

# $K^{\text{bar}}$ -nucleus interaction studied by $^{12}\text{C}(K^-, p)$ spectrum

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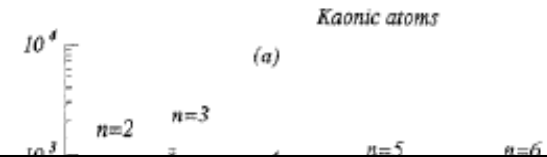
# $K^{\text{bar}}$ -A interaction

An important tool is **kaonic atoms**.

- Simple tp approach

$$[\Delta - 2\mu(B + V_{\text{opt}} + V_c) + (V_c + B)^2]\Psi = 0,$$

$$2\mu V_c(\infty) = A(1 + \mu/A - 1)k_{\text{opt}}(\infty)$$



The depth of  $K^{\text{bar}}$ -nucleus potential **strongly depends** on the **model setting**. It is **not conclusive** whether  $K^{\text{bar}}$ -nucleus potential is “**deep**” or “**shallow**”!! Both type of potential can reproduce the kaonic atoms data.

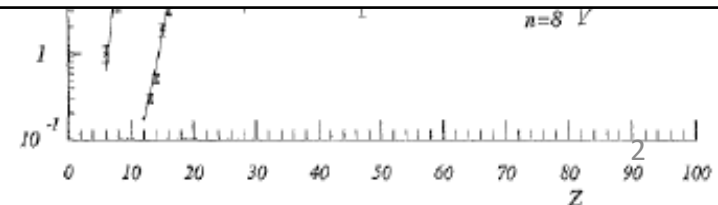


To solve this problem,

**a new experimental constraint is necessary!**

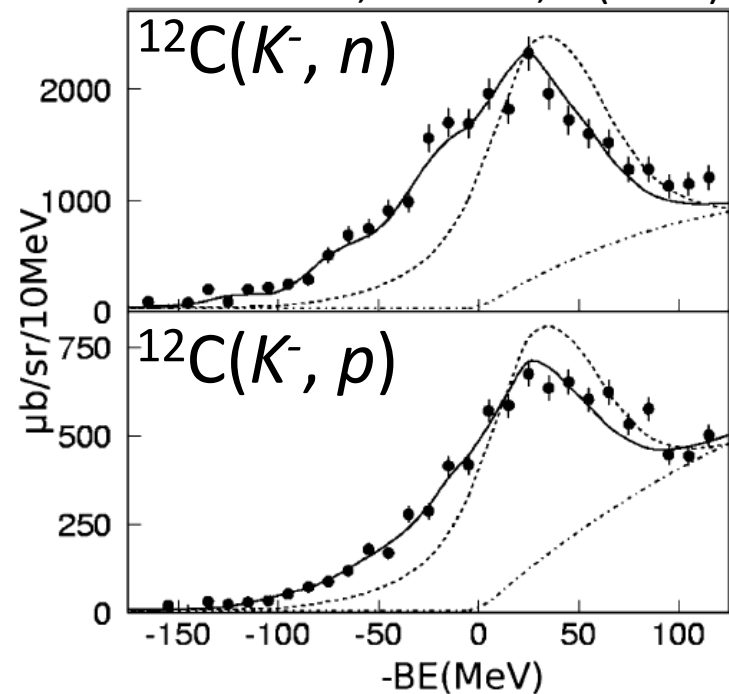
- Chiral motivated model

$$\text{Re}(V_0) \leq -60 \text{ MeV}$$



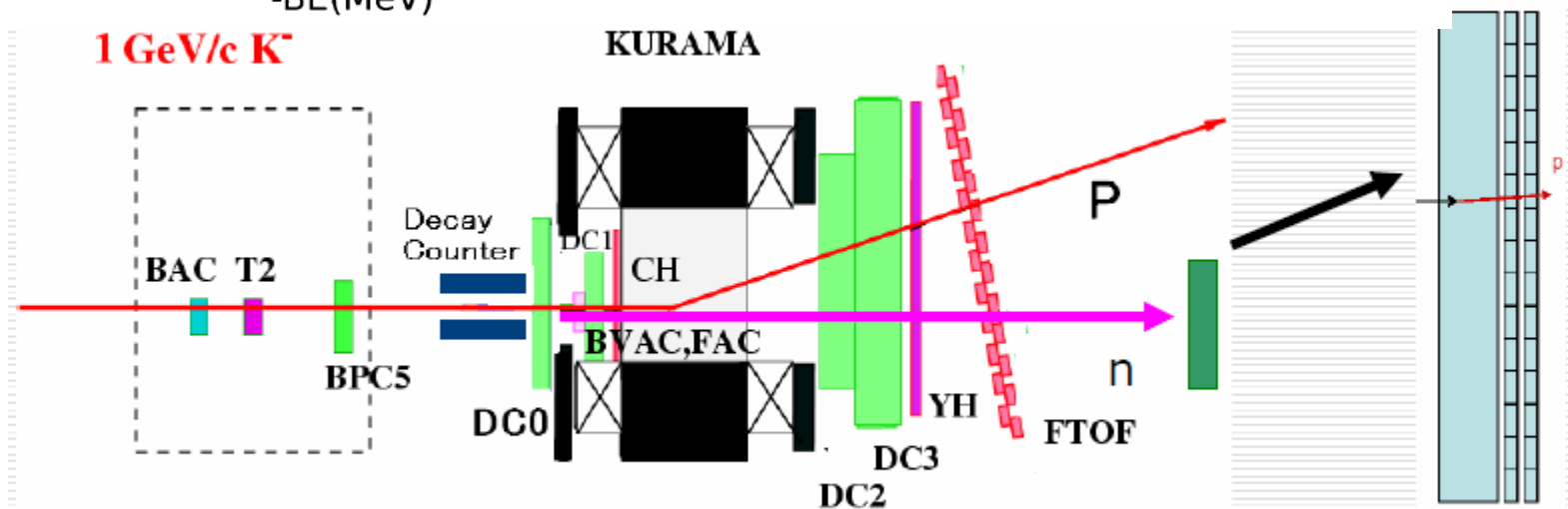
# KEK E548 [ $^{12}\text{C}(K^-, N)$ spectrum]

T. Kishimoto et al., PTP **118**, 1 (2007)



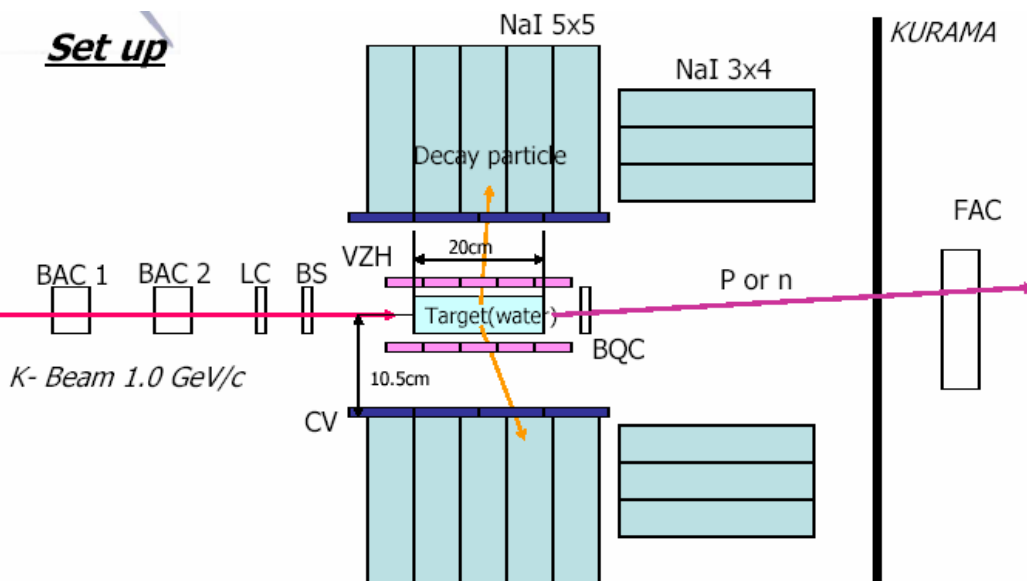
- $^{12}\text{C}(K^-, n), ^{12}\text{C}(K^-, p)$  at 1 GeV/c
  - $K^-$  beam:  $10^4/\text{spill}$
  - KEK-PS K2 beamline + KURAMA
  - MM resolution  $\sim 10$  MeV ( $\sigma$ )
  - $\theta_{sc} < 4.1^\circ$  was chosen
- $V_{\text{opt}}$  was studied comparing DWIA
  - $C(K^-, n)$ :  $V_{\text{opt}} = (\text{Re } -190, \text{Im } -40)$  MeV
  - $C(K^-, p)$ :  $V_{\text{opt}} = (\text{Re } -160, \text{Im } -50)$  MeV

