Performance of segmented lead glass absorber calorimeter prototype

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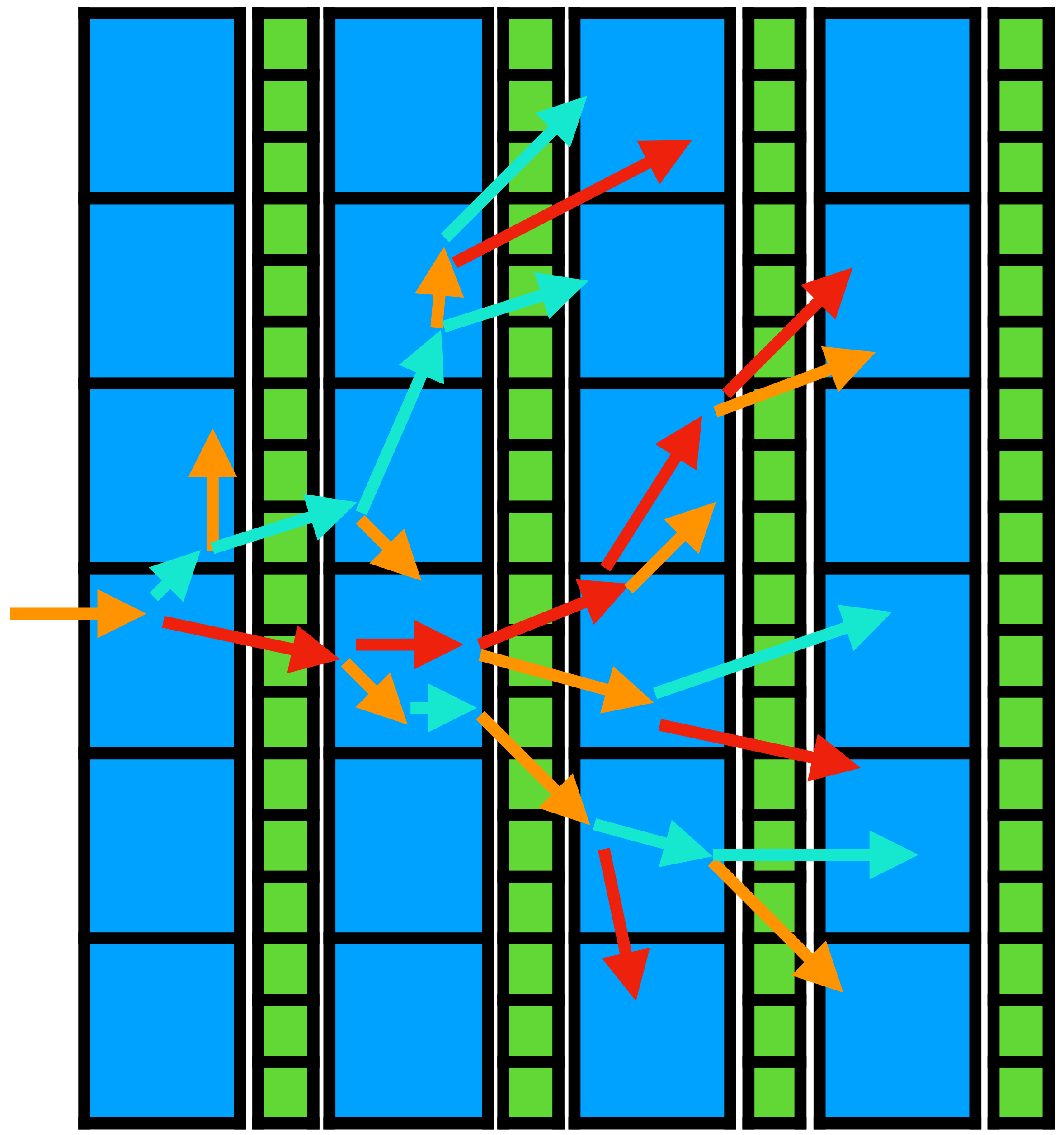
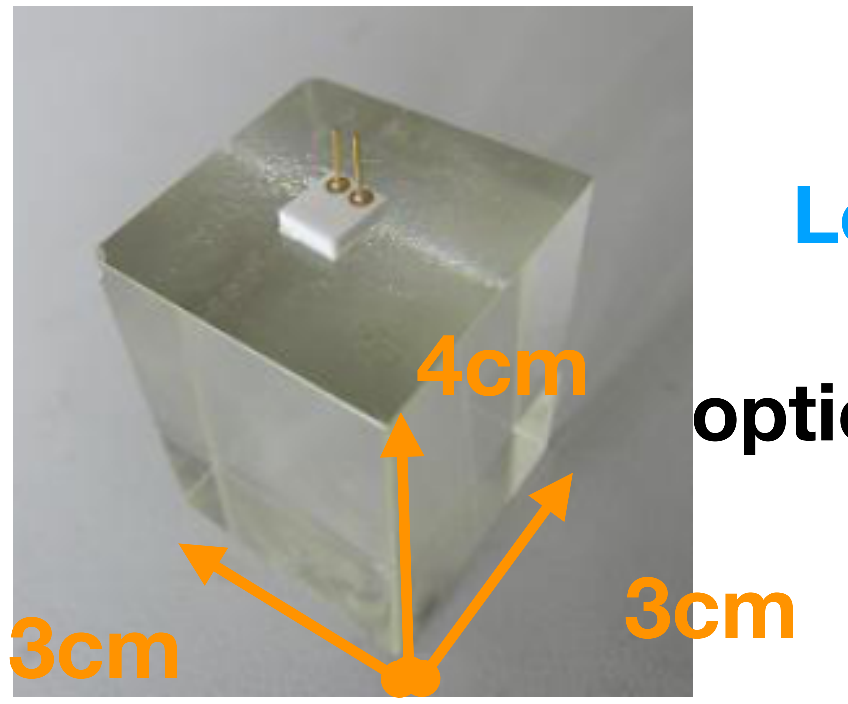
What is segmented lead glass absorber CAL?

- Improving calorimeter performance is necessary for future high-energy frontier collider experiments.
- The use of a homogeneous calorimeter is effective for improving energy resolution.
- For hadron calorimeters that require higher resolution, the cost of using a crystalline scintillator is a problem
- Lead glass is useful as a cheaper material
- On the other hand, Partcile Flow Algorithm is very useful for improving jet energy resolution.
- In order to use PFA, it is necessary to be an imaging calorimeter that can acquire detailed 3D information.
- The detection layer of the sampling calorimeter is optimal for acquiring position information
- In order to use both, it is better to use lead glass for the absorption layer and provide the detection layer independently.
- The position information can be acquired by dividing lead glass.



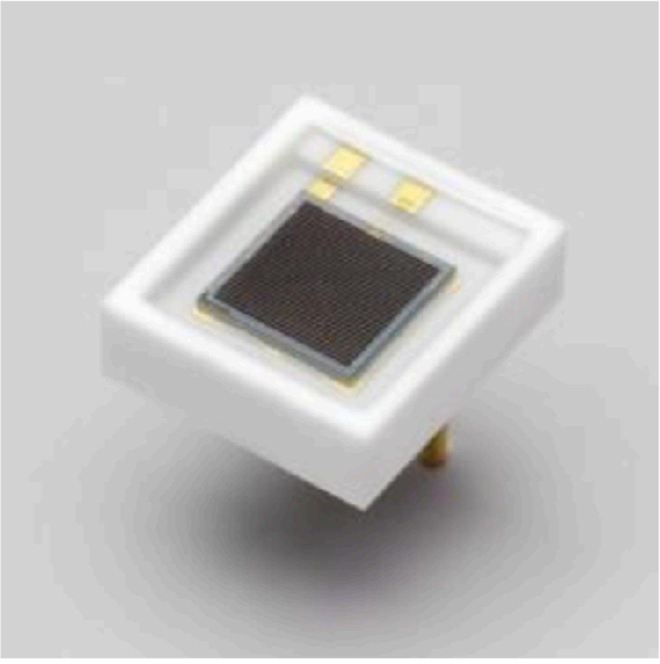
Energy Measurement: Lead Glass
Position Measurement: Scintillator



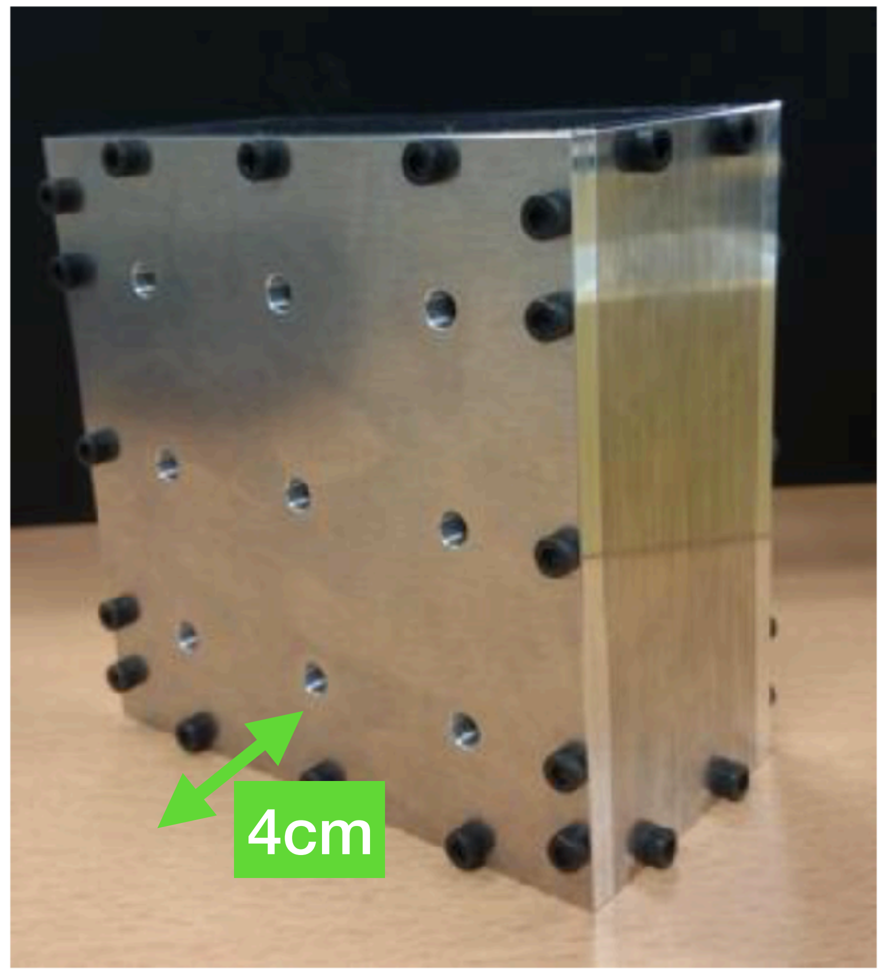
Lead glass block
and
optical sensor (MPPC)

Lead Glass Absorber

- Lead glass is transparent, so Cherenkov light can be measured with an optical sensor.
- MPPC, a thin light sensor, can reduce dead volume
- 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.
- 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)
- 1 layer has 9 lead glass blocks
  (3 x 3 ch lead glass blocks array)
  and we manufactured 3 layers.



3 x 3mm^2 MPPC

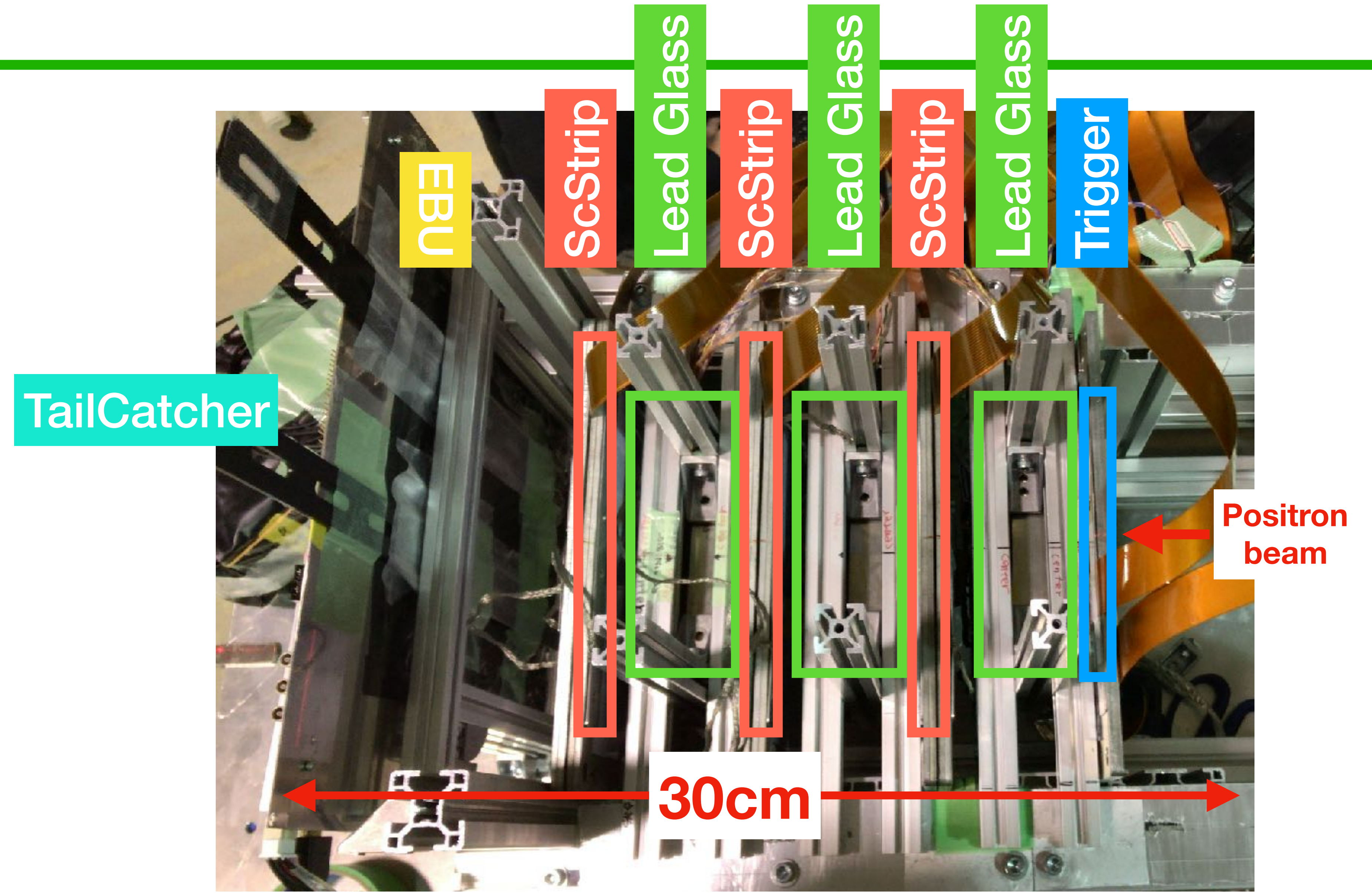


Active Absorber Layer

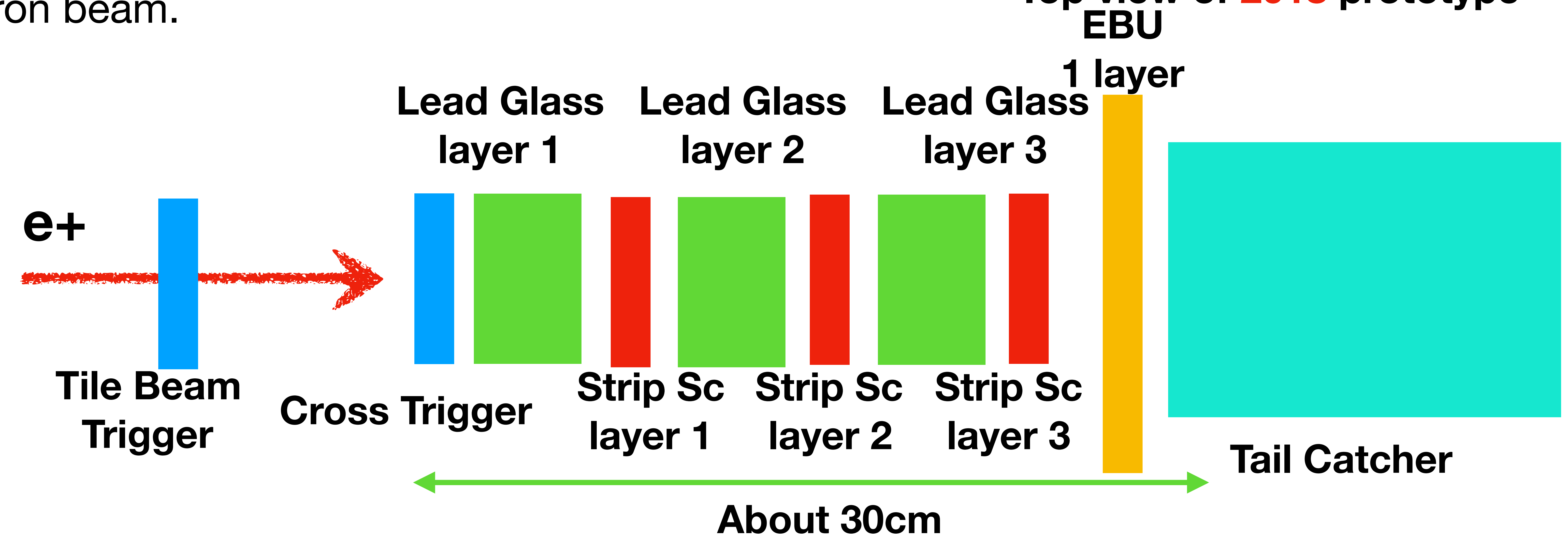
Lead Glass blocks Array

Prototype of active absorber ECAL

- We manufactured 3 layers sampling calorimeter as an active absorber ECAL.
    - Active Absorber layer: Segmented lead glasses with MPPCs
    - Finely granulated detection layer: Strip scintillators.
    - Tail catcher: Lead glass large block
- We did test at 3 times (2016, 2017, 2018) at ELPH at Tohoku University
- Injection of 50MeV to 800MeV positron beam.

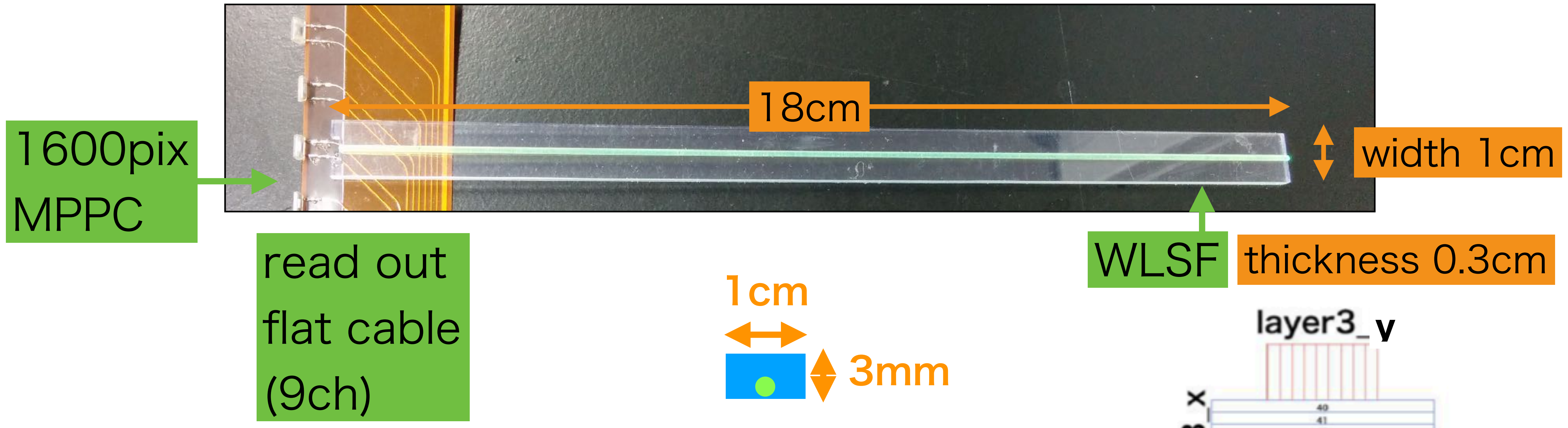


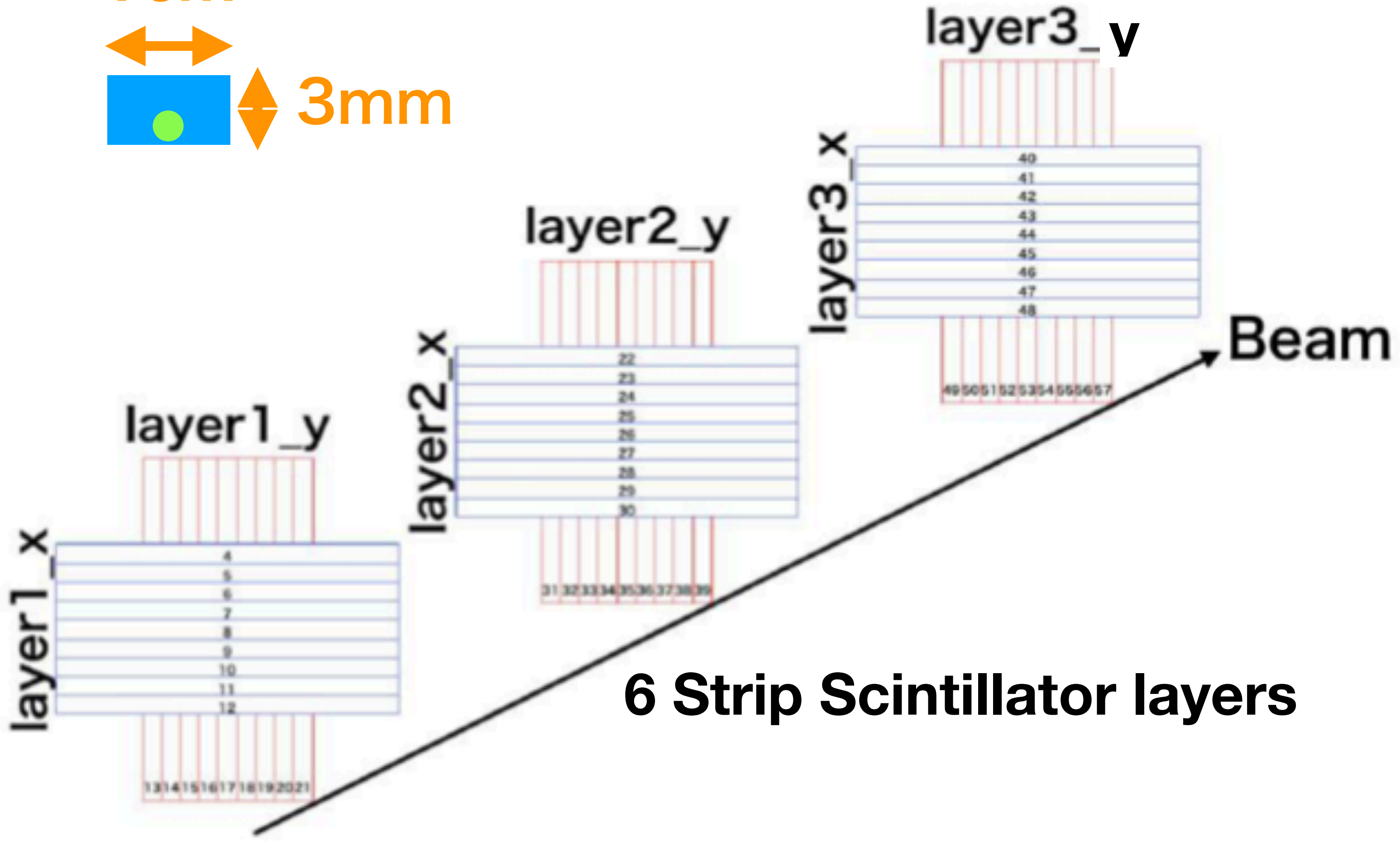
Top view of 2018 prototype



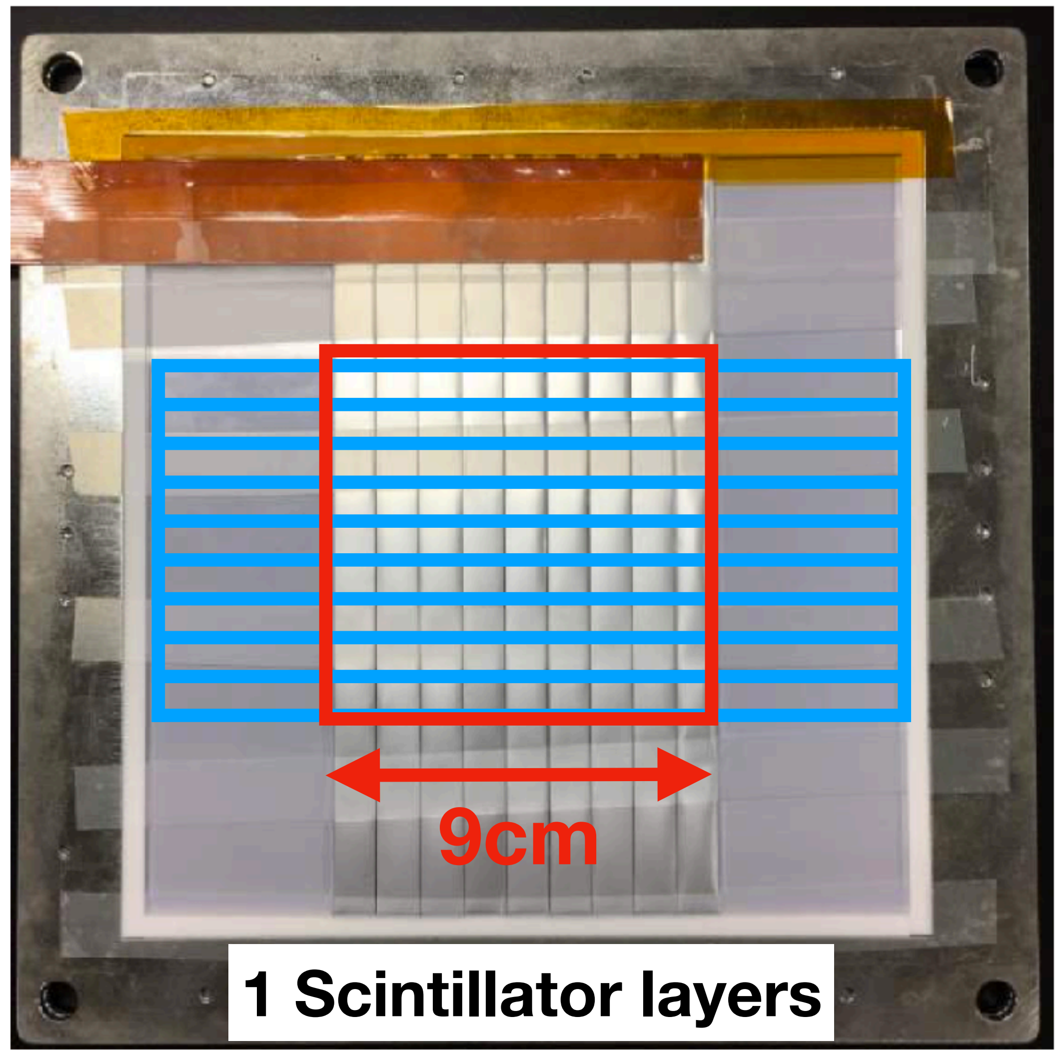
Strip scintillator layer

- A scintillator layer: 9 x 9 cm^2 sensitive area
- 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.

