中国科学院高能物理研究所
Institute of High Energy Physics
Chinese Academy of Sciences

CEPC

季度考核报告

报 告 人 ： 夏 欣

导 师 ： 阮曼奇

合作导师 ： 刘勇, 陆波

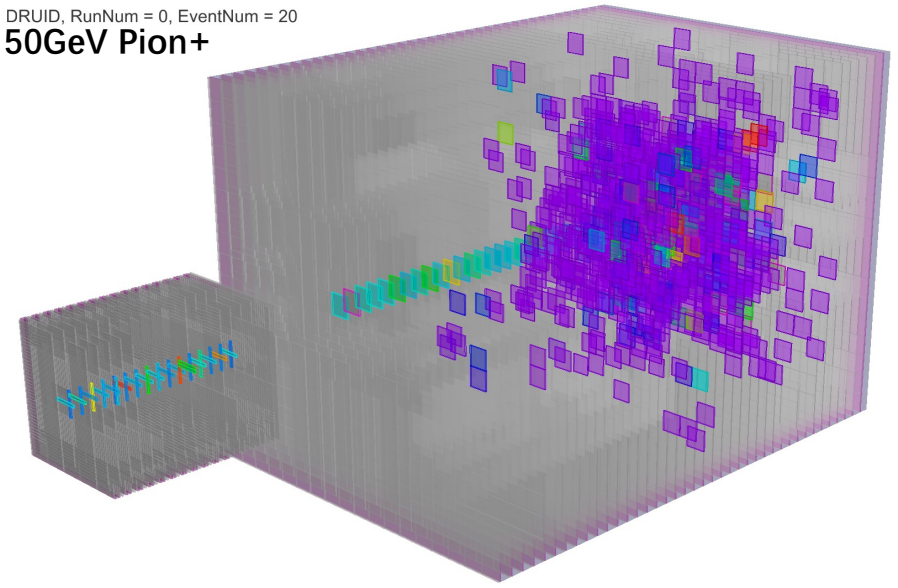
实验物理中心 高能量组

2023/4/23

Motivation

- CEPC ScEcal & AHcal prototype commissioned
  - *ScEcal :Scintillator, W*
  - *AHcal: Scintillator, Iron*
- Test beam at CERN at 2022/10
  - *Data size: 533G*
  - *e^+, π^+, μ^+ samples from 10GeV-120GeV*
- **Object**: Quantify key performance
  - *Energy Resolution, Energy Linearity,*

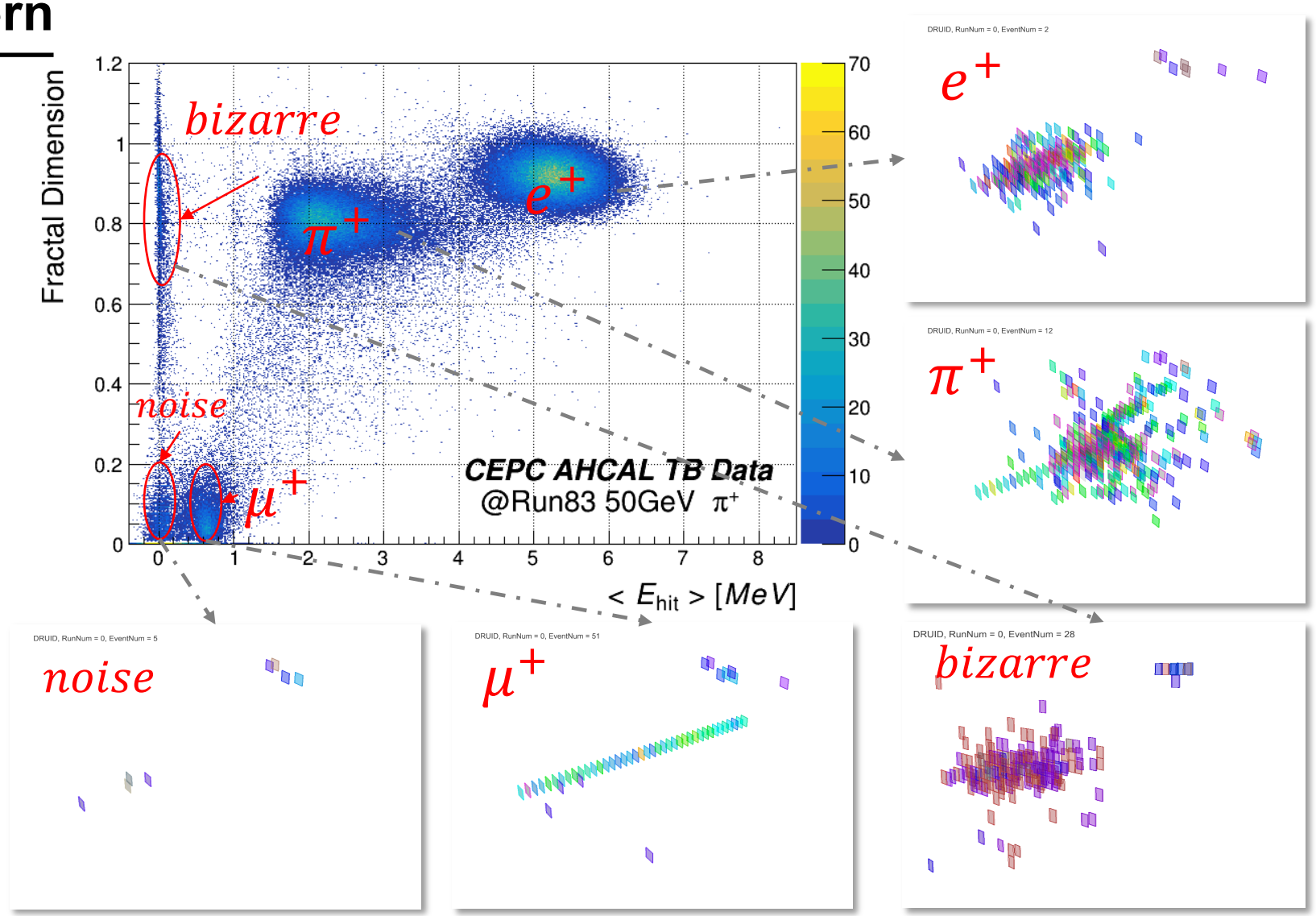
  PID Capability, etc
- **Challenge**: Mixed Beam, MC/data discrepancy
- **My Job**: **Pattern Recognition, Particle Identification, Quantify key performance**



Test beam Data pattern

- **Variables used to distinguish:**
  - Conventional
    - #.Hits per event
    - Energy deposition per event
    - Center of gravity of shower
    - …
  - Novel
    - **Fractal Dimension**[1]

      (dedicated for HGCAL)
- **Test Beam Data Components:**
  - e^+, π^+, μ^+, noise, bizarre



[1] M. Ruan et al, PRL 112, 012001

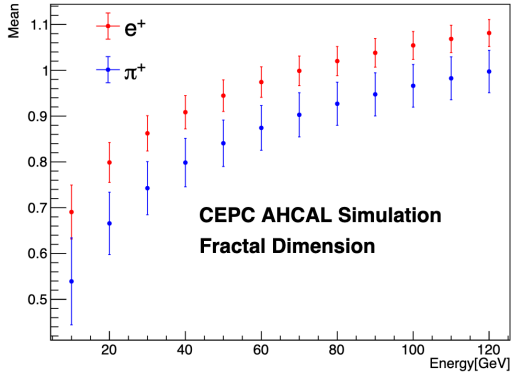
PID & Significance

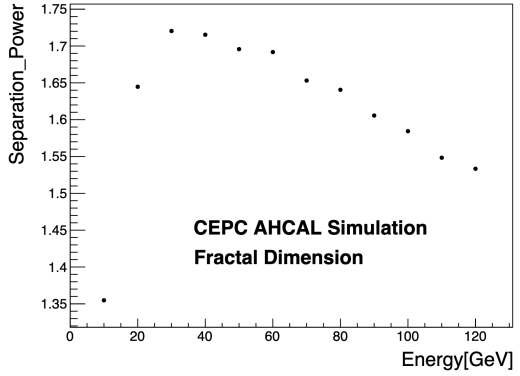
PID Capability & Result:

- Combine Fractal dimension, #.Hits and Total energy per event, good separation achieved.
- Basic pattern is consistent.
  - *Peak shift: SiPM Saturation*

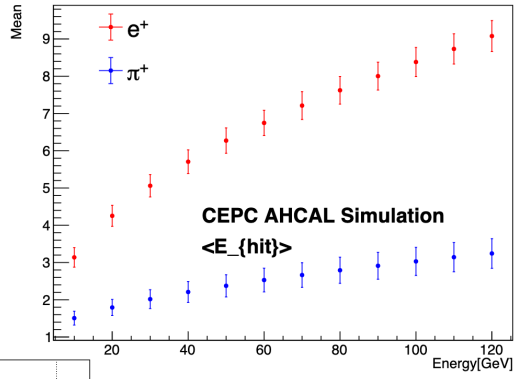
Significance :

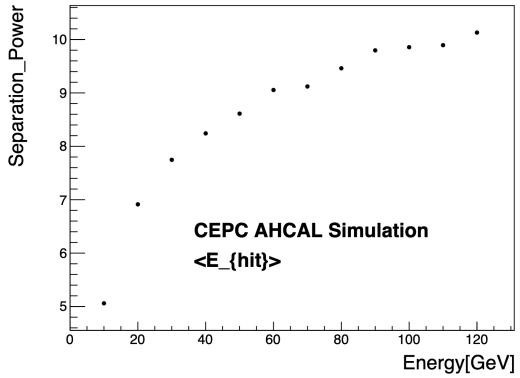
- Pure EM/Hadrnoic sample achieved
  - **Basis of Quantifying prototype performance**
  - **Validate and Tune MC**
  - Machine learning(BDT/ANN) input for automatic PID

