Development of active absorber CAL

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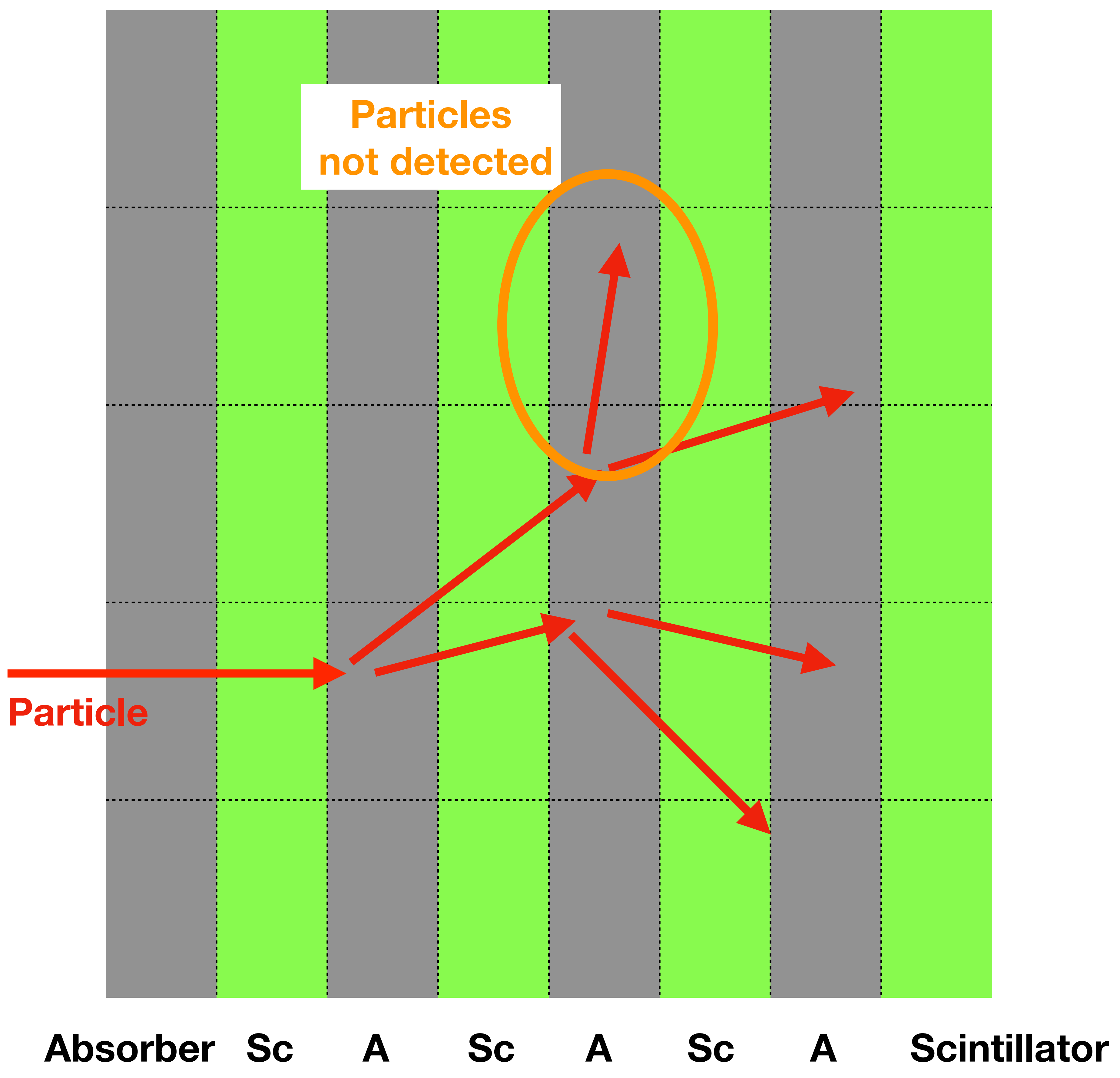
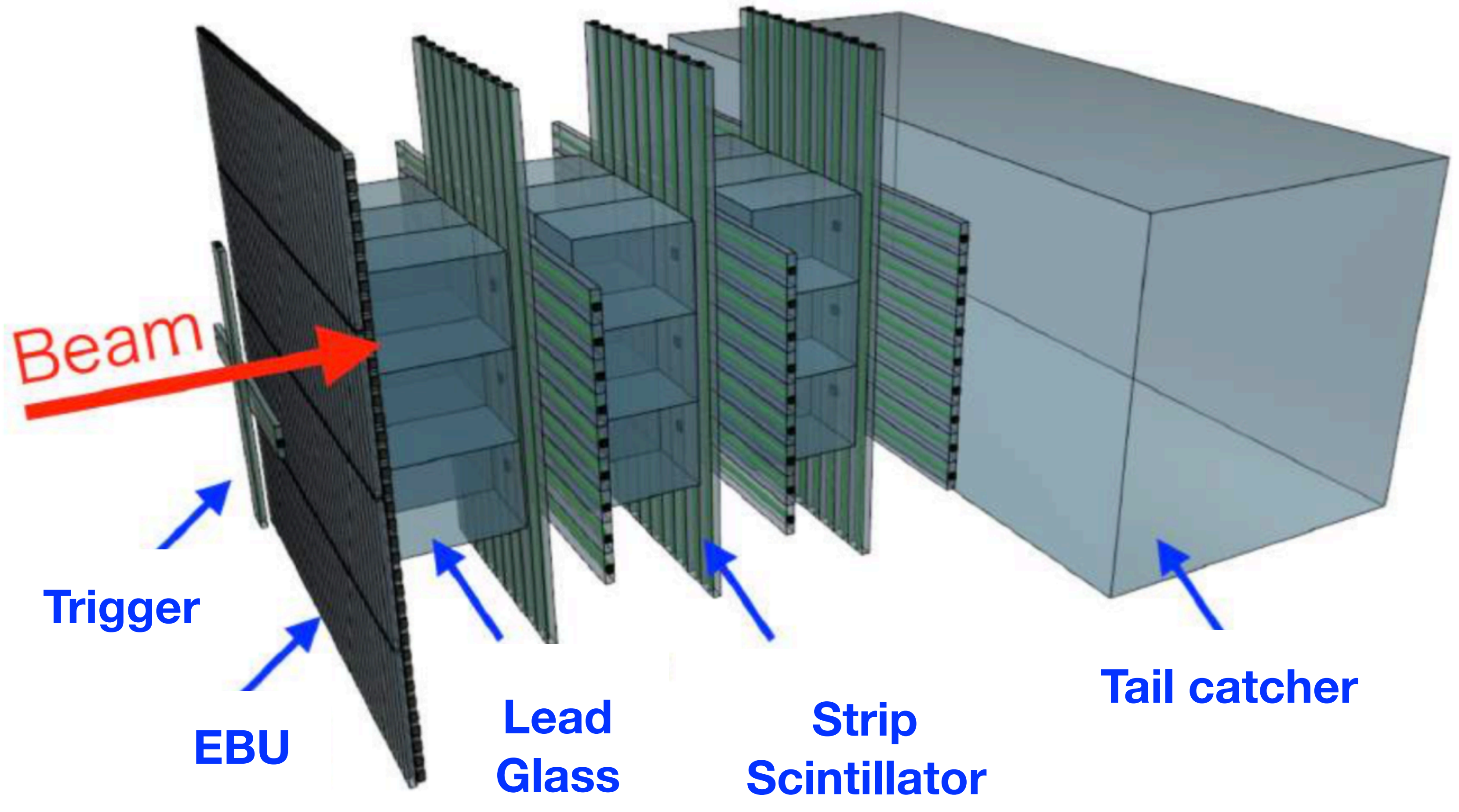
Introduction of active absorber CAL

- In case of sampling calorimeter, energy deposited in the absorber is estimated by measuring active material such as scintillator
- If energy deposit in absorber layers can be measuring, the performance will be improved significantly
- Position information is also important in PFA, so consider dividing absorbers
- Lead glass is a candidate for absorber material
- Lead glass is transparent, so Cherenkov light can be measured with a optical sensor
- Since an MPPC is very thin, it makes insensitive area of a sampling calorimeter small when it is used for a sampling calorimeter
- Lead glass is inexpensive compared to crystal scintillator

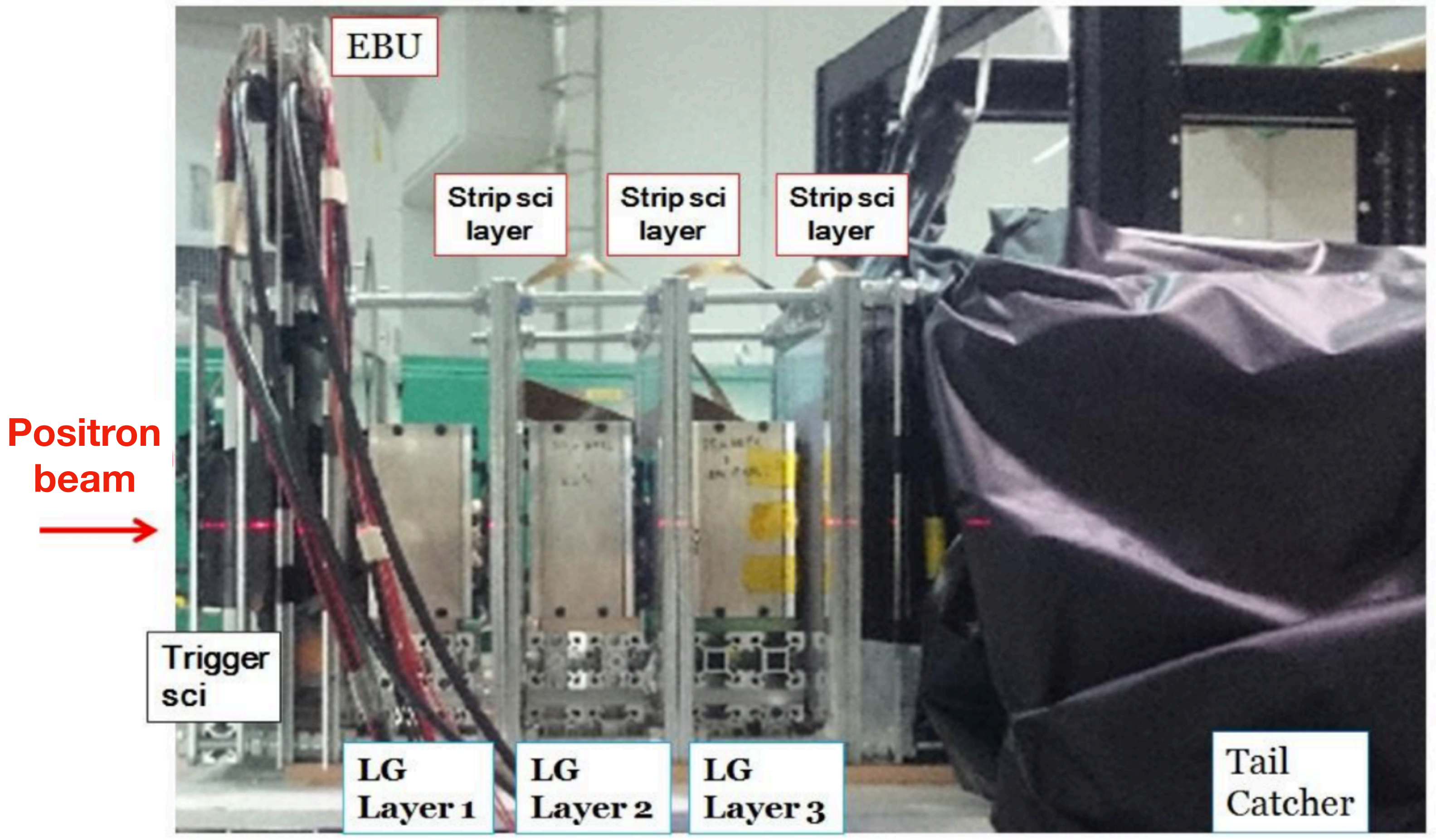


Prototype of active absorber CAL

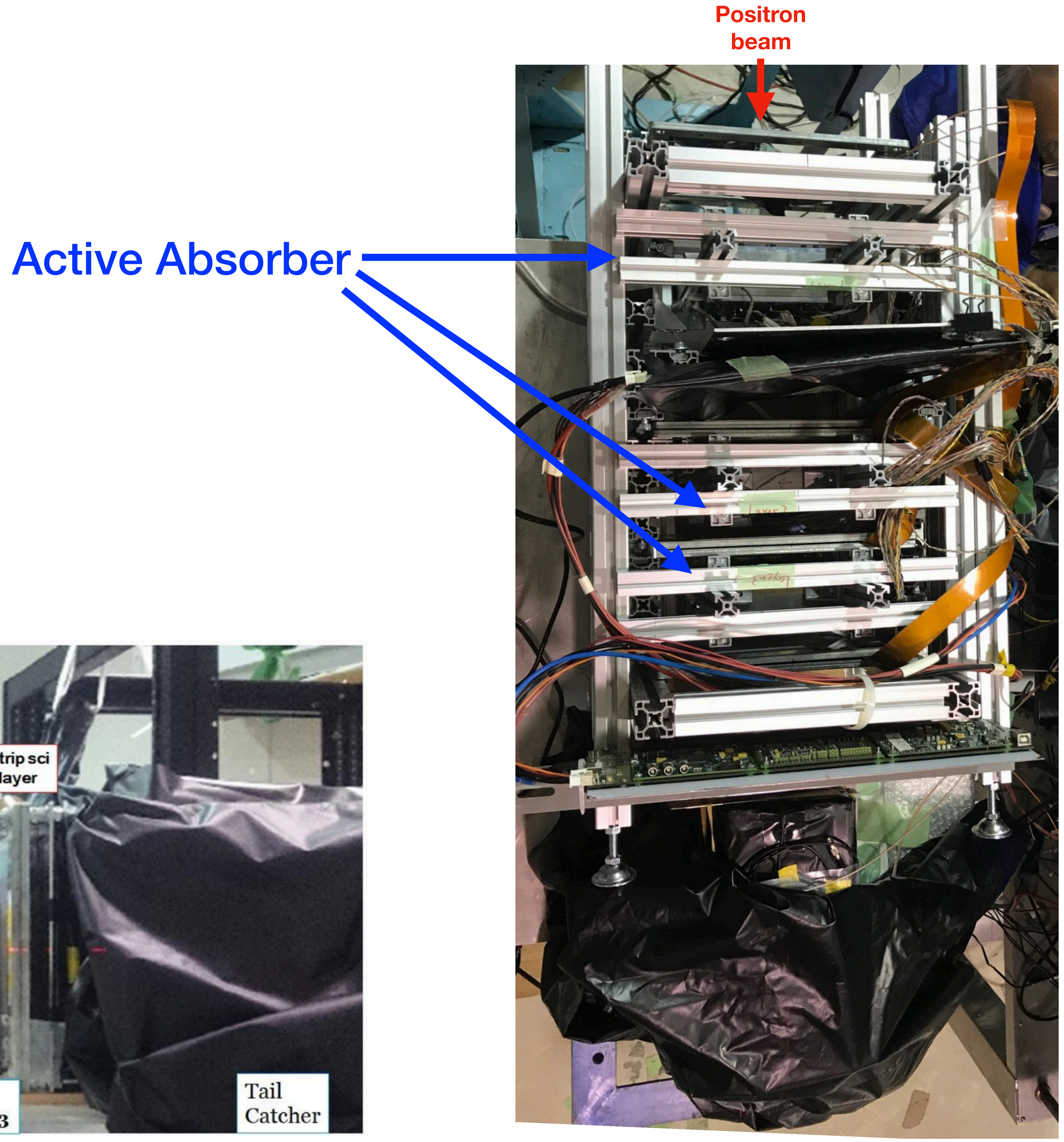
- Test beam at ELPH at Tohoku University in 2016 and 2017 each 3 days
- Injection 100MeV to 800MeV positron beam
- Manufactured 3 layers sampling calorimeter with active absorber
- Segmented lead glasses with MPPCs as an active absorber layer
- Strip scintillators as an detection layer
- Tail catcher made of large lead glass at the end of the setup



