Challenges on doubly strange systems at J-PARC

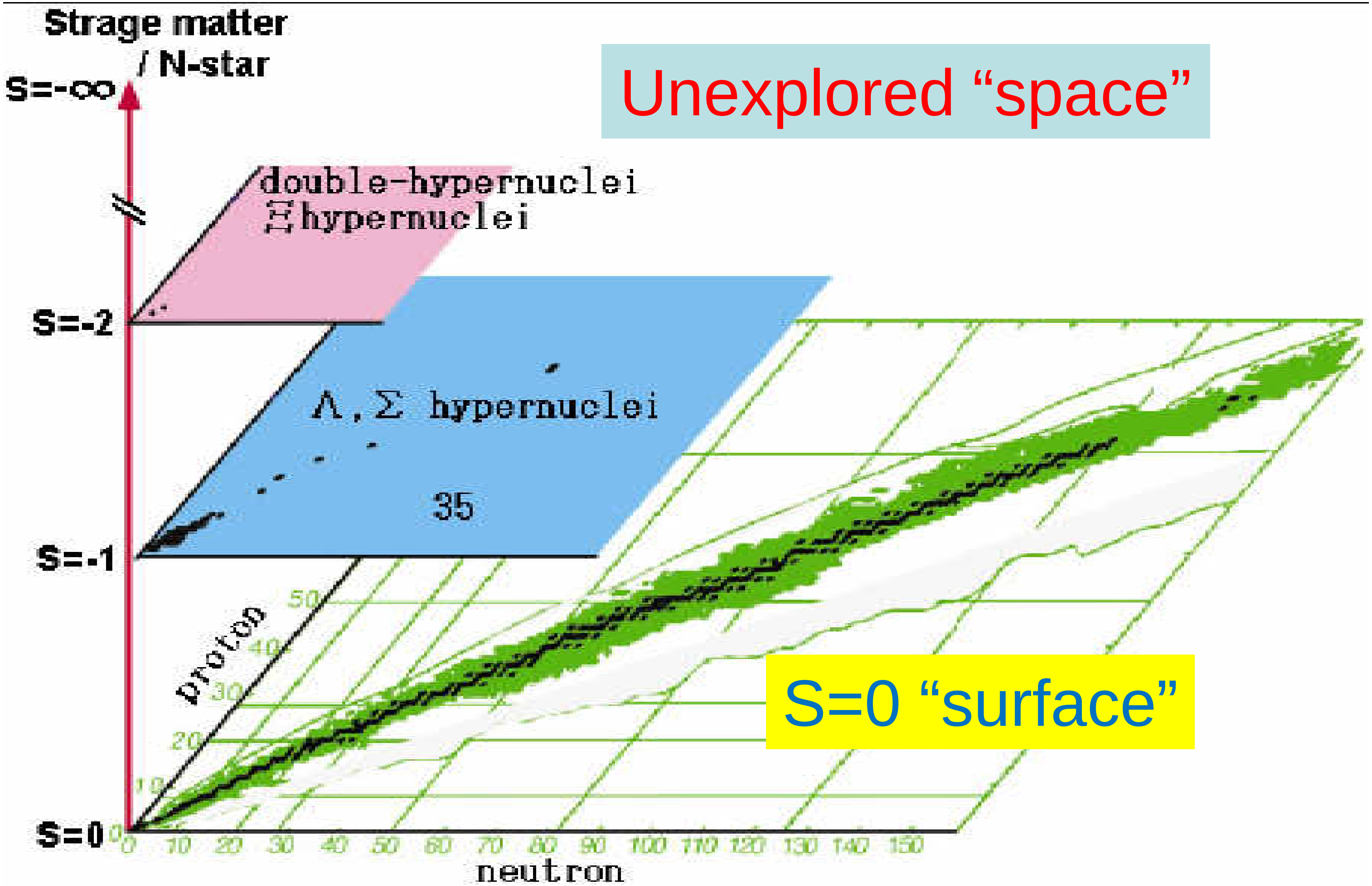
Yongpyong Ski Resort

Feb. 22, 2010

Kiyoshi Tanida

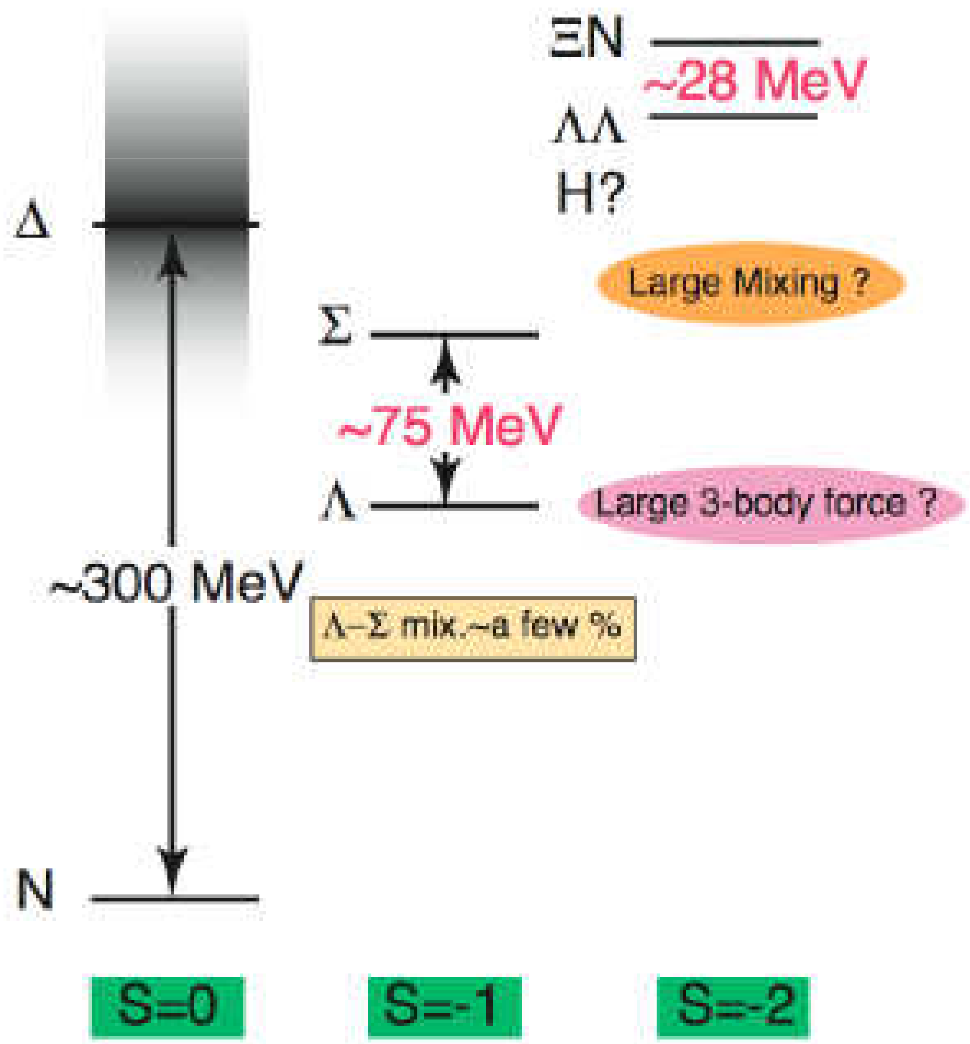
(Seoul National University)

Hyper-nuclear chart



S=–2 systems

- A doorway to the multi-strangeness system
  - YY interaction appears for the first time
- 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



B_8B_8 systems classified in the SU_3 states with (λ, μ)

