The Development of High Granularity Calorimeter

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On behalf of CEPC Calorimeter working group

Outline

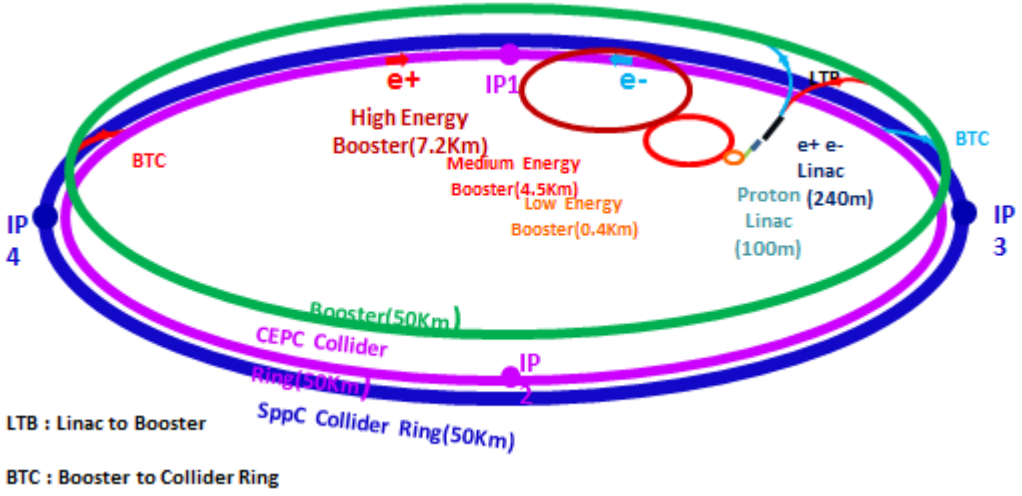
- Motivation
- Calorimeter prototypes introduction
- Beam test at CERN
- Summary

Motivation

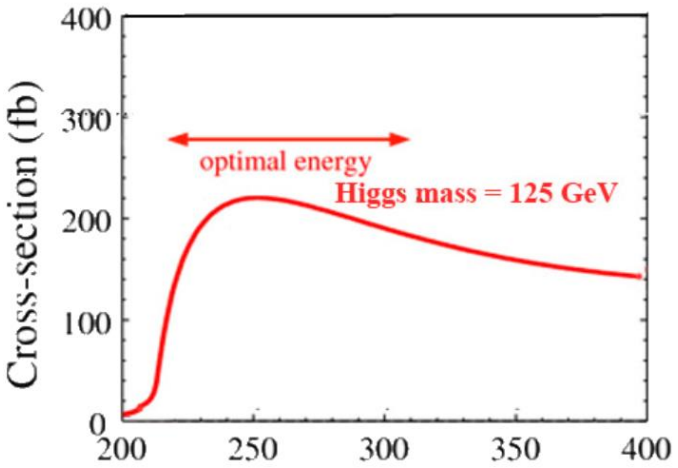
Circular Electron Positron Collider (CEPC)

$E_{cm} \approx 240$GeV, luminosity $\sim 2 \times 10^{34}$ $cm^{-2}s^{-1}$ can also rum at the Z-pole

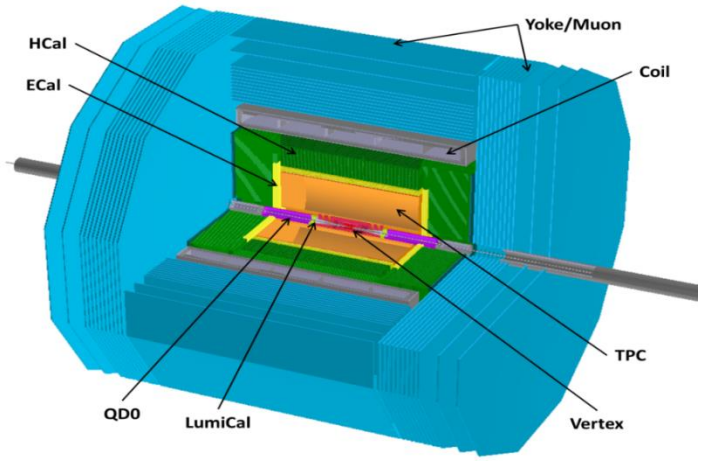
Precision measurement of the Higgs boson (and the Z boson)



$e^+e^- \rightarrow ZH$



Requirements of CEPC Calorimeter

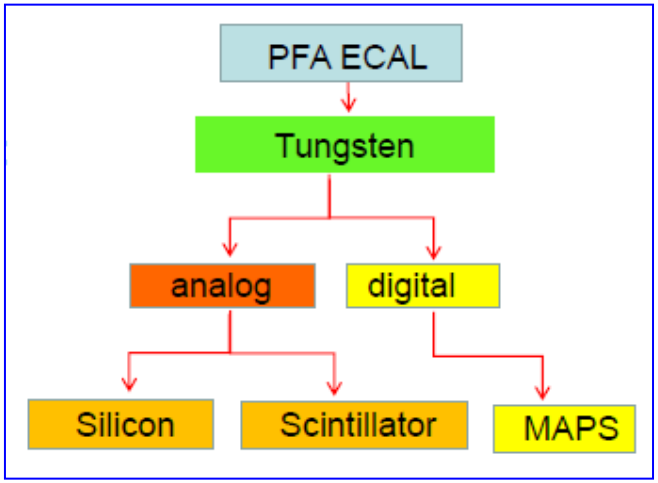


- **ILD-like detector with additional considerations.**

Challenges:

- **Momentum:** $\sigma_{1/p} < 5\times10^{-5}\ \mathrm{GeV}^{-1}$
- **Impact parameter:** $\sigma_{r\phi} = 5 \oplus 10/(p\cdot\sin^{\frac{3}{2}}\theta)\ \mu\mathrm{m}$
- **Jet energy:** $\frac{\sigma_E}{E} \approx 3-4\%$

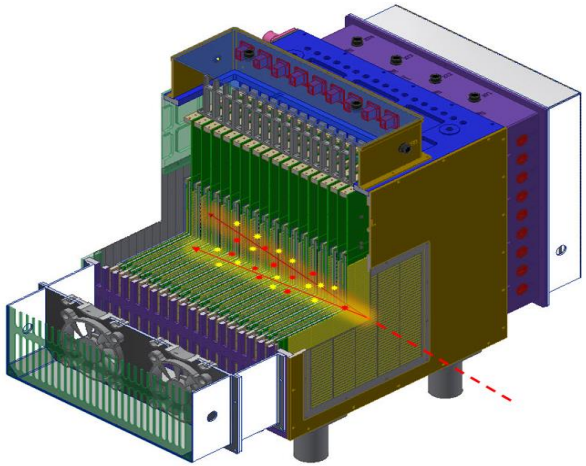
- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - Good energy resolution



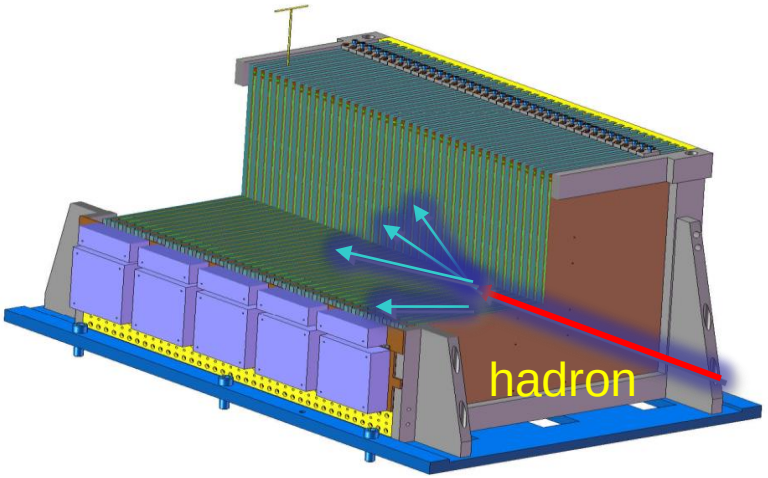
PFA Calorimeter

Sampling Calorimeter

Calo	Sampling No.	Sensitive detector	Absorber	Granularity	Electronics	Absorb length	Energy Resolution	weight
Sci-W ECAL	32	PSD+SiPM	W-Cu	5mm×5mm	SP-2E	22 X_0	16%@ 1 GeV	0.3 T
AHCAL	40	PSD+SiPM	Fe	40mm×40mm	SP-2E	4.6 NIL	60%@ 1 GeV	5.0 T



Sci-W ECAL



AHCAL

Elements of ECAL

Scintillator （5mm*45mm*2mm）

SiPM（1mm＊1mm, 10k pixels）

- Dynamic range：~100fC~200pC
- channels：36
- Dead time：2ms
- Polar: positive
- power：8mW/channel

Single Layer assembly

Cutting

Grooving

Polishing

Annealing

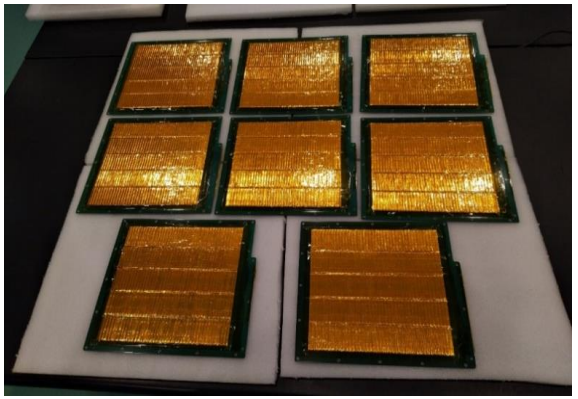
Cleaning

Packing

Visual inspection

cleaning

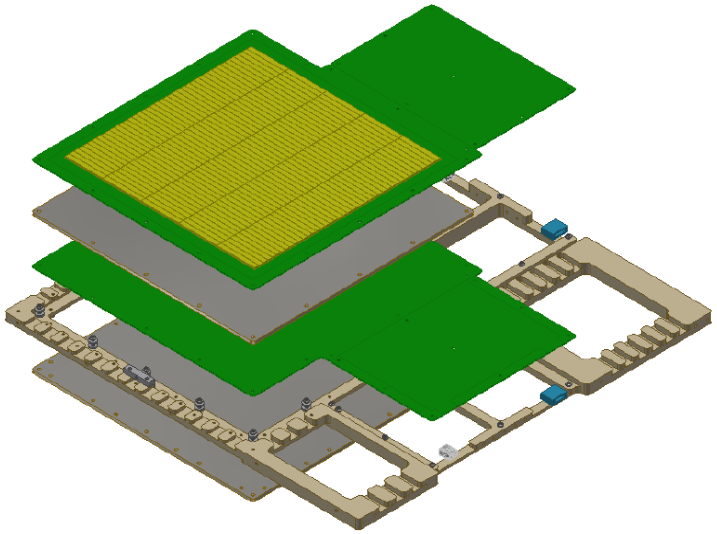
assembling

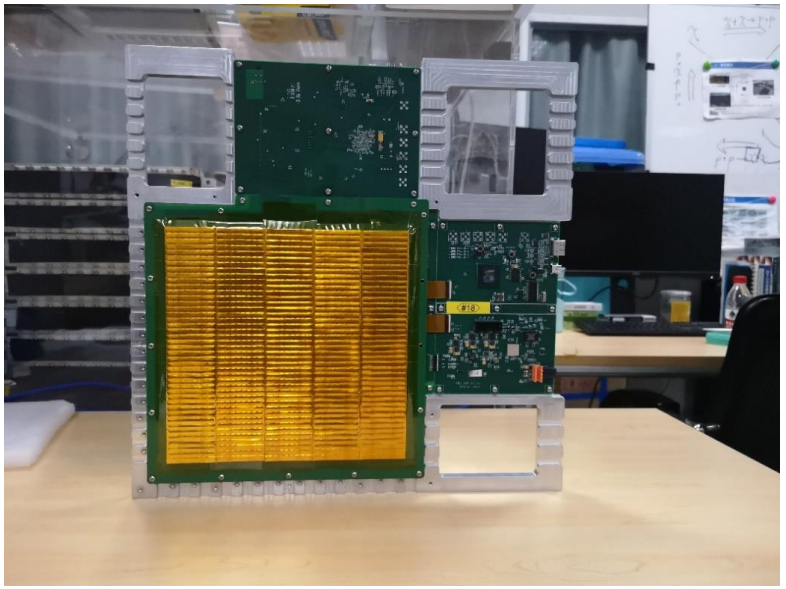


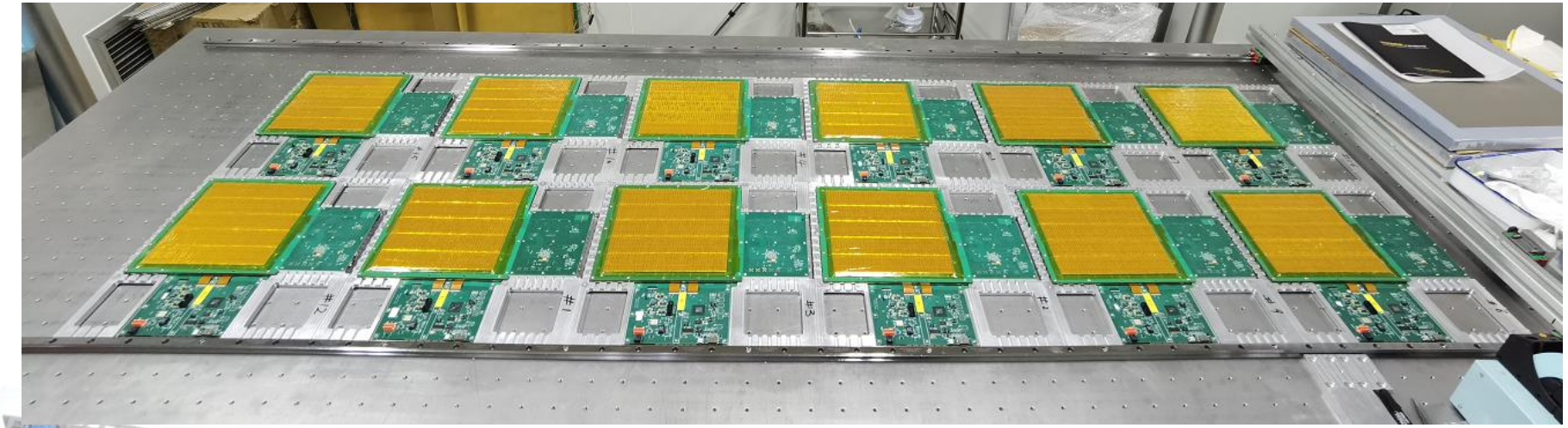
EBU

The single layer prototype was assembled in Shanghai Institute of Ceramic (SIC)

