K^{bar}-nucleus interaction study at J-PARC

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for J-PARC E05 Collaboration

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K^{bar}-A interaction

An important tool to study the K^{bar}-nucleus interaction 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

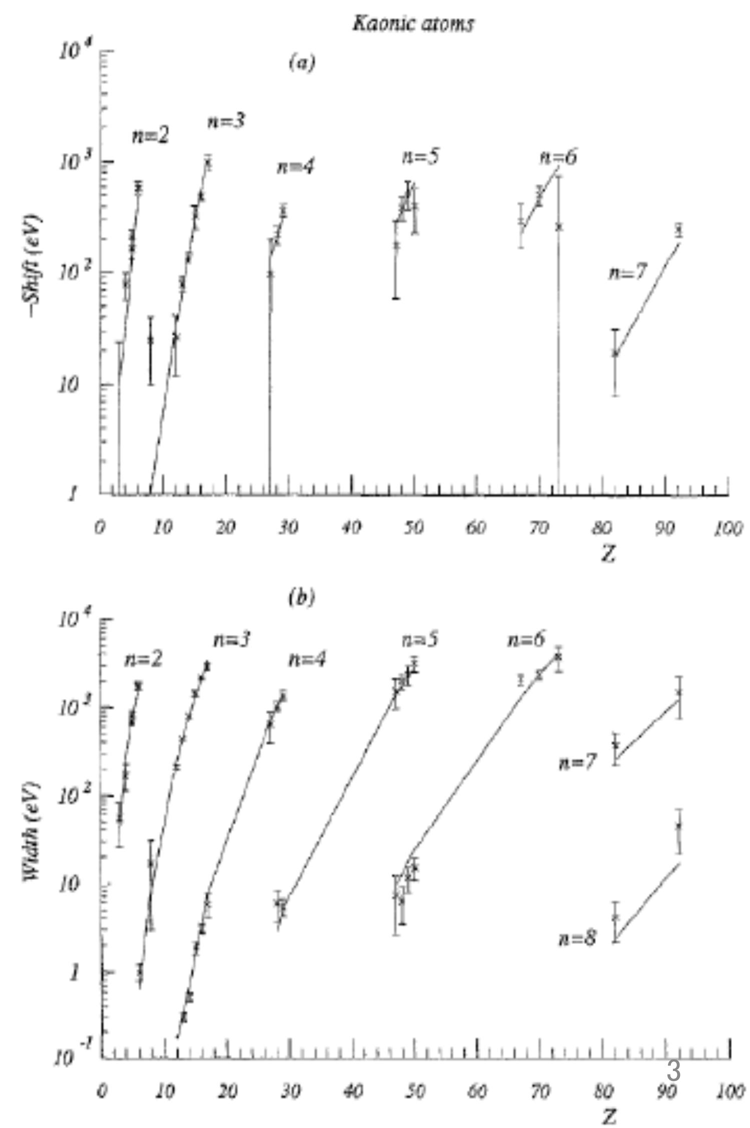
Re(V_0) ~ —(170) MeV

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

Re(V_0) ~ —(170) MeV

- Chiral motivated model

Re(V_0) ≦ —60 MeV



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An important tool to study the K^{bar}-nucleus interaction is kaonic atoms.

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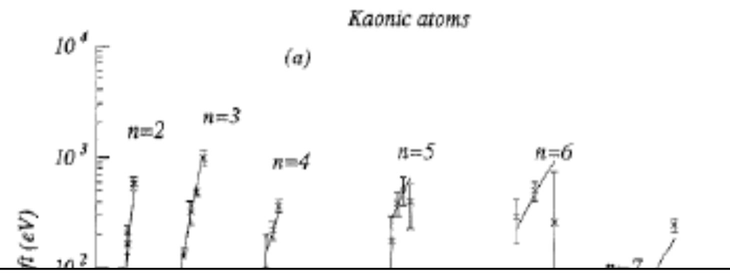
$Re(V_0) \sim -80$ MeV



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.

↓

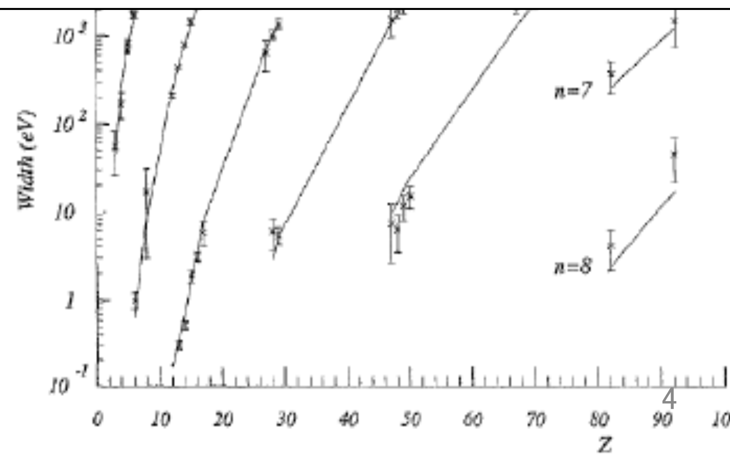
In order to solve this problem, a new experimental constraint is necessary!

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

$Re(V_0) \sim -(170)$ MeV

– Chiral motivated model

$Re(V_0) \lesssim -60$ MeV



K^{bar}-A interaction

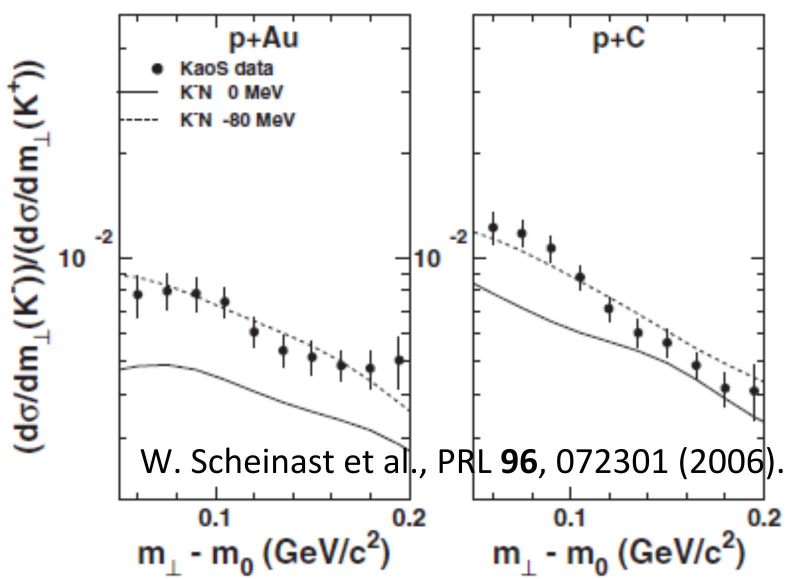
Kaos data

- $d\sigma/d\Omega$ of $K^{\pm}$ in p+C and p+Au at 1.6, 2.5, and 3.5 GeV.
- 1.58 GeV: pp→$K^+\Lambda p$ threshold, 2.5 GeV: pp→K^+K^-pp threshold
- Comparing with BUU transport model.

