Performance evaluation of sampling calorimeter using segmented lead glass absorber with positron beam

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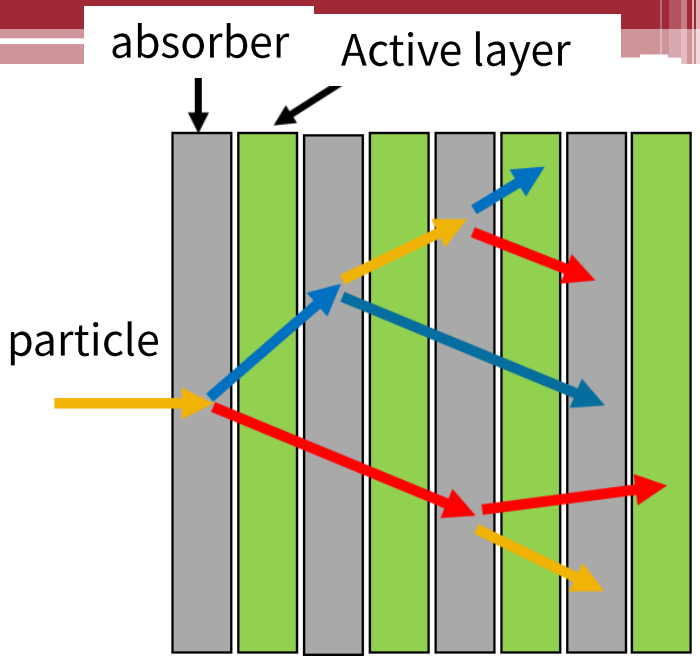
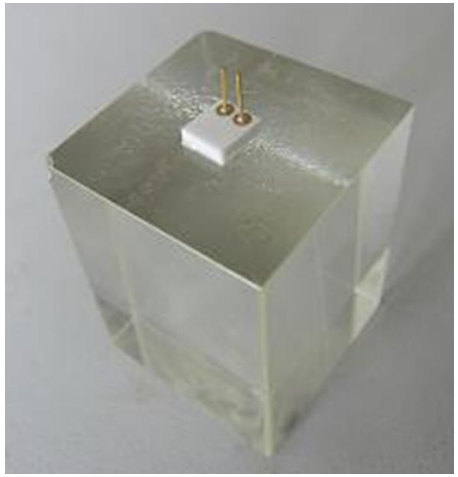
Introduction

- In case of sampling calorimeter, energy deposited in absorber is estimated by measuring active material such as scintillator.
- If energy deposit in absorber layers can be measured, the performance will be improved significantly.
- Lead glass is a candidate for absorber material.
- Lead glass is transparent, so Cherenkov light can be measured with an optical sensor(MPPC).
- Since MPPC is very thin, it makes insensitive area of a sampling calorimeter thin.
- Lead glass is dense with heavy amount of substances and inexpensive compared with crystal scintillator.
- Position information is also important for PFA at ILC, so we consider segmented absorbers.



Sampling calorimeter



Lead Glass

Lead Glass for Active Absorber layer

- By detecting Cherenkov light generated in lead glass with MPPC, energy can be measured with absorber.

- Lead glass is segmented in size of 3 x 3 x 4 cm^3 for PFA.

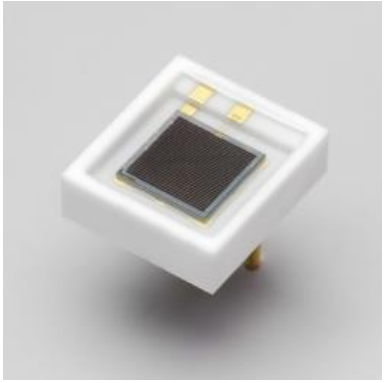
- 4cm thickness corresponds to $2.4X_0$. ($X_0 = 1.7$ cm)

- We use 3 x 3 mm^2 MPPC (2 types) for optical read out with optical grease.
  - 50 μm pitch MPPCs are used for 2 layers
  - 75 μm pitch MPPCs are used for 1 layer

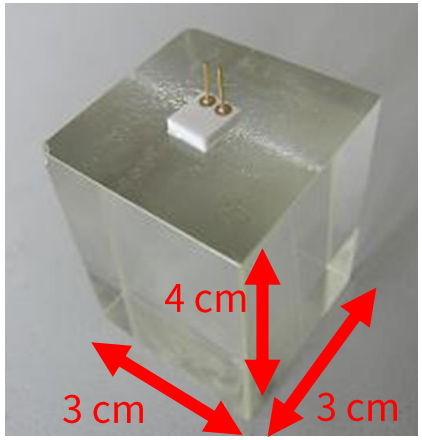
- 1 layer has 9 lead glass blocks (3 x 3 ch lead glass block array) and we manufactured 3 layers.

- To readout each lead glass block independently, each block is enveloped with reflector film.

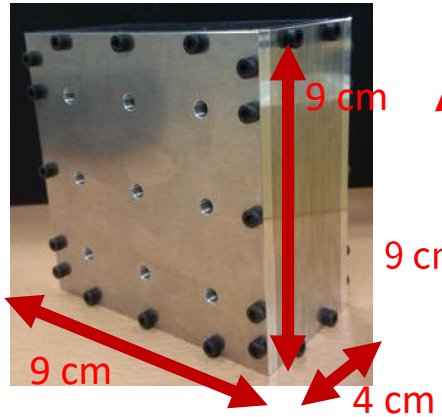
- Signals are amplified and digitized by EASIROC module.



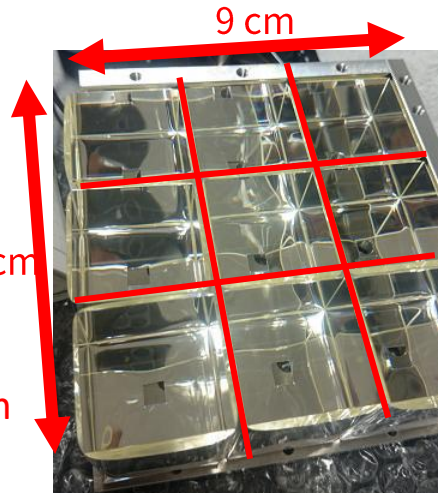
3 x 3mm^2 MPPC



Single lead glass block



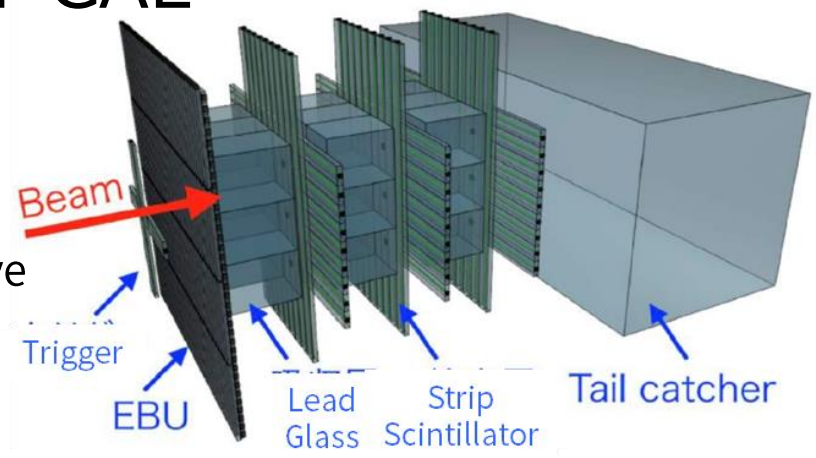
Active absorber layer



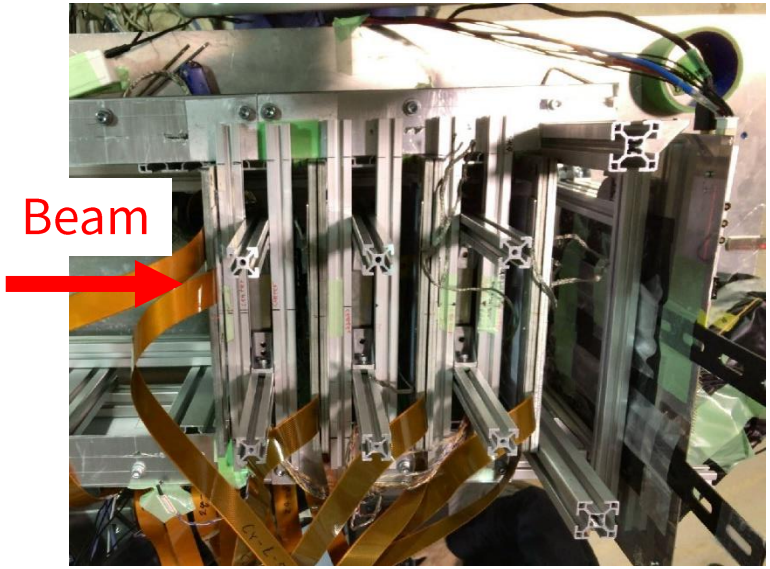
Lead glass block array (3 x 3 = 9 blocks¥/layer)

Prototype of Active Absorber CAL

- We fabricated a three-layer sampling calorimeter using active absorber layer.
- Segmented lead glass blocks with MPPCs as an active absorber layer.
- Finely granulated detection layer using strip Scintillator (green layers in picture).
- Tail catcher using a large lead glass is put most down stream at beamline measures the leakage energy.
- We carried out to verify the performance with positron beam at 3 times (2016, 2017, 2018) at ELPH in Tohoku University.
- Injected energy of positron beam can be changed 100 to 800 MeV.
- We also tested ECAL baseboard unit (EBU) for ILC at the same time.



