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PRODUCTION OF DOUBLE-Λ HYPERNUCLEI : BNL-AGS E906 *

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We have carried out an experiment at BNL-AGS (E906) to search for double-Λ hypernuclei by observing sequential pionic decays . We will describe the principle of the experiment and report the present status.

1 Introduction

The study of double-Λ hypernuclei will give us information concerning the Λ-Λ force, which is quite important to understand the baryon-baryon interactions in a unified way. Moreover, the existence of the double-Λ hypernuclei may place limits on the mass of the predicted stable dibaryon (H), i.e. the observation of a double-Λ

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hypernucleus will exclude an H mass smaller than $2M_\Lambda$ - (binding energy of the two Λ's in the double- Λ hypernucleus).

However, the experimental studies on double-Λ hypernuclei have been limited so far; in the 1960's only two double-Λ hypernucleus events were reported, one $^{10}_{\Lambda\Lambda}$Be[1] and one $^{6}_{\Lambda\Lambda}$He[2], although the event in reference 2 is not convincing[3]. These events remained the only ones until recently when a new observation was made at the KEK-PS E176 experiment[4]. However the interpretation of the event is not unique; i.e. either $^{10}_{\Lambda\Lambda}$Be or $^{13}_{\Lambda\Lambda}$B, and accordingly the extracted Λ-Λ interaction energy is either -4.9 ± 0.7MeV (repulsive Λ-Λ interaction) or $+4.9\pm0.7$MeV (attractive Λ-Λ interaction).

We proposed a new way to study the double-Λ hypernuclei with much more statistics (BNL-AGS E906)[5]. In the following sections, we will discuss the experimental principle and describe the present status of the experiment.

2 PRINCIPLE OF THE EXPERIMENT

The production of double-Λ hypernuclei has been made so far by the stopped-Ξ^- method, where Ξ^- is emitted via a quasi-free process in the (K^-,K^+) reaction and stopped in the target material. Then a Ξ^- -atom is formed and Ξ^- is eventually absorbed by a nucleus, and a proton in the nucleus and the Ξ^- will be converted into two Λ's by the $\Xi^- p \to \Lambda\Lambda$ strong interaction. Then, the double-Λ sticking state is formed with probability of more than ~10 %[6], and it decays into some fragments including a double-Λ hypernuclei or twin single-Λ hypernuclei.

On the other hand, in the (K^-,K^+) reaction, the Ξ^- emission probability is about 70-80 % of the total quasi free events and the rest can be attributed to more complicated processes, such as secondary interaction of Ξ^- inside a nucleus[7,8]. After these complicated processes, there may be a chance for $S=-2$ (eventually two Λ's) to be trapped in a nucleus and to form a double-Λ hypernucleus. A theoretical attempt[9] was made in order to evaluate the production rate of the double-Λ hypernuclei through the quasi-free production of Ξ^- followed by the secondary reaction of Ξ^- inside a nucleus. The estimated rate of the formation of double-Λ compound nucleus is about 0.3 % per quasi free reaction for ^{12}C target, assuming the Ξ^--nucleus potential of 15 MeV depth. The double-Λ compound nucleus will then decay into hyperfragments such as $^{6}_{\Lambda\Lambda}$He and $^{5}_{\Lambda\Lambda}$H etc or twin single-Λ hypernuclei.

