Sampling calorimeter to measure the photon's incident angle

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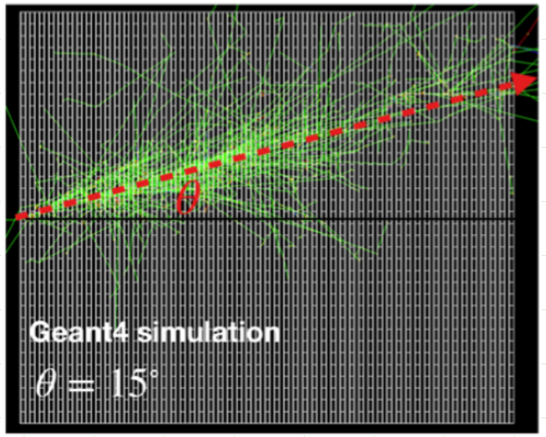
IPNS/KEK

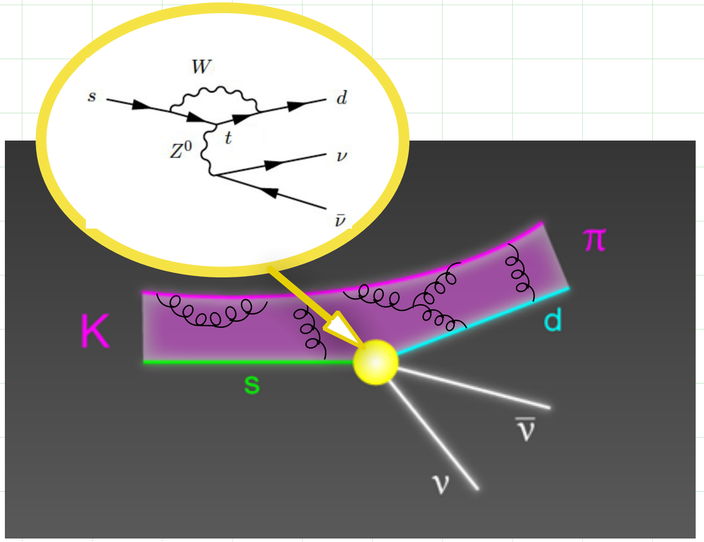
CALOR2024, 24th May 2024

Photon Angle Sampling calorimeter

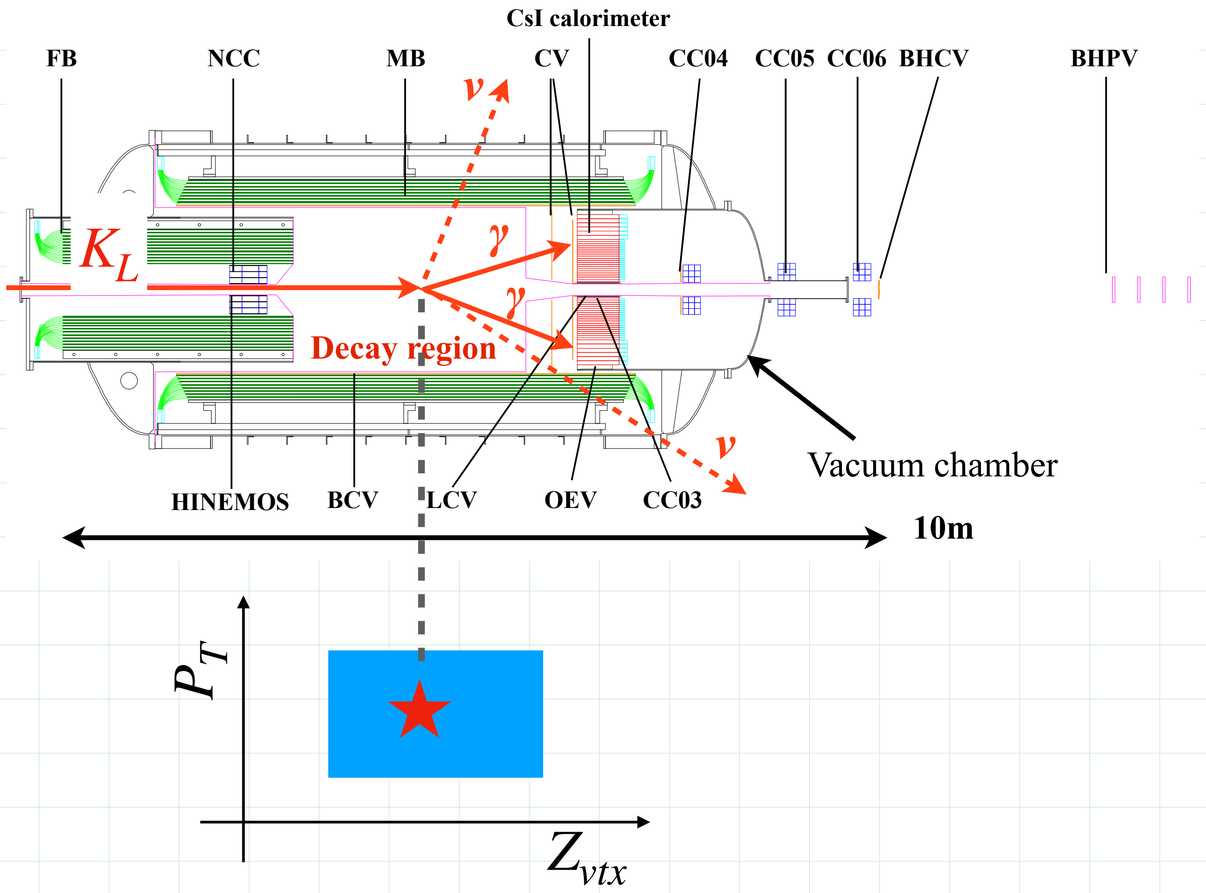
- A sampling calorimeter to measure an incident angle of photon
  - Detailed measurement of shower profile



- KOTO
  - Measurement of Br($K_L \to \pi^0 \nu\bar{\nu}$) performing at J-PARC
  - Highly suppressed process expected to be 3×10^{-11}
  - Exceptionally small theoretical uncertainty
  - Accessible to the high energy scale O(100TeV)



