E492

Test of a Scintillating Fiber Target for the Hypernuclear Spectroscopy

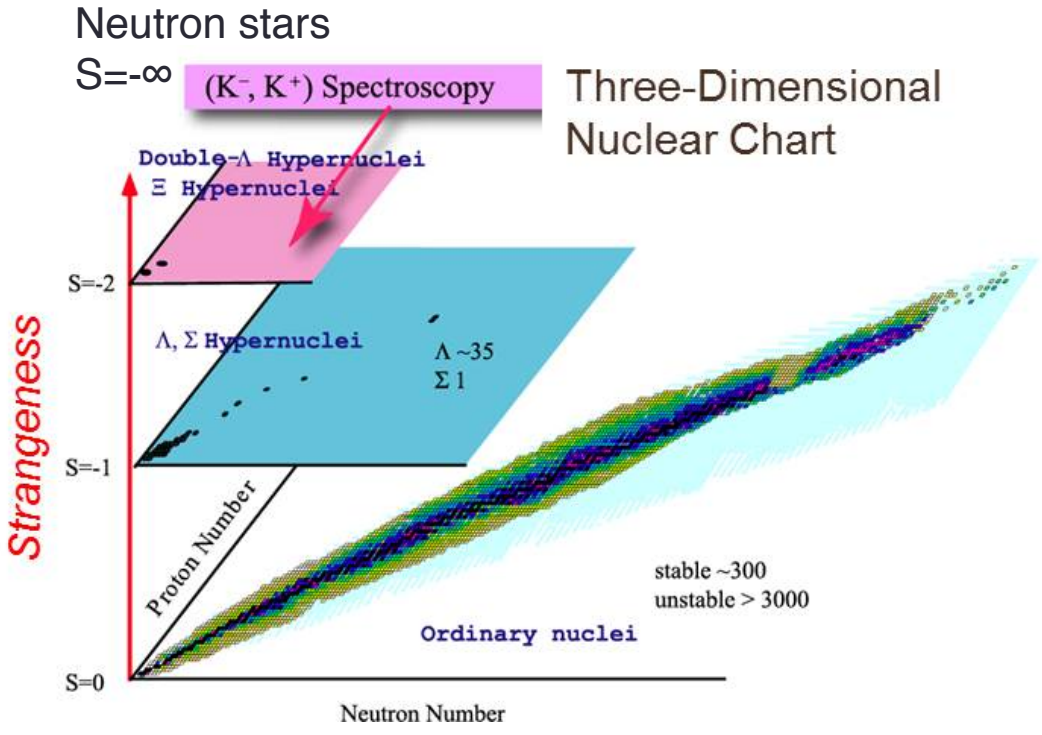
Shunsuke Kanatsuki for the E492 collaboration
Kyoto University
2016/8/24

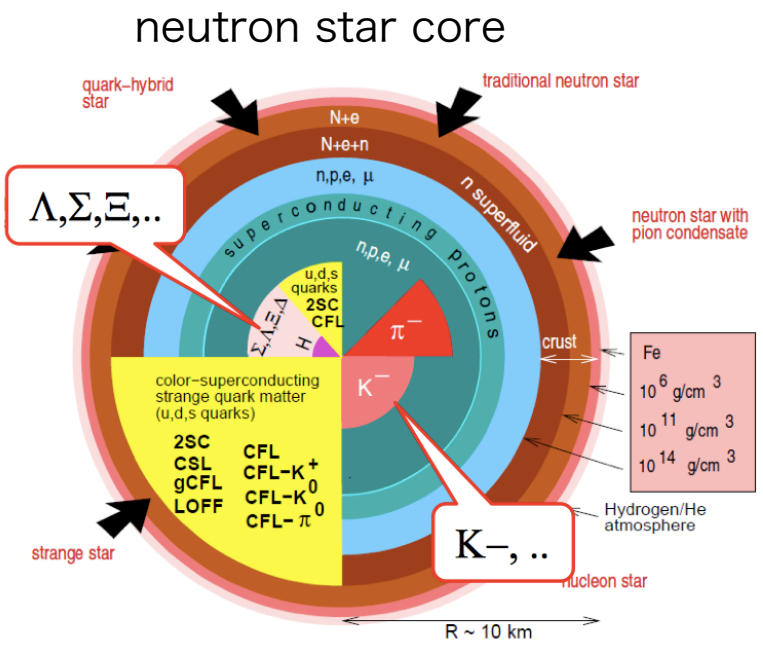
Outline

- Motivation
  - Spectroscopy of hypernuclei at J-PARC
  - Active fiber target
- Experiment at RCNP
  - Purpose : study response of a fiber using proton beam
  - Setup
  - Run time estimation : 2 days including beam tuning.
- Summary

Physics Motivation

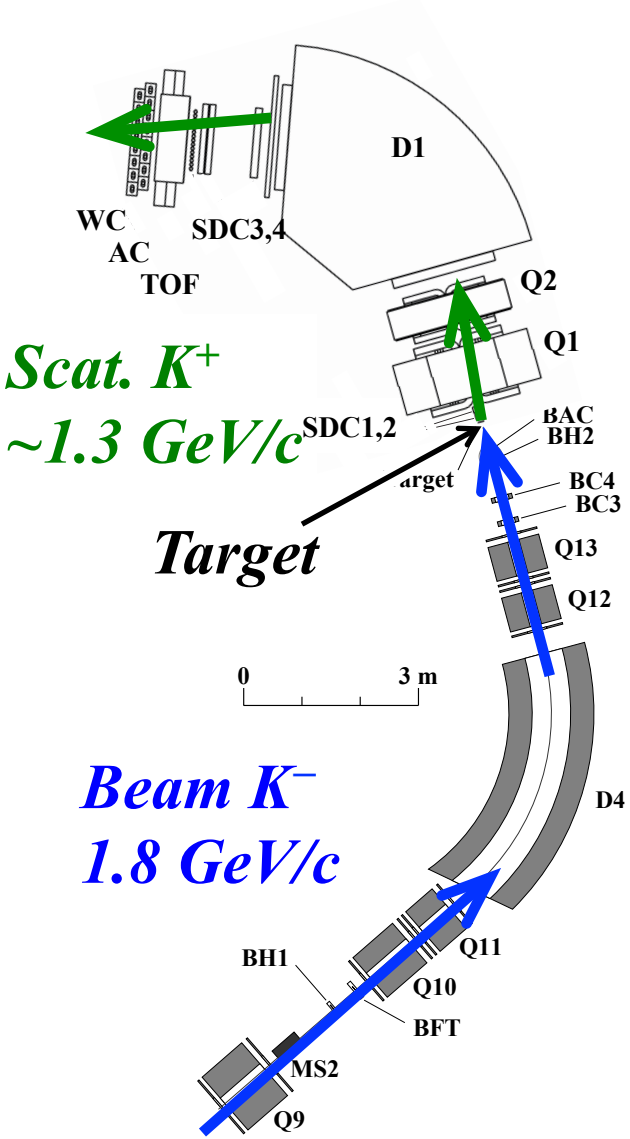
- Hypernuclear spectroscopy
  - Baryon-baryon interaction ← extended → nuclear force
  - A role of strangeness in dense nuclear matter





F. Weber, PPNP 54(2005)193

Spectroscopy at J-PARC K1.8BL



J-PARC E05

- Missing-mass spectroscopy of Ξ-hypernucleus, using the $^{12}C(K^-, K^+)^{12}_{\Xi}Be$ reaction (Nagae et al.)
- observe peak structures of the bound states
  → deduce the information of ΞN interaction
- Approved as highest priority "Day-1 experiment"

Momentum analysis

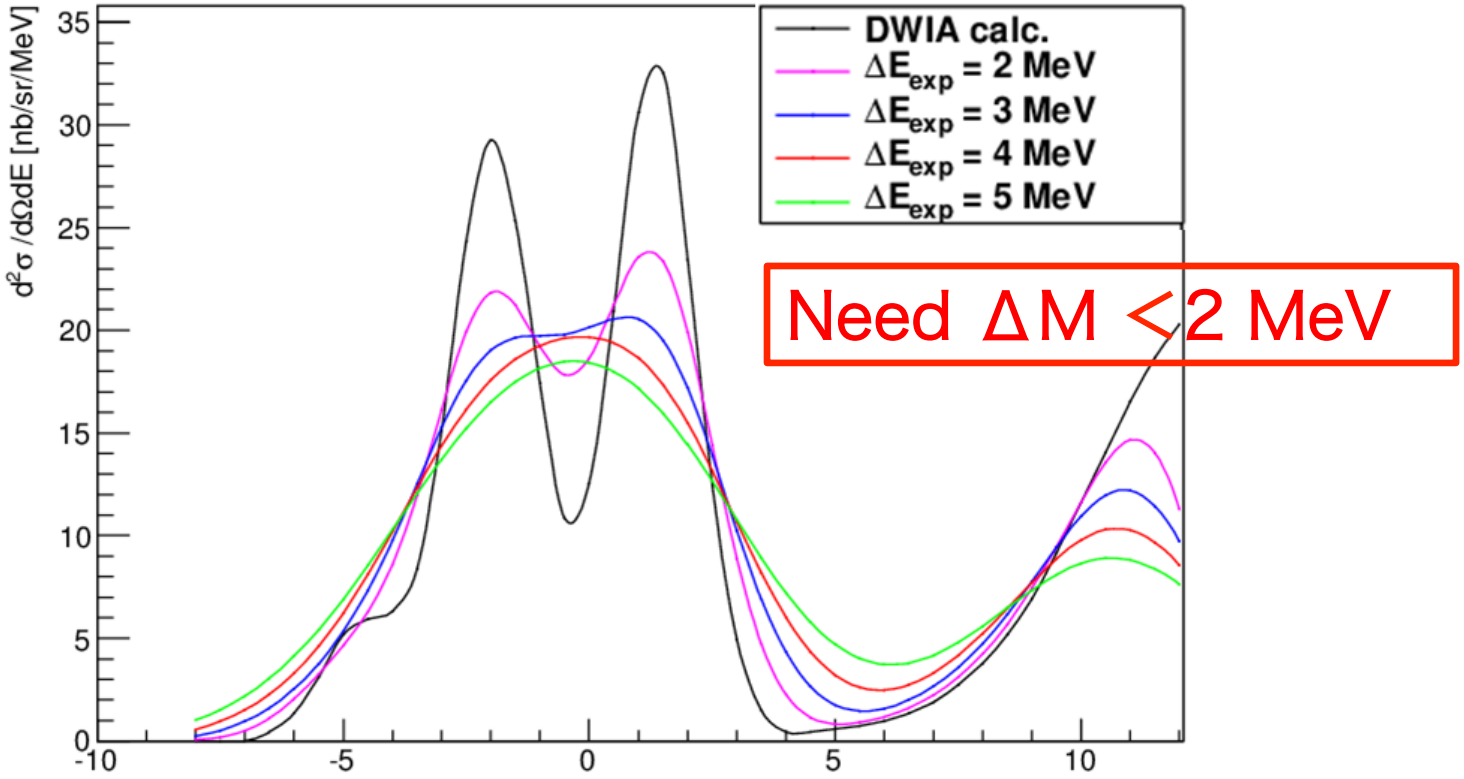
- K^+ : S-2S spectrometer
  - magnet construction completed in 2015
  - will be installed to J-PARC in 2018
- K^- : Beam spectrometer

