The E07 Experiment at J-PARC

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From:	Imai, K. (Kyoto University) Nakazawa, K. (Gifu University) Tamura, H. (Tohoku University)
Title:	Systematic Study of Double Strangeness System with an Emulsion-Counter Hybrid Method
Beam:	1.7 GeV/c K^-; 3×10^5 K^-/spill with $K^-/\pi^- \geq 6$ at 4.8 sec. cycle (spill time 2.0 sec.)
Beam Line:	K1.8 beam line
Detectors:	Nuclear emulsion, double-sided Si strip detectors, Ge detectors (Hyperball-J), Scintillating fiber detecters, KURAMA magnet, drift chambers, plastic counters
Time Requested:	150 hours for tuning the beam line and detectors 600 hours for data taking

List of collaborators

Kyoto University	:	E. Hayata, M. Hayata, M. Hirose, K. Imai, S. Kamigaito, N. Saito, K. Tanida, M. Togawa, T. Tsunemi, C. J. Yoon
Gifu University	:	M. Kawasaki, H. Nakamura, K. Nakazawa, K. T. Tint, T. Watanabe
Tohoku University	:	K. Hosomi, T. Koike, Y. Ma, K. Shirotori, H. Tamura, M. Ukai
Aligarh Muslim University	:	R. Hasan and graduate atudents
BNL	:	R.E. Chrien
China Inst. Atomic Energy	:	Y.Y. Fu, C.P. Li, Z.M. Li, J. Zhou, S.H. Zhou, L.H. Zhu
Chonnam Nat'l University	:	J.Y. Kim
Dongshin University	:	M.Y. Pac
Fukui University	:	T. Yoshida and graduate students
Gyeongsang Nat'l University	:	K.S. Chung, S.H. Kim, J.S. Song, C.S. Yoon
KEK	:	M. Ieiri, H. Noumi, M. Sekimoto, H. Takahashi
Nagoya University	:	K. Hoshino, T. Kawai, B.D. Park, T. Sato, T. Watabe
Nat'l Inst. of Rad. Science	:	N. Yasuda
Osaka City University	:	K. Yamamoto
Pusan Nat'l University	:	J.K. Ahn, S.Y. Ryu
Shanxi Normal University	:	D.H. Zhang and graduate students
Toho University	:	C. Fukushima, M. Kimura, S. Ogawa, H. Shibuya
University Colledge of London	:	D.H. Davis, D. Tovee
University of Houston	:	Ed. Hungerfold and graduate students
University of New-Mexico	:	B. Bassalleck and graduate students

Overview

The purpose of the proposed experiment is a systematic study of double strangeness nuclei with 10 times higher statistics than the previous experiment (KEK-E373) and the first measurement of Ξ^- atomic X-ray. In this experiment, we expect to observe 10^4 stopping Ξ^- hyperons (Ξ^- atoms) in the emulsion via quasi-free (K^-,K^+) reactions on a diamond target.

Recently, we have reported Λ-Λ interaction energy showing weak attractive force by an uniquely identified event of ${}^{6}_{\Lambda\Lambda}$He hypernucleus called "NAGARA event". However, it is quite important to measure masses of double hypernuclei for several nuclear species to determine the Λ-Λ interaction without uncertainty due to the nuclear structure. We expect to find 100 events of double hypernuclei and make a mini-chart of them for the first time, and reveal the world of $S=-2$ nuclei. We have also observed an event showing a new weak decay of a double hypernuceus, decaying associated with a Σ^- hyperon. The branching ratio of this decay is expected to be large if the double strangeness exist as the H-dibaryon in the nucleus. We will perform higher sensitivity search for such weak decay to study a possible H-dibaryon state in nuclei. This challenge leads us to the knowledge for the origin of nuclear force, the existence of the H-dibaryon state and strange hadronic matter such as neutron stars.

The proposed experiment became possible due to the improved tagging detectors for the hybrid-emulsion method, high-speed automated emulsion analysis and a high purity K^- beam at the K1.8 beam line. The measurement of Ξ^- atomic X-ray to study Ξ-nuclear potential is made for the first time. It becomes possible by a large acceptance germanium (Ge) detector array called Hyperball which successfully observed many hypernucler γ transitions.

Thus, we request 600 hours for data taking with 3×10^5 K^-/spill, although we will need 150 hours for tuning the detectors and beams, where we do not need high intensity beams. Requested K^- beam intensity is at most 20% of the expected full beam (1.4×10^6 K^-/spill) provided with the primary protons (30GeV, 9μA) at the 1st stage of J-PARC. Therefore the proposed experiment is quite feasible to be carried out even during the start-up period of the operation of J-PARC.

1 Introduction

The purpose of the proposed experiment is a systematic study of double strangeness (S=−2) systems via nearly 100 nuclear samples and several tens of Ξ^- atomic X-ray events.

The evidence of a double strangeness nucleus in the emulsion following Ξ^- hyperon capture at rest was reported more than thirty years ago [1, 2, 3]. At KEK, we carried out an emulsion-counter hybrid experiment (E176) to observe double strangeness nuclei and/or H dibaryon. Among nearly 80 stopping Ξ^- events extracted from 2000 (K^-,K^+) reaction events, existence of the ground state of double strangeness nuclei was confirmed by observing cascade weak decay [4]. This event, however, did not allow us to derive the $\Lambda\Lambda$ interaction energy ($\Delta B_{\Lambda\Lambda}$) uniquely; $\Delta B_{\Lambda\Lambda}$ was obtained to be either -4.9 ± 0.7 MeV (repulsive $\Lambda\Lambda$ interaction) or $+4.9\pm0.7$ MeV (attractive interaction).

The E373 experiment at KEK started to solve the question about the $\Lambda\Lambda$ interaction given by E176, to confirm the findings of E176 with better accuracy, and to provide new discoveries about double strangeness nuclei [5]. In E373, the quasi-free 'p'(K^-,K^+)Ξ^- reactions were induced in the diamond (^{12}C) target located upstream of the emulsion. Some of the Ξ^- hyperons stopped in the emulsion stack. The high precision tracking detector, micro fiber-bundle tracker [6], was placed between the target and the emulsion to guide the Ξ^- tracks into the first emulsion plate. Since the ionization of the Ξ^- hyperons with a momentum of $\sim$ 0.5 GeV/c is several times larger comparing minimum ionizing particles, tracing of the Ξ^- tracks is easier and faster than tracing of K^+ tracks done in E176. The automated scanning system was also successfully developed for Ξ^- track tracing in the emulsion of E373 to reduce the time for emulsion analysis. In E373, we can obtain several hundreds' stopping Ξ^- events which is ten times larger number than that presented by E176. The beam exposure was finished in 2000. We have almost finished the emulsion analysis, two events showing the decay topology of the twin single Λ hypernuclei [7] and an ${}^{6}_{\Lambda\Lambda}$He double hypernucleus event [8] among six events with sequential decay topologies were successfully detected. In particular, the latter is a beautiful event which was uniqely identified and confirmed for the first time that the $\Lambda\Lambda$ interaction was weakly attractive. This method has been thus proved to be promising for the study of nuclei with double strangeness system. Further studies with ten times higher statistics in the proposed experiment will reveal the properties of double strangeness system in detail and provide us a clue to understand the baryon-baryon interactions and the nuclear matter with multi-strangeness.

In strangeness nuclear physics, another type of new experiments, hypernuclear γ spectroscopy, has recently been developed. In 1998 we constructed a germanium (Ge) detector array (Hyperball) and successfully observed hypernuclear γ transitions in ${}^{7}_{\Lambda}$Li and ${}^{9}_{\Lambda}$Be in KEK E419 and BNL E930 with a few keV resolution, which is better by two or three orders of magnitude than the conventional hypernuclear spectroscopy. The results provided unambiguous information of the strengths of the spin-spin [9] and the spin-orbit interactions [10] between a Λ and a nucleon, as well as to confirm the hypernuclear shrinking effect [11]. This new technique can be also applied to the detection of Ξ^- atomic X rays and to measure their energy shifts, which will provide precious information on the ΞN interaction.

We will use almost pure K^- beam of the K1.8 beam line in the experiment. The (K^-,K^+) reaction, $K^- + 'p' \rightarrow K^+ + \Xi^-$, from a carbon target is detected with the spectrometer system using KURAMA magnet from KEK. The target and the emulsion system is almost the same as in E373. A new high position resolution detector, double-sided Si strip detector(DSSD), is placed between the target and the emulsion stack and to tag the Ξ^- hyperons produced in the target and stopped in the emulsion. To condense events associated with stopping Ξ^- hyperons, an additional DSSD is set just downstream of the emulsion. Scintillating fiber (SCIFI) blocks which surround the emulsion is used to detect π^- from decays of the hyperfragments and other particles. These detectors will reduce the number of events to be scanned in emulsion. High purity kaon beam at the K1.8 beam line (K/π ratio of KEK K2-line is 1/4 at most), advanced detectors and automated scanning system enable us to obtain ten times more events than E373 within a few years of data analysis.

We install Hyperball-J, upgraded Hyperball, around the target to detect Ξ^- atomic X rays, where stopped Ξ^- events are clearly identified from the emulsion analysis. Hyperball has worked quite well at KEK and BNL. A few hundreds of events of both of Ag-Ξ^- atomic X rays and Br-Ξ^- atomic X rays will be detected, and their energy shifts will be measured with 0.3 keV accuracy.

By the above experimental condition to achieve statistics with ten times more than that of E373, we can systematically measure a nuclear mass number (A) dependence of the $\Lambda\Lambda$ interaction energy from at least several kinds of S=-2 nuclear species in nearly 100 samples to be detected as S=-2 nuclei. We can thus provide a chart of S=-2 nuclides for the first time. The decay mode of S=-2 nuclei can also be systematically measured for the first time. In the previous experiment, we have observed an event showing Σ^- weak decay of a double hypernucleus. Theoretically the branching ratio of Σ^- decay of two Λ hyperons in double hypernuclei is expected to be an order of 0.1% [12, 13, 14, 15]. On the other hand, the branching ratio of the Σ decay of the H-dibaryon is as large as 50%. Therefore, the measurement of the branching ratio of this decay mode is quite important to study the H-dibaryon and the structure of double hypernuclei. Existence of the bound H particle is now very unlikely after many experimental efforts. However, there still remain a possibility of the H as a resonance near the $\Lambda\Lambda$ threshold. Invariant mass spectrum $\Lambda\Lambda$ obtained by E522 shows a peak-like structure just above the threshold [16]. It is theoretically suggested that the H dibaryon like state may possibly exist as a mixing state of $\Lambda\Lambda$, ΞN and $\Sigma\Sigma$ in a nucleus. Experimental results of the A dependence of $\Delta B_{\Lambda\Lambda}$ and the decay mode can give definitive information on how the H dibaryon exists in S=-2 nuclei. We will also obtain the $\Lambda\Lambda$ invariant mass spectrum with ten times higher statistics than E522 ,which can be obtained mainly by a scintillation fiber detectors.

The energy measurement of X rays from the decay of S=-2 system is carried out for the first time. We expect that several tens of X ray events from Ξ^--Ag and Ξ^--Br atoms will clarify the Ξ^--nucleus potential and to reveal the $\Xi^- N$ interaction.

