Beam Test of Sci-W ECAL and AHCAL Prototypes

Yunlong Zhang

State Key Laboratory of Particle Detection and Electronics

University of Science and Technology of China

On behalf of CEPC Calorimeter working group

Outline

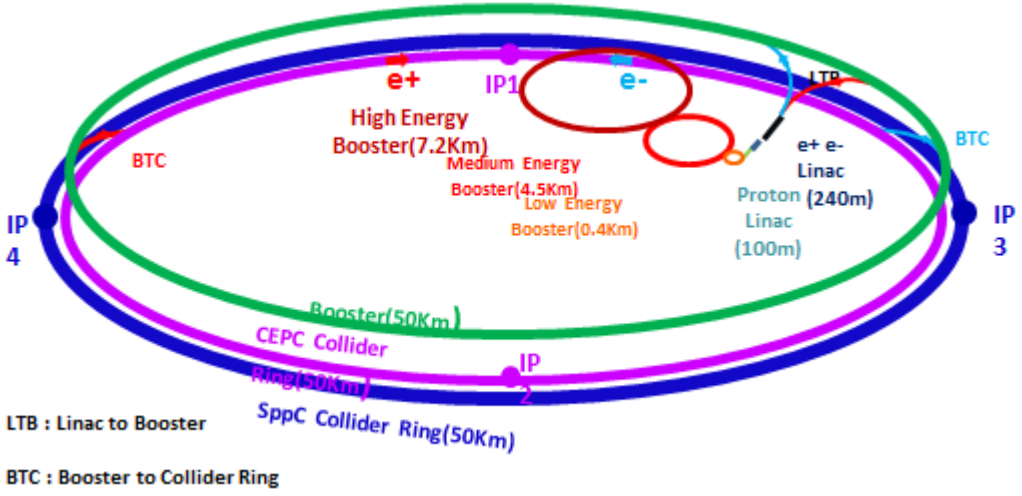
- Motivation
- Calorimeter prototypes introduction
- Beam test at CERN
- Summary

Motivation

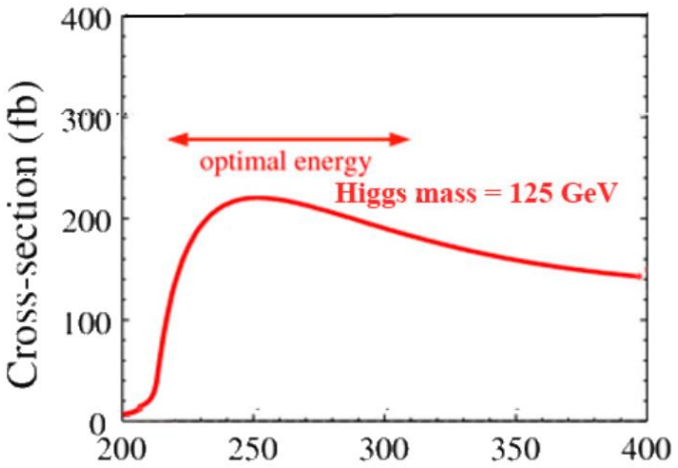
Circular Electron Positron Collider (CEPC)

E_{cm}≈240GeV, luminosity ~2×10^{34} $cm^{-2}s^{-1}$ can also rum at the Z-pole

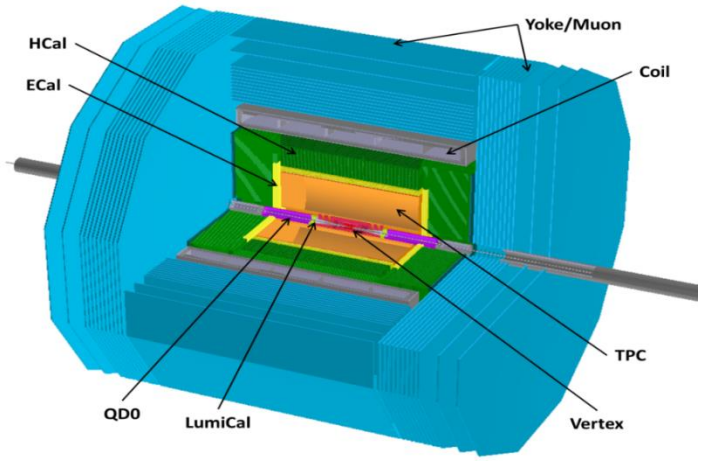
Precision measurement of the Higgs boson (and the Z boson)



$e^+e^- \rightarrow ZH$



Requirements of CEPC Calorimeter

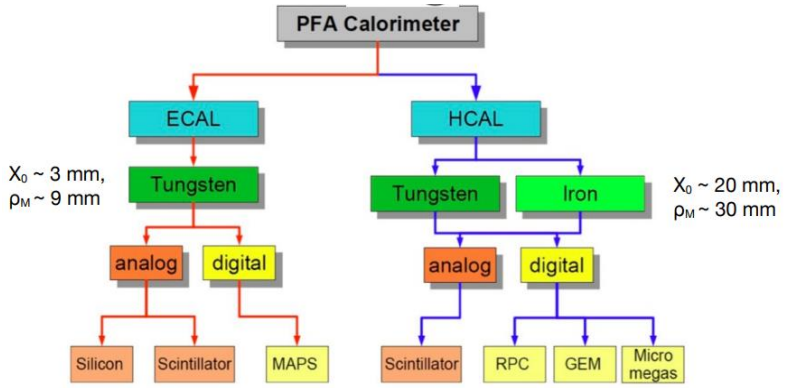


- **ILD-like detector with additional considerations.**

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:** $\frac{\sigma_E}{E} \approx 3-4\%$

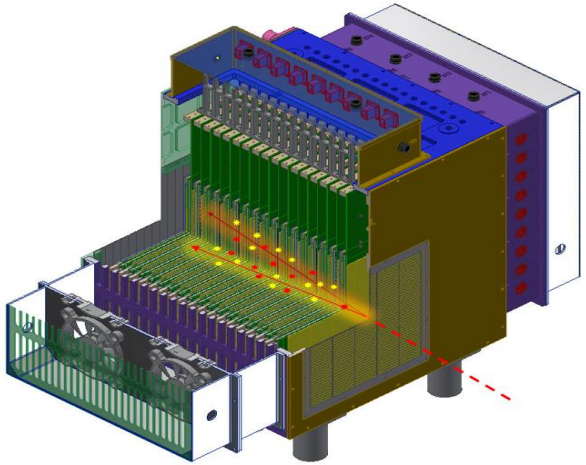
- The Particle Flow Algorithm (PFA) calorimeter concept was proposed
  - High granularity
  - Good track finding
  - Good energy resolution



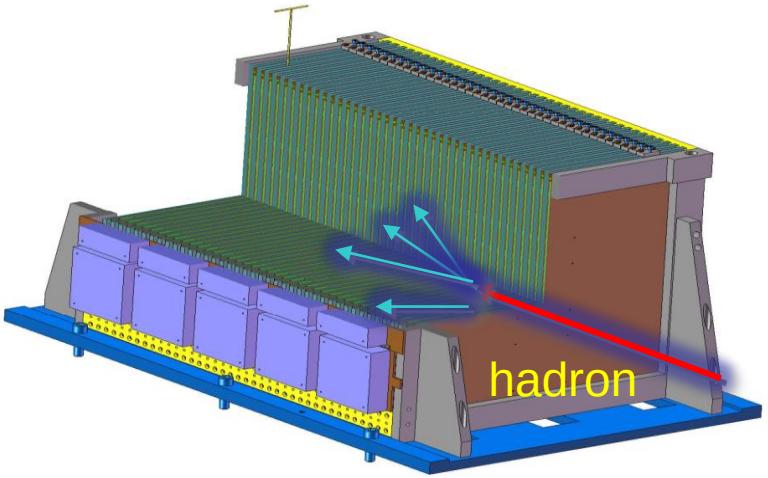
PFA Calorimeter prototype

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	4.7 NIL	60%@ 1 GeV	5.0 T



Sci-W ECAL



AHCAL

PFA Calorimeter prototype

Sci-W ECAL

AHCAL

Brief review of last year beam test

- Two weeks 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						D. Lazic PPE172							Y. Itow PPE172							H. Schindler PPE172													
	T2 - H4	V. Gninenko PPE134+PPE144							EB. Holzer														M.R. Jäkel, E. Oliveri PPE134, PPE154												
	T4 - H6 main user	CMS PIXELS	A. Rummler PPE146						A. Rummler PPE156							Dannheim Dao PPE156							E. Figueras							H. Danielsson PPE136					
	T4 - H6 parallel user	EP hybrid	A. Rummler PPE146						A. Rummler PPE146							V. DaoD. Dannheim PPE146, PPE156							H. Danielsson PPE136, PPE146							EP hybrid ATLAS HGTD E. Gkougkousis					
	T4 - H8	UA9 Totem	W. Scandale PPE128						H. Schindler, N. Neri PPE128, PPE138, PPE158, PPE168														J. Liu, E. Scomparin 158 or 168, PPE138												

Transport

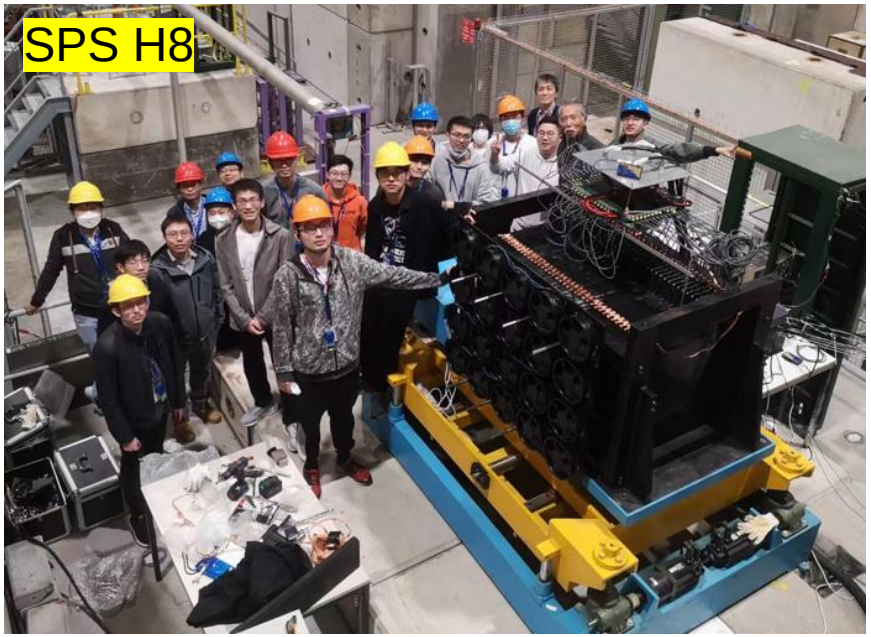
- In the middle of Sep. 2022, The detectors were sent to CERN from Hefei. The total weight is 10.6 tons.
- On Oct. 14 2022, the detectors arrived at CERN.

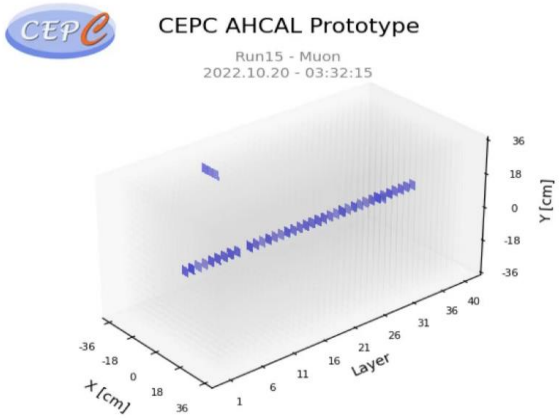
Hefei, 15/9

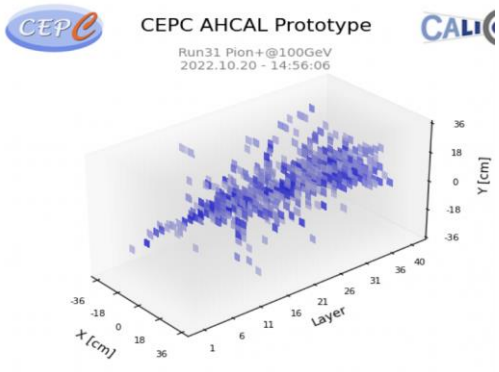
CERN, 14/10

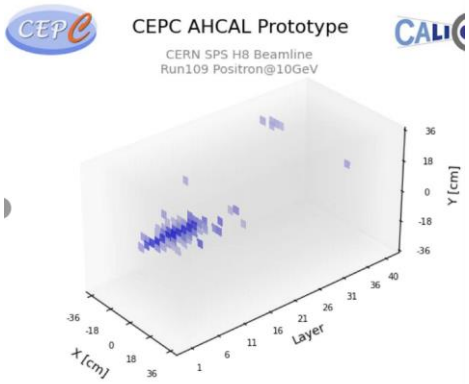
Beam test

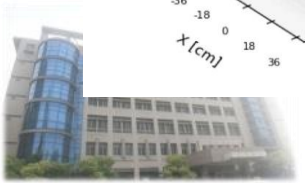
- Beam Test
  - Muon+
    - 160 GeV/c, 108 GeV/c
    - 5 million
  - Pion+
    - 10 - 120 GeV/c
    - 17 million
  - Positron
    - 10 - 120 GeV/c
    - 3 million
- beam purity is poor









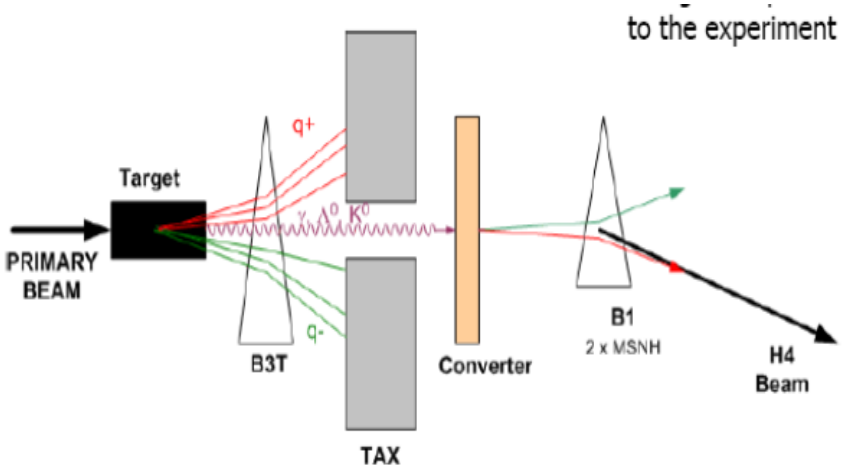


Stored in CERN

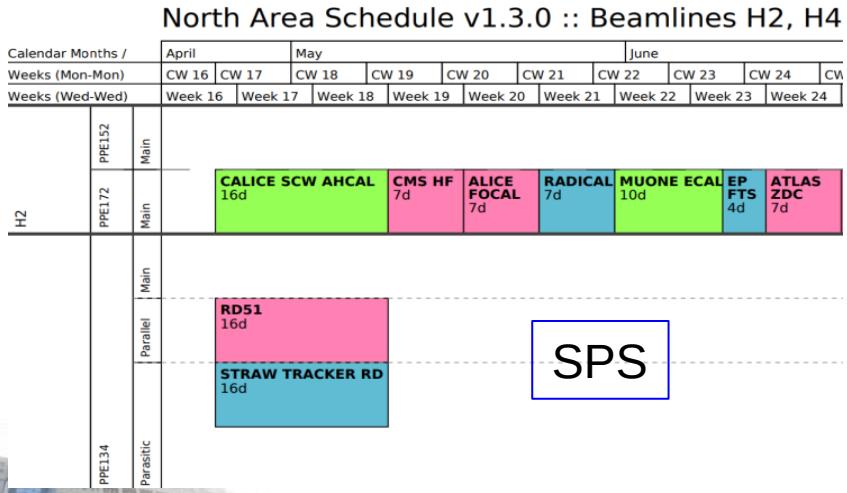
- After this beam test, We have stored the detectors in CERN Meyrin site
  - Nov.8, stored in bat.190