Active Absorber Prototype



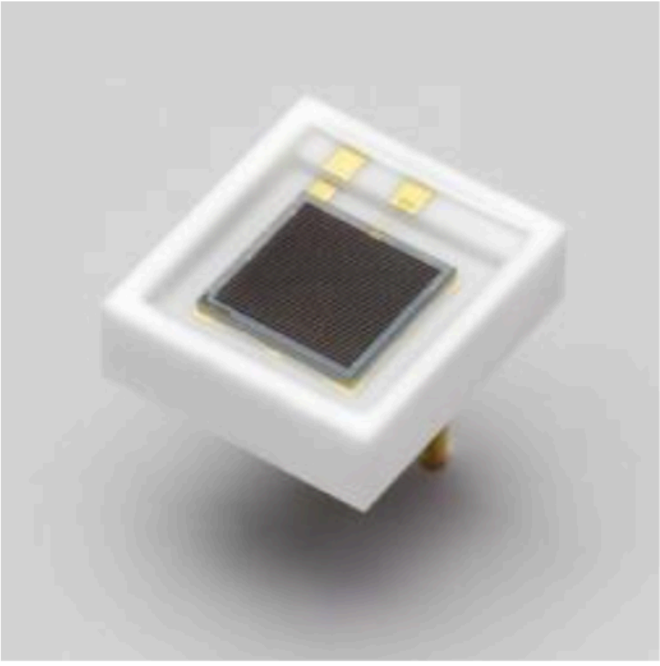
Side view of 2016 prototype



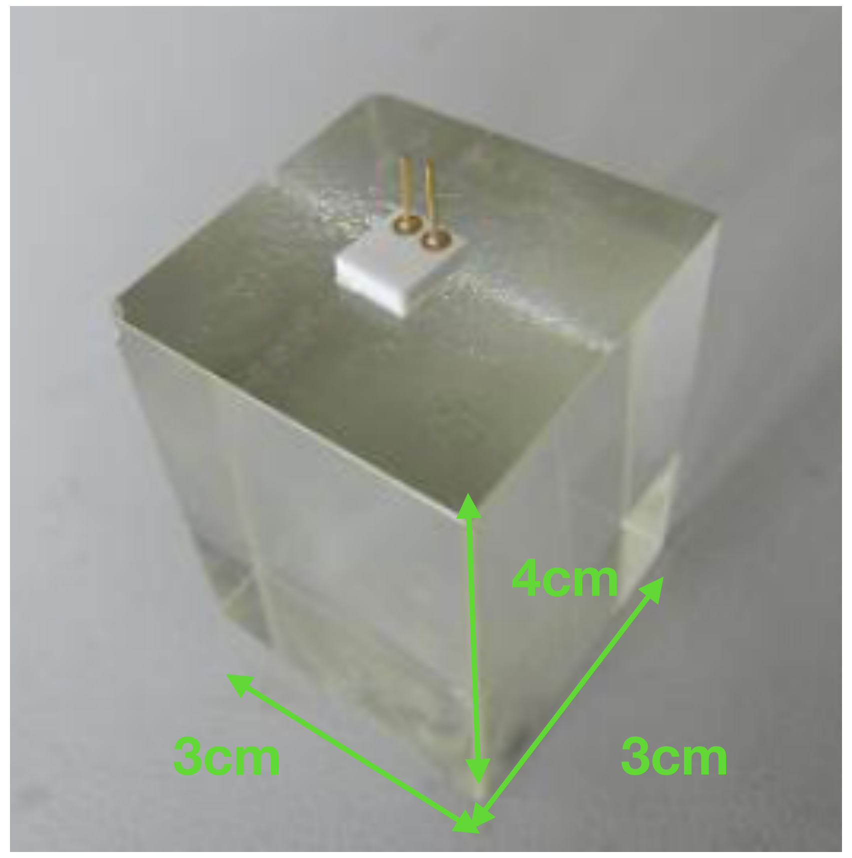
Top view of 2017 prototype

Active absorber layer

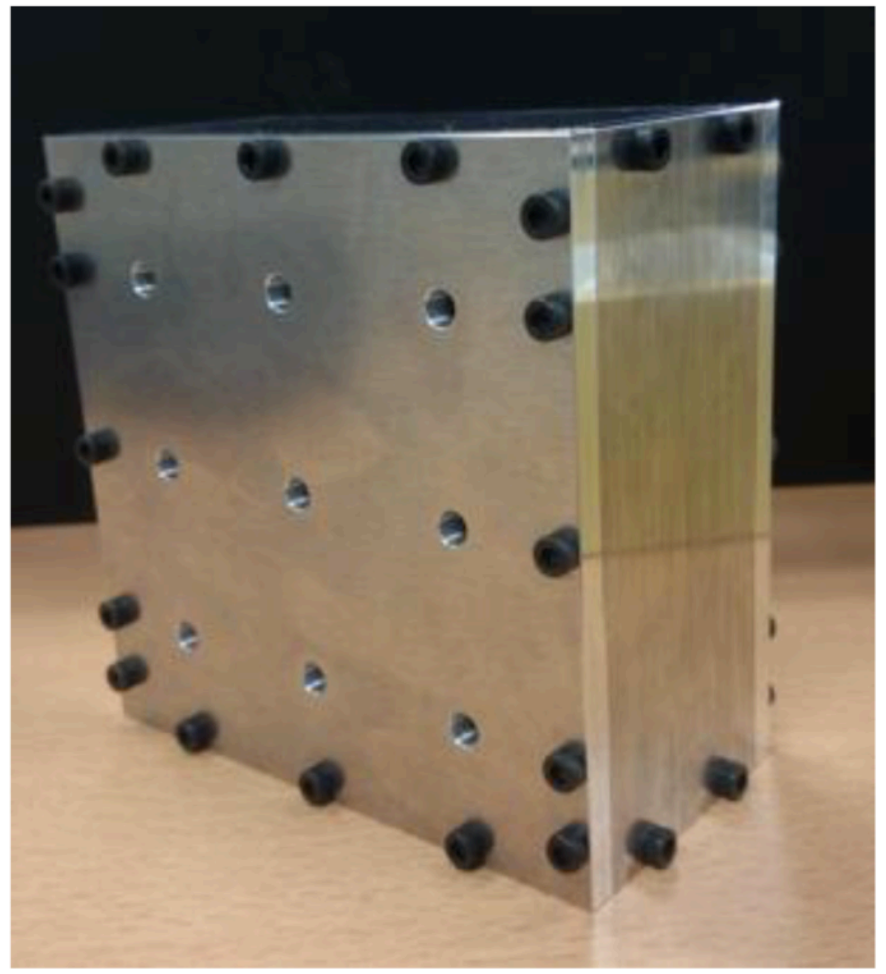
- Lead glass is segmented in size of 3 x 3 x 4 cm^3 for PFA
- Using a 3 x 3 mm^2 MPPC (50μm pitch and 75μm pitch)
- Lead glass block enveloped with reflector film
- 1 layer has 9ch (3 x 3 ch lead grass blocks array)
- Manufactured 3 layers
- 27 MPPCs are read by an EASIROC Module
- Pre-calibration using cosmic muons at bench test



3 x 3mm^2 MPPC



Lead Glass Block

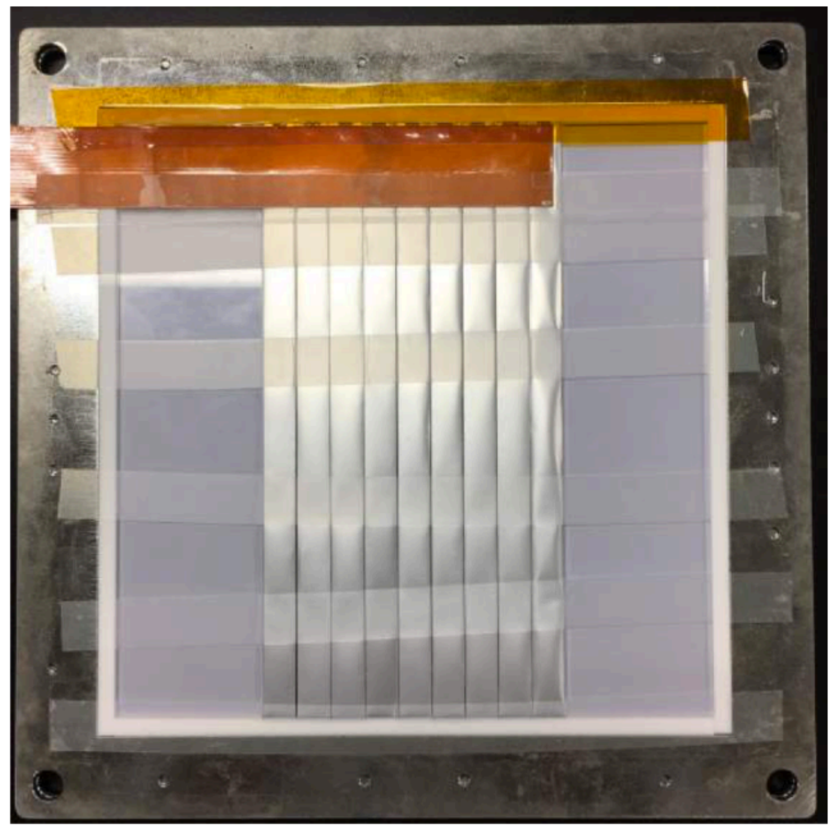


Active Absorber Layer

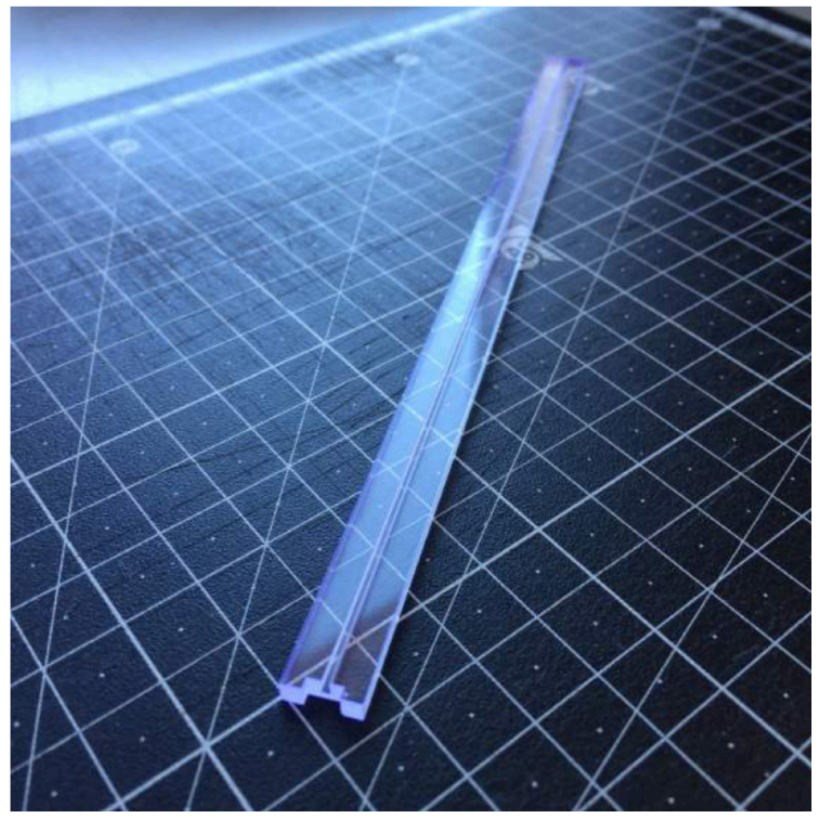
Lead Glass blocks Array

Strip scintillator layer

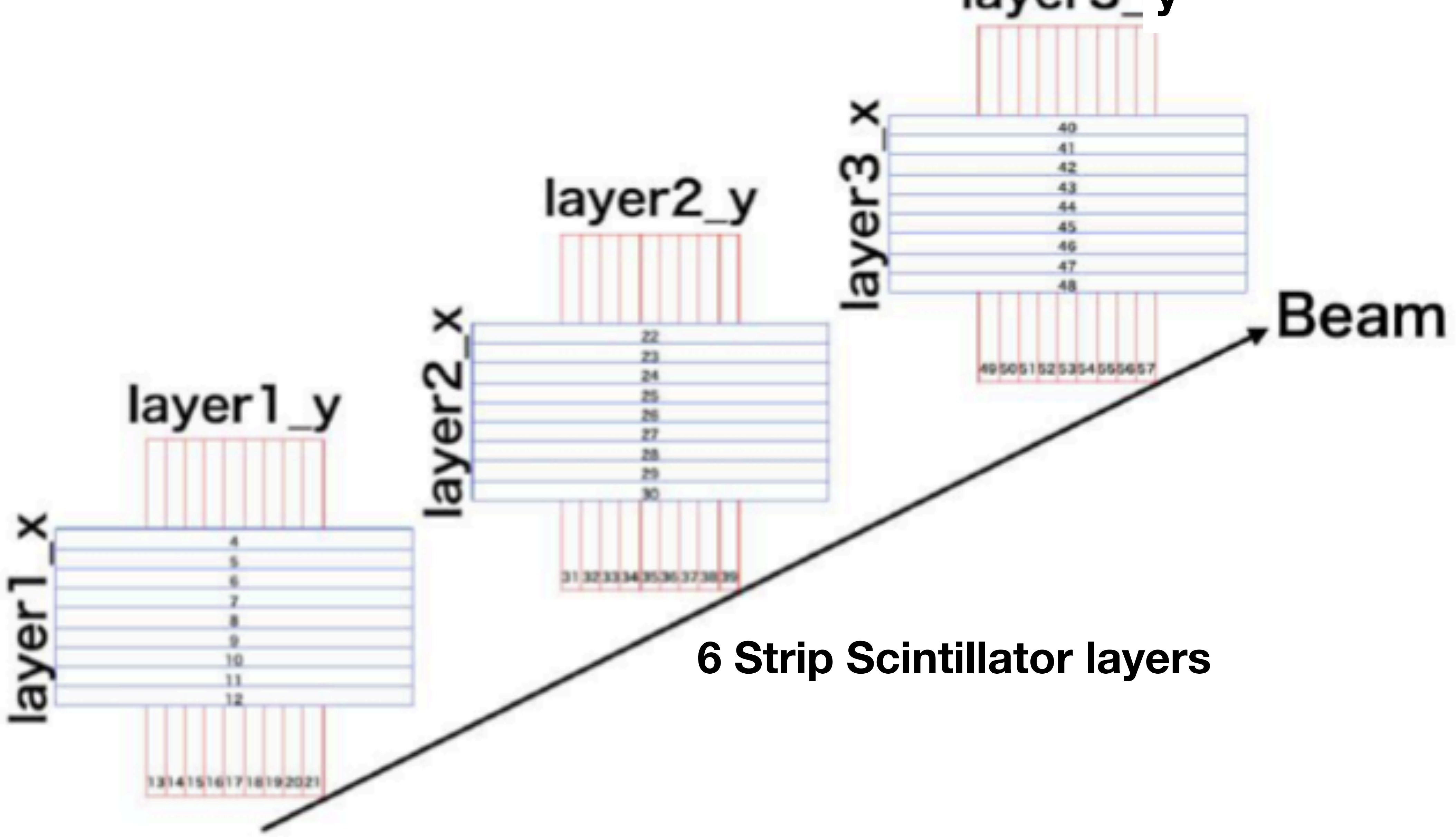
- Create scintillator layers to match 9 x 9 cm^2 lead glass layer
- Using 9 strip scintillators of 18 x 1 x 0.3 cm^3
- Enveloped with 3M reflector film
- Assembling strips in a pair of layers orthogonally makes the resolution to be 1 x 1 cm^2
- Read out by a MPPC(1 x 1 mm^2, 25μm pitch) with wavelength shifting fiber
- Manufactured 6 layers
- Pre-calibration using cosmic muons at bench test
- It has better position resolution than lead glass



1layer 9strips



18 cm x 1cm x 0.3 cm Sc Strip w/ WLSF

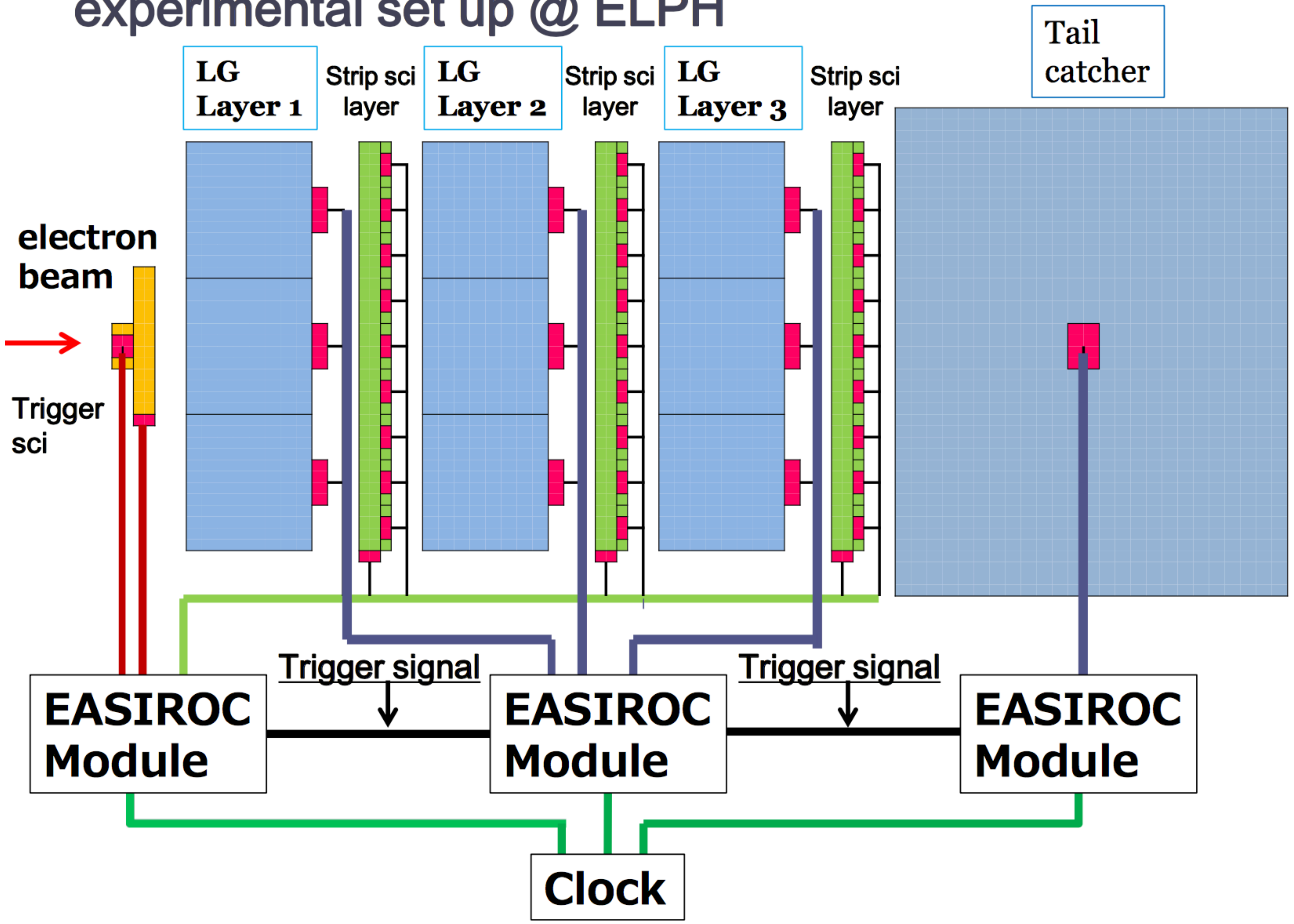


6 Strip Scintillator layers

Read out and Trigger system

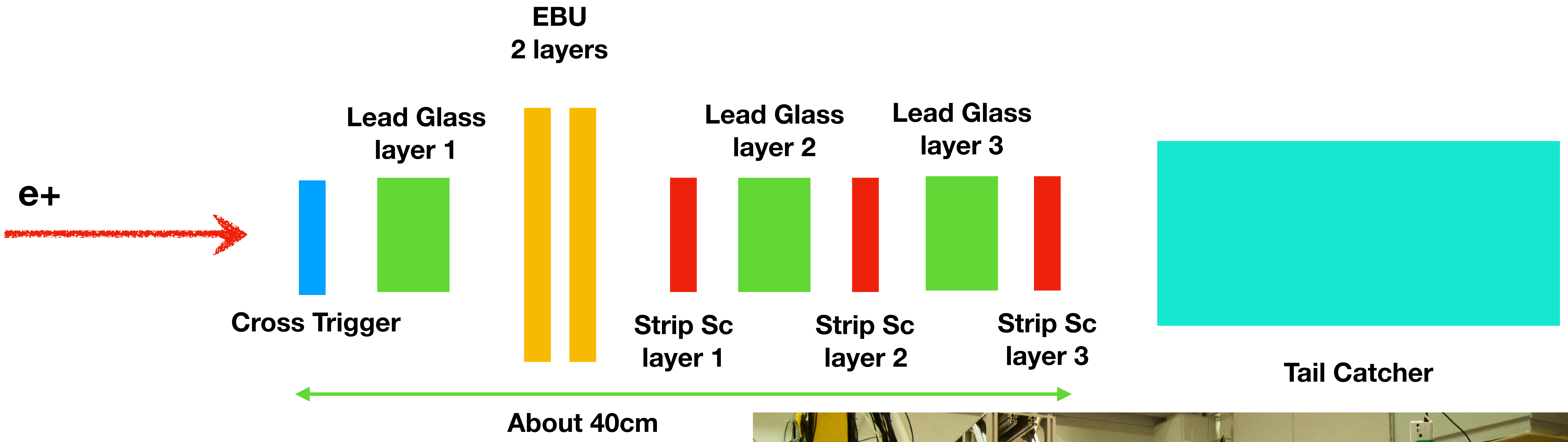
- Use 85 MPPCs were prepared to read out
- 3 EASIROC Modules to read out MPPC signals for different of 3 types MPPCs
- Trigger signals are made by one EASIROC Module for events when signals from 2 trigger scintillators coincide and fed into the other modules
- All EASIROC Modules are read out with 250kHz and 40MHz synchronized clocks

