S=–2原子核実験

T.Takahashi (KEK)

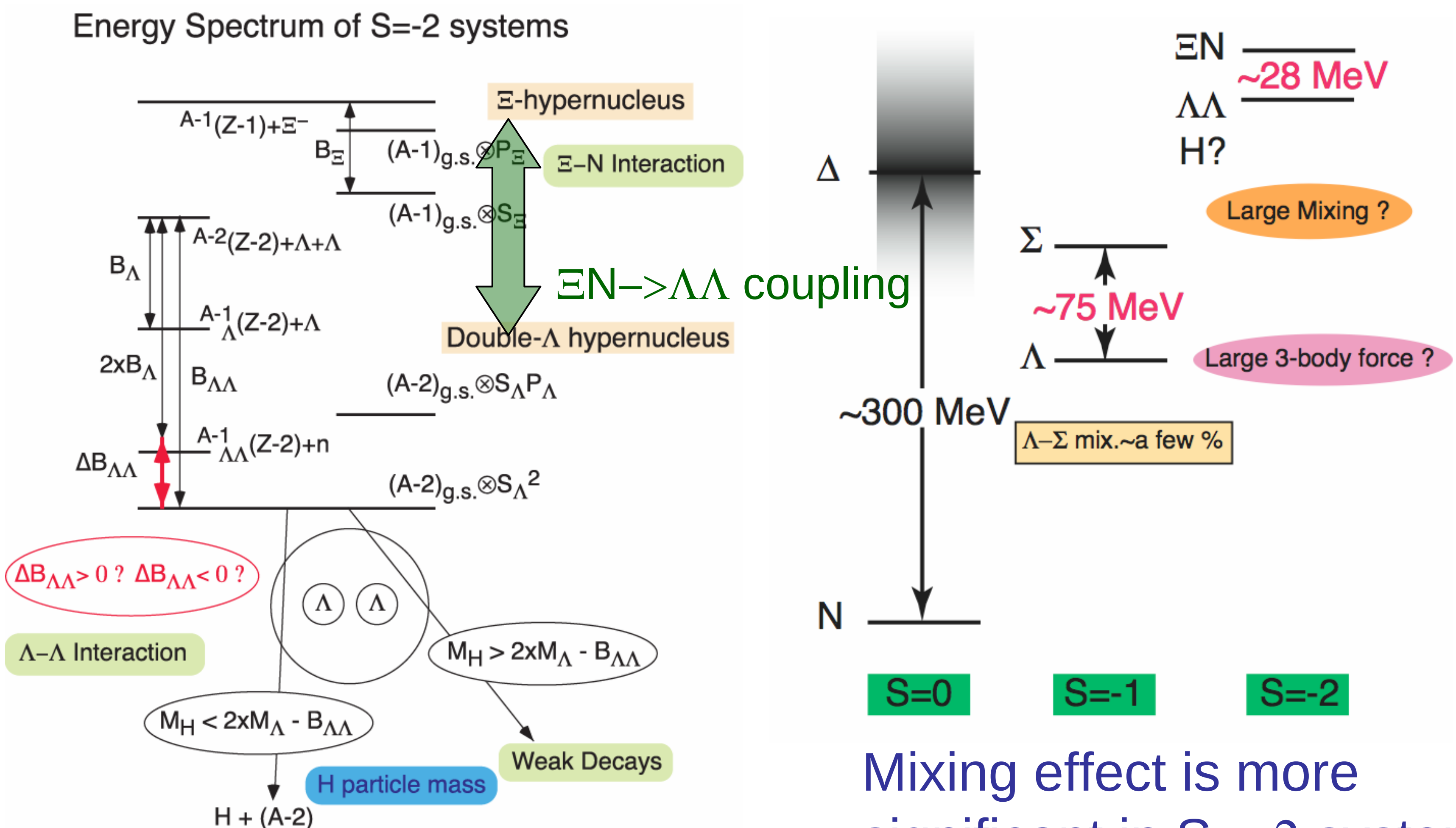
Contents

- Introduction
  - Motivation to Study S=-2 System
- Experiments at Early Stage
  - Spectroscopy of Ξ-Nucleus
- Future Plans
- Summary

Motivation to Study S=–2 Systems

- New sector of Baryon-Baryon interaction
  - A little information on B-B Int.
    - ΛΛ weakly attractive
    - ΞN attractive ?
    - ΞN–>ΛΛ weak or strong
- Very dynamic system
  - Mixing of ΞN and ΛΛ
- Significant step toward multi-strangeness systems
  - Core of neutron stars

S=–2 System



Mixing effect is more significant in S=–2 system

Ξ Potential and B-B Int. Models

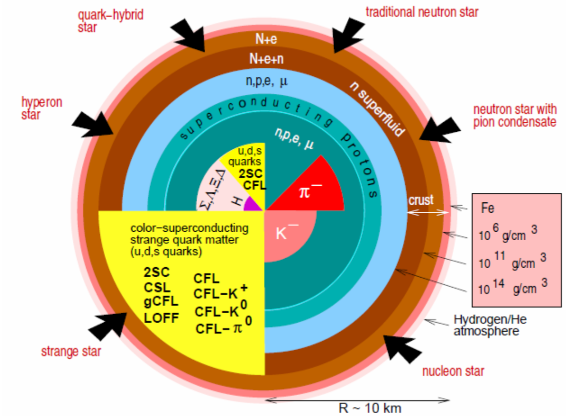
U_Ξ , Γ_Ξ and Partial Wave Contributions in Nuclear Matter (MeV)