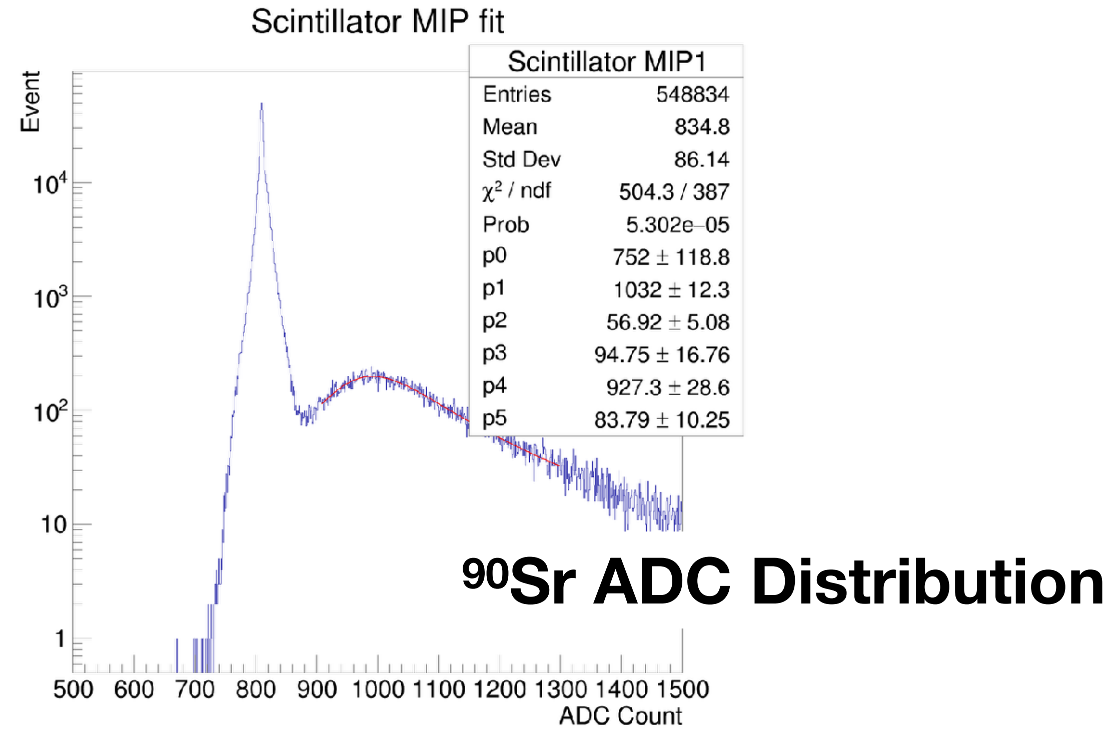




6 Strip Scintillator layers



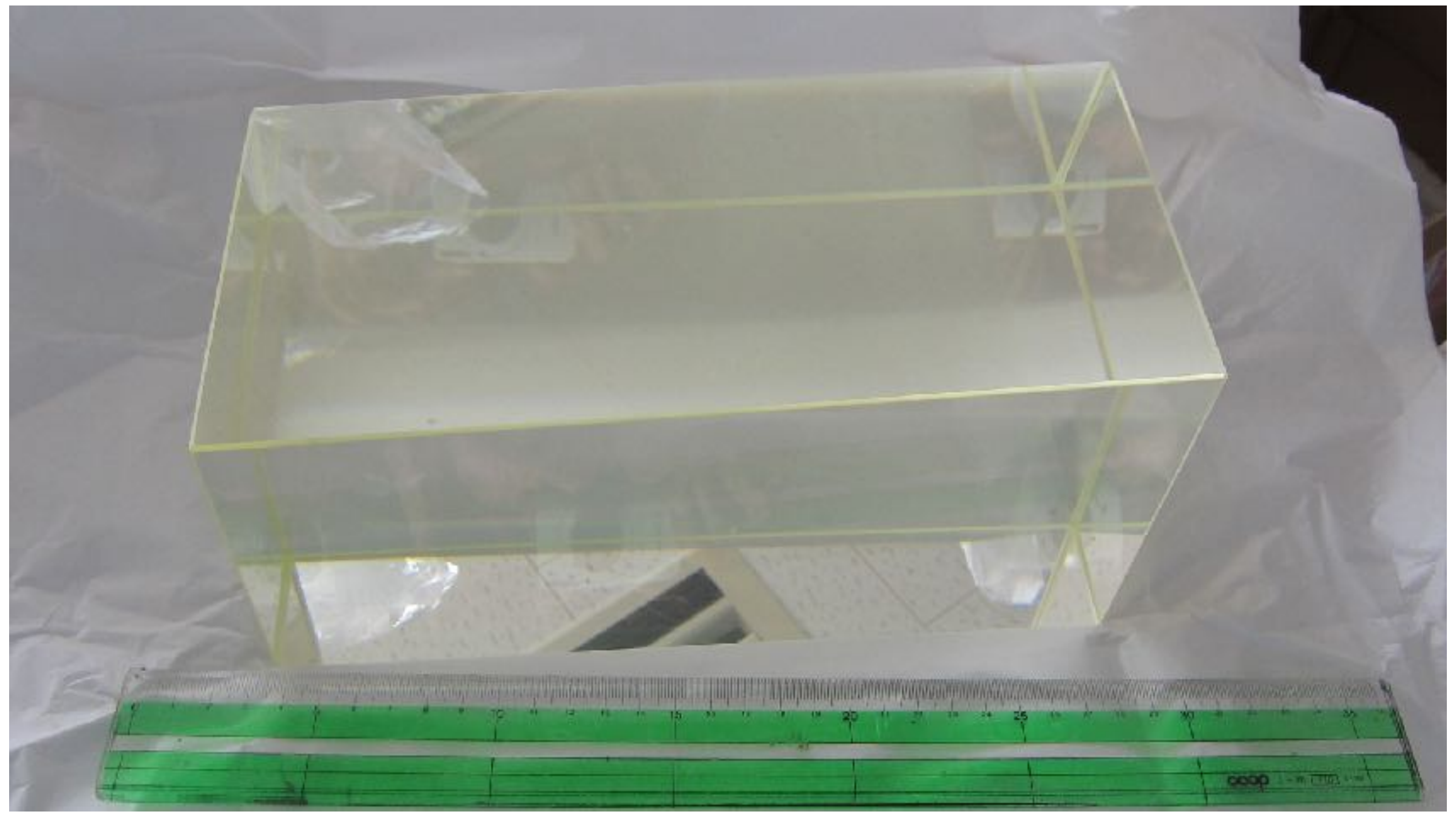
1 Scintillator layers



^{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

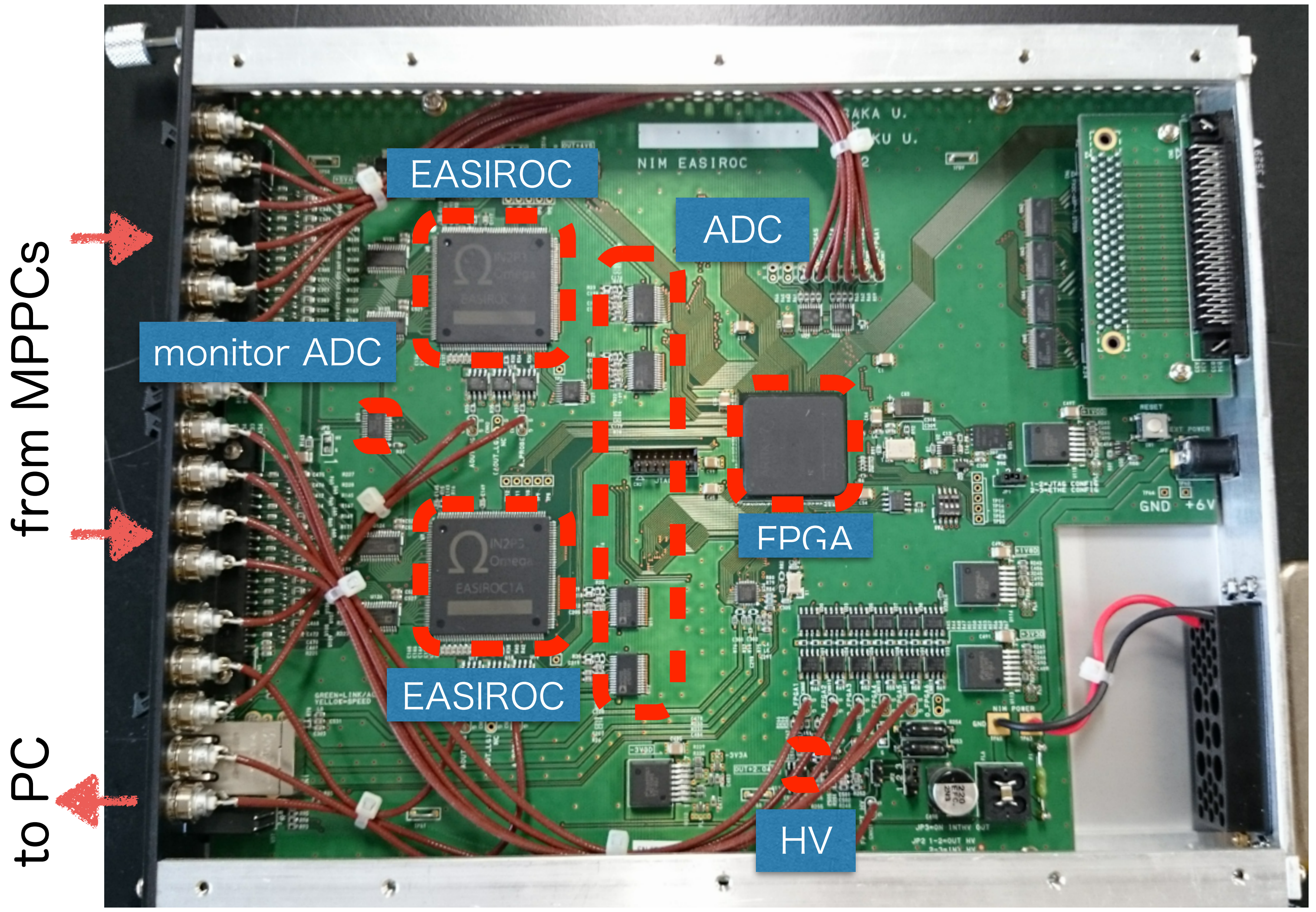


$12x12x25cm^3$ lead glass block

Tail Catcher

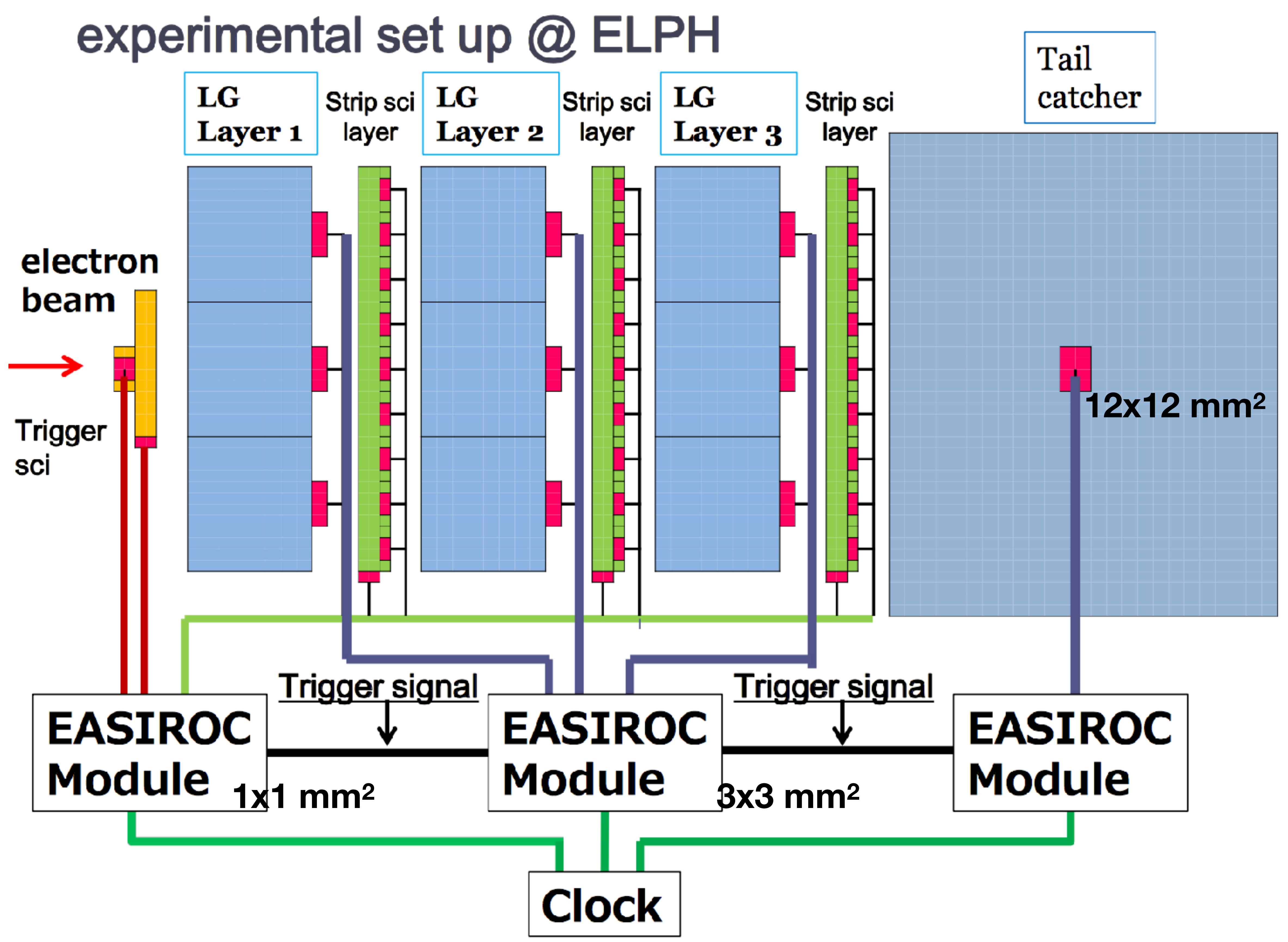
EASIROC Module

- 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

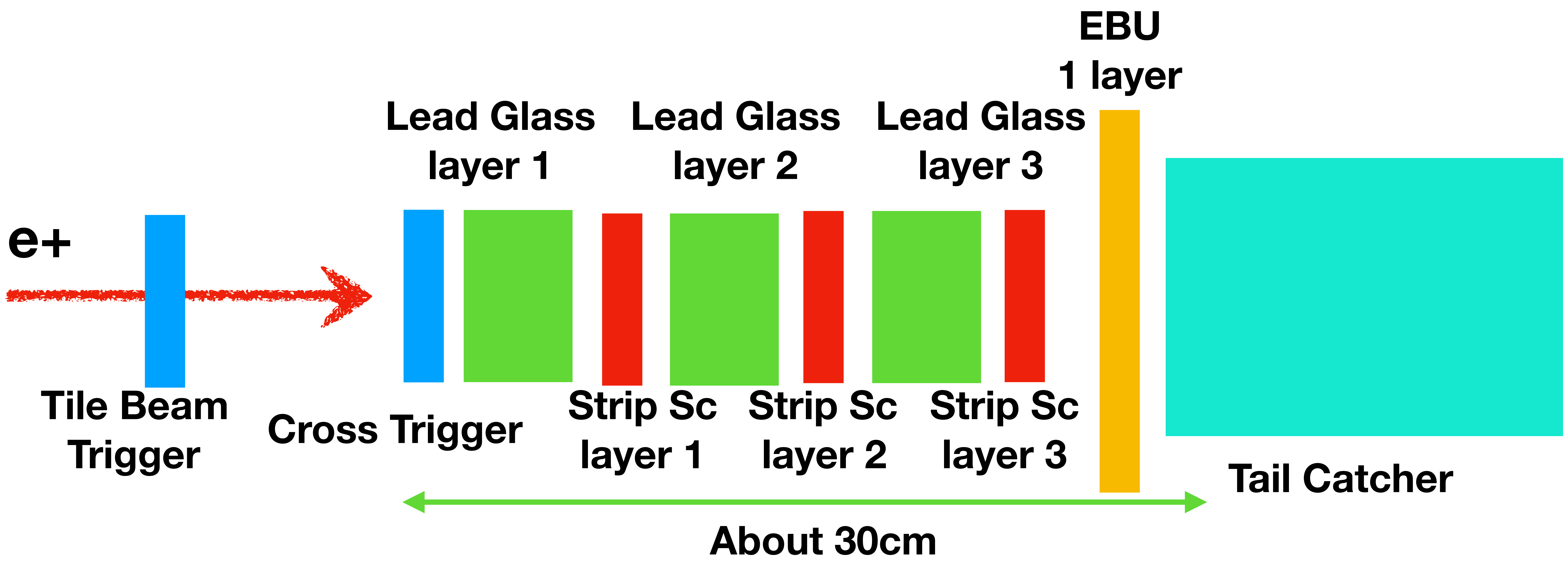
- This prototype has 83 MPPCs.
  - Active absorber layers have 27 MPPCs
  - Strip scintillator layers have 54 MPPCs
  - Tail catcher has 2 MPPCs
- 3 EASIROC Modules to read out MPPC signals for 3 types MPPCs as different breakdown voltages. (1 x 1 mm^2, 3 x 3 mm^2, 12 x 12 mm^2)
- Trigger signals are made by one EASIROC Module for events with signals from 2 trigger scintillators coincidence.
- Trigger signals are fed into the other modules.
- All EASIROC Modules are read out with 250kHz and 40MHz synchronized clocks.



Read Out and Trigger system

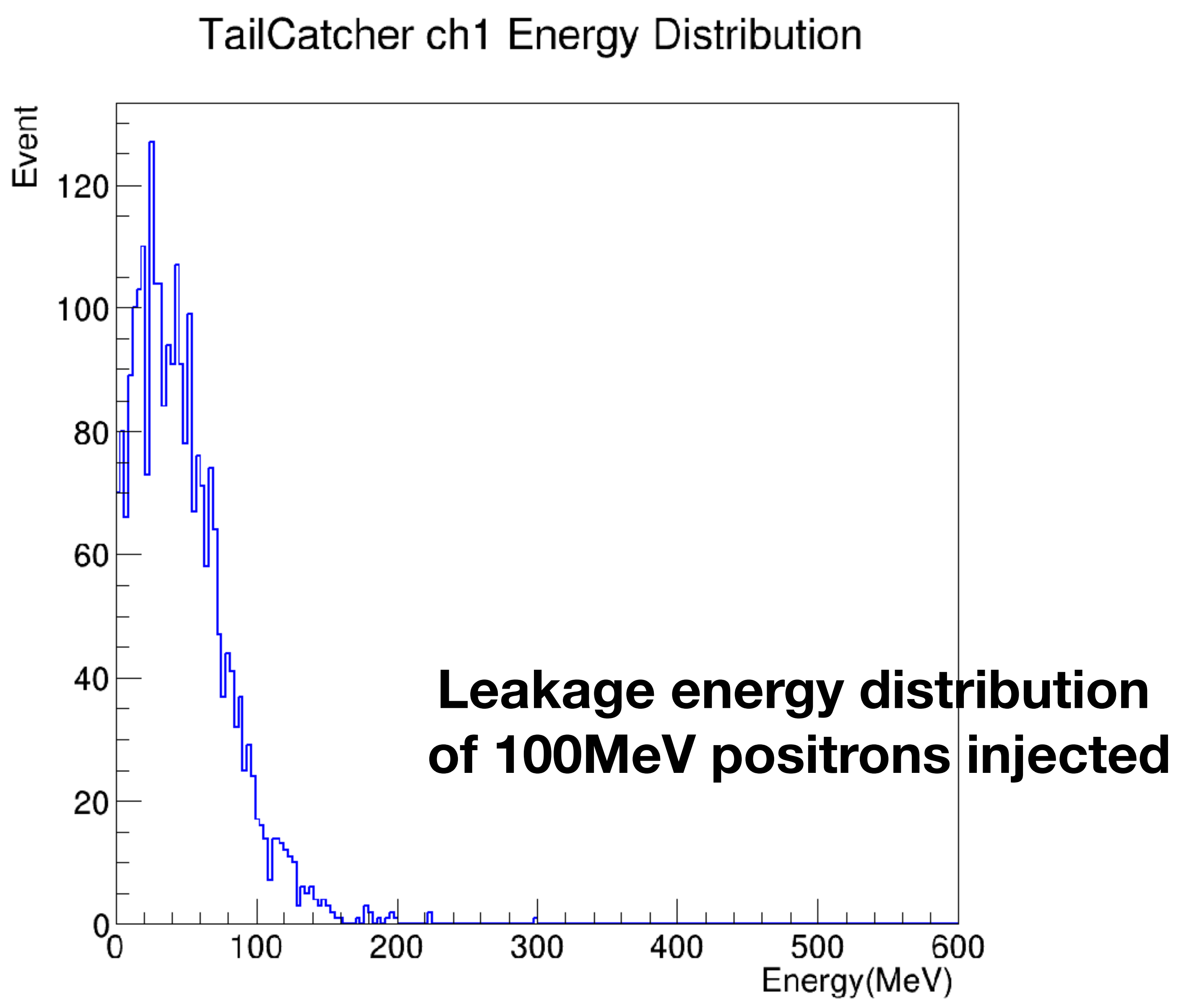
Test Beam

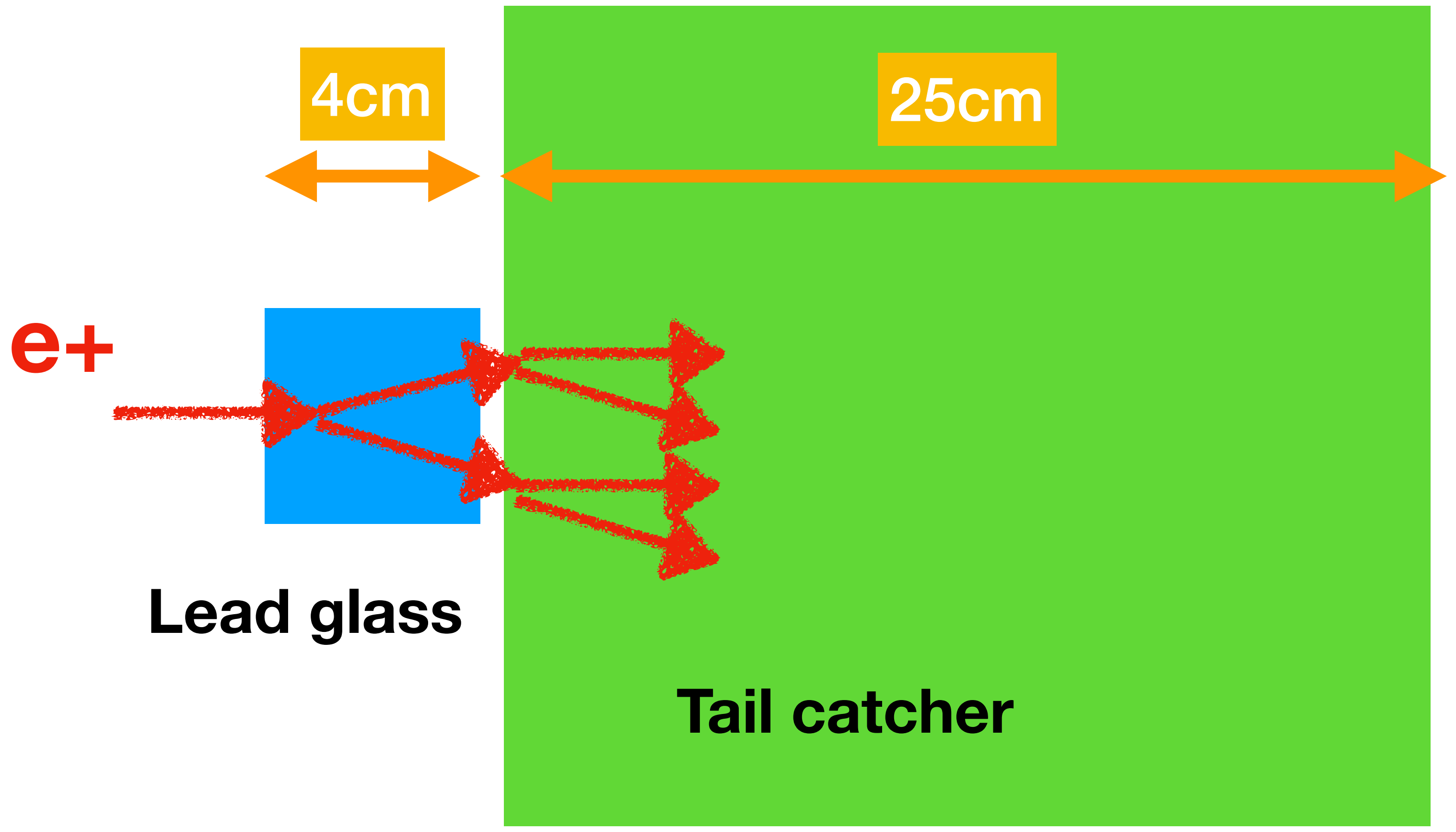
- test beam, 22 to 25 November at 2018
- This test beam is focus
  - We did calibration all Lead Glass block channels with beam.
  - Check Energy resolution



Calibration of lead glass block

- Calibration is important for calorimeter.
- The mean energy deposit to the single lead glass block was 50 MeV at 100MeV positron injection because of EM shower back leakage.
- 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.
- We did calibrate all the lead glass blocks 2018 TB at 400MeV positron.

