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DETERMINATIONOF TYPEOF HYPERNUCLEUSFROMA SINGLE LAMBDA HYPERNUCLEUS EVENT IN NUCLEAR EMULSION OF KEK-E373 EXPERIMENT

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Abstract

The main aim of this research paper is to determine the type of hypernucleus from a single lambda hypernucleus event, which is an event accompanied by one single Λ hyperfragment and invisible Λ hyperon emitted from a Ξ^- nuclear captured at rest, was found in nuclear emulsion of KEK- E373 experiment . It is interpreted as Ξ^- - ^{14}N system decaying into ${}^{12}_{\Lambda}B + {}^{2}_{1}H + \Lambda$ and hyperfragment decay into $t + d + {}^{6}_{3}Li + n$. The type of hypernucleus can be determined as lambda boron 12 hypernucleus (${}^{12}_{\Lambda}B$).

Keywords: single lambda hypernucleus, nuclear emulsion, lambda boron 12 hypernucleus.

Introduction

The universe consists of various kinds of materials, which are composed of more fundamental particles. They are cluster of atoms consisting of nucleus and electron. Nuclei formed from nucleons, protons and neutrons, are known for nearly three thousand species, experimentally. At present, we have understood that nucleon would be made of quarks, ‘u’ (up), ‘d’ (down), ‘c’ (charm), ‘s’ (strange), ‘t’ (top) and ‘b’ (bottom). For each quark there is an anti-quark. Baryon and meson are formed from three quarks and a pair of a quark and an anti-quark, respectively. A proton (uud) consists of two up quarks and one down quark along with short-lived constituent of the strong force field. A neutron (udd) consists of one up quark and two down quarks. A lambda (Λ) consists of one up quark, one down quark and one strange quark.

A hypernucleus is a nucleus which contains at least one hyperon (a baryon carrying the strangeness quantum number) in addition to the normal protons and neutrons. Baryon including “*s”* quark is called hyperon.The first hypernucleus was discovered in Warsaw in September 1952 by the Polish physicists Marian Danysz and Jerzy Pniewski, in a stack of photographic emulsions as shown in Figure 1. A hypernucleus was produced by cosmic ray particle (track p) which interacted with a nucleus in the emulsion at A. The ejected hyperfragment (track f) was brought to rest at B where it decayed into three charged particles (A. Zenoni and P. Gianotti)

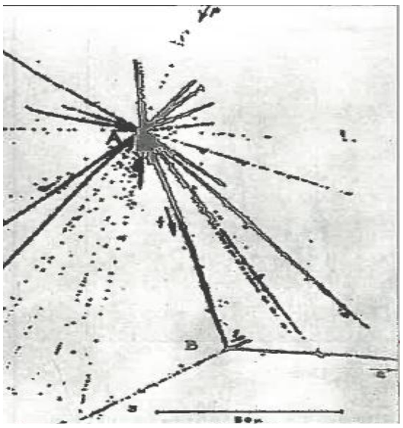

Figure 1 The first hypernuclear event obtained in a nuclear emulsion.

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KEK-PS E373 Experiment

A hybrid emulsion experiment (E373) was carried out at the KEK proton synchrotron using a 1.66 GeV/c separated K^- beam in 1998, 1999 and 2000. The purpose of the experiment was to study double-strangeness nuclei, such as double-Λ hypernuclei, single Λ hypernucleus , twin Λ hypernuclei and the H dibaryon produced via Ξ^- capture at rest in emulsion with ten times larger statistics than E176 experiment. In this experiment, Ξ^- hyperons were produced in a diamond target via the (K^-, K^+) reaction and were brought to rest in the nuclear emulsion and could form compound nucleus with S = -2 in the emulsion. At the decay of the nucleus, a double-Λ hypernucleus, twin Λ–hypernuclei, single-Λ hypernucleus or *H*- dibaryon (if exist) is emitted, in some case, as shown in Figure (2). The experimental set up of the KEK-PS E373 Experiment and a schematic view at the target region are shown in Figure. 3 and 4, respectively.(H. Takahashi.)

