Performance of segmented lead glass absorber calorimeter prototype

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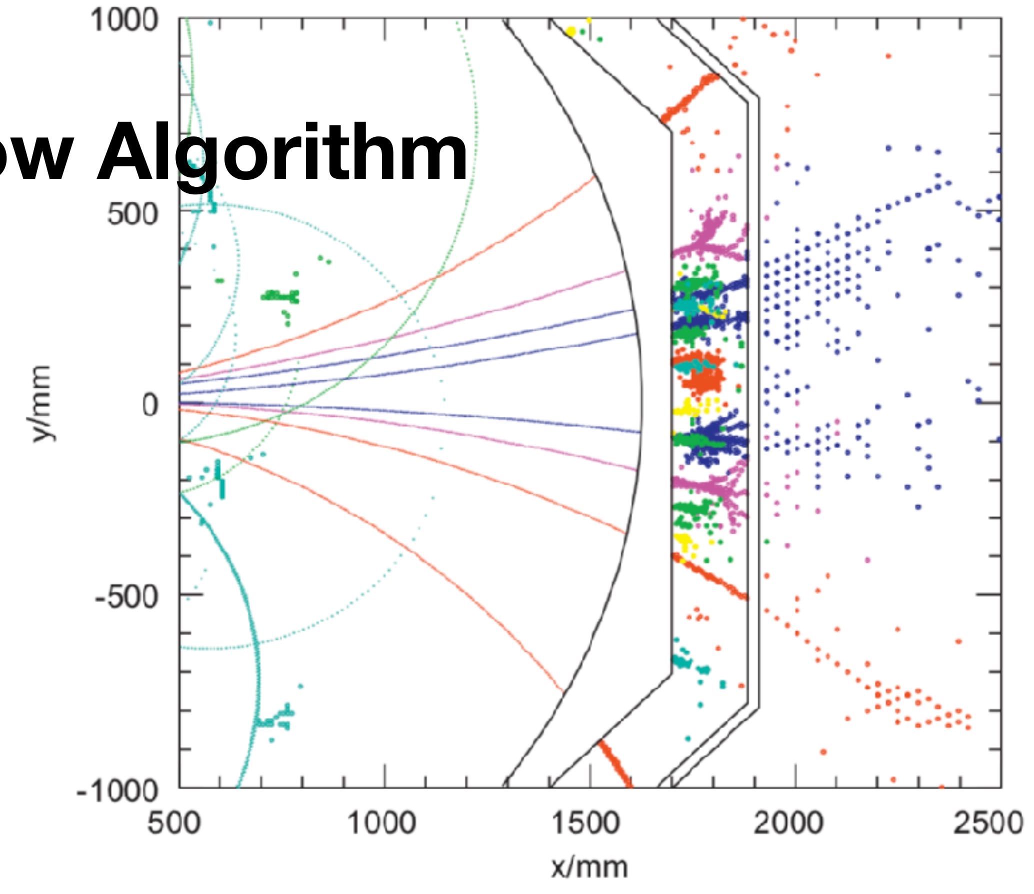
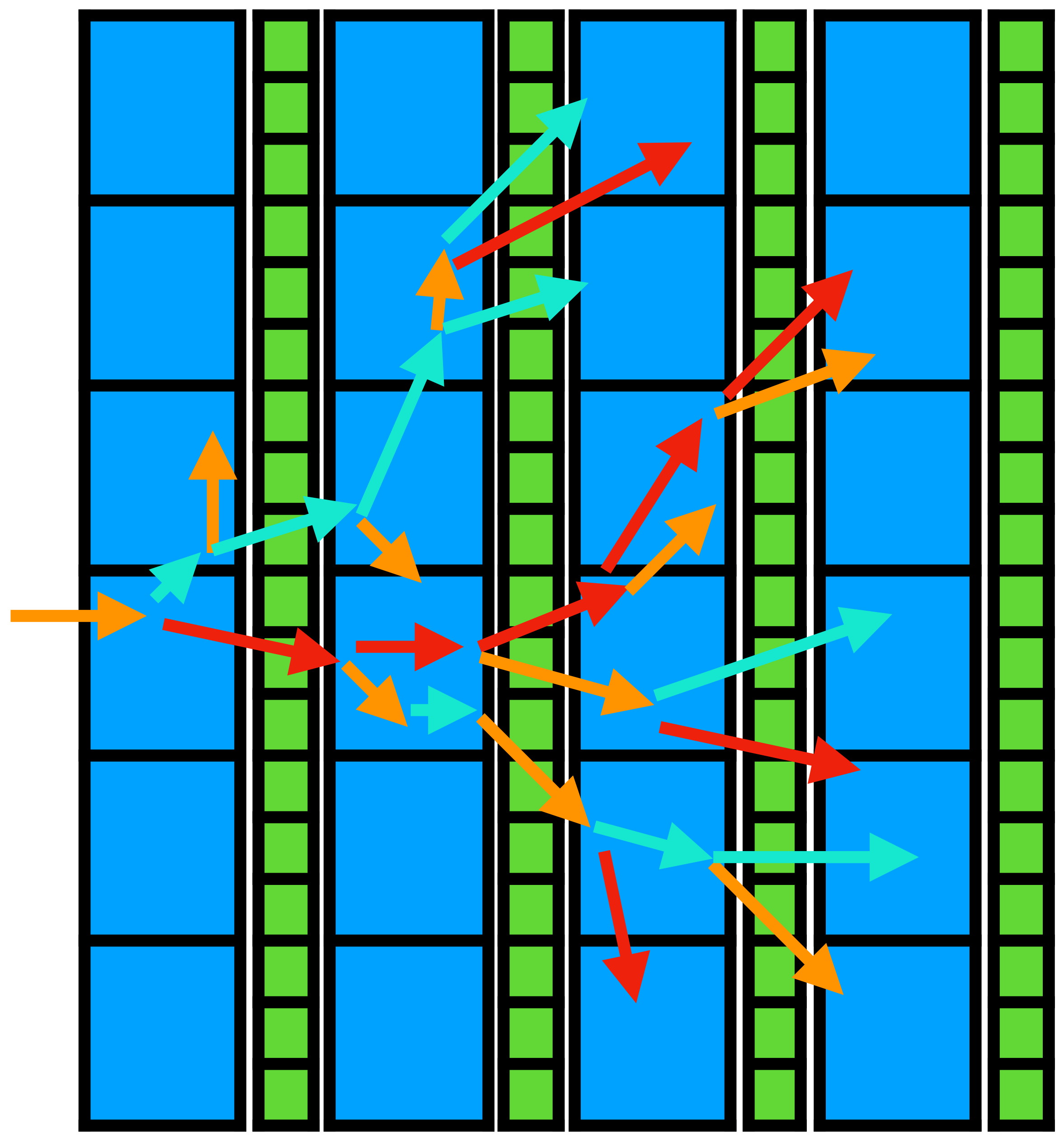
Segmented Active Absorver Calorimeter



Particle Flow Algorithm

- Improving calorimeter performance is necessary for future high-energy frontier collider experiments.
- Particle Flow Algorithm is indispensable for future experiments.
- To use PFA, a sampling calorimeter is required.
- If the energy of the absorber layer is taken into account, the energy resolution can be improved.
- The active absorption layer should be subdivided accordingly for PFA.
- Therefore, we considered Segmented Active Absorber Calorimeter



Energy Measurement: Absorber
Position Measurement: Detector

Segmented Lead Glass Absorber

- One of the active absorber materials is lead glass.

- The lead glass is transparent.
  -> Cherenkov light can be measured with an optical sensor.

- MPPC is a thin photosensor.
  -> It can reduce dead volume.
  -> We use 3x3mm^2 sensor(S13360-3050CS, S13360-3075CS).

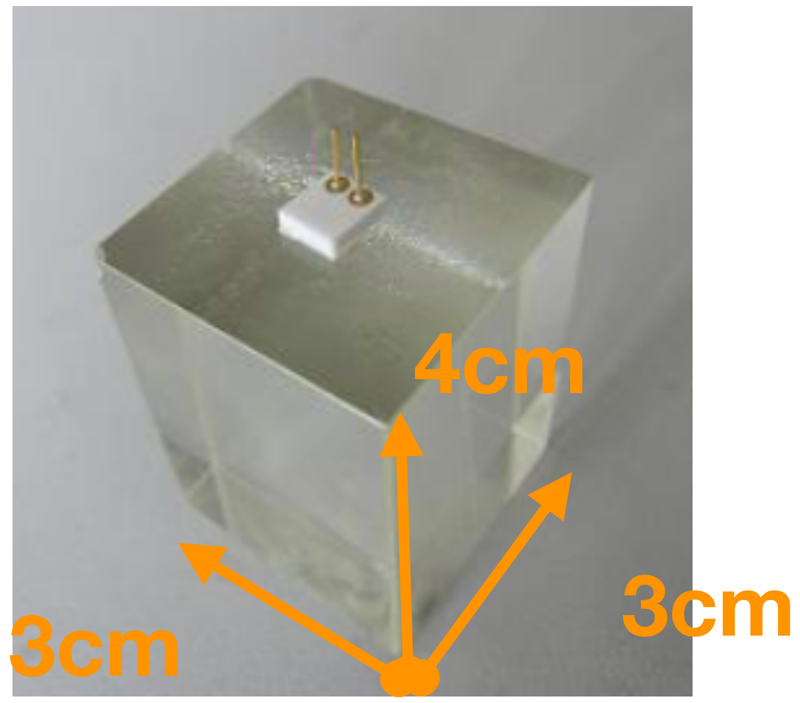
- Segmentation is necessary for PFA.
  -> 3 x 3 x 4 cm^3 size lead glass block

- To read out each lead glass independently for PFA
  -> Each block was enveloped with reflector.

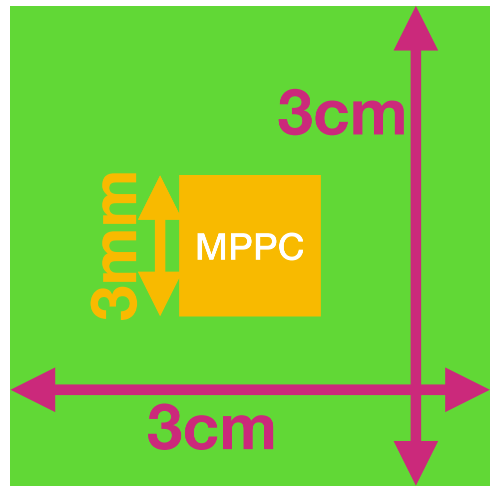
- This one lead glass has 2.4X_0 (4cm thickness)
  (lead glass X_0 = 1.7 cm)

- 1 layer consists of 9 lead glass block array.
  (This array is enclosed by a 5 mm stainless steel case.

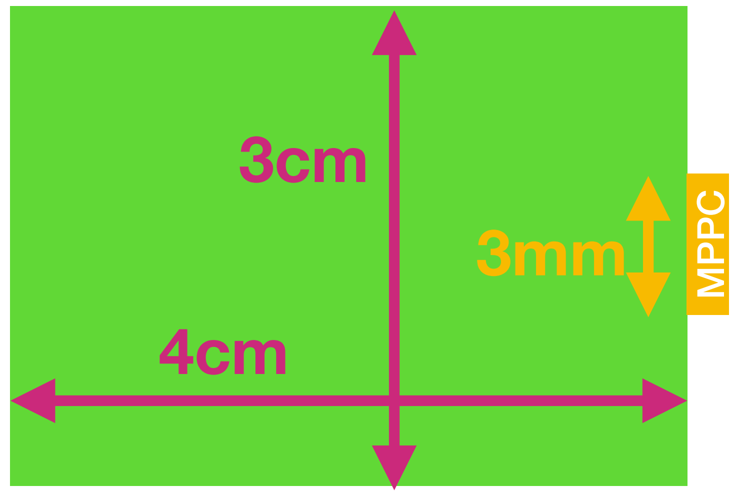
- We manufactured 3 layers for the prototype.



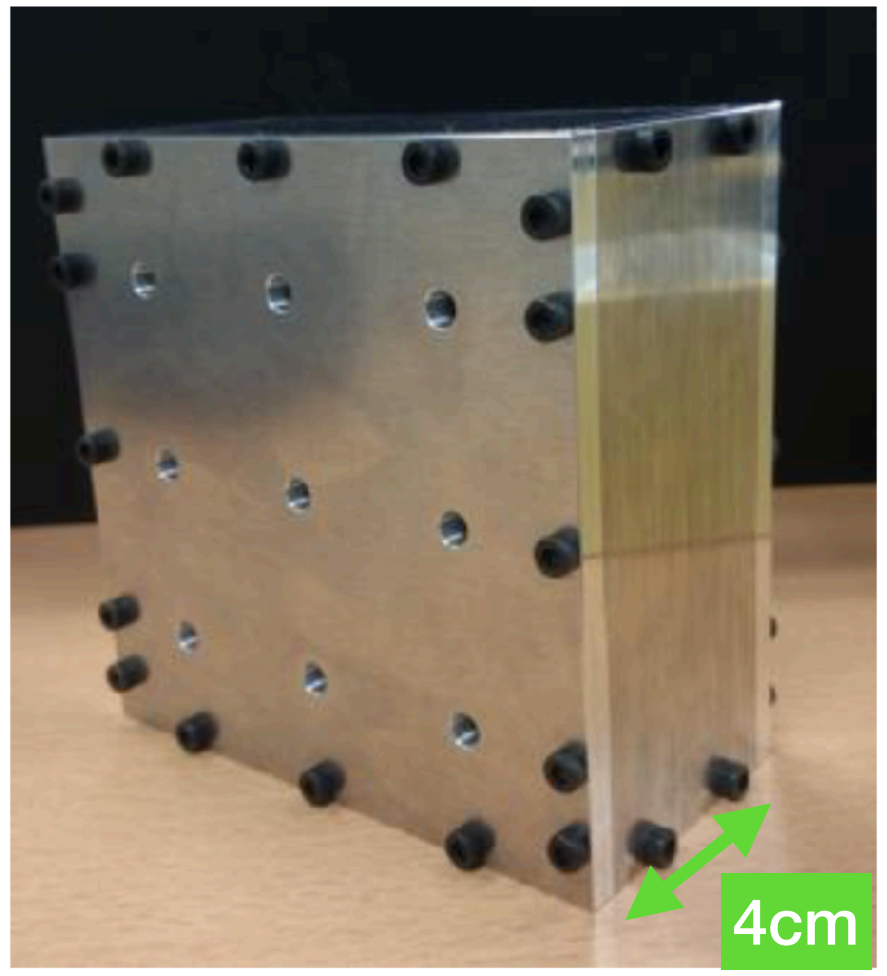
Lead glass block with optical sensor (MPPC)