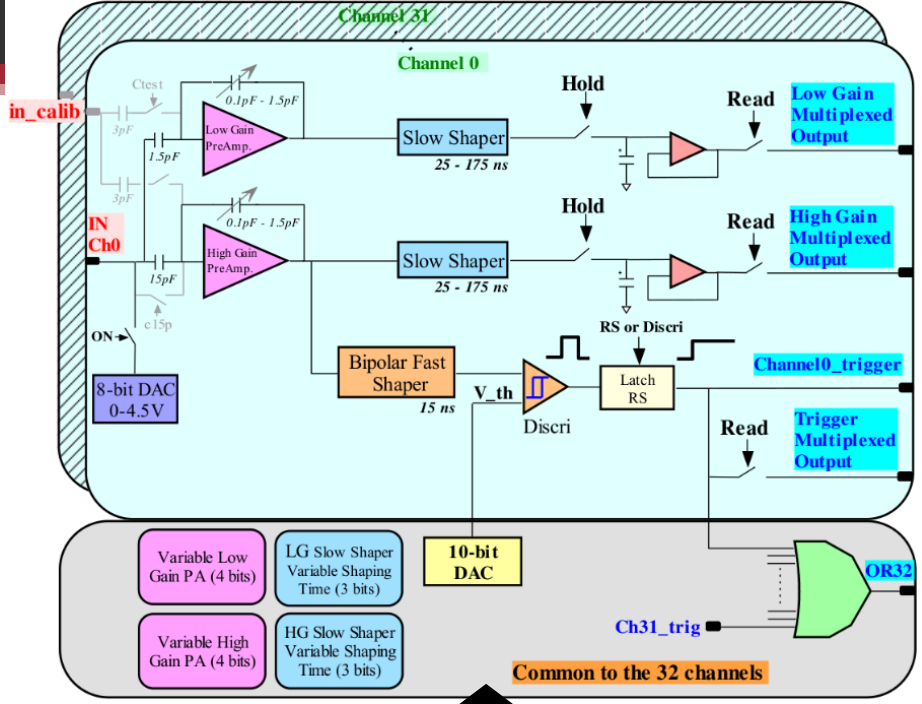
Components of AACAL prototype at test beam in 2016

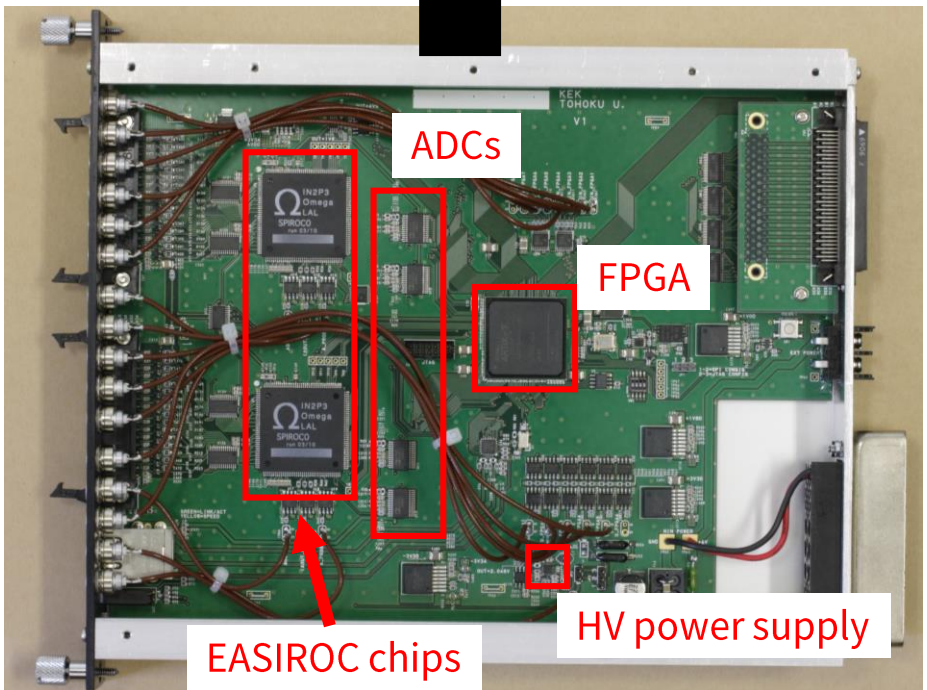


Top view of AACAL prototype in 2018

EASIROC module

- DAQ system uses EASIROC modules.
- It is developed by KEK and Osaka University to read out multiple channel MPPCs.
- The module equips two EASIROC chips (developed by Omega group) for 64 channels.(32ch/chip)
- Includes ADC and HV power supply.
- We have modified the FPGA firmware and added TDC capability.
- Multiple modules can be synchronized by external clock.
- These modules are controlled by PC via Ethernet.





DAQ system

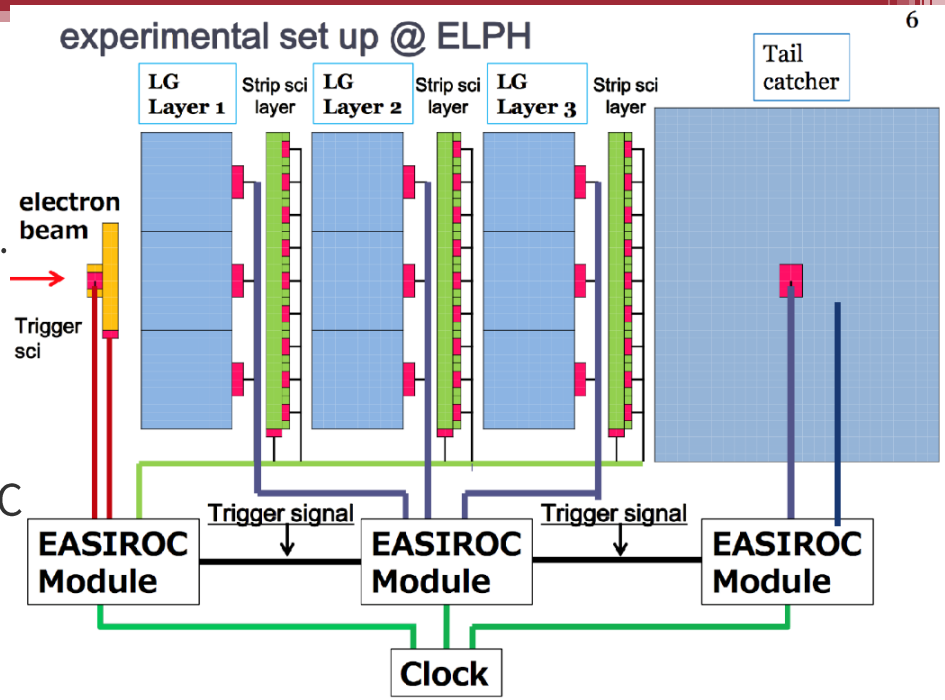
- This prototype has 85 MPPCs.
  - Segmented lead glass absorber layers : 27 MPPCs.
  - Strip scintillator layers : 54 MPPCs.
  - Tail catcher : 2 MPPCs
  - Tile trigger scintillator : 2 MPPCs

- We used 3 EASIROC modules to read out MPPC signals for 3 types MPPCs due to different breakdown voltages.
  - Segmented lead glass : 3 x 3 mm^2 MPPC
  - Strip scintillator : 1 x 1 mm^2 MPPC
  - Tail catcher : 12 x 12 mm^2 MPPC
  - Tile trigger scintillator : 1.3 x 1.3 mm^2 MPPC

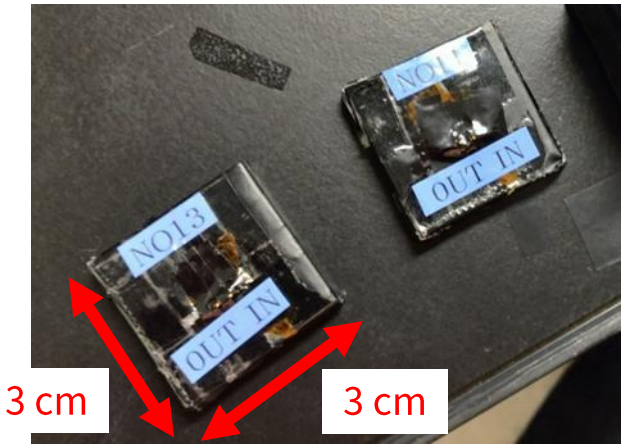
- Trigger signals are made by one EASIROC module for events with signals from 2 trigger scintillators coincidence.

- Trigger signals are fed into the other modules.

- All EASIROC modules are read out with 250kHz and 40MHz synchronized clocks.



Read out and Trigger system



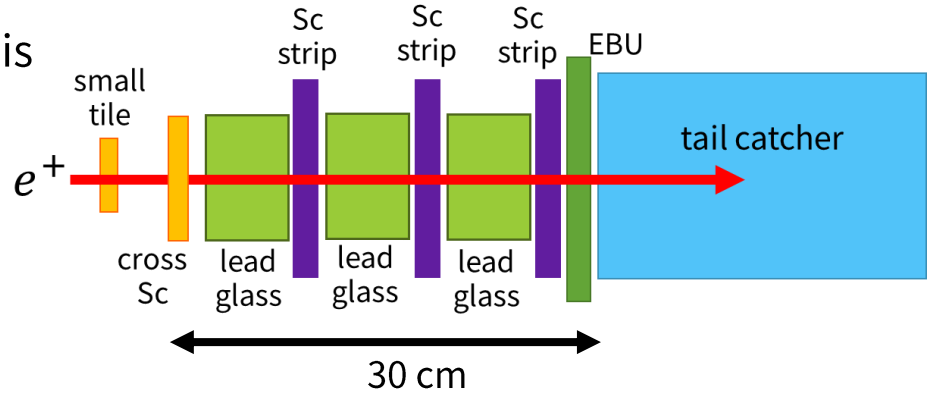
Tile trigger scintillator

Test Beam in 2018

- 2018 Test Beam was carried out at ELPH (at Tohoku University) from November 22nd to 25th.
- Beam time was 48hours .
- We injected 100 to 800 MeV positron beam.

Detectors in beamline

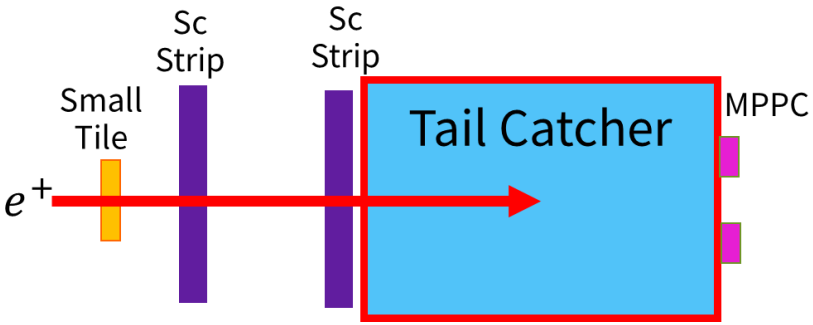
- At test beam, we calibrated all of lead glass block channels with beam.
- We tested linearity and energy resolution of this prototype.



