P15: A search for deeply-bound kaonic nuclear states by in-flight ^{3}He(K^-, n) reaction at J-PARC

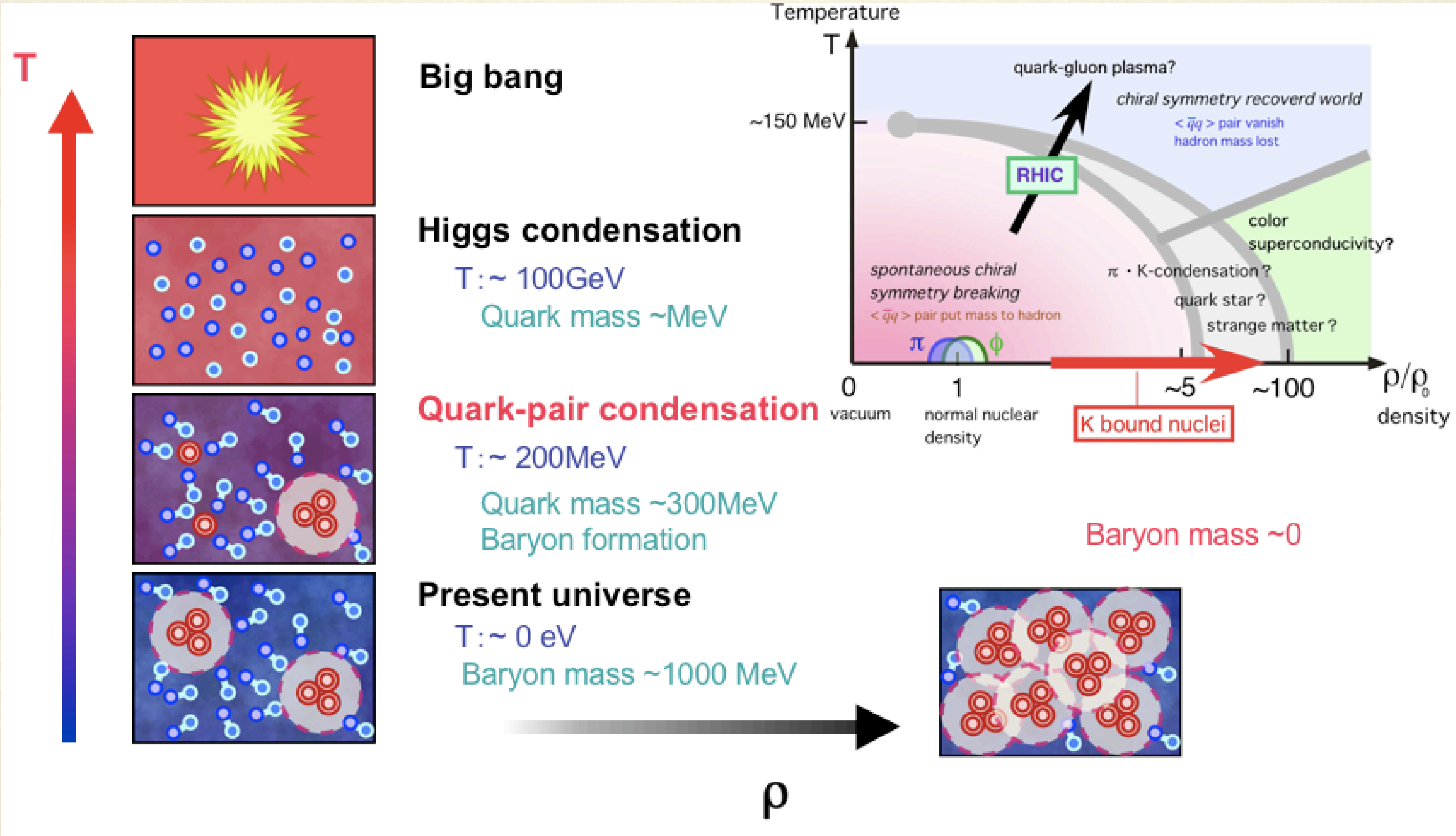
S. Ajimura[a], G. Beer[b], H. Bhang[c], P. Buehler[d], M. Cargnelli[d], J. Chiba[e], S. Choi[c], C. Curceanu[f], F. Diego[g] H. Fujioka[h*], T. Fukuda[i], Y. Fukuda[j], C. Guaraldo[f], T. Hanaki[e], R. S. Hayano[h], A. Hirtl[d], M. Iio[k], M. Iliescu[f], T. Ishikawa[h], S. Ishimoto[l], T. Ishiwatari[d], K. Itahashi[k], M. Iwasaki[k,j†], P. Kienle[d,m], B. Luigi[n], J. Marton[d], Y. Matsuda[k], Y. Mizoi[i], T. Nagae[l‡], H. Ohnishi[k§], S. Okada[k], M. Ombretta[o], H. Outa[k], A. Sakaguchi[a], M. Sato[j], M. Sekimoto[l], D. Sirghi[f], F. Sirghi[f], S. Suzuki[l], T. Suzuki[k¶], D. Tomono[k], A. Toyoda[l], H. Tatsuno[h], E. Widmann[d], T. Yamazaki[k], H. Yim[c], J. Zmeskal[d]

M. Iwasaki

Why dense matter?

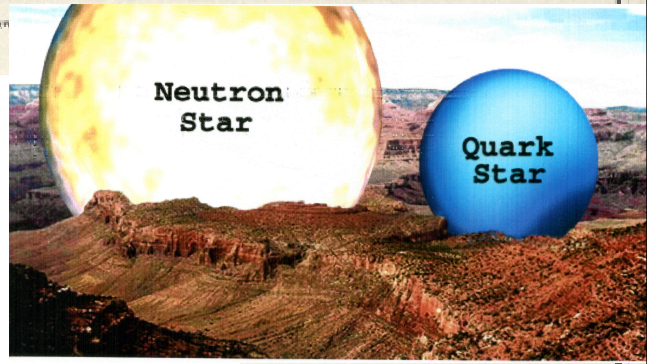
Why proton is heavy?

quark-antiquark condensation (Nanbu)



What's happening in the dense star?

