Letter of Intent for the E05 next physics run with S-2S

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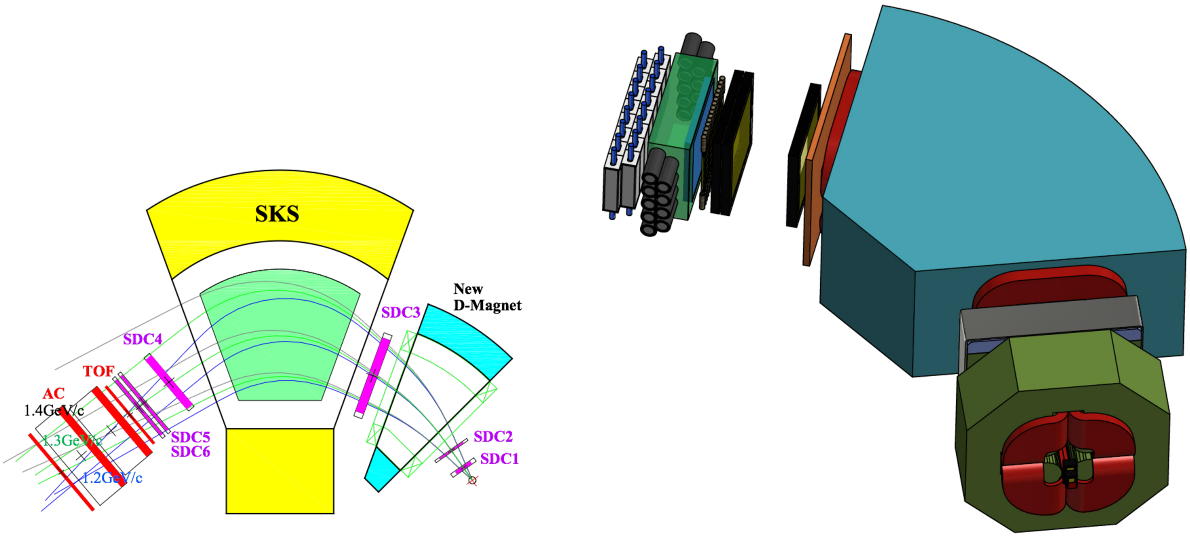
1. Original E05 Proposal

The E05 proposal entitled "Spectroscopic Study of Ξ -Hypernucleus, ${}^{12}_{\Xi}\mathrm{Be}$, via the ${}^{12}\mathrm{C}(K^-, K^+)$ Reaction" was submitted during the 1st PAC meeting, and had been considered to be the 1st priority experiment among the five Day-1 experiments (E05, E13, E15, E17, E19) in the Hadron Hall experiments. Among the Day-1 experiments, three experiments, E13, E15, and E19, have already taken the physics data(part of the E13 program was newly proposed as E63 at the new K1.1 beam line). Interesting results were already reported from these experiments in scientific journals. The E17 experiment was newly registered as a new measurement of E62. The E05 is the only experiment left to be carried on in the Day-1 experiments, somehow.



1. SKS+ **2.** S-2S

Figure 1:
Schematic views of the E05 experimental setup using the SKS+ (1) in the original E05 proposal, and the S-2S (2).

In fact, we presented a revised run plan upon the PAC request considering the realistic beam conditions, during the 13th PAC meeting in January, 2012. One of the major improvements in E05 was that in 2011 we succeeded to obtain a grant budget of about $3M to construct a new spectrometer system dedicated to the study of the (K^-,K^+) reaction; we call it "Strangeness -2 Spectrometer (S-2S)". As shown in **Table 1** , the performance of the S-2S supersedes that of SKS+ in all aspects. We then submitted the beam time request for a pilot run of E05, at the 19th PAC meeting in December, 2014. As result, we got about 14 days of successful data taking in Oct. and Nov., 2015, by using the SKS spectrometer at the K1.8 beam line; it was the last chance to use it at the K1.8. A preliminary analysis indicates a possible signal of the Ξ-hypernucleus production.

Performance	**SKS+**	**S-2S**	**SKS**
Solid angle (Ω)	30 msr	60 msr	110 msr
Missing-mass resolution (FWHM)	3 MeV	~1.5 MeV	6 MeV
Magnets Configuration	DD	QQD	D

Table 1:

Comparison of two spectrometers: SKS+ in the original proposal and S-2S. In the last column, the SKS performance in the pilot run is listed for comparison.

