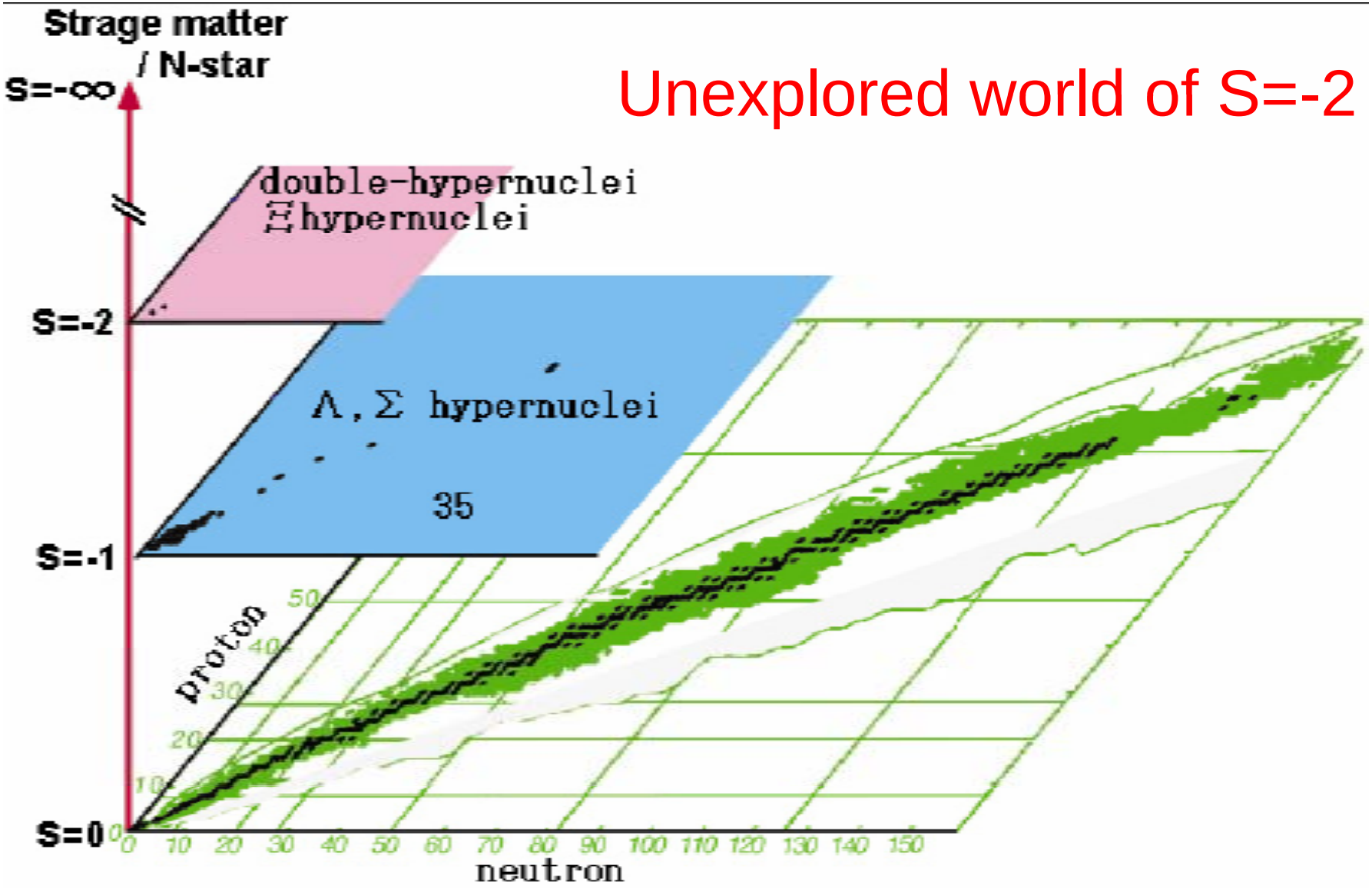
Spectroscopic studies of $S = -2$ systems

Kiyoshi Tanida (Kyoto Univ.)

06 Mar. 2008

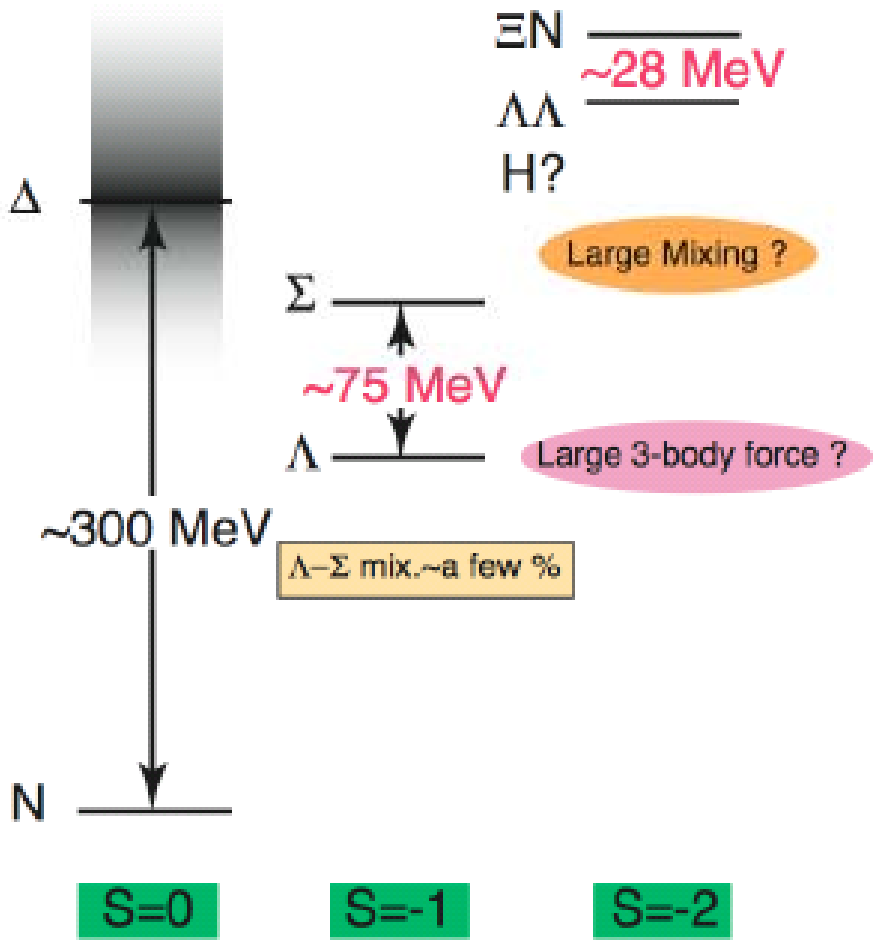
NP08@Mito

Hyper-nuclear chart



Physics Motivation

- A doorway to the multi-strangeness system
- Very dynamic system?
  - Large baryon mixing? Inversely proportional to mass difference.
  - H dibaryon as a mixed state of ΛΛ-ΞN-ΣΣ?
- Little is known so far
  → Main motivation of the J-PARC



Approved experiments

—— J-PARC PAC Approval summary ——

		(Co-)Spokespersons	Affiliation(*)	Title of the experiment	Approval status	Slow line priority	
						Day1?	Day1 Priority
P01		V. Sumachev	Petersburg Nulear Physics Institute	Proposal on measurements of the spin rotation parameters A and R at the J-PARC in the resonance region of π-N elastic scattering	Rejected		
P02	LoI	P. Aslanyan	Laboratory for High Energy, JINR	Study of Exotic Multiquark States with Λ-Hyperons and K^0_S Meson Systems at JPARC	-		
P03		K. Tanida	Kyoto U	Measurement of X rays from Ξ^- Atom	Stage 1		E03
P04		J. C. Peng; S. Sawada	U. of Illinois at Urbana-Champaign; KEK	Measurement of High-Mass Dimuon Production at the 50-GeV Proton Synchrotron	Deferred		
P05		T. Nagae	KEK	Spectroscopic Study of Ξ-Hypernucleus, $^{12}_{\Xi}$Be, via the ^{12}C(K^-, K^+) Reaction	Stage 2	Day1	1 E05
P06		J. Imazato	KEK	Measurement of T-violating Transverse Muon Polarization in $K^+ \to \pi^0 \mu^+ \nu$ Decays	Stage 1		
P07		K. Imai, K. Nakazawa, H. Tamura	Kyoto U., Gifu U., Tohoku U.	Systematic Study of Double Strangeness System with an Emulsion-counter Hybrid Method	Stage 1		E07
P08		A. Krutenkova	ITEP	Pion double charge exchange on oxygen at J-PARC	-		
P09	LoI	T. Nakano	RCNP, Osaka U	Study of Exotic Hadrons with S=+1 and Rare Decay $K^+ \to \pi^+ \nu \bar{\nu}$ with Low-momentum Kaon Beam at J-PARC	-		
P10		A. Sakaguchi	Osaka U	Study on Λ-Hypernuclei with the Charge-Exchange Reactions	Deferred		
P11		K. Nishikawa	KEK	Tokai-to-Kamioka (T2K) Long Baseline Neutrino Oscillation Experimental Proposal	Stage 2		
P12	LoI	S. Choi	Seoul National University	Study of Parton Distribution Function of Mesons via Drell-Yan Process at J-PARC at High-p beamline	-		
P13		T. Tamura	Tohoku U.	Gamma-ray spectroscopy of light hypernuclei	Stage 2	Day1	2
P14		T. Yamanaka	Osaka University	Proposal for $K_L \to \pi^0 \nu\bar{\nu}$ Experiment at J-PARC	Stage 1		
P15		M. Iwasaki, T. Nagae	RIKEN, KEK	A Search for deeply-bound kaonic nuclear states by in-flight 3He(K-, n) reaction	Stage 1	Day1	
P16		S. Yokkaichi	RIKEN	Electron pair spectrometer at the J-PARC 50-GeV PS to explore the chiral symmetry in QCD	Deferred		
P17		R. Hayano, H. Outa	U. Tokyo, RIKEN	Precision spectroscopy of Kaonic ^{3}He 3d->2p X-rays	Stage 1	Day1	
P18		H. Bhang, H. Outa, H. Park	SNU, RIKEN, KRISS	Coincidence Measurement of the Weak Decay of $^{12}_{\Lambda}$C and the three-body weak interaction process	Deferred		
P19		M. Naruki	RIKEN	High-resolution Search for Θ^+ Pentaquark in $\pi^- p \to K^- X$ Reactions	Stage1	Day1	
P20	LoI	Y. Kuno	Osaka U	An Experimental Search for $\mu^- - e^-$ Conversion at Sensitivity of 10^{-18} with a High Intense Muon Source, PRISM	-		