(dotted line:  $V_{\text{opt}} = (-60, -60)$  MeV)



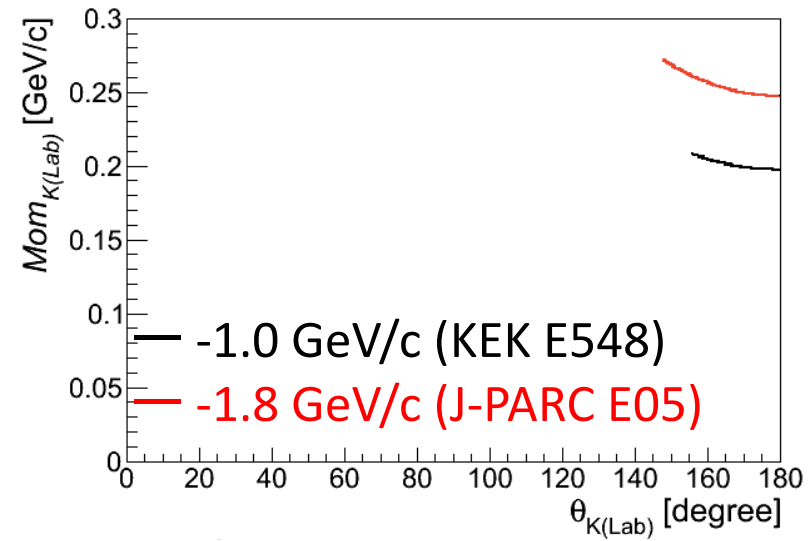
# Discussion for KEK E548

- V. K. Magas *et al.*, pointed out a serious drawback in their experimental setup.
  - In E548, at least one charged particle detected by their decay counter was required (**semi-inclusive spectrum**).  
V. K. Magas et al., PRC 81, 024609 (2010).



## [Simulation]

$\theta_K$  and  $\text{mom}_K$  of  $K^-$  for  $K^-p \rightarrow K^-p$  ( $\theta_p < 4.1^\circ$ )  
w/o FM for  $p_K = -1.0$  and **-1.8 GeV/c**



# $^{12}\text{C}(K^-, p)$ data as a by-product of J-PARC E05 experiment

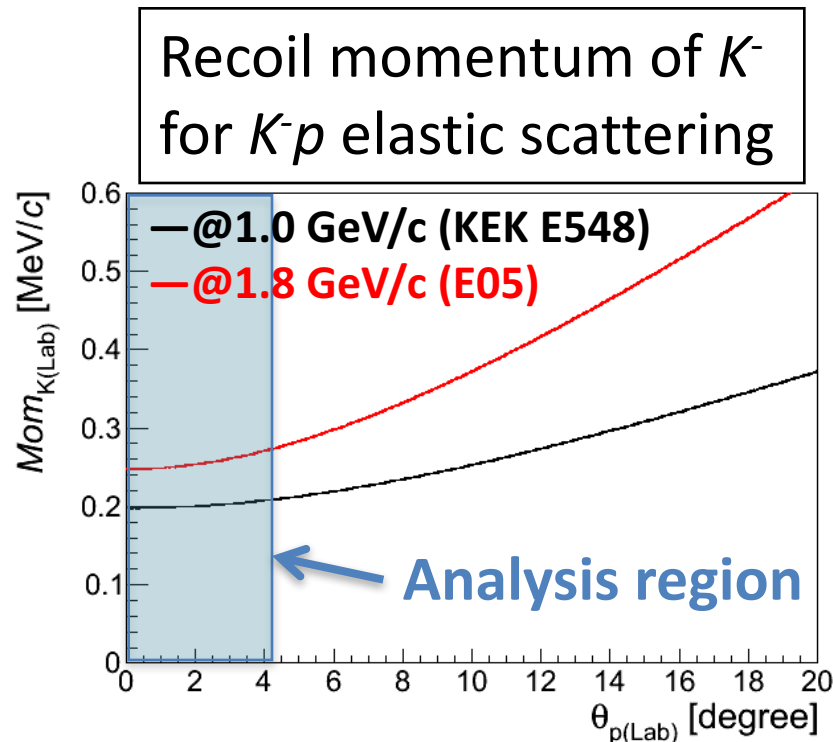
J-PARC E05 experiment:

$\Xi$  hypernuclei search by  $^{12}\text{C}(K^-, K^+)$  reaction

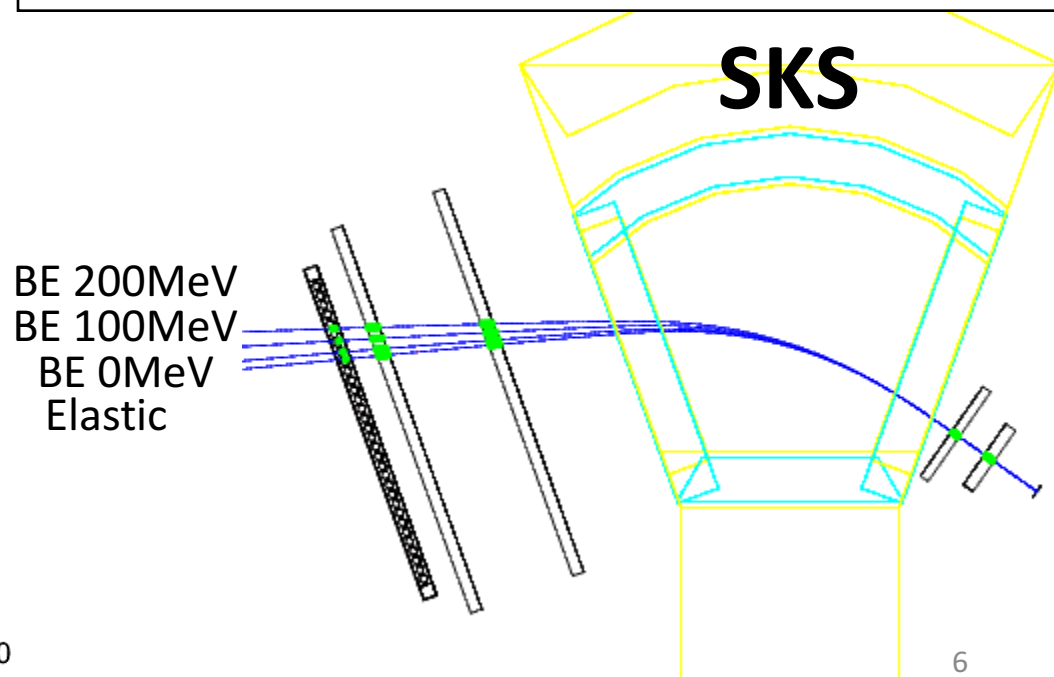
# $^{12}\text{C}(K^-, p)$ in E05 pilot run