In this LoI, we are going to present a current idea of the next E05 beam time with the S-2S spectrometer at the K1.8, based on the preliminary result from the pilot run.

2. Updates on Ξ -hypernuclei

The experimental information on Ξ-hypernuclei has been so much limited so far. The missing-mass measurements with the ^{12}C(K^-,K^+) reaction were carried out at KEK[1] and BNL[2], although the statistics and the energy resolution were poor. An initial analysis by the BNL E885 group suggested an attractive Ξ potential, with a depth of about 14 MeV. A reanalysis by Kohno et al. suggested almost zero[3] or even a weakly repulsive potential[4]. Recently, KEK E373 group discovered the "Kiso" event[5] as the first evidence of a deeply-bound $\Xi^{-}-{}^{14}\mathrm{N}$ system with the binding energy of 3.87±0.21 MeV(or 1.03±0.18 MeV) depending on the ${}^{10}_{\Lambda}\mathrm{Be}$ state(the ground state or an excited state) emitted as a decay product. Unfortunately, from a single event, it is hard to determine the binding energy precisely because of the possible finite conversion width due to a strong conversion process, $\Xi^- + p \to \Lambda + \Lambda$.

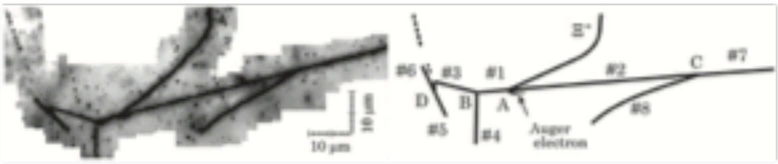


Figure 2:
"Kiso" event[5] observed in KEK E373 experiment. The process of $\Xi^- - {}^{14}\mathrm{N} \to {}^{10}_{\Lambda}\mathrm{Be} + {}^{5}_{\Lambda}\mathrm{He}$ *is recorded on an emulsion.*

3. Preliminary Results obtained in a pilot run

A preliminary result from the E05 pilot run was already reported in the 22nd PAC meeting. Analysis is still going on to carefully evaluate the differential cross sections of the $p(K^-, K^+)\Xi^-$ reactions from 1.5 GeV/c to 1.9 GeV/c, and to obtain the excitation energy spectrum of the ${}^{12}\mathrm{C}(K^-, K^+){}^{12}_{\Xi}\mathrm{Be}$ reaction at 1.8 GeV/c. Here we show again the excitation energy spectrum of the ${}^{12}\mathrm{C}(K^-, K^+){}^{12}_{\Xi}\mathrm{Be}$ reaction as a function of $-$B.E.(Binding Energy). The histogram bins in red color could be the signals which have significant excess over a flat background.The number of excess events is about 40.

