Study of Non-Mesonic Weak Decay of Λ Hyper-nuclei and 3-Body Processes

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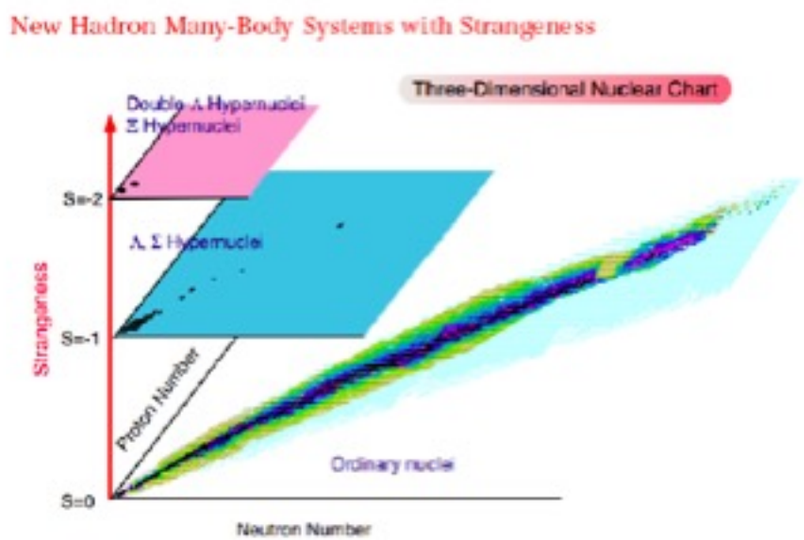
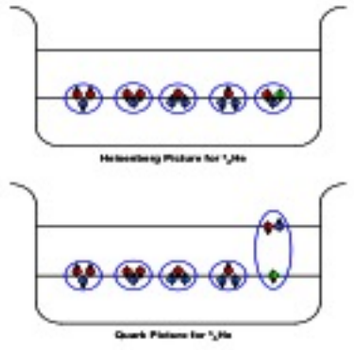
Overview

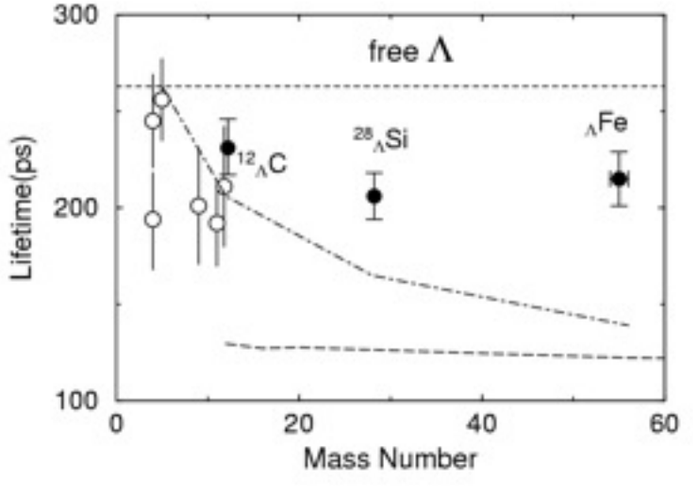
- Hypernuclear physics
- Non-Mesonic Weak Decay of Λ Hypernuclei
- Experiments at KEK-PS
- Challenges and New Experiment at J-PARC
- Summary

Hypernuclear Physics

- Why Hypernuclear Physics?
  - New dimension
  - Quark picture
  - Microlab for strong and weak interactions
- Some Issues of Hypernuclear Physics
  - $\Lambda+N\longrightarrow\Lambda+N$ (Strong Interaction)
    - Hypernuclear γ spectroscopy
  - $\Lambda+N\longrightarrow N+N$ (Weak Interaction)
  - Hadron property in nuclear medium
  - Long standing Γ_n/Γ_p puzzle







Decay Modes of Λ Hypernuclei

$\Gamma_{tot}(=1/\tau)$

- Γ_m
  - $\Gamma_{\pi^-}(\Lambda \rightarrow p\pi^-)$
  - $\Gamma_{\pi^0}(\Lambda \rightarrow n\pi^0)$

  } Mesonic

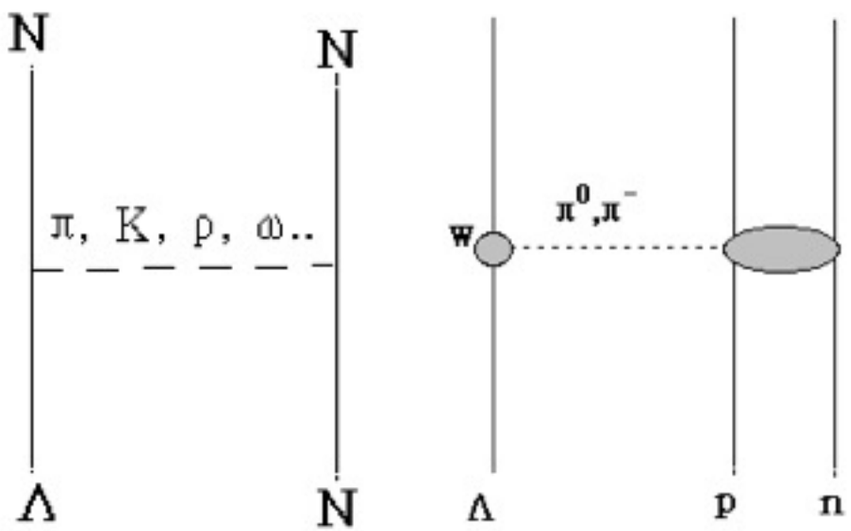
  q~ 100 MeV/c

- Γ_{nm}
  - $\Gamma_p(\Lambda p \rightarrow np)$ (1N)
  - $\Gamma_n(\Lambda n \rightarrow nn)$ (1N)
  - $\Gamma_{2N}(\Lambda NN \rightarrow nNN)$ (2N)

  } Nonmesonic

  q~ 400 MeV/c

Γ_n/Γ_p puzzle



3-Body Process;

Predicted theoretically

Status of NMWD of Λ hyper nuclei

- Fundamental Motivation
  - Study the elementary baryon-baryon weak interaction

$$\Lambda + N \longrightarrow N + N \quad (\Delta S = 1 \quad \text{B-B Weak Interaction})$$

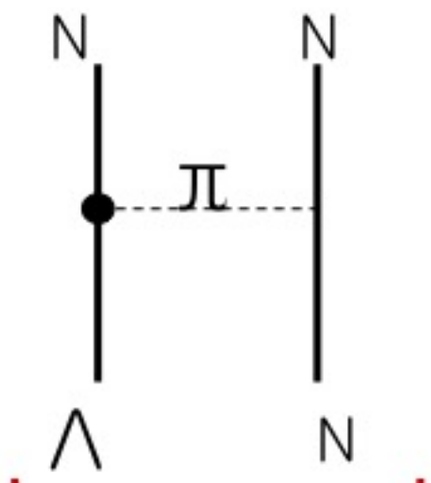
    - Γ_n/Γ_p and A_y have been mainly studied so far
- Outstanding Issues
  - Decay widths: Γ_n , Γ_p Γ_{2N} (3-body process)
  - Asymmetry
  - ΔI = 1/2 rule in NMWD

Γ_n/Γ_p Puzzle

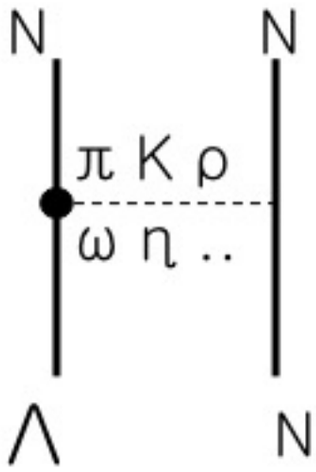
1. Γ_n/Γ_p Puzzle :

