RIKEN

2008 / 06 / 06~10

Experimental Study of the Kaonic Bond State

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Advanced Meson Science Lab.

MESON 2008 @ CRACOW

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仁科加速器研究センター

Purpose in perspective manner

similar to other meson studies...

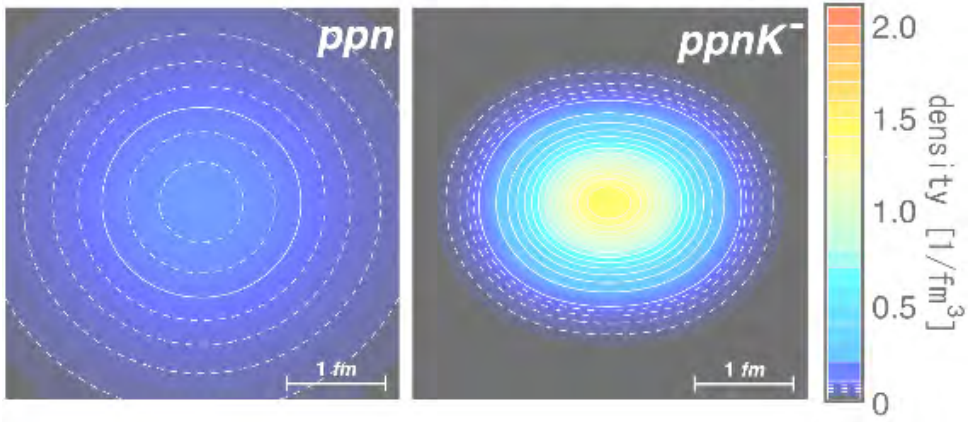
- to detect quark degree of freedom

  nature of confinement ...

- chiral symmetry breaking and its restoration

  origin of hadron mass ...

Dote et al., PLB 590 (2004) 51



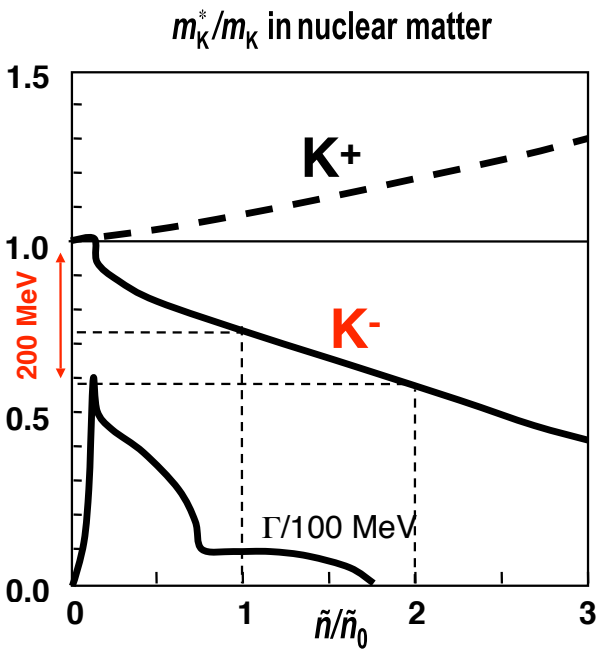
- kaon condensation?

- high density object?

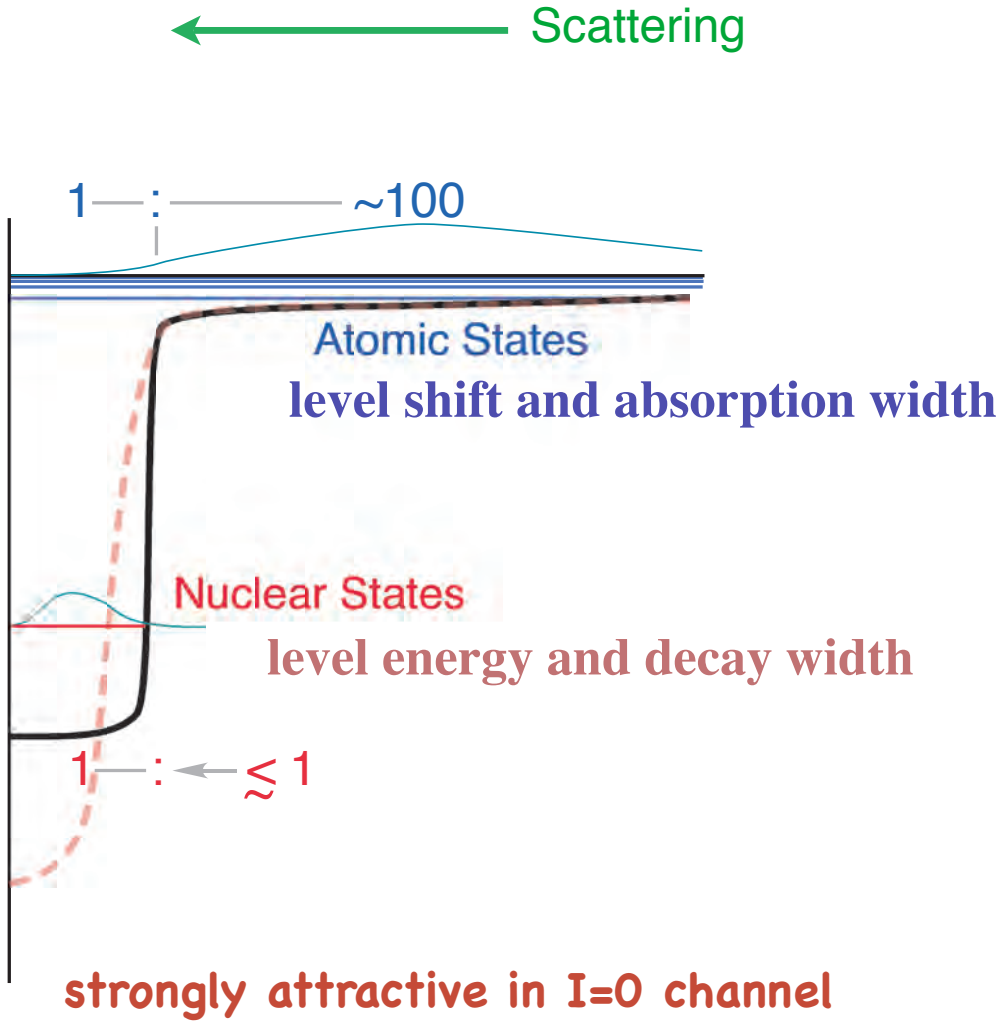
  neutron star ... ?

... long way to go ...

Study of $\bar{K}N$ interaction



T. Waas, N. Kaiser & W. Weise, Phys. Lett. B379 (1996) 34.



$\bar{K}N$ study by atomic states

level shift and absorption width

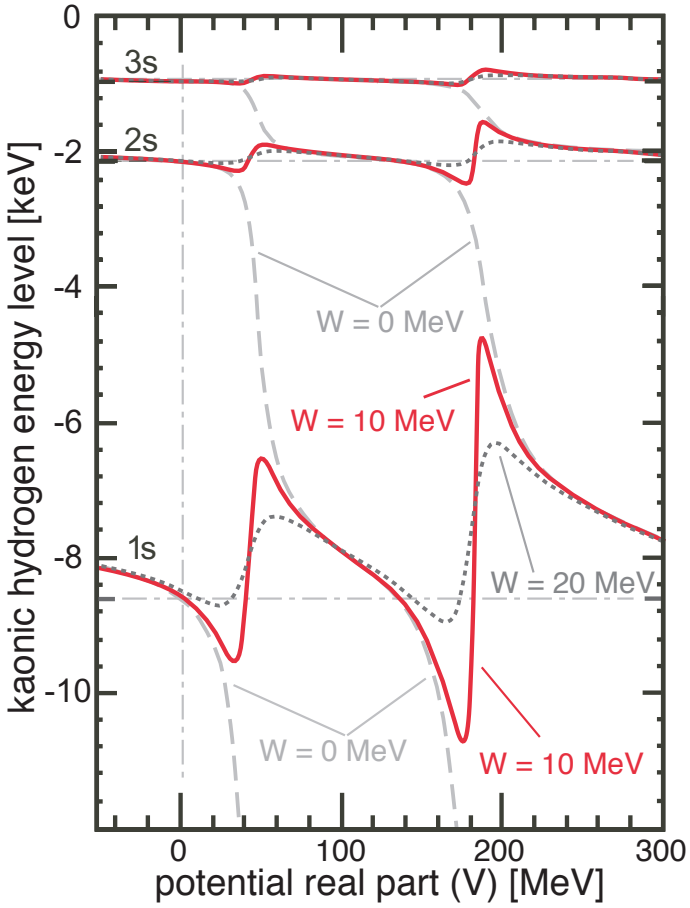
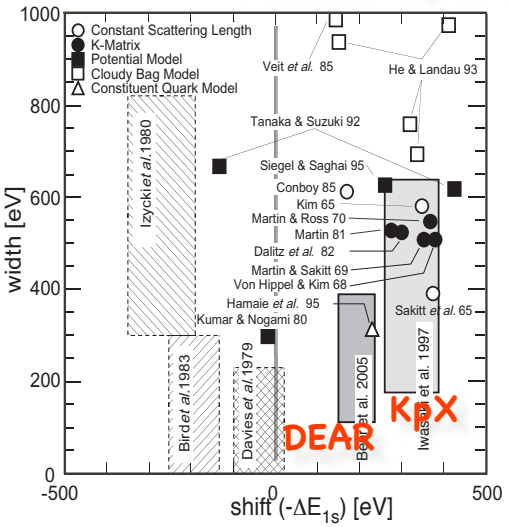
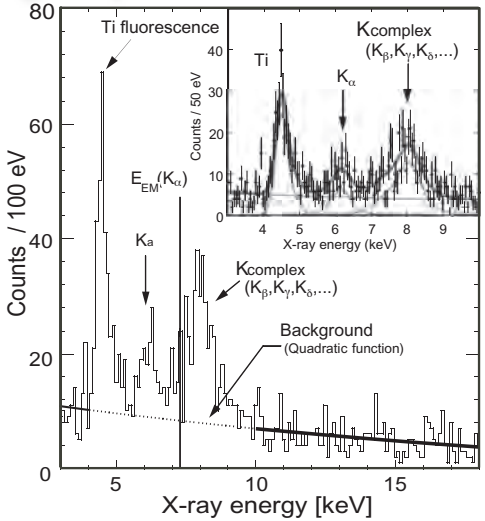


Fig. 3. A diagram of the level shift of the s-wave kaonic-hydrogen atom as a function of real part of the local potential. The level shift is calculated by the simple Schrödinger equation in a Coulomb field together with the Yukawa potential as a local part, $(V + iW)\exp(-r/\lambda)/r$. Three curves of the imaginary part, $W = 0$ (dashed), 10 (solid) and 20(dotted line), are plotted. The range parameter λ is fixed to be 1 fm.