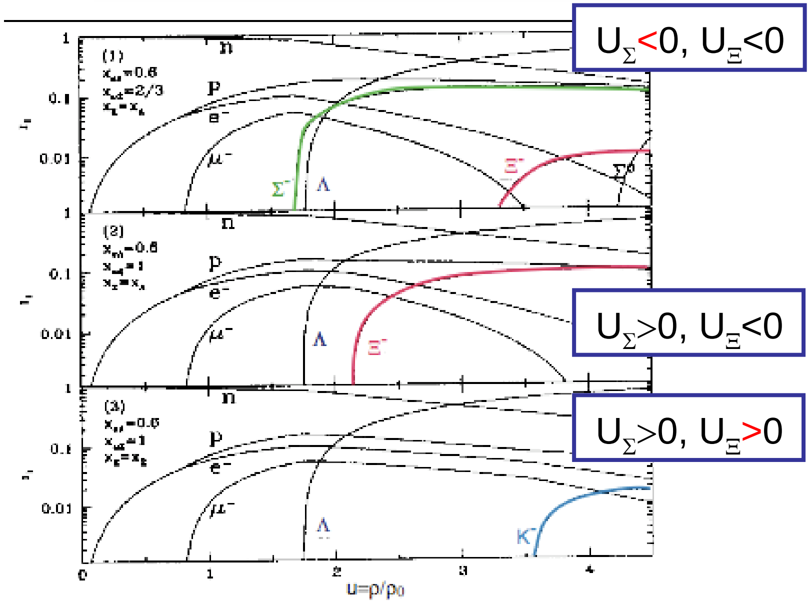
Model	T	$^1S_0$	$^3S_1$	$^1P_1$	$^3P_0$	$^3P_1$	$^3P_2$	U_Ξ	Γ_Ξ
NHC-D	0	–2.6	0.1	–2.1	–0.2	–0.7	–1.9		
	1	–3.2	–2.3	–3.0	–0.0	–3.1	–6.3	–25.2	0.9
Ehime	0	–0.9	–0.5	–1.0	0.3	–2.4	–0.7		
	1	–1.3	–8.6	–0.8	–0.4	–1.7	–4.2	–22.3	0.5
ESC04d*	0	6.3	–18.4	1.2	1.5	–1.3	–1.9		
	1	7.2	–1.7	–0.8	–0.5	–1.2	–2.8	–12.1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

- OBE (NHC-D, Ehime)
  - no t-channel meson exchange
  - odd-state attraction
    - ⇒ strong A-dependence of V_Ξ
  - small width
- ESC04d*
  - strong attraction of $^3S_1$(T=0)
  - large width

Ξ Potential and Impact on Neutron Stars

- Strange hadrons appear in the core of neutron star...
- What kind of hadrons? / How much density?
  - depends on mass, charge, and interaction
  - Negative baryons are favored.
- Σ^- was supposed to be important. However its interaction with neutron matter is found to be strongly repulsive.
- Ξ^- and its interaction should be important.



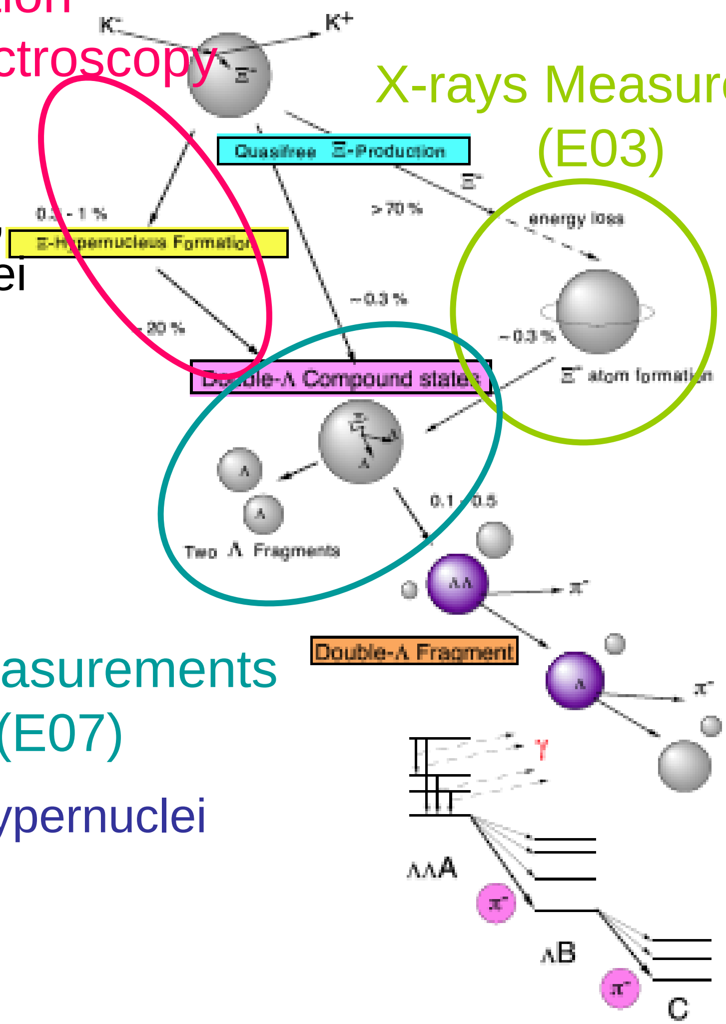


How to produce and study S=–2 systems

Direct production
Reaction Spectroscopy
(E05)

Ξ-hypernuclei,
$\Lambda\Lambda$-hypernuclei

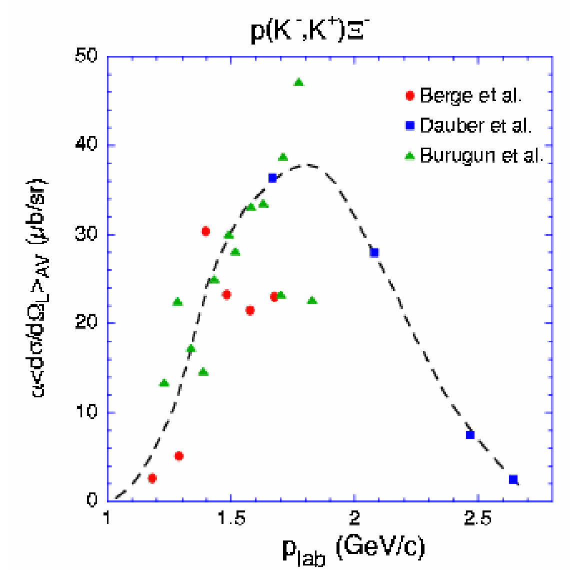
X-rays Measurements
(E03)