: Letter of Intent
: No presentation this time
: Experiment at the fast extraction beam
: Experiment at the third extraction beam
(*) : Affiliation of the spokespersons

3 experiments approved for S=-2 nucl. phys.

Approved experiments

E03 : Measurement of X rays from Ξ^- atom
Spokesperson – K. Tanida (Kyoto)

E05: Spectroscopic study of Ξ-hypernucleus, $^{12}_{\Xi}$Be,
via the ^{12}C(K^-,K^+) reaction (Day 1 – 1st priority)
Spokesperson – T. Nagae (Kyoto)

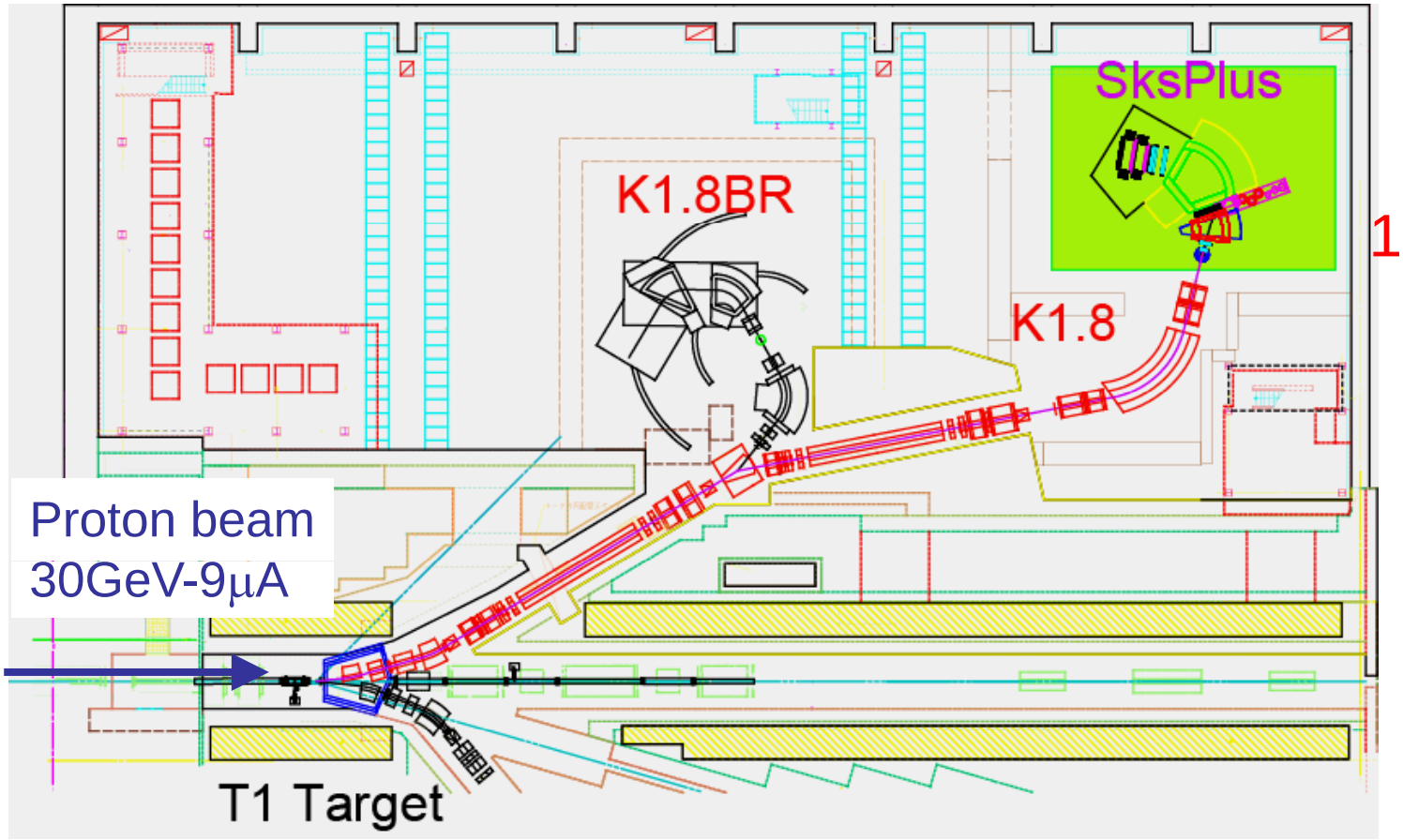
E07: Systematic study of double strangeness system
with an emulsion-counter hybrid method
Spokespersons – K. Imai (Kyoto)
K. Nakazawa (Gifu)
H. Tamura (Tohoku)

3 experiments approved for S=-2 nucl. phys.

E05 Ξ-hypernuclei

Missing mass spectroscopy of $^{12}C(K^-,K^+)X$

→ $^{12}_{\Xi}Be$, $^{12}_{\Lambda\Lambda}Be$



1.8 GeV/c
K^- beam

high intensity
1.4×10^6 K^- /spill
(Phase-1)

high purity
K^-/π^- ~6.9

Importance of Ξ systems

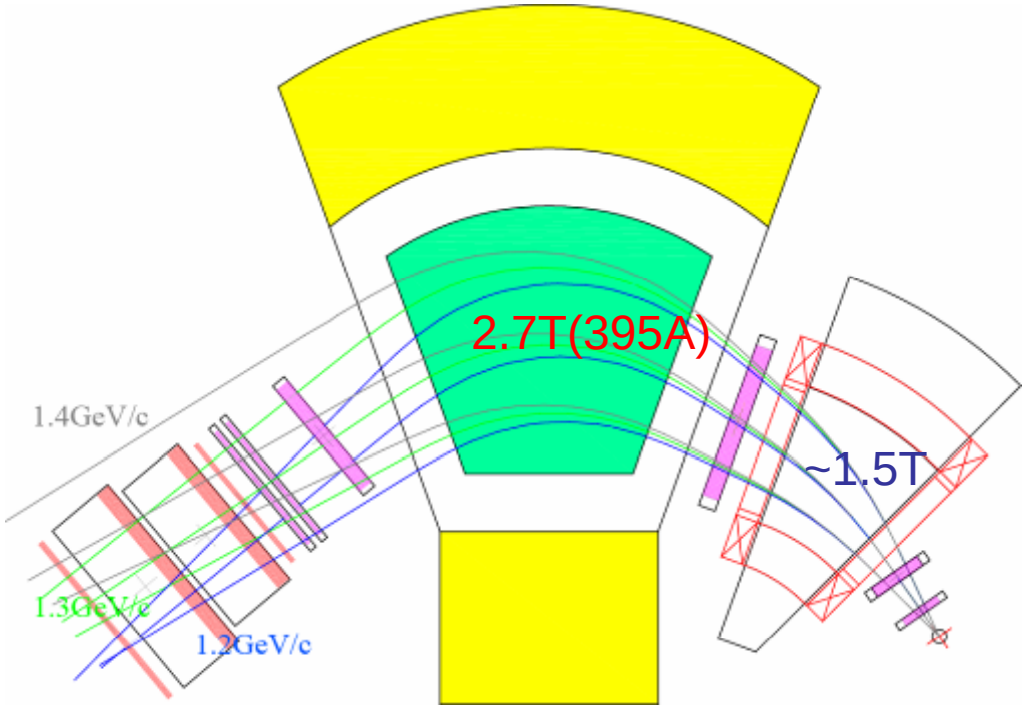
- Valuable information on ΞN (effective) interaction
  - e.g., How strong ΞN → ΛΛ (and thus ΞN-ΛΛ mixing) is?
    - Relevant to the existence of H dibaryon
    - ΞN component in ΛΛ-hypernuclei
  - Exchange interaction is prohibited in one-meson exchange models
- How about A dependence?
- Impact on neutron stars
  - Does Ξ^- play significant role in neutron stars because of its negative charge?
  - Σ^- was supposed to be important, but its interaction with neutron matter is found to be strongly repulsive.

