Title	A Method for Particle Identification in Nuclear Emulsion
All Authors	Khin Than Tint, Kazuma Nakazawa, Junya Yoshida
Publication Type	Local publication
Publisher (Journal name, issue no., page no etc.)	2nd Myanmar Japan International Symposium, Pathein University, Vol 1, No 5.133-141
Abstract	The particle identification technique in nuclear emulsion is on-going by measuring multiple Coulomb scattering, which means measuring second difference. Several thousands of tracks of the Ξ- Hyperion and pion in nuclear emulsion stacks are generated by GEANT 4 simulation and obtained second difference in constant Sagitta Method. On the other hand, the second difference of Ξ- Hyperion and pion tracks are measured in nuclear emulsion of E373 experiment. The consistency of a second difference in the constant Sagitta Method of Ξ- Hyperion and pion tracks in nuclear emulsion of E373 experimental and simulation results are also confirmed.
Keywords	particle identification, nuclear emulsion, multiple Coulomb scattering
Citation	
Issue Date	2016

A Method for Particle Identification in Nuclear Emulsion

Khin Than Tint[1], Kazuma NAKAZAWA[2], Junya YOSHIDA[3]

Abstract

The particle identification technique in nuclear emulsion is on-going by measuring multiple Coulomb scattering, which means measuring second difference. Several thousands of tracks of the Ξ^- Hyperion and pion in nuclear emulsion stacks are generated by GEANT 4 simulation and obtained second difference in constant Sagitta Method. On the other hand, the second difference of Ξ^- Hyperion and pion tracks are measured in nuclear emulsion of E373 experiment. The consistency of a second difference in the constant Sagitta Method of Ξ^- Hyperion and pion tracks in nuclear emulsion of E373 experimental and simulation results are also confirmed.

Key words: particle identification, nuclear emulsion, multiple Coulomb scattering

Introduction

Nuclear emulsion is the key detector for the production and decay of double strangeness (S= -2) nuclear system such as Ξ^--hypernucleus, double-Λ hypernucleus and twin-singleΛ hypernuclei with very good resolution. The nuclear emulsion was used as a detector not only for the production and decay of double- Λ hypenuclei but also (K^-, K^+) reaction target in KEK- E176 experiment [1]. In E373, a Ξ^- Hyperion is produced via quasi-free 'p'(K^-, K^+) Ξ^- reaction in a diamond target and captured at rest by one of the atoms (H, C, N, O, S, Br, Ag, I) in nuclear emulsion [2]. Single-Λ (S= -1)or double-Λ (S= -2) hypernucleus events can be found at the stopped point of Ξ^- hyperon..

According to the topologies at the rest point of Ξ^- hyperons, we can categorize into two groups, "σ stop" and "ρ stop". The event with evaporation tracks is called "σ stop" which shows that the primary particle carried negative charge. On the other hand, the event without evaporation tracks is called "ρ stop" events. In ρ stop events, with and without Auger electron emission can be seen at the stopping point. "ρ stop" with Auger electron emission can be regarded as the charge of primary particle is negative.

The events with Ξ^- stopped events are associated with σ stop events. Moreover, it will be necessary to know the primary particle even for ρ stop events to understand the formation rates of hypernuclei via at rest capture reaction of Ξ^- hyperon. Therefore, we tried to identify primary particles those are Ξ^- hyperon among the possible particles such as Ξ^-, proton, K meson and π mesons (pion). The another identification method is measuring the thickness of track for the case of short range particles in emulsion is developed and introduced [3]. The measurement of multiple Coulomb scattering which means measurement of second difference is applied for long range particle tracks to identify the primary particle causing capture reaction in the nuclear emulsion. Therefore, we applied multiple Coulomb scattering in constant Sagitta method to identify the primary particles causing captured reaction in nuclear emulsion of KEK-E373 experiment.

1. Lecturer, Physics Department, Myingyan Degree College.
2. Professor, Physics Department, Education Faculty, Gifu University, Japan.
3. Researcher, Physics Department, Education Faculty, Gifu University, Japan.

