Recent (Exp.) Progresses in the Study of Nonmesonic Weak Decay of Λ Hypernuclei.

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Sendai Int. Symposium (SENDAI08) on
Strangeness in Nuclear and Hadron Systems.
Dec. 15-18, 2008

I. Weak Decay Modes of Λ Hypernuclei.

II. Γ_n/Γ_p ratio puzzle and 3-body NMWD process.

III. Urgent issues; Asymmetry and ⊿I=1/2 Rule.

IV. J-PARC Weak Decay Experiments; 3-body process (E18) & ⊿I=1/2 rule (E22) in NMWD

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

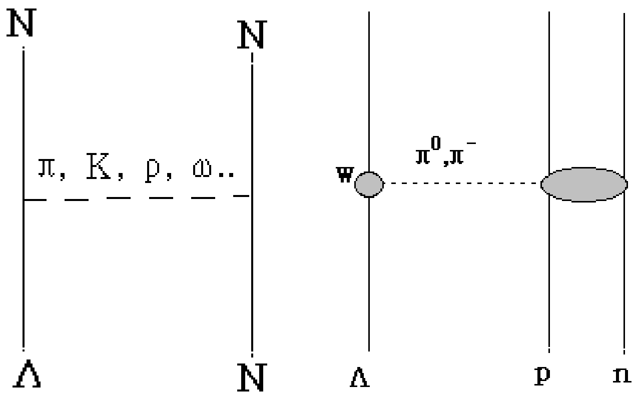
- Γ_{nm}
  - $\Gamma_p(\Lambda p \rightarrow np)$
  - $\Gamma_n(\Lambda n \rightarrow nn)$

    (1N) → Previous Searches
  - $\Gamma_{2N}(\Lambda NN \rightarrow nNN)$

    (2N) → 3-Body Process; Predicted theoretically

  Nonmesonic

  q~ 400 MeV/c



(2N-NMWD)

Status of NMWD of Λ hypernuclei

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

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

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

II. **Outstanding Issues ;**

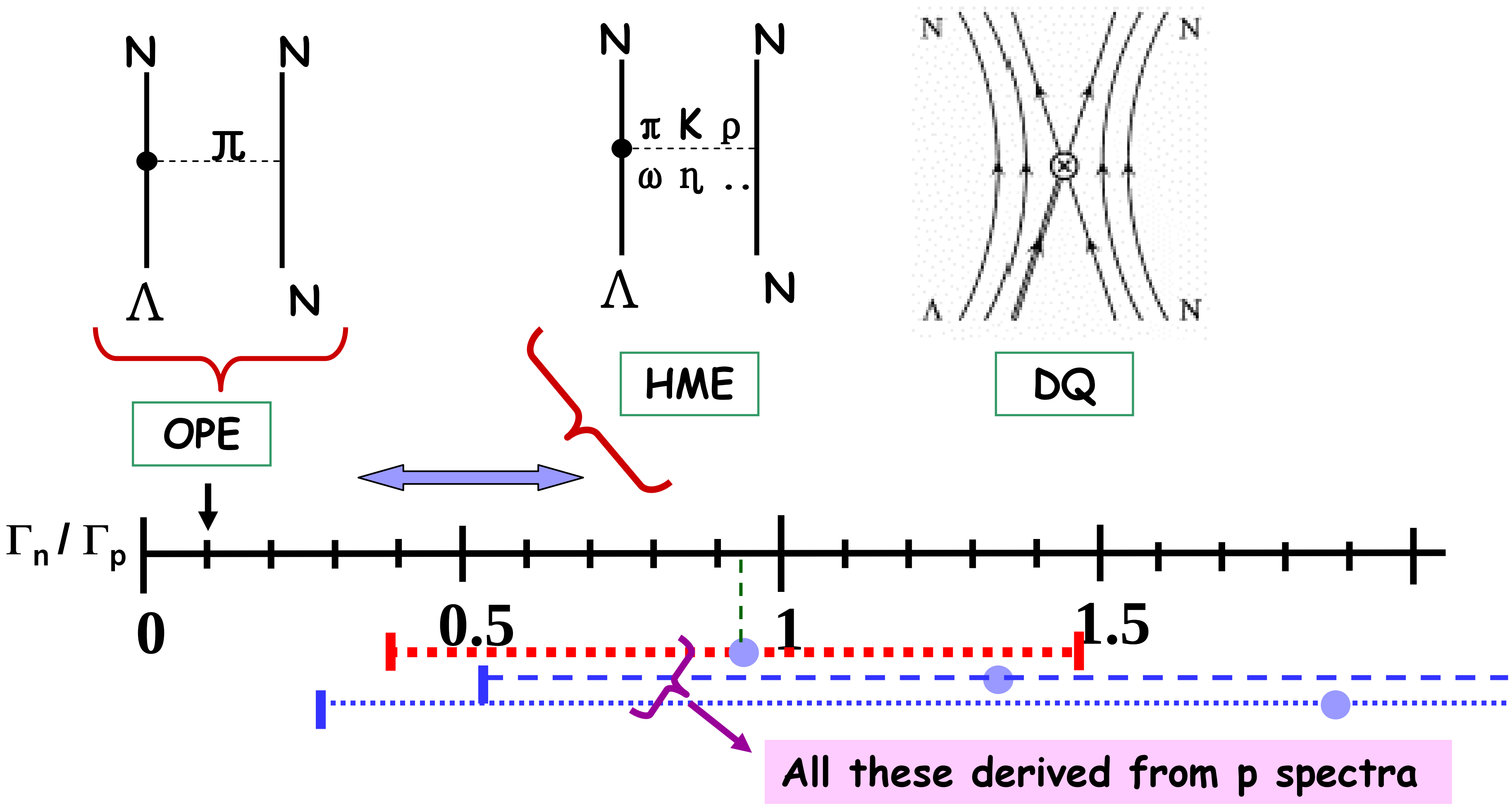
- Decay widths; Γ_n, $\Gamma_p \leftrightarrow \Gamma_{2N}$ (3-body process)
- Asymmetry;
- $\Delta I=1/2$ rule in NMWD ;