Missing-mass resolution ΔM

- 1-1.8 MeV_{FWHM} w/o energy loss straggling in the target (E_{strag})
- Our goal: ΔM < 2 MeV
  ⟶ E_{strag} < 0.8 MeV

Expected Spectrum

- DWIA calculation
  - ^{12}C (K^-,K^+)$_{\Xi}$ ^{12}Be at 1.8 GeV/c
  - Core nucleus excitation is taken into account



T. Motoba and S. Sugimoto, Nucl. Phys. A 835, 223 (2010)

Production Rate

	Cross section	Yield [/4weeks /1g/cm2]
$^{12}_{\Xi}$Be	89±14 nb/sr*	37 counts

- K^- beam intensity = 0.6MHz
- *BNL-E885 exp. : P. Khaustov, et al., PRC 60, 054603 (2000)

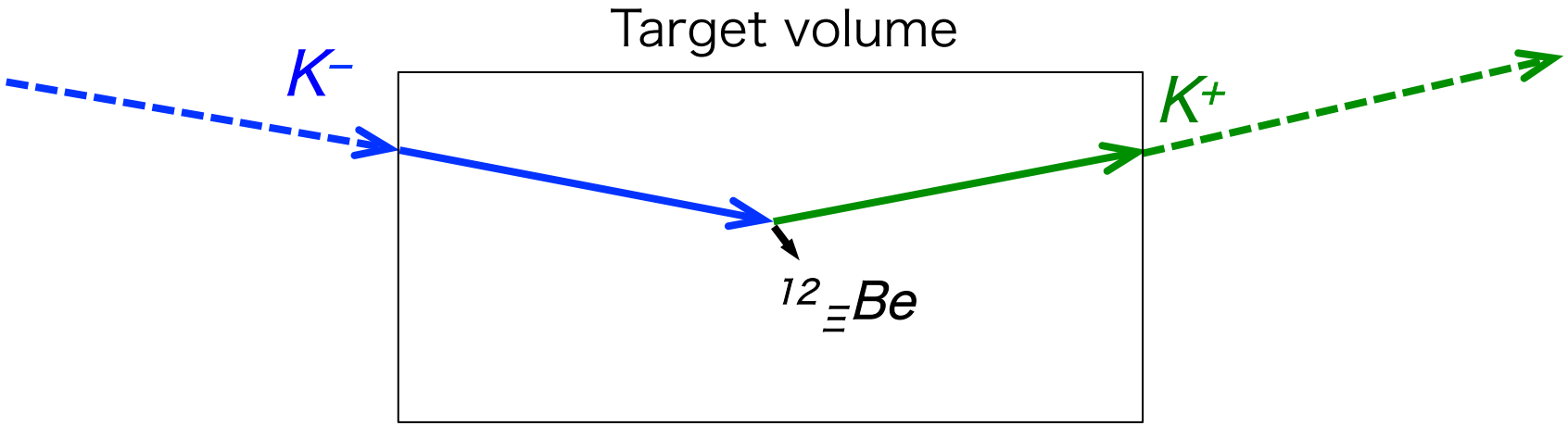
- Target thickness
  - 10 g/cm^2 is desirable to achieve good statistics within reasonable run time at J-PARC

→ $E_{strag.} > 4\ MeV_{FWHM}$

→ Direct measurement of the energy loss event-by-event to achive both high mass resolution and statistics

Active Fiber Target

- Scintillating fiber
  - scintillation light yield → correction of the energy of kaons event-by-event



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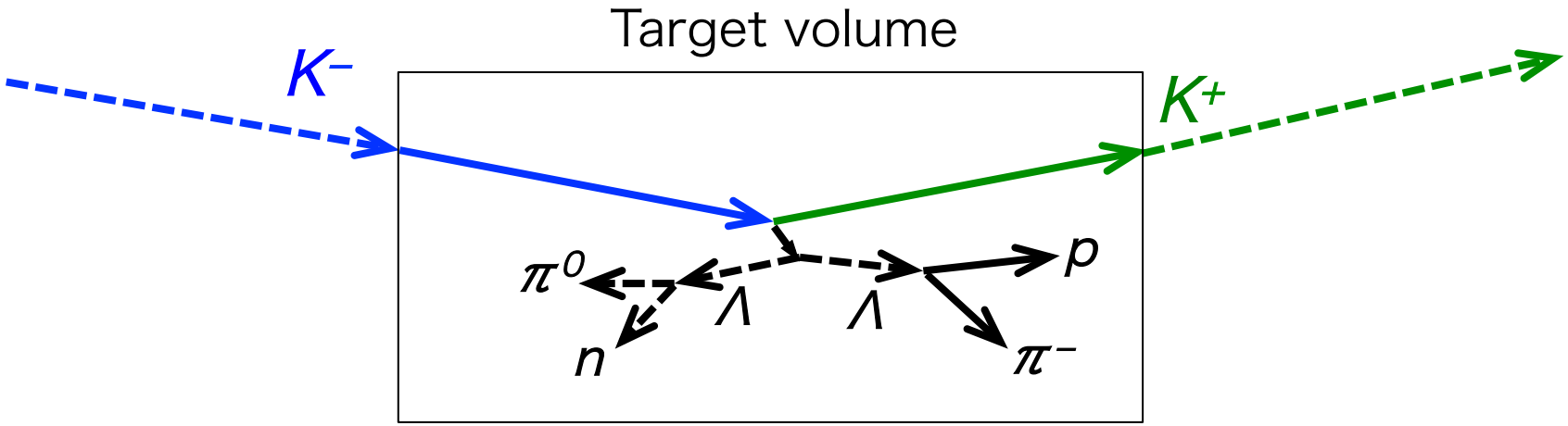

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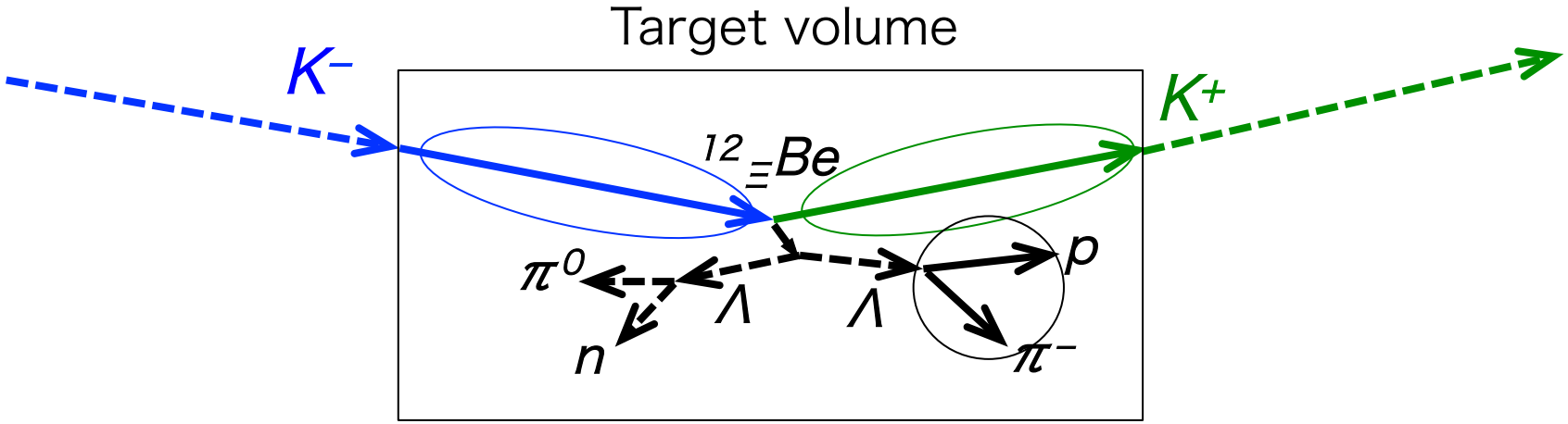
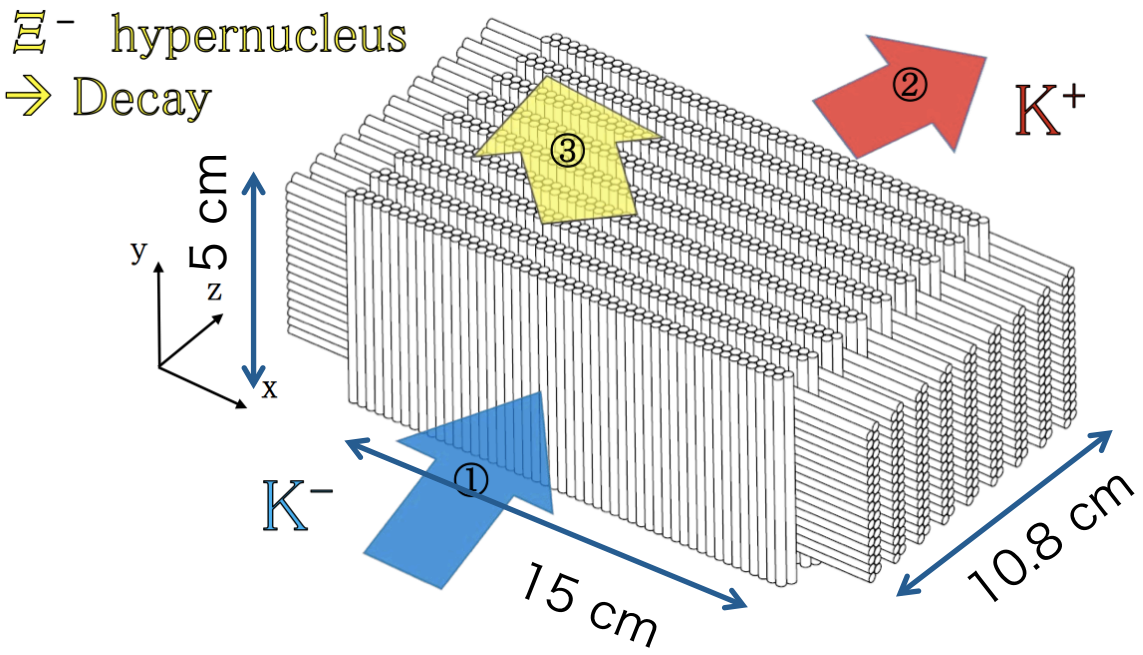


