Proposal for J-PARC 50 GeV Proton Synchrotron

# A search for deeply-bound kaonic nuclear states by in-flight $^3$He$(K^-, n)$ reaction

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## Abstract

We propose to perform an experimental search for deeply bound kaonic states using $^3$He target by the in-flight kaon reaction, both the invariant mass and missing mass spectroscopy with design resolution of 37 MeV/$c^2$ (FWHM) and 20 MeV/$c^2$ (FWHM), respectively.

Since, the interaction between $K^-$ and proton is confirmed to be strongly attractive[1], one can assume that $\Lambda(1405)$ would be a bound state between $K^-$ and proton. This assumption is naturally extended by Akaishi and Yamazaki[2] to the light nucleus, such as $^3$He, $^4$He and $^8$Be, to investigate whether $K^-$ forms bound state with light nuclei or not. Their coupled channel calculation predicted $K^-$ bound states to have narrow widths and large binding energies.

The KEK-PS E471[3] experiment was motivated with the possible formation of deeply bound kaonic nucleus $K^-ppn$ with isospin zero, which is expected to be detected most easily. The result is much different from the prediction in mass (twice bigger in terms of binding energy) and in isospin (T=1 instead of 0). To understand the difference between the data and the theory, study on simple system would be most efficient.

The second simplest kaonic nuclear system is $\bar{K}$ bound with two nucleons, such as a $K^-pp$ state. Theoretically, binding energy and width is calculated to be 48 MeV and 61 MeV[4], respectively. Experimentally, this reaction allows to perform missing mass study using primary neutron, and invariant mass spectroscopy via the decay chain $K^-pp \rightarrow \Lambda p \rightarrow \pi^- pp$, simultaneously. Detailed study of this simple system would be a doorway towards investigation of the kaon bound states in heavy nucleus and/or a multi-kaon bound system in a nucleus.

# Summary of the Proposed experiment

| | | |
|---|---|---|
| Beamline | : | K1.1 or K1.8BR |
| Primary beam | : | 30 GeV, 9 $\mu$A proton |
| Secondary beam | : | 1.0 GeV/c $K^-$ |
| Beam intensity | : | $0.8 \times 10^6$ per pulse (K1.1) |
| | : | $1.4 \times 10^6$ per pulse (K1.8BR) |
| Reaction | : | In-flight ($K^-$,$n$) |
| Detector | : | Cylindrical Detector system (NEW) |
| | : | Beam line spectrometer for K1.1 or K1.8BR (NEW) |
| | : | Neutron Counter (exist) + Beam sweeping magnet (exist) |
| Target | : | Liquid $^3$He |
| Beam time | : | two weeks for commissioning |
| | | +5.5 weeks at K1.8BR (assuming full PS intensity) or |
| | | +2.5 weeks at K1.1 (assuming full PS intensity) |
| Estimated Yield | : | 1000 $K^-pp$ events |

This proposal is closely related with another proposal to the J-PARC 50 GeV-PS, "Precision spectroscopy of Kaonic Helium 3 $3d \rightarrow 2p$ X-ray". Both experiment will use same beam line and same $^3$He target.

# 1 Purpose of the Proposed Experiment

The final goal of the proposed experiment is to investigate $\bar{K}$ meson property in nuclei. The $\bar{K}N$ interaction is pretty much puzzling, because of the existence of sub-threshold resonance $\Lambda(1405)$, which is very difficult to explain by naive quark model. Therefore, many theoretical models are proposed, such as double pole resonance [5]. Another explanation is to assume that it is $K^-$ and proton bound state due to the strong interaction, which is the natural theoretical extension from the strongly attractive nature seen between $K^-$ and proton[1]. If deeply bound kaonic state really exists as it is predicted in reference[2], we can extend our experimental study to the ultra high dense matter, $<\bar{q}q>$ condensation in vacuum, and so on. To understand in detail, we must search other possible candidates in wide range. If we assume $\Lambda(1405)$ to be a $K^-p$ bound state, the next simplest bound state should be $K^-pp$. This state can be produced directly from a $^3$He nucleus via in-flight $(K^-, n)$ interaction. Therefore we propose to perform an experimental search for deeply bound kaonic states in a $^3$He target by the in-flight kaon reaction.

# 2 Experiments to search for deeply bound kaonic nucleus

The first report related with deeply bound kaonic nuclear is presented by the experiment KEK-PS E471 [3] as a proton missing mass spectrum obtained by TOF method. This experiment is motivated by recent Akaishi and Yamazaki's prediction using coupled channel calculation [2] that the $K^-$ (or $\bar{K}$) can form a meta-stable state inside nuclei, based on the assumption that the $\Lambda(1405)$ to be a $K^-p$ bound state. According to their calculation, mono-energetic neutron can be observed via the reaction,

$$(K^- \ ^4\mathrm{He})_{\mathrm{atomic}} \rightarrow \text{“}K^-ppn\text{”}^{T=0} + n \tag{1}$$

with the binding energy of about $\sim$ 100 MeV. However, narrow mono-energetic peak formation in the proton energy spectrum, instead, via the

$$(K^- \ ^4\mathrm{He})_{\mathrm{atomic}} \rightarrow \mathrm{S}^0(3115)^{T=1} + p \tag{2}$$

reaction, named as a strange tribaryon $\mathrm{S}^0(3115)$. The observed state should have isospin $T = 1$, charge $Z = 0$ and mass $M_{\mathrm{S}^0} \sim 3117$ MeV/$c^2$, which locates below the threshold energy by about $\sim$ 200 MeV with the small width (<20MeV). The result is much different from the original theoretical prediction by energy and isospin, so that observed peak is not assigned as a kaon bound state and denoted as $\mathrm{S}^0$. It is suggested that the peak in the proton spectrum could be formed by kaon absorption by “at-rest $NN$-pair” in $^4$He nucleus, and may not need deeply bound kaonic state nor $\mathrm{S}^0$ formation [7]. It is also true that the E471 setup was designed to detect neutron spectrum, so that there was no tracking device and no proton-oriented TOF counters to obtain inclusive spectrum. Therefore, upgraded experiments E549/E570 were performed to confirm and to observe the width of $S^0(3115)$, until the end of year 2005. Analysis of newly accumulated data is in progress.