Backend view



Top view

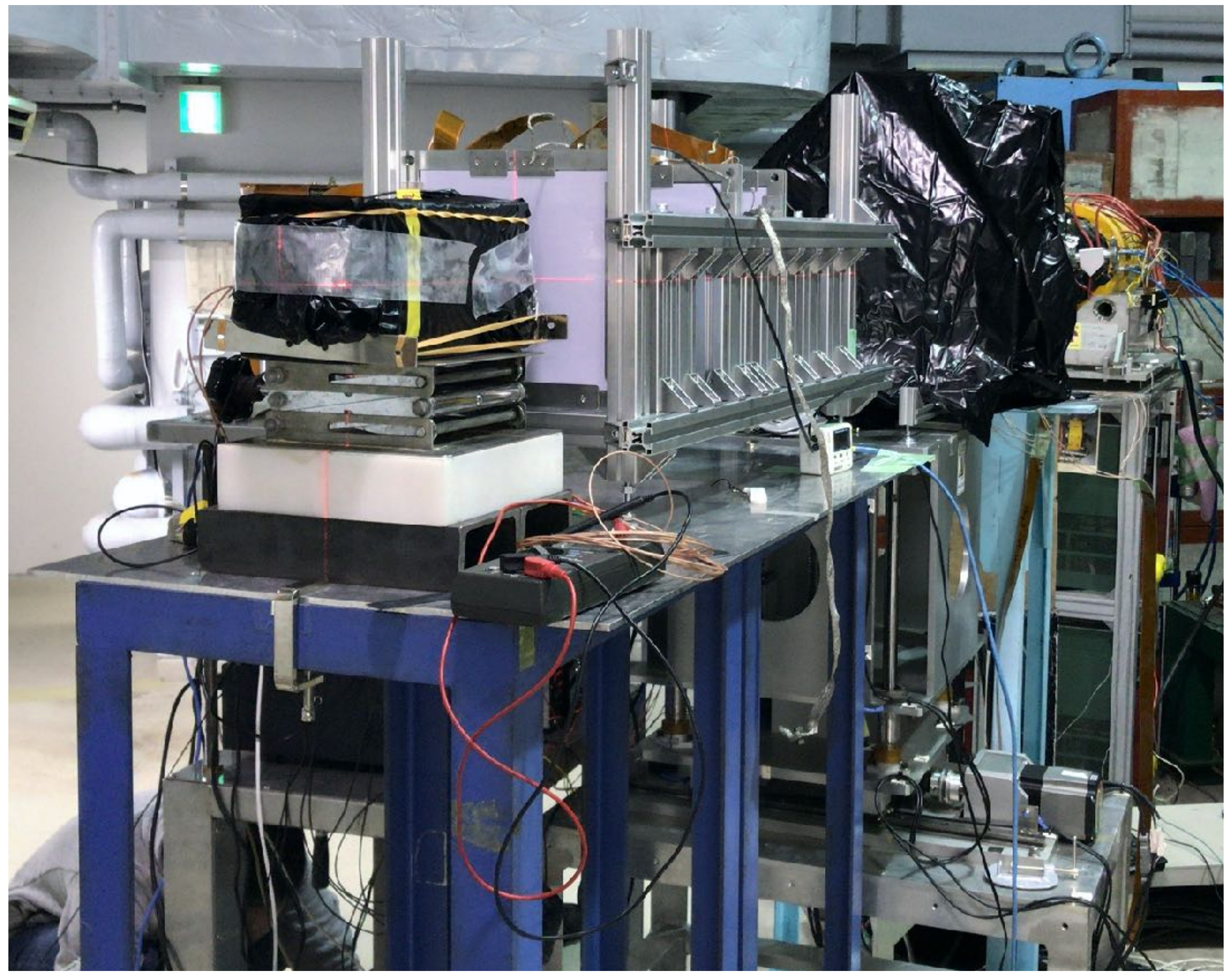


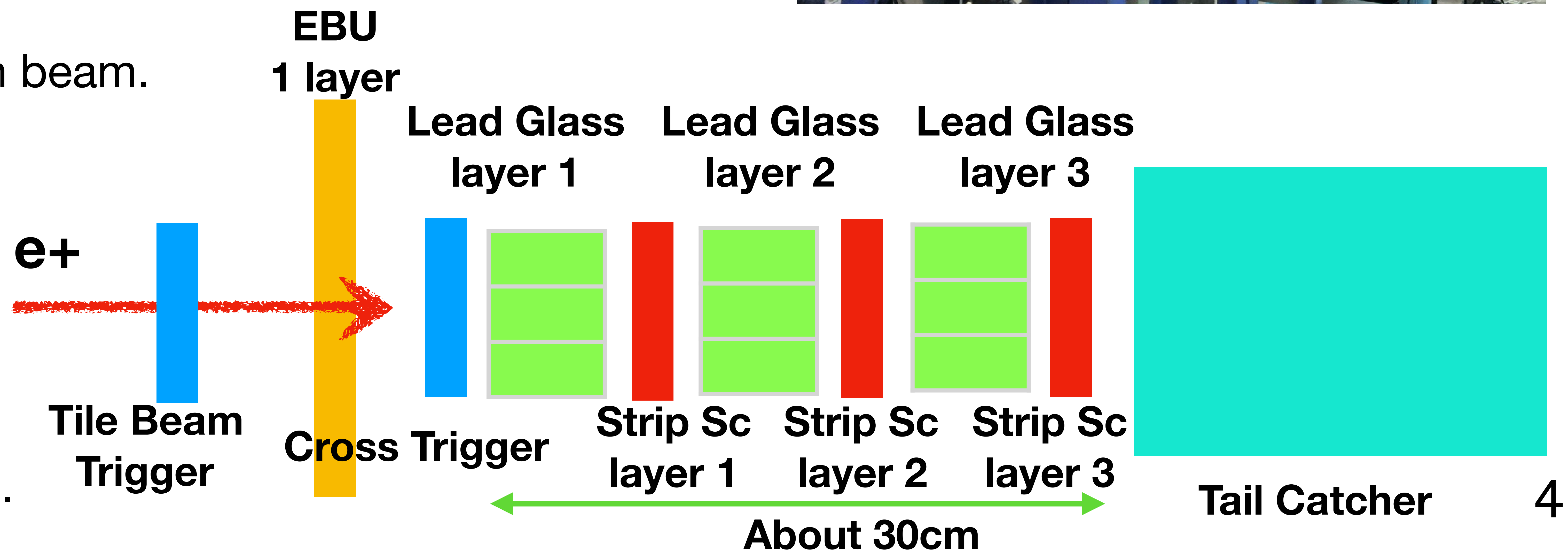
Active Absorber Layer


Lead Glass blocks Array

Prototype of active absorber ECAL

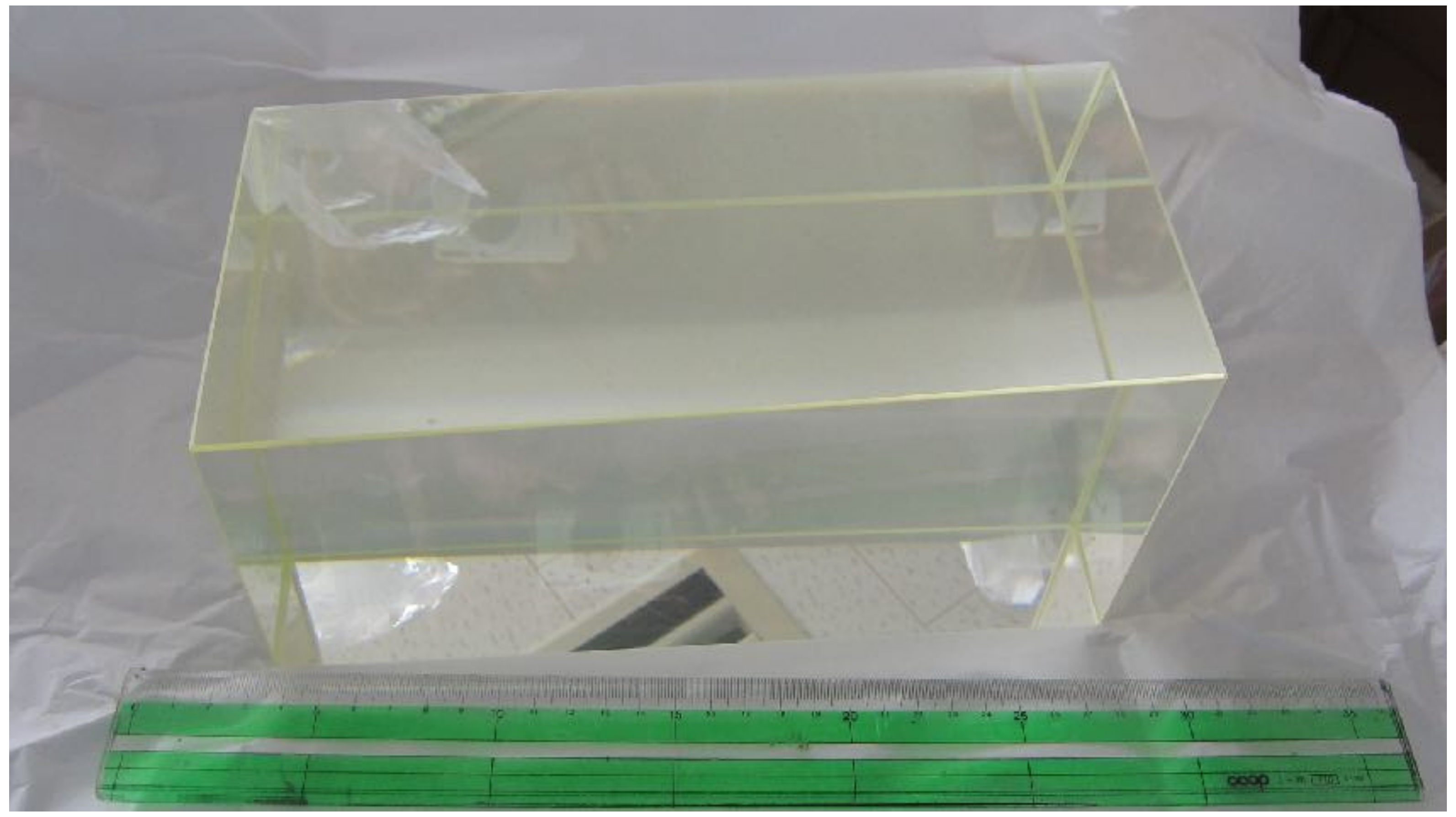
- We manufactured 3 layers sampling calorimeter as an active absorber ECAL.
  - **Active Absorber layer**: Segmented lead glasses with MPPCs
  - **Fine granulated detection layer**: Strip scintillators
  - **Tail catcher**: A large lead glass
- We performed test beam at ELPH at Tohoku University (ELPH: Research Center for ELectron PHoton Science
- Injection from 100MeV to 800MeV positron beam.
- The tests were performed in this order.
  - Tail catcher calibration
  - Lead glass block calibration
  - Entire prototype performance evaluation.



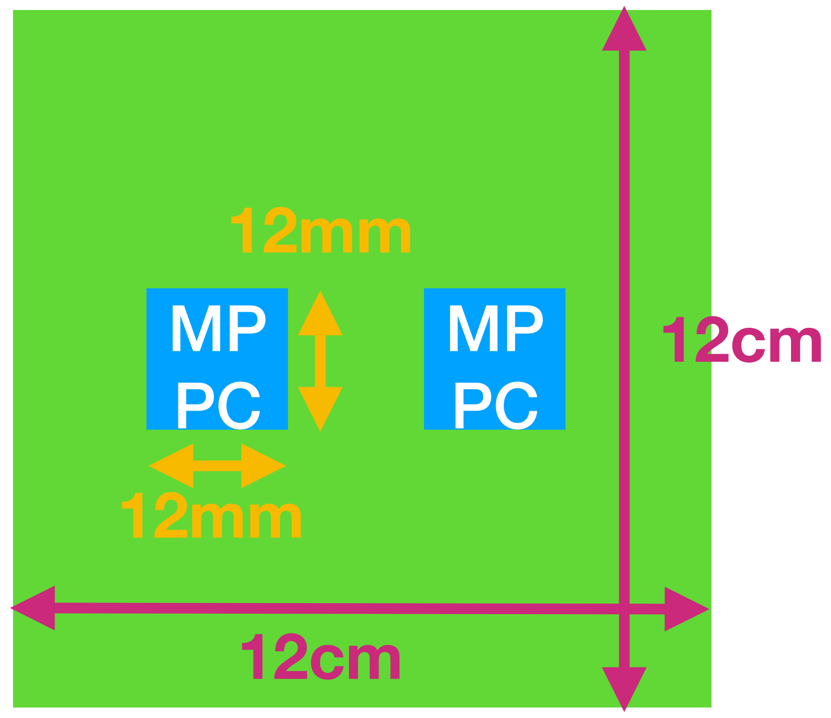


Tail Catcher

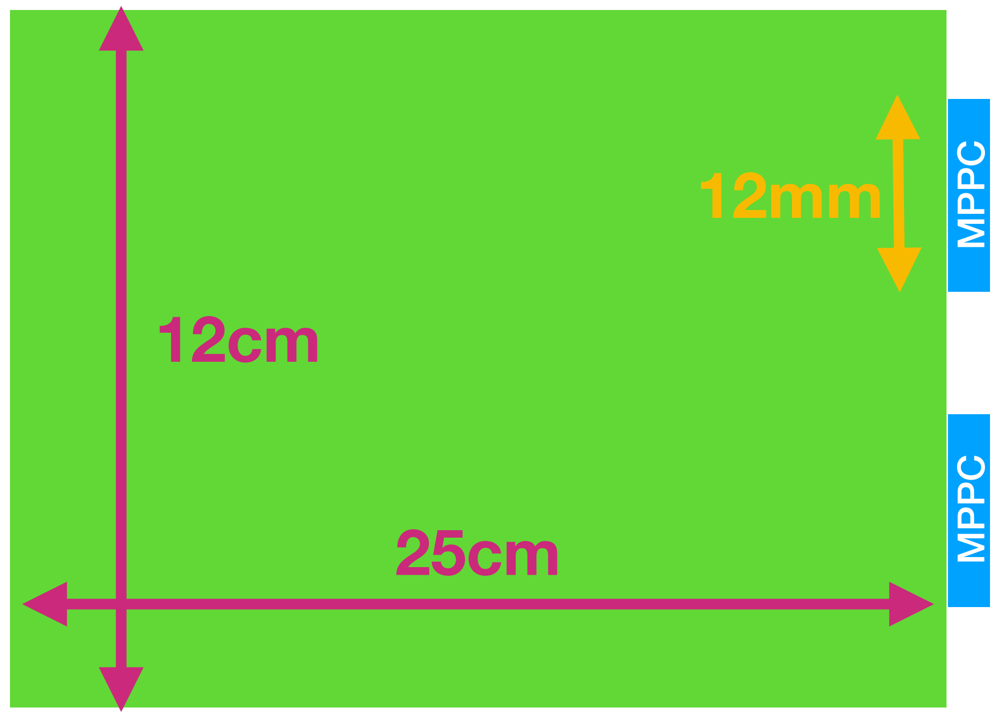
- Put most downstream at the beamline, to detect the leakage energy.
- Single large lead glass bock (12x12x25cm^3) (14.7X_0)
- The optical readout is done by two MPPCs of 12 x12 mm^2.
- Two MPPCs are glued directory on the backend of the tail catcher.
- Area radio is 100:1 (Lead glass surface:MPPC)
- Energy calibration with the beam.



12x12x25cm^3 lead glass block



Backend view

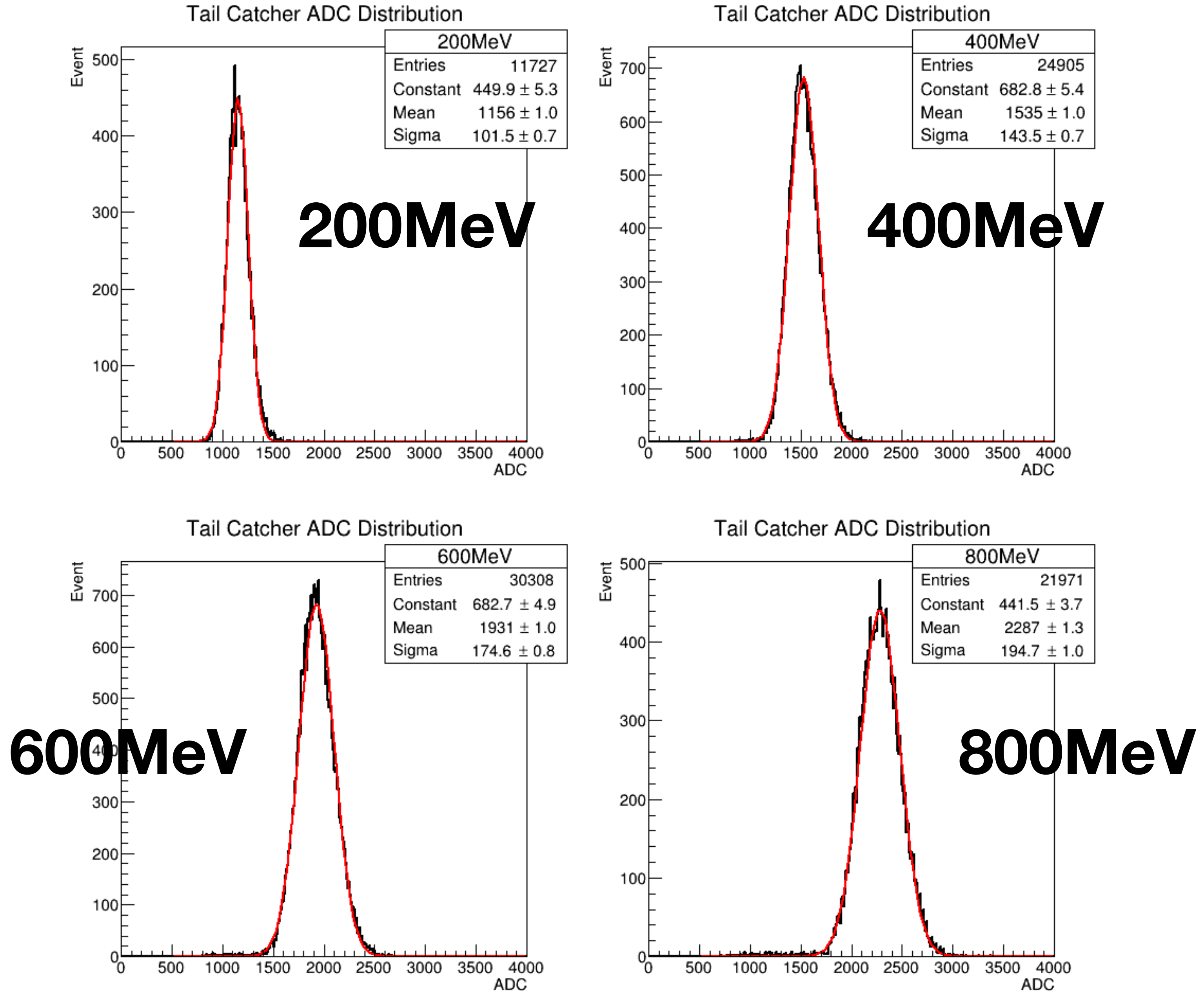


Top view

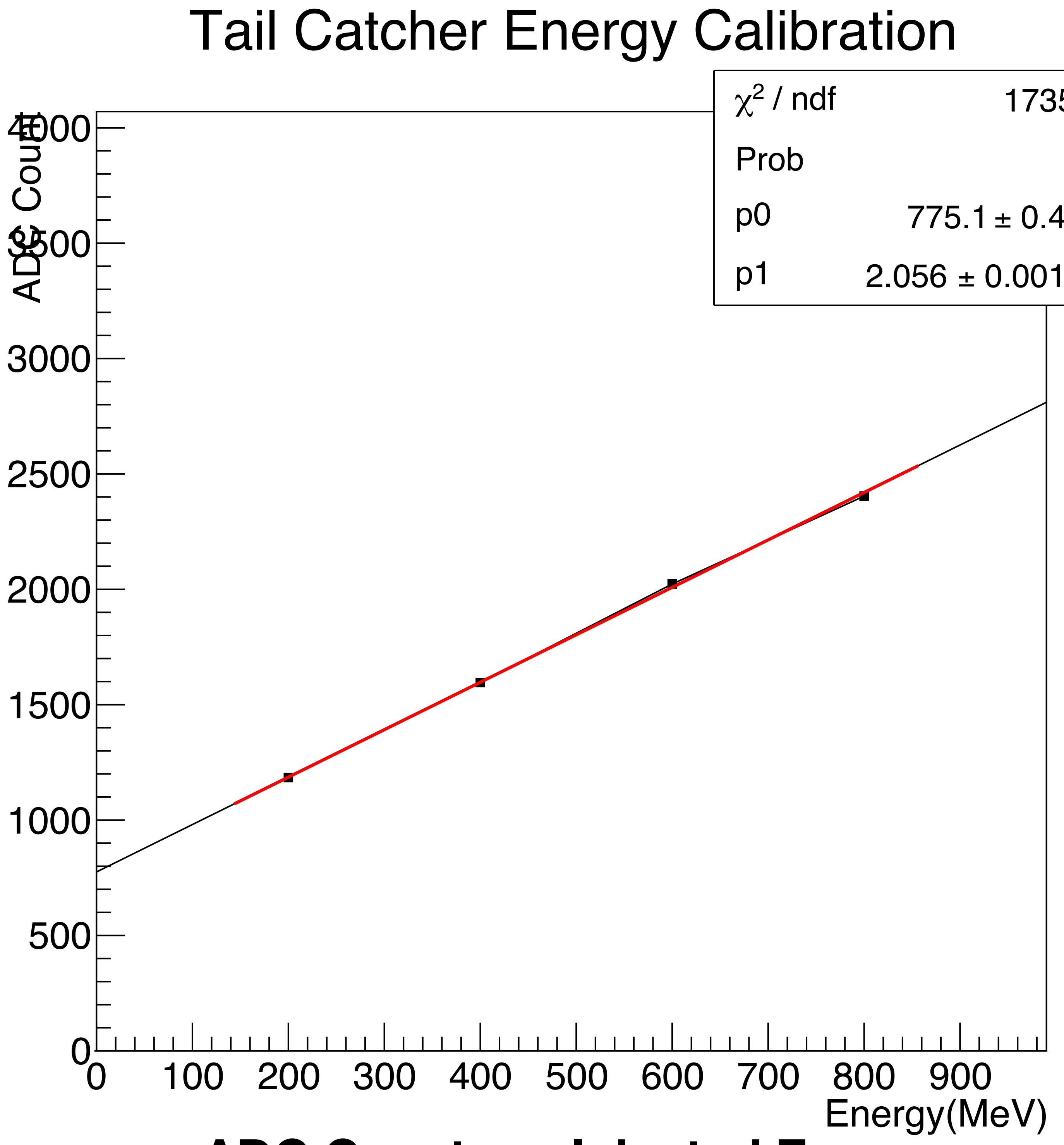
Tail Catcher

Tail Catcher energy calibration and resolution

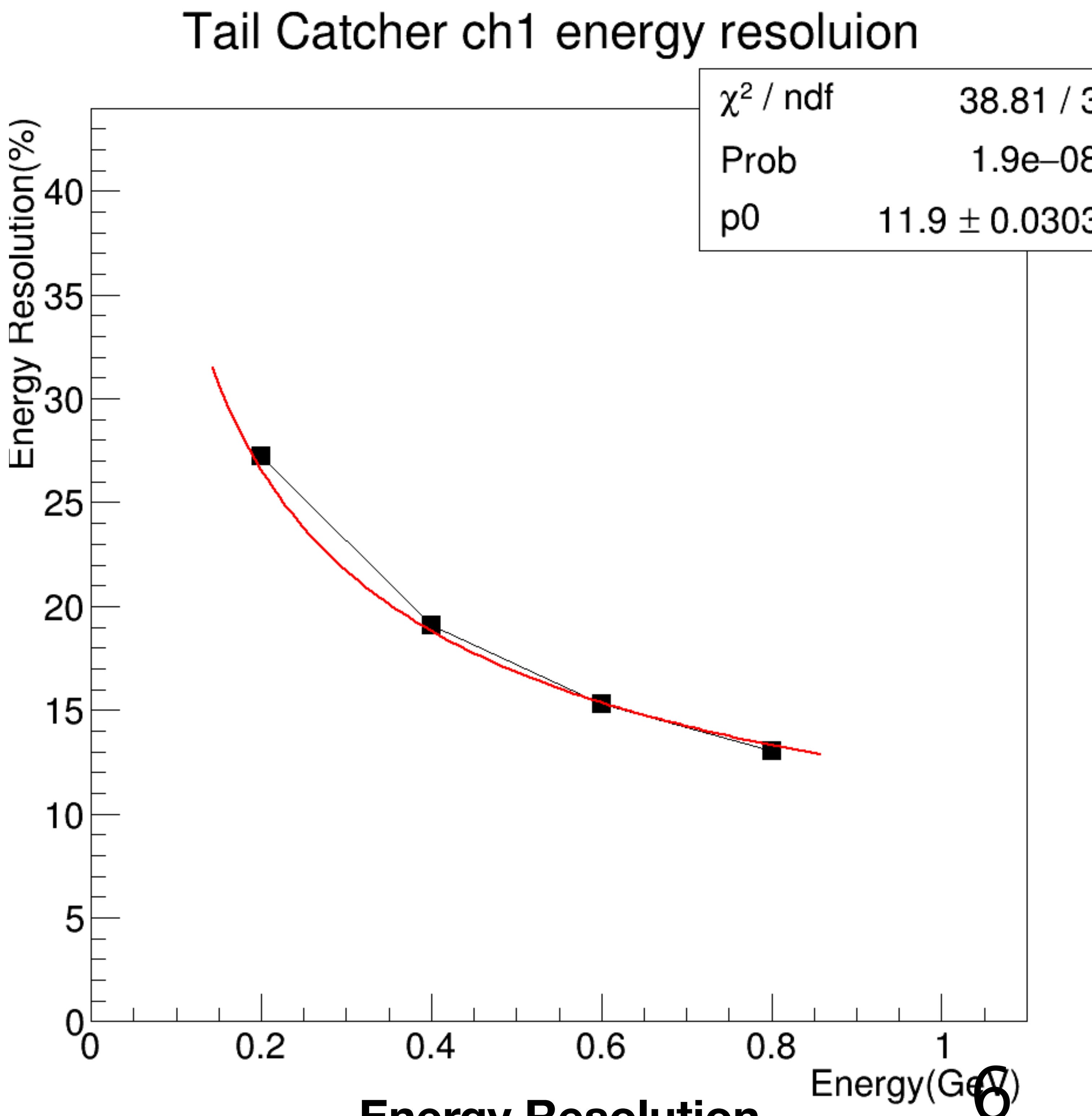
- First, we calibrated the tail catcher with an MPPC of 12 x 12 mm^2.
- The gaussian response was measured with several beam energies.
- A sufficiently linear response to the injected energy was confirmed.
- The Energy resolution of σ/E is fitted with $1/\sqrt{E}$.
- Tail catcher energy resolution resulted in $12\%/\sqrt{E}$.