This proposed experiment is based on the experience of KEK-E176, E224, E373, E419, E522 and BNL-E813, E885, E930. We combine their newly-developed but already-established techniques of hybrid emulsion method, scintillating fiber detectors, diamond target, high-rate Ge detectors, etc. The collaborators are mainly from the members of those experiments.

2 Physics

2.1 Double strangeness nuclei and H dibaryon

The double Λ hypernuclei, H nuclei and Ξ hypernuclei are all double strangeness nuclei. Which is the ground state? The conventional idea is that it is double Λ hypernuclei. However, it is not trivial, since we do not know the mass of the H particle, H nucleon interaction and Ξ nucleon interaction, experimentally. Theoretically, the baryon-baryon interaction in the S=-2 state can be attractive at short distance, compared with the repulsive core of the nucleon-nucleon interaction. That is the reason why the H dibaryon can be a stable 6-quark state [17]. Therefore, the double strangeness nuclei can be quite different nuclei from the ordinary nuclei or Λ hypernuclei. The strange quark matter or quark star is a good example of these discussion. However, very little is known about the double strangeness nuclei, experimentally. One of the most important thing for the study of double strangeness nuclei is to identify the nuclear species and measure their masses (binding energies).

Recently, we have succeeded in observing an event which is uniquely identified as *Lambpha*, ${}^{6}_{\Lambda\Lambda}$He double Λ hypernucleus, in the ground state [8]. The photographic image and a schematic drawing of the event named "NAGARA" is shown in Fig. 1. The formation and the decay of *Lambpha* was interpreted as: $\Xi^-+{}^{12}\mathrm{C} \to {}^{6}_{\Lambda\Lambda}\mathrm{He}+{}^{4}\mathrm{He}+t$, ${}^{6}_{\Lambda\Lambda}\mathrm{He} \to {}^{5}_{\Lambda}\mathrm{He}+\pi^-+p$, ${}^{5}_{\Lambda}\mathrm{He} \to p+d+2n$ *etc*. The binding energy of the two Λ hyperons ($B_{\Lambda\Lambda}$) provides the $\Lambda\Lambda$ interaction energy $\Delta B_{\Lambda\Lambda}$ as follows,

$$\Delta B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}\mathrm{Z}) = B_{\Lambda\Lambda}({}^{A}_{\Lambda\Lambda}\mathrm{Z}) - 2B_{\Lambda}({}^{A-1}_{\Lambda}\mathrm{Z}).$$

$\Delta B_{\Lambda\Lambda}$ provides important information on the $\Lambda\Lambda$ interaction. $B_{\Lambda\Lambda}$ and $\Delta B_{\Lambda\Lambda}$ (${}^{6}_{\Lambda\Lambda}$He) from the NAGARA event were obtained as $7.25 \pm 0.19\ ^{+0.18}_{-0.11}$ MeV and $1.01 \pm 0.20\ ^{+0.18}_{-0.11}$ MeV, respectively, using the most probable Ξ^- binding energy of 0.13 MeV which is the level energy of ^{12}C atomic $3D$ state [18, 19]. This value demonstrates the $\Lambda\Lambda$ interaction is attractive but very weak rather than 4$\sim$5 MeV which has been believed for forty years. In two old emulsion events [1, 2] [4] and our $Demachi-Yanagi$ event obtained by E373 [20, 21], there is a possibility that single hypernucleus was produced in excited states, and $\Delta B_{\Lambda\Lambda}$ cannot be uniquely extracted. If excited states are taken into account, their values of $\Delta B_{\Lambda\Lambda}$ do not

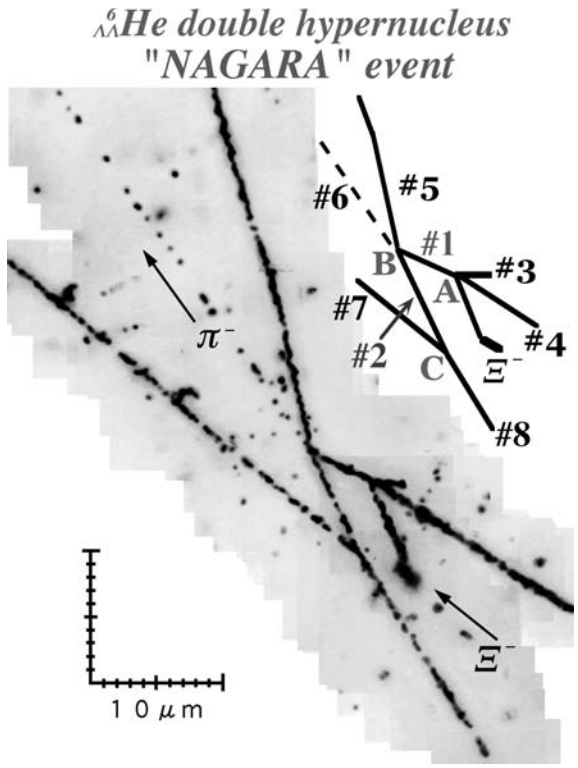

Figure 1: NAGARA event showing production and decay of *Lambpha* ($^{\;6}_{\Lambda\Lambda}$He double hypernucleus) observed in E373. A Ξ^- hyperon is captured by a ^{12}C nucleus at the point A, and a double hypernucleus (#1) and two stable nuclei are emitted. At the point B, track #1 decays to #2 (single-Λ hypernucleus), #5 and #6. Track #7 and #8 are decay daughters of #2 from the point C. #6 can be identified as π^- by its characteristic topology at the end point in the emulsion. Track #7 is escaping from the emulsion stack. By the analysis of brightness of the track in SCIFI block, it was recognized that the track cannot be π^-. This event is uniquely identified as: $\Xi^-+{}^{12}\mathrm{C} \to {}^{\;6}_{\Lambda\Lambda}\mathrm{He}+{}^{4}\mathrm{He}+t$, ${}^{\;6}_{\Lambda\Lambda}\mathrm{He} \to {}^{5}_{\Lambda}\mathrm{He}+\pi^-+p$, ${}^{5}_{\Lambda}\mathrm{He}$ $\to p+d+2n$ *etc.*

contradict with our new result. However, the disagreement between our $\Delta B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}\mathrm{He})$ and that reported in Ref. [3] confirms the doubts on the authenticity of the event in [3].

The binding energy $B_{\Lambda\Lambda}$ of the ground state provides the lower bound of the mass of the possible H particle, since the double strangeness nuclei can decay into the H and a residual nucleus by the strong interaction if the mass of the H is smaller than ($2M_{\Lambda} - B_{\Lambda\Lambda}$).

For more than a decade, many experiments were carried out to search for the H particle in the mass range from below NN threshold to over the mass of two Σ hyperons. However, none of them has reported definitive observation of the bound H particle and/or its resonance state yet [22]. An enhancement just above the threshold observeded in the $\Lambda\Lambda$ invariant mass spectrum by E224 [23] has been studied with higher statistics by E522. The peak structure has been confirmed again. They suggested the peak as a possible evidence of H-resonance since it can not be explained by the final state interaction [16]. In the proposed experiment, we can study the $\Lambda\Lambda$ invariant mass spectrum about ten times more statistics than the previous data. Even with the new E373 event, there still remains a small window for the mass of the H particle, $2M(\Lambda) \geq M(H) \geq 2M(\Lambda) - 7.25$ MeV, but the existence of the deeply-bound H dibaryon appears very unlikely. A possible evidence of ${}^{4}_{\Lambda\Lambda}\mathrm{H}$ observed by E906 may reject the bound H almost completely.

Two cases can be considered for the bound state of S=-2 nuclear system in relation with the H, namely,

case 1.: $\Lambda\Lambda$ nucleus, or

case 2.: H-nucleus state with a loosely-bound H.

In reality, they can be mixed as well as with ΞN and $\Sigma\Sigma$ states. Yamada et al. calculated the ground state for the case 2. of the system, core[^{8}Be] + (3q) + (3q) [24], based on Quark Cluster Model. They found a "loosely-bound H dibaryon state" which is the flavor SU(3)×SU(3) singlet state but consists of two loosely bound baryons having a strongly-mixed $\Lambda\Lambda$-ΞN-$\Sigma\Sigma$ function.

How can we distinguish the above two cases?

One way is to measure the nuclear mass number (A) dependence of the binding energies, especially $\Delta B_{\Lambda\Lambda}$. If the ground state of S=-2 system consists of the H particle made of six quarks, '$\Delta B_{\Lambda\Lambda}$' is expected to be same for different nuclear species. However, in the case of the two baryonic state (case 1) $\Delta B_{\Lambda\Lambda}$ may be not constant when the core nucleus is changed. Yamada et al. showed that $\Delta B_{\Lambda\Lambda}$ for ${}^{14}_{\Lambda\Lambda}\mathrm{C}$ becomes ~ 1 MeV larger than that for ${}^{6}_{\Lambda\Lambda}\mathrm{He}$ [25].

The other way is a measurement of the decay mode of the S=-2 ground states. In the case of H-nuclei, it is expected to decay into ΣN and ΛN as well as $\Lambda N\pi$ at large branching ratio. Recently, an event showing the topology of ΣN decay has been observed in the E373 emulsion data. The event is shown in Fig. 2. A Σ hyperon emitted from the Ξ^- stopping point decays in flight into π. This is the first observation of the ΣN decay of double strangeness nuclei. Since it is only one event, we can not determine the branching ratio of the ΣN decay. A recent theoretical calculation of the branching ratio of ΣN decay of double $\Lambda\Lambda$ hypernuclei shows that it is an order of 0.1% [12, 13, 14, 15]. However, the branching

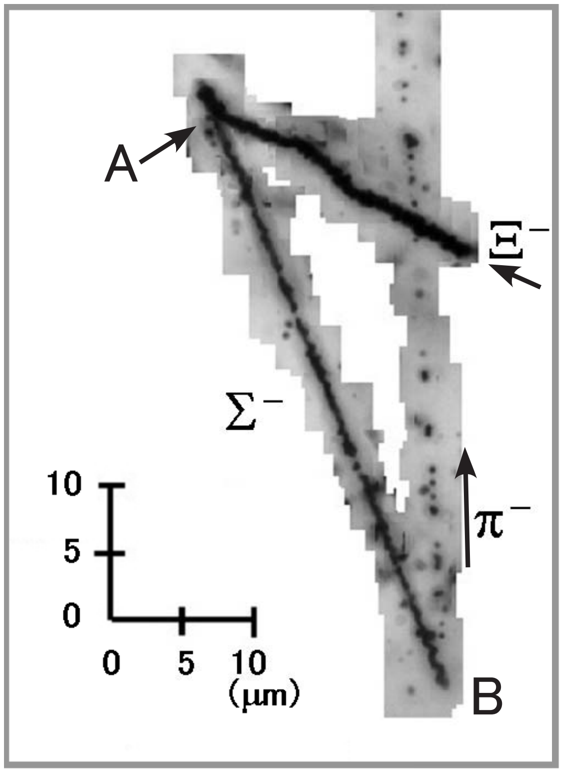

Figure 2: At the stopping point of a Ξ^- hyperon, point A, there were a short track (5.3μm) and a straight track (56.6μm). The latter particle decayed into a charged one with the decay angle of 153.5 ± 0.4 (deg) and other neutral(s) at point B. The track from the point B was identified as a charged π meson by the measurement of its ionization. According to the kinematic analysis, the decay at the point B is identified as $\Sigma^- \rightarrow \pi^- + n$.

ratio of the ΣN decay of the H-dibaryon is expected to be about 50%. Therefore, it is quite important to provide the branching ratio of this weak decay. The proposed measurement has ten times sensitivity for the study of the ΣN decay of double strangeness nuclei.