Another experiment to search for the Kaon bound system in nucleus is performed by FINUDA at DAΦNE using slow kaon, which created by the decay of $\phi$ meson, stopped in three kind of light nuclear targets ($^6$Li, $^7$Li and $^{12}$C) [8]. They focus on the $K^-pp$ state formation as a result of the fragment reaction, which will decay to $\Lambda$ + proton. Therefore invariant mass reconstruction is possible. The reconstructed invariant mass distribution shows a structure below $K^-pp$ threshold. One interpretation is that it is the signal of $K^-pp$ bound state, but the similar interpretation with [9] is noted by itself, namely reduction of the invariant mass due to the final state interaction after the two-nucleon absorption reaction $K^-NN \rightarrow \Lambda N$. Another criticism. sometimes quoted to the result is that the acceptance of the given spectrum is too narrow for the clear determination of the background below the suggested peak structure.

There is the other experiment using in-flight $K^-$ reaction by Kishimoto group. Independent to Akaishi and Yamazaki, Kishimoto also predicted possible existence of kaonic bound state in nuclei using simple optical model calculation and estimated the production cross section. The experiment was performed firstly at BNL and successively at KEK (KEK-PS E548) with $^{16}$O and $^{12}$C as a target [10]. In this experiment, neutrons were measured by an array of neutron counter placed 6.8 m downstream of the target and the momentum of neutron is measured by time-of-flight method. Then the missing mass is calculated. The resulting nucleon spectrum clearly shows that one of the advantage of in-flight ($K^-$,N) reaction is less background compared with ($K^-$,N) reaction at rest. They indicate the signals below the sub-threshold energy region. Hirenzaki group calculated the spectral function at the experimental condition showing that the smooth tail formation in the sub-threshold region can be produced simply due to the attractive potential with absorption in the chiral unitary model, and small peak structure could be barely visible at the deepest energy in the phenomenological potential, which is not consistent with the interpretation given in Ref. [10].

At any rate, there is no global understanding on the sub-threshold kaon resonances nor any definitive reason why the resonances should be interpret as deeply bound kaonic state except for its energy, even if it exist. The situation could only be resolved by the systematic experimental studies.

It would be worth while to mention that there are several proposals or running experiments to obtain confirmative and/or systematic study, such as FINUDA and AMADEUS at DAΦNE, and FOPI at GSI.

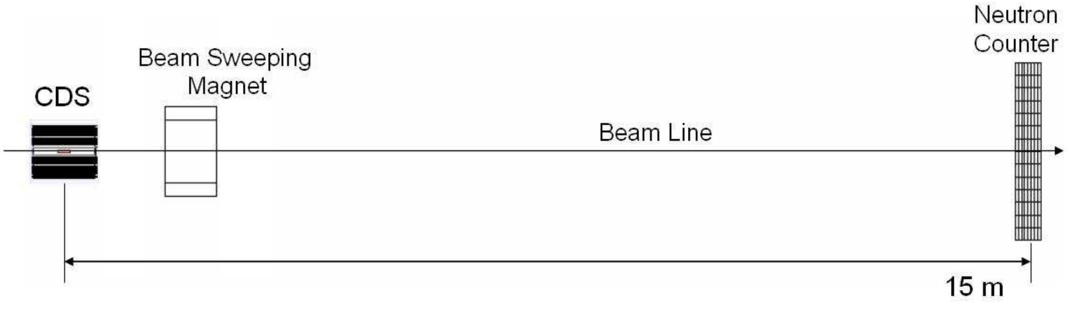

Figure 1: Detector setup for the proposed experiment

# 3 Experimental Method and Apparatus for the proposed experiment

Basic concept of the detector for the proposed experiment is described as follows. Incoming K$^-$ beam is identified and its momentum is analyzed by the beam spectrometer. Then beam is shooting onto $^3$He target. Once reaction happened, neutron from (K$^-$,n) reaction is detected by forward Time of Flight (TOF) wall for neutron. Charged particles from the decay of $K^-pp$ bound state will be tracked by the tracking detector around target. To maximize tracking efficiency of the decay product of $K^-pp$ bound state, we will construct Cylindrical Detector System (CDS). CDS consists of Cylindrical Drift Chamber (CDC) for charged particle tracking and Cylindrical Detector Hodoscope (CDH) for the trigger and particle identification. Incident kaon which is not interacted with the target will be bending away from the neutron counter acceptance by dipole magnet which is placed just after CDS. To reduce fake triggers caused by decay of beam kaons after the target, Beam Veto counter will be installed between CDS and beam sweeping magnet. Schematic view of the detector configuration is shown in Figure 1.

## 3.1 Choice of Beam Momentum

Momentum of the incident Kaon is chosen to maximize $K^-N$ reaction rate. Figure 2 shows cross section of $K^-$N reaction, where we will be able to see peak structure around incident beam momentum at 1.0 GeV/$c$. On the other hand, as you can see in Figure 3, beam intensity is increasing monotonically as a function of incident kaon momentum but up to 1.1 GeV/$c$, where is the maximum momentum we will be able to use for both K1.1 and K1.8BR beam line. Therefore, it is very natural to choose beam momentum at the point where physical cross section is maximized. We will use 1.0 GeV/$c$ momentum kaon for the proposed experiment.