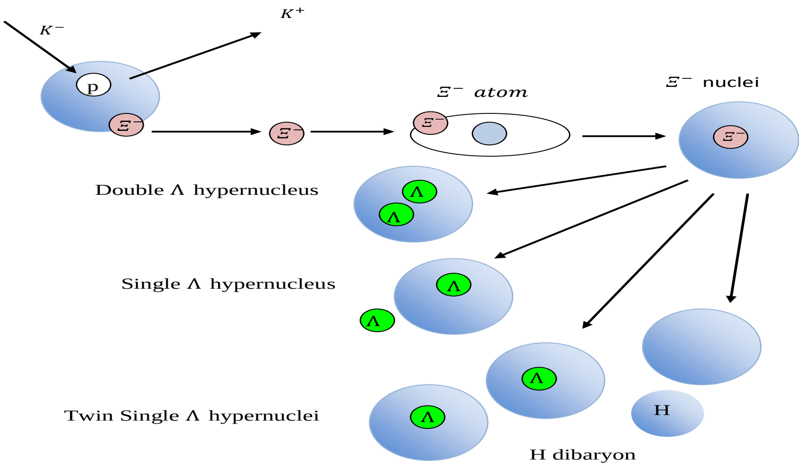

Figure 2 Production process of double-Λ hypernucleus, single Λ hypernucleus, Twin Single Λ hypernuclei and the H dibaryon

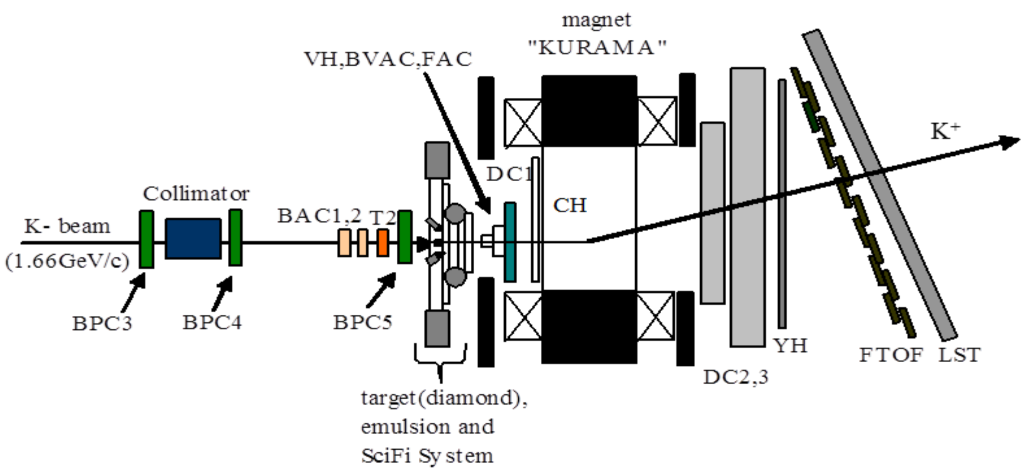

Figure 3 KEK-PS E373 Experiment set up

The Ξ^- hyperon tracks were searched for and followed in the emulsion with an automatic track scanning system guided by the position and angle data of Scintillating-Fiber (Sci-Fi) detector. We have detected 7 double-Λ hypernucleus and 2 twin Λ–hypernuclei events and 35 single Λ hypernucleus events.

