Dec. 6, 2015

S-2Sスペクトロメーターと三ハイパー核

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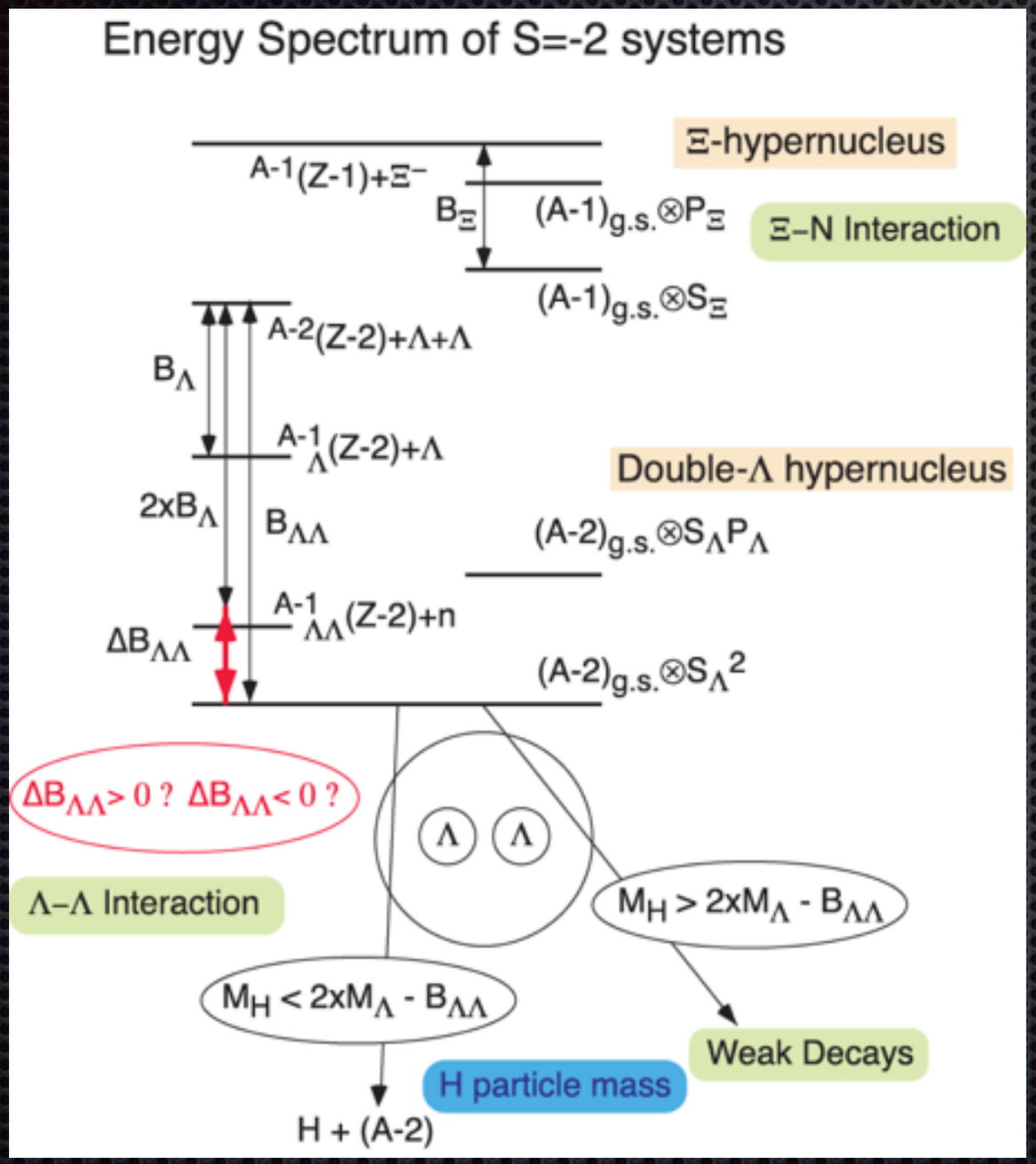
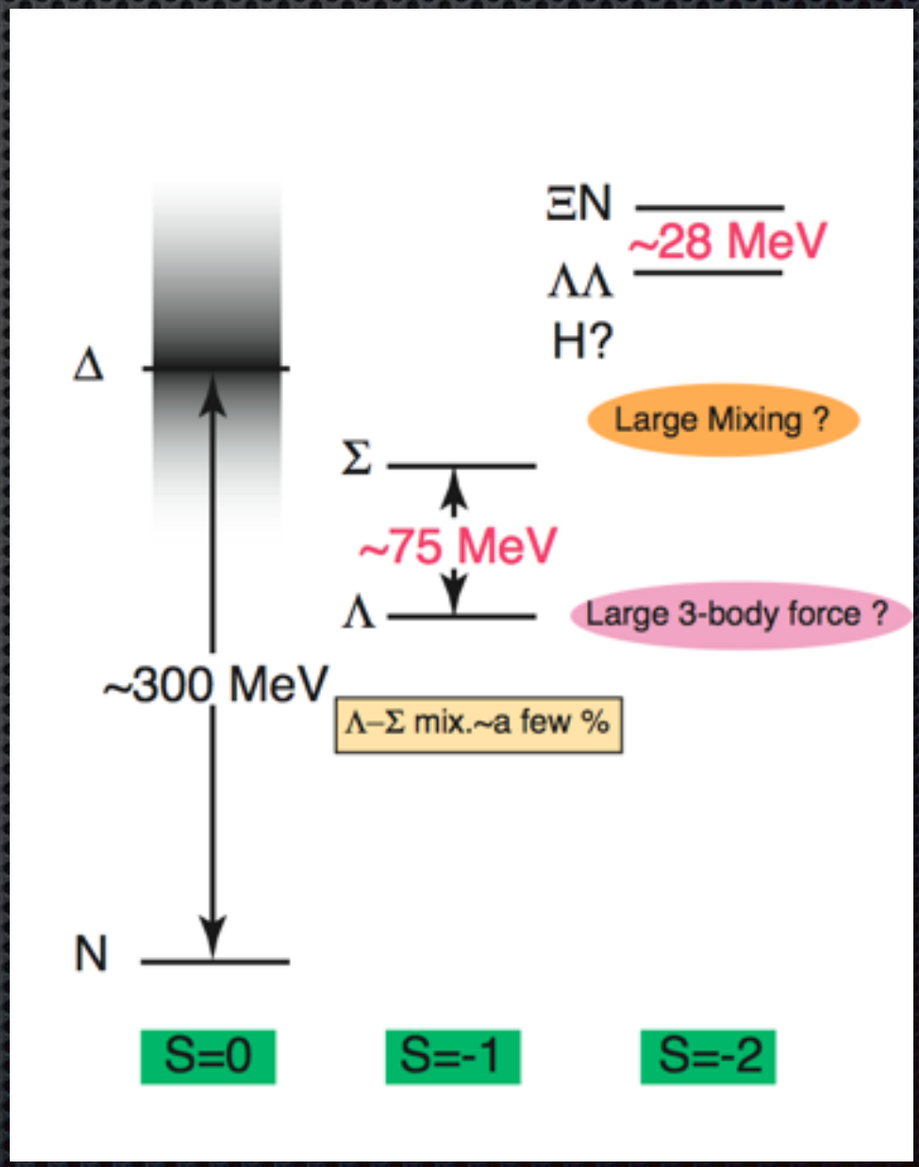
- Introduction to S=-2 Systems
  - Double Λ hypernuclei
  - Ξ hypernuclei
- J-PARC E05 experiment
  - S-2S
  - Pilot run with SKS
- Summary

S=-2 World


Energy Spectrum of S=-2 systems
Ξ-hypernucleus
A-1(Z-1)+Ξ⁻
BΞ
(A-1)g.s.⊗PΞ
Ξ–N Interaction
(A-1)g.s.⊗SΞ
A-2(Z-2)+Λ+Λ
BΛ
A-1Λ(Z-2)+Λ
Double-Λ hypernucleus
2xBΛ
BΛΛ
(A-2)g.s.⊗SΛPΛ
A-1ΛΛ(Z-2)+n
ΔBΛΛ
(A-2)g.s.⊗SΛ2
ΔBΛΛ> 0 ? ΔBΛΛ< 0 ?
Λ Λ
Λ–Λ Interaction
MH > 2xMΛ - BΛΛ
MH < 2xMΛ - BΛΛ
Weak Decays
H particle mass
H + (A-2)


ΞN
~28 MeV
ΛΛ
H?
Large Mixing ?
Δ
Σ
~75 MeV
Λ
Large 3-body force ?
~300 MeV
Λ–Σ mix.~a few %
N
S=0
S=-1
S=-2

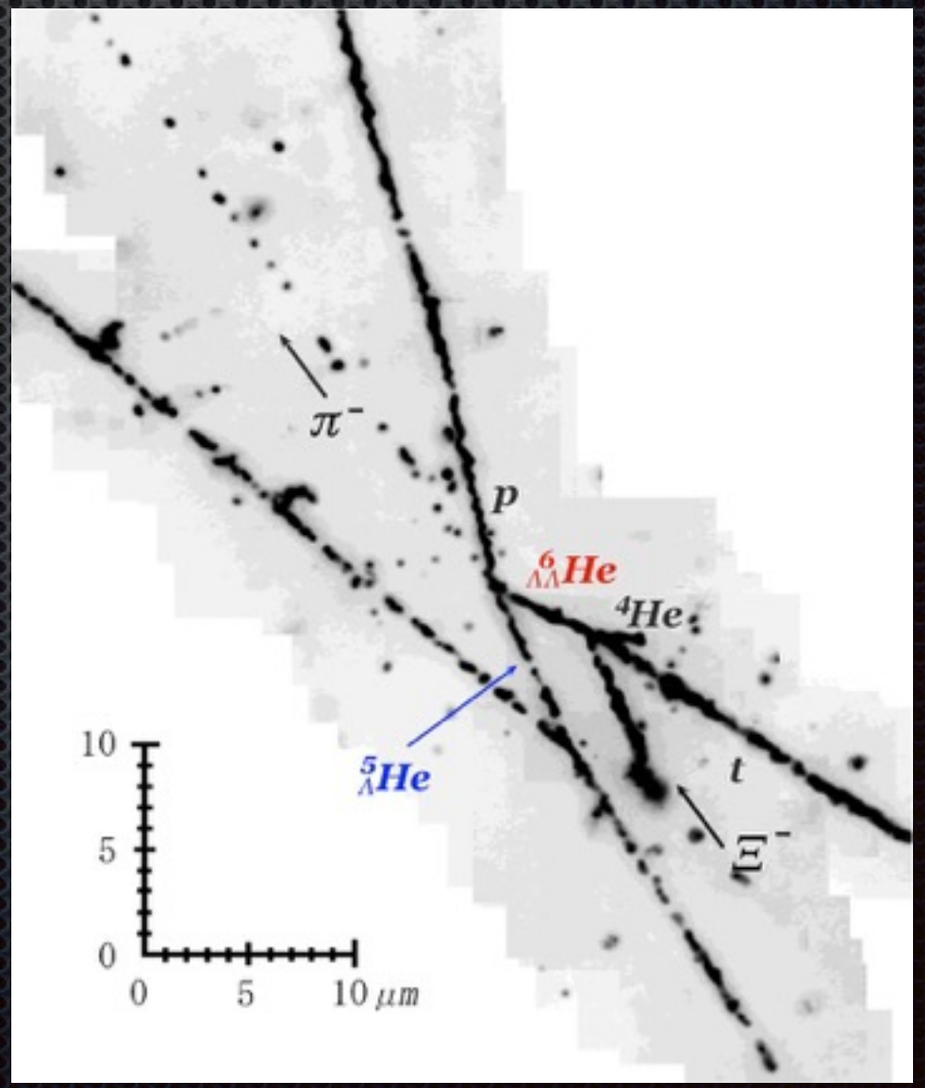
Double-Λ Hypernuclei

- "Nagara" event; ${}^{\Lambda\Lambda}{}^{6}\mathrm{He}$
  - Uniquely identified
  - $\Delta B_{\Lambda\Lambda}$=0.67±0.17 MeV

J.K. Ahn et al., PRC 88 (2013) 014003.