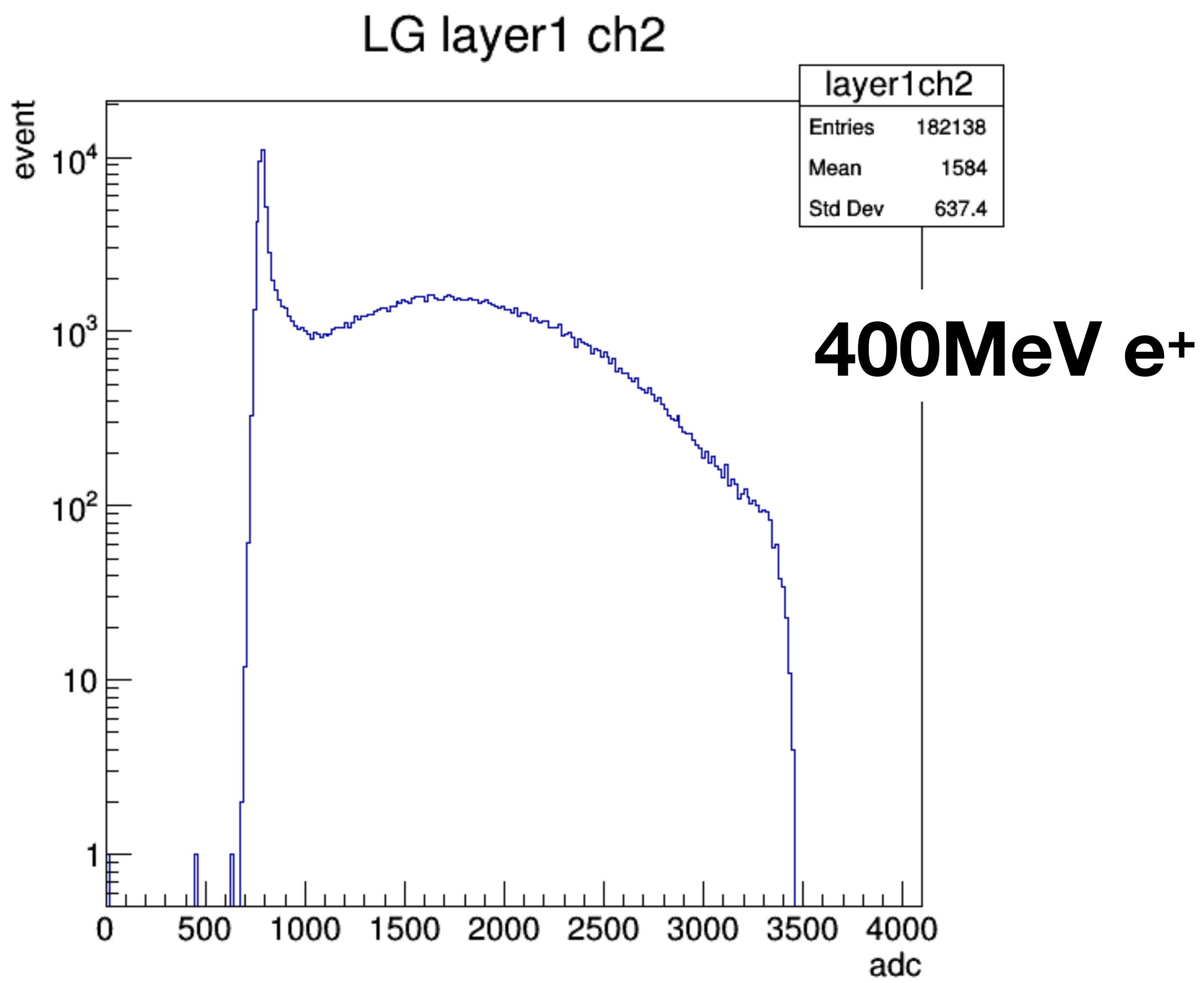




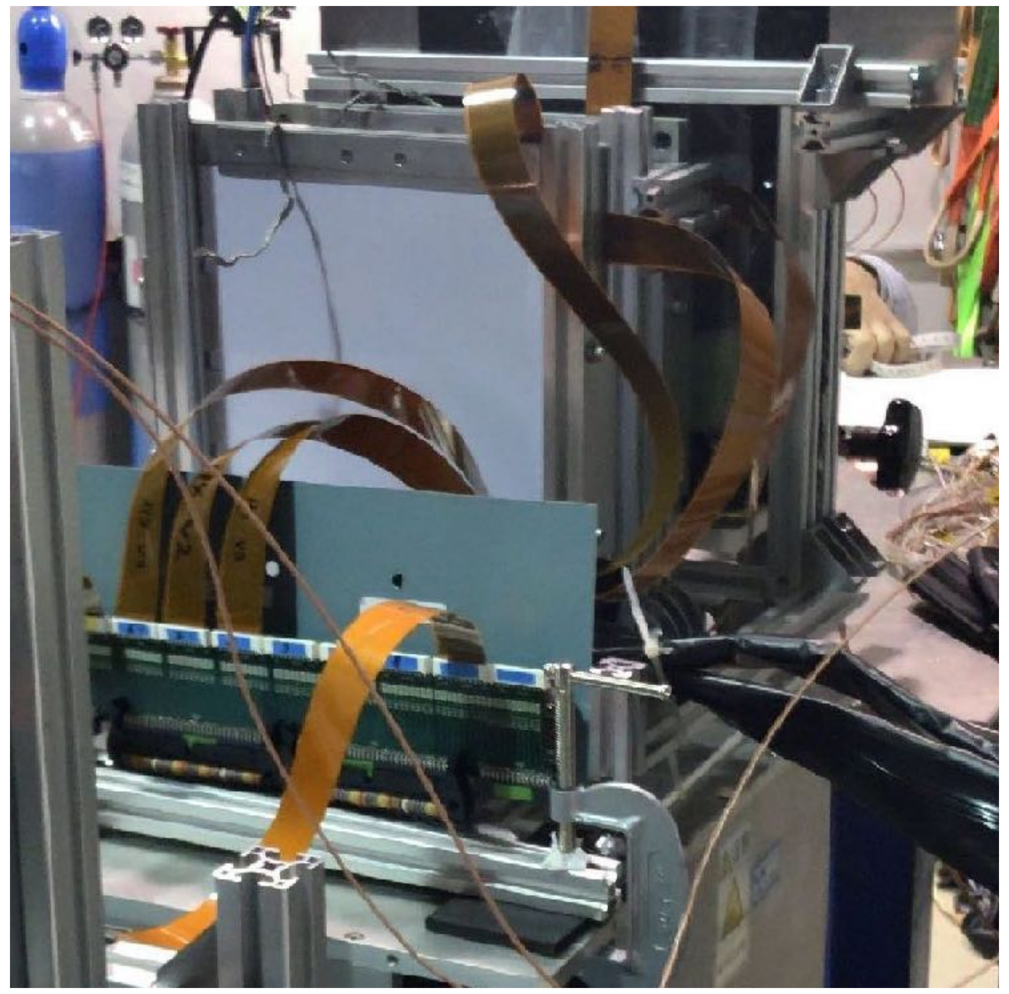
calibration method at 2017 test

Set Up of Energy Calibration

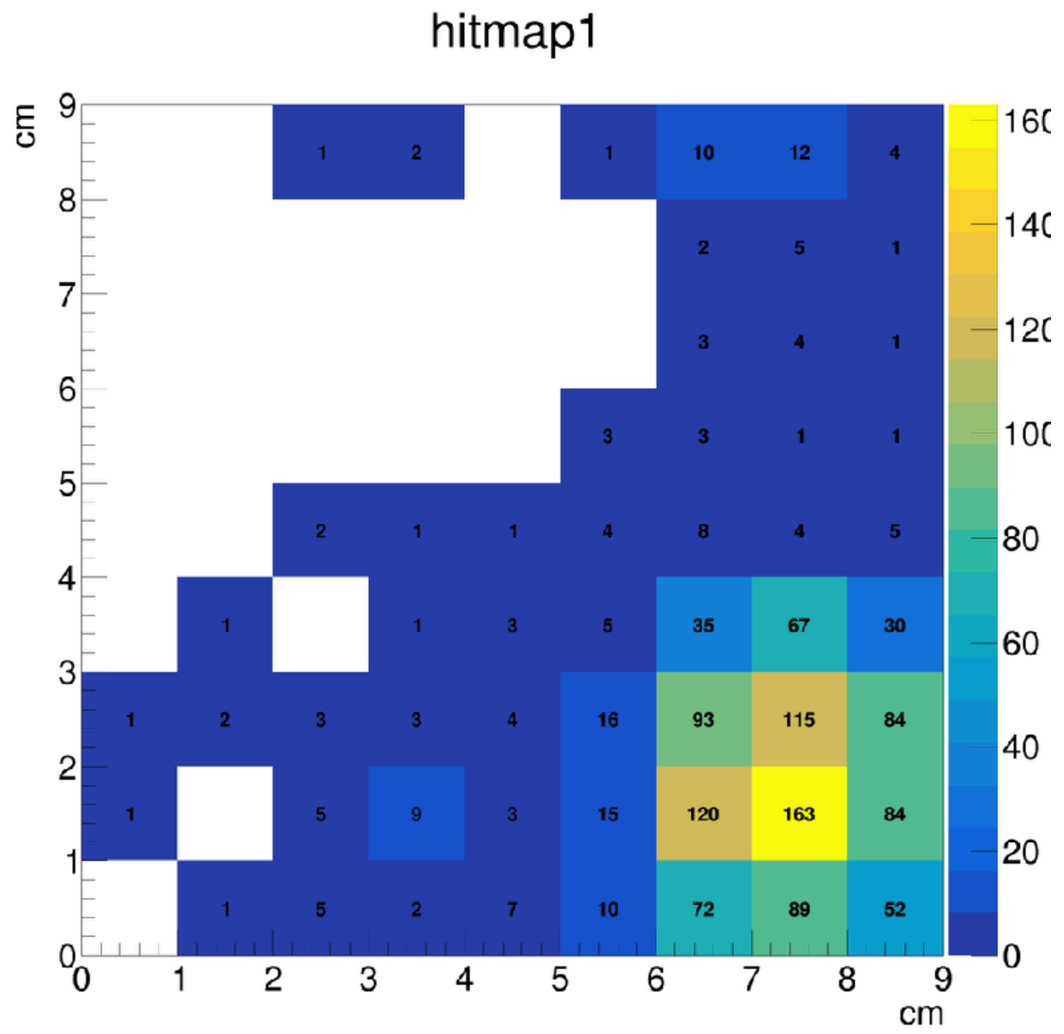
- We did calibration all Lead Glass block channels with 400MeV beam.
- We moved the position of the detector using an electric moving stage by remote control
- Beam position was confirmed by using strip layer in front of lead glass layer
- Lead glass at the center of the layer confirmed the response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



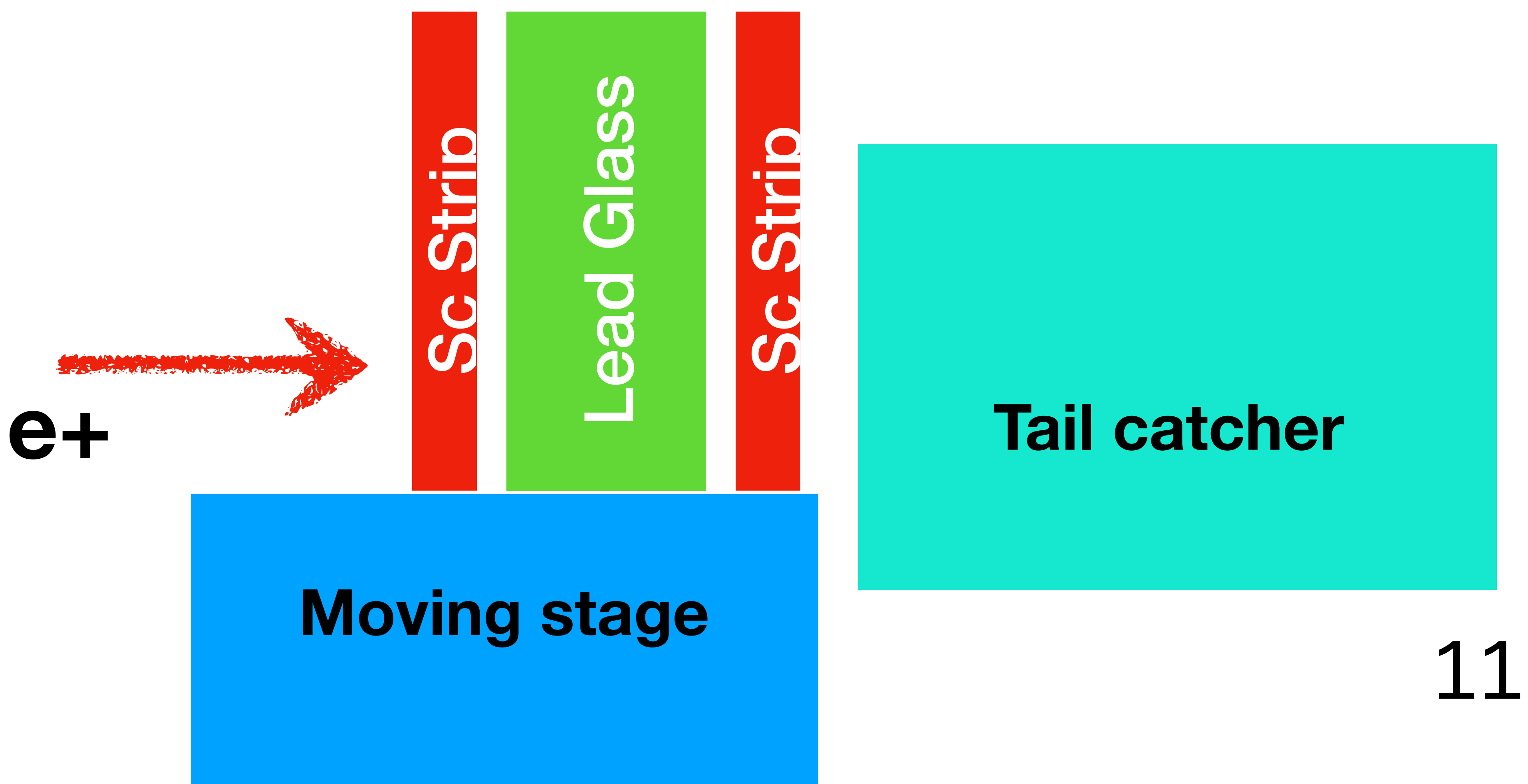
Lead glass ADC distribution



Set up of energy calibration



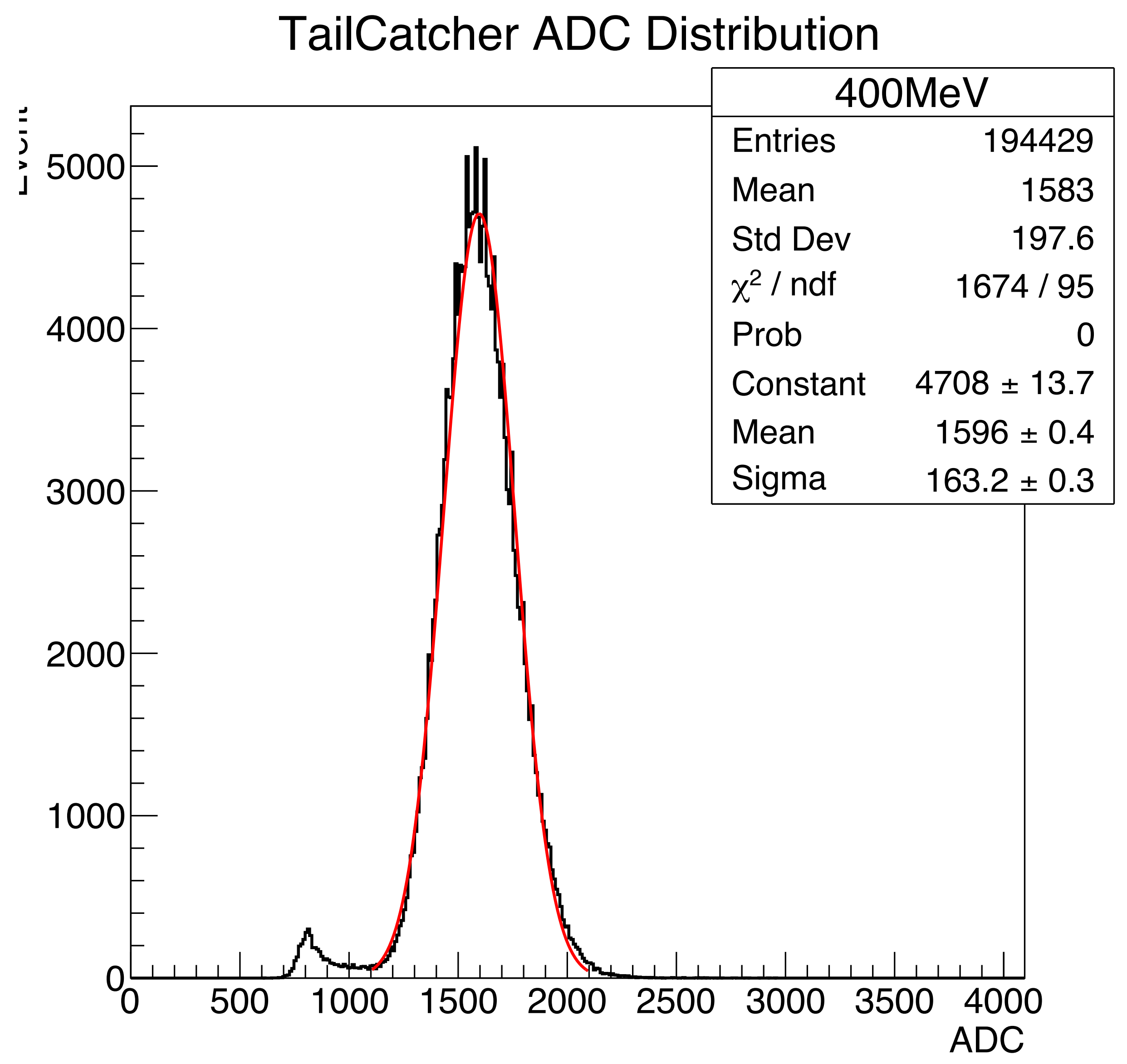
Sc hitmap for Beam position



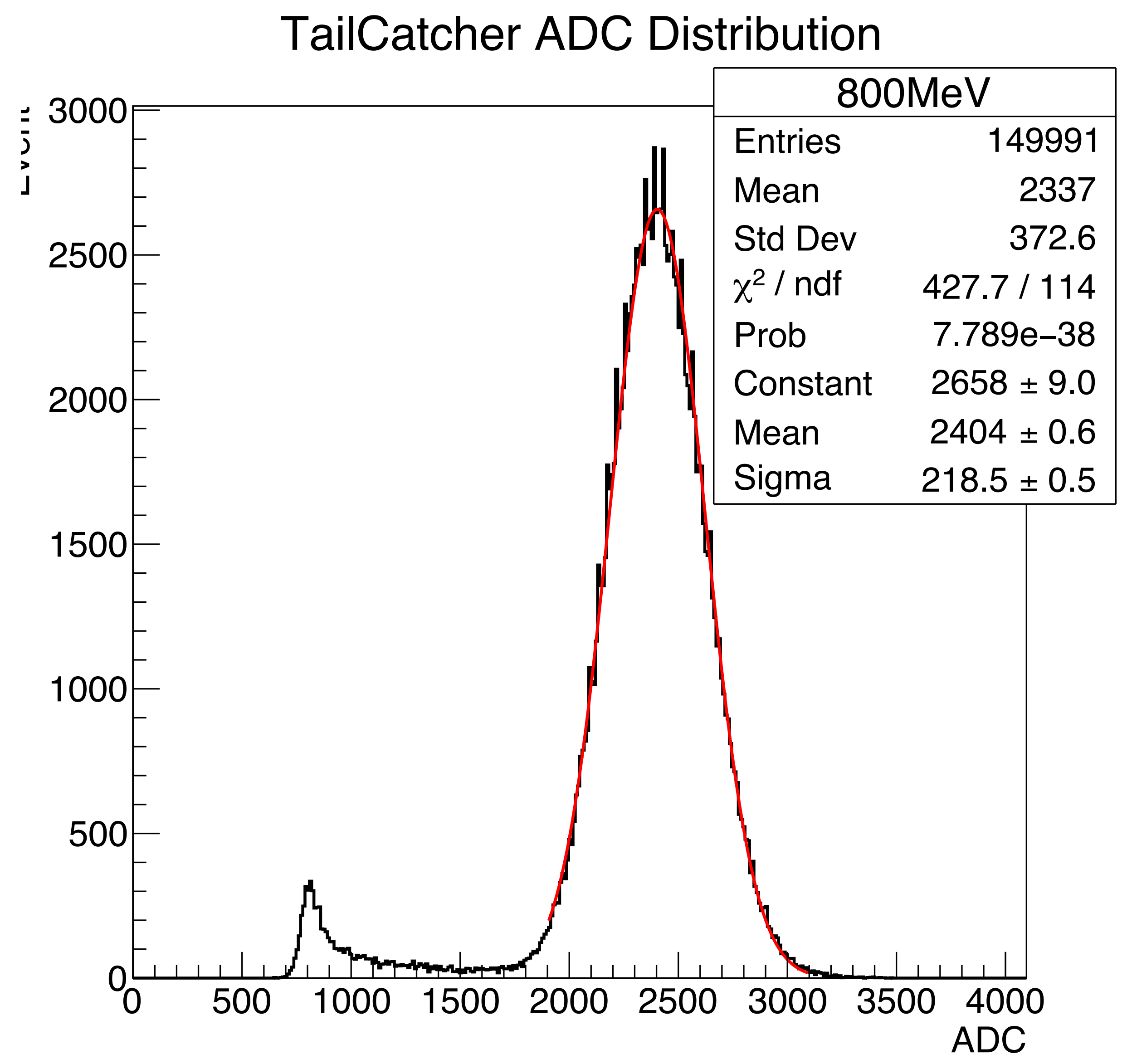
Tail Catcher Energy Calibration

- We need the tail catcher energy information to know the energy to drop in the lead glass block.

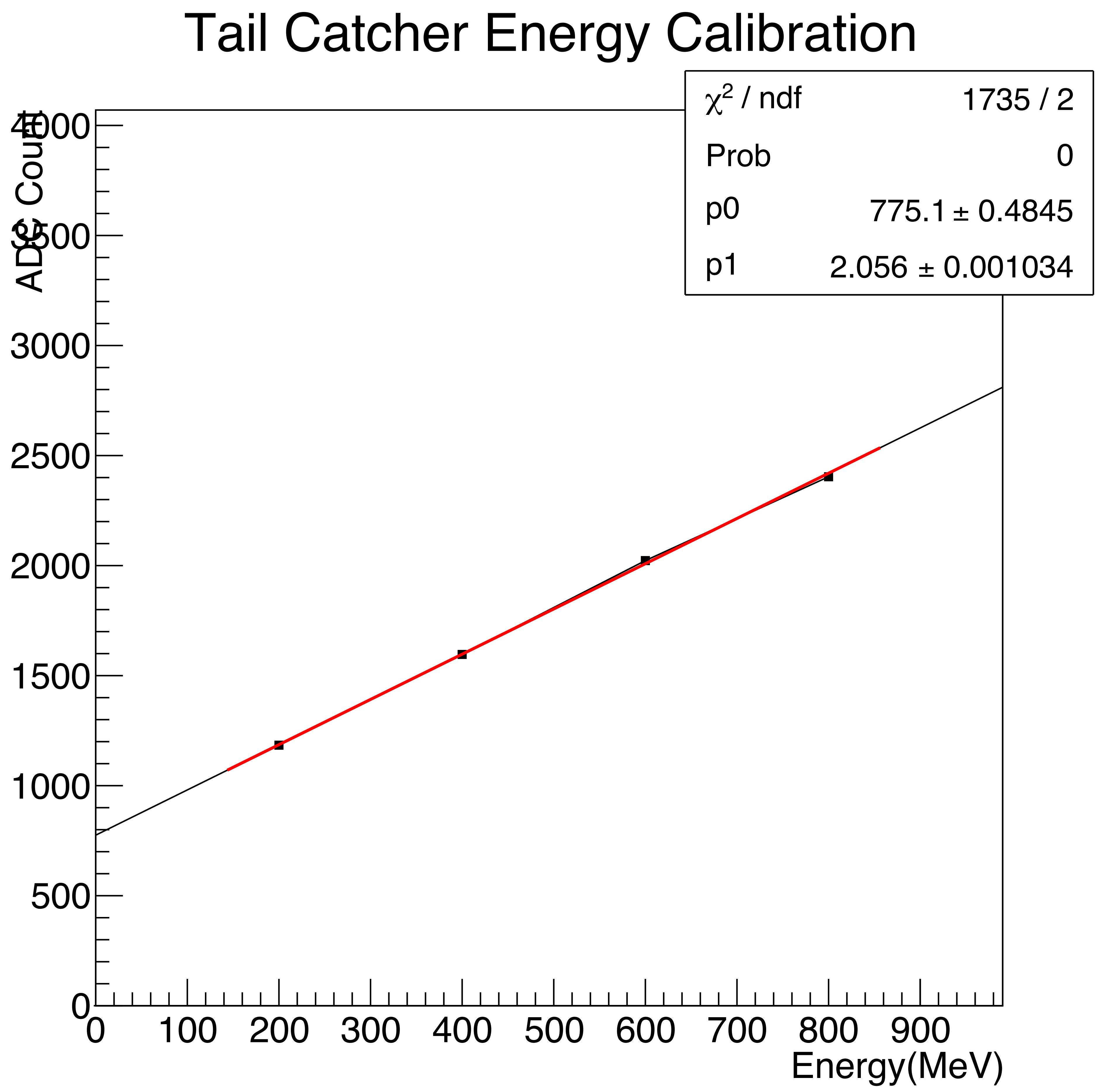
- A sufficiently linear response to the injected energy was confirmed.



