Hypernuclear γ-ray spectroscopy via the (K^-, π^0) reaction

K. Shirotori
Tohoku Univ.

Motivation

- Mirror hypernuclei
- Neutron-rich hypernuclei
- sd-shell hypernuclei

Mirror hypernuclei

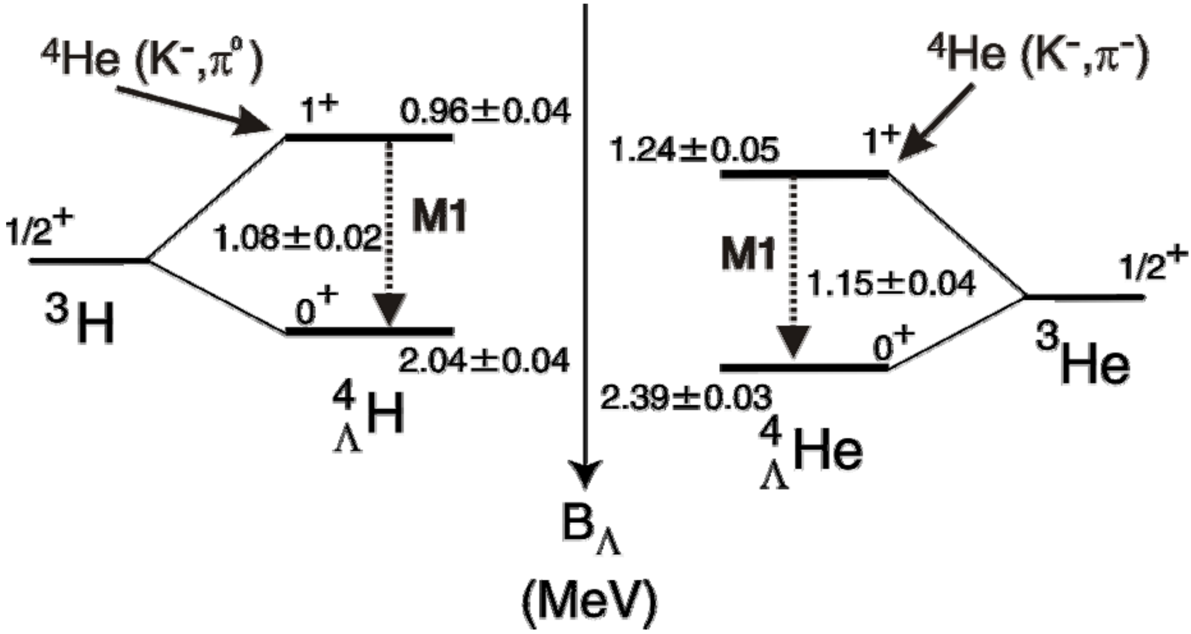
Charge symmetry breaking in hypernuclei

⇒Systematic data by precise measurement by γ ray spectroscopy

Target

^{4}He : $^{4}_{\Lambda}H$ ⇔ $^{4}_{\Lambda}He$

^{12}C : $^{12}_{\Lambda}B$ ⇔ $^{12}_{\Lambda}C$

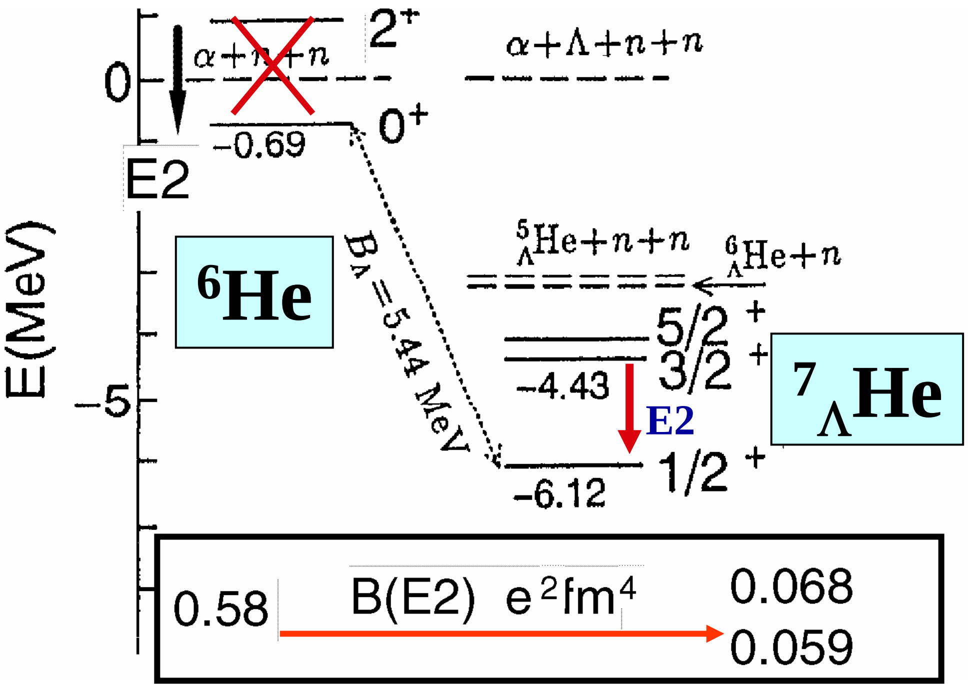


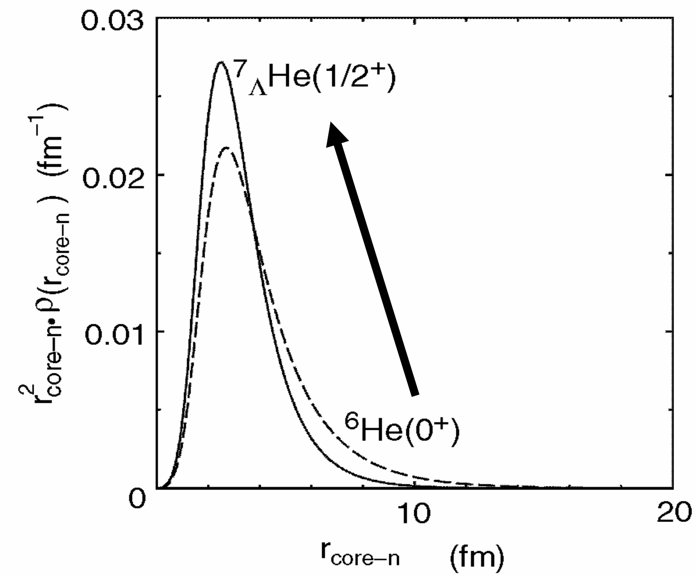
Neutron-rich hypernuclei

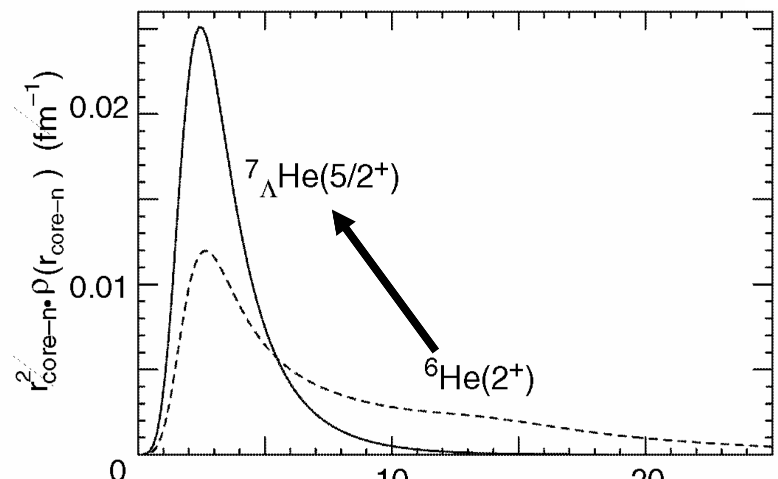
$^{7}_{\Lambda}He$

: **Disappearance of neutron-halo**

