Study of the K^{bar}-nucleus interaction by using the $^{12}C(K^-, p)$ reaction at J-PARC

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for the J-PARC E05 Collaboration

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

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K^{bar}-A interaction

An important tool is kaonic atoms.

- Simple tρ approach

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

$$2\mu V_{opt}(r) = -4\pi\left(1 + \frac{\mu}{m}\frac{A-1}{A}\right)b_0\rho(r)$$

Re(V_0) ~ −80 MeV

- DD(Density dependent) potential

$$b_0 \;\rightarrow\; b_0 + B_0[\rho(r)/\rho_0]$$

Re(V_0) = −(150-200) MeV

- Fourier-Bessel method

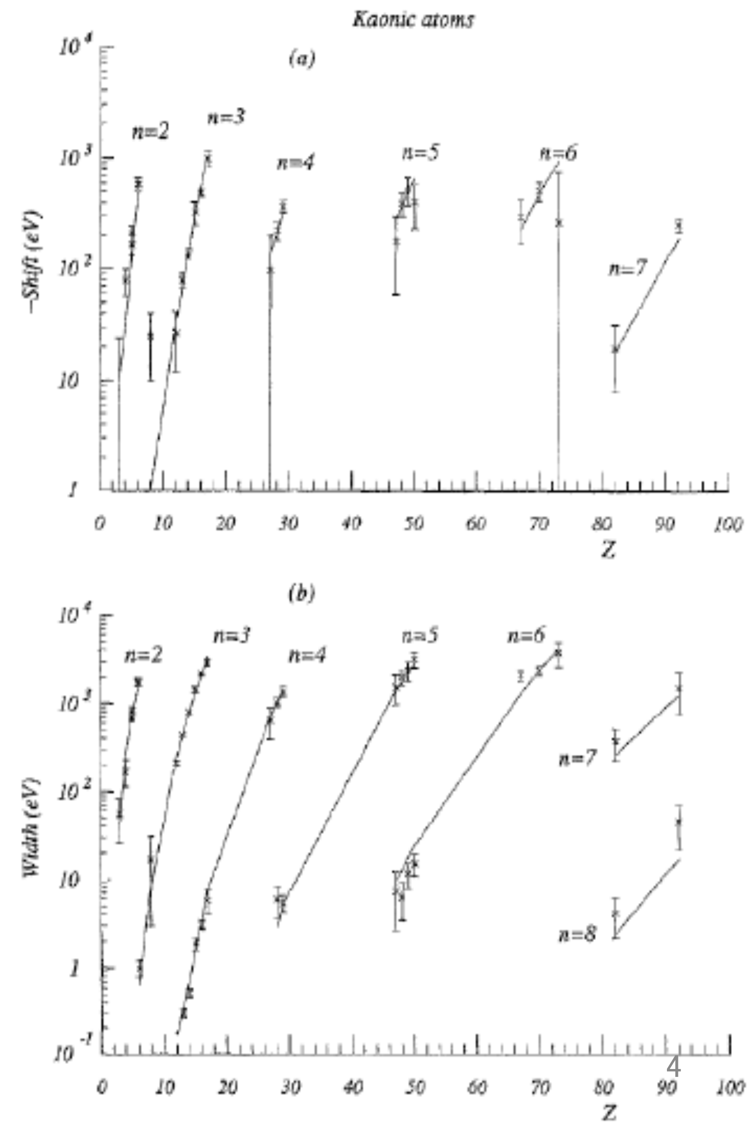
Re(V_0) ~ −(170) MeV

- IHW K^{bar}N interaction+phenomenological multi-nucleon absorption

Re(V_0) ~ −(170) MeV

- Chiral motivated model

Re(V_0) ≦ −60 MeV



K^{bar}-A interaction

An important tool is kaonic atoms.

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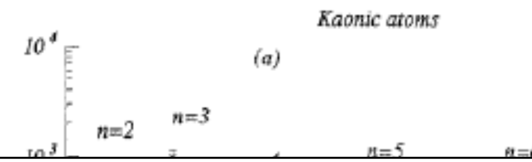


The depth of K^{bar}-nucleus potential strongly depends on the model setting. It is not conclusive whether K^{bar}-nucleus potential is "deep" or "shallow"!! Both type of potential can reproduce the kaonic atoms data.

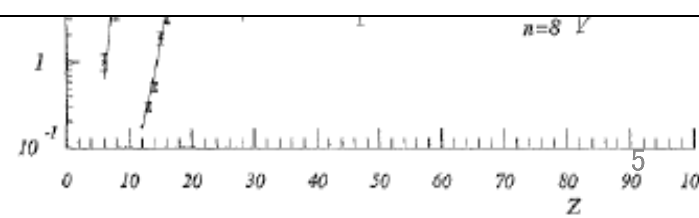
⬇

To solve this problem,

a new experimental constraint is necessary!

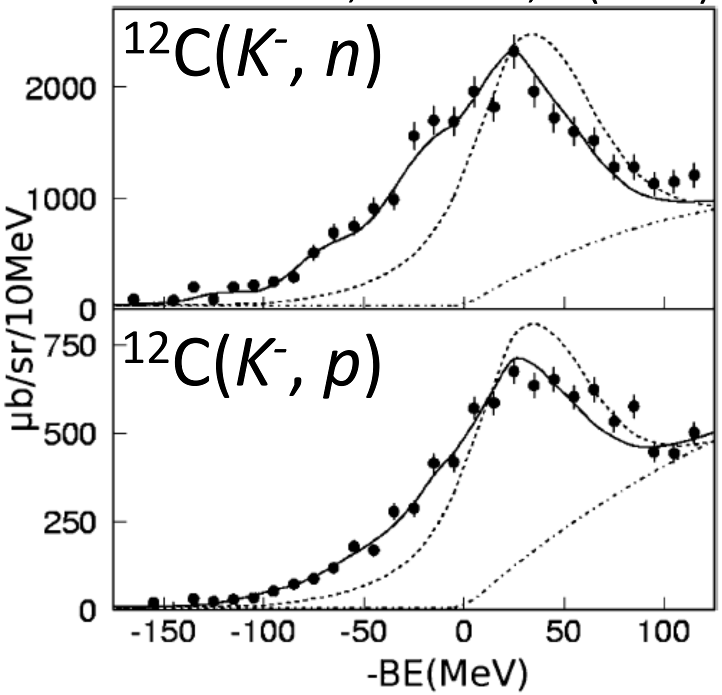
– Chiral motivated model

Re(V_0) ≦ −60 MeV



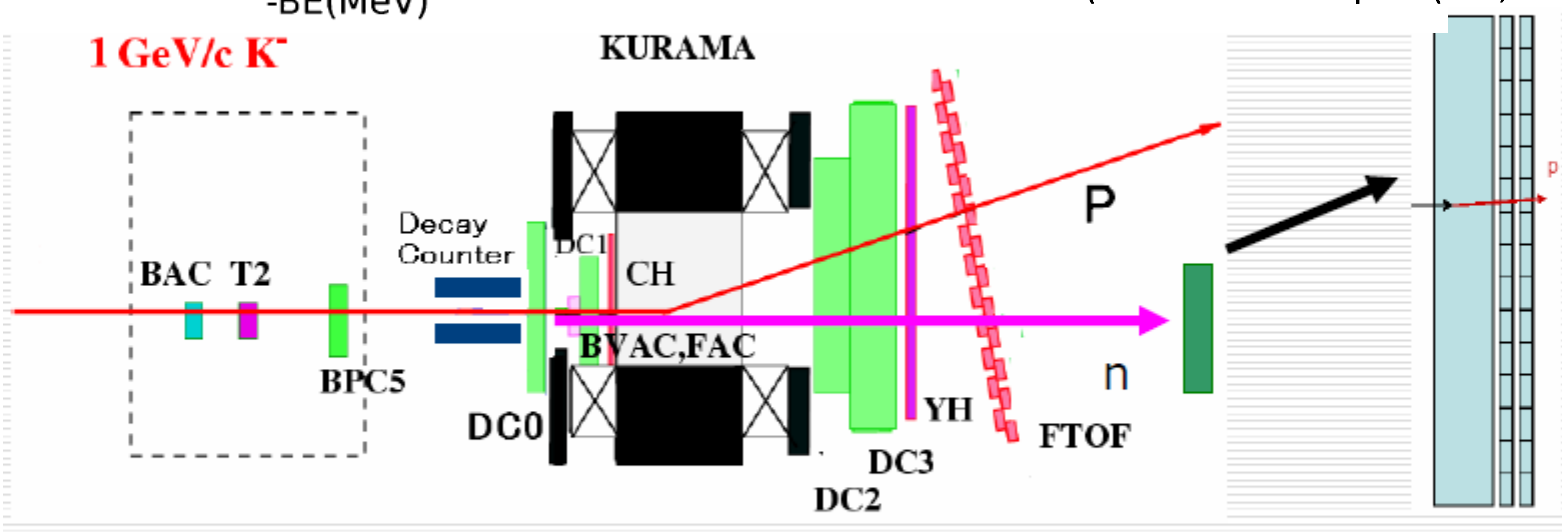
KEK E548 [$^{12}C(K^-, N)$ spectrum]