ADC Distribution of 400MeV e+ injected



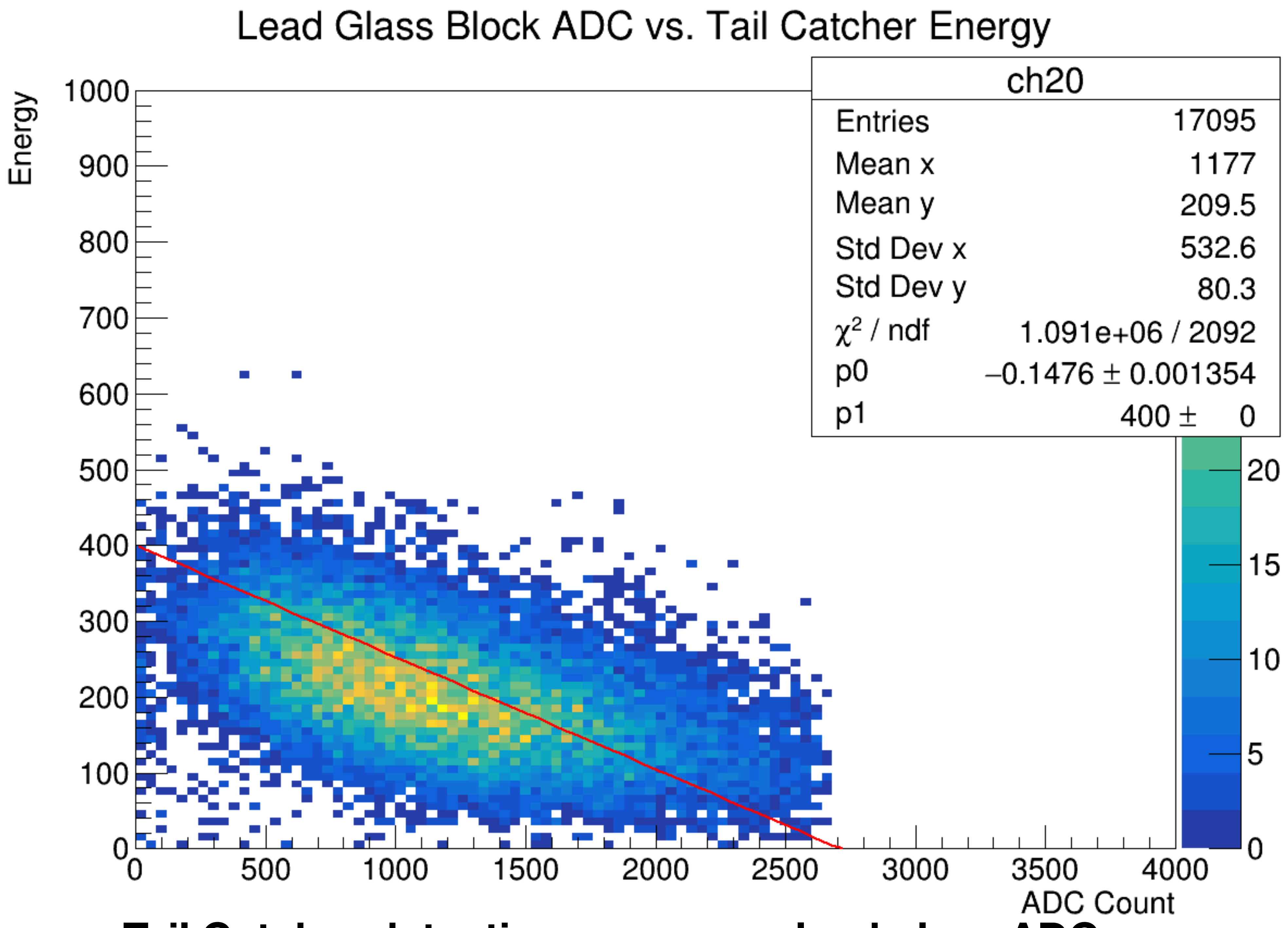
ADC Distribution of 800MeV e+ injected



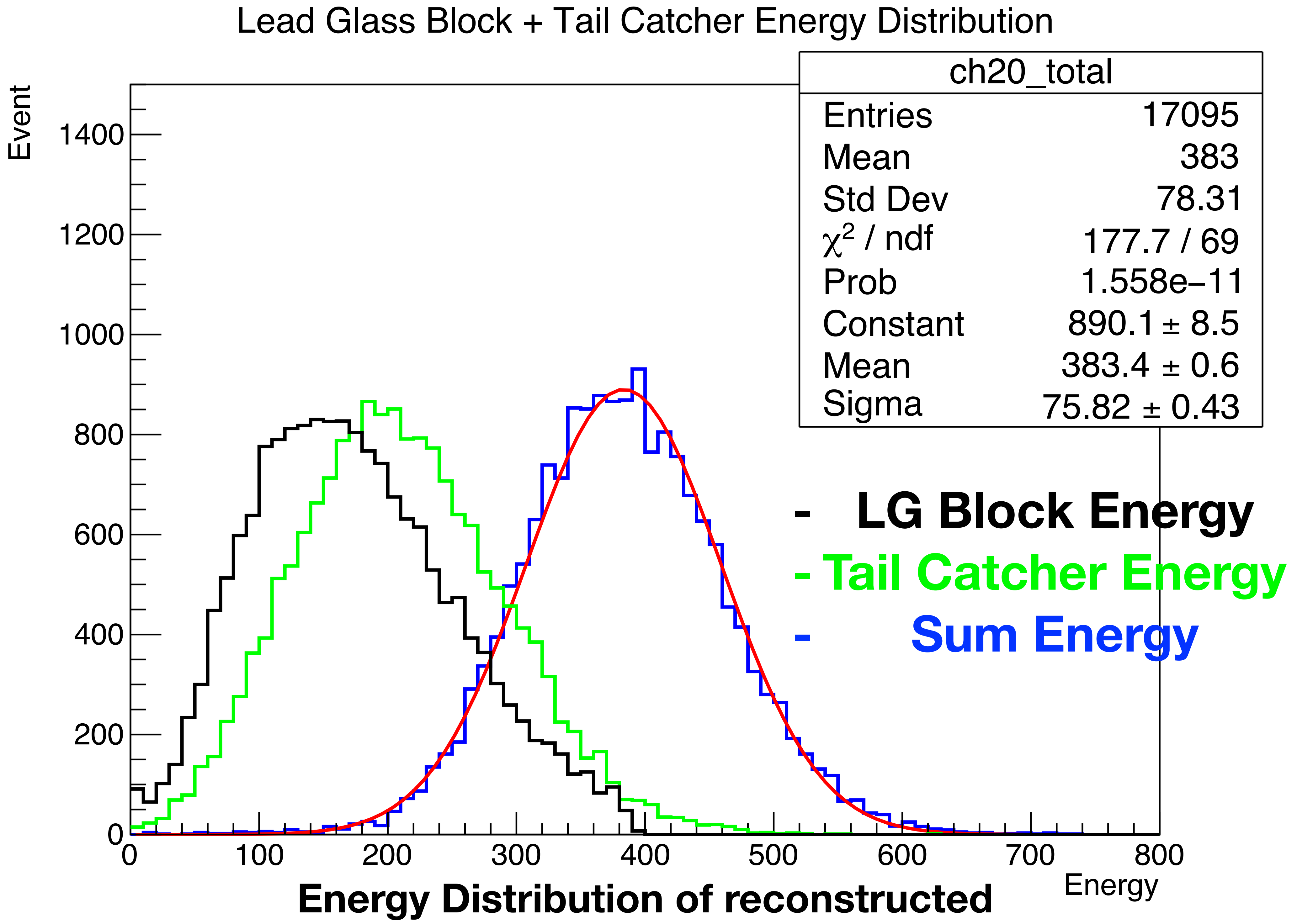
ADC Count v.s. Injected Energy

LG Block Energy Calibration

- The energy of LG Block energy and Tail Catcher energy is equal to the injection energy.
- A lead glass block ADC/E was obtained by plotting the energy of the tail catcher and the ADC distribution of LG in a two-dimensional plot.
- We obtain roughly result of this parameter.
- At first, a plot of energy distribution was created from this rough result.



Tail Catcher detection energy v.s. lead glass ADC



Energy Distribution of reconstructed

カロリメータ全体での測定結果

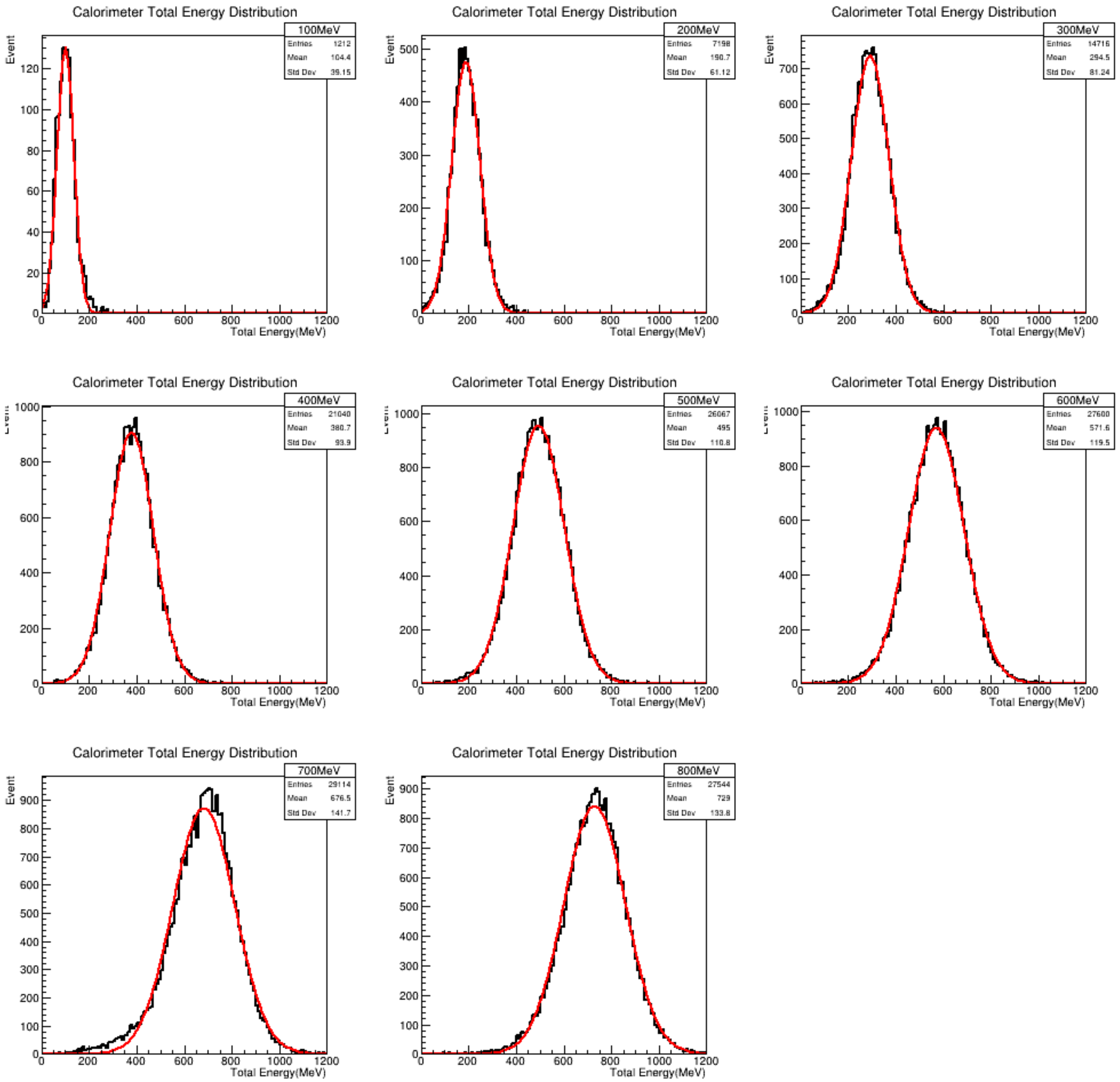
- After all lead glass channel calibration, we reconstructed calorimeter energy.
  (Results of 3 lead glass absorption layers and tail catcher)

- Incident energy entered 100-800 MeV in 100MeV increments

- The energy distribution is in good agreement with the Gaussian distribution

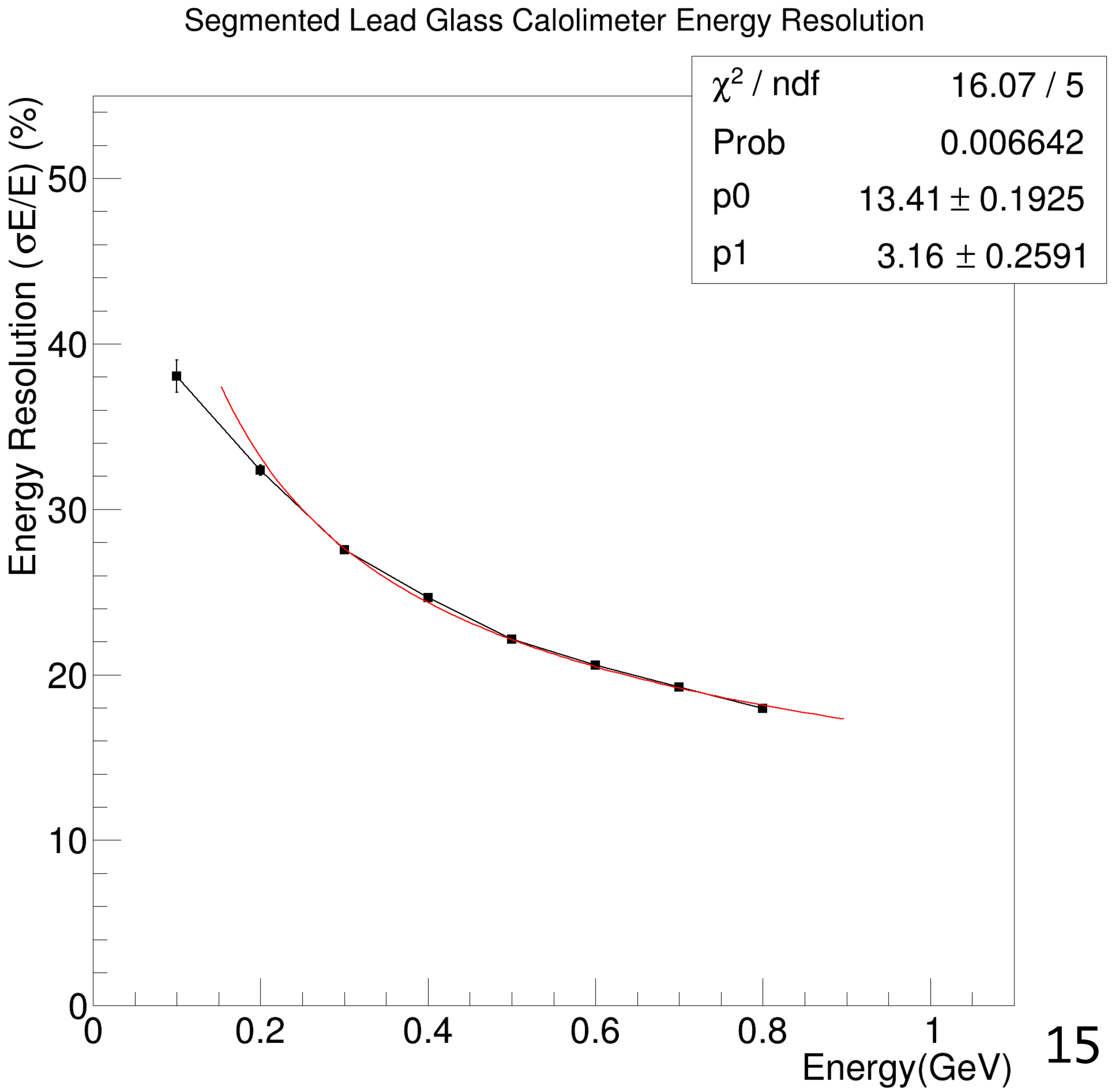
- Up to 700 MeV, energy can be reconstructed correctly

- At 800 MeV, it is about 10% smaller, which is currently being investigated.



カロリメータ全体でのエネルギー分解能

- The energy resolution was calculated from the energy reconstruction results.
  (Results of 3 lead glass absorption layers and tail catcher)
- Excluding 100 MeV, the results are in good agreement with $1/\sqrt{E}$ fit results
- From this result, the resolution is 13.5%
- The constant term is as large as 3%
- We are ckecking these cause.
  - Being out of fit at 100MeV
  - Large constant terms



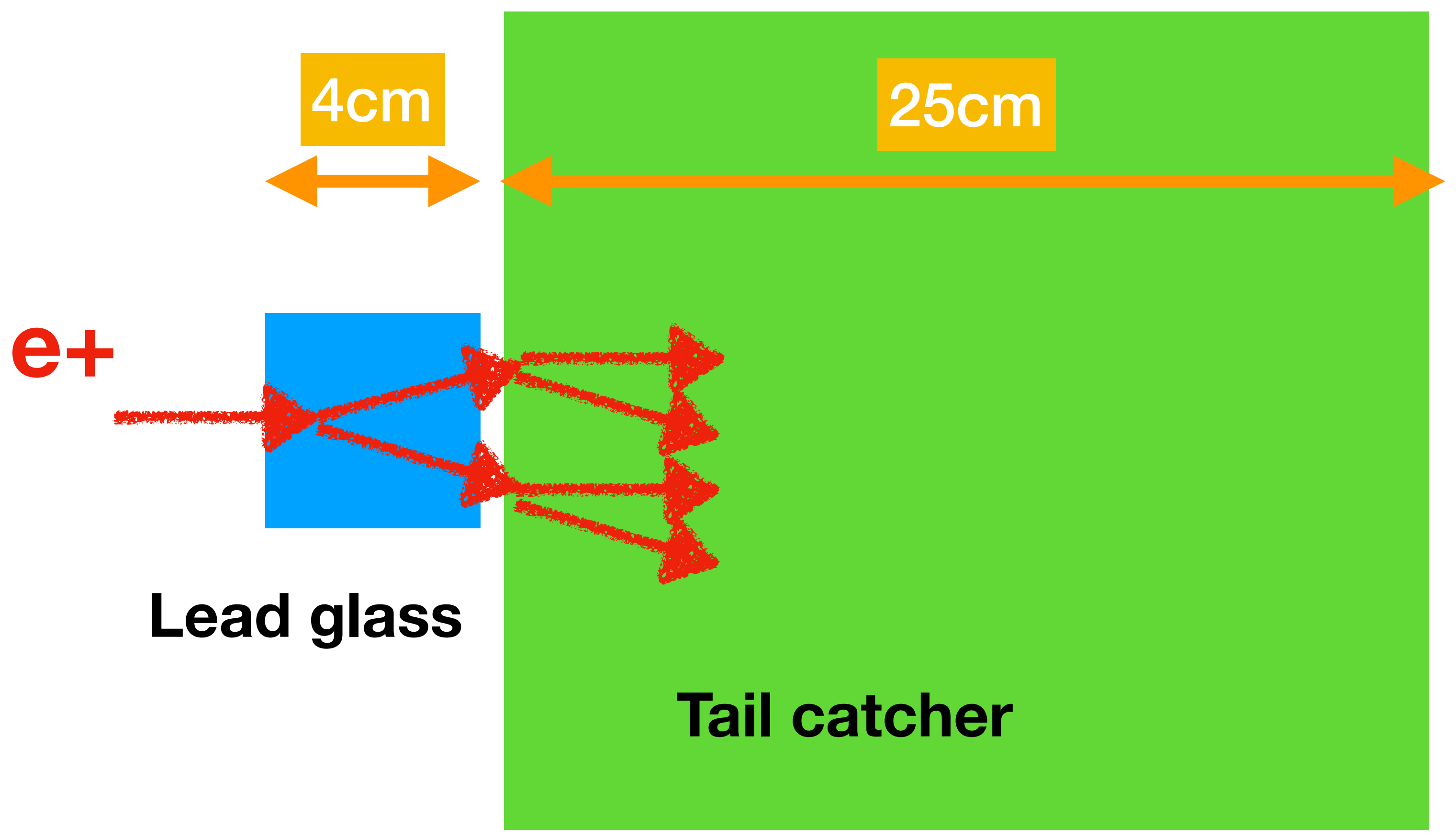
Summary

- Performance improvement of calorimeter is indispensable for future high energy frontier collider experiment.
- We are developing and testing segmented lead glass CAL.
- Test beam was performed and the operation as a calorimeter was confirmed.
- The reconstructed energy distribution is a Gaussian distribution, which matches the incident energy within 5% below 700 MeV.
- About the energy resolution of this prototype, fitting with was performed and the energy resolution was 13%.
- Future Plan
  - Improved resolution with finer calibration
  - Comparison with simulation
  - Improved detection efficiency of Cherenkov light to improve energy resolution

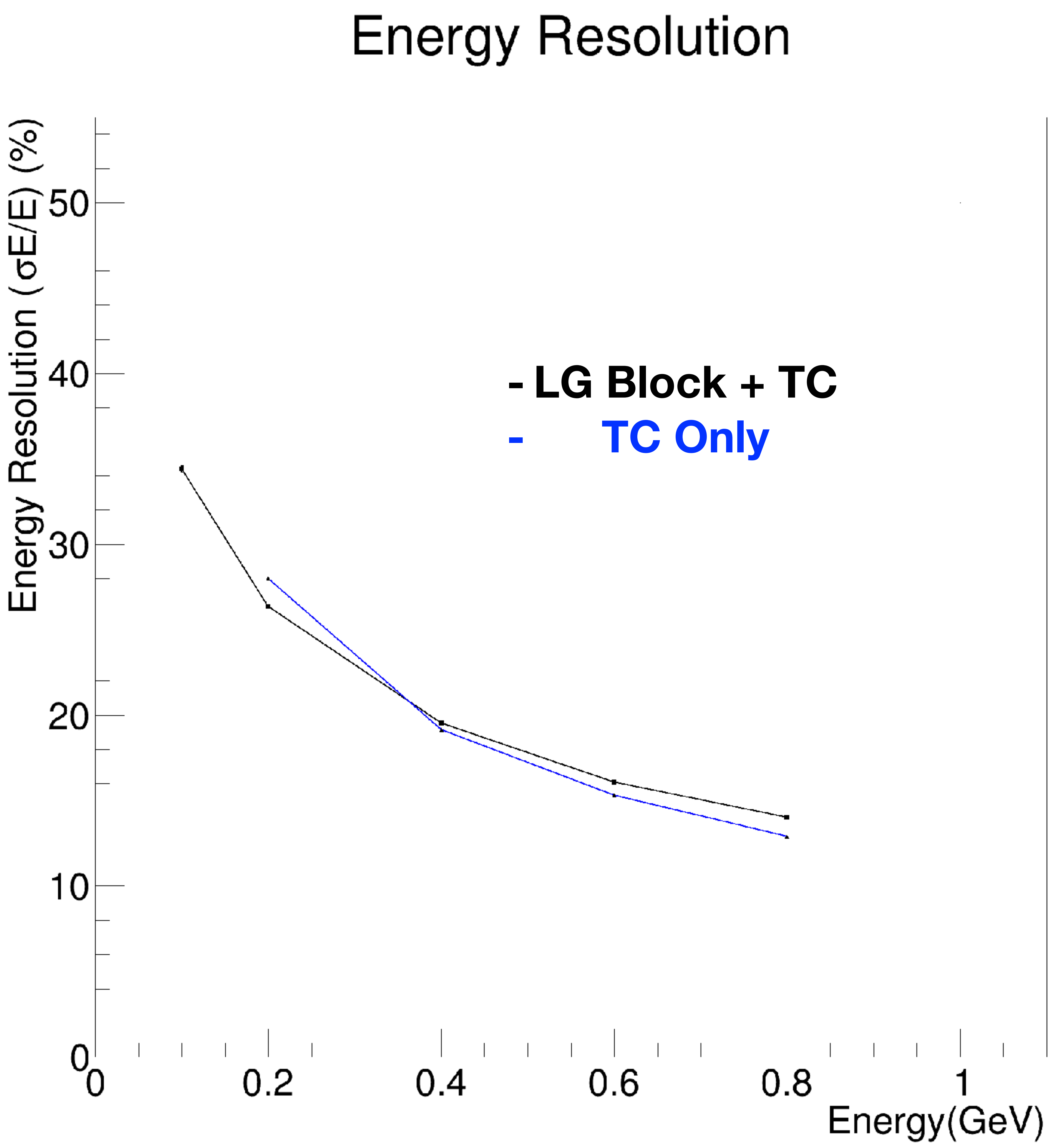
Backup

Single Block Energy Resolution

- Based on this results, the simple energy resolution of a single block is calculated.
- Comparison of energy resolution of single LG block with tail catcher and tail catcher only.
- Most of the energy is passing, so depending on the performance of the TC, the result is the same.
- Slightly low energy region is good, but high energy one is degraded.
- It may be due to an energy leak.
- Whole detector energy resolution checking is on going.