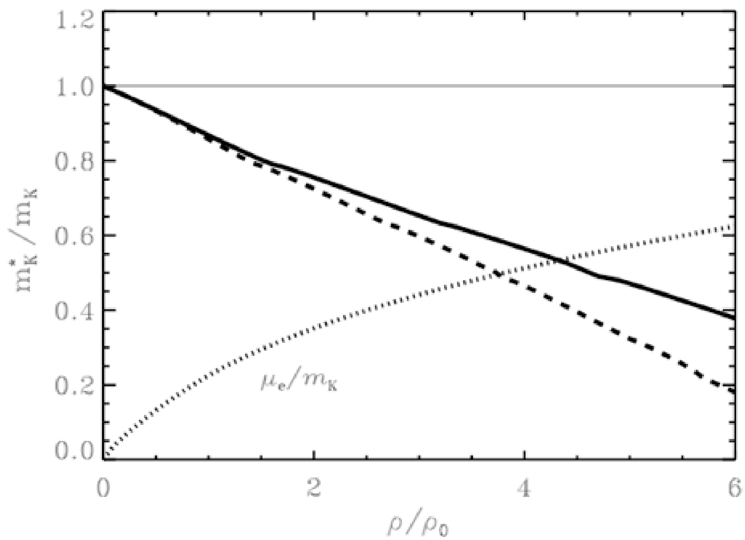
kaon condensation ?



KAON CONDENSATION in NEUTRON STAR MATTER

(first suggested by D. Kaplan & A. Nelson on the basis of the attractive K^-n Weinberg-Tomozawa term)

- at high density, energetically favourable to condense K^-



T. Waas, M. Rho, W.W.: Nucl. Phys. A 617 (1997) 449

electron chemical potential

incl. NN correlations

chiral SU(3) dynamics "in-medium"

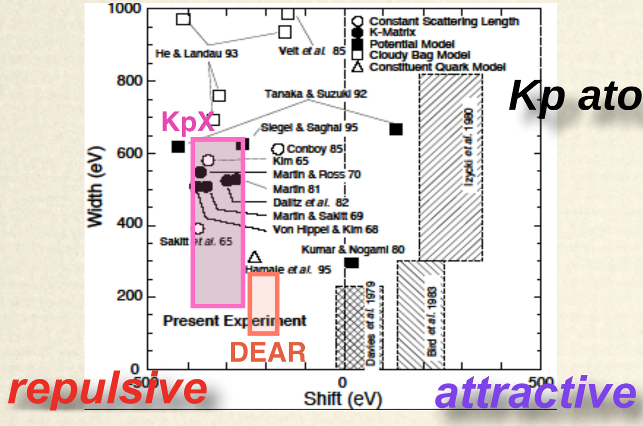
$$p + e^- \rightarrow K^- + p + \nu_e \, ?$$

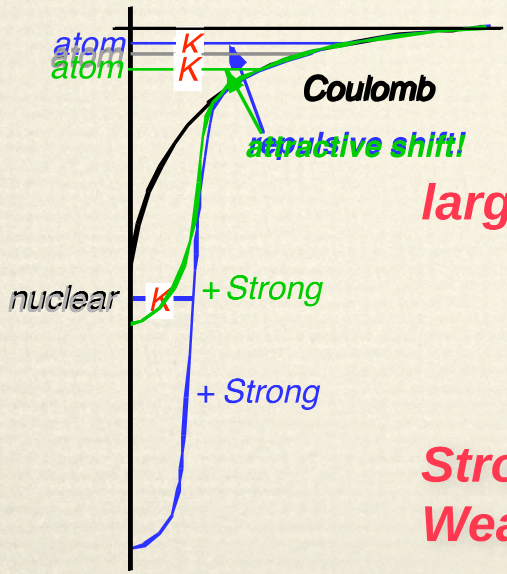
- conversion to hyperons via $K^-NN \rightarrow YN$?

W. Weise @ ETC*

Why we expect that it might be studied via the $\bar{K}N$ interaction?