The double-Λ hypernuclei, which are produced via stopped-Ξ^- process and/or through the quasi-free production of Ξ^- followed by the secondary reaction, can be identified by detecting characteristic mesonic-decaying pions. Let's consider the $^{5}_{\Lambda\Lambda}$H case as an example; $^{5}_{\Lambda\Lambda}$H can be identified by observing two characteristic pions from the successive pion decays ($^{5}_{\Lambda\Lambda}\mathrm{H} \to {}^{5}_{\Lambda}\mathrm{He} + \pi^-$ and $^{5}_{\Lambda}\mathrm{He} \to {}^{4}\mathrm{He} + p + \pi^-$), provided the widths of the pion spectrum are small enough. A recent calculation [10] shows that the widths of the pion spectrum for $^{5}_{\Lambda}$He is about 1.0 MeV, which is consistent with the experimental data of $^{5}_{\Lambda}$He decay[11]. From the momentum spectrum of pions in coincidence with the pions with momentum of ~100 MeV/c ($^{5}_{\Lambda}\mathrm{He} \to {}^{4}\mathrm{He}+p+\pi^-$), we can determine the mass of $^{5}_{\Lambda\Lambda}$H. Note that the branching ratios of pion decay rates $\Gamma_{\pi^-}/\Gamma_{tot}$ will be large enough to be observed ; ~ 0.21 and ~ 0.39 for $^{5}_{\Lambda\Lambda}$H and $^{5}_{\Lambda}$He[12], respectively. It should be also noticed that the

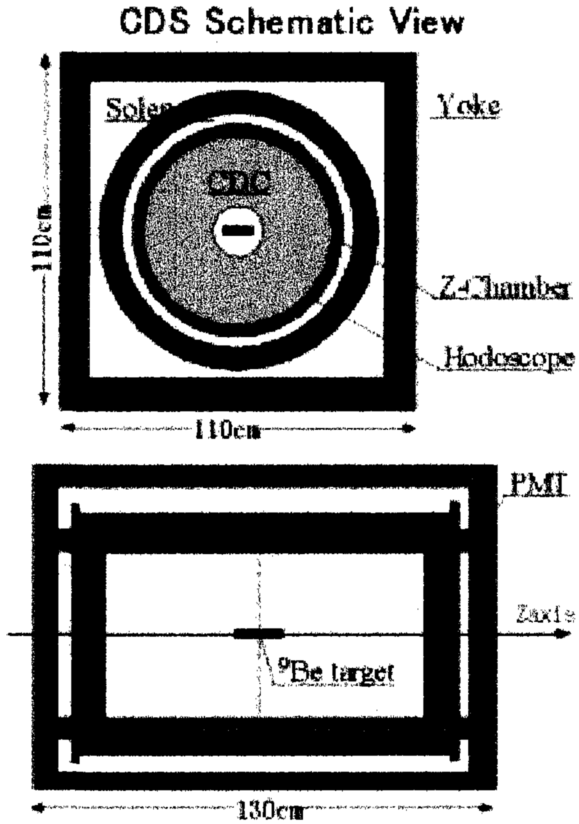

Figure 1: A schematic drawing of the Cylindrical Detector System (CDS)

momenta of decaying pions of ${}^{5}_{\Lambda\Lambda}$H are expected to be around 130 MeV/c and well separated from other decaying pions. In addition to this decay mode, ${}^{5}_{\Lambda\Lambda}$H will also decay to ${}^{4}_{\Lambda}\mathrm{H} + \mathrm{p} + \pi^-$ with a large branching ratio ($\sim$ 0.33) to the total. The width of this π^- is expected to be small enough ($\sim$ 2 MeV) and ${}^{4}_{\Lambda}$H will decay with a high energy pion (132.9 MeV/c) and with a large branching ratio ($\sim$ 0.36), so that this decay mode can be also used to identify ${}^{5}_{\Lambda\Lambda}$H . Note that the branching ratio $\Gamma_{\pi^-}/\Gamma_{\mathrm{tot}}$ of ${}^{5}_{\Lambda\Lambda}$H depends slightly on the binding energy of ${}^{5}_{\Lambda\Lambda}$H but not too much [12].