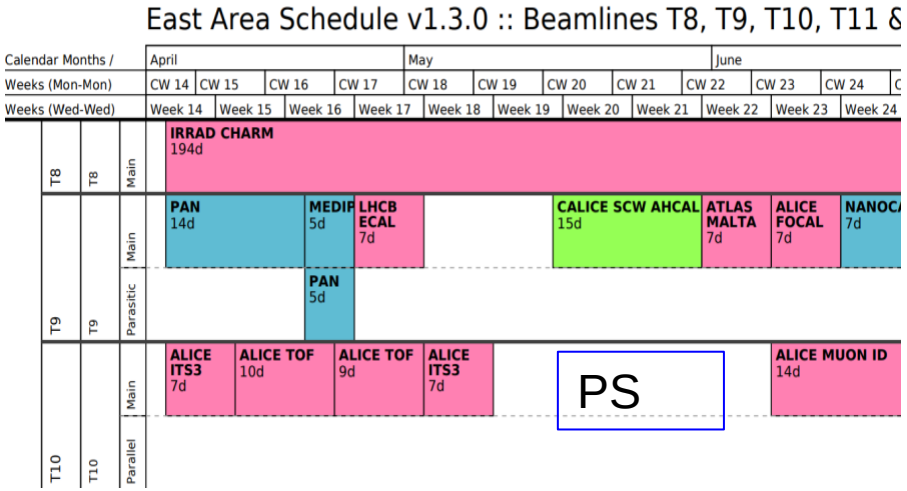
Beam Test in 2023

- Major motivations
  - Much Better beam purity at SPS-H2
  - Study low-energy in 1-10 GeV at PS
  - Update some problems of last year
- CERN PS/SPS schedule in 2023
  - SPS-H2: Apr. 24 – May 10 (16 days)
  - PS-T9: May 13 – 31 (15 days)



Similar to H2 and T9



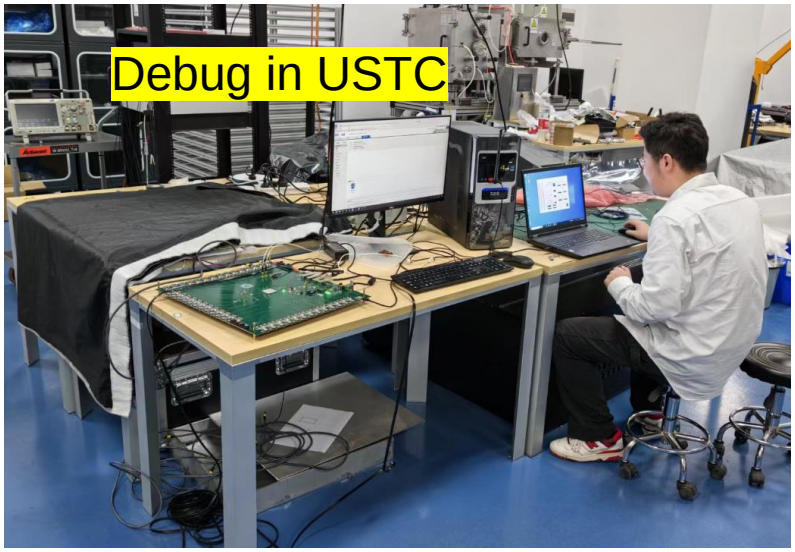


Beam test in SPS H2

- 17/4，The detectors were shipped to bat. 887 of SPS
- The package are the same as last year :-)

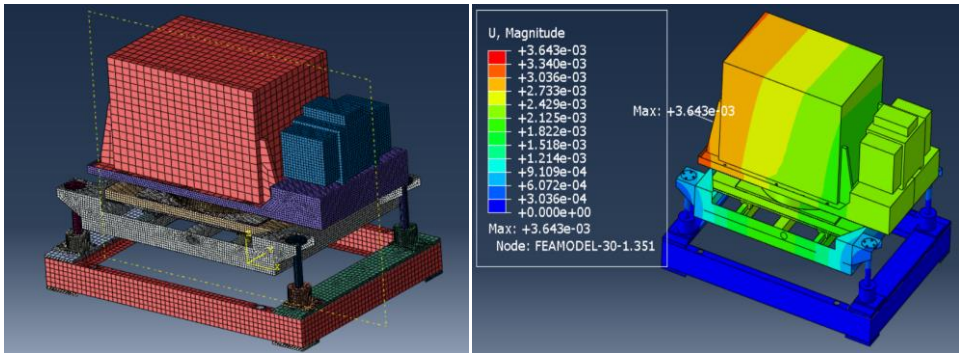
ECAL Update

- We have rebuilt two layers in the laboratory to study the problems discovered during last year's testing process
- The ECAL temperature
  - The temperature data in ECAL are disordered last year. This problem is fixed and tested.
- The autogain
  - We think the select thresholds used in 2022 are too low. We calibrate new thresholds for each chip
- ECAL stuck
  - In Beam test of 2022, the ECAL always got stuck and had no data for sometime. We modify a firmware bug and update the hardware.



Load Test

- 24/4, after Load test, we obtained beam permission



CALICE ScW-ECAL and AHCAL Experiment

Safety clearance

Experiment Details

ISIEC ID
815

Experiment Name
CALICE ScW-ECAL and AHCAL

Beam Line
H2

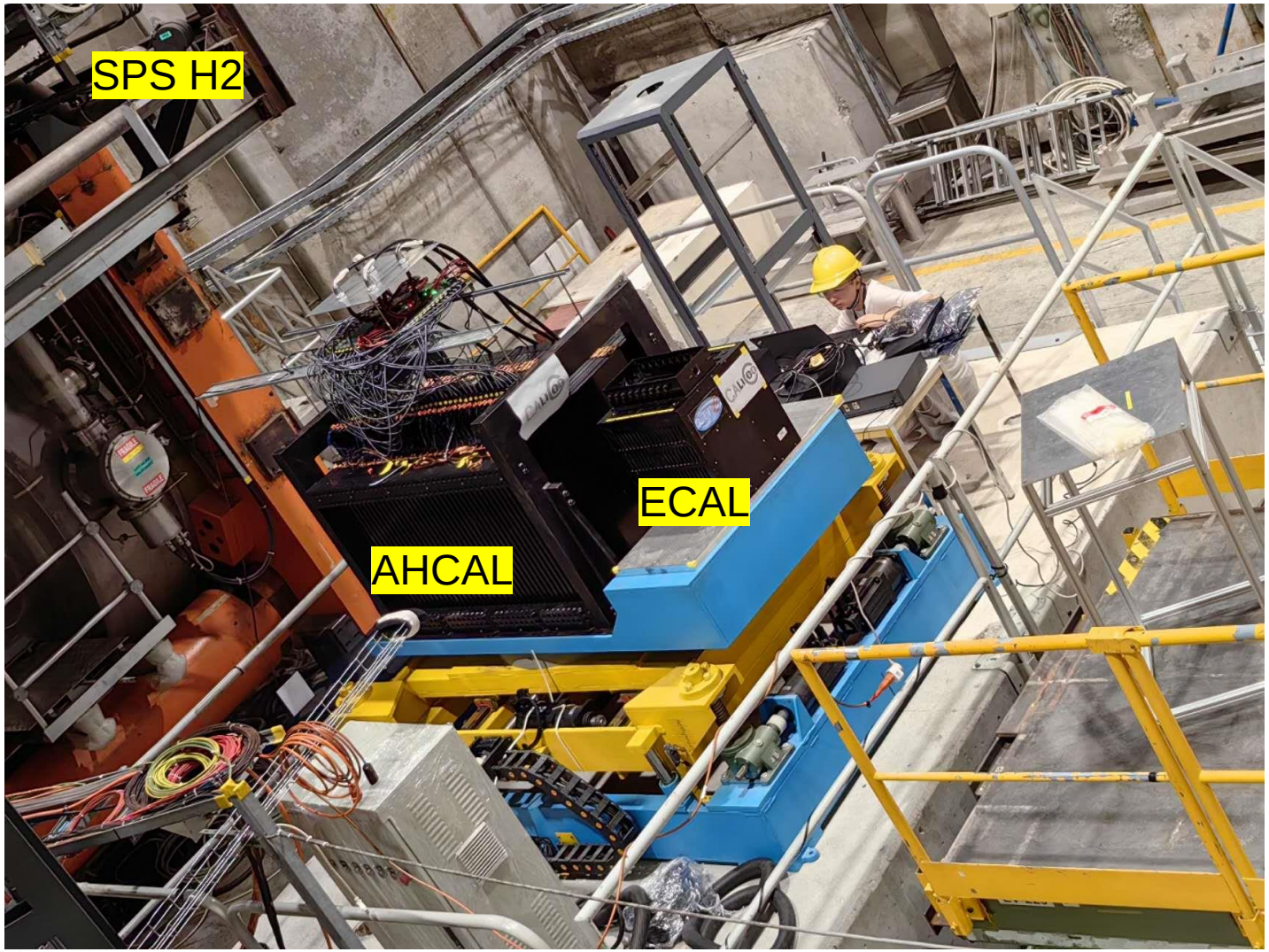
Door (PPE)
172

Counting Room
{Empty}

Building Number
887

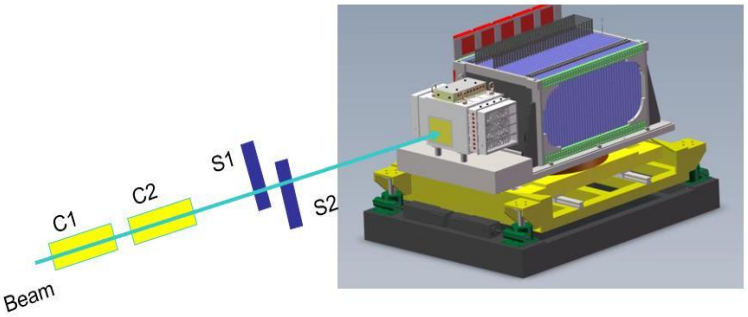
Safe for Operation
Yes

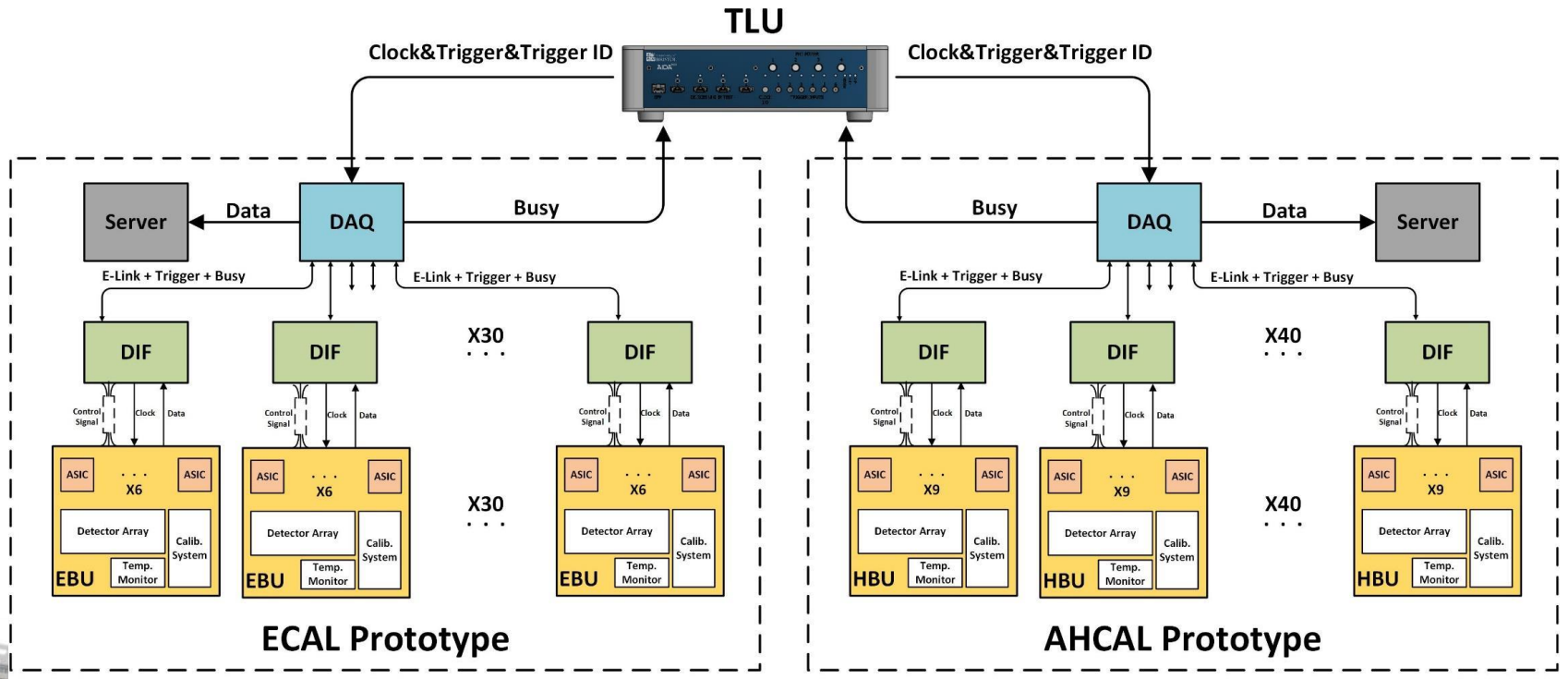
Calorimeter Test



Calorimeter Test

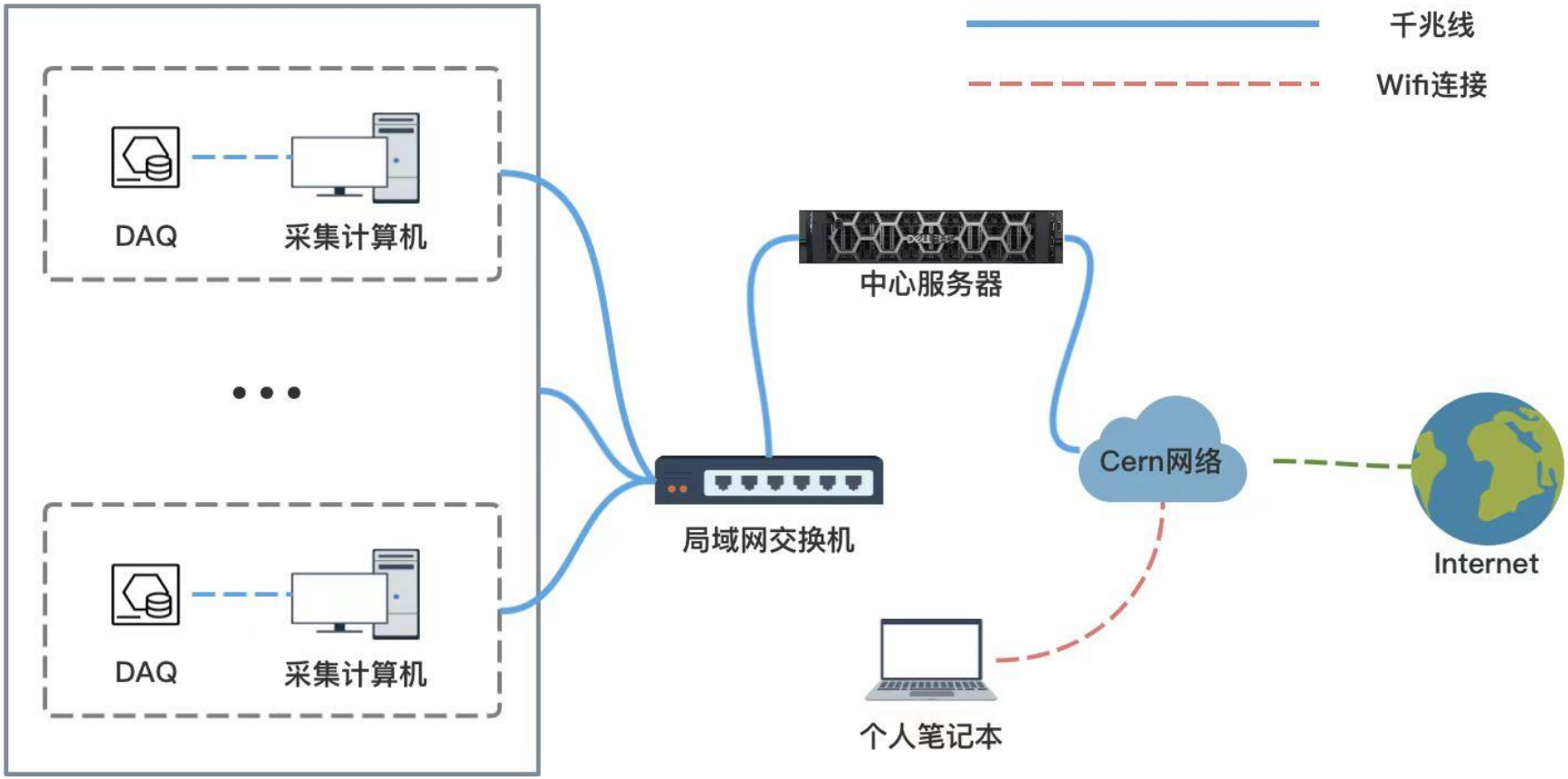
- **DAQ system for ECAL and AHCAL Prototypes**
  - **ECAL has 30 DIFs, AHCAL has 40 DIFs**
  - **Using TLU to synchronize two systems**