Super-layer assembly

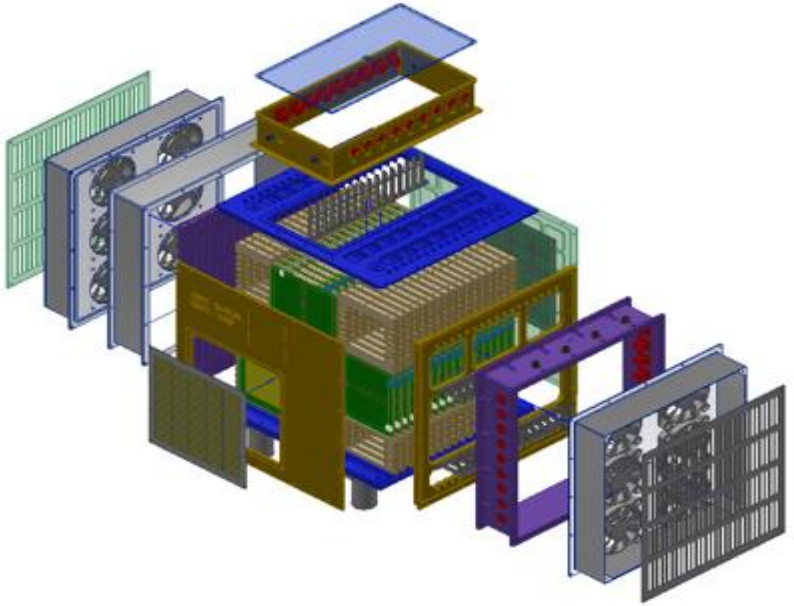






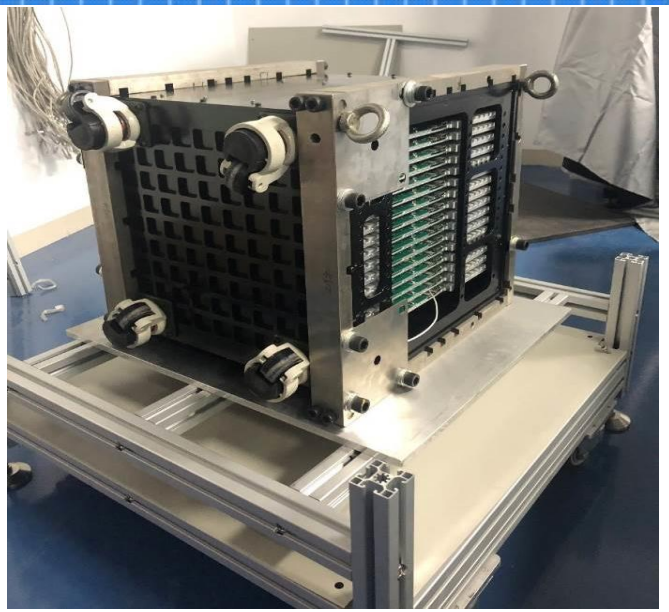
Sci-W ECAL

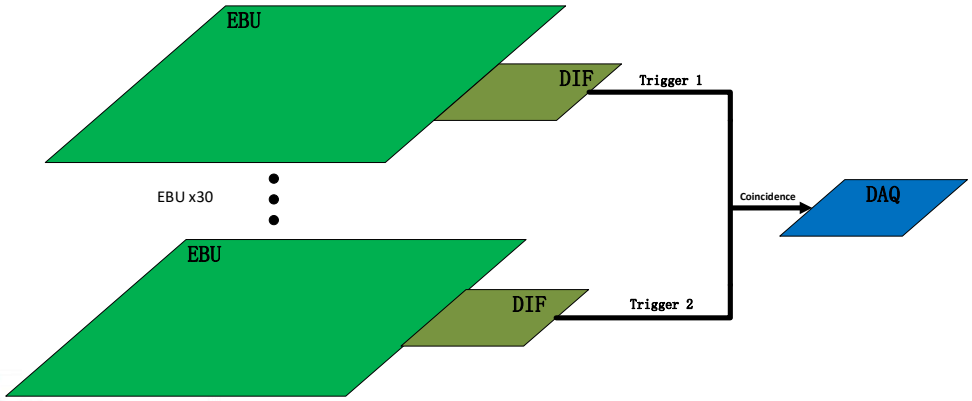
- Sci-W ECAL
  - 32 layers，16 super-layes
  - 210 channels of each layer，total channels:6720
  - Sensitive area：22cm×22cm

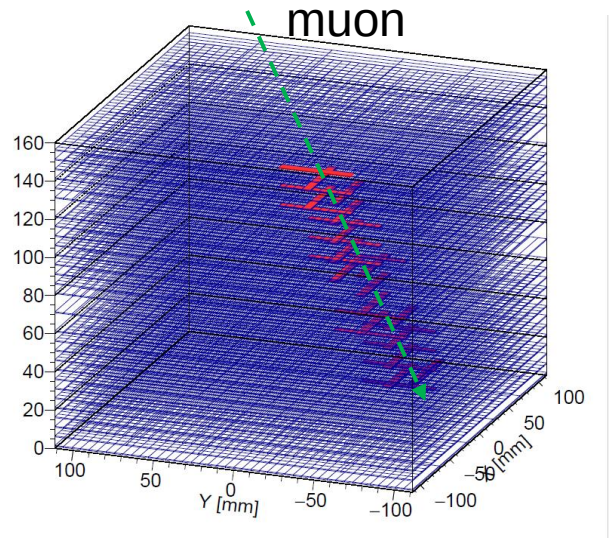


Cosmic Ray test

- Long term cosmic ray test: 90 DAYs
  - ScECAL has been rotated by 90 degree
  - Coincidence trigger of Layer1 & Layer29
  - Event rate : ~ 16 per minute
  - ~1.5 million cosmic ray events collected
- Purpose
  - Function verification (stability, temperature correction, etc)
  - EBU efficiency and Position resolution
  - Cell-to-cell MIP calibration

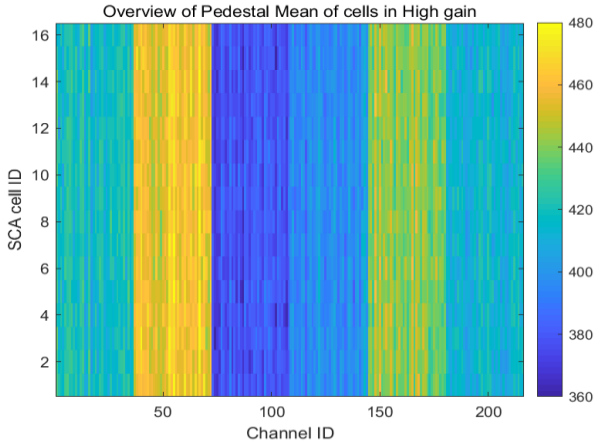




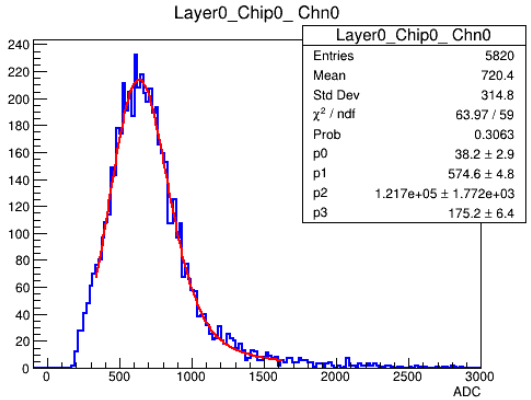


pedestal

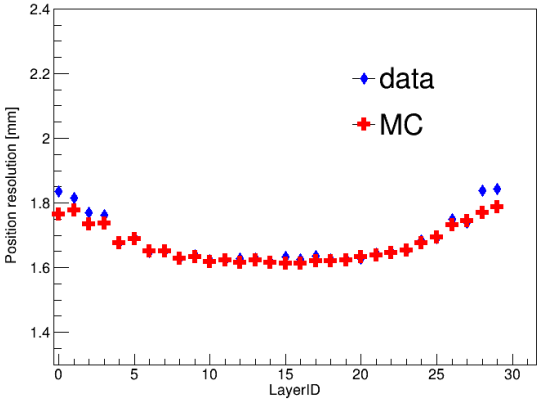
- The noise of each cell in each channel tested by random trigger from DIF boards
  - The pedestal position of different chips is a little different
  - The pedestal position of the same chip is more uniform
  - The pedestal position is very stable with the change of time



Pedestal position of each cell in each channel



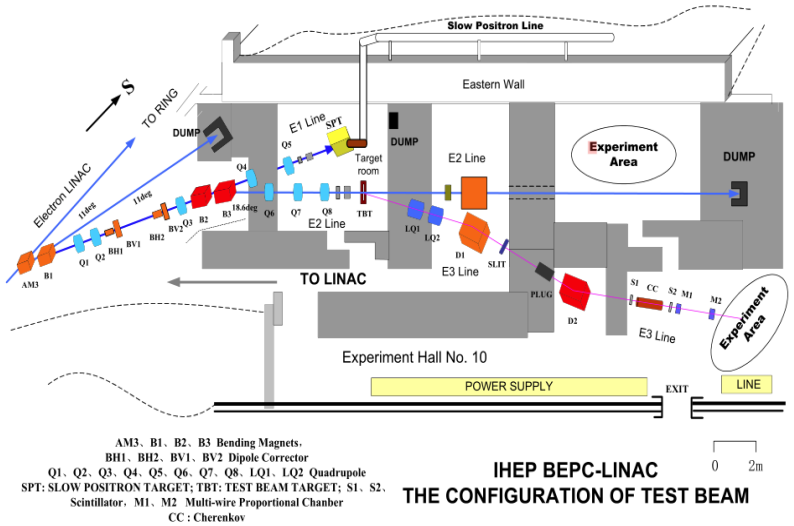
MIPs

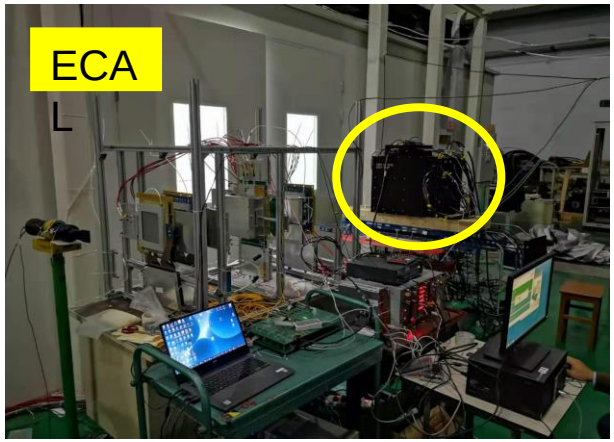


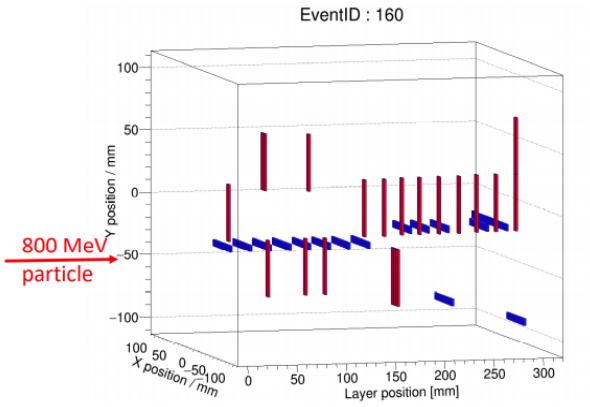
Position Resolution

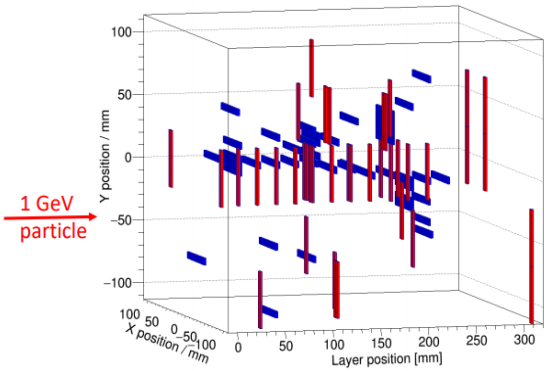
Beam Test in IHEP

- 2020, E3 beam line
- 2.5 GeV e- interacted with Be target
- Three momentums were selected in the beam
  - 500 MeV/c, 800 MeV/c, 1000MeV/c