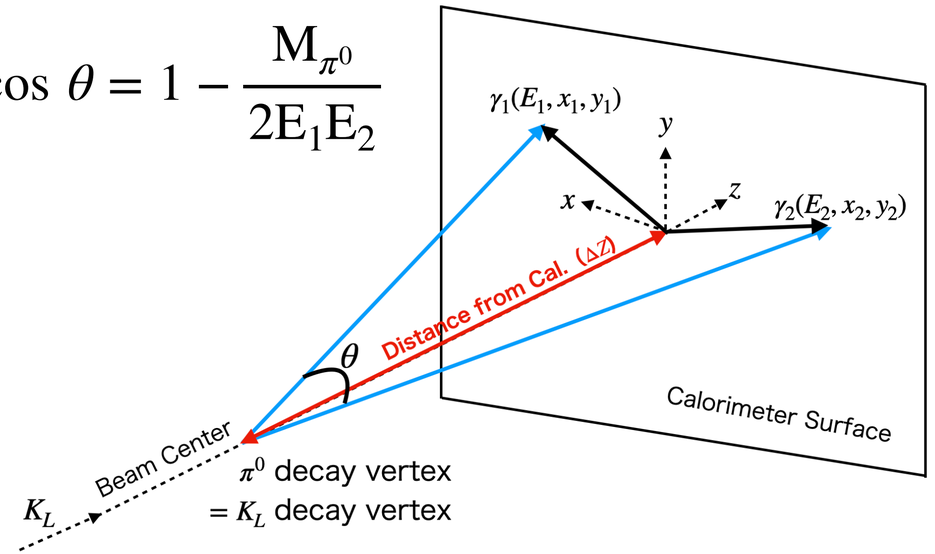
Event reconstruction



$$K_L \rightarrow \pi^0 \nu\bar{\nu}$$

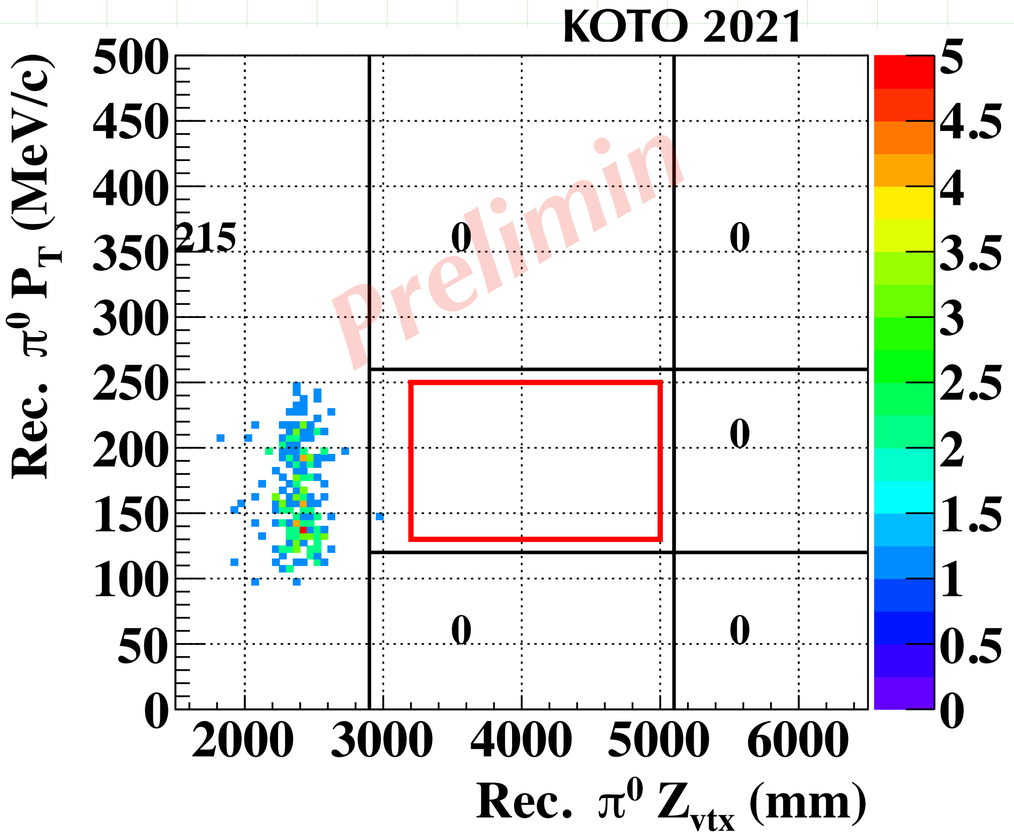
2γ + Nothing

$$\cos\theta = 1 - \frac{M_{\pi^0}}{2E_1E_2}$$



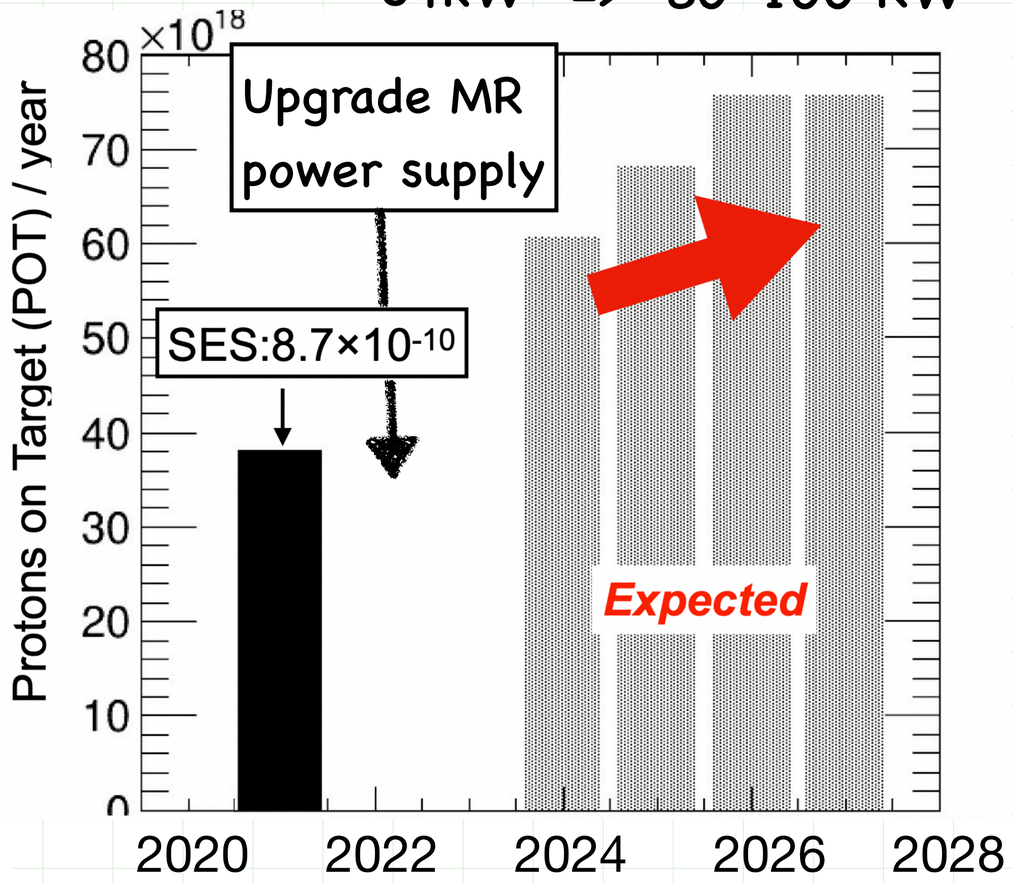
With an assumption of π^0 decay on the beam axis

Current status and expectation



Single Event Sensitivity: 8.7×10^{-10}

64kW => 80-100 KW



Aiming to improve the S.E.S. < 10^{-10}

Hadron Experimental Facility Extension

Expand research programs at the Hadron Experimental Facility to explore Origin & Evolution of Matter more deeply

< 1.1GeV/c K beam
Kaonic nuclei

< 2GeV/c K beam
Ξ hypernuclei

K^0_L beam
$K^0_L \to \pi^0\nu\bar{\nu}$

30GeV p beam
hadron physics

μ beam
μ→e conversion

Present

Extended

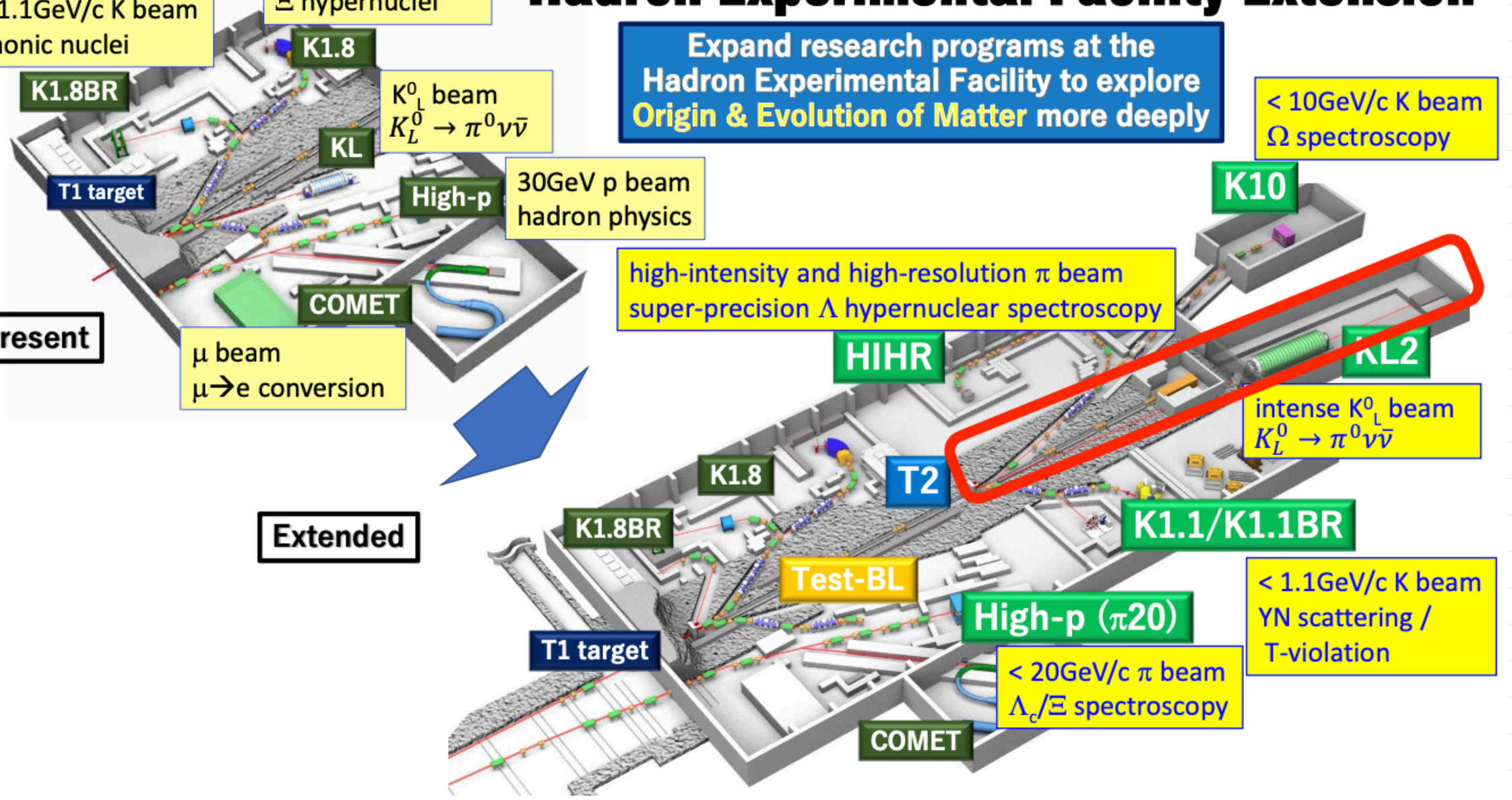
< 10GeV/c K beam
Ω spectroscopy

high-intensity and high-resolution π beam
super-precision Λ hypernuclear spectroscopy

intense K^0_L beam
$K^0_L \to \pi^0\nu\bar{\nu}$

< 1.1GeV/c K beam
YN scattering /
T-violation

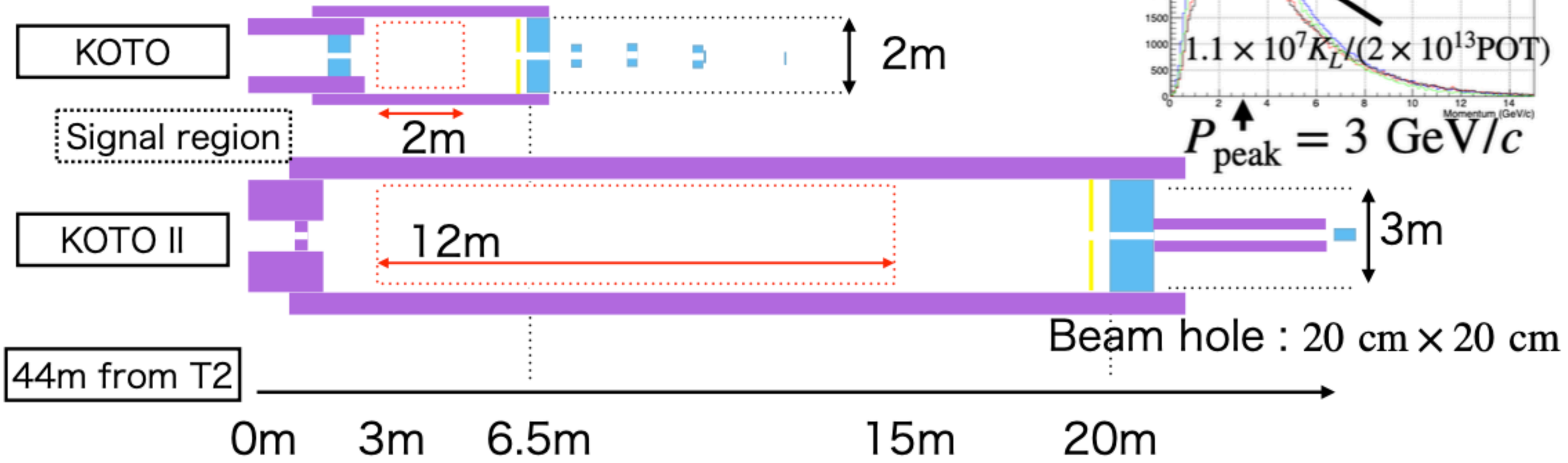
< 20GeV/c π beam
Λ_c/Ξ spectroscopy

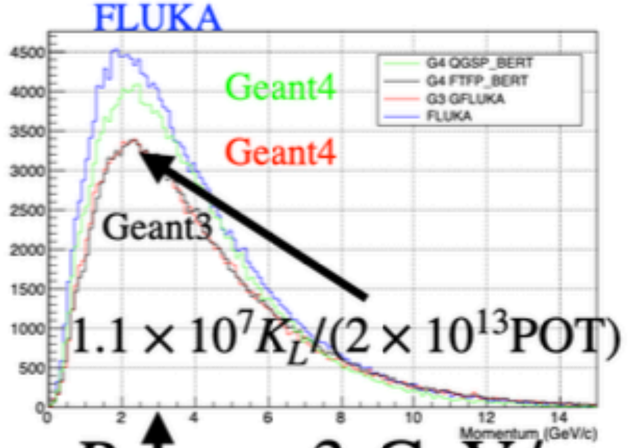


Peak K_L momentum : 1.4 GeV/c (KOTO) → 3 GeV/c (KOTO II)

Possible to use longer decay volume (2 m → 12 m)