Decay measurements
Emulsion (E07)

$\Lambda\Lambda$-hypernuclei

$K^- + p \rightarrow K^+ + \Xi^-$
$p(K^-)$~1.8GeV/c



Previous Studies on Ξ-Hypernuclei and Ξ Potential (1)

- Dover & Gal; Analysis of old emulsion data

$$U_{\Xi} = -24 \pm 4\ \text{MeV}$$

Ann. of Phys. 146 (1983) 309

- Ξ-Captured events at KEK E176

Prog. Thoer.Phys. 89 (1993) 493

$$\Xi^- + {}^{12}C \to {}^{4}_{\Lambda}H + {}^{9}_{\Lambda}Be\ (0.54 \pm 0.20\text{MeV})$$
$$\Xi^- + {}^{14}N \to {}^{4}_{\Lambda}H + {}^{11}_{\Lambda}B\ (0.35 \pm 0.20\text{MeV})$$
$$\Xi^- + {}^{16}O \to {}^{4}_{\Lambda}H + {}^{13}_{\Lambda}C\ (6.62^{+0.22}_{-0.23}\text{MeV})$$

Phys. Lett. B355 (1995) 45

$$\Xi^- + {}^{12}C \to {}^{4}_{\Lambda}H + {}^{9}_{\Lambda}Be\quad (3.70^{+0.18}_{-0.19}\text{MeV})$$
$$\to {}^{4}_{\Lambda}H + {}^{9}_{\Lambda}Be^{*}\ (0.62^{+0.18}_{-0.19}\text{MeV})$$
$$\to {}^{4}_{\Lambda}H^{*} + {}^{9}_{\Lambda}Be\ (2.66^{+0.18}_{-0.19}\text{MeV})$$

- Analysis by Yamamoto

$$U_{\Xi} = -(16 - 17)\ \text{MeV}$$

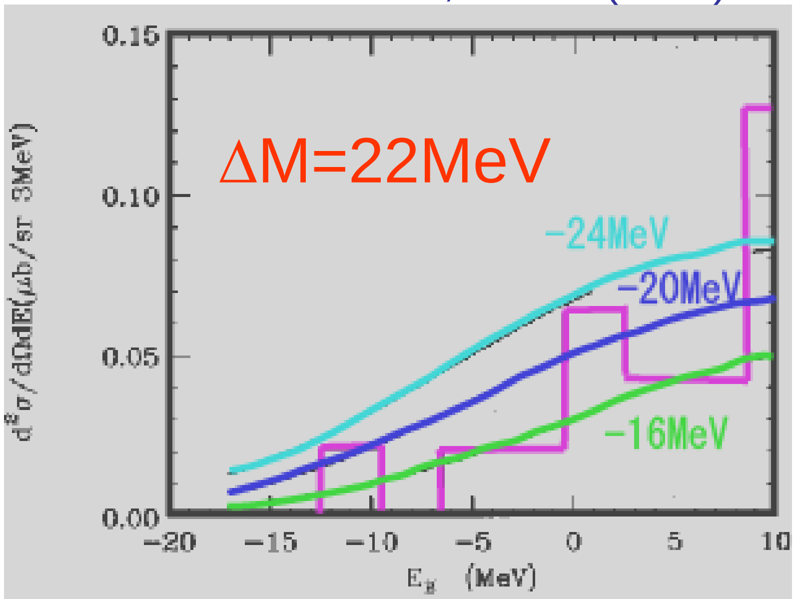
Few-Body Syst. Suppl. 9 (1995) 145

Previous Studies on Ξ-Hypernuclei and Ξ Potential (2)

(K^-,K^+) Missing Mass Spectroscopy

KEK-E224

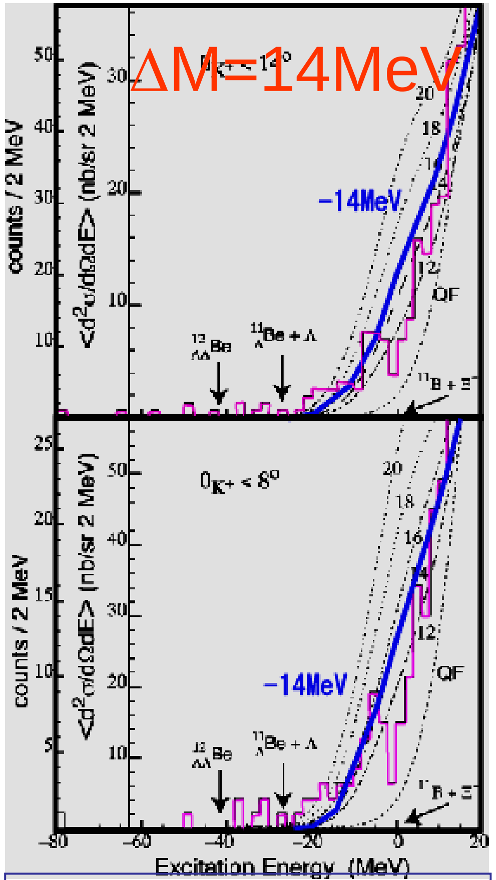
T.Fukuda et. al, PRC58(1998)1306



0.21±0.07 μb/sr	E_{Ξ}<7 MeV
60 ±45 nb/sr	–20<E_{Ξ}<0 MeV

BNL-E885

P.Khaustov et al, PRC61(2000)0546



Evidence !?
V_{Ξ} = –14 MeV

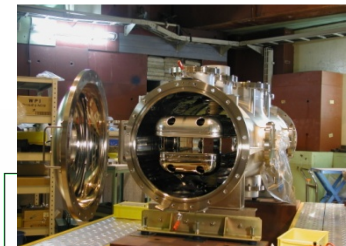
–20 < E_{Ξ} < 0 MeV
89±14 nb/sr θ< 8°
42± 5 nb/sr θ<14°

