Calorimeter Simulation and Optimization

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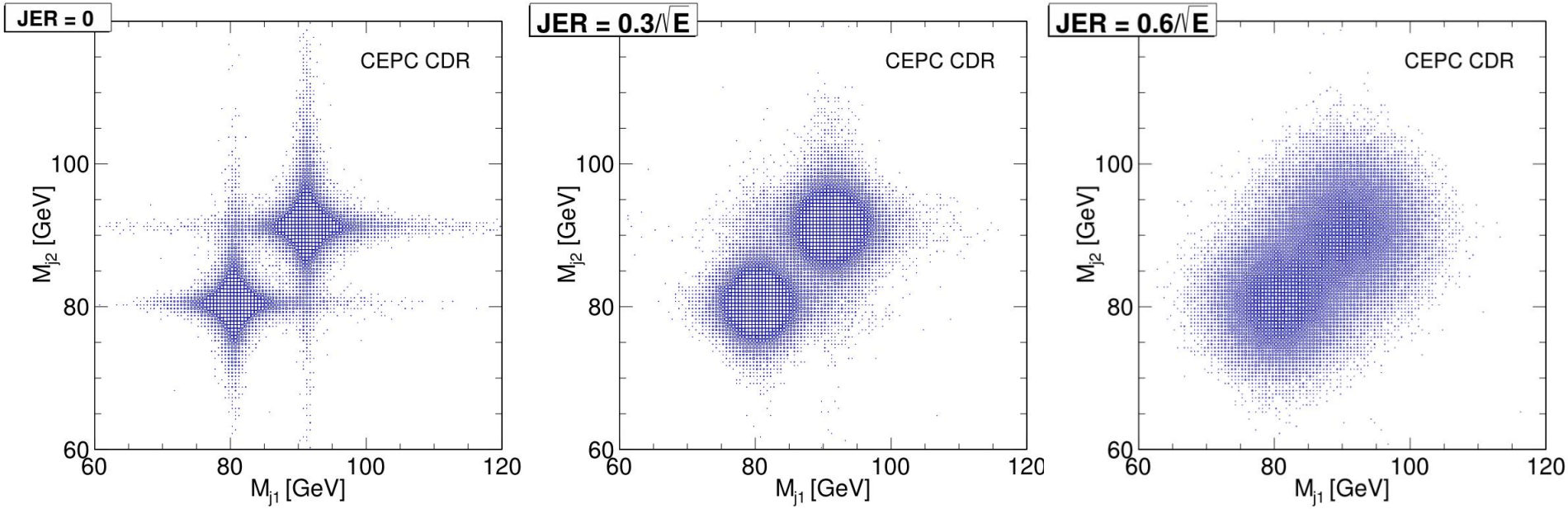
Outline

- Detectors and Simulation tools
- Critical Performance Requirements on Calorimeter at CEPC
- Simulation and Optimization Results
- Next Step

Jet Energy Resolution

Separation of W/Z bosons in their hadronic decays translates into a jet energy resolution requirement of ~ 30% /√E (E<100GeV).

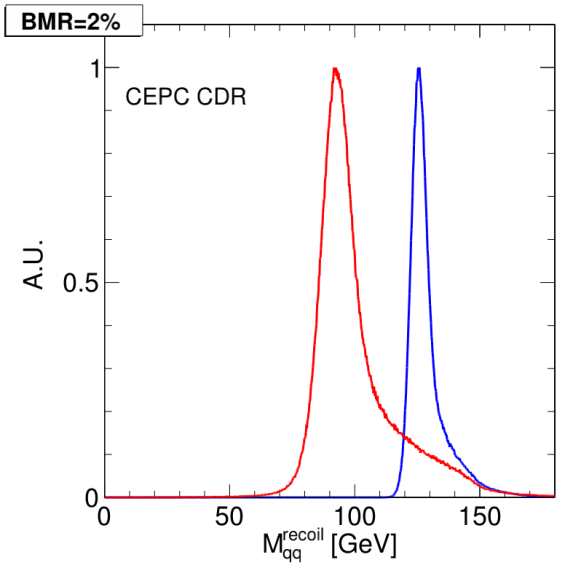


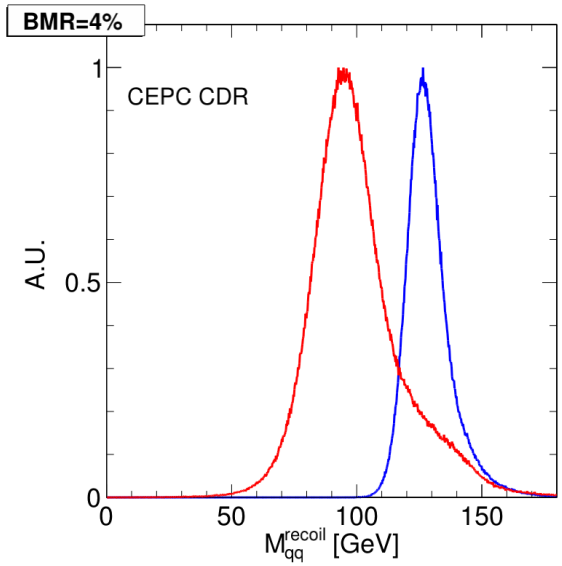
WW→4j and ZZ→4j

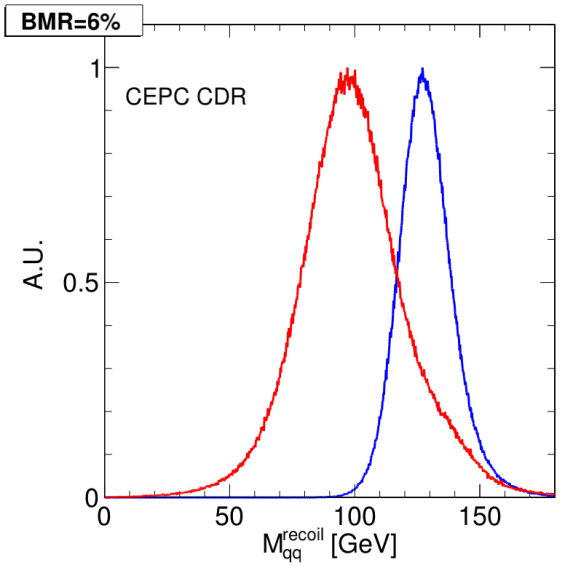
Jet Energy Resolution

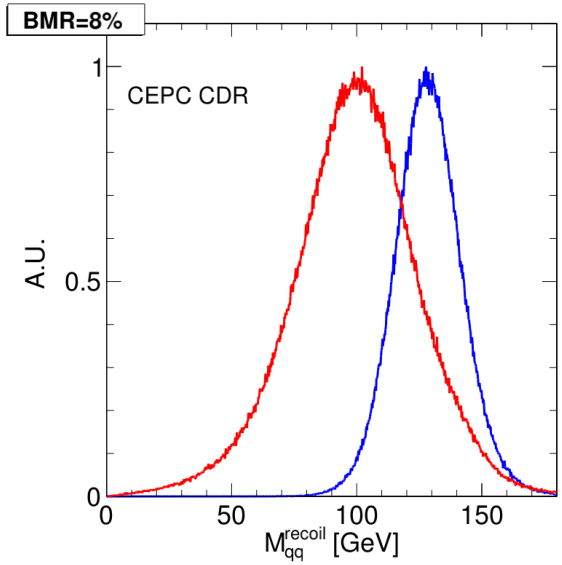
e+e→ZH, ZZ
Z->qq
H or Z ->invisible

a BMR of ~4% or better will be needed.



