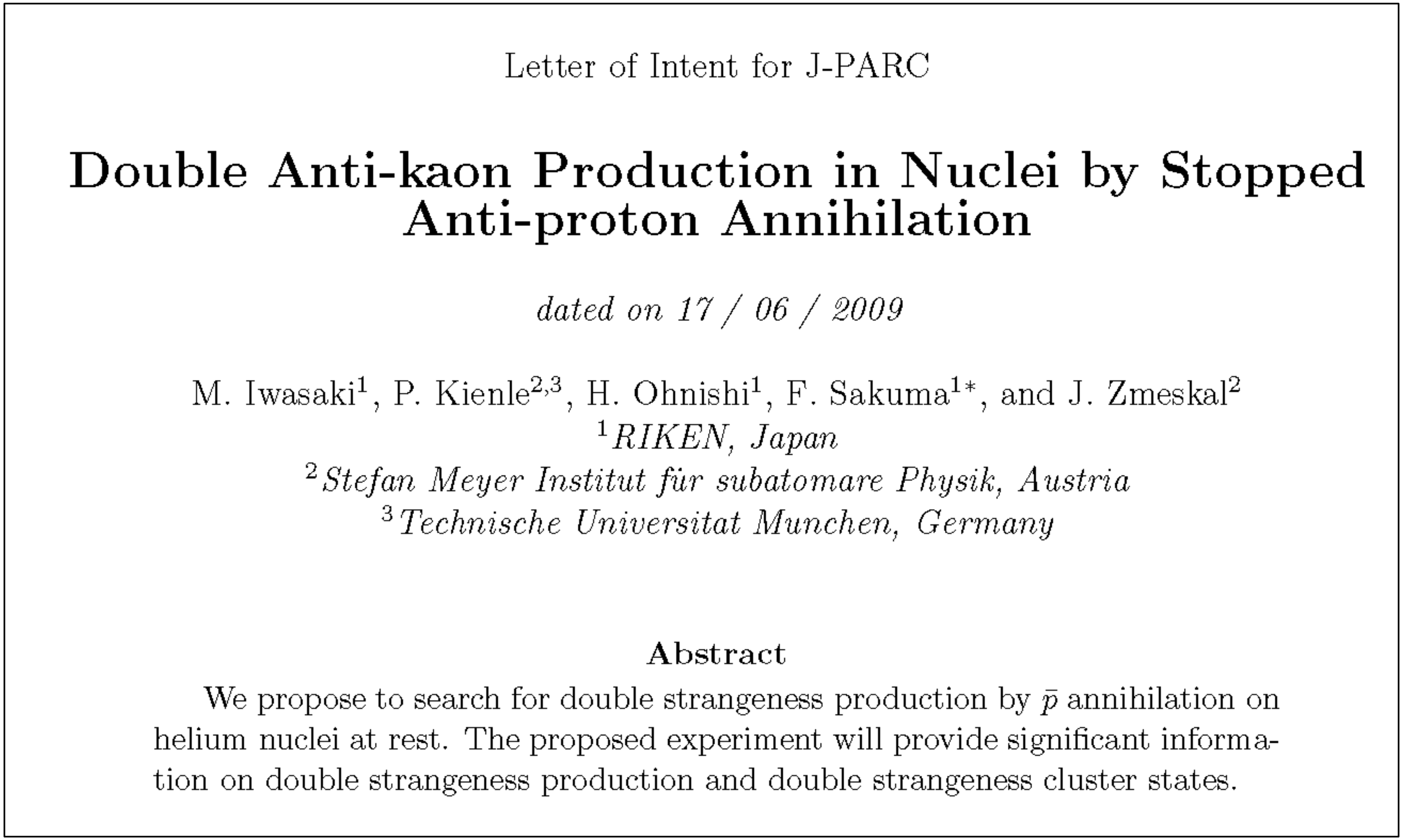
A search for double anti-kaon production in antiproton-^{3}He annihilation at J-PARC

F.Sakuma, RIKEN

Strangeness in Nuclei @ RIKEN, June 12, 2010.

This talk is based on the LoI submitted in June, 2009.



Letter of Intent for J-PARC

Double Anti-kaon Production in Nuclei by Stopped Anti-proton Annihilation

dated on 17 / 06 / 2009

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Abstract

We propose to search for double strangeness production by $\bar{p}$ annihilation on helium nuclei at rest. The proposed experiment will provide significant information on double strangeness production and double strangeness cluster states.

Contents

- Possibility of "Double-Kaonic Nuclear Cluster" by Stopped-p^{bar} Annihilation
- Experimental Approach
- Summary

What will happen to put one more kaon in the kaonic nuclear cluster?

Possibility of
“Double-Kaonic Nuclear Cluster”
by Stopped-p^{bar} Annihilation

Double-Kaonic Nuclear Cluster

- The double-kaonic nuclear clusters have been predicted theoretically.
- The double-kaonic clusters have much stronger binding energy and a much higher density than single ones.

	B.E. [MeV]	Width [MeV]	Central-Density
K-K-pp	-117	35	
K-K-ppn	-221	37	$17\rho_0$
K-K-ppp	-103	-	
K-K-pppn	-230	61	$14\rho_0$
K-K-pppp	-109	-	

PL,B587,167 (2004). & NP, A754, 391c (2005).

How to produce the double-kaonic nuclear cluster?

- heavy ion collision
- (K^-,K^+) reaction
- $p^{bar}A$ annihilation

We use $p^{bar}A$ annihilation

Double-Strangeness Production with p^{bar}

The elementary p^{bar}-p annihilation reaction with double-strangeness production:

$$\overline{p} + p \rightarrow K + \overline{K} + K + \overline{K} \ \mathbf{-98MeV}$$

This reaction is **forbidden for stopped p^{bar}**, because of a negative Q-value of 98MeV

If multi kaonic nuclear exists with deep bound energy, following p^{bar} annihilation reactions **will be possible**!

theoretical prediction

$$\overline{p} + {}^{3}He \rightarrow K^{+} + K^{+} + K^{-}K^{-}pn + B_{KK}^{pn} - 106\mathrm{MeV}$$

$$\overline{p} + {}^{3}He \rightarrow K^{+} + K^{0} + K^{-}K^{-}pp + B_{KK}^{pp} - 109\mathrm{MeV}$$

→ ***B.E.=117MeV***
Γ=35MeV

$$\overline{p} + {}^{4}He \rightarrow K^{+} + K^{+} + K^{-}K^{-}pnn + B_{KK}^{pnn} - 126\mathrm{MeV}$$

$$\overline{p} + {}^{4}He \rightarrow K^{+} + K^{0} + K^{-}K^{-}ppn + B_{KK}^{ppn} - 129\mathrm{MeV}$$

→ ***B.E.=221MeV***
Γ=37MeV

K^-K^-pp in $p^{bar}+{}^3He$ annihilation at rest?

The possible mechanisms of the K^-K^-pp production are as follows:

① direct K^-K^-pp production with 3N annihilation
② $\Lambda^*\Lambda^*$ production with 3N annihilation followed by the K^-K^-pp formation
③ elementally $p^{bar}+p \rightarrow KKKK$ production in nuclear matter followed by the K^-K^-pp formation

However, there are many unknown issues, like:

① $\Lambda\Lambda$ pair is likely to be formed compared with the K^-K^-pp!
② how large is the $\Lambda^*\Lambda^*$ binding energy?
③ is it possible?

Anyway, if we extrapolate simply the experimental results of the K^-pp:
FINUDA@DAFNE → B.E. ~ 120 MeV, Γ ~ 70 MeV
DISTO@SATURNE → B.E. ~ 100 MeV, Γ ~ 120 MeV
then, we can assume the double binding strength:
B.E ~ 200 MeV, Γ ~ 100 MeV.

Past Experiments of Double-Strangeness Production in Stopped-p^{bar} Annihilation

A result of a search for double-strangeness productions in antiproton-nuclei annihilations was reported by using the **BNL bubble chamber**, in association with the H-dibaryon search.

They did NOT observed any double-strangeness event in antiproton - C, Ti, Ta, Pb annihilation (~80,000 events, $p(p^{bar}) < 400$ MeV/c)

[Phys.Lett., **B144**, 27 (1984).]

