This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824093

Study of Ξ and Kaonic nuclear bound states using $^{12}C(K^-, K^+)$ and $^{12}C(K^-, p)$ reaction at J-PARC

Result of J-PARC E05 and E42 experiments
SPICE: Strangeness hadrons as a Precision tool for strongly InterCting systEms (ECT* workshop)
2024/05/13-17

Yudai Ichikawa
(Tohoku University)

Contents

- $^{12}C(K^-, K^+)$ reaction for Ξ hypernucleus (Ξ-A interaction)
  - E05: Inclusive $^{12}C(K^-, K^+)$ spectrum (*Paper has been submitted*)
  - E42: Exclusive spectrum by tagging escape Ξ^- and converted ΛΛ particles → Sensitive to imaginary part of Ξ-A interaction
- $^{12}C(K^-, p)$ reaction for Kaonic nucleus ($\bar{K}$-A interaction)
  - E05 : Inclusive $^{12}C(K^-, p)$ spectrum (*Paper is published*)
  - E42: Exclusive spectrum by requiring decay particles to suppress the QF backgrounds

E05 papers

(K⁻, K⁺) paper has been submitted

PTEP

Prog. Theor. Exp. Phys. **2015**, 00000 (13 pages)
DOI: 10.1093/ptep/0000000000

Missing-mass measurement of the $^{12}C(K^-, K^+)$ reaction at 1.8 GeV/c with the SKS spectrometer

Yudai Ichikawa[1, 2], Jung Keun Ahn[3], Yuya Akazawa[4], Kanae Aoki[4], Elena Botta[5, 6], Hiroyuki Ekawa[7], Petr Evtoukhovitch[8], Alessandro Feliciello[5], Manami Fujita[2], Toshiyuki Gogami[9], Shoichi Hasegawa[2], Tomoyuki Hasegawa[10], Shuhei Hayakawa[1], Tomonori Hayakawa[11], Ryotaro Honda[4], Kenji Hosomi[2], Ken'ichi Imai[2], Wooseung Jung[3], Shunsuke Kanatsuki[9], Shin Hyung Kim[12], Shinji Kinbara[13], Kazuya Kobayashi[11], Jaeyong Lee[14], Simonetta Marcello[5, 6], Koji Miwa[1], Taejin Moon[14], Tomofumi Nagae[9], Yoshiyuki Nakada[11], Manami Nakagawa[7], Takuya Nanamura[2], Megumi Naruki[9], Atsushi Sakaguchi[11], Hiroyuki Sako[2], Susumu Sato[2], Yuki Sasaki[1], Kotaro Shirotori[15], Hitoshi Sugimura[16], Toshiyuki Takahashi[3], Hirokazu Tamura[1, 2], Kiyoshi Tanida[2], Zviadi Tsamalaidze[8], Mifuyu Ukai[4], and Takeshi O. Yamamoto[2]

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We performed a measurement of the inclusive missing-mass spectrum of the $^{12}C(K^-, K^+)$ reaction at an incident beam momentum of 1.8 GeV/c. This measurement was carried out by using the Superconducting Kaon Spectrometer (SKS) and the K1.8 beamline spectrometer at the Hadron Experimental Facility in J-PARC. Our experimental setup yielded a good energy resolution of 8.2 MeV (FWHM), which allowed us to observe significant enhancements in the proximity of the $^{12}_{\Xi}Be$ production threshold

(K⁻, p) paper was published in 2020

PTEP

Prog. Theor. Exp. Phys. **2020**, 123D01 (34 pages)
DOI: 10.1093/ptep/ptaa139

An event excess observed in the deeply bound region of the $^{12}C(K^-, p)$ missing-mass spectrum

Yudai Ichikawa[1,*], Junko Yamagata-Sekihara[2], Jung Keun Ahn[3], Yuya Akazawa[4], Kanae Aoki[4], Elena Botta[5,6], Hiroyuki Ekawa[7], Petr Evtoukhovitch[8], Alessandro Feliciello[5], Manami Fujita[1], Toshiyuki Gogami[9], Shoichi Hasegawa[1], Tomoyuki Hasegawa[10], Shuhei Hayakawa[11,1], Tomonori Hayakawa[11], Satoru Hirenzaki[12], Ryotaro Honda[4], Kenji Hosomi[1], Ken'ichi Imai[1], Wooseung Jung[3], Shunsuke Kanatsuki[9], Shin Hyung Kim[3], Shinji Kinbara[14,1], Kazuya Kobayashi[11], Jaeyong Lee[15], Simonetta Marcello[5,6], Koji Miwa[13], Taejin Moon[15], Tomofumi Nagae[9], Yoshiyuki Nakada[11], Manami Nakagawa[7], Takuya Nanamura[9], Megumi Naruki[9,1], Atsushi Sakaguchi[11], Hiroyuki Sako[1], Susumu Sato[1], Yuki Sasaki[13], Kotaro Shirotori[16], Hitoshi Sugimura[17], Toshiyuki Takahashi[4], Hirokazu Tamura[13,1], Kiyoshi Tanida[1], Zviadi Tsamalaidze[8], Mifuyu Ukai[4,13], and Takeshi O. Yamamoto[1]

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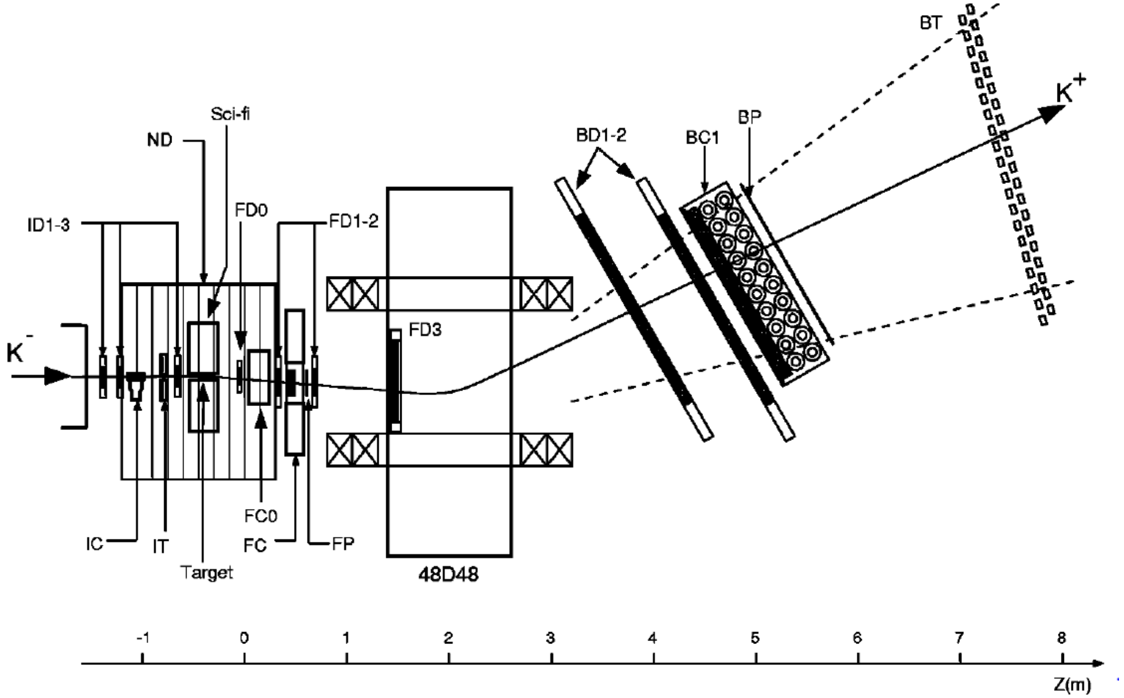
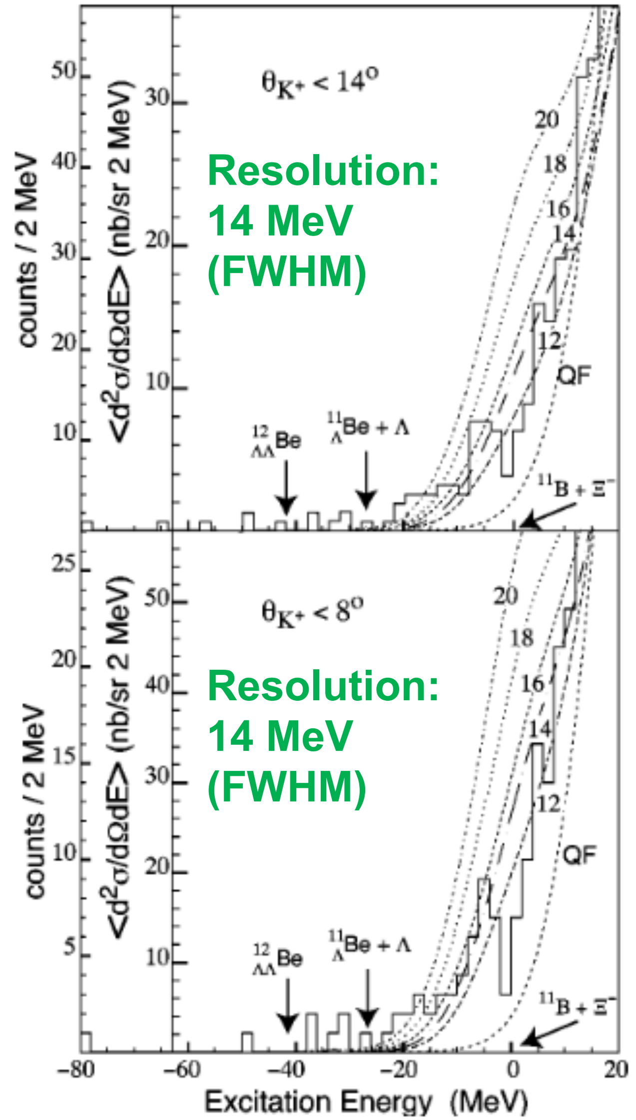
We have measured, for the first time, the inclusive missing-mass spectrum of the $^{12}C(K^-, p)$ reaction at an incident kaon momentum of 1.8 GeV/c at the J-PARC K1.8 beamline. We observed a prominent quasi-elastic peak ($K^-p \to K^-p$) in this spectrum. In the quasi-elastic peak region, the effect of secondary interaction is apparently observed as a peak shift, and the peak exhibits a tail in the bound region. We compared the spectrum with a theoretical calculation based on the Green's function method by assuming different values of the parameters for the $\bar{K}$–nucleus optical potential. We found that the spectrum shape in the binding-energy region −300 MeV $< B_K <$ 40 MeV is best reproduced with the potential depths $V_0 = -80$ MeV (real part) and $W_0 = -40$ MeV (imaginary part). On the other hand, we observed a significant event excess in the deeply bound region around $B_K \sim 100$ MeV, where the major decay channel of $K^-NN \to \pi\Sigma N$ is energetically closed, and the non-mesonic decay modes ($K^-NN \to \Lambda N$ and ΣN) should mainly contribute. The enhancement is fitted well by a Breit–Wigner function with

Introduction BNL E885 experiment

$^{12}C(K^-, K^+)$ reaction @1.8 GeV/c



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



V_0^{Ξ} ~ -14 MeV

Introduction BNL E885 experiment

$$U_B(r) = -V_{0B} f(r) + V_{LS\,B}\left(\frac{\hbar}{m_\pi c}\right)(\mathbf{l}\cdot\mathbf{s})\frac{1}{r}\frac{df(r)}{dr} + U_{coulomb}(r),$$

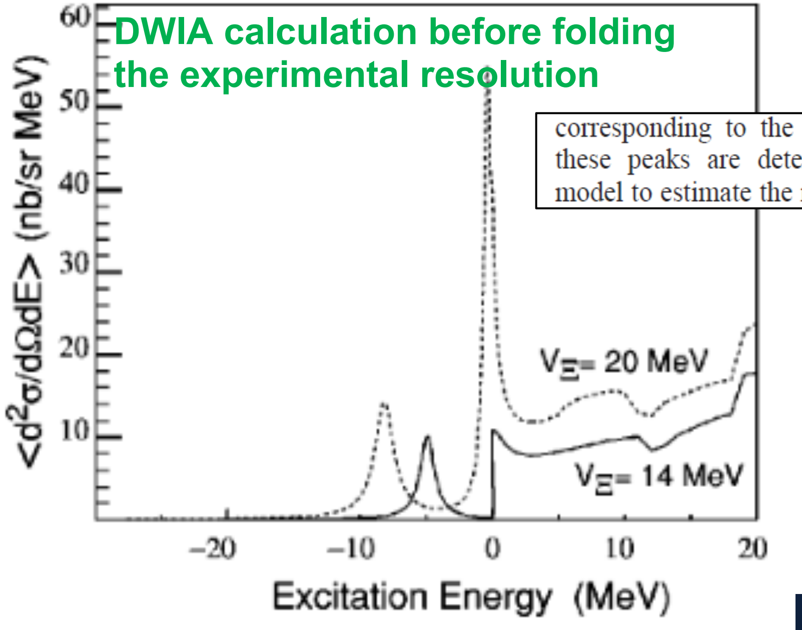
$$f(r) = (1 + e^{\frac{r-R}{a}})^{-1},$$

P. Khaustov Doctor thesis

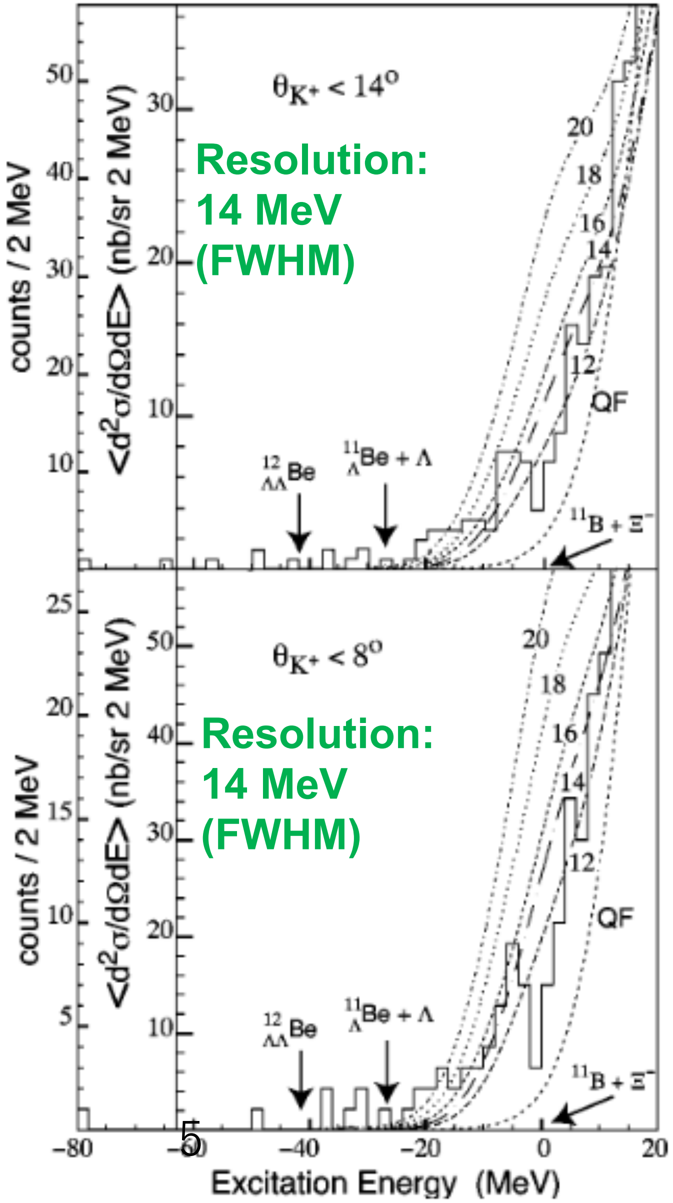
$$R = r_0(A-1)^{1/3},$$

r_0, fm	a, fm	$V_{0\Xi}$, MeV	$V_{LS\,\Xi}$, MeV	V_{0p}, MeV	$V_{LS\,p}$, MeV
1.1	0.65	20, 16	1	72.5	7

Maybe, they did not consider the imaginary part W_0^{Ξ}.
The width of peaks are considered.
However, resolution will be more effective than Γ.



corresponding to the Ξ^- s- and p-orbitals. The widths of these peaks are determined using a one-boson-exchange model to estimate the rate for the $\Xi N \rightarrow \Lambda\Lambda$ conversion. For



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

Theoretical study by Kohno

BNL E885

W_0 is assumed to be 0 MeV

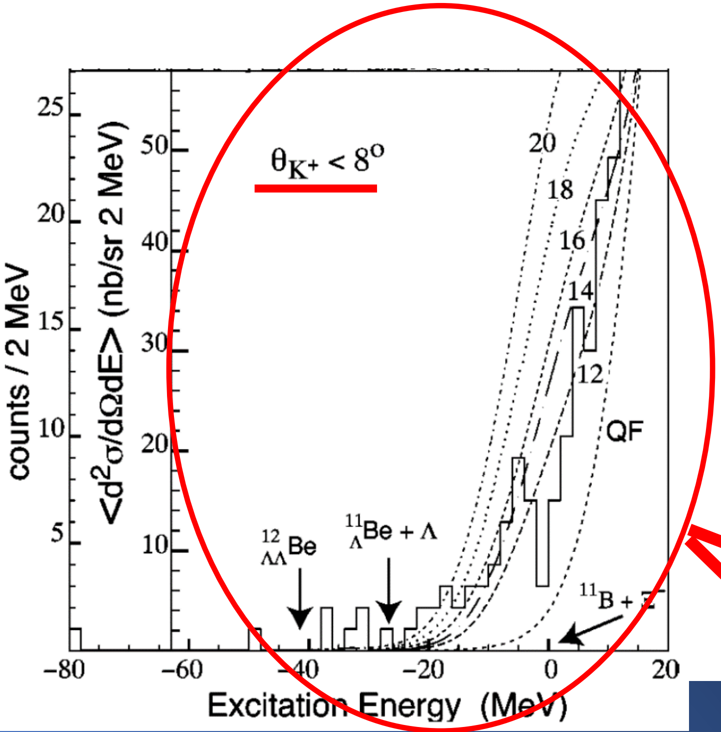
→ **V_0^{Ξ} ~ -14 MeV**

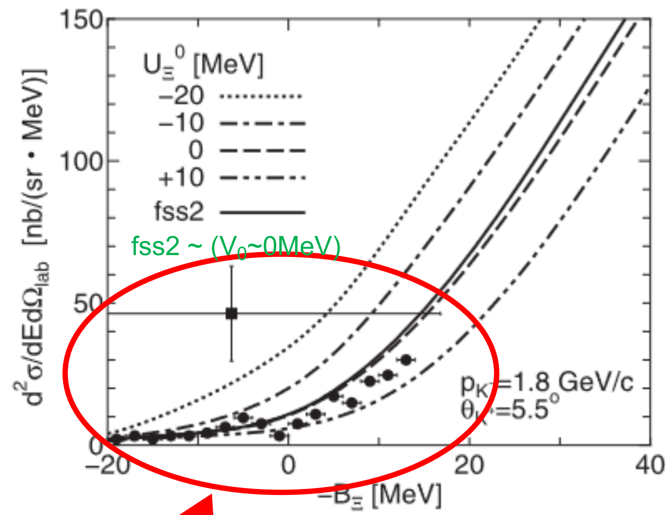
Γ/2 is assumed to be 2 MeV

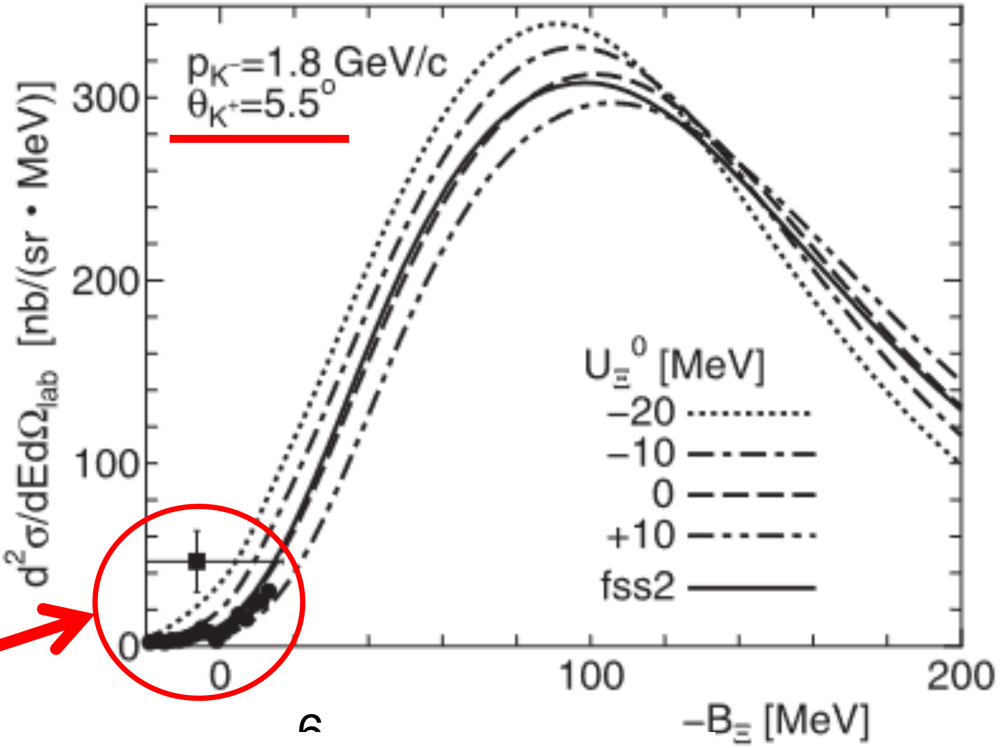
$\sigma_{\Xi^- p \to \Lambda\Lambda}$ ~ 4.3 mb (~0.5 GeV/c)
J.K. Ahn et al., PLB 663, 214 (2006) (Γ_{Ξ} ~ 3 MeV)