S	B_8B_8(I)	^1E, ^3O (P=symmetric)	^3E, ^1O (P=unsymmetric)
0	NN(0)	—	(03)
	NN(1)	(22)	—
-1	ΛN	$\frac{1}{\sqrt{10}}[(11)_s+3(22)]$	$\frac{1}{\sqrt{2}}[-(11)_a+(03)]$
	ΣN(1/2)	$\frac{1}{\sqrt{10}}[3(11)_s-(22)]$	$\frac{1}{\sqrt{2}}[(11)_a+(03)]$
	ΣN(3/2)	(22)	(30)
-2	ΛΛ	$\frac{1}{\sqrt{5}}(11)_s+\frac{9}{2\sqrt{30}}(22)+\frac{1}{2\sqrt{2}}(00)$	—
	ΞN(0)	$\frac{1}{\sqrt{5}}(11)_s-\sqrt{\frac{3}{10}}(22)+\frac{1}{\sqrt{2}}(00)$	$(11)_a$
	ΞN(1)	$\sqrt{\frac{3}{5}}(11)_s+\sqrt{\frac{2}{5}}(22)$	$\frac{1}{\sqrt{3}}[-(11)_a+(30)+(03)]$
	ΣΛ	$-\sqrt{\frac{2}{5}}(11)_s+\sqrt{\frac{3}{5}}(22)$	$\frac{1}{\sqrt{2}}[(30)-(03)]$
	ΣΣ(0)	$\sqrt{\frac{3}{5}}(11)_s-\frac{1}{2\sqrt{10}}(22)-\sqrt{\frac{3}{8}}(00)$	—
	ΣΣ(1)	—	$\frac{1}{\sqrt{6}}[2(11)_a+(30)+(03)]$
	ΣΣ(2)	(22)	—
-3	ΞΛ	$\frac{1}{\sqrt{10}}[(11)_s+3(22)]$	$\frac{1}{\sqrt{2}}[-(11)_a+(30)]$
	ΞΣ(1/2)	$\frac{1}{\sqrt{10}}[3(11)_s-(22)]$	$\frac{1}{\sqrt{2}}[(11)_a+(30)]$
	ΞΣ(3/2)	(22)	(03)
-4	ΞΞ(0)	—	(30)
	ΞΞ(1)	(22)	—

S=−2 system

—— 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 $K^+ \to \pi^+ \nu$ ν-bar 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 $K_L \to \pi^0 \nu$ ν-bar 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 ^3He 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
(*) : Affiliation of the spokespersons
: Experiment at the fast extraction beam
: Experiment at the third extraction beam

S=–2 system

―― J-PARC PAC Approval summary ――

E03: Measurement of X rays from Ξ^- atom

Spokesperson – K. Tanida (Seoul)

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)

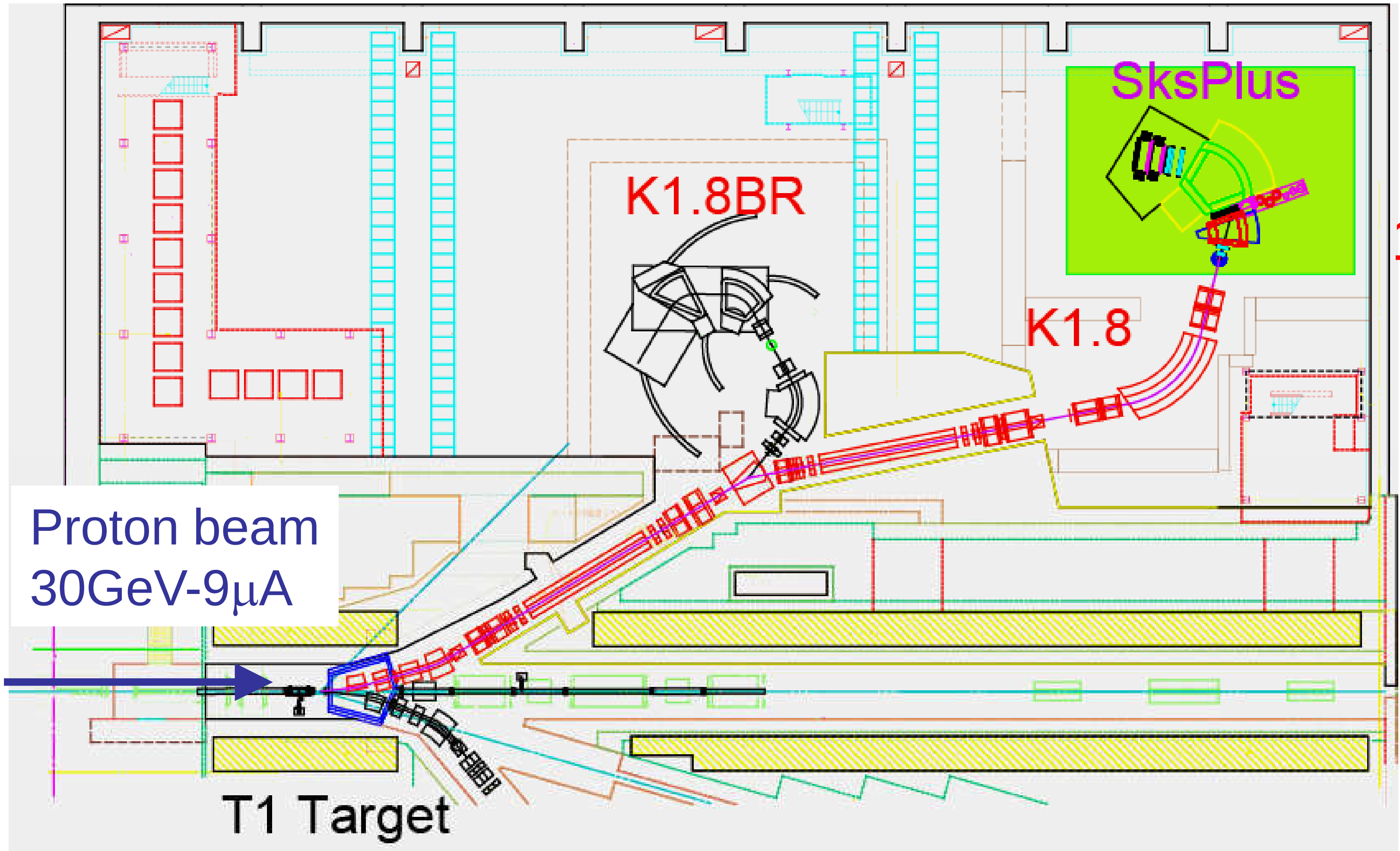
: No presentation this time : Experiment at the third extraction beam

(*) : Affiliation of the spokespersons

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

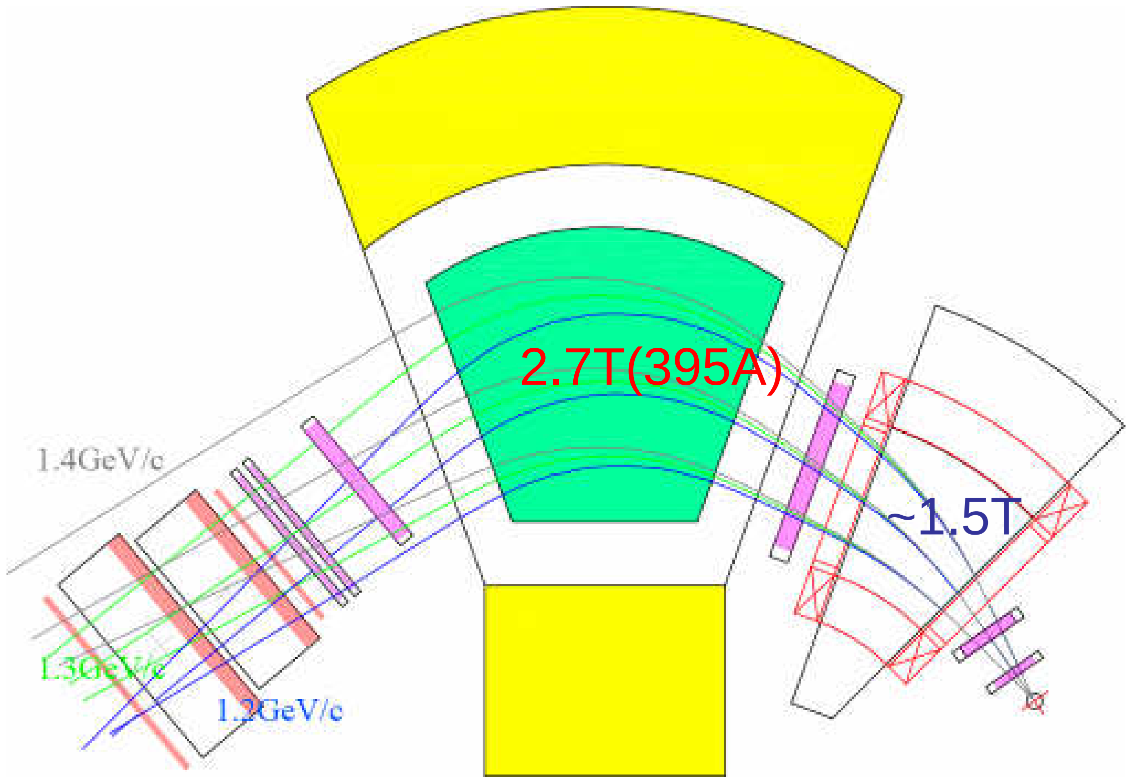
- Valuable information on ΞN (effective) interaction
  - e.g., How strong $\Xi N \rightarrow \Lambda\Lambda$ (and thus ΞN-$\Lambda\Lambda$ mixing) is?
    - Relevant to the existence of H dibaryon
    - ΞN component in $\Lambda\Lambda$-hypernuclei
  - Exchange interaction is prohibited in one-meson exchange 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.