- smaller than before (~4 MeV)

KEK E373



H. Takahashi et al., PRL87, (2001) 212502.

Double-Λ predicted by Hiyama

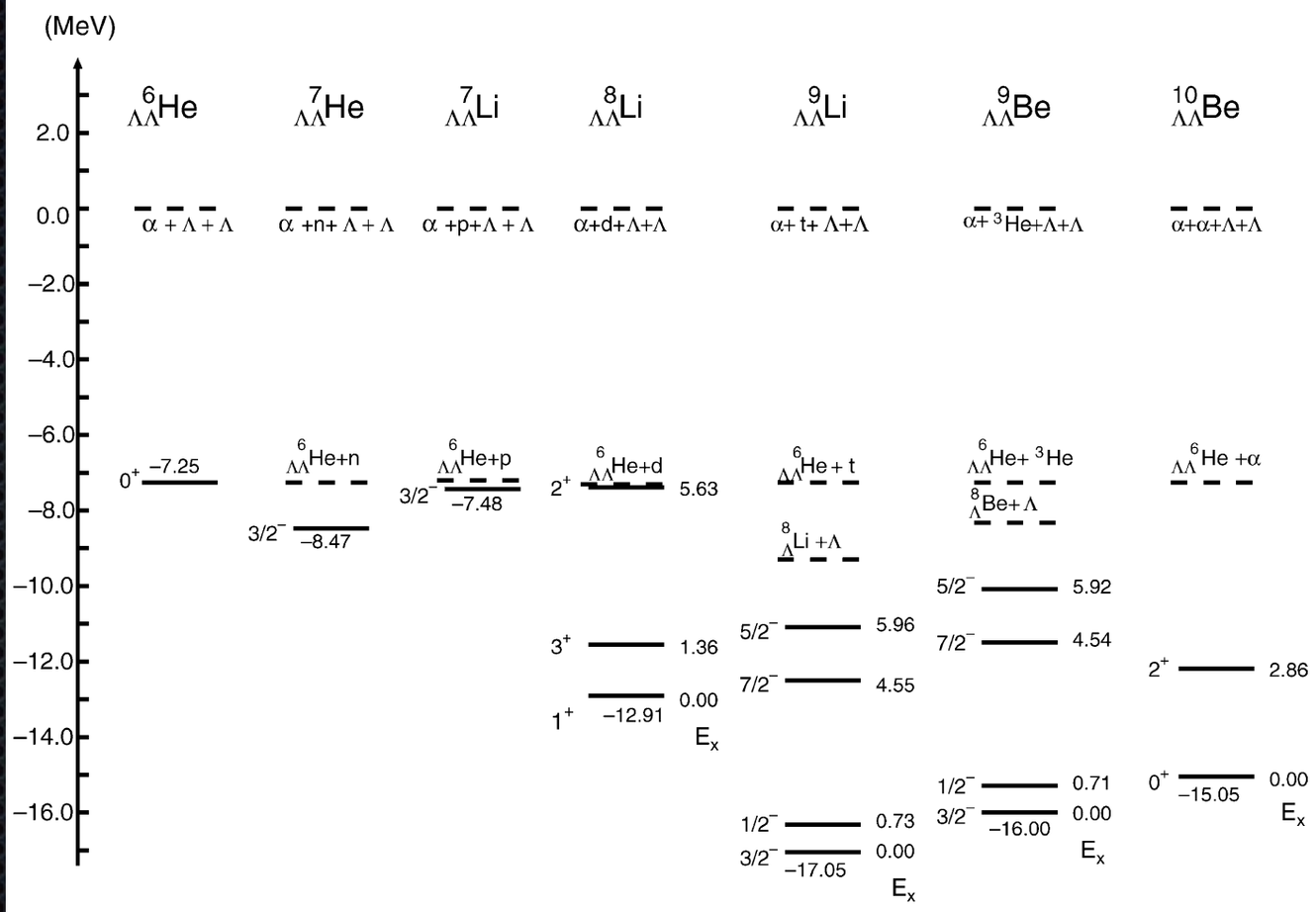


Fig. 3. Calculated energy levels of $A = 7$–10 double Λ hypernuclei.

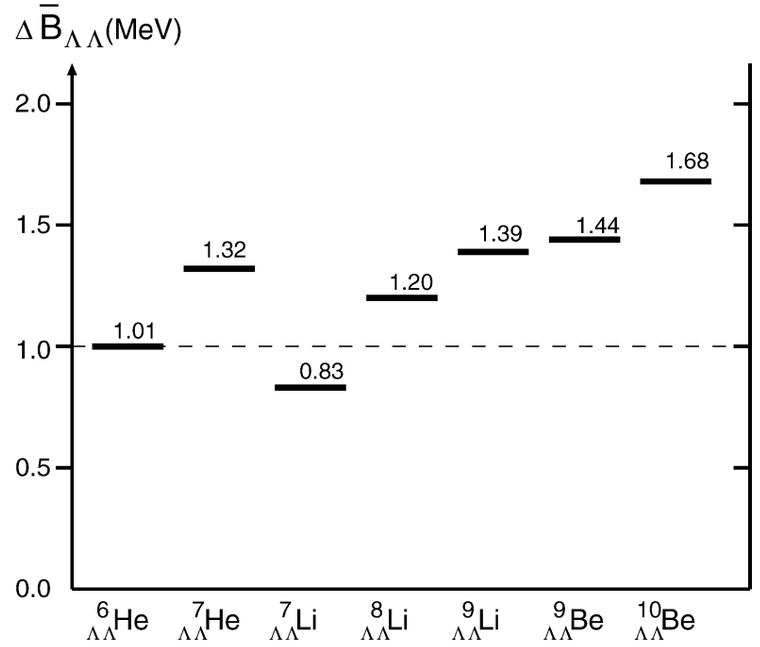
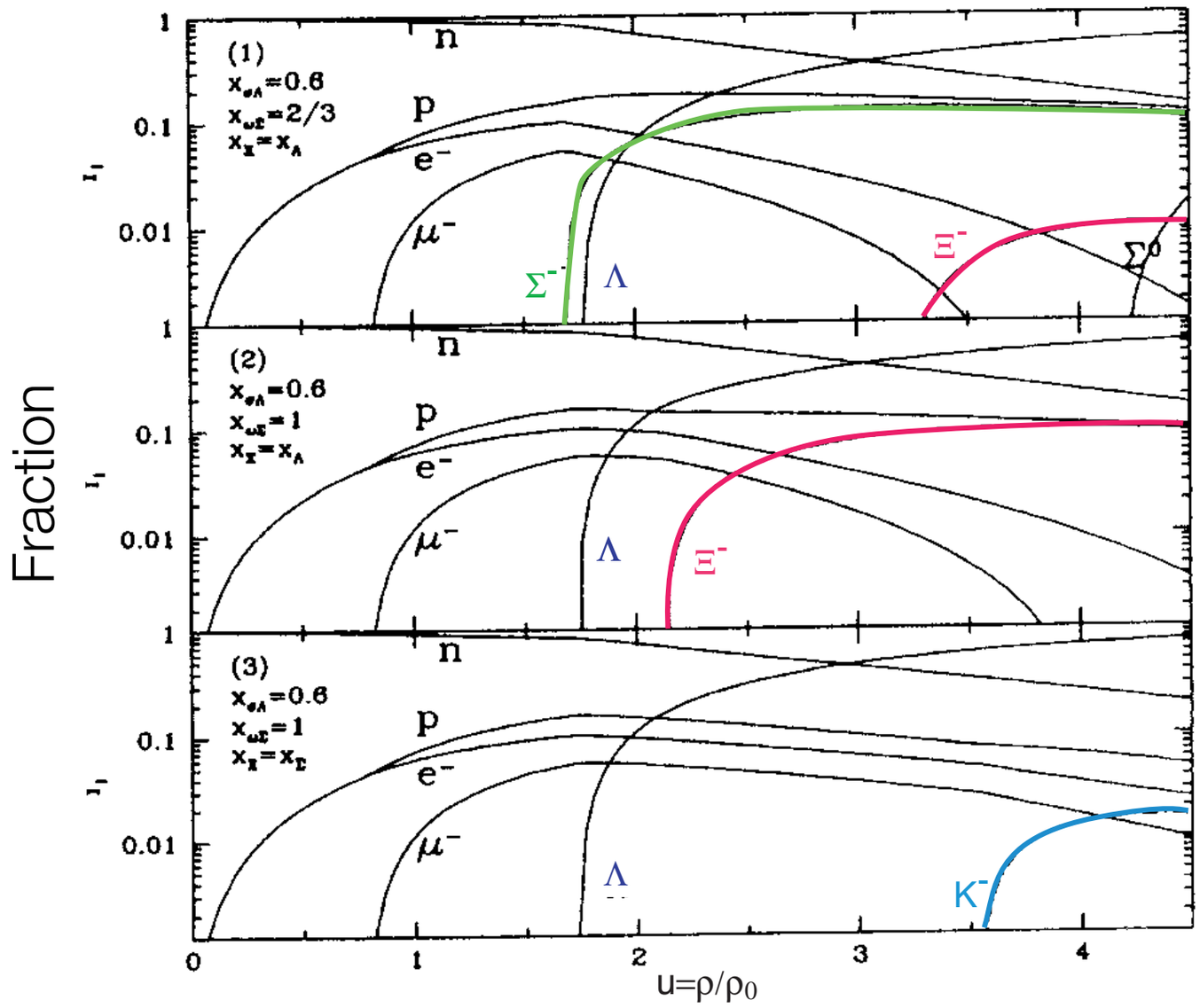


Fig. 4. Calculated values of $\Delta\bar{B}_{\Lambda\Lambda}$.

Ξ-Nucleus potential ?

- Chemical Potential:

$$\mu_B = m_B + \frac{k_F^{\,2}}{2m_B} + U(k_F)$$



$U_\Sigma < 0,\ U_\Xi < 0$

$U_\Sigma > 0,\ U_\Xi < 0$

$U_\Sigma > 0,\ U_\Xi > 0$

Experimental situations before 1990

Ξ⁻'s binding energy

$^{8}_{\Xi}$He: 5.9 ± 1.2 MeV[1]

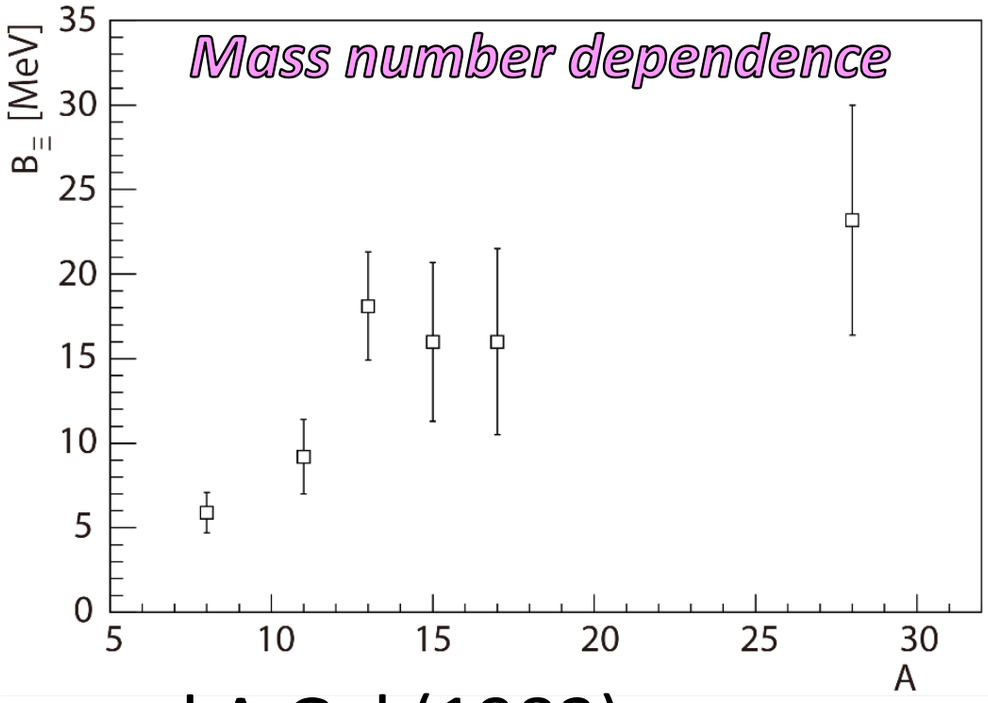
$^{11}_{\Xi}$B: 9.2 ± 2.2 MeV[2]