Drastic B(E2) change







Calc. by E. Hiyama

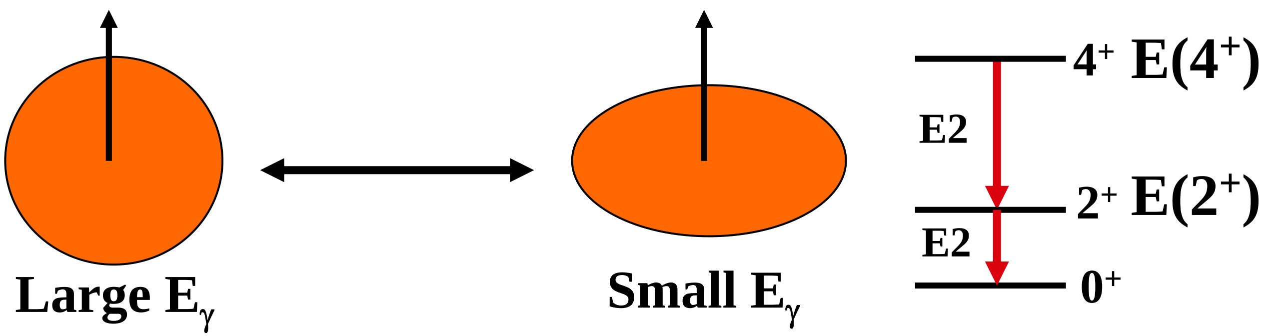
r_{core-n} (fm)

sd-shell hypernuclei

Even-even core hypernuclei

Even-even core B(E2) transition : $4^+ \longrightarrow 2^+$, $2^+ \longrightarrow 0^+$

⇒ Moment of inertia : $E_{rot} = I(I+1)/2\vartheta$



$E(4^+)/E(2^+)$
= 3.3 :Rotation
= 2.0 :Vibration

The energy of those transition has the information of the nuclear deformation/collectivity.

- **Energy spacing and B(E2) measurement**

⇒Effects of Λ on the collective motion

Even-even core hypernuclear production

-Advantages of the (K^-, π^0) reaction-

