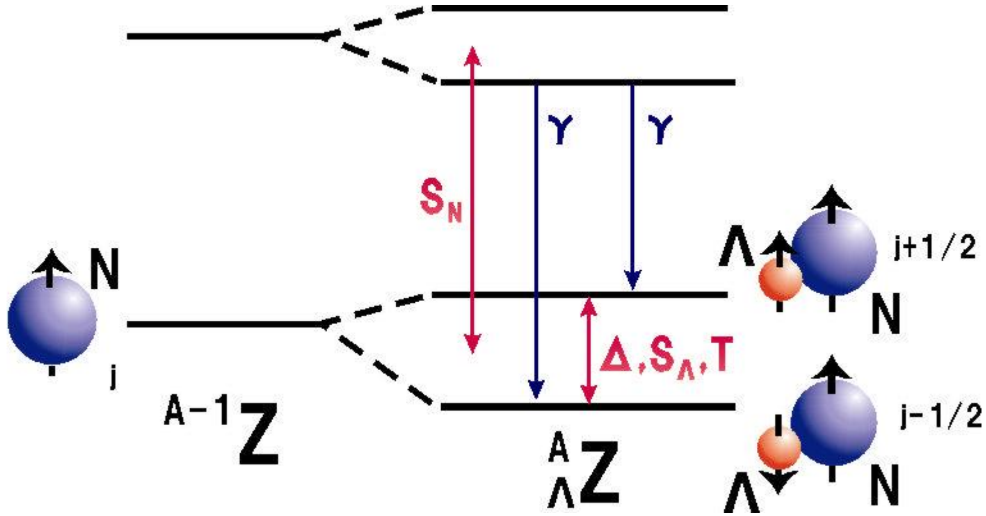
12th. Sep. 2003 D2-WS (Alghero)

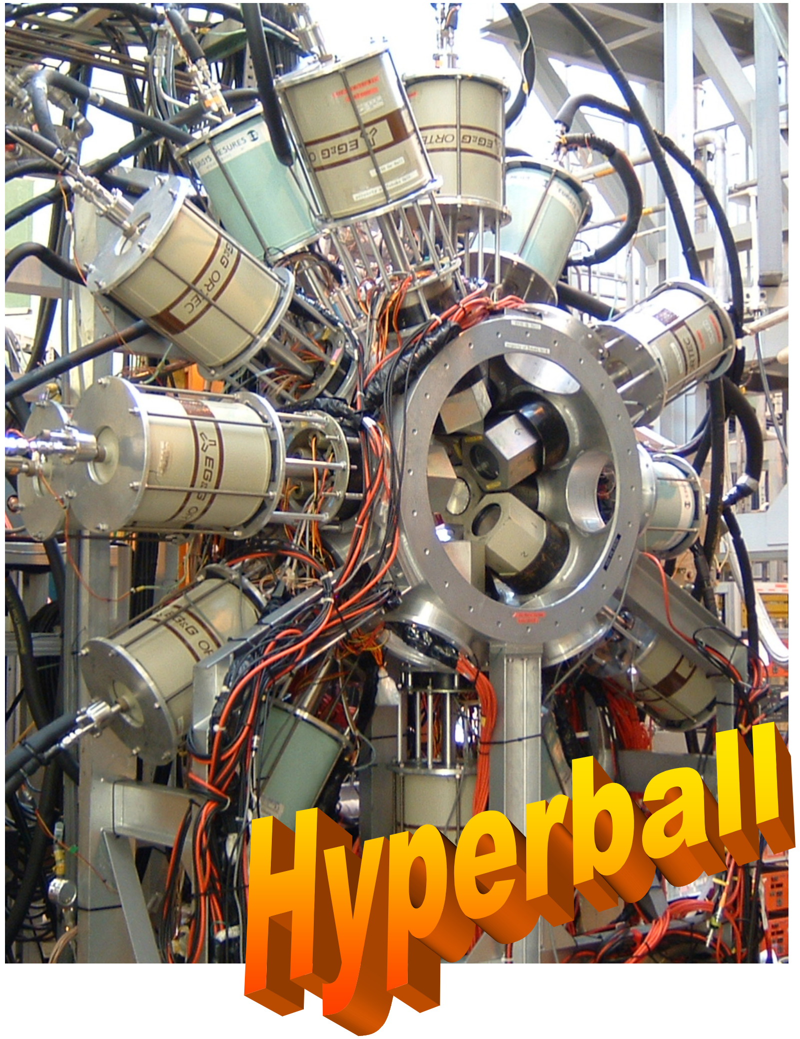
Latest results from KEK on Hypernuclear Physics and Perspective at J-PARC

- γ spectroscopy of $^{11}{}_{\Lambda}B$ (E518: 2002)
- n-rich hypernuclear production with $^{10}B(\pi^-,K^+)\,^{10}{}_{\Lambda}Li$ reaction (E521:2002-3)
- np/nn double coincidence detection from $^{5}{}_{\Lambda}He$ & $^{12}{}_{\Lambda}C$ (E462/508: 2000-2002)
- Proposed experiments at J-PARC

H.Outa (RIKEN)

γ spectroscopy of $^{11}_{\Lambda}B$ (E518: 2002)





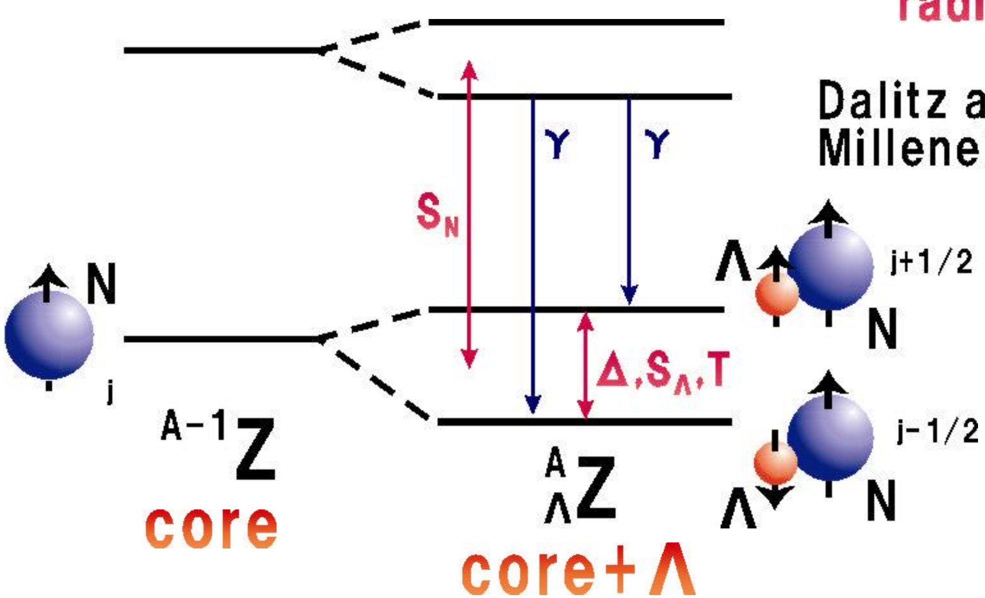
ΛN effective interaction

Spin-dependent forces of p-shell hypernuclei

$$V(r) = V_0(r) + \underbrace{V_\sigma(r)\,\vec{s}_N \cdot \vec{s}_\Lambda}_{\Delta} + \underbrace{V_N(r)\,\vec{l}_{N\Lambda} \cdot \vec{s}_N}_{S_N} + \underbrace{V_\Lambda(r)\,\vec{l}_{N\Lambda} \cdot \vec{s}_\Lambda}_{S_\Lambda} + \underbrace{V_T(r)\,S_{12}}_{T}$$

radial integral for p_N s_Λ wave function

Dalitz and Gal, Ann. Phys. 116 (1978) 167
Millener et al., Phys. Rev. C31 (1985) 499



Splitting ~100 keV

Only Ge can separate this fine structure

Present status of the experiments with Hyperball

- $(\pi^+, K^+\gamma)$

  $^{7}_{\Lambda}Li$ (KEK-PS E419,1998) Δ, S_N, B (E2)

  H.Tamura, et.al., Phys. Rev. Lett. 84 (2000) 5963

  K. Tanida, et.al., Phys. Rev. Lett. 86 (2001) 1982

  $^{11}_{\Lambda}B$ (KEK-PS E518,2002) B (M1)

- $(K^-, \pi^-\gamma)$ Large cross section

  $^{9}_{\Lambda}Be$ (BNL-AGS E930,1998) S_Λ

  H.Akikawa, et.al., Phys. Rev. Lett. 88 (2002) 082501

  $^{16}_{\Lambda}O$, $^{10}_{\Lambda}B$ (BNL-AGS E930, 2001) T

- (stopped K^-, γ)

  Hyperfragments from

  ^{7}Li, ^{9}Be, ^{10}B, ^{11}B, ^{12}C target (KEK-PS E509,2002)