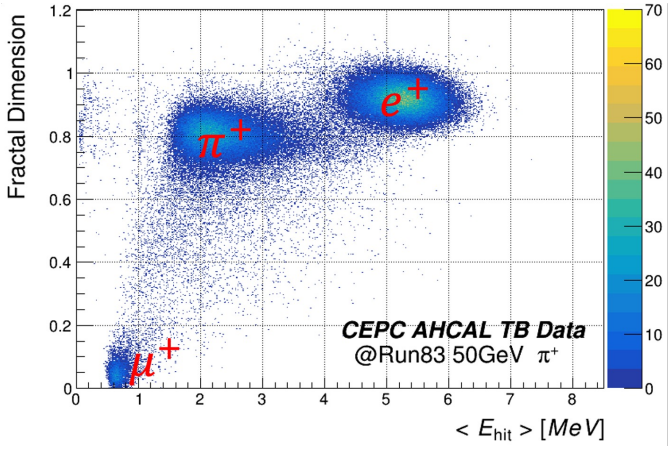


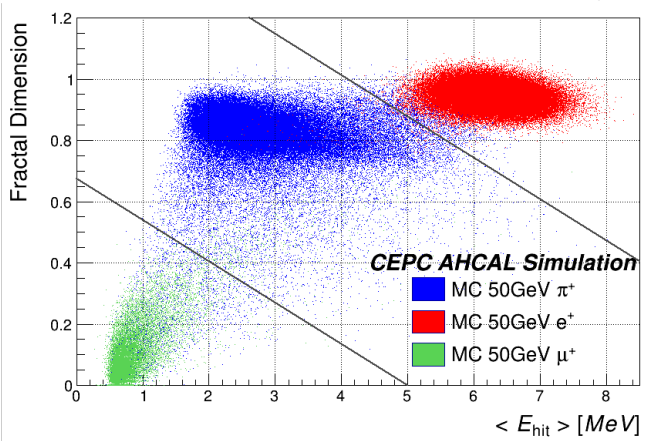


$$\frac{Mean_e - Mean_\pi}{\sqrt{\sigma_e^2 + \sigma_\pi^2}}$$









Efficiency

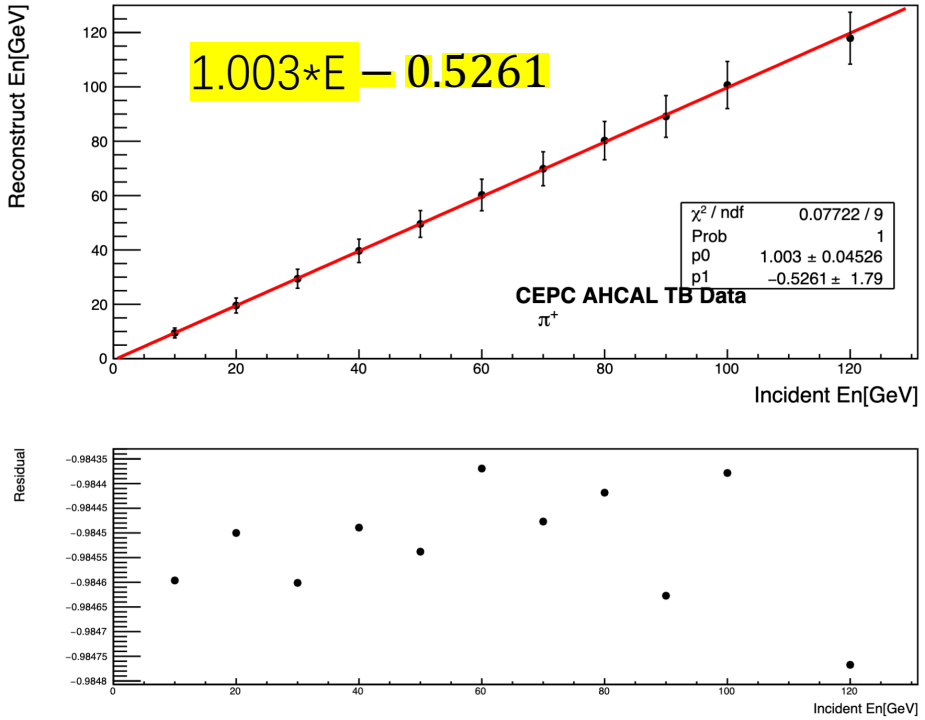
Truth \ ID	μ^+	π^+	e^+
μ^+	99.4%	0.60%	0
π^+	3.60%	94.10%	2.30%
e^+	0	0.30%	99.70%

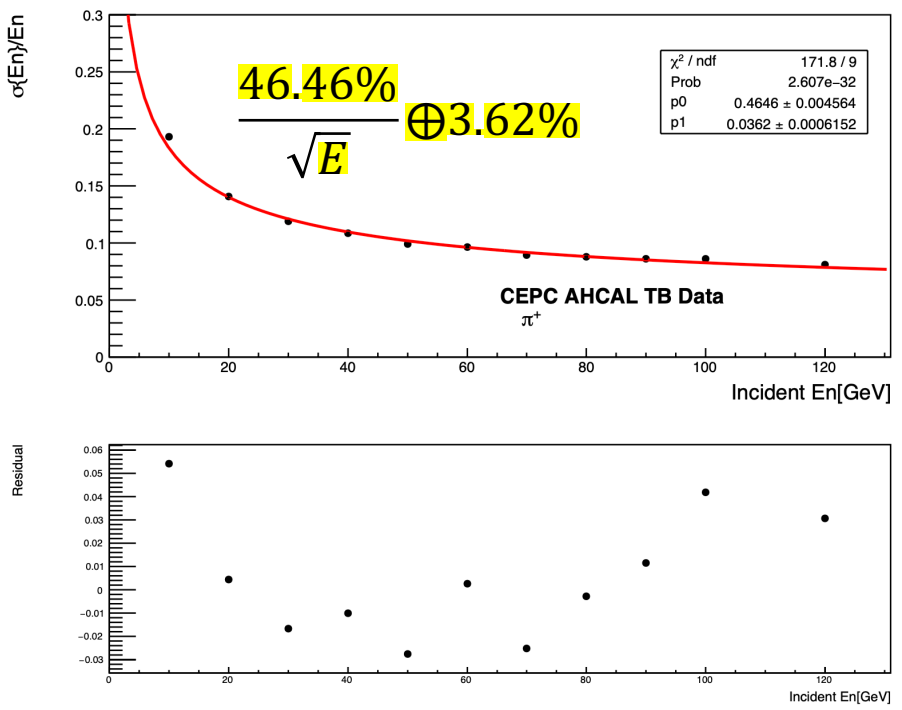
Energy Response

AHcal prototype preliminary performance achieved !

- Energy Linearity: $1.003*E - 0.5261$
- Enerdy Resolution: $\frac{46.46\%}{\sqrt{E}} \oplus 3.62\%$

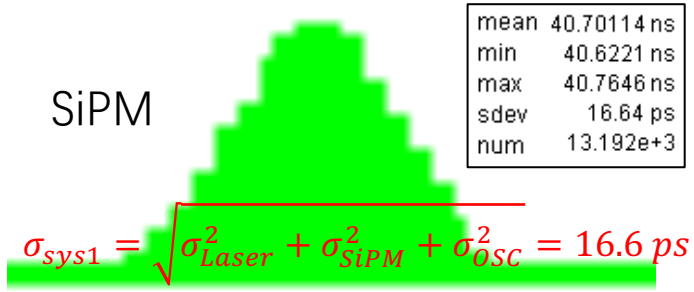
Future Plan: Reduce the impact of energy leakage, Improve energy response performance

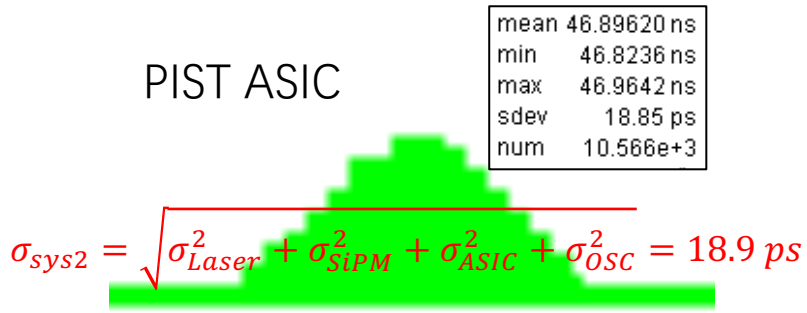




➢ Test of PIST ASIC

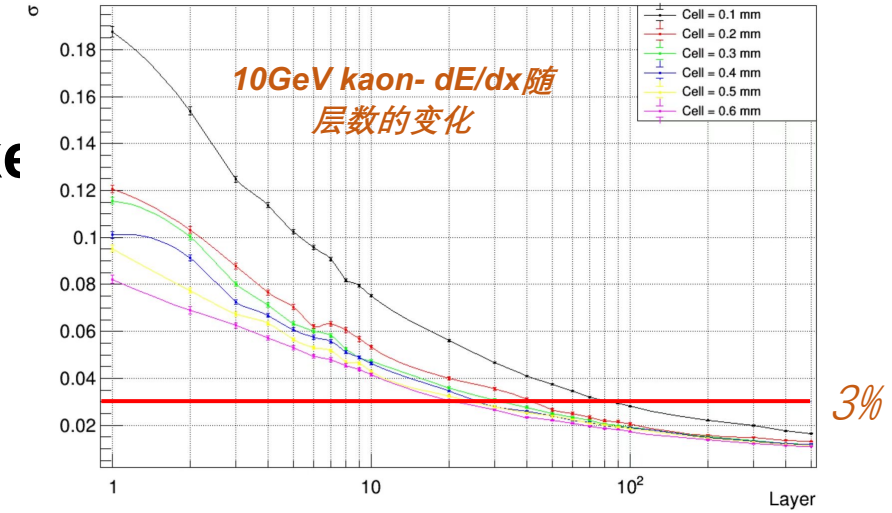
- **Motivition:** High precision time detector is critical for CEPC, 50ps time resolution is required. Accordingly, **PI**co**S**econd **T**imeing ASIC designed for CEPC ECAL SiPM by Bo Lu et al
- **My work:** **Build test platform and test PIST ASIC**
- **Result:**
  - $\sigma_{intrinsic} = \sqrt{\sigma_{sys2}^2 - \sigma_{sys1}^2} = 9.0\ ps$





➢ Potential of dE/dx Measurement of Silicon Tracke

- **Motivation:** dE/dx is an essential variable for PID, CEPC require 3% resolution
- **My work:** Simulation and analysis



Summary

Data analysis of Testbeam

1. Pattern Recognition
2. Give PID Scheme and pure sample
3. Preliminary performance of energy response achieved
4. Future, Reduce the impact of energy leakage to Improve energy response performance
5. Participate in beam test in May 2023

Test of PIST ASIC

1. 20ps time resolution achieved(systemic)
2. Future, quantify time resolution at different energy point

CEPC Generic Simulation Study

1. 20 layers, 0.6 mm silicon could achieve 3% resolution of dE/dx

Reports

https://indico.ihep.ac.cn/event/19214/

https://indico.ihep.ac.cn/event/19045/

https://indico.ihep.ac.cn/event/18769/

https://indico.ihep.ac.cn/event/18769/

https://indico.ihep.ac.cn/event/19045/

…

Thanks!

