Summary for Strangeness Nuclear Physics Session

L. Tang (Hampton University)

Talks: 13 in parallel session

Topics includes:

- S=-2 hypernuclei (YY interaction)
- S=-1 Λ–hypernuclei (YN interaction, γ spectroscopy, ΔS=1 weak decay, and exotic strange nuclei)
- Kaonic nuclei (new physics)
- Results from FINUDA (Foreign facility)

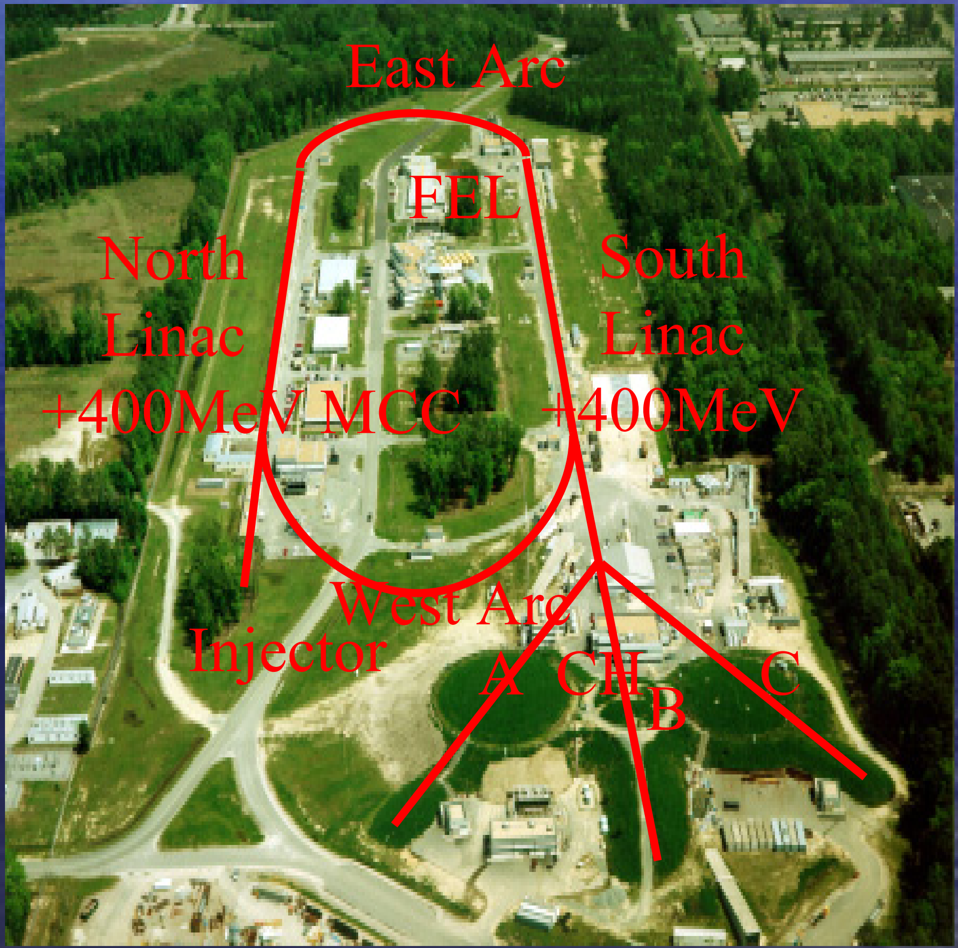
Why study hypernuclei? - *A. Gal (Plenary speaker)*

- YN and YY interactions are not (and will not be) fully available from free-space measurement; unified BB phenomenology
- Study hypernuclei illuminates strange matter at medium and (occasionally) high density; connection to QCD properties
- Connection to other strange hadrons in matter: K^-, …
  hyperonic excitations: $\Lambda(1405)$, $\Lambda(1520)$, …
  hidden strangeness: ϕ, f_0, …
- Connection to strange quark matter, strangelets, neutron stars, hyperstars, …
- Hyponuclei (S=+1) ? θ^+ nuclei?

Development From New Facilities (JLAB)

- Electro- and Photo-productions
- New spectroscopy of Λ-hypernuclei with different spin-parity states
- High precision mass spectroscopy
- Can have other future possibilities
- The most significant program: *HKS Exp*. led by Prof. O. Hashimoto

CEBAF



Development of New Facilities (FINUDA, presented by S. Marcello)

- Current: $A(K^-_{stop}, \pi^-)_\Lambda A$ (K^- from ϕ at rest)
- Spectroscopy, achieved 1.4MeV resolution stil preliminary
- Weak decay can be studied but not yet done
- Found hint for rare weak decay of $^4{}_\Lambda$He (DD)
- Other possiblities:
  - Σ-hypernuclei
  - High neutron rich Λ-hypernuclei
  - Kaonic nuclei
- Near future: more data taking in 2005-2006
- Far future: upgrade for higher L_{int} and energy
- γ-spectroscopy?

Development From New Facilities and New Technique (J-PARC)

- World leading and unique hadron facility
- High intensity and better quality beam
- Good chances for *Strangeness and Hypernuclear Physics*
- Unique facility to study
  - S=-2 hypernuclei (a gateway to multi-strangeness)
  - γ spectroscopy for Λ-hypernuclei (S=-1)
  - Weak decay of Λ-hypernuclei
  - Kaonic Nuclei
  - YP scattering
  - Mass spectroscopy of S=-1 hypernuclei (no presentation)

S=-2 hypernuclei (YY interaction)

Six speakers: four Exp. and two Theo.

- T. Nagae (KEK - Exp): Ξ-Hypernuclei (Day 1 exp.)
- T. Fukuda (Osaka-EC): $^{4}_{\Lambda\Lambda}$H and $^{5}_{\Lambda\Lambda}$H hypernuclei
- K. Nakazawa (Gifu): Study of $\Lambda\Lambda$-H hypernuclei
- M. Natsume (Nagoya): Nano Imaging Tracker (NIT)

- H. Namura (KEK): 4-, 5-, & 6-body cal. of S=-2 s-shell hypernuclei
- Y. Fujiwara (Kyoto): A microscopic approach to the YN and YY interactions in hypernuclei

Ξ Hypernuclear Spectroscopy:
A gateway for the spectroscopic studies of S=-2 systems

