EXPERIMENTAL PLAN FOR Ξ-HYPERNUCLEAR SPECTROSCOPY

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EXPERIMENTAL PLAN FOR Ξ-HYPERNUCLEAR SPECTROSCOPY

Contents

Introduction

(K⁻, K⁺) Spectroscopy

Three-Dimensional Nuclear Chart

Double-Λ Hypernuclei
Ξ Hypernuclei

Λ, Σ Hypernuclei

Λ ~35
Σ 1

Strangeness

S=-2

S=-1

S=0

Proton Number

stable ~300
unstable > 3000

Ordinary nuclei

Neutron Number

S = -2
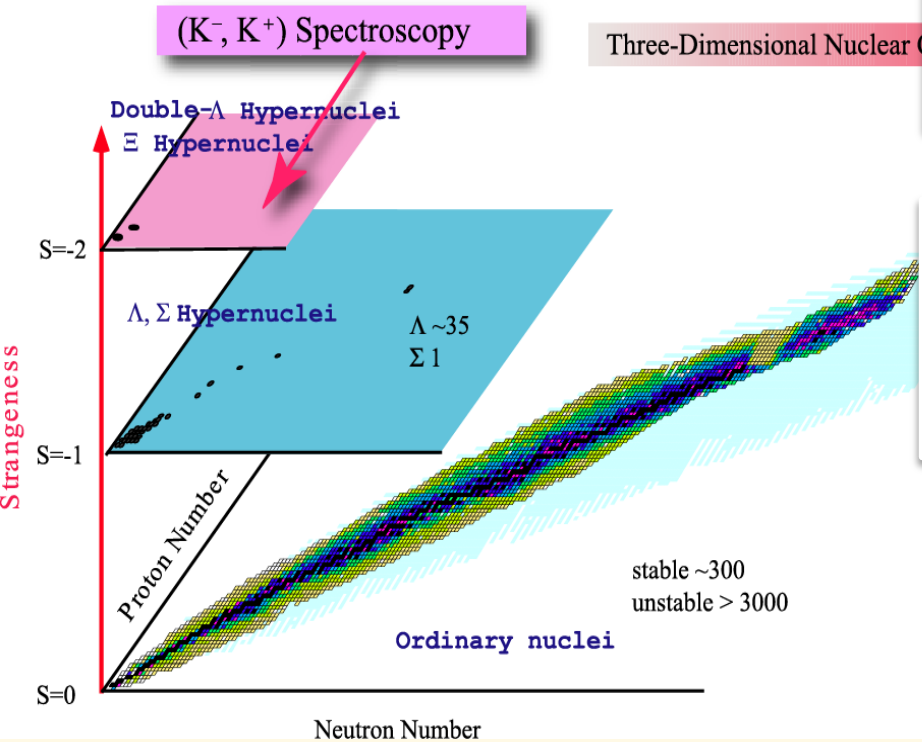
◆ From now at J-PARC

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

S = -1

◆ So far : Λ,Σ-hypernuclei

◆ successful theoretical understanding.

Introduction

(K^-, K^+) Spectroscopy

Double-Λ Hypernuclei
Ξ Hypernuclei
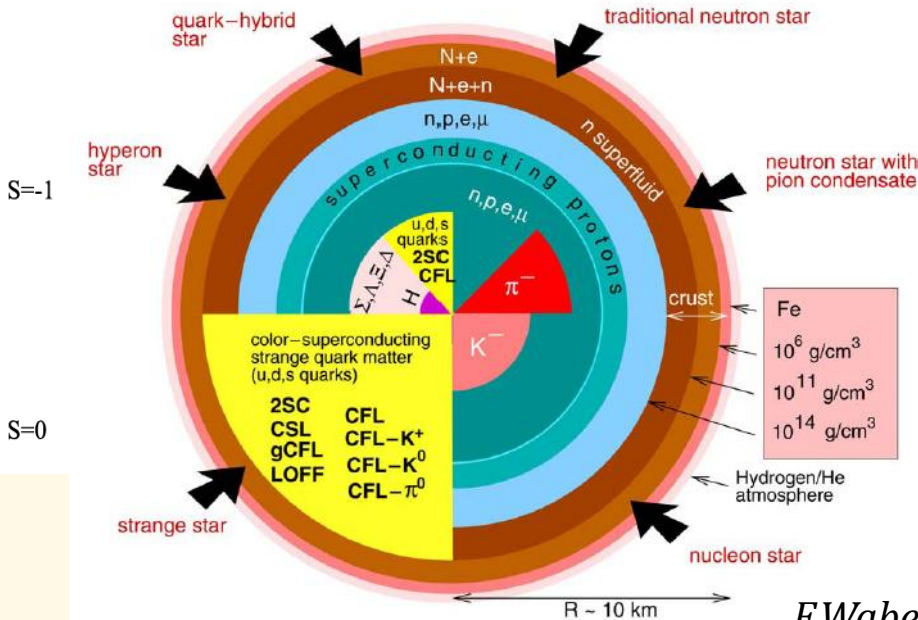
Three-Dimensional Nuclear (

S = -2

- From now at J-PARC
- $\Lambda\Lambda$-hypernuclei , Ξ-hypernuclei
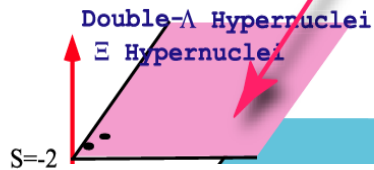
S = -1

So

su

- No definite evidence for a bound state.
- Strangeness in dense nuclear matter, (ex.. core of N.S.)
- Theoretical predictions are quite different for Ξ-N int

F.Waber, PPNP54(2005)193

Experimental information is strongly awaited.

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Ξ-hypernuclei : previous experiment

$^{12}C (K^-, K^+)$

$\theta_{K^+} < 14^o$

$\Delta M_{exp} = 14$ MeV (FWHM)