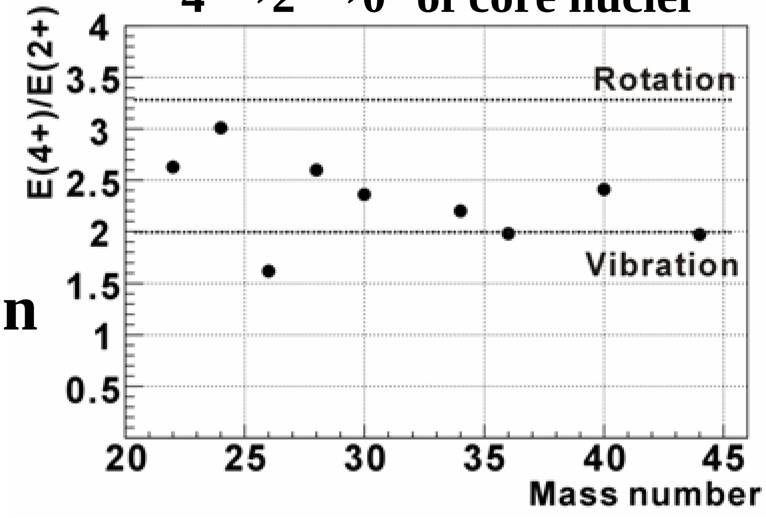
- **(K^-, π^-) reaction (NCX)**

Difficult to produce hypernuclei with even-even core

- **Direct : ^{25}Mg(10%), ^{29}Si(4.7%) : enrich target**

⇒Hyperfragment (need unique identification method and how about DSAM difficulty ?)

$4^+ \rightarrow 2^+ \rightarrow 0^+$ of core nuclei



- **(K^-, π^0) reaction (SCX)**

Possible direct production

⇒Systematic study of $2^+ \rightarrow 0^+$ transition

- **$^{23}Na(^{23}{}_{\Lambda}Ne)$, $^{27}Al(^{27}{}_{\Lambda}Mg)$, $^{31}P(^{31}{}_{\Lambda}Si)$, $^{35,37}Cl(^{35,37}{}_{\Lambda}S)$, $^{39}K(^{39}{}_{\Lambda}Ar)$, $^{45}Sc(^{45}{}_{\Lambda}Ca)$**