Larger diameter calorimeter (2 m → 3 m)



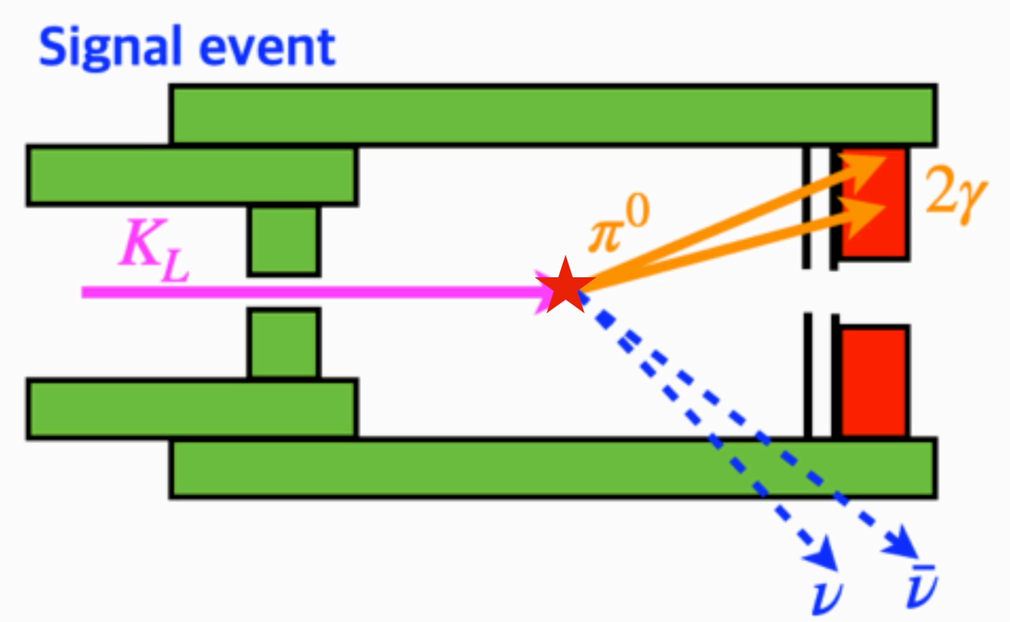


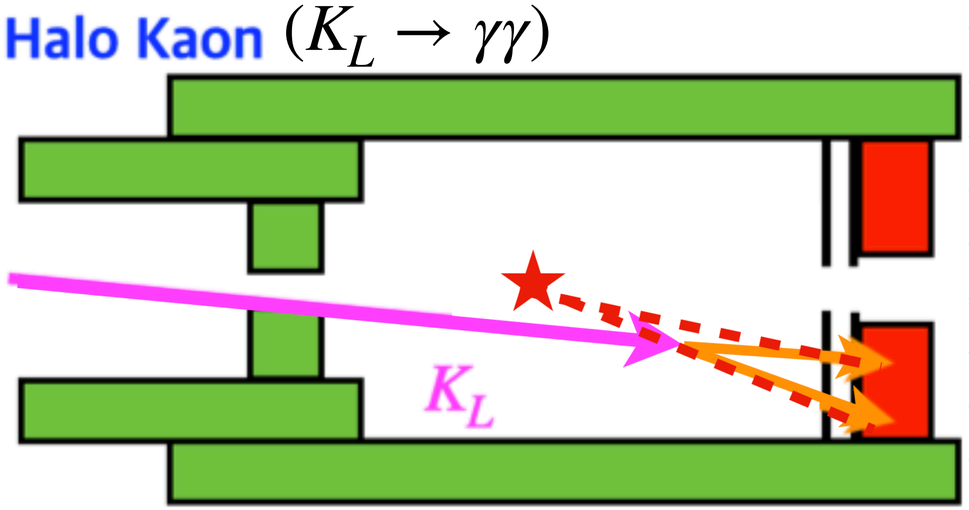
$P_{\mathrm{peak}} = 3\ \mathrm{GeV}/c$

H. Nanjo @ HEF-ex 2024

3X10⁷s data taking with 100 kW Beam: 35 SM event (S/B=0.9)

Off-axis decay



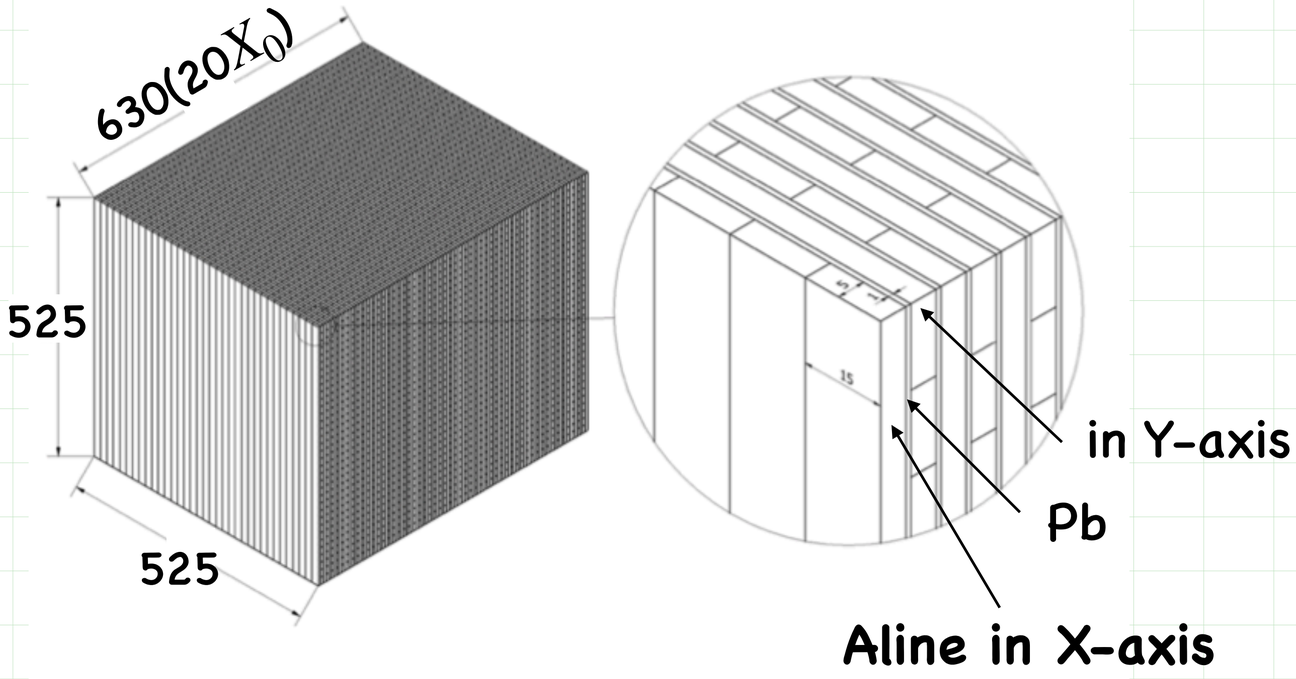


Halo Kaon: Small fraction of KL scattered at the beamline and entered the detector apart from the beam axis

We can require the consistency of the decay vertex from energy measurement and angle measurement

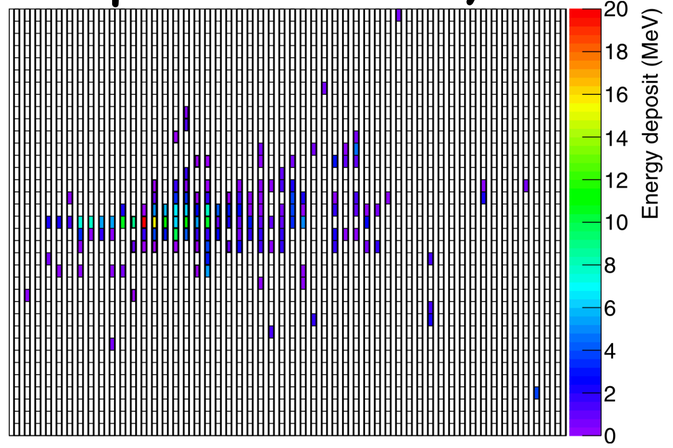
Detector setup for the study

Pb(1mm)+Scin.(5mm)



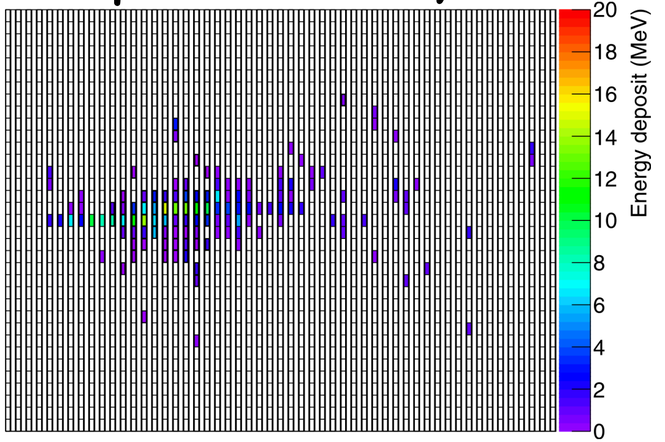
YZ plane - Even layers

1GeV γ →



XZ plane - odd layers

1GeV γ →



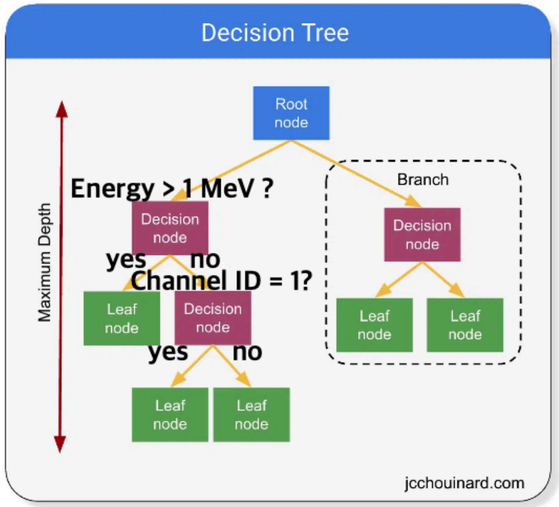
GEANT4 simulates the energy deposit in each module