Energy losses of
- Beam K^-
- Scat. K^+
- Decay particles from hypernucleus

should be measured separately → Target must be segmented
→ Use fibers

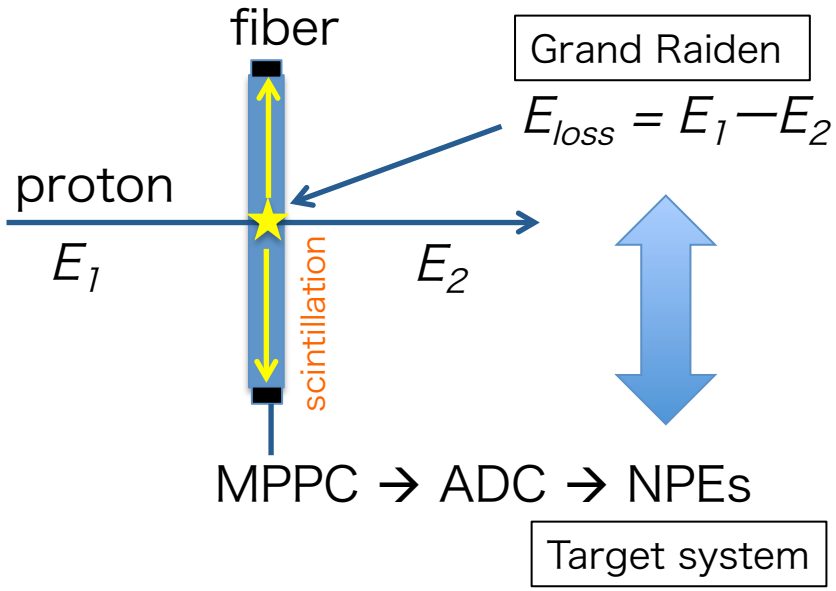
Active Fiber Target

- Scintillating fiber bundle
  - 3x3 mm square or 3 mm Φ (→ 50×18+16×18 ≒ 1000)
  - MPPCs attached on the both ends of each fiber



Performance Test at RCNP

- Measurement with a single fiber
  - study the correlation between
    1. the energy loss → measured with → Grand Raiden
    2. light yield → measured with → Scintillating Fiber

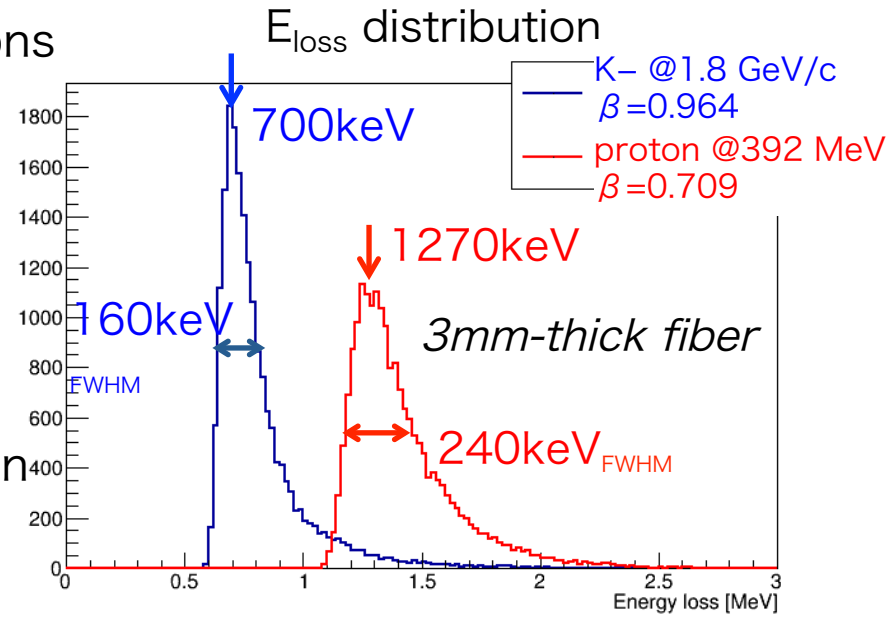


- The whole performance of the target (fiber bundle)

→ estimate by simulation using the response of a single fiber

Experimental Setup

- Beam
  - WS beam line
  - proton at 392 MeV
    - E_{loss} should be close to that of kaons
  - intensity: 5 kHz
- Grand Raiden
  - 0 degree
  - Eloss resolution 30 keV
    - need dispersion matching condition

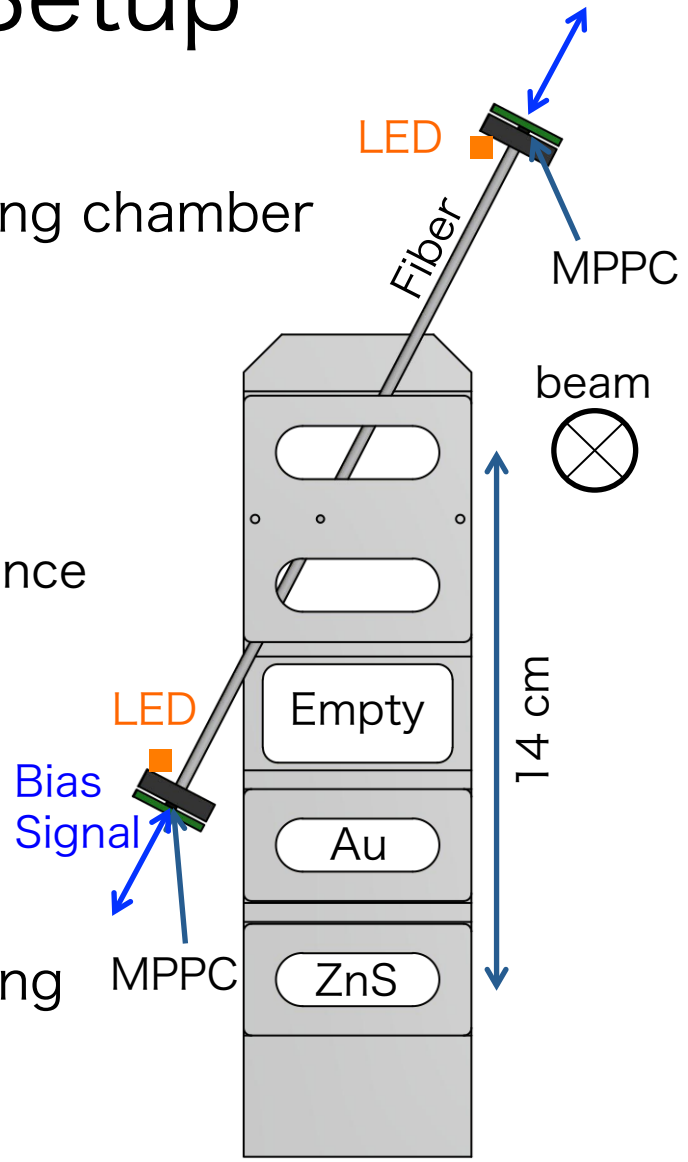


- High-resolution measurement with high velocity particle feasible only in RCNP with the Grand Raiden

Experimental Setup

- Fiber
  - fixed by a target ladder in the scattering chamber
  - specification
    - cross-section: 3x3mm^2 square, 3mmΦ
    - crad: single, double
    - company: KURARAY, SAINT-GOBAIN
      - candidates narrowed down in advance

- Target ladder
  - will be newly fabricated
  - hold a fiber and
    - Au foil : beam & spectrometer tuning
    - ZnS : beam profile check
    - Empty : beam energy check



Schematic of target ladder

Run time estimation

- Beam tuning and spectrometer start-up : 1 day
  - start up the spectrometer
  - tuning the accelerator
  - optimization the dispersion matching condition