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



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

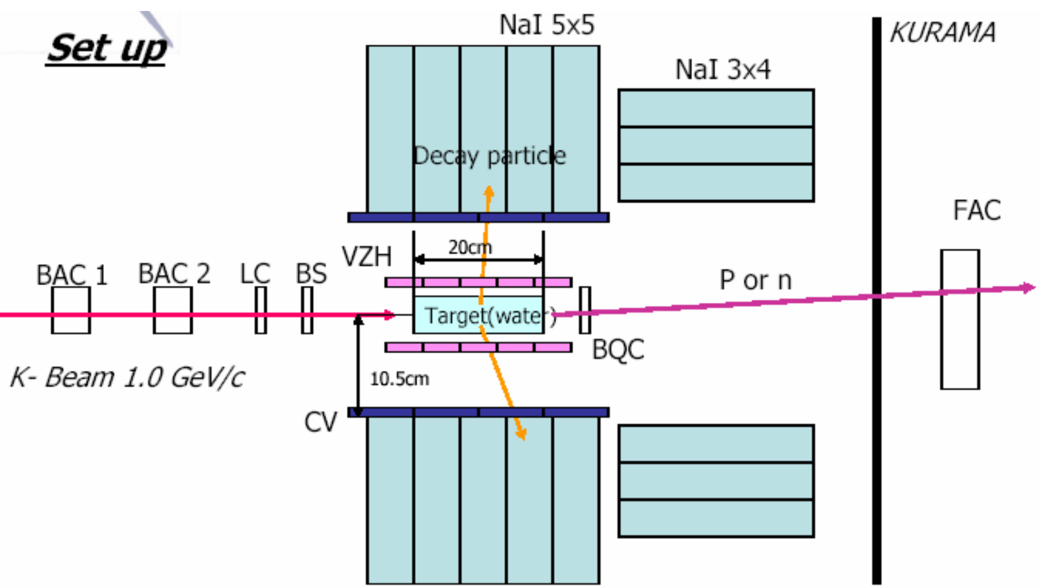
(dotted line: Vopt = (-60, -60) MeV)



Discussion for KEK E548

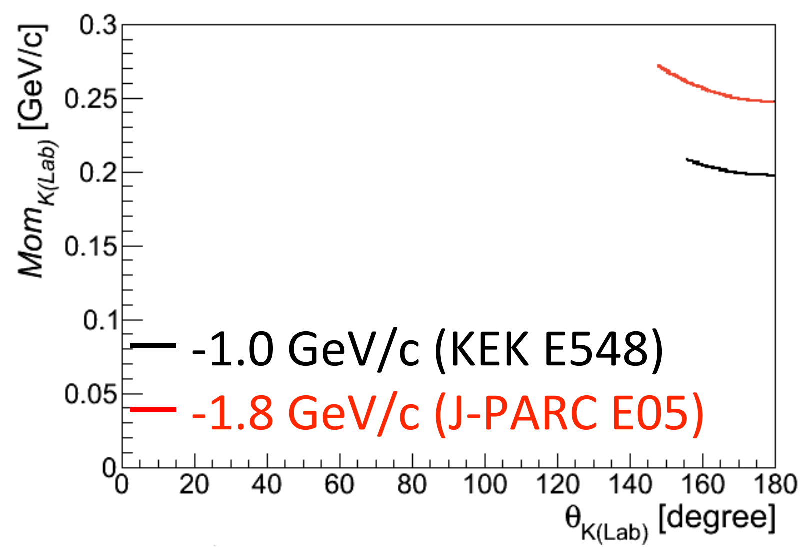
- V. K. Magas *et al.*, pointed out a serious drawback in this experimental setup.
  - In E548, at lest one charged particle detected by their decay counter was required (semi-inclusive spectrum).

V. K. Magas et al., PRC 81, 024609 (2010).



[Simulation]

θ_K and mom_K of K^- for $K^-p \to K^-p$ ($\theta_p < 4.1^\circ$) w/o FM for p_K = -1.0 and -1.8 GeV/c



Criticism for KEK-PS E548

V. K. Magas et al., PRC 81, 024609 (2010).

Monte Carlo study for the semi-inclusive spectra.

Although their calculation is not realistic, they conclude the semi-inclusive spectra can distort the original inclusive spectra.

→ Semi-inclusive spectra doesn't have enough sensitivity !!

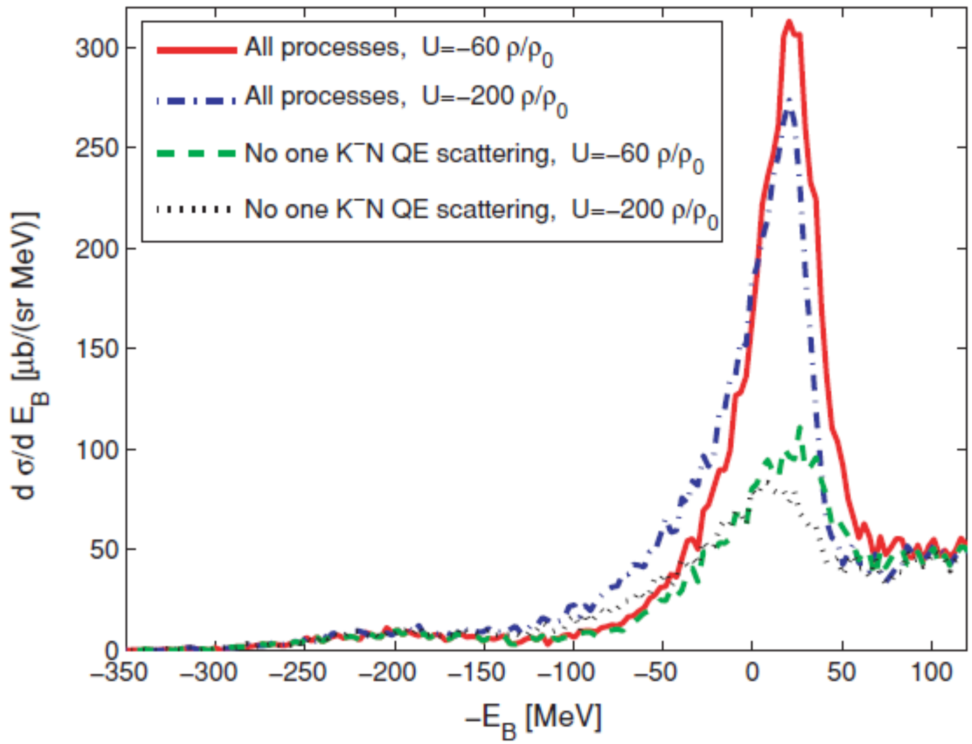


FIG. 8. (Color online) Calculated $^{12}C(K^-, p)$ spectra for $V_{opt} = (-60, -60)\rho/\rho_0$ MeV and $V_{opt} = (-200, -60)\rho/\rho_0$ MeV, taking into account all contributing processes (solid and dot-dashed lines) and imposing the minimal coincidence requirement (dashed and dotted lines).

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

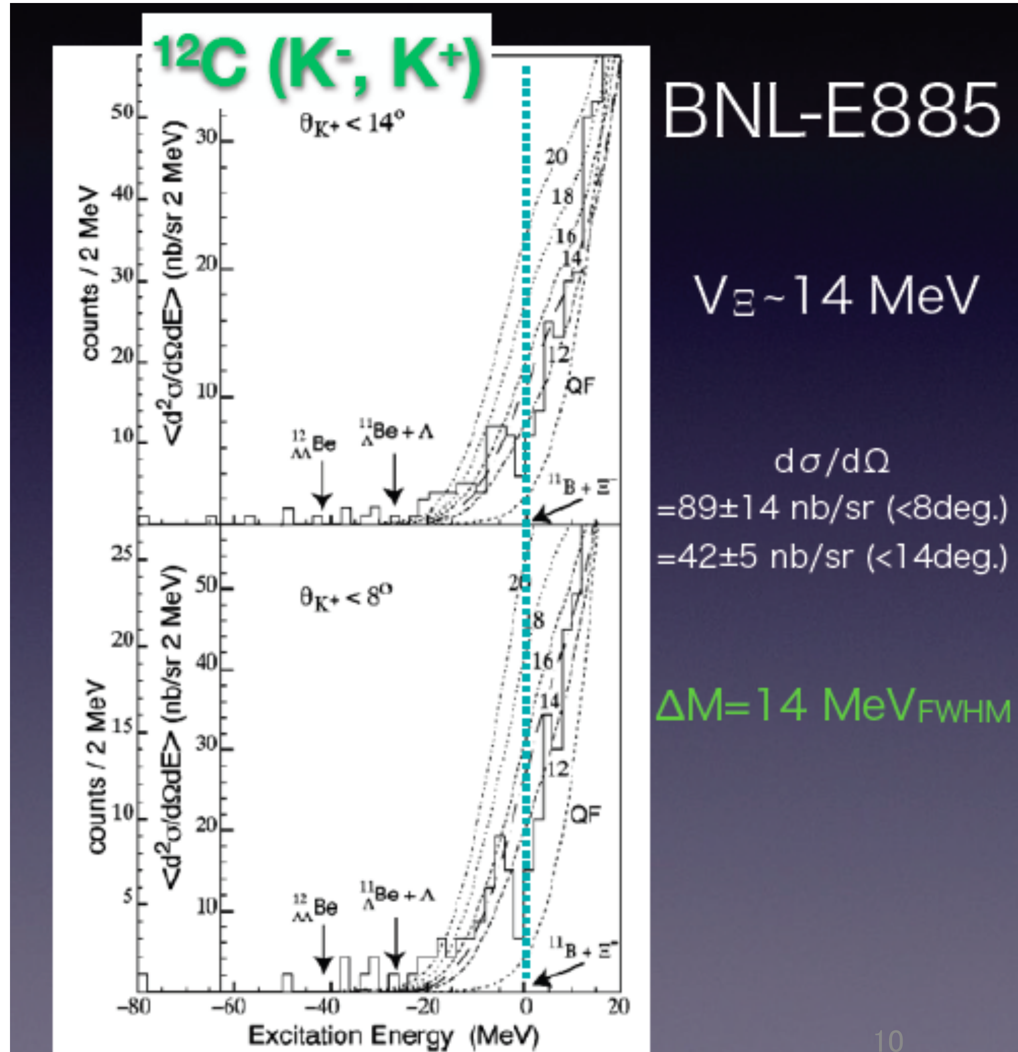
J-PARC E05 experiment

Search for Ξ-hypernucleus $^{12}{}_{\Xi}$Be by using ^{12}C(K^-, K^+) reaction at p_K = 1.8 GeV/c

*Purpose

- Confirm the existence of Ξ-hypernucleus as a peak
- Ξ-nucleus potential depth and width

S-2S spectrometer will be used for the E05 experiment.
In the last October, pilot run using the SKS was carried out.