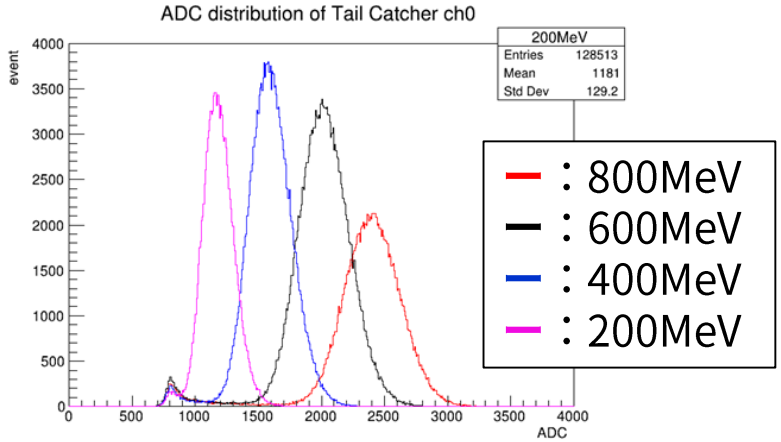
Components of AACAL prototype at test beam in 2018

Energy Calibration of Tail Catcher

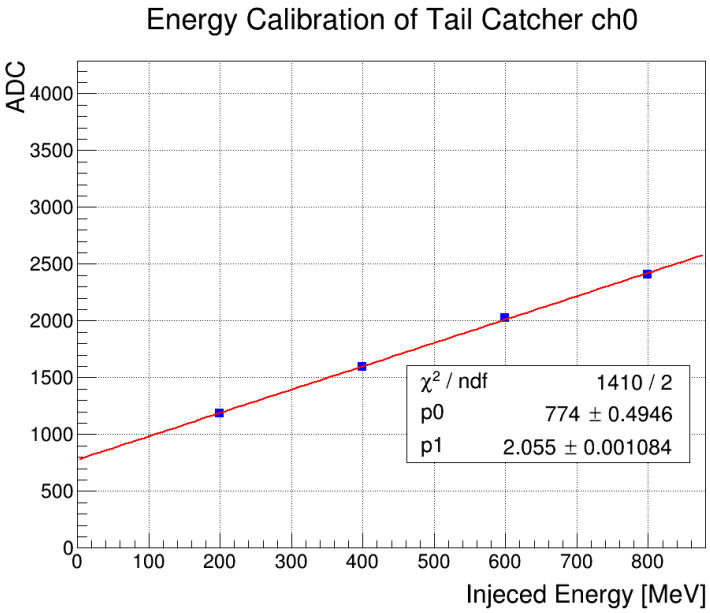
- At first, in order to calibrate lead glass blocks, we calibrated tail catcher with right setup.
- Two 12 x 12 mm^2 MPPCs are used for optical read out from tail catcher.
- We took data changing beam energy 200 to 800 MeV.
- We calibrated energy for each channel.
- We confirmed a good linear response to the injected energy with offset subtraction.



Setup of tail catcher calibration



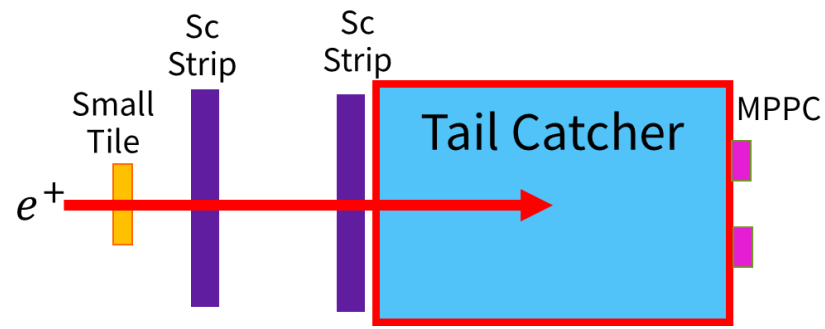
ADC distribution of tail catcher



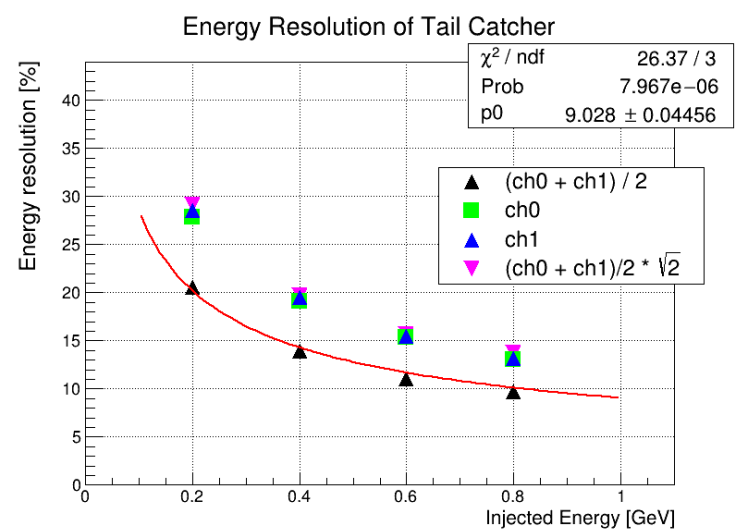
ADC counts v.s. Injected energy

The energy resolution of Tail catcher

- Each channel is converted ADC to deposit energy using conversion factor and offset value.
- After conversion, we take the average energy ($E = (E_{ch0}+E_{ch1})/2$) of two channels.
- We defined energy resolution as σ_E/E.
- Fit with function: $f(E) = p0/\sqrt{E}$.
- Energy resolution is calculated as $9.0\ \%/\sqrt{E}$.
- Also, energy resolution of single channel is calculated as $12.5\ \%/\sqrt{E}$
- Energy resolution using two channels is $\sqrt{2}$ times better than using single channel of MPPC.
- This is clearly understood from the photon statistics.



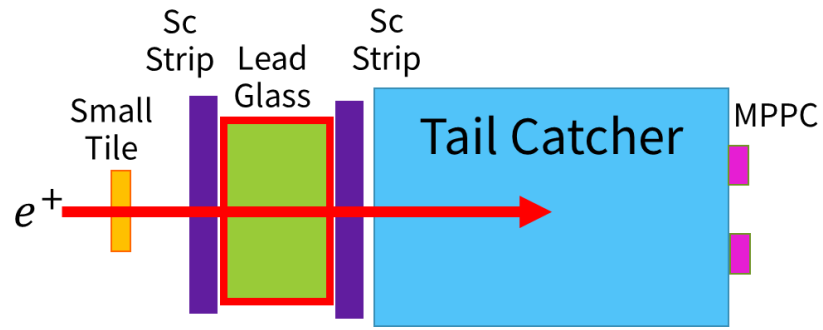
Setup of tail catcher calibration



The energy resolution of tail catcher

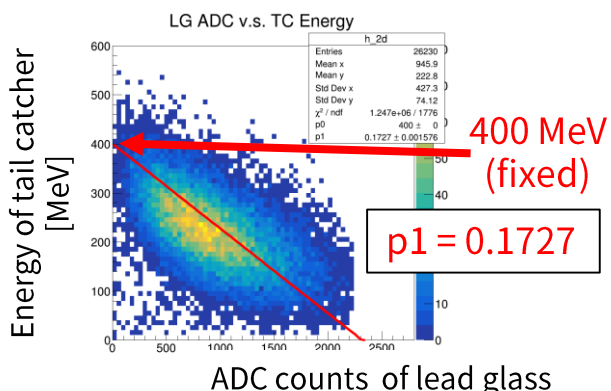
Energy Calibration of Lead Glass block①

- We installed a lead glass in front of the tail catcher and injected 400 MeV positron beam.
- We can measure energy leakage from lead glass block using tail catcher event by event.
- Calibration constant of lead glass block is obtained by scatter plot.
- There is correlation between lead glass ADC and tail catcher energy.
- We fitted scatter plot with linear function and fixed deposit energy of tail catcher to 400 MeV when no energy in a lead glass block.
- We obtain calibration constant and reconstructed the total energy with the fitting result.
- But reconstructed energy is lower than injected energy (400 MeV).

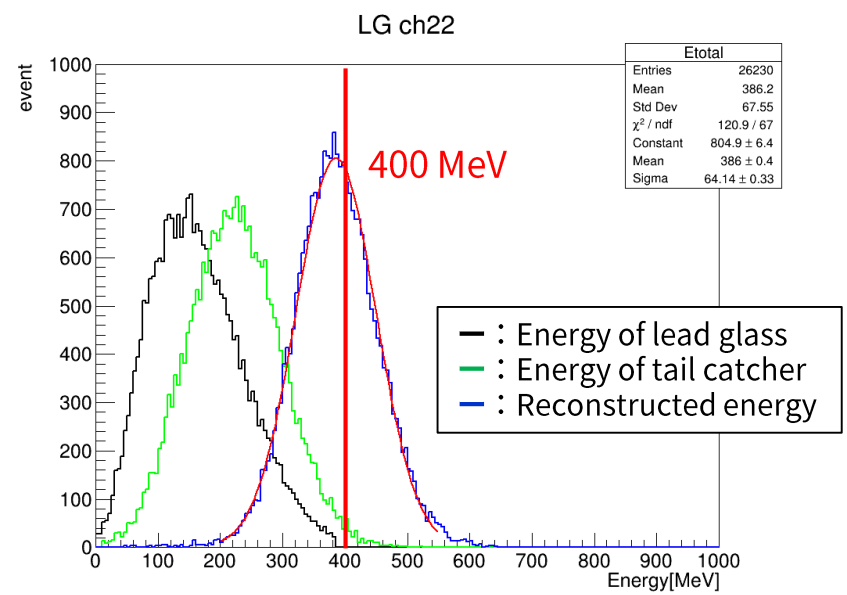


Setup of lead glass calibration

$$E_{reconstructed} = p1 \times ADC_{Lead\ glass} + E_{Tail\ catcher}\ [\mathrm{MeV}]$$



