4th/Aug/2004
NP04@Tokai

Experiments of the weak decay of Λ hypernuclei at KEK-PS & J-PARC

J-PARC LOI21
(S. Ajimura) -Phase 1

Riken H. Outa

1. Weak decay of Λ hypernuclei
2. Results of recent KEK-PS experiments
3. Experiments at J-PARC

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

$$1/\tau_{HY} = \Gamma_{tot} \begin{cases} \Gamma_m \begin{cases} \Gamma_{\pi^-} \ (\Lambda \rightarrow p + \pi^-) \\ \Gamma_{\pi^0} \ (\Lambda \rightarrow n + \pi^0) \end{cases} \\ \Gamma_{nm} \begin{cases} \Gamma_p \ (\Lambda + \text{“}p\text{”} \rightarrow n + p) \\ \Gamma_n \ (\Lambda + \text{“}n\text{”} \rightarrow n + n) \end{cases} \end{cases}$$

Mesonic
q～100MeV/c

Non-Mesonic(NMWD)
q～400MeV/c

Study of the mechanism of baryon-baryon weak interaction.

Motivation

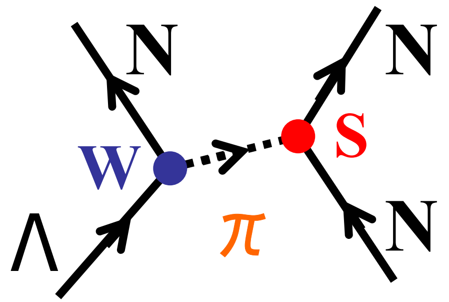
Γ_p (Λ+"p"→ n + p)
Γ_n (Λ+"n"→ n + n)

ratio ⇒ Γ_n / Γ_p

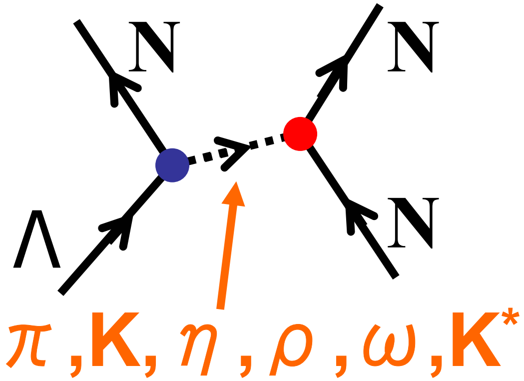
The most important observable to study the isospin structure of the NMWD

Theoretical

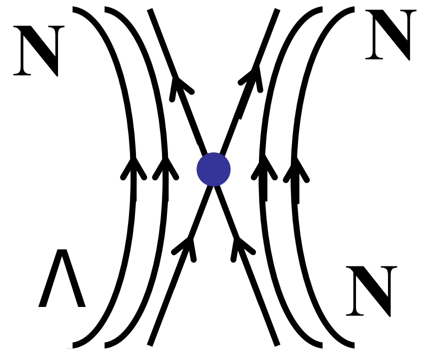
One Pion Exchange (OPE)

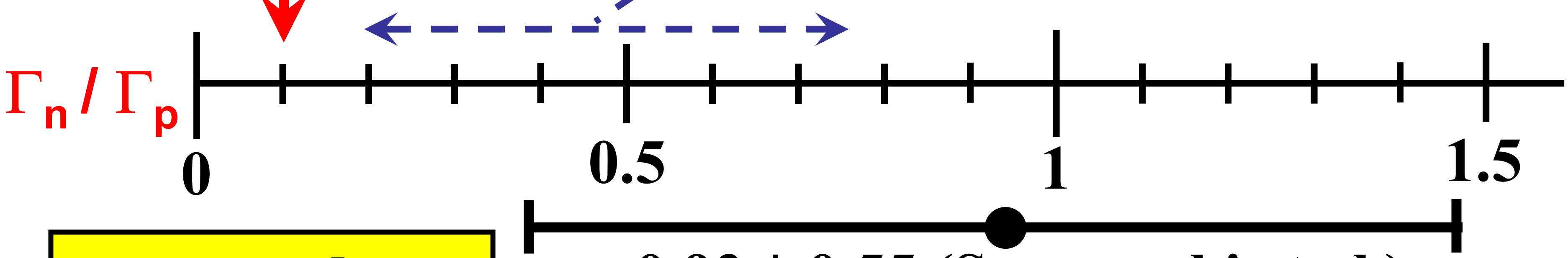


Meson Exchange mechanism



Direct Quark mechanism





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

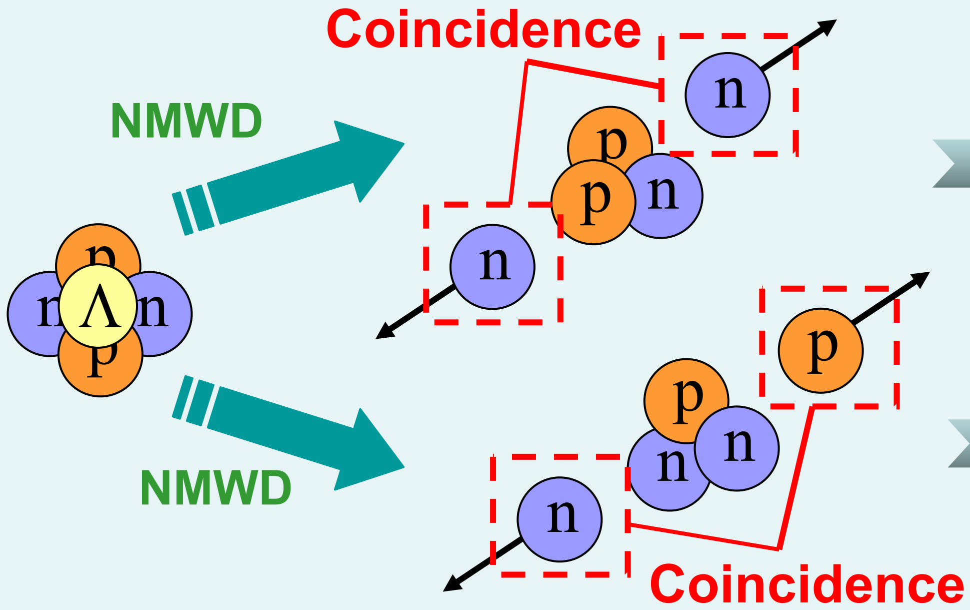
0.93±0.55 (Szymanski et al.)