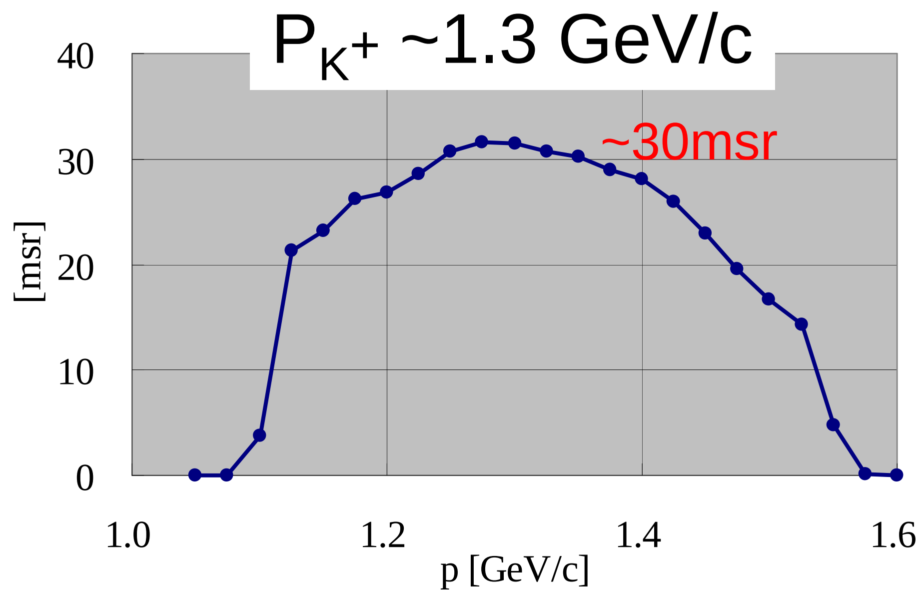
ΞN interaction model and ΞA optical potential

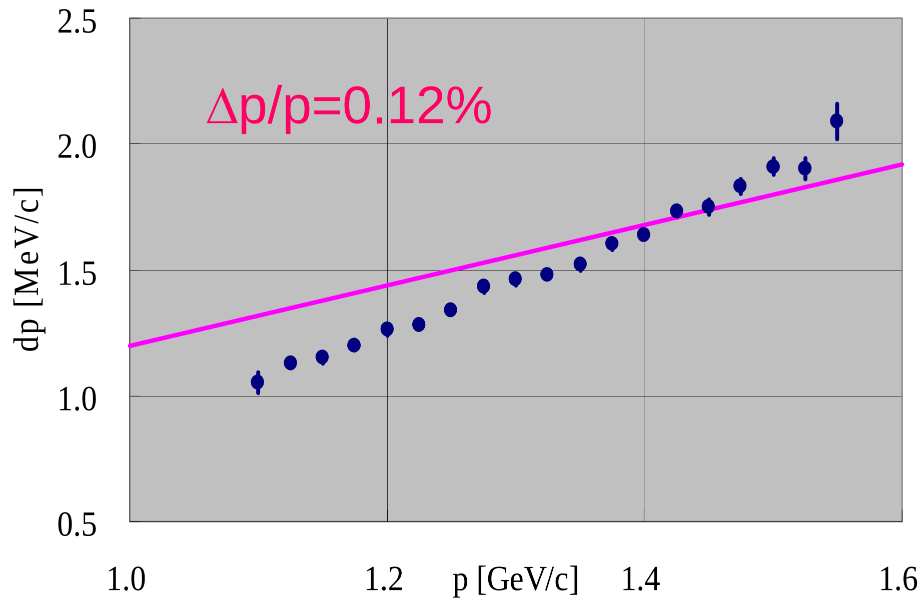
Model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ_Ξ
NHC-D	0	−2.6	0.1	−2.1	−0.2	−0.7	−1.9		
	1	−3.2	−2.3	−3.0	−0.0	−3.1	−6.3	−25.2	0.9
Ehime	0	−0.9	−0.5	−1.0	0.3	−2.4	−0.7		
	1	−1.3	−8.6	−0.8	−0.4	−1.7	−4.2	−22.3	0.5
ESC04d*	0	6.3	−18.4	1.2	1.5	−1.3	−1.9		
	1	7.2	−1.7	−0.8	−0.5	−1.2	−2.8	−12.1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



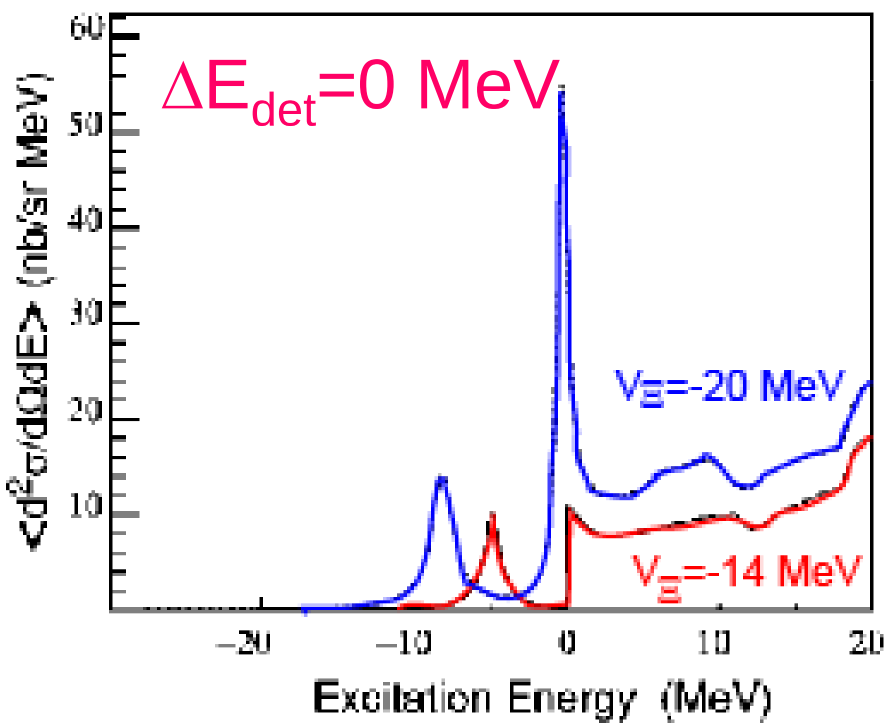




- 95° total bend
- ~7m flight path
- Δx=0.3 mm (RMS)