Theoretical studies on the binding energy of H-nuclei as well as double Λ nuclei and non-mesic decays of S=-2 have just begun. Together with these theoretical studies, data from the present experiment will answer the question. The mesonic decay π^-/π^0 ratio will also provide important information on the S=-2 ground state [25].

The proposed experiment expects to obtain 10^4 stopping Ξ^- events in the emulsion. Among those events, we expect to detect about 100 double strangeness nuclei. A chart of nuclei with double strangeness will be made for the first time. The masses and binding energies will be obtained without any ambiguity for, at least, several nuclear species. If we observe the same nuclide but with 'different binding energy', it provides the first observation of an excited state of S=−2 nuclei [26].

The A dependence of the ΛΛ interaction energy is, thus, provided for the first time. We can also investigate decay modes of those S=−2 nuclei and provide information on their structure. The measurements of the A dependence of $\Delta B_{\Lambda\Lambda}$ and the decay modes of S=−2 nuclei will answer the question on the existence of the H dibaryon near threshold.

2.2 Ξ^- atoms and Ξ-nucleus interaction

In order to understand the properties of the S=−2 system, namely, the mixing of ΛΛ-ΞN-ΣΣ and possibly also with H dibaryon state, study of Ξ^--nucleus interaction is of particular importance.

A stopped Ξ^- hyperon is captured by an atom in the emulsion (C, N, O, Ag, or Br). It is firstly captured by a highly excited atomic orbit and transferred into lower orbits by Auger effect and radiative transitions. Finally the Ξ^- hyperon is absorbed by the nucleus via strong interaction when the atomic orbit and the nucleus has a large overlap. We can obtain information on the Ξ-nuclear interaction from the last radiative transition, because the Ξ^--nucleus interaction affects the energy and the width of the atomic level in which the nuclear capture takes place, as well as the yield of the transition (the branching ratio of the upper level going to the radiative decay or to the nuclear absorption).

The Ξ-nucleus interaction was studied by the ^{12}C(K$^-$,K$^+$) reaction in KEK E176, E224 and BNL E885 [27]. Although they did not observe Ξ hypernuclear peaks, the well depth of the Ξ-nucleus potential was found to be weakly attractive (around -14 MeV assuming the Woods-Saxon shape) from the spectrum shape. But the potential shape may not be simply proportional to the nuclear density, as is discussed in the case of Σ nucleus potential [28], depending on the 2-body ΞN interaction.

Since the X-ray data provide information on the nuclear potential (both of real and imaginary parts [1]) at the nuclear surface region, combination of X-ray data with two or more atomic numbers together with the previous (K$^-$,K$^+$) data will allow us to determine both of the depth and the shape of the Ξ-nucleus potential. Therefore, the other proposed Ξ-atomic X-ray experiment without using emulsion [29] will be also important. In addition, if we combine the X-ray data with a result on the Ξ-nuclear potential depth which will be obtained in the proposed experiment [30] on Ξ-hypernuclear spectroscopy with SKS at the K1.8 beam line, we can fully understand the property of ΞN interaction, which will play an essential role to development of the baryon-baryon interaction models.

According to theoretical calculation by Batty, Friedman and Gal [19, 31], the shift and the width are predicted as listed in Table 1. As shown in Fig. 3, the Ξ-nuclear potential

[1] In the proposed experiment, we cannot measure the widths smaller than 1.5 keV, while we can obtain the X-ray yields which also give information on the imaginary part of the potential.

$Z(n,l)$	E (keV)	shift (keV)	width (keV)
Ag (8,7)→(7,6)			
case 1	370.45	0.28	0.15
case 2		3.3	0.79
Br (7,6)→(6,5)			
case 1	315.5	0.73	0.44
case 2		5.5	1.74

Table 1: Calculated shifts and widths of Ξ^- X rays on Ag and Br [31]. Case 1 is calculated assuming the potential shape to be the same as the nuclear density ($t\rho$ potential). Case 2 is calculated using the potential derived from G matrix calculation with the ΞN interaction in the Nijmegen D model but corrected to reproduce the potential depth of about 14 MeV.

was calculated for two extreme cases; They have different shapes but both reproduce the potential depth of 14 MeV suggested by the ^{12}C(K$^-$,K$^+$) data. In the case 1 ($t\rho$ potential, proportional to nuclear density), where the effect of the potential at the surface region is smallest, 0.3–0.7 keV shifts are predicted. It is within the accuracy of our measurement. In the case 2, they used the potential derived from a density-dependent effective ΞN interaction which was calculated by G matrix method from the ΞN interaction in the one-boson exchange model (Nijmegen D) (this potential roughly reproduces the averaged potential depth of 14 MeV). In this case, the potential extends outwards than the $t\rho$ potential and gives much larger shifts that can be easily detected from X-ray data.

It is to be mentioned that, by detecting photons for Ξ^- absorption events, we may be able to detect γ transitions in double Λ hypernuclei as well as Ξ atomic X rays. Expected numbers of such γ rays are very small in the present experiment, but our measurement will provide a good test data for future experiments of γ spectroscopy of double Λ hypernuclei.

Information on Ξ^- nucleus potential can also be obtained from the decay of the Ξ^--nucleus system; if all the emitted particles are well identified, the mass of the parent Ξ^- bound system can be obtained. If two Λ hyperons are captured by different fragments, namely, two single-Λ hypernuclei are produced, after the Ξ^- hyperon is absorbed, then we can determine the mass of the Ξ^- bound system because we know binding energies of all kinds of light single Λ hypernuclei. In E176, two such events, so-called twin single Λ hypernuclei, where two single hyperfragments are emitted back to back from the Ξ^- hyperon stopping points were found. One was interpreted as Ξ^- C-atomic state with the binding energy of 0.53 ± 0.22 MeV [32] and the other as possible Ξ^- C-nucleus with the binding energy of 3.70 $\pm$ 0.19 MeV [33], although other interpretations were not excluded.

When Ξ^- hyperon is captured by a light emulsion nucleus (C,N,O), then it is mainly absorbed by $3D$ atomic orbit. But theoretical calculations show that the absorption takes

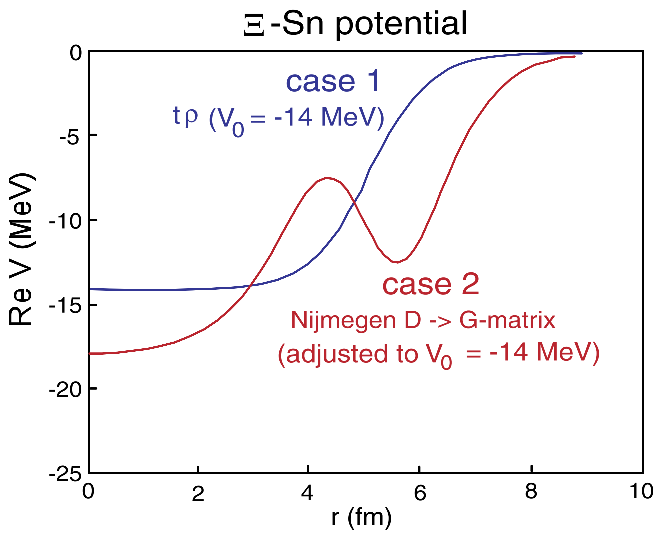

Figure 3: Theoretically expected Ξ-nuclear potentials. Case 1: calculated assuming the potential shape to be the same as the nuclear density ($t\rho$ potential) and corrected the potential depth to be 14 MeV. Case 2: calculated using the potential derived from the density-dependent ΞN effective interaction calculated via G matrix from the ΞN interaction in the Nijmegen D model (the averaged potential depth reproduces the experimentally suggested value of 14 MeV. [19]

place at $2P$ orbit for a few percent probability, in which case a large binding energy of Ξ (of the order of MeV) may be observed. In the proposed experiment, we may be able to observe events which provide binding energies of deeply-bound Ξ^- nuclear states with a help of 10 times statistics.

3 Experimental Method

3.1 Introduction

We propose an emulsion-counter hybrid method to study double strangeness system produced at Ξ^- stopping points in the emulsion. The double strangeness nuclei are identified by the characteristic cascade weak decay. Short tracks of hyperfragments and their decay vertices are extensively studied in the emulsion together with other decay particles. The emulsion is surrounded by scintillating fiber detectors which detect long tracks such as π^- from hyperfragments, decay particles from H dibaryon, and decay particles of Λ hyperon from the weak interaction such as $\Lambda\Lambda \to \Lambda N$. Ge detectors measure X rays from Ξ^- atoms formed by Ξ^- hyperon capture at rest.

The quasi-free reaction, $K^- + p \rightarrow K^+ + \Xi^-$, from a diamond target is detected by the spectrometer system using KURAMA magnet from KEK. Some of Ξ^- hyperons from the target are stopped in the emulsion stack placed downstream of the target. A high precision position detector, double-sided Si strip detector (DSSD), placed between the target and the emulsion is used to identify the tracks of the Ξ^- hyperon going to the emulsion. We will set an additional DSSD to recognize that the Ξ^- hyperon does not go through out of the emulsion, to measure the energy of charged particles escaping from the emulsion and, if possible, to locate some vertices in the emulsion by tracing back the tagged K^+ or other tracks. In the emulsion, the Ξ^- track is traced down to its stopping point, and the vertices of the stopping Ξ^- events are studied in detail under a microscope to find out a double strangeness system. According to track lengths emitted from the stopping point, the nuclei which captured Ξ^- hyperons are classified to two categories, light elements (C, N, O) or heavy ones (Ag, Br).

The emulsion is expensive ($7,000 for 1 *liter* including the fee for development). In addition, analysis of the emulsion is time and man-power consuming job, even after we successfully develop a fully automated emulsion scanning system. The experiment is thus designed to save the amount of the emulsion and to make the analysis easier and faster.

3.2 Setup of the experiment

The 1.7 GeV/c K^- beam is used for this experiment. We need only 3×10^5 K^-/spill(2.0sec) as a beam intensity but require a pure K^- beam with the K^-/π^- ratio of better than 6. A schematic drawing of the experimental setup is shown in Fig. 4. The apparatus near the emulsion are also shown in Fig. 5. The time-of-flight counters (T1 - T2) and an aerogel Cherenkov counter (BAC; n=1.03) are used to identify the K^- mesons. The beam size at the target is expected to be ($20[x]\times3.2[y]$ mm^2) at the target [34]. A diamond target sized $50[x]\times10[y]$ mm^2 and 30mm in length is placed upstream of the emulsion stack. It is used as the Ξ^- production target and as an energy degrader for the Ξ^- hyperons. Two sets of DSSD's are placed between the target and the emulsion stack to measure the angle and position of the Ξ^- hyperons with high precision instead of a fiber-bundle tracking detector which was employed in E373.