Structure of $^{11}_{\Lambda}B$

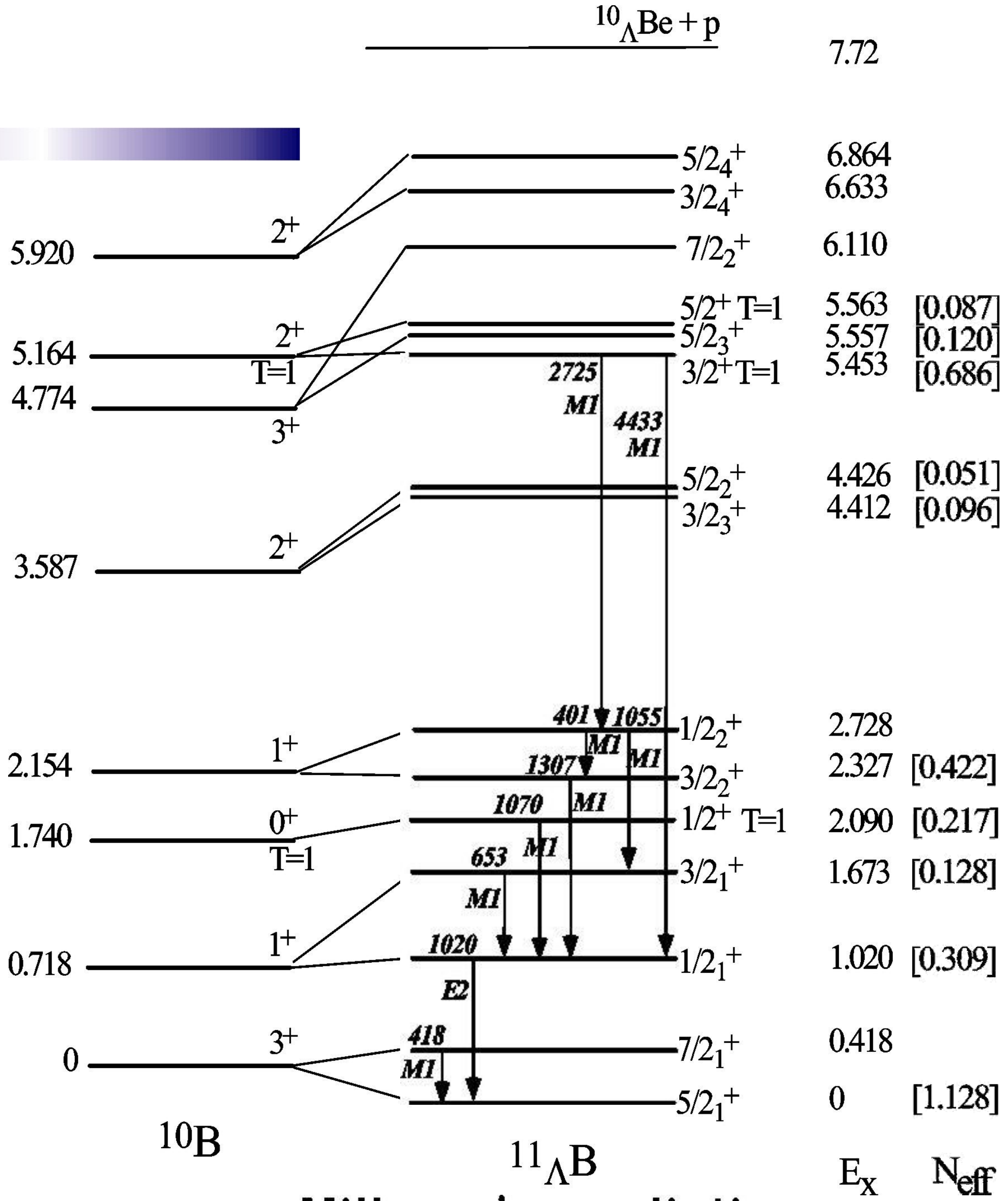
Many bound states exist

- $^{11}_{\Lambda}B\,(3/2^{+} \rightarrow 1/2^{+})$

B (M1) can be measured

- $^{11}_{\Lambda}B\,(1/2^{+} \rightarrow 5/2^{+})$

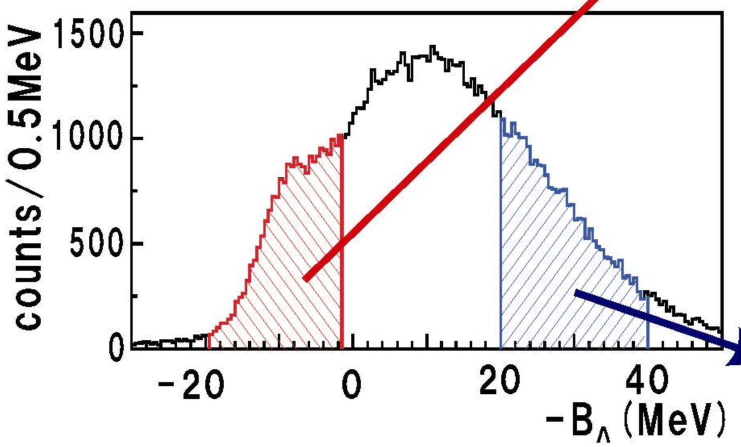
largest yield

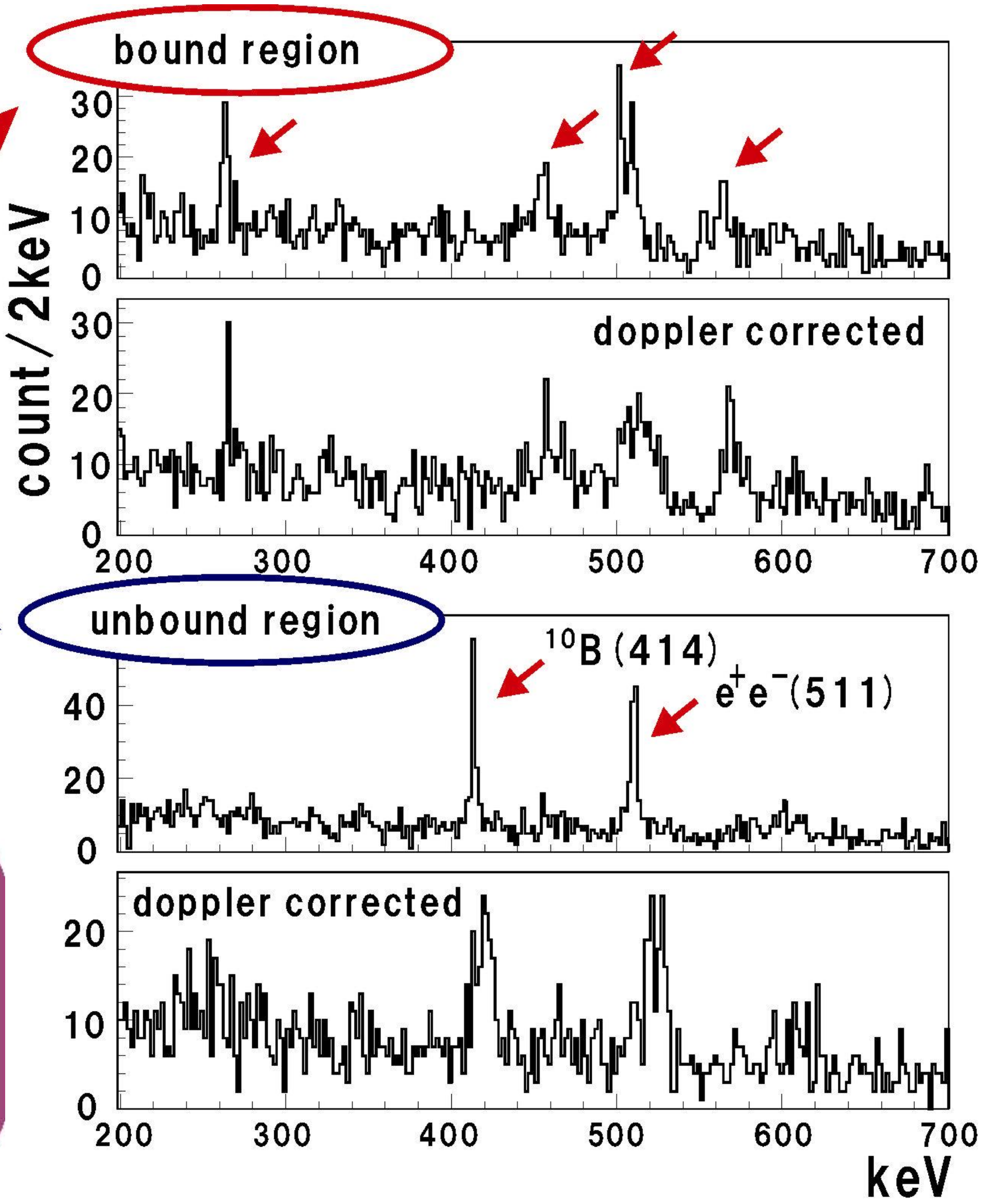


Millener's prediction

γ-spectrum of ${}^{11}_{\Lambda}\mathrm{B}$

10cm and 6cm target



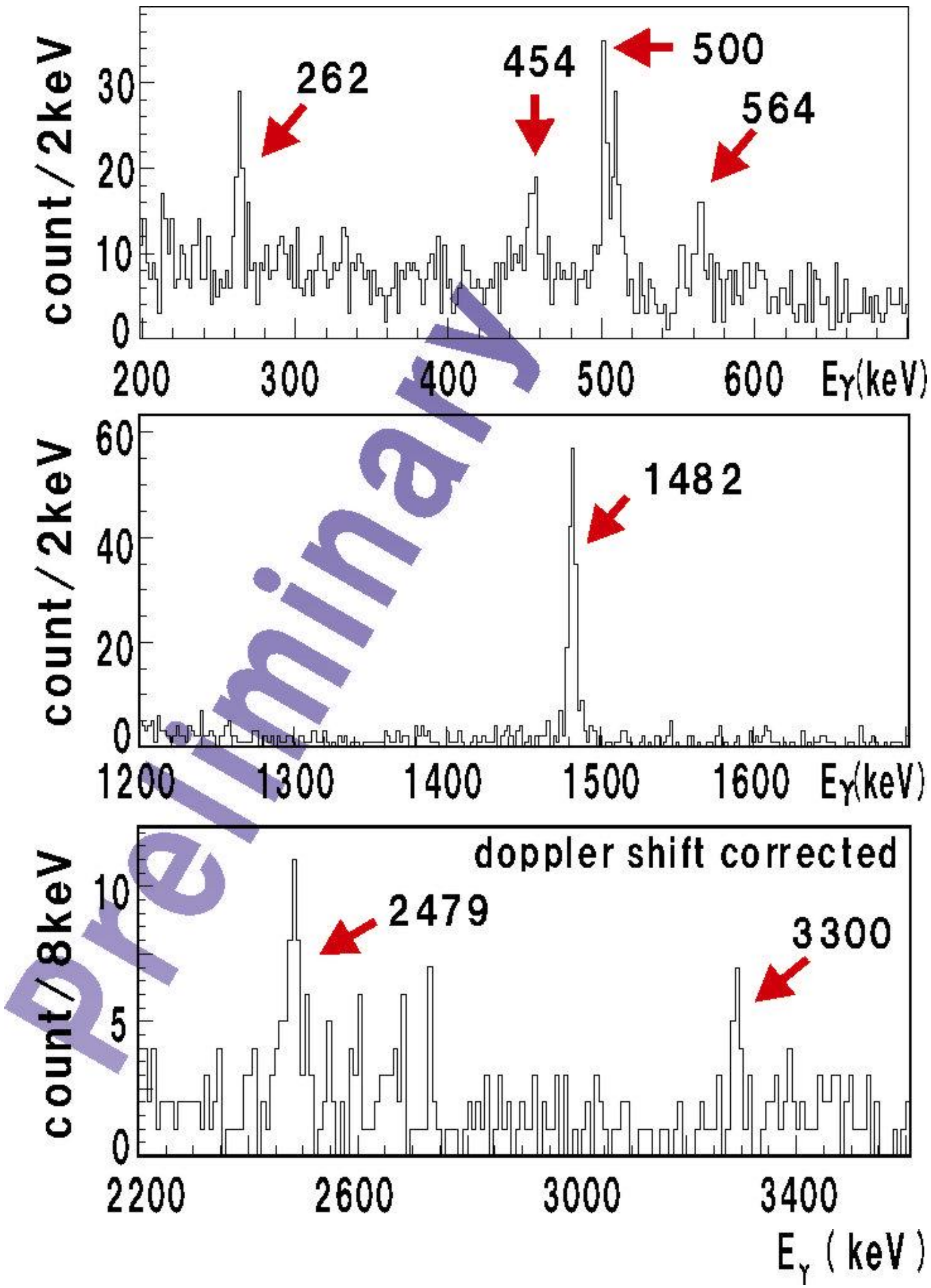


thick target → bad resolution

Total amount of irradiation
(one month)

10cm target : $0.85 \times 10^{12} \pi^{+}$

6cm target : $0.75 \times 10^{12} \pi^{+}$



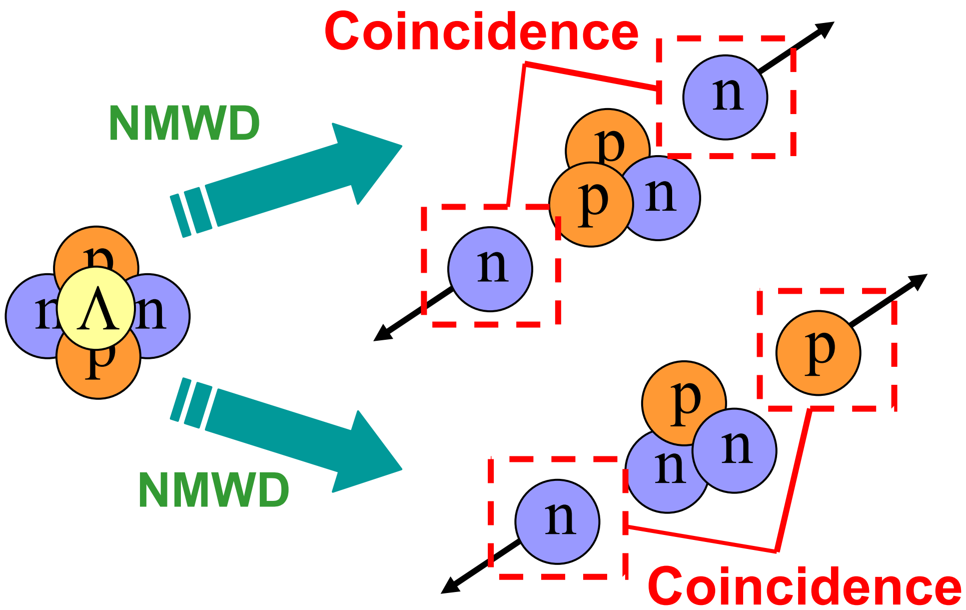
Observed γ-rays from $^{11}_{\Lambda}B$

Eγ(keV)	number of events	relative intensity
262	71	0.14
454	54	0.13
500	50	0.13
564	78	0.21
1482	203	1.00
2479	45	0.37
3286	10	0.10

relative intensity =

$$\frac{[\#event]}{203} \cdot \frac{[\text{efficiency of Ge}]}{[\text{efficiency@1482keV}]}$$

np/nn double coincidence detection from $^{5}_{\Lambda}$He & $^{12}_{\Lambda}$C (E462/508: 2000-2002)



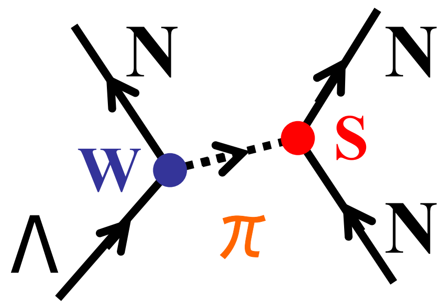
Motivation

Γ_p (Λ+"p"→ n + p)
Γ_n (Λ+"n"→ n + n)

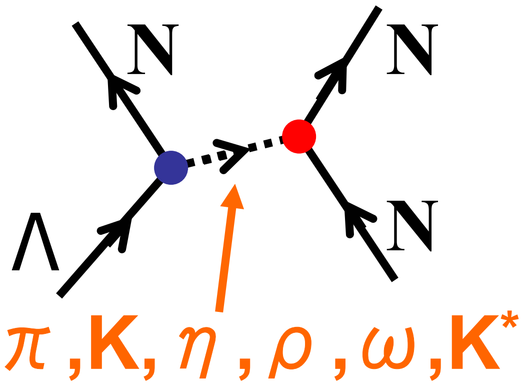
Γ_n / Γ_p ratio (theoretical & experimental results)

Theoretical

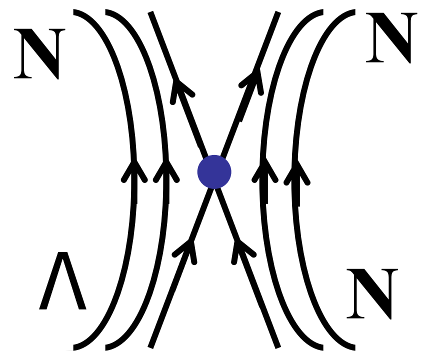
One Pion Exchange (OPE)

