Weak Decay Studies at KEK

RIKEN H. Outa

for KEK-PS E462 / E508 collaborations

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Review of non-mesonic & mesonic decay results focusing on
* Precise measurement of the decay widths and
* $\Lambda NN \rightarrow NNN$ decay for ${}^{12}_{\Lambda}C$; 29±13% of NMWD

for KEK-PS E549 collaboration

H. Bhang, J. Chiba, S. Choi, Y. Fukuda, T. Hanaki, R. S. Hayano, M. Iio, T. Ishikawa, S. Ishimoto, T. Ishiwatari, K. Itahashi, M. Iwai, M. Iwasaki, P. Kienle, J. H. Kim, Y. Matsuda, H. Ohnishi, S. Okada, H. Outa, M. Sato, S. Suzuki, T. Suzuki, D. Tomono, E. Widmann, T. Yamazaki, H. Yim

Measurement of the rare ${}^{4}_{\Lambda}He \rightarrow d + d$
non-mesonic decay branching ratio (6×10^{-4})

Summary of E462/E508

$^{5}_{\Lambda}$He (E462) and $^{12}_{\Lambda}$C (E508) formed via (π+,K+) reaction w/ SKS

Γ(Λn→nn)/Γ(Λp→np) ratio

- n/p spectra from A=5,12 S. Okada *et al.* — **PLB 597 (2004) 249-256**
- A= 5 B.H. Kang *et al.* — **PRL 96 (2006) 062301**
- A=12 M. Kim *et al.* — **PLB 641 (2006) 28**

Asymmetry parameter

- T. Maruta *et al.* — **nucl-ex/0509016; EPJ A33(2007) 255-258**

Mesonic & non-mesonic decay widths

- S. Kameoka *et al.* — **Nucl. Phys. A754 (2005) 173c-177c**
- S. Okada *et al.* — **Nucl. Phys. A754 (2005) 178c-183c**

Two nucleon-induced NMWD (ΛNN→NNN)

- A=12 M. Kim *et al.* — **PRL submitted (→ Parallel 2-B)**

Weak decay mode of Λ hypernucleus

$$1/\tau_{HY} = \Gamma_{tot} \begin{cases} \Gamma_m \begin{cases} \Gamma_{\pi^-} \ (\Lambda \rightarrow p + \pi^-) \\ \Gamma_{\pi^0} \ (\Lambda \rightarrow n + \pi^0) \end{cases} \\ \Gamma_{nm} \begin{cases} \Gamma_p \ (\Lambda + \text{"p"} \rightarrow n + p) \\ \Gamma_n \ (\Lambda + \text{"n"} \rightarrow n + n) \\ \Gamma_{2N} \ (\Lambda NN \rightarrow NNN) \end{cases} \end{cases}$$

Mesonic q∼100MeV/c

Non-Mesonic(NMWD) q∼400MeV/c

Decay particle identification @E462/E508

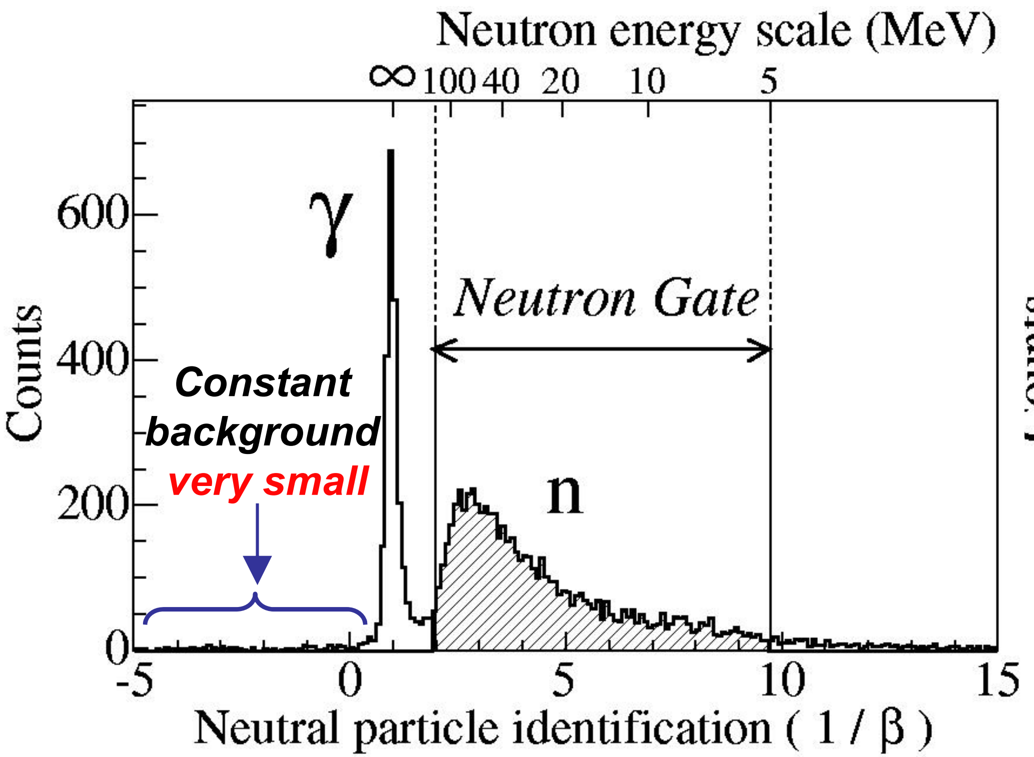
Neutral PID

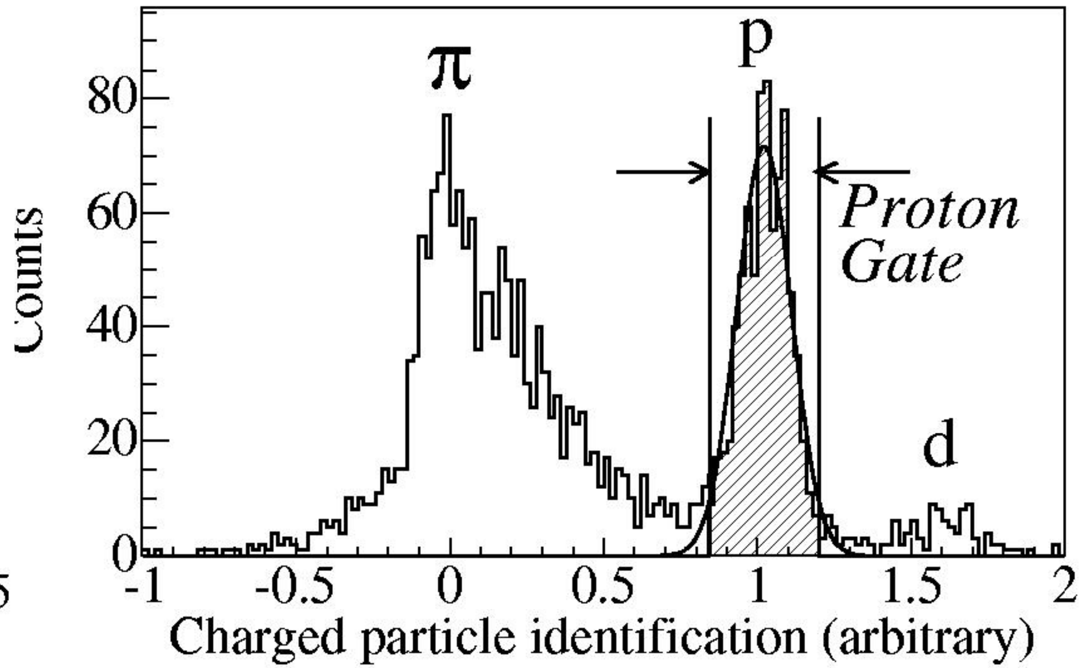
Neutral particles from $^{12}{}_{\Lambda}C$

Charged PID

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

Sensitive to all the decay modes





1 / β spectrum

PID function

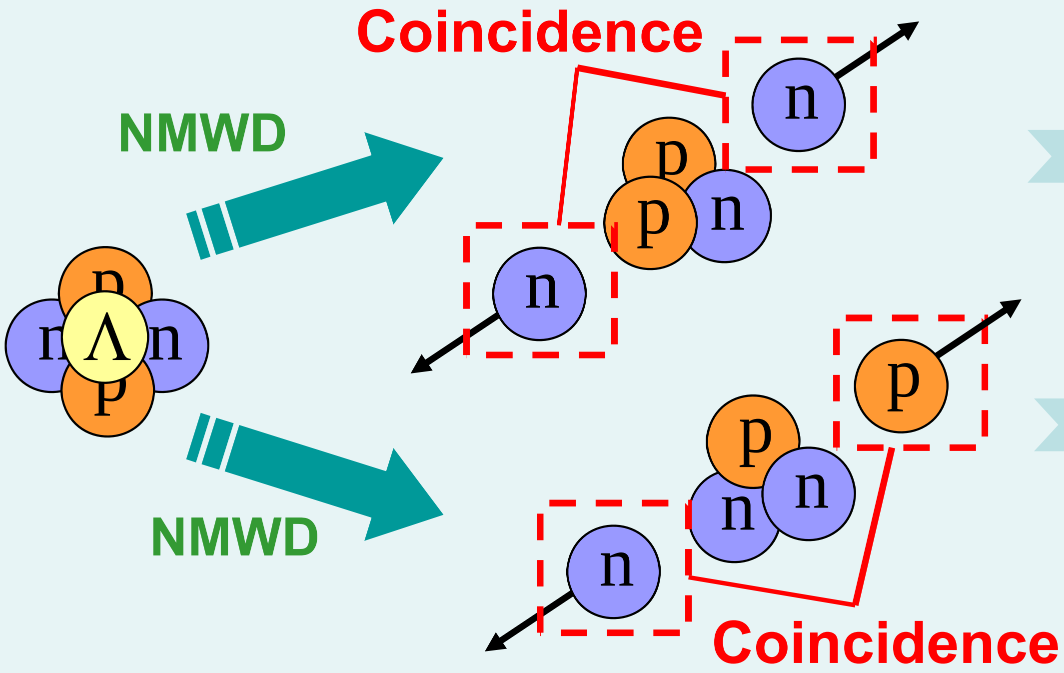
Good γ n separation

Good π p d separation

The present experiment

KEK-PS E462/E508

NMWD : ΛN→NN



1) Angular correlation

(back-to-back, $\cos\theta < -0.8$)

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.*

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

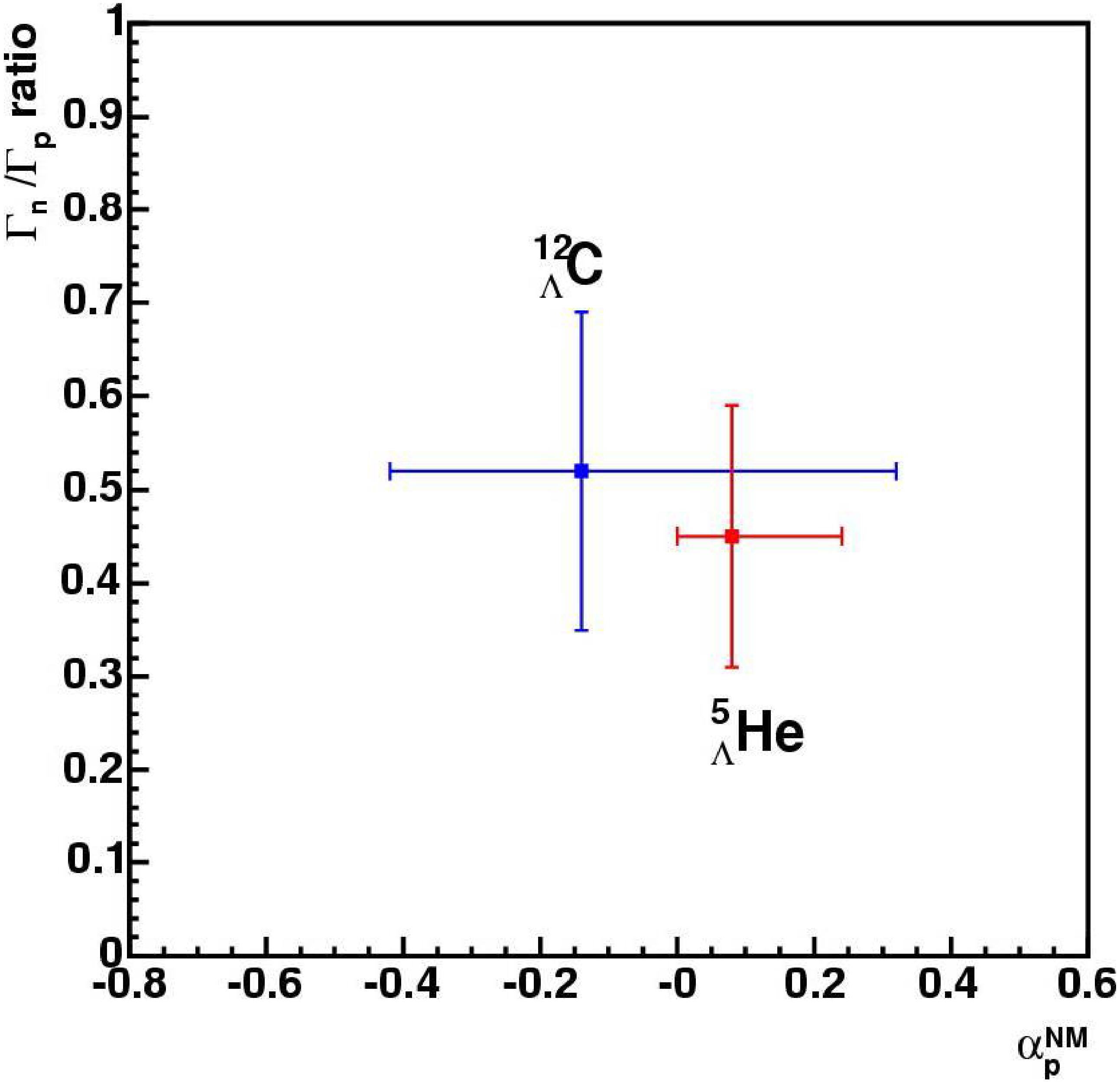
$$N(\Lambda p \to np) \times (\Omega_n \times \Omega_p)_{av.} \times \varepsilon_n \times \varepsilon_p \times (1 - R_{FSI})$$

* $\cos\theta < -0.8$
* 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 light hypernuclei to minimize FSI effect, $^{5}_{\Lambda}He$ and $^{12}_{\Lambda}C$