Γ_n/Γ_p puzzle and the previous searches

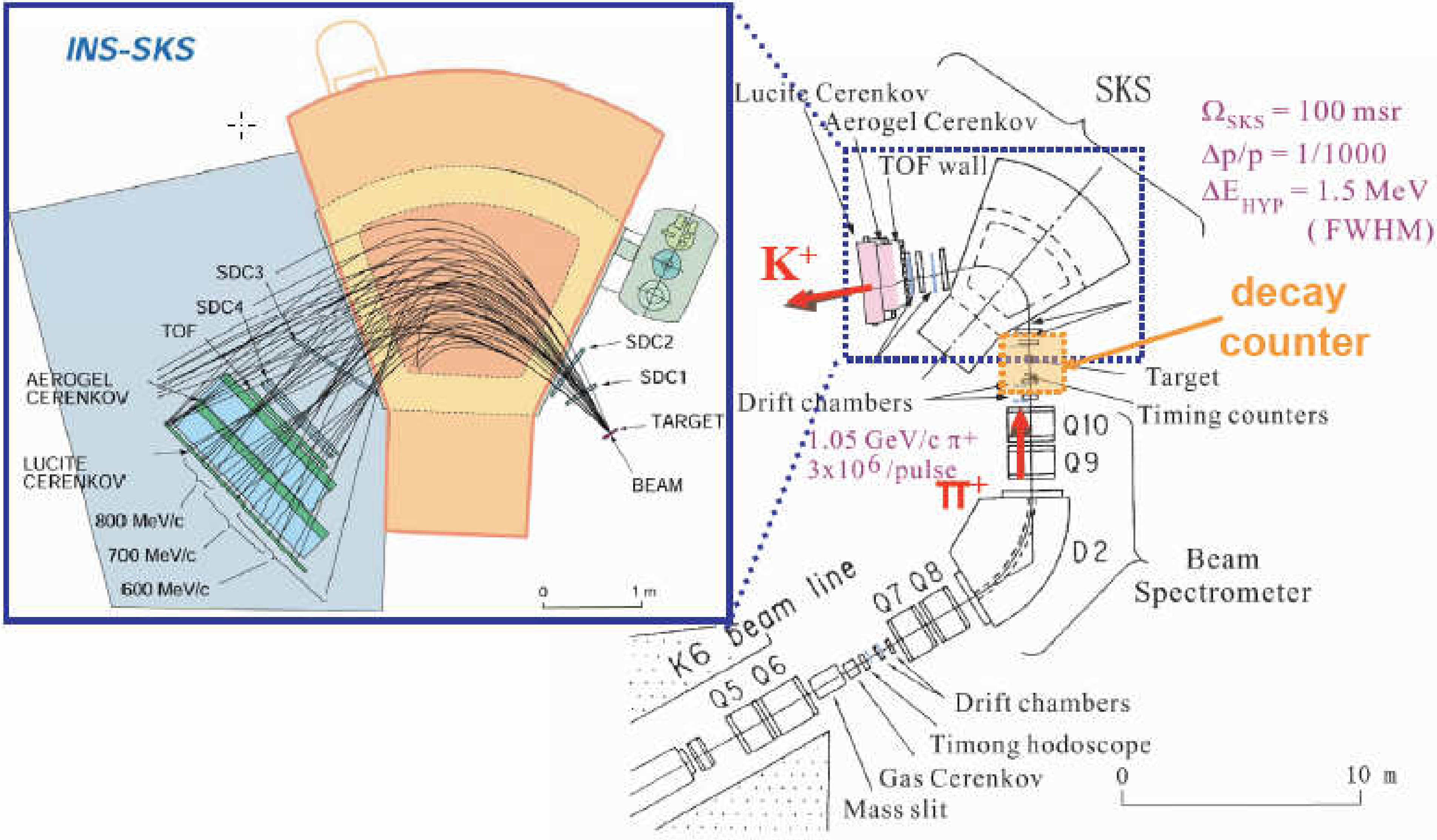
1. Γ_n/Γ_p Puzzle :

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

~ 1 ~0.1



KEK-PS K6 beamline and SKS spectrometer

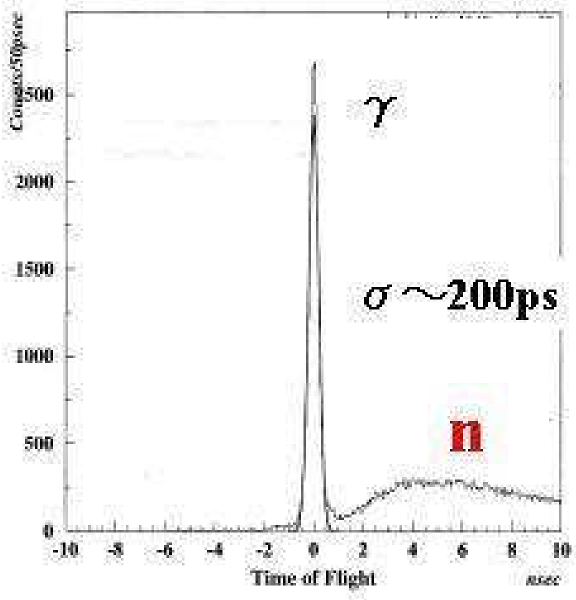


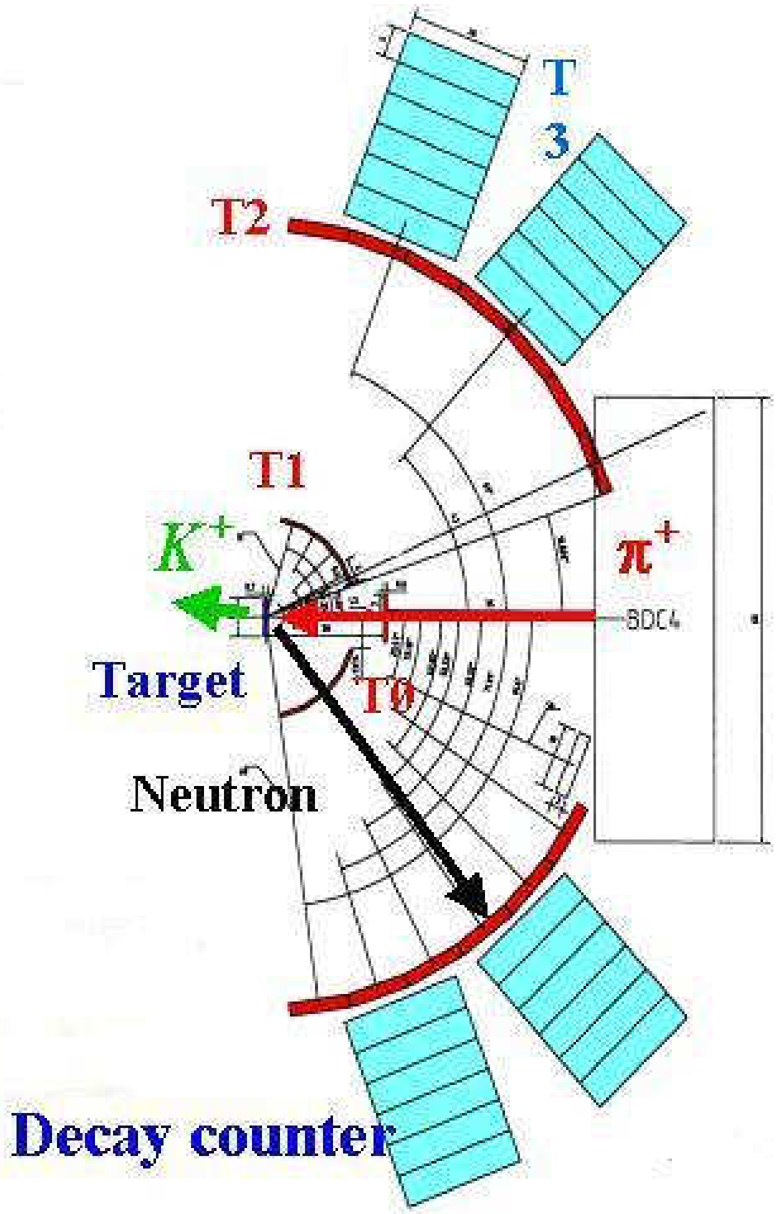
E369 Experiment/Setup

Neutron spectra measured.