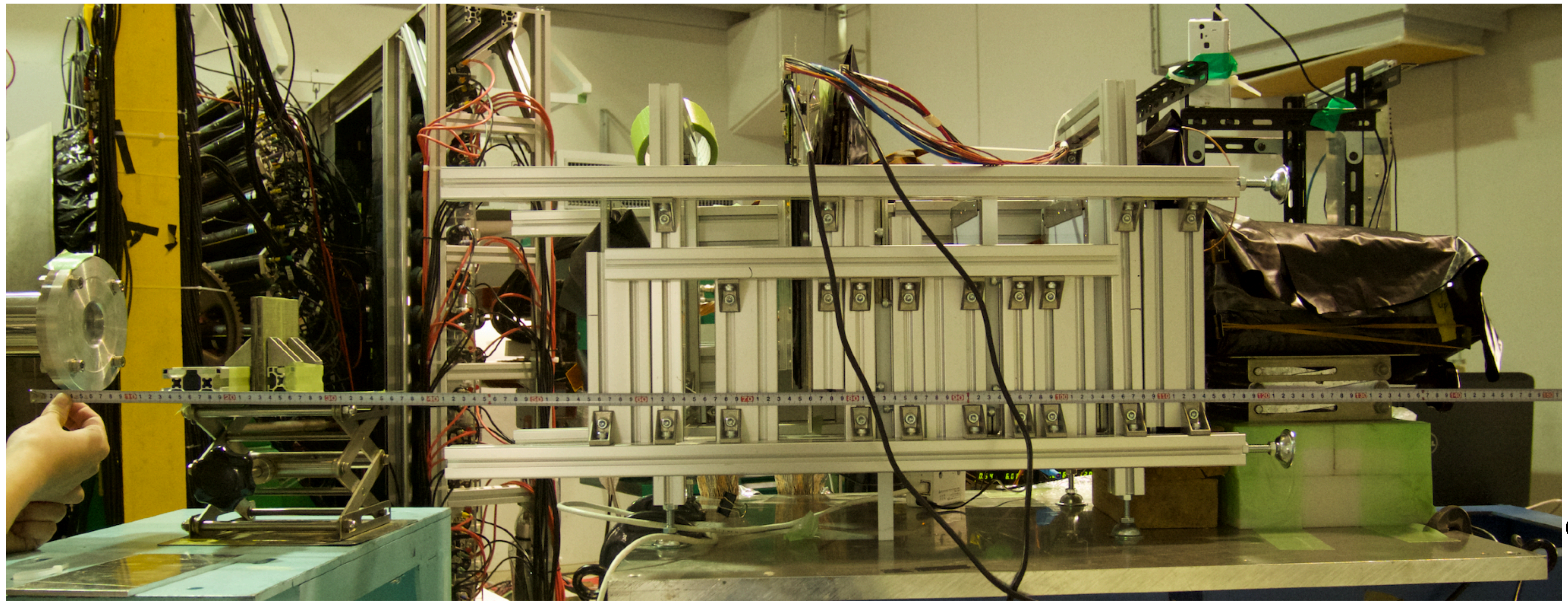
experimental set up @ ELPH



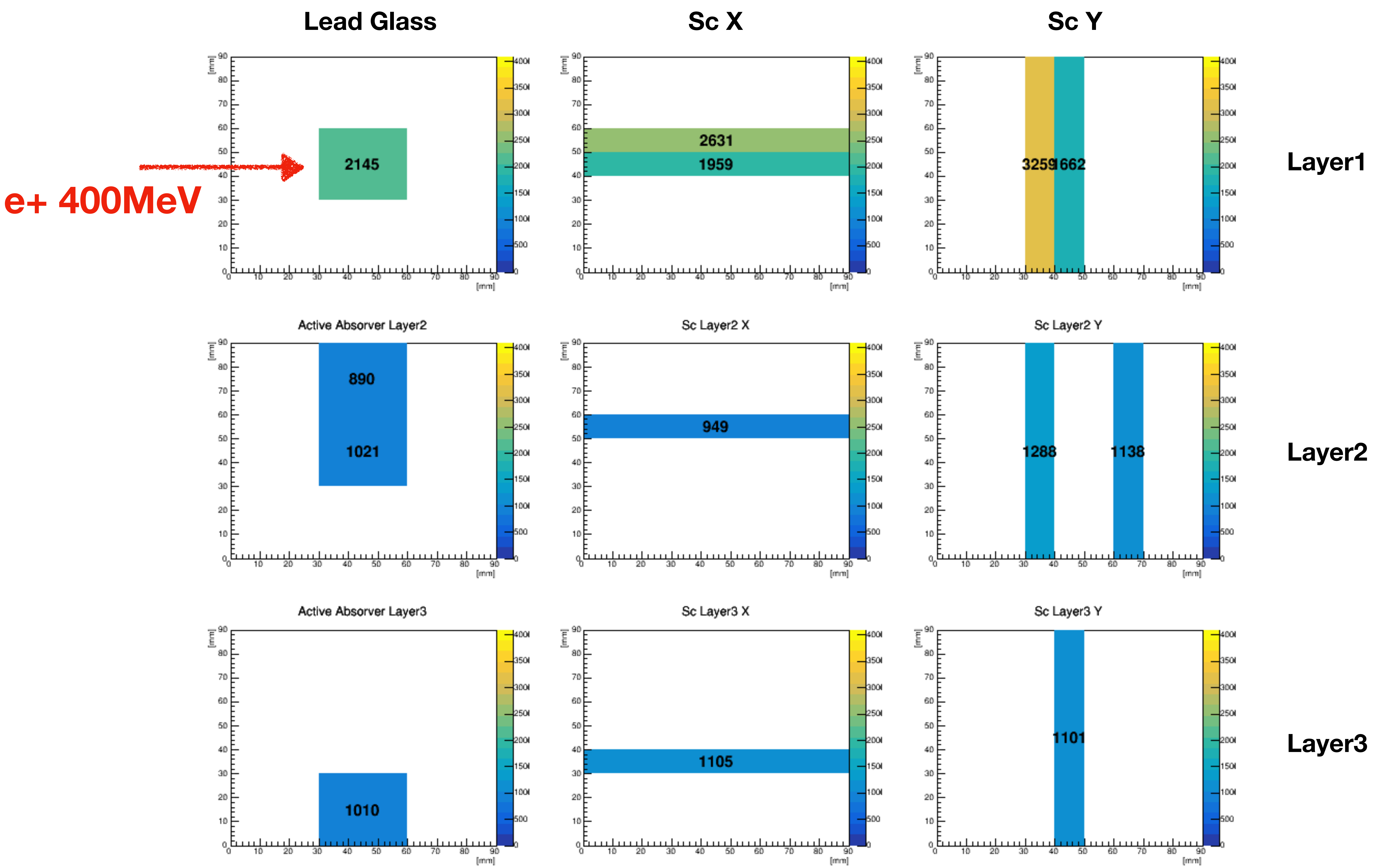
Read Out and Trigger system

Test Beam Detector Setup





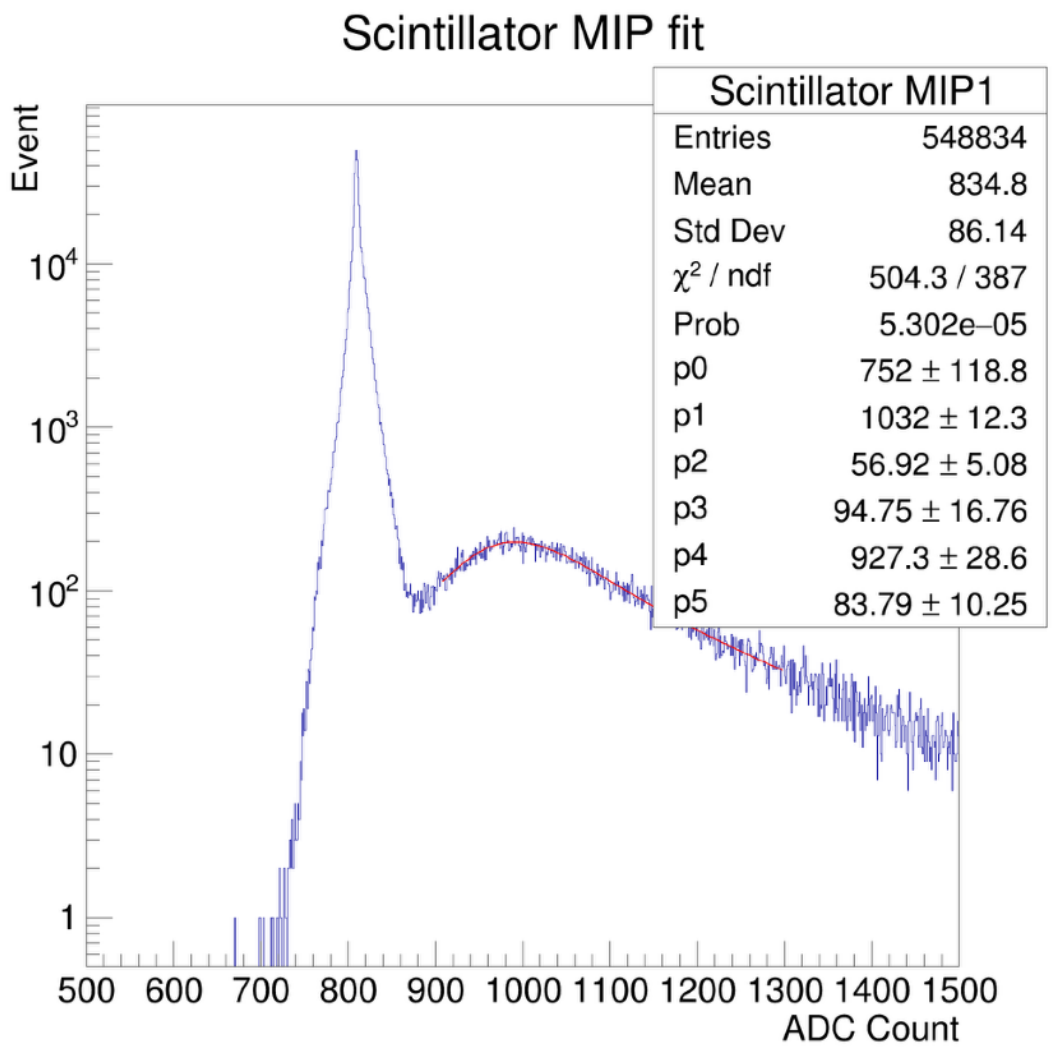
Event Display(2016)

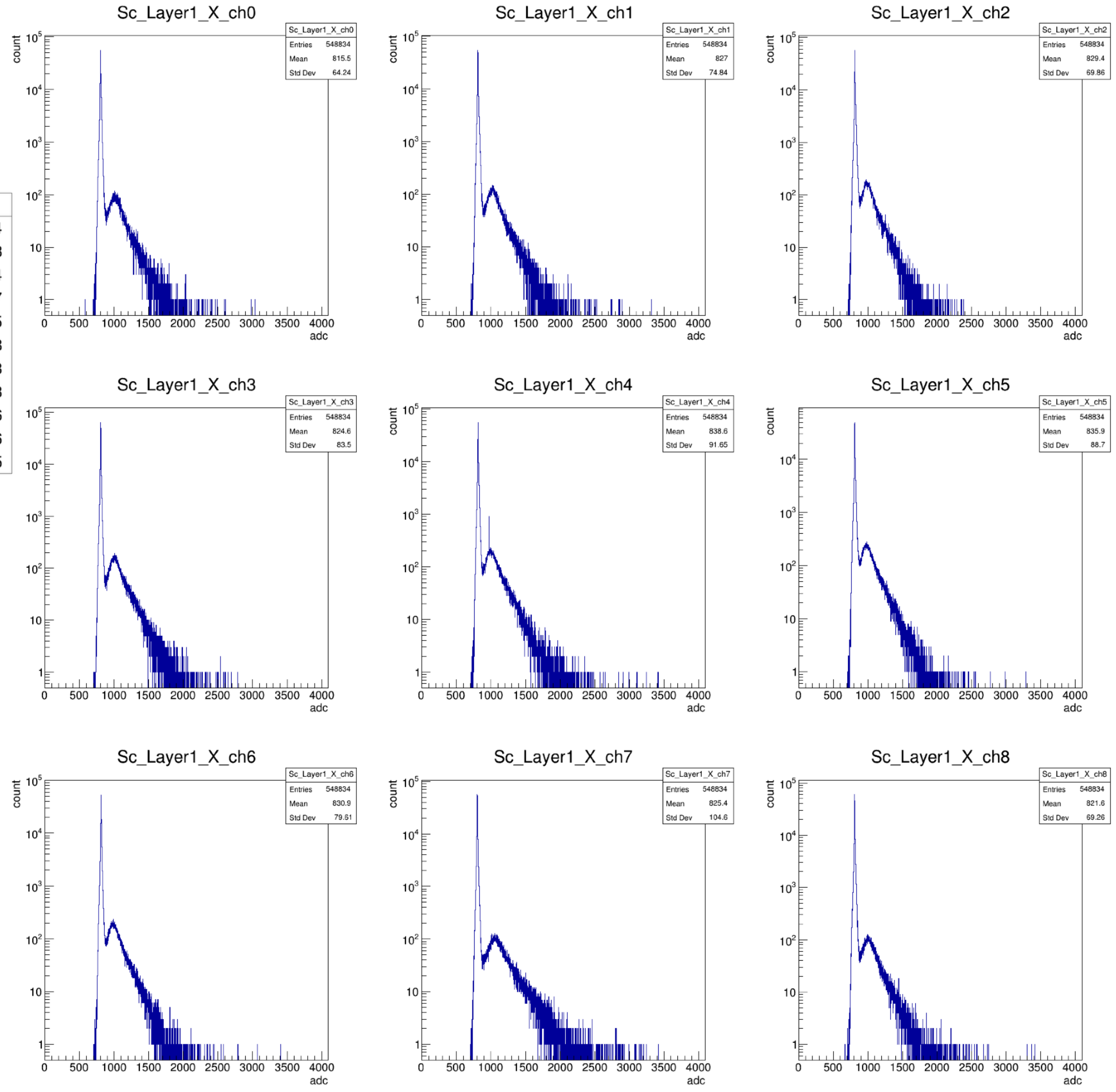


400MeV Event Display

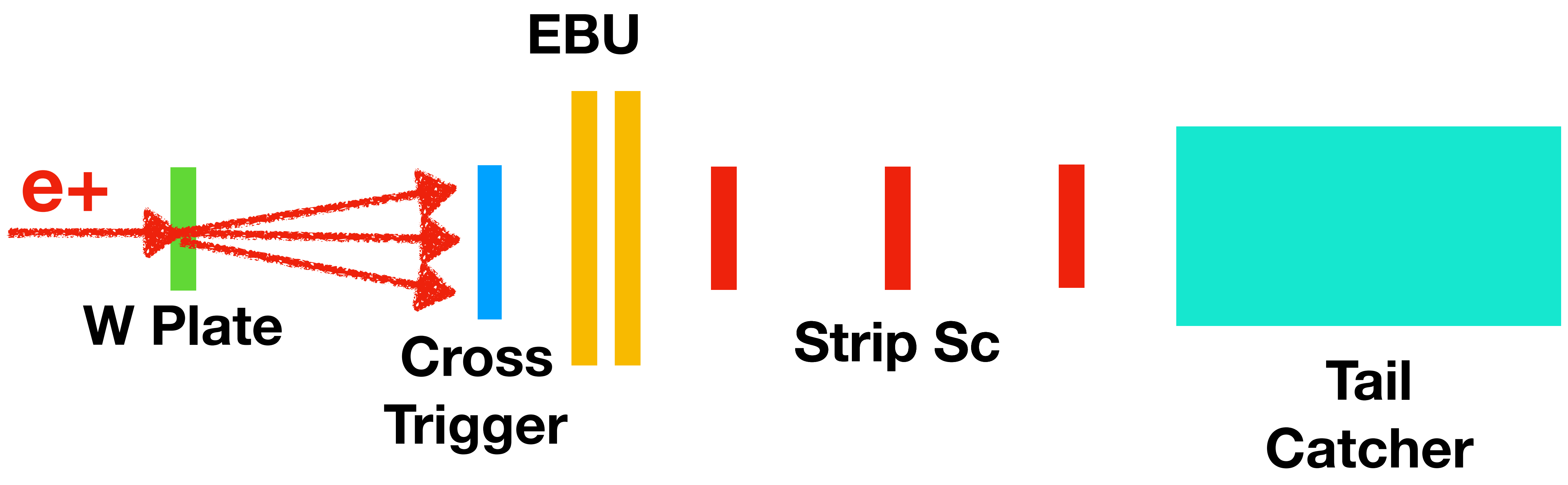
Scintillator Calibration

- 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





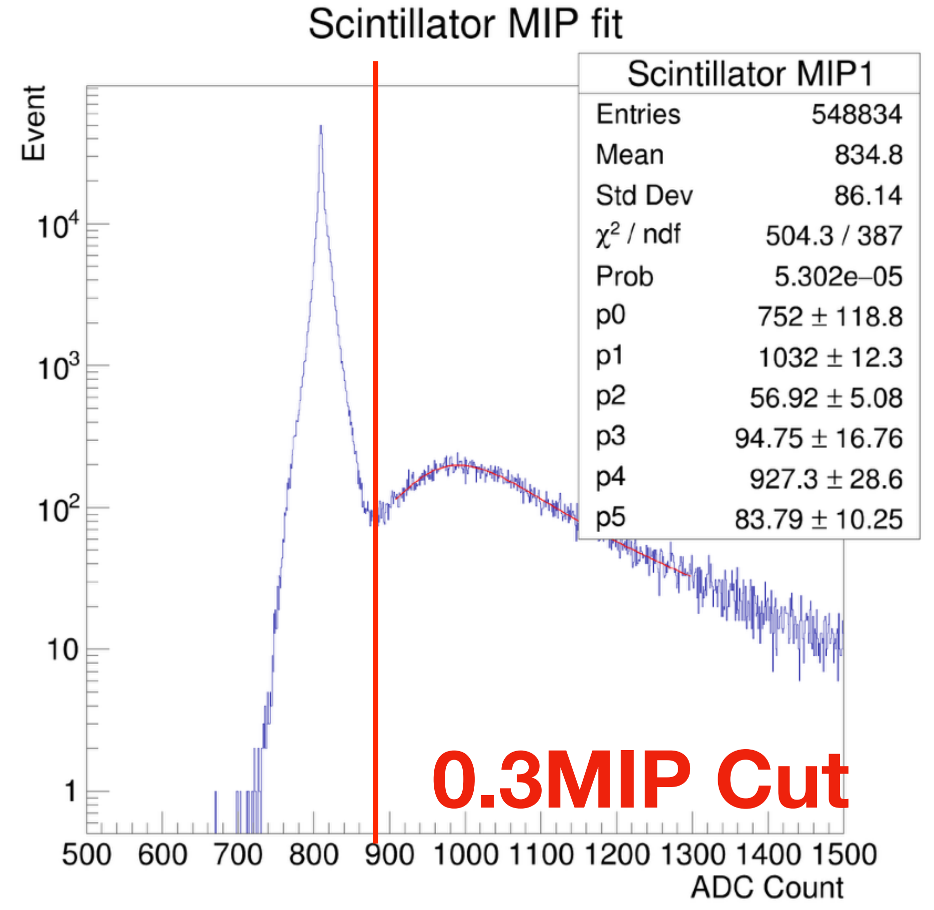
Layer 1 X direction ADC distribution at calibration run (2017)