Comparison with recent calculations



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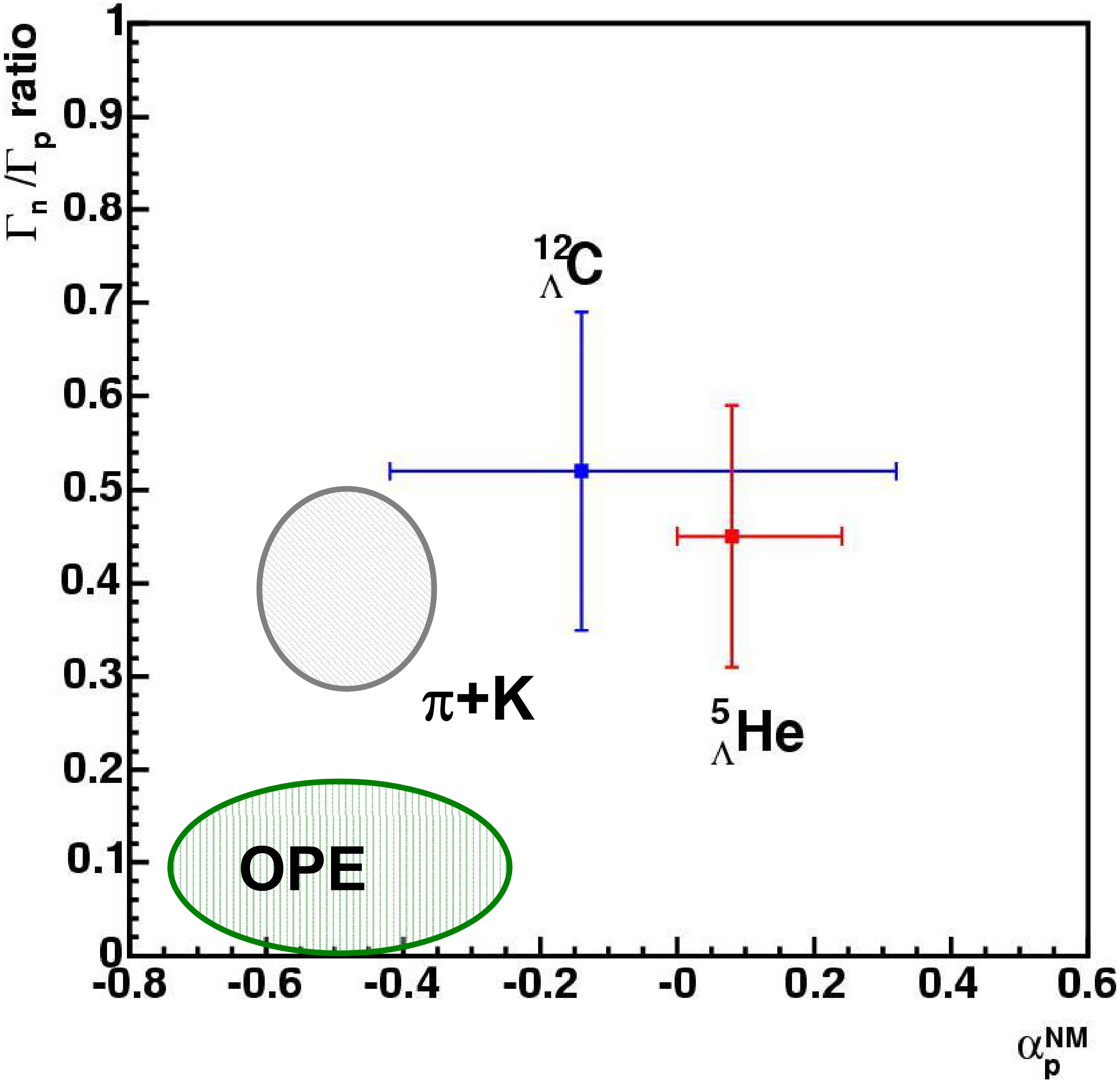

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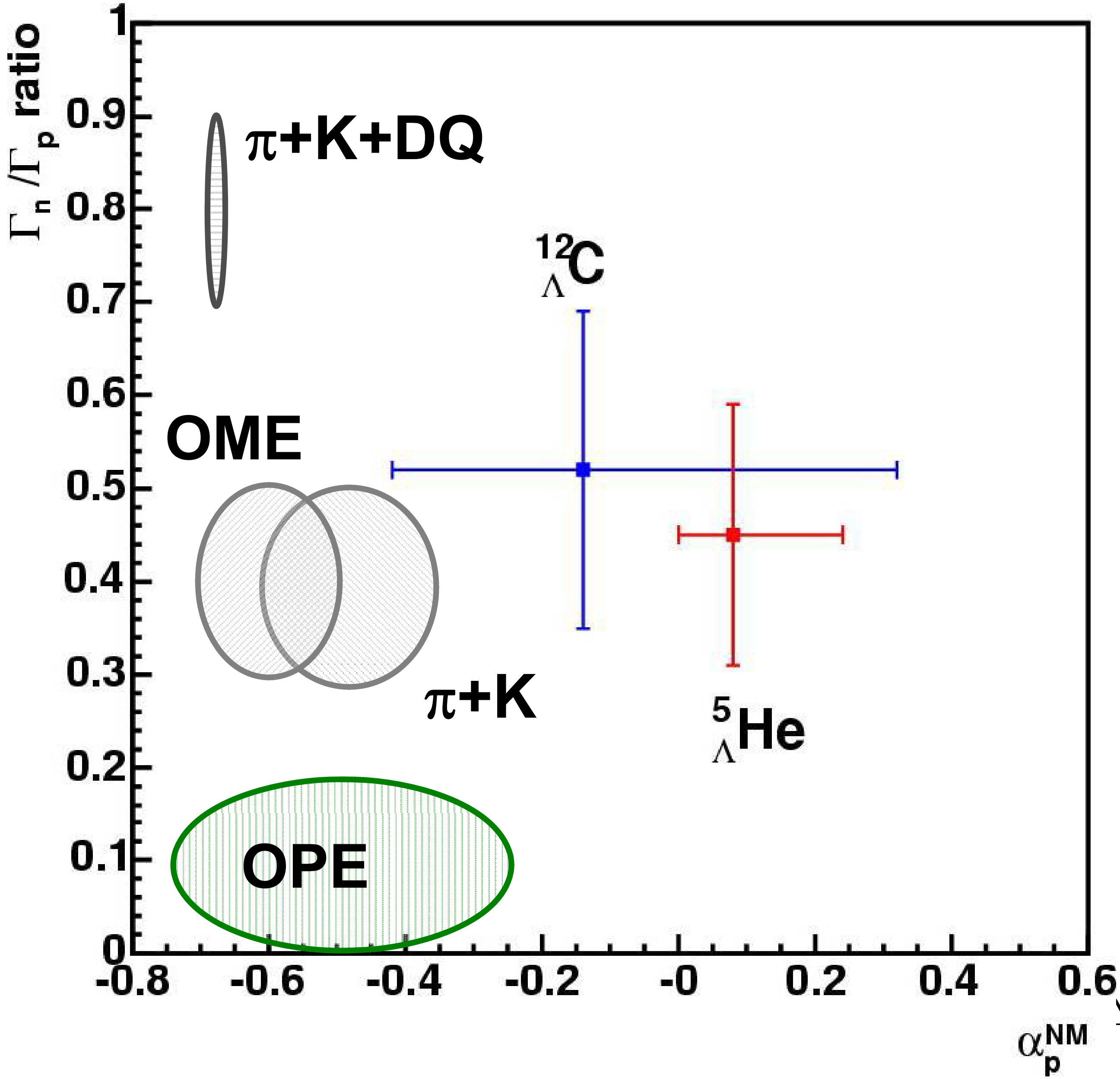


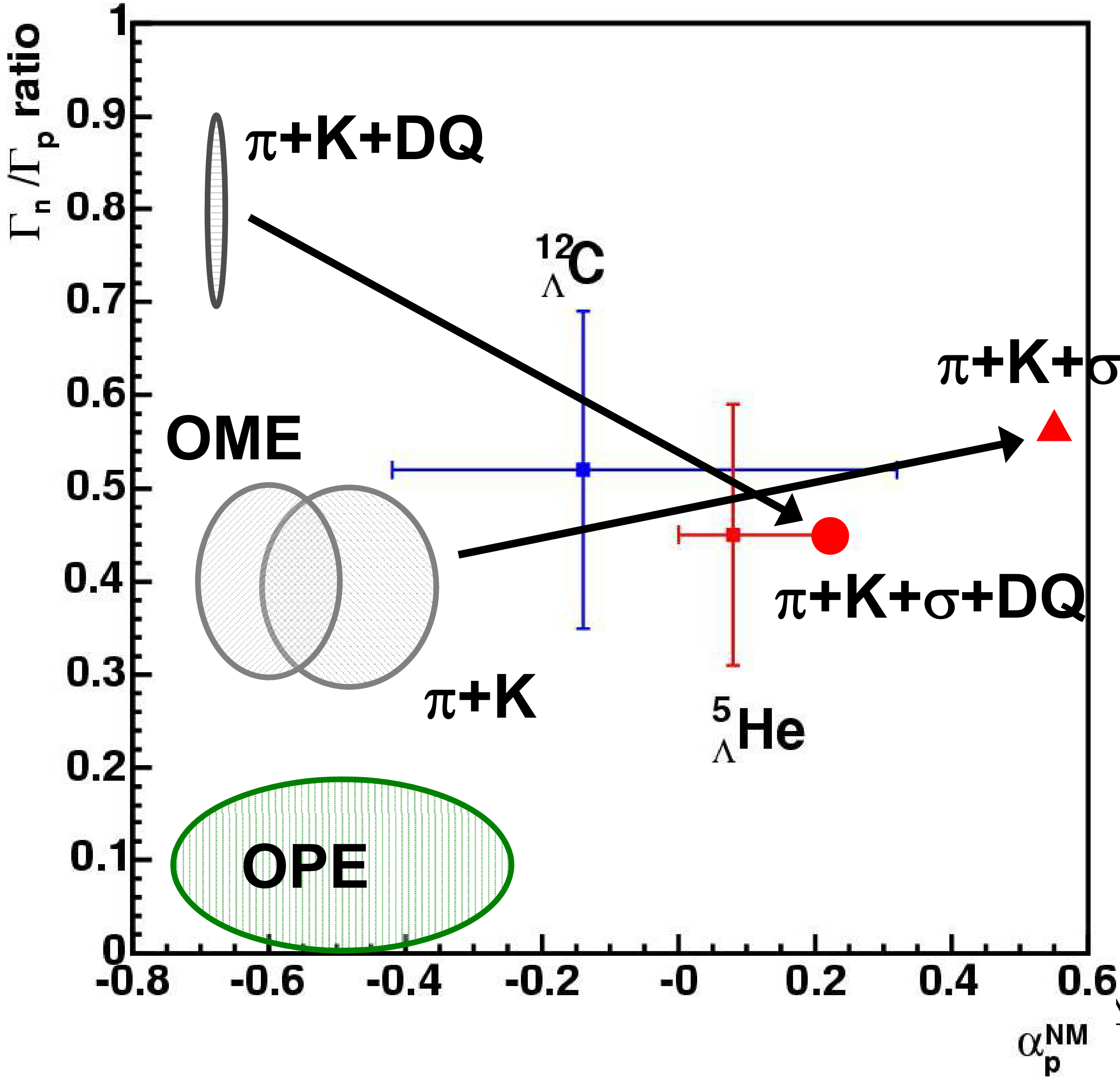
π+K,OME can reproduce Γ_n/Γ_p ratio but predict large negative α^{NM}

(1) Large $b(^1S_0 \to {}^3P_0)$ and $f(^3S_0 \to {}^3P_1)$ amplitude

(2) Violation of $\Delta I = 1/2$ rule considered

$$\frac{\sqrt{3}/2[-ae + b(c - \sqrt{2}d)/\sqrt{3} + (\sqrt{2}c + d)f]}{1/4\{a^2 + b^2 + 3(c^2 + d^2 + e^2 + f^2)\}}$$

Comparison with recent calculations



π+K,OME can reproduce Γ_n/Γ_p ratio but predict large negative α^{NM}

Γ_n/Γ_p and α^{NM} can be reproduced by π+K+σ+DQ model

Sasaki *et al.*
PRC71 (2005)035502

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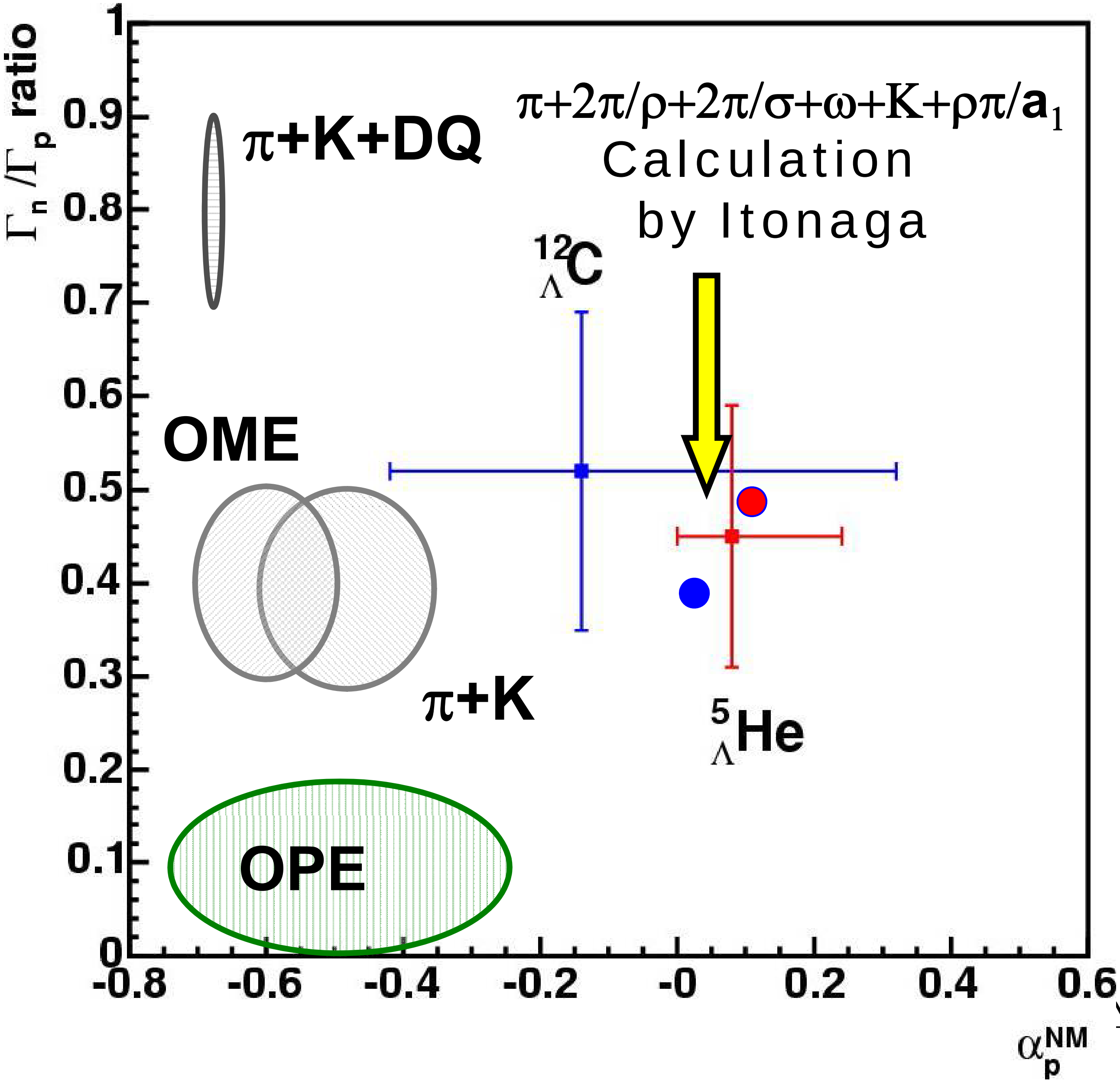