Re(V_0) ~ -80 MeV (“shallow”)

$$R = \frac{d\sigma}{dm_\perp}\Big|_{K^-} \Big/ \frac{d\sigma}{dm_\perp}\Big|_{K^+}$$

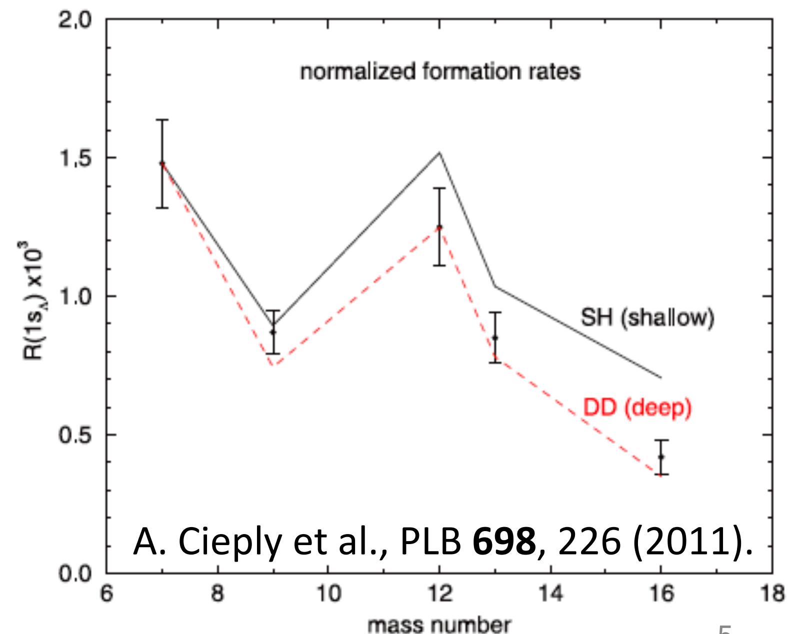
($m_\perp = \sqrt{(p^2_\perp + m^2_K)}$)



W. Scheinast et al., PRL **96**, 072301 (2006).

Calculation for the $1_s\Lambda$ hypernuclear formation rate in stopped K^- reaction.

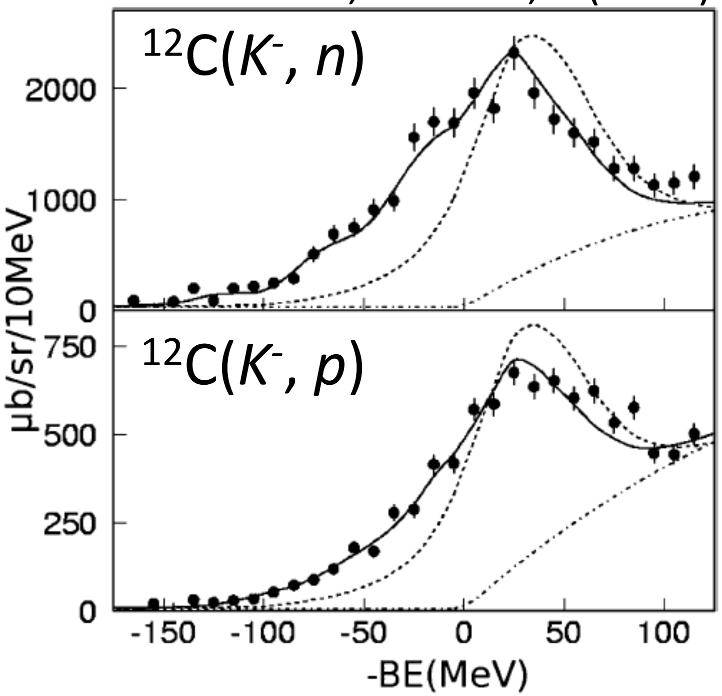
(from FINUDA data)



A. Cieply et al., PLB **698**, 226 (2011).

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

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



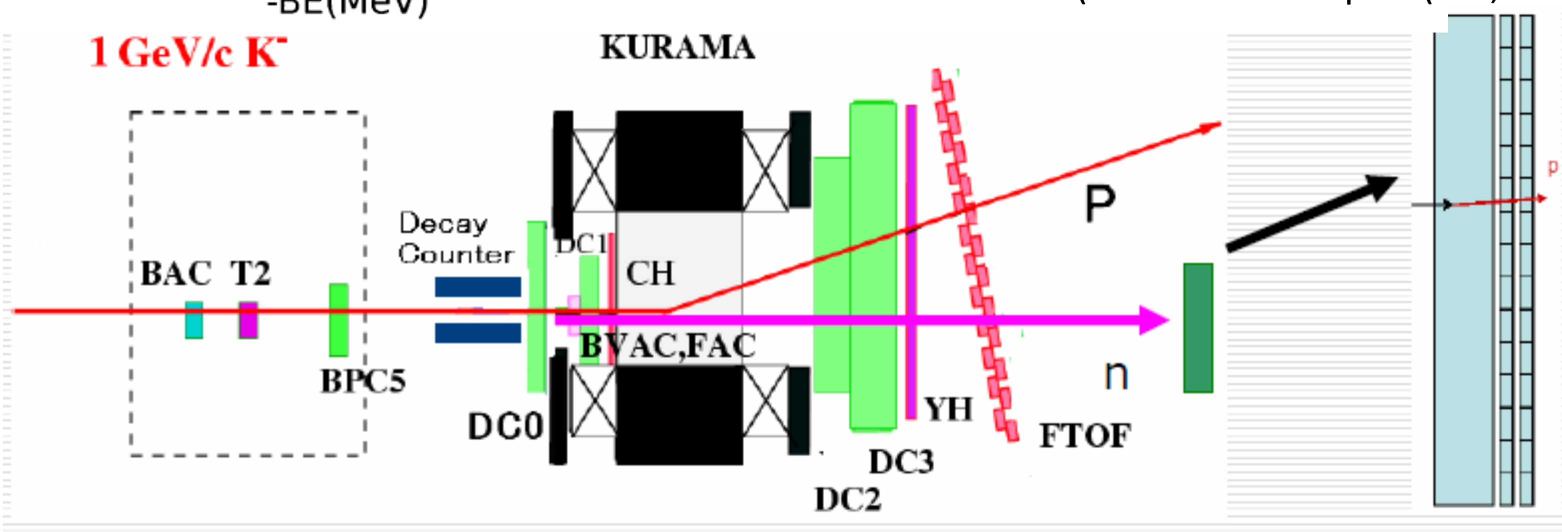
C(K$^-$, n), C(K$^-$, p) reaction at 1GeV/c

- K$^-$ beam: 10^4/spill
- KEK-PS K2 beamline + KURAMA
- MM resolution ~ 10 MeV (σ)
- θ_{sc} < 4.1° was chosen

V_{opt} was studied by comparing DWIA

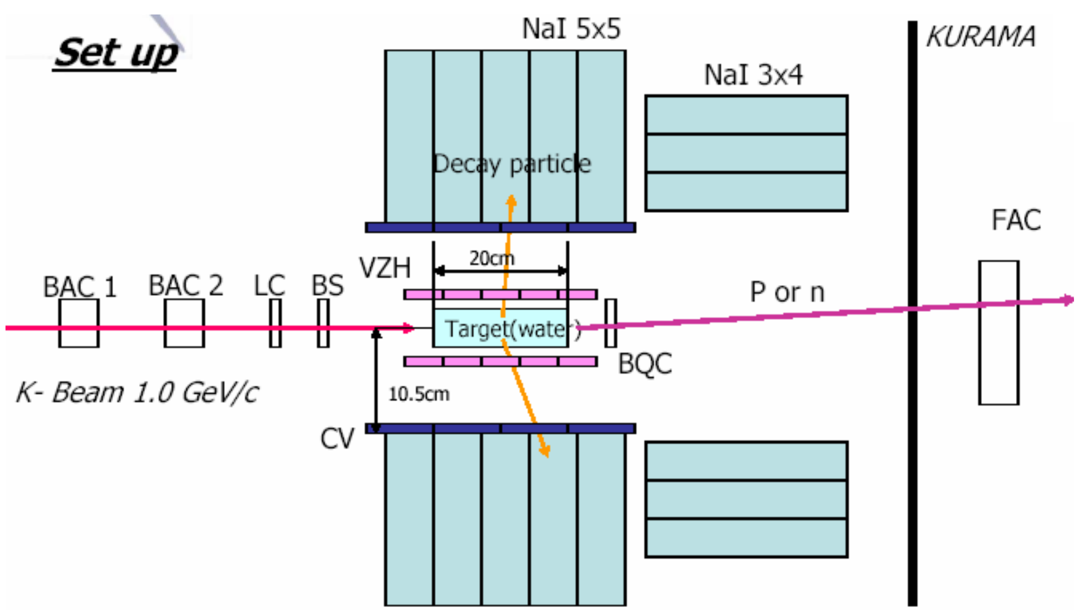
- C(K$^-$, n): V_{opt} = (-190, -40) MeV
- C(K$^-$, p): V_{opt} = (-160, -50) MeV