high resolution: ΔE~ 3 MeV

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

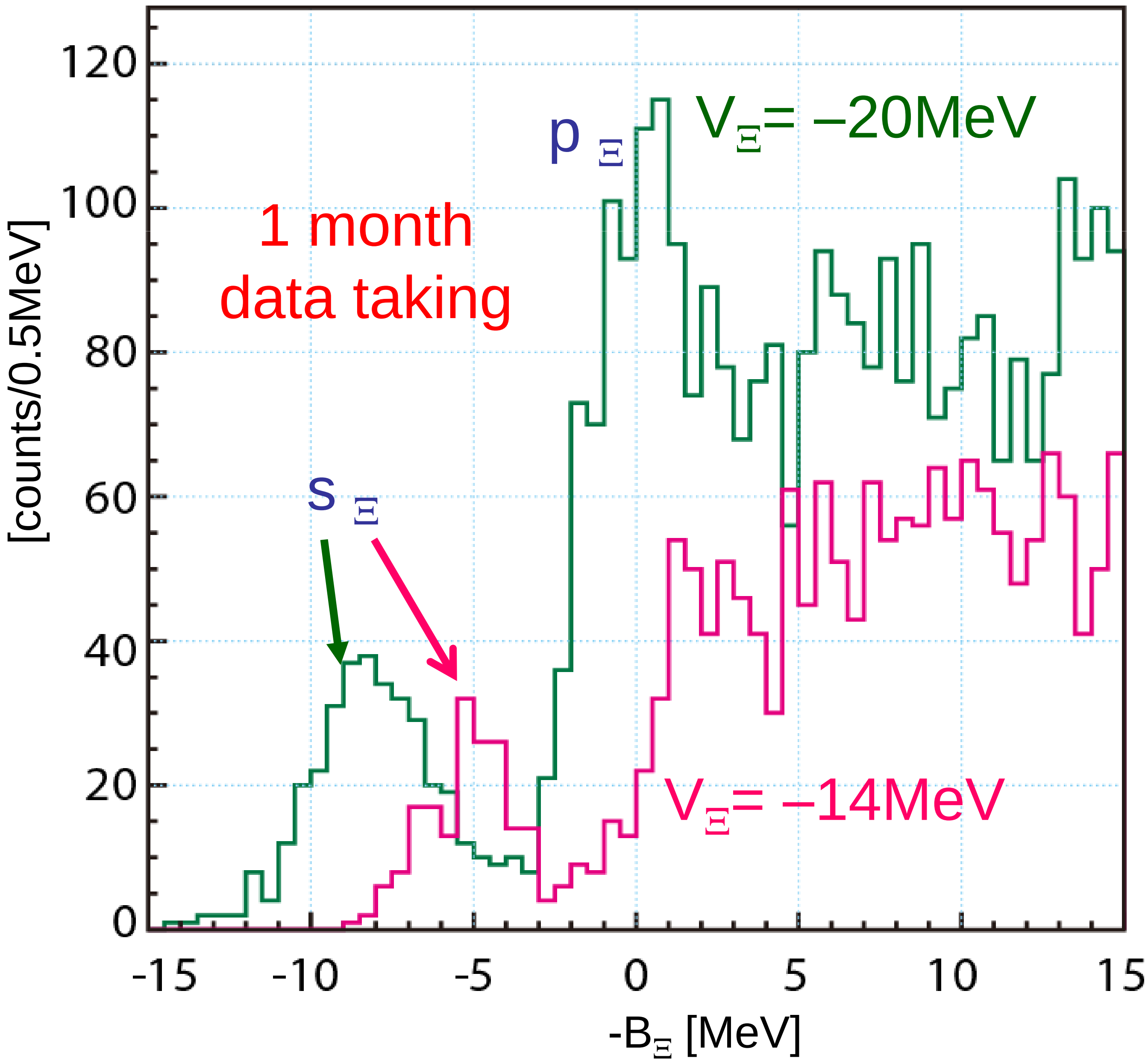


states		V^{Ξ}_0 [MeV] –24	–20	–16	–12
s-state					[nb/sr]
$0p_{3/2} \rightarrow 0s_{1/2}$	1^-	215	168	123	81
p-states					[nb/sr]
$0p_{3/2} \rightarrow 0p_{3/2}$	0^+	29	20	–	–
	2^+	164	103	–	–
$0p_{3/2} \rightarrow 0p1_{/2}$	2^+	152	93	–	–
sum		345	216	–	–

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

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

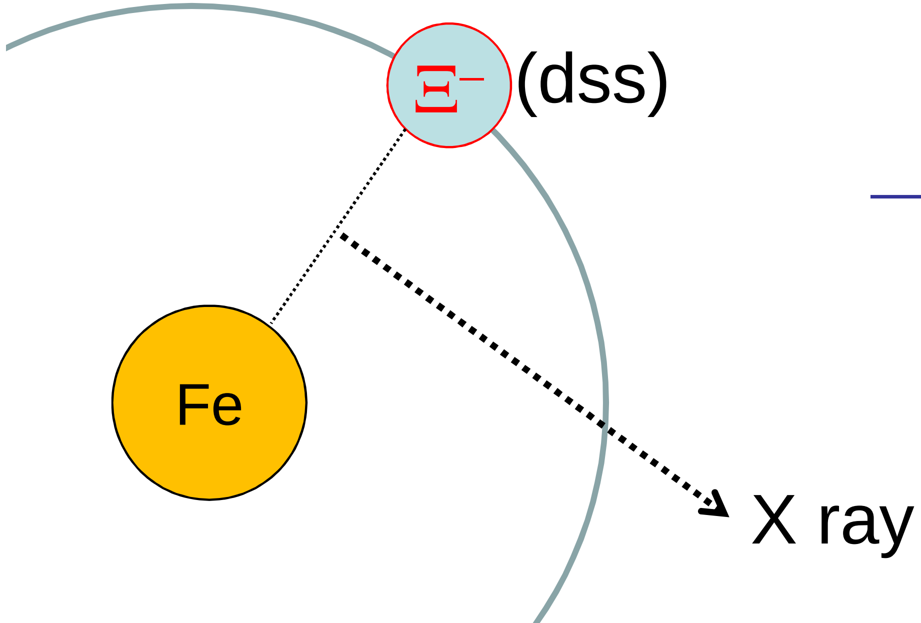


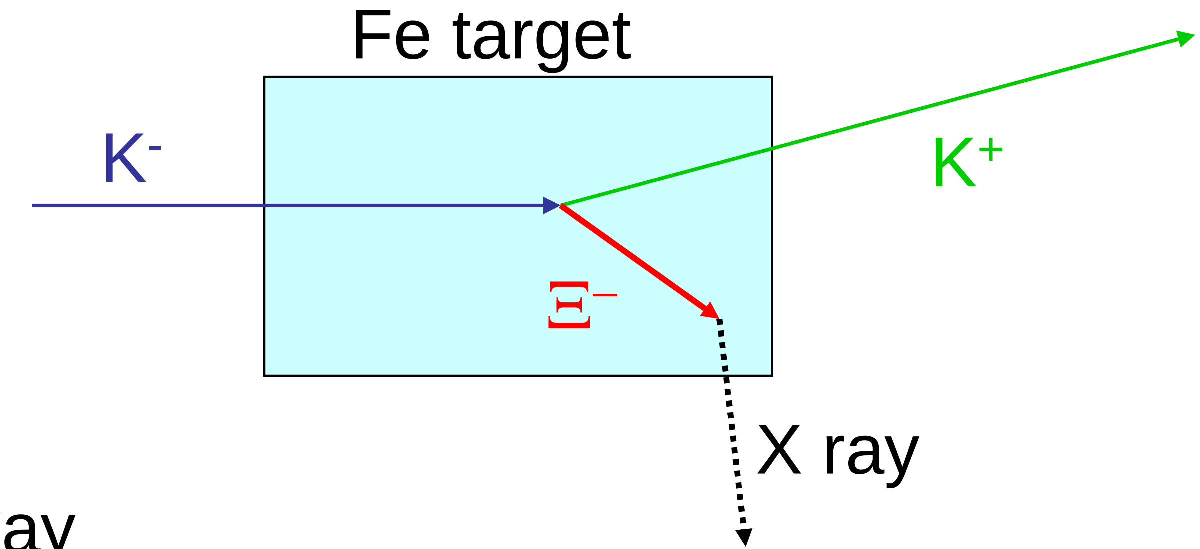
$\Delta E = 3\ \mathrm{MeV}_{\mathrm{FWHM}}$

Optical potential

E03 experiment

- World 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



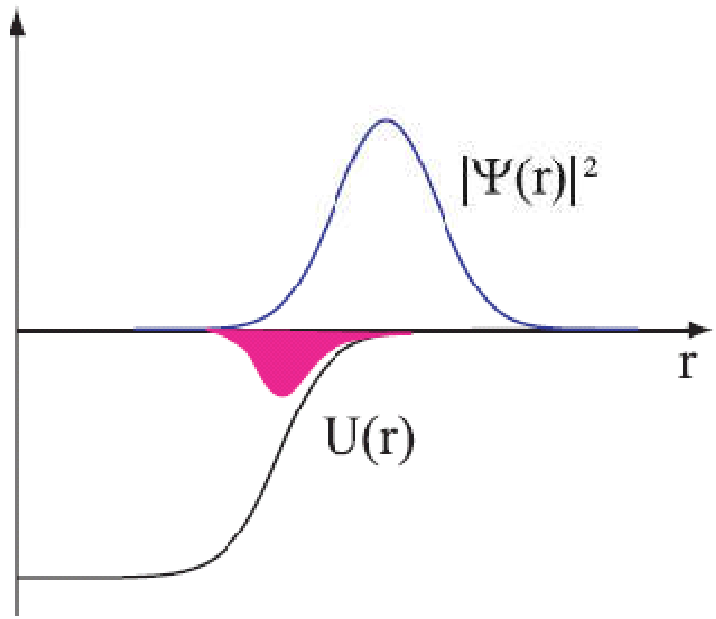


Principle of the experiment

- Atomic state – precisely calculable if there is no hadronic interaction
- 1st order perturbation

