Analysis of A Xi-minus Hyperon Inflight Decay Event

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Abstract

In this research, a Xi-minus hyperon inflight decay event which was found in nuclear emulsion of KEK E373 experiment had been analyzed. The kinetic energy and momentum of Xi-minus hyperon that was the entering point into nuclear emulsion were estimated by using the range and angle information of Xi-minus and its decay daughters, π^- and Λ. The obtained values of kinetic energy and momentum were 56.69 MeV and 391.18 MeV/c, respectively.

Key Words: Xi-minus hyperon, inflight decay, nuclear emulsion

Introduction

The Xi-minus (Ξ^-) hyperons were produced via quasi free 'p' (K^-, K^+) Ξ^- reaction in a diamond target with 1.66 GeV/c K^- meson beam in KEK E-373 Experiment. Emitted Ξ^- hyperons were entered into nuclear emulsion stack which was situated at the downstream of diamond target. One stack of emulsion was composed of one thin plate (plate #1) with thickness ~ 400 μm and 10 or 11 thick plates with thickness ~ 1050μm (plate #2 to #11 or #12). The area of emulsion plates was 24.5 × 25.0 cm^2. Total 100 stacks (module) were used in E373 experiment. Some Ξ^- hyperons were brought to rest in nuclear emulsion and captured by emulsion nuclei and could found compound nucleus with strangeness quantum number S = -2. At the decay of the compound nucleus, a double Λ hypernuleus, twin single Λ hypernucleus, single Λ hypernucleus and H di baryon (if exist) were emitted. On the other hand, some Ξ^- hyperon inflight decayed into π^- meson and Λ hyperon which can be seen thin track (π^-) at the end of straight thick track (Ξ^-) in nuclear emulsion. Track of Λ hyperon cannot be seen in nuclear emulsion because it has no charge. A schematic view of Ξ^- hyperon inflight decay event and around the target region of E 373 experiment is shown in Figure (1). We chose an event in which π^- meson track was stopped at Scintillating Micro Fiber Block (SciFi-Block) detector. This event was found in plate #7 of Module #65.We measured the range of π^- meson track not only in nuclear emulsion (pl #7 to #12) but also in downstream of SciFi-Block. Moreover, the range of Ξ^- hyperon track from plate #7 to plate #1 was measured. We obtained the angle between the Ξ^- hyperon track and π^- meson track. The kinetic energy and momentum of Ξ^- hyperon's decay point was obtained from the range, kinetic energies of its decay daughter and conservation laws of energy and momentum. Finally, kinetic energy and momentum of Ξ^- hyperon at its entering point into nuclear emulsion (pl#1) was estimated from measured range data (from pl #7 to pl#1) and its decay point data.

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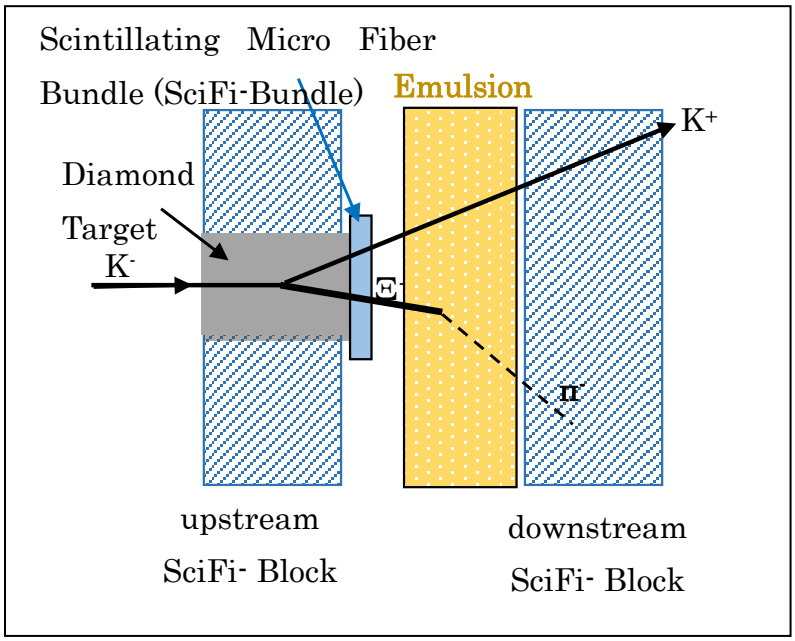