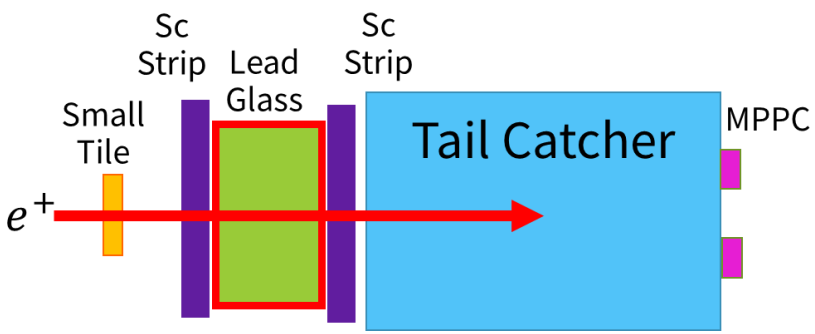
Tail catcher Energy v.s. lead glass ADC



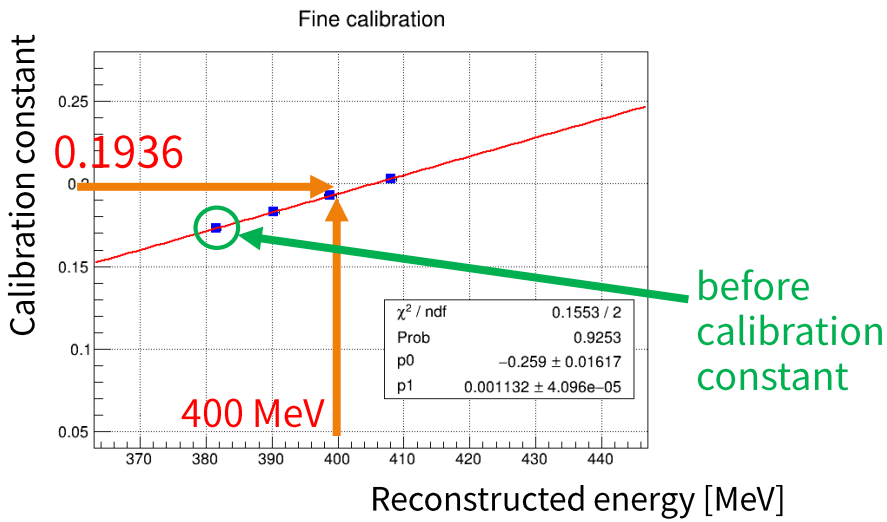
The reconstructed energy distribution

Energy Calibration of Lead Glass block②

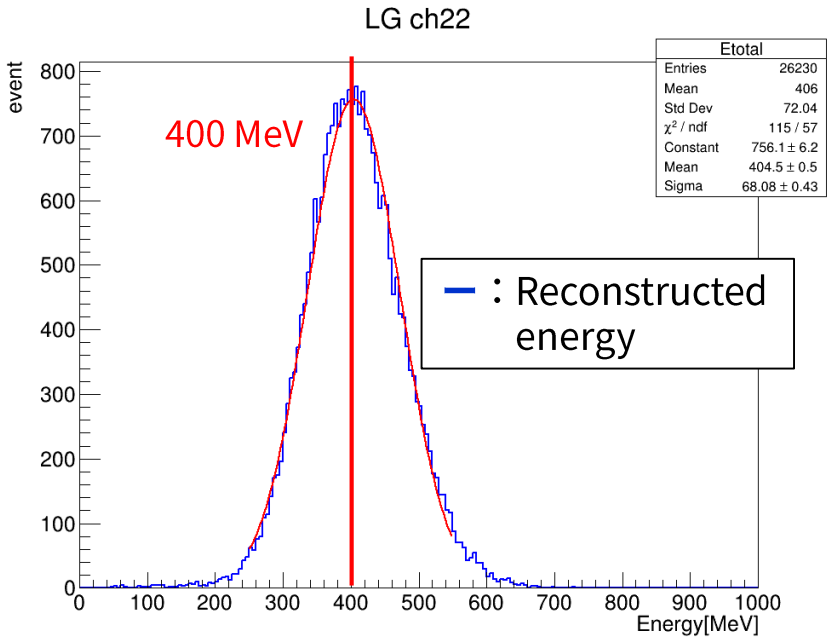
- We adjusted calibration constant to agree the reconstructed energy with the injection energy (400 MeV) by changing the calibration constant.
- A new calibration constant is determined by the result of adjustment.
- Reconstructed energy shows gaussian shape.
- All lead glass blocks are calibrated with this scheme.



Setup of Lead Glass Calibration



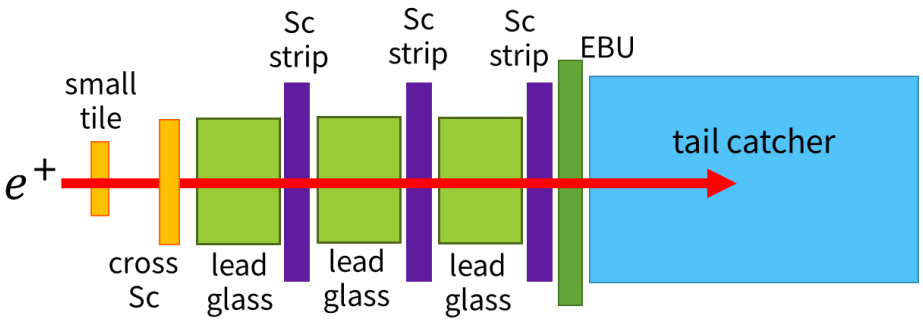
Searching for a new calibration constant using reconstructed energy



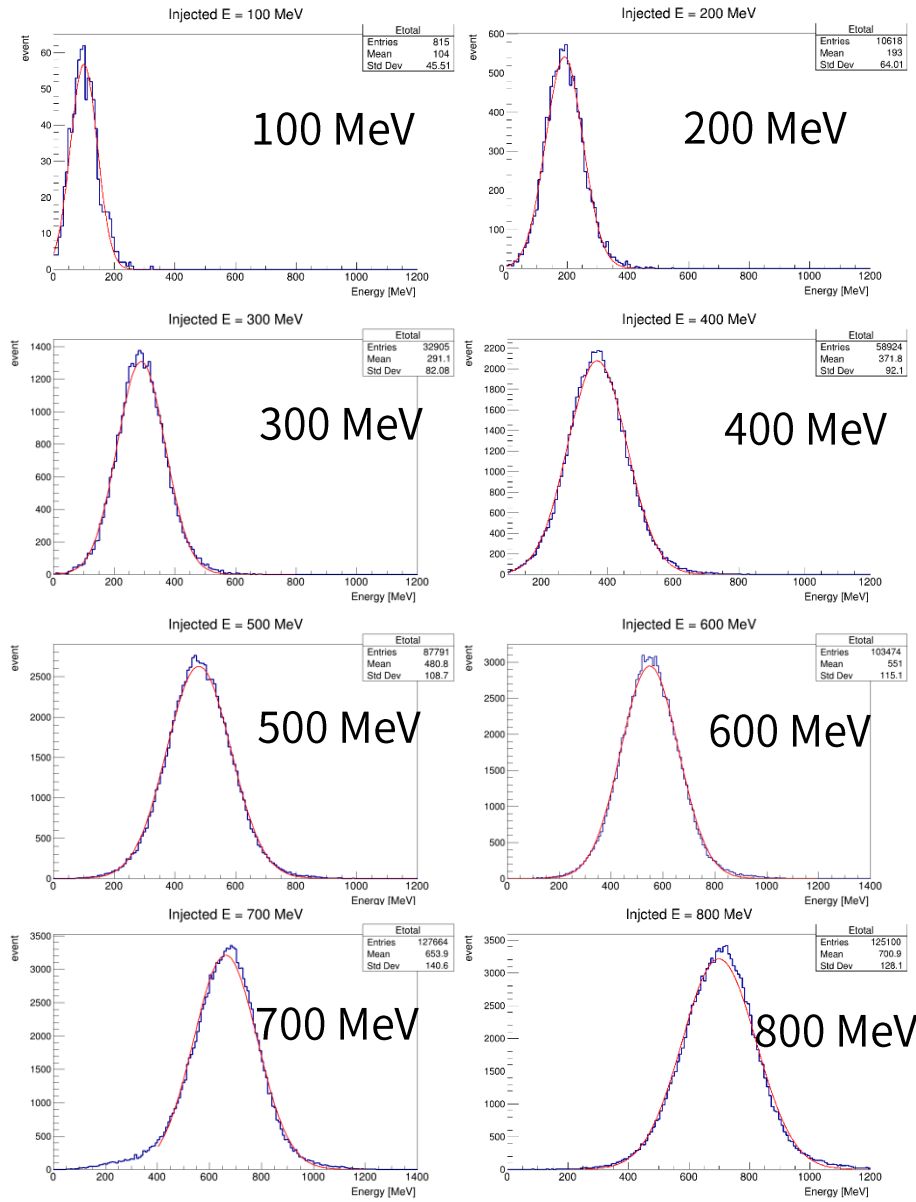
Reconstructed energy using a new calibration constant

The energy reconstruction of AACAL prototype

- After all lead glass blocks were calibrated, we reconstructed energy with the whole calorimeter.
- We injected 100 to 800 MeV positron beam every 100 MeV.
- The reconstructed energies show gaussian shapes.



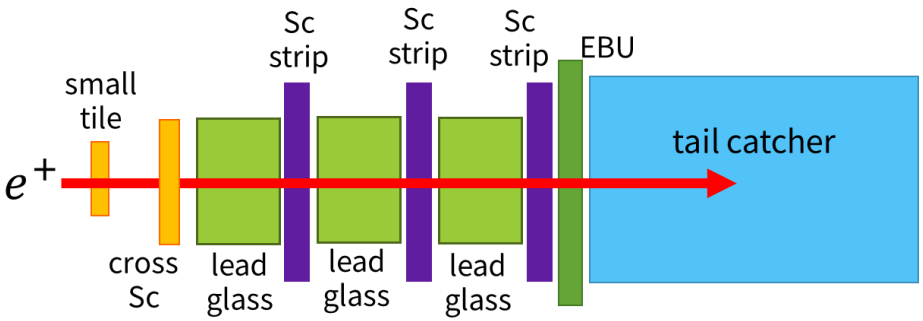
Setup for verifying performance of AACAL prototype