- Goal of this measurement
  - Compare the **real inclusive spectrum** with DWIA calculation.
  - Check the semi-inclusive effect by decay counter (“KIC”).
- Difference from E548: Beam mom [E548: 1.0 GeV/c, E05: 1.8 GeV/c]

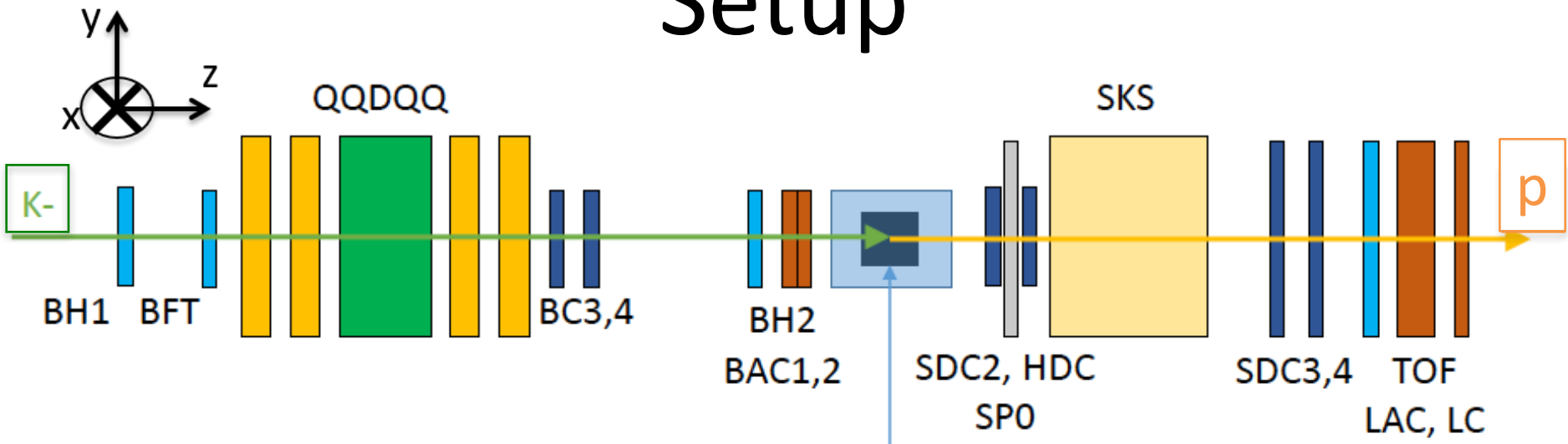
**We took this data as a byproduct of E05 (2015/10).**



Proton orbits at  $0^\circ$  in  $^{12}\text{C}(K^-, p)$  reaction at 1.8 GeV/c



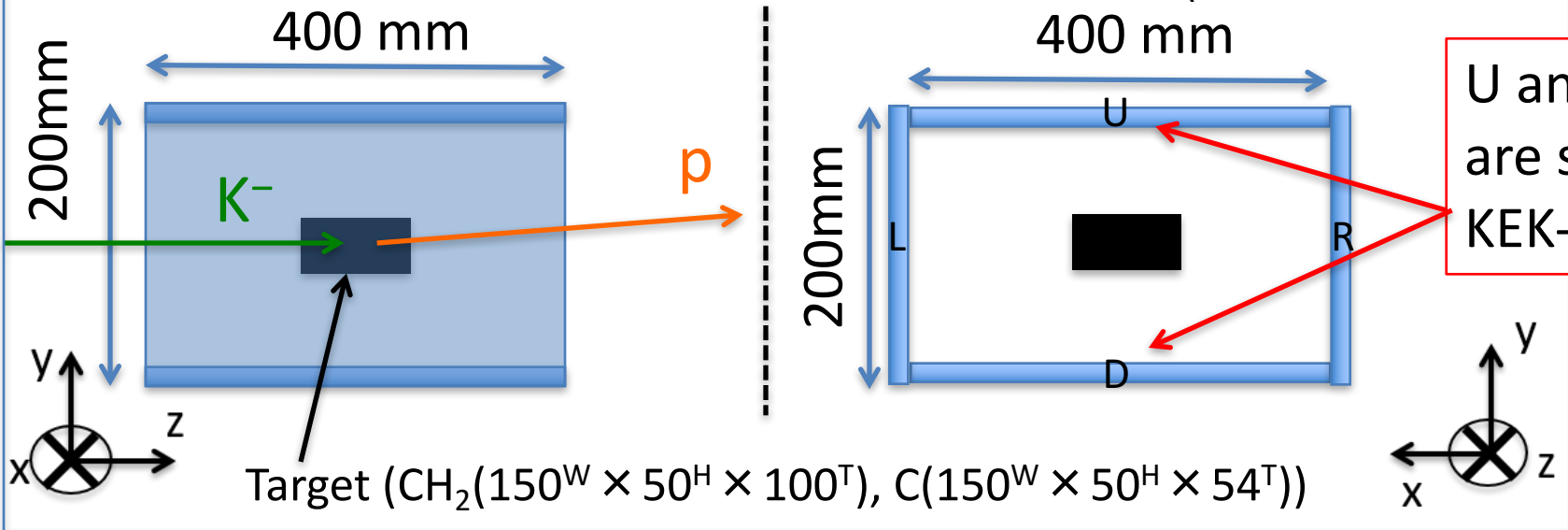
# Setup



Target (C: 9.538 g/cm<sup>2</sup>, CH<sub>2</sub>: 9.364 g/cm<sup>2</sup>)

<KIC counter and target>

Plastic scintillator  
(Thickness: 10 mm)



