CALCULATION OF THE RANGES AND POSITION ANGLES OF SINGLE-Λ HYPERNUCLEUS EVENT IN NUCLEAR EMULSION

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Abstract

In this research work, the ranges and position angles of charged particle tracks which are emitted from a single-Λ hypernucleus event in KEK-PS E373 experiment. The positions (x, y, z) of a single-Λ hypernucleus event are measured in nuclear emulsion. In the analyzed event, the Ξ^- hyperon is stopped and decays into charged particles tracks #1 and #2 which has 4.27±0.001μm range. The charged particle track #1 is a single-Λ hypernucleus according to its decay topology (#1 → #3 + #4). The ranges of charged particles tracks #1,#2, #3 and #4 are 24.7527±0.00047 μm, 4.2698±0.000μm, 11.9915±0.00083, and 1486.8012±0.1358 μm. The measurement of position angles (θ and ϕ) of charged particles is the main work for particles identification as well as that of ranges. The position angles of charged particles tracks #1, #2, #3 and #4 are 147.1130±0.4830, 159.5224±0.2149°, 101.17061±0.3360° and 73.1808±1.7845° for the zenith angle (θ) and 2.4819±0.2775°, -31.0295±0.4417°, 53.10747±0.6409° and 57.1516±2.7838° for the azimuthal angle (ϕ).

Keywords: Single-Λ hypernucleus, nuclear emulsion, range, position angles

Introduction

The hypernuclear physics has a great important in many branches of physics. Nuclei which consists of protons, neutrons and one or more hyperons are called hypernuclei. A hyperon is a strange hadron, larger mass than the nucleon and consisting one or more strange quarks (strangeness). Therefore, hyperons are also known as strange particle. Hyperons are made one or more strange (S) quark. Therefore, strange particle can enter deeply inside the core nucleus. There are four types of hyperons (strange particles); lambda (Λ), sigma (Σ), xi (Ξ), omega (Ω). Strange particles are produced by strong force and their life time have about 10^{-23} s. They decay by the weak force and decay relatively slow about 10^{-10} s. Among the family of hyperon, a Λ particle is lightest and it can stay in contact with nucleons inside the nucleus and form hypernuclei. As the internal structure, a single-Λ hypernucleus consists of protons, neutrons and one Λ hyperon. A single-Λ hypernucleus is generally described by a symbol ${}^{A}_{\Lambda}Z$ in which Z represents the element or charge of hypernucleus and A represents the total number of baryons in hypernucleus. For example, a single-Λ hypernucleus ${}^{5}_{\Lambda}\mathrm{He}$ consists of 2 protons, 2 neutrons and one Λ hyperon as described in figure 1.

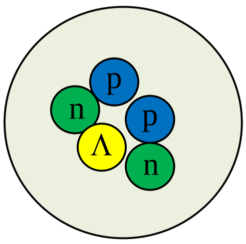

Figure1 Internal structure of ${}^{5}_{\Lambda}\mathrm{He}$

Nuclear emulsion is one of the photographic films, which is used to detect three-dimensional tracks of charged particles. Hybrid emulsion experiments started in the1950`s. Firstly, nuclear emulsion was developed in cosmic-ray experiments with chamber and counters. For an emulsion plate, a transparent material is called base which is used to support against shrinkage and swelling

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in its drying and developing process. The base is not sensitive to particles and that it is a dead space. Many different preprocessing of the base surface have been tried out for acrylic films and polystyrene films. Using those bases, two types of emulsion plates were developed. One is a plate called "thin plate" with 70μm thick emulsion coated on both sides of the base, to be used for the tracking of Ξ^- particles predicted by a fiber-bundle tracker. Another type, the "thick plate", has a 500μm thick emulsion coated on both sides of the thin base.

A hybrid-emulsion experiment, E176, was carried out at the KEK 12 GeV proton synchrotron to study the strangeness hypernucleus events in 1980s [1]. In this experiment 7 events of single-Λ hypernuclei were found among the 80 hyperon capture at rest in nuclear emulsion. Moreover, the experiment E373 was performed using a 1.66 GeV/c K^- beam at the K2 beam line of the proton synchrotron facility at KEK [2]. The purpose of this experiment is to get ten times higher statistics of Ξ^- hyperon and double strangeness nuclei than the previous experiment KEK-PS E176. After emulsion scanning, about 1000 Ξ^- stop events were observed in nuclear emulsion of KEK-PS E373 experiment [4]. Among them 46 events of single-Λ hypernucleus were detected. One of the 46 single-Λ hypernuclei is planned to analyzed and calculations of ranges and position angles using positions data are presented in this paper.

