

Search for Ξ Hypernucleus via the (K^-, K^+) Reaction

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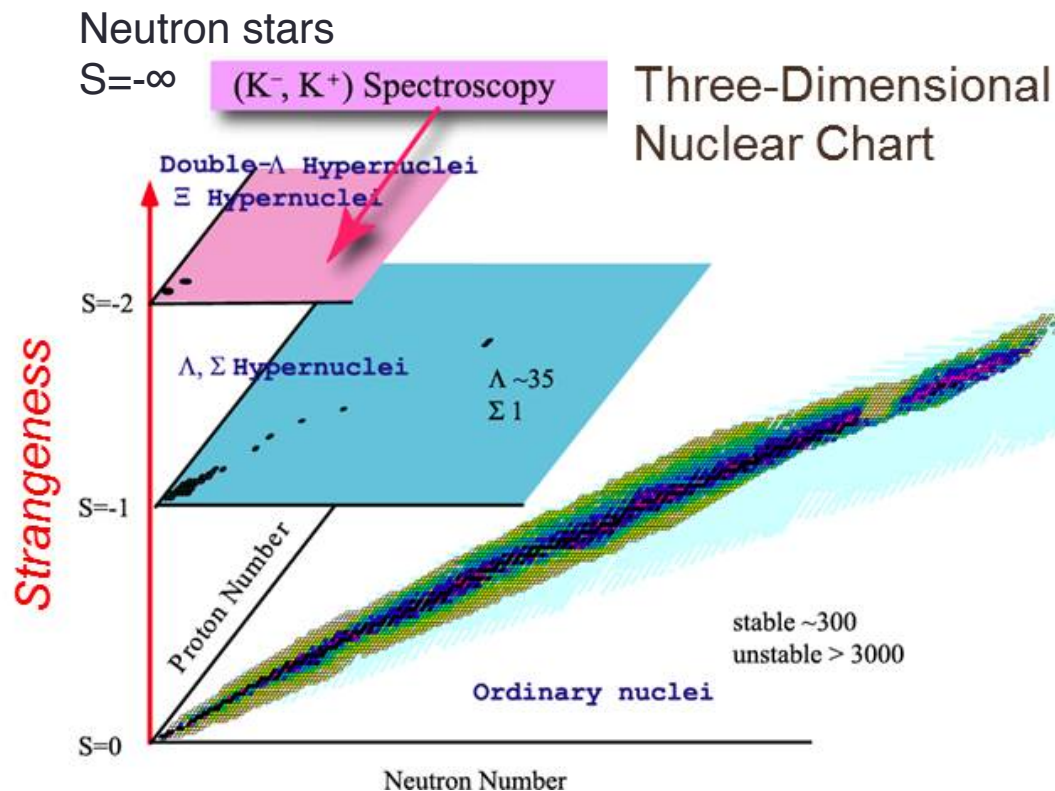
Search for Ξ Hypernucleus via the $^{12}\text{C}(K^-, K^+)$ Reaction

- Introduction
 - KEK-E373 & BNL-E885
- J-PARC E05: $^{12}\text{C}(K^-, K^+)$
 - Motivation and Plan
 - Phase 1: Pilot run with SKS in 2015/Oct-Nov
 - Analysis status
 - Phase 2: High-resolution with S-2S
 - Construction status
- Summary

Introduction

Motivation of Hypernuclear Study

- Baryon-baryon interaction ← Generalization Nuclear force
- A role of strangeness in dense nuclear matter



• $S=-2$ $\Xi, \Lambda\Lambda$

- A few emulsion events
- Information are limited!

$S=-1$ Λ, Σ

- Reaction spectroscopies
 - (K^-, π^-) , (π^+, K^+) , etc.
 - γ -ray spectroscopy
- ΛN , ΣN interactions

• $S=0$ p, n

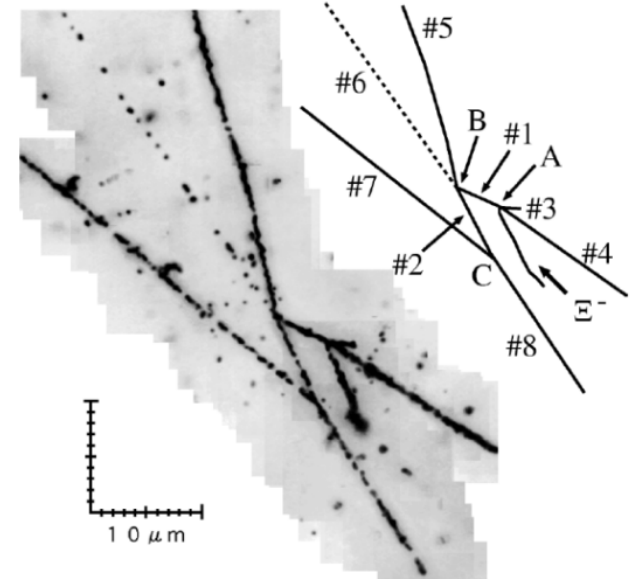
- NN scattering data

KEK-E373: Emulsion exp.

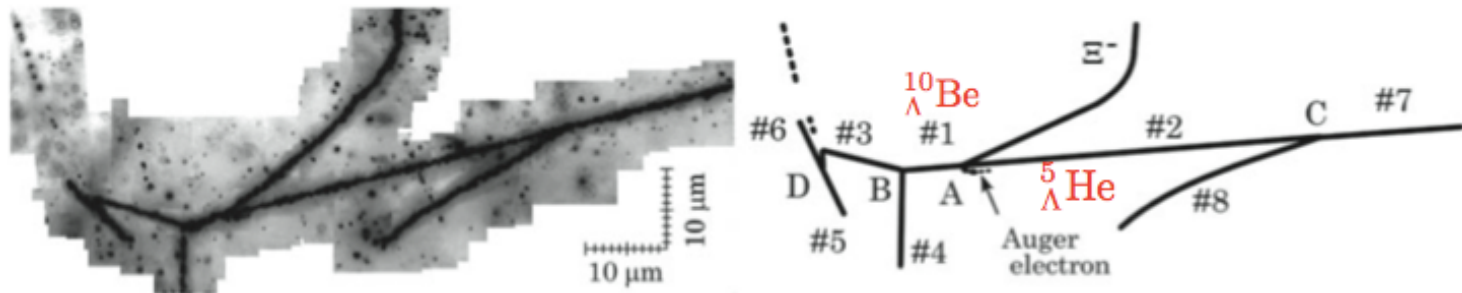
- “NAGARA” event
 - Uniquely identified as $\Lambda\Lambda^6\text{He}$
 - $\Delta B_{\Lambda\Lambda} = 0.67 \pm 0.17 \text{ MeV}$
weakly attractive

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

H. Takahashi et al., PRL 87 (2001) 212502

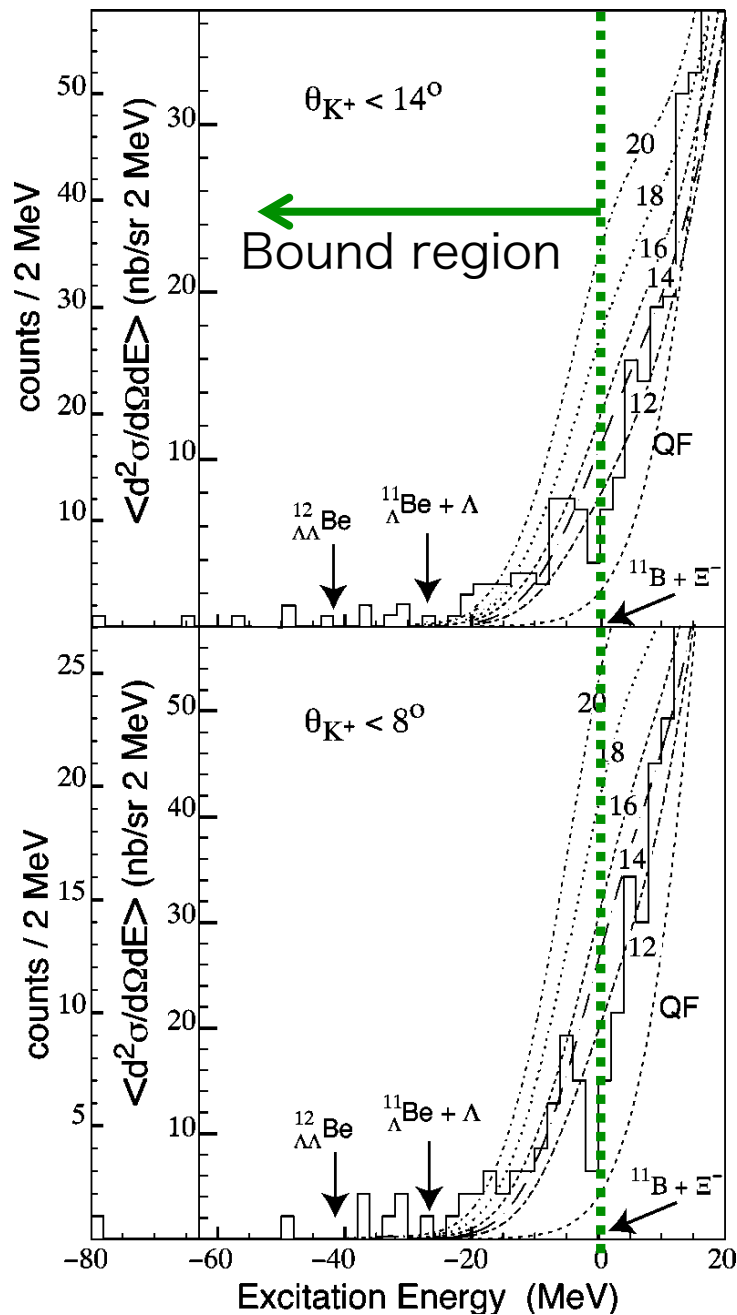


- “KISO” event
 - $\Xi^-^{14}\text{N}$ system
 - $\Xi^- + ^{14}\text{N} \rightarrow ^{10}\Lambda\text{Be} + ^5\Lambda\text{He}$
 - $B_{\Xi} = 1.11 \sim 4.38 \pm 0.25 \text{ MeV} \pm \Gamma/2$