Decaying pions will be detected by using a Cylindrical Detector System (CDS), which surrounds the target region (Fig.1). The momentum resolution and the solid angle of the CDS will be about 3 MeV/c FWHM (1.7MeV in energy) for 100 MeV/c pions and 65 % of 4π, respectively. We chose ^{9}Be as a target because the available species of the final hyperfragment are limited and thus easy to be identified. In fact, a calculation for the hyperfragment formation rate based on a statistical model shows a concentration of ${}^{5}_{\Lambda\Lambda}$H ($\sim$0.4 per double-Λ compound nucleus) [9,12] for the process through the quasi-free production. Concerning the formation rate of each hyperfragment through stopped Ξ^- process, theories only partly succeed to reproduce the experimental data [13]. For ^{9}Be case, we expect an absorption of Ξ^- to the "alpha" in ^{9}Be. This subsystem (Ξ^- plus "alpha") has a large overlap amplitude with the ground state of $^{5}_{\Lambda\Lambda}$H [14], so that it may eventually decay to $^{5}_{\Lambda\Lambda}$H . Here we simply assume a similar formation rate of $^{5}_{\Lambda\Lambda}$H for the stopped Ξ^- process as the quasi-free case.

If we take into account all theoretical inputs and realistic experimental condistions, we expect about 500 counts of decaying pions from $^{5}_{\Lambda\Lambda}$H in coincidence with pions from $^{5}_{\Lambda}$He and $^{4}_{\Lambda}$H for the proposed 2 x 10^{12} K^- on the Be target.

3 EXPERIMENT

The experiment was carried out at the 2 GeV/c K^- beam line (D line) at the AGS. We obtained $(1-2)$x10^6 K^- /spill with a K/π ratio of about 0.72. The accumulated total number of K^- is about 0.9 x 10^{12} for the run from Sep. to Nov. in 1999. The outgoing K^+ was analyzed by the forward spectrometer (48D48), which was built for AGS experiment 813. The target was a ^{9}Be plate 6" long x 2" wide x 1/2" high. The principal equipment of E906 is CDS. CDS comprises three main components, a cylindrical drift chamber (CDC) with a z-chamber, a hodoscope and a solenoid magnet. In order to reduce the effect of multiple scattering as much as possible, we select low Z materials inside the chamber; we use 80 μm Al wire for the field wire, 20 μm W wire for the sense wire and Helium-Ethane mixture gas (50 : 50) for chamber gas. The size of the CDC is 298 mm in radius and 920 mm in length.

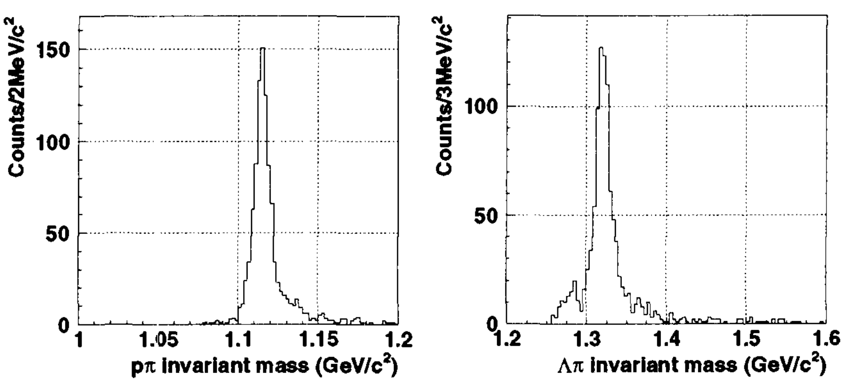

Figure 2: $p\pi^-$ (lefthand side) and $\Lambda\pi^-$ (righthand side) invariant mass spectra for one-positive and two-negative charged track events

The CDC consists of twelve layers; six axial layers and six stereo layers. The total number of the cell is 576. We place a z-chamber outside the CDC in order to get more precise information along the beam direction. The z-chamber has two identical planes, each of which comprises one layer of MWPC with two sheets of cathode readout. The pitch of the anode wires is 2.64 mm. The cathode strip is placed normal to the anode wire which is parallel to the beam direction. The width of the strip and the spacing between adjacent strips are 5 mm and 0.5 mm, respectively. The chamber gas of the z-chamber is a Magic gas. The hodoscope is used for the TOF measurement and the trigger. As the hodoscope is inside the magnetic field, we use a fine-mesh photomultiplier (Hamamatsu H6614). The size of the solenoid magnet is 1180 mm wide, 1180 mm high and 1280 mm long. The maximum field of the magnet is 5 kGauss. The homogeneity of the field is within 0.5 % over the entire CDC volume.

