Development of sampling calorimeter to use information from segmented lead glass absorber with Cherenkov light

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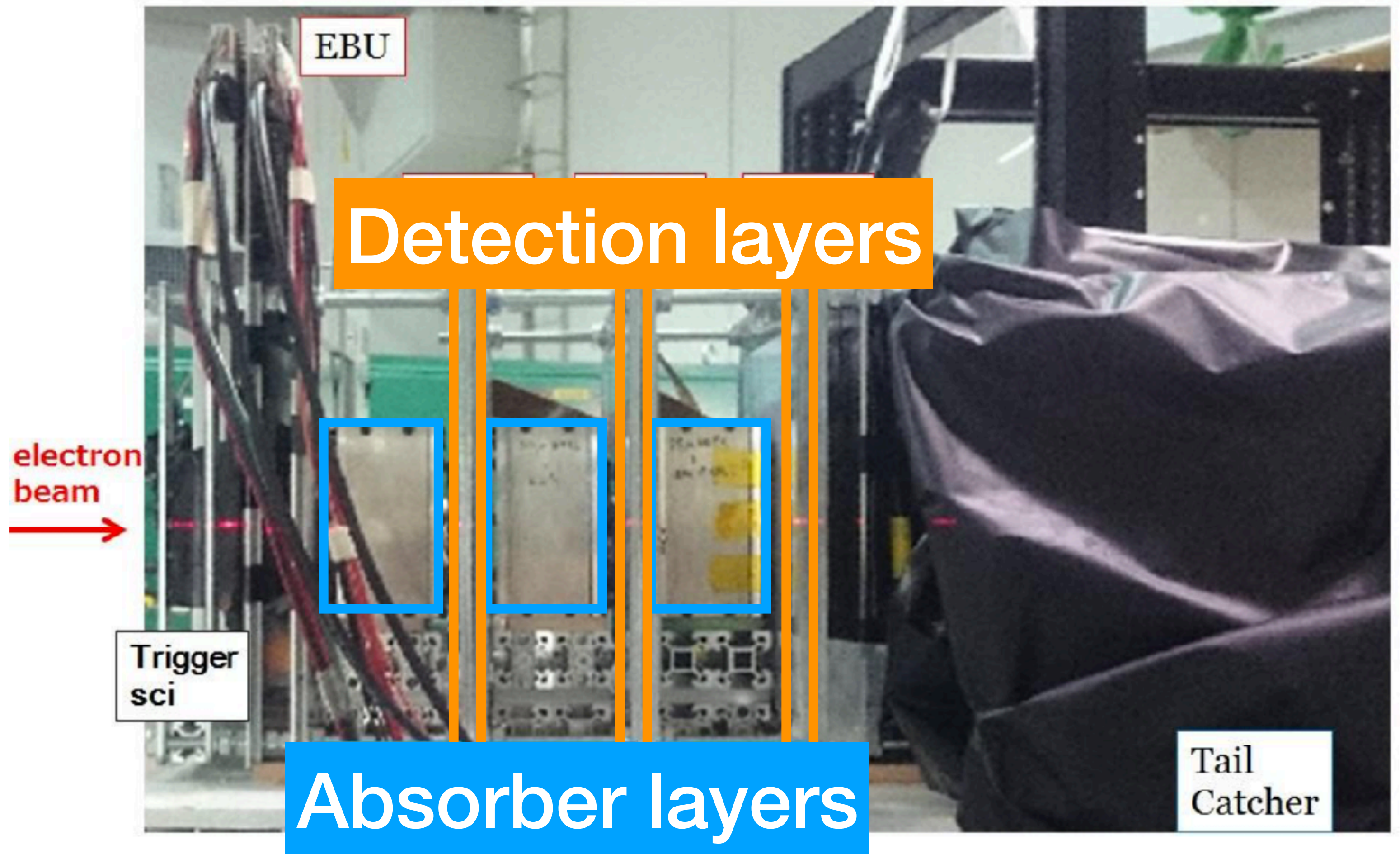
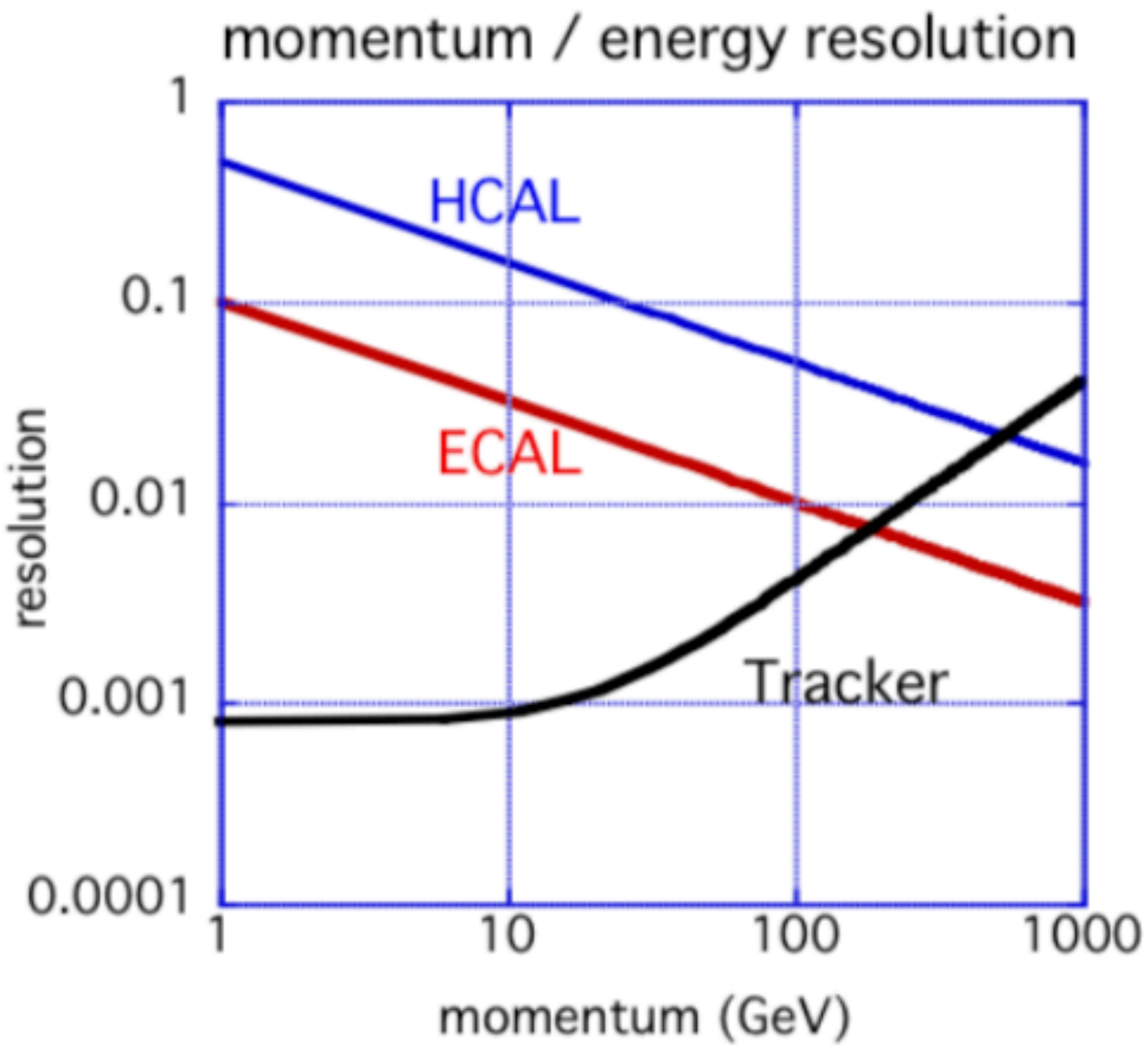
Introduction of active absorber CAL

- The sampling calorimeter has a structure in which a large number of absorption and detection layers are stacked.
- Energy deposit in the absorber is not directory measured but estimated by measuring active material such as scintillator.
- Energy resolution, an important indicator of calorimeter, degrades due to energy fluctuation in the detection layers which is thin.
- If absorber information is usable, active absorber calorimeter will significantly improve the energy resolution.
- At ILC, improve jet energy resolution by using Particle Flow Algorithm (PFA) to identify particles with tracker.
- However, when the energy becomes higher at future experiment, the energy resolution of the calorimeter is still very important.





Tracker's momentum resolution is very high at current energy but it degrades at high energy

Introduction of active absorber CAL

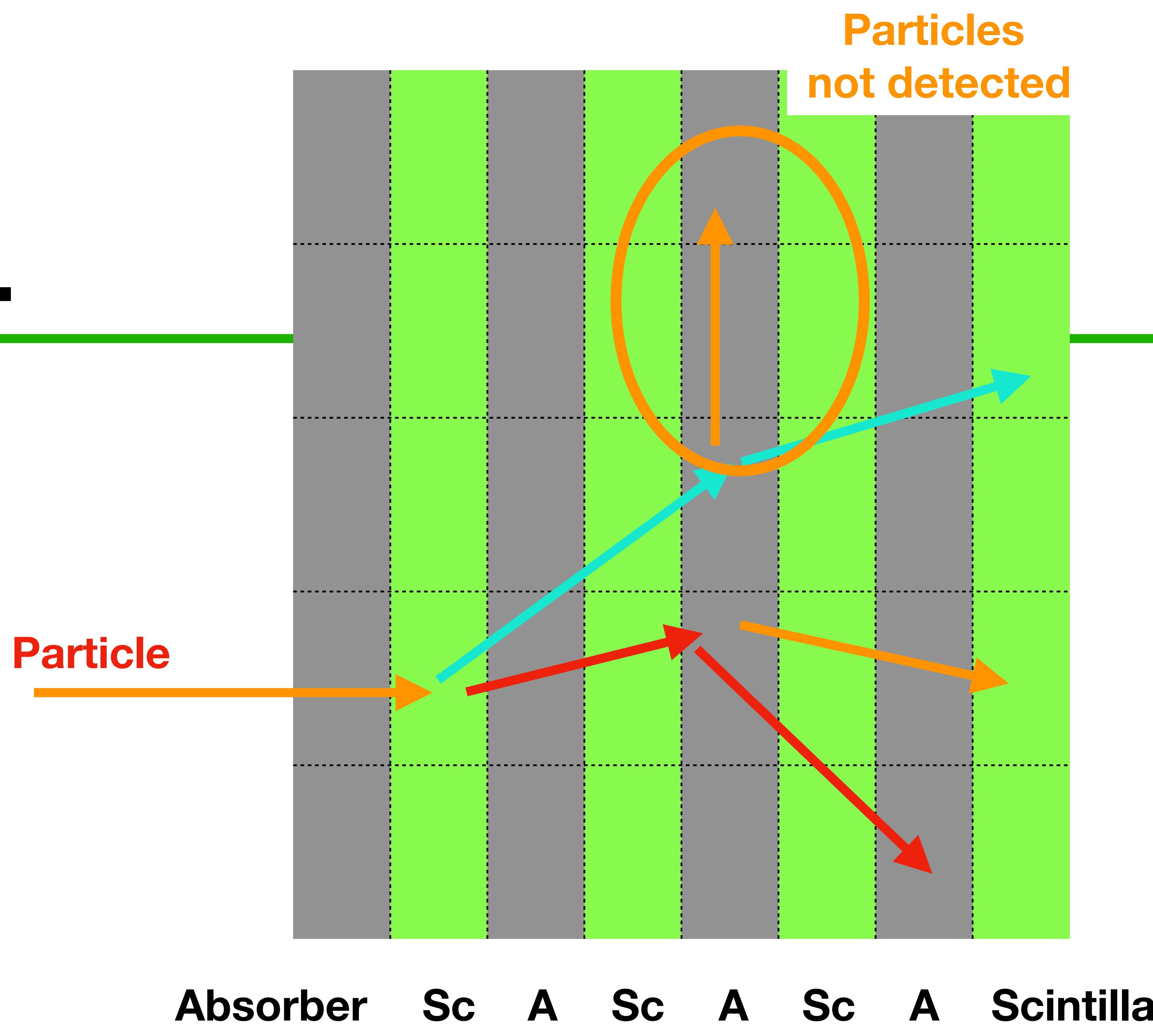
- If energy deposit in absorber layers can be measured directly, the performance will be improved significantly.

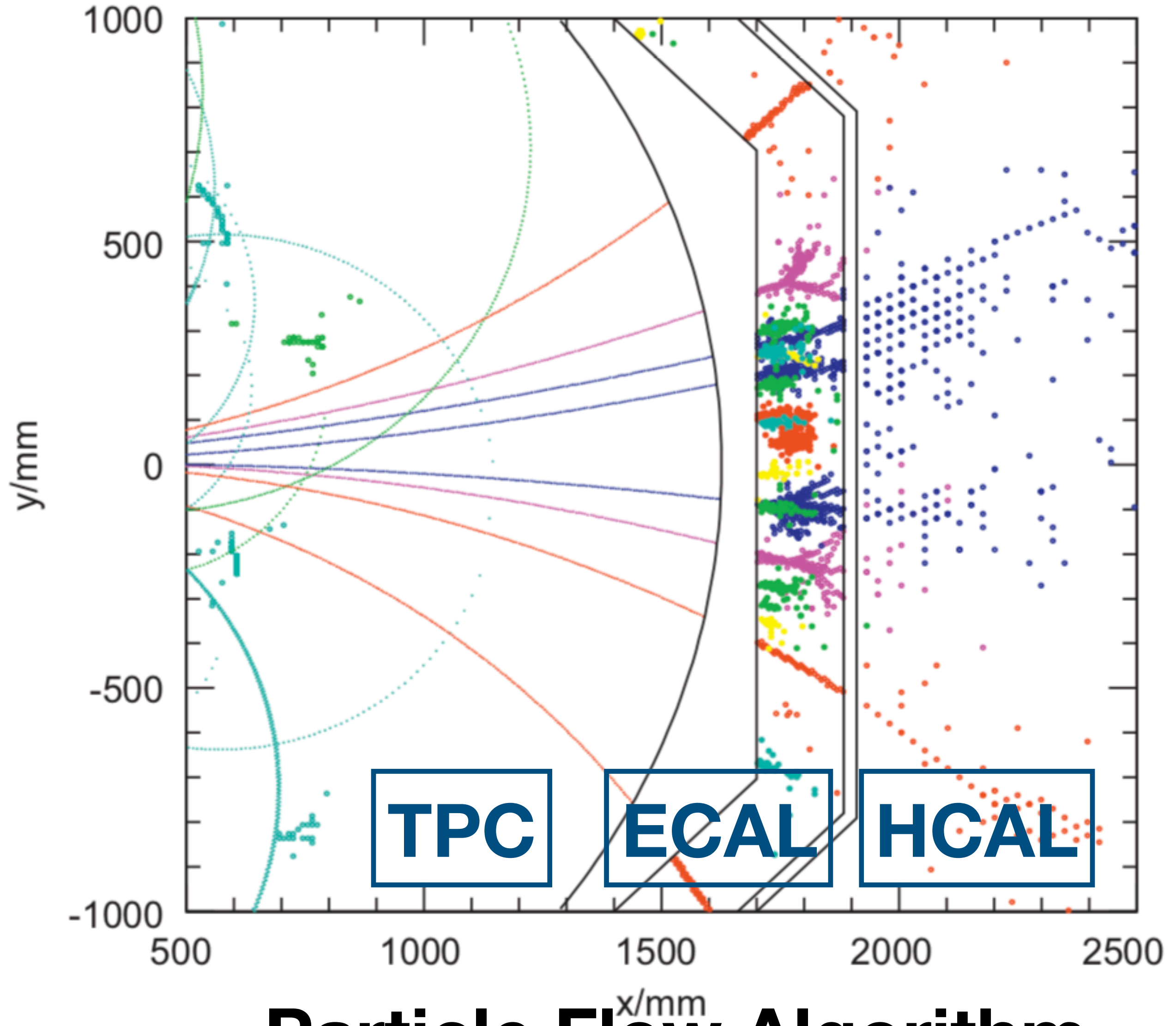
- PFA is very successfull and still important so it is necessary to be a sampling calorimeter with finely granulated detection layer for PFA optimized calorimeter.

- In addition, the absorption layer is divided in order to obtain the position of the particles from them.

- In this calorimeter, it is necessary to use a transparent and heavy substance so that scintillation light or Cherenkov light can be detected as an absorption layer.

- The absorption layer needs a large amount of material volume, therefore inexpensive material is preferable.



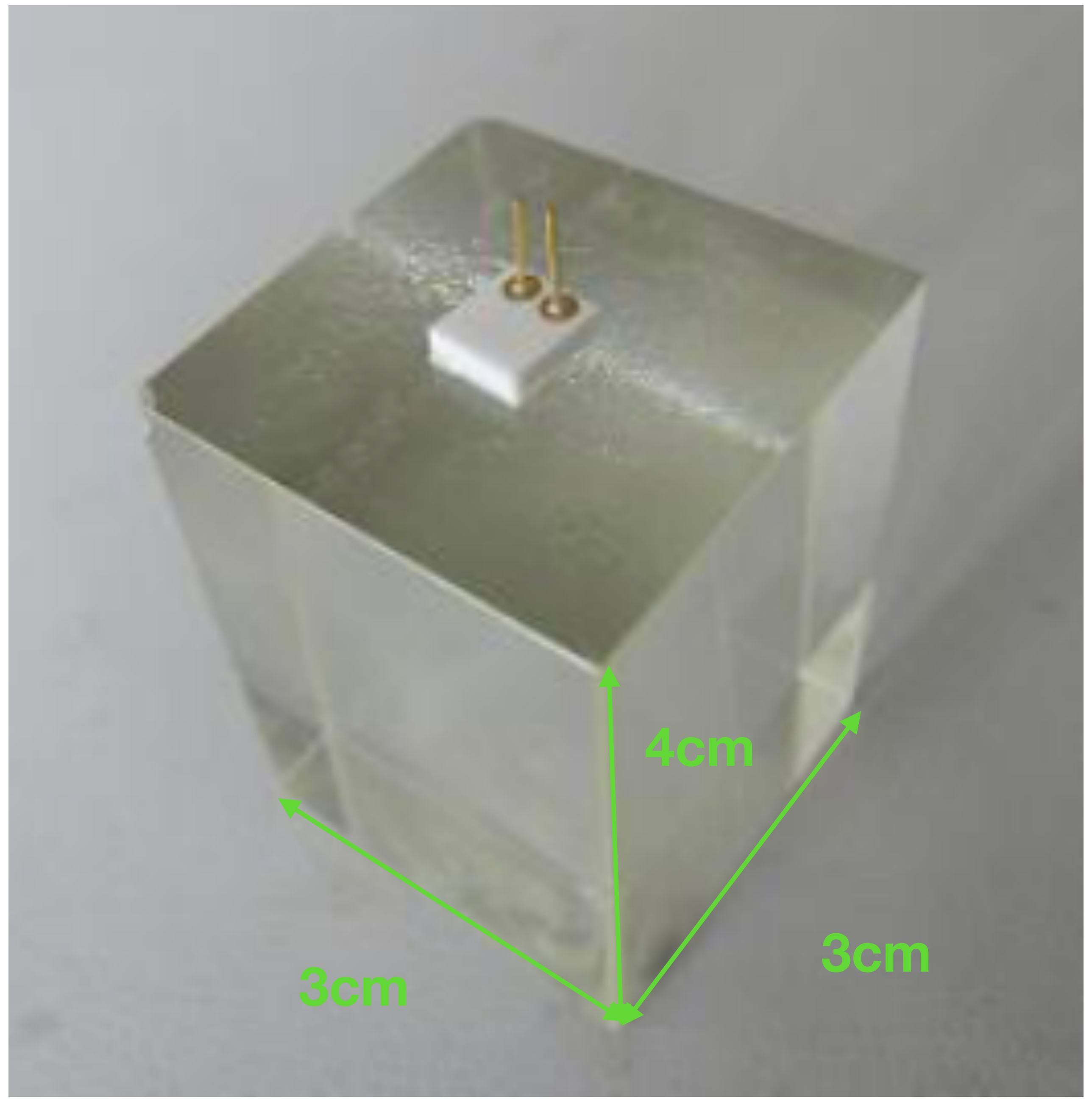


Particle Flow Algorithm

Introduction of active absorber CAL

- Lead glass is a candidate for active absorber layer.
- Lead glass is transparent, so Cherenkov light can be measured with an optical sensor.
- Lead glass is inexpensive compared to crystal scintillator.
- In order to suppress dead volume and independently optically read a large number of blocks, it is necessary to install the thin photo sensor.
- Since MPPC is very thin and small, it can be used for this detector.

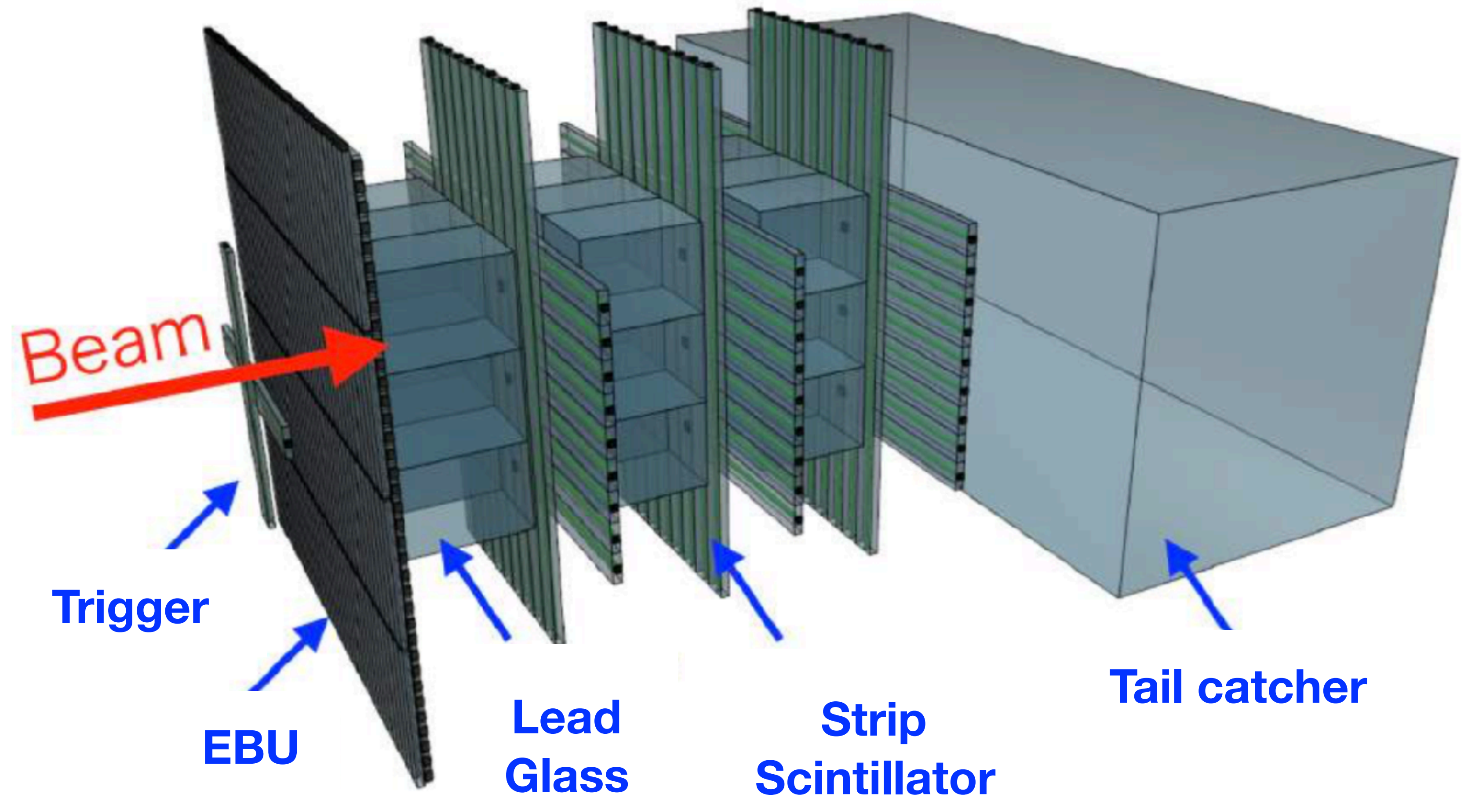
- The calorimeter using information on the absorption layer has the possibility of both ECAL and HCAL.
- We created an electromagnetic calorimeter prototype that can be made compact.



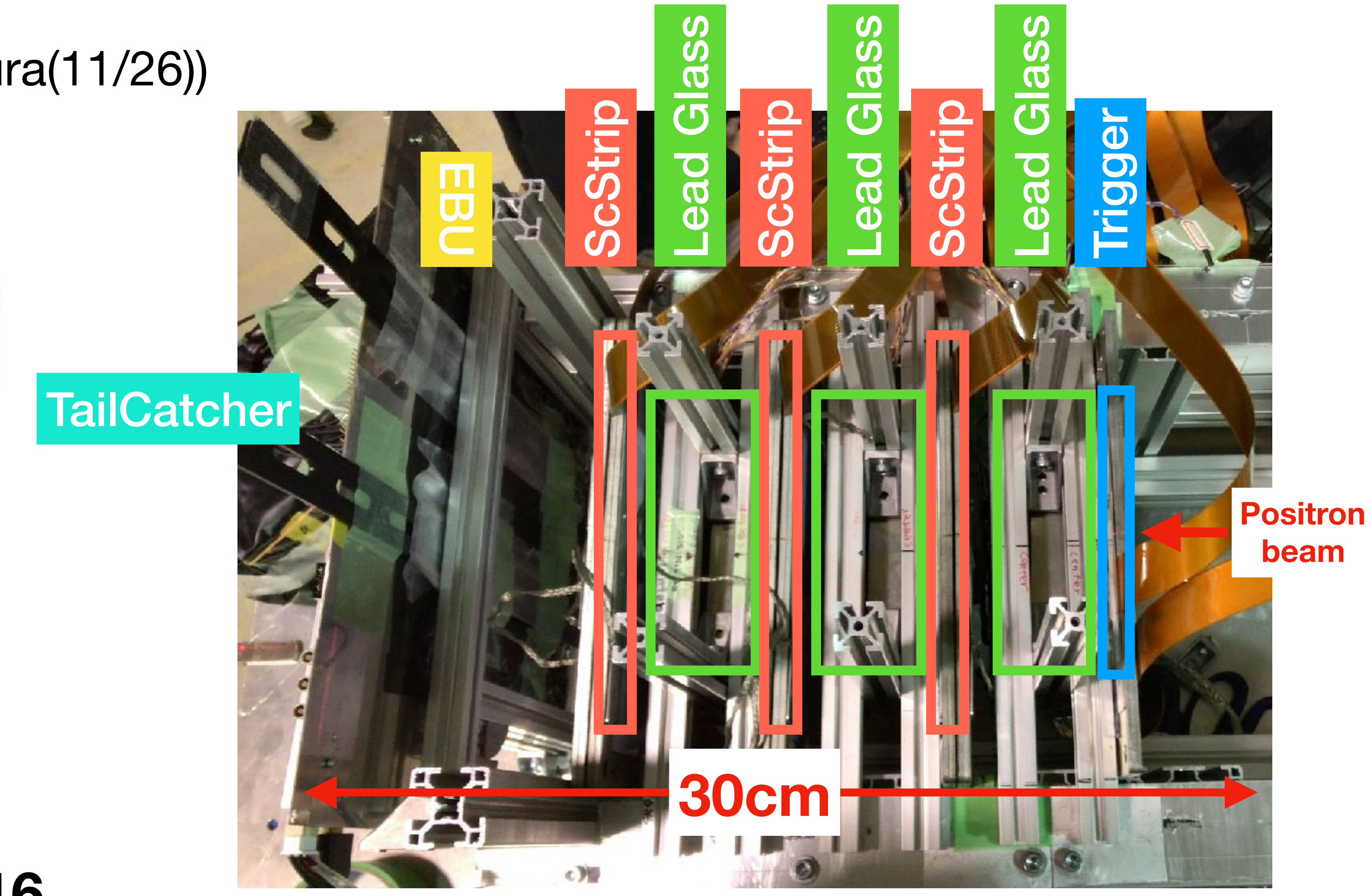
Lead glass block and optical sensor (MPPC)