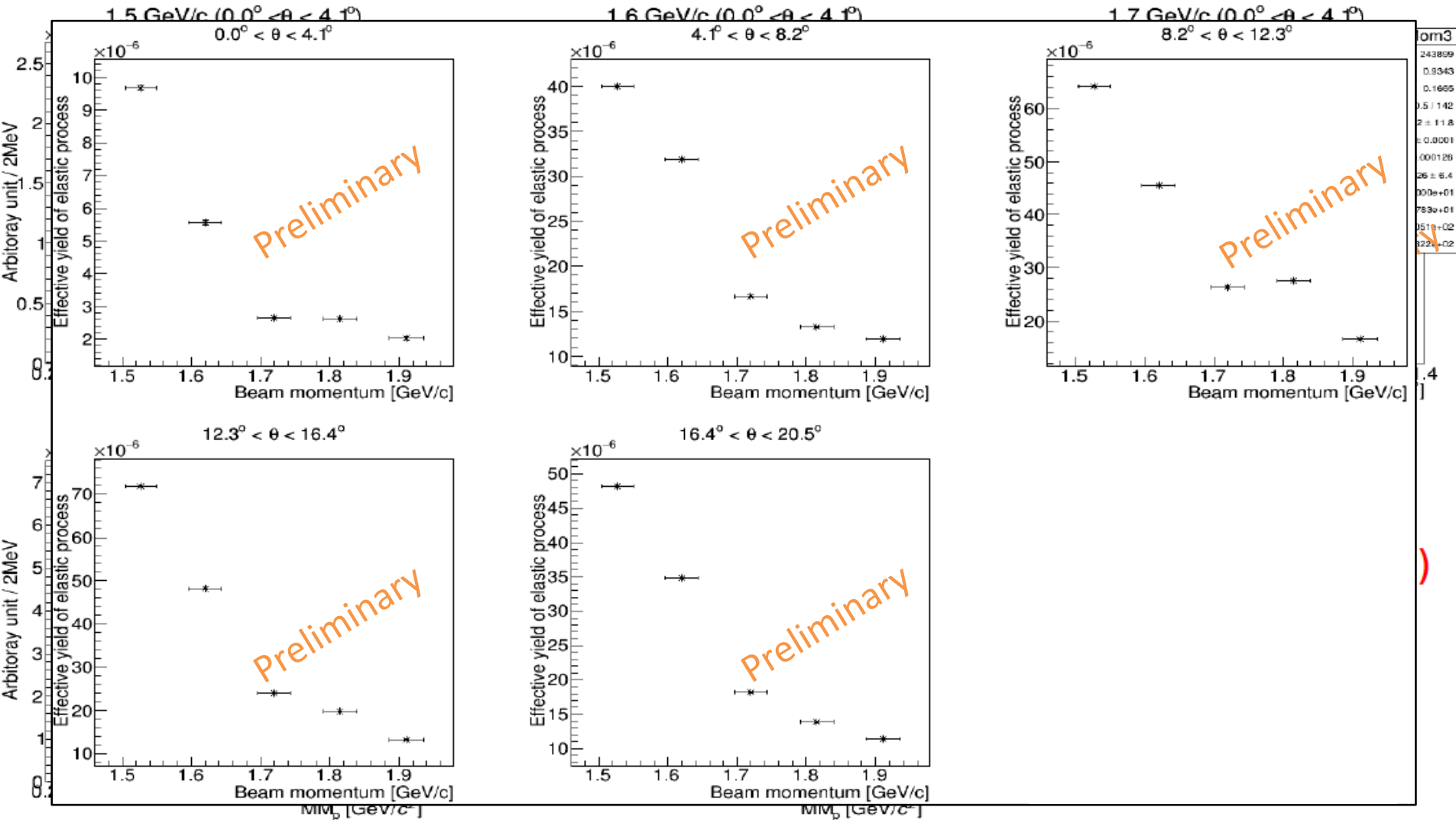
# Data summary

Target	Beam mom ( $p_{K^-}$ ) [GeV/c]	$N_{\text{beam}} \times \epsilon_{\text{DAQ}}$ [G Kaon]
CH <sub>2</sub> [9.54 g/cm <sup>2</sup> ] (Elementary process)	1.5	2.08
	1.6	2.19
	1.7	2.06
	1.8	7.30
	1.9	0.87
Carbon [9.36 g/cm <sup>2</sup> ]	1.5	0.57
	1.8	56.6



# CH<sub>2</sub> data for elementary process

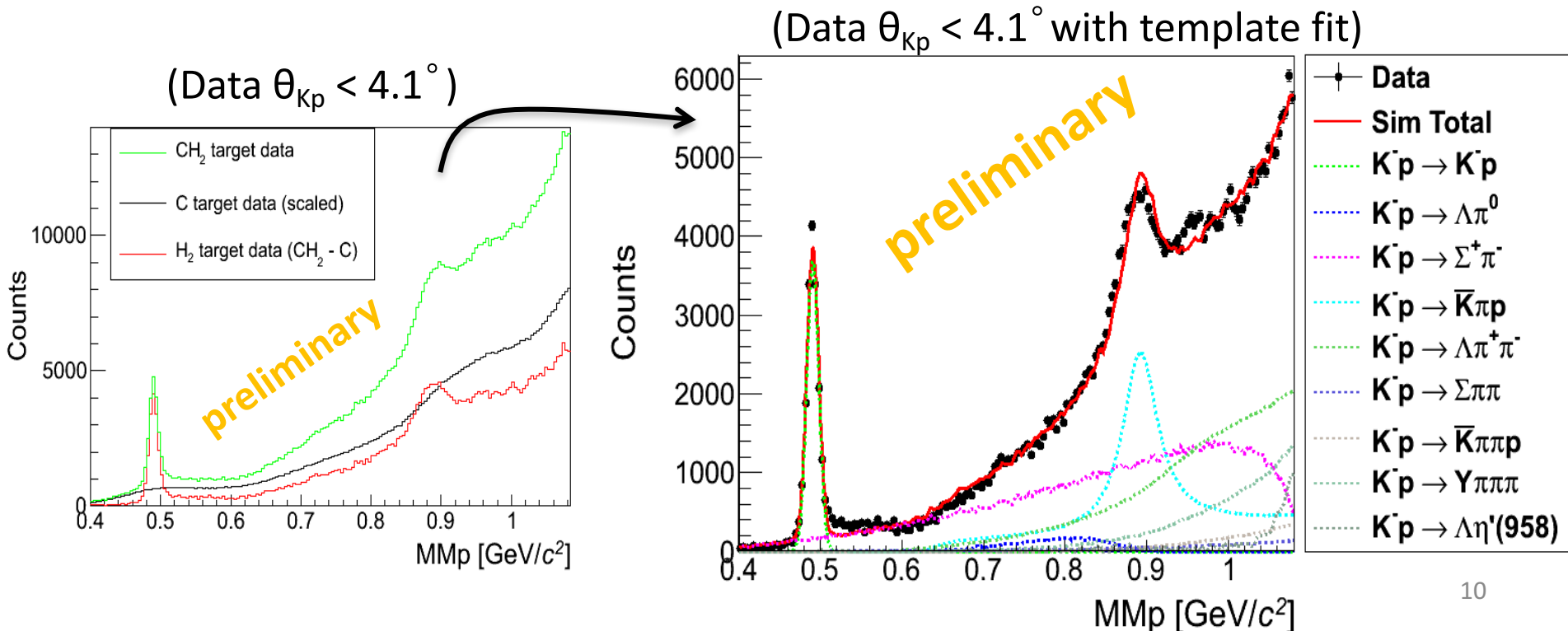
We will evaluate the elementary differential cross section for  $K^-p \rightarrow K^-p$  elastic scattering process precisely.