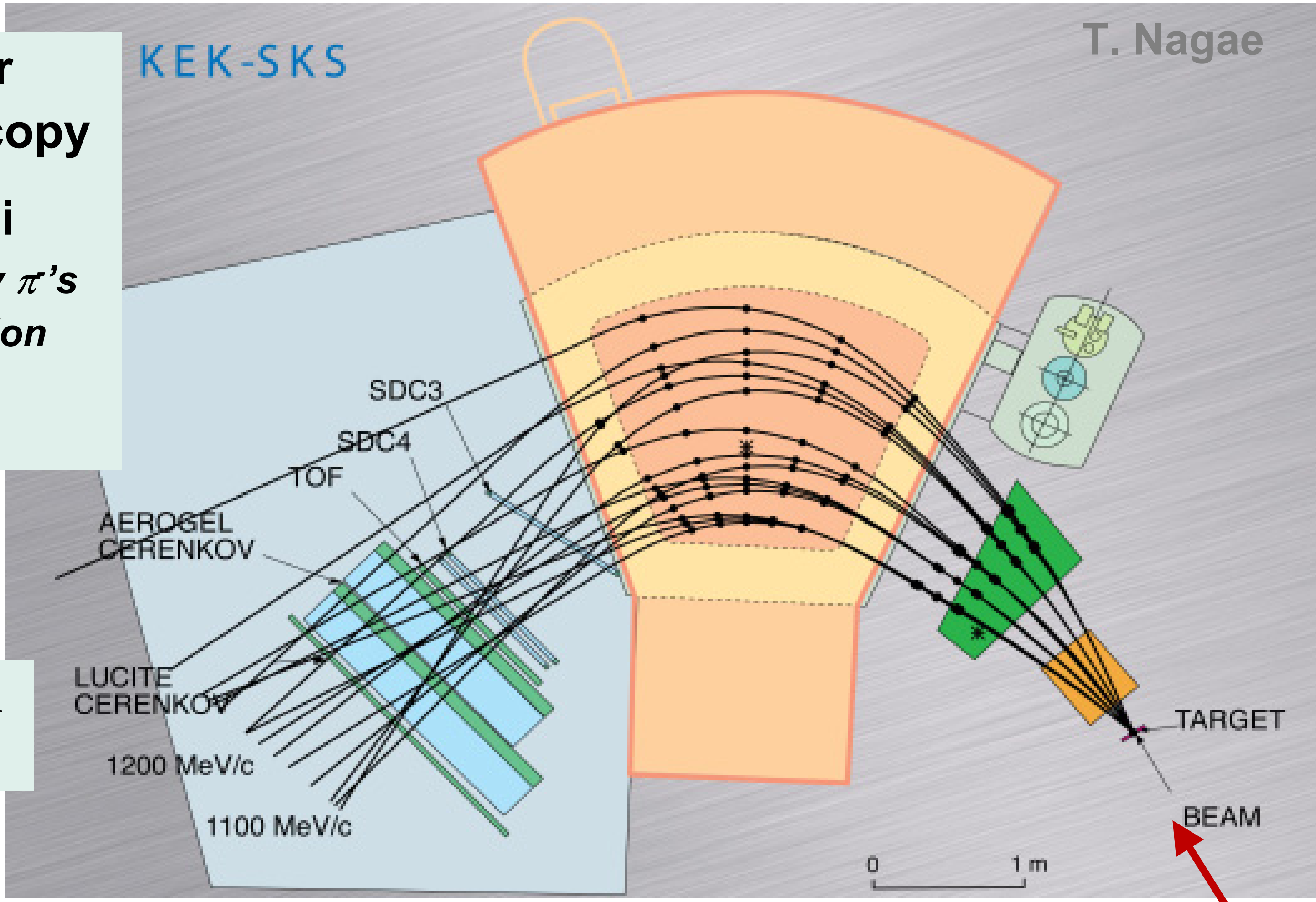
- Not possible in any other facilities
- Ξ-Nucleus potential depth
  - Ξ^- inside a neutron star
- Conversion width
  - ΞN-ΛΛ mixing
- Next target: Double-Λ excited levels
  - direct population through ΞN-ΛΛ mixing
  - Gamma-ray transitions with Hyperball-3

(K^-,K^+) experiments with K1.8 + SKS

1. Ξ **hypernuclear spectroscopy**
2. ΛΛ **hypernuclei**
   + CDS for decay π's
   hybrid emulsion
   weak decays
   γ **rays**

↓

ΞN, ΛΛ, ΞN-ΛΛ interactions



1.8 GeV/c K^- beam
$1.0x10^7$/pulse

Produced Hypernuclear species (S=-2)

T. Fukuda

- Direct process ($K^- + {}^7Li \dashrightarrow X + K^+$)
  - Only ${}^4H_{\Lambda\Lambda}$ and ${}^5H_{\Lambda\Lambda}$
  - No twin single-Λ
- Stopped Ξ^- process ($\Xi^- + {}^7Li$)
  - Smaller contribution due to low stopping power
  - Twin ; ${}^4H_\Lambda + {}^4H_\Lambda$, ${}^4H_\Lambda\ {}^3H_\Lambda$

    (${}^3H_\Lambda\ {}^3H_\Lambda$ not produced due to Q-value)
- Measure $\Delta B_{\Lambda\Lambda}$ with better precision and stat.

  Nagara -- the best event → $\Delta B_{\Lambda\Lambda} = 1.01 \pm 0.20 +0.18$ MeV

  much smaller than old value of ~4-5 MeV, a crucial issue
- New CDS (CDS2) is needed.

BNL E961 improvements over BNL E906

	E906	E961	
Target	^{9}**Be** (15 cm)	^{7}**Li**(LiH) (20 cm)	Limit the produced species Low density --> reduce the multiple scattering and dE (x0.4) --> longer target
CDS momentum resolution	~4.3 MeV/c	~2.4 MeV/c	Improved vertex resolution (dE/ dx correction) + 30 % increased CDS B field (bending power)
Signal to Ξ^- decay background	4:1	16:1	Improved vertex resolution + Momentum resolution a new vertex detector
Statistics	1 450 hours 7Tp/spill 2.0/4.3 sec	16 750 hours 60Tp/spill 8.0/10.3 sec	48D48 (x2.4), CDS (x1.26) Larger target size * lower density = 0.83 If the cross section is the same.

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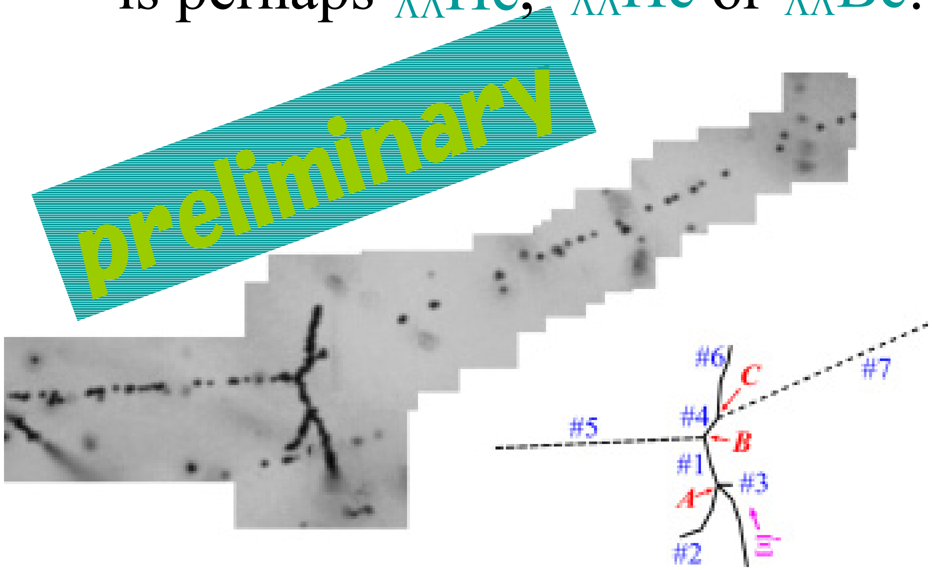
Status of experiments Ⅱ

Double-Λ hypernuclei from E373

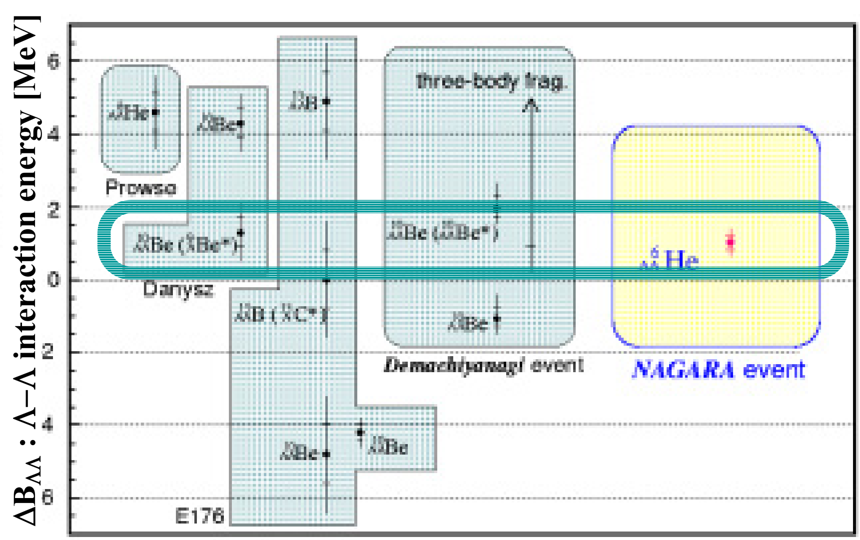
2002

3rd double-Λ hypernucleus

Nuclear species of the double-Λ is perhaps ${}^{6}_{\Lambda\Lambda}He$, ${}^{7}_{\Lambda\Lambda}He$ or ${}^{11}_{\Lambda\Lambda}Be$.