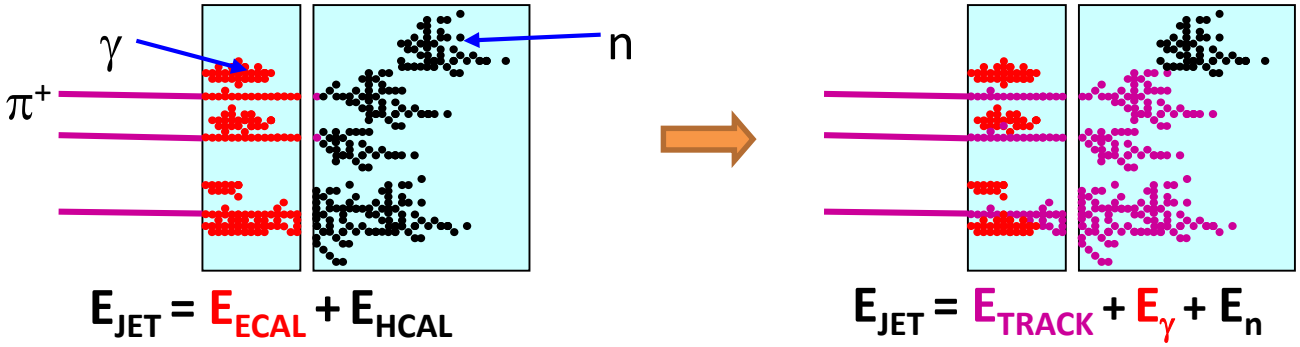






BMR: Boson Mass Resolution at di-jet final states
BMR*sqrt(2) = Jet Energy Resolution

Particle Flow Algorithm



Traditional calorimetric approach:

- Measure all components of jet energy in ECAL/HCAL
- Approximately 70% of energy measured in HCAL: $\sigma_E/E \approx 60\%/\sqrt{E(GeV)}$

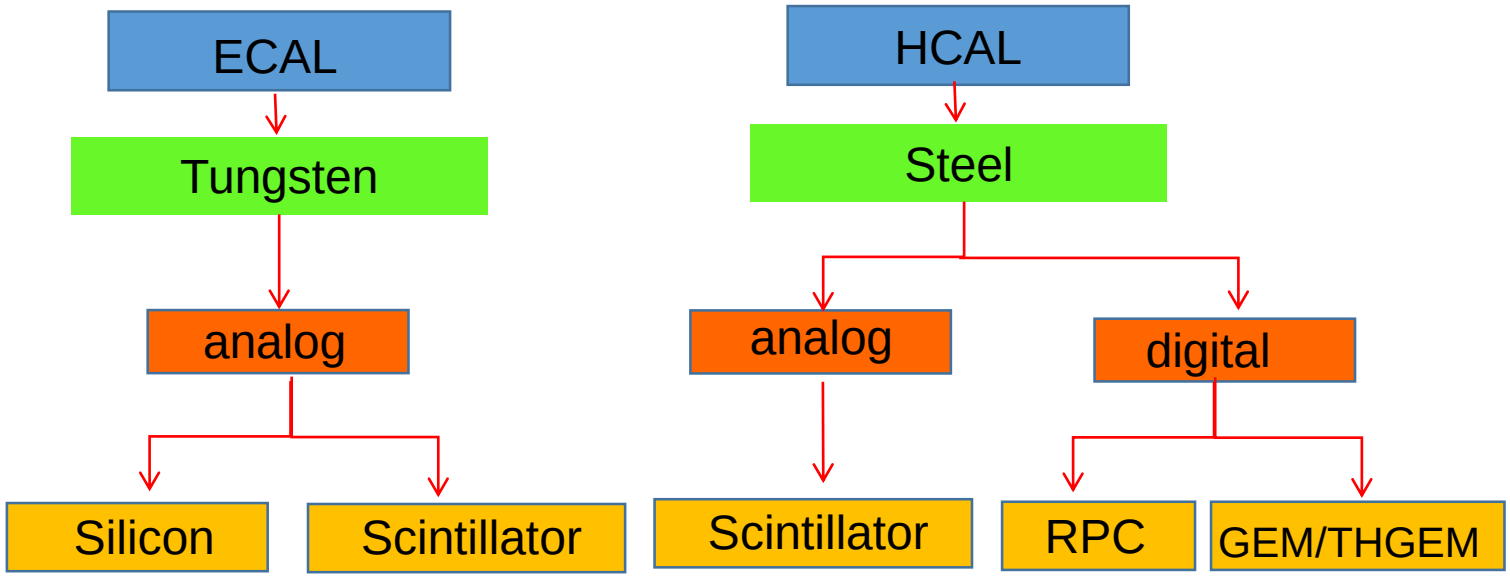
Particle Flow Calorimetry paradigm:

- Charged particle momentum measured in tracker (essentially perfectly)
- Photon energies measured in ECAL:
- Only neutral hadron energies (10% of jet energy) measured in HCAL: **much improved resolution**

Component	Detector	Energy fraction	Energy resolution
Charged particles	Tracker	~0.6 Ej	$10^{-4} * E^2$
Photons	ECAL	~0.3 Ej	0.15 * √E
Neutral Hadrons	HCAL	~0.1 Ej	0.55 * √E