Γ_n/Γ_p^{exp} ⟷ $\Gamma_n/\Gamma_p^{th(OPE)}$

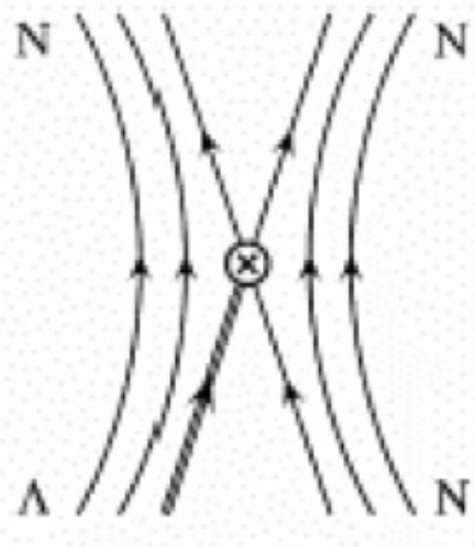
~1 ~0.1



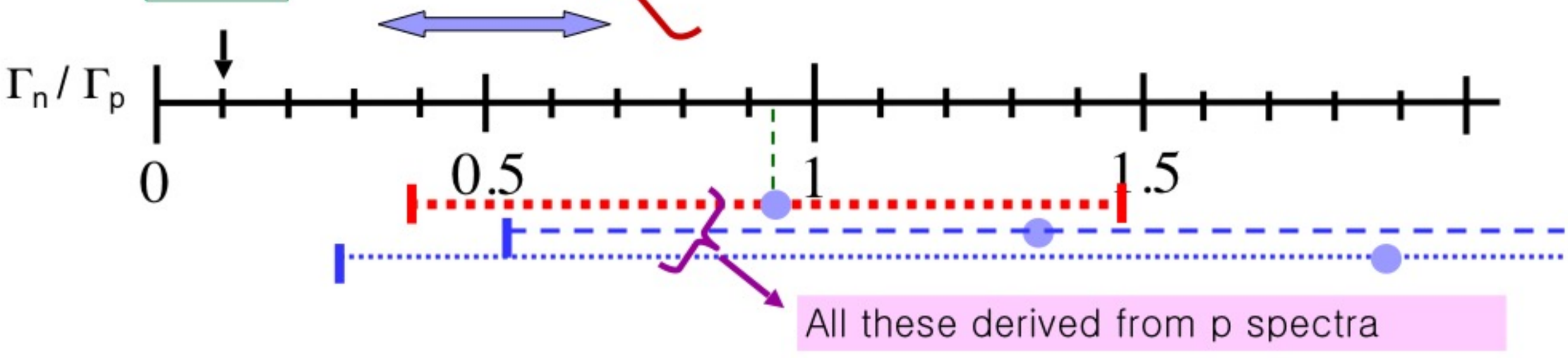
OPE



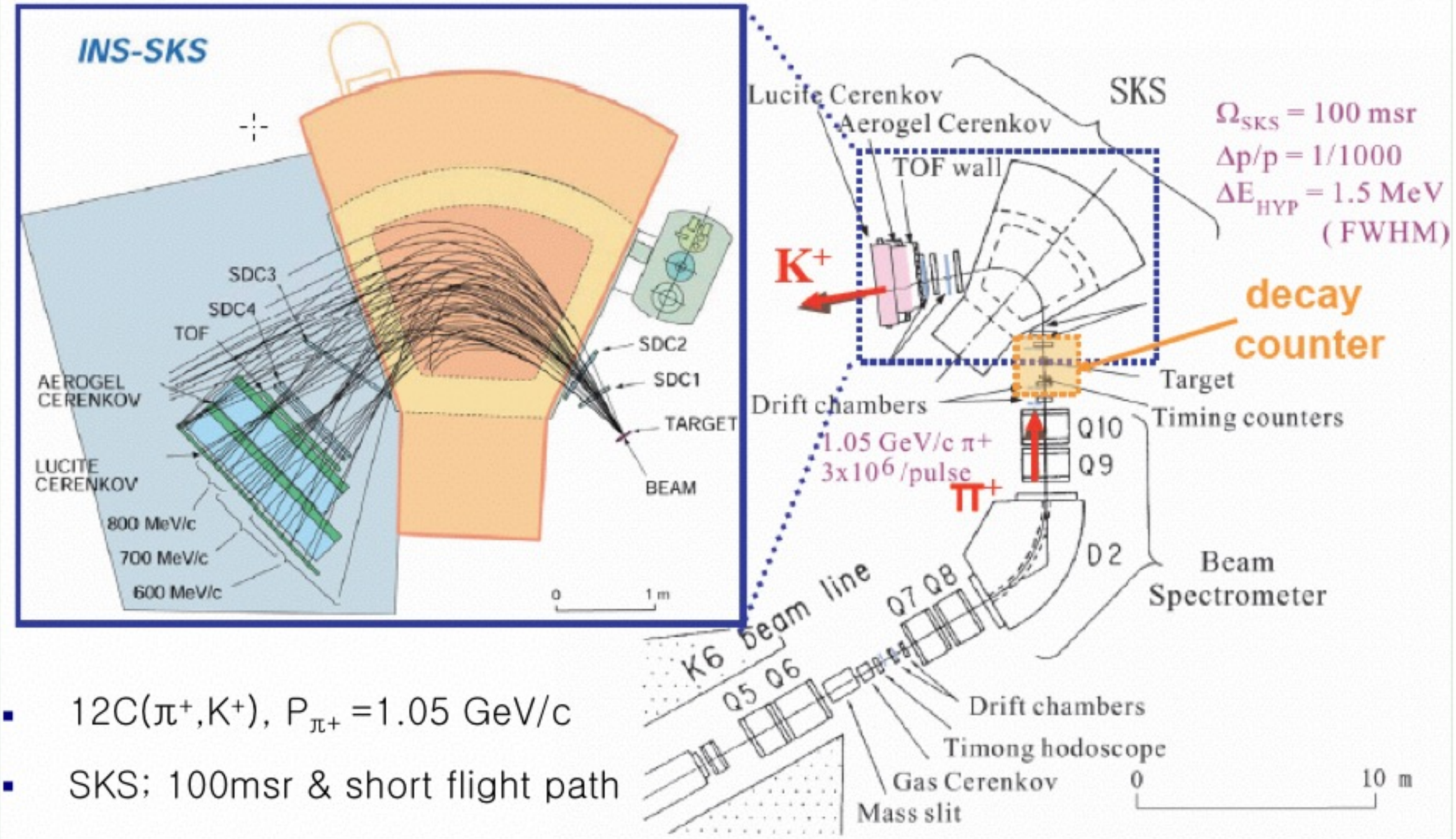
HME



DQ



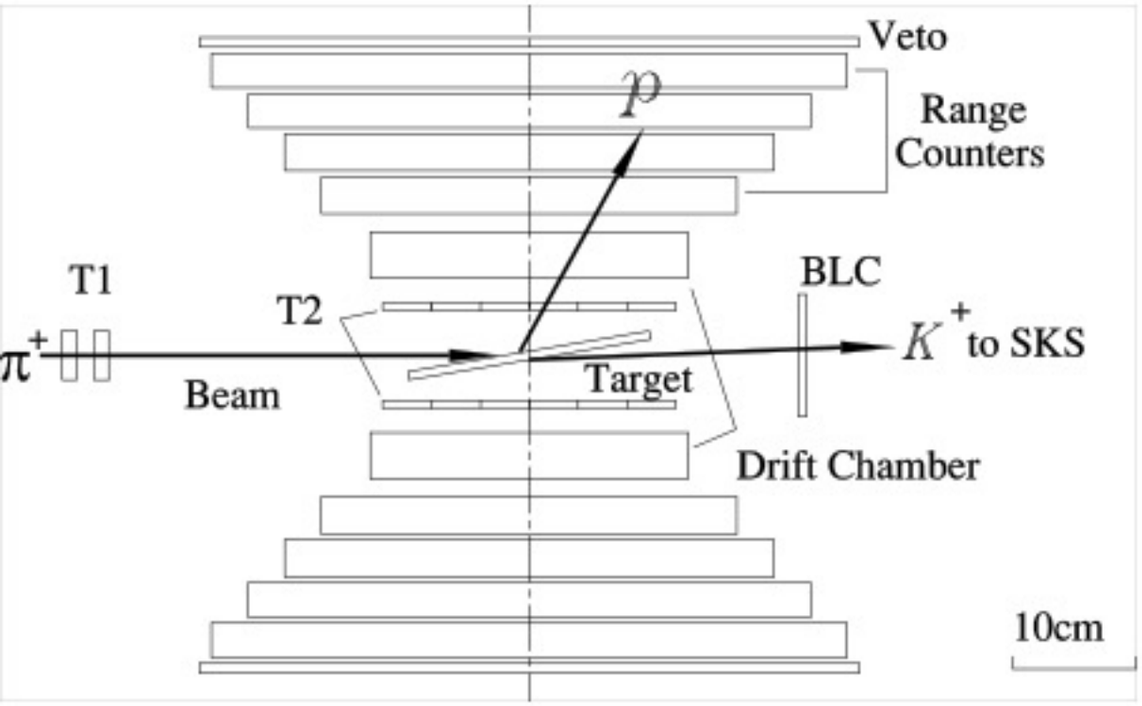
KEK-PS K6 Beamline & SKS Spectrometer



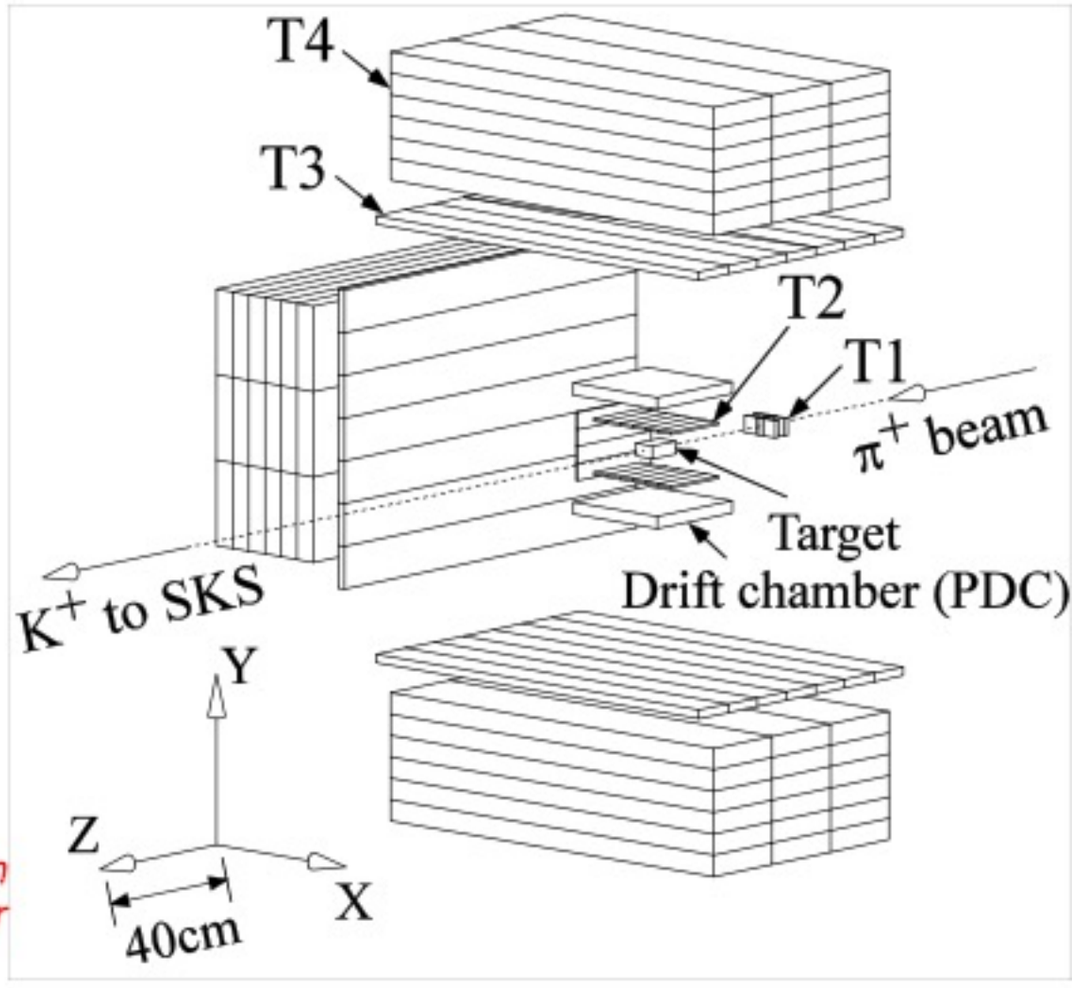
- 12C(π^+,K^+), $P_{\pi+}$ =1.05 GeV/c
- SKS; 100msr & short flight path