Figure (1) A schematic view of Ξ^- hyperon inflight decay event and around the target region of E 373 experiment

Event Description, Range Measurements and Event Reconstruction

Event Description of A Xi-minus Hyperon Inflight Decay in Nuclear Emulsion

The photograph and schematic drawing of Ξ^- hyperon inflight decay event are shown in Figure (2). The Ξ^- hyperon entered and then inflight decayed at point A, from which π^- meson and invisible lambda (Λ) hyperon were emitted. π^- meson track was left the emulsion stack and stopped in SciFi-block detector which was placed downstream of the emulsion chamber. The SciFi image for stopped π^- meson track in his event is shown in Figure (3). Four black sports in D- Block image express the stopped π^-.

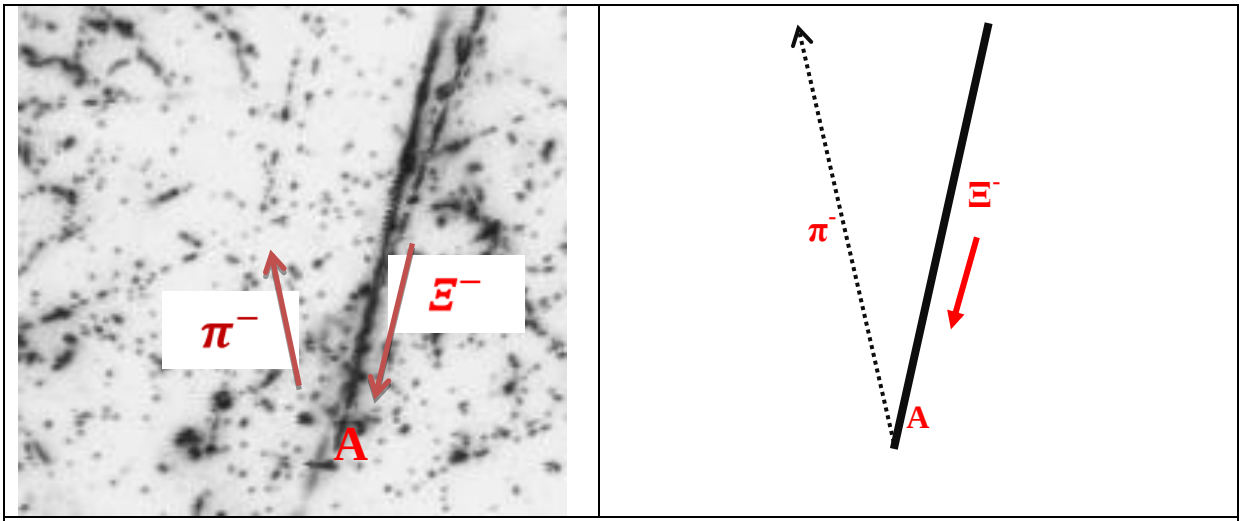

Figure (2) A photograph and schematic drawing of a xi-minus hyperon inflight decay event