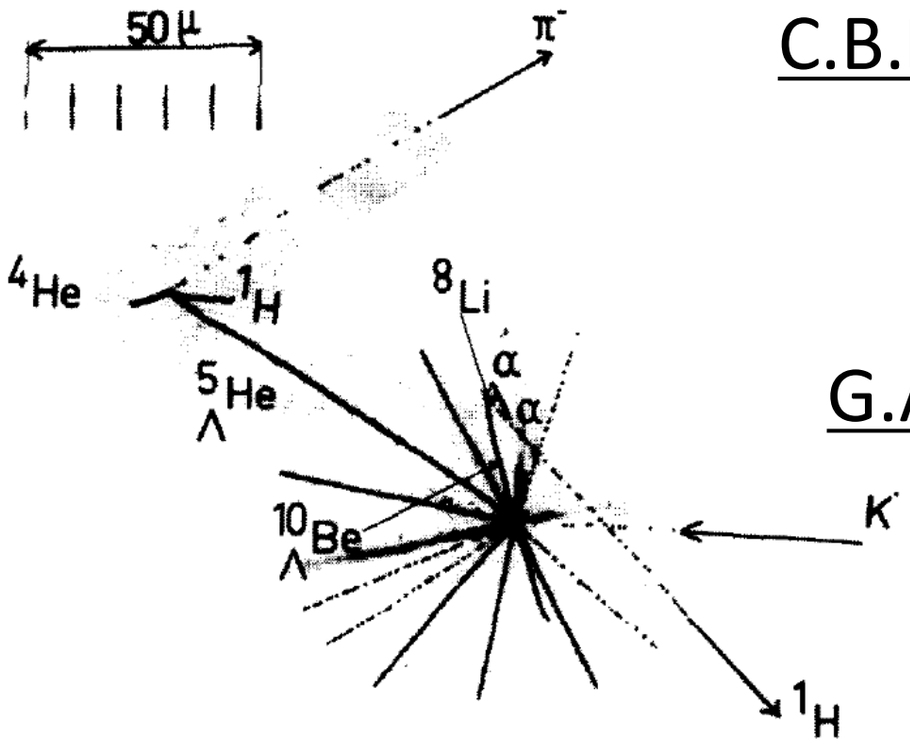
$^{13}_{\Xi}$C: 18.1 ± 3.2 MeV[3]

$^{15}_{\Xi}$C: 16.0 ± 4.7 MeV [4]

$^{17}_{\Xi}$O: 16.0 ± 5.5 MeV[4]

$^{28}_{\Xi}$Al: 23.2 ± 6.8 MeV [4]





C.B.Dover and A.Gal (1983)

$$\begin{cases} V_{0\Xi} = 24 \pm 4 \text{ MeV } (r_0 = 1.1 \text{ fm}) \\ V_{0\Xi} = 21 \pm 4 \text{ MeV } (r_0 = 1.25 \text{ fm}) \end{cases}$$

G.A.Lalazissis *et al.* (1989)

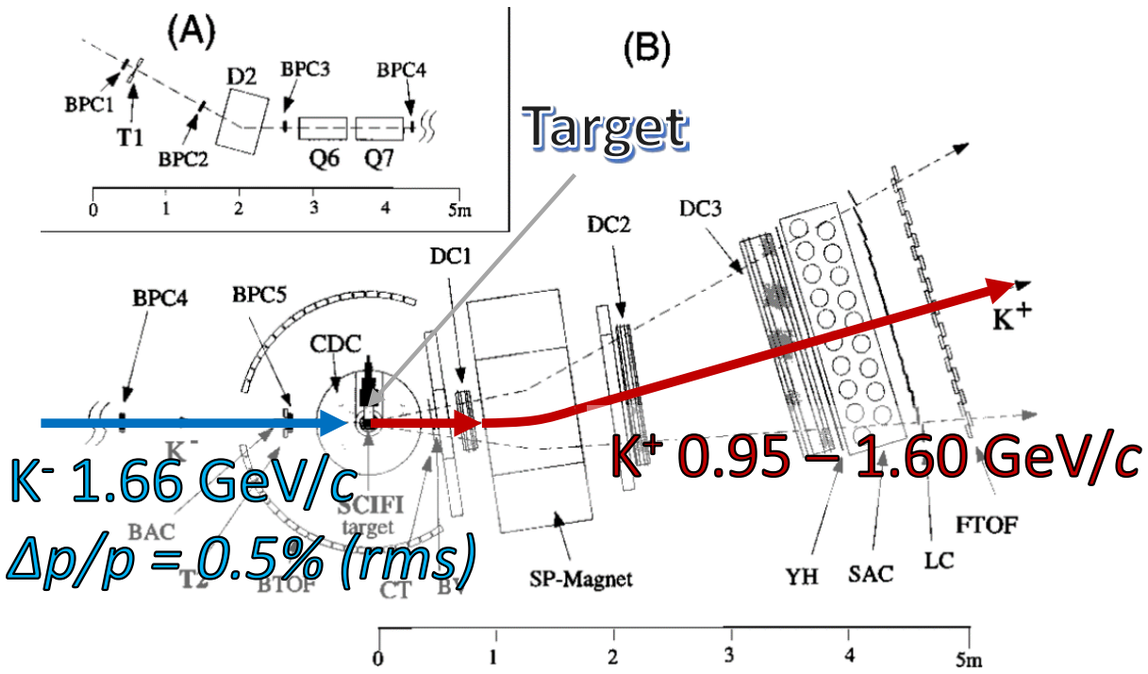
$$V_{0\Xi} = 22 \text{ MeV}$$

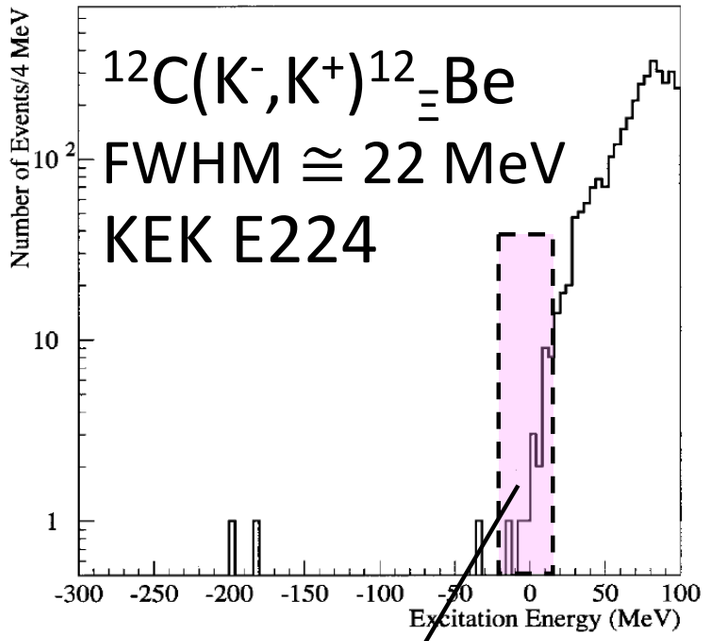
[1]D.H.Wilkinson *et al.*, *PRL* **3** (1959)8
[2]J.Catala *et al.*, *Proc. Int. Conf. on Hypernuclear Physics, Argonne*, Illinois **vol.2**, p.758 (1969)
[3]A.S.Mondal *et al.*, *Nuovo Cimento* **54**A(1979)3
[4]A.Beckdolff *et al.*, *PL***26**B(1968)3

KEK E224

Counter experiment at KEK T.Fukuda *et al.*, *PRC* **58** (1998) 2

*(The **first** direct measurement in the missing mass spectrum.)*

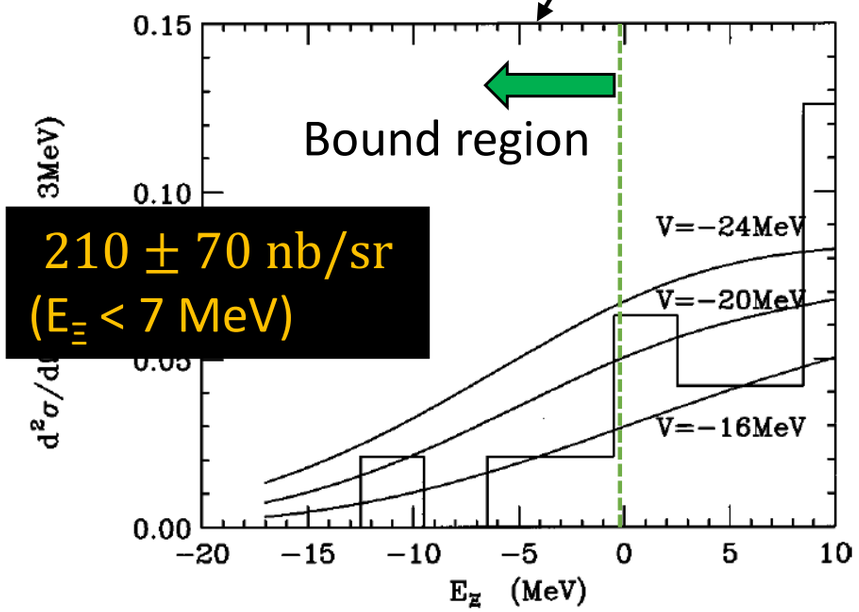




1. Differential cross section (E_Ξ<7 MeV) comparison with theory
2. Distribution shape analysis.

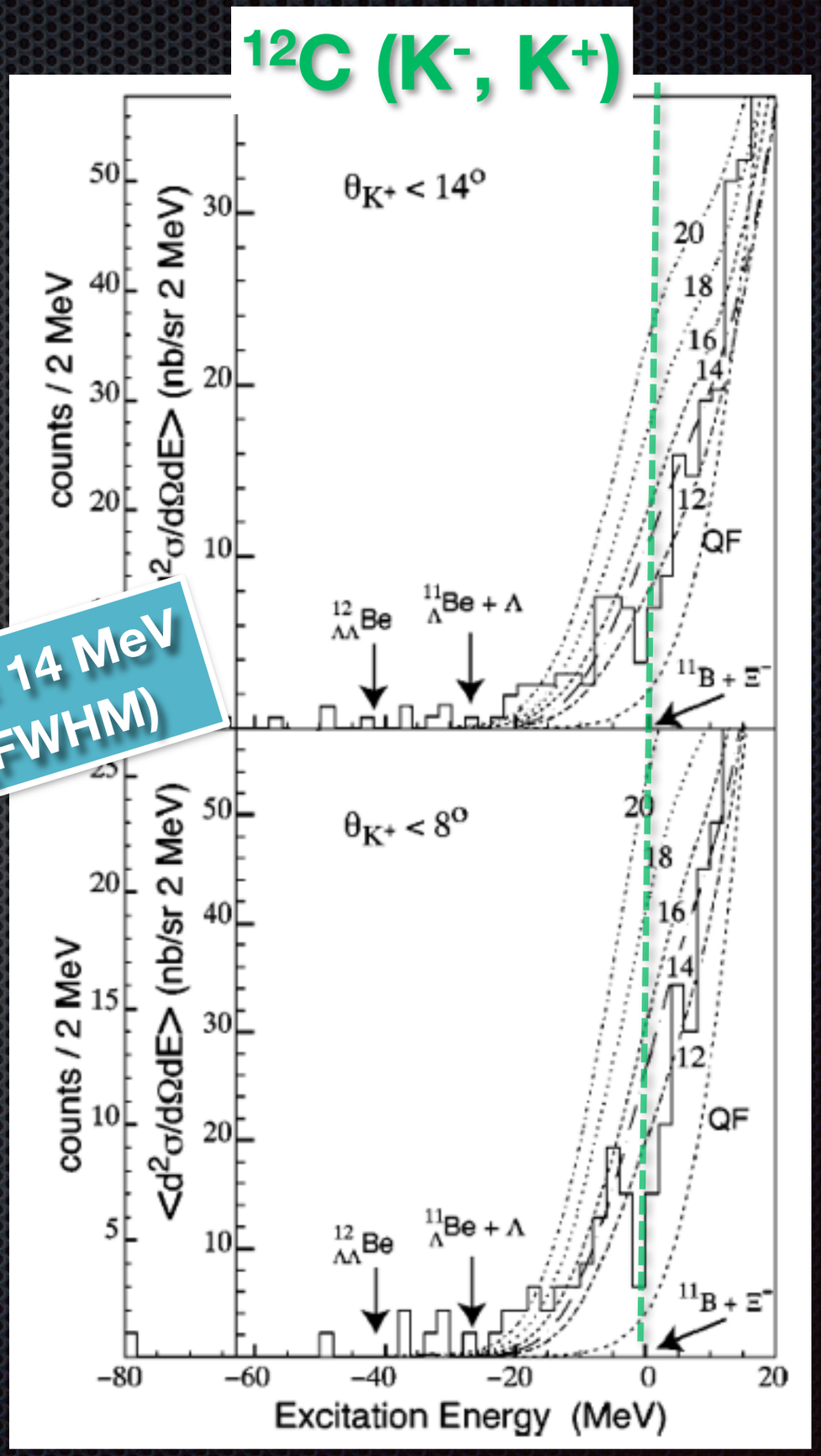
$\Rightarrow V_{0\Xi} < 20$ MeV

Consistent with KEK E176 !!