Calorimeter Test

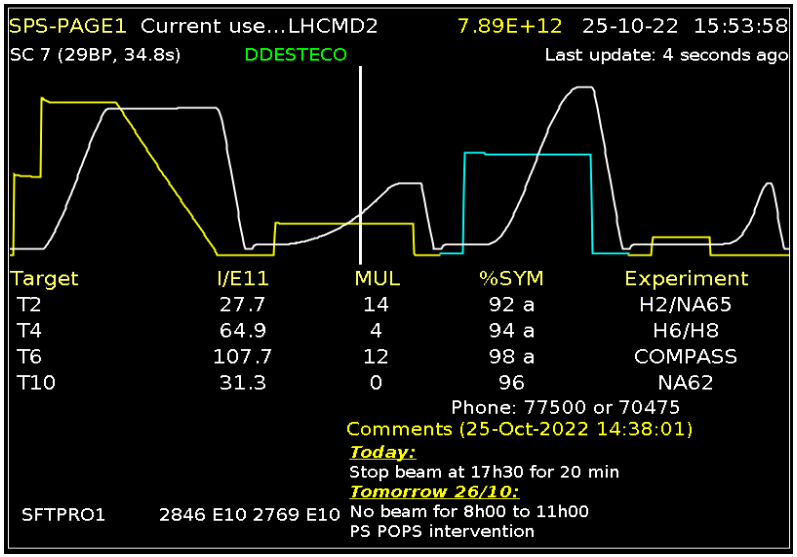
- **Data Collection and analysis**

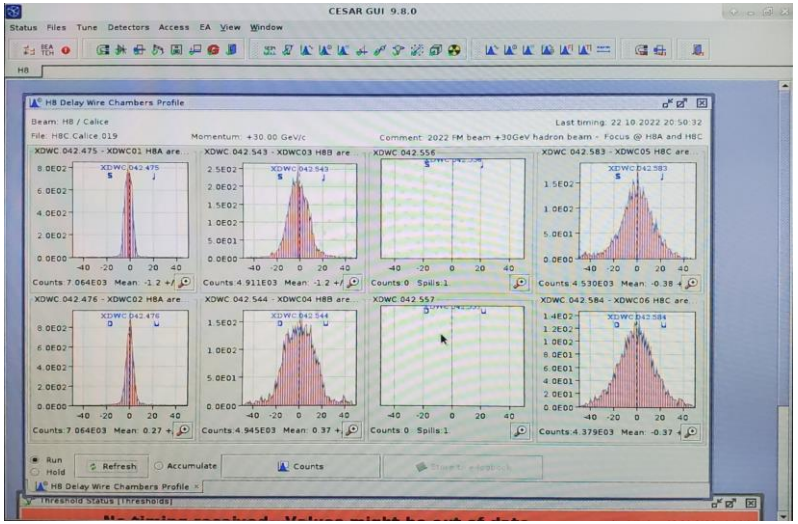


Beam in SPS H2

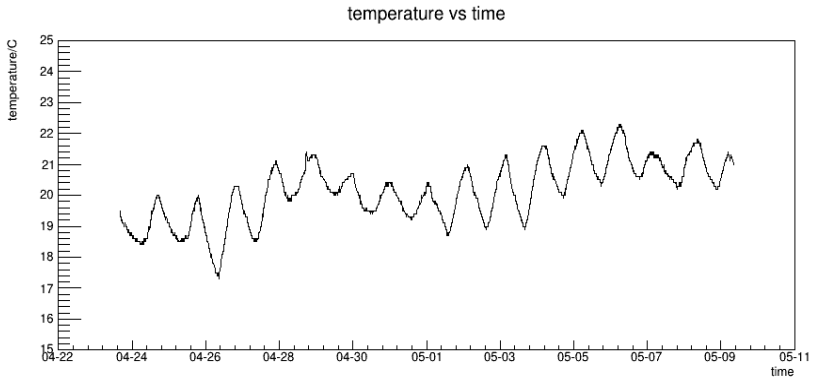
- 1 cycle: 34.8 s, 1 spill: 4.8 s
- About 2-3 k events per spill
- Beam size: ~4 cm (FWHM)

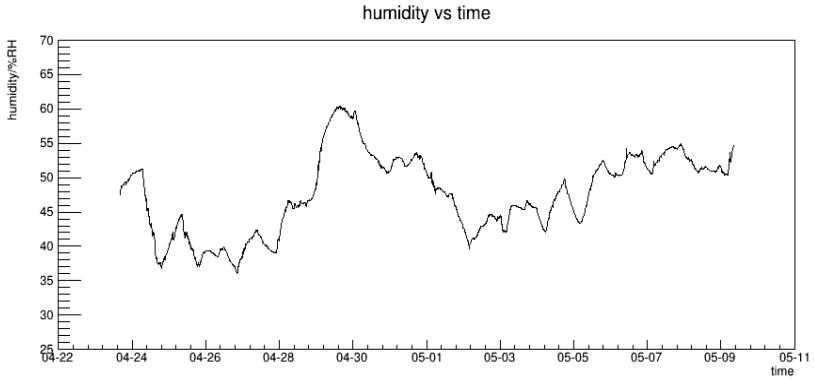
- Muon Test
  - Momentum：100 GeV/c
  - 6 million
- Pion- test
  - 10 – 120 GeV/c， 350 GeV/c
  - 20 million
- Electron Test
  - 10 – 250 GeV/c
  - 4.7 million
- Proton, 350 GeV/c
  - 1 million



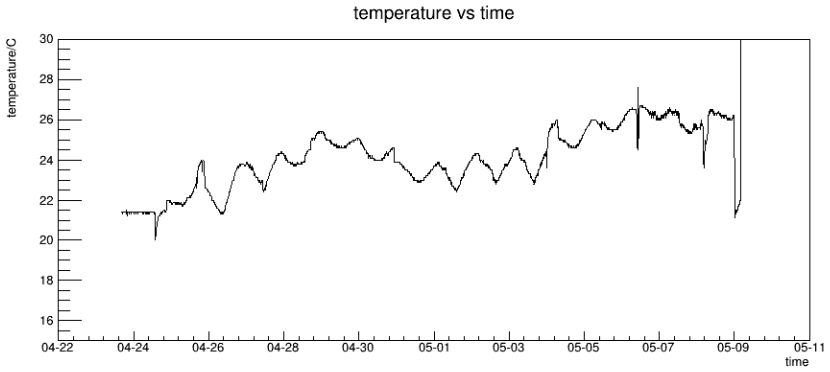


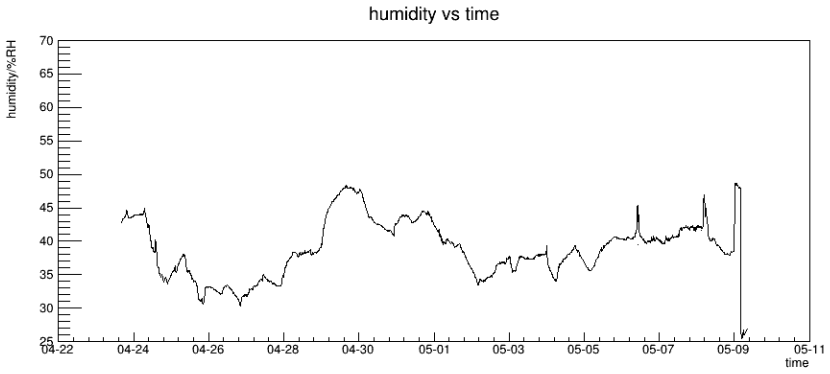
Temperature and Humidity





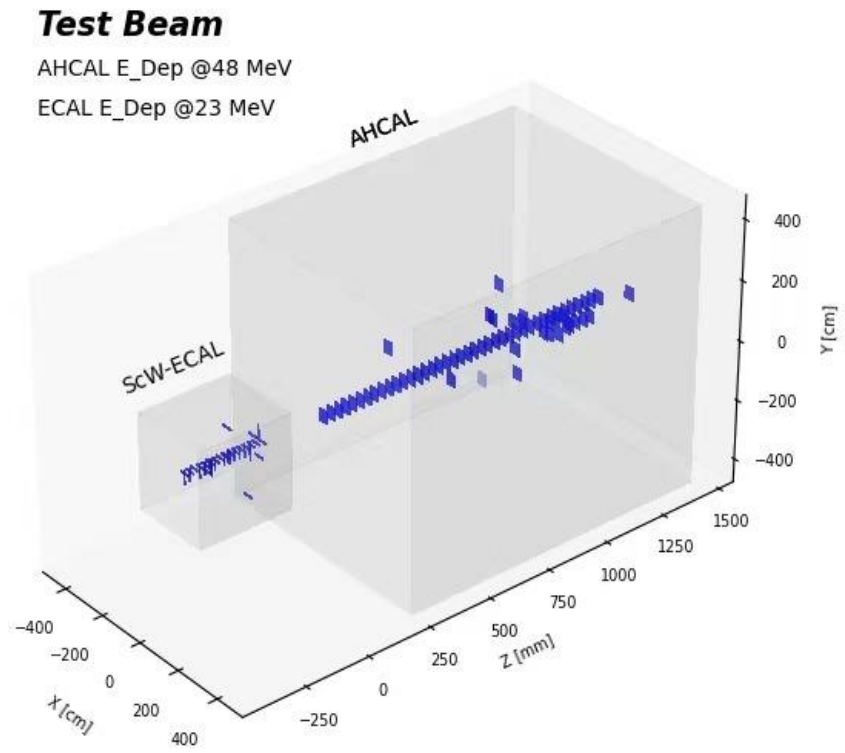
environment

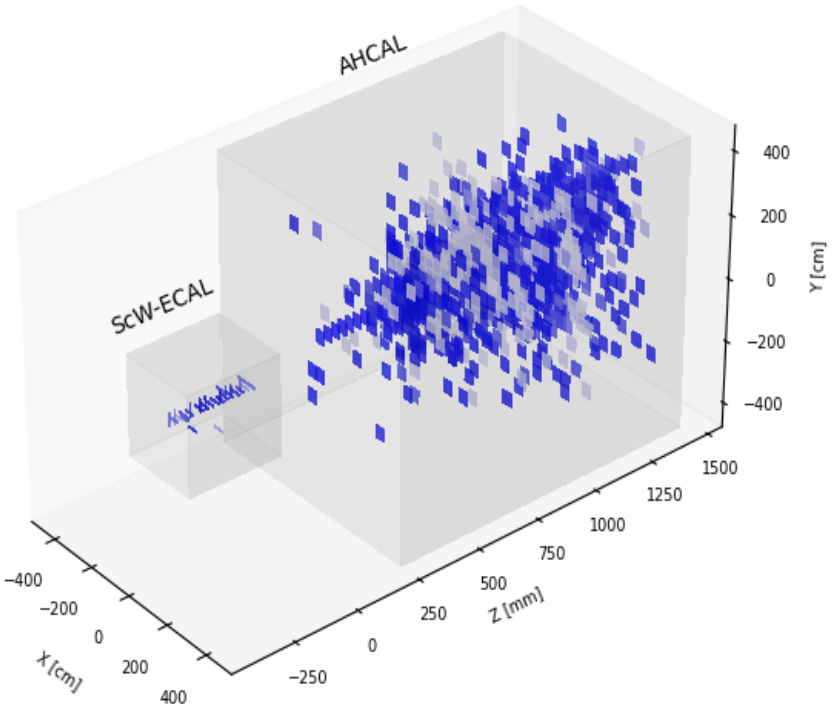




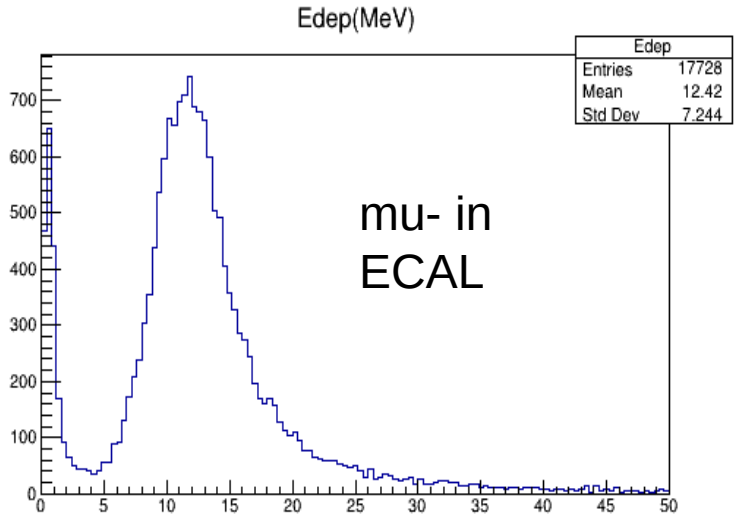
AHCAL

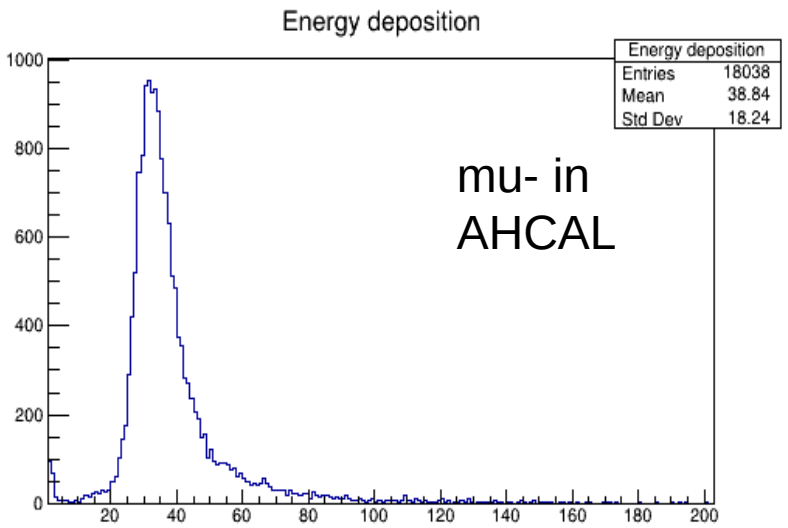
Event display

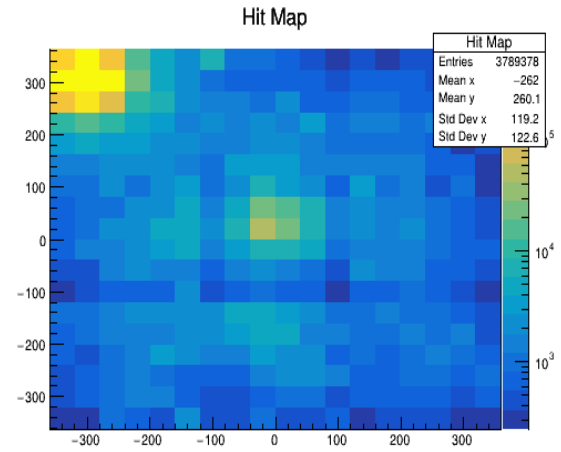


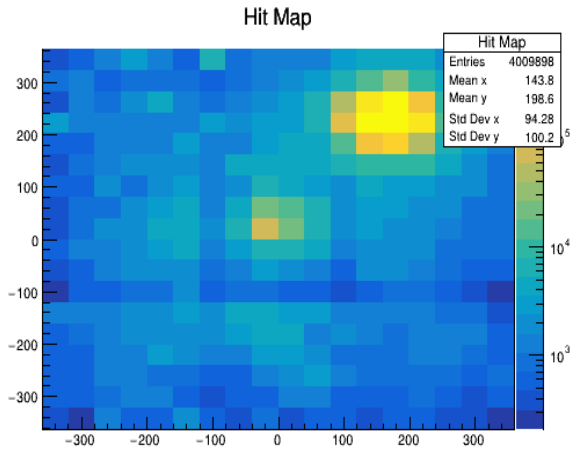


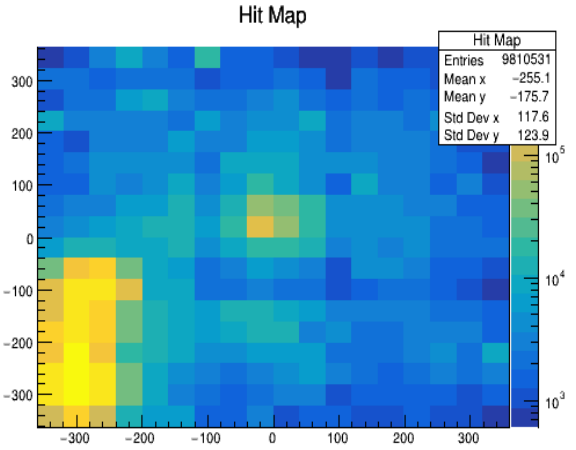
Muon Test


Edep(MeV)
Edep
Entries 17728
Mean 12.42
Std Dev 7.244
mu- in ECAL


Energy deposition
Energy deposition
Entries 18038
Mean 38.84
Std Dev 18.24
mu- in AHCAL


Hit Map
Hit Map
Entries 3789378
Mean x −262
Mean y 260.1
Std Dev x 119.2
Std Dev y 122.6