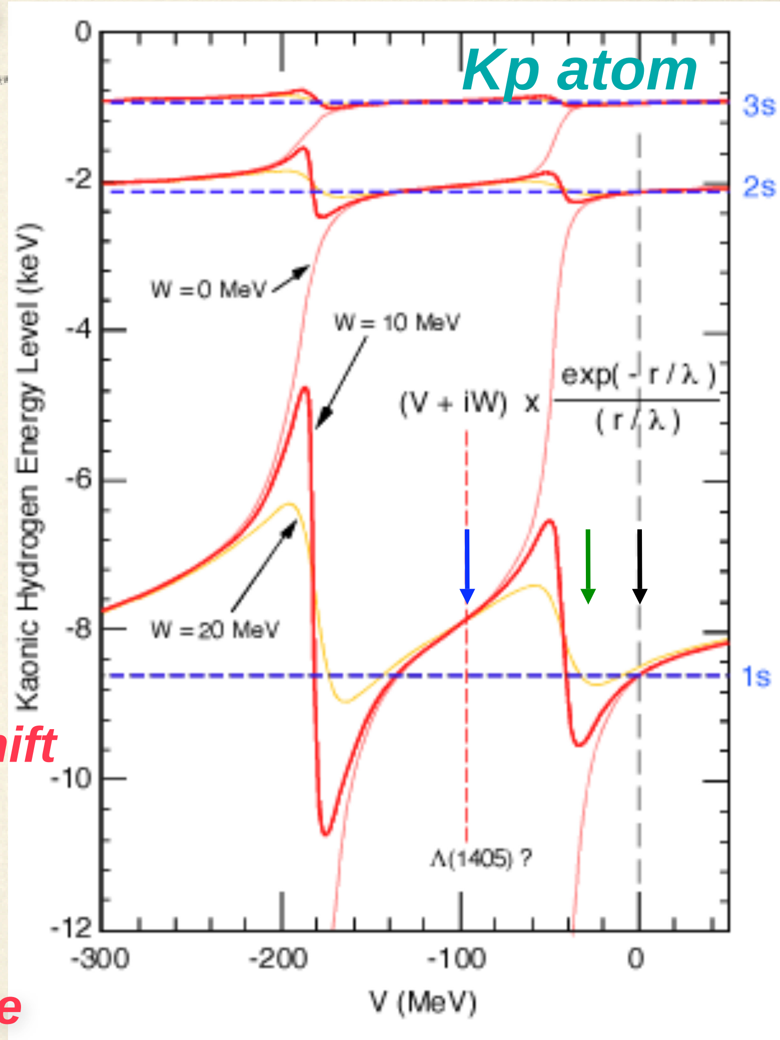
Kp atom data





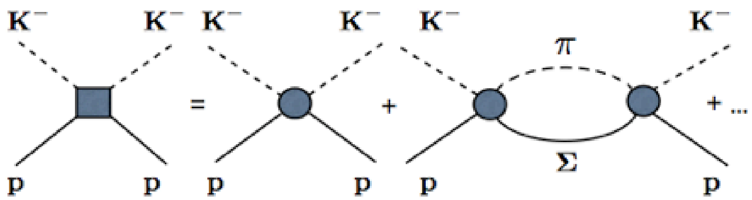
large repulsive shift

suggests :
Strongly attractive
Weakly absorptive



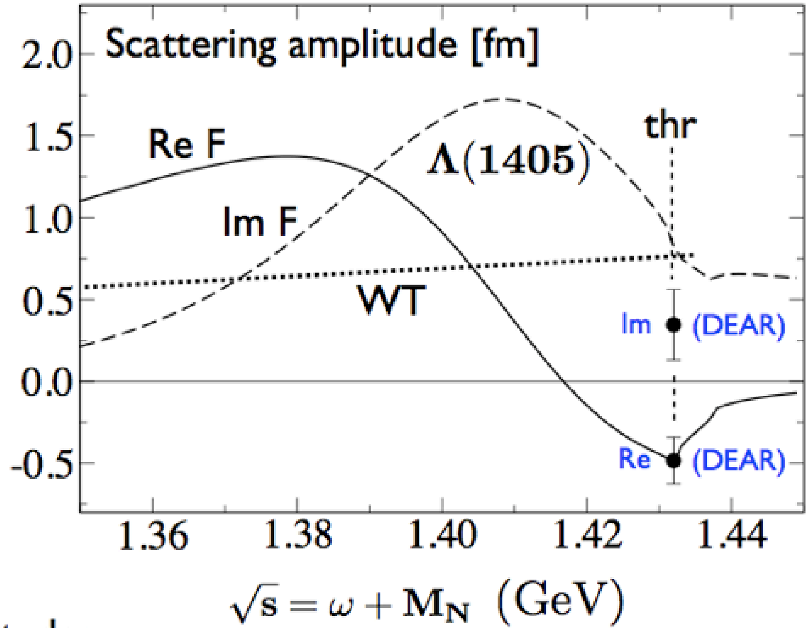
a closer look at the S-wave K¯p amplitude

B. Borasoy, R. Nissler, W.W.:
PRL 94 (2005) 213401, EPJ A 25 (2005) 79



constrained by:

- ➡ scattering data
- ➡ threshold branching ratios ($\pi\Sigma$, $\pi^0\Lambda$)
- ➡ DEAR and KEK kaonic hydrogen data



- Parametrization of subthreshold K¯p amplitude:

$$T(K^-p) = \frac{1}{f^2}\left(\omega + a\,\omega^2 + b\,m_K^2\right)\left[1 + \frac{\sqrt{s}\,\gamma}{M_0^2 - s - i\sqrt{s}\,\Gamma}\right]$$

Weinberg-Tomozawa (WT) — $\Lambda(1405)$

W. Weise @ ETC*

Theoretical backgrounds ...

Possible Existence of K- Light Nucleus Bound States
A.E. Kudryavtsev, V.D. Mur, V.S. Popov (Moscow, ITEP)
Phys. Lett. B143: 41-44, 1984

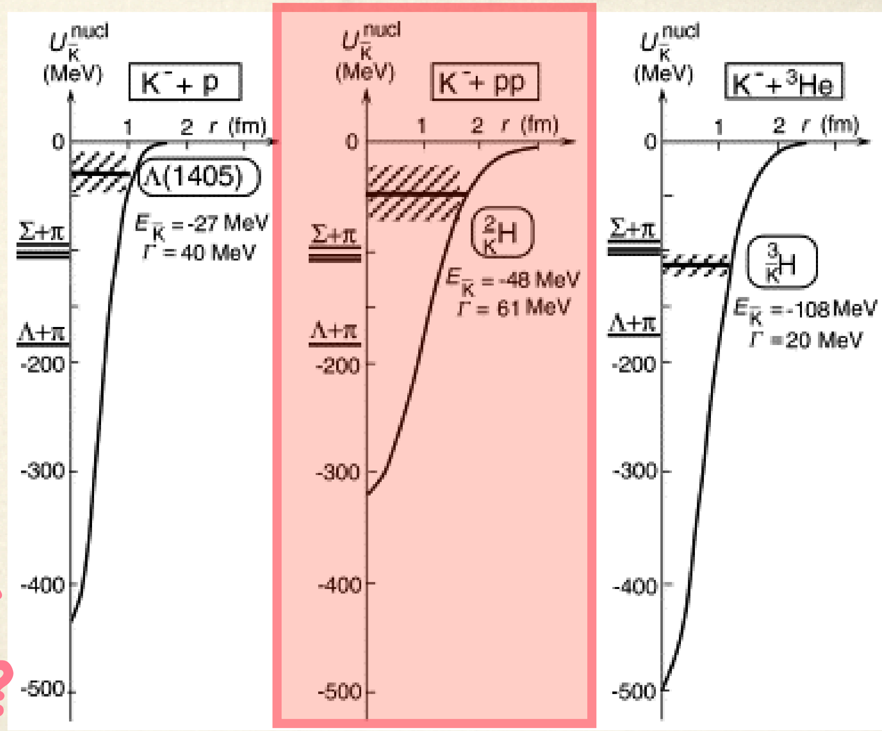
On Possibilities of Narrow Nuclear States of K-
S. Wycech (Warsaw, Inst. Nucl. Studies) . 1986
Nucl. Phys. A450: 399c-402c, 1986

Kaonic nuclei excited by the (K-, N) reaction.
T. Kishimoto (Osaka U.)
Phys.Rev.Lett.83:4701-4704,1999

Nuclear anti-K bound states in light nuclei.
Y. Akaishi (KEK) , T. Yamazaki (RIKEN)
Phys. Rev. C65: 044005, 2002

(K-,pi-) production of nuclear anti-K bound states in proton-rich systems via Lambda* doorways.
T. Yamazaki (RIKEN) , Y. Akaishi (KEK)
Phys. Rev. C65: 044005, 2002

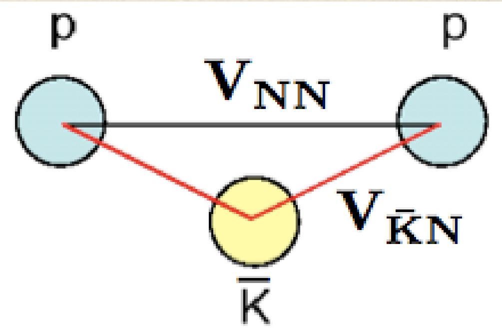
most fundamental system beyond Λ(1405)



Does Λ(1405) can be a member of pentaquark?