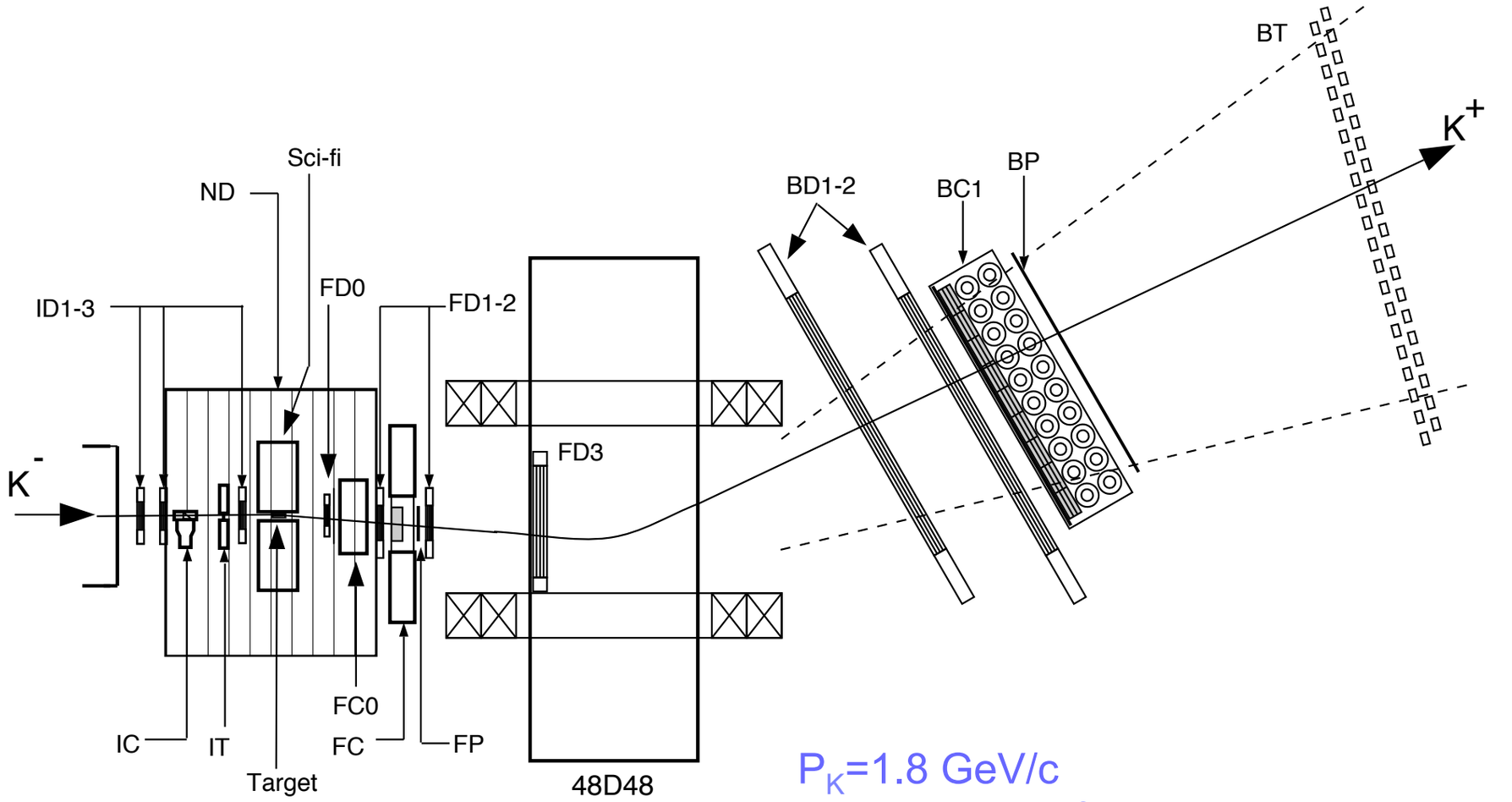
BNL E885

- 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.
- 89±14 nb/sr (<8deg.); 42±5 nb/sr (<14deg.)



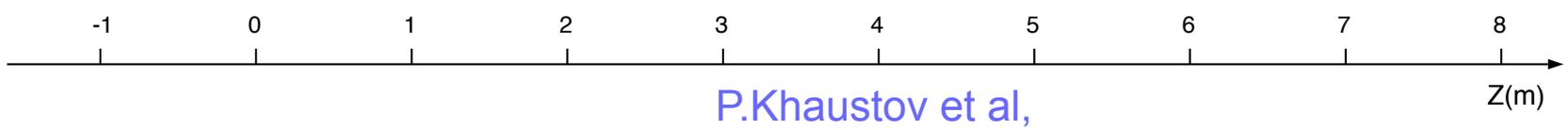
P.Khaustov et al., PRC61(2000)054603

BNL E885



P_K=1.8 GeV/c

ΔM=9.9 MeV/c^2 (FWHM) for $p(K^-,K^+)\Xi^-$



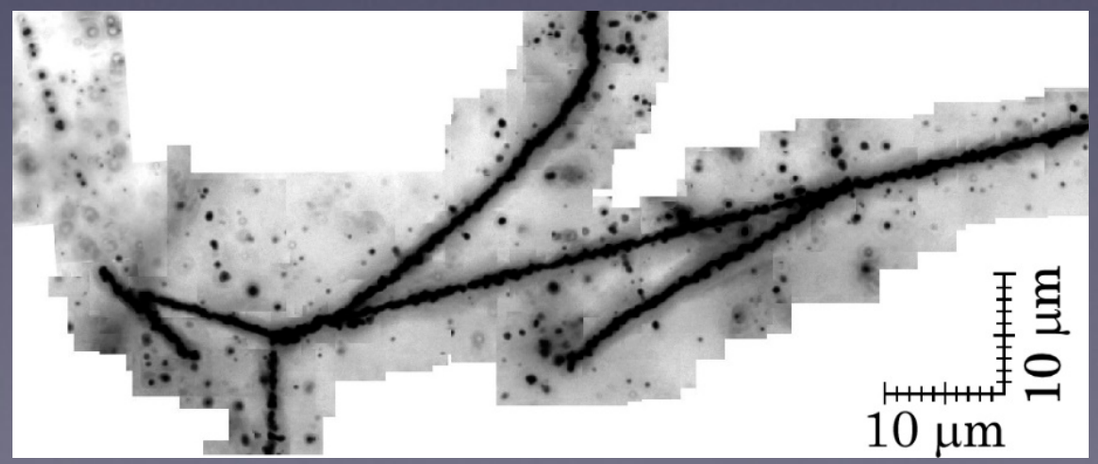
P.Khaustov et al,
PRC61(2000)0546

“KISO” event

K. Nakazawa et al., KEK E373

PTEP (2015) 033D02

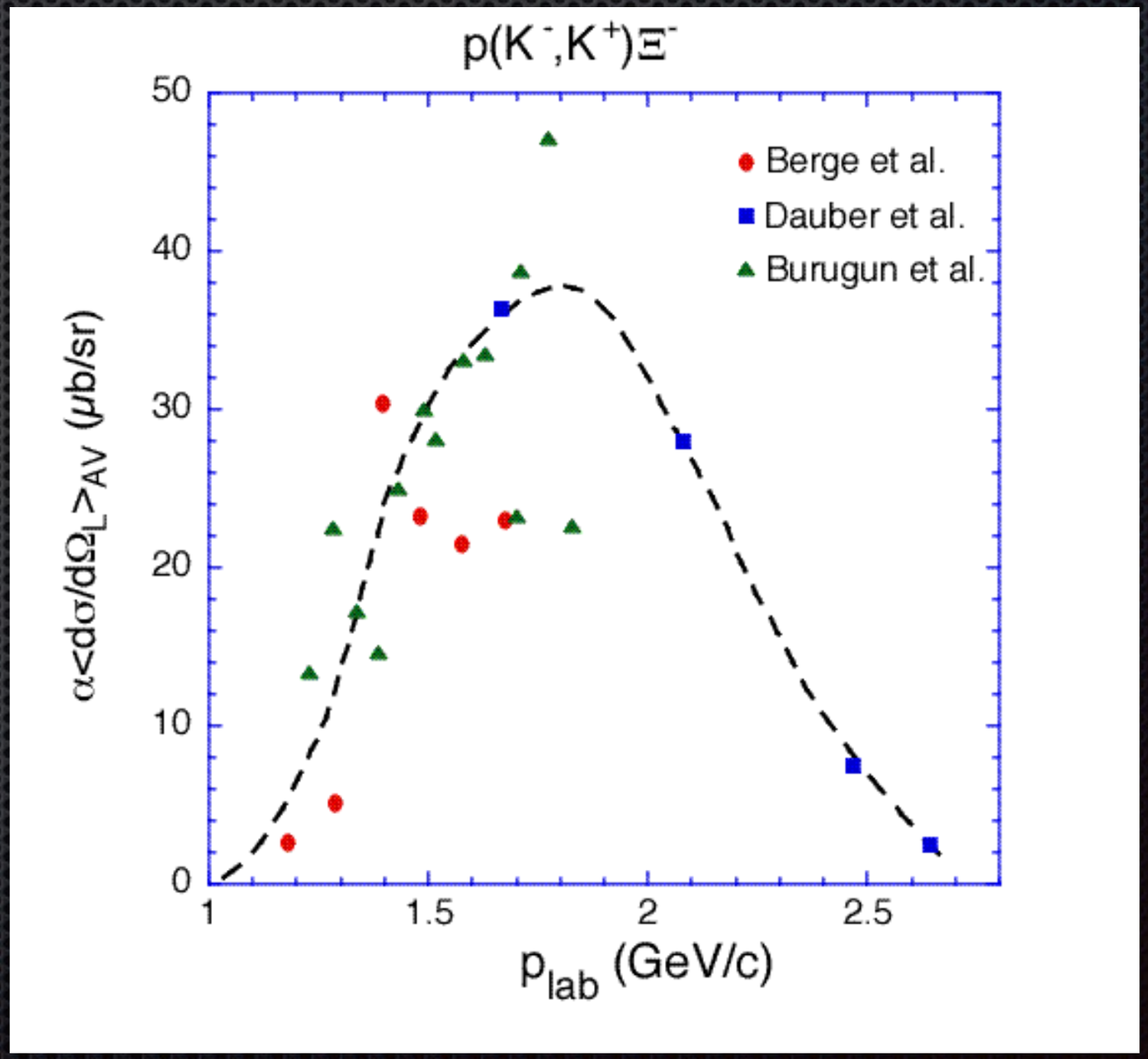
- deeply bound Ξ^--^{14}N system
  - $\Xi^- + {}^{14}\mathrm{N} \rightarrow {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$
    - B_{Ξ}=1.11~4.38 MeV $\pm\Gamma/2$
      - Well beyond the atomic binding of 0.17 MeV

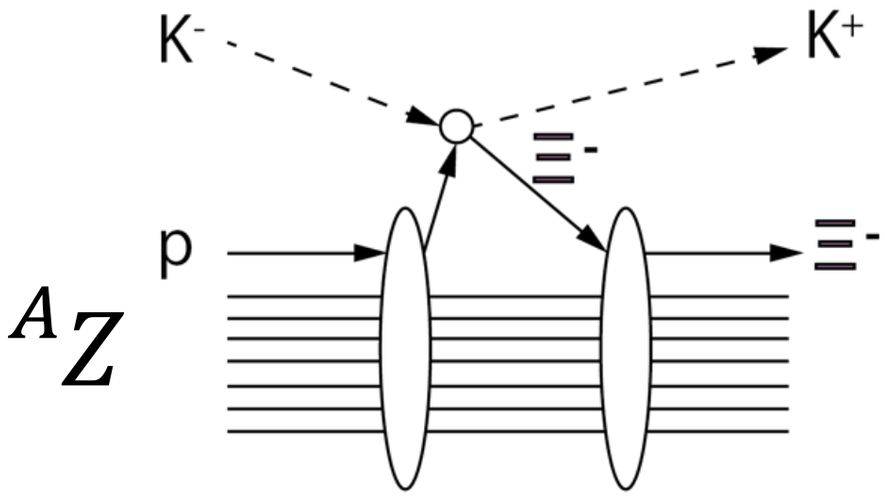


- Ξ hypernuclei do exist !
- Urgency :
  - Measurement of Re($V_Ξ$)
  - Γ ΞN-ΛΛ ?