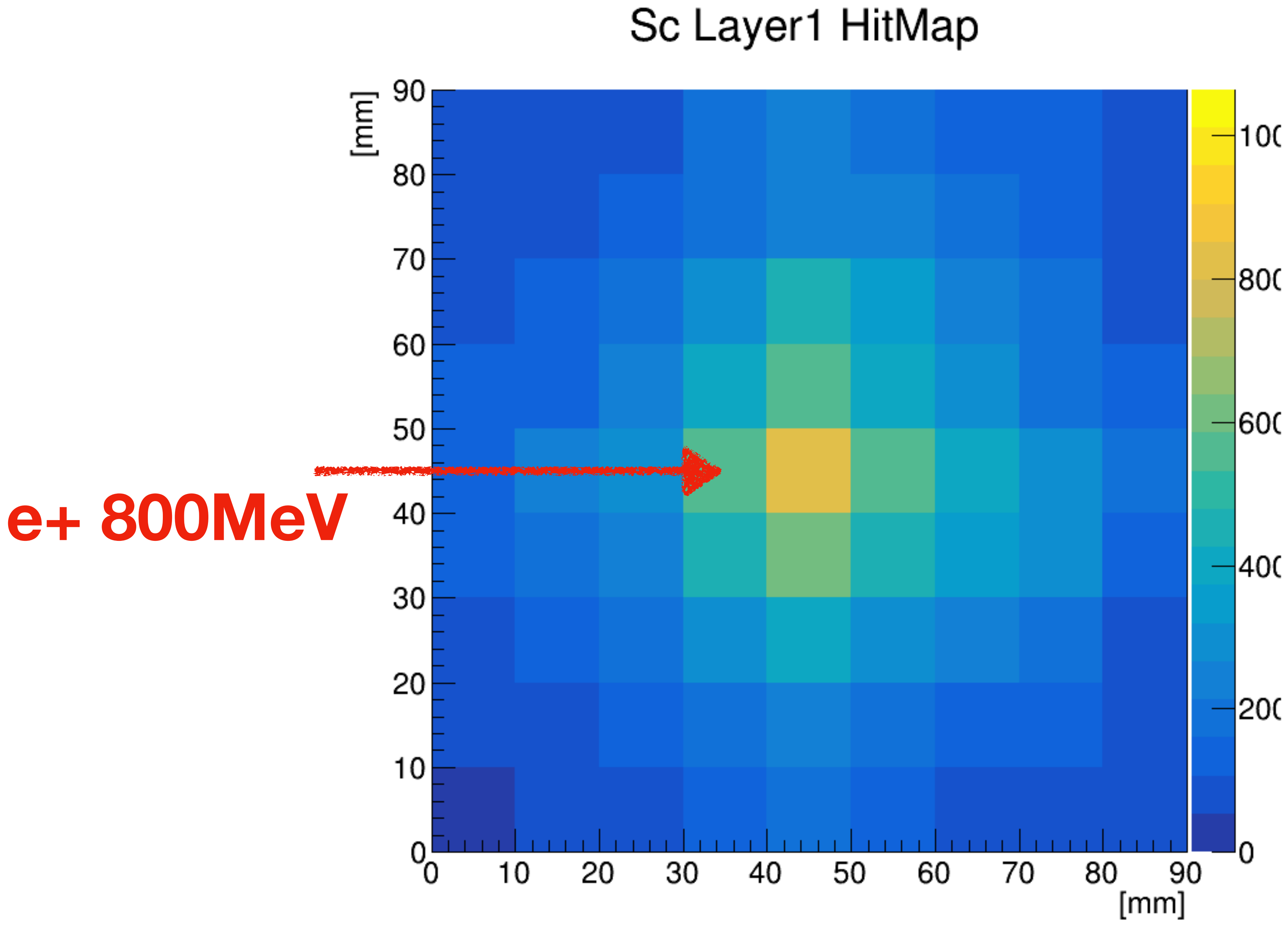


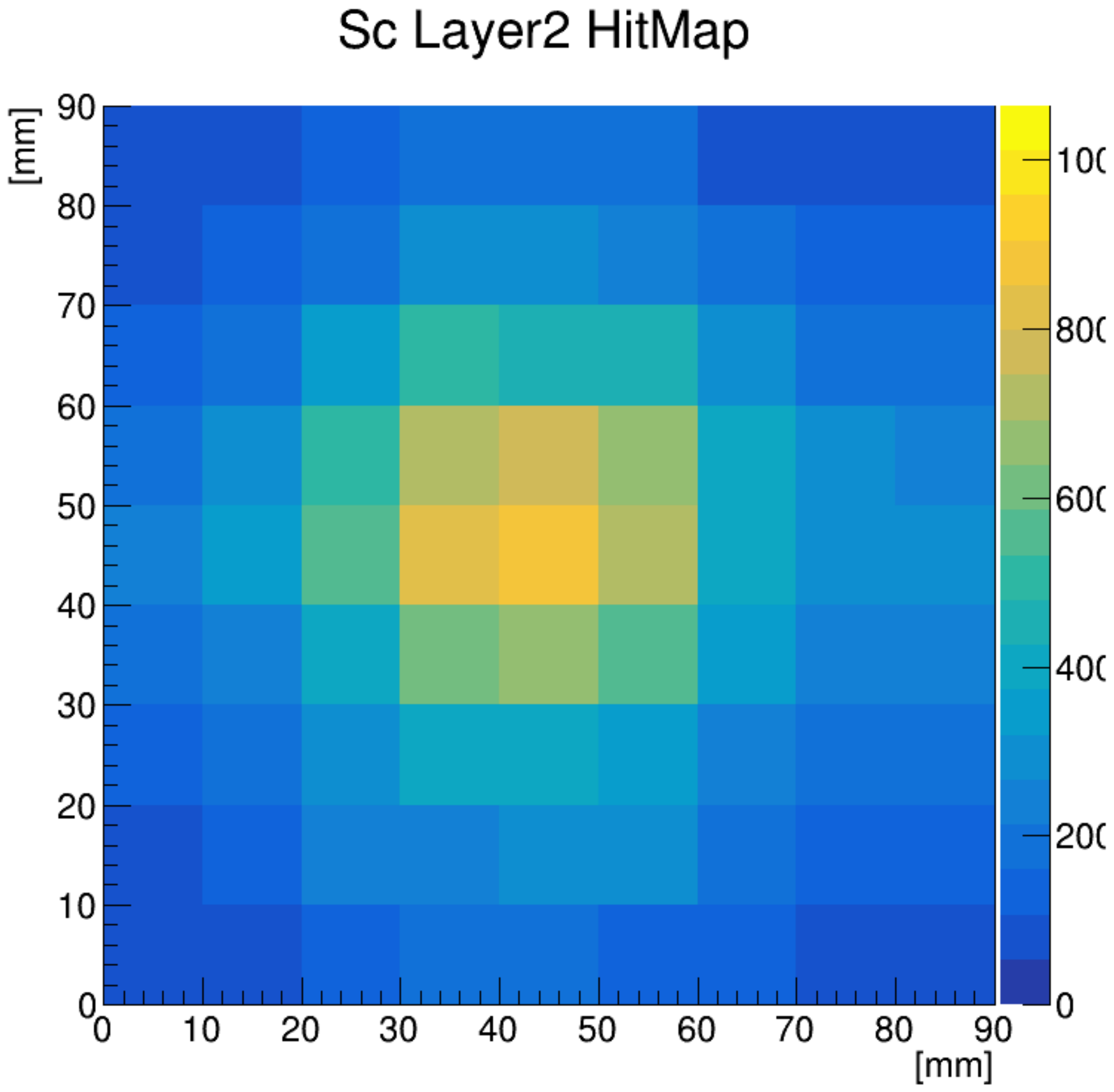
scintillator calibration setup (remove active absorber)

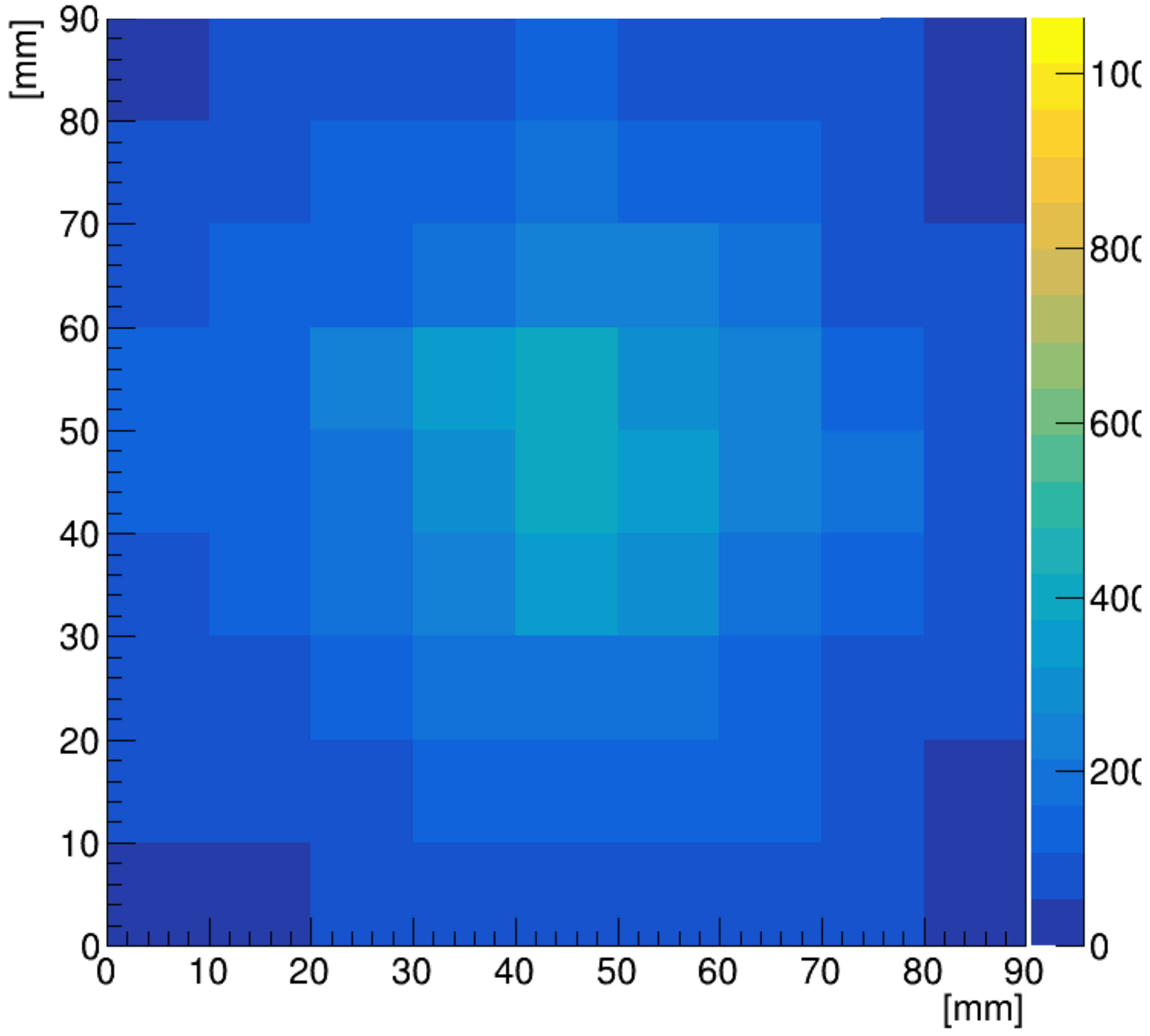
Scintillator Hitmap

- Injection 800MeV positron
- Cutting at 0.3 MIP and taking the coincidence of X and Y layers
- All Channels work well





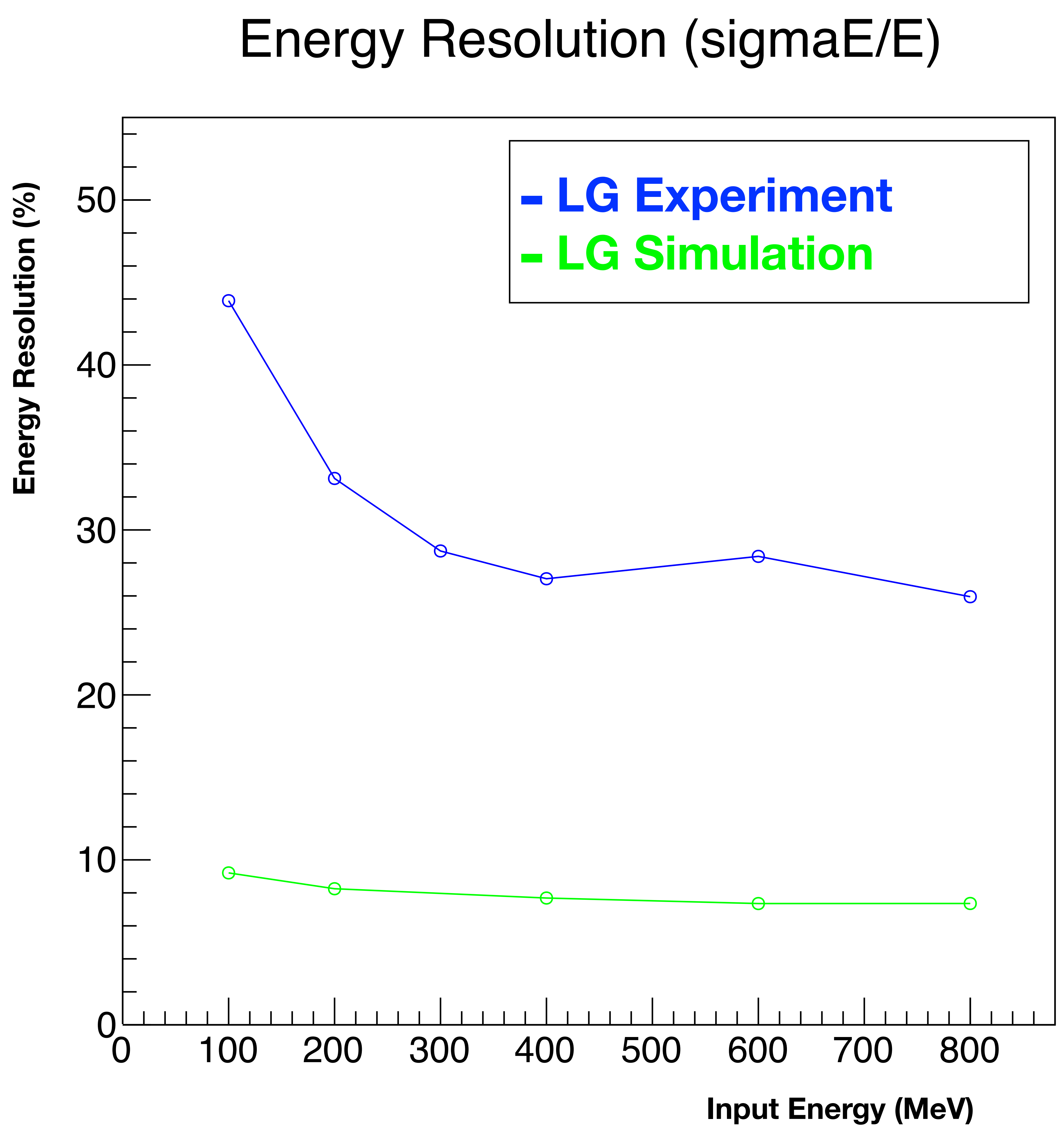




800MeV Sc Hitmap (2017)

