Hypernuclei spectroscopy via the real photo-induced reaction

Atsushi Tokiyasu
ELPH, Tohoku University

SNP2017 @ Osaka
Mar. 12th, 2017.

Abstract

- Recently, we proposed a new experiment (FOREST Upgrade) to perform a hypernuclei spectroscopy via the real photo-induced reaction.

- By using a EM calorimeter and a spectrometer at forward angle, we can study hypernuclei via the $A(\gamma,K^+)X$ reaction.

- Physics motivation and the feasibility of the experiment will be discussed for the following reaction:
  - $^{12}C(\gamma, K^+)^{12}{}_{\Lambda}B$
  - $^{4}He\ (\gamma, K^+)^{4}{}_{\Lambda}H$

Outline

1. photo-induced reaction
2. FOREST Upgrade project
3. $^{12}C(\gamma, K^+)^{12}{}_{\Lambda}B$
4. $^{4}He\ (\gamma, K^+)^{4}{}_{\Lambda}H$

photo-induced reaction

Hypernuclei production via (γ,K^+)

☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.

2. convert proton to Λ

3.Large momentum transfer

4. Spin-flip amplitude ($J_\gamma = 1$)

Hypernuclei production by (γ,K^+)

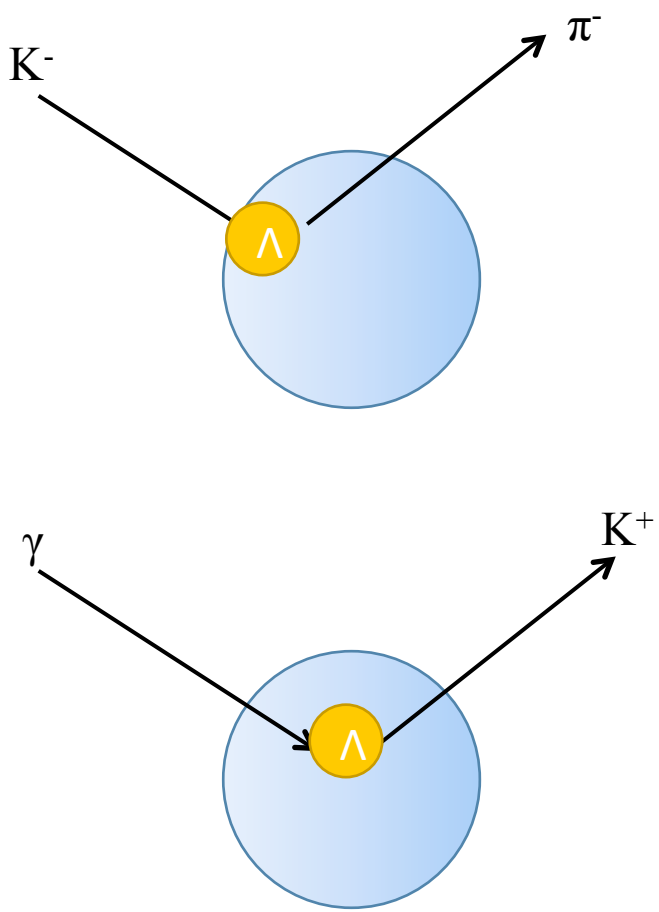
☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.
→Free from ISI, FSI

2. convert proton to Λ

3.Large momentum transfer

4. Spin-flip amplitude ($J_\gamma = 1$)



Hypernuclei production by (γ,K^+)

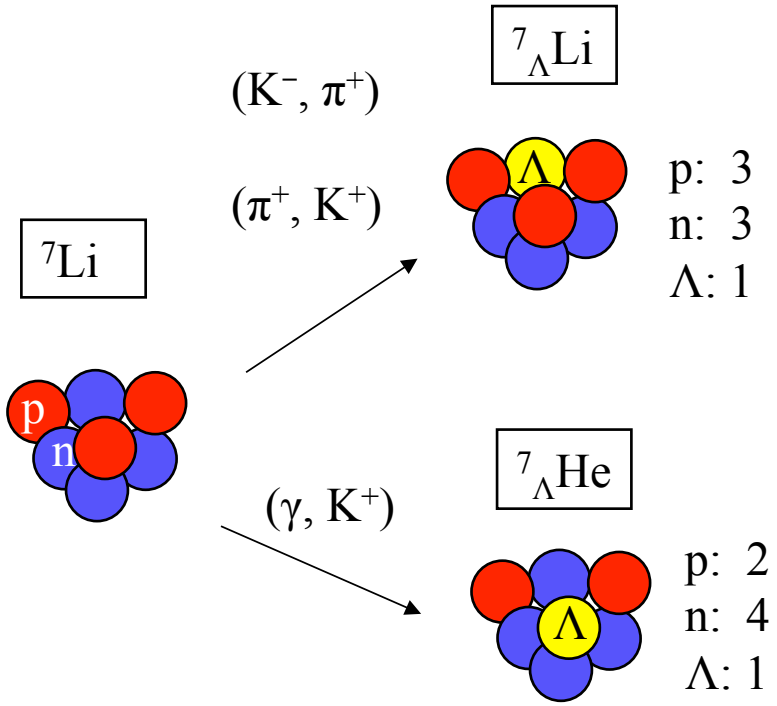
☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.
→Free from ISI, FSI

2. convert proton to Λ
→neutron rich hypernuclei

3.Large momentum transfer

4. Spin-flip amplitude ($J_\gamma = 1$)



cf. (π^-, K^+) 2step reaction

Hypernuclei production by (γ,K^+)

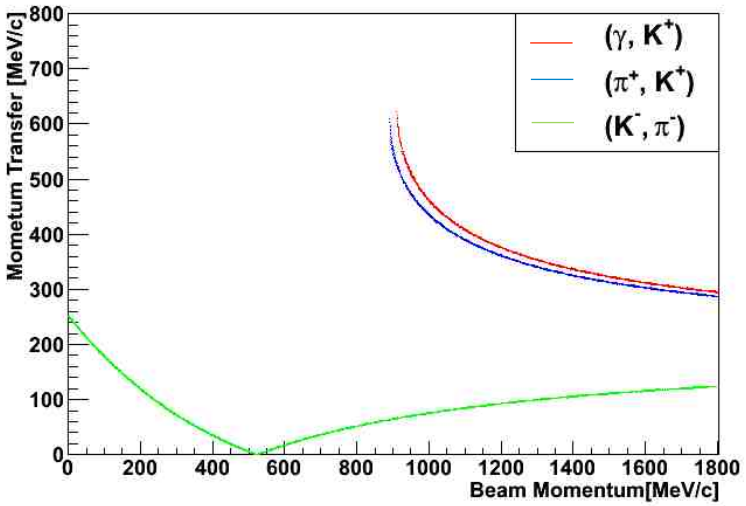
☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.
→Free from ISI, FSI