Entrance to the S=-2 World

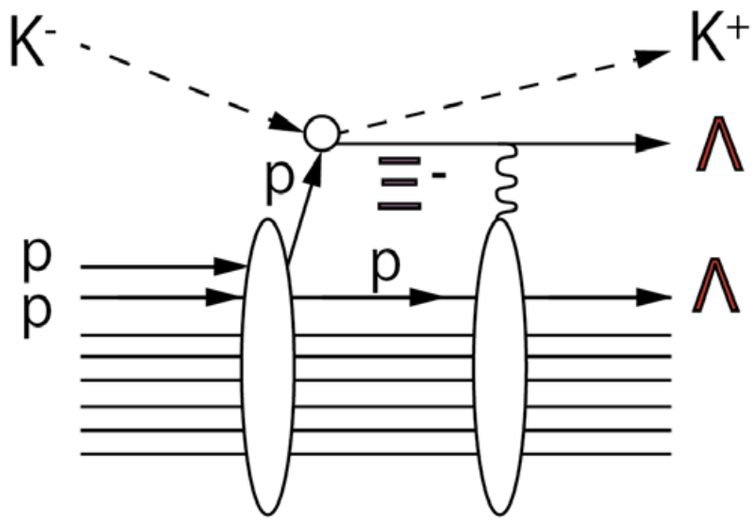
- Doorway Reaction:
  $K^- + p \rightarrow K^+ + \Xi^-$
  at 1.8 GeV/c





$^{A}_{}Z$ $^{A}_{\Xi}Z-2$

Ξ⁻ hypernucleus



$^{A}_{}Z$ $^{A}_{\Lambda\Lambda}Z-2$

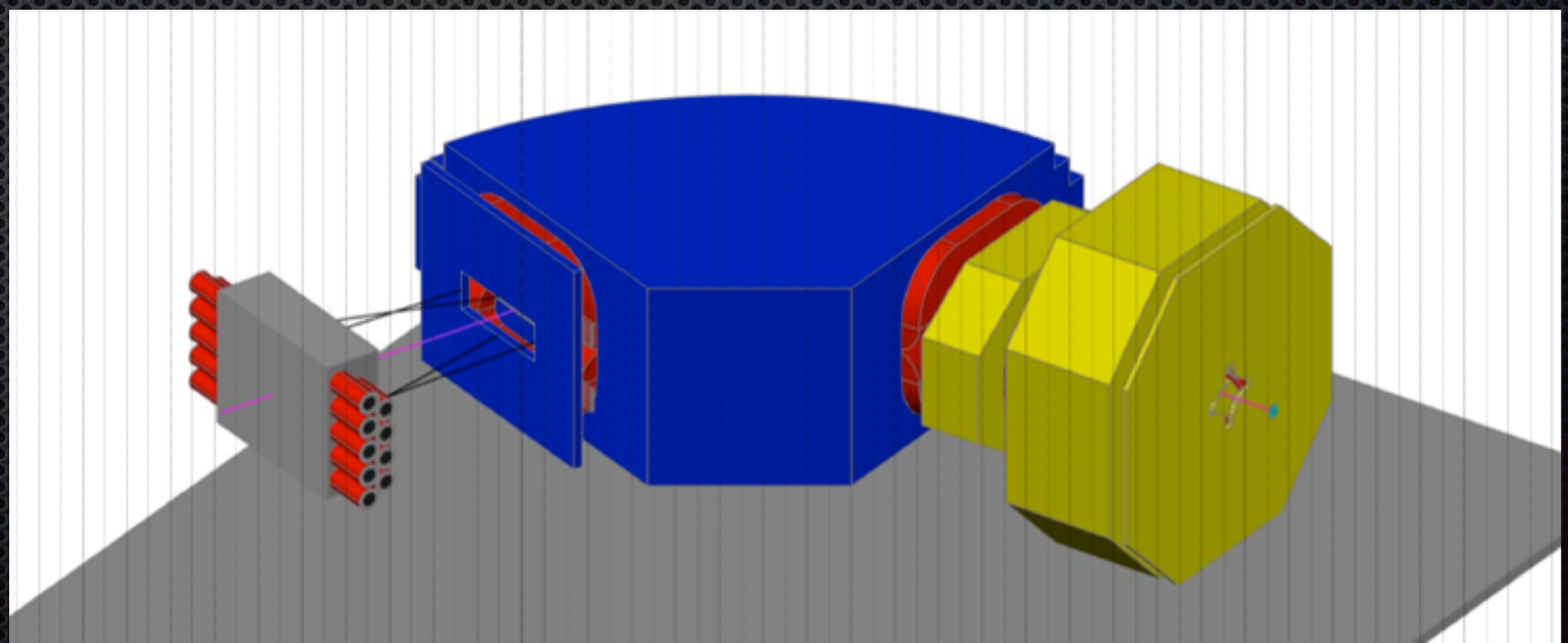
Double Λ hypernucleus

Spectroscopic Study of Ξ-Hypernucleus, $^{12}_{\Xi}$Be, via the ^{12}C(K^-,K^+) Reaction

J-PARC E05
T. Nagae et al.

- Discovery of Ξ-hypernuclei as a peak(s)
- Measurement of Ξ-nucleus potential depth and width of $^{12}_{\Xi}$Be

S=-1 → S=-2 (Multi-Strangeness System)



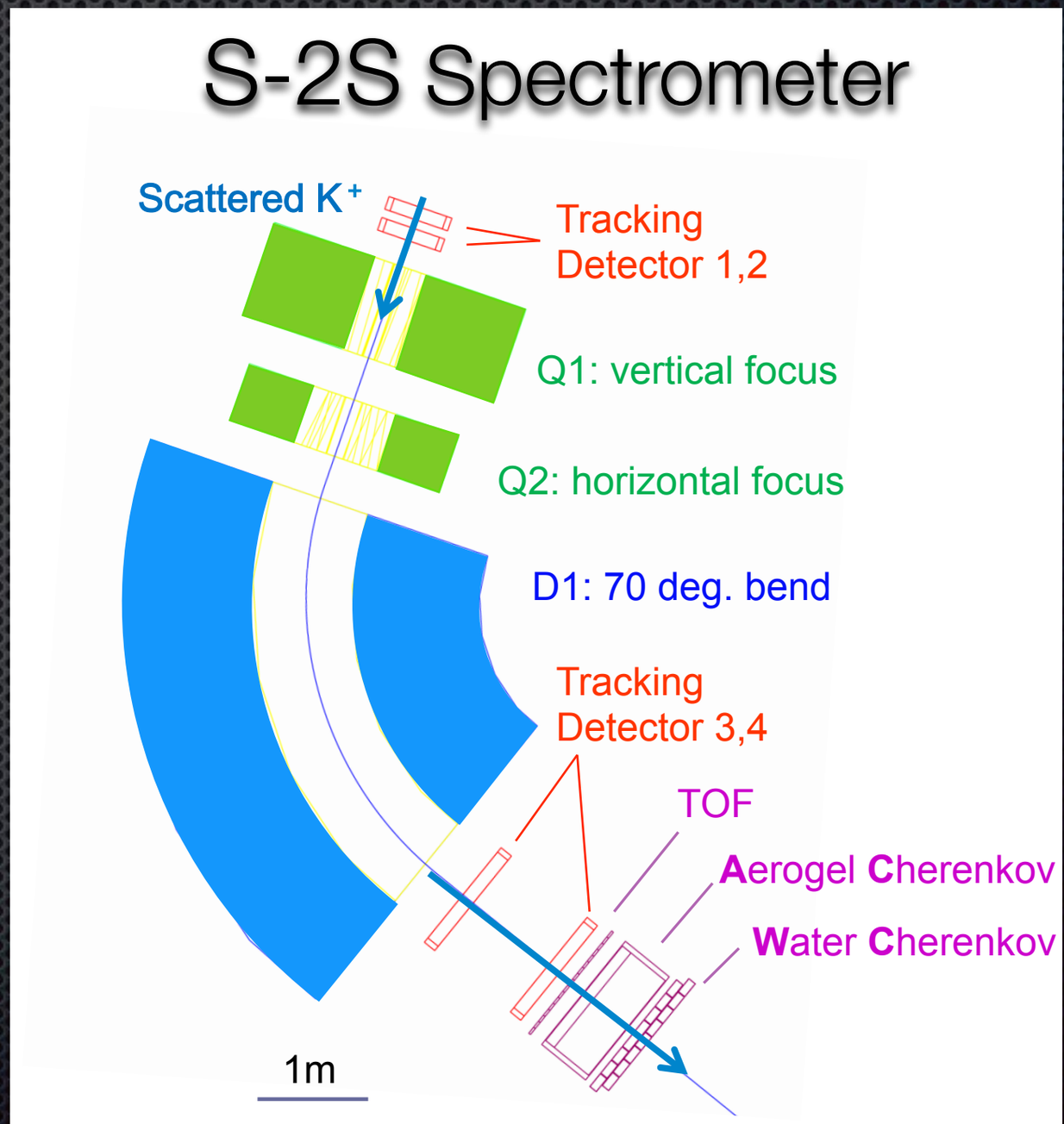
Purpose of E05

- ΞN Interaction: almost no information
  - Attractive (or Repulsive) ? → Potential depth
  - ΞN→ΛΛ conversion ? →Conversion width
  - Isospin dependence ?

