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AHCAL simulation and optimization

YuKun Shi
USTC

OutLine

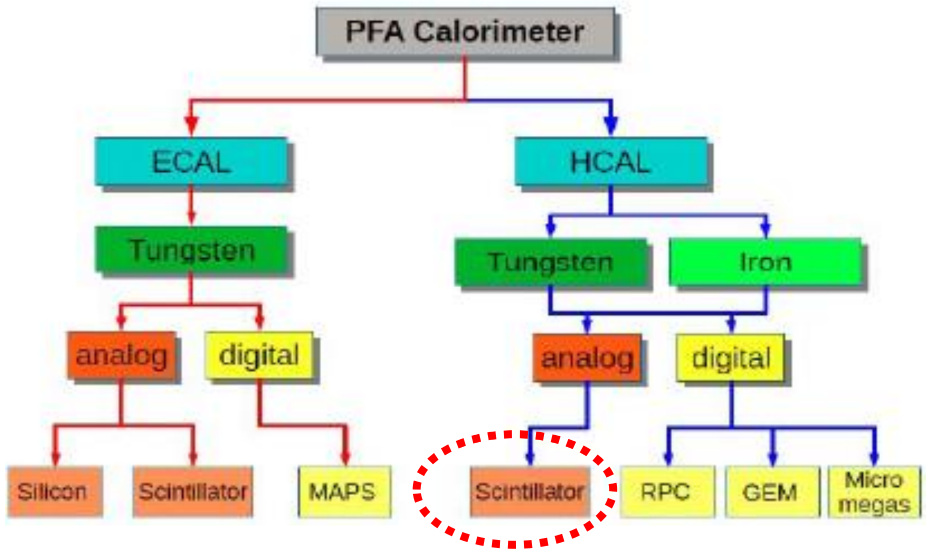
- Background and motivation
- Dynamic range
- Longitudinal Simulation
- Cellsize optimization
- Conclusion

Background and motivation

- For the goal of precisely detecting Higgs,CEPC calorimeter needs to reach a jet resolution of 3-4% which is a big challenge
- PFA calorimeter is one of the options for such challenge.a lot of Simulation and optimization still needs to be done to finally realize the jet resolution

Primarily for the Higgs physics program at CEPC

Physics process	Measurands	Detector subsystem	Performance requirement
$ZH, Z \to e^+e^-, \mu^+\mu^-$ $H \to \mu^+\mu^-$	$m_H, \sigma(ZH)$ $\mathrm{BR}(H \to \mu^+\mu^-)$	Tracker	$\Delta(1/p_T) = 2 \times 10^{-5} \oplus \frac{0.001}{p(\mathrm{GeV}) \sin^{3/2}\theta}$
$H \to b\bar{b}/c\bar{c}/gg$	$\mathrm{BR}(H \to b\bar{b}/c\bar{c}/gg)$	Vertex	$\sigma_{r\phi} = 5 \oplus \frac{10}{p(\mathrm{GeV}) \times \sin^{3/2}\theta} (\mu\mathrm{m})$
$H \to q\bar{q}, WW^*, ZZ^*$	$\mathrm{BR}(H \to q\bar{q}, WW^*, ZZ^*)$	ECAL HCAL	$\sigma_E^{\mathrm{jet}}/E = 3 \sim 4\%$ at 100 GeV
$H \to \gamma\gamma$	$\mathrm{BR}(H \to \gamma\gamma)$	ECAL	$\Delta E/E = \frac{0.20}{\sqrt{E(\mathrm{GeV})}} \oplus 0.01$



Background and motivation

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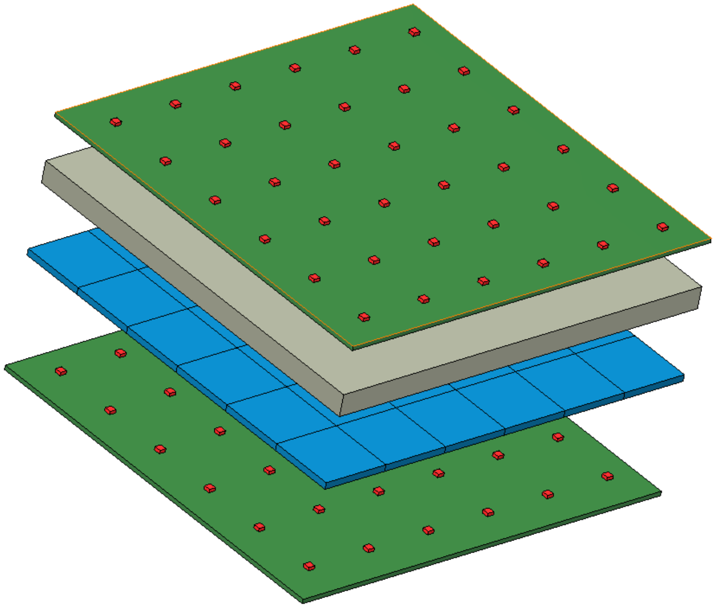
- Simulation environment
  - CEPC software
  - AHCAL geometry
    - 40 layers
    - Absorber:20mm Fe
    - Scintillator:30×30×3mm^3
    - PCB:2mm