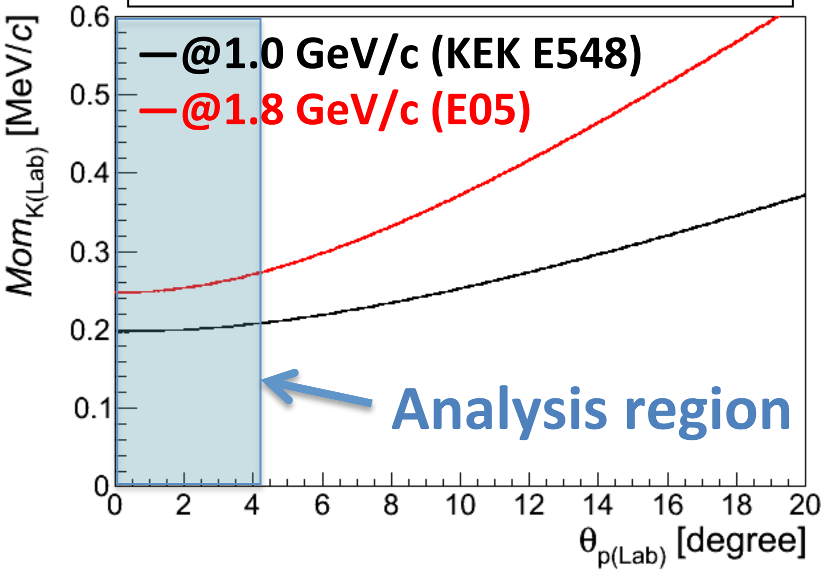
P.Khaustov et al., PRC61(2000)054603

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

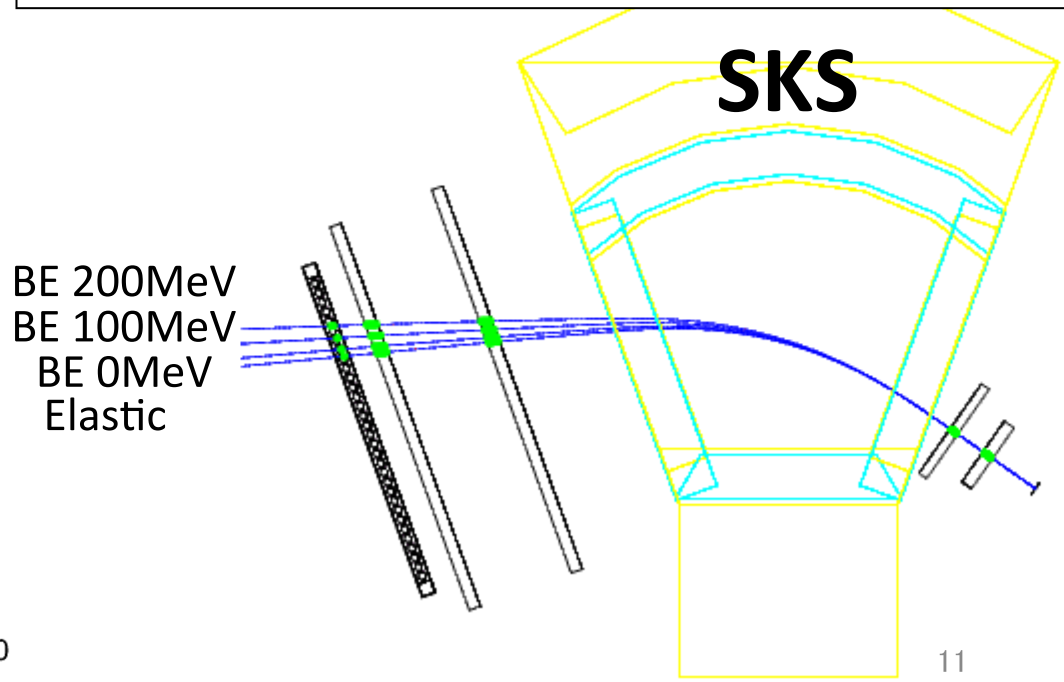
- Goal of this measurement
  - Compare the real inclusive spectrum with DWIA calculation.
  - Search for the Kaonic nuclei
  - Check the semi-inclusive effect by decay counter ("KIC").

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

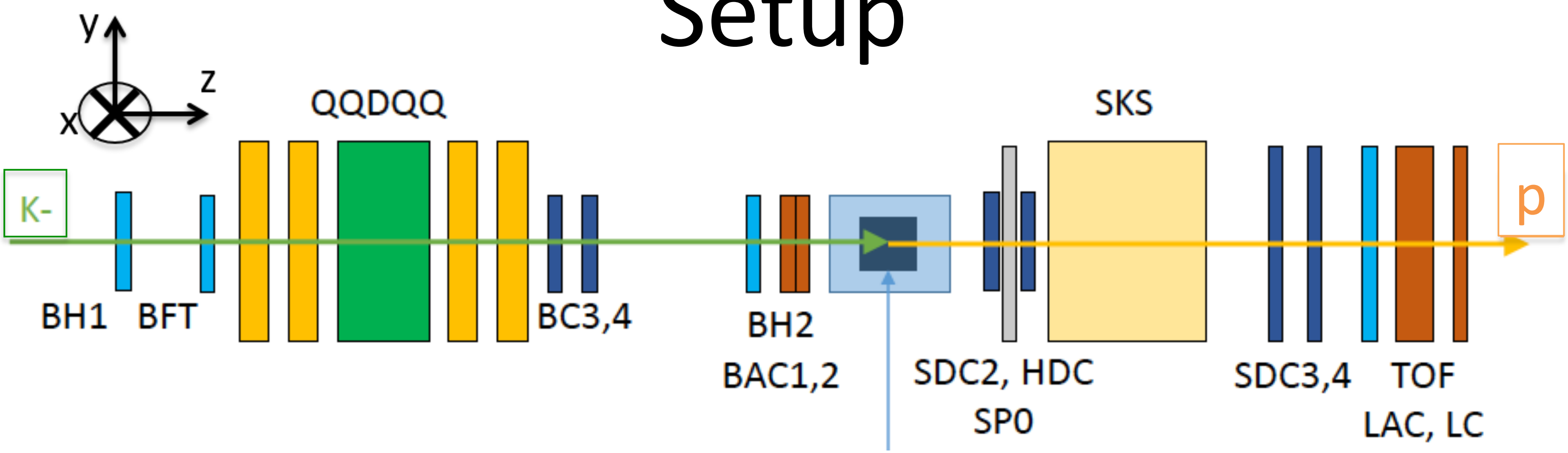
Recoil momentum of K^- for K^-p elastic scattering



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



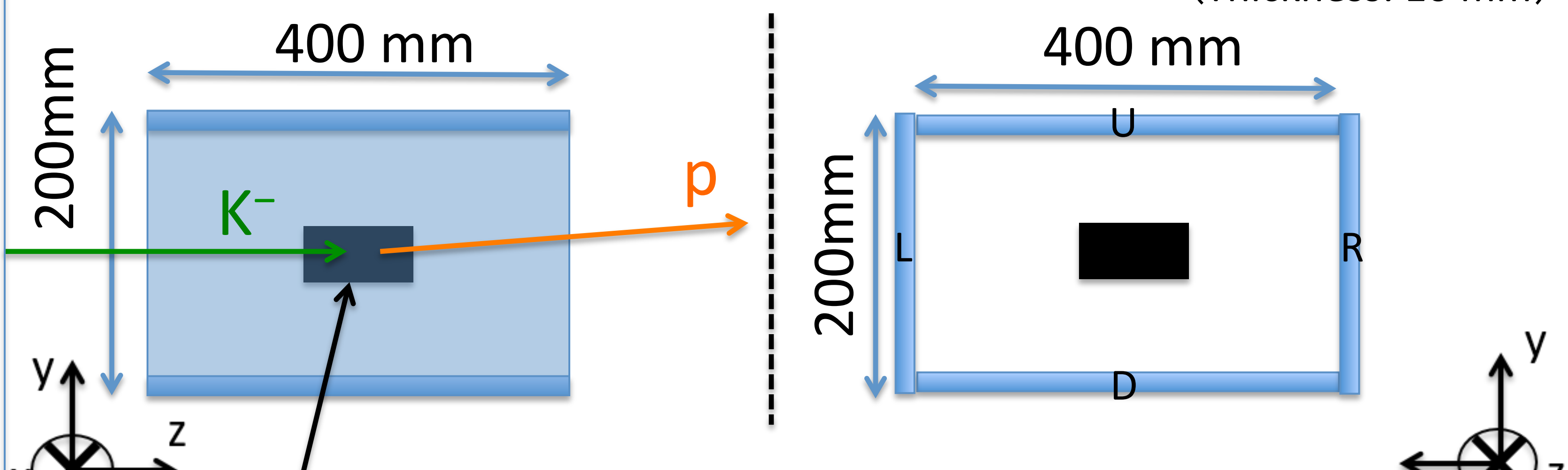
Setup



Target (C: 9.538 g/cm^2, CH_2: 9.364 g/cm^2)

<KIC counter and target>

Plastic scintillator
(Thickness: 10 mm)



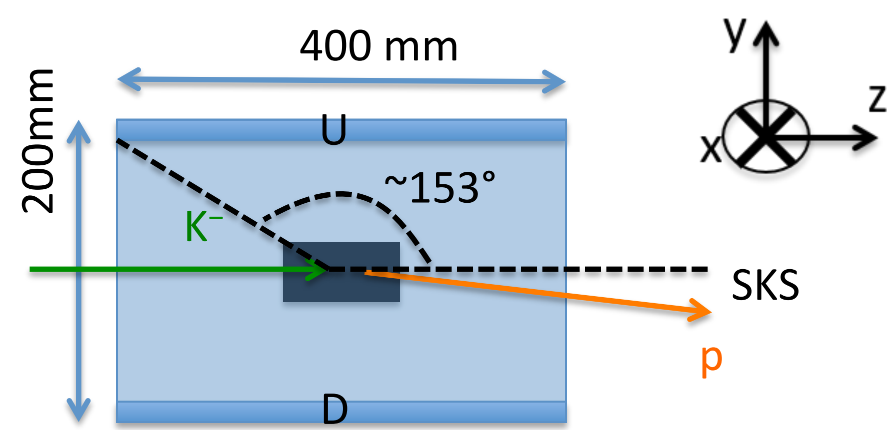
Target (CH_2($150^W \times 50^H \times 100^T$), C($150^W \times 50^H \times 54^T$))