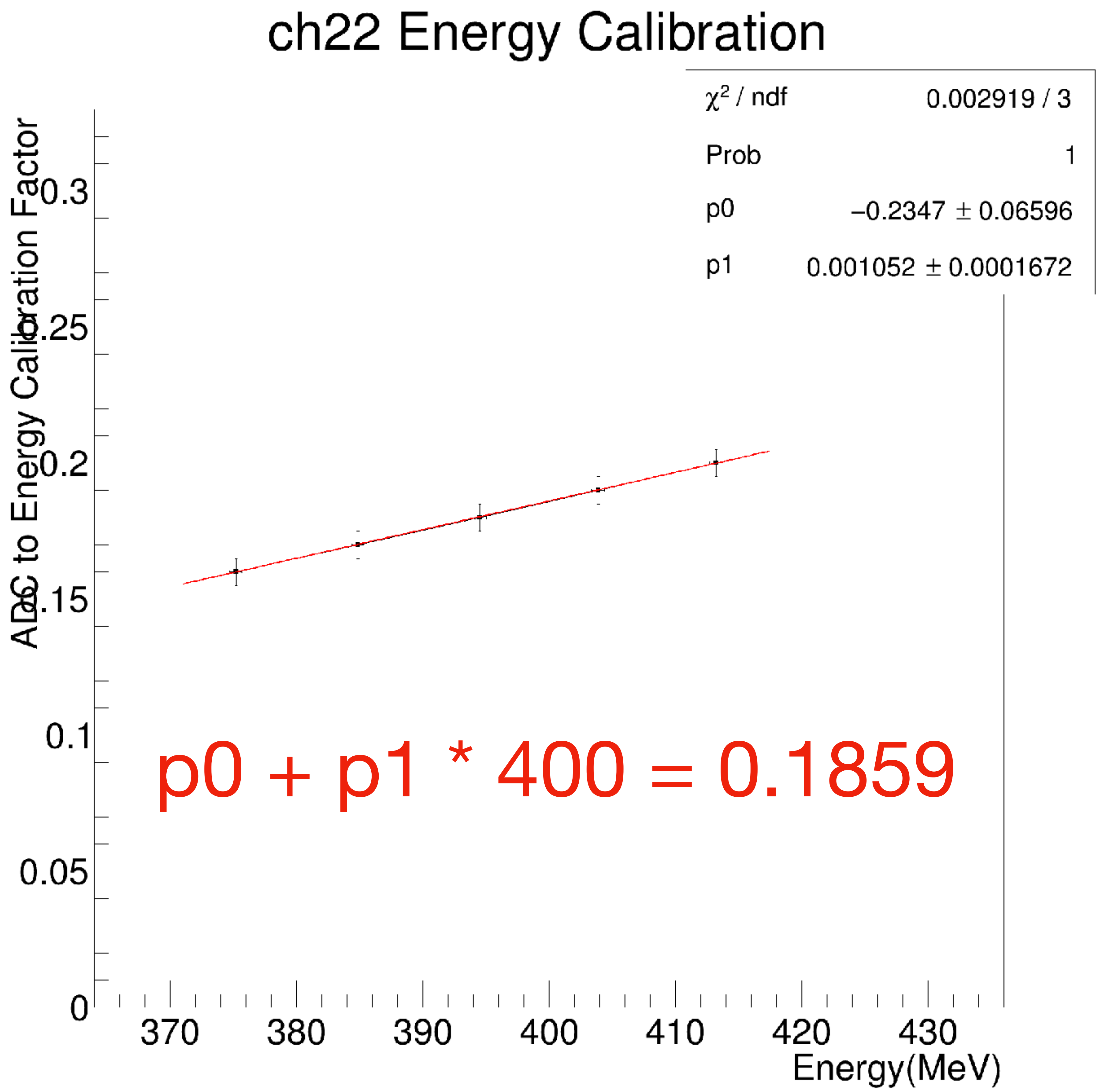


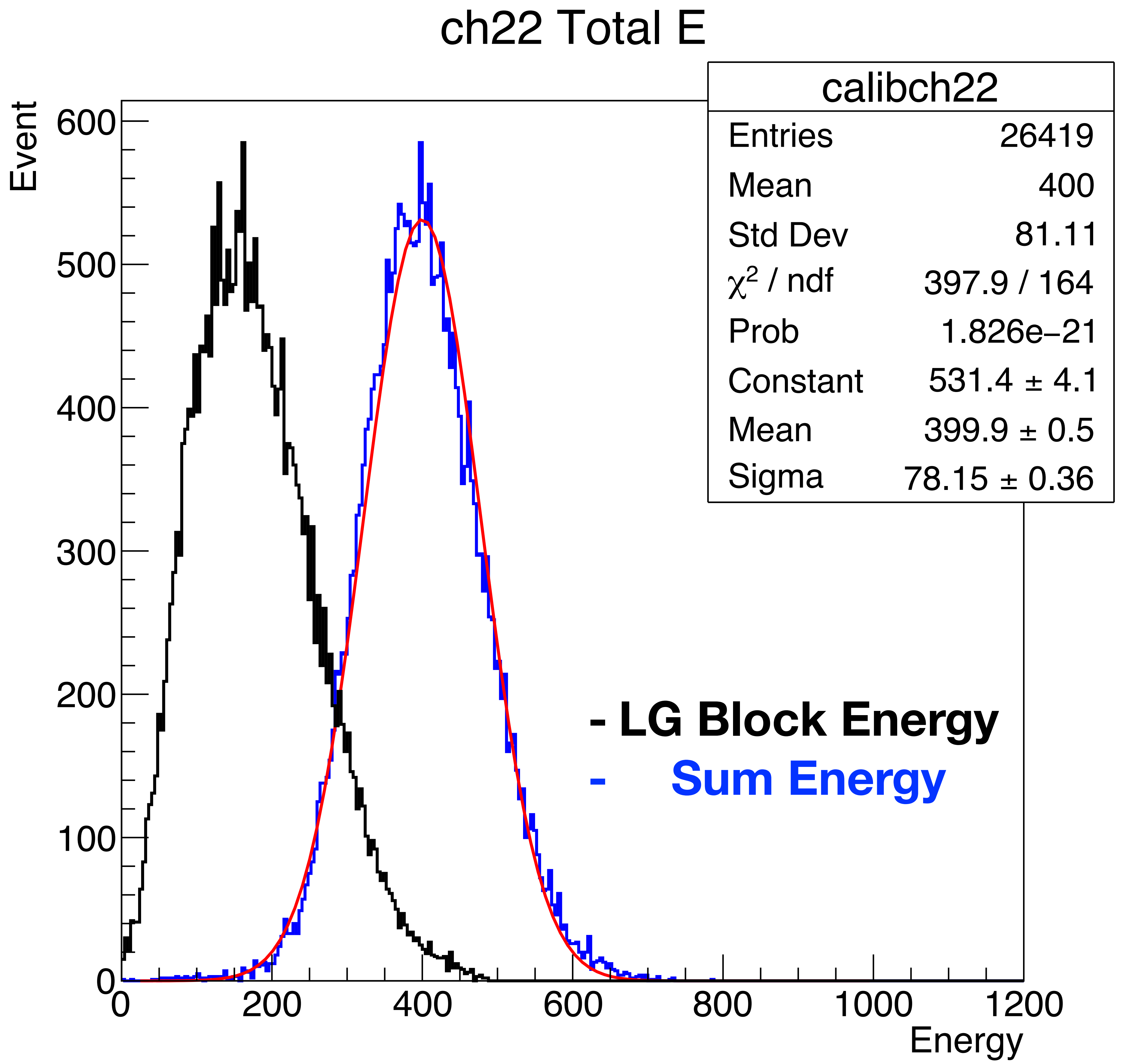
calibration method at 2017 test



LG Block Energy Calibration

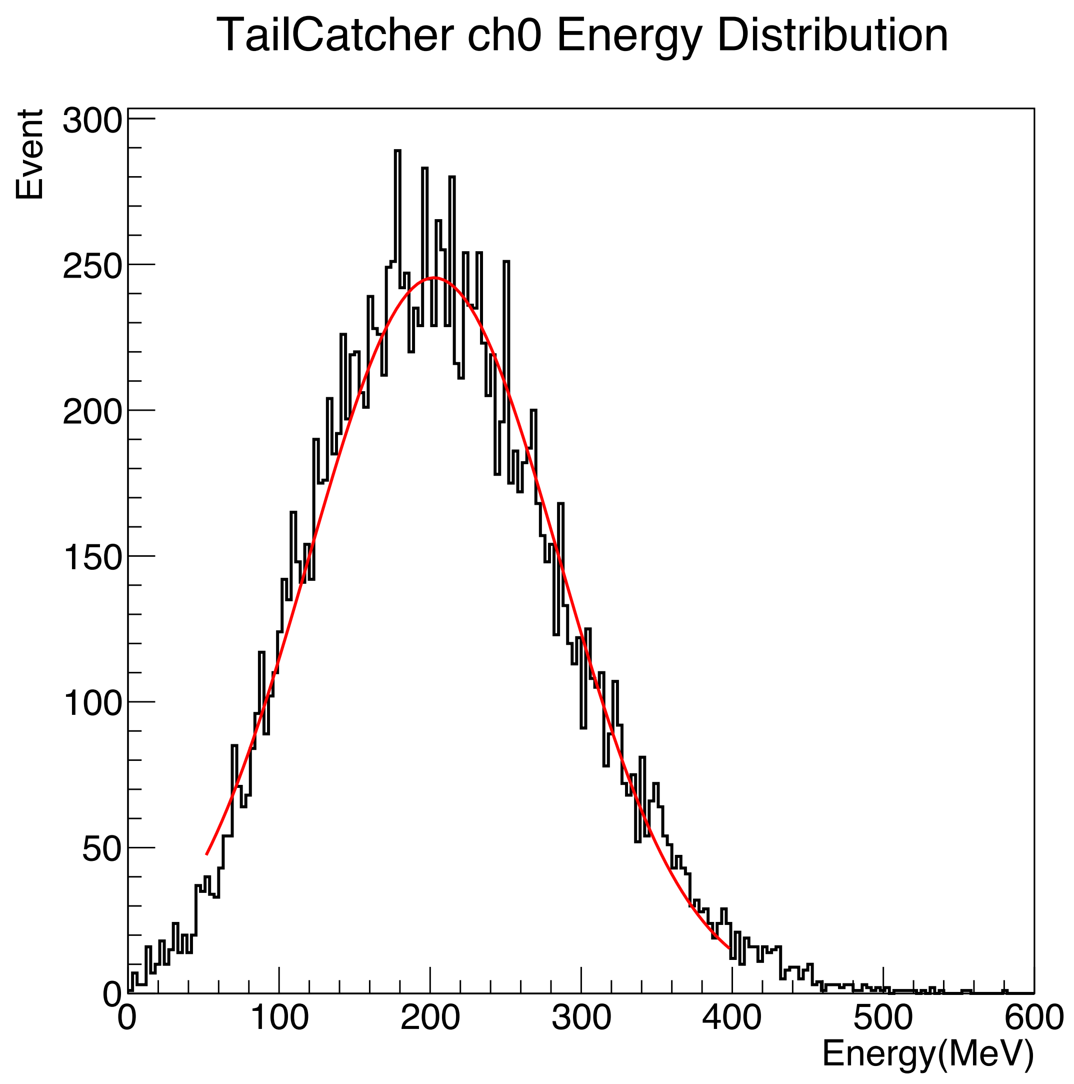
- Adjusted ADC/E based on TH2 plot fit results.
- I changed the calibration factor and looked for a place where the total energy would be just 400 MeV.
- Reconstructed energy is 400MeV and distribution is reasonable.



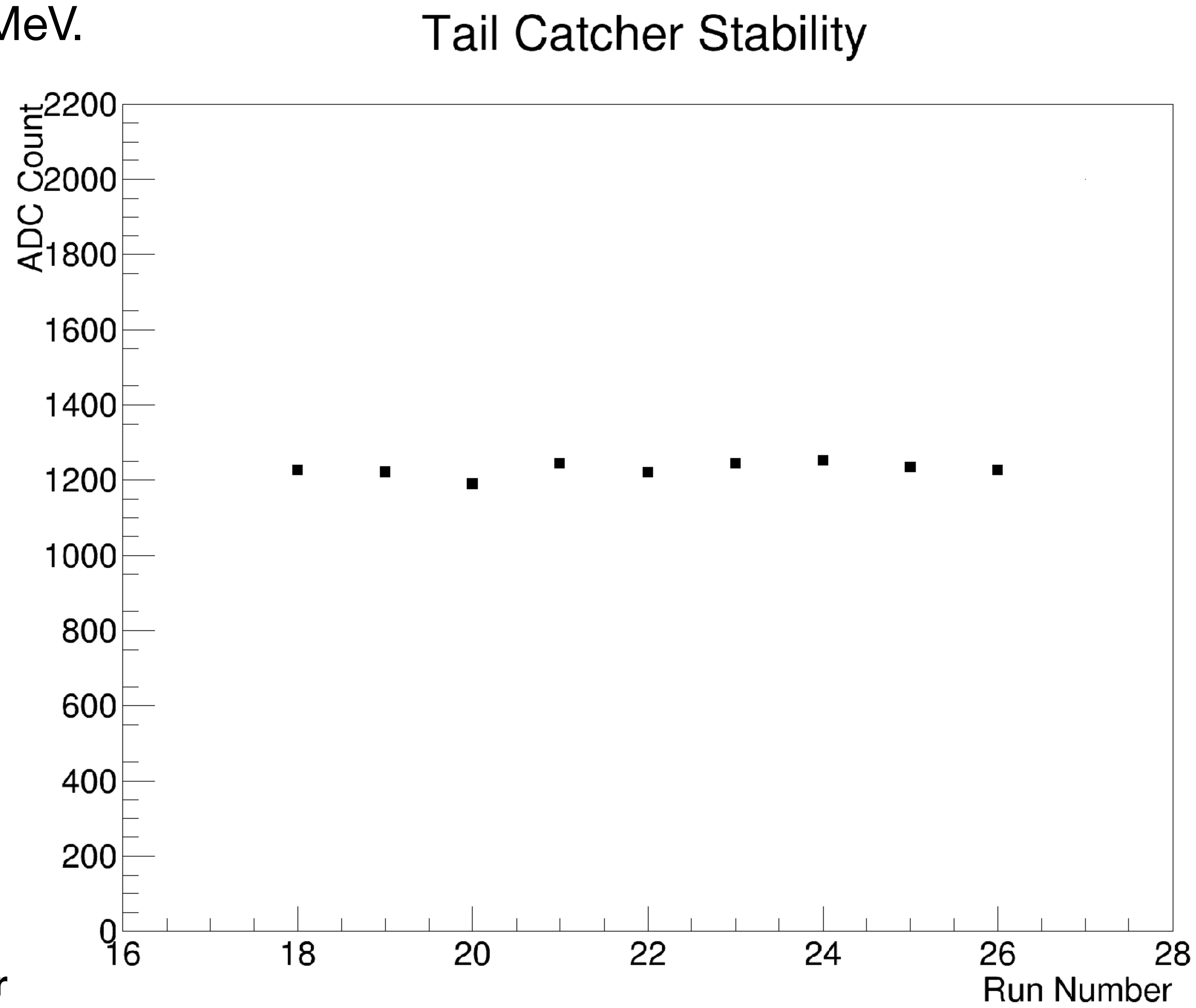


Tail catcher stability

- When evaluating the performance of this calorimeter, all lead glass blocks must be calibrated.
- At 400MeV injection, put one layer tail catcher detected 200MeV.
- If beam energy stable, this energy is not change.
- We checked stability of tail catcher.

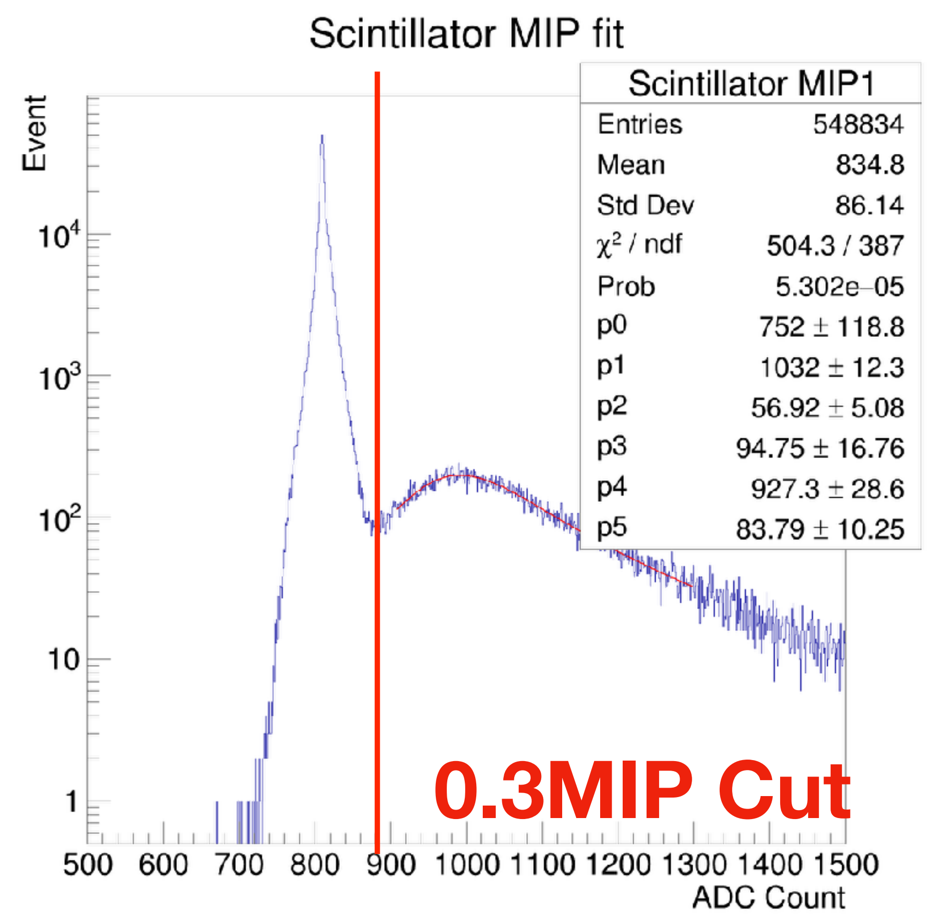


Tail catcher ADC Distribution of 400MeV e+ injected behind one LG Layer

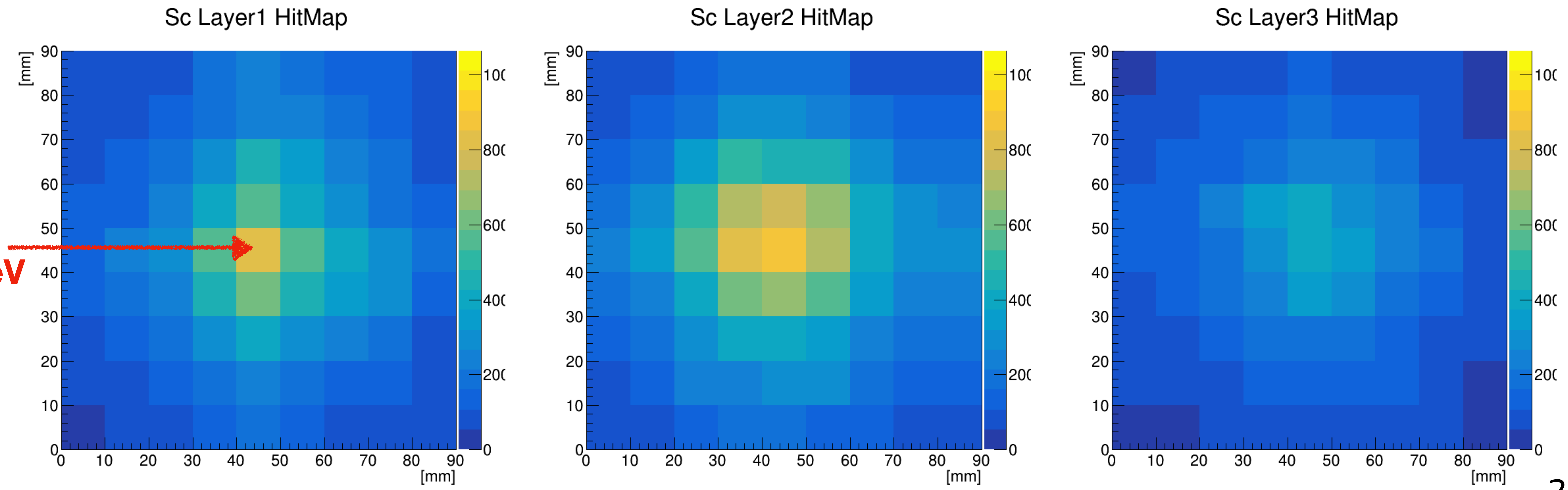


Scintillator Hitmap (2017)

- 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



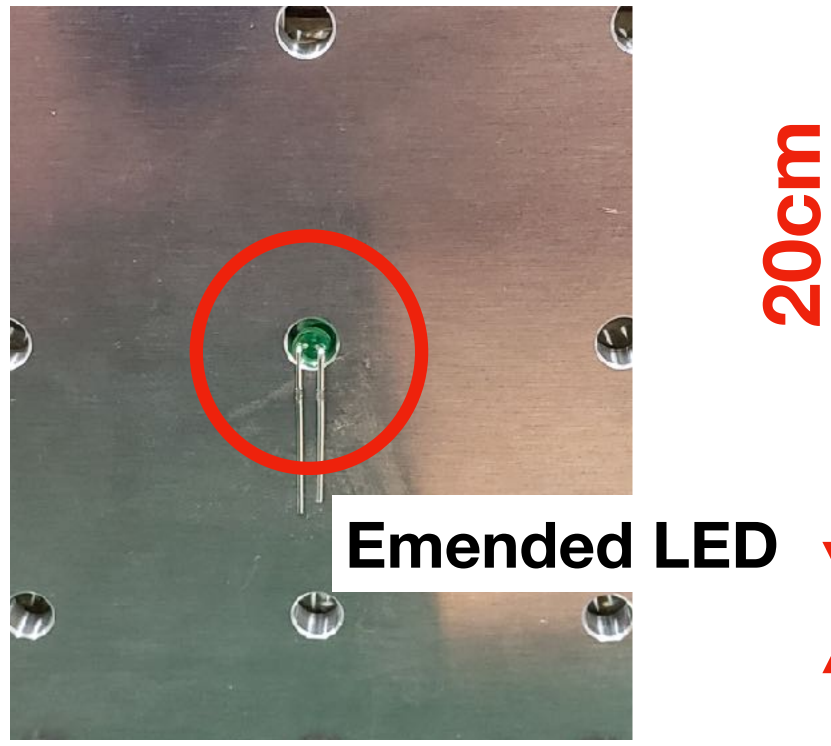
e+ 800MeV

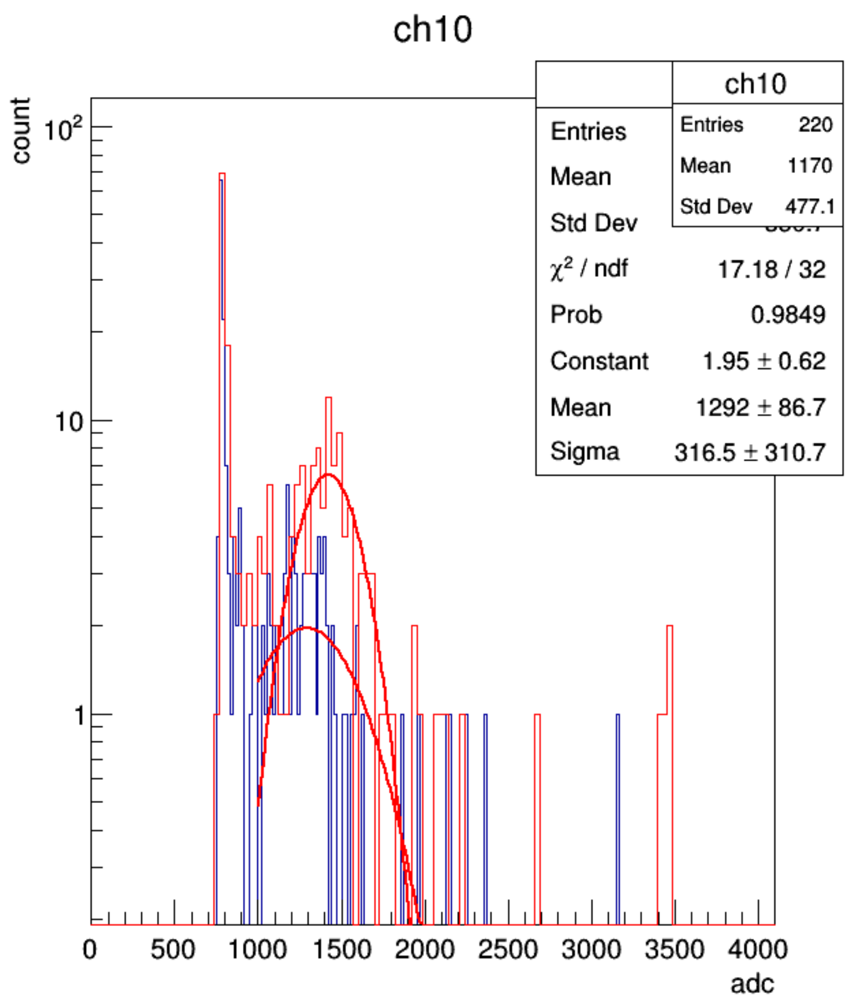


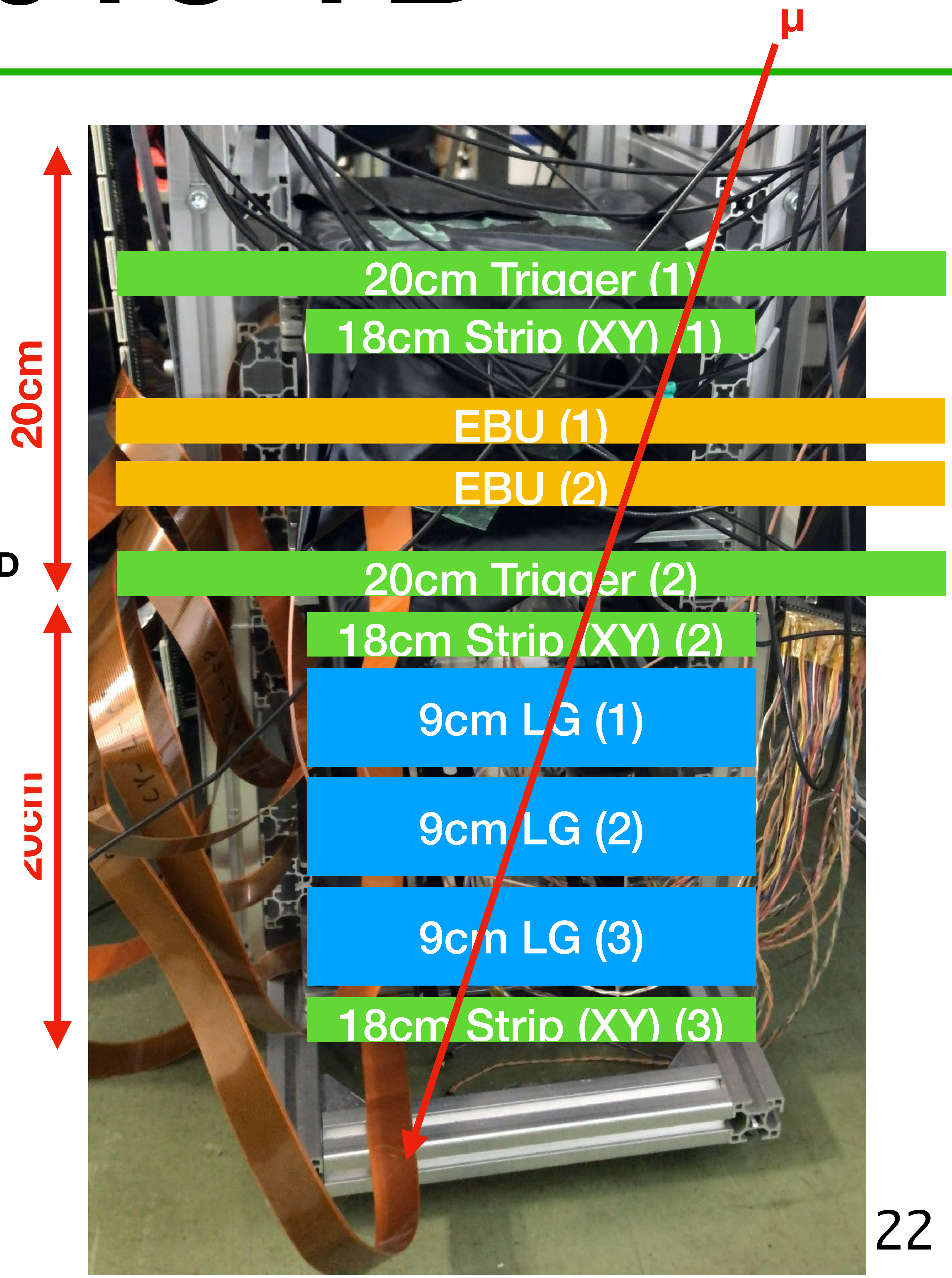
800MeV Sc Hitmap

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)