Prototype of active absorber ECAL

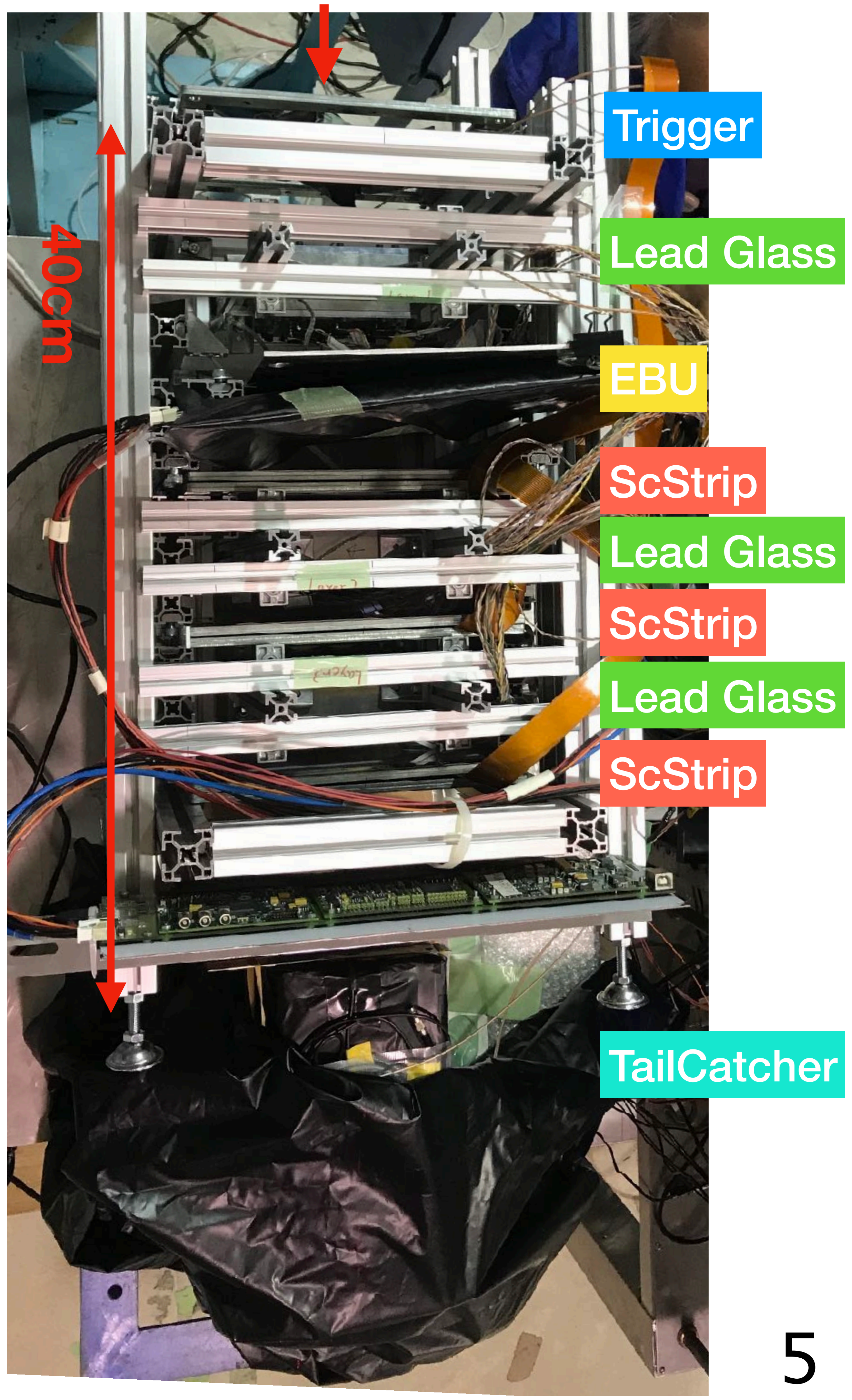
- We manufactured 3 layers sampling calorimeter as an active absorber ECAL.
- Segmented lead glasses with MPPCs as an active absorber layer.
- Finely granulated detection layer using strip scintillator.
- Tail catcher made of a large block of lead glass at the end of the setup.
- We did test at 3 times (2016, 2017, 2018) at ELPH at Tohoku University
- Injection of 50MeV to 800MeV positron beam.
- We also tested EBU at the same time (talked by Yoshiura(11/26))



Active Absorber Prototype at test beam in 2016



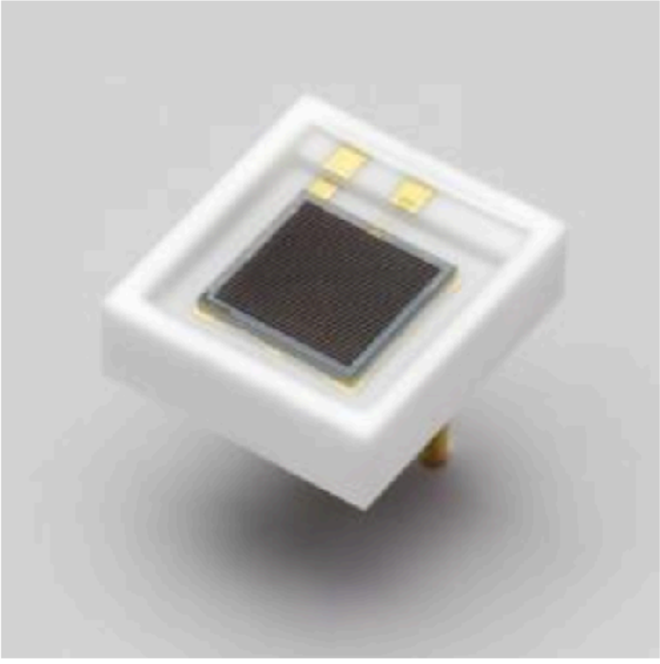
Top view of 2018 prototype



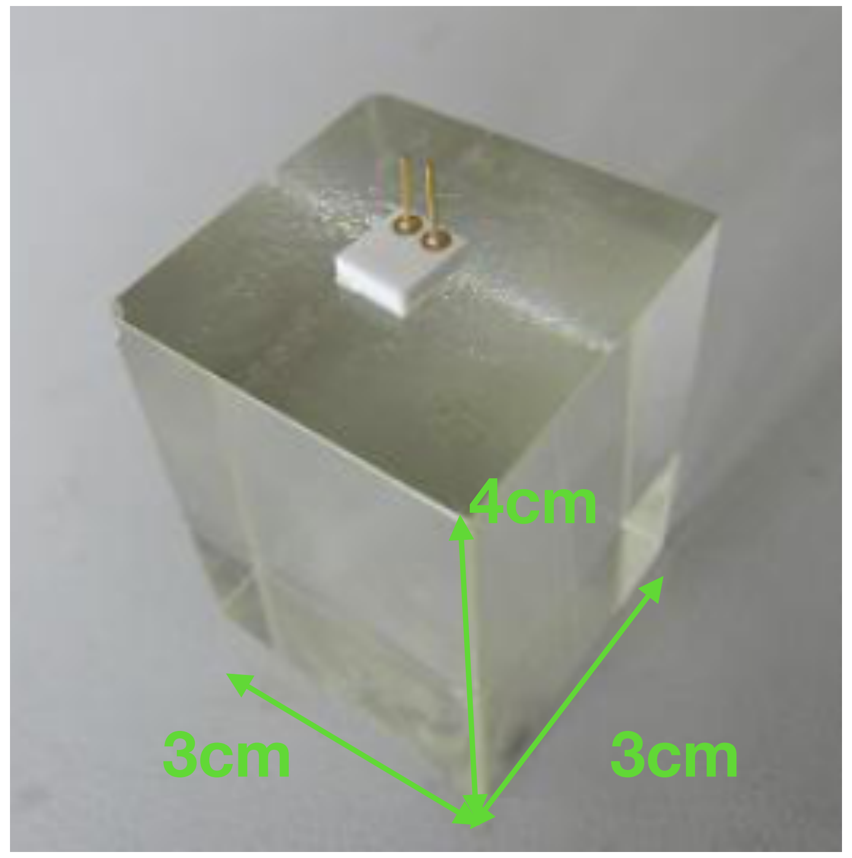
Top view of 2017 prototype

Active absorber layer

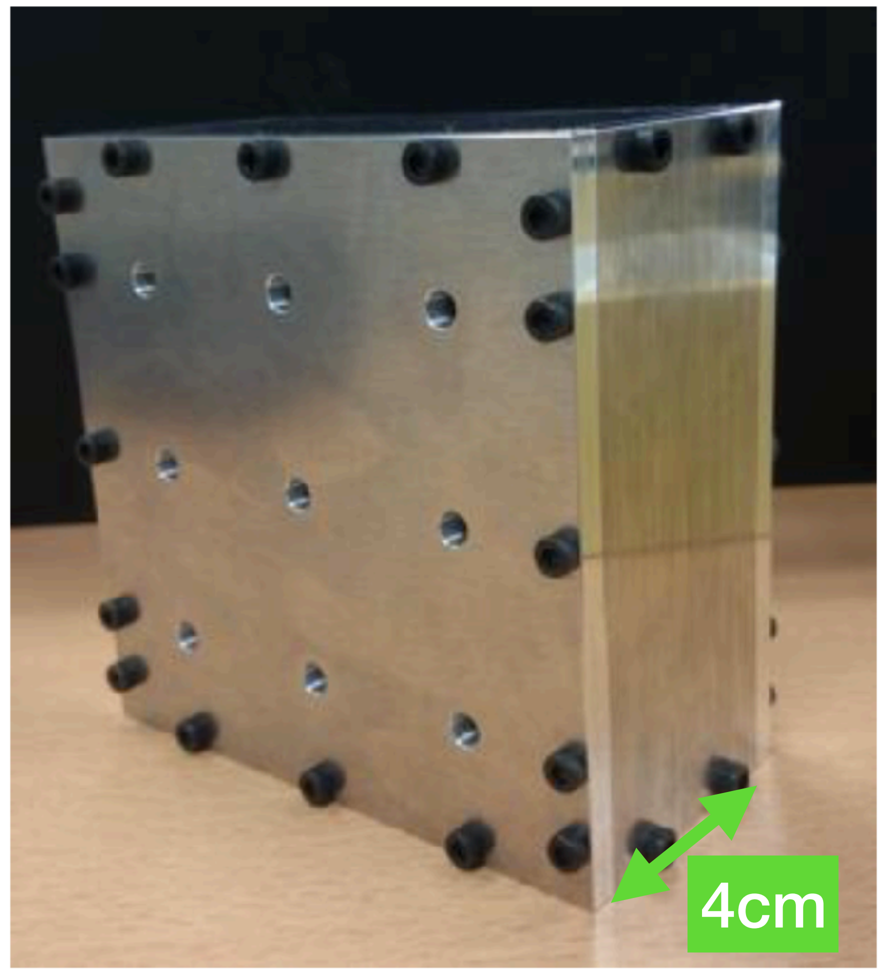
- Lead glass is segmented in size of 3 x 3 x 4 cm^3 for PFA.
- 1 block (4cm thickness) $2.4X_0$ (X_0 = 1.7 cm)
- Using a 3 x 3 mm^2 MPPC(2 types) for optical readout with optical grease
  - 50μm pitch(S13360-3050CS) used 2 layers 75μm pitch(S13360-3075CS) used 1 layer
- To read out each lead glass independently, each block was enveloped with reflector.
- 1 layer has 9 lead glass blocks (3 x 3 ch lead glass blocks array) and we manufactured 3 layers
- 27 MPPCs are read by an EASIROC Module
- Pre-calibration of the layer at the bench test was done with cosmic muon



3 x 3mm^2 MPPC



Lead Glass Block

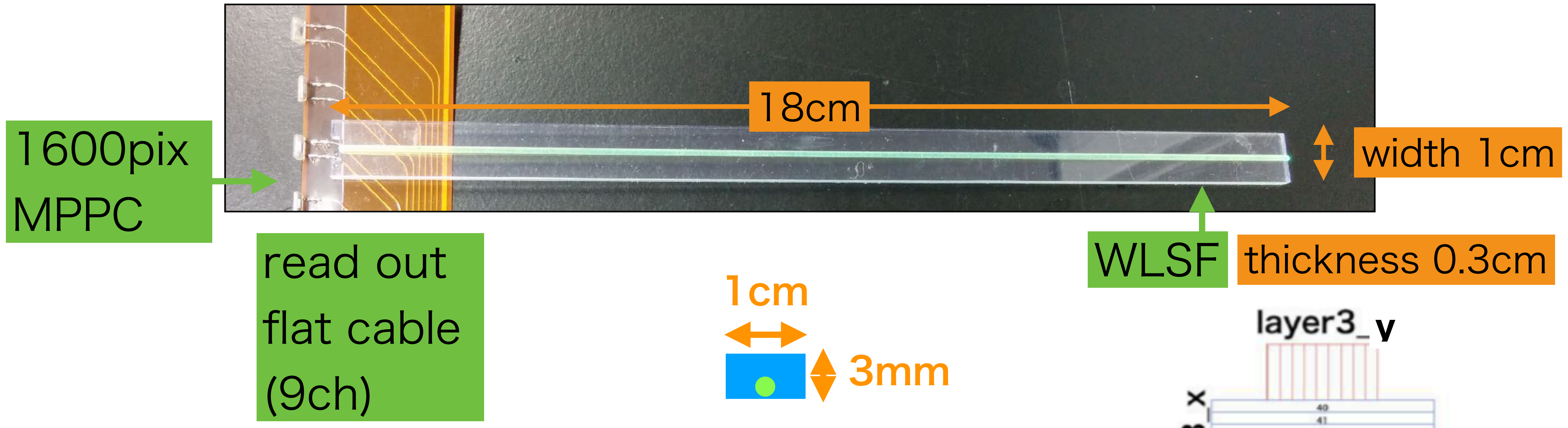


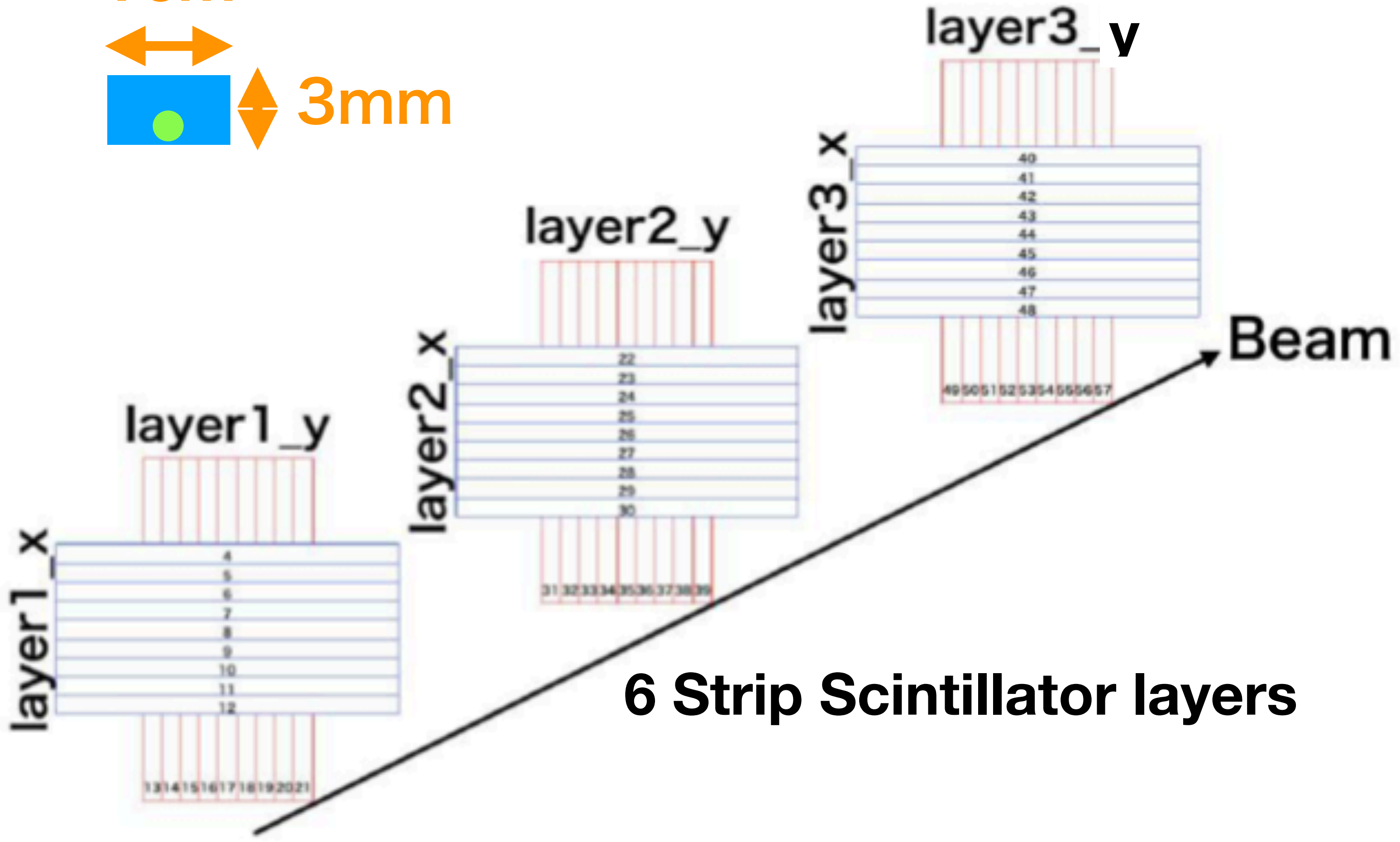
Active Absorber Layer

Lead Glass blocks Array

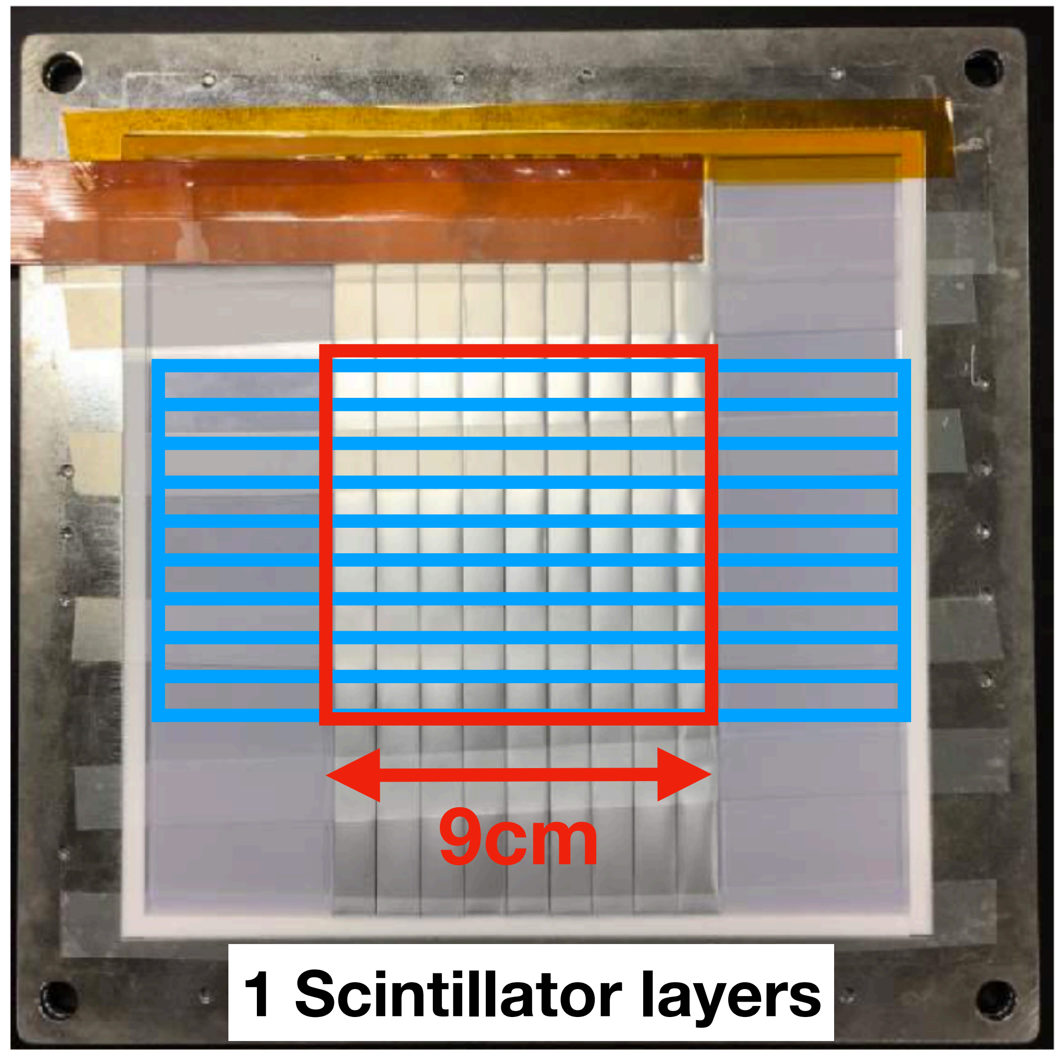
Strip scintillator layer

- A scintillator layer was created with a 9 x 9 cm^2 sensitive area.
- This is the same sizes as the sensitive area of the lead glass layer.
- 9 strip scintillators (EJ-204) with 18 x 1 x 0.3 cm^3 were used for the scintillator layer in one direction.
- Assembling strips in a pair of layers orthogonally each other make the resolution to be 1 x 1 cm^2. It has better position resolution than lead glass.
- Enveloped with 3M reflector film.
- Read out by a MPPC(1 x 1 mm^2, 25μm pitch) with wavelength shifting fiber (Y-11).
- We manufactured 6 layers.
- Pre-calibration of the layer at the bench test was done with cosmic muons and ^{90}Sr.

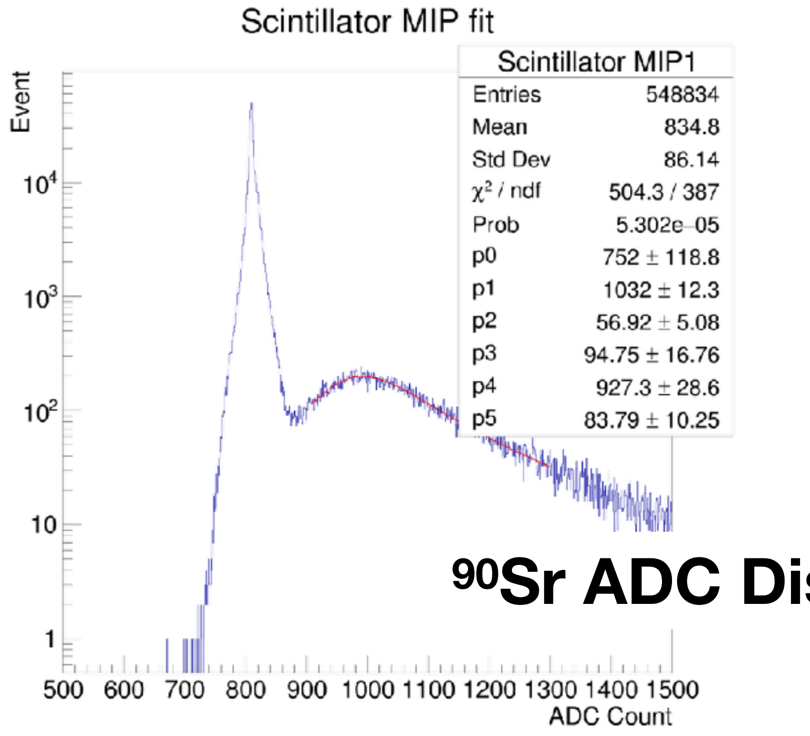




6 Strip Scintillator layers



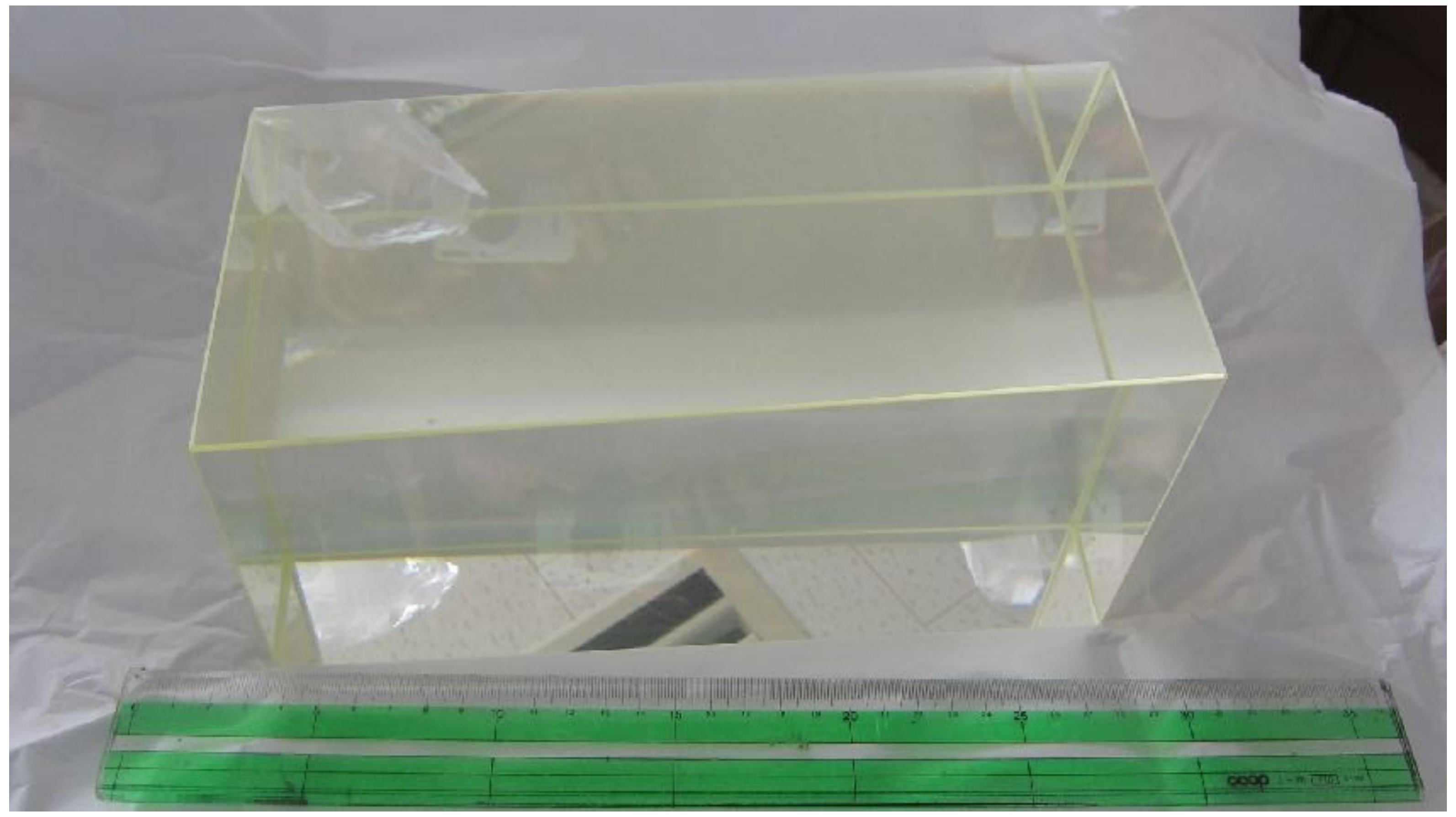
1 Scintillator layers



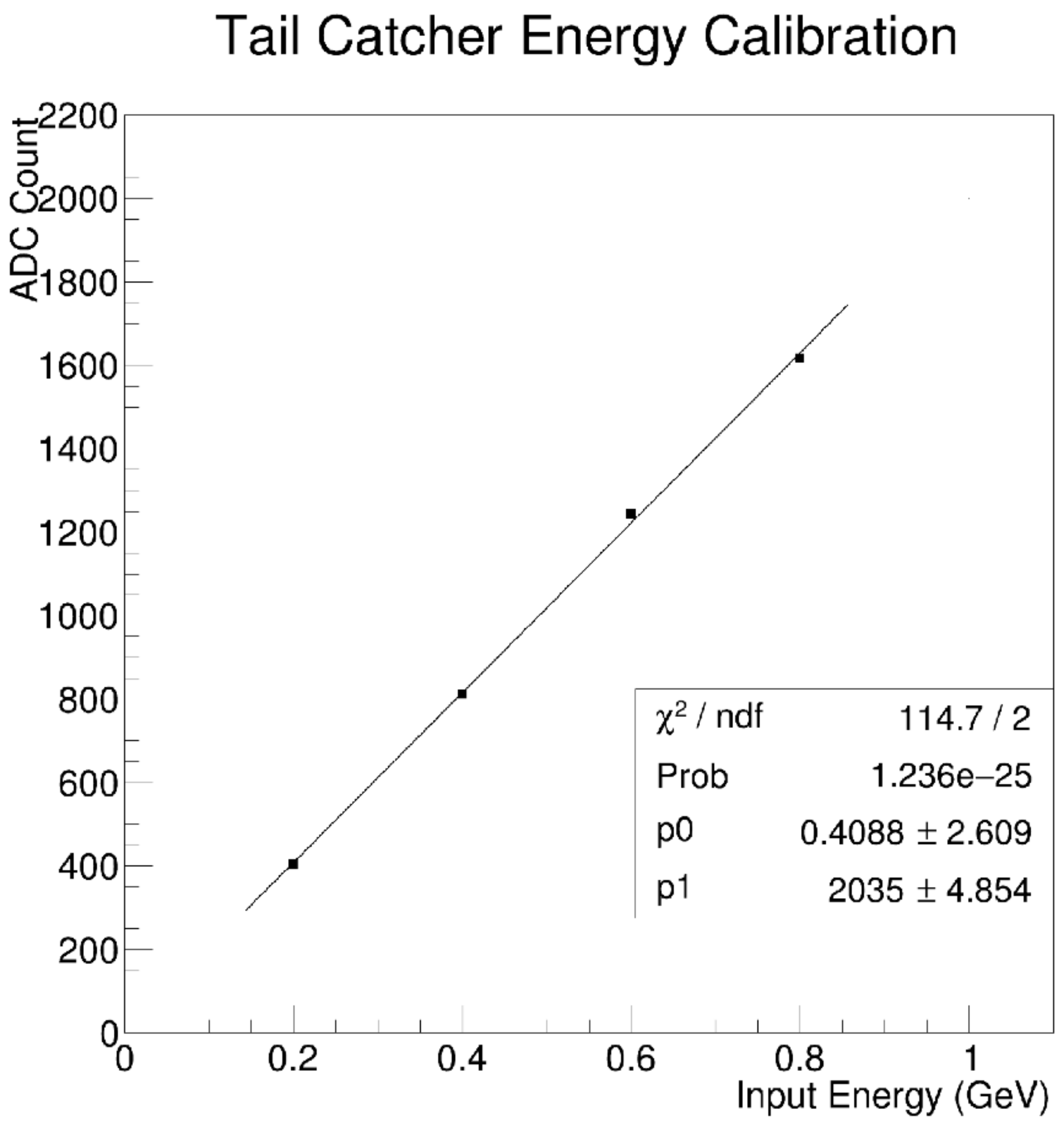
^{90}Sr ADC Distribution

Tail Catcher

- Tail Catcher
  - Put most down stream at beam line
  - Detect energy leakage
  - Single large lead glass bock (12x12x25cm^3)
  - Optical read out is two 12 x 12 mm^2 MPPC
  - This MPPCs glue directory of tail catcher
  - Perform energy calibration with beam
  - Good energy linearity



