Gamma-ray spectroscopy of hypernuclei (at JHF)

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Contents

I Introduction

- Gamma-ray spectroscopy
  — Successful at KEK & BNL

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Proceed further at JHF

- What can be done?

beam intensity : >10 times

⇒ beam time : 1 month → <3 days

upgrade of present hyperball makes this even shorter

⇓

Many things!

Examples:

◎ Systematic study of single Λ hypernuclei possible

- ΛNN 3-body force
- Charge symmetry breaking ΛN (ΛNN) force.
- Heavier hypernuclei
- Property of Λ in nuclear matter

◎ $S=-2$ systems accessible

- Ξ^--atom X-ray measurement
- Double-Λ hypernuclei??

II Systematic study of single Λ hypernuclei

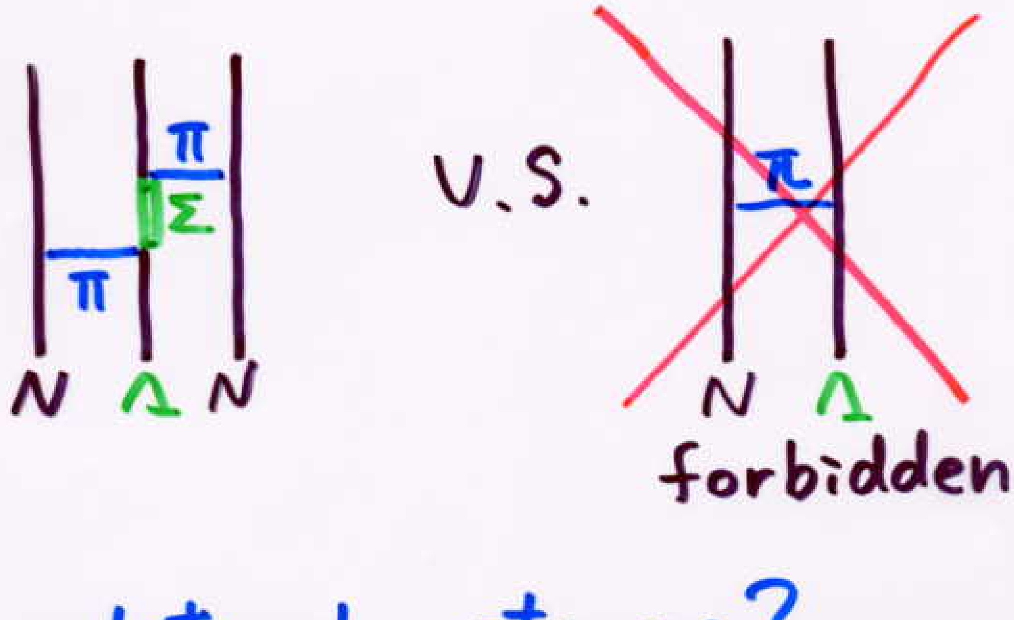
◎ Physics issues

① ΛNN 3-body force

Consistency check of 2-body interaction in various hypernuclei

⇓ If NO

3-body force necessary



- relatively strong?
- $M_\Sigma - M_\Lambda \sim 80$ MeV $\sim 1/4 (M_\Delta - M_N)$

② Charge symmetry breaking ΛN (ΛNN) interaction

- Mirror hypernuclei

  { structure : same
  { no coulomb force between Λn, Λp

  ⇒ Direct information on CSB in ΛN interaction

- ${}^4_\Lambda H$, ${}^4_\Lambda He$

$$
\begin{aligned}
B_\Lambda({}^4_\Lambda H) &= 2.04 \pm 0.03 \text{ MeV} \\
B_\Lambda({}^4_\Lambda He) &= 2.39 \pm 0.02 \text{ MeV} \\
\hline
\Delta B_\Lambda &= 0.35 \pm 0.04
\end{aligned}
$$

⇓

Suggests large CSB

~ 5 times stronger than in ^3H and ^3He

- What is the origin?

(i) $\Lambda - \Sigma^0$ mixing

→ π^0 exchange

(ii) $\Lambda N - \Sigma N$ coupling

via $\Sigma^{+,0,-}$ mass difference

→ 3-body CSB force?

(iii) $K^0, K^\pm$ mass difference

(also for K^*)

→ PS (vector) meson exchange

(iv) $\rho^0 - \omega$ mixing

→ vector meson exchange

(most important in normal nuclear system)

- Spin dependence is very important

e.g. vector ⇒ LS, ...

PS ⇒ tensor, ...

③ Heavy hypernuclei

- Major shell structure

  ⇓

  Detailed "fine" structure

- E369:
  suggests large LS force for heavy hypernuclei ($^{51}_{\Lambda}V$, $^{89}_{\Lambda}Y$)

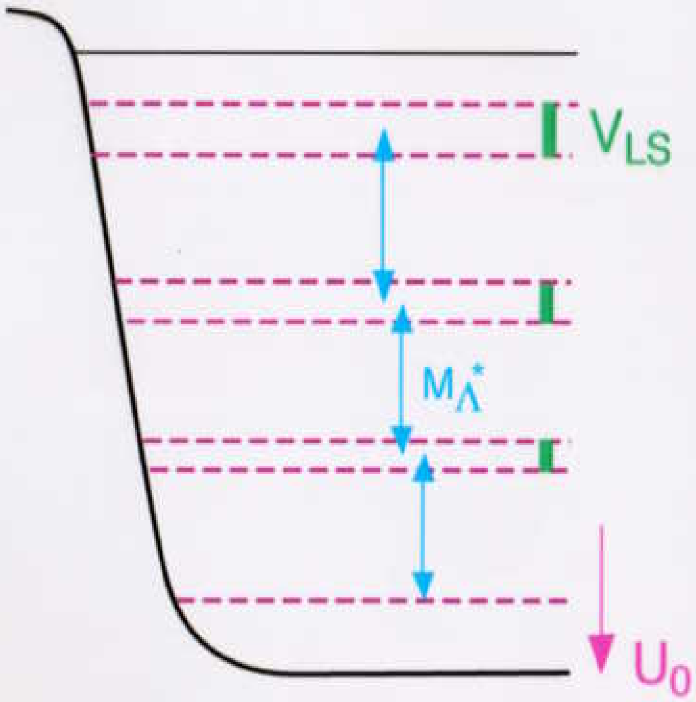
  ⇕

  E929, E930:
  very small LS force in light hypernuclei established.