$\theta_{K^+} < 8^o$

- Previous experiment : BNL-E885
  - not clear evidence of Ξ-hypernuclear bound state.
    - because of limited mass resolution
  - suggest weakly attractive potential of -14 MeV depth.
    - by shape analysis and counts in bound region, compared with DWIA calc.
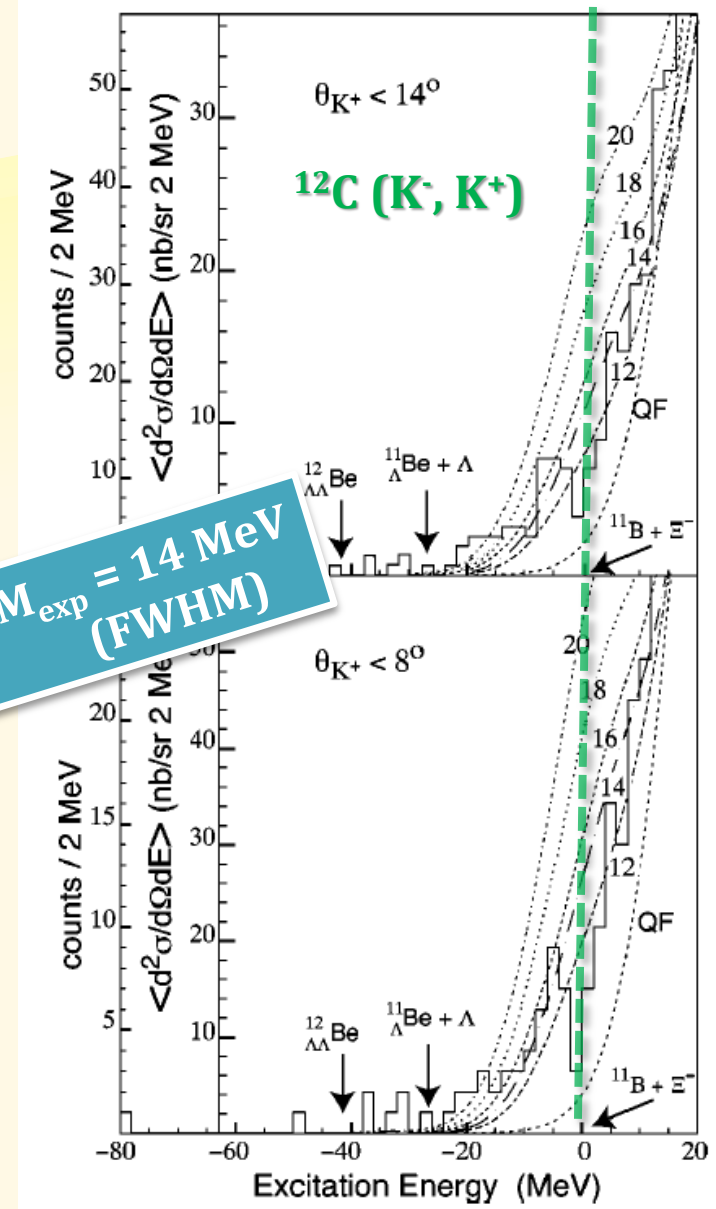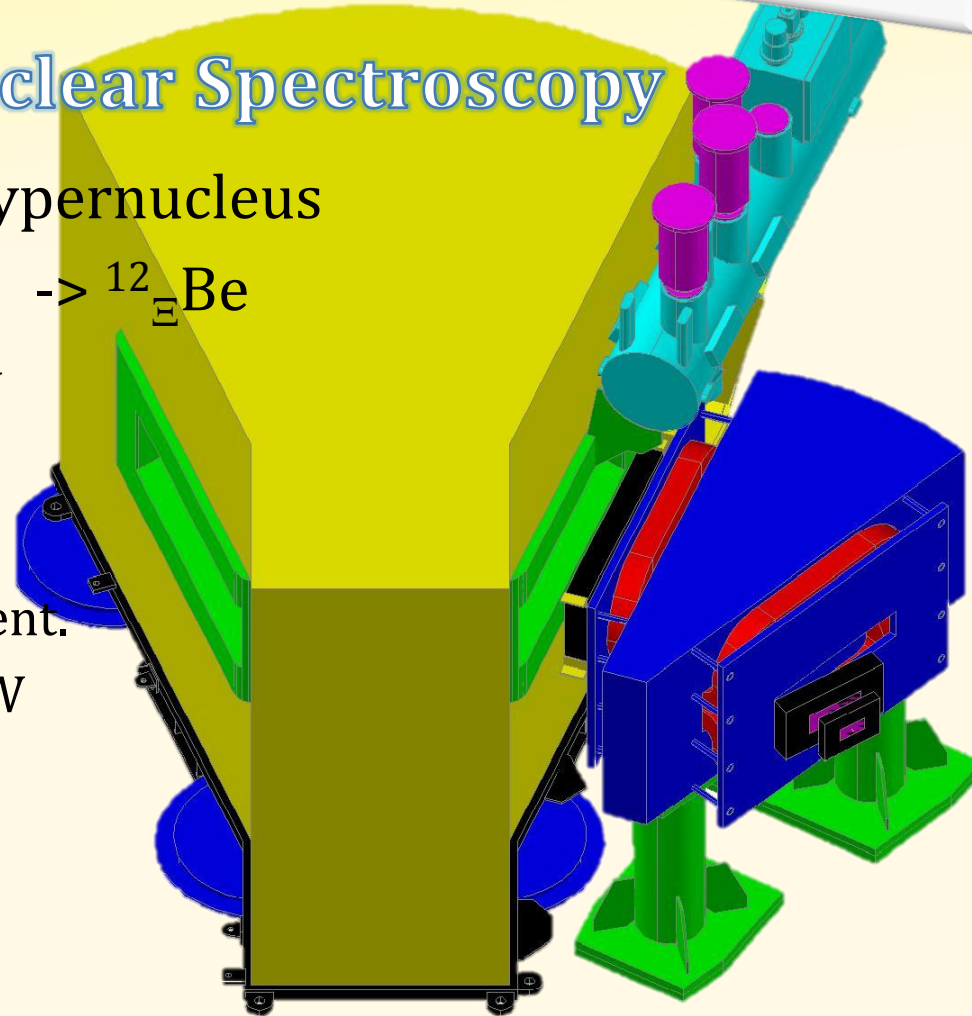
P.Khaustov et al., PRC61(2000)054603

Experiment

J-PARC E05: Ξ-Hypernuclear Spectroscopy

- Spectroscopic study of Ξ-hypernucleus

- using ^{12}C(K$^-$, K$^+$) reaction ; -> $^{12}_{\Xi}$Be

- Missing mass spectroscopy
  - **high-resolution (~3MeV)**
  - **enough statistics**
- Only J-PARC can do this experiment.
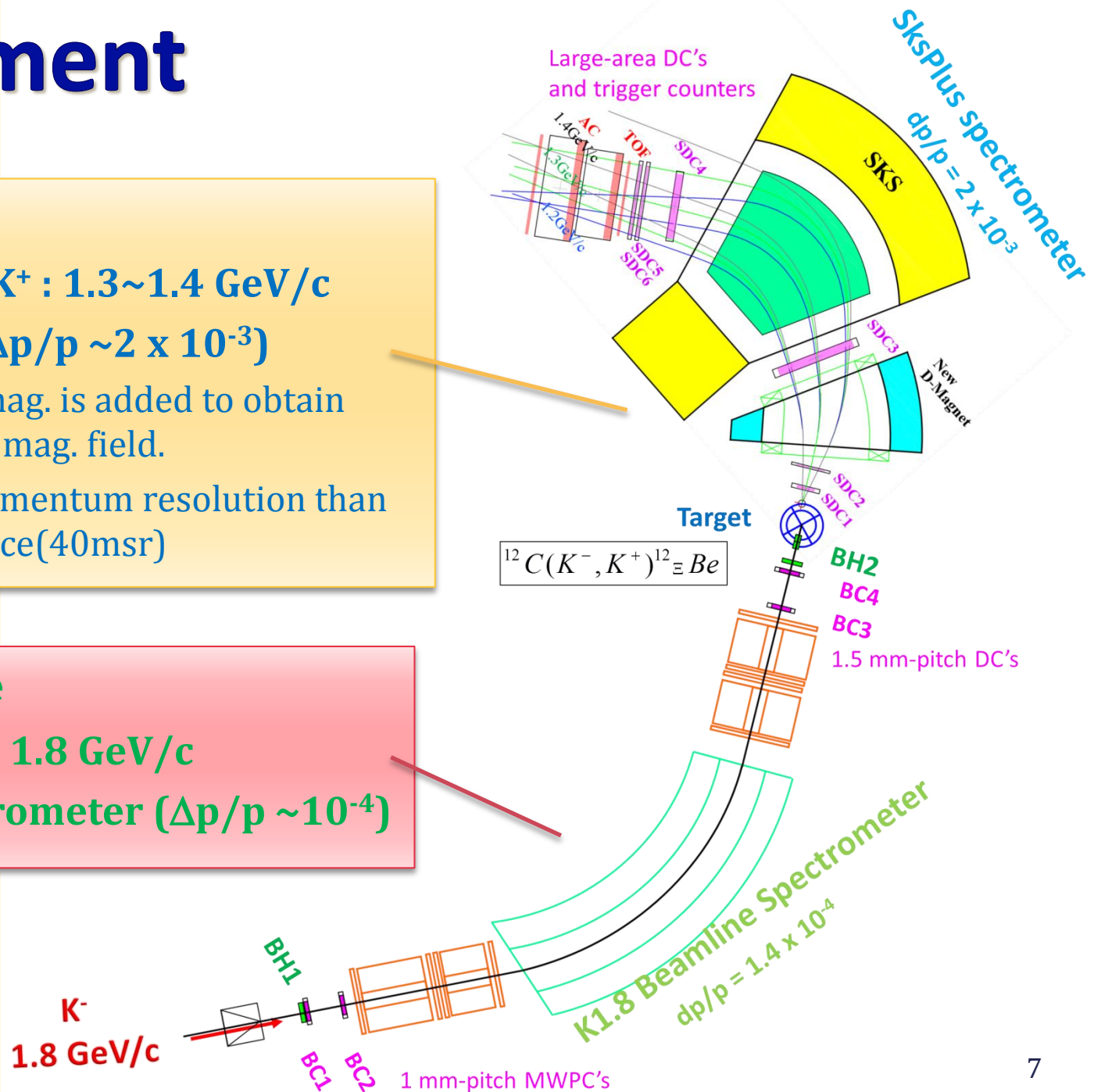 - <= 1.4 x 10^6 K$^-$/spill @ 270kW