2. convert proton to Λ
→neutron rich hypernuclei

3.Large momentum transfer
→deep bound states

4. Spin-flip amplitude ($J_\gamma = 1$)



qΛ ～400 MeV/c

Comparable to (π^+,K^+)

Hypernuclei production by (γ,K^+)

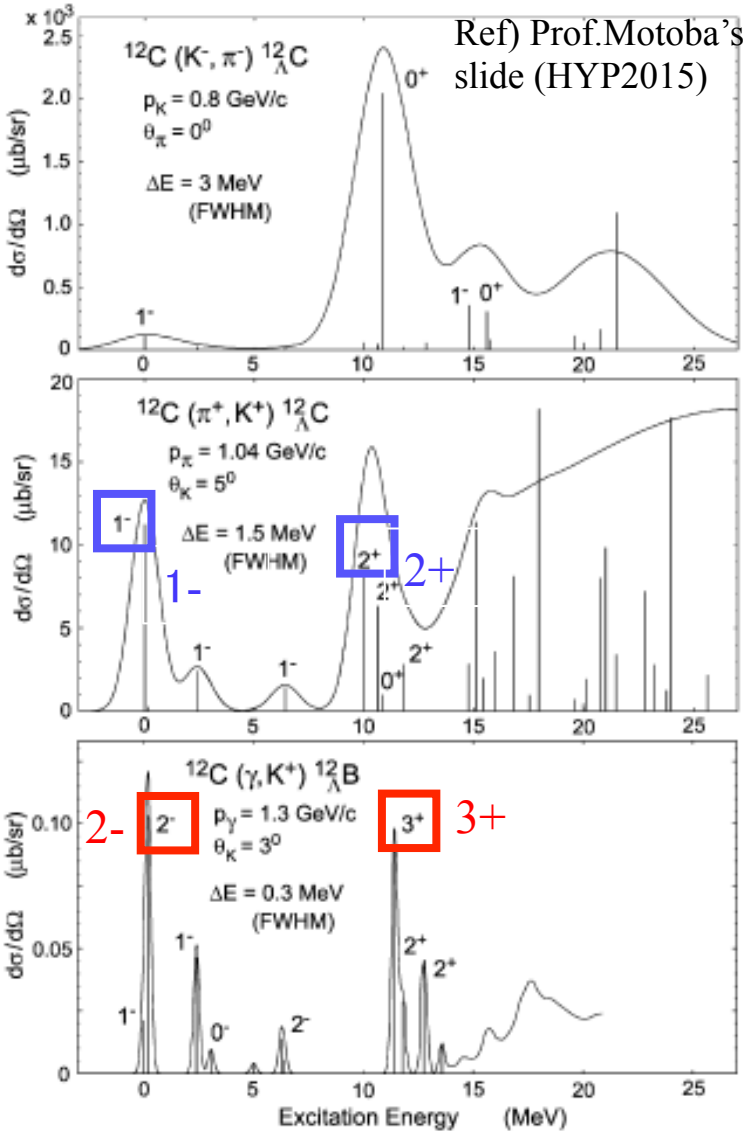
☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.
→Free from ISI, FSI

2. convert proton to Λ
→neutron rich hypernuclei

3.Large momentum transfer
→deep bound states

4. Spin-flip amplitude ($J_\gamma = 1$)
→Unnatural parity state



Hypernuclei production by (γ,K^+)

☆property of the (γ,K^+) reaction.

1.Λ is produced via EM int.
→Free from ISI, FSI

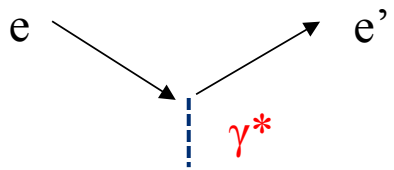
2. convert proton to Λ
→neutron rich hypernuclei

3.Large momentum transfer
→deep bound states

4. Spin-flip amplitude ($J_\gamma = 1$)
→Unnatural parity state

Complementary to Hadron-induced reaction!

-Theoretical calculation :1980s ~
But.
- small cross section.
- No facility for high intensity beam.
- (e,e'K^+) reaction



virtual photon vs real photon

	γ	+	p	→	K^+	+	Λ		
spin	1		1/2		0		2		
Virtual	3	x	2	x	1	x	2	=	12
Real	2	x	2	x	1	x	2	=	8

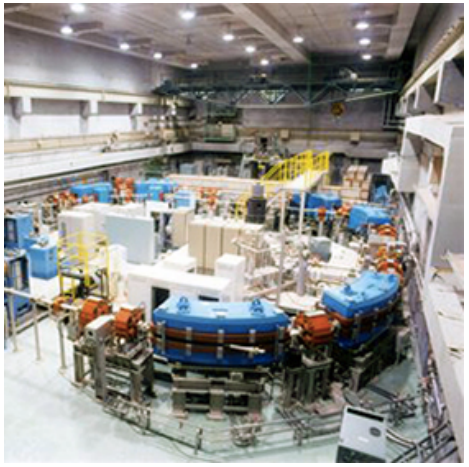
Merit:
- simple elementary process.
- High transparency of γ → long target, low background
- coincidence measurement. (Production and decay)