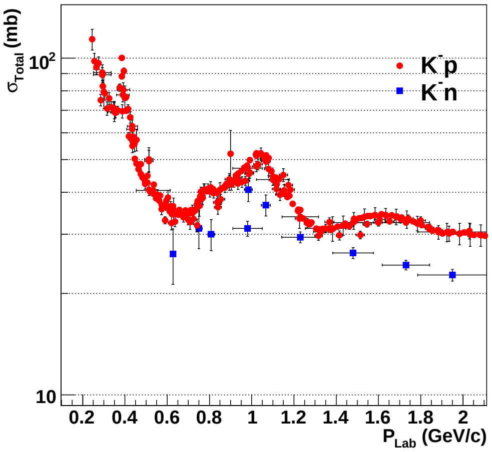

Figure 2: Total cross section of Kaon Nucleon reaction

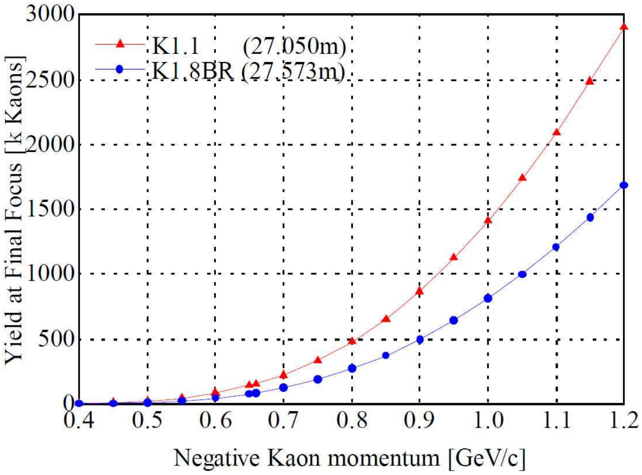

Figure 3: Beam intensity per pulse as a function of incident kaon momentum.

## 3.2 Beam Line Spectrometer

A part of beam line magnets together with beam tracker, kaon identification detector and time zero detector will be a components of the beam line spectrometer.

### 3.2.1 Beam Line Tracker

Trajectory of the incident kaon beam will be tracked with beam line tracker. The momentum of the kaon will be analyzed with this tracking information together with beam optics of beam line magnet. The momentum for the incident kaon will use for the proposed experiment is 1.0 GeV/$c$ so that thickness of the material in beam line tracker will be minimized, because multiple scattering of 1.0 GeV/$c$ koan is not negligible to analyze momentum with good precision. Moreover, beam intensity where we would like to install our tracker upstream of the beam line is estimated to be around 2.5 M particles per pulse (0.7s) with proton energy and intensity in J-PARC proton synchrotron as 30 GeV/9$\mu$ A. It corresponds to 3.5 MHz hits rate. Once this intensity and energy recovery of the J-PARC happened, this number will be increased about factor three higher. Therefore tracking chamber must satisfy two requirements. One is the tracker thickness in term of material budget must be minimize. The other is it should be handle up to 10 MHz event rate, including some safety margin. One possible candidate of the detector is very fine pitch wire chamber, the other possibility is tracking detector using Gas Electron Muiliplier (GEM) technique. For example, thickness of the one tracking detector made with GEM is estimated to be 1.0x$10^{-3}$ % radiation length per tracking plain. For the momentum analysis, we need to measure direction of the beam before and after the dipole magnet, so that we need at least 4 tracking planes. Finally, coulomb multiple scattering angle is calculated as 0.7 mrad with 1.0 GeV/$c$ kaon. Basic R&D project for the beam line chamber has been started and in progress.

### 3.2.2 Beam Identification counters

Four counters will be installed between just after Beam line spectrometer and surface of target. One is Time Zero counter (T0) which will be segmented plastic scintillator counters. The second is Kaon beam identify counter, which will be threshold Cherenkov counter using Aerogel as a radiator. This counter will be installed 60 cm from the surface of the target. Third one is the beam position detector just before the target to reject background line, $K^-$ converted to $K^0$ due to charge exchange reaction in counters before the target (for example in T0), and that $K^0$ decay to $\pi^+\pi^-$. This pions from $K^0$ decay could interact with target therefore it will be a source of background for the experiment. Finally, to reduce background trigger rate in CDH, mainly coming from kaon decay after its identified as kaon, we will install veto counter, Beam Decay Veto counter, which is made by scintillator with shape of tube, between Cherenkov counter and target. Main purpose for this detector is to reject charged particle from $K^-$ decays before the target. Note that inner diameter for beam pipe counter made will be 6cm, which is much bigger than the size of beam which is about 0.6 cm (RMS) in horizontal and 0.3 cm (RMS) in vertical direction respectively. Therefore direct hit of kaon beam must be negligible.

## 3.3 Target

Target for the proposed experiment is a liquid $^3$He target. In the experiment at KEK-PS E471, E549 and E570, we developed and built a liquid $^4$He target. Therefore basic idea and technique to build such a liquid He target is in our hand in principle. One of the requirements to the target is as follows. The target will be placed in the middle of CDS. The charged particle from decay of bound state $K^-pp$ need to coming out from the target. However, for example, the momentum of the $\pi^-$ from $\Lambda$ which is q decay product from $K^-pp$ state is about 130 MeV/c in average. Therefore the energy loss in the material around the target is not negligible and it could be a source of the systematic uncertainty in the final analysis. Thus, we will need to build target cell as thin as possible. Figure 4 shows the first design of the $^3$He target which is now one of the candidate designs for the proposed experiment. First of all, the target is kept inside the vacuum to isolate heat exchange from outside the world. The innermost layer is made from a PET bottle in which liquid $^3$He will be filled. The second layer is a thermal radiation shield made with aluminum. The thickness of aluminum is now designed to be 100 $\mu$m. And the target is covered by the envelope made with 800 $\mu$m thickness of CFRP. In total material budget associated with target is estimated to be 0.5% in terms of the radiation length. Note that this number dose not including the thickness of $^3$He target itself.

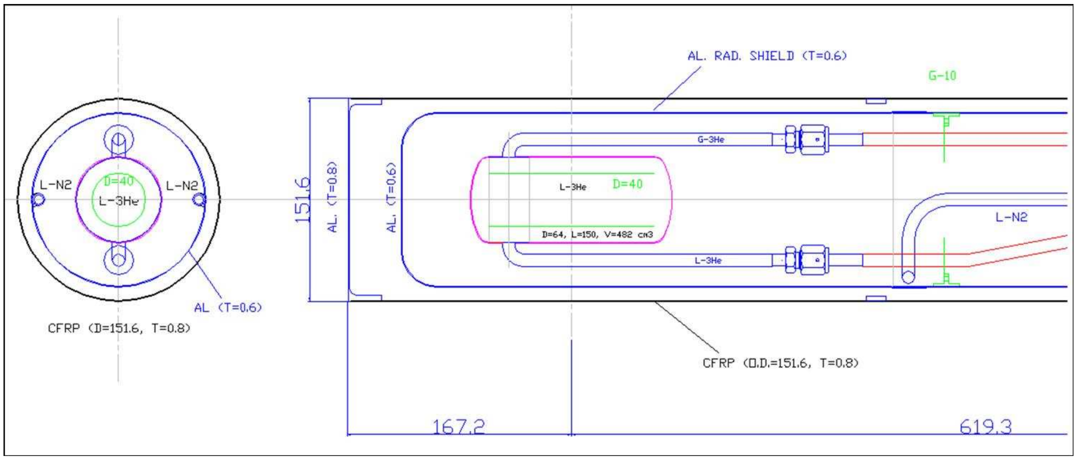

Figure 4: Design of $^3$He target cell

However, still there are many of the mile stones to complete. Basic R&D project for the target construction is in progress.