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



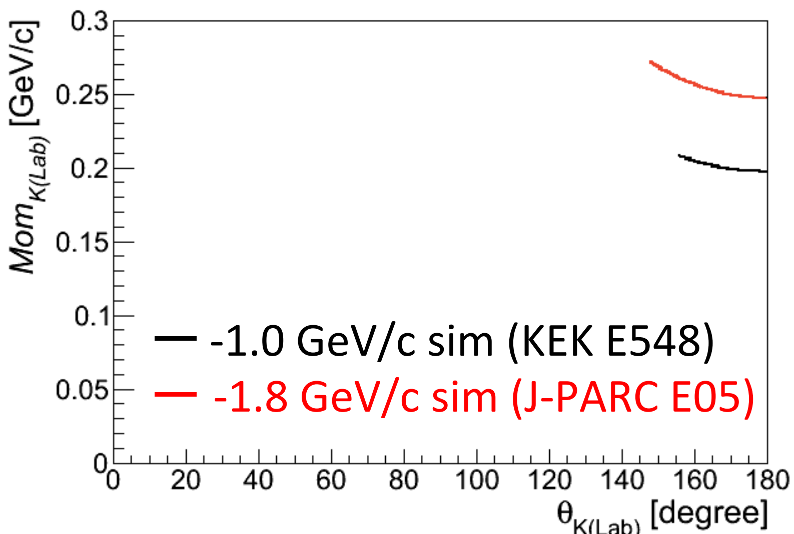
Discussion for KEK E548

- 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)
- We took ^{12}C(K$^-$, *p*) real inclusive spectrum as by-product of E05 pilot run (Ξ hyper nucleus search using ^{12}C(K$^-$, K$^+$)) in Oct, 2015.



[Simulation]

θ_K and mom$_K$ of K$^-$ for K$^-$p→K$^-$p (θ_p < 4.1°) 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 coincidence spectra can distort the original inclusive spectra.

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

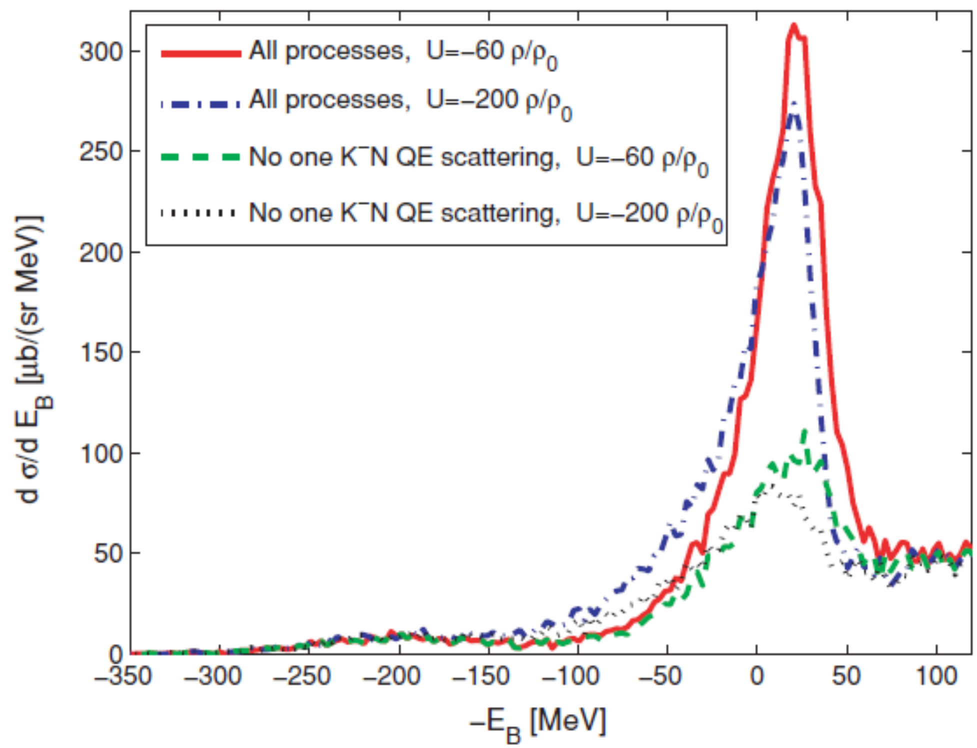


FIG. 8. (Color online) Calculated $^{12}C(K^-, p)$ spectra for $V_{opt} = (-60, -60)\rho/\rho_0$ MeV and $V_{opt} = (-200, -60)\rho/\rho_0$ MeV, taking into account all contributing processes (solid and dot-dashed lines) and imposing the minimal coincidence requirement (dashed and dotted lines).

Criticism for KEK-PS E548

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

- Comparison with calculated coincidence spectrum.

Conclusion	Coincidence spectrum doesn't have the sensitivity for the V_{opt}.

V_{opt} = (-60, -60) MeV

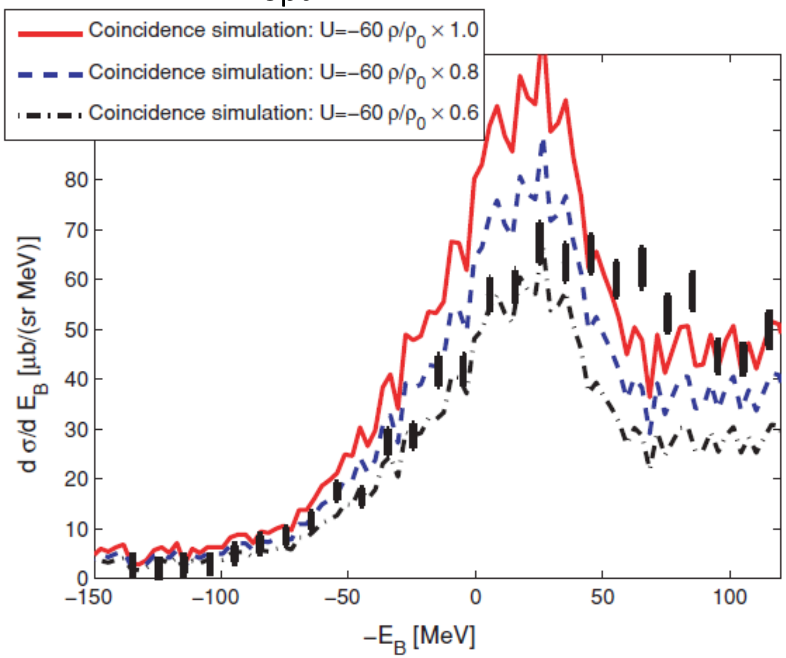


FIG. 9. (Color online) The ^{12}C(K^-, p) spectrum obtained with $V_{opt} = (-60, -60)\rho/\rho_0$ MeV and the minimal coincidence requirement, for several reduction factors. Experimental points are taken from Ref. [44].