→ **V_0^{Ξ} ~ 0 MeV can also reproduce the data**

→ ***Wide energy range and precise angle selection data is essential !!***







M. Kohno and S. Hashimoto, PTP 123, 1 (2010).

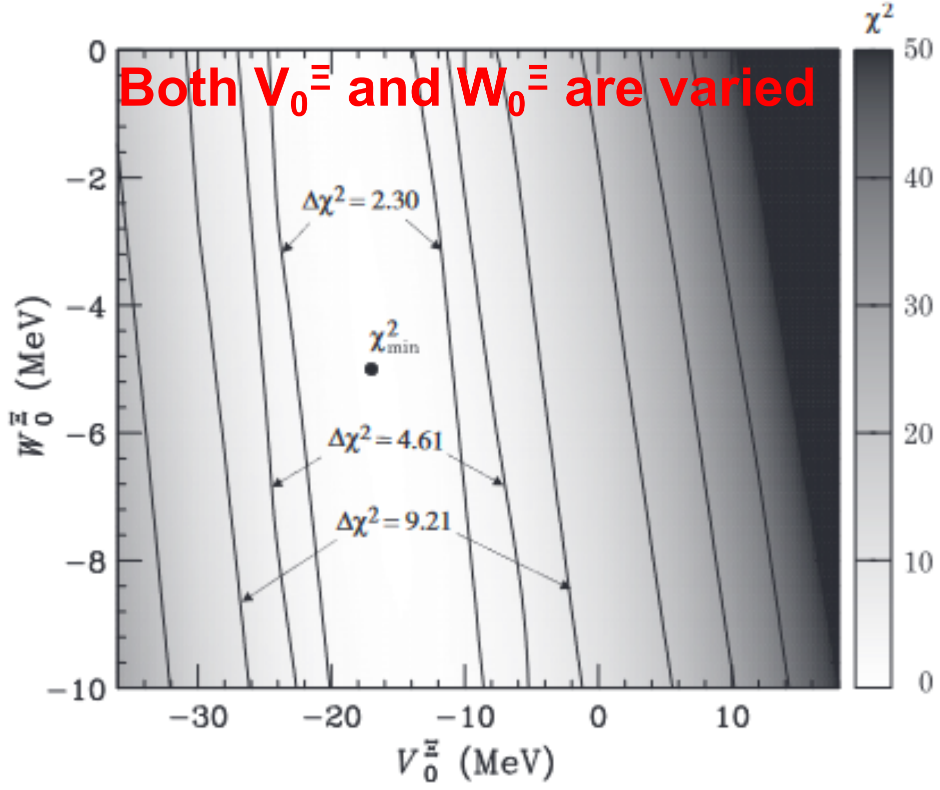
Recent theoretical study by Harada

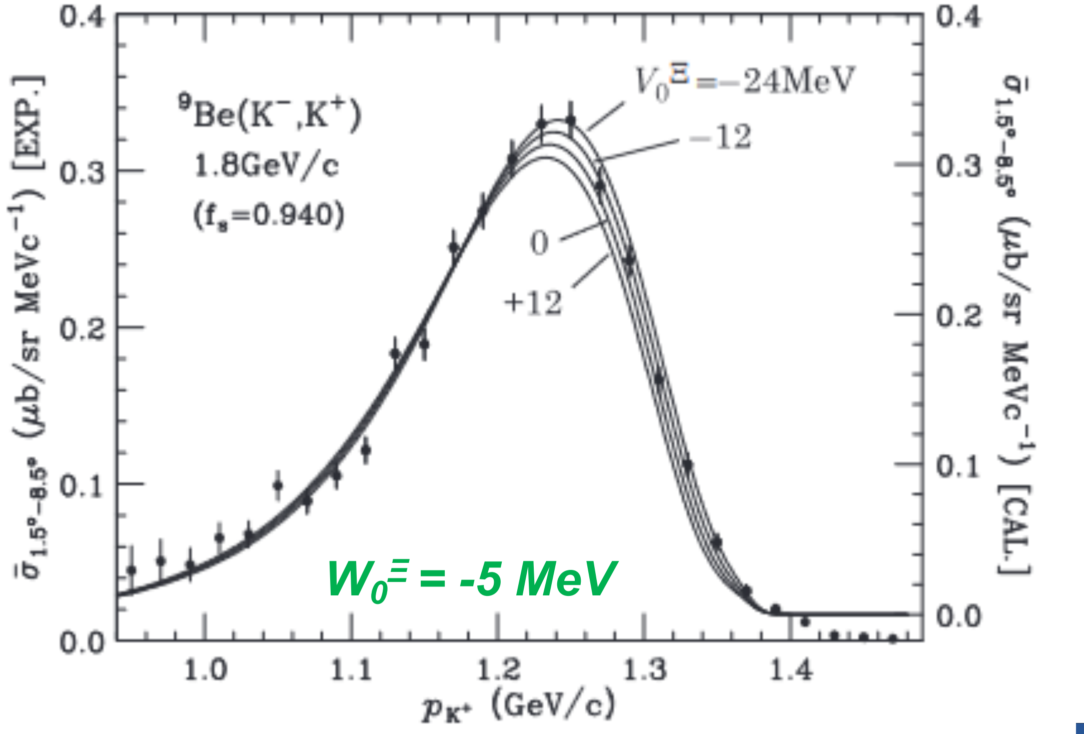
T. Harada and Y. Hirabayashi, Phys. Rev. C **103**, 024605 (2021).

V_0^{Ξ} = -17 ± 6 MeV (W_0^{Ξ} is difficult to determine)

∗ W_0^{Ξ} = $W_0(\Xi^- p \rightarrow \Xi^0 n)$ + $W_0(\Xi^- p \rightarrow \Lambda\Lambda)$

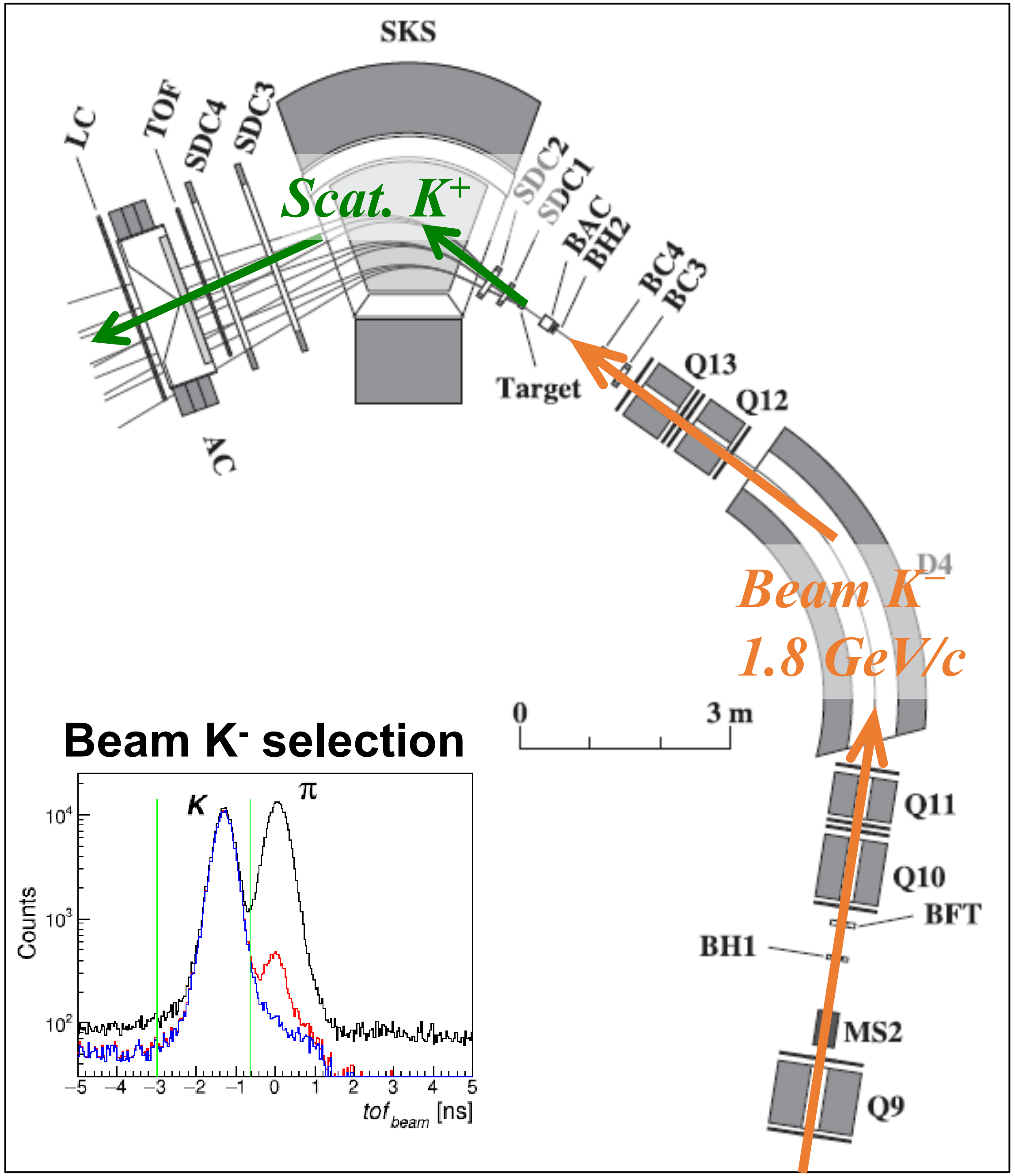
No sensitivity to Imaginary part from the inclusive analysis





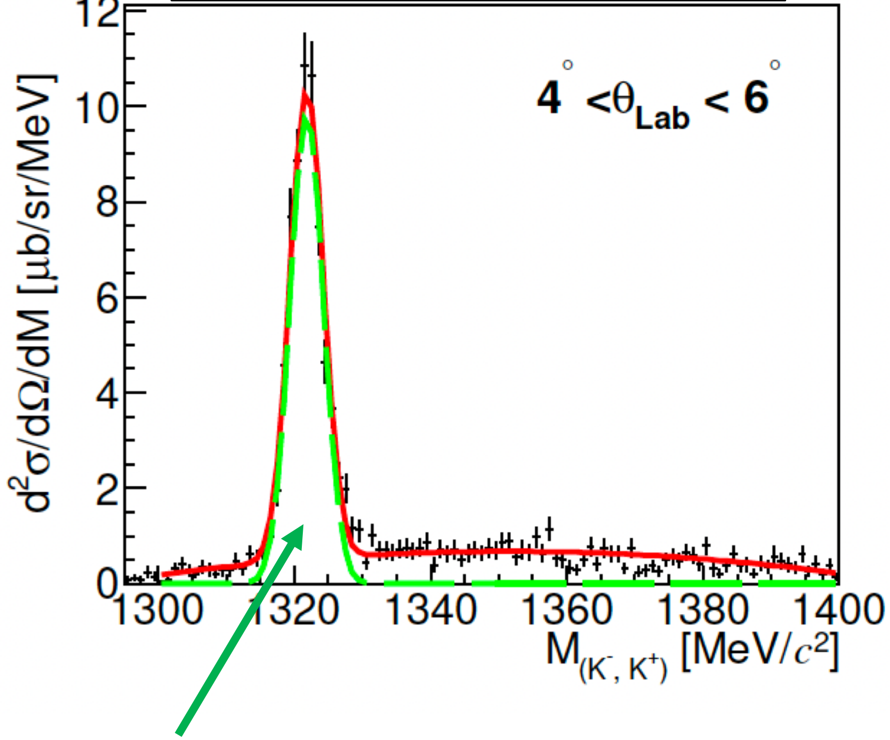
J-PARC E05 EXPERIMENT

Experiment	BNL E885	J-PARC E05	J-PARC E70
Resolution FWHM (MeV)	14	8	2
Momentum range (GeV/c)	0.8-1.4	0.8-2.2	1.2-1.5

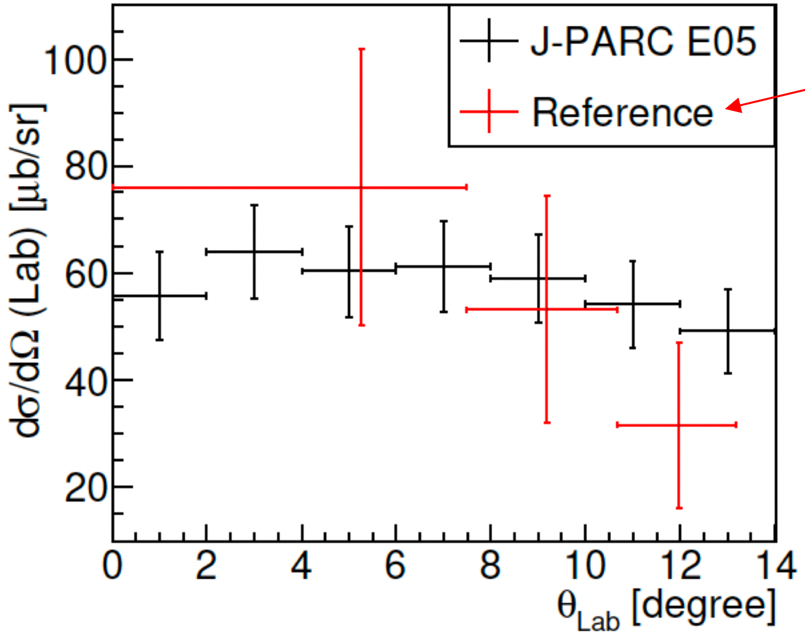


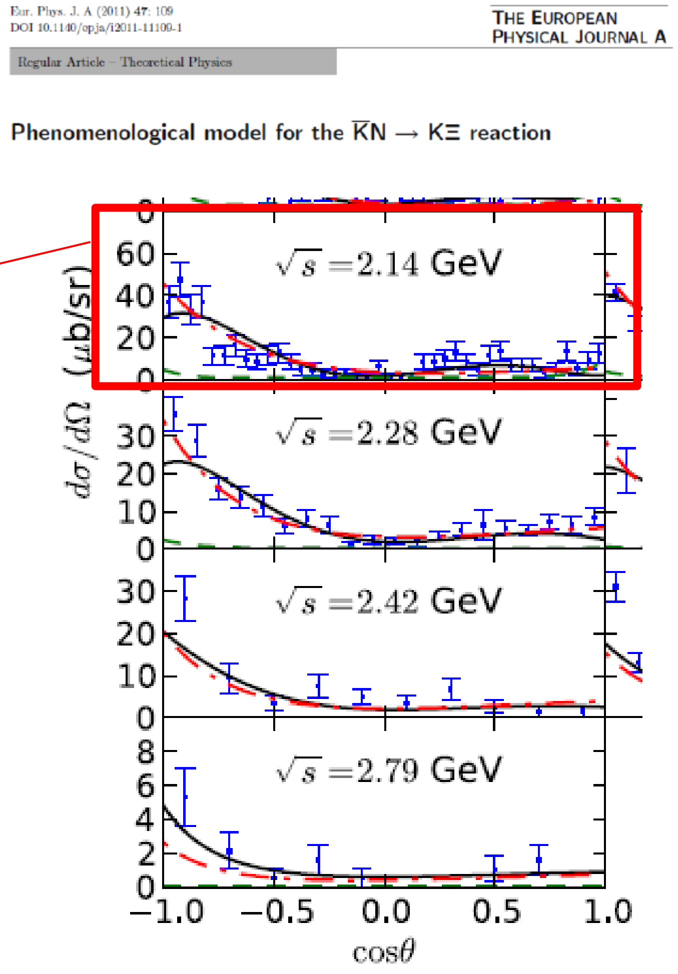
Elementary cross-section $p(K^-, K^+)\Xi^-$

$p(K^-, K^+)\Xi^-$ spectrum with CH_2 target



$d\sigma/d\Omega$ of Ξ^- production at 1.8 GeV/c



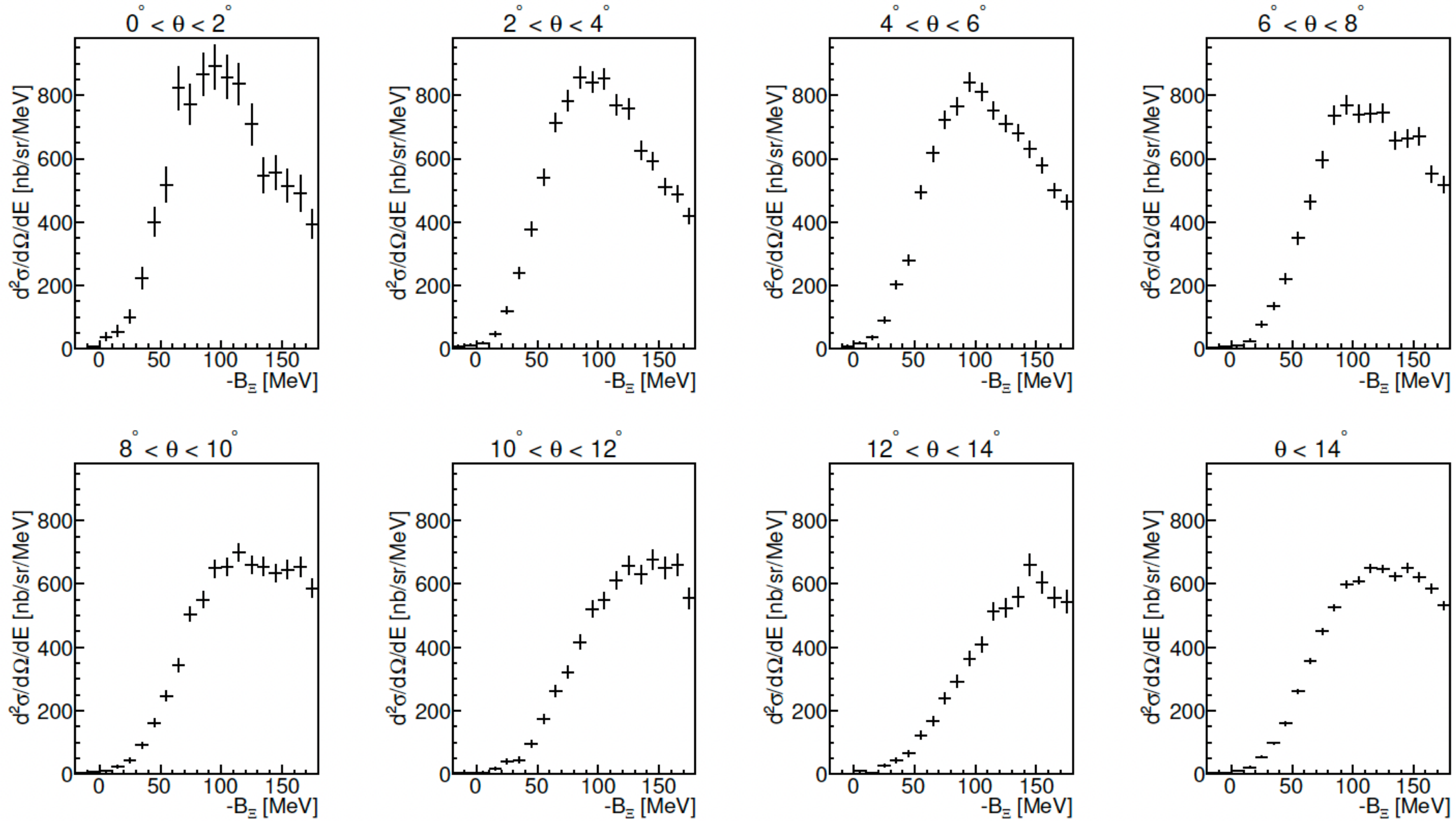


ΔM = 5.8 MeV (FWHM)

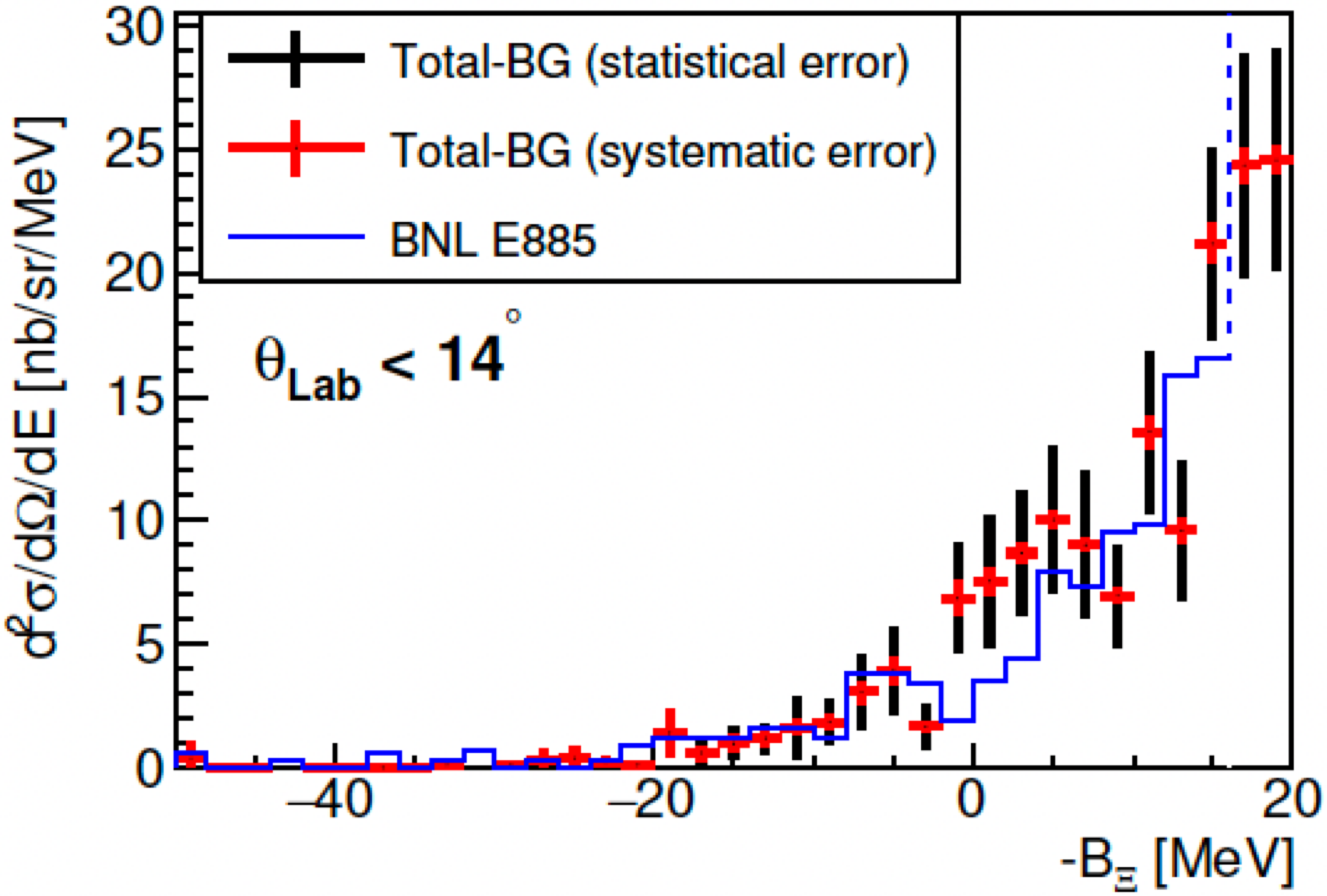
$\rightarrow \Delta B_{\Xi}$ = 8.2 MeV (FWHM)

E05 $^{12}C(K^-, K^+)$ spectrum

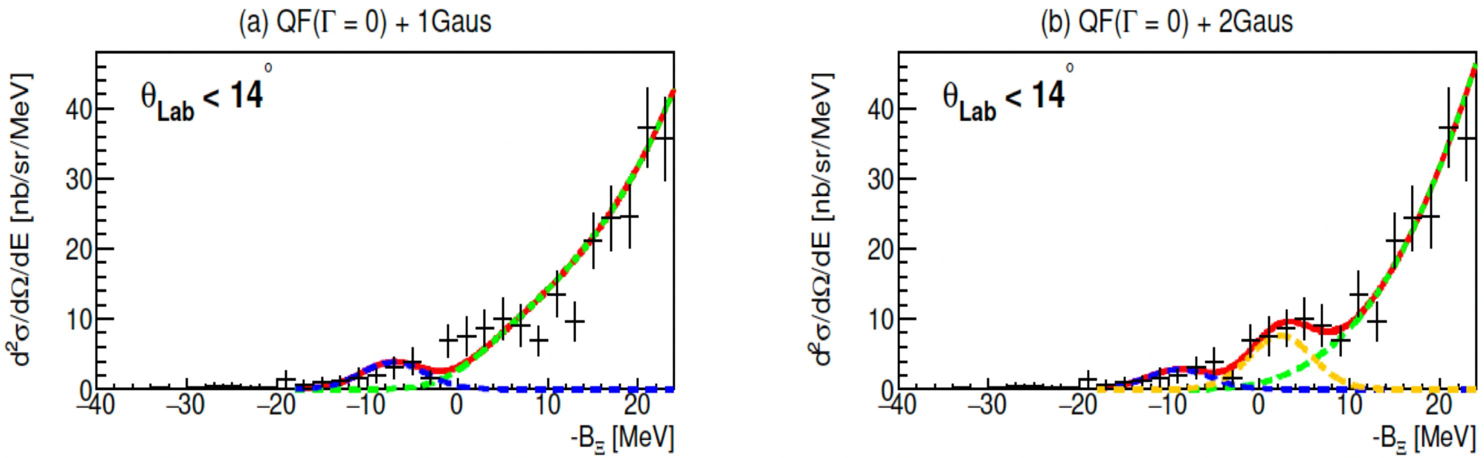
➡ (V_0^{Ξ}, W_0^{Ξ}) will be determined in high precision