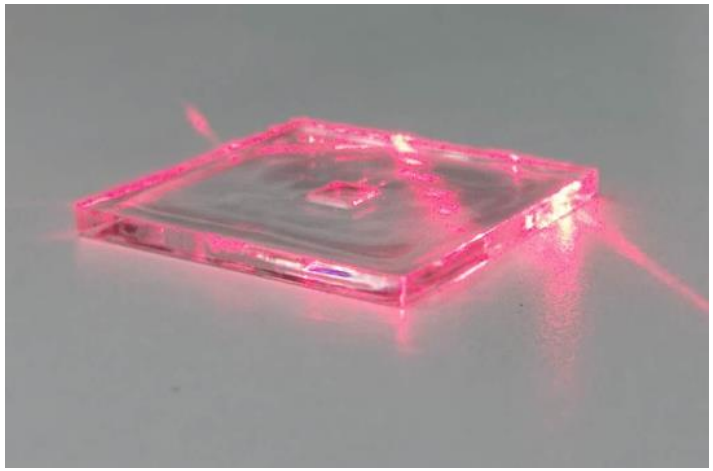






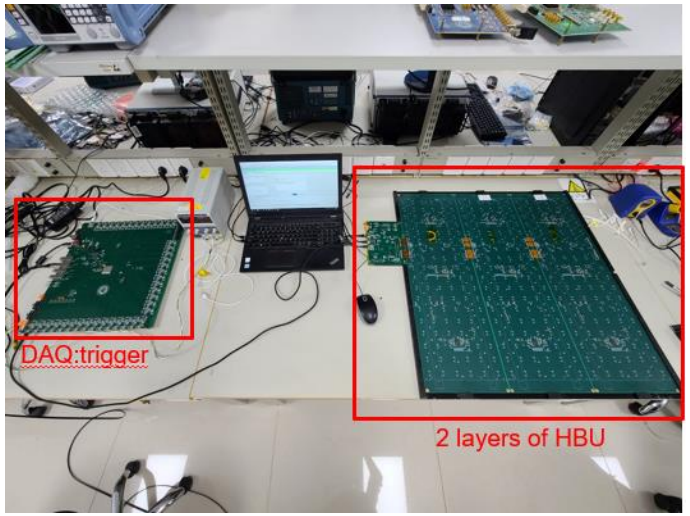
AHCAL

Scintillator



Scintillator Test

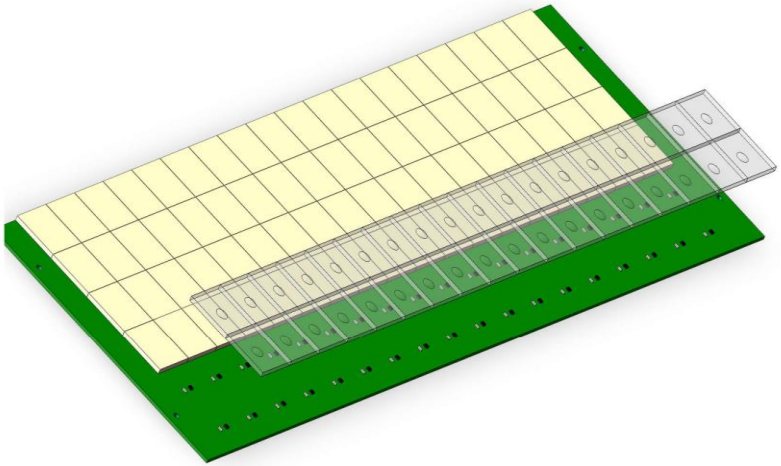
HBU



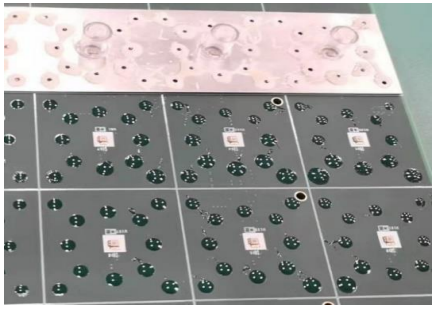
Electronics Test

HBU

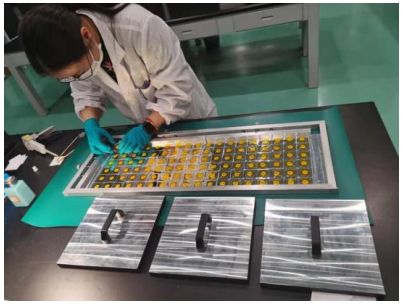
- assemble the scintillator on HBUs
  - Fix the scintillators on the HBU with glue
  - press them with cover plate to make solidify



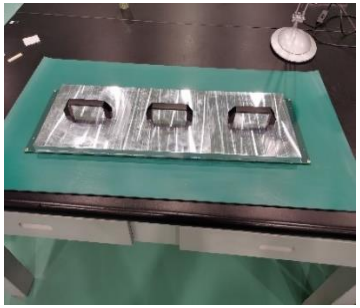
Scintillators on HBU



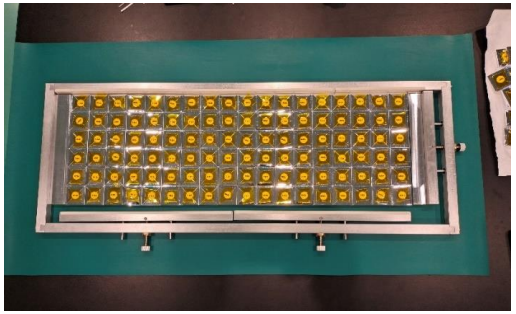
glue



assemble



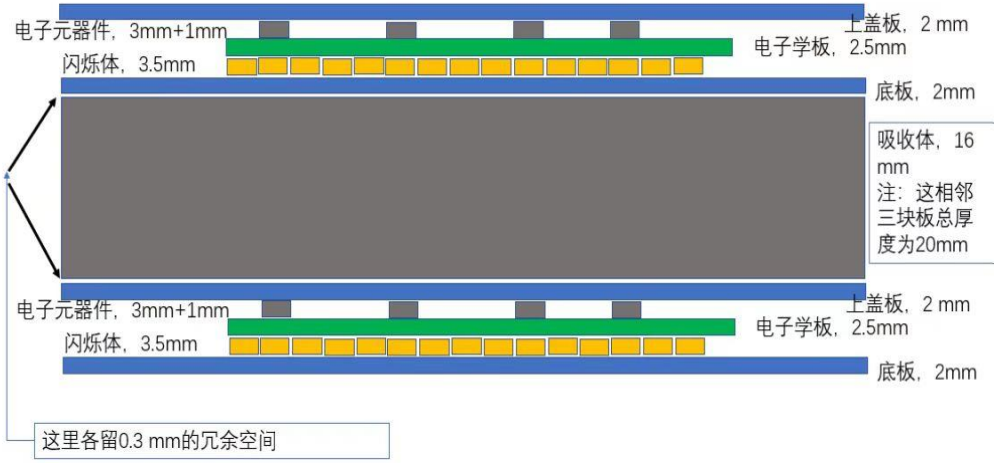
solidification

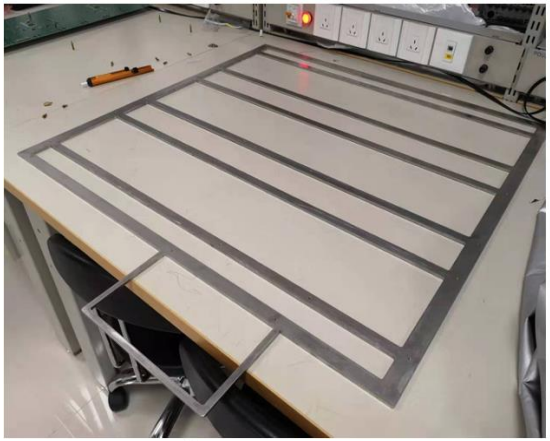


finish

AHCAL

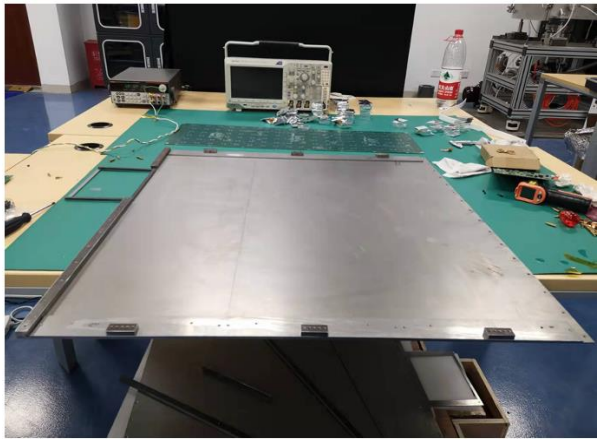
- Sensitive Layer
  - The single layer sensitive layer is encapsulated in a "box“
  - The "box" material is the same as the absorber (iron), and its own thickness is a part of the absorber





V1

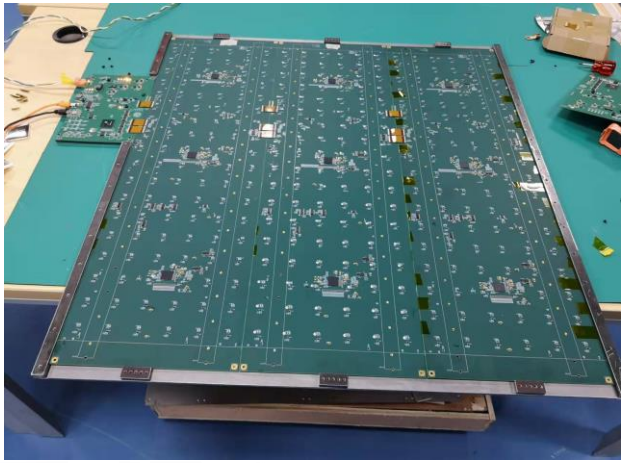
V2

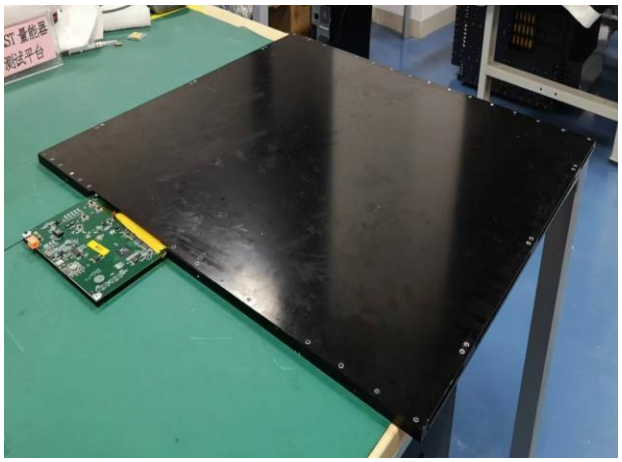


V3

AHCAL Progress I

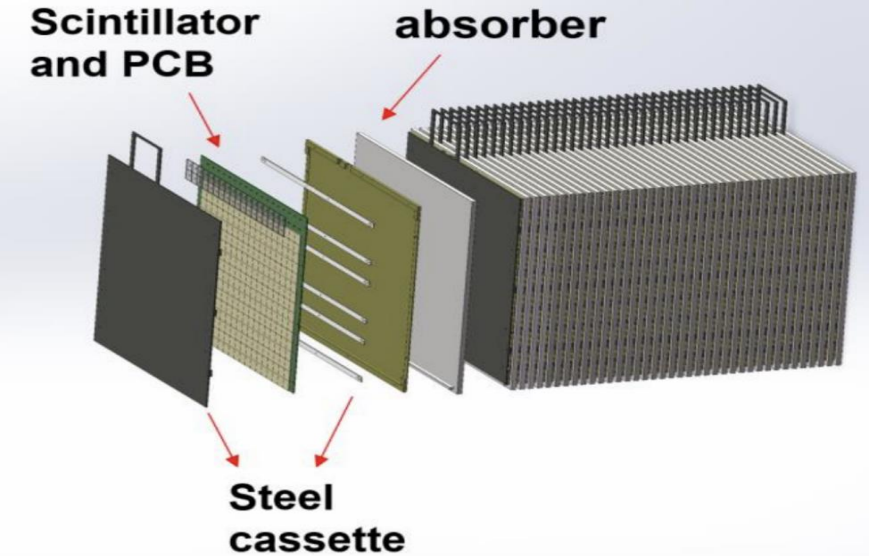
- HBU assembled to cassette
  - The assembly of HBU cassettes have a unified process flow

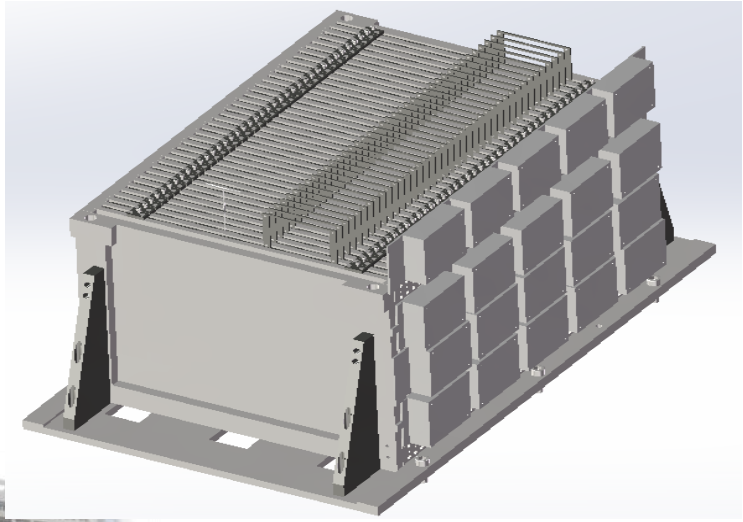


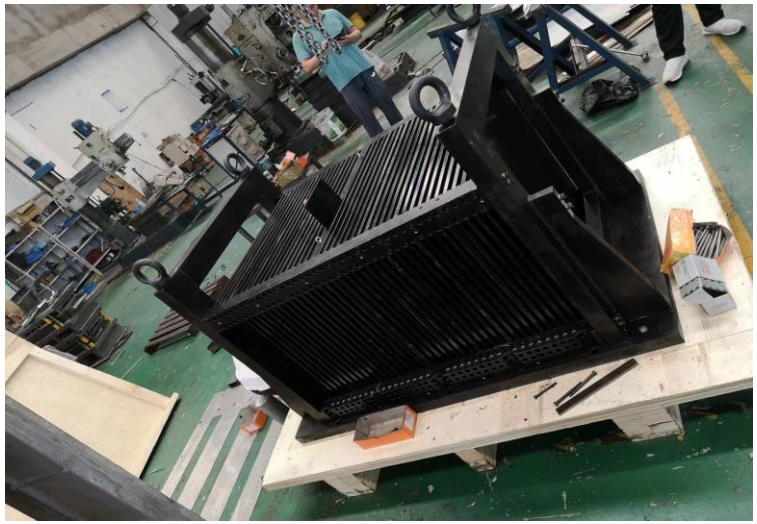


AHCAL

- The AHCAL structure
  - It has 39 iron absorbers, 16mm
  - The gap between two neighbor iron plates is 14.5 mm, and the HBU cassette could be inserted in it