Our knowledge for ΛΛ int. until now.



ΛΛ interaction is attractive but weak

Statistics of experiments via Ξ^- hyperon capture at rest

	Danysz, *et al.* 1963	E176 1991	95% finished E373 2004
# of Ξ^- stop	~4	~80	~10^3
Light nuclei with S=-2	1	1	~6
Twin single-Λ	0	2~3	2

Quite poor statistics until now.

→ BNL-E964 → J-PARC

preliminary

New Hybrid-Emulsion Experiment at J-PARC

- Ξ^- production   10 times larger statistics than BNL-E964

$K^- + p \rightarrow \Xi^- + K^+$ Quasi-free (K^-, K^+) reaction   **(no K^+ tracking x 2)**

$\Xi^- + K^+ + \pi^0$ x2.5 ($\sigma_{\Xi^- prod.}$)

$\Xi^- + K^0 + \pi^+$ **K^- +(p,n) → X : 3.5times**

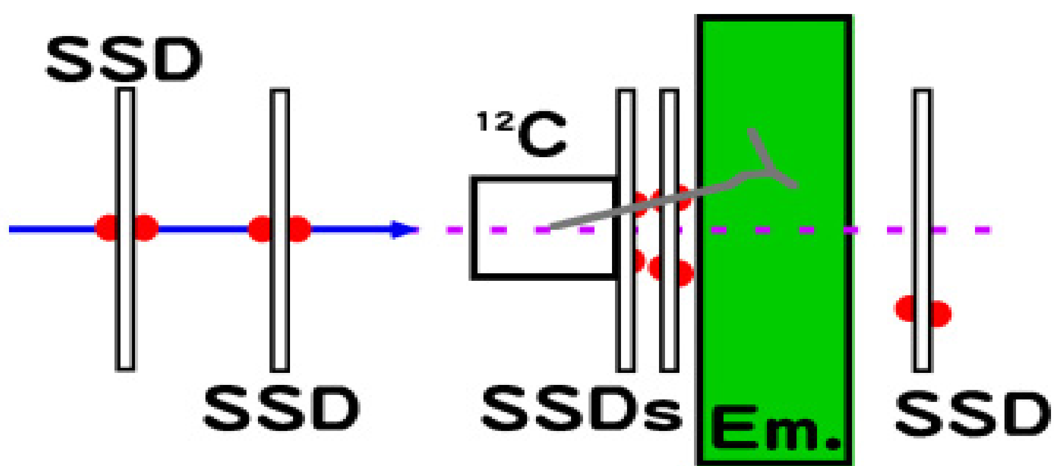
$K^- + n \rightarrow \Xi^- + K^0$

$\Xi^- + K^0 + \pi^0$ **& Em.: × 3**

$\Xi^- + K^+ + \pi^-$

Outline : No K^+ tagging → no spectrometer magnet

Trigger ･･･ **K^--^{12}C reaction** × **X-ray(F→D)**



New Hybrid-Emulsion Experiment at J-PARC

To get ～10^3 double-Λ hypernucleus
via ～10^5 Ξ^- stopping events

Information:

- nuclear chart of S=-2 nuclei
- γ-ray from double-Λ hypernuclei

Developments :

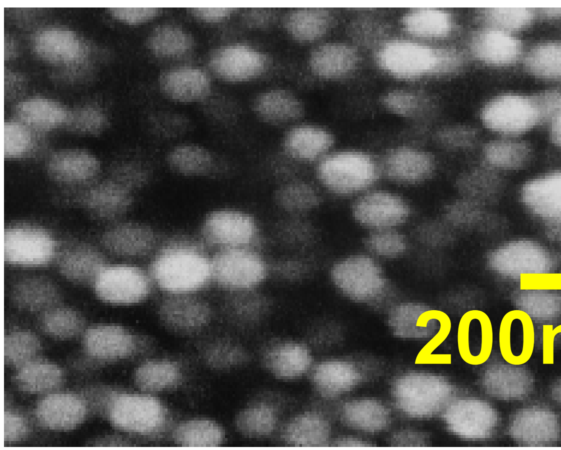
- Hyperball
- fully automated scanning system
- nuclear emulsion itself → next speaker (M. Natsume)
- ・・・・・・・・

Fine grain emulsion crystal to get better position resolution at J-PARC

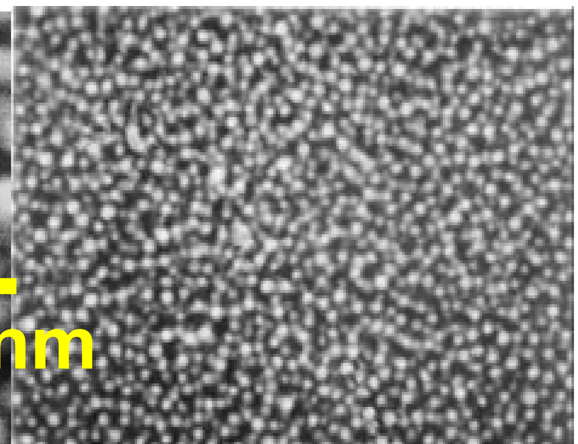
SEM Micrographs of AgBr Grains

SEM : scanning electron microscope

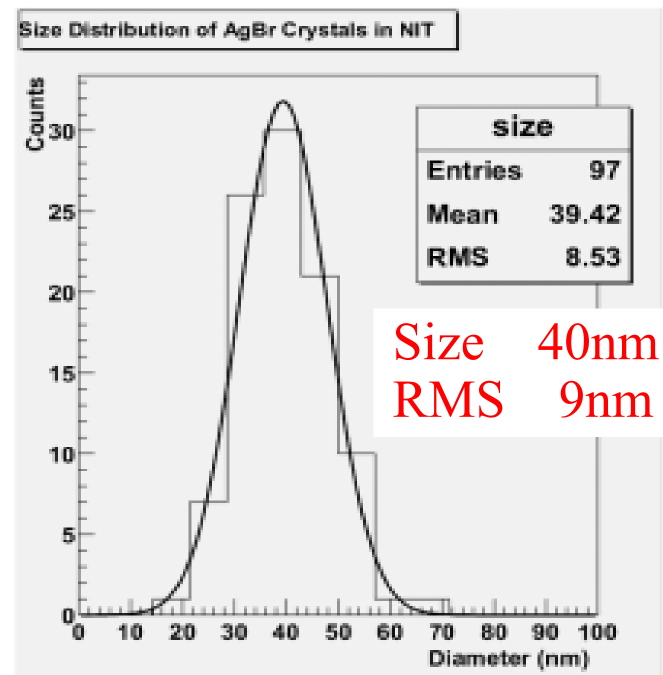
E373 emulsion (ET-7C,D)