Γ_n / Γ_p ratio "puzzle"

Coincidence analysis

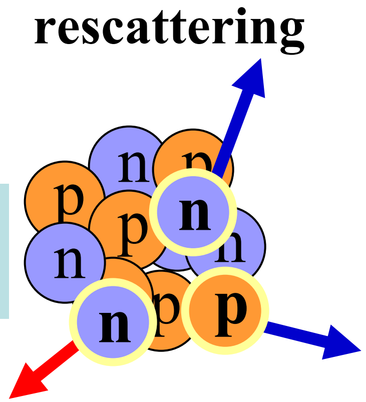
E462($^{5}_{\Lambda}$He) / E508($^{12}_{\Lambda}$C)

NMWD : $\Lambda N \rightarrow NN$



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

Final state interaction (FSI)



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

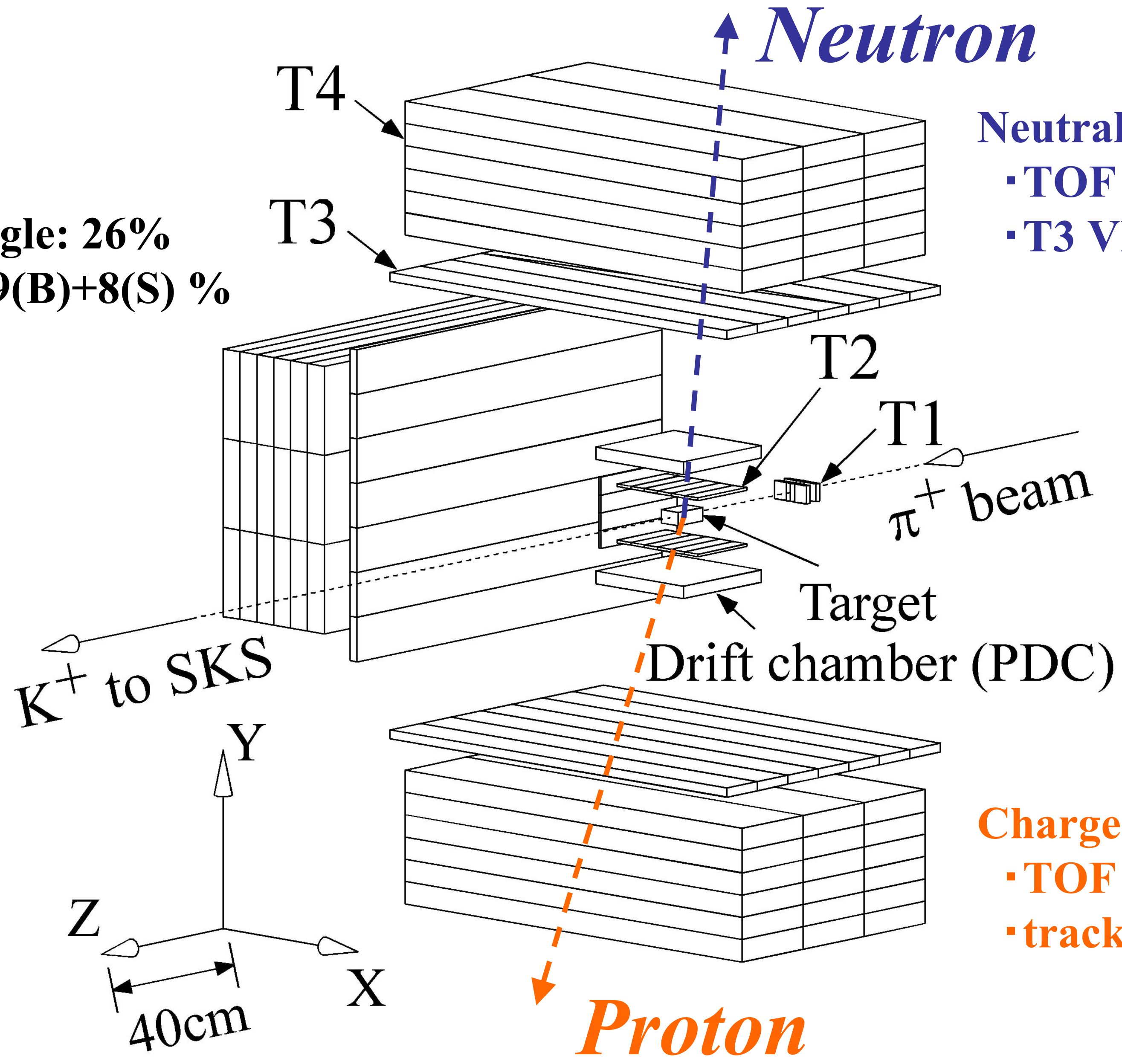
$$N(\Lambda p \rightarrow np) \times (\Omega_n \times \Omega_p)_{av.} \times \varepsilon_n \times \varepsilon_p \times (1 - R_{FSI})$$

* $\cos\theta < -0.8$
* 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

Decay counter system



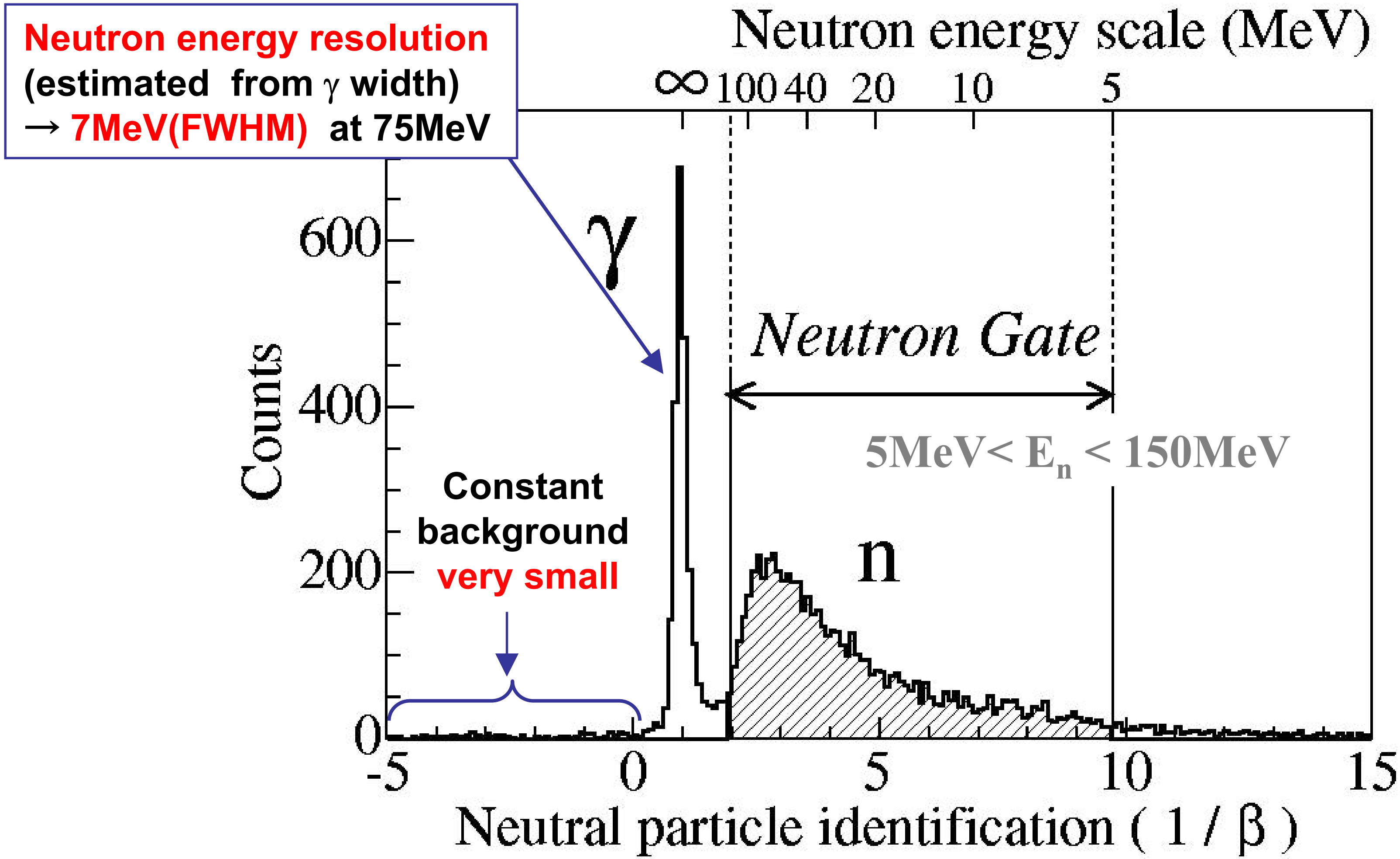
Solid angle: 26%
= 9(T)+9(B)+8(S) %

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

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

Neutral decay particle ID

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



1 / β spectra (TOF spectra)