E05 (K^-,K^+) Spectroscopy on ^{12}C
— $^{12}_{\Xi}Be$ —

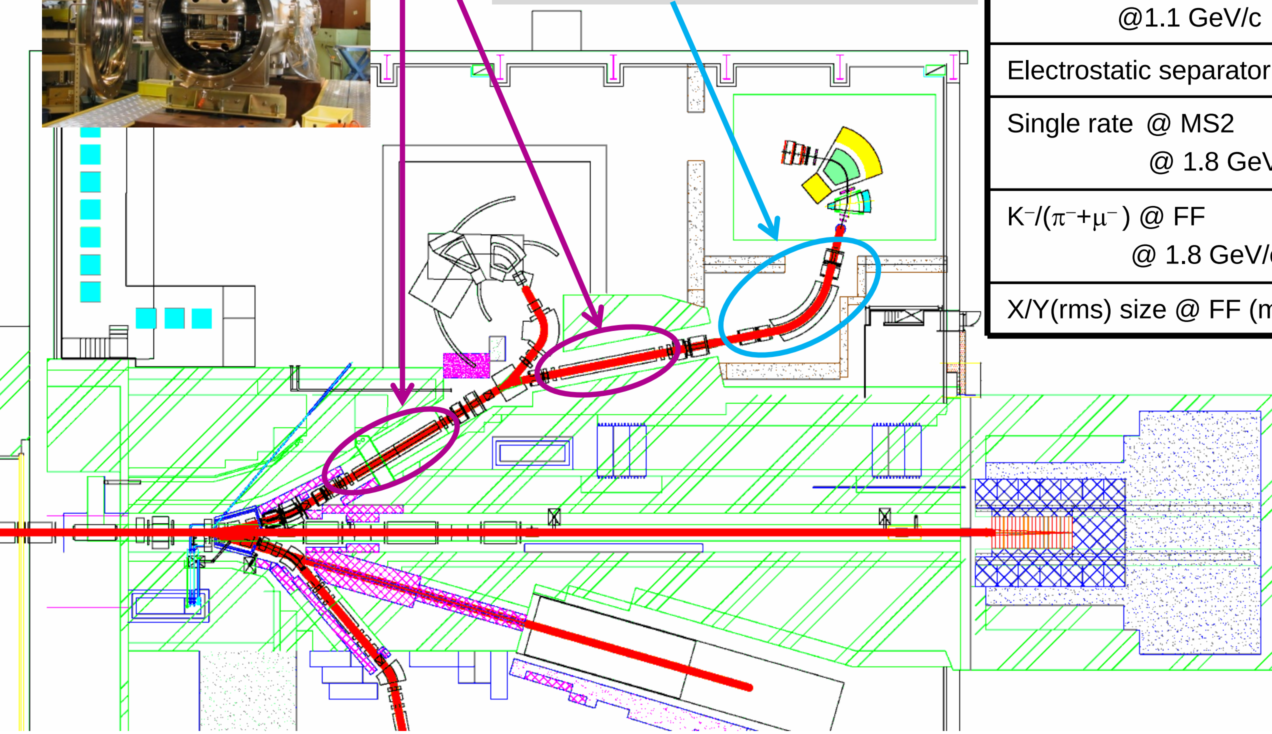
- (K^-,K^+) reaction at p=1.8GeV/c
  - Missing mass resolution ~3 MeV/c^2(FWHM)
- K1.8 beamline@J-PARC
  - High intensity 1.4 x 10^6 /spill @ Phase1
  - High purity K^-/π^- = 6.9
  - H.R. spectrometer $\Delta p/p$ ~3.3x10^{-4}(FWHM)
- SksPlus spectrometer
  - $\Delta p/p$ = 1.2x10^{-3} (FWHM)
  - ~30msr

K1.8 beamline

Double-stage of electrostatic separators



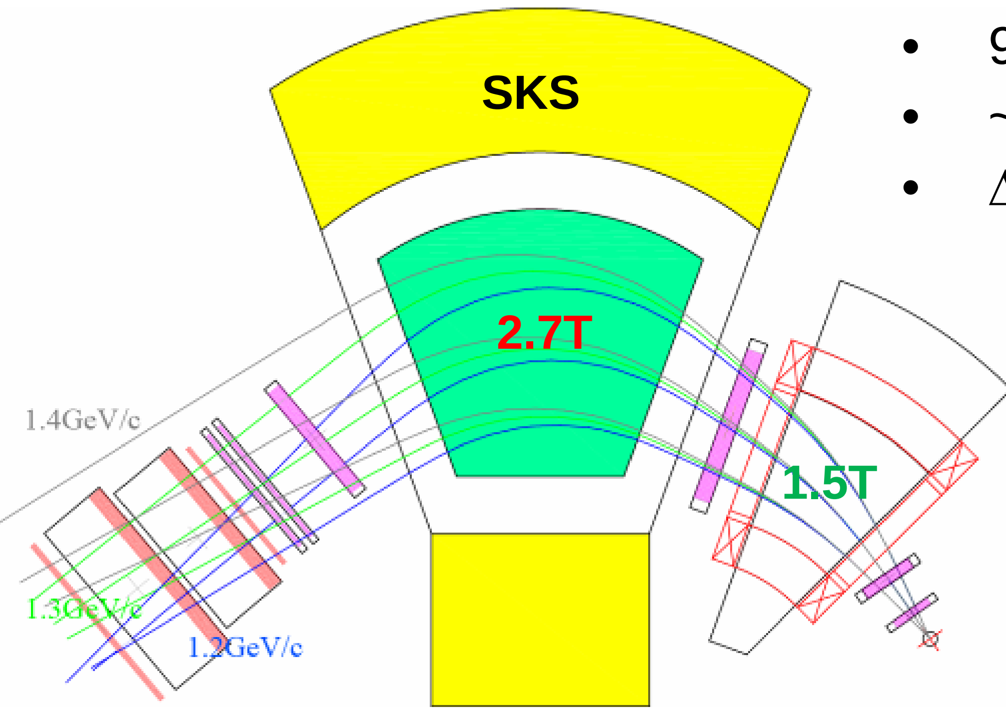
Beam spectrometer
$\Delta p/p \sim 3.3 \times 10^{-4}$(FHWM)