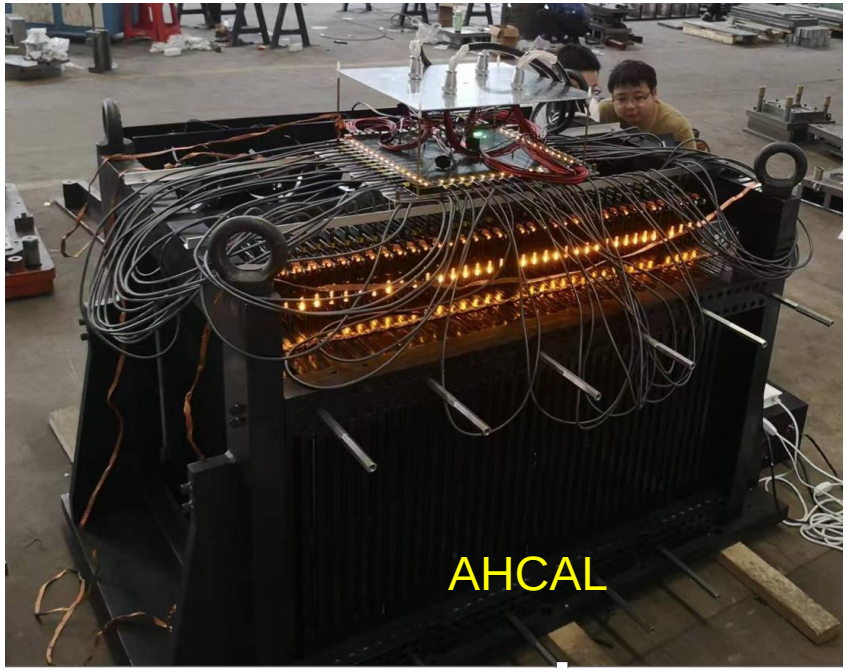


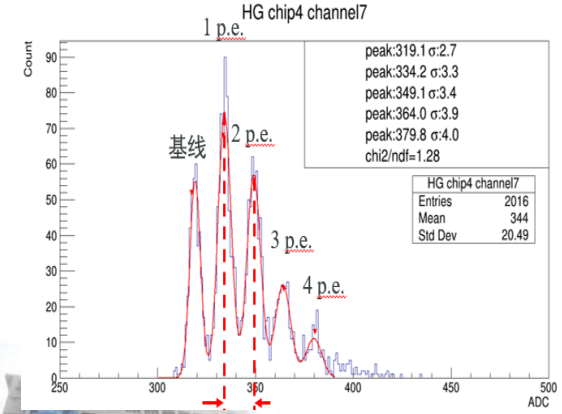


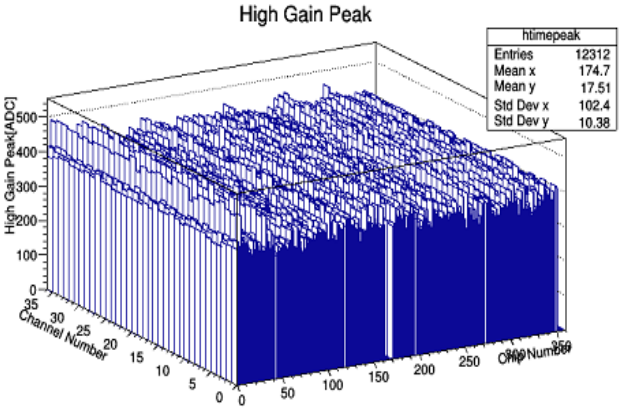


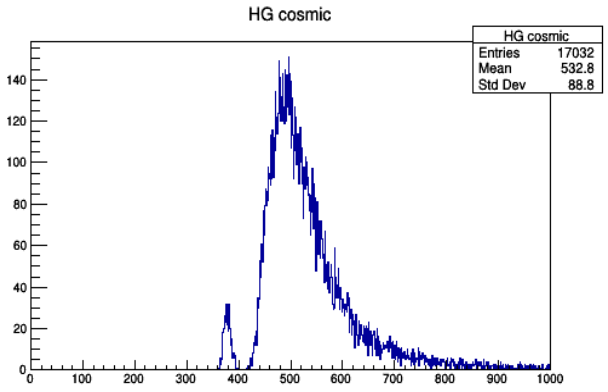
AHCAL

- The AHCAL was assembled this summer
  - 40 sensitive layers, and sensitive area is ~ 72 cm x 72 cm
    - Each layer has 324 sensitive cells
    - Total number is 12960









Supporting Table

- The supporting table for calorimeter beam testing
  - The table can support ECAL and AHCAL at the same time
  - The horizontal movement distance is ±20 cm, and the up and down movement distance is ±15 cm

Supporting table

AHCAL on this table

Beam test

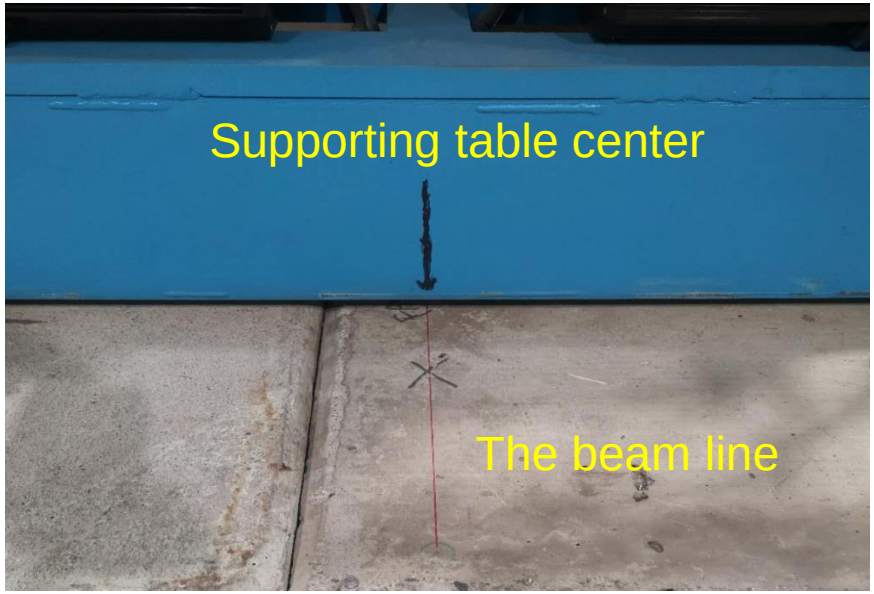
- Two weeks of high-energy particle beam test at H8 of SPS
  - The H8 beam line is a high-energy, high-resolution secondary beam line.
  - The maximum momentum that can be transported in the experiments is 400 GeV/c protons
  - or secondary mixed hadron beams within the range 10-360 GeV/c.
  - the electron beams with variable purity (10 – 99 %) are also possible. The maximum Δp/p acceptance of the line is 1.5%.

SPS: October 2022

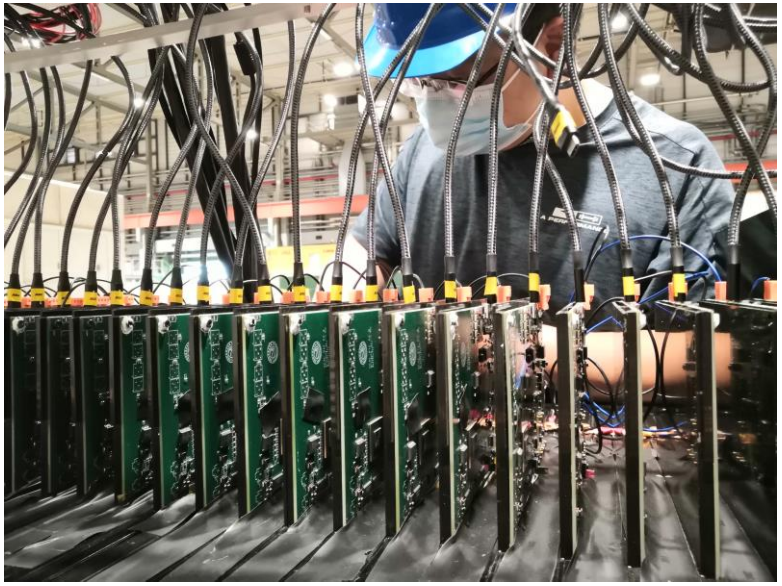
schedule issue date: 30-May-2022 Version: 1.10

		Mon 26 Sep	Tue 27 Sep	Wed 28 Sep	Thu 29 Sep	Fri 30 Sep	Sat 1 Oct	Sun 2 Oct	Mon 3 Oct	Tue 4 Oct	Wed 5 Oct	Thu 6 Oct	Fri 7 Oct	Sat 8 Oct	Sun 9 Oct	Mon 10 Oct	Tue 11 Oct	Wed 12 Oct	Thu 13 Oct	Fri 14 Oct	Sat 15 Oct	Sun 16 Oct	Mon 17 Oct	Tue 18 Oct	Wed 19 Oct	Thu 20 Oct	Fri 21 Oct	Sat 22 Oct	Sun 23 Oct	Mon 24 Oct	Tue 25 Oct	Wed 26 Oct	Thu 27 Oct	Fri 28 Oct	Sat 29 Oct	Sun 30 Oct
Week		39							40							41							42							43							
Machine																																				
North Area	T2 - H2	Calice Sdhcal	A. Ariga PPE172 NA65							D. Lazic PPE172 CMS HGCAL							Y. Itow PPE172 LHCf							H. Schindler PPE172 LHCb ECAL												
	T2 - H4	V. Gninenko PPE134+PPE144 NA64e								EB. Holzer Place-holder														M.R. Jäkel, E. Oliveri PPE134, PPE154 GIF RD51												
	T4 - H6 main user	CMS PIXELS	A. Rummler PPE146 ATLAS ITK PIXEL							A. Rummler PPE156 ATLAS AFP							Dannheim Dao PPE156 MONO LITH							E. Figueras RD50							H. Danielsson PPE136 NA62					
	T4 - H6 parallel user	EP hybrid	A. Rummler PPE146 ATLAS AFP BCM							A. Rummler PPE146 ATLAS ITK PIXEL							V. DaoD. Dannheim PPE146, PPE156 ATLAS MALTA EP PIXEL							H. Danielsson PPE136, PPE146 NA62 ATLAS HGTD							EP hybrid ATLAS HGTD E. Gkougkousis PPE136, PPE146						
	T4 - H8	UA9 Totem	W. Scandale PPE128 UA9							H. Schindler, N. Neri PPE128, PPE138, PPE158, PPE168 LHCb CMS MTD (SPADOM)														J. Liu, E. Scomparin 158 or 168, PPE138 Calice ScW ECAL NA60+												

Install the detectors in beam area



Install the detectors in beam area

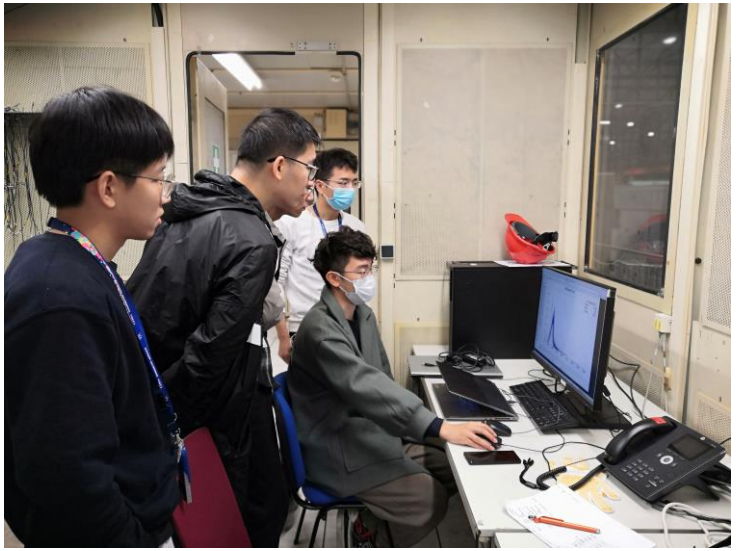


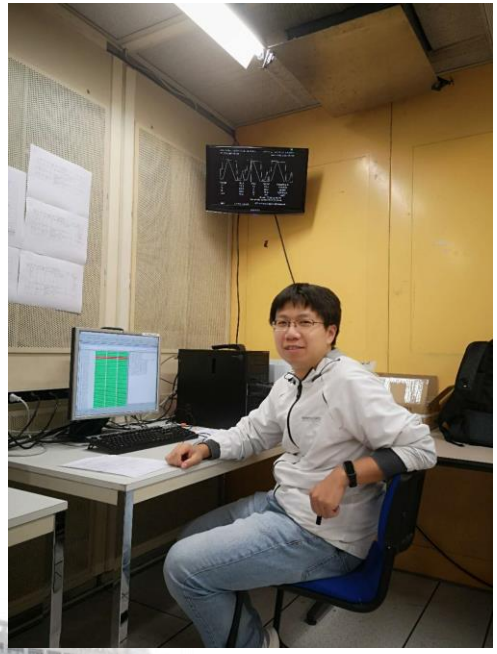
Trigger

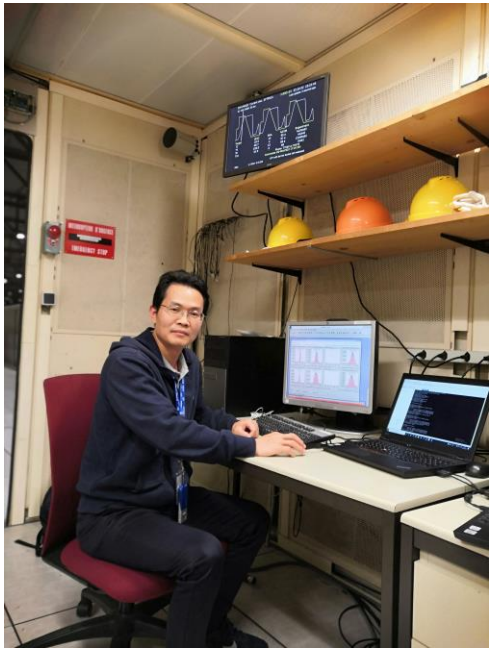
alignment

Beam Test

- The calorimeters has been calibrated in H8
  - 10 – 120 GeV/c pions
  - 10 – 40 GeV/c positrons