K. Nakazawa et al., PTEP (2015) 3, 033D02

BNL-E885

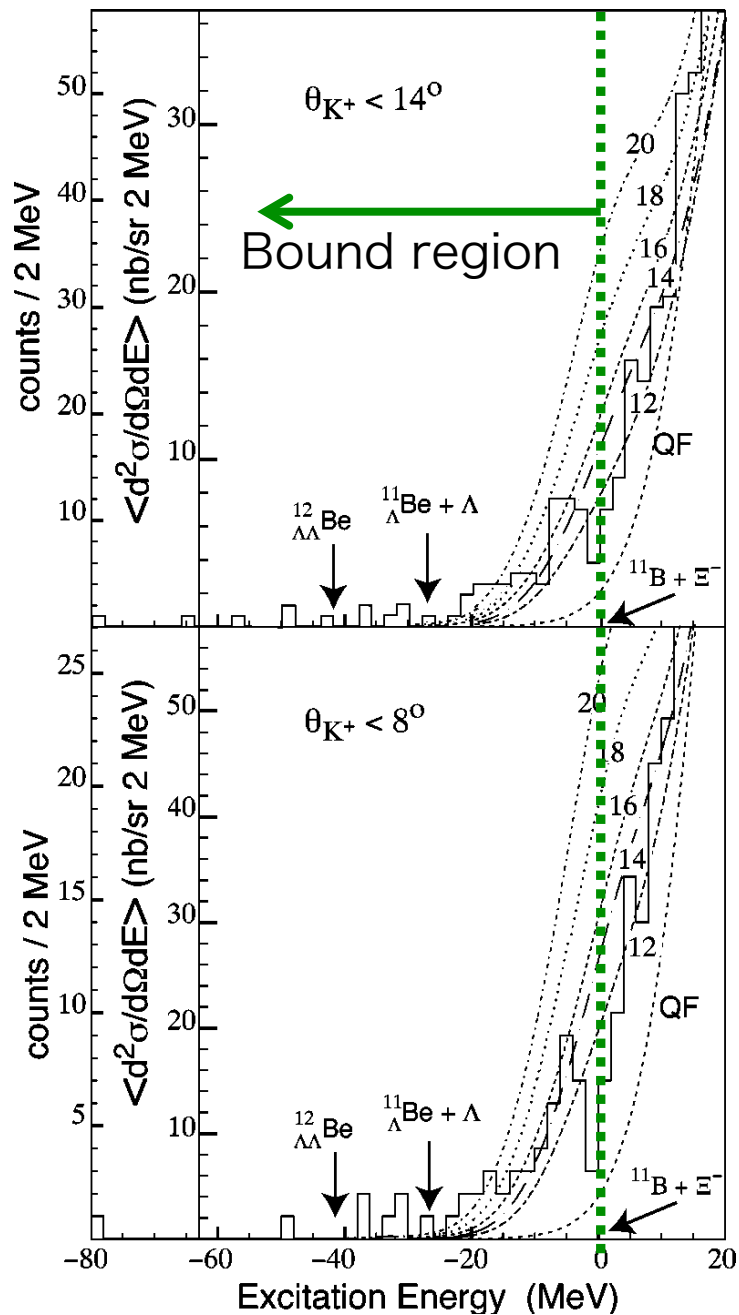


P. Khaustov et al., PRC 61 (2000) 054603

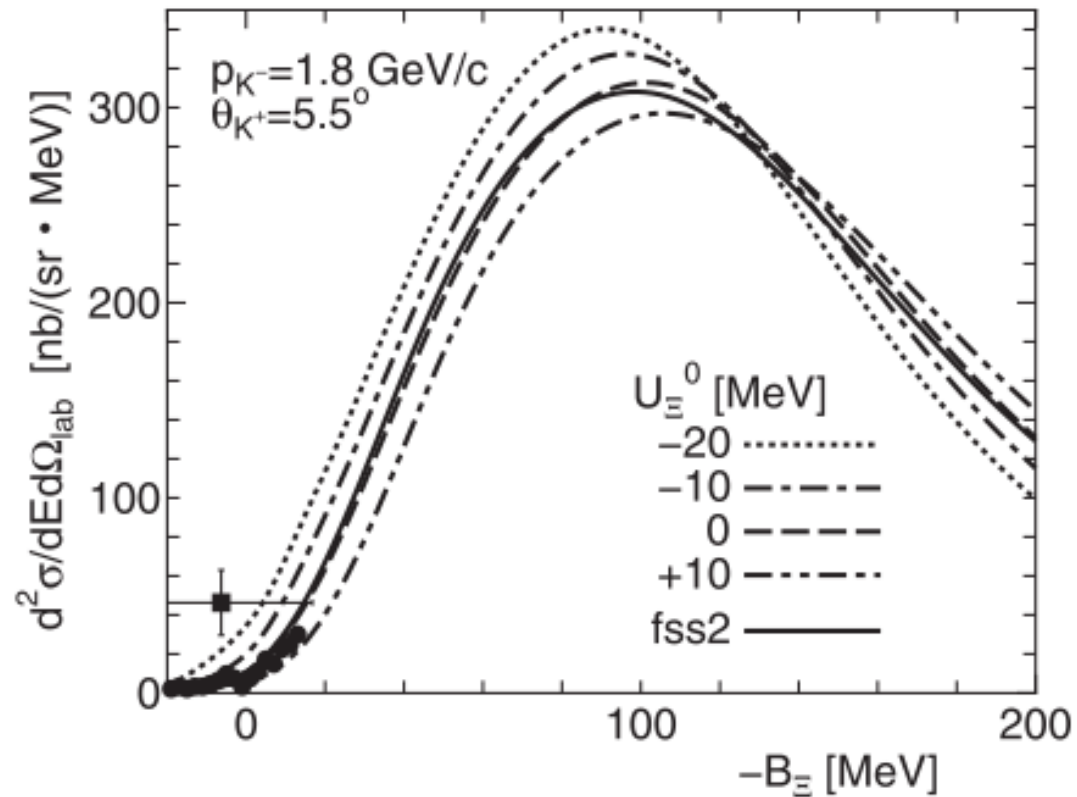
- $^{12}\text{C}(K^-, K^+)^{12}_{\Xi}\text{Be}$
- No clear evidence of a bound state due to poor resolution
 - $\Delta E \sim 14 \text{ MeV}_{\text{FWHM}}$
- $d\sigma/d\Omega$ ($-20 < E < 0 \text{ MeV}$)
 - $\theta < 14^\circ$: 67 events, $42 \pm 5 \text{ nb/sr}$
 - $\theta < 8^\circ$: 42 events, $89 \pm 14 \text{ nb/sr}$
- suggest $V_{\Xi} \sim -14 \text{ MeV}$
 - assuming woods-saxon type potential and **imaginary part = 0**

BNL-E885

The spectrum can be explained with $V_{\Xi} = 0$ MeV, $\Gamma = 4$ MeV

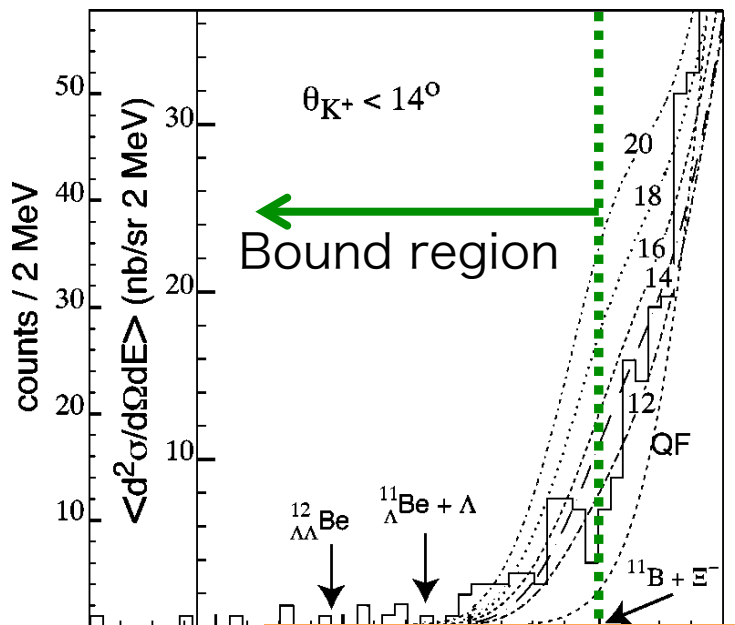


P. Khaustov et al., PRC 61 (2000) 054603



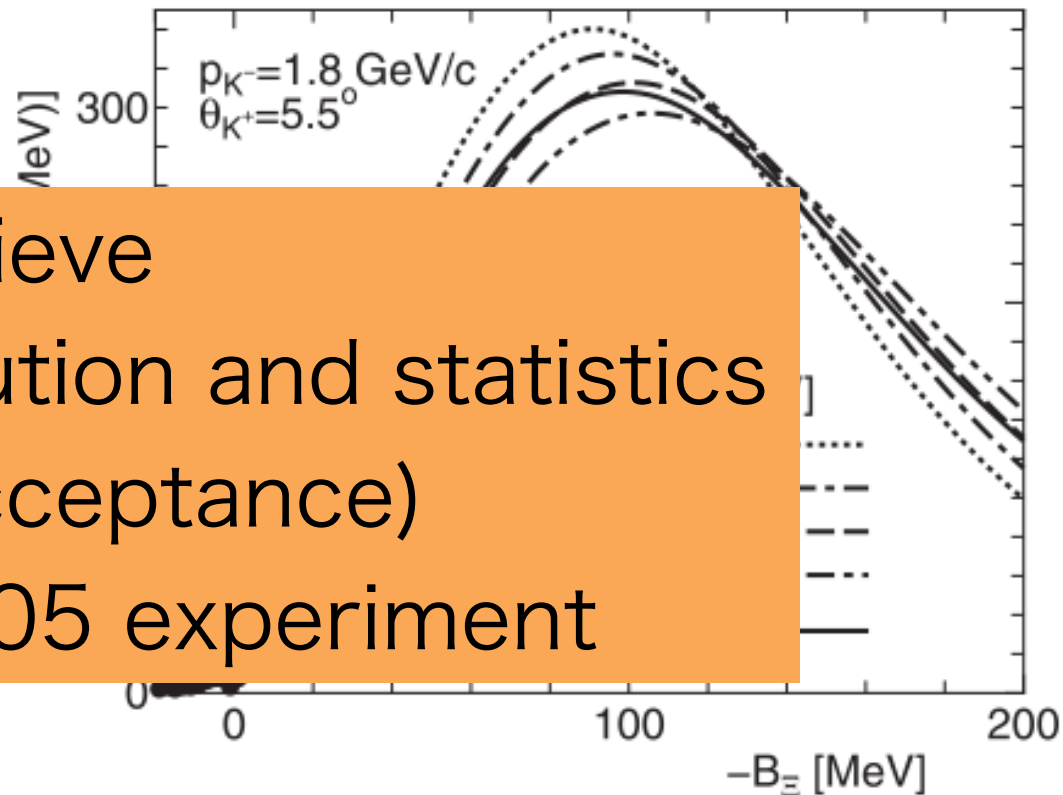
M. Kohno and S. Hashimoto, PTP 123 (2010) 1
 (ΔE_{exp} is taken into account)

BNL-E885



The spectrum can be explained with $V_{\Xi} = 0$ MeV, $\Gamma = 4$ MeV

Need to achieve
better resolution and statistics
(and wide acceptance)
→ J-PARC E05 experiment



M. Kohno and S. Hashimoto, *PTP* 123 (2010) 1
(ΔE_{exp} is taken into account)

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

J-PARC E05

J-PARC E05

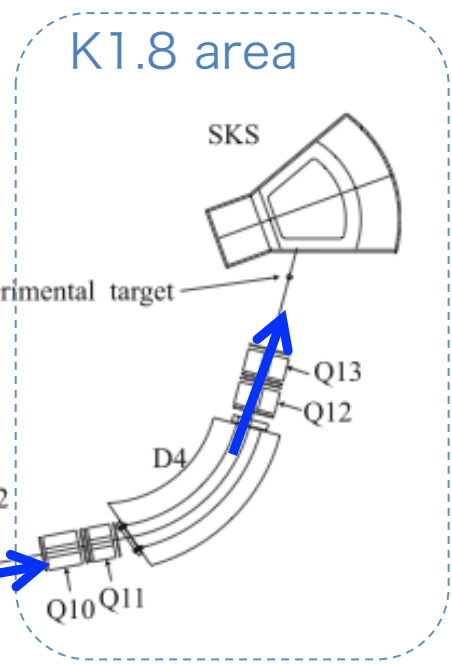
- Missing-mass spectroscopy of $^{12}_{\Xi}\text{Be}$
 - $^{12}\text{C}(K^-, K^+)$ reaction at 1.8 GeV/c
 - $^{12}_{\Xi}\text{Be} = ^{11}\text{B} + \Xi^- \rightarrow$ bound or not?
- High-intensity kaon beam at K1.8 beam line
- High resolution spectrometers
 - Observe Ξ -hypernuclei as a peak(s)
 - Peak position and width
 - Ξ -nucleus potential depth and width