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
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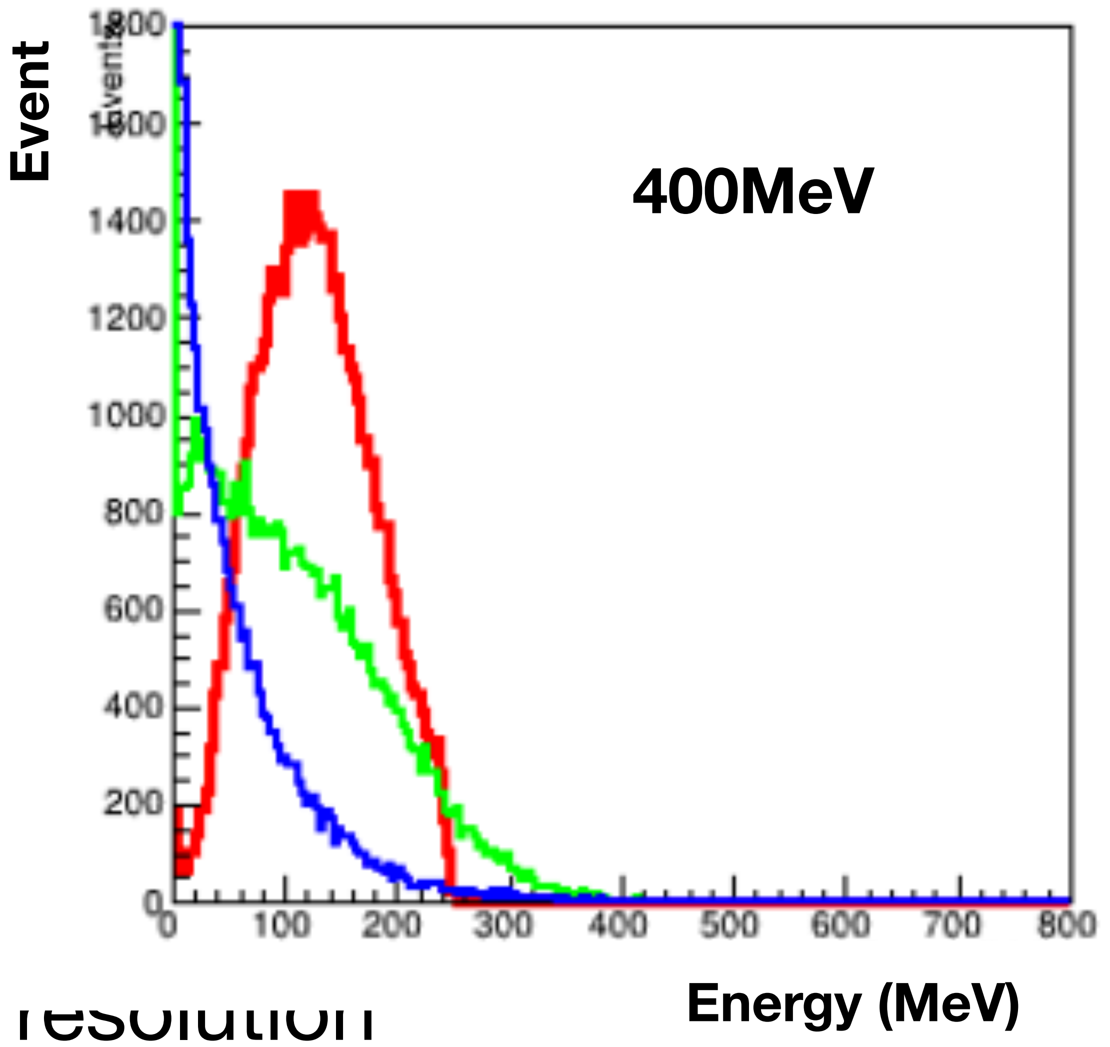
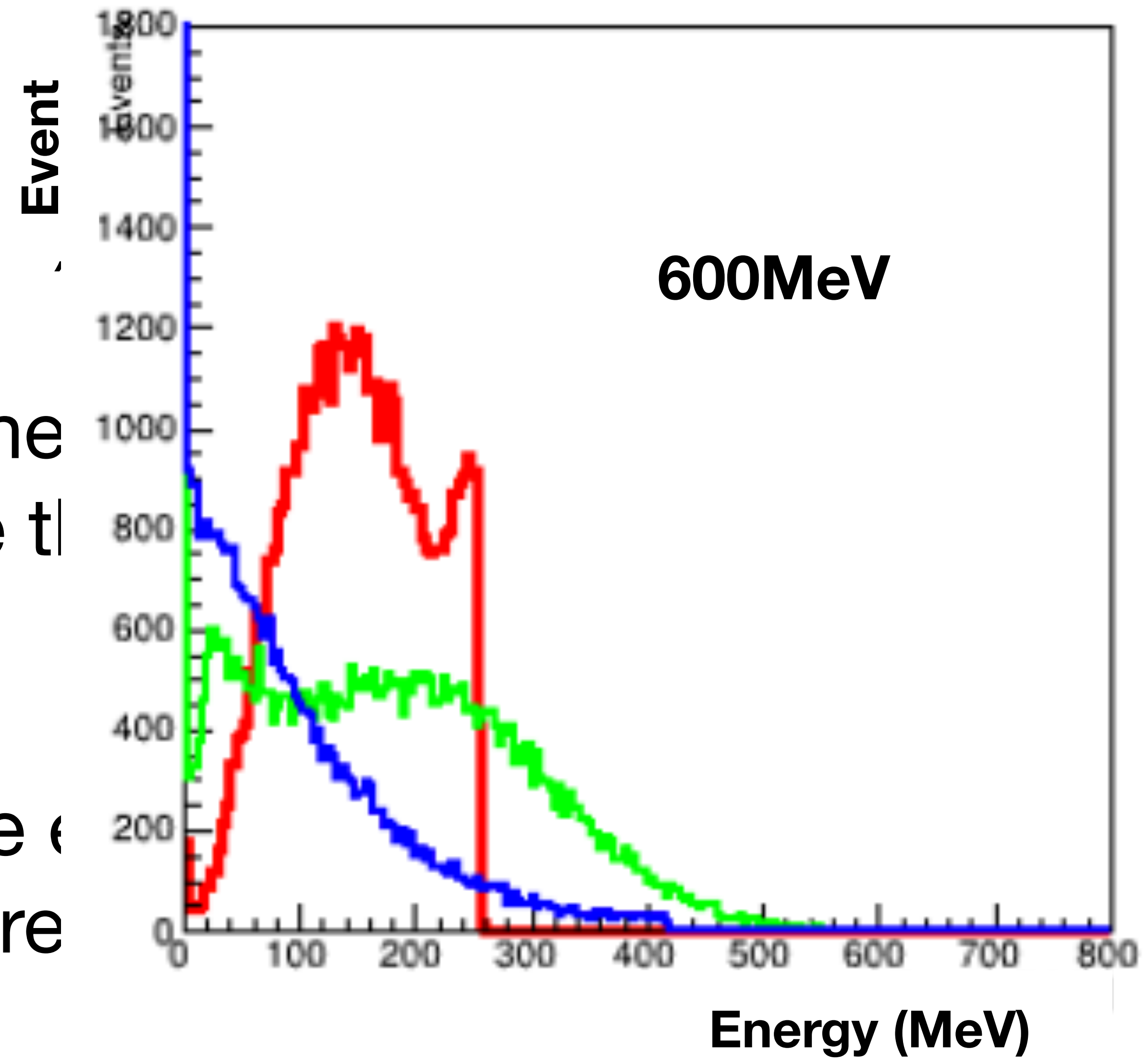
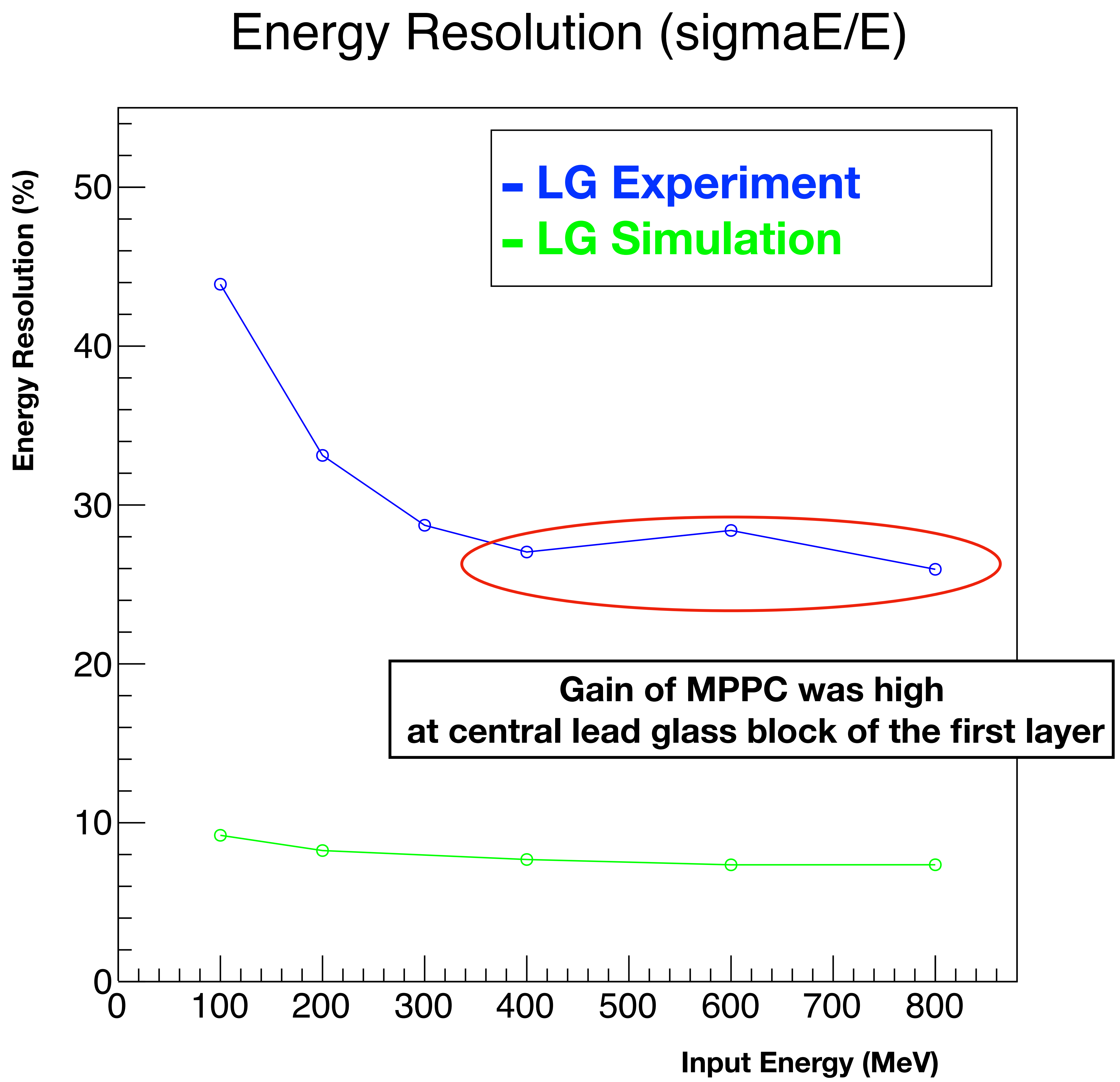


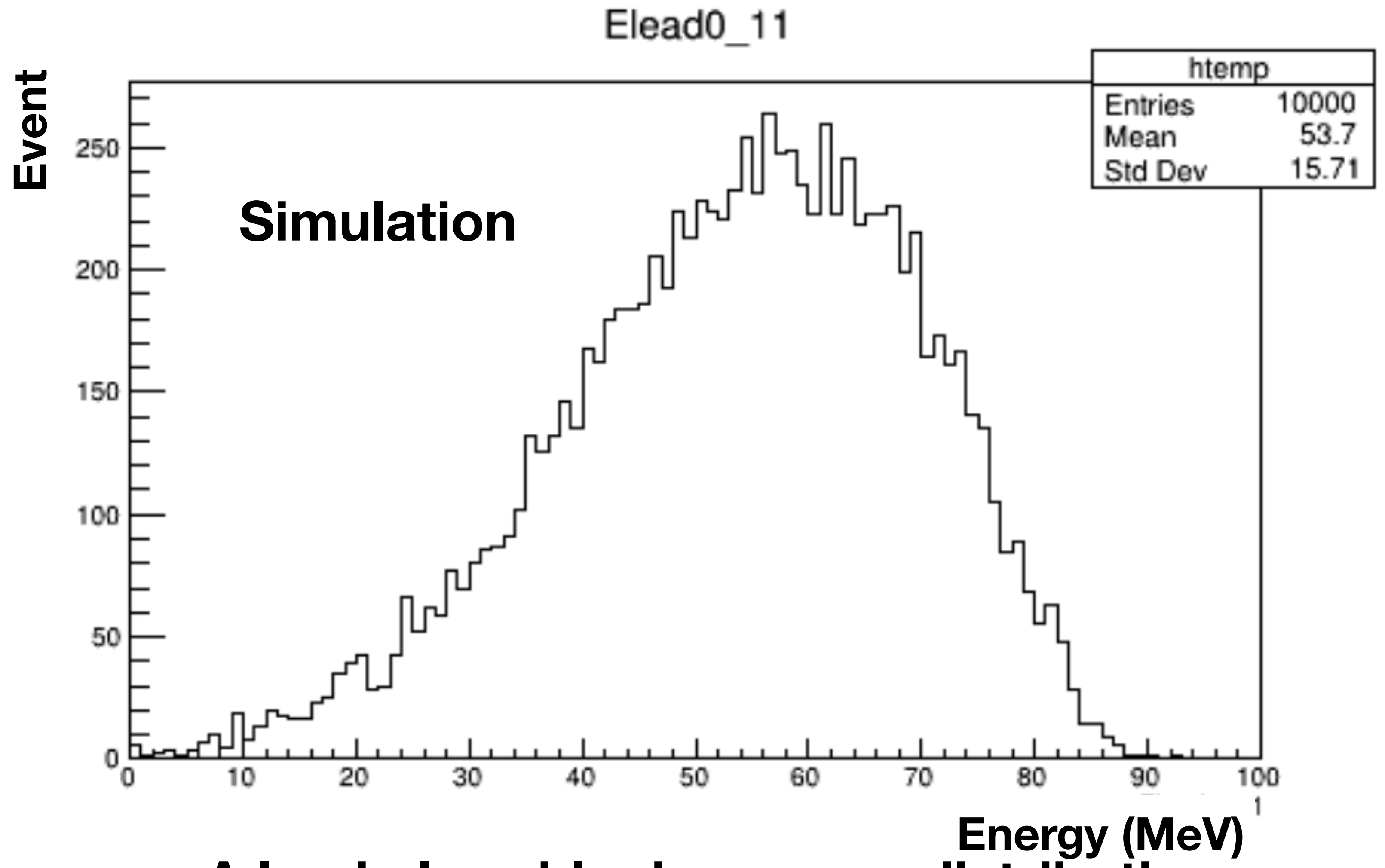




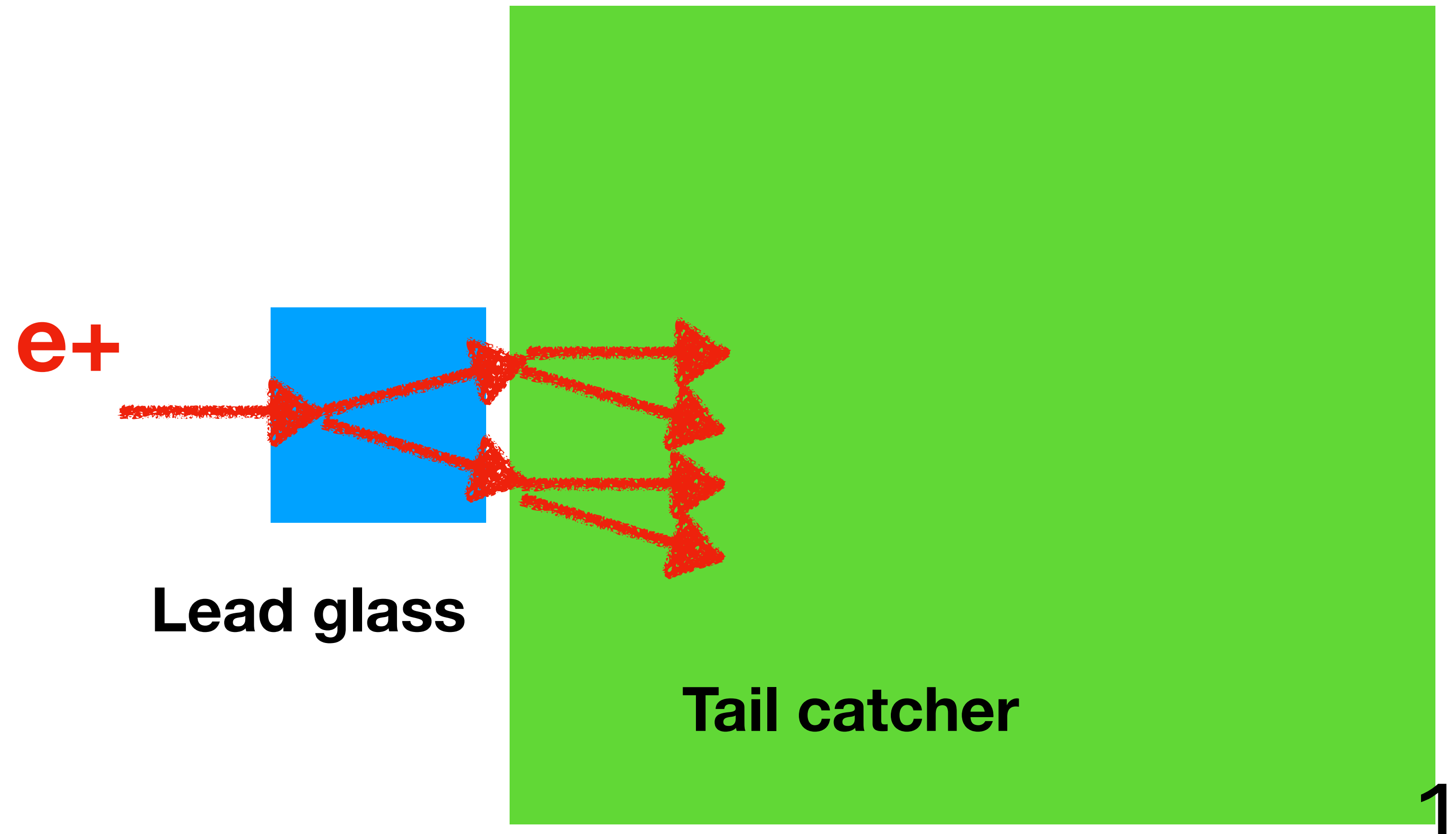
Active absorber energy resolution

Calibration of lead glass blocks

- Calibration of lead glass was a problem in 2016
  - Calibrated by 100MeV electrons
  - Mean energy deposit on lead glass is 53MeV by simulation
- Calibration of lead glass blocks at 2017
  - The performance of the lead glass block would be measured by placing it in front of the tail catcher whose performance is known
  - After lead glass blocks energy measured with the tail catcher, used positron beam from 200 to 800 MeV
- However, in 2017, beam time was reduced due to machine trouble, calibration of 3 center blocks had be carried out