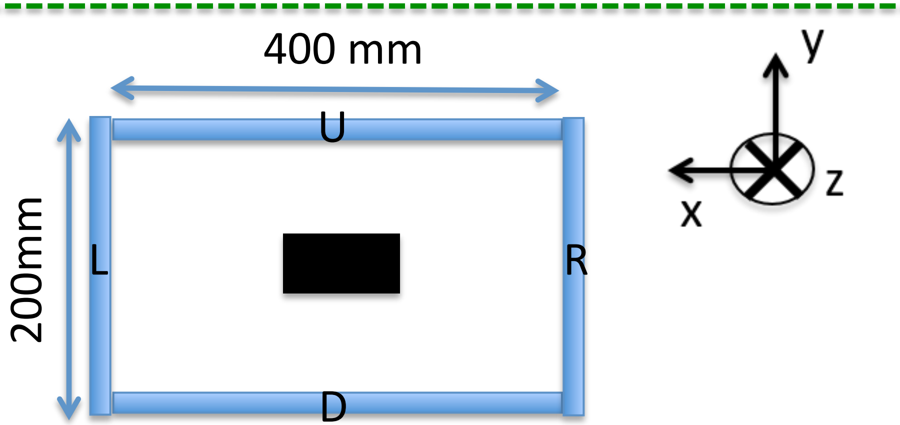
Review of KIC

KIC ("K⁻ identification counter") was installed to check the distortion effect.

KIC: 4 segments (U, D, L, and R). KEK E548: only (U and D) .

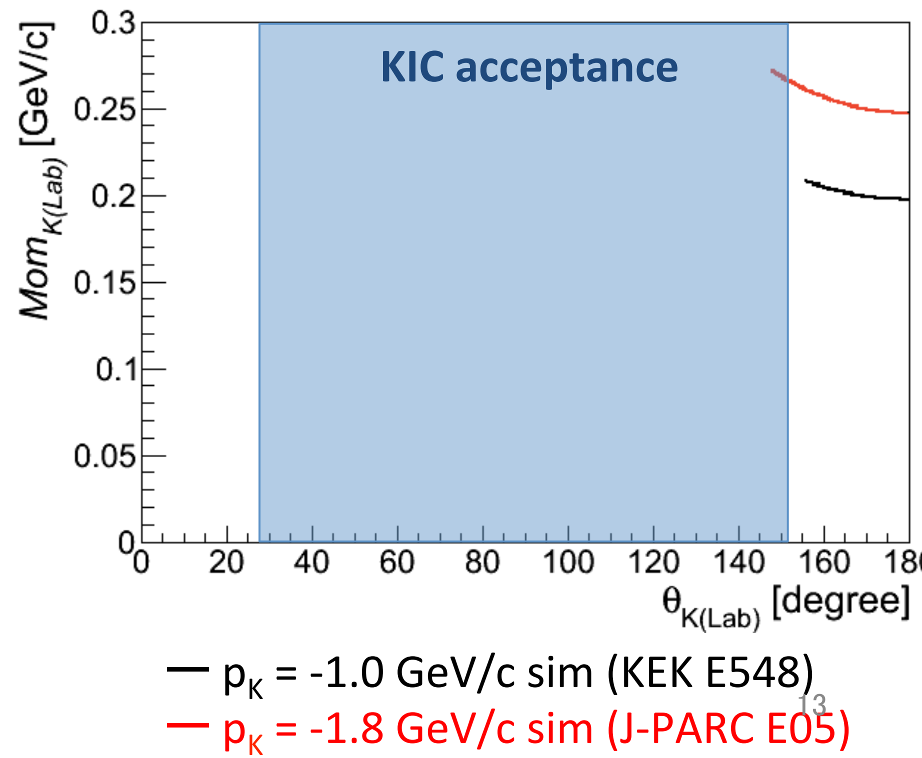
The U and D configuration of KIC is same as KEK E548 detector (called as "CV") .





[Simulation]

θ_K and mom_K of K⁻ for $K^-p \rightarrow K^-p$ (θ_p < 4.1°)
w/o Fermi motion for p_K = -1.0 and -1.8 GeV/c

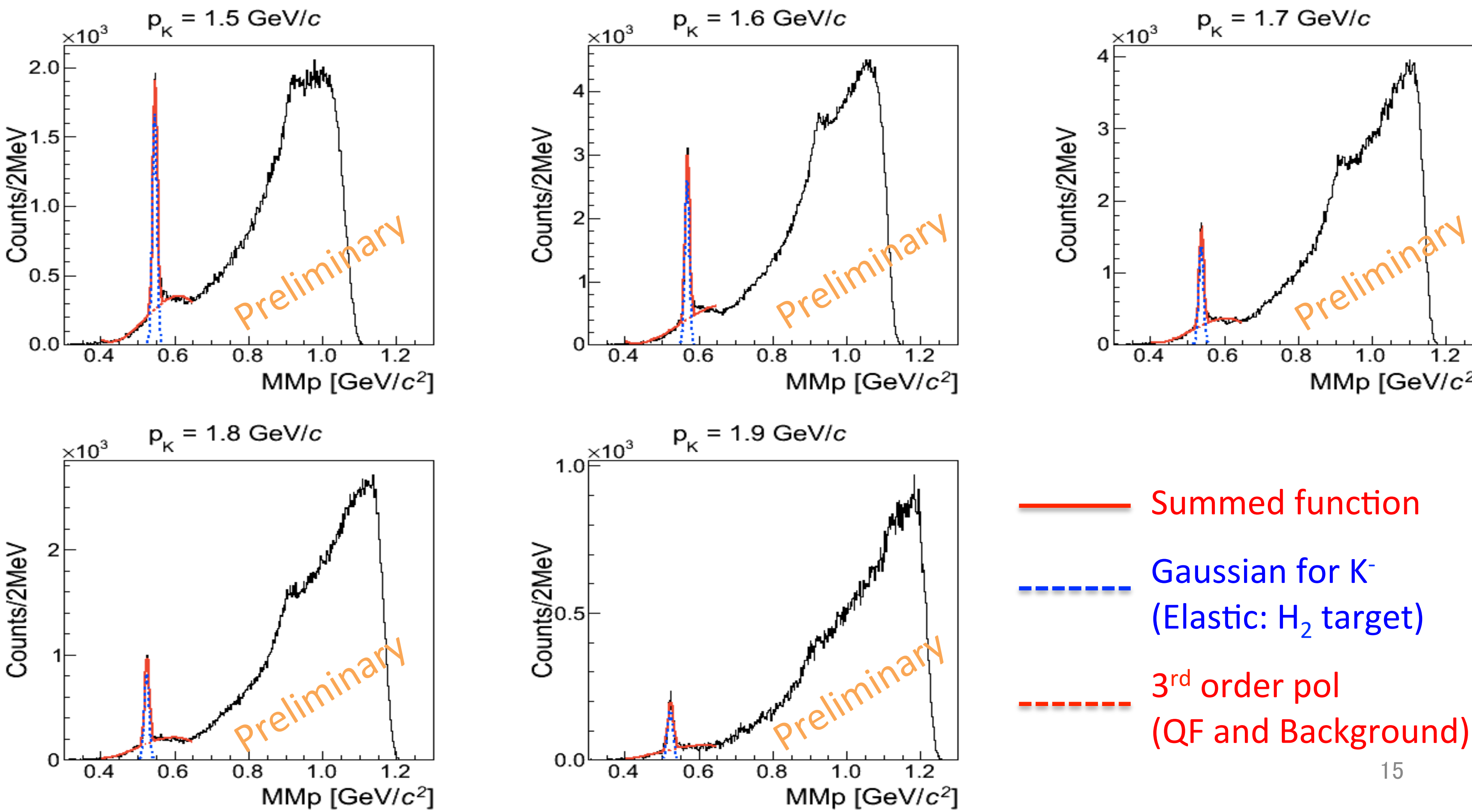


Data summary

Target	Beam mom (p_{K^-}) [GeV/c]	$N_{beam} \times \varepsilon_{DAQ}$ [G Kaon]
CH_2 [9.54 g/cm^2] (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^2]	1.5	0.57
	1.8	56.6

CH_2 data for elementary process

We will evaluate the elementary differential cross section for *K⁻p→K⁻p* elastic scattering process precisely.