12x12x25cm^3 lead glass block

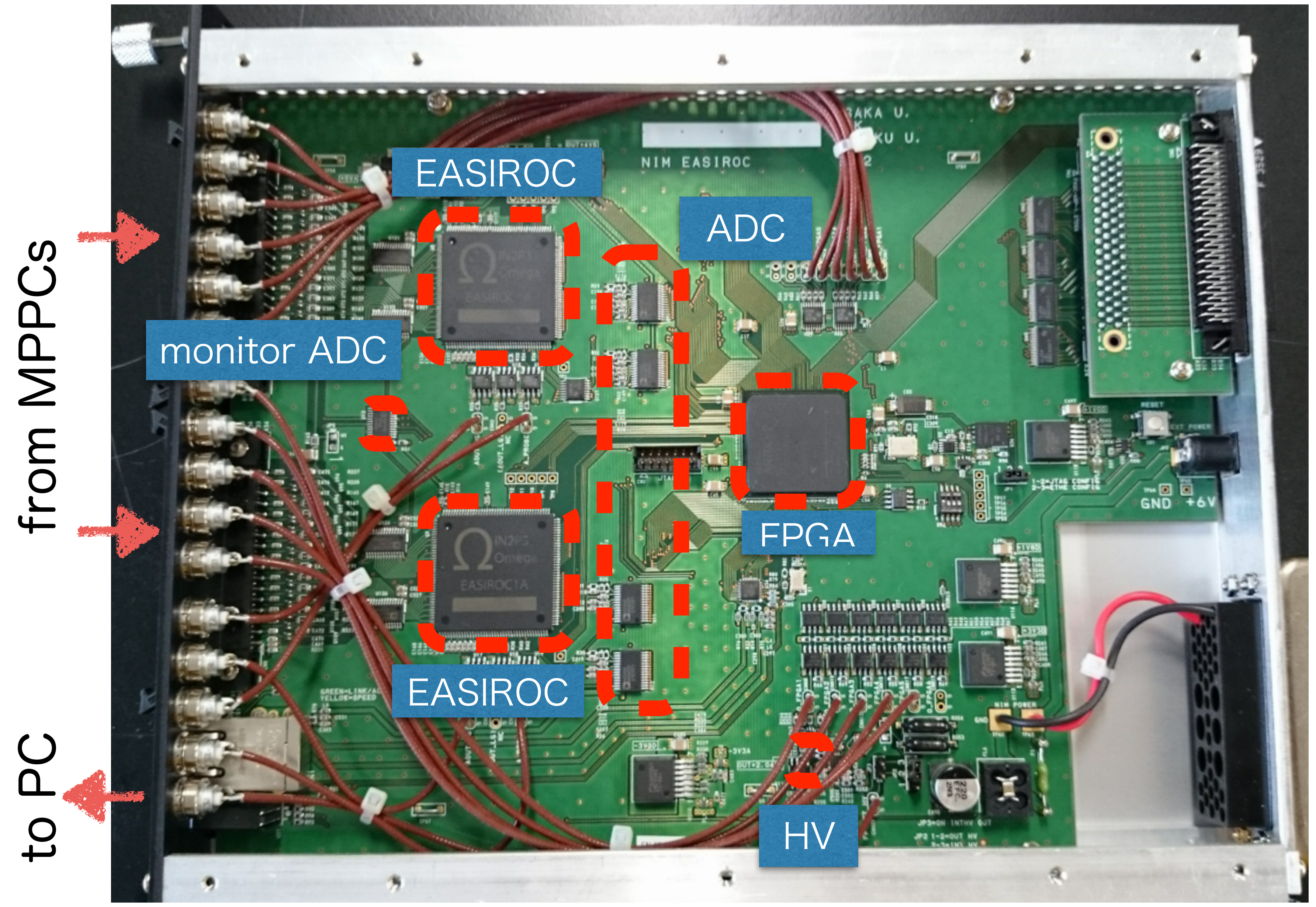


Energy linearity of 2017 TB result

Tail Catcher

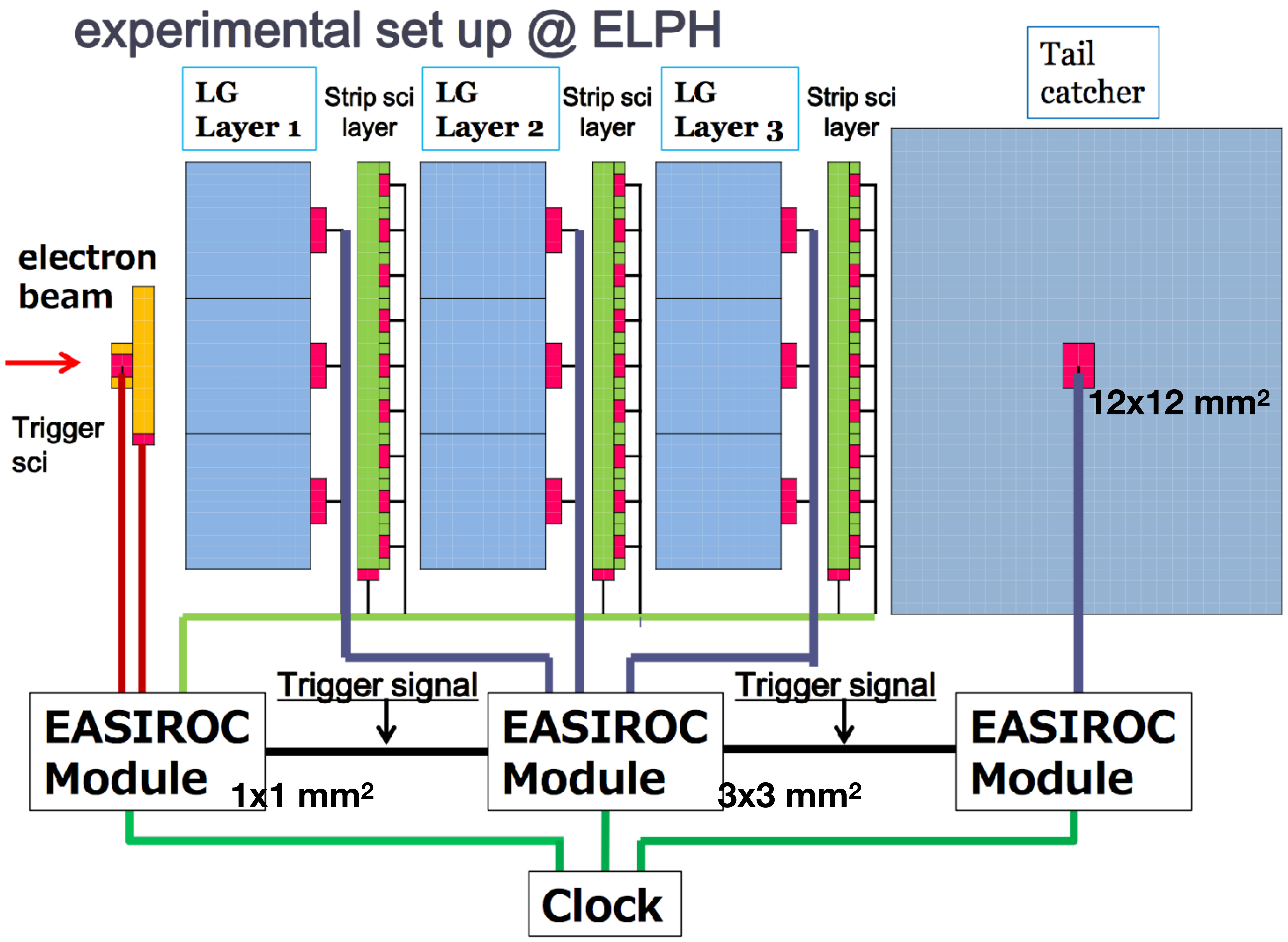
EASIROC Module

- DAQ system uses EASIROC Modules
- Developed by KEK and OSAKA University for MPPC
- We have modified the FPGA firmware and added TDC and coincidence functionality
- Multiple modules can be synchronized by external clock
- A module equips two EASIROC chips (developed by Omega) for 64 channels
- Includes ADC, TDC and HV power supply
- Controlled by PC via Ethernet



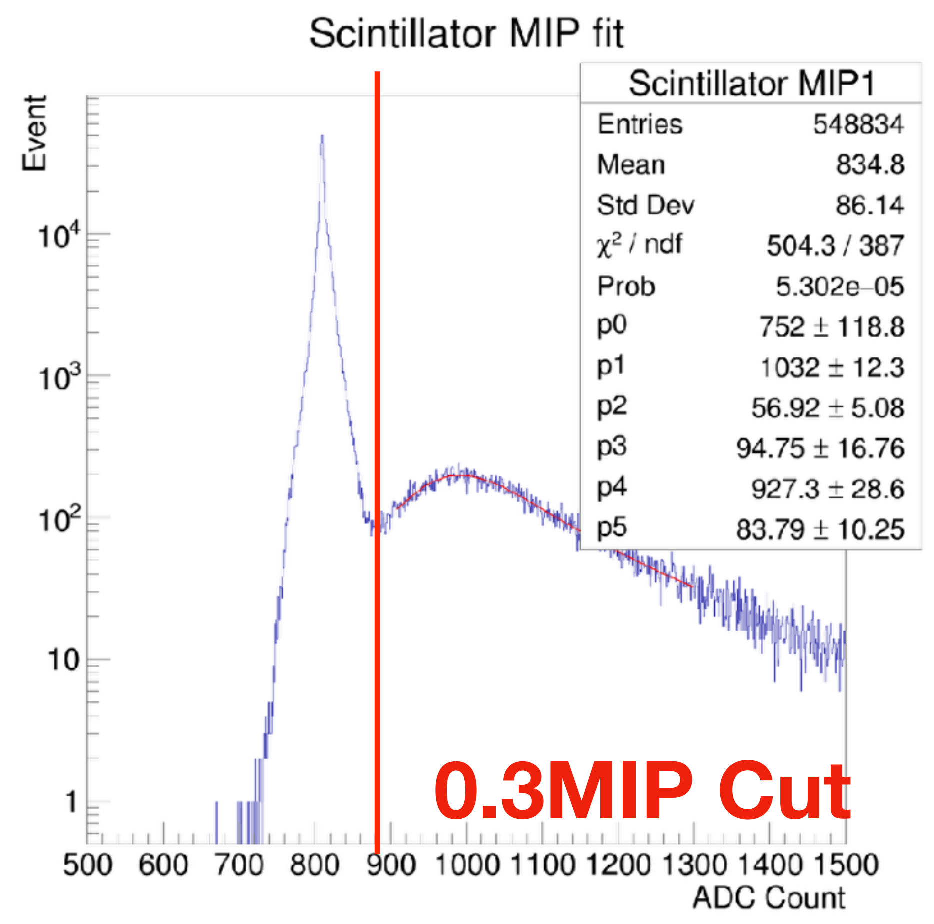
Read out and Trigger system

- This prototype has 83 MPPCs with out trigger.
- 3 EASIROC Modules to read out MPPC signals for 3 types MPPCs as different breakdown voltages. (1 x 1 mm^2, 3 x 3 mm^2, 12 x 12 mm^2)
- Trigger signals are made by one EASIROC Module for events with signals from 2 trigger scintillators coincidence.
- Trigger signals are made by one EASIROC Module for events with signals from 2 trigger scintillators coincide.
- Trigger signals are fed into the other modules.
- All EASIROC Modules are read out with 250kHz and 40MHz synchronized clocks.

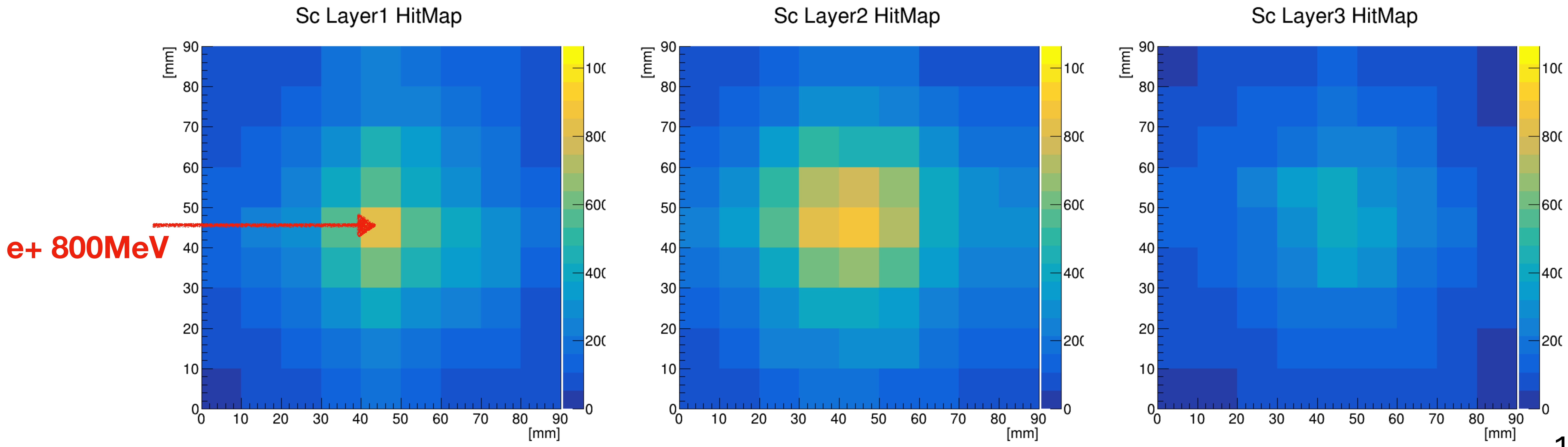


Read Out and Trigger system

Scintillator Hitmap (2017)



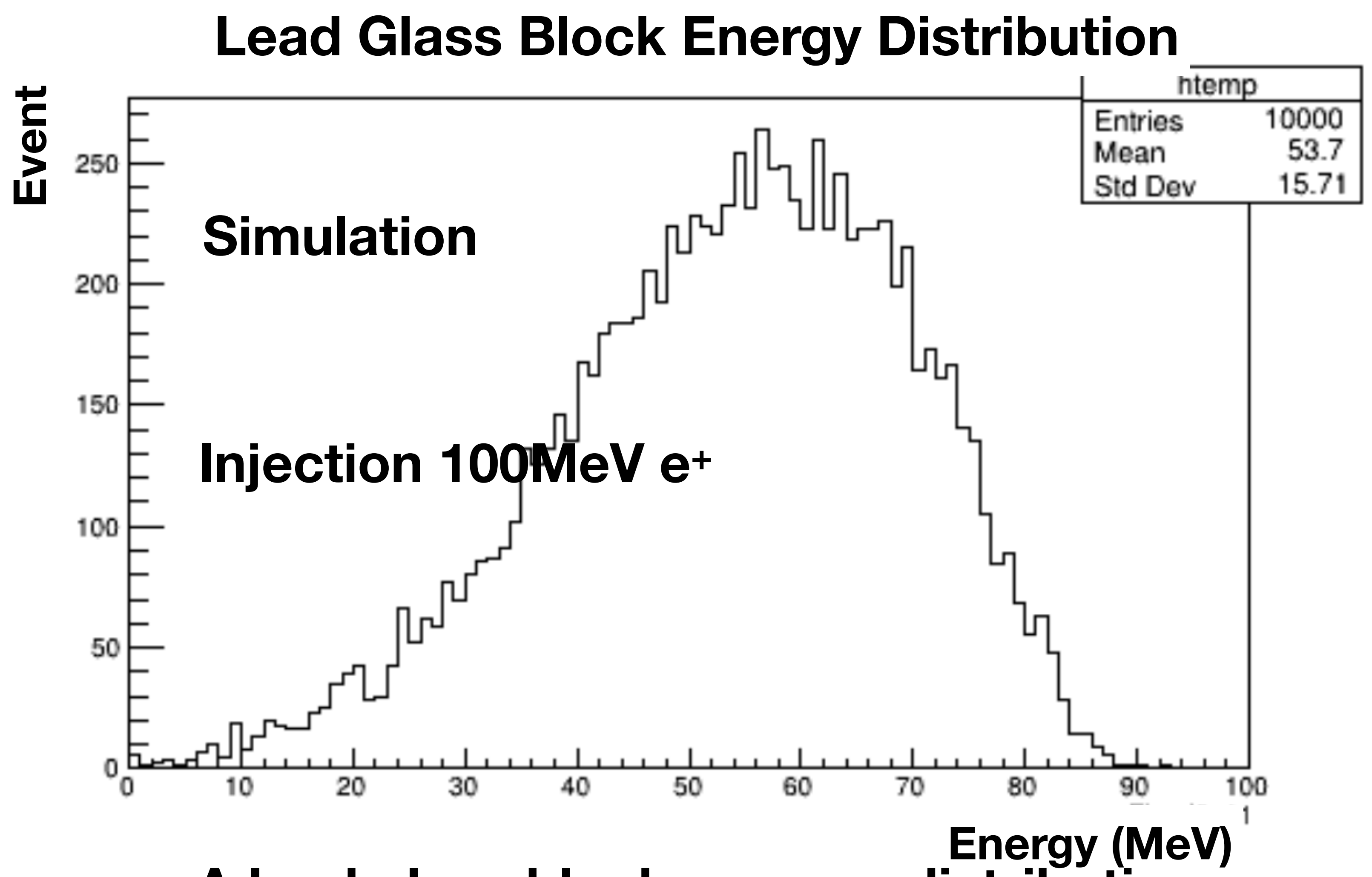
- Injection 800MeV positron
- Cut at 0.3 MIP and took the coincidence of X and Y layers
- We can see the development of EM shower
- All strip scintillator channels work well



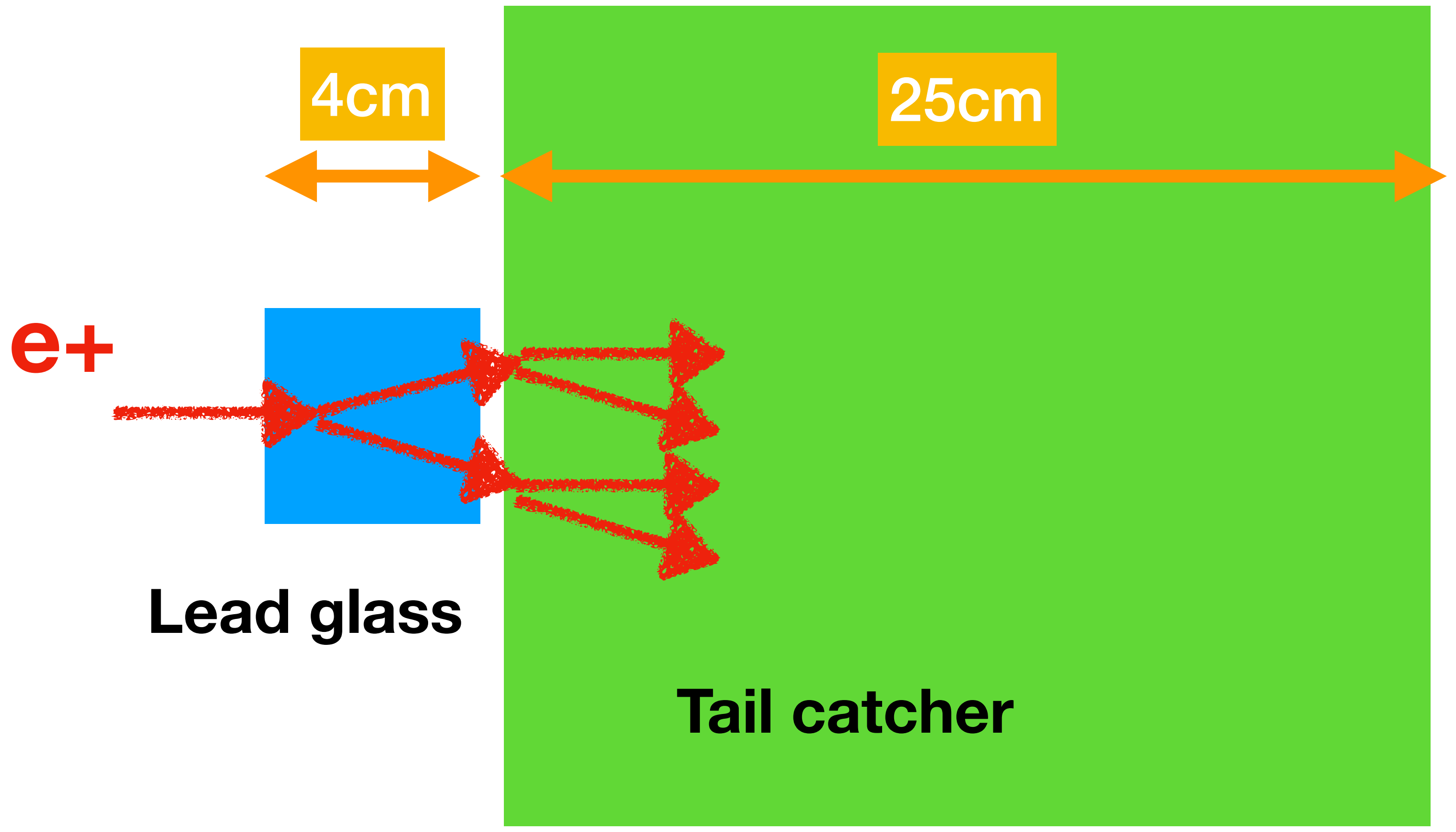
800MeV Sc Hitmap

Calibration of lead glass block

- Calibration is important for calorimeter.
- In the simulation, the mean energy deposit to the lead glass block was 53 MeV at 100MeV positron injection because of EM shower back leakage.
- intensity of 50 MeV position beam is insufficient at ELPH
- We calibrated a lead glass block in front of the tail catcher.
- Because the tail catcher is large, it is possible to catch up all energy.
- The performance of the tail catcher can be directly measured with a beam.
- By using this method, we can know the deposit energy in lead glass block.
- Tests were conducted by injecting energy of 100 MeV to 800 MeV into 3 lead glass blocks out of 27 (only) at 2017 TB because of big beam machine trouble.
- We did calibrate all the lead glass blocks 2018 TB at 400MeV positoron.



A lead glass blocks energy distribution of 100MeV positrons injecting



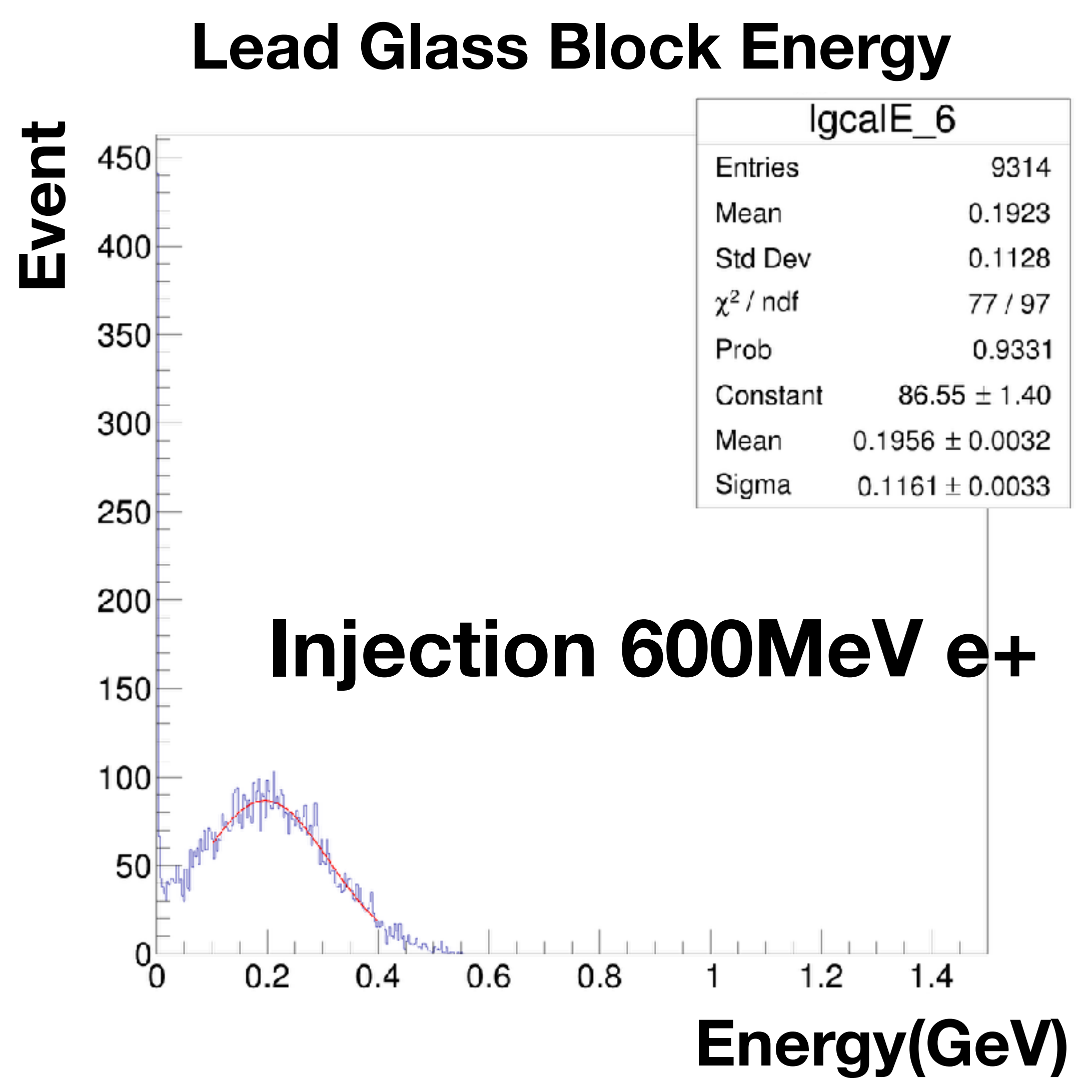
calibration method at 2017 test

Energy deposit of one Lead Glass Block

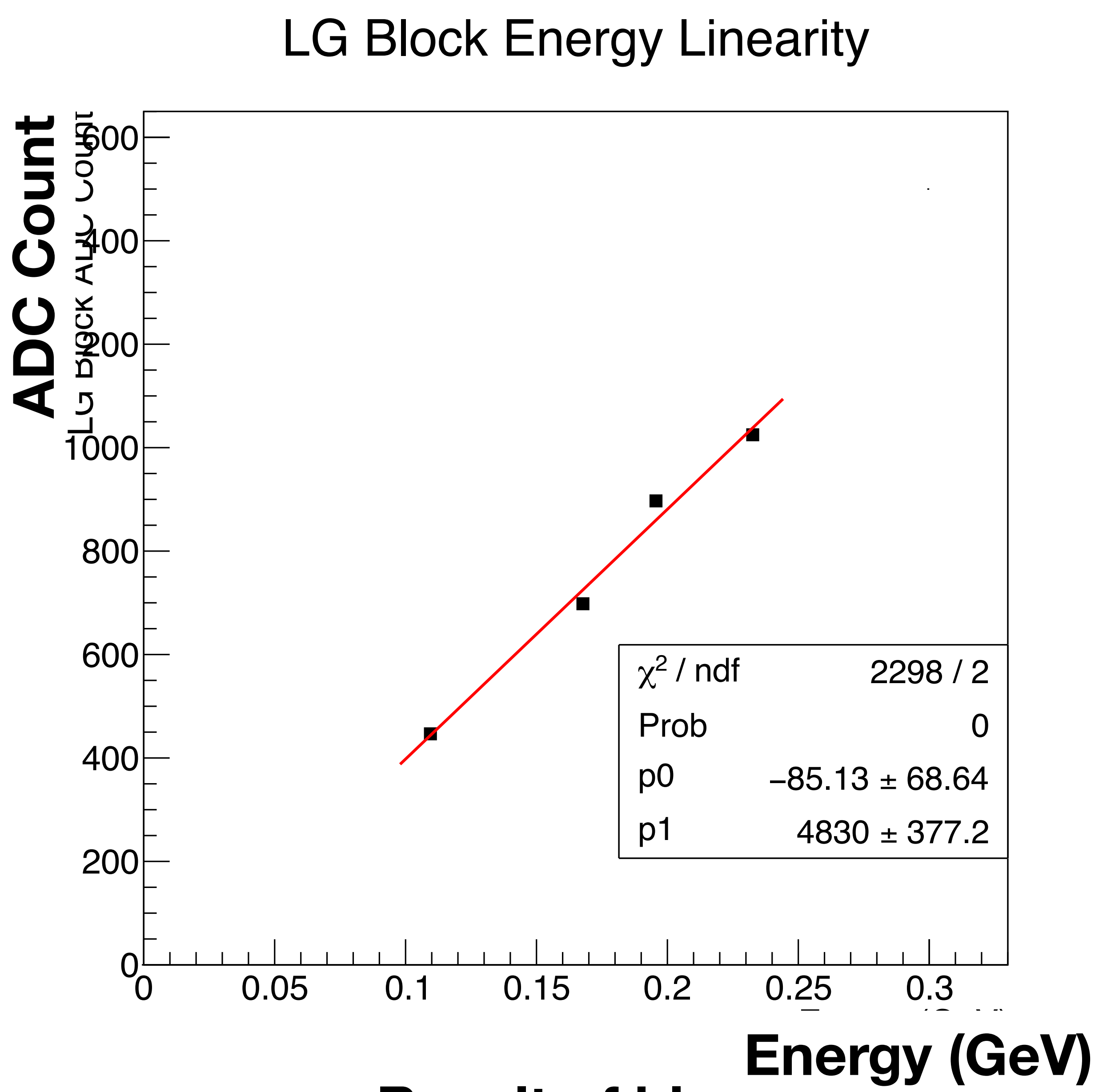
- Energy deposit of one lead glass block is able to calculate of lead glass ADC and tail catcher energy

$$E_{LG\ Block}\ (GeV) = E_{Injection}\ (GeV) - E_{TailCatcher}\ (GeV)$$

- The result of energy response is linear
- Also the intercept is close enough to zero
- From this result, the calibration factor (GeV to ADC counts) of the lead glass blocks were determined