A lead glass blocks energy distribution of 100MeV positrons injecting



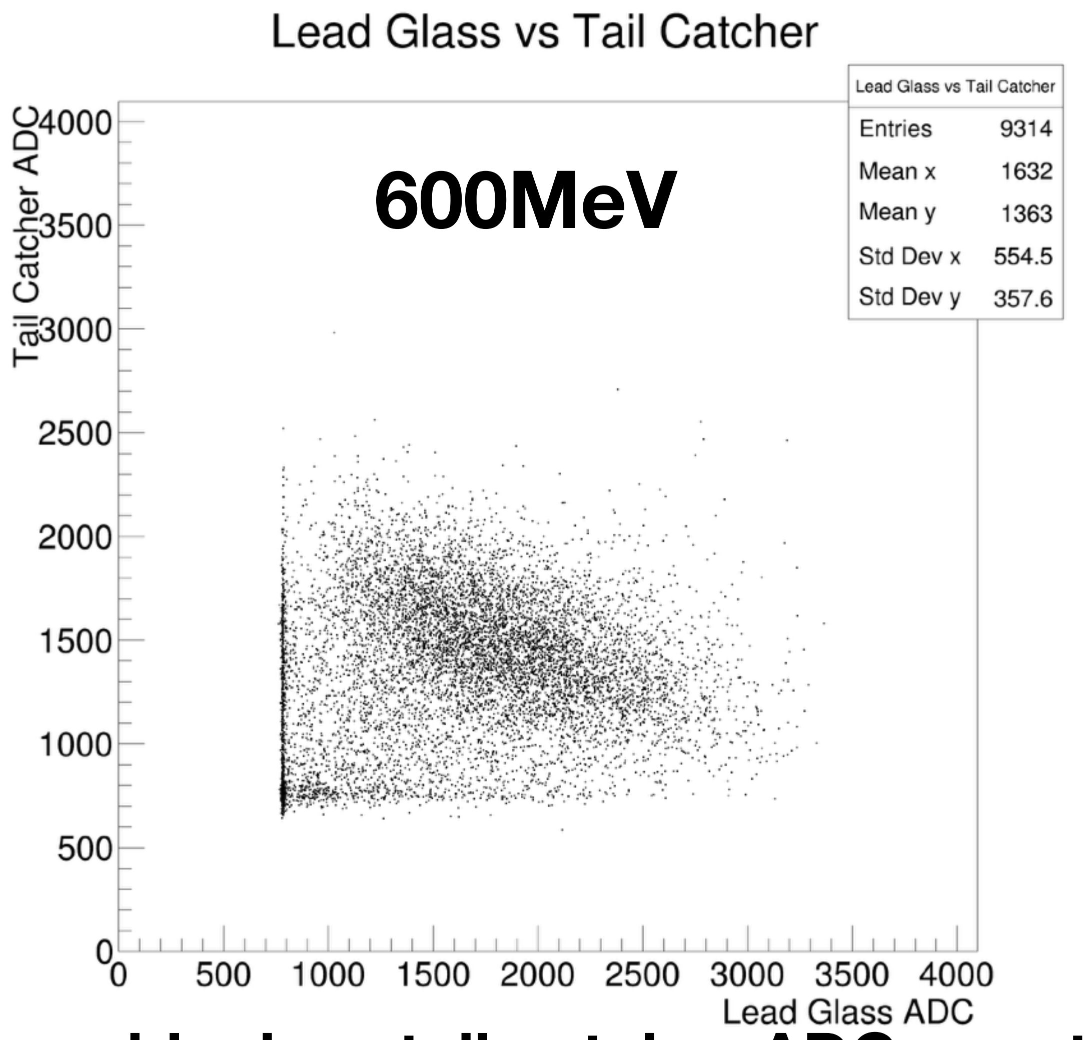
calibration method at 2017 test

Energy calibration of Lead Glass block

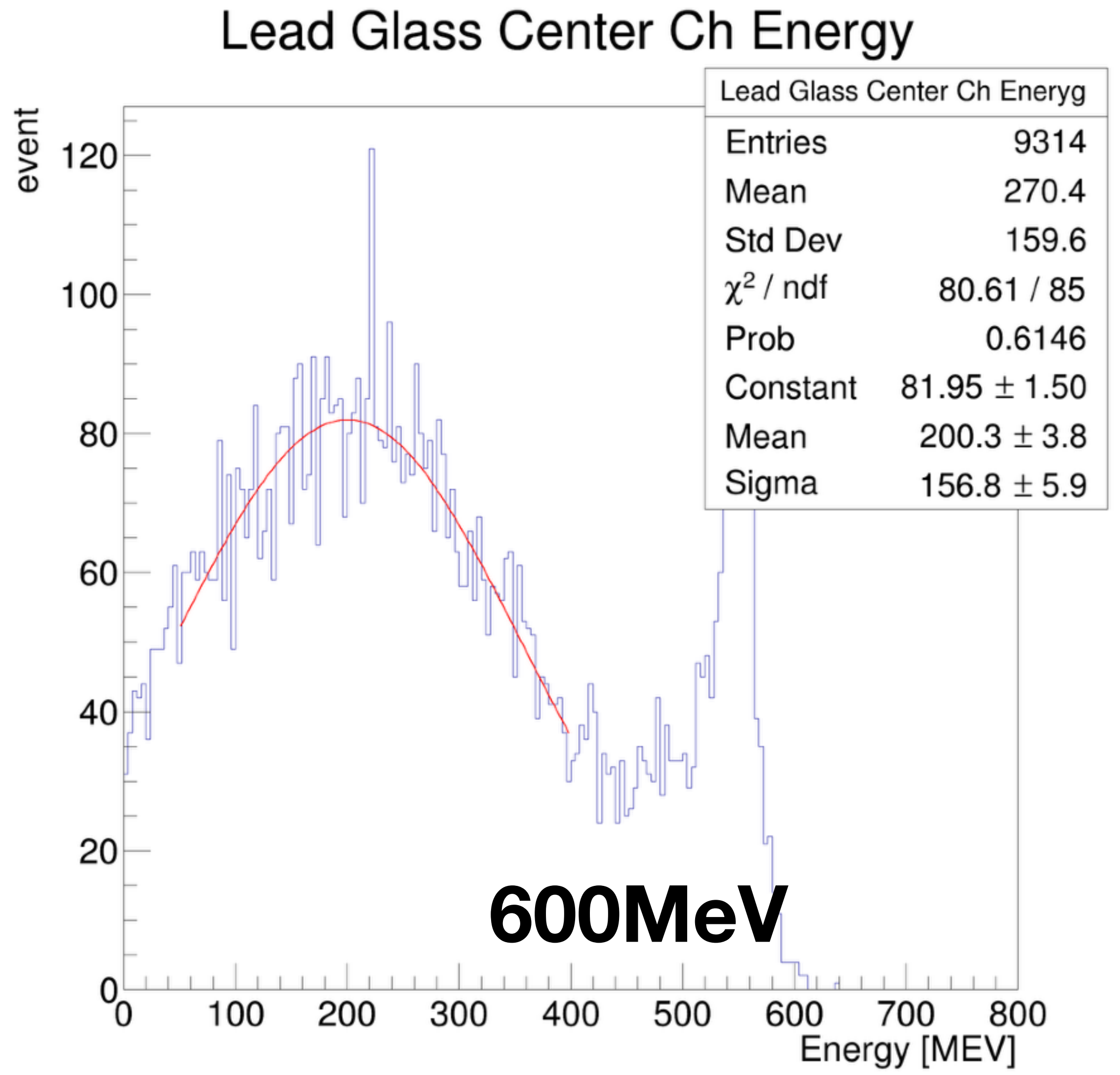
- Injected positron beam from 200 to 800 MeV
- There are good correlation between lead glass blocks and the tail catcher
- Lead glass deposit energy calculated beam energy and tail catcher energy

$$E_{lgblock} = E_{beam} - E_{tailcathcer}$$

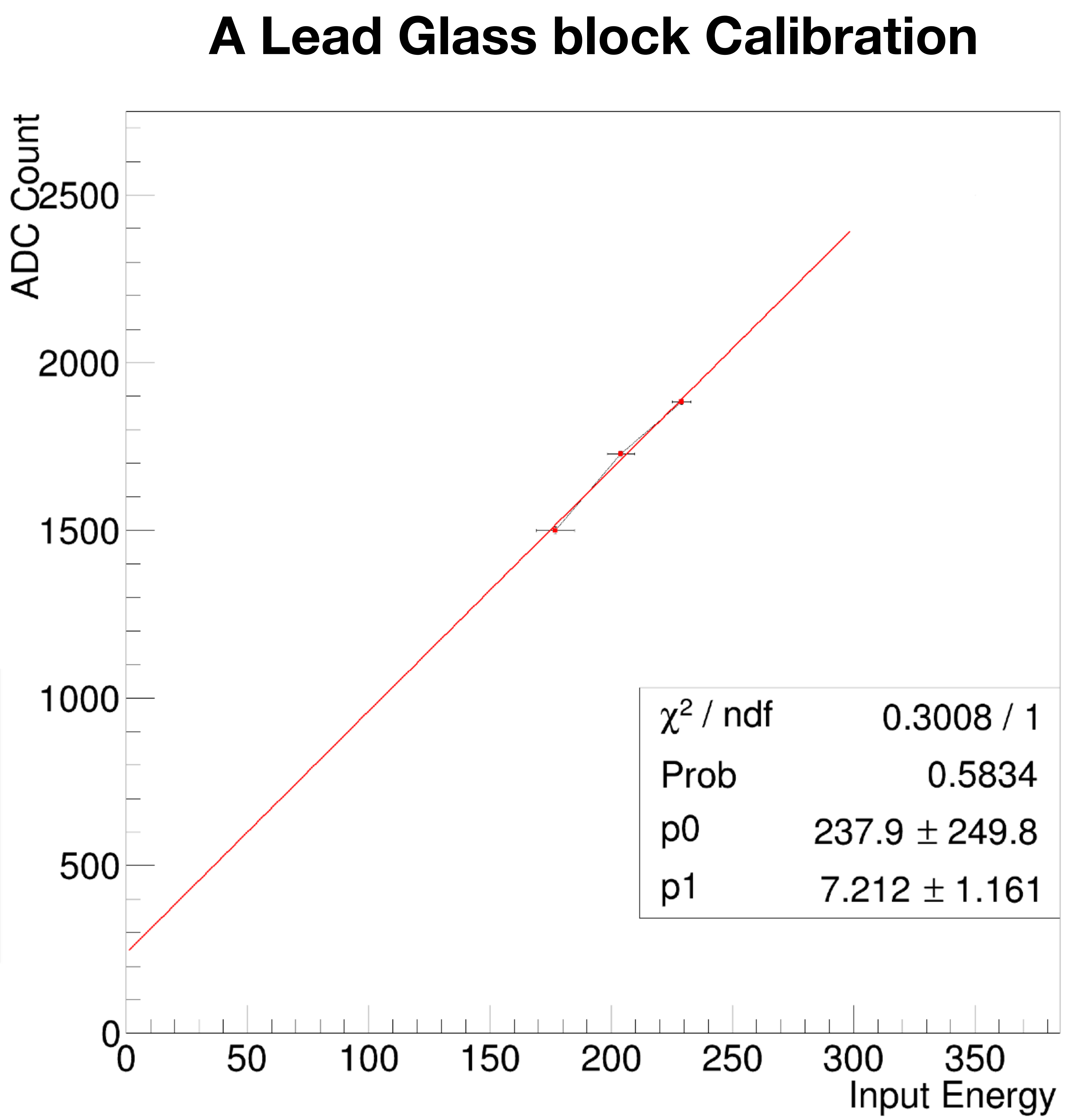
- It is necessary to improve the accuracy of the calibration



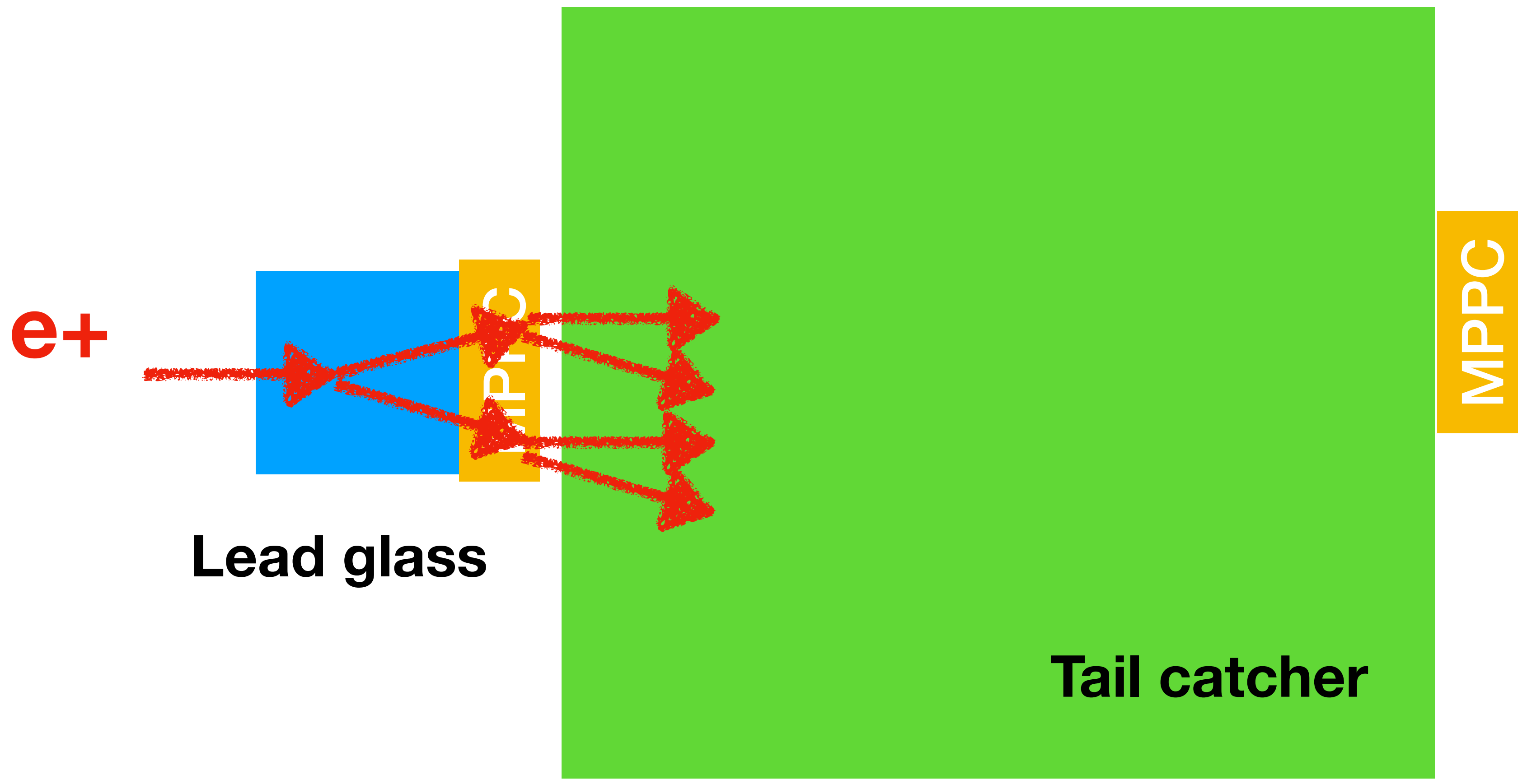
Lead glass block vs tail catcher ADC count