Calculation of Ranges and Position Angles of Single-Λ Hypernucleus Event

Event Description

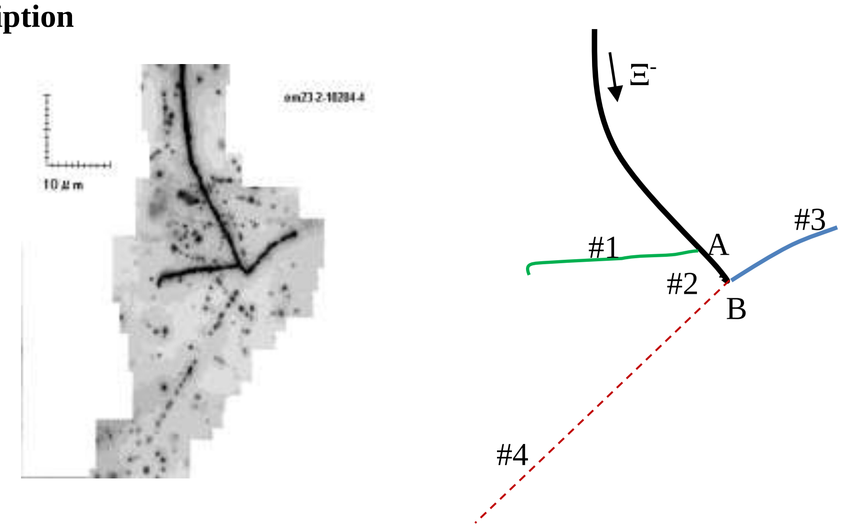

Figure 2 Photograph and schematic diagram of analyzed single-Λ hypernucleus event

The analyzed event is detected in module #023, plate #02 during the semiautomatic scanning of nuclear emulsion in KEK-PS E373 experiment. The event number is 10204-4. In the analyzed event, a Ξ^- hyperon is captured by the emulsion nucleus at point A, from which two charged particles track #1 and track #2 are emitted. The particle of track #2 decays into track #3 and track #4 at point B. So, point A is production point and point B is decay point of single-Λ hypernucleus track #2. The experimental data are provided by Professor Dr Nakazawa and KEK-PS E373 collaborators from Gifu University. Using these data, the ranges and position angles of the analyzed event are calculated. These experimental data for our analysis include in vital role. The range is defined as the distance travelled of a charged particle when passing through the nuclear emulsion before it decay. The photograph and schematic diagram of a single-Λ hypernucleus event are shown in figure 2.

Measurement of Positions (x, y, z) in Nuclear Emulsion and Calculation of Range

In the first step of the measurement, the points formed the tracks of charged particles are clicked. The points through the track travelled in nuclear emulsion are checked. If the points are along a straight line, we click these points between the starting and stopping points. If the points are not straight line, we click each point formed along the track travelled to obtain the accurate range. The range measurement of the charged particle tracks is as follows:

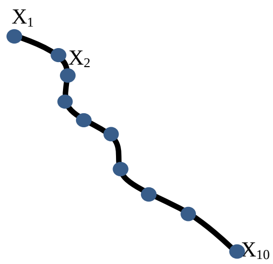

Figure 3 Measurement of a track from point to point

In nuclear emulsion, the tracks of charged particles are measured in three-dimension. The positions (x, y and z) of tracks #1, #2, #3 and #4 are measured in three times to obtain the accurate results.

$$\Delta x = x_2 - x_1, x_3 - x_2, x_4 - x_3, \quad (1)$$

where, Δx refers to the range between each two click point and x_1, x_2, x_3, and x_4 refer to the click points for first, second, third and fourth click points of our measurement in the x-direction. So, the measurement for "y" and z-direction are as in the x-direction. For the measurement, the positions (x, y, z) of charged particles tracks #1, #2, #3 and #4 are shown in table 1.

Table 1 Positions (x, y, z) of track #1, #2, #3 and #4

Track	x (mm)	y (mm)	z (mm)	Remark
#1	-104.06997	53.03572	-2.786	
	-104.06351	53.03600	-2.791	
	-104.05721	53.03807	-2.796	
#2	-104.06972	53.03572	-2.787	
	-104.07100	53.03649	-2.789	
#3	-104.07075	53.03649	-2.788	
	-104.07379	53.03244	-2.789	
#4	-104.07826	53.03115	-2.791	
	-104.07006	53.03594	-2.790	
	-104.02520	53.10542	-2.790	
	-103.98238	53.17091	-2.765	
	-103.92302	53.26002	-2.748	
	-103.86744	53.34064	-2.734	
	-103.82884	53.39874	-2.723	
	-103.78056	53.47005	-2.709	
	-103.72091	53.55768	-2.694	
	-103.69813	53.59066	-2.686	
	-103.77101	53.65645	-2.970	
	-103.74679	53.69172	-2.965	
	-103.72477	53.72648	-2.959	
	-103.68599	53.78332	-2.950	
	-103.6585	53.82436	-2.943	

The range of a charged particle is calculated by the formula,

$$R = \sqrt{\Delta x^2 + \Delta y^2 + (\Delta Z.S)^2} \tag{2}$$

In the equation (2), "S" represents the shrinkage factor in the focusing direction of emulsion plate. The shrinkage factor "S" is defined as the ratio of the thickness of gel at exposure time and that at the measurement time. It is very important to measure the actual range of charged particles. In our analysis, the typical value of shrinkage factor is used. This typical value is 2.