Demerit (compared to e^- beam):
- poor mass resolution
- low intensity beam

→ FOREST Upgrade

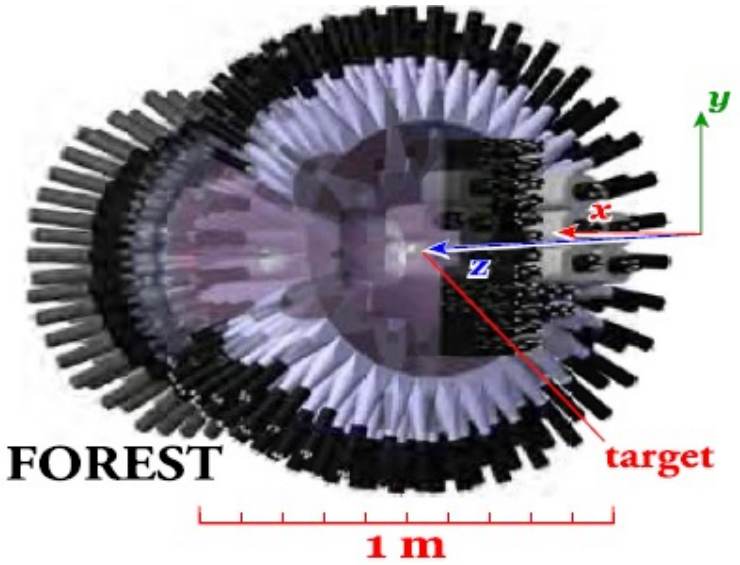
FOREST Upgrade

ELPH @ Tohoku University



- 1.3 GeV Electron Synchrotron
- I = 30 mA
- γ beam produced via bremsstrahlung process
- Tagged photon (Eγ= 0.8 – 1.2 GeV)
- FOREST (this talk), NKS2 (Dr. Nagao's talk)

FOREST detector



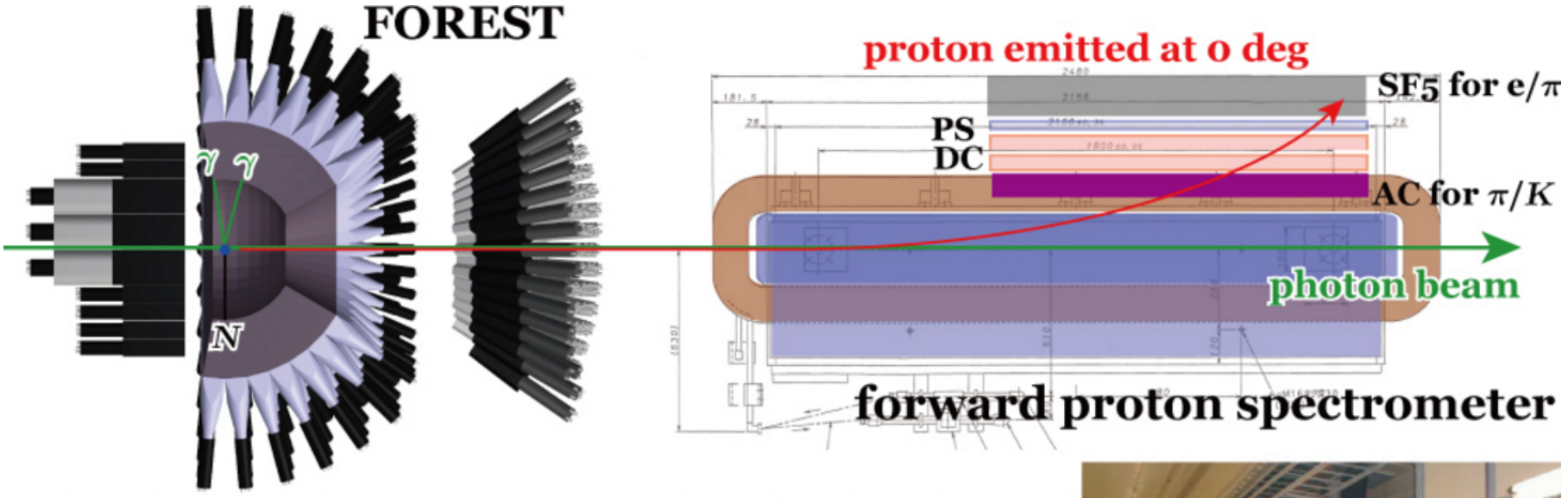
- 4π EM calorimeter (> 90 %)
- CsI + Lead/SciFi + Lead glass
- N* search in the γ n → η n reaction

☆FOREST Upgrade Project

1. Installation of Fwd spectrometer (K^+ detection)
2. New Tagger system : Improve E_γ resolution ($\Delta E_\gamma \sim 1$MeV)

→ (γ, K^+) by Missing Mass Method

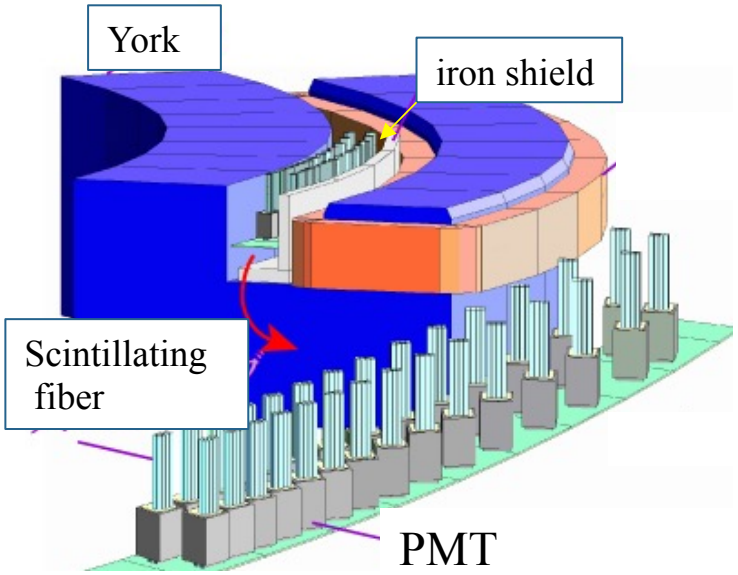
Fwd Spectrometer



- Detection of charged particles at 0 degrees
- Acceptance (vert ±0.6°, hori ±1.2°)
- BL = 1.37 T·m
- Resolution ~ $\Delta p/p < 10^{-3}$