$K^{-}pp$ System: Bound Configurations

Akinobu Dote, W. W. (work in progress)



with stronger repulsive core than Akaishi *et al.*

$$H_0 = T + V_{NN} + V_{\bar{K}N}^{s-wave} - T_{CM}$$

$$V_{K^-p}(r) = -\frac{G(r)}{2f^2}$$

$$G(r) = \left(\frac{1}{\sqrt{\pi}a}\right)^3 \exp\left[-\frac{r^2}{a^2}\right]$$

weak binding — $f = 83\,\mathrm{MeV}$ $\quad$ $B.E. = 3\,\mathrm{MeV}$

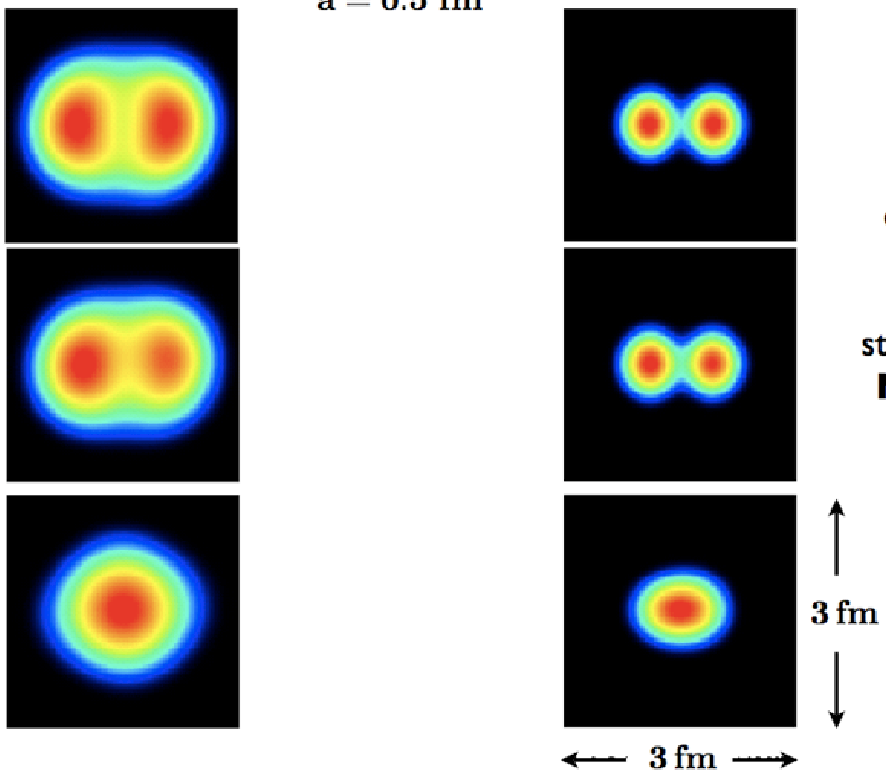
strong binding — $f = 73\,\mathrm{MeV}$ $\quad$ $B.E. = 100\,\mathrm{MeV}$

$a = 0.5$ fm

proton

neutron

kaon



note:

extreme **compression prohibited** by strong short-range **NN repulsion**

without *p*-wave interaction

***p*-wave : could add more attraction**

W. Weise @ ETC*

Theoretically

deep & narrow?

dense & stable?

easy to find?

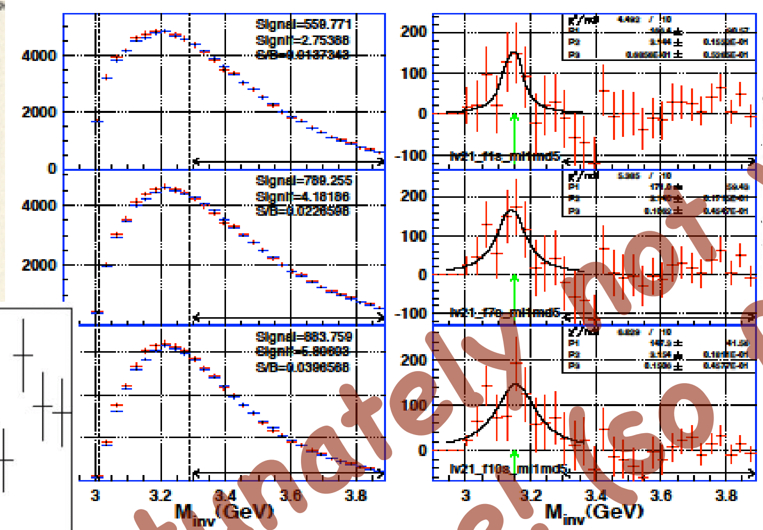
1. No theory against for kaon-bound.
2. Binding energy can be shallower.
3. Width can be wider.

than Akaishi & Yamazaki

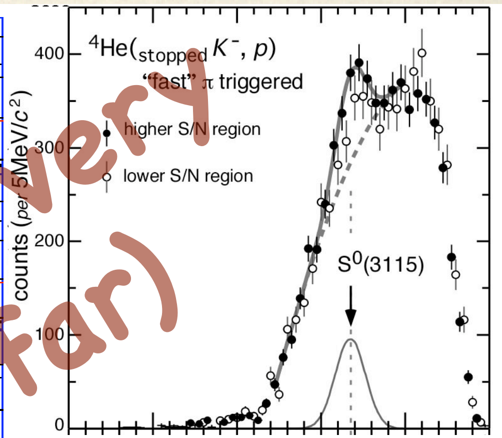
Extremely interesting object to search for ...

What do we know experimentally?