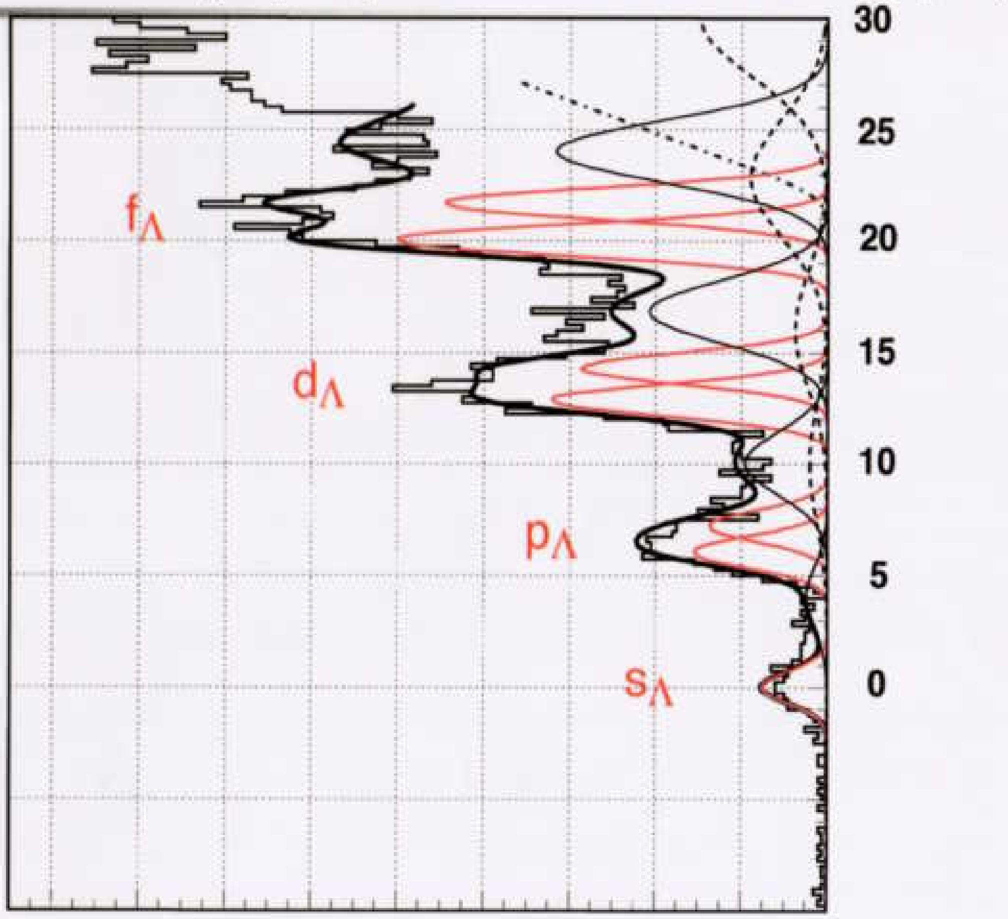
  Uncertainty in interpretation.

  could be solved by γ-ray spectroscopy.

Single-Particle Motion of a Λ in Nuclei



KEK E369



⓪ Experimental method and setup

① $(K^-, \pi^- \gamma)$

- $P_{K^-} = 0.8 \sim 1.8$ GeV/c
- $N_{K^-} = 2 \sim 40$ MK^-/spill
- Detectors must handle $> 4 \times 10^7$ K^-/s

⇒ MWPC?, Sci-fi?, SSD?

An R&D issue

- Ge detector
  - higher efficiency ⇒ ~10% @ 1 MeV
  - high-rate capability required
  - Segmented "Super Clover"?
- γ-ray yield