Experiment

SksPlus

- **outgoing K⁺ : 1.3~1.4 GeV/c**
- **SksPlus ($\Delta p/p \sim 2 \times 10^{-3}$)**
  - New D-mag. is added to obtain stronger mag. field.
  - prior momentum resolution than acceptance(40msr)

K1.8 beam line

- **incident K⁻ : 1.8 GeV/c**
- **Beam Spectrometer ($\Delta p/p \sim 10^{-4}$)**

Large-area DC's and trigger counters

SksPlus spectrometer

dp/p = 2 x 10⁻³

SKS

1.4GeV/c

AC

TOF

SDC4

1.3GeV/c

1.2GeV/c

SDC5

SDC6

SDC3

New D-Magnet

SDC2

SDC1

Target

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

BH2

BC4

BC3

1.5 mm-pitch DC's

BH1

K⁻

1.8 GeV/c

BC1

BC2

1 mm-pitch MWPC's

K1.8 Beamline Spectrometer

dp/p = 1.4 x 10⁻⁴

Constraint...

- ◆ Accelerator intensity is very limited.
  - ◆ **now, ~% of design value (270kW)**
- ◆ In original E05 plan, statistics are miserable. => not realistic
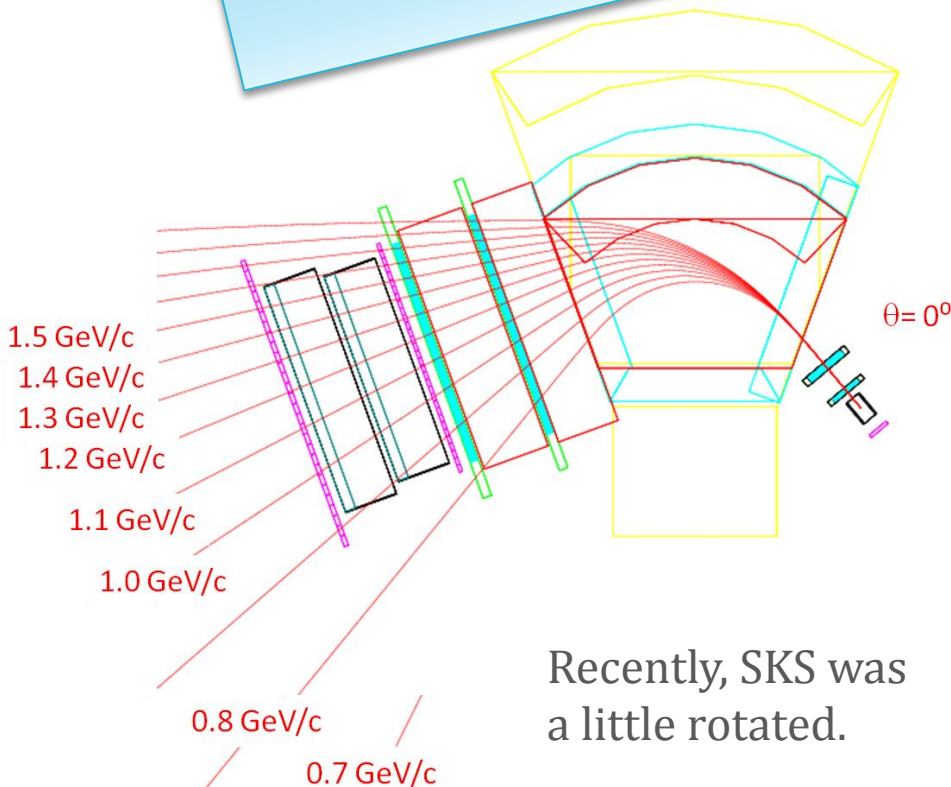
2011.Jul PAC

Plan made after the earthquake		
	User operation	Accelerator study
2011.6−11(shutdown)	SX collimators	
2011.12−2012.6	3 kW	5 kW
2012.7−2012.9(shutdown)	Ti chambers (SMS)	
2012.10−2013. 6	10 kW	50 kW
2013. 7−2014. 1 (shutdown)	Li 400MeV/50 mA, Ti chambers (ESS)	
2014. 2−2014. 6	50 kW	100 kW
2014.7 − 9(shutdown)		
2014. 10−	100 kW	

Modified plan, we have.

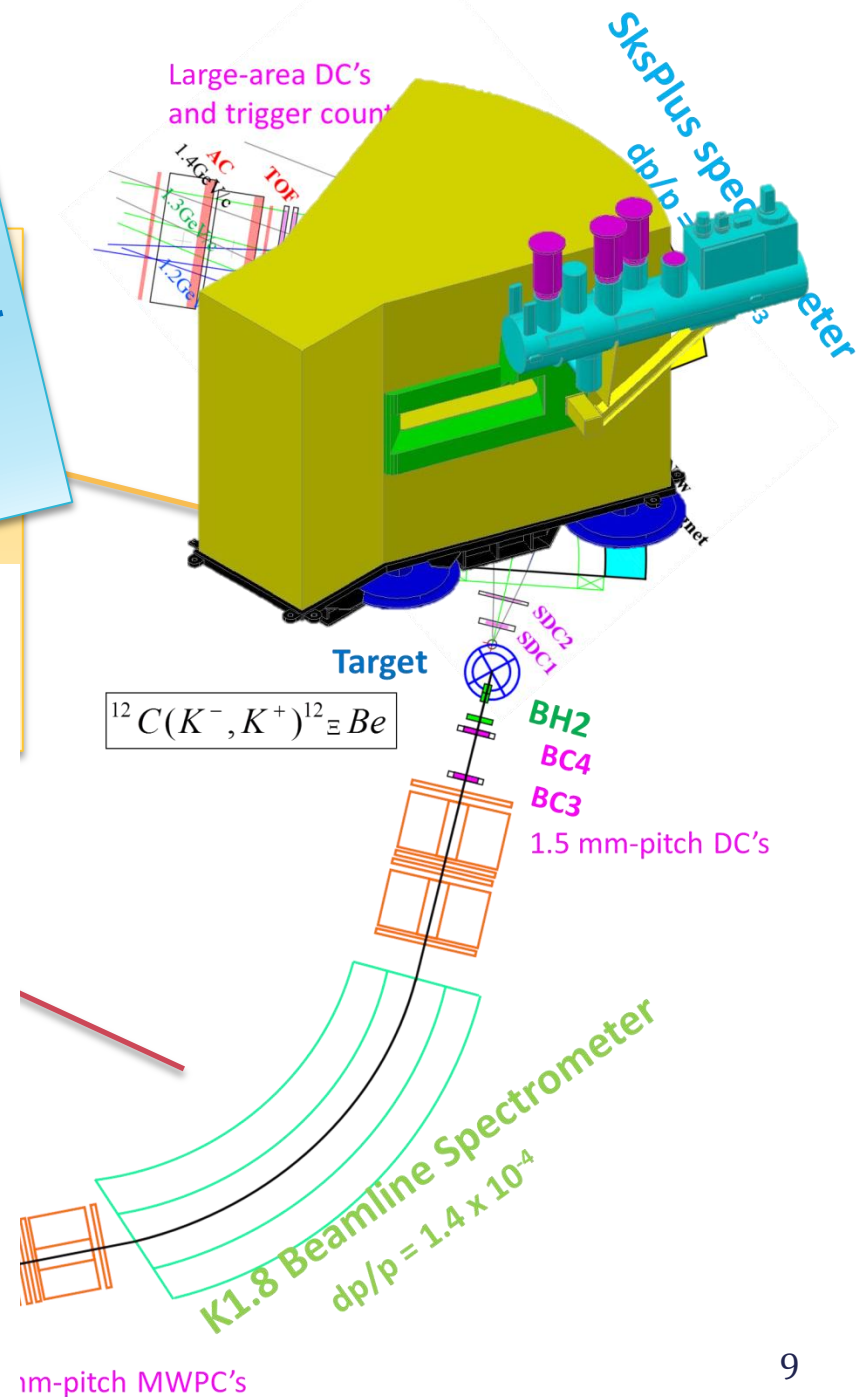Intensity is gradually upgraded
by a factor of a few year by year.