Dynamic range

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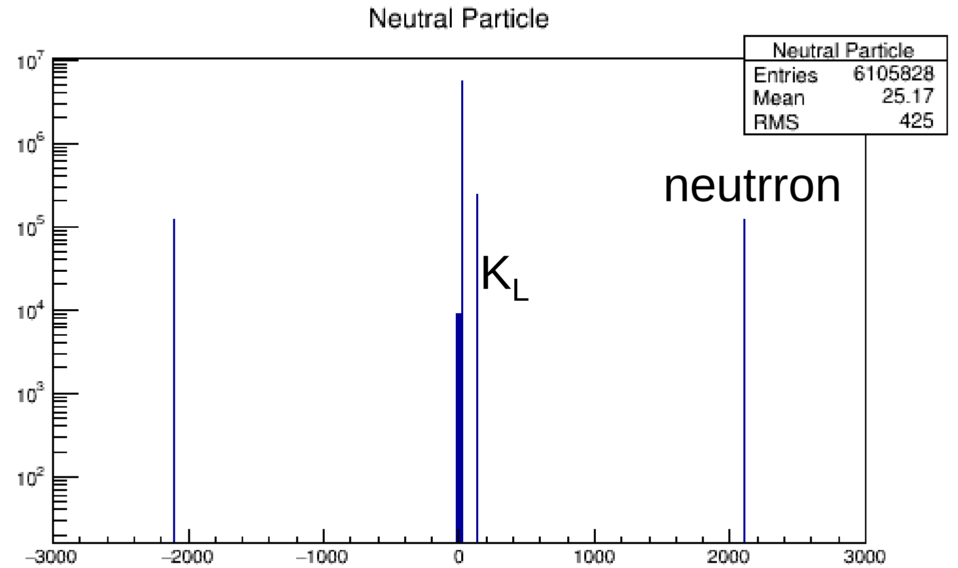
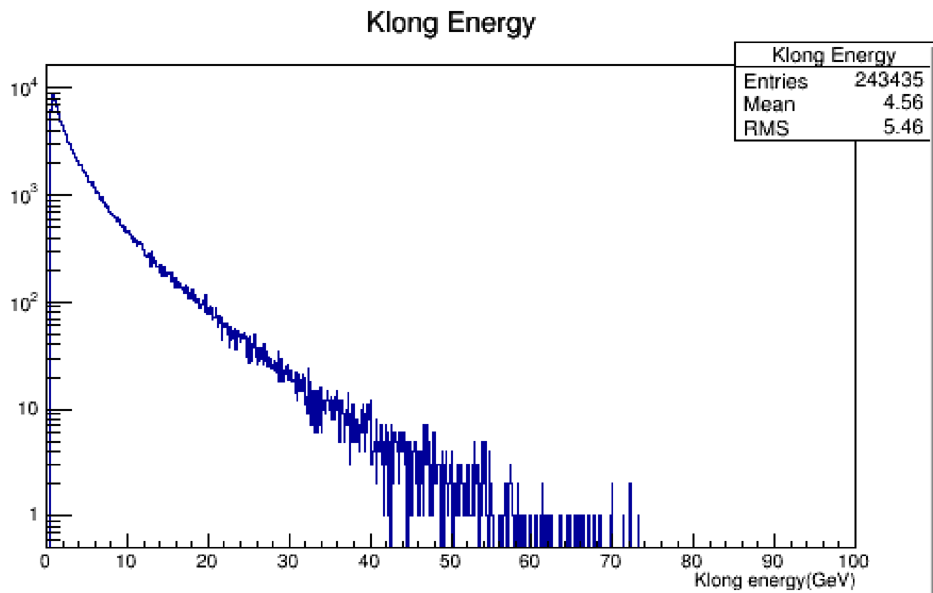
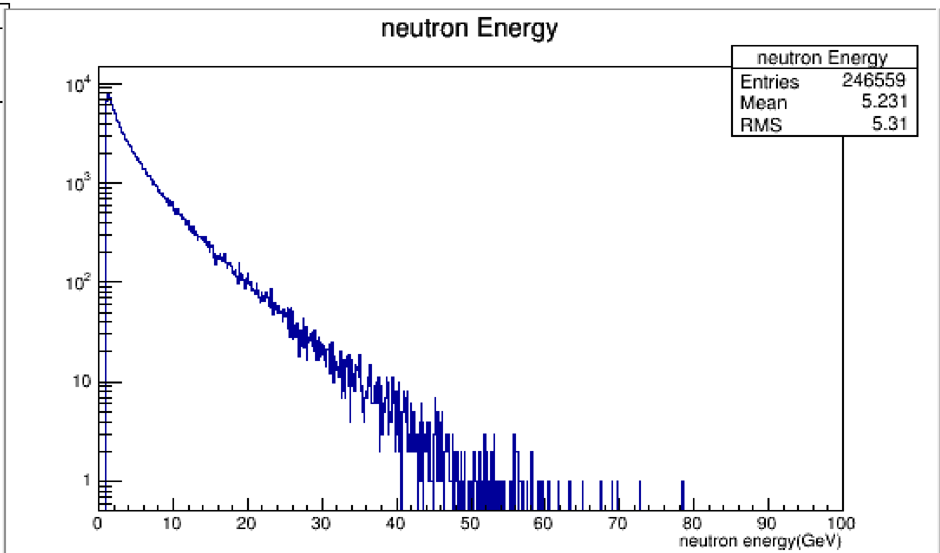
- Neutral Hadron mainly consists of K_L,neutron
- The single neutral Hadron energy < 100GeV
- HCAL should have good response to 0.5MIP-60GeV Hadron

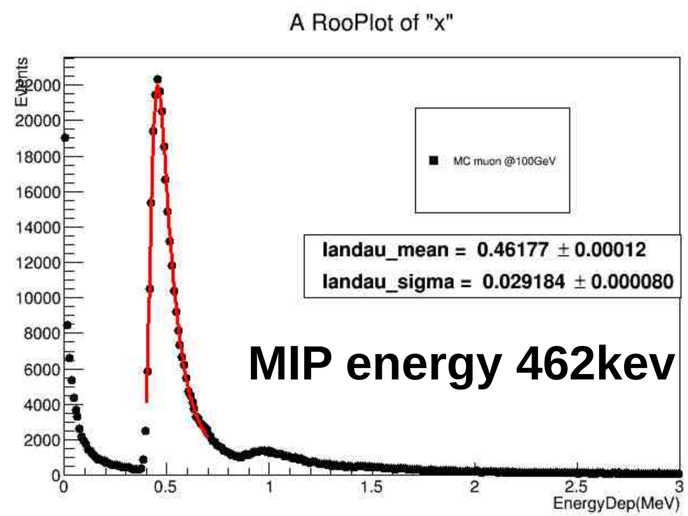


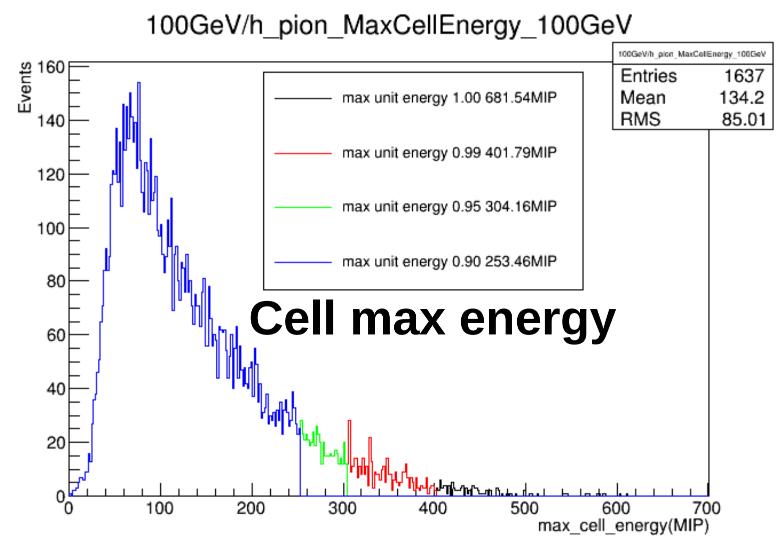




Dynamic range

- Consider 100GeV muon As MIP
- Single cell energy deposition for a MIP is 462 keV
- For a 100GeV π-,energy deposition in a single cell can be as much as 600 MIP energy





Dynamic range

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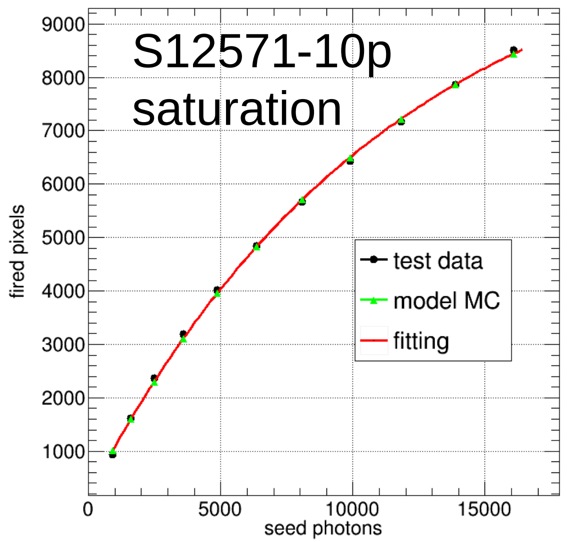
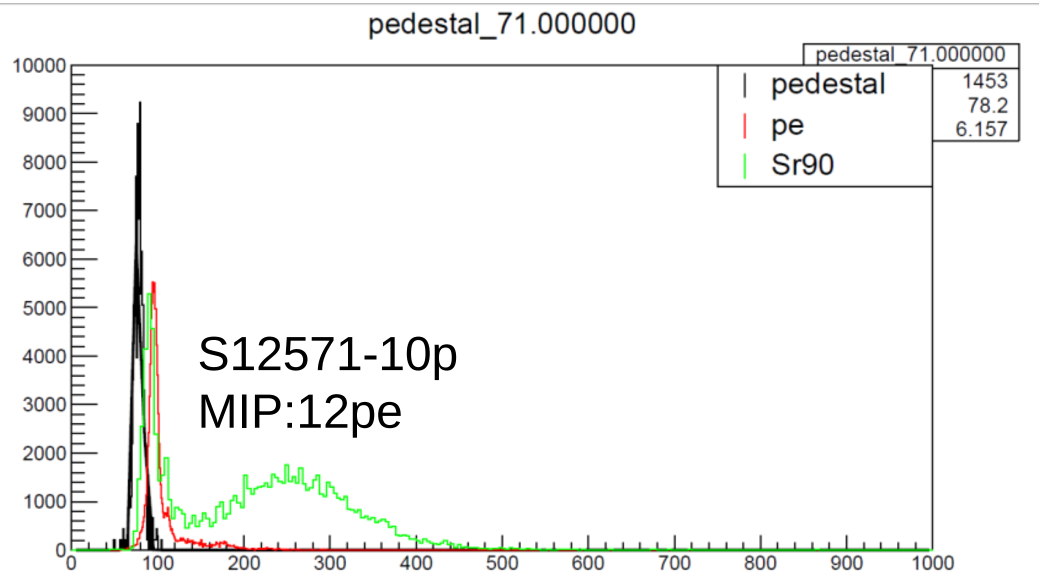
- 10 um SiPM's response for a MIP is 12pe which means to fully detect energy deposition for 100GeV π-,~7000 pixel is needed.
- It's impractical to have such large pixel number, so According to MIP cell energy, scintillator light yield, SiPM saturation, a saturation effect algorithm is used to estimate the influence of pixel number on energy resolution for Hadron