typ. 1000 γ's/day) for light nuclei
100 γ-γ's/day)
100 γ's/day for heavy nuclei

- π-γ, γ-γ angular correlation

⇒ spin-parity assignment

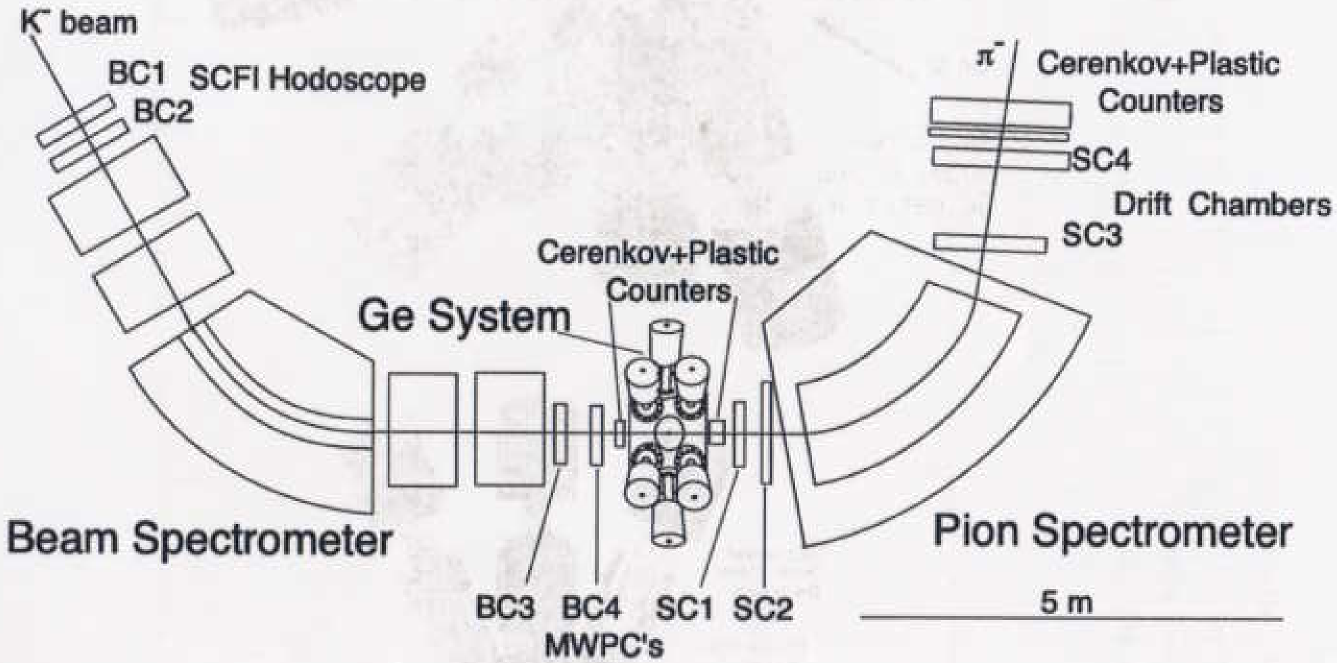
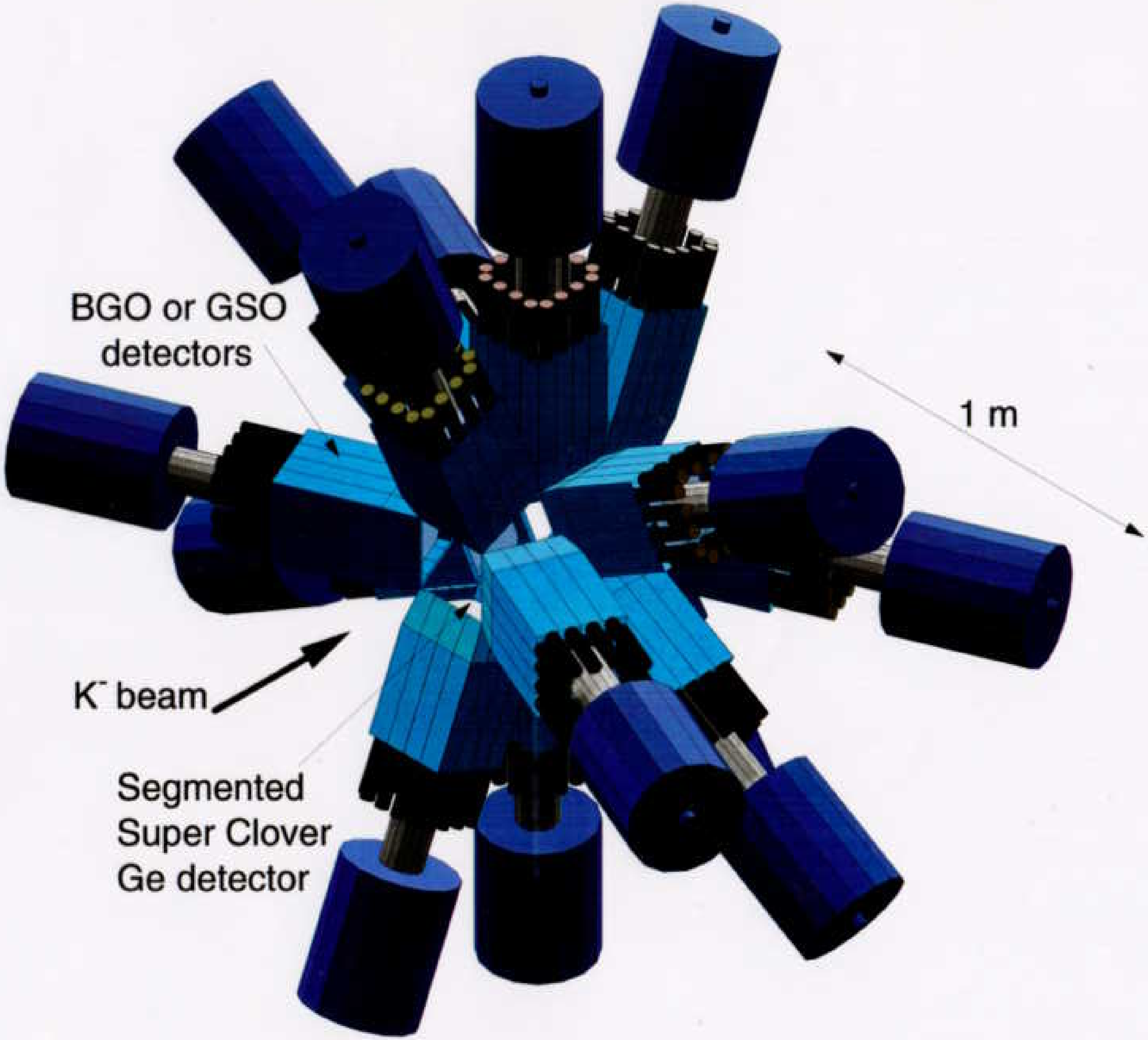


Figure 28: Setup for hypernuclear γ-spectroscopy experiments with the (K^-,π^-) reaction at K1.1 beamline.



