Study of $\overline{K}$-cluster by using (K^-, N) reaction

Reference

https://doi.org/10.1093/ptep/ptaa139

Yudai Ichikawa (JAEA)

2020/09/24, 25

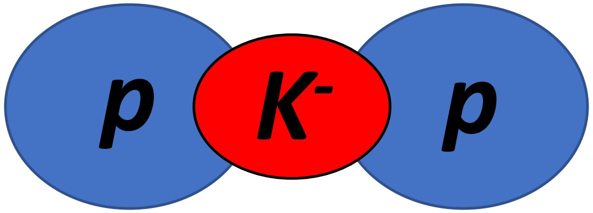
第5回クラスター階層領域研究会

(*Introduction*)
Λ(1405) *and* K^-*pp*

Λ(1405)

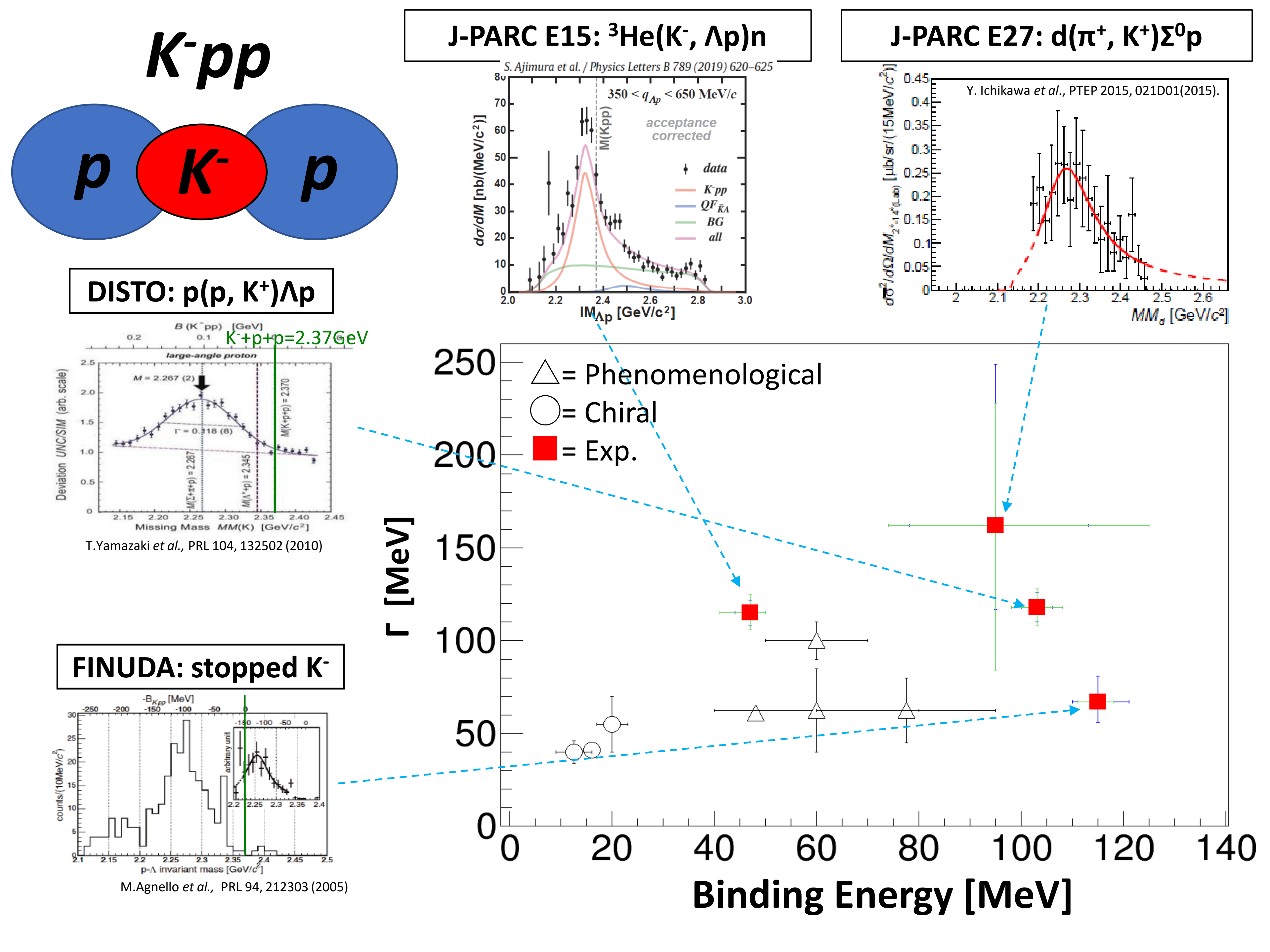
- Λ(1405) is assigned as an excited three quark baryon (u, d, s) with I = 0 and $J^P = (1/2)^-$ in the constituent quark model.
- However, the observed mass is smaller about 80 MeV than the theoretical prediction.
- $\bar{K}N$ bound state(?) two pole state(?)
- Many body system called as Kaonic nuclei is expected. Ex: K^-pp, K^-K^-pp, etc…

K^-pp bound state



- It is expected to be the simplest kaonic nuclei.
- $\bar{K}NN$, Total charge:+1, I = ½, $J^P = 0^-$.
- The bound state was expected due to the $\bar{K}$N strong interaction, which is strongly attractive in I = 0.

- It has a rich information such as the $\bar{K}$N strong interaction in sub-threshold region and behavior of Λ(1405) in many body system.
- It makes high density (?)



K-pp
p
K-
p
J-PARC E15: 3He(K-, Λp)n
S. Ajimura et al. / Physics Letters B 789 (2019) 620–625
350 < q_Λp < 650 MeV/c
acceptance corrected
M(Kpp)
data
K-pp
QF
BG
all
dσ/dM [nb/(MeV/c²)]
IM_Λp [GeV/c²]
J-PARC E27: d(π+, K+)Σ0p
Y. Ichikawa et al., PTEP 2015, 021D01(2015).
MM_d [GeV/c²]
DISTO: p(p, K+)Λp
K-+p+p=2.37GeV
B (K-pp) [GeV]
large-angle proton
M = 2.267 (2)
Γ = 0.118 (8)
M(K+p+p) = 2.370
M(Σ+π+p) = 2.267
M(Λ*+p) = 2.345
Deviation UNC/SIM (arb. scale)
Missing Mass MM(K) [GeV/c²]
T.Yamazaki et al., PRL 104, 132502 (2010)
FINUDA: stopped K-
-B_Kpp [MeV]
counts/(10MeV/c²)
arbitrary unit
p-Λ invariant mass [GeV/c²]
M.Agnello et al., PRL 94, 212303 (2005)
△= Phenomenological
○= Chiral
■= Exp.
Γ [MeV]
Binding Energy [MeV]

Structure of $K^{-}pp$

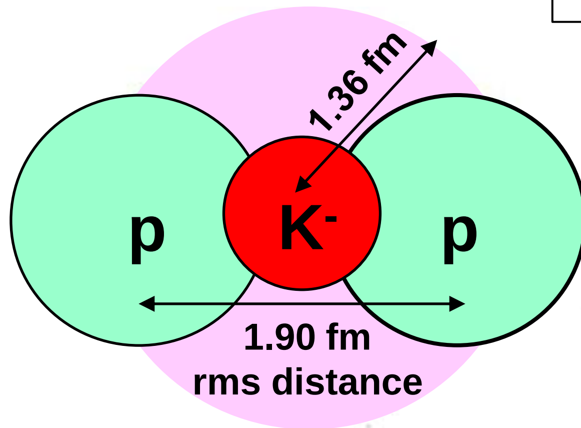
(Theoretical study)

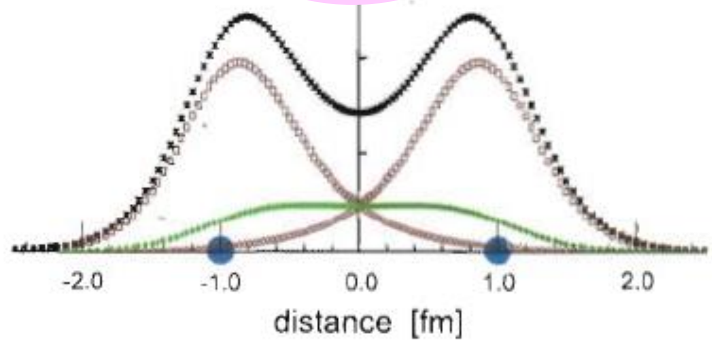
赤石さんの
スライドより

2002

Phys. Lett. B **535** (2002) 70

K^{-}–(pp)



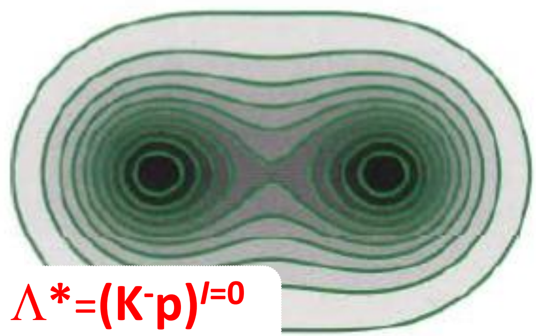


2007

Phys. Rev. C **76** (2007) 045201

(K^{-}p)–p

Λ*-p structure



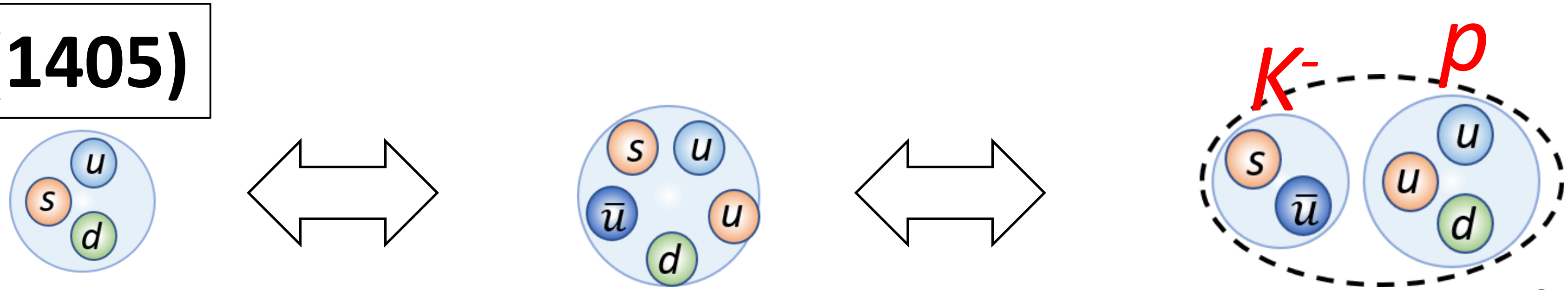
$\Lambda^* = (K^{-}p)^{I=0}$

unit

with a few % covalent part

Hierarchical structure

Λ(1405)