One Lead Glass Block Energy Deposit

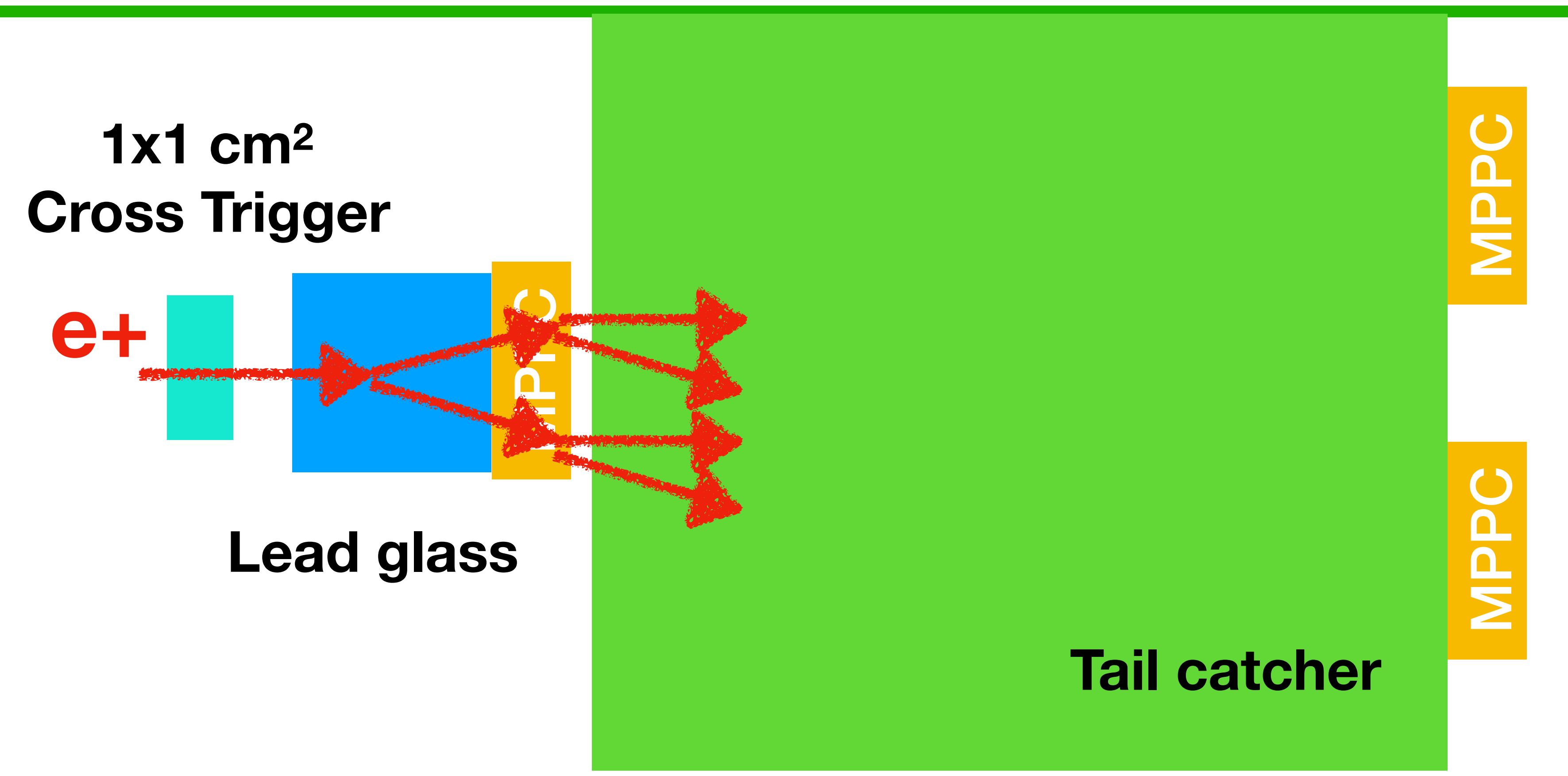


Result of block 1

Block Number (MPPC pixel)	Calib factor (ADC/GeV)
Block 1 (50μm pixel)	4830
Block 2 (50μm pixel)	5225
Block 3 (75μm pixel)	5774

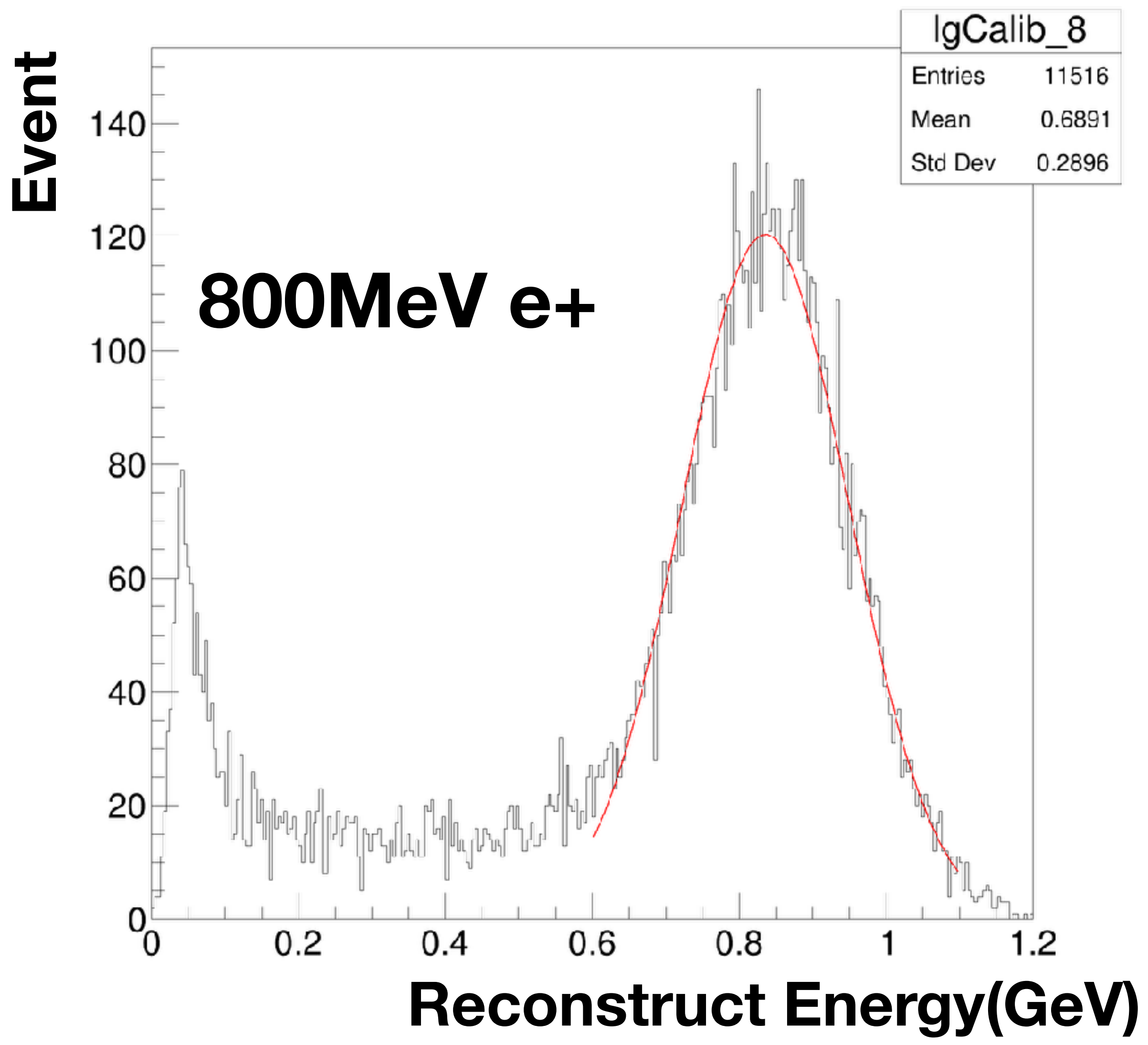
Total Energy Linearity

- After calibration, we reconstructed the total energy event by event (1 LG block Energy + Tail Catcher Energy)
- Energy linearity is good
  - The slope is slightly steeper than block-1 (6%)
- For all blocks, the each fitting lines have no offset
- We confirmed that energy calibration of lead glass block can be done in this method
- We need more investigation and do it for all channels

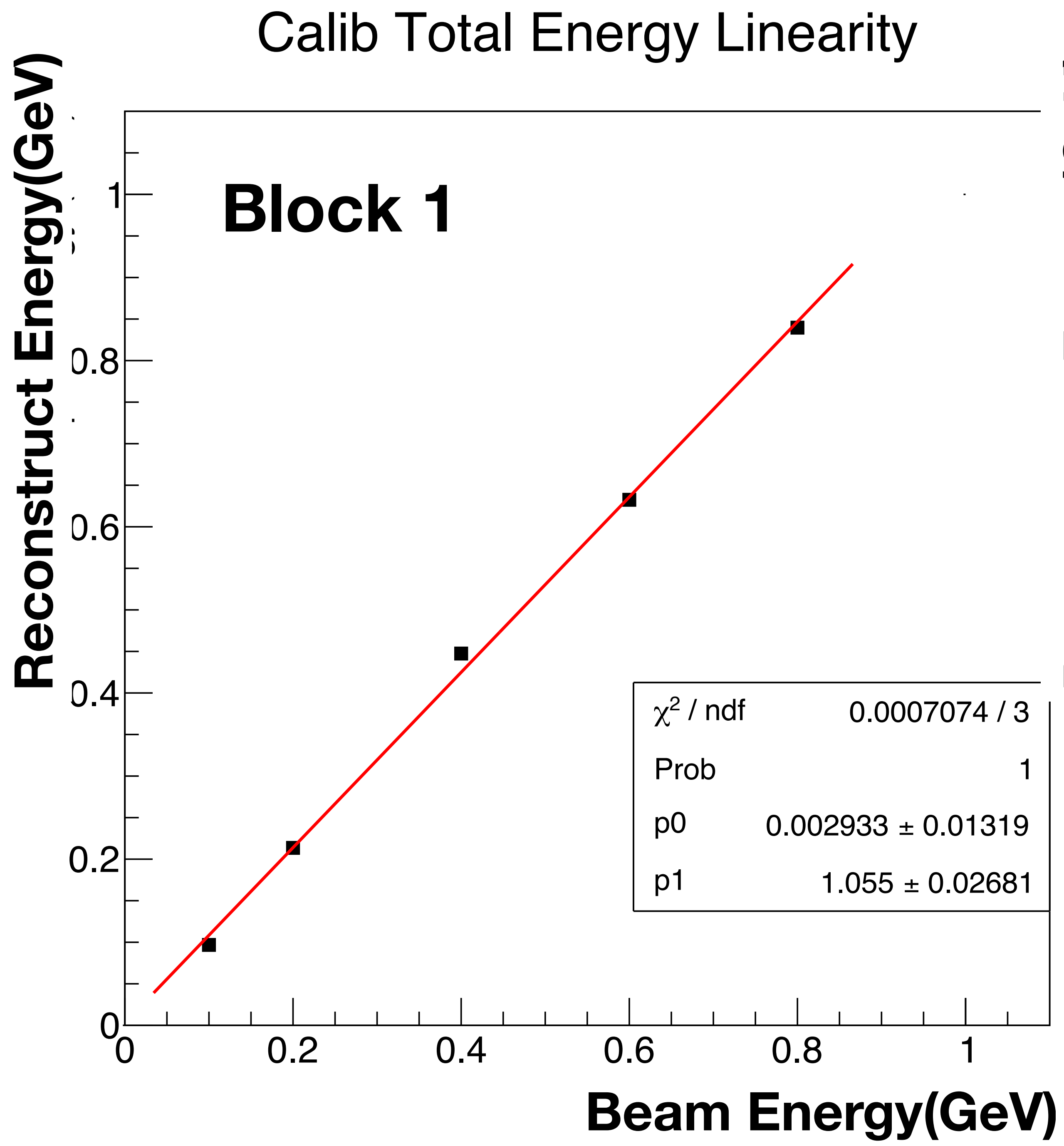


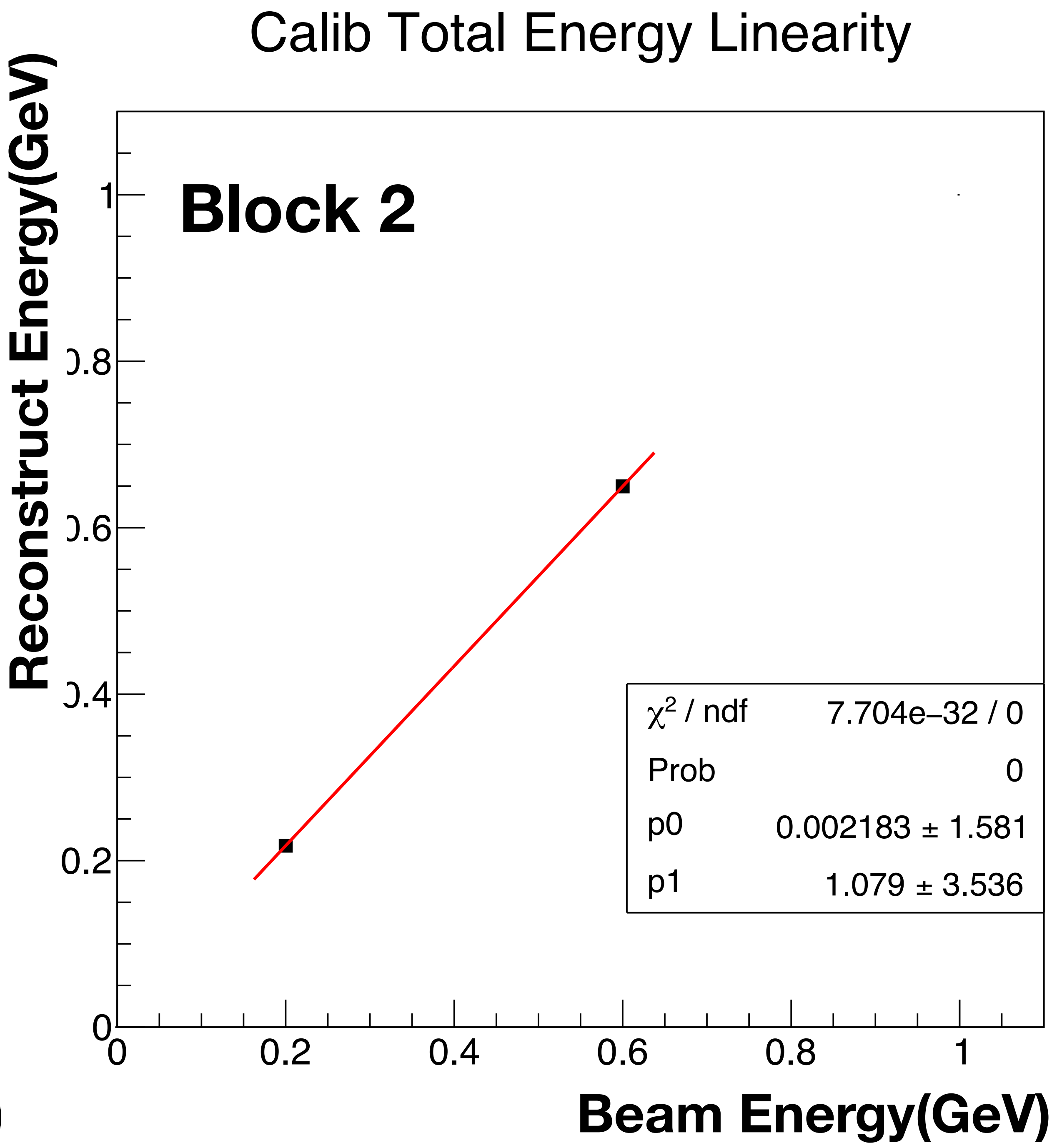
2017 Calibration method

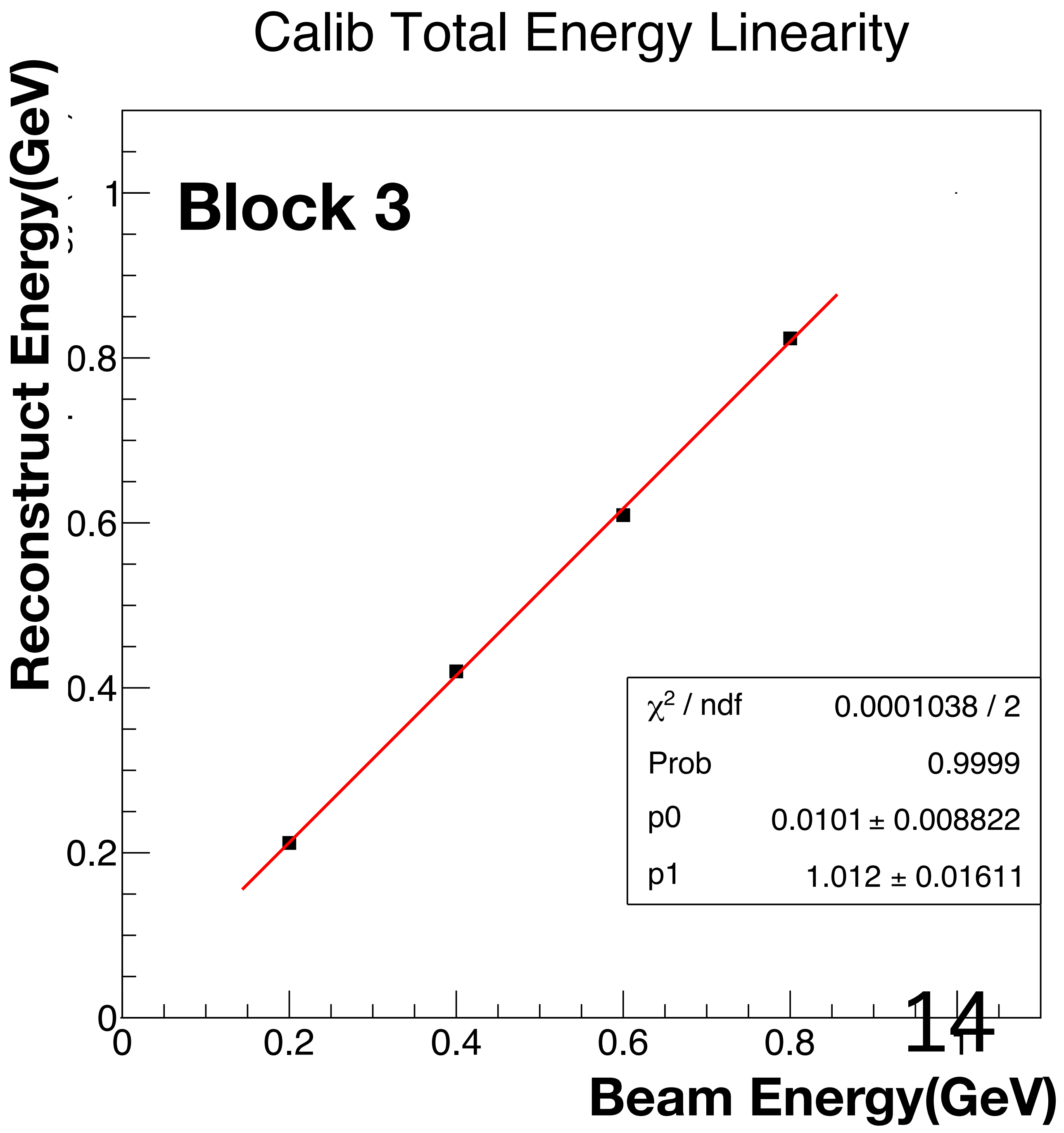
LG Block + TC Energy



Block 1 + TC
Total Energy Distribution

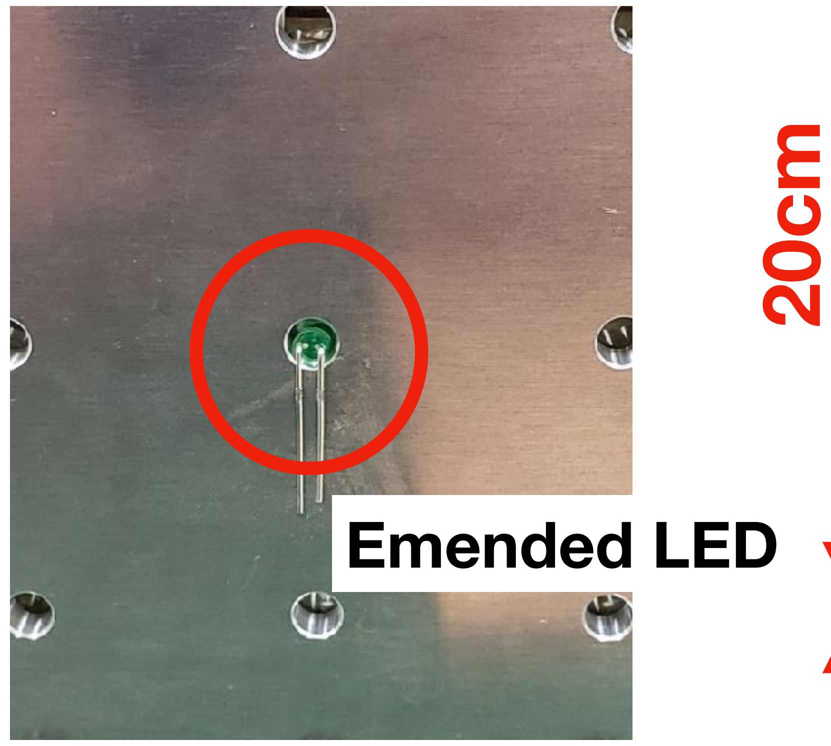


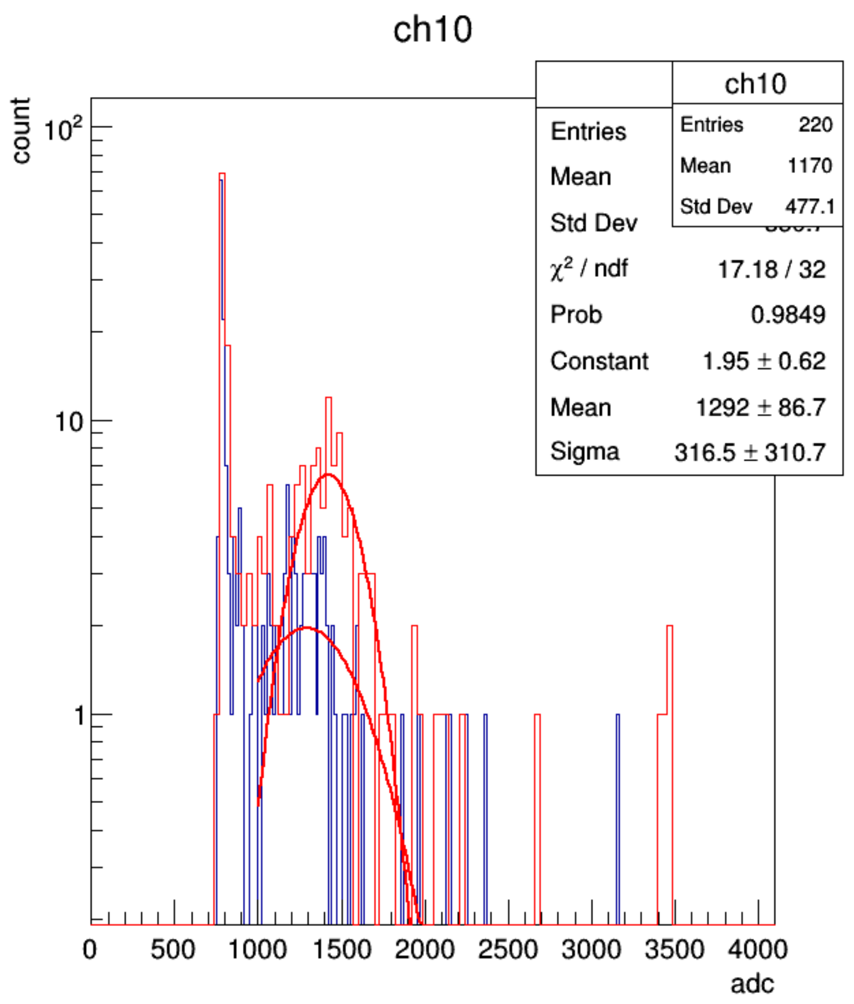


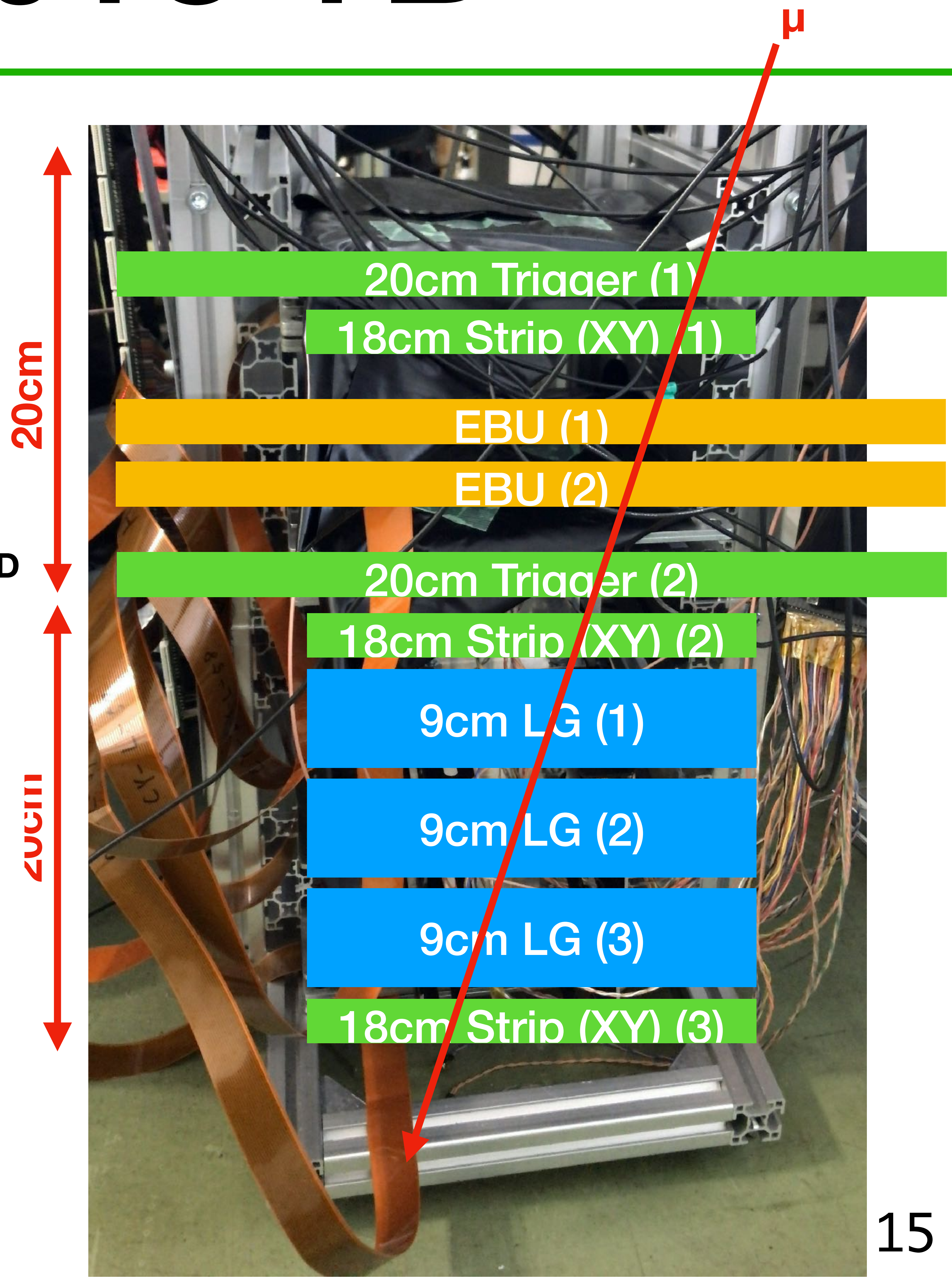


Preparation for 2018 TB

- Operation check of whole detector by cosmic muons
- We also pre-calibrate lead glass blocks by cosmic muons
- For calibration lead glass blocks, it is necessary to inject particles energetic enough to emit Cherenkov light (eg. cosmic muon)
- The energy deposit by a cosmic muon with 4cm thickness lead glass is estimated at 50 MeV
- The position can be detected by using information of strip scintillator layers
- We can see through muon peak and move peak different bias voltage
- Read line peak is 22 p.e (compare with LED calibration result)