Reaction	Frequency (90% C.L.)
$p^{bar}A \rightarrow \Lambda^0\Lambda^0 X$	$<4\times10^{-4}$
$p^{bar}A \rightarrow \Lambda^0 K^- X$	$<5\times10^{-4}$
$p^{bar}A \rightarrow K^+K^+X$	**$<5\times10^{-4}$**
$p^{bar}A \rightarrow HX$	$<9\times10^{-5}$

Past Experiments (Cont'd)

Observations of the double-strangeness production in stopped p^{bar} annihilation have been reported by **2 groups**, DIANA@ITEP and OBELIX@CERN/LEAR.

experiment	channel	events	yield (10^{-4})
DIANA	K^+K^+X	4	0.31+/-0.16
[p^{bar}+Xe]	K^+K^0X	3	2.1+/-1.2
	$K^+K^+\Sigma^-\Sigma^-p_s$	34+/-8	0.17+/-0.04
OBELIX	$K^+K^+\Sigma^-\Sigma^+n\pi^-$	36+/-6	2.71+/-0.47
[p^{bar}+^{4}He]	$K^+K^+\Sigma^-\Lambda n$	16+/-4	1.21+/-0.29
	$K^+K^+K^-\Lambda nn$	4+/-2	0.28+/-0.14

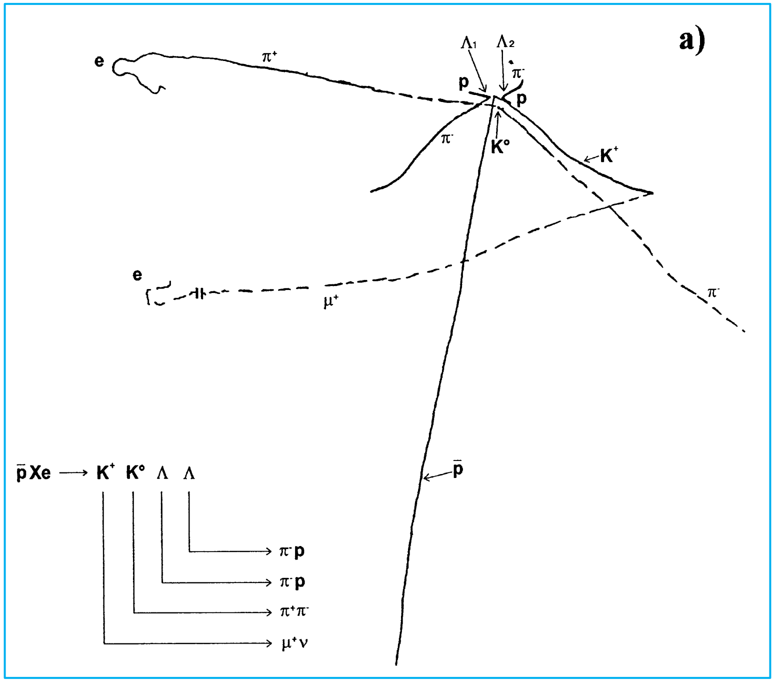
Although observed statistics are very small, their results have indicated a high yield of ~10^{-4}

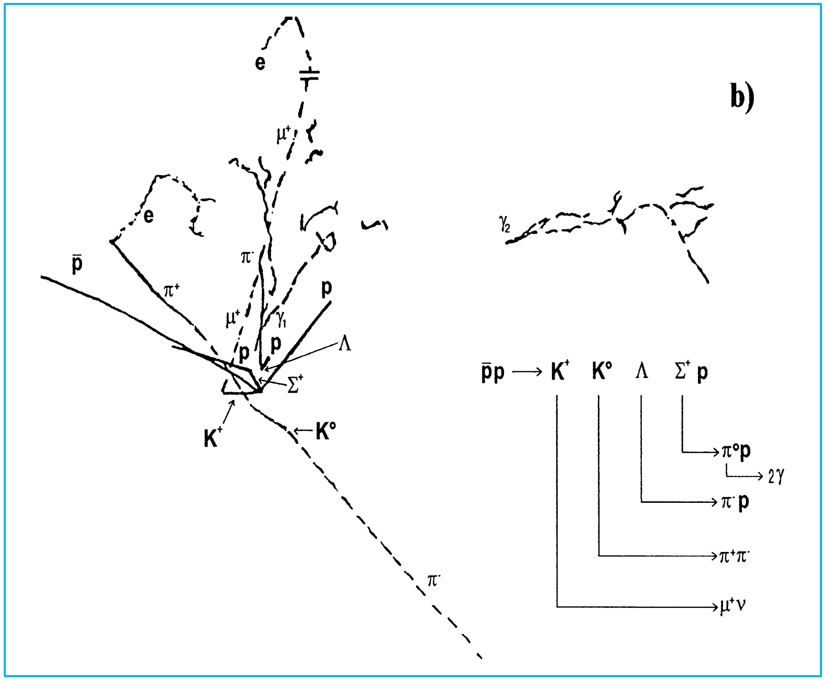
Past Experiments (Cont'd)

DIANA [Phys.Lett., **B464**, 323 (1999).]

- p^{bar}Xe annihilation
- p=<1GeV/c p^{bar}-beam @ ITEP 10GeV-PS
- **700-liter Xenon bubble chamber, w/o B-field**
- 10^6 pictures → 7.8×10^5 p^{bar}Xe inelastic → 2.8×10^5 p^{bar}Xe @ 0-0.4GeV/c

Channel	events	yield (10^{-4})
K^+K^+X	4	0.31+/-0.16
K^+K^0X	3	2.1+/-1.2



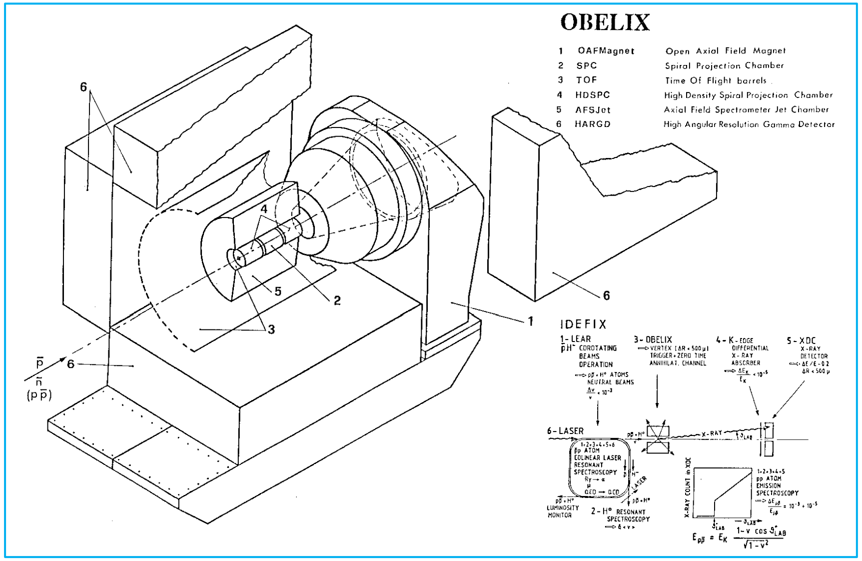


Past Experiments (Cont'd)

OBELIX ('86~'96) [Nucl. Phys., **A797**, 109 (2007).]

- $\bar{p}^{4}$He annihilation
- stopped p^{bar} @ CERN/LEAR
- gas target (^{4}He@NTP, H_2@3atm)
- **cylindrical spectrometer w/ B-field**
- spiral projection chamber, scintillator barrels, jet-drift chambers
- $2.4\times10^5/4.7\times10^4$ events of 4/5-prong in ^{4}He
- p_{min} = 100/150/300MeV/c for π/K/p

channel	events	yield (10^{-4})
$K^+K^+\Sigma^-\Sigma^-p_s$	34+/-8	0.17+/-0.04
$K^+K^+\Sigma^-\Sigma^+n\pi^-$	36+/-6	2.71+/-0.47
$K^+K^+\Sigma^-\Lambda n$	16+/-4	1.21+/-0.29
$K^+K^+K^-\Lambda nn$	4+/-2	0.28+/-0.14



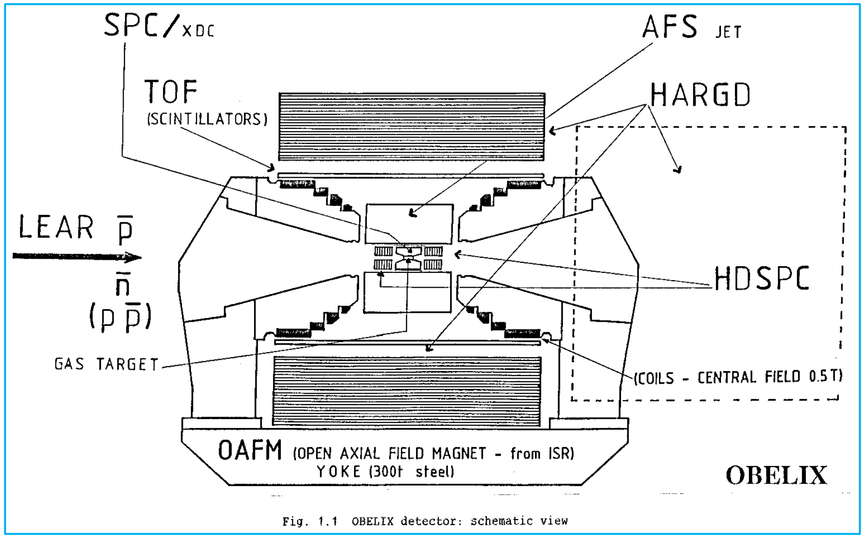


Fig. 1.1 OBELIX detector: schematic view

they discuss the possibility of formation and decay of
K^-K^-nn and K^-K^-pnn bound system