# $p(K^-, p)$ spectrum at 1.8 GeV/c

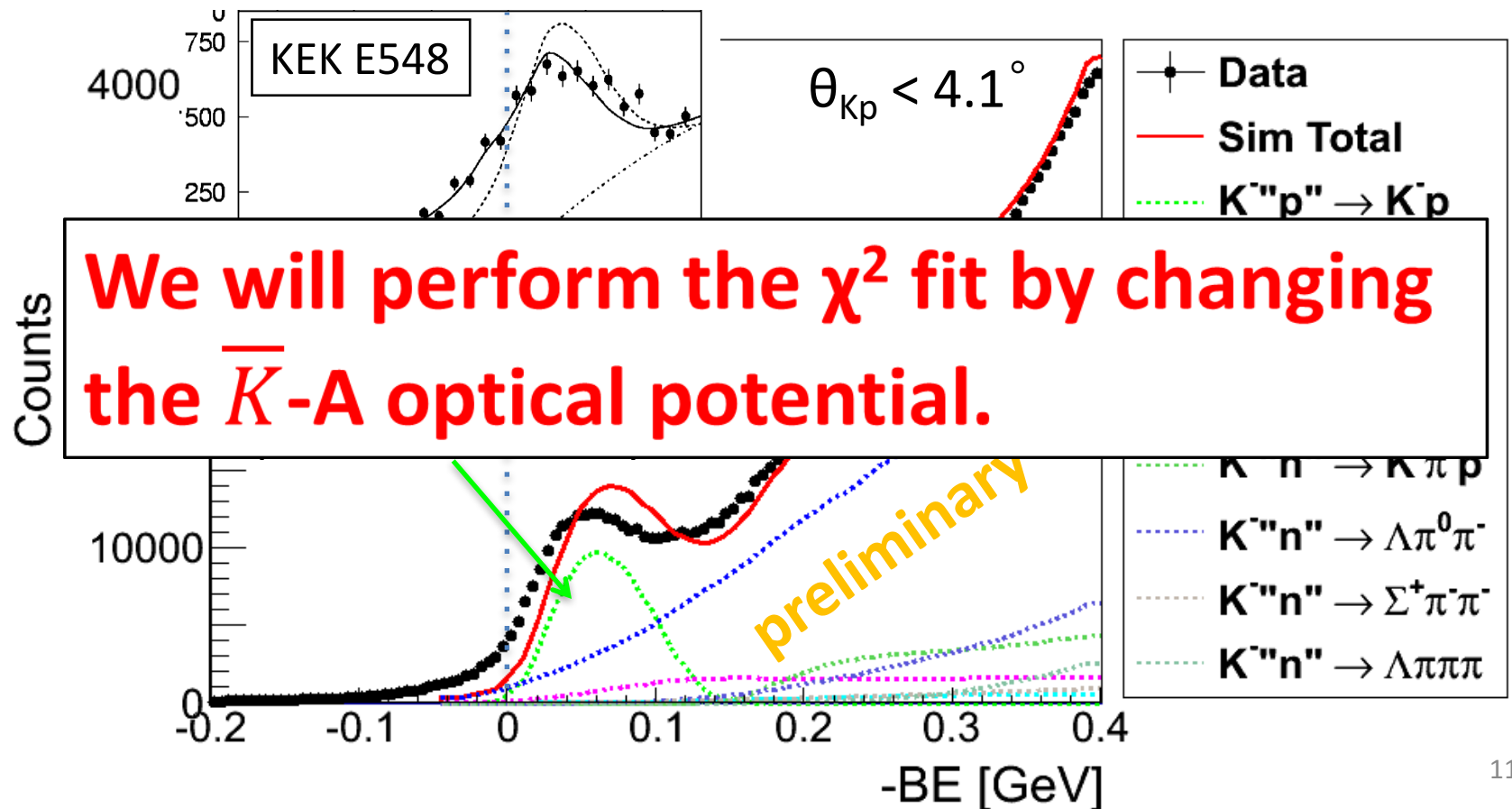
We could fit the obtained spectrum.

- A proton target data was evaluated by using  $\text{CH}_2$  and  $\text{C}$  target data.
- Each yield was free parameter.
- The resonance production processes such as  $K^-p \rightarrow K^*(892)^-p \rightarrow \bar{K}\pi p$  and  $K^-p \rightarrow \Lambda(1520)\pi^0 \rightarrow \bar{K}\pi p$  were included.



# $^{12}\text{C}(K^-, p)$ inclusive spectrum analysis

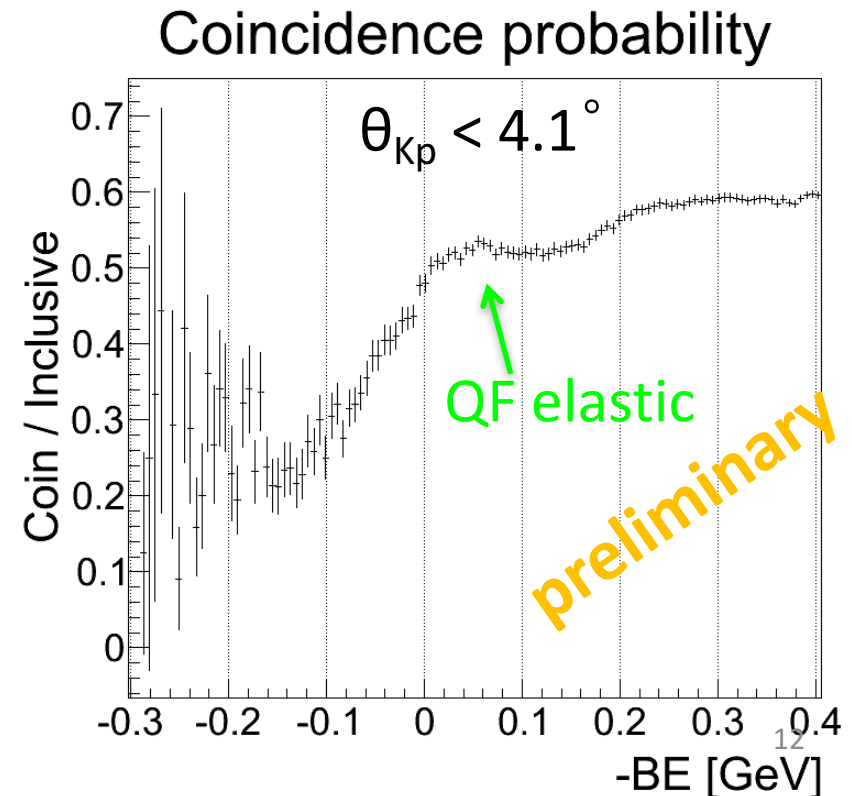
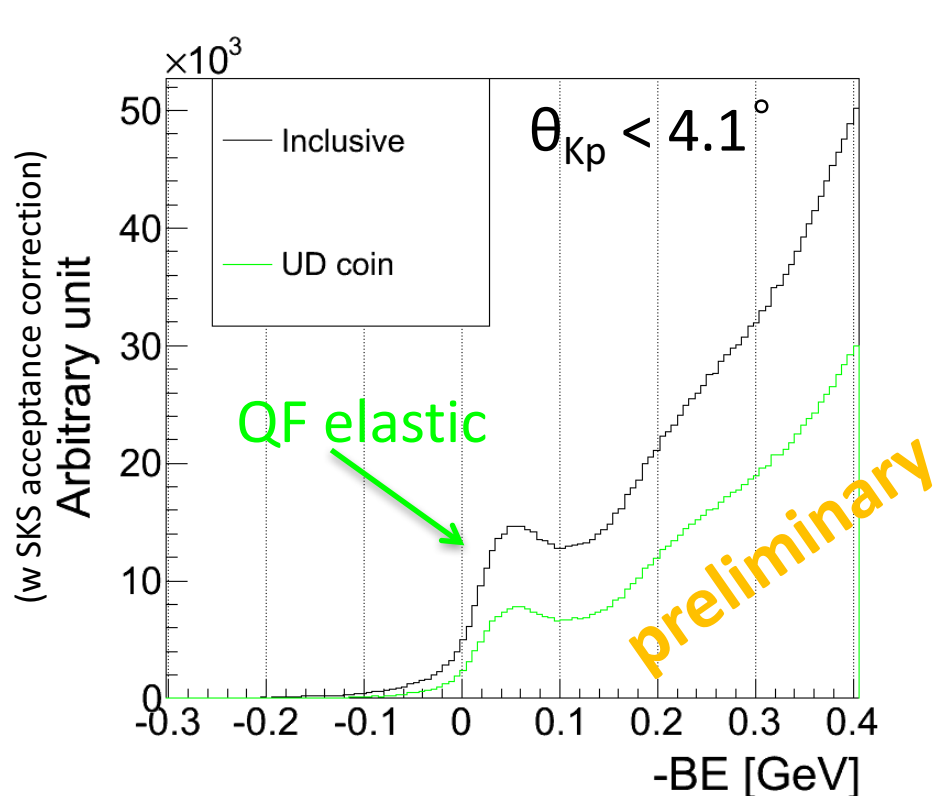
There are significant yield in the bound region same as KEK E548.  
 We could obtain the reasonable solution for  $0.15 < -BE < 0.4$  [GeV]  
 region with toy model fitting, which was not included interactions.  
 However, we could not reproduce  $-BE < 0.1$  [GeV] region.