The scattered K^+ particles are detected with the K^+ spectrometer system which consists of a magnet (KURAMA from KEK), time-of-flight counters (FTOF-T2), aerogel Cherenkov counters (BVAC, FAC), drift chambers (DC1-3) and trigger counters. The scintillating fiber detectors (SCIFI) are placed up- and downstream of the emulsion stack primarily to measure the energy of π^- from the hypernuclei, to detect Λ hyperons, and to search for the H resonance.

The Ge detector array (Hyperball-J) covers the upstream plane of the target and detects Ξ^- atomic X rays around 300-400 keV with an energy resolution of 2 keV (FWHM). Here

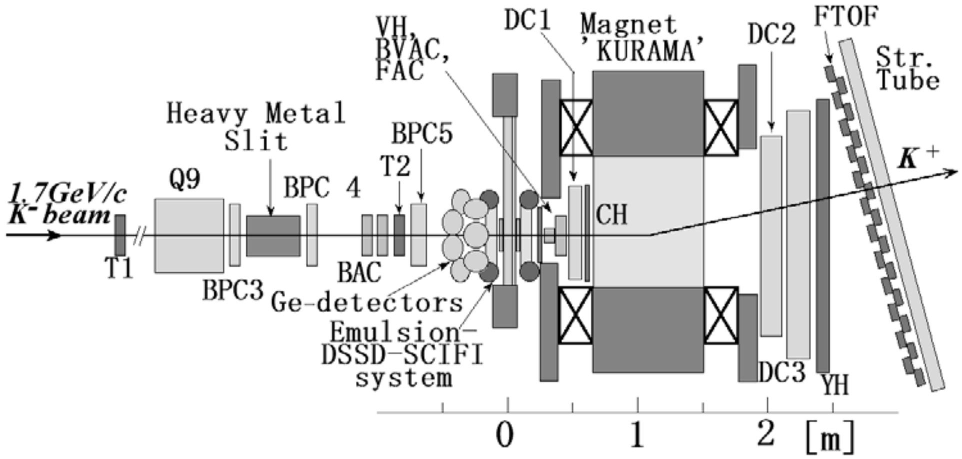

Figure 4: The setup of the experiment (top view).

we use ∼20 Ge detectors and covers about 15% of the total solid angle. Each Ge detector is surrounded by PWO counters. The arrangement is shown in Fig. 6

3.3 K^+ Spectrometer

The K^+ spectrometer is essentially the same as the one used for E373. The K^+ particles are identified by time-of-flight counters and aerogel Cherenkov counters. Almost perfect identification of K^+ is possible as shown in the mass spectrum of scattered particles obtained by E373 (Fig. 7). The kaon beam intensity becomes nearly 10 times larger than that of E373 at the K2 beam line (KEK-PS). In the (K^-,K^+) trigger of E373, we have frequetly misidentified protons to K^+ mesons at the 1st level trigger. By using a recently developed Cherenkov counter ($n \geq 1.1$), we will expect those fake triggers can be decreased by an order of magnitude.

The momentum of the K^+ particle is measured with the magnet (KURAMA) and drift chambers. The momentum resolution obtained by E373 is good enough to identify quasi-free Ξ^- production from the carbon target. The acceptable integral beam flux is limited by the amount of emulsion. Therefore, in order to get as many events as possible with a limited amount of the emulsion, detection efficiency of K^+ mesons must be as high as possible. It is why we use the KURAMA magnet, which has a larger acceptance for K^+, instead of the SKS magnet probably installed at the K1.8 beam line. The TOF counters will be placed downstream of the DC3. The shorter distance from the target to the TOF counters reduces the inefficiency due to the K^+ decay in the spectrometer and increases the acceptance. We expect to obtain an acceptance of 0.20 sr with KURAMA, rather than about 0.10 sr with

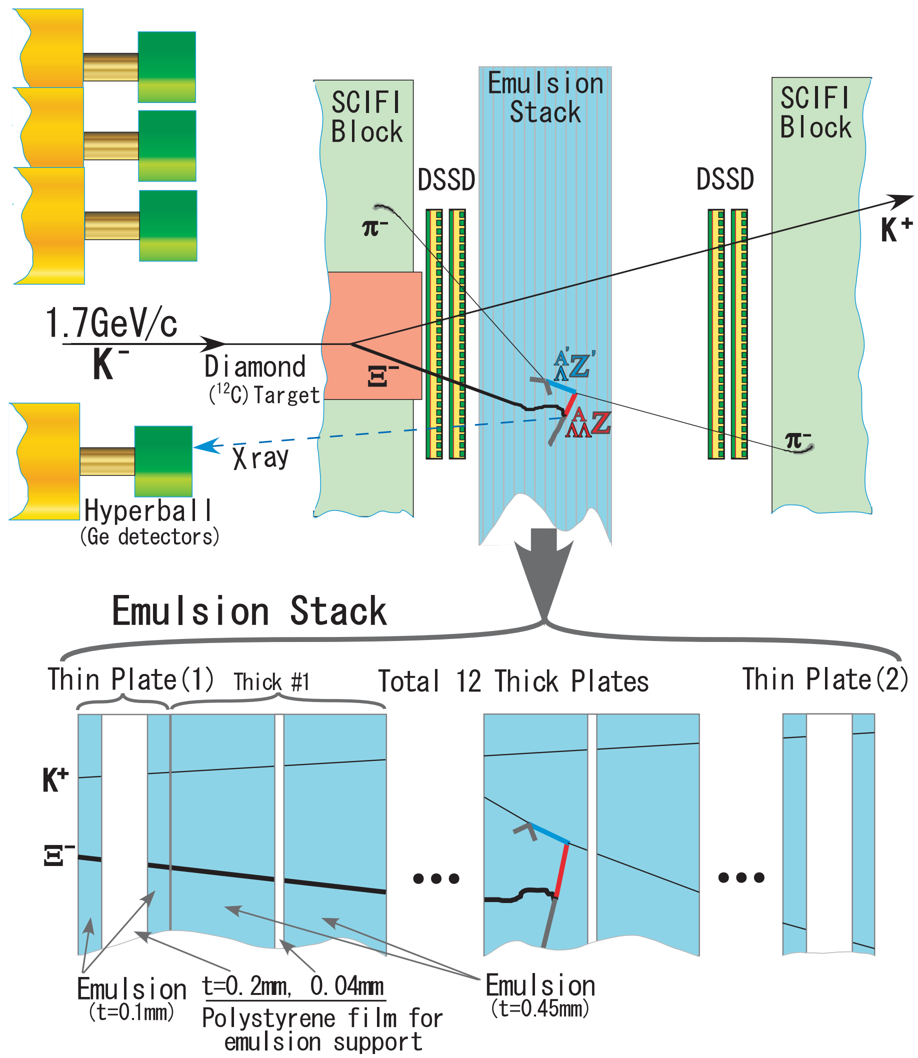

Figure 5: The apparatus around the emulsion and the emulsion stack.

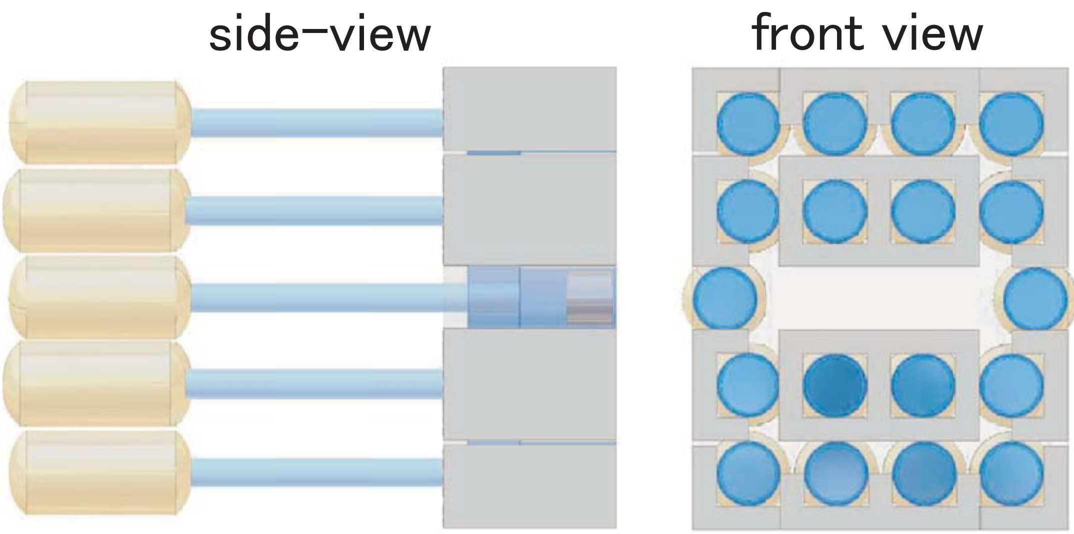

Figure 6: Setup of Hyperball viewed from side and front. Eighteen sets of Ge+PWO detectors are installed upstream plane around the target region.

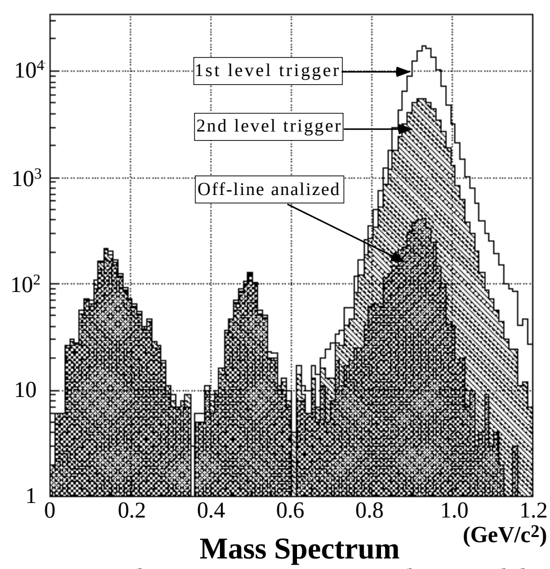

Figure 7: The mass spectrum obtained by E373.

the SKS magnet.

3.4 Tracking detectors

3.4.1 double-sided Si strip detector (DSSD)

In E373, we used micro fiber-bundle tracking detectors for the Ξ^- tracking from the target to the first plate of the emulsion stack. The detector consisted of fine scintillating fibers with a diameter of ~ 40 μm. The image scanning by human eyes was necessary to find the Ξ^- candidate tracks. In the proposed experiment, however, it is necessary to reconstruct the Ξ^- tracks without human eyes, because the number of events to be analyzed becomes ten times more than that of E373, *i.e.* at least 2×10^5 events. And furthermore, image of Ξ^- hyperon tracks wsa broader than the diameter of one fiber, so that the reconstructed angles had large errors of about 100 mrad. For each tagged event, the mean number of the Ξ^- candidate tracks found in the emulsion was, therefore, more than one even by using such fine fibers. To detect ten thousands of Ξ^- stopping events within a reasonable period, it is necessary to get higher accuracy for Ξ^- hyperon tracking than the detector used in the KEK-E373 experiment.