K1.8 Beam line

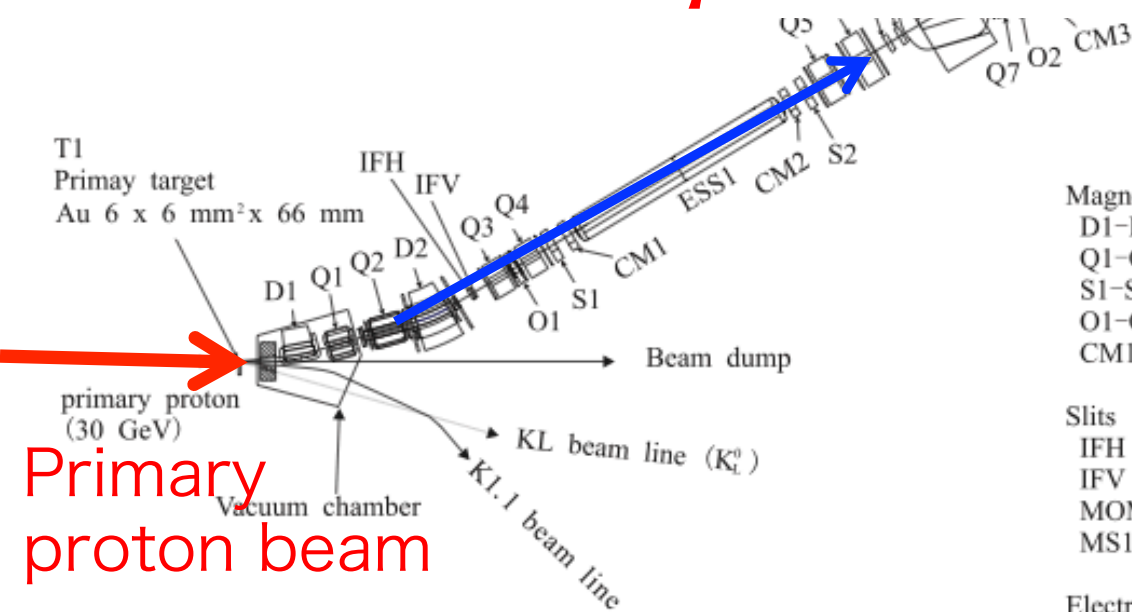
Intensity: $1.1 \times 10^5 K^-/s$
 2015 Nov, 39kW



Start $S=-2$ experiments!



Total length 46 m



Secondary kaon beam

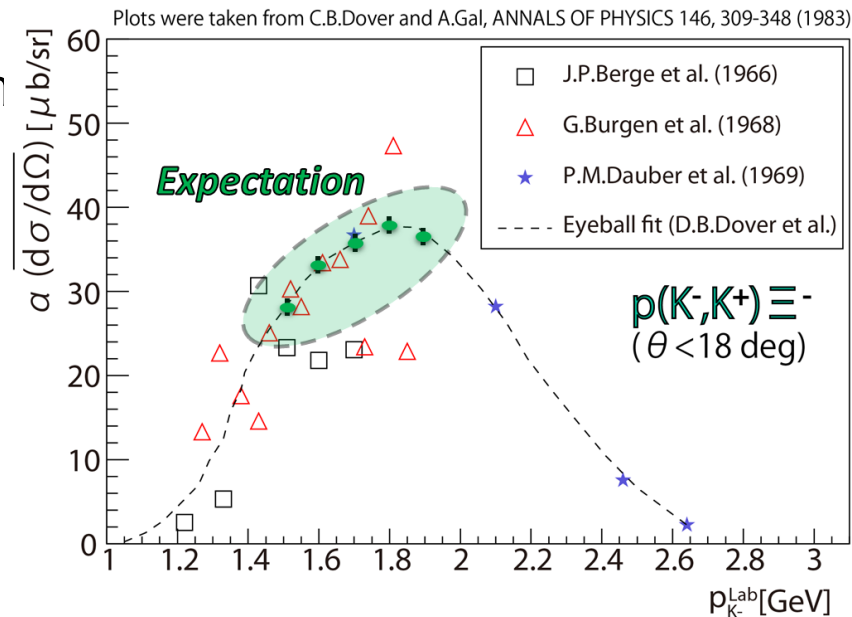
- | | | |
|--------------------------|-----------------------------|------------|
| Magnets | | |
| D1-D4 | Dipoles | |
| Q1-Q13 | Quadrupoles | |
| S1-S4 | Sextapoles | |
| O1-O2 | Octapoles | |
| CM1-CM4 | Vertically steering dipoles | |
| Slits | | |
| IFH | Intermediate focal point | horizontal |
| IFV | Intermediate focal point | vertical |
| MOM | Momentum slit | horizontal |
| MS1, 2 | Mass slit | vertical |
| Electrostatic separators | | |
| ESS1, 2 | | |

Plan

- Phase 1: Pilot run with SKS spectrometer
 - SKS: existing at K1.8 (BNL-E885)
 - better resolution $\Delta M \sim 6 \text{ MeV}_{\text{FWHM}}$ \longleftrightarrow $14 \text{ MeV}_{\text{FWHM}}$
 - large/wide acceptance 110 msr \longleftrightarrow 50 msr
 - Medium intensity $1.1 \times 10^5 \text{ K}^-/\text{s}$ \longleftrightarrow $2.8 \times 10^5 \text{ K}^-/\text{s}$
 - Data taking: 2015/10-11 \rightarrow the last exp. of SKS at K1.8
- Phase 2: S-2S spectrometer
 - Newly developed for K^+ analysis
 - dp/p 0.05% \rightarrow $\Delta E = 2 \text{ MeV}$
 - Precise analysis of hypernuclear structure
 - Data taking within a few years?

Pilot run

- Carbon target : Hypernucleus
 - Observation of bound state(s), $\Delta E \sim 6 \text{ MeV}_{\text{FWHM}} \leftrightarrow 14 \text{ MeV}_{\text{FWHM}}$ SKS BNL-E885
 - Shape analysis on overall QF spectrum ($E_x < 300 \text{ MeV}$)
 - Ξ -nucleus potential
- CH2 target : Elementary process
 - Good data of Ξ - production cross section
 - Input for theoretical calculation
 - Optimization of beam momentum
- Beam time @K1.8 BL
 - 2015/10/26-11/19
 - 100G K^- beams were irradiated on CH2 and Carbon target for Ξ production run



J-PARC E05 Collaboration

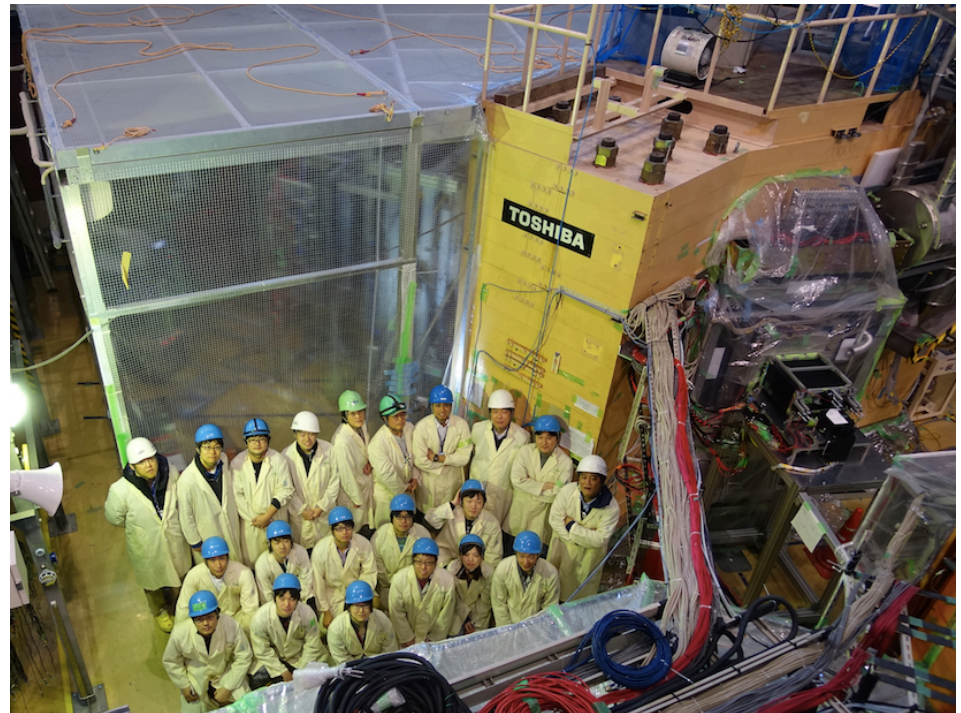
- Kyoto University
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 - Y. Akazawa, M. Fujita, K. Miwa, Y. Sasaki, H. Tamura, Y. Yamamoto
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- Seoul National University
 - J.Y Lee, T. Moon
- Gifu University
 - S. Kinbara
- Kitasato University
 - T. Hasegawa
- RCNP
 - K. Shirotori