Backup

Elements of ECAL

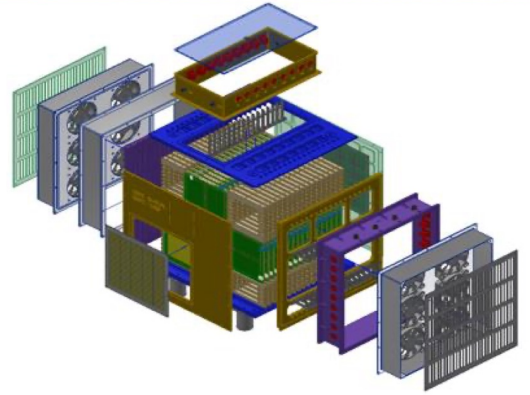
Scintillator （5mm*45mm*2mm）

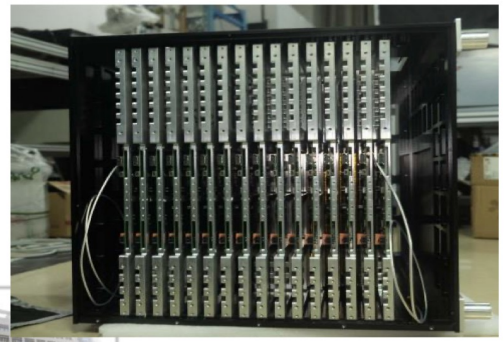
SiPM（1mm＊1mm, 10k pixels）

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

Sci-W ECAL

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

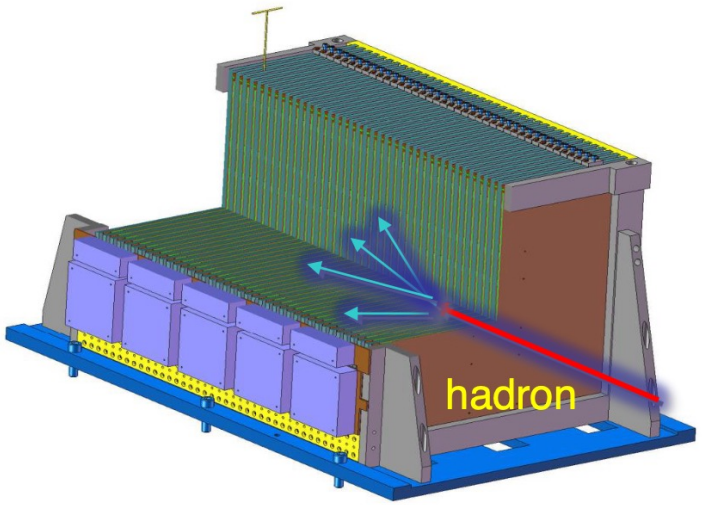


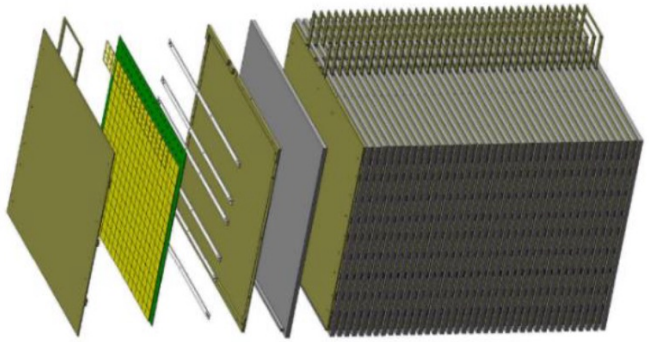


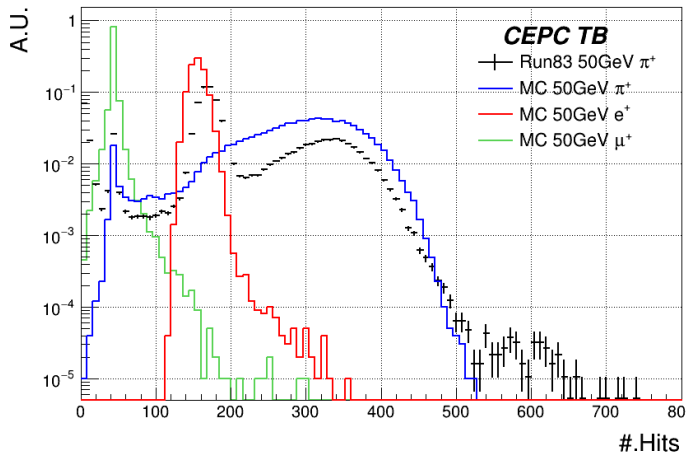
AHCAL Prototype

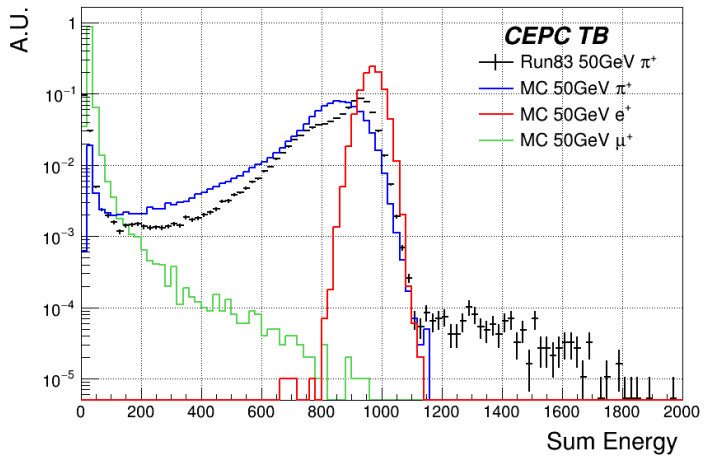
- Sampling Calorimeter
  - 40 layers, ~ 5 N.I.L
  - 72 cm×72 cm
- Absorber
  - Iron，2 cm thickness
- Sensitive Detector
  - Scintillator+SiPM，Number:13,960
  - Cell size：40 mm×40 mm×3mm
  - SiPM：HPK and NDL
- Electronics
  - SPIROC2E ASIC Chip