Multiple Coulomb Scattering and Constant Sagitta Method

A charged particle passing through the nuclear emulsion is deflected by many small- angle scatters due to Coulomb interaction. The second difference which deflects multiple Coulomb scattering is defined as in Equation (1) [4].

$$\theta_0 = \frac{13.6[MeV/c]}{\beta p} z \sqrt{t/X_0}\,[1 + 0.038\ln(t/X_0)]$$

$$\delta_0 = \frac{1}{2\sqrt{3}} t\theta_0 \tag{1}$$

In above equation, p, β and z express momentum, velocity and chage number of the incident particle, respectively. t/ X_0 is the thickness of the scattering medium in radiation length scale. To calculate the second difference, radiation length X_0= 10.52g/cm^2 is used for ET-7D emulsion [5].

A method called "constant Sagitta method" in which the measurement of scattering of particle tracks at the end of their range is carried out in sets of choosing cells of varying length, so that the second difference of the Sagitta remains constant as shown in Fig. 1. In our calculation, second difference δ_0 is maintained to be constant and the cell length t is chosen for various ranges R which is obtained from the coordinates of the tracks of charged particles in nuclear emulsion. The equation to obtain various cell length t for constant second difference of Sagitta is given in Equation (2) [6].

$$t = \left[\delta_0 \times \left(\frac{1}{0.00348 \times K_s}\right) \times R^{0.58} \times Z^{0.16} \times M^{0.42}\right]^{2/3} \tag{2}$$

In the above equation (2), Ks is the scattering constant, however it is a slowly varying function of R and t and not a constant. K_s value is obtained by adjusting the predicted second difference δ_0 and calculated average second difference value for various cell lengths in equation (2). The detail description of step by step procedure for obtaining second difference values is described in elsewhere [7].

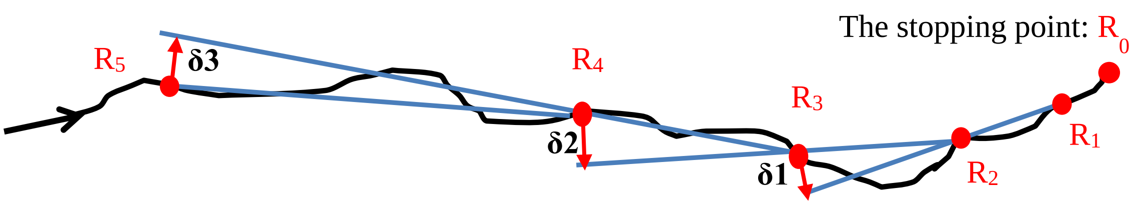

Fig. 1. Schematic drawing of constant Sagitta Method of a track

GEANT 4 (G4) Simulation

GEANT4 (for GEometry ANd Tracking) is a platform for "the simulation of the passage of particles through matter," using Monte Carlo methods. It is the successor of the GEANT series of software toolkits developed by CERN, and the first to use object oriented programming (in C++). Application areas include high energy physics and nuclear experiments, medical, accelerator and space physics studies. The software is used by a number of research projects around the world [8].

Several thousands of Ξ- hyperon and π meson tracks of the particles in nuclear emulsion stack were produced via GEANT4 (G4) simulation. We considered for the range of the particles, Ξ^- hyperon and π meson in emulsion as 4mm. The corresponding energies in that range are 35.5 MeV and 13.5MeV, respectively. The emulsion of 3.6g/cm^3 of ET-7D type was used in the simulation. We checked the validation of range and kinetic energy for G4 simulation and range- energy programming written by Prof: K. Nakazawa based on Bakas's literature [9]. Comparison between simulation (background gray color) and calculated results (dotted line) for range and energy of Ξ^- hyperon are expressed in Fig. 2.

