Letter of Intent for J-PARC 50 GeV Synchrotron

Gamma-ray spectroscopy of hypernuclei at K1.1

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abstract

Following the E13 experiment (Gamma-ray spectroscopy of light hypernuclei) scheduled to run at the K1.8 beam line, further experiments on hypernuclear γ-ray spectroscopy will be proposed at the K1.1 beam line via the (K^-,π^-) reaction with $p_K = 1.1$ GeV/c. At the K1.1 line, we expect much more efficient data collection than at the K1.8 line by an order of magnitude. We are planning systematic studies of various Λ hypernuclei in a wide mass region from *sd*-shell to heavy Λ hypernuclei ($^{20}_{\Lambda}$Ne, $^{28}_{\Lambda}$Si, ... , $^{208}_{\Lambda}$Pb, etc.), and measurement of the Λ g-factor in a nucleus for various mass regions. We require the SKS spectrometer or a similar spectrometer to analyze pion momentum. The Ge detector array Hyperball-J, which is under construction for E13, will be also used.

Background and Motivation

We have been studying precise structures of various Λ hypernuclei by means of the hypernuclear γ-ray spectroscopy technique which was developed by our group [1, 2]. Our studies carried out at KEK-PS and BNL-AGS will be extended with a high intensity K^- beams at J-PARC.

For most of hypernuclear γ spectroscopy experiments, 1.1 or 1.5 GeV/c K^- beams are necessary to produce both spin-flip and spin-non-flip hypernuclear states by the (K^-,π^-) reaction. Both cross sections for spin-flip and spin-non-flip Λ production are almost the same between 1.1 and 1.5 GeV/c. In the latest design, the planned K1.1 beam line provides 1.1 GeV/c K^- beam with an intensity of 1.0×10^6/spill for a full 30 GeV proton intensity (9 μA), while the 1.5 GeV/c K^- beam intensity at the K1.8 beam line is expected to be 0.5×10^6/spill. In addition, the lower momentum transfer in the 1.1 GeV/c (K^-,π^-) reaction allows a better Doppler shift correction than in the 1.5 GeV/c case. Thus the K1.1 line is the ideal apparatus for our γ-spectroscopy experiments, as we described in the Letter Of Intent in 2003 [4]. However, since the K1.1 line is not available for Day-1 experiments (and the K1.8BR line is not preferable due to anticipated worse K^-/π^- ratio giving severer radiation damage to the Ge detectors), we proposed the first γ-ray spectroscopy experiment (E13) [3], which is designed to be carried out at the K1.8 beam line using 1.5 GeV/c K^- beam and the SKS spectrometer. The E13 experiment has been approved as one of the Day-1 experiments and we are now preparing for the run.

Beam line	K1.8	K1.8BR	K1.1
Beam momentum	1.5 GeV/c	1.1 GeV/c	1.1 GeV/c
Beam intensity	0.5×10^6/spill	1.2×10^6/spill	1.0×10^6/spill
$\frac{d\sigma}{d\Omega}({}^{7}_{\Lambda}\mathrm{Li}(3/2^+), \theta = 10^0)$	7.1μb/sr	17μb/sr	
Relative γ-ray yield	1	5.7	4.8
K/π ratio		< 0.9	$\sim$3
γ-ray peak broadening	8.2%	6.1%	

Table 1: Comparison between K1.8, K1.8BR and K1.1 beam lines for hypernuclear γ-ray spectroscopy experiments. Relative γ-ray yields from a typical spin-flip hypernuclear state, ${}^{7}_{\Lambda}\mathrm{Li}(3/2^+)$, are shown.

After E13, we intend to extend our studies of hypernuclear γ spectroscopy to various other hypernuclei in which more physics subjects are involved, as shown in the next section. However, it will take an extremely long time (probably five years or more) if only the K1.8 beam line is available, considering the anticipated overcrowded schedule of the K1.8 line as well as the weak 1.5 GeV/c K^- beam intensity and lower cross sections for hypernuclear production (see Table 1). In order to collect data much more efficiently, we request to construct the K1.1 beam line. With the K1.1 line, the efficiency of running these experiments will be **improved by a factor of ∼10** than the case with the 1.8 line only, where a factor of 5 comes from the beam intensity and the cross section as shown in Table 1, and another factor of 2 is from relaxation of the overcrowded schedule.

Physics motivation and planned experiments

The E13 experiment focuses on a few light hypernuclei, ${}^{4}_{\Lambda}\mathrm{He}$, ${}^{7}_{\Lambda}\mathrm{Li}$, ${}^{10}_{\Lambda}\mathrm{B}$, ${}^{11}_{\Lambda}\mathrm{B}$, ${}^{19}_{\Lambda}\mathrm{F}$, and measure the g_Λ value in a spin-flip M1 transition and study ΛN interaction in detail such as charge symmetry breaking and ΣN-ΛN coupling.

