Analysis of Energy Uncertainties Generated from Density of Emulsion Layer and Range Straggling

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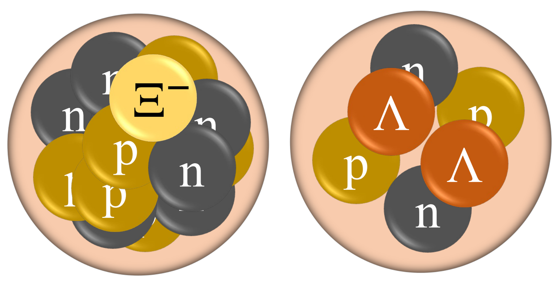
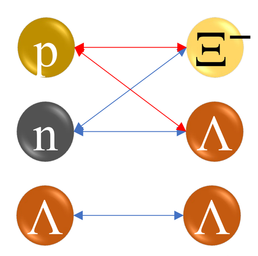
Introduction

Hypernucleus

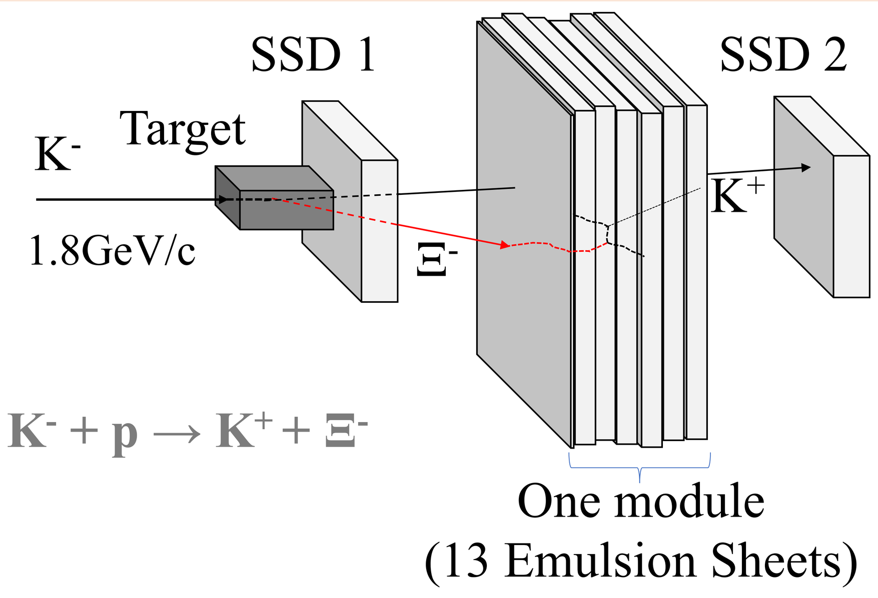


Interaction Strength



Our study!

E07 experiment



- To detect more double hypernuclei.
- Currently, 33 events were detected.

Motivation

Mass reconstruction for double hypernuclei

Λ-Λ interaction energy ⟶ $\Delta B_{\Lambda\Lambda} = B_{\Lambda\Lambda} - 2B_{\Lambda}$

- In the case of NAGARA event,

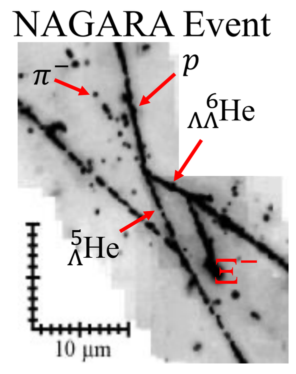
$$B_{\Lambda\Lambda}({}^{6}_{\Lambda\Lambda}He) = M({}^{4}He) + 2M(\Lambda) - M({}^{6}_{\Lambda\Lambda}He)$$

$$M({}^{6}_{\Lambda\Lambda}He) = M({}^{5}_{\Lambda}He) + M(p) + M(\pi^-) + KE({}^{5}_{\Lambda}He) + KE(p) + KE(\pi^-)$$

Range-Energy relation

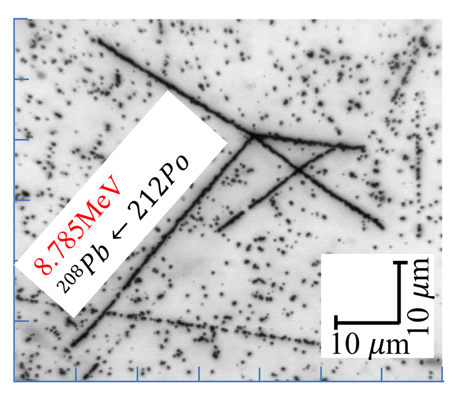
Range of $({}^{5}_{\Lambda}He)$ (p) (π^-)

NAGARA Event



- Range-Energy relation in nuclear emulsion,

$$R = \frac{M}{Z^2}.\lambda(\beta, d) + MZ^{2/3}C_z(\beta/Z)$$



Superimpose image of alpha tracks from thorium series

- It is very important to measure density of emulsion layer at beam exposure time because of shrunk emulsion layer after photographic development.
- Alpha track from ^{212}Po of Thorium series which have monochromatic energy were used to calibrate shrinkage factor (S) and emulsion density.
- The relation between the number of alpha tracks and the error of mass reconstruction have not been sufficiently studied.