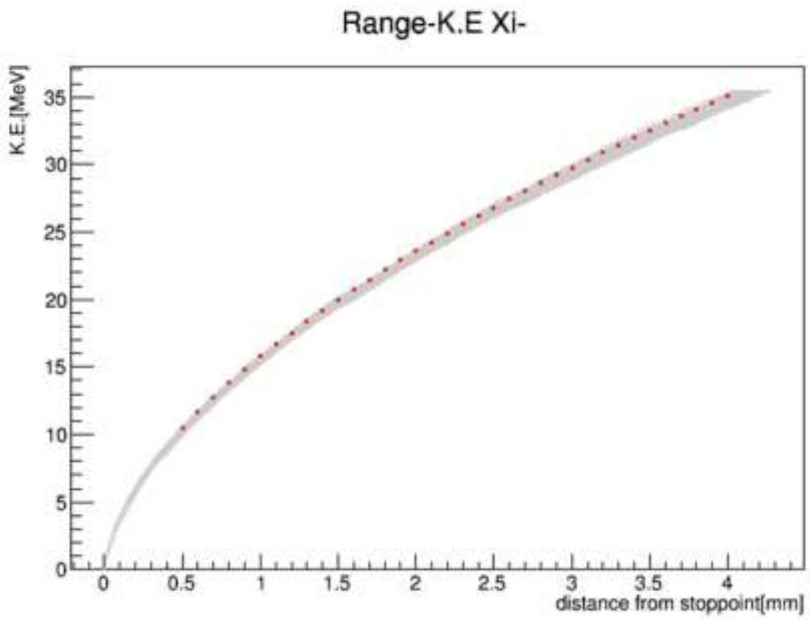

Fig. 2. Comparison between Simulation data and calculated data (based on Bakas's literature) for range and kinetic energy of Ξ^- hyperon.

Position and Range Measurement of Parent Particle Tracks of Heavy double-Λ hypernucleus, twin- single Λ hypernuclei and π->μ->e events in emulsion of KEK-E373 experiment

We measured the Ξ^- hyperon and π meson tracks which are the primary particles of heavy double-Λ hyper nucleus events , twin-single Λ hypernucleus event and π-μ-e events from their stopping point to the origin (until plate #2) with 20μm step in Z axis in nuclear emulsion of E373 experiment as shown in Fig 3 (a). The microscope system for range measurement of particle tracks is presented in Fig 3 (b). We also measured the K^- beam tracks with the same step in the Z axis as primary particle track. We need to maintain temperature and humidity of the room as possible as we can during the measurement. The distortion of measured track is corrected by using K^- beam tracks. Plate to plate alignment was also adjusted.

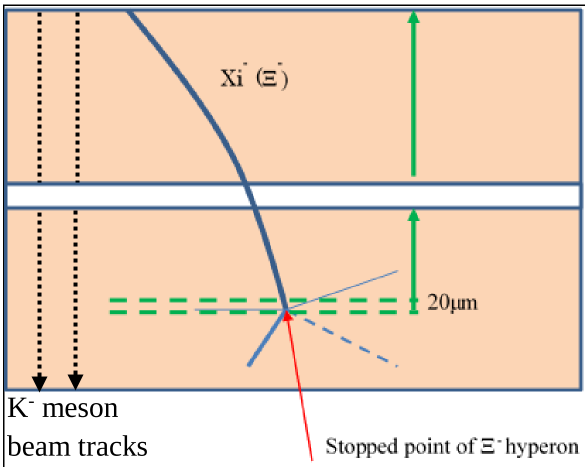

Fig. 3(a). Schematic drawing of Ξ^- track in an emulsion plate

Fig. 3 (b). The microscope system for range measurement of particle tracks

Estimation of the Measurement Error

We need to consider the measurement error in G4 simulation for comparing the second difference value of measured charged particle tracks in nuclear emulsion in E373 experiment and G4 simulation data. The measurement error is estimated by using two K^- meson (1.66 GeV/c) beam tracks which pass through straightly and perpendicularly in each emulsion plate as shown in Fig. 3 (a). Ranges of two beams in one view of the microscope are measured. Fig. 4 shows the plotted two beam tracks to obtain residuals X component in one emulsion plate. Firstly, take one track (track #1) as reference track and draw a track called base track by using the coordinates of the upper and lower surface of the base as shown in Fig 4 (a). The coordinates differences between X components of base track and beam track for same Z coordinates are obtained as marked in back arrow in Fig. 4 (b). Secondly, the second beam track (track #2) is corrected by using the coordinate differences of track#1. Then, the corrected coordinates of track #2 are fitted with a straight line. Finally, residuals are accumulated from coordinate differences between corrected beam (track #2) and linear fitting line. As the same manner, residual Y components were also obtained. The measurement error for X and Y components are estimated from Gaussian fitting of residual values obtained from totally 21 emulsion plates as shown in Fig. 5. The results are $0.329 \pm 0.018\mu m$ and $0.333 \pm 0.011\mu m$ respectively.