} under study

Tagger Upgrade



MPPC + Scintillator

+

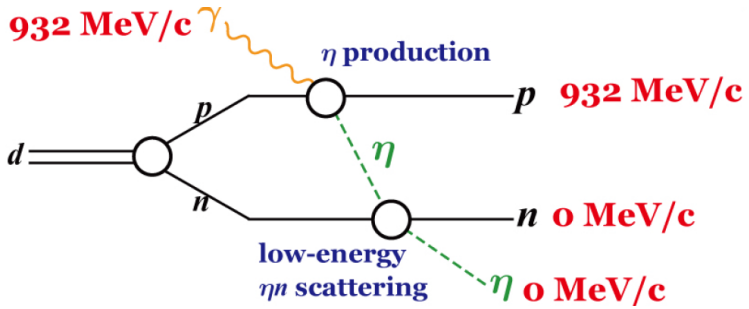
MWDC

	Current Setup	New Setup
ΔE/ch	0.5 – 2.5 MeV (σ)	~1 MeV(σ)
ΔT	0.4 – 0.6 ns (σ)	0.2 n (σ)

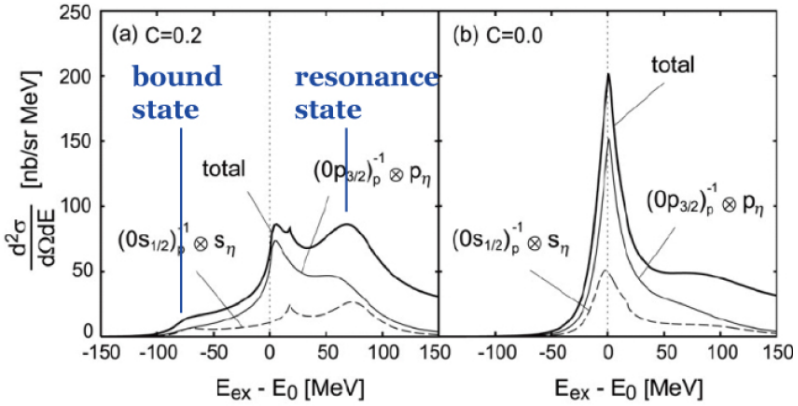
Physics Program of FOREST Upgrade

☆By detecting charged particles at a forward angle, many physics channels are accessible!