2015/11/19 J-PARC K1.8 Counting Room

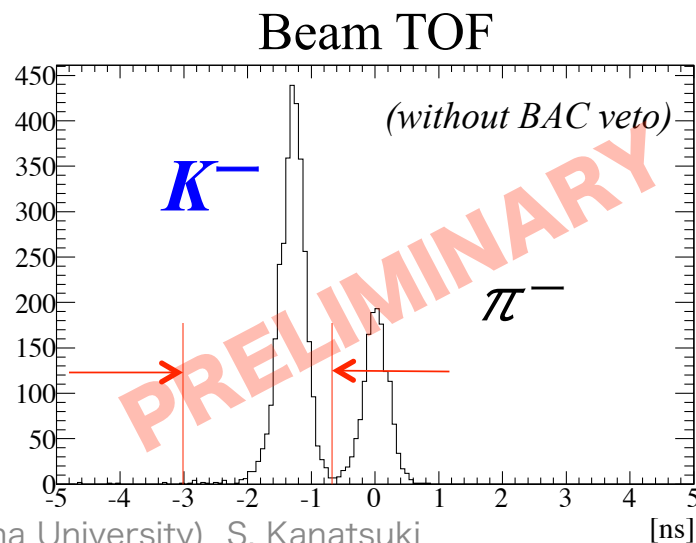
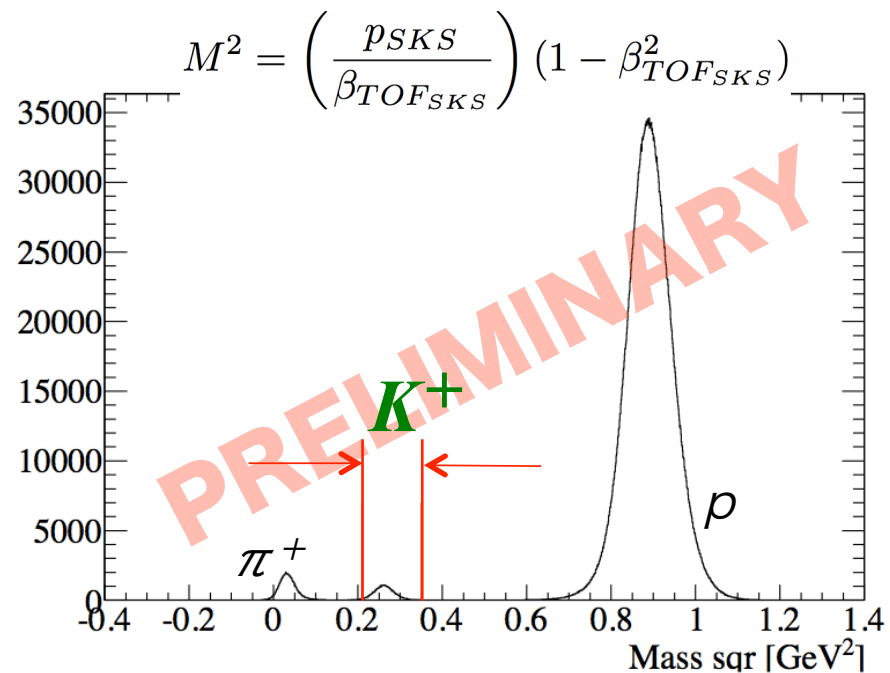
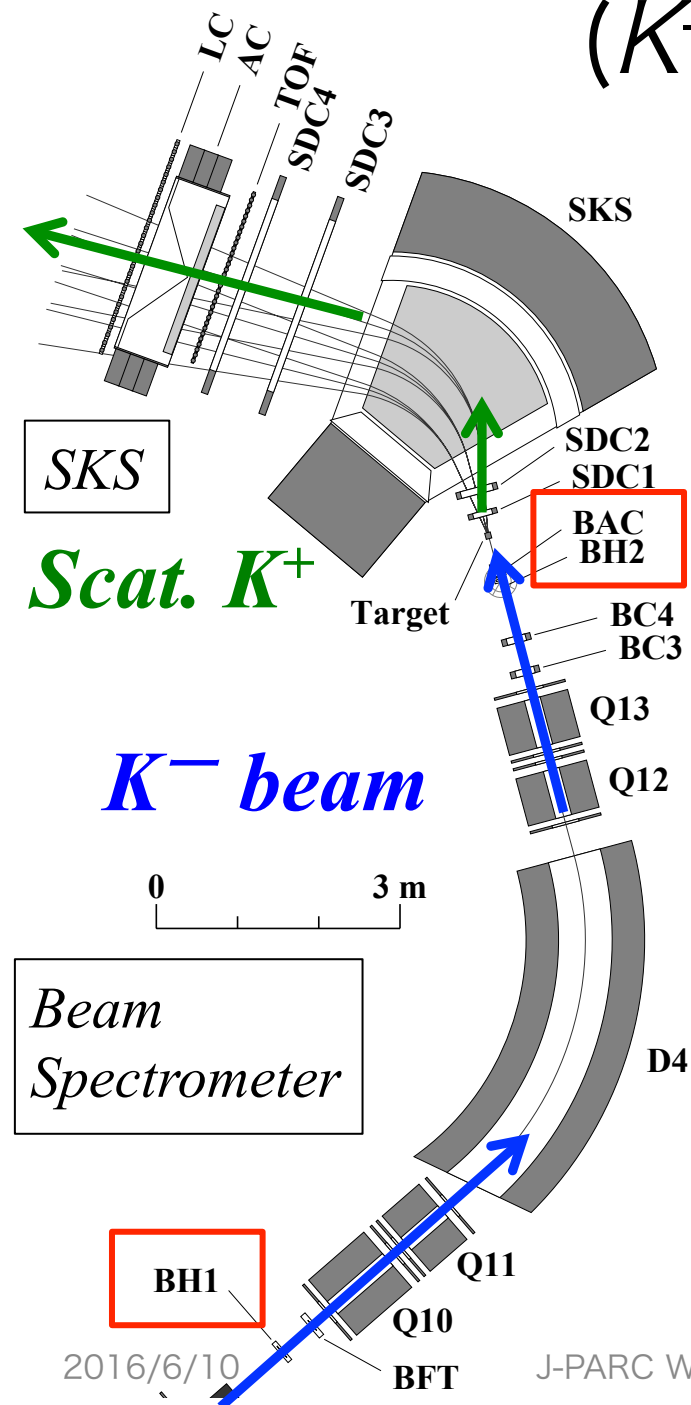
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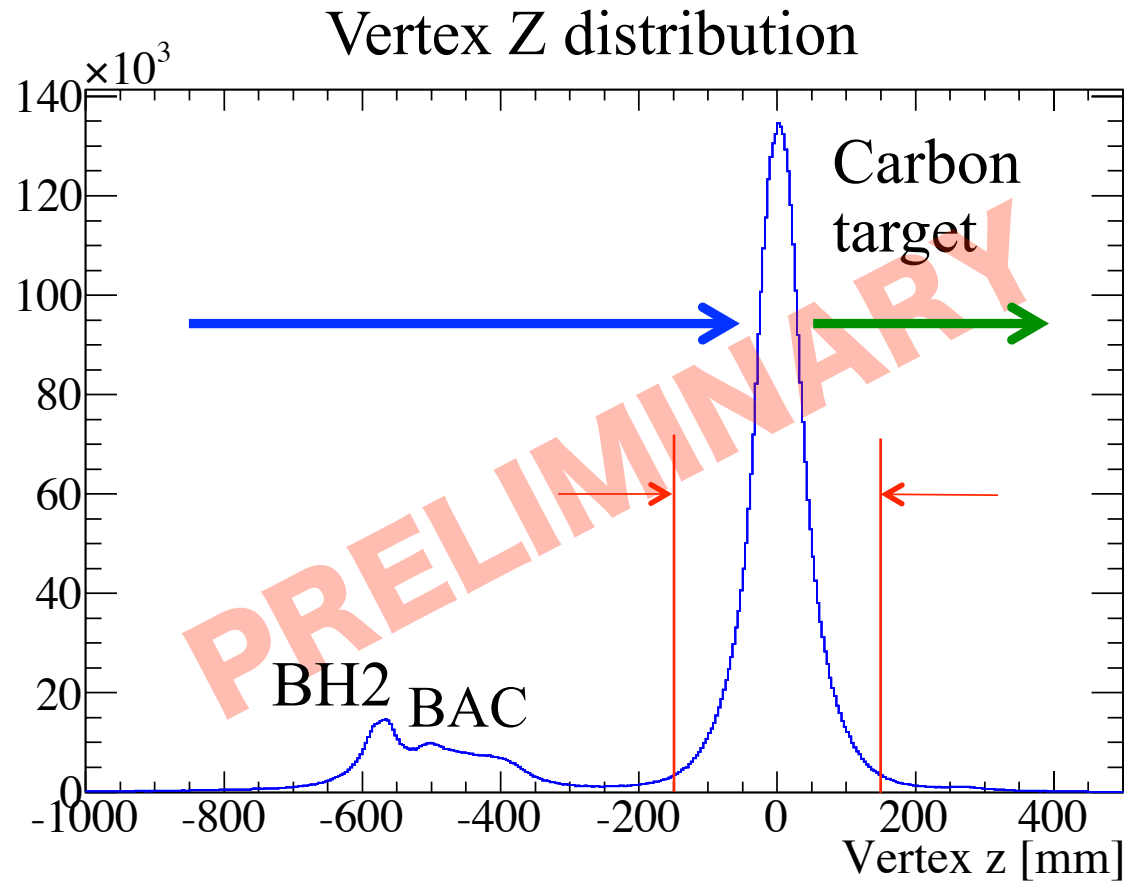
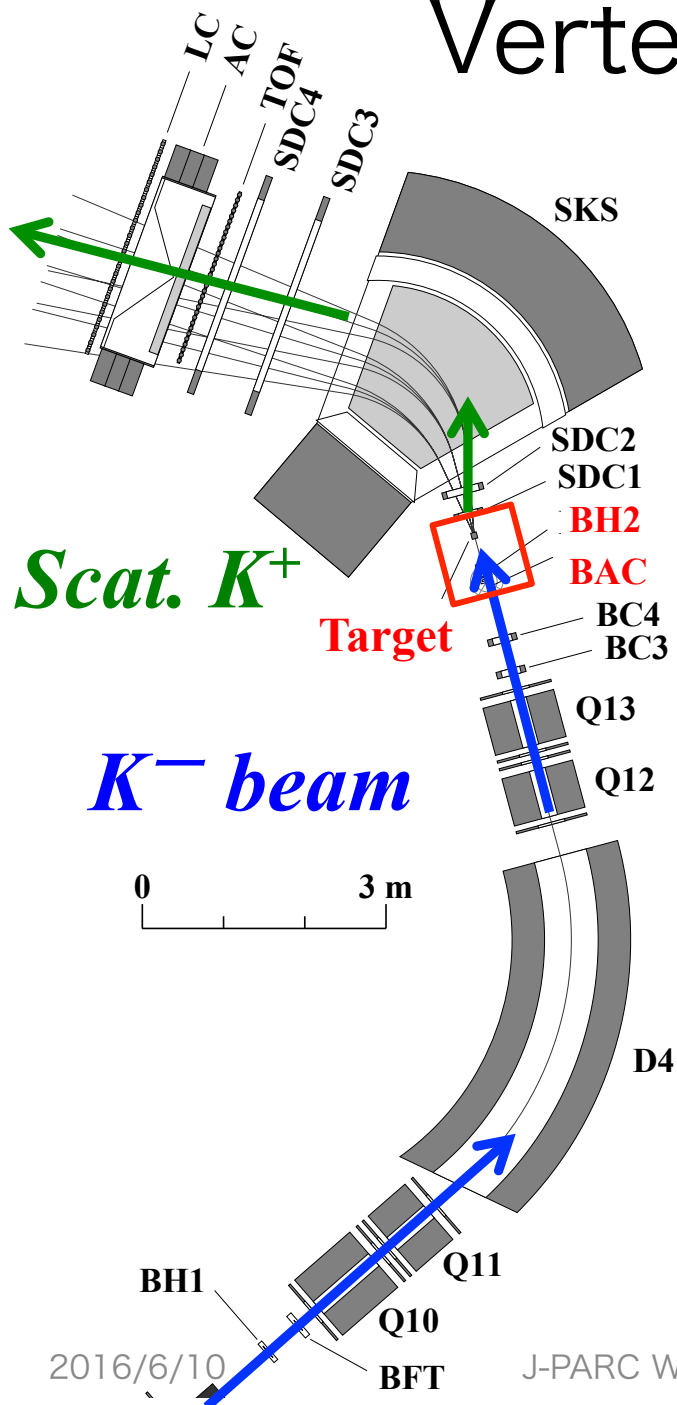