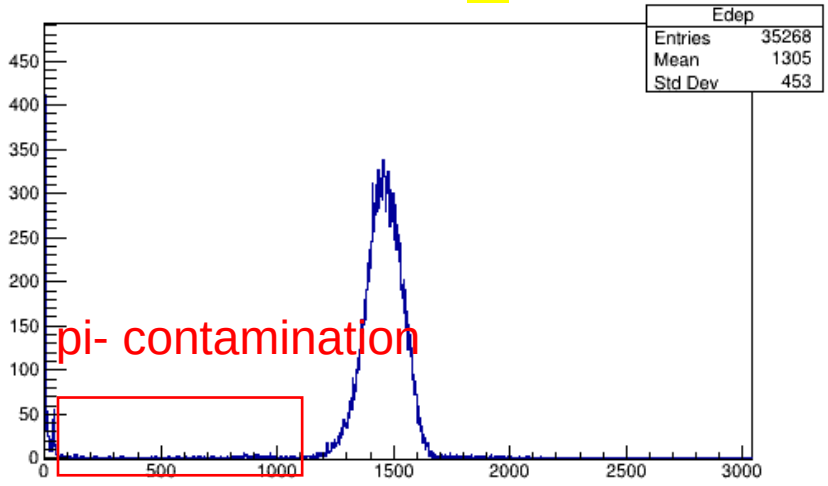

Hit Map
Hit Map
Entries 4009898
Mean x 143.8
Mean y 198.6
Std Dev x 94.28
Std Dev y 100.2


Hit Map
Hit Map
Entries 9810531
Mean x −255.1
Mean y −175.7
Std Dev x 117.6
Std Dev y 123.9

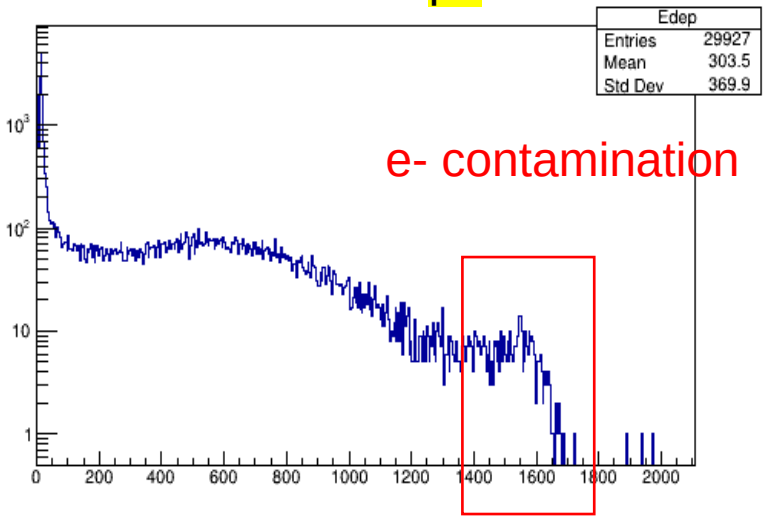
ECAL energy response to e- and pi-

- In H2, the beam purity is very good
  - electron, 10 GeV/c – 250 GeV/c
  - Pi-, 40 GeV/c – 350 GeV/c
- In e- beam, only a few pi- contamination
- In pi- beam, there is also a few e- contamination

40 GeV e-



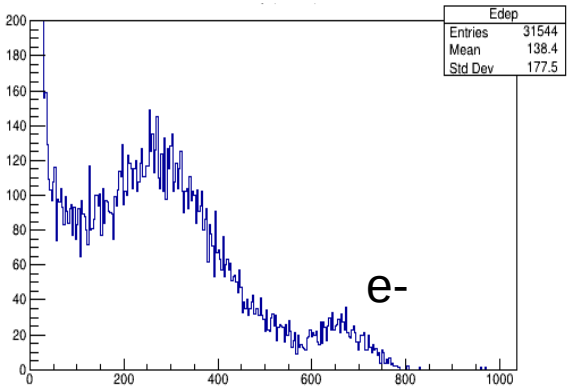
40 GeV pi-



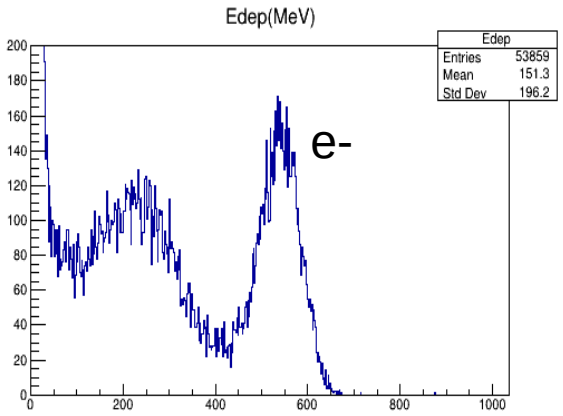
Low energy pi- in H2

- Low energy pi- are not pure
- 10 GeV/c，most of the events are e-

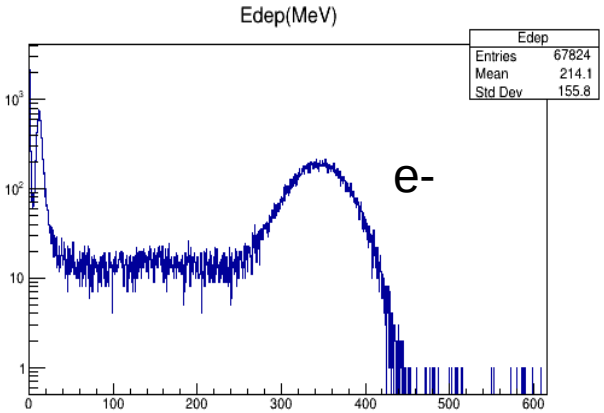
20 GeV



15 GeV

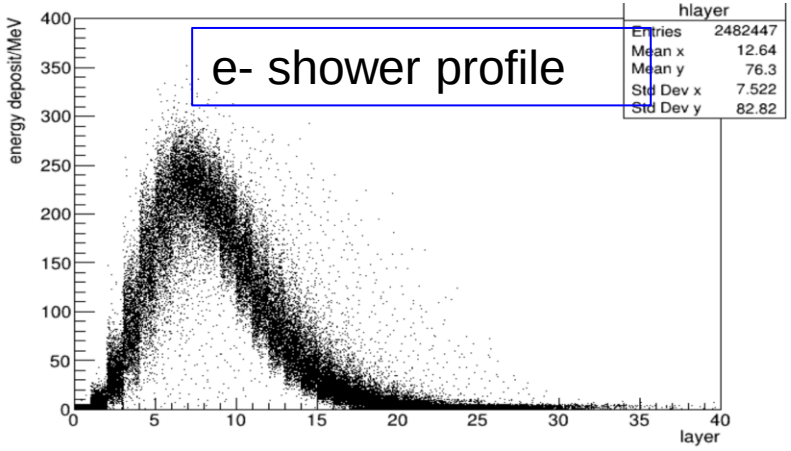


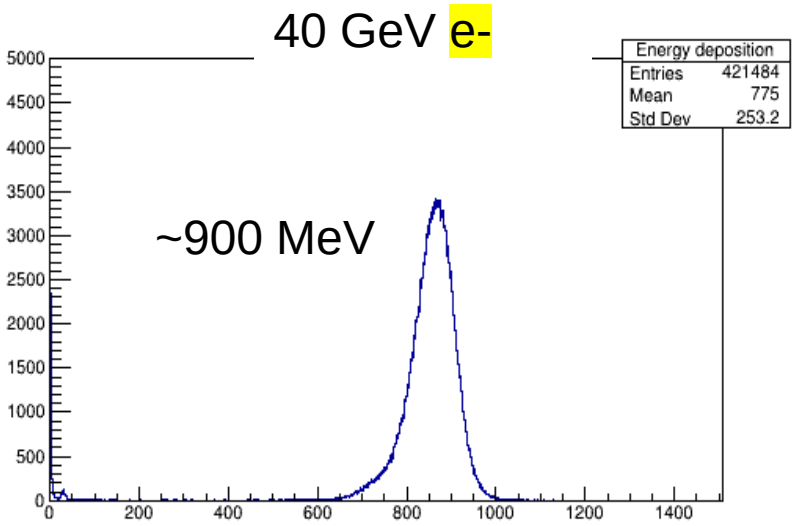
10 GeV

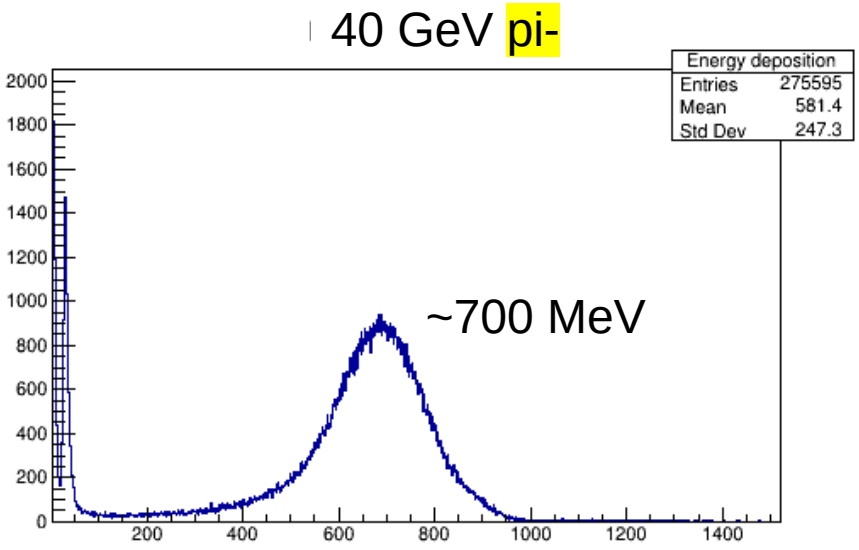


AHCAL energy response to e- and pi-

- In order to study the AHCAL response to EM composition, we also tested AHCAL with e- and pi- both

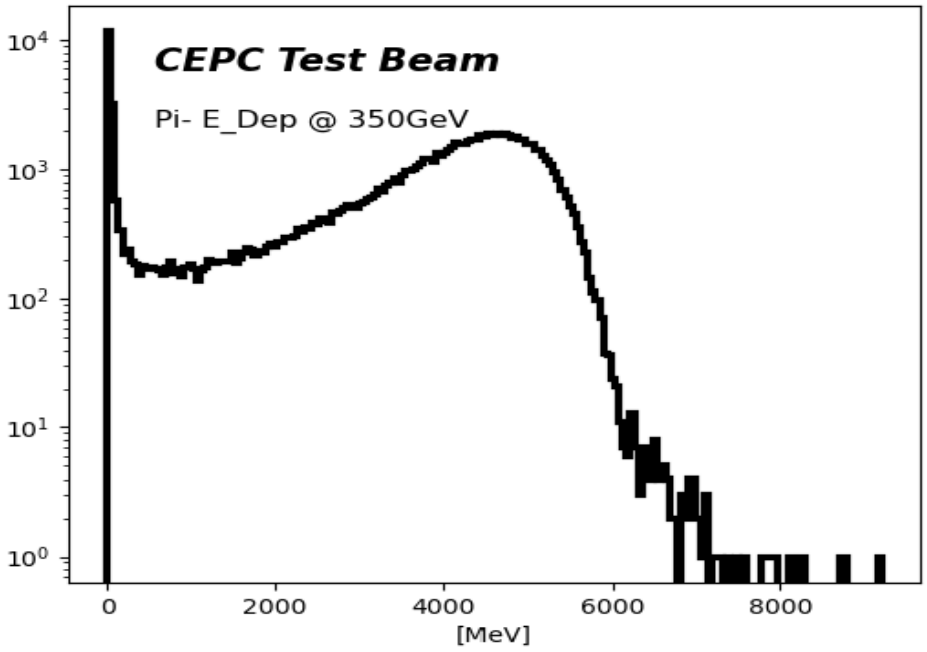


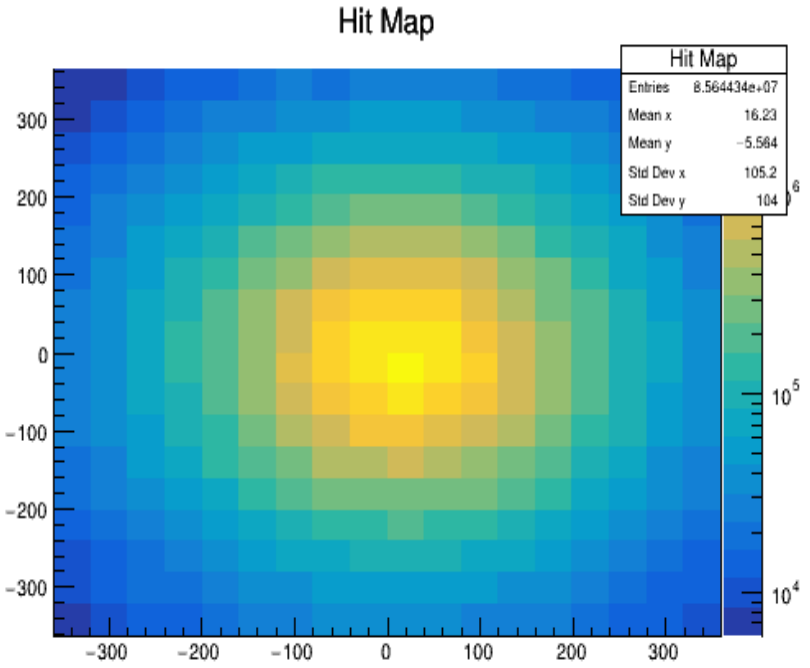




HCAL response to 350 GeV/c pi-

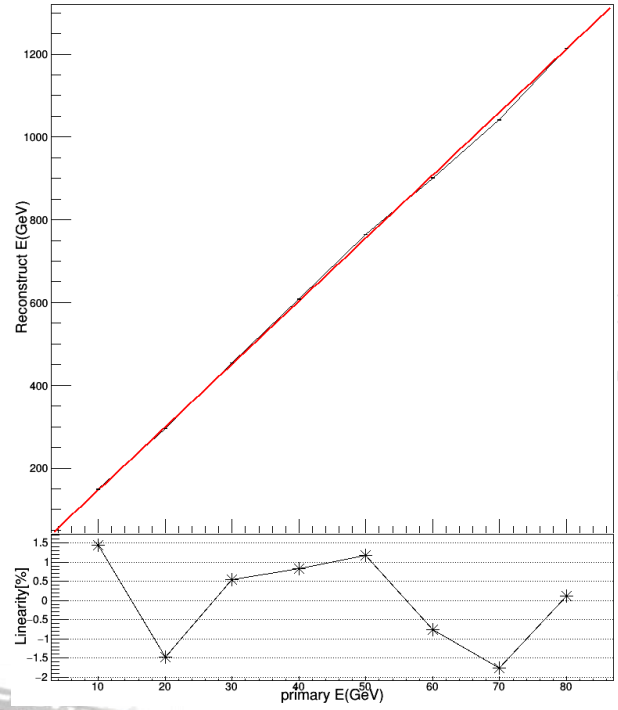
（接近）地表最高能（束流测试）！

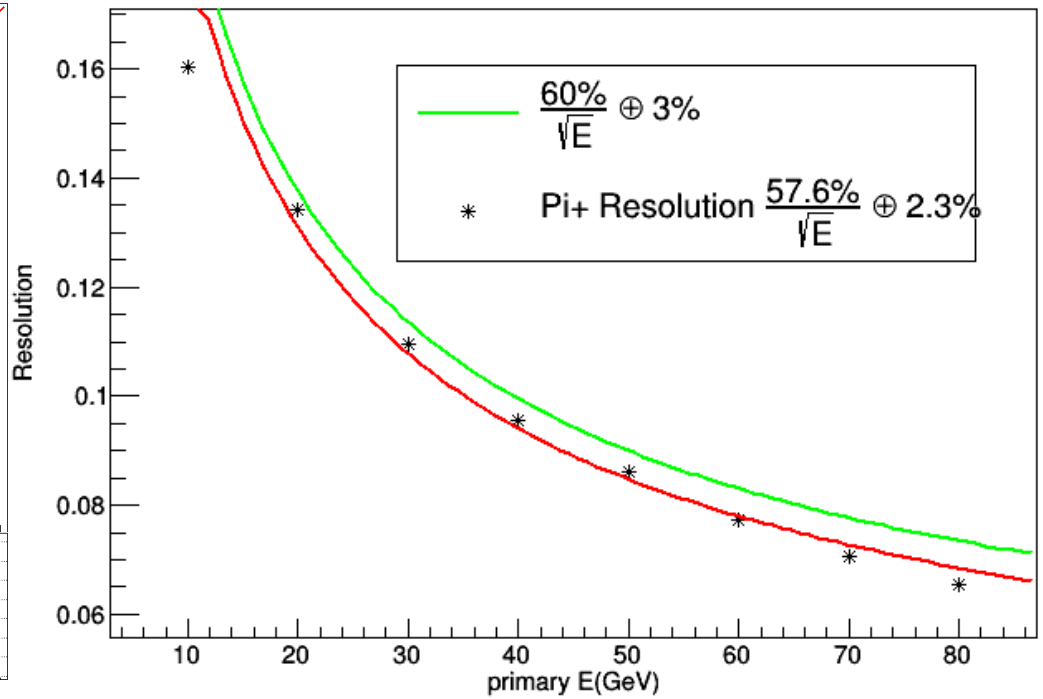




Linearity and energy resolution

- The energy linearity is about $\pm 1.5\%$
- The energy resolution is $\frac{57.6\%}{\sqrt{E}} \oplus 2.3\%$