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

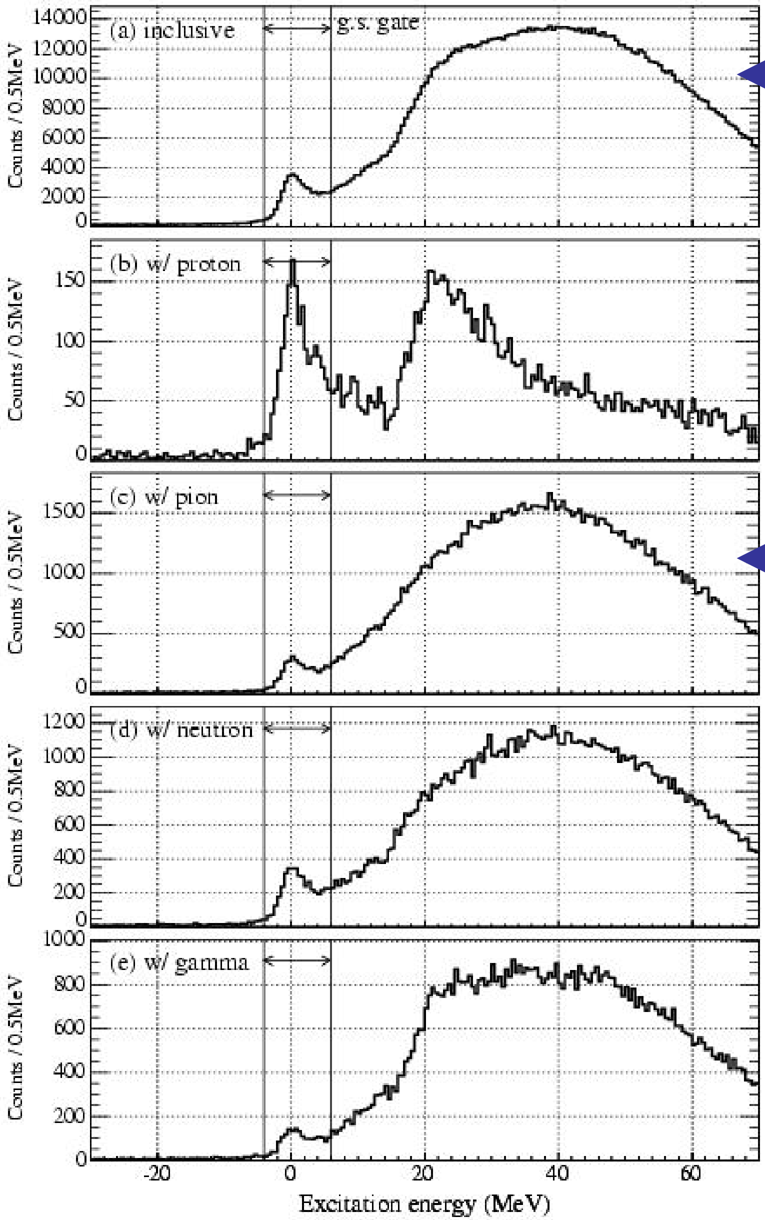
inclusive

w/ proton

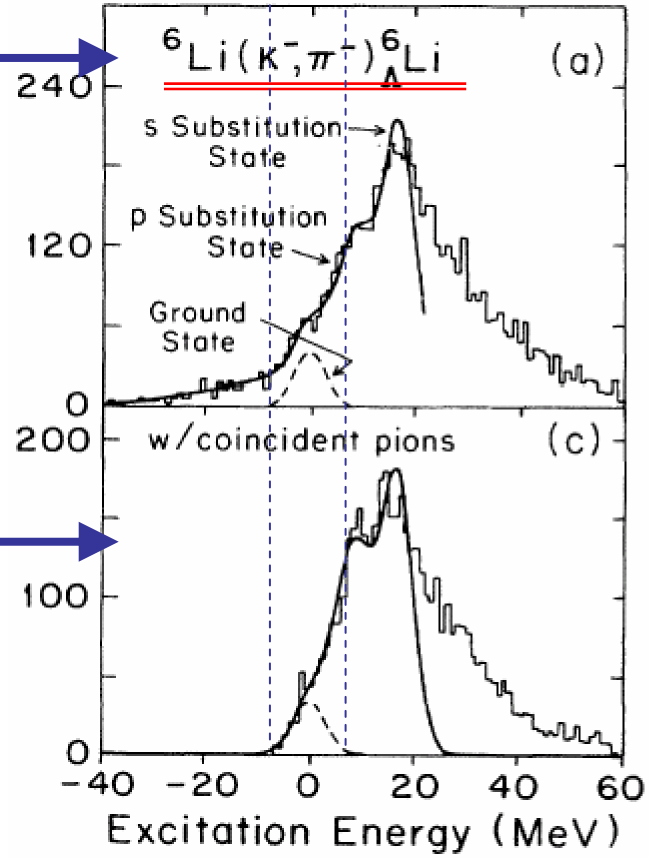
w/ pion

w/ neutron

w/ gamma



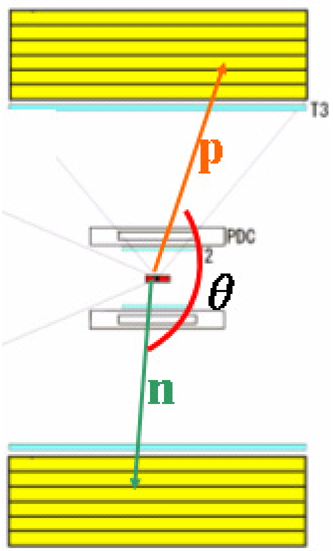
previous experiment at BNL

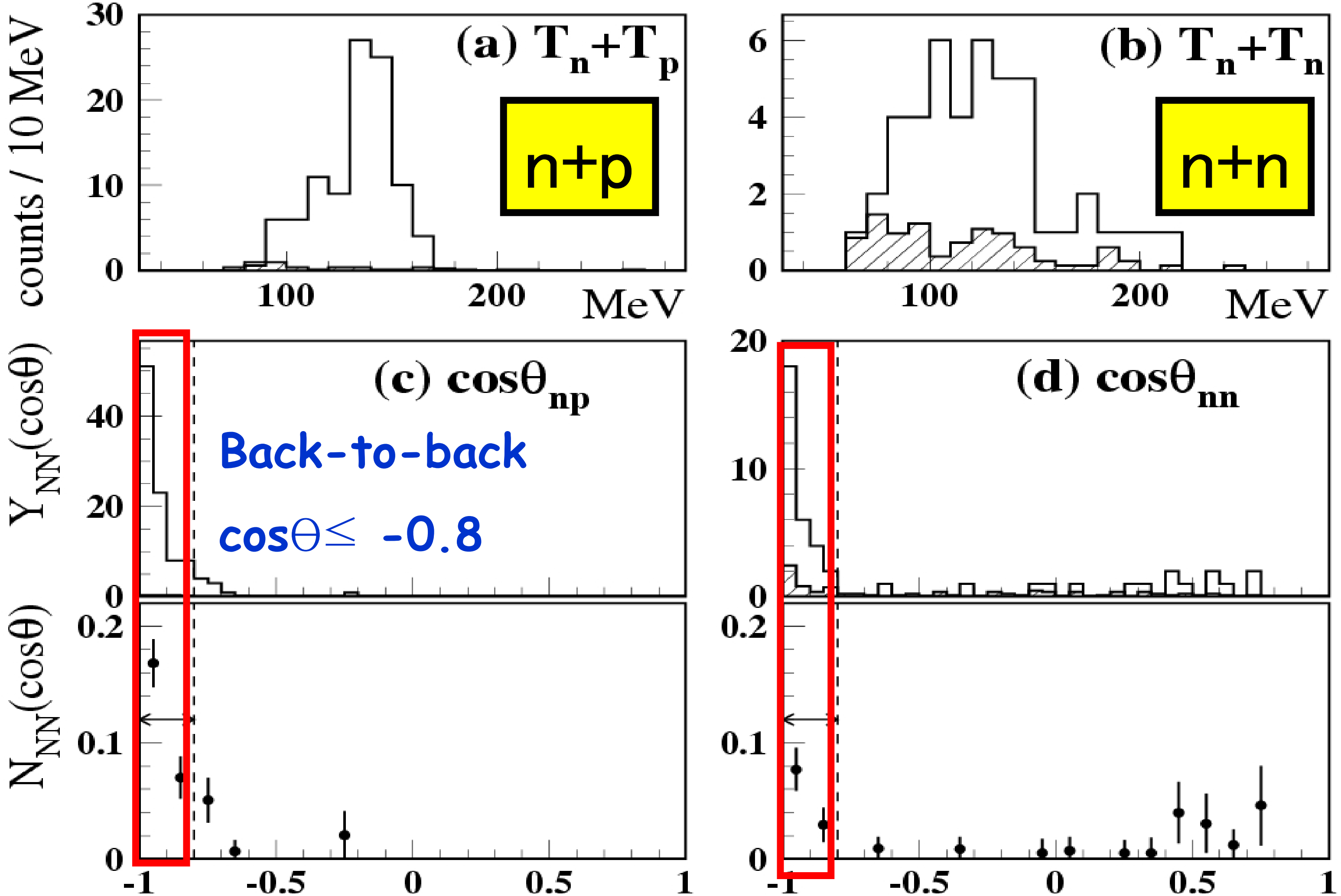


b_{π^-} = 0.359±0.009

Error 25% → 3%

np- & nn- angular distribution





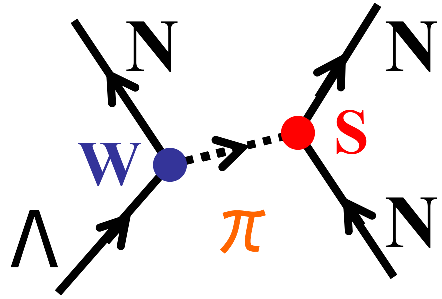