NIT(Nano Image Tracker
developed by Nagoya



Size of AgBr Grains

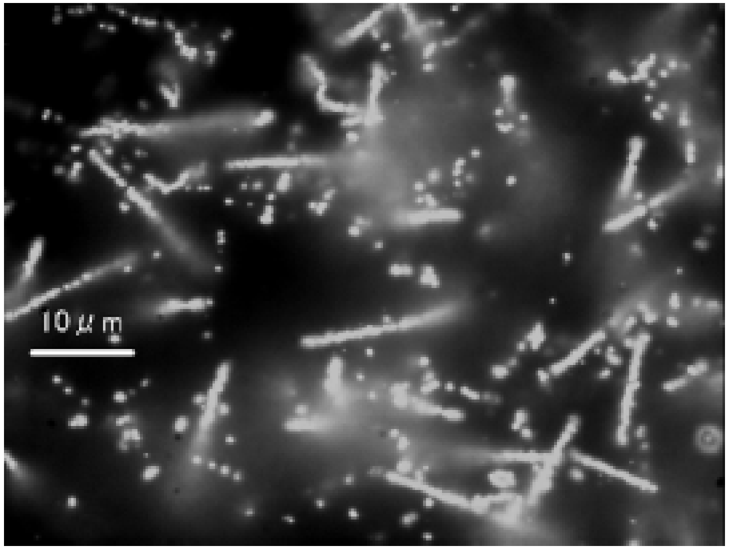


Fine grain emulsion crystal to get better position resolution at J-PARC

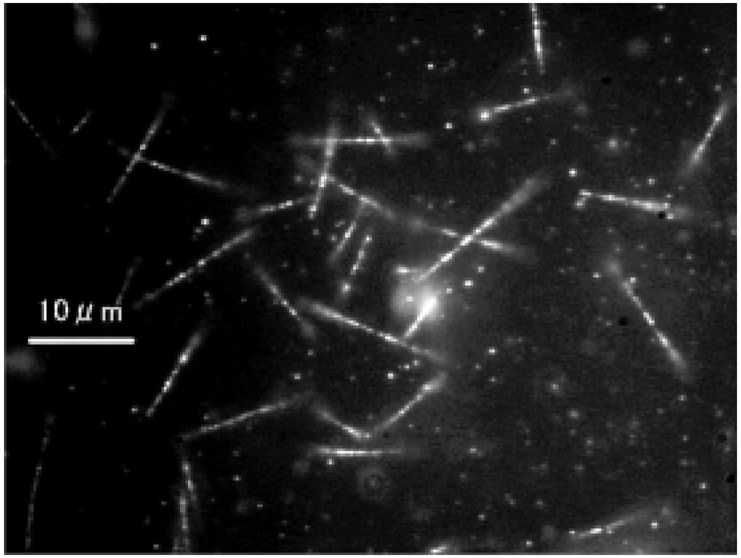
Tracks due to 5MeV α - particles

Dark Field Image of Light Microscope

ordinal emulsion



NIT



Development

1) density 2.8(g/cc) → 3.5(g/cc)

or 2) size : 40nm → 70~80[?]nm

Pions & fast protons without beam tracks → **Higher dense exposure**

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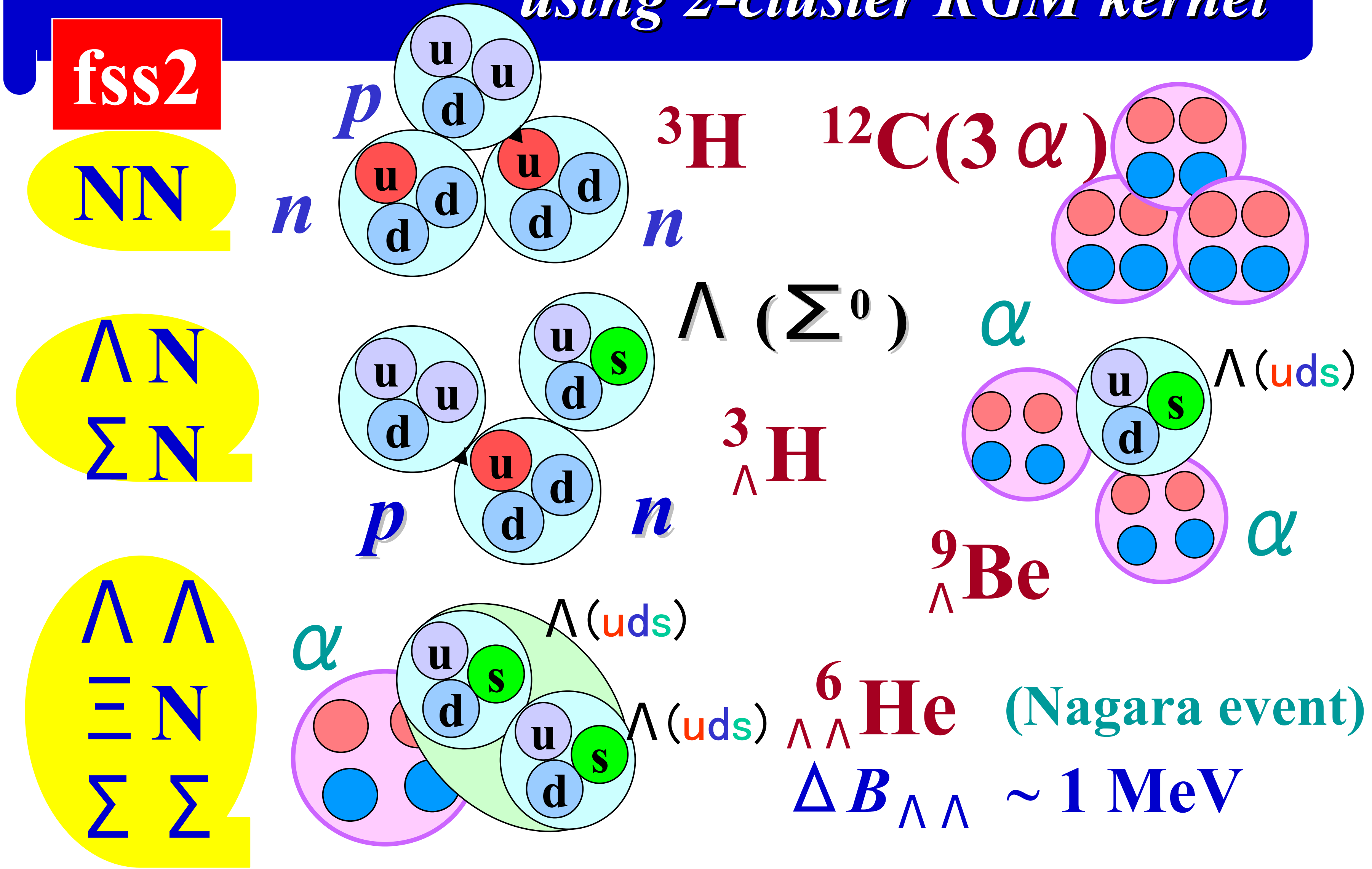
Examples of 3-cluster Faddeev calculations using 2-cluster RGM kernel



Y. Fujiwara

γ Spectroscopy of Hypernuclei at J-PARC

H. Tamura (Tohoku)

- HyperBall has been very successful with energy resolution of ~2-3 keV
- Study spin-dependent interactions,
  Spin-Spin, Spin-Orbital, Tensor Force
- Nuclear Shrinkage (~19%)
- Future in J-PARC

Proposal for DAY1
Hypernuclear γ Spectroscopy by $(K^-, \pi^- \gamma)$

K1.1+ SPESII

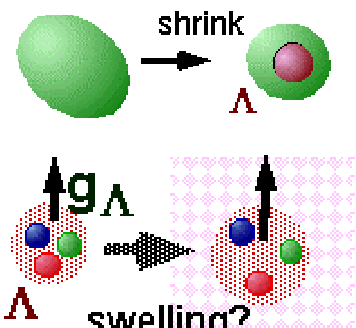
p_K= 1.1 GeV/c (spin-flip) and 0.8 GeV/c (spin-non-flip)

- **Light Hypernuclei, Hyperfragments**
  - A=4－~30 all possible targets
  - $\gamma\gamma$ coin, $\theta\gamma\pi$/ $\theta\gamma\gamma$, polarization -> level scheme, spin-parity
  - Doppler Shift Attenuation Method -> B(E2), B(M1)
- **Medium and Heavy Hypernuclei**
  - E1(p_Λ->s_Λ), large θ -> large q

${}^{4}_{\Lambda}$He, ${}^{7}_{\Lambda}$He, ${}^{8}_{\Lambda}$Li, ${}^{8}_{\Lambda}$Be, ${}^{9}_{\Lambda}$Be, ${}^{11}_{\Lambda}$B, ${}^{12}_{\Lambda}$C, ${}^{13}_{\Lambda}$C/ ${}^{14}_{\Lambda}$N, ${}^{20}_{\Lambda}$Ne, ${}^{23}_{\Lambda}$Na, ${}^{27}_{\Lambda}$Al / ${}^{28}_{\Lambda}$Si, ... etc.