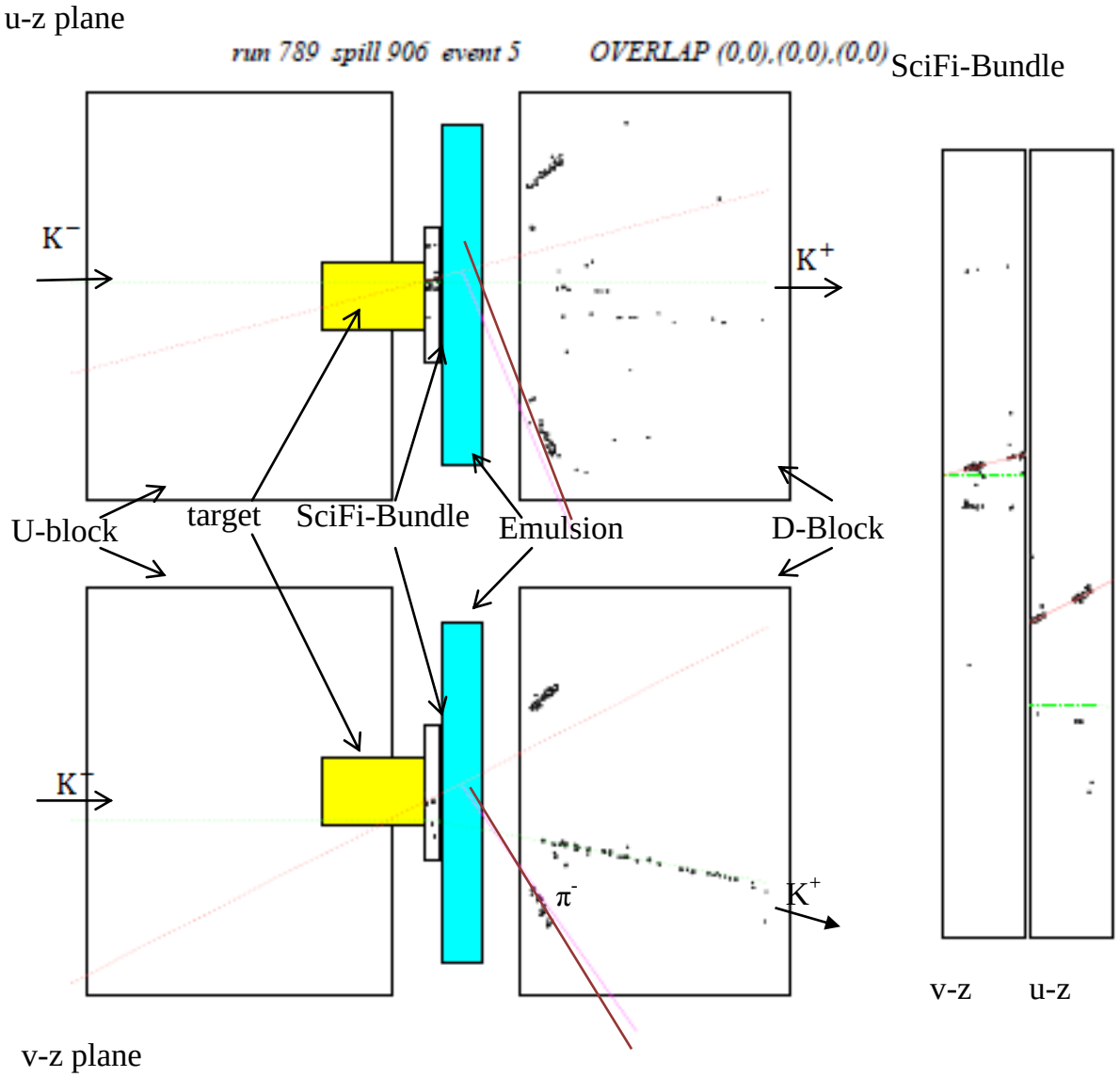

Figure (3) The SciFi image for stopped π^- meson track

Range and Angle Measurement of Xi-minus Hyperon and π- Meson

We measured the range of Ξ^- hyperon (pl #7 to pl #1) and π^- meson (pl #7 to pl #12) tracks in emulsion by using the microscope system. The range of the track, R can be obtained from measured x, y, z coordinates by using the following relation.

$$R = \sqrt{\Delta x^2 + \Delta y^2 + \Delta z^2 . S^2} \qquad (1)$$

Where, Δx, Δy and Δz were the length of the track in the x, y and z direction respectively. The S was the shrinkage factor. We also obtained the angle between Ξ^- hyperon and π^- meson tracks by using equation (2).

$$\vec{\Xi}^- \cdot \vec{\pi}^- = \left|\vec{\Xi}^-\right| \cdot \left|\vec{\pi}^-\right| \cos\theta \qquad (2)$$

Since the π^- meson track was left from the emulsion plate and stopped in downstream of SciFi-Block, we needed to obtain range in SciFi and transform into corresponding range in

nuclear emulsion. The range of the π^- meson track was obtained from the size of D-Block in u, v, z directions (120 mm× 120 mm× 80 mm). The corresponding kinetic energy was obtained by using the range energy relation equation in SciFi-Block detector.

$$R = a \times T^b \quad (3)$$

Where a and b were the fitting parameter. The values of "a" and "b" are, 0.107 and 1.62, respectively. We considered again that the range in nuclear emulsion for that energy value of π^-. Because SciFi-Block and nuclear emulsion were different media.