Objective

- The purpose of this research is to determine sufficient number of alpha tracks for the calibration of density of emulsion layer in order to minimize mass error of double hypernuclei.

Analysis method and results

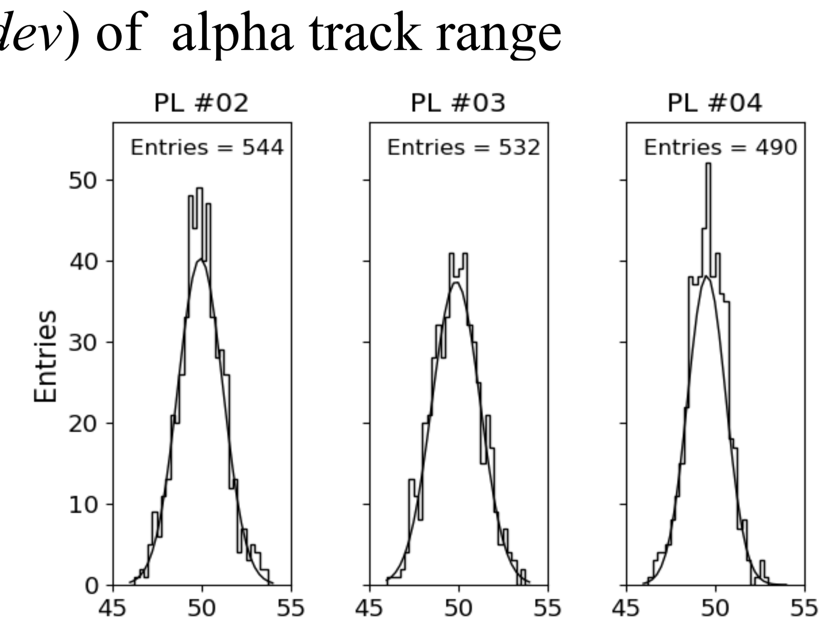
1. Alpha track range measurement

- The range of alpha tracks were calculated using 3D coordinate with the following formula,

$$R = \sqrt{\Delta X^2 + \Delta Y^2 + (\Delta Z * S)^2}$$

where S is shrinkage factor in z-direction and it can be obtained using minimum standard deviation (*Min_Stdev*) of alpha track range

- Alpha track from three emulsion sheets (PL02, PL03, PL04) of module #30 of J-PARC E07 experiment were used for the calibration.
- Consistency of alpha track range was also check by chi-square test.
- The result show that alpha tack range in each emulsion sheet are consistent under normal distribution.



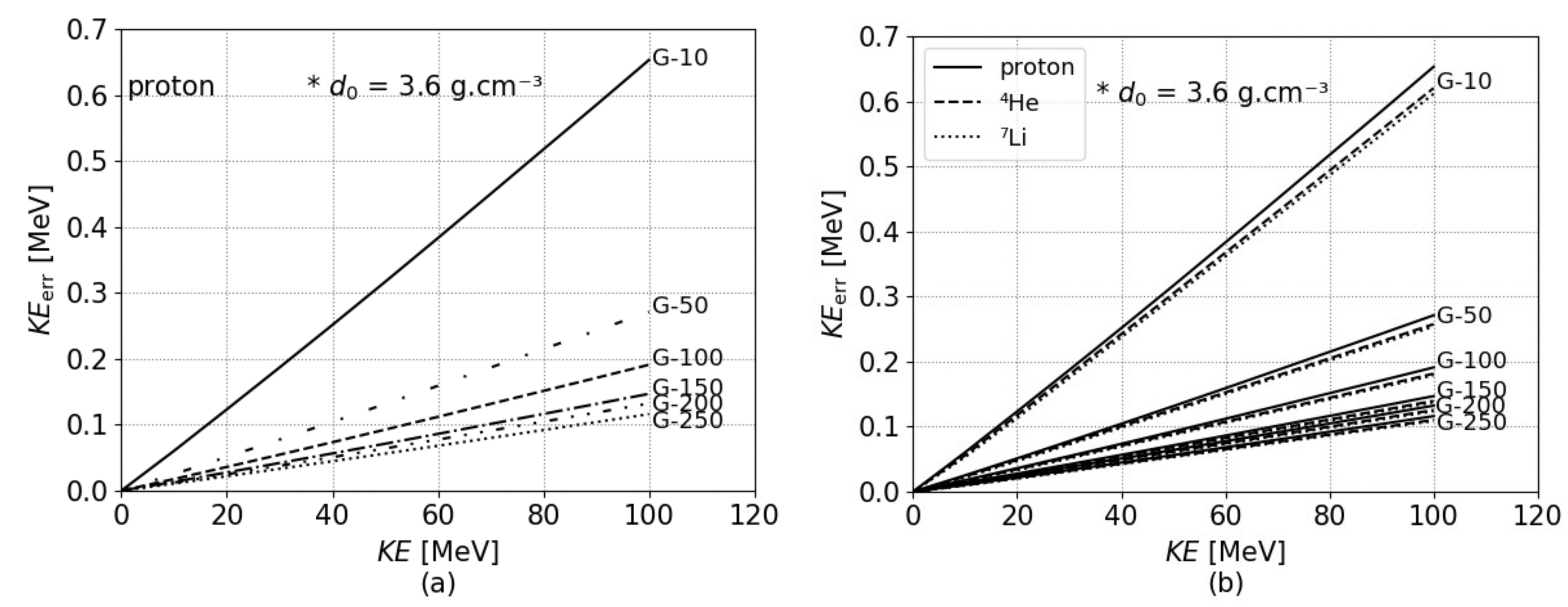
Alpha track range distribution for three emulsion sheets