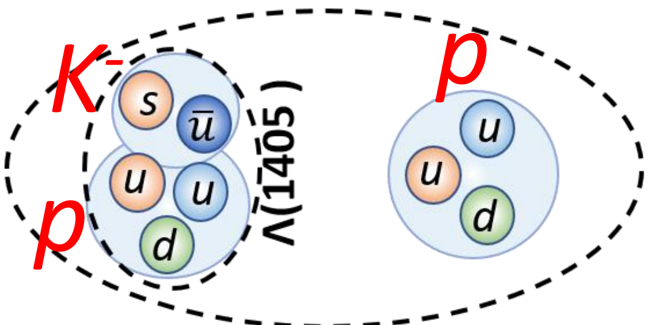


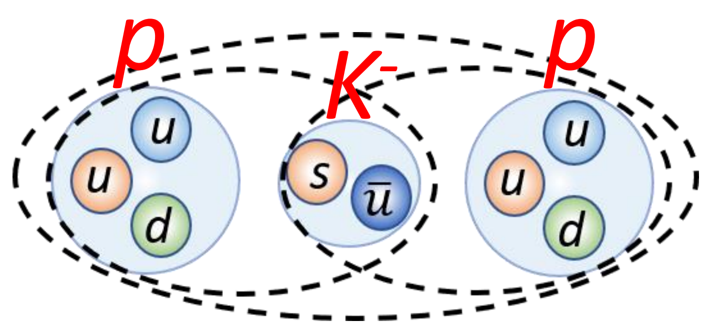
3 quarks
Λ(1405) = Λ*

5 quarks

Meson – Baryon molecule
Λ(1405) = $\bar{K}N$ + (πΣ +…)

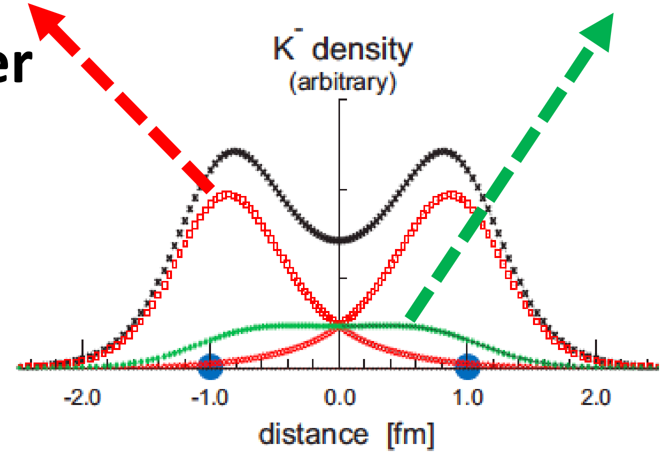
K⁻pp





Λ(1405)-Cluster

Field picture



$\bar{K}$ nuclei in many body system

PTEP

Prog. Theor. Exp. Phys. **2013**, 00000 (37 pages)
DOI: 10.1093/ptep/0000000000

An event excess observed in the deeply bound region of ^{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[13], 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[4], Toshiyuki Takahashi[4], Hirokazu Tamura[13,1], Kiyoshi Tanida[1], Zviadi Tsamalaidze[8], Mifuyu Ukai[4], and Takeshi O. Yamamoto[1]

[1] *ASRC, Japan Atomic Energy Agency, Ibaraki 319-1195, Japan*
[2] *Department of Physics, Kyoto Sangyo University, Kyoto 603-8555, Japan*
[3] *Department of Physics, Korea University, Seoul 02841, Republic of Korea*
[4] *High Energy Accelerator Research Organization (KEK), Tsukuba, 305-[illegible]01, Japan*
[5] *INFN, Istituto Nazionale di Fisica Nucleare, Sez. di Torino, I-10125 T[illegible]rino, Italy*
[6] *D[illegible]partimento [illegible] F[illegible]ica, U[illegible] d[illegible] To[illegible]no, [illegible]-10[illegible]25 [illegible]orino, [illegible]aly*
[7] *[illegible]KEN [illegible] fo[illegible] Pione[illegible]ing [illegible] Wa[illegible] 3[illegible]1-01[illegible]8, [illegible]an*
[8] *[illegible]int In[illegible] fo[illegible] Nucle[illegible] Re[illegible]arch[illegible] D[illegible] Mo[illegible]cow [illegible]egi[illegible] 141980 [illegible]a*
[9] *Department of Physics, Kyoto University, Kyoto 606-850[illegible], Japan*
[10] *Allied Health Sciences, Kitasato University, Sagamihara 252-0373, Japan*
[11] *Department of Physics, Osaka University, Osaka 560-0043, Japan*
[12] *Department of Physics, Nara Women's University, Nara 630-8506, Japan*
[13] *Department of Physics, Tohoku University, Sendai 980-8578, Japan*
[14] *Physics Department, Gifu University, 1-1 Yanagido, Gifu 501-1193, Japan*
[15] *Department of Physics and Astronomy, Seoul National University, Seoul 08826, Republic of Korea*
[16] *Research Center for Nuclear Physics (RCNP), Osaka University, Osaka 567-0047, Japan*
[*] *E-mail: yudai@post.j-parc.jp*

We have measured, for the first time, the inclusive missing-mass spectrum of the ^{12}C(K^-, p) reaction at the 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 parameters for the $\bar{K}$-nucleus optical potential. We found

https://doi.org/10.1093/ptep/ptaa139

should mainly contribute. The enhancement is well fitted by a Breit-Wigner function with a kaon-binding energy of 90 MeV and width of 100 MeV. A possible interpretation is a deeply bound state of a Y^*-nucleus system.

$\bar{K}$-A interaction

An important tool is kaonic atoms.

- Simple tρ approach

$$[\Delta - 2\mu(B + V_{opt} + V_c) + (V_c + B)^2]\Psi = 0,$$
$$2\mu V_{opt}(r) = -4\pi\left(1 + \frac{\mu}{m}\frac{A-1}{A}\right)b_0\rho(r)$$
$$b_0 \;\rightarrow\; b_0 \;+\; B_0[\rho(r)/\rho_0]$$

Re(V_0) ~ −80 MeV

- Chiral motivated model

Re(V_0) ≦ −60 MeV

- DD(Density dependent) potential

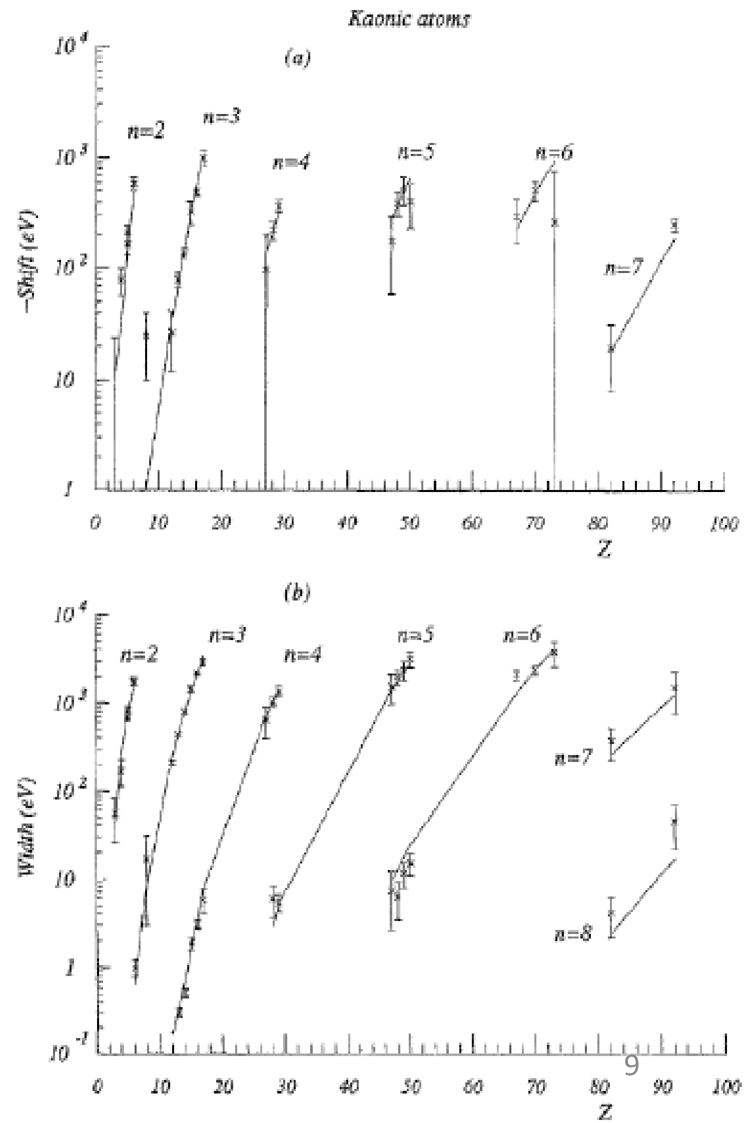
Re(V_0) = −(150-200) MeV

- Fourier-Bessel method

Re(V_0) ~ −(170) MeV

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

Re(V_0) ~ −(170) MeV



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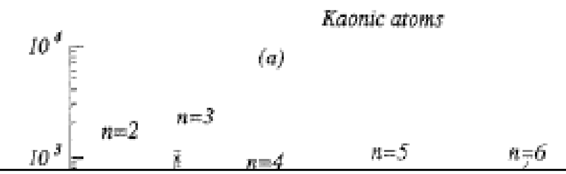


The depth of $\bar{K}$-nucleus potential strongly depends on the model setting. It is not conclusive whether $\bar{K}$ -nucleus potential is "deep" or "shallow"!! Both type of potential can reproduce the kaonic atoms data.

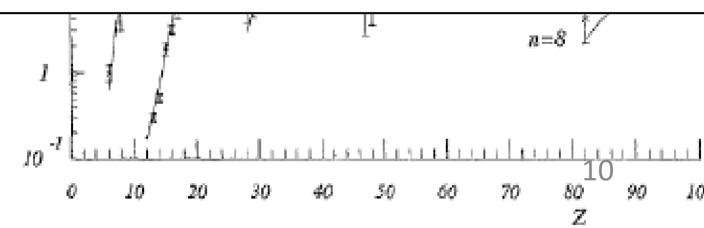
↓

To solve this problem,

a new experimental constraint is necessary!