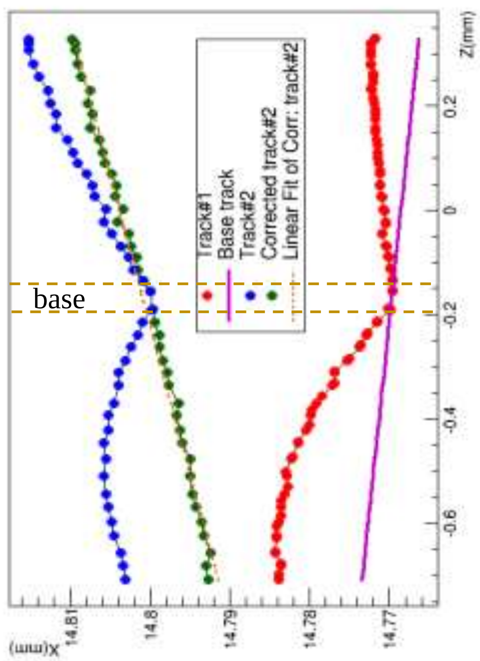

Fig. 4 (a). Plotted track #1, #2, base track and corrected track#2

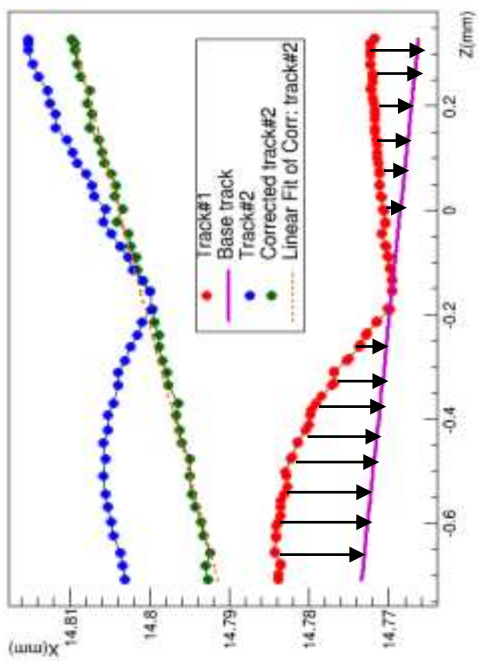

Fig.4(b). Black arrow lines demonstrated the coordinate difference between track#1 and base track

Method of Input Measurement Error in Simulation data

The measurement error = 0.33μm is inserted at X, Y, Z coordinates at every 40μm step in Z axis. The Ξ^- hyperon and π meson tracks are measured in 20μm step. If it is multiplied with shrinkage factor~2, 20*2=40μm is obtained. Therefore, we input measurement error at every 40μm step of Z axis. After the input measurement error, we adjusted mean second difference value and predicted δ_0 for constant Sagitta method and Ks value was obtained. By using that Ks value, we obtained cell lengths for Ξ^- and calculated root mean square second difference values for each particle.

Results and Discussions

We compared the second difference distribution of Ξ^- hyperon and π meson tracks obtained from simulation and measured in emulsion of E373 experiment. The validation of second difference distribution for G4 simulation with measurement error 0.33 μm and measurement in the emulsion is shown in Fig. 6. The histograms with blue line and red line represent the root mean squared second difference (δ_{rms}) distribution of Ξ^- hyperon and π meson respectively for simulation data. On the other hand, the histogram with green lines and pink line represent the second difference distribution of Ξ^- hyperon and π meson which are the primary particle tracks of double-Λ hyper nucleus events, twin-single Λ hypernucleus event and π-μ-e events. We obtained the second difference distribution not only for constant Sagitta (various cell lengths) but also for constant cell length. The second difference distribution for constant cell length are presented in Fig. 7.