# Coincidence analysis

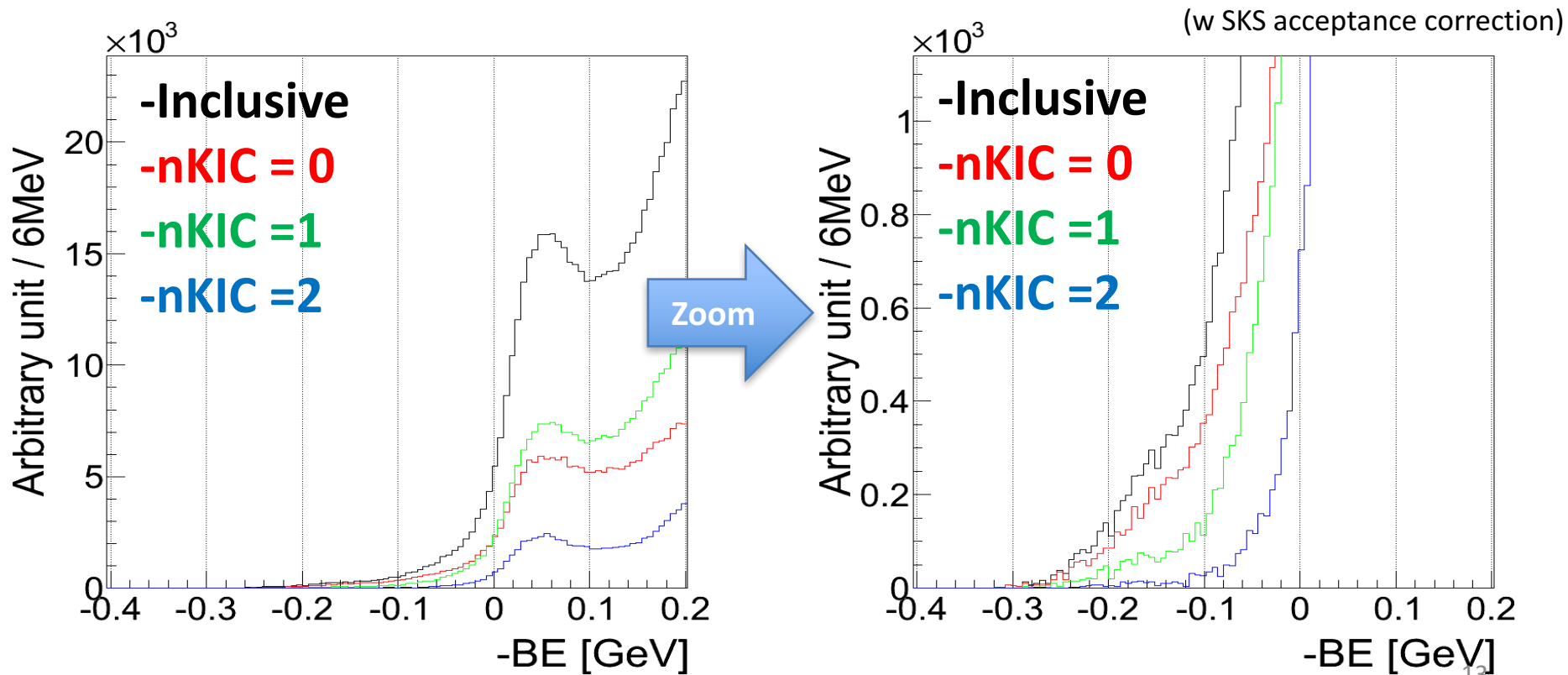
We can see the coincidence probability drop around Elastic region as we expected. However, the coincidence probability is more drastically dropped around  $BE = 0$  GeV. In principle, the final state of  $BE < 0$  region should be included  $\Lambda$  or  $\Sigma$  or  $\pi$ . Thus, the coincidence probability for  $BE < 0$  region should be higher than QF elastic region.

**The KEK E548 coincidence (UD coin)  
has distorted original inclusive spectrum.**



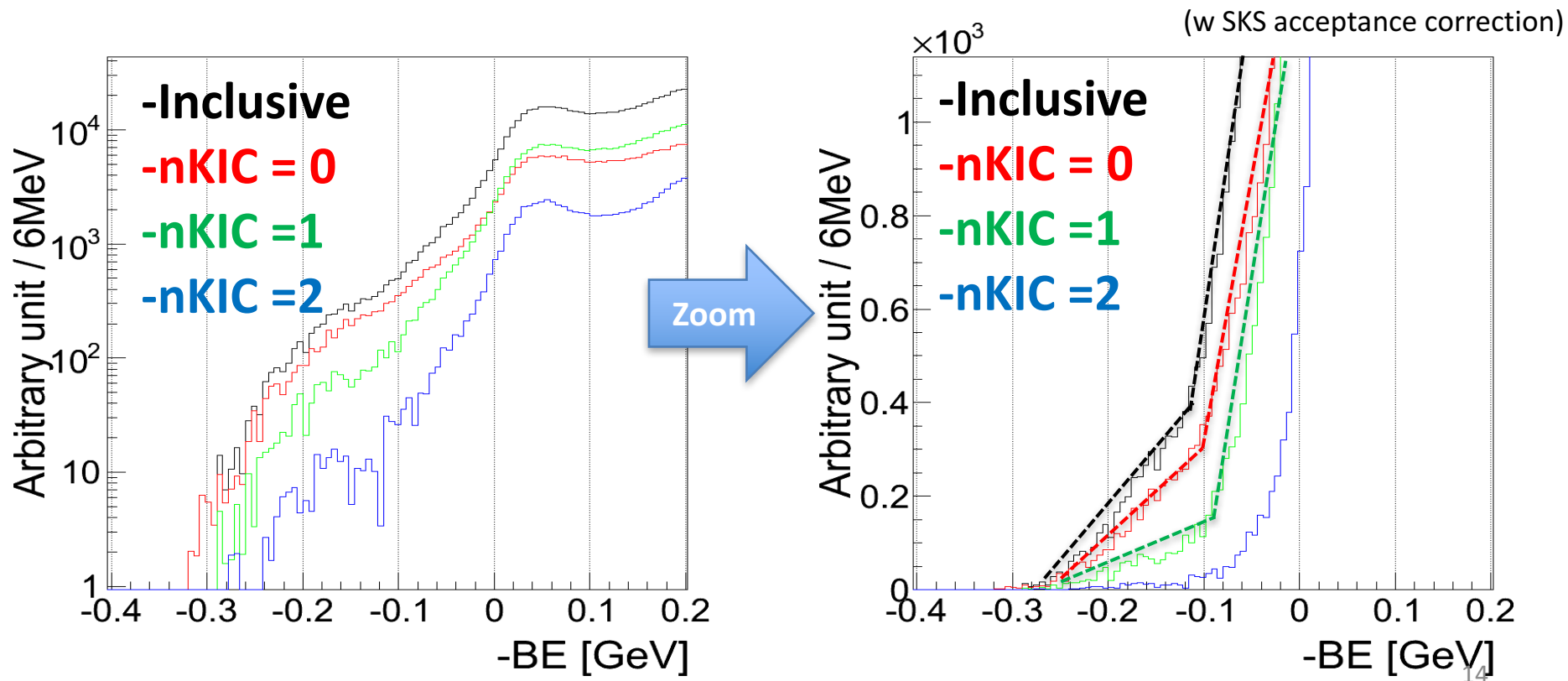
# Coincidence analysis ( $0^\circ < \theta_{Kp} < 4.1^\circ$ )

Comparison the BE spectrum for each **KIC multiplicity** condition. It seems there are non-exponential component (“KINK”) around  $-BE \sim -0.1$  GeV .