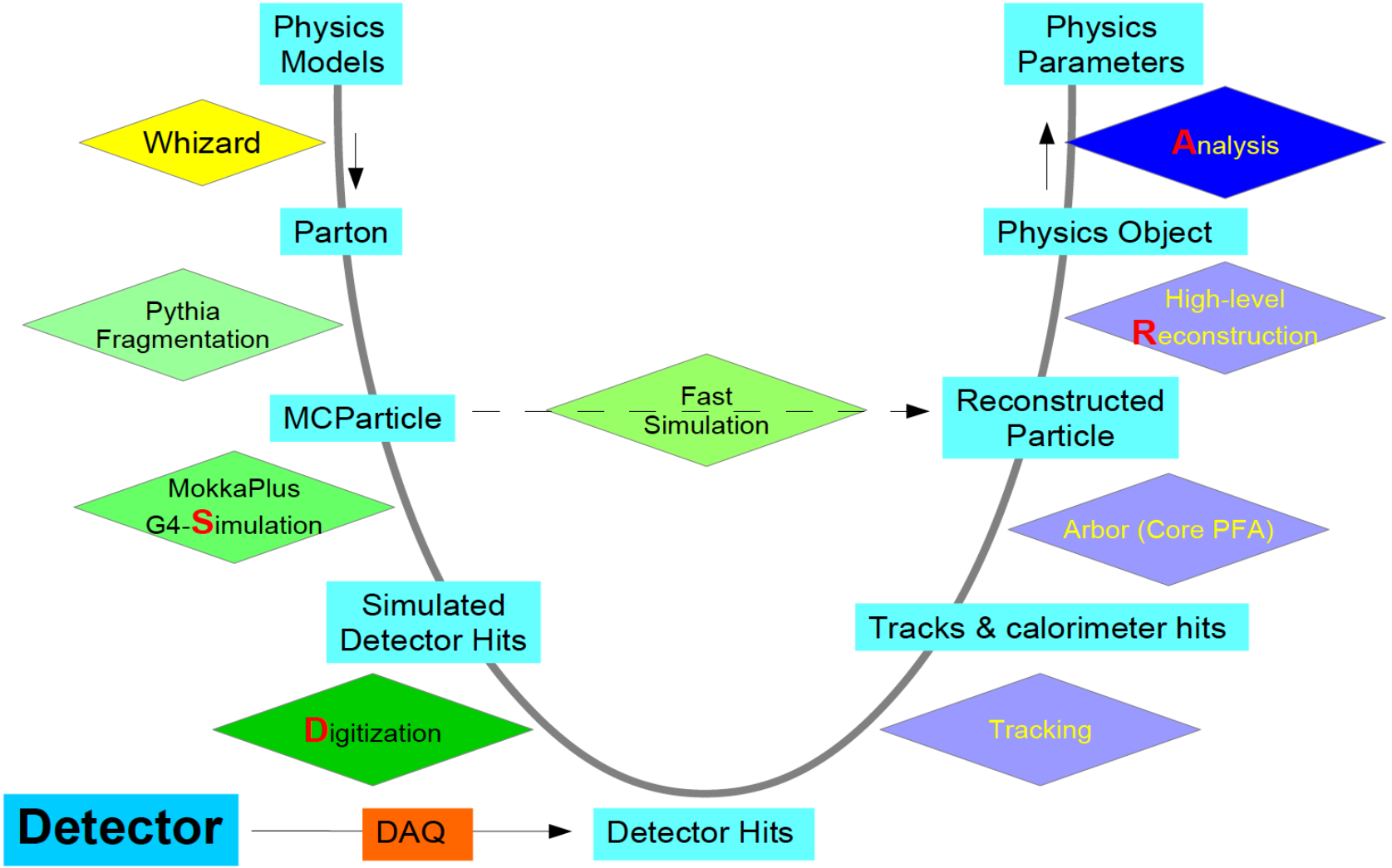
CEPC PFA Calorimeter Options

A highly segmented and full-contained calorimeter system is required



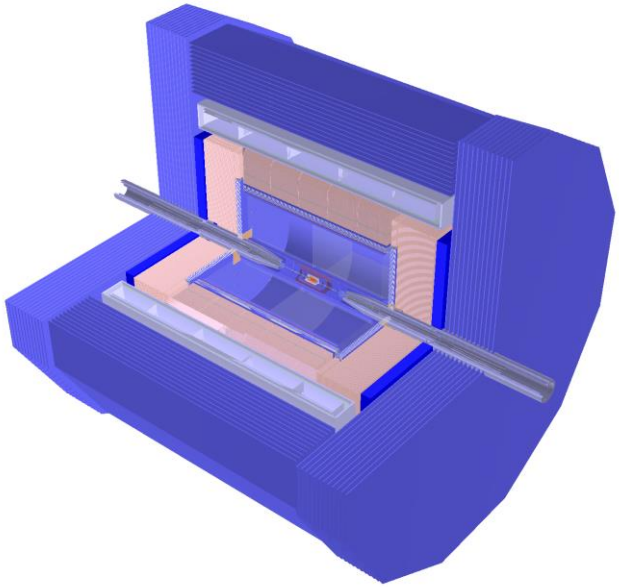
CEPC Full Simulation Software

http://cepcsoft.ihep.ac.cn/



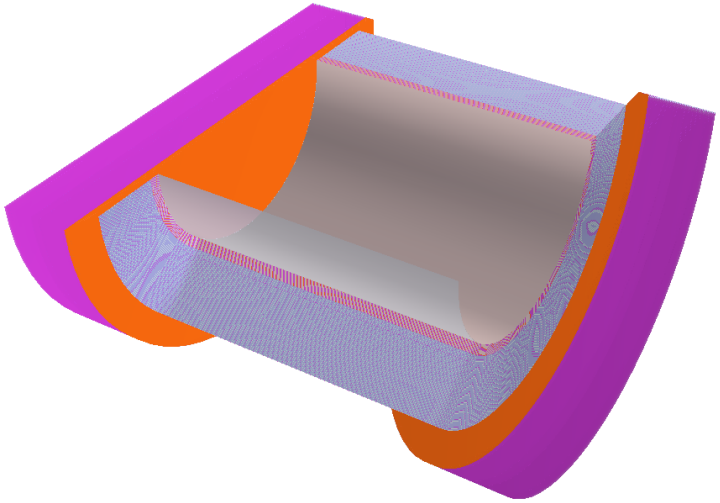
Full Simulation Geometries

CEPC_v4 (APODIS)



Baseline Geometry for CDR

Simplified Geometry



- calorimeter only
- ideal geometry (cylindrical barrel layer and two plate endcaps).

- easily modified for Arbor parameters
- no geometry defects

Critical performance requirements for ECAL

- Good photon energy resolution. A clear Higgs boson mass distribution should be reconstructed from the Higgs->γγ
- Good jet energy response. The boson mass resolution should better than 4%.
- Separation performance, which is crucial for the jet energy resolution and for physics with taus(π0).
- Particle Identification

Critical performance requirements for HCAL

- Good Jet Energy Resolution
  - Neutral Hadron Energy Resolution
  - Confusion (Shower Separation)

- Particle Identification

Calorimeter simulation and geometry optimization results for now

- ECAL geometry optimization
  - Transverse:
    - Cell Size

    photon shower separation, with physics benchmark of Br(tau->X)
  - Longitudinal:
    - Total Absorber Thickness
    - Number of Layers & Sensor Thickness