K^-pp Production with p^{bar} at rest

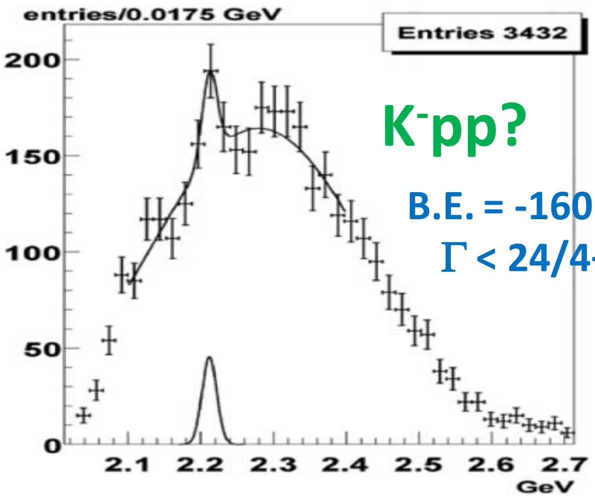
We can also measure K^-pp production
with the dedicated detector, simultaneously!

$$\overline{p} + {}^3He \rightarrow K^0 + K^- pp$$

OBELIX@CERN-LEAR

NP, A789, 222 (2007).

$$\overline{p} + {}^4He \rightarrow K^- pp + X$$
$$\rightarrow \Lambda + p$$



Λ-p invariant mass

K^-pp?

B.E. = -160.9+-4.9 MeV
Γ < 24/4+-8.0 MeV

From several stopped-p^{bar} experiments, the inclusive production yields are:

$$R(\overline{p}p \rightarrow K\overline{K}) \sim 5 \times 10^{-2}$$

Very simply, the expected K^-pp yield is larger than the K^-K^-pp production!

The double-strangeness production yield of ~10^{-4} makes it possible to explore the exotic systems.

Experimental Approach

How to Measure?

we focus the reaction:

$$\overline{p} + {}^{3}He \rightarrow K^{+} + K^{0} + X \quad (X = K^{-}K^{-}pp)$$

(although K^-K^-pp decay modes are not known at all,)

we assume the most energetic favored decay mode:

$$K^{-}K^{-}pp \rightarrow \Lambda + \Lambda$$

final state = $K^+K^0\Lambda\Lambda$

We can measure the K^-K^-pp signal **exclusively**

by detection of all particles, $K^+K^0\Lambda\Lambda$, using $K^0 \rightarrow \pi^+\pi^-$ mode

We need
wide-acceptance detectors.

Expected Kinematics

K^+K^0X momentum spectra

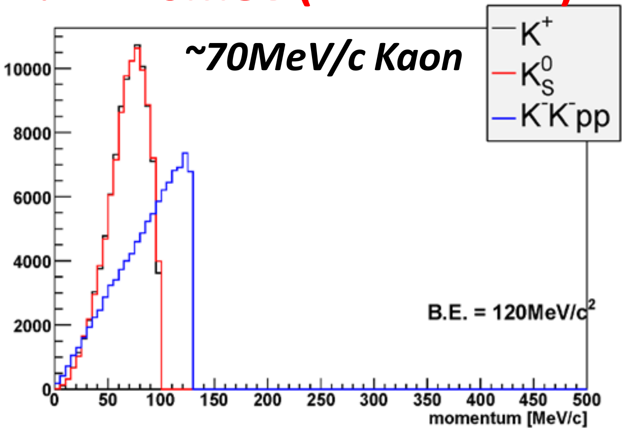
$$\overline{p} + {}^3He \rightarrow K^+ + K_S^0 + K^-K^-pp$$

assumptions:

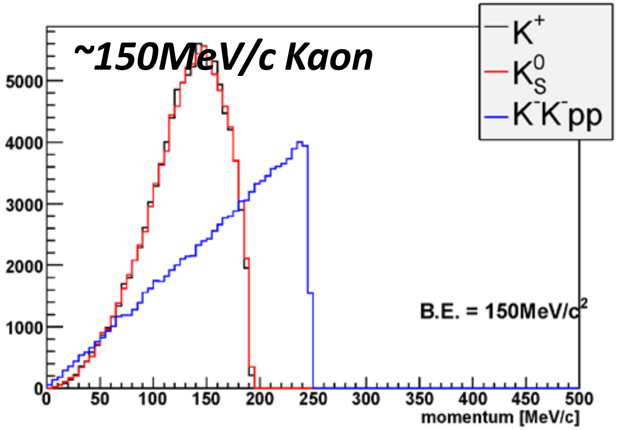
✓widths of $K^-K^-pp = 0$

✓isotropic decay

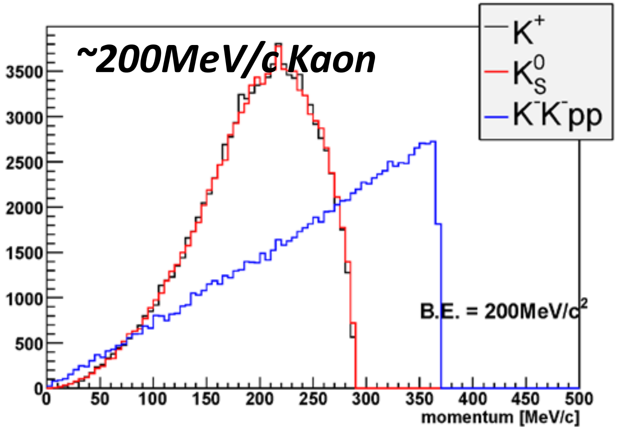
B.E=120MeV (th.+11MeV)



B.E=150MeV



B.E=200MeV



In the K^-K^-pp production channel, the kaons have very small momentum of up to 300MeV/c, even if B.E.=200MeV.

We have to construct low mass material detectors.

~200MeV/c π from K^0_S, ~800MeV/c Λ, ~700MeV/c p from Λ, ~150MeV/c π from Λ

Procedure of the K^-K^-pp Search

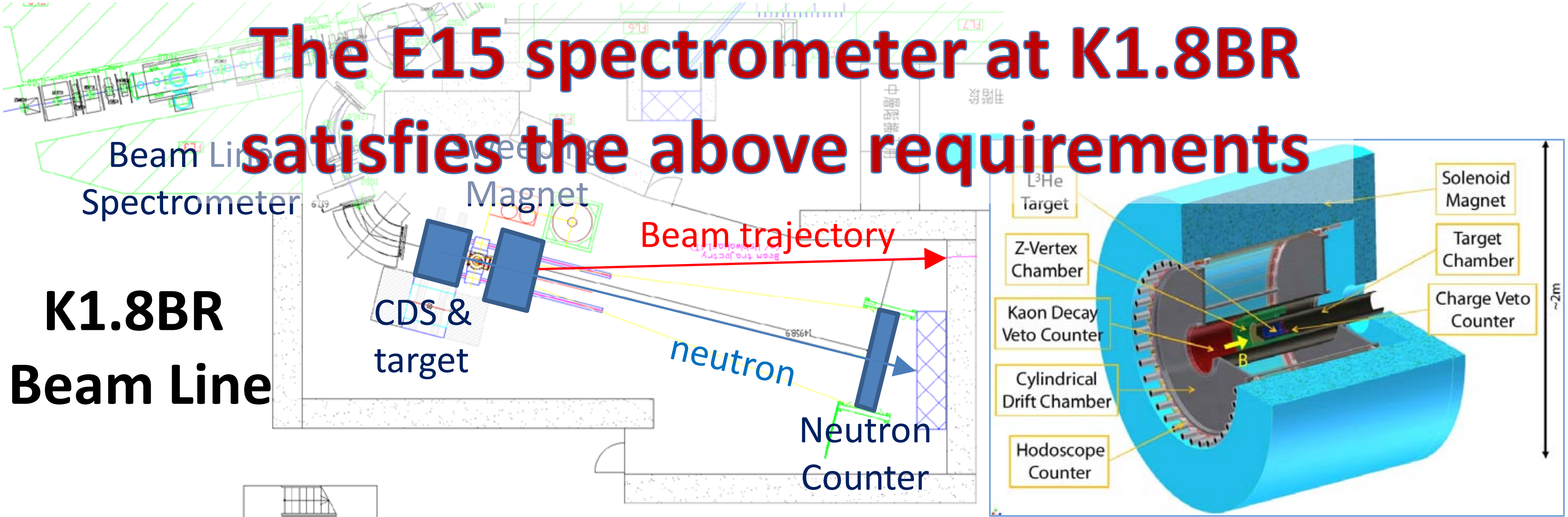
key points of the experimental setup

- high intensity p^{bar} beam
- low mass material detector
- wide acceptance detector