Kaonic hydrogen puzzle





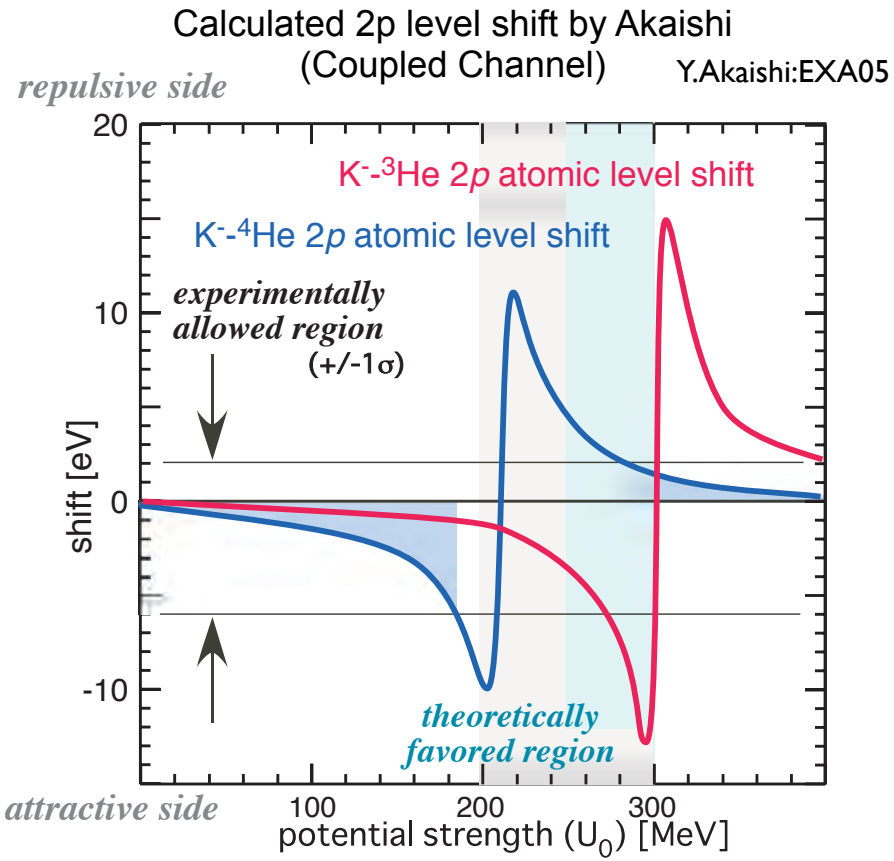
KpX (KEK) & DEAR (DAFNE)

what is the nature of $\Lambda(1405)$?

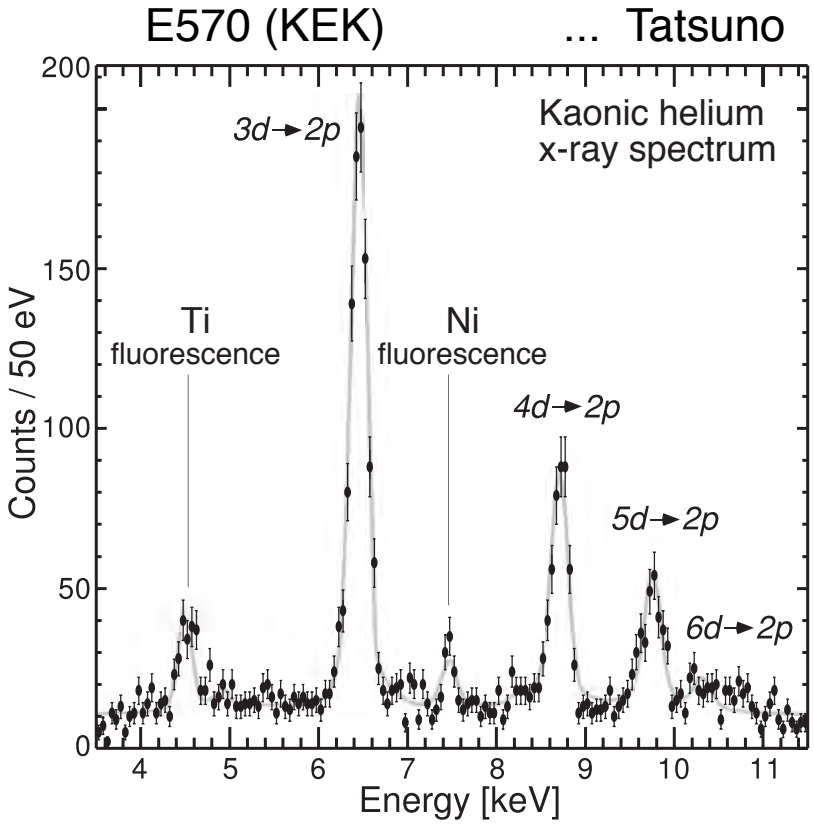
SIDDHARTA (DAFNE) ... Widmann
E17 (J-PARC) ... Hayano

$\bar{K}N$ study by atomic states

level shift and absorption width



first ~ eV precision experiment



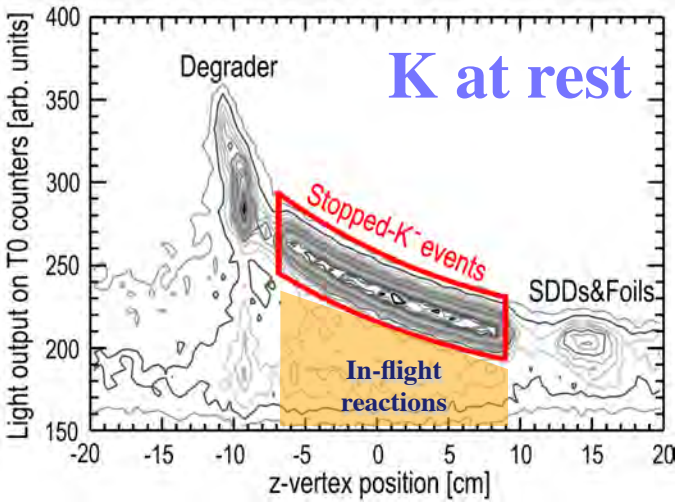
smaller shift is also possible ...