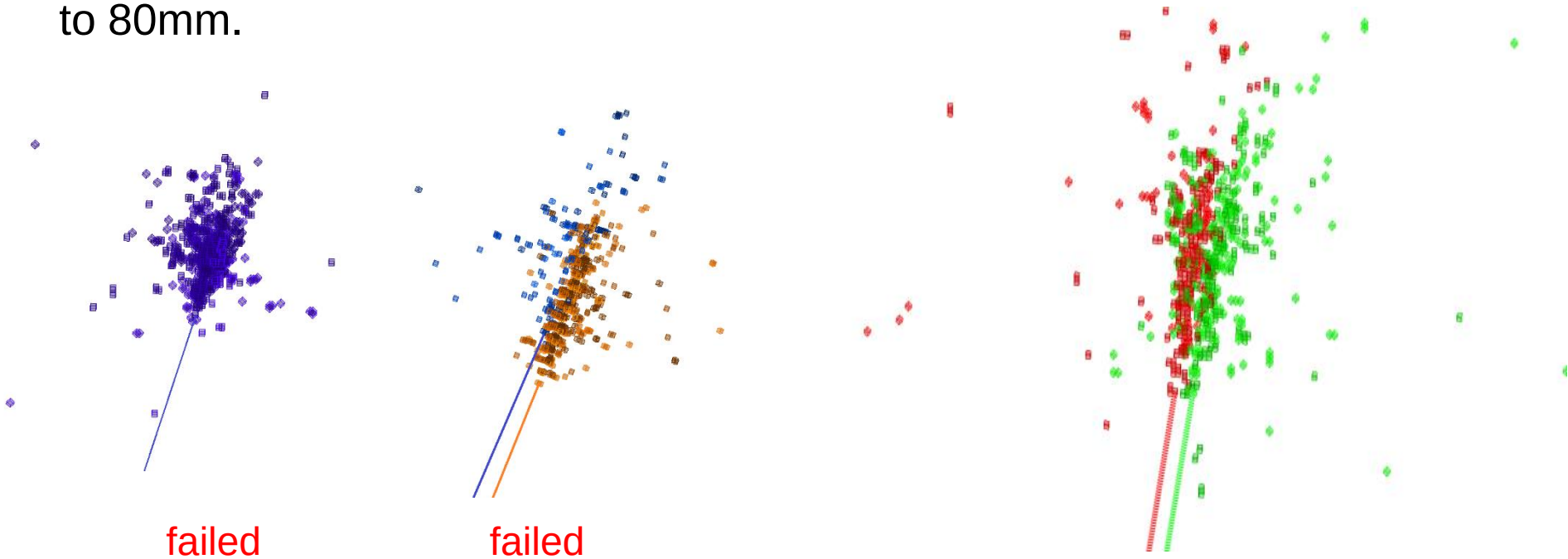
    photon energy resolution
- ECAL corrections and calibrations at CEPCv4

- HCAL geometry optimization
  - Longitudinal Layer Number
- Software compensation for AHCAL

Nearby EM-Shower Separation

Lots of nearby EM-showers exist in jets, the separation and reconstruction of them are important for some physics objecsts.

The reconstruction efficiency of two parallel 5 GeV photons was studied. The distance between these two photons ranges from 1mm to 80mm.



failed

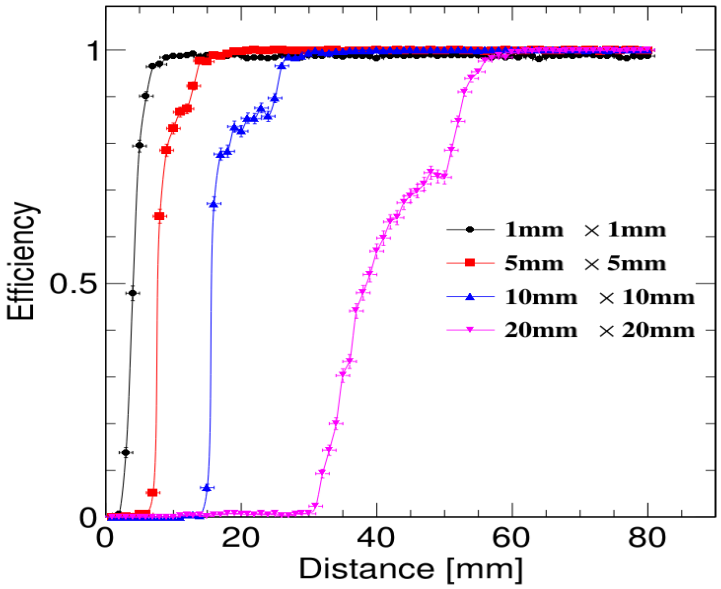
failed

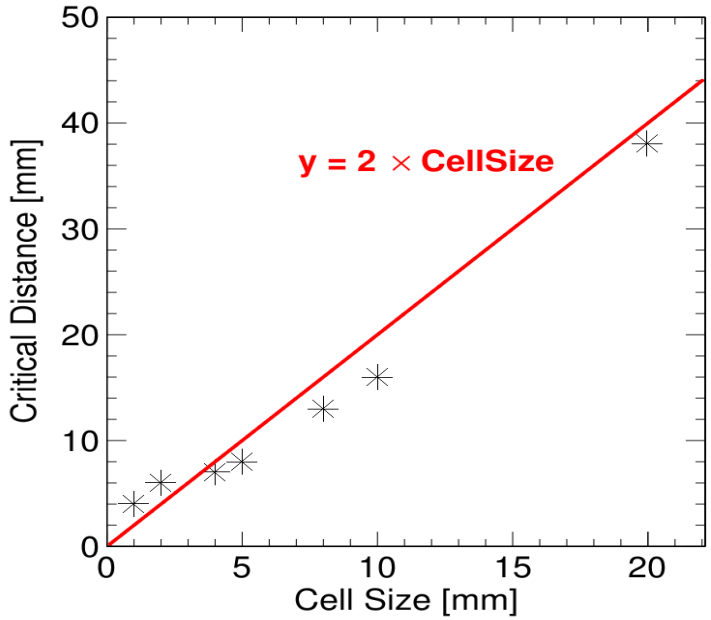
($E_{blue\ cluster} \approx 1/6 E_{orange\ cluster}$)

succeeded

$1/3E_{All}<E_{photon1}<2/3E_{All}$ && $1/3E_{All}<E_{photon2}<2/3E_{All}$: succeeded

Nearby EM-Shower Separation





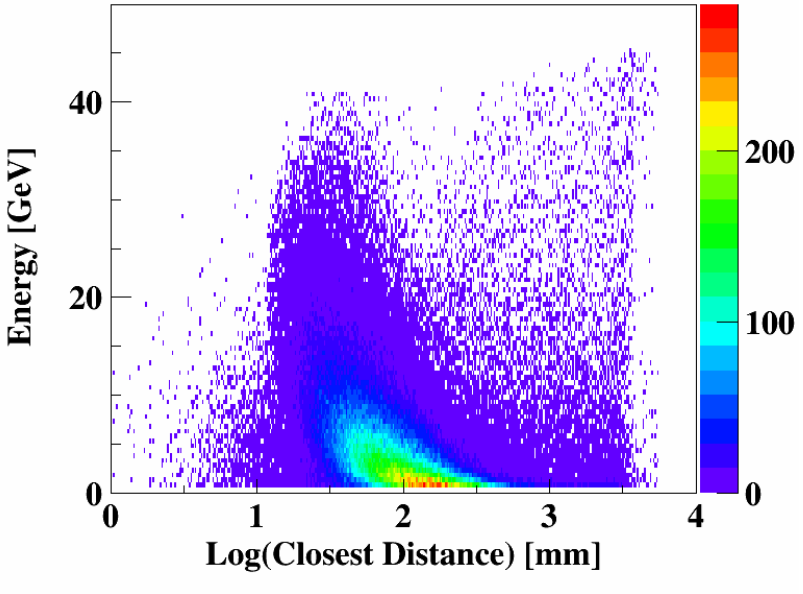
Efficiency with differrent cell size was checked
At large distance, the reconstruction efficiency converges to 100%
At very closed by distance, the reconstruction efficiency drops significantly

The critical separation distance is defined as the distance with which the successful reconstruction efficiency is 50%.