KEK-PS Experiments

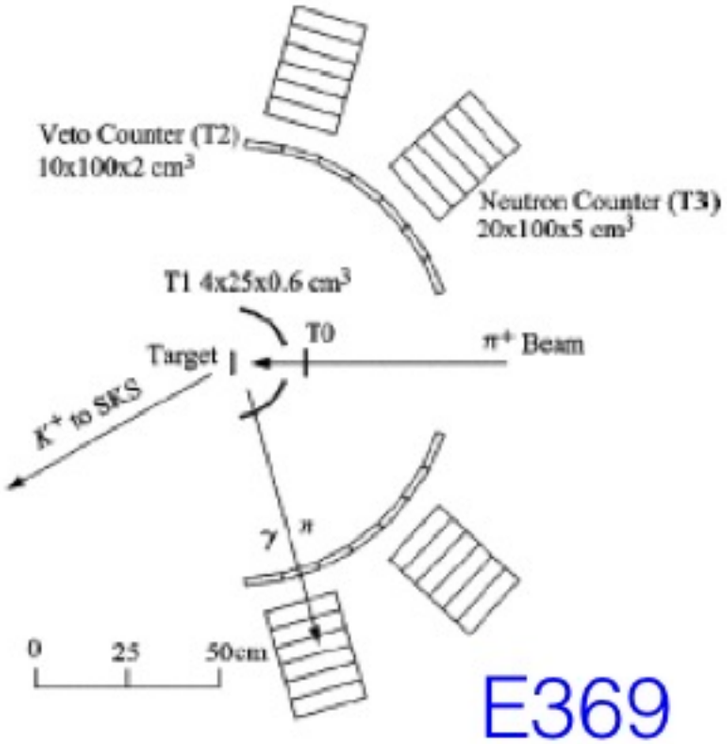
- E307: Proton singles from ${}^{12}_{\Lambda}\mathrm{C}$
- E369: Neutron singles from ${}^{12}_{\Lambda}\mathrm{C}$
- E462: pn coincidence from ${}^{5}_{\Lambda}\mathrm{He}$
- E508: pn coincidence from ${}^{12}_{\Lambda}\mathrm{C}$