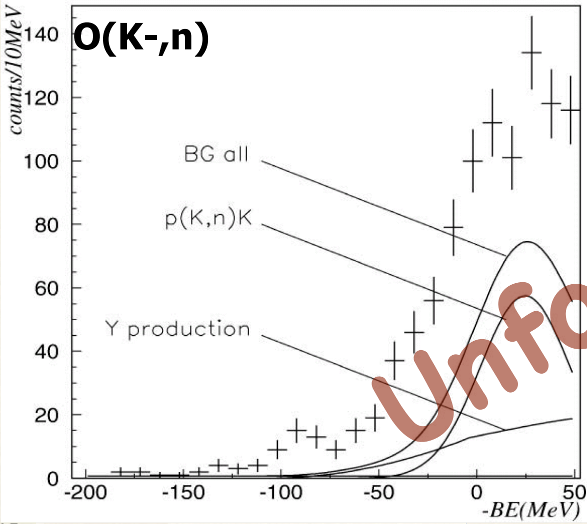
FOPI/GSI



KEK-E471

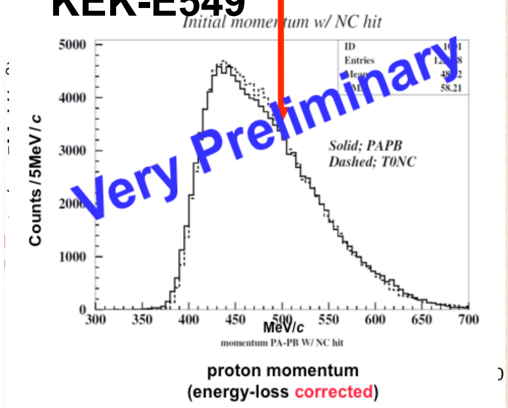


AGS E930



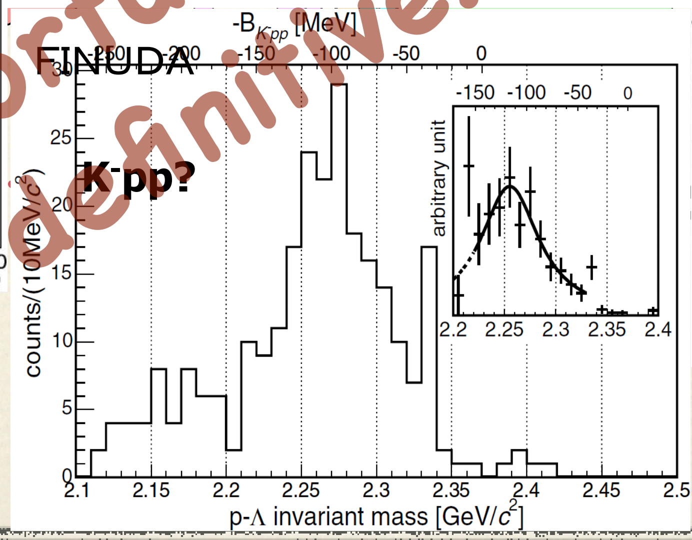
E471 S0 position

KEK-E549



Very Preliminary

FINUDA



Unfortunately not very definitive! (so far)

Experimentally

1. **Not definitive signal so far ...**

   some hints though

2. **Exclusive experiment is needed.**

   in simplest system

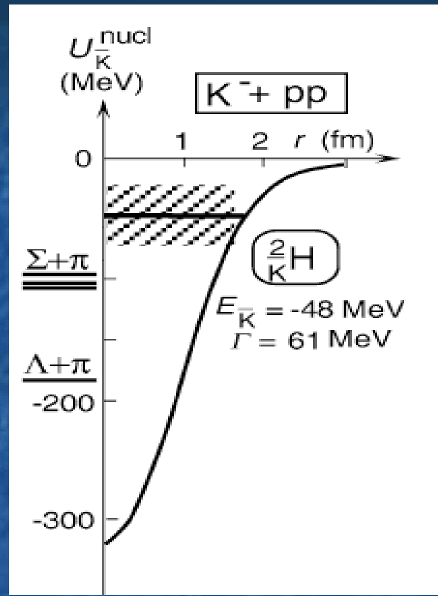
$$K^- + {}^3\mathrm{He} \to \langle K^- pp \rangle + \boxed{n} \quad \text{TOF}$$

$$\langle K^- pp \rangle \to \Lambda + p \to \boxed{p\pi^- + p} \quad \text{CDS}$$

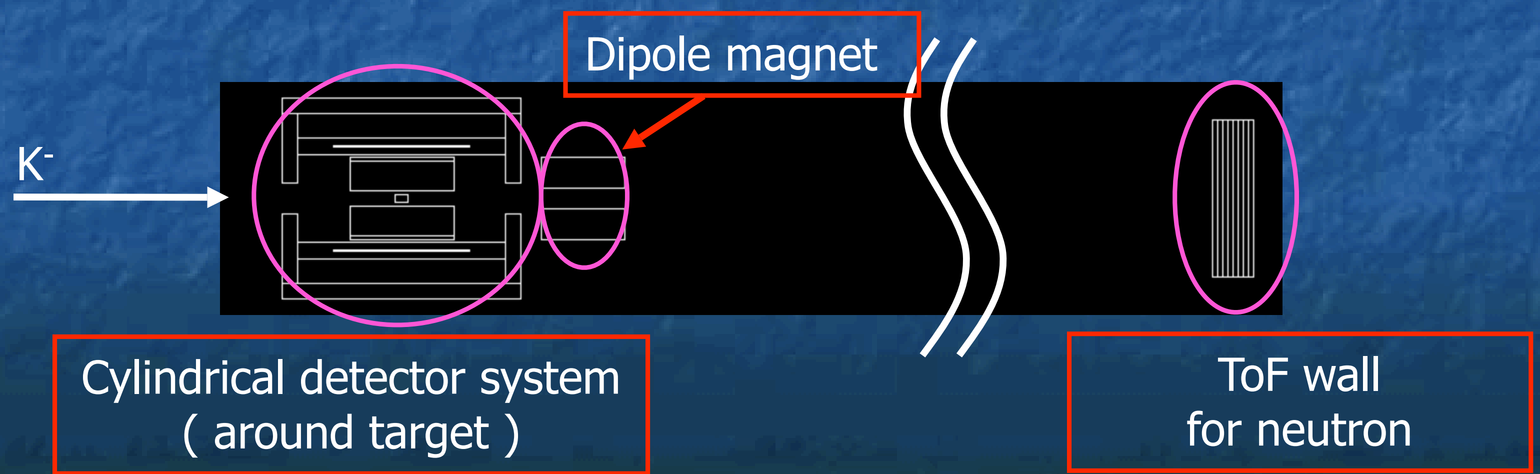
	S/N	formation	decay
in-flight	good	O	-
stop-K	poor	O	-
invariant mass	?	-	O
in-flight + invariant mass	**better (QF-free)**	**O**	**O**