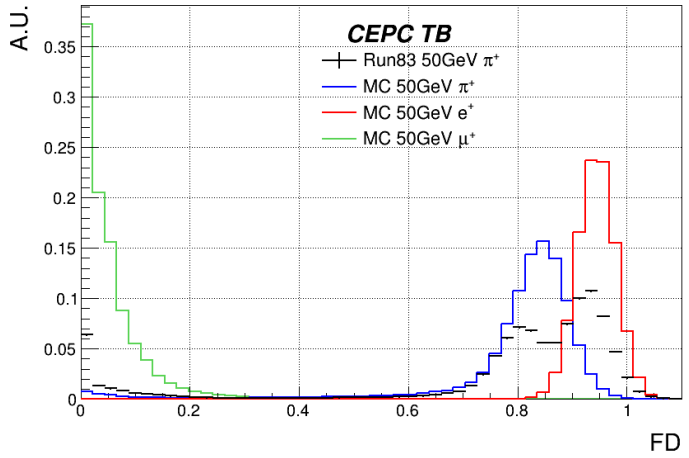
AHCAL Structure

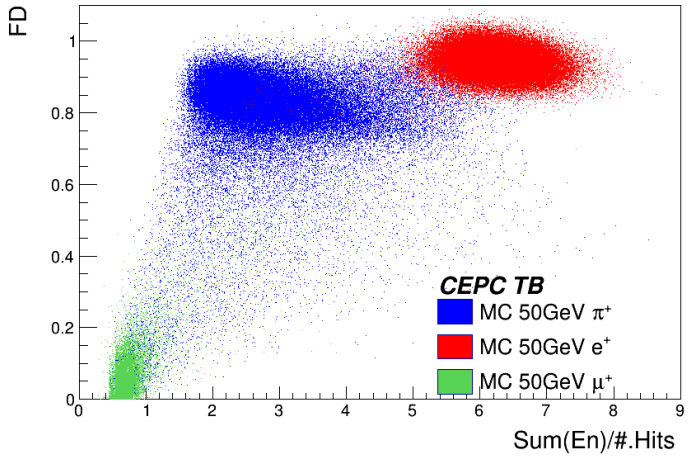


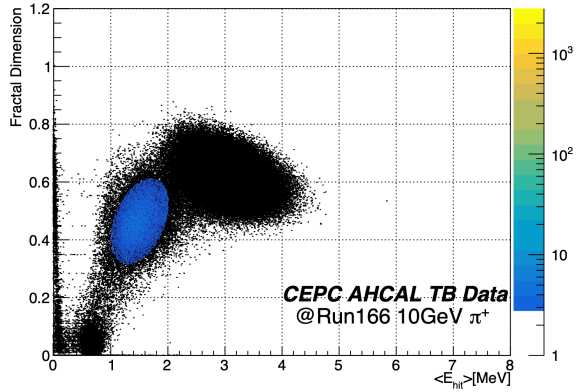


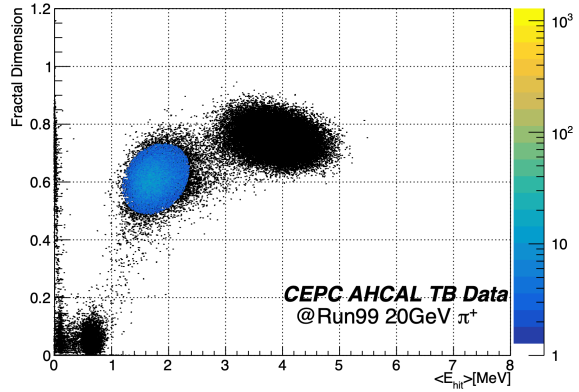

CEPC TB
Run83 50GeV π+
MC 50GeV π+
MC 50GeV e+
MC 50GeV μ+
A.U.
#.Hits

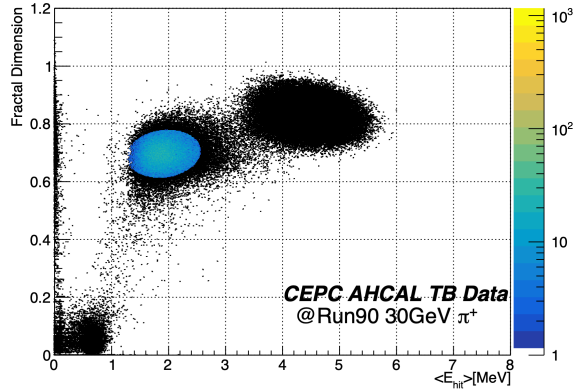

CEPC TB
Run83 50GeV π+
MC 50GeV π+
MC 50GeV e+
MC 50GeV μ+
A.U.
Sum Energy

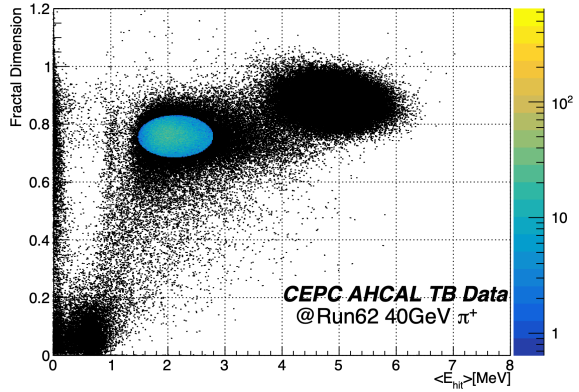

CEPC TB
Run83 50GeV π+
MC 50GeV π+
MC 50GeV e+
MC 50GeV μ+
A.U.
FD


CEPC TB
MC 50GeV π+
MC 50GeV e+
MC 50GeV μ+
FD
Sum(En)/#.Hits


Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run166 10GeV π+


Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run99 20GeV π+


Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run90 30GeV π+


Fractal Dimension
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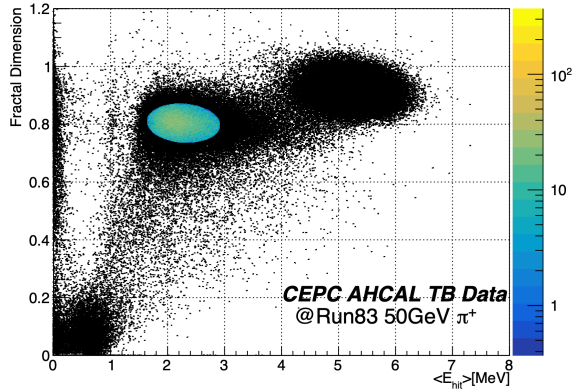
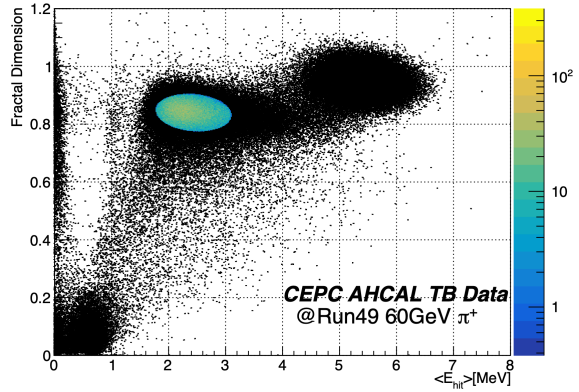
CEPC AHCAL TB Data
@Run62 40GeV π+


Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run83 50GeV π+


Fractal Dimension
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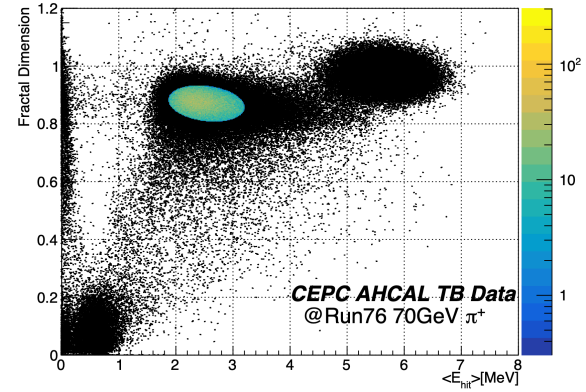
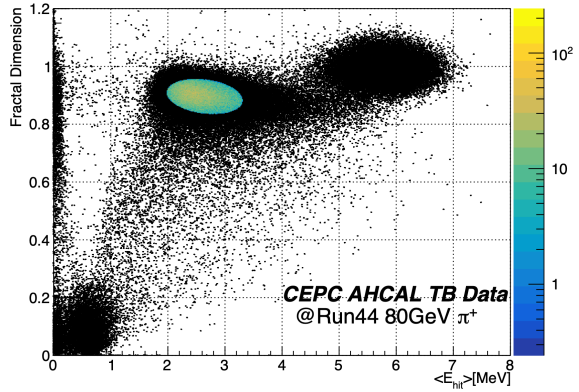
CEPC AHCAL TB Data
@Run49 60GeV π+


Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run76 70GeV π+


Fractal Dimension
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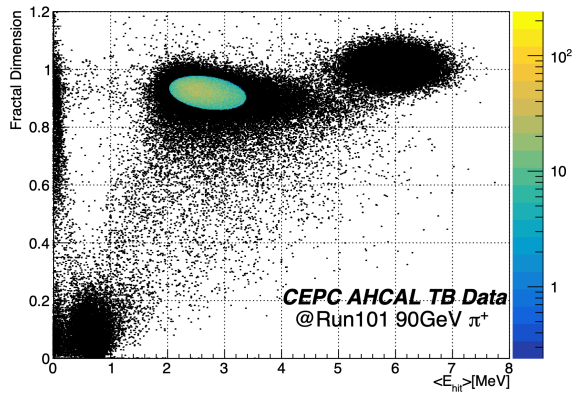
CEPC AHCAL TB Data
@Run44 80GeV π+


Fractal Dimension
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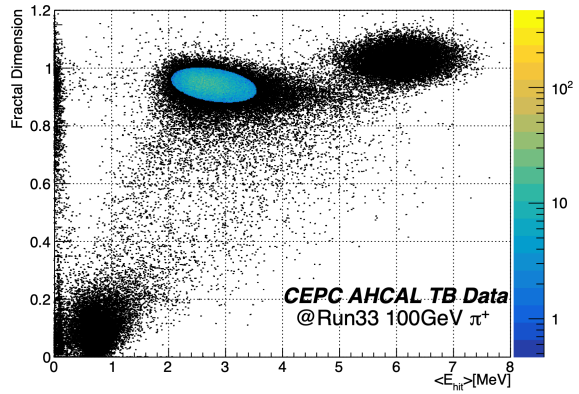
CEPC AHCAL TB Data
@Run101 90GeV π+


Fractal Dimension
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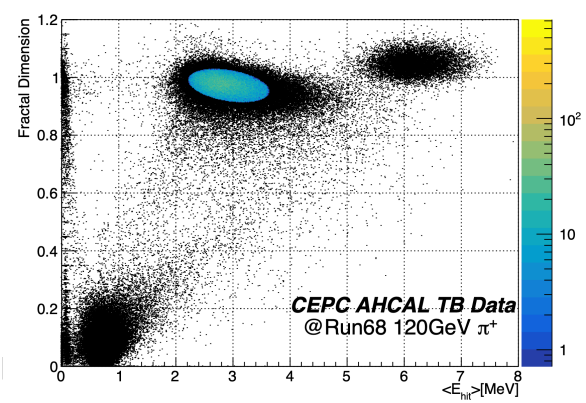
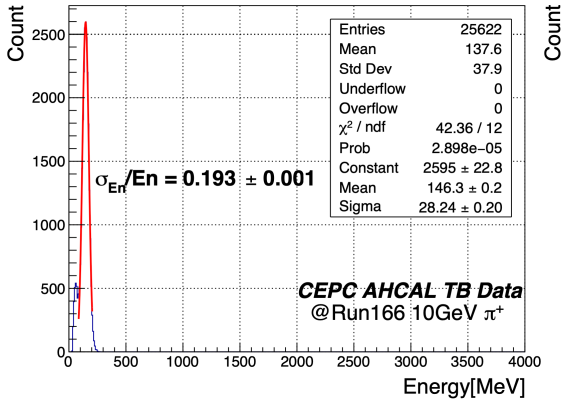
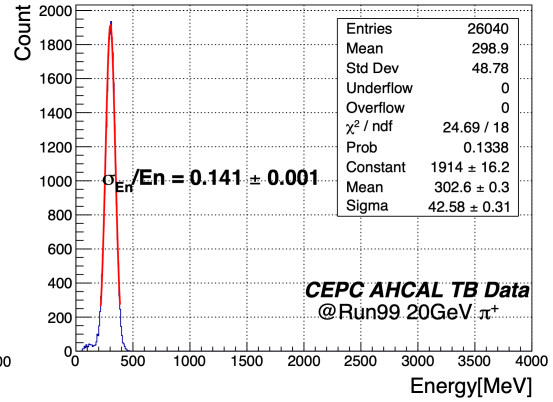
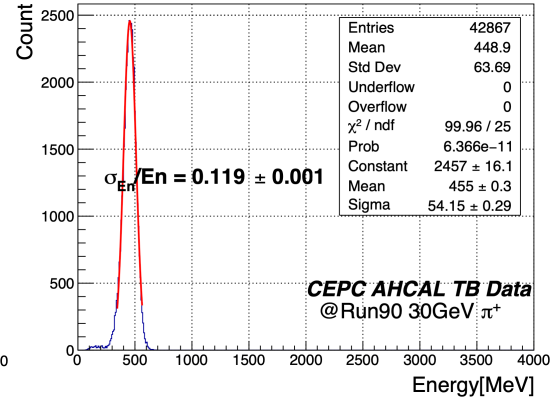
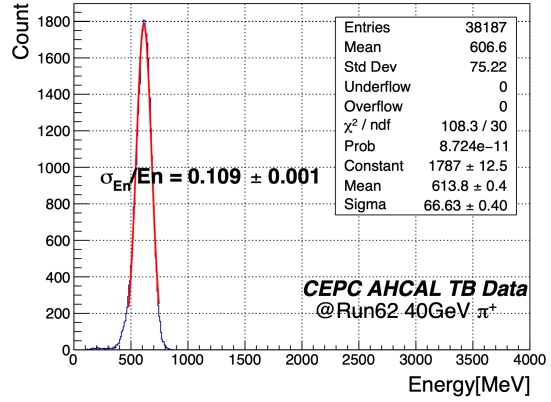
CEPC AHCAL TB Data
@Run33 100GeV π+