E307

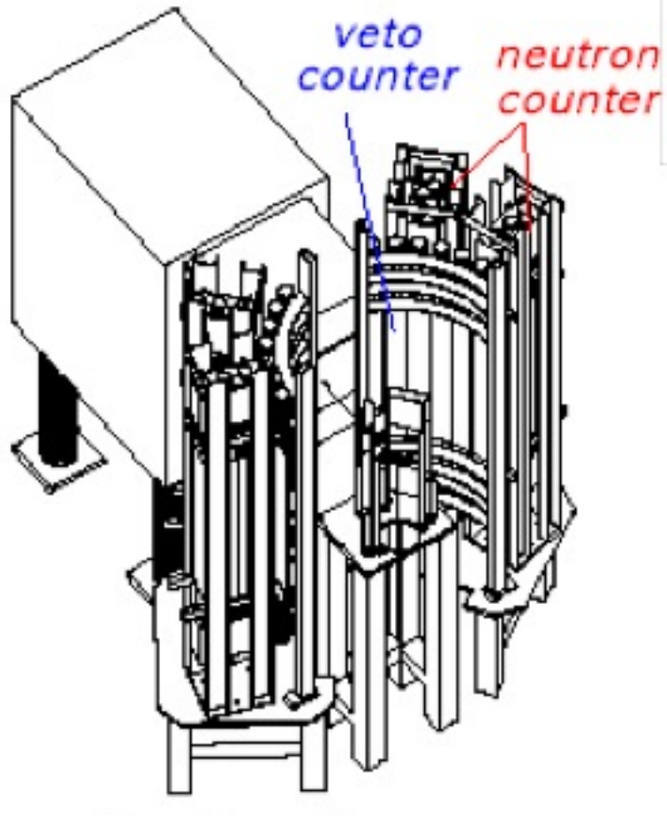


E462/E508



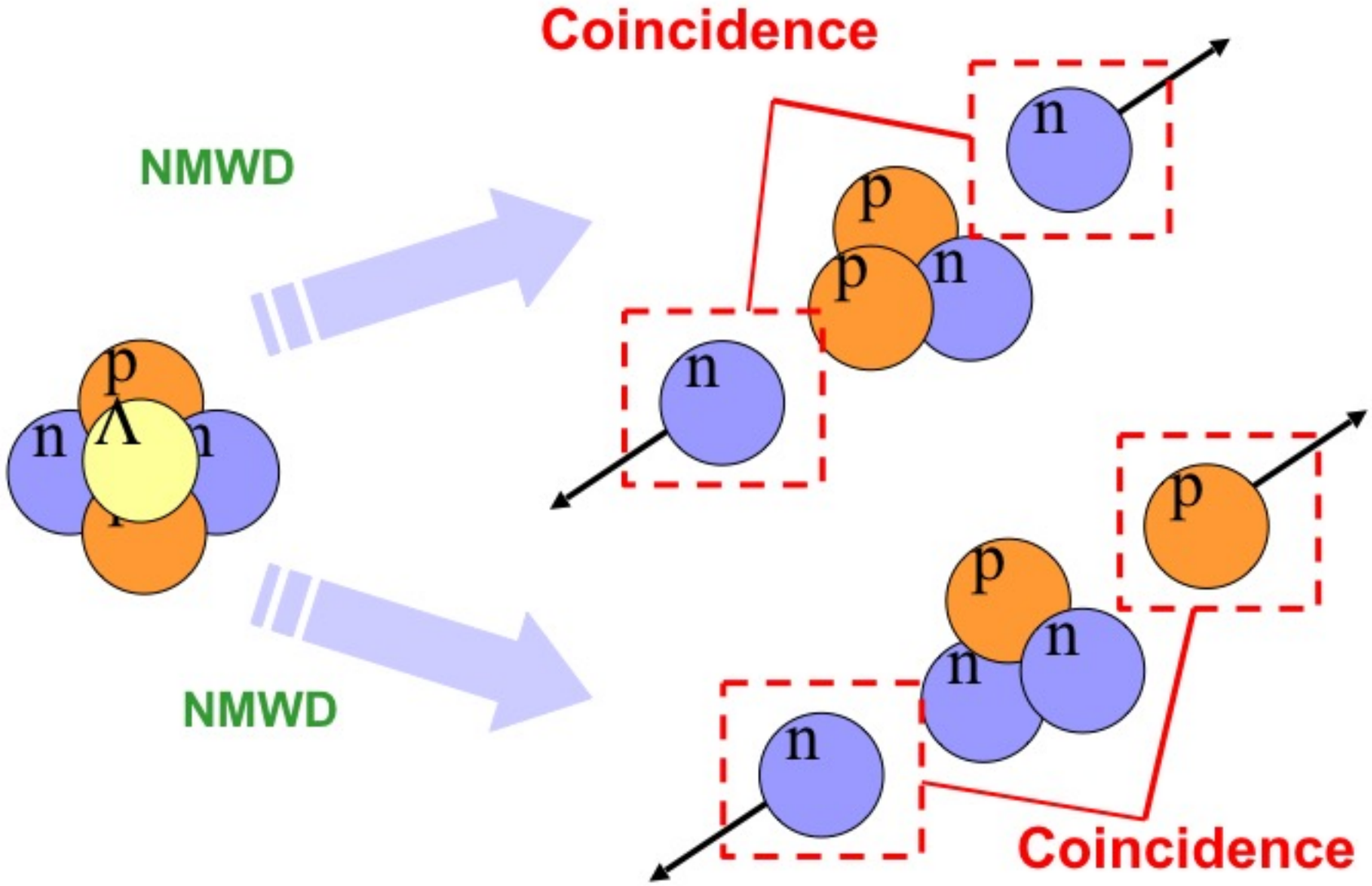
E369

Top view

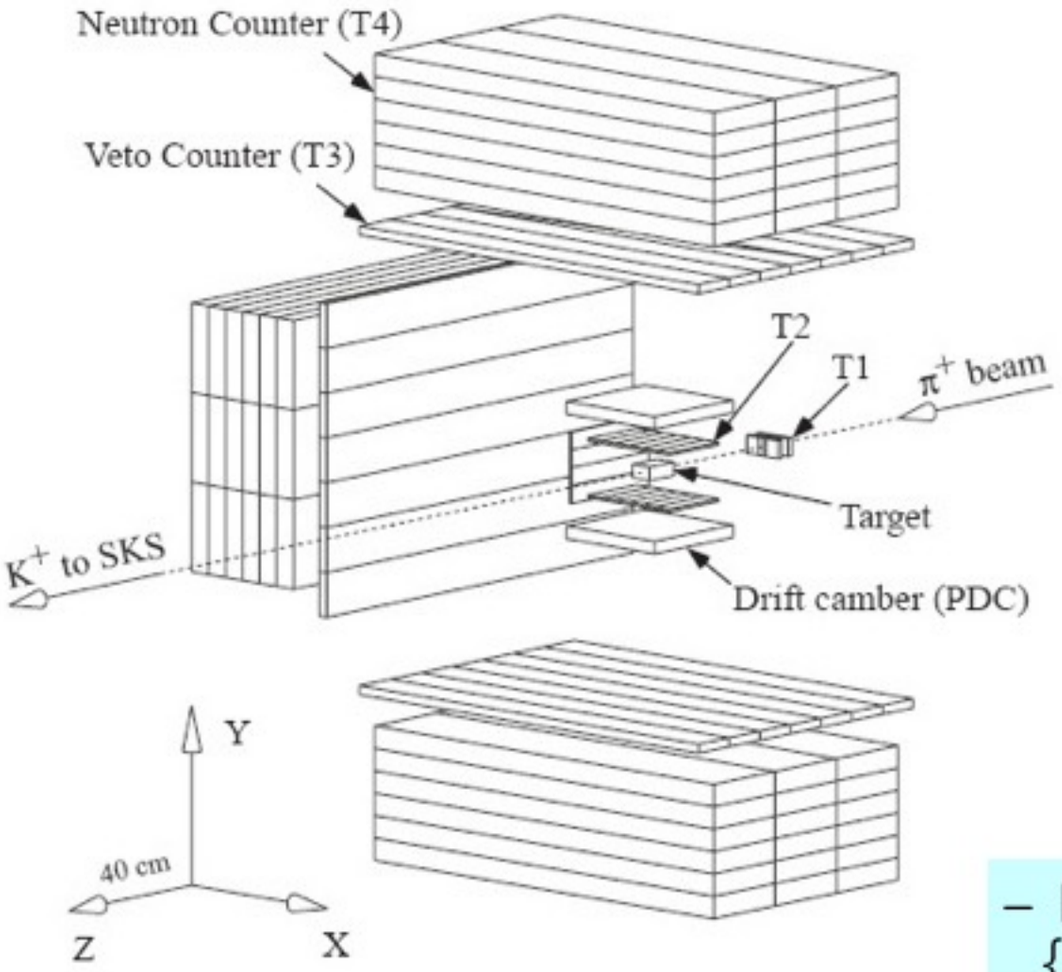


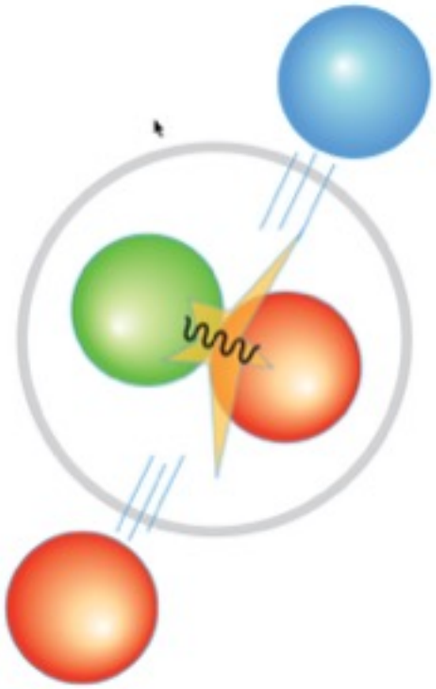
Bird eye's view

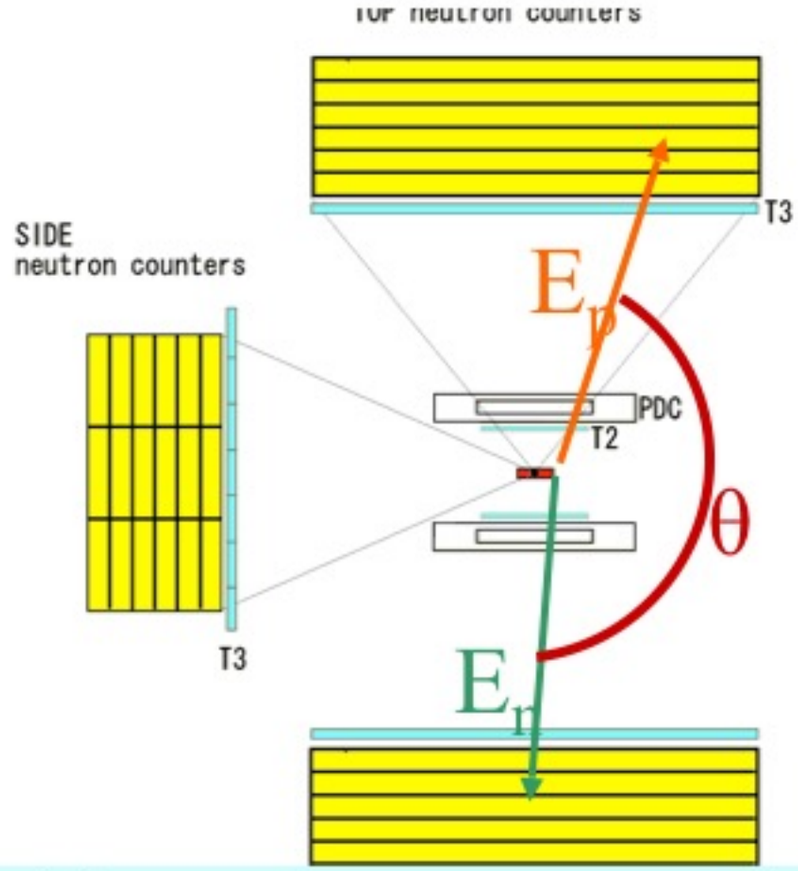
Coincidence Detection of np/nn Pairs



Coincidence Measurement (KEK-PS E462/E508)





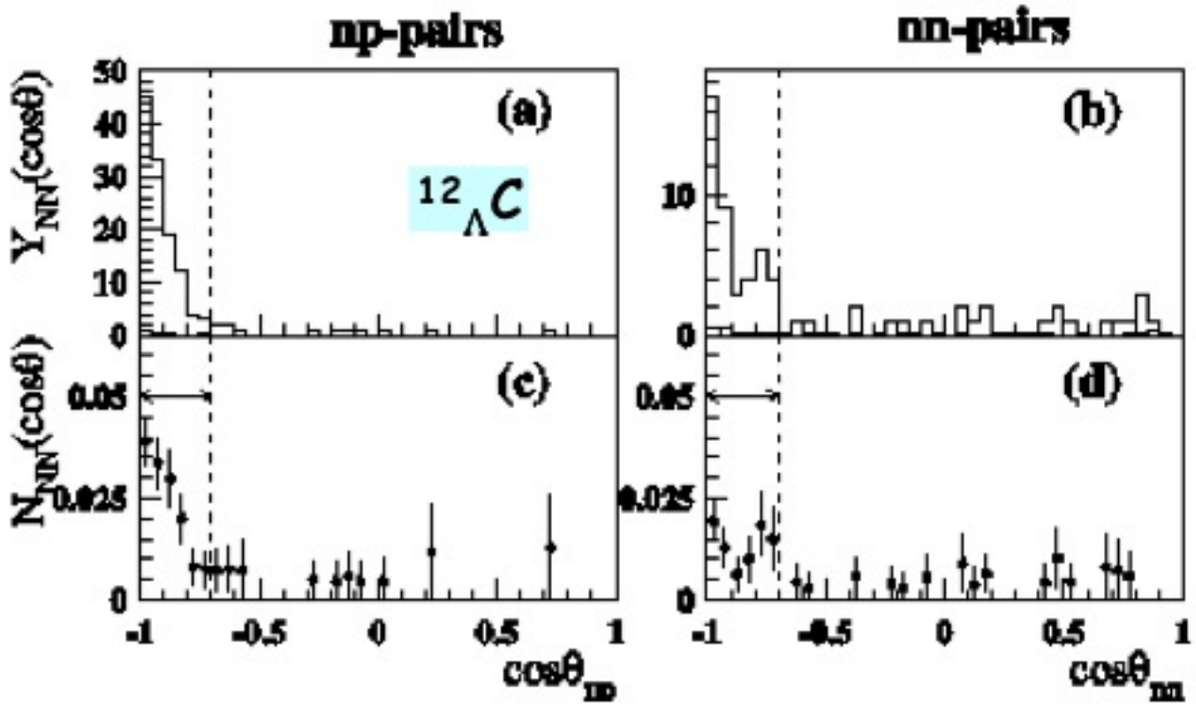


- Pair yields, Y_{np} and $Y_{nn}(\Theta)$ meas.
  $\{Y_{nn}(\Theta), Y_{np}(\Theta)\}/N_{nm} \equiv \{N_{nn}(\Theta), N_{np}(\Theta)\}$

- 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

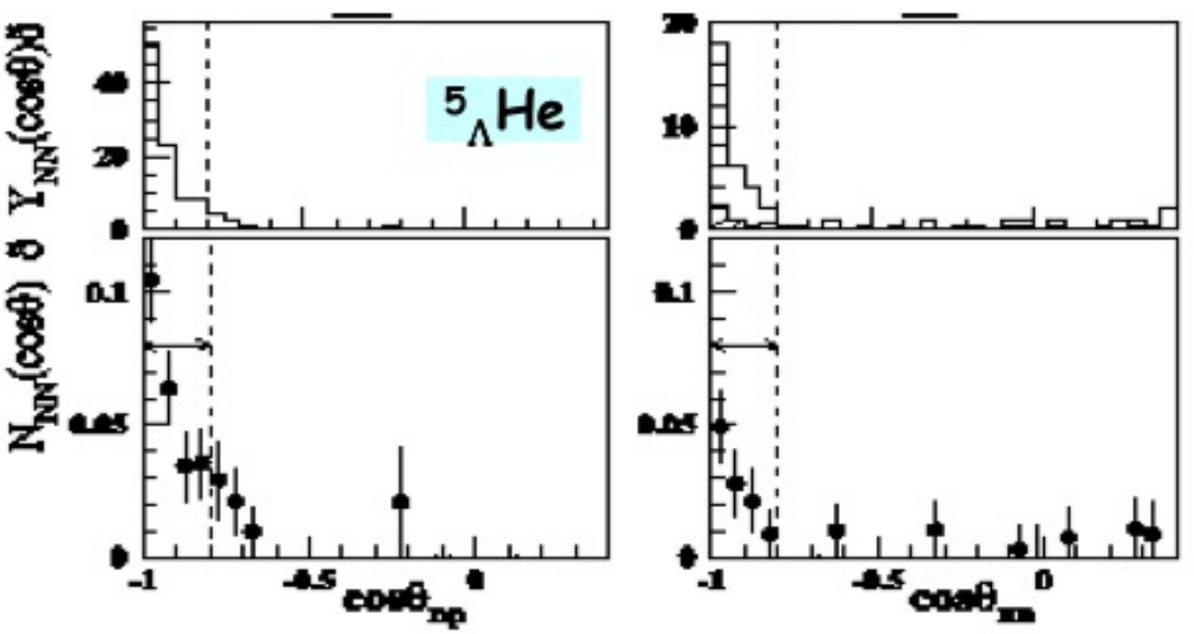


- bb ; cosΘ < -0.7
- FSI/3-B broaden the angular corr.