- d (γ, p)η n
  - Scattering Length measurement



- d (γ, K^+)Λ n
  - Λ-n interaction measurement



- C(γ, p) $_\eta$B
  - η mesic nuclei search

Commissioning run

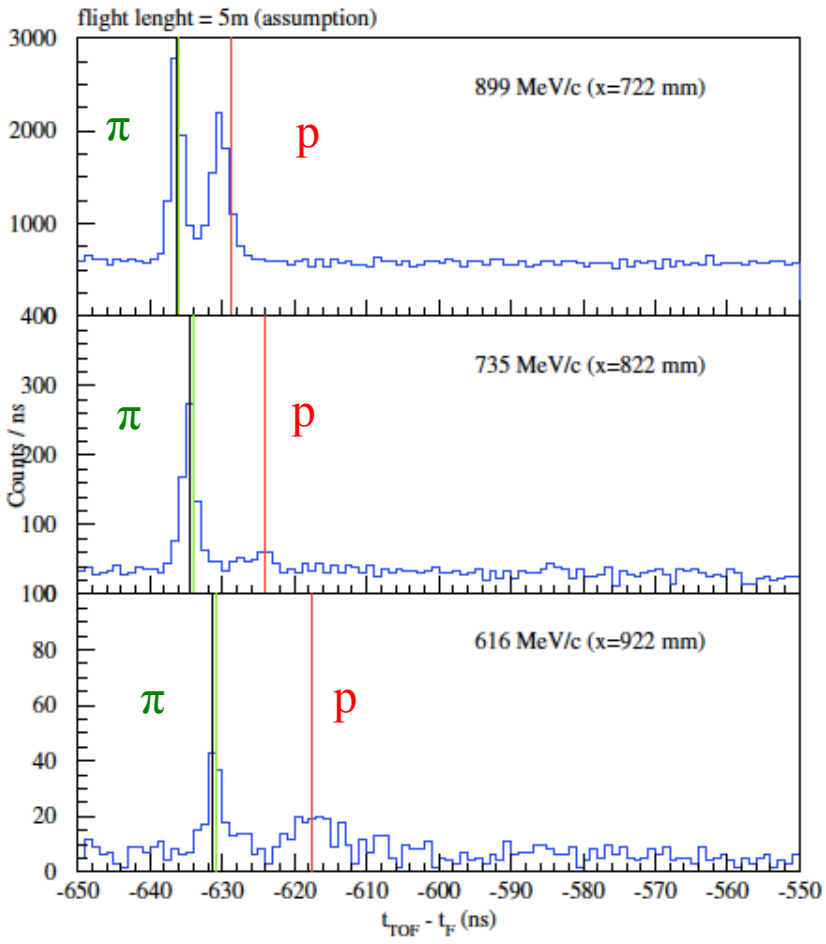
- Beam time:
  2017 Jan 12h – Jan 16th

- Target:
  Liquid Deuterium

- p/π separation

- Physics run will start from next FY

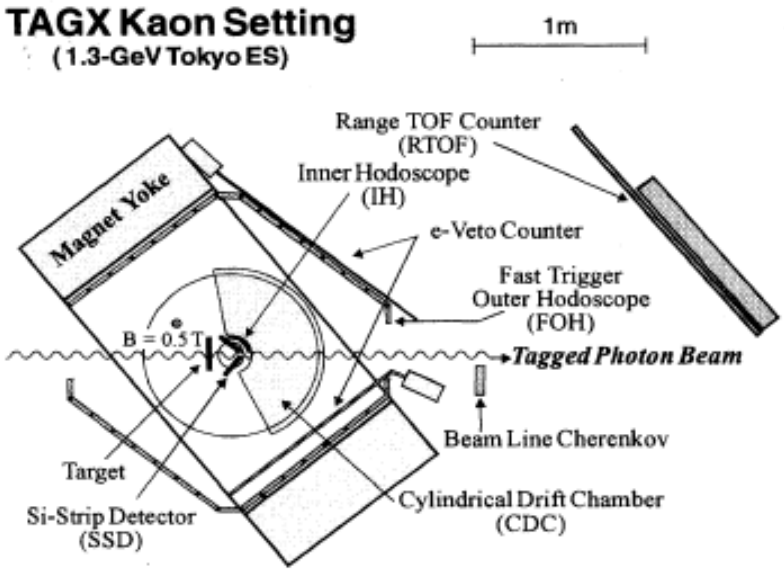
TOF Spectrum

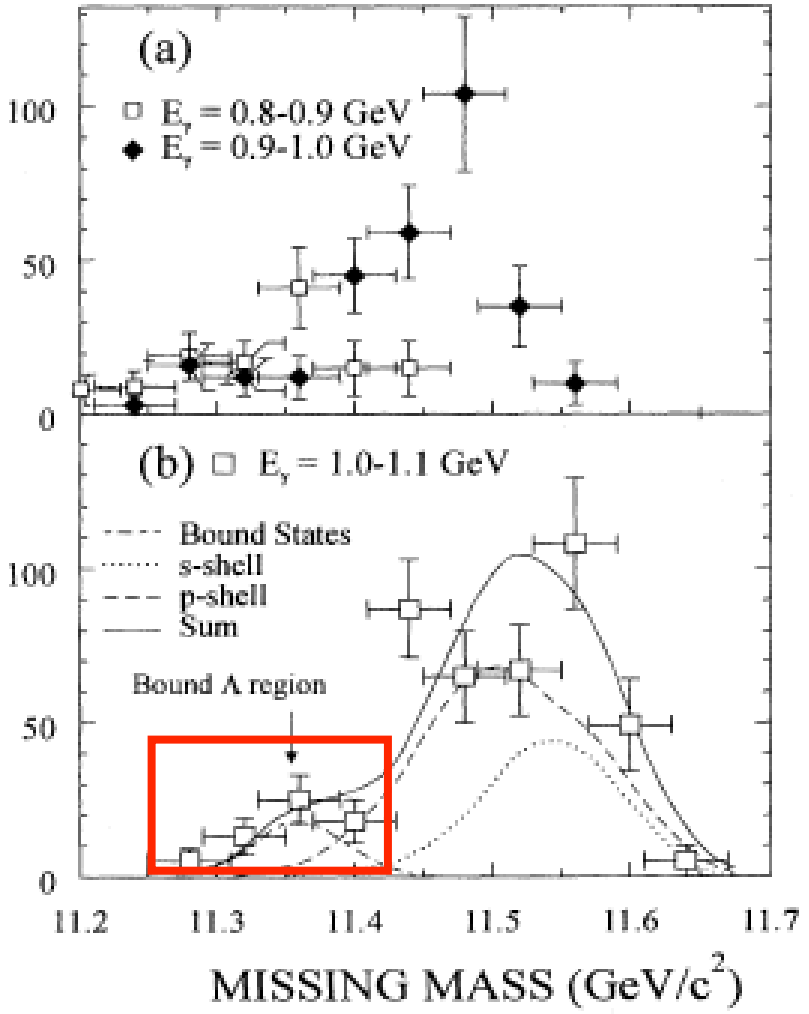


$^{12}C(\gamma, K^+)^{12}{}_{\Lambda}B$

ES132 @ INS-TAGX

Ref) PRC52, R1157

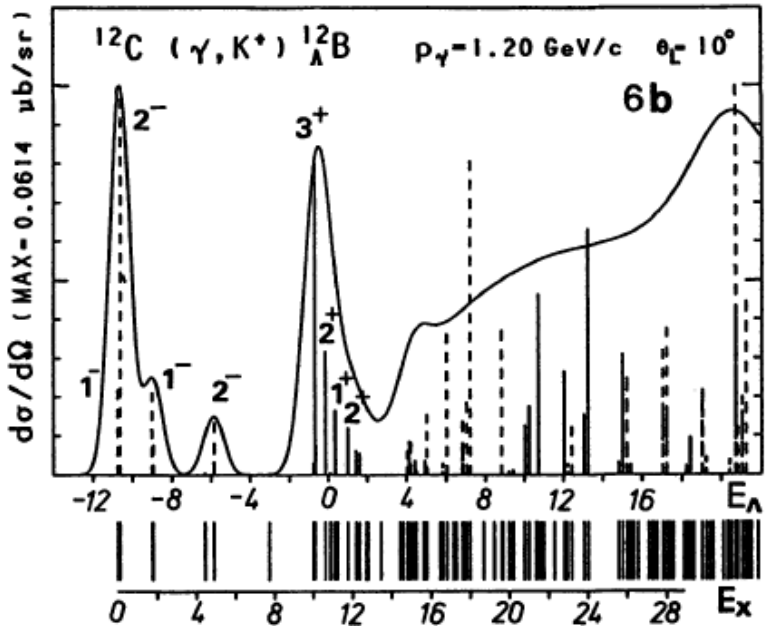


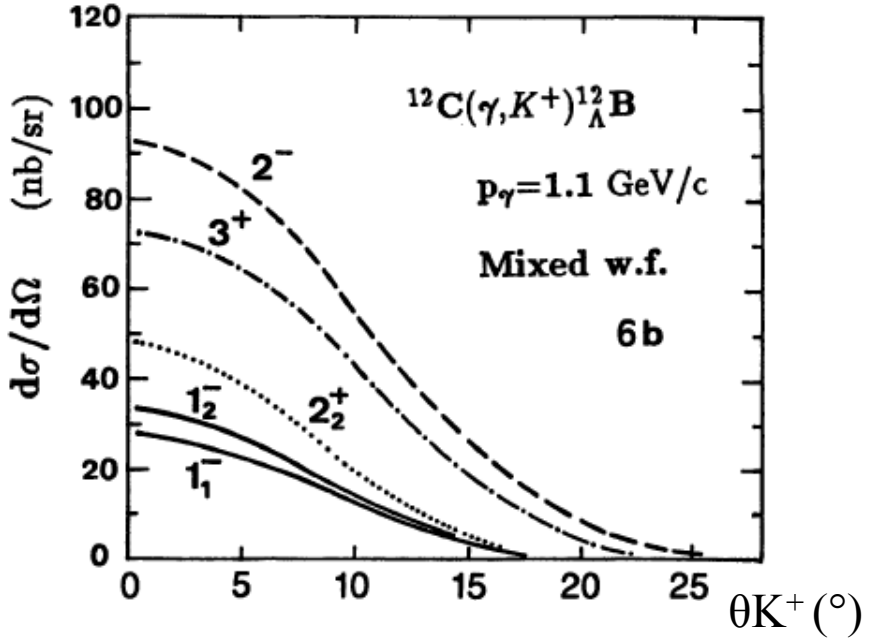


- $0° < \theta_{lab} < 40°$
- $-0.8\ GeV < E\gamma < 1.1\ GeV$
  → Comparable
- Photon flux = $4.5 * 10^5$ /s
  → ~10 times @ ELPH
- $\Delta p/p \sim 0.06$ (RMS), $\Delta E_\gamma \sim 5MeV$
  → $\Delta p/p \sim 10^{-3}$, $\Delta E_\gamma \sim 1MeV$