ΞN interaction model and ΞA optical potential

Model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ_Ξ
NHC-D	0	−2.6	0.1	−2.1	−0.2	−0.7	−1.9		
	1	−3.2	−2.3	−3.0	−0.0	−3.1	−6.3	−25.2	0.9
Ehime	0	−0.9	−0.5	−1.0	0.3	−2.4	−0.7		
	1	−1.3	−8.6	−0.8	−0.4	−1.7	−4.2	−22.3	0.5
ESC04d*	0	6.3	−18.4	1.2	1.5	−1.3	−1.9		
	1	7.2	−1.7	−0.8	−0.5	−1.2	−2.8	−12.1	12.7

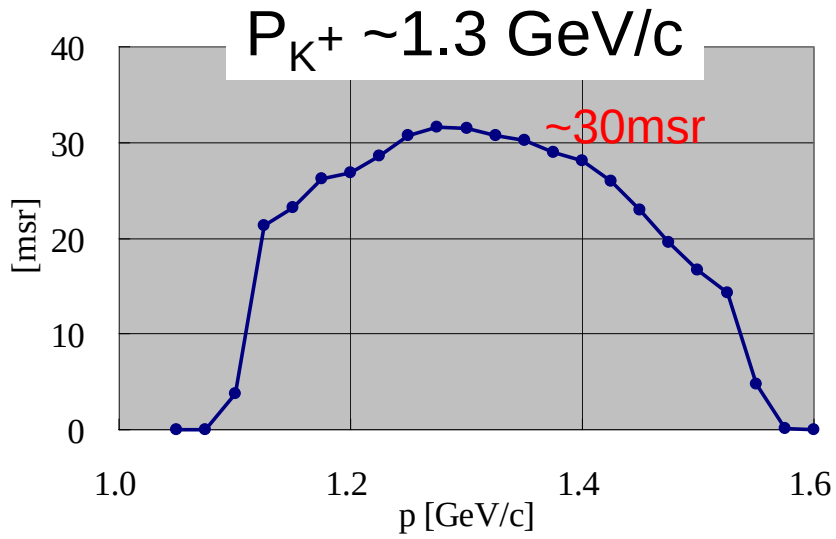
- One boson exchange (NHC-D, Ehime)
  - strong attraction in odd states → strong A dependence
- ESC04d*
  - strong attraction in $^3S_1$ (T=0)

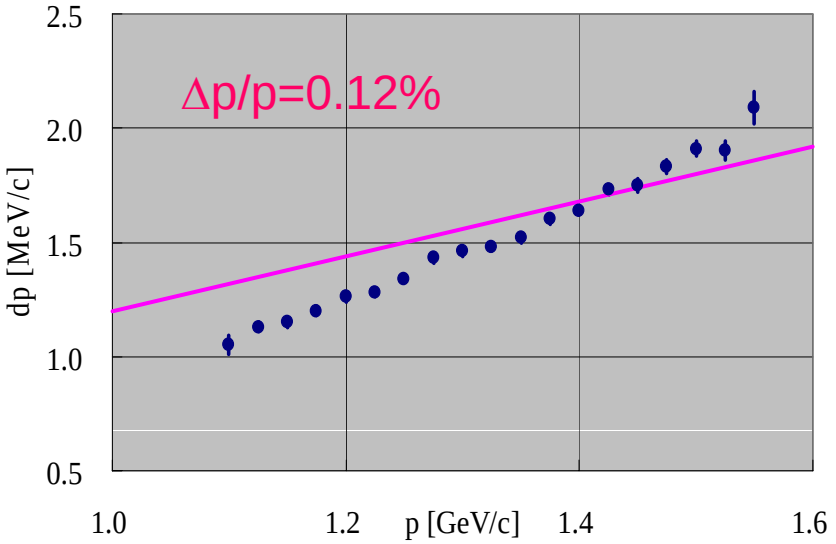
SksPlus Spectrometer



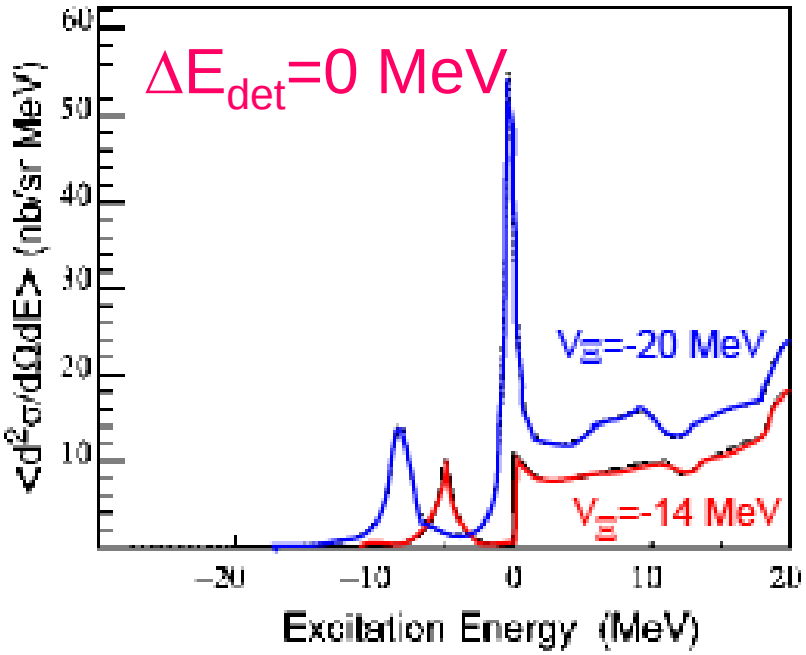
- 95° total bend
- ~7m flight path
- Δx=0.3 mm (RMS)

high resolution： ΔE~ 3 MeV





$^{12}C(K^-,K^+)^{12}_{\Xi}Be$ spectra calculated by W.S. potential

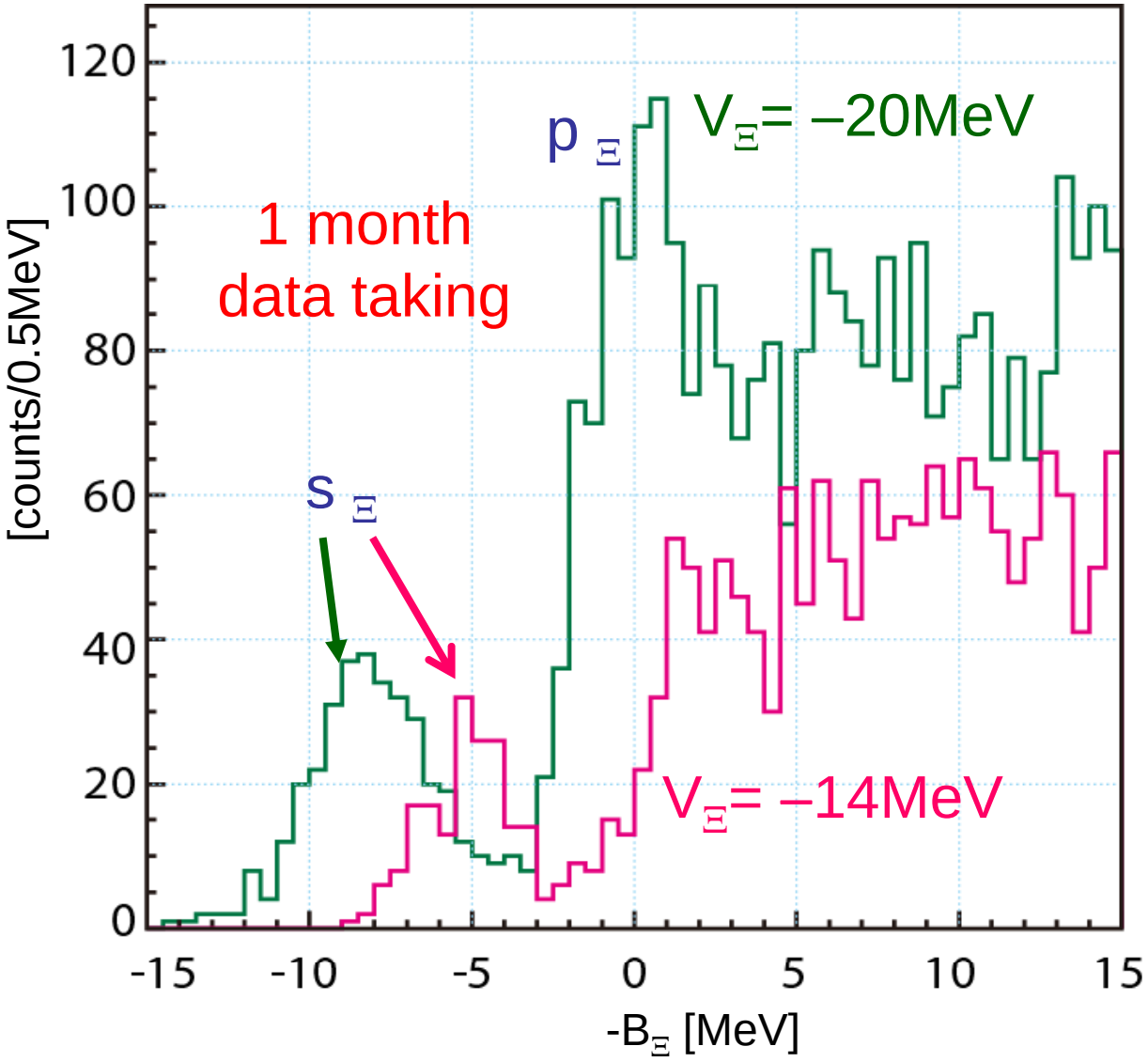


P.Khaustov, et al.
Phys. Rev. C61(2000)054603

states		V^{Ξ}_0 [MeV] −24	−20	−16	−12
s-state					[nb/sr]
$0p_{3/2} \rightarrow 0s_{1/2}$	1^-	215	168	123	81
p-states					[nb/sr]
$0p_{3/2} \rightarrow 0p_{3/2}$	0^+	29	20	–	–
	2^+	164	103	–	–
$0p_{3/2} \rightarrow 0p1_{/2}$	2^+	152	93	–	–
sum		345	216	–	–