methods of the measuremt

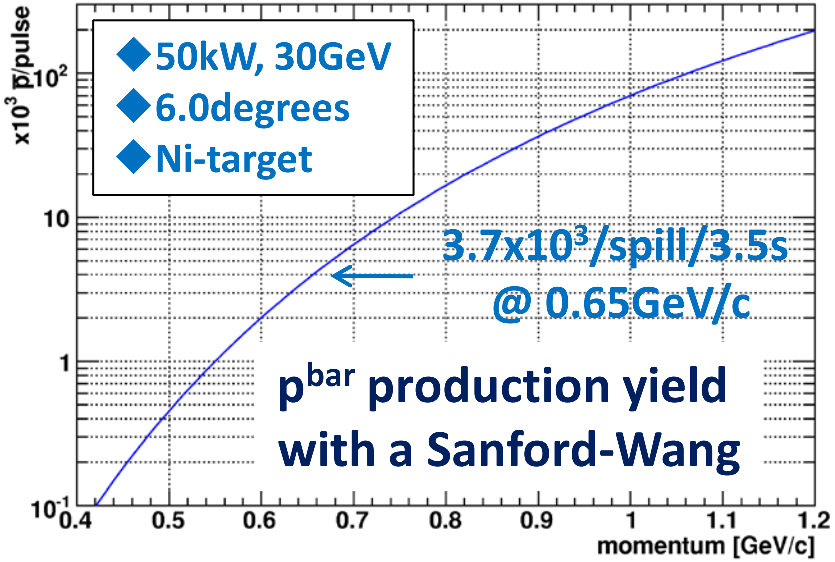
- (semi-inclusive) $K^0_SK^+$ missing-mass w/ Λ-tag
- (inclusive) $\Lambda\Lambda$ invariant mass
- (exclusive) $K^0_SK^+\Lambda\Lambda$ measurement

The E15 spectrometer at K1.8BR satisfies the above requirements



Beam-Line

We would like to perform the proposed experiment at J-PARC K1.8BR beam line



◆50kW, 30GeV
◆6.0degrees
◆Ni-target

3.7×10^3/spill/3.5s @ 0.65GeV/c

p^{bar} production yield with a Sanford-Wang

p^{bar} stopping-rate evaluation by GEANT4

Incident Beam

●momentum bite : +/-2.5% (flat)

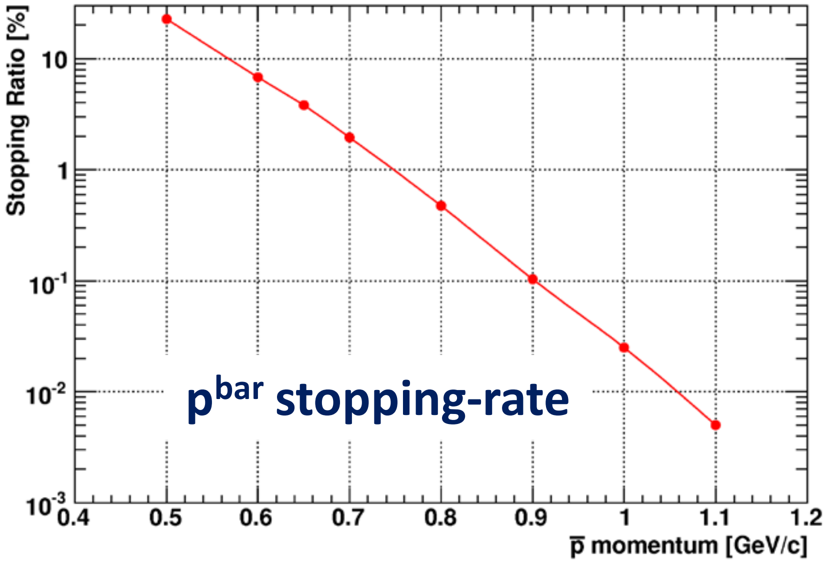
●incident beam distribution : ideal

Detectors

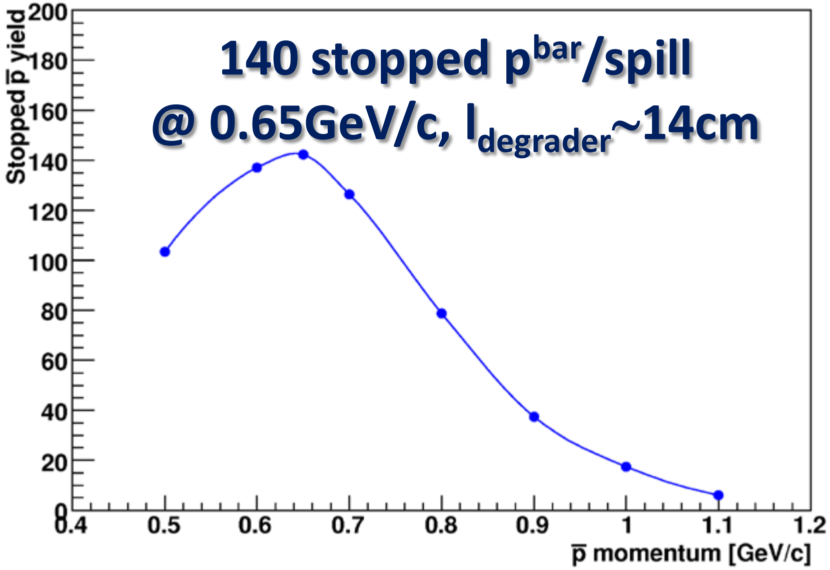
●Carbon Degrader : $\rho=1.99 g/cm^3$

●Plastic Scintillator : $l=1cm$, $\rho=1.032 g/cm^3$

●Liquid He3 target : $\phi=7cm$, $l=12cm$, $\rho=0.080 g/cm^3$



p^{bar} stopping-rate



140 stopped p^{bar}/spill @ 0.65GeV/c, $l_{degrader}$~14cm

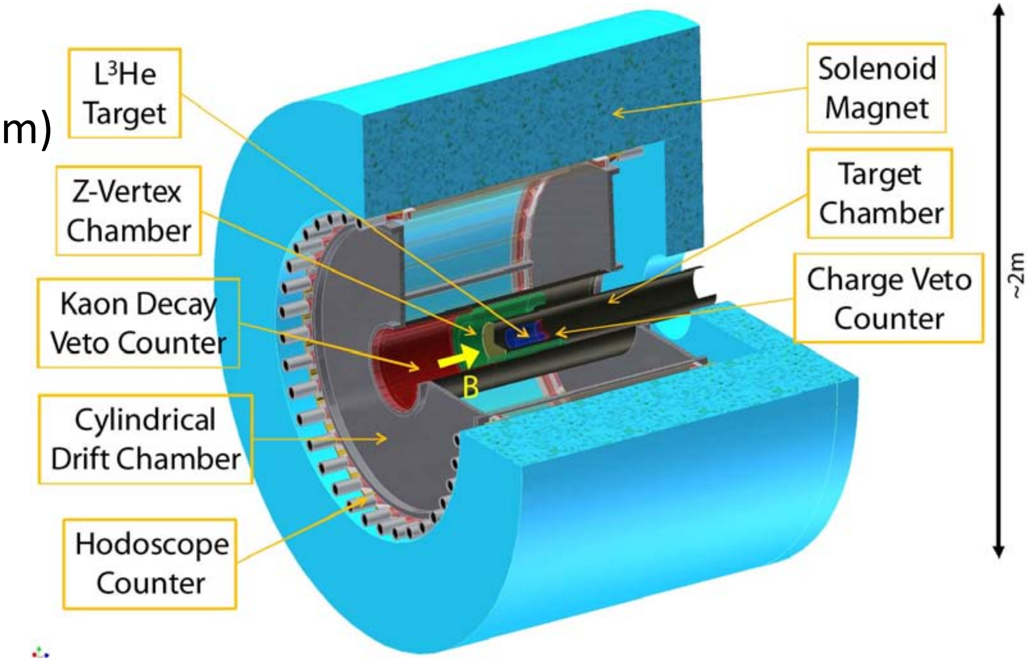
Detector Design

Key points

- ●low material detector system
- ●wide acceptance with pID

E15 CDS @ K1.8BR

- ●B = 0.5T
- ●CDC resolution : $\sigma_{r\phi}$ = 0.2mm
  σ_z's depend on the tilt angles (~3mm)
- ●ZTPC resolution : σ_z = 1mm
  $\sigma_{r\phi}$ is not used for present setup