2015/11/19 J-PARC K1.8 Area with SKS

(K^-, K^+) selection



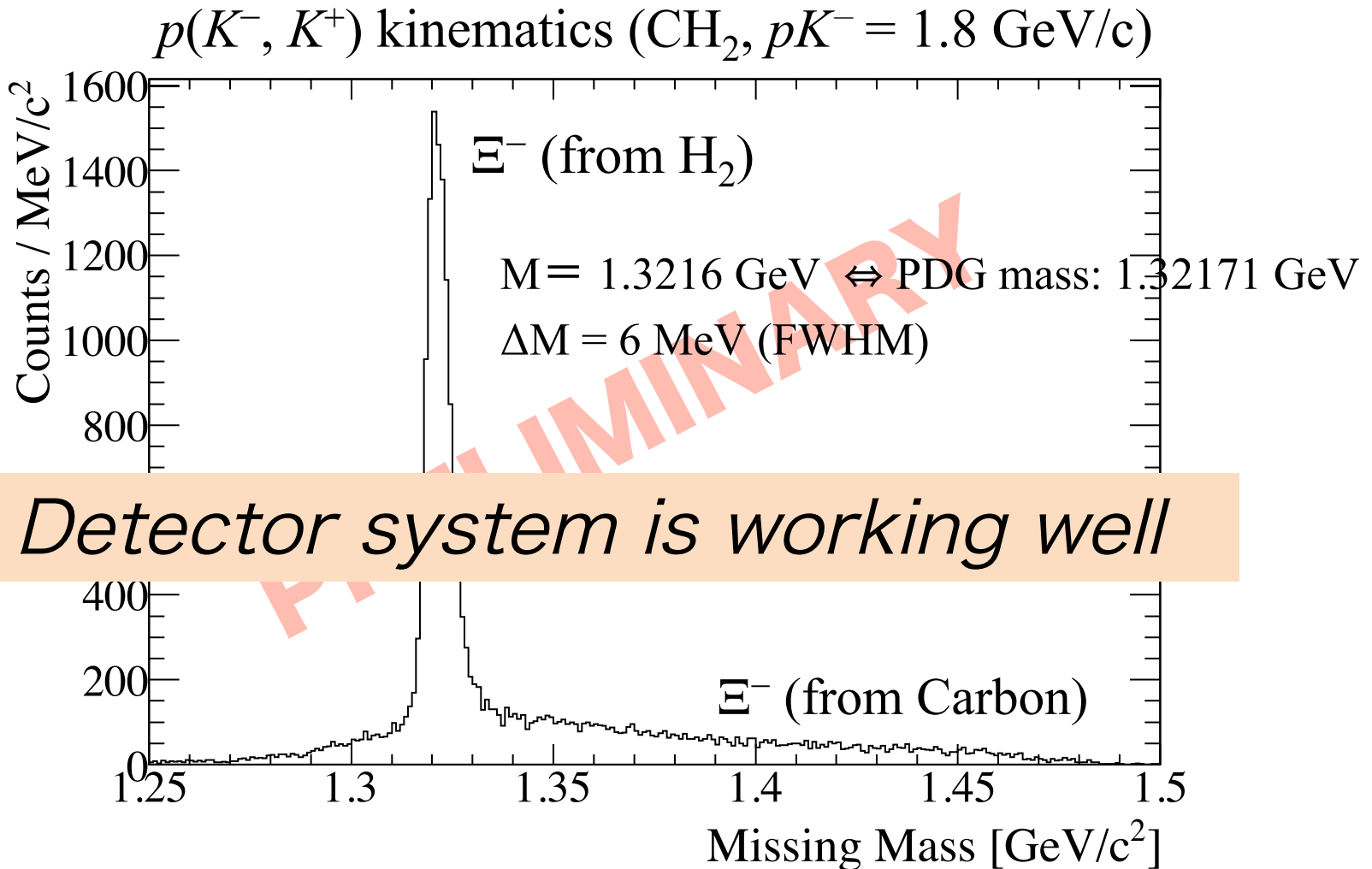
Vertex reconstruction



Target thickness : 9.4 g/cm^2

Ξ^- production

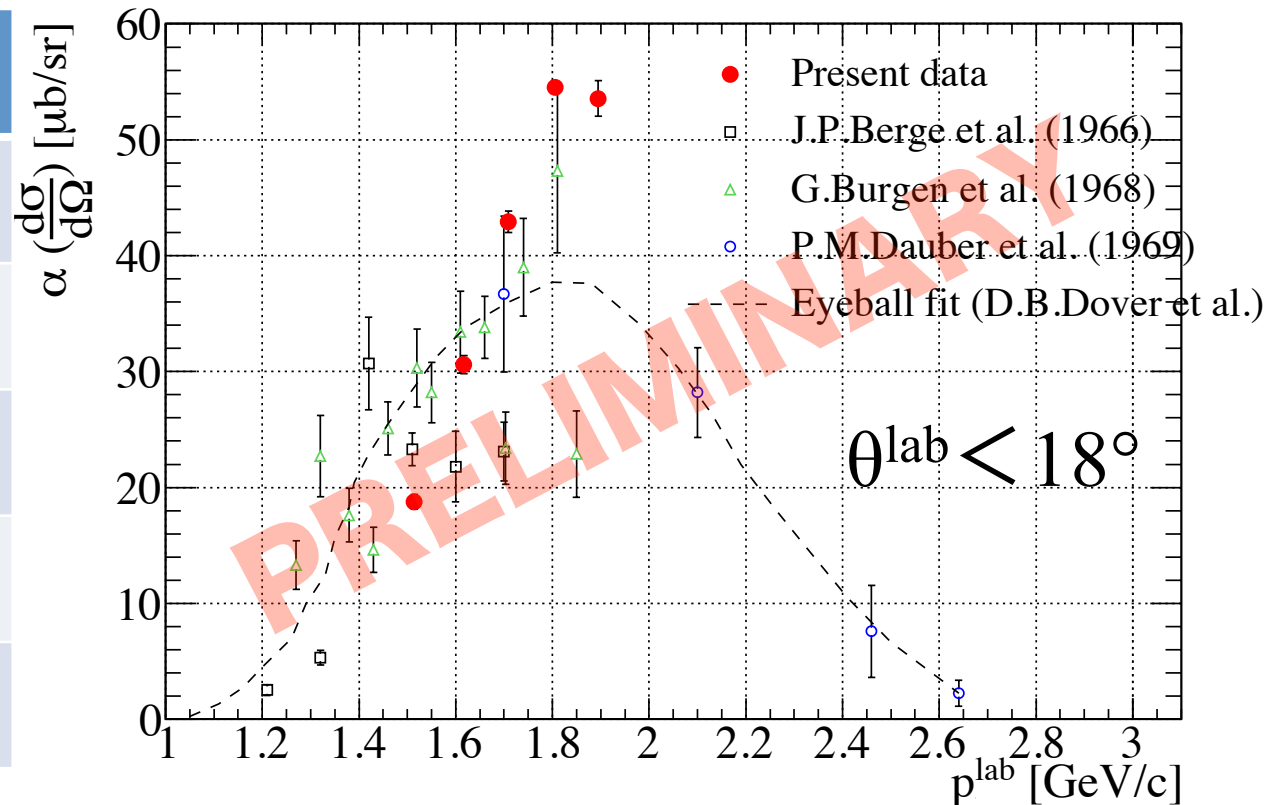
- Missing mass $M^2 = (E_B + m_T - E_S)^2 - (\underline{p_B} - \underline{p_S})^2$



Elementary Ξ^- - yields

- Yield max. at pK^- 1.8 GeV/c
- Enough statistics to obtain momentum and angular distribution

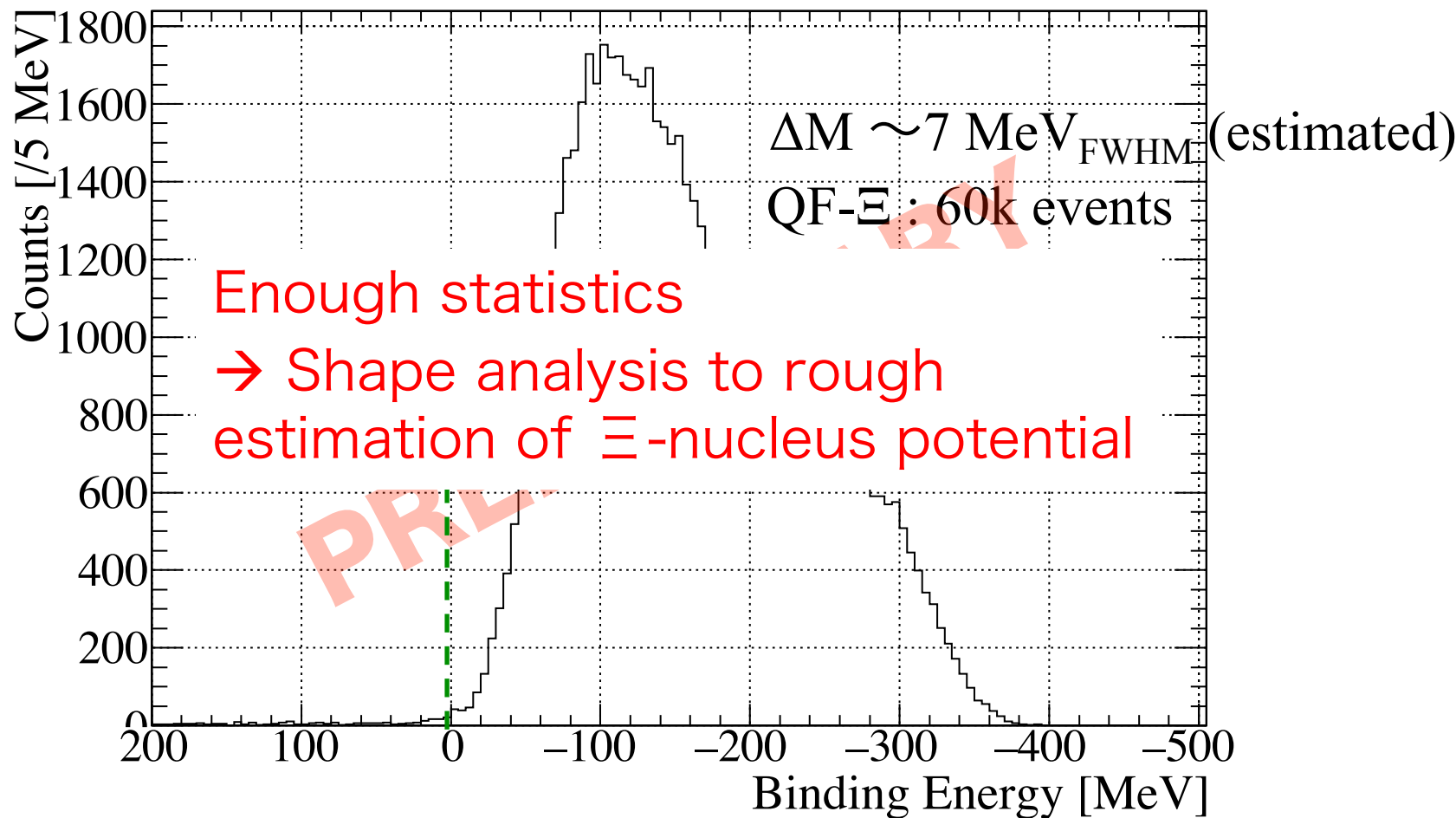
| pK^- [GeV/c] | Counts | Beam [G] |
|-------------------|--------|-------------|
| 1.5 | 844 | 1.9 |
| 1.6 | 1551 | 1.9 |
| 1.7 | 2153 | 1.9 |
| 1.8 | 10061 | 6.6 |
| 1.9 | 1239 | 0.8 |



Present data are normalized arbitrarily
to fit the past data.