ADC Distribution of e+ injected



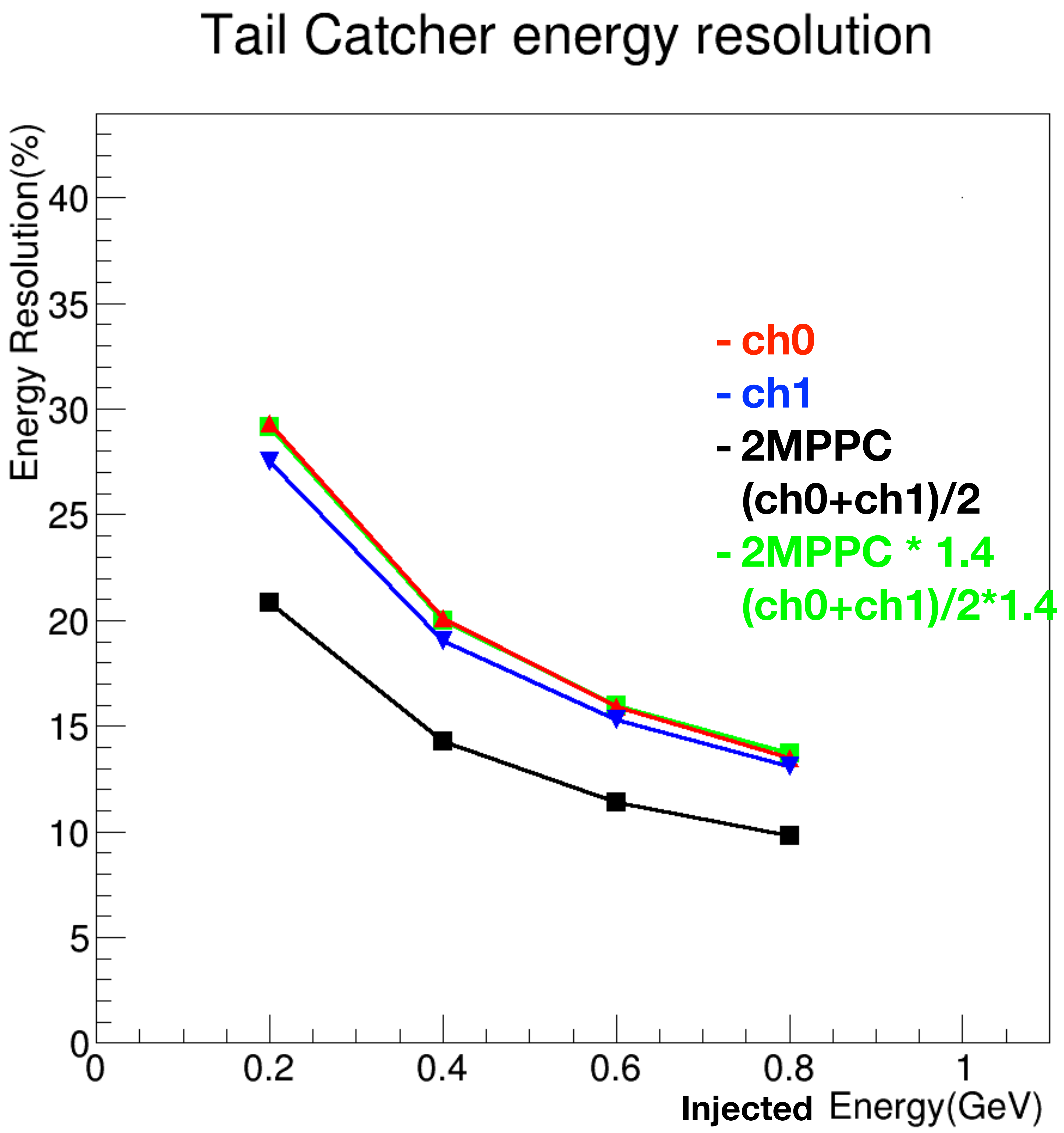
ADC Count v.s. Injected Energy



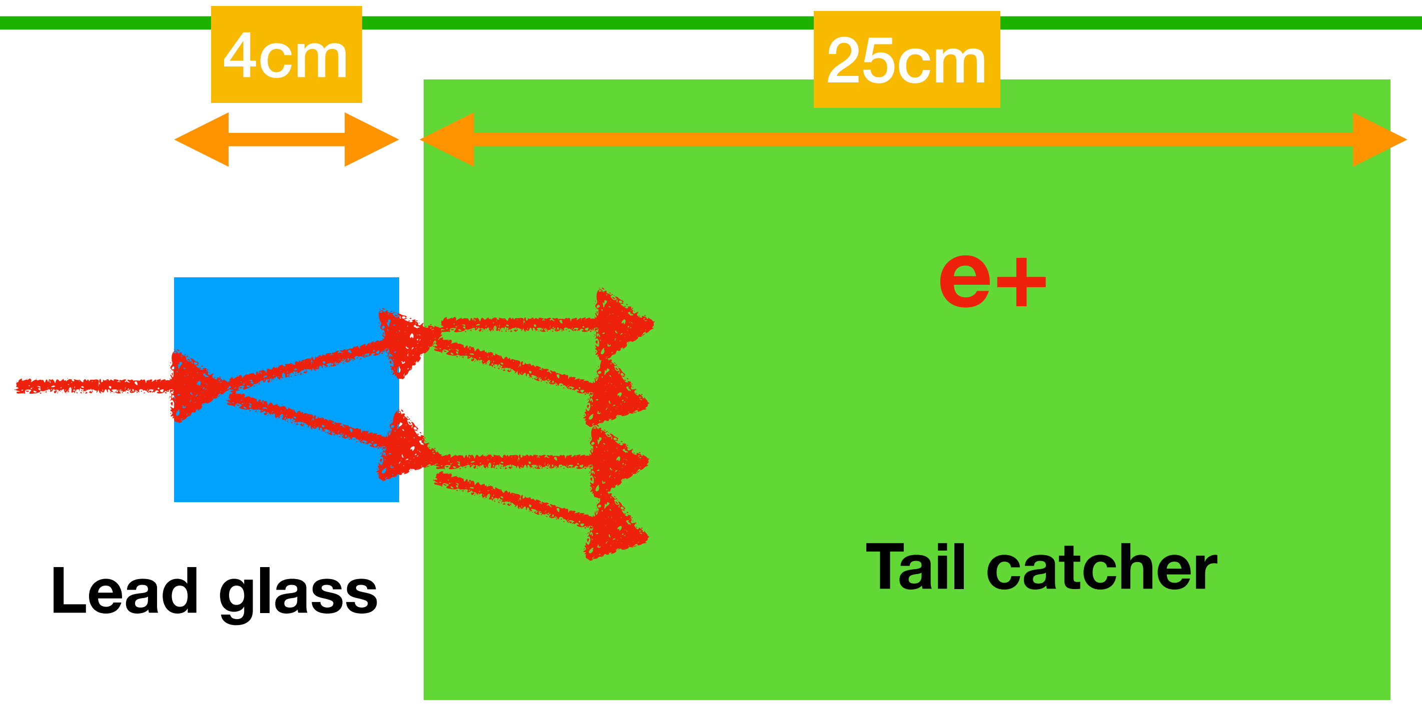
Energy Resolution

Effect of photon statics to energy resolution

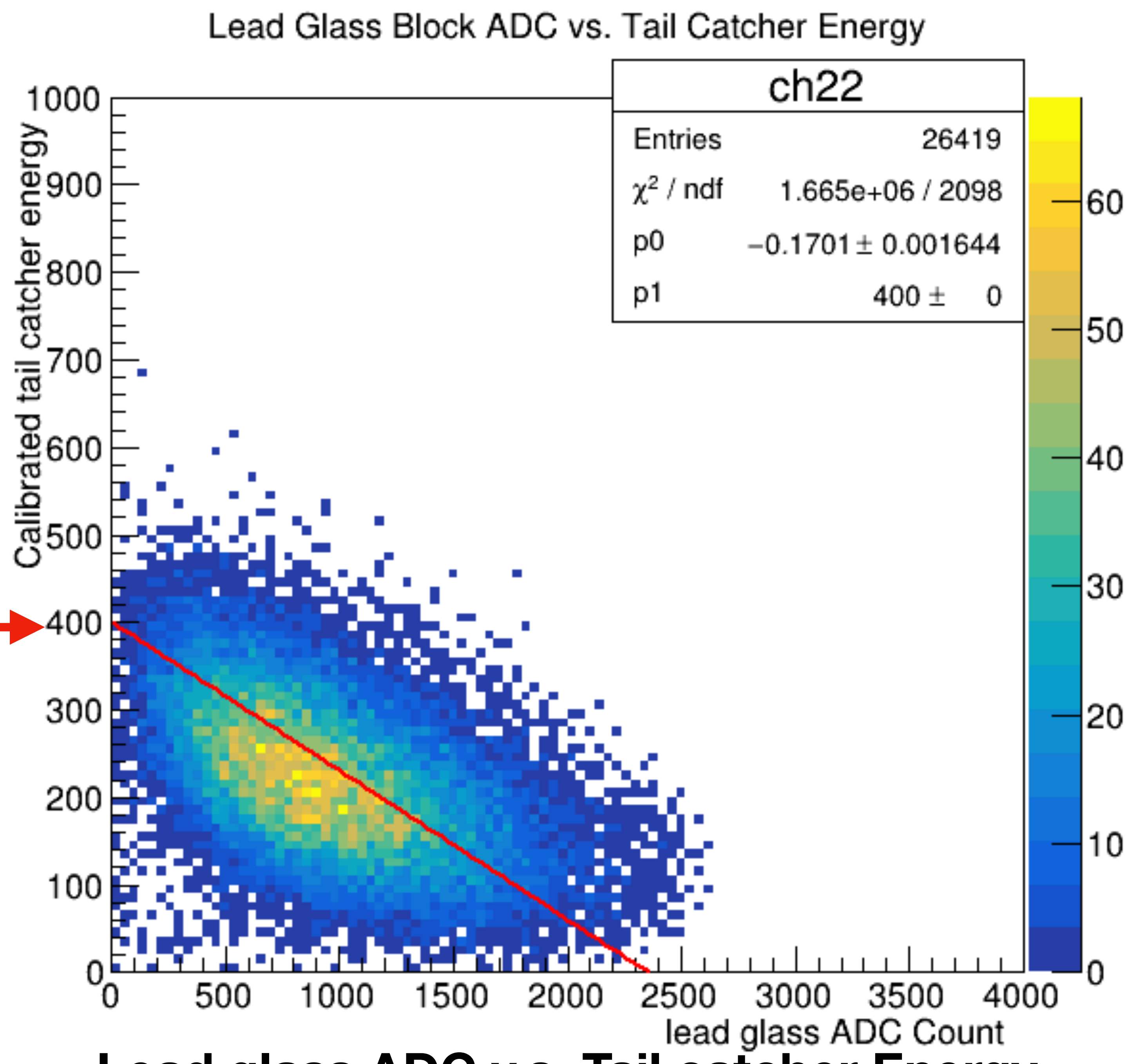
- Tail catcher energy resolution is about $12\%/\sqrt{E}$
- This resolution comes from photon statics.
- The tail catcher surface is 12x12cm^2 but MPPC size is 1.2x1.2cm^2(1/100)
- The tail catcher has 2 same MPPCs, we can estimate this size effect.
- Using 2 MPPCs, the number of a detected photons is two times bigger.
  -> The resolution is expected to be improved by a factor of $\sqrt{2}$.
  -> This is consistent with the experimental results.
- The small lead glass blocks are also suffering from the photon statistic effect. (3x3cm^2 : 3x3mm^2 -> 100:1)
- It also affects the energy resolution of the entire calorimeter.
- We need to simulate to estimate the photon statistic effect.



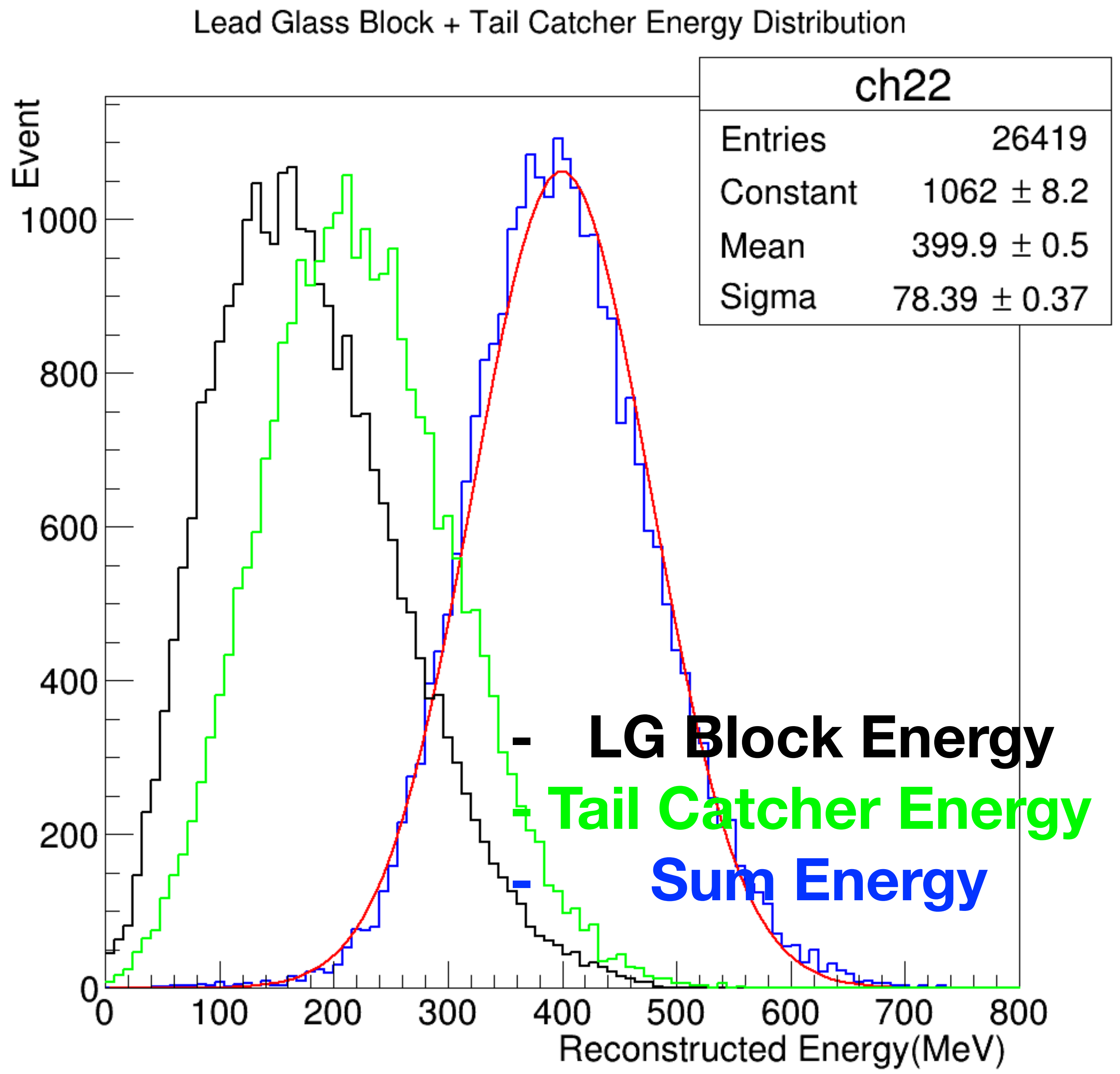
Energy calibration of lead glass block



- Calibration of each small lead glass blocks.
- Since the single block is small and energy leaks.
  -> Measurement was performed with a tail catcher.
- We did calibrate all the lead glass blocks at 400MeV positron.
- We get a slope parameter from the scatter plot by linear fitting to be 0.170 ADC/Energy. (This is ch22 calibration constant)
- Sum (the lead glass block + tail catcher) energy distribution is Gaussian.
- Reconstructed energy is very close to the injected energy (400MeV), successfully calibrated.



Lead glass ADC v.s. Tail catcher Energy



Energy Distribution of reconstructed

Energy reconstruction

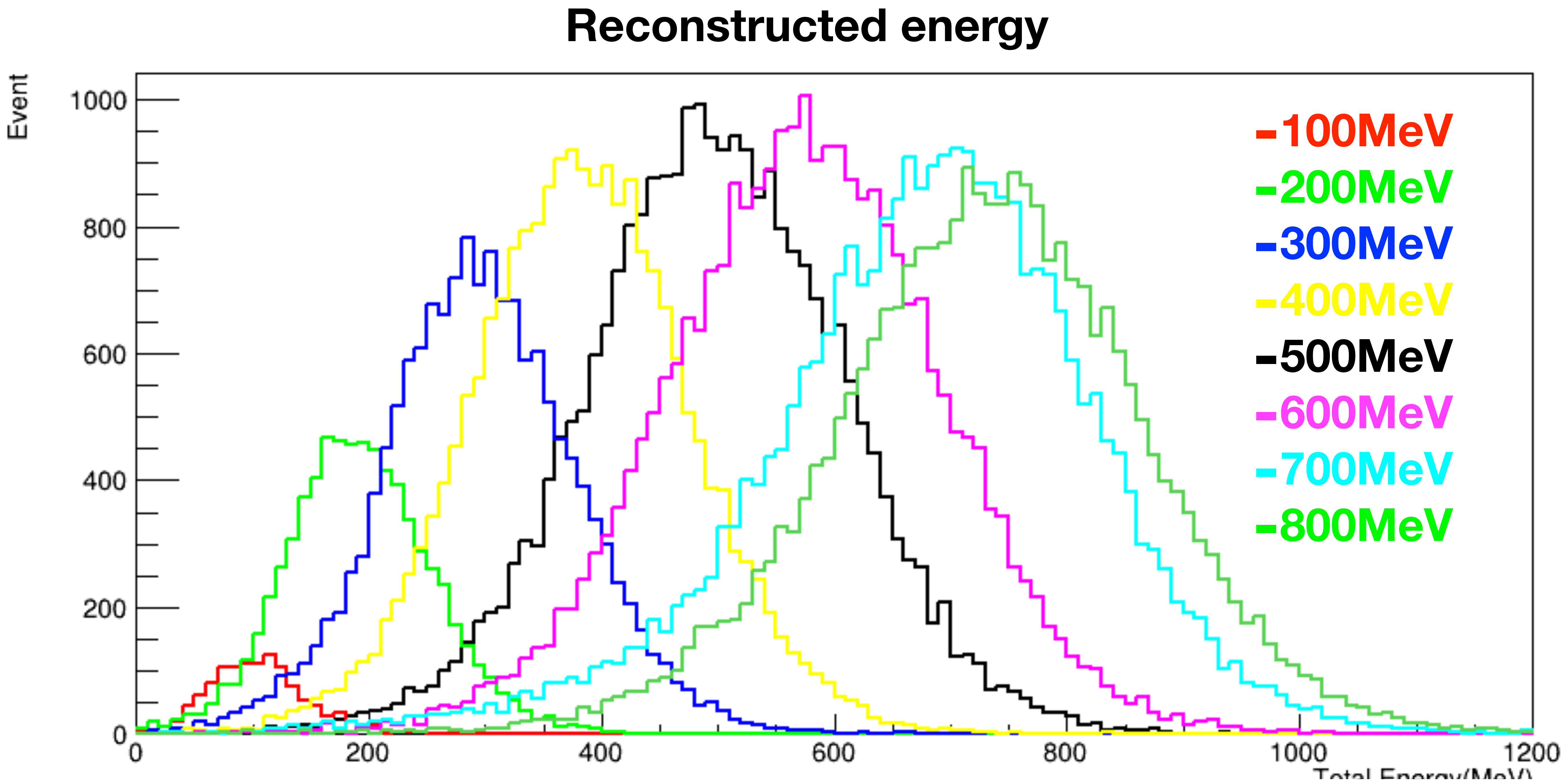
- After all lead glass channel calibration, we reconstructed calorimeter energy. (Results of 3 lead glass absorber layers and tail catcher without Scintillator)

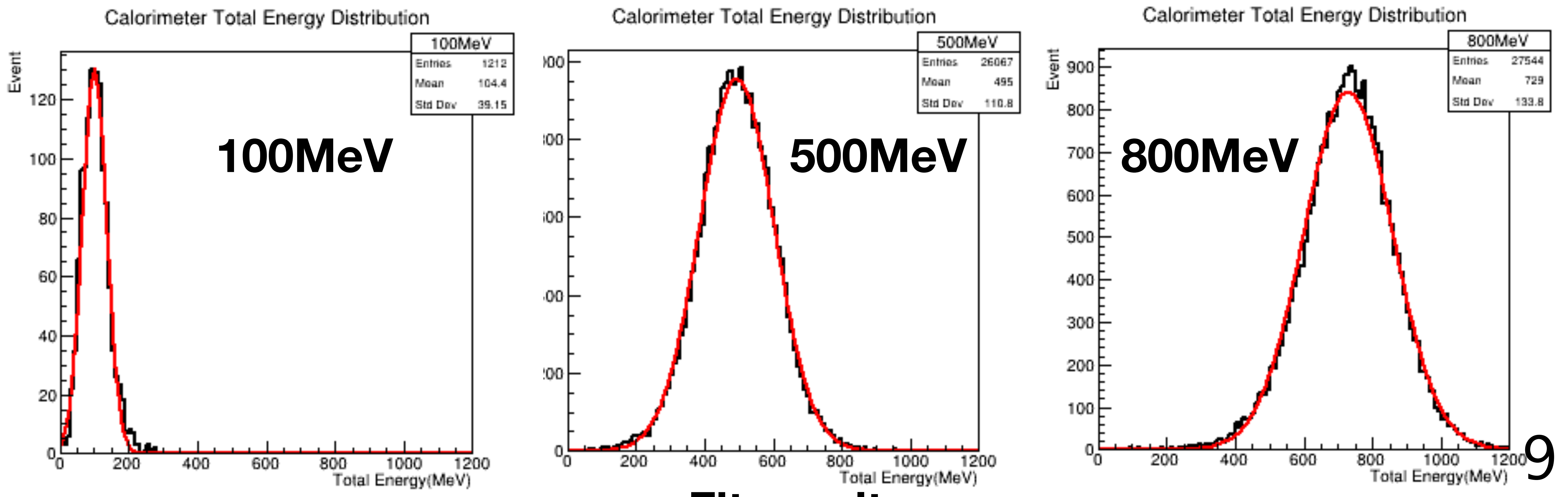
- Incident energy entered 100-800 MeV in 100MeV increments

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

- Up to 700 MeV, energy can be reconstructed well.