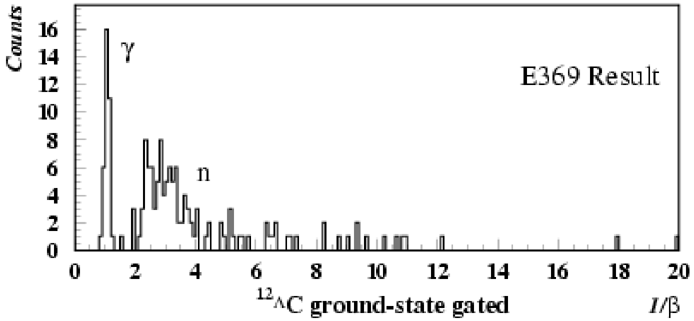
target: ^{12}C, ^{51}V and ^{89}Y

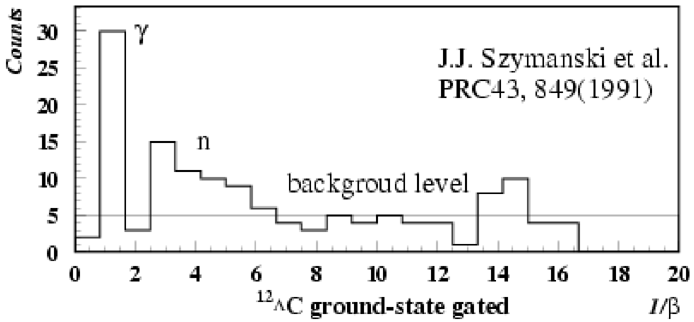
n / γ separation by TOF method

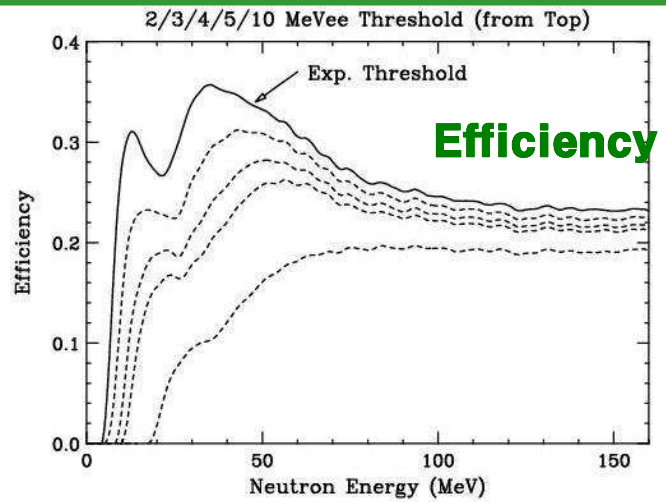


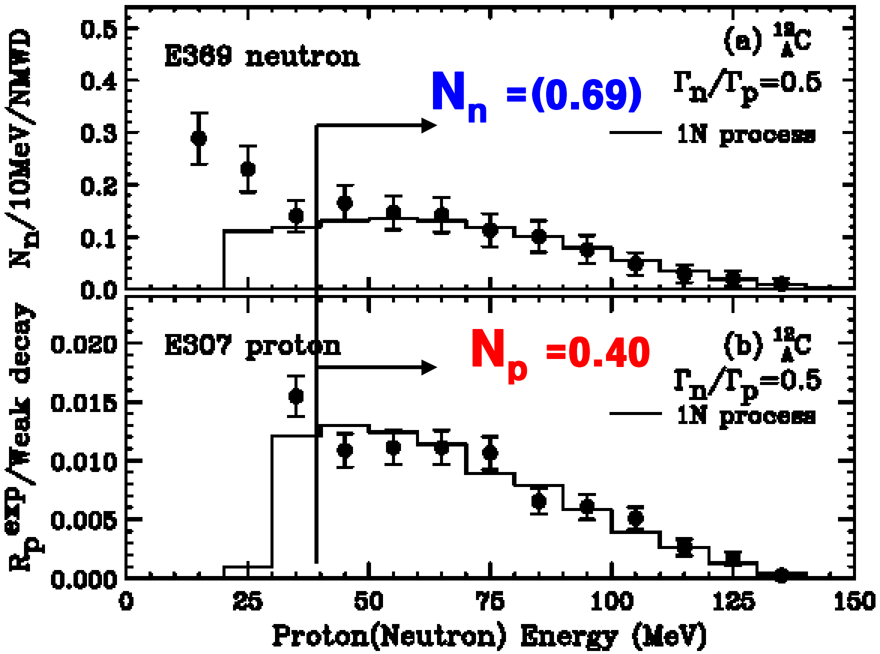


Neutron Spectrum (E369)









1. $\varepsilon \sim 31\%$; Simulation
2. **N_n/nm is compared with that of N_p/nm.**
3. **N_n above 40 MeV** is about **(0.69) while N_p is 0.40 (E307)**

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.

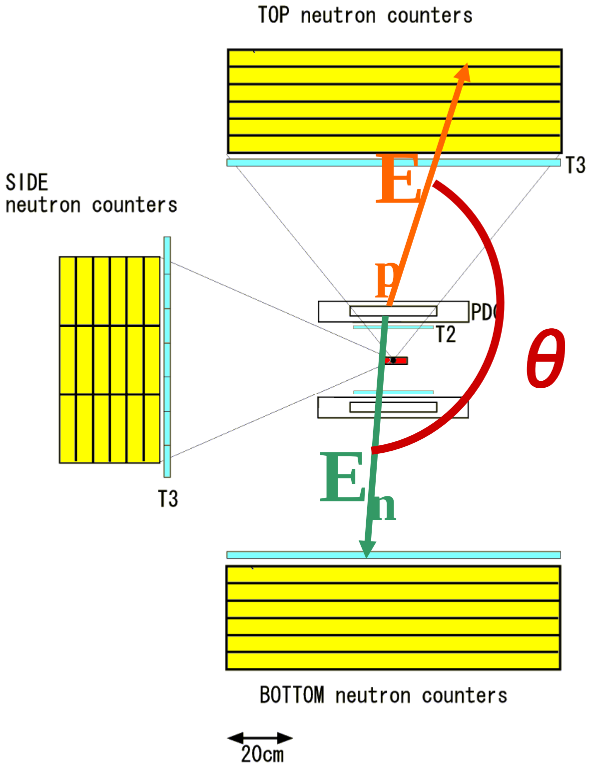
→

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

Asymmetry issue:

Serious inconsistency among a_{nm} for C.

Coincidence Measurement (KEK-PS E462/E508)

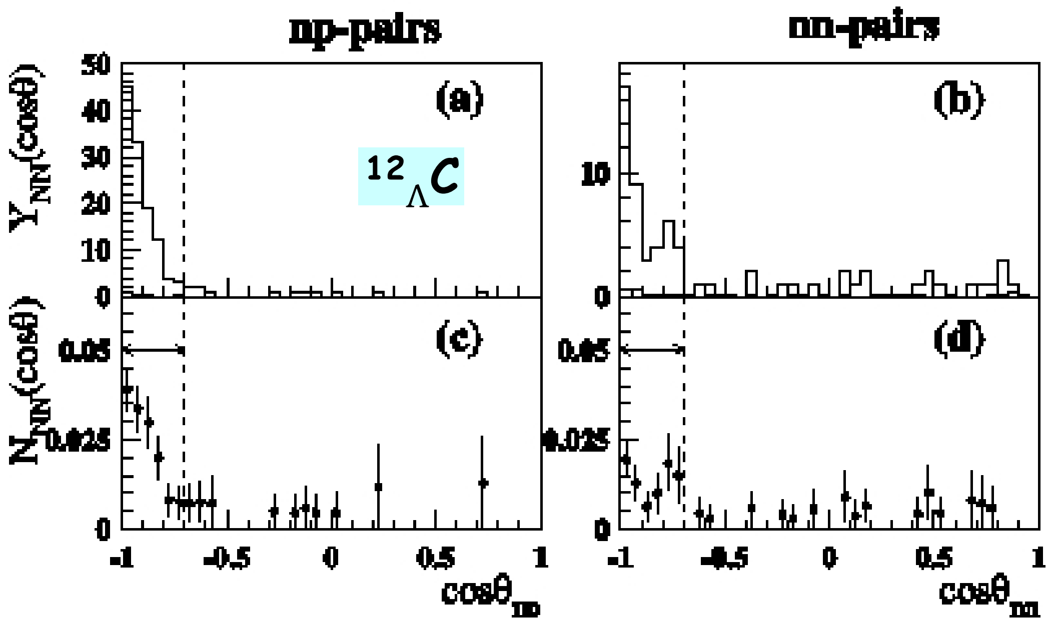


- Pair yields, Y_{np} and $Y_{nn}(\Theta)$ meas.
  $\{Y_{nn}(\Theta),\ Y_{np}(\Theta)\}/N_{nm} \equiv \{N_{nn}(\Theta),\ N_{np}(\Theta)\}$

- 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)