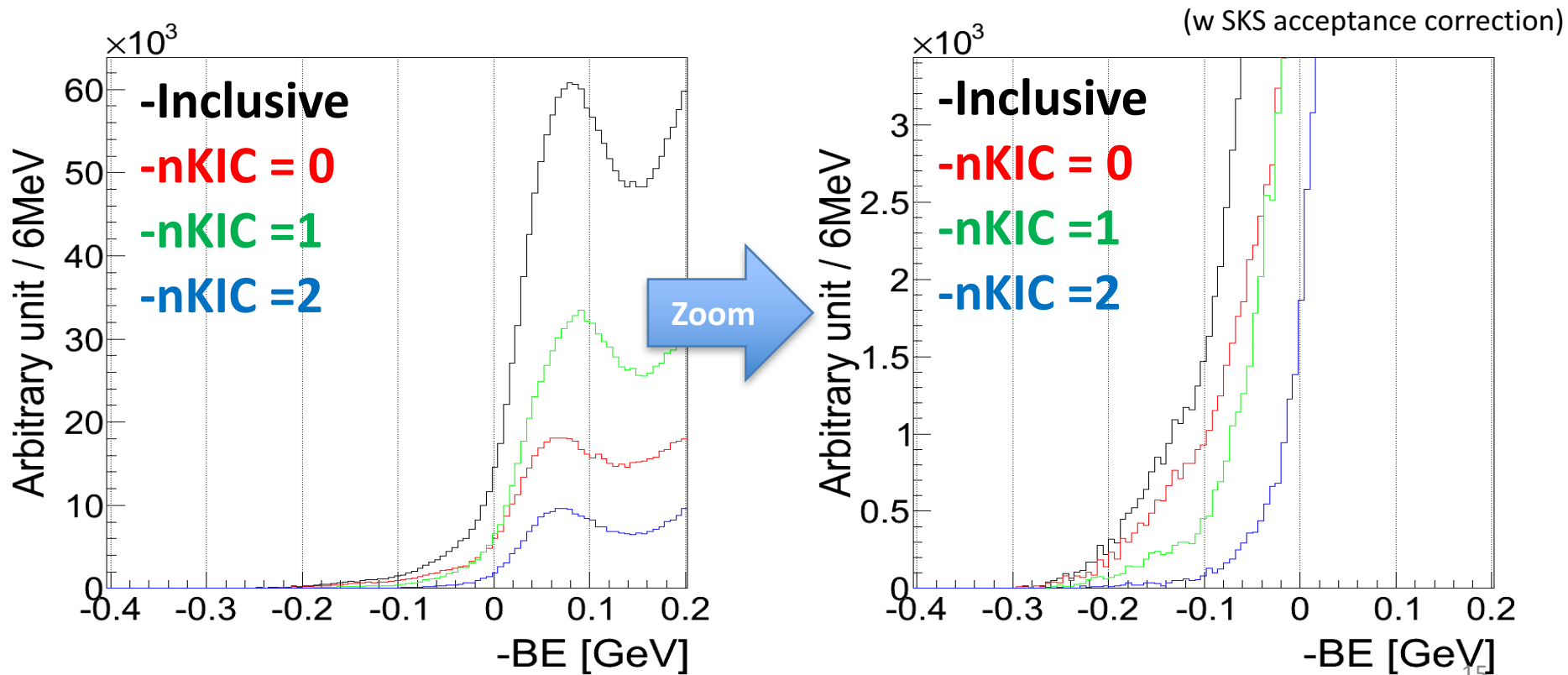
# Coincidence analysis ( $0^\circ < \theta_{Kp} < 4.1^\circ$ )

Comparison the BE spectrum for each **KIC multiplicity** condition. It seems there are non-exponential component (“KINK”) around  $-BE \sim -0.1$  GeV .



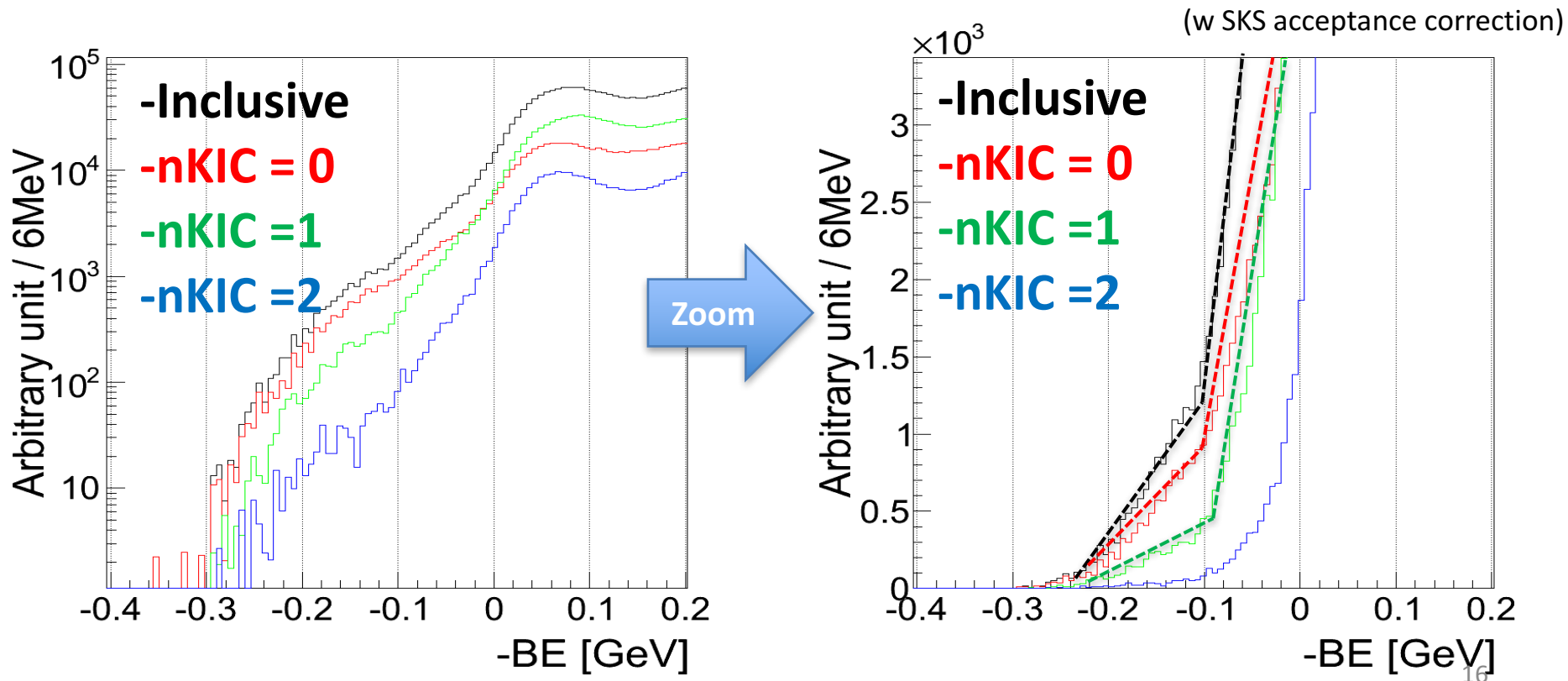
# Coincidence analysis ( $4.1^\circ < \theta_{Kp} < 8.2^\circ$ )

Similar “KINK” structures can be seen in the larger scattering angle ( $4.1^\circ < \theta_{Kp} < 8.2^\circ$ ) spectra.