Nearby Photon Showers in Physics Objects

Z->tau tau

(at Zpole Energy)



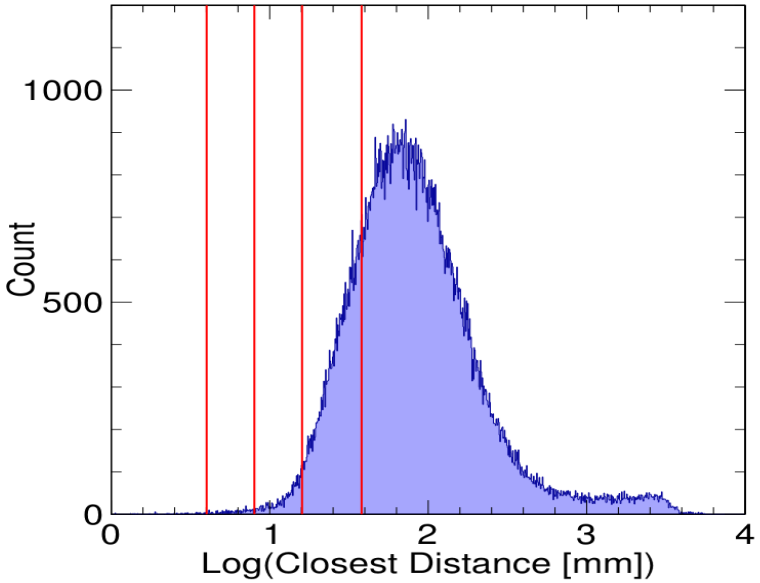
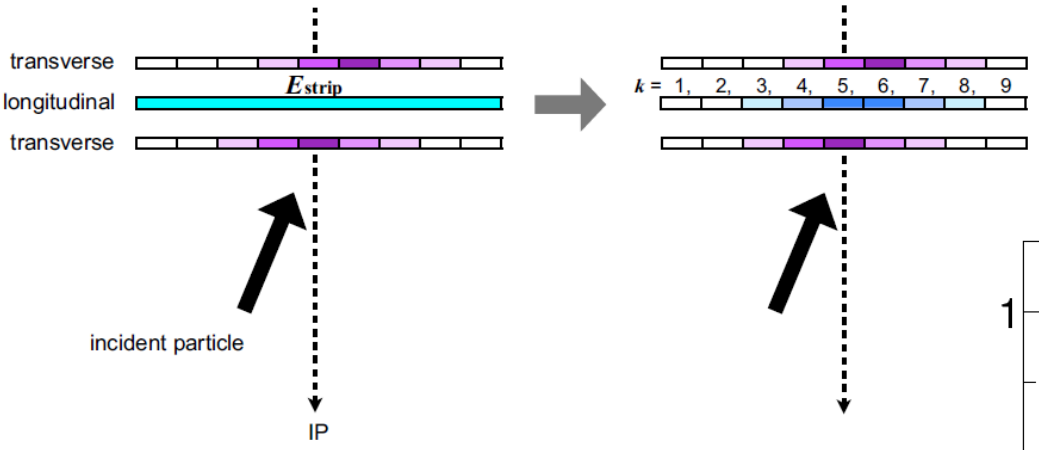


Table 2. Percentages of photons that would be polluted by neighbor particles

Cell Size	Critical Separation Distance with Arbor	Percentage of $Z \rightarrow \tau^+\tau^-$
1 mm	4 mm	0.07%
5 mm	8 mm	0.30%
10 mm	16 mm	1.70%
20 mm	38 mm	19.6%