BGO or GSO
detectors
1 m
K⁻ beam
Segmented
Super Clover
Ge detector

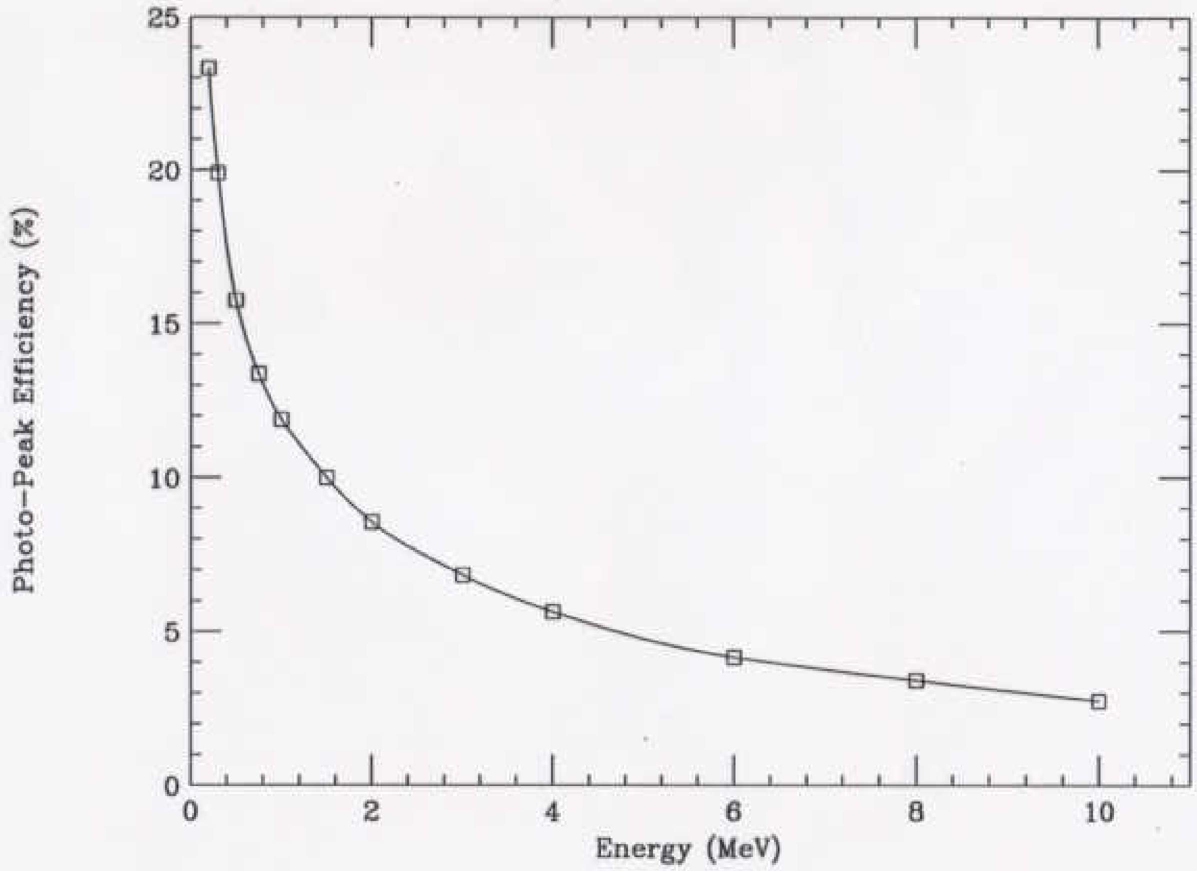
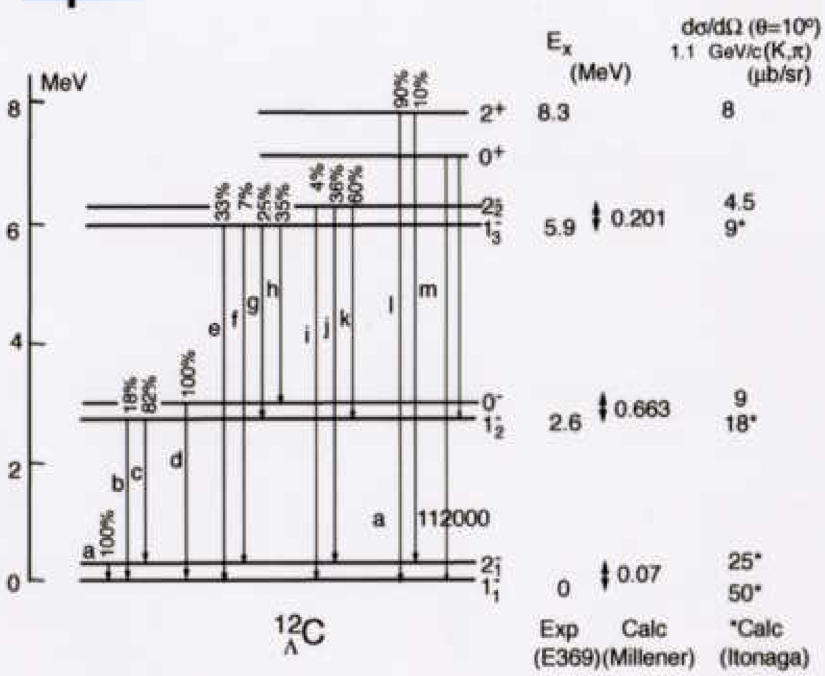


Figure 6: Absolute photo-peak efficiency of the Ge detector system which consists of 14 sets of segmanted Super-Clover Ge detectors.