V_{opt} = (-200, -60) MeV

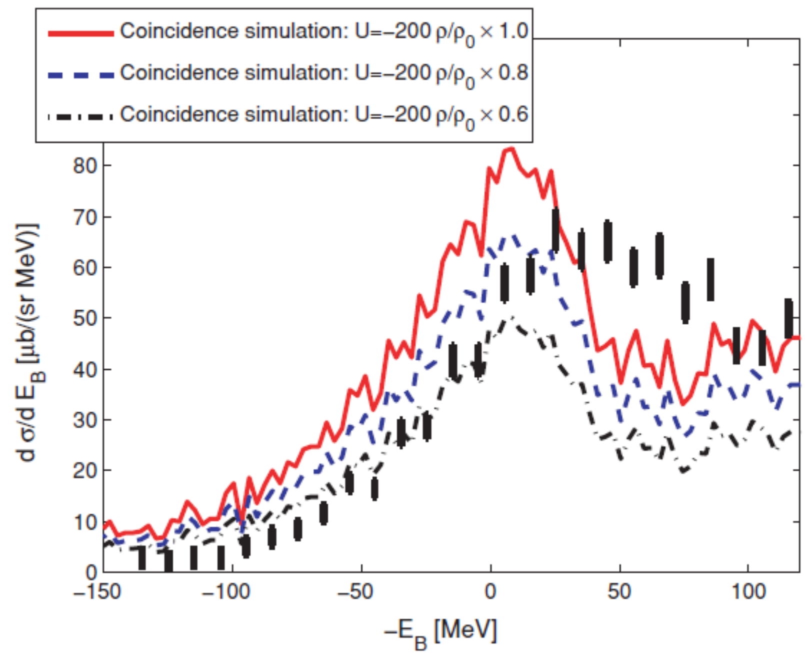


FIG. 10. (Color online) The same as Fig. 9, but for $V_{opt} = (-200, -60)\rho/\rho_0$ MeV.

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

E05 experiment

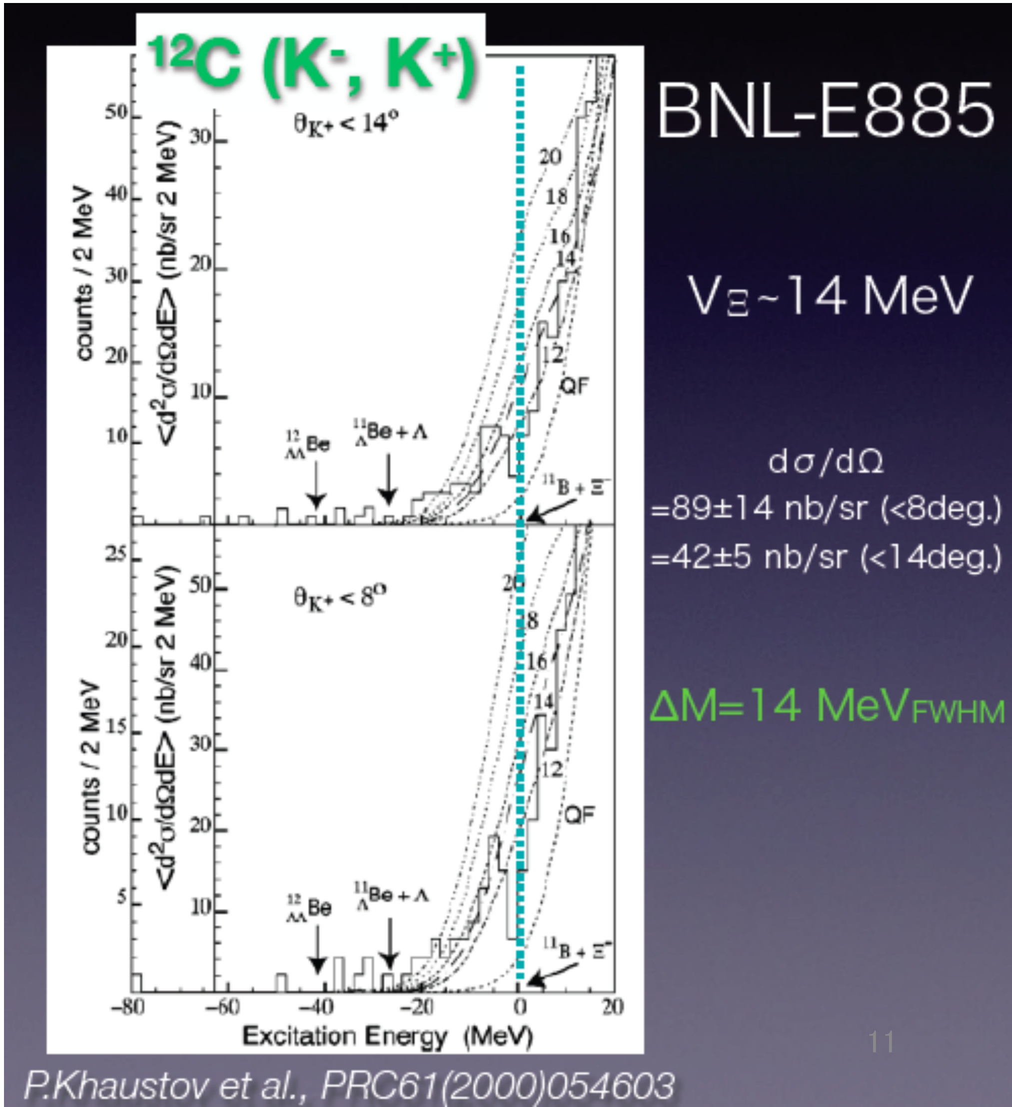
Study of Ξ-hypernucleus $^{12}_{\Xi}Be$ using $^{12}C(K^-, K^+)$reaction

*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.

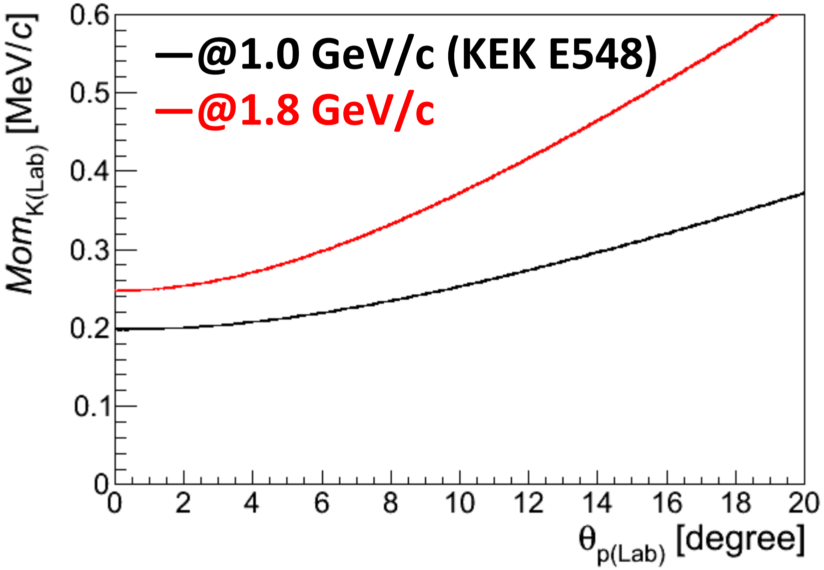
In the last October, pilot run using the SKS was carried out.