## 3.4 Cylindrical Detector System (CDS)

Efficient reconstruction of $\Lambda$ with high resolution will be a key measurement for the proposed experiment. Therefore, CDS is designed to maximizing detection efficiency and reconstructed mass resolution of $\Lambda$. The concept of the detector system is as follows. CDS will consist of 3 components, Solenoid magnet, Cylindrical Drift Chamber (CDC) for the charged particle tracking and Scintillation Counter Hodoscope (CDH) for the charged particle trigger.

It is well known that momentum resolution of the CDC, which takes into account special resolution of the detector, is expressed as follows[14].

$$\delta P = \sqrt{\left(\frac{\delta P_T}{\sin\theta}\right)^2 + \left(P_T \frac{\cos\theta}{\sin^2\theta}\delta\theta\right)^2}, \tag{3}$$

where $P_T$ is the transverse momentum expressed by $P_T = Psin\theta$, $\delta P_T$ is the transverse momentum resolution, and $\delta\theta$ is the polar angle resolution. Transverse momentum resolution is expressed as follows

$$\frac{\delta P_T}{P_T} = \sqrt{\left(\frac{\delta P_T}{P_T}\right)_m^2 + \left(\frac{\delta P_T}{P_T}\right)_{MS}^2} \tag{4}$$

where $(\delta P_T/P_T)_m$ represents resolution from measurement error of special position and $(\delta P_T/P_T)_{MS}$ is the effect from multiple coulomb scattering. Each component will be described as follows.

$$\left(\frac{\delta P_T}{P_T}\right)_m = \frac{P_T \sigma_{r\phi}}{0.3L^2B}\sqrt{A_N} \tag{5}$$

$$\left(\frac{\delta P_T}{P_T}\right)_{MS} = \frac{0.05}{\beta B}\sqrt{\frac{1.43}{LX_0}} \tag{6}$$

where

$$\begin{aligned}
\sigma_{r\phi} &= \text{special resolution in the } r-\phi \text{ plane per wire (m)}\\
L &= \text{lever arm length (m)}\\
B &= \text{magnetic field (T)}\\
A_N &= \frac{720}{N+5}\text{where N is the number of sampling points}\\
\beta &= \text{velocity of the particle}\\
X_0 &= \text{radiation length of chamber gas.}
\end{aligned} \tag{7}$$

On the other hand, over all angular resolution, $\delta\theta$ is given as follows.

$$\delta\theta = \sqrt{(\delta\theta)_m^2 + (\delta\theta)_{MS}^2} \tag{8}$$

where each components are given as follows.

$$(\delta\theta)_m = \frac{\sin^2\theta}{L_{arm}}\delta_z \tag{9}$$

$$(\delta\theta)_{MS} = \frac{0.015}{p\beta c}\sqrt{\frac{L_{arm}}{X_0}} \tag{10}$$

where, $\delta z$ is special resolution of $z$ coordinate, $L_{arm}$ is an arm length of measurement points. Detail study has been done to optimize these parameters, and finally we choose parameters for the CDC as follows. Inner radius of the CDC will be 8.0 cm, which is the constraint from size of the target. Outer radius is now designed to be 40.0 cm which maintain lever arm in the tracking system to be 30 cm. To install trigger scintillator around CDC, we defined diameter of the CDS magnet to be 1 m. Finally, the CDS magnet will be operated 0.5 T magnetic field which is chosen to compromise $\Lambda$ triggering efficiency and final invariant mass resolution of $\Lambda$. In figure 5, expected momentum resolution of the $\pi$ and proton with given parameters for CDC are shown. Then the reconstructed mass distribution of the $\Lambda$ with given CDC parameters is shown in figure 6.

In Figure 7, schematic view of CDS together with beam line detectors are shown. Parameters defined for the CDC is including in the detector simulation based on GEANT4 model. Farther evaluation of the detector performance and trigger efficiencies etc. are evaluated using this detector simulation. Figure 8 shows typical event of $K^-pp$ bound state production in $^3\text{He}(K^-,n)$ reaction. Reconstructed invariant mass resolution from simulation is achieved as 37 MeV/$c^2$.

## 3.5 Neutron Counter (NC)

The simplest way to detect neutron with this energy is Time of Flight (TOF) method using plastic scintillators. TOF distance is optimized to be 15m from the target which

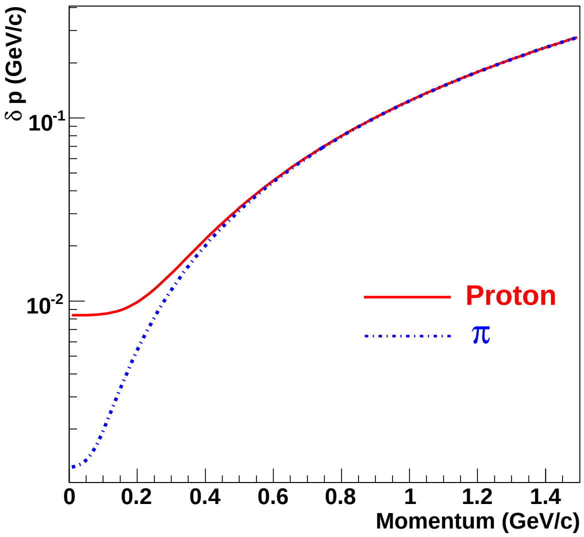

Figure 5: Expected momentum resolution of Pion and Proton which emitted from center of the target with $\theta$=90°