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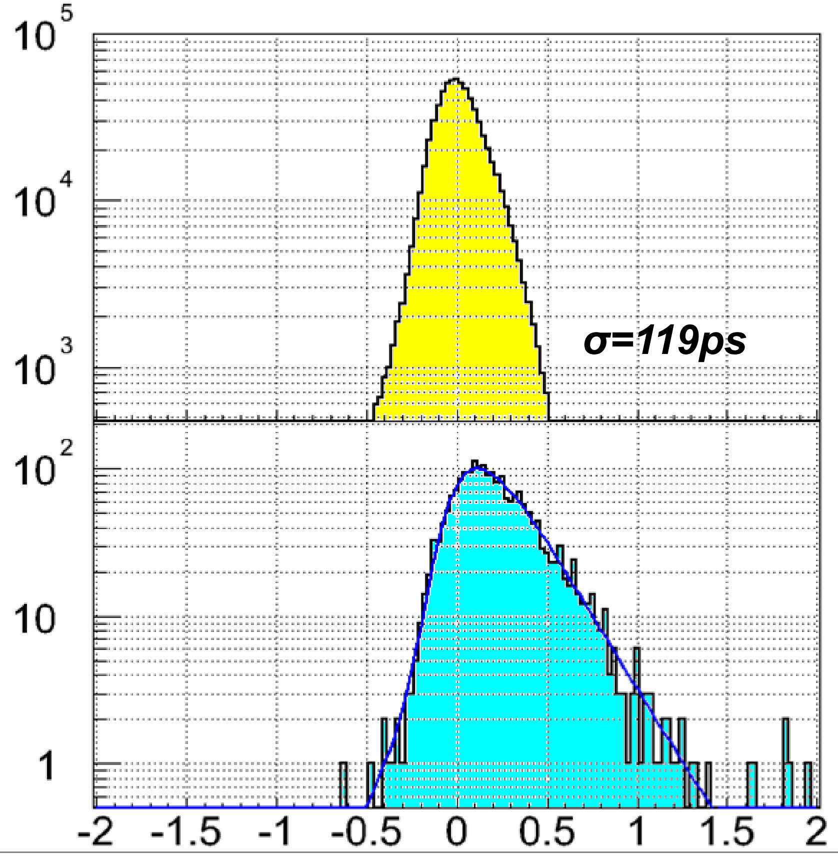
Mesonic decay widths??

∗ ***Important to study the NMWD widths***

$$Br(NMWD) = 1 - Br(\pi^-) - Br(\pi^0)$$

$$\Gamma_{nm} = 1/\tau \times Br(NMWD)$$



$\tau = 217 \pm 6$ ps

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

Mesonic decay widths??

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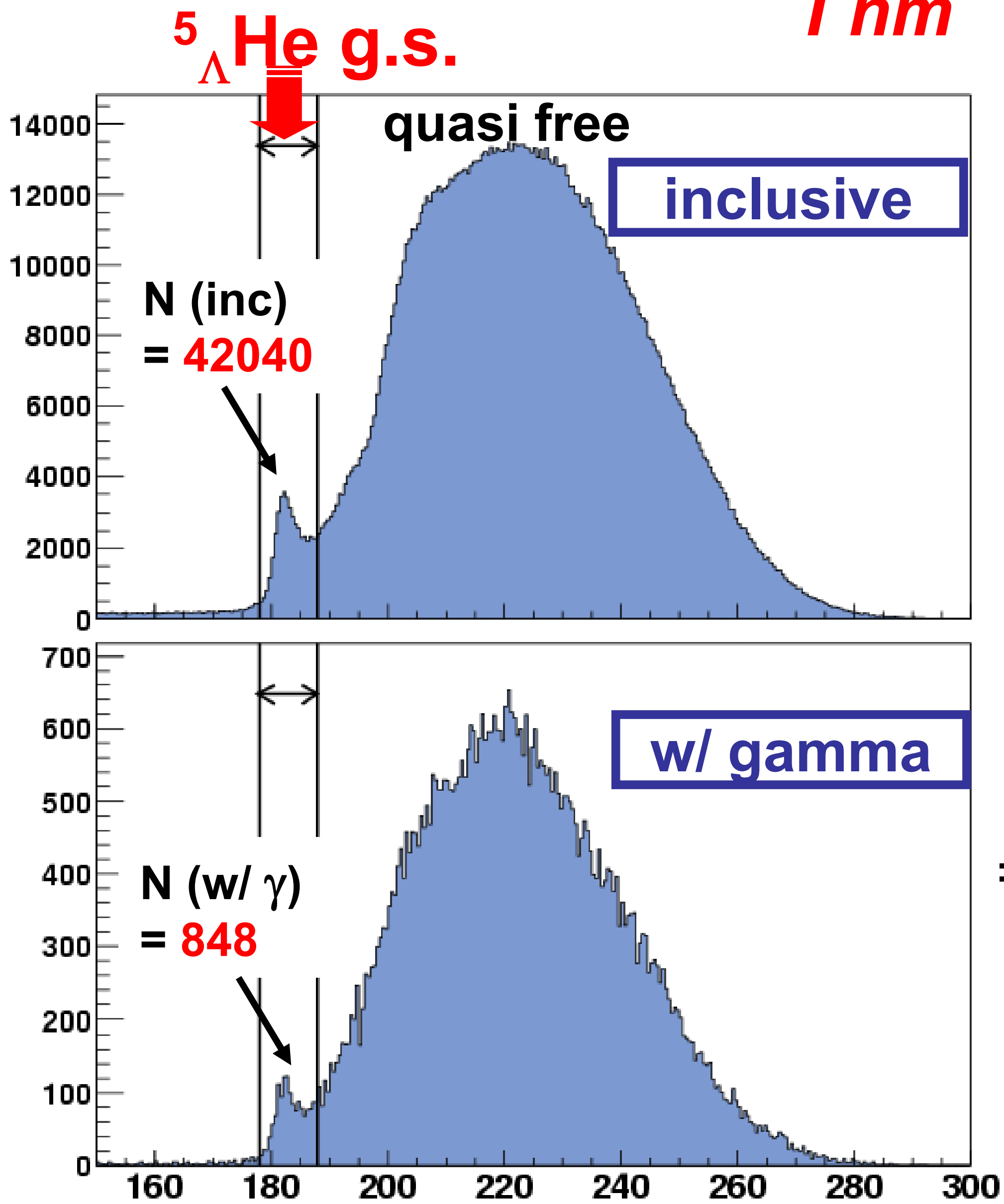
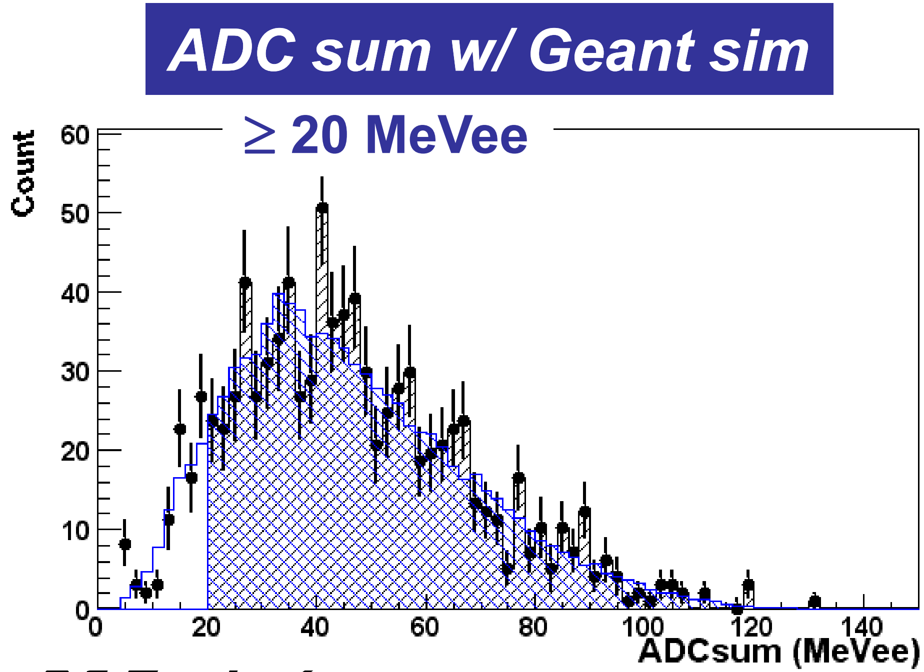
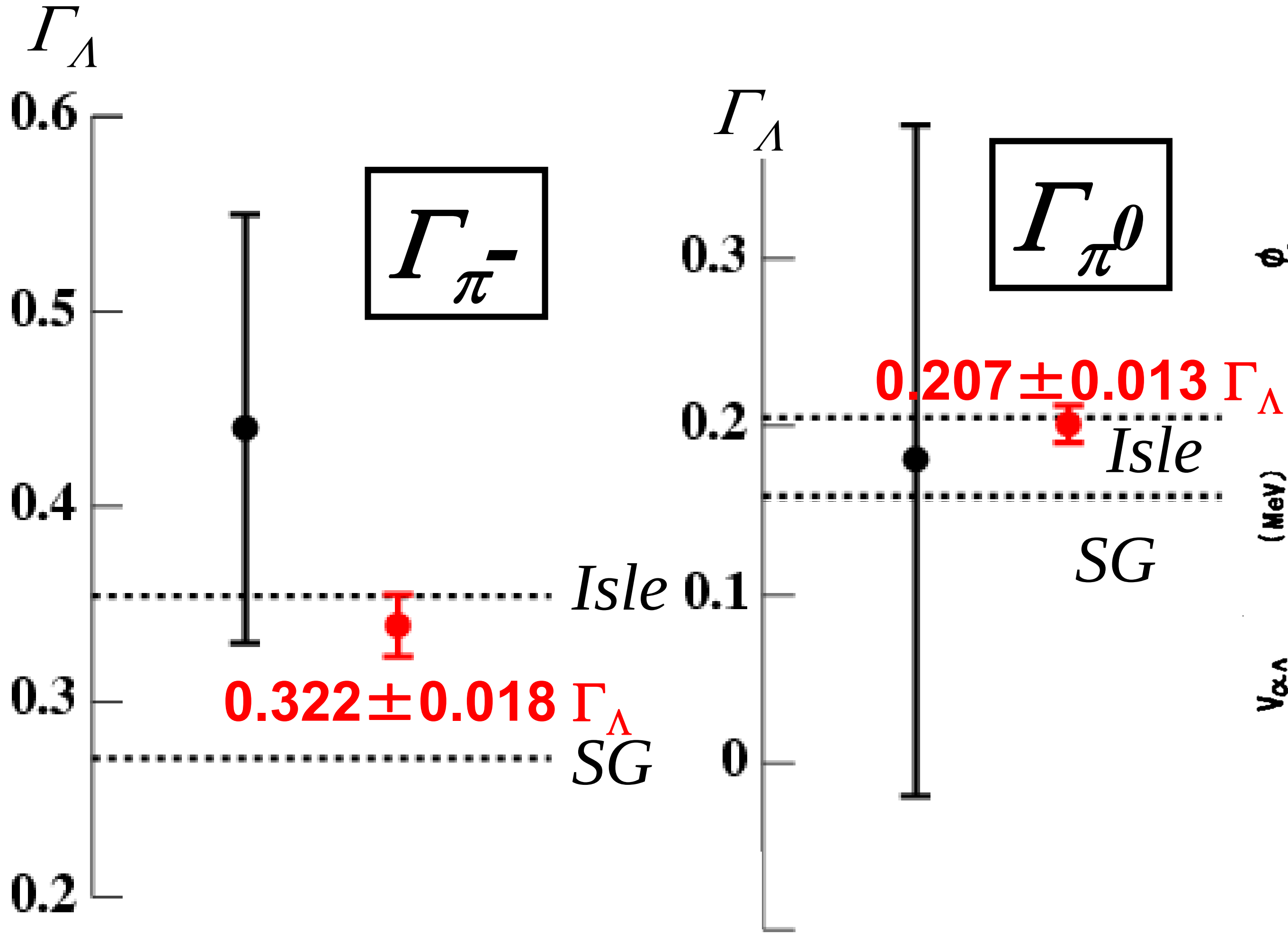
$$\Gamma nm = 1/\tau \times Br(NMWD)$$