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

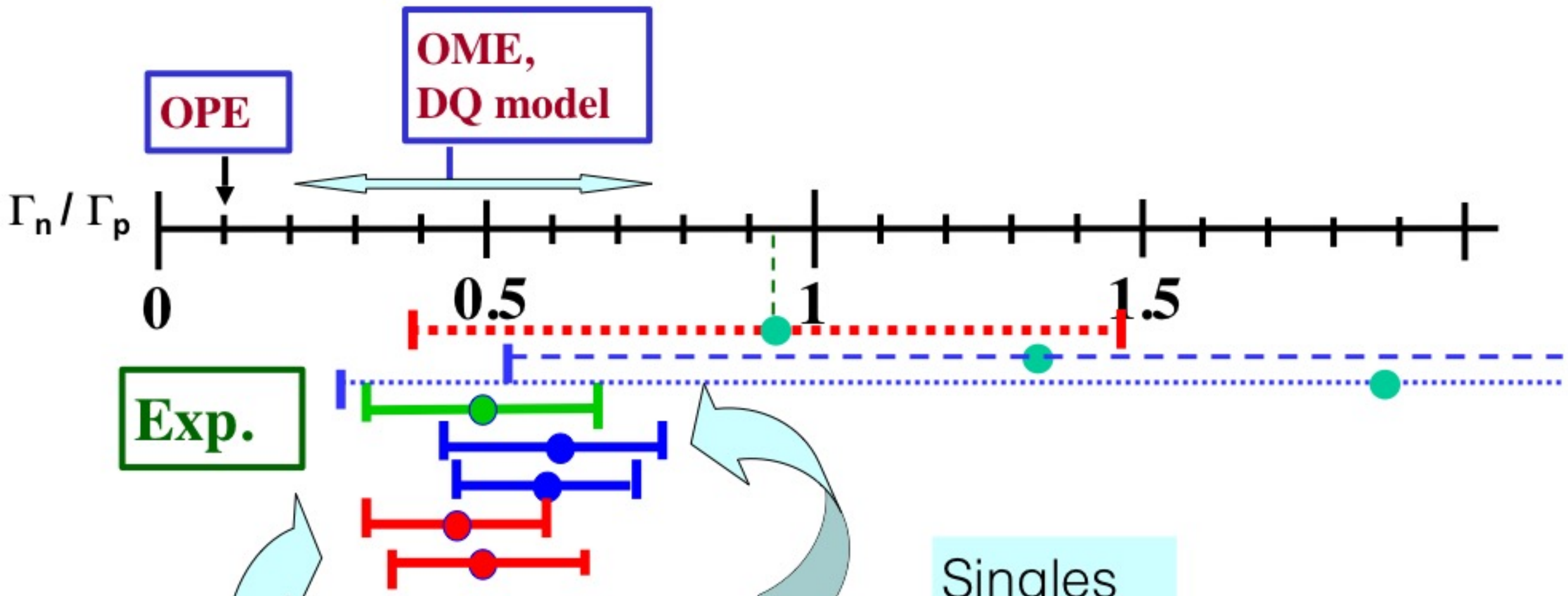
$\Gamma_n/\Gamma_p = 0.51 \pm 0.13 \pm 0.05$
M. Kim et al., PLB ('06)

$\Gamma_n/\Gamma_p = 0.45 \pm 0.11 \pm 0.03$
B.Kang et al., PRL 96 ('06)



1. Well agreed with those of Th.
2. Γ_n/Γ_p puzzle finally solved.

Γ_n/Γ_p Results



Singles

$^{5}_{\Lambda}$He : 0.61±0.081±0.082 (E462)

$^{12}_{\Lambda}$C : 0.58±0.06±0.08 (E508)

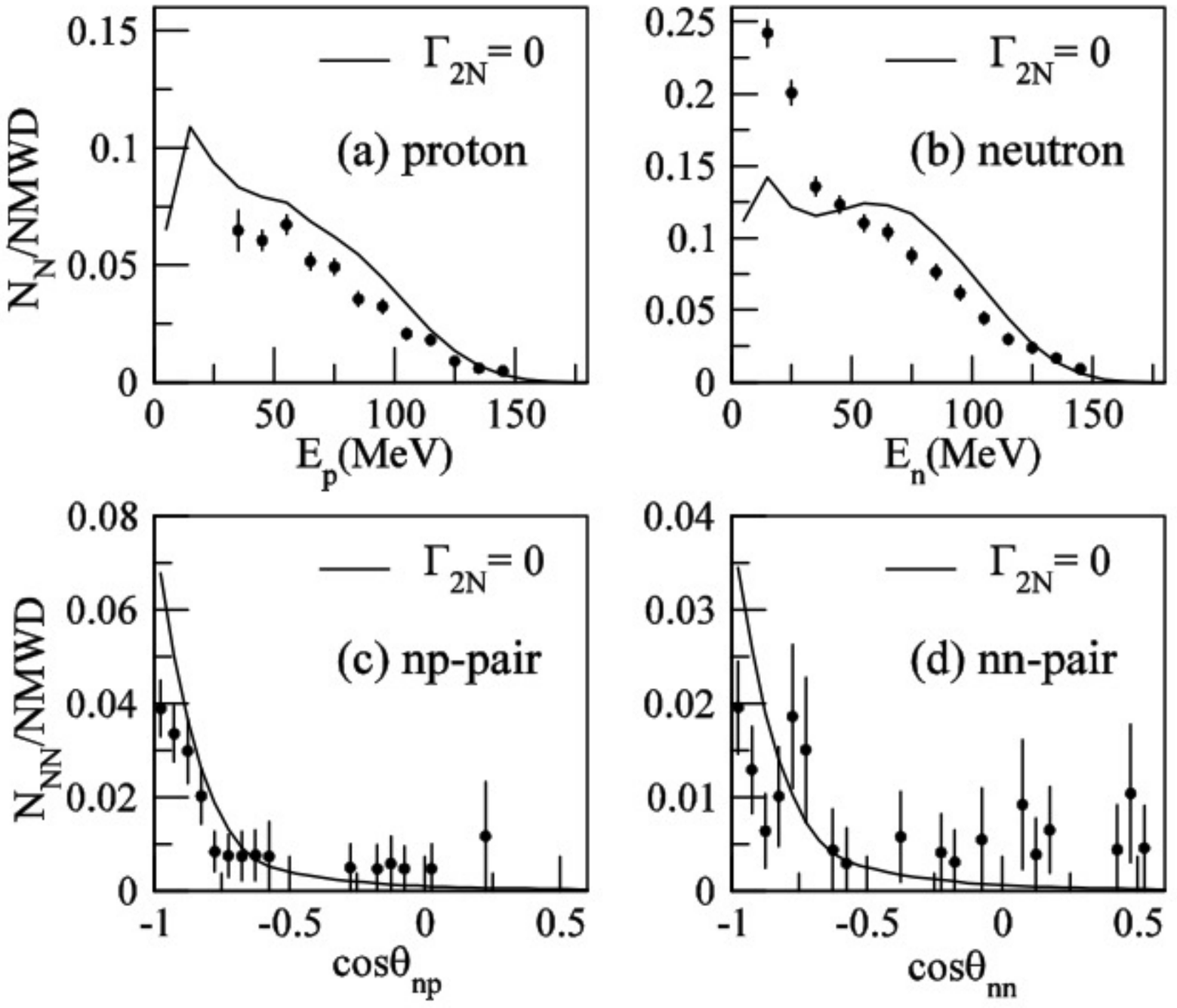
: (0.45~0.51)±0.15 (E307/E369)

Coincidence

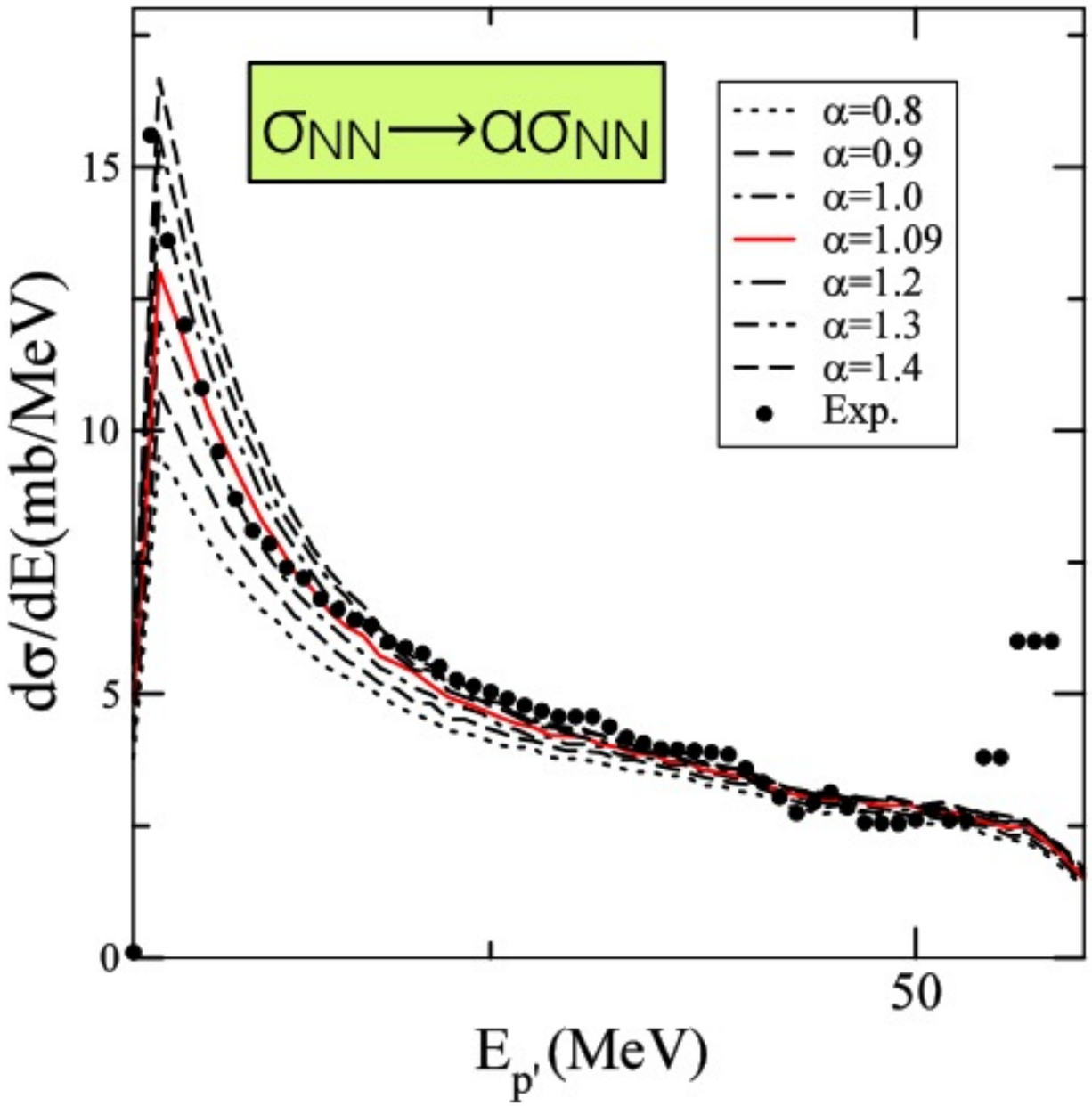
$^{5}_{\Lambda}$He : 0.45 ±0.11 ±0.03±(E462)