At least ~10mm×10mm effective cell size

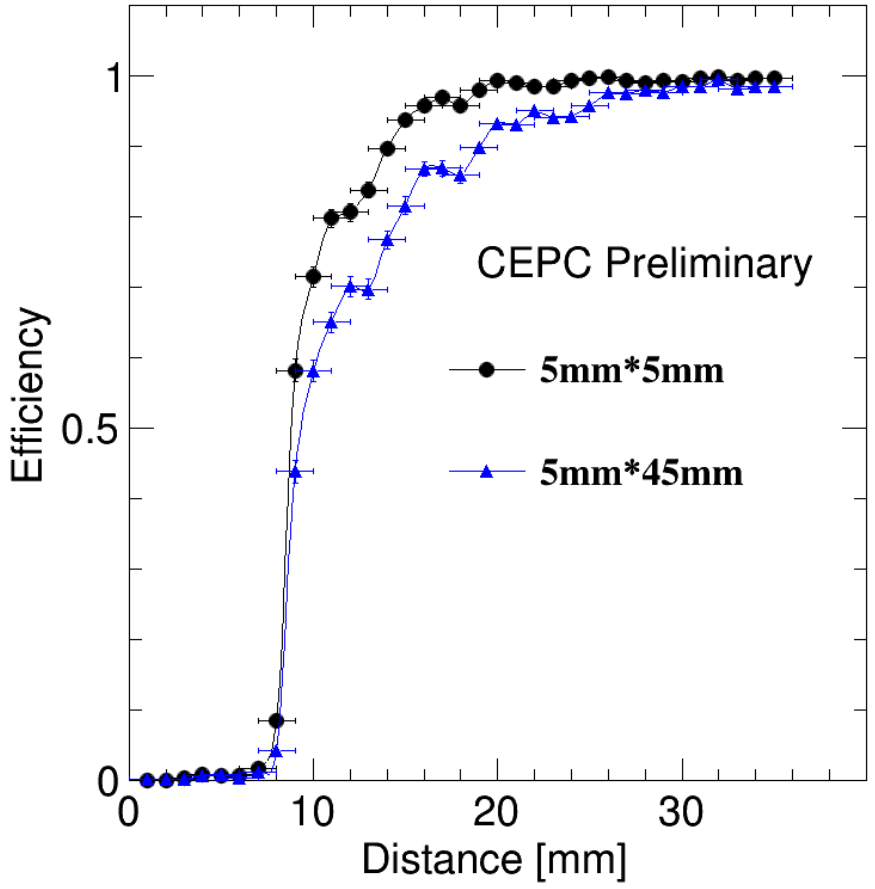
Separation at Strip Readout



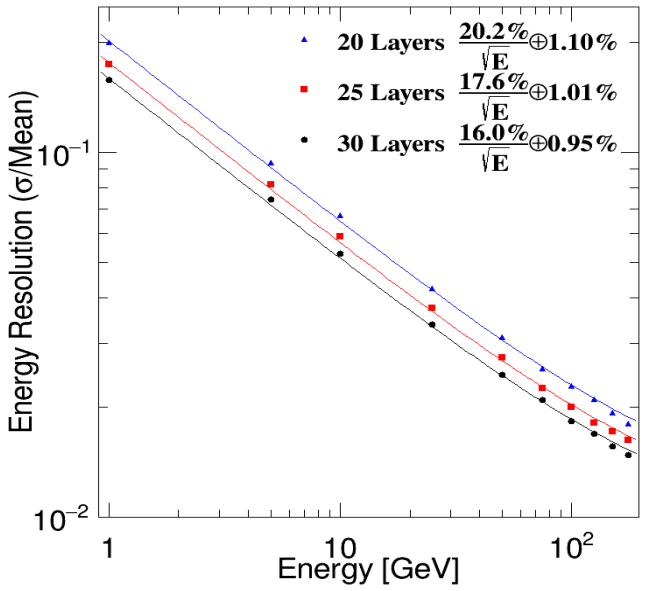
5*45mm Cell -> 5*5mm Cell

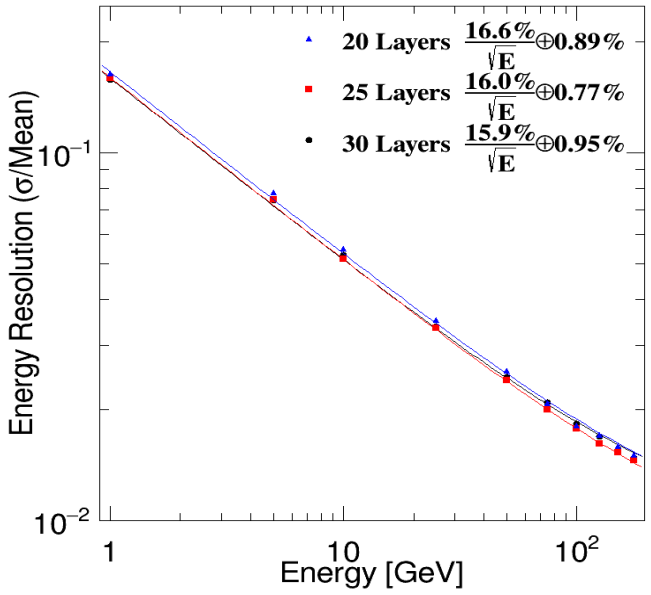
Energies of Neighbor Layer Strips (2*9) are used to calculate the splitting weights

Next: further study at jet reconstruction



Photon energy resolution at different ECAL layer number





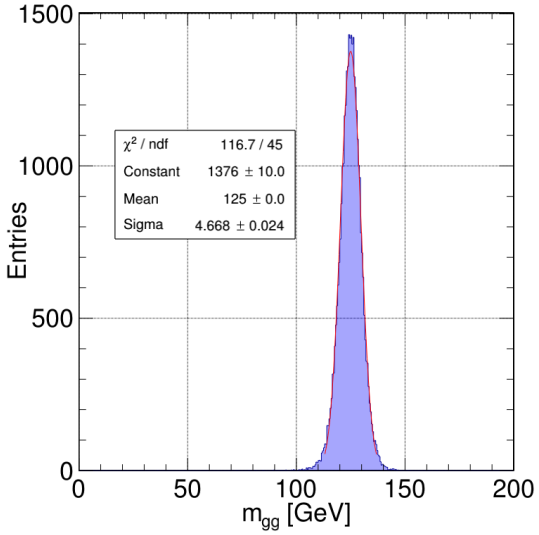
0.5mm thick silicon in each layer

less layer gets worth photon energy resolution, due to the less sensor/absorber ratio

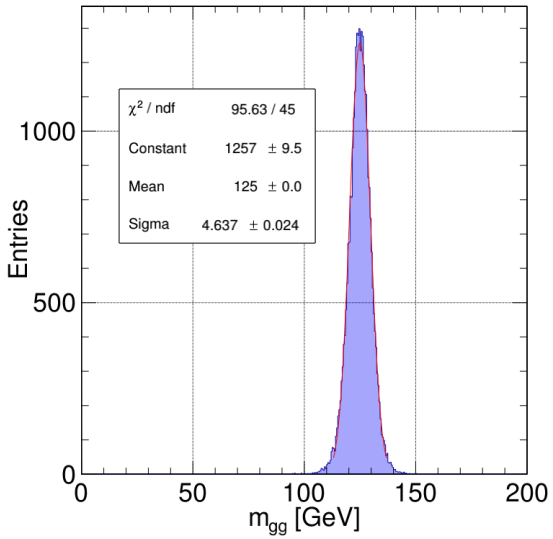
thicker sensor can compensate photon energy resolution loss

30layers 0.5mm silicon
25layers 1mm silicon
20layers 1.5mm silicon

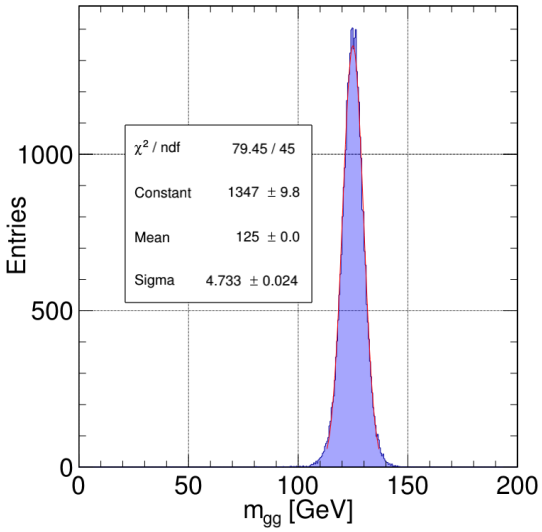
CEPC Detector Model Results
vvHiggs->gluon gluon