ZTPC				
Layer	1	2	3	4
radius	92.5	97.5	102.5	107.5

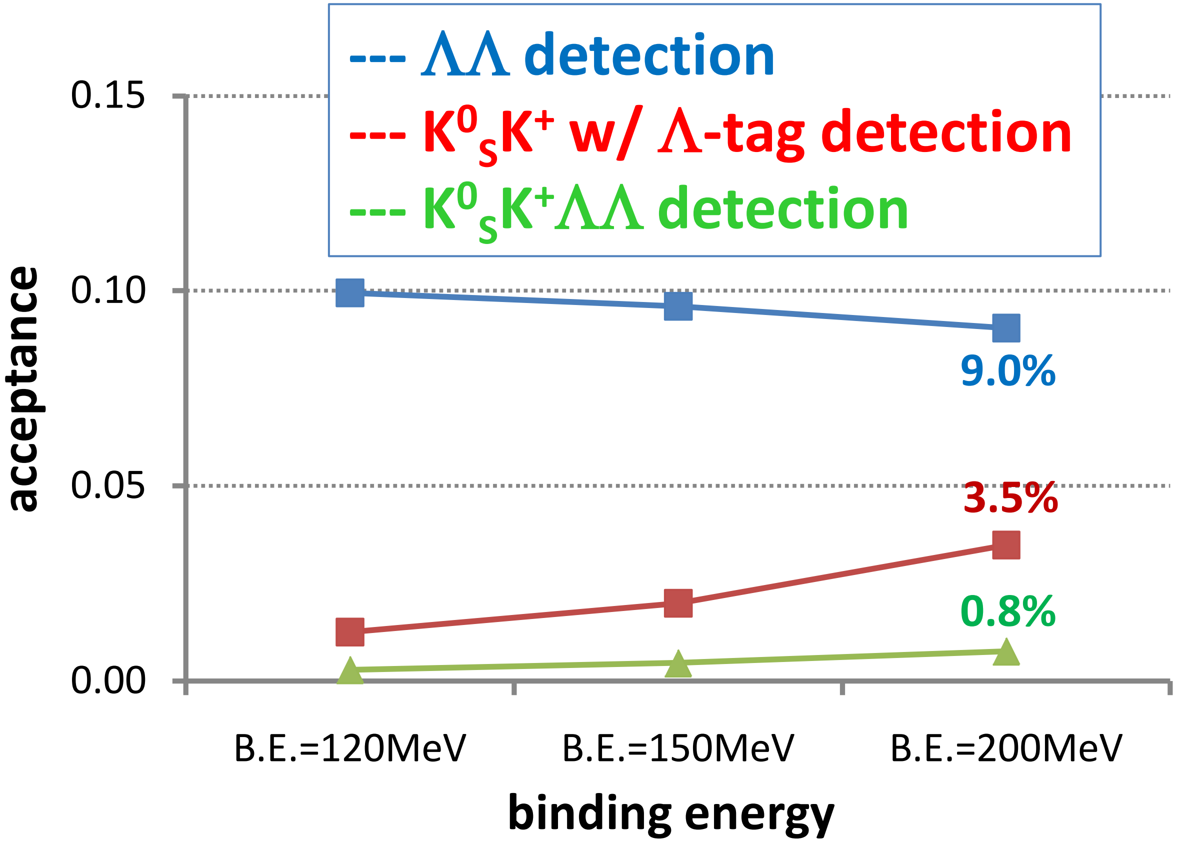
CDC															
Type	A	A'	A	U	U'	V	V'	A	A'	U	U'	V	V'	A	A'
Layer	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
radius	190.5	204.0	217.5	248.5	262.0	293.0	306.5	337.5	351.0	382.0	395.5	426.5	440.0	471.0	484.5

Detector Acceptance

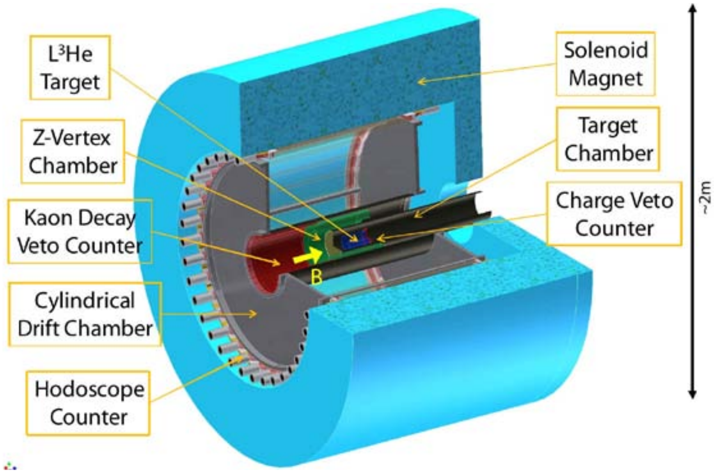
$P^{bar}+{}^{3}He \rightarrow K^{+}+K^{0}_{S}+K^{-}K^{-}pp,$

$K^{-}K^{-}pp \rightarrow \Lambda\Lambda,$

$\Gamma(K^{-}K^{-}pp)=100MeV$



E15 CDS @ K1.8BR



Expected K^-K^-pp Production Yield

- pbar beam momentum : 0.65GeV/c
- beam intensity : $3.7x10^3$/spill/3.5s @ 50kW
- pbar stopping rate : 3.8%

- stopped-p^{bar} yield : 140/spill/3.5s

we assume:

- K^-K^-pp production rate = 10^{-4}
- duty factors of the accelerator and apparatus = 21/24

20% of the upper limit of the double-strangeness production

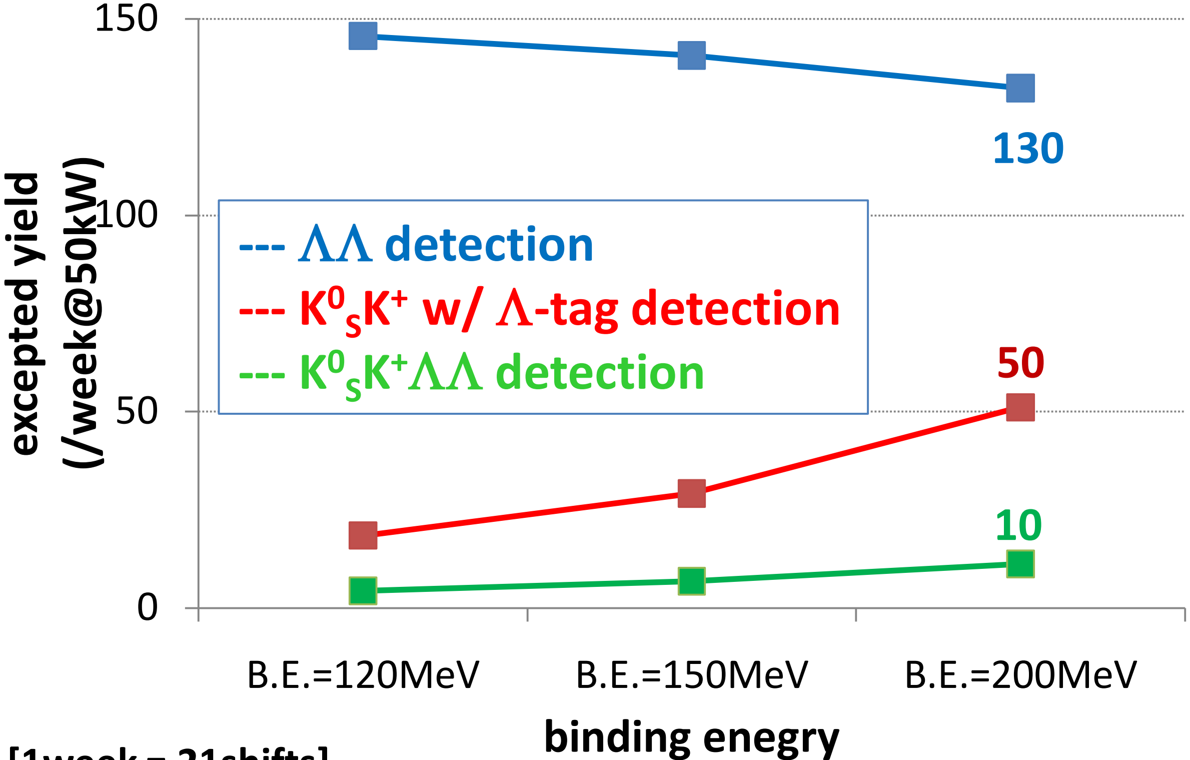
K-K-pp production yield = 300 / day @ 50kW

[1day= 3shifts]

Expected K^-K^-pp Detection Yield

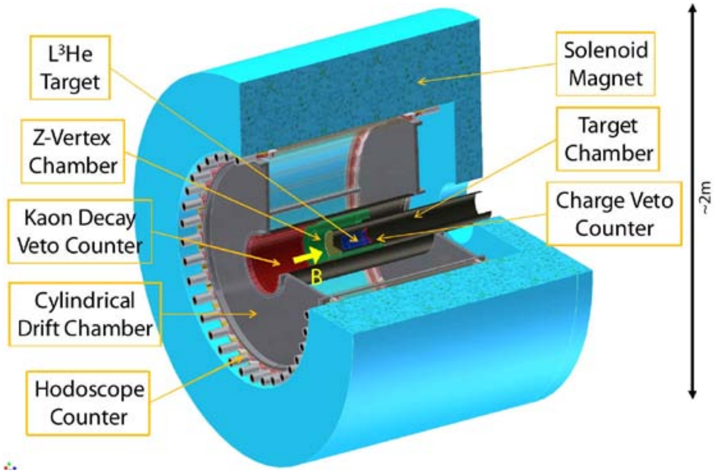
$$P^{bar}+{}^3He \rightarrow K^+ + K^0_S + K^-K^-pp,$$
$$K^-K^-pp \rightarrow \Lambda\Lambda,$$
$$\Gamma(K^-K^-pp)=100\text{MeV}$$

- w/ K^-K^-pp production rate = 10^{-4}
- w/ DAQ and analysis efficiency of 0.7



[1week = 21shifts]

E15 CDS @ K1.8BR



Trigger Scheme

expected stopped-p^{bar} yield = 140/spill

All events with a scintillator hit can be accumulated

p^{bar3}He charged particle multiplicity at rest

CERN LEAR, streamer chamber exp. NPA518,683 (1990).