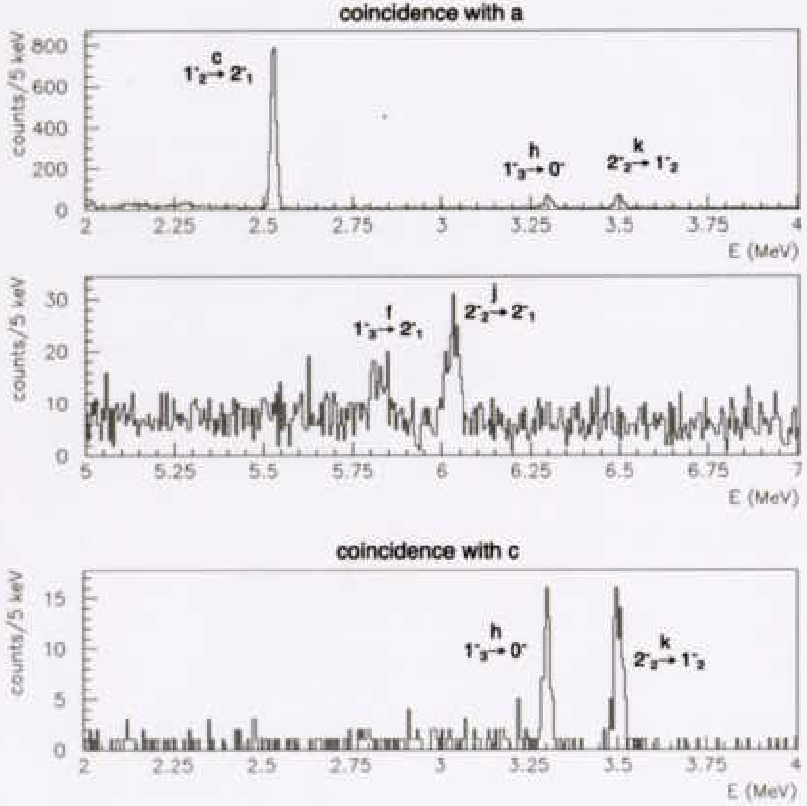
γ-γ coincidence measurement



Expected Yield (5 days)

single				γγ coincidnece with a		with c		with d	
a	112000	h	1700	c	1900	a	1900	h	55
b	2600	i	64	f	50	g	39		
c	12000	j	580	g	150	k	50		
d	7500	k	1400	j	94				
e	1100	l	2000	k	170				
f	240	m	230	m	31				
g	1300								

- $^{12}C(K^-, \pi^-)$ in 5 days



② $(K^-, \pi^0\gamma)$

— for mirror hypernuclei

- π^- spectrometer

  ⇓

  π^0 spectrometer : NMS type
  CsI + chamber + BGO

- $\frac{d\sigma}{d\Omega}$: 1/2 of (K^-, π^-)
  $\Omega_{eff.}$: ~1/3 of π^- spectrometer

  ⇓

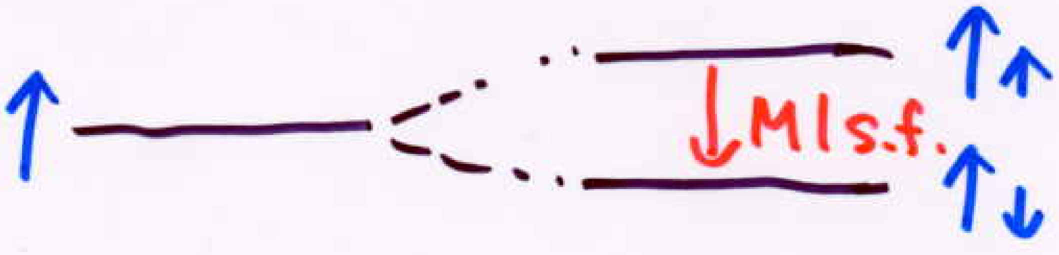
  requires ~6 times more beamtime, but still feasible.

III Property of Λ in nuclear matter

— B(M1) measurement for μ_Λ

- μ_Λ could be modified by
  - Partial quark deconfinement / Pauli blocking
  - $\Lambda\Sigma$ mixing
  - meson current
  - ⋮

- B(M1) — sensitive to μ_Λ



$$B(M1\,s.f.) \propto (g_A - g_\Lambda)^2$$

⑥ Experimental method

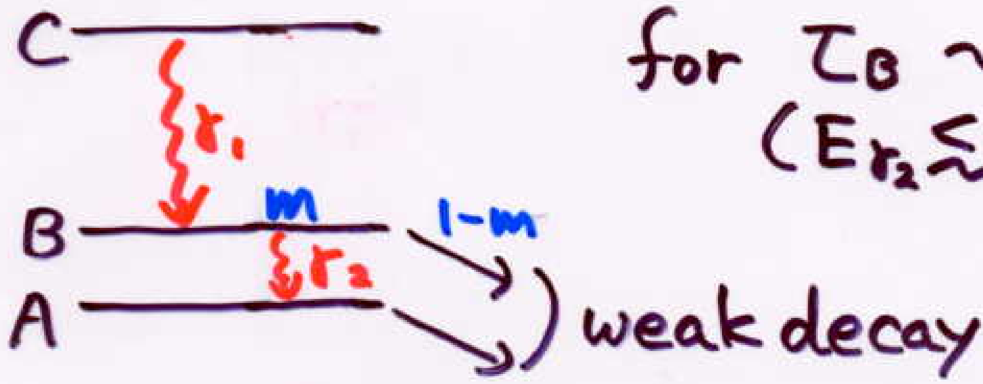
① Doppler shift attenuation method

Successfully applied in E419

$B(M1) \propto \frac{1}{\tau} \Longleftrightarrow$ peak shape

for $\tau = 0.3 \sim 10$ ps
($E_\gamma = 0.3 \sim 1$ MeV)