Lead glass block energy distribution



Result of lead glass block energy calibration



2017 Calibration method

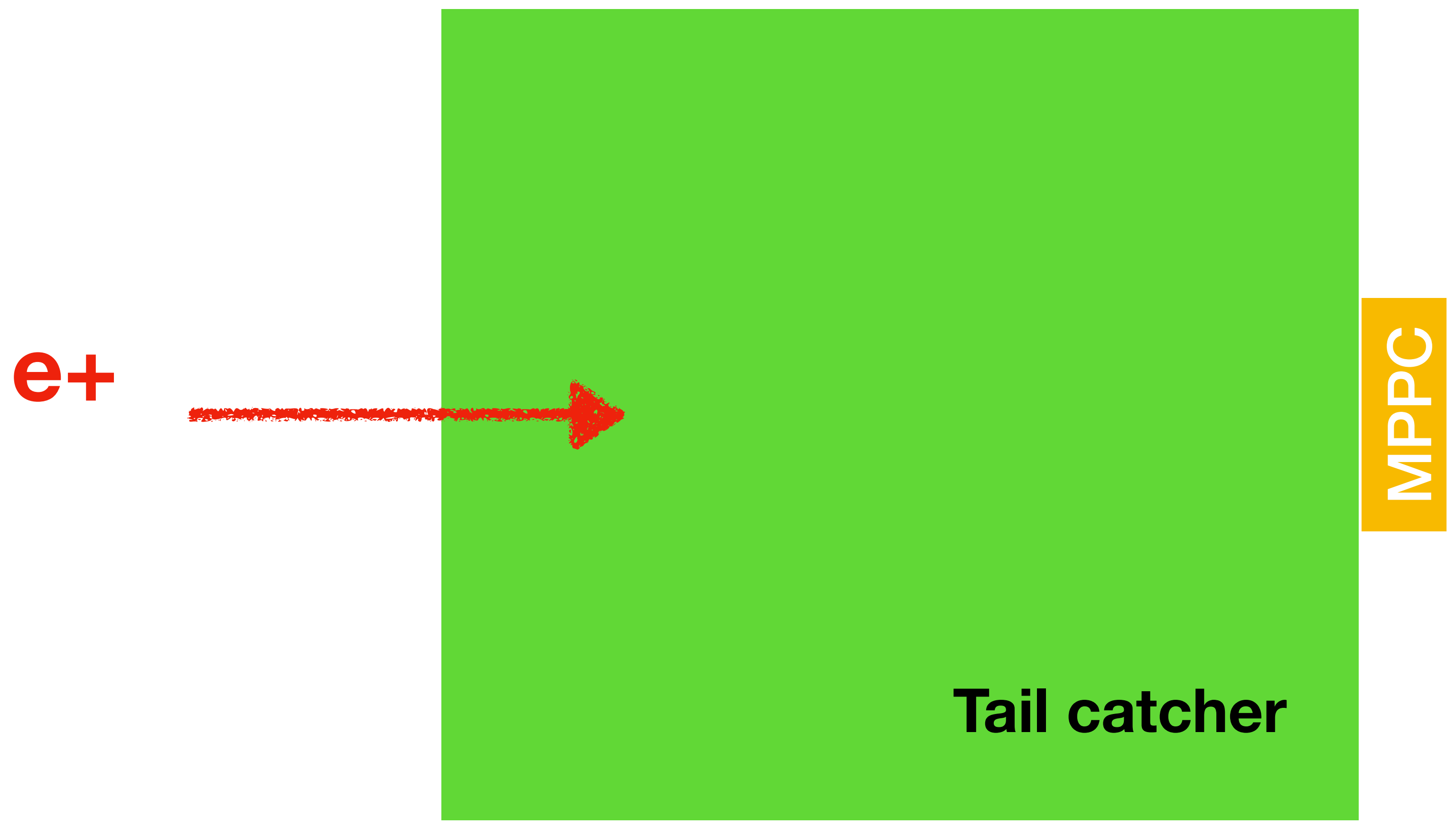
Summary

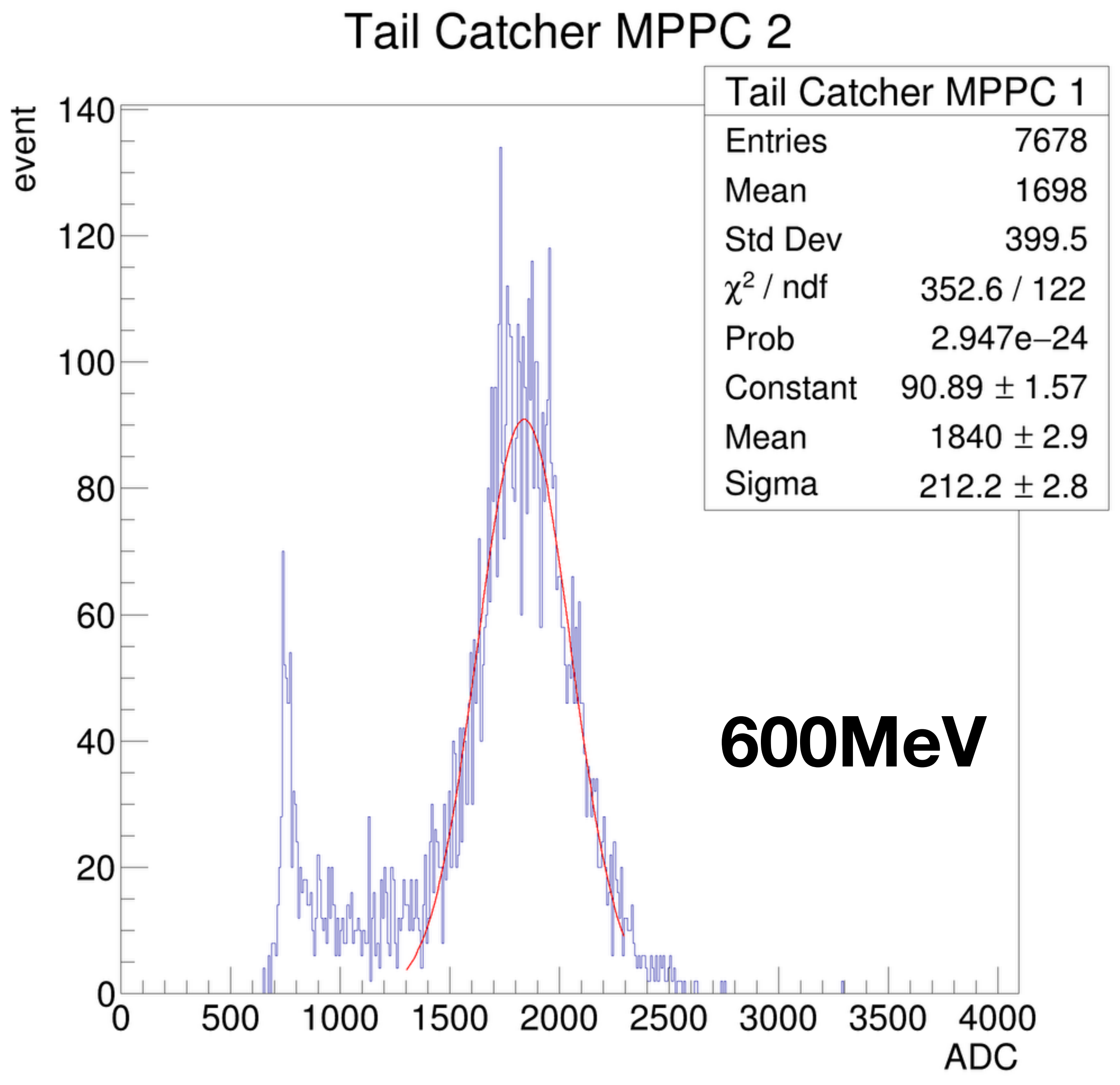
- We are developing and testing active absorber CAL
- The absorption layer of lead glass using Cherenkov light is working
- Scintillator strip layer is working as well
- A method to calibrate the lead glass block was developed
- Full detector performance will be examined necessary to calibrate all the channels and measure the energy resolution

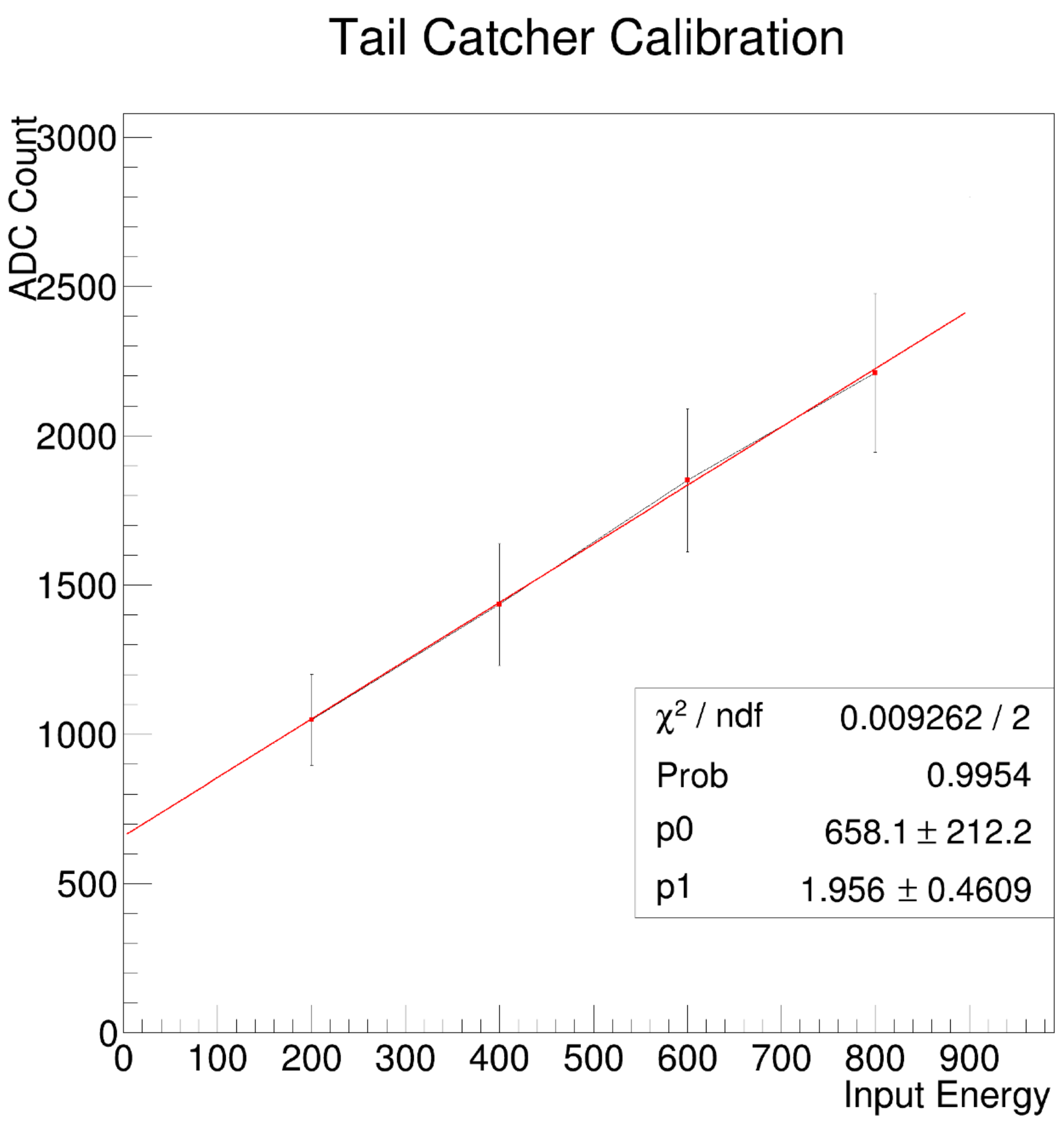
Backup

Energy calibration of Tail Catcher

- Injected positron beam from 200 to 800 MeV
- Correct ADC with beam energy
- response is Linear
- The problem is that the pedestal is around 760, but 0 MeV is 650, so there have a gap
- We have to investigate this phenomena.

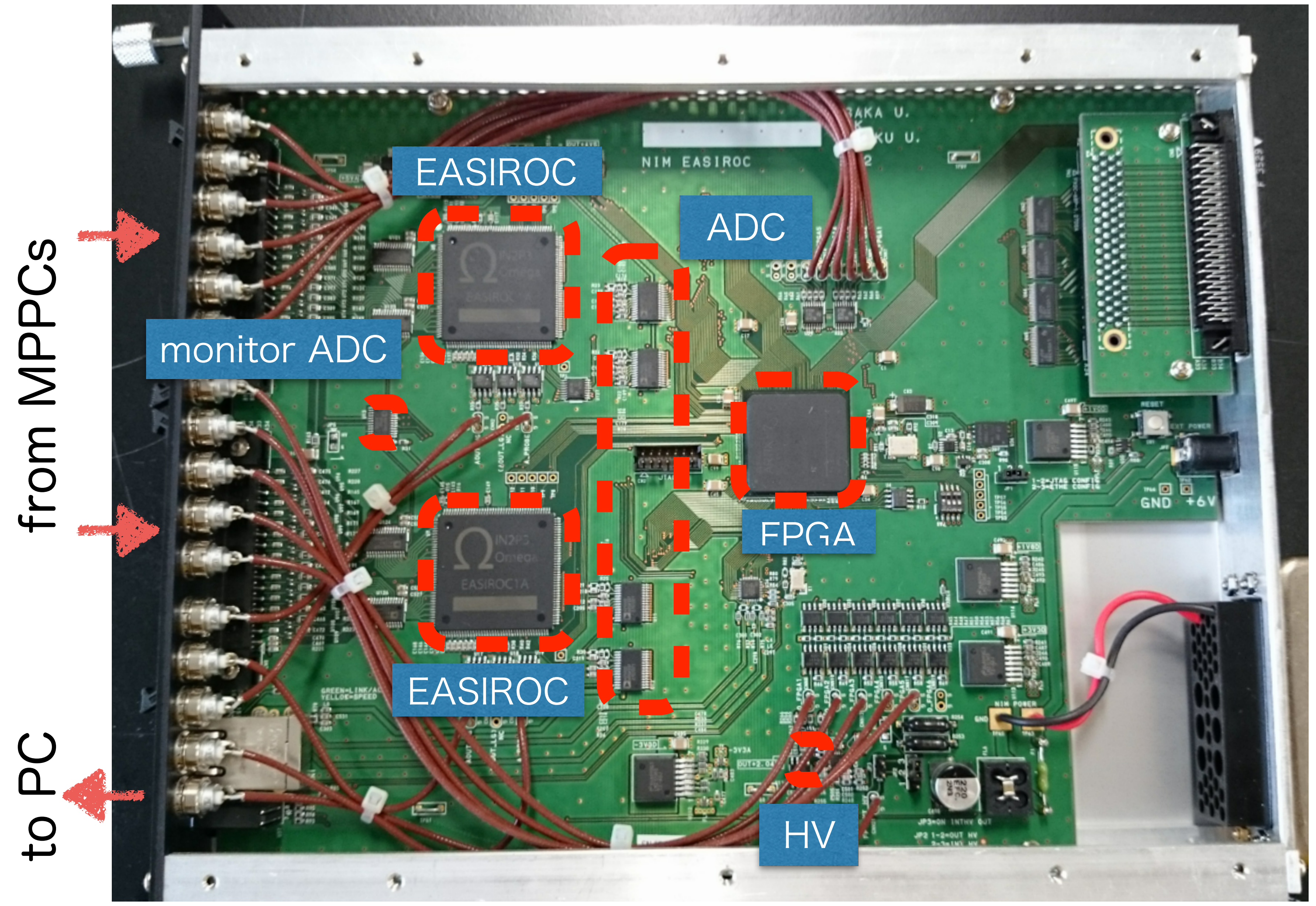






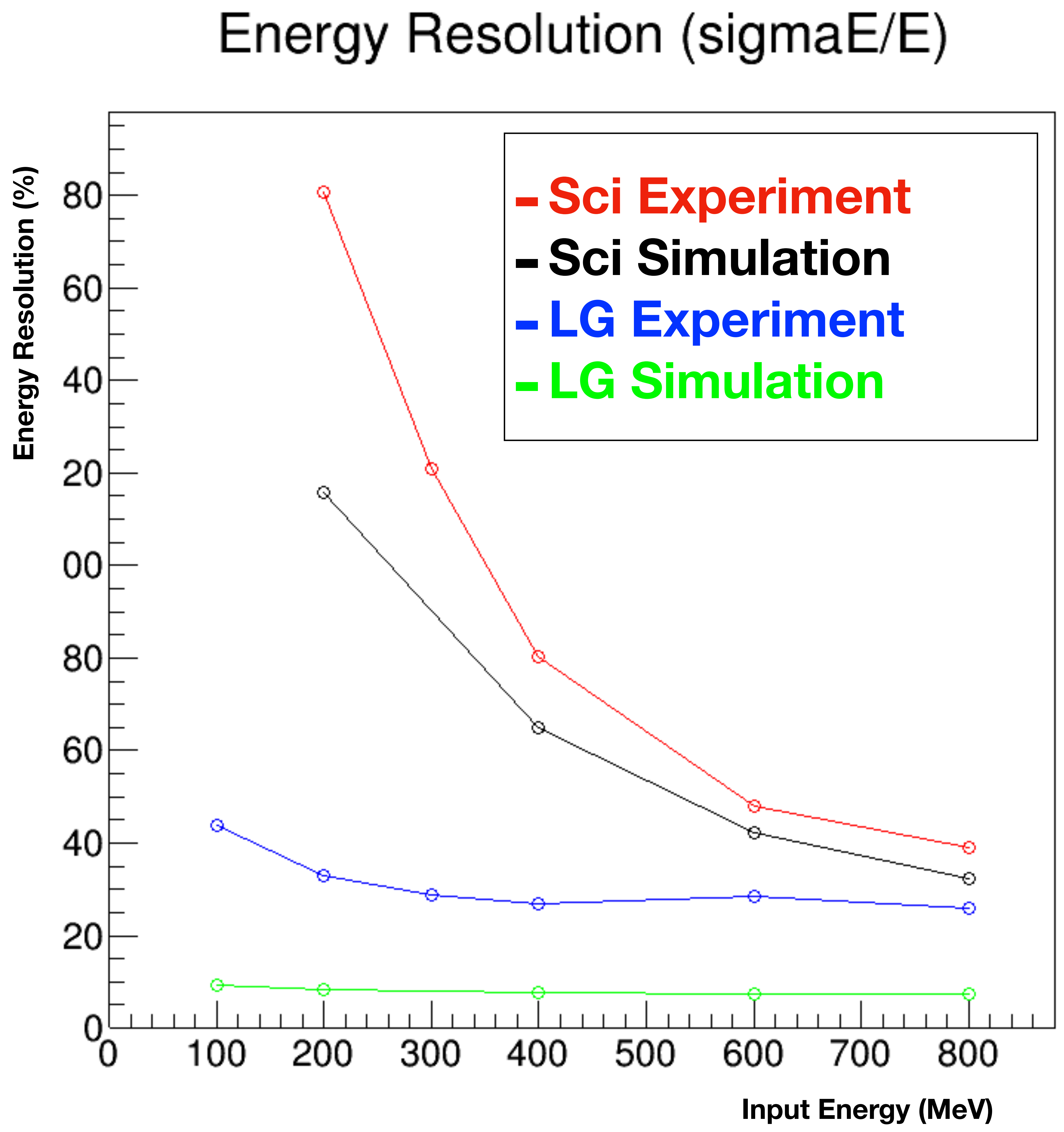
EASIROC Module

- 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



Strip scintillator Energy Resolution(2016)

- Simulation (black)
  - Geant4 Simulation
  - Use raw energy deposit in strip scintillators
  - Photon statistics are not simulated
  - Not correct energy leakage
- Experiment (red)
  - 0.3 MIP CUT
  - Not correct energy leakage
- Difference is smaller at higher energies