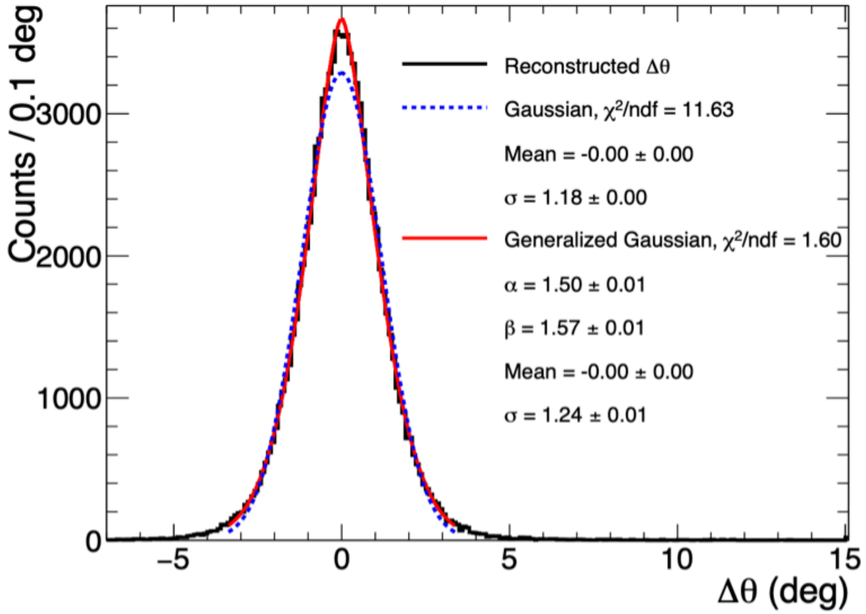
For training: $0 < \phi < 2\pi$, $0 < \theta < 50^0$

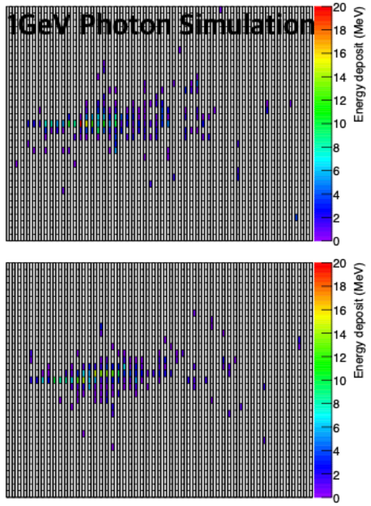
For testing: $0 < \phi < 2\pi$, given θ

Angle reconstruction

- eXtreme Gradient Boosting (**XGBoost**)
  - Boosting (Decision tree)
  - High performance and fast training







E_i (feature)

XGBoost

p_x/p_z, p_y/p_z (target)

Training sample: features, target

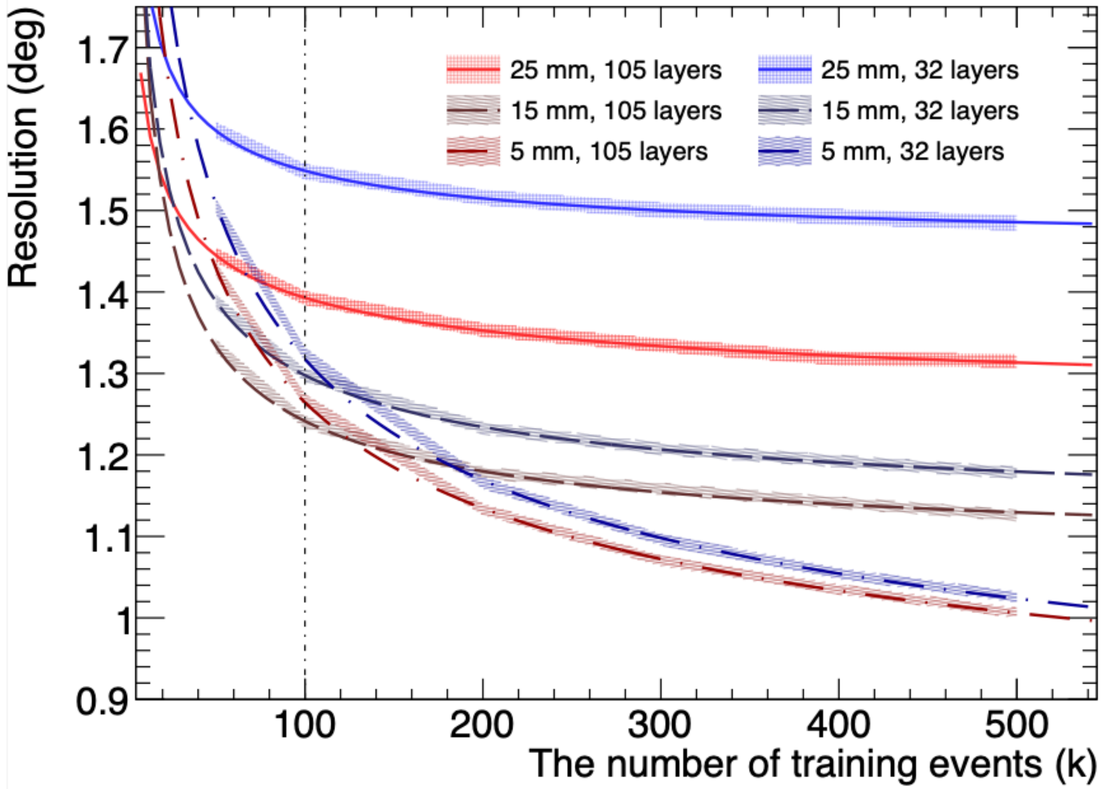
Test sample: features

$$f(x;\mu,\alpha,\beta) = \frac{\beta}{2\alpha\Gamma(1/\beta)} e^{-(|x-\mu|/\alpha)|^\beta}$$

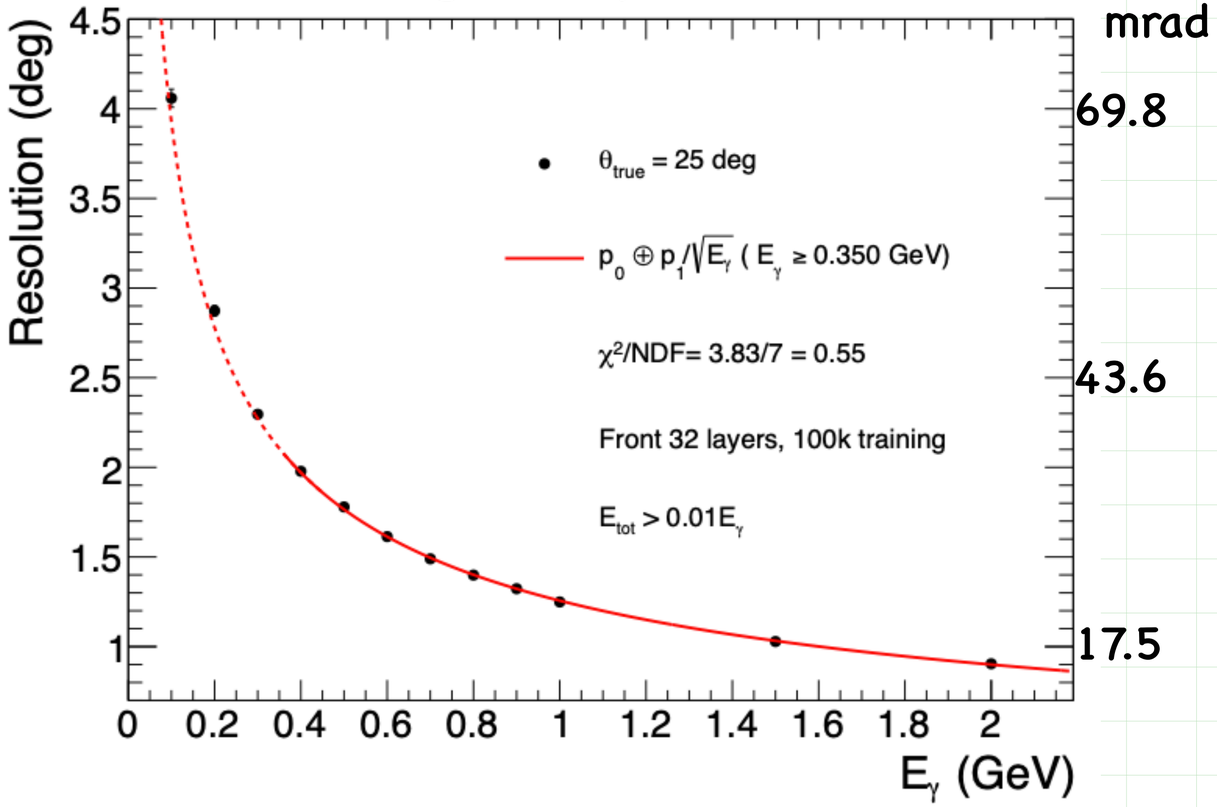
$$\sigma = \alpha\sqrt{\frac{\Gamma(3/\beta)}{\Gamma(1/\beta)}}$$