② γ - weak coincidence method

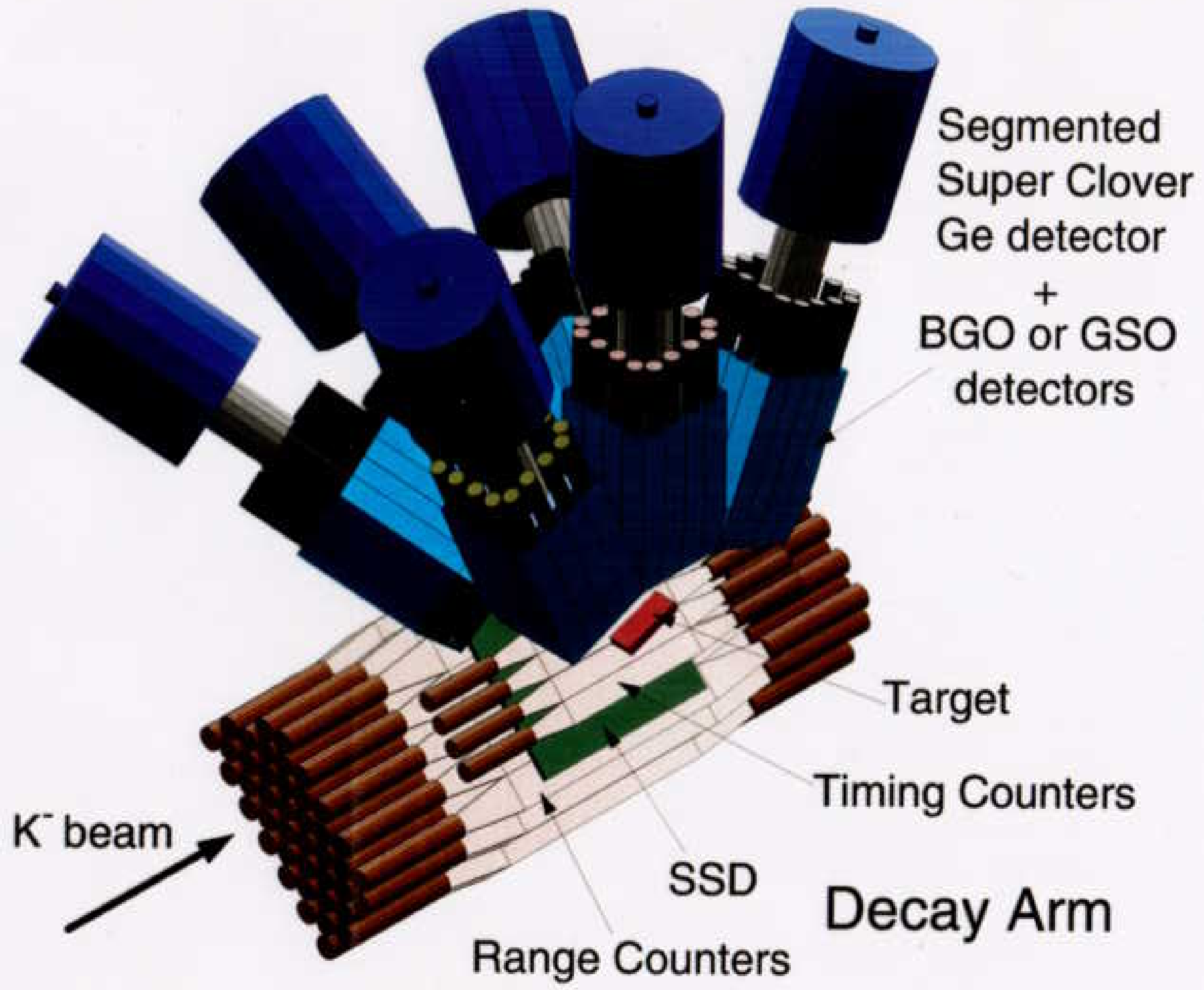


for $\tau_B \sim 100$ ps
($E_{\gamma_2} \lesssim 100$ keV)

τ_B : time spectrum of weak decay in γ_1-weak and γ_2-weak coincidence

m : γ_1-γ_2 coincidence

$B(M1) \propto \frac{m}{\tau_B}$


Segmented
Super Clover
Ge detector
+
BGO or GSO
detectors
Target
Timing Counters
K⁻ beam
SSD
Decay Arm
Range Counters