- Fiber test : 2 hours ×12 conditions = 1 day
  - Conditions
    - 3 kinds of fibers × 4 (for check the individual difference)
  - Setup change : 1.5 hour
    - replace a fiber with chamber open
  - Beam irradiation : 0.5 hour
    - ZnS, Empty : beam check
    - Fiber : energy loss measurement

Summary

- We propose a performance test of a scintillating fiber using proton beam at 392 MeV at WS course.
  - Feasible only at RCNP with Grand Raiden
- The responses of fibers for the energy loss of proton beams are studied.
  - correlation between light yield in fiber and the energy loss measured by Grand Raiden
- The study is very important for the Ξ hypernuclear spectroscopy at J-PARC.
  - to optimize the mass resolution and statistics
  - will be carried out in FY2018 in the earliest case.
  - We request beam time for this test in FY2017

Collaboration List

- Kyoto University
  - H. Fujioka, T. Furuno, S. Kanatsuki, T. Kawabata, M. Murata, T. Nagae, T. Nanamura, A. Sakaue
- Osaka University, RCNP
  - T. Gogami, A. Inoue, N. Kobayashi, A. Tamii
- JAEA, ASRC
  - Y. Ichikawa

Back up

PROPOSAL FOR EXPERIMENT AT RCNP

2 July 2016

TITLE:
Test of a scintillating fiber target for the hypernuclear spectroscopy

SPOKESPERSON:

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Nobuyuki Kobayashi	Research Center for Nuclear Physics, Osaka University	Assistant Professor
Atsushi Tamii	Research Center for Nuclear Physics, Osaka University	Associate Professor

RUNNING TIME:	Installation time without beam	3 days
	Beam commissioning	1 days
	Data runs	1 days
BEAM LINE:		Ring : WS course
BEAM REQUIREMENTS:	Type of particle	unpolarized p
	Beam energy	392 MeV
	Beam intensity	$\leq 5 \times 10^3$ pps
	Other requirements	energy resolution ~100 keV halo-free, small emittance

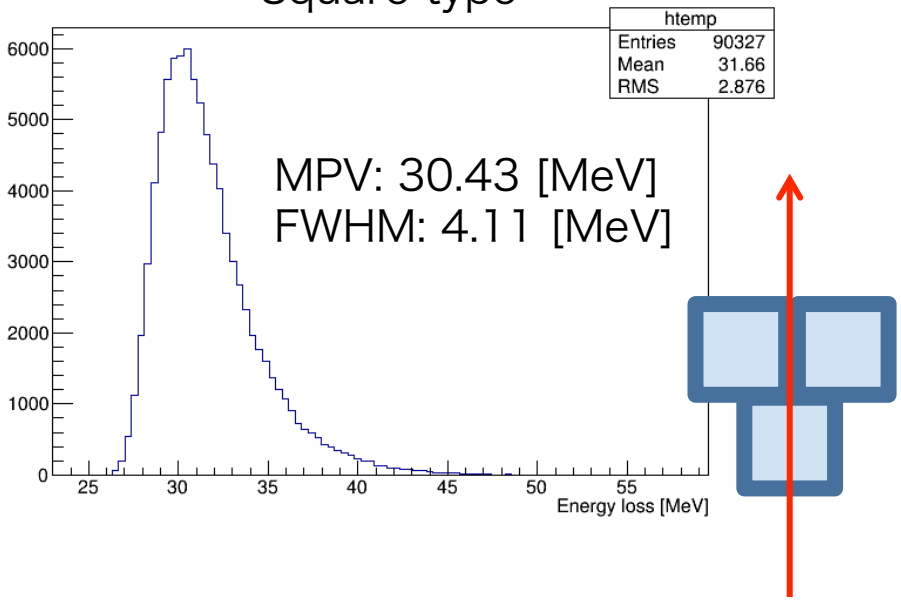
BUDGET:	Vacuum feedthrough	100,000 yen
	Travel expense	200,000 yen

Energy Loss Distribution

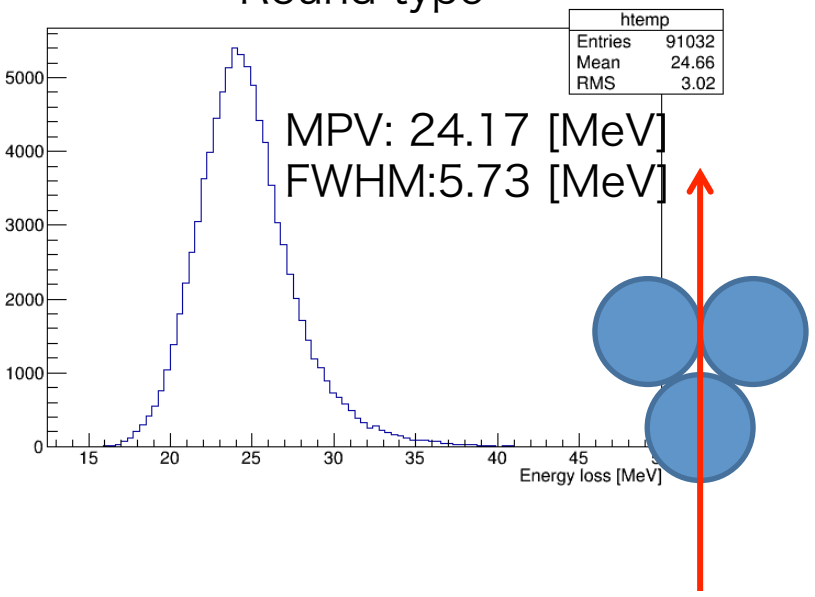
Geant4 simulation

- Sum of the energy losses in the whole target
- Target system : xx'yy' ×9 sets = 36 layers
- Thickness : 10.8 cm = 11.23 g/cm^2 (Carbon fraction: 10.4 g/cm^2)
- Beam: K^- 1.8 GeV/c, position: uniform, direction: 0 degree

Square type

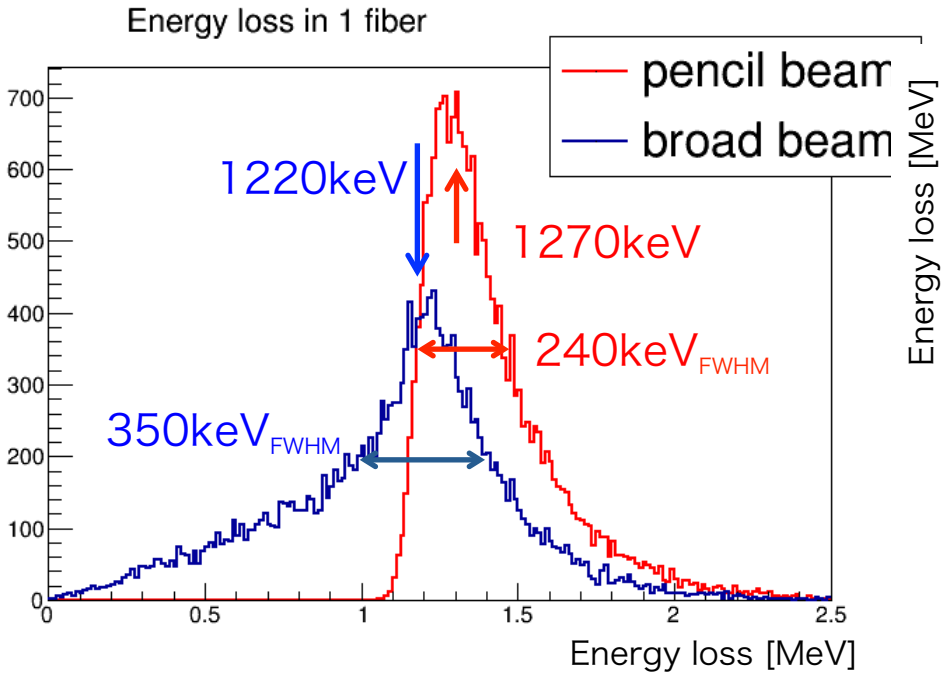


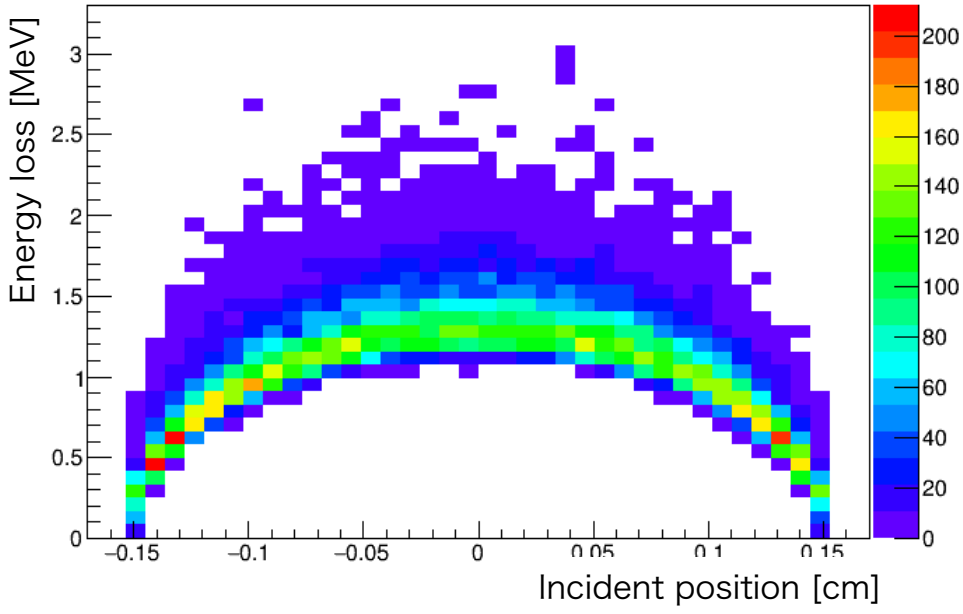
Round type



Incident Position Dependence

- 3mmΦ Round type fiber
- Energy loss of proton at 392 MeV
- Pencil beam : incident position fixed at center
- Broad beam : incident position uniform
  - distribution includes position dependence