$\Gamma_n/\Gamma_p \sim N_{nn} / N_{np} =$
$0.45 \pm 0.11 \pm 0.03$

systematic error is mainly come from efficiency for neutron (6%) + acceptance(3%)

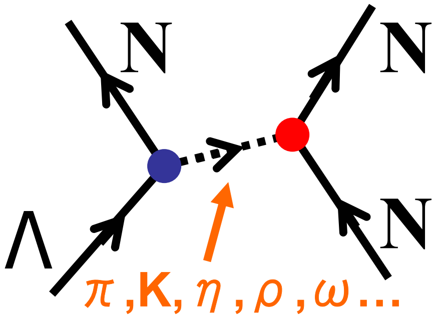
Γ_n / Γ_p ratio

Theo.

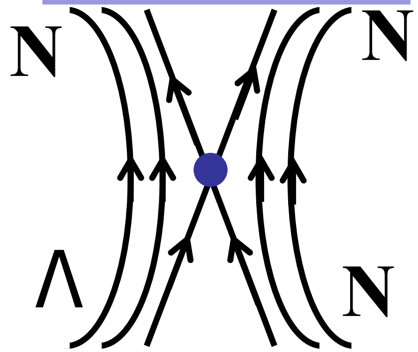
One Pion Exchange (OPE)

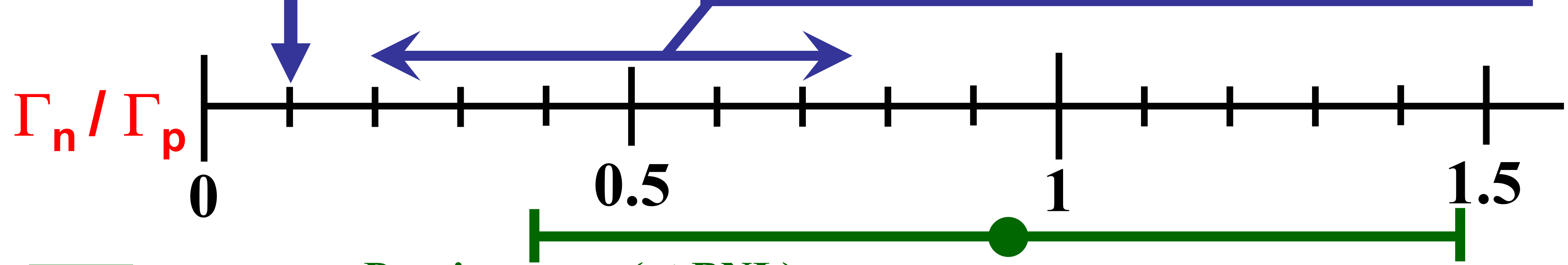


Meson Exchange mechanism



Direct Quark mechanism





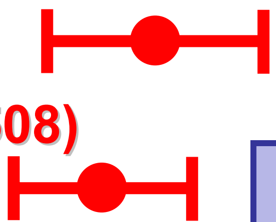
Exp.