By analyzing the data of the beam line spectrometer and K^+ spectrometer we have clearly seen the quasi-free Ξ^- production peak in the missing mass spectrum. Concerning the performance of CDS, we have observed many clear examples of the Ξ^- decay event; $\Xi^- \rightarrow \Lambda + \pi^-$ and $\Lambda \rightarrow p + \pi^-$. By using these decay events, we have constructed $p + \pi^- \rightarrow \Lambda$ and $\Lambda\pi^-$ invariant mass spectrum, which shows a Ξ^- peak with a mass resolution of 8.3 MeV in sigma (Fig. 2).

4 PRELIMINARY RESULTS

At first, we analyze "two negatively-charged track events", which are considered to be mainly due to two-π^- coincidence events. Fig. 3 shows a preliminary result for the events; the momentum of pions with higher momentum is plotted when the lower momentum pion is within 90 MeV/c and 110 MeV/c, where most of the lower-momentum pions relevent to the present study should be included, e.g. ${}^5_\Lambda$He (~99 MeV/c). The other cuts for the histgrams are rather loose at present; chi squares of each track are less than 5, the distance of closest approach of two tracks is less than 3 cm, and the vertex of the two tracks should be within the target boundary.

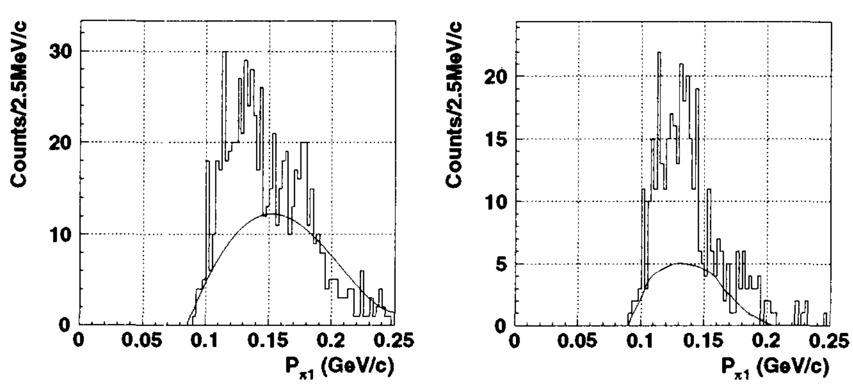

Figure 3: Spectra of the higher momentum pions gated by the lower momentum pions with 90 - 110 MeV/c. The righthand figure is the result by requiring polar angle of two pions to be greater than 60 degree. See the text for other cuts.

The energy loss in the target has been corrected for by using the information of the vertex of the two tracks. The momentum scale has been calibrated by observing the π^+ from the decay of stopped/in-flight Σ^+ produced in the (K^-, π^-) reaction on CH_2. The main background is thought to come from the decay of the quasi-free cascade, where the proton is missing. In order to reduce this backgrond, pions whose polar angle is greater than 60 degree are selected because the pions from cascade decay tend to be emitted forward. The righthand figure shows the result with this requirement. We can clearly see that the events less than around 150 MeV/c survive but those with higher momenta are suppressed. In the histgram the shape of the cascade decay by a Monte Carlo simulation is overlaid in order to estimate the background more quantitatively. We tentatively conclude that the events above the solid lines are due to the two-π^- decays from S = -2 nuclear systems. However they may contain both double-Λ hypernuclear decays and twin single-Λ hypernuclear ones. We are now trying to discriminate them by improving the momentum resolution and the vertex resolution etc. At present the momentum resolution of CDS is estimated to be around 5 MeV/c for 100 MeV/c pions, however ambiguity in the energy loss correction due to the vertex resolution may still exist.