γ-weak coincidence method

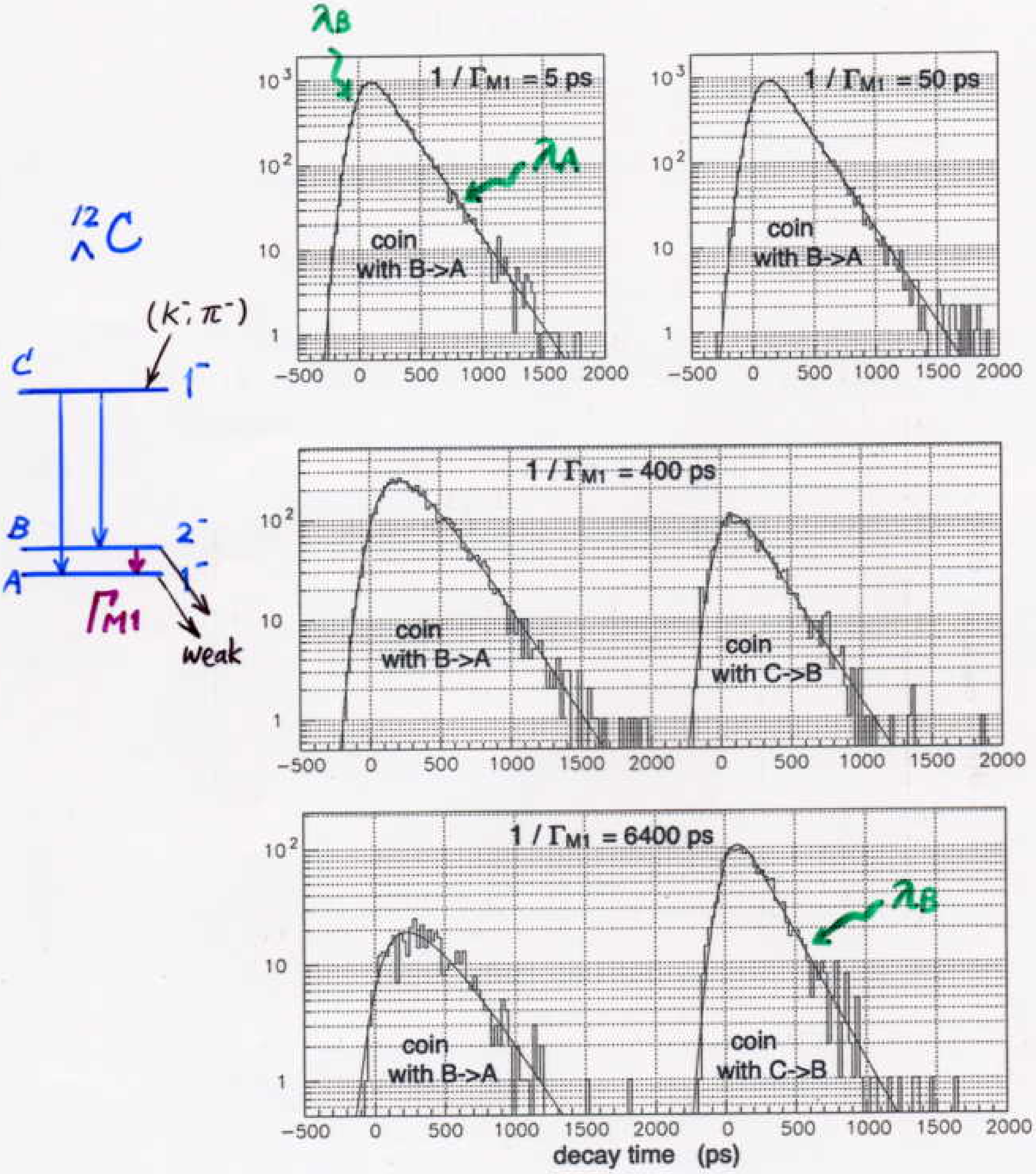


Figure 42: Simulated time spectrum of weak-decay particles of $^{12}_{\Lambda}$C measured in coincidence with B→A (the spin-flip M1($2^- \to 1^-$) transition) and with C→B (the $1_1^- \to 1^-$ transition) for various values of the B→A (spin-flip M1) transition rate (Γ_{M1}). A time resolution of 200 ps FWHM is folded. By fitting these two histograms simultaneously to the expected functions (see text), both decay rates λ_A and λ_B can be determined within 5% statistical errors.

B(M1) accuracy ~ ±5%
for B(M1) = 0.1 ~ 10 μ_N^2

400 hours at JHF
Simulation by Outa + Tamura

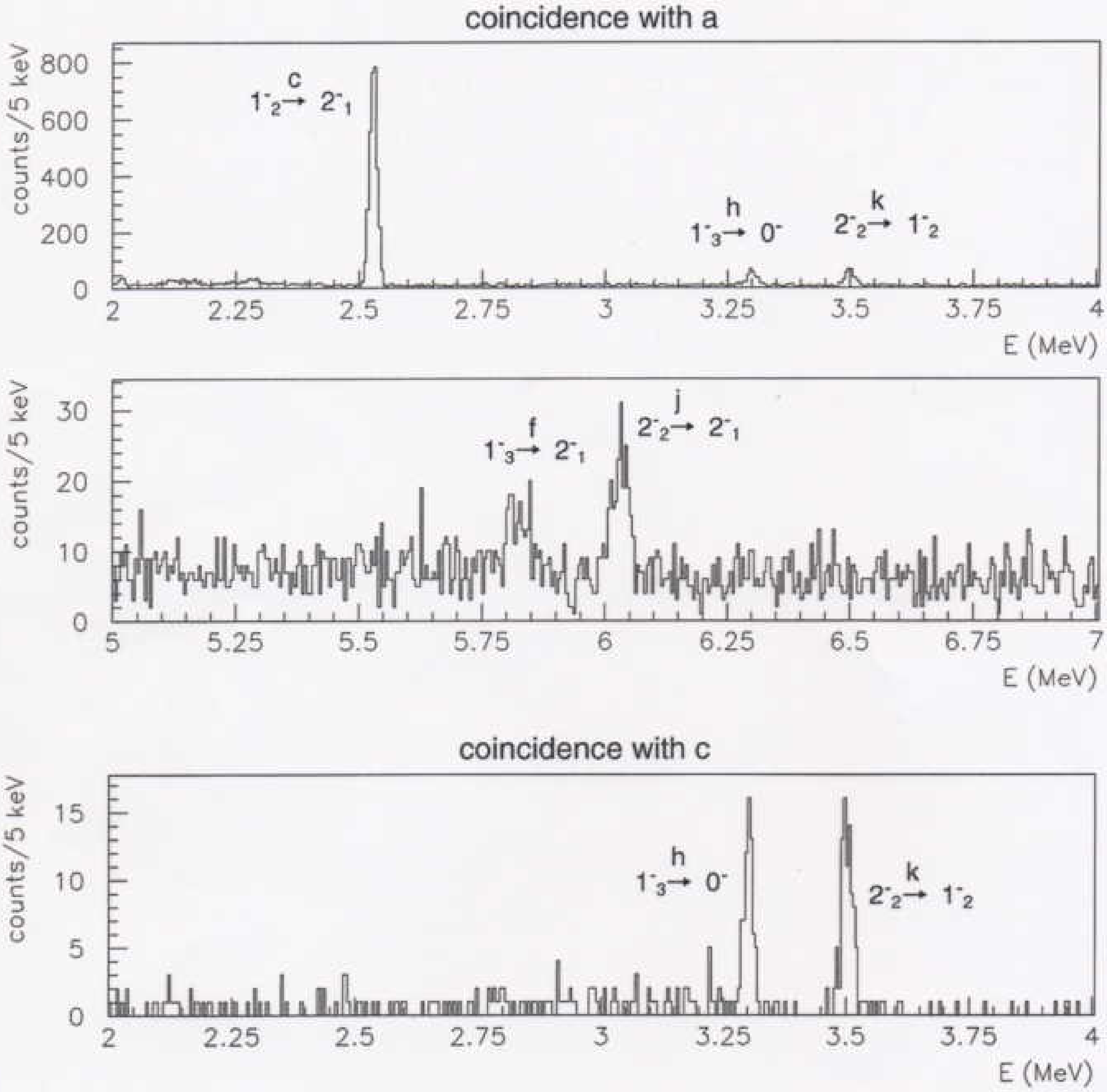


Figure 9: Simulated γ-γ coincidence spectrum of ${}^{12}_{\Lambda}$C. Top two: coincidence with γ-ray "a" ($1_2^- \to 1_1^-$). Bottom: coincidence with γ-ray "c" ($1_2^- \to 2_1^-$).