Nc	Branch (%)
1	5.14 +/- 0.04
3	39.38 +/- 0.88
5	48.22 +/- 0.91
7	7.06 +/- 0.46
9	0.19 +/- 0.08
<Nc>	**4.16 +/- 0.06**

K-K-pp event

Backgrounds

(semi-inclusive) $K^0_S K^+$ missing-mass w/ Λ-tag

◆ **stopped-p^{bar} + ^{3}He → K^0_S + K^+ + K-K-pp**

3N annihilation

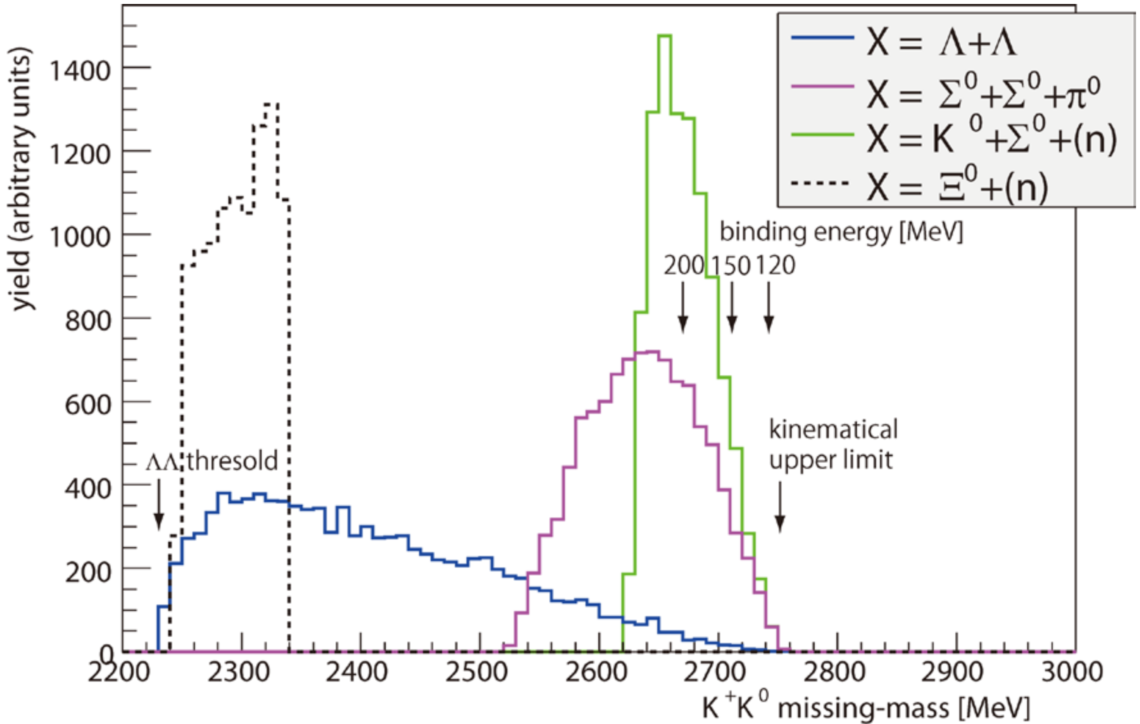
◆ stopped-p^{bar} + ^{3}He → $K^0_S + K^+ + \Lambda + \Lambda$

◆ stopped-p^{bar} + ^{3}He → $K^0_S + K^+ + \Lambda + \Lambda + \pi^0$ …

2N annihilation

◆ stopped-p^{bar} + ^{3}He → $K^0_S + K^+ + K^0 + \Sigma^0$ + (n)

◆ stopped-p^{bar} + ^{3}He → $K^0_S + K^+ + \Xi^0$ + (n) …



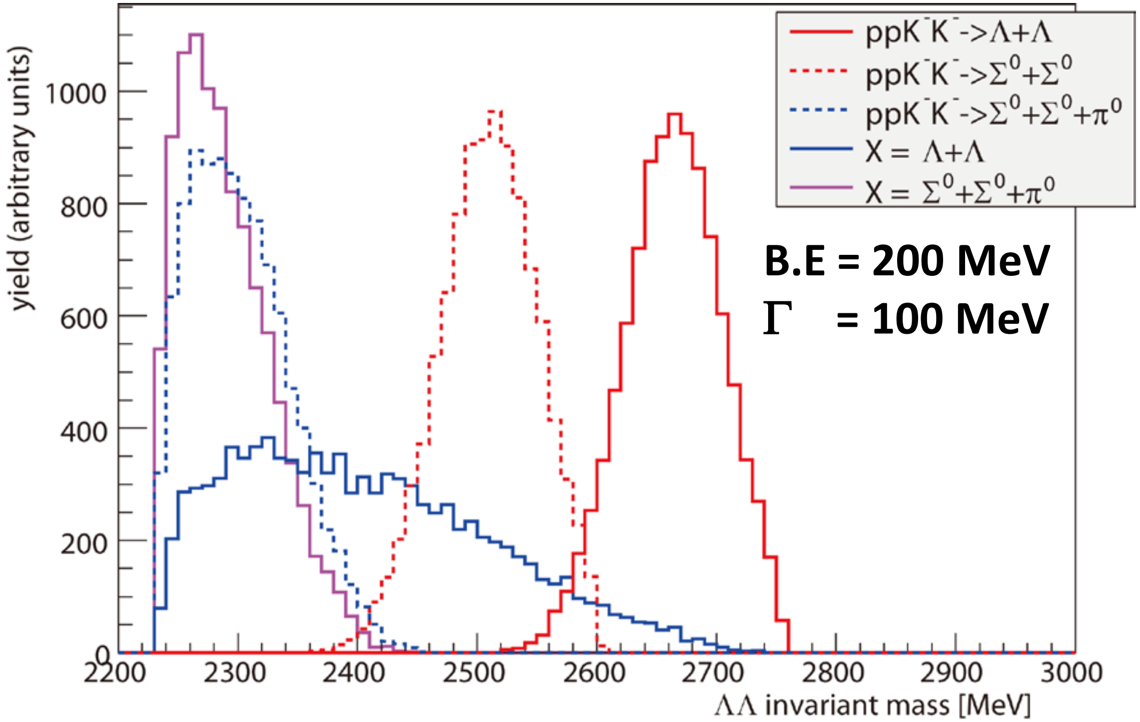
Backgrounds (Cont'd)

(inclusive) $\Lambda\Lambda$ invariant mass

◆ **stopped-p^{bar} + ^{3}He → K^0_S + K^+ + K-K-pp**
→ Λ + Λ

missing 2γ ◆ stopped-p^{bar} + ^{3}He → K^0_S + K^+ + K-K-pp
→ $\Sigma^0 + \Sigma^0$

missing $2\gamma+\pi^0$ ◆ stopped-p^{bar} + ^{3}He → K^0_S + K^+ + K-K-pp
→ $\Sigma^0 + \Sigma^0 + \pi^0$ …



B.E = 200 MeV
Γ = 100 MeV

Expected Spectra

- ●Monte-Carlo simulation using GEANT4 toolkit
- ●reaction and decay are considered to be isotropic and proportional to the phase space
- ●energy losses are NOT corrected in the spectra
- ●w/o Fermi-motion

expected spectra are obtained with the following assumptions:

●production rate:

- **•K^-K^-pp bound-state = 1×10^{-4}**
- **•(3N) $K^-K^-\Lambda\Lambda$ phase-space = 5×10^{-5}**
- **•(3N) $K^+K^0\Sigma^0\Sigma^0\pi^0$ phase-space = 5×10^{-5}**
- **•(2N) $K^+K^0K^0\Sigma^0(n)$ phase-space = 3×10^{-4}**