Previous exp. (at BNL)

0.93±0.55 (Szymanski et al.) for $^5_\Lambda$He

$^5_\Lambda$He (E462)

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



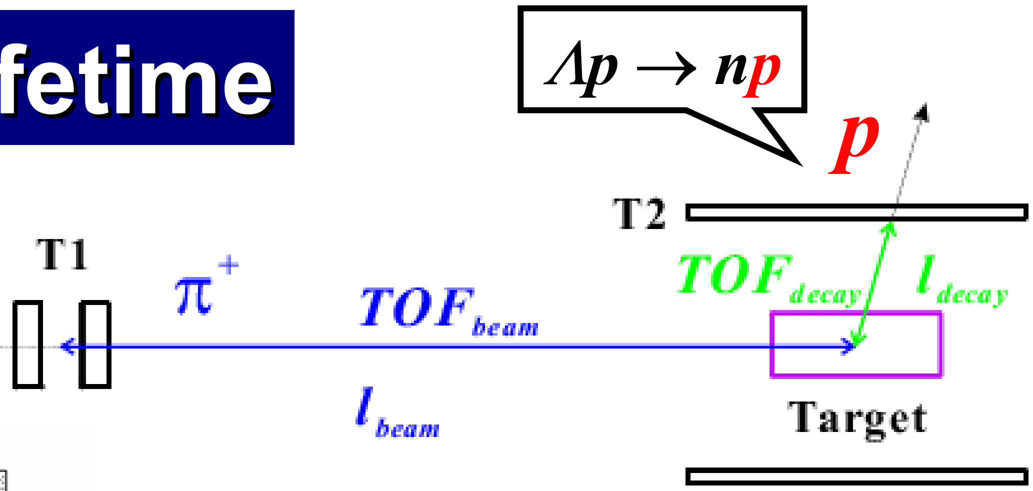
N_{nn} / N_{np} ($^5_\Lambda$He)= 0.45±0.11±0.03

N_{nn} / N_{np} ($^{12}_\Lambda$C)= 0.40±0.09 *(preliminaly)*

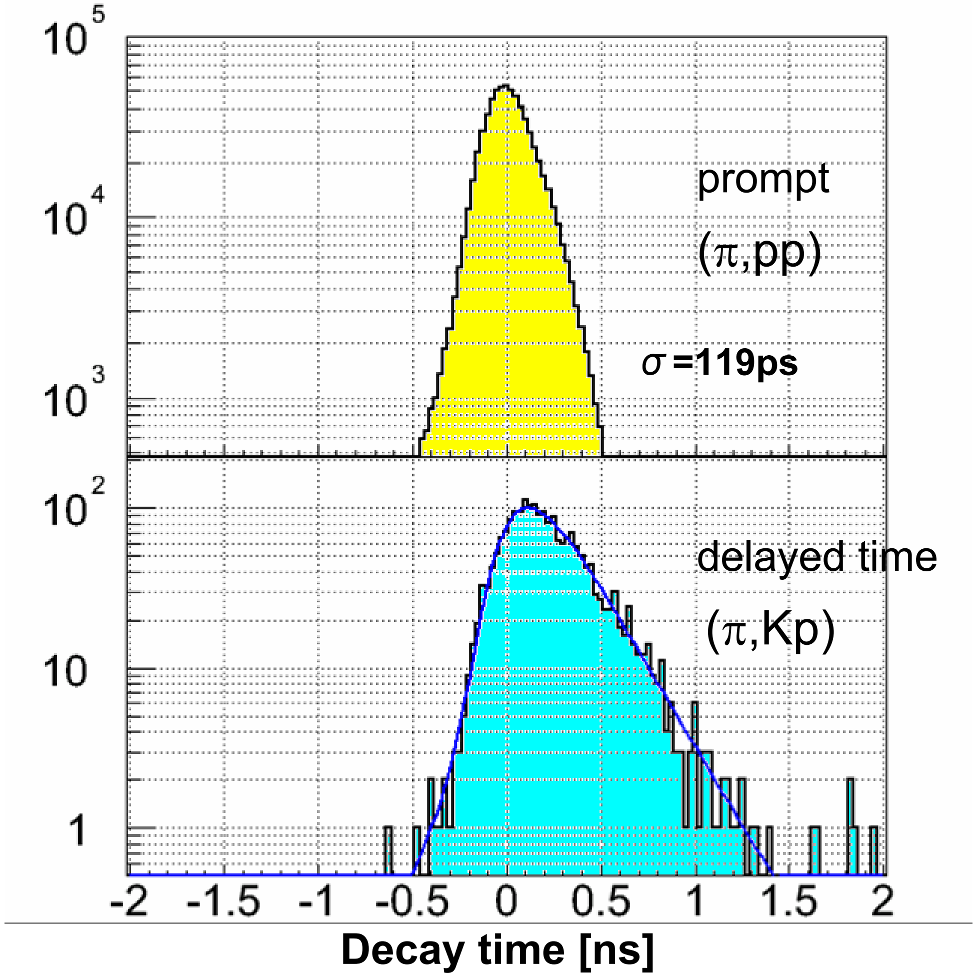
Lifetime

$$\Delta t = t_{T2} - TOF_p - TOF_\pi - t_{T1}$$

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



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



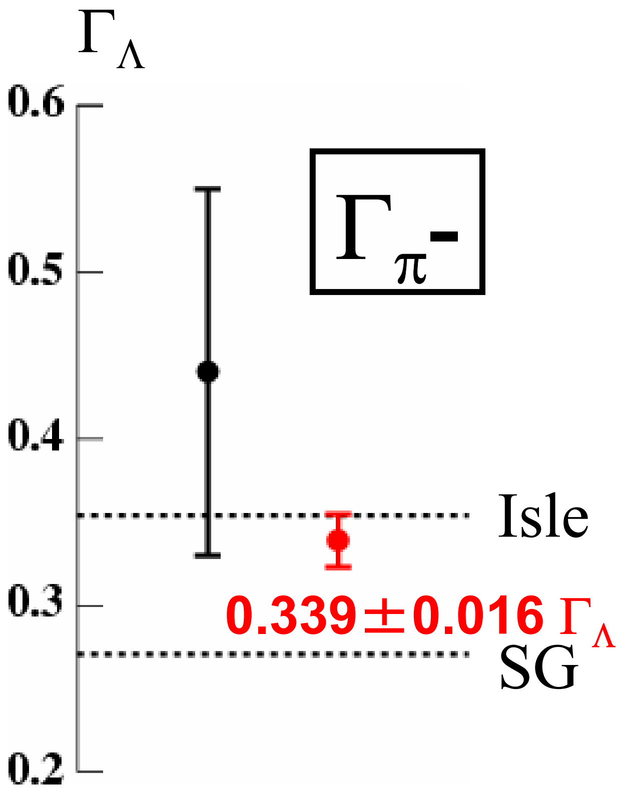
τ = 212 ± 6 ps
for $^{12}{}_\Lambda$C

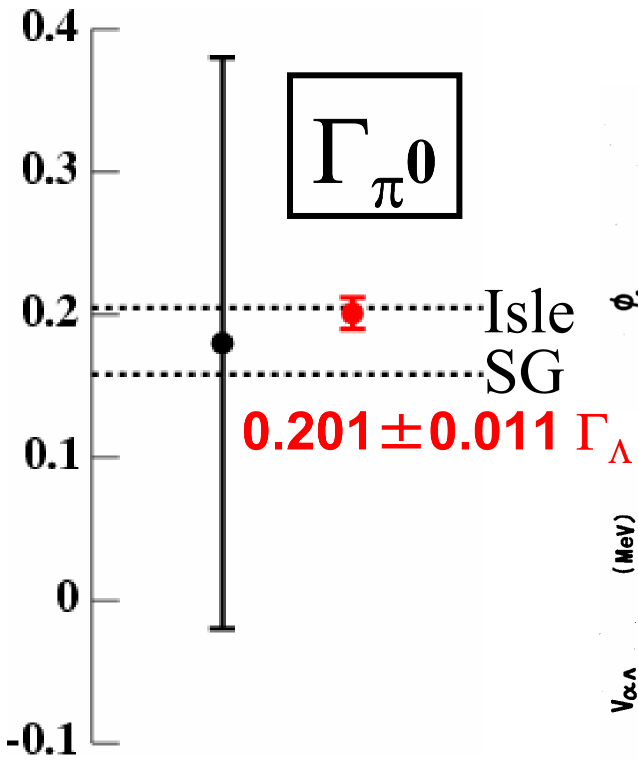
3% error!!