Dynamic range

- Saturation effect algorithm
  - For each cell,considering the saturation effect
    - $N_{in} = E_{dep} \times \text{photon}_{MIP} \div E_{MIP}$
    - Every photon is decided whether detected or not by PDE
    - If detected, a photonelectron can fire a pixel
    - There are chances more than one photonelectron hit one pixel,in this situation the output signal is as single photonelectron
    - Thus the output signal is determined by fired pixel not photonelectron
  - saturation effect correction
    - Use $N_{fired} = N_{pixel}(1 - e^{\frac{N_{in}\times \text{PDE}}{N_{pixel}}})$ determined by test result to calculate N_{in},then get the corrected energy deposition

Dynamic range

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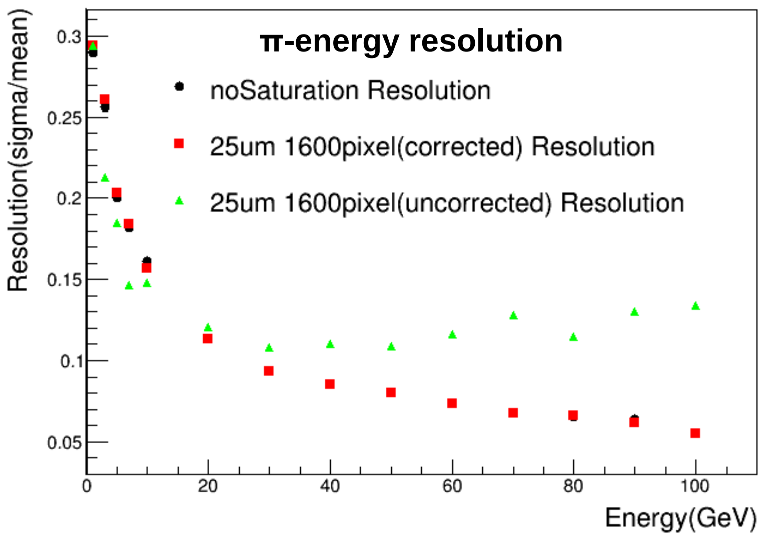
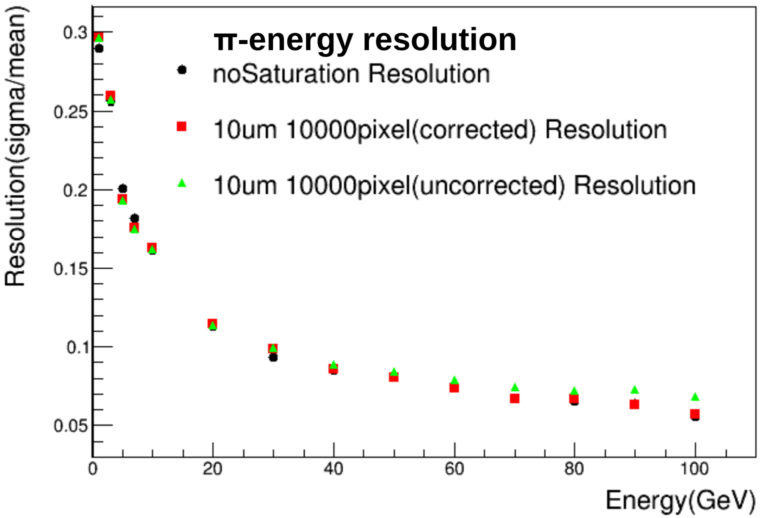
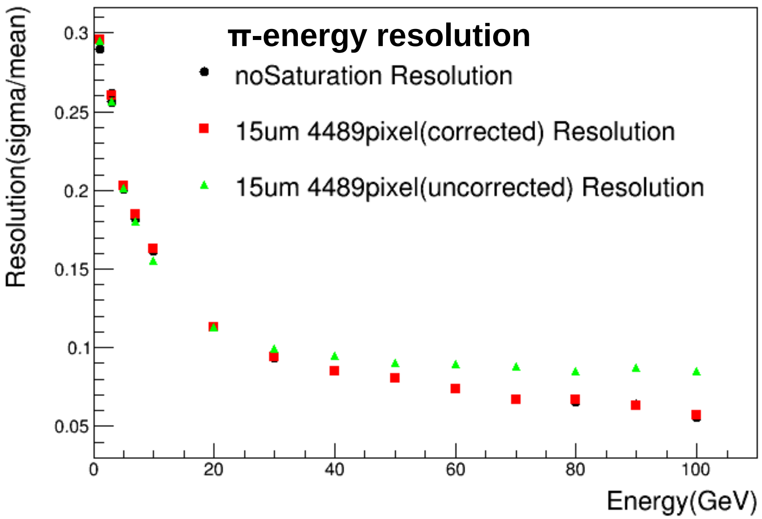
- Saturation effect obviously makes resolution worse with the increase of energy
- by applying the saturation effect correction,HAMMATSU SiPM's range is enough for our need







Longitudinal simulation

- CEPC CDR states that the basic resolution of HCAL is $50\%/\sqrt{E}$,Jet resolution should reach 3-4%
- Explicit simulation is required for AHCAL layer number,absorber and scintillator thickness to fulfill the target
- $\frac{\sigma}{E} = a/\sqrt{E} \oplus b$

name	absorber	sensitive	Layer（λ）	a(%)	b(%)
ATLAS	14mm Iron	3mm Scintillator	11 7.4 λ	electron:28 pion:50	2.8 3
CMS	~50mm Brass	3.7mm scintillator	16 5.82 λ	pion:93.8	4.4
ZEUS	3.3mm DU	2.6mm Scintillator	22Scint,21DU 3.09 λ	electron:21.2 pion:35	0