Conceptual design of the detector

Predicted by
Akaishi and Yamazaki

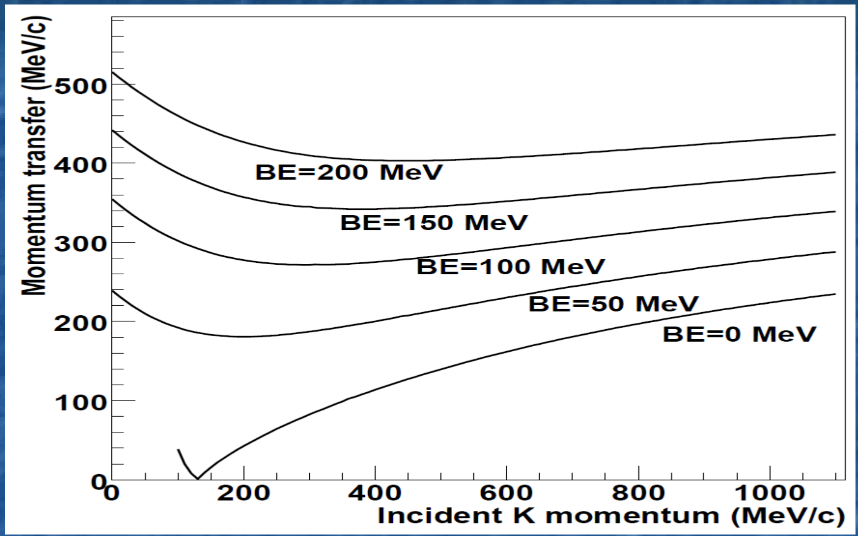


- Predicted property of the K-pp bound state
  - Binding energy = 48 MeV
  - Width = 61 MeV
  - ⇒ Detector resolution need to better than this
- Three major components
  - Forward (0 degree) neutron detector (ToF wall) for **missing mass spectroscopy**
  - Dipole magnet to **sweep-out Kaon** from neutron detector acceptance
  - Detect all decay product from K-pp for **invariant mass spectroscopy**

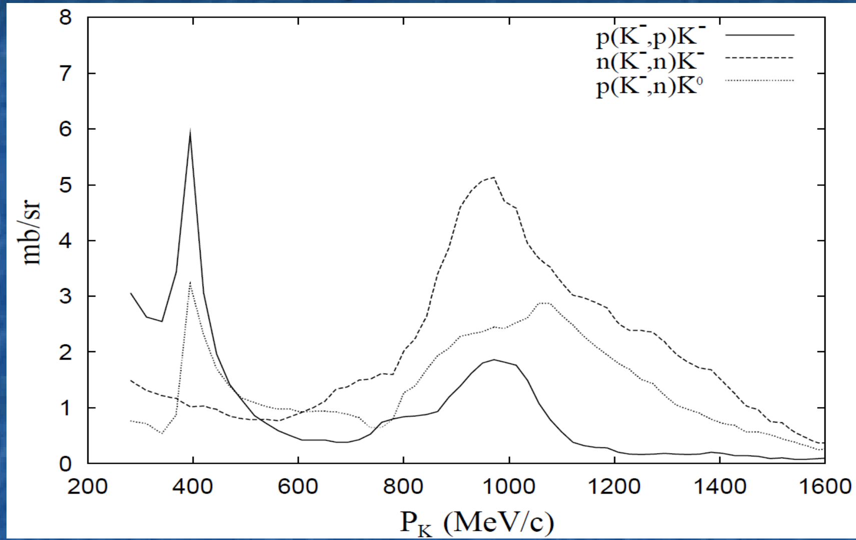


Kaon beam momentum selection

- Momentum transfer



- Elementary cross section

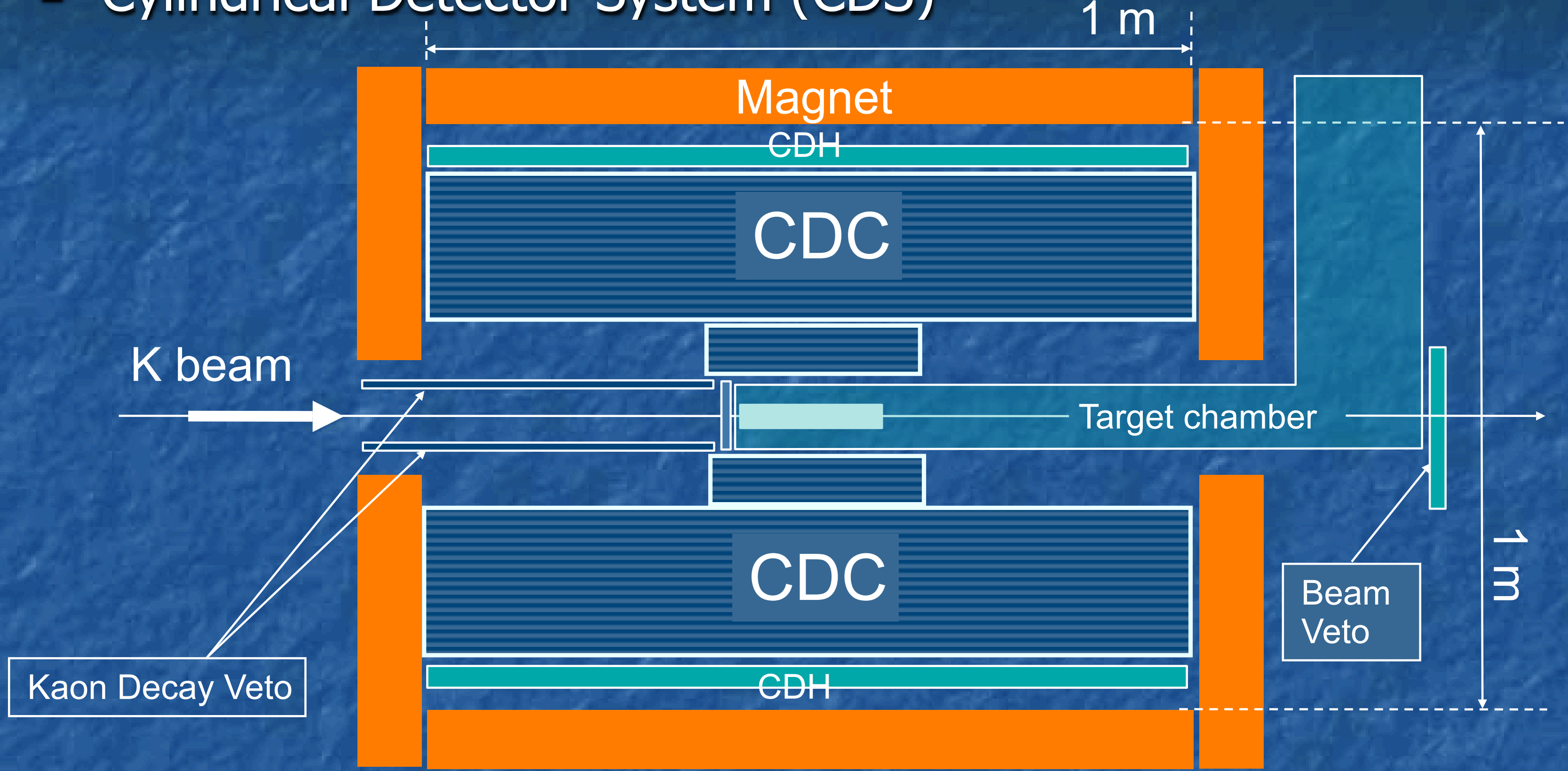


- Neutrons from ^{3}He(K-,n) are **accelerated!!**
- Elementary cross section has peak around 1.0 GeV/c