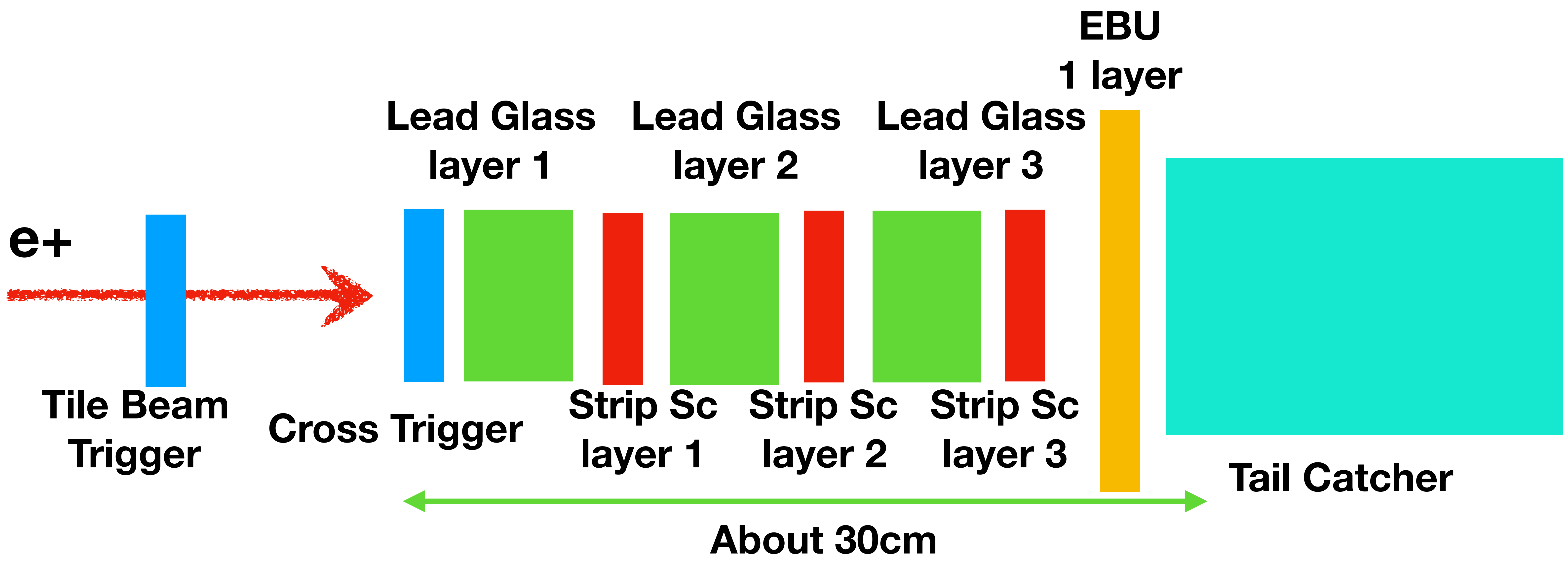






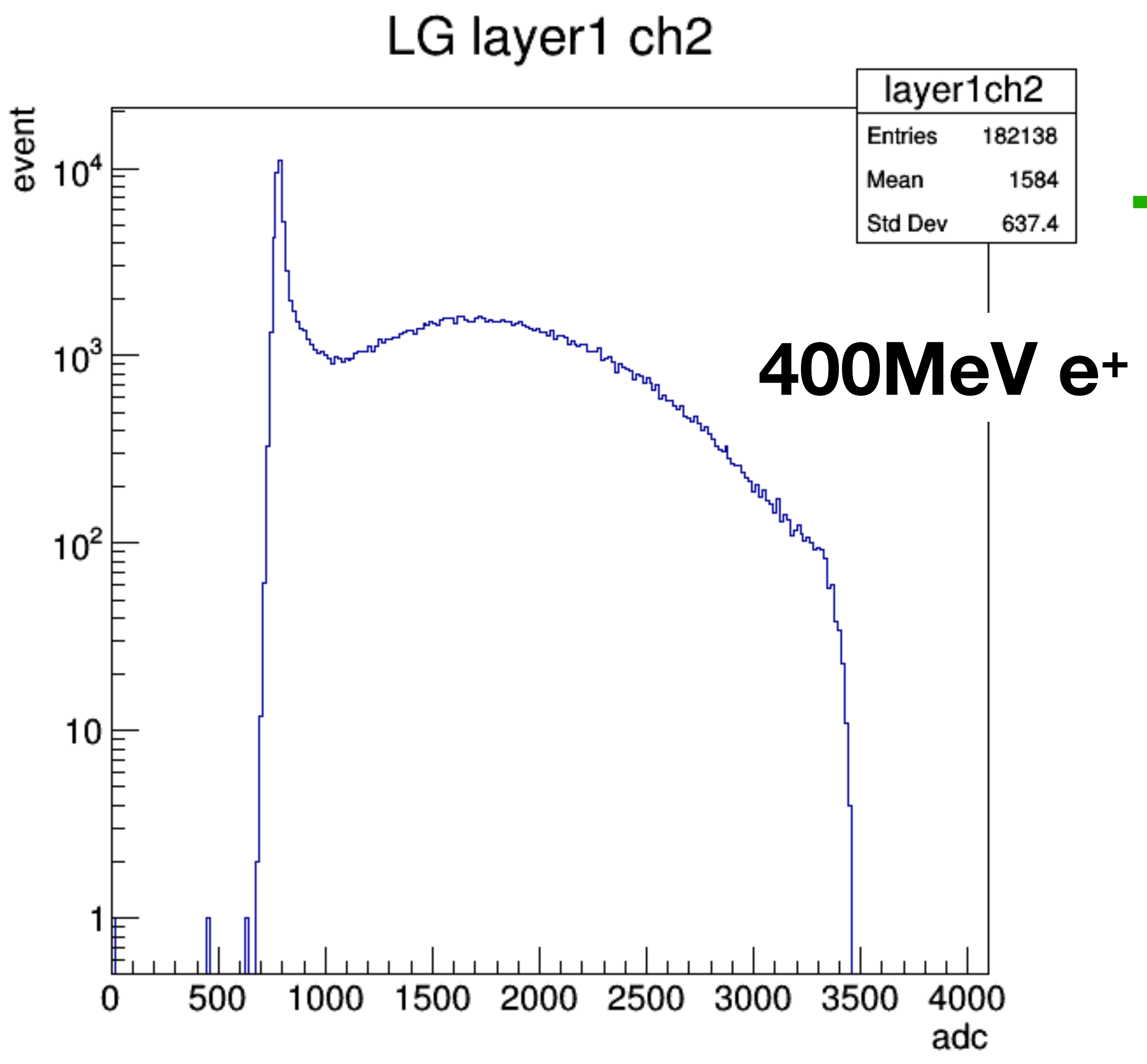
2018 Test Beam

- 2018 test beam, 22 to 25 November this year
- Our plan was approved and Our beam time will be 4days (48hours) at ELPH at Tohoku University.
- This test beam is focus
  - We did calibration all Lead Glass block channels with beam.
  - Close the detectors tightly because reduce shower leakage
- Measure the resolutions of energy and position for this prototype.
- Analysis is on going

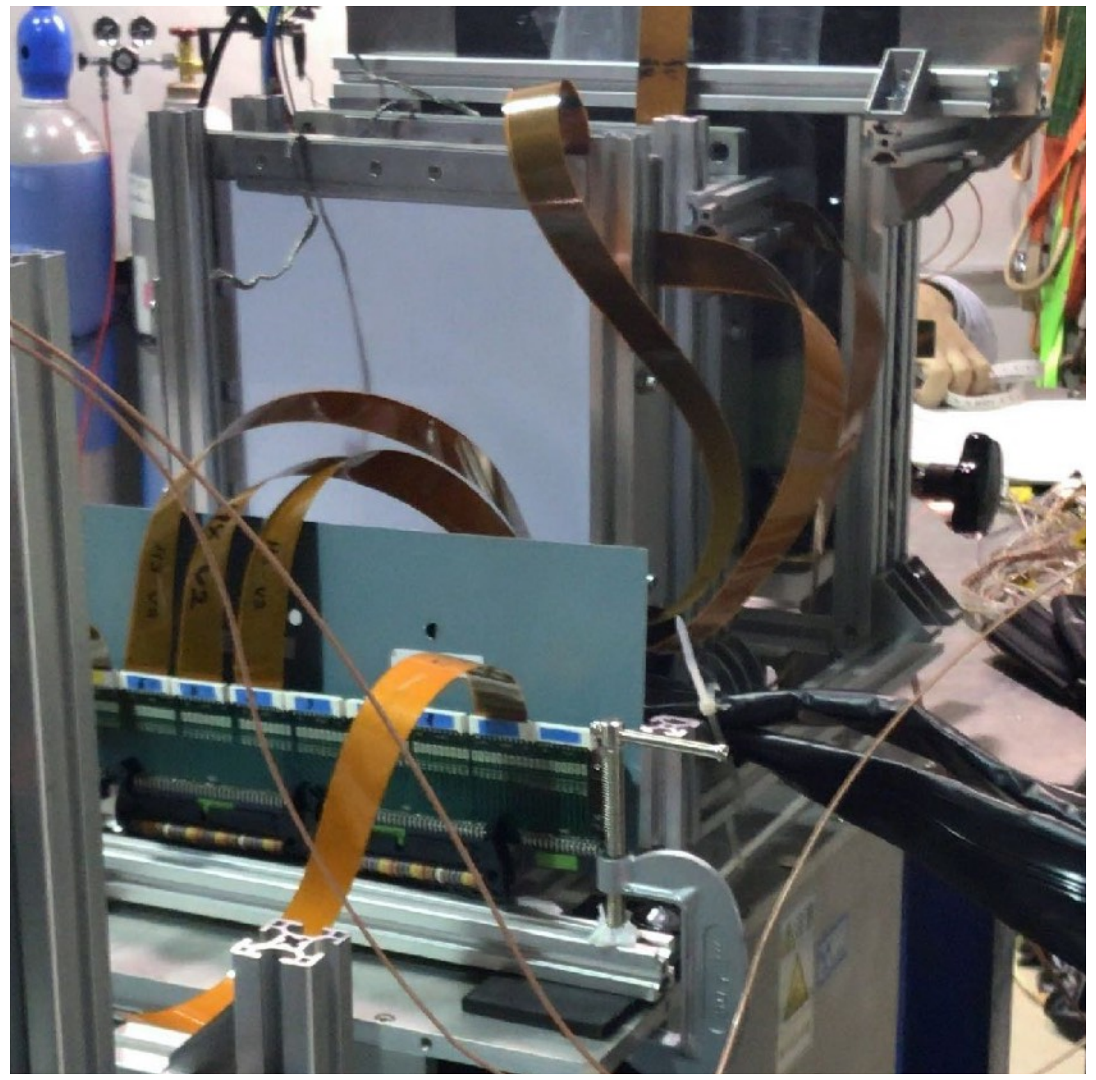


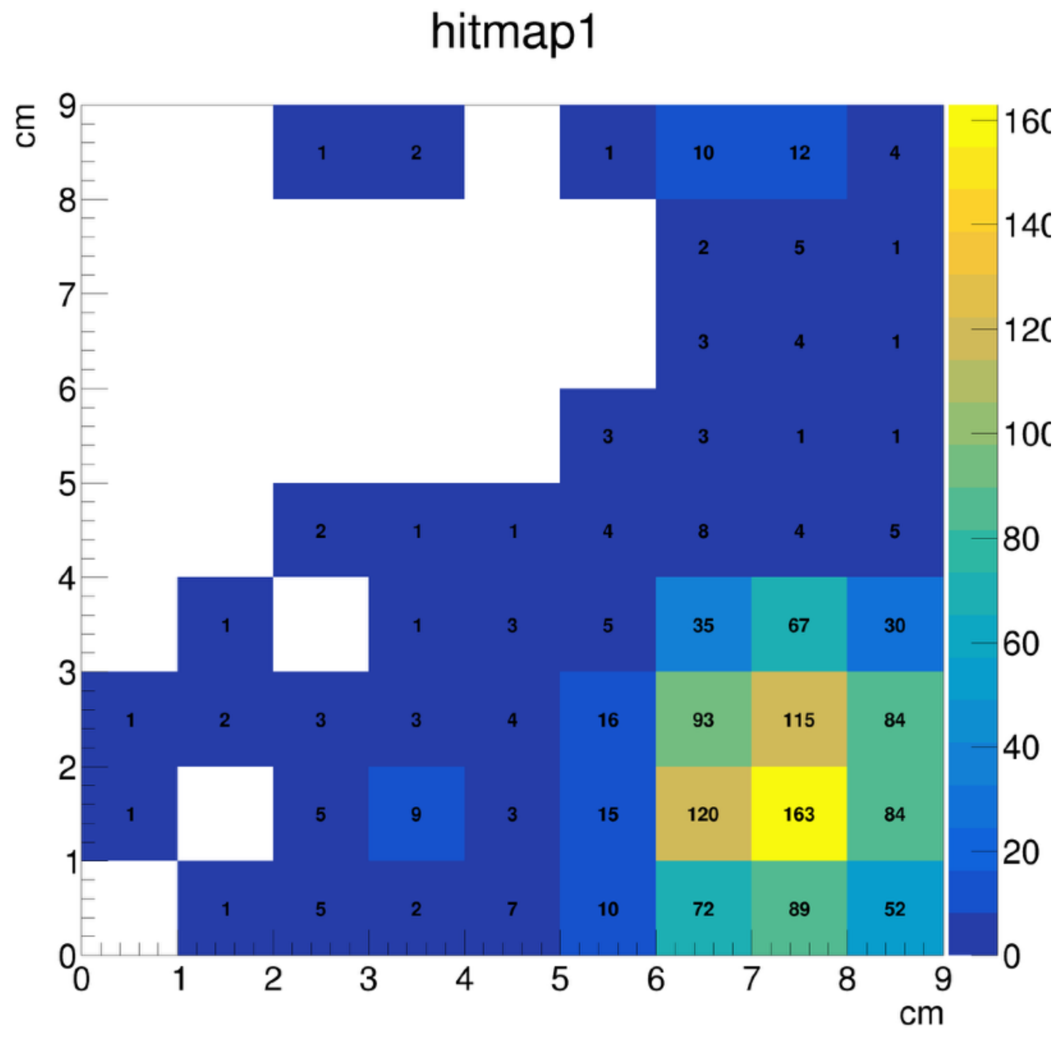
2018 Test Beam

- We did calibration all Lead Glass block channels with 400MeV beam.
- We moved the position of the detector using an electric moving stage by remote
- Beam position was confirmed by using strip layer in front of lead glass layer
- Lead glass at the center of the layer confirmed the response by changing incident energy(100, 200, 400, 600, 800MeV)

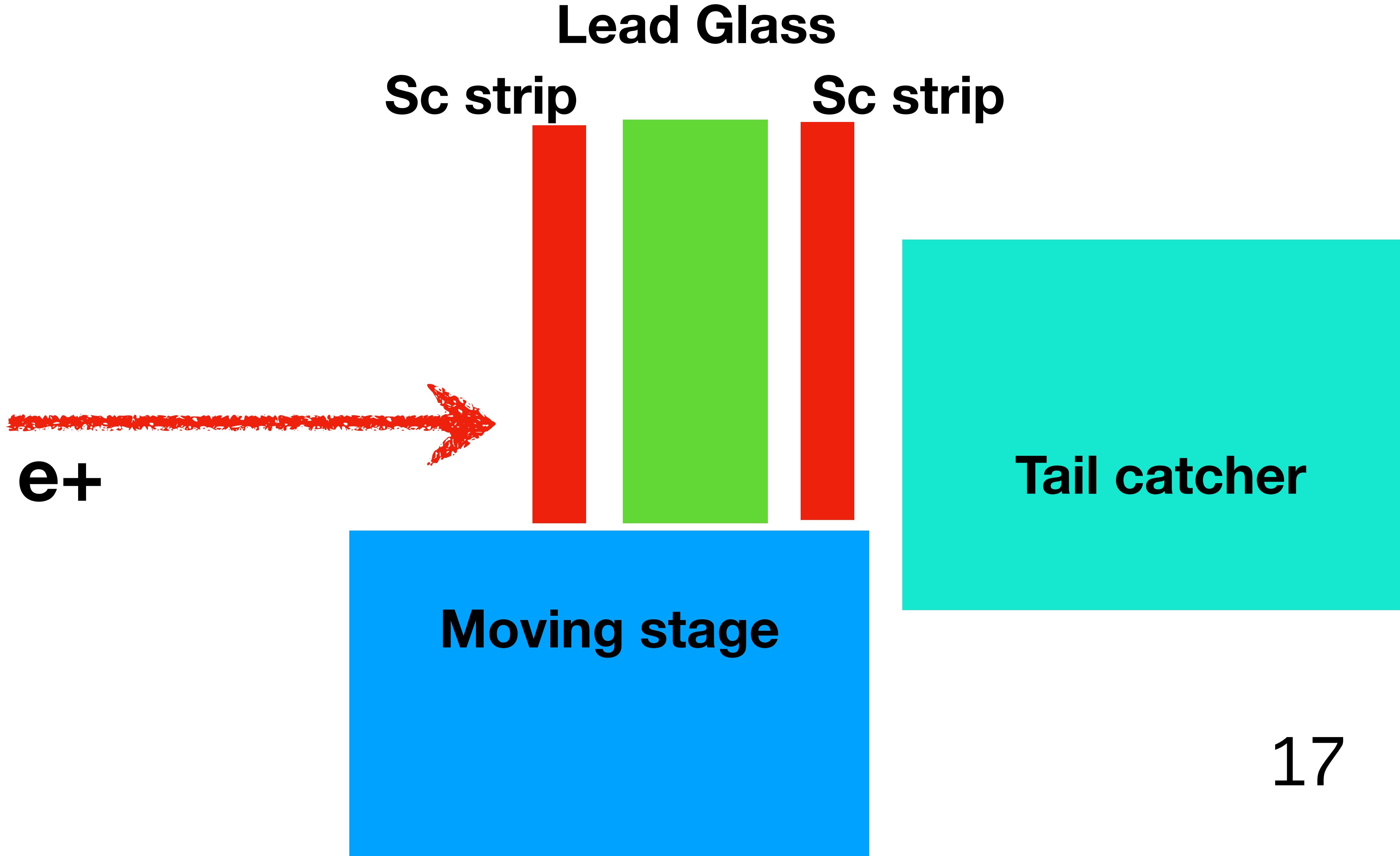


Lead glass add distribution





Sc hitmap for Beam position



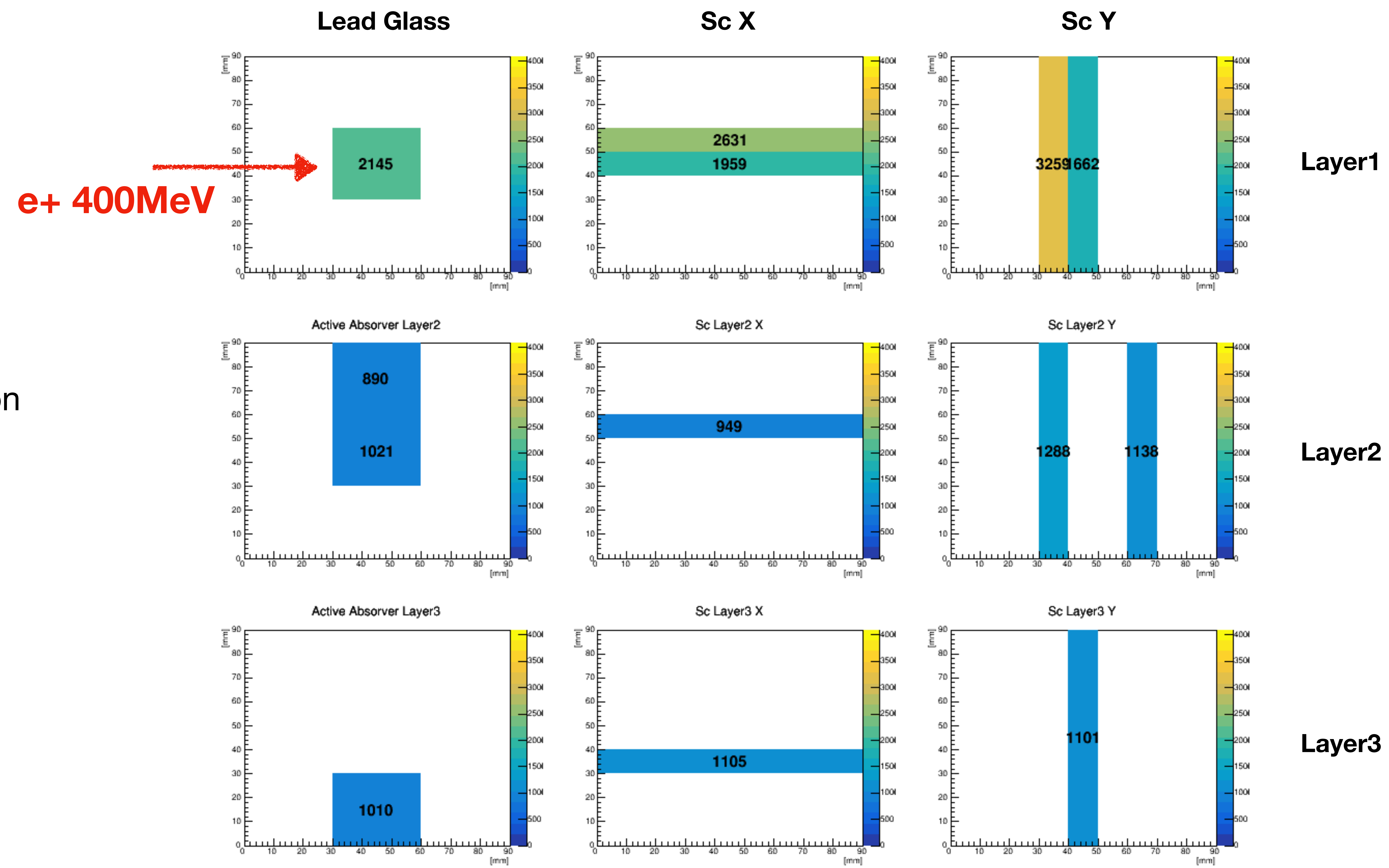
Summary

- Performance improvement of calorimeter is indispensable for future high energy frontier collider experiment.
- We are developing and testing active absorber ECAL.
- Prototype of active absorber ECAL to read information with lead glass absorber is working.
- A method to calibrate the lead glass block with beam was developed in 2017.
- We did test beam at Nov 22-25 2018
- Full detector performance are examined after energy calibration of all the lead glass channels, the energy and position resolution are measured.
- This years analysis is on going.

Backup

Event Display (2016)

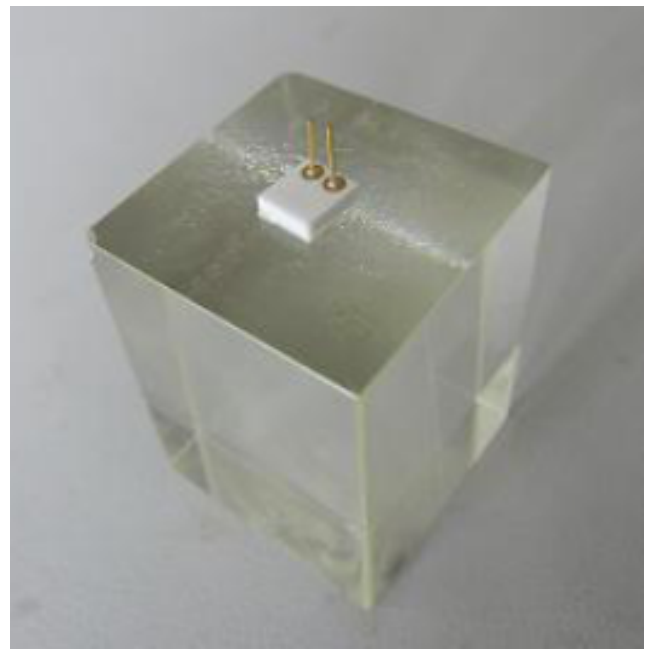
- 400MeV positron injection
- Detector is working



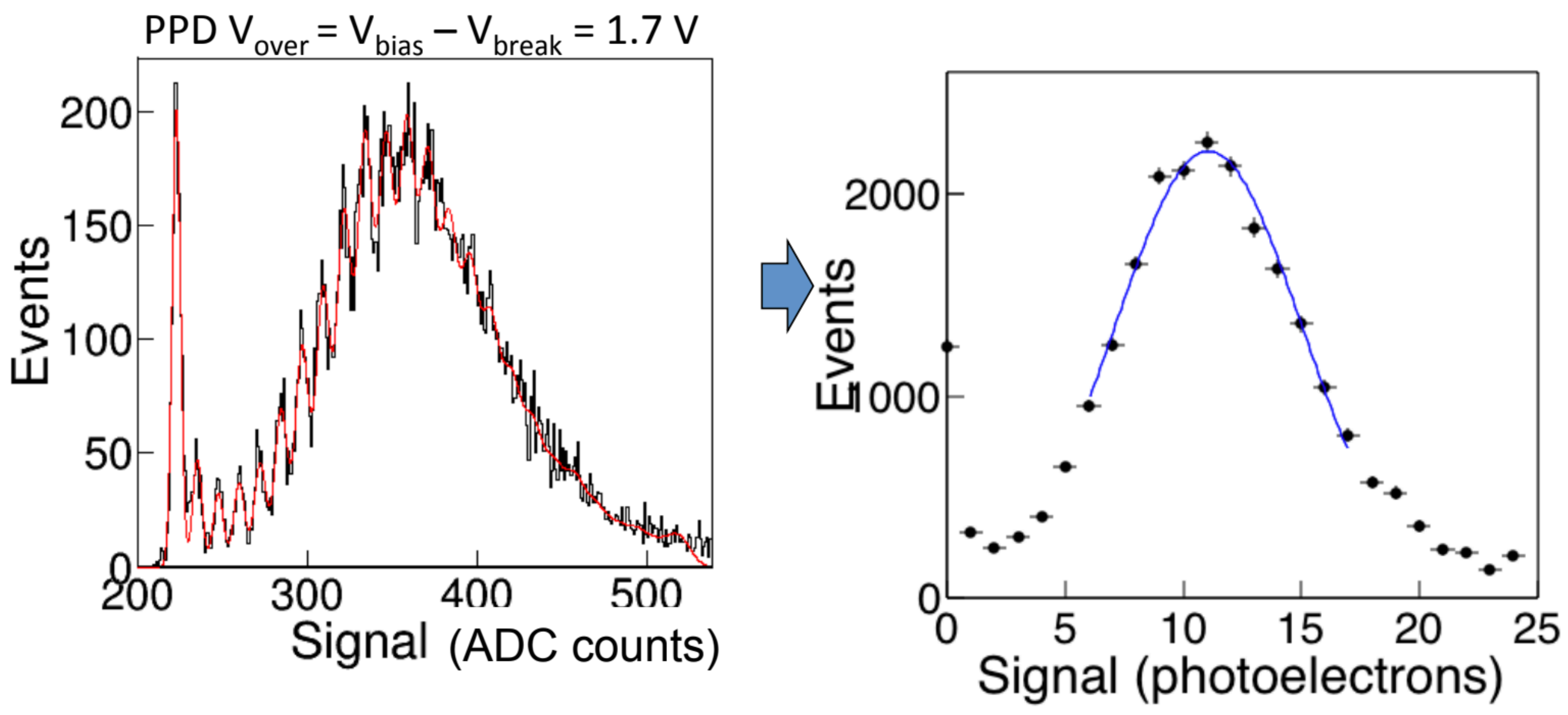
400MeV Event Display

Readout Cherenkov light

- Lead glass block surface is 3x3cm^2 but MPPC sensor area is very small (3x3mm^2) (1/100).
- We want to avoid dead volume increase, we try directory readout (no optical guide)
- Cherenkov light can be read under 350nm, if air gap Cherenkov light is totally reflect because of heavy lead glass density.
- This problem was solved by putting in optical grease between lead glass and MPPC
- Cherenkov light is very small but can be read 12 p.e. by cosmic muon