Angular Resolution

Training sample statistics



Energy Dependency



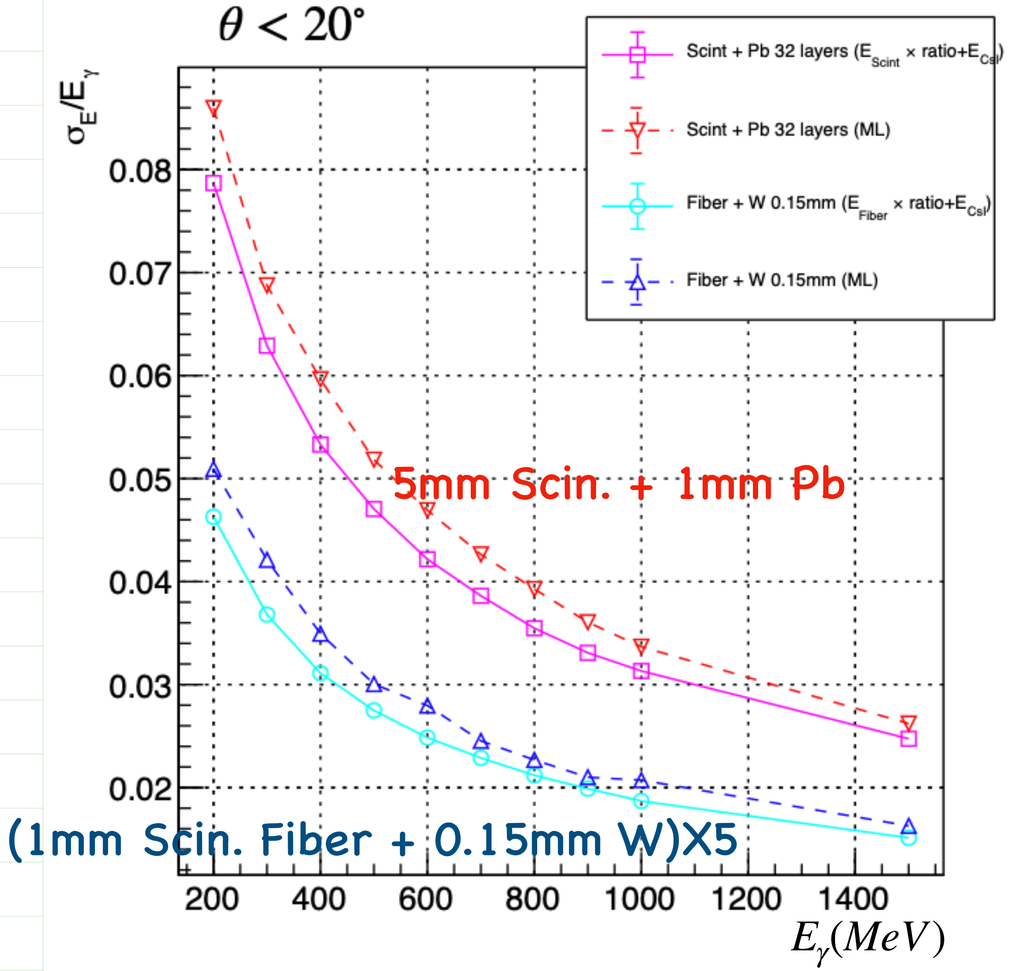
1 GeV gamma incident

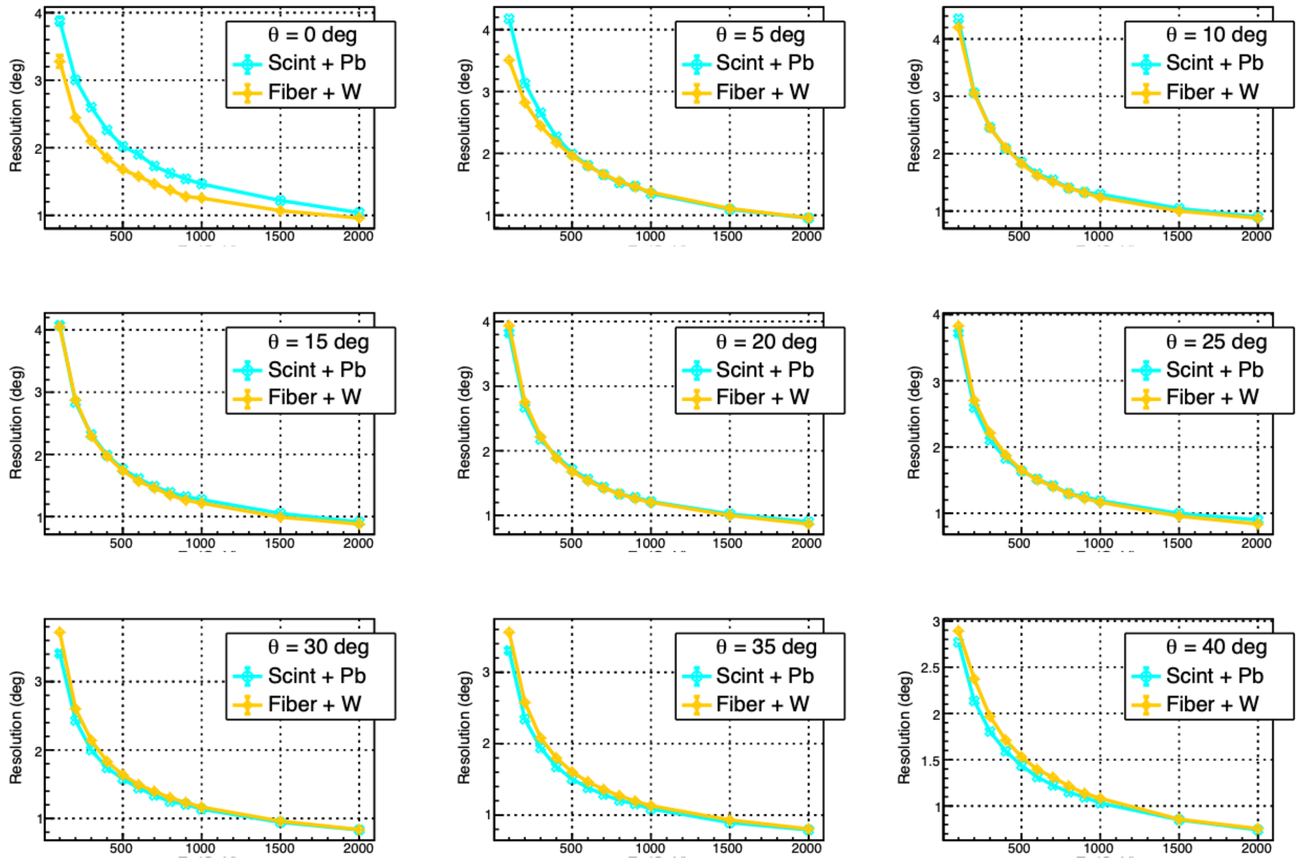
Needs more training samples for narrower strips

We need not full length for angle measurement

NIM A1052 (2023) 168261

W-Fiber Configuration



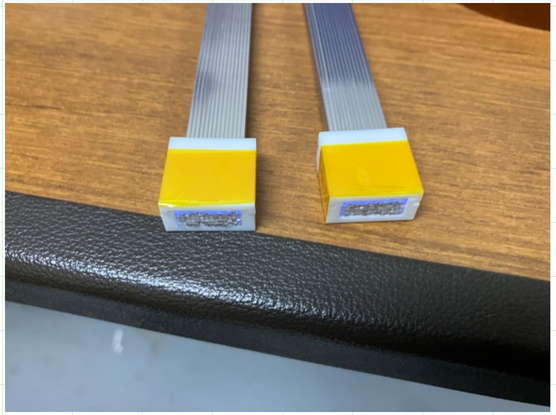


The thinner the layers, the better the energy resolution

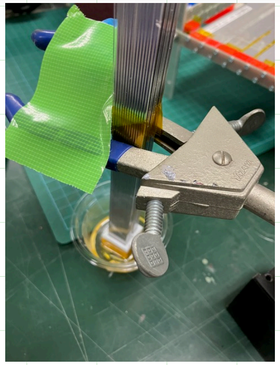
No significant change in angular resolution

Module fabrication

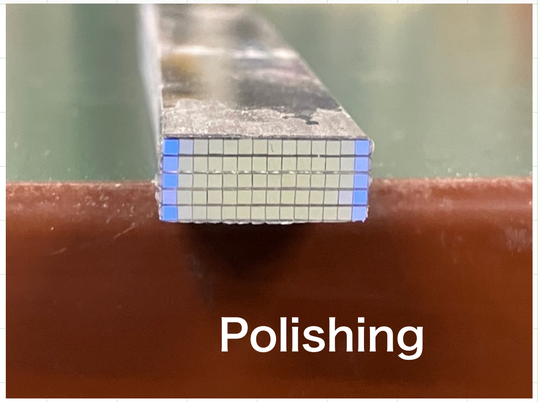
1mm sq Scin. Fiber (14)
and 0.15mm W-strip