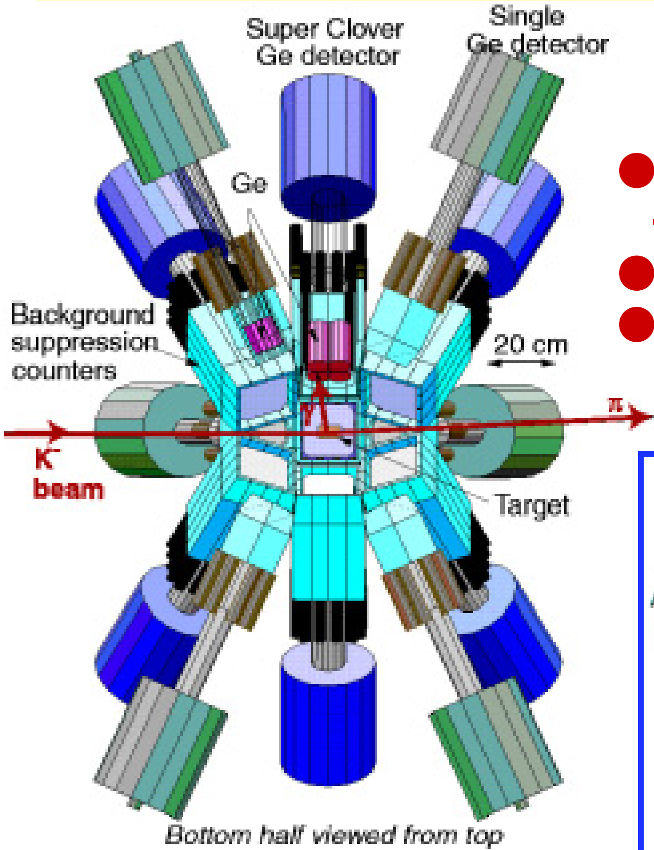
${}^{89}_{\Lambda}$Y, ${}^{139}_{\Lambda}$La, ${}^{208}_{\Lambda}$Pb ...etc. **1-5day / target, Low-intensity beam usable**

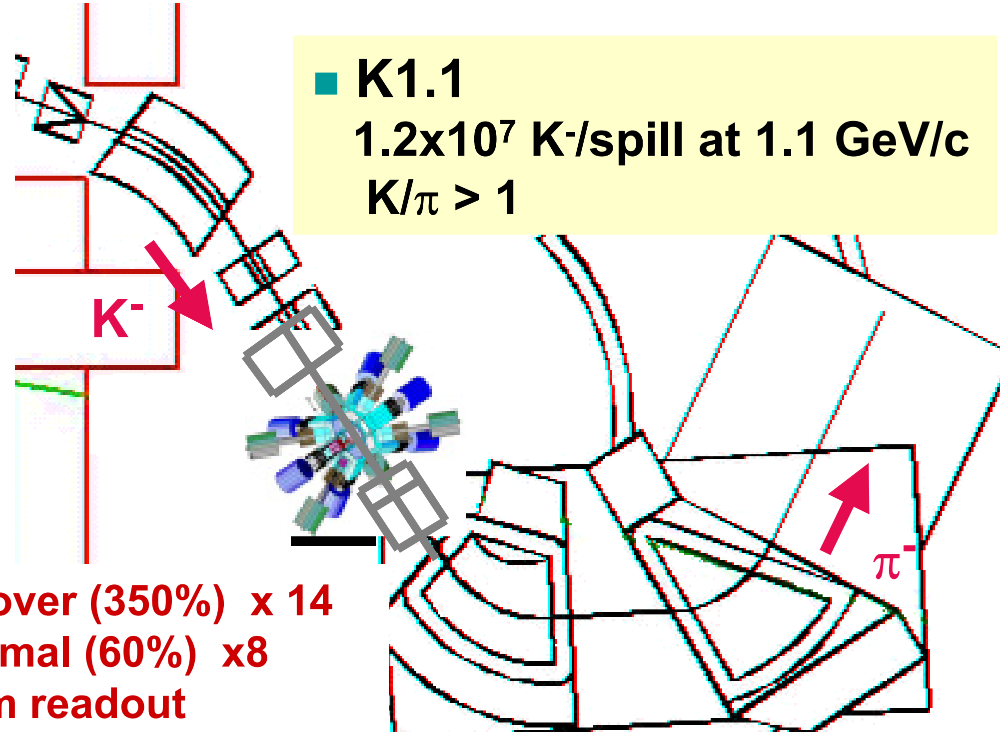
- **Table of hyper-isotopes**
- **ΛN interaction ($\Lambda N-\Sigma N$, CSB, p-wave int..)**
- **B(E2) -> shrinking effect, Parity inversion, ...**
- **B(M1) -> μ_Λ in nucleus (medium effect)**



Setup for γ spectroscopy

- **Hyperball-J**
  - ε ~ 10% at 1 MeV
  - Rate limit
    - ~2x10^7 particles /s (x5)
  - Yield: x20 for single γ
    - x80 for γγ

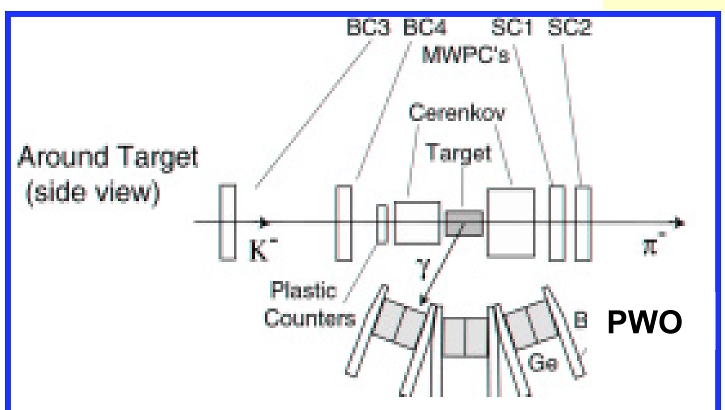




- **K1.1**
  - 1.2x10^7 K^-/spill at 1.1 GeV/c
  - K/π > 1

- Super Clover (350%) x 14
  + old normal (60%) x8
- Waveform readout
- Fast suppression counters
  (BGO=>PWO?)

- **SPESII**
  - Δp/p < 2 MeV FWHM
  - Ω ~ 20 msr



Weak decay of Λ hypernucleus

H. Outa (RIKEN)

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)

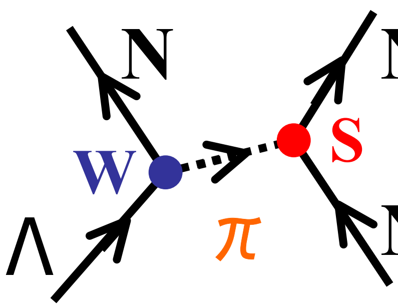
ratio ⇒ Γ_n / Γ_p

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

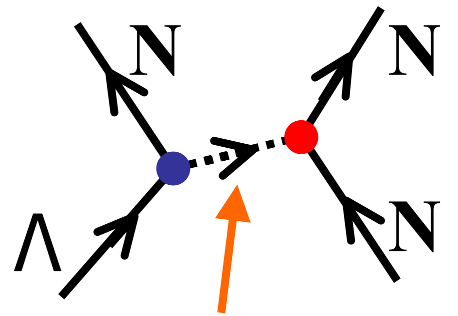
Theoretical

Simple theoretical model

One Pion Exchange (OPE)