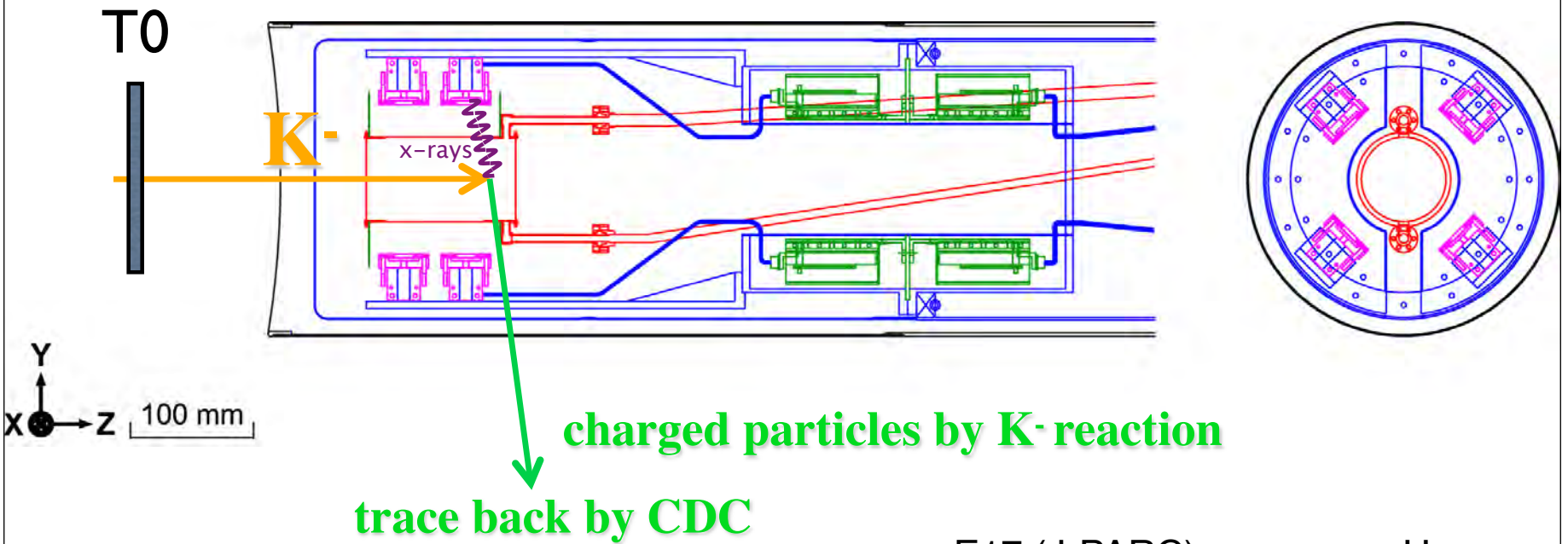
$\bar{K}N$ study by atomic states

level shift and absorption width

E17: K^- ^{3}He $3d$ - $2p$ x-ray

application of well proven experimental method in KEK PS-E570



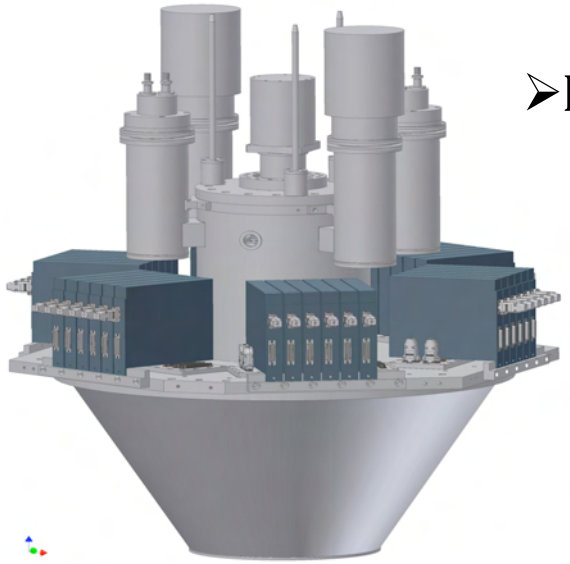


E17 (J-PARC) ... Hayano

$\bar{K}N$ study by atomic states

isospin dependence of KN

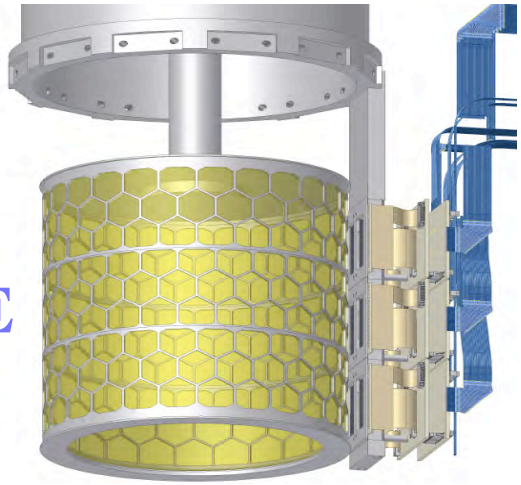
SIDDHARTA (DAFNE) ... Widmann



➢ **kaonic hydrogen run (with improved shielding) is possible with an integrated luminosity of 400 pb^{-1}**

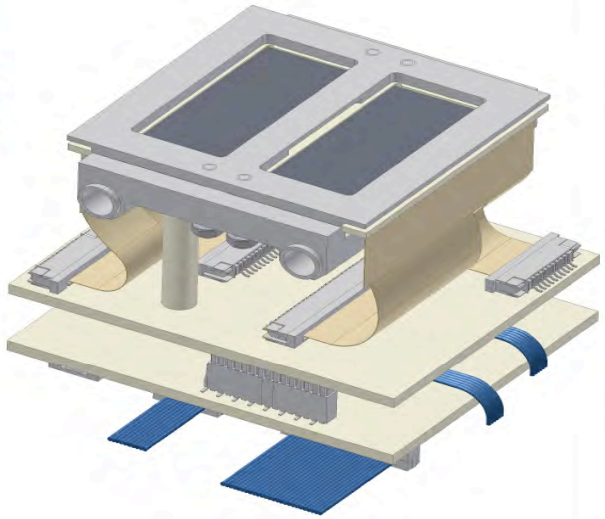
shift ~ ± 10 eV

width ~ ± 35 eV



SIDDHARTA DAFNE

K^- p & K^- d 2*p* - 1*s*



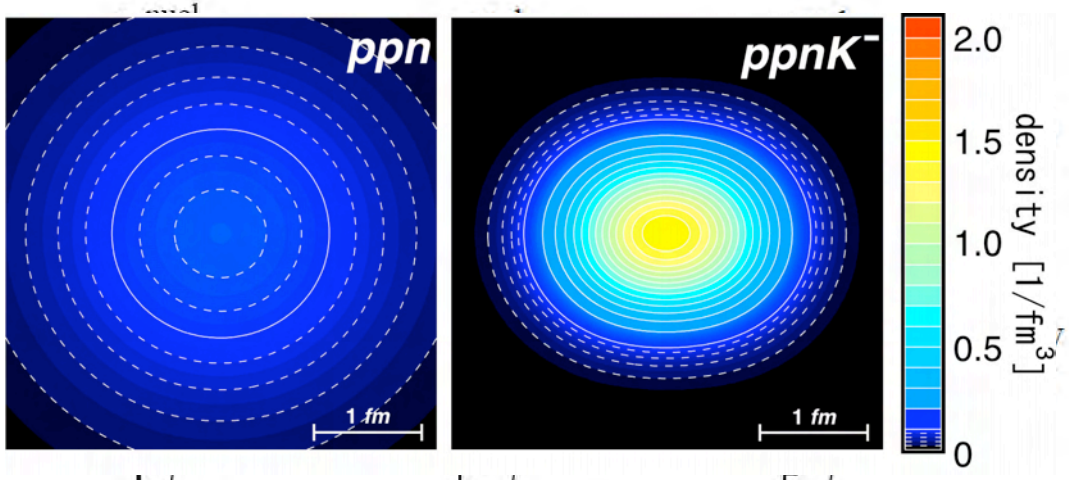
➢ **a first kaonic deuterium experiment needs improvement - has to be achieved during the kaonic hydrogen run**

$\bar{K}N$ study by nuclear states

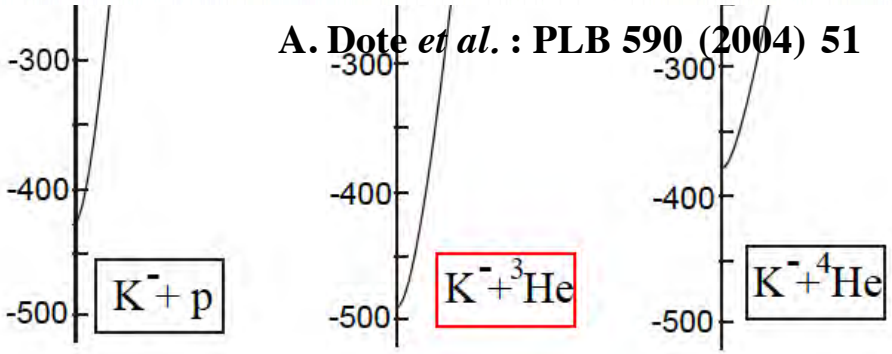
Does it exist? ... need more study

$\Lambda(1405)$ as a K^-p bound state

resolved kaonic hydrogen puzzle



A. Dote *et al.* : PLB 590 (2004) 51



Y. Akaishi & T. Yamazaki : PRC 65 (2002) 044005

- **Deep!**
  - KEK-PS E228 (KpX)
  - ~ 100 MeV
  - cf: B_N ~ 10 MeV
- **Narrow!**
  - ~ 20 MeV
  - = meta-stable
- **Shrink!**
  - = high density!

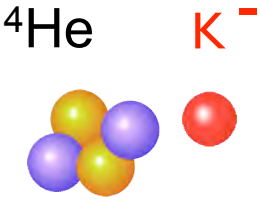
☞ hadron mass

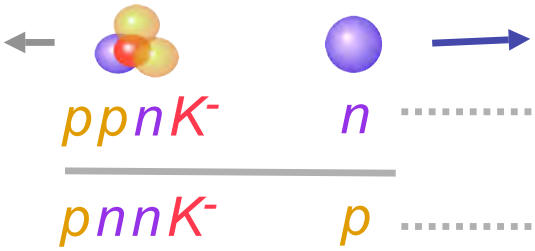
☞ astronomical study

KN study by nuclear states

KEK PS-E549: ^{4}He(*stopped* K$^-$, N)