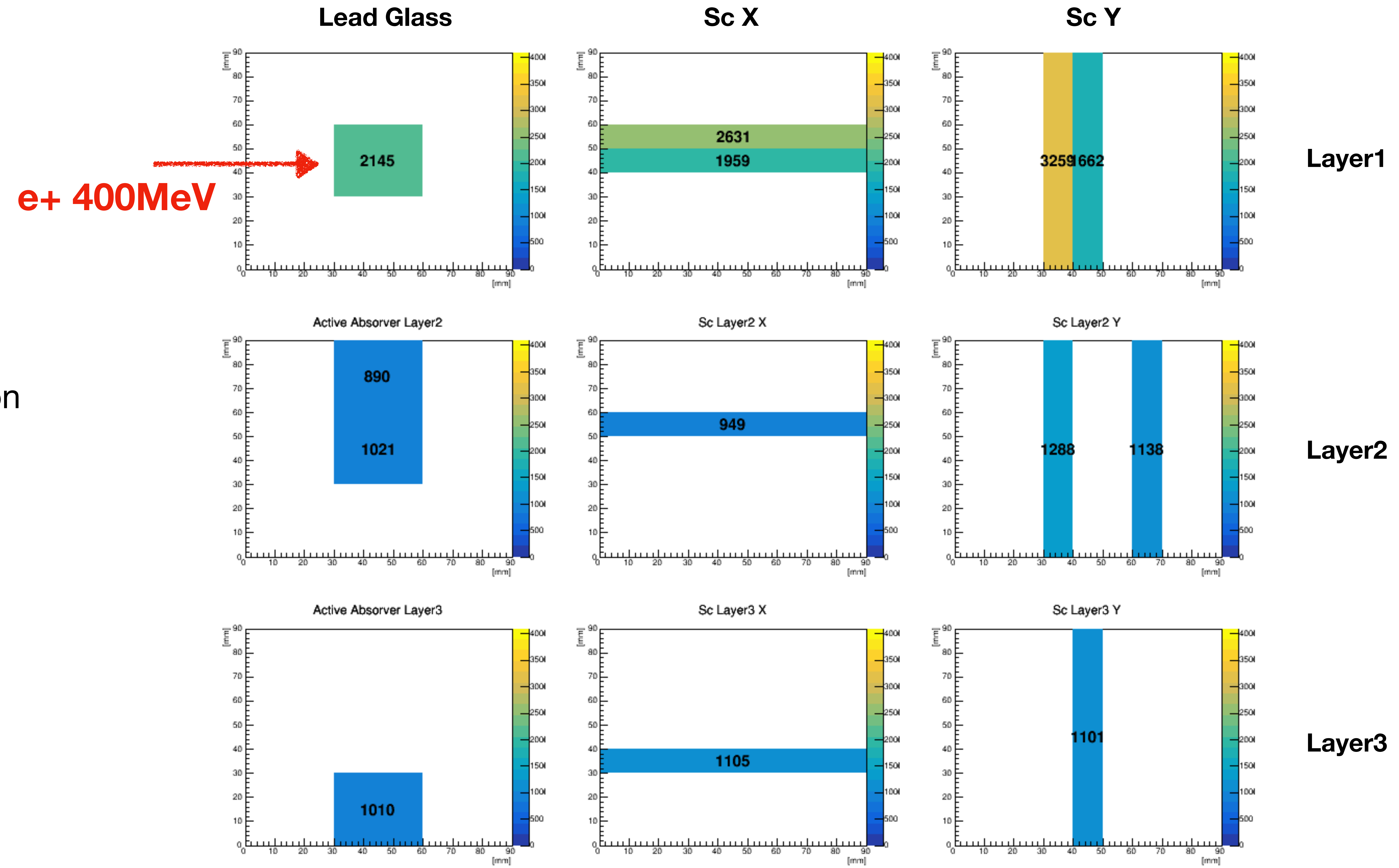






Event Display (2016)

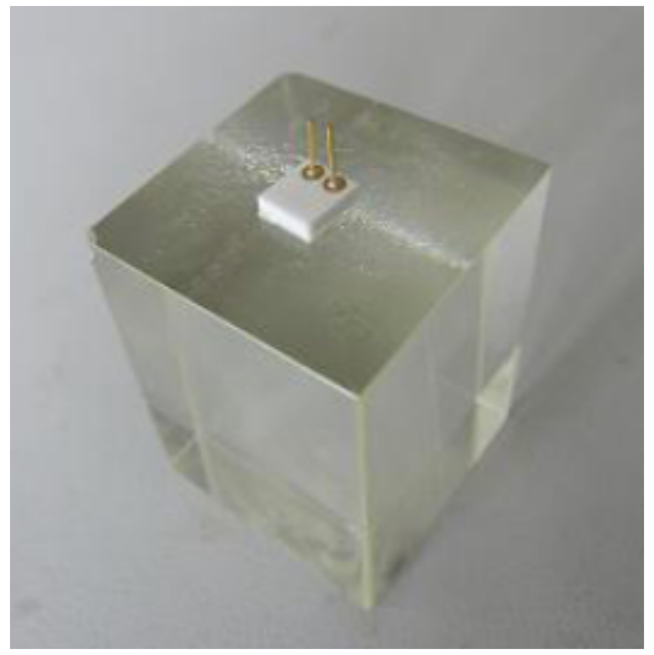
- 400MeV positron injection
- Detector is working



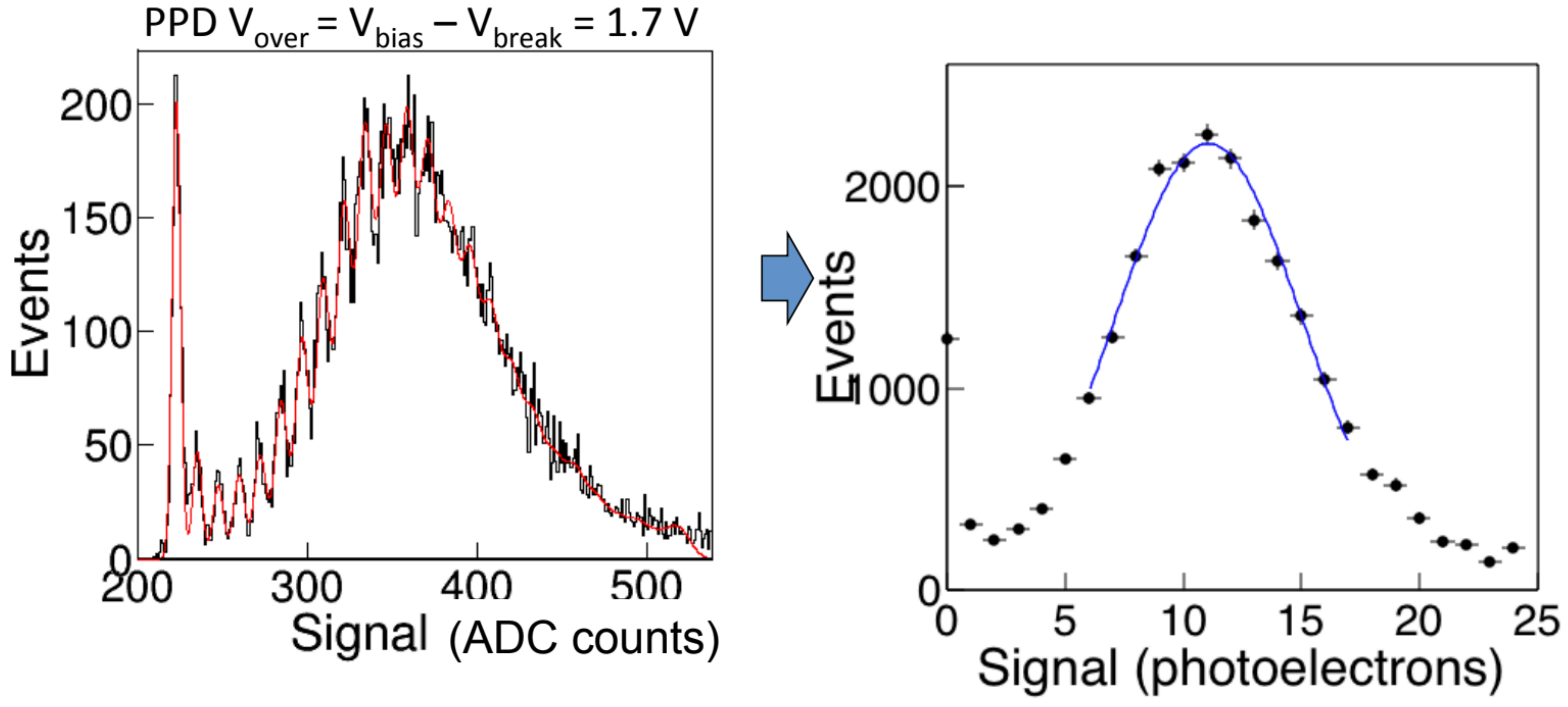
400MeV Event Display

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



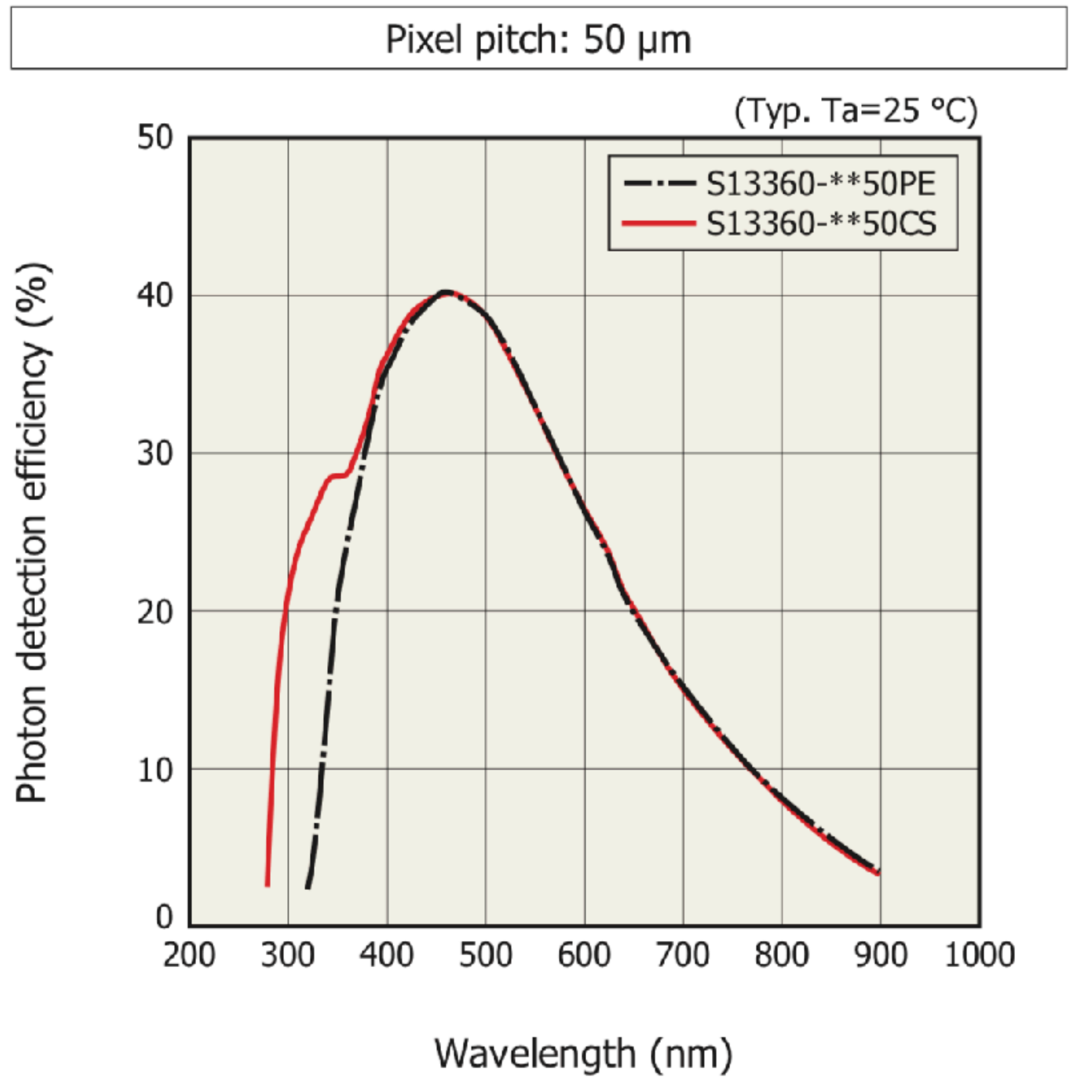
Lead glass block and MPPC



Muon signal

By Uozumi

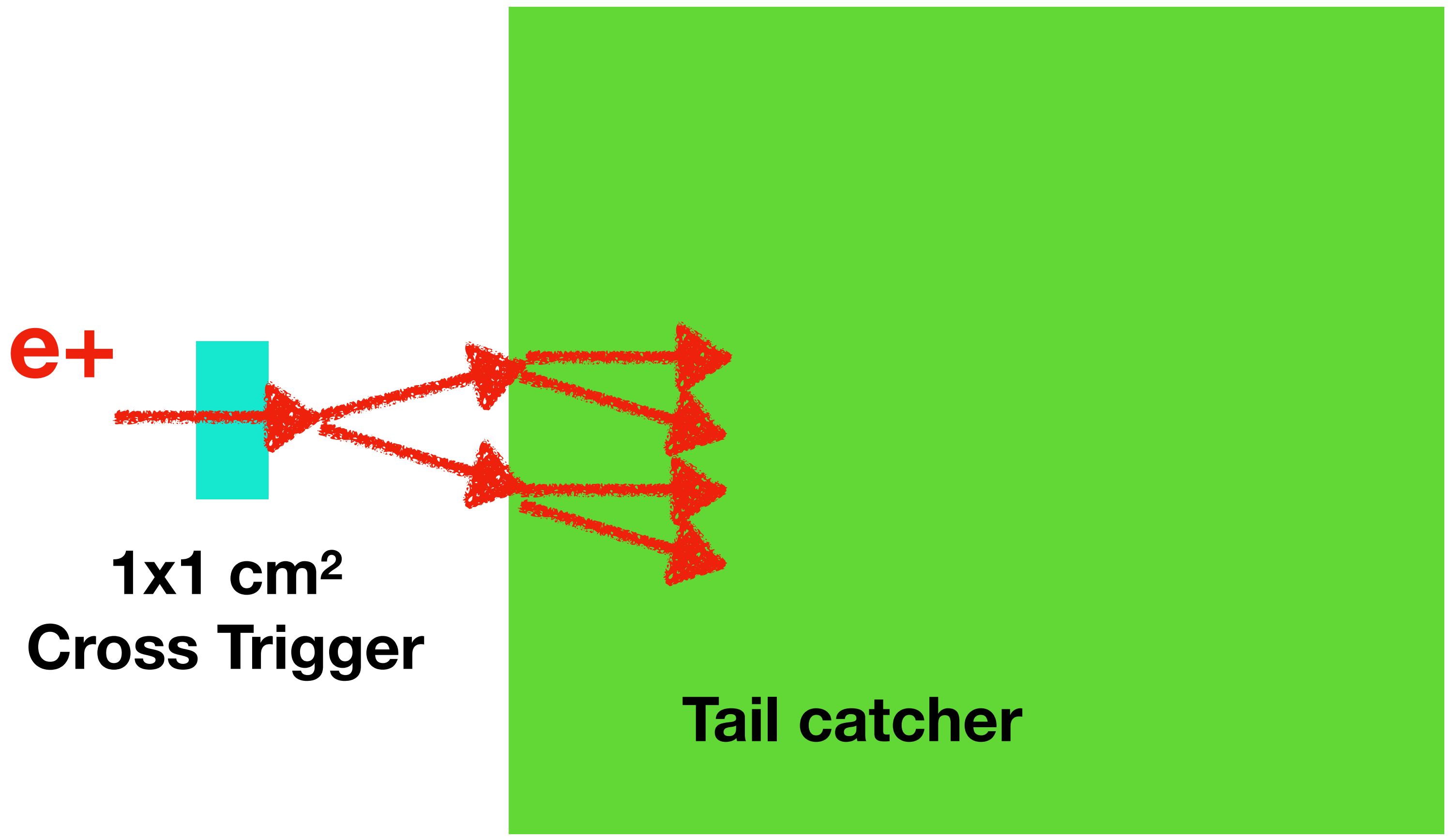
Optical coupling of Lead glass block and MPPC

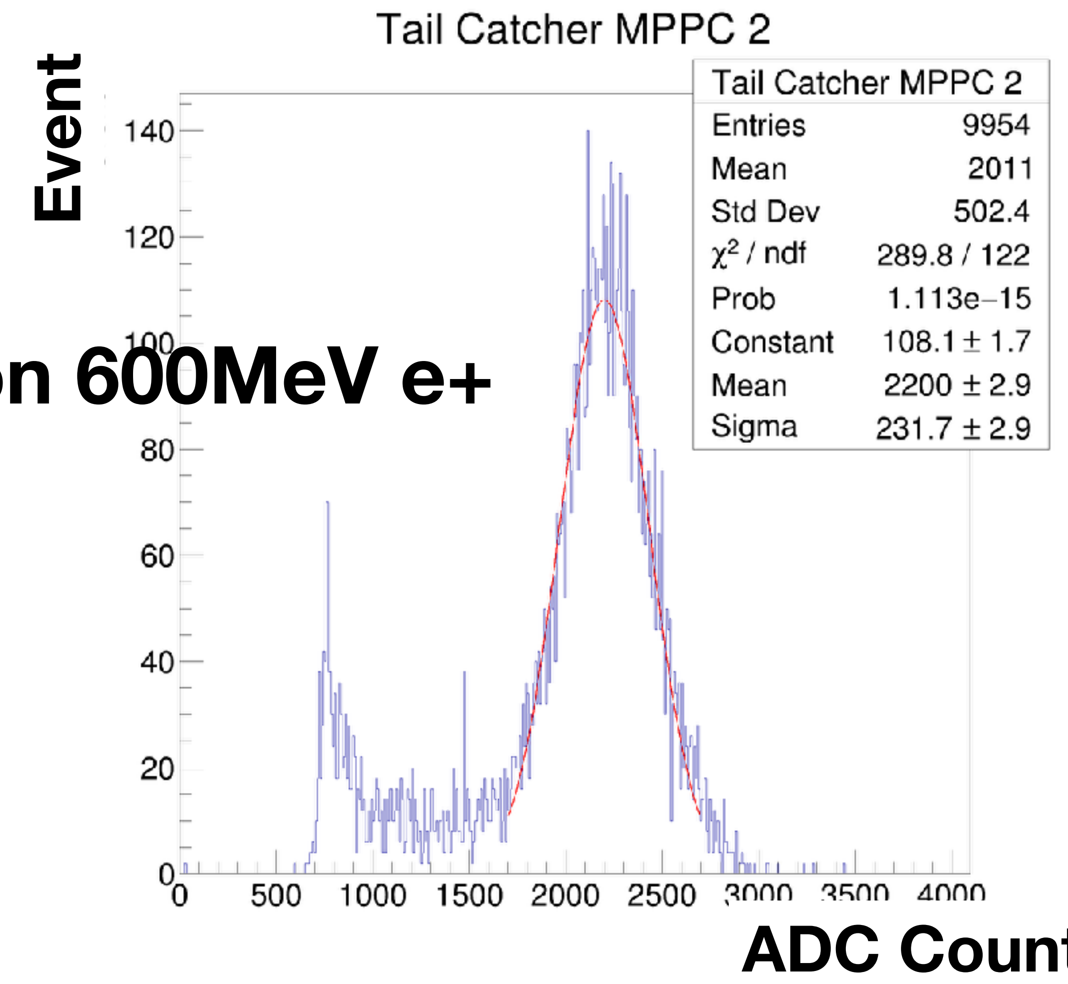


Dependence of wavelength

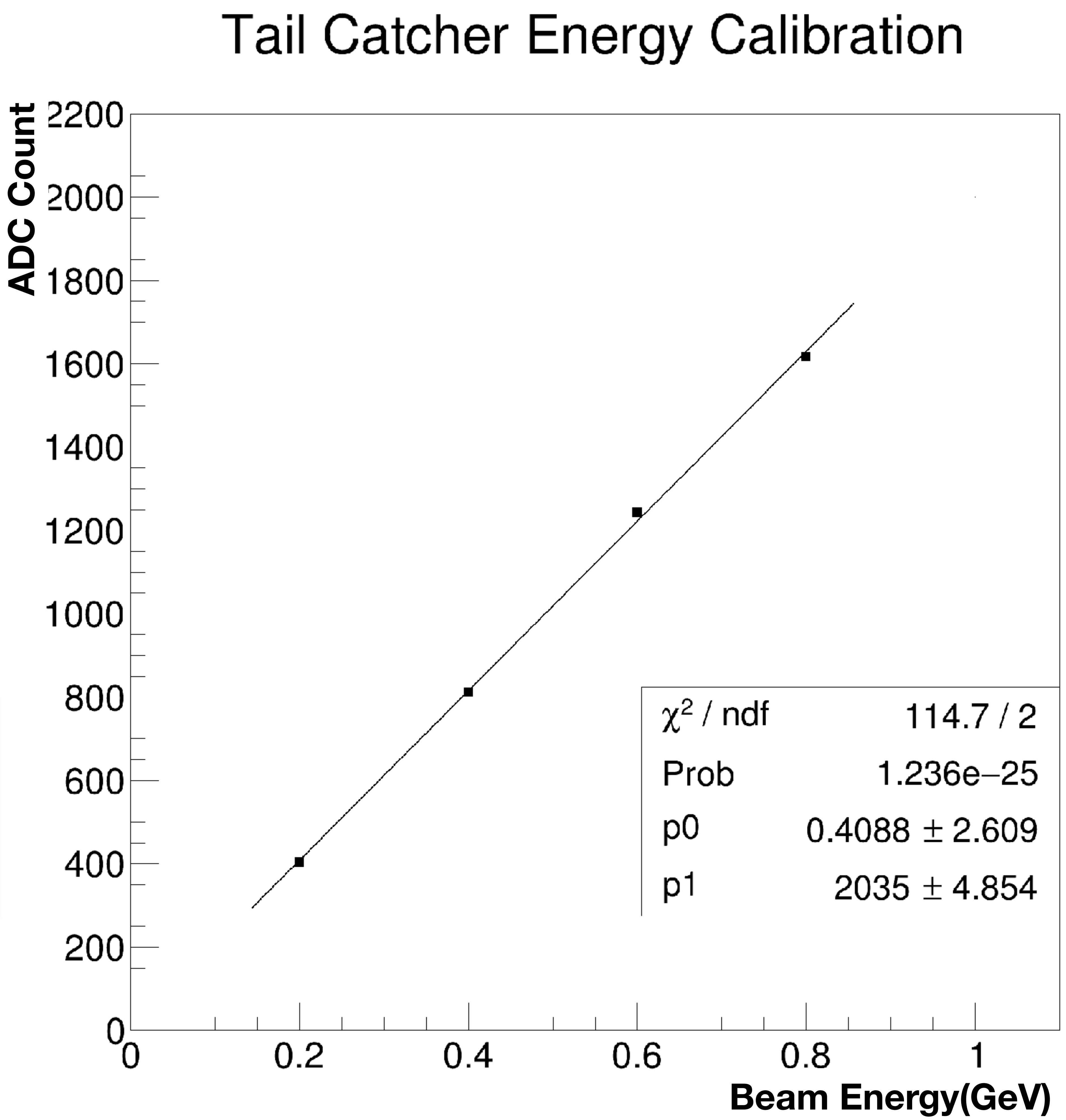
Tail Catcher Calibration

- 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)