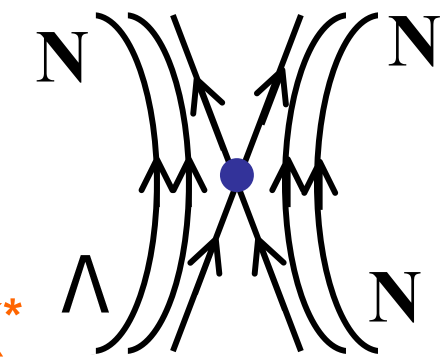


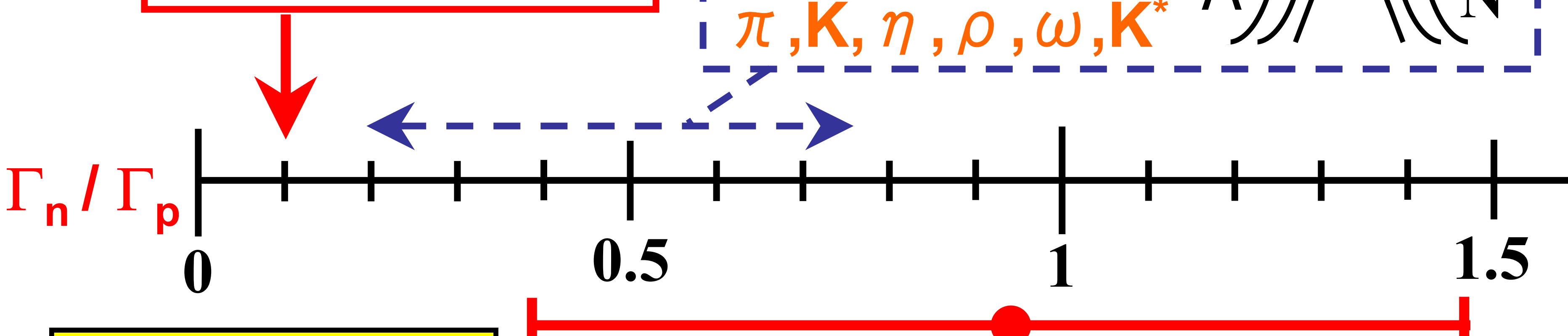
Meson Exchange mechanism



π, K, η, ρ, ω, K*

Direct Quark mechanism





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

0.93±0.55 (Szymanski et al.)

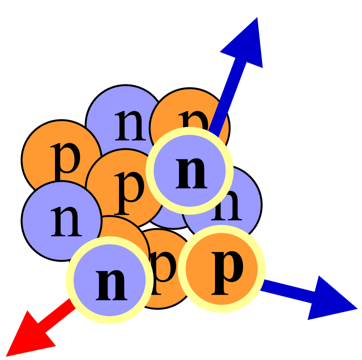
Γ_n / Γ_p ratio "puzzle"

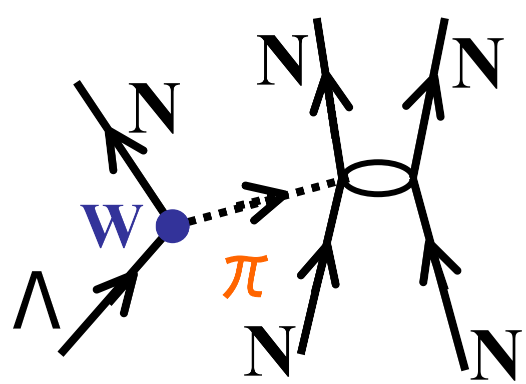
Experimental difficulty in the nucleon measurement

- ✓ **Difficulty in detecting neutrons.**
  → **There is no experiment to observe both of the protons and neutrons simultaneously.**
- ✓ **Final state interaction (FSI) effect**
  → **not well established theoretically**
- ✓ **Distinguish between the FSI and "ΛNN→nNN" process**

Final state interaction (FSI) effect	**ΛNN→NNN (2N-induced process)**

rescattering

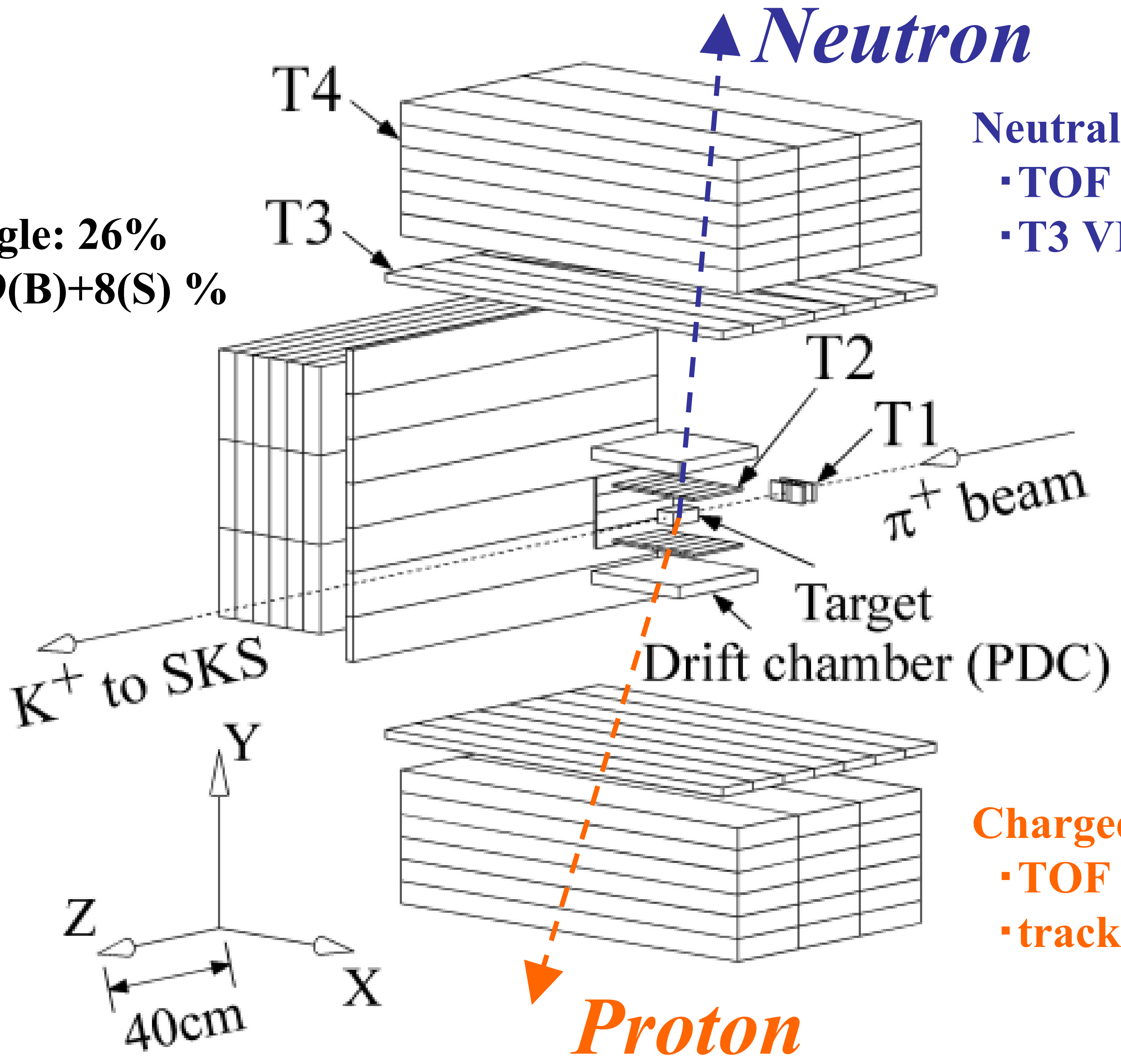




(One of the theoretical model)