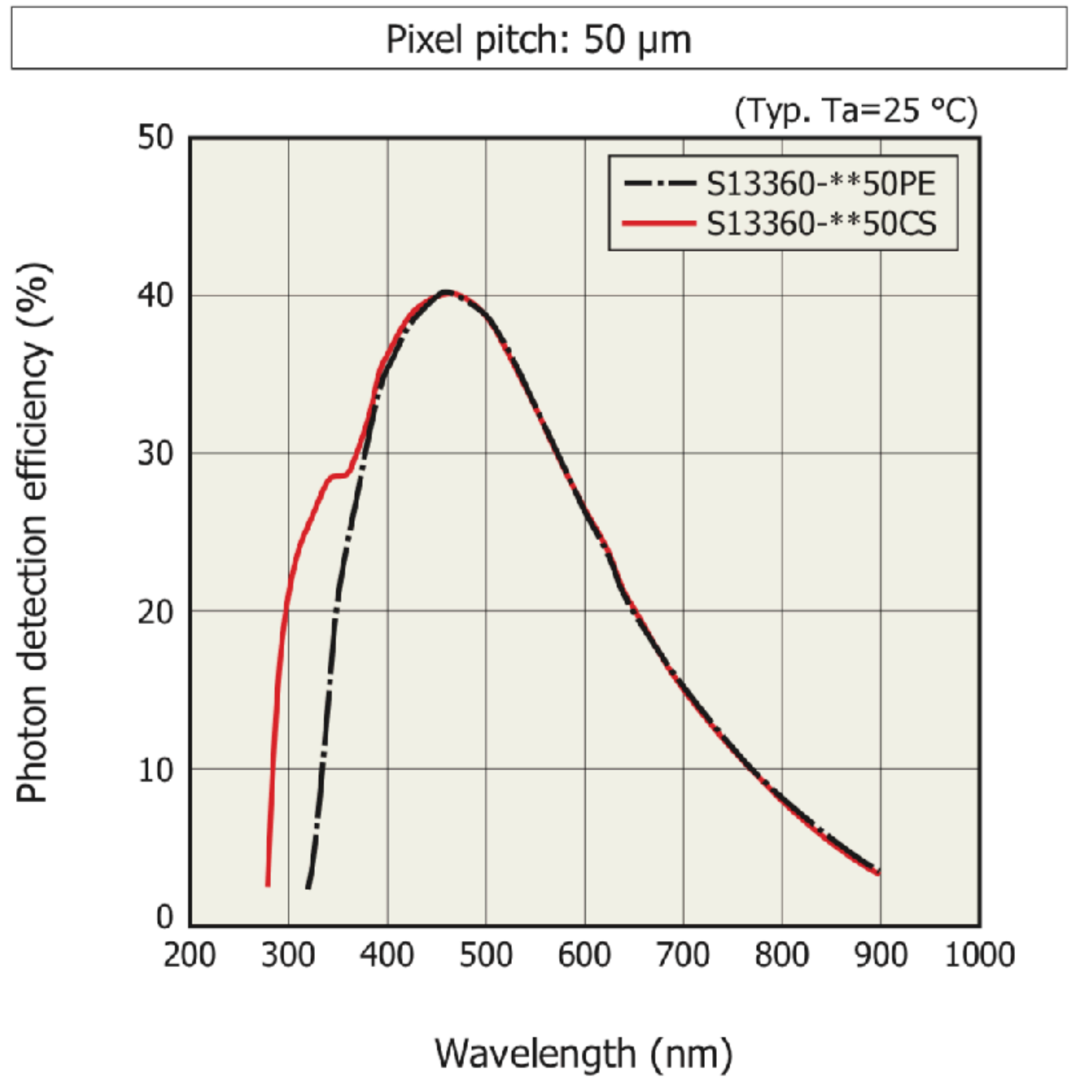
Lead glass block and MPPC



Muon signal

By Uozumi

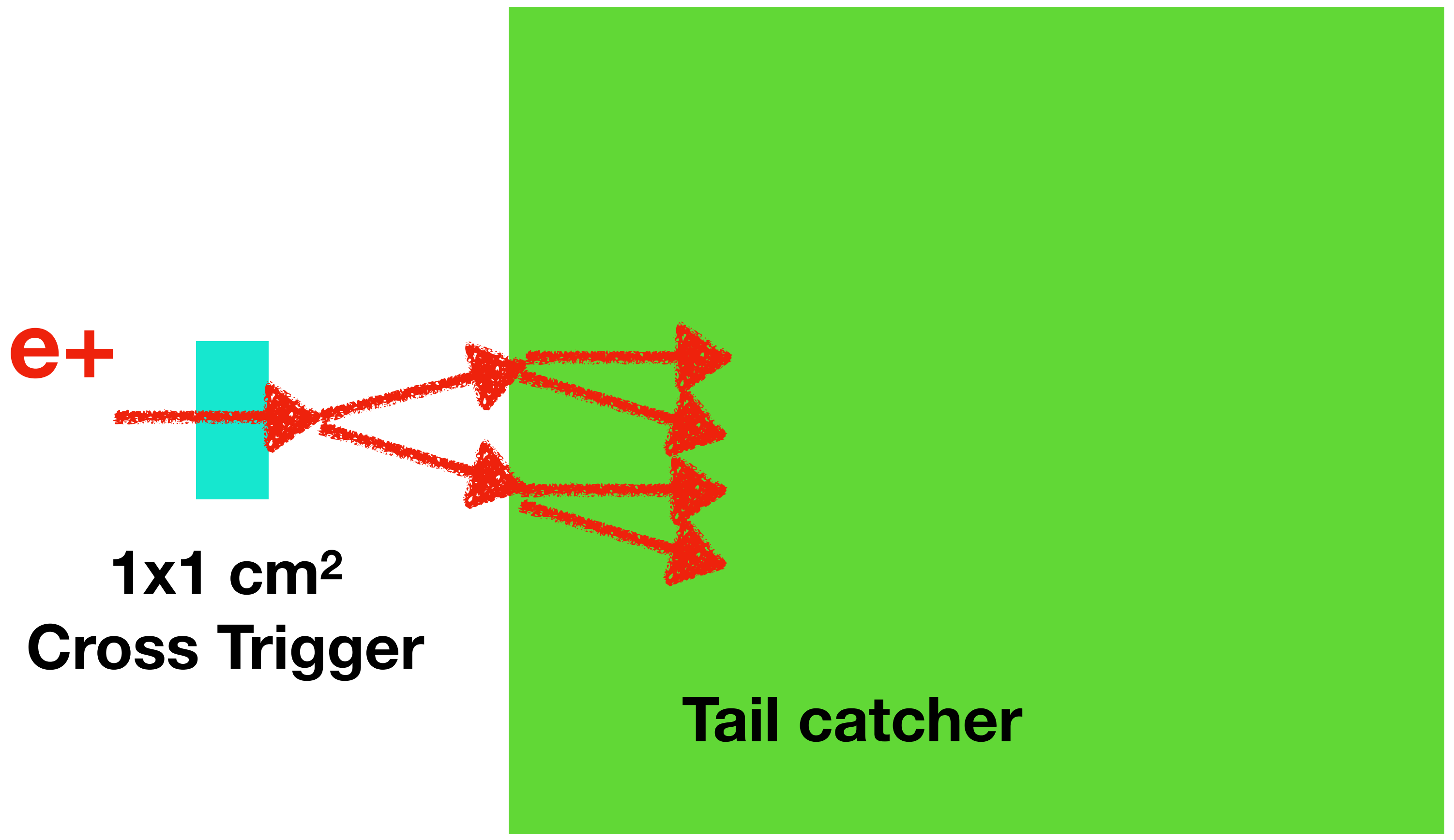
Optical coupling of Lead glass block and MPPC



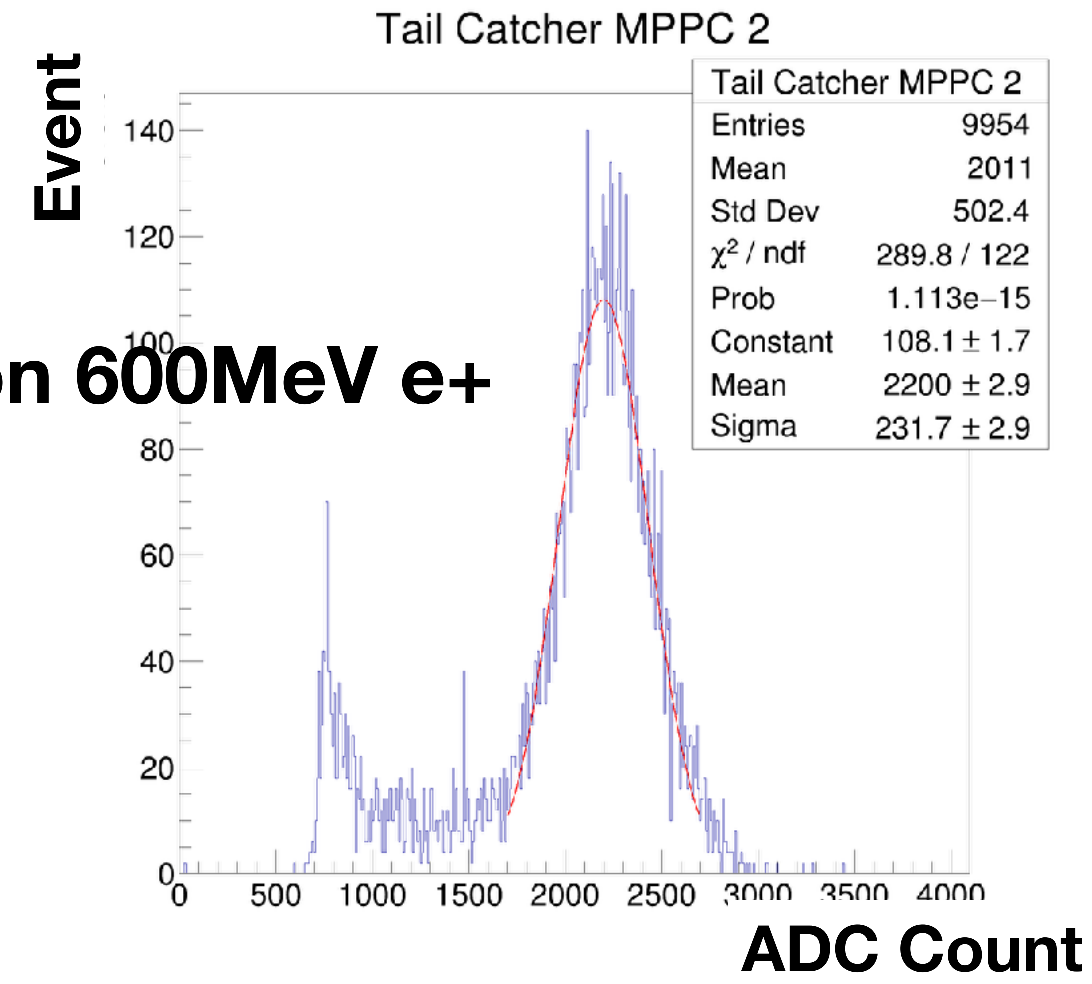
Dependence of wavelength

Tail Catcher Calibration

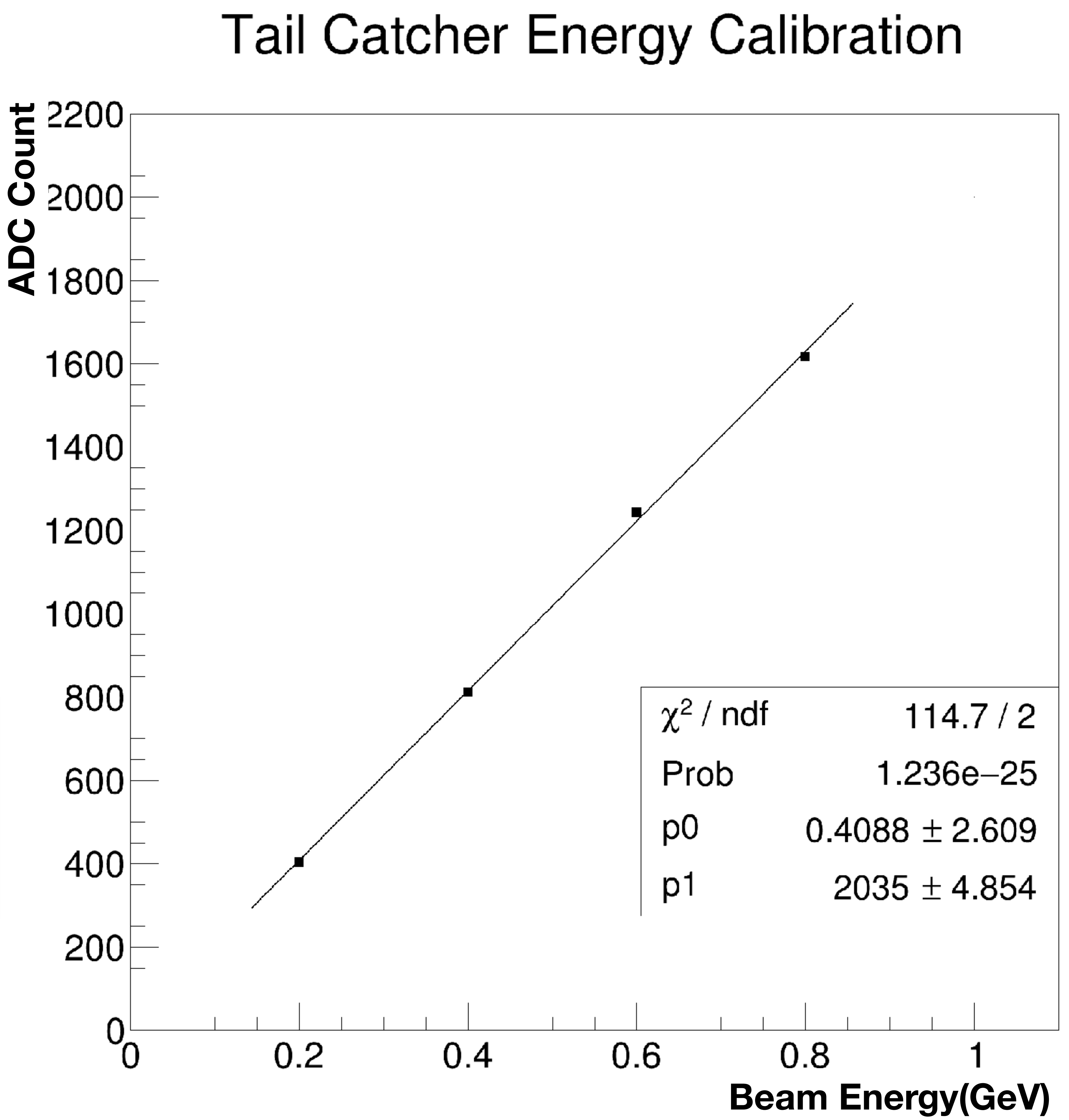
- We did calibrate of tail catcher with positron beam at ELPH directory.
- Beam energy is 200 - 800MeV
- Use plastic scintillator trigger which has 1 x 1 cm^2 area
- Energy linearity is good
- We determined conversion factor of ADC/GeV as 2035 (fit results shown by p1)



Injection 600MeV e+



Tail catcher ADC Distribution



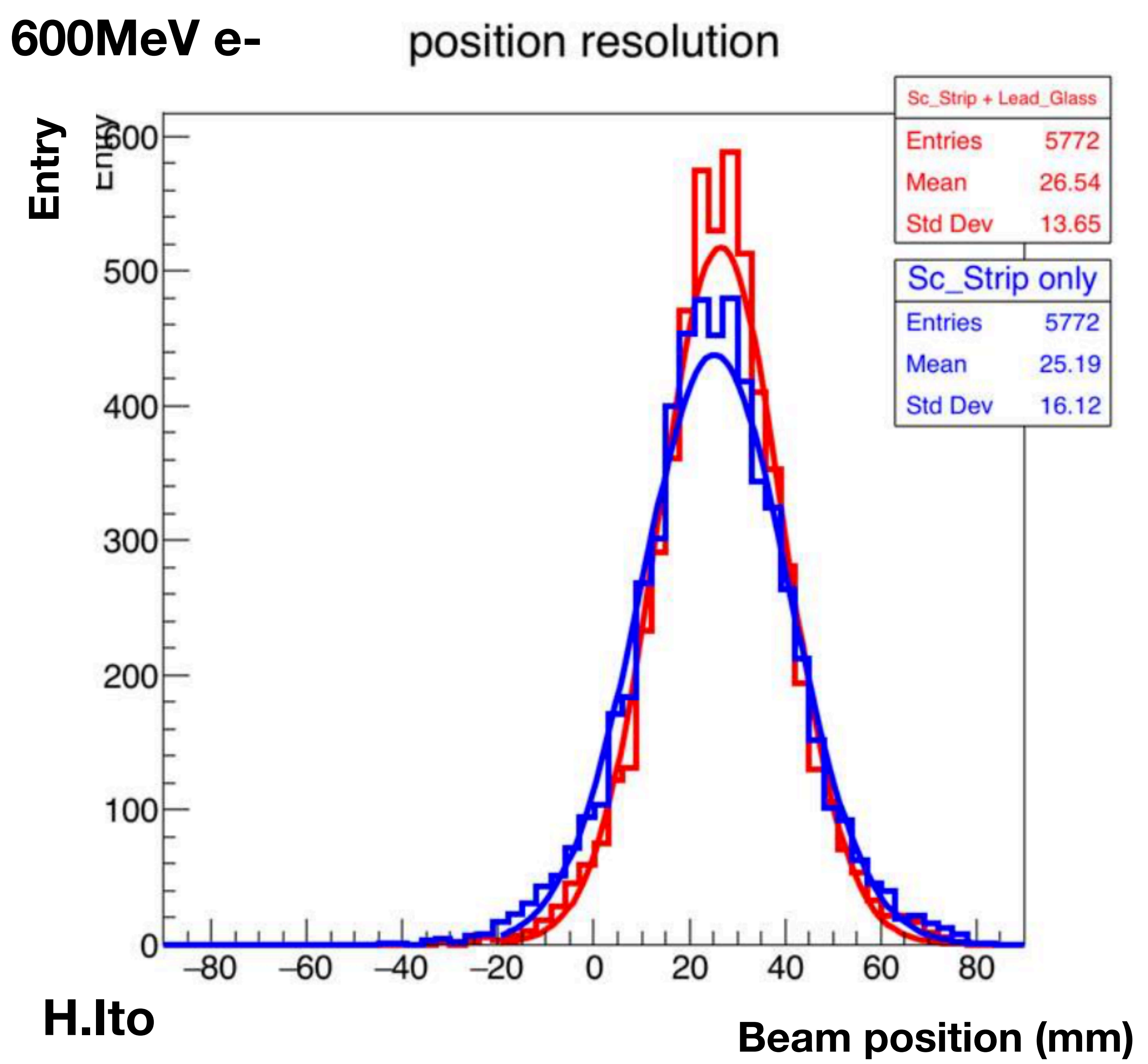
Tail catcher energy linearity

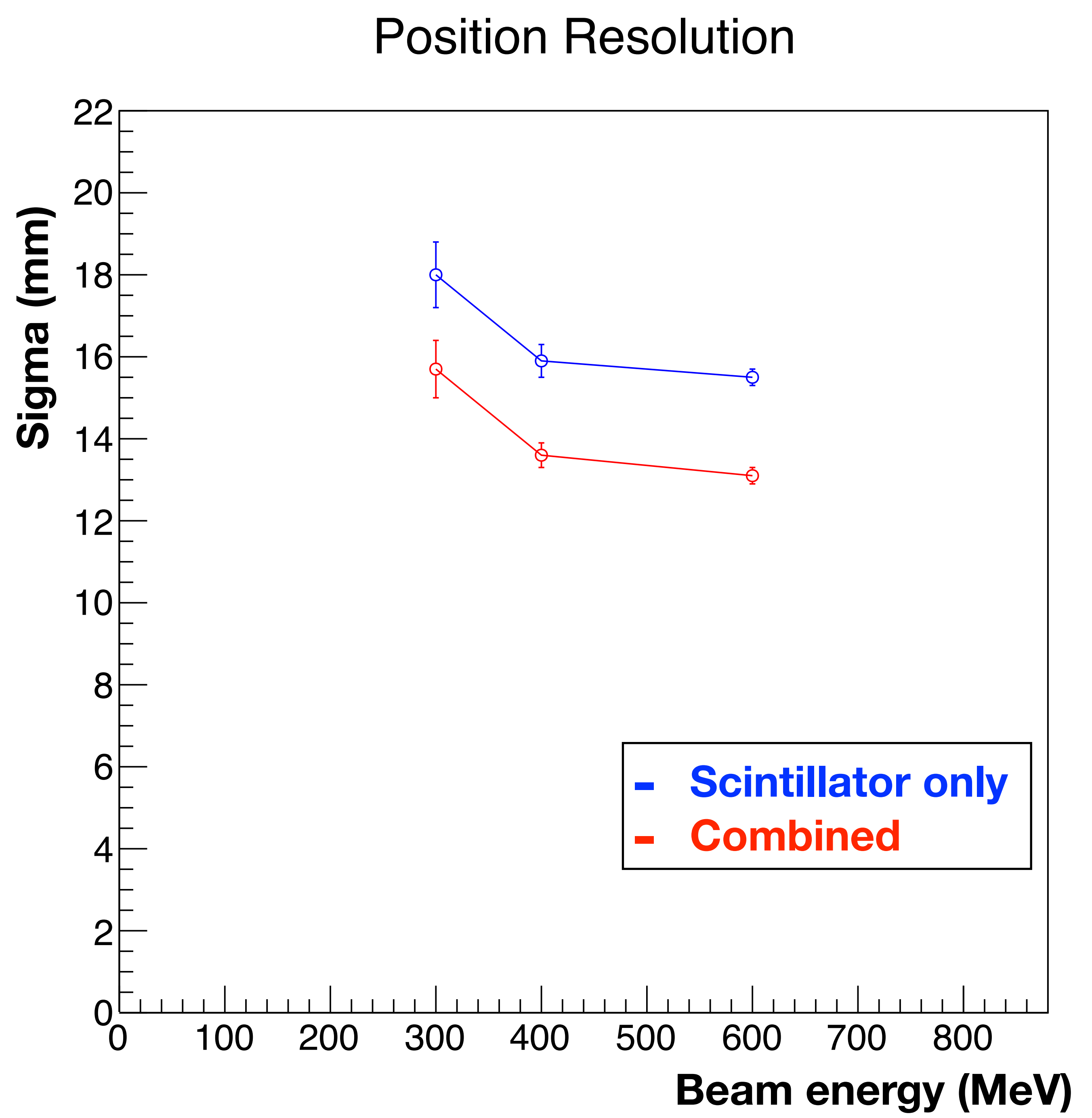
Parameter of Lead Glass

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

Position Resolution

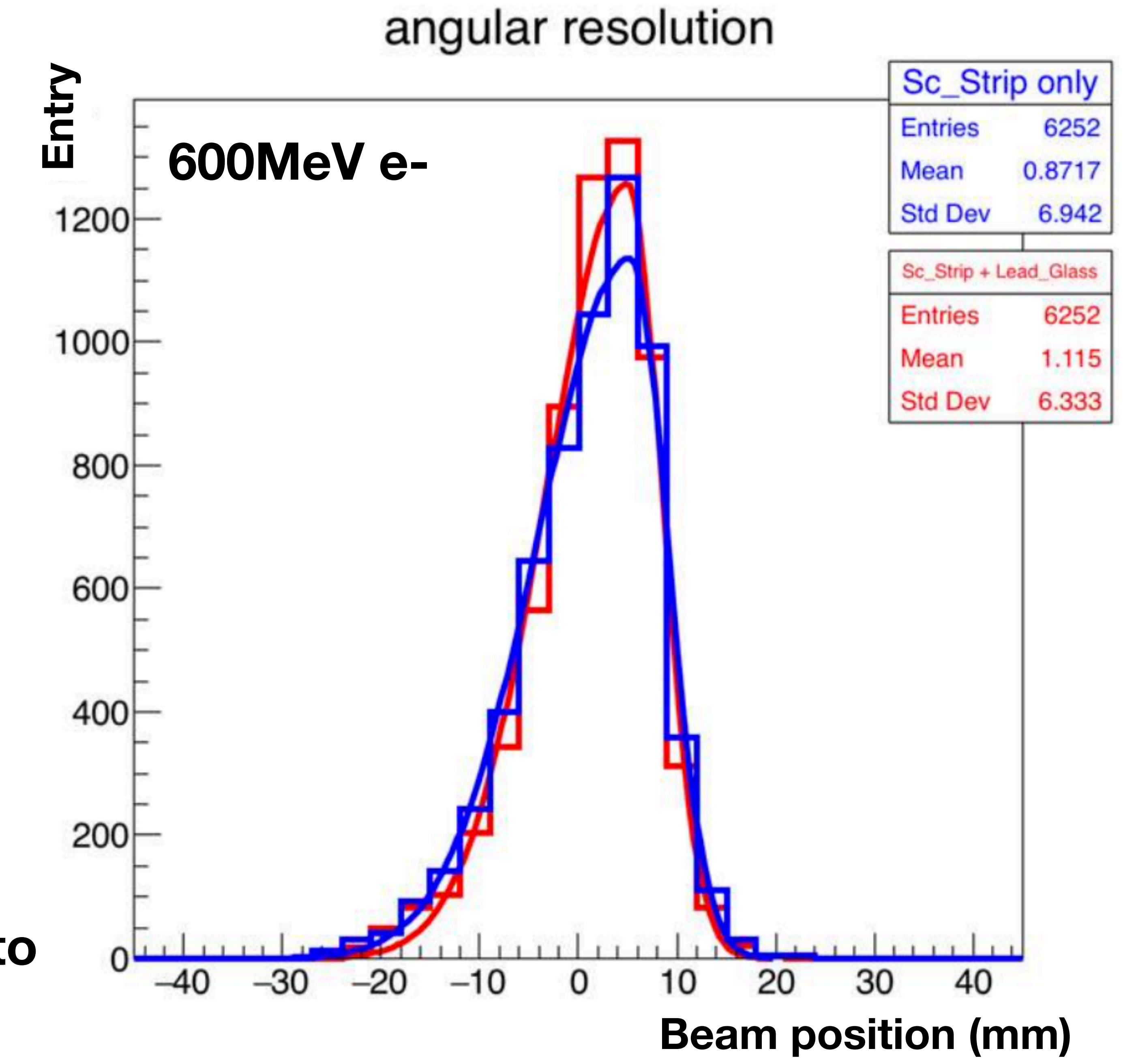
- The beam was shifted 30 mm in parallel at beam line
- The position distribution results for scintillator layer only (blue) and with lead-glass information combined (red)
- The beam position is reconstructed by calculating centroid in each layers and fitted with a straight line
- Results with absorber and scintillator layers are 10% better than those with scintillator only



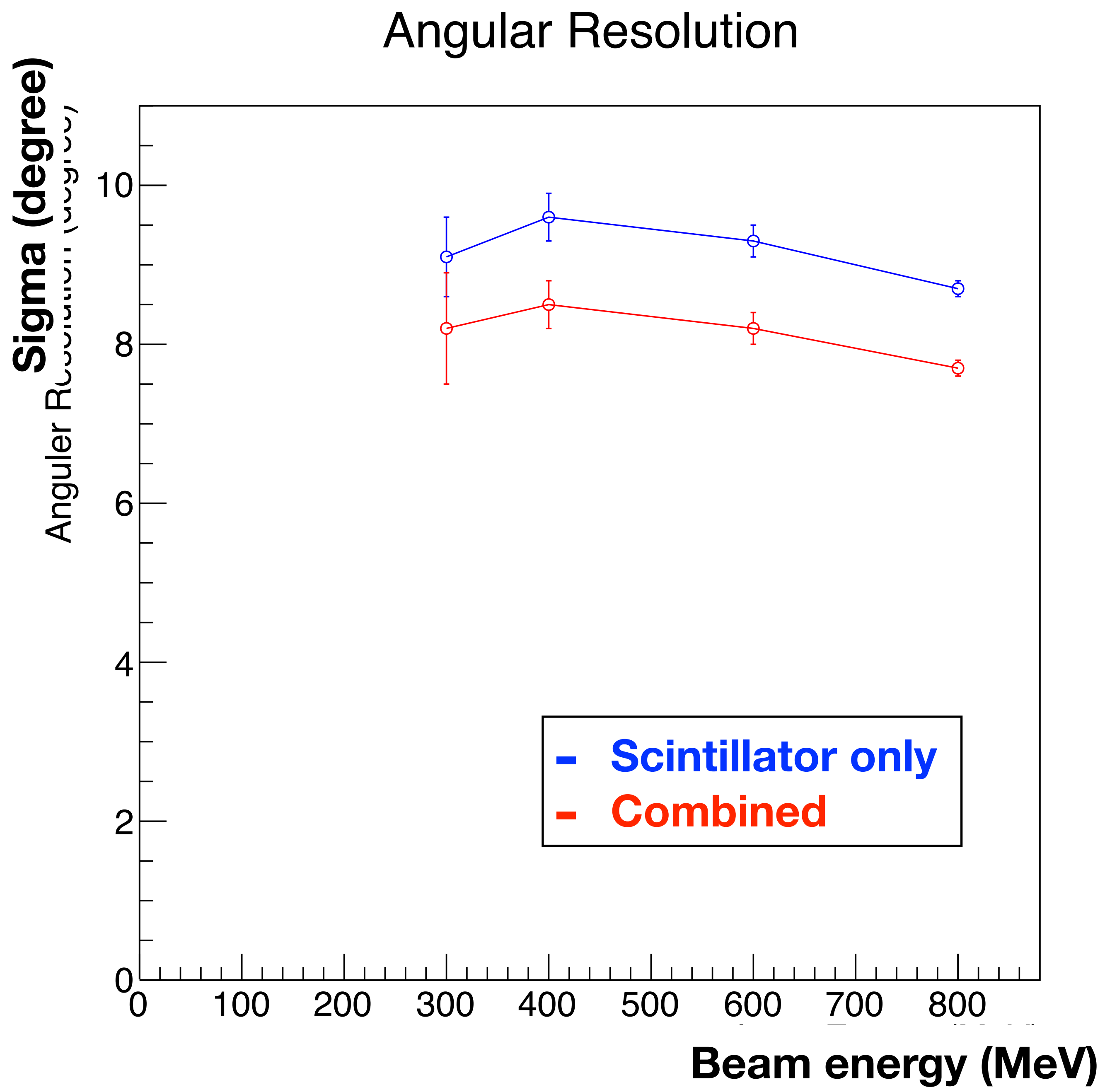


Angular Resolution

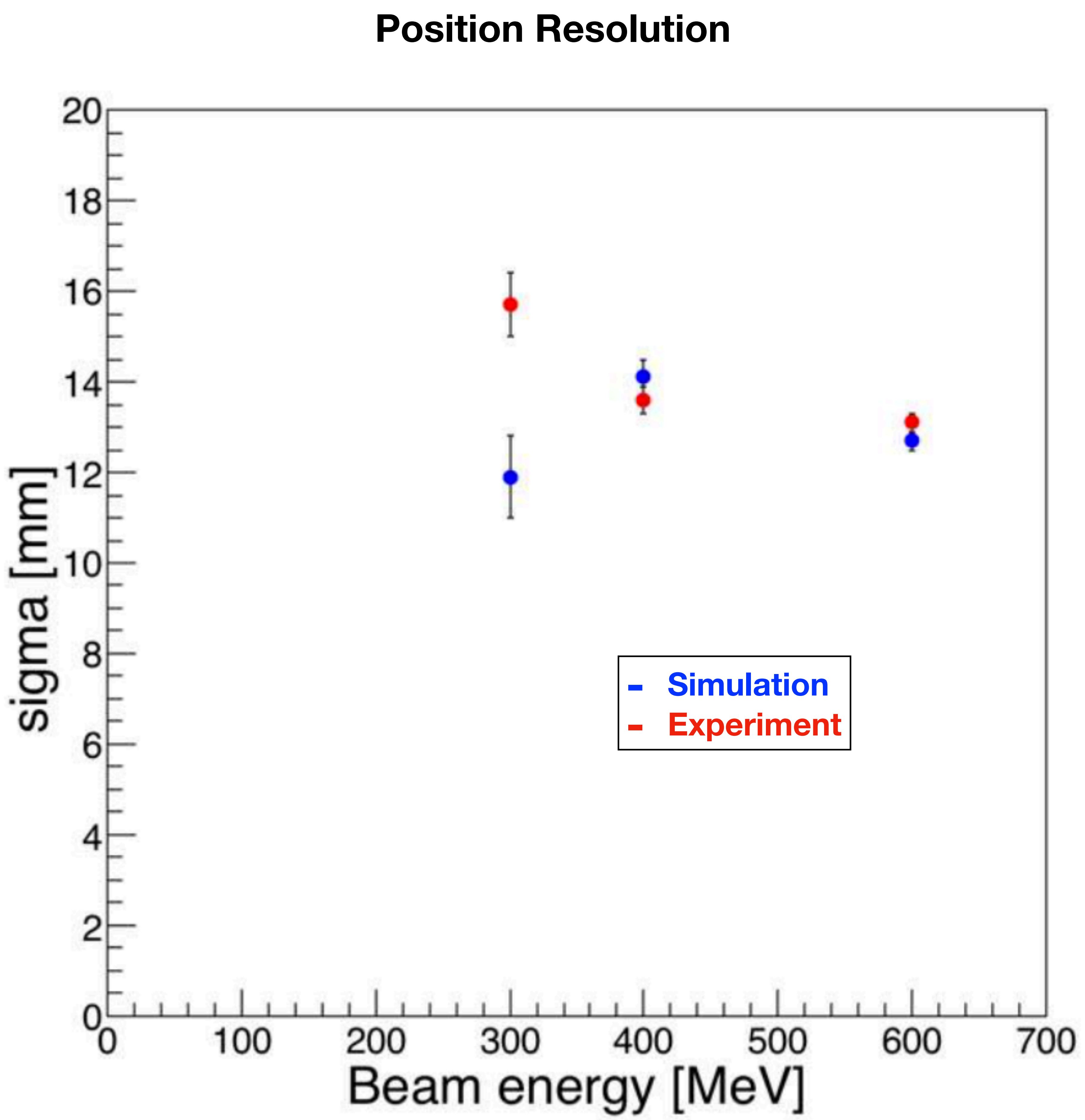
- The beam was injected at an angle of 5 degree with the center axis of the calorimeter setup
- The angular distribution results for scintillator layer only (blue) and with lead-glass information combined (red)
- The beam angle is reconstructed by calculating centroid in each layers and fitted with a straight line
- Results of absorber and scintillator layers are 10% better than scintillator only