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



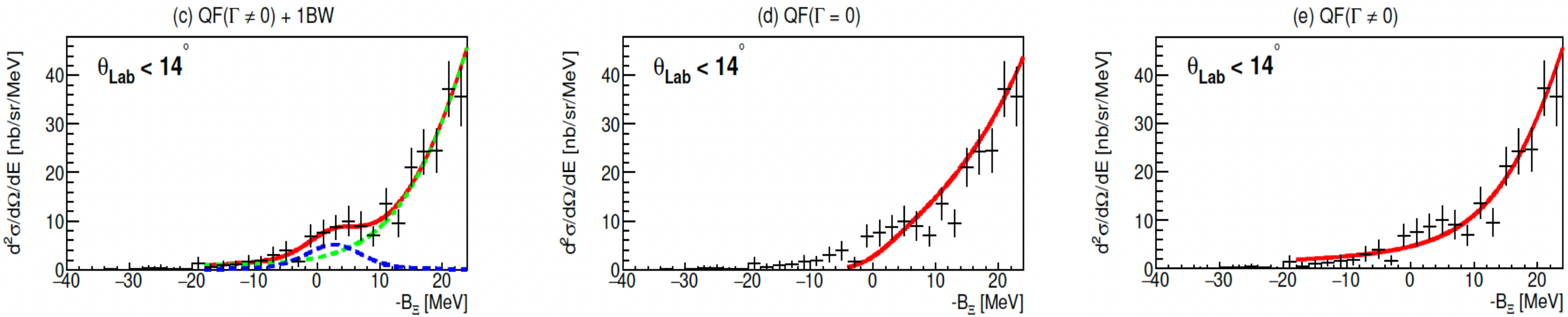
Spectrum fitting



QF function

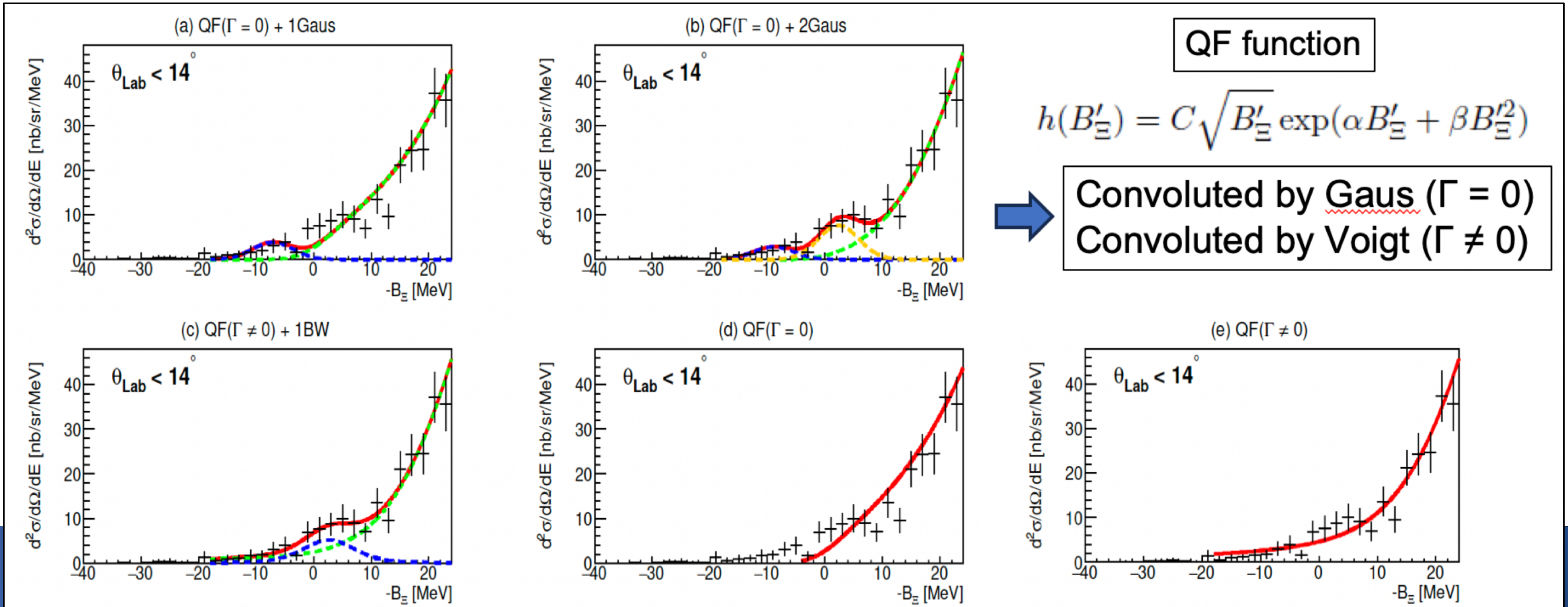
$$h(B'_\Xi) = C\sqrt{B'_\Xi}\exp(\alpha B'_\Xi + \beta B'^2_\Xi)$$

Convoluted by Gaus (Γ = 0)
Convoluted by Voigt (Γ ≠ 0)



Result of spectrum fitting

Function	$\chi^2/ndf\ (ndf)$	P-value	Fitting parameters (MeV)
(a) $\mathrm{QF}(\Gamma=0)$ + 1Gaus	1.83 (23)	0.00896	$B_\Xi = 7.1 \pm 1.5\ (\mathrm{stat.})\ ^{+2.4}_{-6.1}\ (\mathrm{syst.})$
(b) $\mathrm{QF}(\Gamma=0)$ + 2Gaus	0.849 (22)	0.665	$B_\Xi^{1st} = 8.9 \pm 1.4\ (\mathrm{stat.})\ ^{+3.8}_{-3.1}\ (\mathrm{syst.})$ $B_\Xi^{2nd} = -2.4 \pm 1.3\ (\mathrm{stat.})\ ^{+2.8}_{-1.2}\ (\mathrm{syst.})$
(c) $\mathrm{QF}(\Gamma\neq 0)$ + 1BW	0.954 (23)	0.524	$B_\Xi = -2.7 \pm 2.2\ (\mathrm{stat.})\ ^{+0.5}_{-0.7}\ (\mathrm{syst.})$ $\Gamma = 4.1 \pm 2.1\ (\mathrm{stat.})\ ^{+1.2}_{-0.7}\ (\mathrm{syst.})$
(d) $\mathrm{QF}(\Gamma=0)$	2.49 (19)	0.000332	
(e) $\mathrm{QF}(\Gamma\neq 0)$	1.39 (25)	0.0914	$\Gamma = 8.7 \pm 1.1\ (\mathrm{stat.})$



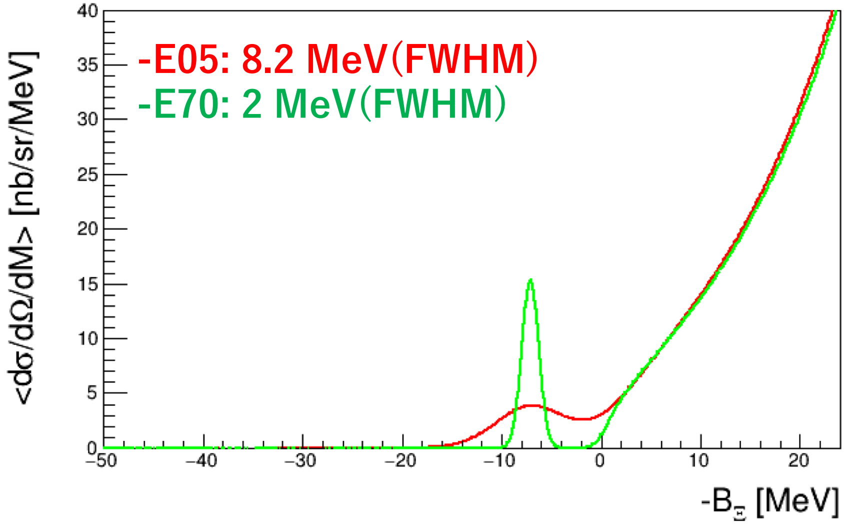
QF function

$$h(B'_\Xi) = C\sqrt{B'_\Xi}\exp(\alpha B'_\Xi + \beta B'^2_\Xi)$$

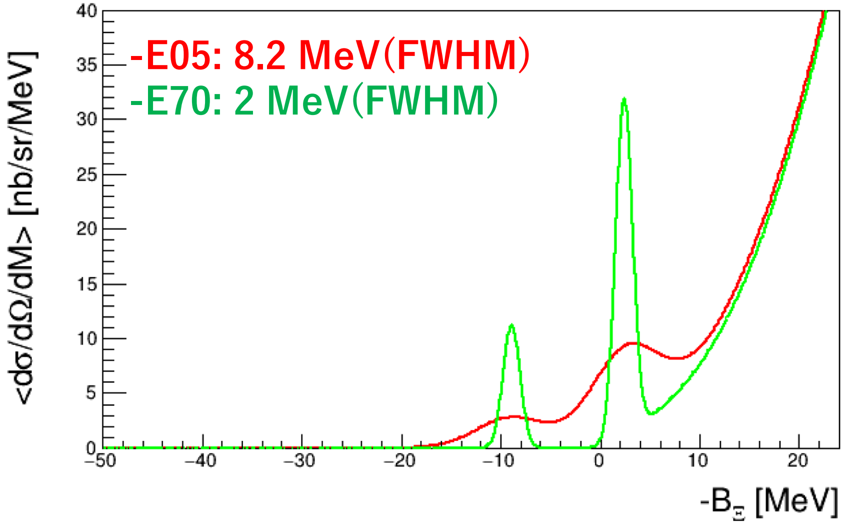
Convoluted by Gaus ($\Gamma = 0$)
Convoluted by Voigt ($\Gamma \neq 0$)

Comparison between E05(8.2 MeV) and E70(2 MeV)

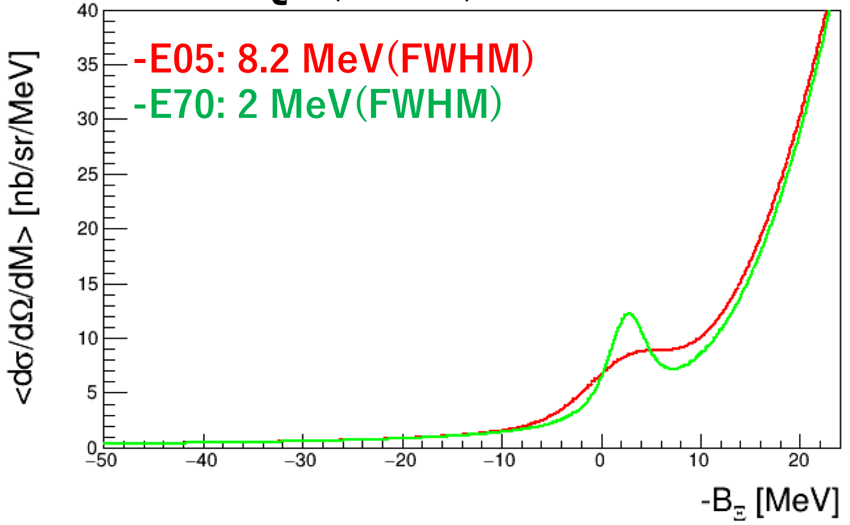
QF(Γ=0)+1gaus



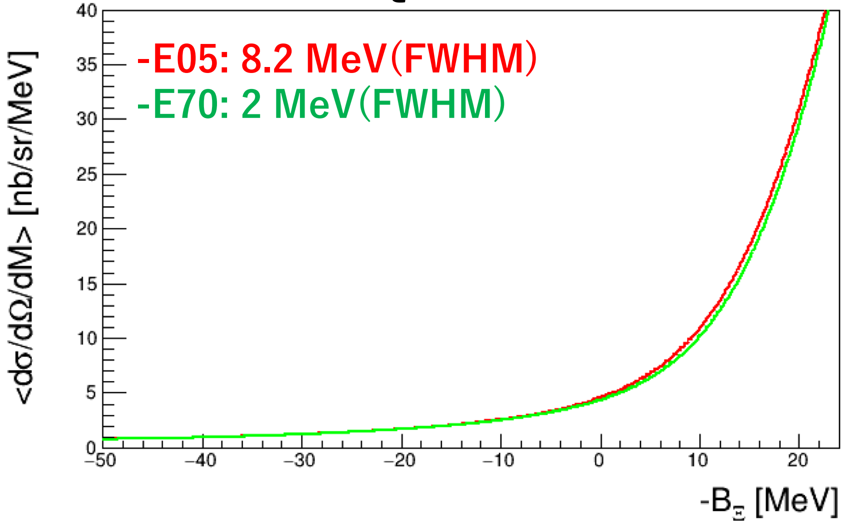
QF(Γ=0)+2gaus



QF(Γ≠0)+1BW

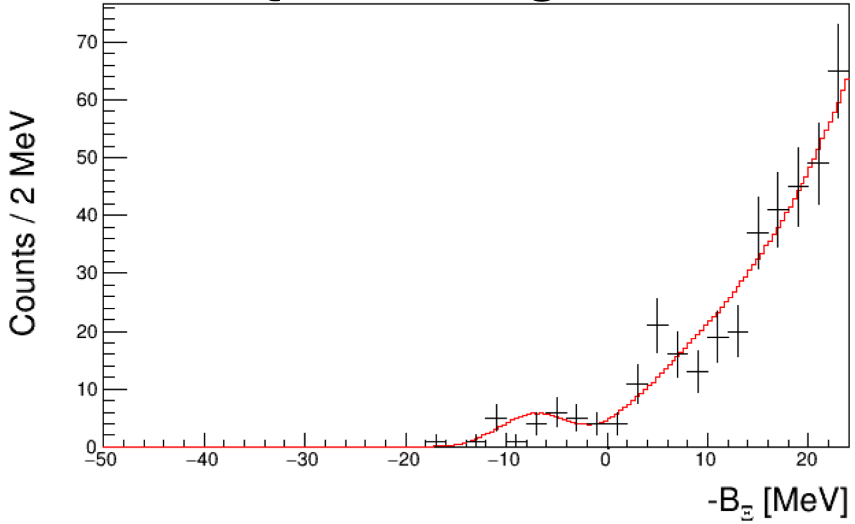


QF(Γ≠0)

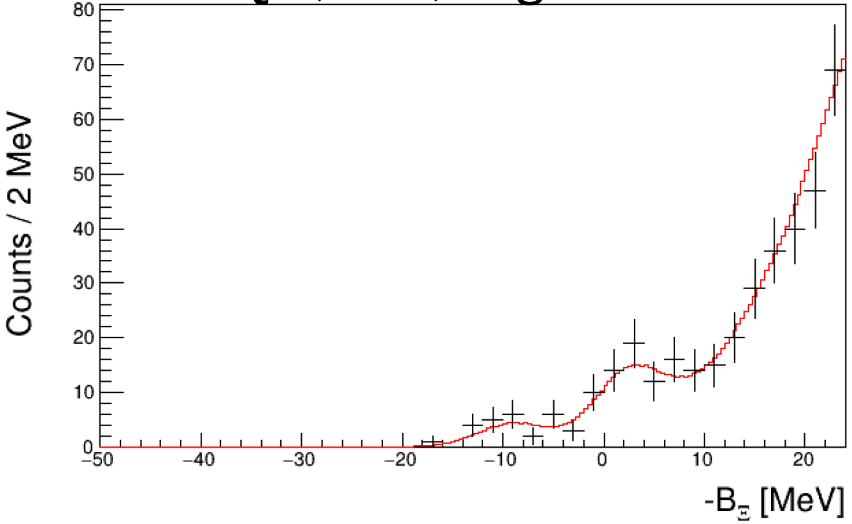


Simulated spectra with E05(8.2 MeV) condition

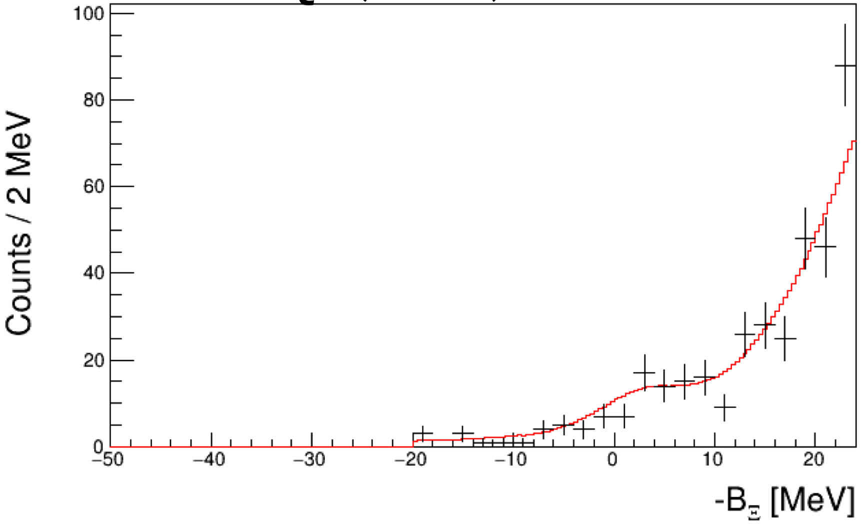
QF(Γ=0)+1gaus



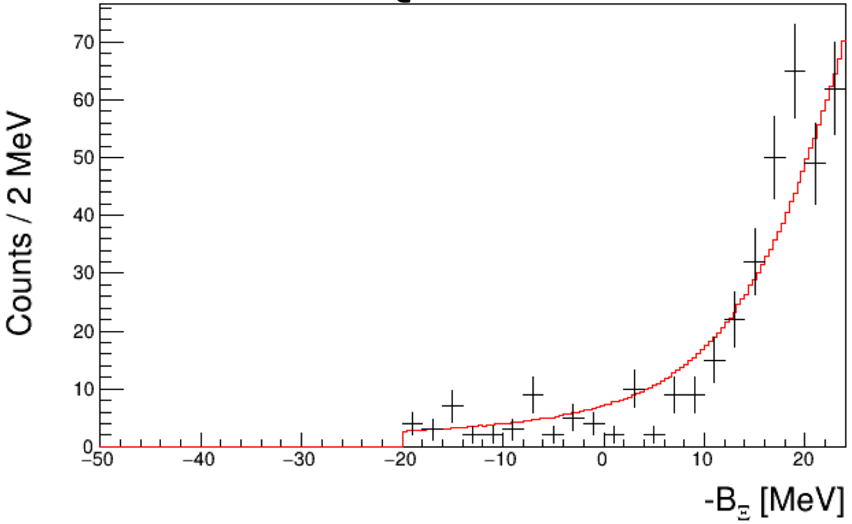
QF(Γ=0)+2gaus



QF(Γ≠0)+1BW



QF(Γ≠0)

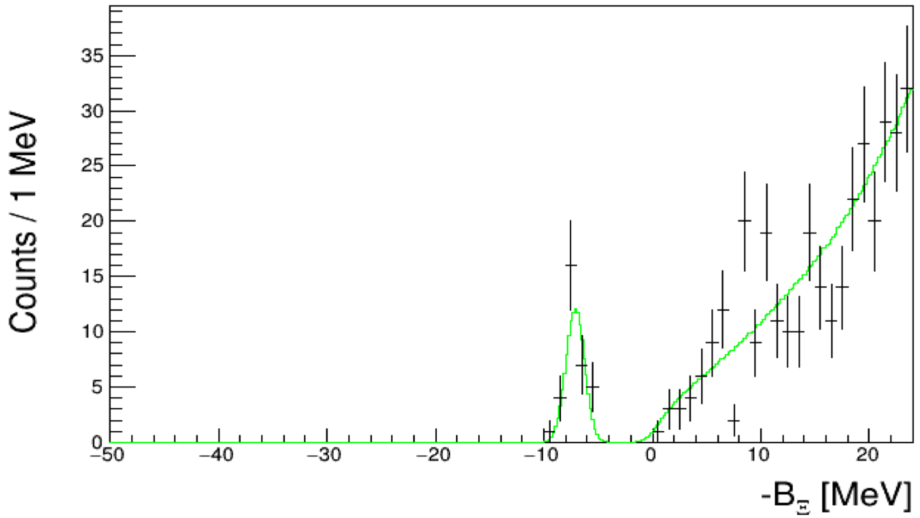


Simulated spectra with E70(2 MeV) condition

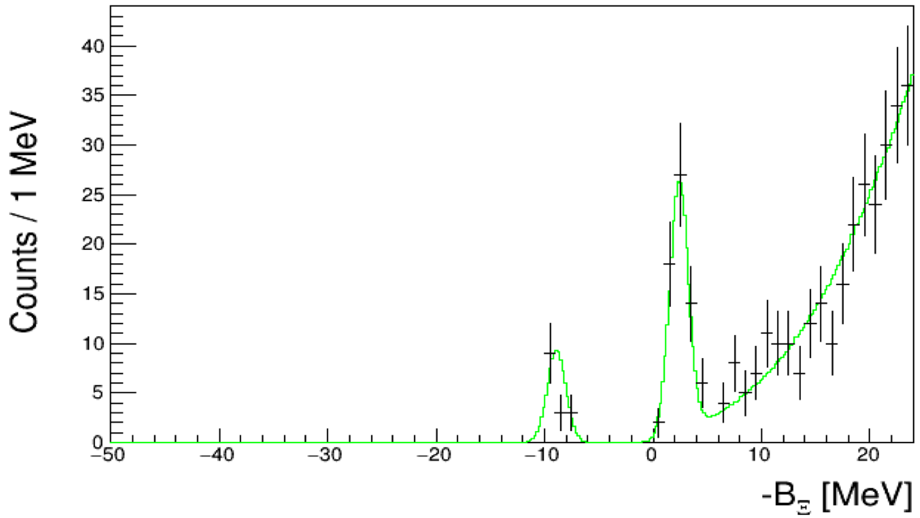
Same statistic is assumed

Peak structure should be prominent!!