Energy linearity and resolution

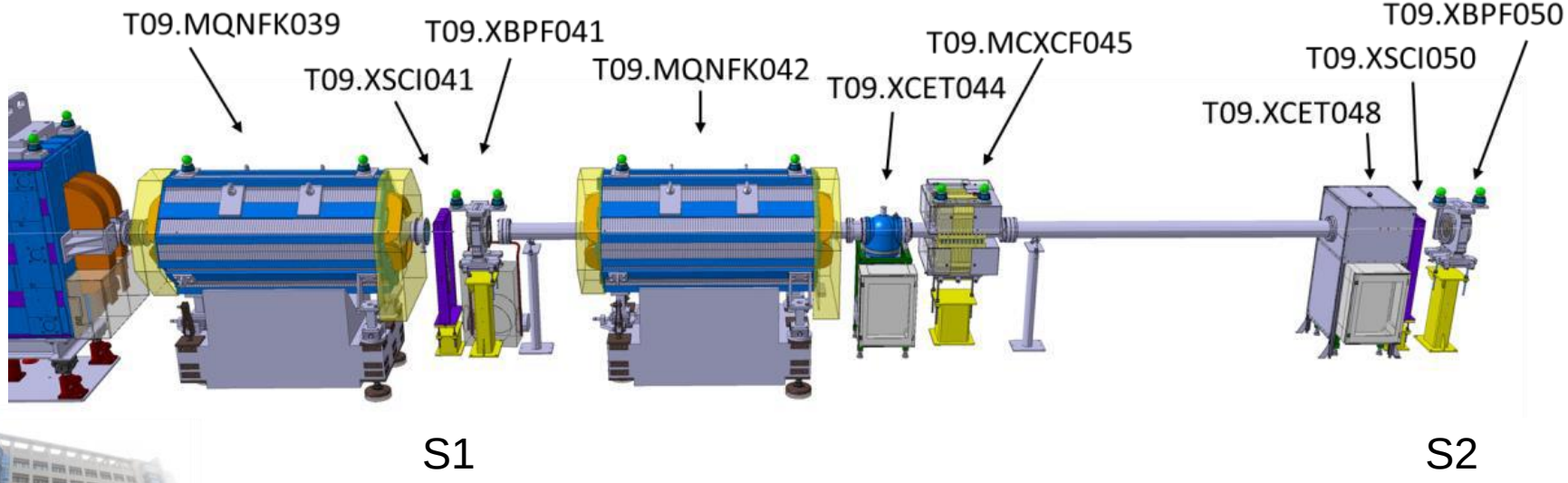
Beam Test in PS

- 12/5，the detectors were shipped to PS T9

Calorimeters in PS T9

T09 Beamline

- Two Cherenkov detectors with CO2
  - C1, 16 bars
  - C2, 4 bars
- Two trigger counters

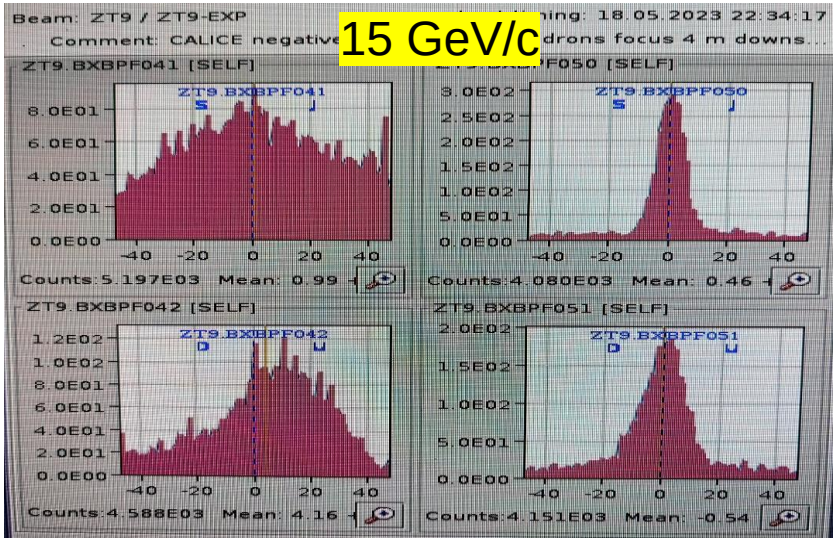


Material in the beam line

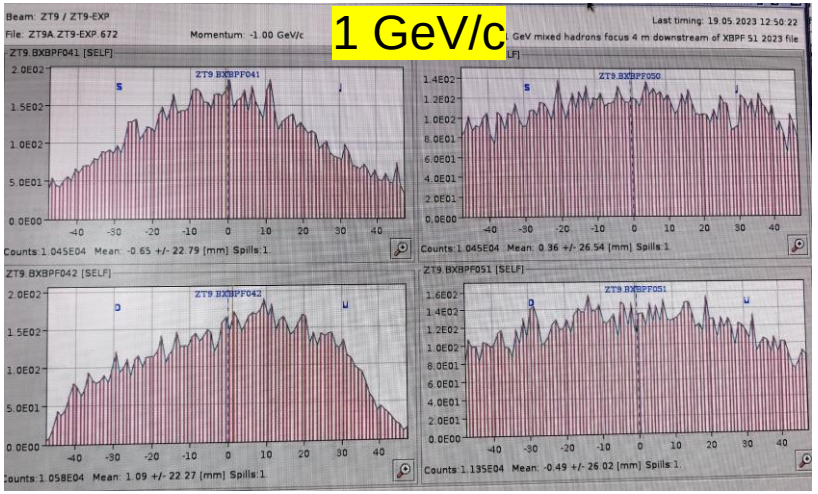
- Cherenkov detectors
  - beam pipe window: 2.8 mm Al (1.4 mm Al at the entrance and exit each) for the high pressure XCET44
  - Two Cherenkov detectors: 3.8 m long each，depends on the pressure
  - Beam pipe window: 0.4 mm Mylar (0.2 mm for the entrance and exit each) for the low pressure XCET48
- Two plastic scintillator trigger counters
  - 0.6% radiation length each
- Two beam profile monitors (scintillator fiber)
  - 0.5% radiation length each
- Air
  - 4.25 m from the last beam profile monitor (XBPF 050/051) to ECAL (Yong test)

Beam in PS T9

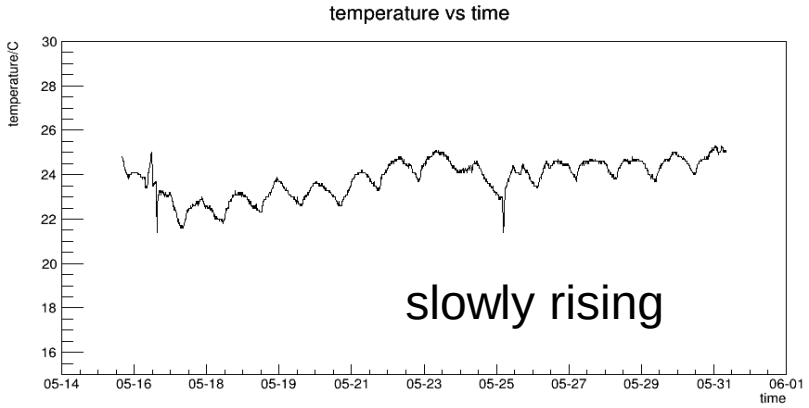
- Energy: 0.5 – 16 GeV/c
- Spill duration: ~ 2.4 sec with 0.4 sec flat-top, typically 1-2 spills / min
- About 2-3 k events per spill
- Typical beam size: ~1-2 cm

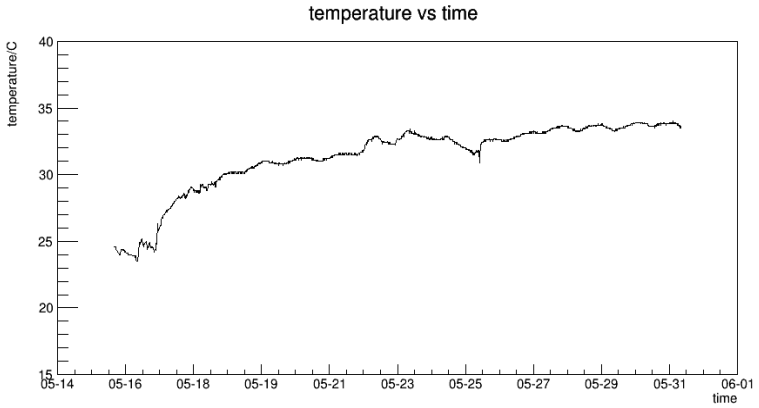


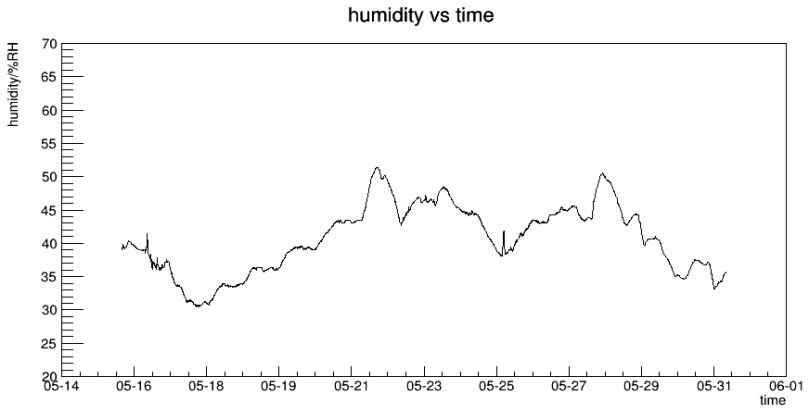
- Muon Test
  - Momentum： 10 GeV/c
- Pion- test
  - 1 – 15 GeV/c
  - 8 million
- Electron Test
  - 0.5 – 5 GeV/c
  - 2.6 million

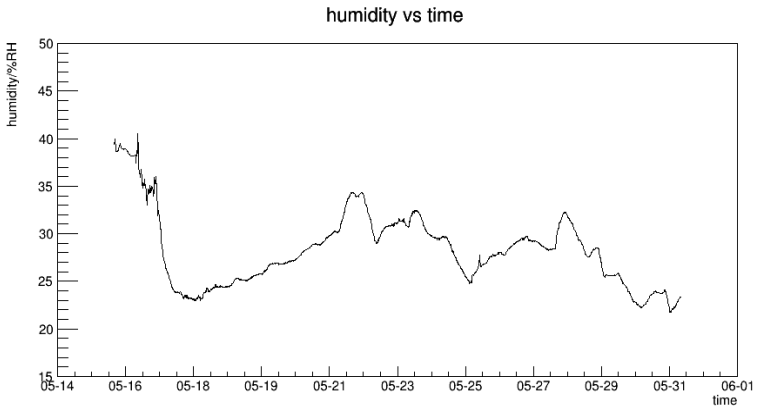


Temperature and Humidity





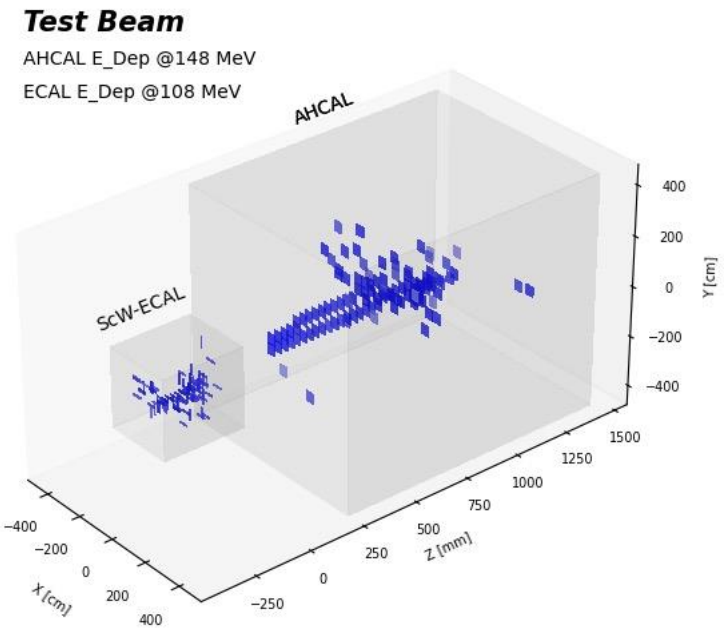


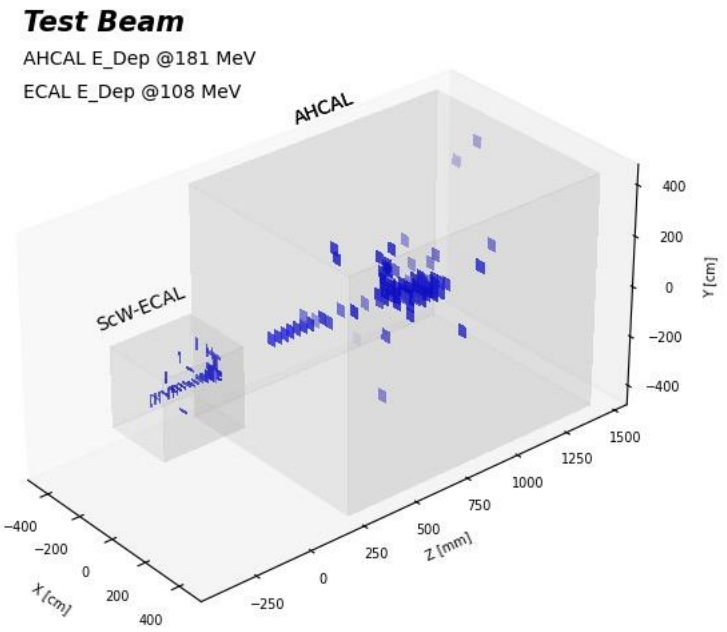


environment

AHCAL DAQ Board

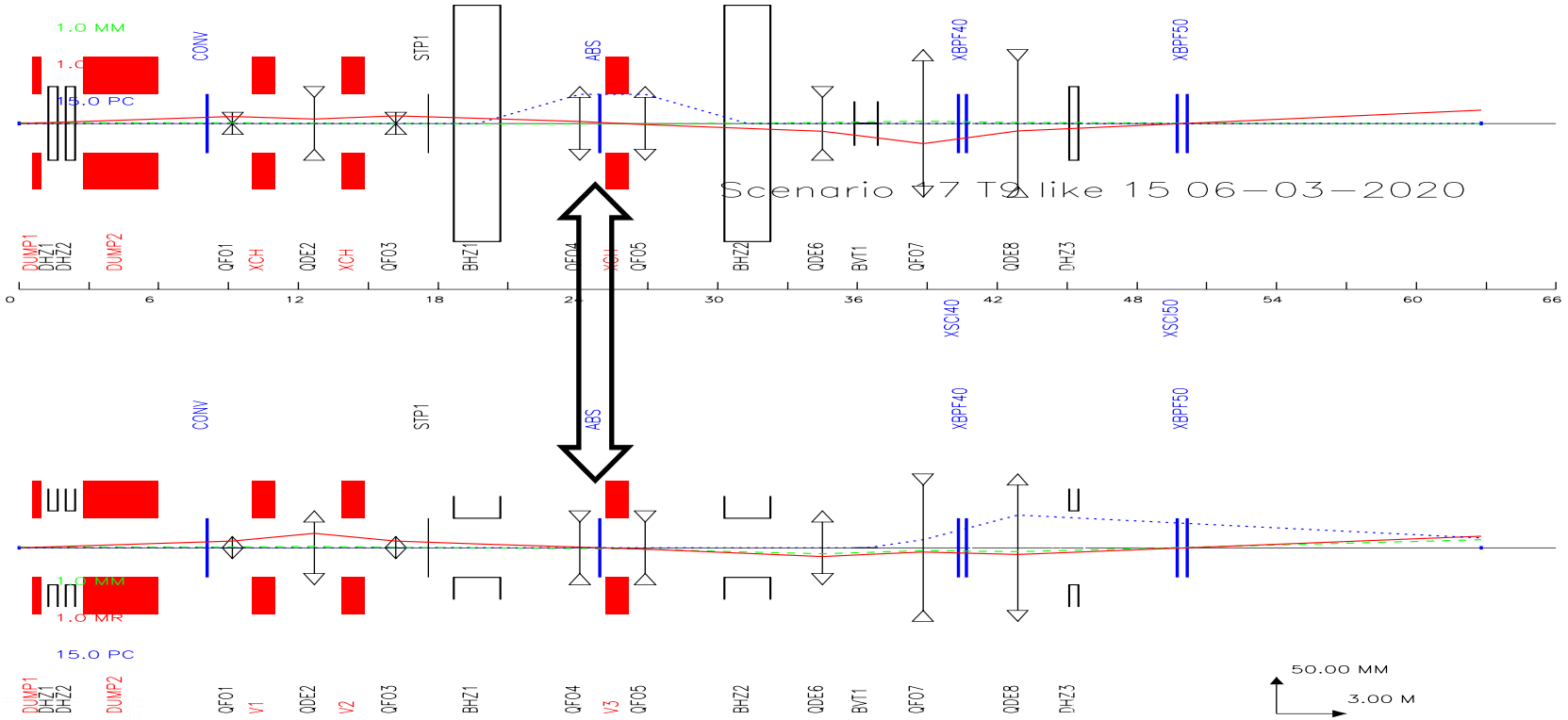
Event display





Suppress e- yield using Absorber

- Take an obstacle in the beam to “absorb” the electrons
  - The secondary e+/- will be bended later