Therefore, we will employ a double-sided Si strip detector (DSSD) as the most suitable detector. The ionization of the Ξ^- hyperon which can stop in the emulsion is much larger than that of minimum ionizing particles. Such Ξ^- hyperons give large energy deposit in a DSSD of the thickness of 300 μm. We plan to use 50 μm strip pitch DSSD to obtain high position resolution. Since the life time of Ξ^- hyperon is very short, two DSSD's are installed in the 4 mm gap between the target and the emulsion to measure the angle and position of Ξ^- hyperons, so that we allow only one candidate track in the top emulsion plate. The resolution of deposit energy by charged particles is much better than the fiber scintillators, then the selection of Ξ^- hyperons which can stop in the emulsion and separation from other particles like pions will be much more improved. We will also install two DSSD's downstream of the emulsion stack to determine whether the Ξ^- stops in the emulsion or passes through it and to provide the additional event identification capability. We can, thus, reduce the number of events to be scanned by about one order of magnitude with use of the DSSD's compared to E373.

The silicon chip has an effective area of 30×60mm^2 and 50μm-pitch readout in both sides. Six DSSD chips have been produced by the Hamamatsu Photonics Co.,Ltd. Circuit boards for the readout and the wire bonding were made by the end of 2004. We use the "viking chip" for the read-out. An overview and a photograph of the DSSD board are shown in Fig. 8 and 9, respectively. In Fig. 10, the pulsehight distribution of β rays is shown. The signal of β ray is well separated from the noise.

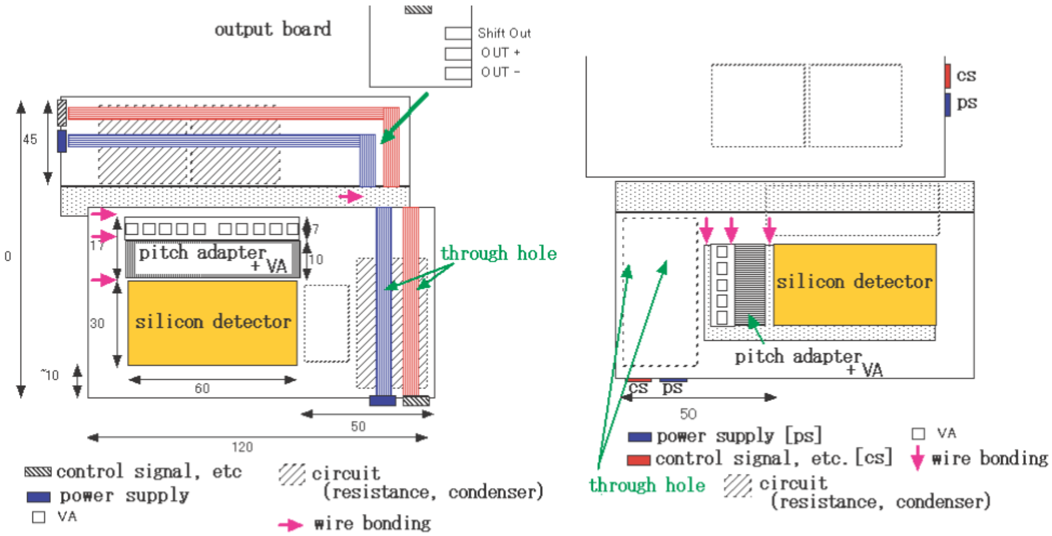

Figure 8: Layout of DSSD.

Figure 9: Photograph of DSSD.

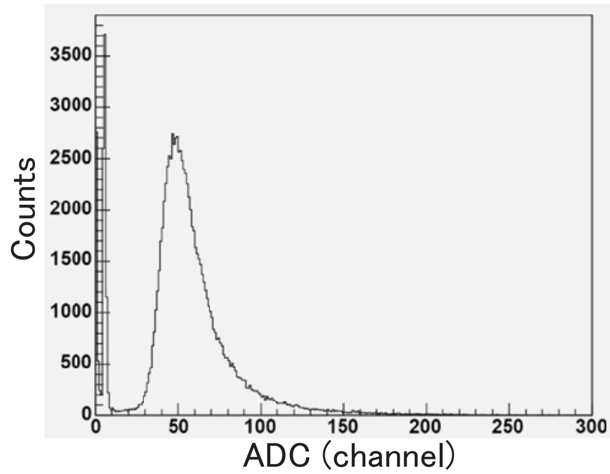

Figure 10: Pulsehight distribution of DSSD for β ray from ^{90}Sr.

3.4.2 Scintillating fiber (SCIFI)

The scintillating fiber (SCIFI) detector has been developed as a live target to search for the H particle about ten years ago. We employ SCIFI blocks installed up- and downstream of the emulsion to measure the energy of π^- mesons escaping from sequential weak decay of double strangeness nuclei produced in the emulsion. They are also used to find the decay topologies of $H \rightarrow \Sigma^- + p$ and $\Lambda + p + \pi^-$, if the bound H particle exists, as well as to detect the decay of Λ (Σ) via $\Lambda\Lambda$ weak interaction of $\Lambda\Lambda \rightarrow \Lambda(\Sigma)N$ [12, 13, 14]. The cross section of each fiber is 0.5×0.5mm^2. About one hundred fiber sheets are alternately packed in the u and v directions in order to reconstruct tracks in three dimensions. To degrade π^- energy, aluminum sheets with 0.3 mm thickness are inserted between each SCIFI sheet.

An example of SCIFI image obtained by E373 is displayed in Fig. 11. The decay topology of Ξ^- is clearly understood with a tagged K$^+$ tracks. In Fig. 12, the sum of brightness of the fibers along π^- or proton tracks measured in E373 is presented in both of the up and down SCIFI blocks [35]. The identification of particles stopped in SCIFI has been well carried out. The SCIFI detector with Image Intensifier Tube (IIT) worked quite successfully at the particle rate of 10^5 Hz in the previous KEK experiments. The similar quality of SCIFI data is expected in the proposed experiment.

3.5 Nuclear emulsion

The emulsion stack as shown in Fig. 5 consists of 12 thick emulsion plates and two thin plates with each cross section of 35×34.5 cm^2. A thin plate has 100 μm thick emulsion on both sides of 200 μm thick polystyrene base. In the upstream thin plate, Ξ^- tracks are searched

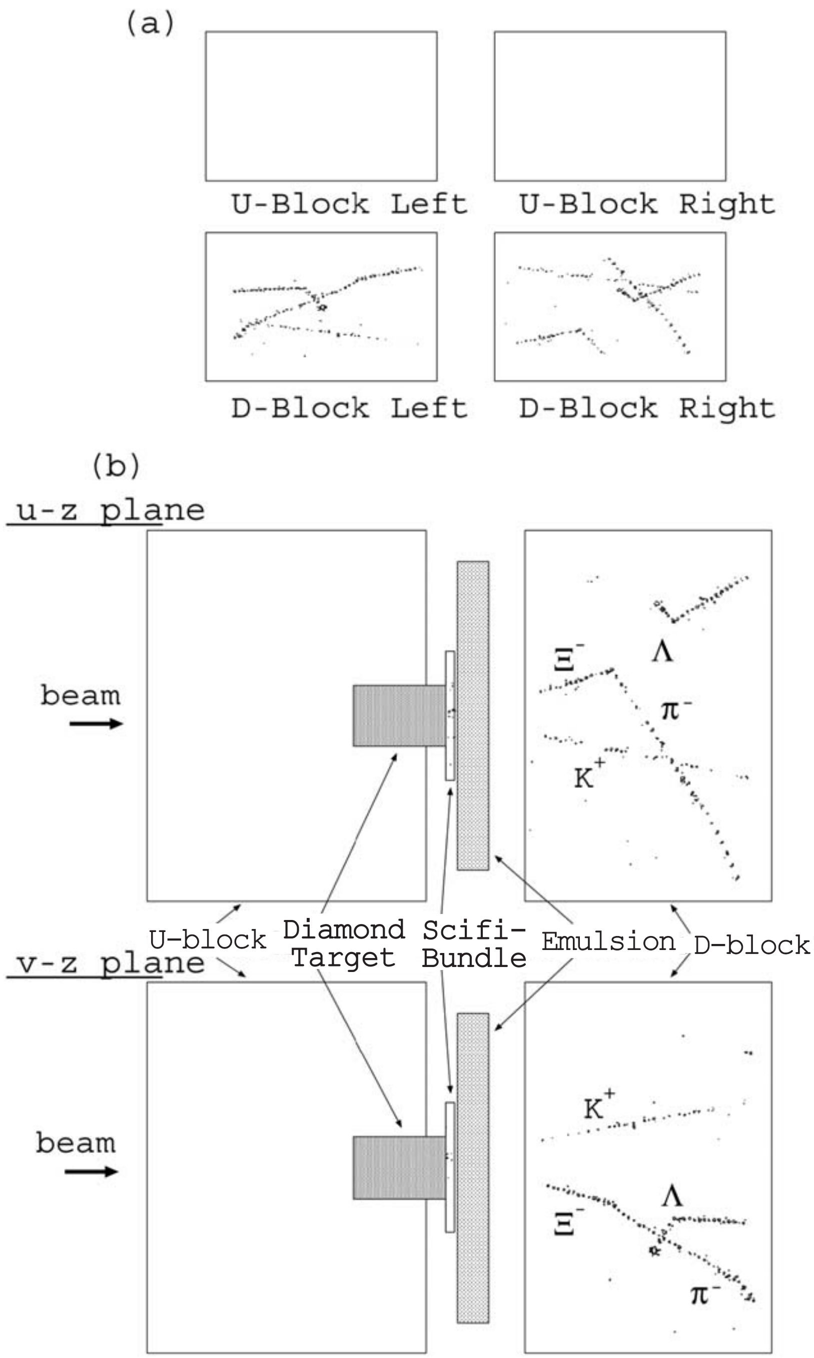

Figure 11: Pictures (a) and (b) of Ξ^- decay sequence shown in SCIFI blocks in E373.

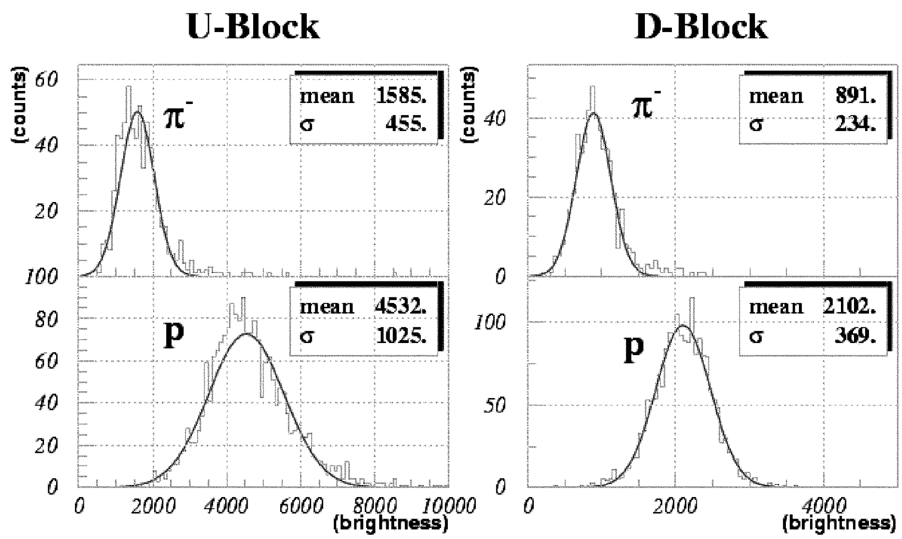

Figure 12: Brightness for stopped π^- and proton in SCIFI blocks obtained by E373.

for according to the prediction by the Ξ^- tracking detector (DSSD). This scanning will be done by the fully automated scanning system developed in E373. In a thick plate, emulsion of 450μm thickness is coated on both sides of polystyrene base with the thickness of 40 μm. These bases were successfully preprocessed on its both surfaces by an atmosphere pressure Corona-discharge method so that the emulsion did not separate from the base. More than one thousand plates were successfully prepared in E373 [36].

