7th. June. 2004 KEK-PS External Review

Non-Mesonic Weak Decays of ${}^{5}_{\Lambda}He$ and ${}^{12}_{\Lambda}C$ hypernuclei in (π^{+},K^{+}) reactions

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for KEK-PS E462 / E508 collaborations

KEK-PS E462 (2000 – 2001) : ${}^{5}_{\Lambda}He$

KEK-PS E508 (2002) : ${}^{12}_{\Lambda}C$

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* Spokesperson

* Present main analysis member (Ph.D student)

Weak decay of Λ hypernucleus

Λ weak decay in free space

$\Lambda \rightarrow p + \pi^-$: 63.9±0.5 %

$\Lambda \rightarrow n + \pi^0$: 35.8±0.5 %

$\tau_\Lambda = 263.2 \pm 2.0$ ps

→ Well known.

Weak decay mode of Λ hypernucleus

$1/\tau_{HY} = \Gamma_{tot}$

- Γ_m
  - Γ_{π^-} $(\Lambda \rightarrow p + \pi^-)$
  - Γ_{π^0} $(\Lambda \rightarrow n + \pi^0)$

  Mesonic q～100MeV/c

- Γ_{nm}
  - Γ_p $(\Lambda + \text{"}p\text{"} \rightarrow n + p)$
  - Γ_n $(\Lambda + \text{"}n\text{"} \rightarrow n + n)$

  Non-Mesonic(NMWD) q～400MeV/c

Study of the mechanism of baryon-baryon weak interaction

Non-mesonic weak decay

$\Lambda + N \rightarrow N + N$

TABLE II. Six amplitudes in NM decay process whose initial ΛN system is relative S states.

Initial	Final	Matrix element	Rate	I_f	Parity change
$^1S_0$	$^1S_0$	a	a^2	1	no
	$^3P_0$	$\frac{b}{2}(\sigma_1 - \sigma_2)q$	b^2	1	yes
$^3S_1$	$^3S_1$	c	c^2	0	no
	$^3D_1$	$\frac{d}{2\sqrt{2}}S_{12}(q)$	d^2	0	no
	$^1P_1$	$\frac{\sqrt{3}}{2}e(\sigma_1 - \sigma_2)q$	e^2	0	yes
	$^3P_1$	$\frac{\sqrt{6}}{4}f(\sigma_1 + \sigma_2)q$	f^2	1	yes

$\Lambda + p \rightarrow n + p$

$: \Gamma_p = a^2+b^2+c^2+d^2+e^2+f^2$

$\Lambda + n \rightarrow n + n$

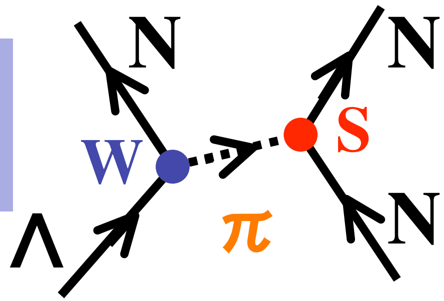
$: \Gamma_n = a^2+b^2+f^2$

Γ_n / Γ_p ratio

: The most important observable to study the isospin structure of the NMWD.

Simple theoretical model

One Pion Exchange (OPE) model



strong tenser coupling (ΔL=2, ΔS=2)
→ dominant term
$^3S_1 \rightarrow {}^3D_1$ (amplitude "d")

OPE : $\Gamma_n / \Gamma_p \sim 0.1$ ↔ **Exp. : $\Gamma_n / \Gamma_p \sim 1$**

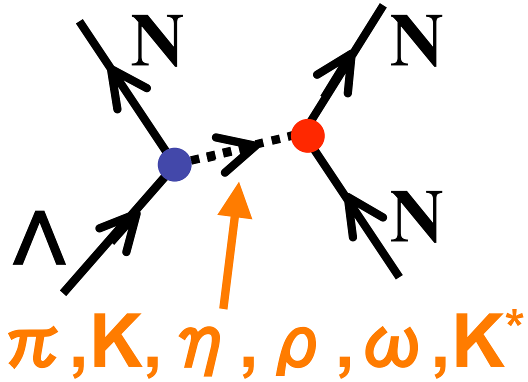
Γ_n / Γ_p ratio puzzle

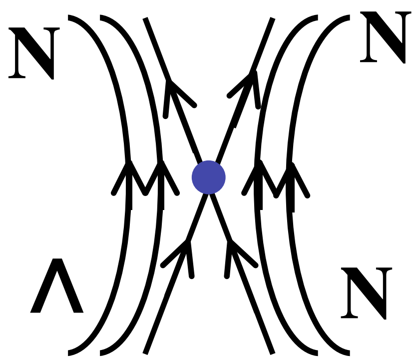
with large error

Theoretical approach

q～400MeV/c (← large!) → short-distance interaction
(→ range ～ 0.5 fm)

One Meson Exchange (OME) mechanism	Direct Quark (DQ) mechanism





- Kaon exchange model (OME)

→ dominant term $^3S_1 \rightarrow {}^1P_1$ (amplitude "f")

→ large Γ_n / Γ_p (～0.4-0.7)

Experimental difficulty

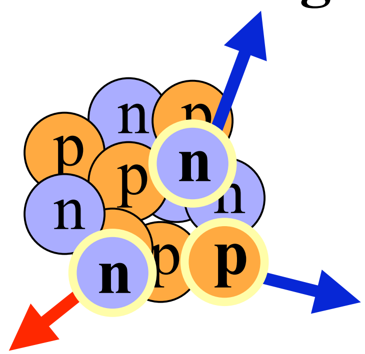
Most of the experiments measured **only proton** energy specra

→ $\Gamma_n / \Gamma_p = (\Gamma_{nm} - \Gamma_p) / \Gamma_p$

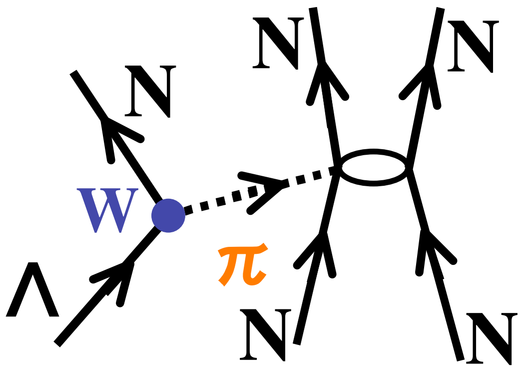
(because of the difficulty in detecting neutrons)

- ✓ Proton energy loss inside a target and detectors
- ✓ Final state interaction (FSI) effect
  (← not well established theoretically)
- ✓ to distinguish between the FSI and 2N-induced process (ΛNN→nNN)

Final state interaction (FSI) effect



ΛNN→NNN (2N-induced process)