0.5mm Si, 30 layers



1mm Si, 25 layers



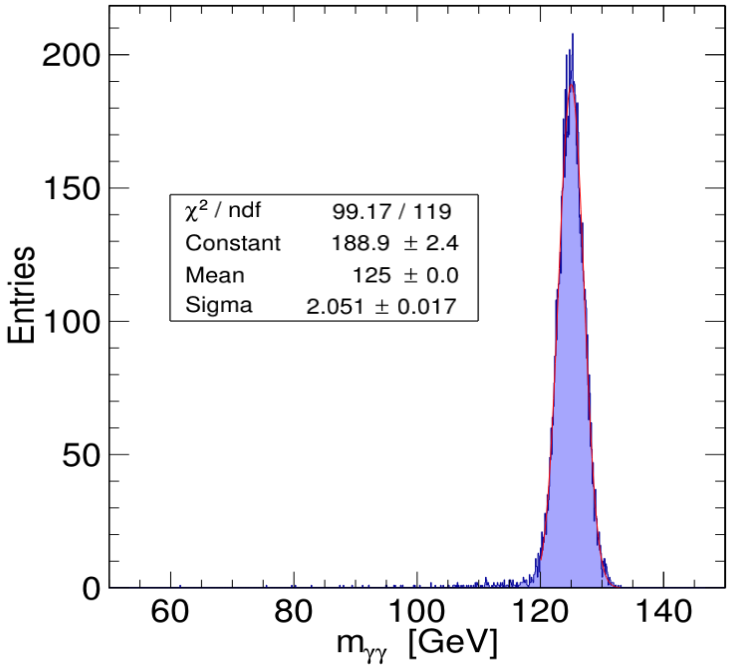
1.5mm Si, 20 layers

Table 1. Resolution of reconstructed Higgs boson mass through $\nu\nu Higgs, Higgs \rightarrow gluons$ events using different longitudinal structures at CEPC_v1 geometry.

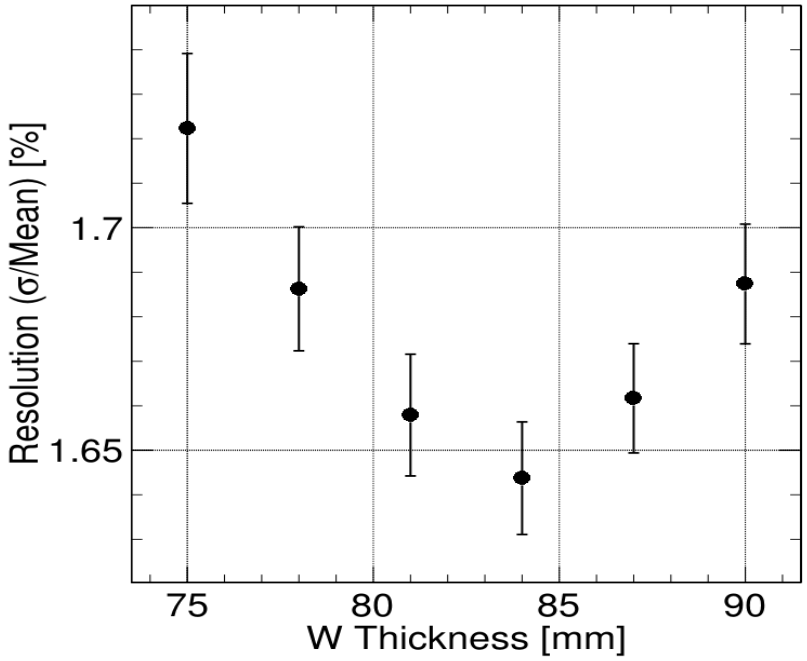
Layer number	Silicon sensor thickness	Higgs boson mass resolution (Statistic error only)
30	0.5 mm	3.74 ± 0.02 %
25	1 mm	3.71 ± 0.02 %
20	1.5 mm	3.78 ± 0.02 %

vvHiggs->diphoton Reconstruction

the reconstruction accuracy is mainly decided by the photon energy resolution because the spatial resolution is negelectable.

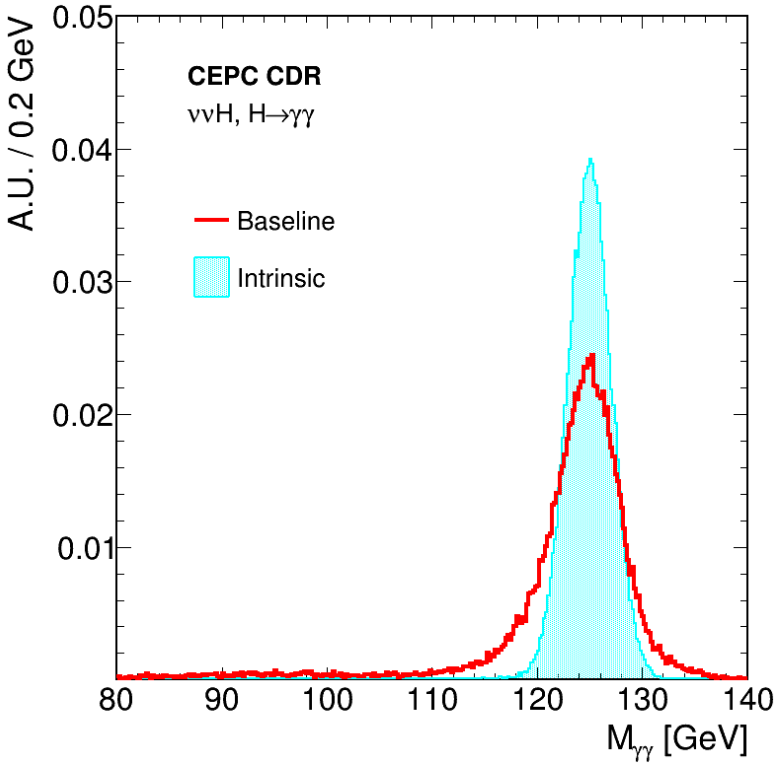


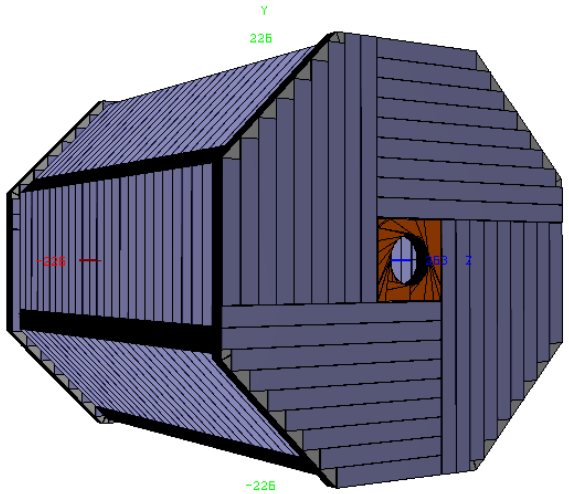
30layers ECAL with
2.8mmW+0.5mmSi in each layer