- At 800 MeV, the peak position of 800MeV data is about 10% smaller than expected.
  -> Checking now



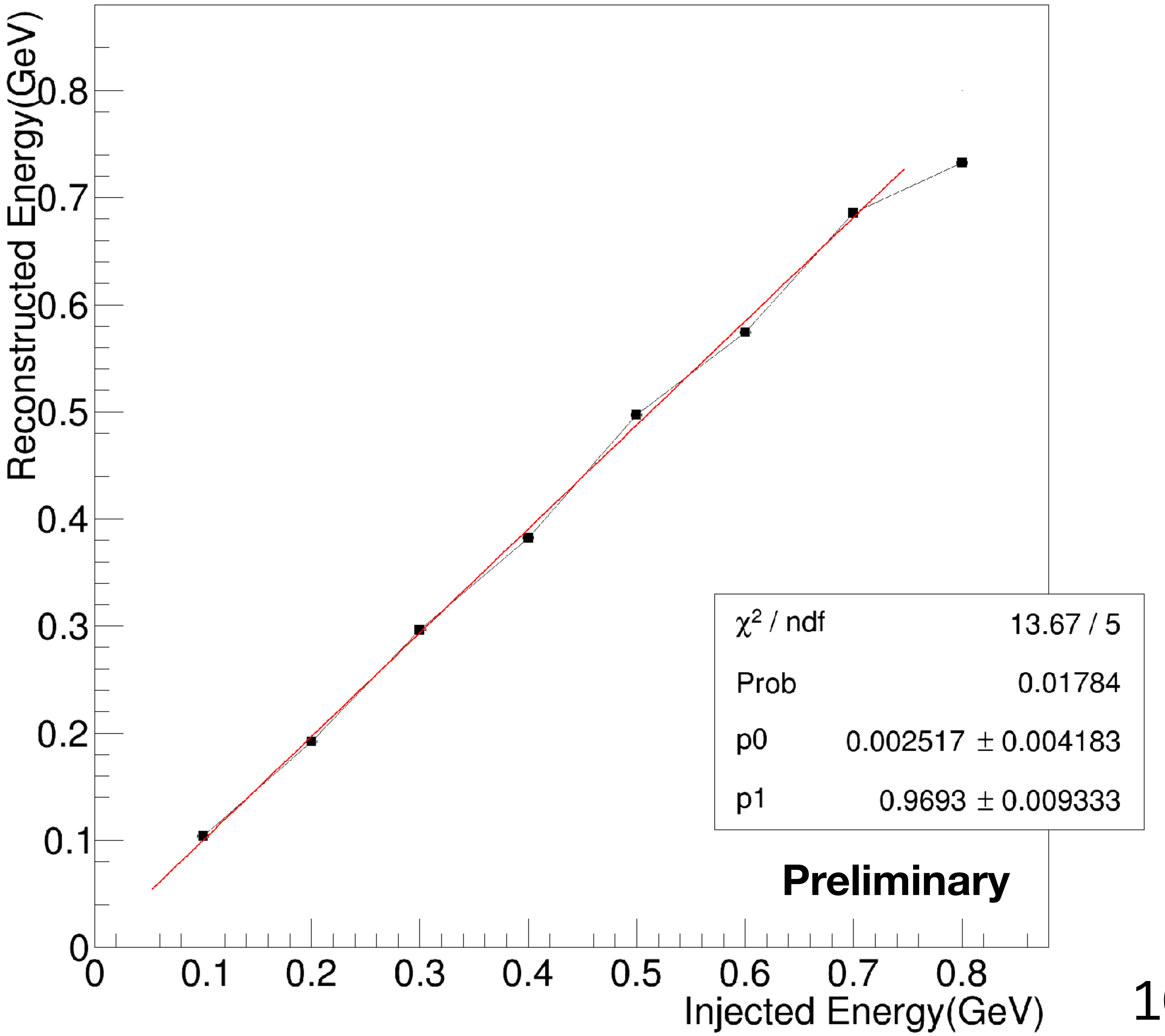


Fit result

Energy linearity

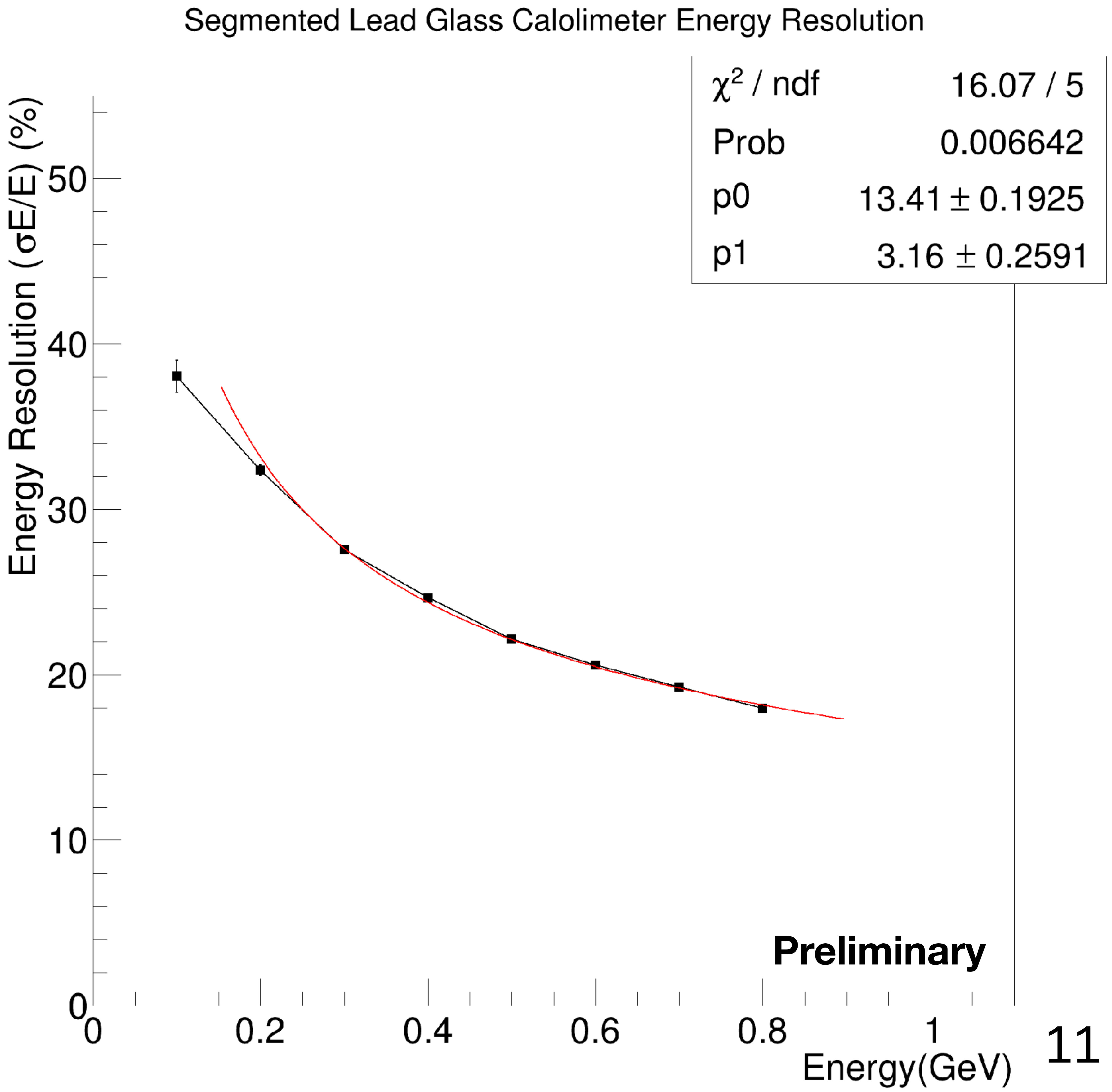
- Linearity is calculated based on the result of energy reconstruction.
- Results up to 700MeV are linear enough.
  -> Slope is 0.970
- The intercept of 0.003GeV is small enough to be consistent with zero.
- At 800 MeV, it is not included in the fitting.
- This reason is also investigated using simulation.

Reconstructed Energy linearity



Energy resolution

- The energy resolution was calculated from the energy reconstruction results.
- Excluding 100 MeV, the results are in good agreement with $1/\sqrt{E}$ fit results
- From the result, the resolution results is 13.5%$/\sqrt{E}$
- The constant term is as large as 3%
- We are checking 100MeV data and large constant term.
- This resolution is greatly influenced by photon statistics and stainless steel case.
- We are investigating the effect of photon statistics and material effect by simulation



Summary

- Performance improvement of the calorimeter is expected for future high-energy frontier collider experiments.
- We are developing and testing segmented active absorber lead glass calorimeter.
- The beam was used to verify the performance of the 3layer prototype.
    - The reconstructed energy distribution is a Gaussian at all energy.
    - The linearity is very good except 800MeV.
    - The energy resolution was $13.5\%/\sqrt{E}$ excluding 100 MeV, which is dominated by photon statistics.
- Future Plan
    - More analysis
        - Perform temperature correction.
        - Use both the scintillator layer and lead glass information
    - Comparison with simulation(energy leak, absorption of stainless steel case and photon statics)
    - Increase of photon correction efficiency in order to improve energy resolution.

Backup

Parameter of Lead Glass

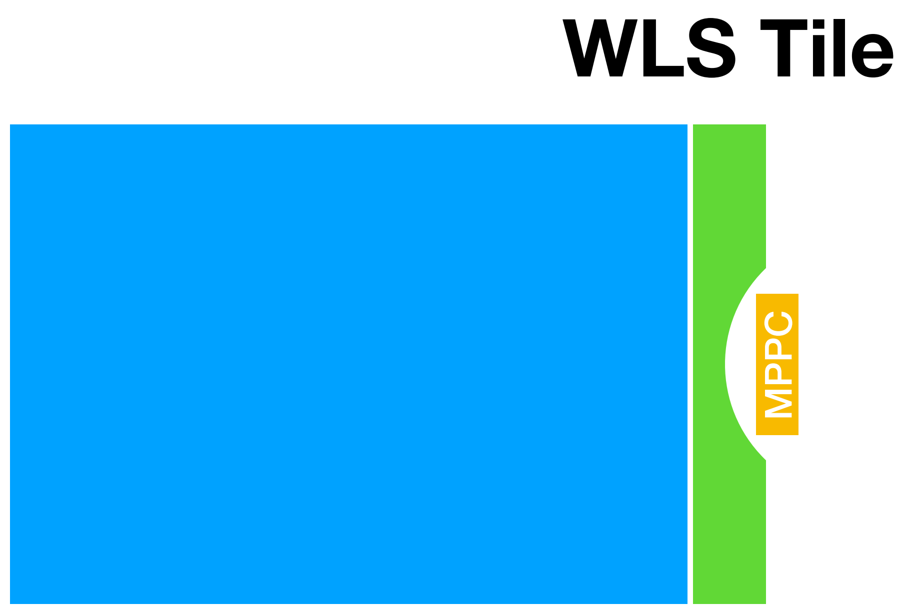
Chemical composition (wt%)	
SiO_2	27.3
PbO	70.9
K_2O	0.9
Na_2O	0.6
Sb_2O_2	0.3
Radiation length (cm)	1.7
Refractive index	1.8
Density (g/cm_3)	5.2
Critical energy (MeV)	12.6
Molière unit (X_0)	1.7

Light yield improvement structure

Now testing

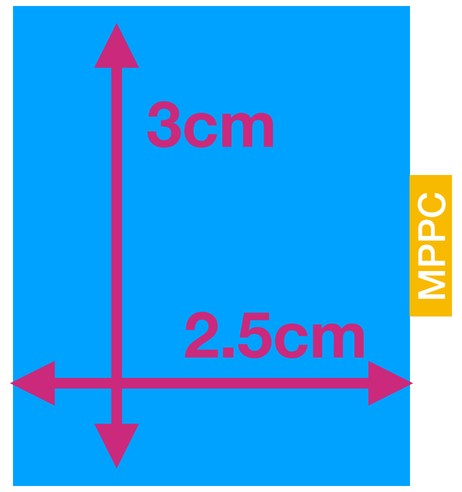
Current type
Directory one MPPC readout

Simple method
Several MPPCs readout

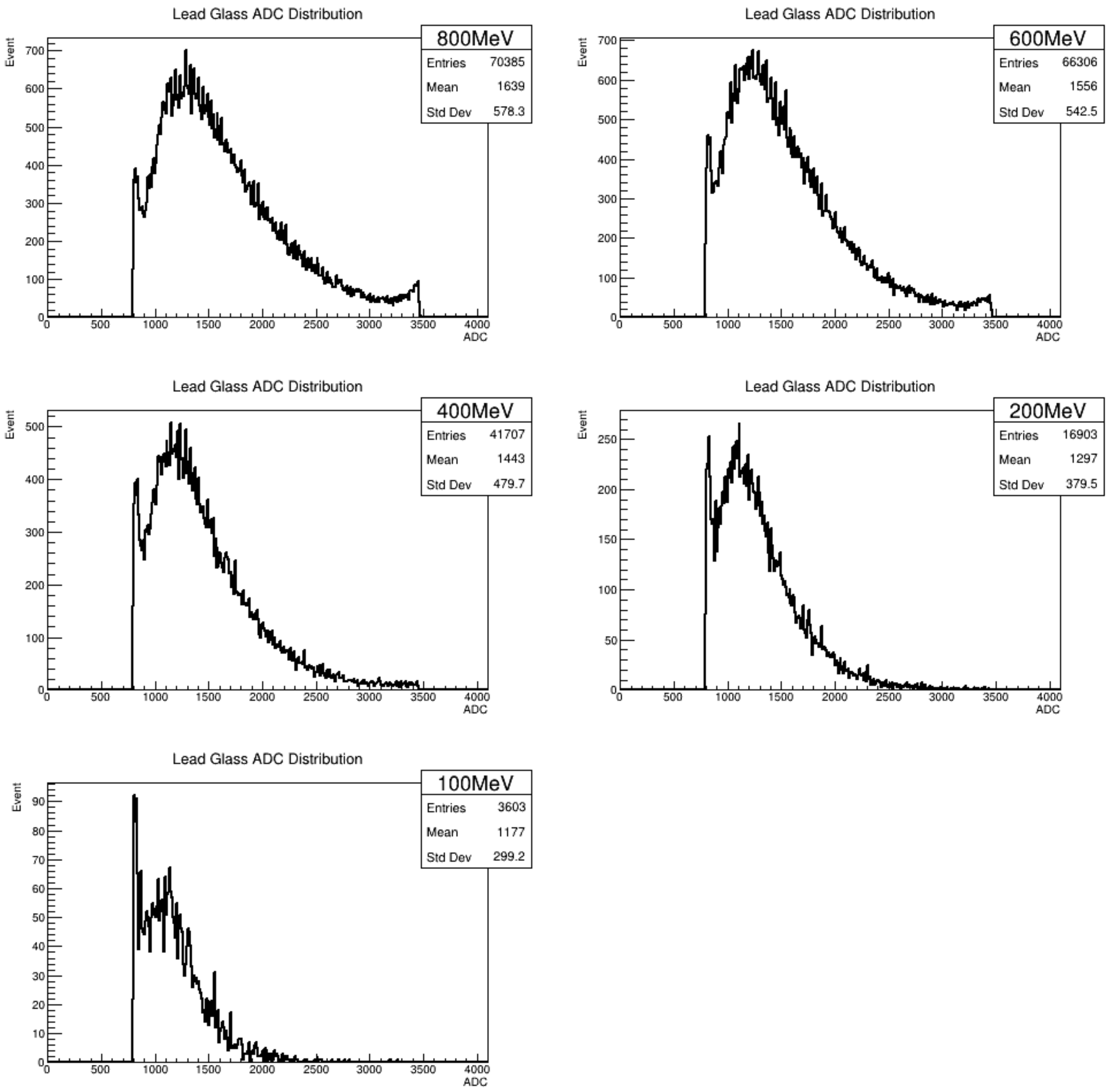


Use WLS Tile
One MPPC readout

2.5cm thickness lead glass

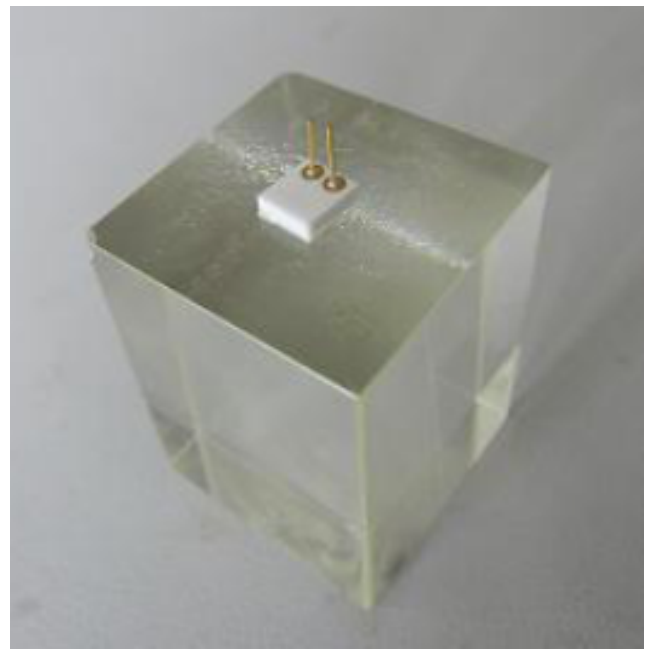


2.5cm thickness lead glass

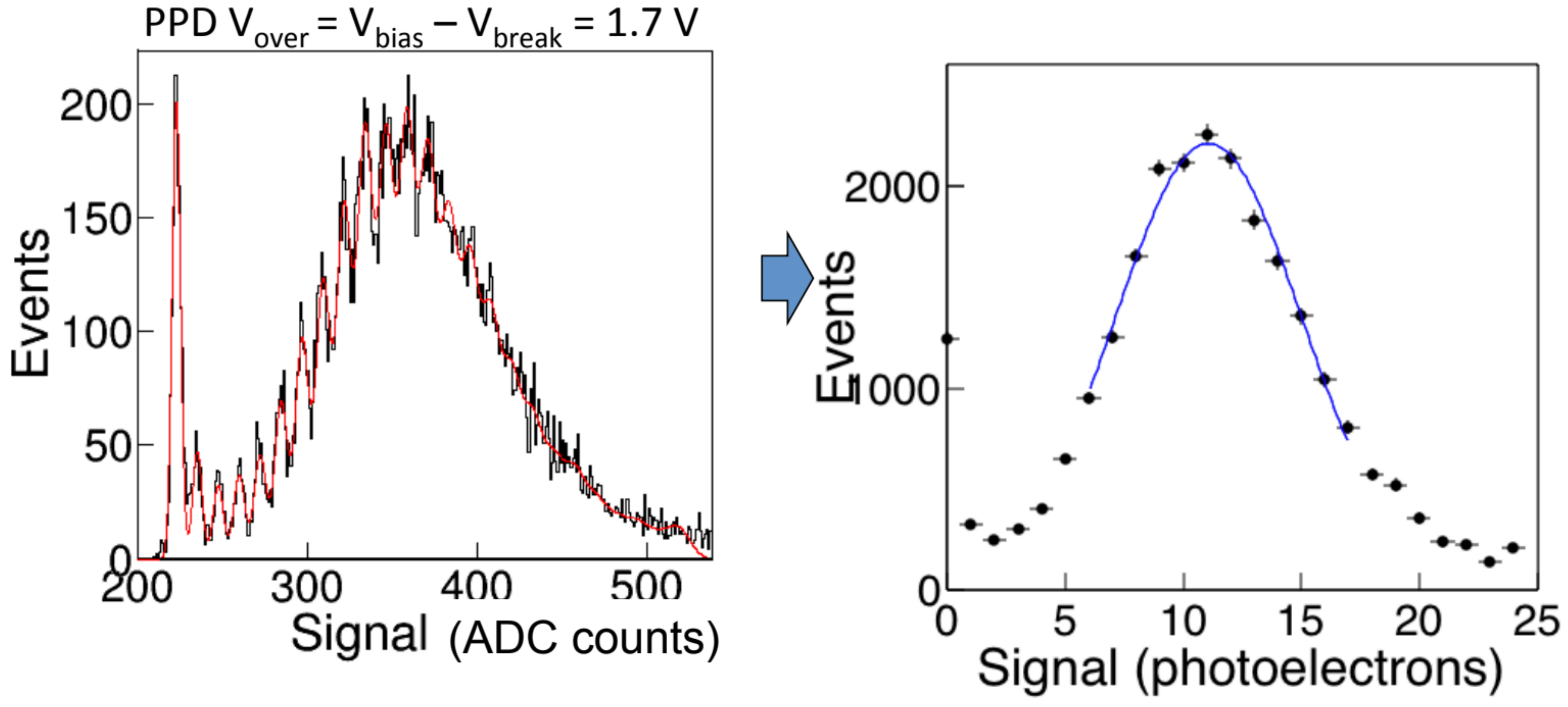


Readout Cherenkov light

- Lead glass block surface is 3x3cm² but MPPC sensor area is very small (3x3mm²) (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 reflected because of heavy lead glass density.
- This problem was solved by putting in optical grease between the lead glass and MPPC
- Cherenkov light is very small but can be read 12 p.e. by cosmic muon