The emulsion crystal (AgBr) have been developed to get better position resolution. In this experiment, we use the emulsion with fine and uniform crystal of the size of 0.20$\pm$0.019 μm (GIFL type), which was improved from that used in E176 (0.24$\pm$0.078μm).

In the proposed experiment, we have to use huge amount of emulsion gel, that is nearly 2.6 tons. To produce such amount of the gel with the current method, more than one year is necessary even by skilled workers. Fuji Photofilm Co.,Ltd. has tried to make emulsion gel using the production line to make commarcial photofilm and provided us several samples. We have measured thier stopping power and physical characteristics by the exposure to protons and α particles. It has been found that one of them is suitable for our experiment. Since the emulsion gel can be made by the production line, the emulsion price decreases to about a half of that used in the previous experiment.

The emuslion stack should be mechanically moved at the beam line by an emulsion mover. When the emulsion stack is installed in the beam line, its left-bottom position is set on the beam center. Firstly y coordinate (vertical direction) of the stack is fixed. The emulsion mover moves the stack horizontally (x:right diection) to irradiate the beam uniformly by

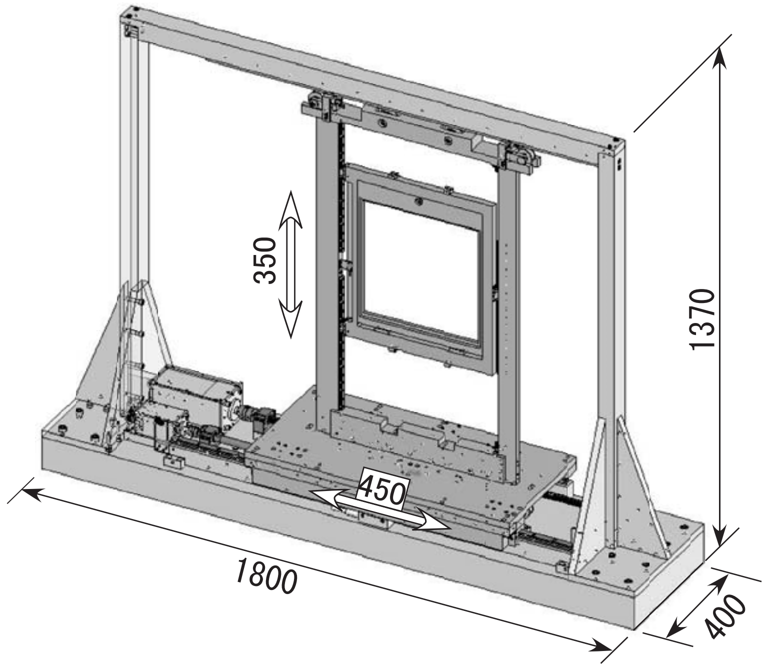

Figure 13: An overview of the emulsion mover.

counting exposed number of beam particles in the previous spill. At the end of horizontal movement of 33 cm, the stack is shifted vertically about 5mm. And then the emulsion mover drives the stack horizontally, but in the opposite direction. By this method, the emulsion stack is driven in the 33 × 32 cm^2 area with a position accuracy about 10 μm and is unformly exposed to the beam. If we obtain 3×10^5 K$^-$/spill, it takes 4 hours for the full beam exposure on one emulsion stack. An overview of the mover (under construction) is shown in Fig. 13.

3.6 Ge detector

Hyperball-J is a large-acceptance Ge detector array dedicated to hypernuclear γ spectroscopy experiments at J-PARC [37]. It is an upgraded version of Hyperball and Hyperball2 which were successfully used for various hypernuclear γ spectroscopy experiments at KEK and BNL [9, 38].

Hyperball-J is designed to work efficiently under high counting-rate conditions. In the proposed experiment, we install about 20 coaxial Ge detectors with a 73 mm ϕ × 73 mm crystal (70% relative efficiency) for each and cover the upstream plane of the target. The distance from the emulsion center to the Ge detector endcap is 15–20 cm.

Each Ge detector is surrounded by PWO counters, which are used to suppress Compton scattered events in the Ge crystal and high energy photons from π^0. It is expected that the PWO counters reduce Compton background from 1 MeV photons by a factor of 4, and reject π^0 induced background by a factor of 20 or more.

We will modify the PWO detector shape so that we can install Ge+PWO detectors as many as possible in the upstream plane of the target in more compact arrangement. Including photon absorption in the emulsion stack and the scintillation counters, the photo-peak efficiency is expected to be 4–5% at 350 keV, as shown in the simulated efficiency curve (Fig. 14).

Hyperball-J is equipped with fast readout electronics so that it works well with beam intensity even more than 1×10^6 mesons per second. The present beam intensity gives no effect to the detector performance; we expect no deterioration of the energy resolution (~2 keV FWHM) and no gain shift due to the beam. However, as we need precise measurement of absolute photon energy, we will monitor the in-beam performance of the Ge detectors during the whole beam time using triggerable ^{22}Na $\beta-\gamma$ sources embedded in plastic scintillation counters. Absolute energy calibration with various γ-ray standard sources will also be frequently (more than once a day) carried out. We can thus calibrate the absolute energy scale within ±0.1 keV at 350 keV. The absolute photo-peak efficiency will also be obtained by calibration with the standard source and the in-beam dead time measurement with the triggerable ^{22}Na sources, after a correction for the target absorption with a simulation. The absolute efficiency will be determined within $\pm5\%$ accuracy.

3.7 Analysis

3.7.1 track reconstruction and event selection

After the selection of (K^-,K^+) reaction events from the diamond target by the analysis of the spectrometer data, Ξ^- tracks are searched and reconstructed in the DSSD. Candidate events of the stopping Ξ^- are selected by the energy deposit in the upstream DSSD and event topologies in the downstream DSSD and SCIFI. A π^- track reconstruction in the downstream DSSD and SCIFI block is necessary for the rejection of Ξ^- decay events. Since the energy of such π^- mesons is mostly much larger than that of the π^- from the decay of a hypernucleus, Ξ^- decay events can be rejected with use of DSSD and SCIFI. This event selection is very important, because the number of Ξ^--decay events is expected to be about 10 times larger than that of stopping Ξ^- events according to a Monte Carlo simulation.

We can also reject those events with Ξ^- hyperon passing through the emulsion stack without stopping, by identifying a Ξ^- track in the downstream DSSD and (SCIFI block).

3.7.2 emulsion, DSSD and SCIFI image scanning

We will trace a Ξ^- candidate track found in the first emulsion plate up to its stopping point. In the Ξ^- stopping point, the decay topology is measured precisely. When we find

	"Events"	"Tracks[bundle]"	"Tracks[emulsion]"	"Through"
[E373]				
	495 (1)	947 (1.9)	2862 (5.8)	1076 (2.2)
[proposed experiment]				
	(1)	(1)	(1)	(0)

Table 2: Number of tracks traced in emulsion for a sample of E373 data and expected number in the proposed experiment. "Events", "Tracks[bundle]", "Tracks[emulsion]" and "Through" are the number of stopping Ξ^- candidate events in the emulsion, reconsturucted tracks in the fiber-bundle, found tracks in the first emulsion plate and tracks passing through the emulsion stack, respectively. Their ratios are also shown in parentheses. In the second row, expected ratios in the proposed experiment are listed assuming that the track in DSSD shall be detected uniquely at the top emulsion plate

.

(sequential) weak decay of a double- or single-Λ hypernucleus, all decay products will be traced up to those end points in order to measure their energies and to study characteristics of the stopping points. Particle identification will be made by the measurement of change of I/I_0 (energy loss ratio to minimum ionizing particle). With the downstream DSSD, one can trace a track back to the emulsion from downstream, if necessary. It may enhance the physics capability such as the decay-mode study of S=-2 nuclei and the $\Lambda\Lambda$-resonance search.

In the E373 experiment, the tracks reconstructed in the fiber-bundle tracker are full-automatically scanned in the first emulsion plate by the computer-aided emulsion scanning system [20, 39]. The number of found tracks in emulsion is nearly 3 times larger than the number of the predicted tracks due to the limited resolution of the fiber-bundle tracker. We follows those tracks, plate by plate, by human eyes with a guidance of the computer-aided system until their end points. About 40 % of those tracks go through the final emulsion plate, even after we cut such bad events using track images in the downstream SCIFI. The time necessary to trace such penetrating tracks is about 60% of the total time for the emulsion analysis. In table 2, the result of tracing tracks for a sample of E373 data is shown. In this method, however, all of the emulsion can be scanned within two years in E373.

In the present experiment, the candidate track can be detected uniquely at the first emulsion plate, because the DSSD's have much better resolution of the position and the angle for the Ξ^- tracks. By detecting true Ξ^- tracks at the first emulsion plate, we don't need to follow the tracks with their end point out of the emulsion, as listed in "Through" in table 2. Thus, the total number of tracks to be scanned is considerably reduced. By this reduction, the scanning of Ξ^- candidate tracks is expected to be made 6 times faster than that in E373.

3.7.3 Speed-up of the Emulsion Scanning System

Our experience has shown that the speed-up of the emulsion scanning system is necessary to detect and trace a huge number of Ξ^- hyperon candidate tracks in the emulsion.

An upgraded scanning system has already been made with several improvements such as a CCD camera with a 120Hz read-out, an image processing board with 100Hz driving and a new pulsed light source without infra-red radiation. In a test operation of the system, we have achieved the improvement of the scanning speed by nearly three times faster than that of the current system used for the analysis of E373 emulsions.

Besides that, we will improve the softwere for the automatic scanning. The current software needs a support of human eyes in the process of connecting tracks between the emulsion plates. In that process, we will introduce a method of pattern matching of beams in the emulsion so that it will be mostly free from human eyes. This development will realize a reliable scanning by 2∼3 times faster than that of the current one. In our collaboration, the scanning system including the pilot system has been prepared twice as many as for the case of E373, so far. Therefore, the scanning of the emulsion plates can be done by about one order faster than E373, and we will finish the scanning of all of the stopping Ξ^- candidate tracks within a few years.