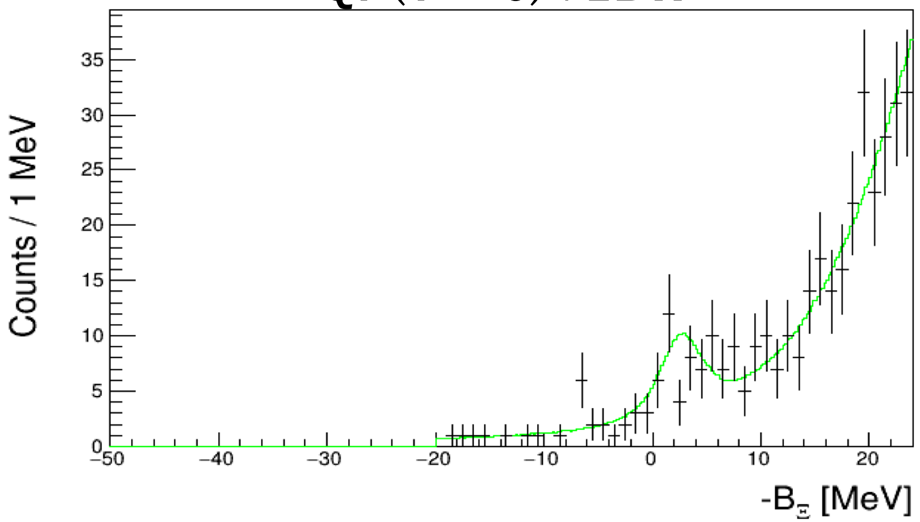
QF(Γ=0)+1gaus



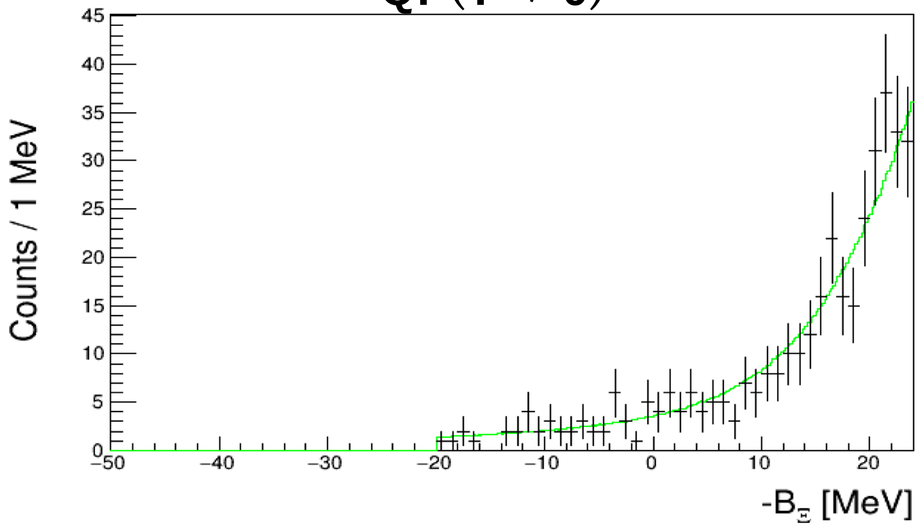
QF(Γ=0)+2gaus



QF(Γ≠0)+1BW



QF(Γ≠0)



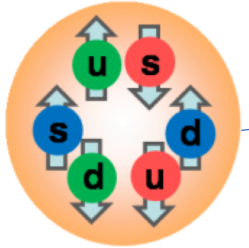
J-PARC E42 experiment

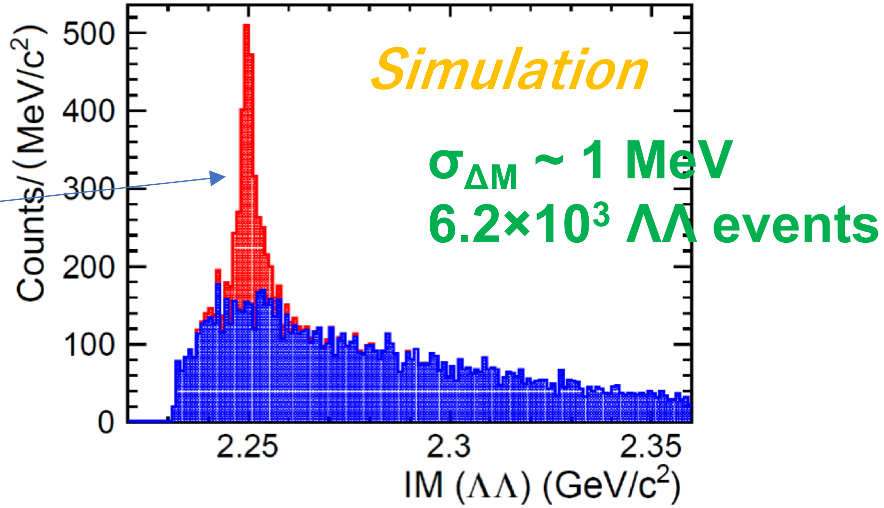
J-PARC E42（H-dibaryon search）

E42 Completed June 29, 2021

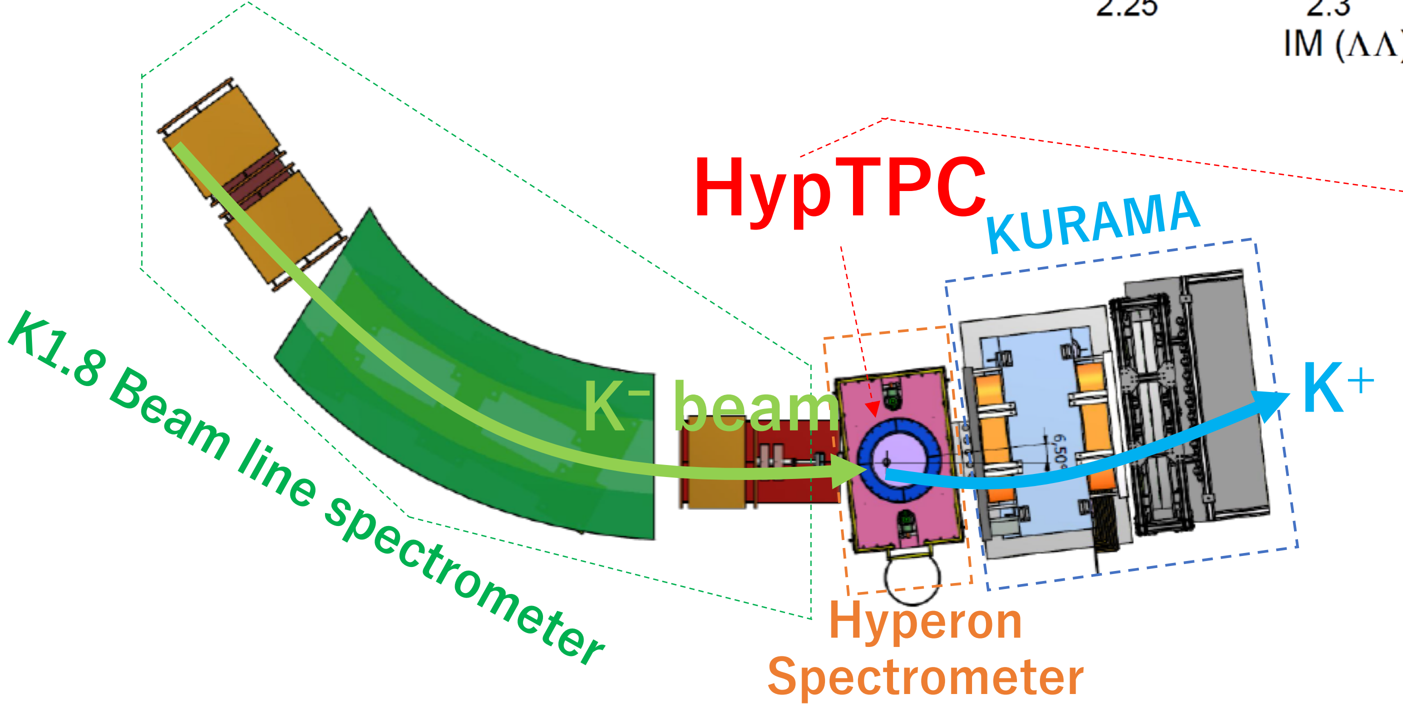
$K^- + \text{“pp”} \rightarrow H\ K^+$, $H \rightarrow \Lambda\Lambda$, $\Lambda p \pi^-$, $\Xi^- p$ (Invariant-mass spectroscopy)

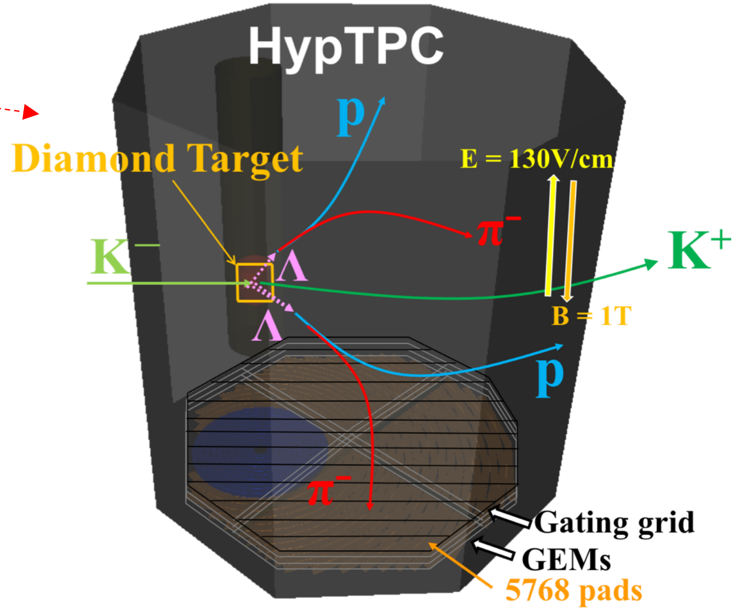
H-dibaryon



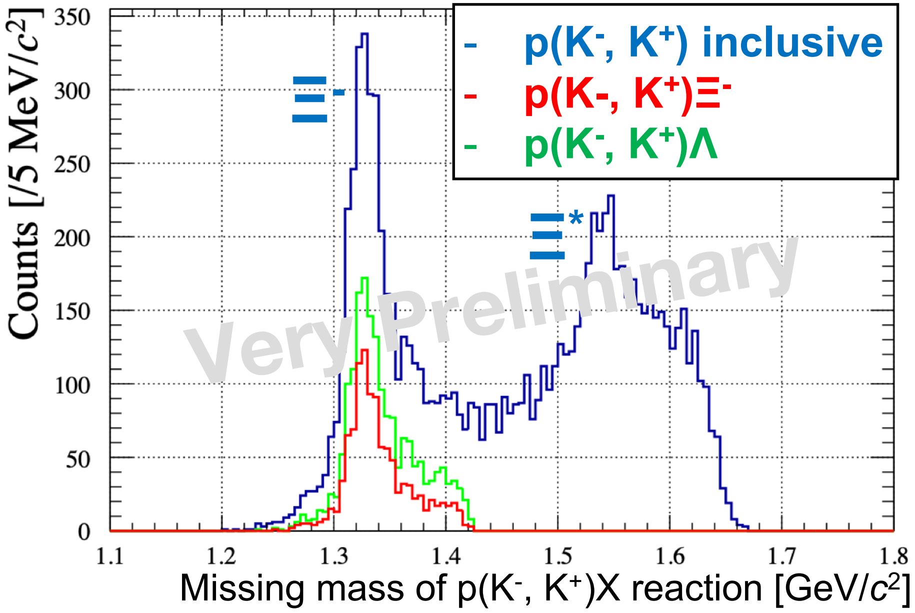


$^{12}C(K^-, K^+)$ reaction

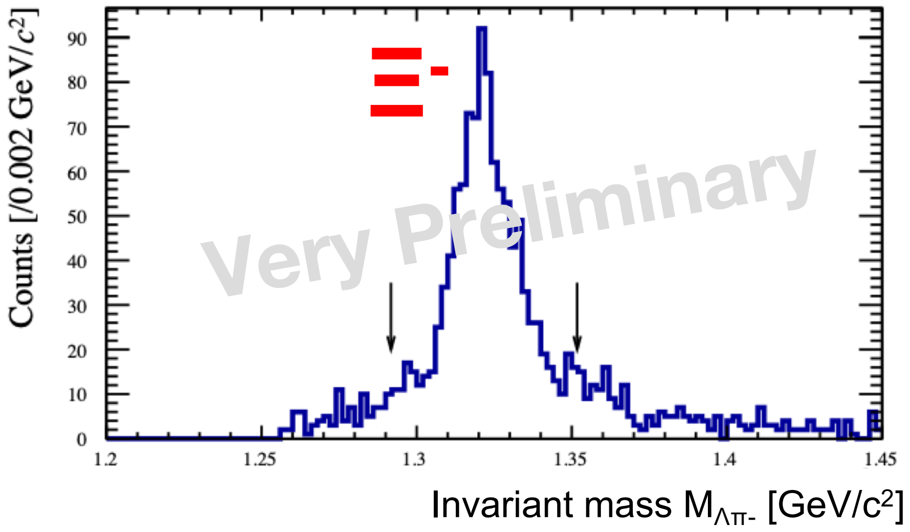


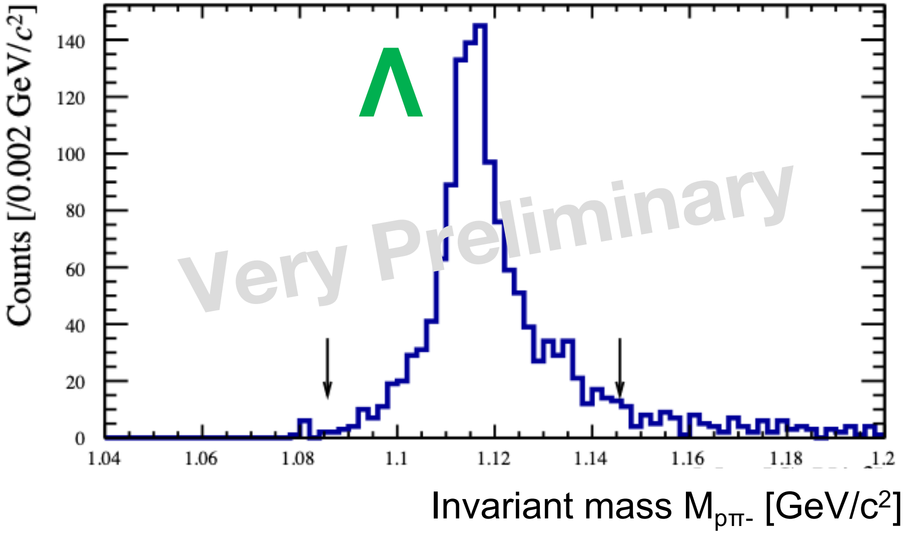


p(K⁻, K⁺) missing-mass analysis with CH2 target

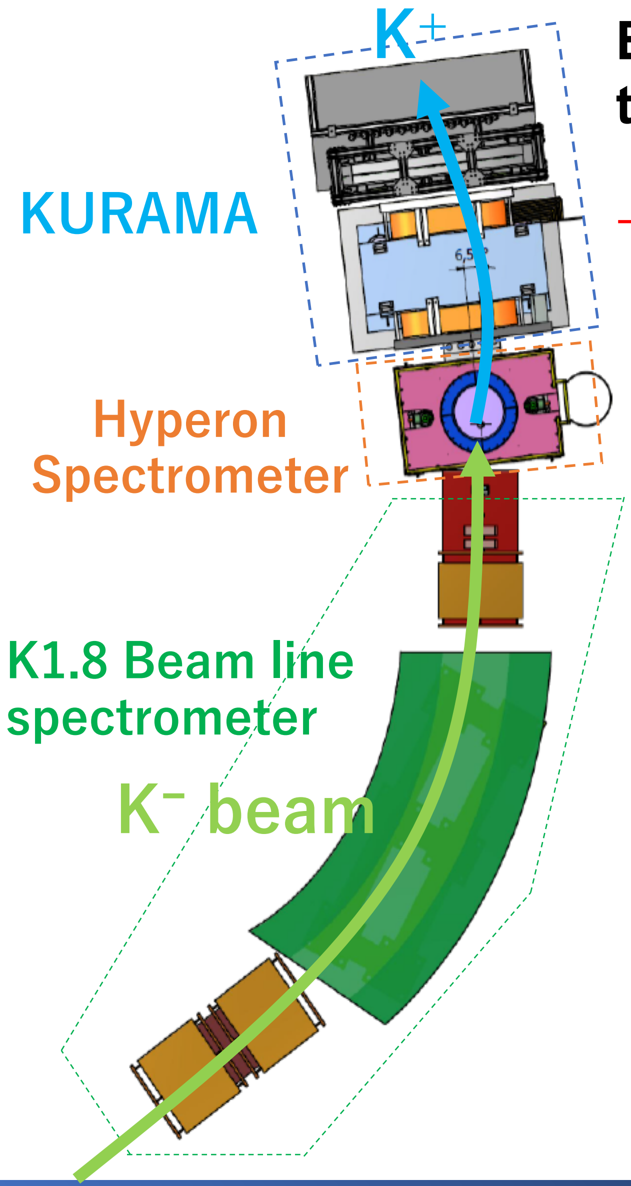


	Inclusive	Coin with Ξ⁻	Coin with Λ
Yield (C(QF) + H)	4022 events	1076 events	1770 events
Yield (H)	1591 events	556 events	742 events
Coincidence Prob. (H)		0.34 (CoinΞ⁻ / Inclusive)	0.47 (CoinΛ / Inclusive)
Br × Acceptance (Ξ→Λπ⁻, Λ→pπ⁻)		0.64 × 0.87 =0.56	0.64 × 0.92 =0.59





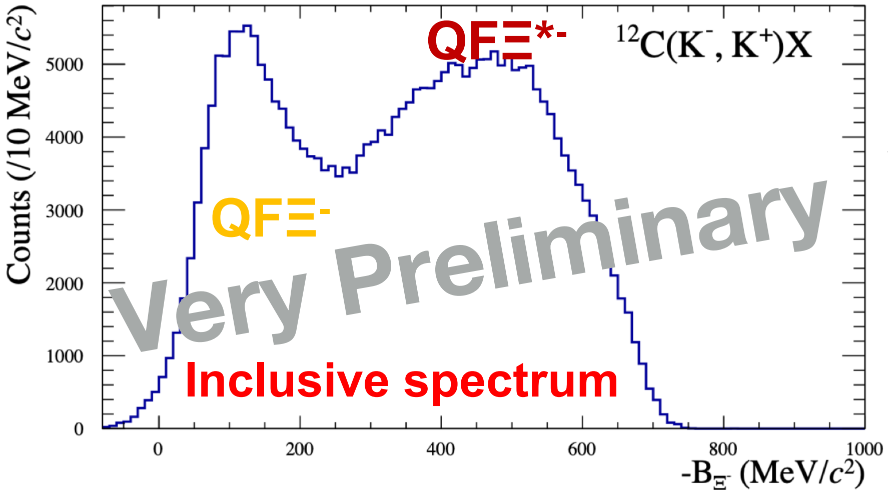
E42 byproduct: Ξ-A potential determination



E42 can decompose $^{12}C(K^-, K^+)$ inclusive spectrum to Ξ^- escape/$\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectra

→ Sensitive to W_0^{Ξ} (Im) !!

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

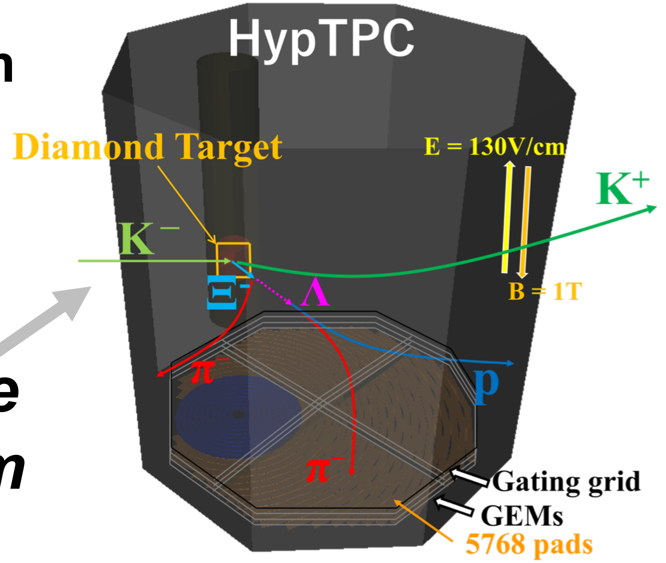


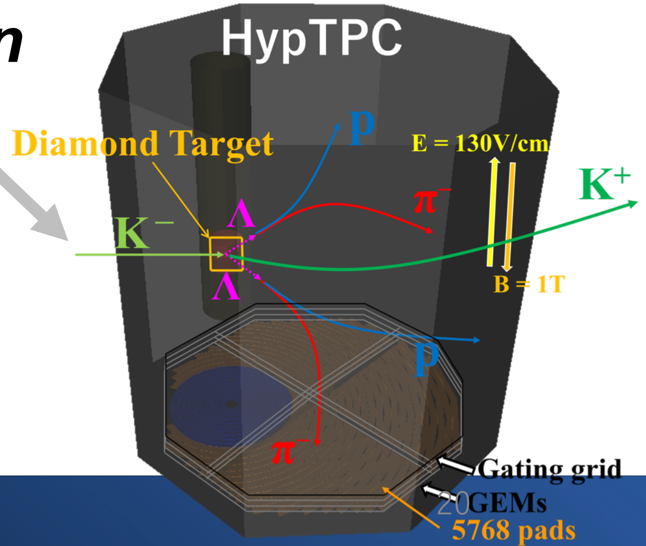
QFΞ⁻: K^- "p"→ $\Xi^- K^+$

QFΞ*: K^- "p"→Ξ*(1535) K^+
K^- "p"→Ξ π K^+

Ξ^- escape spectrum

$\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectrum

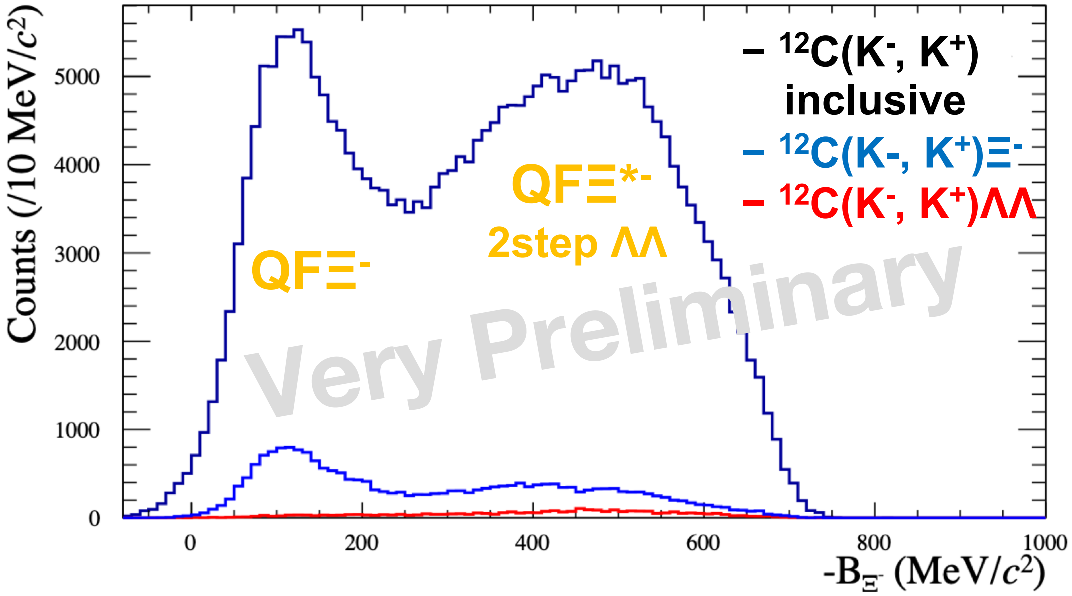




Exclusive Binding-energy Spectra for Ξ-A Potential Study

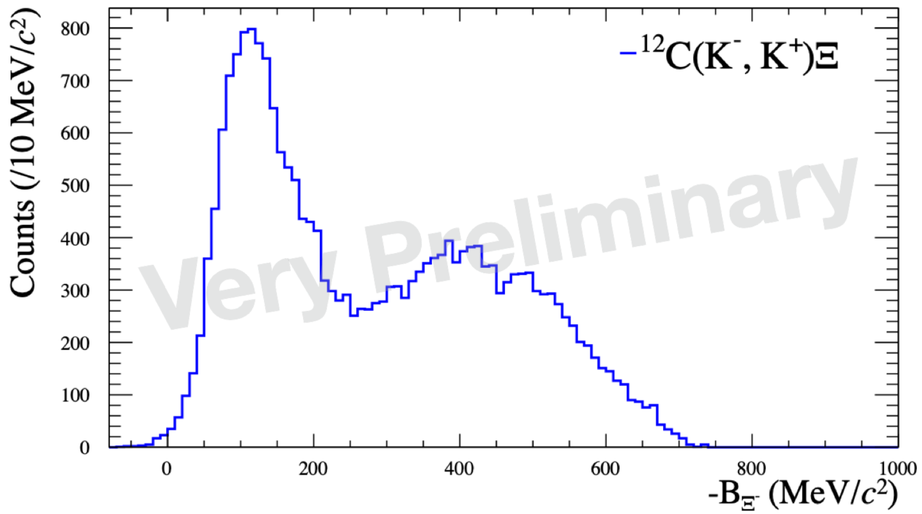
Yield ratio (Ξ^- escape / $\Xi^- p \rightarrow \Lambda\Lambda$ conversion)