Energy spectrum

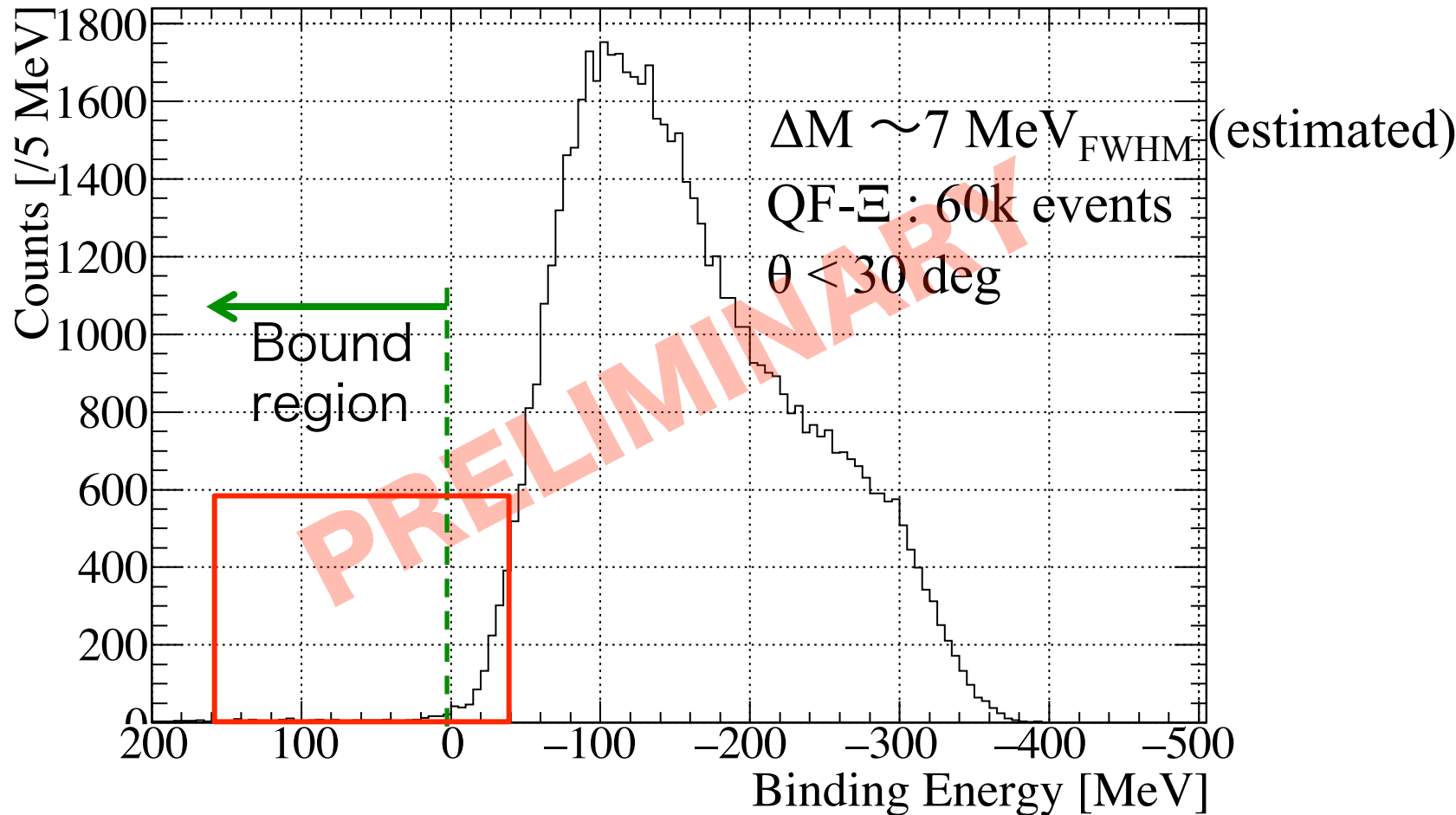
^{12}C (K^- , K^+) kinematics (^{12}C 9.4g/cm 2 , 1.8 GeV/c)



$$\text{Binding energy} = ({}^{11}\text{B}(\text{g.s.}) + \Xi^-) - \text{Missing-mass}$$

Energy spectrum

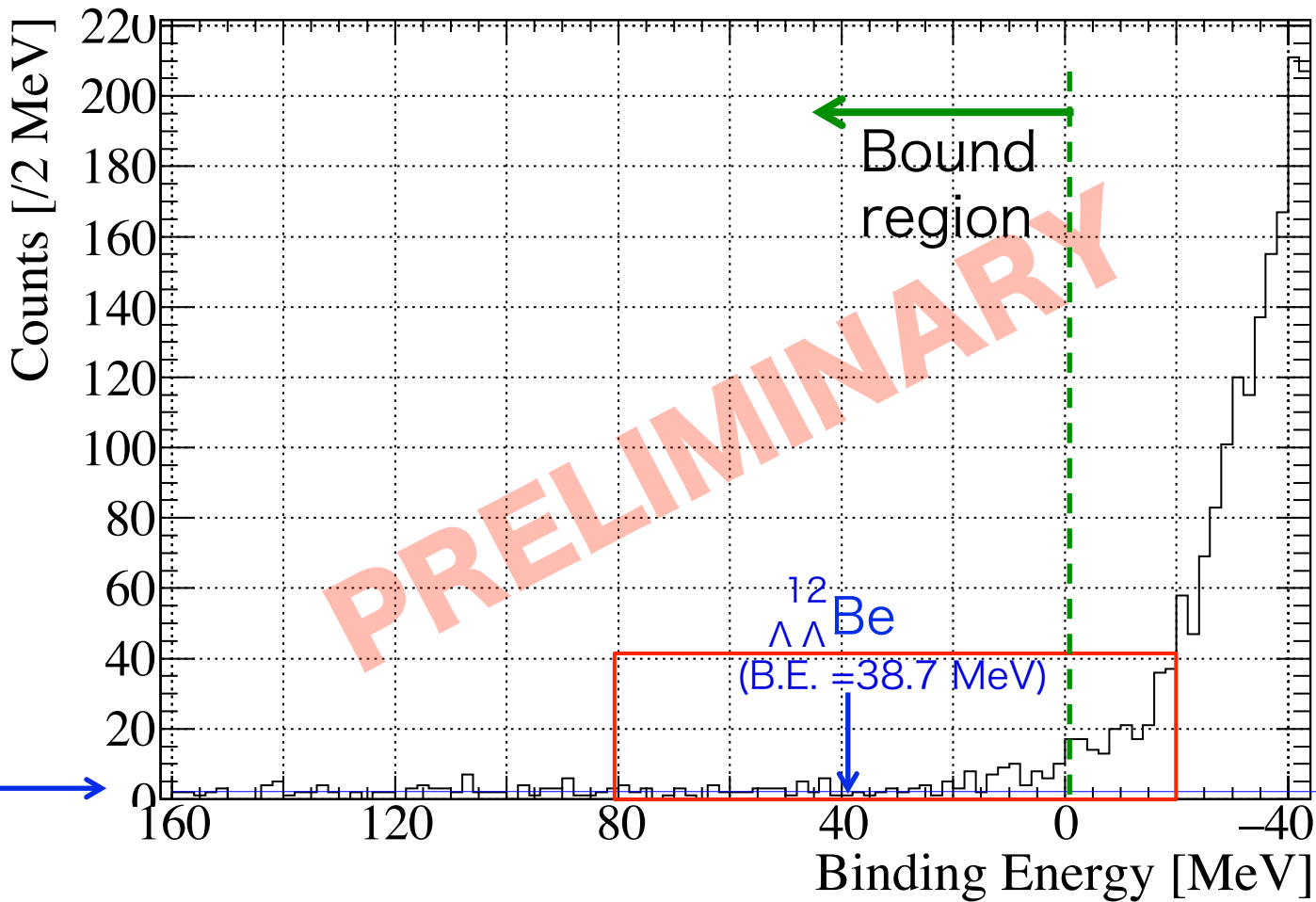
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Energy spectrum

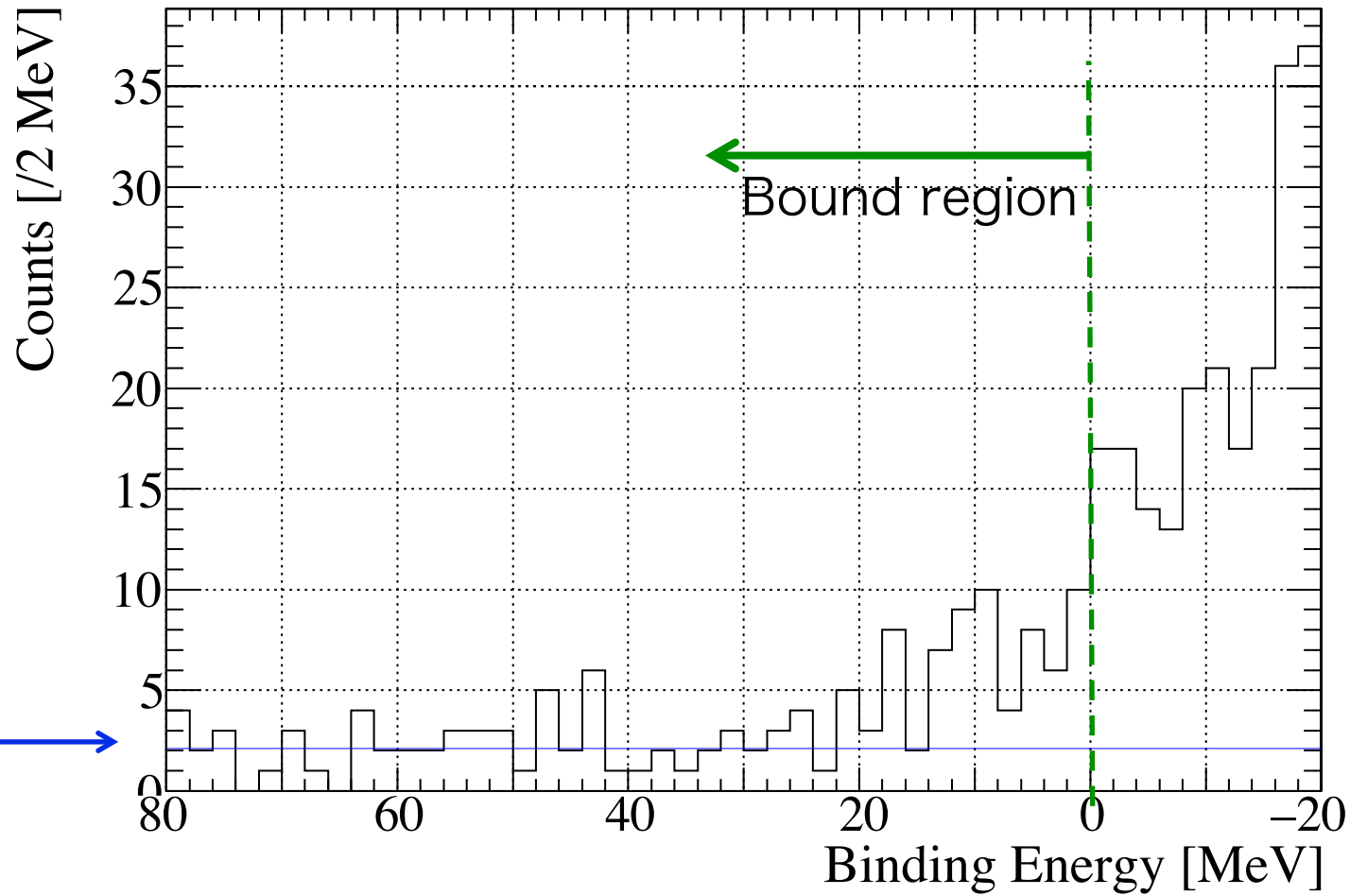
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Background level 2.1 counts/bin (average in 160 ~ 60 [MeV])