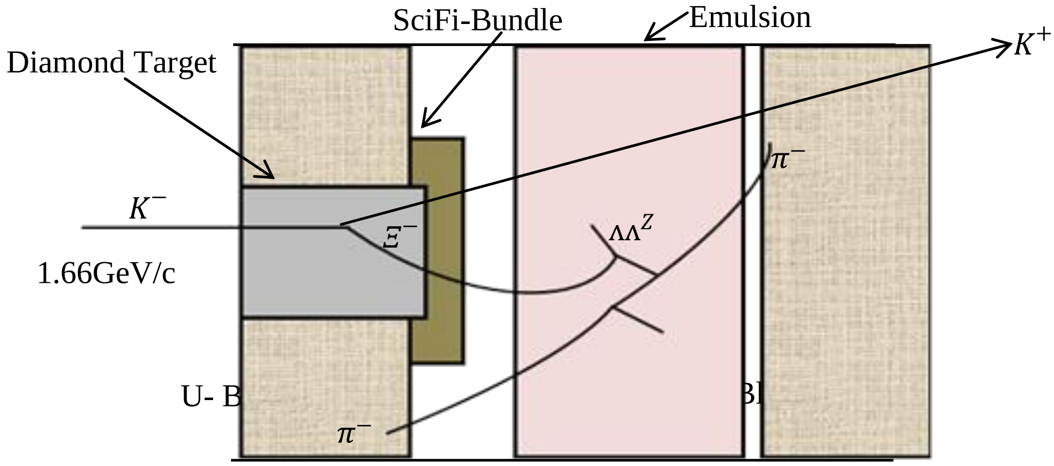

Figure 4 Schematic view at the target region

Nuclear Emulsion

Nuclear emulsion is the key detector to observe the production and decay of S = -2 nuclear system. A nuclear emulsion plate is a photographic plate with a particularly thick emulsion layer and with a very uniform grain size. After exposing and developing the plate, charged particle tracks can be observed and measured using a microscope. The stacks of nuclear emulsion are kept under specific conditions. Thus the photographed events can be preserved for many years.

In E373 experiment, total one hundred stacks made of 69 liters emulsion gel were used. Each stack was composed of eleven (for first ten stacks) or twelve (for the rest stacks) plates with the area of 250×245 mm^2. Figure.5 represents the side view of the constitution of an emulsion stack. Since the first plate was used to connect Ξ^- hyperon tracks from the SciFi-Bundle detector to nuclear emulsion, it was necessary to minimize the distortion of the emulsion gel of the plate.

The emulsion gel was Fuji ET-7C and Fuji-7D, which were developed by Fuji film and Gifu University. All emulsion plates were prepared in Gifu University with the following procedure. First, emulsion gel was poured to one side of the plastic films. They were dried in a drying cabinet which moved emulsion plates automatically so that they were dried uniformly. After drying the emulsion gel, gel was poured to the other side of the plates and dried in the same manner. Then, the emulsion plates were dried again with lower humidity. Each of the emulsion plates was divided to four plates with the size of $24.5 \times 25.0 cm^2$. The density of the emulsion gel can be determined from the volume size and weight measured before and after the beam exposure, the accuracy is not sufficient. The density of the emulsion was 3.60 g/cm^3 on average(A. Ichikawa).

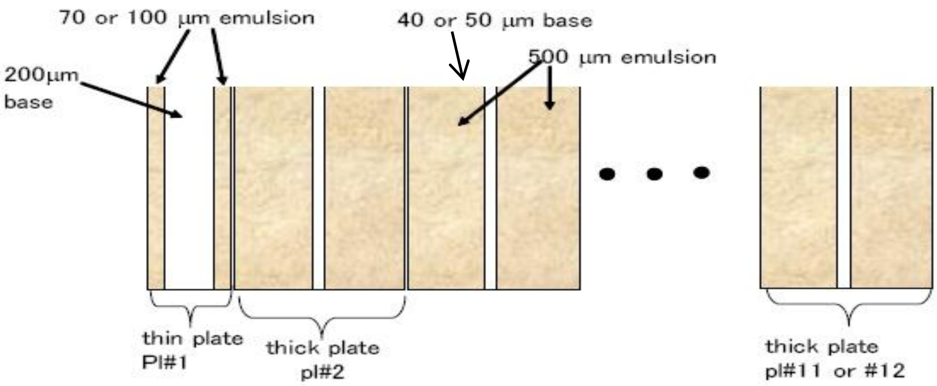

Figure 5 Constitution of an emulsion stack (side view)

Emulsion scanning

The tracks of Ξ^- candidates were searched for the most stream thin-type nuclear emulsion plates (#1) in the area of $24.5 \times 25.0cm^2$ around the position predicted by the Fiber-bundle.The photograph of the microscope system is shown in Figure (7) for the automatic and semi-automatic scanning system. The thin type emulsions plate is shown in Figure6(a).The events selected by the automatic scanning on the plate #1 were scanned in the remaining thick type plates by the automatic scanning system supported by the human eyes check. Thus, we called the scanning method for thick type emulsion as "semi-automatic". The thick type nuclear emulsions plate is shown in Figure 6(b) (K. T. Tint).

	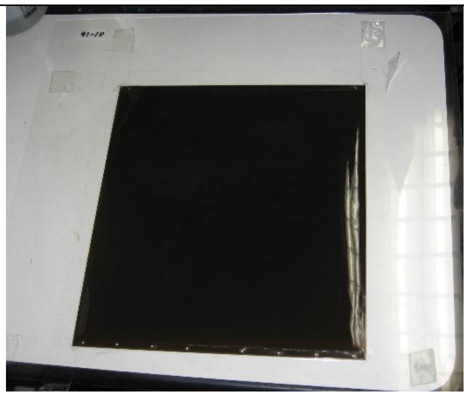
Figure 6(a) Thin type nuclear emulsion plate	**Figure 6(b)**Thicktype nuclear emulsion plate

Figure 7 The Photograph of a microscopic system.