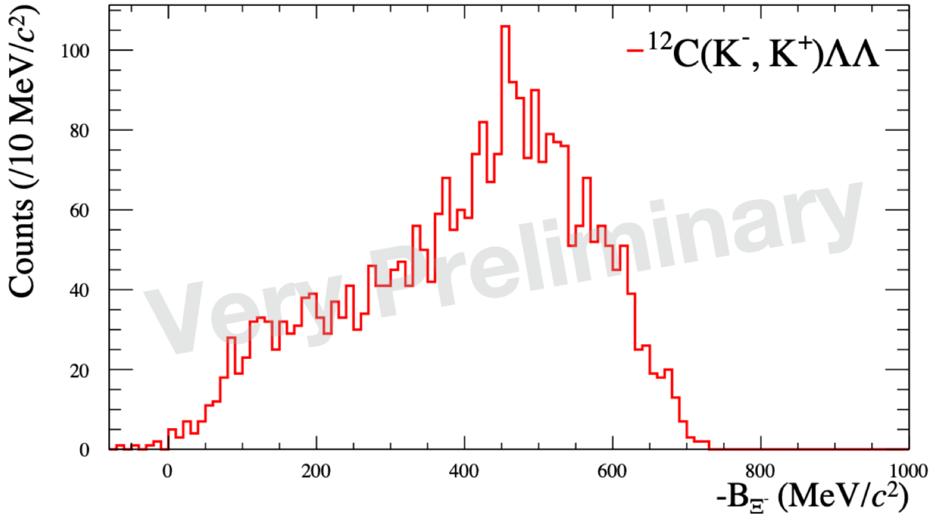
→ Sensitive to W_0^{Ξ} (Im)



Ξ^- escape spectrum

$\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectrum



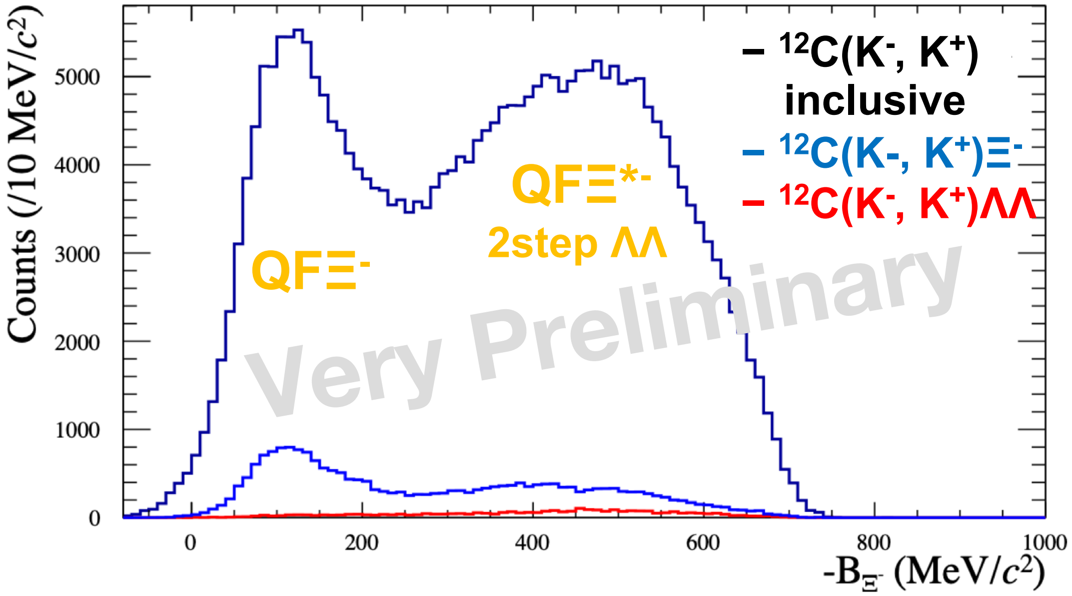


Exclusive Binding-energy Spectra for Ξ-A Potential Study

Coincidence probability = N(coin.)/N(Inclusive)

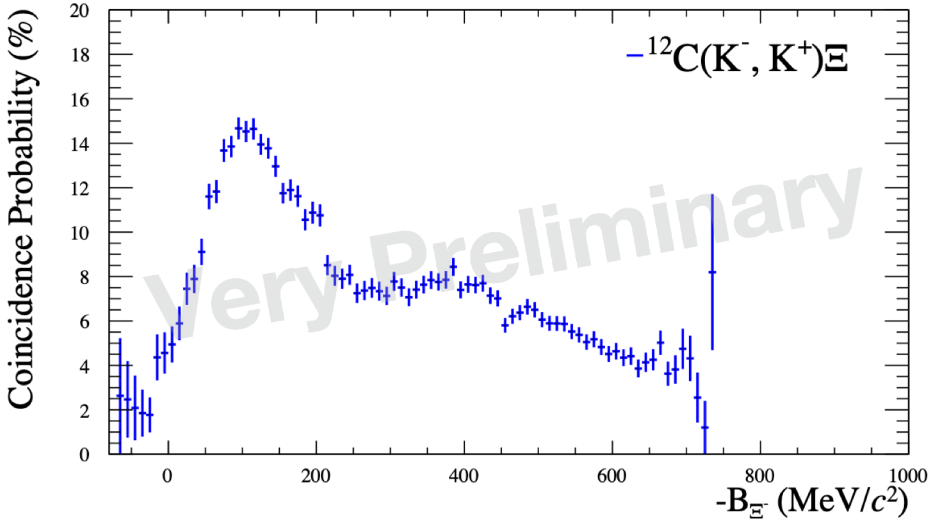
Yield ratio (Ξ^- escape / $\Xi^- p \to \Lambda\Lambda$ conversion)

→ Sensitive to W_0^{Ξ} (Im)

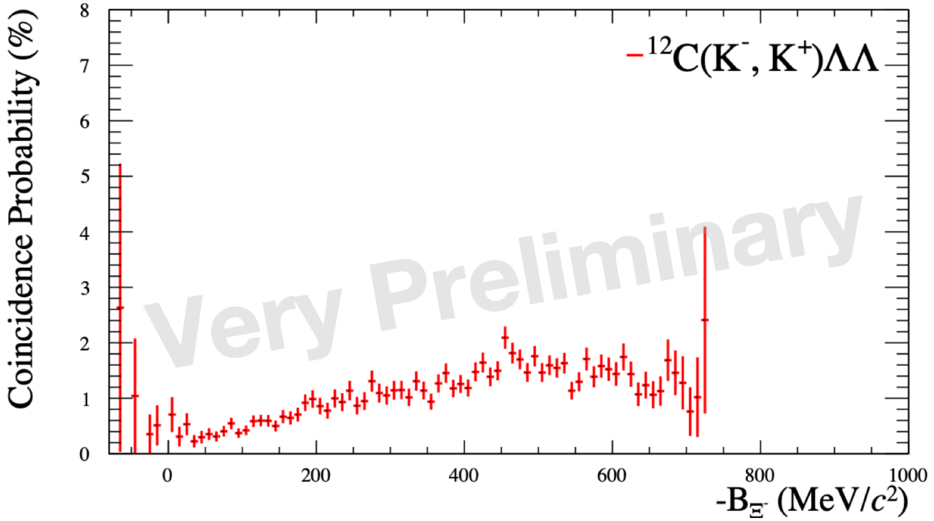


Acceptance correction of HypTPC is necessary and on going.

Ξ^- escape spectrum



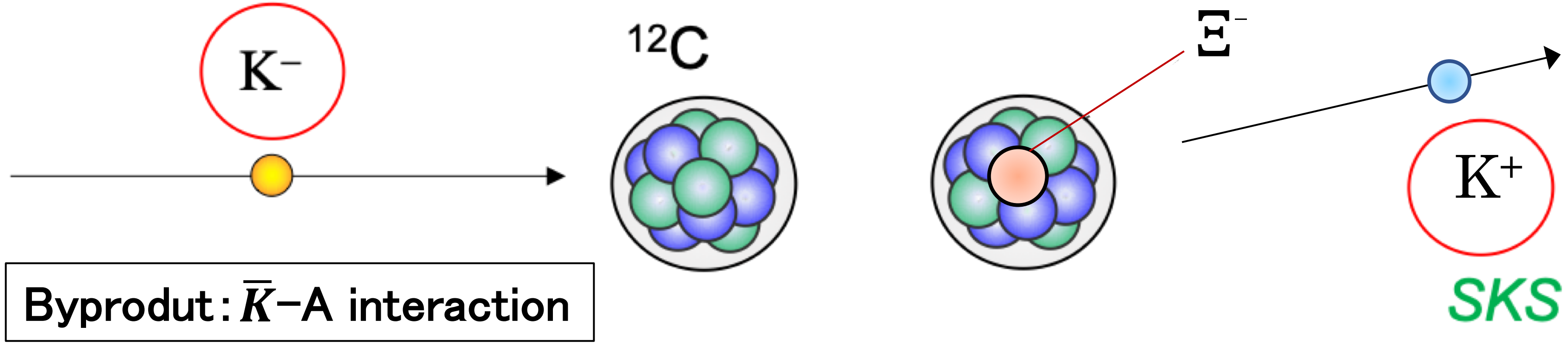
$\Xi^- p \to \Lambda\Lambda$ conversion spectrum



$^{12}C(K^-, p)$ spectrum with J-PARC E05

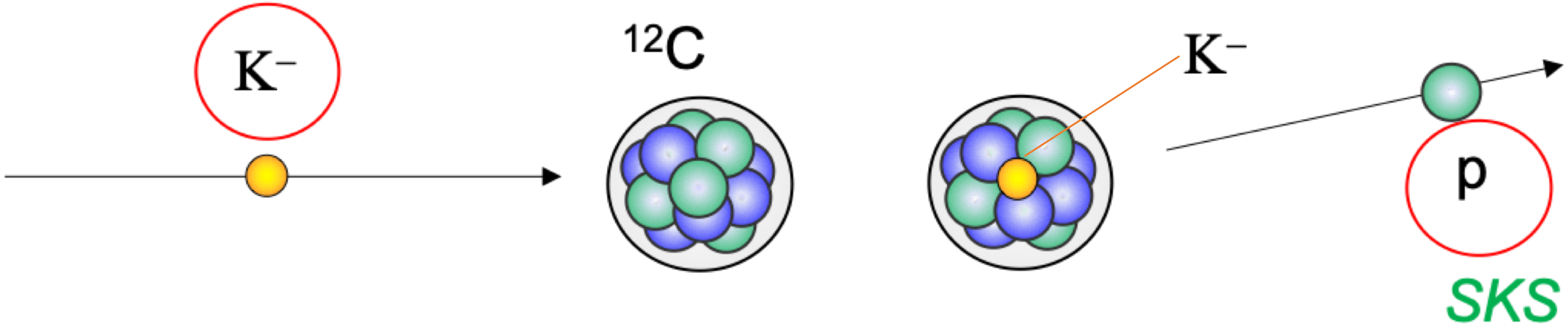
Main : Ξ hypernucleus search

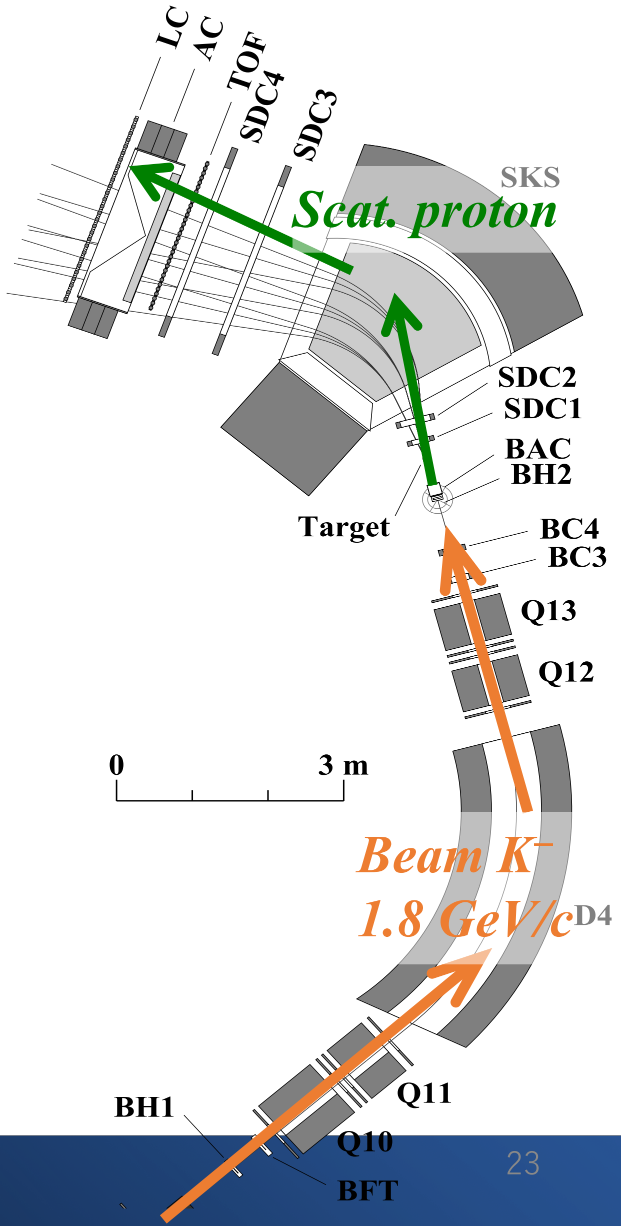
K1.8 Beamline



Byprodut : $\bar{K}$−A interaction

K1.8 Beamline





(V_0, W_0) determination from ^{12}C(K^-, p) spectrum

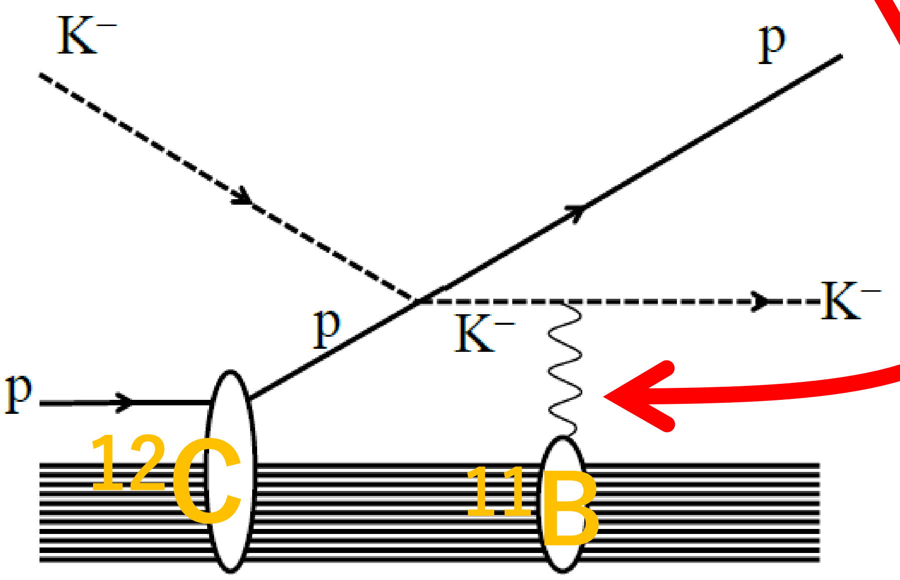
Y. Ichikawa et al., PTEP 2020, 123D01(2020)

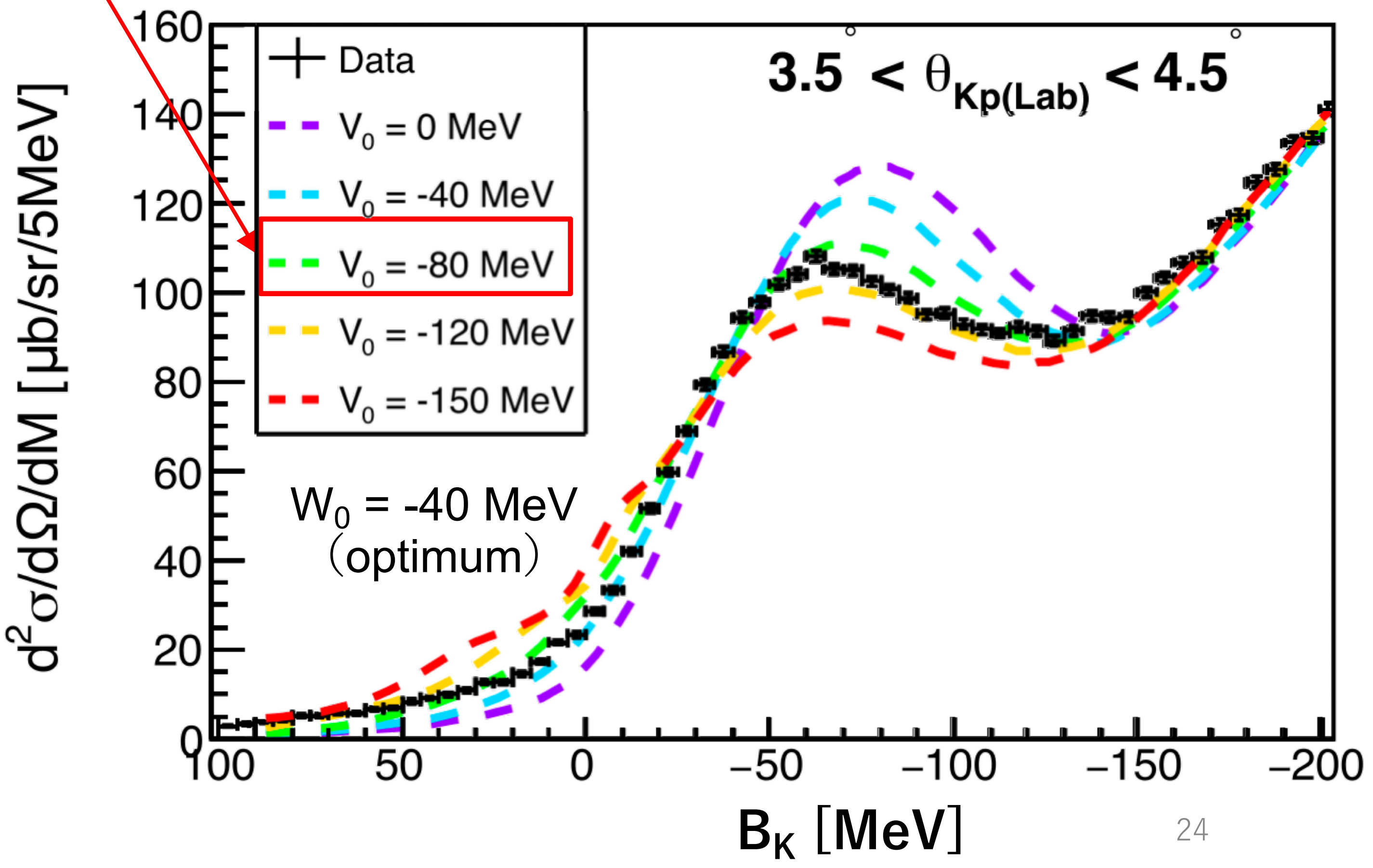
(V_0, W_0) = (-80, -40) MeV!