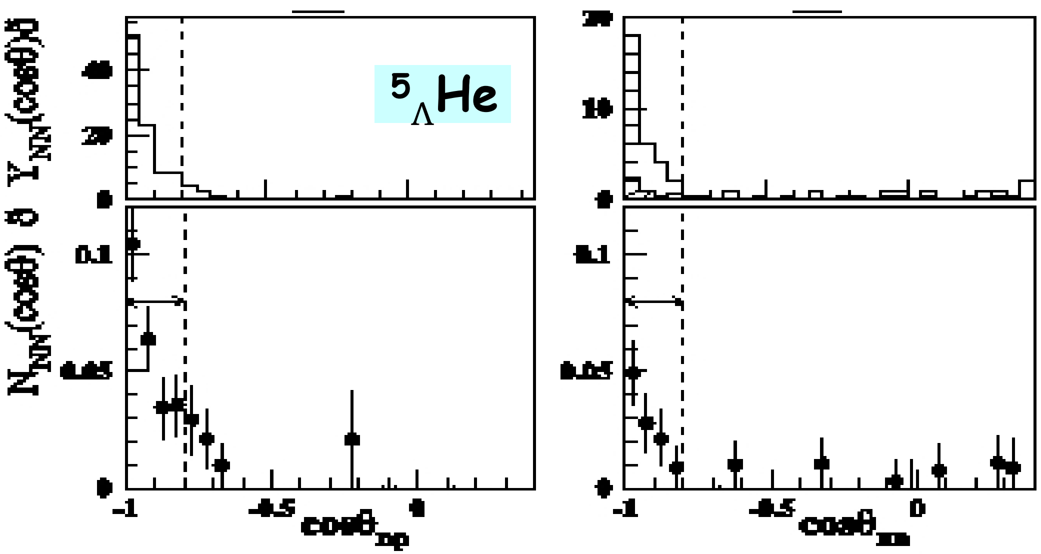


- bb ; cosΘ < -0.7
- FSI/3-B broaden the angular corr.

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

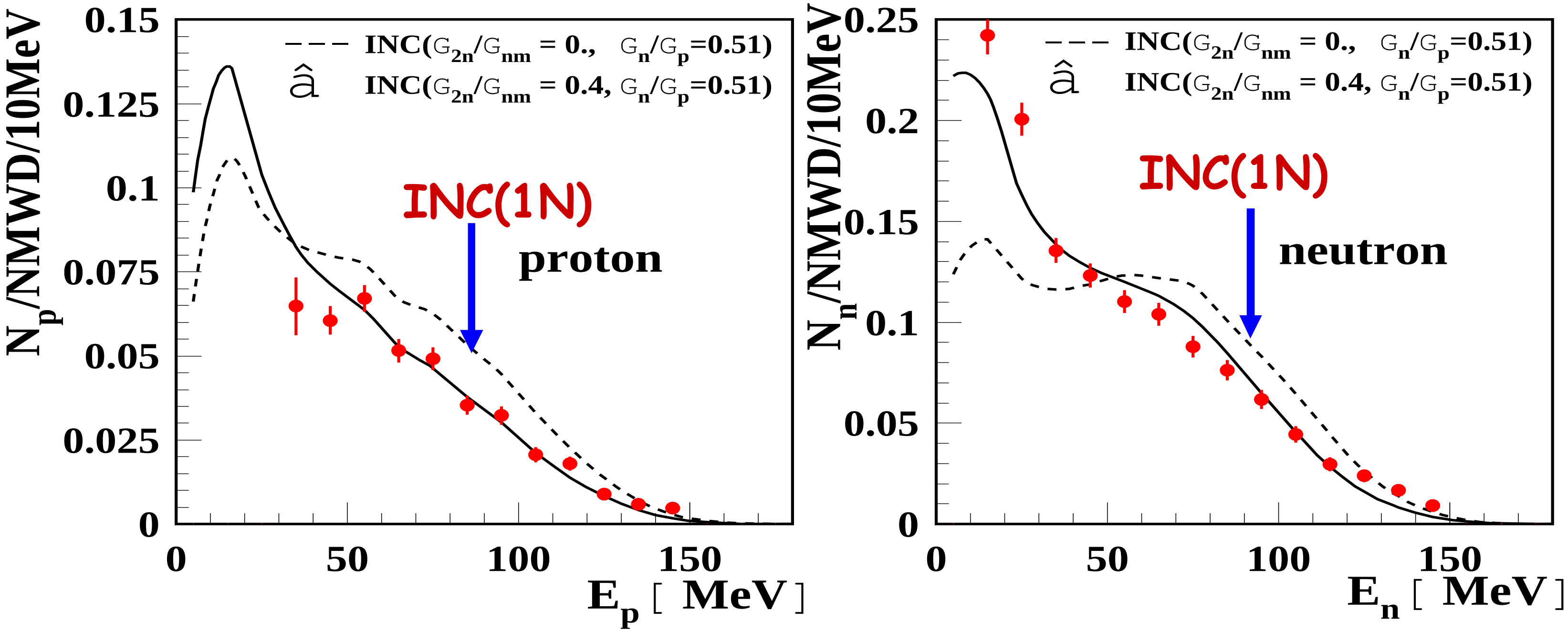
$\Gamma_n/\Gamma_p = 0.51 \pm 0.13 \pm 0.05$
M. Kim et al., PLB ('06)

$\Gamma_n/\Gamma_p = \mathbf{0.45 \pm 0.11 \pm 0.03}$
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. ; ${}^{11}{}_{\Lambda}B$

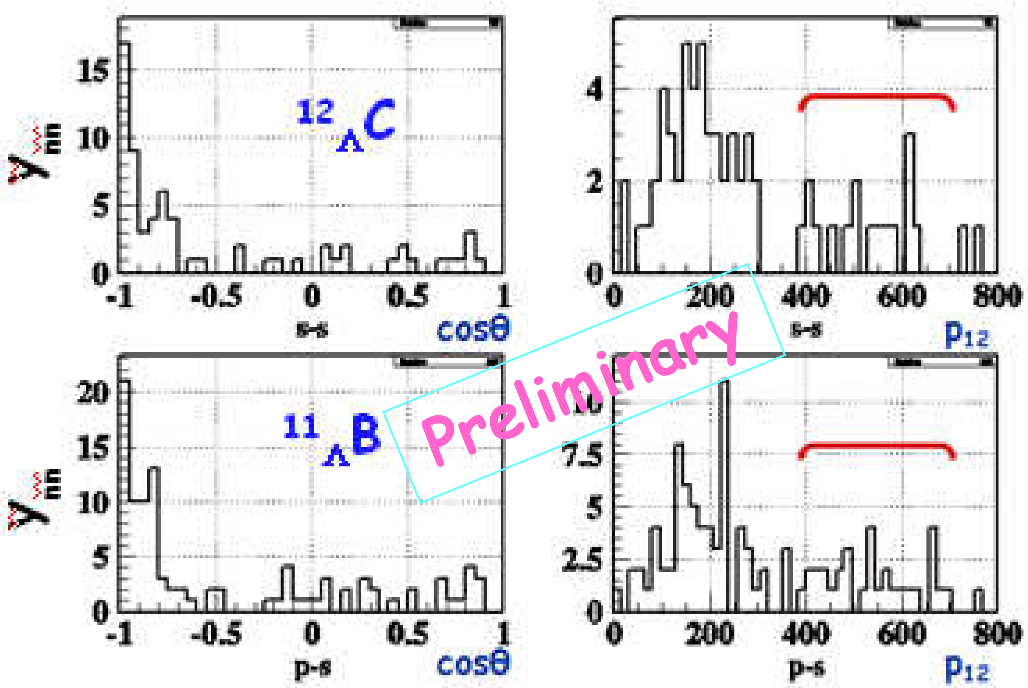
We observe two groups;

- 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;**

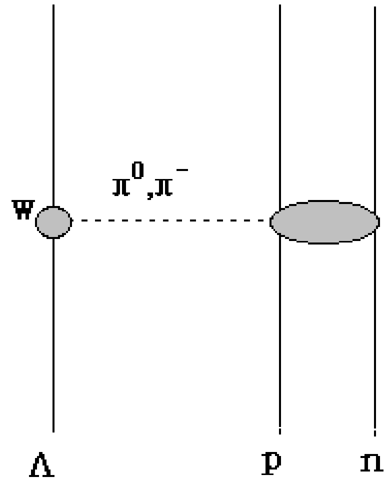
  Alberico-Ericson proposed ('91), and
  Ramos-Oset extensively calculated ('94).