Single Λ Hypernucleus Event

Event Description

A photograph and schematic drawing of a "single Λ hypernucleus" event are shown in Figure 8(a) and (b).A Ξ^- hyperon was captured by a nucleus at point A, from which two charged particles (track #1, #2) and an invisible Λ hyperon were emitted. The particle of track #1 decayed into three charges particles (track #3, #4 and #5) at point B.

Range and Angle Measurement

The range and angles of each track in Single-Λ hypernucleus event were measured by using the microscope system as expressed in Figure 7. The range of the track, R, can be obtained from measured (x, y, z) coordinates which are the clicked points on a track by using the following equation,

$$R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2 \times S^2}$$

where, Δx, Δy and Δz as the lengths in the x, y and z direction respectively. The S is the shrinkage factor for the emulsion gel, defined by the ratio of the original thickness of the plate to the thickness at the time of measurement. The zenith angle ($\boldsymbol{\theta}$) and azimuthal angle (ϕ) of each tracks can be obtained from the coordinates at vertex and suitable click point on track. The imagine range and angles for a track in three dimensional space are shown in Figure.9. The measured lengths and emission angles of these tracks are expressed in Table (1).

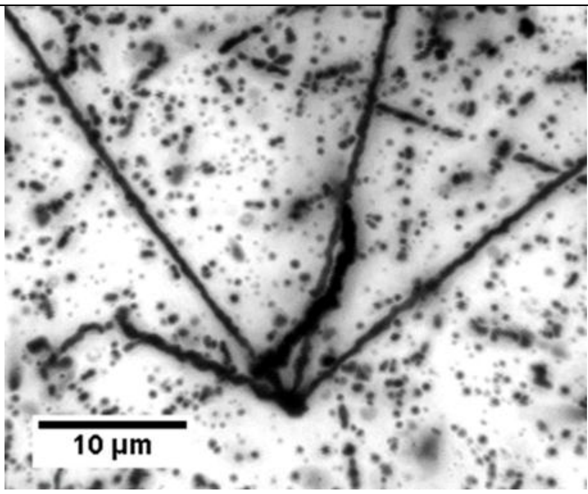

Figure 8(a) Photographic Image of single Lambda hypernucleus

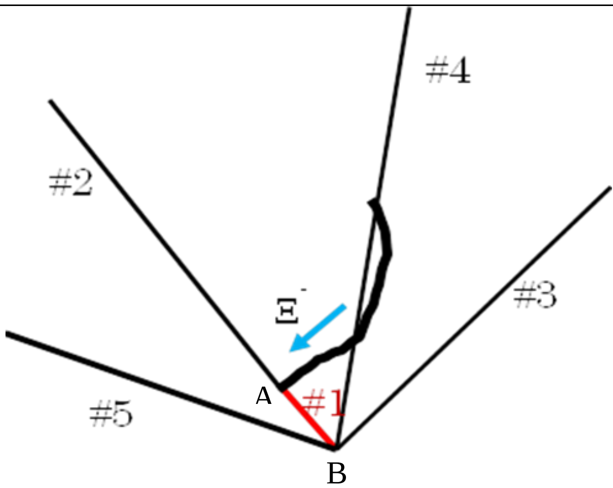

Figure 8(b) Schematic drawing of above single Λ hypernucleus event

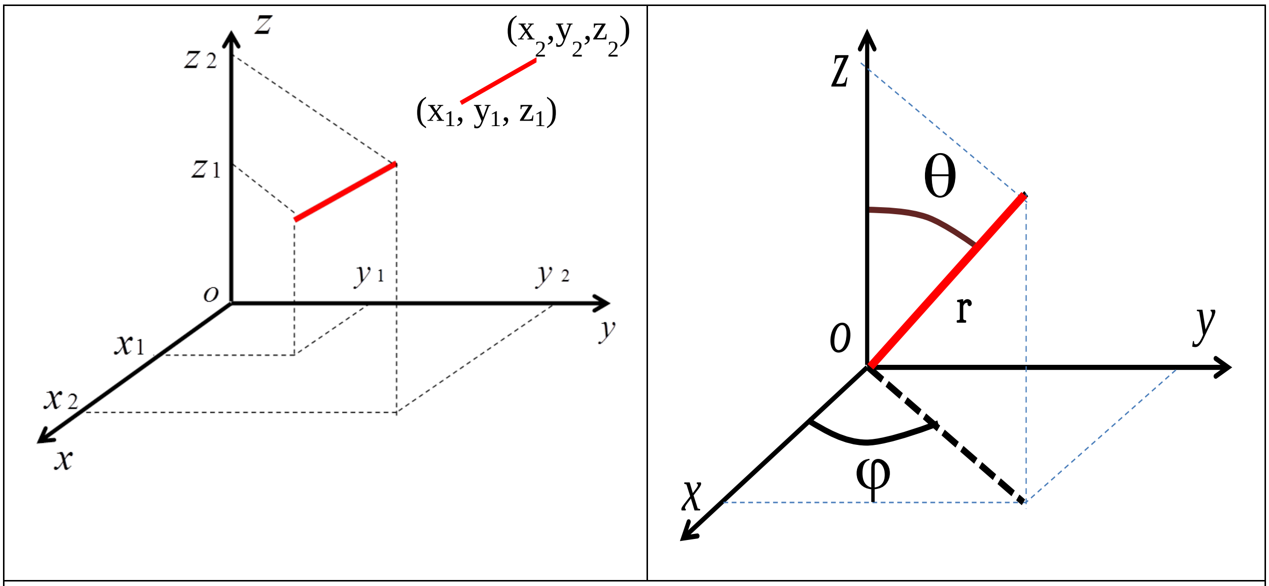

Figure 9 Range and angles of a track in three dimensional space

Table 1 Range and Angle of each track in Single Λ hypernucleus

vertex	Track #	Range(μm)	θ(degree)	ϕ(degree)
A	#1	4.9±0.1	138.2±9.1	139.0±3.6
	#2	47.8±0.4	88.6±1.4	305.8±0.1
B	#3	24.7±0.2	95.2±0.9	221.2±0.4
	#4	475.5±4.1	66.7±0.1	266.2±0.1
	#5	25.4±0.9	97.5±0.3	335.8±1.3

Reconstruction of the event