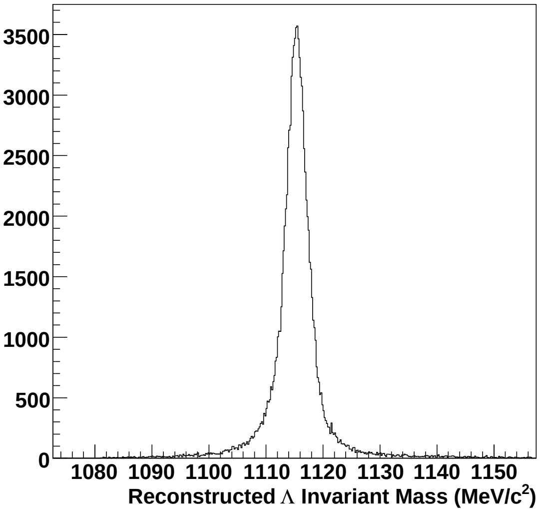

Figure 6: Reconstructed $\Lambda$ mass distribution where $\Lambda$ is generated as a decay product of $K^- pp$.

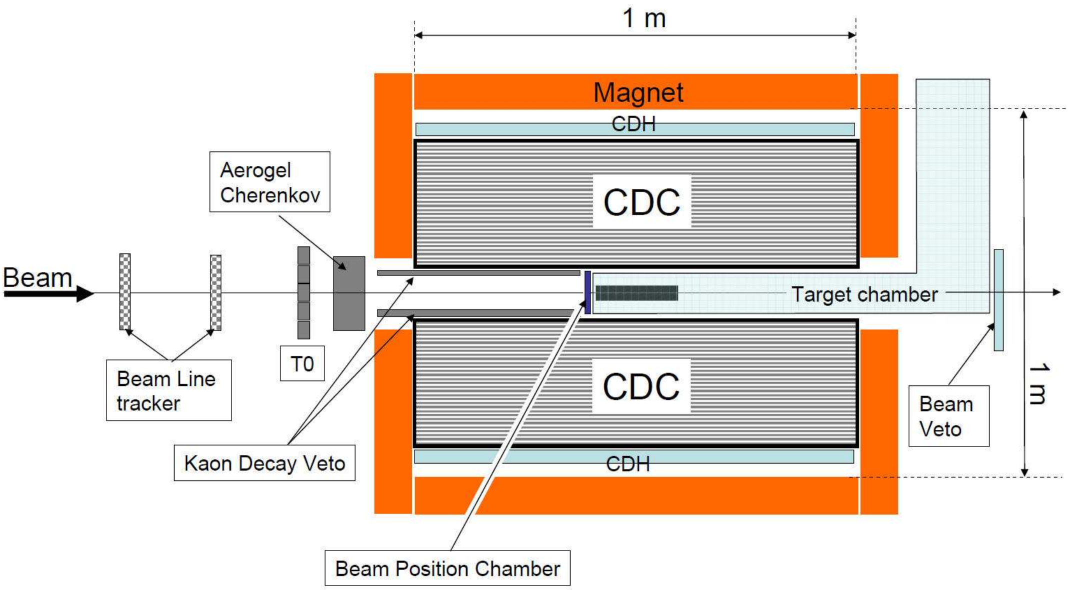

Figure 7: Schematical view of CDS together with beam line counters

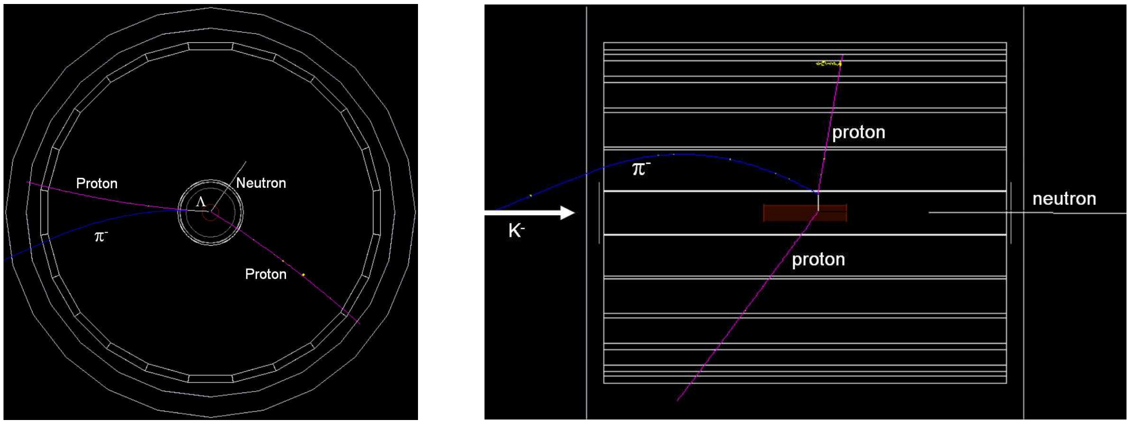

Figure 8: Typical event of $^3$He$(K^-, n)K^-pp$ in simulation

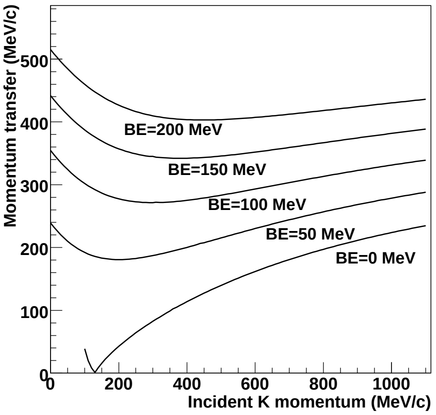

Figure 9: Momentum transfer as a function of beam momentum

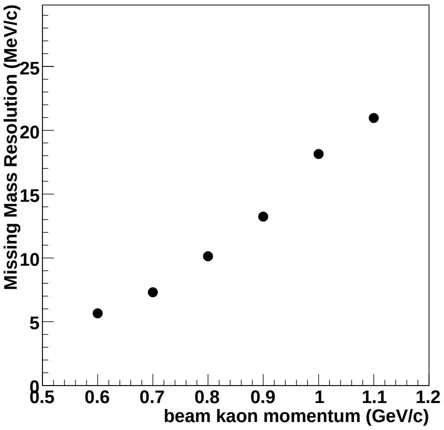

Figure 10: Missing mass resolution as a function of beam momentum

allowed us to achieve total missing mass resolution of 20 MeV/$c^2$ (FWHM). Missing mass resolution is slightly depending on momentum of incident kaon. Figure 9 shows momentum transfer of $^3$He$(K^-, n)ppK^-$ which indicates how much neutron gain momentum from the reaction. Figure 10 shows missing mass resolution as a function of momentum of incident kaon, where we assume ToF resolution of the system as 120 ps. Flight length of 15 m satisfy our goal of missing mass resolution with any momentum of kaon. It is interesting to note that, if we shorten flight path length to 10 m, then missing mass resolution is changed to be 64 MeV/$c^2$. For the detector itself, we are planning to use neutron counter used by KEK-PS E549 experiment with configuration optimized for the proposed experiment. Neutron counter consist of array of scintillator counters. Each scintillator counter has dimension of 20cm x 5cm x 150 cm with two Photo Multipliers (PMT) attached on both long side of scintillator. Figure 11 shows

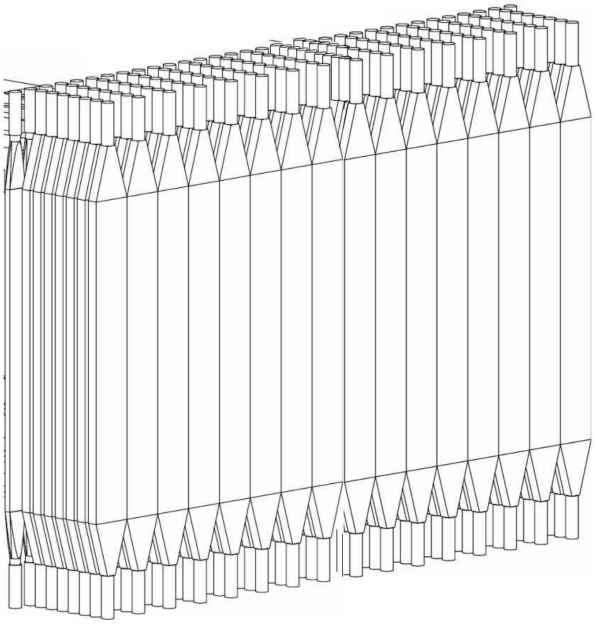