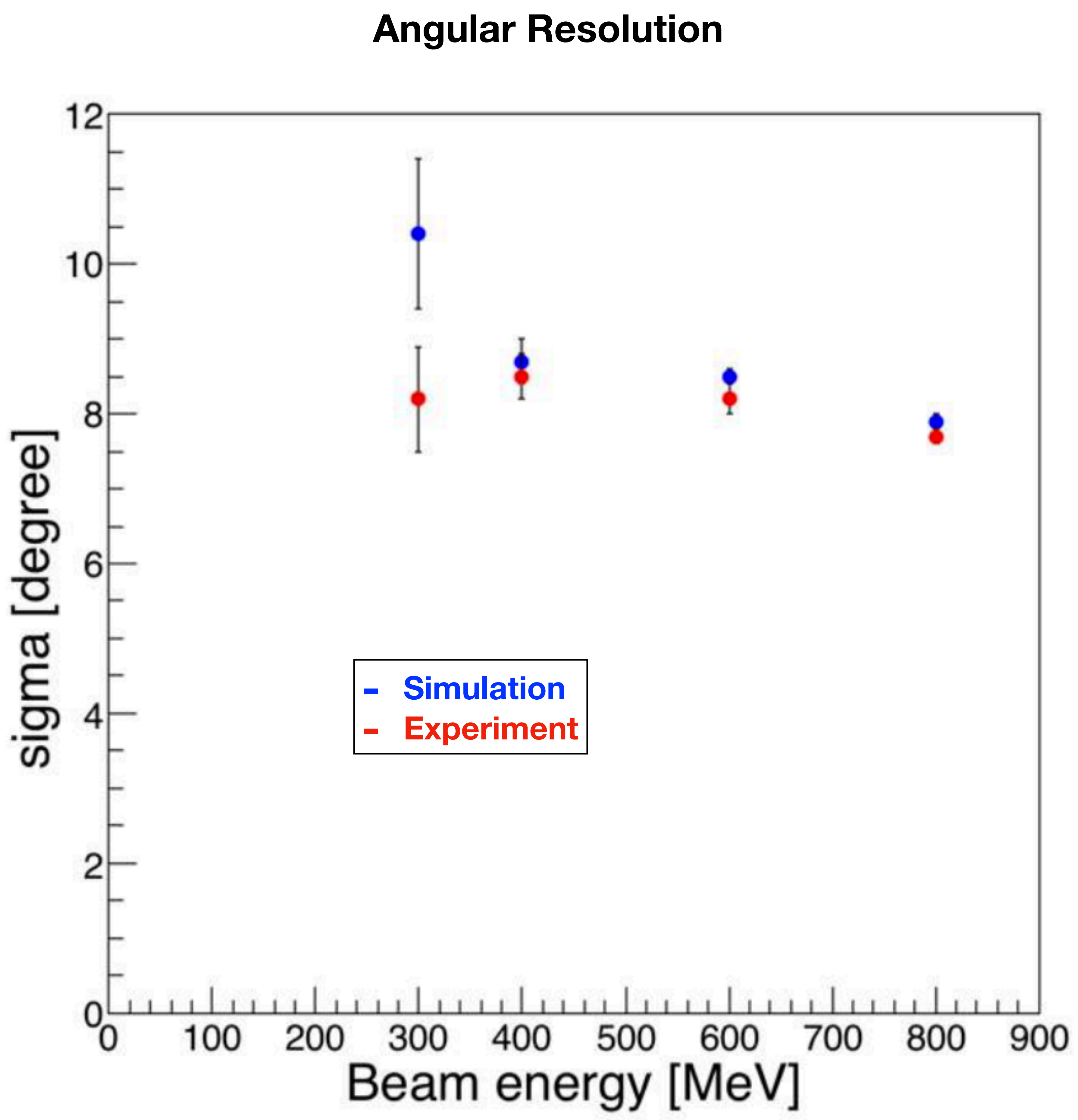


H.Ito



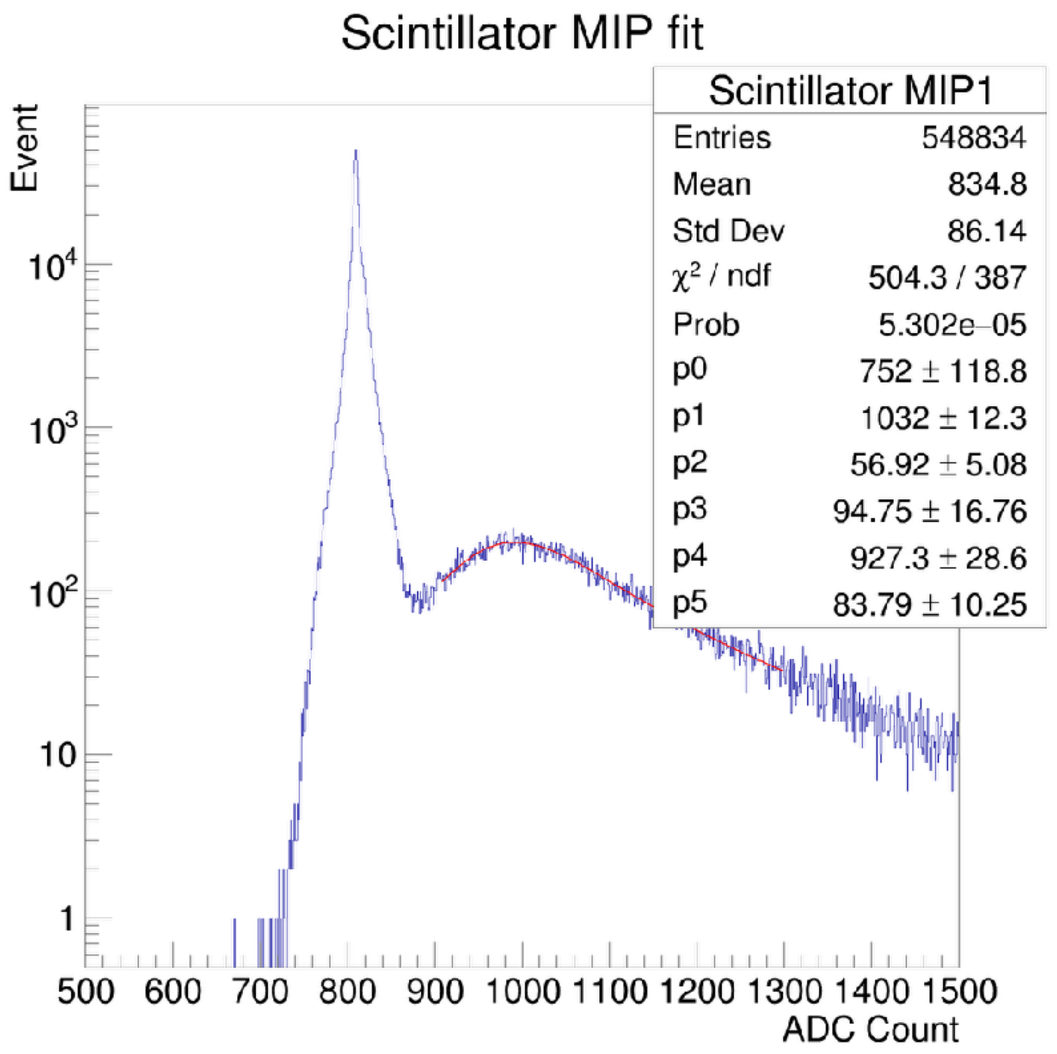
Position and angular resolution (simulation vs experiment)

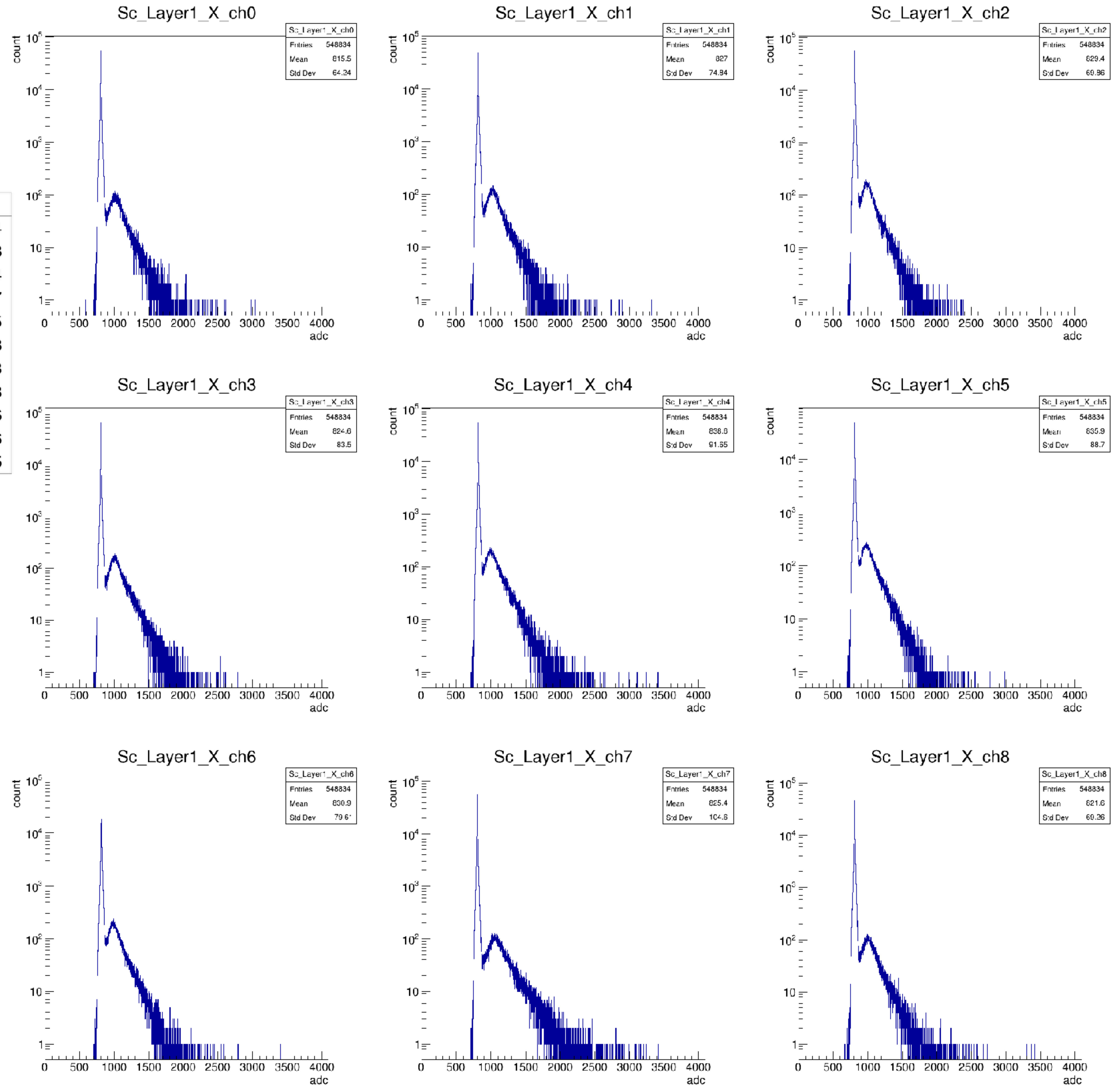




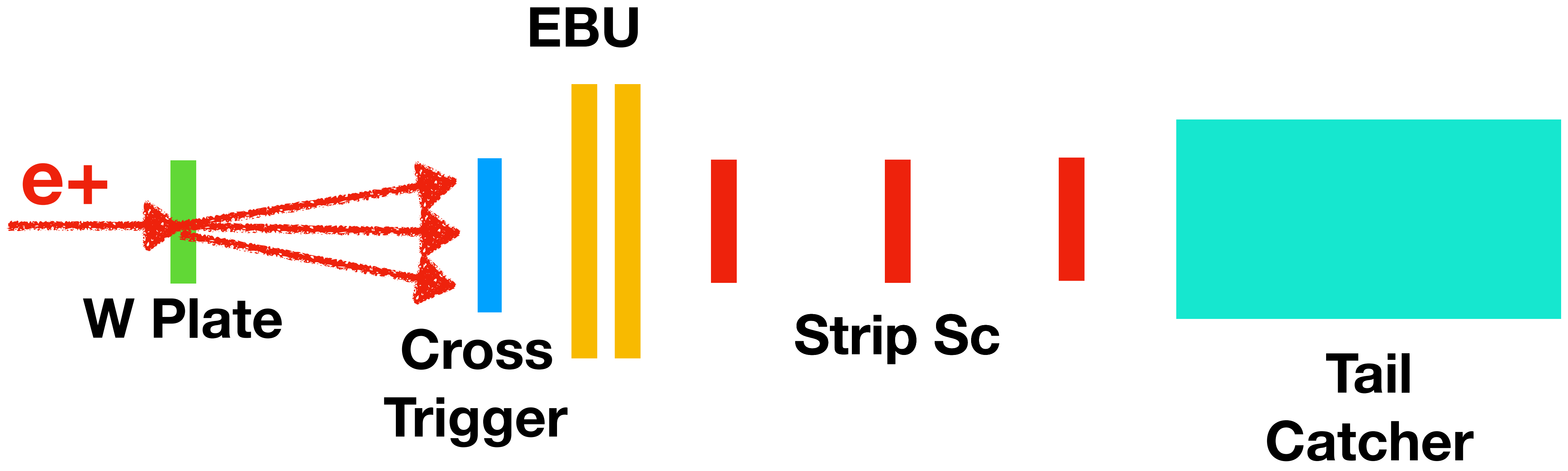
Scintillator Calibration

- Injection 800MeV positron
- Makes shower by W plate set at most upstream
- Trigger is using tail catcher signal at most downstream
- All Chanels can see MIPs, and work well (2016 test, 2 channels were dead)
- Calibrate scintillator using MIP fit result





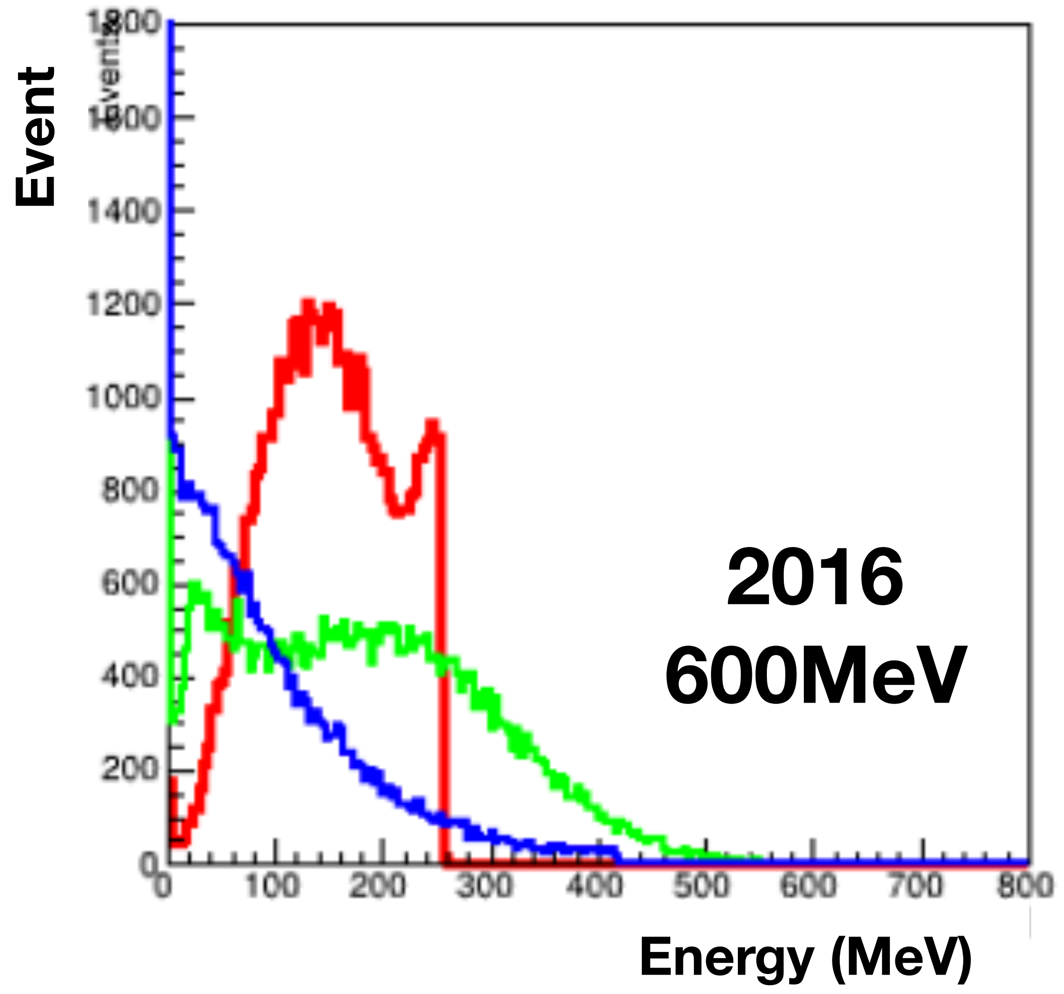
Layer 1 X direction ADC distribution at calibration run (2017)

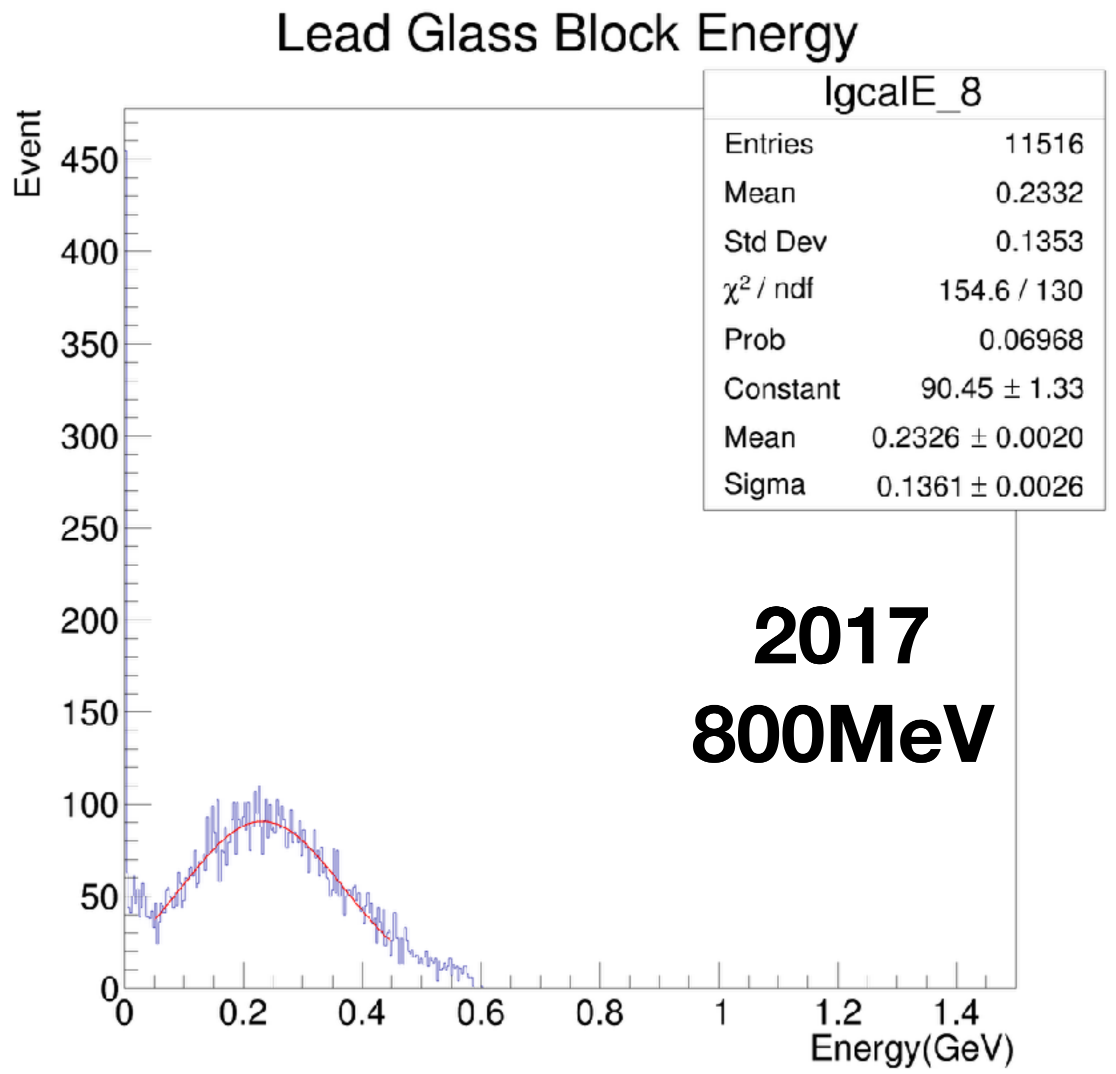


scintillator calibration setup (remove active absorber)

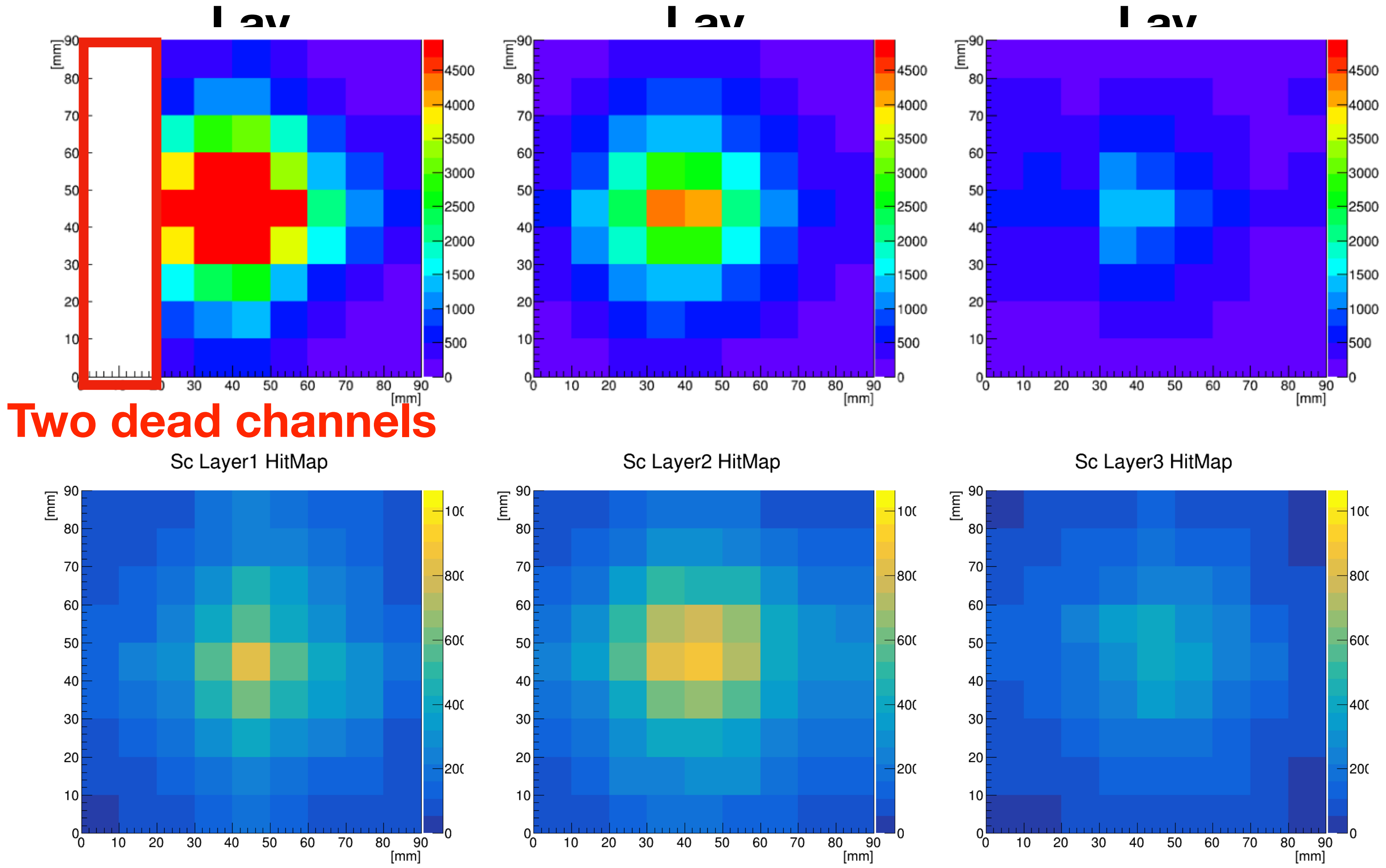
Problem of 2016 TB

- ADC Overflow at high energy
- We could not reconstruct in the high energy region
- We cannot estimate energy at high energy
- At 2017 Test Beam
  - Change a MPPC with lower gain at first layer
  - Careful HV setting at Cosmic ray and test Beam calibrations





- Two dead channels at Sc layer1
- Since it is an edge, the influence is not big, but it is effective for the position resolution
- At 2017 Test Beam
  - Make new cable and change
    -> It works well