K.Ikeda, et al,
Prog. Theor. Phys. 91 (1994) 747 ;
Y.Yamamoto, et al,
Prog. Theor. Phys. Suppl. 117 (1994) 281

Expected $^{12}_{\Xi}$Be Spectrum

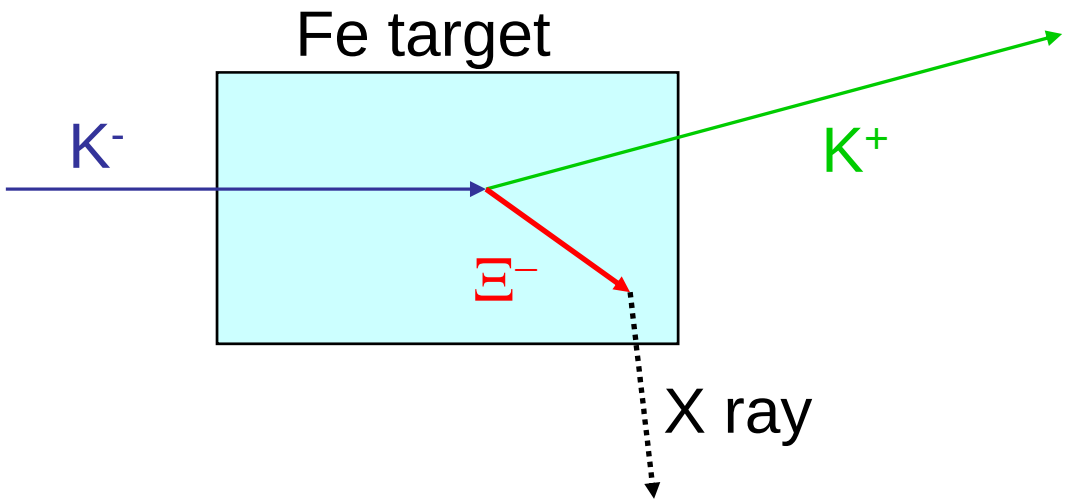


$\Delta E = 3\ MeV_{FWHM}$

Optical potential

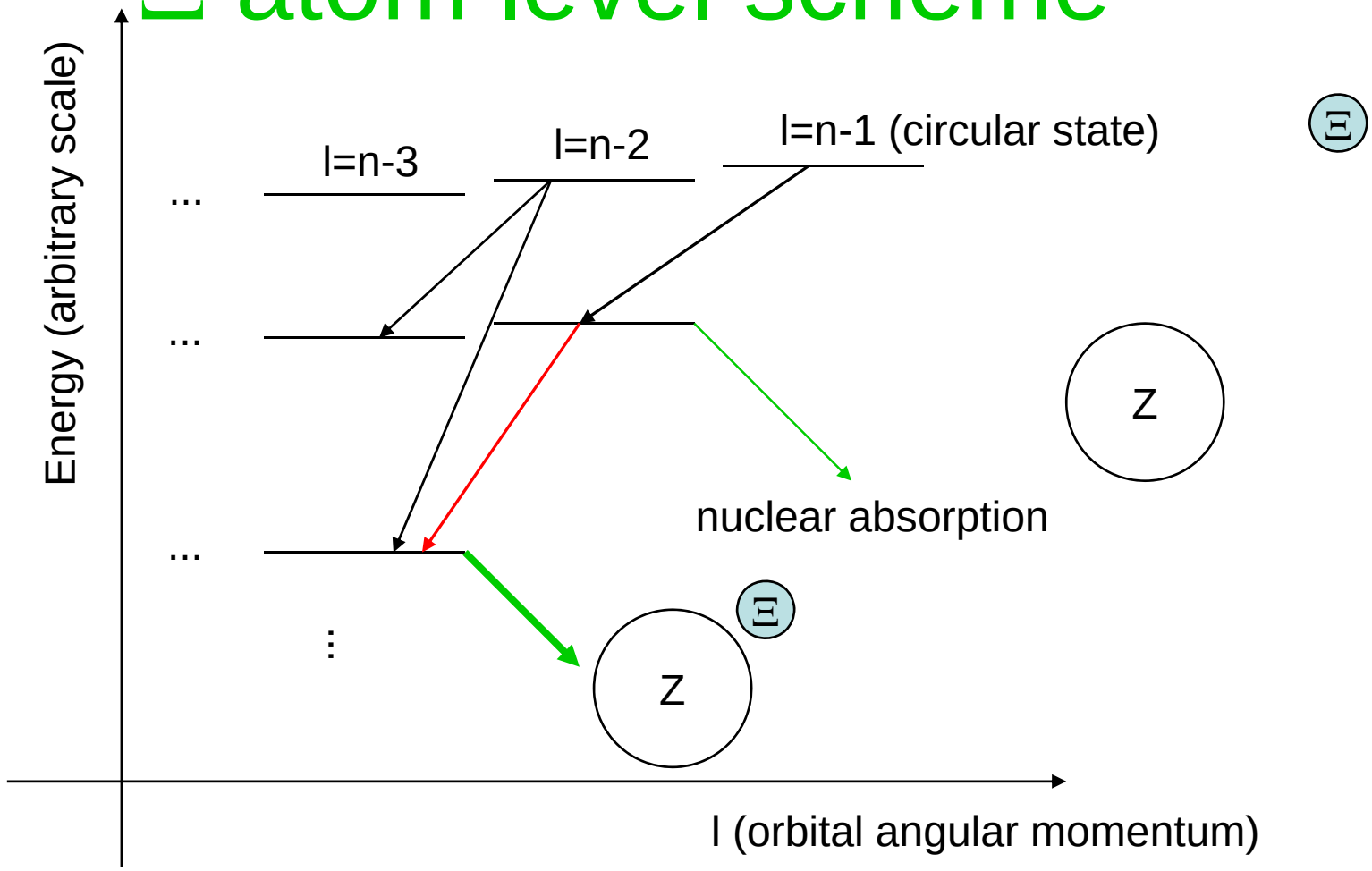
E03 X-ray spectroscopy of Ξ atom

- The first measurement of X rays from Ξ-atom
  - Gives direct information on the ΞA optical potential
- Produce Ξ^- by the Fe(K^-,K^+) reaction, make it stop in the target, and measure X rays.



- Aiming at establishing the experimental method
- Possibility for double-Λ γ-ray