Energy spectrum

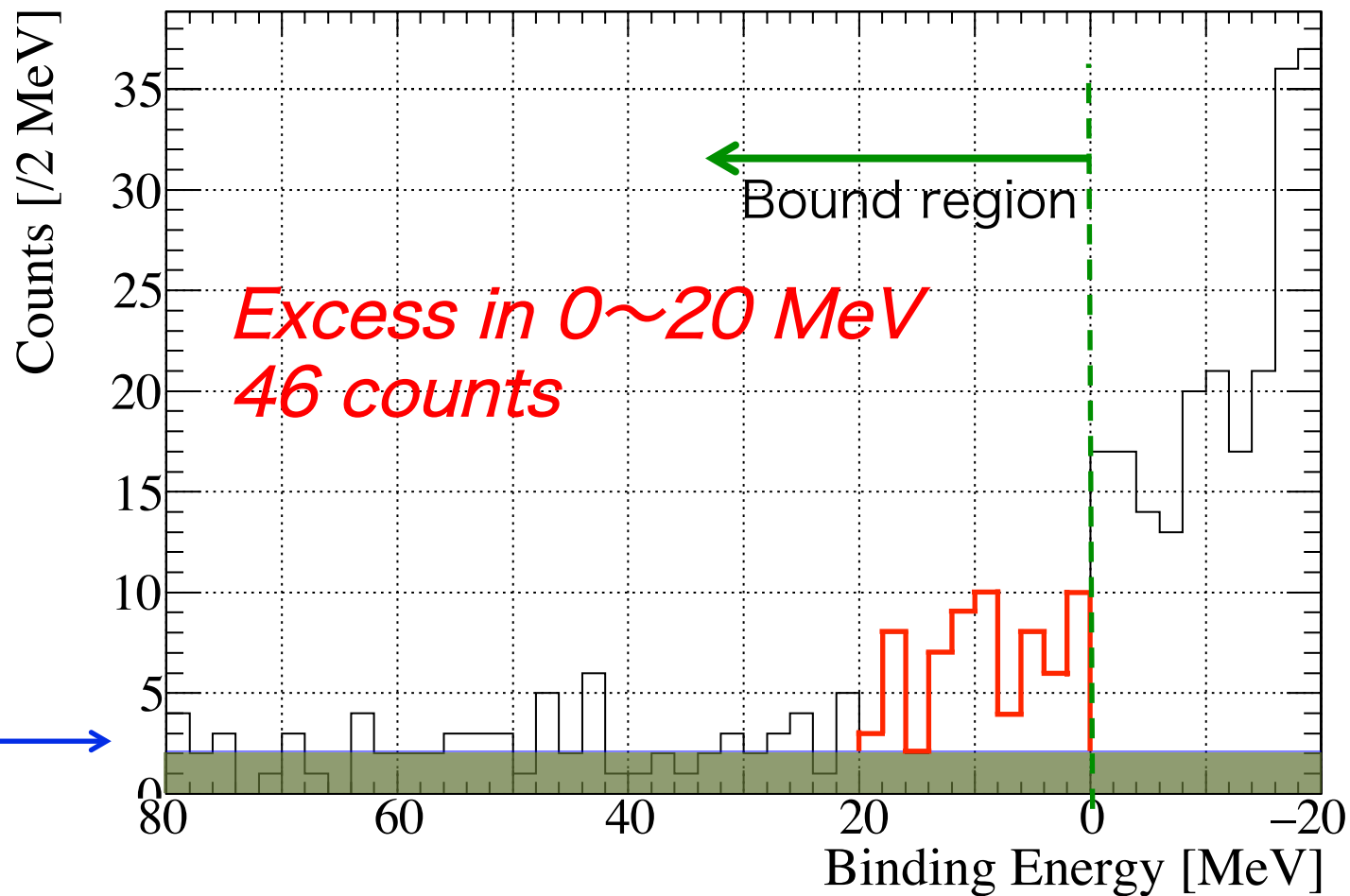
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Energy spectrum

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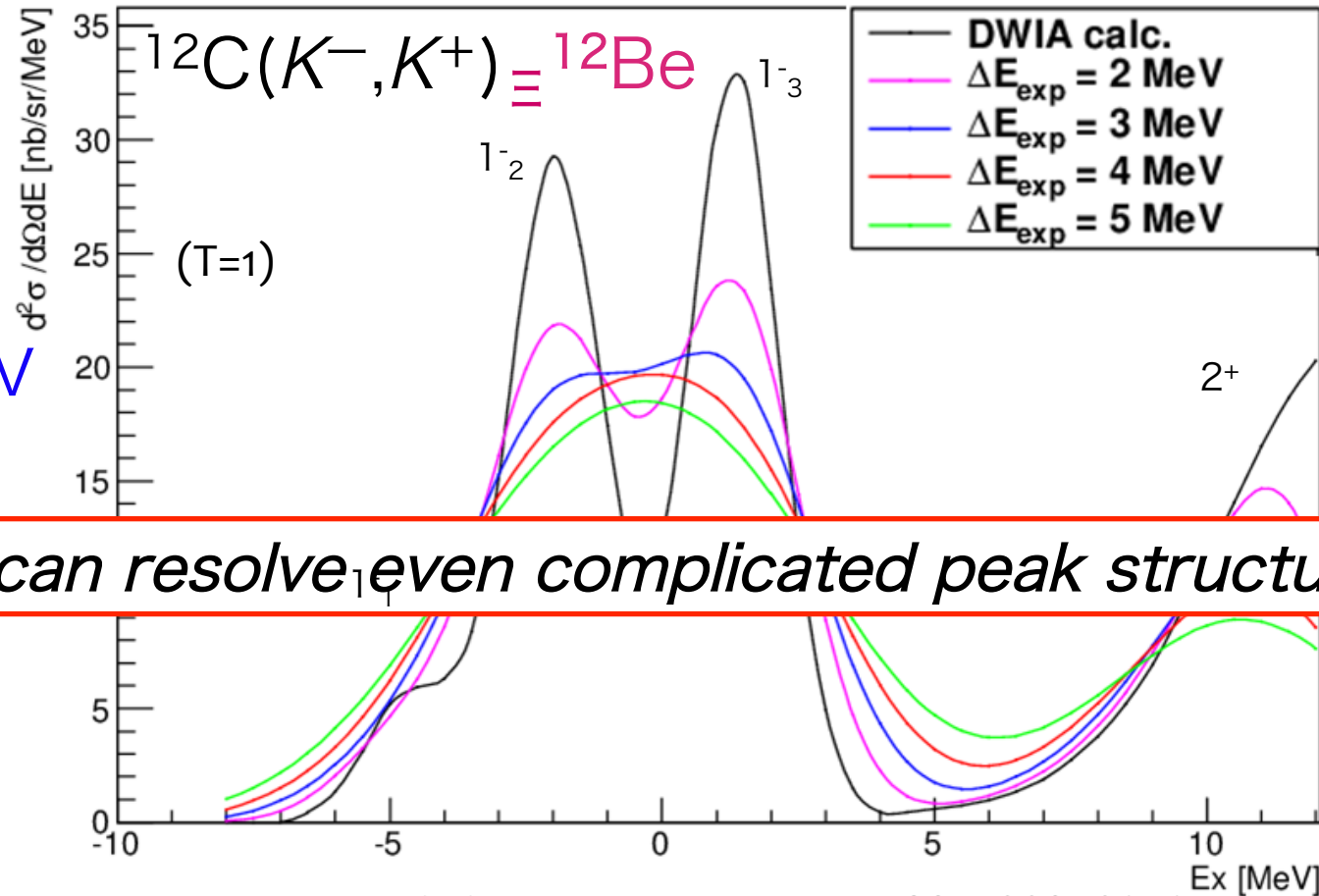
Background level 2.1 counts/bin (average in 160 ~ 60 [MeV])

Prospects

- J-PARC E05 pilot run
 - The first experiment on $S=-2$ at J-PARC
 - Analysis is ongoing
 - ✓ Ξ production: 10k events
 - ✓ QF- Ξ production: 60k events
 - ✓ Excess in the bound region
- 
- ✓ (Diff.) cross section
 - ✓ Shape analysis
 - ✓ Hypernuclear state(s)?
-
- J-PARC E05 Phase2
 - much better $\Delta E_{\text{exp}} = 2$ MeV with S-2S spectrometer
 - precise observation of peak structures
 - ready for installation in 2017 and taking data of the $^{12}\text{C}(K^-, K^+)$ reaction in 2018

Expected spectrum

- DWIA spectrum for ESC08a interaction
- Nuclear core excitation is taken into account.



$\Delta E > 2$ MeV
 \rightarrow 1 peak

S-2S can resolve even complicated peak structure

Black line: *T. Motoba and S. Sugimoto, Nucl. Phys. A 835, 223 (2010)*

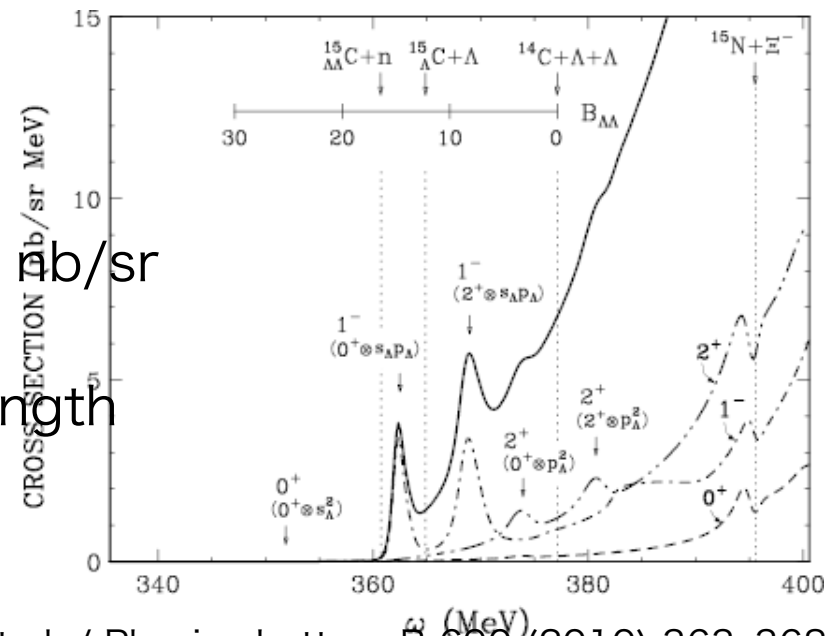
Colored line : calculation convoluted with experimental resolution

Future Extension

- Systematic studies on $S=-2$ hypernuclei
- Various targets
 - Light: ${}^7\text{Li} \rightarrow \Xi^{\prime}{}^7\text{H}(\alpha nn \Xi)$, ${}^{10}\text{B} \rightarrow \Xi^{\prime}{}^{10}\text{Li}(\alpha \alpha n \Xi)$
 - Spin, isospin dependence of ΞN potential
 - Heavy: ${}^{89}\text{Y} \rightarrow \Xi^{\prime}{}^{89}\text{Rb}$, etc.
 - A dependence

$$V_{\Xi N} = V_0 + \sigma \cdot \sigma V_{\sigma \cdot \sigma} + \tau \cdot \tau V_{\tau \cdot \tau} + (\sigma \cdot \sigma)(\tau \cdot \tau)V_{\sigma \cdot \sigma \tau \cdot \tau}$$

- Double Λ -hypernuclei
 - via Ξ doorway in the ${}^{16}\text{O}(K^-, K^+)$ at 1.8 GeV/c
 - $d\sigma/d\Omega$ is expected to be a several nb/sr
 - Excited states
 - Sensitive to $\Xi\text{N}-\Lambda\Lambda$ coupling strength