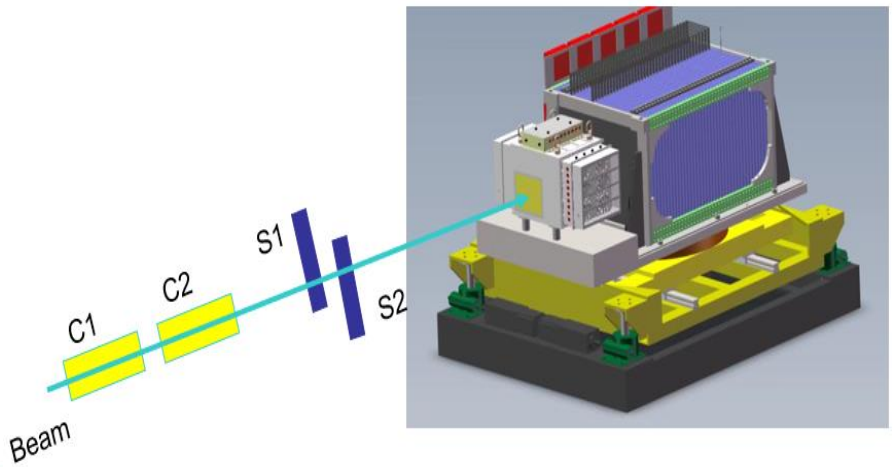


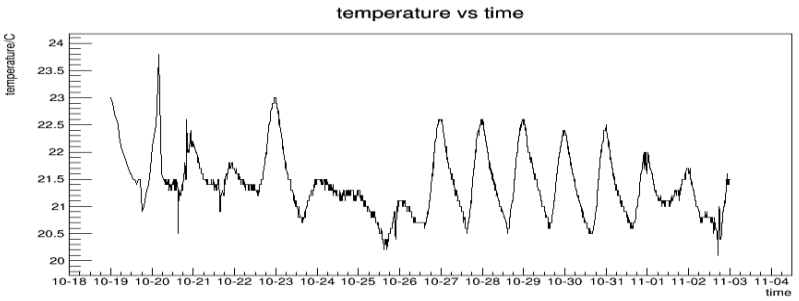


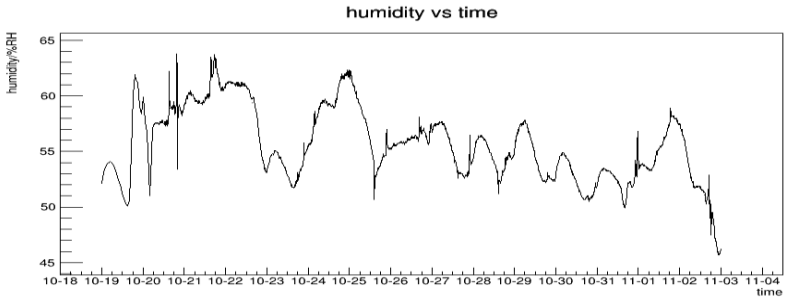


Beam test

- We tested calorimeter with mu+, pi+, positron
  - Muon+
    - 160 GeV/c, 108 GeV/c
  - Pion+
    - 10 - 120 GeV/c, one million per point
  - Positron
    - 10 - 120 GeV/c, 100 thousand per energy point

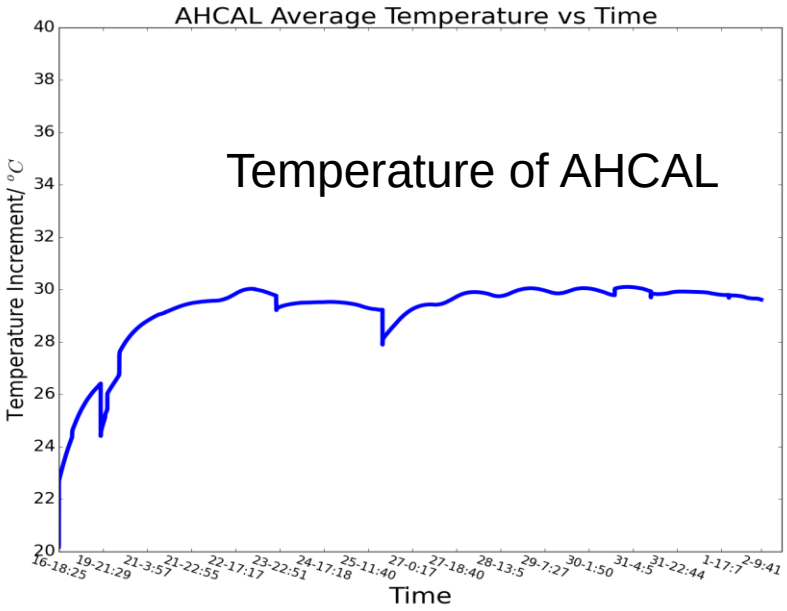






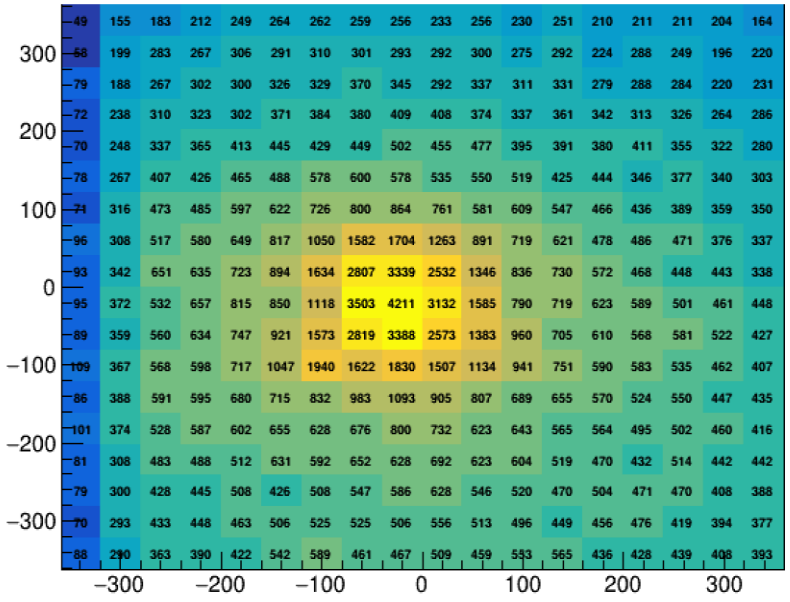
AHCAL test

- First of all, we tested AHCAL independently
- The internal temperature of AHCAL rose slowly in the first three days of the test and then tended to be stable

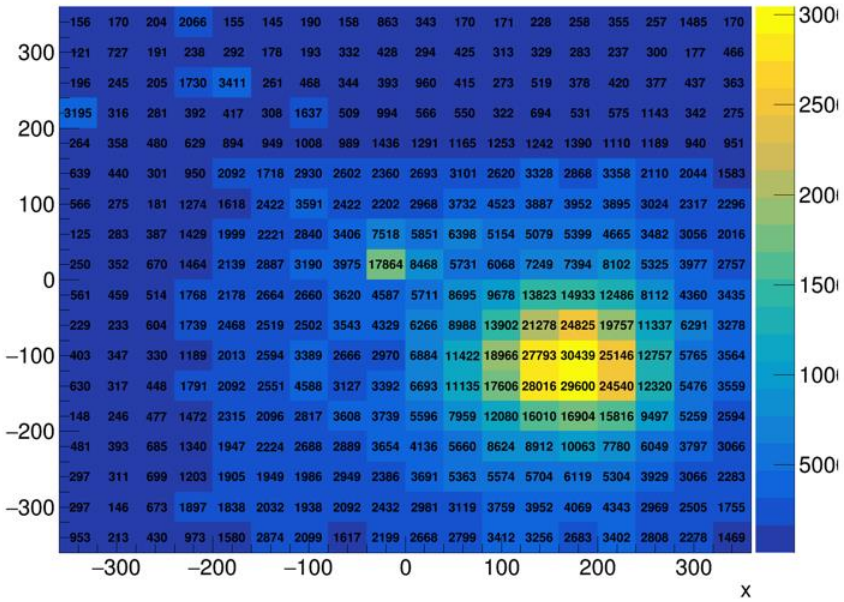


AHCAL Test with Mu+

- The energy reference should be taken from MIPs which could be calibrated using high energy muons
- Muon halo mode with 160/108 GeV/c
- The halo size is about 20 cm x20 cm, and we changed the supporting table to test different area



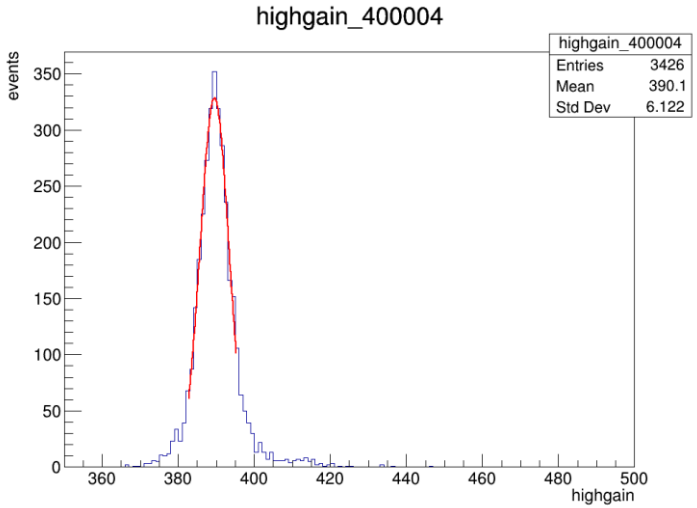
Hitting map

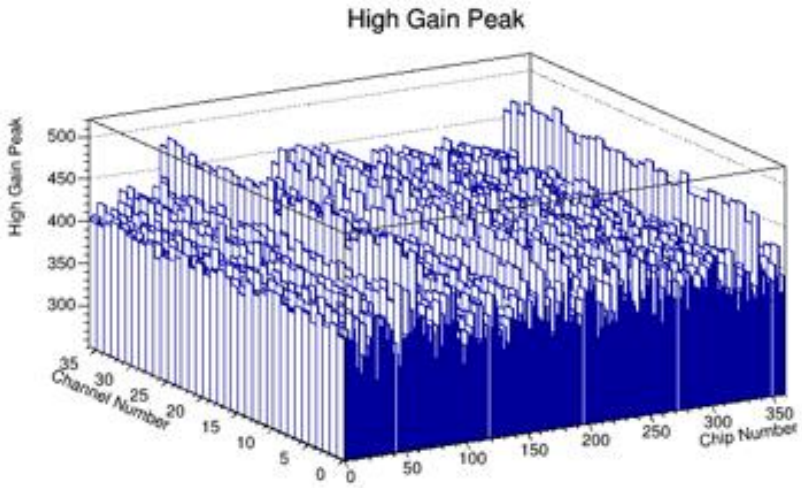


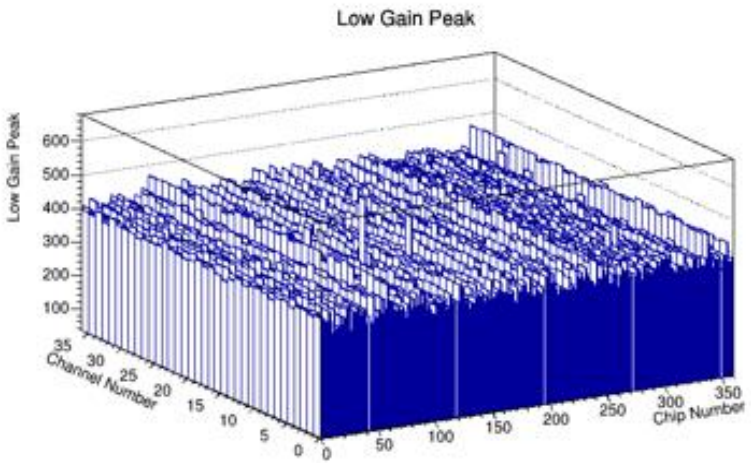
Hitting map

AHCAL Test with Mu+

- Pedestal represents the offset and noise level of the readout channel
- We can easily obtain from the muon beam data to select the unit that have not been hit