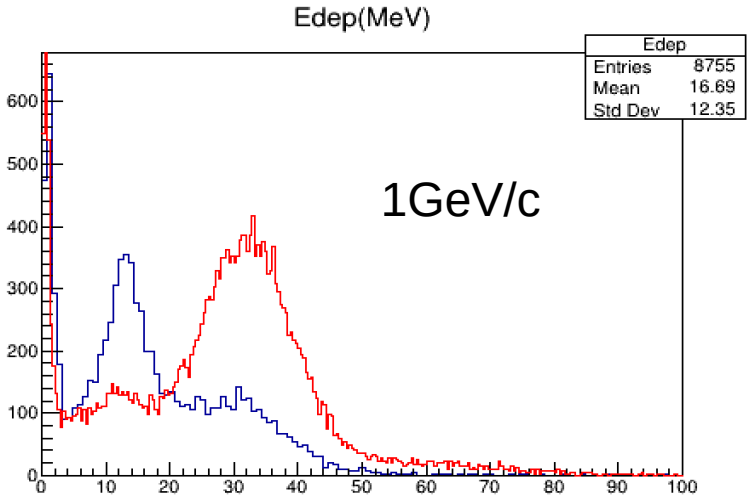


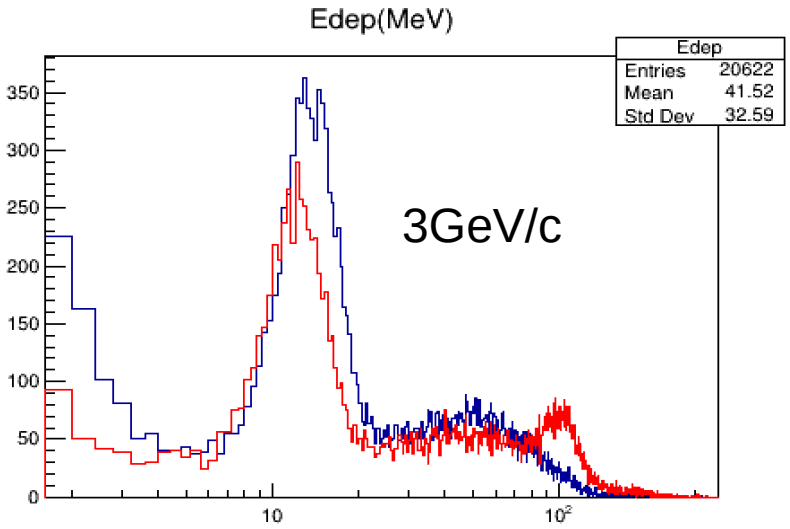
ECAL Energy Response to pi-

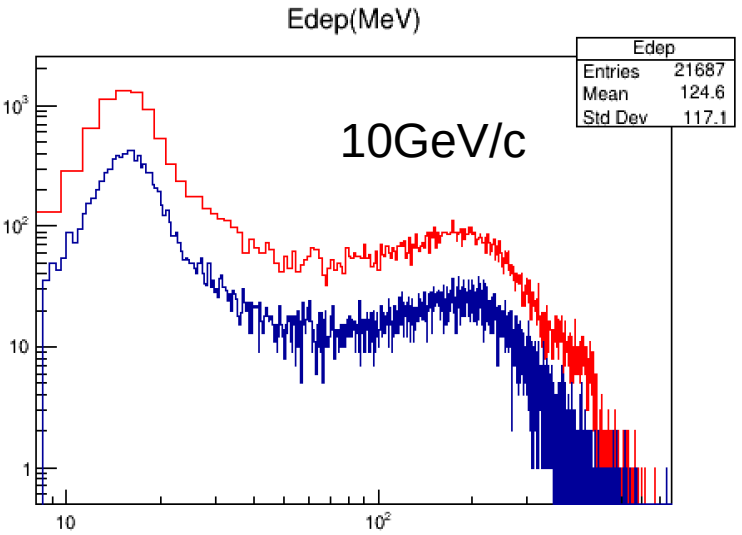
- Take an obstacle in the beam
  - XCON025, 4 mm lead

w/ obstacle

w/o obstacle

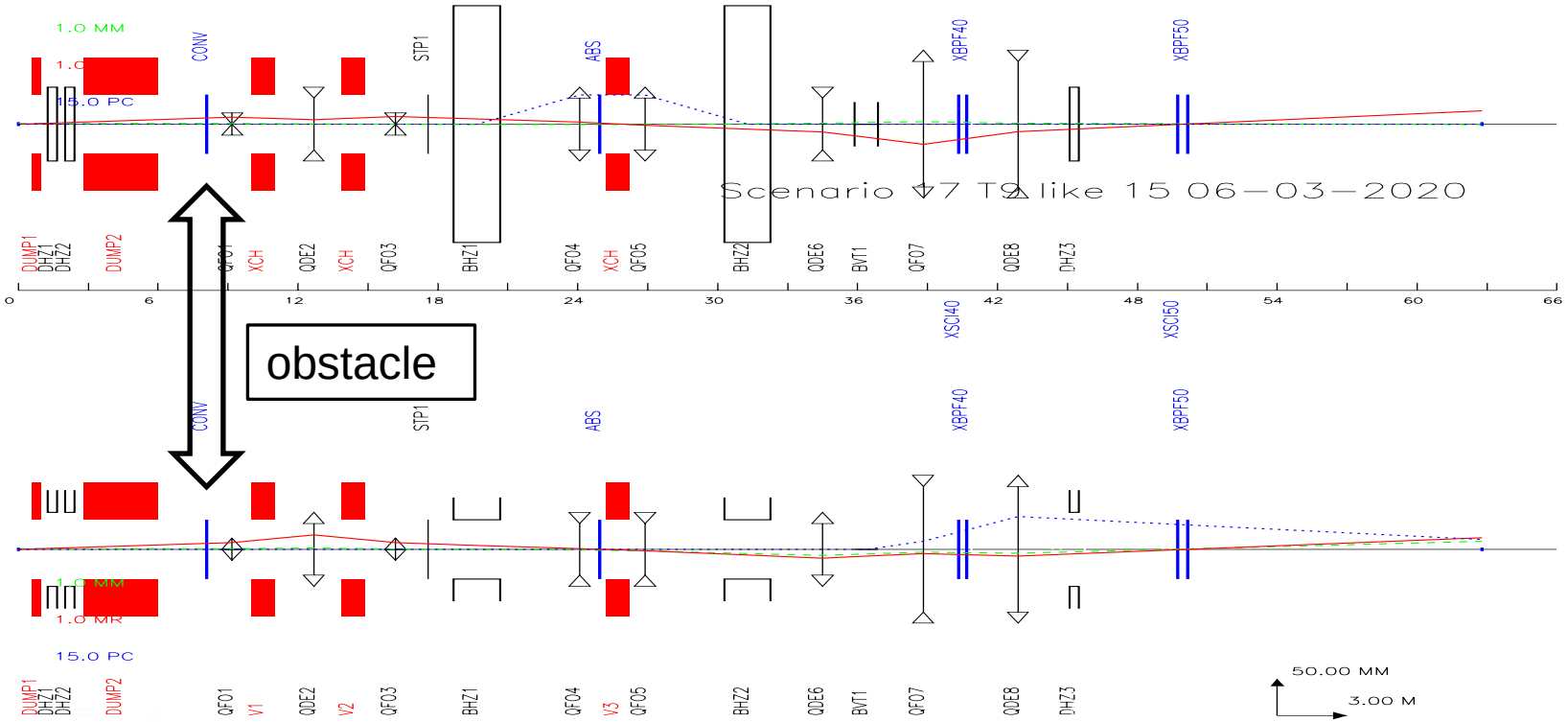






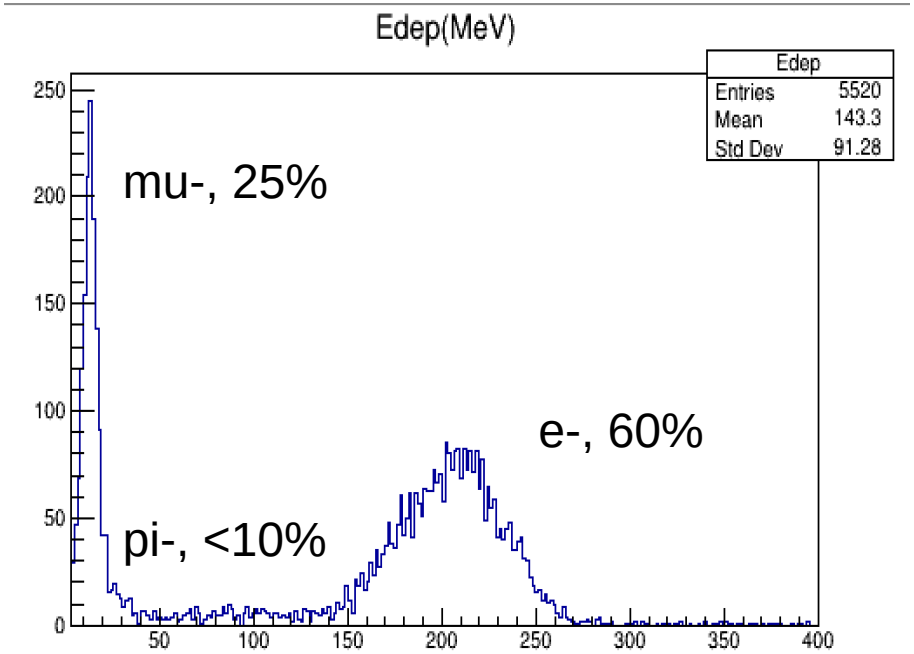
ECAL Energy Response to e-

- Take an obstacle as converter to produce electrons
  - Photon incident converter to produce e+/e-