K^--^{11}B interaction potential

$$U(r, E) = (\underline{V_0} + i\underline{W_0} f_{\mathrm{phase}}(E))\frac{\rho(r)}{\rho(0)} \ ,$$

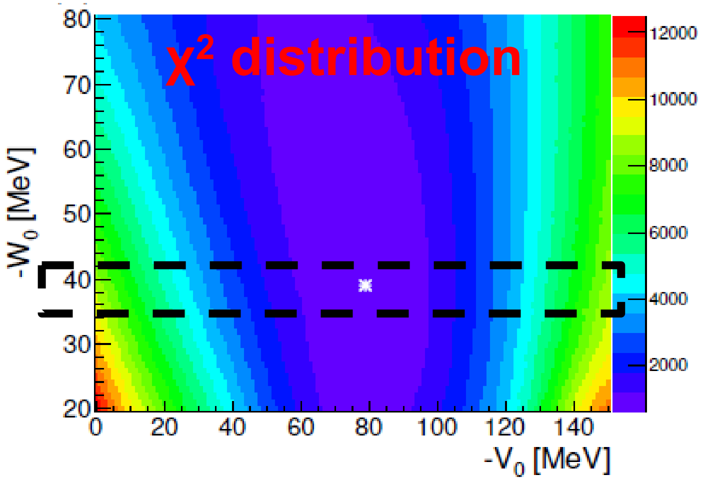
Parameters

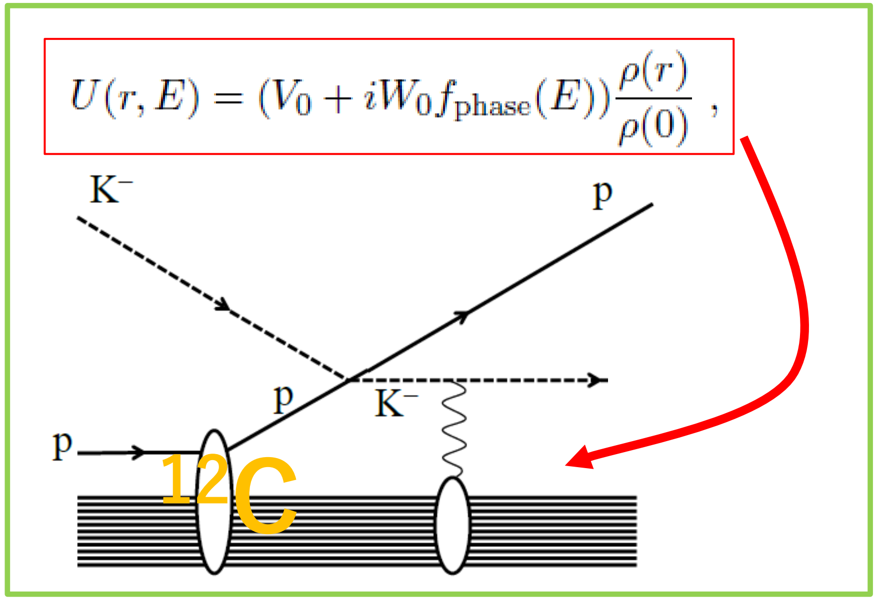




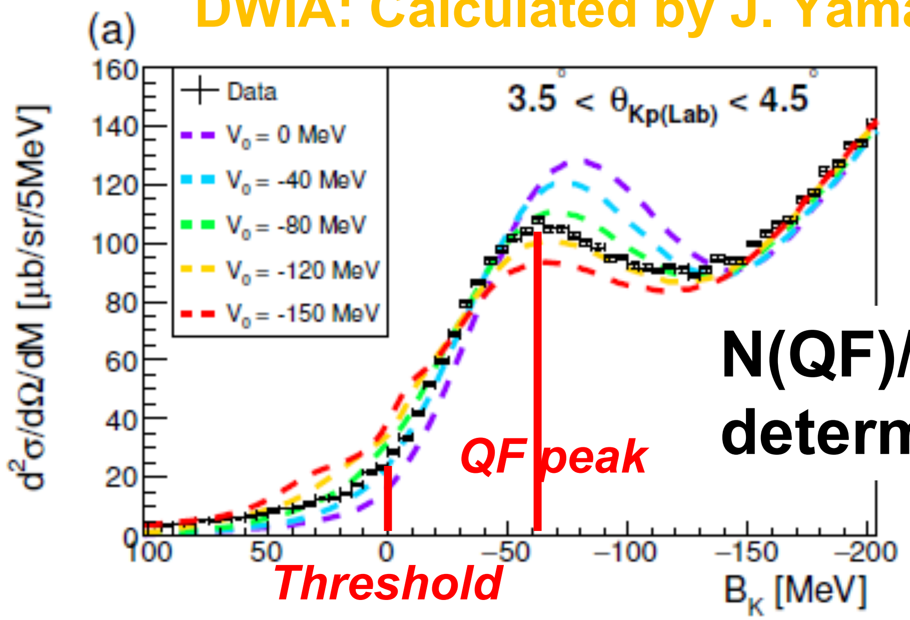
$^{12}C(K^-, p)$ spectrum by varying (V_0, W_0)

Optimum: (V_0, W_0) = (-80, -40) MeV!
Corresponding to shallow potential

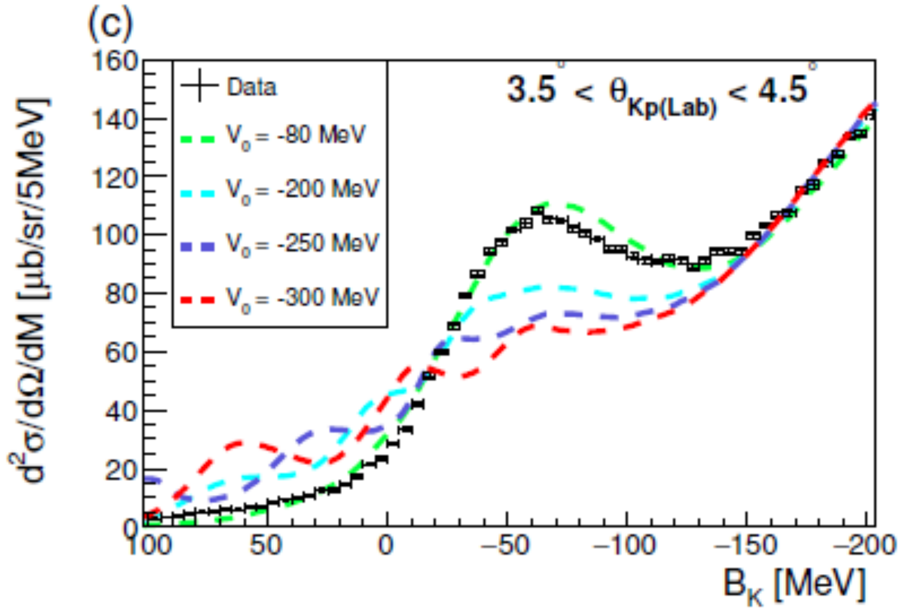




DWIA: Calculated by J. Yamagata-Sekihara.



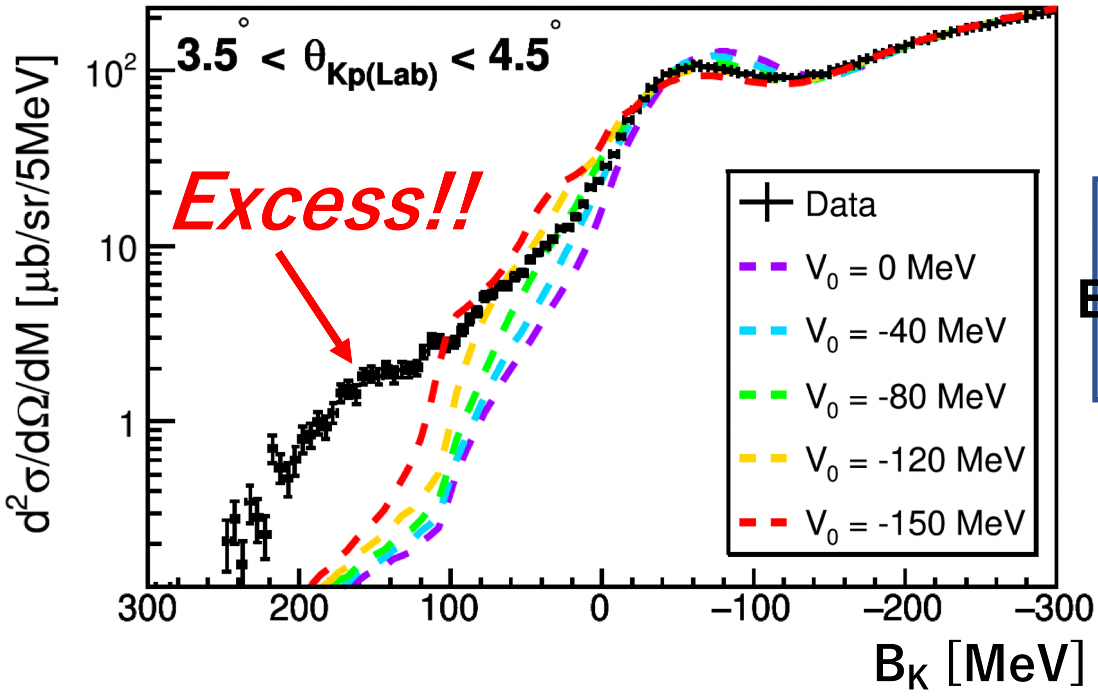
N(QF)/N(Threshold) determines the χ^2



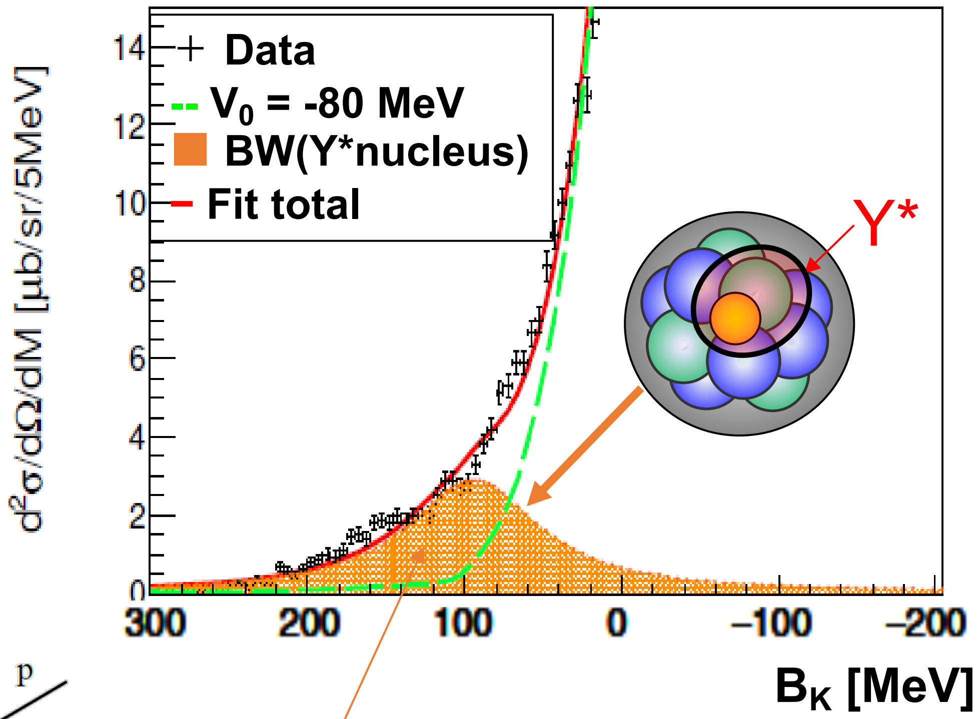
Suggestion of Y*-nucleus state

Y. Ichikawa et al., PTEP 2020, 123D01(2020)

Semi-Log plot

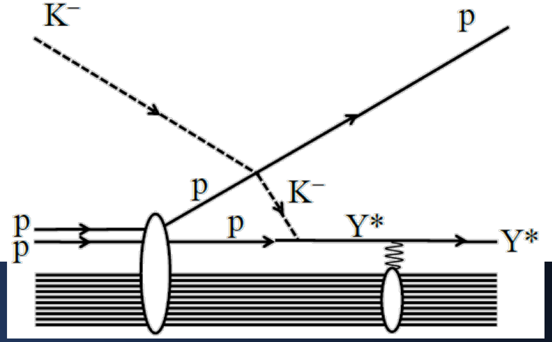


Add the BW contribution (Y*-nucleus)



$B_K \sim 100$ MeV
$\Gamma \sim 100$ MeV

Unintroduced reaction diagram

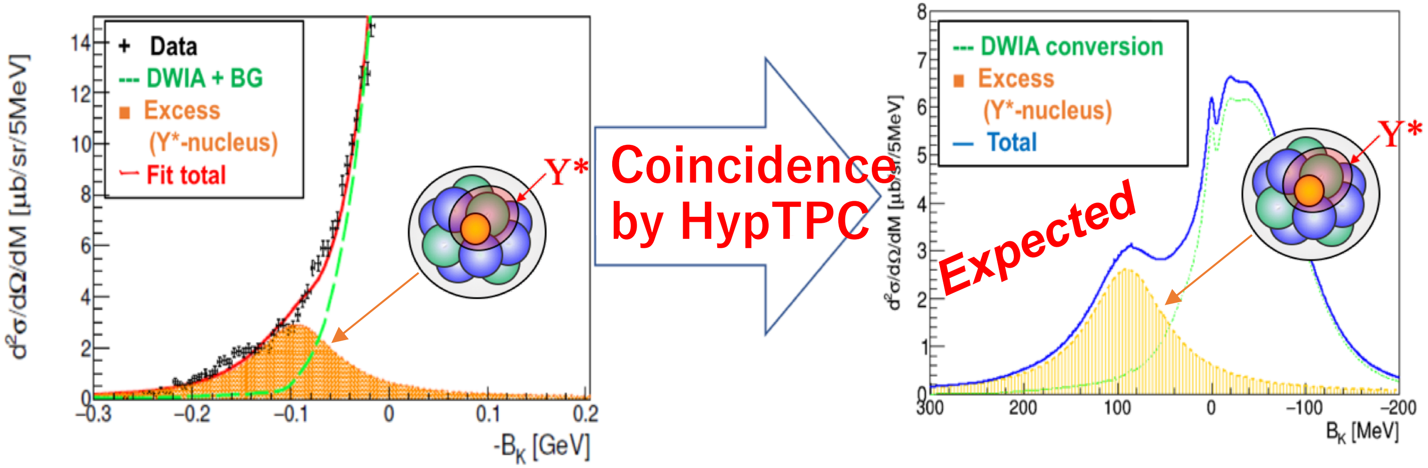


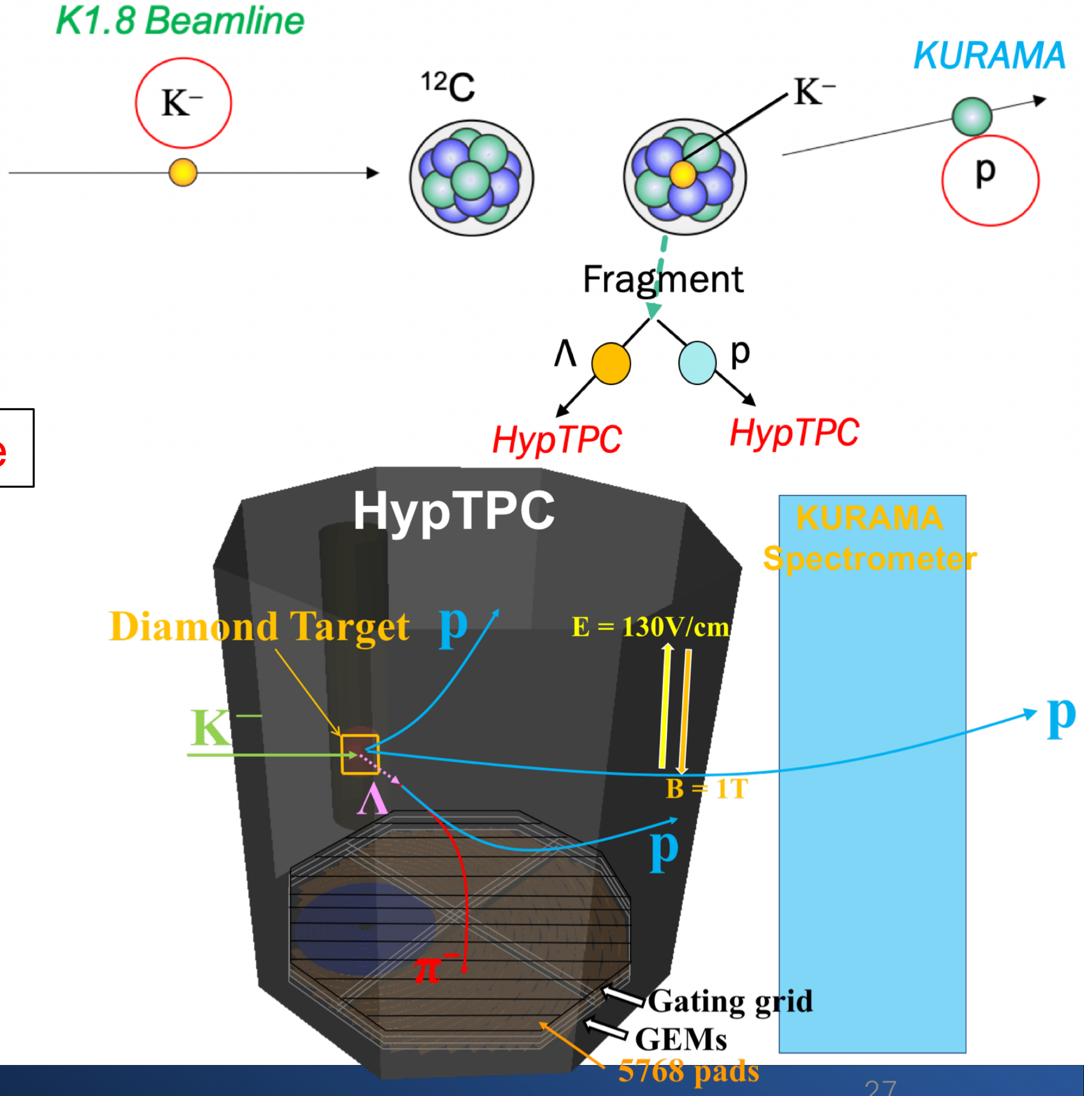
E42 Kp Coincidence measurement

E05 Kp: Inclusive $^{12}C(K^-, p)$ measurement
E42 Kp: Exclusive $^{12}C(K^-, p)\ \Lambda p$ measurement
We can improve S/N ratio!!

E05Kp: $^{12}C(K^-, p)$ Inclusive

E42Kp: $^{12}C(K^-, p)\Lambda p$ Exclusive





Summary

- $^{12}C(K^-, K^+)$ reaction to study Ξ-hypernucleus and Ξ-A interaction
  - E05 (K^-, K^+) paper has been submitted.
  - We showed the wide energy-range spectrum (Carbon graphite target).
  - We have performed spectrum fitting around the threshold region.
    - (b) QF(Γ=0) + 2Gaus and (c) QF(Γ≠0) + 1BW are likely.
    - The peak structures will be prominent with E70's resolution, 2MeV.
  - E42 can decompose the inclusive spectrum to escape and conversion one.
    → Good sensitivity to determine the W_0^{Ξ}.
- 12C(K^-, p) reaction to study $\bar{K}$-A interaction
  - (V_0, W_0) = (-80, -40) MeV, shallow potential, well reproduced the spectrum.
  - We found the significant event excess (Y*-nucleus state?), around B_K ~ 100 MeV.
  - E42 exclusive study will conclude the existence of event excess.

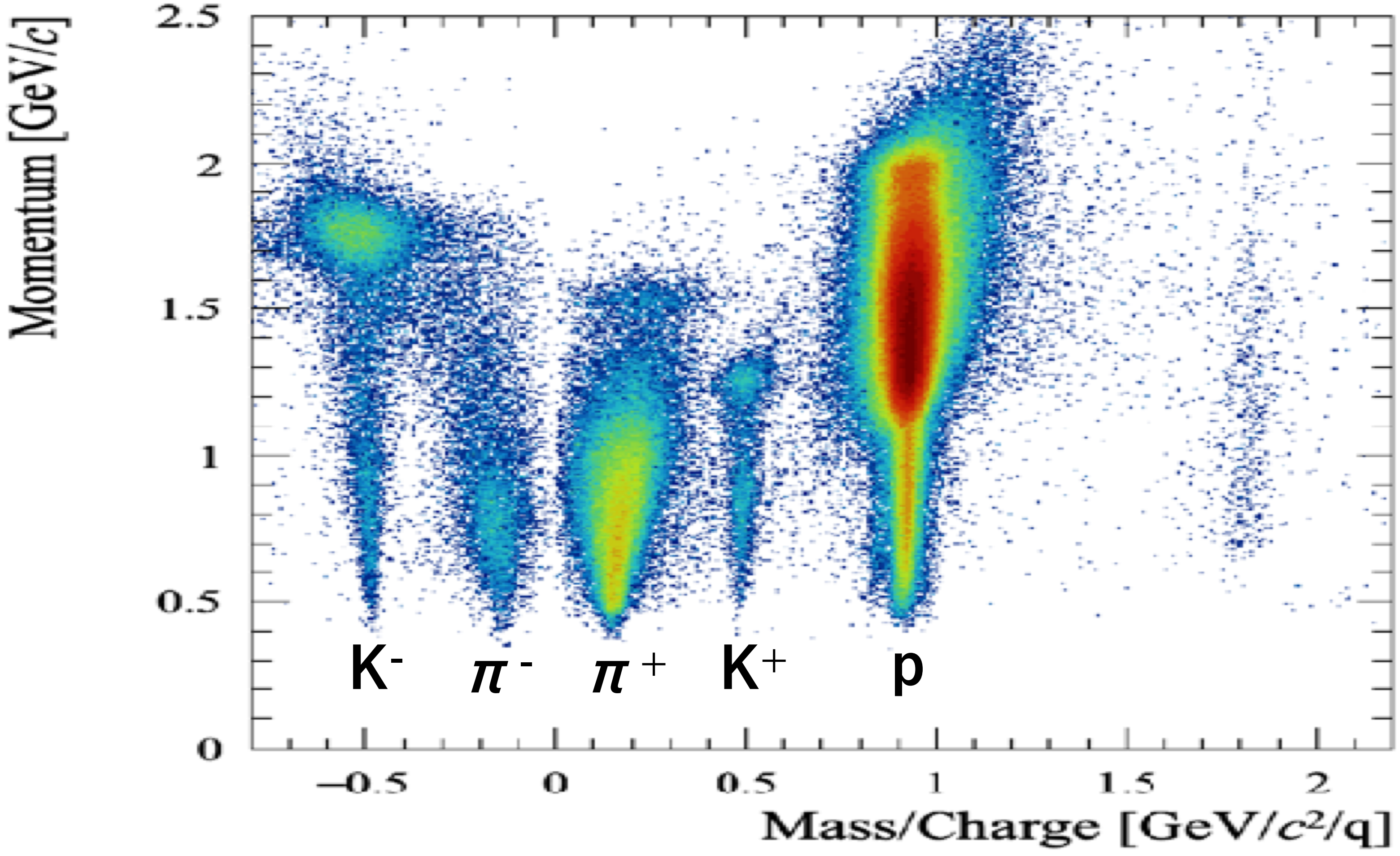
Back up

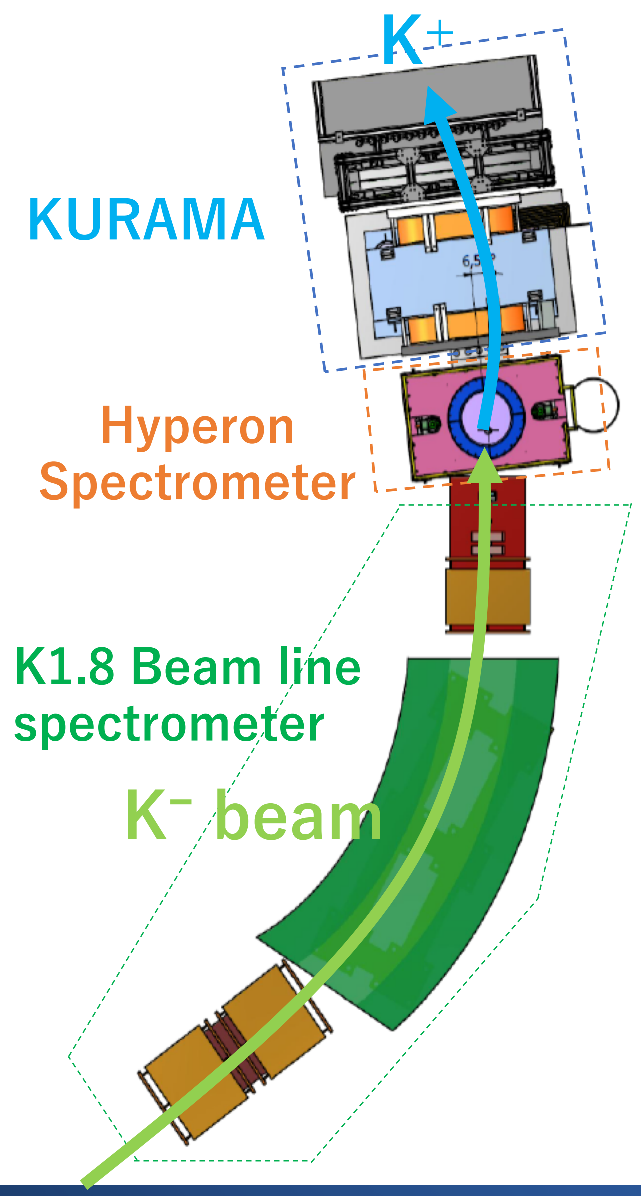
Introduction

- H-dibaryon:
  Six-quark state consisting of *uuddss* quarks due to color magnetic force.
- History of H-dibaryon search