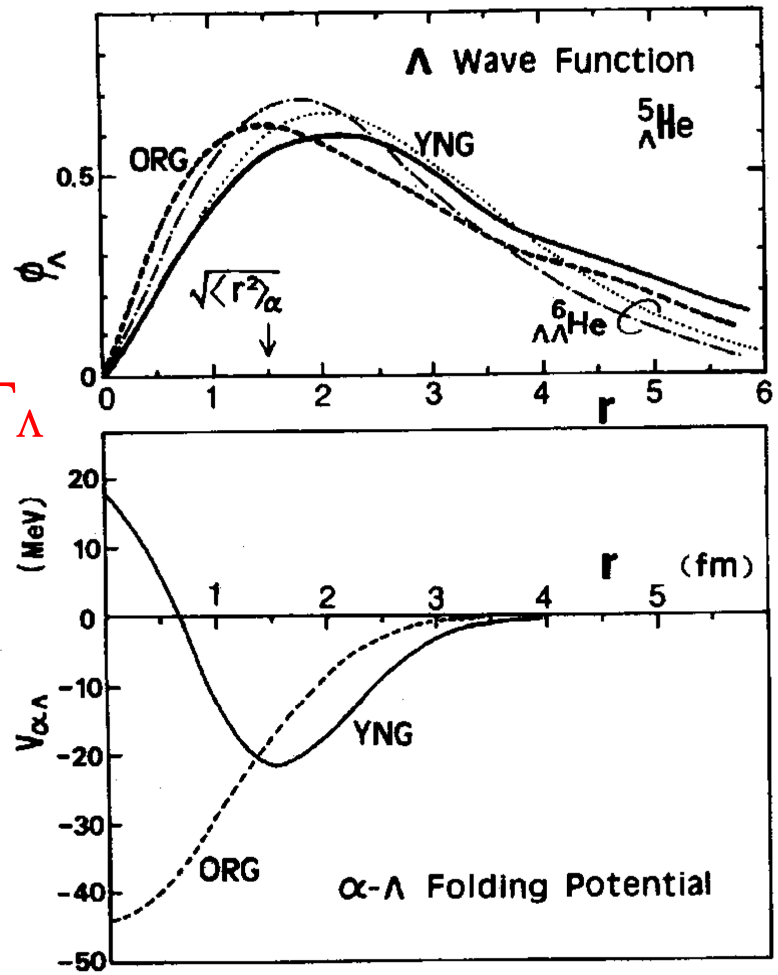




$$b_{\pi^0} = N\,(w/\ \gamma)\ /\ N\,(inc)\ \times\ eff$$
$$= 0.212 \pm 0.008$$

Γ_{π^-} and Γ_{π^0} for $^5_\Lambda He$

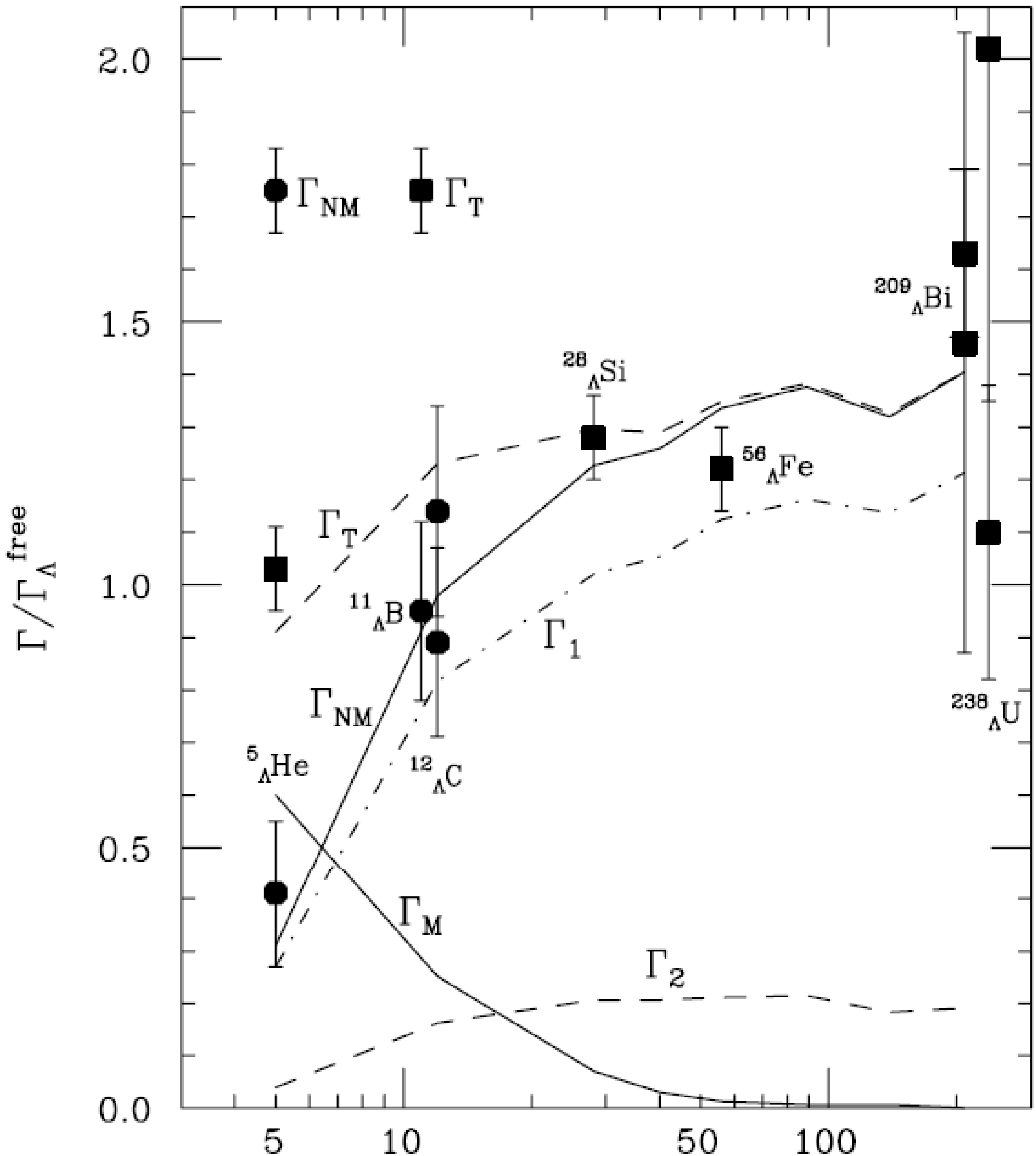




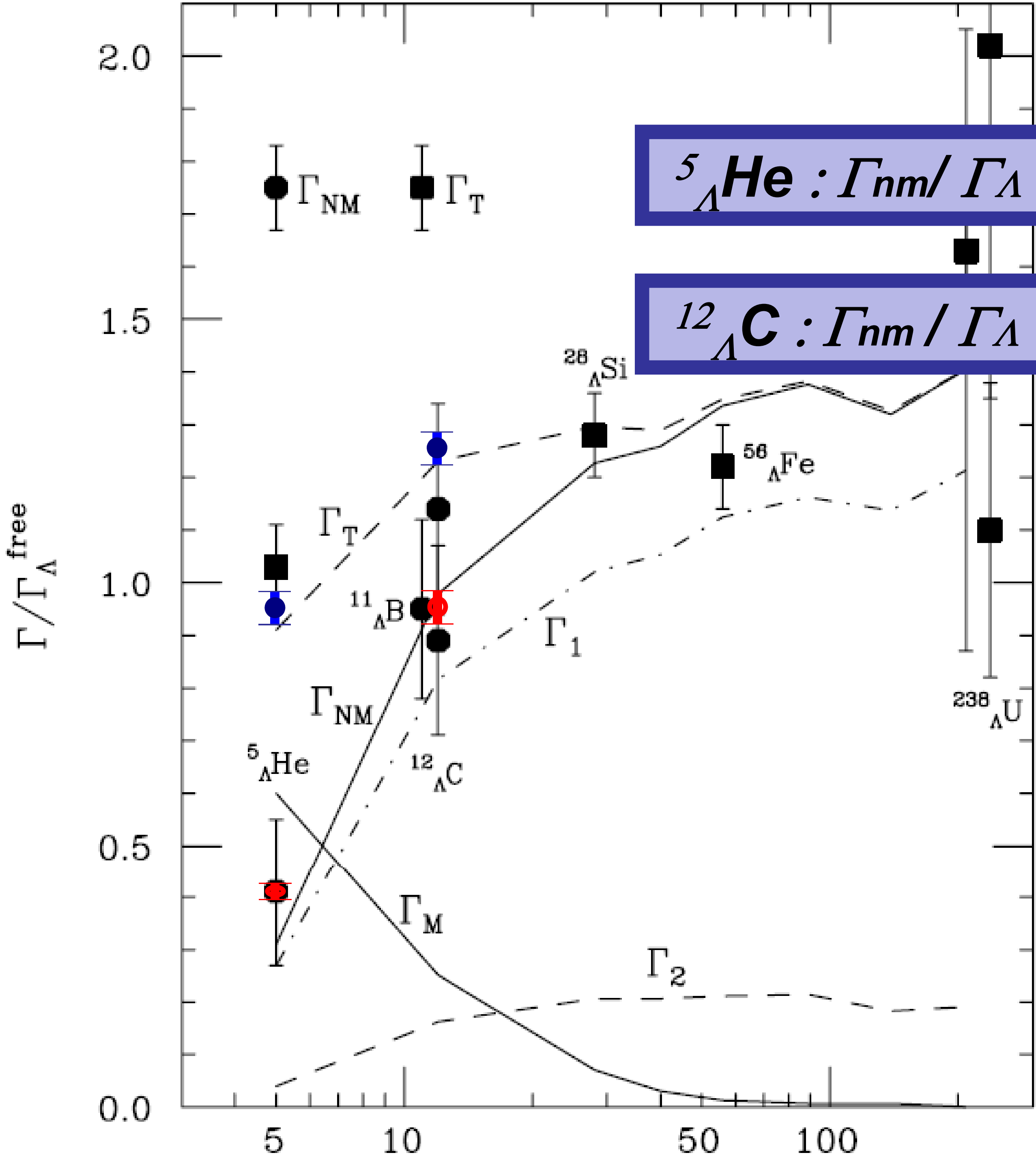
Measured with much improved accuracy

Λ-nucleus potential with inner repulsive core can reproduce present experimental results

Mass number dependence of Γ_{NM}



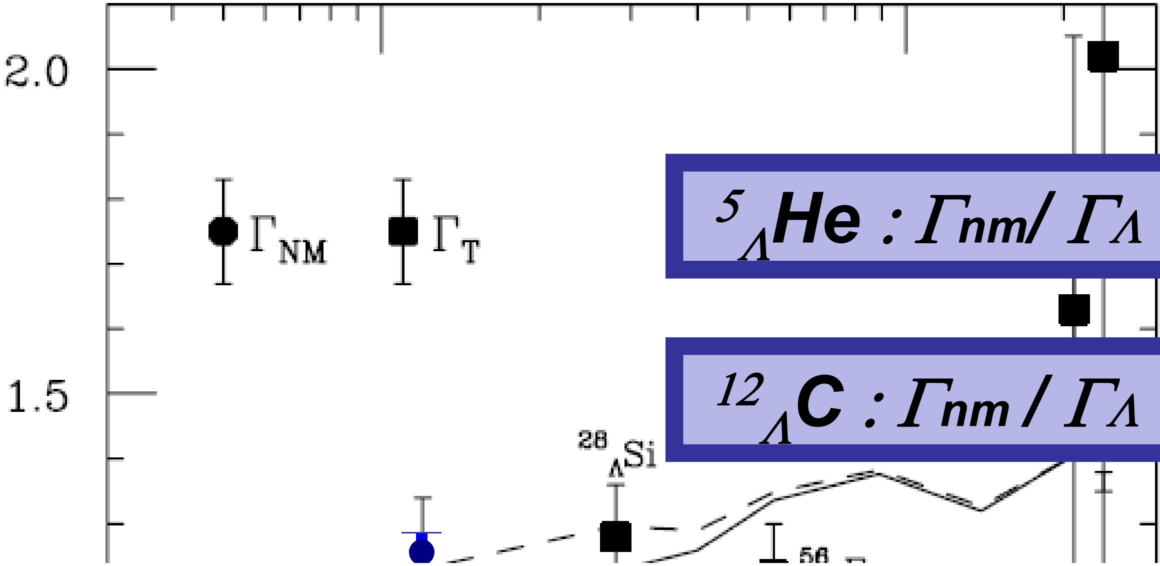
Mass number dependence of Γ_{NM}



$^{5}_{\Lambda}$**He** : $\Gamma_{nm}/\Gamma_\Lambda$ = **0.411±0.024**

$^{12}_{\Lambda}$**C** : $\Gamma_{nm}/\Gamma_\Lambda$ = **0.929±0.031**

Mass number dependence of Γ_{NM}

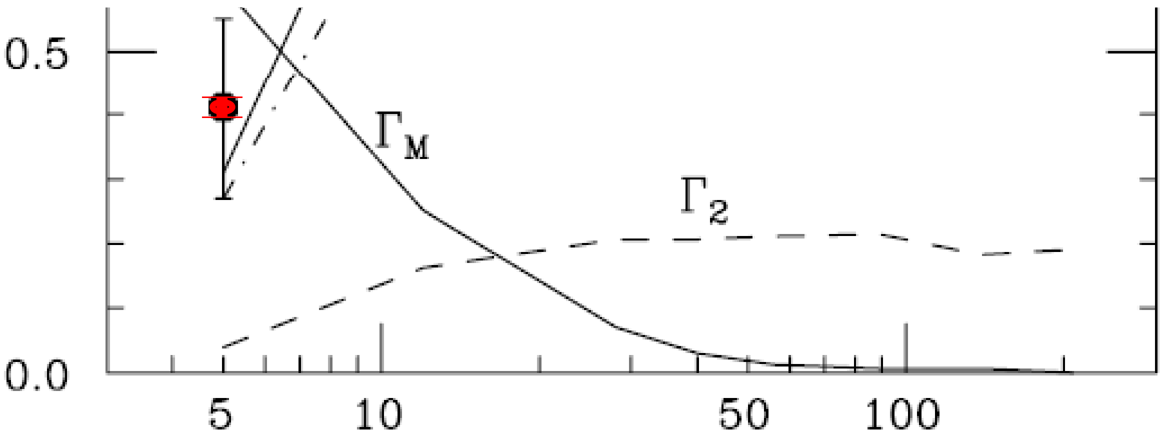


$^{5}{}_{\Lambda}$He : $\Gamma_{nm}/\Gamma_{\Lambda}$ = **0.411±0.024**

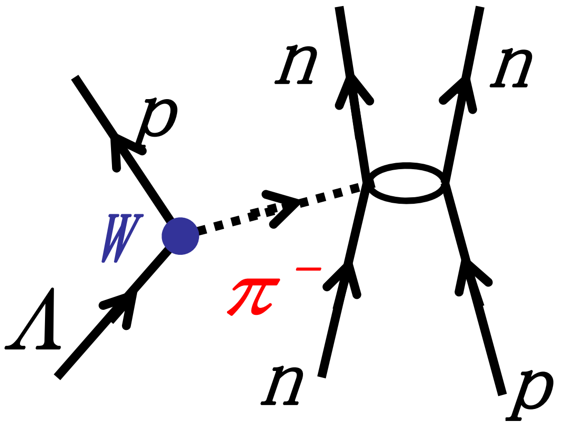
$^{12}{}_{\Lambda}$C : $\Gamma_{nm}/\Gamma_{\Lambda}$ = **0.929±0.031**

	Refs.	$\Gamma_{tot}/\Gamma_{\Lambda}$	$\Gamma_{\pi^-}/\Gamma_{\Lambda}$	$\Gamma_{\pi^0}/\Gamma_{\Lambda}$	$\Gamma_{nm}/\Gamma_{\Lambda}$
$^{5}_{\Lambda}$He (exp.)	[2]	1.03±0.08	0.44±0.11	0.18±0.20	0.41±0.14
$^{5}_{\Lambda}$He (ORG,SG)	[1][5]		0.321(ORG), 0.271(SG)	0.177(ORG), 0.158(SG)	
$^{5}_{\Lambda}$He (YNG,Isle)	[1][5]		0.393(YNG), 0.354(Isle)	0.215(YNG), 0.205(Isle)	
$^{12}_{\Lambda}$C (exp.)	[3][4]	1.14±0.08	0.113±0.015	0.200±0.068	0.828±0.087
$^{5}_{\Lambda}$He (exp.)	present	0.940 ± 0.040 ± 0.007	0.322 ± 0.018 ± 0.003	0.207 ± 0.012 ± 0.005	0.411 ± 0.023 ± 0.006
$^{12}_{\Lambda}$C (exp.)	present	1.213 ± 0.034 ± 0.009	0.120 ± 0.014 ± 0.005 [3]	0.164 ± 0.008 ± 0.004	0.929 ± 0.027 ± 0.016

Table 1: Theoretical calculations and experimental results of Γ_{tot}, Γ_{π^-}, Γ_{π^0} and Γ_{nm}.