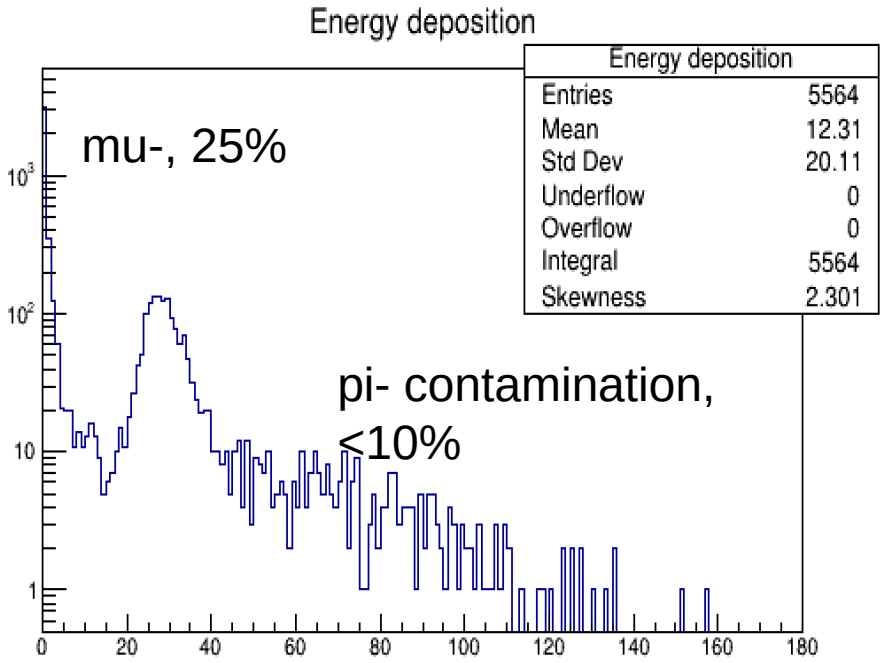
ECAL Energy Response to e-

5 GeV/c e- energy deposition in ECAL



ECAL

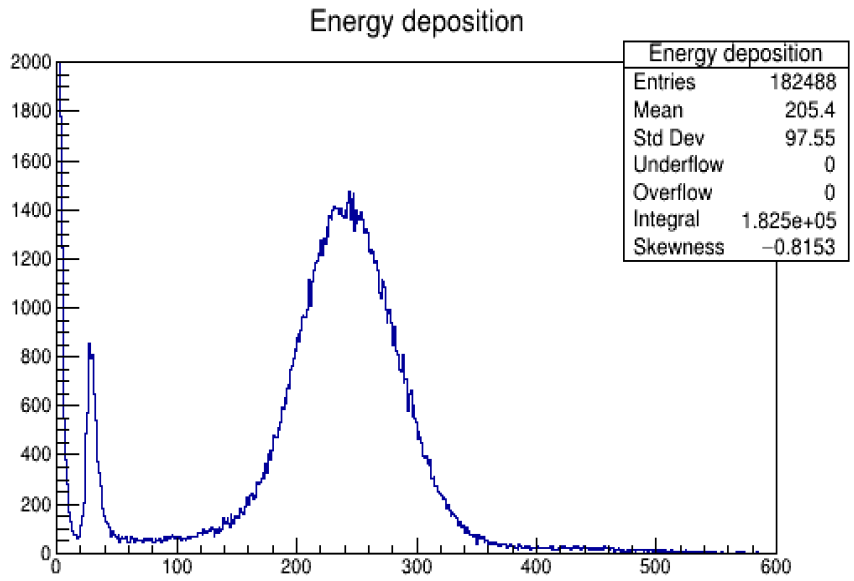
5 GeV/c e- energy deposition in AHCAL



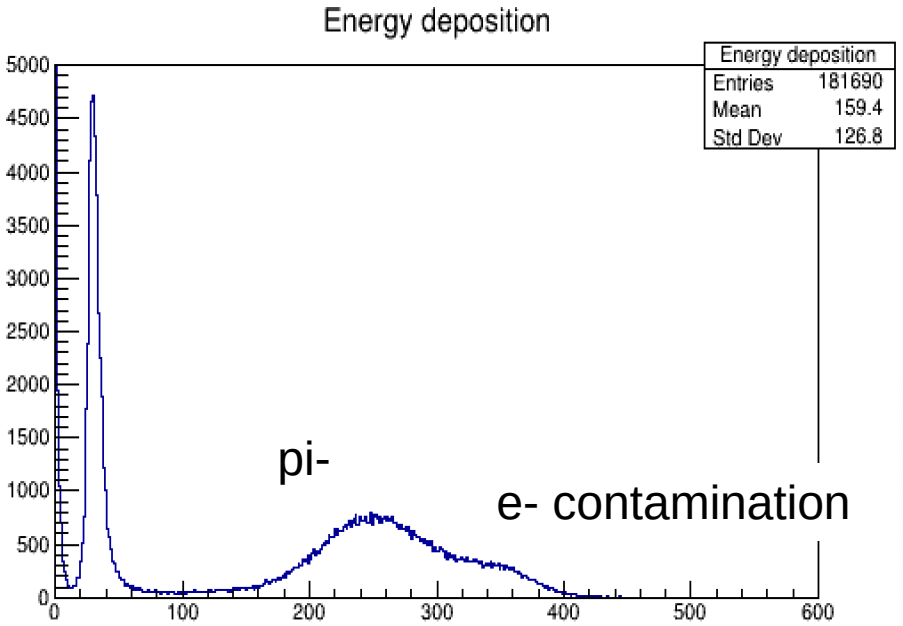
AHCAL

HCAL response： pi- Test

15 GeV/c

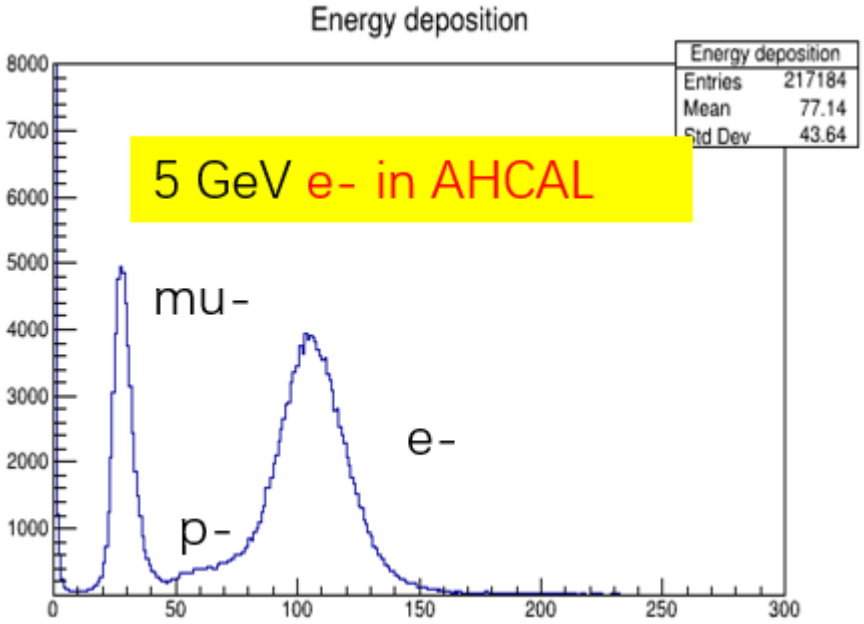


15 GeV/c in SPS

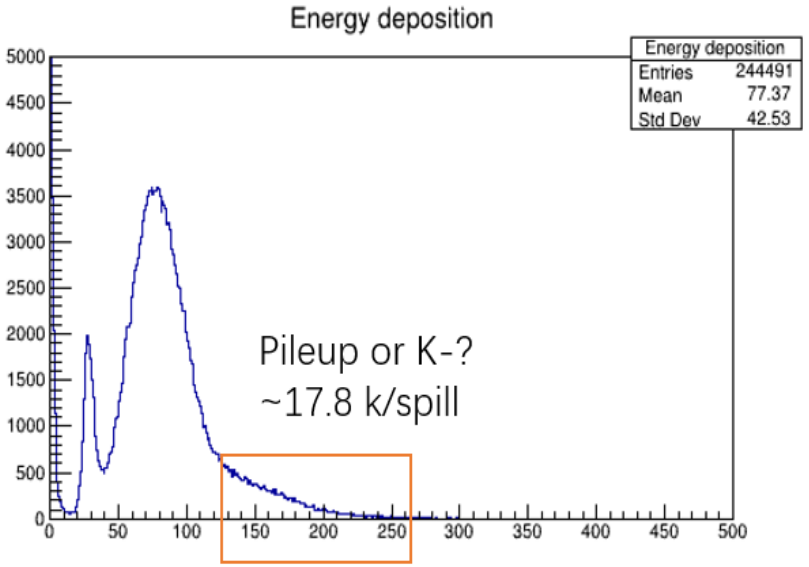


HCAL response to e-

5 GeV/c e- energy deposition in AHCAL



5 GeV/c pi- energy deposition in AHCAL



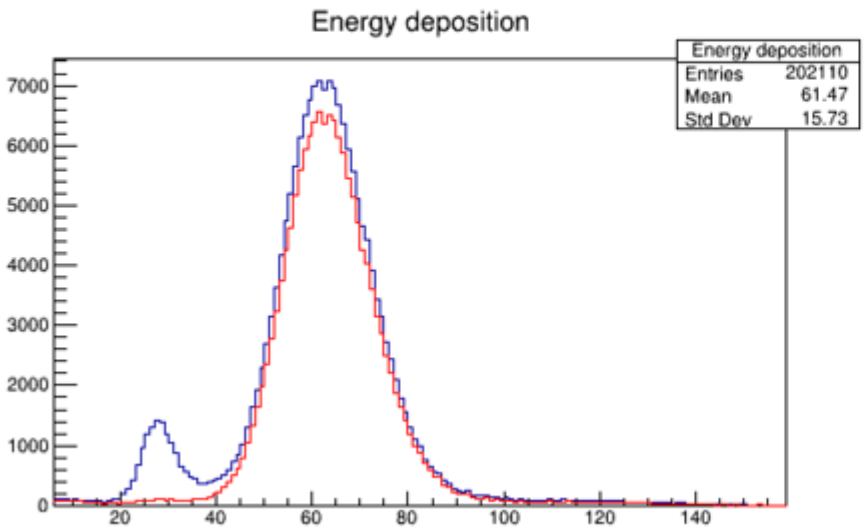
Cherenkov Detector

- The Cherenkov detectors were used to identify e-, mu-, pi-
- The muon peak disappear after we used the C signals

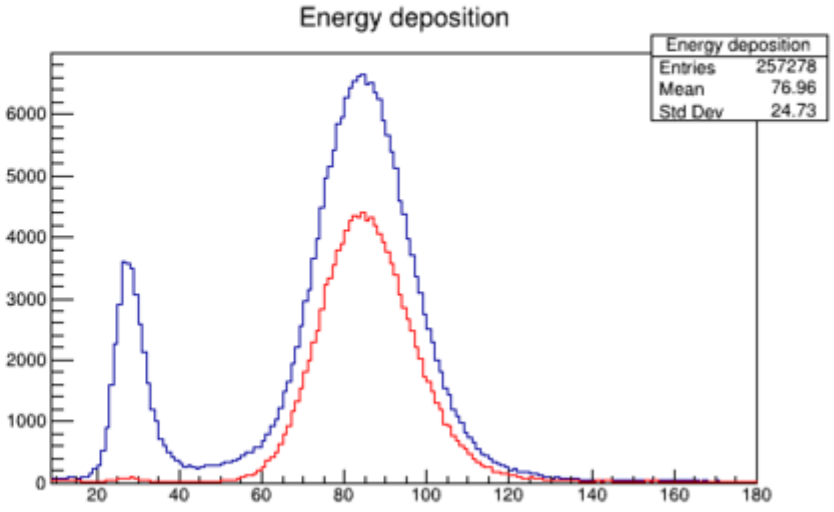
W/O Cherenkov

W/ Cherenkov

3 GeV/c e- in AHCAL



4 GeV/c e- in AHCAL



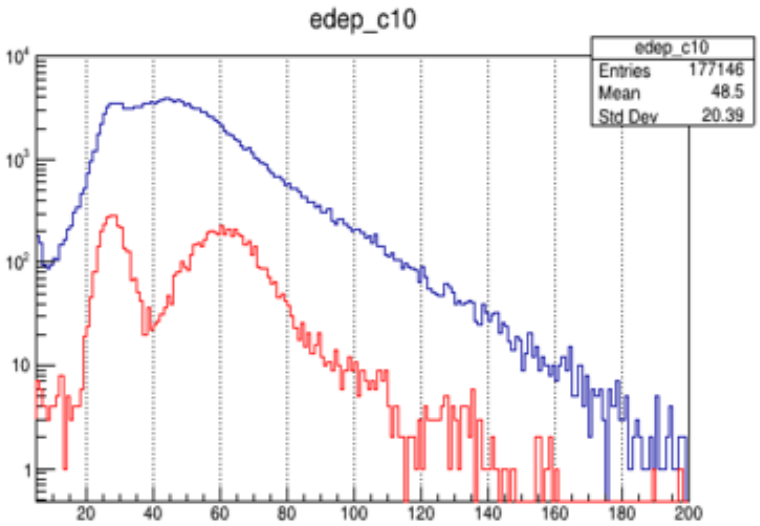
Cherenkov Detector

- We also could “see” the mu- and e- events in pi- data

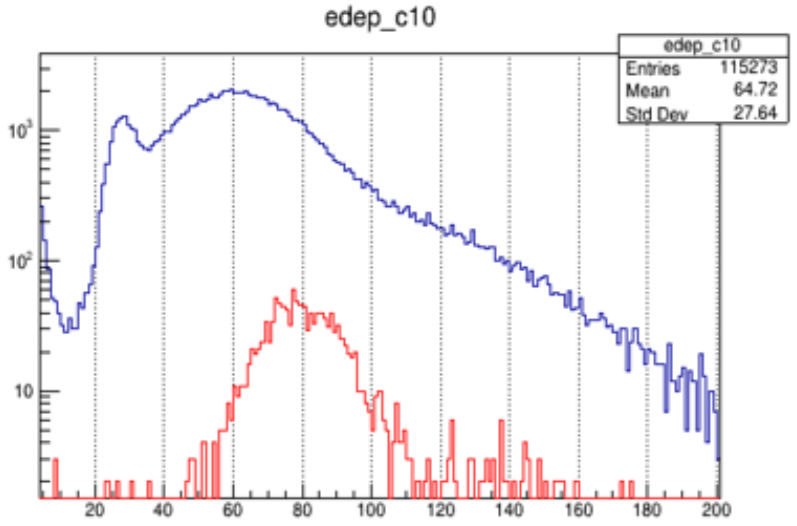
W/O Cherenkov

W/ Cherenkov， e-/mu- candidates

3 GeV/c pi- in AHCAL



4 GeV/c pi- in AHCAL



Final transportation back to China

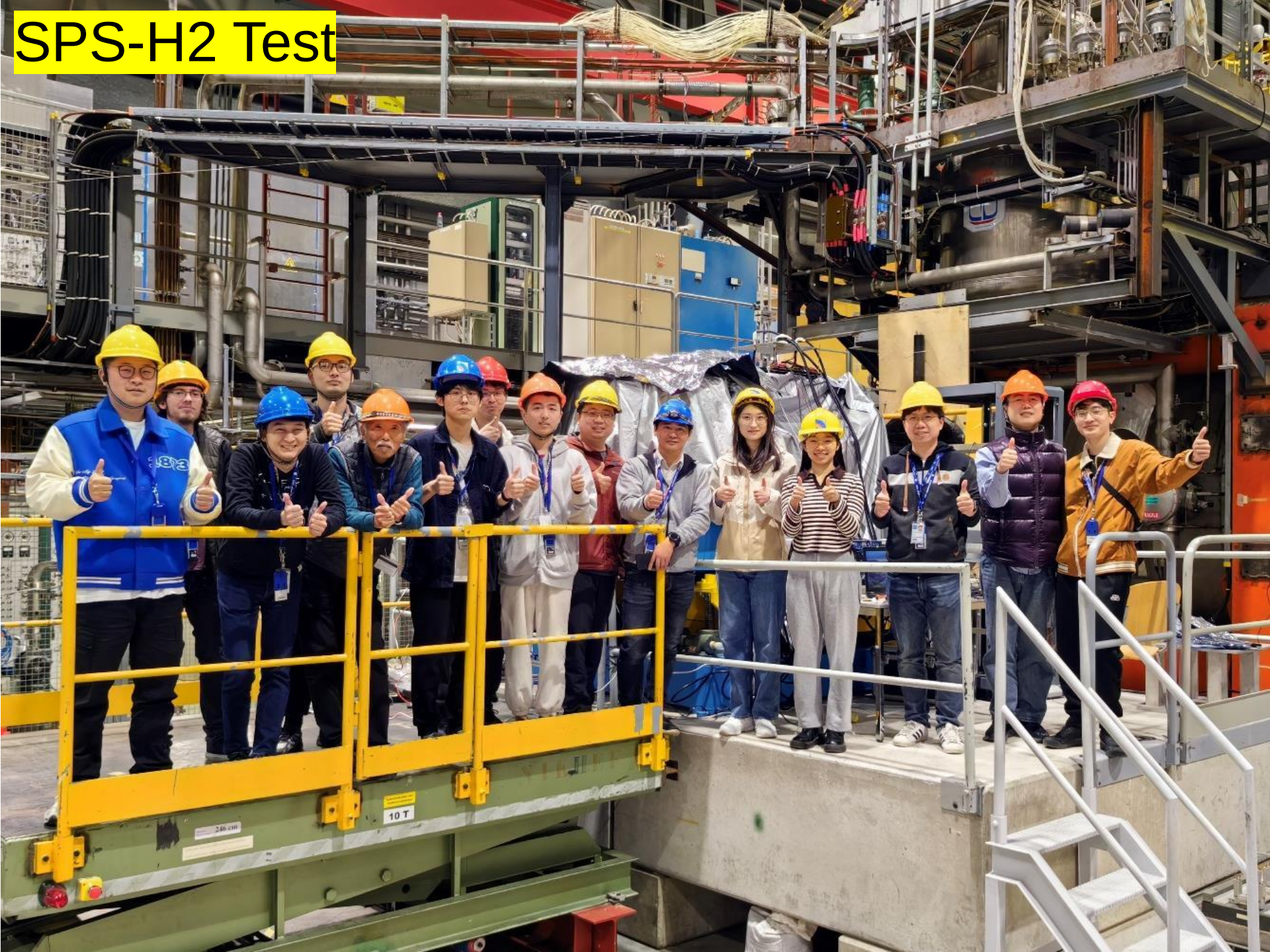
7/6, shipped to China

Final transportation back to China

17/6, arrived in Hefei

Summary

- The two calorimeters has been taking beam test from April 24 to May. 31, the preliminary results show the calorimeters work very well
  - The Sci-W ECAL and AHCAL were tested with pions and electrons from 10 GeV/c to 120 GeV/c (SPS) and 0.5 GeV/c – 15 GeV/c (PS)
  - We collected about 40 million events in this beam test
- We will continue a detailed analysis of the data to further tap the potential of the data