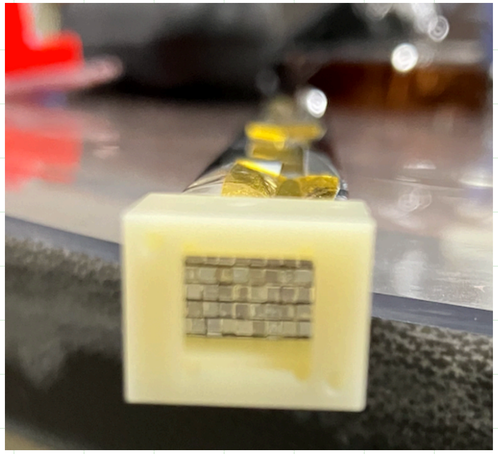


Accumulate 5 sheets

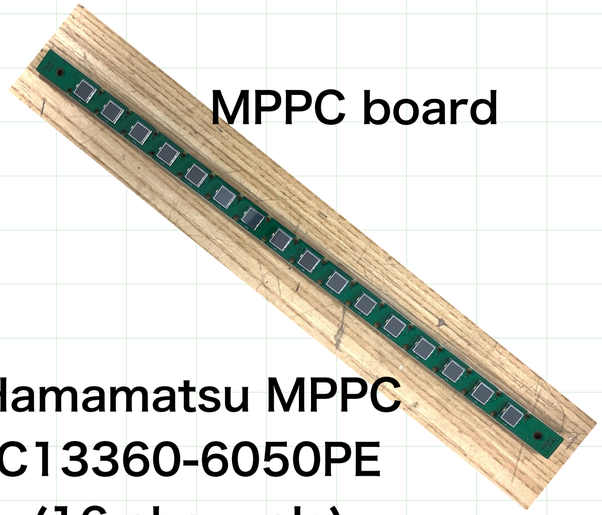


Gluing

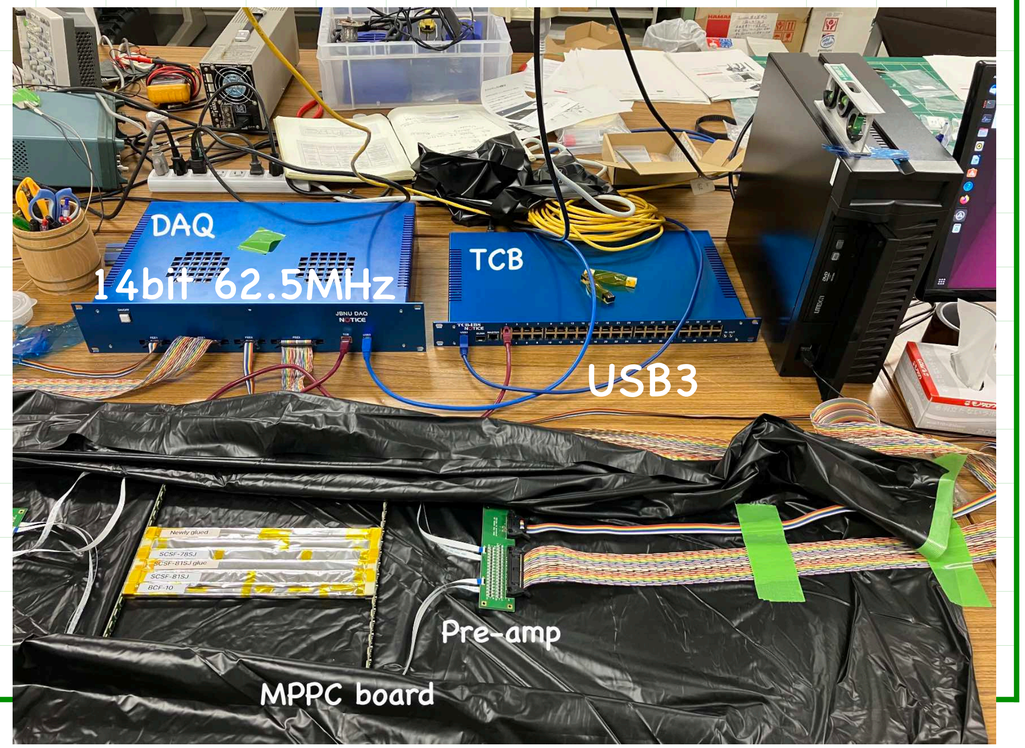




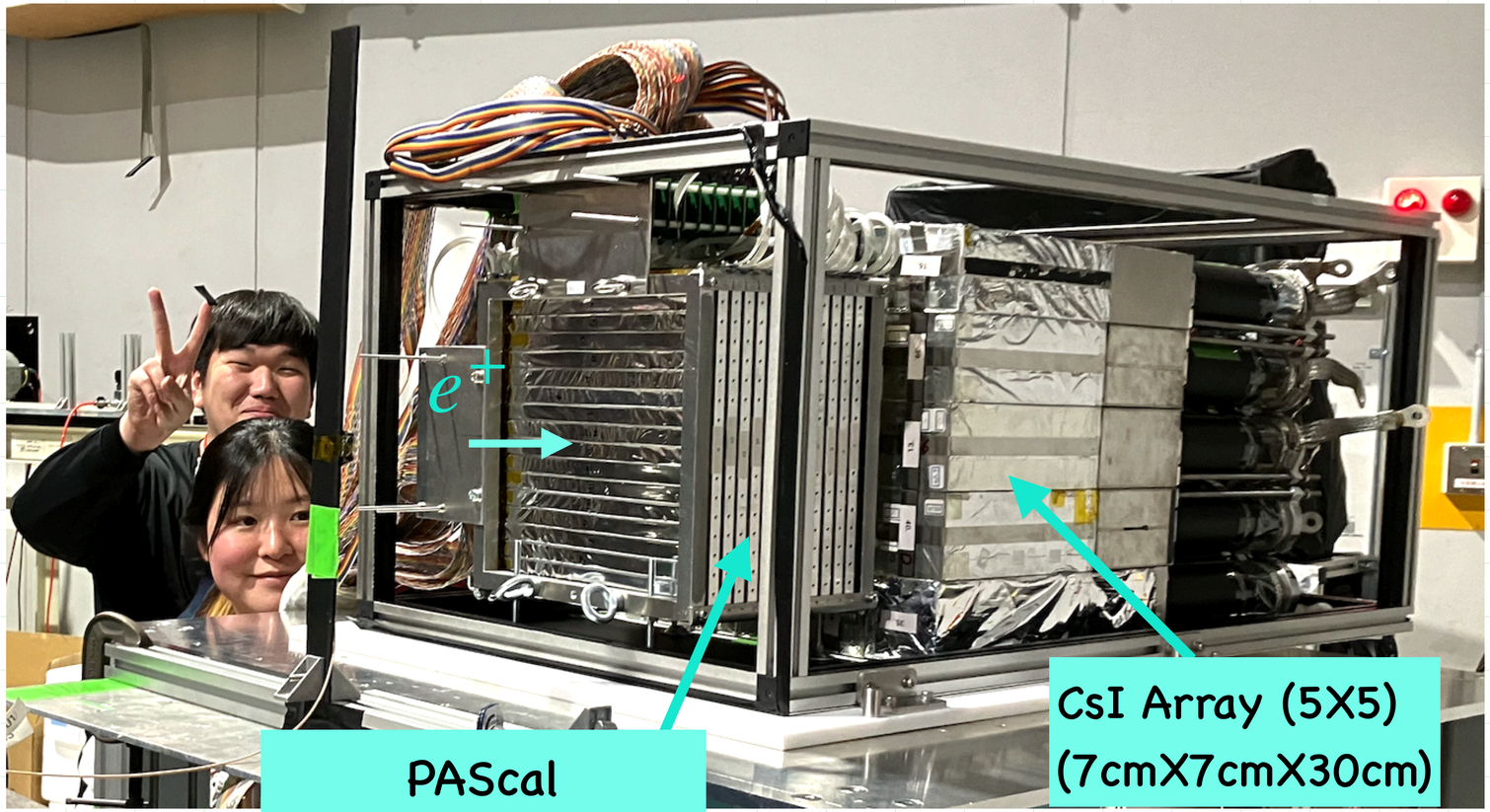
Attach light guide
for SiPM read-out



Hamamatsu MPPC
C13360-6050PE
(16 channels)



Test with positron beam



Research Center for ELectron PHoton Science (ELPH), Tohoku University @Sendai city

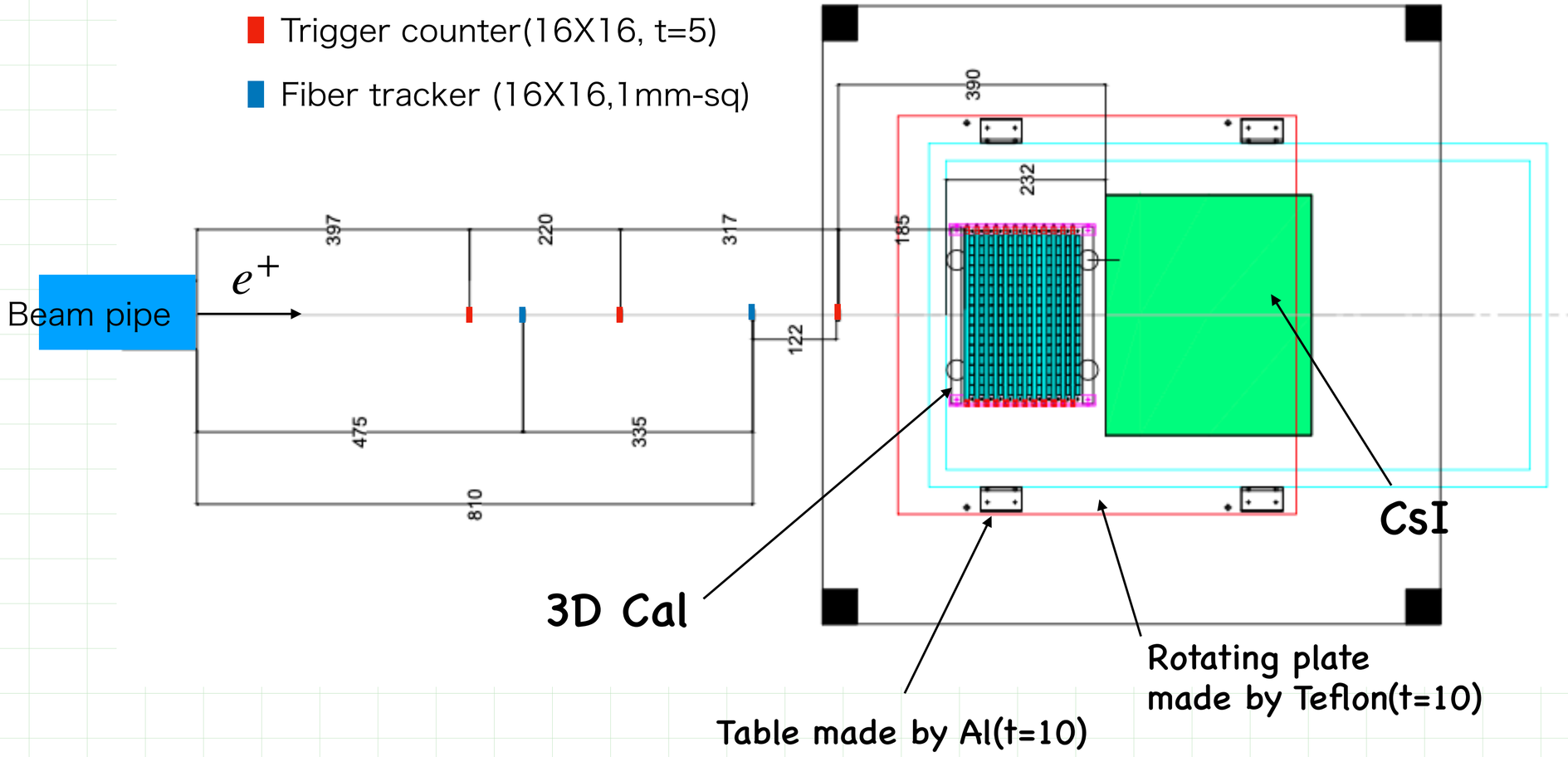
1.3 GeV Electron synchrotron

Available 0.1~0.8 GeV/c $e^{\pm}$

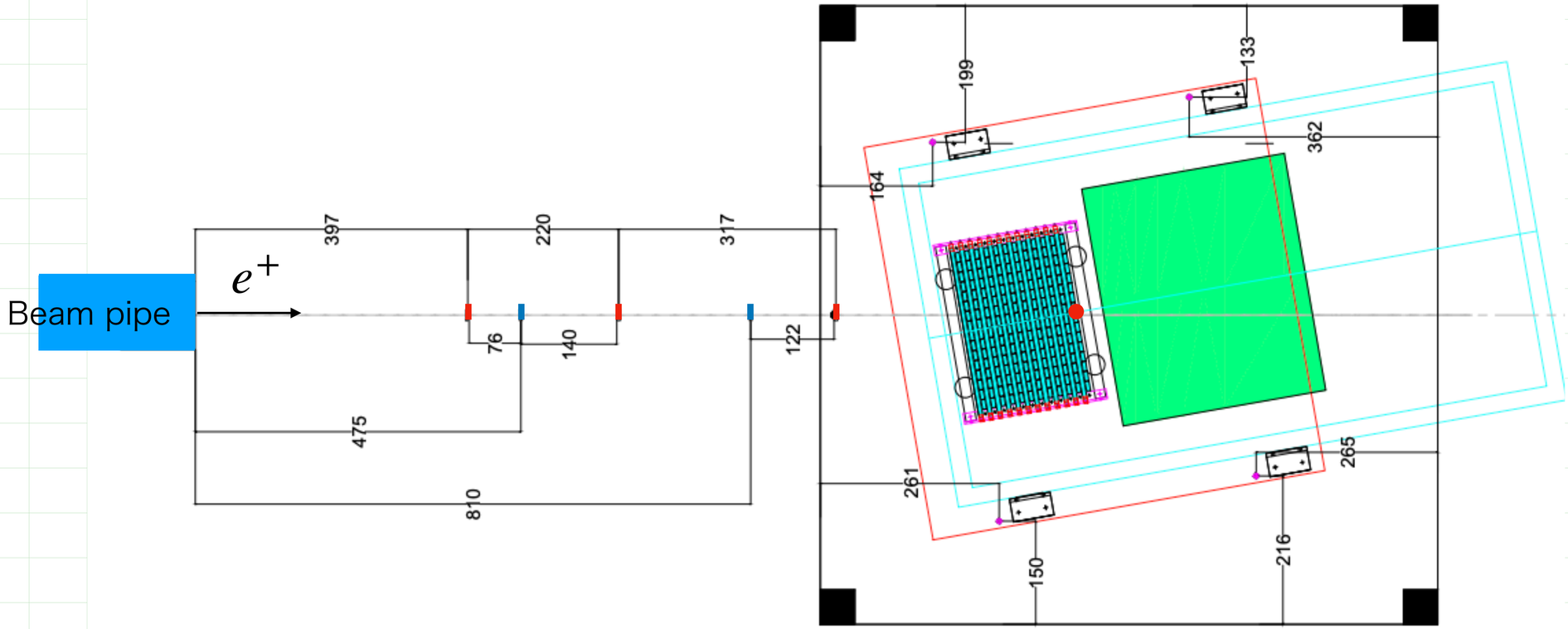
200 MeV/c: 0, 20 degrees
400 MeV/c: 0, 10, 20 degrees
600 MeV/c: 0, 10, 20, 30 degrees
800 MeV/c: 0, 10, 20, 30 degrees