Yield Estimation

Ref) PTPS117.123
Notice date 1994





Yield (2-) = dσ/dΩ * Ω * R_K * N_{target} * N_{beam}

= 100 nb/sr * 1.0E-4 * 0.8 * 1.0E+23 * 5.0E+13

inside FOREST C(10 mm) 10^7cps, eff=50%

~ 1 events /day (current setup)

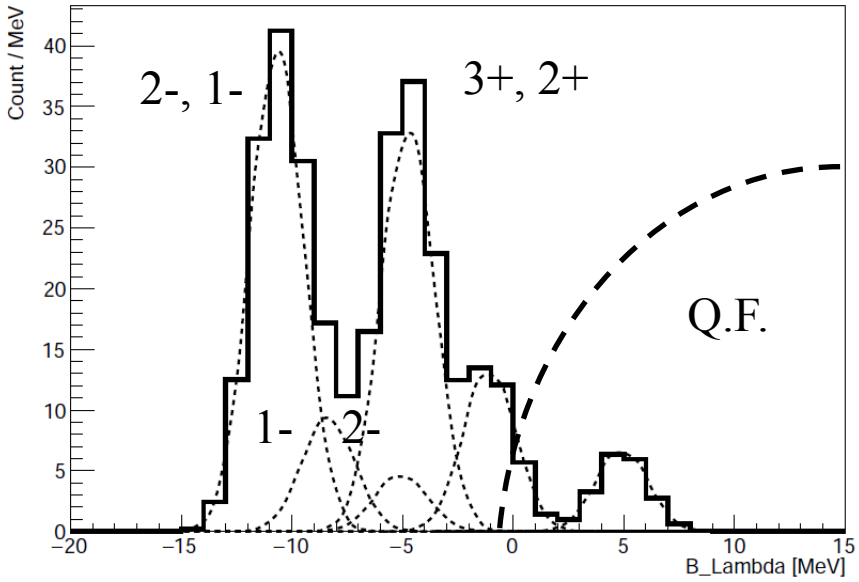
→ ~ 100 events/day (future: target pos, higher intensity…)

Expected Spectrum

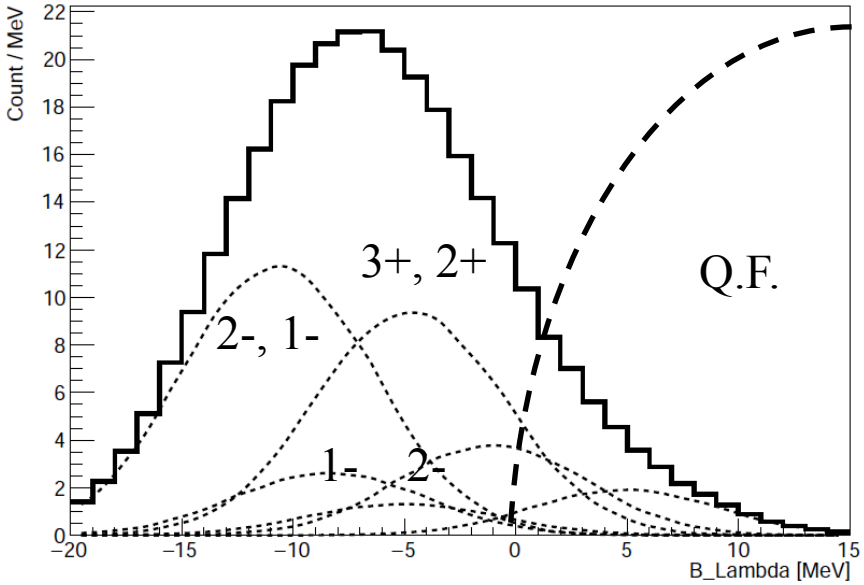
The missing mass spectrum was obtained by MC simulation.

- Eγ = 1.1 GeV fix
- 100 day beamtime (current setup)
- Energy straggling in Target ΔE/E << 10^{-3} %, w.o. energy loss correction
- Multiple Scattering angle is not considered.
- scattering angle was assumed to be 0 degree.

$\Delta p_K/p_K$ = 0.1 % (r.m.s)
ΔE_γ = 1 MeV (r.m.s) *best*



$\Delta p_K/p_K$ = 0.6 % (r.m.s)
$\Delta E_\gamma/E_\gamma$ = 2 MeV (r.m.s) *worst*



Coincidence Measurement

Measurement of Decay product of hypernuclei with FOREST

- Free:
  - $\Lambda \rightarrow N\pi$
- Hyper nuclei :
  - $\Lambda \rightarrow N\pi$ Mesonic Weak decay
  - $\Lambda N \rightarrow NN$
  - $\Lambda NN \rightarrow NNN$