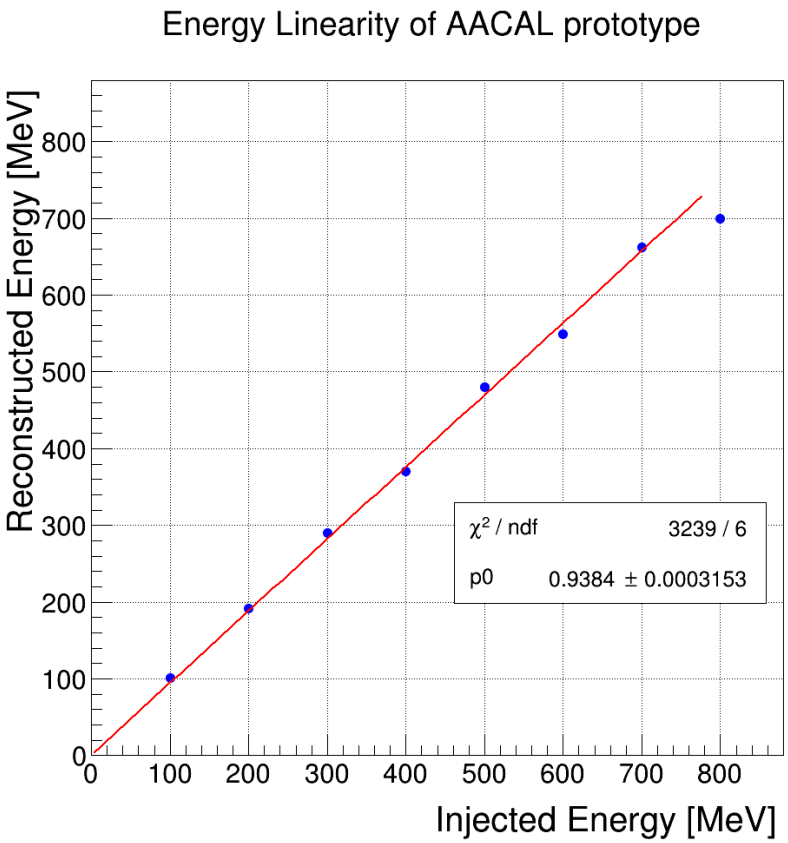
The reconstructed energy distribution (100MeV to 800MeV)

The energy linearity of AACAL prototype

- We verified the energy linearity.
- This prototype has good linearity.
- However, the reconstructed energy is lower at 800 MeV.
- At 800 MeV, there seems to exist shower energy leakage.
- We need to investigate whether energy leakage exists at 800 MeV with simulation.



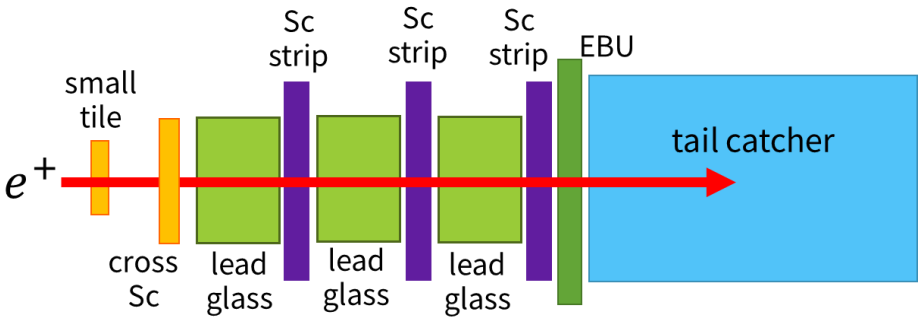
Setup for verifying performance of AACAL prototype



The linearity of reconstructed energy (100MeV to 800MeV)

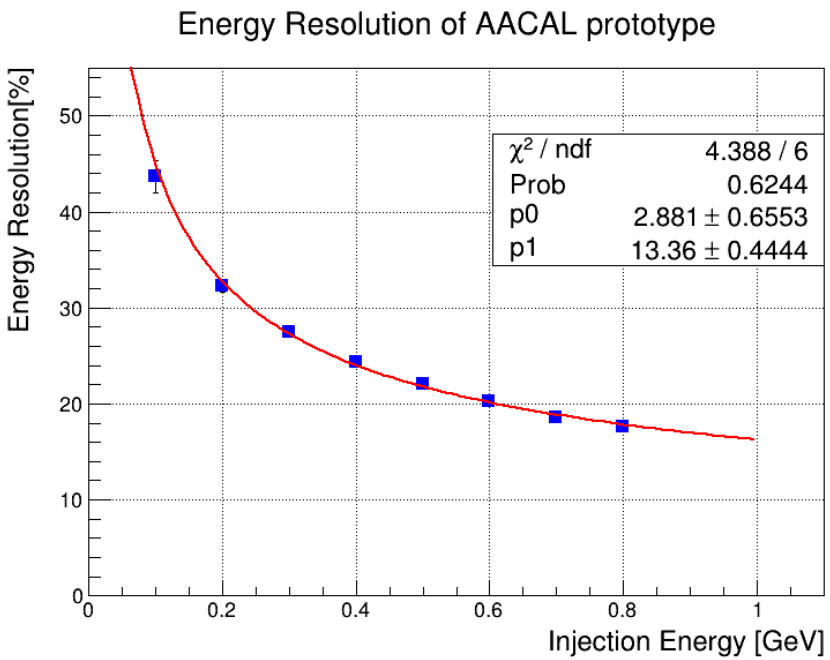
The energy resolution of AACAL prototype

- We calculated the energy resolution of the whole calorimeter
  (3 Active Absorber layers + tail catcher)
  from the reconstructed energy.



Setup for verifying performance of AACAL prototype

- We calculated energy resolution as σ_E/E.
- Fit with function: $f(E) = p0 + p1/\sqrt{E}$.
- The energy resolution is calculated as $13.4\ \%/\sqrt{E} + 2.9\ \%$.
- The constant term is calculated as 2.9 % .
- We need to investigate the constant term with simulation.



The energy resolution of the whole calorimeter

Summary

- Performance improvement of calorimeter is desired for future high energy frontier collider experiment.

- We are developing and testing active absorber calorimeter using segmented lead glass as absorber layer.

- we have established the calibration scheme for the segmented active absorber calorimeter.

- The prototype shows good linearity.

- The energy resolution of prototype is $13.4\ \%/\sqrt{E} + 2.9\ \%$.

【In future】

- Comparison and evaluation with simulation including experimental conditions.

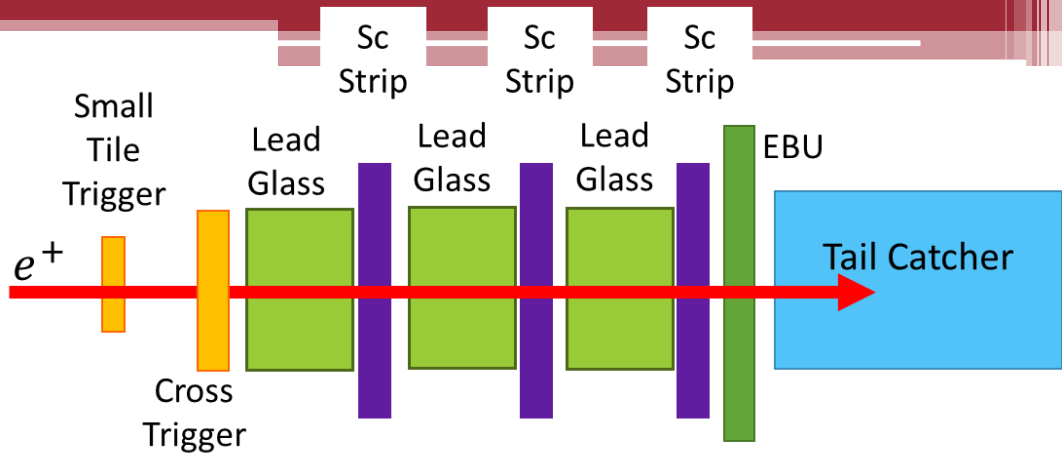
- In order to have better energy resolution, We need to increase the number of Cherenkov photons.

Back up

Physical properties of Lead Glass(SF6W)

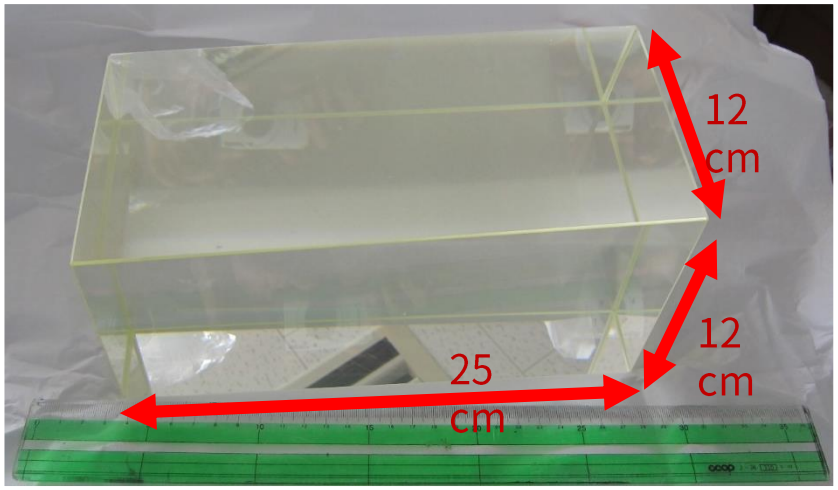
Chemical composition (wt%)	
SiO_2	27.3
PbO	70.9
K_2O	0.9
Na_2O	0.6
Sb_2O_2	0.3
Radiation length (cm)	1.7
Refractive index	1.8
Density (g/cm_3)	5.2
Critical energy (MeV)	12.6
Molière unit (X_0)	1.7

Tail Catcher (TC)



- 12 x 12 x 25 cm^3 Lead Glass block
- This is put most down stream at beamline.
- This measures the leakage energy.
- Two 12 x 12 mm^2 MPPCs are used for optical read out with optical glue.
- Tail Catcher is used for LG blocks (AACAL) calibration in order to measure beam leakage from LG block.