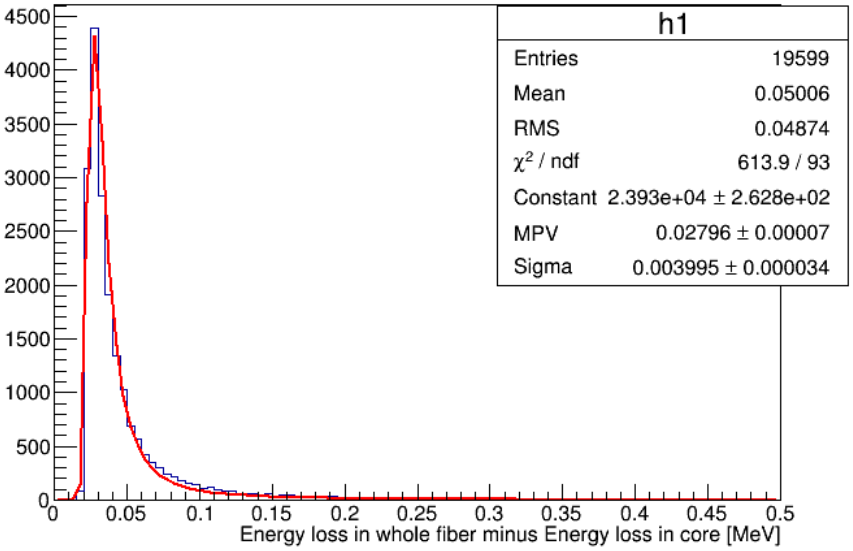




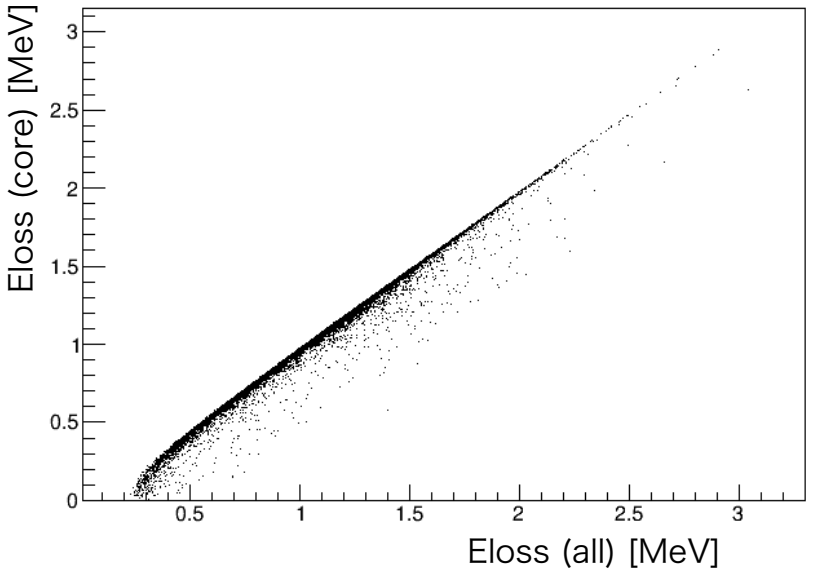
Energy Loss in Crad

- Simulation condition
  - 3mmΦ Round type fiber
  - Energy loss of proton at 392 MeV
  - Broad beam : incident position uniform
- Eloss(all) – Eloss(core)

Eloss(all) – Eloss(core)



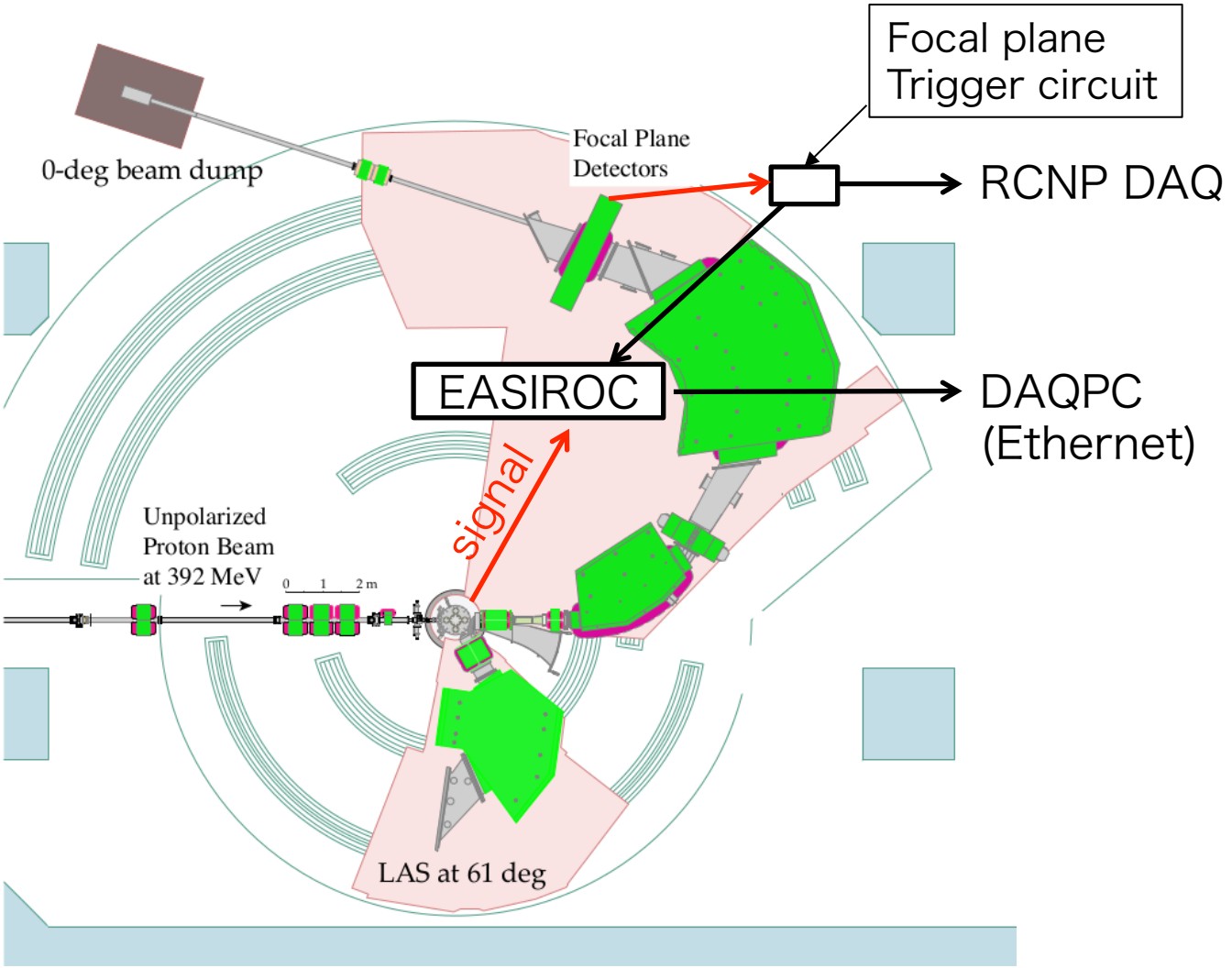
Correlation



Beta and Eloss

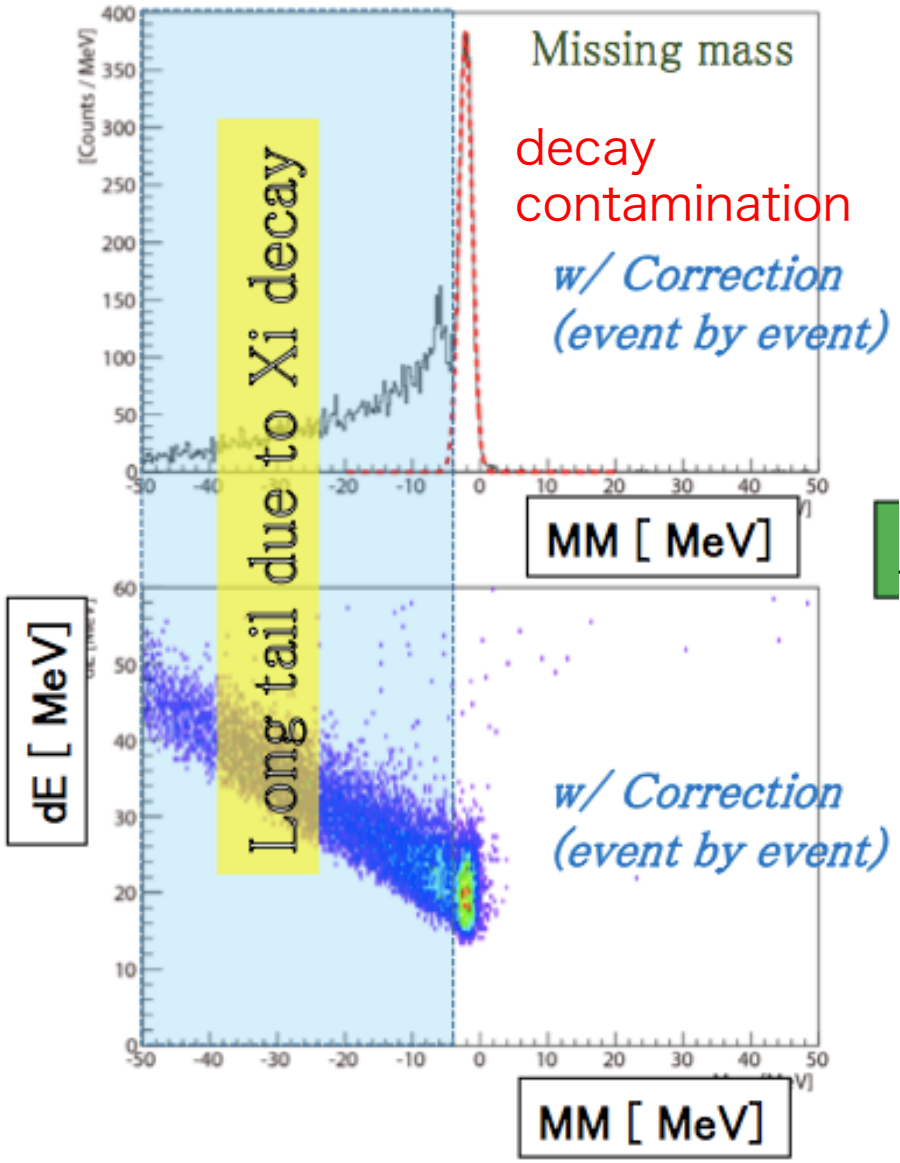
particle	beta	Energy loss (MPV) [MeV]	ΔE (FWHM) [MeV]
1.8 GeV/c K-	0.964	0.701	0.16
1.3 GeV/c K+	0.935	0.745	0.18
392 MeV proton	0.709	1.267	0.24
350 MeV proton	0.685	1.370	0.29
300 MeV proton	0.653	1.500	0.32
250 MeV proton	0.614	2.098	0.48
200 MeV proton	0.566	2.355	0.62