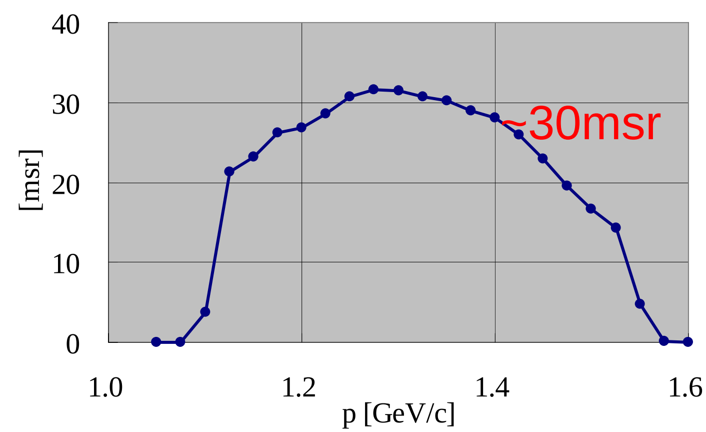
Primary proton beam	50 GeV-15μA	30 GeV-9μA
Length (m)	45.853	
Acceptance (msr.%)	1.4	
$K^-(\pi)$ intensity (ppp) @1.8 GeV/c	6.6E+06	1.4E+06
@1.5 GeV/c	2.7E+06	0.54E+06
@1.1 GeV/c	0.38E+06	0.08E+06
Electrostatic separator	750kV/10cm, 6m×2	
Single rate @ MS2 @ 1.8 GeV/c	＞33E+06	＞8E+06
$K^-/(\pi^-+\mu^-)$ @ FF @ 1.8 GeV/c	4	3.5
X/Y(rms) size @ FF (mm)	19.8/3.2	

Singles-rate of B.S.
assumed 0.6s ext.
13.3MHz@upstream
3.0MHz@downstream

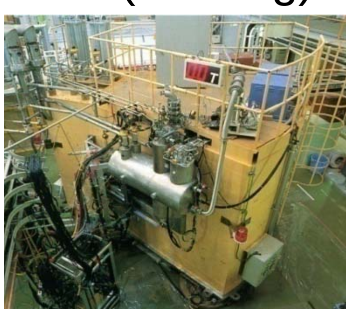
SksPlus spectrometer



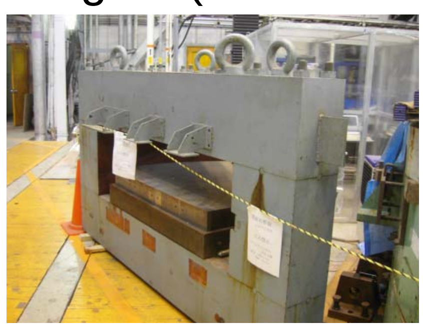
- 95° total bend
- ~7m flight path
- Δx=0.3 mm (RMS)

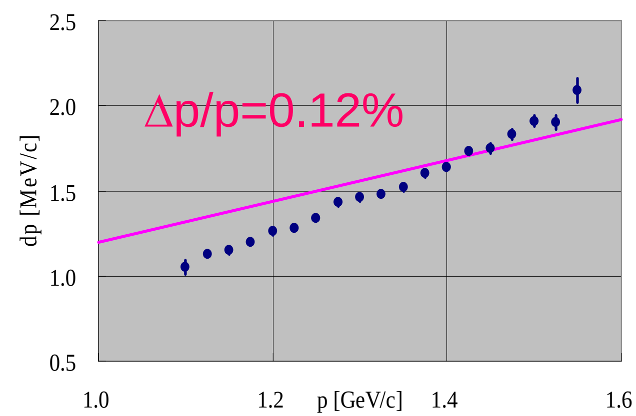


SKS(existing)



D magnet (modification)



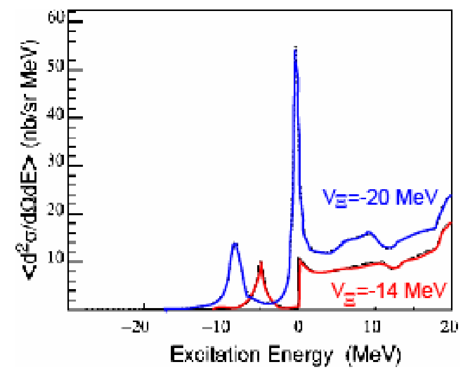


E05 Expected Yield

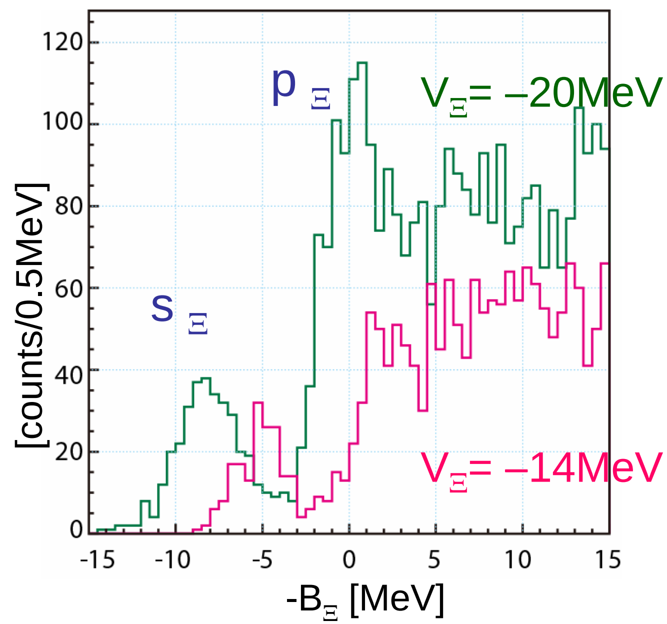
- 60nb/sr
- 4.0x10^{10} K^{-}/day
  - 1.4x10^{6} K^{-}/spill
  - 0.7 sec. FT (2.3MHz@FF)
  - 95% running efficiency
- 3 cm (5.4 g/cm^{2}) target
- 30 msr
- fdecay ~0.5
- fana ~0.7
- 1month data-taking