Residual X component	Residual Y component

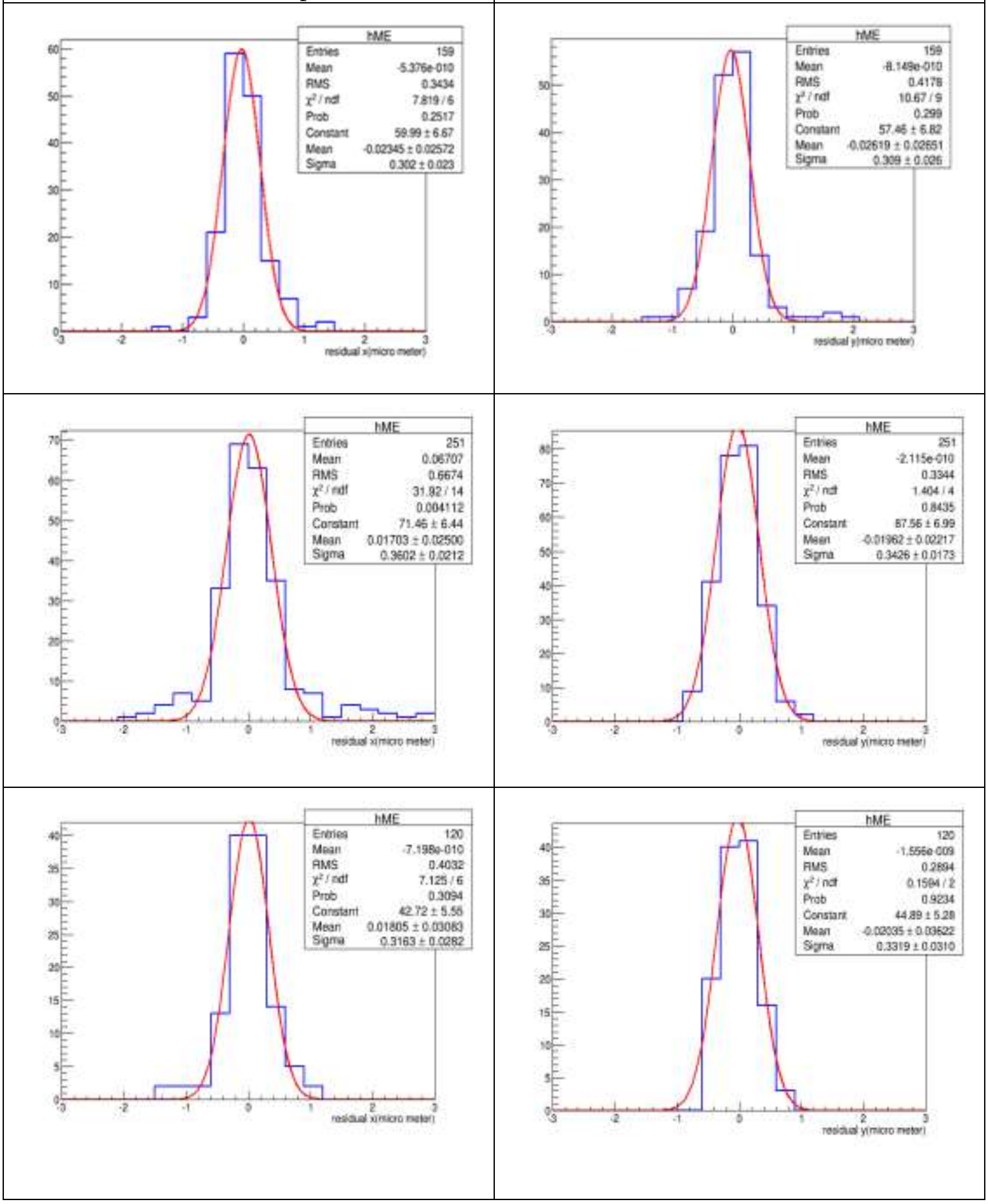

Fig. 5. Gaussian fitting of residual values to obtain the X and Y component of measurement error