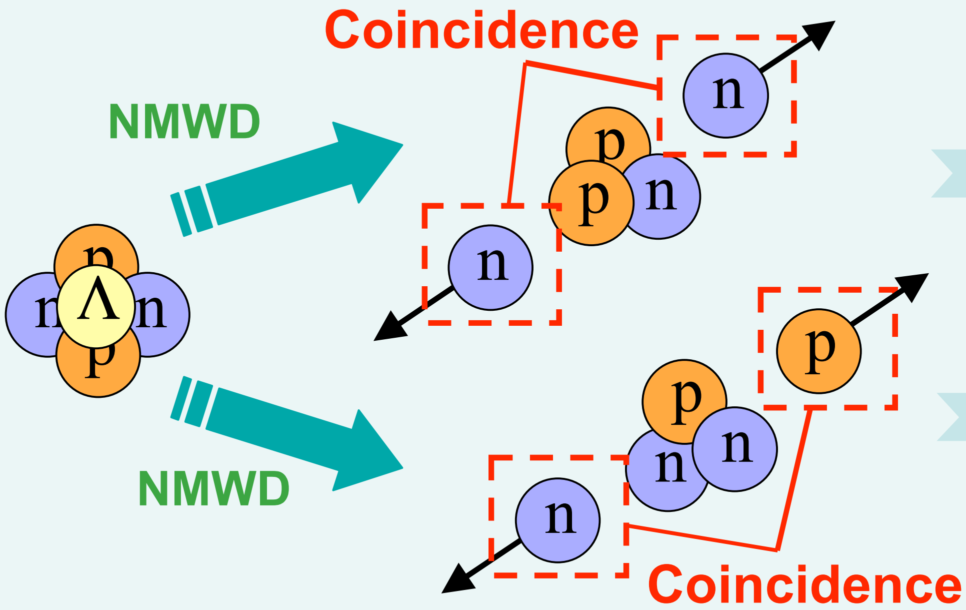


(One of the theoretical model)

The present experiment

KEK-PS E462/E508

NMWD : ΛN→NN



1) **Angular correlation**
(back-to-back, cosθ<-0.8)
2) **Energy correlation**
(Q∼E(N1)+E(N2) ∼152MeV)

Direct measurement of the Γ_n / Γ_p ratio

⇨ *Select ΛN→NN events w/o FSI effect & ΛNN→NNN.*

$$N(\Lambda n \rightarrow nn) \times (\Omega_n \times \Omega_n)_{av.} \times \varepsilon_n^2 \times (1 - R_{FSI})$$

$$N(\Lambda p \rightarrow np) \times (\Omega_n \times \Omega_p)_{av.} \times \varepsilon_n \times \varepsilon_p \times (1 - R_{FSI})$$

* $\cos\theta < -0.8$
* E(N1)+E(N2) cut

$$\frac{\Gamma_n}{\Gamma_p} = \frac{N(nn - \text{pair coin})}{N(np - \text{pair coin})} \times \frac{\varepsilon_p}{\varepsilon_n}$$

Feature of the present experiment

- Λ + "p" → n + p
  Λ + "n" → n + n

} Measure both np- and nn- pair!

⇒ Direct measurement of the Γ_n / Γ_p ratio (N_{nn}/N_{np} ratio)

- Detect all decay particles (p, n, π^-, γ (π^0)) with very high statistics.

- Select Light hypernuclei

  ✓ Light s-shell hypernucleus, ${}^{5}_{\Lambda}He$
  (to minimize the FSI effect)

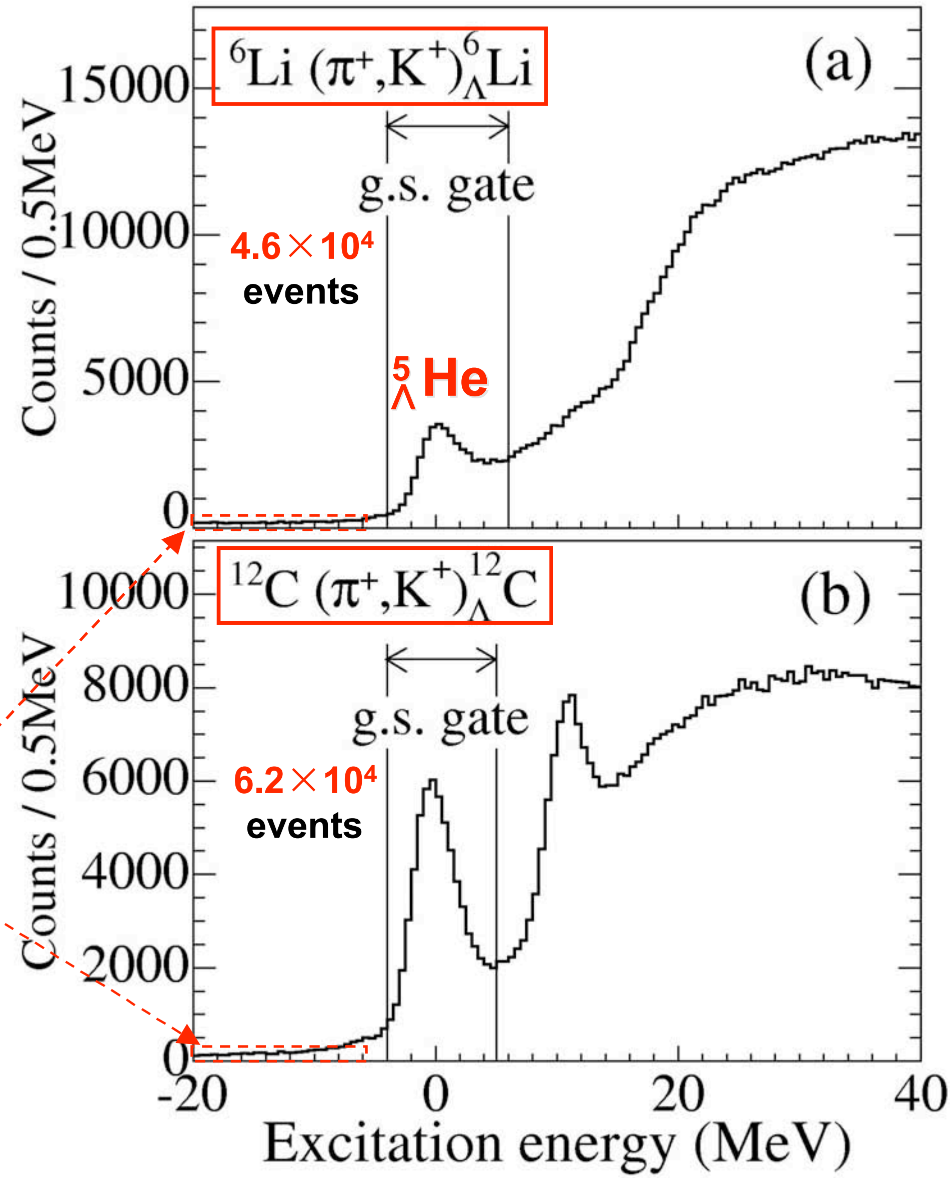
  ✓ Typical p-shell hypernucleus, ${}^{12}_{\Lambda}C$
  (to investigate the p-wave effect)

Excitation-energy spectra for $^{6}_{\Lambda}Li$ and $^{12}_{\Lambda}C$

The ground state of $^{6}_{\Lambda}$Li is
above the threshold of $^{5}_{\Lambda}$He + p.

$$^{6}_{\Lambda}\mathrm{Li}\ (\mathrm{g.s.}) \rightarrow\ ^{5}_{\Lambda}\mathrm{He} + p$$