ΛNN→NNN consideration



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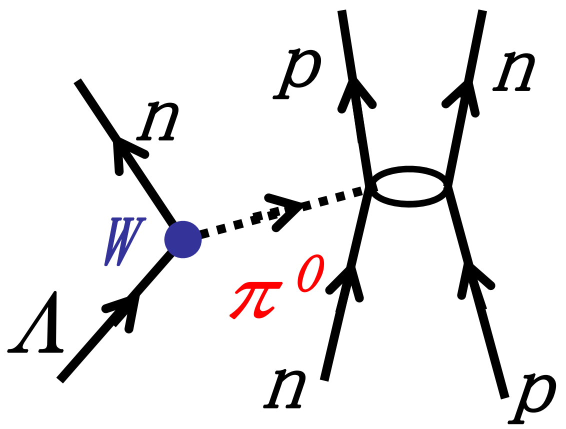
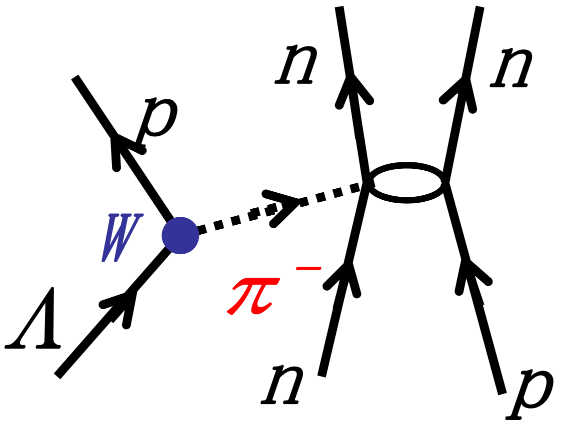


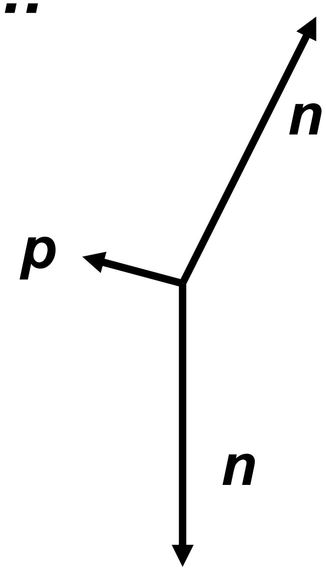
1

ΛNN→NNN consideration

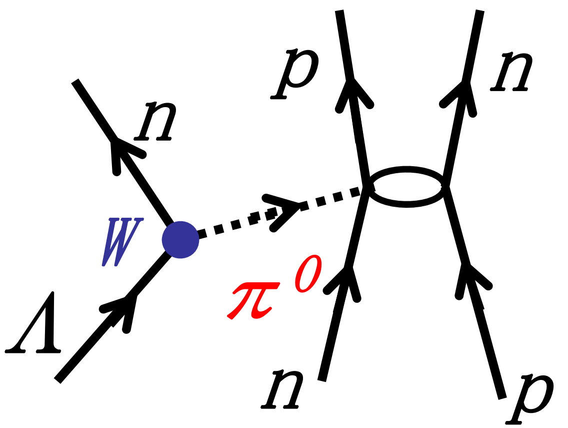


4

Seen as….



Λn→nn like



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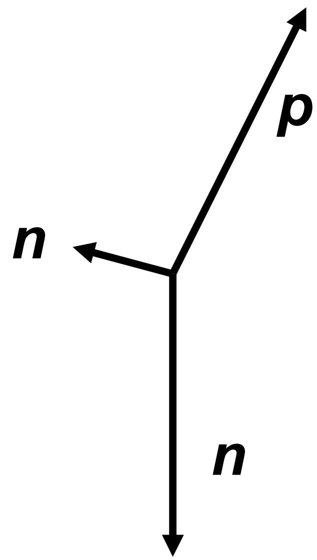
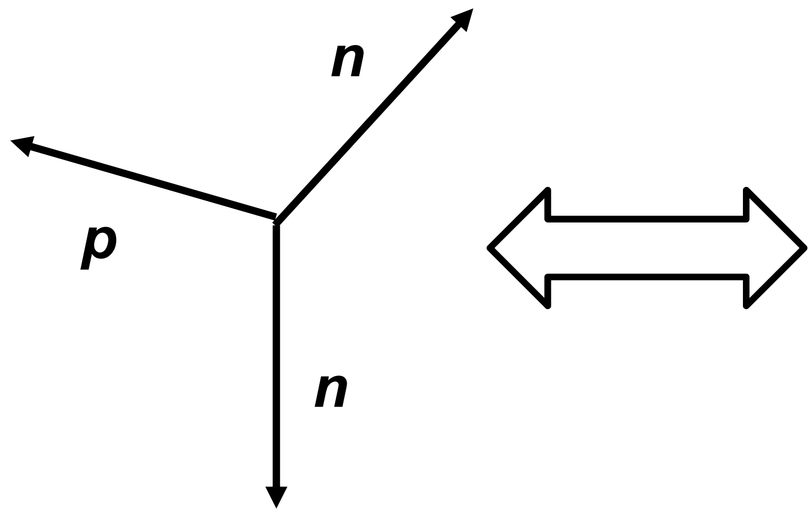
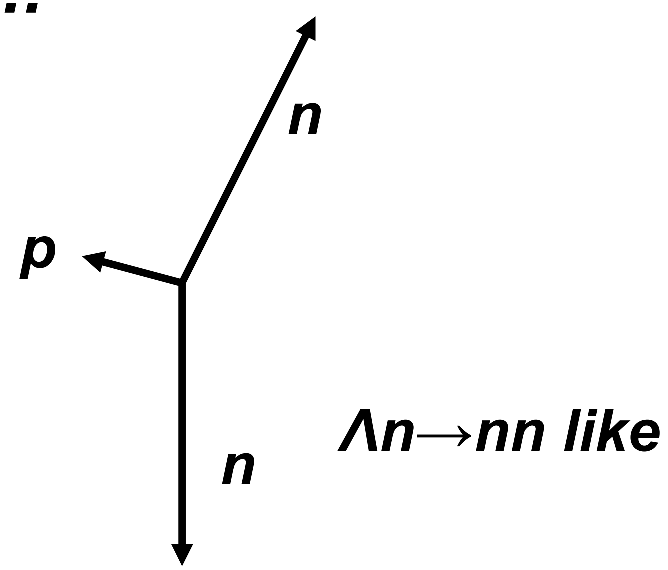


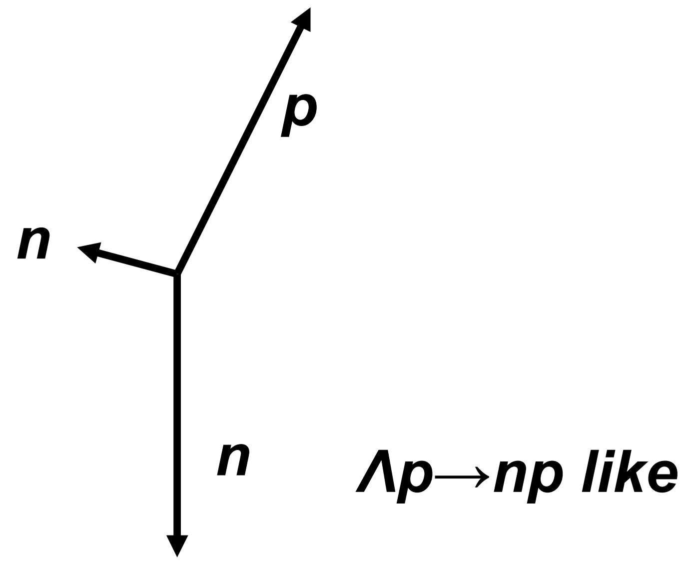
Λp→np like

ΛNN→NNN consideration

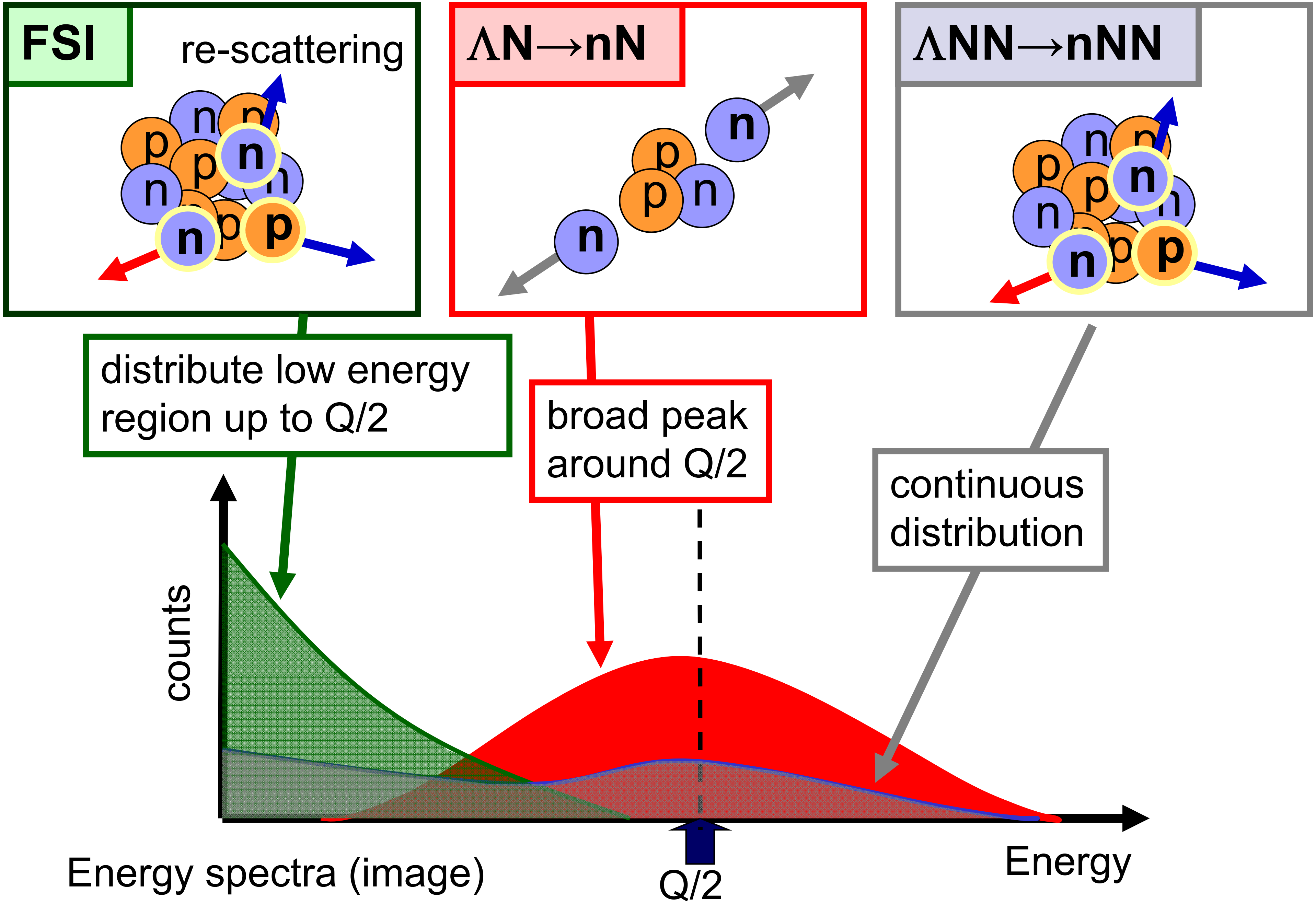


Seen as….