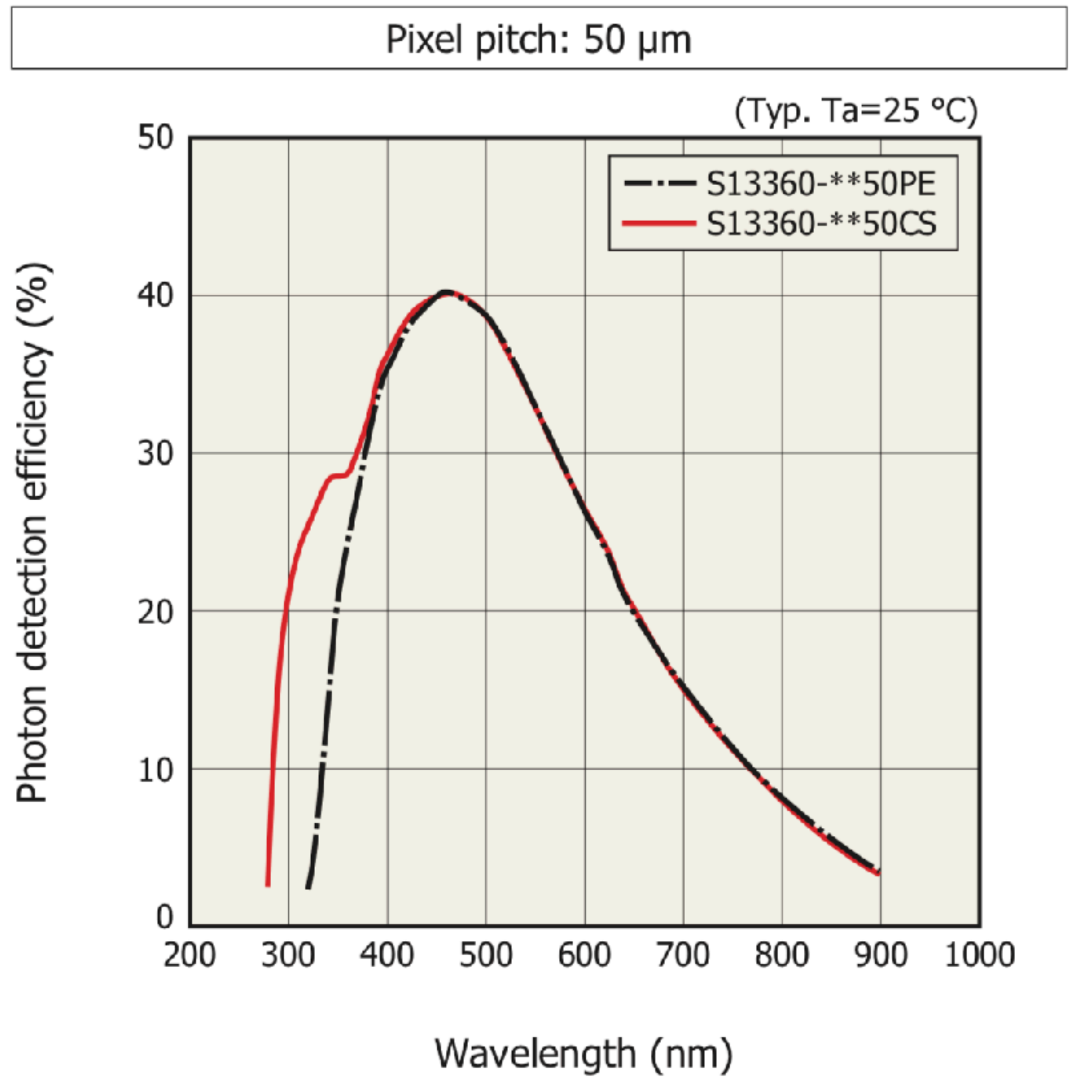
Lead glass block and MPPC



Muon signal

By Uozumi

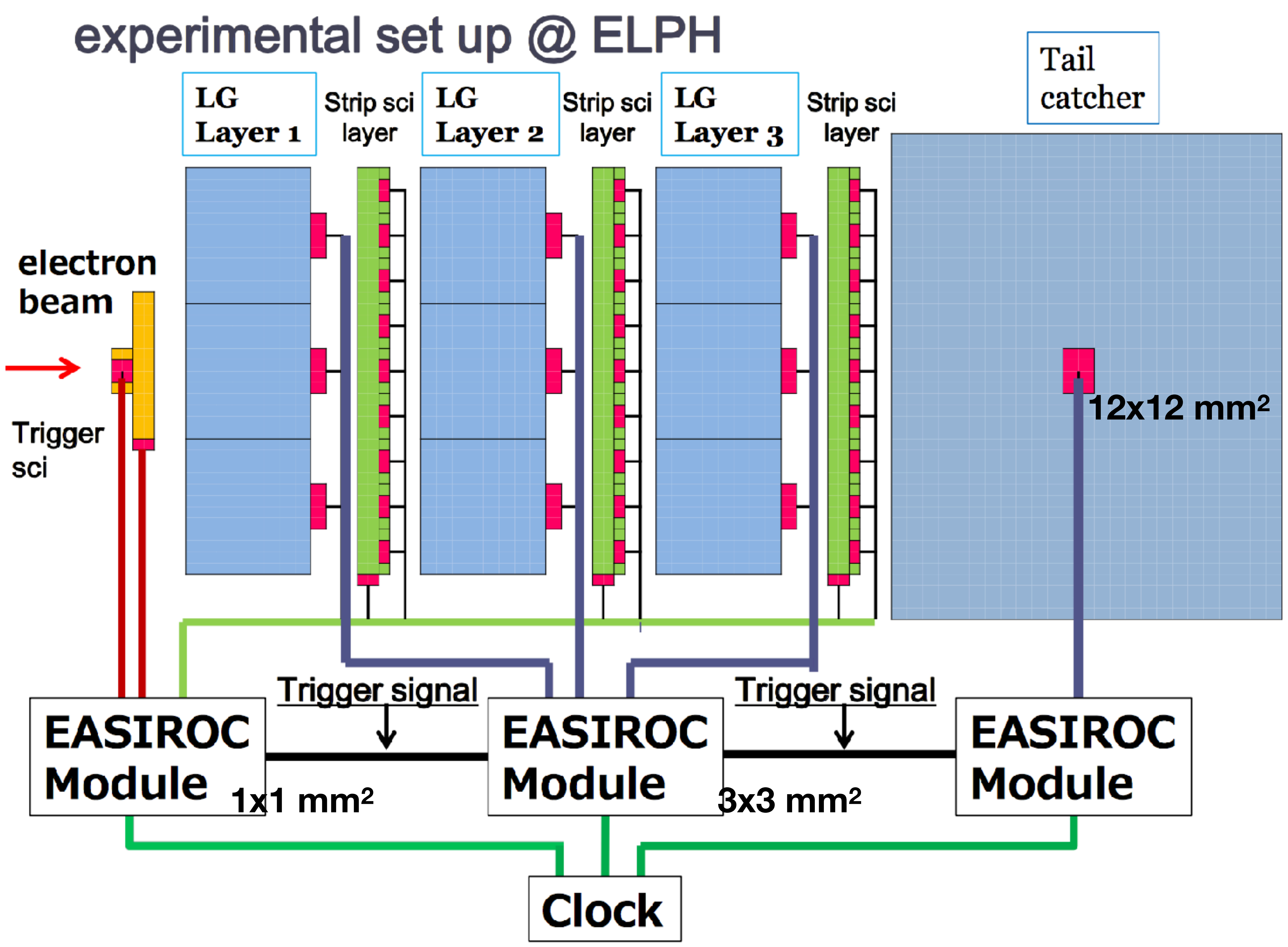
Optical coupling of Lead glass block and MPPC



Dependence of wavelength

Read out and Trigger system

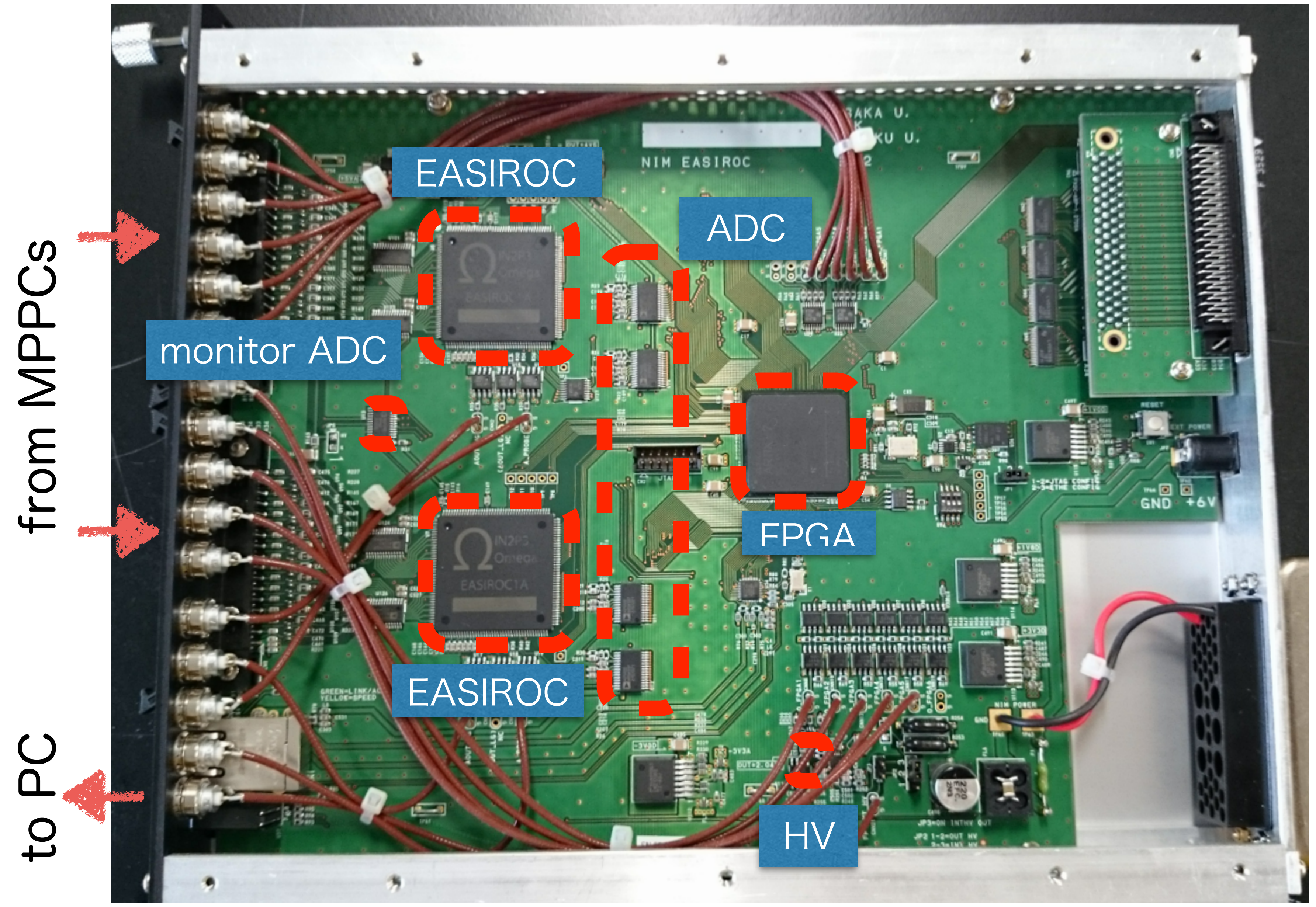
- This prototype has 83 MPPCs.
  - Active absorber layers have 27 MPPCs
  - Strip scintillator layers have 54 MPPCs
  - The tail catcher has 2 MPPCs
- 3 EASIROC Modules to read out MPPC signals for 3 types of MPPCs as different breakdown voltages. (1 x 1 mm^2, 3 x 3 mm^2, 12 x 12 mm^2)
- Trigger signals are made by one EASIROC Module -> 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

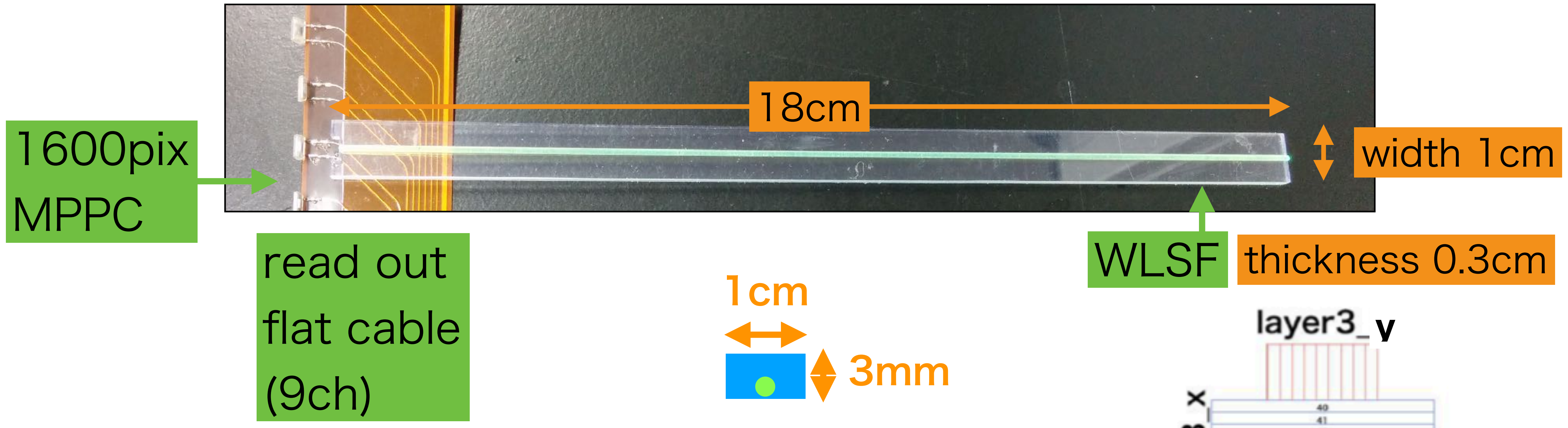
EASIROC Module

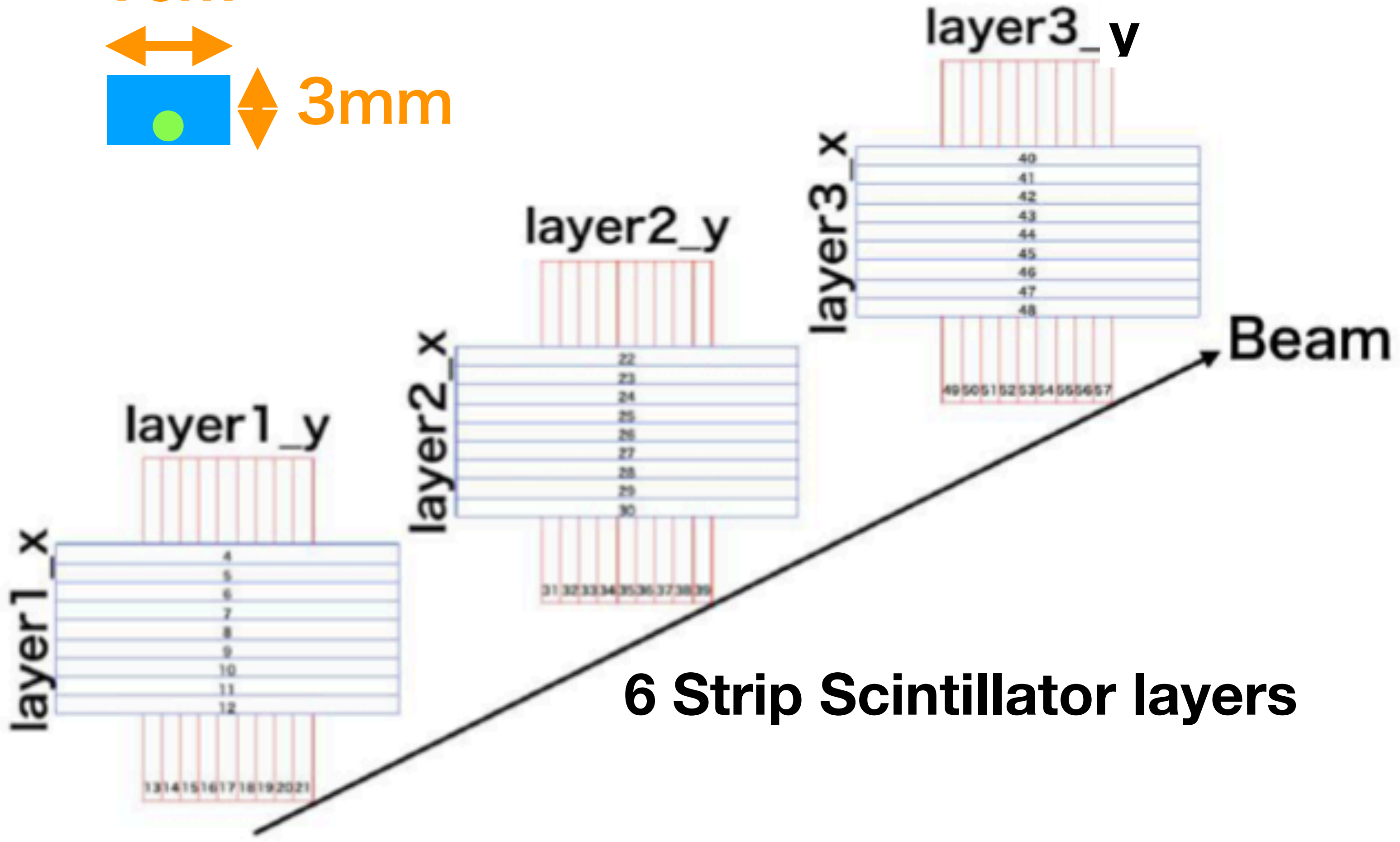
- DAQ system uses EASIROC Modules
- Developed by KEK and OSAKA University for MPPC
- We have modified the FPGA firmware and added TDC and coincidence functionality
- Multiple modules can be synchronized by the external clock
- A module equips two EASIROC chips (developed by Omega) for 64 channels
- Includes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

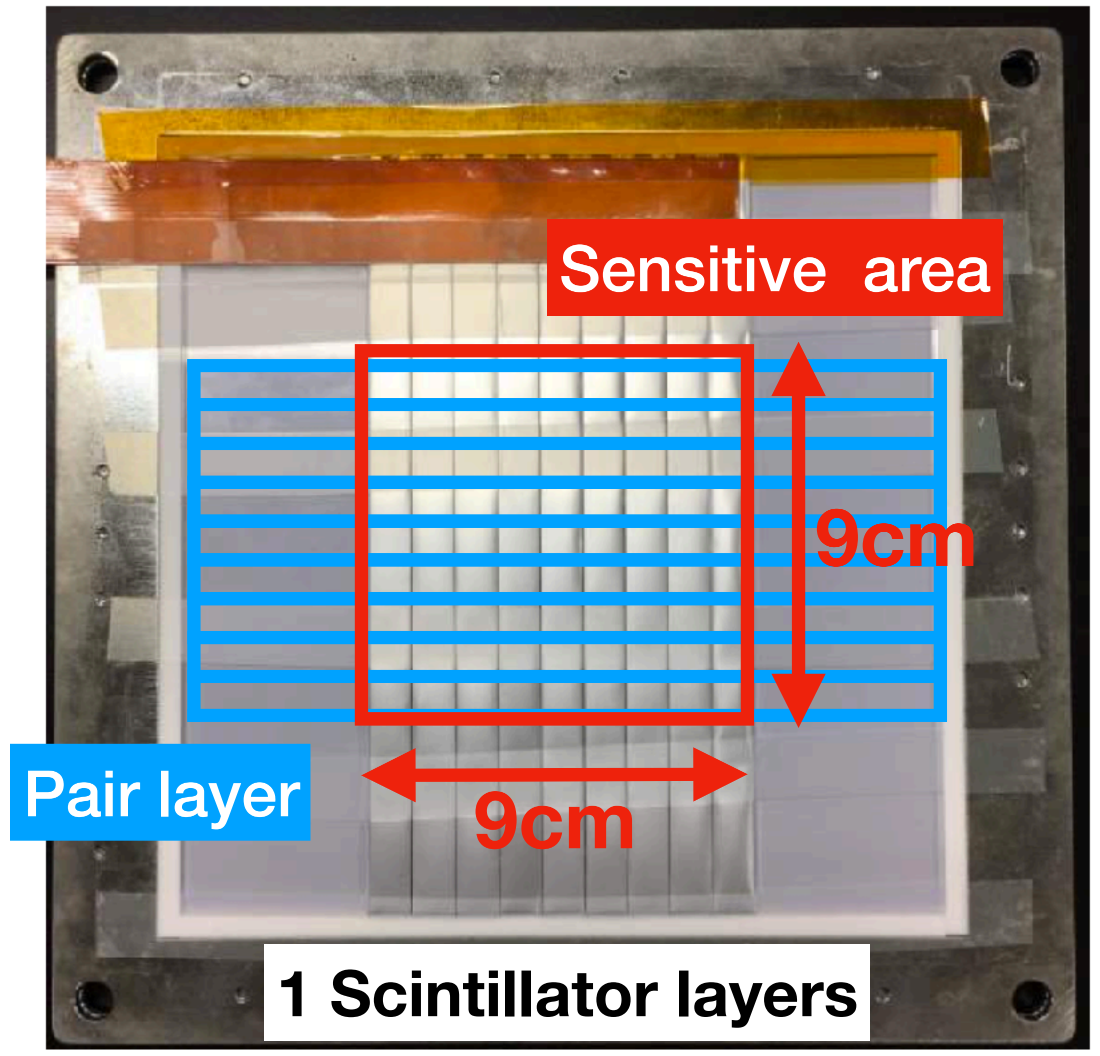


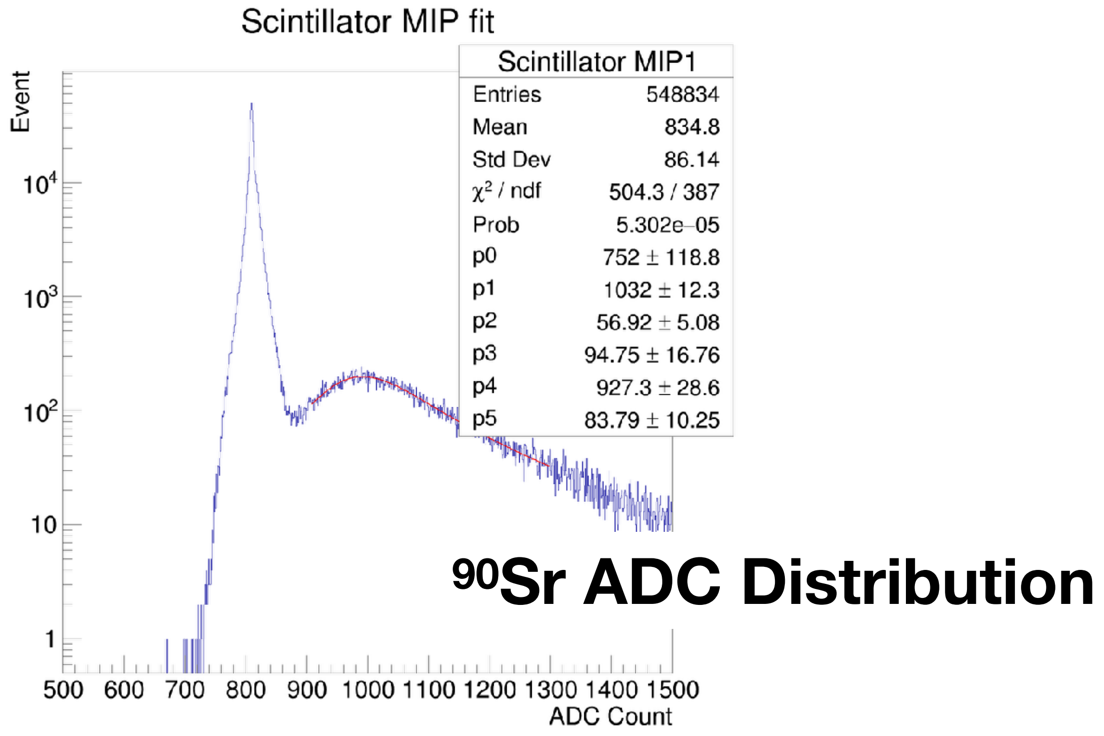
Detection layer (strip scintillator)

- A scintillator layer: 9 x 9 cm^2 sensitive area
- Same sizes as the lead glass layer.
- Component
  - 9 strip scintillator in one layer
  - Strip scintillators (EJ-204) with 18 x 1 x 0.3 cm^3
  - Wavelength shifting fiber (Y-11).
  - 1 x 1 mm^2, 25μm pitch, 1600pixel MPPC
  - Enveloped with 3M reflector film.
- We manufactured 6 layers.
- Pre-calibration of the layer at the bench test was done with cosmic muons and ^{90}Sr.