After the energy calibration and gain drift correction, if necessary, the photon energy spectrum will be summed up for all the Ge detectors. The PWO counter veto will be also applied to each of the Ge detectors. Then the Ξ^- stopped events identified in the emulsion analysis will be selected. Since the Ξ-nucleus energy shift is expected to be less than a few keV, identification of Z (Ag or Br) for the observed photon peaks is trivial. Using the absolute efficiency curve, the branching ratio per Ξ^- stop will be derived for each X ray peak. The absolute efficiency curve of Hyperball in the previous experiment is shown in Fig. 14. The measured efficiency curve using standard sources is well reproduced by a simulation, which indicates that the absolute efficiency in the proposing experiment will also be obtained within ±3% accuracy in the same manner.

4 Yield estimation to obtain 10^4 Ξ^- stop events

4.1 Maximum number of exposed K^- particle for one stack :n_{K^-}

Since the emulsion records all the charged particles during exposure, the maximum number of exposed beam particles is limited. That is given as follow;

$$n_{K^-} = n_e \cdot r_s \cdot s \cdot r_{K^-}$$

where

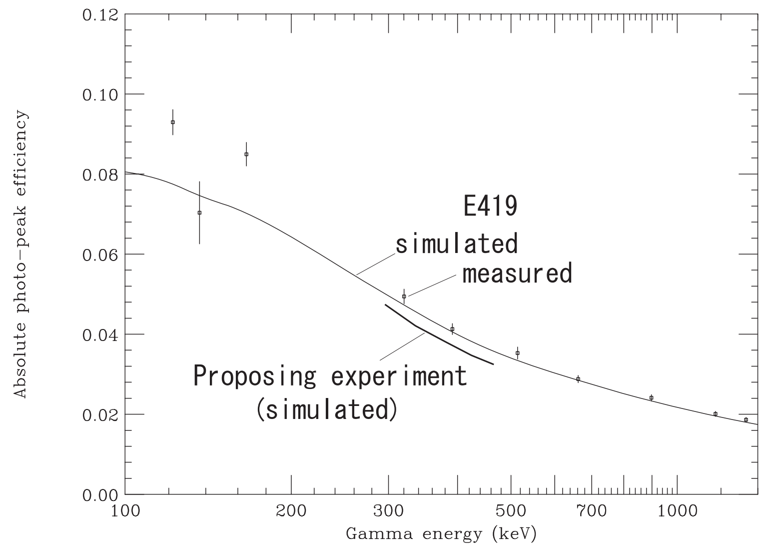

Figure 14: Photo-peak efficiency of Hyperball-J in the proposed experimental setup using 18 Ge detectors in the upstream plane of the traget. The efficiencies in the E419 experiment (measured and simulated) using the full set of Hyperball are shown together.

n_e	=	maximum number of charged particles in emulsion to recognize thin tracks. $\Rightarrow 1 \times 10^6/\text{cm}^2$
r_s	=	damage by shower particles produced in the diamond target. $\Rightarrow 1/1.14$ given by Monte Carlo.
s	=	cross section of emulsion stack. $\Rightarrow 33 \times 32\ \text{cm}^2$
r_{K^-}	=	K^-/π^- ratio in beams $\Rightarrow 6$ (assumed)

It is found to be able to expose K^- of 8.34×10^8 ($= n_{K^-}$) to one emulsion stack.

4.2 Yield of Ξ^- stop in one emulsion stack : $y_{\Xi\text{stop}}$

We estimated the yield of stopping Ξ^- event in the emulsion. The yield depends on the acceptance of the spectrometer and on the distance from the target to TOF counter. The yield estimation is based on the parameters of the KURAMA spectrometer in E373. The Ξ^- stopping yield is written by

$$y_{\Xi\text{stop}} = y_{K^+} \cdot \eta_\Xi \cdot R_{\text{stop}}$$

where

η_Ξ = Ξ^-escaping ratio from the target nucleus,
i.e. ^{12}C of diamond.
⇒ 0.8 from the previous experiment [40]

R_{stop} = Ξ^-stopping probability in the emulsion stack
estimated by Monte Carlo.
⇒ 0.017(KURAMA)

Momentum spectrum of tagged Ξ^- hyperons by the spectrometer using KURAMA magnet was simulated as shown in Fig. 15 together with that of Ξ^- stopped in the emulsion.

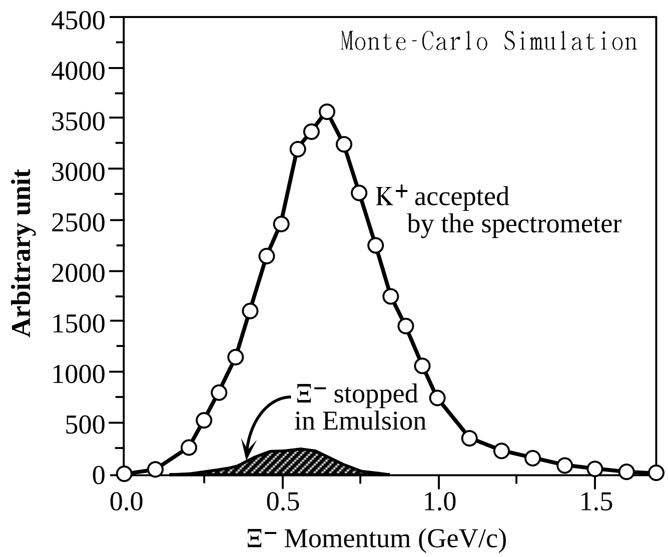

Figure 15: Momentum spectrum of Ξ^- tagged by the spectrometer and stopped in emulsion (Monte Carlo simulation).

y_{K^+} is the number of tagged K^+ in one stack exposure which is written as follow;

$$y_{K^+} = \frac{d\sigma}{d\Omega_L} \cdot \Delta\Omega \cdot N_p \cdot \eta_{abs} \cdot \eta_{K^+} \cdot \eta_{eff} \cdot n_{K^-}$$

where

$\frac{d\sigma}{d\Omega_L}$ = the cross section of quasi-free 'p'(K^-,K^+)Ξ^- reaction.
⇒ 50×10^{-30} cm^2/ sr.

$\Delta\Omega$ = acceptance of the spectrometer.
⇒ 0.20 sr (KURAMA)

N_p = effective proton number of the 3 cm long diamond target (10 g/cm^2).
⇒ 1.36×10^{24}

η_{abs} = beam absorption rate in the diamond target.
⇒ 0.947

η_{K^+} = detection rate of K^+ without decay before reaching the TOF.
⇒ 0.735(KURAMA)

η_{eff} = reconstruction efficiency of the tagged K^+.
⇒ 0.70 is assumed.

Finally, $y_{\Xi stop}$ is estimated to be 75.1 Ξ^- stops in one stack when we use the KURAMA magnet.

4.3 Emulsion volume and Beam time

The volume of one stack of the emulsion is 1430 cc. To get 10^4 Ξ^- stop events, we need the emulsion volume of

$$1430 \times 10000/75.1 = 190 \text{ liters},$$

and 133 stacks in total. This emulsion volume is more than twice of that used in our previous E373 experiment, 70 liters (100 stacks). The total number of K^- we expose is 1.1×10^{11}. If we get almost pure K^- beam with an intensity of 3×10^5 K^-/spill (2.0 sec), we require 600 hours beam time in total including the time for the exchange of emulsion stacks, where 4 hours and $\sim$ 0.5 hours are necessary for the beam exposure on one emulsion stack and the exchange, respectively. We request beam time of 750 hours, which includes the time to tune up all the detectors (150 hours).

4.4 Yield of X rays with Hyperball

The number of X-ray events is estimated as

$$Y_{\Xi(n,l)\rightarrow(n-1,l-1)} = Y_{\Xi\text{stop}}\ P_{\Xi(n,l)}\ BR_{(n,l)\rightarrow(n-1,l-1)}\ \epsilon_{\text{Ge}}$$

In E176, the number of observed events of Ξ^- absorption on the heavy nuclei (Br and Ag) was 47±5 and that on the light nuclei (C,N,O) was 31±5 in total 80 events of stopped Ξ^-. Considering the atomic ratio of Br:Ag=1:1 and assuming the Z dependence of the atomic

$Z(n,l) \to (n-1,l-1)$	Ag(8,7)→(7,6)	Br(7,6)→(6,5)
E (keV)	370.45	315.5
$Y_{\Xi\mathrm{stop}}$	3400	2500
ϵ_{Ge} $(= \epsilon_{peak} \times \epsilon_{live})$	0.044 (= 0.055×0.8)	0.047 (= 0.059×0.8)
$P_{\Xi(n,l)}$	0.3–0.6	
$BR_{(n,l)\to(n-1,l-1)}$	0.88	0.73
$Y_{\Xi\mathrm{X}}$	39–79	26–52
Accuracy(±stat.±syst.) (keV)	±0.21±0.10 — ±0.15±0.10	±0.26±0.10 — ±0.18±0.10
Calculated shift (case 1) (keV)	0.28	0.73
Calculated shift (case 2) (keV)	3.3	5.5

Table 3: Expected yields of Ξ atomic X rays and accuracy of the X-ray energy measurement. See Table 1 for the case 1 and the case 2 of the Ξ X-ray calculation.

capture ratio, Br:Ag=35:47, then the numbers of identified stopped Ξ^- events $Y_{\Xi\mathrm{stop}}$ on Br and Ag is 2500 and 3400 in the total 1×10^4 stopped Ξ^- events. $P_{\Xi(n,l)}$ is the probability that the stopped Ξ reaches the (n,l) atomic state. It depends on the distribution of the initial state of the Ξ atom. It was estimated in Ref. [19] for the Ξ-Pb case using the measured yields of Σ-Pb X-ray yields. Here we assume the same value of $P_{\Xi(n,l)} \sim 0.3$ for Ξ-Ag and Ξ-Br atoms. If the inital l distribution is statistical $(P(l) \propto 2l+1)$, $P_{\Xi(n,l)}$ is calculated to be $P_{\Xi(n,l)} \sim 0.6$ for Ξ-Pb. So we also take this value in the table. $BR[(n,l)/to(n-1,l-1)]$ is the branching ratio of the $(n,l)/to(n-1,l-1)$ transition from the (n,l) state and was calculated [31] as shown in Table 1. ϵ_{Ge} is the photo-peak efficiency of the Ge detectors including the X-ray loss in the target and surrounding material and the electronics live time.

The accuracy of the energy shift of the X ray has a statistical error calculated as $\Delta E/\sqrt{Y_{\Xi(n,l)\to(n-1,l-1)}}$, where ΔE is the energy resolution of the Ge detectors at this energy ($\sim$ 1.3 keV rms or 3.1 keV FWHM). The systematic error from the calibration of the absolute energy will be about ±0.1 keV. As shown in Table 3, the accuracy less than ±0.23 keV for Ag and ±0.28 keV for Br will be achieved for the absolute energy of the X rays. This accuracy is smaller than the predicted energy shifts in Table 1.