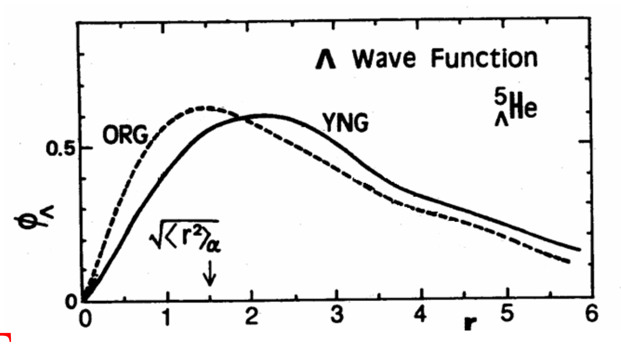
τ = 278 ± 10 ps
for $^{5}{}_\Lambda$He

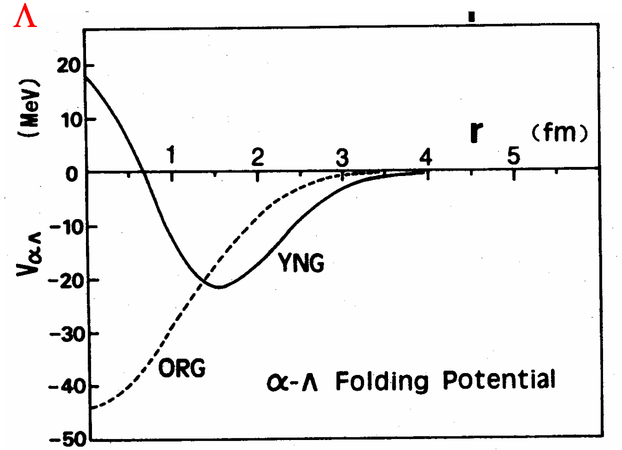
Error: ~2.5 times improved over previous experiments

Γ_{π^-} and Γ_{π^0} for $^{5}_{\Lambda}$He *(preliminary)*







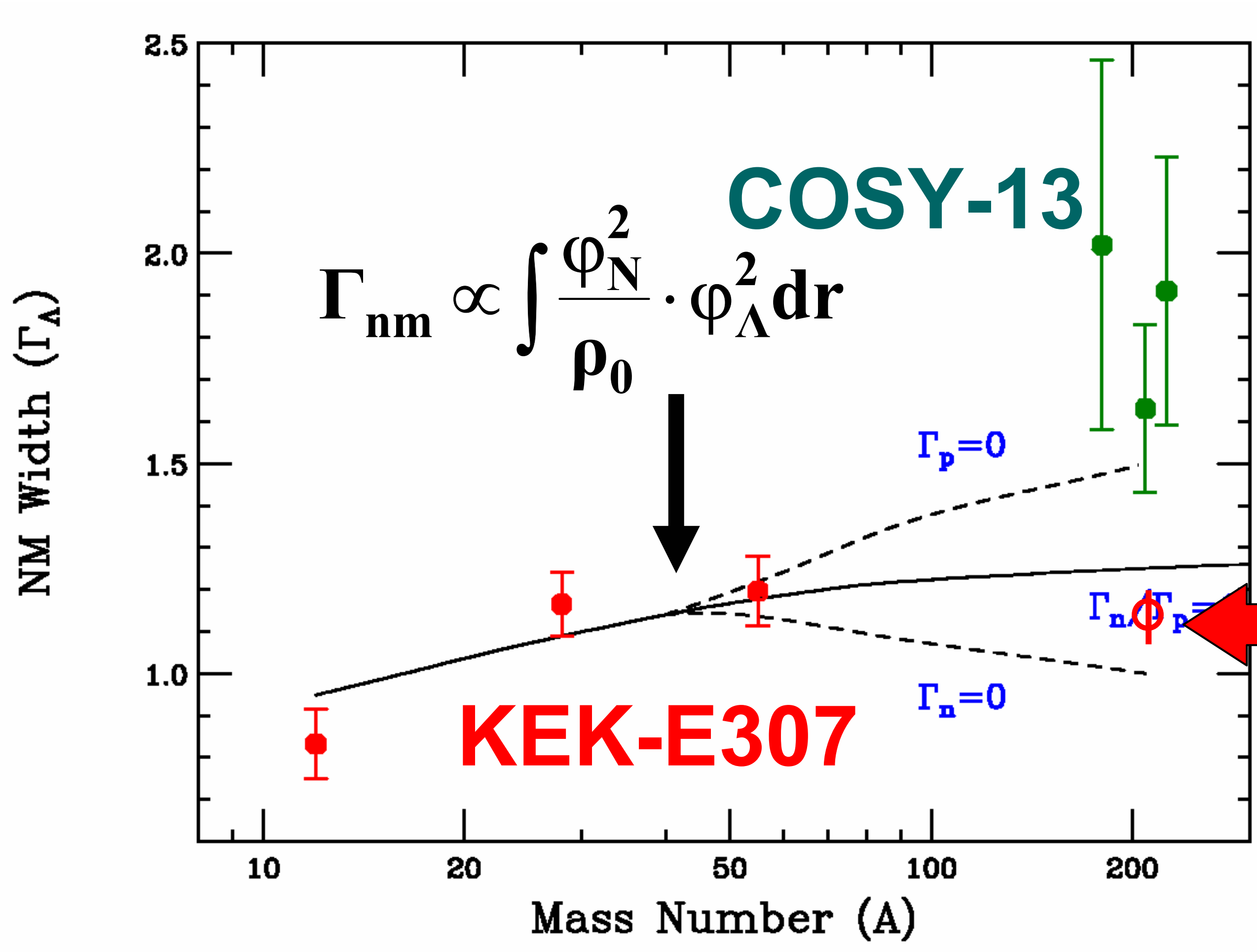


Measured with much improved accuracy

Excellent agreement with calculation based α-Λ potential with repulsive core (Kumagai-Fuse et al.)

At J-PARC

Lifetime of very-heavy hypernuclei ?



(π,K)
K1.1

?