S-2S

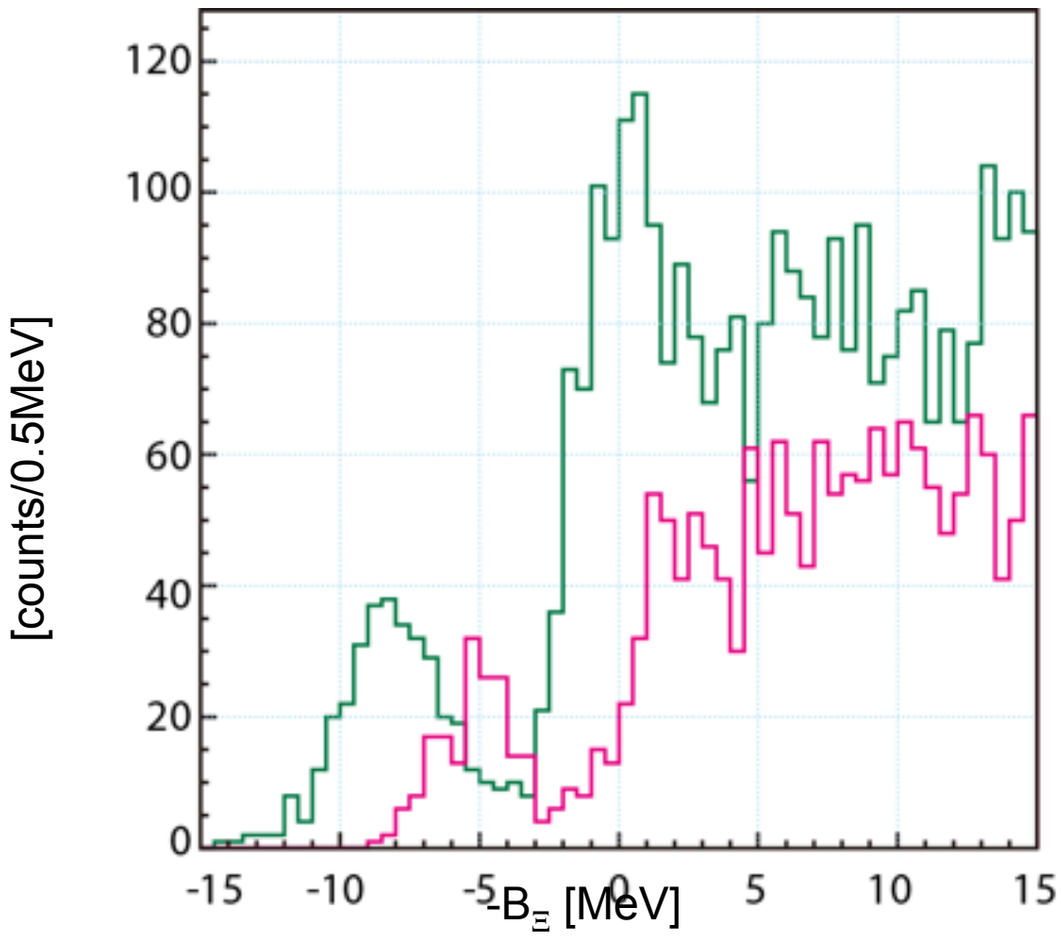
- (K^-,K^+) Spectroscopy @J-PARC
  - $K^-+p \rightarrow K^+ + \Xi^-$ @~1.8 GeV/c
- S-2S: (2010-2015)
  - Acceptance~60 msr
  - $\Delta p/p < 5\times10^{-4}$(FWHM)
  - ΔE=1.5 MeV

	Acceptance $\Delta\Omega$ (msr)	Energy Resolution ΔE (MeV)
BNL	19	14
SKS+	25	3
S-2S	60	1.5



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

$\Delta E_{meas.}$ = 3 MeV_{FWHM}



V_{Ξ}= -20MeV

V_{Ξ}= -14MeV

U_{Ξ} in Recent Nijmegen Models

Table 3. $U_{\Xi}(\rho_0)$ and partial wave contributions. Conversion width Γ_{Ξ}.

	T	$^1S_0$	$^3S_1$	$^1P_1$	^3P	U_{Ξ}	Γ_{Ξ}
08a	0	6.0	−1.0	−0.3	−2.1		
	1	8.5	−28.0	0.6	−3.8	−20.2	5.8
08a’	0	5.6	−1.1	−0.3	−2.2		
	1	8.4	−21.5	0.6	−3.9	−14.5	7.0
08b	0	2.4	1.9	−0.6	−2.0		
	1	9.1	−37.8	0.6	−5.4	−31.8	1.2
04d	0	6.4	−19.6	1.1	−2.2		
	1	6.4	−5.0	−1.0	−4.8	−18.7	11.3

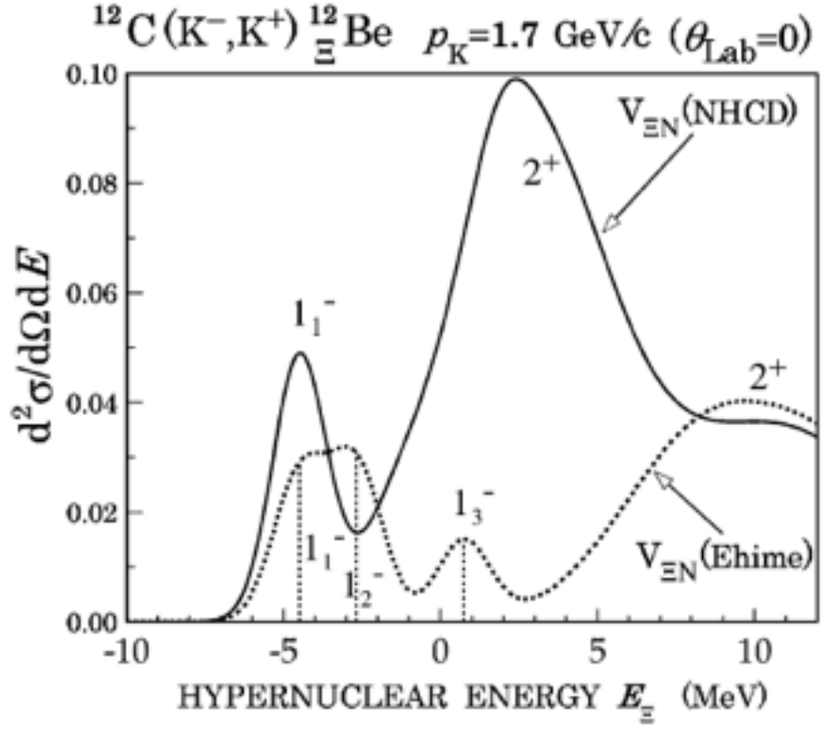


Figure 6: DWIA spectra with NHC-D and Ehime.

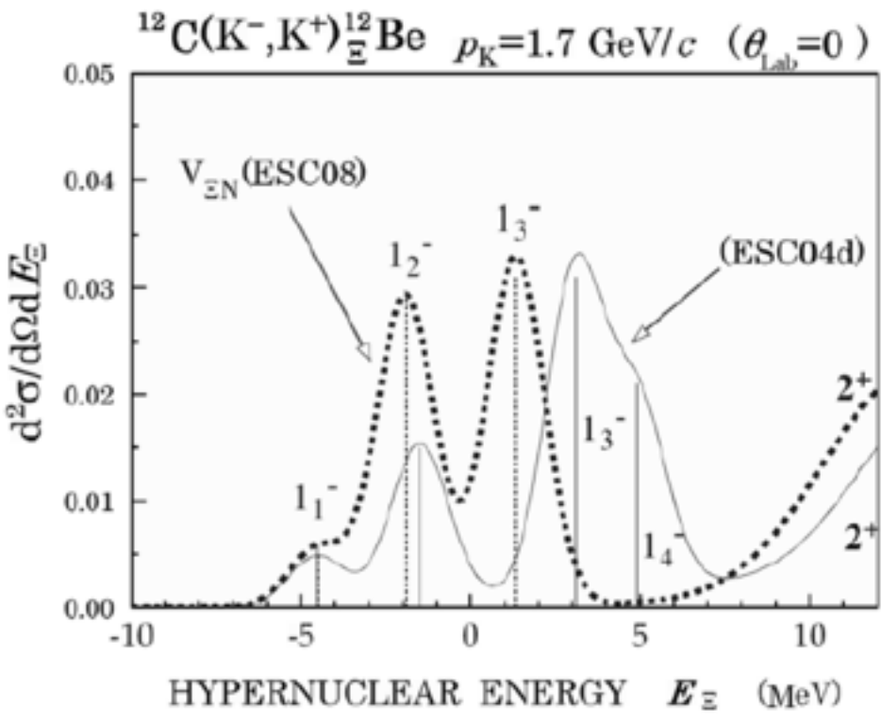
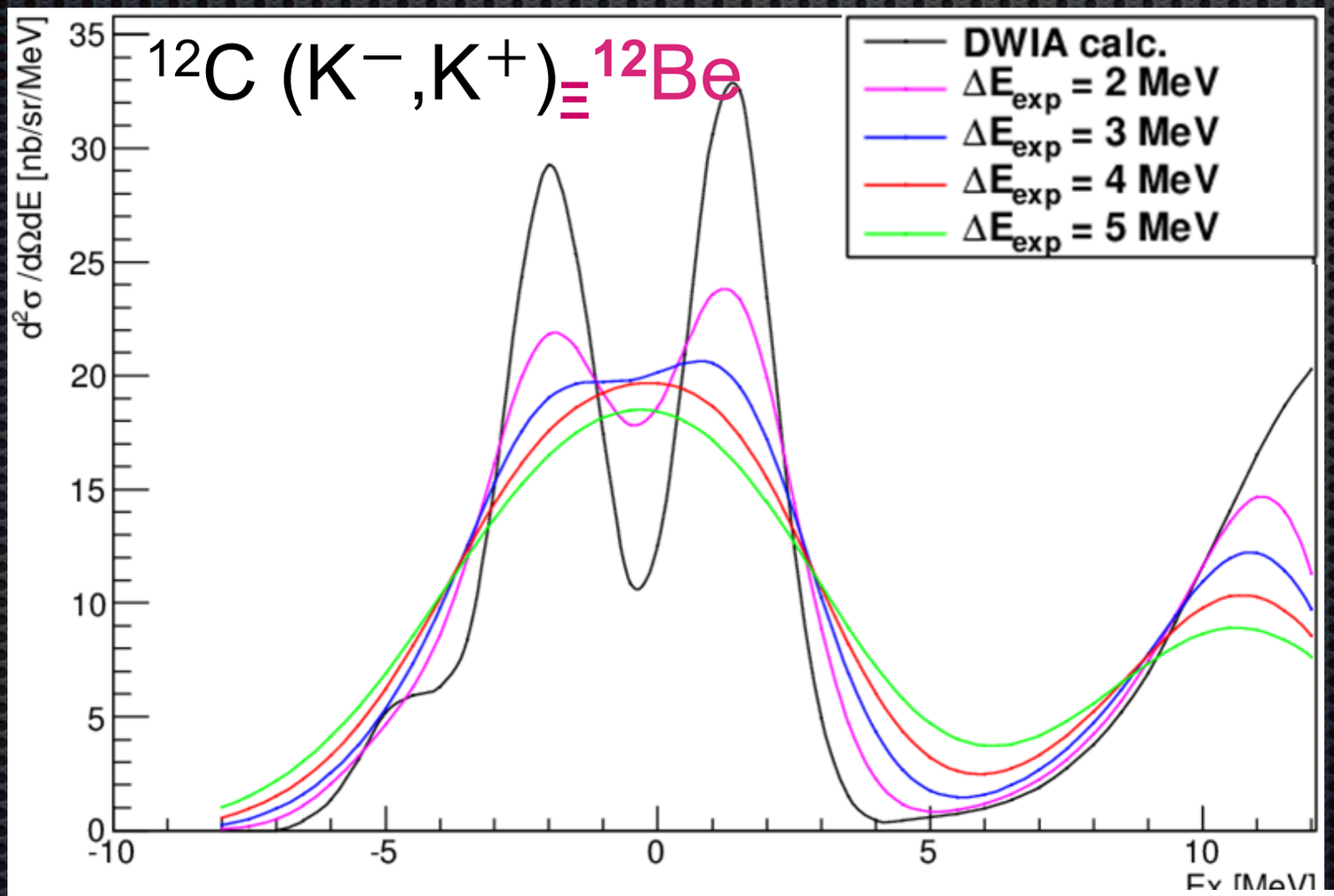