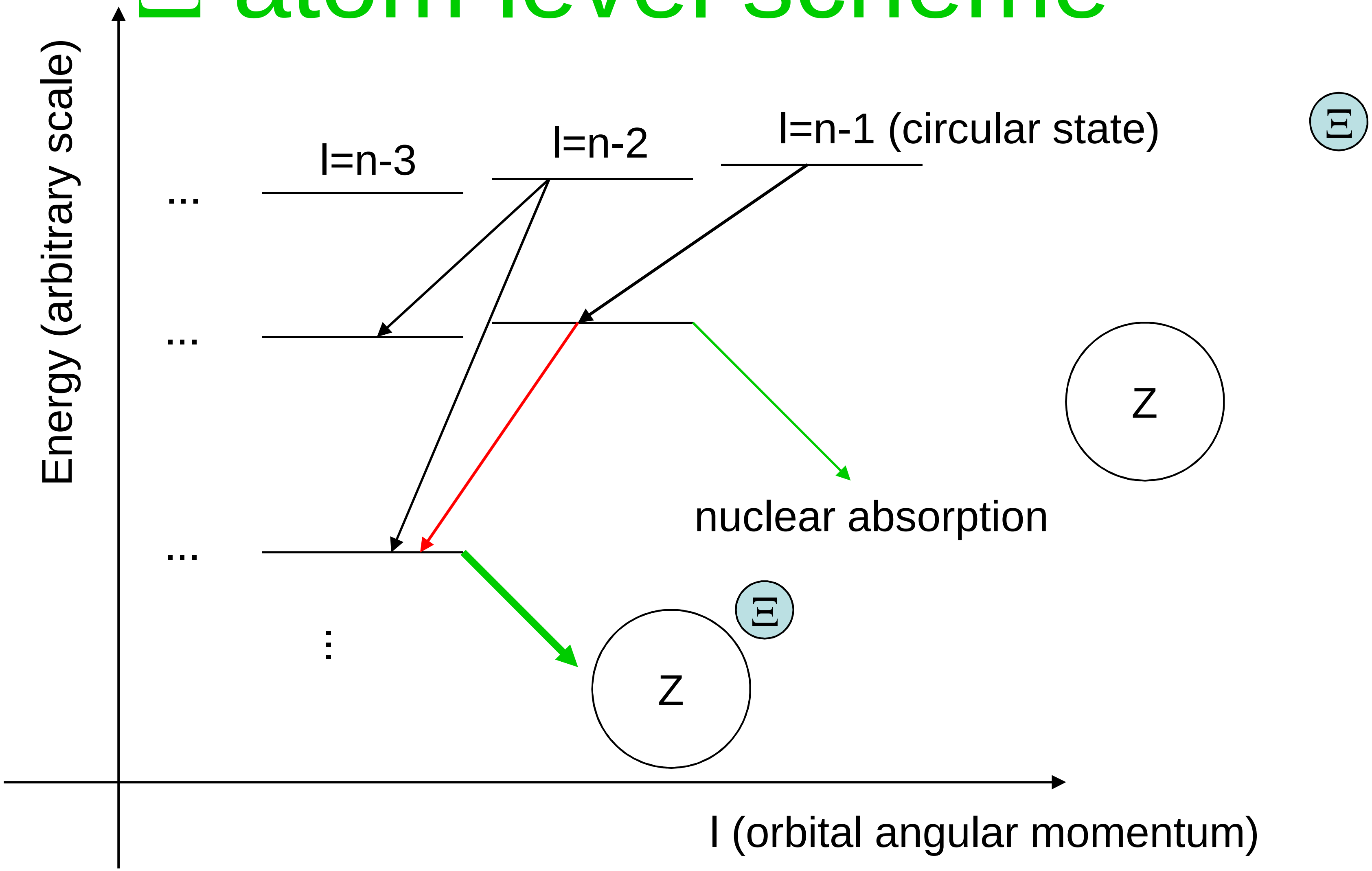
$$\Delta E = \int |\Psi_{\Xi}(r)|^2 U_{\Xi}(r) dr$$

  - If we assume potential shape, we can accurately determine its depth with only one data
  - Shape information can be obtained with many data
  - Even if 1st order perturbation is not good, this is still the same.



- Peripheral, but direct (⇔Ξ-nuclei spectroscopy)