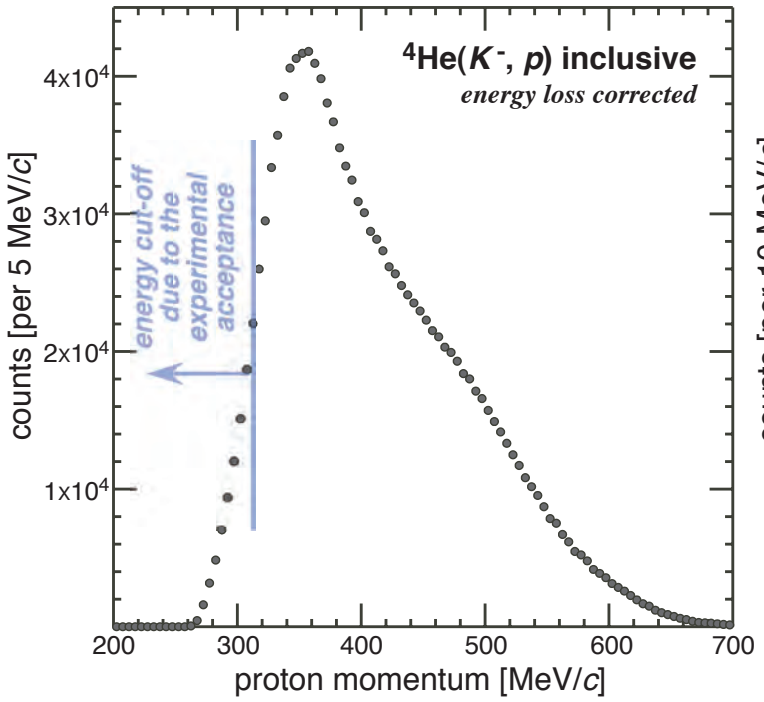
^{4}He(stopped K-, n) spectroscopy

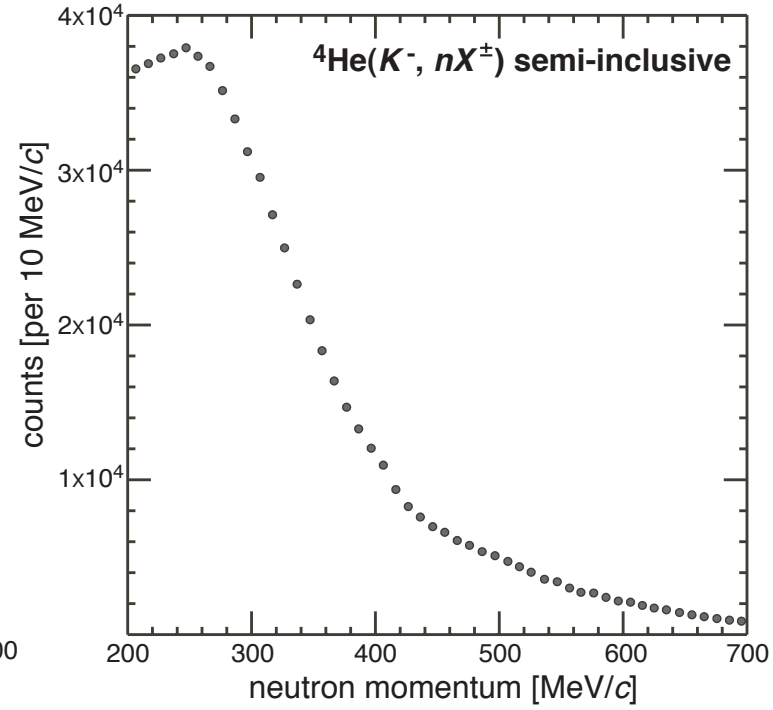




Z : +1, T : 0 *or* 1

Z : 0, T : 1

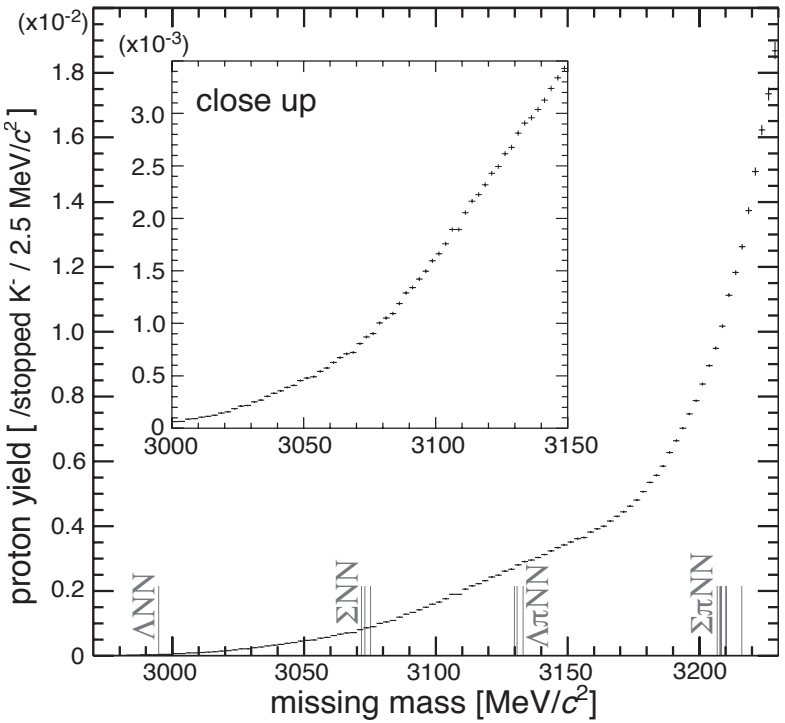


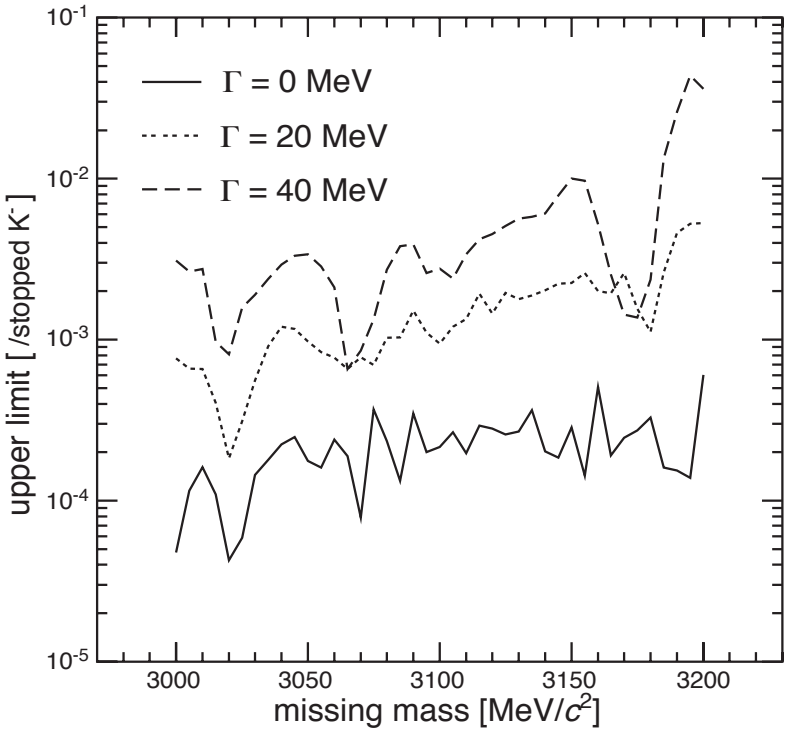


E549 (KEK) ... Sato

KN study by nuclear states

KEK PS-E549: ^{4}He(*stopped* K$^-$, N)





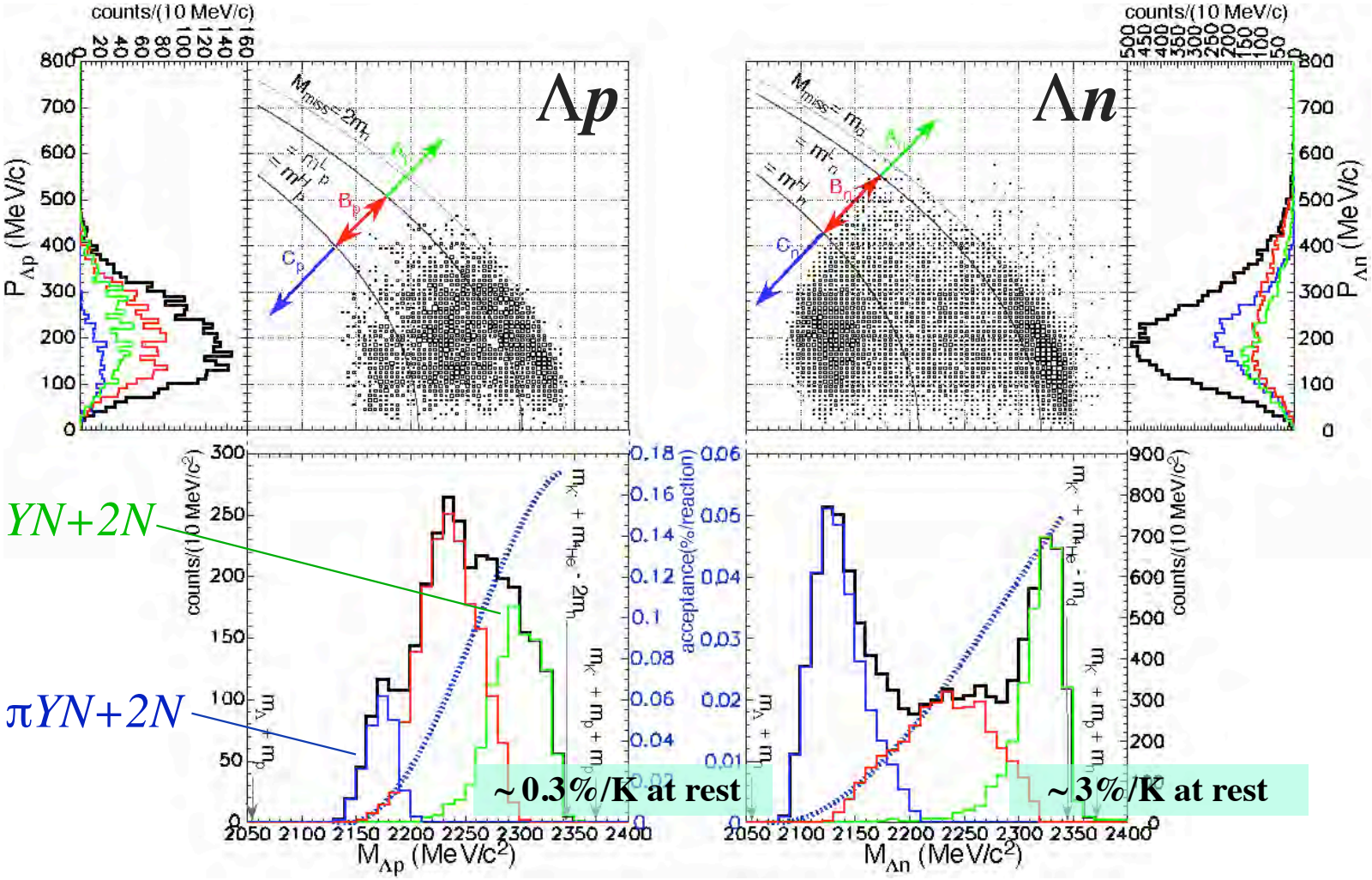
deep & narrow excluded.