After E13, we plan the following experiments using the 1.1 GeV/c (K^-,π^-) reaction at the K1.1 line. Details of each experiment are described as a part of the Letter Of Intent submitted in 2003 [4].

1) Light hypernuclei up to $A \sim 30$ (${}^{9}_{\Lambda}\mathrm{Be}$, ${}^{13}_{\Lambda}\mathrm{C}$, ${}^{20}_{\Lambda}\mathrm{Ne}$, ${}^{23}_{\Lambda}\mathrm{Na}$, ${}^{27}_{\Lambda}\mathrm{Al}$, ${}^{28}_{\Lambda}\mathrm{Si}$, etc.)

   From precise structure data of these hypernuclei, together with the previous data in the *s*-shell and *p*-shell regions, we will study the ΛN interaction further. In particular, the ΣN-ΛN coupling force and the *p*-wave interaction, which have not been clarified yet, will be investigated. Comparing the ΛN effective interactions between p-shell and sd-shell hypernuclei, radial dependence of the ΛN spin-dependent interactions will be also examined.

   From $B(E2)$ measurements in ${}^{9}_{\Lambda}\mathrm{Be}$ and ${}^{13}_{\Lambda}\mathrm{C}$, the hypernuclear shrinking effect, which was measured only in ${}^{7}_{\Lambda}\mathrm{Li}$ [2], can be systematically investigated. In the *sd*-shell region, various new aspects of impurity effect are expected. For example, parity inversion of the ground state in ${}^{20}_{\Lambda}\mathrm{Ne}$ is predicted [4], and a drastic change of nuclear deformation is expected when a Λ is added to some *sd*-shell nuclei [5]. These phenomena can be investigated from level schemes.

Concerning the p-shell and sd-shell hypernuclei, a small momentum transfer (<150 MeV/c) by 1.1 GeV/c K^- makes the cross sections of low-lying levels much larger than by 1.5 GeV/c as shown in Table 1.

2) Medium and heavy hypernuclei ($^{51}_{\Lambda}$V, $^{89}_{\Lambda}$Y, $^{208}_{\Lambda}$Pb, etc.)

From systematic studies of level schemes in a wide mass number range, particularly of the $1\hbar\omega$ energy spacing measured from the $p_\Lambda \to s_\Lambda$ $E1$ transitions, detailed information on the Λ single particle potential (depth, effective mass, shape) can be obtained. These data may be related to a possible modification of baryons (or "identify" of baryons) deeply embedded in nuclear matter. Such a study is impossible in ordinary nuclei. There is also a chance to extract the strength of the p-wave ΛN interaction. For medium and heavy hypernuclei, a large momentum transfer ($>$ 250 MeV/c) is desirable to populate low-lying bound states. So we need to measure data at large scattering angles ($> 15^0$) for 1.1 GeV/c beam. A higher beam momentum using the K1.8 beam line with a smaller scattering angle can be an option.

3) Spin-flip B(M1) measurement by Doppler shift attenuation method and γ-weak coincidence method ($^{12}_{\Lambda}$C, and heavier hypernuclei)

In the E13, we will measure the g-factor of a Λ in the $^{7}_{\Lambda}$Li hyeprnucleus from a B(M1) value for the spin-flip M1 transition between the ground state doublet in order to examine possible modification of baryon properties in a nucleus. This subject will be extended to other hypernuclei for the purpose of investigating isospin and nuclear-density dependence of the g factor change in a nucleus. A large isospin dependence is expected if the g-factor is changed due to the Σ-Λ mixing, while a large nuclear-density dependence is to be found if the change is caused by partial restoration of chiral symmetry. For $^{12}_{\Lambda}$C and heavier hypernuclei, the lifetime of the spin-flip M1 transition is expected to be too slow to apply the Doppler shift attenuation method. In such cases, we will apply the gamma-weak coincidence method proposed by our group [6].

In future, we are planning to build a high-resolution π^0 spectrometer to utilize the (K^-,π^0) reaction for the following experiments.

4) Mirror and neutron-rich hypernuclei by (K^-,π^0) reaction ($^{7}_{\Lambda}$He, $^{9}_{\Lambda}$Li, $^{12}_{\Lambda}$B, etc.)