Event Reconstruction

The Ξ^- hyperon was identified from event reconstruction of its decay at point A. We assumed that Ξ^- hyperon inflight decayed into a π^- meson and another neutral particle, a Λ hyperon. We considered the kinematic of decay event where the direction of Ξ^- hyperon as x-axis is shown in the following Figure (4).

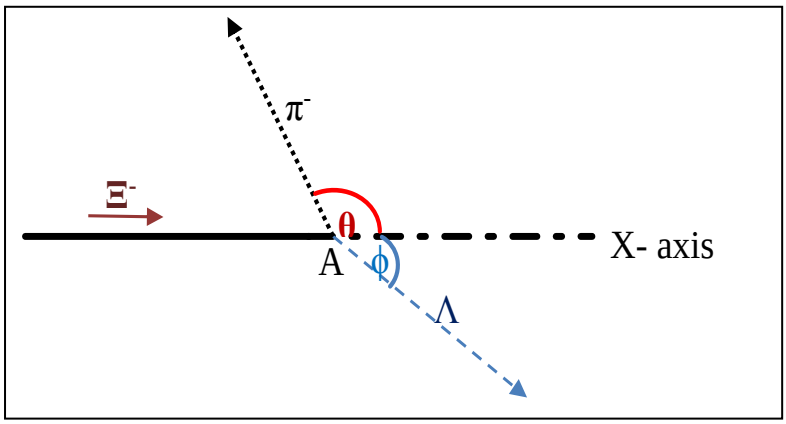

Figure (4) The kinematic of decay event

Firstly, we considered the decay point of Ξ^- hyperon, point A in Figure (4). Invariant mass of Ξ^- hyperon was obtained from the information of its decay daughters, π^- meson and Λ hyperon, by using the following Equation (3).

$$M_{\Xi^-}^2 = \left(\sqrt{M_{\pi^-}^2 + P_{\pi^-}^2} + \sqrt{M_\Lambda^2 + P_\Lambda^2}\right)^2 - (P_{\pi^-}cos\theta + P_\Lambda cos\phi)^2 \quad (4)$$

The values of ϕ were obtained from momentum conservation relation, $P_\pi \sin\theta = P_\Lambda \sin\phi$ by inserting the various value of P_Λ. And then, we deduced the momentum of Ξ^- hyperon at point A from the following momentum conservation relation,

$$P_{\Xi^-} = P_\pi - \cos\theta + P_\Lambda \cos\phi \quad (5)$$

The value of momentum and kinetic energy for Ξ^- hyperon at point A were obtained. Then, we calculated the corresponding range in nuclear emulsion by using energy-range program. The total range of Ξ^- hyperon was obtained from estimated range at point A plus measured range from pl #7 to pl #1. Finally, we calculated the kinetic energy and momentum of Ξ^- hyperon at plate#1 from its total range by using range- energy program.

Results and Discussions

Result of Range Measurement of Ξ^- hyperon and π^- meson in Nuclear Emulsion

We measured the range of Ξ^- hyperon and π^- meson in decay event of #9501-3 which was found in nuclear emulsion plate of #7, Mod # 65 of KEK E373 experiment by using the microscope system. The range of Ξ^- hyperon from Pl#7 to Pl#1 was measured. Similarly, the range of π^- meson from Pl#7 to Pl # 12 was measured. The range of each track was obtained from measured coordinates by using the Equation (1). The range of Ξ^- hyperon in nuclear emulsion was 6700 μm and that of π^- meson was 18700 μm.

Result for Estimation of Range and Kinetic Energy of π^- meson in Down Stream of SciFi Block

π^- meson track was left the emulsion stack and stopped in downstream block (D-Block) of Scintillation Microfiber block (SciFi-block) detector. The ranges of tracks in SciFi-Blocks can be obtained by using the size of D-Block in u, v, z directions, 120 mm × 120 mm × 80 mm. The range of the π^- meson track which was emitted from decay event in D-Block was 21.8 mm (21800 μm). The corresponding kinetic energy was obtained by using the range energy relation equation, Equation (3), in SciFi-Block detector. The kinetic energy of π^- meson track would be 26.7 MeV.