In the estimation of the accuracy of the energy shift, we assumed that effect of the background in the photon spectrum is negligible. Possible backgrounds are only γ-rays emitted after Ξ^- absorption followed by formation of excited nuclear fragments. Several γ rays from various nuclei may be emitted per each Ξ^- stop event. Considering the energy resolution and peak-to-Compton ratio of the Ge detectors and also the Compton suppression effect by the PWO counters, we can safely expect that the background level in the Ge detector energy spectrum will be of the order of 0.05 events per keV at around 350 keV. It gives almost no effect to the sensitivity of the energy measurement of the X ray peaks. It is also noted that a possibility of confusion between the Ξ atomic X ray and any nuclear γ ray is expected to be very small, considering the energy resolution of 2 keV and a possible X-ray shift less than a few keV.

4.5 Emulsion handling

In the E373 experiment, we made 100 stacks of the emulsion plates, by pouring emulsion gel on base plates and drying them. It took 7 months in total by three people at Gifu University. This plate-making speed is limited by the number of the drying machines. Since the size of the emulsion plate is larger than that in E373 and we have prepared three drying machines, we will be able to make all of the emulsion plates in three months. We request dark rooms for the emulsion handling before the beam exposure at KEK and J-PARC.

- **gel pouring room at KEK**

To make emulsion plates from gel, we have to use distilled water or ion exchanged water to wash and clean every tools which directly attach to the emulsion. Therefore, water supply and sewer system of waste water have to be equipped in the dark area. We will melt emulsion gel in the hot bath of which size is about 0.5m$\times$1m in area and 0.3m in depth. In the previous experiment, we used a tank like a kitchen sink. To make the flat emulsion plate, we will prepare three stone bases, of which weight is 250kg each. The room has to be equipped with an exhaust air duct and air intake duct for workers' safty.

- **emulsion drying room at KEK**

After fixing of melted emulsion on a thin film support on the base, it is uniformlly dried in a drying machine under 75% Relative Humidity (R.H.). One machine can dry 12 plates. Three drying machines and humidifiers will be set in the room. The size of the drying machine is 1.3m(width)$\times$2.5m(length)$\times$2.7m(hight above floor). To drive the three machines, the electric power of at least 200V$\times$30A is necessary in the dark room. By these electricity consumptions, the room should be heated up. Therefore an air conditioner have to be equipped to keep the room temparature at 30°C.

- **plate cutting at KEK**

Dried emulsion plates have to be dried finally at the lower humidity (60%R.H.) and cut out to the exposure size (35$\times$35cm^2) in another dark room. We will bring a cutting machine (a large guillotine cutter) of the weight about 100kg into the room.

- **stacking room at J-PARC**

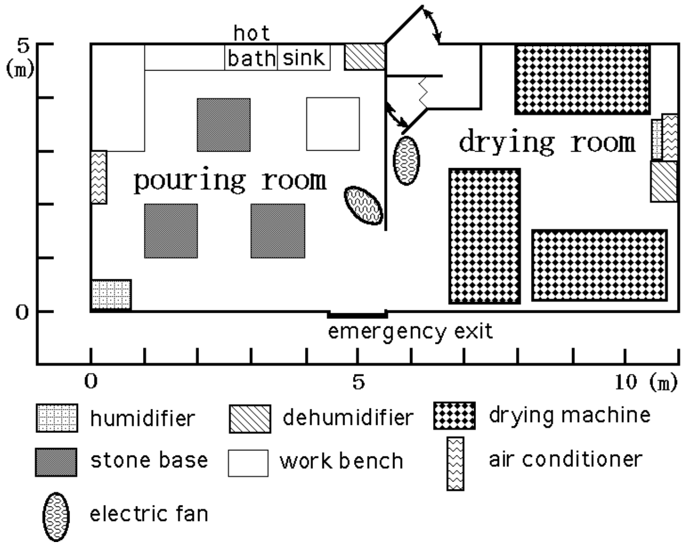

Figure 16: A sample layout of the room for emulsion pouring.

A dark room will be also used for stacking of the emulsion plates just before the beam exposure and unstacking it just after the exposure. At the unstacking, we have to expose each plate to UV-rays to calibrate the position between each emulsion plate and the beam line cordinate. Therefore, the location of the room will be near the beam line such as a container with ordinal power supply.

We summarize our request for the dark rooms at KEK with sample layouts which are shown in Fig. 16 and Fig. 17.

The emulsion has to be developed as soon as possible after the beam exposure, because latent images fade away. According to our experience in E373, if the exposed emulsion was stored at a low temperature of 5°C, a sufficient number of developed grains was obtained for minimum ionizing particles within 5 months after the beam exposure. On the other hand, the emulsion accumulates all the charged particles mainly from cosmic rays during the period. To decrease the cosmic radiation, we will store the exposed emulsion plates in underground such as a coal mine until they are developed. We will develop all of the emulsion at Gifu University or ICRR (Institute for Cosmic Ray Research). We expect to finish the development within 5 months at Gifu University in which the facility has to be newly built.

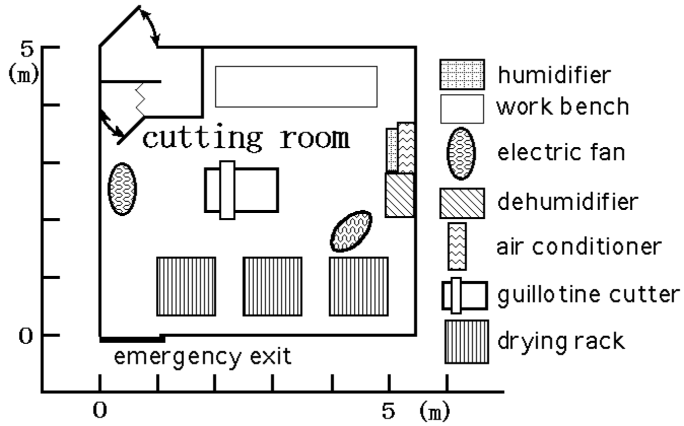

Figure 17: A sample layout of emulsion cutting room.

5 Readiness for the experiment

We have developed experimental tools and method for the proposed experiment supported by Grant-in-Aid for Specially Promoted Research and for Scientific Research (B). Although some of them are introduced in the previous chapters, we summarize the preparation.

- **DSSD :** We have prepared six sets of DSSD which has effective area of 30×60 mm^2. By using the proton beam at KEK-PS (T594), we have checked a DSSD system. Altough the data analysis is on-going, we will be also able to check track connection between DSSD and the emulsion plate.

- **Emulsion :** The production of huge amount of emulsion gel (2.6 tons) becomes available to be made using the production line to make commercial photofilm at Fuji Phtofilm Co., Ltd. By this development, the price of the gel decreased to about a half of that used in the previous experiment. We have also developed the method how to make large emulsion plate. We already have about a half volume of the gel for the proposed experiment.

- **Ge detectors :** Hyperball-J is under construction with the Grant-in-Aid (about 300M yen, 2005–2009, spokesperson: Tamura). It is an upgraded version of our previous Ge detector arrays (Hyperball and Hyperball2) and we have no technical difficulty. It will be ready by the fall in 2008. The supporting frame of the Hyperball-J detectors for the proposed experiment will be constructed in 2007.

- **Emulsion scanning system :** In the prevous experiment, we have used five scanning systems to search for the Ξ^- stopping events. We have developed more fast and reliable system than that in the previous experiment. Additinal six scanning systems (total 11 systems) shall be used for the proposed experiment.

- **Emulsion Mover :** The emulsion plate will be enlarged in the area by twice rather than that of the previous experiment, in order to save time to exchange the emulsion stacks. The emulsion mover for uniform irradiation of the beam has been newly made for the large emulsion stacks. The accuracy of the stack moving is 10 μm that is same as we have achieved in the previous experiment.

6 The condition for the experiment and the budget

The full intensity of K^- beam provided at the K1.8 beam line shall be (1.4×10^6 K^-/spill) [34] under the condition of the primary proton beams with 30GeV, 9μA at the 1st stage. To get full intensity beams, it will be necessary to take some time period to reach the expected intensity.

Even during such period, it will be possible to use the higher intensity beam than that provided at KEK-PS. This proposed experiment to study double-strangeness system is very feasible to be carried out during such period because our requested intensity is at most 20% of the full one.

As for the experimental budget, we have prepared most of new experimental equipments and half of emulsion gel supported by several Grant-in-Aids as commented in the previous section. We also hope to use chambers, hodoscopes, read-out modules and etc., exsisting already at KEK. We need only a modest amount of additional budget for materials specialized to this experiment, for example additional emulsion gel, chemicals for emulsion development, waste liquid treatment, and others. However we will request for the dark rooms at KEK and J-PARC. The support is also requested for the transportation of the KURAMA magnet from KEK to J-PARC and other equipments, e.g. for area construction, on-line analysis computers and so on, which can be used also for other experiments at J-PARC.

7 Summary

We propose an experiment for the systematic study of nuclear systems with double strangeness by using a new emulsion-counter hybrid method. The emulsion is used to detect especially hyperfragments and to identify formation and decay of Ξ^- atoms. Counters are used to identify (K^-,K^+) reaction and Ξ^- emission, and to measure energies of X rays from Ξ^- atoms.

About ten years ago, the 1st generation hybrid emulsion experiment, KEK-E176, found that double strangeness nuclei are efficiently produced through Ξ^- nuclear capture at rest (stopping Ξ^- events in the emulsion). In order to obtain ten times more stopping Ξ^- events, the 2nd generation experiment using an emulsion-scintillating fiber hybrid method, KEK-E373, was carried out. We have established weakly attractive $\Lambda\Lambda$ interaction by observation of an uniquely identified ${}^{\ 6}_{\Lambda\Lambda}$He event.

The goal of the proposed experiment is to obtain 10^4 stopping Ξ^- events in emulsion, which will provide one thousand events showing formation of double strangeness nuclear systems. Among them, we will detect one hundred nuclear fragments with double strangeness and make a chart of S=−2 nuclide.

The objective of the experiment is a systematic measurement S=−2 nuclei and to determine their binding energies, especially (A) dependence of the 'ΛΛ interaction energy' for, at least, several nuclides.

If the H dibaryon state exists in nuclei, study of not only the A dependence of the $\Lambda\Lambda$ interaction energy but also decay modes of double strangeness nuclei will clarify the existence of such a H dibaryon state.

Since the number of stopping Ξ^- events is ten times more than in E373, the sensitivity will be greatly improved for double strangeness nuclei, the H dibaryon and also Ξ^- atoms. By selecting stopping Ξ^- events in emulsion analysis, we precisely measure the energies of X rays from Ξ^- atoms on Ag and Br nuclei using Ge detectors. The enegy shifts and yields of X rays will provide definite information on the Ξ-nucleus potential and then the ΞN interaction.

In order to improve statistics by ten times, we take advantage of almost pure K^- beam obtained at the K1.8 beam line, which is compared to $K^-/\pi^- \sim 1/4$ at KEK. We employ a new high position resolution detector, a double-sided Si strip detector, to reconstruct Ξ^- tracks rather than scintillating fiber bundle used in E373 in order to make the time-consuming emulsion scanning easier and faster. They are essential to observe 10^4 stopping Ξ^- events in the emulsion. The scintillating fiber blocks which surround the emulsion are used to detect π^- and higher energy particles, and the emulsion is used to detect mainly hyperfragments. The Ge detectors will catch X rays from Ξ^- atomic orbits.

Various new techniques developed in our previous experiments will be combined in this experiment. It is, technically, the third generation experiment of this kind.

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