Ξ atom level scheme

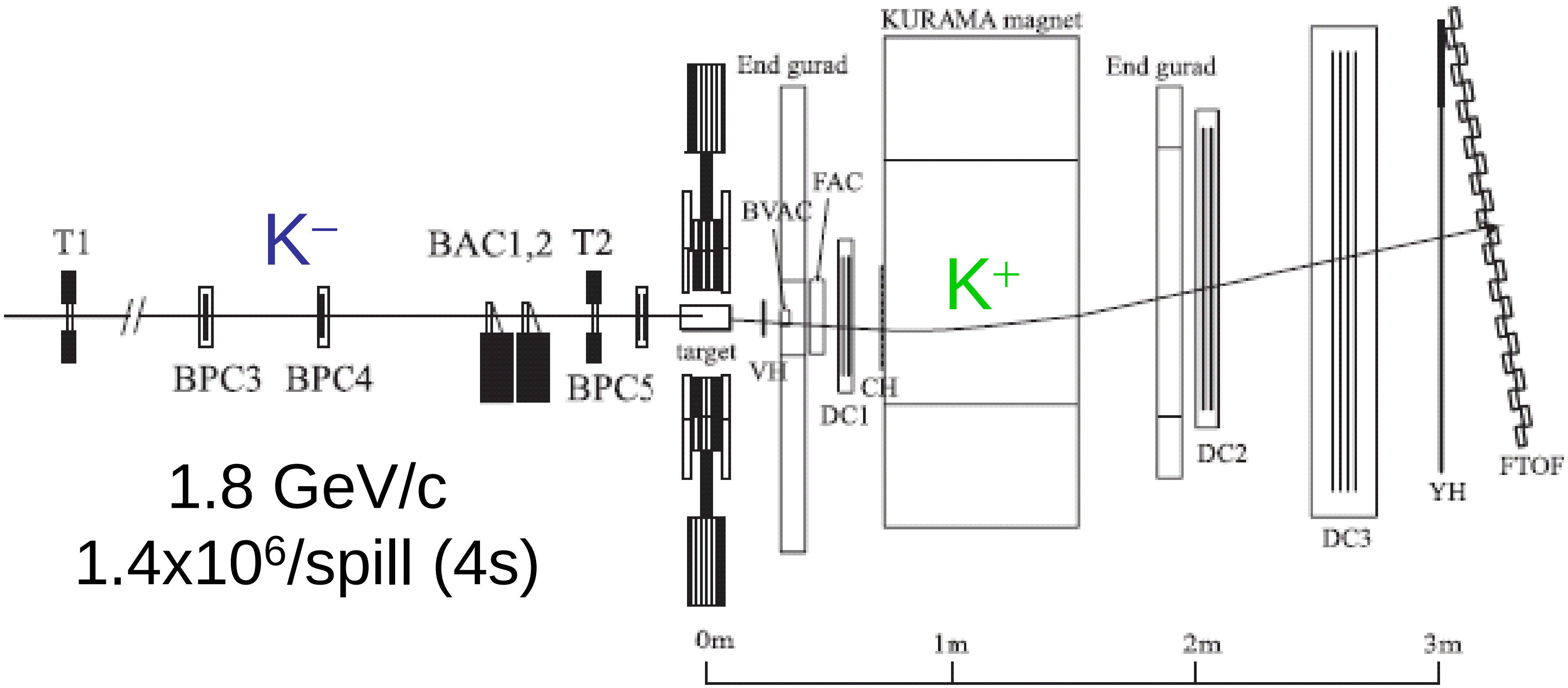


X ray energy shift – real part

Width, yield – imaginary part

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

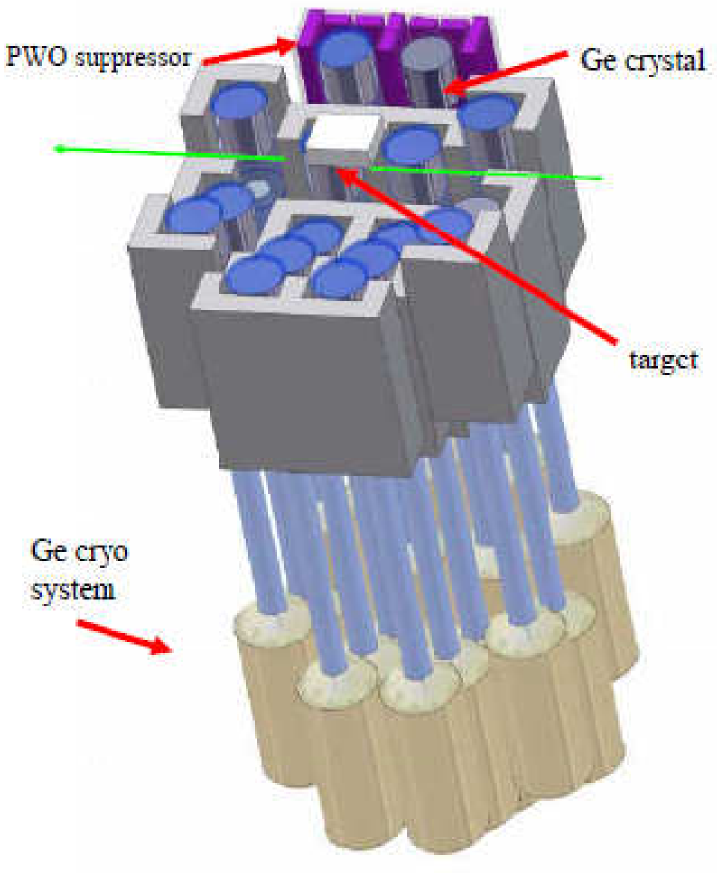
Experimental setup

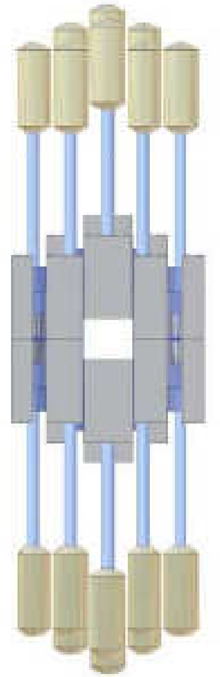


- Long used at KEK-PS K2 beamline (E373, E522, ...)
  - Minor modification is necessary to accommodate high rate.
- Large acceptance (~0.2 sr)

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)





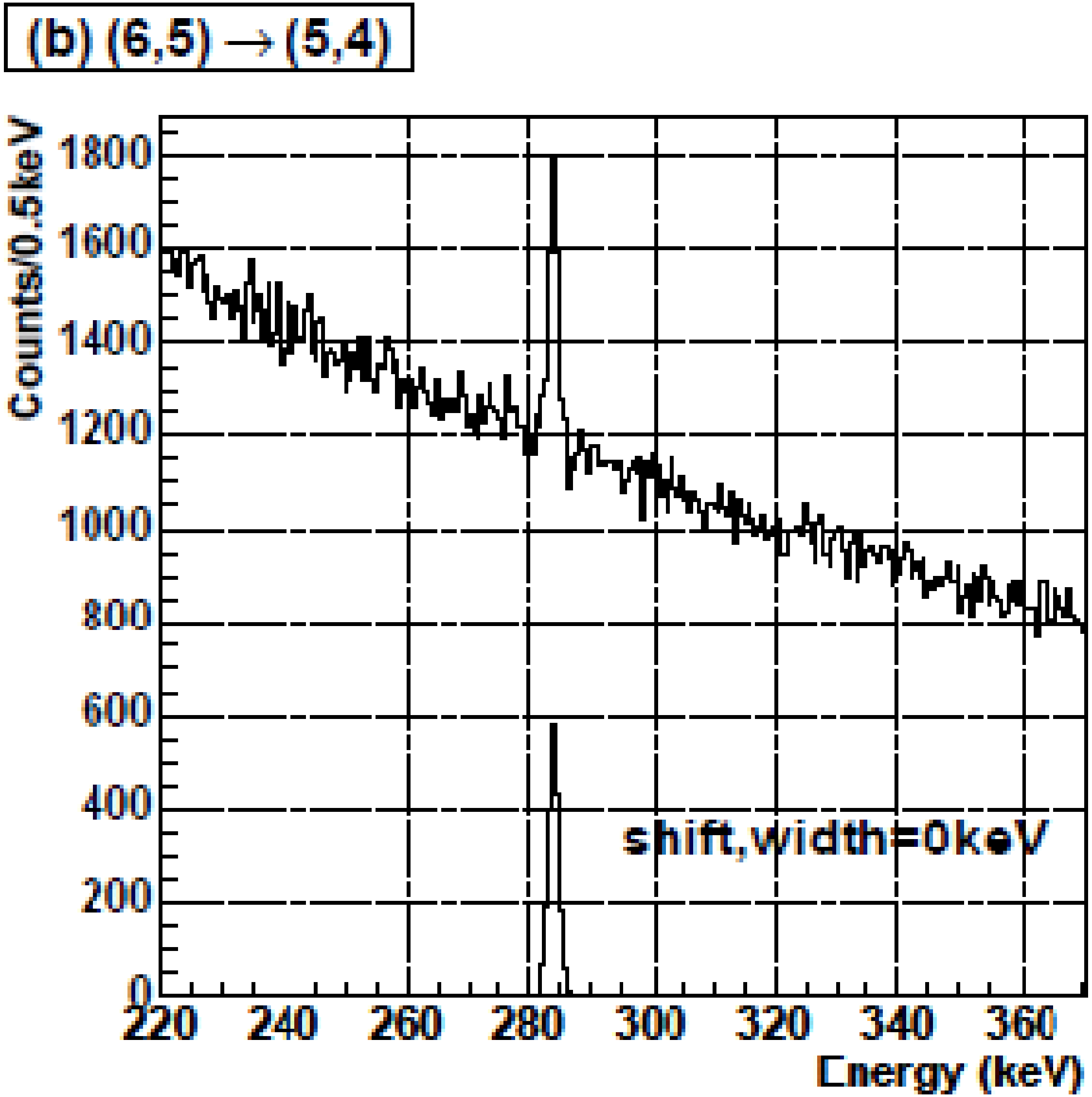
Yield & sensitivity estimation

- 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.

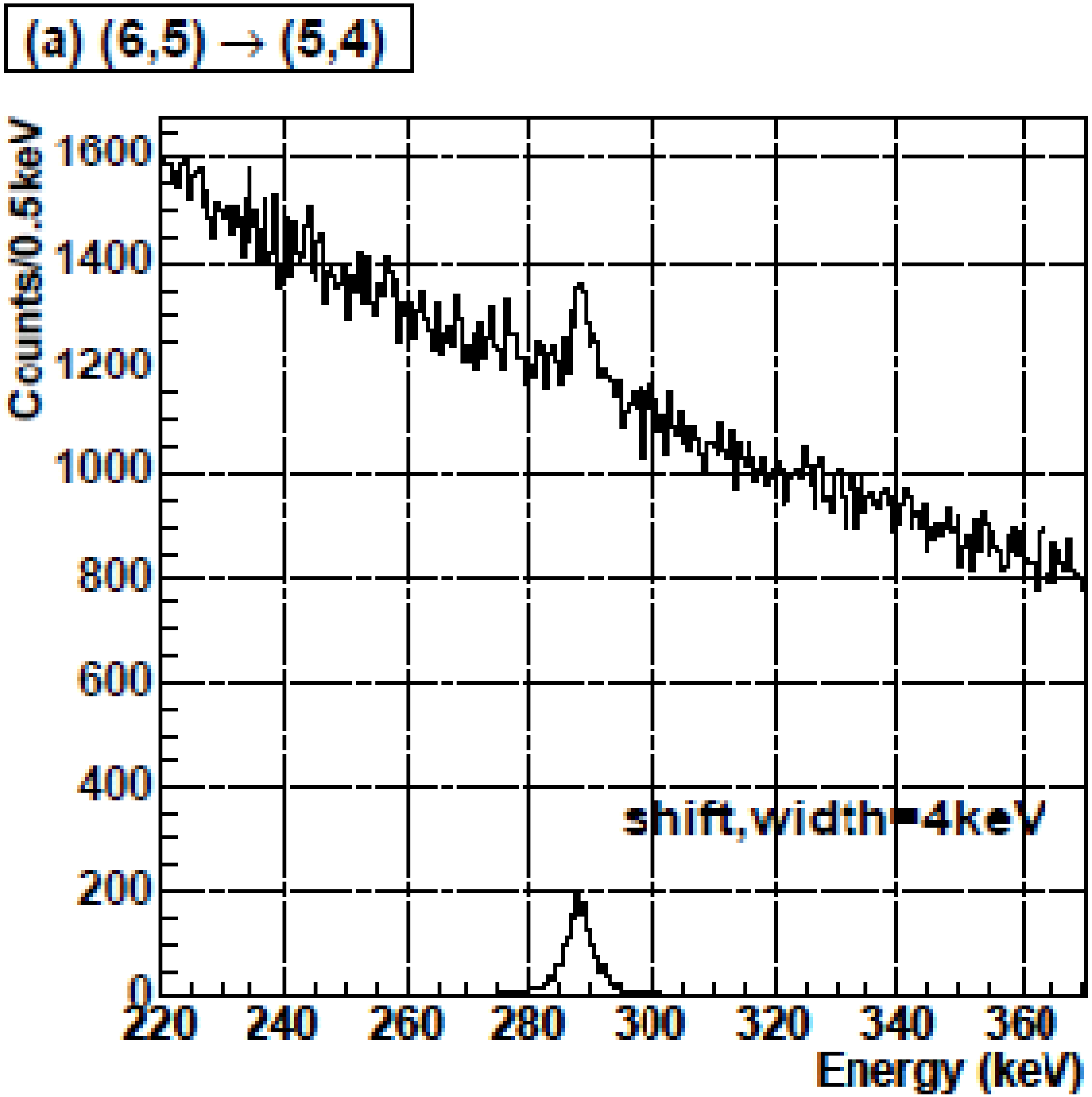
Expected X-ray spectrum



n= 6→5

shift & width
0 keV

Expected X-ray spectrum(2)