(BE>100MeV) (Γ<20MeV)

wide, if exist (more difficult)

E549/E570 (KEK) ... Suzuki

ΛN invariant mass *vs* ΛN total momentum



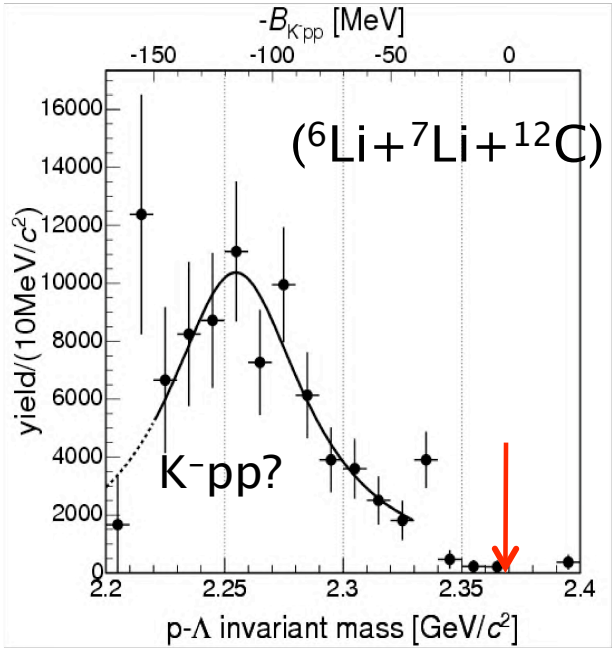
1. **'NN'$_{I=0,S=1}$ dominance of** K^- 'NN'$_{I,S}$ -> ΛN
2. **More intense contribution of $B_{p/n}$**

severe background 2N abs. for kaon at rest kinematics

FINUDA experiment

invariant mass of back-to-back Λp pair from kaon absorption at rest

RUN-I (2003-2004)
PRL 94, 212303 (2005)



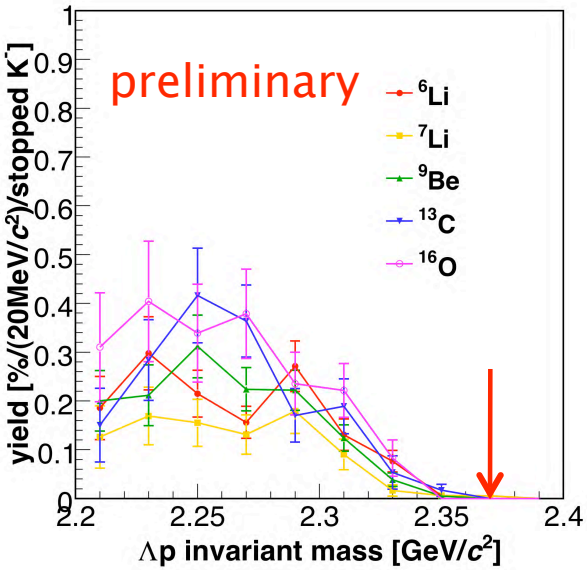
$$B = 115^{+6}_{-5}(\text{stat})^{+3}_{-4}(\text{syst})\ \text{MeV}$$

$$\Gamma = 67^{+14}_{-11}(\text{stat})^{+2}_{-3}(\text{syst})\ \text{MeV}$$

- **target dependence**
- **effect of FSI**

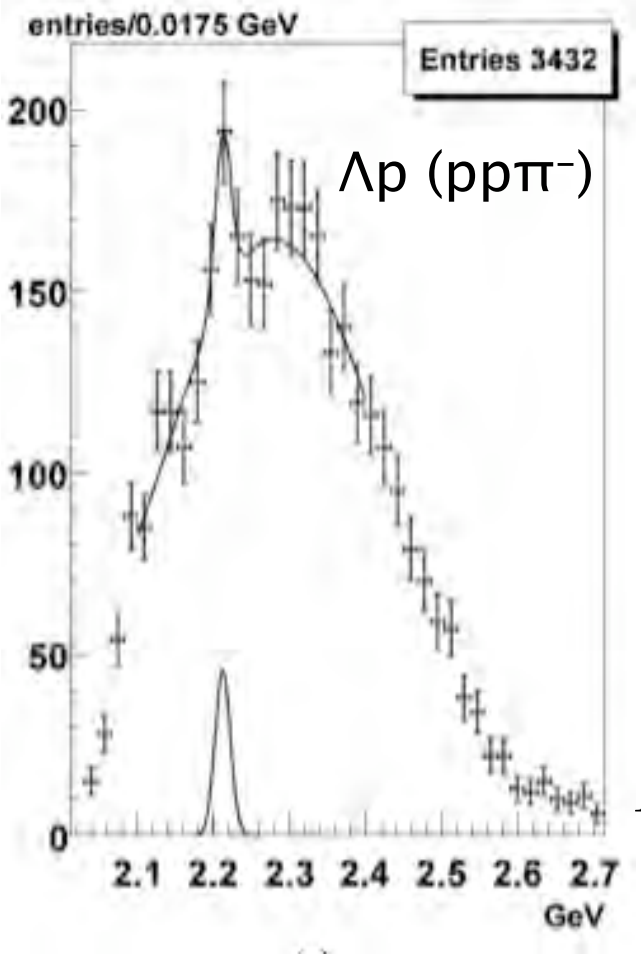
(pointed by Magas et al.)

RUN-II (2006-2007)



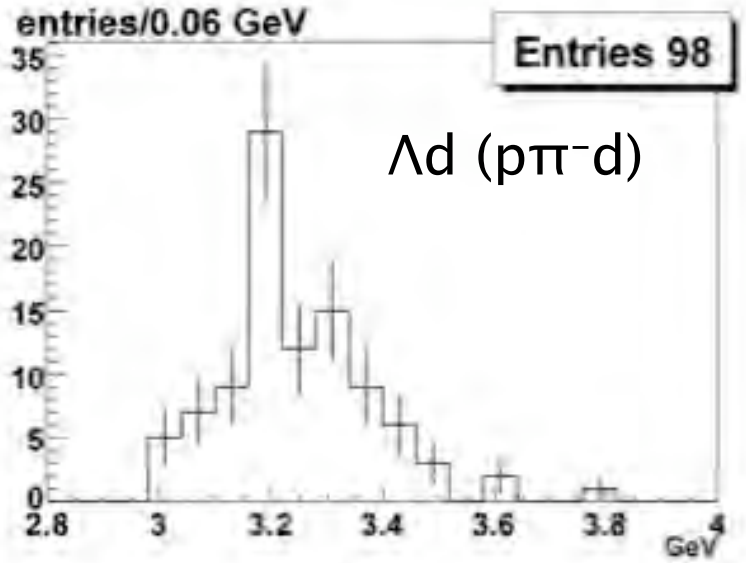
The correlation between another YN pairs (Λn, Σ⁻p) has been also investigated.

OBELIX experiment (pbar annihilation on ^{4}He at rest)



$B = 160.9 \pm 4.9\,\mathrm{MeV}$

$\Gamma < 24.4 \pm 8.0\,\mathrm{MeV}$



$B = 121 \pm 15\,\mathrm{MeV}$

$\Gamma < 60\,\mathrm{MeV}$

not highly consistent though

New data from Osaka group

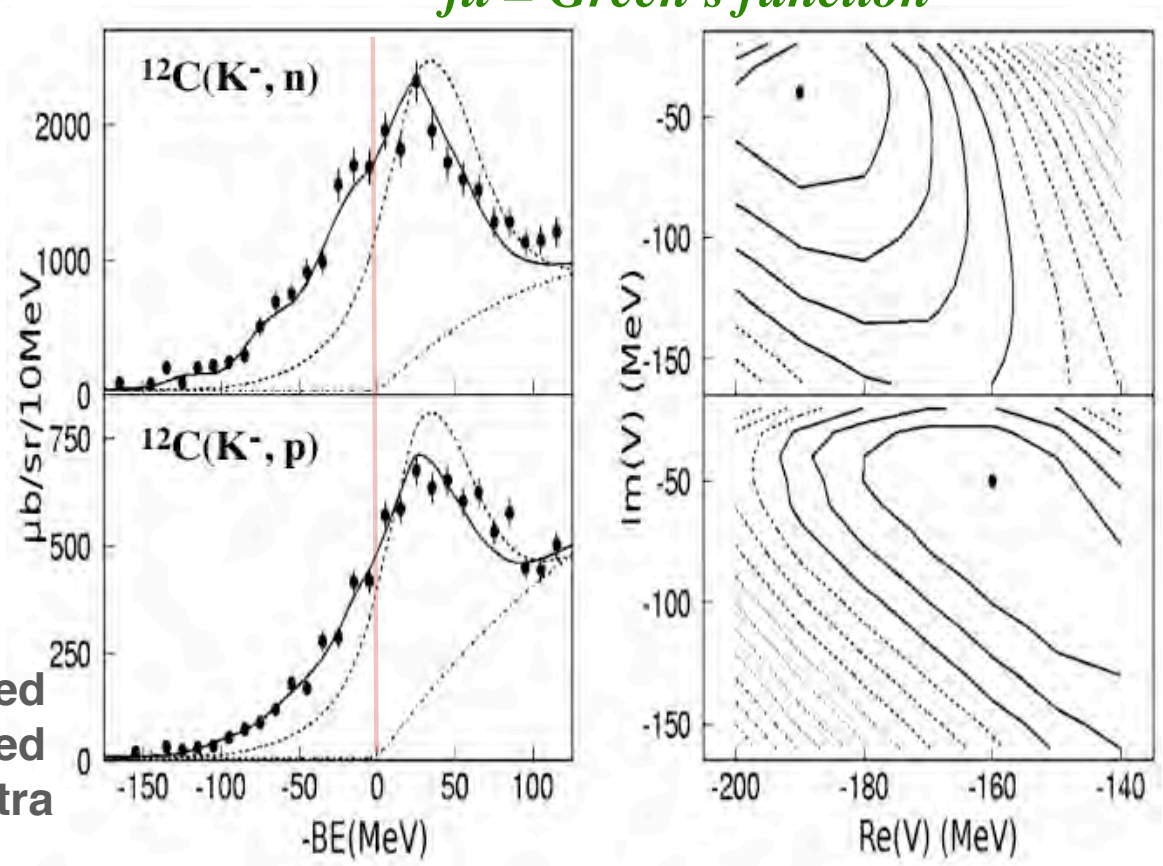
(one of new data : in-flight)