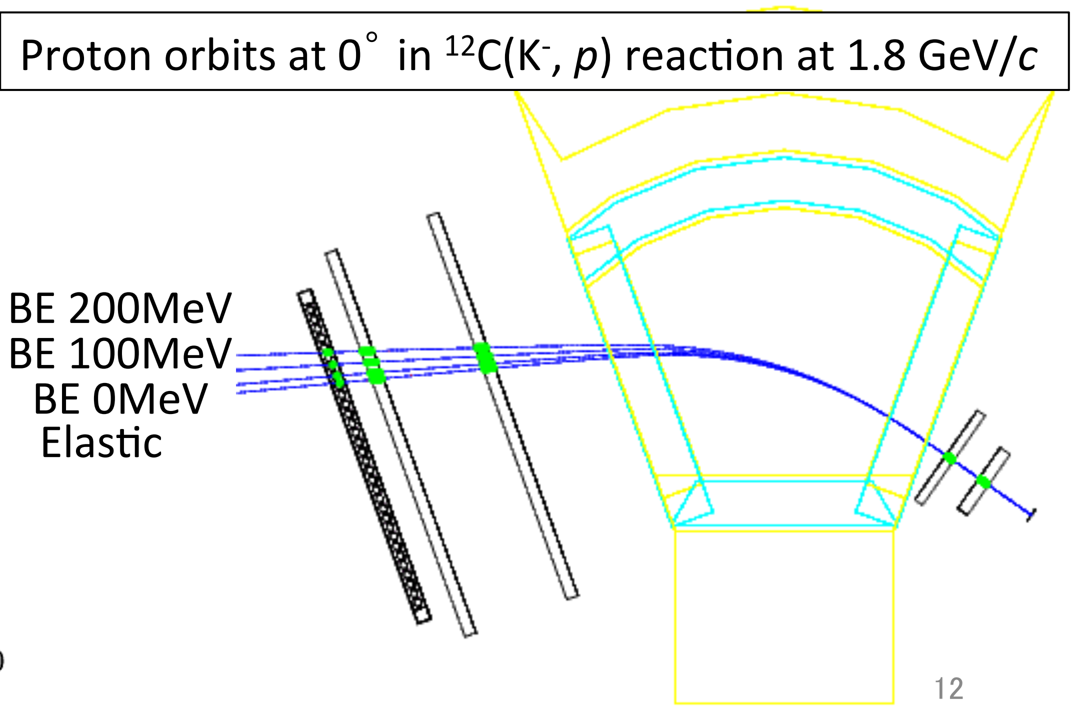
^{12}C(K$^-$, *p*) study in E05 pilot run

- Goal of this measurement
  - Determine the K^{bar}-A optical potential from QF inclusive spectrum.
  - Check the semi-inclusive effect by installing the scintillation counter.
- We can take this data with E05 setup at the same time.