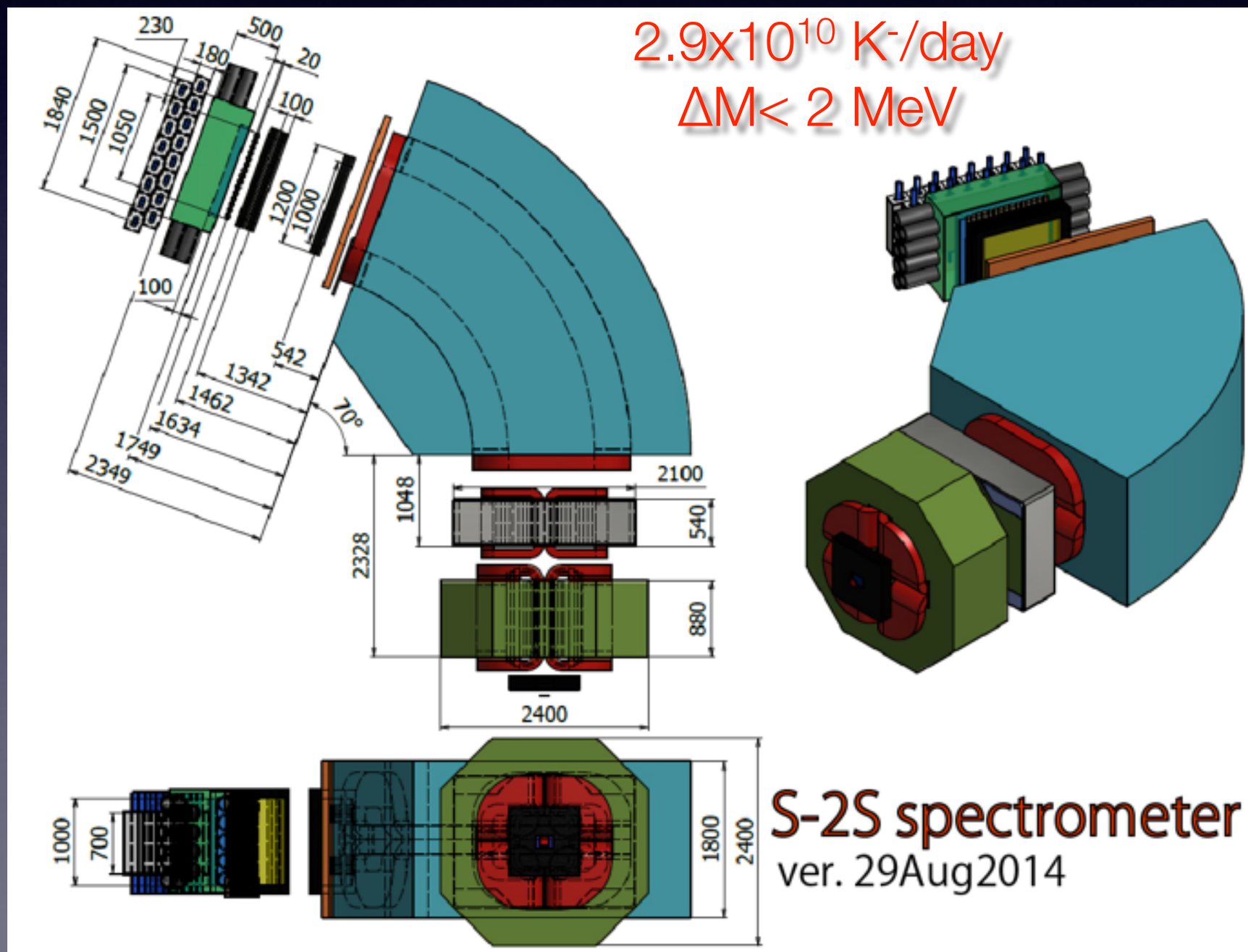
Figure 7: DWIA spectra with ESC04d and ESC08a.



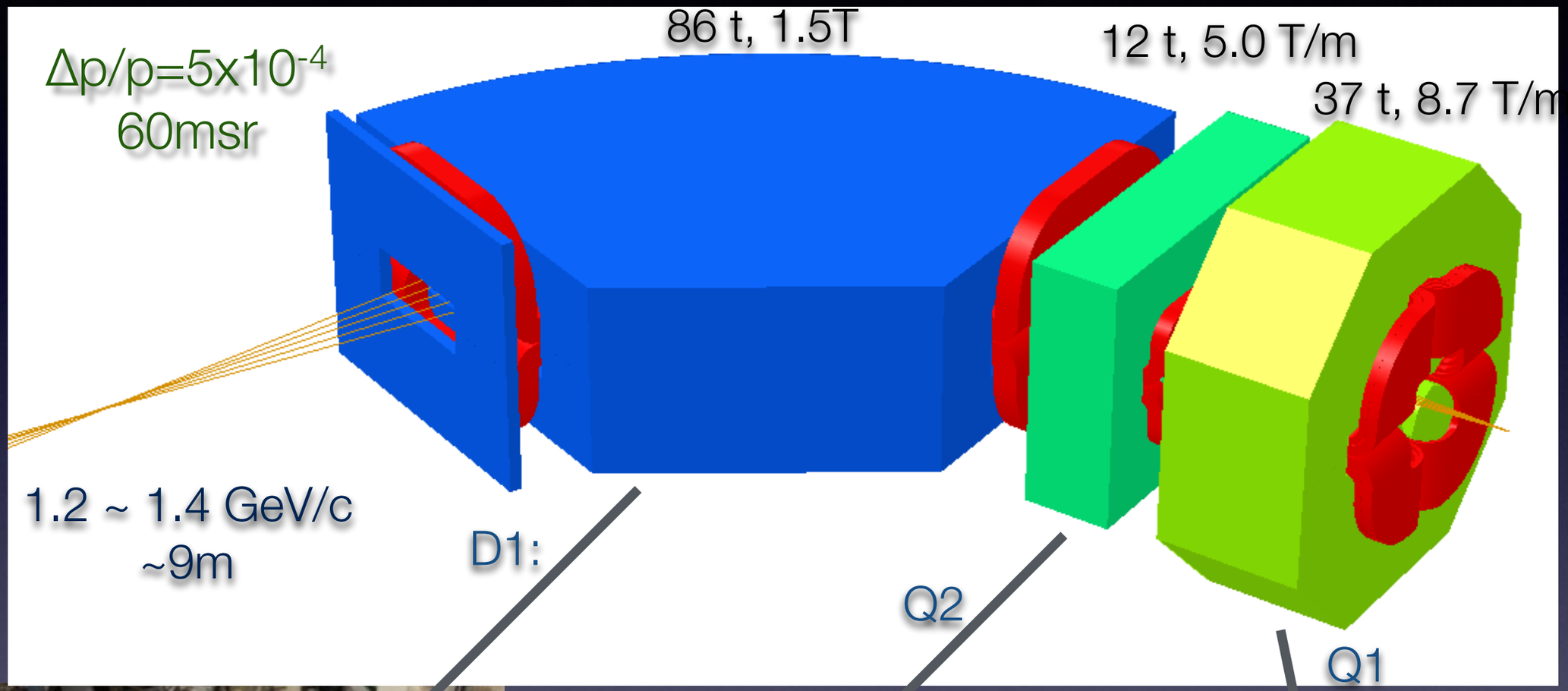
T. Motoba and S. Sugimoto, Nucl. Phys. A 835, 223 (2010)

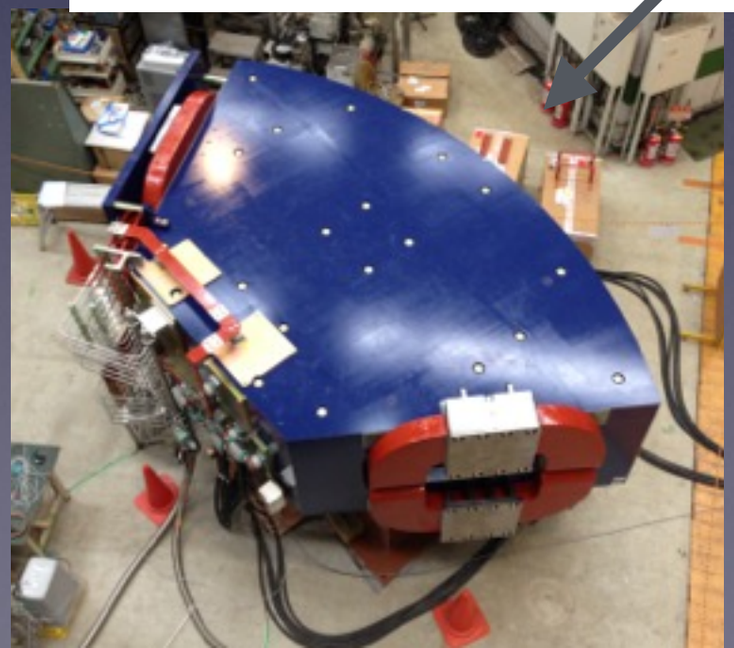
E05 with S-2S

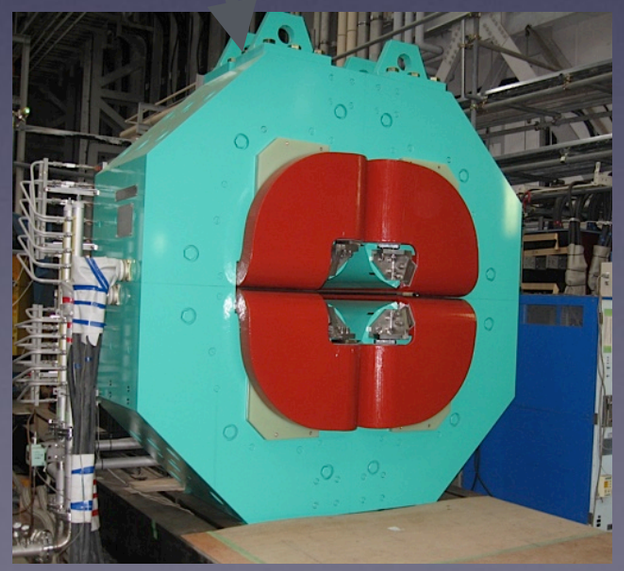
- Grant-In-Aid for Specially promoted research: 2011 – 2015, Total ~$3M
- 60 msr, Δp/p=0.05%
  → ΔM=1.5 MeV
- Construction of S-2S(QQD): ~3 years
  ★Installation in 2016
  ★Data taking in 2017
  with > 100 kW !!



S-2S Construction

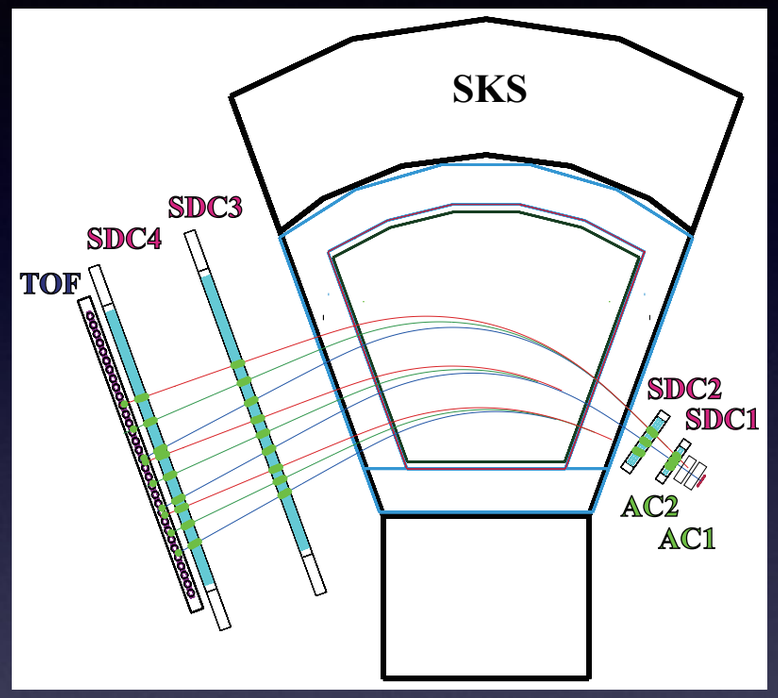






E05 Pilot Run

- K1.8 beam line with SKS (E13 setup')
  - Two AC's(p, π^+) at the entrance of SKS
  - $CH_2(K^-,K^+)$ 9.3g/cm^2 → ΔM=5 MeV$_{FWHM}$