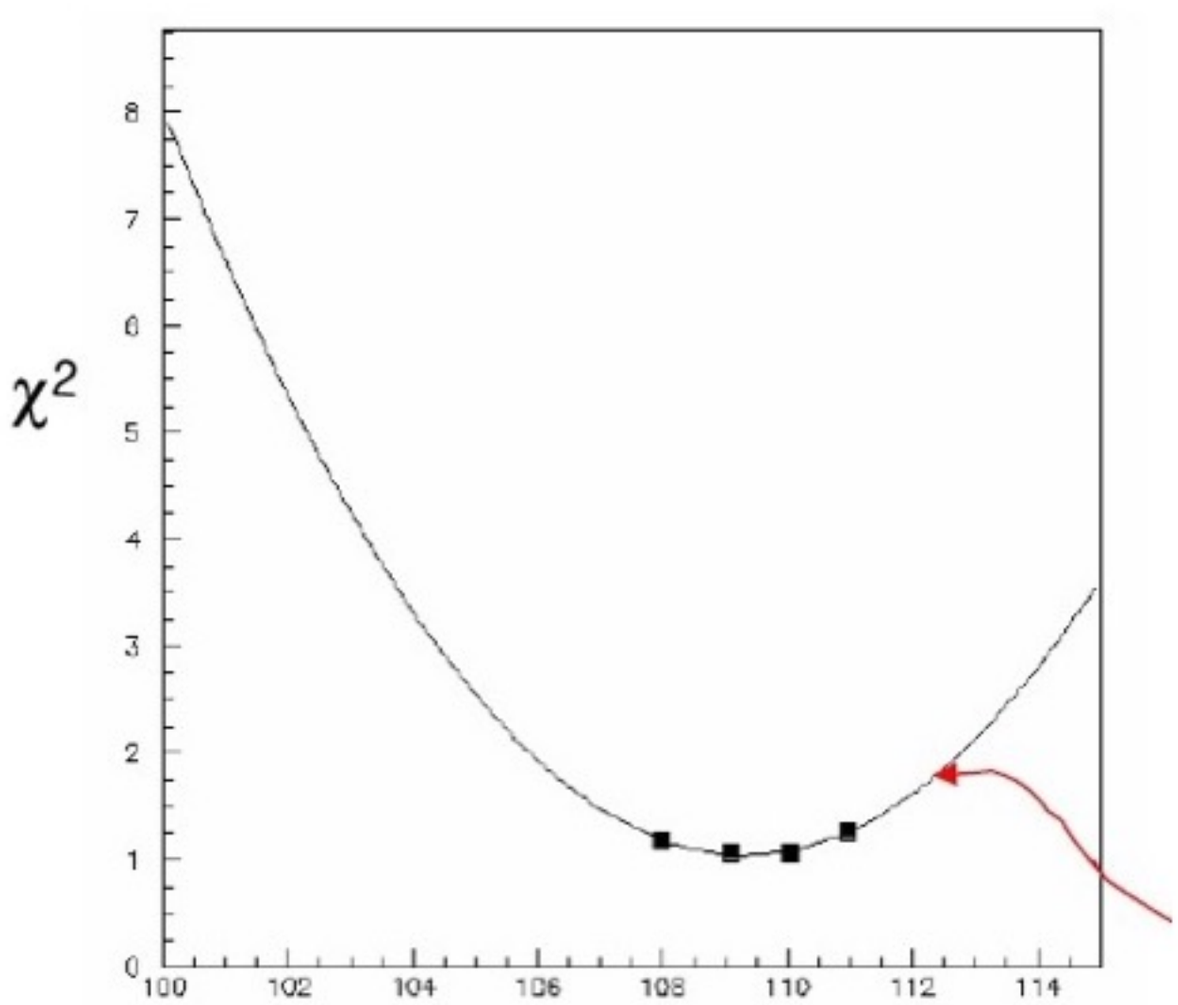
$^{12}_{\Lambda}$C : 0.50 ±0.13 ±(0.05) (E508)