Decay counter system

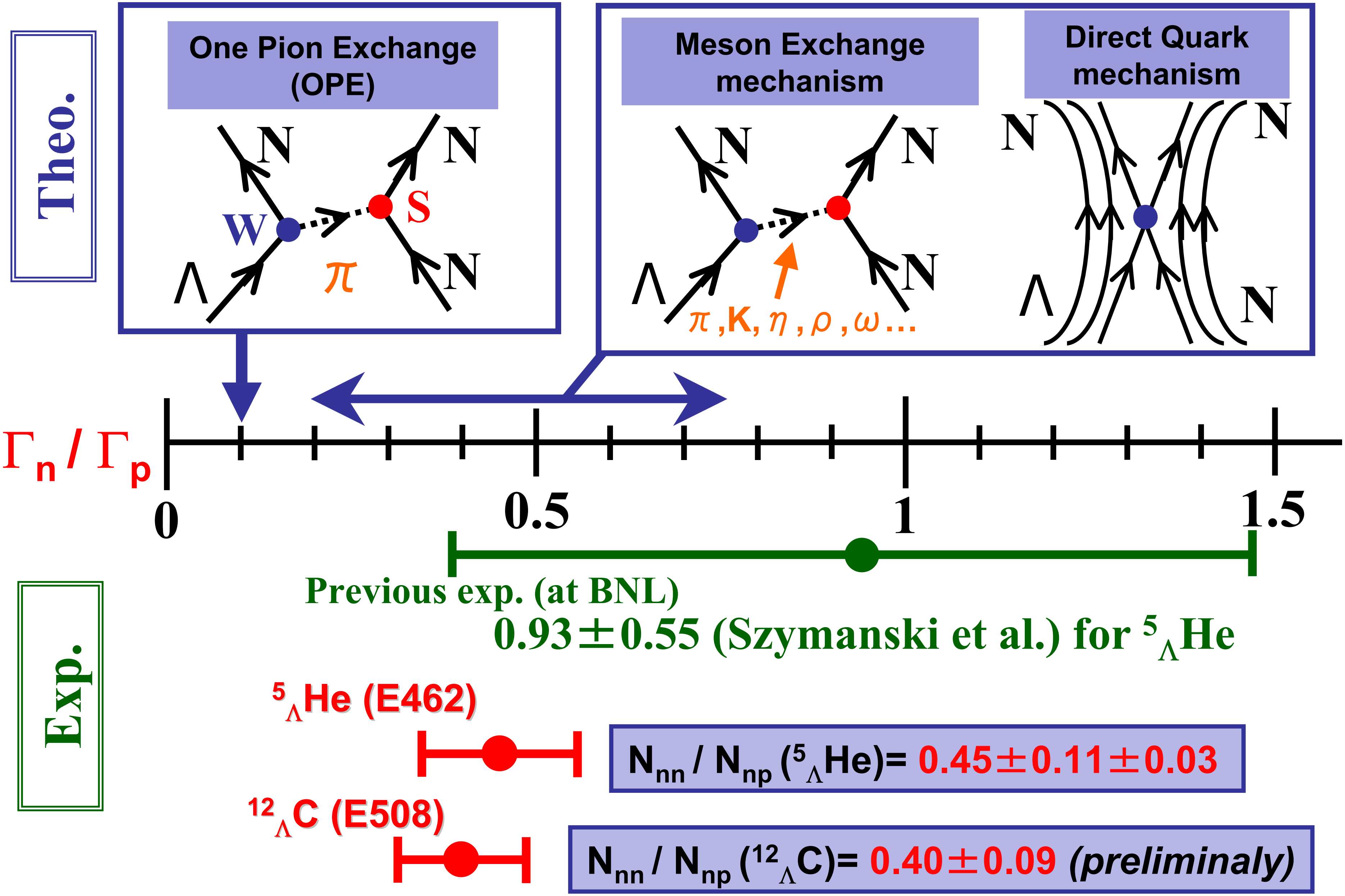
Solid angle: 26%
= 9(T)+9(B)+8(S) %



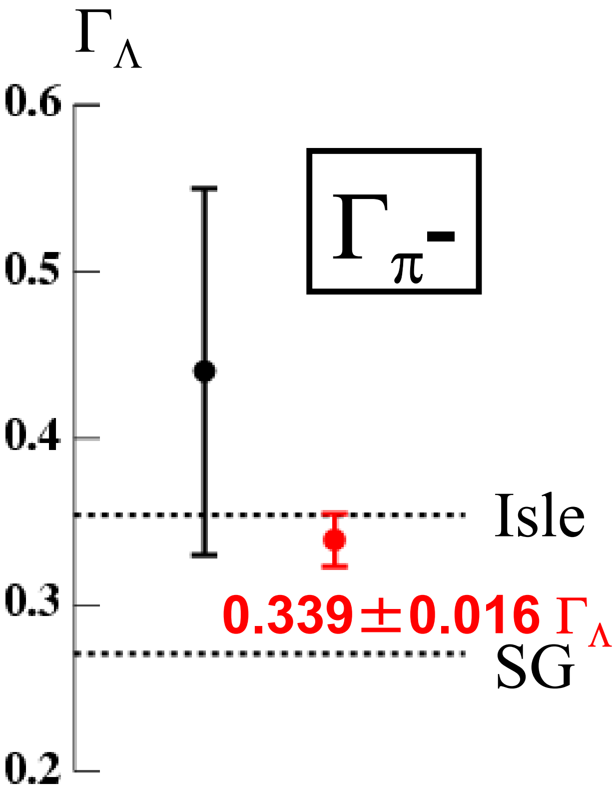
Neutral particle:
- TOF (target→NT)
- T3 VETO

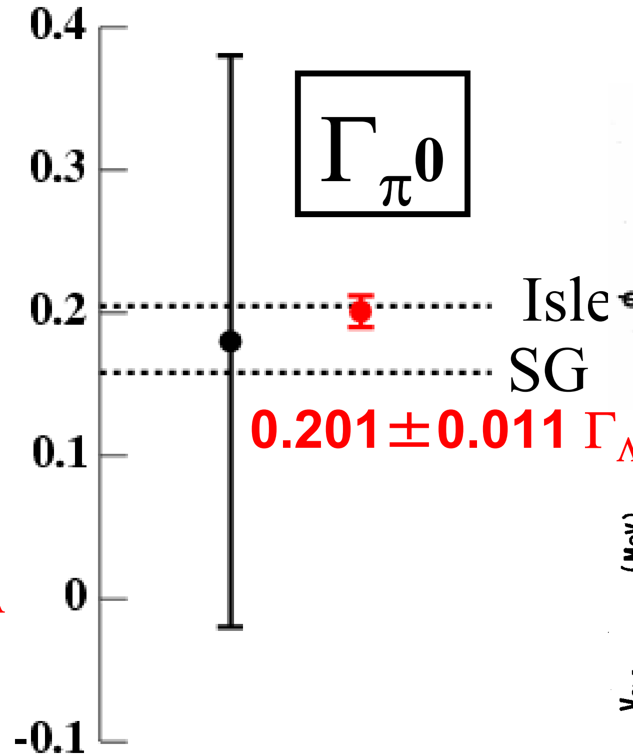
Charged particle:
- TOF (T2→T3)
- tracking（PDC）