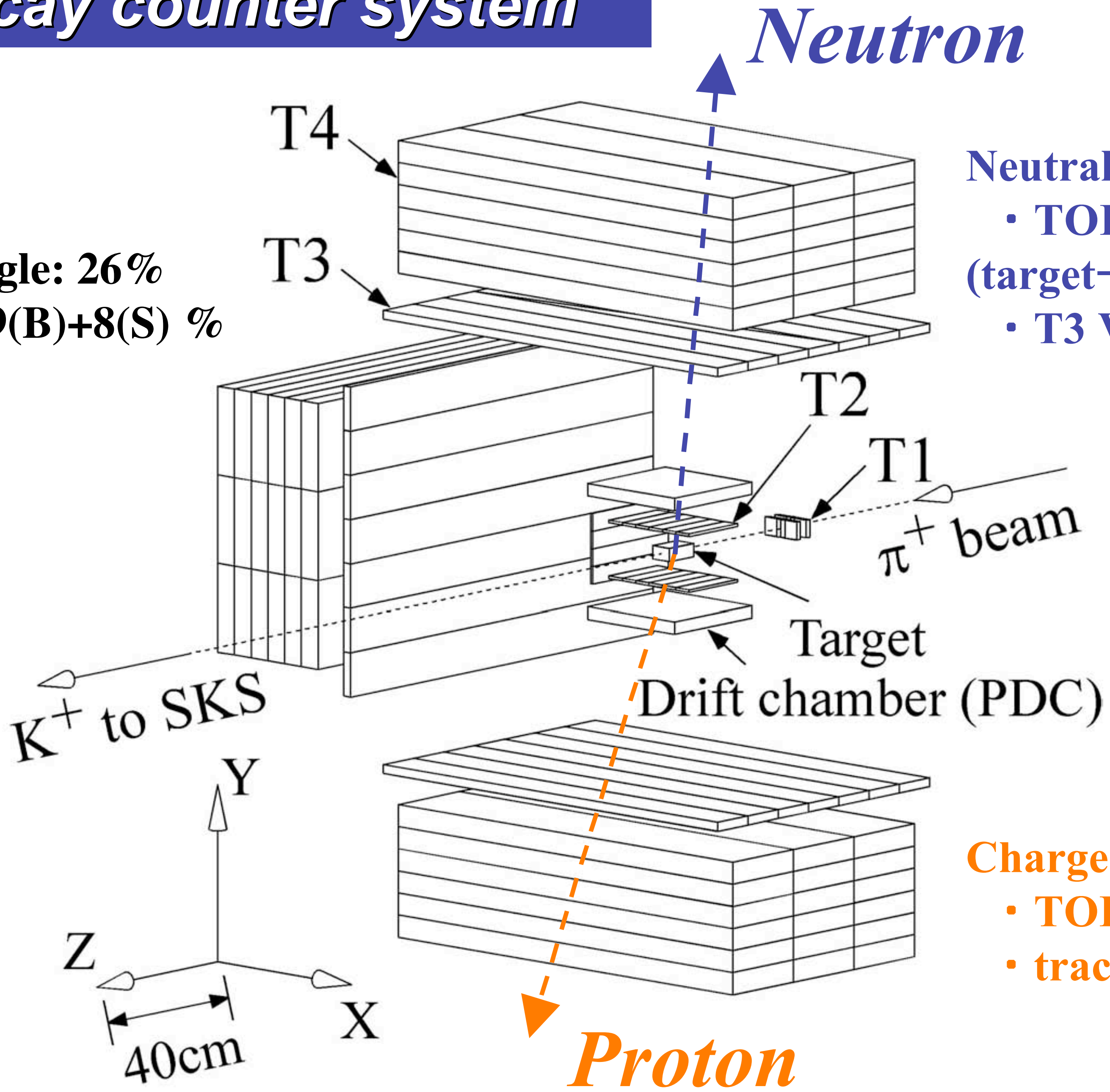
$^{6}_{\Lambda}$Li (g.s.) promptly decays into $^{5}_{\Lambda}$He emitting a low-energy proton.



- ✓ Good S/N ratio ∼ 10
- ✓ High statistics
  (one-order of magnitude higher than those of previous experiments.)

Decay counter system

Solid angle: 26%
= 9(T)+9(B)+8(S) %



Neutral particle：
- **TOF (target→NT)**
- **T3 VETO**

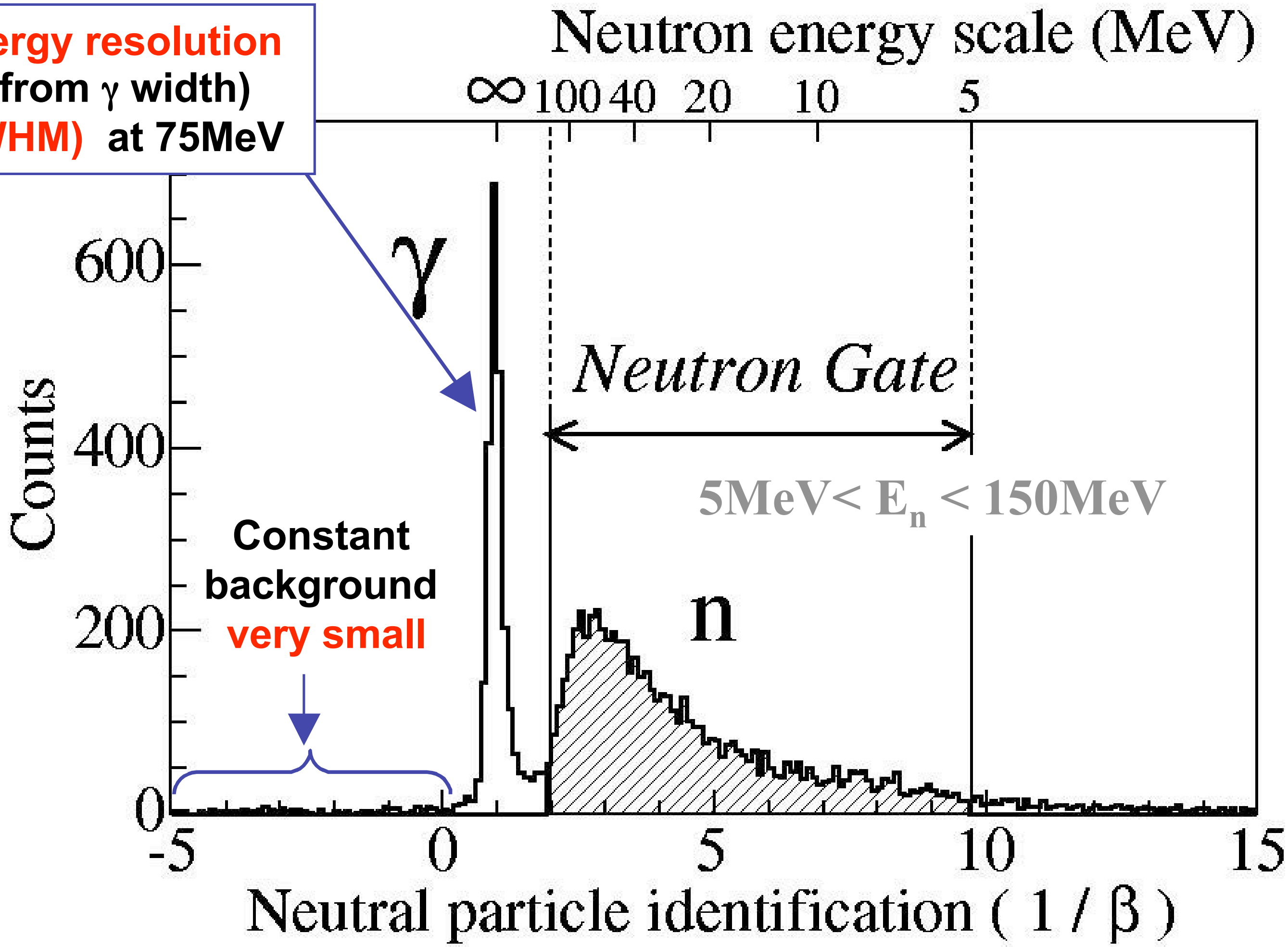
Charged particle：
- **TOF (T2→T3)**
- **tracking（PDC）**