Figure 11: The configuration of neutron counter.

configuration of the Neutron counter for the proposed experiment. We are going to reconfigure this scintillators as stuck of 14 in wide × 8 in depth to maximize neutrons acceptance coming from the target.

### 3.6 Beam Sweeping Magnet

As described in previous section, neutron counter is placed 15 m away from center of the target with zero degree with respect to beam direction. To guarantee sufficient neutron detection efficiency, i.e. to reduce background hits created by the decay of kaons in beam, beam kaon must be swept out from the acceptance of neutron counter, otherwise close to 1 MHz charged particle is expected to hit on the neutron counter. Various possibilities are evaluated as sweeping magnet. Figure 12 shows hit position of the beam at $z$=15 m, where surface of the neutron counter, with different field in the dipole magnet, 0.5 T·m, 0.75 T·m, 1.0 T·m and 1.5 T·m, respectively. Box on the figure represents acceptance of neutron counter. In case of 0.5 T·m magnetic field applied in the magnet, beam kaon is clearly hit on the edge of neutron counter. This study shows that at least 0.75 T·m field strength are necessary to sweep beam away from NC counter acceptance. One of the candidates of the dipole magnet will be a KURAMA spectrometer magnet which placed now at KEK-PS K2 beam line. Note that The B$l$ of KURAMA magnet is 0.88 T·m.

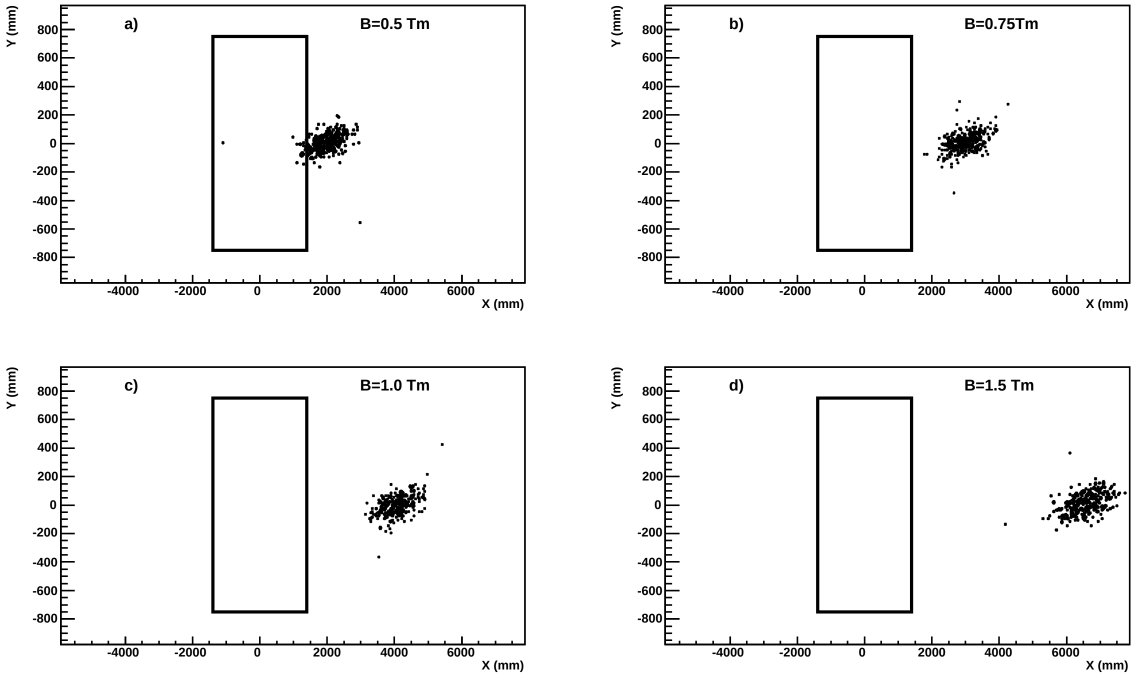

Figure 12: Beam Profile on the 15 m away from the target center, where the surface of neutron counter is. Strength of the magnetic field in beam sweeping magnet is different in each figure.