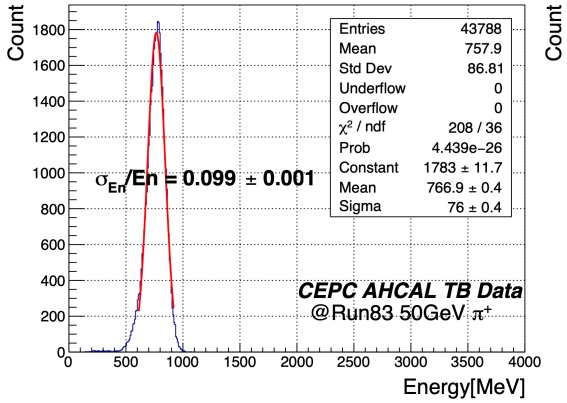

Fractal Dimension
<E_hit>[MeV]
CEPC AHCAL TB Data
@Run68 120GeV π+

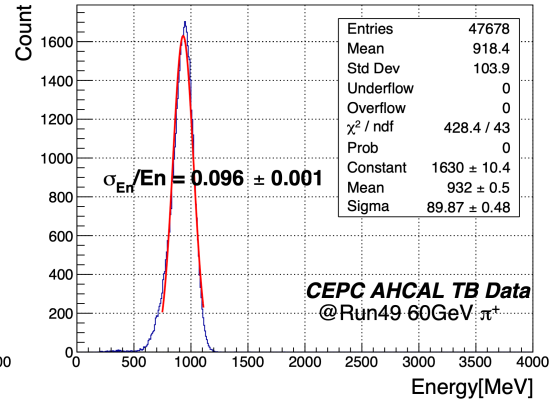

Entries 25622
Mean 137.6
Std Dev 37.9
Underflow 0
Overflow 0
χ² / ndf 42.36 / 12
Prob 2.898e−05
Constant 2595 ± 22.8
Mean 146.3 ± 0.2
Sigma 28.24 ± 0.20
σEn/En = 0.193 ± 0.001
CEPC AHCAL TB Data
@Run166 10GeV π+
Count
Energy[MeV]

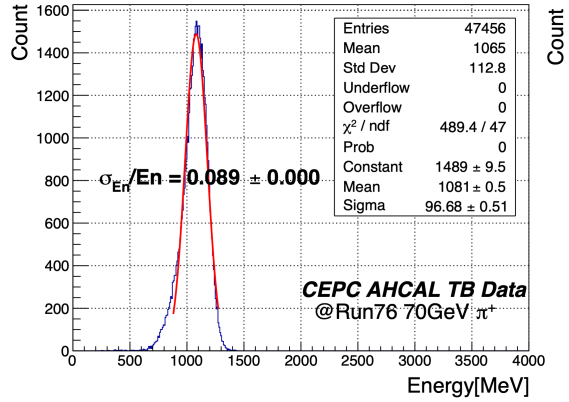

Entries 26040
Mean 298.9
Std Dev 48.78
Underflow 0
Overflow 0
χ² / ndf 24.69 / 18
Prob 0.1338
Constant 1914 ± 16.2
Mean 302.6 ± 0.3
Sigma 42.58 ± 0.31
σEn/En = 0.141 ± 0.001
CEPC AHCAL TB Data
@Run99 20GeV π+
Count
Energy[MeV]

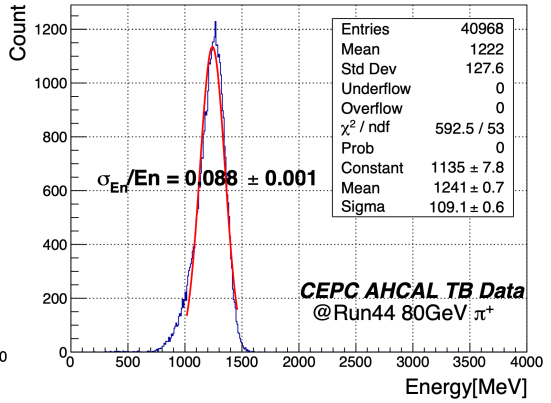

Entries 42867
Mean 448.9
Std Dev 63.69
Underflow 0
Overflow 0
χ² / ndf 99.96 / 25
Prob 6.366e−11
Constant 2457 ± 16.1
Mean 455 ± 0.3
Sigma 54.15 ± 0.29
σEn/En = 0.119 ± 0.001
CEPC AHCAL TB Data
@Run90 30GeV π+
Count
Energy[MeV]

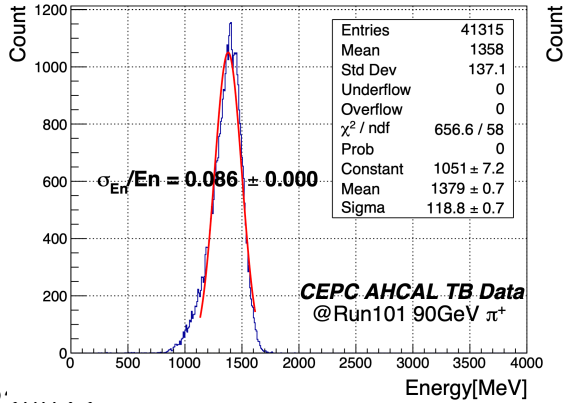

Entries 38187
Mean 606.6
Std Dev 75.22
Underflow 0
Overflow 0
χ² / ndf 108.3 / 30
Prob 8.724e−11
Constant 1787 ± 12.5
Mean 613.8 ± 0.4
Sigma 66.63 ± 0.40
σEn/En = 0.109 ± 0.001
CEPC AHCAL TB Data
@Run62 40GeV π+
Count
Energy[MeV]

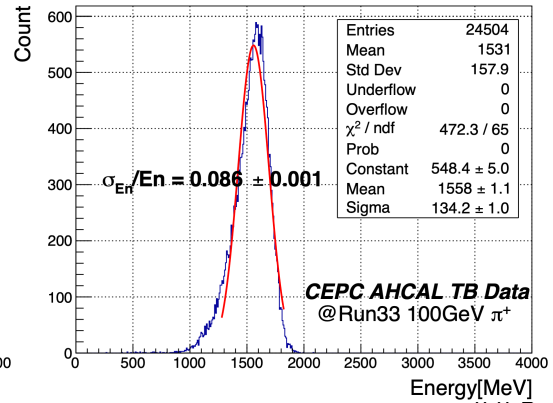

Entries 43788
Mean 757.9
Std Dev 86.81
Underflow 0
Overflow 0
χ² / ndf 208 / 36
Prob 4.439e−26
Constant 1783 ± 11.7
Mean 766.9 ± 0.4
Sigma 76 ± 0.4
σEn/En = 0.099 ± 0.001
CEPC AHCAL TB Data
@Run83 50GeV π+
Count
Energy[MeV]

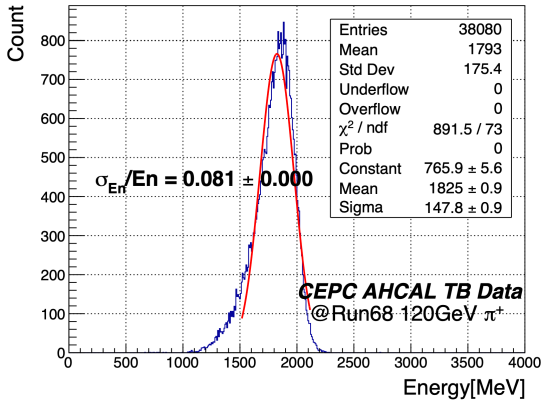

Entries 47678
Mean 918.4
Std Dev 103.9
Underflow 0
Overflow 0
χ² / ndf 428.4 / 43
Prob 0
Constant 1630 ± 10.4
Mean 932 ± 0.5
Sigma 89.87 ± 0.48
σEn/En = 0.096 ± 0.001
CEPC AHCAL TB Data
@Run49 60GeV π+
Count
Energy[MeV]


Entries 47456
Mean 1065
Std Dev 112.8
Underflow 0
Overflow 0
χ² / ndf 489.4 / 47
Prob 0
Constant 1489 ± 9.5
Mean 1081 ± 0.5
Sigma 96.68 ± 0.51
σEn/En = 0.089 ± 0.000
CEPC AHCAL TB Data
@Run76 70GeV π+
Count
Energy[MeV]

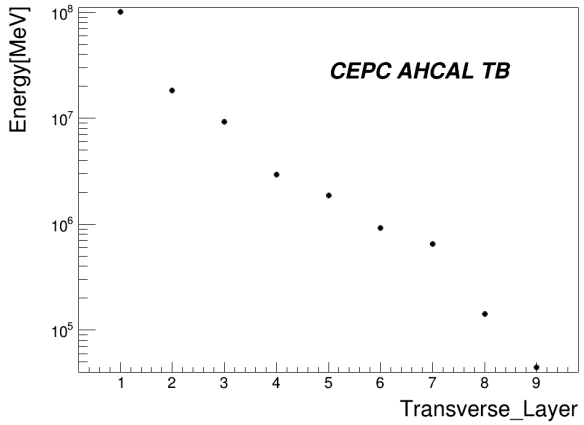

Entries 40968
Mean 1222
Std Dev 127.6
Underflow 0
Overflow 0
χ² / ndf 592.5 / 53
Prob 0
Constant 1135 ± 7.8
Mean 1241 ± 0.7
Sigma 109.1 ± 0.6
σEn/En = 0.088 ± 0.001
CEPC AHCAL TB Data
@Run44 80GeV π+
Count
Energy[MeV]

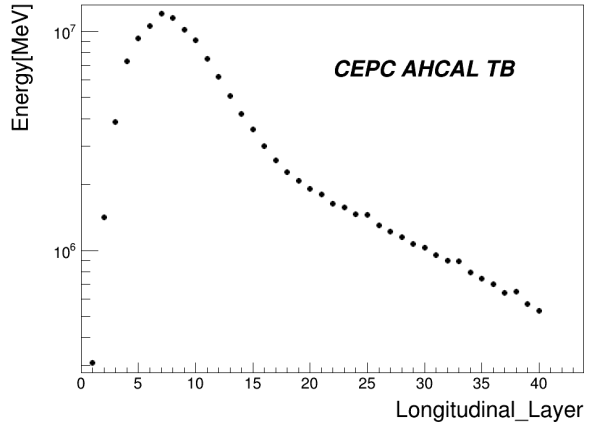

Entries 41315
Mean 1358
Std Dev 137.1
Underflow 0
Overflow 0
χ² / ndf 656.6 / 58
Prob 0
Constant 1051 ± 7.2
Mean 1379 ± 0.7
Sigma 118.8 ± 0.7
σEn/En = 0.086 ± 0.000
CEPC AHCAL TB Data
@Run101 90GeV π+
Count
Energy[MeV]