Recoil momentum of K$^-$ in K$^-$p elastic scattering

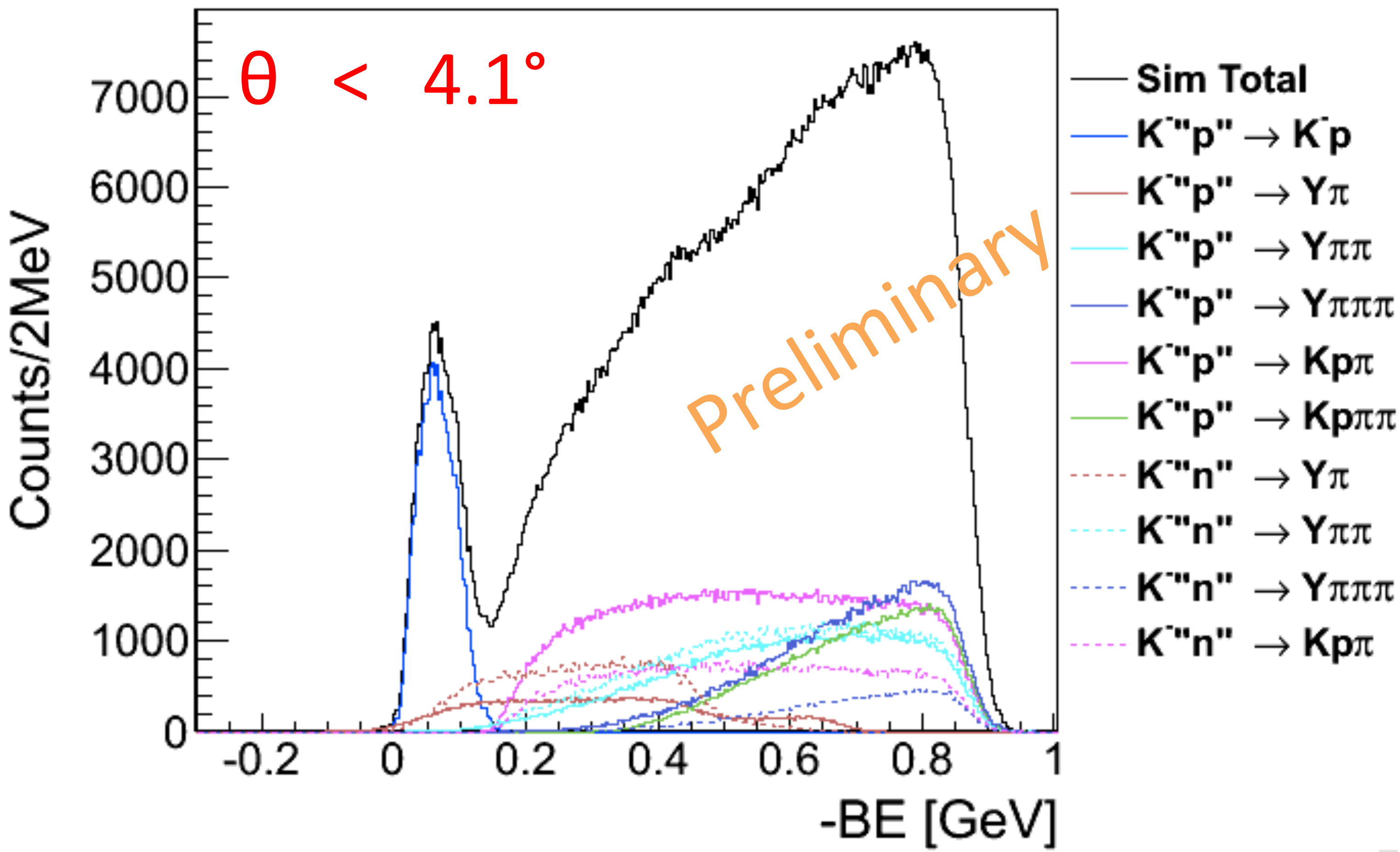


Proton orbits at 0° in ^{12}C(K$^-$, *p*) reaction at 1.8 GeV/*c*

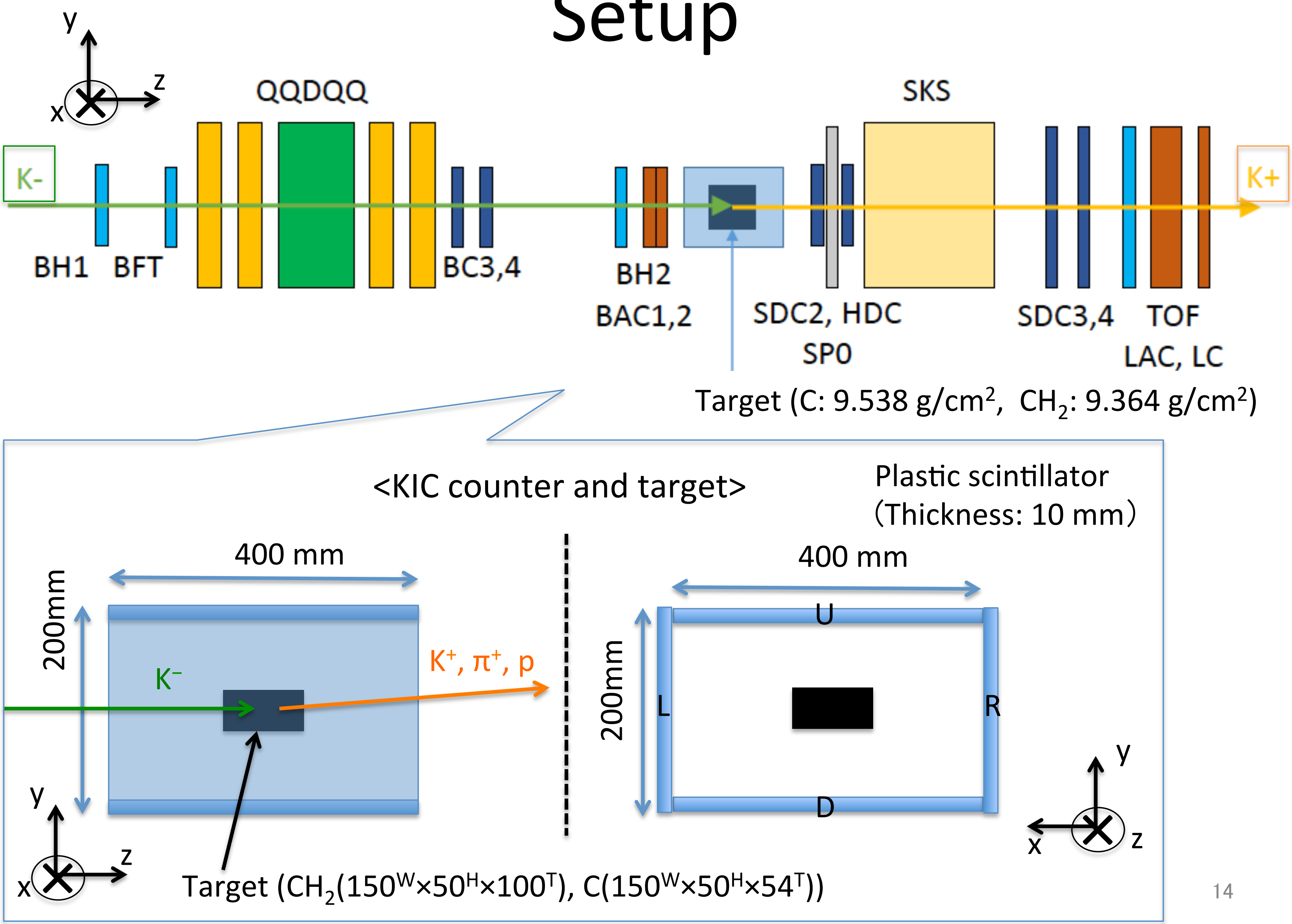


Simulated BE spectrum

This figure is simulated BE spectrum for θ < 4.1 ° events by using old bubble chamber data and Fermi-motion. The effective #K- beam is used real value. The effective nucleon number 1.5 is used for this simulation .



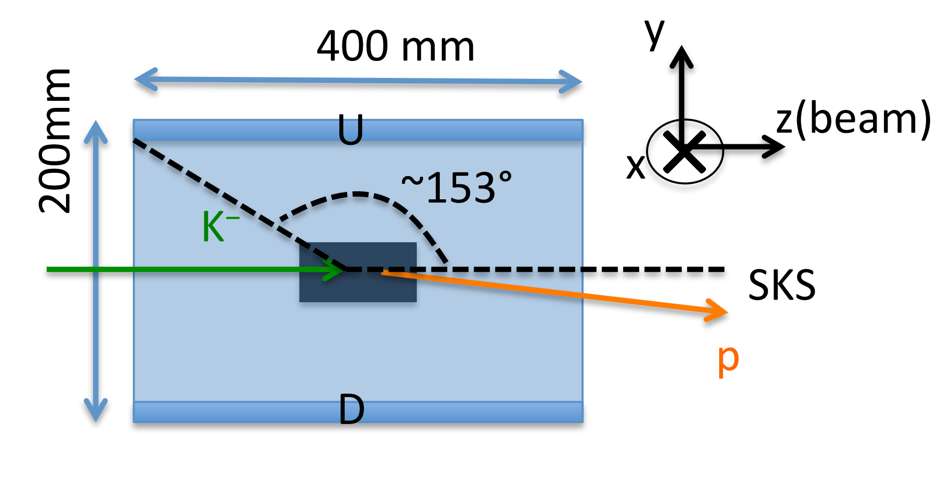
Setup

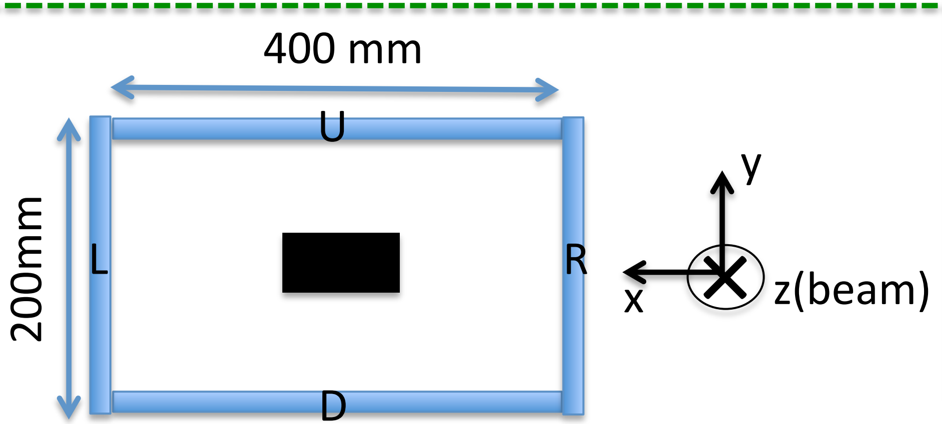


y
z
x
QQDQQ
SKS
K-
K+
BH1
BFT
BC3,4
BH2
BAC1,2
SDC2, HDC
SP0
SDC3,4
TOF
LAC, LC
Target (C: 9.538 g/cm^2, CH_2: 9.364 g/cm^2)
<KIC counter and target>
Plastic scintillator
(Thickness: 10 mm)
400 mm
200mm
K^-
K^+, π^+, p
400 mm
200mm
U
L
R
D
y
z
x
Target (CH_2($150^W \times 50^H \times 100^T$), C($150^W \times 50^H \times 54^T$))

Review of KIC

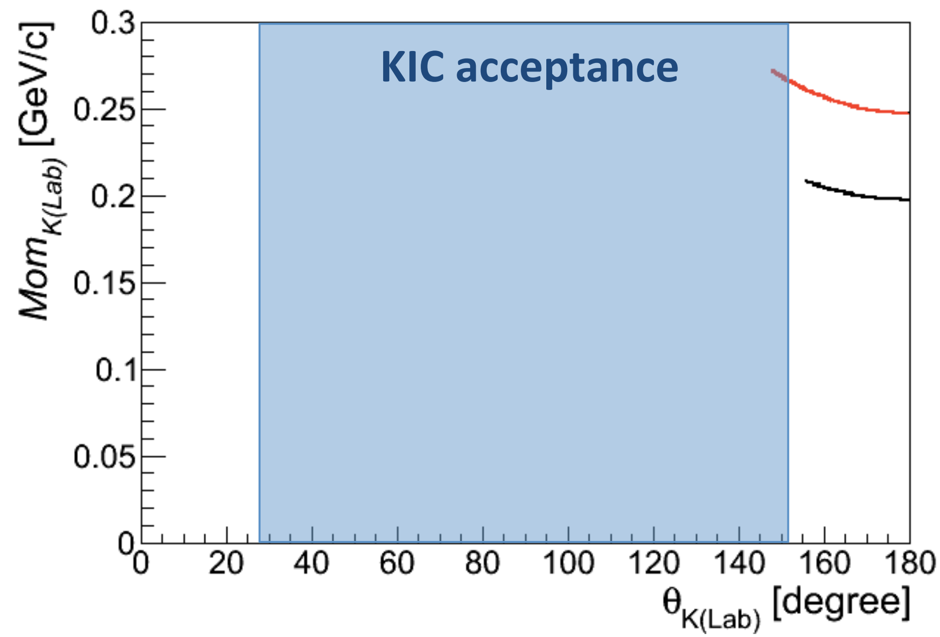
KIC ("K⁻ identification counter") was installed to check the distotion effect. KIC is composed from 4 segments (U, D, L, and R). In the KEK E548, their decay counter is installed at U and D side not L and R side. The U and D configuration of KIC is same as the decay counter of KEK E548 (called as "CV") .