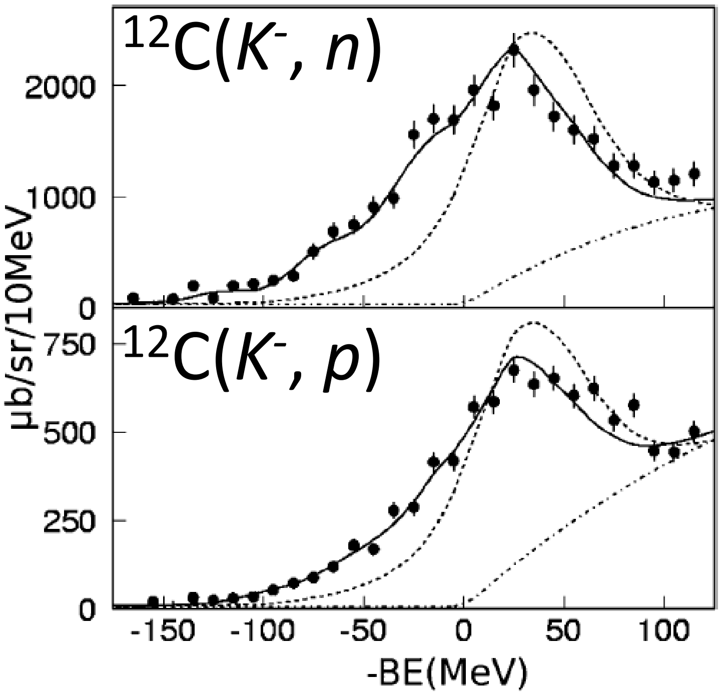
- IHW $K^{bar}N$ interaction+phenomenological multi-nucleon absorption

Re(V_0) ~ −(170) MeV



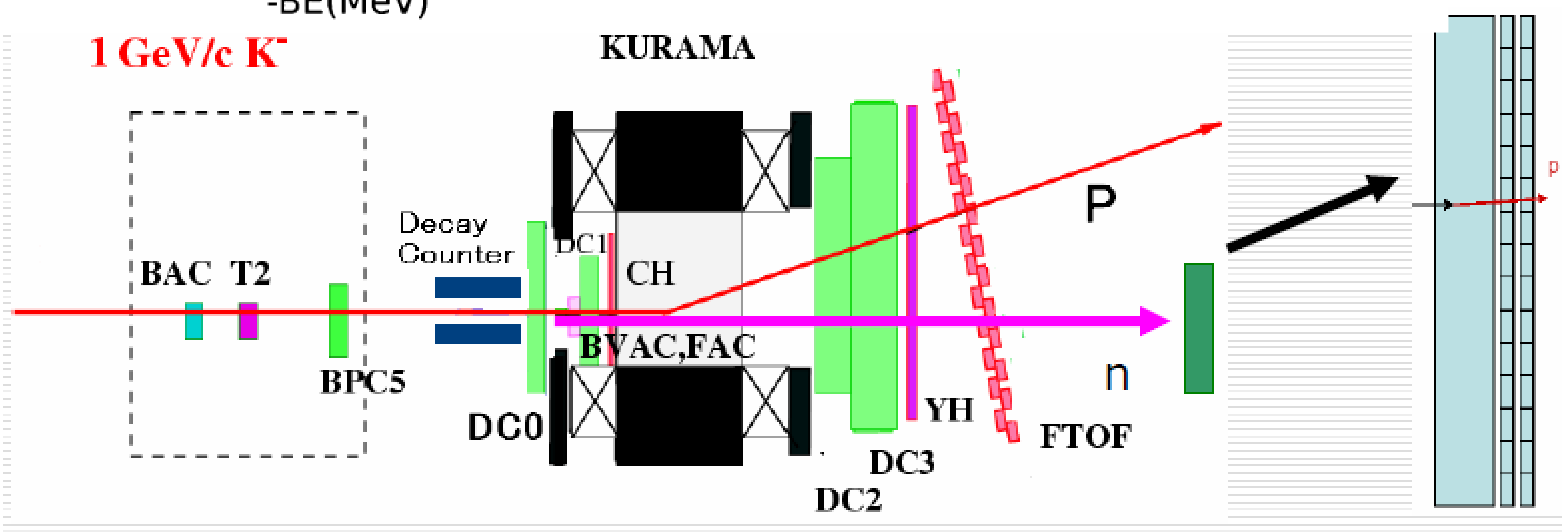
Past experiment: KEK E548 [^{12}C(K^-, N)]

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} = (V_0: **-190**, W_0: -40) MeV
  - C(K^-, p): V_{opt} = (V_0: **-160**, W_0: -50) MeV

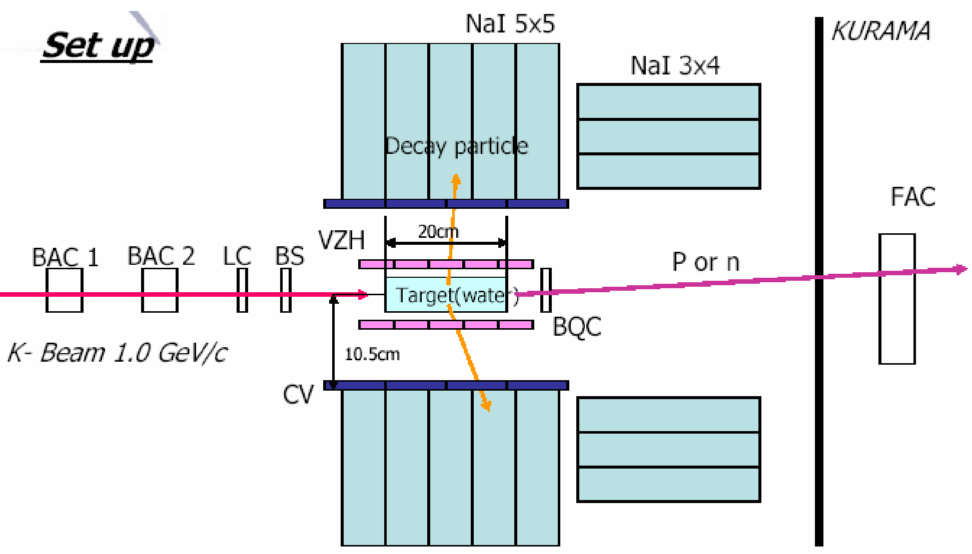
(dotted line: Vopt = (V_0:-60, W_0:-60) MeV)



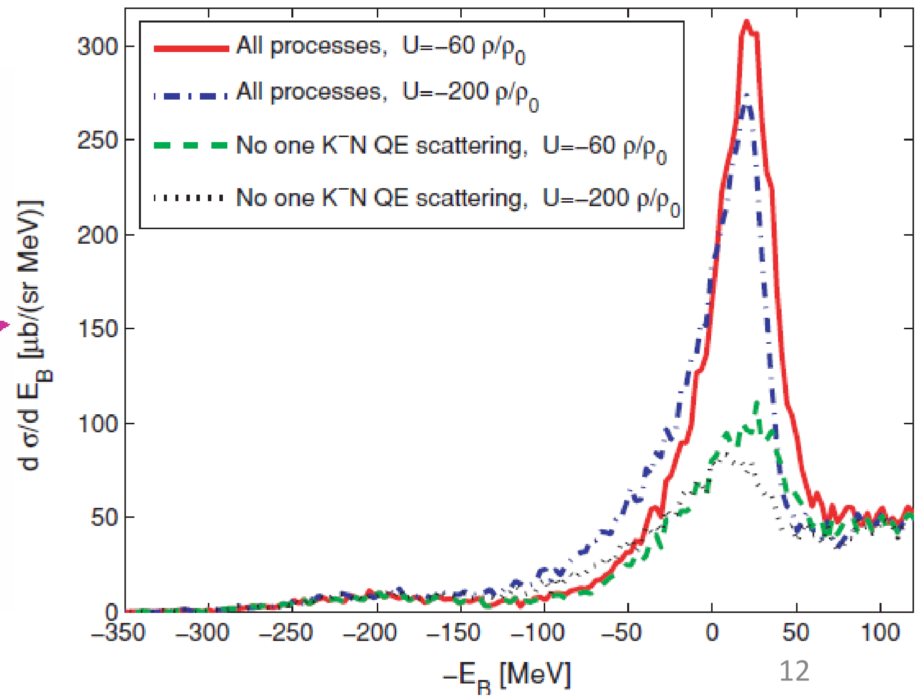
Discussion for KEK E548

- 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).

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



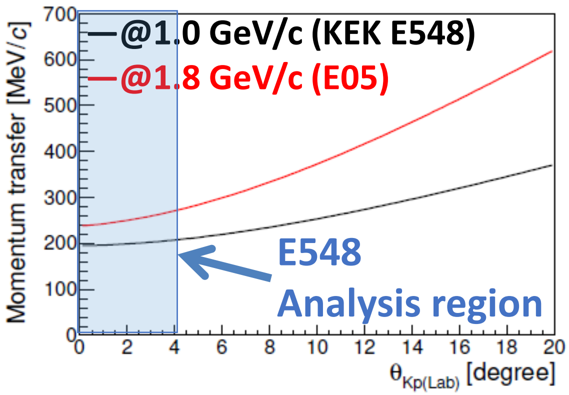
V. K. Magas et al., PRC 81, 024609 (2010).