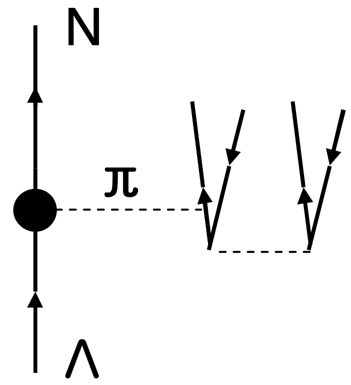
- **Absorption of virtual pion by 2p-2h states.**
  - **$\Lambda \rightarrow p\pi^-$ is dominant at the weak vertex and**
  - **Pions are absorbed dominantly on the pn pair.**

  In the process 3 nucleons are emitted;

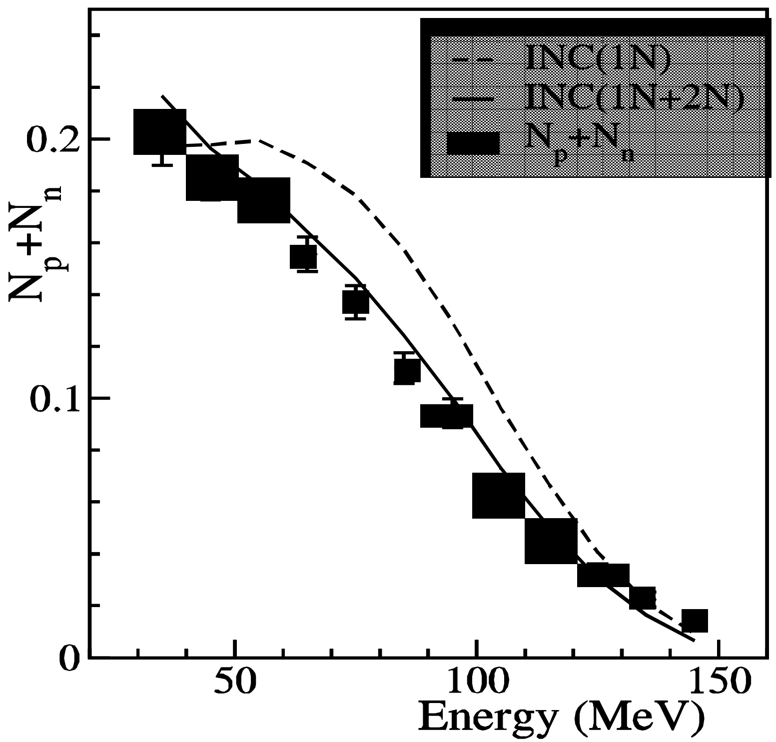
  1p(LE) + 2n (HE)

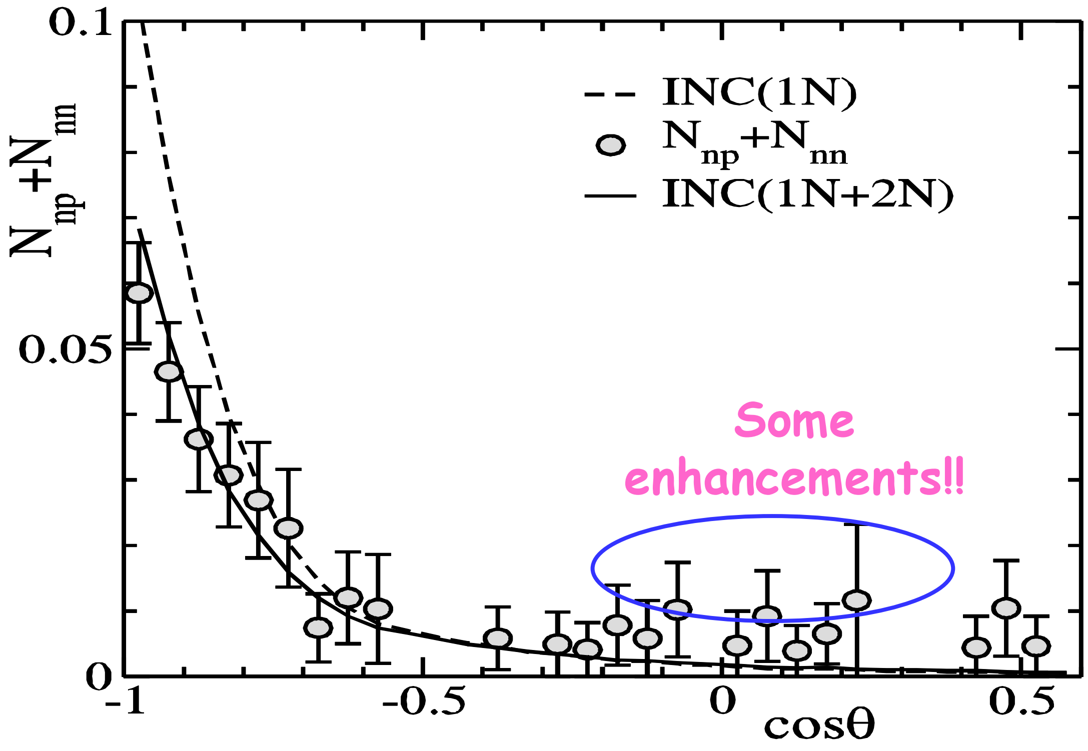
- Γ_{2N} ~ 0.2 Γ_{nm}





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).