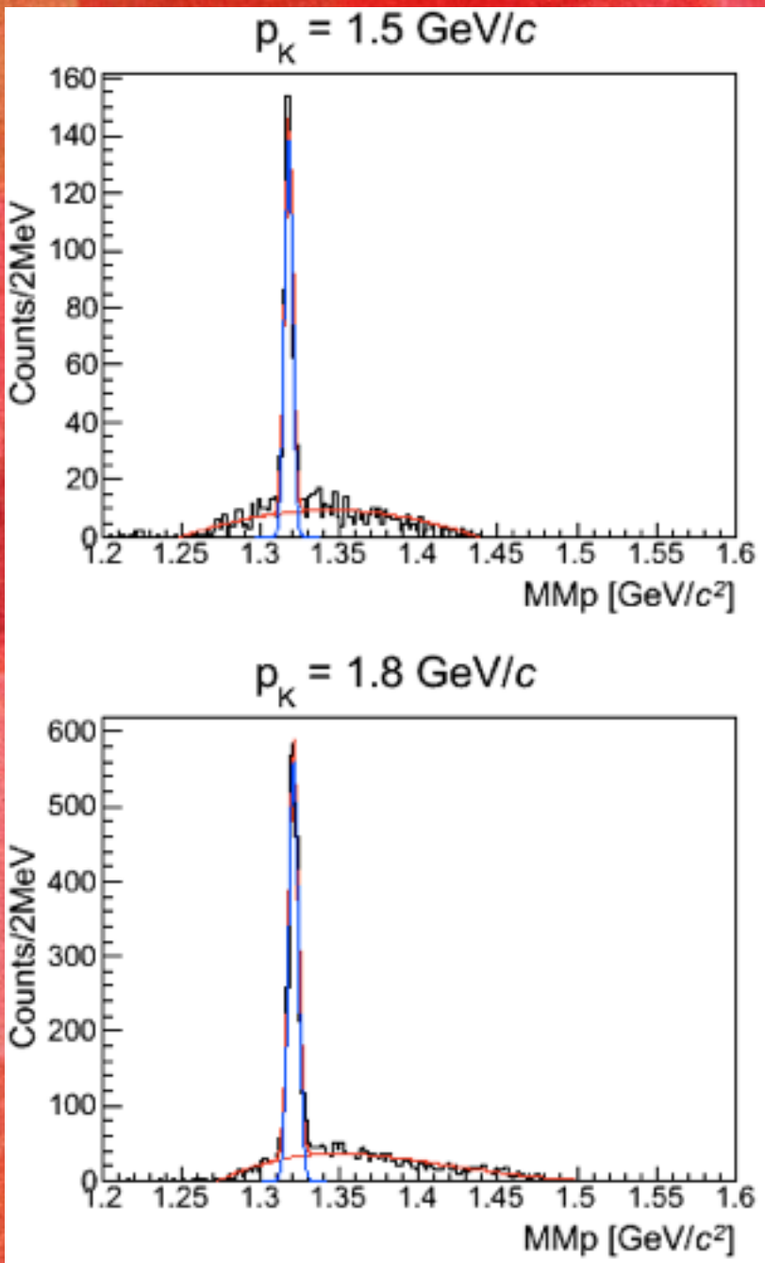


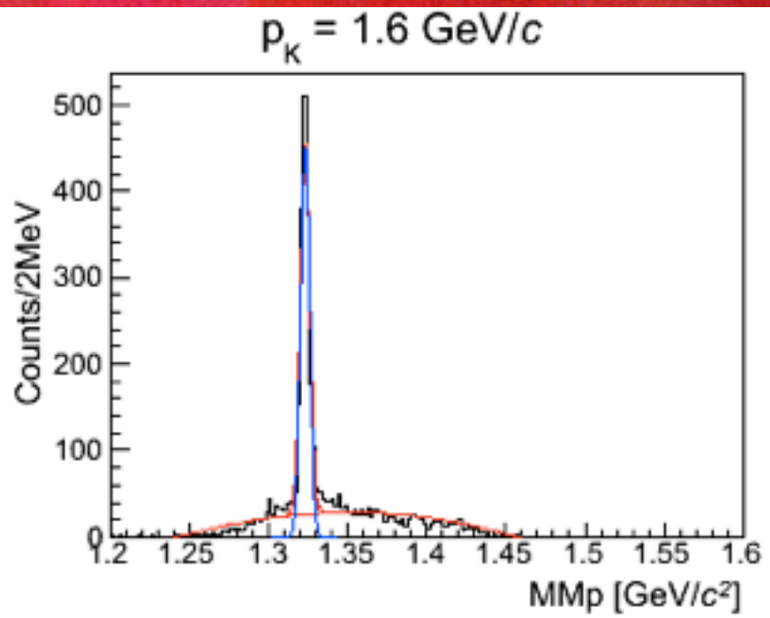
- Two weeks of beam time
  - Detector tuning 1 day
  - $p(K^-,K^+)\Xi^-$@1.5-1.9 GeV/c 2 days
  - $^{12}C(K^-,K^+)$ >10 days

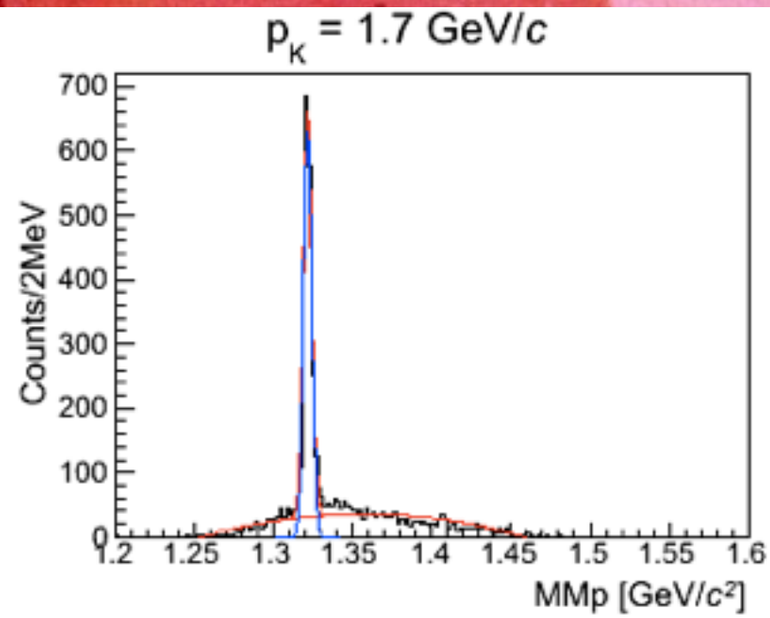
Comparison of Spectrometers

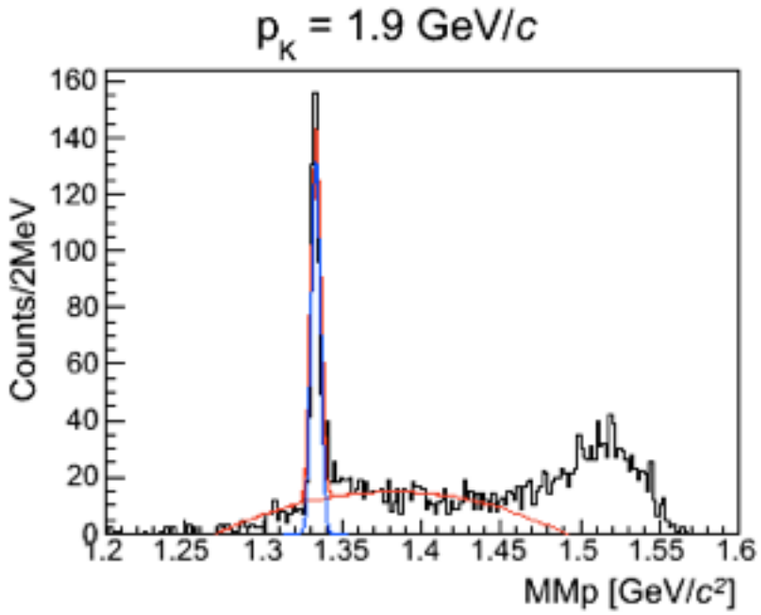
	ΔΩ (msr)	ΔE (MeV)
BNL	19	14
SKS’	110	5
S-2S	60	1.5

Ξ production from CH2



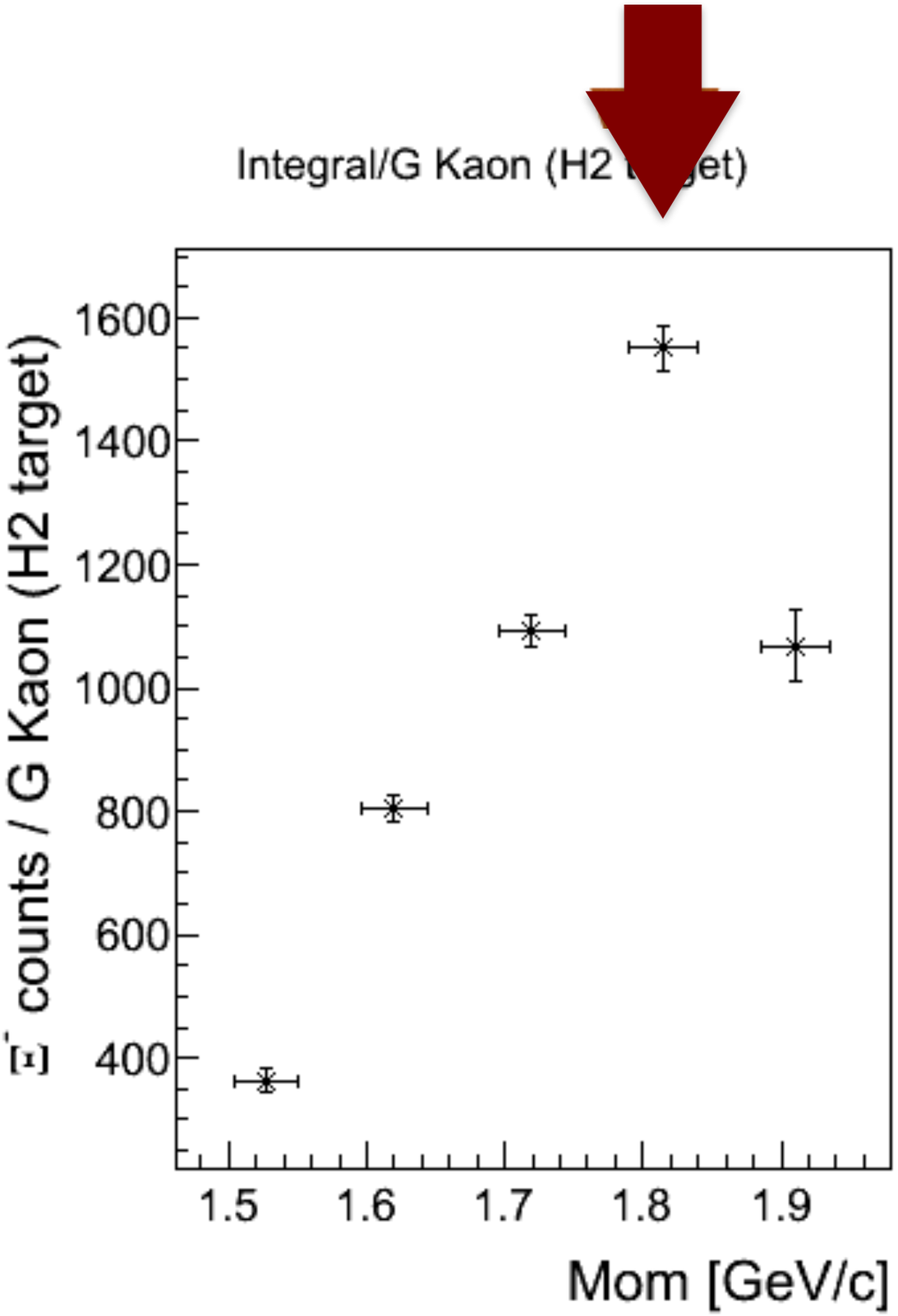






$\Delta E \sim 6\ MeV\ fwhm$

YIELD MAXIMUM ?



- Pinc=1.8 GeV/c is the optimum as expected !!
- Ξ production rate:
  - ~6000 Ξ's/day
  - ⇅
  - ~4000/day @BNL


Run #64, 65
完遂
100G Kaon達成！
KEEP
CALM

Summary

- S-2S construction is almost completed.
  - waiting for installation in JFY2017.
- Pilot run of E05 was successfully carried out with SKS.
  - Elementary cross section + $^{12}C(K^-,K^+)$