Experiment

SksPlus

modified SKS

- Original SKS is not suited for analyzing high momentum K+.
- Modification of configuration is needed.

Large-area DC's and trigger count

SksPlus spectrometer

dp/p

1.4GeV/c
1.3GeV
1.2GeV

AC TOF

Target

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

SDC2
SDC1

BH2
BC4
BC3
1.5 mm-pitch DC's

θ= 0º

1.5 GeV/c
1.4 GeV/c
1.3 GeV/c
1.2 GeV/c

1.1 GeV/c

1.0 GeV/c

0.8 GeV/c

0.7 GeV/c

Recently, SKS was a little rotated.

K1.8 Beamline Spectrometer
dp/p = 1.4 x 10⁻⁴

mm-pitch MWPC's

E05 (low intensity beam version)

mod. SKS

	SksPlus	Sks0v2	SksMinus
Acceptance [msr]	40	80	100
K^+ Survival Rate	0.5	0.6	0.6
dp/p [%]	0.20	0.24	0.27
ΔM [MeV]	3.3	3.7	4.0
$Y(^{12}_{\Xi}Be)$ [/month]	30	55	70

E05 (low intensity beam version)

mod. SKS

	SksPlus	Sks0v2	SksMinus
Acceptance [msr]	**40**	**80**	**100**
K+ Survival Rate	0.5	0.6	0.6
		0.24	0.27
		3.7	4.0
		55	70

Momentum Acceptance

mod. SKS

- SksZero2
- SksMinus
- SksPlus

SksZero2

SksMinus

SksPlus

Ξ-hyp.

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E05 (low intensity beam version)

mod. SKS

mod. SKS

	SksPlus	Sks0v2	SksMinus
Acceptance [msr]	40	80	100
K$^+$ Survival Rate	0.5	0.6	0.6
dp/p [%]	**0.20**	**0.24**	**0.27**
ΔM [MeV]	**3.3**	**3.7**	**4.0**
Y($^{12}_\Xi$Be) [/month]			

Momentum Resolution

dP vs P

SksMinus
SksZero2

SksPlus

E05 (low intensity beam version)

mod. SKS

	SksPlus	Sks0v2	SksMinus
Acceptance [msr]	40	80	100
K^+ Survival Rate	0.5	0.6	0.6
dp/p [%]	0.20	0.24	0.27
ΔM [MeV]	3.3	3.7	4.0
$Y(^{12}_{\Xi}Be)$ [/month]	30	55	70

E05 (low intensity beam version) : Yield Estimation @ 30kW

Supposition
- **4.5×10^5** K$^-$/spill @ 30kW

Kaon measurement @ J-PARC K1.8 <3kW>

Date : 2010 Nov. 16
MR intensity : **3.8e12** (3.0 kW)
T1 : **Pt** target
2ndary beam : **-1.8 GeV/c**
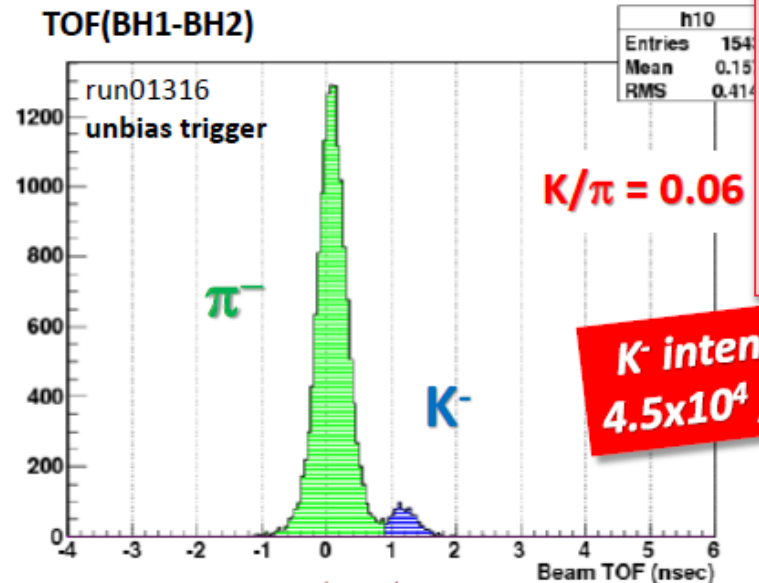
Plot Condition :
BH1/BH2 (# of Clusters) = 1

Separator Condition

ESS1 : 400kV/10cm
ESS2 : 400kV/10cm

about half of full HV

Slit Condition [mm]

IFX :   ±130
IFY :   (+1.5, +3.5)   ← half of design opening
Mom: ±180
MS1 : ±2.35
MS2 : ±2.5

TOF(BH1-BH2)

	h10
Entries	154
Mean	0.15
RMS	0.414

run01316
unbias trigger

K/π = 0.06

π^-

K$^-$

K$^-$ intensity
4.5×10^4 /spill

Beam TOF (nsec)