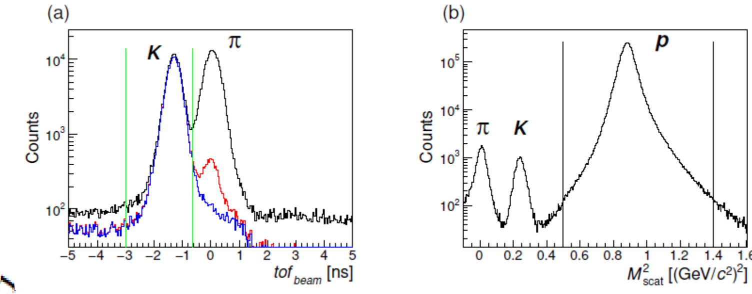


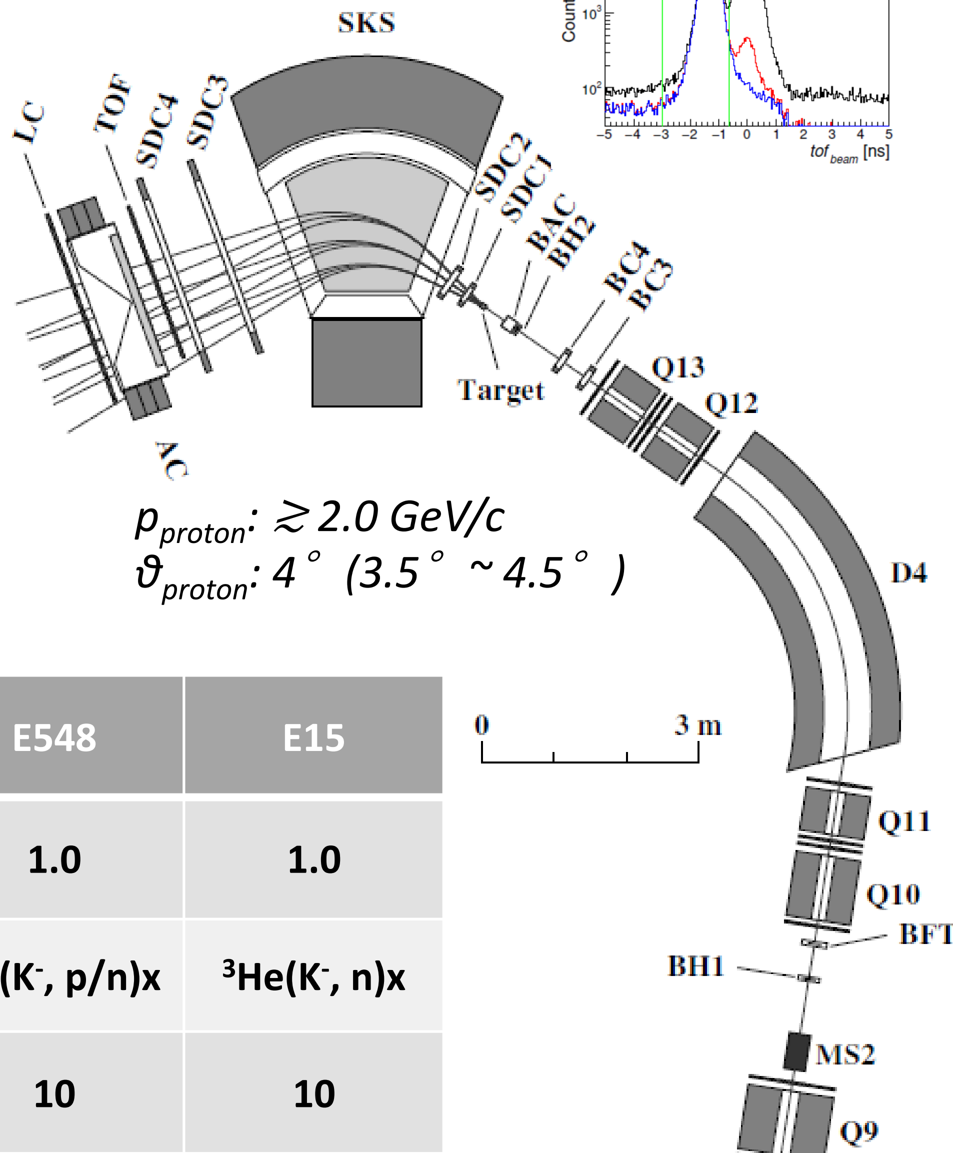
J-PARC E05 [^{12}C(K$^-$, p) @1.8 GeV/c]

Inclusive measurement

Momentum transfer for K^-p elastic scattering





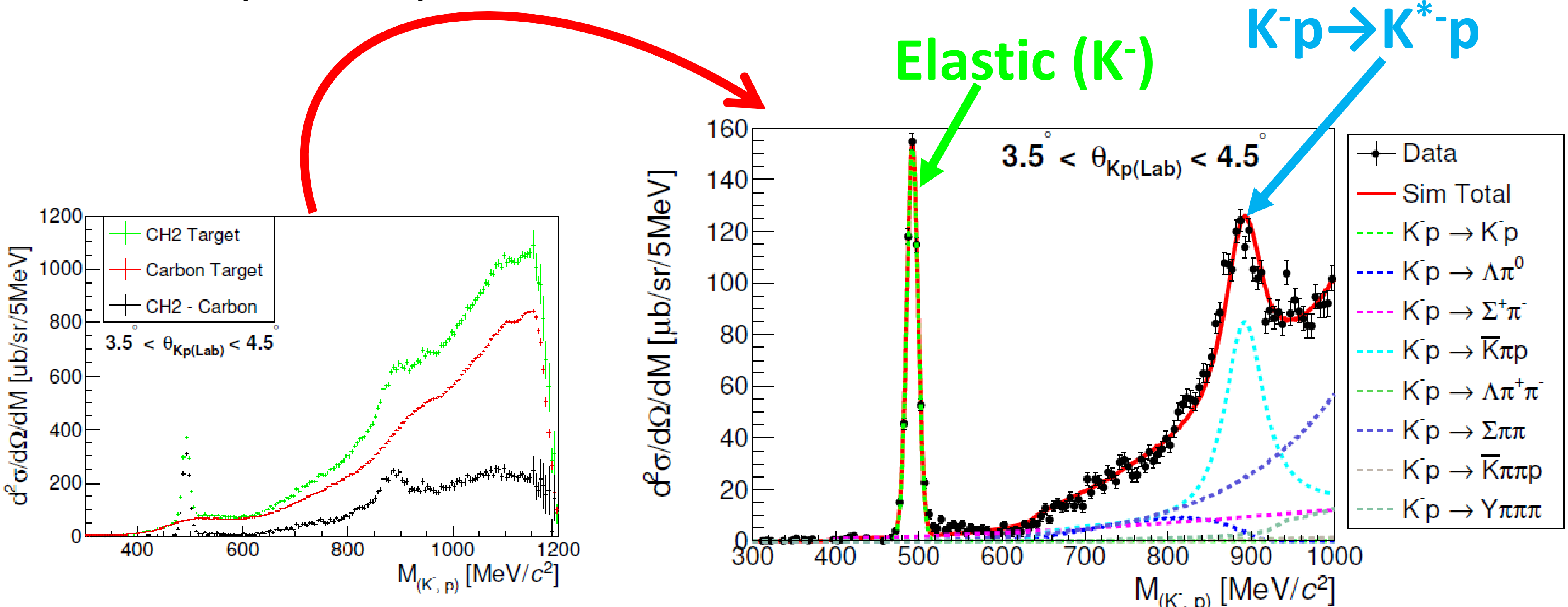


p_{proton}: $\gtrsim$ 2.0 GeV/c
ϑ_{proton}: 4° (3.5° ~ 4.5°)

(K$^-$, N) data	E05	E548	E15
p_{K^-} [GeV/c]	1.8	1.0	1.0
Reaction	^{12}C(K$^-$, p)	^{12}C(K$^-$, p/n)x	^{3}He(K$^-$, n)x
σ_M [MeV]	4.2	10	10

Calibration: $p(K^-, p)$ @1.8 GeV/c

- We obtained the reasonable solution by the template fit.
  - Each yield was free parameter
  - Resonance productions via $K^*(K^-p \rightarrow K^{*-}p)$, Δ, Y^* are included.
- We fixed the "p"-target component in ^{12}C for the $^{12}C(K^-, p)$ analysis.



^{12}C(K$^-$, p) spectrum $(V_0, W_0) = (0, 0)$

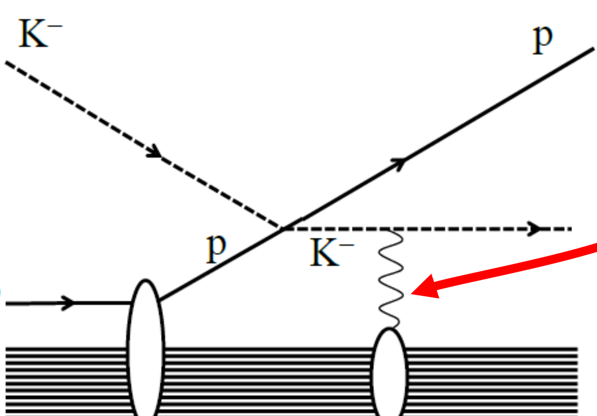
- Interesting component
  - --- K$^-$"p" (QF-Elastic): Calculated by DWIA($(V_0, W_0) = (0, 0)$)
- Background
  - --- K$^-$"p" (QF-InElastic): Monte-Carlo simulation based on *p*(K$^-$, *p*) analysis
  - K$^-$"n"→ X (QF) : Monte-Carlo simulation, Yield: free parameters

$$\left(\frac{d^2\sigma}{d\Omega dE}\right)_A^{\rm lab} = \left(\frac{d\sigma}{d\Omega}\right)_{\rm ele}^{\rm lab} \times S(E) \ .$$

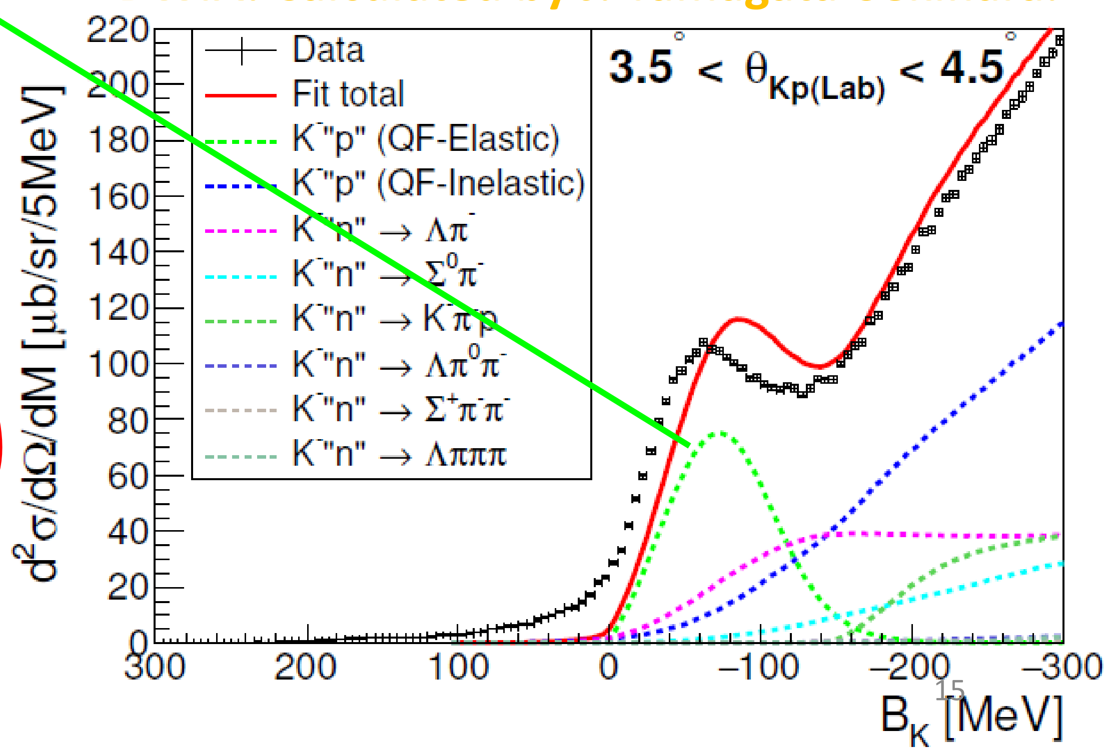
$$S(E) = -\frac{1}{\pi}{\rm Im}\sum_f K \int dr dr' \tau_f^\dagger(r) G(E;r,r')\tau_f(r'),$$