Hanging file calorimeter

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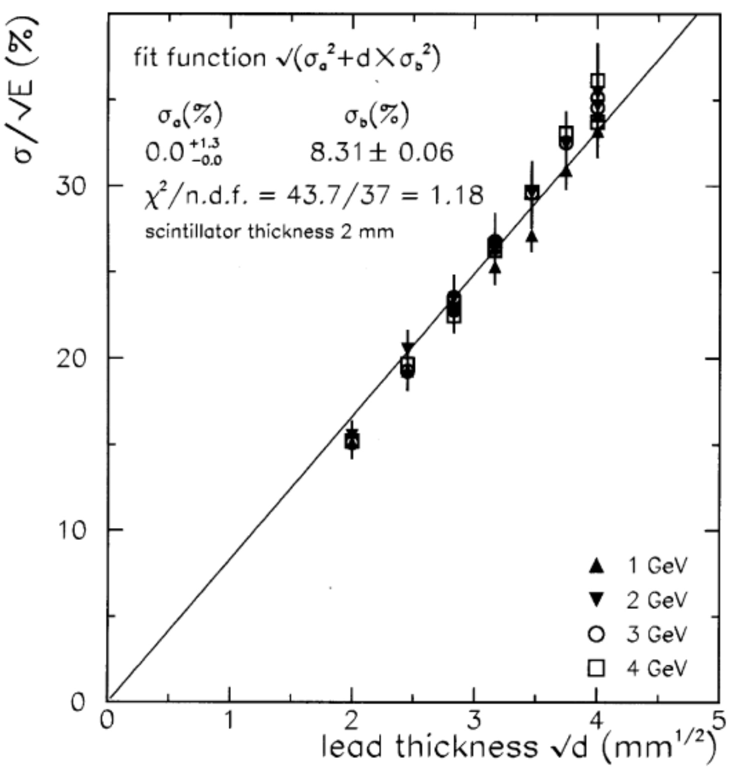

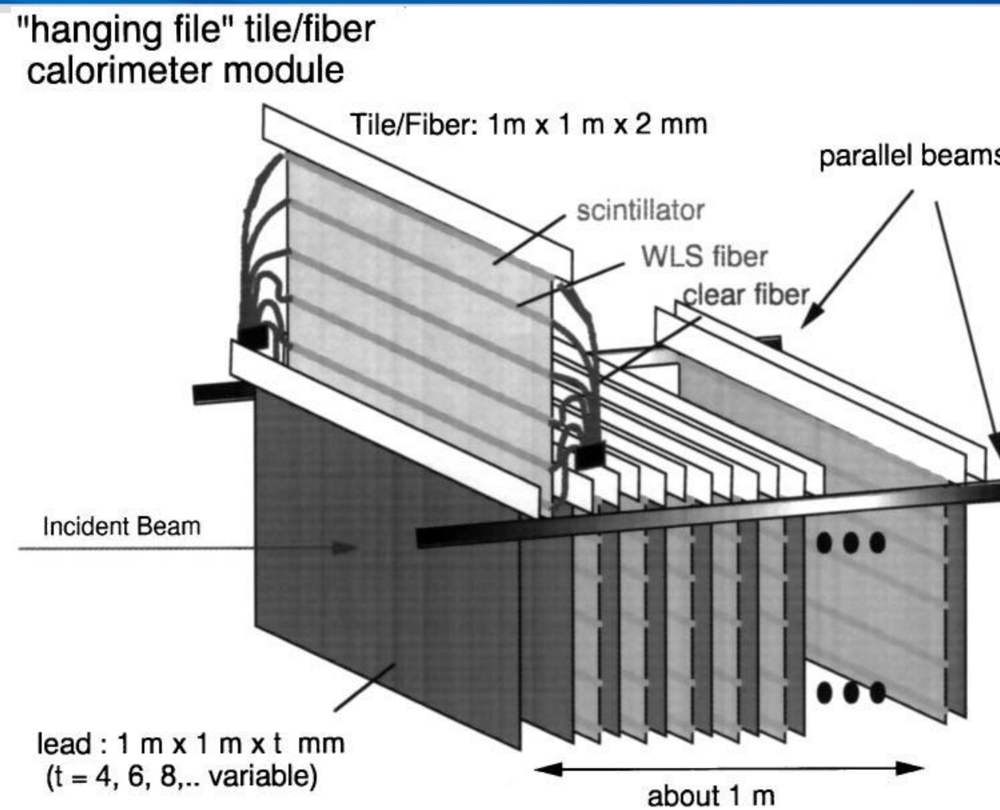

- $\frac{\sigma}{E} = \sqrt{\sigma_{intrinsic}^2 + (\sigma_{sample}^2 + \sigma_{pe}^2) \times d}/\sqrt{E} \oplus \sigma_{constant} \oplus \sigma_{noise}$/E
- Electron:$\frac{\sigma}{E}$ =$(0\% \oplus 8.3\% \times \sqrt{d})/\sqrt{E}$
- pion:$\frac{\sigma}{E}$ =$(24.4\% \oplus 11.2\% \times \sqrt{d})/\sqrt{E}$

Longitudinal simulation

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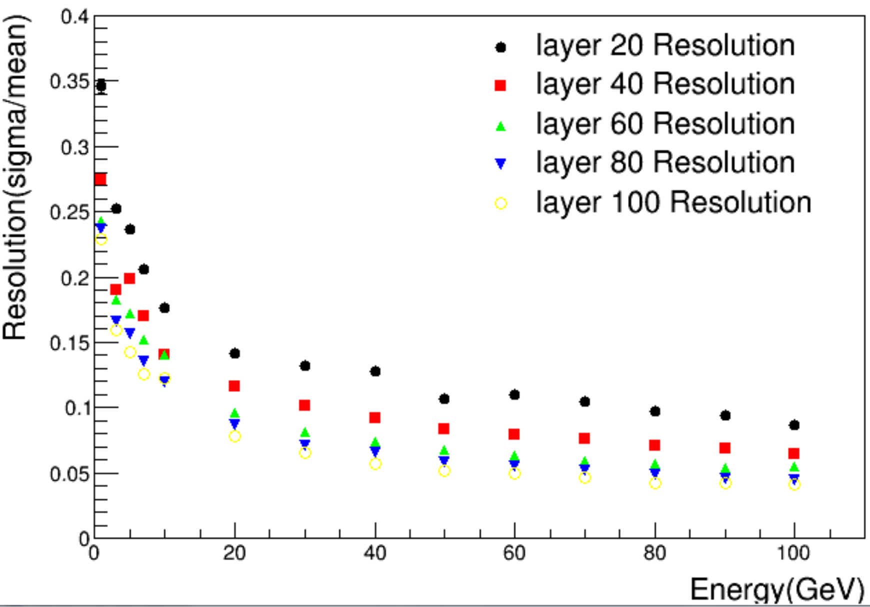
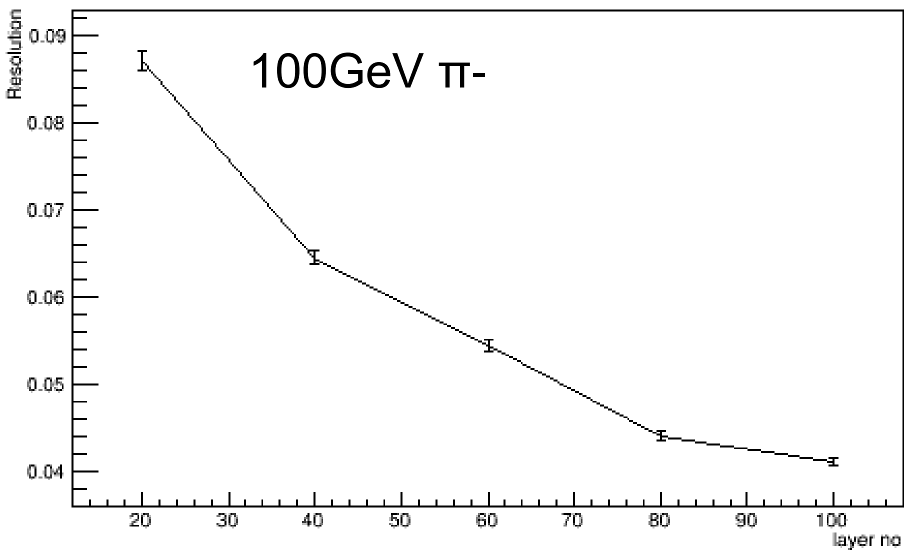
- Scintillator:3mm
- Absorber(Fe) total 800mm
- layer from 20 to 100 by step of 20
- Incident particle: pion-