The event reconstruction in nuclear emulsion is based on the conservation laws of energy and momentum. Once the particle species has been assigned to a track, the kinetic energy of the charged particles can be calculated from their range by means of a range-energy relation. The kinetic energy of neutral particle was calculated from the momentum balance. The errors of kinetic energy come from the errors of range. On the other hand, the errors of total energy were obtained from the errors of range, angles and rest mass.

Firstly, the single Λ hypernucleus (track #1) was identified from its decay point B. The particle species of decay daughters, track #3, #4 and #5, are assigned and considered all the possible decay modes of single Λ hypernucleus. The Q values for each decay mode are obtained and compared with total kinetic energy of track #3, #4 and #5. Since, the total kinetic energies, visible energy E_{visi}, of the three charged particles were smaller than the Q value of the possible decay mode, the total energy for track #1 and decay daughters were considered again and compared. All decay modes of single Λ hypernucleus (track#1) at vertex point B are shown in Table (2). Among them, the most possible decay mode of the single Λ hypernucleus is non-mesonic with neutron emission. Only ${}^{12}_{\Lambda}B$was found to be acceptable for track #1 candidate due to agree their total energy within three standard deviation 3σ.

Secondly, we considered that the Ξ^- hyperon was absorbed by a light nucleus (${}^{12}_{6}C$, ${}^{14}_{7}N$, ${}^{16}_{8}O$) in the nuclear emulsion at point A. From which single Λ hypernucleus(track#1), charged particle track (track#2) and invisible Λ hyperon were emitted. The Q value, the kinetic energy of the emitted charged particles (E_{visi}) and the total energy of emitted particles (E_{total}) are calculated and compared. Table (3) summarized the possible decay modes from Ξ^- $+{}^{12}_{6}C/{}^{14}_{7}N/{}^{16}_{8}O$ to a Λ hypernucleus (track#1), track #2 and invisible Λ hyperon. The total rest mass energy (Ξ^- and nuclides of C, N, O) and total energy of (#1 +#2+Λ) were compared.