Neutral decay particle ID

Neutral particles from $^{12}_{\Lambda}C$

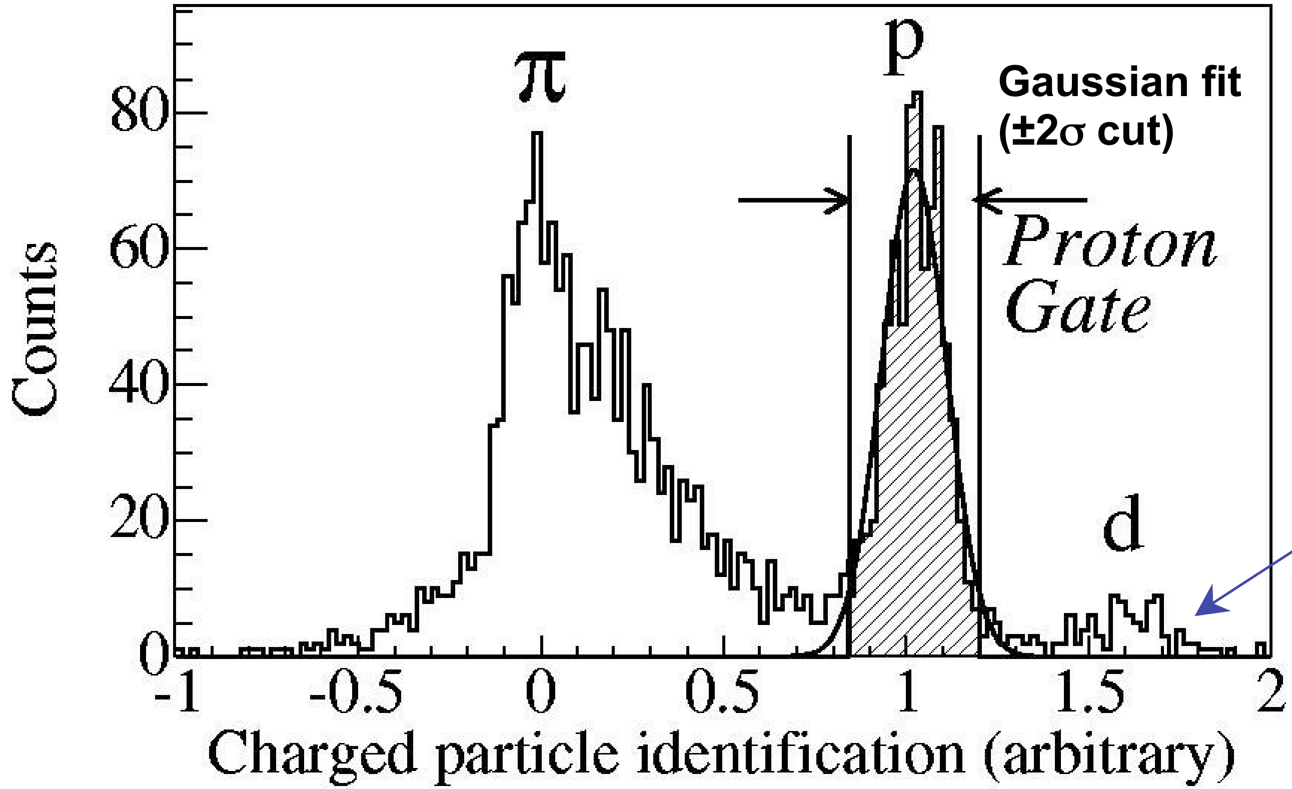
Neutron energy resolution
(estimated from γ width)
→ 7MeV(FWHM) at 75MeV

- **Good γ *n* separation**
- **Good S/N ratio (~30)**
  (previous exp.
  S/N ratio ($^{5}_{\Lambda}He$) ~1)
  →~30 times (for $^{5}_{\Lambda}He$) higher than previous exp.
- **High statistics**
  (~ 5000 neutrons)
  →~200 times (for $^{5}_{\Lambda}He$)
  ~30 times (for $^{12}_{\Lambda}C$)
  higher than previous exp.



1 / β spectra **(TOF spectra)**

Charged decay particle ID



Charged particles from $^{5}_{\Lambda}He$

Deuterons were separated from the protons. (for the first time!)

PID function

derived from

- *dE/dx* (at T2)
- **Total energy deposit** (sequentially fired counters (T2,T3,T4).)
- **TOF** (between T2 and T3)