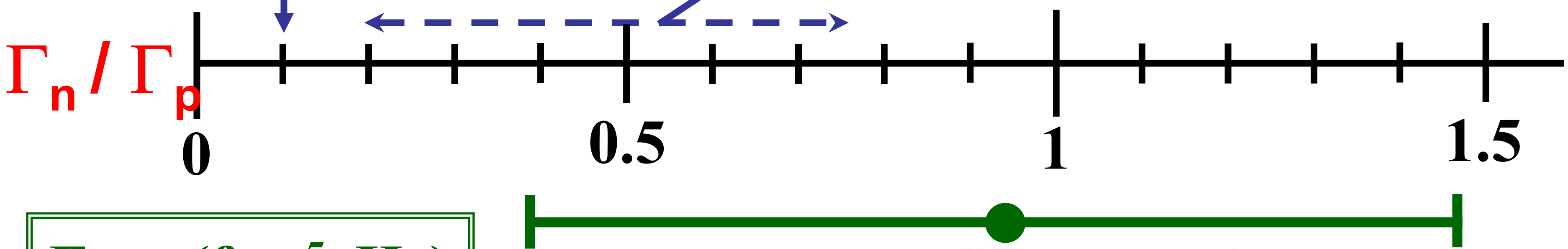


Meson Exchange mechanism



Direct Quark mechanism





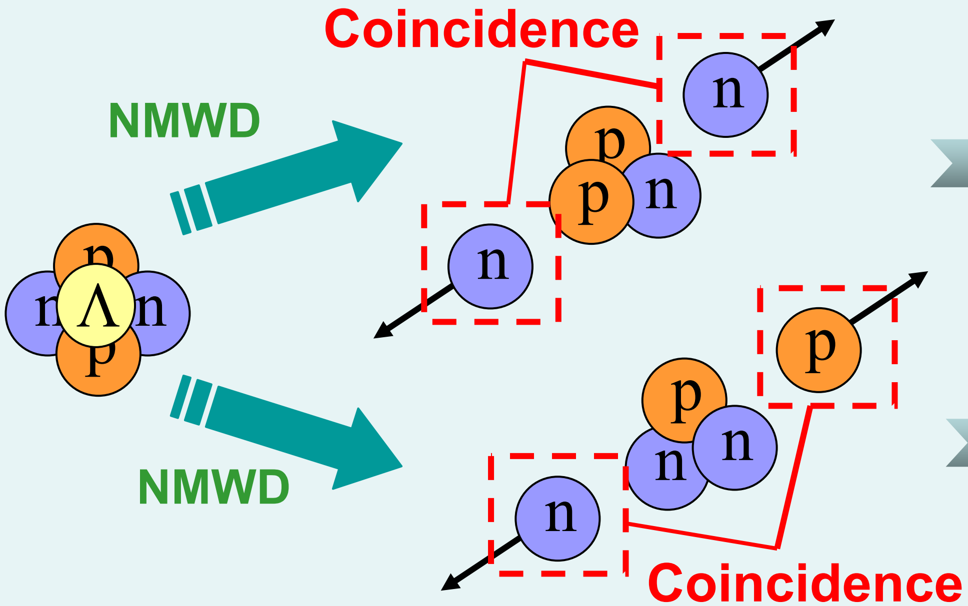
Exp. (for $^5_\Lambda He$)

0.93 ± 0.55 (Szymanski et al.)

Coincidence analysis

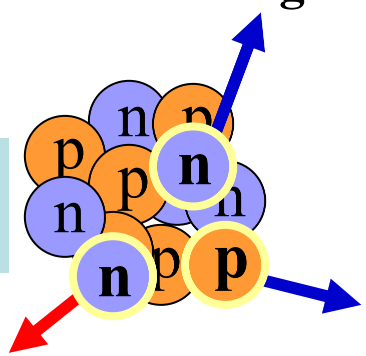
E462($^{5}_{\Lambda}$He) / E508($^{12}_{\Lambda}$C)

NMWD : $\Lambda N \rightarrow NN$



1) **Angular correlation**
(back-to-back, $\cos\theta < -0.8$)
2) **Energy correlation**
(Q～E(N1)+E(N2) ～152MeV)

Final state interaction (FSI)



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

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

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

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

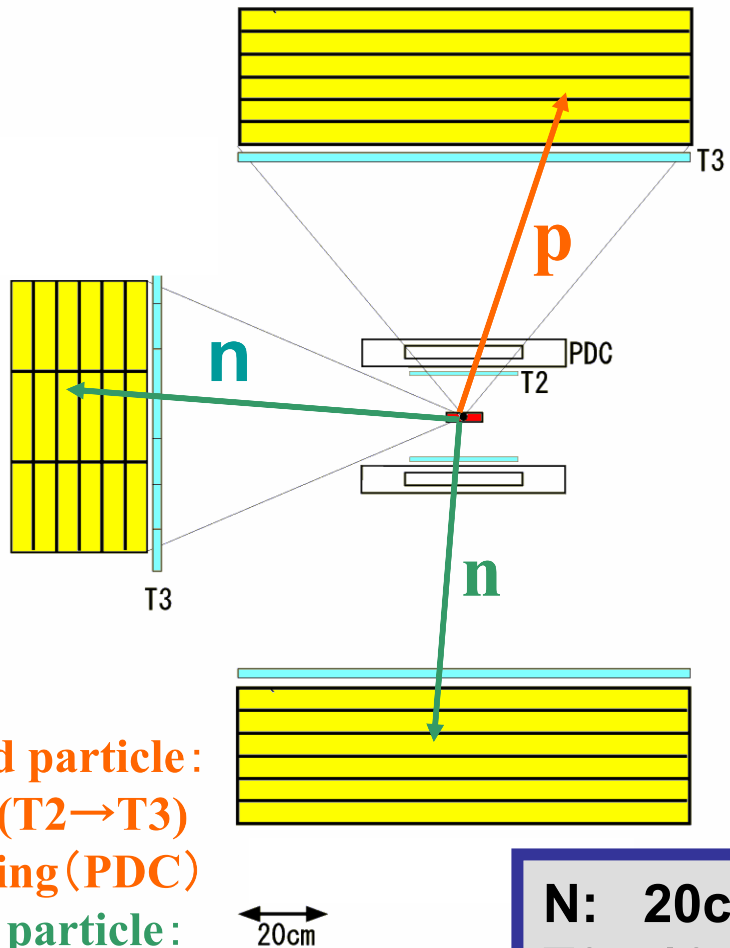
Select $\Lambda N \rightarrow NN$ events without $\Lambda NN \rightarrow NNN$ & FSI effect

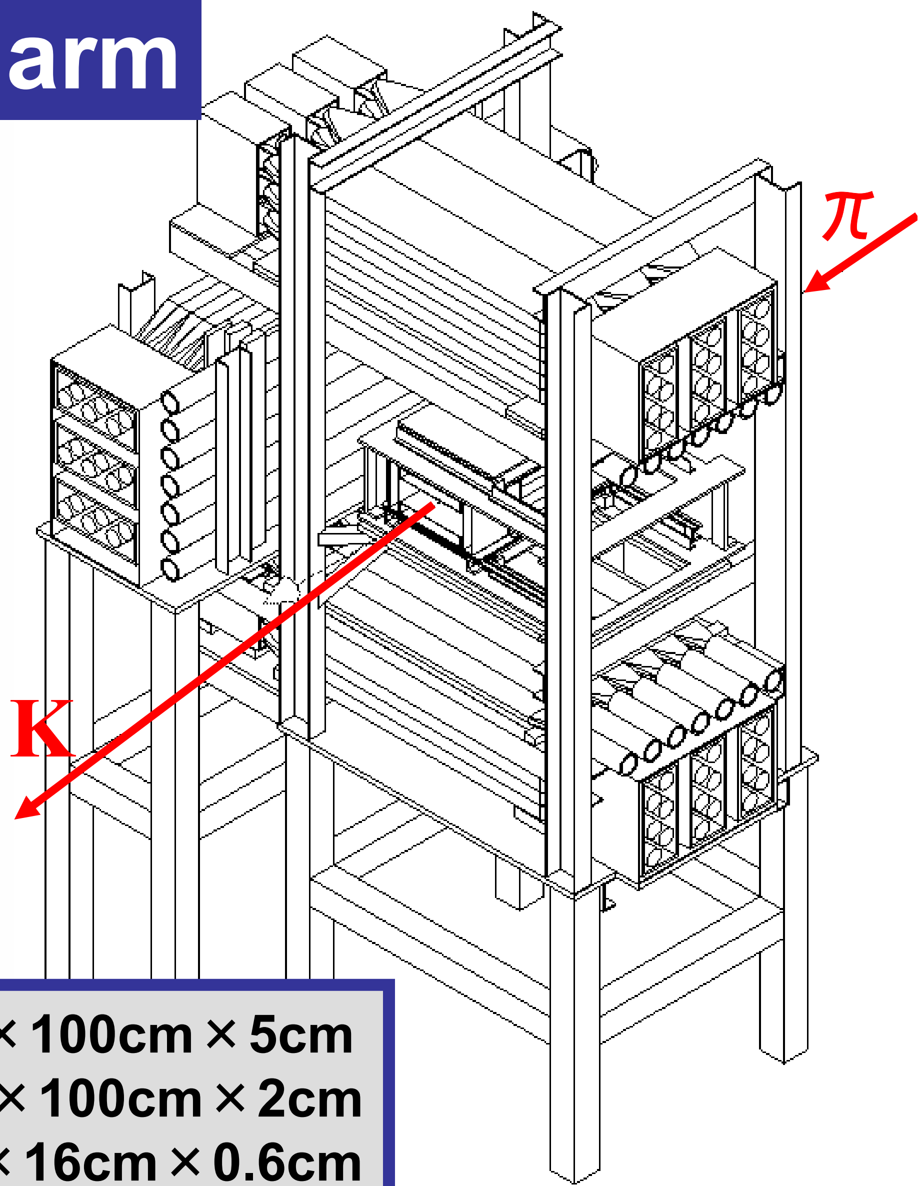
Setup (E462)

(KEK-PS K6 beamline & SKS)

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

Decay arm





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

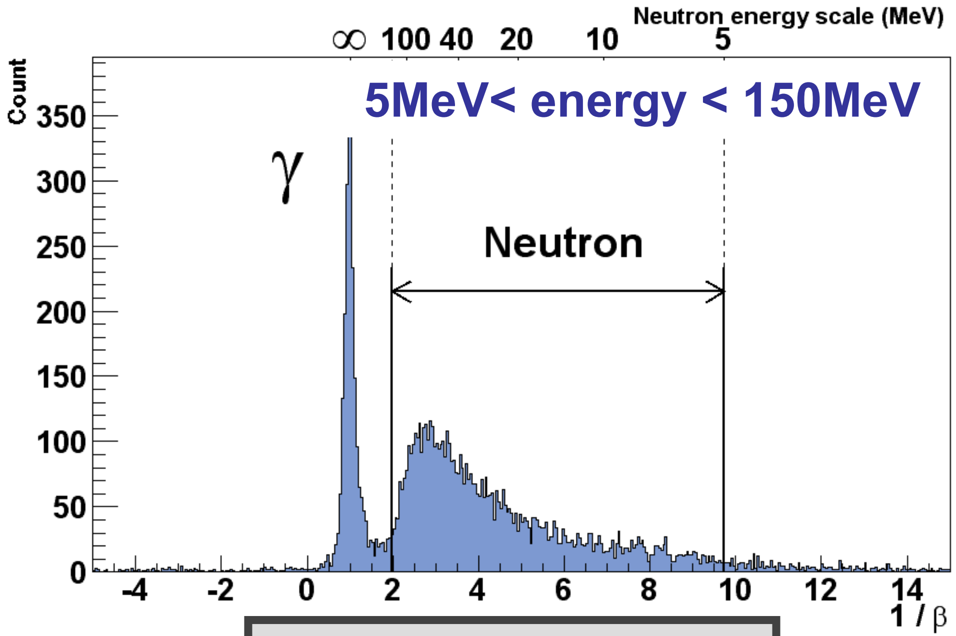
Neutral particle:
- TOF (target→NT)
- T2/T3 VETO