[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



— p_K = -1.0 GeV/c sim (KEK E548)
— p_K = -1.8 GeV/c sim (J-PARC E05)

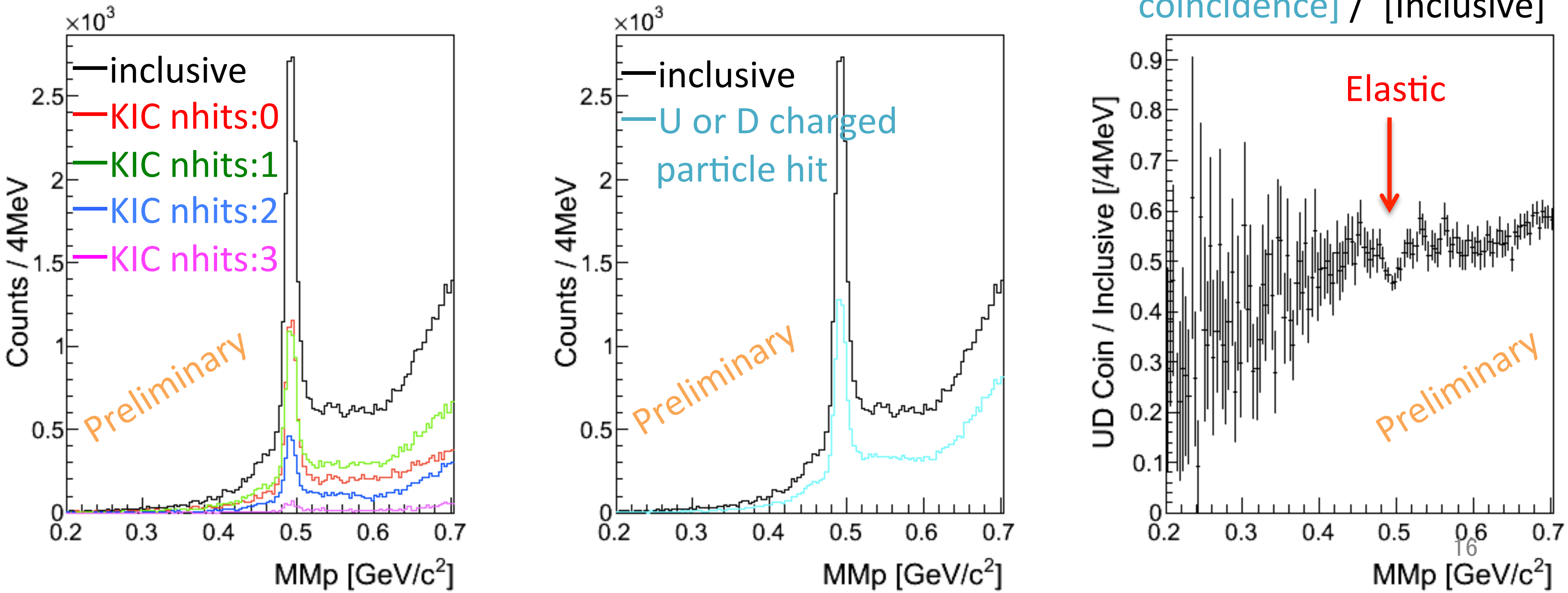
KIC coincidence effect (MM_p)

Missing mass for p(K^-, p) reaction (MM_p) at p_K = -1.8 GeV/c (CH_2 target)

We checked the coincidence effect of KIC.

θ < 4.1° (same as KEK E548) [Zoom]

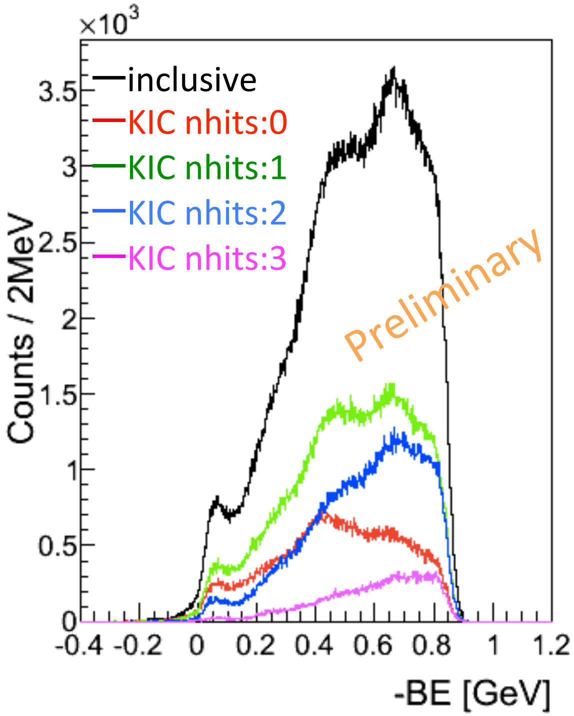
Coincidence probability = [U or D charged particle coincidence] / [Inclusive]

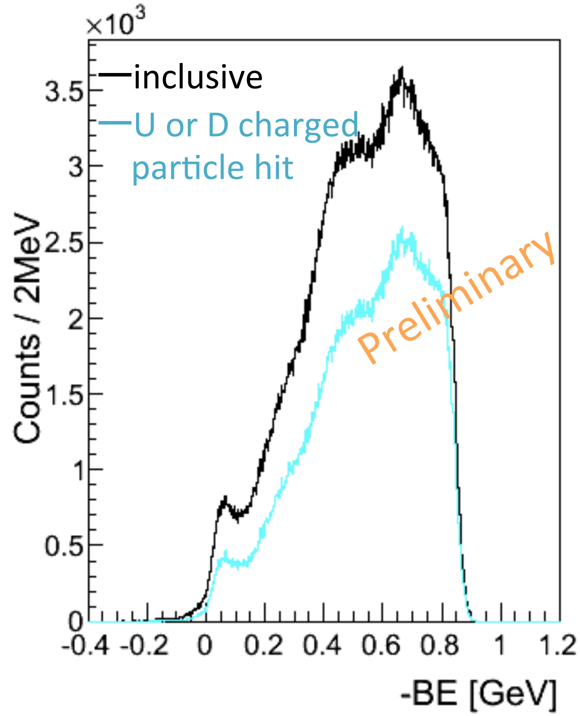


KIC coincidence effect (BE)

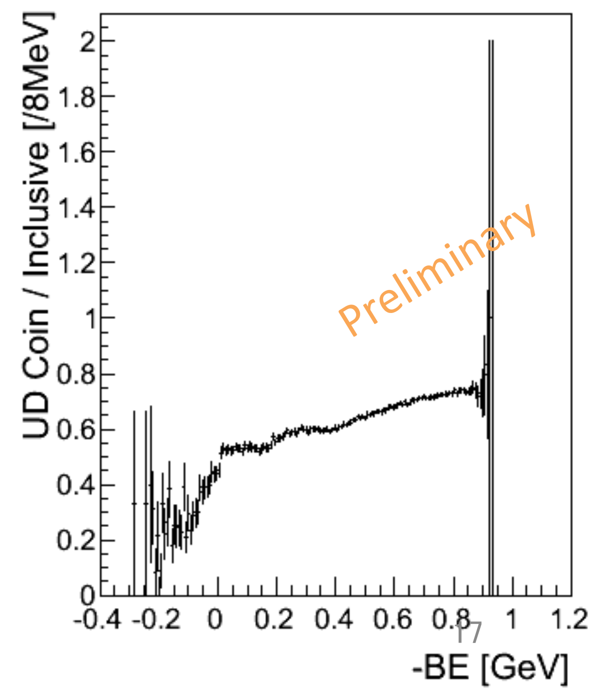
They are BE spectrum for C target at p_K = -1.8 GeV/c.