1.18 ns
@1.8GeV/c π-K

E05 (low intensity beam version) : Yield Estimation @ 30kW

Supposition

- 4.5 x 10^5 K$^-$/spill @ 30kW
- modified SKS : 100msr

$$Y(^{12}_{\Xi}Be) = N_{beam} \times N_{target} \times d\sigma/d\Omega \times \Delta\Omega \times f_{decay} \times f_{analysis}$$

$$= 4.5 \times 10^5 [/spill] \times 24 \times 3600/6 \text{ [spill/day]}$$

$$\times 5.4 \times 6.02 \times 10^{-7}/12 \text{ [/}\mu b]$$

$$\times 0.042 [\mu b/sr] \times 0.1 \text{ [sr]} \times 0.6 \times 0.5$$

= 2.3 events/day
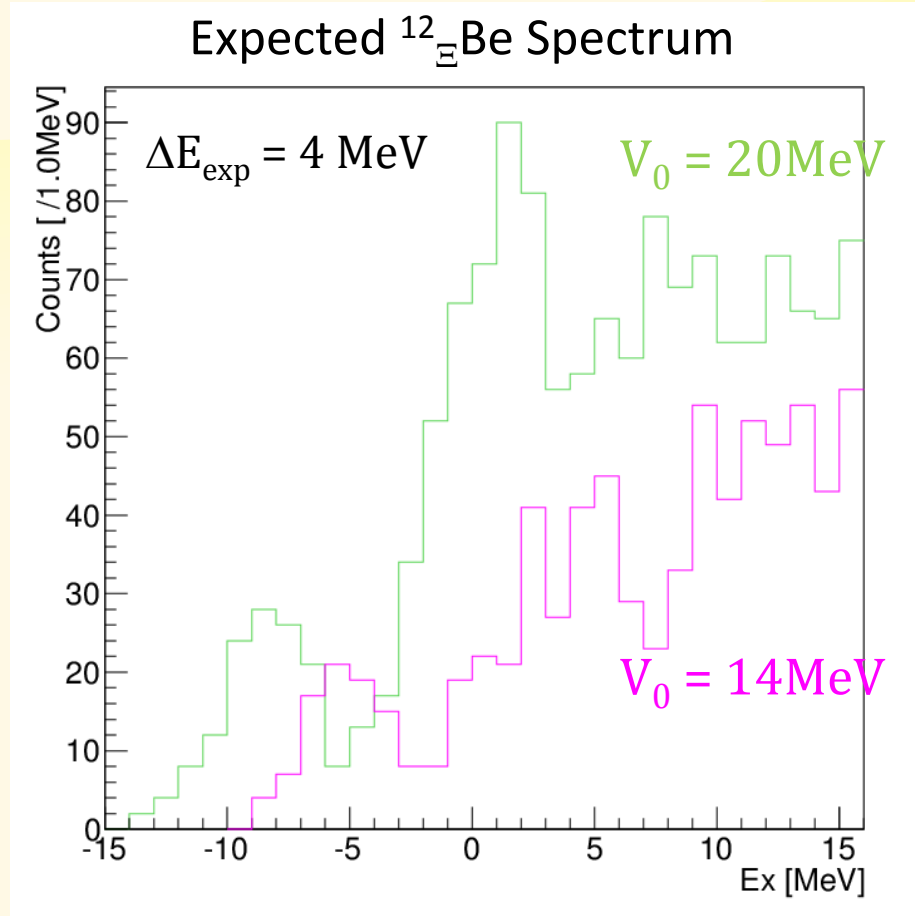
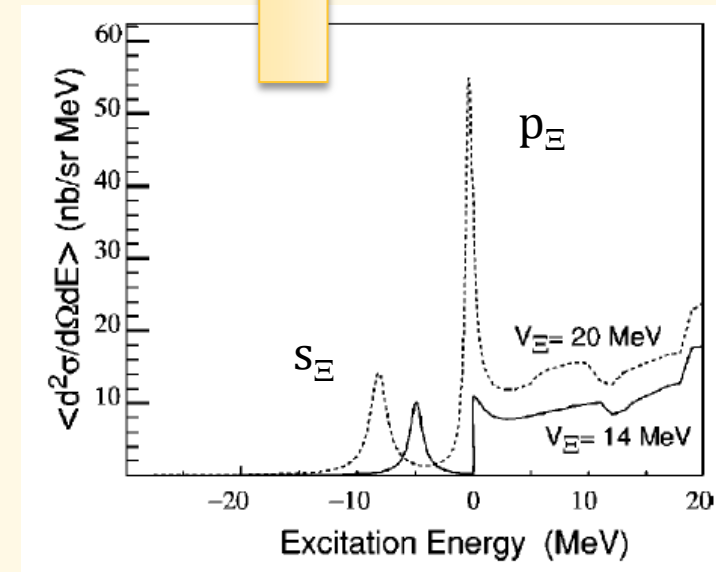= 70 events/month

40% statistics of proposal one

We can take ~70/month statistics at 30kW as the first step of E05.

E05 (low intensity beam version) : Expected Spectrum 1

in case of W.S. potential

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

$\Delta E_{exp} = 4$ MeV

$V_0 = 20$ MeV

$V_0 = 14$ MeV

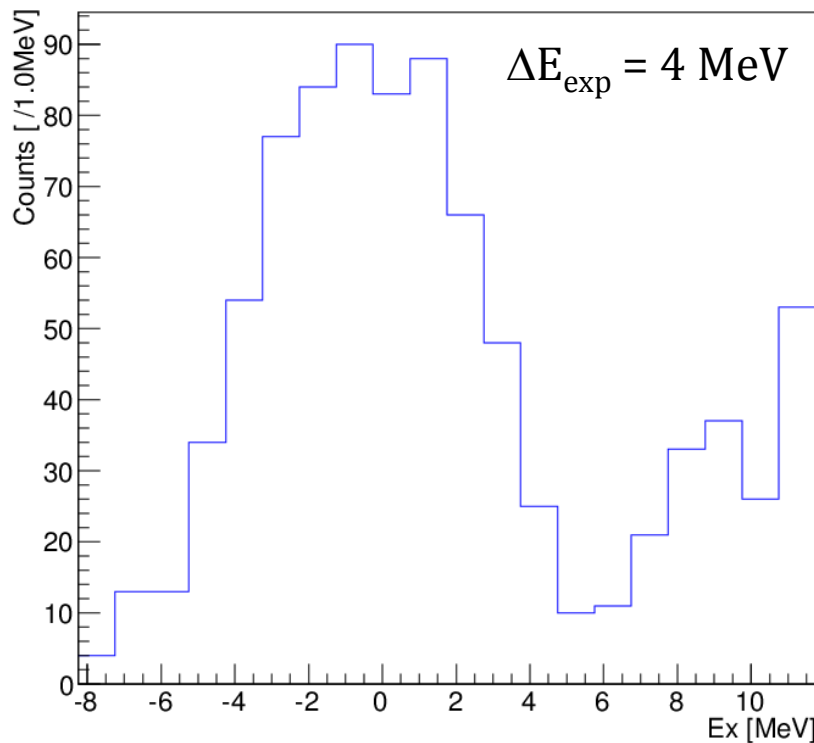DWIA spectra from *P.Khaustov et al., PRC 61 (2000) 054603*

✓ **can identify bound state.**

simple peak structure

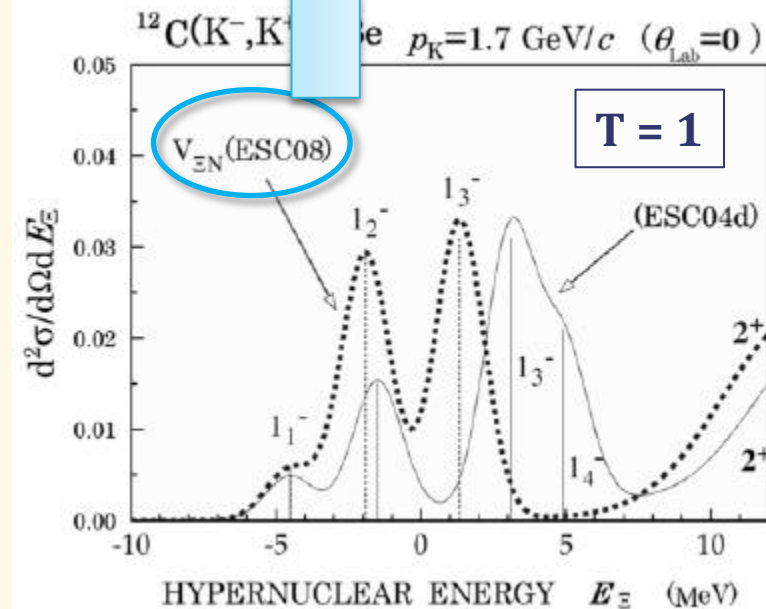# E05 (low intensity beam version) : Expected Spectrum 2

in case of ESC08a int.