Use kaon beam @ 1.0 GeV/c

Detector around target

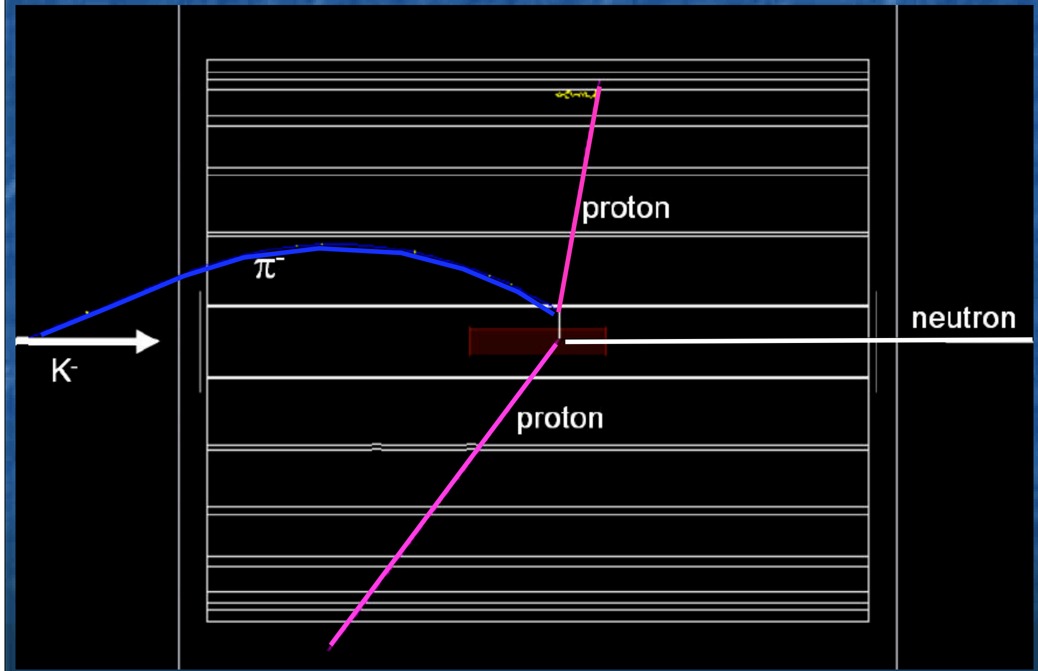
- Cylindrical Detector System (CDS)

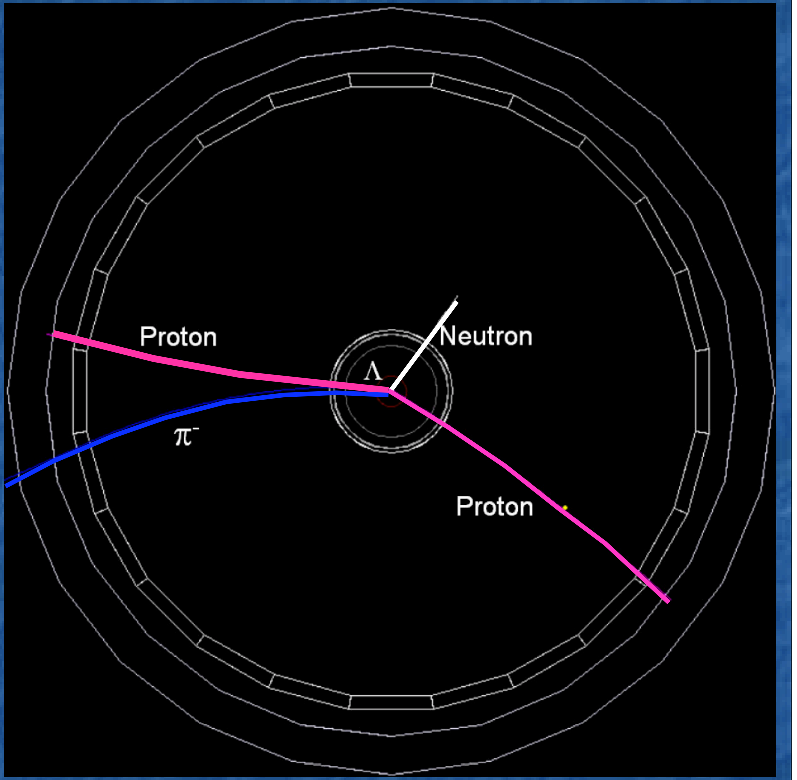


- CDS magnet : Solenoid magnet
- Cylindrical Drift Chamber (CDC) + inner tracker
- Cylindrical Detector Hodoscope (CDH)
- Veto counter : Kaon Decay Veto and Beam Veto