Using the (K^-,π^0) reaction at K1.1 beam line, we can produce neutron-rich hypernuclei, and mirror hypernuclei to those produced by the (K^-,π^-) reaction. The γ-ray spsctroscopy experiments of these hypernuclei allow us to investigate charge symmetry breaking in the ΛN interaction which is suggested to be extraordinary large, and to study impurity effect induced by a Λ particle such as disappearance of a neutron halo in $^{7}_{\Lambda}$He.

Magnetic spectrometers

The setup of the experiments is illustrated in Fig. 1.

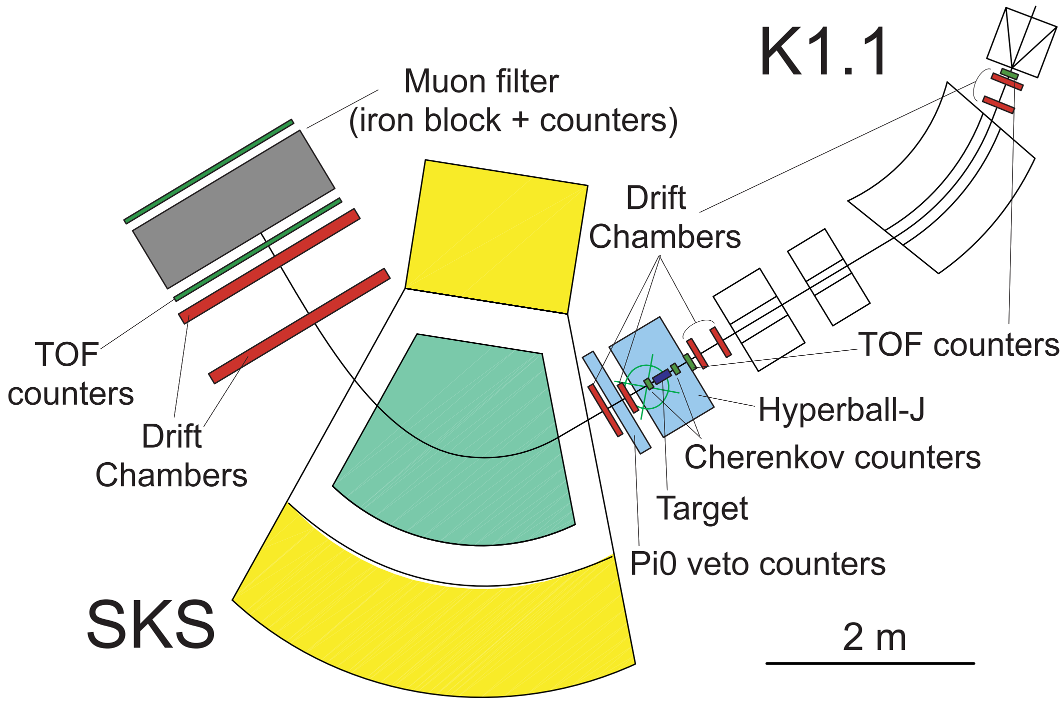

Figure 1: Experimental setup for hypernuclear γ spectroscopy experiment using 1.1 GeV/c (K^-,π^-) reaction at J-PARC K1.1 beam line. The SKS spectrometer together with the detectors used in E13 is assumed to be used. The new Ge detector array used for E13 (Hyperball-J) will be installed around the target.

The final stage of K1.1 should be a magnetic spectrometer with a resolution better than 0.15% (FWHM). At the upstream and downstream of the spectrometer magnet, we install a set of tracking chambers (1 mm pitch MWPC and 3mm pitch drift chambers) and timing counters similar to those used at K1.8.

To analyze pion momentum, we need the SKS spectrometer, or a similar spectrometer with a large acceptance ($\sim$100 msr) and a good momentum resolution better than 0.15% (FWHM). The SKS spectrometer can be employed at K1.1 when it is not used at K1.8. However, since the movement of the SKS between K1.8 and K1.1 is costly, it is desirable to construct a similar new spectrometer dedicated to the K1.1 line. The detector system for the spectrometer will be similar to the one at K1.8. Large drift chambers which will be used for E13 at K1.8 will be moved to K1.1.

Ge detector array

The new-generation Ge detector array "Hyperball-J" is under construction for the E13 experiment. This detector array [7] consists of about 30 Ge detectors and designed to be tolerant to a severe radiation expected in the full beam intensity at J-PARC. It is characterized by newly-developed technique, (1) a new mechanical cooling method, instead of the ordinary liquid nitrogen method, which keeps the detector temperature lower and reduces radiation damage effects, and (2) PWO counters having a fast decay time of light emission instead of slow BGO counters. In addition, (3) a waveform analysis method in data processing, which is under development, will be introduced to Hyperball-J before higher beam intensity is realized by 50 GeV 12μA proton beam.

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