# Coincidence analysis ( $4.1^\circ < \theta_{Kp} < 8.2^\circ$ )

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# Discussion for the origin of “KINK”

Woods-Saxon type potential + Coulomb potential

$$U^{\bar{K}}(E, \mathbf{r}) = U^{\bar{K}}(E, r) \\ = \left( \underline{V_c^{\bar{K}}} f(r) + V_{Coulomb}^{\bar{K}}(r) \right) + i \left( \underline{W_c^{\bar{K}}} f^{ps}(E) f(r) \right)$$

- $V, W$  -- parameter
- $f(r)$  -- Fermi function
- $f^{ps}(E)$  -- phase space suppression factor

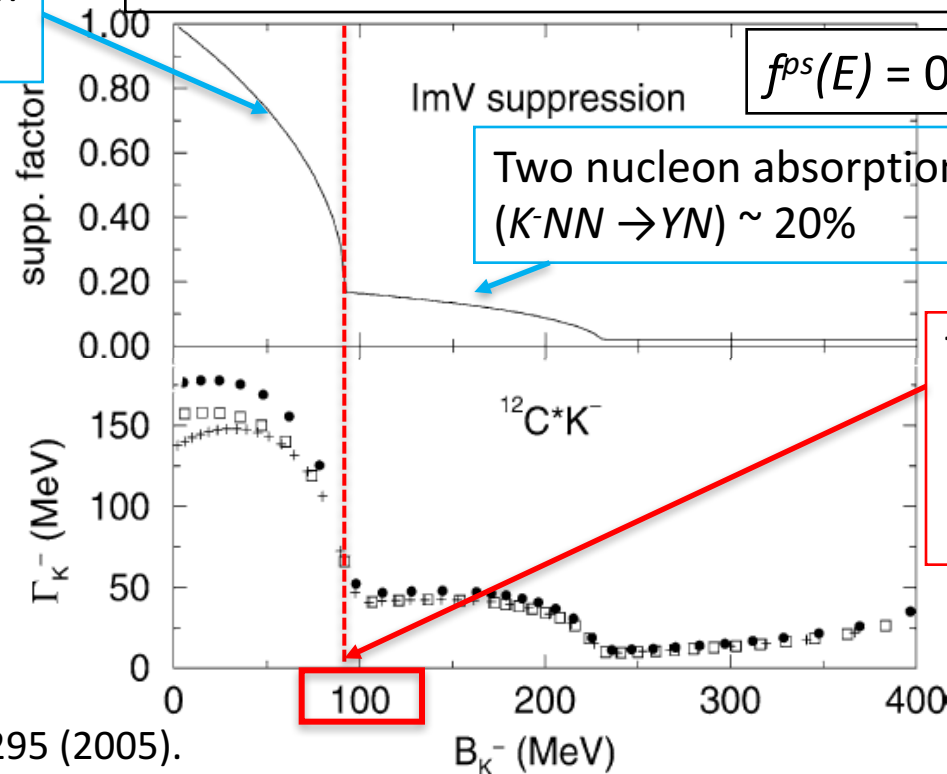
T. Hayakawa presentation

$$f(E) = q / q_0$$

One nucleon absorption  
( $K^-N \rightarrow \Sigma\pi$ ) ~ 80%

Phase space suppression factor ( $f^{ps}$ )

$$f^{ps}(E) = 0.8 f_{KN \rightarrow \Sigma\pi} + 0.2 f_{KNN \rightarrow YN}$$



Threshold of ( $K^-N \rightarrow \Sigma\pi$ )  
is BE ~ 0.1 GeV.  
It is almost same as  
“KINK” position.

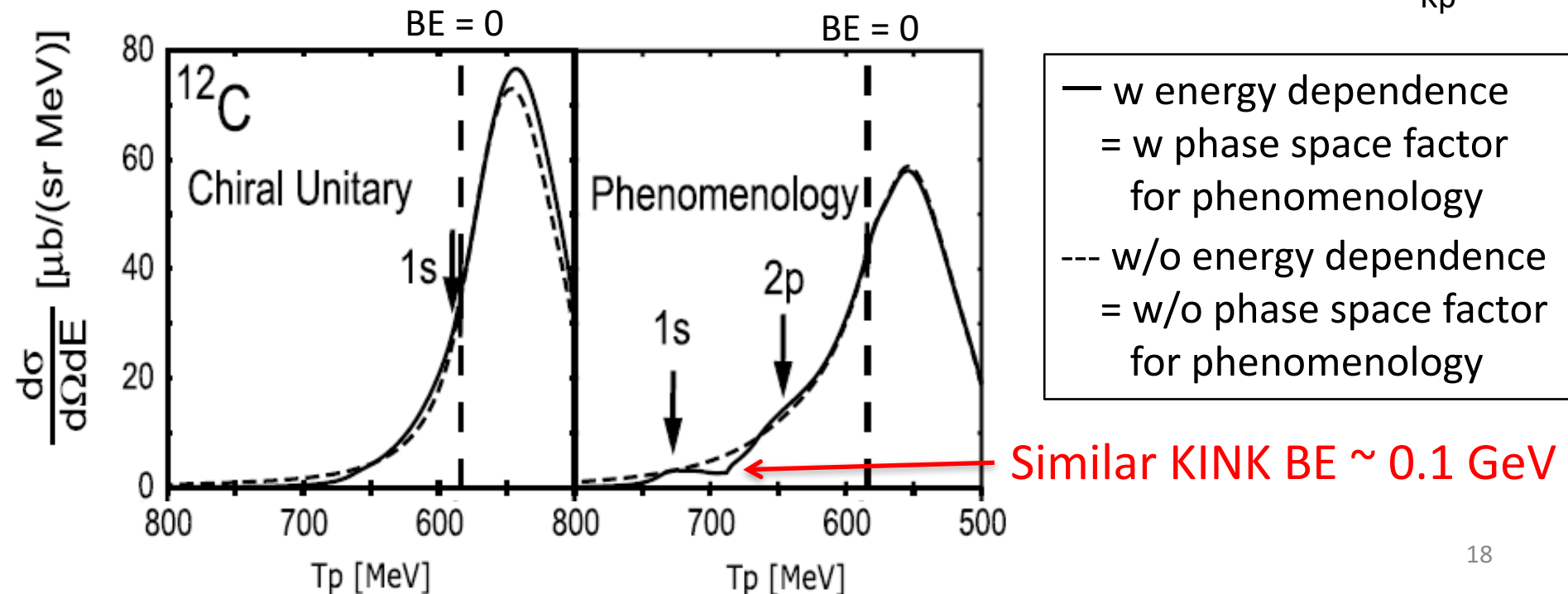
# Theoretical calculation

Theoretical calculation for  $^{12}\text{C}(K^-, p)$  reaction of  $p_K = 1.0 \text{ GeV}/c$  was carried out by J. Yamagata-Sekihara et al.

We hope to compare the obtained spectrum with theoretical calculation of  $p_K = 1.8 \text{ GeV}/c$ .

J. Yamagata et al., Phys Rev C 74, 014604 (2006).

$$\theta_{Kp} = 0^\circ$$



# Summary

- $K^{\text{bar}}$ -A interaction is studied by kaonic atom data *etc.*.
  - It is still under discussion whether the potential is “**deep**” or “**shallow**”.
  - $^{12}\text{C}(K^-, N)$  spectra were compared with DWIA calculation by KEK E548.  
The charged particle hit requirement might distort the inclusive spectrum.
- We took  $^{12}\text{C}(K^-, p)$  **real inclusive spectrum** as a by-product of J-PARC E05 experiment in October 2015.
  - We will show  $d\sigma/d\Omega_{K^-p \rightarrow K^-p}$  at  $p_K = 1.5, 1.6, 1.7, 1.8, \text{ and } 1.9 \text{ GeV}/c$ .
  - We observed the significant yield in bound region same as KEK E548. The  $^{12}\text{C}(K^-, p)$  spectrum couldn't be reproduced  **$-BE < 0.1 \text{ GeV}$**  region by toy model fitting, which is not included secondary reactions.
  - We have found the coincidence distorted the original spectrum.
  - It seems there are “**KINK**” structure around  $BE \sim 0.1 \text{ GeV}$ . It might be originated from the threshold of  $K^-N \rightarrow \Sigma\pi$  absorption.
  - **We will compare our spectrum with theoretical calculation.**

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