CH_2 data for elementary process

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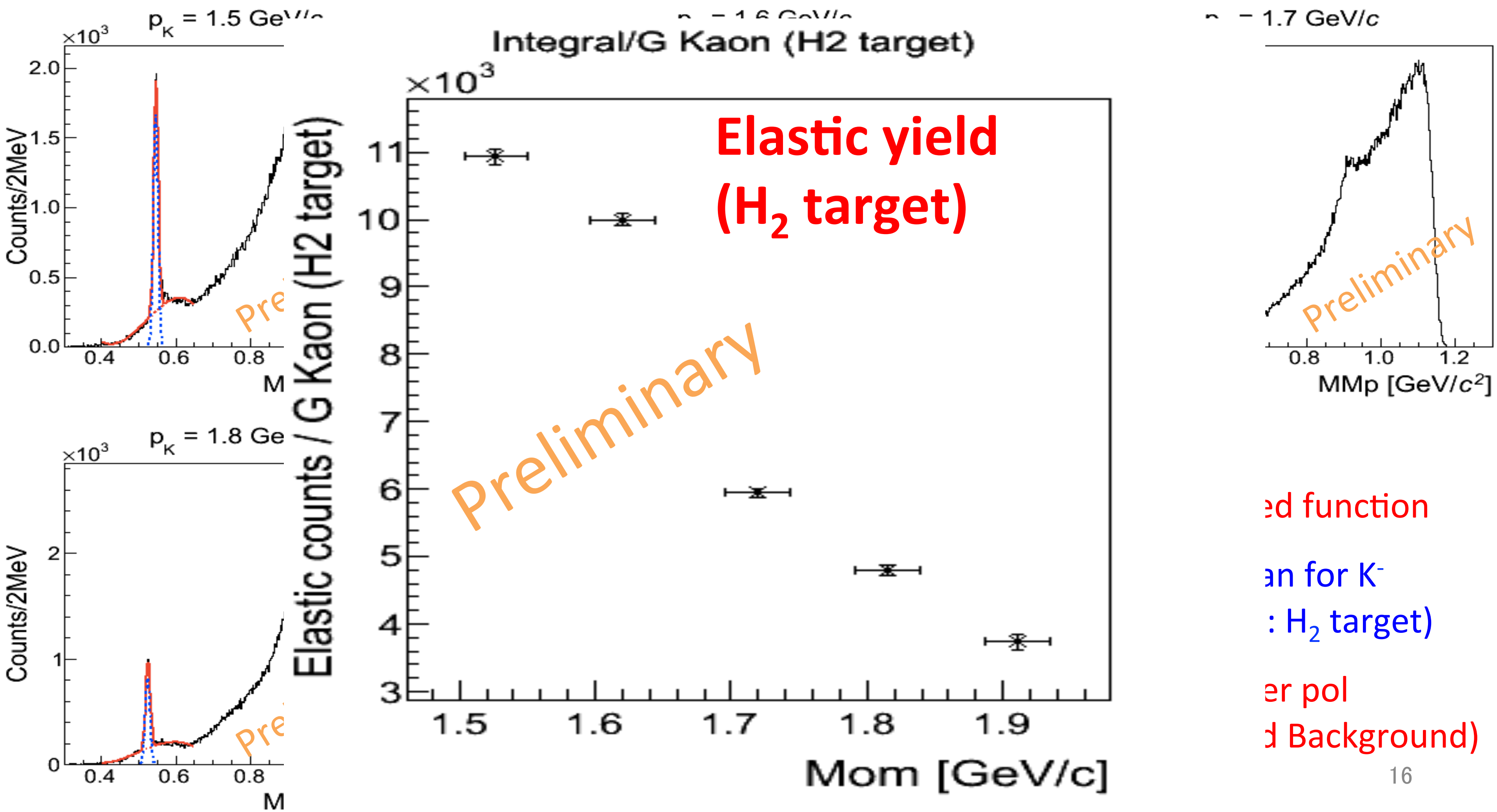
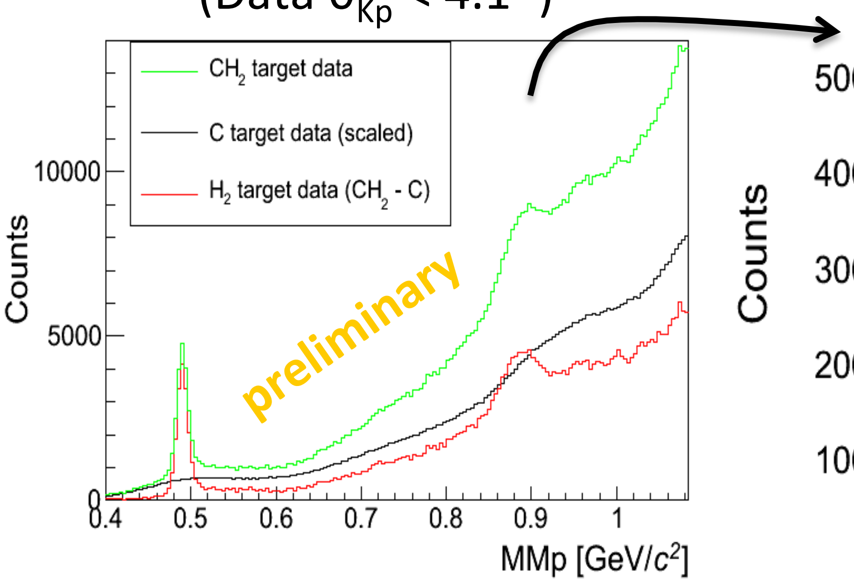


$p(K^-, p)$ spectrum at 1.8 GeV/c

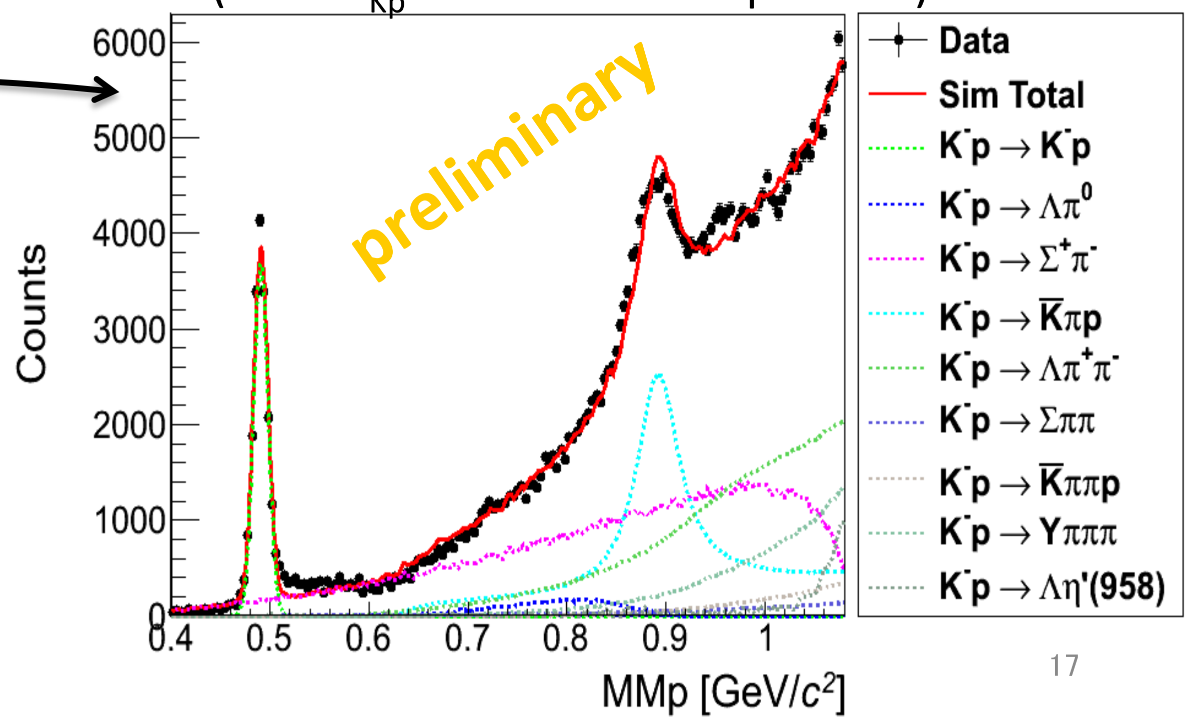
We could fit the obtained spectrum.

- A proton target data was evaluated by using **CH_2** and **C** target data.
- Each yield was free parameter.
- The resonance production processes such as $K^-p \rightarrow K^*(892)^-p \rightarrow \overline{K}\pi p$ and $K^-p \rightarrow \Lambda(1520)\pi^0 \rightarrow \overline{K}\pi p$ were included.

(Data $\theta_{Kp} < 4.1^\circ$)

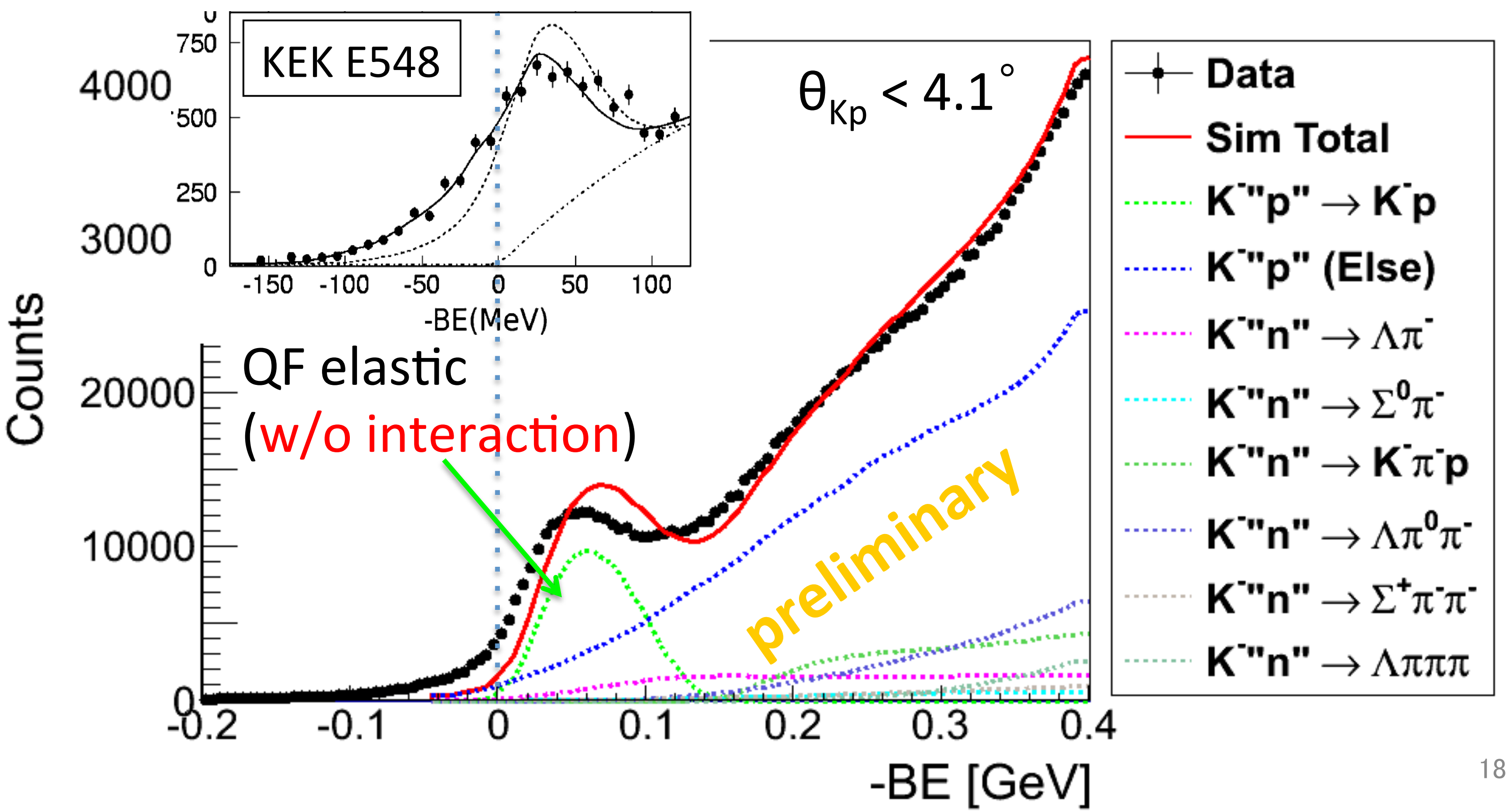


(Data $\theta_{Kp} < 4.1^\circ$ with template fit)



$^{12}C(K^-, p)$ 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, whose yields were free parameters.
However, we could not reproduce -BE < 0.1 [GeV] region.