100~200k events for each setup

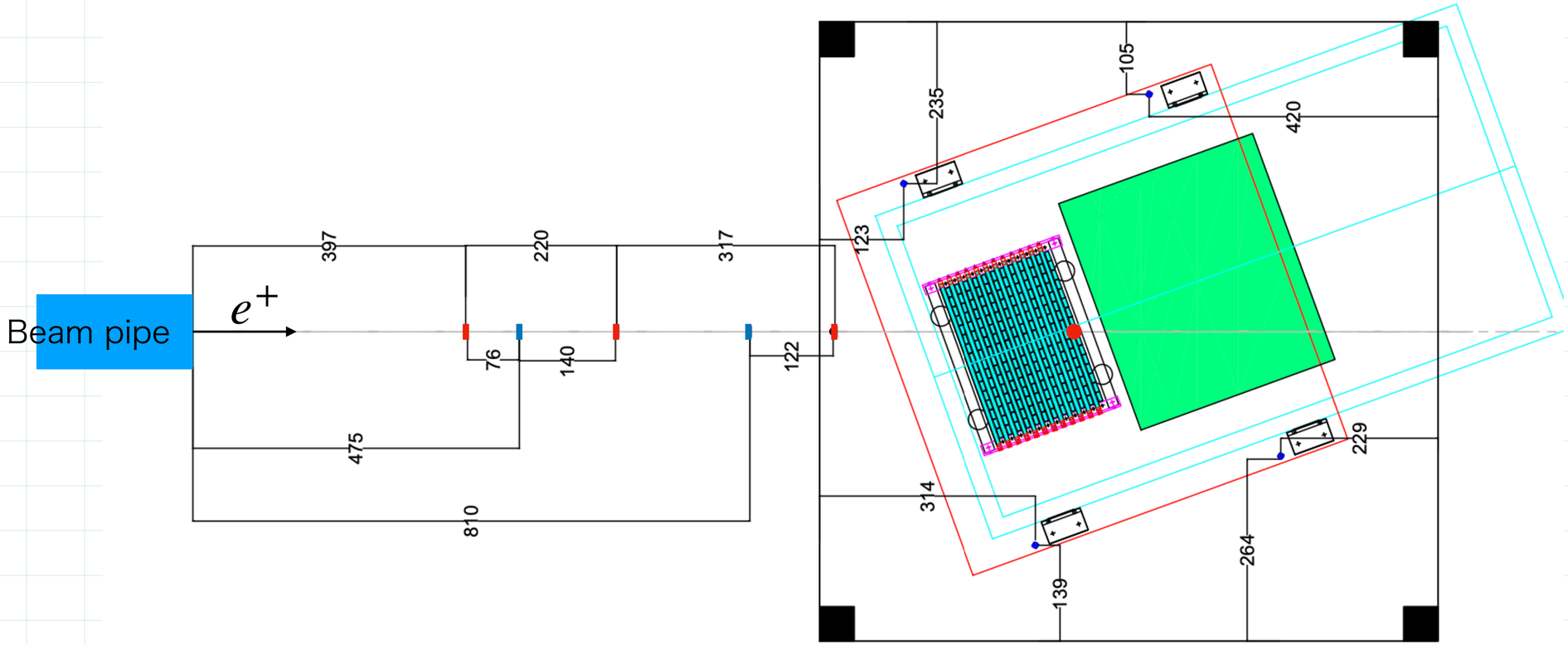
Performance test



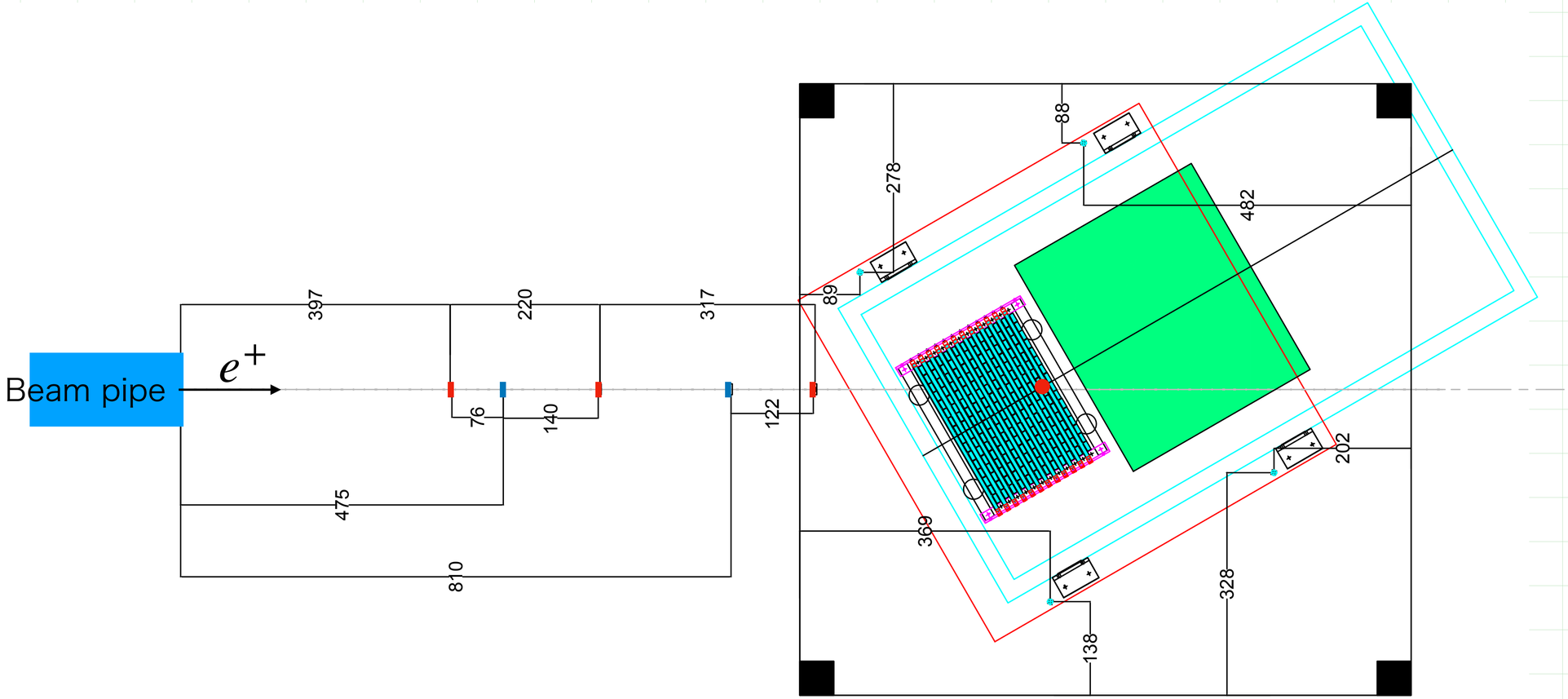
Performance test



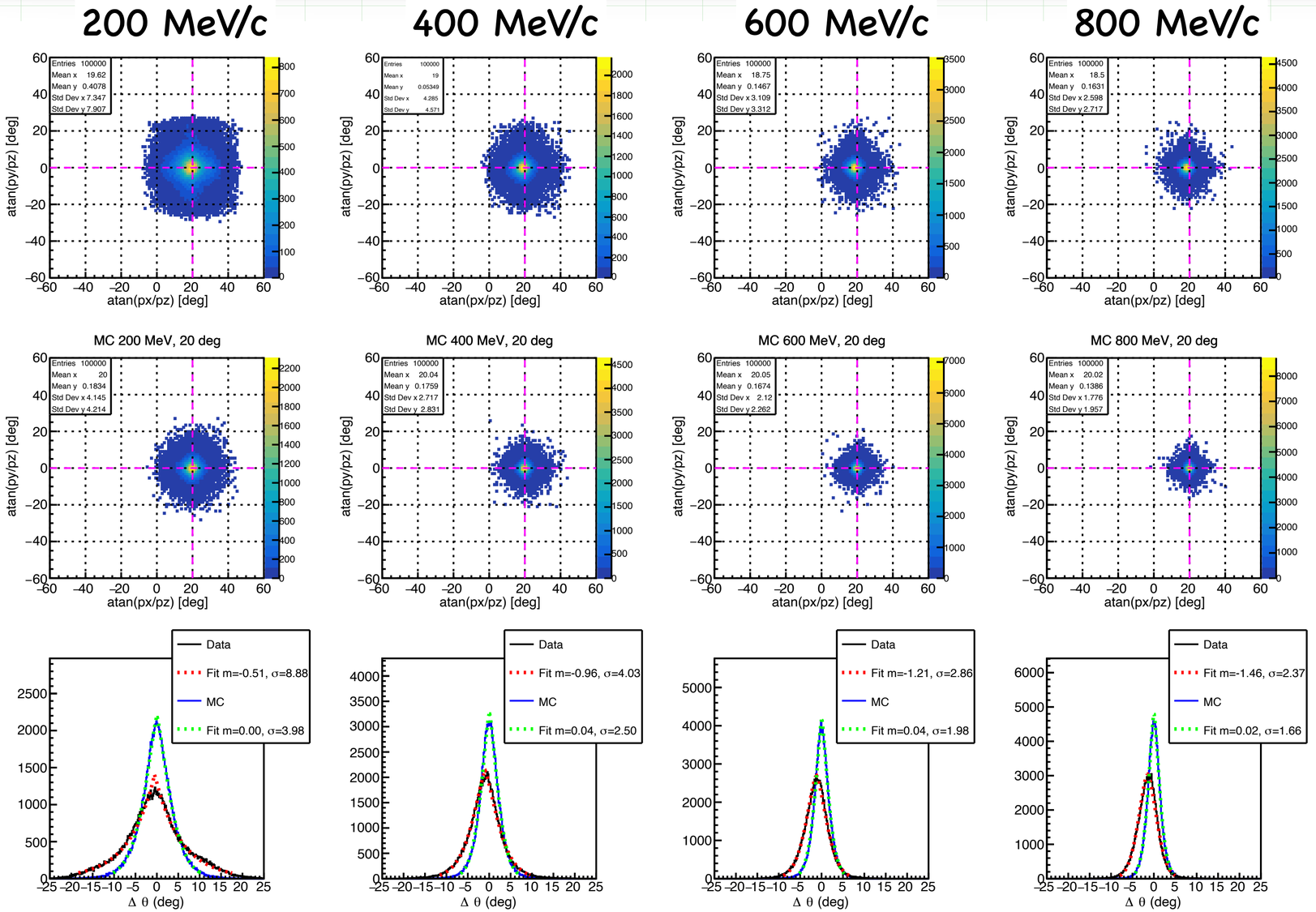
Performance test



Performance test



First glance (energy)



Incident angle: 20 degrees

Angular resolution(degrees)