To J-PARC

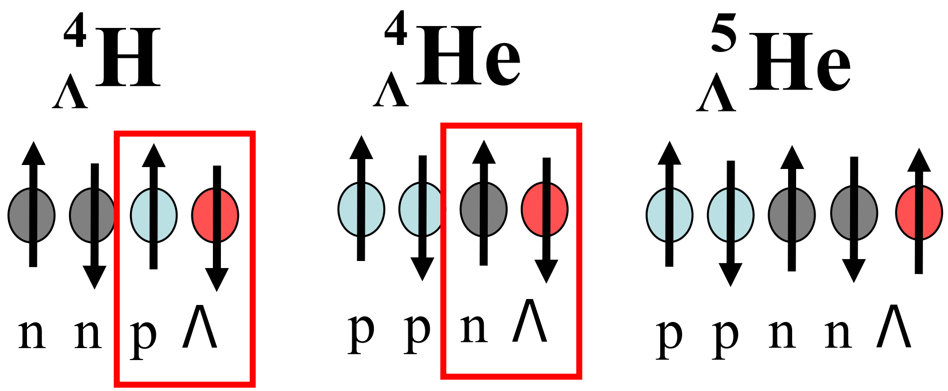
Non-mesonic weak decay of ${}^{4}_{\Lambda}$He and ${}^{4}_{\Lambda}$H

see S.Ajimura : J-PARC LOI 21

Spin / isospin dependence

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

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 !!

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

Estimation from E462 statistics

$^{5}_{\Lambda}$He 50K → n+p back-to-back～200

To achieve same n+p pair numbers….

$^{4}_{\Lambda}$H 50K × 3 × 2 × 5 × 1/2 ～800K

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

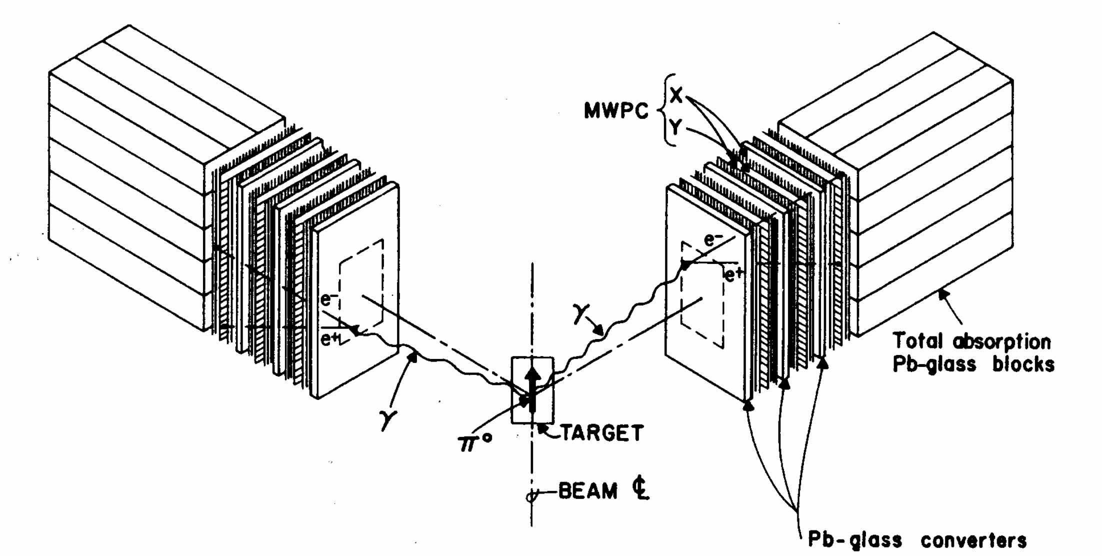
Need 30,000 $^{4}_{\Lambda}$H /day

1 × 0.6 × 0.3m@60cm

↓

1.5 × 1.2 × 0.45m@90cm

π^0 spectrometer



NIM180 (1981) 445-459

$$E\pi^0 = \frac{\sqrt{2} m_{\pi^0}}{\sqrt{(1-\underline{\cos\eta})\times(1-x^2)}}$$

$$x = \frac{E_1 - E_2}{E_1 + E_2}$$

$p_{\pi 0}$=257 MeV/c

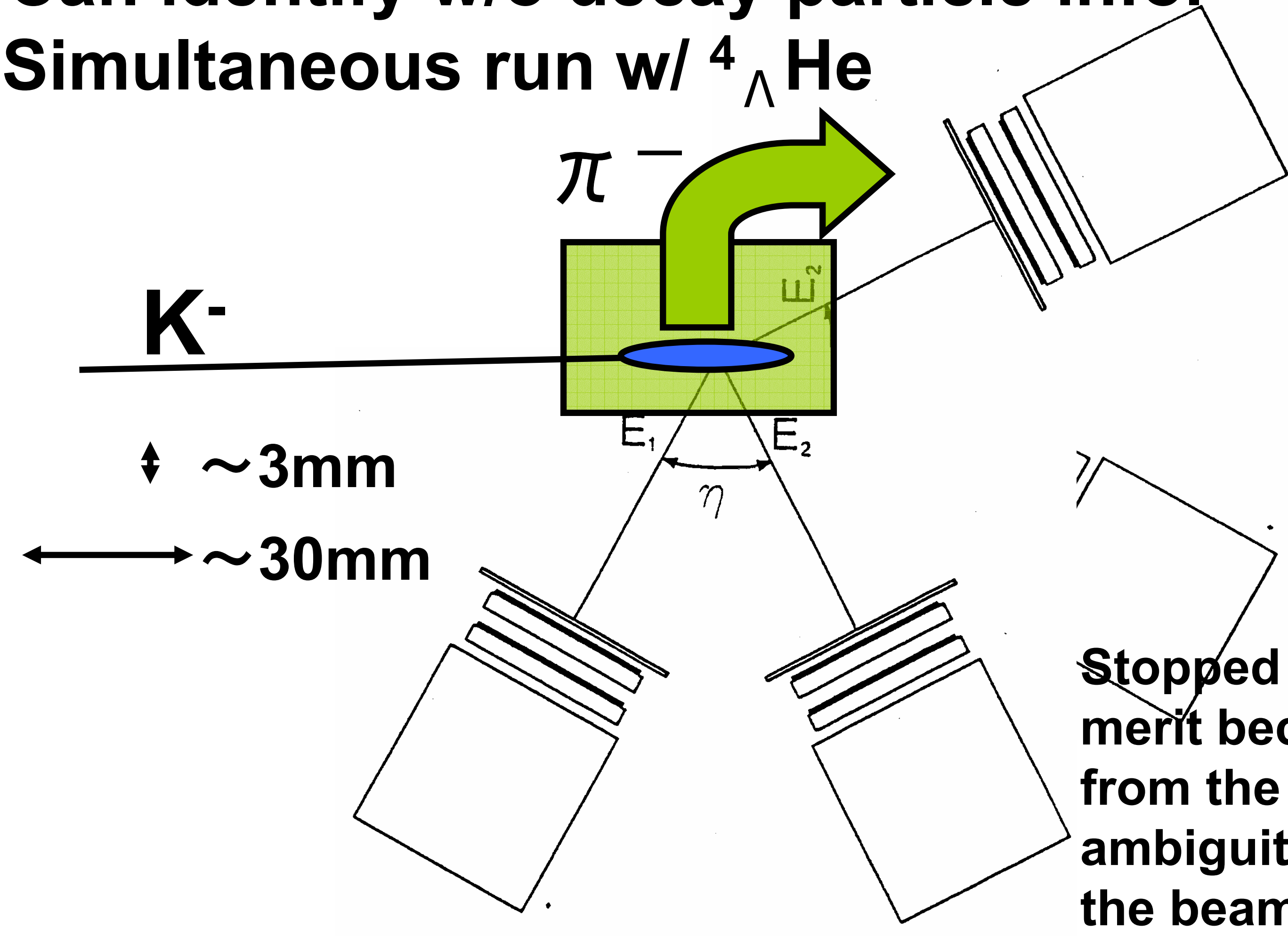
γ =2.15
β = 0.89
η =55.4°

$p_{\pi 0}$=600 MeV/c

γ =4.56
β = 0.98
η =25.4°

$^{4}{}_{\Lambda}$H: (stopped K, π)? In-flight ?