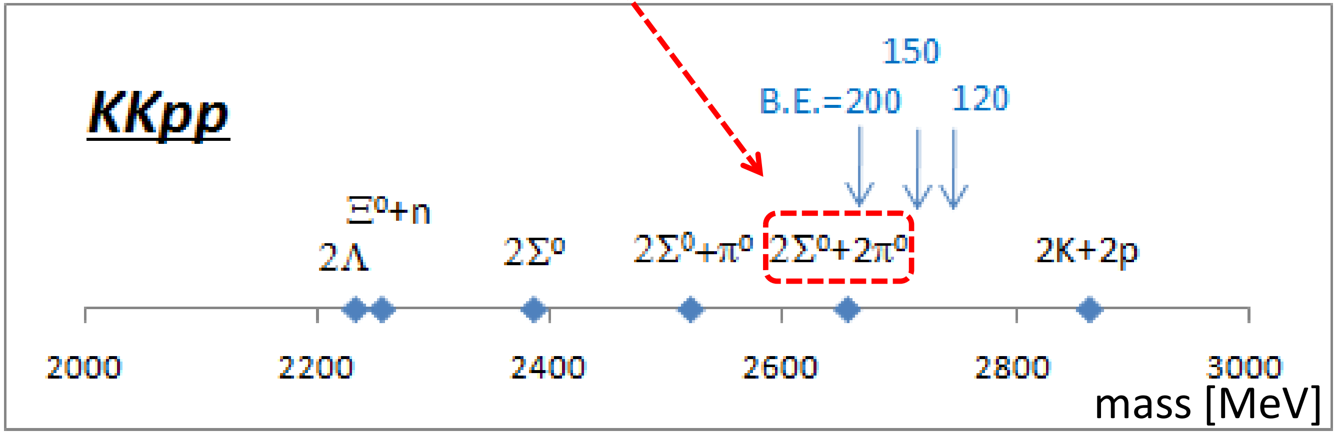
- ➢ **total yield :** upper limit of $p^{bar}A \rightarrow KKX$, 5×10^{-4}
- ➢ **3N :** 20% of total yield, and 3N:2N = 1:3
- ➢ **K^-K^-pp yield :** 20% of total yield

Expected Spectra (Cont’d)

- **branching ratio of K^-K^-pp:**
  - **BR($K^-K^-pp \rightarrow \Lambda\Lambda$) = 0.25**
  - **BR($K^-K^-pp \rightarrow \Sigma^0\Sigma^0$ = 0.25**
  - **BR($K^-K^-pp \rightarrow \Sigma^0\Sigma^0\pi^0$) = 0.5**

➢ **non-mesonic : mesonic = 1 : 1**

because the $\Sigma\Sigma\pi\pi$ decay channel expected as the main mesonic branch of the K^-K^-pp state could decrease due to the deep binding energy of the K^-K^-pp

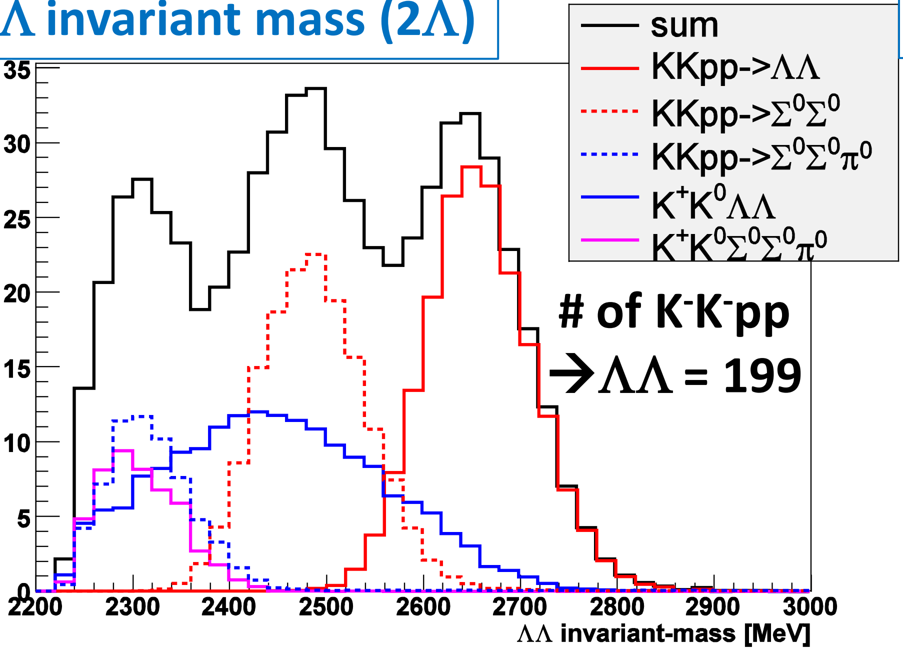


Expected Spectra @ 50kW, 6weeks (126shifts)

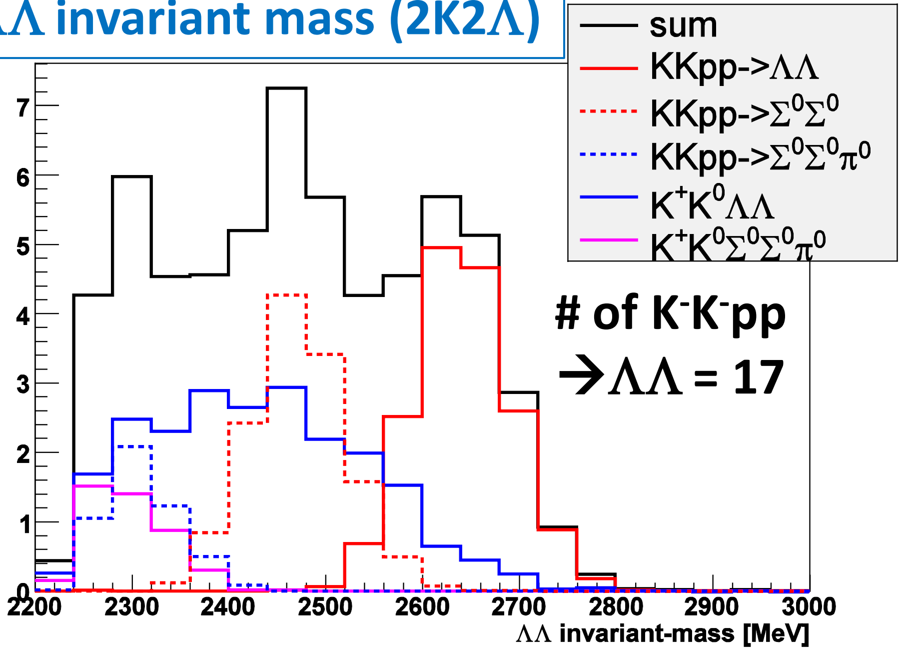
$\bar{p} + {}^3He \rightarrow K^+ + K^0 + \boxed{\Lambda + \Lambda} + X$

$\bar{p} + {}^3He \rightarrow \boxed{K^+ + K^0 + \Lambda + \Lambda} (+X\ )$

ΛΛ invariant mass (2Λ)



ΛΛ invariant mass (2K2Λ)