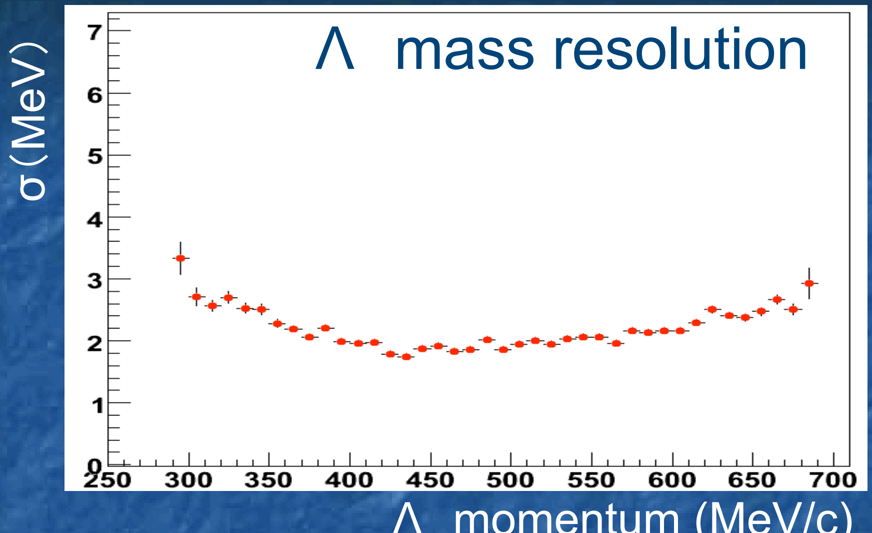
Event display

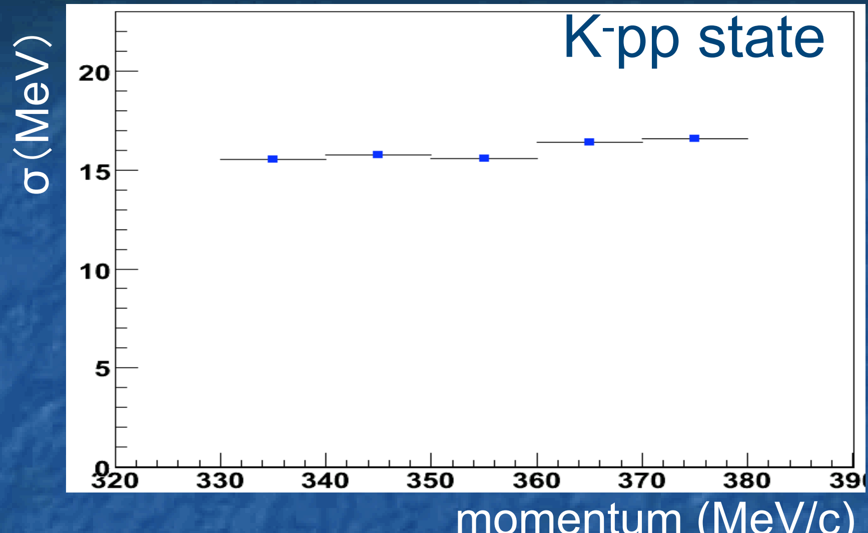
- Conceptual detector in GEANT4 simulation
- Assumed $K^{-}pp$ BE = 100 MeV
- Neutron hit on the forward neutron-counter wall required





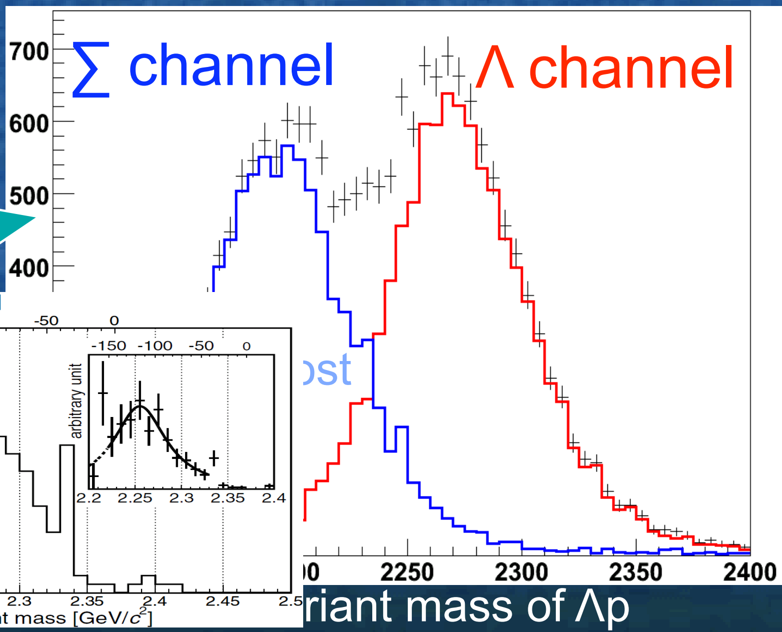
Simulation study (reconstructed invariant mass)

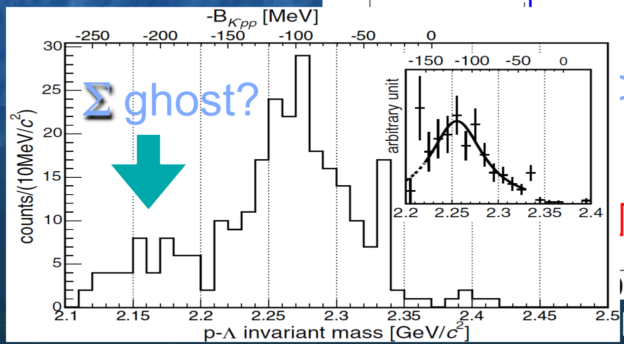




- Decay of K-pp **(branch unknown)**
  - K-pp ⇛ Λp ⇛ pπ-p
  - K-pp ⇛ Σ^0p ⇛ γΛp ⇛ γ pπ-p

Assumed $\Gamma_{K\text{-}pp}$= 60 MeV





need formation info.!

Event rate estimation

- Parameters
  - Assume production cross section as $\sigma_{3He(K-,n)K-pp} = 10\ \mu b/sr$
  - Acceptance of Neutron counter = 19.4 msr
  - Target thickness = 20cm, density = 0.080 g/cm^3
  - Neutron detection efficiency = 30%
  - Assume 1/3 of K-pp decay in to (Λ+p or Σ^0+p)
  - Λ+p reconstruction efficiency in CDC = 47%
- Expected event rate
  - 1.86×10^{-9} per an incident K^-
- Event rate per day @ K1.8BR
  - 0.8×10^6 K- per 3.53s (0.7s flat top)
  - 24475 spill per day = 1.96×10^{10} K- per day
  - ~ 35 events per day

Summary table for the request

reaction	in-flight ^{3}He(K$^-$, n)
primary beam	30GeV, 9μA
secondary beam	1GeV/c
beam line	K1.8BR
target	liquid He: 6.4 cm *dia*. 15 cm *long*
detectors	beam line counters & chambers: P17 CDS: 1m *dia*., 1m *long*, 0.75T: P17 inner tracker: new TOF: KEK PS-E549
beam time	~ 1 month @ full intensity ~ 4 month @ 2μA *cf* : 1 month @ 1μA with looser trigger

Proposed Experiment

1. In-flight method
   for better S/N (proven by BNL-E930)
   + excluding QF background!
2. Exclusive
   detect both formation and decay
3. Most fundamental system
   avoid complex spectral structure
   answer nature of $\Lambda(1405)$

Present to GOOD data for detailed theoretical study

Thank you for the attention!