$$G(E,r,r') = \left\langle p^{-1}\left|\phi_K(r)\frac{1}{E-H_K+i\epsilon}\phi^\dagger(r)\right|p^{-1}\right\rangle \ ,$$

$$U(r,E) = (V_0 + iW_0 f_{\rm phase}(E))\frac{\rho(r)}{\rho(0)} \ ,$$

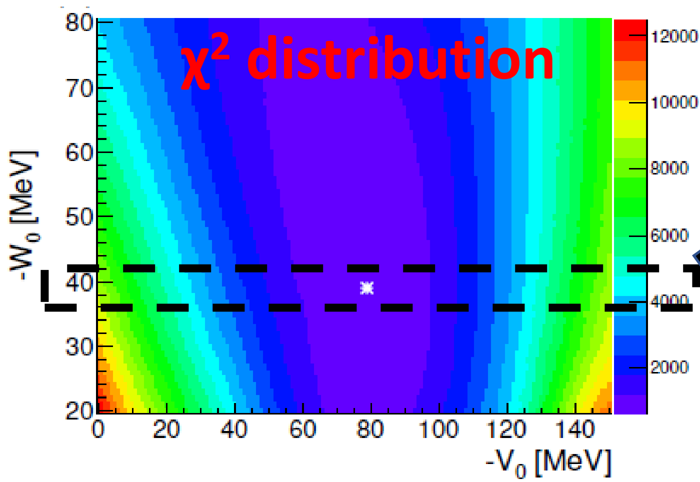


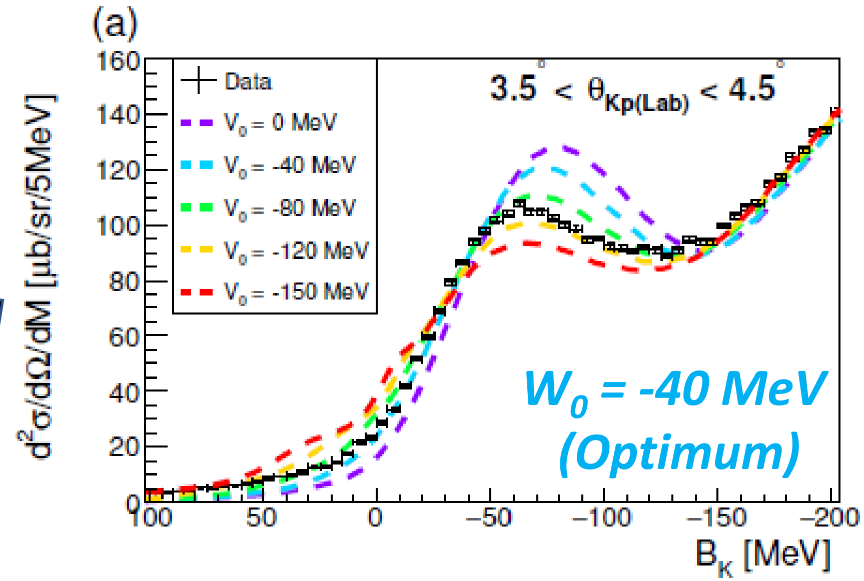
DWIA: Calculated by J. Yamagata-Sekihara.



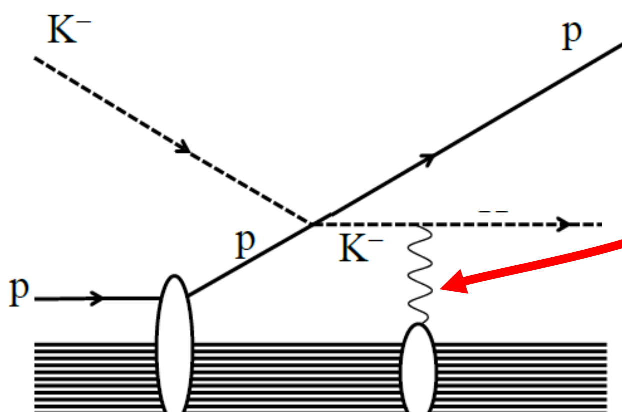
Comparison by change (V_0, W_0)

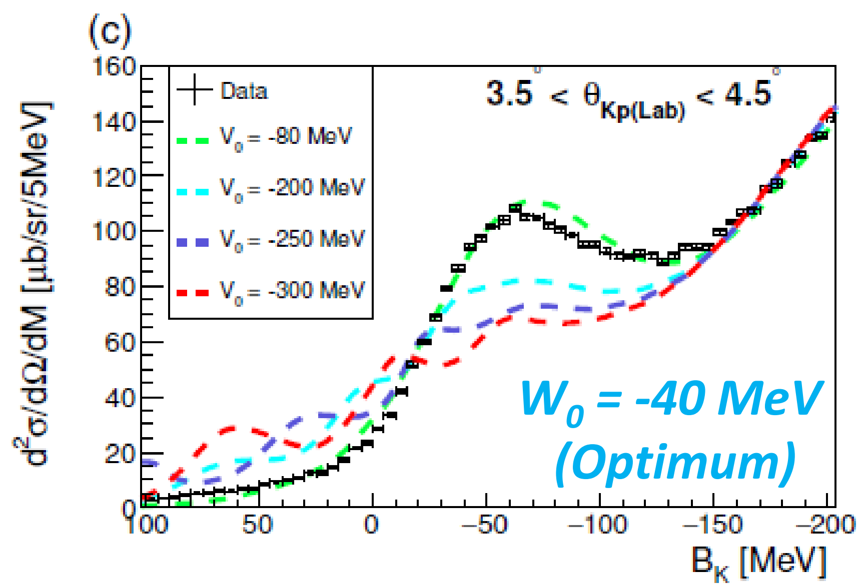
Optimum: (V_0, W_0) = (-80, -40) MeV!
Corresponding to shallow potential