θ < 4.1° (same as KEK E548)





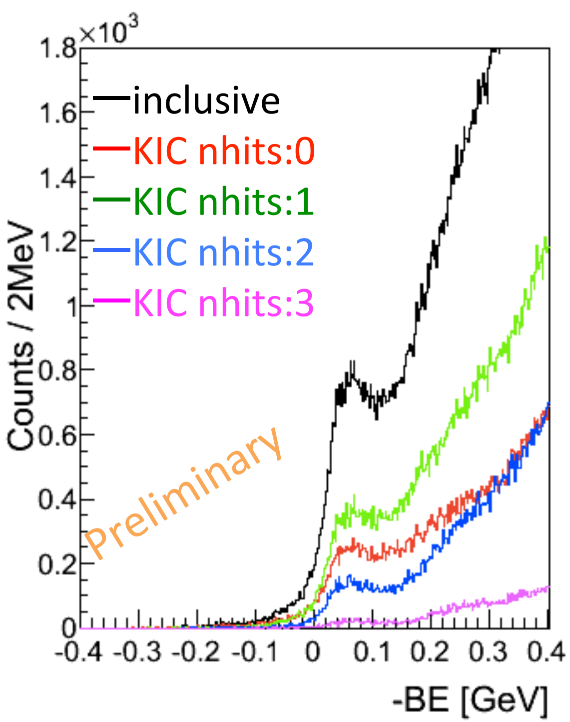
Coincidence probability
= [U or D charged particle coincidence] / [Inclusive]

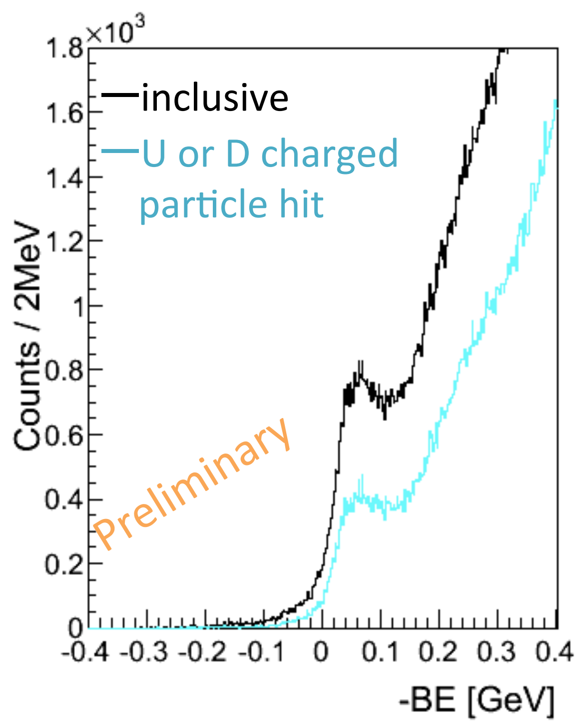


We can see the coincidence probability drop around Elastic region as we expected. However, the coincidence probability is more drastically dropped around BE = 0 GeV. In principle, the final state of BE < 0 region should be included Λ or Σ or π. Thus, the coincidence probability for BE < 0 region should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

Anyway, this coincidence has distorted original inclusive spectum.

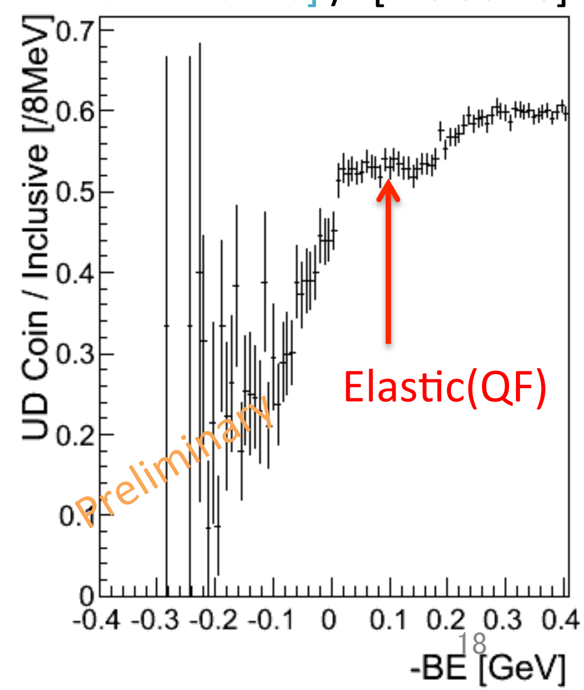
θ < 4.1° (same as KEK E548) [Zoom]





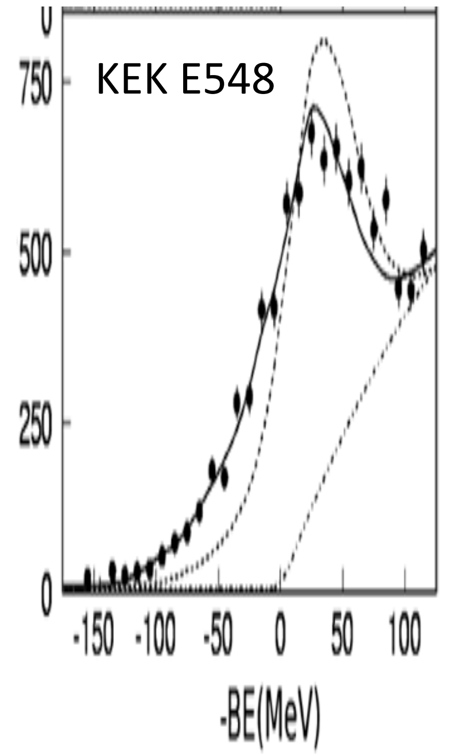
Coincidence probability

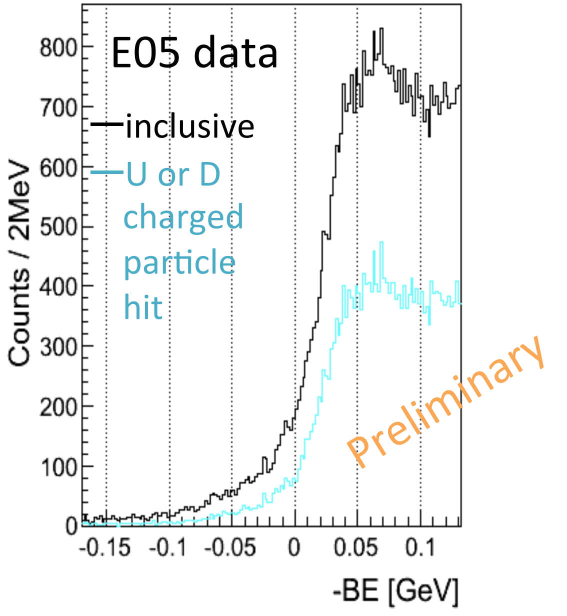
= [U or D charged particle coincidence] / [Inclusive]



Comparison between E05 and KEK E548

It is comparison between J-PARC E05 and KEK E548 data.





Summary

- K^{bar}-A interaction has been studied from kaonic atom data *etc*..
  - However, it is not conclusive whether K^{bar}-A potential is "deep" or "shallow".
- KEK E548 experiment studied K^{bar}-A interaction by comparing $^{12}C(K^-, N)$ spectra with DWIA calculation.
  - It is pointed out that charged particle hit requirement might distort the inclusive spectrum.
- We have taken $^{12}C(K^-, p)$ real inclusive spectrum as a by-product of J-PARC E05.
  - We have found the coincidence distorted the original spectrum.
  - We will determine the interaction by comparing our spectrum with DWIA calculation.