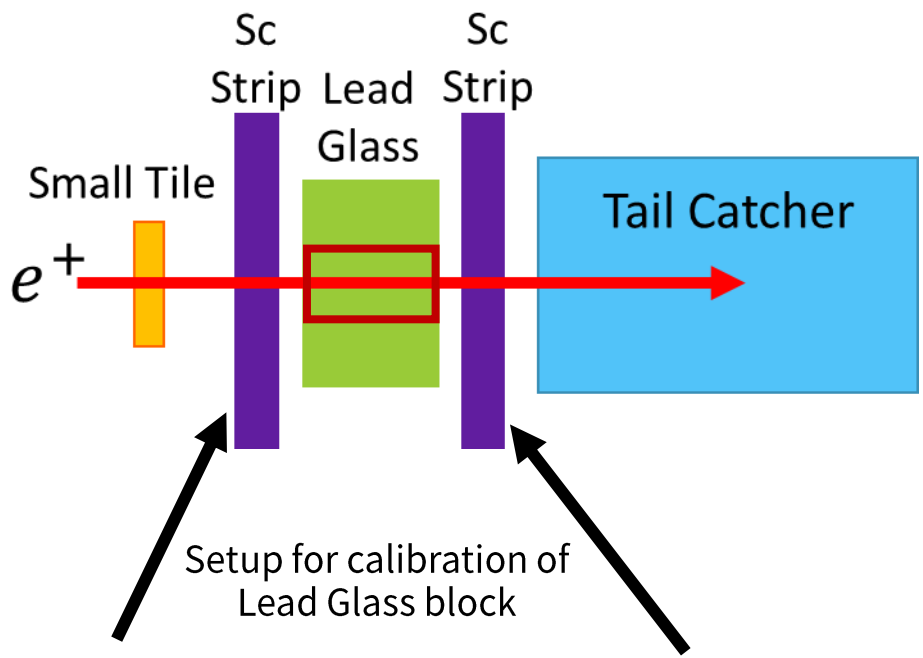
Components of AACAL prototype

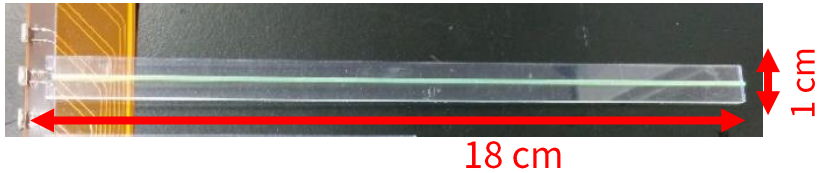


12 x 12 x 25 cm^3 Tail Catcher

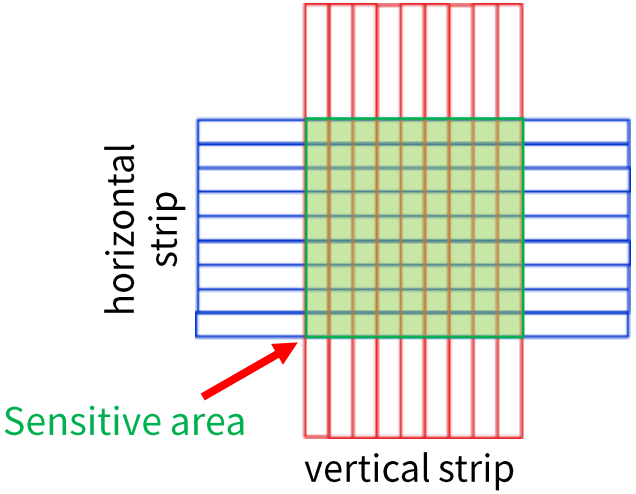
Strip Scintillator layer

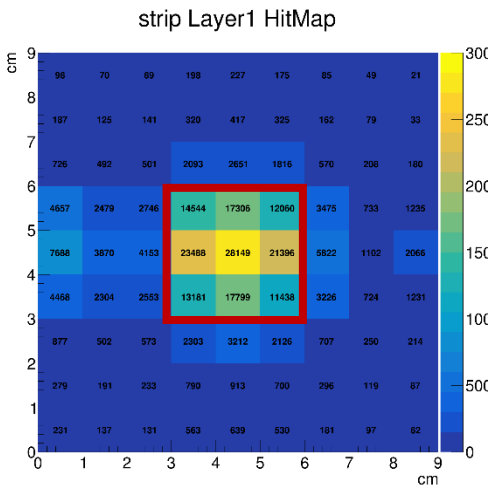
- Strip Scintillator : 18 x 1 x 0.3 cm^3
- We create 9 x 9 cm^2 sensitive area which is segmented 1 x 1 cm^2 effectively by requiring coincidence of orthogonal Strip Scintillator layers.
- We can see beam position and the spread of the shower with two Strip Sc layer hitmaps.

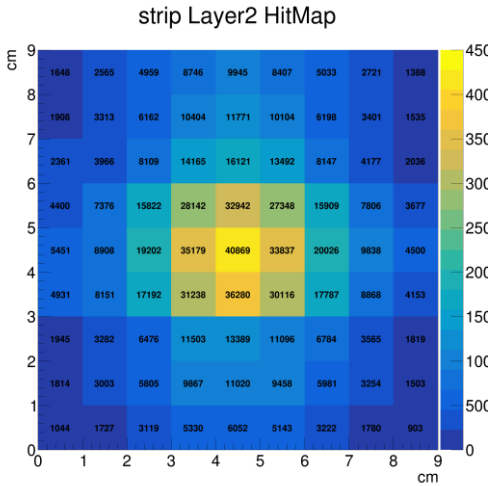




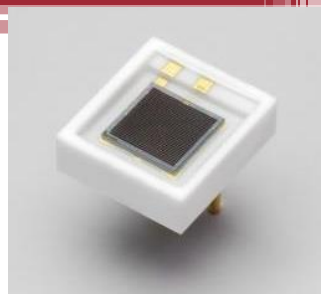
A single strip Scintillator



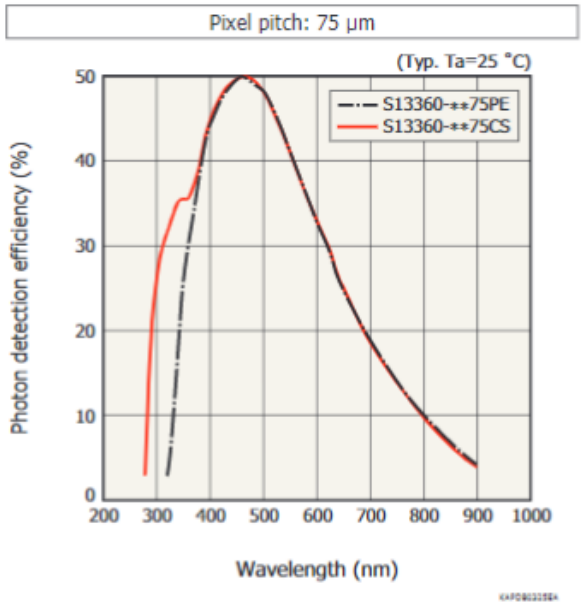




MPPC（S13360 series）

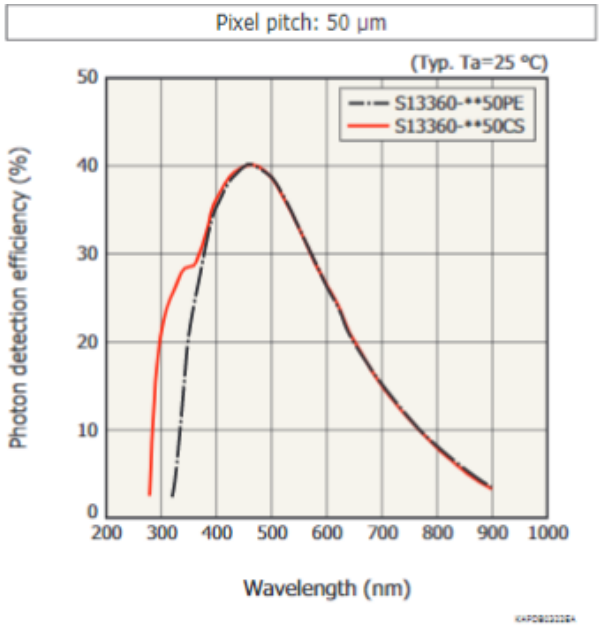


- 75 um pitch (1600pix)
  - photosensitive area: 3 x 3 mm^3
  - V_{over} = 3 V
  - Aperture ratio: 74%
  - Sensitivity wavelength range : 270 ～ 900 nm
  - Photon detection efficiency (PDE): 50 %
  - closstalk rate: 7%



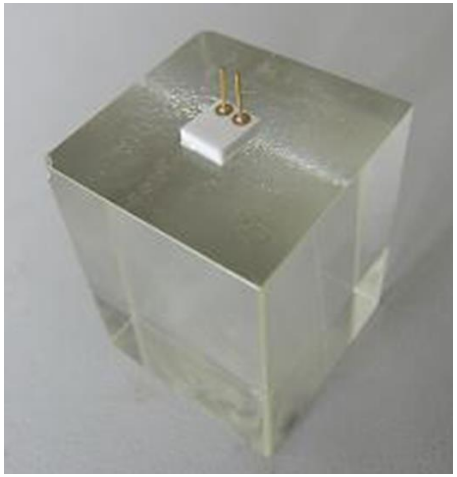
PDE vs. Wavelength of 75 um pitch MPPC

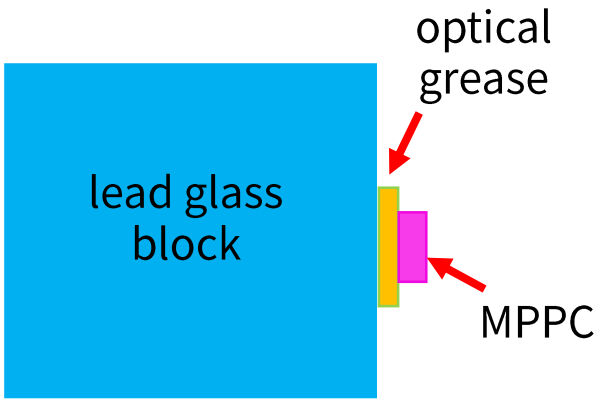
- 50 um pitch (3600pix)
  - photosensitive area: 3 x 3 mm^3
  - V_{over} = 3 V
  - Aperture ratio: 74%
  - Sensitivity wavelength range : 270 ～ 900 nm
  - PDE: 40 %
  - closstalk rate: 3%