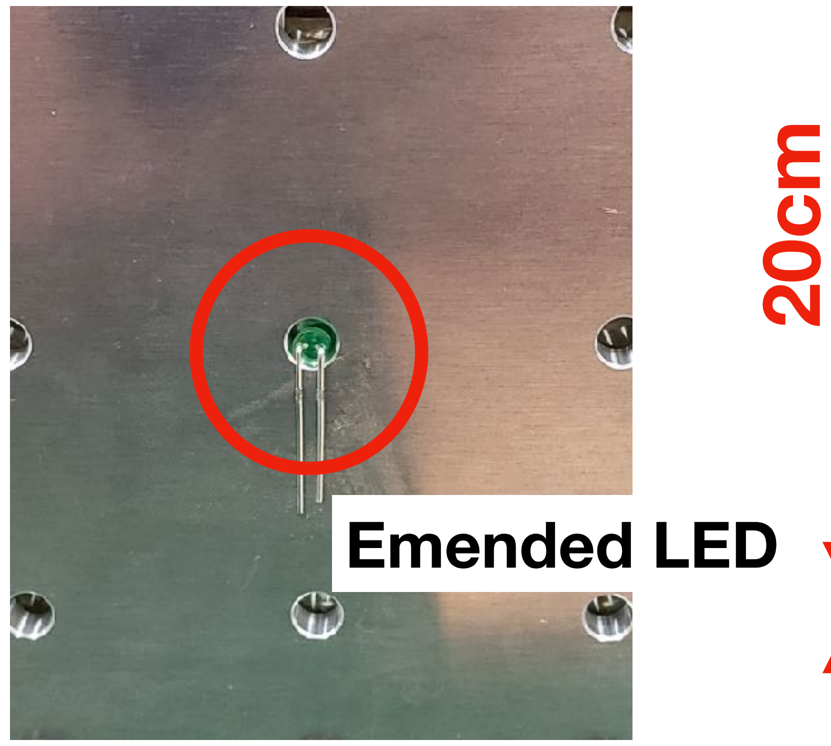


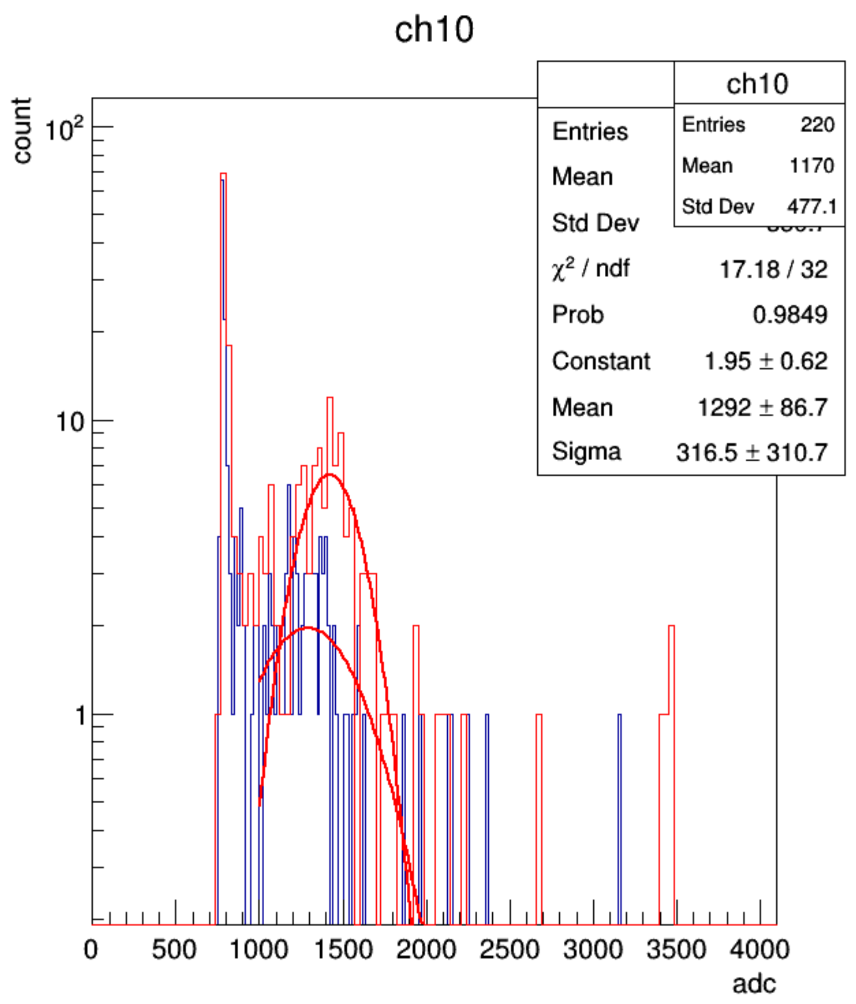


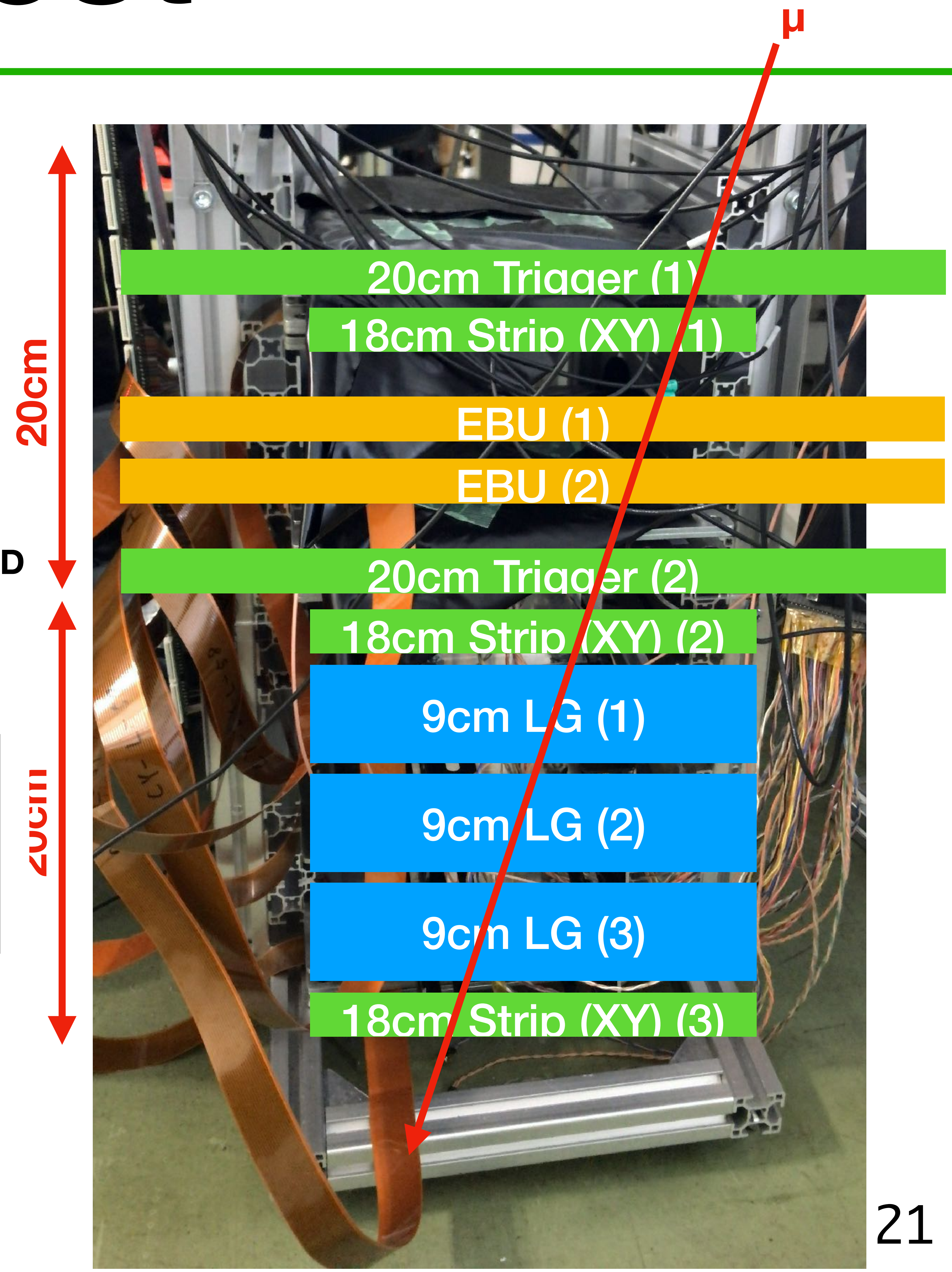
^{90}Sr ADC Distribution

Cosmic ray test

- Operation check of the 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 the information of the 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)

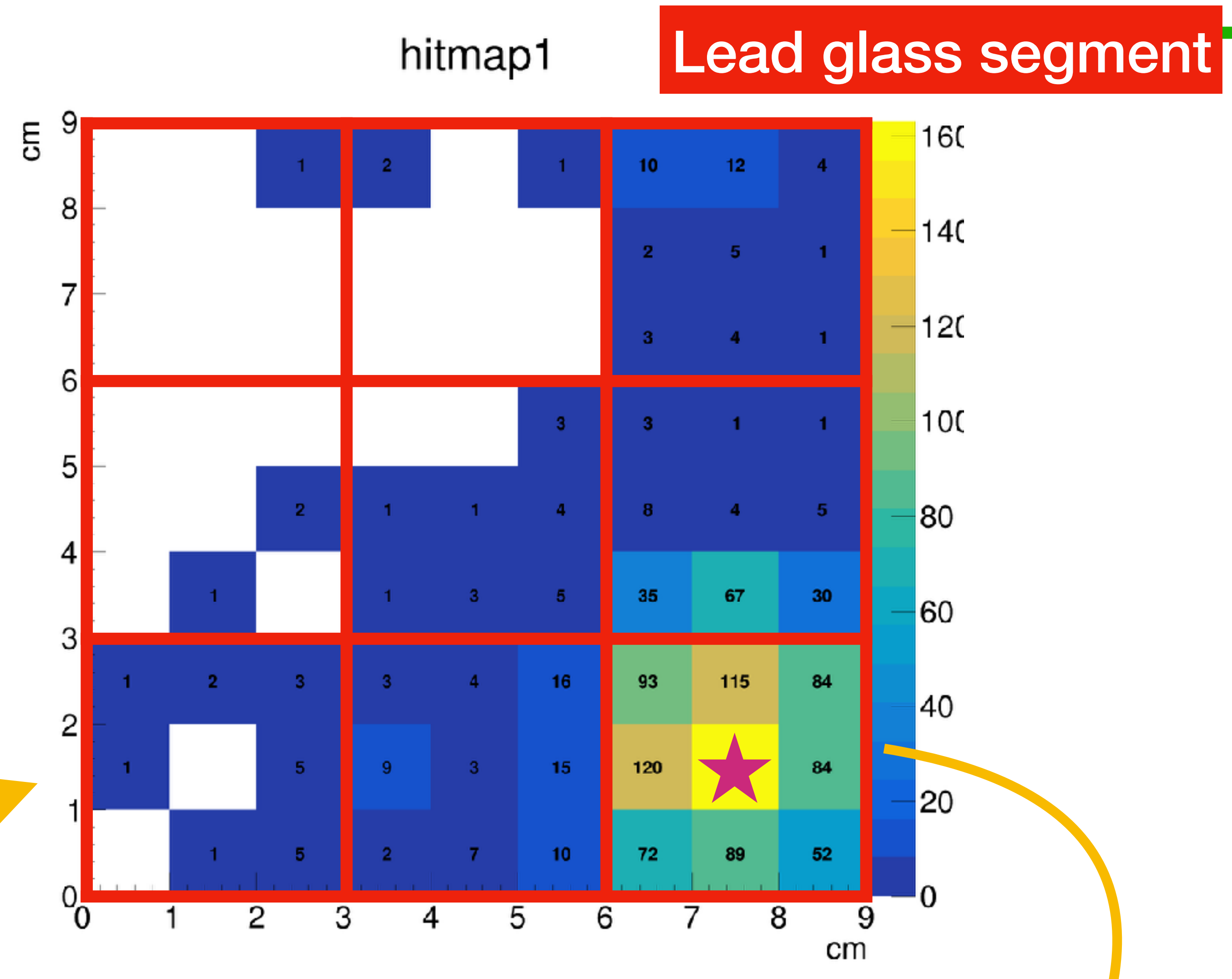




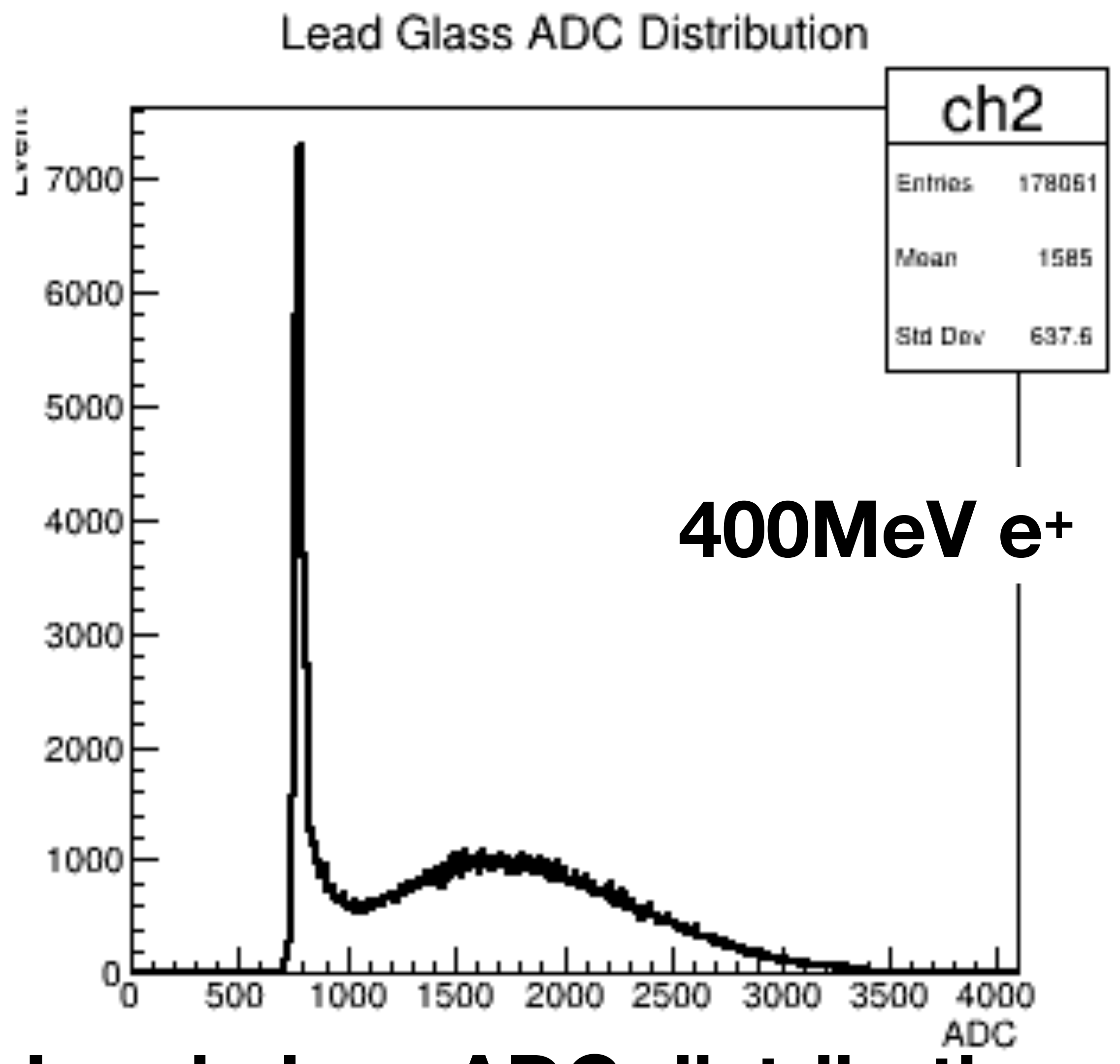


Set Up of Energy Calibration

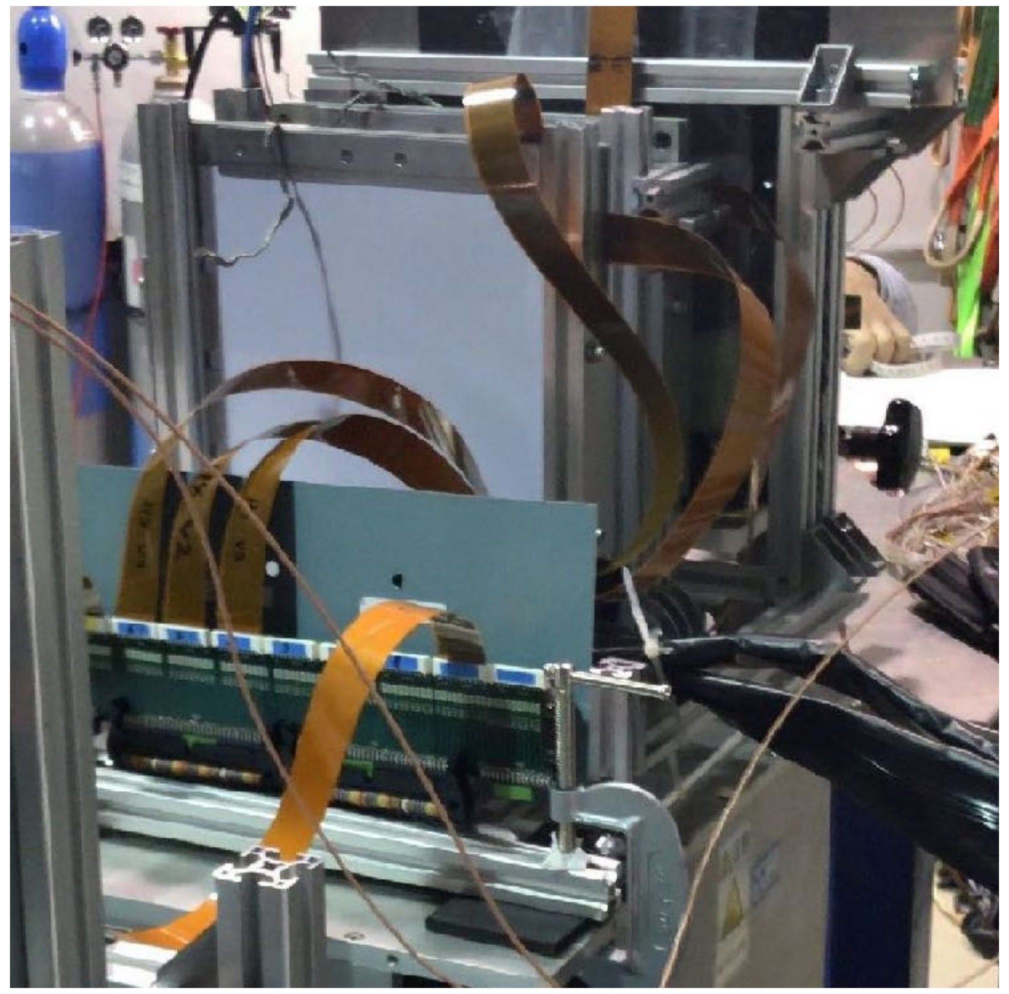
- We did calibration all Lead Glass block channels with 400MeV beam.
- We moved the position of the detector using an electric moving stage by remote control
- Beam position was confirmed by using strip layer in front of the lead glass layer
- Lead glass at the center of the layer confirmed the response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