Readout

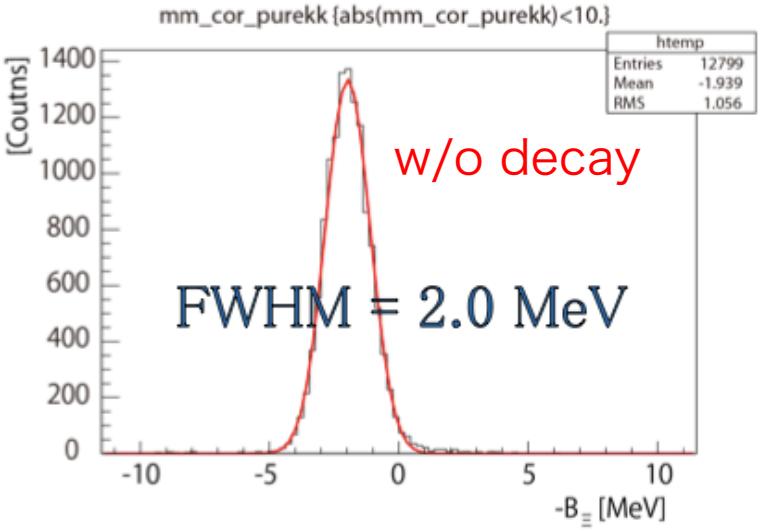


EASIROC: Multi-channel Readout Module

Event-by-event correction



Simulation of 10g/cm-thick fiber bundles
Correction using total Eloss without distinguish the decay particle result in making long and large tail in the low mass side.



Energy Resolution

Missing-mass Resolution

$$\Delta M^2 = \underbrace{\left(\frac{\partial M}{\partial p_B}\right)^2 \Delta p_B^2}_{\text{Beam } K^-} + \underbrace{\left(\frac{\partial M}{\partial p_S}\right)^2 \Delta p_S^2}_{\text{Scat. } K^+} + \underbrace{\left(\frac{\partial M}{\partial \theta}\right)^2 \Delta \theta^2}_{\text{Angular}} + \underbrace{\Delta E_{\text{strag.}}^2}_{\text{Energy loss straggling}}$$

unit : MeV

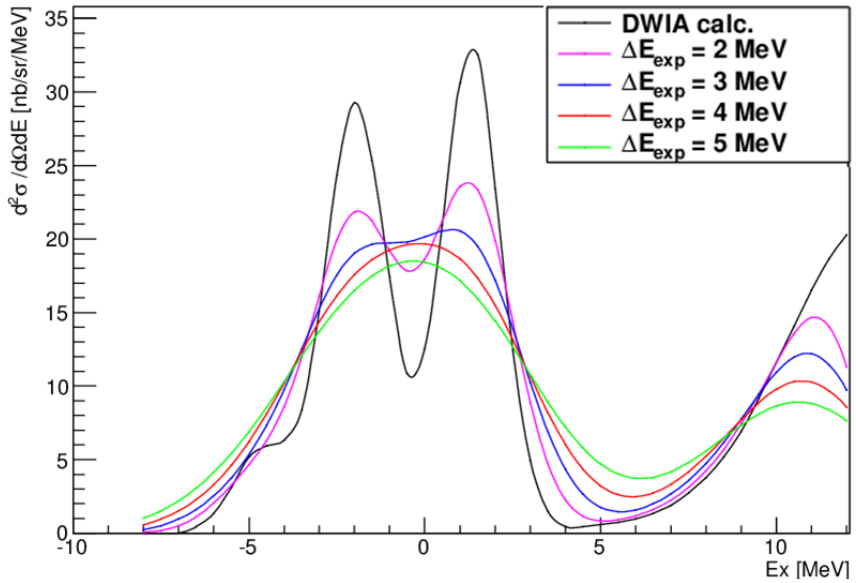
	Beam	Scat	θ	ΔM
Case 1	0.84	0.62	0.04	1.0
Case 2	1.67			1.8

- Assumption
  - Case 1: good spectrometer resolution (dp/p = 5×10^{-4} for both Beam and S-2S)
  - Case 2: current performance of beam spectrometer (dp/p = 1×10^{-3})

- $\Delta E_{\text{strag.}}$ should be <0.8 MeV_{FWHM} in case 2 for $\Delta M<2$ MeV_{FWHM}

Expected Spectra

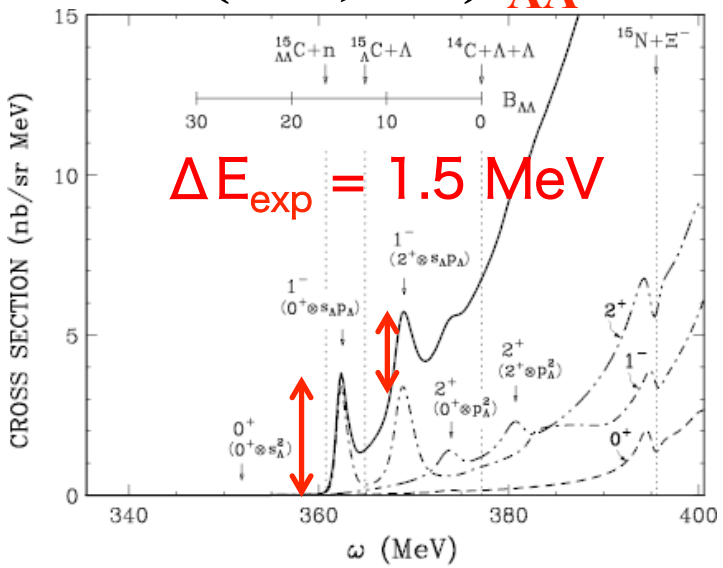
$^{12}C\ (K^-,K^+)_{\Xi}{}^{12}Be$

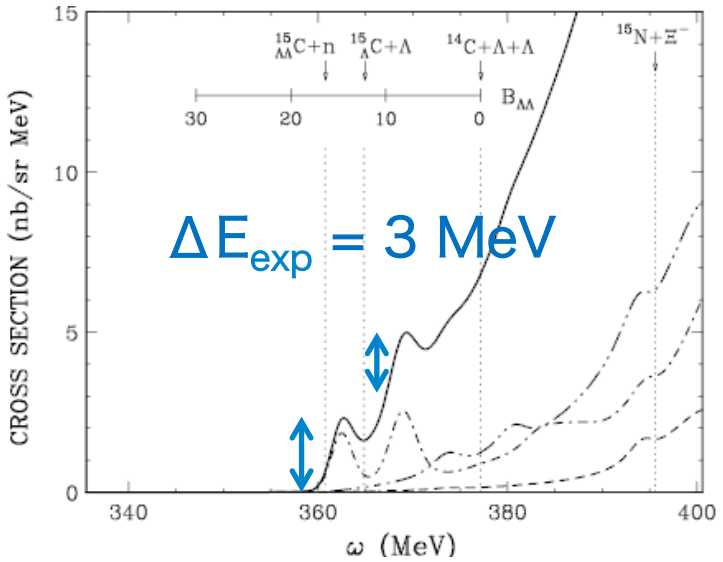


T. Motoba and S. Sugimoto, Nucl. Phys. A 835, 223 (2010)

Need 2 MeV
or further better ΔM
→ J-PARC and
new spectrometer

$^{16}O\ (K^-,K^+)_{\Lambda\Lambda}{}^{16}C$





T. Harada et al., Phys. Lett. B 690, 363 (2010)

Production Rate

	Cross section	Yield [/4weeks /1g/cm2]
$^{12}_{\Xi}$Be	89±14 nb/sr (ref.1)	37 counts
$^{12}_{\Lambda\Lambda}$Be	5-7 nb/sr (ref.2)	3 counts

- K^- intensity = 1M/4s, (Acc. Power ~80kW in 2018?)
- ref1. BNL-E885 exp. : P. Khaustov, et al., PRC 60, 054603 (2000),
- ref2. T. Harada, et al., PLB 690, 363 (2010)

- Target thickness
  - >10 g/cm^2 is desirable to achieve good statistics within reasonable run time at J-PARC