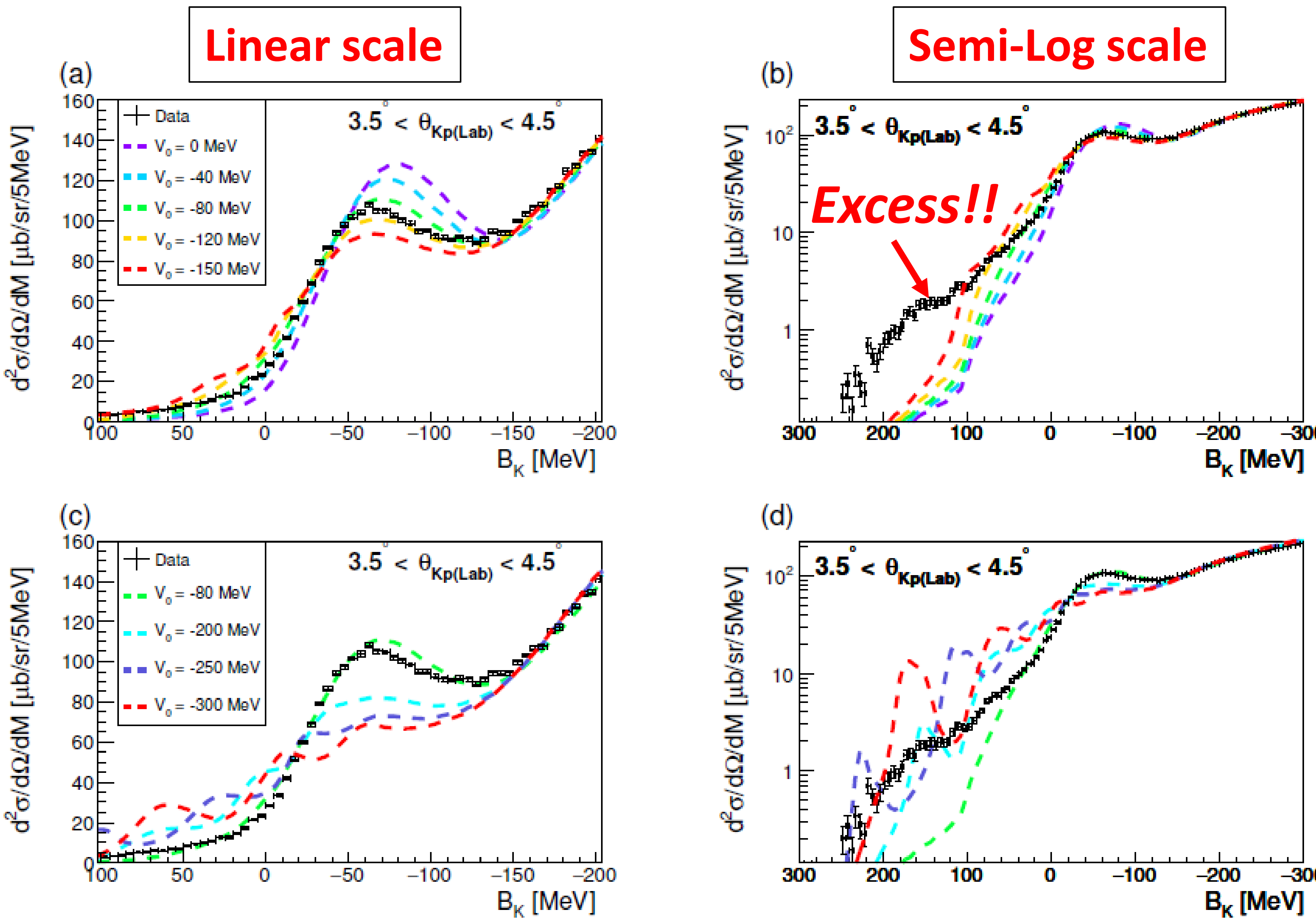


$$U(r,E) = (V_0 + iW_0 f_{\text{phase}}(E))\frac{\rho(r)}{\rho(0)} ,$$

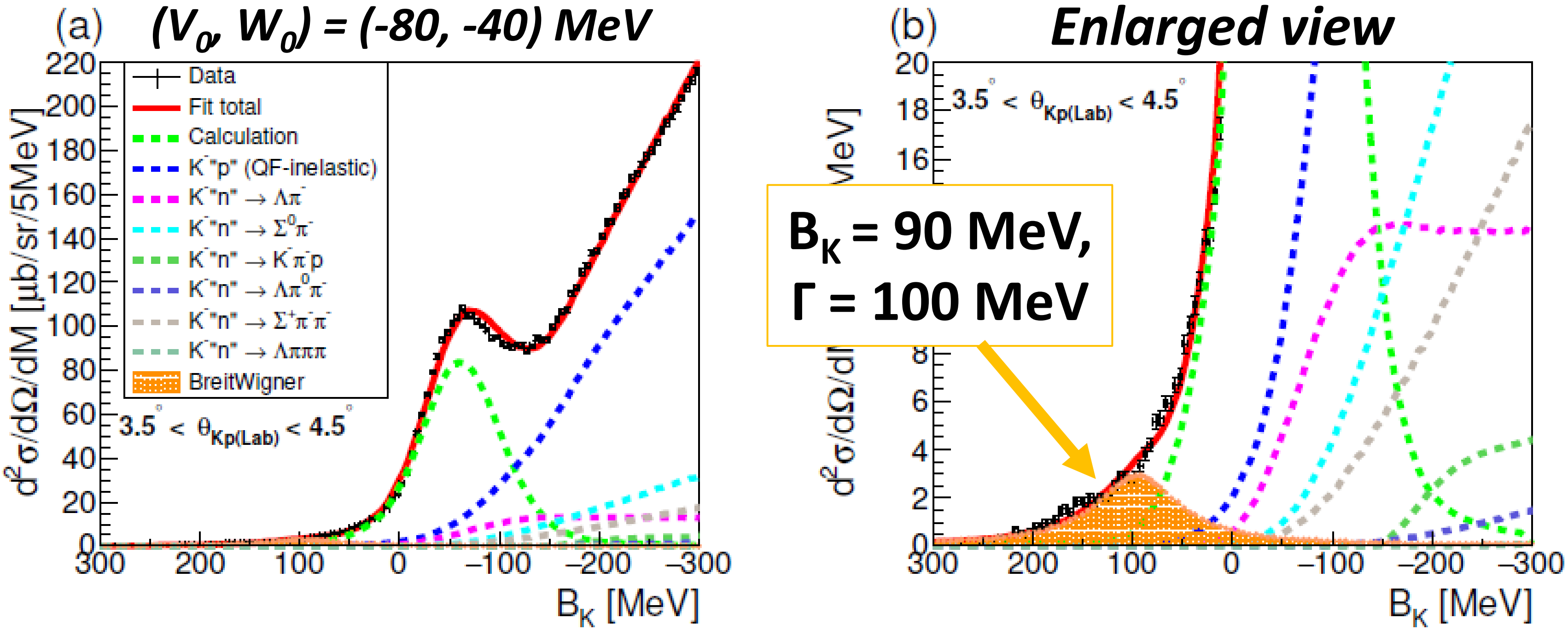


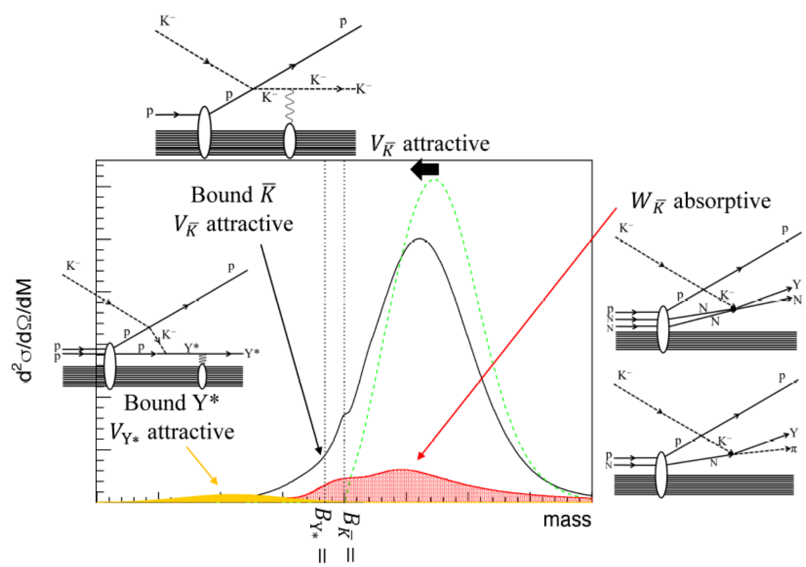


Event Excess



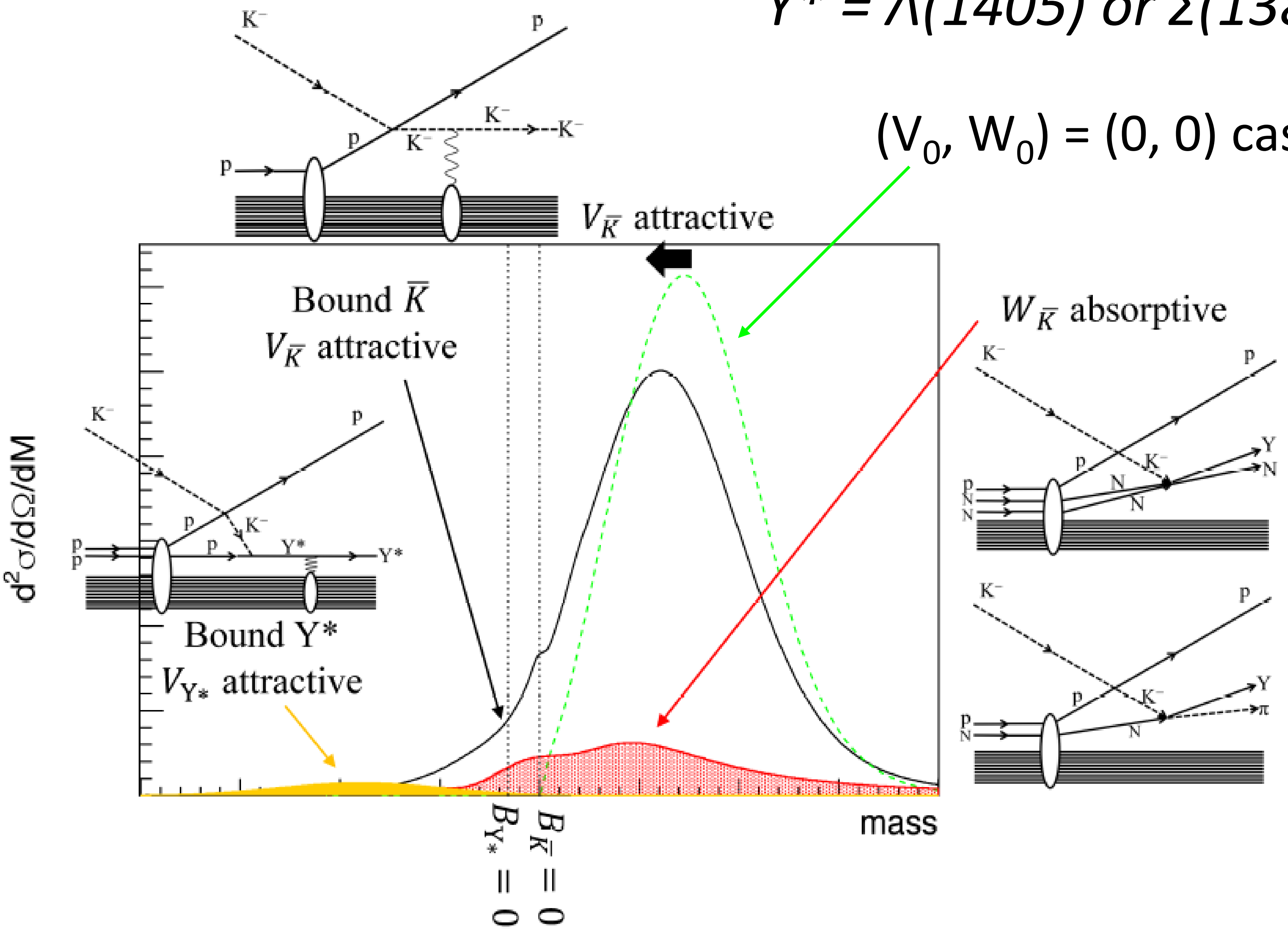
Event Excess: Fitted by BW (Y*-nucleus?)





Event Excess: Fitted by BW (Y*-nucleus?)

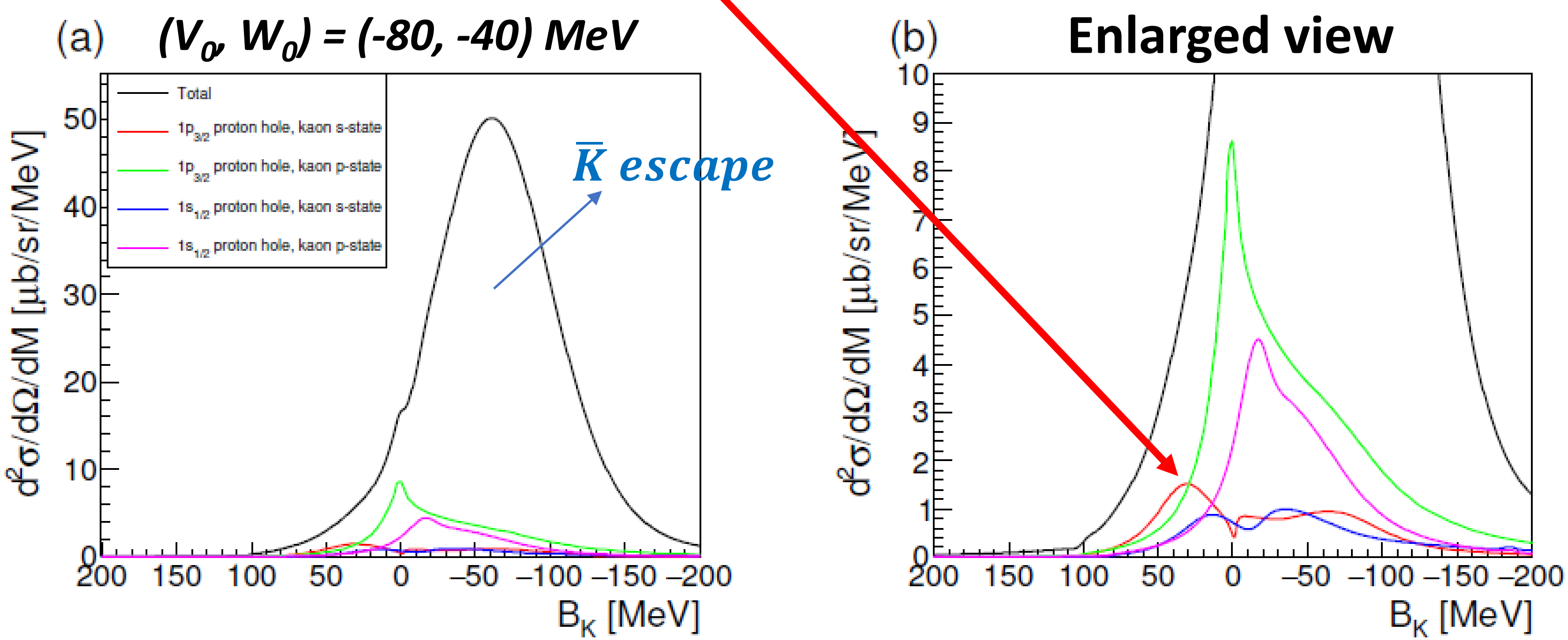
Y = Λ(1405) or Σ(1385)*



Kaonic nuclear state (Decomposed theoretical spectrum)

proton-hole: $1p_{3/2}$, $\bar{K}$: s-state

Kaonic nuclear state: B_K = 31 MeV, Γ = 53 MeV



Discussion: Relationship with kaonic-atom X-rays

$V_K^{(1)}$: 1N absorption term derived by IHW NLO chiral K⁻N scattering amplitude