Longitudinal simulation

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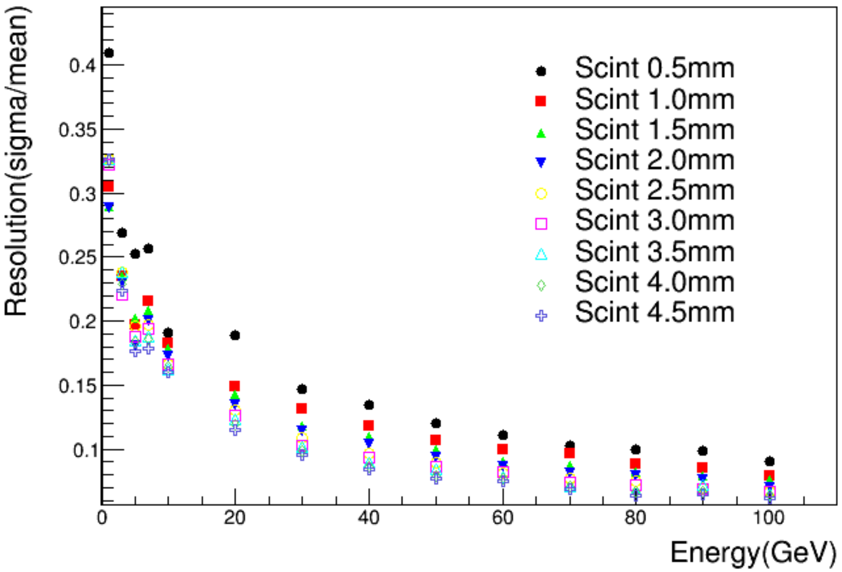
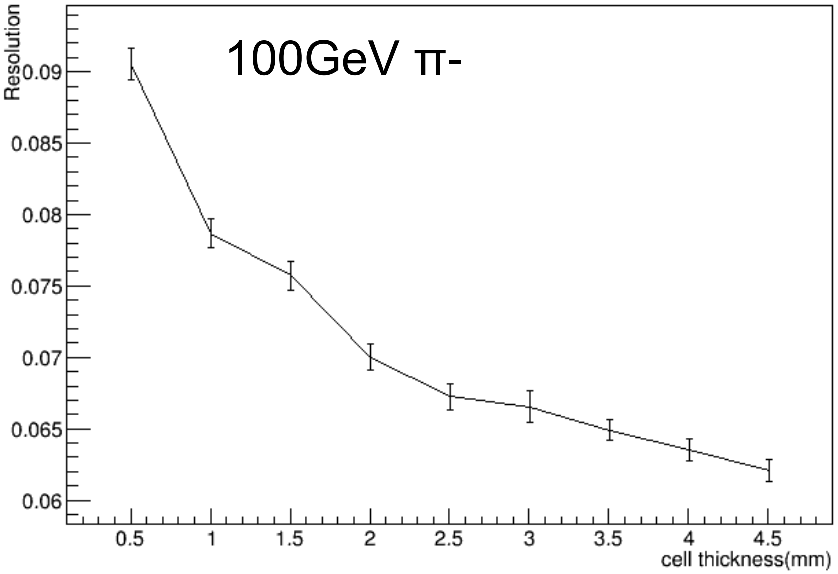
- Absorber:20mm Fe
- Scintillator:0.5-4.5mm by step of 0.5mm
- Layer:40
- Incident particle:pion-





Longitudinal simulation

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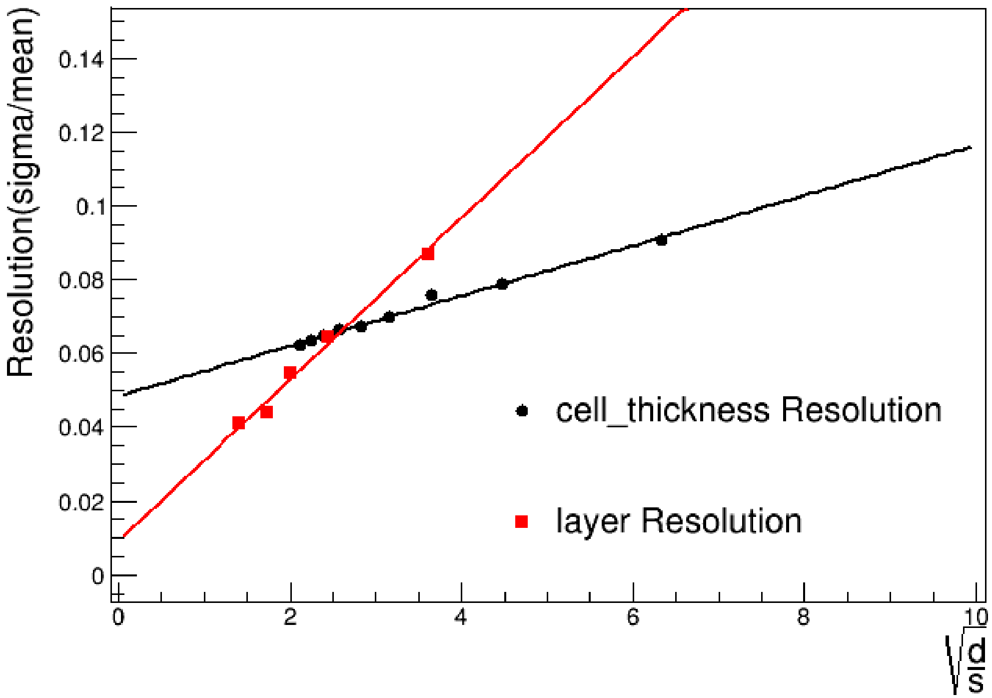
- $\frac{\sigma}{E} = \sqrt{\sigma_{intrinsic}^2 + (\sigma_{sample}^2 + \sigma_{pe}^2) \times d/\sqrt{E}} \oplus \sigma_{constant}$ may add s term which is scintillator thickness
- In simulation, σ_{pe}^2 should be 0
- Layer number has bigger effect than sampling ratio