→ Energy loss straggling >4 MeV$_{FWHM}$

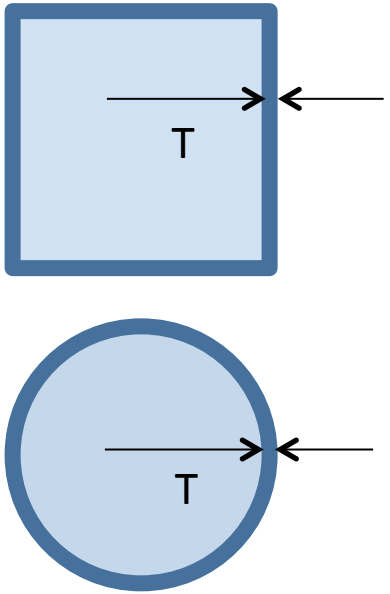
→ Can't perform high-resolution spectroscopy

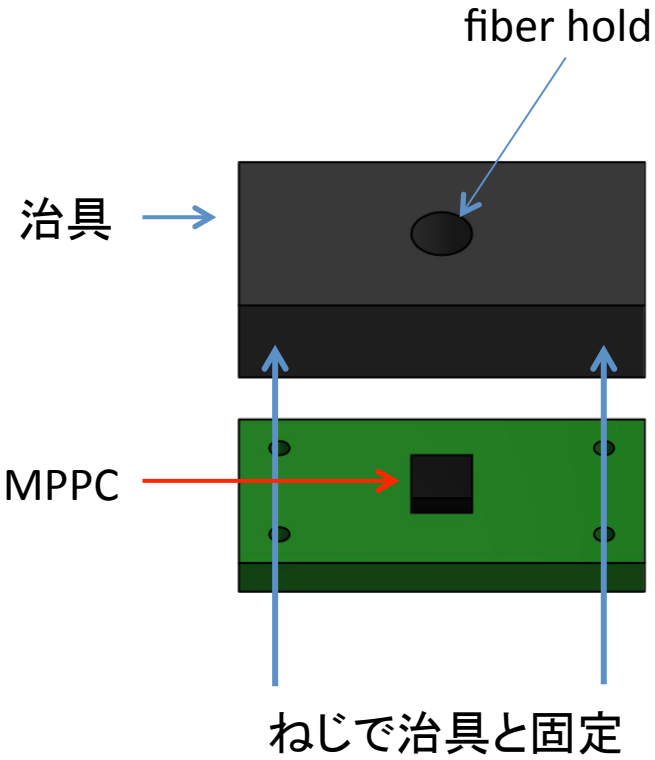
Scintillating Fiber and MPPC

Fiber: Material

- Core: Polystyrene(CH) (1.05 g/cm^3)
- Cladding: Acrylic (1.18 g/cm^3)

Clad thickness T: 2% of fiber size





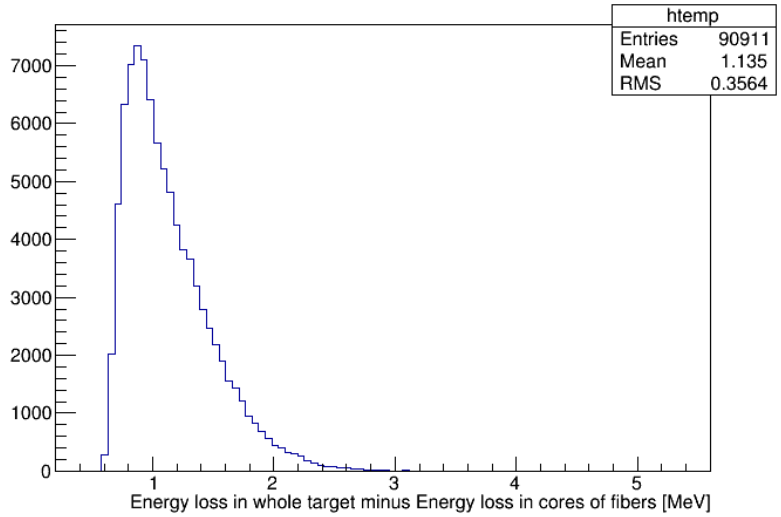
MPPC

- HAMAMATSU S13360-3075PE
- Photosensitive area: 3mm×3mm
- Gain 1.7×10^6
- Air contact to fiber

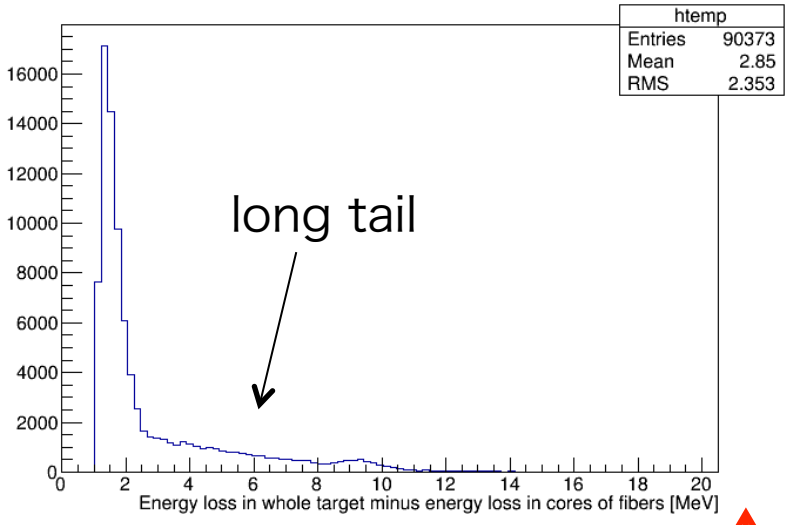
Eloss in Crad (all)

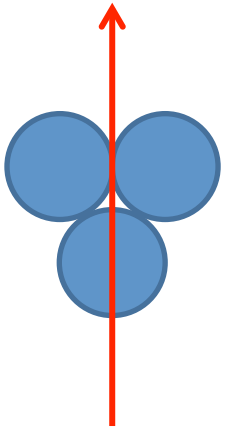
- Simulation for 36 layers
- Eloss(all) – Eloss(core)