Ξ atom level scheme

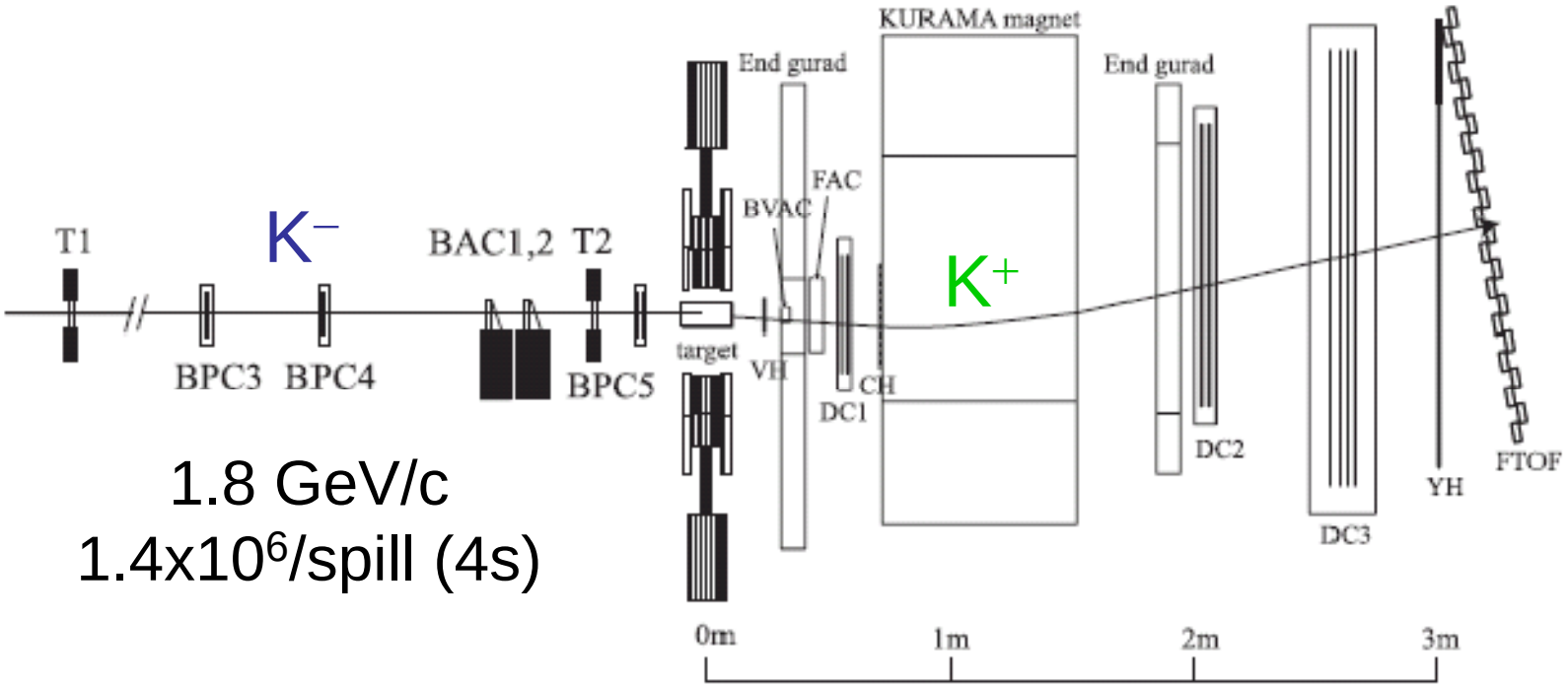


X ray energy shift – real part

Width, yield – imaginary part

Successfully used for π^-, K^-, $\bar{p}$, and Σ^-

Experimental setup



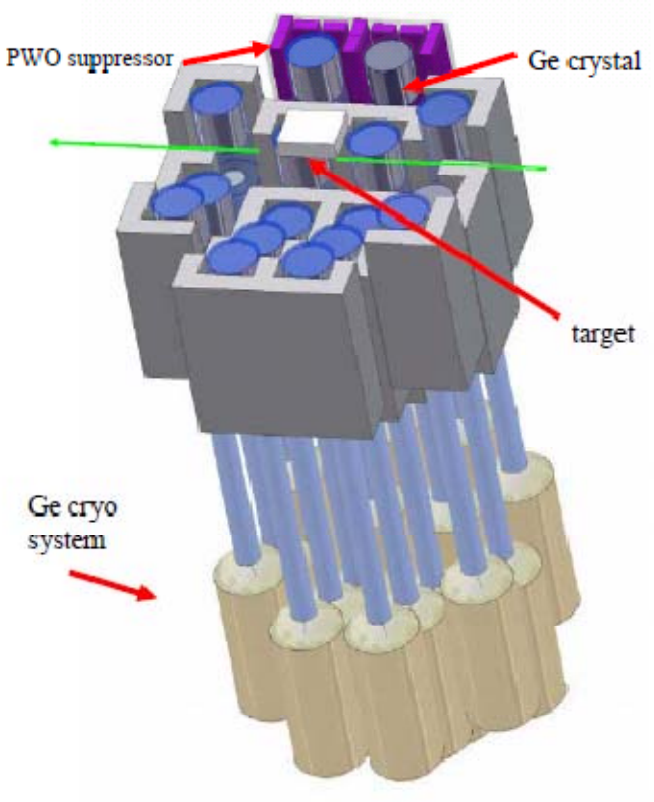
1.8 GeV/c

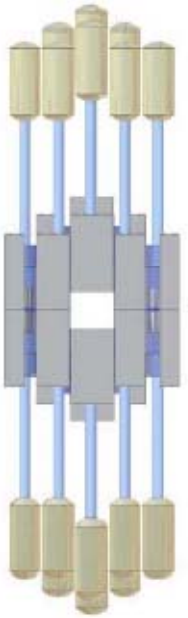
1.4×10^6/spill (4s)

- Long used at KEK-PS K2 beamline (E373, E522, ...)
  - Minor modification is necessary to accommodate high rate.
- Large acceptance (~0.2 sr)

X-ray detector

- Hyperball-J
  - 40 Ge detectors
  - PWO anti-Compton
- Detection efficiency
  - 16% at 284 keV
- High-rate capability
  - < 50% deadtime
- Calibration
  - In-beam, frequent
  - Accuracy ~ 0.05 keV
- Resolution
  - ~2 keV (FWHM)





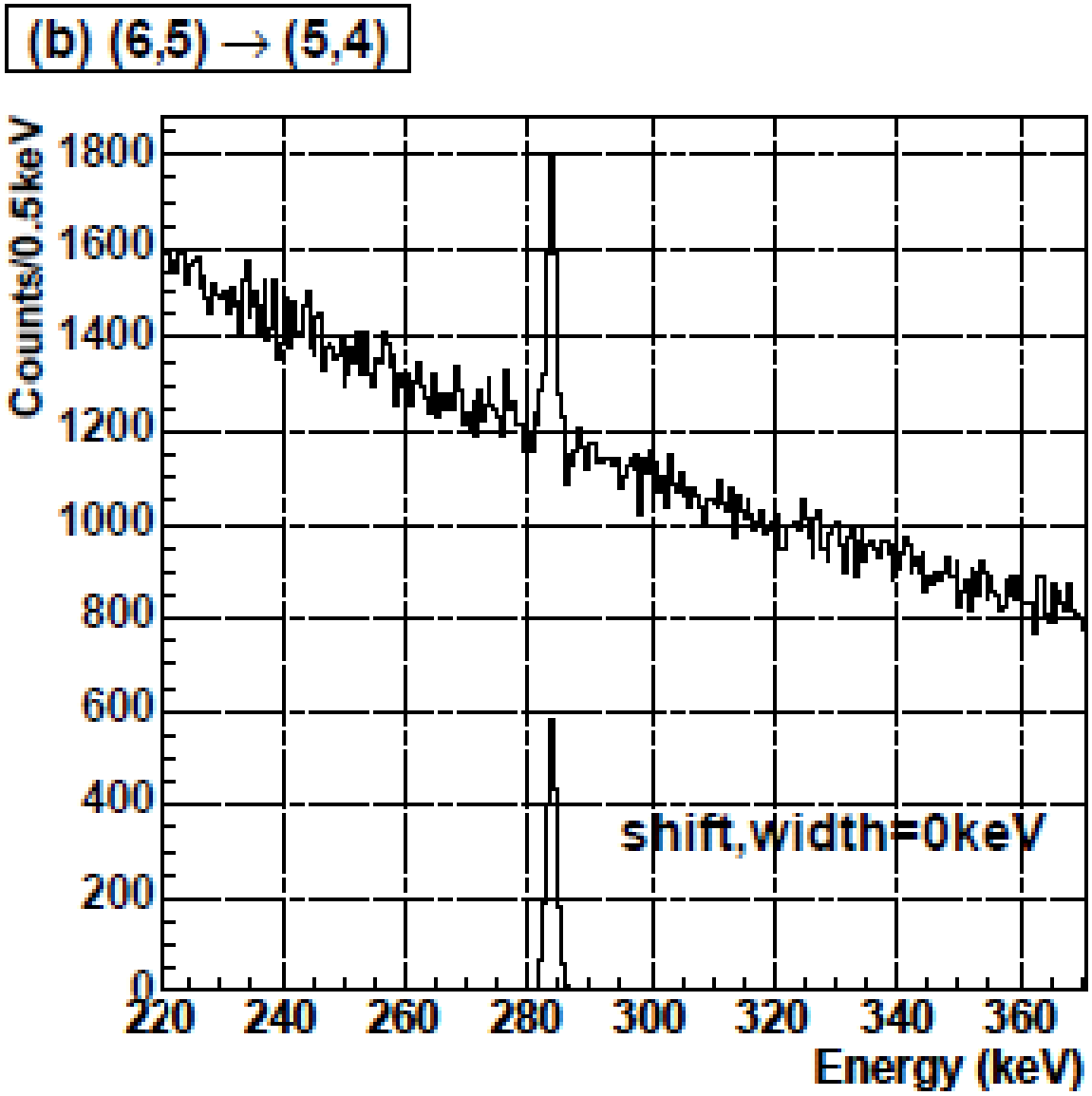
Yield & sensitivity estimation

- Total number of K^-: 1.0×10^{12} for 800 hours.
- Yield of Ξ
  - production: 3.7×10^6
  - stopped: 7.5×10^5
- X-ray yield: 2500 for n=6→5 transition
  - 7200 for n=7→6
- Expected sensitivity
  - Energy shift: ~0.05 keV (systematic dominant)

    → Good for expected shift (~1 keV, 4.4 keV by Koike)

    < 5% accuracy for optical potential depth
  - Width: directly measurable down to ~ 1 keV
  - X-ray yield gives additional (indirect) information on absorption potential.

