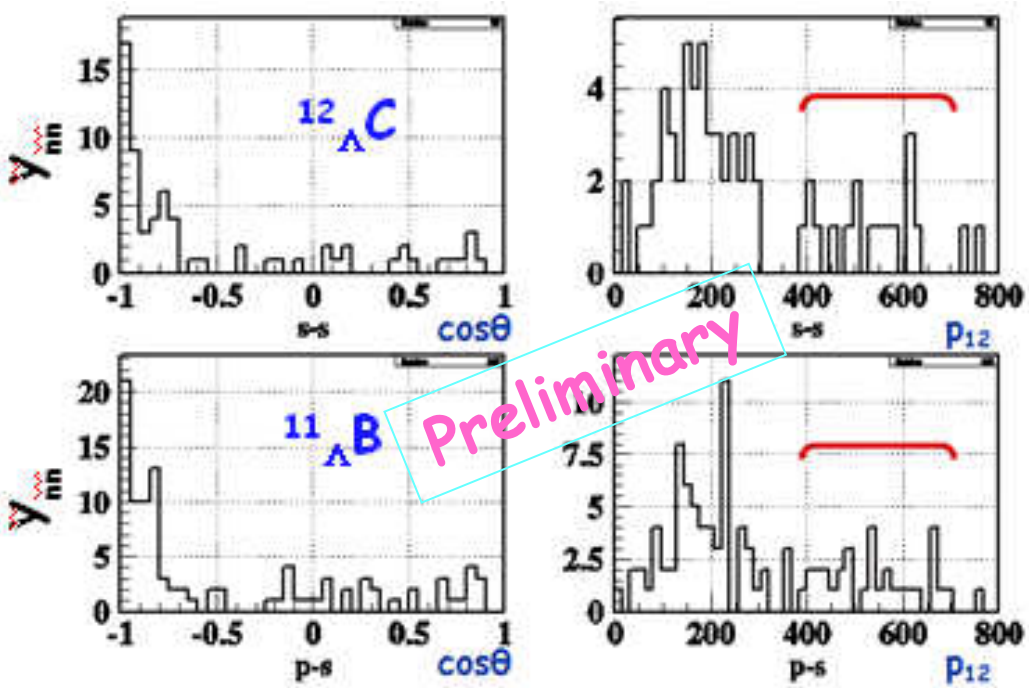
- Missing momentum dist.
  - $|p_1+p_2| \equiv p_{12}$
  - upper fig.; $^{12}{}_{\Lambda}C$
  - lower fig. ; $^{11}{}_{\Lambda}B$

We observe two groups;

- low mom(~150 MeV/c);

  1N NMWD?
- high mom(~500 MeV/c);

  What is this high mom group?



- Though the recoil momentum is high, the recoil energy should be small.
- It seems that not only the 3-nucleon-induced, but also many-nucleon induced NMWD exists..

E369 Experiment/Setup

Neutron spectra measured.

target: ^{12}C, ^{51}V and ^{89}Y

n / γ separation by TOF method