Excitation spectra w/ coincident decay particles for $^{5}_{\Lambda}He$

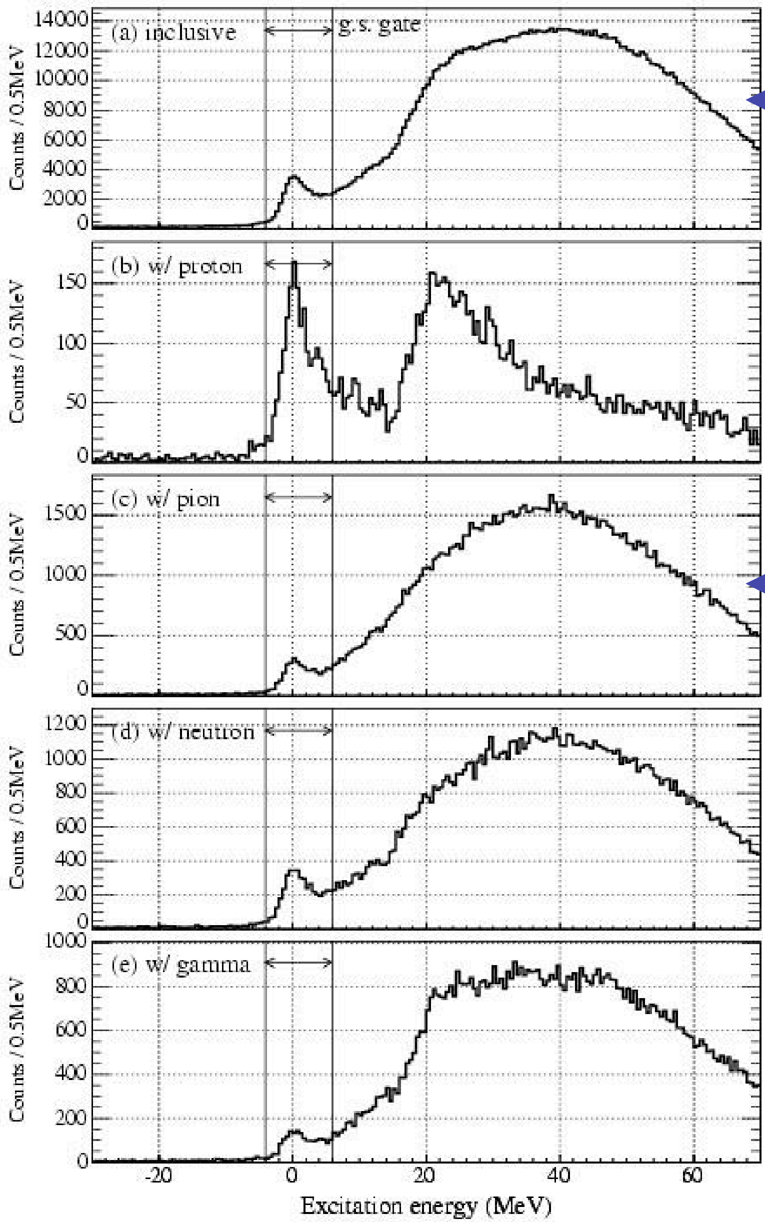
inclusive

w/ proton

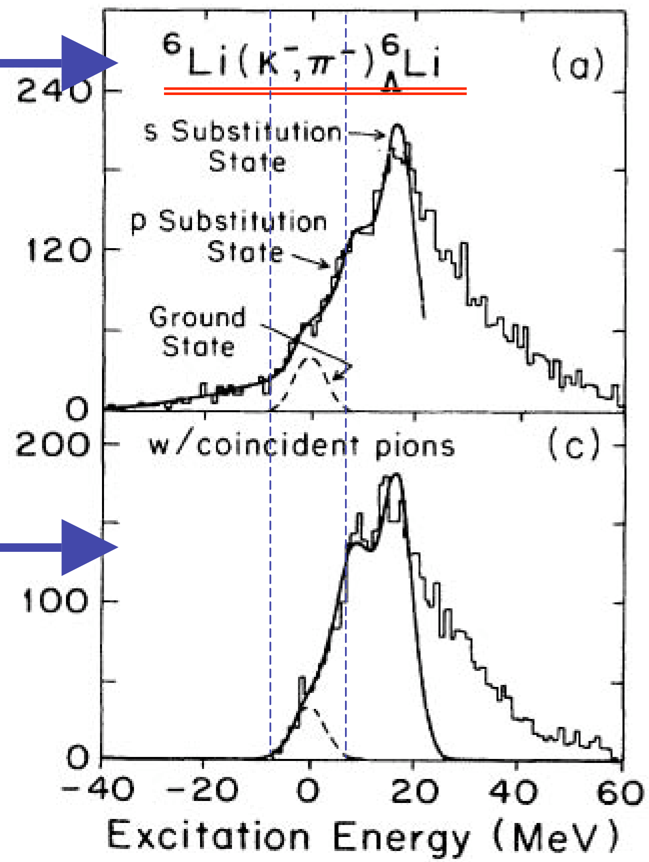
w/ pion

w/ neutron

w/ gamma



previous experiment at BNL



The **g.s. peak is clearly seen** in all spectra with coincident decay particles.