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

ΔE_{exp} = 4 MeV

DWIA spectrum from *T. Motoba and S. Sugimoto, NP A 835 (2010) 223.*

✓ **difficult to separate 2 peaks.**
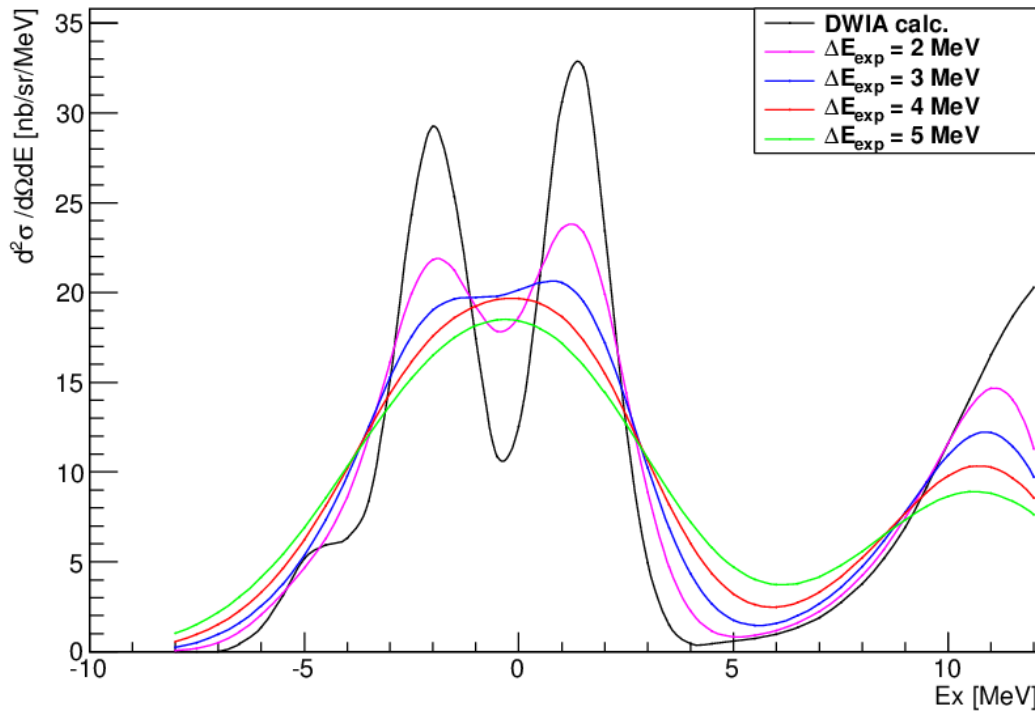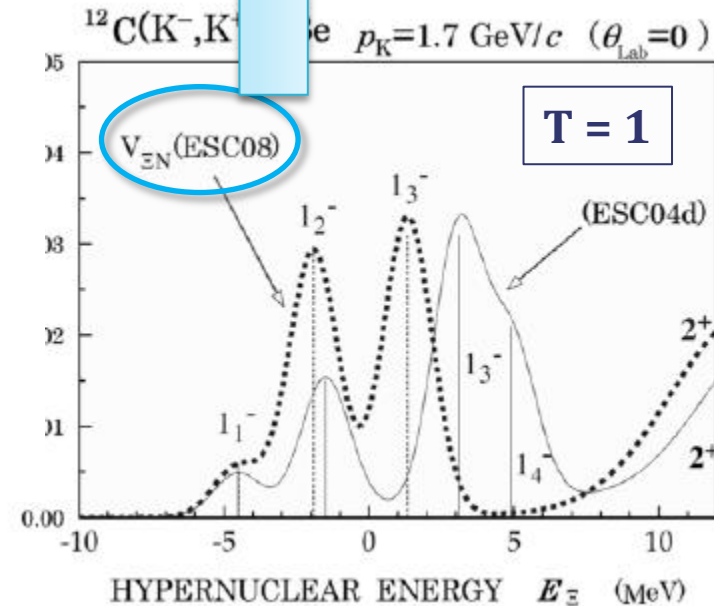✓ **lack of resolution**

* QF is not concerned.

E05 (low intensity beam version) : Expected Spectrum 2

in case of ESC08a int.

Resolution dependence

DWIA spectrum from
*T. Motoba and S. Sugimoto,*
NP A 835 (2010) 223.

T = 1

✓ **higher-resolution system (< 2MeV) is indispensable.**
=> Mid-term plan

Direct production of double-Λ hypernuclei

Theoretical Prediction

T.Harada, Y.Hirabayashi, A.Umeya,
PLB 690 (2010) 363.

Theoretical Calculation for $^{16}_{\Lambda\Lambda}$C,
via Ξ^- doorways

in the $^{16}O(K^-,K^+)$ reaction at 1.8 GeV/c

two-step process

(a)

one-step process

(b)

ΞN-$\Lambda\Lambda$
coupling strength:

5 ~10 nb/sr

V_Ξ = -14 MeV,
$\Delta E_{EXP.}$ = 1.5 MeV
(FWHM) included

$^{16}O(K^-,K^+)$

$v^0_{\Xi N,\Lambda\Lambda}$

$^{16}_{\Lambda\Lambda}C^*$

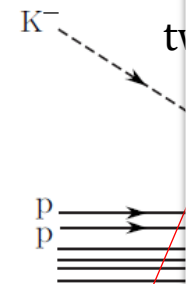# *Direct production of double-Λ hypernuclei*

Theoretical Prediction   T.Harada, Y.Hirabayashi, A.Umeya, PLB 690 (2010) 363.

Theoretical Calculation for $^{16}_{\Lambda\Lambda}$C,
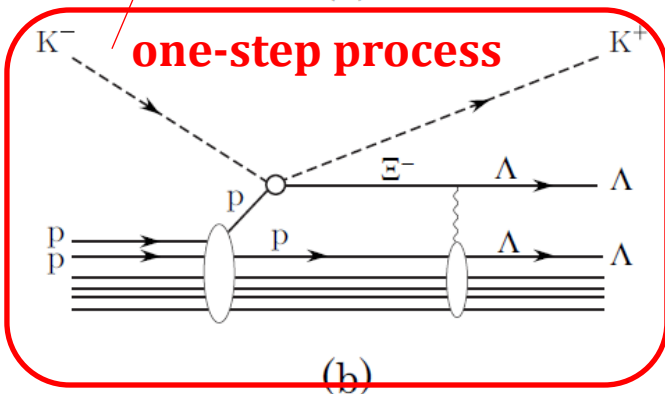**via Ξ⁻ doorways**

in the ^{16}O(K⁻,K⁺) reaction at 1.8 GeV/c

^{16}O(K⁻,K⁺)