- Snapshot -

	M.C.	Data
200 MeV/c	3.98	8.88
400 MeV/c	2.50	4.03
600 MeV/c	1.98	2.86
800 MeV/c	1.66	2.37

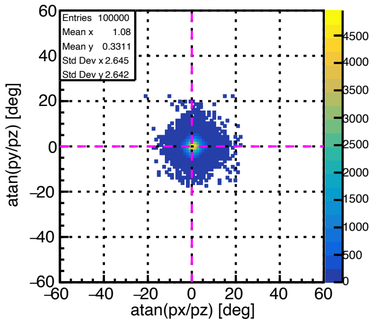
Large difference in low P

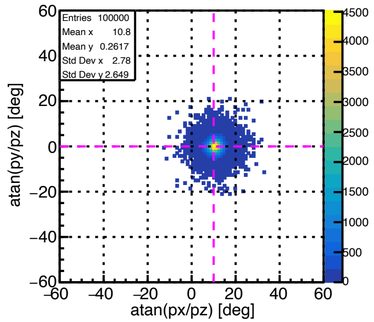
Intense study is needed

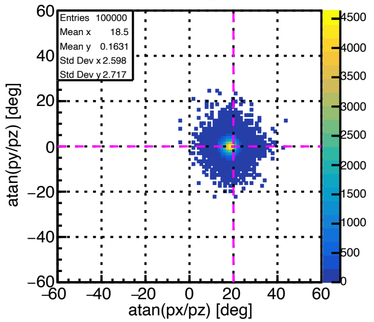
First glance (angle)

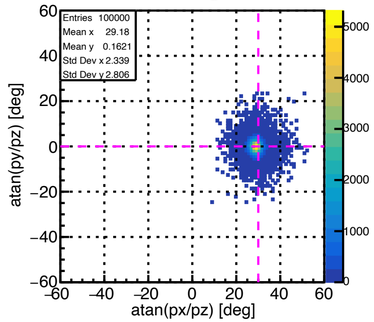
0 degree | 10 degrees | 20 degrees | 30 degrees

Data

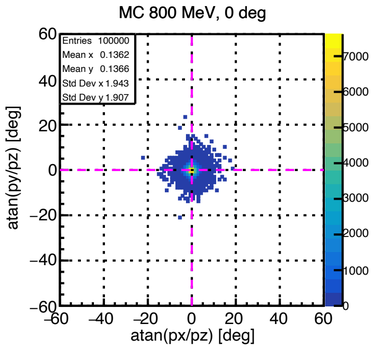


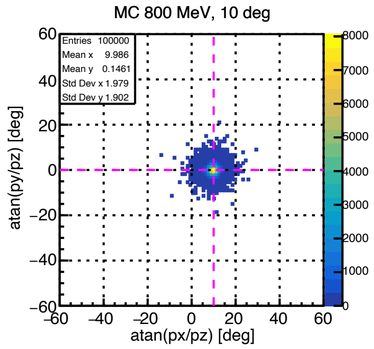


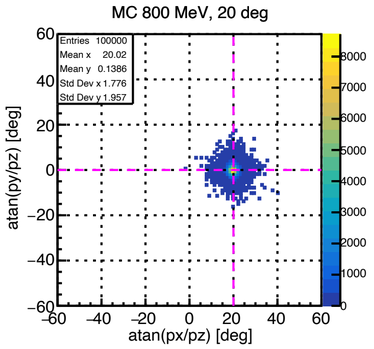


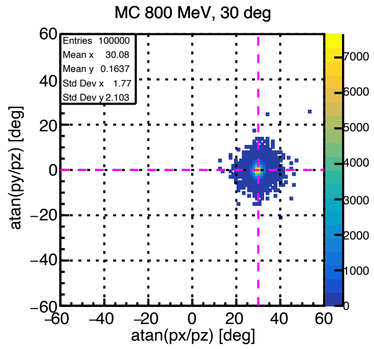


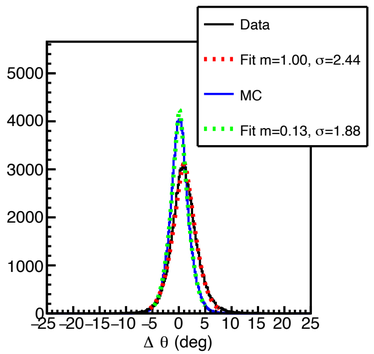
M.C.

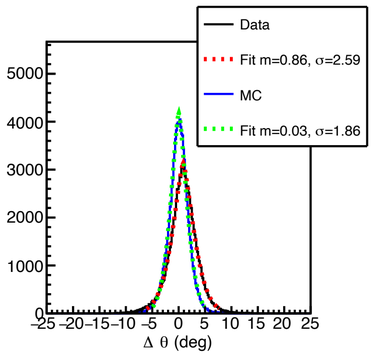


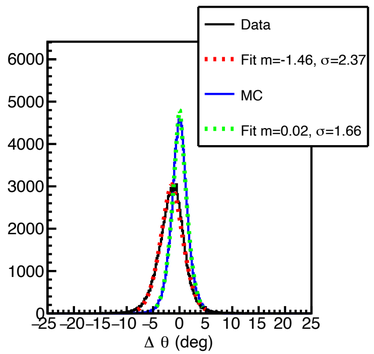


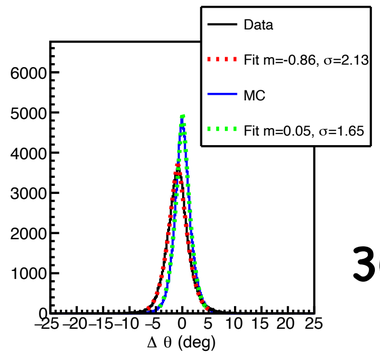












e+ momentum: 800 MeV/c

Angular resolution(degrees)

- Snapshot -

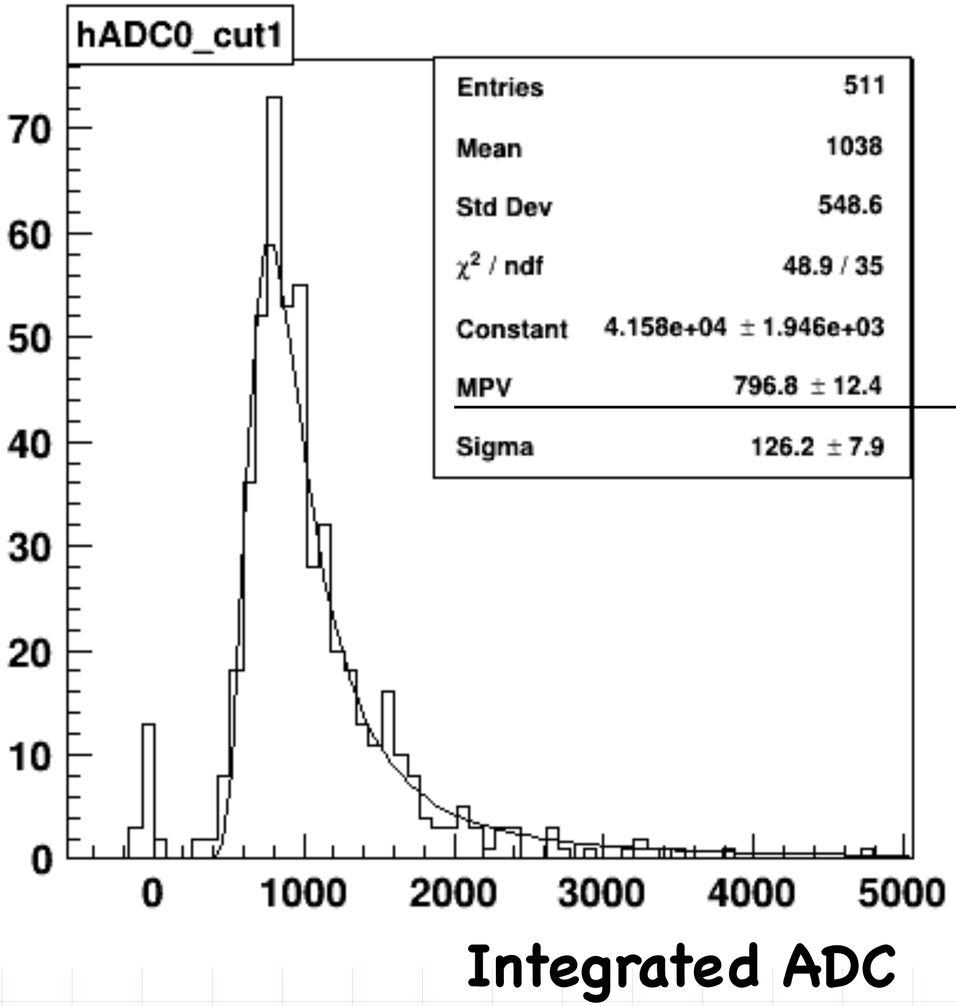
	M.C.	Data
0^0	1.86	2.44
10^0	1.88	2.59
20^0	1.66	2.37
30^0	1.65	2.13

30-40% of degradation in data

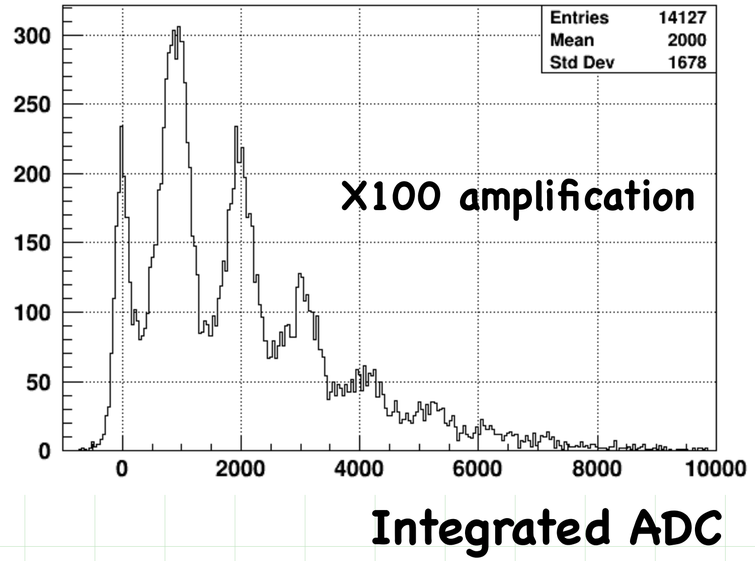
Summary

- KOTO
  - Aiming to measure the Br($K_L \to \pi^0 \nu\bar{\nu}$)
  - Promising channel to access the new physics beyond the standard model
- PAScal
  - Fine-segmented sampling calorimeter
  - XGboost for the angle reconstruction
  - Angular resolution will be given by the strip width and deepness of the training.
  - Suppress sampling fluctuation with Scintillating Fibers + W plates
- Performance test with positron beam has been performed
  - We start to analyze them

Response to the cosmic ray



~ 100 p.e./MeV



Halo KL ($K_L \to \gamma\gamma$ decay)