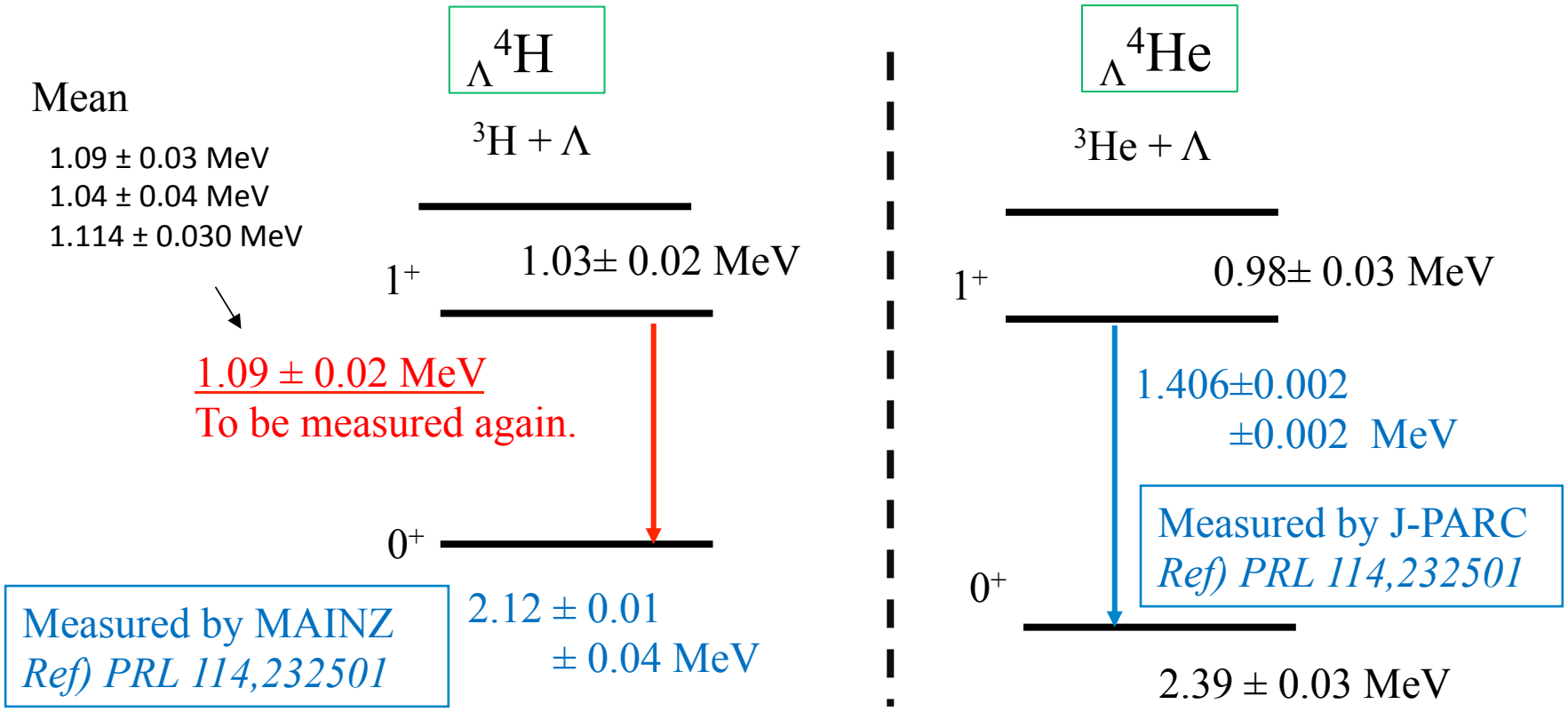
  } Non-Mesonic Weak decay
- Exp : KEK-E462/E508
- $\Gamma_p/\Gamma n \sim 0.5$ (solve the NMWD puzzle)
- Measurement of $\Lambda NN \rightarrow NNN$ is awaited.
- PID (n/p/π), Large acceptance (non-back-to-back event)

  →Detection with FOREST

  (> 10 times statistic)

$^{4}\mathrm{He}(\gamma, K^{+})^{4}_{\Lambda}\mathrm{H}$

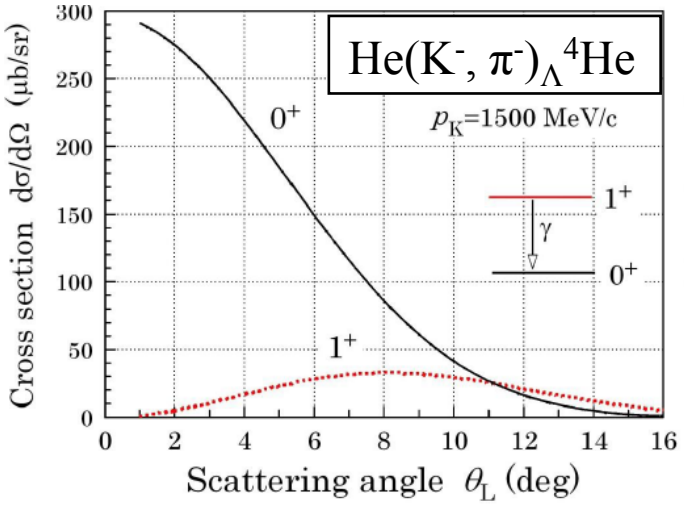
Charge Symmetry breaking

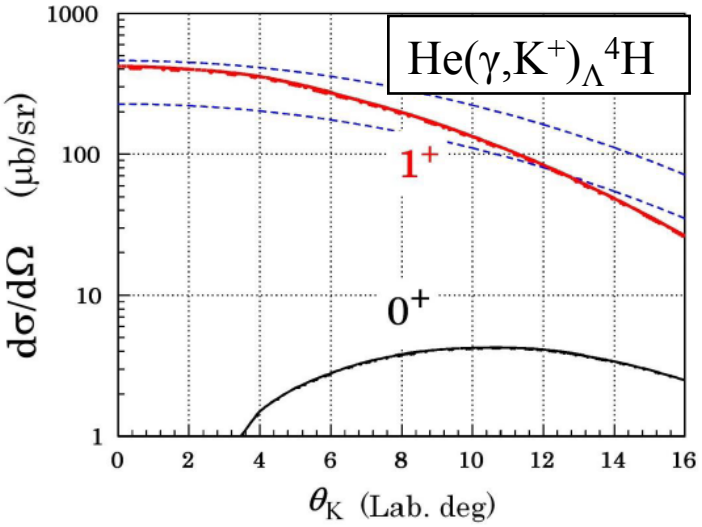


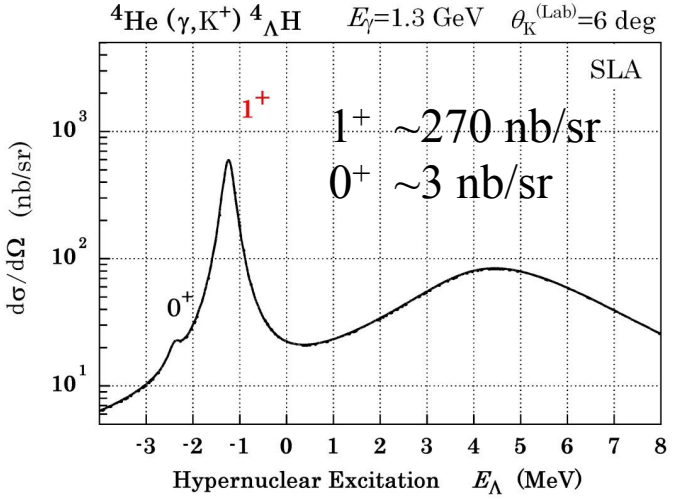
-He(π^-, K_s) $^{4}_{\Lambda}$H
-He(K^-, π^0)$^{4}_{\Lambda}$H
-Hyper fragment