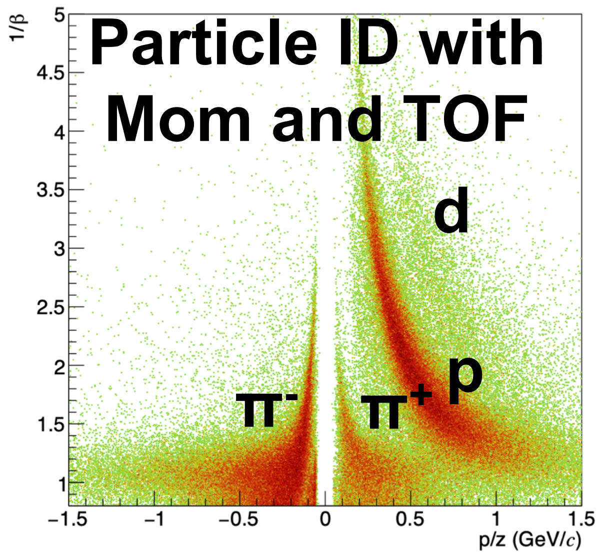
1977 • Deeply-bound di-hyperon predicted by R. Jaffe
1980-2000 • No evidence for the deeply-bound H from KEK, BNL,
• and CERN experimental efforts by more than 80 MeV
2001 • Mass constraint from observation of ${}^{6}_{\Lambda\Lambda}$He (E373)
1998,2007 • Enhanced $\Lambda\Lambda$ production near threshold was
• reported from E224 and E522 at KEK-PS.
2011 • LQCD calculations predict the H-dibaryon near $m_{\Lambda\Lambda}$
2013-2015 • No evidence for $H \to \Lambda p \pi^-$ and $H \to \Lambda\Lambda$
• in high-energy e^+e^-, pp and AA experiments
2021 • LQCD calculations point to the mass the H-dibaryon
• very close to ΞN threshold ($m_\pi \approx 146$ MeV)
2021 • **J-PARC E42 has successfully completed with HypTPC.**

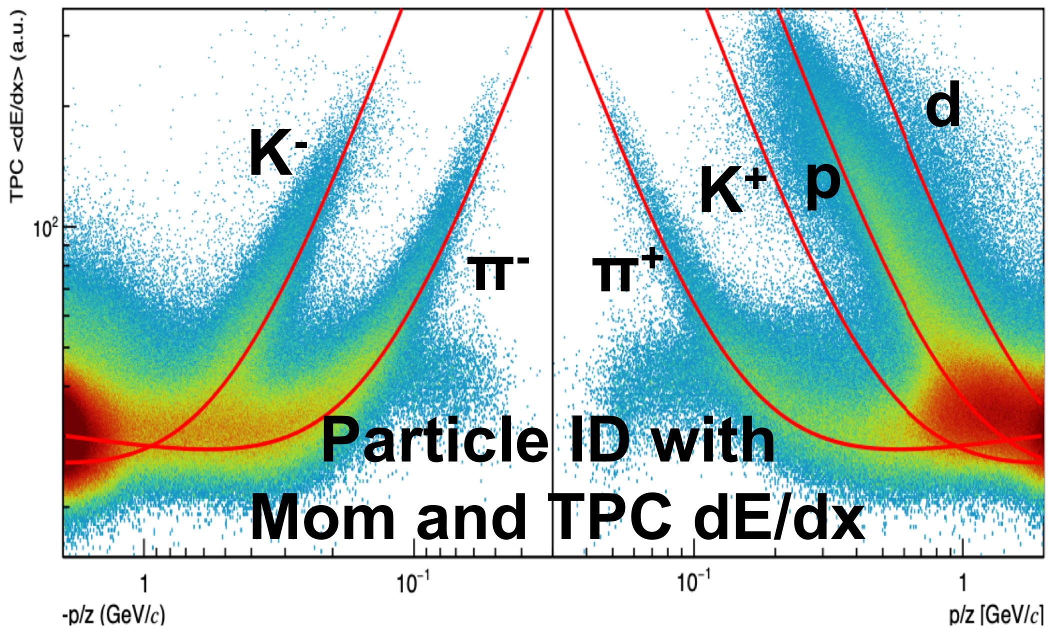
Analysis of KURAMA spectrometer for the forward scattered particles

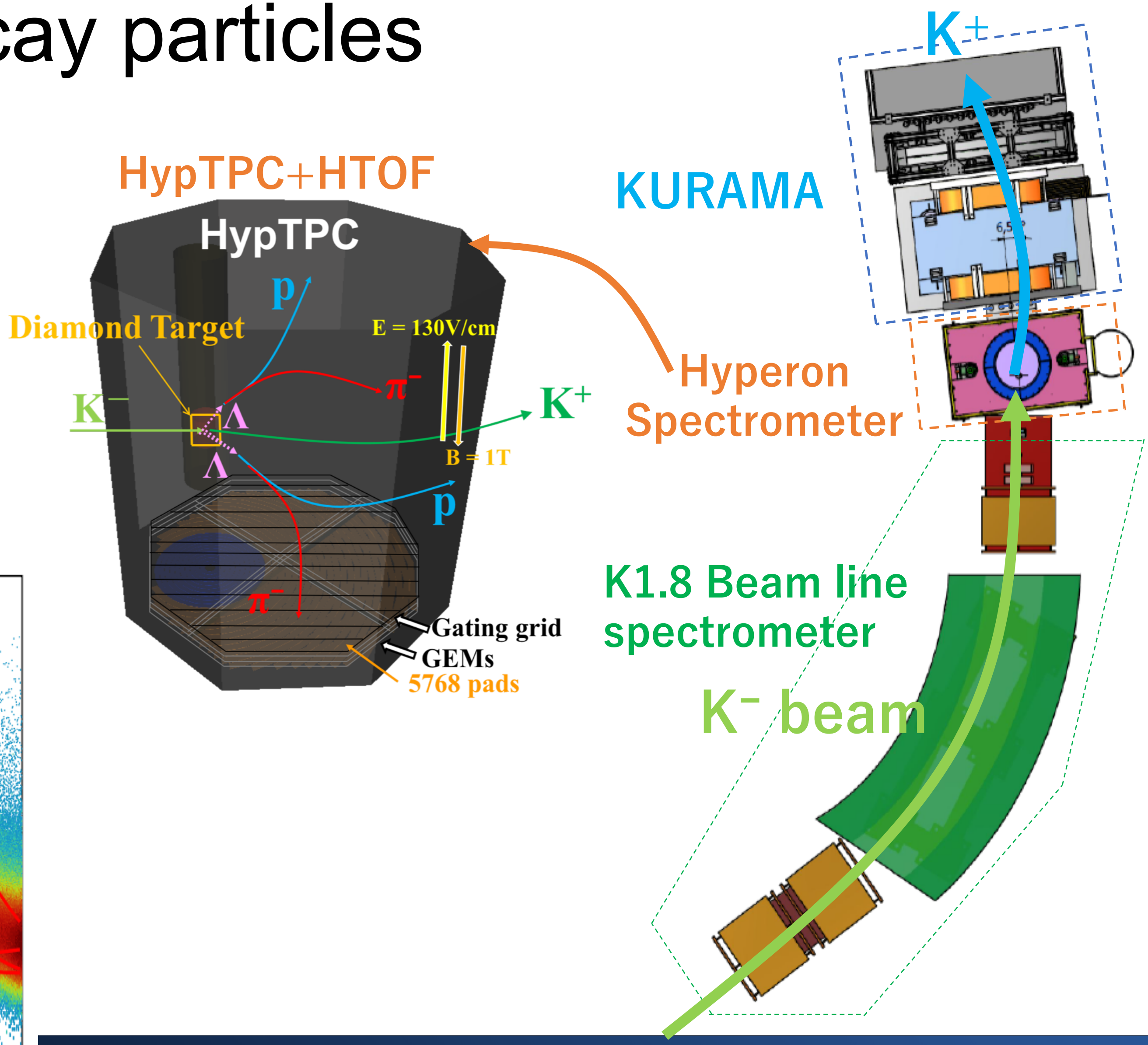




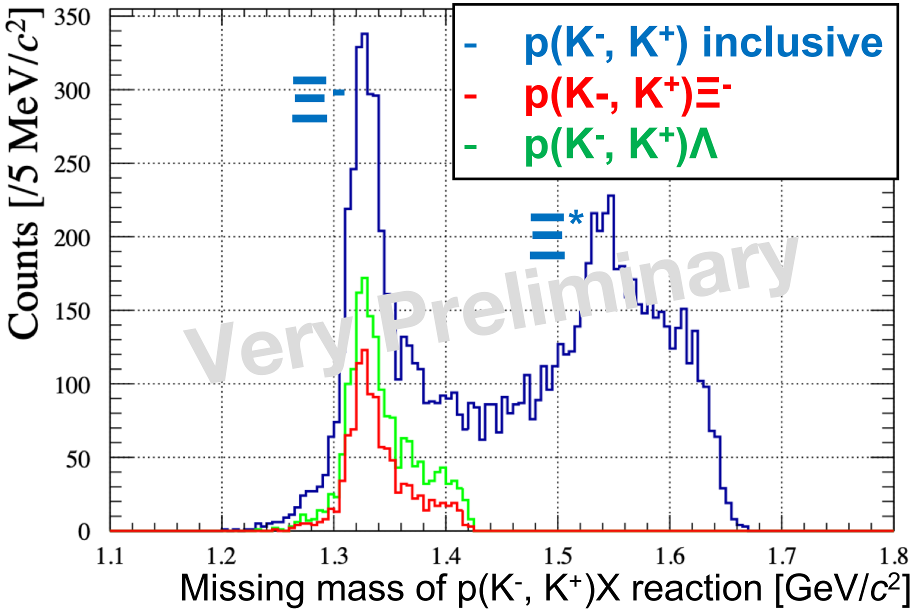
Analysis of Hyperon spectrometer (HypTPC) for the decay particles





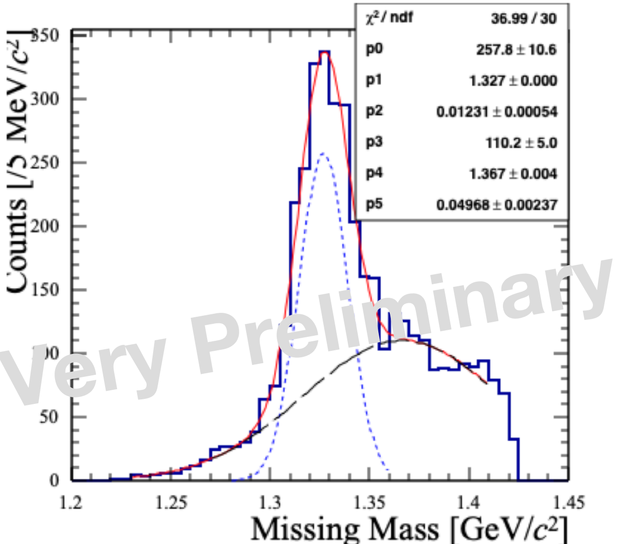


p(K^-, K^+) missing-mass analysis with CH2 target

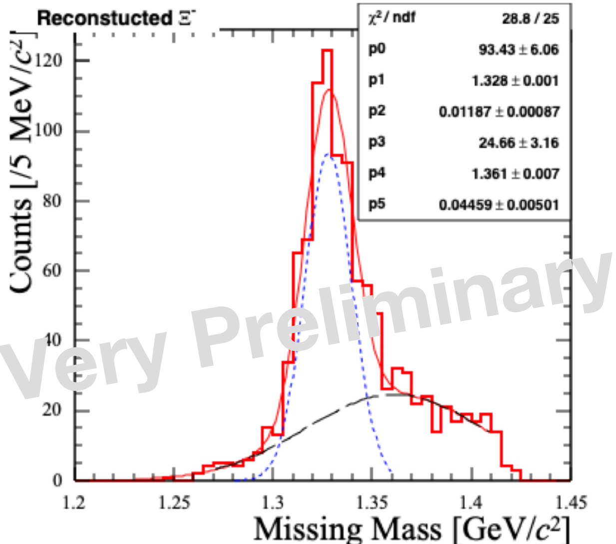


	Inclusive	Coin with Ξ^-	Coin with Λ
Yield (C(QF) + H)	4022 events	1076 events	1770 events
Yield (H)	1591 events	556 events	742 events
Coincidence Prob. (H)		0.34 (CoinΞ^- / Inclusive)	0.47 (CoinΛ / Inclusive)
Br × Acceptance ($\Xi\to\Lambda\pi^-$, $\Lambda\to p\pi^-$)		0.64 × 0.87 =0.56	0.64 × 0.92 =0.59

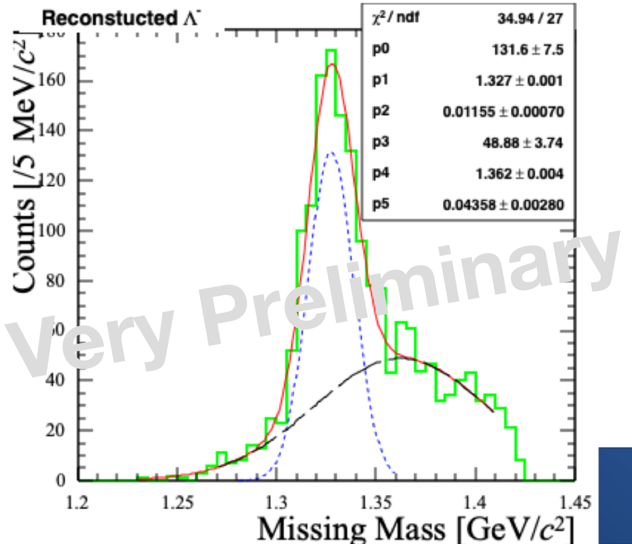
p(K^-, K^+) inclusive



p(K^-, K^+) Ξ^-

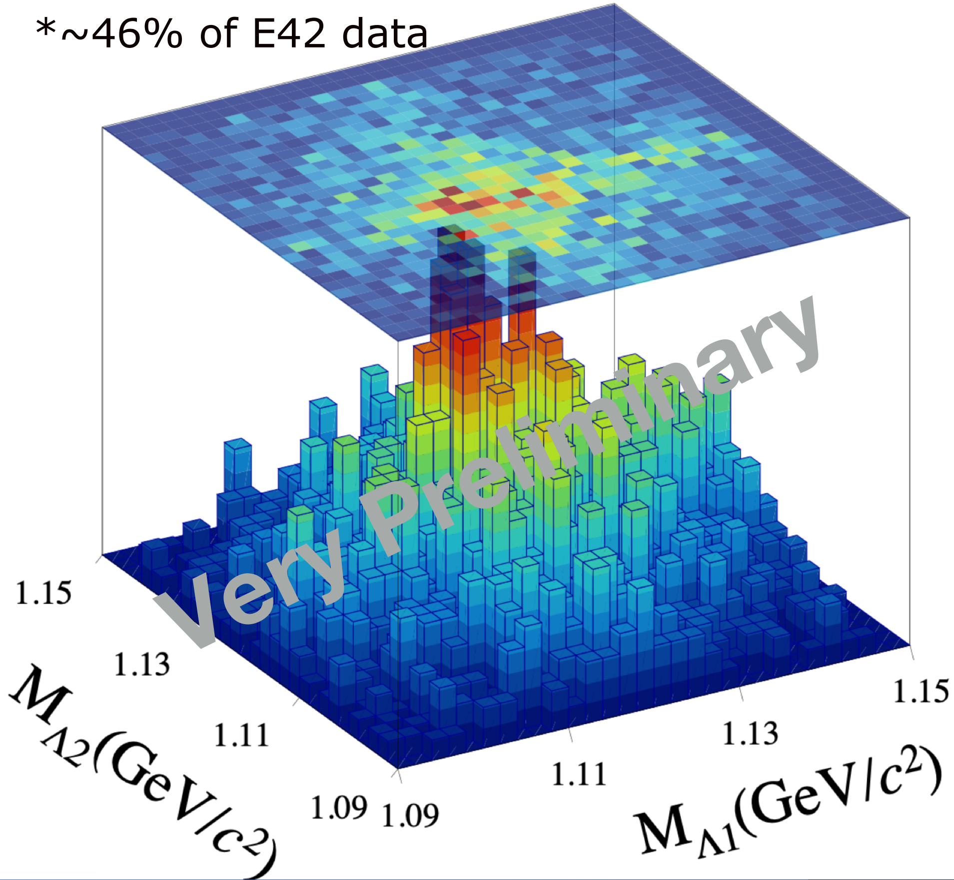


p(K^-, K^+) Λ



ΛΛ reconstruction using HypTPC

3,000 ΛΛ events are reconstructed with 46% E42 data
→ 6,600 ΛΛ events with 100% data



Summary of past experiments

	KEK E224	KEK E522
Beam K^-	$p\_(K^-)$ = 1.65 GeV/c	$p\_(K^-)$ = 1.66 GeV/c
$p\_(K^+)$ [GeV/c]	$0.95<p\_(K^+)<1.3$	$0.9<p\_(K^+)<1.3$
$d\sigma/d\Omega^C$ (ΛΛ)	**7.6 μb/sr**	**12.8 μb/sr**
ΛΛ yield	35 events	68 events

E42 used $p\_(K^-)$ = 1.8 GeV/c beam
Considering 1.5 times larger cross section of Ξ^- production

Comparison with expected yield

$p\_(K^+)$ [GeV/c]	**$0.95<p\_(K^+)<1.3$**		**$0.5 < p\_(K^+)$**
Assumed $d\sigma/d\Omega^C$(ΛΛ)	**7.6 μb/sr**	**12.8 μb/sr**	
Expected ΛΛ yield	337 events	570 events	
Expected scaled ΛΛ yield	520 events	880 events	
Measured ΛΛ yield	1,390 events		3,030 events

Measured ΛΛ yield is larger than the expectation

Other physics topics of E42

4 Ph.D. students are analyzing the E42 data

Wooseung (Korea Univ.)

- Ξ^--nucleus interaction study (close relation with H-dibaryon)
  - E42 is sensitive for the W_0 (imaginary part) determination

Byungmin (Korea Univ.)

- $d\sigma/d\Omega$ and P_Ξ measurement of $K^- p \rightarrow K^+ \Xi^-$ / $\Xi^-(1535)$ reaction

Sungwook (Korea Univ.)

- $d\sigma/d\Omega$ measurement of $p(K^-, p)K^*(892)$ and $^{12}C(K^-, p)K^*(892)X$

F. Oura (Tohoku Univ.)

- Kaonic nuclear search by $^{12}C(K^-, p)$ reaction

H-dibaryon box will be opened after we perfectly confirm the analysis

Experiments related to Ξ-A interaction study

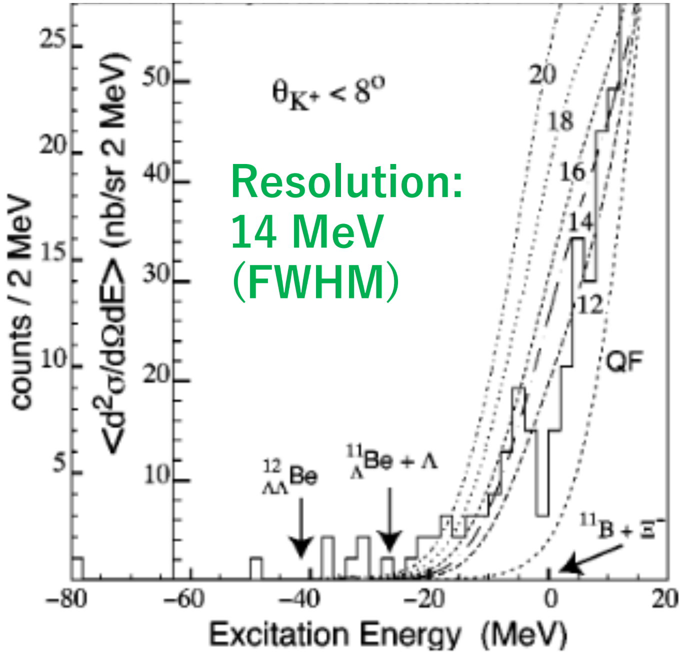
Ξ-A potential:

$$U_\Xi(r) = V_\Xi(r) + iW_\Xi(E, r) = [V_0^\Xi + iW_0^\Xi g(E)] f(r)$$

V_0^Ξ(Re): Interaction strength of Ξ-A
W_0^Ξ(Im): Absorption strength
($\Xi^- p \to \Lambda\Lambda$, $\Xi^- p \to \Xi^0 n$)

BNL E885

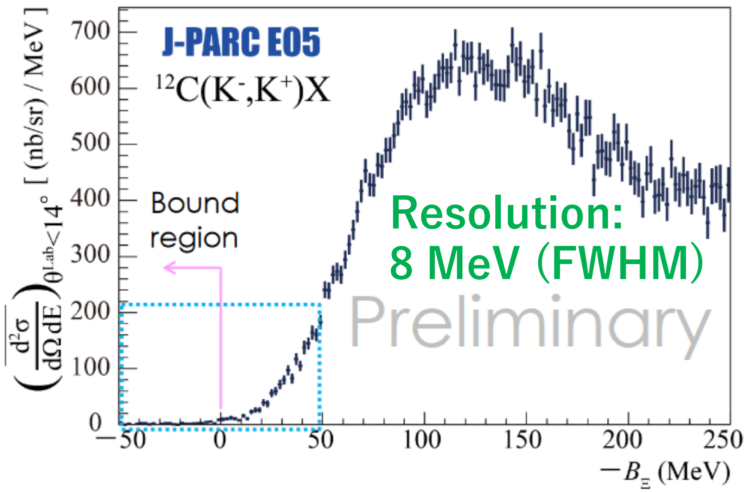
^{12}C(K$^-$, K$^+$) inclusive spectrum
→ V_0^Ξ ~ -14 MeV by neglecting W_0^Ξ



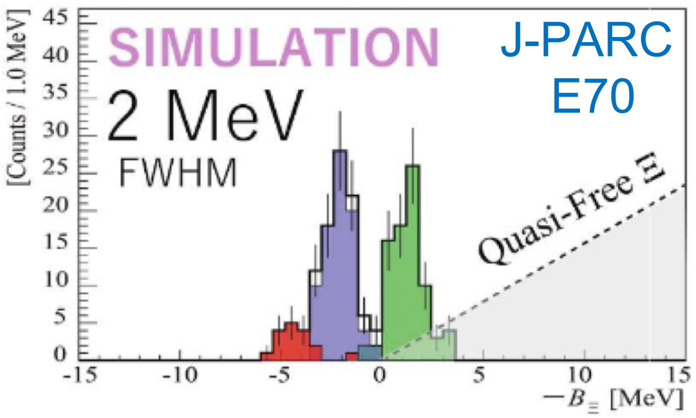
P. Khaustov et al., PRC 61, 054603 (2000)

J-PARC E05/E70

^{12}C(K$^-$, K$^+$) inclusive spectrum with wide B_Ξ range is taken.