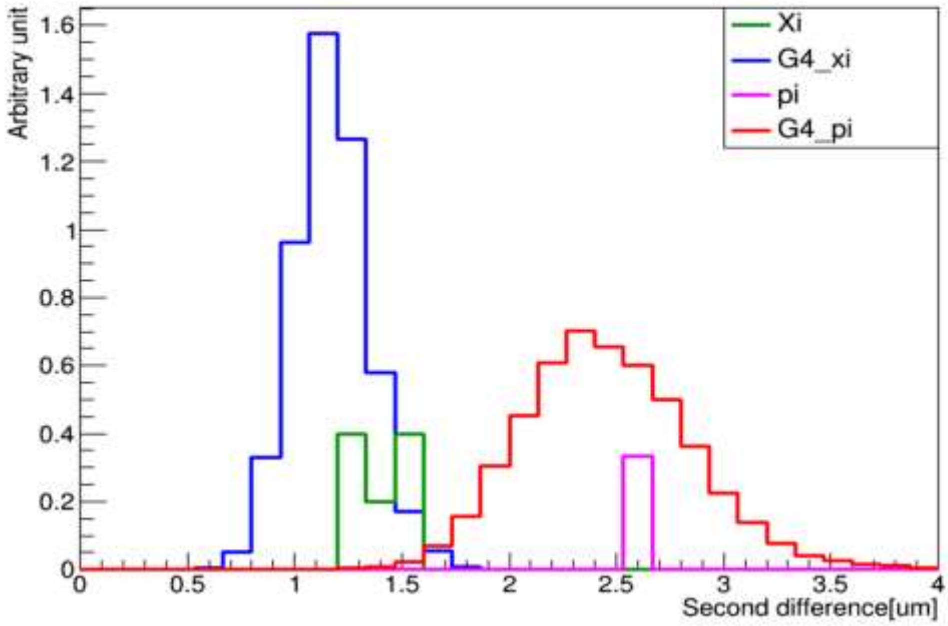

Fig. 6. Second difference distribution of Ξ- hyperon and π meson for constant Sagitta (various cell lengths)

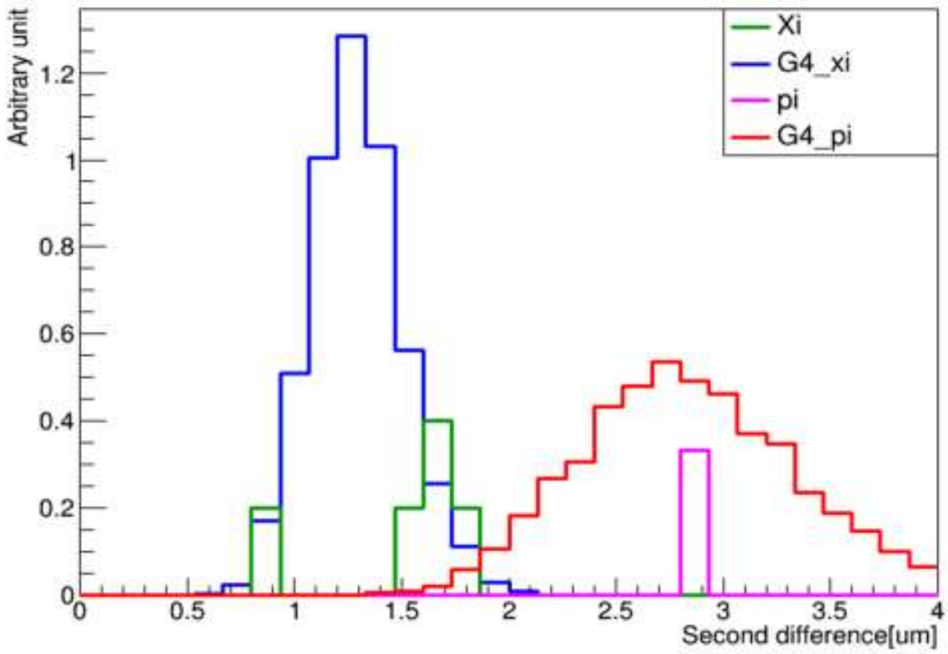

Fig. 7. Second difference distribution of Ξ^- hyperon and π meson for constant cell length