in-flight (K-, n) reaction @ 1 GeV/c

indicating very deep potential
Kaon condensation?

T. Kishimoto et al., Prog. Theor. Phys. 118 (2007) 181

fit = Green's function

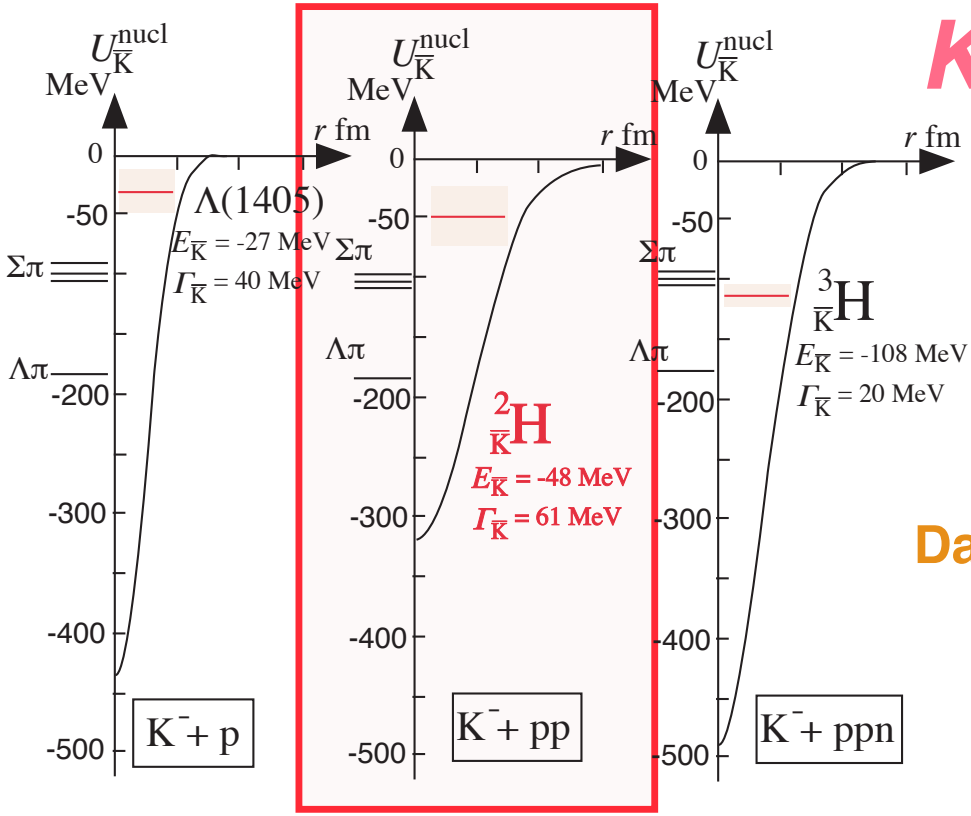


- deep & wide KN pot.
  - Re(V) ~ 200 MeV
  - Im(V) ~ 50 MeV
- lower background
  - in-flight ensures ...
  - 2N process suppressed
  - kinematically separated
  - not seen in the spectra

$\bar{K}N$ study by nuclear states

level energy and decay width

E15: ^{3}He(K$^-$, n) missing & invariant mass



T. Yamazaki, Y. Akaishi / Physics Letters B 535 (2002) 70

K$^-$pp

- **simplest system**
  - less excited states
  - less ambiguity
    - *full kinematical reconstruction*
- **minimum absorption**
  - multi-nucleon absorption

Data from FINUDA group

M. Agnello et al.
Phys. Rev. Lett. 94 (2005) 212303

Faddeev Calculations of K^-pp

N.V. Shevchenko, A. Gal and J. Mares, Phys. Rev. Lett. 98 (2007) 082301

E = -55~-70 MeV, Γ = 90~110 MeV

"Because the coupling of the K^-p channel to the absorptive pY channels was substituted by an **energy-independent complex $K^{bar}N$ potential**, the **YA results** for *BE* and Γ of the K^-pp system provide **at best only a rough estimate**."

"Although the BE calculated here is similar to YA's, the calculated **width is considerably larger than YA's** estimate Γ=61 MeV."

Y. Ikeda and T. Sato, arXiv:nucl-th/0704.1978

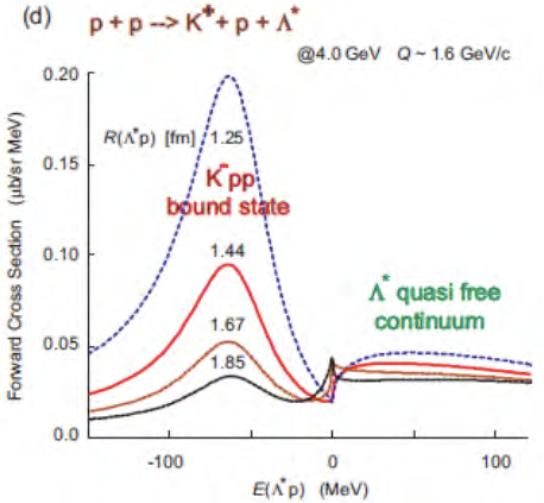
E ~ -80 MeV, Γ ~ 73 MeV

"Our resonance has a **deeper *BE*** and a **similar Γ** compared with YA's. However **it is not straightforward to compare with YA's** pole energy because of the differences in the method and on the model for the $K^{bar}N$ interaction."

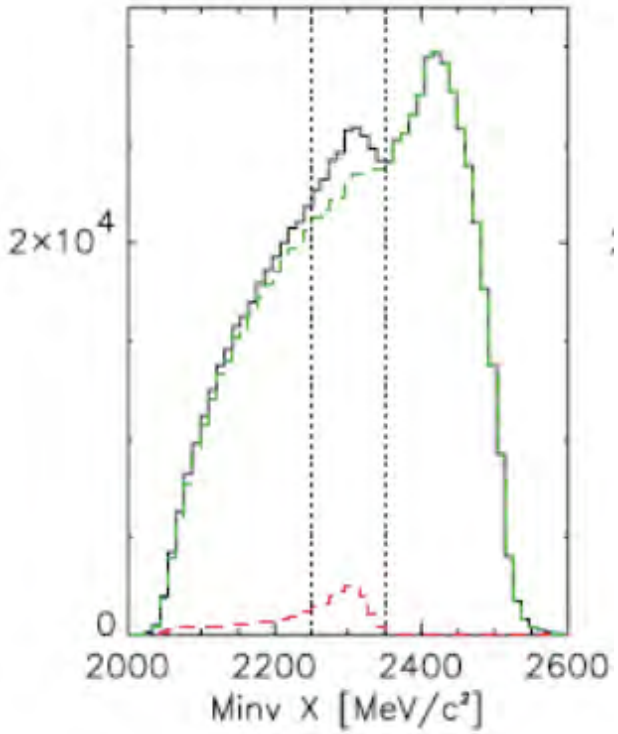
p(p, K+) **pp -> "pp K- " + K+**

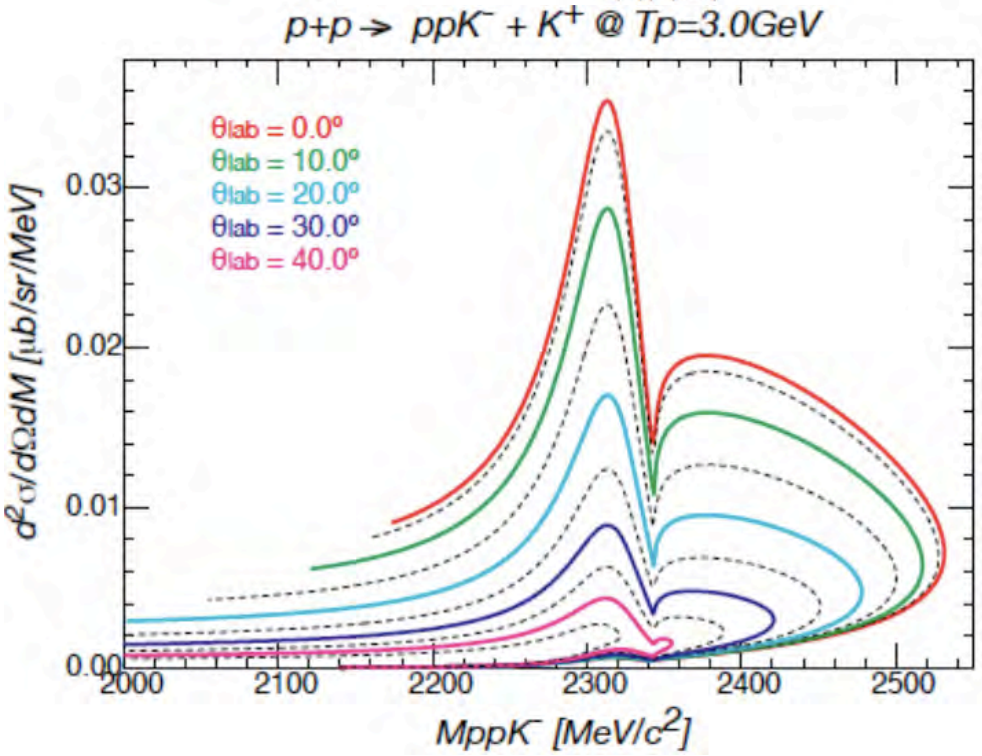
ANKE? @ COSY **missing mass**

FOPI @ GSI **invariant mass**



FOPI simulation (from proposal)