$^{12}C(K^{-}, p)$ 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.
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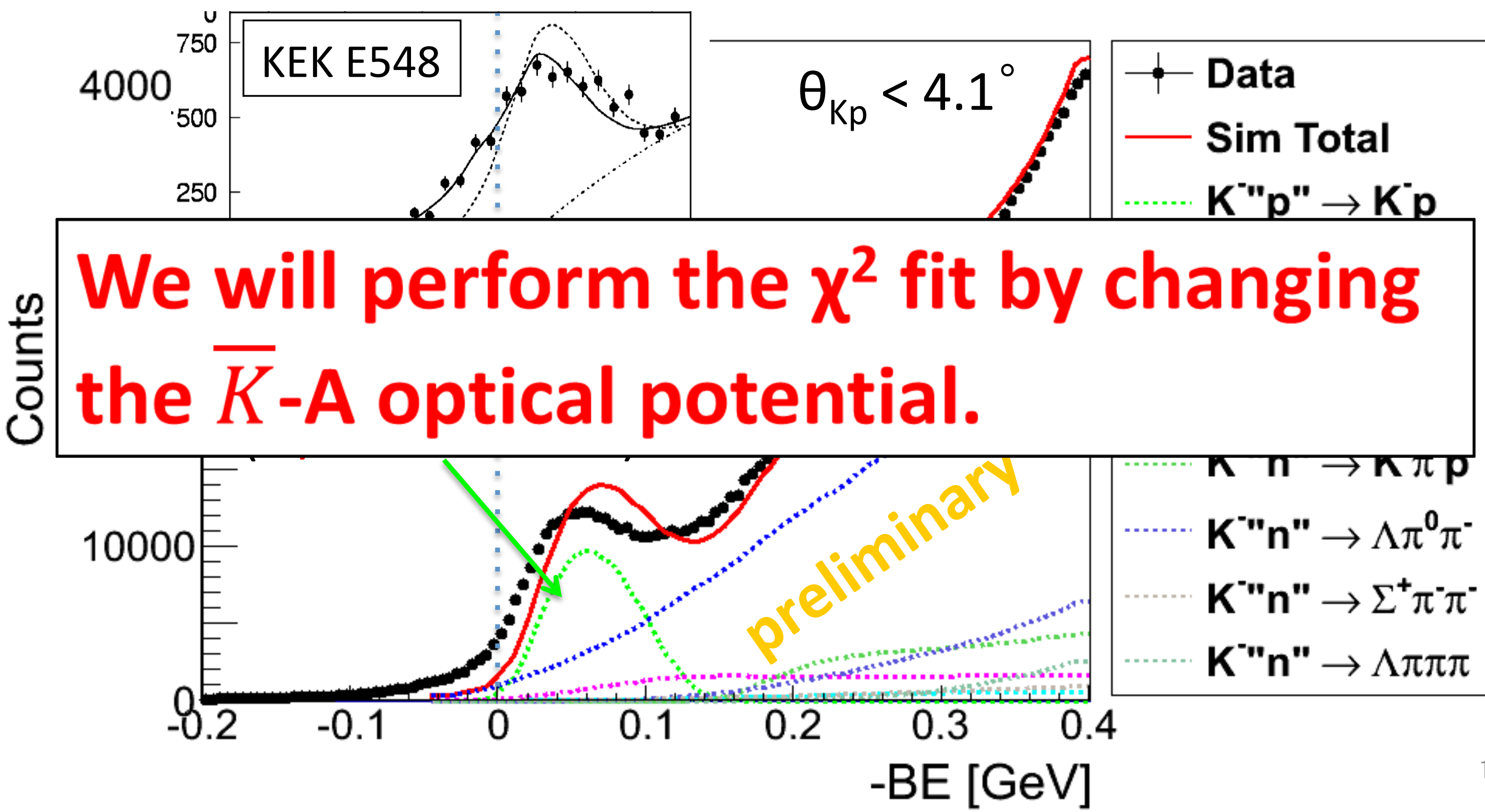
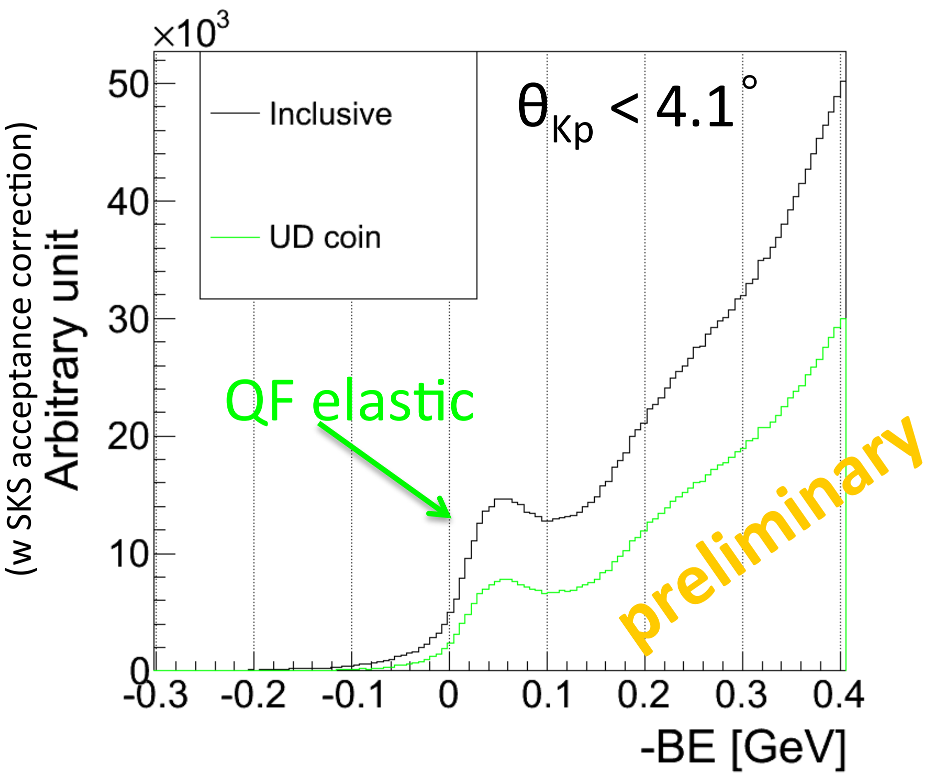


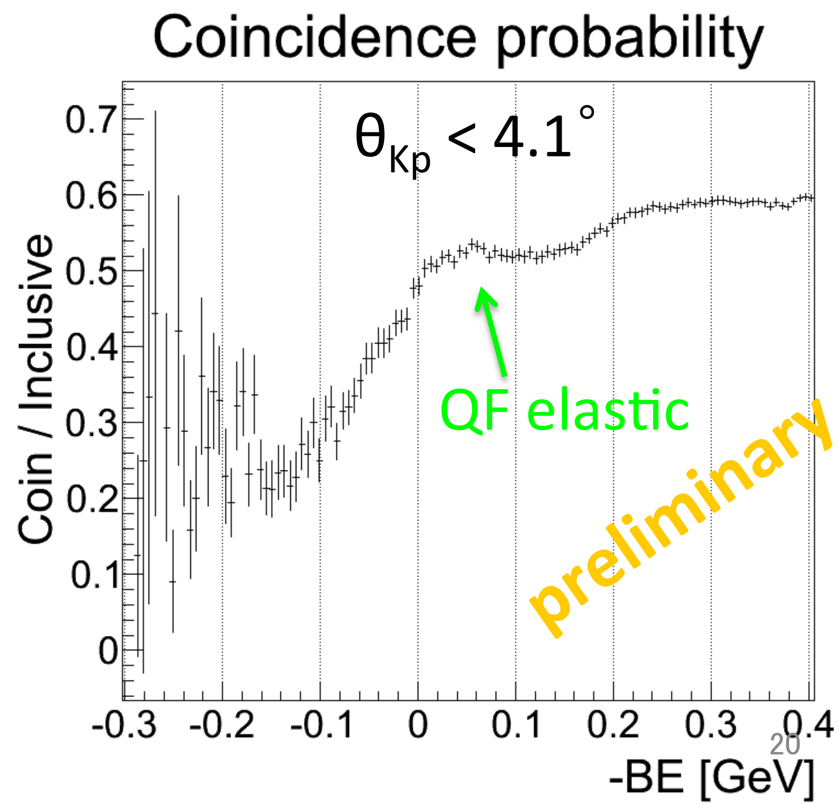
We will perform the χ^2 fit by changing the $\overline{K}$-A optical potential.

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 Λ or Σ or π. Thus, the coincidence probability for BE < 0 region should be higher than QF elastic region.