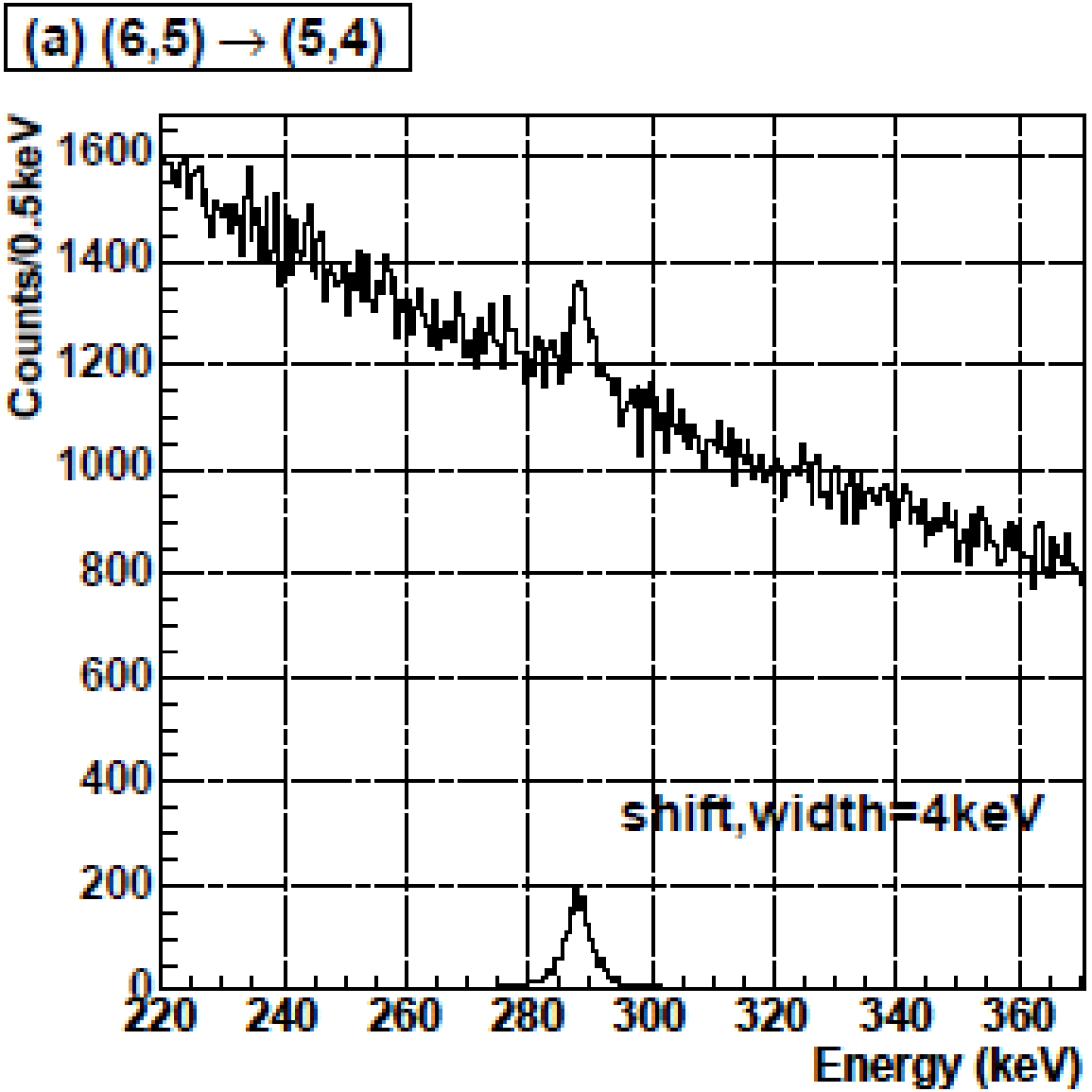
Expected X-ray spectrum



n= 6→5

shift & width
0 keV

Expected X-ray spectrum(2)