Tail catcher ADC Distribution



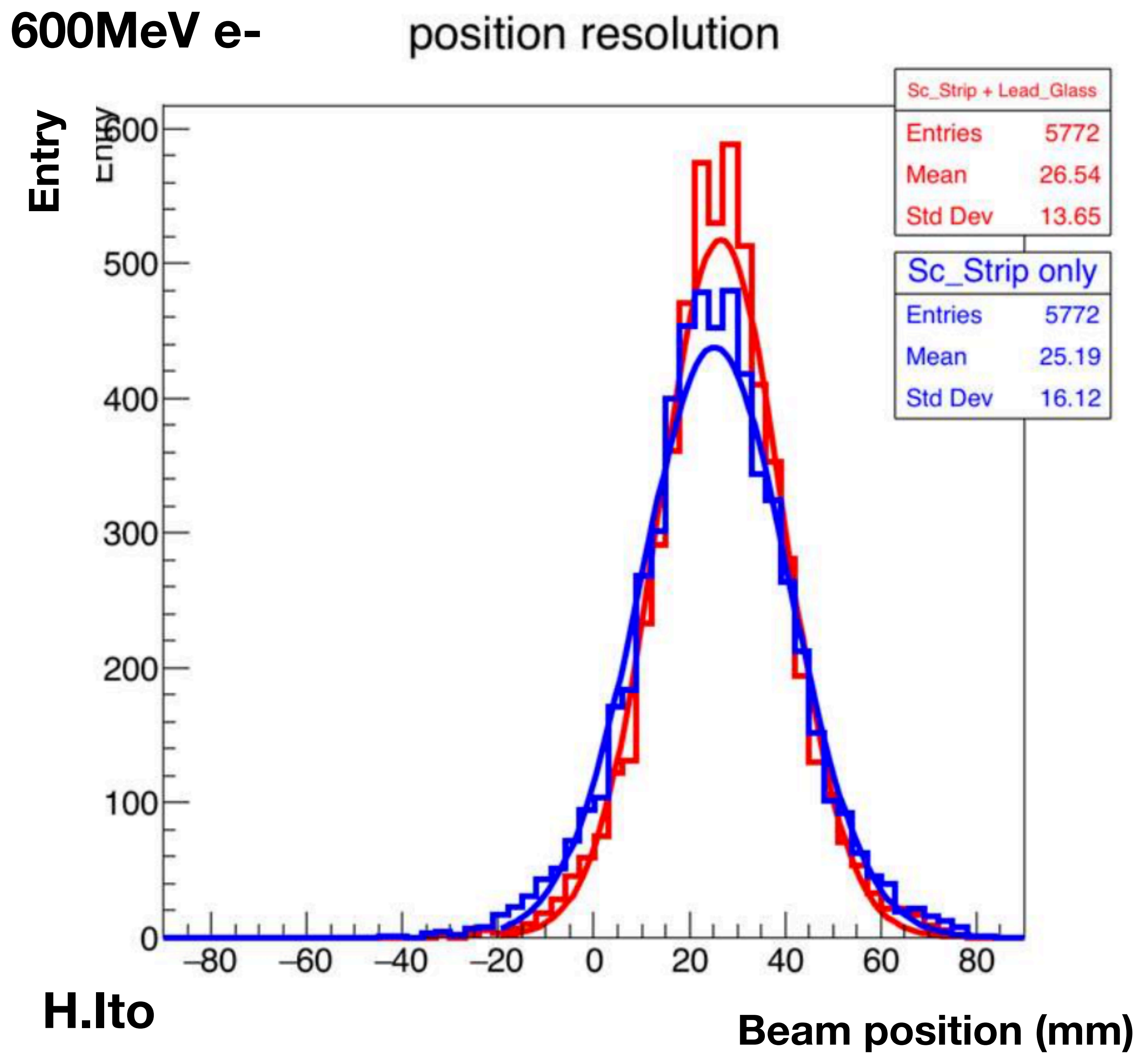
Tail catcher energy linearity

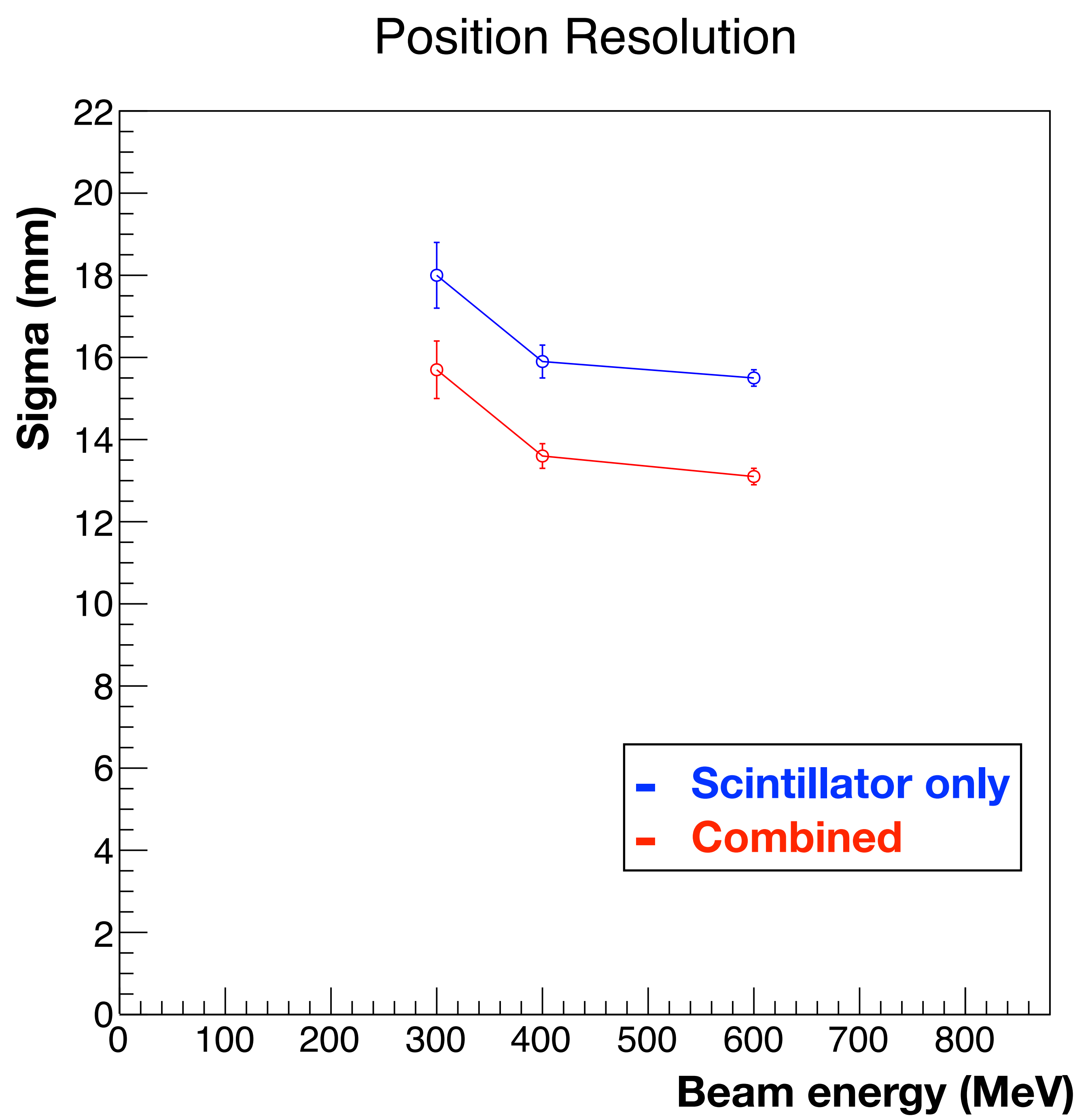
Parameter of Lead Glass

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

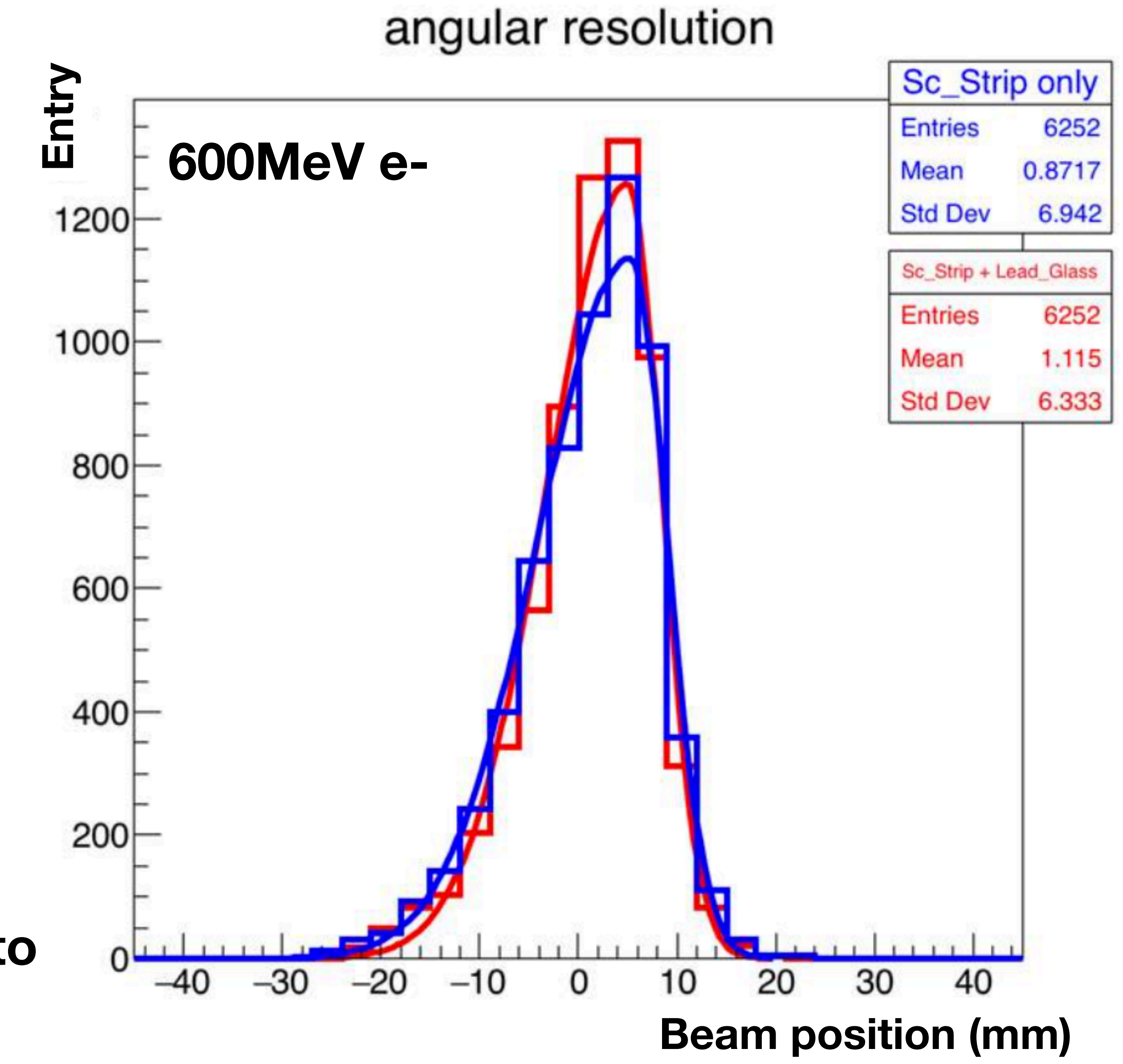
- The beam was shifted 30 mm in parallel at beam line
- The position distribution results for scintillator layer only (blue) and with lead-glass information combined (red)
- The beam position is reconstructed by calculating centroid in each layers and fitted with a straight line
- Results with absorber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



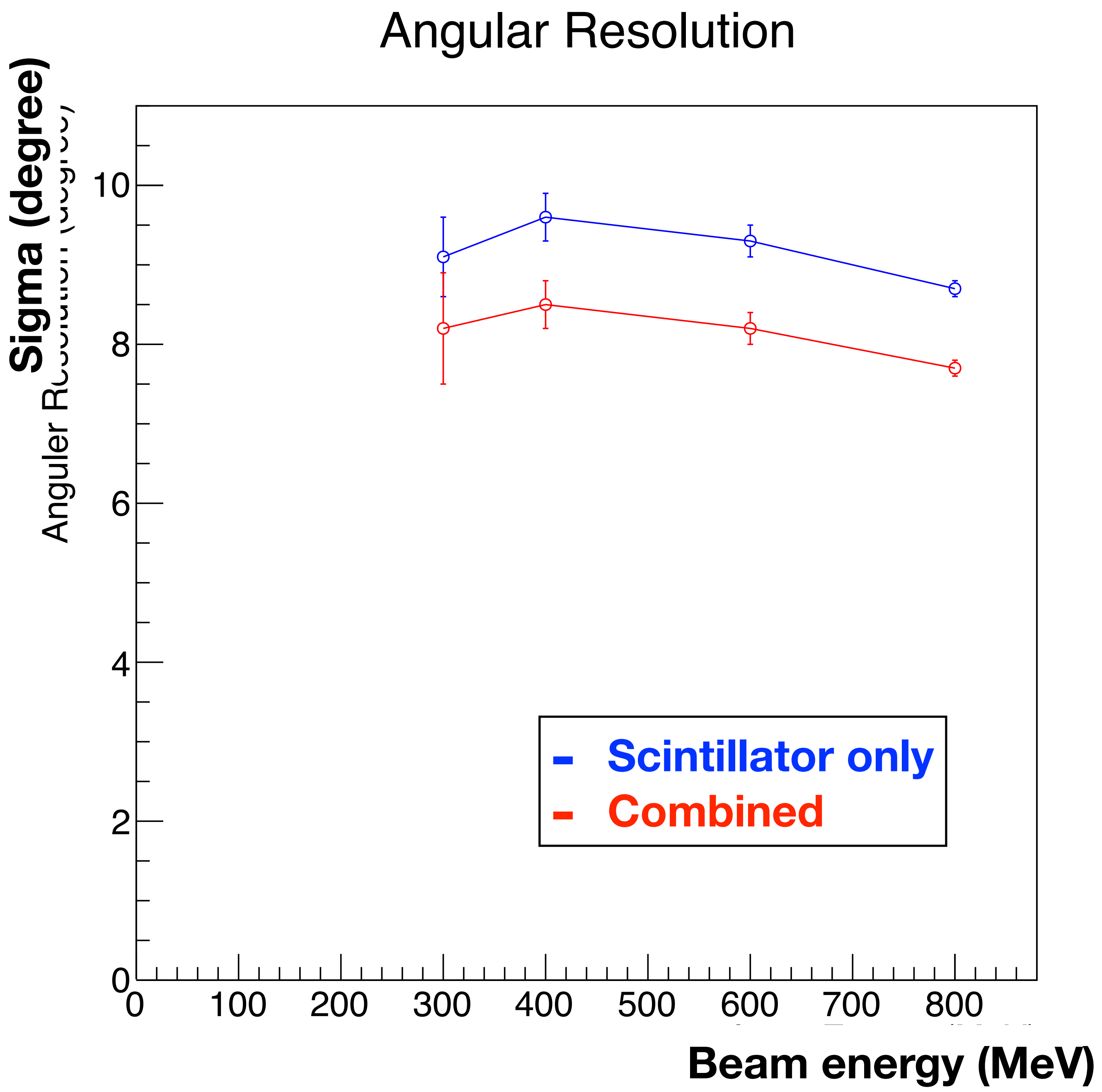


Angular Resolution

- 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

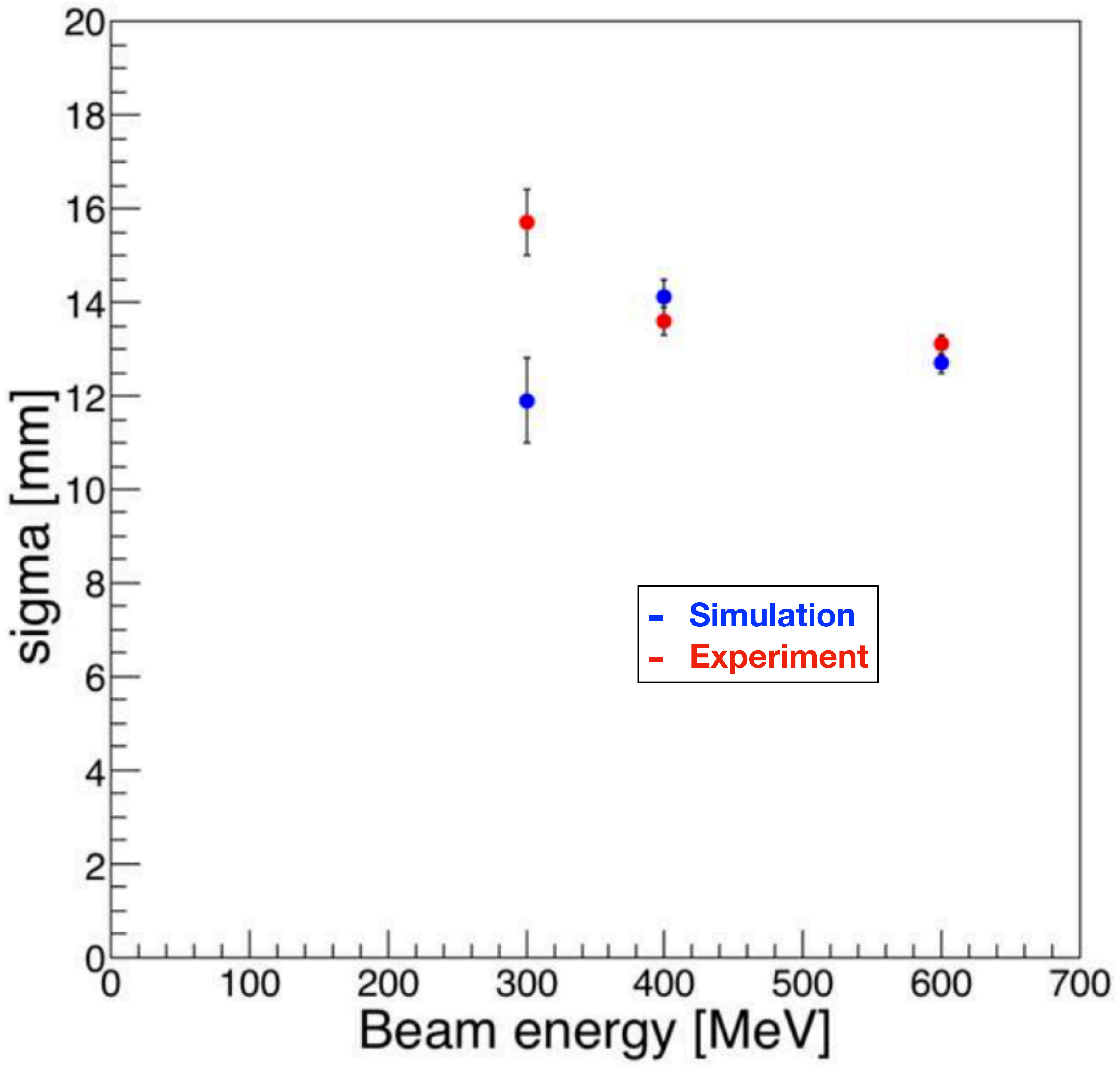


H.Ito

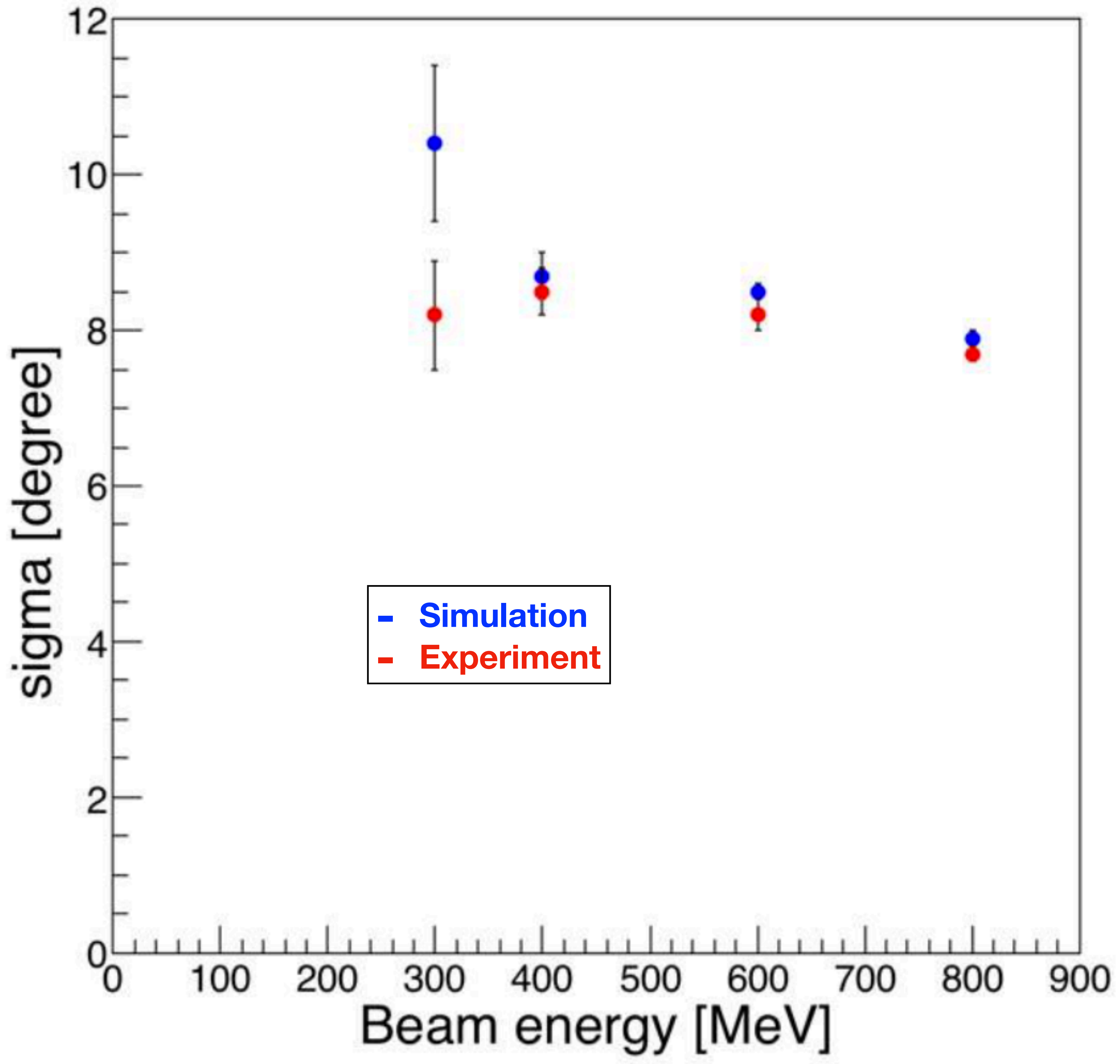


Position and angular resolution (simulation vs experiment)

Position Resolution

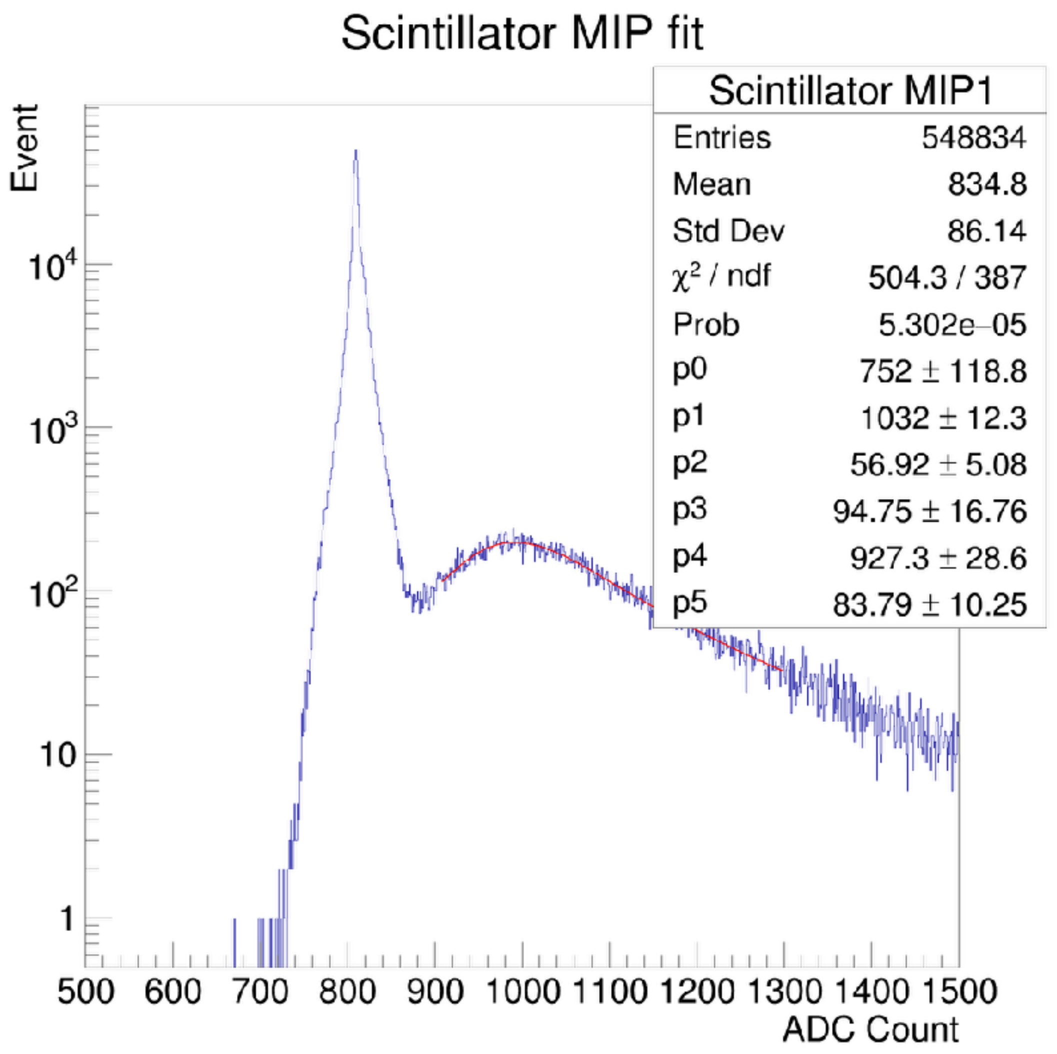


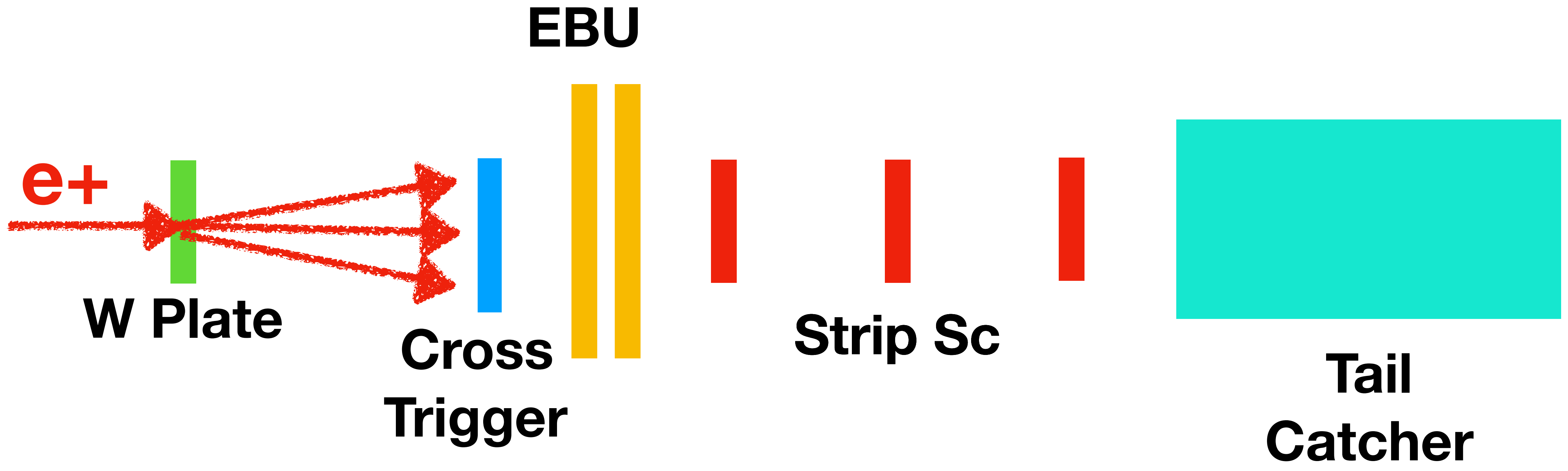
Angular Resolution



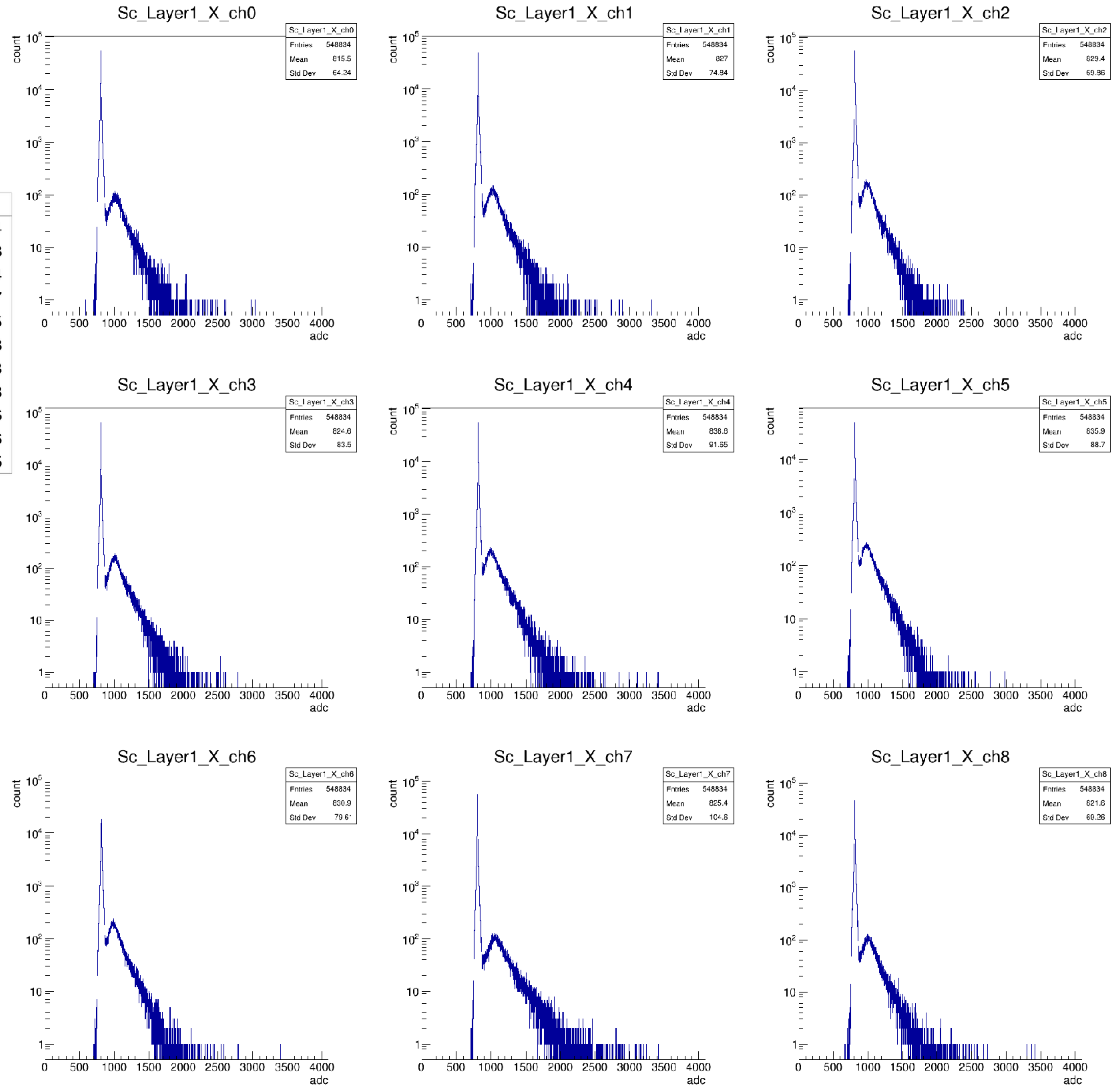
Scintillator Calibration

- 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





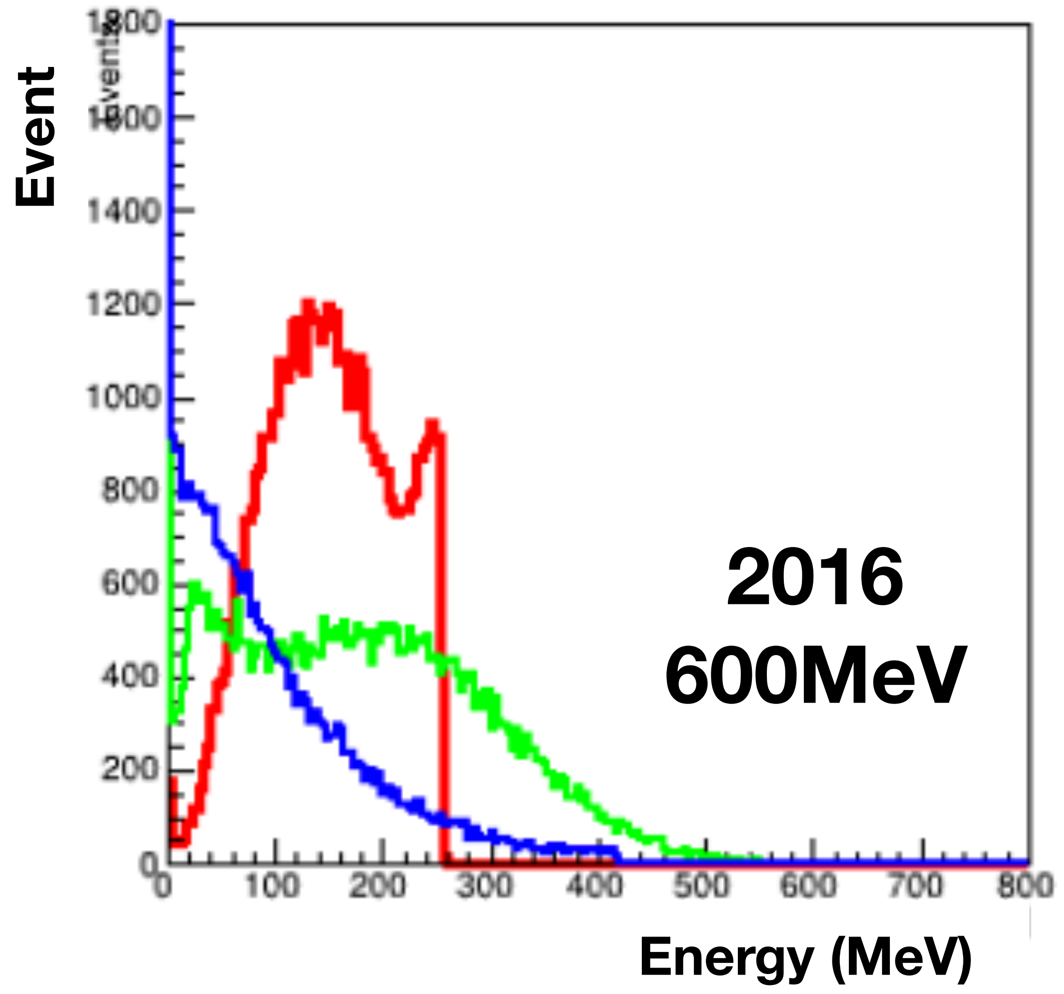
scintillator calibration setup (remove active absorber)