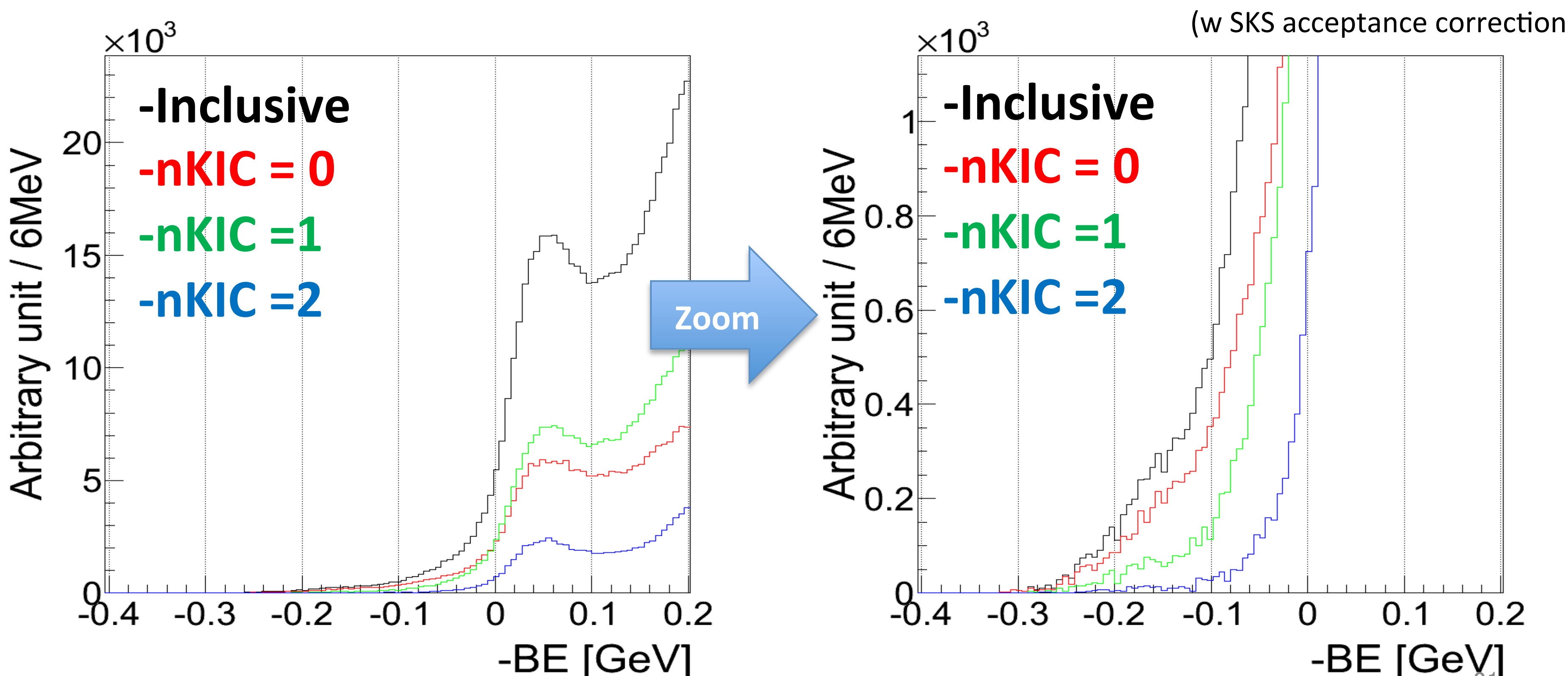
The KEK E548 coincidence (UD coin) has distorted original inclusive spectrum.





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 ~ – 0.1 GeV .



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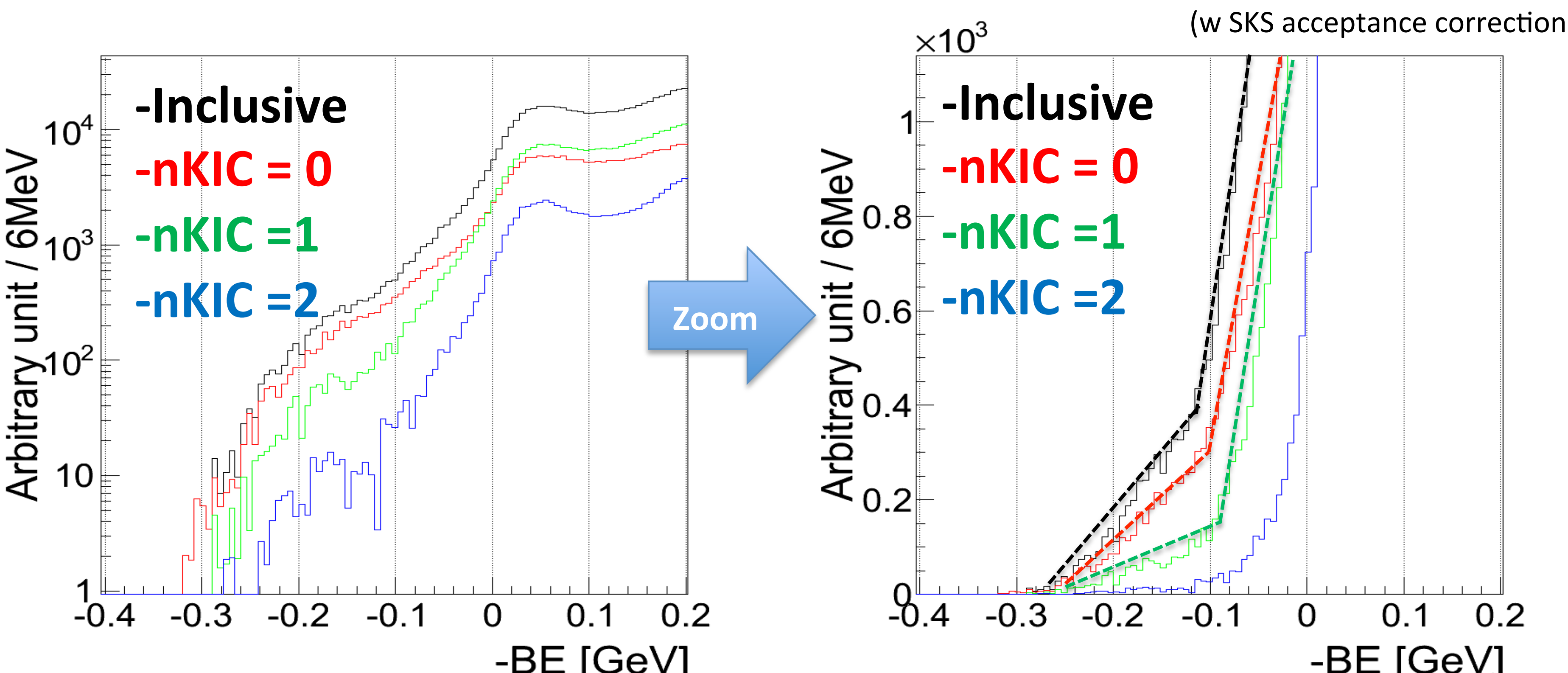
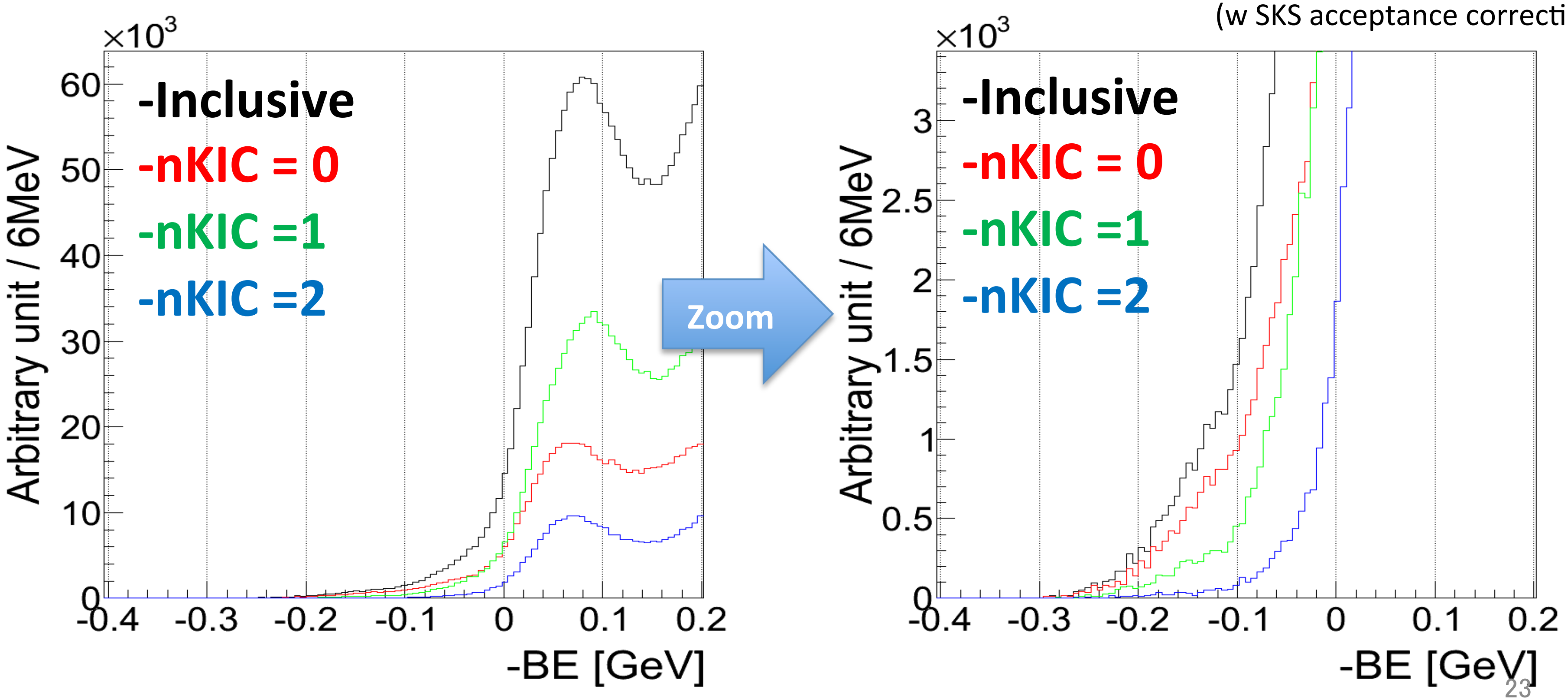