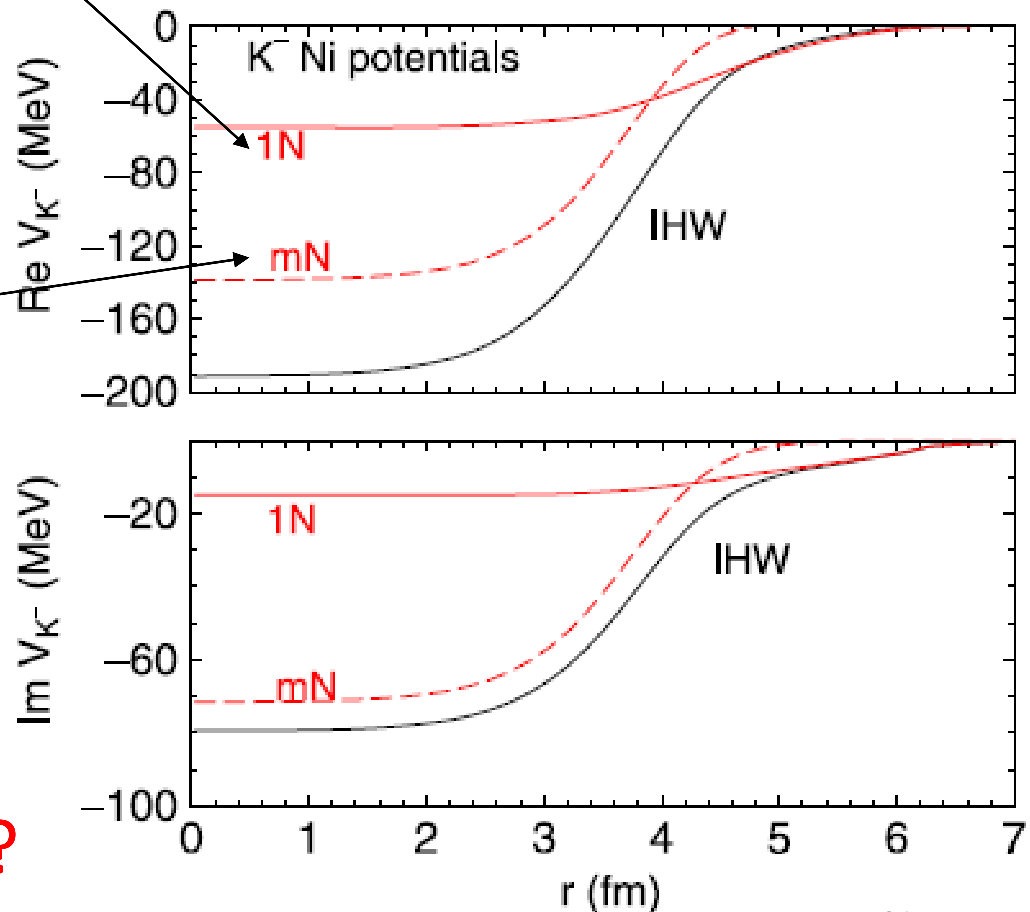
$V_K^{(2)}$: mN absorption term Phenomenological potential (fitted by X-ray data)

For the deep $V_K^{(2)}$ potential, Y* doorway process as K^-"p"→Y*, Y*"N"→ YN should play an important role!!

$V_K^{(2)}$ corresponding to V_{Y*}?

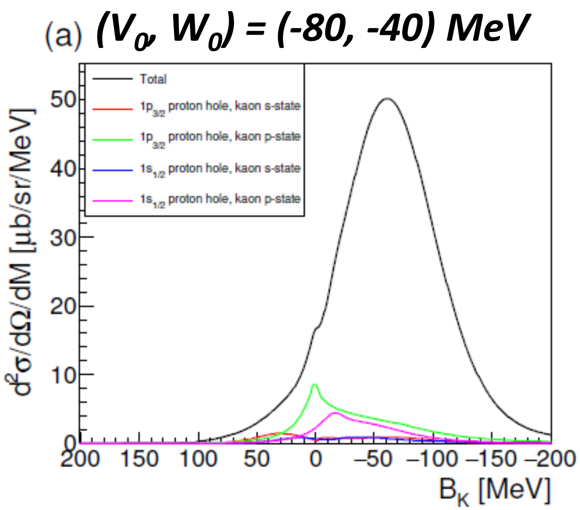
E. Friedman, A. Gal / Nuclear Physics A 899 (2013) 60–75

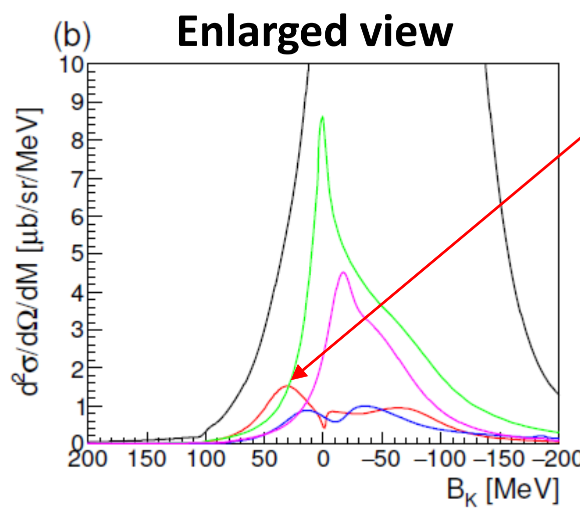
$$V_{K^-} = V_{K^-}^{(1)} + V_{K^-}^{(2)}:$$



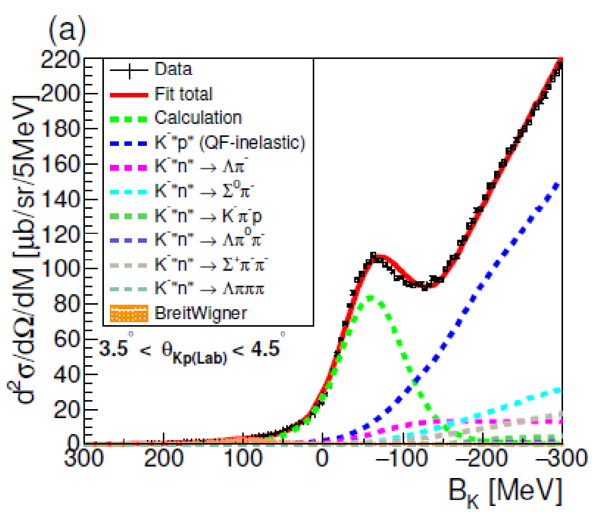
Outlook

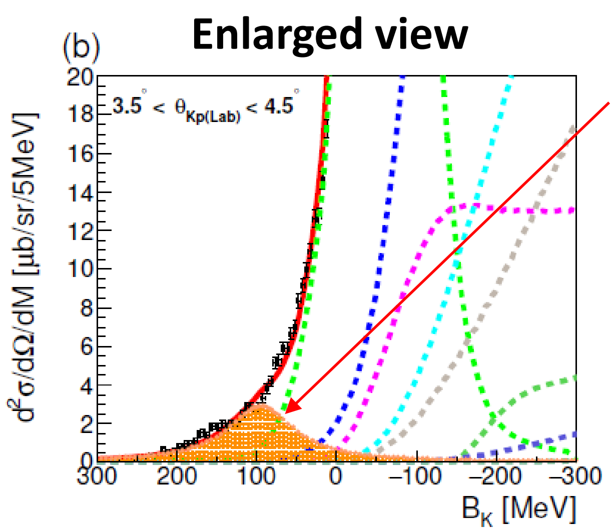
Exclusive measurement (Motivation)





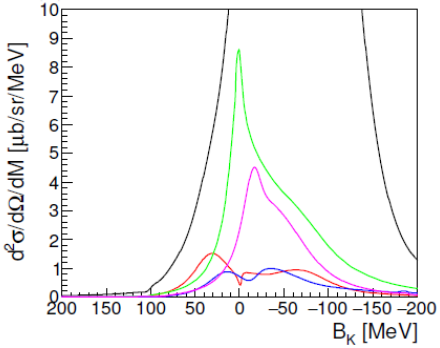
Motivation:
To observe the 1s state as a distinct peak!
Method:
$^{12}C(K^-, p)\Sigma\pi p$ measurement(?)





Motivation:
To observe the excess as a distinct peak!
Method:
$^{12}C(K^-, p)\Lambda p$ measurement(?)