Cellsize optimization

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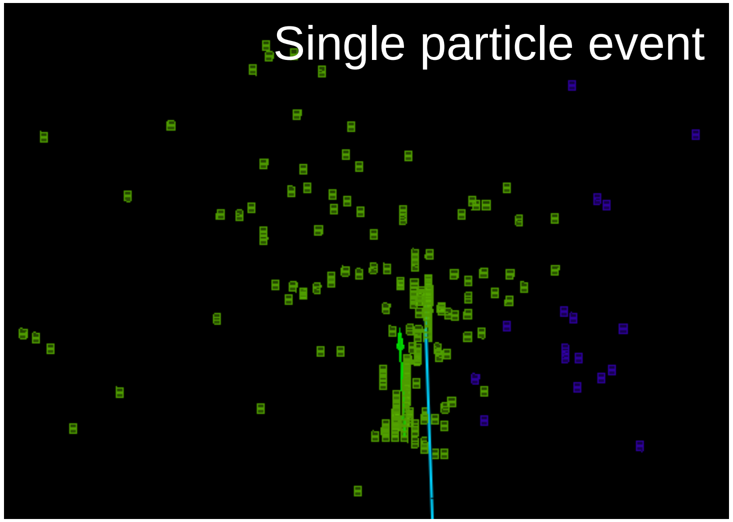
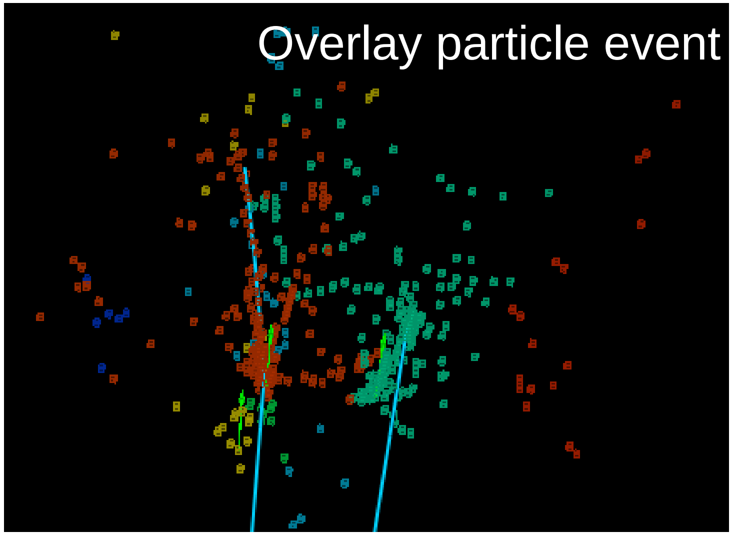
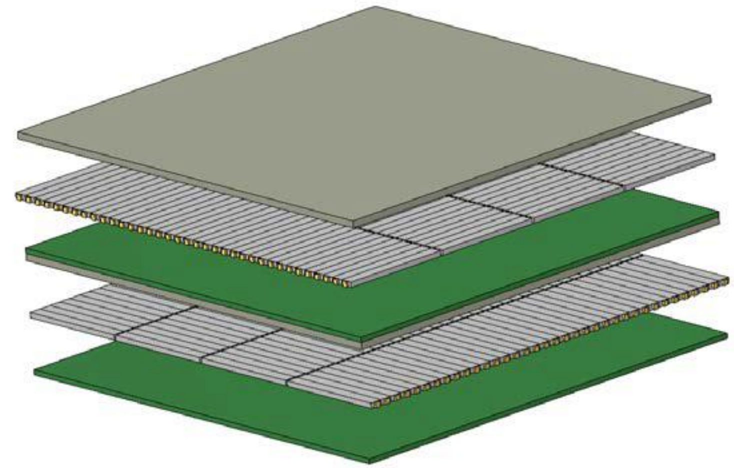
- Cell size is considered has nearly no influence on energy resolution theoretically
- Cell size mainly affects reconstruction efficiency in PFA
- Use single particle and “overlay” event to determine the cell size

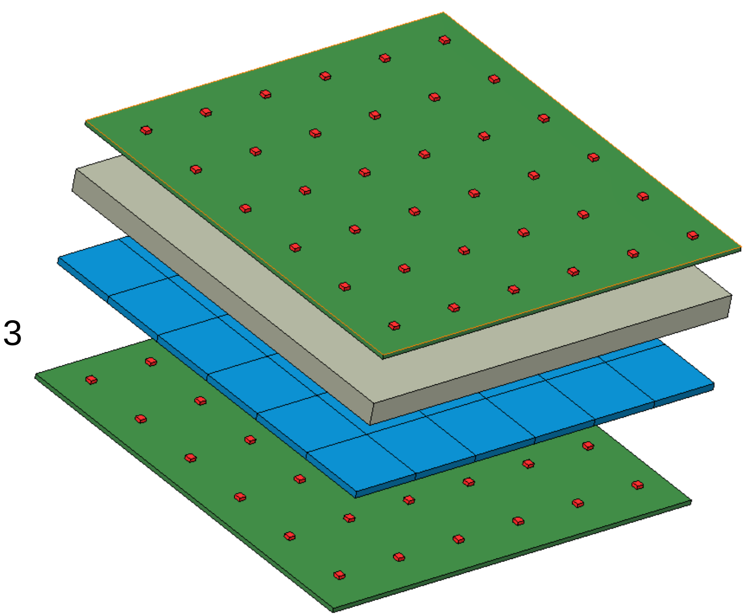




Cellsize optimization

- Simulation Setup
  - ECAL
    - 30 layers
    - Absorber:2.8mm tungsten
    - Si:$10 \times 10 \times 0.5 mm^3$
    - PCB:2mm
  - AHCAL
    - 40 layers
    - Absorber:20mm Fe
    - Scintillator:$10 \times 10 \times 3 mm^3$
    - PCB:2mm
  - Incident particle
    - pion-:10GeV





Cellsize optimization

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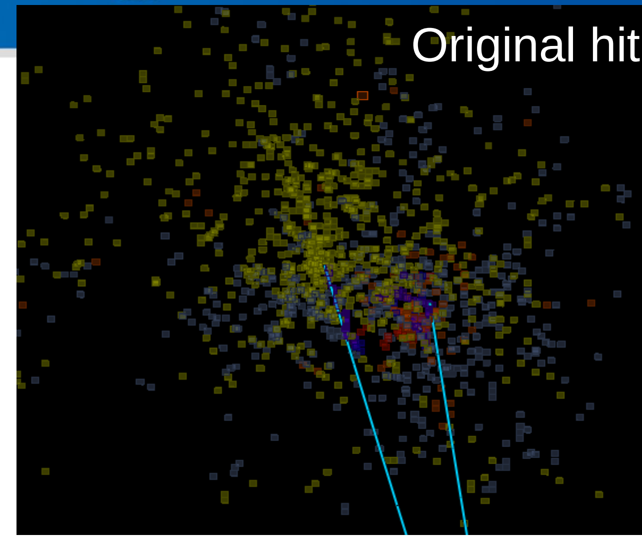
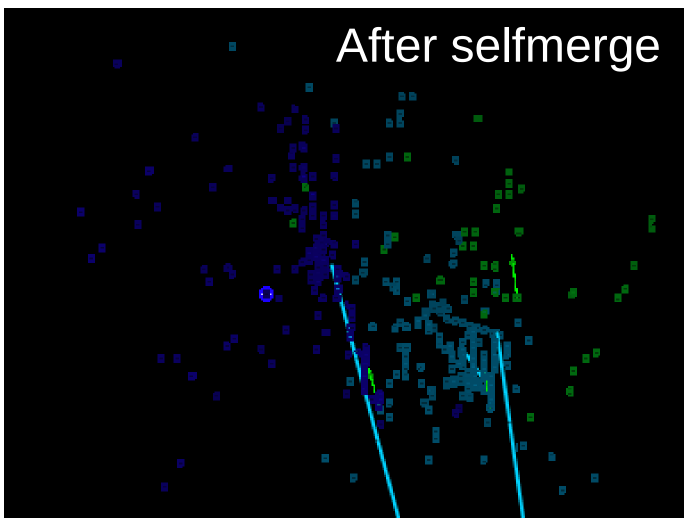
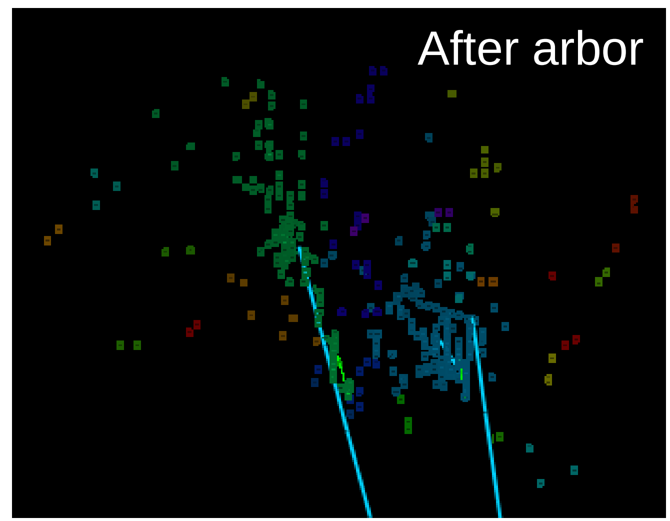
- Reconstruction procedure
  - Arbor: connect Hit into Cluster
  - Selfmerge: merge small Cluster into bigger ones