B_{Ξ^-}

$^{15}_{\Lambda\Lambda}$C+n $^{15}_{\Lambda}$C+Λ
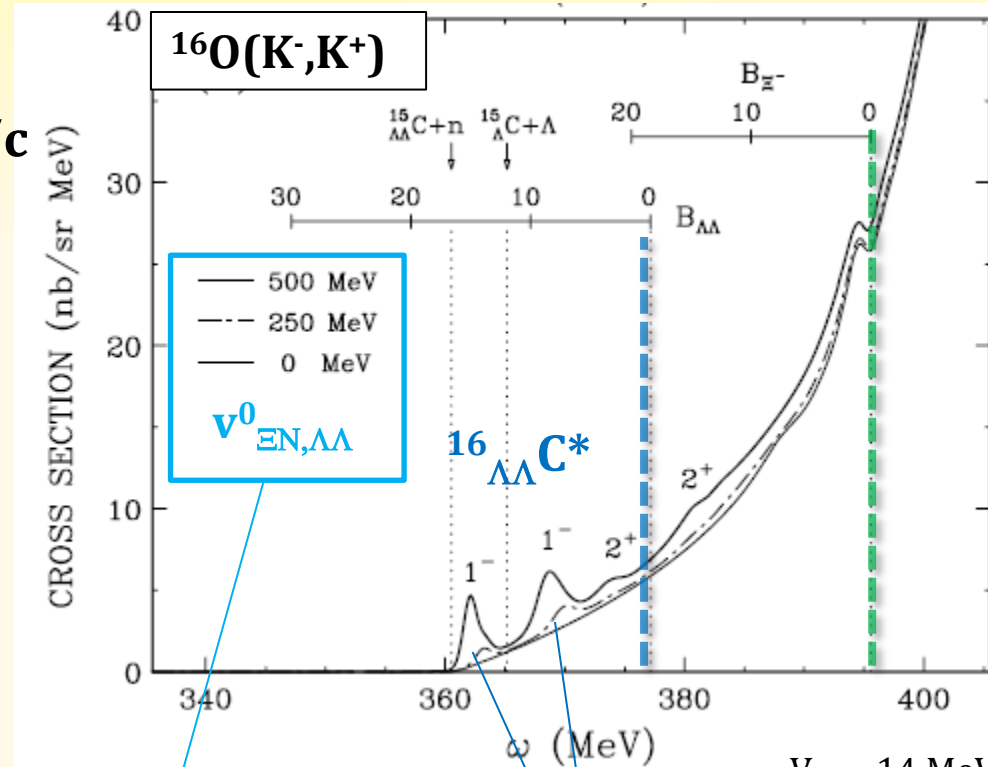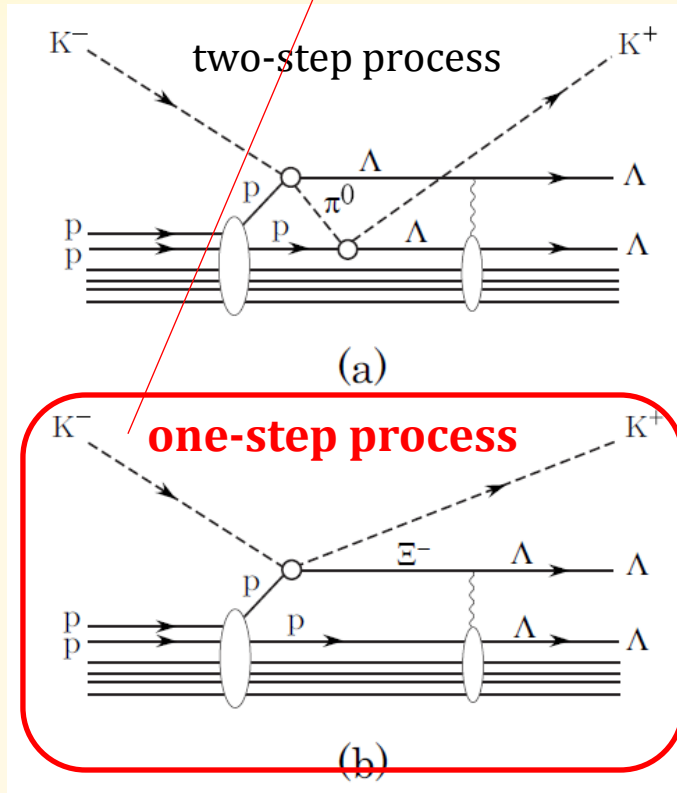
Beyond E05
- ☐ **Statistical study is possible. c.f.) emulsion**
- ☐ **can observe excited states of double-Λ hyp.**
- ☐ **sensitive to ΞN-ΛΛ coupling strength.**

one-step process

(a)

(b)

ω (MeV)

V_Ξ = -14 MeV,
$\Delta E_{EXP.}$ = 1.5 MeV
(FWHM) included

ΞN-ΛΛ
coupling strength:
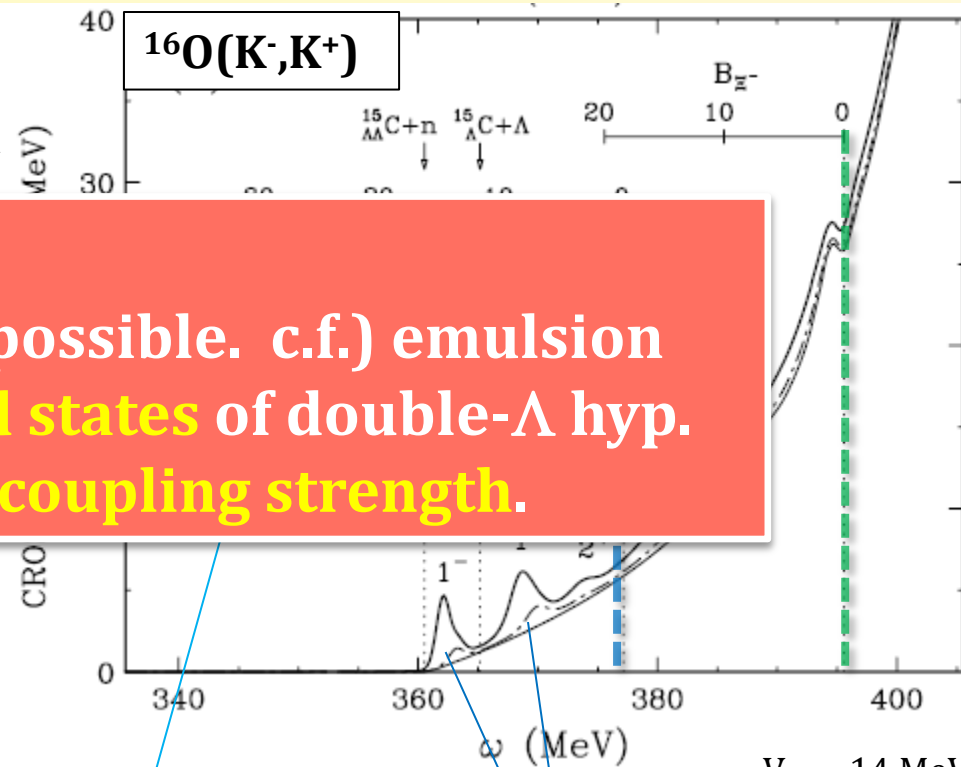
5 ~10 nb/sr

S-2S under designing

Strangeness -2 Spectrometer

- **Especially for (K^-, K^+) reaction @ 1.8 GeV/c**
  Double-Λ hypernuclei
  and Ξ-hypernuclei
- **High-Resolution : $\sim 5 \times 10^{-4}$**
  (corresponds to $\Delta M_{FWHM} < 1.5$ MeV)
- **Large Acceptance : > 60 msr**
  (as large as possible)
- **Path Length :**
  as short as possible
  ex.) $K_{survive} = 50\% \rightarrow 6.8$ m
  @1.3 GeV/c