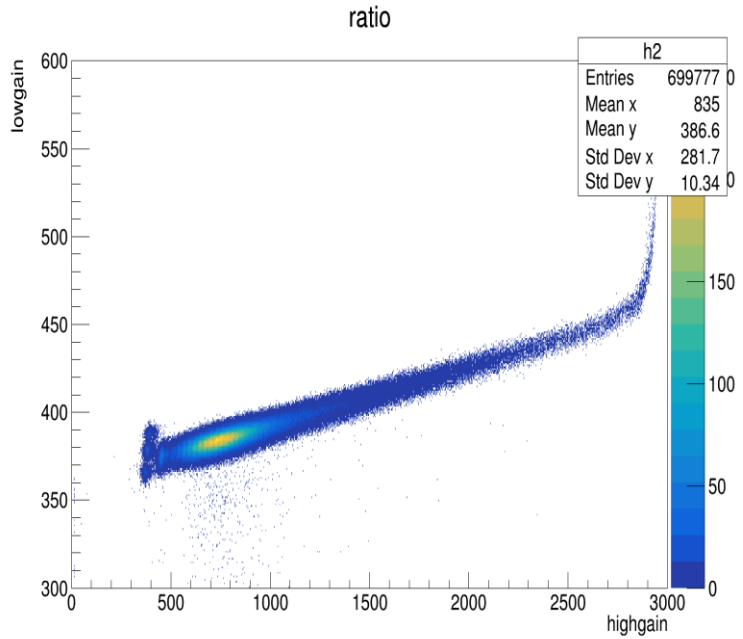


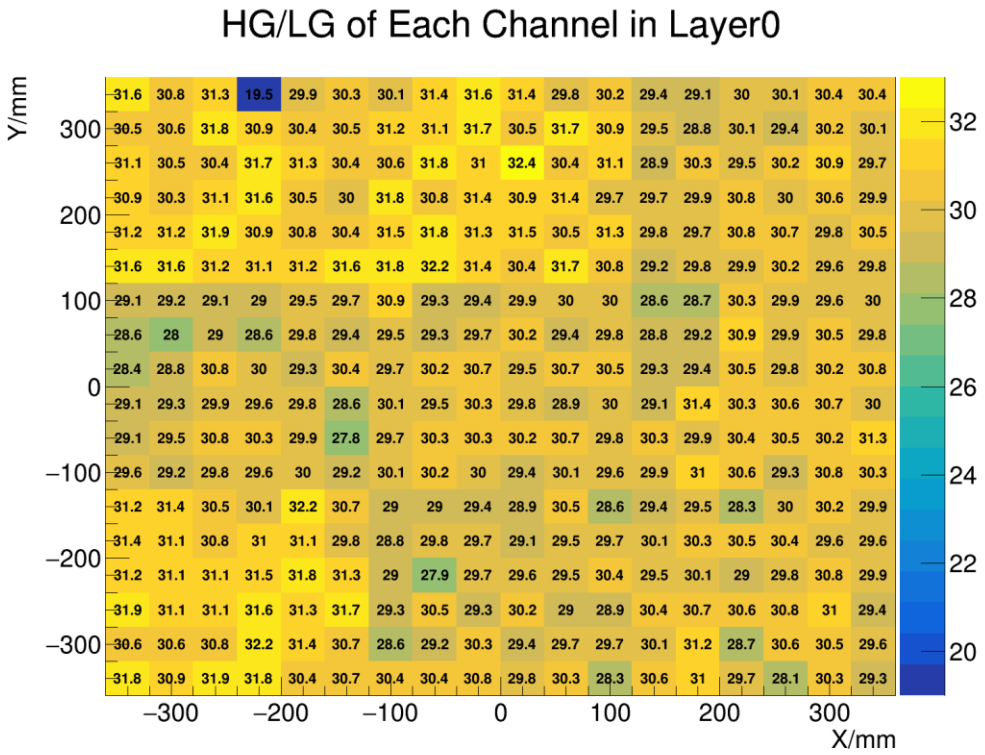




AHCAL Test with Mu+

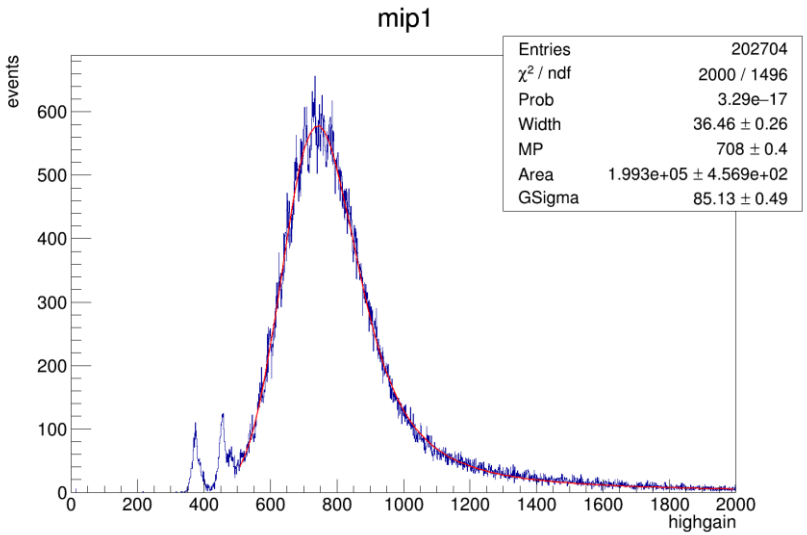
- The ratio of High/low gain is another important parameter for energy reconstruction
- The relationship could be get from the muon test data
- Most of them are around 30

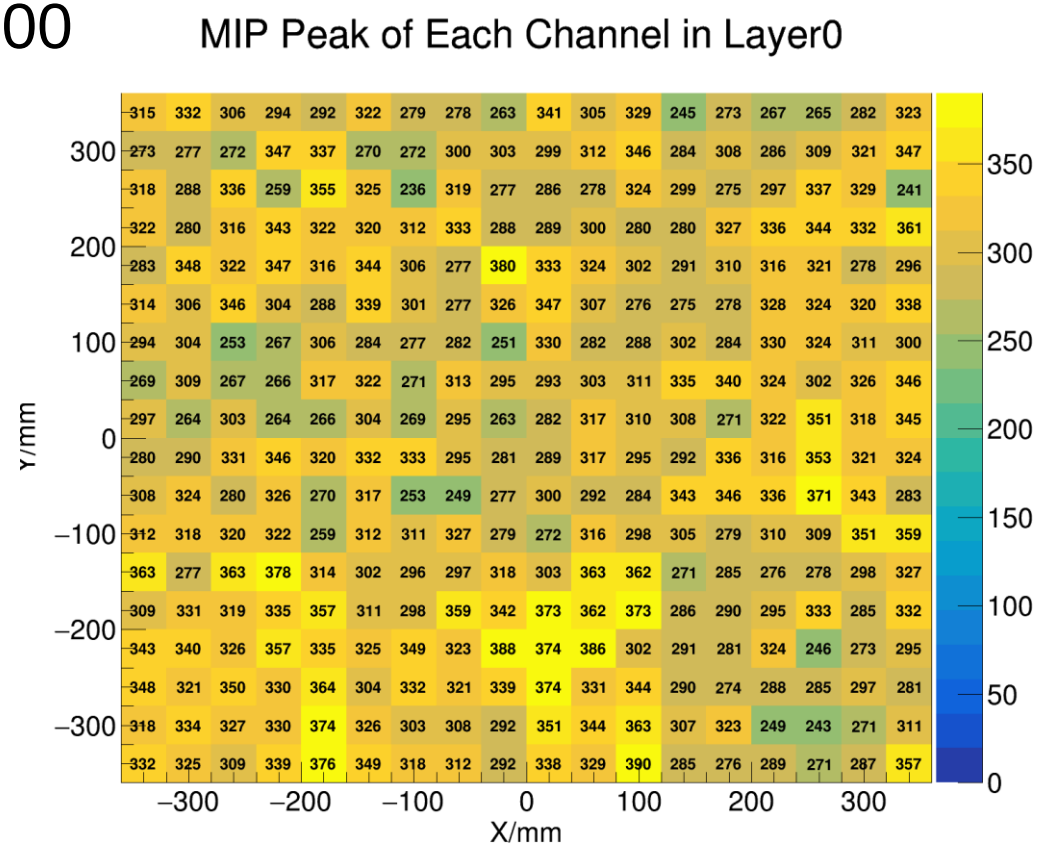




AHCAL Test with Mu+

- The MIPs value is the energy reconstruction reference
- The relationship could be get from the muon test data
- Most of them are around 300

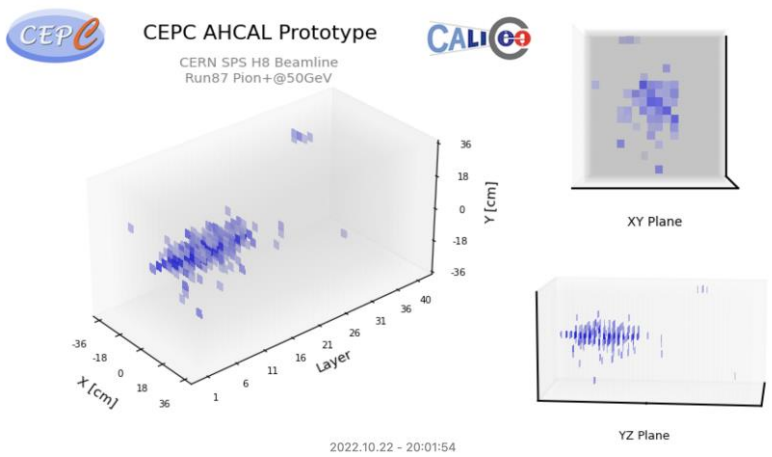




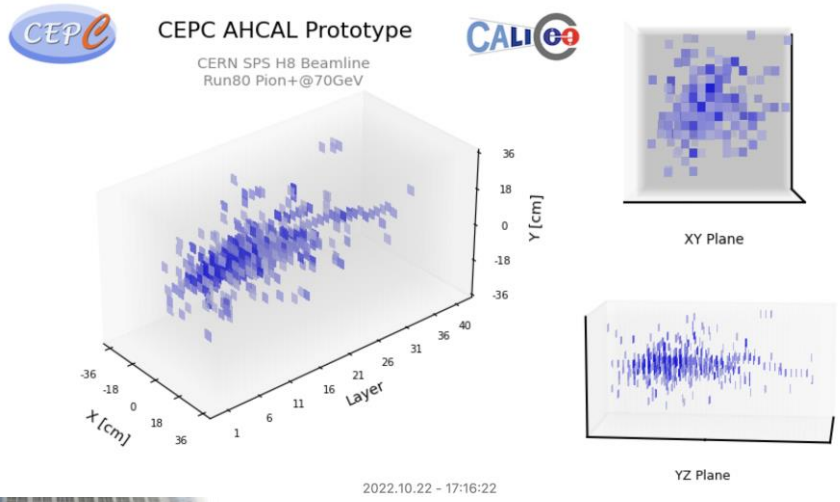
AHCAL Test with pion+

- The energy response of AHCAL was studied by pions
- The calorimeter could cover the whole shower

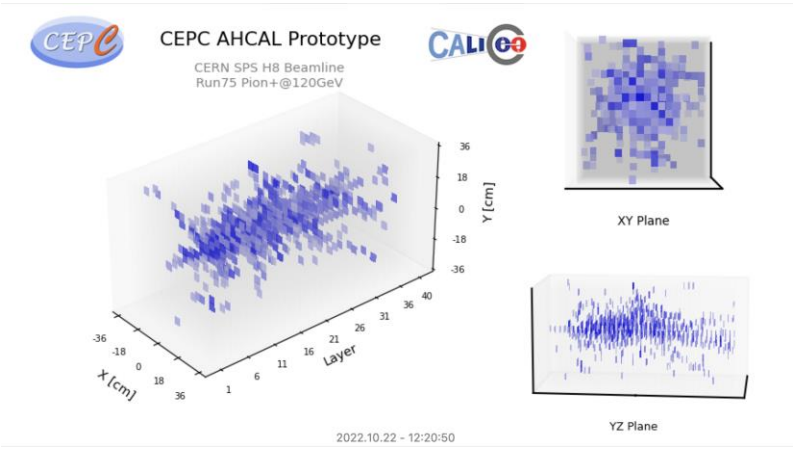
50 GeV



70 GeV

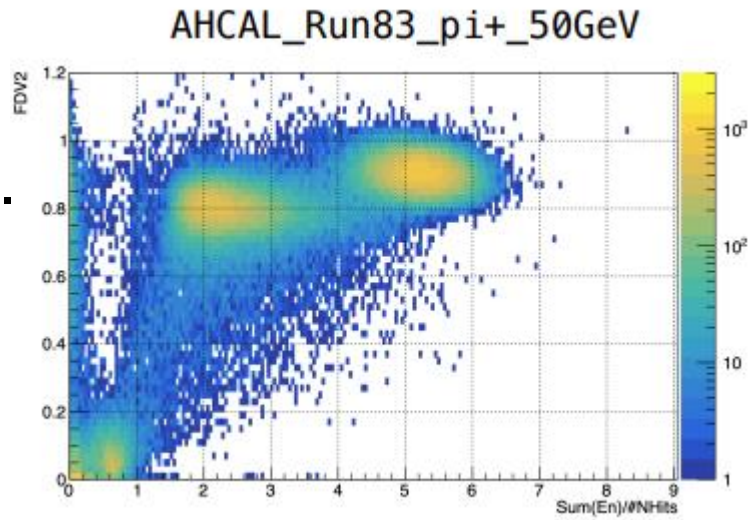


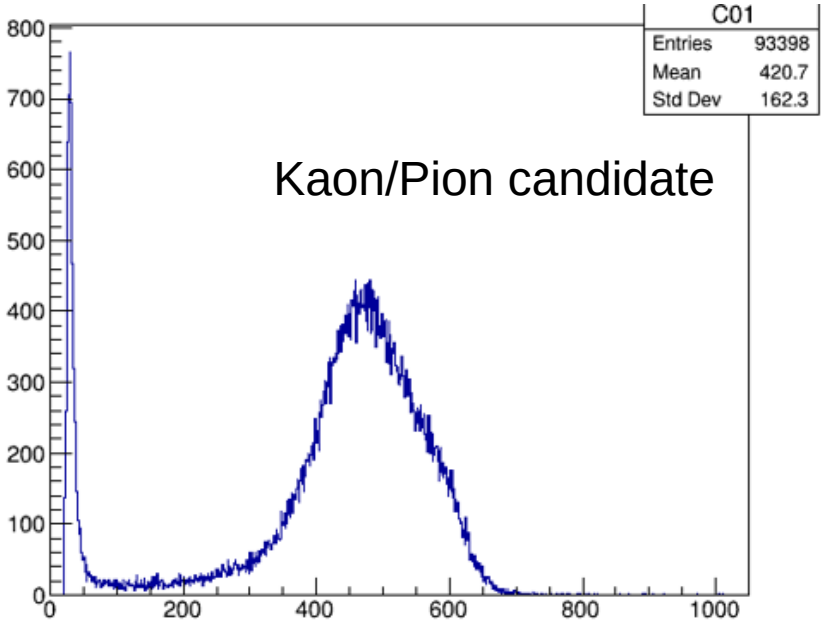
120 GeV

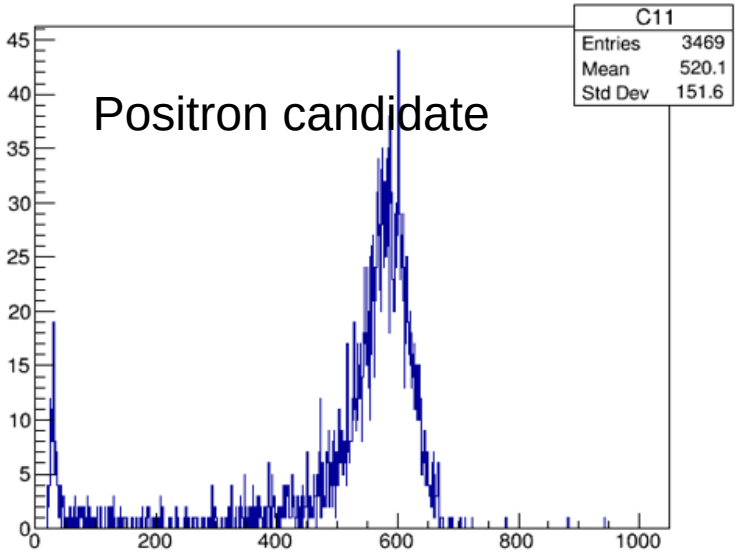


AHCAL Test with pion+

- The Cherenkov detectors in the beam were also used to do the PID.
  - One is low pressure
  - The other is high pressure