→

6.8 evts/day
48 evts/week
~200 evts/month



P.Khaustov et al, PRC61(2000)0546



After E05 …

- No narrow peak
  - No bound state
  - Broad width
    - Direct production of ΛΛ-nucleus

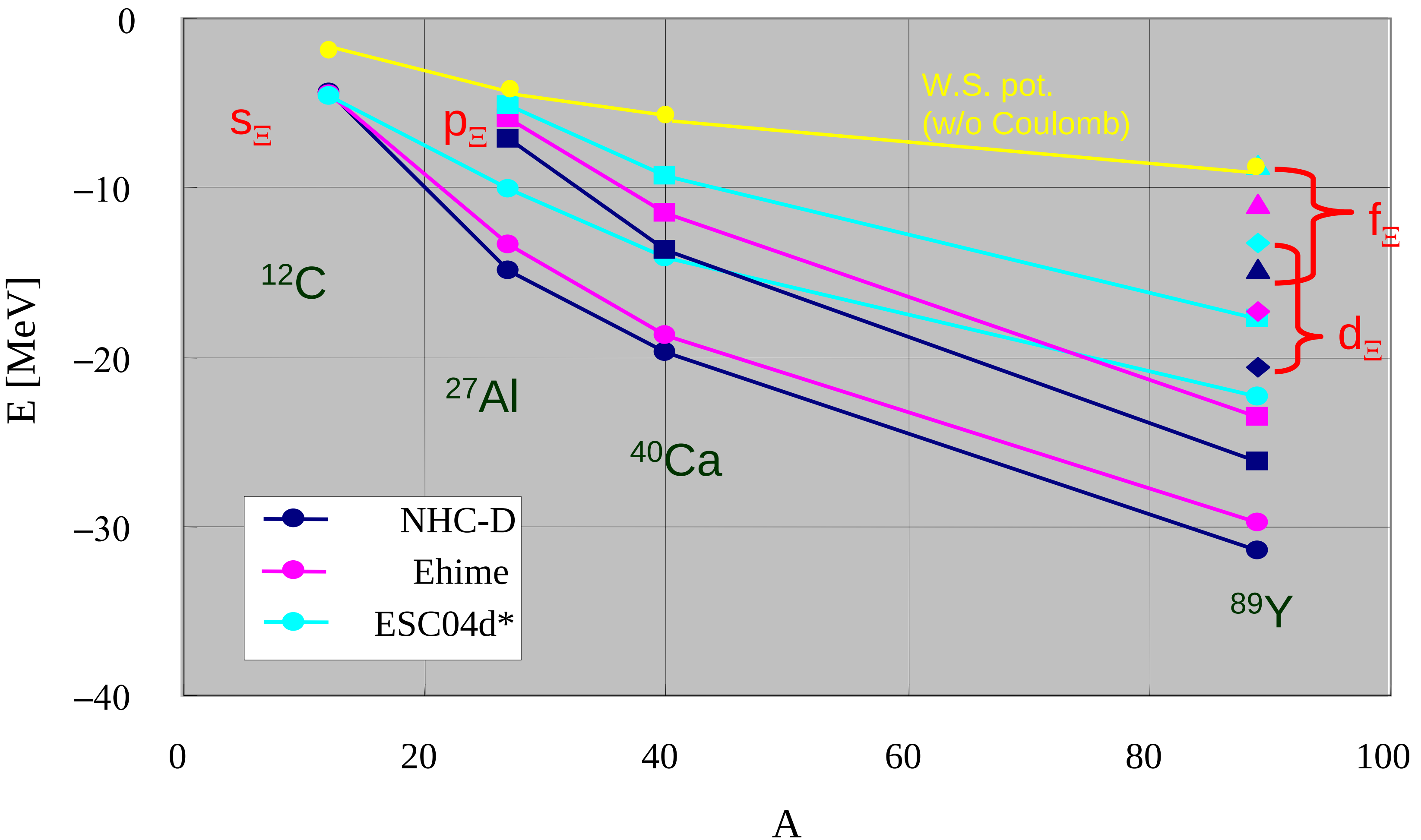
  (ΛΛ spectroscopy)

  Other than nuclear spectroscopy is necessary to study ΞN int.

  • Quasi-free shape analysis
  • Atomic X-ray measurement

- Obs. bound state(s)
  - Heavier targets for mass dependence
    - ^{27}Al, ^{40}Ca, ^{89}Y, …
  - Coulomb-assisted states
    - Narrow width for high-*l*
  - ^{3}He(K^{-},K^{+}) reaction
    - p-n-Ξ^{-}(n-n-Ξ^{0}) state
    - Spin-isospin structure
  - (K^{-},K^{0}) reaction
    - Isospin ΔI=0 excitation