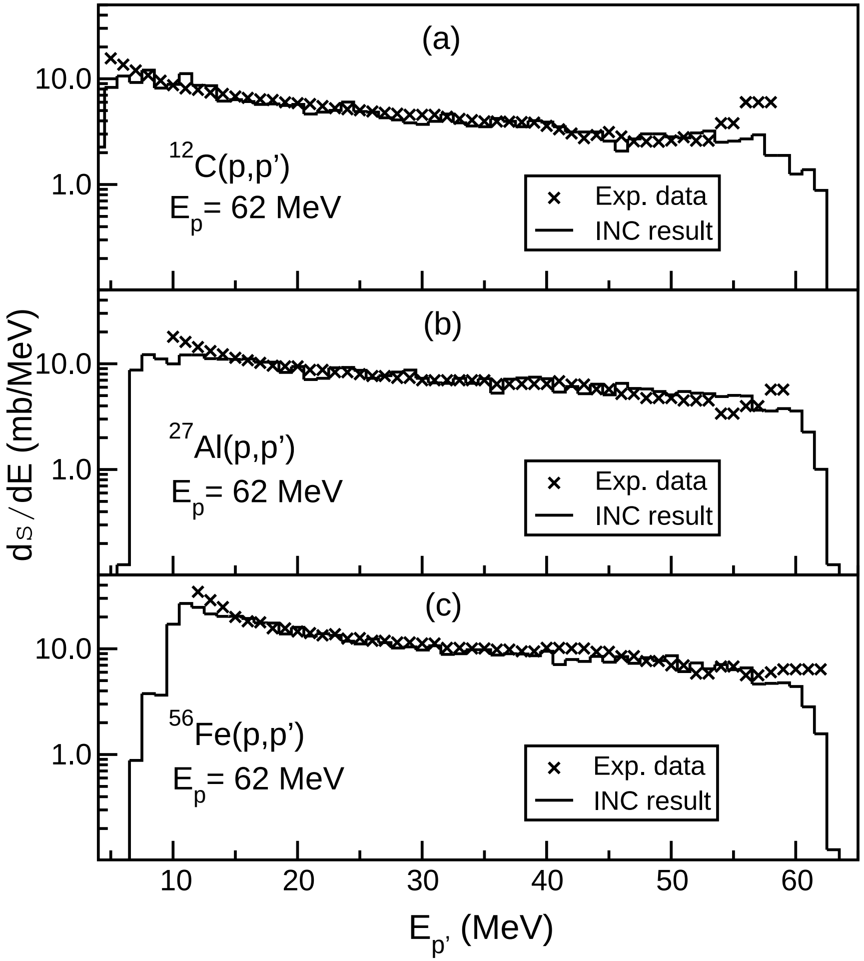
In order to explain the quenching,

→ Γ_{2N}~0.4Γ_{nm}

INC (IntraNuclear Cascade) calculation

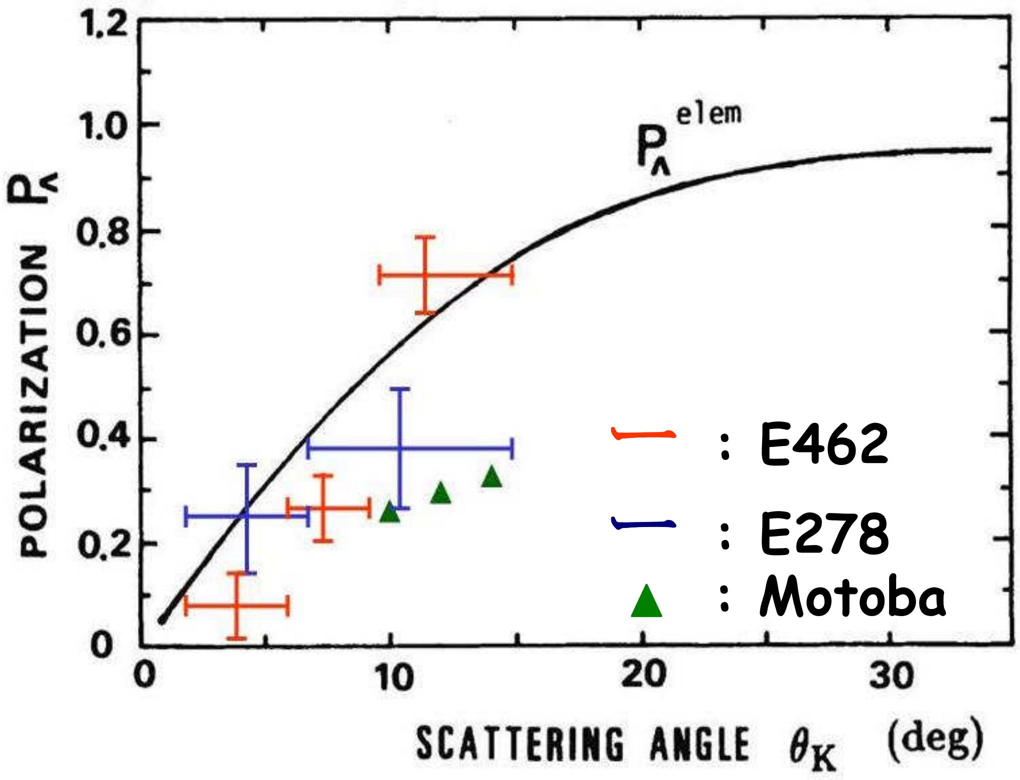
- A nucleus as a Fermi gas.
- $\rho(x) \rightarrow V(x)$
- FSI is simulated as a cascade free NN scattering along with Fermi blocking imposed.
- Density geometry parameters are adopted from the reactions, (p,p') and (p,n) data with which Mass and Energy dependence were checked
- These parameters are fixed for the decay INC calc.

Mass Dependence



M. Kim, JKPS 46 ('05) 805

Asymmetry measurement of decay proton

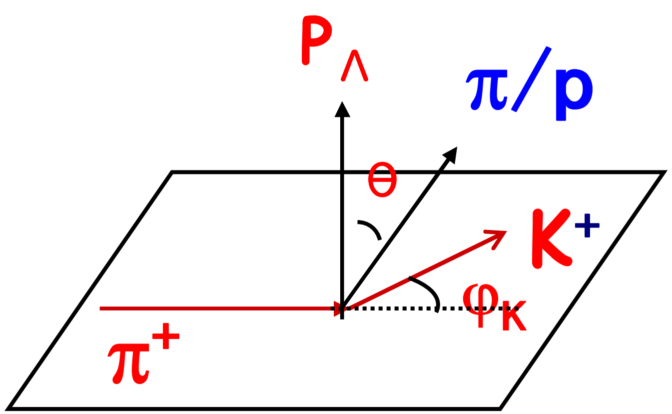


$$N(\theta) = N_0 (1 + Ay \cos\theta)$$

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

(α_p: Asymmetry parameter)

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



Previous situation of Asymmetry Parameter

Asymmetry Parameter

Previous experiments

$^{5}_{\Lambda}He$: 0.24 ± 0.22

$^{12}_{\Lambda}C, ^{11}_{\Lambda}B$: -1.3 ± 0.4

Ajimura *et al.*

Theoretical prediction

-0.6 ~ -0.8

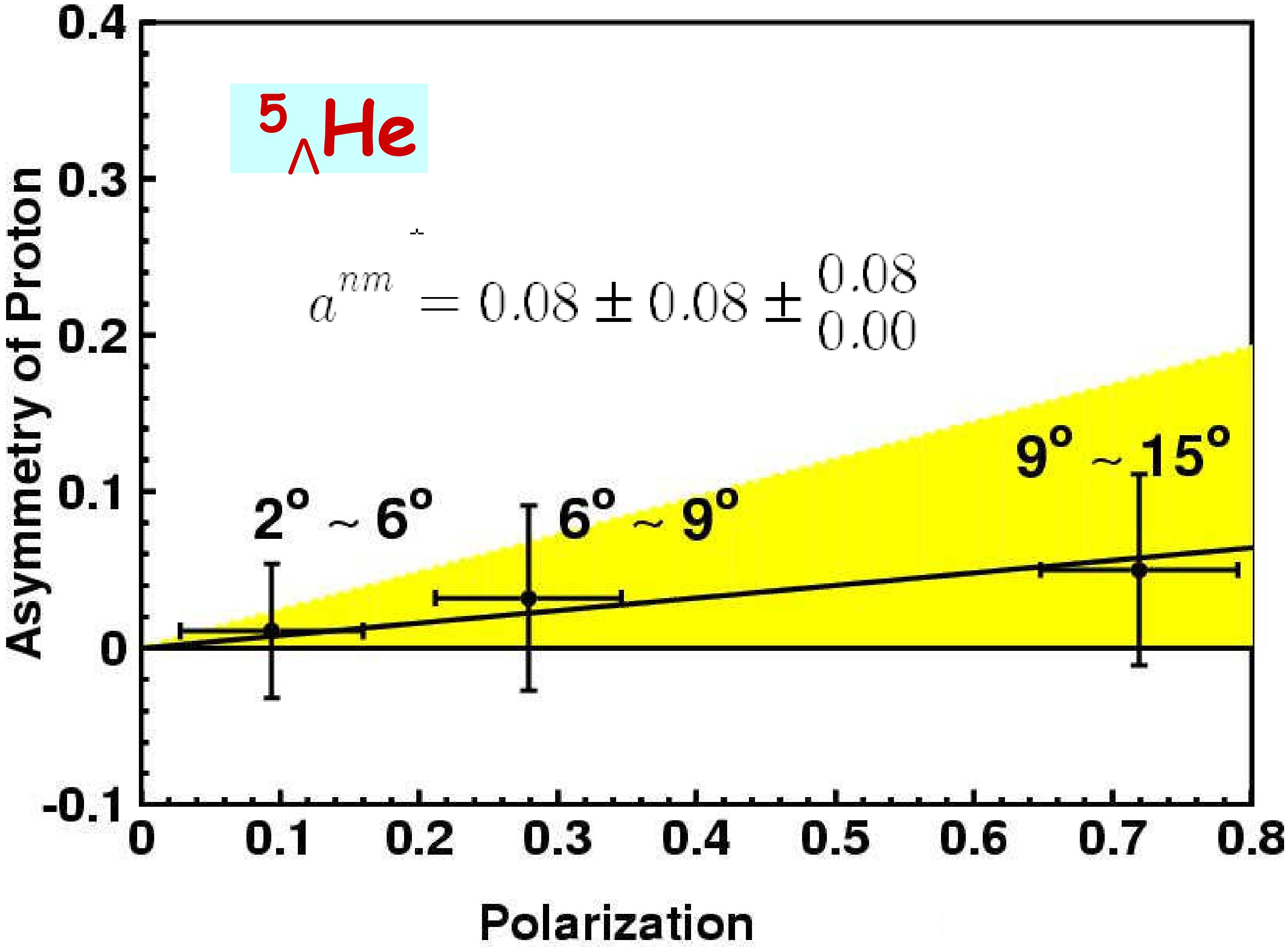
OME Ex.
π+K+DQ Ex. etc.