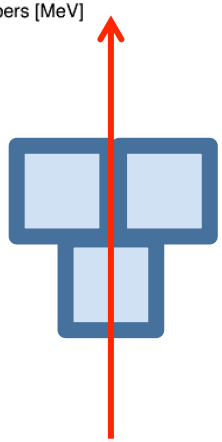
Round type



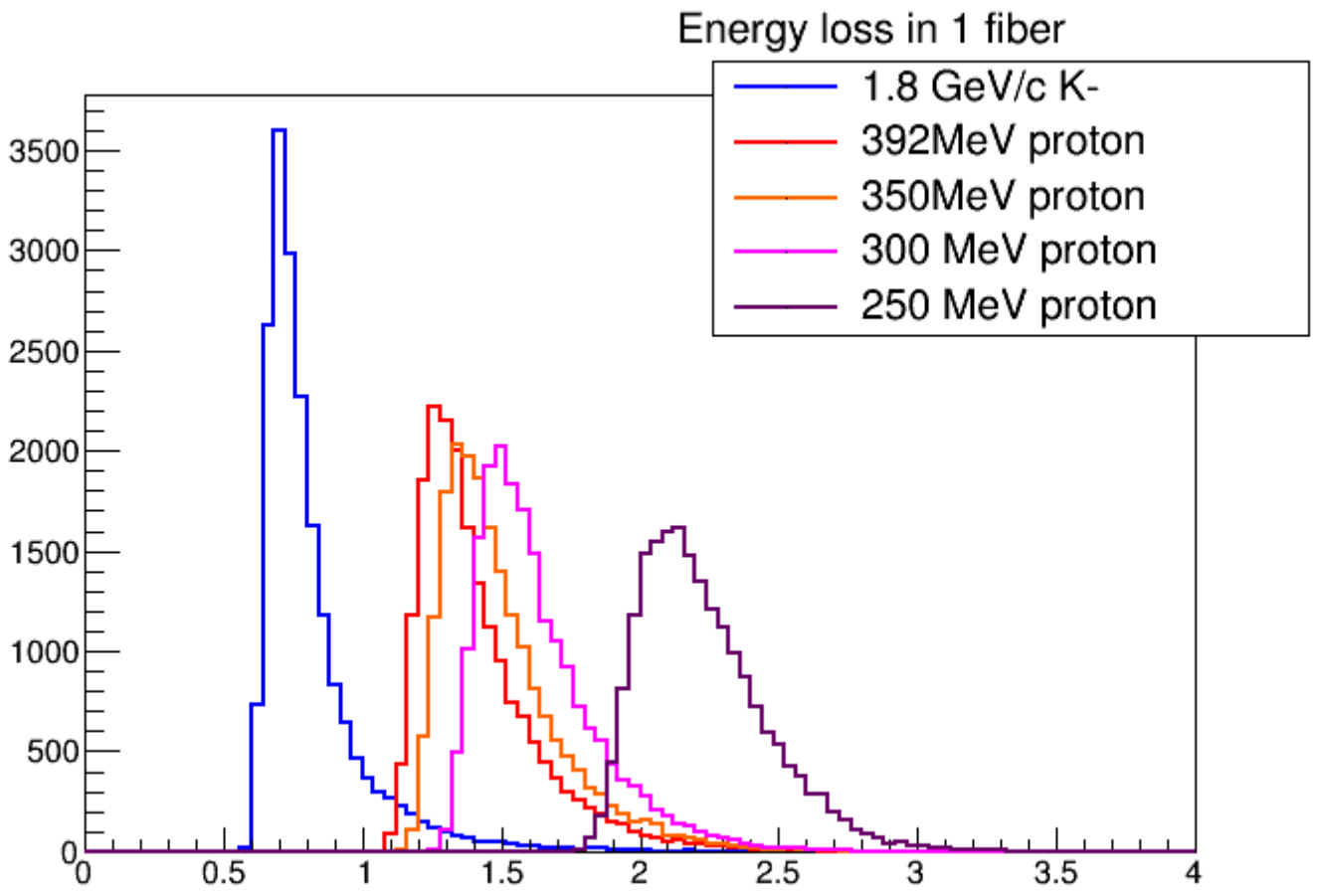
Square type







Energy loss in 1 fiber



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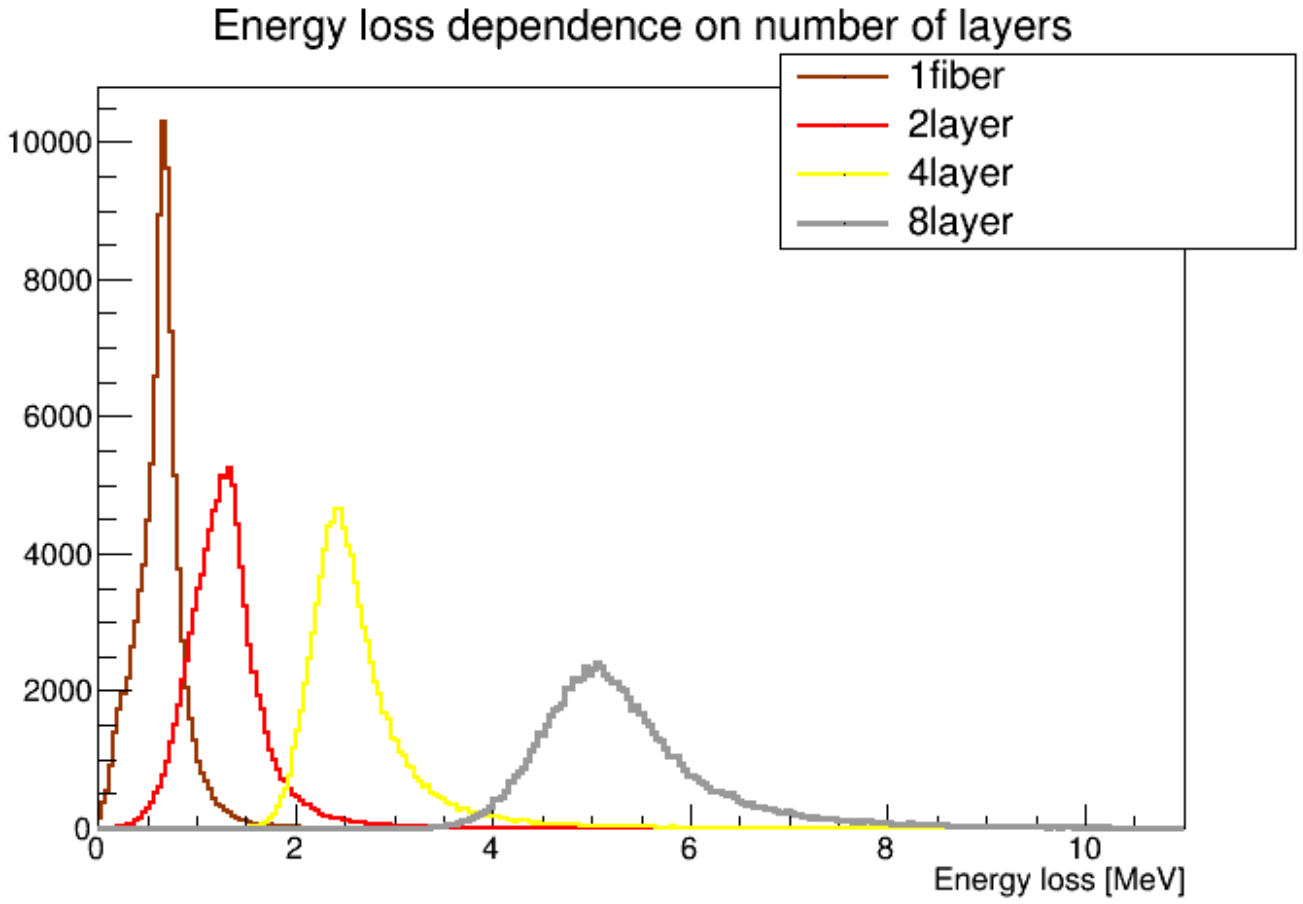
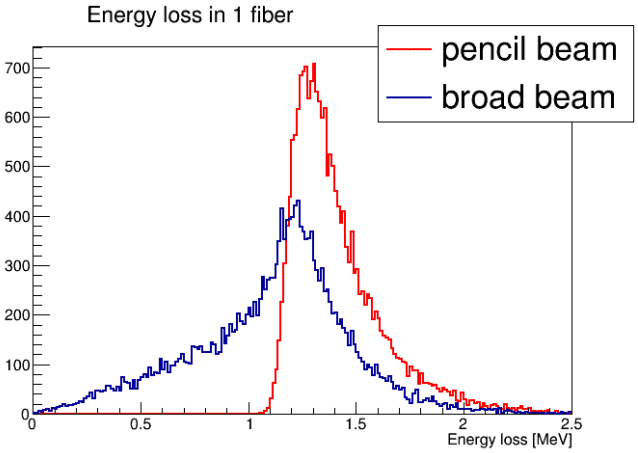
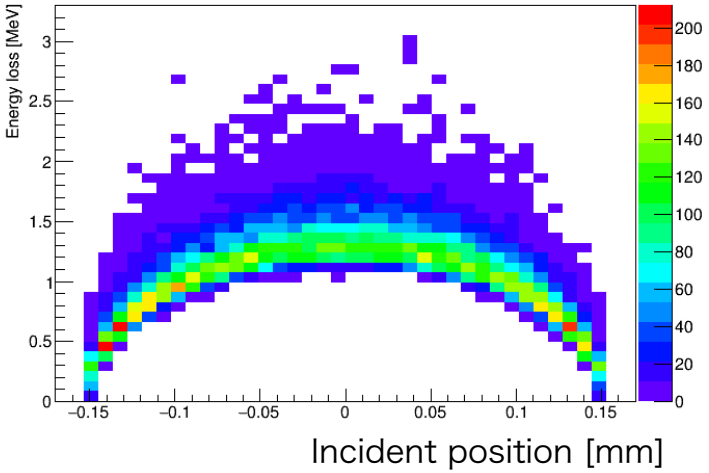


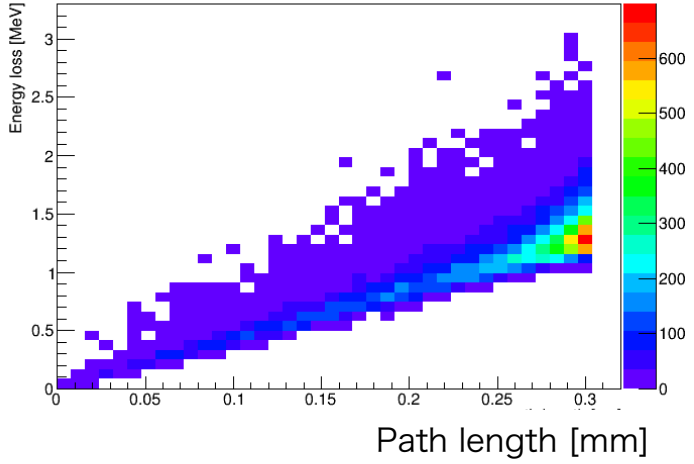
Position Dependence

- 中心だけに当てた時との比較



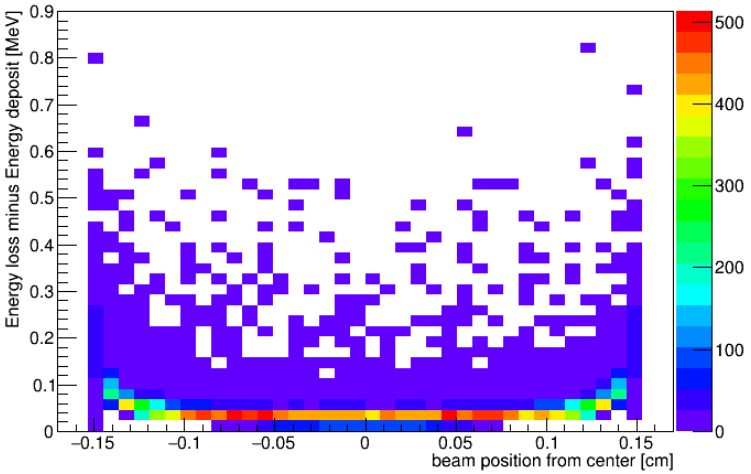
- 位置依存性

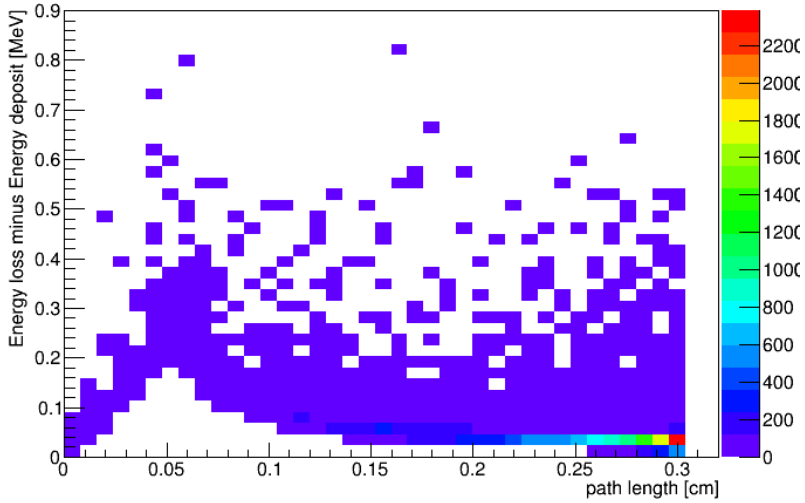




クラッドの効果の位置依存性(p)

- Energy loss – Energy deposit





- (Energy loss – Energy deposit) /Energy loss