## 3.7 Trigger

At least four types of hardware triggers will be implemented in the proposed experiment.

1. **GoodBeam** incident beam particle identified as Kaon with Aerogel counter just before the target "and" no hit on kaon decay veto.
2. **GoodCDC** two or more slats hits on CDH, i.e more than equal two charged particle reached to ourter diameter of CDC.
3. **BeamVeto** No hit on charged veto counter which is installed just after the CDS. No charged particle emitted to zero degree with respect to beam direction from target.
4. **NCHit** There is a hit on Neutron counter.

Experimental trigger will be logical "and" for all above four condition.

# 4 Yield Estimation

The production cross sections of the $K^-pp$ bound state in the $(K^-, n)$ reaction with $^3$He is not known and moreover, theoretical calculation is also not done yet for $^3$He. The only calculation available is $(K^-, p)$ reaction on $^{12}$C target[11]. Here, to have rough estimation of production cross section of the kaonic nucleus in $^3$He$(K^-, n)$ reaction, we will make following assumptions.

- We assume $\sigma_{(K^-,p)} = \sigma_{(K^-,n)}$.
- Here, $A$ is the number of nucleon in target nucleus. We assumed that total cross section in nucleus A will satisfy following relation,$\sigma_K A = \sigma_{KN} \times A$.
- Then the estimated production cross section for $^3$He will be, $\sigma_{^3He} = \sigma_{^{12}C} \times 3/12$

Finally, estimated total cross section of $^3$He$(K^-, n)$ using above assumptions are summarized in Table 1.

| | $(d\sigma/d\Omega)_{(K^-,N)}[\mu b/sr]$ | | | | |
|---|---|---|---|---|---|
| | calculation based on | | | | |
| Target | Chiral Unitary | Phenomenology | Ref. [12] | Ref. [13] | comment |
| $^{12}C$ | 425 | 65 | 47 | 100-490 | table listed in Ref.[11] |
| $^3$He | 106 | 16 | 11 | 25-122 | naive estimation |

Table 1: Production total cross section of Kaonic nucleus

Therefore, conservative estimation of the cross section, $\sigma_{^3\mathrm{He}(K^-,n)K^-pp}$=10$\mu$ b/sr is used for farther event rate estimation. The acceptance of the neutron counter (NC) is estimated to be 19.4 msr. Thickness of $^3$He target is designed as 20 cm with target density of 0.080 g/cm$^3$. Formation probability of $K^-pp$ bound system in $(K^-, n)$ reaction per an incident K$^-$ including NC acceptance is 6.2$\times$10$^{-8}$. Here we assumed that neutron detection efficiency with the neutron counter is 30% and 1/3 of bound $K^-pp$ system decay to $\Lambda$ + proton or $\Sigma^0$ + proton. On the other hand, 47 % of the events will have $\Lambda$ and proton reconstructable in CDC. So total number of event both missing mass and invariant mass spectroscopy will be 1.86$\times$10$^{-9}$ per an incident $K^-$.

Finally, The number of expected yield per shift(=8 hours) are summarized in Table 2 based on full beam intensity expected beam lines both K1.1 and K1.8BR respectively. Here we assumed pulse structure of slow extraction as 3.53s repetition with 0.7s flat top operation.

# 5 Trigger rate estimation

Trigger condition is also satisfied by background events. Therefore the trigger rate from background events must be evaluated to know the trigger rate in the total system. The possible source of background will be listed as follows.

| | K1.1 | K1.8BR |
|---|---|---|
| Number of neutron hit on NC | 637 | 364 |
| $\Lambda + p$ reconstructable in CDC | 63 | 34 |

Table 2: Event estimation of Kaonic nucleus per day for both K1.1 and K1.8BR beam lines.

- Decay of kaon in beam
- Quasi free scattering and reaction
- Two nucleon absorption

In this section, background trigger rate is evaluated in each above three cases using detector simulation based on GEANT4 which described in previous sections.

## 5.1 Decay of kaon in beam

The kaon generated from 60 cm away from the target center. Then those kaons are transported and decay in GEANT4 simulation. We checked trigger condition of the detector. It is interesting that 69% of the back ground trigger comes from decay of K$^-$ gose to $\pi^-\pi^0$ In total, background trigger rate from beam particle is estimated to be $\sim$ 81/pulse and $\sim$ 46/pulse for K1.1 and K1.8BR beam line respectively.

## 5.2 Quasi free scattering and reaction

Following eleven reactions are investigated for the trigger rate estimation, $K^-p \rightarrow K^-p$, $K^-n \rightarrow K^-n$, $K^-p \rightarrow K^0_Sn$, $K^-p \rightarrow K^0_Ln$, $K^-p \rightarrow \Lambda\pi^0$, $K^-p \rightarrow \Sigma^0\pi^0$, $K^-p \rightarrow \Sigma^+\pi^-$, $K^-p \rightarrow \Sigma^-\pi^+$, $K^-n \rightarrow \Lambda\pi^-$, $K^-n \rightarrow \Sigma^0\pi^-$, $K^-n \rightarrow \Sigma^-\pi^0$. In total, the number of event which will satisfy our trigger condition will be 40 and 23 for K1.1 and K1.8BR beam line, respectively.

## 5.3 Two nucleon absorption

The result of in-flight $(K^-, n)$ experiment previously done at BNL[10] clearly indicates that event from two nucleon absorption seems negligible compared with Quasi free processes.

## 5.4 Summary of trigger rate

Finally, total background rate is summarized in Table 3.