N: 20cm × 100cm × 5cm
T3: 10cm × 100cm × 2cm
T2: 4cm × 16cm × 0.6cm

Particle identification

Neutral particle

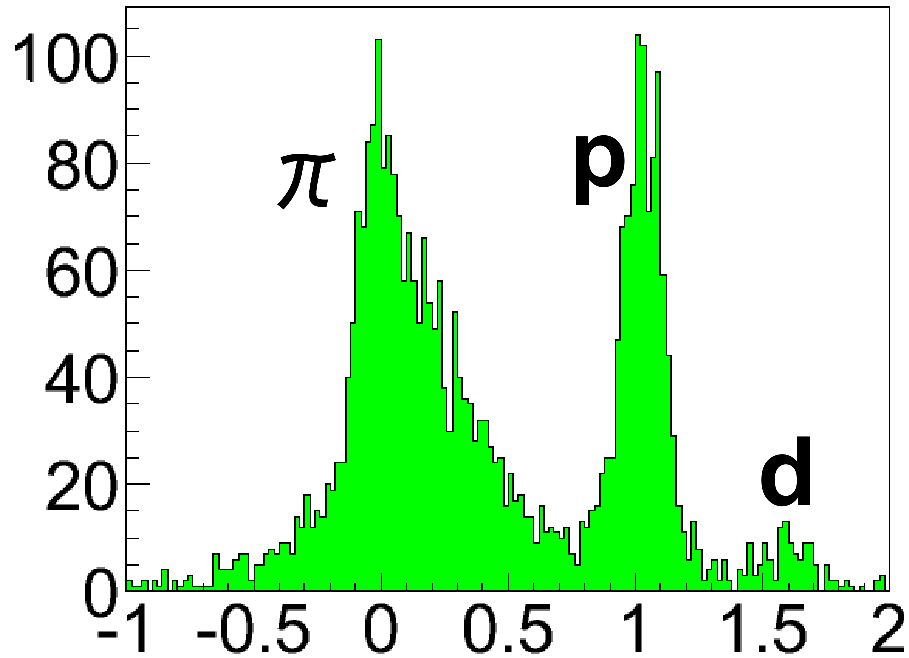
1 / β spectra



Energy resolution
$\sigma \sim$ 8MeV
(around 80MeV)

gated $^{12}_{\Lambda}$C ground state

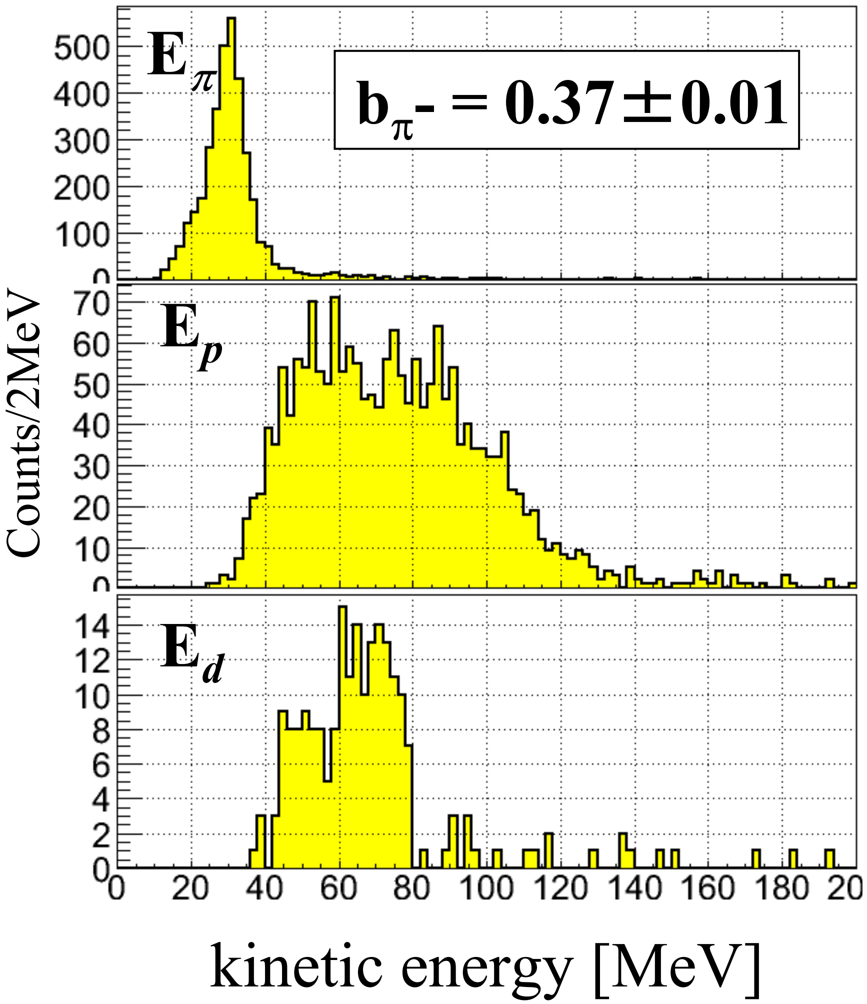
Charged particle



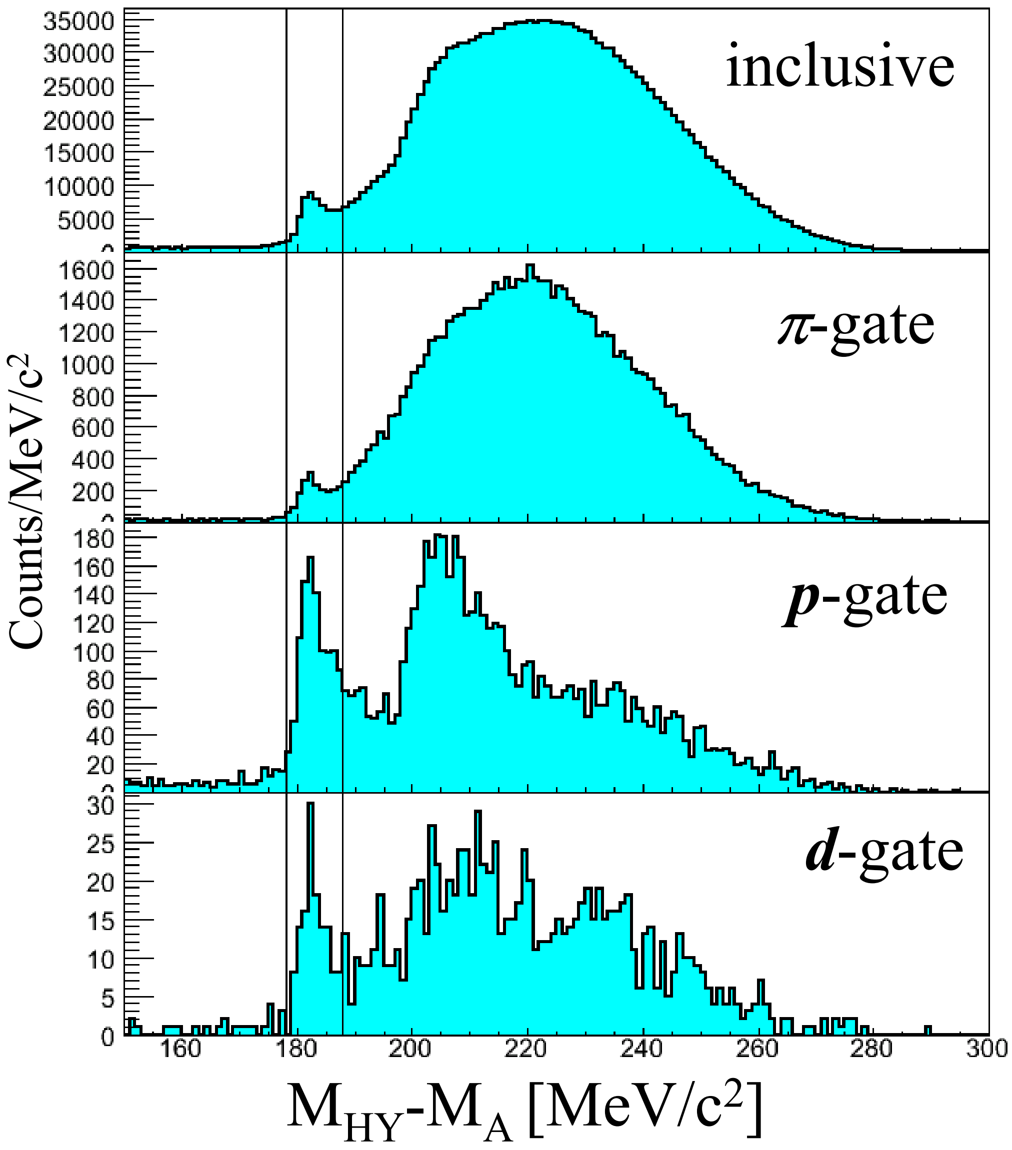
PID1 : total energy vs dE/dx
PID2 : total energy vs TOF
→ (PID1+PID2) / 2

gated $^{5}_{\Lambda}$He ground state

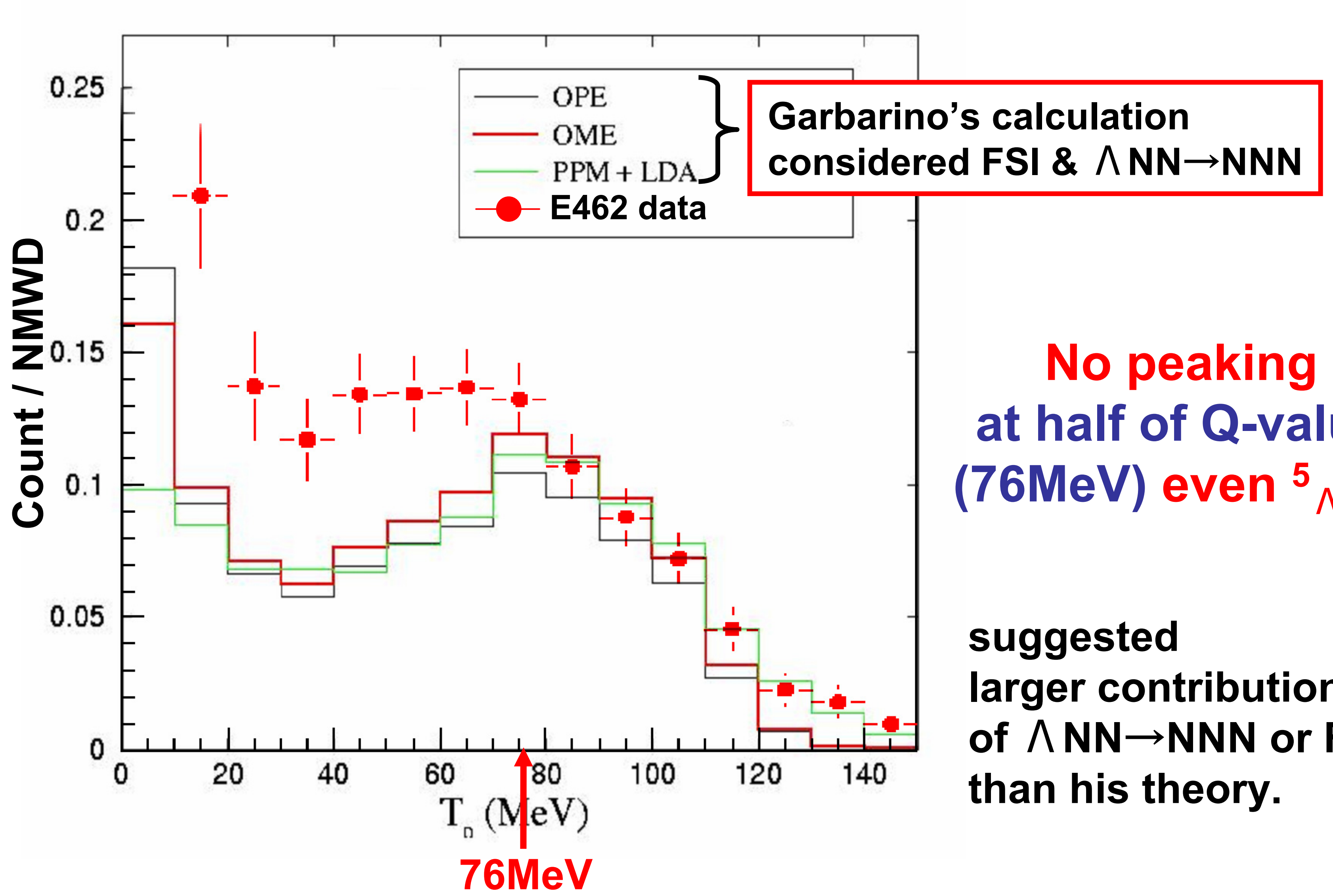
Energy spectra of $\pi/p/d$ from the decay of $^5_\Lambda He$



$^6Li(\pi^+, K^+)$ excitation spectra



Neutron energy spectra of $^5{}_\Lambda He$



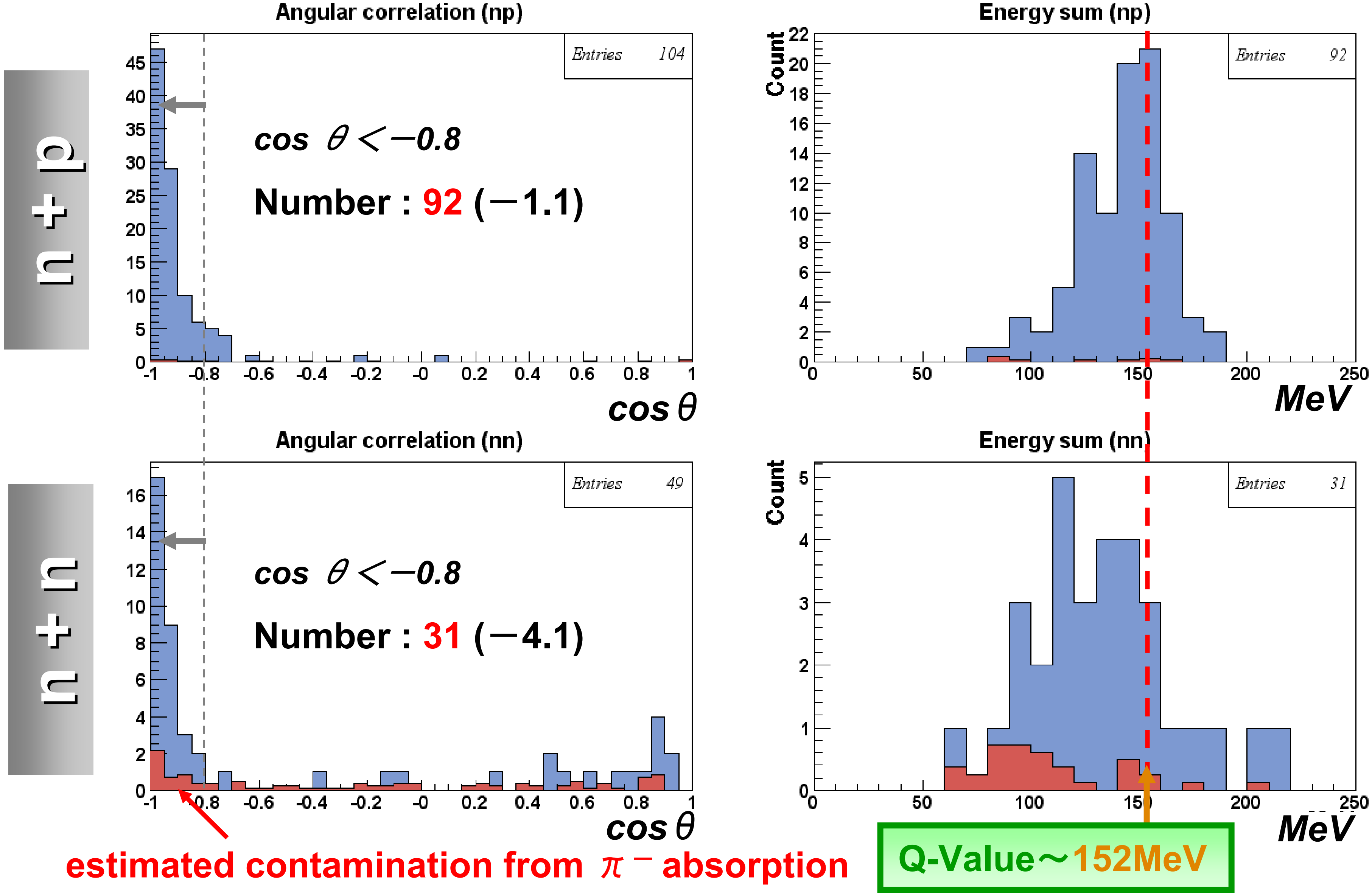
No peaking at half of Q-value (76MeV) even $^5{}_\Lambda He$

suggested larger contribution of Λ NN→NNN or FSI than his theory.