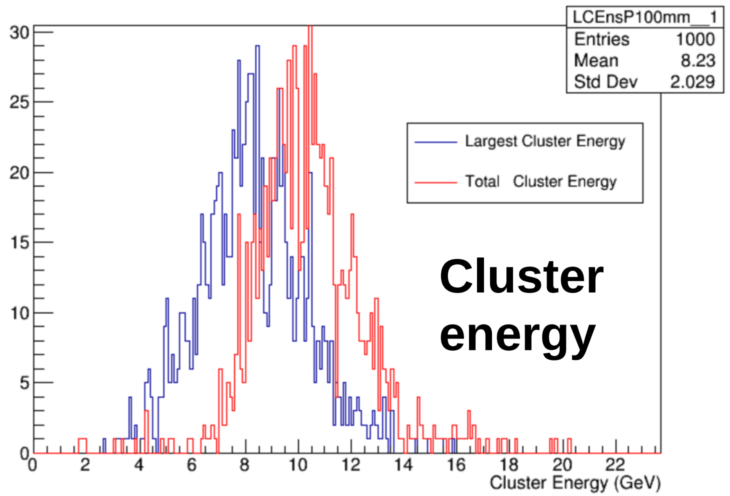


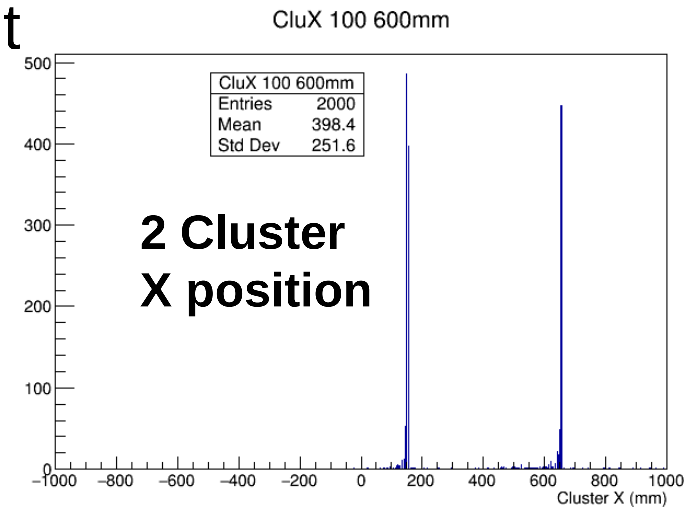


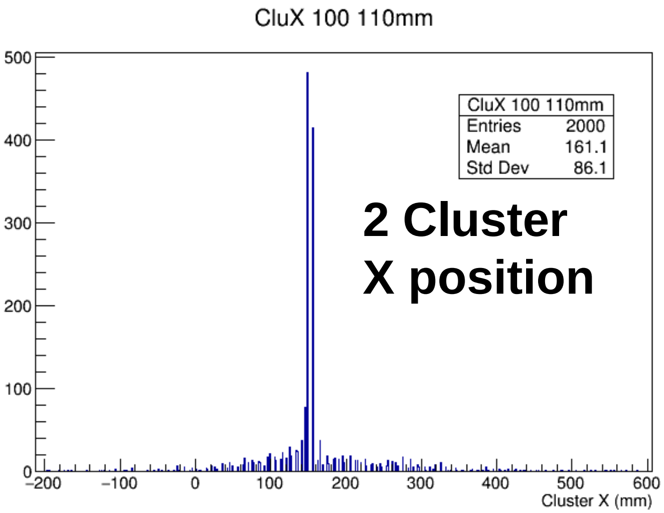


Cellsize optimization

- Reconstruction result
  - Reconstruct single particle energy through cluster, largest cluster energy is roughly 80% of total energy
  - Position of the overlay event



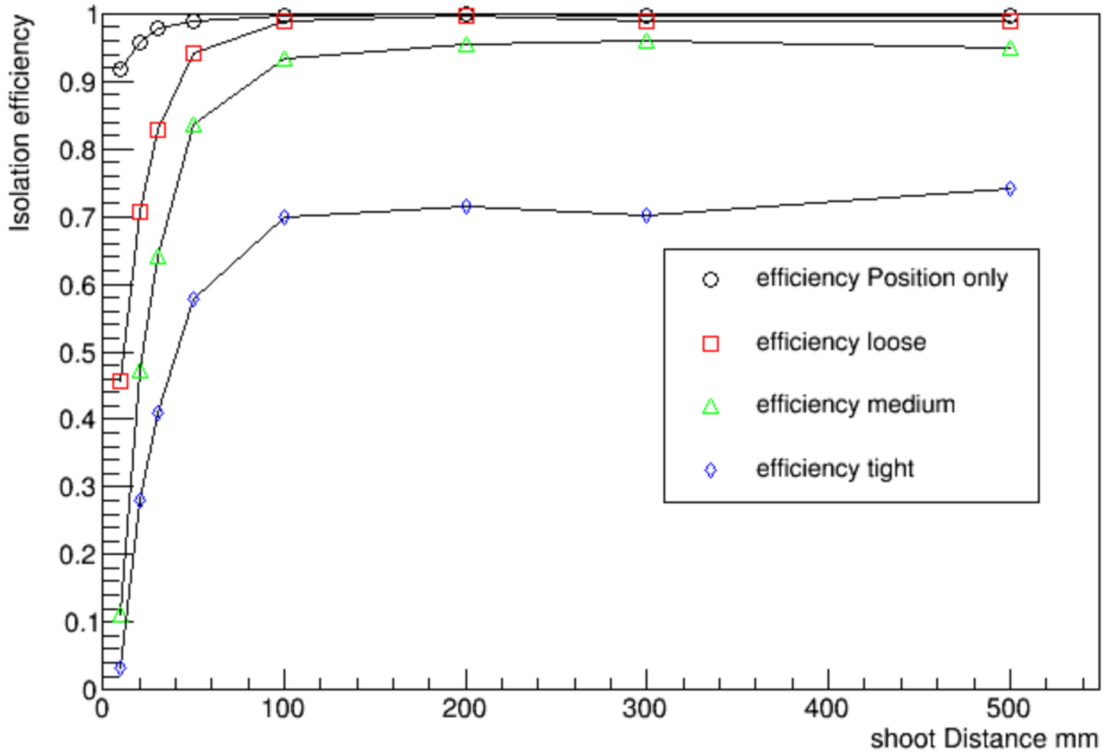




Cellsize optimization

- Separation efficiency
  - Select 2 cluster with largest energy
  - Position cut: cluster distance larger than 10mm（cell size）
  - Energy cut: according to single particle event cluster largest energy distribution, get mean and σ

- Loose:
  - 2 cluster energy both larger than mean -3σ
- medium:
  - 2 cluster energy both larger than mean -2σ
- tight:
  - 2 cluster energy both larger than mean -1σ