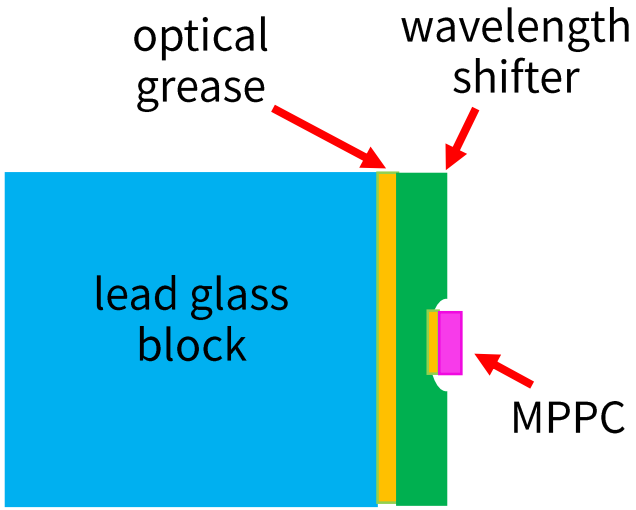
PDE vs. Wavelength of 50 um pitch MPPC

The next readout model





The current readout model

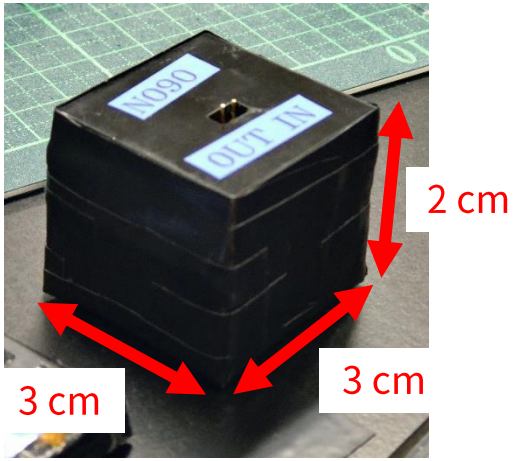


The next readout model

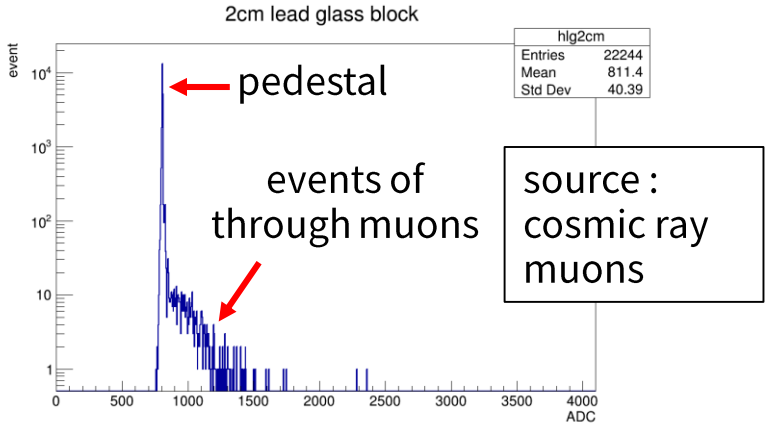
Using WLS, light guide, etc.

2cm thick lead glass block

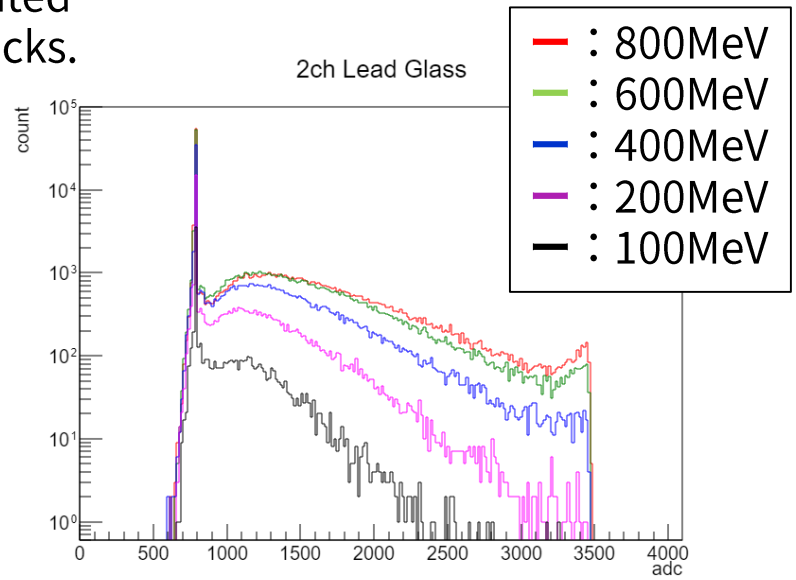
- Lead glass is segmented in size of 3 x 3 x 2 cm^3.
- We use 3 x 3 mm^2 MPPC (50 μm pitch) for optical read out with optical grease.
- We checked signals with cosmic ray thorough muons.
- Data analysis of test beam is on going.
- We devise to make an active absorber finely segmented in the depth direction using 2cm thick lead glass blocks.