n= 6→5

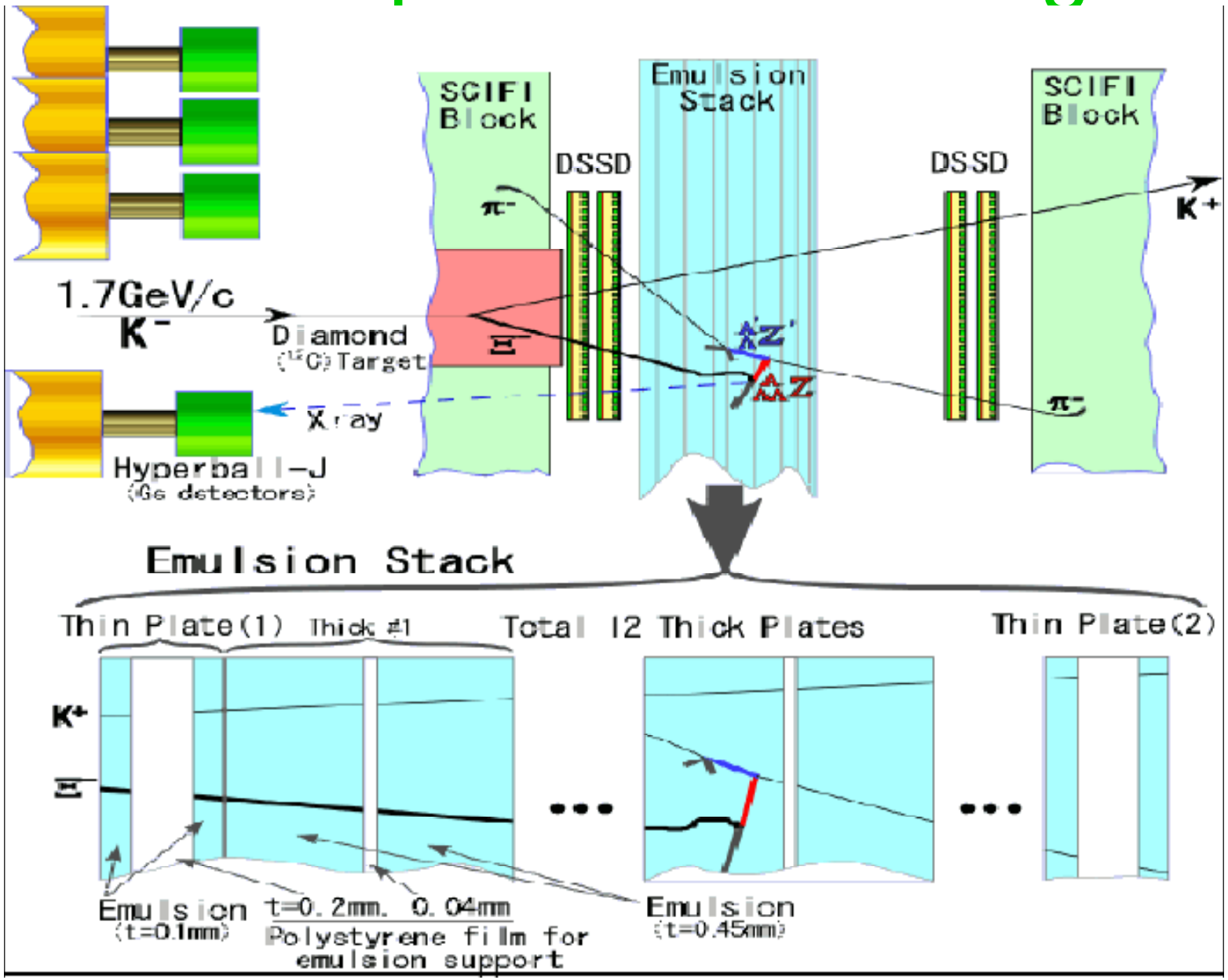
shift & width
4 keV

E07 ΛΛ Hypernuclei

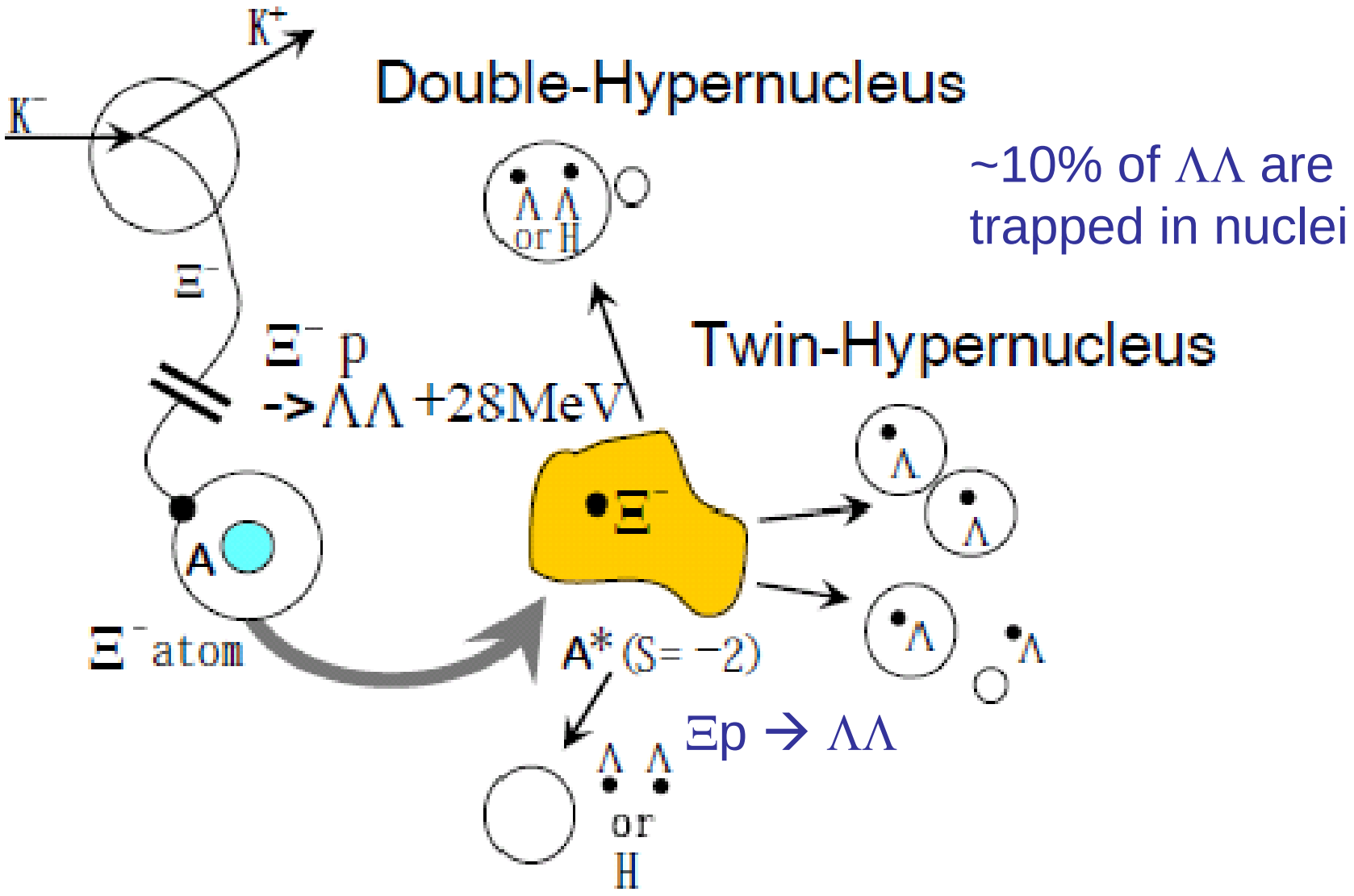
- Hybrid emulsion method
  - Production of Ξ^- by the (K^-,K^+) reaction is tagged by counters (almost the same as E03)
  - Then Ξ^- is tracked down in emulsion for possible production of double-Λ hypernuclei.
- Goal: 10000 stopped Ξ^- on emulsion
  100 or more double-Λ hypernuclei events
  10 species of double-Λ hypernuclei

→ Chart of double-Λ hypernuclei

Setup around the target

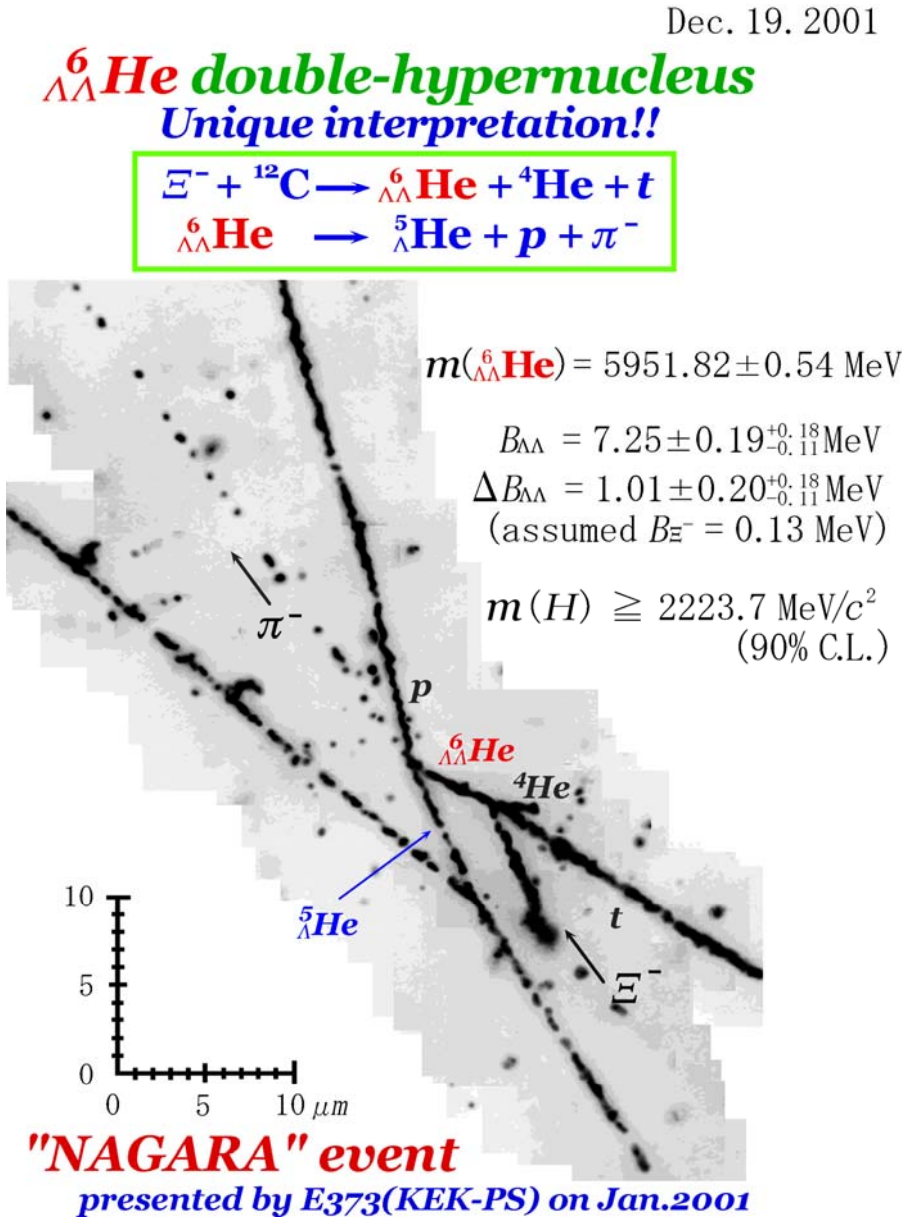


Production of ΛΛ hypernuclei

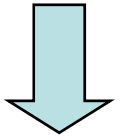


~10% of ΛΛ are trapped in nuclei

Example event in emulsion



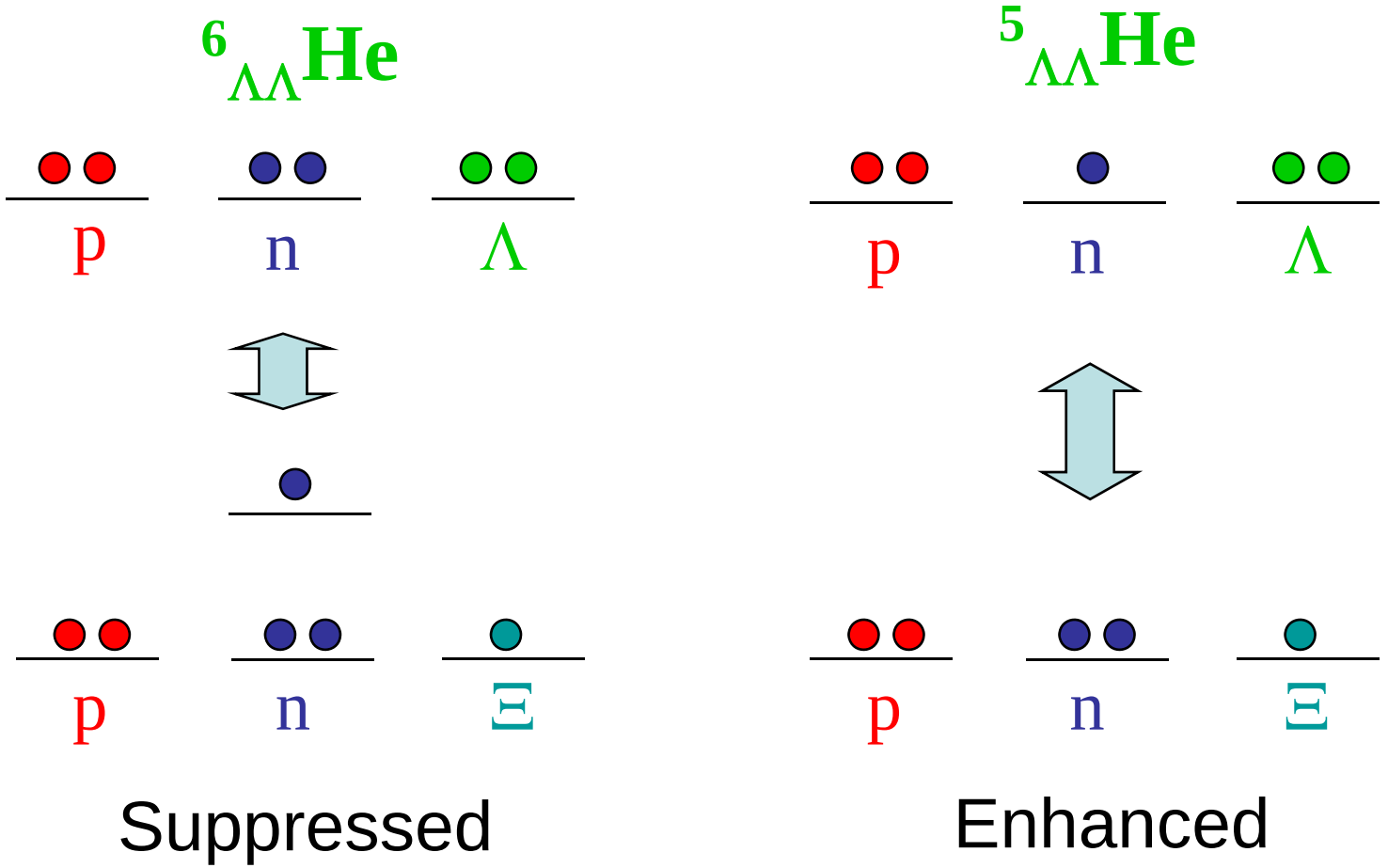
- Track length, thickness
  - PID/energy
- Presume what are produced at each vertex
  - Then check consistency
  - Unique assignment is sometimes possible