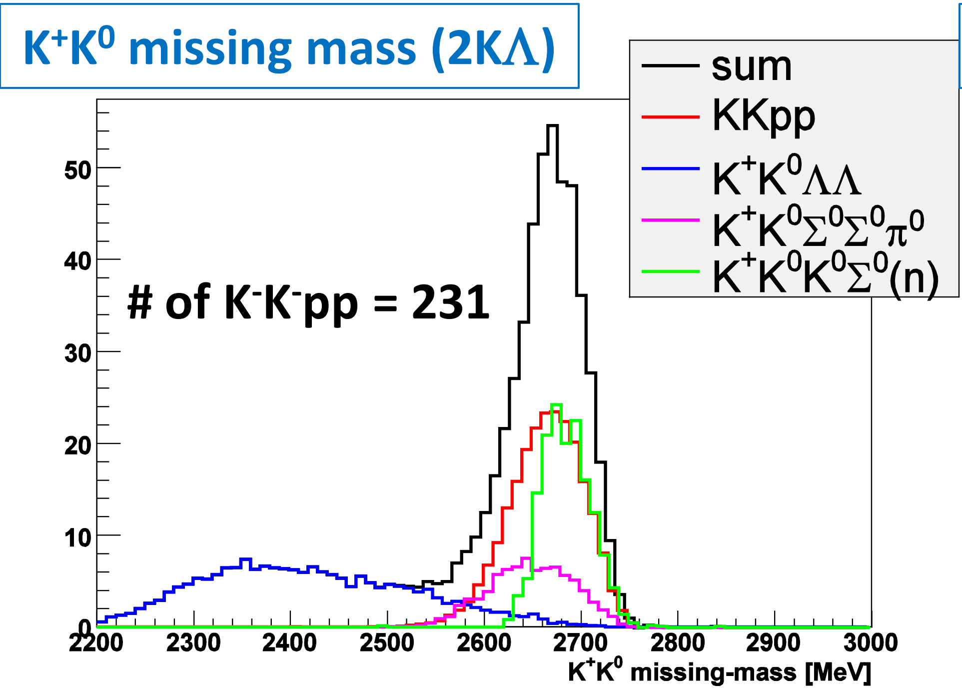


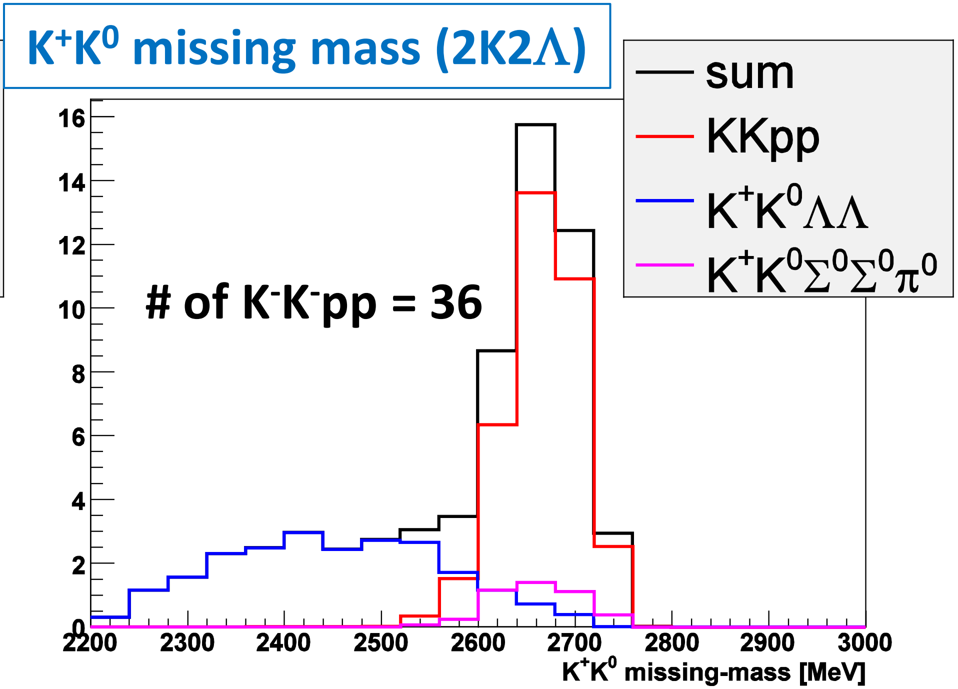
In the ΛΛ spectra, we cannot discriminate the K-K-pp → ΛΛ signals from the backgrounds clearly, if we assume the above parameters.

Spectra @ 50kW, 6weeks (126shifts) (Cont'd)

$\bar{p} + {}^{3}He \rightarrow \boxed{K^{+} + K^{0} + \Lambda} + X$

$\bar{p} + {}^{3}He \rightarrow \boxed{K^{+} + K^{0} + \Lambda + \Lambda} (+X\ )$


K^{+}K^{0} missing mass (2KΛ)

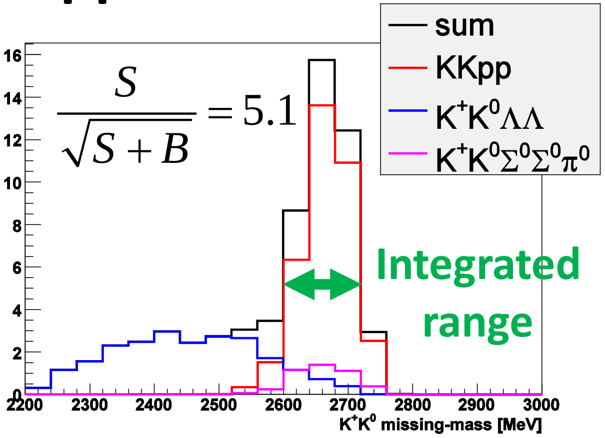

K^{+}K^{0} missing mass (2K2Λ)

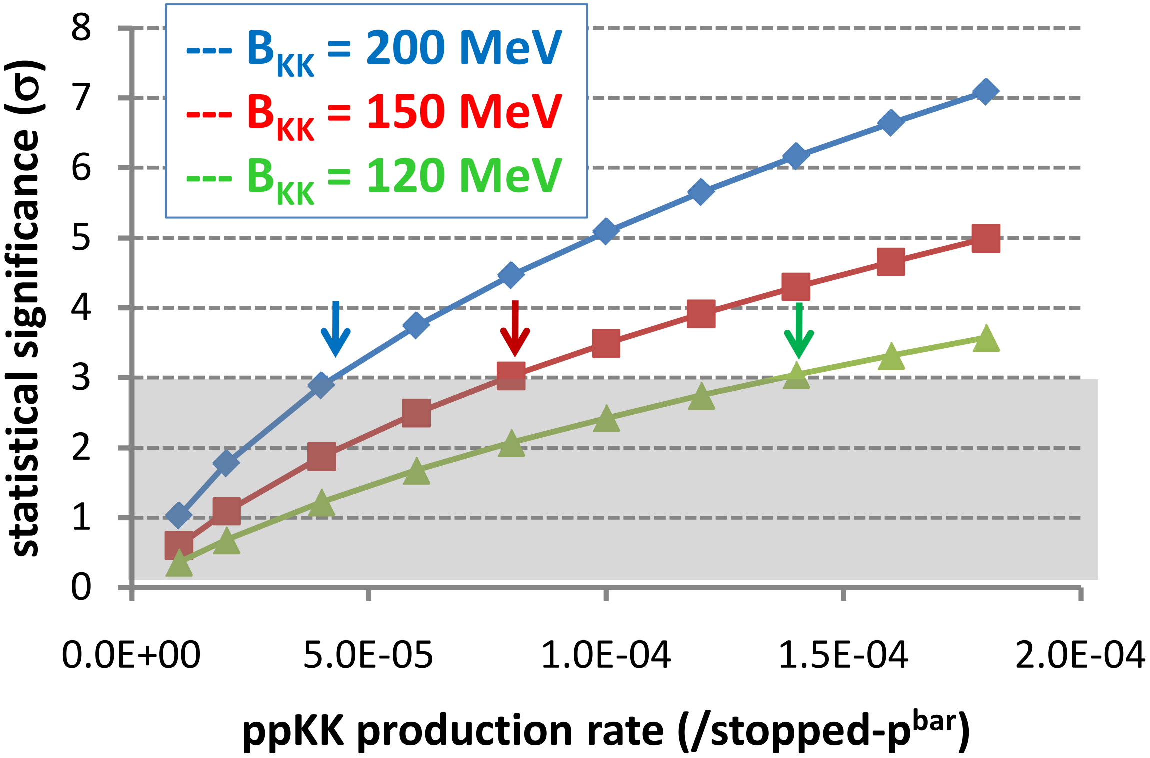
The K^{0}K^{+} missing mass spectroscopy with ΛΛ is attractive for us because we can ignore the 2N-annihilation, even though the expected statistics are small.

Sensitivity to the K^-K^-pp signal @ 50kW, 6weeks (126shifts)

- **the K^-K^-pp production rate is varied**
- **but the background yields are constant as used above**
- significance [S/sqrt(S+B)] is obtained in 2600 – 2720 MeV

ppK^-K^- rate = 1×10^{-4}





Summary

Summary

- **We will search for double anti-kaon nuclear bound states by pbar annihilation on 3He nuclei at rest, using the $p^{bar} + {}^{3}He \rightarrow K^{+} + K^{0} + X$ ($X = K^{-}K^{-}pp$) channel.**

- The produced $K^{-}K^{-}pp$ cluster will be identified with missing mass spectroscopy using the $K^{+}K^{0}$ channel with a Λ-tag, and invariant mass analysis of the expected decay particles from the $K^{-}K^{-}pp$ cluster, such as $\Lambda\Lambda$ by using the E15 spectrometer at the K1.8BR beam line.

- **We are preparing the proposal to J-PARC now.**

However, there are problems.

●The assumption of the K^-K^-pp production yield is not realistic, because the yield of 10^{-4} is very optimistic assumption and the maximum upper limit.

●The past measurement of the OBELIX group, which is our baseline of the assumptions, is very doubtful experimentally, because they could NOT reconstruct the $\Lambda \rightarrow p\pi^-$ channel. *(This channel is used as fundamental test of spectrometer performances.)*

●So we are reconstructing our strategy from the basics, e.g., measurement of

$p^{bar}+d \rightarrow K^0+\Lambda(1405)$

which has never been tried, and also

$p^{bar}+{}^3He \rightarrow K+\Lambda(1405)+N$.