Result for Estimation of Total Range and Kinetic Energy of π^- meson

Since the kinetic energy of π^- meson track in Sci-Fi block was 26.7 MeV. We considered that the range of π^- meson track in nuclear emulsion if it has 26. 7 MeV, kinetic energy. The corresponding range in nuclear emulsion was obtained by using the energy-range program for nuclear emulsion which was based on Barks's literature. The range obtained by using range energy relation in nuclear emulsion was 13284.30 μm. The total range of π^- meson track which included range in emulsion as well as in Sci-Fi block was 31984 μm. Its kinetic energy was 45. 25 MeV. The symmetrized range and kinetic energy for π^- meson were expressed in Table 1.

Table 1. The symmetrized range and kinetic energy for π^- meson

Range in Emulsion (μm) (pl# 7 ~ 12)	**Range in Sci-Fi Block (μm)**	**Kinetic Energy in Sci-Fi Block (MeV)**	**Corresponding Range in Emulsion (μm)**	**Total Range of π^- meson (μm)**	**Total Kinetic Energy of π^- meson (MeV)**
18700	21800	26.7	13284.3	31984.3	45.3

Result for Estimation of Momentum of Λ hyperon

Decay event was reconstructed at Ξ^- hyperon decay point by using the conservation laws of energy and momentum. We imagined that Ξ^- hyperon was decay into π^- meson and Λ hyperon at point A. The invariant mass of Ξ^- hyperon was obtained by using Equation (4) with the information of decay daughters. The value of ϕ were deduced from momentum

conservation relation, $P_\pi \sin\theta = P_\Lambda \sin\phi$ by inserting the various value of momentum of lambda hyperon P_Λ which was from minimum value 113.6 MeV/c to 350.6 MeV/c. The various value of mass of Ξ^- hyperon obtained from corresponding momentum of Λ hyperon, as shown in Figure (5). The invariant mass of Ξ^- hyperon, $M_{\Xi^-} = 1321.31 MeV/c^2$, was obtained at momentum of Λ hyperon, $P_\Lambda = 330.10$ MeV/c. The kinetic energy and momentum of π^- meson, Λ hyperon and Ξ^- hyperon at point A are summarized in Table 2.

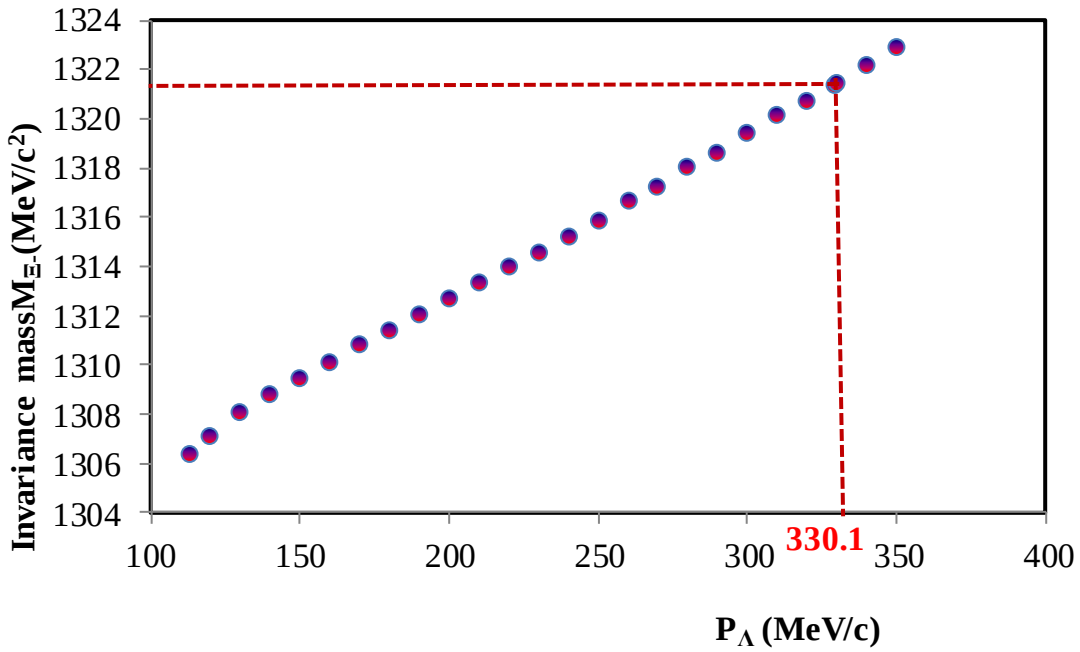

Figure (5) Invariance mass of Ξ^- hyperon and momentum of Λ hyperon

Table 2. The kinetic energy and momentum of π^- meson, Λ hyperon and Ξ^- hyperon at point A.