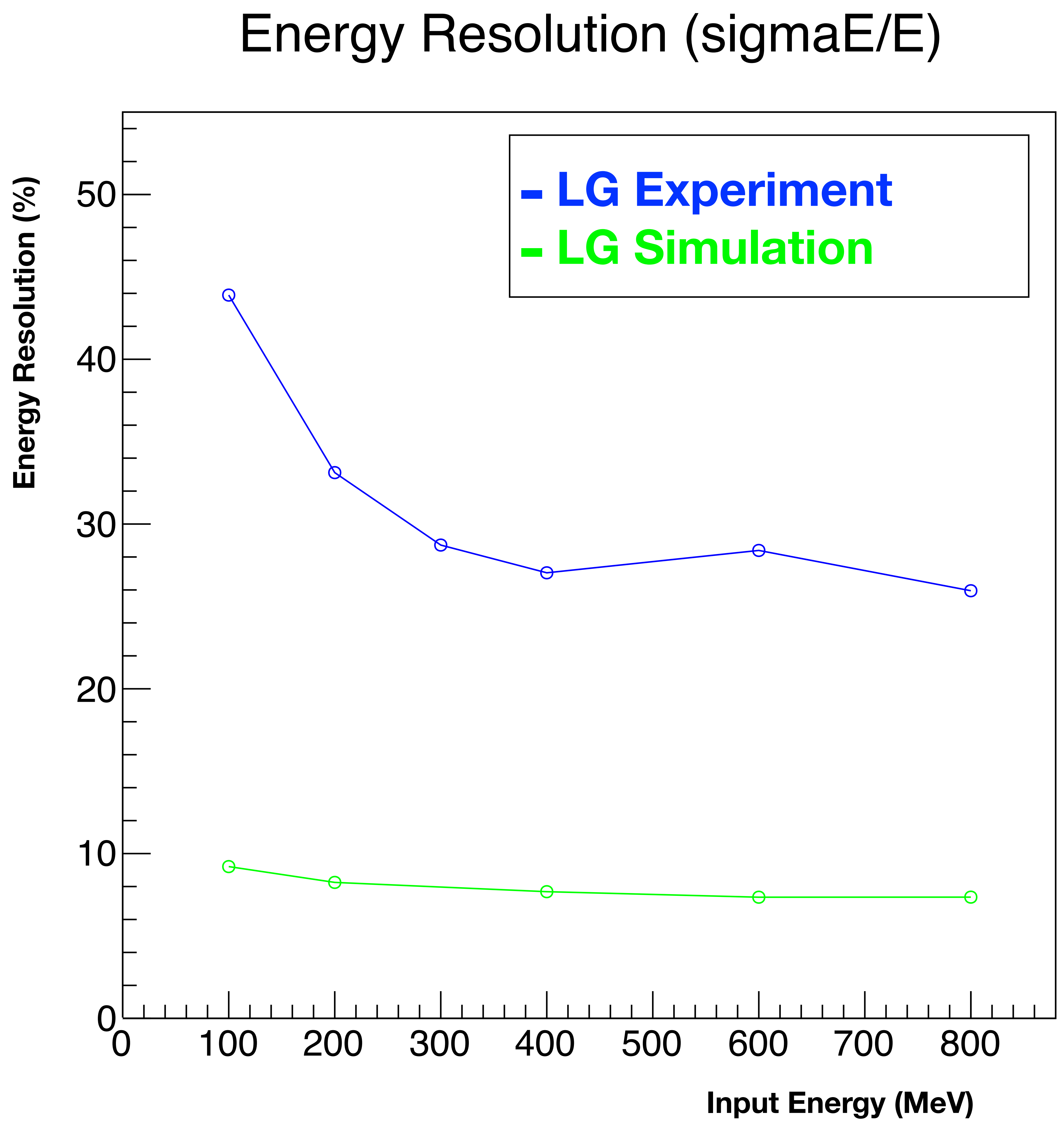


2016
HitMap

2017
HitMap

Lead glass Energy Resolution (2016)

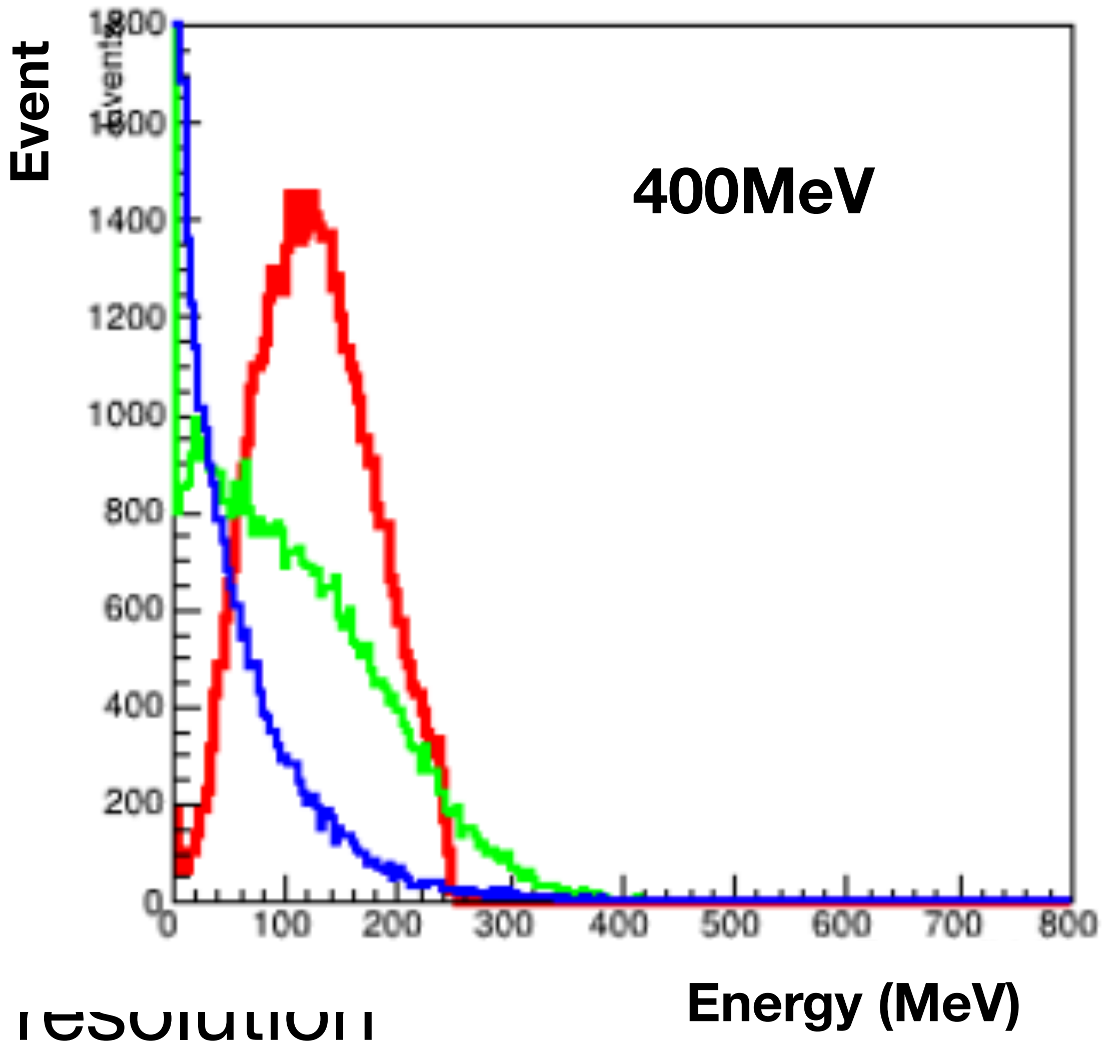
- Compare experimental data with Geant4 simulation
- Combined with Tail Catcher, calculated from the energy actually dropped to the lead glass layer
- In the simulation, as a result of adding 5% energy smearing as a detector error
- Reason of deterioration of energy resolution
  - Because it is a small detector, leakage of shower has occurred with high energy (20%)
  - Compared to the simulation, the measured resolution is lower overall than in the simulation because the block-by-block calibration was not perfect
  - Future more in the high energy region of the experiment, the ADC overflow had occurred, so the resolution is degraded

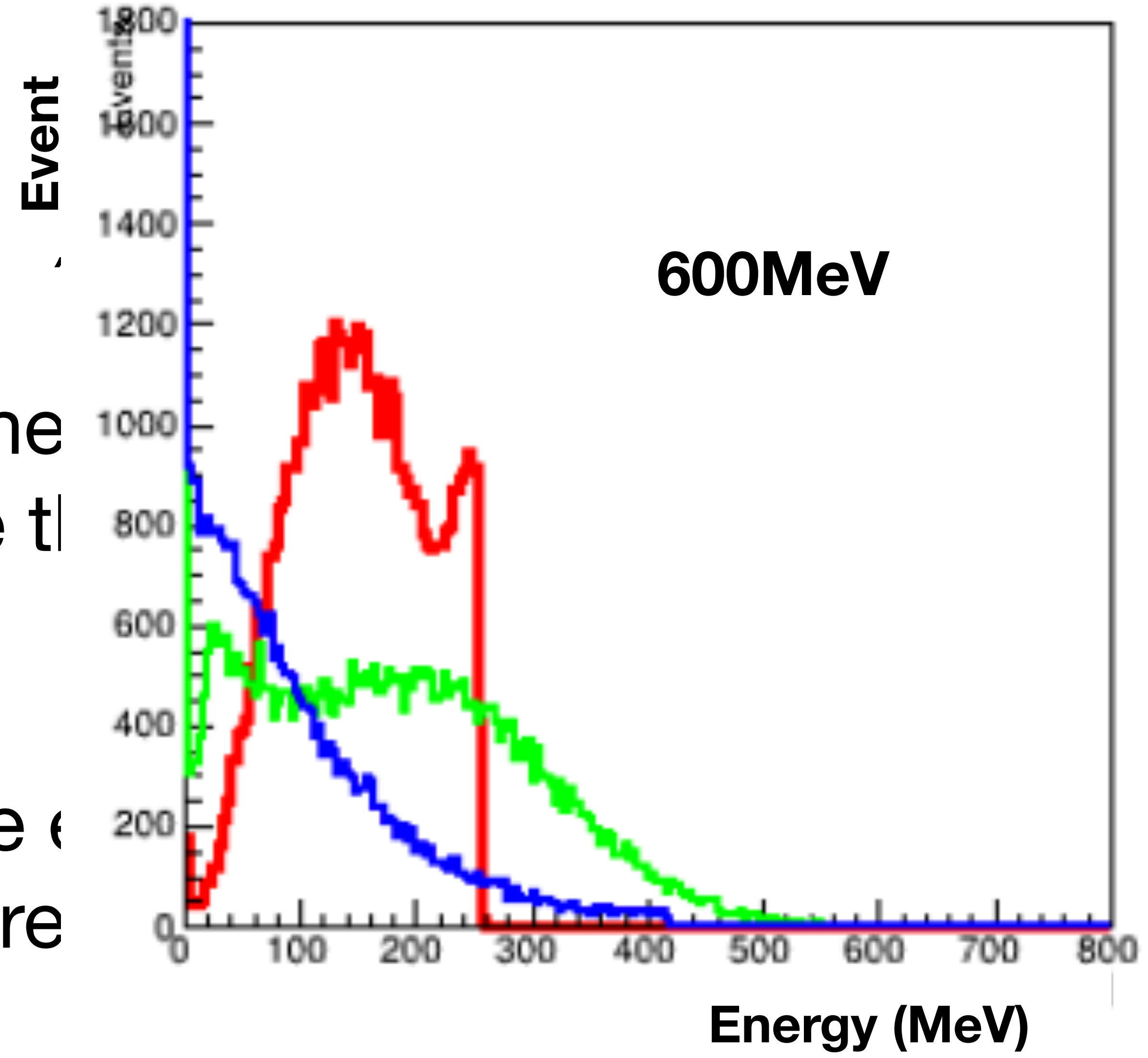


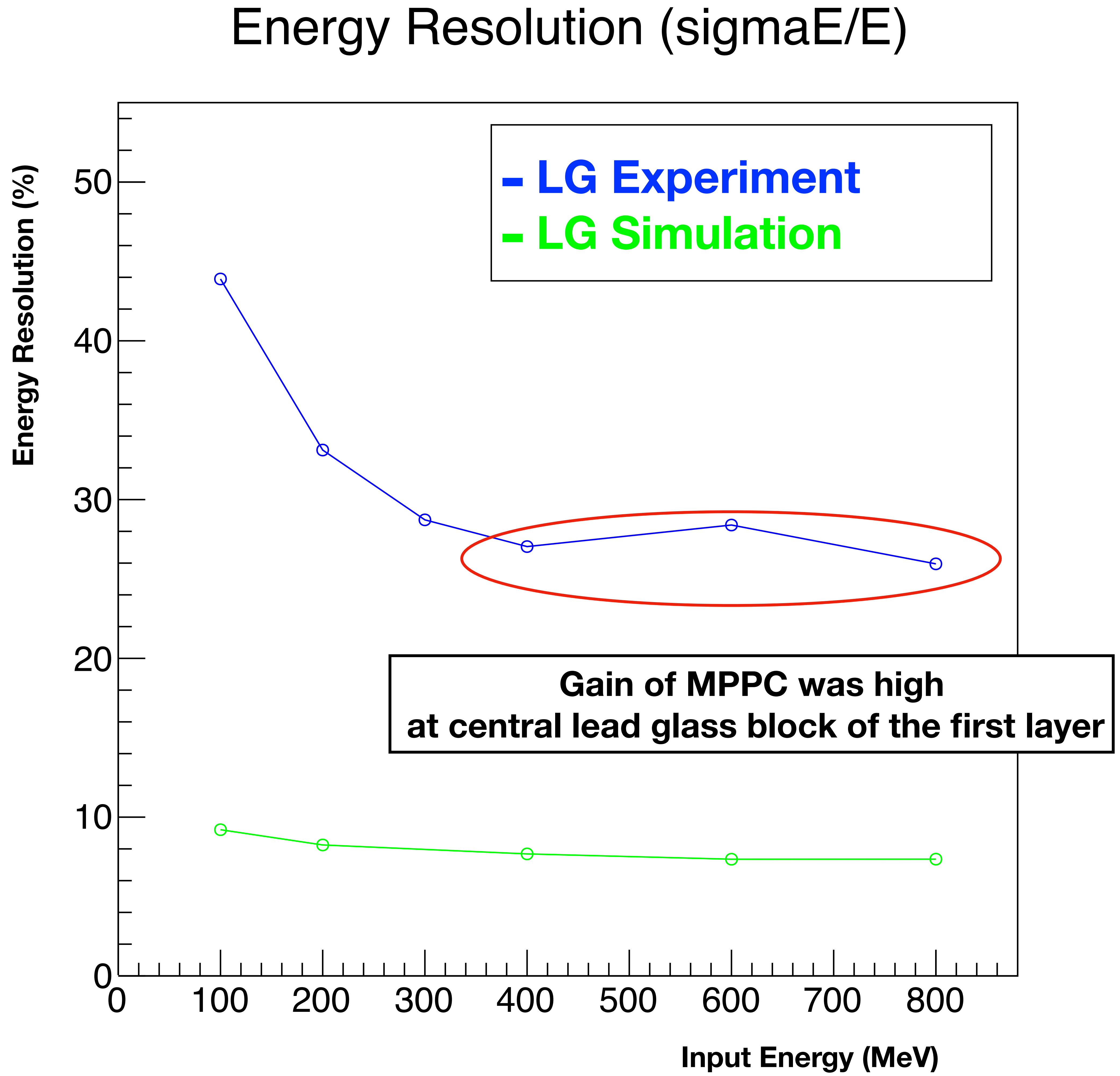
Active absorber energy resolution

Lead glass Energy Resolution (2016)

- Compare experimental data with (
- Calibrate each channel at experi
- Combined with Tail Catcher, calcu
  actually dropped to the lead glass
- In the simulation, as a result of ad
  a detector error
- Factors of deterioration of energy resolution
  - Because it is a small detector,
    occurred with high energy (20
  - Compared to the simulation, the
    than in the simulation because t
    calibration was not perfect
  - In the high energy region of the
    overflow has occurred, so the re



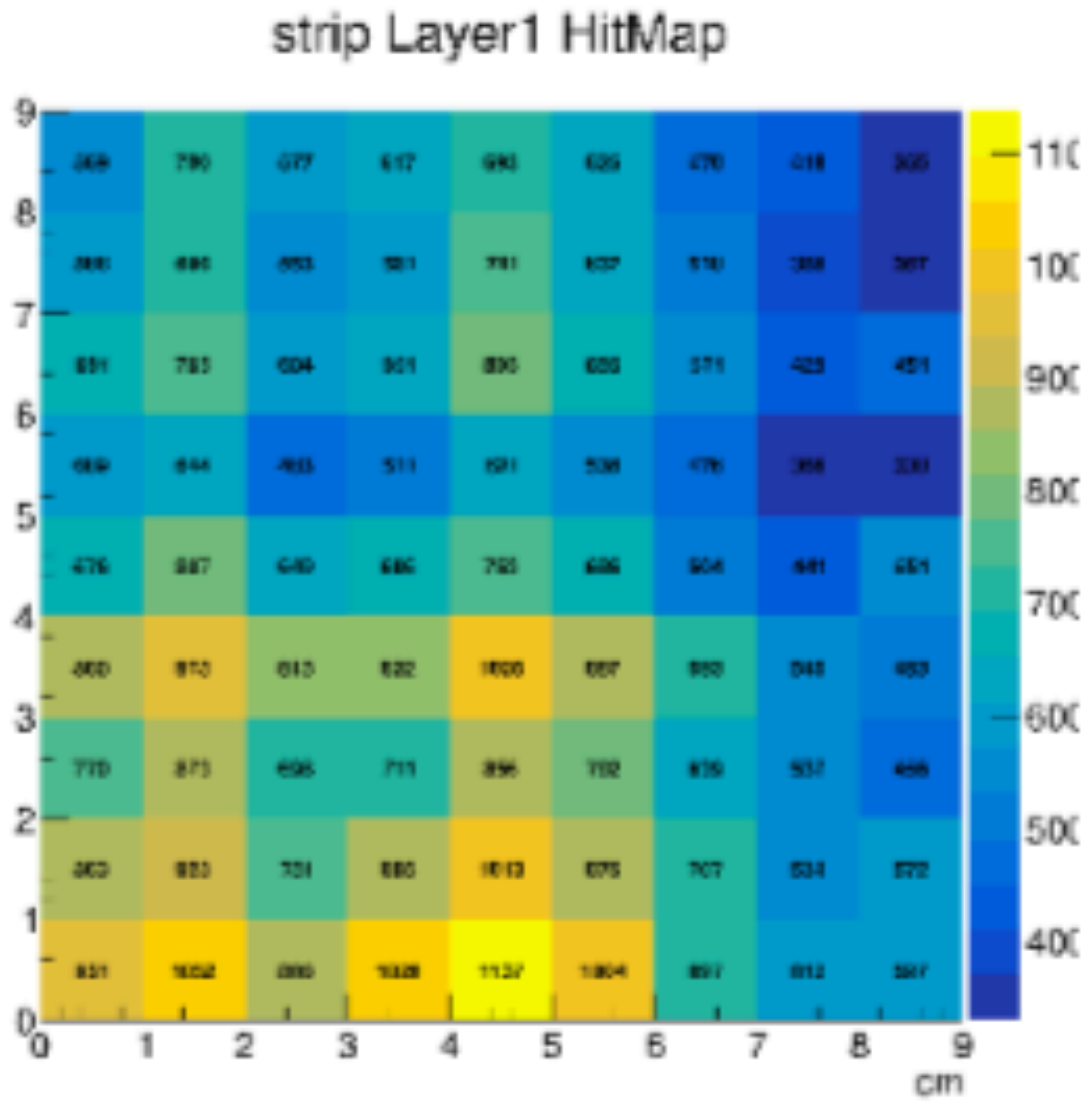




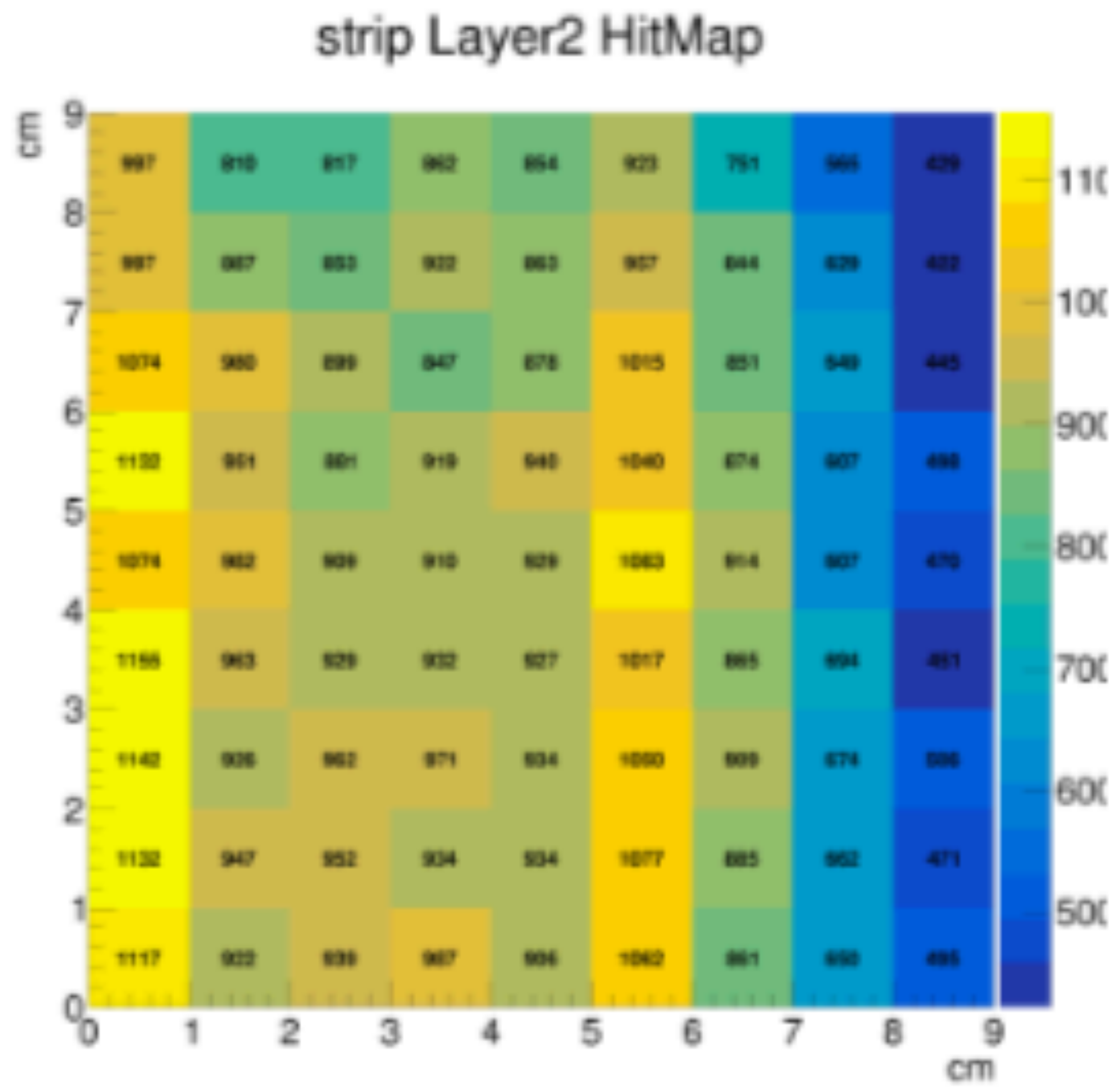
Active absorber energy resolution

Cosmic muon test

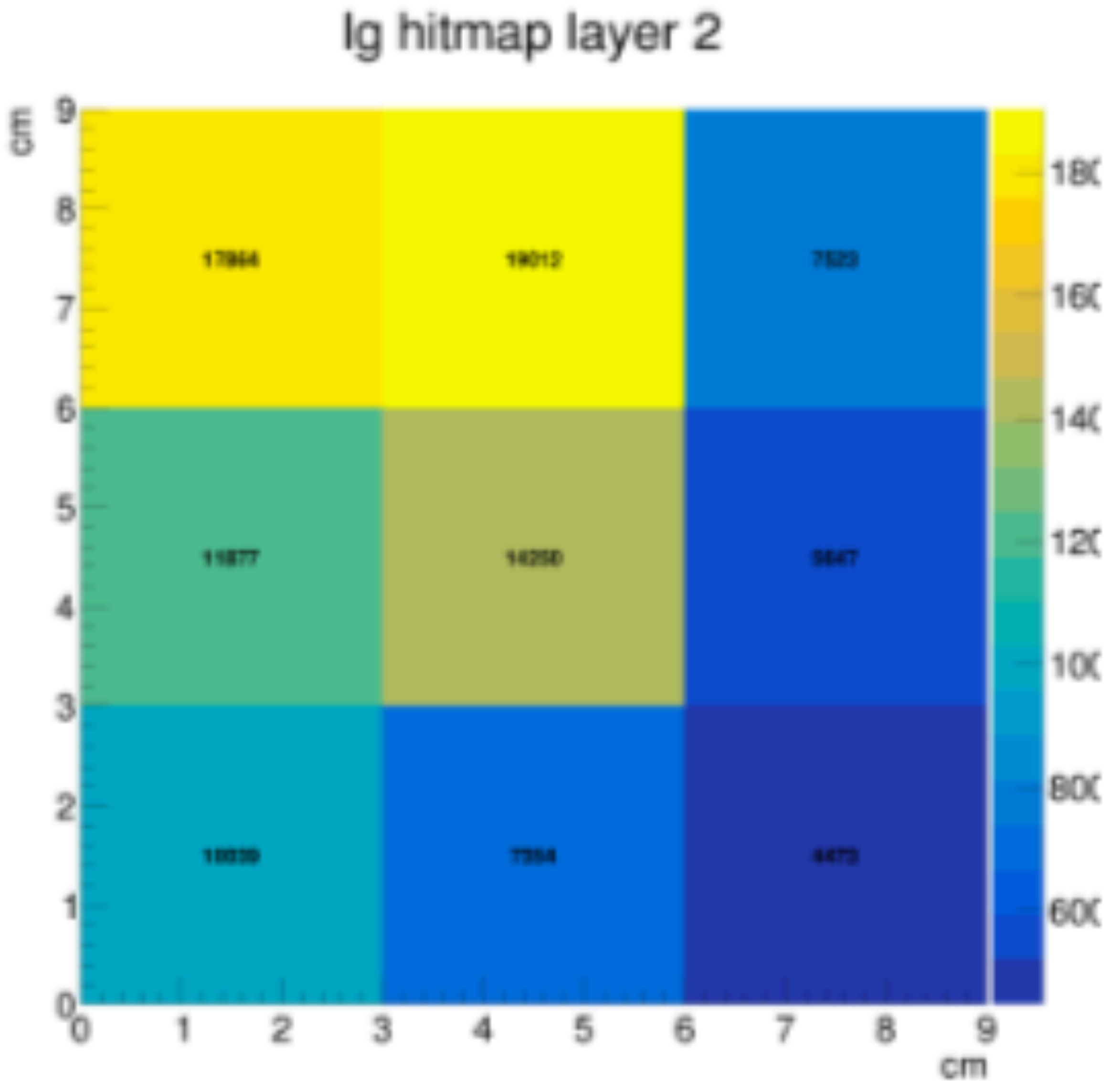
Hit Map



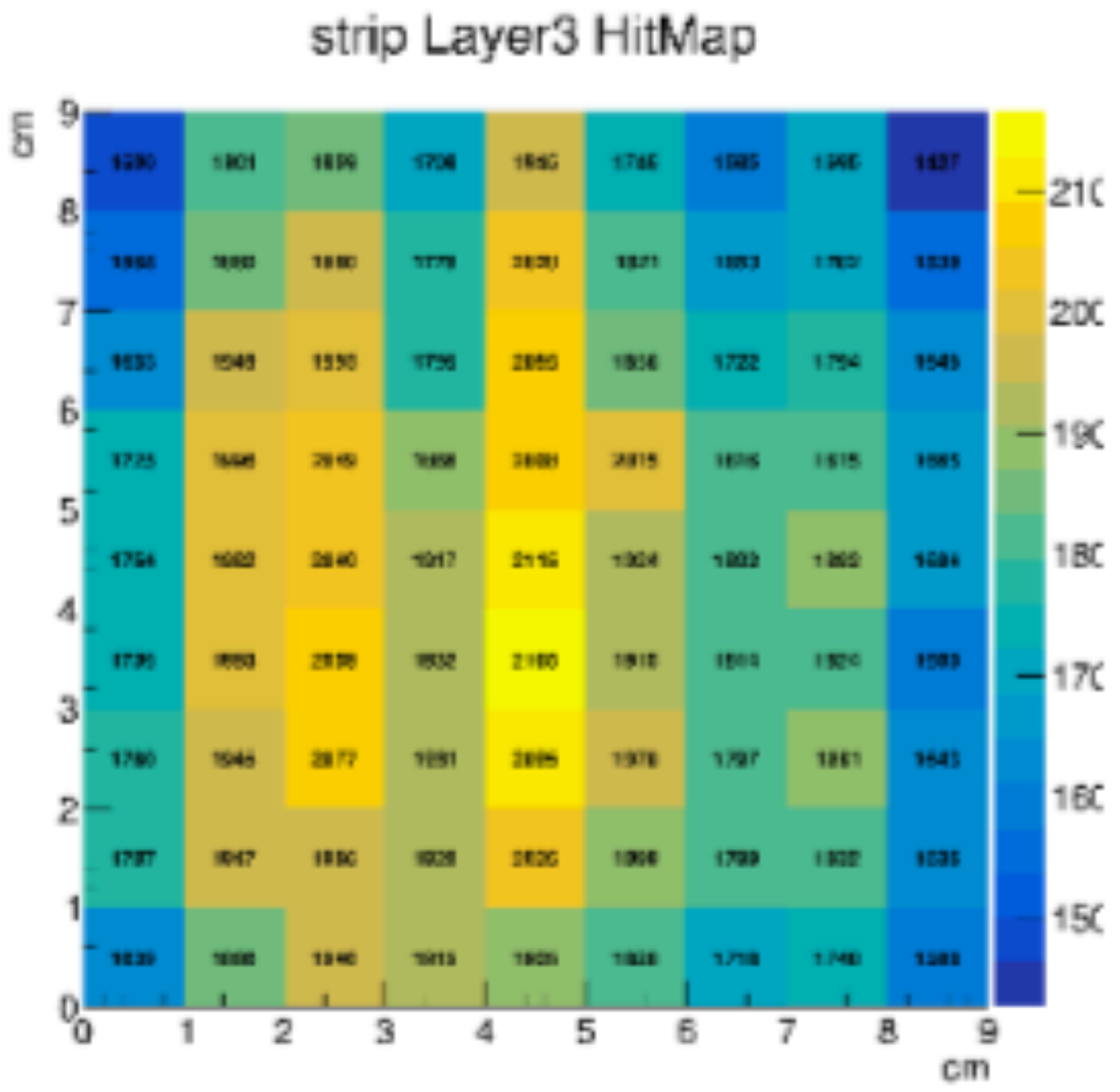
Strip(1)



Strip(2)



LG(2)



Strip(3)