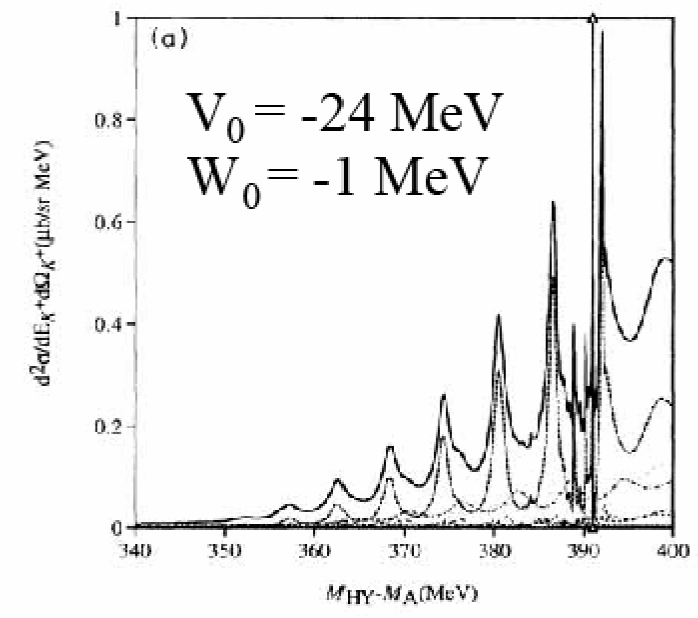
Ξ Single-Particle Energy

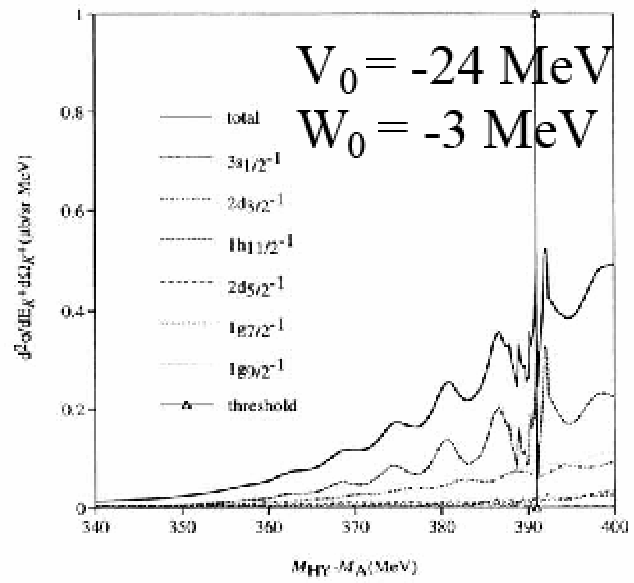


^{208}Pb(K^{-},K^{+}) Spectrum

Woods-Saxon potential

S.Tadokoro, H.KObayashi and Y.Akaishi,
Phys. Rev. C 51 (1995) 2656.





Centrifugal barrier
Low nuclear density region

Suppression of ΞN–>ΛΛ Conversion

Very narrow peaks with a large orbital angular momentum.

Yield for heavier targets

- Cross section ? $\propto A^{1/3}$ (best case?)
- Target (thickness) $\propto 1/A$
- Yield for the same intensity and time
  - $Y \propto A^{-2/3}$
- $Y(^{89}Y) = (12/89)^{-2/3}\, Y(^{12}C) = 0.26 Y(^{12}C)$
- $Y(^{208}Pb)=(12/208)^{-2/3}Y(^{12}C)=0.15Y(^{12}C)$

- Higher intensity & long beam time are necessary.

If 50GeV-15μA is achieved …

- 6.6×10^6/spill with 0.7s FT
  - 14MHz singles rate @ downstream — O.K.
  - 55MHz singles rate @ upstream — N.G.?
  - 1.5×10^{11} K^- /day — x 3.75
- Why N.G.?
  - Detector rate ability — other than wire chamber
  - Accidental backgrounds — fast device / analysis
- 1.7s FT
  - 20 MHz singles rate @ upstream
  - 1.2×10^{11} K^-/day — x 3
- Give up point-to-point condition of B.S.
  - Larger beam size at upstream
  - loose resolution. How much?

(K^-,K^0) reaction

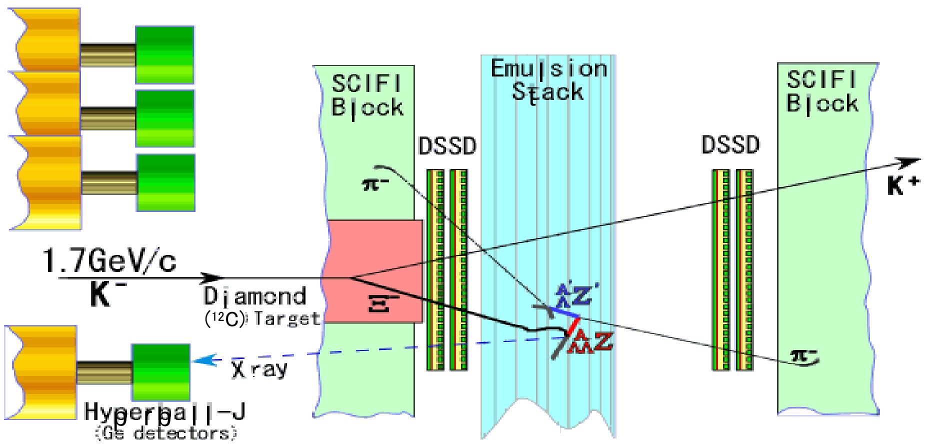
- (K^-,K^+) can excite only $\Delta I=1$, but (K^-,K^0) can excite $\Delta I=0$.
  - Isospin dependence
- K^0 is measured by $K_S \to \pi^+\pi^-$.
  - Opening angle $\eta \sim 35°$ @1.3GeV/c
  - How to distinguish K0 and K0bar
    - Tagged with weak decay
  - Resolution
    - ~10MeV is OK, but a few MeV is ?