1) Resolution 2～3MeV (FWHM)
2) Can identify w/o decay particle info.
3) Simultaneous run w/ $^{4}{}_{\Lambda}$He



Stopped K- method has merit because it is free from the stopping point ambiguity along the beam direction

π^0 detection efficiency

CsI: 80cm(w)×120cm(h)×30cm
(600liter)

BGO: 0.5Xo ×3 layers

R=1m |x| cut <0.15

Effective acceptance

$\Omega \times \varepsilon_{\text{conversion}} = 15\sim20$ msr

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

K1.1; 700MeV/c K-

0.5×10^{6} K-/sec

↓ **10% stop**

50×10^{3}/sec stopped K- on ^{4}He

↓ **${}^{4}_{\Lambda}H$ branch ~ 0.9%**

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

↓

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

π^0 energy resolution

$$\Delta E\pi^0 \cong \left(C + \boxed{\frac{m_0}{2}\gamma^2\beta\Delta\eta} \right)^{1/2}$$

～0.5MeV

Stopped R=1m

$\Delta\eta = 3\ mrad;\ \gamma^2\beta \approx 4$

⇨ ～1MeV

In-flight R=2m

$\Delta\eta = 2\ mrad;\ \gamma^2\beta \approx 20$

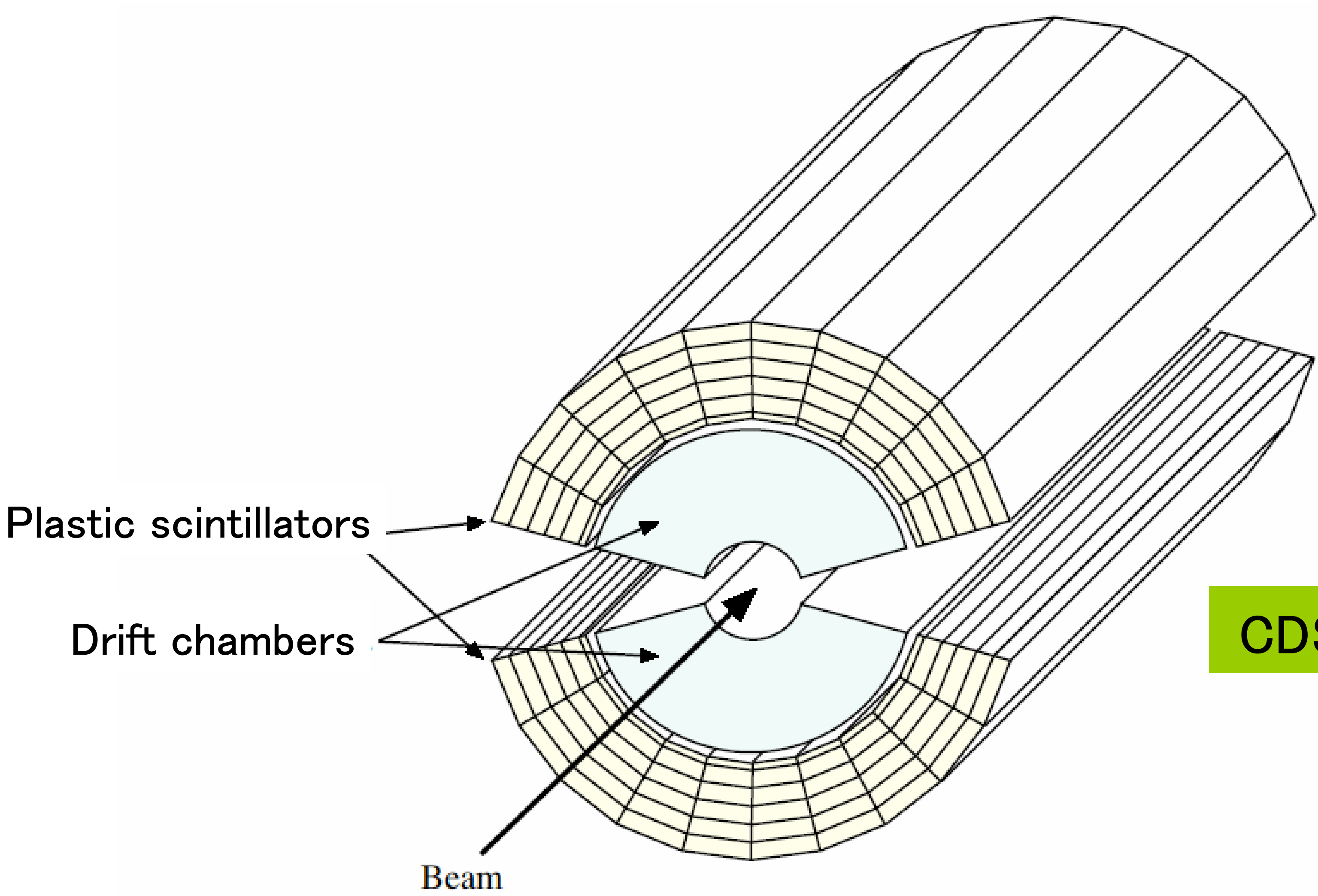
⇨ ～3 MeV

* We do need to use very thin ^4He target (～1cm; ～0.1g/cm^2) for in-flight reaction case
* BG from target cell ?!
* More expensive....

(stopped K, π)? In-flight ?-2

	Stopped K	In–flight
BG process	π^0 in the decay stage; $\Sigma^0 \to \Lambda\gamma$ decay cause combinatorial BG	Clean
Peak separation	Good	Worse E(QF)～$q^2/2M$
Target cell BG	Little	Serious; probably need to give up $\Lambda n \to nn$ mode
Cost	Reasonable	Higher
$^4_\Lambda$He run	Simultaneous	Different experiment

Setup example-2 (Ajimura, LOI)



CDS

Summary

- Precision measurement of the hypernuclear weak decay *just started !!*
  Measurements must be sensitive to all the τ / γ &n / π^-&p
  Back-to-back n+p/n+n pairs must be measured for good $\Gamma n/\Gamma p$ determination

- 1. NMWD measurements of $^4{}_\Lambda H$ / $^4{}_\Lambda He$ are feasible only at J-PARC

  2. Lifetime measurement at A～209 (～3% accuracy rather easily achieved)

Requirements / Detectors

Requirement for the beam

＊ K1.1/0.8 w/double stage separator

＊ Neutron BG/π^- halo in the beam line must be carefully considered

Detectors

＊ Construction of π^0 spectrometer needed

- In-flight OR stopped (K^-, π^0) reaction

＊ General purpose CDS detector in the target region

＊ Neutron counters/decay tracking chambers for K-nucleus experiments can be re-used