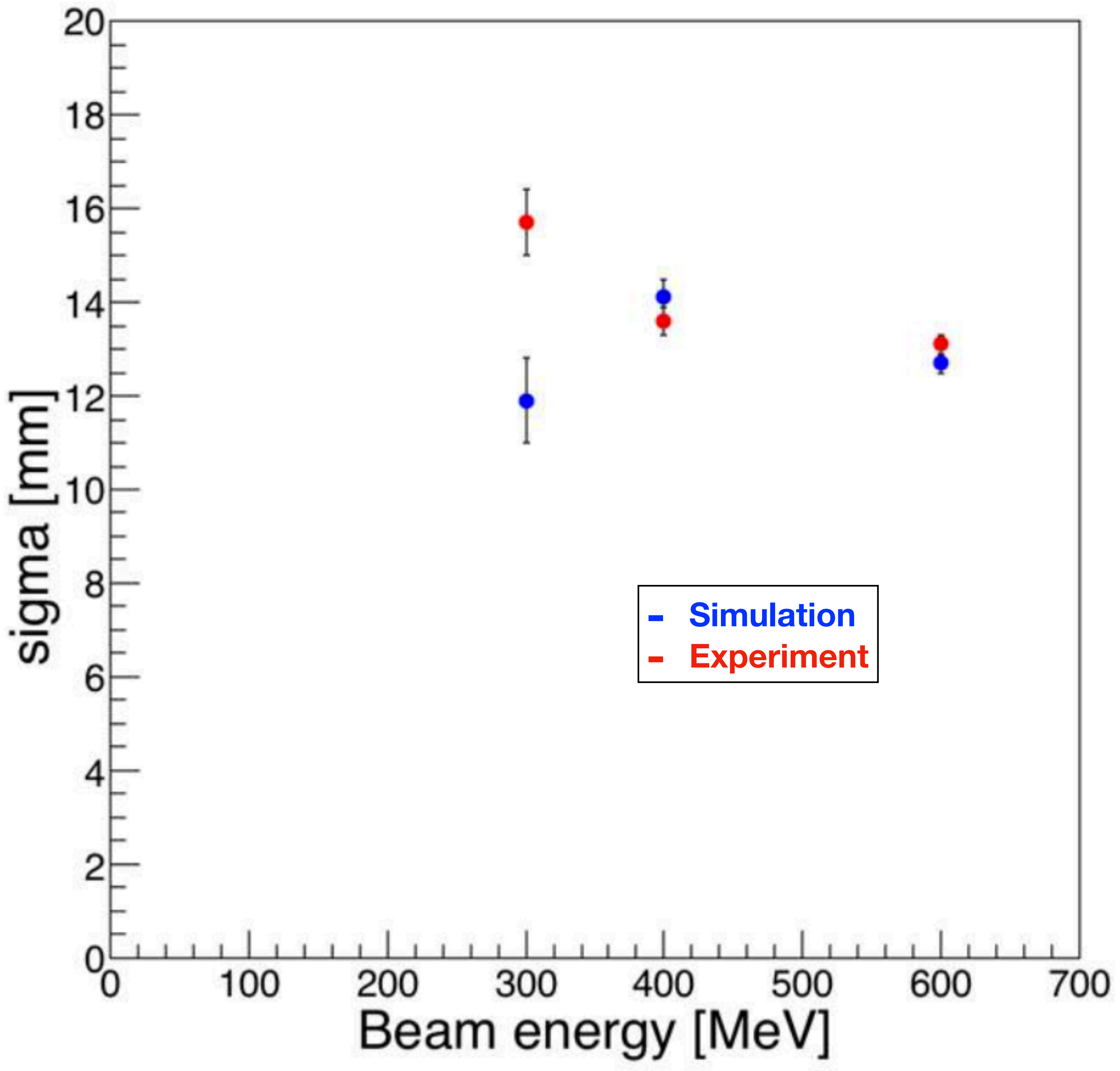


Parameter of Lead Glass

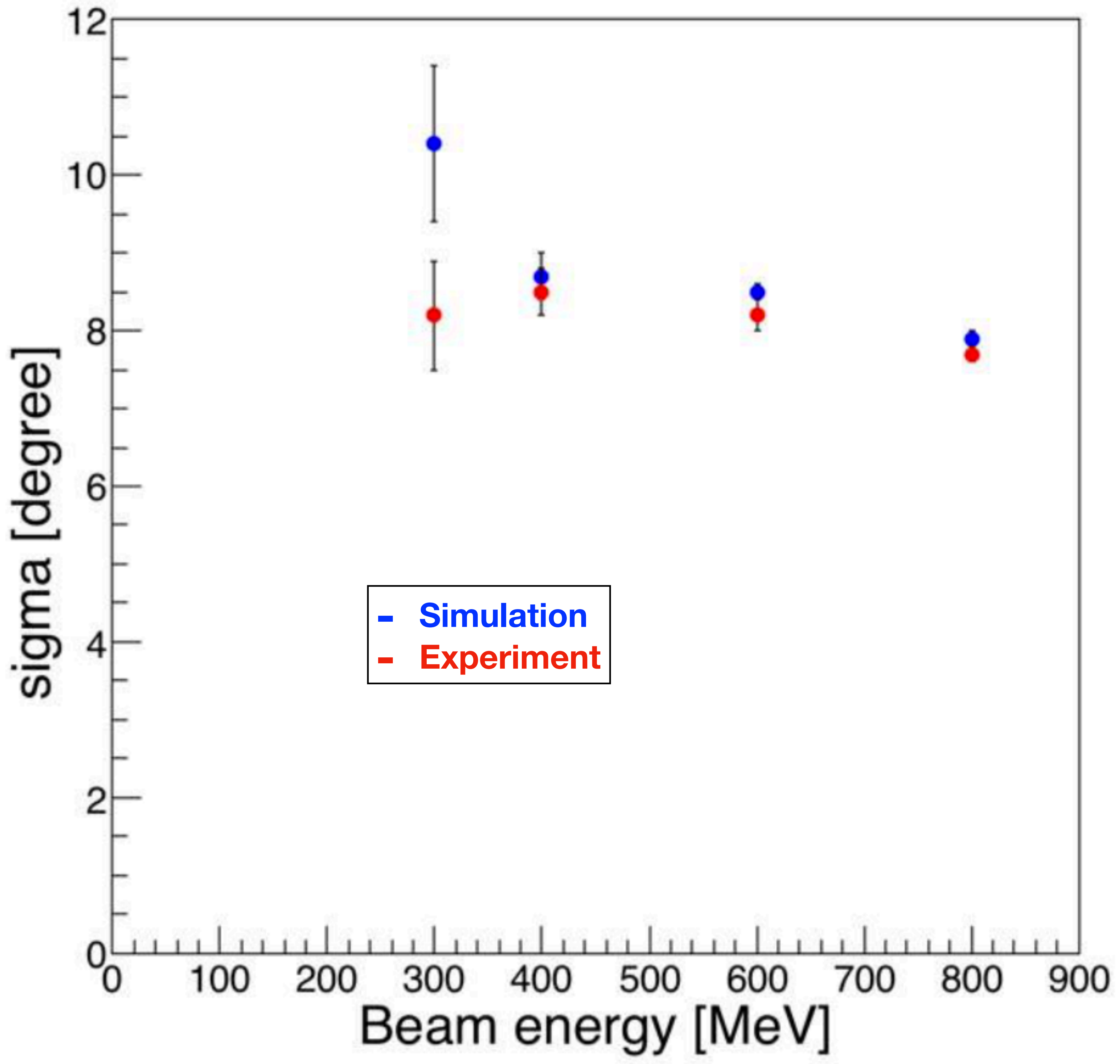
Chemical composition (wt%)	
SiO_2	27.3
PbO	70.9
K_2O	0.9
Na_2O	0.6
Sb_2O_2	0.3
Radiation length (cm)	1.7
Refractive index	1.8
Density (g/cm_3)	5.2
Critical energy (MeV)	12.6
Molière unit (X_0)	1.7

Position and angular resolution (simulation vs experiment)

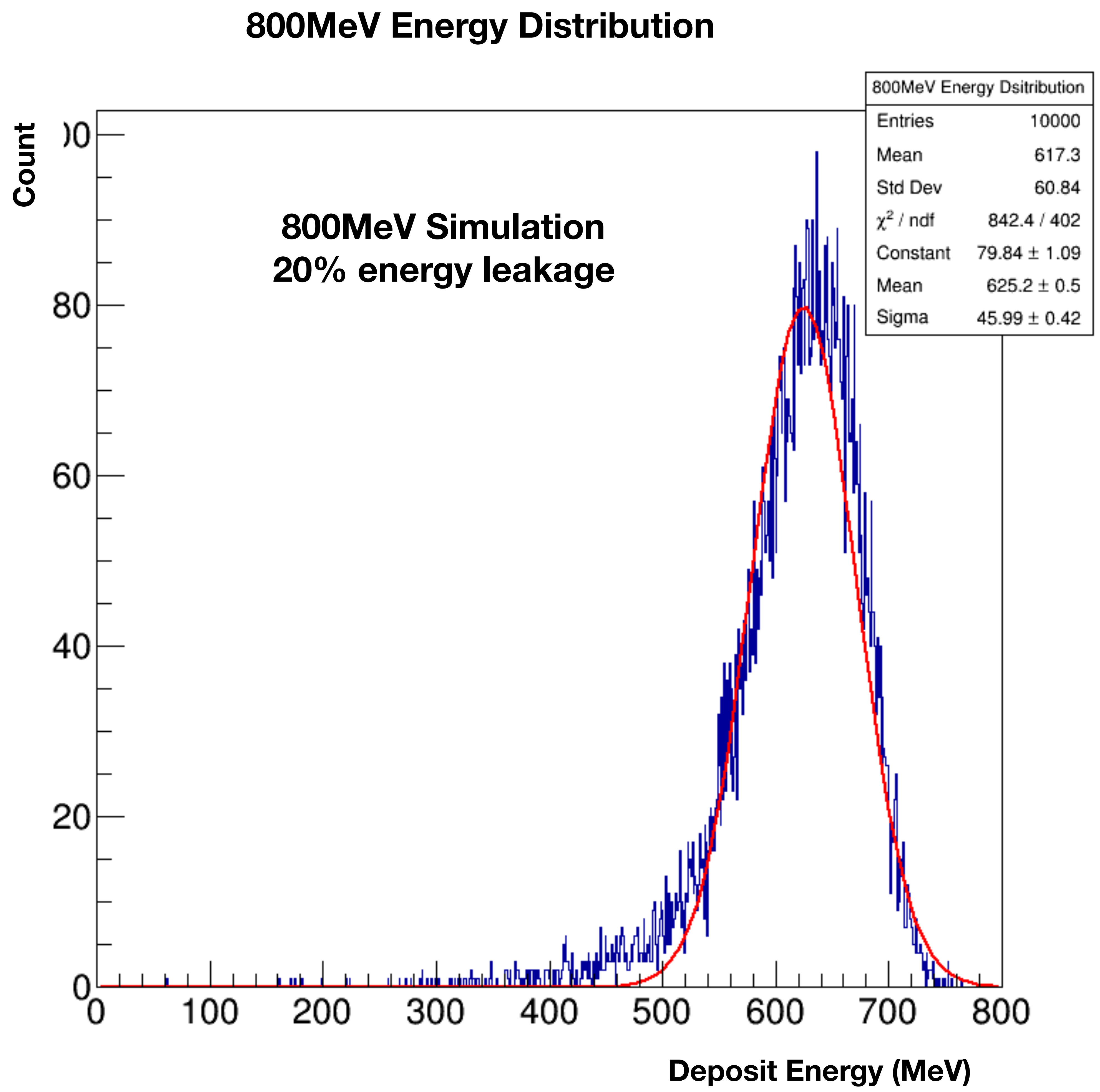
Position Resolution



Angular Resolution



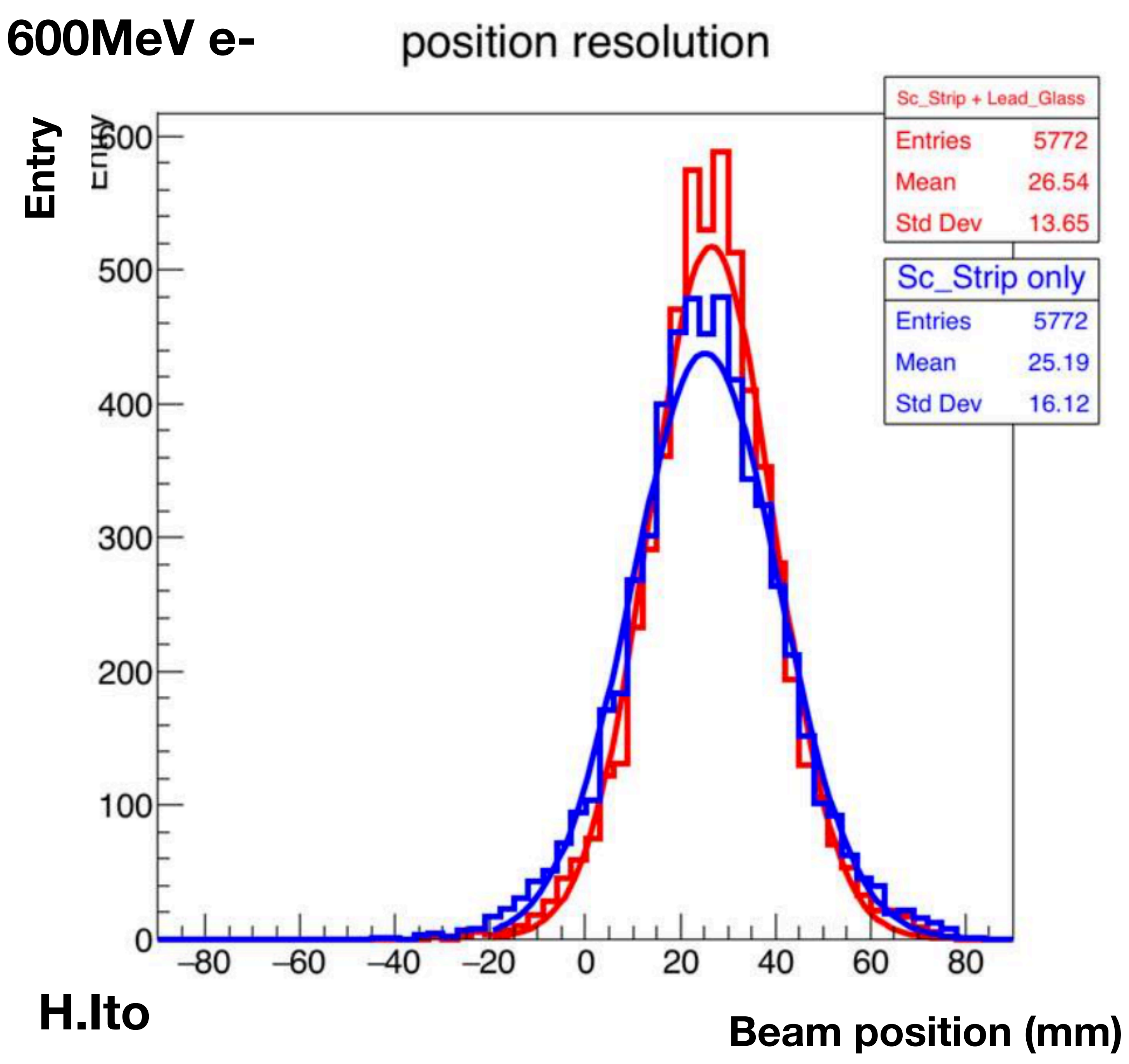
Lead glass energy resolution



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

600MeV e-



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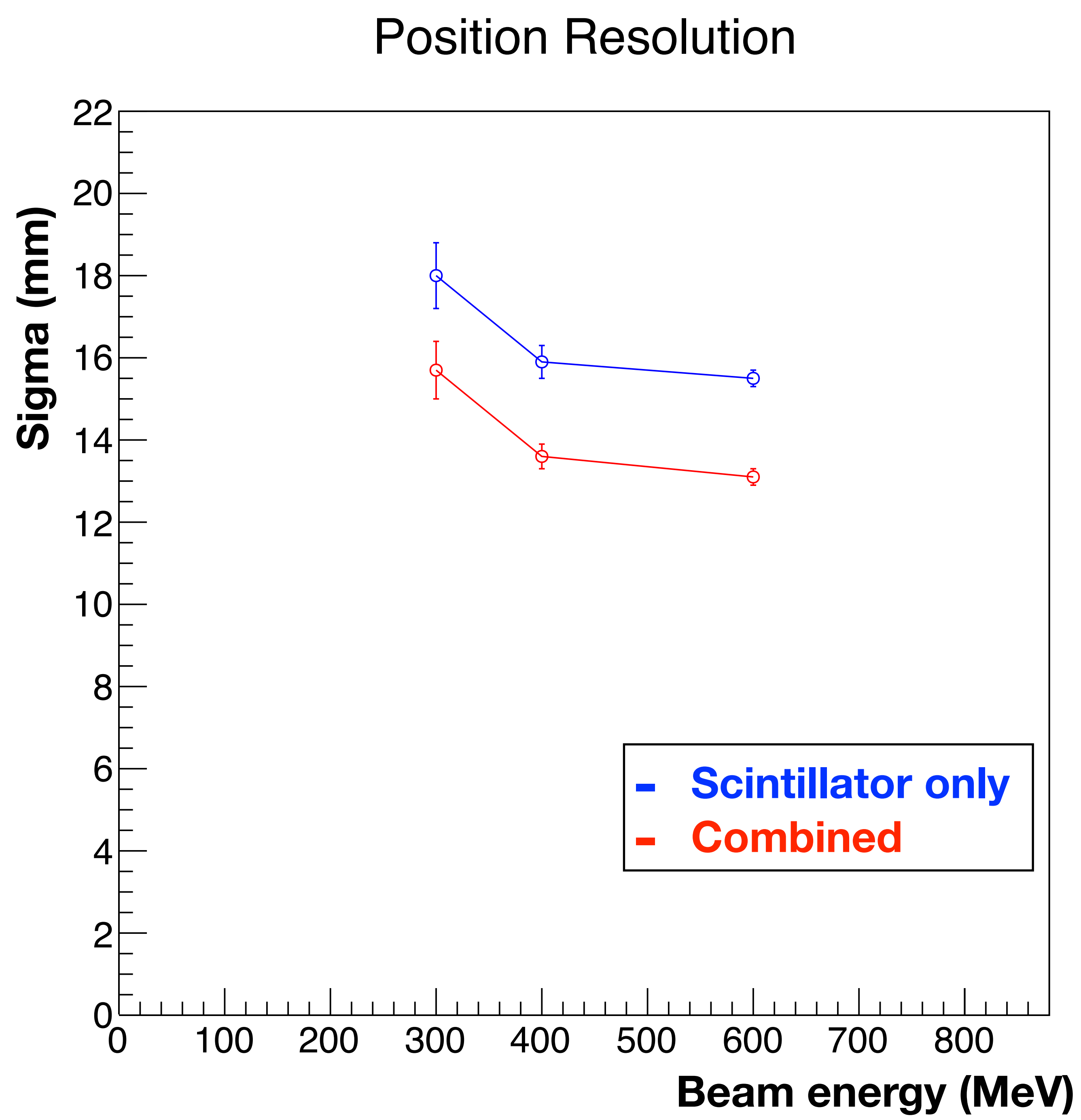

Angular Resolution

- 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