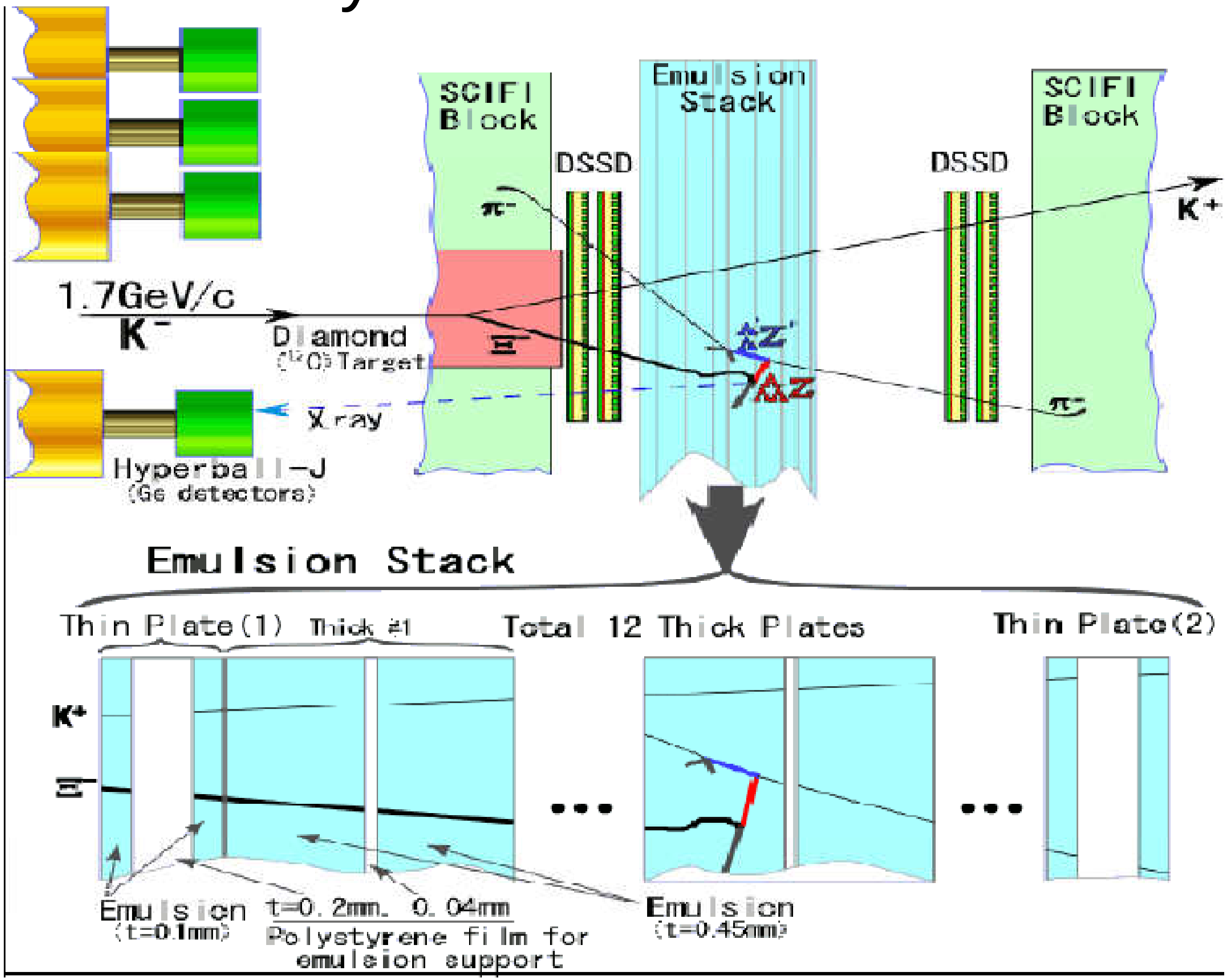


n= 6→5

shift & width
4 keV

E07 ΛΛ Hypernuclei

Hybrid emulsion method

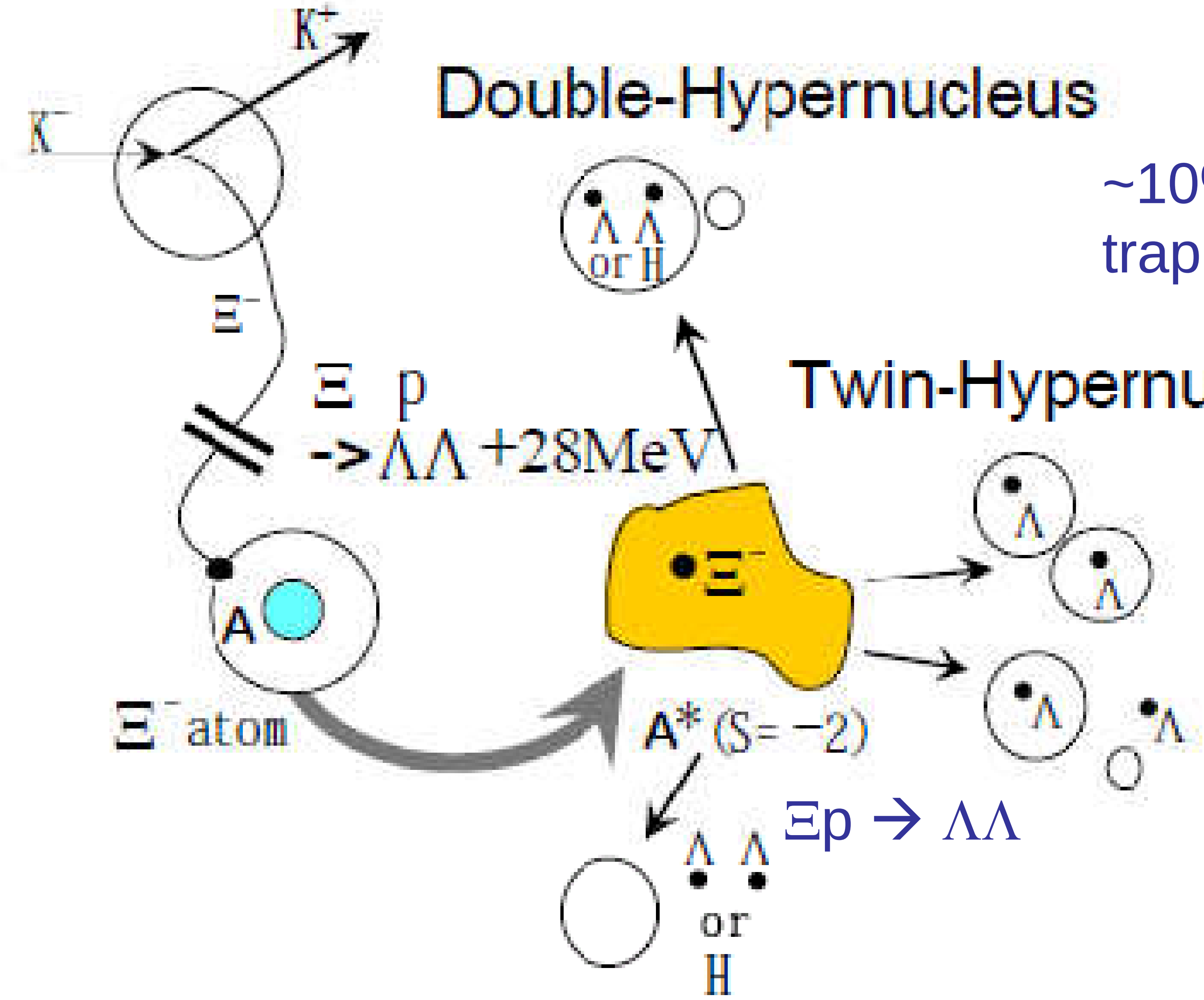


Goal:

- 10000 stopped Ξ^- on emulsion
- 100 or more double-Λ HN events
- 10 nuclides

Chart of double-Λ hypernuclei

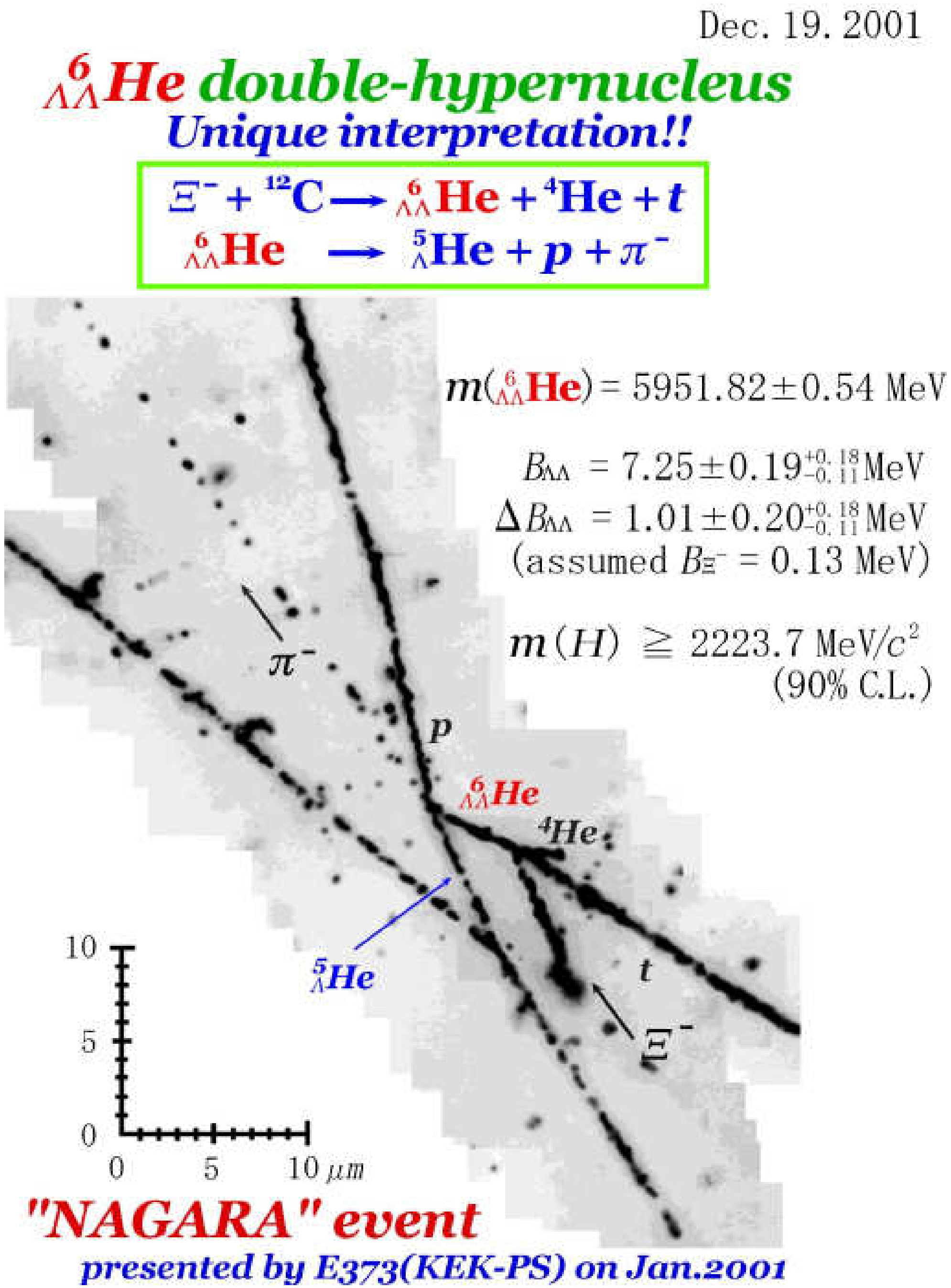
Production of ΛΛ hypernuclei



~10% of ΛΛ are trapped in nuclei

Ξp → ΛΛ

Example event in emulsion

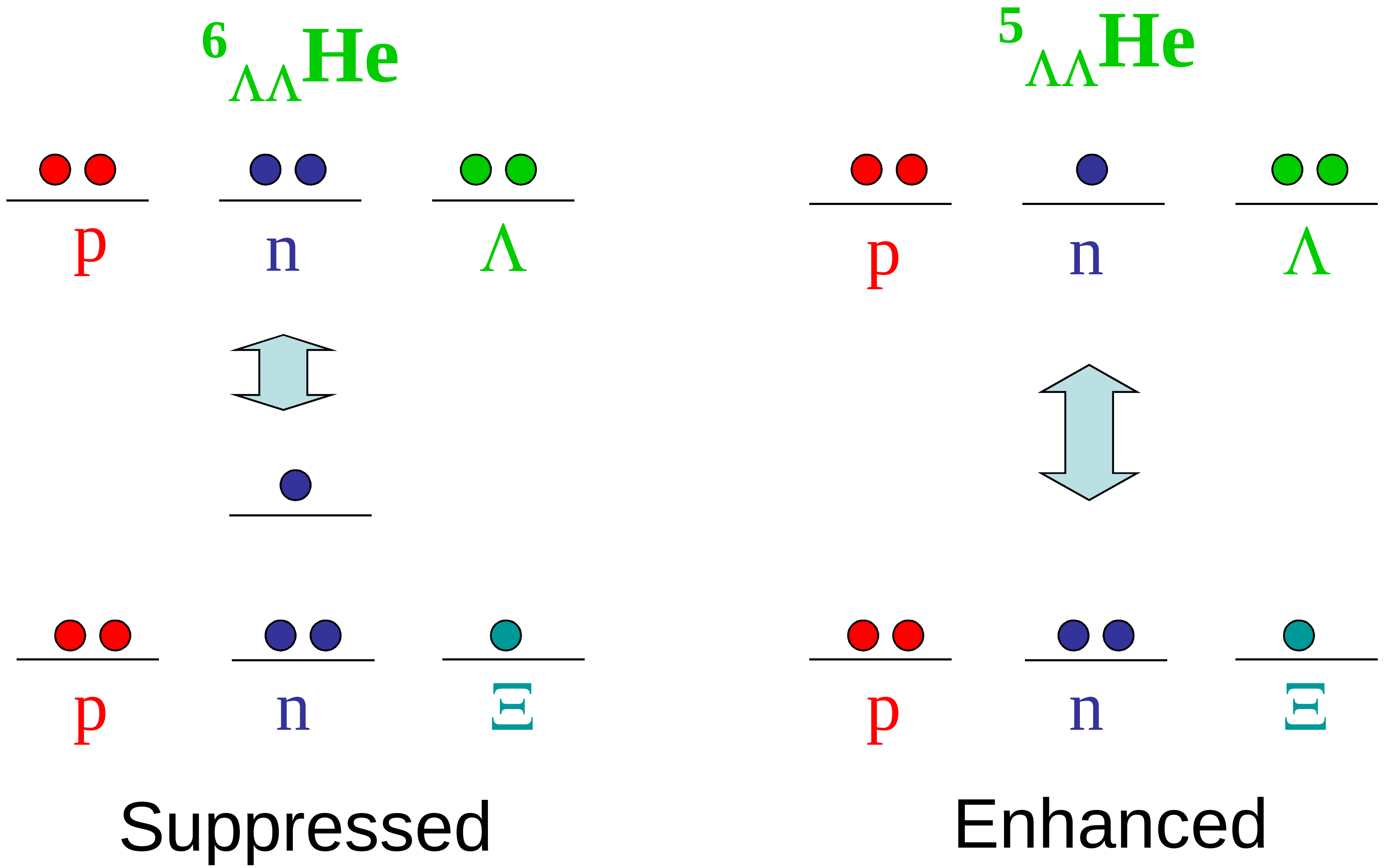


- Track length, thickness
  - PID/energy
- Presume what are produced at each vertex
  - Then check consistency
  - Unique assignment is sometimes possible

- 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 be different for each nucleus
  - For example by hyperon mixing effect



Summary

- S=–2 studies at J-PARC
  - 3 experiments proposed (and approved)
    E05 – Spectroscopy of Ξ hypernuclei
    E03 – X-ray spectroscopy of Ξ atoms
    E07 – Hybrid Emulsion for double-Λ hypernuclear chart
  - More are to come
- Utilizes the world ever-strongest kaon beam
  - Unique opportunity at J-PARC
- More information on J-PARC:
  - Plenary session talk tomorrow morning
    (By Prof. Tamura → KT will talk on his behalf)