Closer Look at np/nn Pairs



Tweaking INC



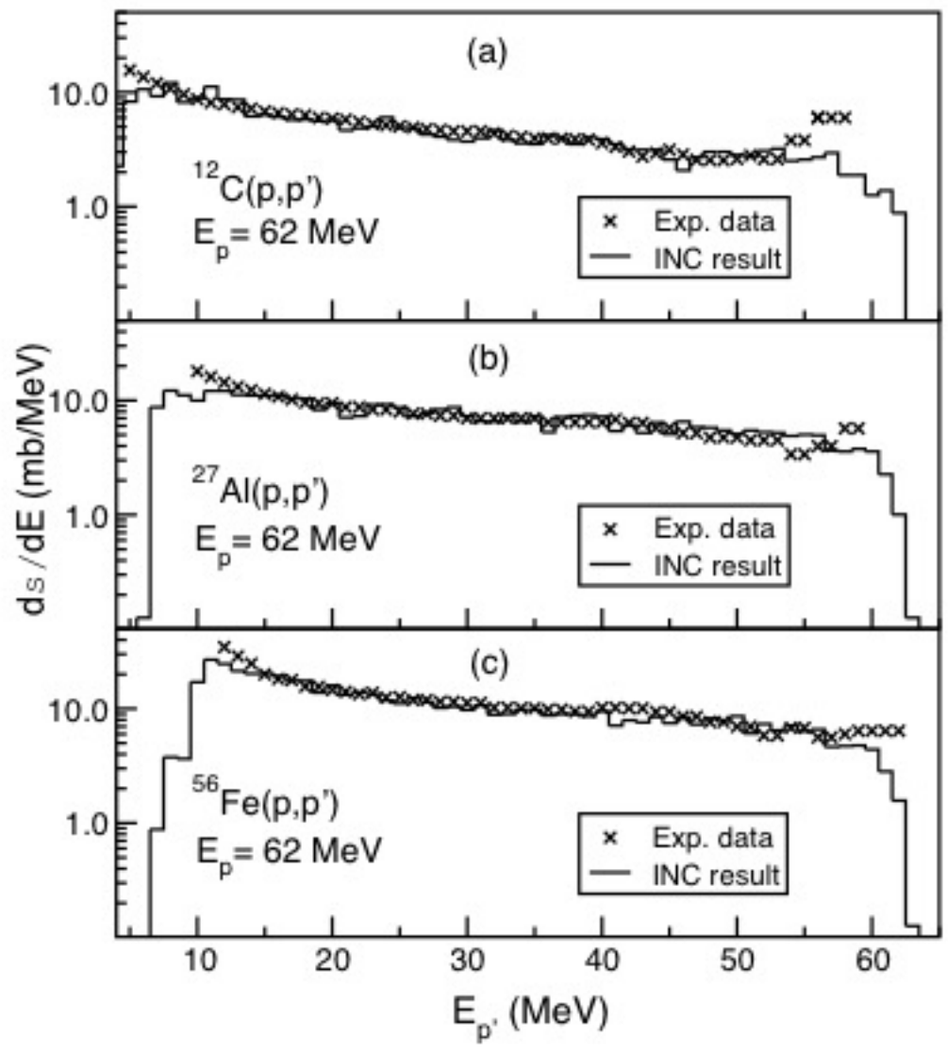


$\chi^2=0.08(\alpha-109.3)^2+1.04$

IntraNuclear Cascade (INC) Calculation

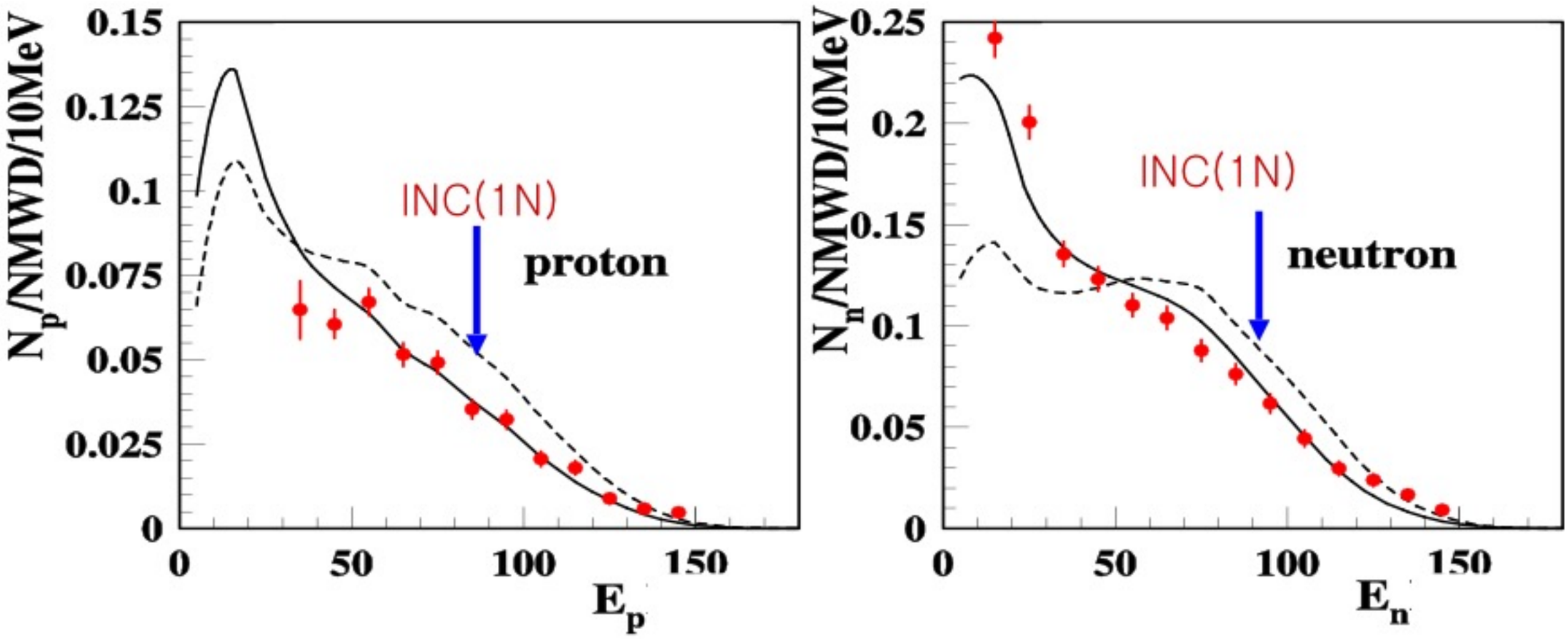
- A nucleus as a Fermi gas.
- ρ(x) → V(x)
- FSI is simulated as a cascade free NN scattering along with Fermi blocking imposed.
- Density geometry parameters are adopted from the reactions, (p,p') and (p,n) data with which Mass and Energy dependence were checked
- These parameters are fixed for the decay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

Mass Dependence



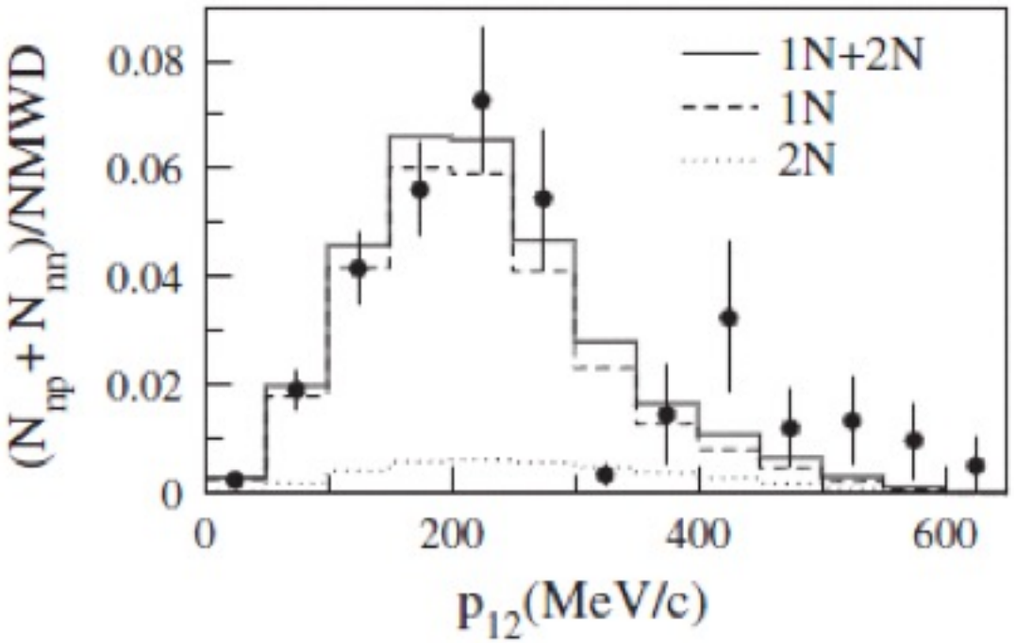
M. Kim, JKPS 46 ('05) 805

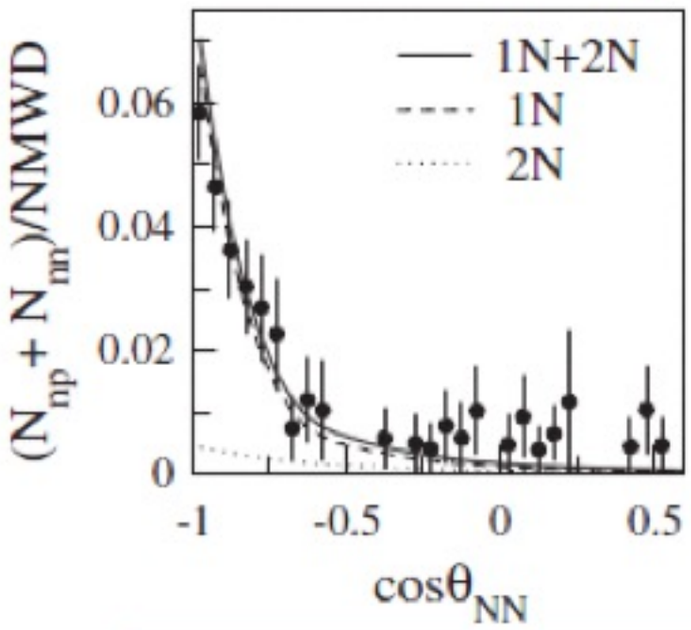
Quenching of Singles Yield

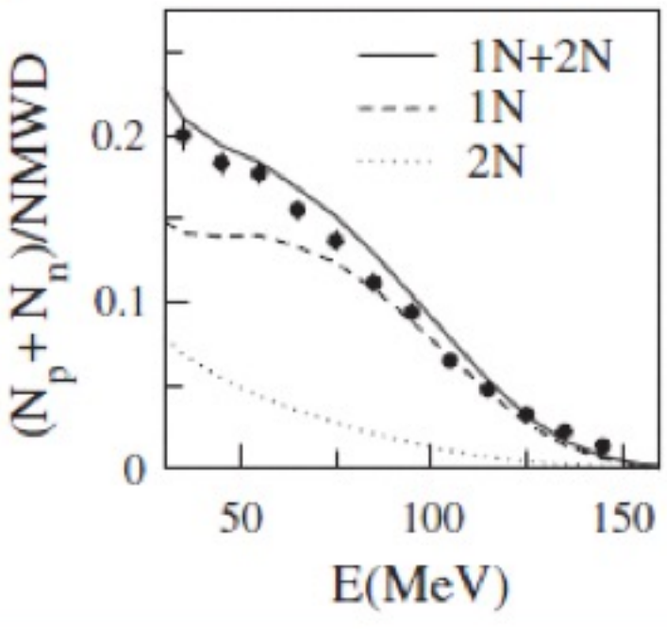


- Quenching in both p and n spectra from INC(1N) The Quenching is overall.
- The quenching can be attributed to 3-body NMWD
- 3-body NMWD simulated assuming a uniform phase space distribution of the 3 nucleons

Determination of Γ_{2N}







	Present Experiment (Γ_Λ)
Γ_n/Γ_p	**0.51±0.13±0.05**
Γ_{nm}	**0.95±0.04**
b_{2N}	**0.29±.13**
Γ_{2N}	**0.27±.13**
Γ_n	**0.23±0.08**
Γ_p	**0.45±0.10**

M. Kim et al., PRL 103 ('09) 182502

- With Γ_{2N}/Γ_{nm} =0.29±0.13,
  both singles and all the pair correlations are well reproduced.

Theoretical Prediction for 3-body Process of NMWD

- **Model for 2N-NMWD;**

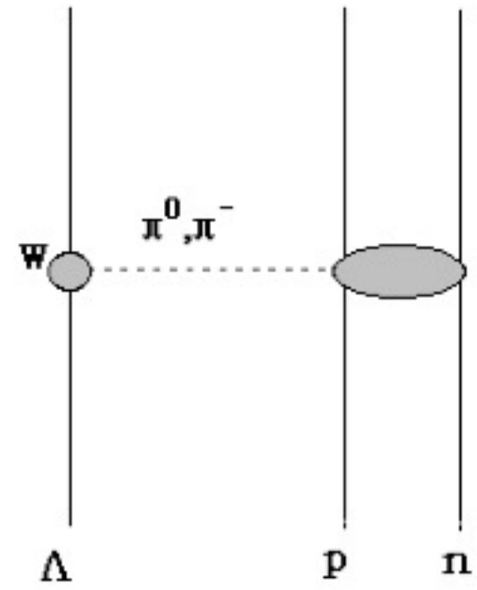
  Alberico-Ericson proposed ('91), and Ramos-Oset extensively calculated ('94).