coincidence analysis for $^5_\Lambda He$

Angular correlation

energy sum

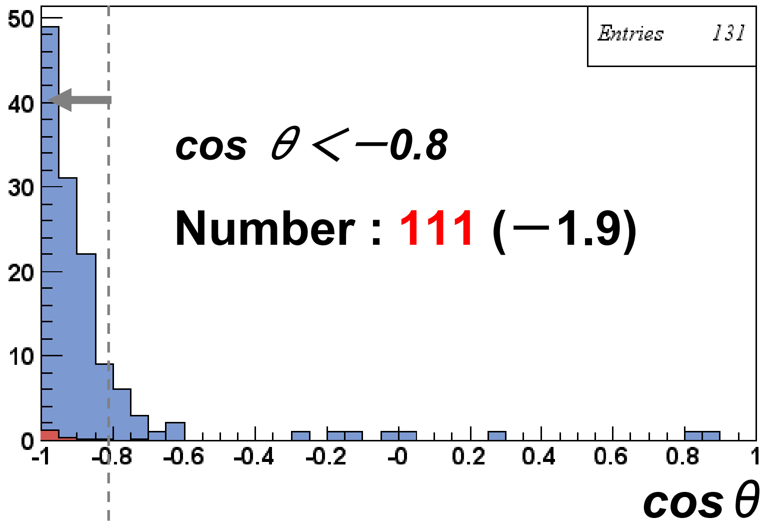


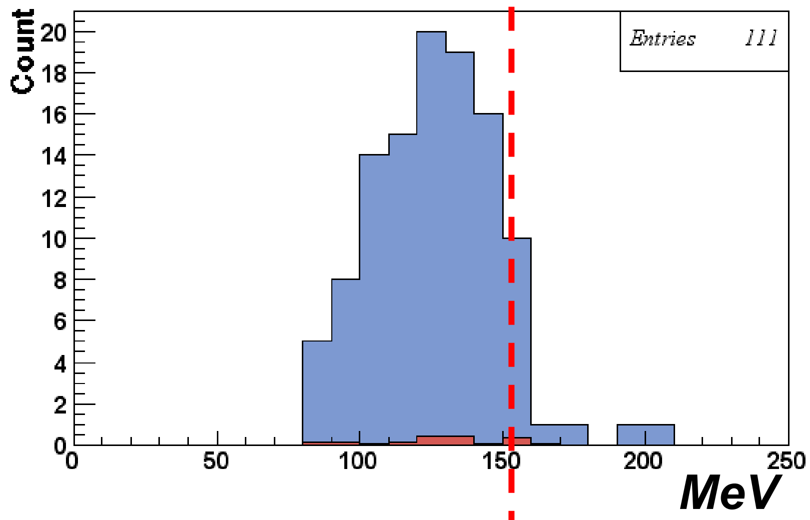
coincidence analysis for $^{12}_{\Lambda}C$

Angular correlation

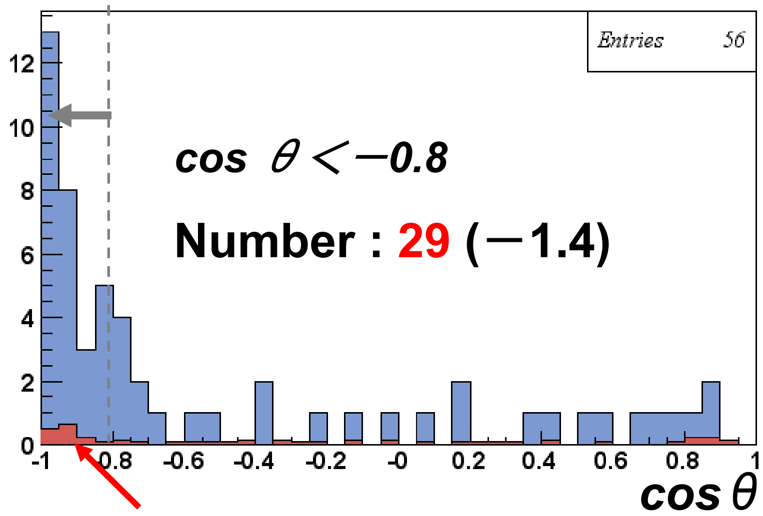
energy sum

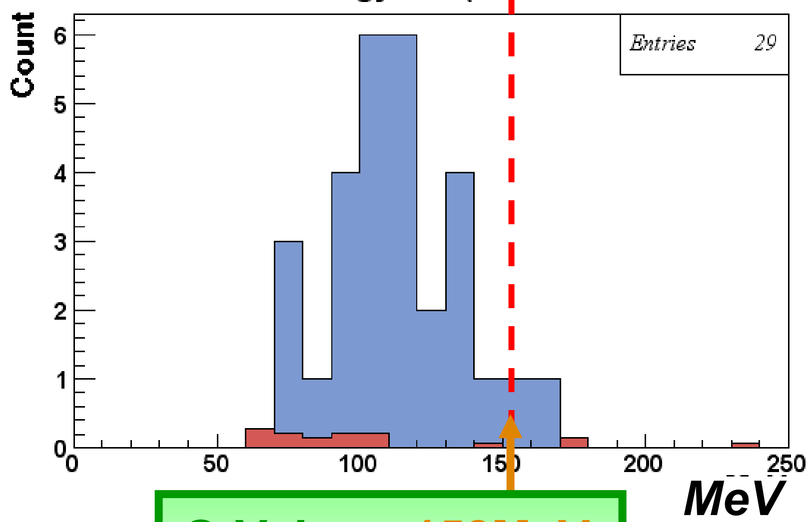
n + p





n + n





estimated contamination from π^- absorption

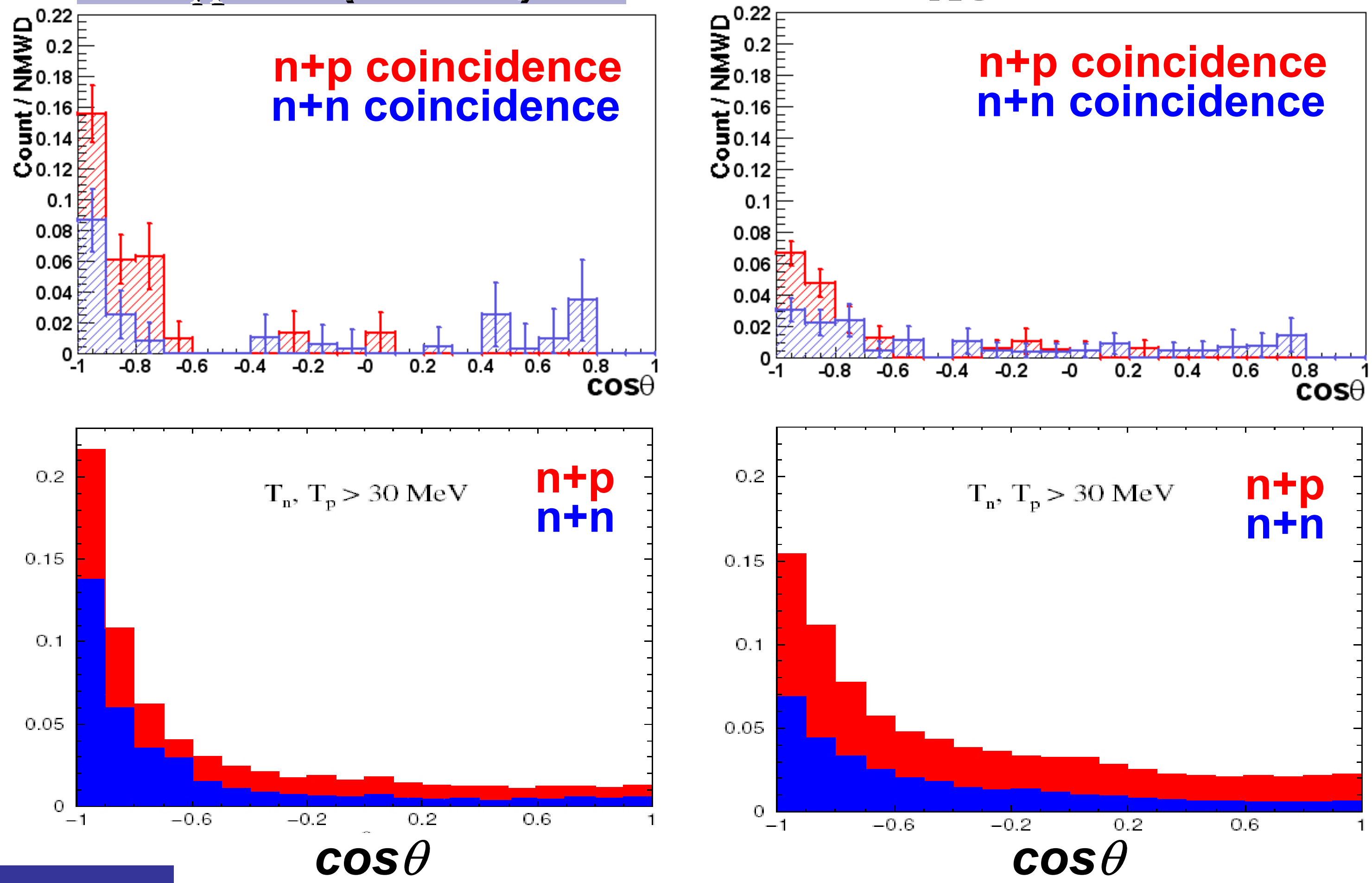
Q-Value～152MeV

Comparison with theoretical calc. for angular correlation

$^{5}_{\Lambda}$He (E462) | **$^{12}_{\Lambda}$C (E508)**

experimental data

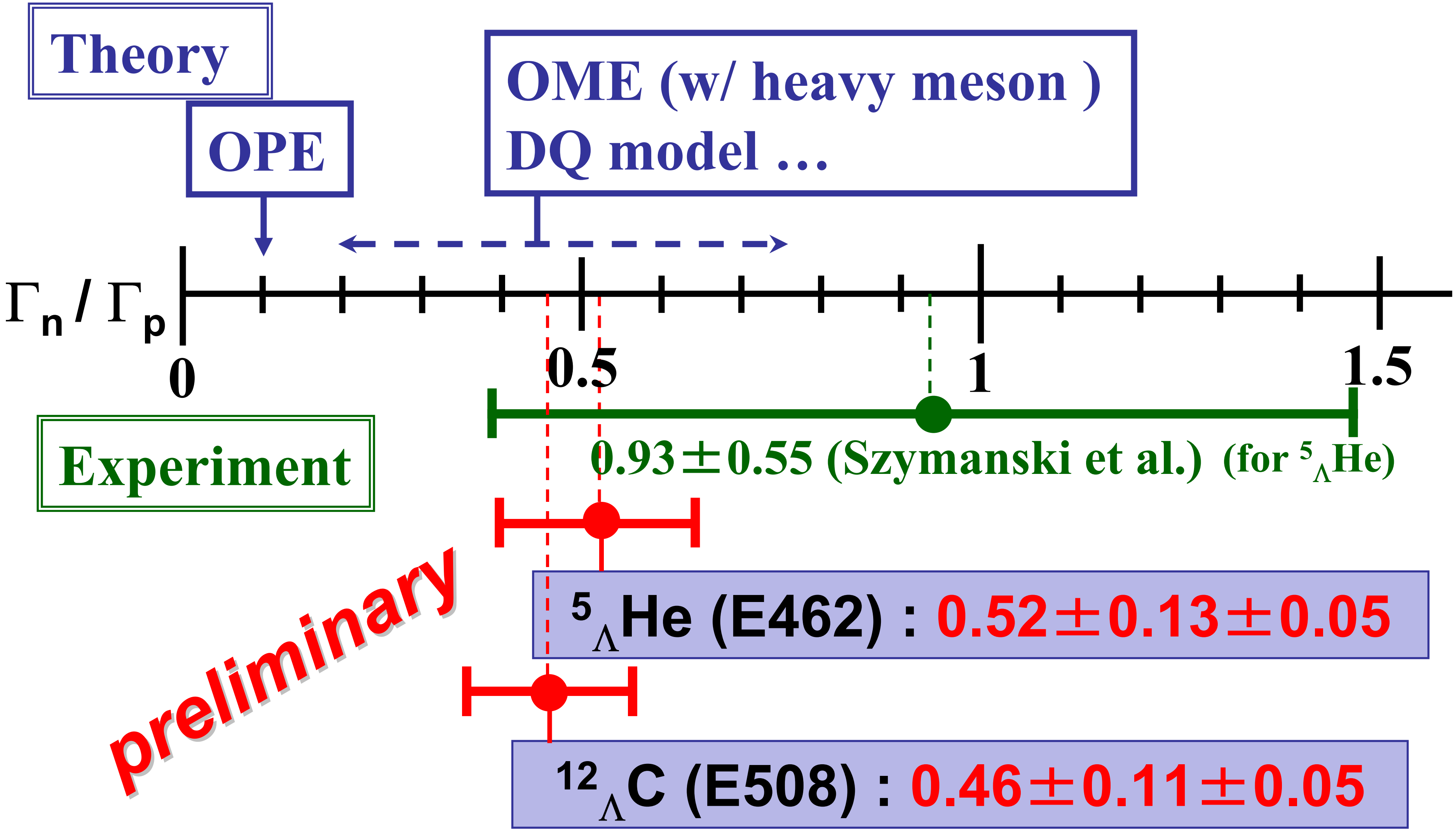
theoretical calc.