π^-		Λ		Ξ^-	
Kinetic energy (MeV)	**Momentum (MeV)**	**Kinetic energy (MeV)**	**Momentum (MeV/c)**	**Kinetic energy (MeV)**	**Momentum (MeV)**
45.3	121.155	48.8	330.10	27.3	268.5

Result for Determination of Kinetic Energy and Momentum of Ξ^- hyperon at Plate#1

The momentum and kinetic energy of Ξ^- hyperon at point A were obtained by using the momentum conservation and energy-momentum relations. Its values have to be 68.5 MeV/c and 27.3 MeV, respectively. The range of Ξ^- hyperon obtained from kinetic energy at point A was 2578.73 μm. The range of Ξ^- hyperon from point A at plate #7 to plate #1 was 6700 μm. The total range of Ξ^- hyperon was 9278.73μm. The kinetic energy and momentum of Ξ^- hyperon at plate#1 were 56.7 MeV and 391.2 MeV/c respectively. The symmetrized range, kinetic energy and momentum of Ξ^- hyperon were expressed in Table 3.

Table 3. Range, kinetic energy and momentum of Ξ^-hyperon at point A and at Pl#1

Kinetic Energy of Ξ^- at point A (MeV)	**Corresponding Range (μm)**	**Range of Ξ^- Pl#1 to Pl#7 (μm)**	**Total Range of Ξ^- hyperon (μm)**	**Kinetic Energy of Ξ^-hyperon at Pl#1 (MeV)**	**Momentum of Ξ^- hyperon at Pl#1 (MeV/c)**
27.3	2578.73	6700	9278.73	56.7	391.2

Discussions

The event reconstruction in nuclear emulsion is based on the conservation laws of energy and momentum. A Ξ^- hyperon decayed into a charged particle and some neutral one at point A. The emitted particle from event left the emulsion stack and stopped in downstream of SciFi-Block (D-block). That particle was identified as a π^- meson because of the mean brightness value of the track. We measured the range of tracks in Ξ^- hyperon decay event. We obtained the angle between the Ξ^- hyperon and π^- meson. The kinetic energy and momentum of π^- meson was obtained from the total range which included range in emulsion plus corresponding range in emulsion changed from range in Sci-Fi block by using the range energy relation. And then, we also calculated he invariant mass of Ξ^- hyperon by using the various value of P_Λ and ϕ based on momentum conservation relation. The value of ϕ was obtained by using this equation $P_\pi \sin\theta = P_\Lambda \sin\phi$ and inserting the various value of P_Λ. Then, we estimated momentum and kinetic energy of Ξ^- hyperon at point A. The momentum and the kinetic energy were 2 68.5 MeV/c and 27.3 MeV, respectively. The corresponding range in nuclear emulsion, 2578.73 μm, was obtained by using the energy-range program. The measured range of Ξ^- hyperon form plate#1 to #7 was 6700 μm by using microscope system. Then, total range of Ξ^- hyperon was 9278.73 μm. Finally, the kinetic energy and momentum of Ξ^- hyperon at plate#1 were 56.7 MeV and momentum was 391.2 MeV/c respectively.

Conclusion

We have analyzed one of the decay events in nuclear emulsion of E373 experiment. The decay event is the cascade decay of, $\Xi^- \longrightarrow \pi^- + \Lambda$; $\Lambda \longrightarrow p + \pi^-$. However, $\Xi^- \longrightarrow \pi^- + \Lambda$ decay mode can be detected in nuclear emulsion of E373 experiment. We measured the range of π^- meson not only in emulsion but also in SciFi-Block detector. We obtained the kinetic energy and momentum of π^- meson from its range. Moreover, the momentum of Λ hyperon was estimated. In our analysis, the momentum of Ξ^- hyperon at pl#1 was estimated by using the information of its decay daughter, $\pi^- and\ \Lambda$, based on the conservation laws of energy and momentum.

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