Best resolution 2 MeV will be achieved in E70



T. Gogami et al., EPJ Web Conf. 271, 1102 (2022).

Experiments related to Ξ-A interaction study

Ξ-A potential:

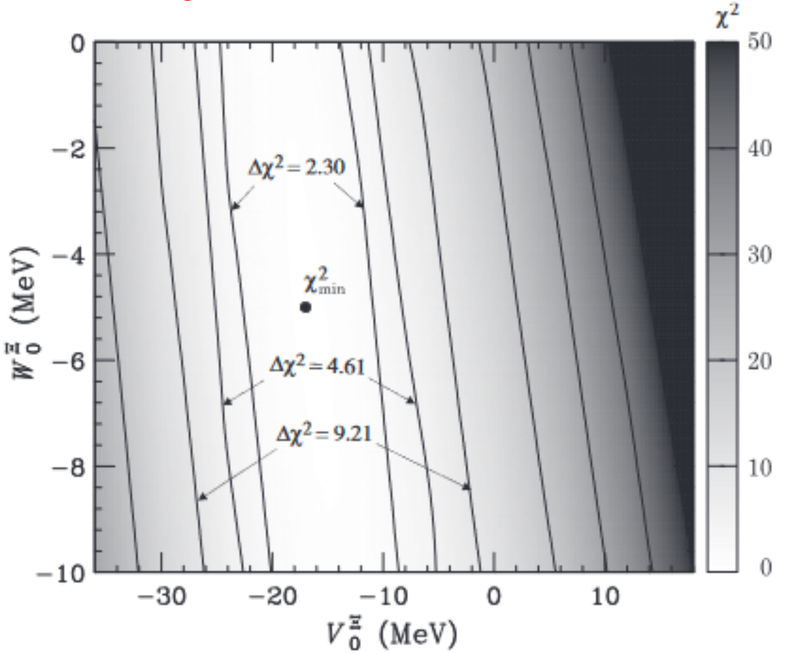
$$U_\Xi(r) = V_\Xi(r) + iW_\Xi(E,r)$$
$$= [V_0^\Xi + iW_0^\Xi g(E)]f(r)$$

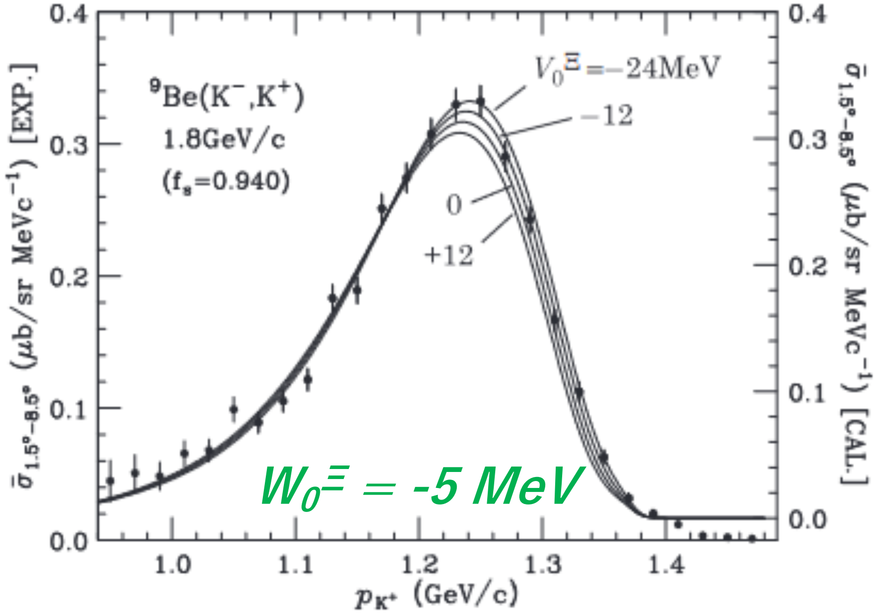
V_0^Ξ(Re): Interaction strength of Ξ-A
W_0^Ξ(Im): Absorption strength
($\Xi^- p \to \Lambda\Lambda$, $\Xi^- p \to \Xi^0 N$)

Reinvestigation using old BNL-E906 data by Harada and Hirabayashi

V_0^Ξ = -17±6 MeV

W_0^Ξ is difficult to determine by the inclusive spectrum.



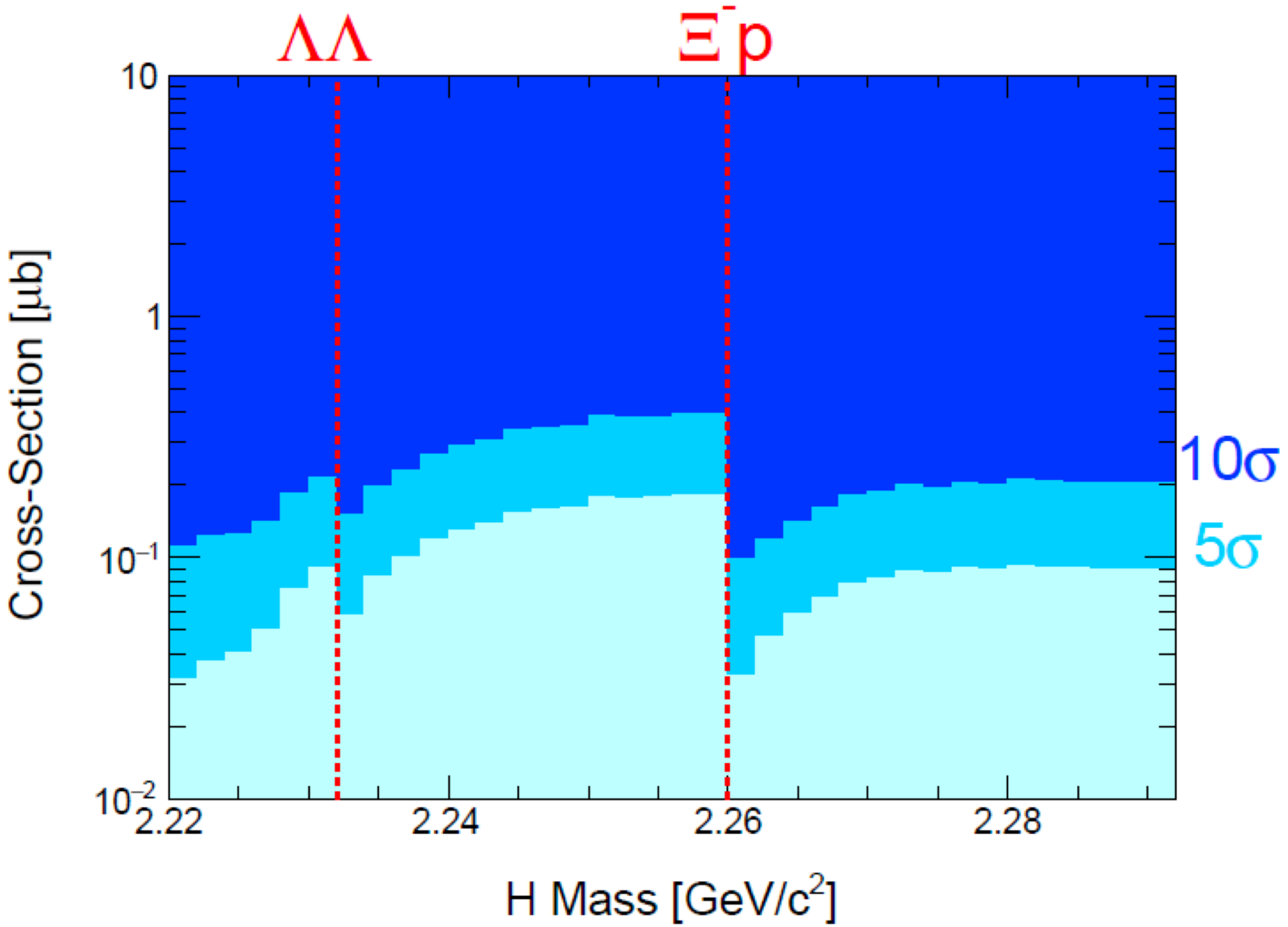


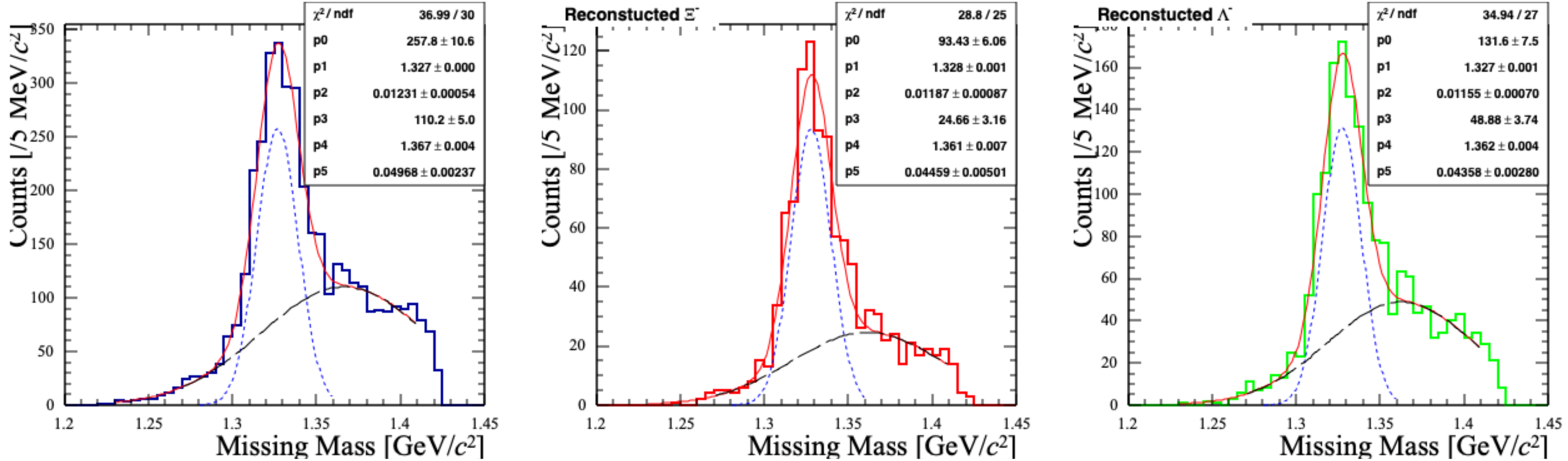
T. Harada and Y. Hirabayashi, Phys. Rev. C **103**, 024605 (2021).

Summary

- We have updated analysis code to improve the tracking efficiency and resolutions.
- Ξ^- and Λ reconstruction efficiency is improved and it is checked by the CH_2 target data analysis.
- 3,000 ΛΛ events are reconstructed using 46% dataset.
  Reconstructed ΛΛ yield is larger than the expectation.
  6,600 ΛΛ events are expected with 100% dataset.
- We show preliminary result of the byproduct to study the Ξ-A interaction.
  We can decompose the inclusive $^{12}C(K^-, K^+)$ spectrum to Ξ^- escape and $\Xi^- p \rightarrow \Lambda\Lambda$ conversion spectra. E42 is sensitive for the W_0^{Ξ} determination.
- We hope to open the H-dibaryon box soon.

Sensitivity of E42 experiment



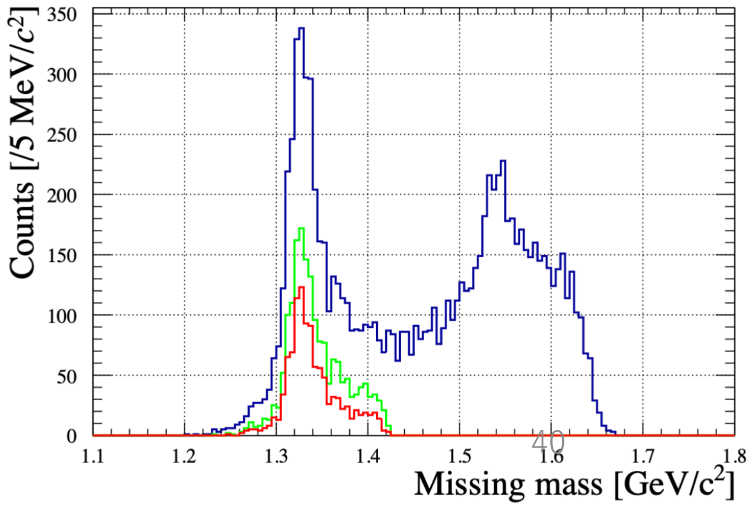


	All	Ξ^- reconstructed	Λ reconstructed
All events	4022	1076	1770
$\mathbf{p}(K^-, K^+)X$ events	1591	556	742

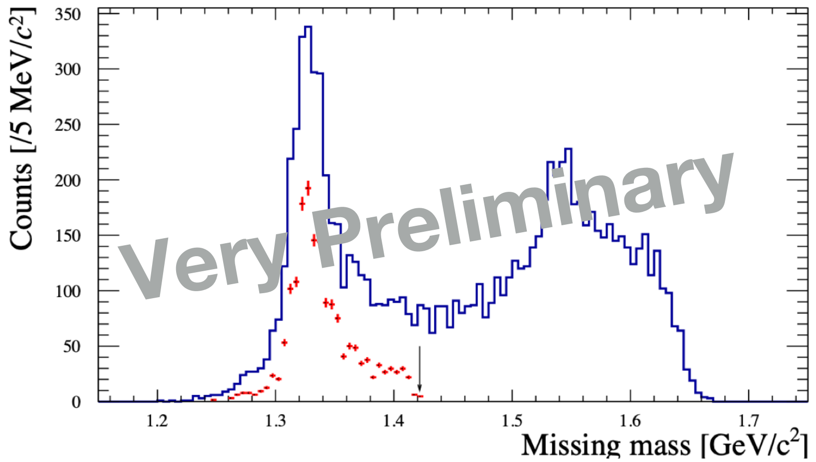
Xi- coincidence prob. : 556/1591/0.639 = 0.55

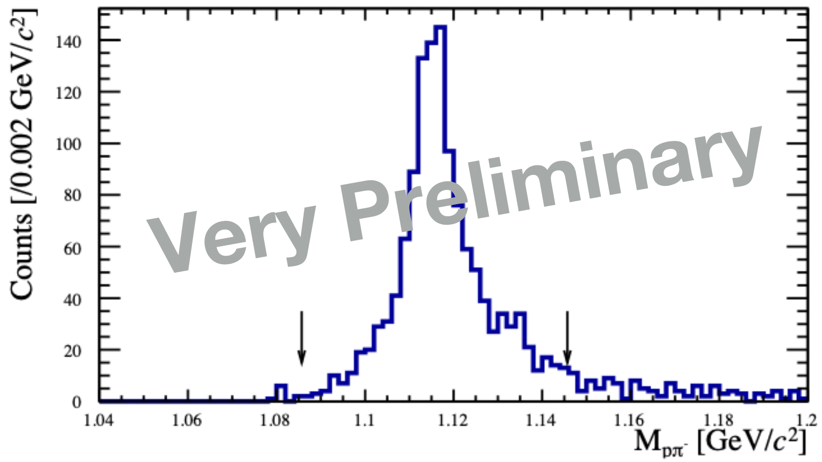
L coincidence prob. : 742/1591/0.639 = 0.73

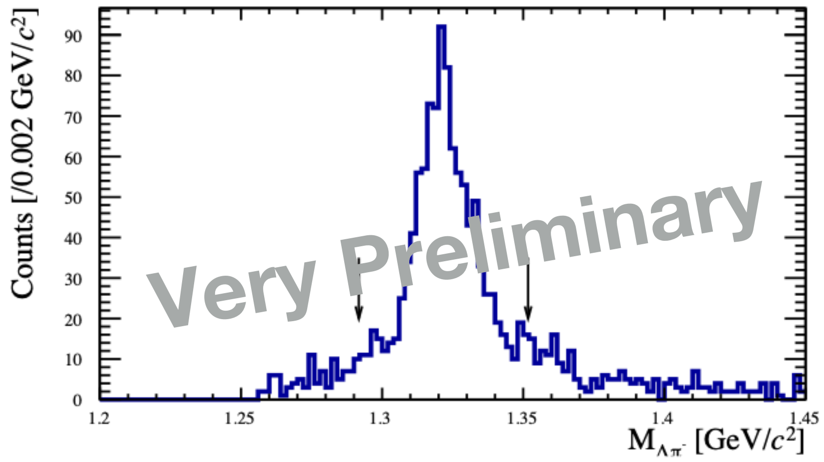
Raw histograms



Preliminary Λ / Ξ^- reconstruction via the $\mathbf{CH_2}(K^-, K^+)X$ reaction







K^+ Momentum Spectrum with Exclusive Processes

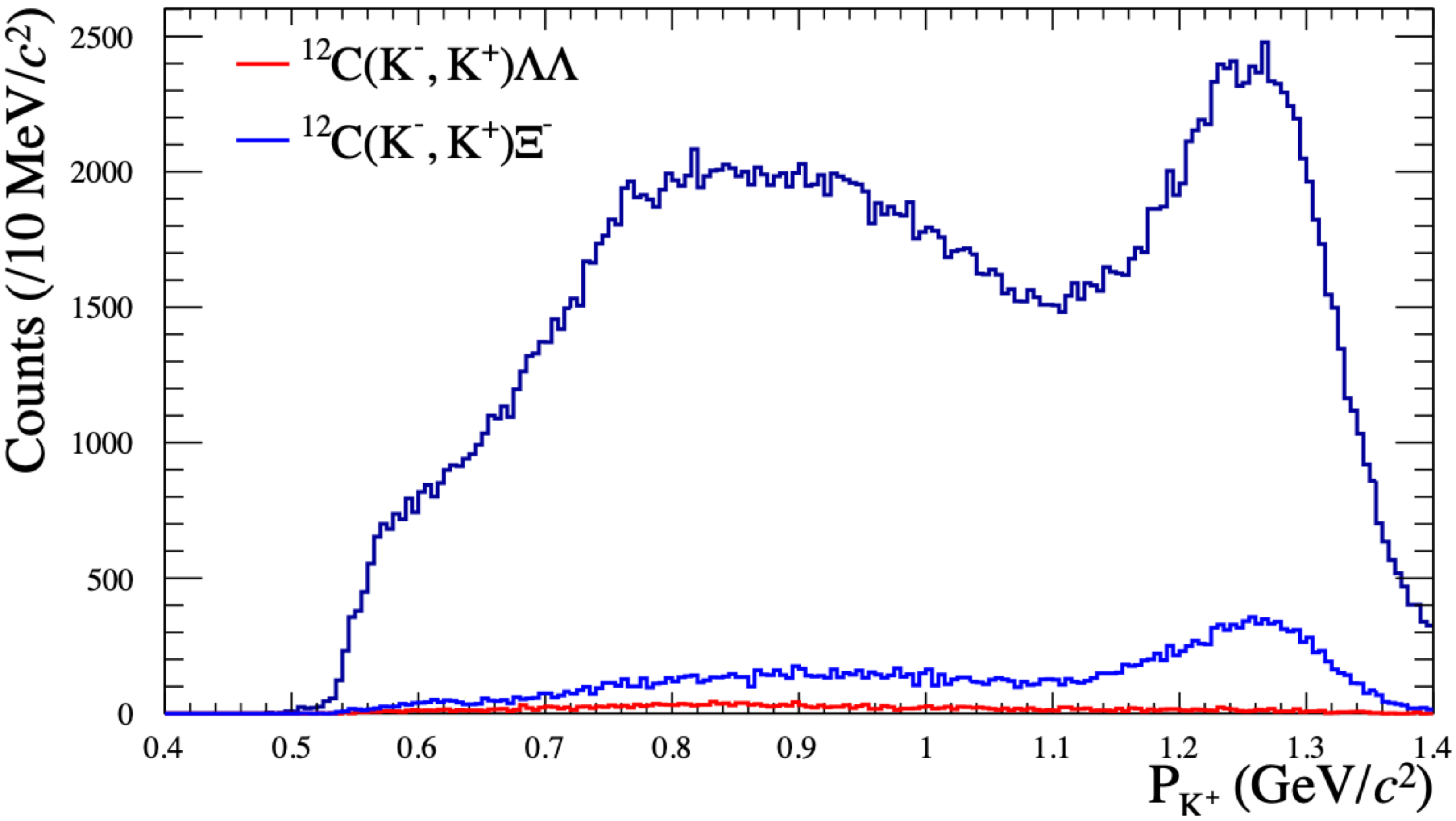


Table 5.2: Yield estimates for ΛΛ production events.

Parameters	PAC	E42
Beam power	60 kW	64 kW
K^- beam (M/h) (F_{K^-})	415	
Accelerator operation ($\varepsilon_{\mathrm{acc}}$)	90%	92%
Physics run (day)	29	27
Number of K^- particles	3.19×10^{11}	1.8×10^{11}
Target size R_{target}	0.95	0.80
Number of nuclei (N_{target})	$3.53 \times 10^{23}/\mathrm{cm}^2$	$3.27 \times 10^{23}/\mathrm{cm}^2$
Density (ρ)	3.515 g/cm^3	3.223 g/cm^3
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr	10 μb/sr
$\Delta\Omega(K^+)$	0.09 sr	
$\mathrm{Br}(\Lambda \to p\pi^-)^2$	0.41	
K^+ decay	0.63	
ΛΛ reconstruction	0.45	
$\varepsilon_{\mathrm{DAQ}} \cdot \varepsilon_{\mathrm{offline}}$	80%= 95%·85%	
Event rate (event/h)	7.9	
ΛΛ Yield (events)	6200	4500

	KEK-E224[43]	KEK-E522[44]	J-PARC E42
p_{K^-}(GeV/c)	1.65	1.66	1.82
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr	12.8 μb/sr	10 μb/sr
p_{K^+}(GeV/c)	$0.95 < p_{K^+} < 1.3$	$0.90 < p_{K^+} < 1.3$	$0.50 < p_{K^+}$

Expected Yield and Reconstructed ΛΛ Production Events

*SH Kim's thesis

Table 5.2: Yield estimates for ΛΛ production events.

Parameters	PAC	E42
Beam power	60 kW	64 kW
K^- beam (M/h) (F_{K^-})	415	
Accelerator operation (ε_{acc})	90%	92%
Physics run (day)	29	27
Number of K^- particles	3.19×10^{11}	1.8×10^{11}
Target size R_{target}	0.95	0.80
Number of nuclei (N_{target})	$3.53 \times 10^{23}/cm^2$	$3.27 \times 10^{23}/cm^2$
Density (ρ)	$3.515\ g/cm^3$	$3.223\ g/cm^3$
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr	10 μb/sr
$\Delta\Omega(K^+)$	0.09 sr	
$Br(\Lambda \to p\pi^-)^2$	0.41	
K^+ decay	0.63	
ΛΛ reconstruction	0.45	
$\varepsilon_{DAQ} \cdot \varepsilon_{offline}$	80%= 95%·85%	
Event rate (event/h)	7.9	
ΛΛ Yield (events)	6200	4500

K- decay : 0.96

	KEK-E224[43]	KEK-E522[44]	J-PARC E42
p_{K^-}(GeV/c)	1.65	1.66	1.82
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$	7.6 μb/sr	12.8 μb/sr	10 μb/sr
p_{K^+}(GeV/c)	$0.95 < p_{K^+} < 1.3$	$0.90 < p_{K^+} < 1.3$	$0.50 < p_{K^+}$

E42

P_{K^+} (GeV/c)	$0.5 < P_{K^+}$	$0.95 < P_{K^+} < 1.3$	$0.5 < P_{K^+}$	$0.5 < P_{K^+}$
Number of K^-	1.8×10^{11}	0.46×10^{11}	1.8×10^{11}	1.8×10^{11}
$d\sigma/d\Omega_L^C(\Lambda\Lambda)$		$7.6\ \mu b/sr$	$7.6\ \mu b/sr$	$12.8\ \mu b/sr$
(expcectd) ΛΛ Yield		750	2900	4900
(expcected) Scaled ΛΛ Yield		1100	4450	7500
(Measured) ΛΛ Yield	8200	2800	8200	8200

$$0.46 \times 10^{11} = (1.8 \times 10^{11}) \times (99/(289 + 99))$$

The cross section for $^{12}C(K^-, K^+)$ reactions at 1.65 GeV/c (KEK-E176)

0.95 < P_k+ <1.3 GeV/c : 99 ± 4 μb/s

0.5 < P_k+ <0.95 GeV/c : 289 ± 12 μb/sr

1.65 -> 1.8 GeV/c scaling factor : 54/35

The Ξ^- production cross section

$\langle d\sigma/d\Omega \rangle (K^- p \to K^+ \Xi^- = 54\ \mu b/sr)$ at 1.8 GeV/c

$\langle d\sigma/d\Omega \rangle = 35\ \mu b/sr$ at 1.65 GeV/c