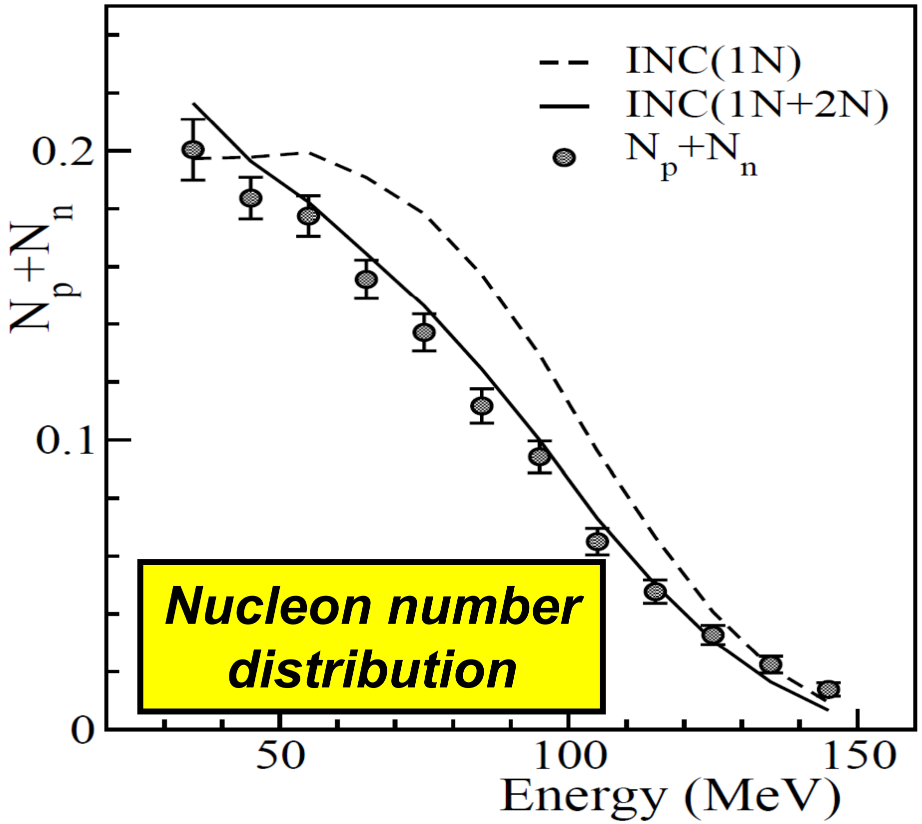


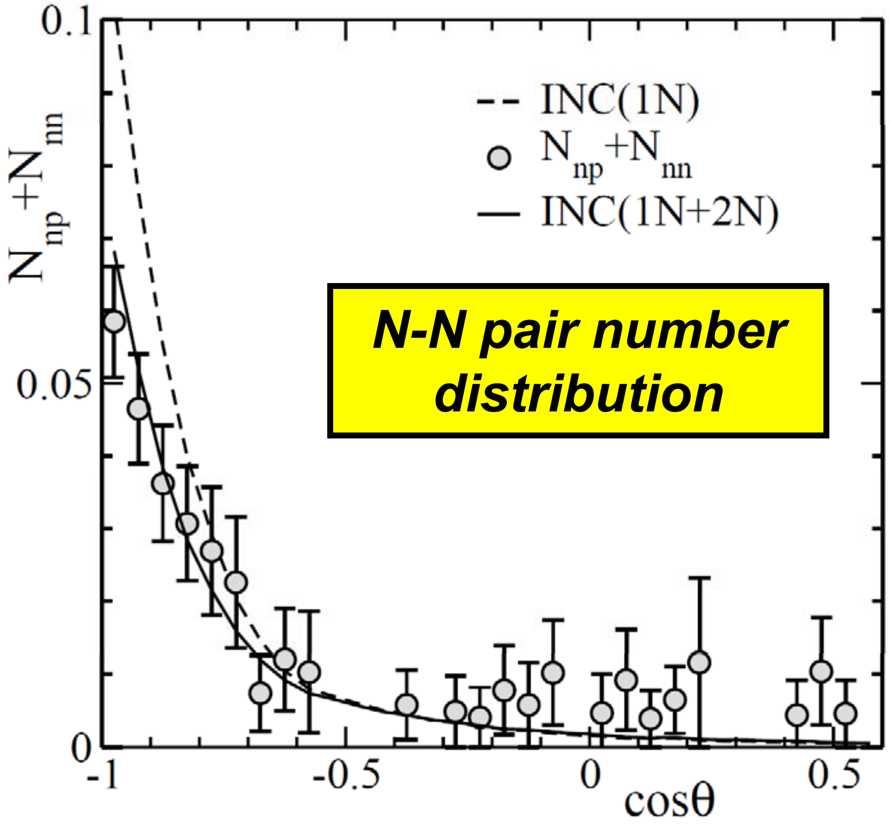
Expected Spectrum



N_n+N_p and (N_{nn}+N_{np}) back-to-back yield

- ✔ *When we summed up Nnn+Nnp (b-to-b) and Nn+Np the spectra becomes free from Γn/Γp ratio*
- ✔ *Both of Nnn+Nnp and Nn+Np yields are smaller than those of INC calculation with only ΛN→NN process (1N)*
- ✔ *ΛNN → NNN decay is assumed to occur uniformly in three-body phase space.*
- ✔ *Good agreement obtained when we assume $\Gamma_{2N}/\Gamma_{nmwd} = 0.29 \pm 0.13$*





N_n+N_p and $(N_{nn}+N_{np})$ back-to-back yield

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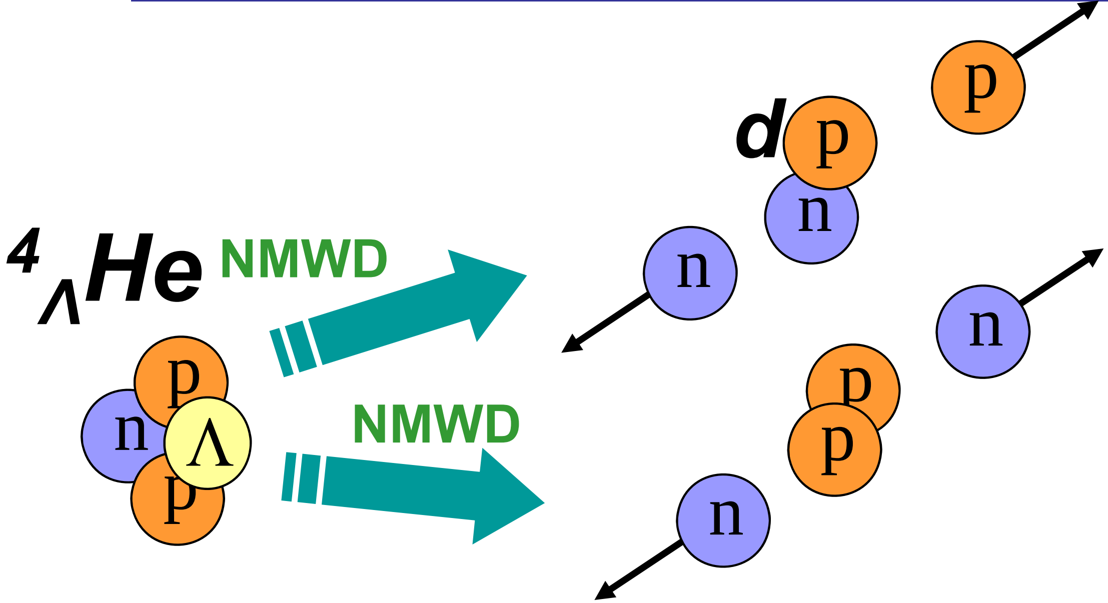
TABLE I: Branching ratios and decay widths of NMWD of ${}^{12}_{\Lambda}C$ are measured and compared with the current theoretical values. The bold letters are the present results determined along with Γ_{2N} in this work. The unit of the widths is Γ_Λ.

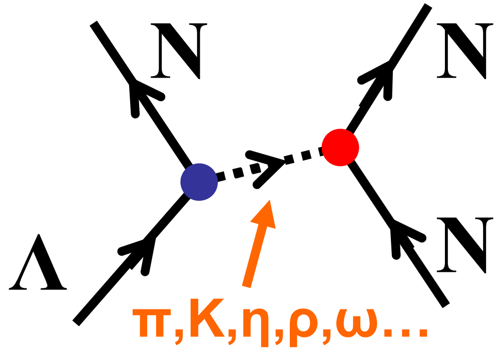
	Present Experiment	Theory Bauer[9]	Jido[18]	Itonaga[19]
Γ_n/Γ_p	0.51±0.13±0.05 [4]	0.327	0.53	0.503
Γ_{nm}	0.95±0.04 [16, 17]	0.876		
b_{2N}	**0.29 ± 0.13**	0.288		
Γ_{2N}	**0.27 ± 0.13**	0.252		
Γ_{1N}	**0.68 ± 0.13**	0.624	0.769	0.660
Γ_n	**0.23 ± 0.08**	0.154	0.265	0.222
Γ_p	**0.45 ± 0.10**	0.470	0.504	0.438

M. Kim, PRL submitted
Parallel 2-B (Sep. 17)

Non-mesonic weak decay of $^{4}_{\Lambda}He$ (E549)



Meson Exchange mechanism



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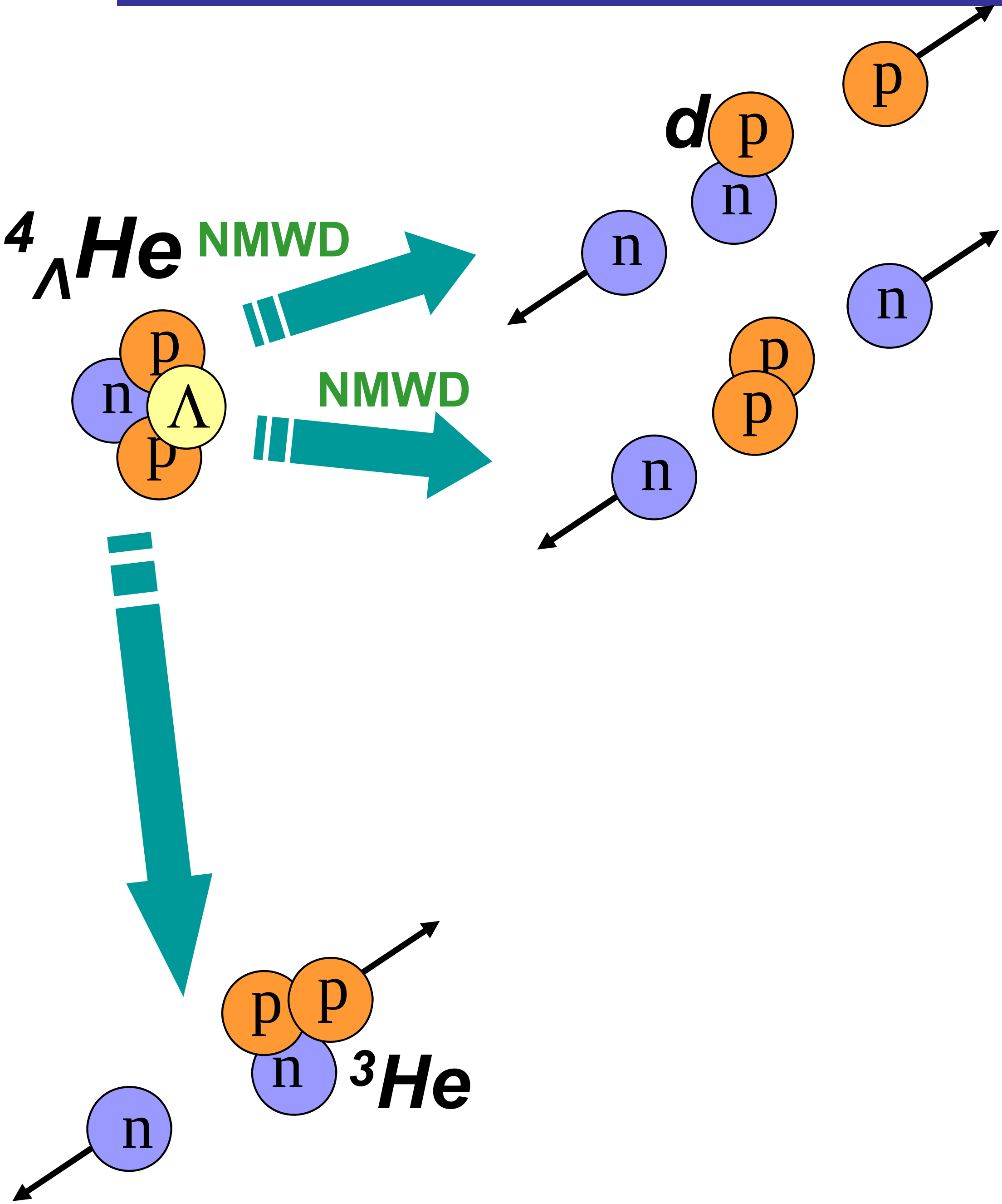

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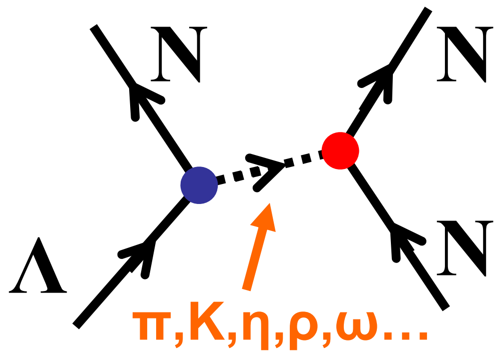

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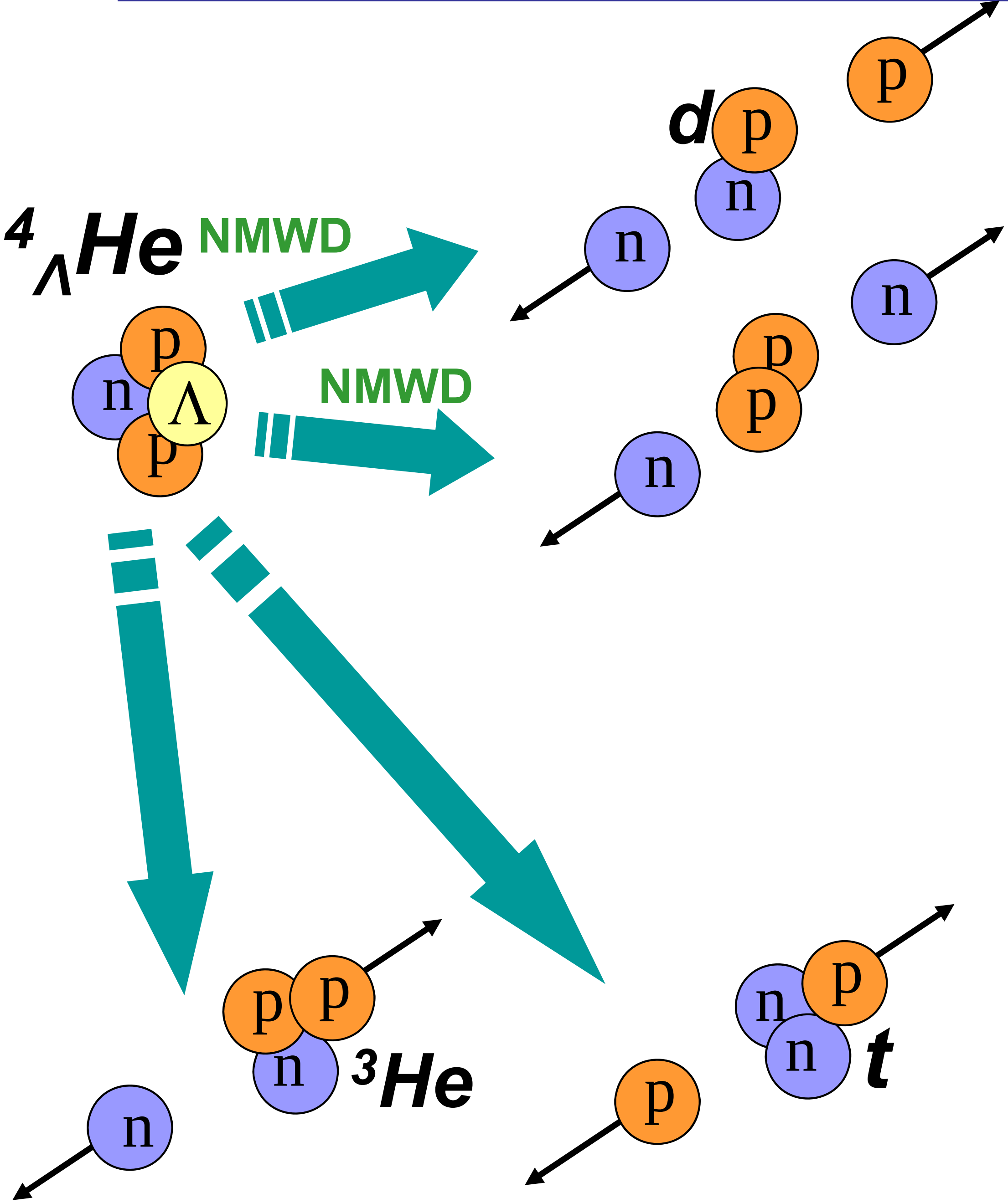