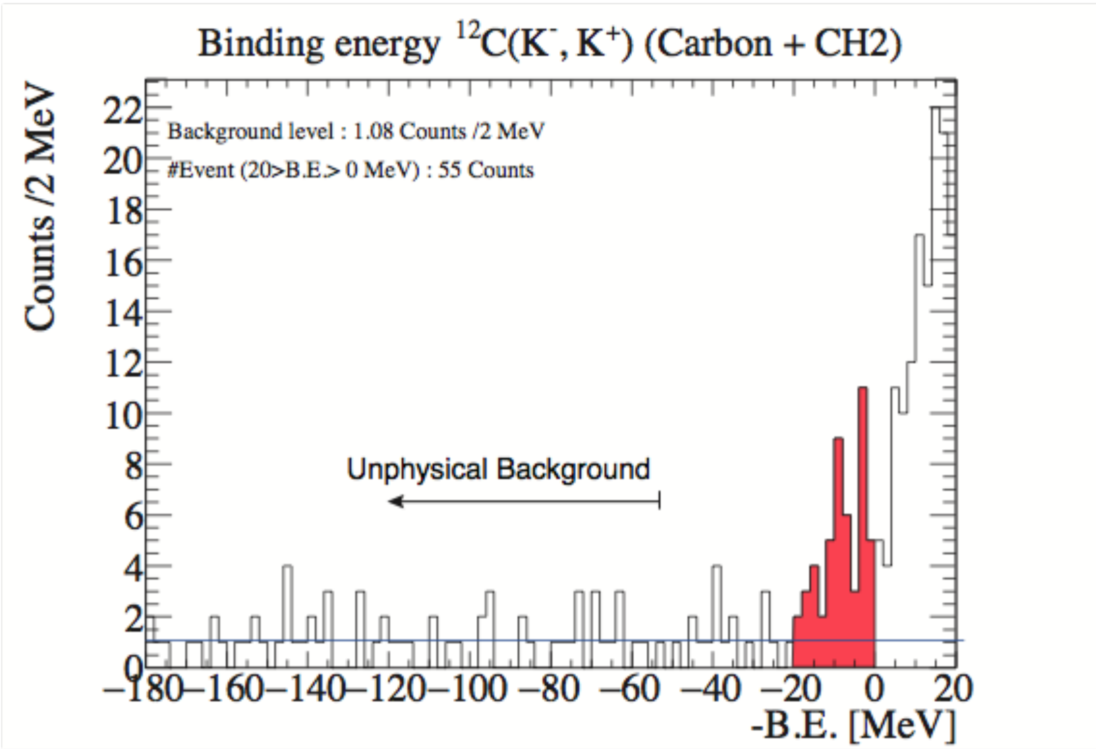


Figure 3:

The excitation energy spectrum of $^{12}_{\Xi}$Be *near the binding threshold. A significant enhancement over a flat unphysical background component is observed.*

The condition to observe this signal is summarized in the second column of **Table 2** .

Run conditions	**Pilot Run**	**Next physics Run**
K$^-$ intensity	0.6 M/spill	1.23 M/spill
MR beam power (kW)	39	80
Spill cycle	5.52 s	4 s
Target thickness	9.3 g/cm^2	10 g/cm^2 active
Spectrometer acceptance (Ω)	110 msr	55 msr
Missing-mass resolution (FWHM)	6 MeV	< 2 MeV
Signal events/ days of run	40/10 days	~120/20 days

Table 2:

Run condition in the pilot run to observe the $^{12}_{\Xi}$Be *signal. The last column contains the expected run condition for the E05 physics run with S-2S.*

4. Run Plan of E05 with S-2S

Based on the results of the pilot run, we can surely estimate the yield of the Ξ-hypernucleus in the case of S-2S. Here, as far as the MR operation is concerned, we assume that the beam power for the slow extraction will reach at 80 kW sometime in 2018, which is the time we want to run. The current production target made of Au in the Hadron Experimental Hall will sustain up to 80 kW safely. Then, the K^- beam intensity will be doubled, while we have a reduction of the forward K^+ spectrometer acceptance by 50%. We would like to shorten the spill length to be about 1-second flat top to increase the repetition rate. Even at 1-second flat top, the K^- beam rate is 1.23 M/sec, which is below the beam rate assumed in the original proposal, 1.4 M/0.8 s = 1.75 M/sec. For the experimental target, we are going to use a scintillating fiber target with a total thickness of about 10 g/cm^2; almost the same thickness we had in the pilot run. Here, our idea is to correct the energy-loss straggling event-by-event with the measured energy loss in the fiber target along the particle paths; in this case, K^- and K^+. Thereby we could keep the energy resolution as good as ~1.5 MeV (FWHM). In total, after a 20-day long run, we expect to have three-times better number of signal events, ~120 events in the bound region. Please note that the expected energy resolution is increased by more than three-times, so that the signal to background ratio is improved significantly. Further, the flat background component in present **Figure 3**, which is mainly due to the π^+ originated from K^- beam decay-in-flight will be suppressed in the S-2S.

In summary, we would like to carry out the physics data taking of E05 with the scintillating fiber target by using the S-2S spectrometer at the K1.8 beam line, when the beam power for slow extraction reaches about 80 kW. The expected running time is about one month.

References

[1] T. Fukuda et al., Phys. Rev. C 58 (1998) 1306.

[2] P. Khaustov et al., Phys. Rev. C 61 (2000) 054603.

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[5] K. Nakazawa et al., Prog. Theor. Exp. Phys. 2015 (2015) 033D02.