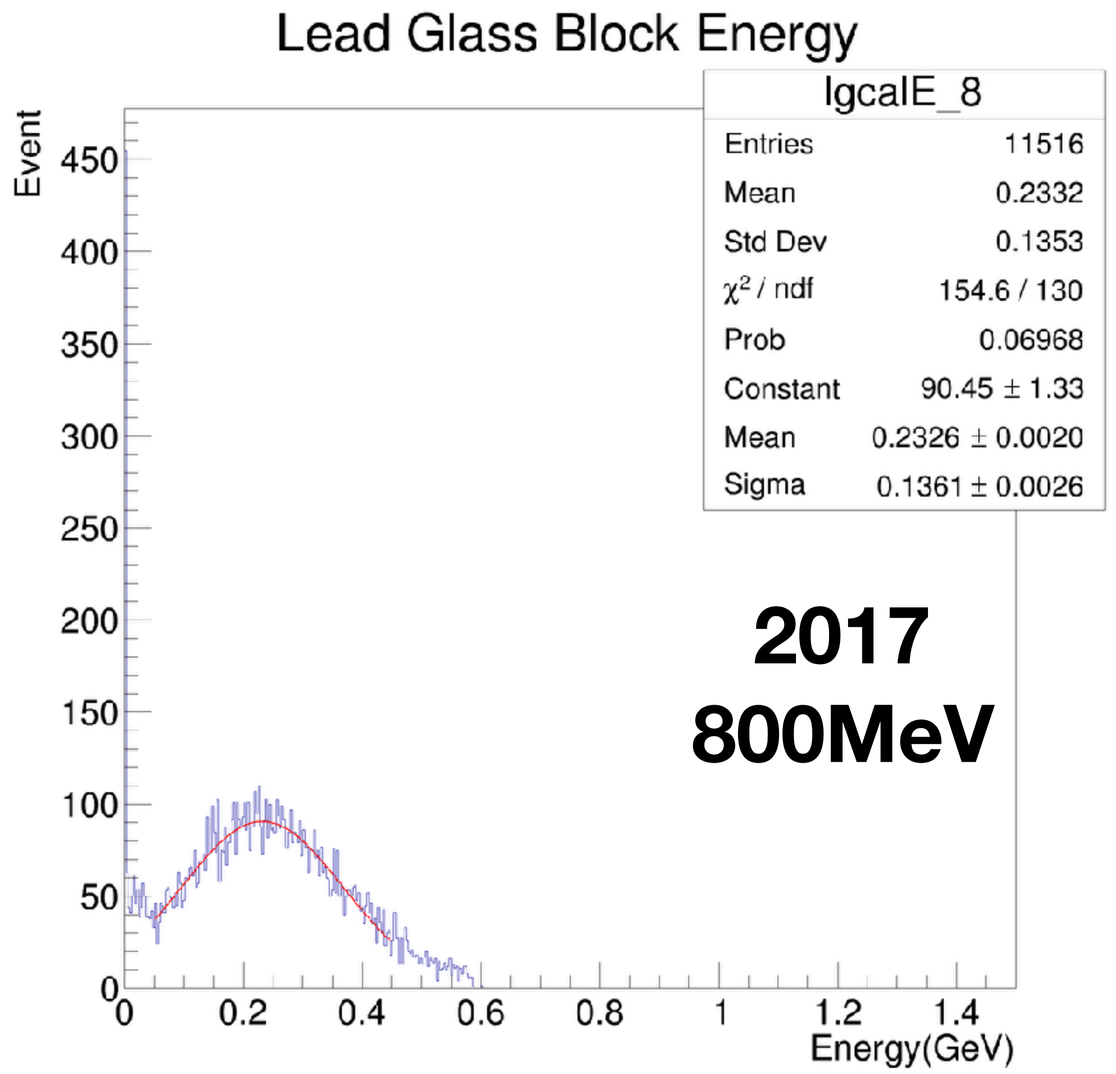


Layer 1 X direction ADC distribution at calibration run (2017)

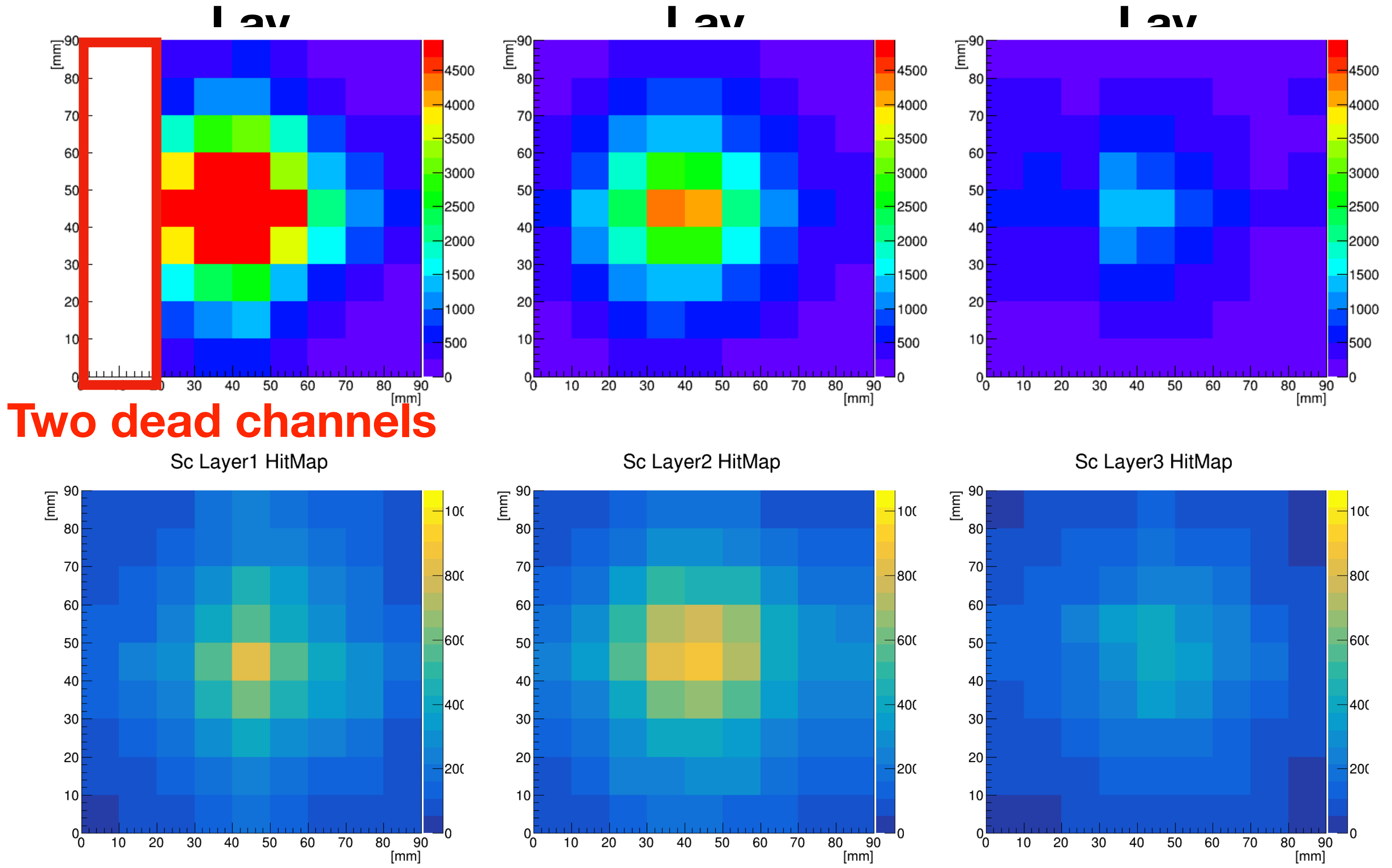
Problem of 2016 TB

- 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

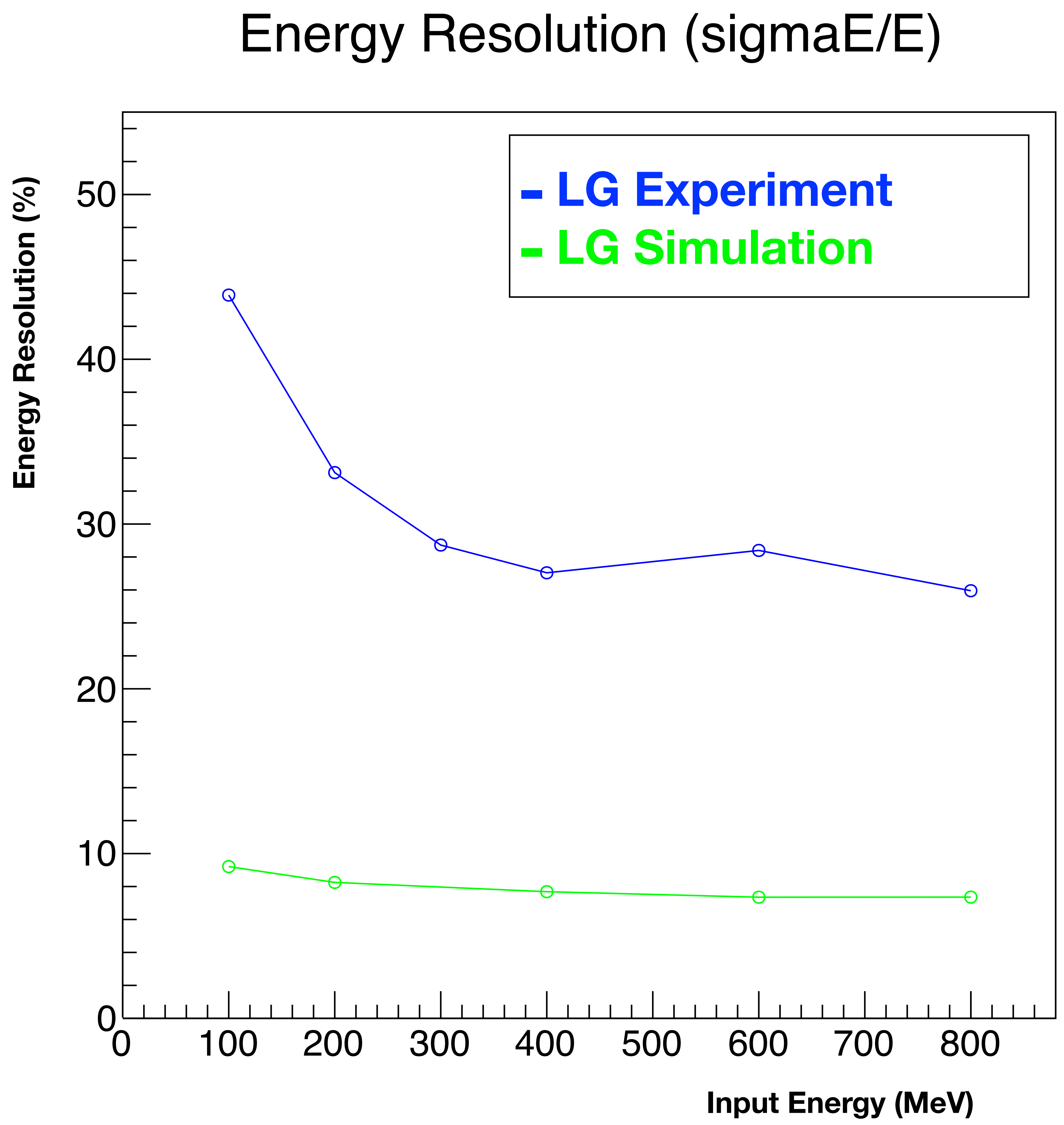


2016 HitMap

2017 HitMap

Lead glass Energy Resolution (2016)

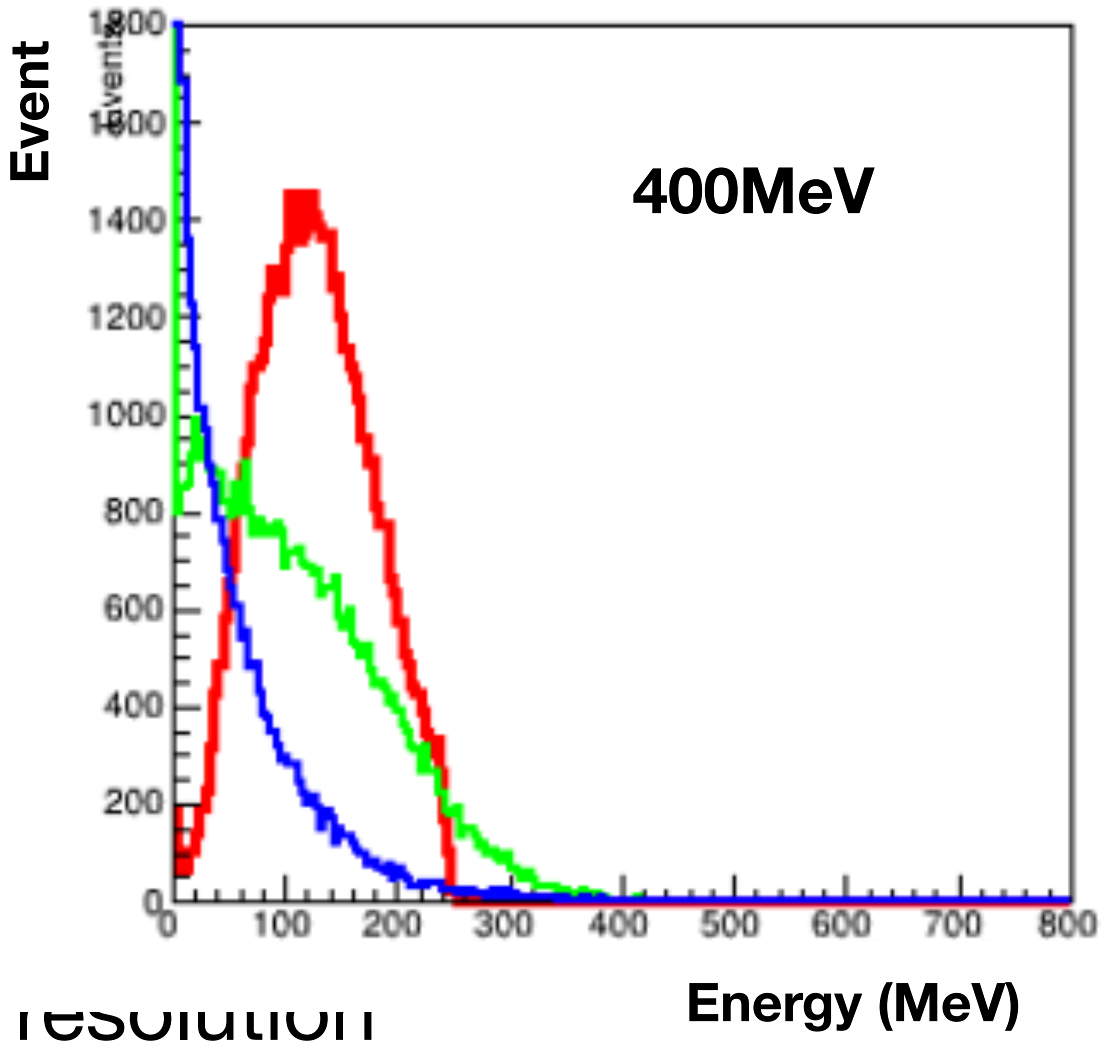
- Compare experimental data with Geant4 simulation
- Combined with Tail Catcher, calculated from the energy actually dropped to the lead glass layer
- In the simulation, as a result of adding 5% energy smearing as a detector error
- Reason of deterioration of energy resolution
  - Because it is a small 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



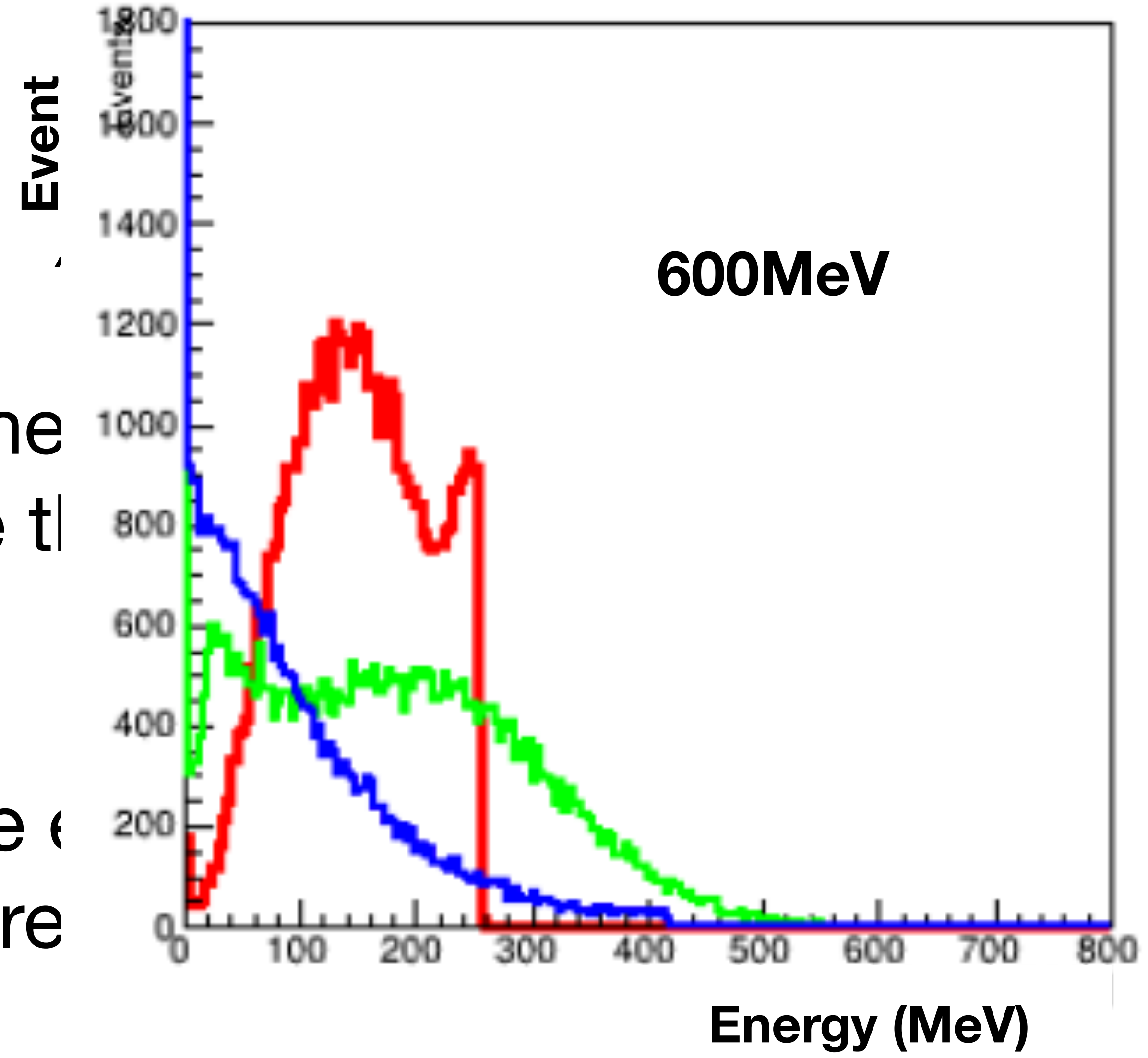
Active absorber energy resolution

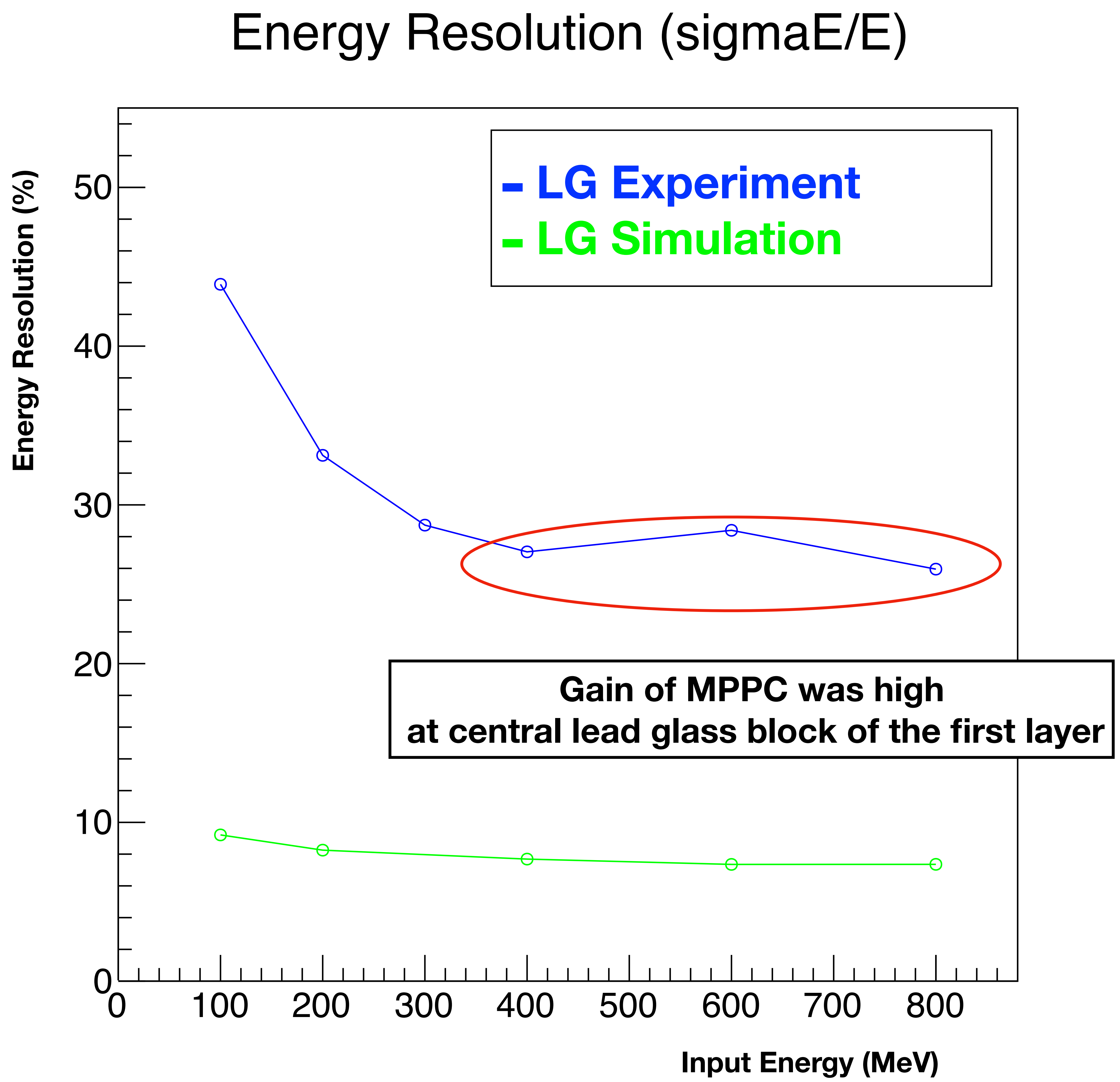
Lead glass Energy Resolution (2016)

- Compare experimental data with (
- Calibrate each channel at experir
- 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 e
    overflow has occurred, so the re





Active absorber energy resolution

Cosmic muon test

Hit Map

Strip(1) Strip(2) LG(2) Strip(3)