Summary

- Physics of S=-2
  - Baryon-baryon interaction
  - High density matter
- Experiments at early stage
  - Spectroscopy of Ξ-nucleus
  - Emulsion exp.
  - X-rays of Ξ-atomic state
- Future
  - Spectroscopy for heavy targets
  - (K^-,K^0) reaction
  - High intensity beam & handling technology

Target	NHC-D			Ehime			ESC04d*			WS
	E	Γ	r	E	Γ	r	E	Γ	r	E
	[MeV]	[MeV]	[fm]	[MeV]	[MeV]	[fm]	[MeV]	[MeV]	[fm]	[MeV]
^{12}C										
s	–4.4	0.5	3.2	–4.5	0.3	3.1	–4.6	4.6	3.3	
w/o Coul.	–1.9	0.5	3.7	–1.9	0.2	3.7	–2.1	3.9	3.7	–2.2
^{27}Al										
s	–14.9	0.7	2.0	–13.4	0.2	2.3	–10.1	5.7	3.0	
w/o Coul.	–8.4	0.7	2.2	–7.3	0.2	2.6	–4.7	4.7	3.4	–5.1
p	–7.1	0.4	3.4	–5.9	0.2	3.6	–5.2	2.8	4.1	
w/o Coul.	–2.0	0.3	4.0	–1.1	0.1	4.5	–0.8	1.9	5.1	
^{40}Ca										
s	–19.7	0.6	2.2	–18.7	0.2	2.4	–14.1	5.9	3.0	
w/o Coul.	–10.8	0.6	2.4	–9.9	0.2	2.6	–6.2	4.9	3.4	–6.5
p	–13.7	0.5	3.0	–11.5	0.2	3.3	–9.3	3.3	3.9	
w/o Coul.	–5.7	0.4	3.3	–3.9	0.2	3.7	–2.4	2.5	4.5	–1.2
^{89}Y										
s	–31.4	0.6	2.3	–29.8	0.2	2.5	–22.4	6.5	3.0	
w/o Coul.	–16.4	0.6	2.5	–15.0	0.2	2.8	–8.5	5.2	3.7	–9.0
p	–26.2	0.5	3.0	–23.6	0.2	3.3	–17.8	3.9	4.0	
w/o Coul.	–12.0	0.4	3.2	–9.8	0.2	3.6	–5.3	2.8	4.6	–4.6
d	–20.6	0.4	3.5	–17.3	0.2	3.9	–13.3	2.4	4.7	
w/o Coul.	–7.3	0.3	3.9	–4.6	0.1	4.4	–2.0	1.7	5.5	–0.2
f	–14.8	0.3	4.1	–11.0	0.1	4.6	–8.7	1.6	5.4	

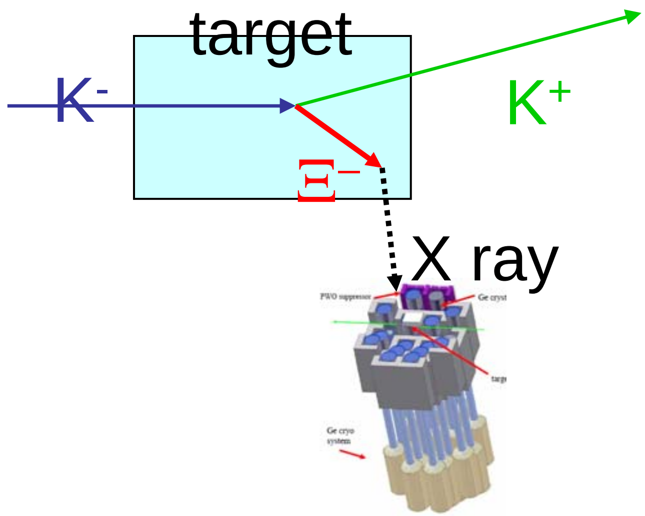
E07 Systematic Study of Double Strangeness Systems with an Emulsion-counter Hybrid Method

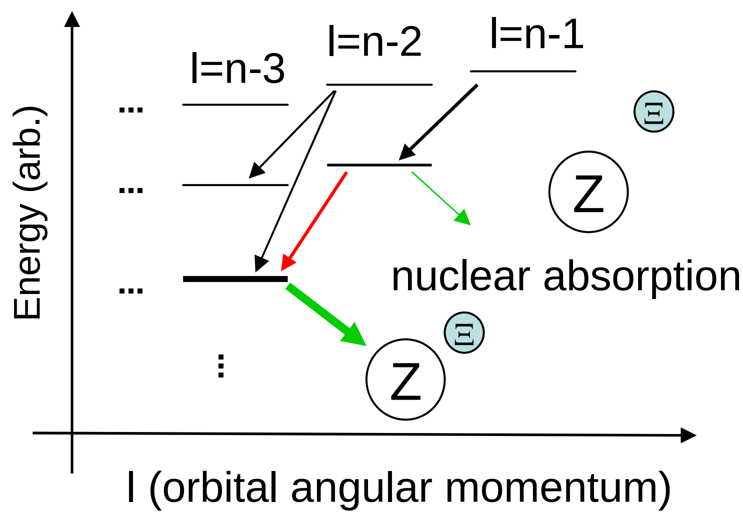


	# of absorbed Ξ^-	# of $\Lambda\Lambda$-hypernuclei	# of twin hypernuclei
1965 D. Davis	4 (expected)	1	
1987-1997 (KEK-E176)	80	1	2
1998-present (KEK-E373)	~800	7 (1)	3
J-PARC E07	~10000	~100	20-30?

- Double Λ Hypernuclei
  - expected ~100 events
  - extend known species
    - species dependence of $\Delta B_{\Lambda\Lambda}$
    - decay form
- H-dibaryon
- Ξ-Nucleus Interaction
  - twin hypernuclei
  - X-ray from atomic states
- Unknown Phenomena

E03 Measurement of X rays from Ξ^- Atom





- Ξ^- Nuclues potential
  - Real part
    - Level energy shift
  - Imaginary part
    - Width
    - X ray yield
- Regardless of potential detail
  - attractive / repulsive
  - strong / weak absorption
- Complementary to E05
  - E03 surface region of the potential
  - E05 inner part of the potential