3 x 3 x 2 cm^3 lead glass

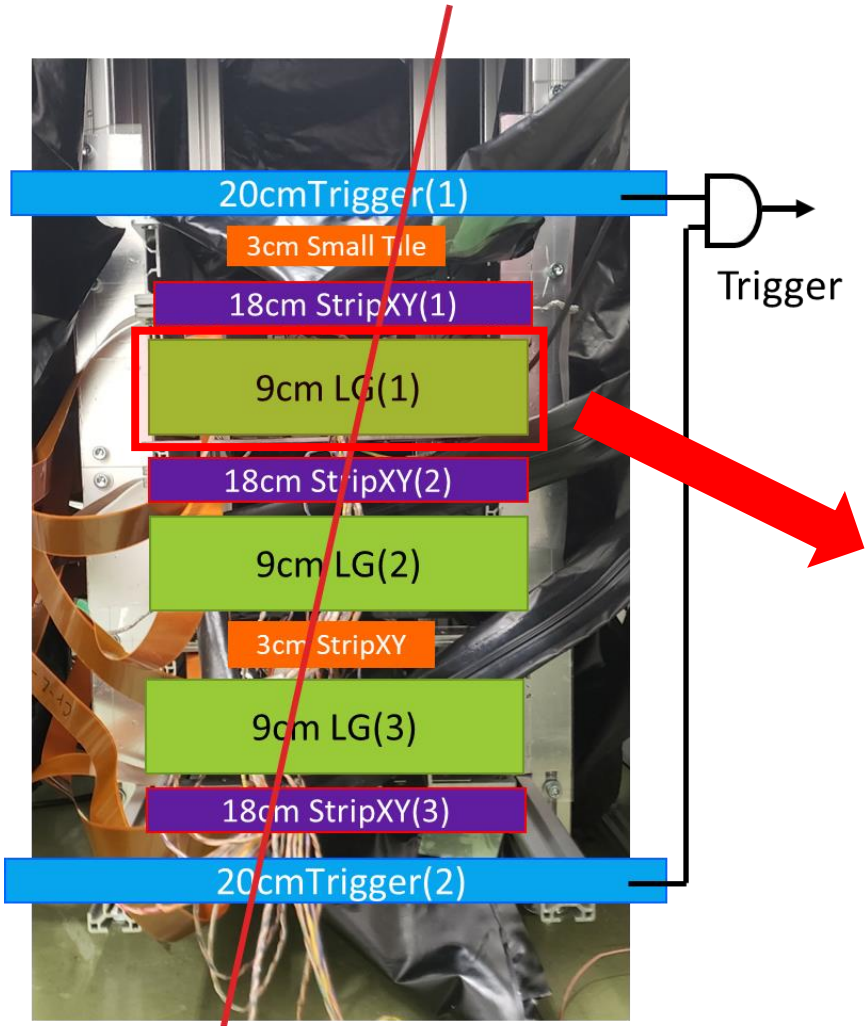


ADC distribution of 2cm thick lead glass using cosmic ray through muons

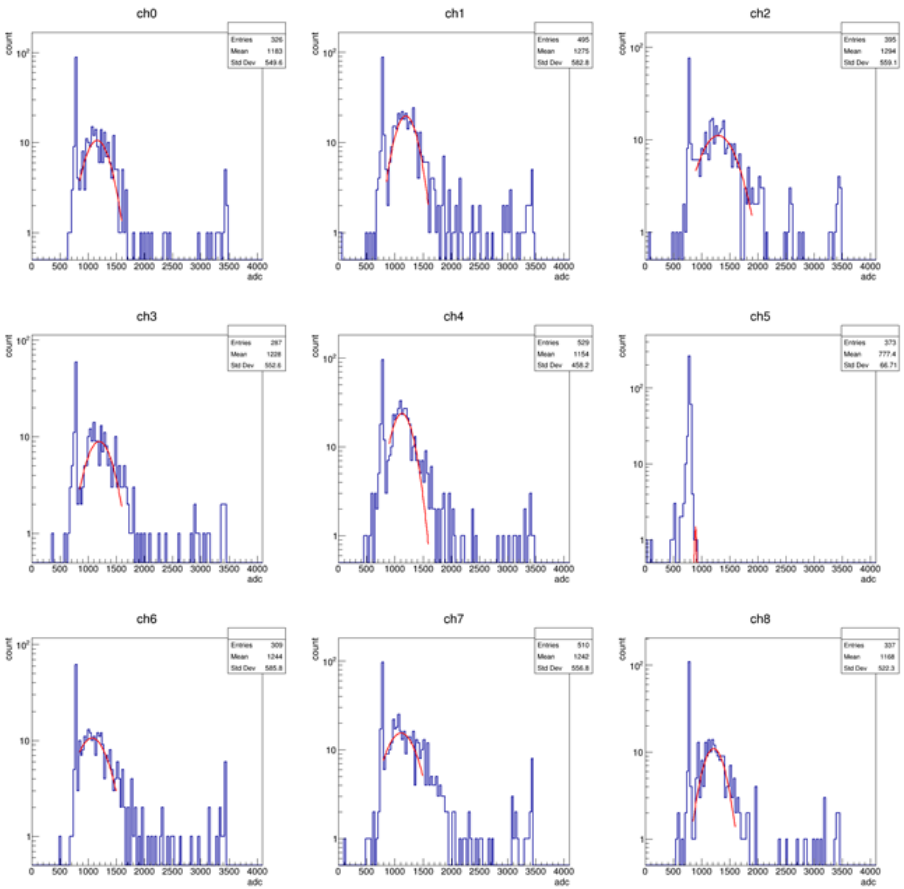


ADC distribution of 2cm thick lead glass using 100 to 800 MeV positron beam

The cosmic ray muons test of active absorber CAL①

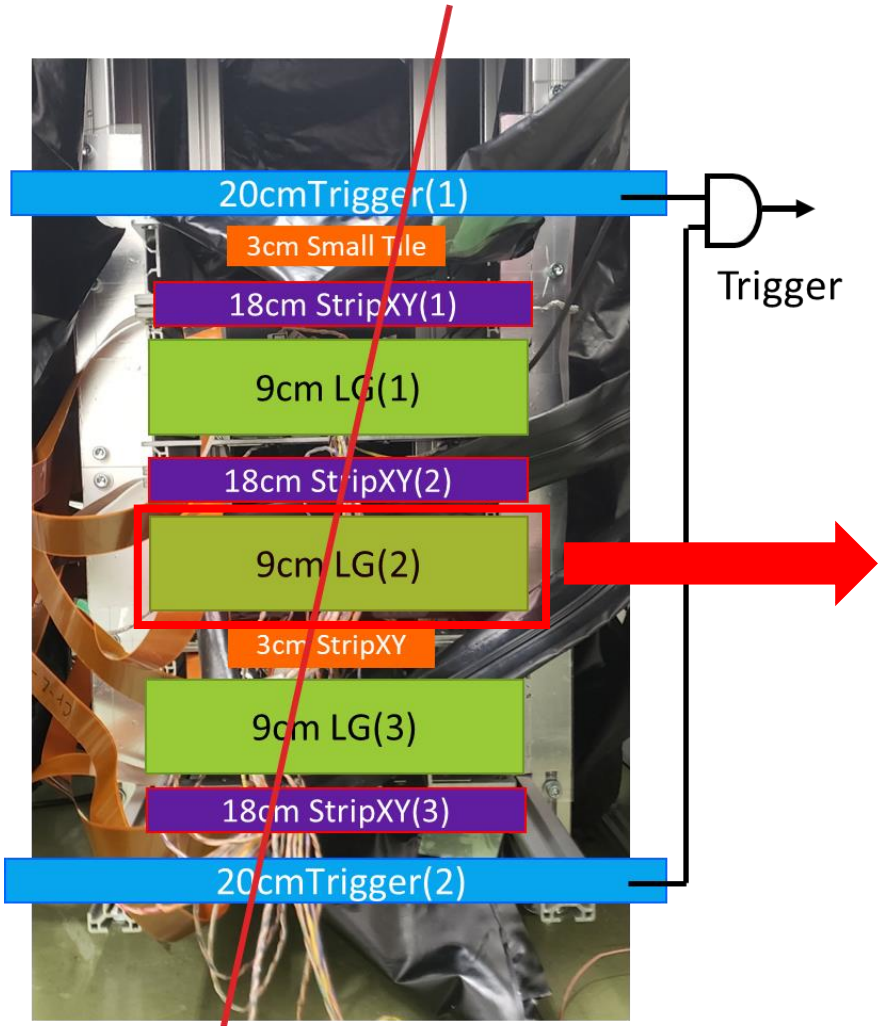


The setup of cosmic ray muons test

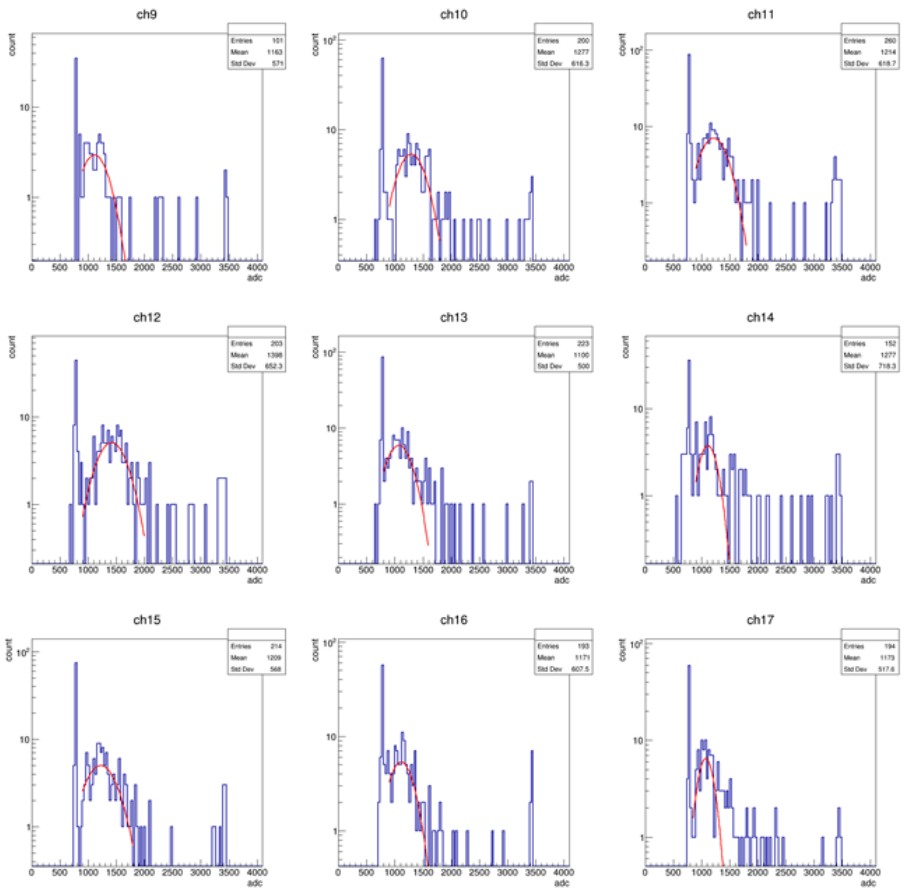


ADC distribution of active absorber layer ①
using through muons

The cosmic ray muons test of active absorber CAL②

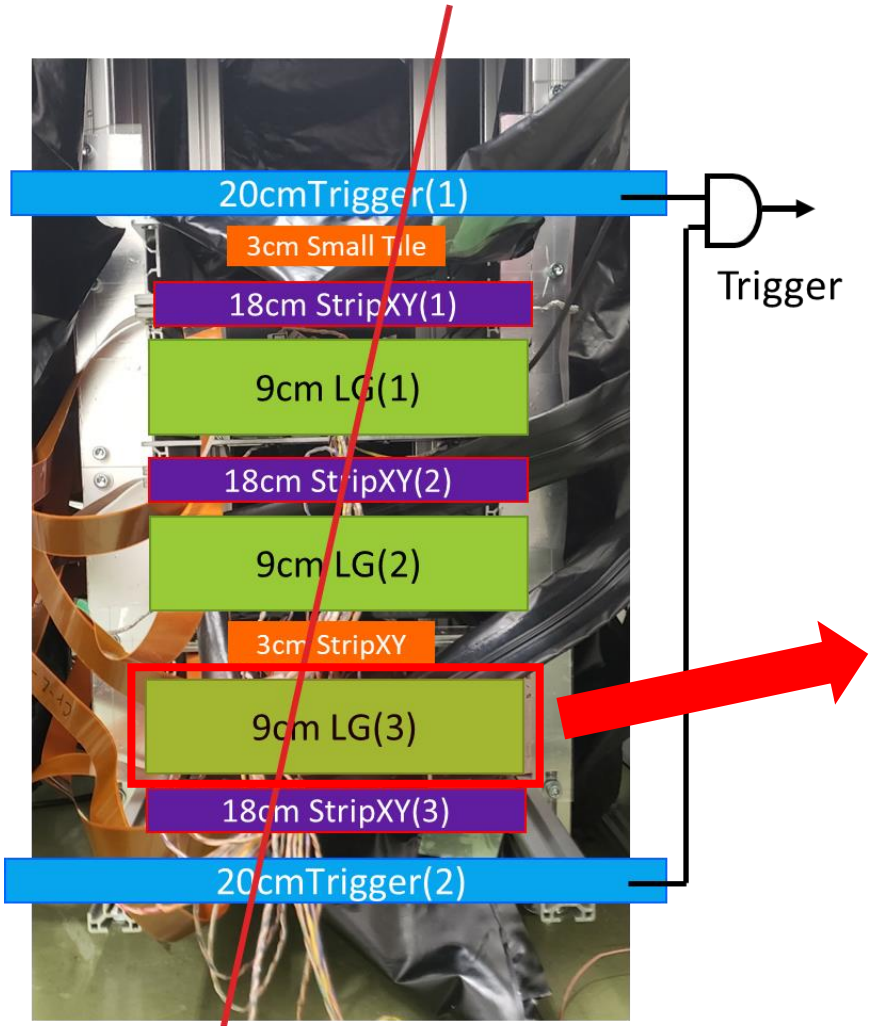


The setup of cosmic ray muons test

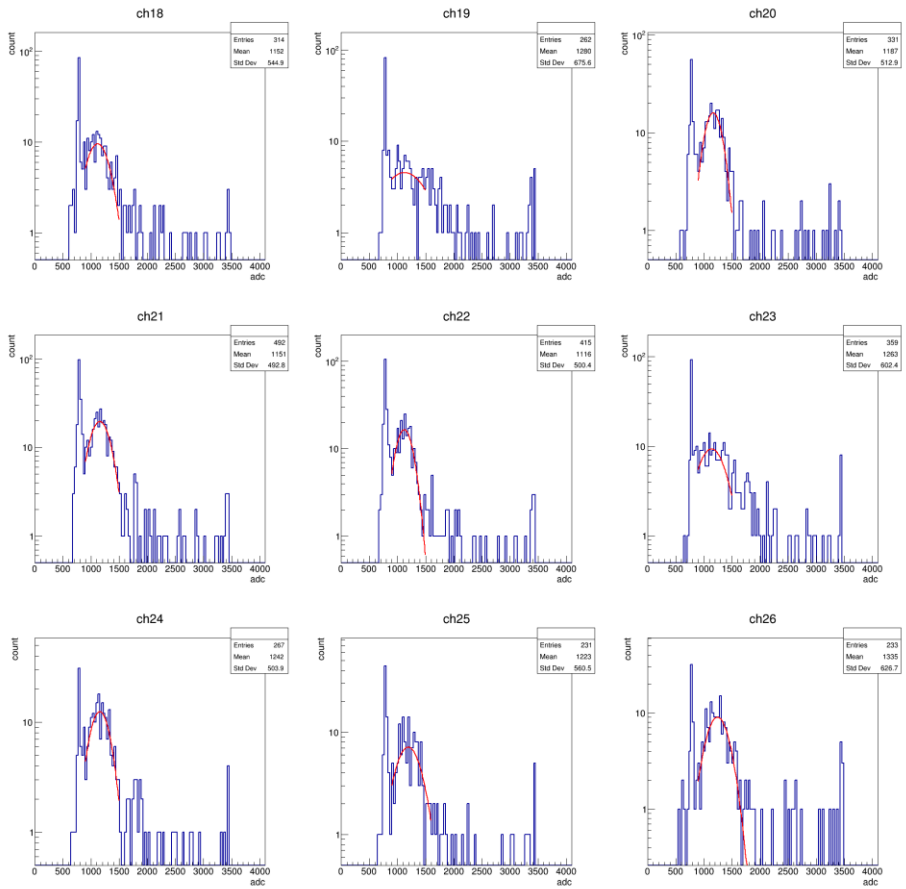


ADC distribution of active absorber layer ②
using through muons

The cosmic ray muons test of active absorber CAL③



The setup of cosmic ray muons test



ADC distribution of active absorber layer ③ using through muons