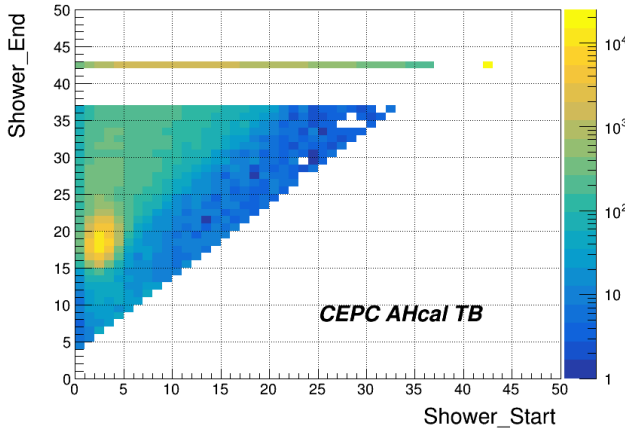

Entries 24504
Mean 1531
Std Dev 157.9
Underflow 0
Overflow 0
χ² / ndf 472.3 / 65
Prob 0
Constant 548.4 ± 5.0
Mean 1558 ± 1.1
Sigma 134.2 ± 1.0
σEn/En = 0.086 ± 0.001
CEPC AHCAL TB Data
@Run33 100GeV π+
Count
Energy[MeV]

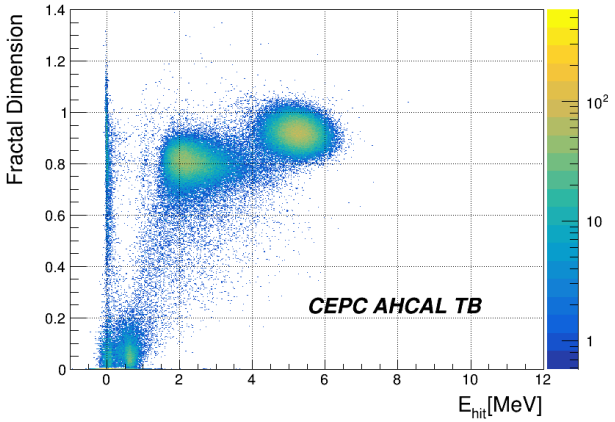

Entries 38080
Mean 1793
Std Dev 175.4
Underflow 0
Overflow 0
χ² / ndf 891.5 / 73
Prob 0
Constant 765.9 ± 5.6
Mean 1825 ± 0.9
Sigma 147.8 ± 0.9
σEn/En = 0.081 ± 0.000
CEPC AHCAL TB Data
@Run68 120GeV π+
Count
Energy[MeV]

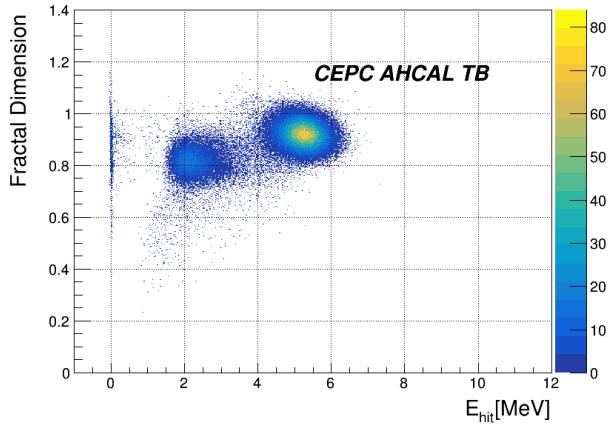
Reduce the impact of energy leakage, Improve energy resolution!





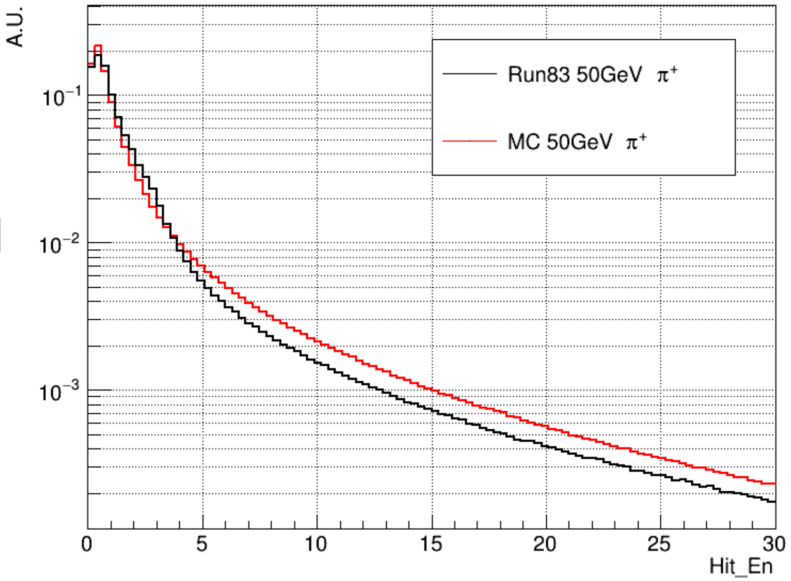


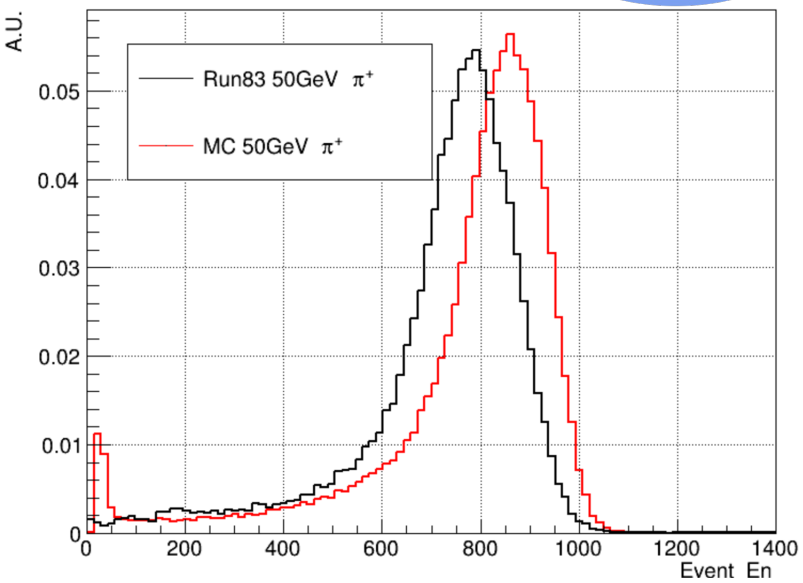


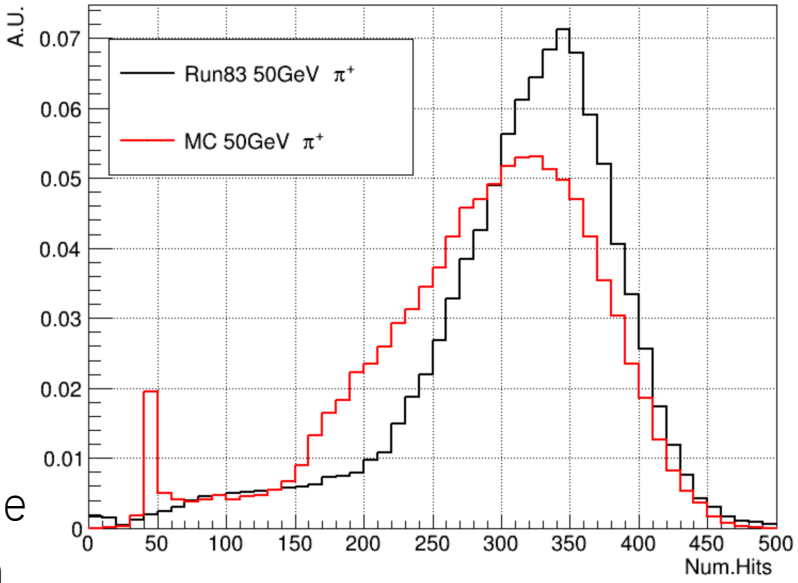


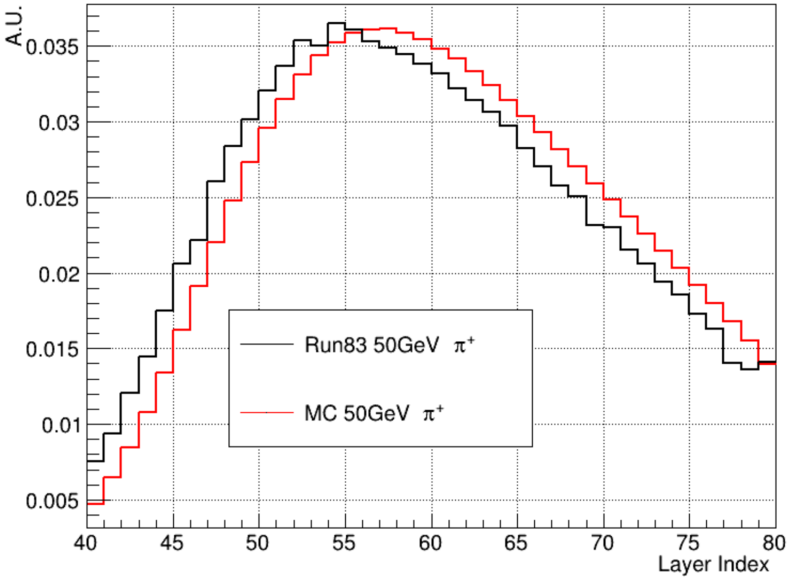
omparison of MC and Run83——pi+

- Experiment:
  - Pion Run83(ParticleID = 211)
  - Cut: Hit_Energy > 0
  - The light-leaking cell was muted
- Simulation:
  - Cut: Hit_Energy > 0.3MIP(1MIP=0.461MeV)
  - The cell that be muted in experiment was also muted in MC
- Conclusion:
  - For Hit_Energy and Event_Energy ,MC is higher than TestBeam;
  - For number of hits, MC is lower than TestBeam;
  - The shower depth of MC is a little bit bigger than that of TestBeam.