Coincidence analysis ($4.1^\circ < \theta_{Kp} < 8.2^\circ$)

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

(w SKS acceptance correction)



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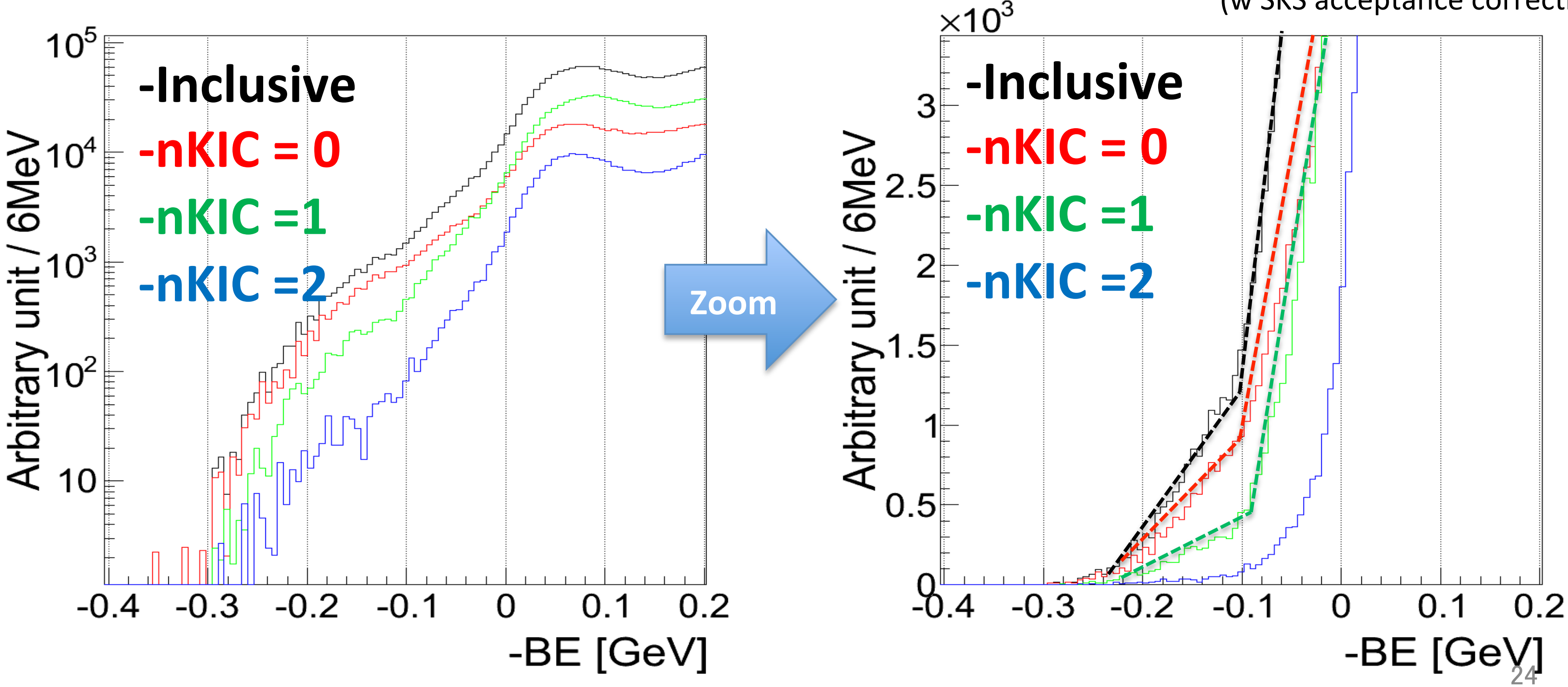


Discussion for the origin of "KINK"

Woods-Saxon type potential + Coulomb potential

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

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

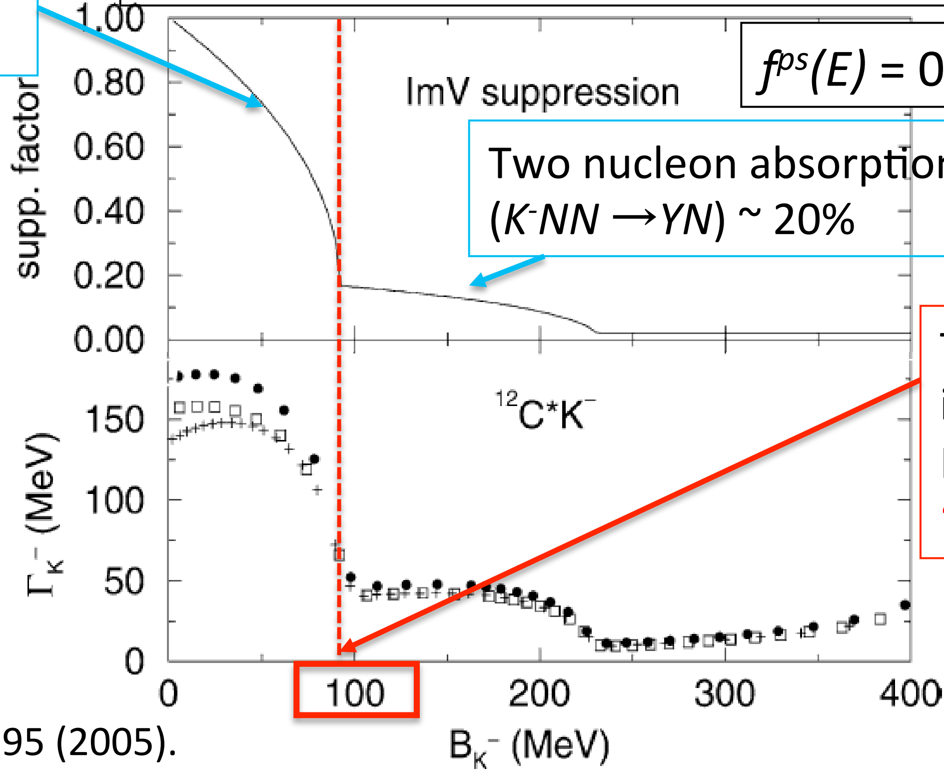
T. Hayakawa presentation

Phase space suppression factor (f^{ps})

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

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

Two nucleon absorption ($K^-NN \rightarrow YN$) ~ 20%



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

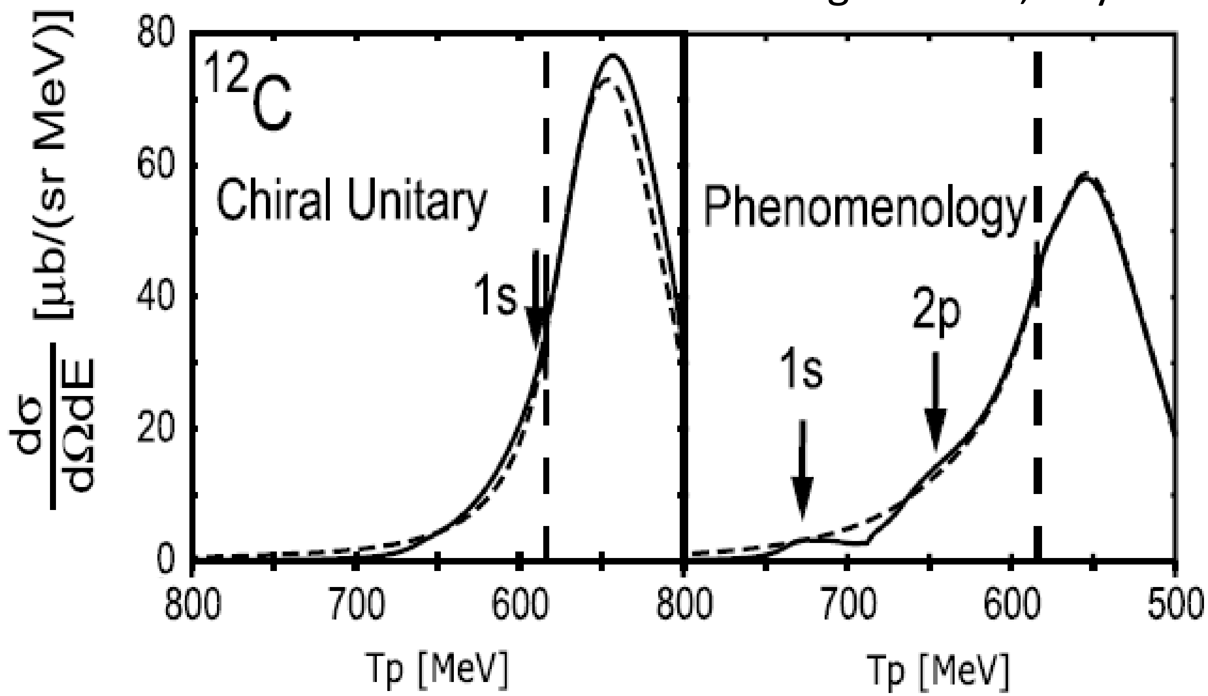
J. Mares et al., PLB 606, 295 (2005).

Theoretical calculation

Theoretical calculation for $^{12}C(K^{-}, p)$ reaction of p_K = 1.0 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 GeV/c.

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



$\theta_{Kp} = 0°$

Summary

- K^{bar}-A interaction is studied by kaonic atom data *etc*..
  - It is still under discussion whether the potential is "deep" or "shallow".
  - $^{12}C(K^-, N)$ spectra were compared with DWIA calculation by KEK E548.

    The charged particle hit requirement might distort the inclusive spectrum.

- We took $^{12}C(K^-, p)$ 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, and 1.9 GeV/c.
  - We observed the significant yield in bound region same as KEK E548. The $^{12}C(K^-, p)$ spectrum couldn't be reproduced $-BE < 0.1$ 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 ~ 0.1 GeV. It might be originated from the threshold of $K^-N \rightarrow \Sigma\pi$ absorption.
  - We will compare our spectrum with theoretical calculation.