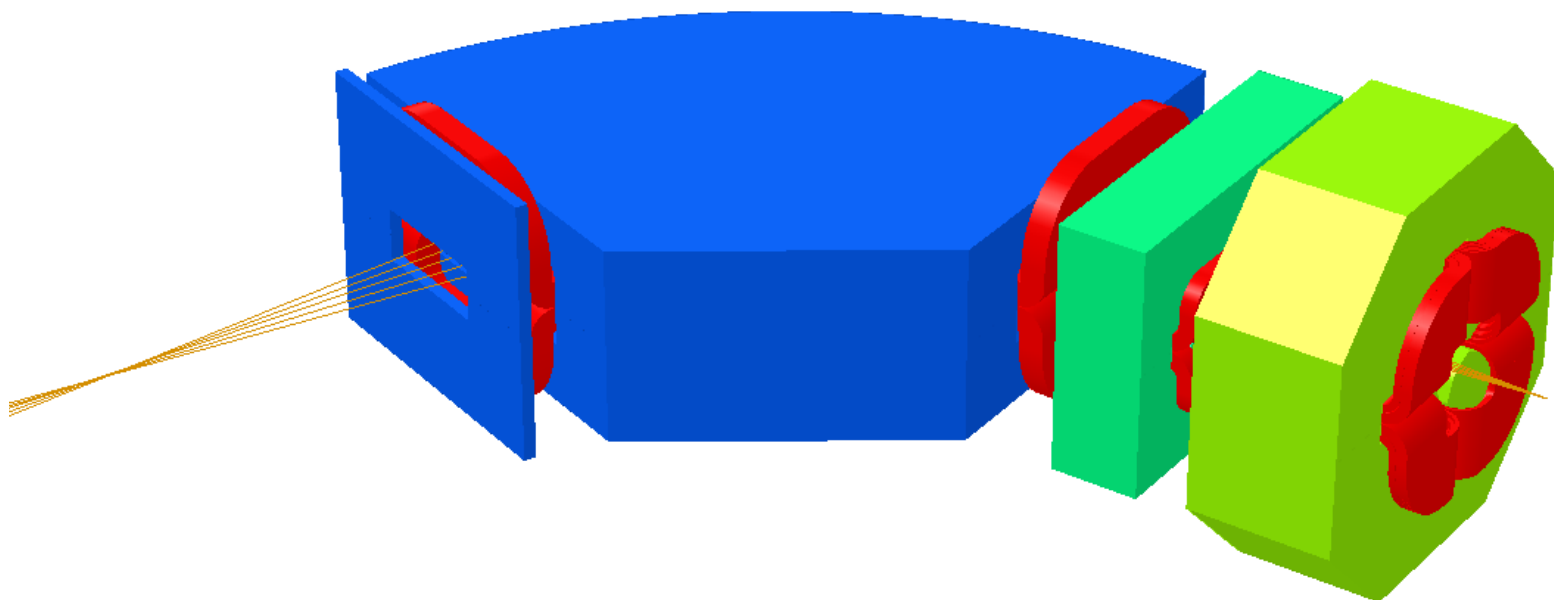


T. Harada et al. / Physics Letters B 690 (2010) 363–368

Construction of S-2S

S-2S spectrometer

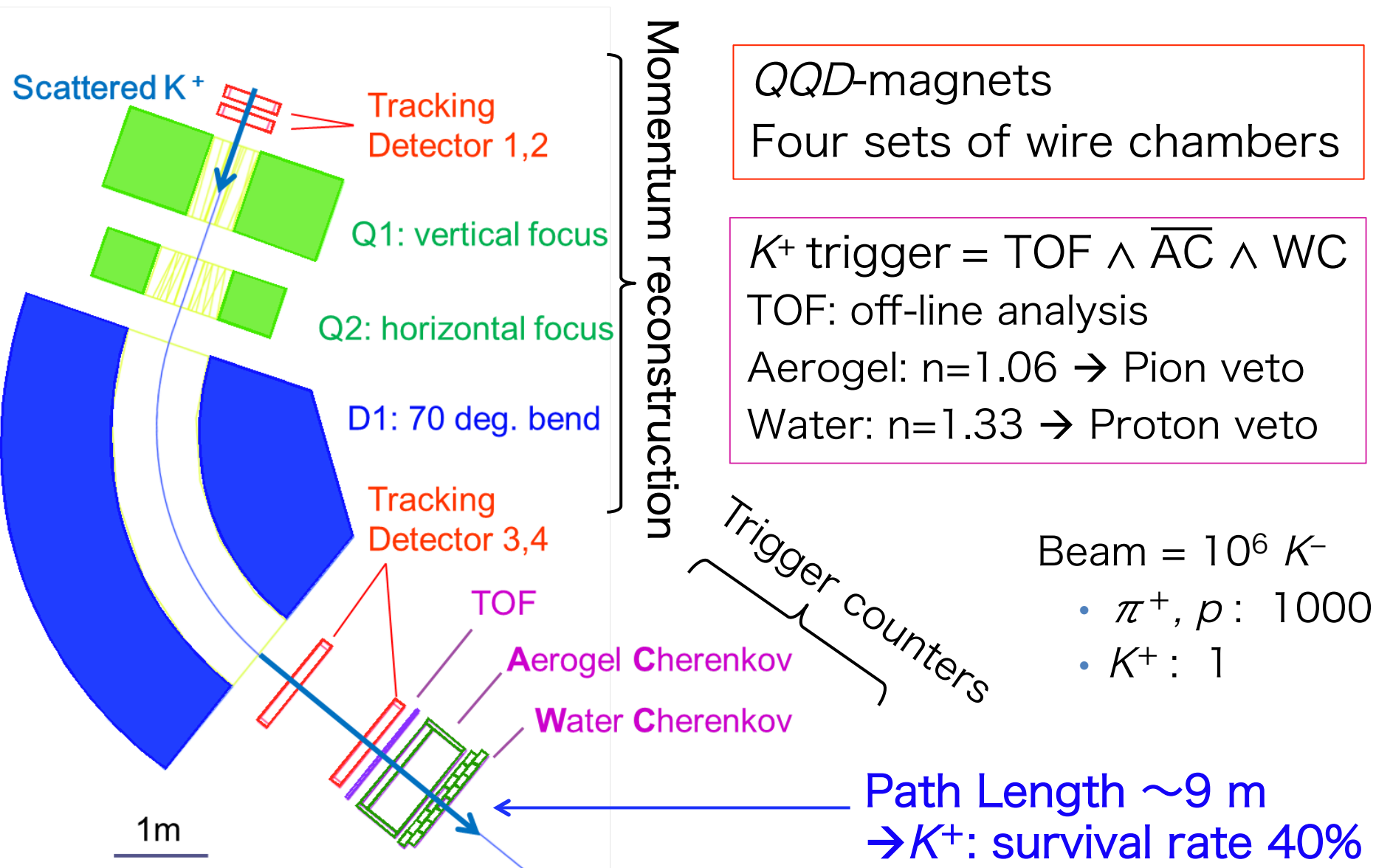
- Newly constructed magnetic spectrometer
 - Strangeness -2 Spectrometer [es-tu'-es]
 - Analysis for scattered K^+ at 1.3~1.4 GeV/c
 - $d\Omega = 55 \text{ msr}$, $dp/p = 5 \times 10^{-4} \rightarrow \Delta E = 2 \text{ MeV}$
 - SKS: 110 msr, $dp/p \sim 3 \times 10^{-3} \rightarrow \Delta E \sim 6 \text{ MeV}$



Comparison with other spectrometer

| | $\Delta \Omega$ [msr] | ΔE [MeV _{FWHM}] | θ [deg] | pK^+ [GeV] |
|-------------------|--------------------------|--------------------------------------|----------------|-----------------|
| BNL-E885 48D48 | 50? | 14 | <8, 14 | 1.0 – ? |
| SKS | 110 | 6 | <16 | 1.0< |
| S-2S | 55 | 2 | <8 | 1.2 – 1.6 |

Configuration of S-2S



Magnets

- Q1 (vertical focus)
 - 8.72 T/m
 - aperture 31 cm
 - 37 ton
 - $2.4 \times 2.4 \times 0.88 \text{ m}^3$

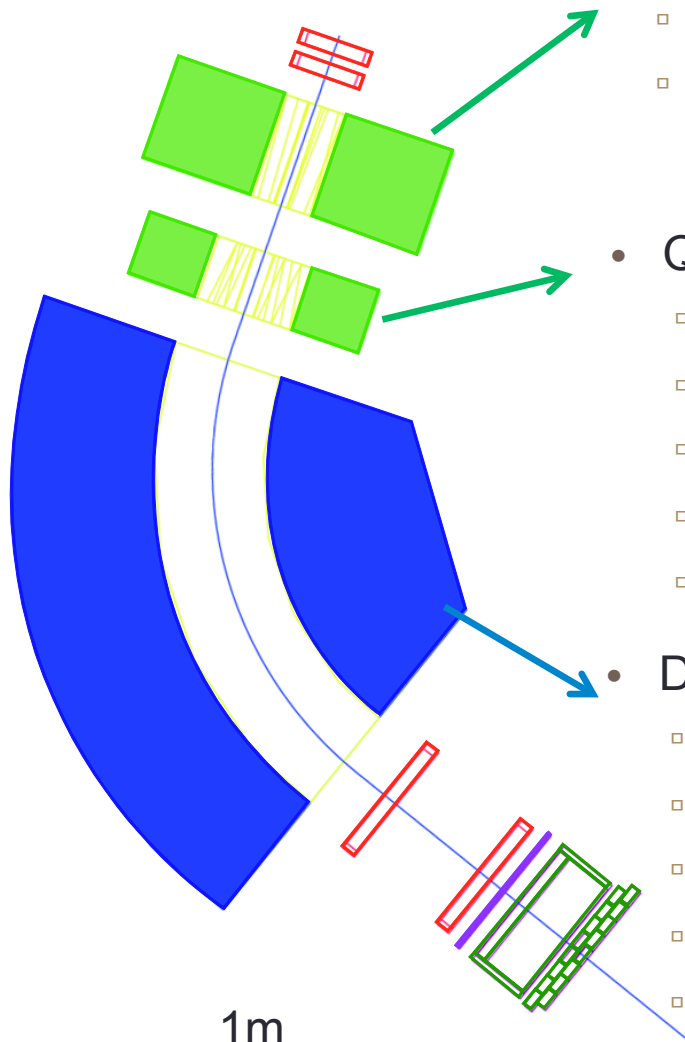
Completed (2013/3)

Completed (2014/3)

- Q2 (horizontal focus)
 - 5.0 T/m
 - aperture 36 cm
 - 12 ton
 - $2.1 \times 1.54 \times 0.5 \text{ m}^3$
 - Modified pole and coil

- D1
 - 1.5 T (70° bend @ 1.37 GeV/c)
 - pole gap $30 \times 80 \text{ cm}^2$
 - 86 ton
 - Central trajectory 3.7 m
 - Field measurement to be done

Completed (2015/5)



Summary

- Ξ -hypernuclear spectroscopy
 - Baryon-baryon interaction
 - Peak position and width \rightarrow Ξ -nucleus potential
- J-PARC E05
 - Phase 1: Pilot measurement with SKS
 - The first experiment on $S=-2$ at J-PARC
 - Analysis is ongoing
 - Ξ production: 10k events
 - QF- Ξ production: 60k events
 - Excess in the bound region
 - Phase 2: high resolution measurement with S-2S
 - S-2S magnets have been completed
 - $\Delta E = 2\text{MeV}$
 - Systematic studies on Ξ and $\Lambda\Lambda$ hypernuclei
 - in preparation for installation and waiting for experiments