Results and Discussion

The measured range and angles of all the tracks in single Λ hypernucleus event are described in Table (1). The visible energy E_{visi} is the sum of the kinetic energies of the tracks #3, #4 and #5. The errors of visible energy of the particles of the tracks were obtained from their error of range. We considered not only the total kinetic energy of parent (track #1) and daughters (tracks #3, #4, #5 and n) but also the total energy which includes the kinetic energy and rest mass energy. The errors for total energy of all emitted particles (charged and neutral particles) were obtained from range, angles and mass errors. The some possible decay mode are listed in Table (2).

Table 2 Some possible decay modes of Single lambda hypernucleus (track #1)

Decay mode	$\Delta\mathbf{E}_{total}$(MeV) [$E_{Total\#1}$- $E_{Total\#3+\#4+\#5+n}$]	Q-value (MeV)	E_{visi}(MeV)	Remark
${}^{7}_{\Lambda}Li \rightarrow$ p + d + t + n	98.23 $\pm$0.47	148.01	15.26±0.45	rejected
${}^{11}_{\Lambda}B \rightarrow$ d + d+ ${}^{6}_{3}Li$ + n	**1.64$\pm$ 0.69**	**-43.66**	**24.15±0.53**	**rejected**
${}^{12}_{\Lambda}B \rightarrow$ p + t+ ${}^{7}_{3}Li$ + n	-18.64 $\pm$0.70	135.80	26.29±0.53	rejected
${}^{12}_{\Lambda}B \rightarrow$ t + d+ ${}^{6}_{3}Li$ + n	**2.87$\pm$0.70**	**130.24**	**24.39±0.53**	**acceptable**

We compared the Q value and E_{visi} for each decay modes. Q-value for all decay modes are greater than the E_{visi}. Since the total energy difference was greater than the three standard deviation, most of the decay modes were rejected. Among all the decay modes of single Λ hypernucleus (track #1), two acceptable decay modes were found. They are, ${}^{11}_{\Lambda}B \rightarrow$ d + d+ ${}^{6}_{3}Li$ + nand ${}^{12}_{\Lambda}B \rightarrow$ t + d+ ${}^{6}_{3}Li$ + n. Q values for these two decay modes are - 43.66 MeV and 130.24 MeV respectively. Since the Q value of 1st decay mode is negative. Therefore, we choose 2nd decay mode as most possible decay mode for single Λ hypernucleus (track #1) for our analyzed event.

The event reconstruction at point A, we considered that the $\Xi-$ hyperon was absorbed by the light nuclei (${}^{12}_{6}C, {}^{14}_{7}N, {}^{16}_{8}O$) in the nuclear emulsion. The results of the possible production modes of the single Λ hypernucleus are listed in Table (3). Among the possible production modes, we choose some decay modes for single Λ hypernucleus which was selected from decay modes. We got two possible production modes, which are described in Table (3). By comparing the total energy differences, the most probable production mode of single Λ hypernucleus (track #1) to be

$${}^{14}_{7}N + \Xi- \rightarrow {}^{12}_{\Lambda}B + {}^{2}_{1}H + \Lambda.$$

The value of density of emulsion was taken as 3.6 gcm^{-3}. On the other hand, the value of shrinkage factor, 2 was used in the measurement of range.

Table 3 Possible production mode of single lambda hypernucleus (track #2)

Target	#1	#2		(total rest mass energy) Ξ⁻ and Target (MeV)	#1+#2+ Λ (MeV) Total energy	ΔE_{total}	Q-value (MeV)	E_{visi}(MeV)
$^{14}_{7}N$	$^{12}_{\Lambda}B$	$^{2}_{1}H$	Λ	**14361.52**	**14436.09**	**74.58**	**13.36**	**7.48±0.44**
$^{16}_{8}O$	$^{12}_{\Lambda}B$	$^{4}_{2}He$	Λ	16216.39	16342.77	126.38	16.47	8.20±0.44

Conclusion

One of the single Λ hypernucleus events has been analyzed based on the conservation laws of energy and momentum. The nuclide of the hypernucleus of the track#1 was selected from its decay point B comparing with production point A. By comparing, the total energy, visible energy and Q value for each decay mode, the possible production event can be interpreted as $^{14}_{7}N + \Xi- \rightarrow {}^{12}_{\Lambda}B + {}^{2}_{1}H + \Lambda$ and $^{12}_{\Lambda}B \rightarrow$ t + d+ $^{6}_{3}Li$ + n. We conclude that the type of hypernucleus of our analyzed event can be determined as lambda boron 12 hypernucleus ($^{12}_{\Lambda}B$).

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