Garbarino's calc.

assuming Gn/Gp = 0.46 (for $^{5}_{\Lambda}$He), 0.34 (for $^{12}_{\Lambda}$C)
considered 2N-induced(～20%), FSI

Results of Γn / Γp



systematic error :
neutron efficiency(8%) + proton (6%)

Summary

- ***A-dependence of neutron energy spectra (for A=5,12,89)***

  … No peak at half of Q-value even A=5.

- Γ_n / Γ_p **ratio**

  $^{5}_{\Lambda}$**He (E462) ～ 0.52±0.13±0.05** (*preliminary*)

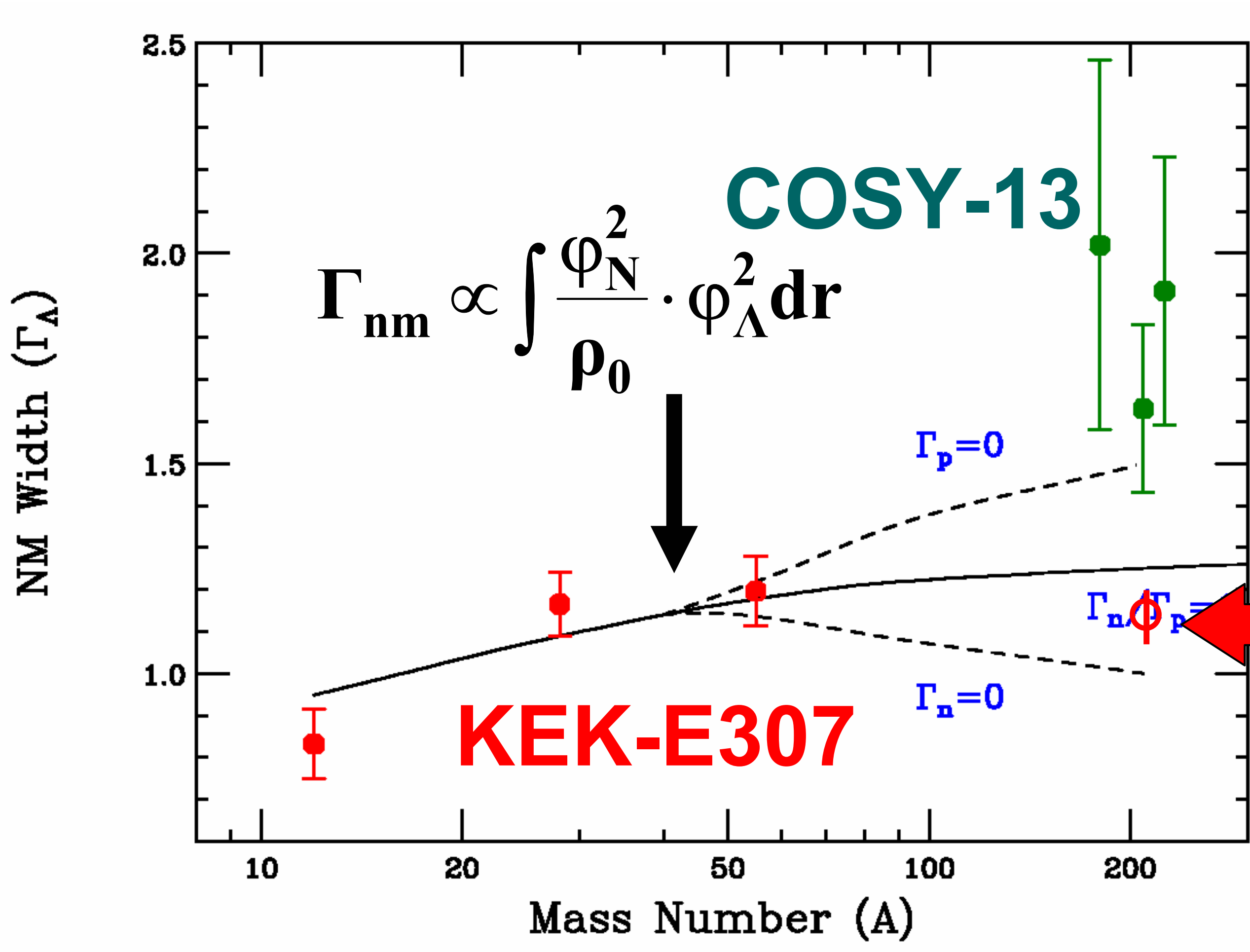
  $^{12}_{\Lambda}$**C (E508) ～ 0.46±0.11±0.05** (*preliminary*)

- ***Angular & Energy correlation***

  → Number (/NMWD) of back-to-back component is smaller than Garbarino's calculation.

Experiments at J-PARC (Decay)

1. Lifetime of heavy hypernuclei ? (J-PARC)

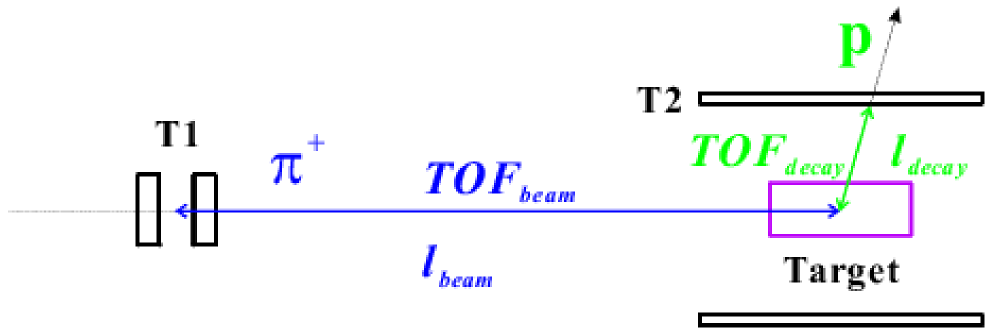


(π,K)反応
K1.1BR

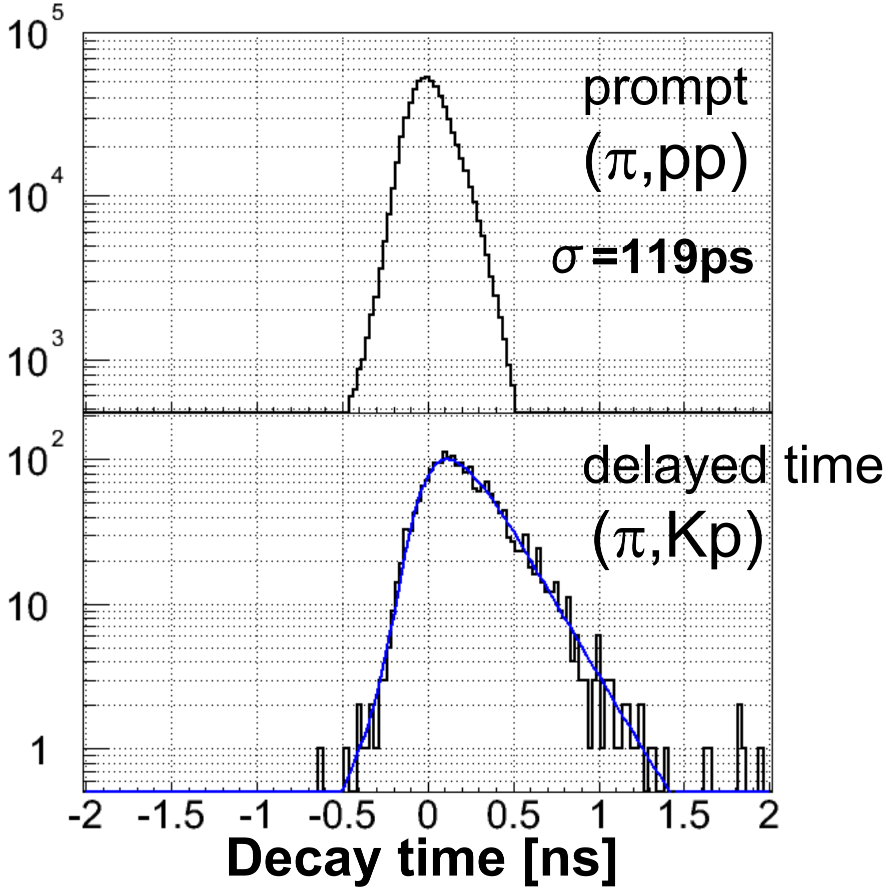
?

Lifetime analysis

$$\Delta t = t_{T2} - \mathrm{TOF}_p - \mathrm{TOF}_\pi - t_{T1}$$
$$= t_{T2} - \frac{l_p}{\beta_p c} - \frac{l_\pi}{\beta_\pi c} - t_{T1}$$



$^{12}_{\Lambda}$C



preliminary

τ = 212 ± 6 ps

(statistical only)

cf. <KEK-E307>

τ = 230 ± 15 ps

(Park *et al.*)

2. NMWD of $^4_\Lambda$He and $^4_\Lambda$H

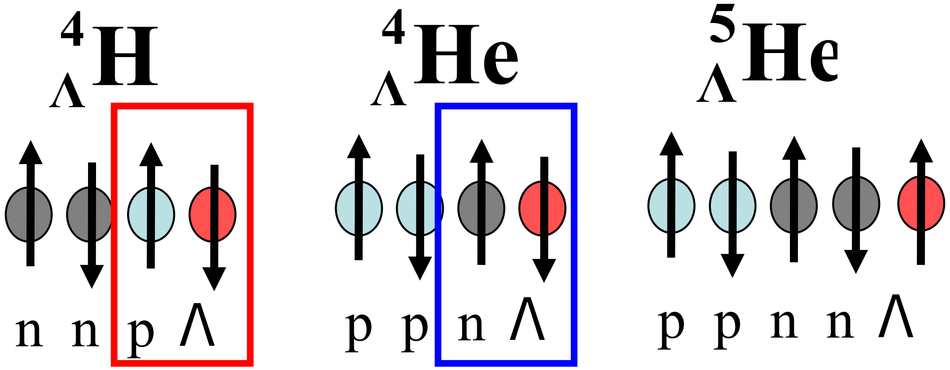
- Test of $\Delta I = 1/2$ rule
- Spin/isospin dependence

R_{NS} N Λp→np Λn→nn
S Spin=0/1

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

$^4He(K^-, \pi^0)^4_\Lambda H$
$^4He(K^-, \pi^-)^4_\Lambda He$

$$R_{n0} \equiv 2R_{p0}\ ?\ \left[\Delta I = 1/2 \text{rule}\right]$$
$$\Leftrightarrow \quad \Gamma_p({}^4_\Lambda H) = 2\Gamma_n({}^4_\Lambda He)??$$



Ratio of
Γ(Λn→nn)
for $^4_\Lambda$He and
Γ(Λp→np)
for $^4_\Lambda$H

Required ${}^{4}_{\Lambda}He$ / ${}^{4}_{\Lambda}H$ numbers

Estimation from E462 statistics….

${}^{5}_{\Lambda}He$ 55K → n+p back-to-back～170

To achieve same statistics….