We obtained the likelihood ratio in order to confirm Ξ^- hyperon and π (pion) for the parent particle tracks of Heavy double hyper events, twin hyper event and π→ μ → e events in emulsion of KEK-PS E373 experiment by using the probability of Ξ^- hyperon and pion for the range from 200μm to 3900μm of second difference values of G4 simulation. Firstly, we obtained second difference values of Ξ^- and π with measurement error = 0.33μm, for G4 simulation. Secondly, the second difference value distribution is obtained according to their ranges and number of tracks according to the values of second difference. The probability of Ξ^- and π for each range (bin range) of second difference value is obtained by using the following relations,

$$P_{\Xi^-} = \frac{N_\Xi}{Number of\ simulation sample},\ \text{and}\ P_\pi = \frac{N_\pi}{Number of\ simulation sample}.$$

On the other hand, the second difference values of measured Ξ^- hyperon and pion tracks in emulsion of E373 experiment are obtained. Finally, we obtained Likelihood ratio of each measured track by using probability of Ξ^- and π of simulation for each range by using the relations

$L_\Xi = \prod_{i=1}^{N} P_{\Xi_i}$, $L_\pi = \prod_{i=1}^{N} P_{\pi_i}$, . $PID(\Xi) = \frac{L_\Xi}{L_\Xi + L_\pi}$, $PID(\pi) = \frac{L_\pi}{L_\pi + L_\Xi}$. Particle identification PID (Ξ^-/π) result for parent particle tracks of heavy double and twin hyper events for Constant cell length and constant Sagitta are shown in Table 1. On the other hand, PID (π/Ξ^-) result for parent particle tracks of π -> μ -> e events are shown in Table 2. Particle identification expressions not only for comparing second difference distributions of measured track and simulation, but also for Likelihood ratio are satisfied both for constant cell length and constant Sagitta (various cell lengths).

Table1. Particle identification Ξ^-/π for parent particle tracks of heavy double and twin hyper events

Event type	Mod#	Event#	PID (Ξ^-)		PID (π)	
			Constant Cell	Constant Sagitta	Constant Cell	Constant Sagitta
Heavy Double	8	15601-7	0.8067	0.9989	0.1933	0.0010
Heavy Double	15	8202-25	0.9483	0.9998	0.0517	0.0001
Heavy Double	19	10001-7	0.5833	0.9999	0.4167	4.3_10^{-6}
Heavy Double	56	1001-8	0.9984	0.9997	0.0016	0.0003
Twin Hyper	36	701-3	0.9951	0.9999	0.0049	1.0_10^{-7}

Table 2. Particle identification π /Ξ^- for parent particle tracks of π → μ → e events

Event type	Mod#	Event#	PID(π)		PID(Ξ-)	
			Constant Cell	Constant Sagitta	Constant Cell	Constant Sagitta
π→μ →e	25	13601-1	1.00	1.00	0.0	0.0
π→μ →e	30	13901-5	0.99	1.00	~0.0	0.0
π→μ →e	64	4101-8	1.00	1.00	~0.0	0.0
π→μ →e	79	2701-2	1.00	1.00	0.0	0.0

Acknowledgements

We would like to gratitude Dr Htun Hlaing, Principal of Myingyan Degree College, for his encouragement. We also appreciate to Professor Dr Kyi Kyi Thein, Head of Department of Physics, Myingyan Degree College for her permission and encouragement.

References

[1] S. Aoki, et al. : Nuc. Phys. A 828 (2009) 191.

[2] H. Takahashi, Doctor of Science Thesis (2003), Phys. Dept., Kyoto Univ., Japan.

[3] S. Kinbara, et al : proc. 2nd Inter: Symp: on Science at J-PARC (2014).

[4] H. Bichsel, D. E. Groom and AS. R. Klein: PDG (2013).

[5] A. Fukunaga : Master Thesis (2012), Phys. Dept., Gifu Univ., Japan.

[6] C. Dilworth, S. J. Goldsack and L. Hirschbere: Nuovo Cimento 6 (1954) 113.

[7] K. T. Tint et al : proc. 2nd Inter: Symp: on Science at J-PARC (2014).

[8] https://en.wikipedia.org/wiki/Geant4.

[9] H. H. Heckman, et al.: Phys: Rev.117 (1960) 544.