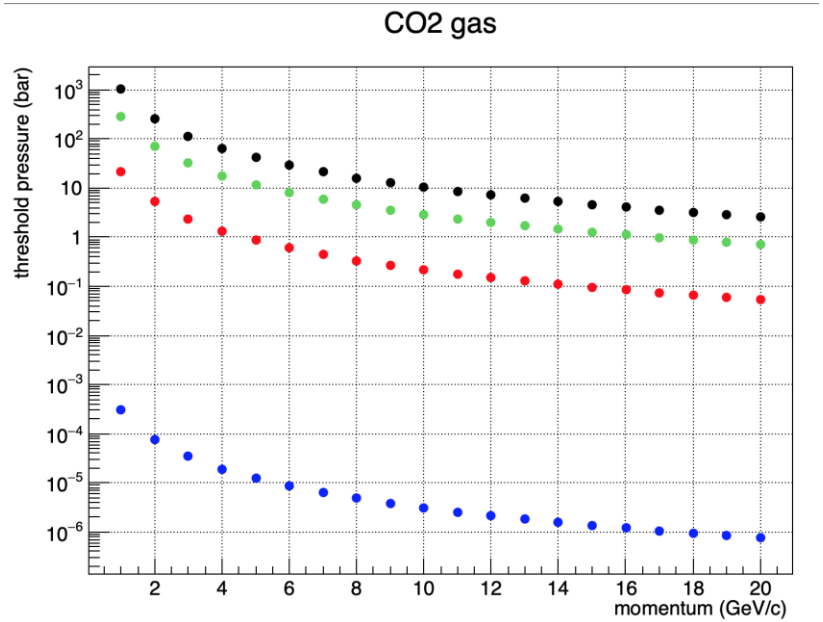

SPS-H2 Test
10 T

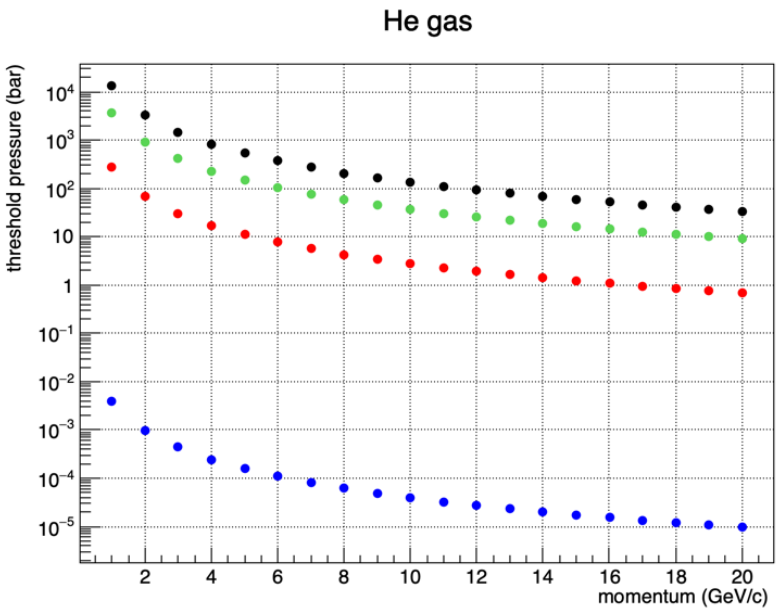

PS-T9 Test


谢谢大家
ありがとうございました
Merci à tous
Thank you all

Cherenkov Detector Threshold （

by Takeshita-san）

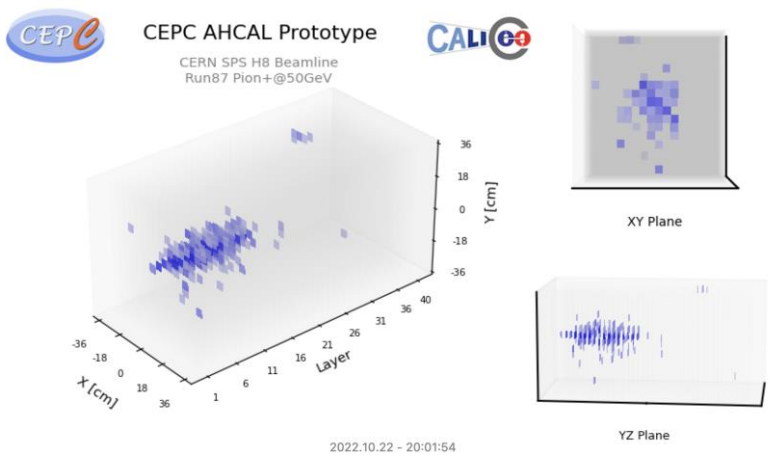




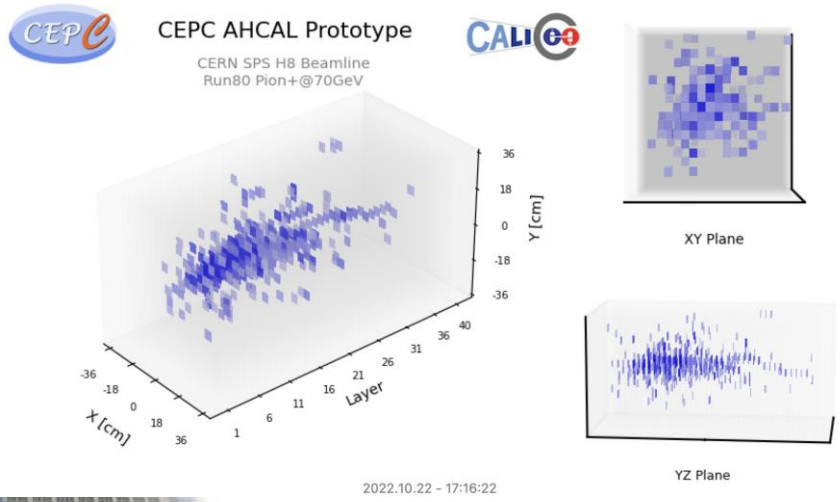
AHCAL Test with pion+

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

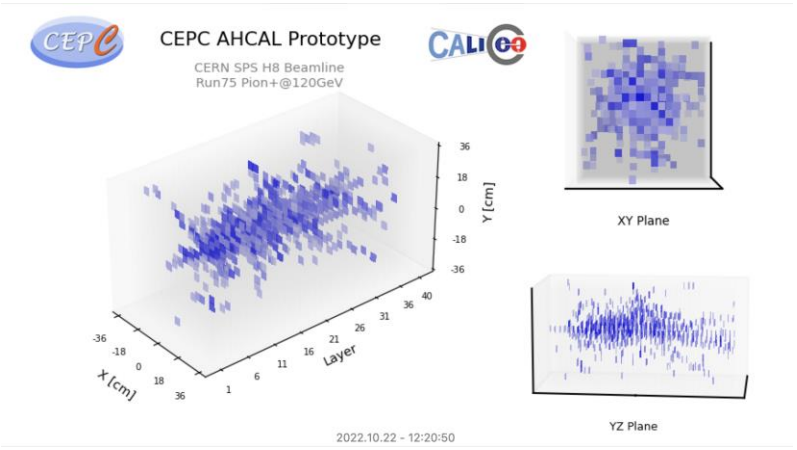
50 GeV



70 GeV

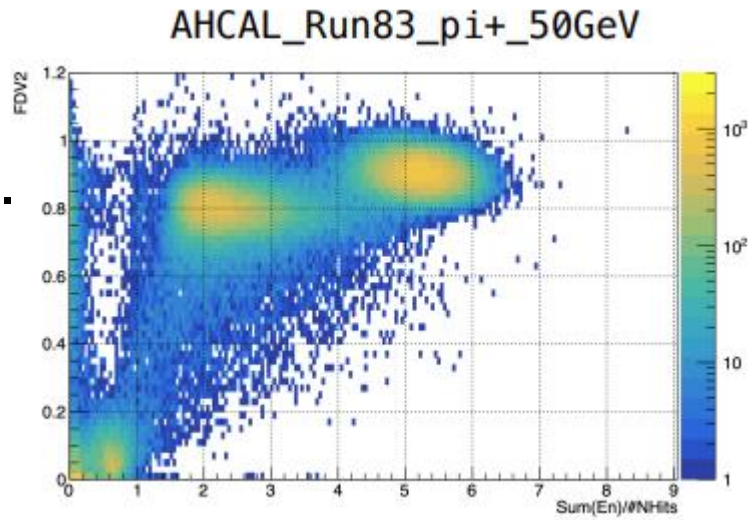


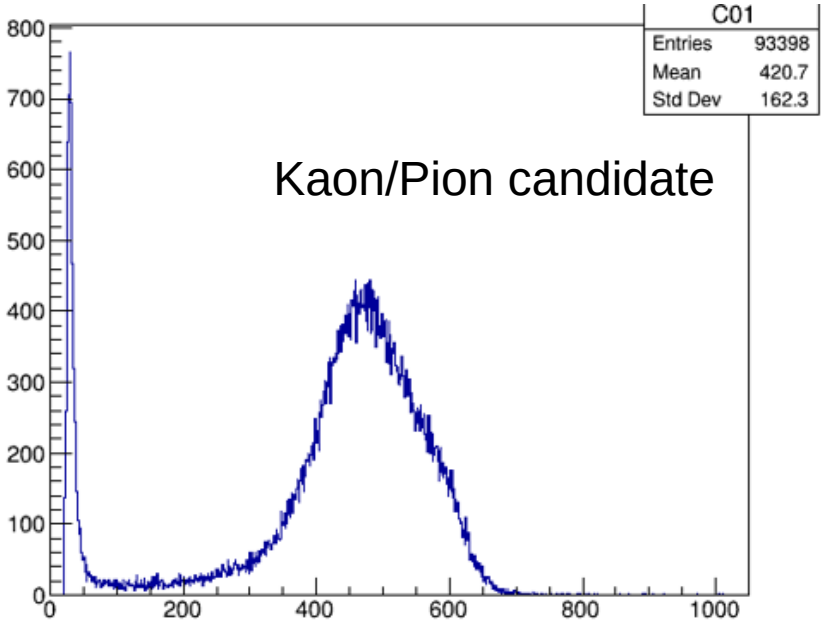
120 GeV

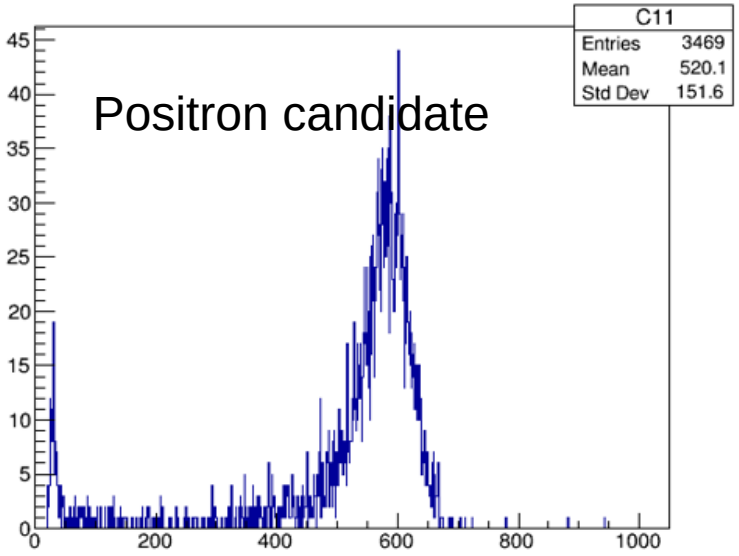


AHCAL Test with pion+

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



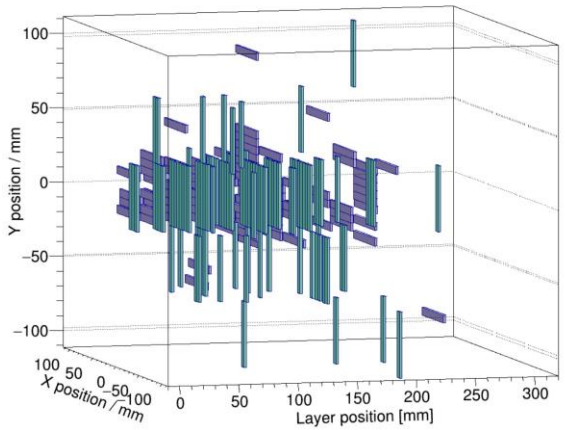




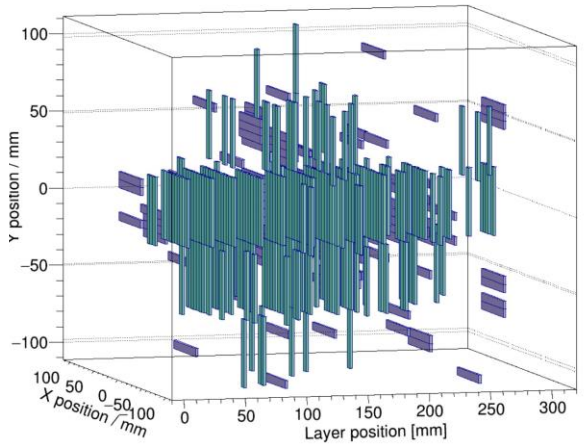
Sci-W ECAL Test with Positron

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

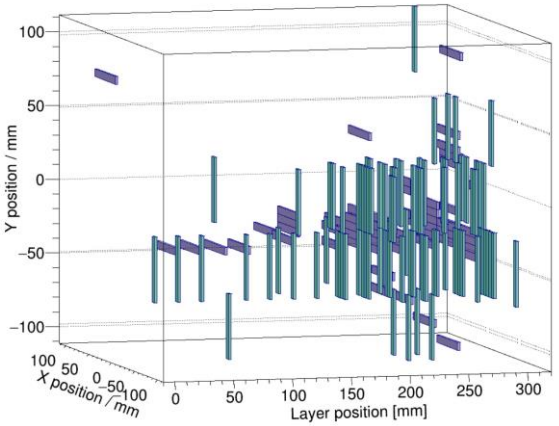
10 GeV e+



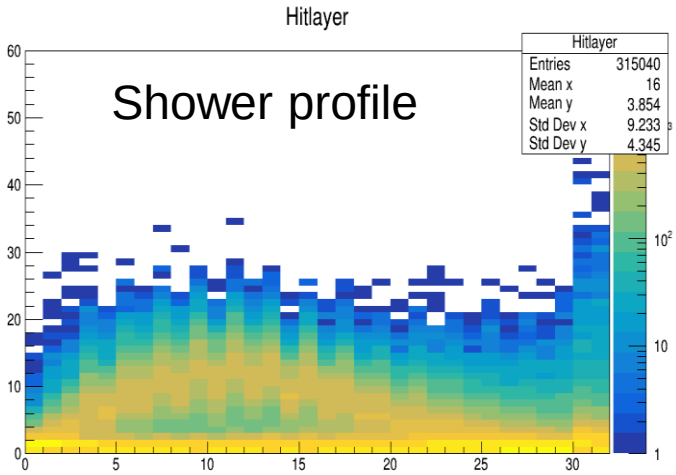
40 GeV e+



10 GeV hadron

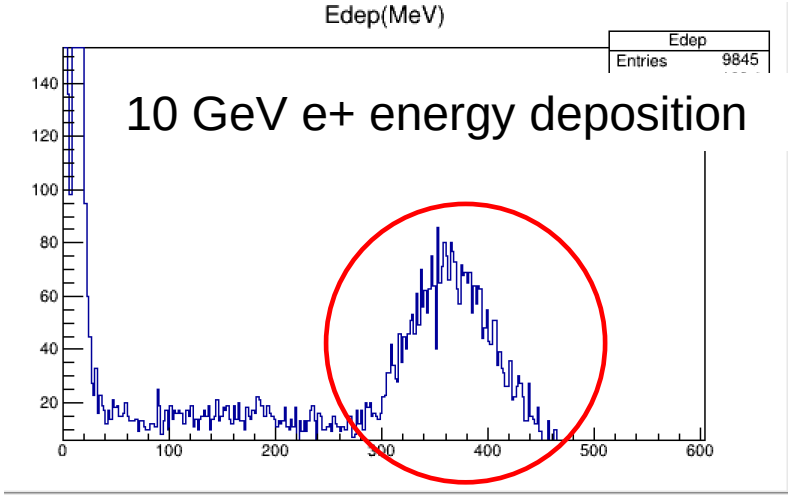


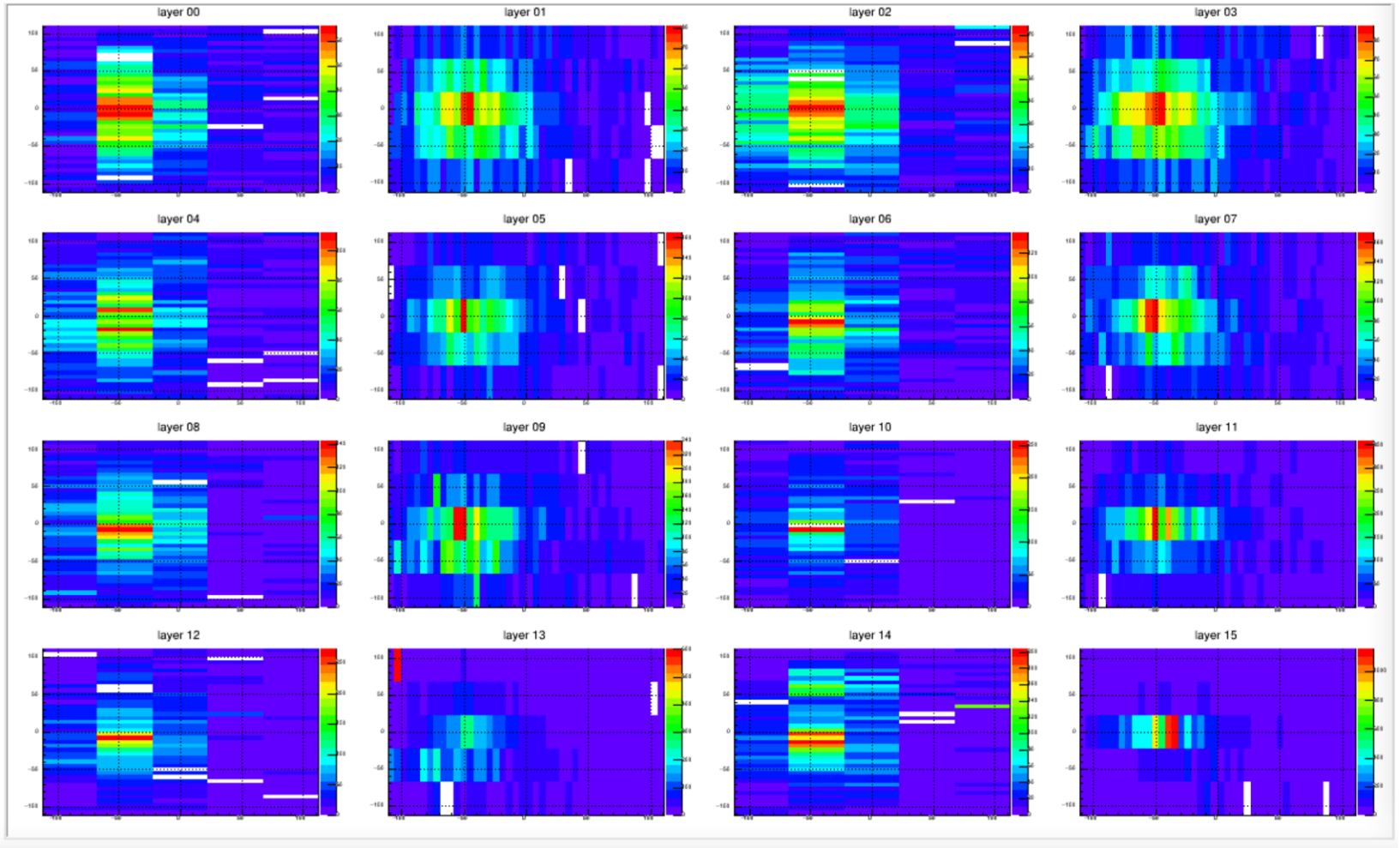
Shower profile



ECAL layer

10 GeV e+ energy deposition




layer 00
layer 01
layer 02
layer 03
layer 04
layer 05
layer 06
layer 07
layer 08
layer 09
layer 10
layer 11
layer 12
layer 13
layer 14
layer 15

AHCAL Test with Mu+

- The thresholds were calibrated using muon beam