2. Calibration of density of emulsion layer

- To determined sufficient alpha tracks, density (d) and density error (d_{err}) were calibrated using six different number of alpha track groups (G-10, G-50, G-100, G-150, G-200, and G-250).
- The d for all groups vary from 3.57 to 3.64 g/cm^3. Average d for each group is closed to 3.6 g/cm^3 (approximate density, $d_0 \cong 3.6$ g/cm^3).

3. Kinetic energy (KE) and its error (KE_{err})

- The sufficient alpha tracks will be determined using KE_{err} generated from d_{err}.
- To calculate KEerr from d_{err}, $d_0 \cong 3.6$ g/cm^3 and average d_{err} (d_{err_avg}) of same number of alpha track group were used.
- KE was varied from 0 to 100 MeV with intervals of 10 MeV.
- The following figures shows relation between KE and KE_{err} for proton, ^{4}He, and ^{7}Li.



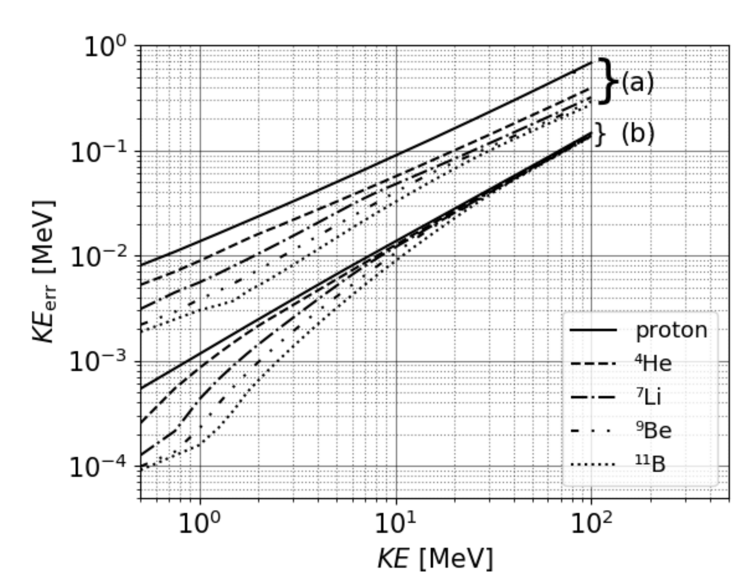
(a) Relation between KE and KE_{err} for proton and (b) Comparison result for proton, ^{4}He, and ^{7}Li .

- The gaps of KE_{err} in the groups between G-10 and G-150 is large in comparison to between G-150 and G-250.
- Tendencies of KE_{err} gap for ^{4}He and ^{7}Li are similar to those for the proton.
- Since we used d_0 = 3.6 g/cm^3, we check KE_{err} variation by changing ± 0.10 to d_0. The result gives a difference of ± 2.35 % (0.004MeV) of KE_{err} at 100 MeV. It was sufficiently small to be ignored
- Therefore, sufficient number of alpha tracks was determined to be at least 150.

4. KE_{err} from d_{err} and range straggling (ΔR)

- As ΔR is a statistical error in the analysis of double hypernuclei, the KE_{err} obtained from ΔR was also calculated using following equation.

$$\Delta R\ (KE) = \frac{\sqrt{M}}{Z^2}.\Delta R_p\left(\frac{KE}{M}\right)$$



Comparison of KE_{err} value for each KE obtained from (a) ΔR and (b) d_{err_avg} for proton, ^{4}He, ^{7}Li, ^{9}Be, and ^{11}B.

- KE_{err} from ΔR is one order of magnitude larger than that from d_{err_avg} for five particles, namely, the proton, ^{4}He, ^{7}Li, ^{9}Be, and ^{11}B.

5. Summary

- Suitable number of alpha tracks for density calibration was decided to be at least 150.
- Variation of d_0 with ± 0.10 g/cm3 generated a difference of ± 2.35 % of KE_{err} at 100 MeV. It is small enough to be ignored.
- KE_{err} from ΔR is one order of magnitude larger than that from d_{err_avg}.
- This study aimed to provide for the analysis scheme of double hypernuclei in the future to minimize mass error.