Experiment

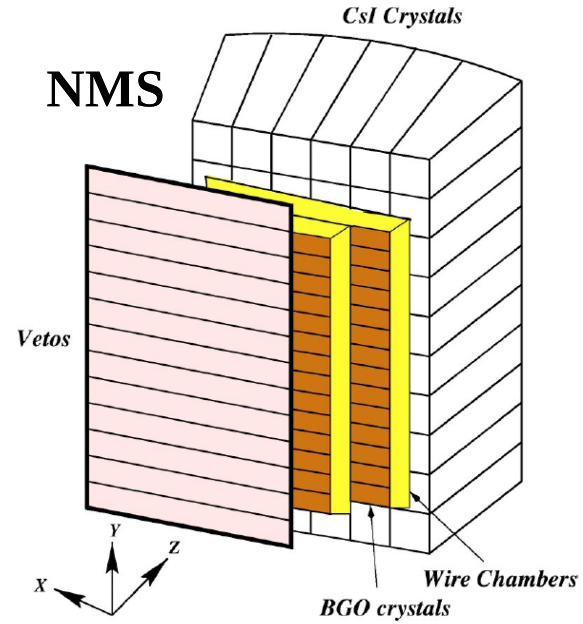
Past experiment : BNL E907

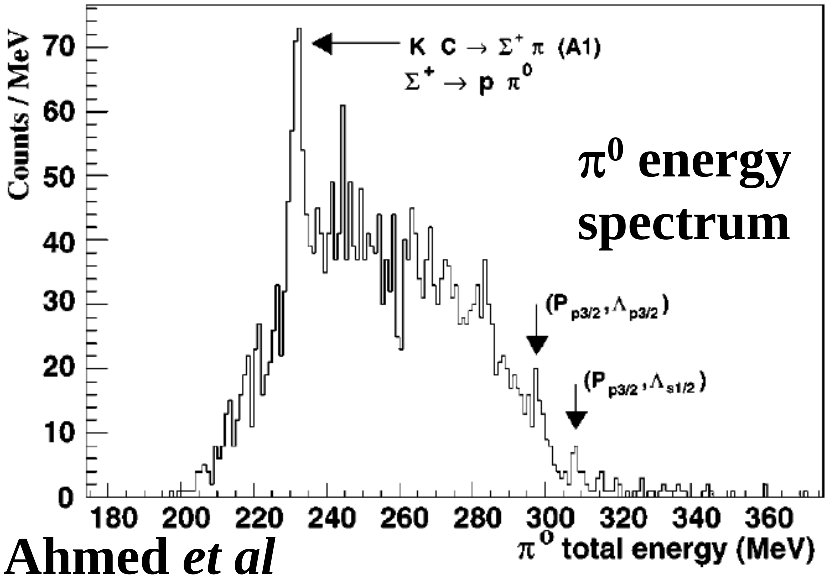
- ${}^{12}_{\Lambda}B$ reaction spectroscopy via the (K^{-}_{stop}, π^0) reaction
- NMS

: Neutral Meson Spectrometer

  - Pre-shower BGO detector
  - Shower tracking DC
  - CsI calorimeter

- ΔE_{mass} ~2.2 MeV (${}^{12}_{\Lambda}B$ g.s)





M. W. Ahmed *et al*

Requirements of the (K^-, π^0) reaction spectroscopy

- **Mass resolution : A few MeV @ E_1=E_2**
- **Position resolution and Vertex resolution**
  - **Energy resolution by measuring opening angle**
  - **Doppler correction**
  - **Angular selection**

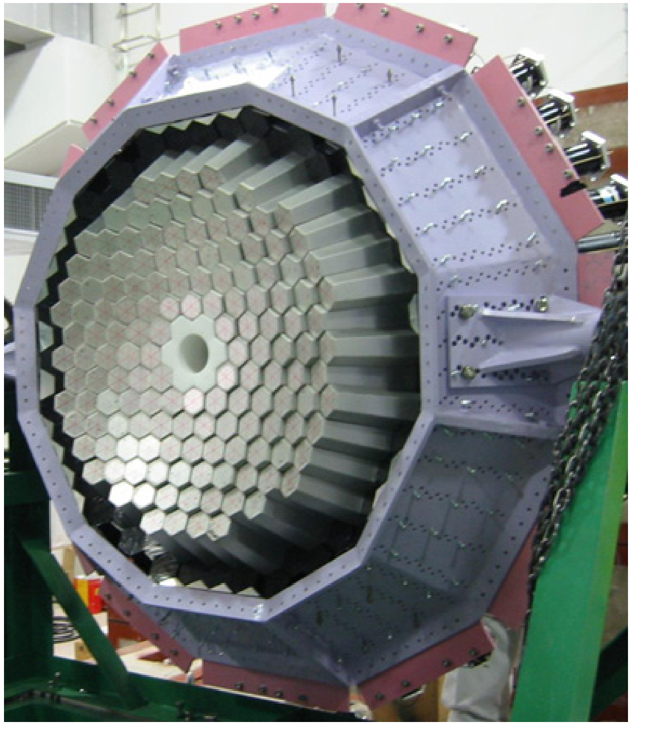
    $\theta < 5^\circ$ ($\Delta L = 0$) : substitutional states ⇒ Hyperfragment