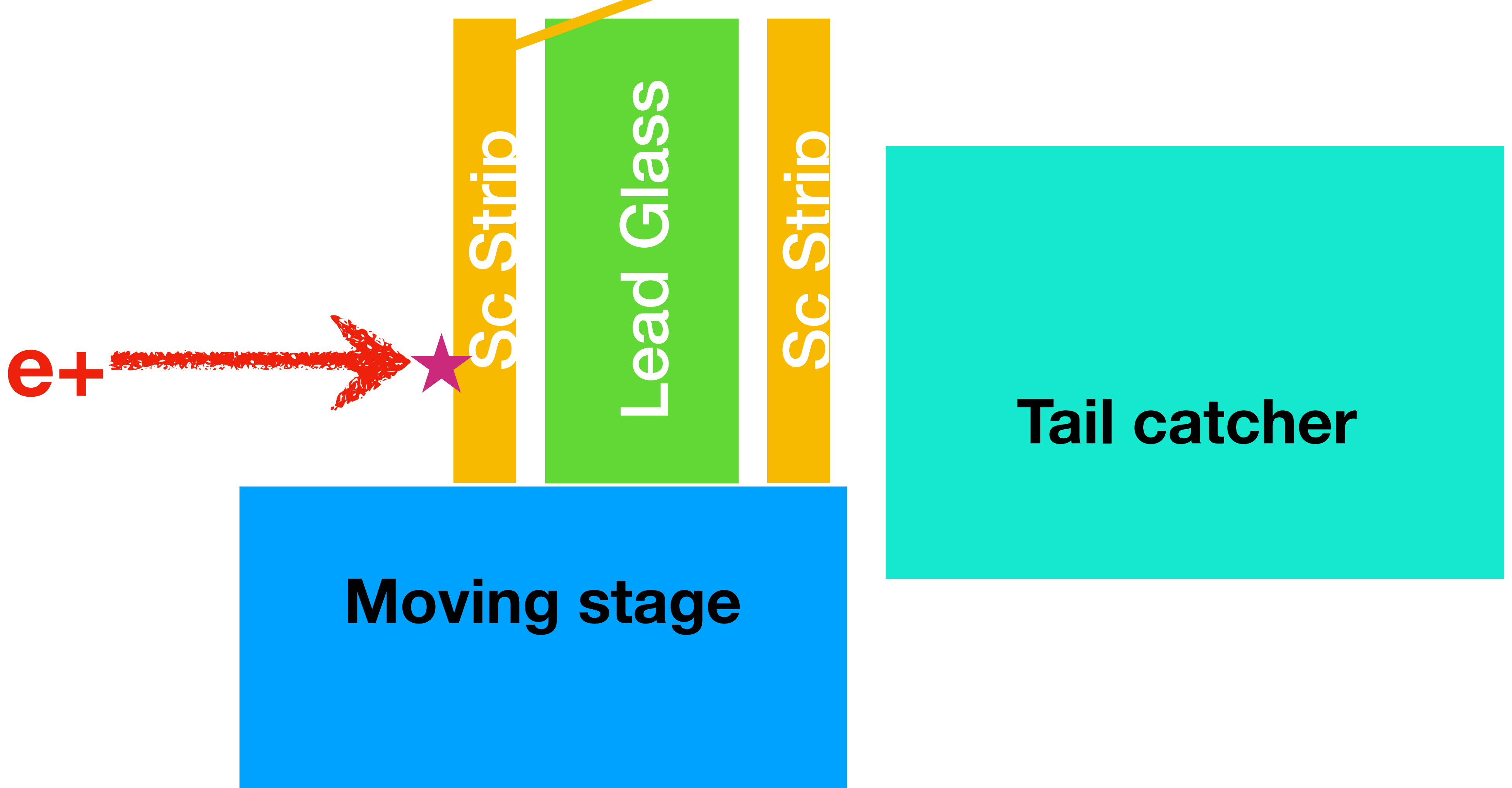
Sc hitmap for Beam position



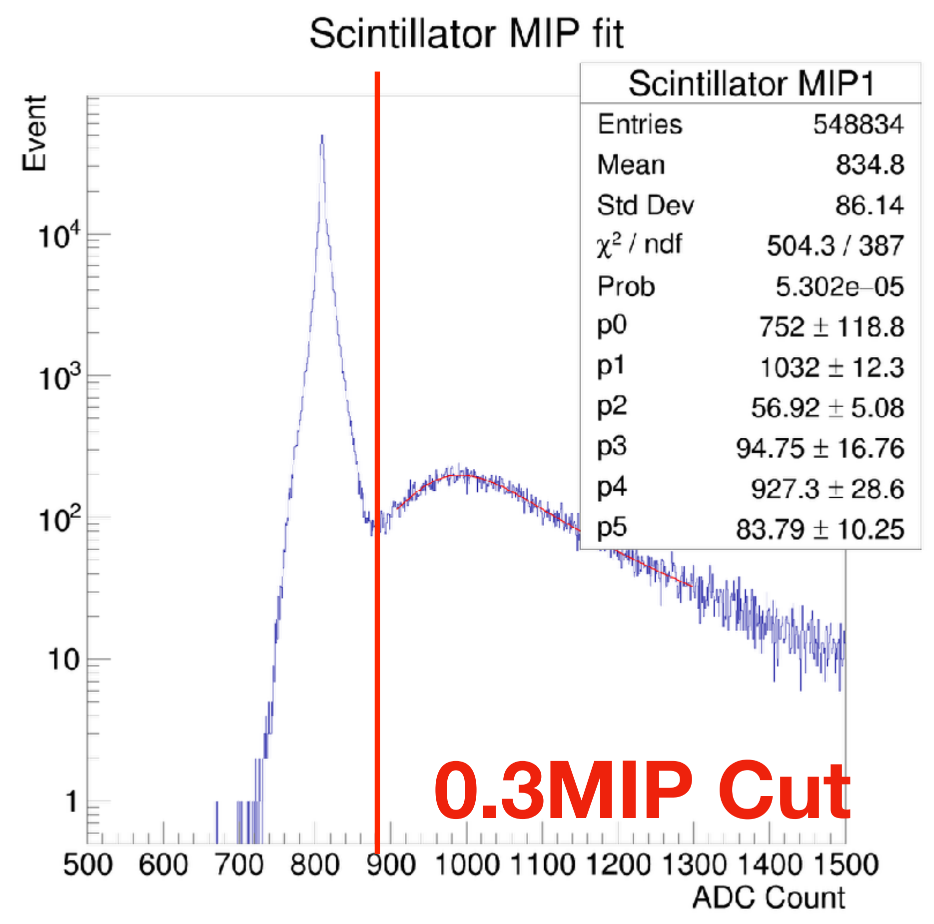
Lead glass ADC distribution



Set up of energy calibration

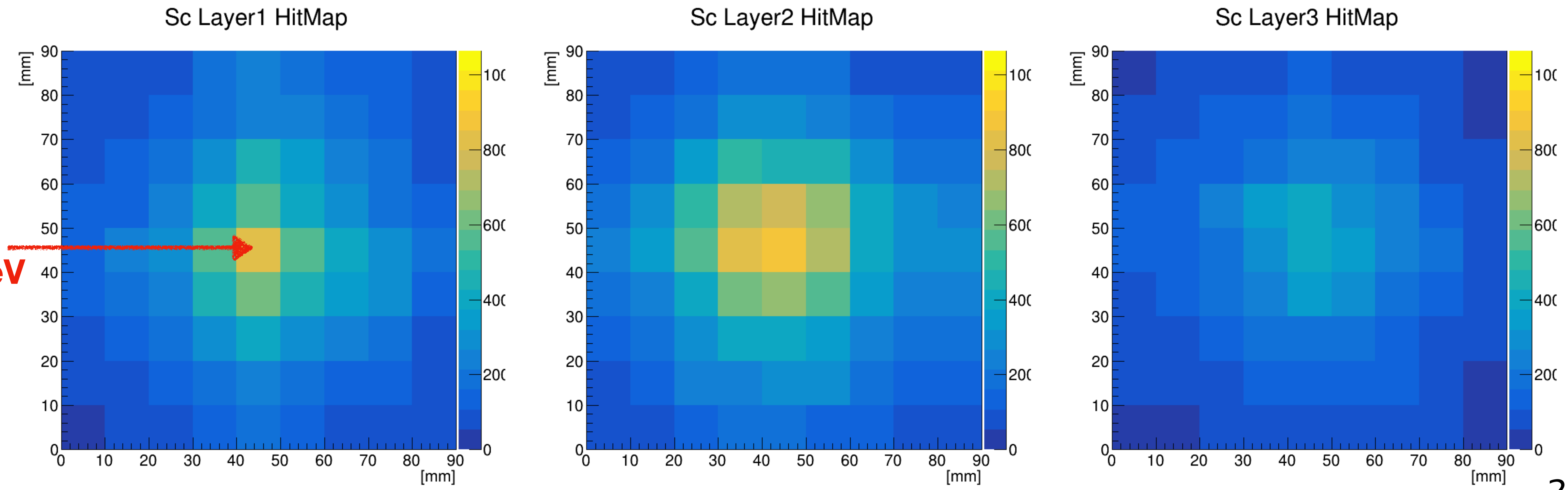


Scintillator Hitmap (2017)



- 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

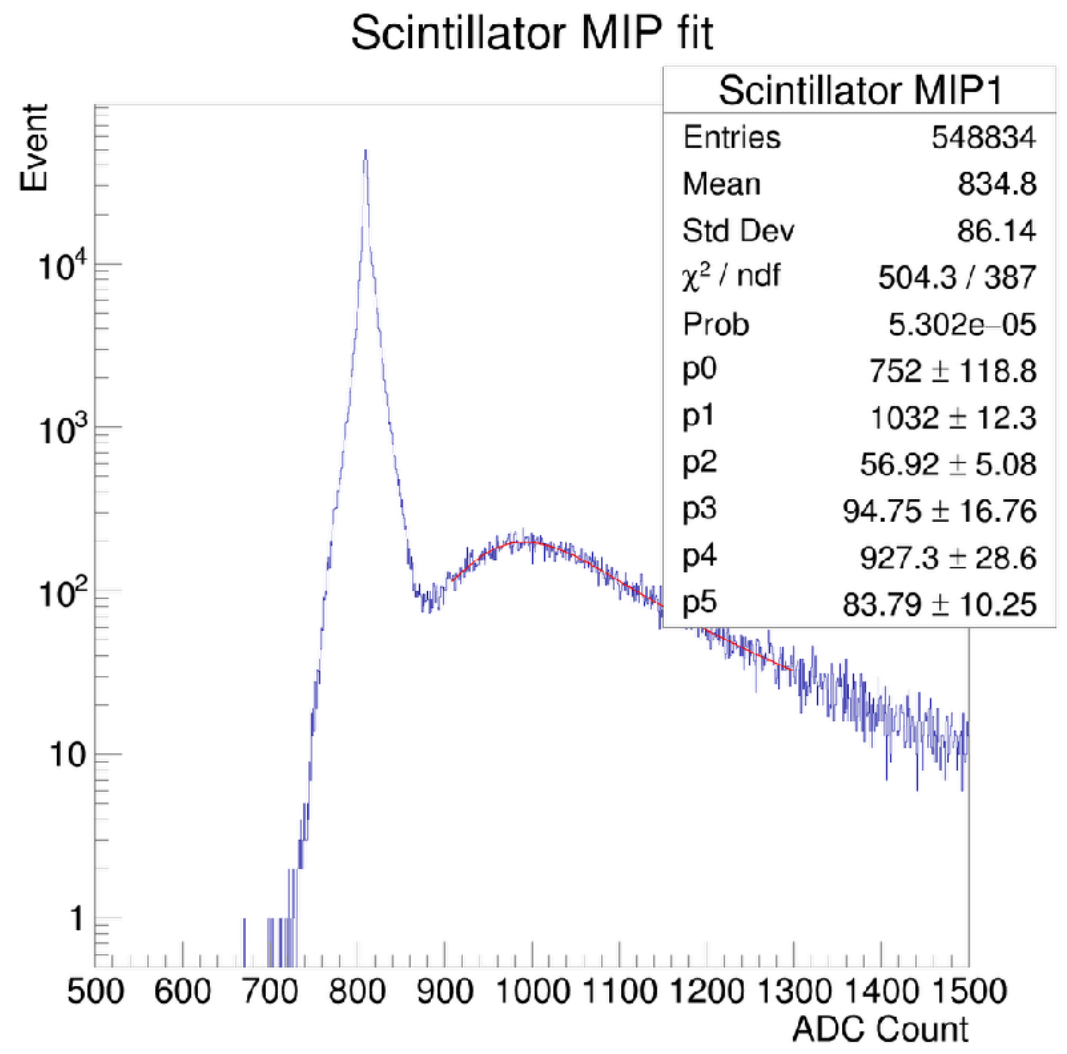
e+ 800MeV

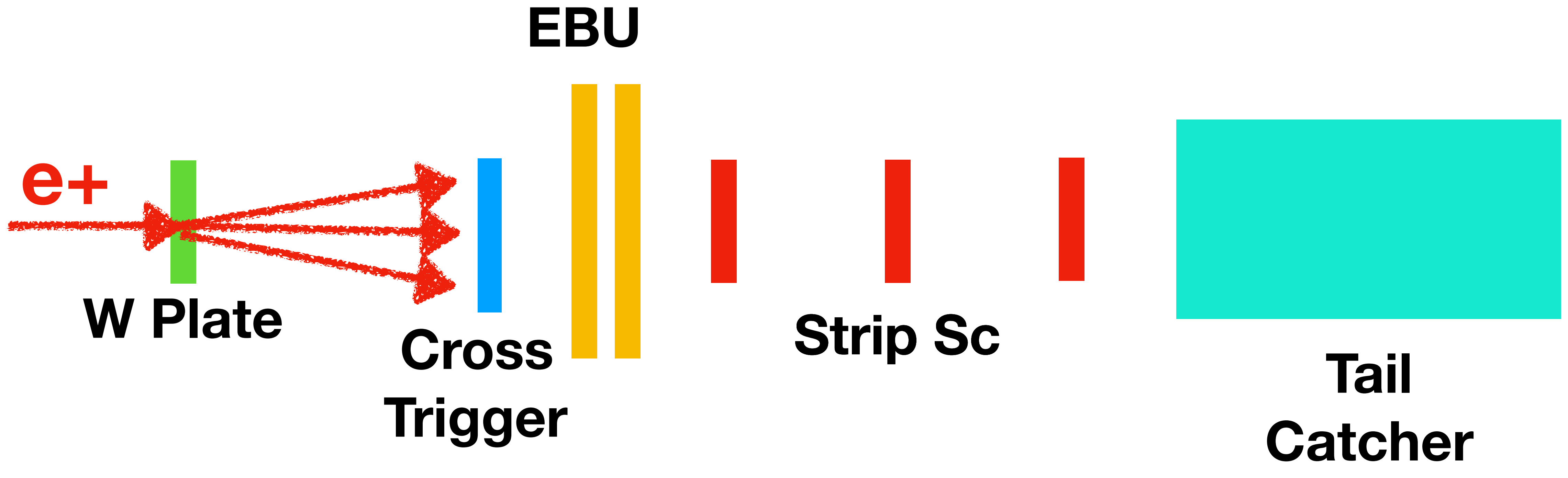


800MeV Sc Hitmap

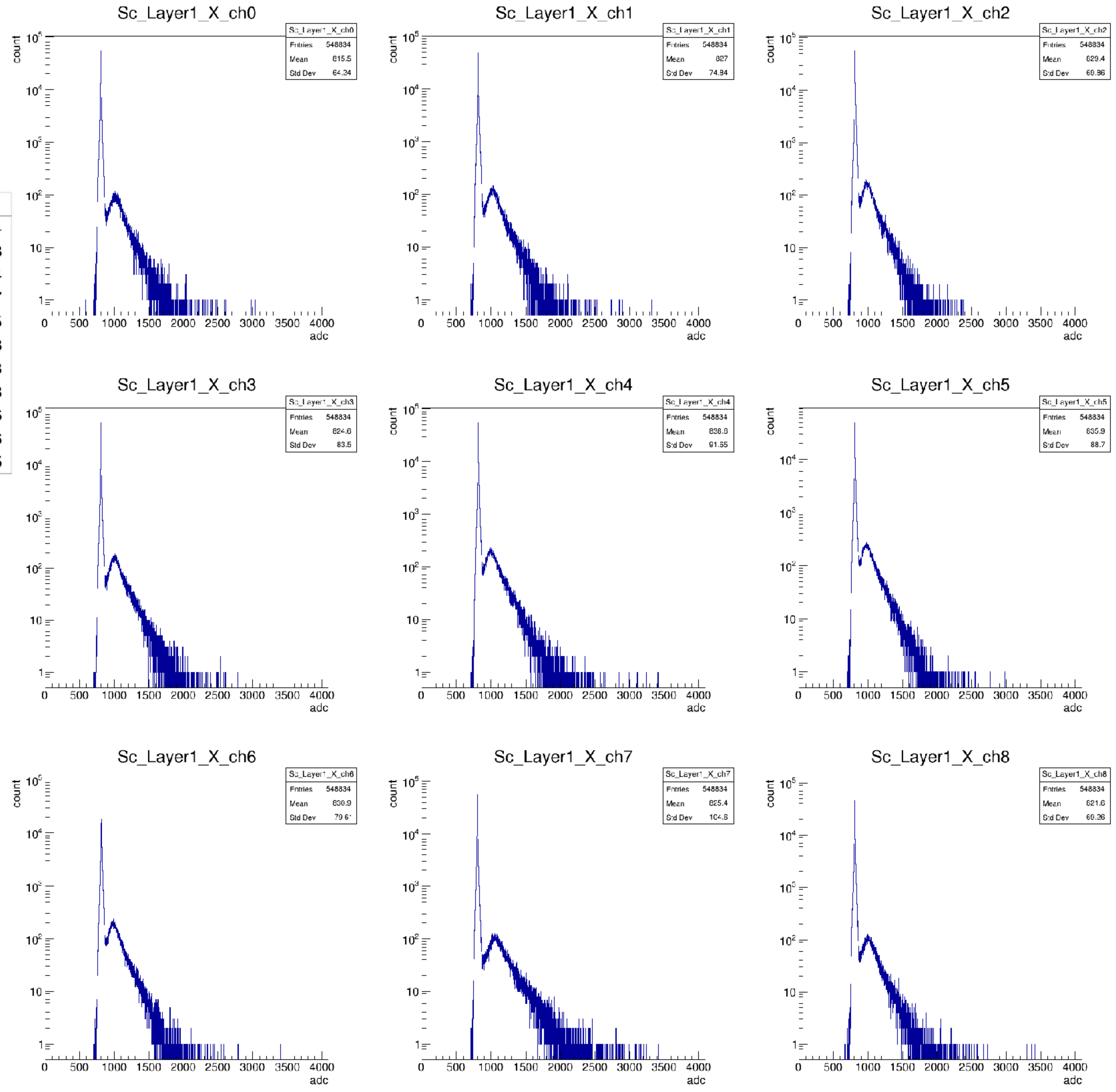
Scintillator Calibration

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





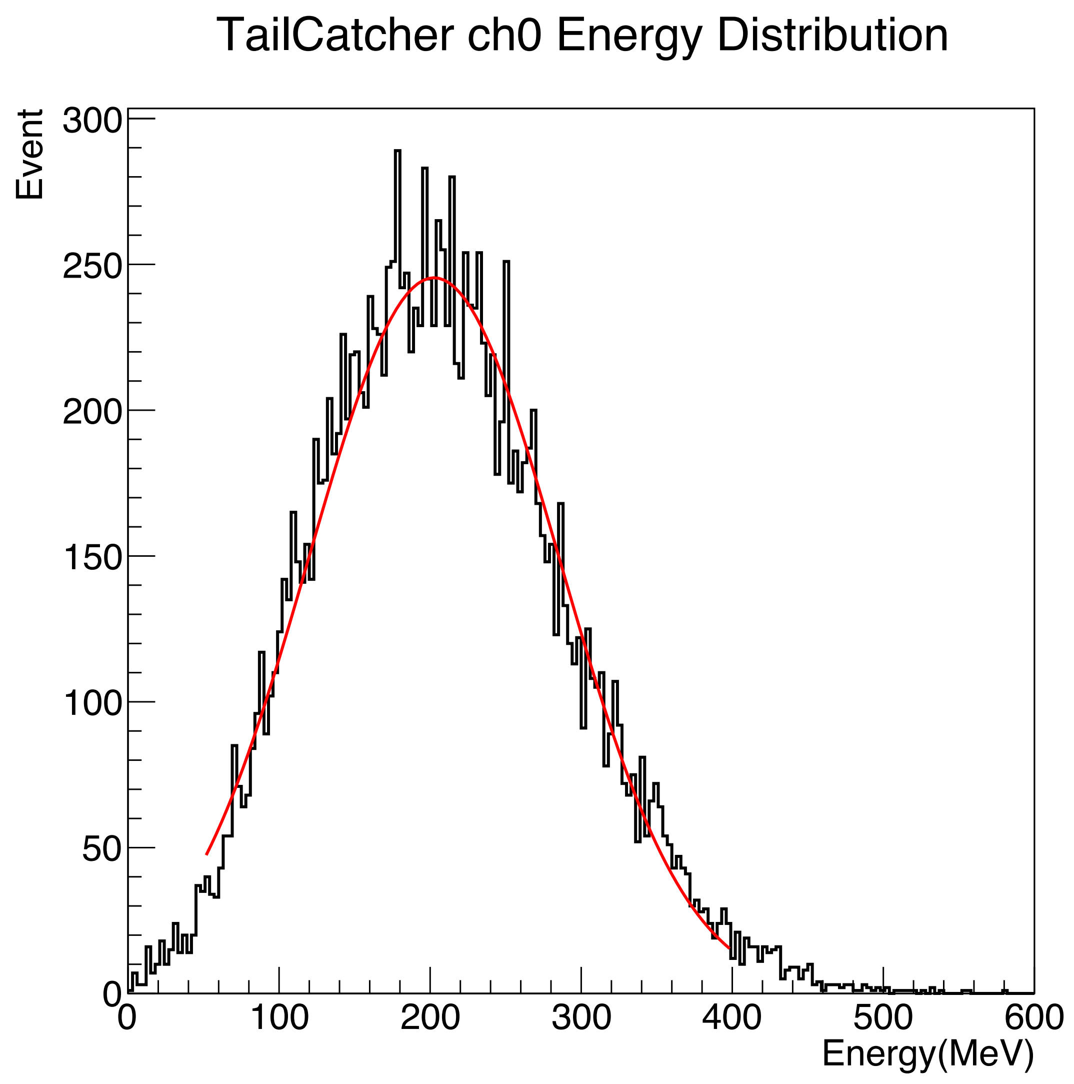
scintillator calibration setup
(remove active absorber)