Excitation spectra w/ coincident decay particles for $^{12}_{\Lambda}C$

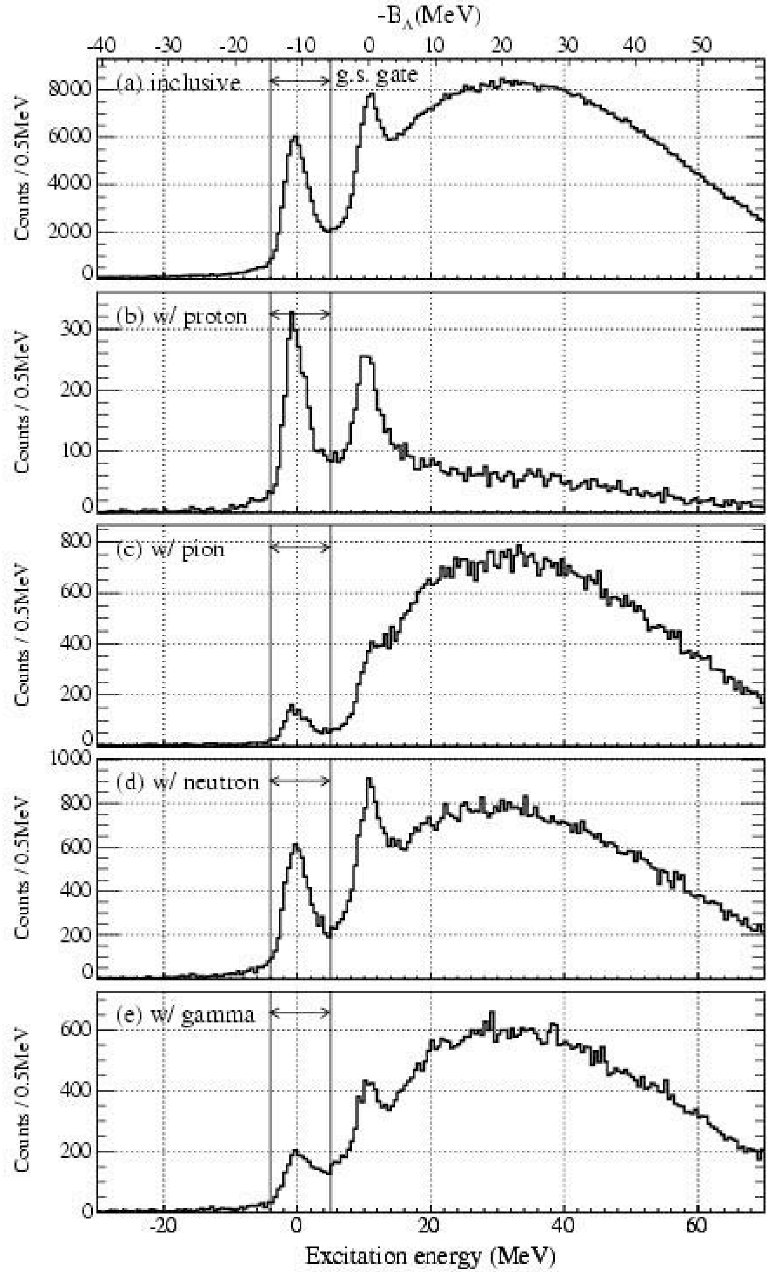
inclusive

w/ proton

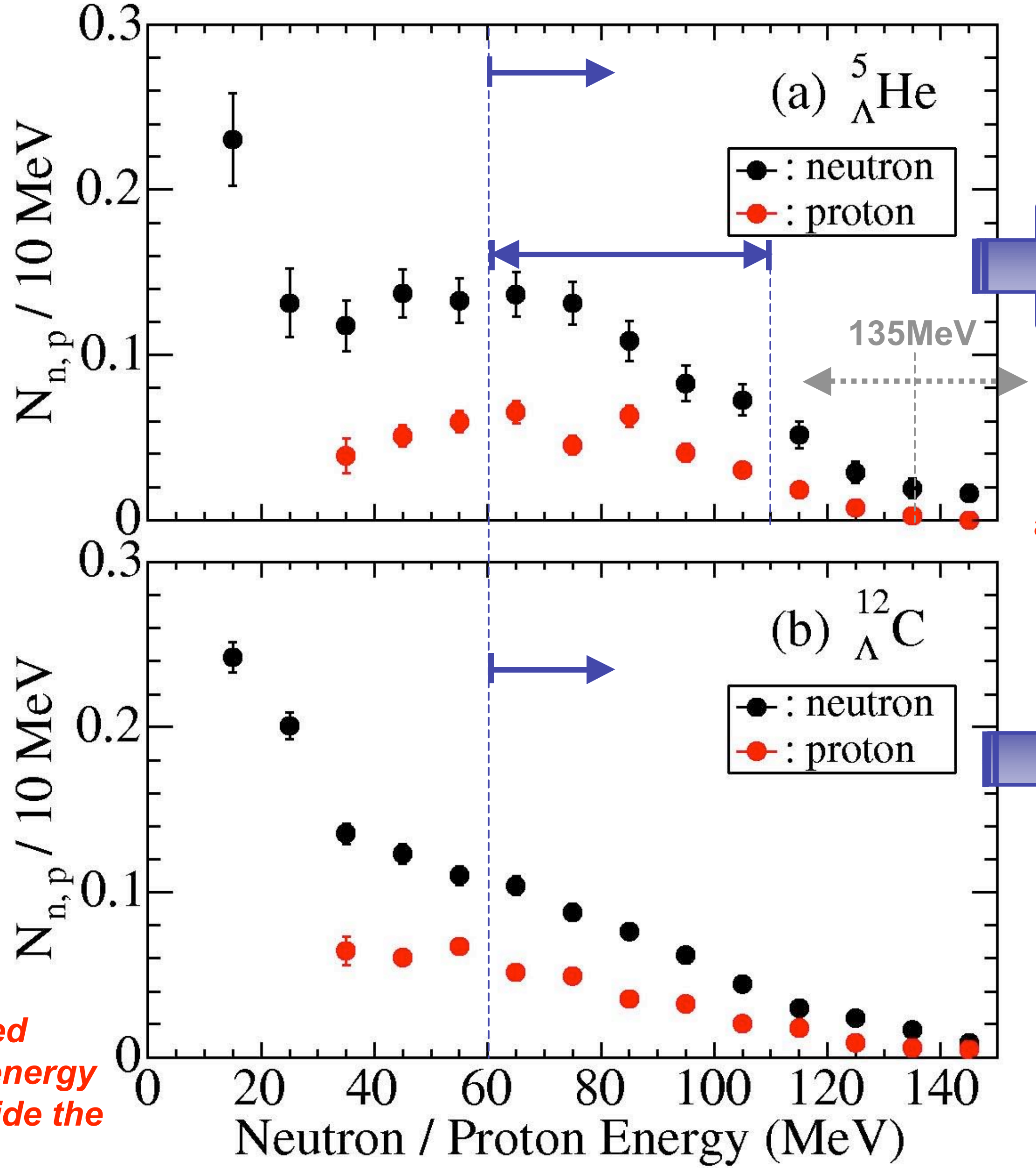
w/ pion

w/ neutron

w/ gamma



Neutron and Proton energy spectra of $^{5}_{\Lambda}He$ and $^{12}_{\Lambda}C$



To avoid suffering from FSI effect & $\Lambda NN \to NNN$

→ High energy threshold

N_n / N_p (60<E<110MeV) ～ 2.17±0.15±0.16

$^{5}_{\Lambda}He \to n + \alpha$: Q～135MeV (rate : 0.049±0.01Γ_{π^-})

apply upper energy limit of 110MeV !

N_n / N_p (E>60MeV) ～ 2.00±0.09±0.14

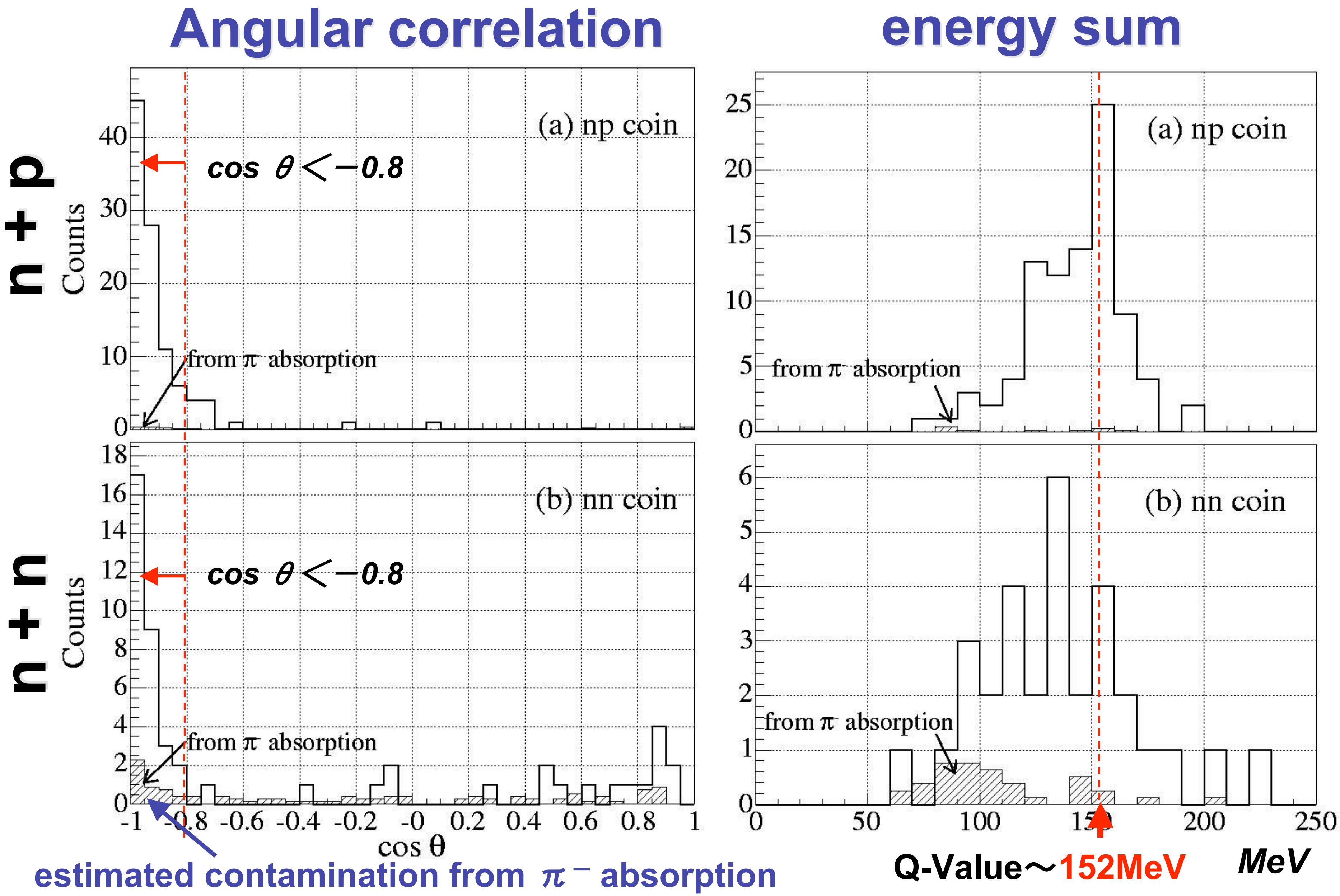
Corrected proton energy loss inside the target !!