    $\theta > 5^\circ \sim 15^\circ$ (ΔL = 1 or 2) : bound states ⇒s, p, sd-shell
  - **Spin-flip cross section at large angles ($\theta > 10^\circ$)**
- **Good efficiency**

  To keep large production rate (/beam) : order of mb

Detector type

- Size : Beam momentum
  - 0.9, 1.1, 1.5, 1.8 GeV/c ?
- Energy resolution
  - Inorganic-scintillator : CsI
- Position resolution
  - With position detector ?



SCISSORS III @ LNS

Homogeneous inorganic-scintillator

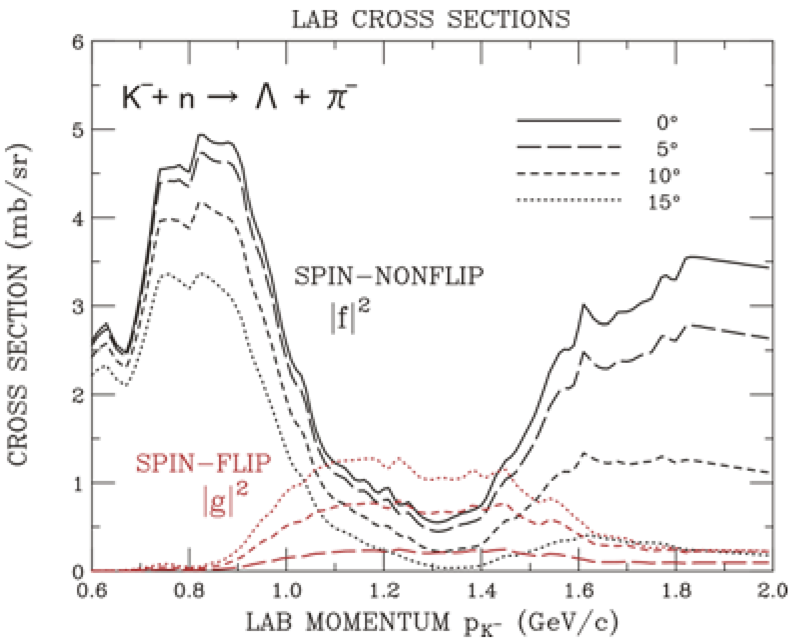
OR

Inorganic-scintillator with position detectors

Beam momentum

- Large production
  0.9 GeV/c or 1.8 GeV/c
- Spin-flip and non-spin-flip
  1.1 GeV/c or 1.5 GeV/c

⇒ K1.1 or K1.8 ?