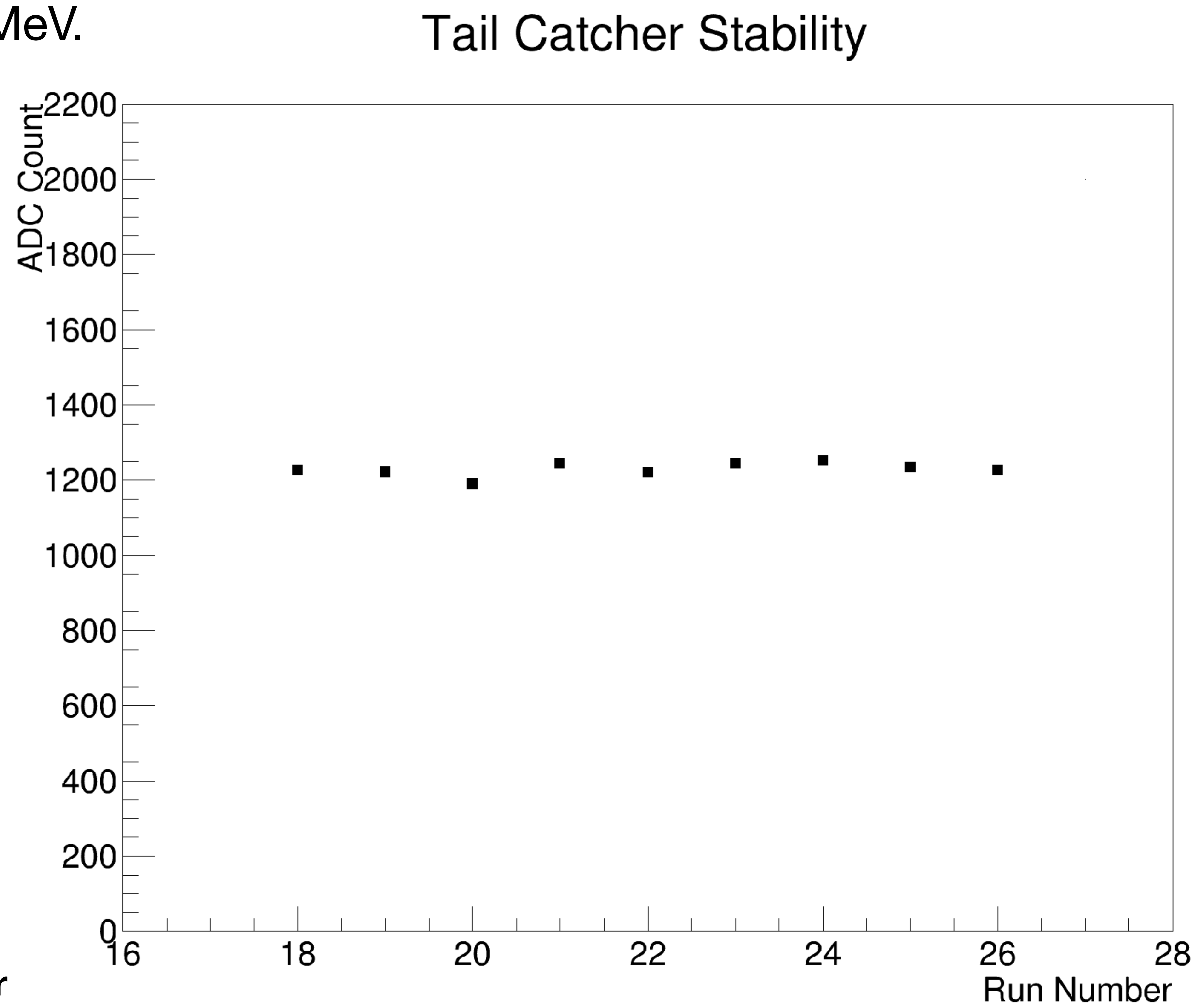
Layer 1 X direction ADC distribution at calibration run (2017)

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 changed.
- We checked the stability of the tail catcher.



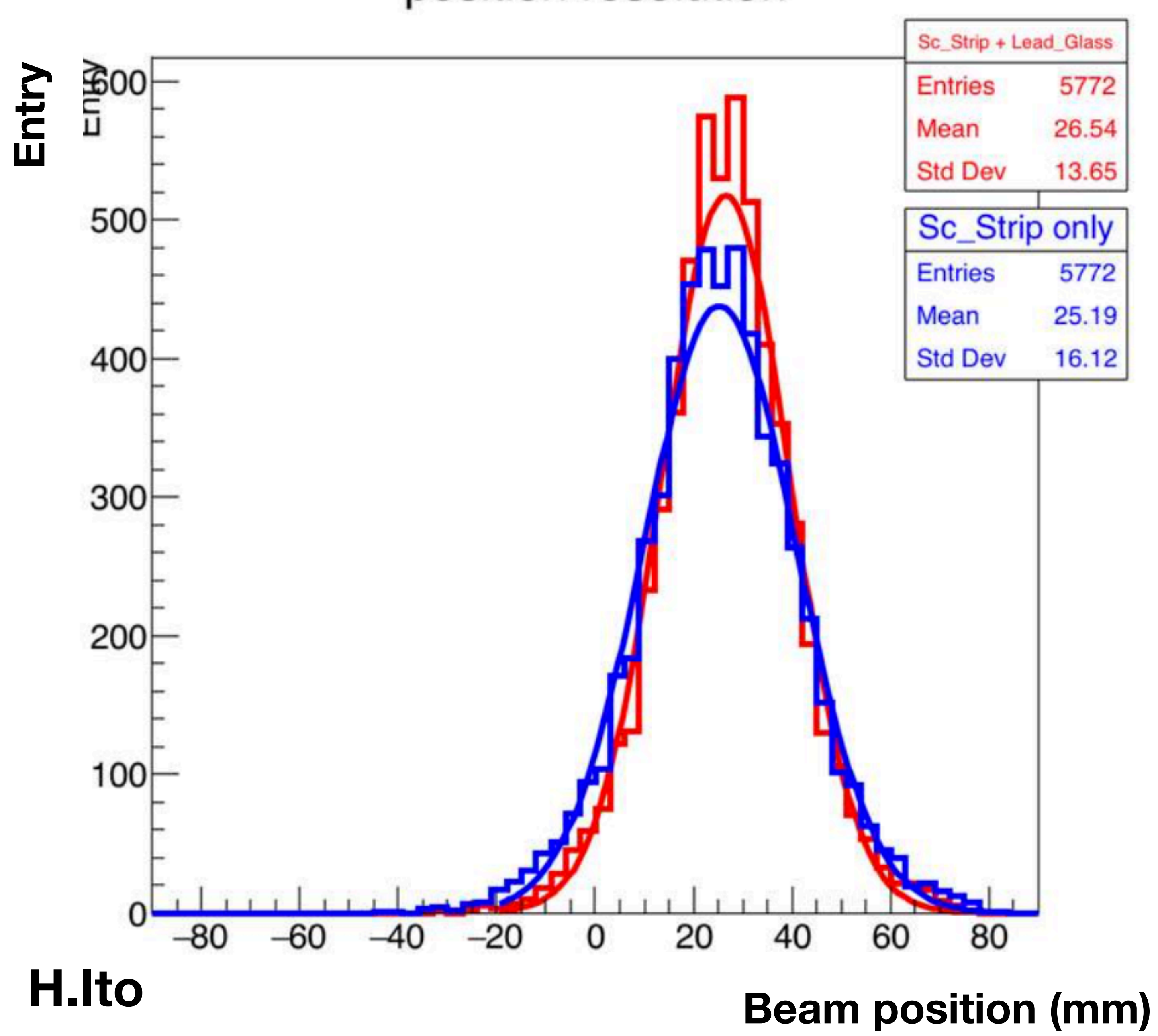
Tail catcher ADC Distribution of 400MeV e+ injected behind one LG Layer



Position Resolution

- The beam was shifted 30 mm in parallel at beam line
- The position distribution results for the scintillator layer only (blue) and with lead-glass information combined (red)
- The beam position is reconstructed by calculating centroid in each layer 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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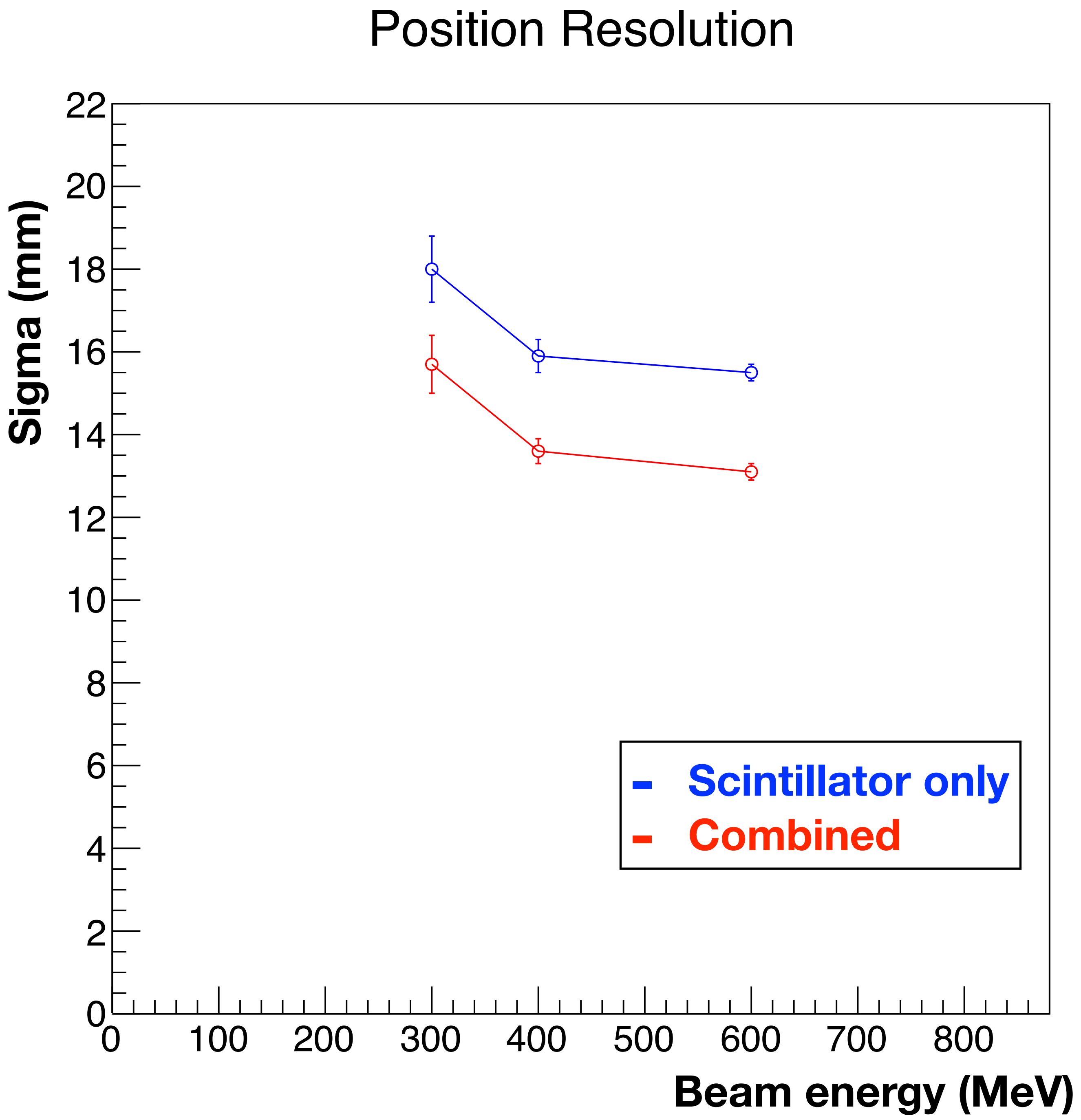
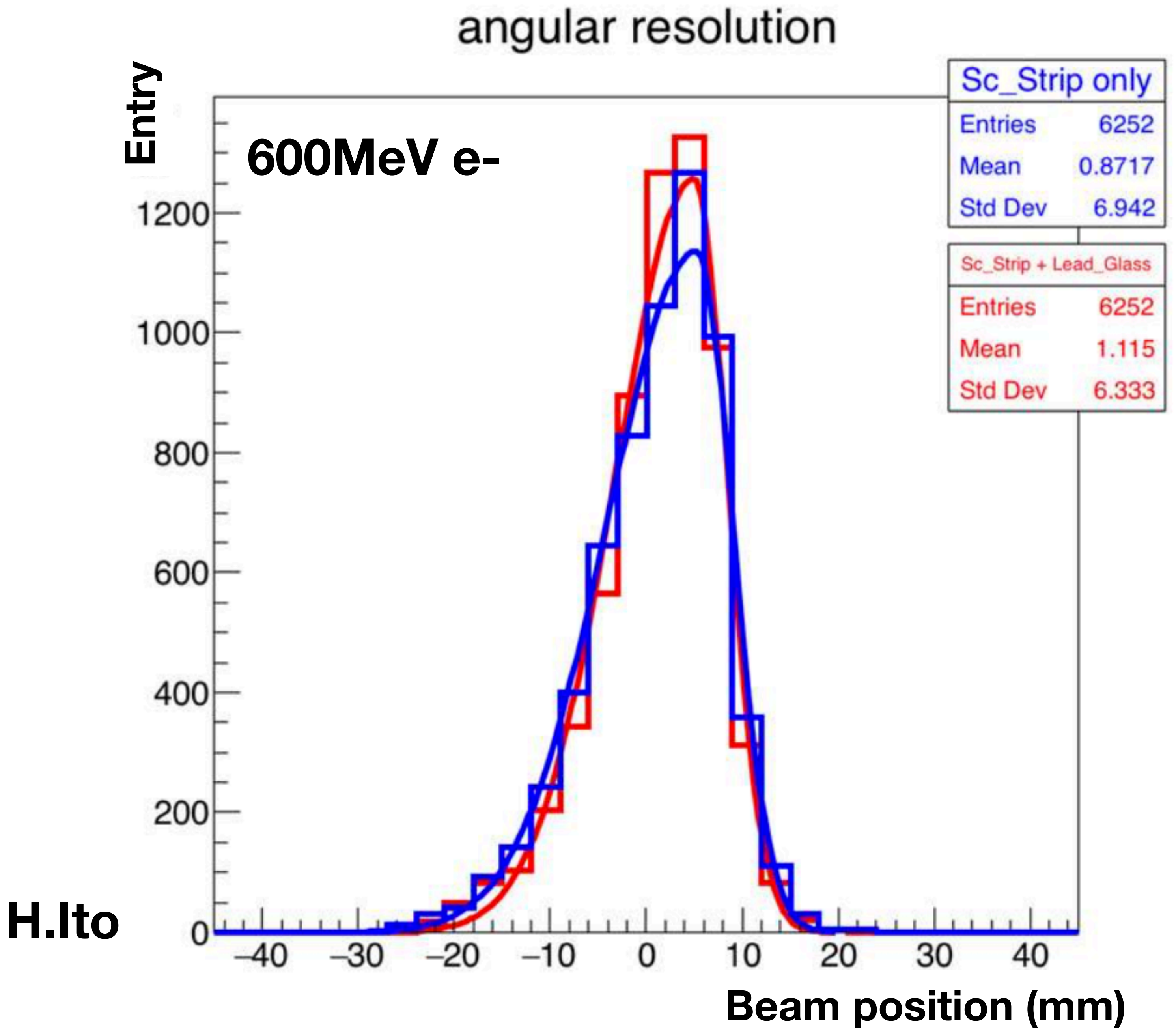
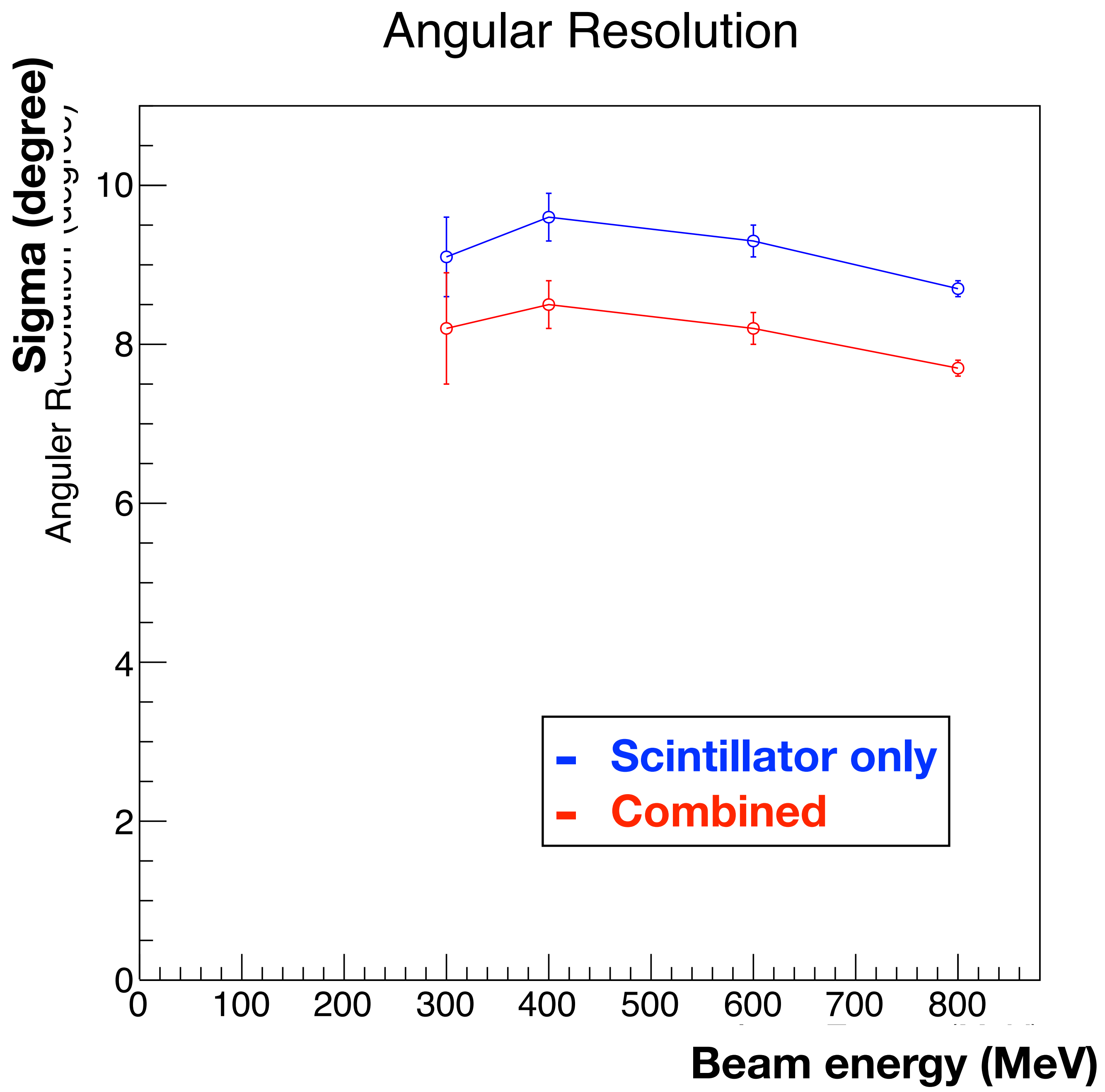


Angular Resolution

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





Position and angular resolution (simulation vs experiment)