apply a simple relation

$\Gamma_n / \Gamma_p = (N_n / N_p - 1) / 2$

→ Γ_n / Γ_p ～ 0.5

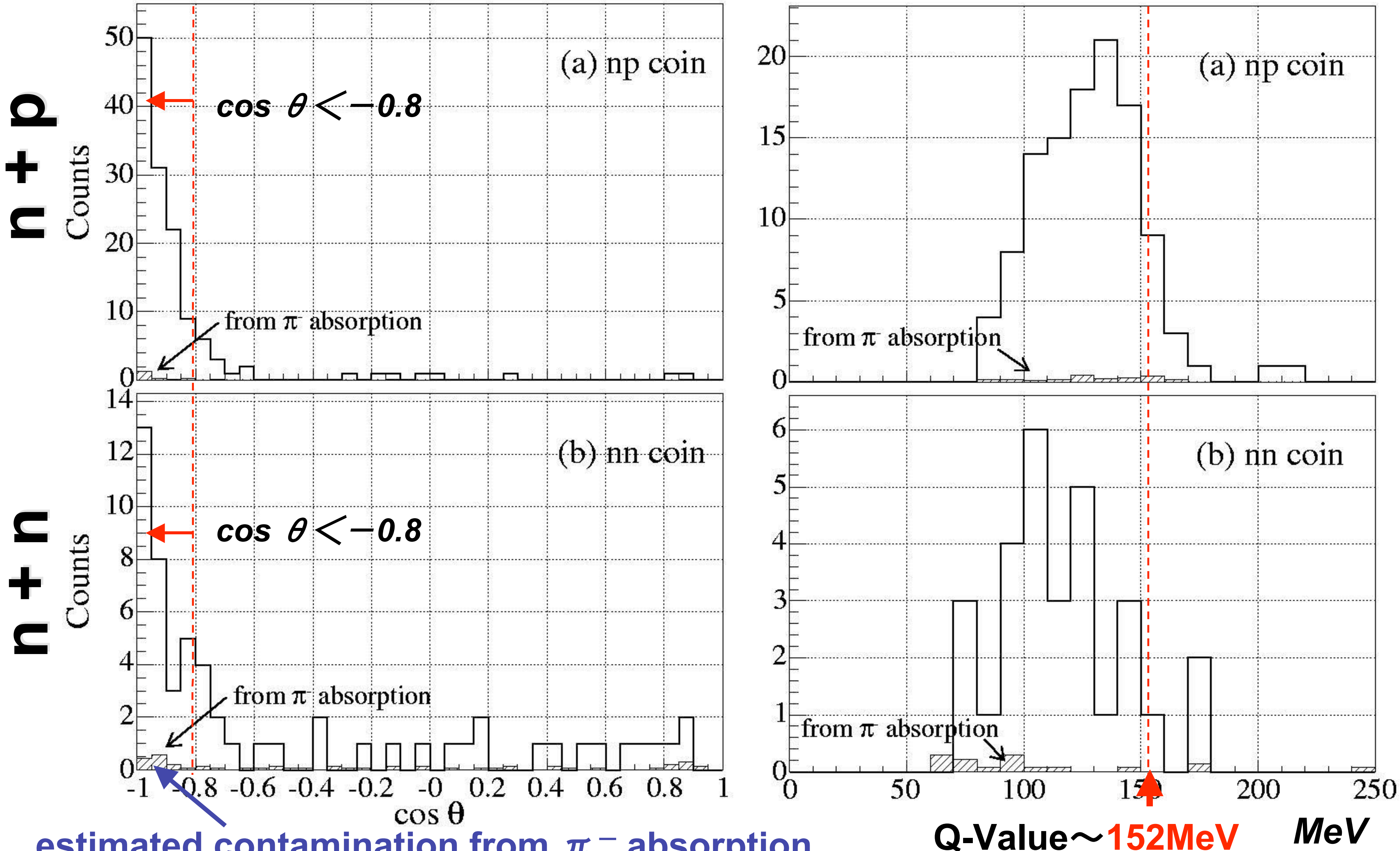
Coincidence analysis for $^{5}_{\Lambda}He$



Coincidence analysis for $^{12}_{\Lambda}C$

Angular correlation

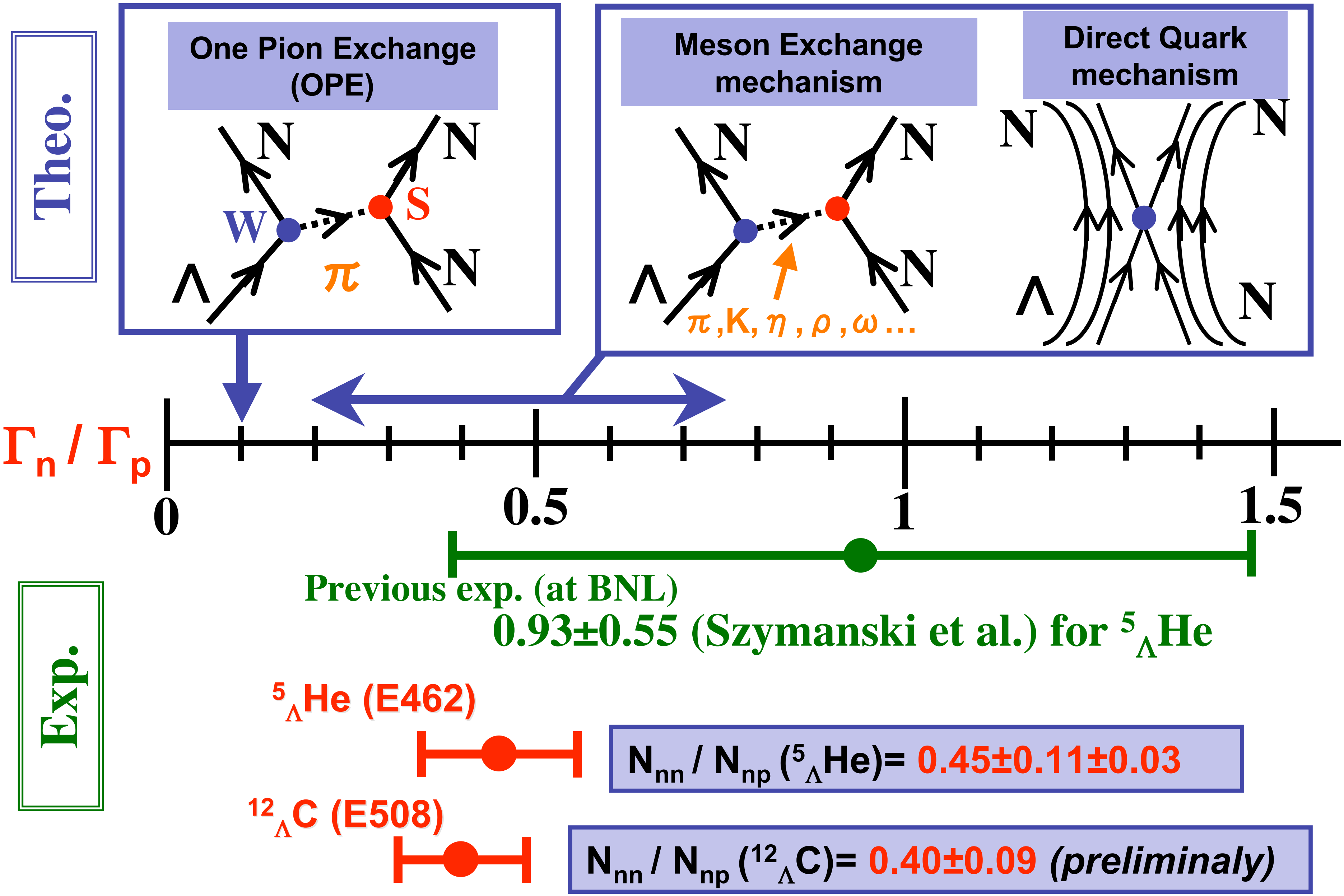
energy sum



estimated contamination from π^- absorption

Q-Value～152MeV

Γ_n / Γ_p ratio



Summary

- $\Lambda N \rightarrow NN$ was directly observed for the first time !

  ${}^{5}{}_{\Lambda}$He : Γ_n / Γ_p ratio ∼ N_{nn} / N_{np} = 0.45±0.11±0.03

  ${}^{12}{}_{\Lambda}$C : Γ_n / Γ_p ratio ∼ N_{nn} / N_{np} = 0.40±0.09 (preliminaly)

- N_n / N_p ratio with a high threshold (60MeV) was approximately equal to 2 (Γ_n / Γ_p ∼ 0.5) → consistent with coincidence results.