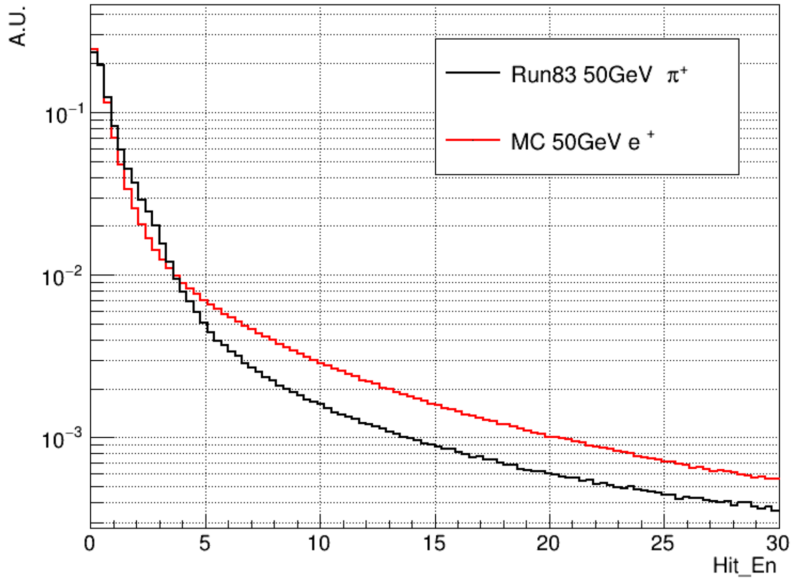


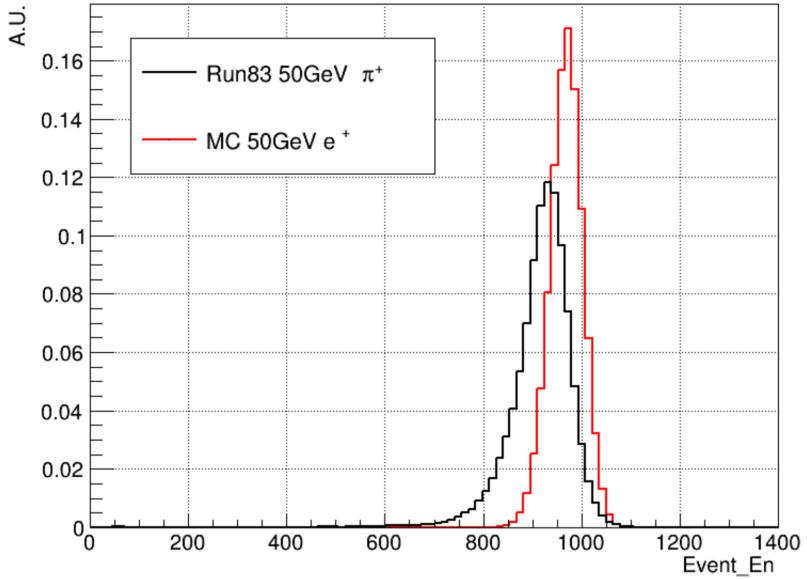


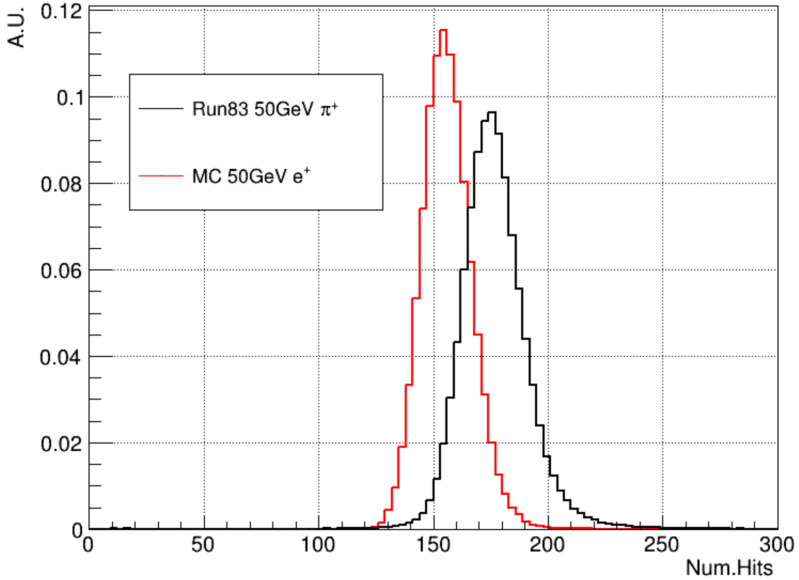


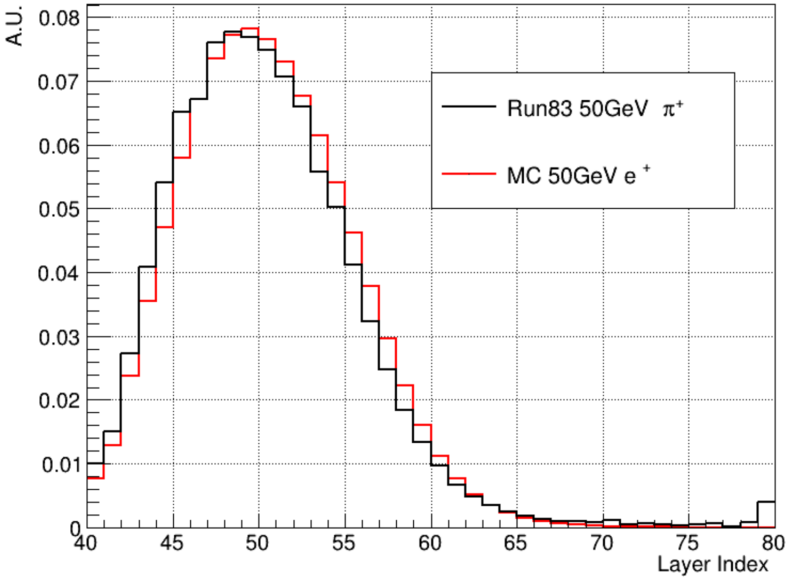
omparison of MC and Run83——e+

- Experiment:
  - Pion Run83(ParticleID = 11)
  - Hit_Energy Cut > 0
  - The light-leaking cell was muted
- Simulation:
  - Hit_Energy Cut > 0.3MIP(1MIP=0.461MeV)
  - The cell that be muted in experiment was also muted in MC
- Conclusion:
  - For Hit_Energy and Event_Energy ,MC is higher than TestBeam;
  - For number of hits, MC is lower than TestBeam;
  - The shower depth of MC is consistent with TestBeam.