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S-2S under designing

D

B = 1.44 T (Normal Conducting)
70° bend
gap = 36 cm

1.1

3.665

0.4

0.55

0.4

1.02

0.4

Q2
Horizontal Focus
B = 1.15 T @pole
half-aperture = 18 cm

Q1
Vertical Focus
B = 1.6 T @pole
half-aperture = 16 cm
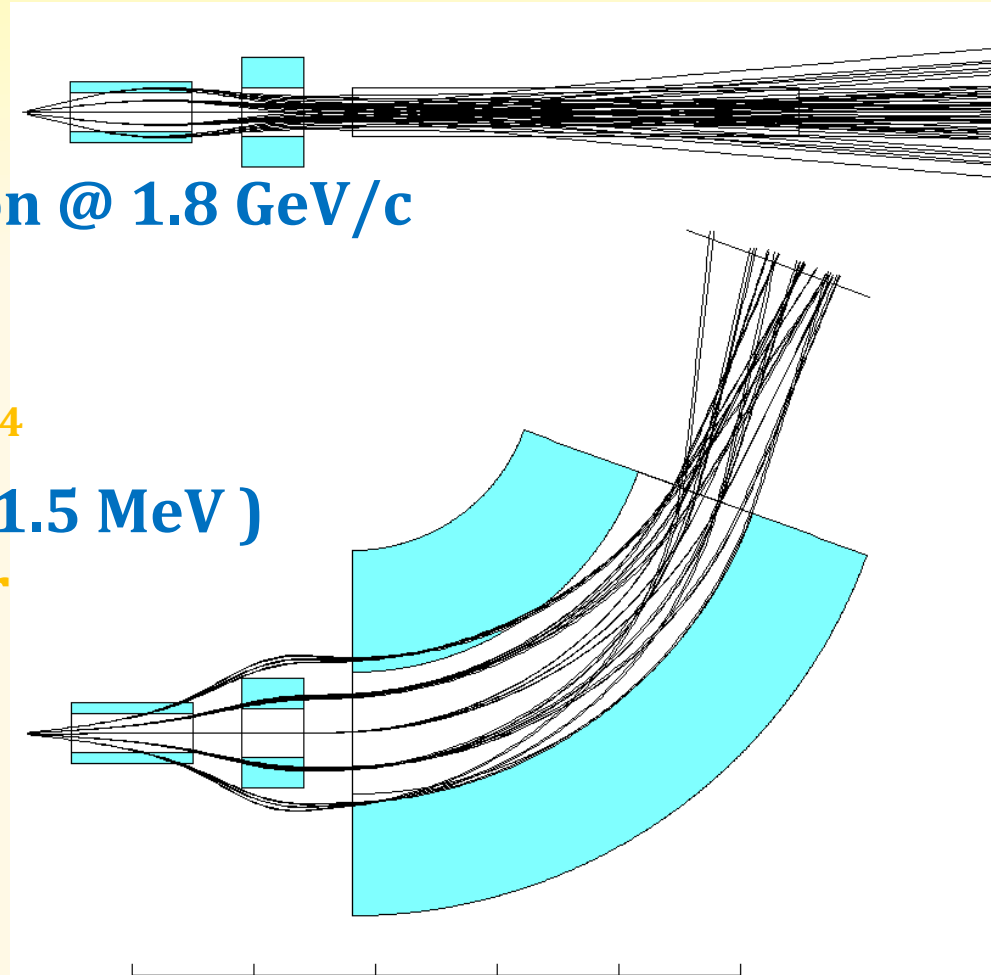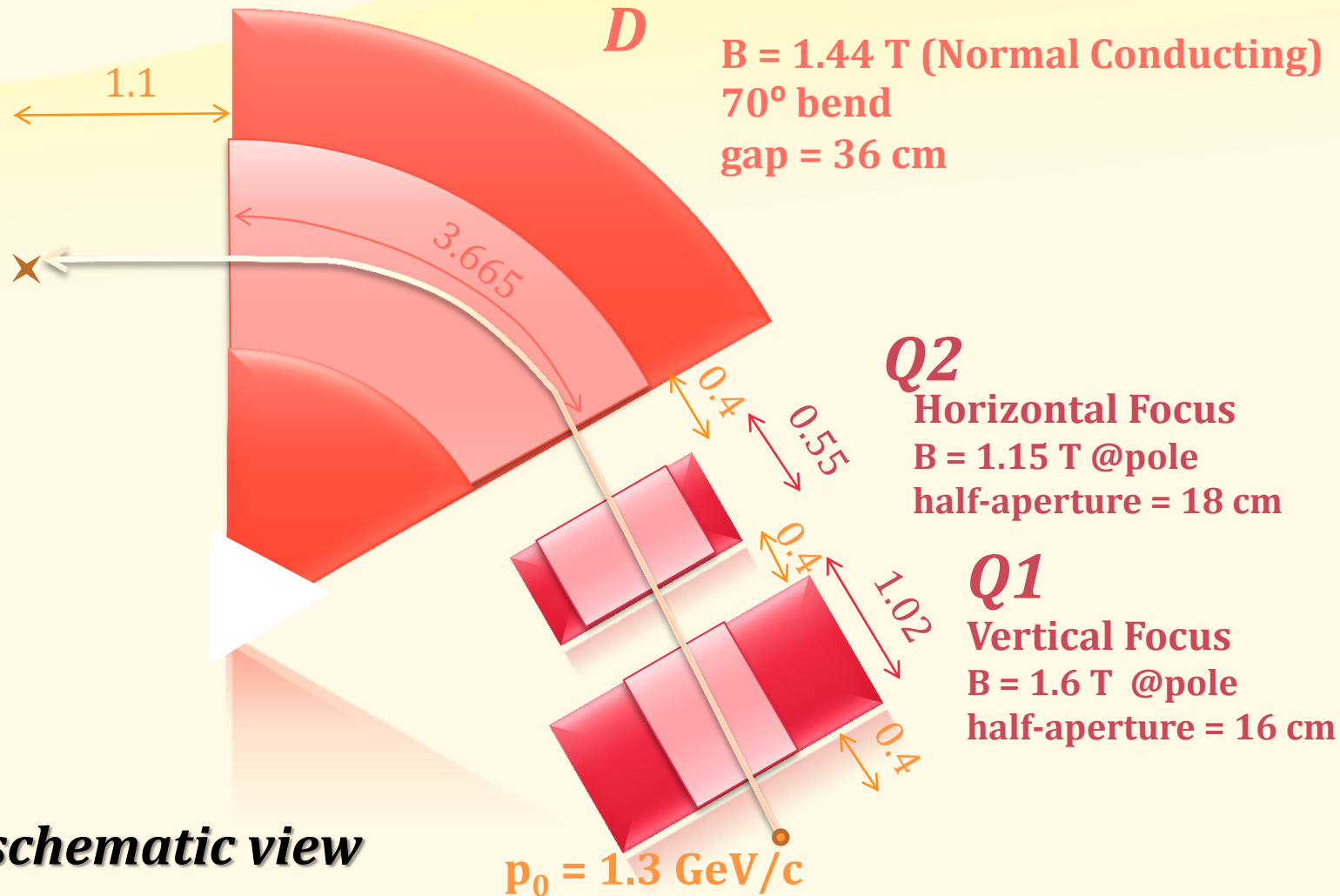
tentative schematic view

$p_0 = 1.3$ GeV/c

Summary

- J-PARC E05 is planed to observe Ξ-hypernuclei via (K^-, K^+) missing mass spectroscopy.

- It provides essential information to S=-2.

- We are preparing modified experimental plan.

  i. Near future plan = low intensity version.
     - Larger acceptance
     - Tolerable resolution
     - Modest yield → Expected spectrum
     - Possibility to start exp. at ~30kW as the first step.

  ii. Mid-term plan
     - new higher-resolution spectrometer (S-2S) is under designing.
     - Ξ-hypernuclei and double-Λ hypernuclei.