↓

✓ excludes the earlier experimental claim Γ_n / Γ_p ∼ 1.

✓ rules out theoretical calculations based on the OPE (Γ_n / Γ_p∼0).

The longstanding "Γ_n / Γ_p ratio puzzle" is solved.

It supports recent calculations based on short-range interactions such as heavy-meson exchange and the direct quark exchange.

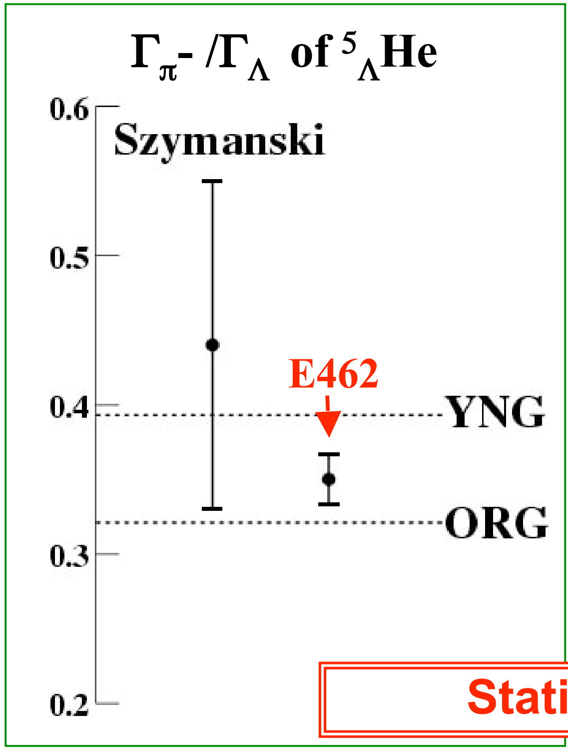
Other results

Lifetime
π^- branching ratio
π^0 branching ratio

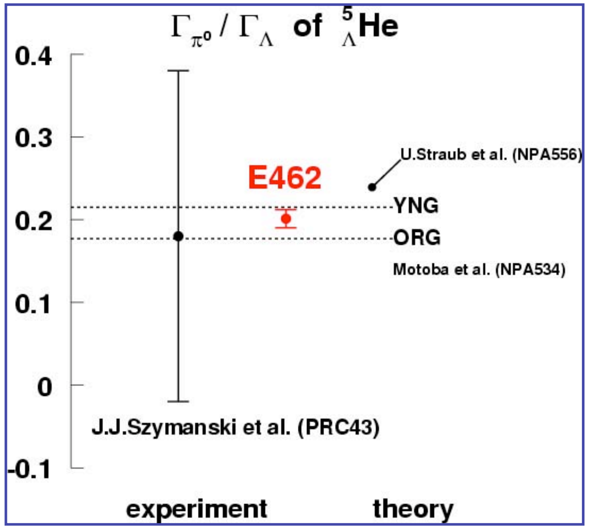
	${}^{5}_{\Lambda}$He	comment	${}^{12}_{\Lambda}$C	comment
t_{HY}	278^{+11}_{-10} (ps)	present	212^{+7}_{-6} (ps)	present
b_{π^-}	0.359 ± 0.009	present	0.099 ± 0.011 ± 0.004	Ref. [18]
b_{π^0}	**0.212 ± 0.008 ± 0.005**	present	**0.133 ± 0.005 ± 0.003**	present

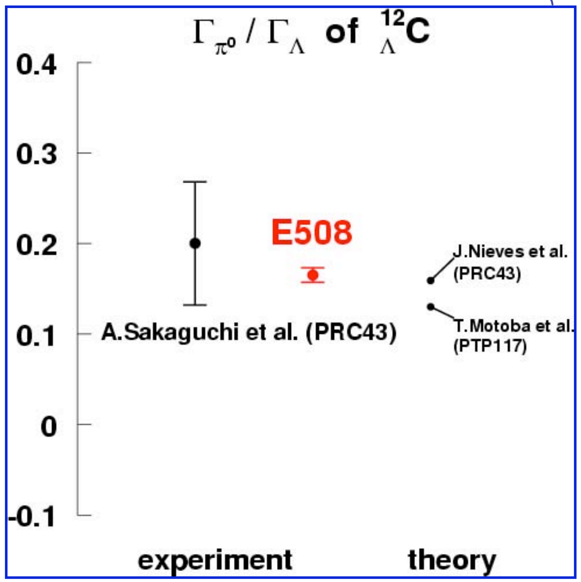
	${}^{5}_{\Lambda}$He	comment	${}^{12}_{\Lambda}$C	comment
$\Gamma_{tot}/\Gamma_{\Lambda}$	0.947 ± 0.037 ± 0.007	present	1.242 ± 0.041 ± 0.009	present
$\Gamma_{\pi^-}/\Gamma_{\Lambda}$	0.340 ± 0.016 ± 0.003	present	0.123 ± 0.014 ± 0.005	Ref. [18]
$\Gamma_{\pi^0}/\Gamma_{\Lambda}$	**0.201 ± 0.011 ± 0.005**	present	**0.165 ± 0.008 ± 0.004**	present
$\Gamma_{nm}/\Gamma_{\Lambda}$	**0.406 ± 0.020 ± 0.006**	present	**0.953 ± 0.032 ± 0.017**	present

π^- decay width for ${}^{5}_{\Lambda}$He



π^0 decay width for ${}^{5}_{\Lambda}$He and ${}^{12}_{\Lambda}$C





Statistical errors were much improved !!

E462 / E508 publication

- ***International conference***
  - ✓ ***PANIC02 : oral (invited)×1 , poster×2***
  - ✓ ***SENDAI03 : oral×6***
  - ✓ ***HYP2003 : oral (invited)×2, oral×3, poster×3***
- ***Doctor thesis***
  Japan×1
- ***Master thesis***
  Japan×4, Korea×2

- ***International conference***
  - ✓ ***INPC2004 : oral×1***
- ***Doctor thesis***
  Japan×2, Korea×3 (or 2)
- ***Refereed journals***
  Letter paper ×5, Full paper×1

To J-PARC

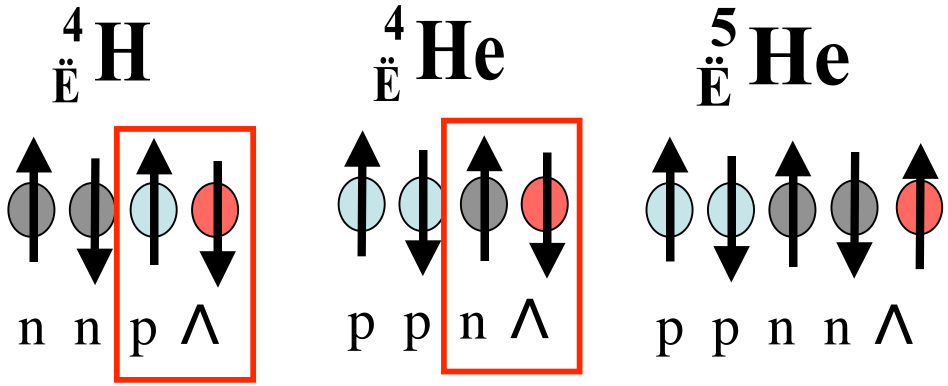
Non-mesonic weak decay of $^{4}_{\Lambda}$He and $^{4}_{\Lambda}$H

see S.Ajimura : J-PARC LOI 21

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 : Λn→nn, Λp→np
S : spin = 0 or 1



^{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