Severe BG ⇒ He(γ, K^+) $^{4}_{\Lambda}$H

$^4He\ (\gamma, K^+)\ {}^4_\Lambda H$ reaction







1+ state will be enhanced
in the (γ、K+) reaction
~100 events/day @ FOREST Upgrade
→ K^+ tag and γ-ray measurement. (Ge array?)
→ Measurement of NMWD mode (BR ~0.1)

100 - 200 days beam time (dep. BG)

Ref) Prof. Motoba's slide (HYP2015)

Summary

FOREST Upgrade experiment

4π EM calorimeter

+ Forward spectrometer

+ New Tagger System

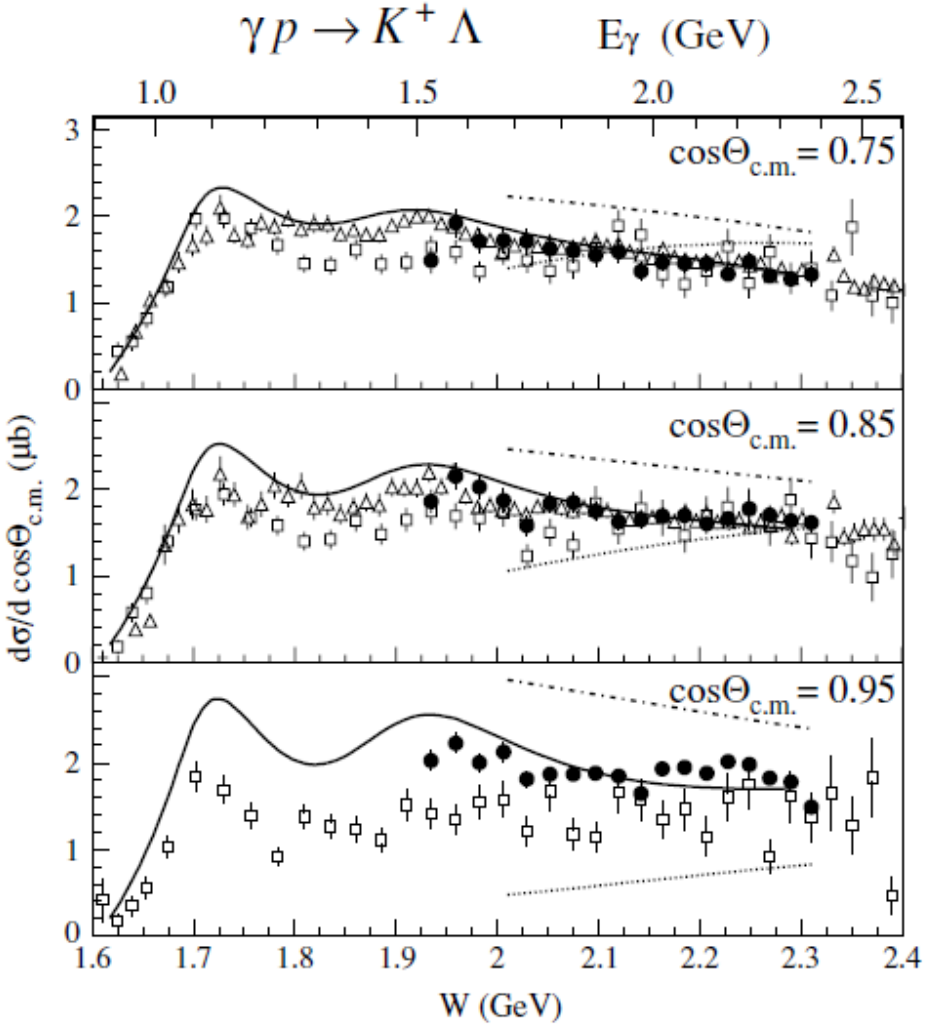
Hypernuclei spectroscopy via the (γ, K+) reaction.

$^{12}C(\gamma, K^+)^{12}_{\Lambda}B$ → coincidence measurement (NMWD)

$^{4}He\ (\gamma, K^+)^{4}_{\Lambda}H$ → CSB test by measuring γ-ray

BackUp

Elementary cross section



SAPHIR
CBELSA/TAPS
GRAAL
CLAS
LEPS

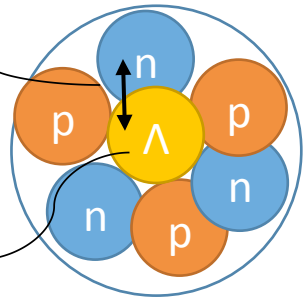
N* contribution

$d\sigma/d\cos\theta \sim 3\mu b$

Ref) PRC73, 035214

Hypernuclei

Λ-N interaction
Unified Baryon-Baryon Interaction



-impurity effect: Shrink
-glue like role
extraordinaly neutron rich $^{7}_{\Lambda}$H etc

g-factor in medium
:chiral symmetry restoration?
(g=eħ/2mc)

- Experiment → K^+ trigger, Signal as peak structure, low physics BG
- Theory → Shell model, DWIA …
- Recent Progress
  - neutron rich Hypernuclei : Unstable Hypernuclei
  - Light Hipernuclei : CSB, precise information on 3-body int
  - S=-2 Hypernuclei : Ξ-n int., Dibaryon?
  - Excited Hypernuclei : Λ(1405)-Nuclei, KaonicNuclei?
- Reaction : (K^-, π^-) , (π^+, K^+), $(e,e'K^+)$, Heavy Ion… + (γ, K^+)