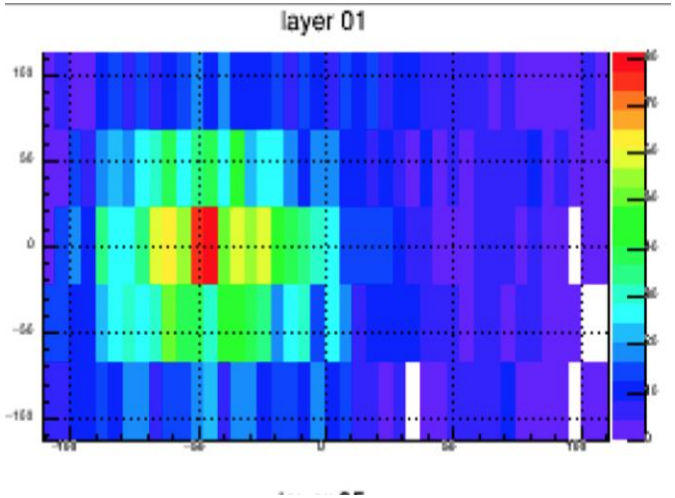


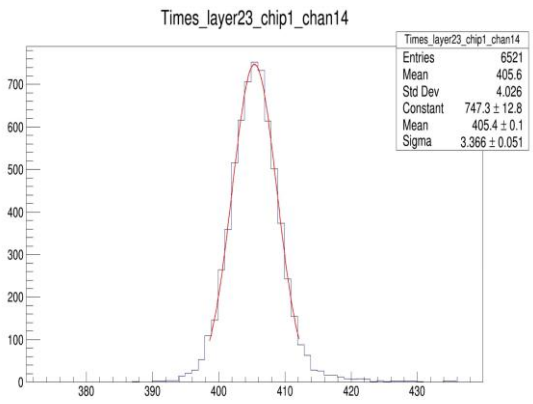


Combined Test

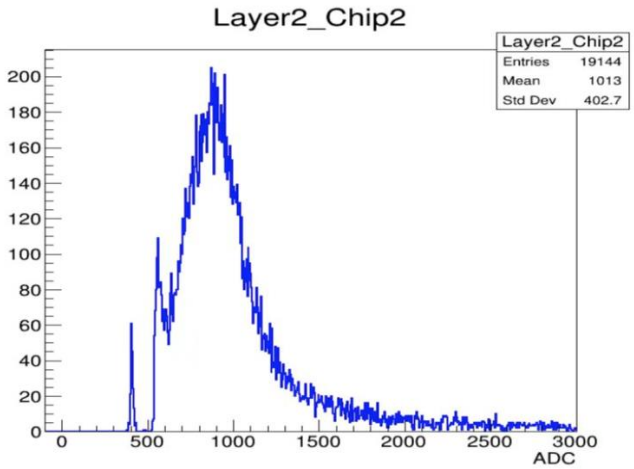
Sci-W ECAL Test with Mu+

- The ECAL also tested using muons with 108 GeV/c
- Different locations were scanned during the test

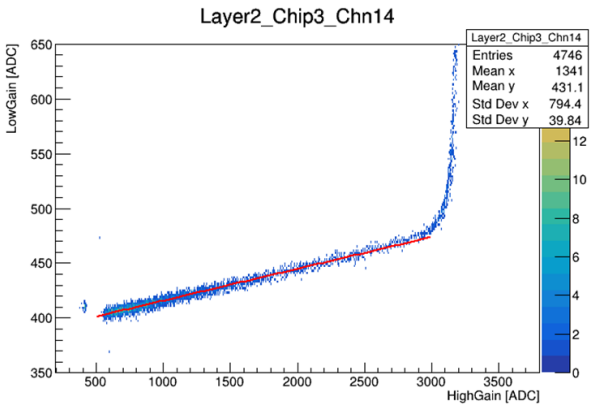




Pedestal



MIPs

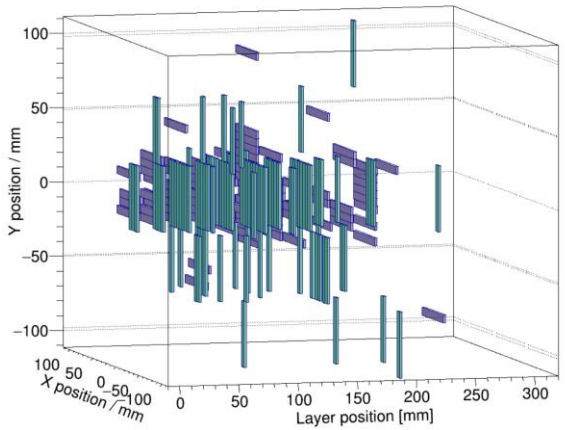


Low – High gain ratio

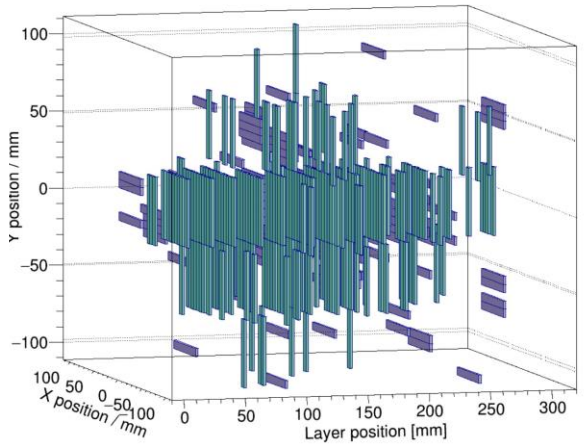
Sci-W ECAL Test with Positron

- The e+ test, also the beam has hadrons.

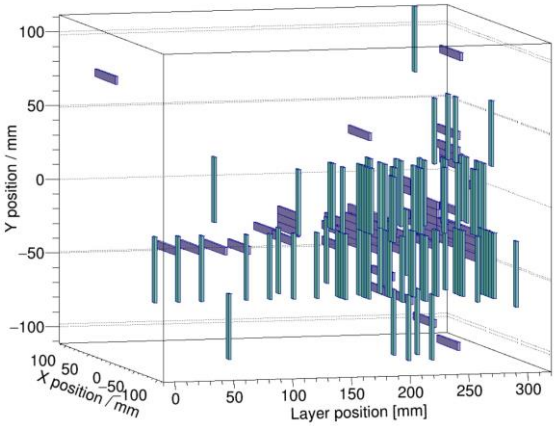
10 GeV e+



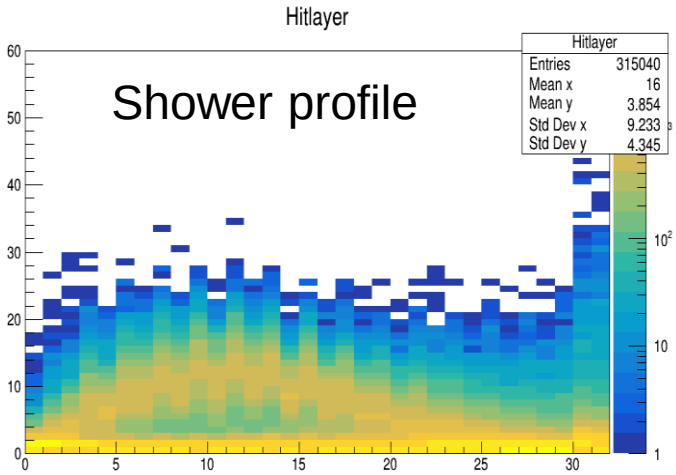
40 GeV e+



10 GeV hadron

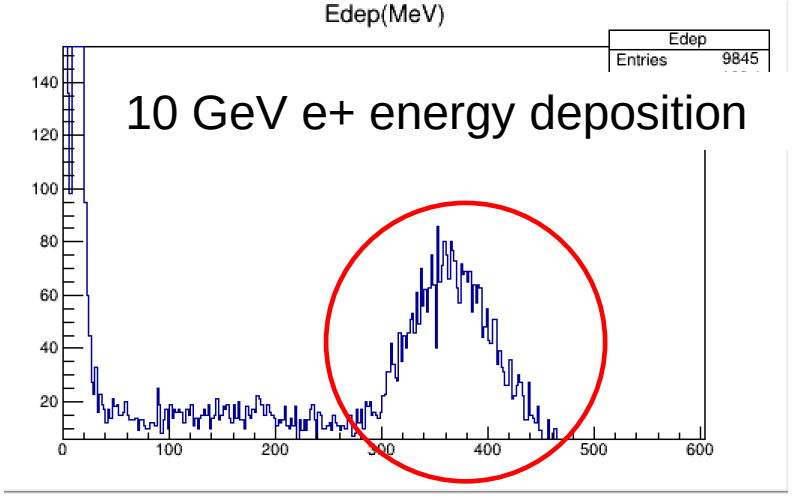


Shower profile

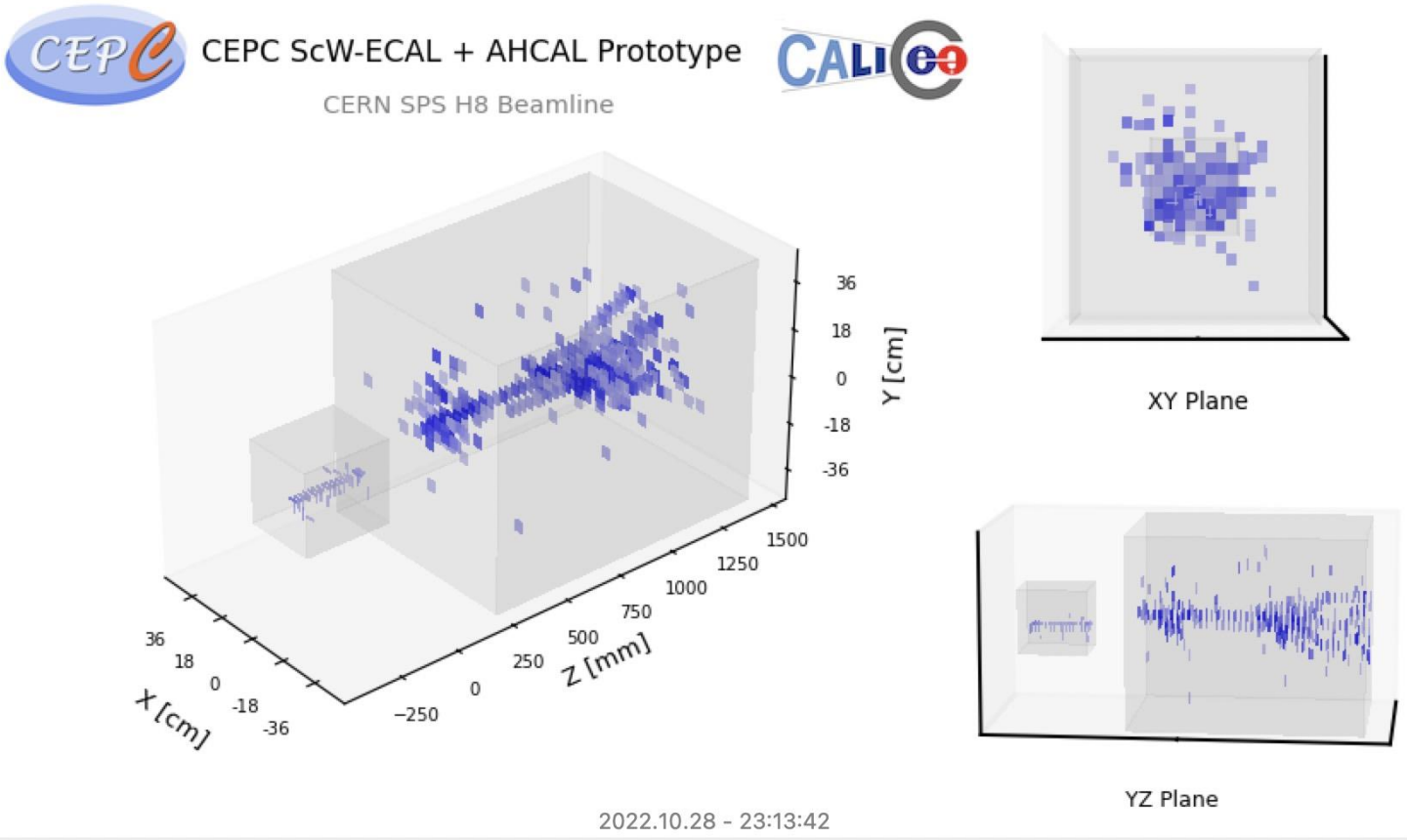


ECAL layer

10 GeV e+ energy deposition



Combined Test with pions



Beam test this year

- SPS
  - Apr 24 – May 10: 16 days at SPS H2
  - Similar test plan with last years but more high energy events
- PS
  - May 14 – May 31: 2 weeks at PS T9
  - Study in detail low-energy particles
  - Muons : wide beam profiles desirable
  - Electrons: energy scans for EM shower studies + calibrations
  - Hadrons: energy scans for hadronic shower studies

particle	momentum	position	test
Pion	10,20,30,40, 50,60,80 GeV/c	center	ECAL energy response
Electron	10,20,30,40, 50,60,80 GeV/c	center	ECAL energy response
Muon	108 GeV/c	Position scanning	ECAL MIPs response