- Calculate binding energy $\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2B_{\Lambda}$ gives net $\Lambda\Lambda$ interaction

Systematics of ΛΛ binding energy

- $\Delta B_{\Lambda\Lambda}$ may different for each nucleus
  - For example by hyperon mixing effect



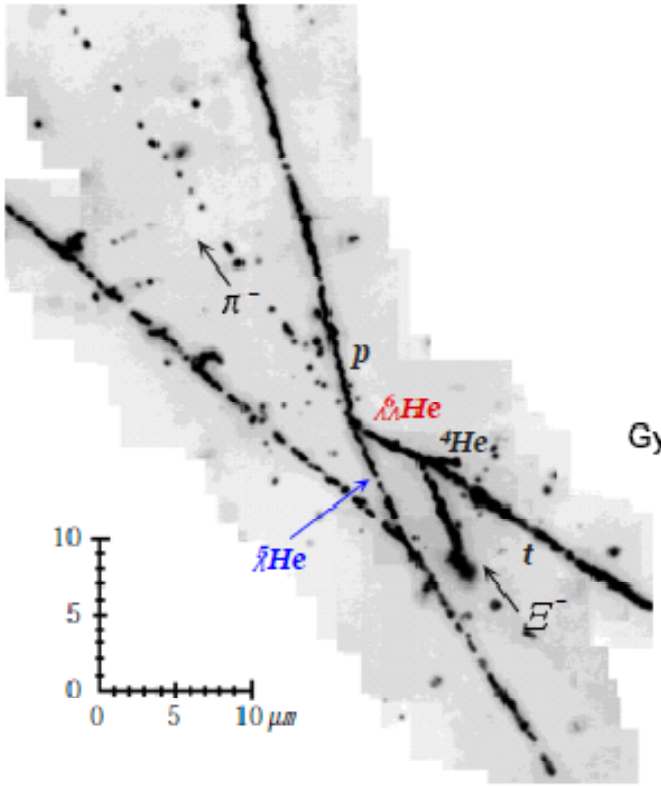
Summary & perspective

- Nuclei with S=-2 at J-PARC
  - Main topic of strangeness nuclear physics
- 3 experiments are approved
  - Spectroscopy of Ξ hypernucleus (E05)
  - X-ray spectroscopy of Ξ atom (E03)
    → ΞA optical potential, ΞN interaction
    attractive or repulsive? how strong is ΞN → ΛΛ?
  - Hybrid emulsion study of double Λ hypernuclei (E07)
    → ΛΛ interaction in nuclei, S=-2 hypernuclear chart
    evidence for ΛΛ-ΞN mixing seen in ΛΛ hypernuclei?
- More to come
  - E05 & E03 will do systematic measurements
  - γ-ray spectroscopy of ΛΛ-hypernuclei may be possible

Collaboration list: E07

Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method

NAGARA event (KEK-E373)



Kyoto: E.Hayata, M.Hayata, M.Hirose, K.Imai, S.Kamigaito, N.Saito, K.Tanida, M.Togawa, T.Tsunemi, C.J.Yoon

Gifu: M.Kawasaki, H.Nakamura, K.Nakazawa, K.T.Tint, T.Watanabe

Tohoku: K.Hosomi, T.Koike, Y.Ma, K.Shirotori, H.Tamura, M.Ukai

AMU: R.Hasan

BNL: R.E.Chrien

CIAE: Y.Y.Fu, C.P.Li, Z.M.Li, J.Zhou, S.H.Zhou, L.H.Zhu

Chonnam: J.Y.Kim

Dongshin: M.Y.Pac

Fukui: T.Yoshida

Gyeongsang: K.S.Chung, S.H.Kim, J.S.Song, C.S.Yoon

KEK: M.Ieiri, H.Noumi, M.Sekimoto, H.Takahashi

Nagoya: K.Hoshino, T.Kawai, B.D.Park, T.Sato, T.Watabe

NIRS: N.Yasuda

OsakaCity: K.Yamamoto

Pusan: J.K.Ahn, S.Y.Ryu

Toho: C.Fukushima, M.Kimura, S.Ogawa, H.Shibuya

UCL: D.H.Davis, D.Tovee

U.Houston: Ed.Hungerfold

U.New-Mexico: B.Bassalleck

Collaborators

E05

J.K.Ahn[k], S.Ajimura[g] , K.Aoki[a], J.Arvieux[o], B.Bassalleck[n], B.H.Choi[k], R.E.Chrien[m], F.Diego[s], P.Evtoukhovitch[j], Y.Fu[l], Y.Fujii[b], H.Fujioka[d], T.Fukuda[i], O.Hashimoto[b], M.Ieiri[a], K.Imai[a], T.Ishikawa[b], V.Kalinnikov[j], W.Kallies[j], H.Kanda[b], M.Kaneta[b], T.Kishimoto[g], T.Koike[b], N.Kravchuk[j], A.P.Krutenkova[p], V.V.Kulikov[p], C.Li[l], X.Li[l], B.Luigi[r], Y.Ma[b], K.Maeda[b], S.Marcello[r], T.Maruta[a], K.Miwa[f], A.Moiseenko[j], D.Mzhavia[j], T.Nagae[a](Spokesperson), D.Nakajima[d], S.N.Nakamura[b], K.Nakazawa[e], H.Noumi[a], M.Ombrella[t], J.Reinhold[q], P.K.Saha[c], A.Sakaguchi[g], V.Samoilov[j], Y.Sato[a], S.Sawada[a], M.Sekimoto[a], K.Shirotori[b], H.Takahashi[a], T.N.Takahashi[u],T.Takahashi[a], H.Tamura[b], L.Tang[u], K.Tanida[f], A.Toyoda[a], Z.Tsamalaidze[j], M.Ukai[b], T.Watanabe[e], H.Yamazaki[b], M.Yosoi[h], O.Zaimidoroga[j], C.Zhou[l], S.H.Zhou[l], L.H.Zhu[l]

(a) *High Energy Acclerator Research Organization (KEK), Japan*
(b) *Tohoku University, Japan*
(c) *Japan Atomic Energy Agency (JAEA), Japan*
(d) *University of Tokyo, Japan*
(e) *Gifu University, Japan*
(f) *Kyoto University*
(g) *Osaka University*
(h) *Research Center for Nuclear Physics (RCNP), Osaka University, Japan*
(i) *Osaka Electro-Communication University*
(j) *Joint Institute for Nuclear Research (JINR), Russia*
(k) *Pusan National University, Korea*
(l) *China Institute of Atomic Energy (CIAE), China*
(m) *Brookhaven National Laboratory (BNL), USA*
(n) *University of New Mexico, USA*
(o) *IPN-O, Universite Paris-Sud, France*
(p) *Insititute of Thoretical and Experimental Physics (ITEP), Russia*
(q) *Florida International University, USA*
(r) *Universita di Torino, Italy*
(s) *INFN, Sezione di Torino, Italy*
(t) *INAF-IFSI, Sezione di Torino, Italy*
(u) *Hampton University, USA*

66 members
from 21 institutes

Collaboration list: E03

- *Kyoto University*
  - S. Dairaku, H. Fujimura, T. Hiraiwa, K. Imai, K. Miwa, A. Okamura, **K. Tanida** (spokesperson), C. J. Yoon
- *Brookhaven National Laboratory*
  - R. E. Chrien
- *China Institute of Atomic Energy*
  - Y. Y. Fu, C. P. Li, X. M. Li, J. Zhou, S. H. Zhou, L. H. Zhu
- *Gifu University*
  - K. Nakazawa, M. Ukai, T. Watanabe,
- *KEK*
  - H. Noumi, Y. Sato, M. Sekimoto, H. Takahashi, T. Takahashi, A. Toyoda
- *JINR(Russia)*
  - E. Evtoukhovitch, V. Kalinnikov, W. Kallies, N. Karavchuk, A. Moissenko, D. Mzhavia, V. Samoilov, Z. Tsamalaidze, O. Zaimidoroga
- *Tohoku University*
  - O. Hashimoto, K. Hosomi, T. Koike, Y. Ma, M. Mimori, K. Miwa, K. Shirotori, H. Tamura