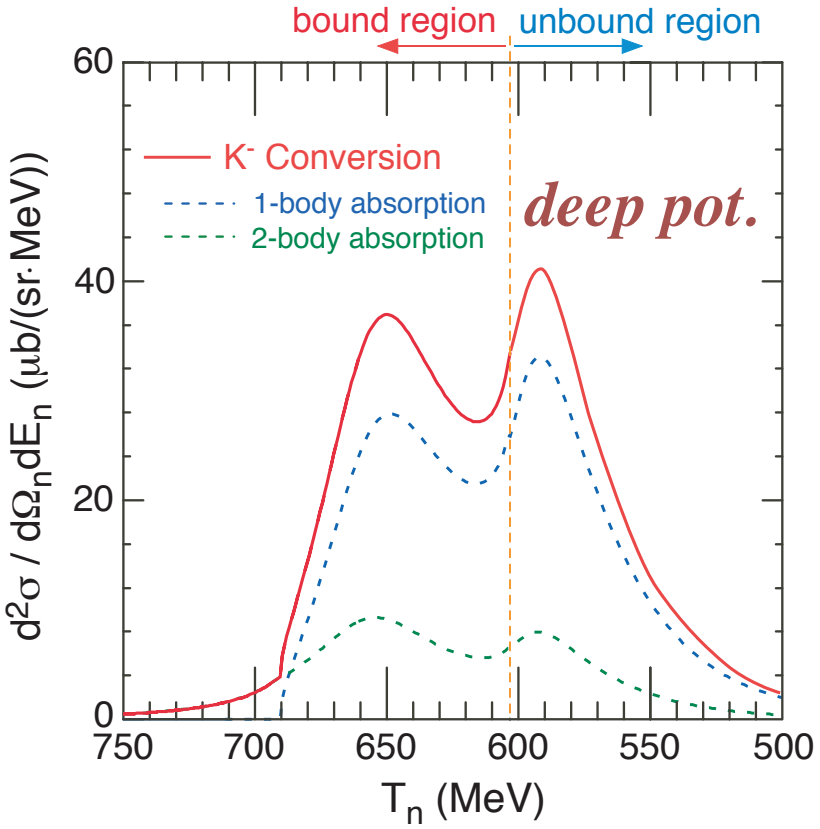




Theoretical progress

^{3}He(K$^-$, n) K$^-$ ^{3}He -> "pp K$^-$" + n

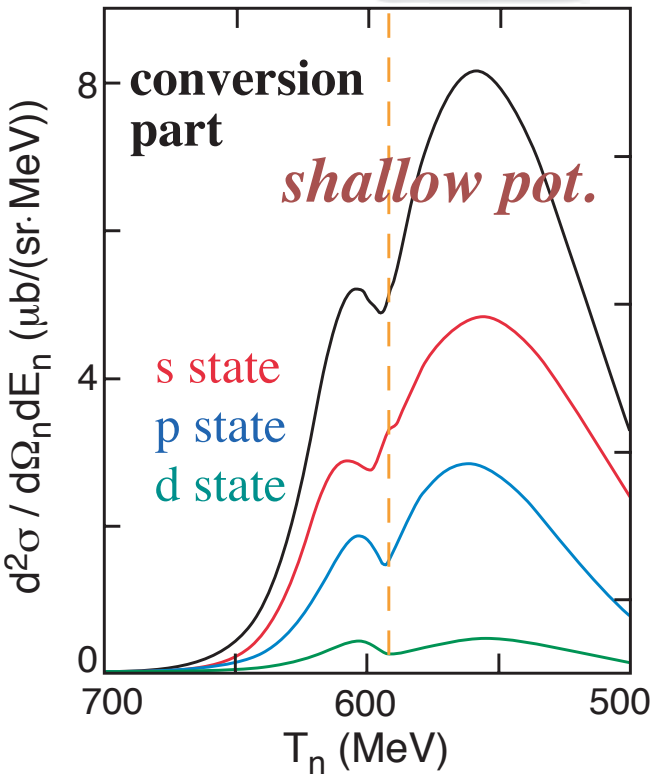
- bound state will be seen
- yield 5 ~ 40 μb / (sr MeV)
- resolution must < 20MeV



T. Koike, T. Harada, Phys. Lett. B652 (2007) 262

Chiral unitary

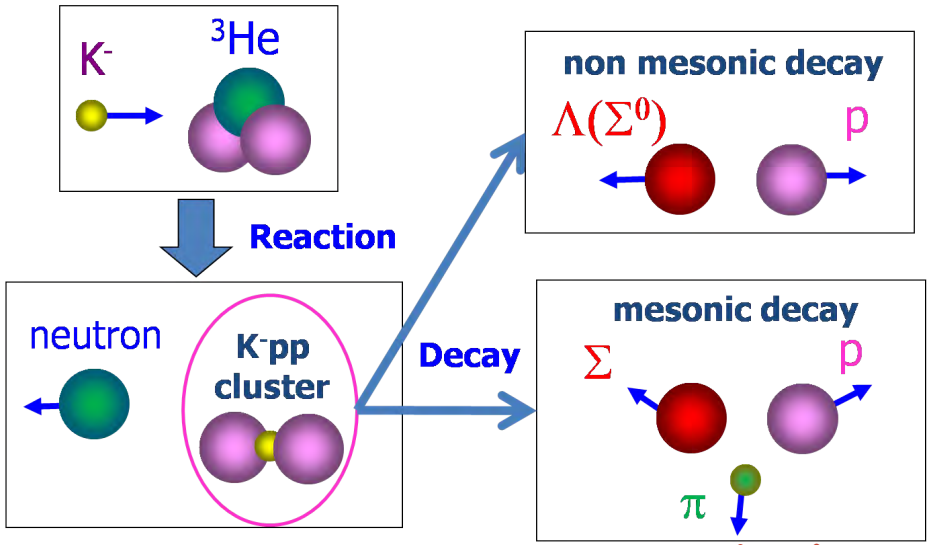
^{3}He (K$^-$, n) K$^-$ pp



J. Yamagata, S. Hirenzaki, H. Nagahiro, D. Jido, Mod. Phys. Lett. A accepted. Proc. of Chiral07.

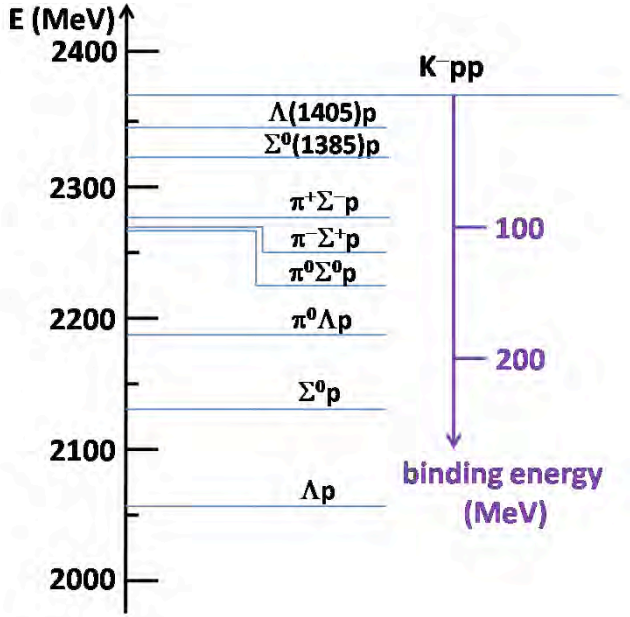
mesonic decay mode

shallow pot. case



I=0 dominance

$\Sigma^{\pm}\pi^{\mp}$p *decay channel*
can also be tagged
by π^+ π^- tag



Theoretical progress

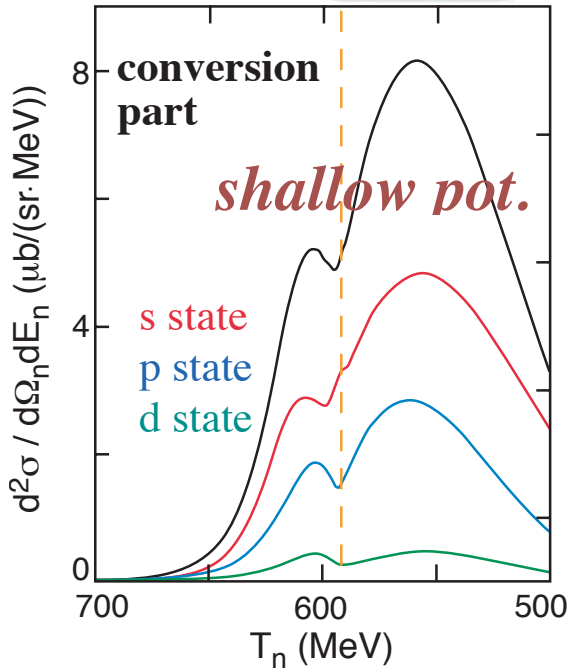
Chiral unitary
shallow pot.