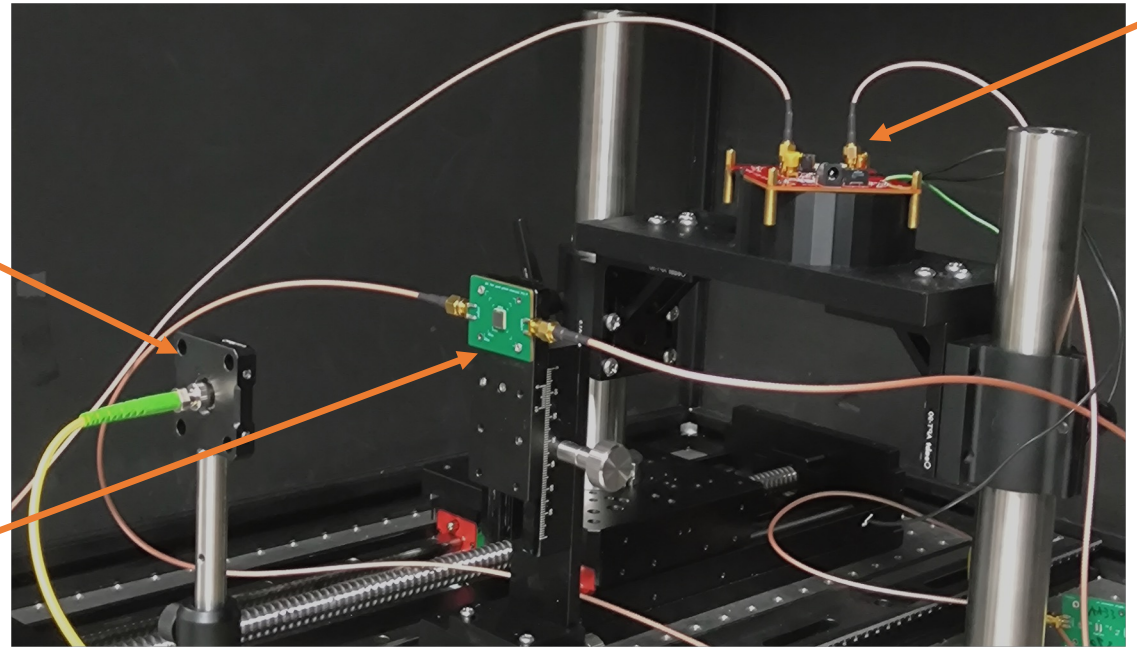


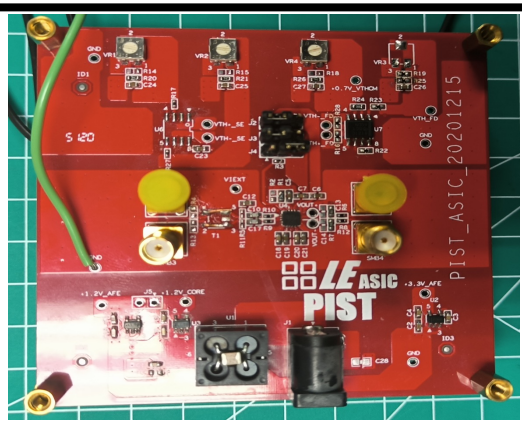


PIST ASIC

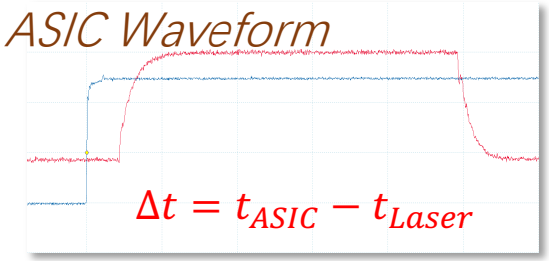
Laser

SiPM



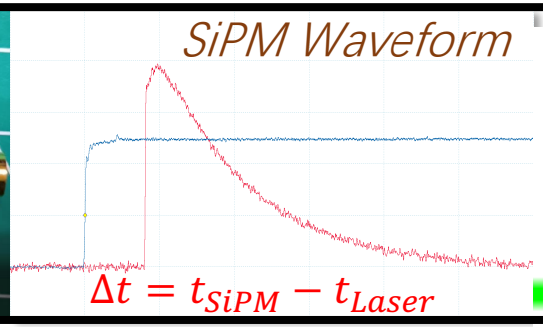


ASIC Waveform

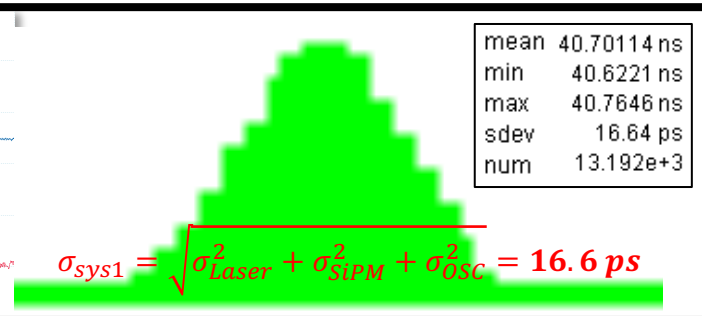


$\Delta t = t_{ASIC} - t_{Laser}$

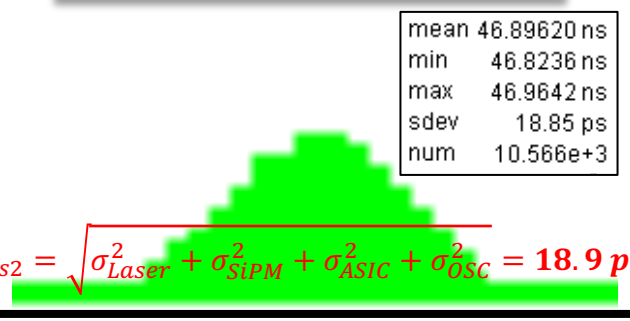
SiPM Waveform



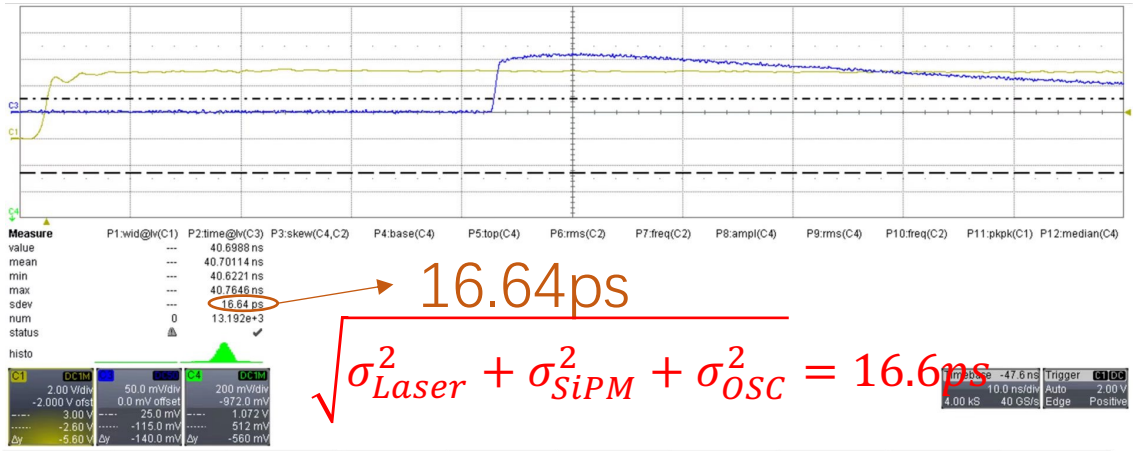
$\Delta t = t_{SiPM} - t_{Laser}$



$\sigma_{sys1} = \sqrt{\sigma_{Laser}^2 + \sigma_{SiPM}^2 + \sigma_{OSC}^2} = 16.6\ ps$

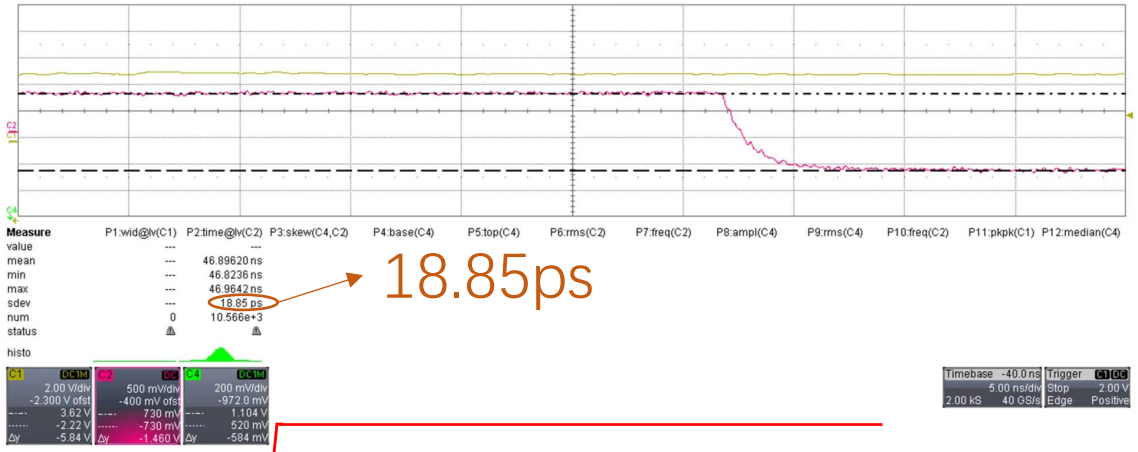


$\sigma_{sys2} = \sqrt{\sigma_{Laser}^2 + \sigma_{SiPM}^2 + \sigma_{ASIC}^2 + \sigma_{OSC}^2} = 18.9\ ps$



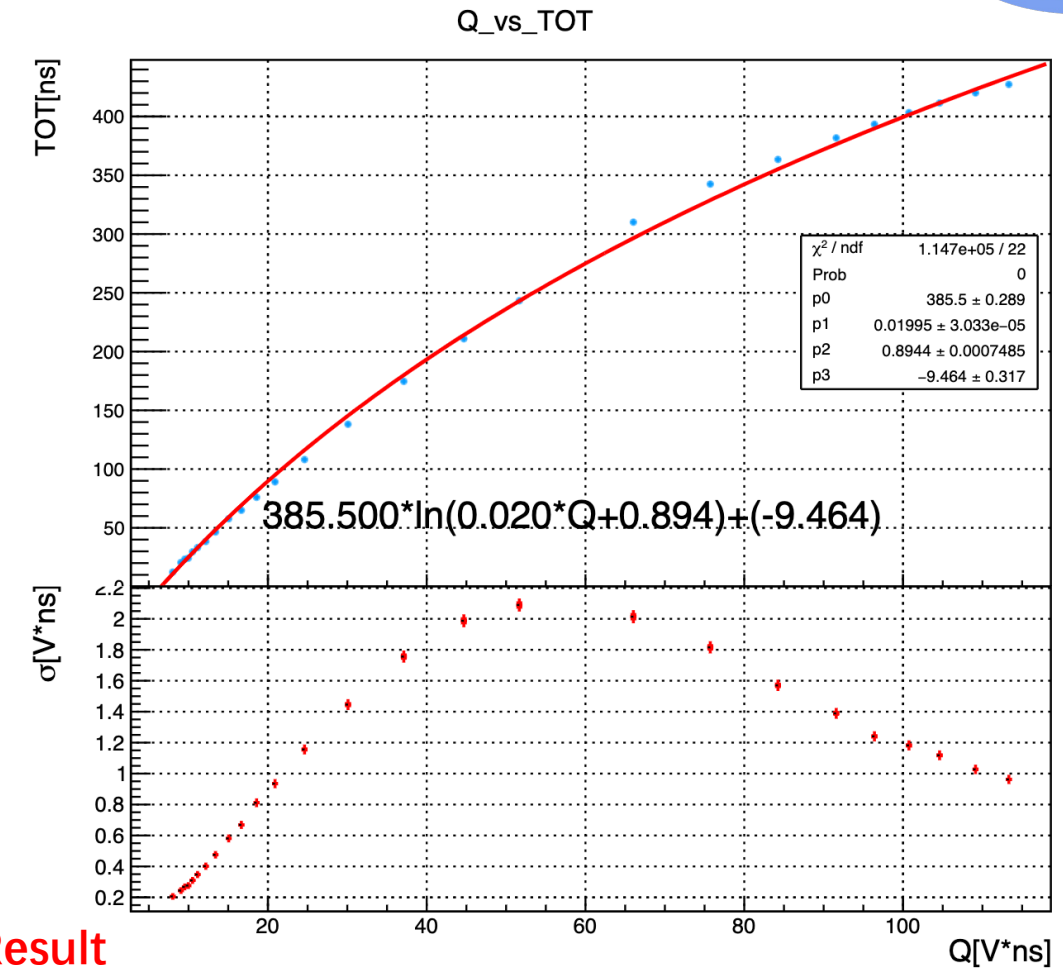
16.64ps

$$\sqrt{\sigma_{Laser}^2 + \sigma_{SiPM}^2 + \sigma_{OSC}^2} = 16.6ps$$



18.85ps

$$\sqrt{\sigma_{Laser}^2 + \sigma_{SiPM}^2 + \sigma_{ASIC}^2 + \sigma_{OSC}^2} = 18.9ps$$



- **Result**
  - Timing measurement: System-level time resolution~19ps；PIST ASIC time resolution~9ps
  - Energy measurement

- Limited by the accuracy of the oscilloscope(1GHz), time resolution is bad.
  - Selection of threshold
    - 低阈甄别
    - 横比定时
  - Calculation of threshold
    - 插值
    - 波形拟合
      - 单边拟合
      - 全域拟合
  - Use 16GHz oscilloscope
- Impedance at the load does not match the asic, witch affects the time resolution greatly
  - Use standard wire
  - Use D400A-AT-PB2 probe