At the experiment, length of flat top is 0.7s, thus the background rate will be $\sim$ 170 Hz and $\sim$100 Hz in K1.1 and K1.8BR beam lines respectively.

|  | K1.1 | K1.8BR |
|---|---|---|
| Decay of kaon in beam | 81 | 46 |
| Quasi free scattering and reaction | 40 | 23 |
| Total | 121 | 69 |

Table 3: Estimation of number of triggers background per pulse for both K1.1 and K1,8BR beam lines

# 6 Beam Time Request

Most of the detectors for the proposed experiment will be newly build, including tracking detector for beam line spectrometer. Therefore, we would like to request significant amount of time for detector commissioning with beam. However, it should be noted that for the detector commissioning, it is not necessary to have full beam intensity. We would like to request two weeks of beam time for the detector commissioning as a first phase of the proposed experiment.

After completion of the detector commissioning, we would like to request beam time for physics run. According to the event rate estimation done in the previous section, number of signals which have all decay product from $K^-pp$ state detected in our detector system will be 63 events per day and 32 events per day, in K1.1 and K1.8BR beam line, respectively. However, we must take into account duty factor of the experiment, which is an avoidable stop of the data taking due to run change, maintenance of target etc. We estimate the factor to be 80%. Therefore the effective event rate will be 50 events per day and 26 events per day, in K1.1 and K1.8BR beam line, respectively.

First goal for the experiment will be to collect 1000 signal from $K^-pp$ bound state which allows us to define the mass of the $K^-pp$ system about a few MeV/$c^2$, if we assume that the mass width of $K^-pp$ bound state to be $\sim$ 20 MeV/$c^2$ which is the case of $K^-pp$ will be a deeply bounded Kaonic nucleus system. To satisfy this requirement, we need to $\sim$ 2.5 weeks and $\sim$ 5 weeks of beam time with full beam intensity of the K1.1 or K1.8BR beam line respectively.

In summary, the requested beam time will be as follows.

- Phase 0: Detector commissioning. We would like to request 2 weeks (42 shifts) in total for this study. Full beam intensity is not required.
- Phase 1: Physics run. Full beam intensity is requested.
  - with K1.1 beam line : 2.5 weeks (∼51 shifts)
  - with K1.8BR beam line : 5 weeks (84 shifts)

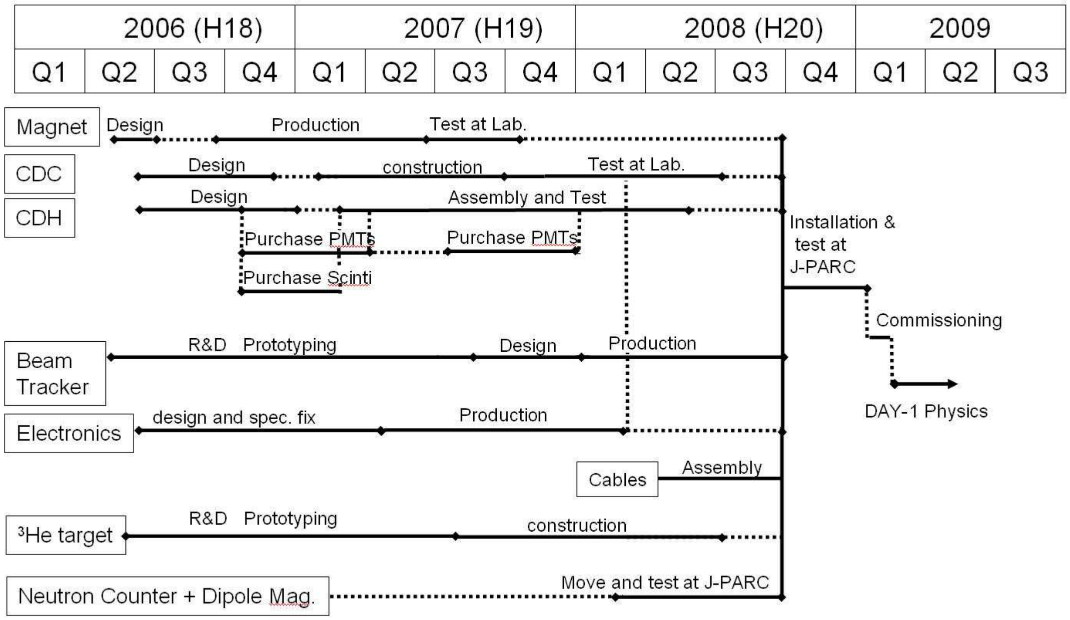

Figure 13: Schedule of preparations for the proposed experiment towards DAY-1.

# 7 Schedule

Figure 13 shows time line of preparation of the proposed experiment. All works should be done by end around Oct-Nov 2008. We are planning to have detector commissioning from December 2008, to preparing commissioning with beam. Therefore, all materials and detectors should be delivered at J-PARC by end of year 2008. We will ready for the detector commissioning with beam from Jan/2009 when we are expected to have first beam in J-PARC.

# 8 Cost estimation

The cost to implement proposed experiment includes tracking detector of beam line spectrometer, CDS, beam counters and cryogenic liquid $^3$He target. Those will be constructed with the budget of the Grant-In-Aid for Priority Areas (Kakenhi), Quark many-body systems with strangeness (2005-2009). Neutron counter, beam sweep magnet and big fraction of readout electronics will be recycled one. The detail cost estimation for are listed in Table 4.

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| Item | cost [JPY] | source |
|---|---:|:---:|
| CDS magnet | 15M | Grant-In-Aid |
| CDS magnet power supply | 10M | Grant-In-Aid |
| CDC | 20M | Grant-In-Aid |
| Beam line tracker | 15M | Grant-In-Aid |
| Electronics for CDC+Beamline tracker | 70M | Grant-In-Aid |
| Scintillator for CDH | 5M | Grant-In-Aid |
| PMTs for CDH | 12M | Grant-In-Aid |
| $^3$He gas | 30M | Grant-In-Aid |
| construction of He target (R&D including) | 15M | Grant-In-Aid |
| Beam line trigger counters | 5M | Grant-In-Aid |
| Cables for readout, HV etc. | 10M | Grant-In-Aid |
| Beam sweep magnet | 0 | exist |
| Neutron Counter + read out electronics | 0 | exist |
| Total | 207M | |

Table 4: Cost estimation

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