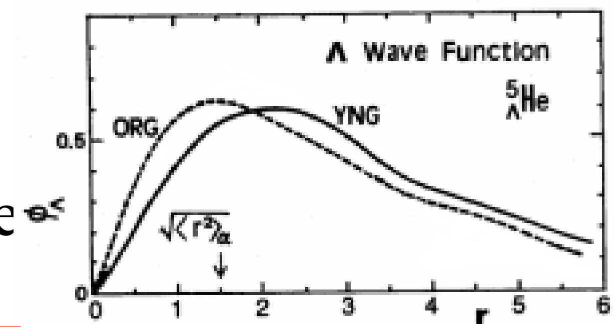
Γ_n / Γ_p ratio

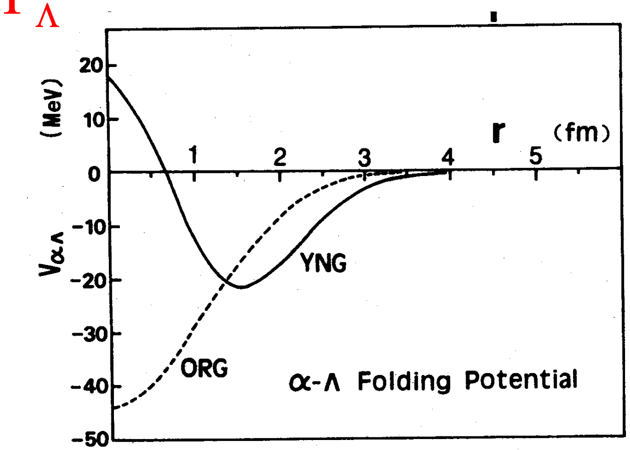


Γ_{π^-} and Γ_{π^0} for $^5_\Lambda$He *(preliminary)*







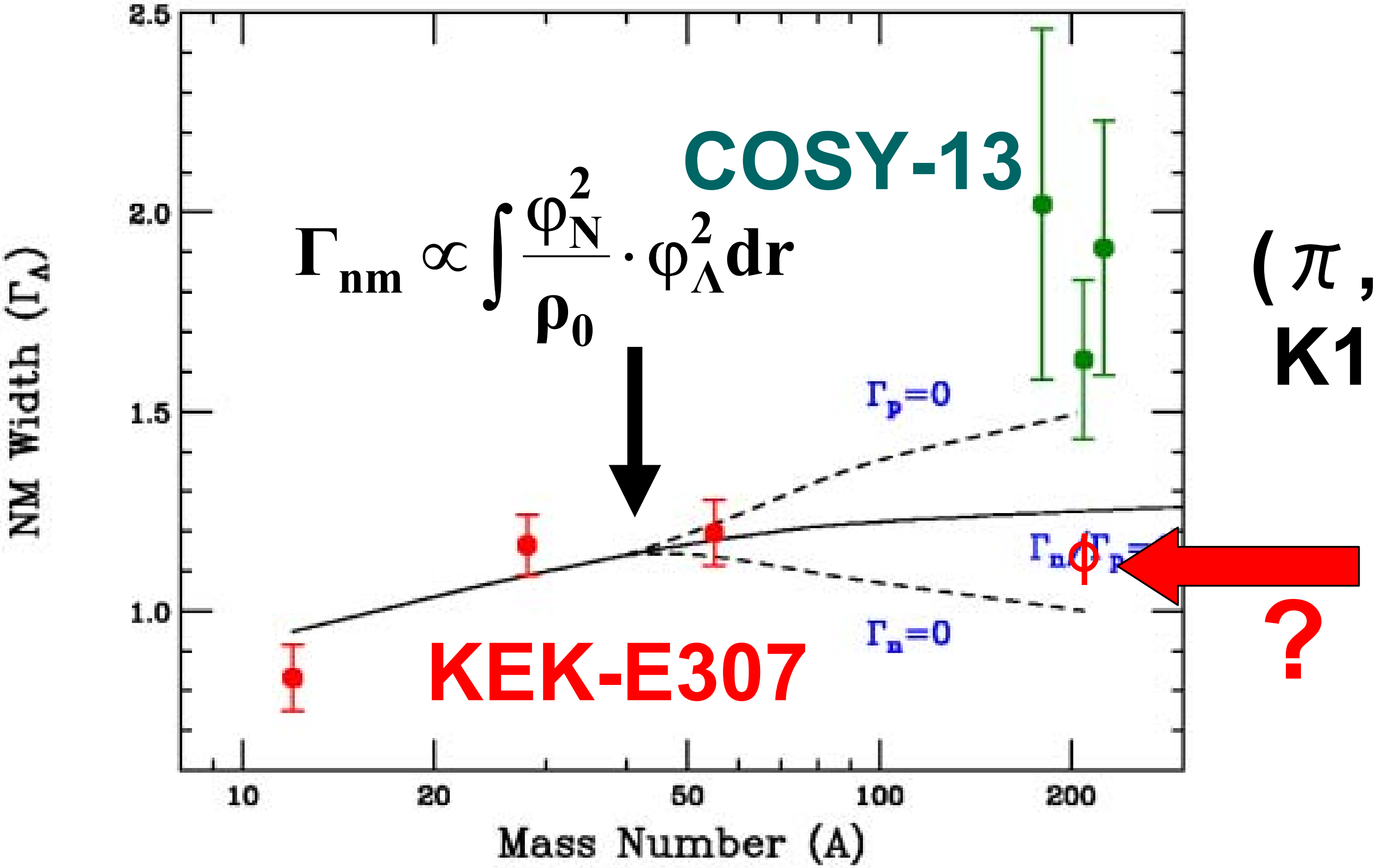


Measured with much improved accuracy

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

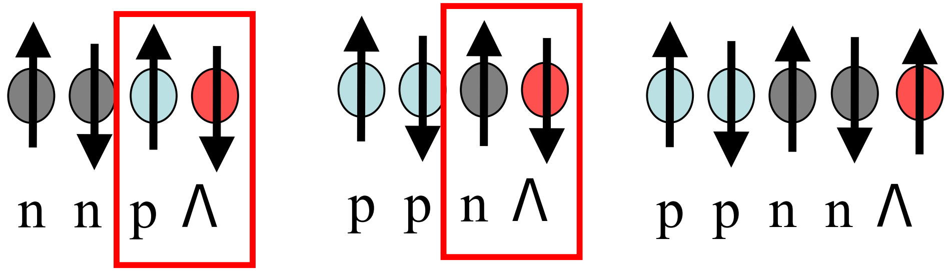
see S.Ajimura : J-PARC LOI 21

Spin / isospin dependence

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

R_{NS} … N : Λn→nn, Λp→np
S : spin = 0 or 1

${}^{4}_{\Lambda}$H ${}^{4}_{\Lambda}$He ${}^{5}_{\Lambda}$He



^{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 !!

Kaonic Nuclei - *M. Iwasaki (RIKEN)*

- New mass spectrum of $^3He(K^-, n)X$ - Evidence of state is more significant than that seen also in $^3He(K^-, n)X$
- The state seems corresponding to
  - Baryon No. = 3
  - Strangeness = -1
  - Charge = 0
  - Isospin = 1
- Need more study on:
  - Intepretation? *Most naively, deeply bound K?*
  - Size, Spin, and Parity
- Future experiments at KEK and J-PARC (1.1 K beam)
  - Higher statistics but lower background
  - Stop K^-, also in flight K^-?
  - K^-K^- bound state (highly densed strangeness matter)?

YP Scattering Experiments at J-PARC

M. Ieiri (KEK)

- Short lifetime of Y makes it very difficult
- Existing data is in poor quality with great efforts
- J-PARC brings good hopes for such experiments however the existing Tracking/CCD camera technique cannot handle the rate
- Main reactions considered: $\Xi^- p$, $\Sigma^+ p$, and Λp

  must against strong interaction conversion BG

Requests and Works Needed

- Requests
  - Separated beam line around 1.5-1.8 GeV/c
  - K^- intensity 10^7/s with K/p > 1
  - Liquid H facility
- Works
  - Realistic optimization of setup
  - Background estimation (physical & inst.)
  - Fast imaging device
  - Trigger consideration

Exotic Strange Nuclei

Lanskoy (Moscow)

- Neutron rich hypernuclei
  - Reaction mechanisms of $^{10}B(\pi^-,K^+)^{10}{}_{\Lambda}Li$ and $^{12}C(\pi, K^+)^{12}{}_{\Lambda}Be$; one- and two-step process
  - Theo. to exp. (T. Fukuda's exp.) cross sections were compared; there is a factor of two difference
- θ^+ nuclei
  - To maximize cross section momentum transfer needs to be minimized
  - Magic momentum exist only for three body initial state reaction, for example, $KNN \rightarrow \theta N$ ($P_K = 0.6$ GeV/c and $P_\theta = 0$), $\pi NN \rightarrow \theta \Lambda$ ($P_K = 1.64$ GeV/c and $P_\theta = 0$), and $\gamma NN \rightarrow \theta \Sigma$ ($P_K = 1.93$ GeV/c and $P_\theta = 0$)
  - The narrow width (<5 MeV) may make bound θ^+ nuclei possible