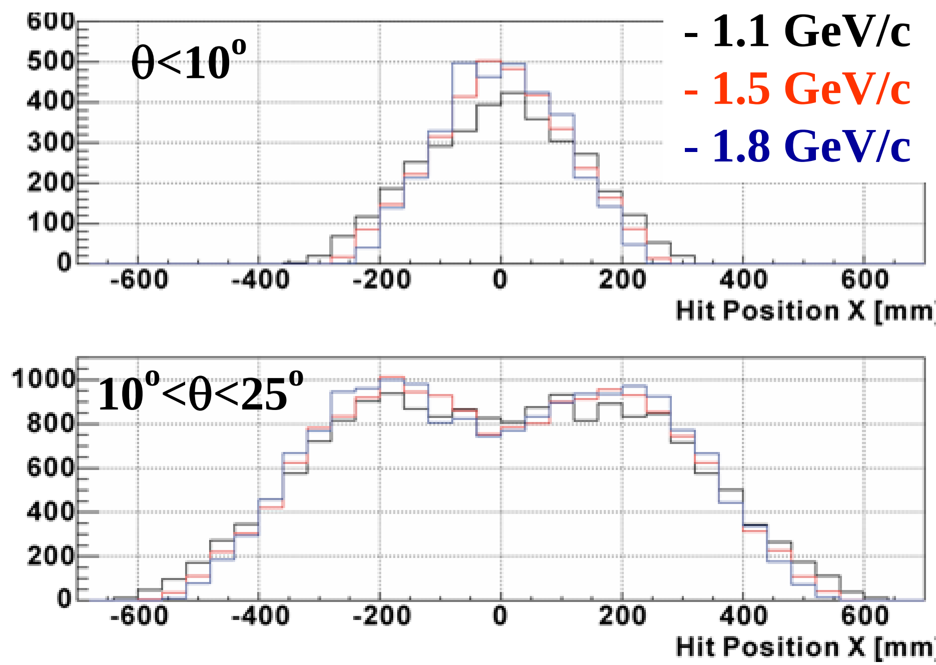
Deeply-bound for sd-shell : K1.8

Both NCX and SCX with spin-flip : K1.1

⇒Both K1.1 and K1.8 are available.

Acceptance of both two decay γ rays

- No large difference by changing the beam momentum
  - Hit position of two γ rays are averaged within π^0 scattering angles.
- The size of detector cannot be optimized to each beam momentum.
- The detector can be used at both K1.1 and K1.8.



γ-ray hit position on the detector @ $|E_1-E_2|/(E_1+E_2) < 0.3$ (1 m from the target, w/o the angular correlation of the cross section)

Size : 1000 mm × 1000 mm (with beam through hole)

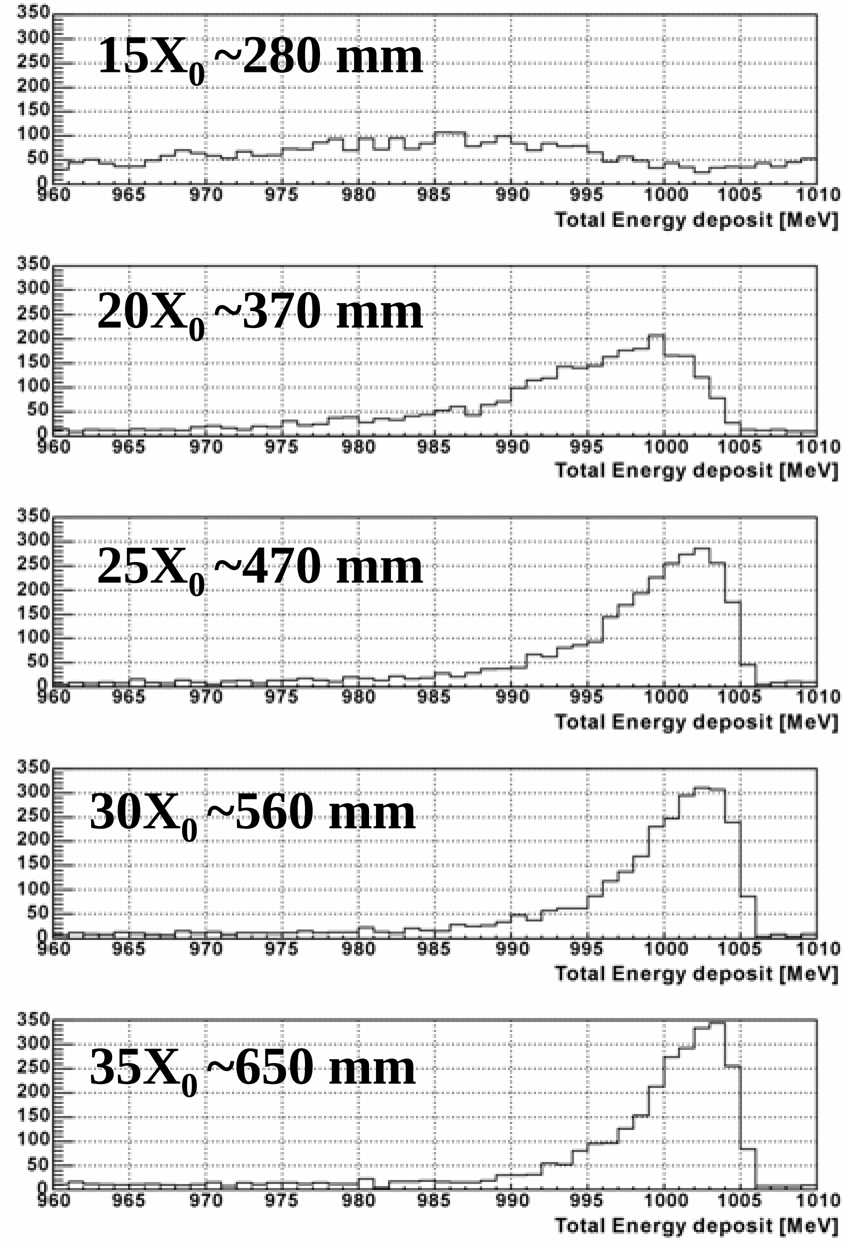
Detector thickness

- **The simulation shows that the thickness of detector is needed to be more than $20X_0$ by using the CsI crystal.**
  - **CsI : X_0 =18.6 mm**