- High Statistics
- Exclusive identification of Λp→np channel

Exclusive Coin. Exp.

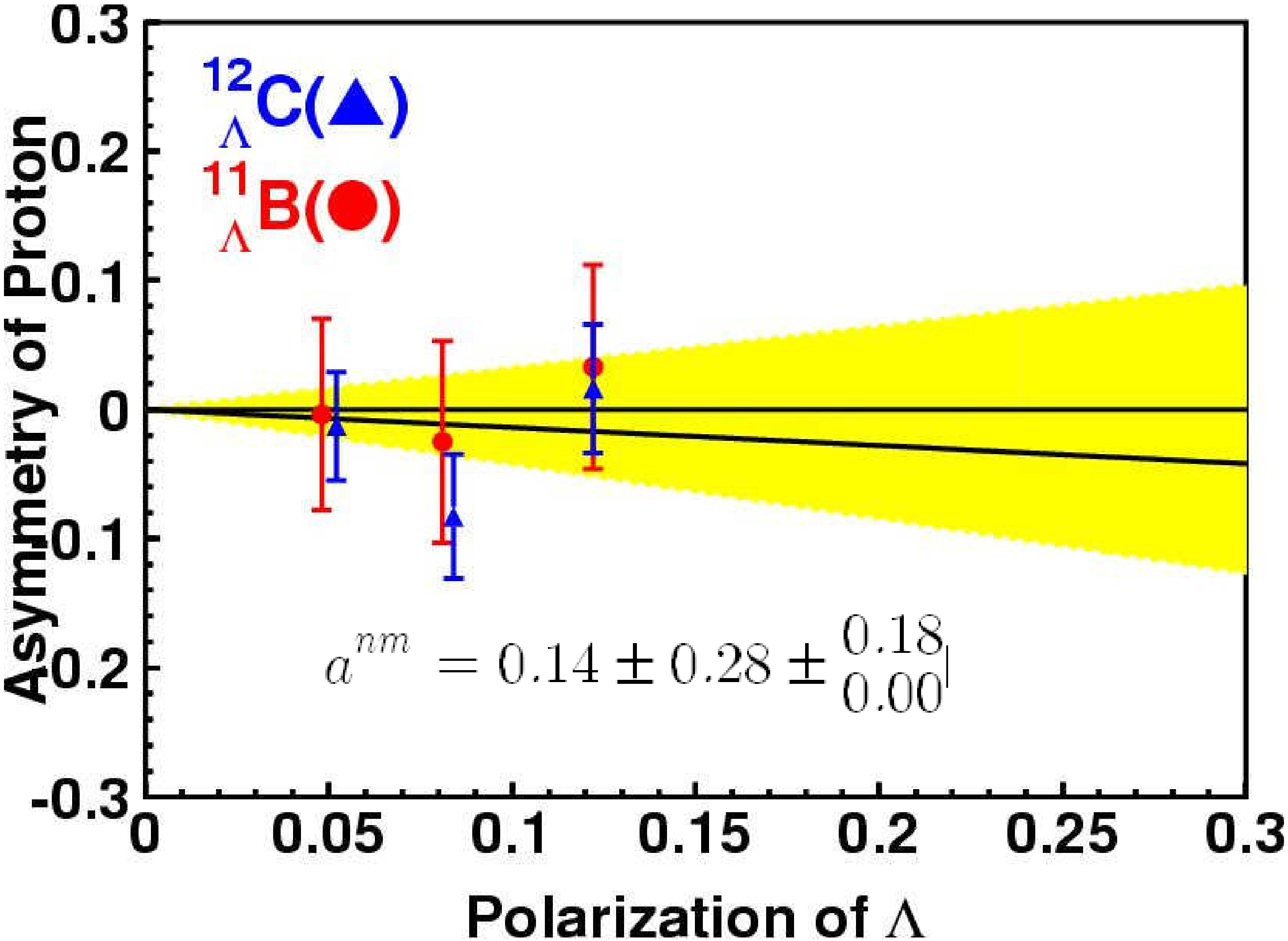
E462/E508

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

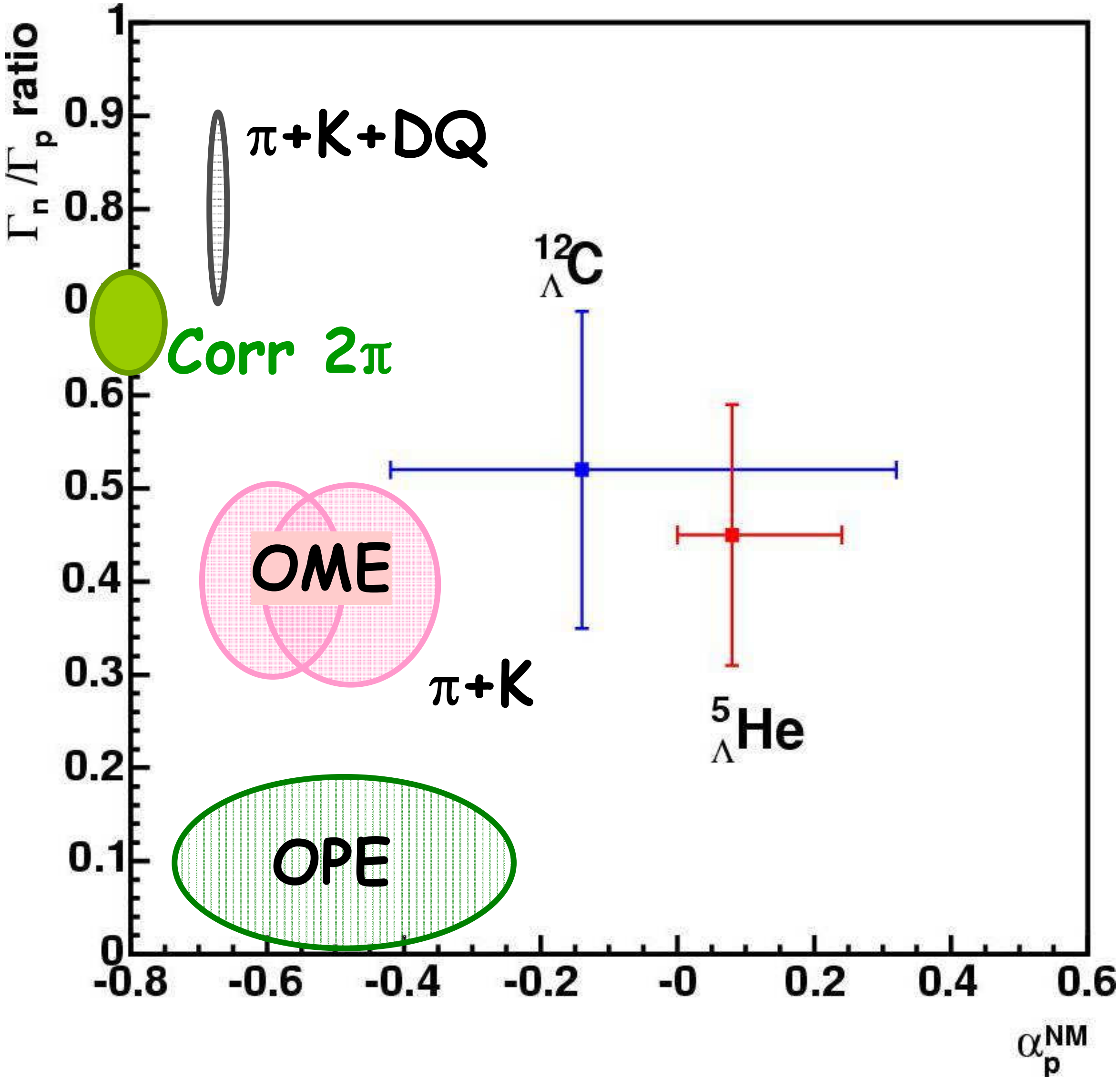


⟺ **Theory: - 0.6 ~ - 0.8**

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

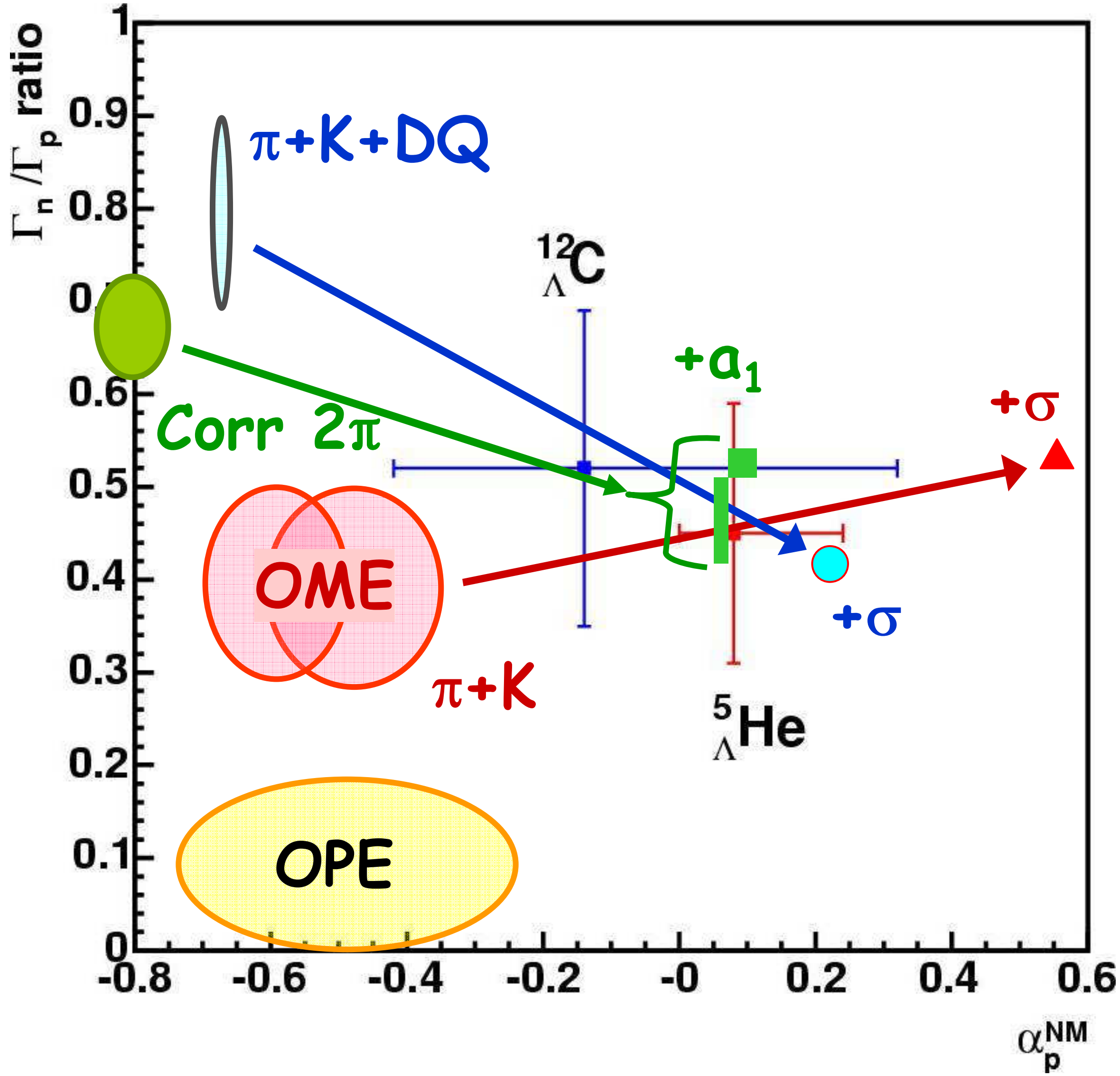


Status of Γ_n/Γ_p and α_p^{nm}



- 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}



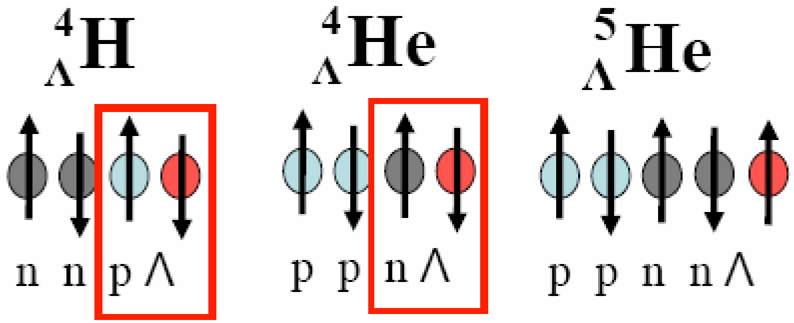
- +σ meson; Sasaki et al., PRC 71 035502 ('05)
- +a_1 meson; Itonaga et al PRC 77 044605 ('08)

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

Spin / isospin dependence

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

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



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

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

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

Status of NMWD of Λ hypernuclei

Urgent problems to be solved ;

- **ΔI=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?
- **Branching ratios of NMWD;** It has been so long, but accurate branching ratios are not available yet.

(3-body process of Weak Decay; Branching ratios of NMWD) → **J-PARC E18**

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

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. We obtained small a^{nm} consistent with zero in both s- and p-shell nuclei, which is contrasting to the large negative theoretical values (-0.6 ~ -0.8).

3. Now the urgent issues of NMWD to solve are α^{nm} (asymmetry parameter) inconsistency, ΔI =1/2 rule and the contribution of the 3-body 2N-NMWD channel.

4. However, recent theoretical models, such as DQ and corr. 2π-exch models, can reproduce small a^{nm} by incorporating σ meson in DQ and a_1 meson in the latter.

4. There are two NMWD experiments approved for J-PARC.

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

   2) E22 ; for $^{4}{}_{\Lambda}He$ (ΔI =1/2 rule)

KEK- PS E462/508 collaboration

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