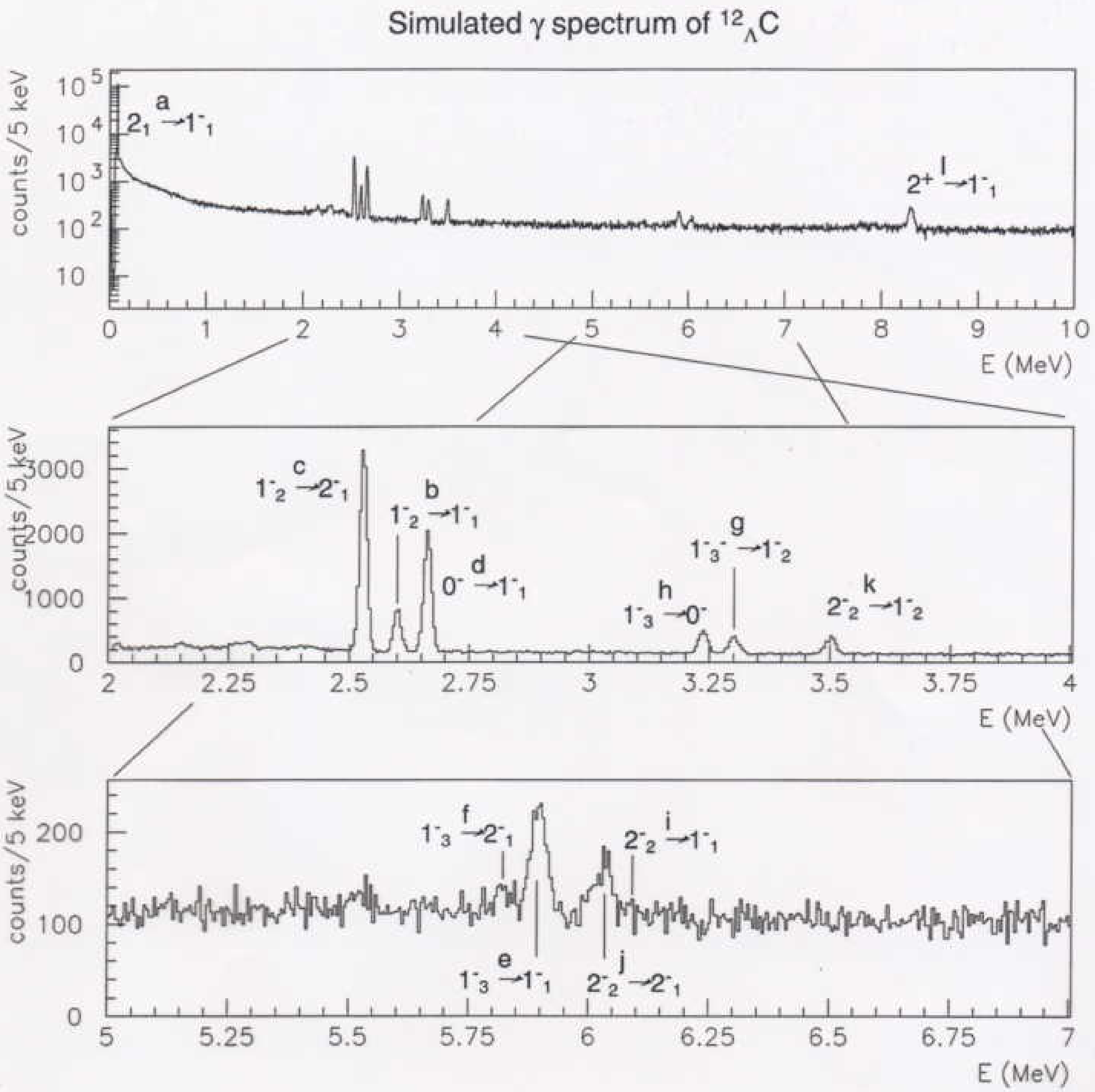


Figure 8: Simulated spectrum of $^{12}_{\Lambda}$C γ rays for 5 days' run with the (K^-,π^-) reaction at 1.1 GeV/c at the 50 GeV PS. Compton/π^0 suppression and Doppler-shift correction are applied.

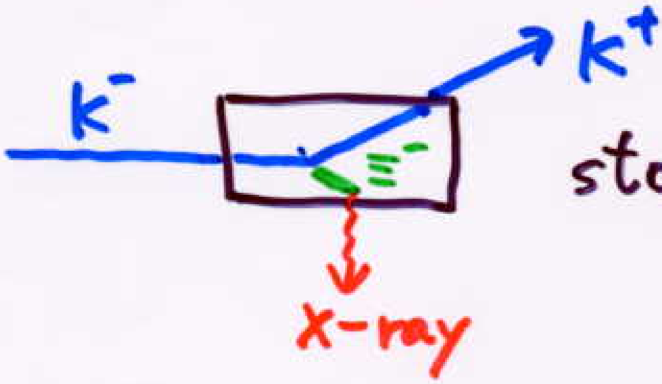
IV $S=-2$ system

— Ξ^--atom X-ray

- Valuable information on
  Ξ^--nucleus interaction

$$V(r) + iW(r)$$

δE_x ($\lesssim$ 1 keV) Γ_x ($\lesssim$ 1 keV)



stopped Ξ^- in target
(Pb, W, ...)

- Ξ^-_{stop} yield .... $\sim 10^4$/day
  X-ray yield .... $\sim 10^3$/day

- δE_x : < 0.1 keV achievable
  Γ_x : possible only for
  $\Gamma \gtrsim 0.5$ keV

V Summary

- High intensity K^- beam

$\Rightarrow$ { Systematic study
  $S=-2$

- single Λ hypernuclei
  - ΛNN force
  - CSB
  - B(M1)

    ⋮

- $S=-2$
  - Ξ^--nucleus interaction

$\Downarrow$

γ-ray spectroscopy is promising at JHF.