Conversion spectrum

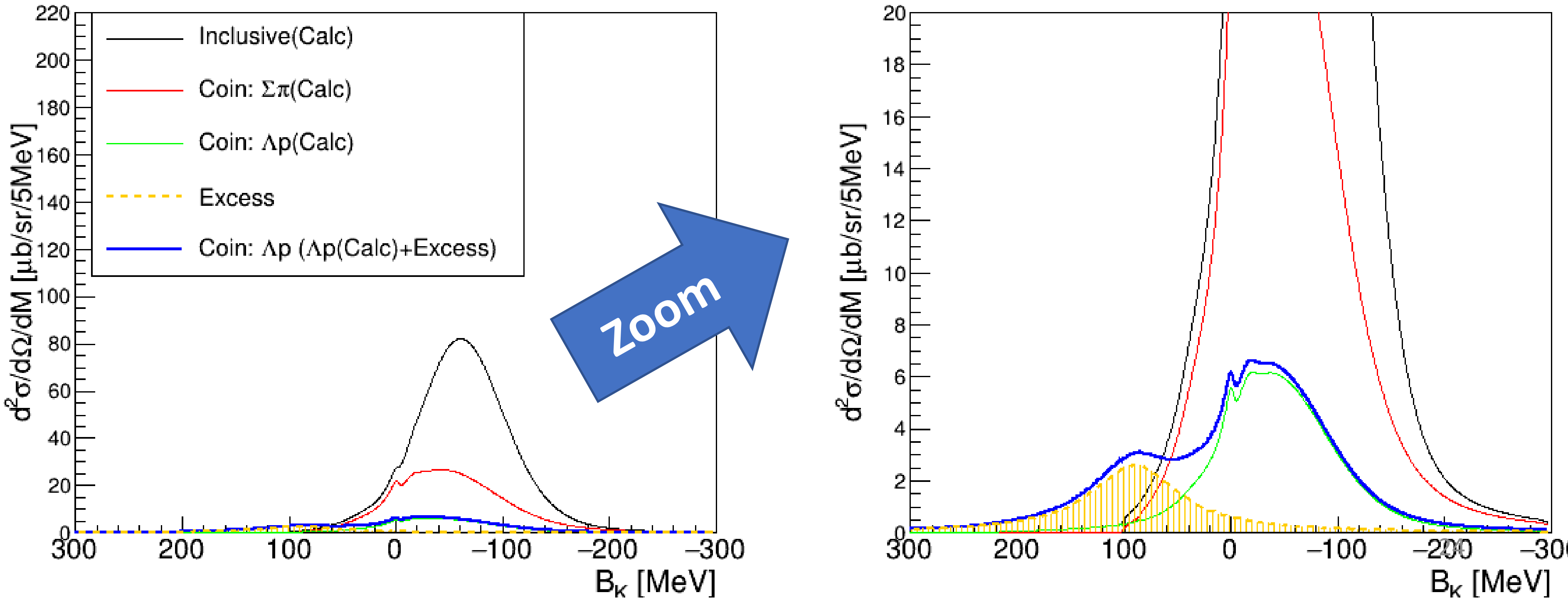


Difficult to see the 1s peak by One body abs. ($^{12}C(K^-, p)\Sigma\pi$).
The one of the possible channel is $^{12}C(K^-, p)\Sigma\pi p$.

$^{12}C(K^-, p)\Lambda p$ probability is low.
→ Possibility to see the Y*-nucleus state.

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

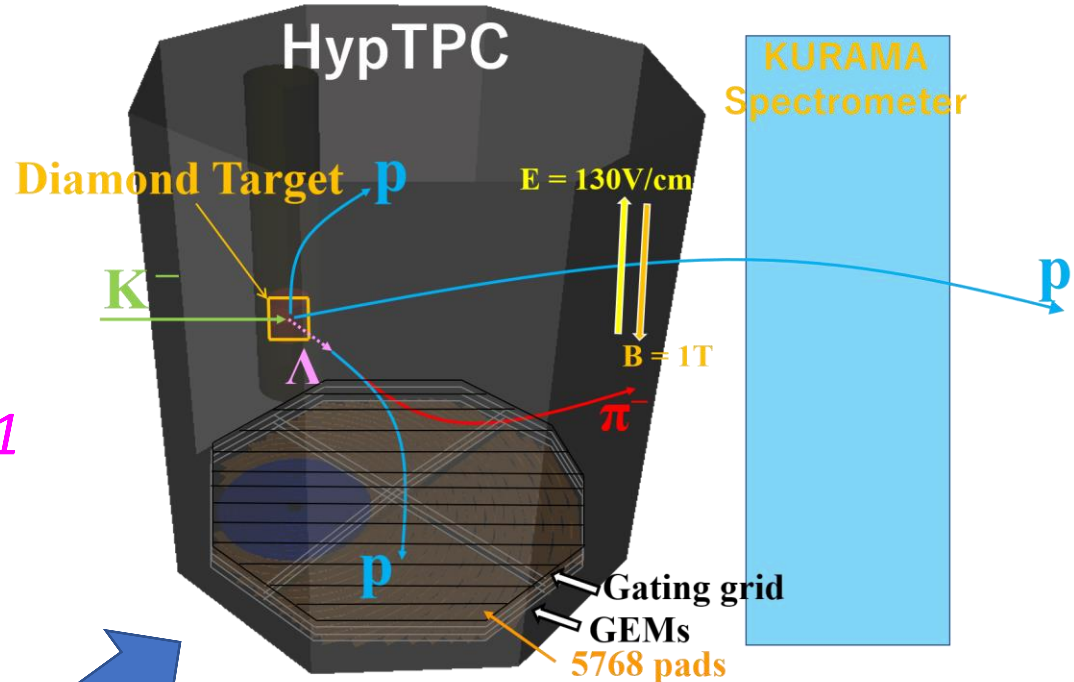
Calculated by J. Yamagata-Sekihara.

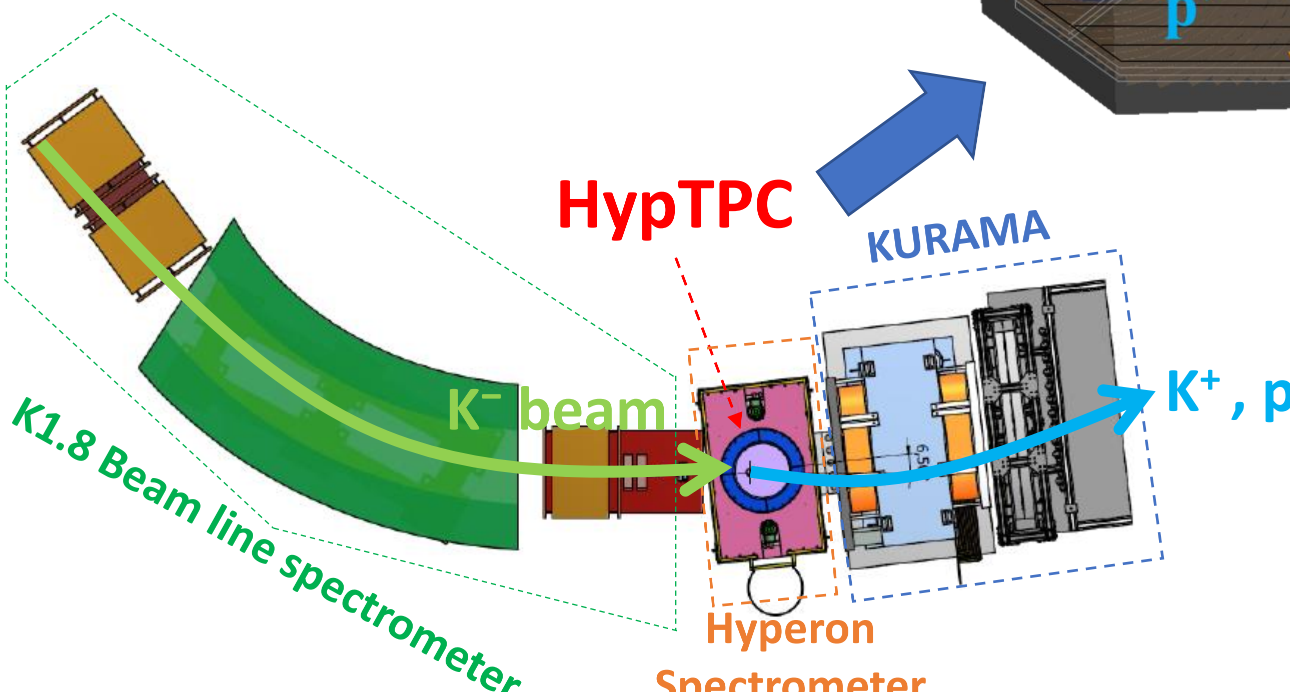


Beyond E05 = E42 (H-dibaryon search)

Outgoing proton: KURAMA
Decay particle: HypTPC
 Λp: measured by p, π^-, p
 Σπp: identified by $\pi^{\pm}\pi^{\pm}$p

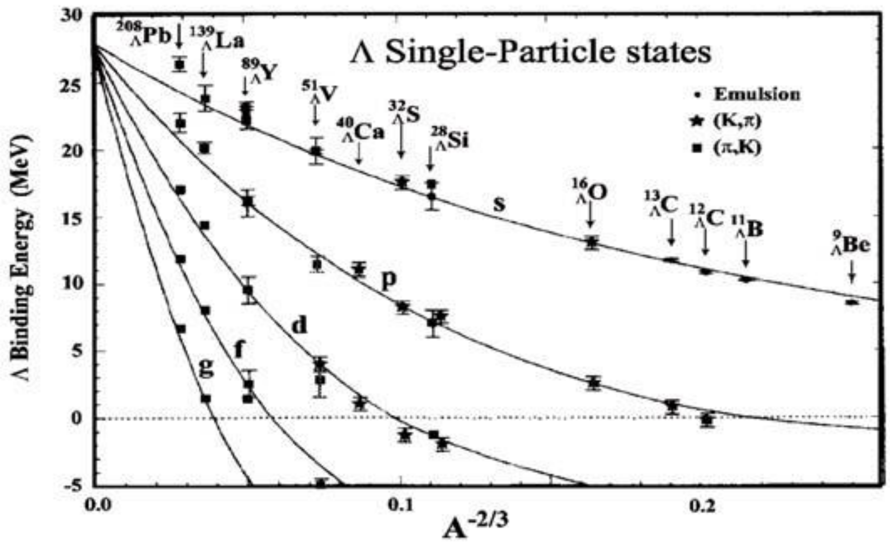
E42 experiment: Spring of 2021





Further (K^-, p) study: A-dependence

In case of Λ hypernucleus,
we can see the clear single-particle states.
(Described by single-particle potential)



Measurement of the (K^-, p) A-dependence

How about the Kaonic (Y*) nucleus?
Can we see the shell structures?

→ Key points

- Hierarchical structures
- $\bar{K}N$ sigma term

Summary

- We have measured the inclusive $^{12}C(K^-, p)$ spectrum at J-PARC (J-PARC E05 byproduct).
- (V_0, W_0) = (-80, -40) MeV, corresponding to shallow potential, well reproduced the measured spectrum.
  - This potential contains the B_K ~ 30 MeV Kaonic bound sate.
- We also have found the significant event excess, which can be interpret as a Y*-nucleus state, around B_K ~ 100 MeV.
- Outlook
  - Coincidence measurement: E42
    - Decay charged particles will be measured by using the HypTPC.
    - $^{12}C(K^-, p)\Lambda p$ reaction is promising to confirm the event excess.
  - Systematic study (A-dependence) will tell us the exotic property of the K-nucleus.