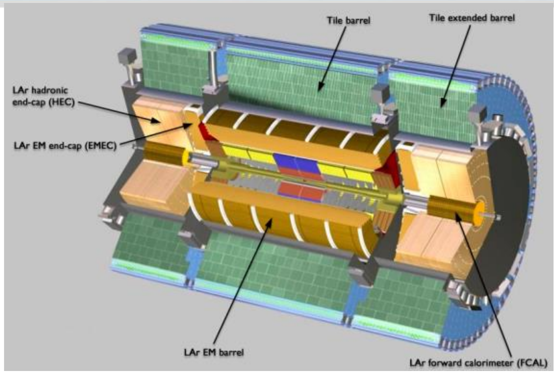
conclusion

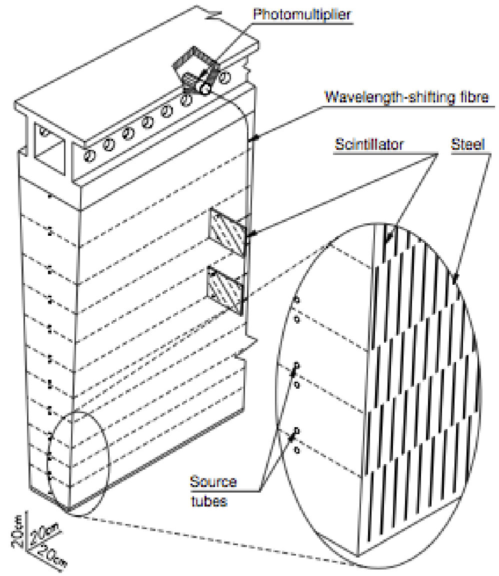
- After correcting SiPM saturation effect,SiPM with 1600 pixel is still enough for 100GeV π-
- The energy resolution obeys $\frac{\sigma}{E} = \sqrt{\sigma_{intrinsic}^2 + \sigma_{sample}^2 \times \frac{d}{s}} / \sqrt{E} \oplus \sigma_{constant}$,more simulation can figure out what determines $\sigma_{intrinsic}^2$ and σ_{sample}^2
- The 10mm cell separation efficiency for 10GeV π- has been studied, by adjusting parameter in arbor and selfmerge a efficiency of 90% at 50mm has been reached

backup

ATLAS Hadron calorimeter

- Absorber
  - Iron:14mm per layer $7.4\lambda_I$ in total
- Sensitive
  - Scintillator:3mm
  - $\Delta\eta \times \Delta\varphi = 0.1 \times 0.1(0.2 \times 0.1\ outer)$
- Calibration
  - Cs:scintillator
  - Laser YVO4:PMT
  - Charge injection:electronics

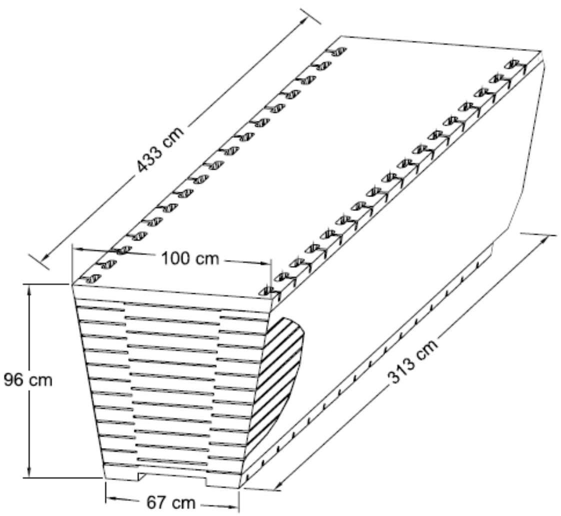


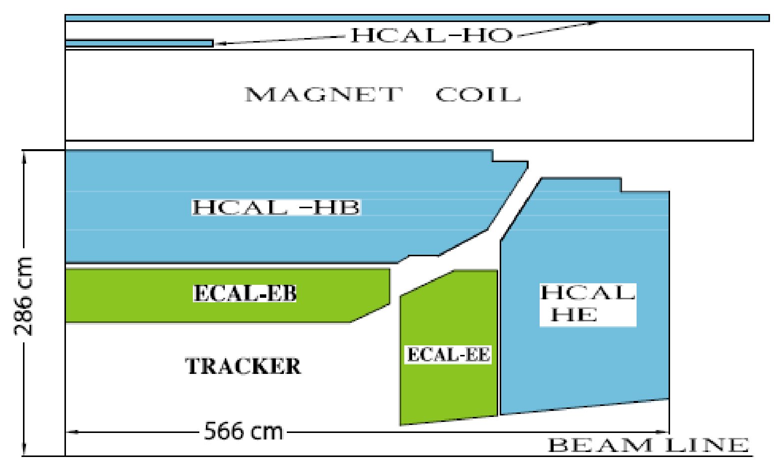


Barrel tower

CMS Hadron calorimeter

- Geometry
  - Absorber
    - Brass（70%Cu+30%Zn）
      - $50.5\mathrm{mm} \times 8 + 56.5mm \times 6 (5.82\lambda_I)$
  - Sensitive
    - Scintillator
      - BC408:9mm(layer0)
      - SCSN81:3.7mm(layer1-15)
      - SCSN81:9mm(layer16)
      - Long term stability
      - Radiation hardness
    - Wrapper:Tyvek 1073D 0.5mm
    - WLS fiber:Kuraray Y11
    - Hybrid photodiode
  - Calibration
    - Source tube
    - Laser calibration via quartz fiber





ZEUS

- DU:98.4%U238,0.2%U235,1.4%Nb

Table 1
Main parameters of the prototype calorimeter

	EMC	HAC
Absorber material	depleted uranium (DU)	
Absorber cladding	stainless steel	
Readout material	SCSN-38 scintillator (SCI)	
DU thickness	3.3 mm	3.3 mm
Cladding thickness	0.2 mm	0.4 mm
SCI thickness	2.6 mm	2.6 mm
Effective X_0	7.4 mm	7.6 mm
Effective λ	210 mm	207 mm
Effective R_M	20.2 mm	20.0 mm
Effective density	8.7 g/cm^3	8.7 g/cm^3
Transverse segmentation	5×20 cm^2	20×20 cm^2
Longitudinal segmentation	$25.9 X_0$ (0.96λ)	HAC1 (3.09λ) HAC2 (3.09λ)
Total length	24.1 cm	128.0 cm
Total cross-section	80×80 cm^2	80×80 cm^2
Optical readout	2 mm thick WLS plates + light guides	
WLS material	PMMA + Y7 (45 ppm)	PMMA + Y7 (30 ppm)
Photomultipliers	XP2972 (Valvo)	XP2081 (Valvo)
Readout channels	128	64

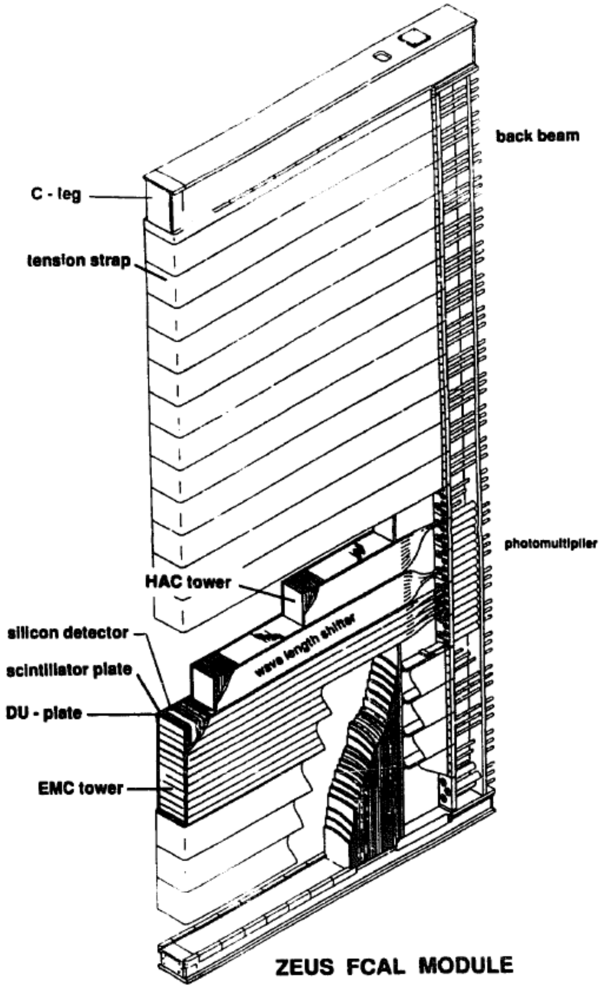


Fig. 2. View of a full size FCAL module.