J. Yamagata-Sekihara, H. Nagahiro,
D. Jido, S. Hirenzaki, in preparation

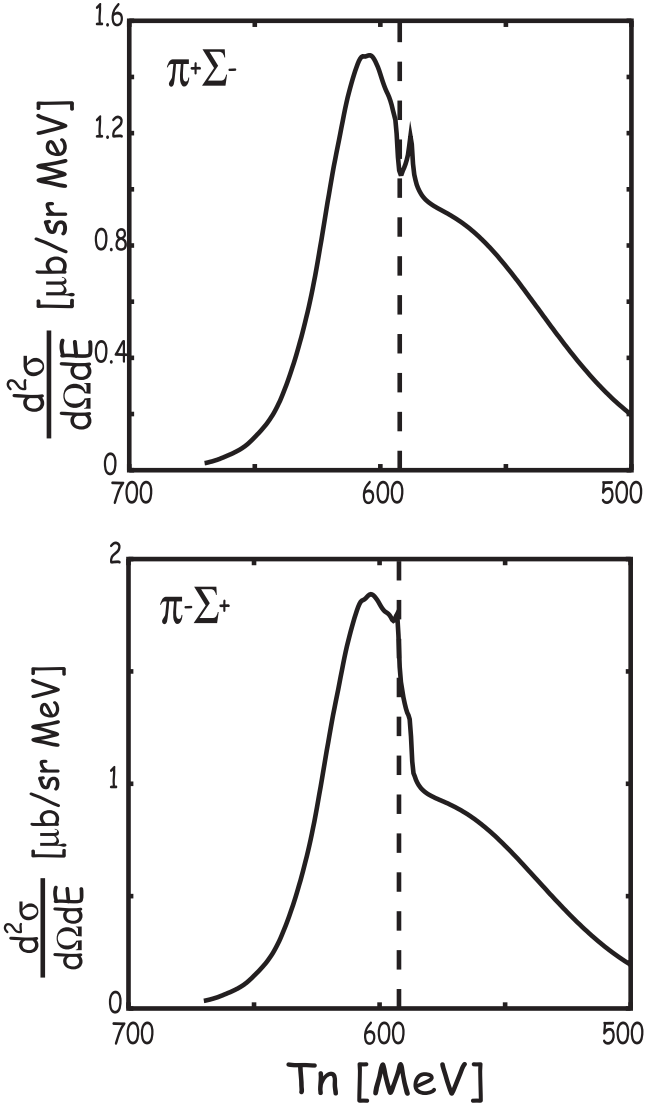
$\Sigma^{\pm}\pi^{\mp}$p *decay channel*
can also be tagged
by π^+ π^- tag

Chiral unitary

^{3}He (K^-, n) **K^-pp**



J. Yamagata, S. Hirenzaki, H. Nagahiro, D. Jido,
Mod. Phys. Lett. A accepted. Proc. of Chiral07.

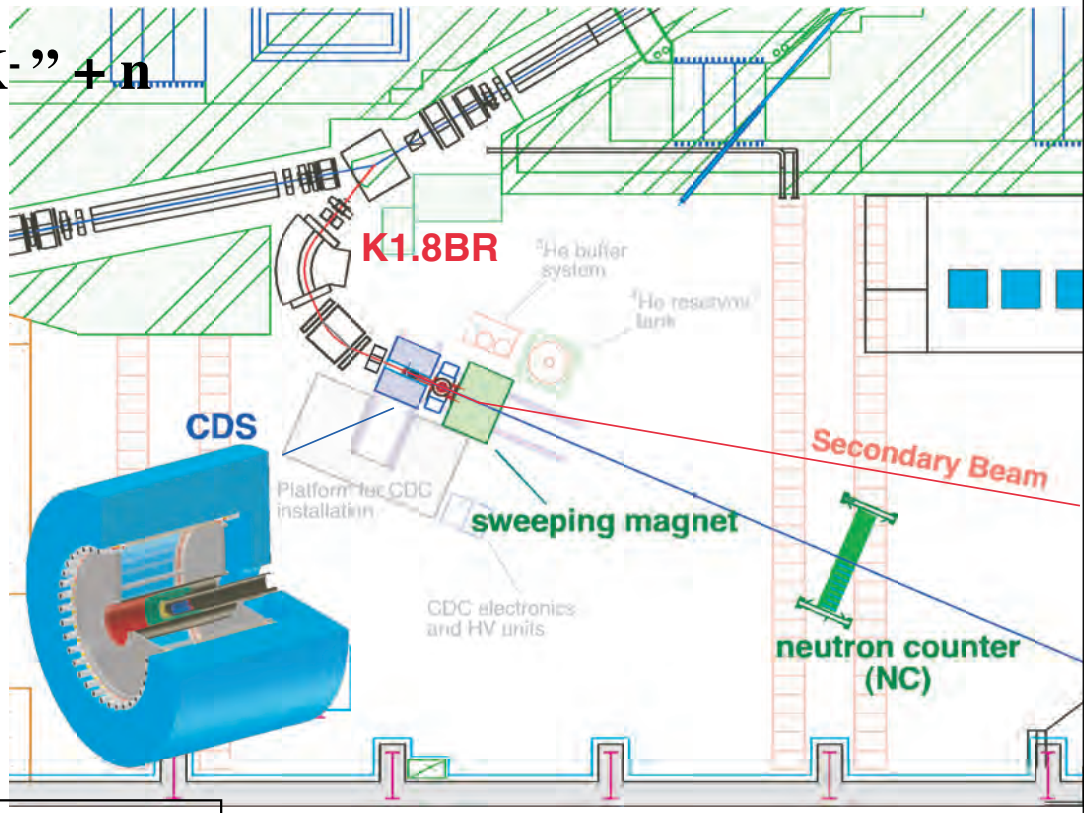


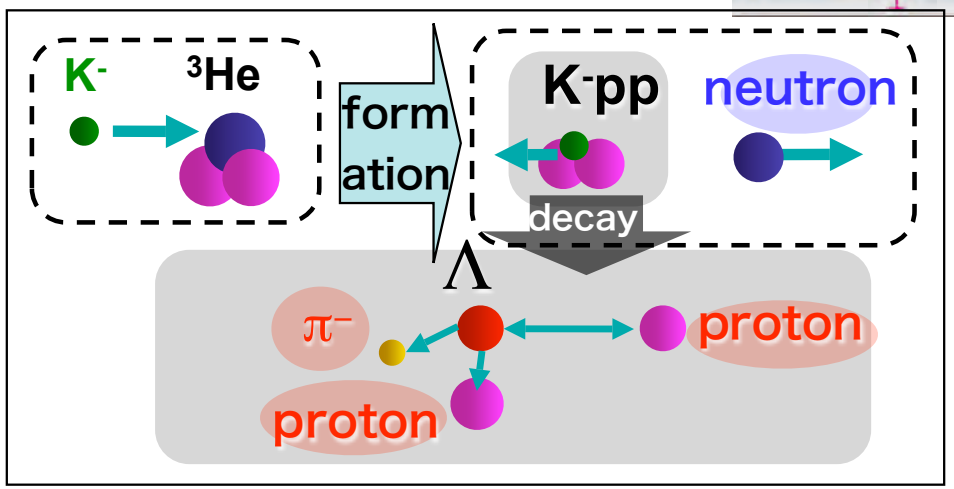
^{3}He(K$^-$, n) K$^-$ ^{3}He -> "pp K$^-$" + n

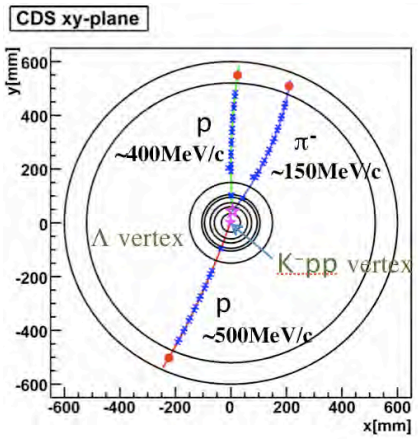
E15 @ J-PARC

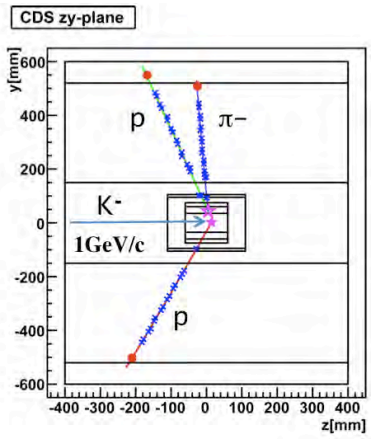
1 GeV/c
missing & invariant mass

- Cylindrical Detector System
  1) solenoid
  2) CDC
  3) hodoscope
- ^{3}He target
- neutron counter
- beam line detector









Summary

... atomic states

DAFNE SIDDARTA: K^- p & K^- d $2p$ - $1s$

J-PARC E17: K^- ^{3}He $3d$ - $2p$

... nuclear states (not clear so far)

COSY ANKE: p(p, K^+) missing mass

GSI FOPI: p(p, K^+) invariant mass

J-PARC E15: ^{3}He(K^-, n) missing & invariant mass

DAFNE AMADEUS: ^{3}He(*stopped* K^-, N)

LEPS ? more..?

situation will be clarified soon

Thank you!