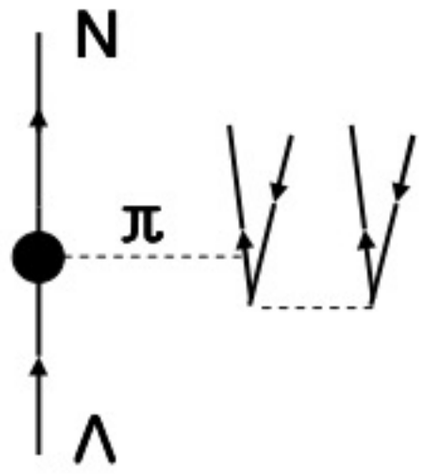
- **Absorption of virtual pion by 2p-2h states.**
  - **$\Lambda \rightarrow p\pi^-$ is dominant at the weak vertex and**
  - **Pions are absorbed dominantly on the pn pair.**

  In the process 3 nucleons are emitted;

  1p(LE) + 2n (HE)

- $\Gamma_{2N} \sim 0.2\ \Gamma_{nm}$





Status Report for Γ_{2N}

	Λ Hypernuclei	**Γ_{2N}/Γ_{nm}**
E508	$^{12}_{\Lambda}C$	0.29 ± 0.13
	$^{11}_{\Lambda}B$	0.26 ± 0.13
FINUDA	s- and p- shell	0.24 ± 0.10
Theory (Alberico, Ramos, Garbarino, Bauer, …)		0.20 ~ 0.37

J-PARC E18

Coincidence Measurement of the Weak Decay of ${}^{12}_{\Lambda}$C and the three-body weak interaction process.

J.K. Ahn[*], K. Aoki, T. Nagae, H. Noumi, Y. Sato, M. Sekimoto, T. Takahashi, A. Toyoda[†], A. Banu[**], H. Bhang, S. Choi, B. H. Kang, M. J. Kim, H. So, K. Tshoo, H.J. Yim[‡], T. Fukuda[§], O. Hashimoto, S. Kameoka, Y. Miura, S. N. Nakamura, Y. Okayasu, H. Tamura, K. Tsukada, T. Watanabe[¶], J. H. Kim, H. Park[‖], W. Kim[††], T. Maruta, M. Nakamura[‡‡], Y. Miyake[§§], S. Okada, H. Outa[¶¶], P. K. Saha[***] and M. Youn[†††]

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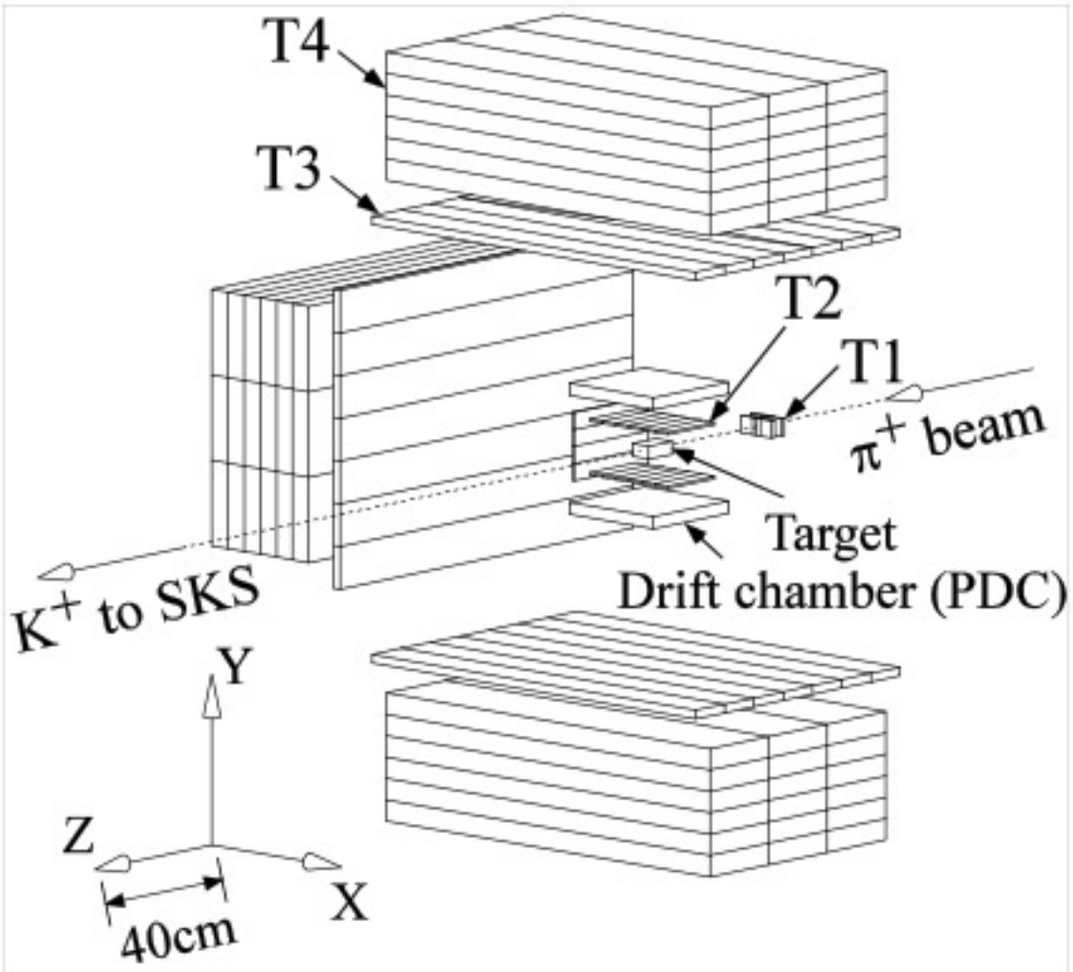
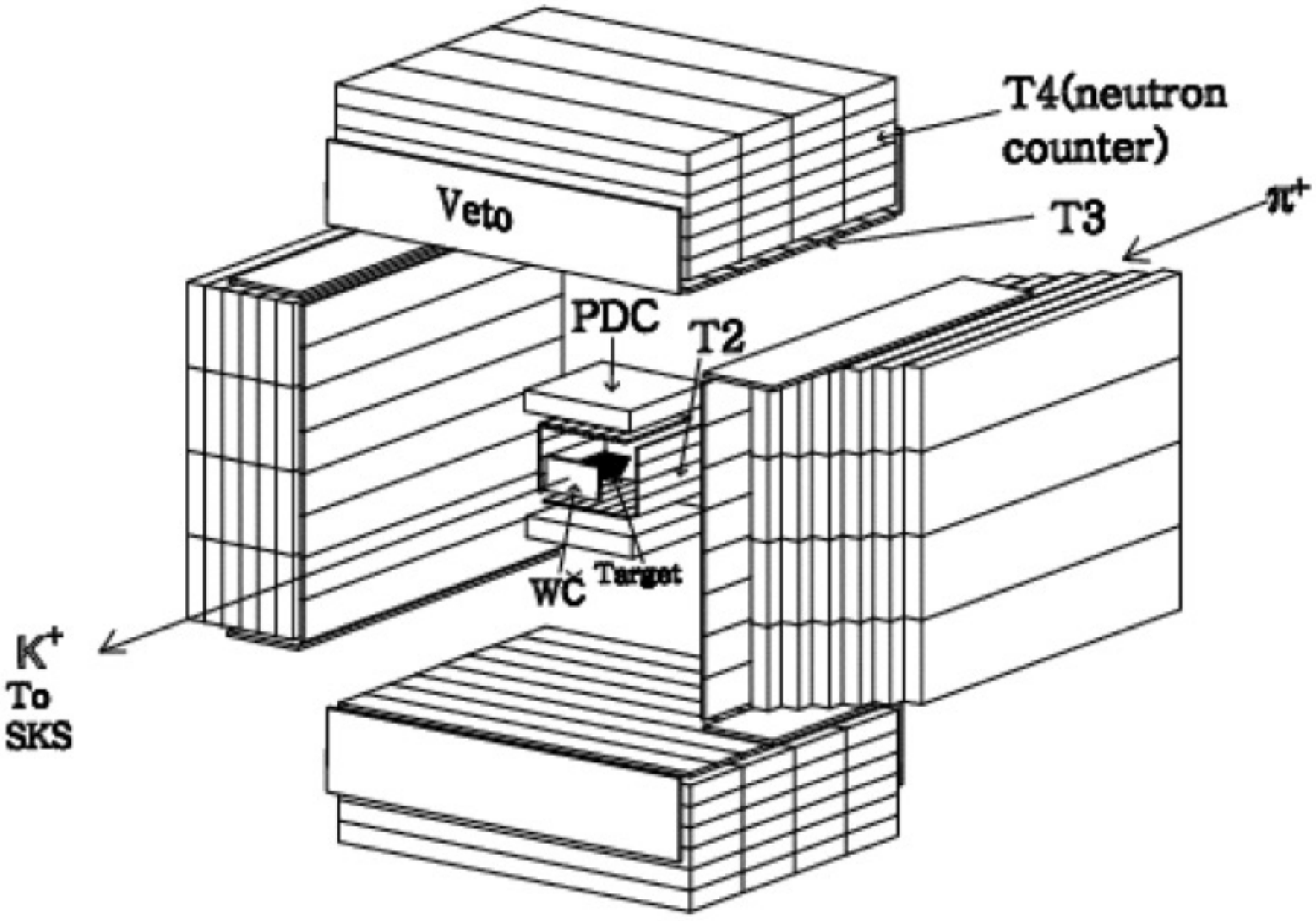
[***]*Japan Atomic Energy Research Institute, Tokai 319-1195, Japan.*
[†††]*AMS Laboratory, Seoul National University, Seoul 151-742, Korea*

KEK-PS E462/508



E18 @ J-PARC



E18 @ J-PARC

	E508	E18_main	E18_1st-step
N_{π}^{tot}	2T	5T (80shifts)	0.8T (70 shift)
n_{π}/spill	4 M/4s	10 M/spill(6s)	2 M/spill(6sec)
d.f.	~1	~1	~0.3
N_{np}(bb)	116	~2030	~320
N_{nn}(bb)	43	~376	~60
N_{pp}(bb)	8	~320	~51
N_{np}(nbb)	9	~270	~43
N_{nn}(nbb)	16	~280	~45
N_{NNN}	6	~325	~52

Summary

- Γ_n/Γ_p for s- and p-shell hypernuclei
  - exclusive measurements and consistent with ~0.5
- Quite large values of Γ_{2N}/Γ_{nm} of about 0.26 to 0.3
  - Consistent within experiments
  - Consistent with theoretical expectation
  - With new experiment (E18) at J-PARC, improved statistics expected.