${}^{4}_{\Lambda}H$ 55K × 3 × 2 × 5 × 1/3 ～500K

- 3: NMWD Br.
- 2: p/n ratio
- 5: Spin triplet/singlet
- 1/3: Decay arm upgrade

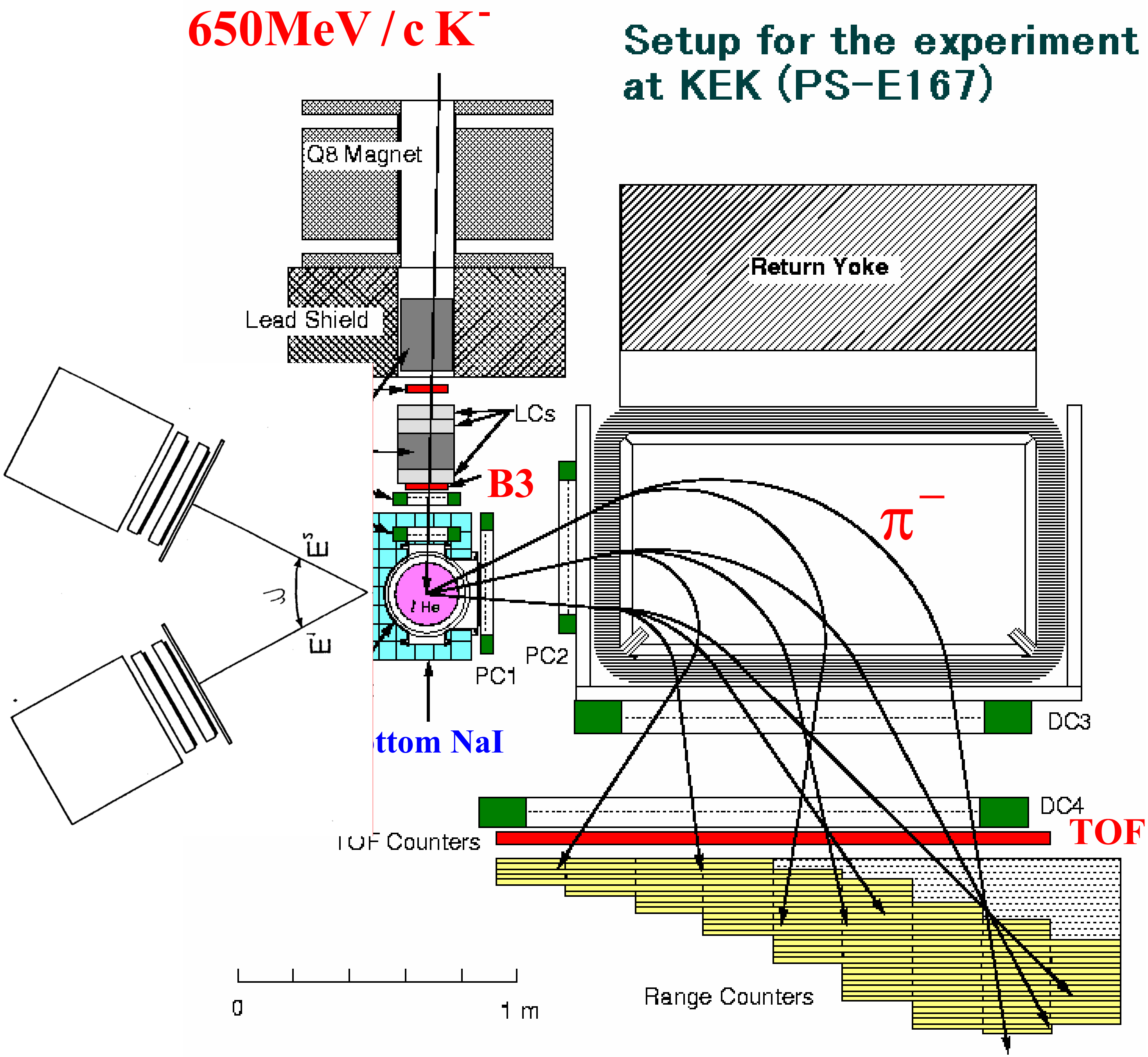
20,000 ${}^{4}_{\Lambda}H$ In one day

1 × 0.6 × 0.3m@60cm

↓

1.5 × 1.5 × 0.4m@90cn

Setup for the experiment at KEK (PS-E167)



${}^{4}_{\Lambda}H$ production rate

K1.1/K1.1BR; 600MeV/c K-

0.5×10^6 K-/sec

⇓ **10% stop**

50×10^3/sec stopped K- on ^4He

⇓ **${}^{4}_{\Lambda}H$ branch～0.9%**

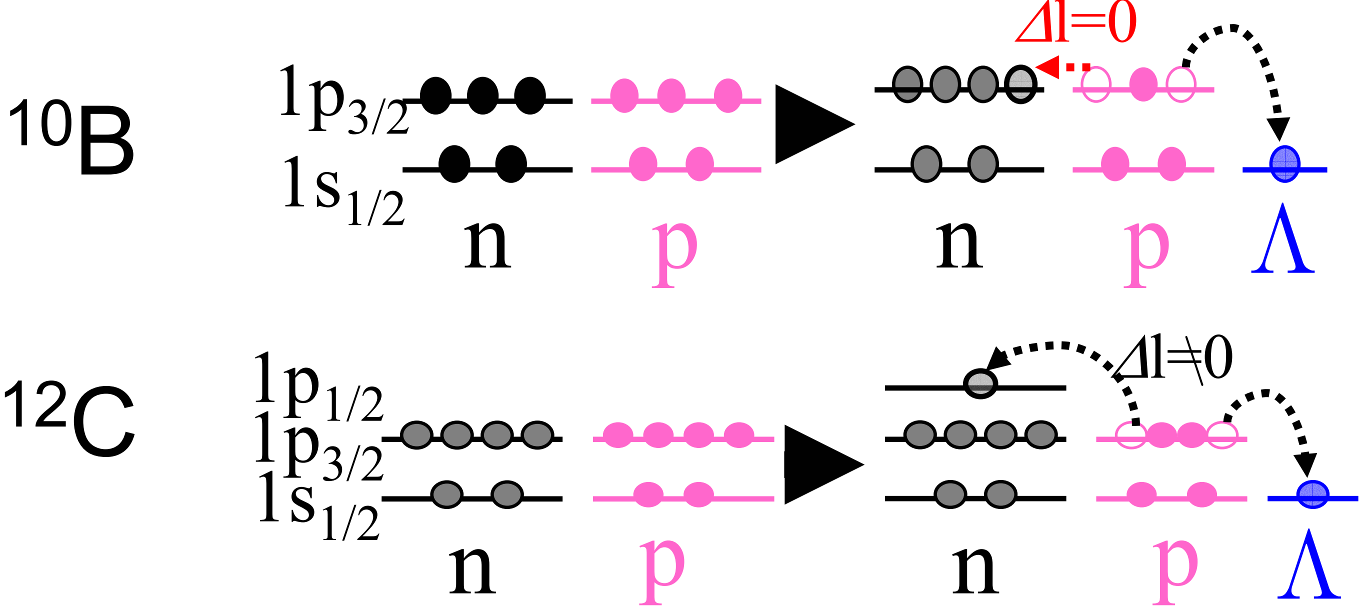
450/sec ${}^{4}_{\Lambda}H$ formation

⇓

0.35/sec ${}^{4}_{\Lambda}H$ detection OK !?

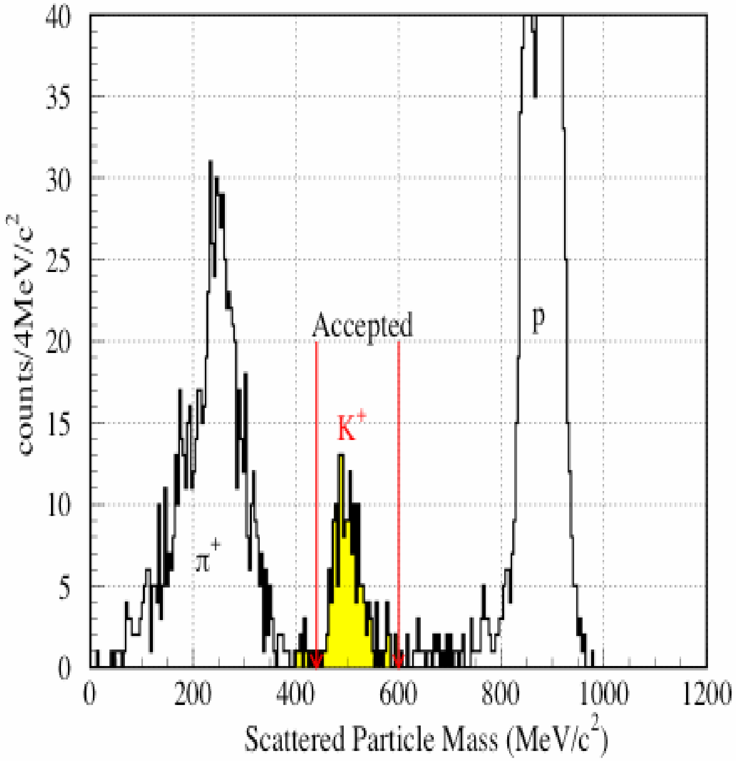
Spare OHPs

n-rich hypernuclear production with $^{10}B(\pi^-,K^+)\,^{10}_{\Lambda}Li$ reaction (E521:2002-3)

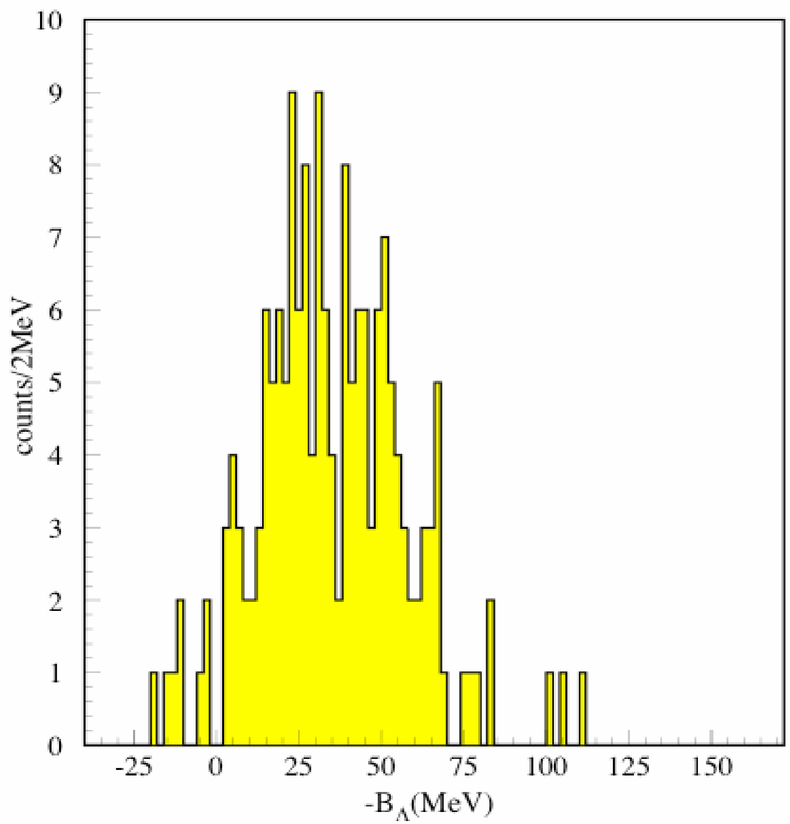


target	reaction	Beam [GeV/c]	SKS [A]	Injection π [Gπ]	
				2002	2003
^{10}B	(π^-, K^+)	1.05	272	440	
^{10}B	(π^-, K^+)	1.2	395	460	716

$^{10}B(\pi^-,K^+)$ 1.05GeV/c

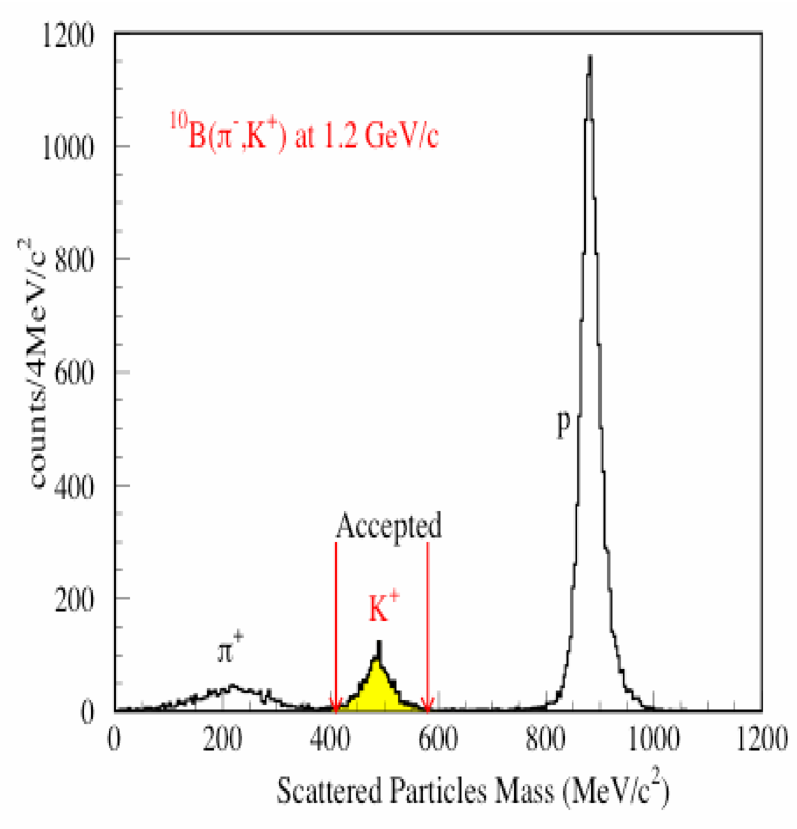


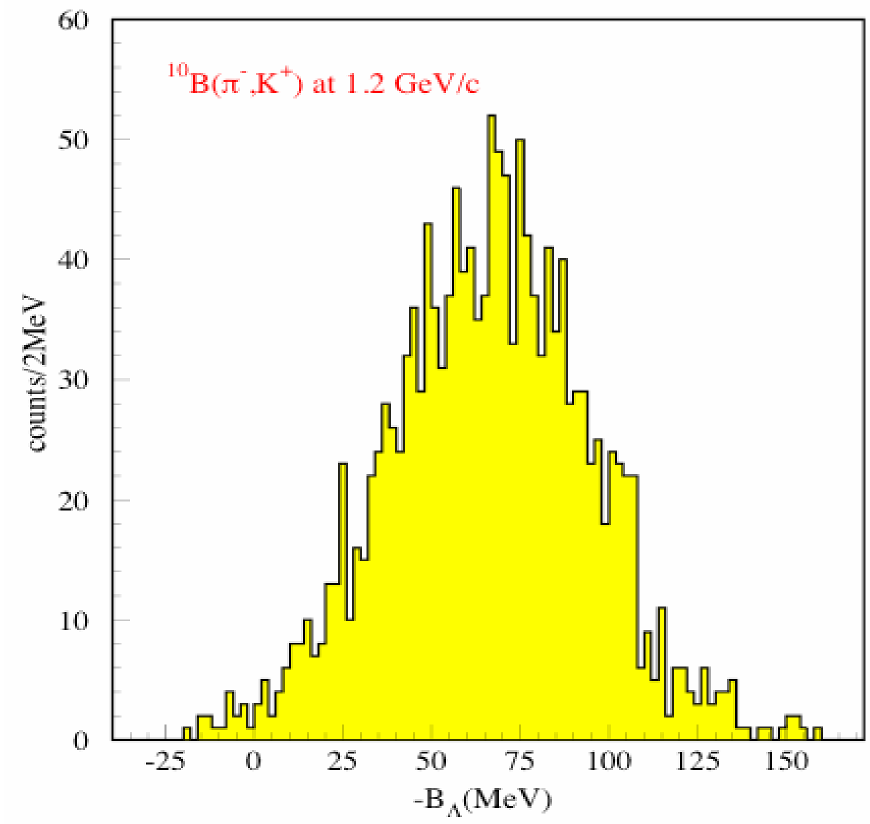
散乱粒子の質量[MeV/c]