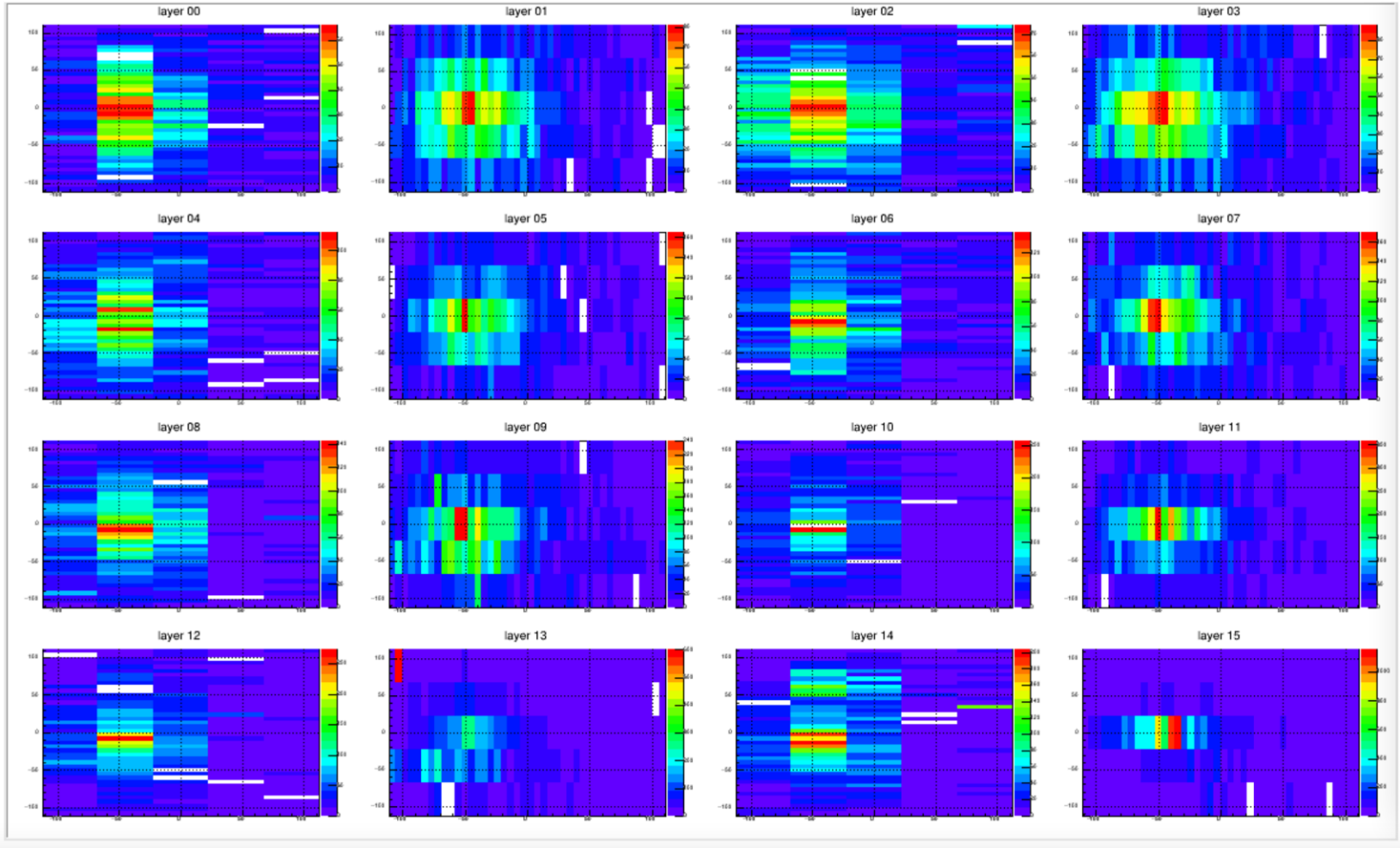
Summary

- Both the Sci-W ECAL and AHCAL prototypes were assembled, and tested at CERN last year.
- The two calorimeters has been taking beam test from Oct. 19 to Nov. 2, the preliminary results show the calorimeters work very well
  - The Sci-W ECAL and AHCAL were tested with pions and positrons from 10 GeV/c to 120 GeV/c
  - We collected about 25 million events in this beam test
- We will conduct a detailed analysis of the data to further tap the potential of the data
- We are actively preparing for the next beam test


THANKS

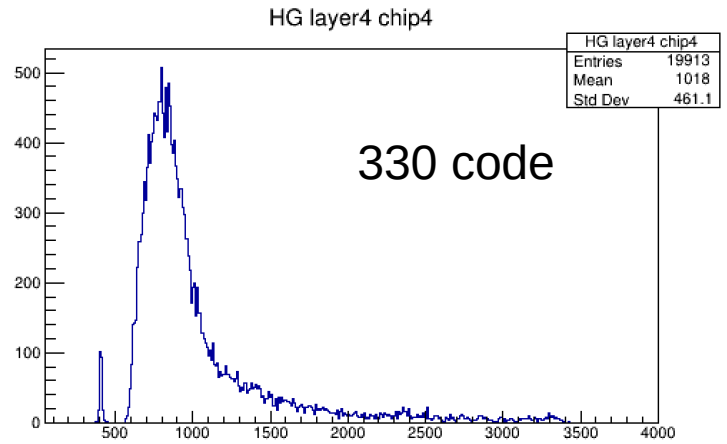
backup

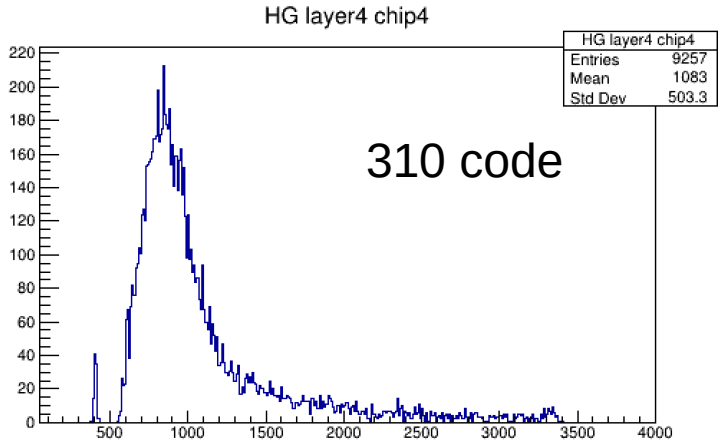
PFA Calorimeter

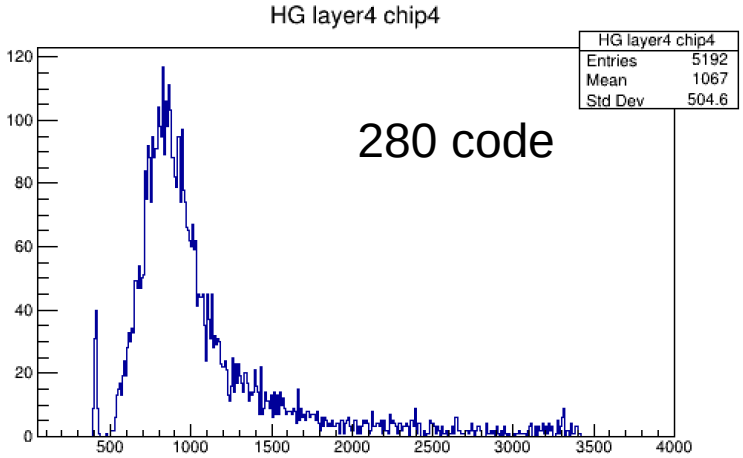


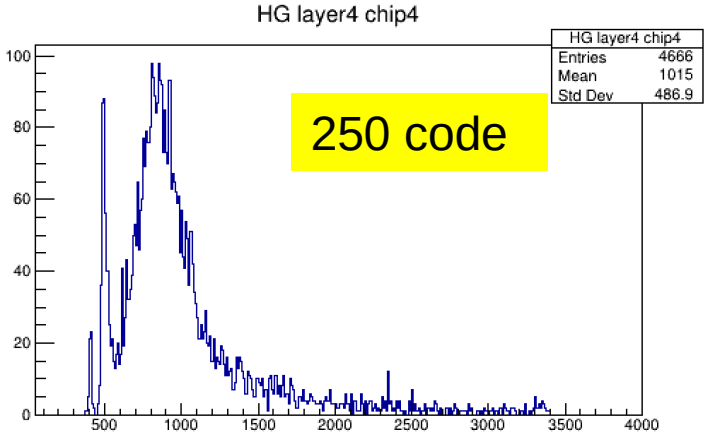
AHCAL Test with Mu+

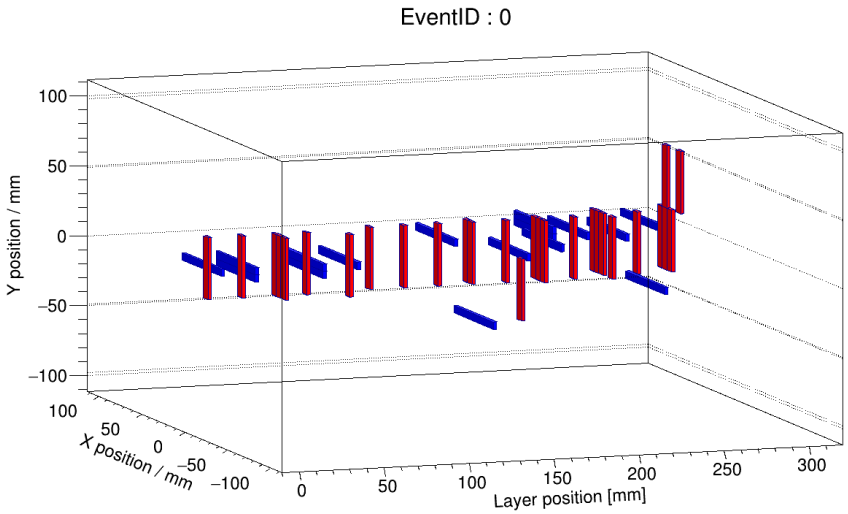
- The thresholds were calibrated using muon beam







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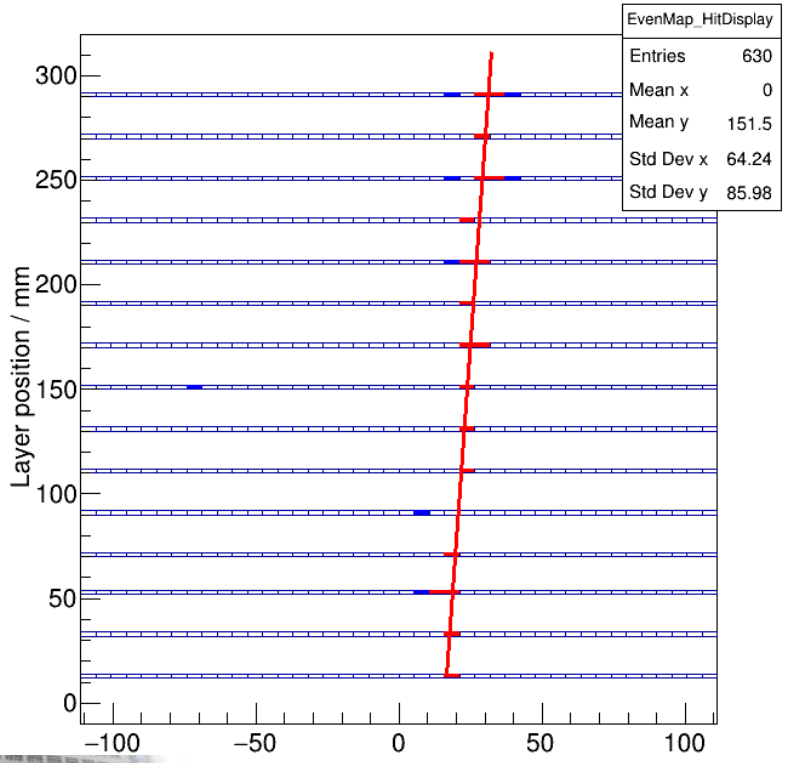
Y position / mm
X position / mm
Layer position [mm]

moun+ 160GeV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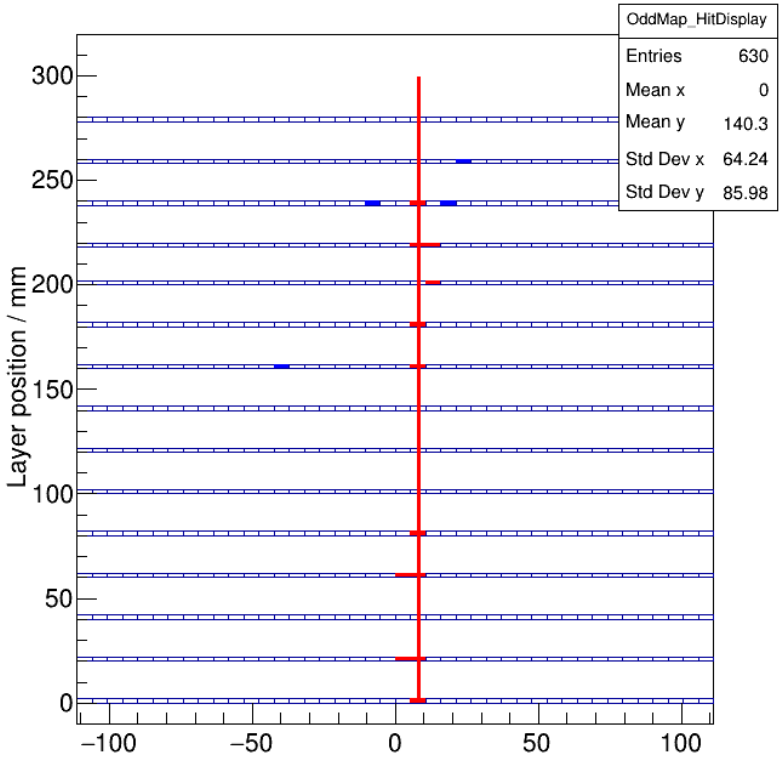
Mean x 0
Mean y 151.5
Std Dev x 64.24
Std Dev y 85.98
Layer position / mm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Mean y 140.3
Std Dev x 64.24
Std Dev y 85.98
Layer position / mm