- **The scattered π^0 has large energy because the (K, π) reaction is the endoergic reaction.**

Thickness 300~400 mm

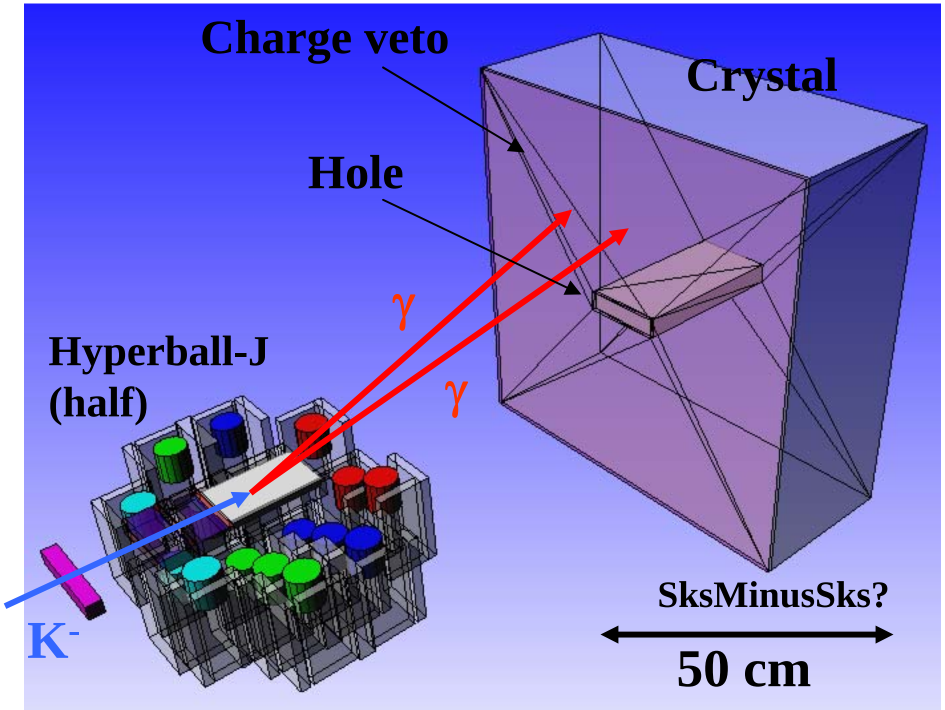
Energy deposit of both two γ rays from the π^0 of 1.0 GeV/c.



Choice of detector type

- Large target size
- Wide scattering angle

⇒Homogeneous crystal colorimeter
+ Shower Tracker ?(to determine the precise position)



Rough setup figure

- Pre-shower detector

Converter :BGO, PWO
→ Tracker : DC
→ Calorimeter : CsI

- Segmented target sandwiched by scintillation counter

⇒Need to study

Cost of the crystal : ~1 cm^3/$5
→ 100 cm × 100 cm × 40 cm = 4 × 10^5 cm^3
→ ~¥ 2.4 × 10^8 @ $1 = ¥120

Future plan

- **Detector type selection**
  - **Homogeneous crystal : Vertex resolution ?**
  - **Pre-shower + tracker : Efficiency ?**
  - **Target segmentation**
- **Realistic simulation**
  - **Vertex resolution**
  - **Energy resolution**
  - **Doppler correction**
- **Background estimate**
- **Trigger, DAQ …..**

Summary

- **Purposes of γ-ray spectroscopy via the (K^-, π^0) reaction**
  - **Mirror hypernuclei : Charge symmetry breaking**
  - **neutron-rich hypernuclei : Disappearance of neutron-halo**
  - **sd-shell hypernuclei : The effects of Λ on the collective motion**
- **Detector for the (K^-, π^0) reaction spectroscopy**
  - **Both K1.1 and K1.5 can be available.**
  - **Large CsI detector array + α**
- **Need to study the experimental feasibility**