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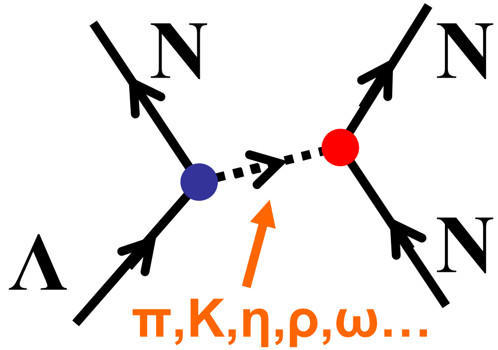
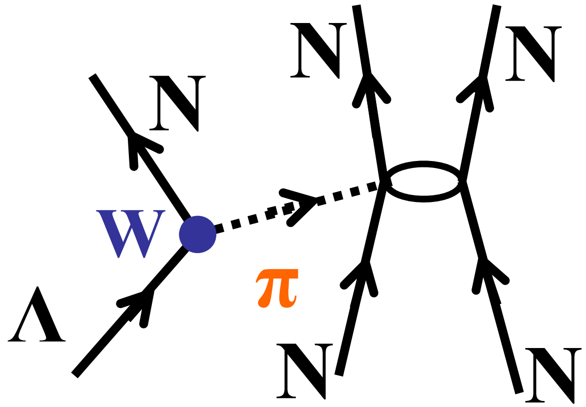
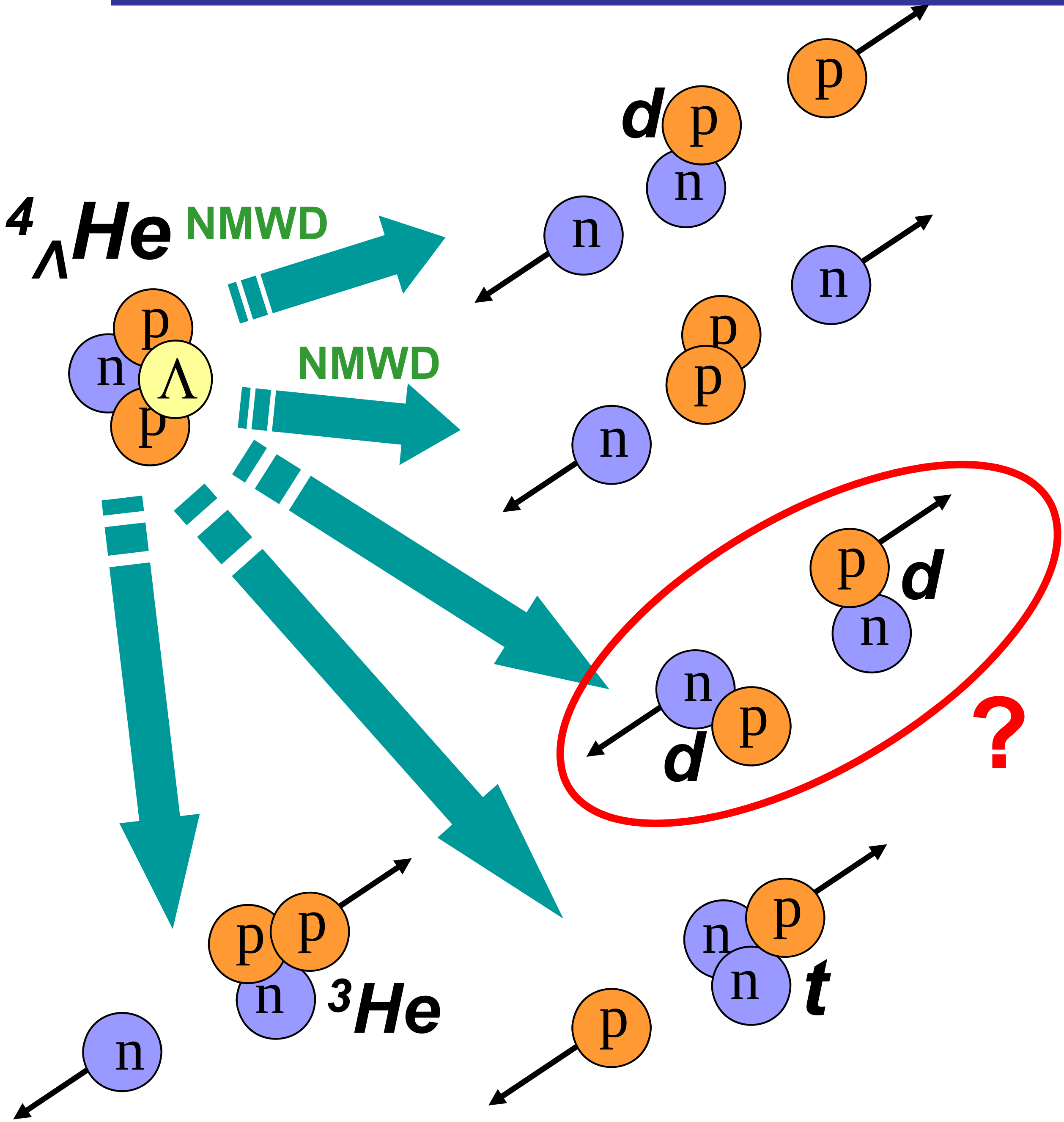


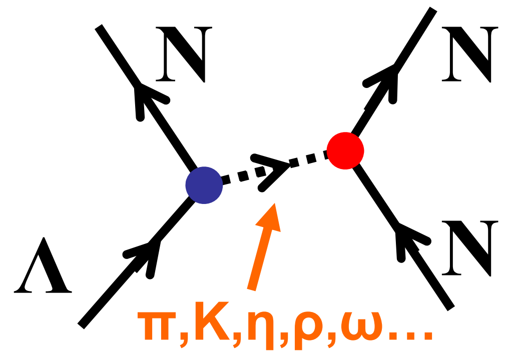
ΛNN→NNN (2N-induced process)



Non-mesonic weak decay of $^{4}_{\Lambda}He$ (E549)



Meson Exchange mechanism



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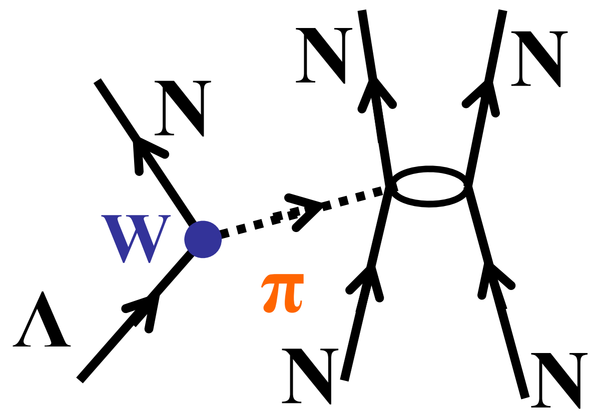
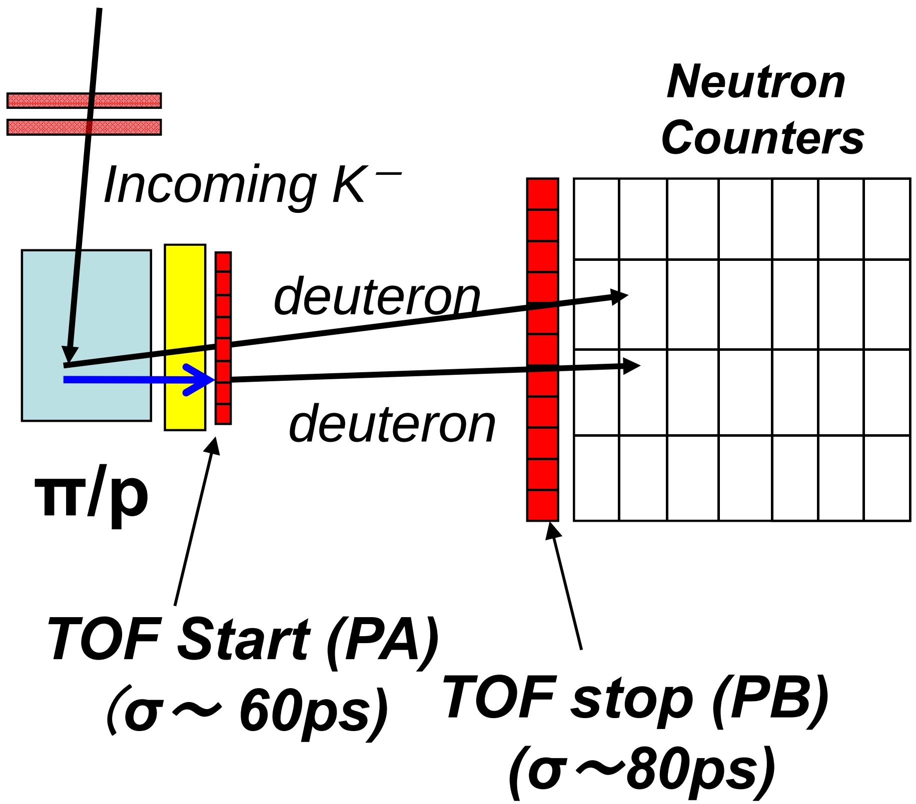
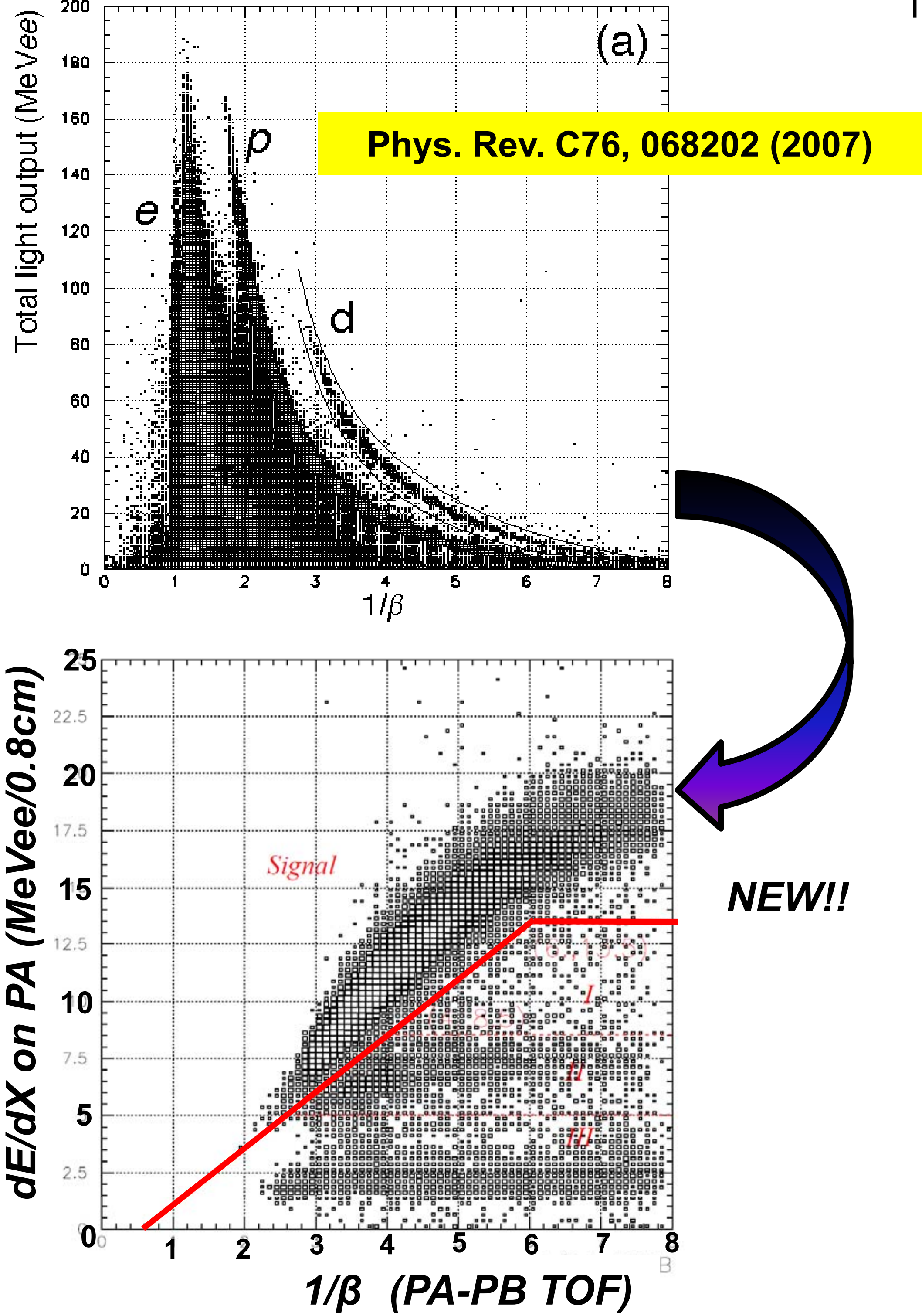
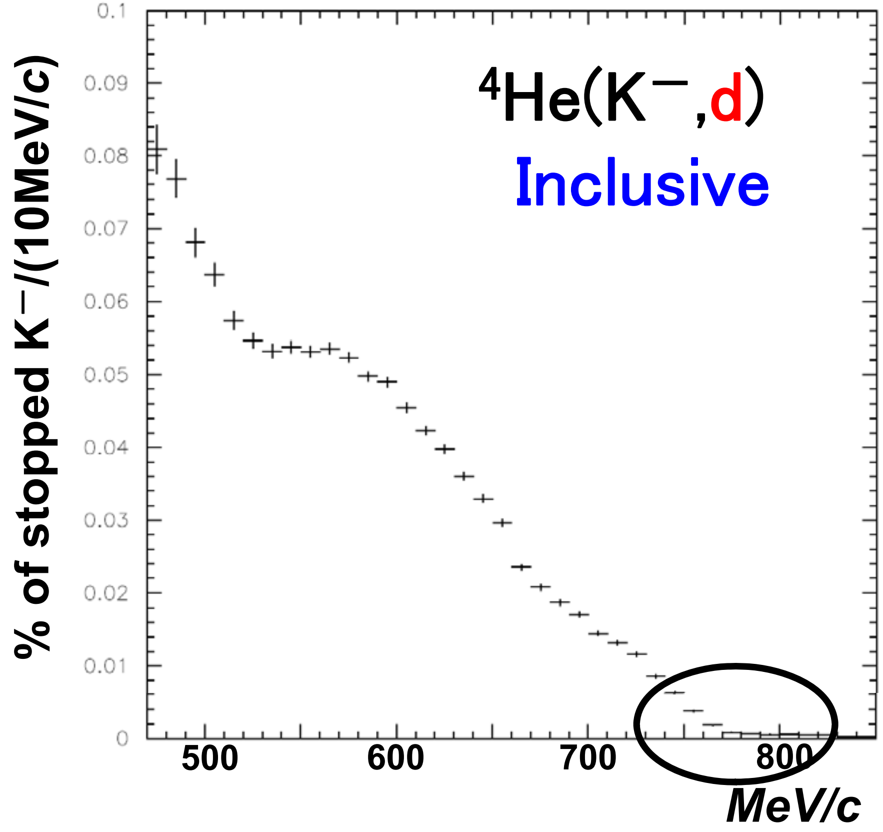