The other interesting subject is an enhanced $\Lambda\Lambda$ production near threshold in the $\Lambda\Lambda$ invariant mass spectrum, which has been discussed by Ahn et al. [15] for the KEK-E224 experiment. It is claimed that the enhancement may indicate either the possible existence of a $\Lambda\Lambda$ resonance, which is referred to as an H-particle, a strong-attractive $\Lambda\Lambda$ final state interaction, or both. Unfortunately their data can't make a definite identification due to the limited statistical significance of the data.

According to a Monte Carlo simulation, our data should contain a larger number of $\Lambda\Lambda$ pairs than E224 by more than one order of magnitude. We analyze "two negatively- and two positively- charged track events", which should include $\Lambda\Lambda$ pairs. At first we find the best candidate of Λ out of possible combinations and construct the invariant masses for two pairs thus selected. Here we assume negative and positive particles as pions and protons, respectively. A preliminary result of the constructed invariant masses for two pairs of p and π are shown in Fig. 4, which indicates that most of the events are due to two Λ's. Fig. 5 shows the constructed invariant mass spectrum for two Λ's, where the invariant mass regions of 1.09 - 1.14 GeV are selected for two pairs of p and π. The solid curve shows, for reference, a spectral shape of the prediction based on a two-step process model; the $K^-p \rightarrow K^+\Xi^-, \Xi^-p \rightarrow \Lambda\Lambda$ process in the same nucleus. Other models like an intranuclear cascade model have been also considered in reference 15, but any simple models with no interaction between two Λ's. will not predict a larger cross section near threshold. Although the number of analyzed events are smaller than expected by an order of magnitude due to the low track-finding efficiency at present, we clearly see the similar enhancement near the threshold as reference 15. For more quantitative discussion, we are now trying to improve the track-finding efficiency and also to correct for CDS acceptance, which should enhance the cross section for lower invariant mass.

Finally it should be noted that E906 is the first measurement to detect decay particles from a large amount of S=$-$2 nuclear systems (around million events), so that we can expect to get better information on S=$-$2 nuclear systems by this new technique, i.e. cascade hypernuclei and their decays, H $\rightarrow p\pi^-\Lambda$ decays, Ξ - p interactions and so on.

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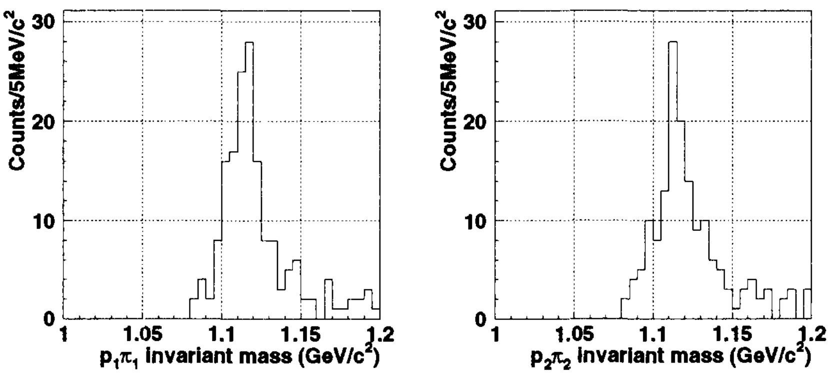

Figure 4: Constructed p π^- invariant mass spectra for p π^- p π^- events.

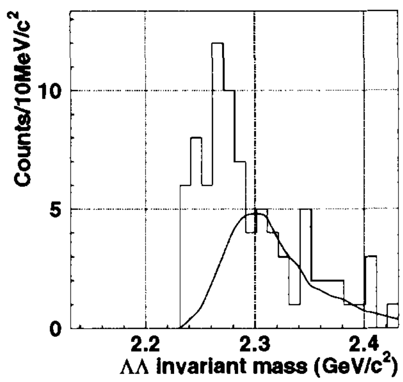

Figure 5: Constructed $\Lambda\Lambda$ invariant mass spectrum.

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