$-B_{\Lambda}$ [MeV/c]

$^{10}B(\pi^-,K^+)$ 1.2GeV/c





$-B_\Lambda$ [MeV/c]

Two-step process and incident momentum depecdence

$\pi^- p \rightarrow K^0\Lambda$; $K^0 p \rightarrow K^+ n$

$\pi^- p \rightarrow \pi^0 n$; $\pi^0 p \rightarrow K^+\Lambda$

$\pi^- p \rightarrow K^0\Lambda$	Same kinematics like $n(\pi^+,K^+)\Lambda$ reaction
$\pi^0 p \rightarrow K^+\Lambda$	
$K^0 p \rightarrow K^+ n$	Charge-exchange (Favors $\Delta I=0$)
$\pi^- p \rightarrow \pi^0 n$	

Two-step process: theoretical cross section

is maximum at π incident momentum at 1.05GeV/c

(π^-,K^+) reaction: Λ formation mechanism

1. Two-step Process

$$\pi^- p \rightarrow K^0\Lambda \;;\; K^0 p \rightarrow K^+ n$$
$$\pi^- p \rightarrow \pi^0 n \;;\; \pi^0 p \rightarrow K^+\Lambda$$

2. One-step Process via Σ^- state

$$\pi^- p \rightarrow K^+\Sigma^-$$
$$\hookrightarrow \Sigma^- p \rightarrow \Lambda n$$

Incident π-	**Σ– state**	**Formation**
1.2 GeV/c	**Real**	**Σ^- p⇔ Λn conversion**
1.05GeV/c	**Virtual**	**Mixing of wavefunction of Σ^- and**

Problems and solutions

- Huge background
  π^0 and Compton suppression
  → surrounded by BGO
  select events
  from excitation spectrum
- Small yield
  Cover large solid angle
  → solid angle 15% with 14 Ge
  Detection efficiency
  ~2.5% @1MeV
- High background rate
  from beam pions
  → Fast readout electronics

Identify observed γ-rays

- 1482 keV

  largest yield

  narrow peak → long lifetime → ${}^{11}_{\Lambda}B$ (E2;$1/2^+ \rightarrow 5/2^+$)

  Millener's prediction

  $\Delta = 0.5$ MeV , $S_N = -0.4$ MeV , $S_\Lambda = -0.01$ MeV , $T = 0.03$ MeV

  $$\Delta E(1/2^+_1 \rightarrow 5/2^+_1)$$
  $$= \Delta E_{core} - 0.243\Delta + 1.234 S_\Lambda - 1.090 S_N - 1.627 T + \Lambda\Sigma$$
  $$= 1020 \text{ keV}$$

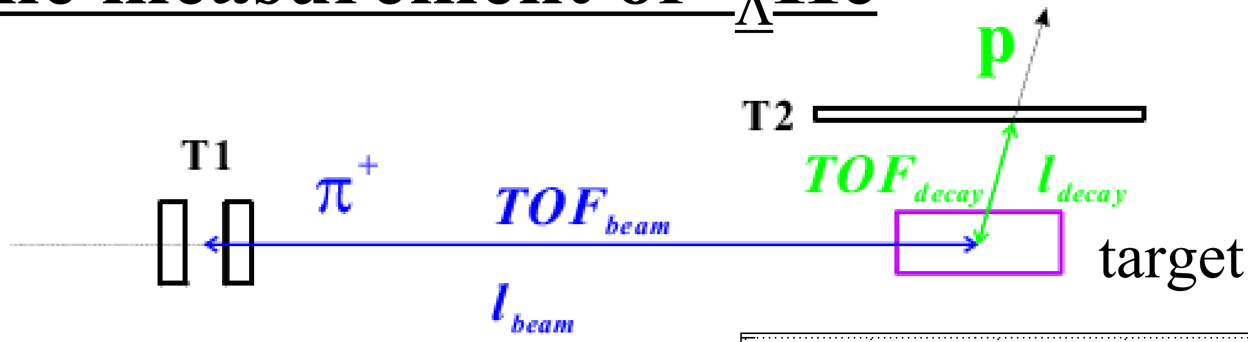
  Not consistent with experiment

- Other γ transitions

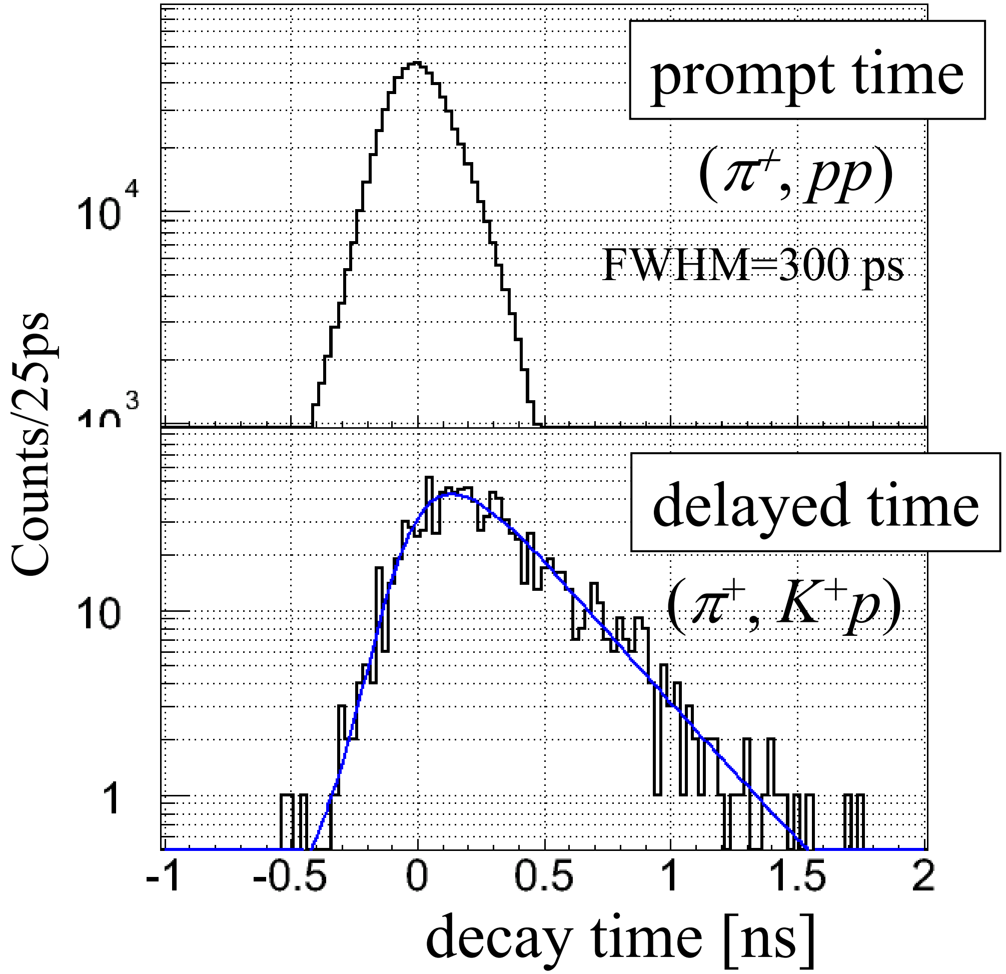
  Not identified yet → analysis is now under way

  ${}^{11}_{\Lambda}B$ (M1;$3/2^+ \rightarrow 1/2^+$) will be identified

Lifetime measurement of $^5_\Lambda$He



$$\Delta t = t_{T2} - TOF_p - TOF_\pi - t_{T1}$$
$$= t_{T2} - \frac{l_p}{\beta_p c} - \frac{l_\pi}{\beta_\pi c} - t_{T1}$$



Present experiment
τ= **278** $^{+11}_{-10}$ ps
(statistical error only)

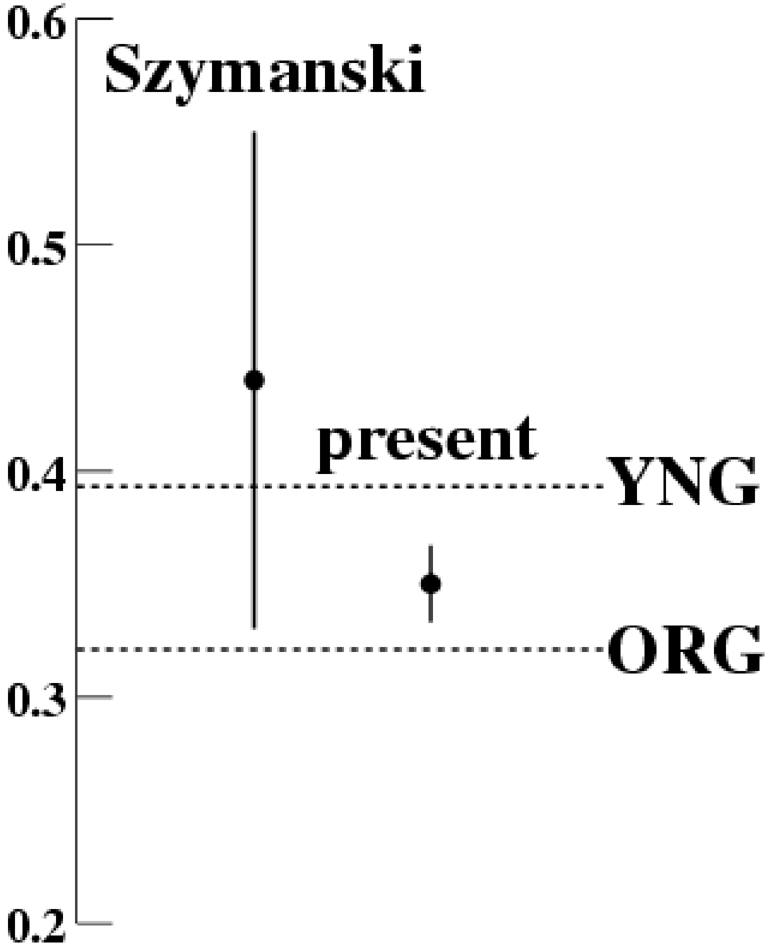
cf. Szymanski *et al.*(1991)
$\tau = 256 \pm 20$ ps

Results

	Present experiment	Szymanski *et al.*(1991)
$\Gamma_{tot} / \Gamma_{\Lambda}$	**0.947 ± 0.037**	1.03 ± 0.08
$\Gamma_{\pi^-} / \Gamma_{\Lambda}$	**0.350 ± 0.017**	0.44 ± 0.11
$\Gamma_{nm} / \Gamma_{\Lambda}$	0.400 ± **0.023**	0.41 ± 0.14

- $\Gamma_{\pi 0} / \Gamma_{\pi^-} ({}^5_{\Lambda}He) \equiv \Gamma_{\pi 0} / \Gamma_{\pi^-} (\Lambda) = 0.560 \pm 0.011$
- $\Gamma_{nm} \equiv \Gamma_{tot} - \Gamma_{\pi^-} - \Gamma_{\pi 0}$
- Statistical error only

π^- decay width



Significantly larger α-Λ overlap than YNG potential is indicated

⇩

New potential is required

Summary

- π- branching ratio and lifetime of ${}^{5}_{\Lambda}He$ is precisely measured.
- $\Gamma_{\pi^-}/\Gamma_{\Lambda}({}^{5}_{\Lambda}He) = 0.350 \pm 0.017$
- $\Gamma_{nm}/\Gamma_{\Lambda}({}^{5}_{\Lambda}He) = 0.400 \pm 0.023$
- New α-Λ potential must be considered.