In figure 2, a single-Λ hypernucleus track #2 decays into tracks #3 and #4. So, we calculate the range of track#1 as follows;

$\Delta x_1 = x_2 - x_1 = 0.00646$mm

$\Delta y_1 = y_2 - y_1 = 0.00028$mm

$\Delta z_1 = z_2 - z_1 = -0.005$mm

So, $R_1 = 0.0119084004$ mm using equation 2.

$\Delta x_2 = x_3 - x_2 = 0.0063$ mm

$\Delta y_2 = y_3 - y_2 = 0.00207$mm

$\Delta z_2 = z_3 - z_2 = -0.0055$ mm

Therefore, $R_2 = 0.01284425553$ mm also using equation 2.

The total range of track #1 is as follows;

$R_{total} = R_1 + R_2 = 0.02475265593$ mm which is the range of track #1 in nuclear emulsion.

Track #1, #2 and #3 are stopped in plate 2 and track #4 is passed through plate 2 and stopped in plate 1. The ranges of tracks #2, #3 and #4 are calculated by using equation 2 as the same way in track #1 and the calculated results are presented in table 2.

Table 2 Calculated Results of Tracks #1, #2, #3 and #4 for each point

Track	Δx(mm)	Δy(mm)	Δz(mm)	R (mm)	Total R (μm)
#1	0.00646	0.00028	-0.005	0.0119084	24.7527±0.00047
	0.0063	0.00207	-0.0055	0.0128443	
#2	-0.00128	0.00077	-0.002	0.0042698	4.2698±0.0001
#3	-0.00304	-o.00405	-0.0005	0.0051618	11.9915±0.00083
	-0.00447	-0.00129	-0.0025	0.0068297	
#4	0.04486	0.06948	0.0125	0.0863996	1486.8012±0.1358
	0.04282	0.06549	0.0125	0.0821431	
	0.05936	0.08911	0.0165	0.1120411	
	0.05558	0.08062	0.014	0.1018466	
	0.0386	0.0581	0.0115	0.0734477	
	0.04828	0.07131	0.0135	0.0902501	
	0.05965	0.08763	0.015	0.1101687	
	0.02278	0.03298	0.0085	0.0435386	
	-0.07288	0.06579	-0.2845	0.5774087	
	0.02422	0.03527	0.005	0.0439384	
	0.02202	0.03476	0.0065	0.0431524	
	0.03878	0.05684	0.009	0.0711244	
	0.02749	0.04104	0.007	0.0513418	

Calculation of Position Angles

The position angles of charged particles need to be measured because the main work of our analysis is to measure the ranges and position angle of analyzed event. We can decide what the particles are emitted from the analyzed event only when we know the position angles of charged particles which are observed in nuclear emulsion.

The angle θ is the zenith angle which is defined as the angle between the track of particles, ranges, and a vertical line, passing through the z-direction. The angle ϕ is the azimuthal angle which refers to the angle counterclockwise angle from the x-axis formed when the point is projected onto the xy-plane. The position angles (θ and ϕ) of charged particles tracks #1, #2, #3 and #4 are shown in figure 4.

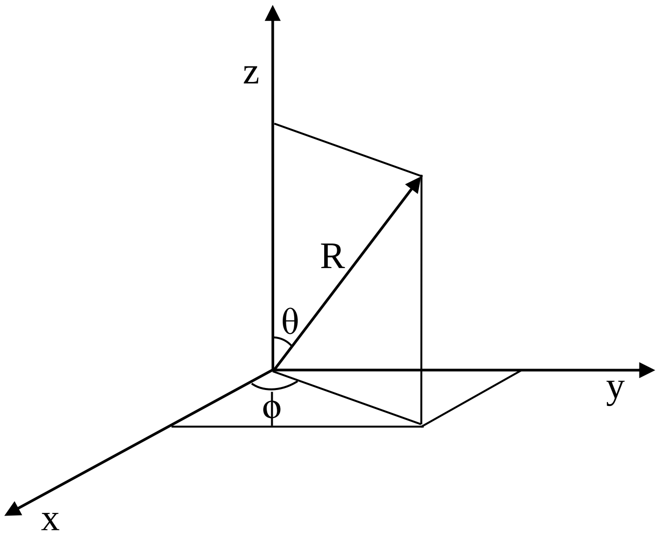

Figure 4. Schematic drawing for position angles θ and ϕ of the emitted tracks

To find the appropriate and accurate angles of charged particles #1, #2, #3 and #4, their ranges of which they are observed approximately about 10 μm are used. So, the angles of charged particles are also calculated by using the following formulae:

$$\theta = \cos^{-1}\left[\frac{\Delta z}{\sqrt{\Delta x^2 + \Delta y^2 + (s.\Delta z)^2}}\right] \quad (3)$$

$$\phi = \tan^{-1}\left[\frac{\Delta y}{\Delta x}\right] \quad (4)$$

The position angles of charged particles are summarized in table 3.

Table 3 Calculated Results of Angles θ and ϕ of #1, #2,#3 and #4

Track	θ (degree)	ϕ (degree)
#1	147.1130±0.4830	2.4819±0.2775
#2	159.5224±0.2149	-31.0295±0.4417
#3	101.17061±0.3360	53.10747±0.6409
#4	73.1808±1.7845	57.1516±2.7838

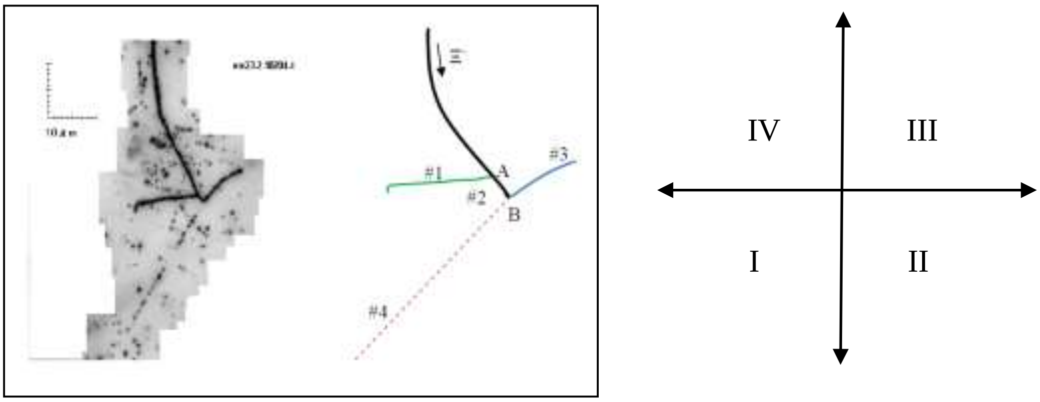

Figure 5 Photograph, schematic drawing and quadrant for position angle ϕ of the emitted tracks #1, #2, #3 and #4.

In figure 5, a photograph, schematic diagram and quadrant figure for position angle ϕ are presented. According to figure track #1 is located in quadrant IV (270<ϕ<360°), track #2 is located in quadrant II (90<ϕ<180°), track #3 is located in quadrant III (180°<ϕ<270°) and track #4 is located in quadrant I (0<ϕ<90°). Due to their location the position angles are expressed in table 4.

Table 4 Calculated Results of Angles θ and ϕ of #1, #2,#3 and #4 due to their location

Track	θ (degree)	ϕ (degree)
#1	147.1130±0.4830	357.5181±0.2775
#2	159.5224±0.2149	121.0295±0.4417
#3	101.17061±0.3360	216.8925±0.6409
#4	73.1808±1.7845	57.1516±2.7838

Results and Discussions

We planned to identify a single-Λ hypernucleus event which was observed in nuclear emulsion of KEK-PS E373 experiment. In this paper, the ranges and position angles of emitted charged particle tracks from single-Λ hypernucleus are calculated using experimental data (positions x, y and z). According to present research, the following results are obtained.

Table 5 Calculated results of range and position angles of analyzed event

Track	R (μm)	θ (degree)	ϕ (degree)
#1	24.7527±0.00047	147.1130±0.4830	357.5181±0.2775
#2	4.2698±0.0001	159.5224±0.2149	121.0295±0.4417
#3	11.9915±0.00083	101.17061±0.3360	216.8925±0.6409
#4	1486.8012±0.1358	73.1808±1.7845	57.1516±2.7838

Conclusion

Our analysis of a single-Λ hypernucleus will provide to identify the hypernuclear species observed in nuclear emulsion. In hypernuclear physics, the understanding of nucleon-baryon interaction and baryon-baryon interaction is important. To do so, observations of more and more hypernuclei are needed and identification of observed event is important work. For hypernuclei identification work, kinematical analysis is usually used. Therefore, the measurement of range and position angles is very fundamental for hypernuclear research.

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