Deuteron identification



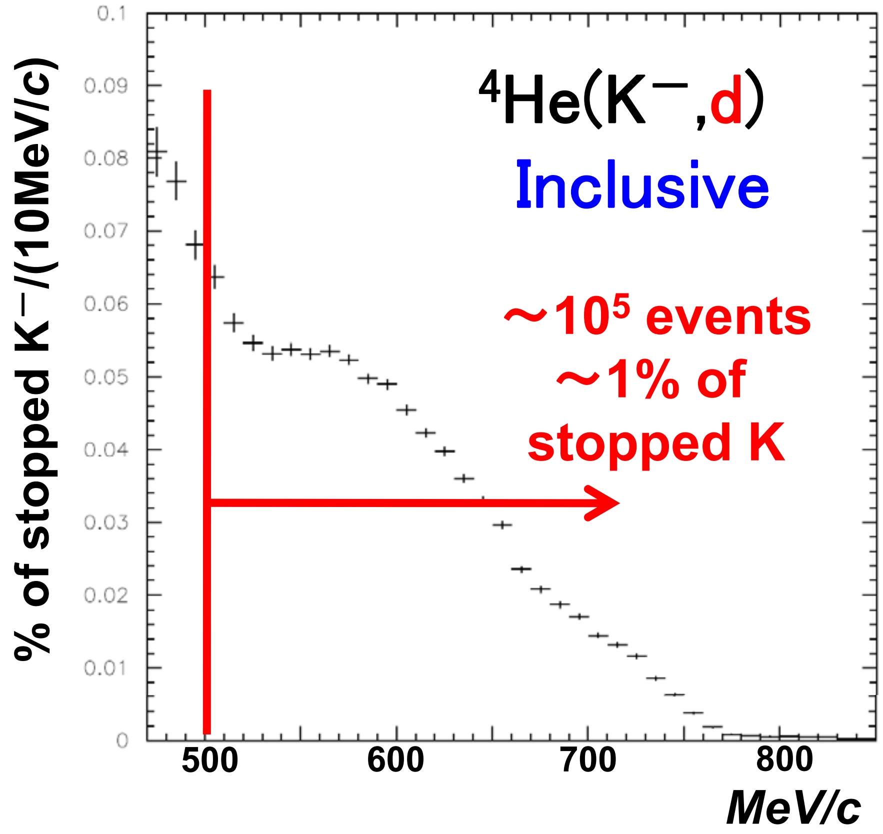


Deuteron momentum spectra



Deuteron momentum spectra

(1) P_d>500 MeV/c ＞2×P_{Fermi}
Abundant emission of fast deuterons:
hard to be explained by twice-pickup of nucleons with Fermi momentum



Deuteron momentum spectra

(1) P_d>500 MeV/c ＞2×P_{Fermi}
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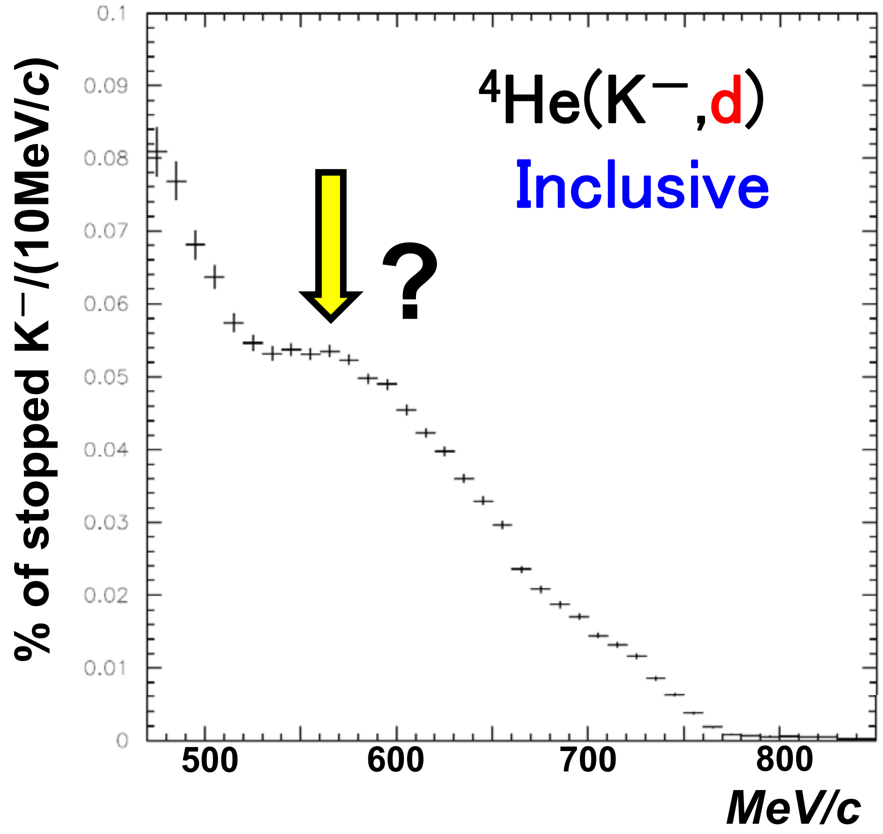
(2) Observation of back-to-back dd-pairs from stopped $^4{}_\Lambda He \rightarrow d + d$ (P_d = 571.8MeV/c)



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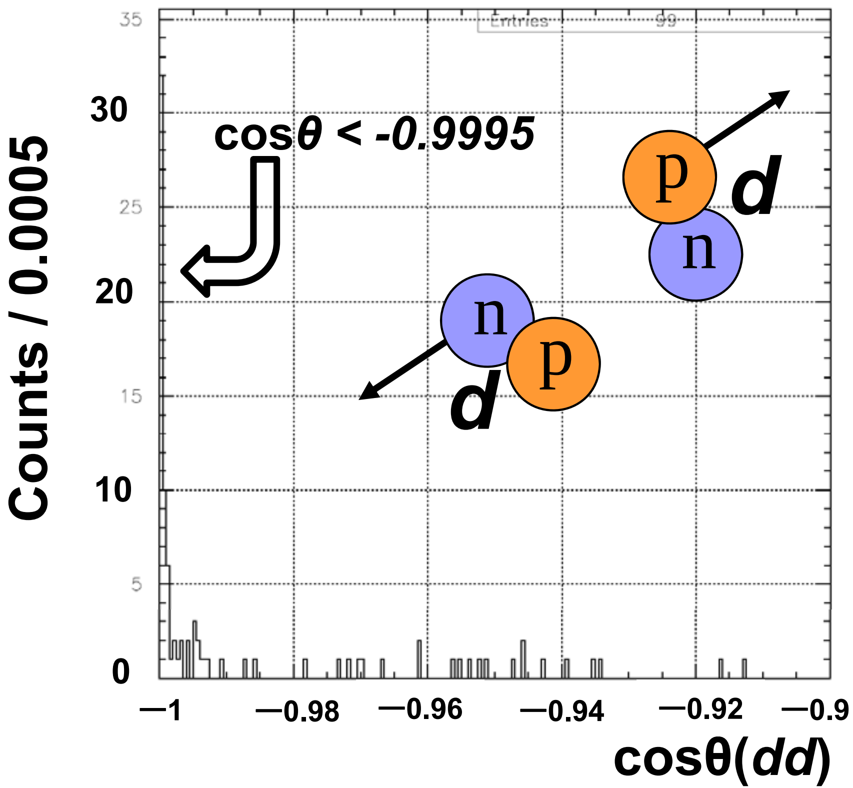

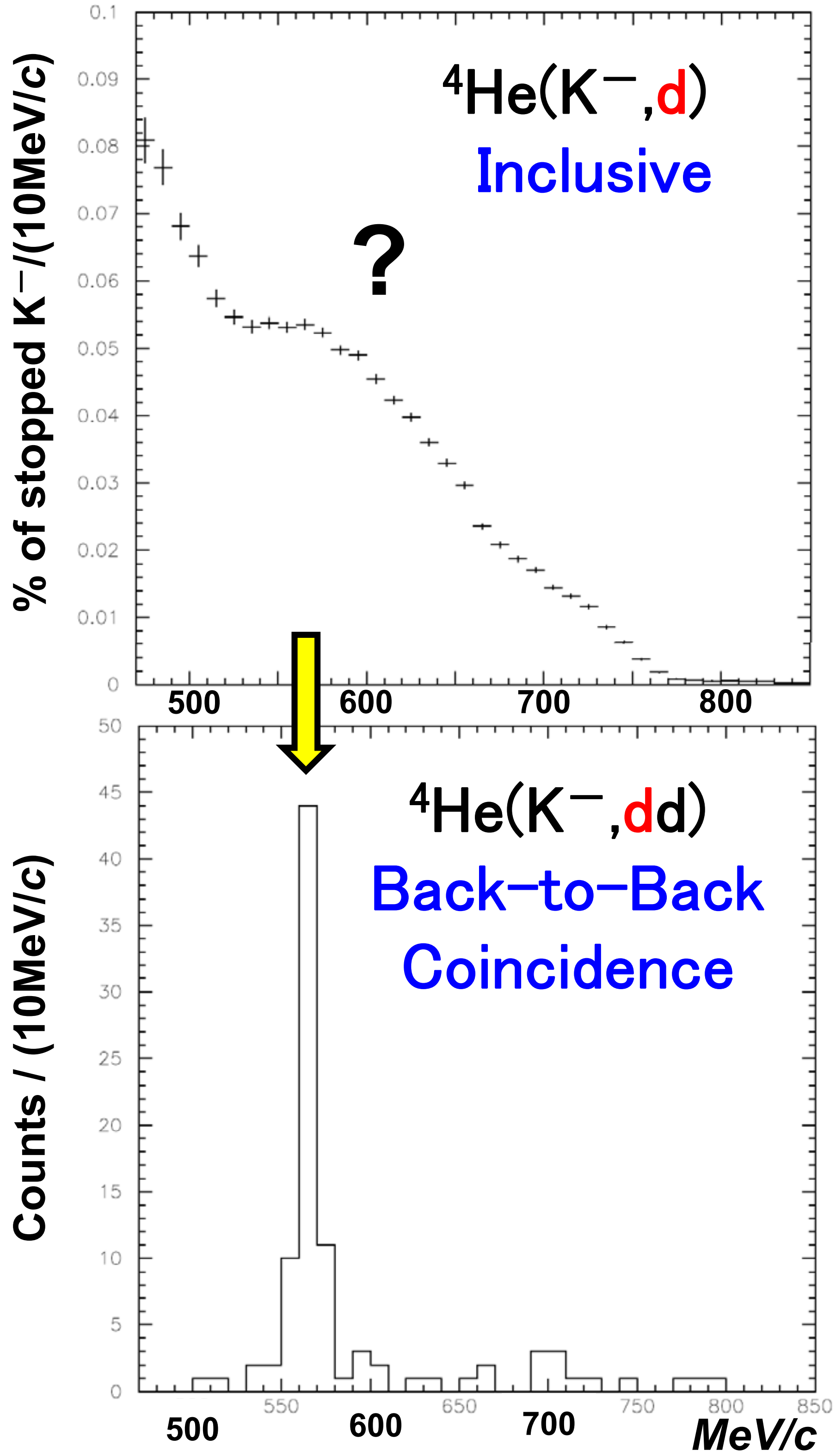

${}^{4}_{\Lambda}He \to d + d$ branching ratio

$$Br({}^{4}_{\Lambda}He \to d + d / stopK) = N_{DETECT} / \left(N_{stopK} \cdot \varepsilon_{DAQ} \cdot Acc\right)$$

N_{DETECT} = 60±10
ε_{DAQ} = 0.80
N_{stop} = 2.5×10^{8} (~14% error: ambiguity of metastable state branch)
Acc = 0.027 (Simulation including d reaction loss ; detector efficiency)

Br(${}^{4}_{\Lambda}$He → d+d) = 1.1±0.3 × 10^{-5}/stopped K^{-}

Br(K^{-}+ ^{4}He → ${}^{4}_{\Lambda}$He + π^{-})=1.79±0.15 × 10^{-2} /stopped K^{-}

$\Gamma_{nmwd}/\Gamma_{total}$ = 0.163±0.049

Br(${}^{4}_{\Lambda}$He) = 1790±150 × 10^{-5}/stopped K^{-}

Br(${}^{4}_{\Lambda}$He NMWD) = 290±90 × 10^{-5}/stopped K^{-}

Br(${}^{4}_{\Lambda}$He → d+d) = 1.1±0.3 × 10^{-5}/stopped K^{-}

6×10^{-4}

Summary

- $\Lambda N \to NN$ was directly observed for the first time
  $\Gamma(\Lambda n \to nn)/\Gamma(\Lambda p \to np) \sim 0.5$
  $\alpha_{nm} \sim 0$
- Total & partial decay rates are measured accurately
- Quenching of ($N_{nn}+N_{np}$) back-to-back and N_n+N_p yield in high energy region suggests large contribution of $\Lambda NN \to NNN$ (~30% of total NMWD width)

⇓

[1] Inner repulsive core in Λ-nucleus potential
[2] Importance of shorter-range mechanism
OPE ⇒ Heavy meson & DQ exchange
[3] Suggesting significant contribution from $\Lambda NN \to NNN$

Observation of $^4_\Lambda He \to d+d$ rare non-mesonic decay with branching ratio $\sim 6 \times 10^{-4}$ at KEK-PS E549