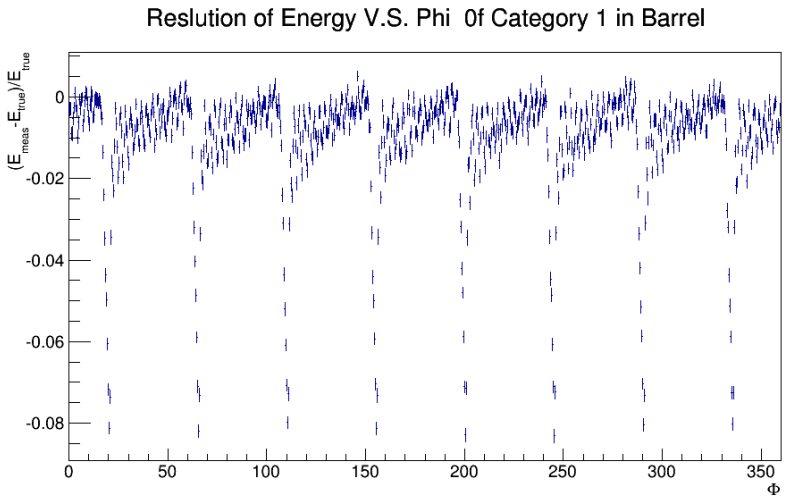


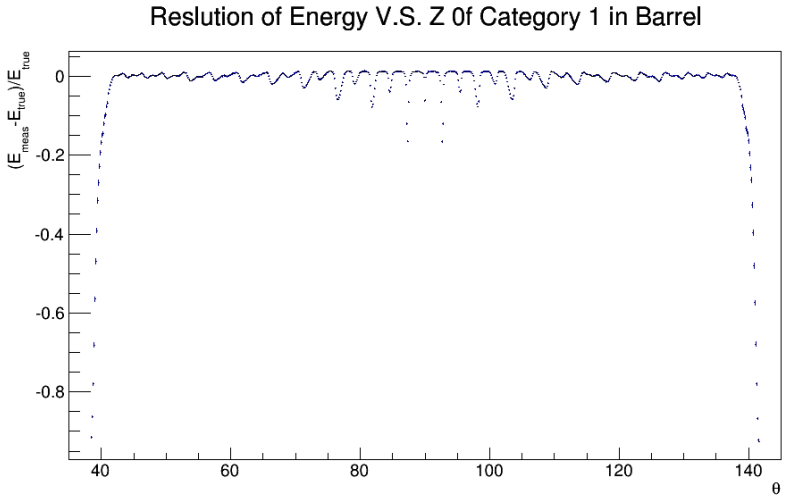
resolution(σ/mean) with different total tungsten thickness

ECAL Corrections and Calibrations at CEPCv4





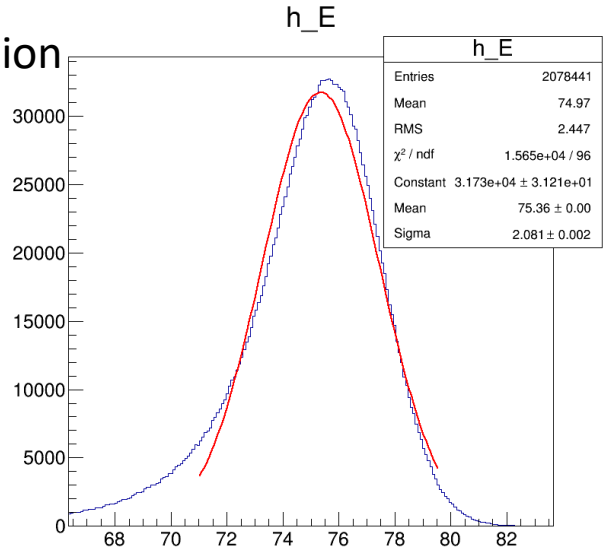




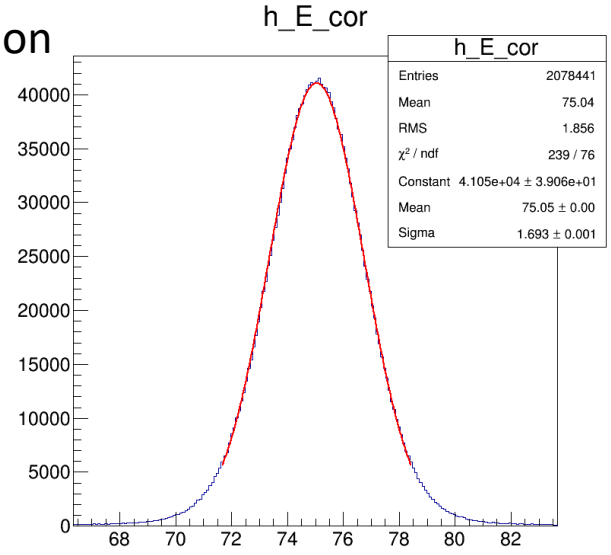
From Yuqiao

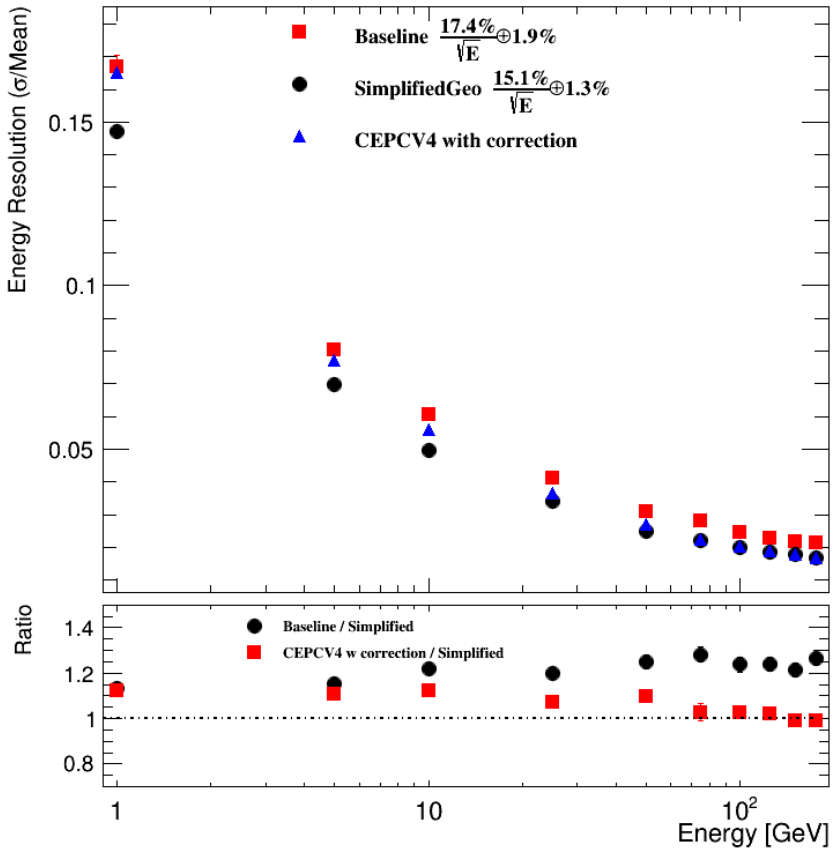
ECAL Corrections and Calibrations at CEPCv4

Before correction



After correction





From Yuqiao

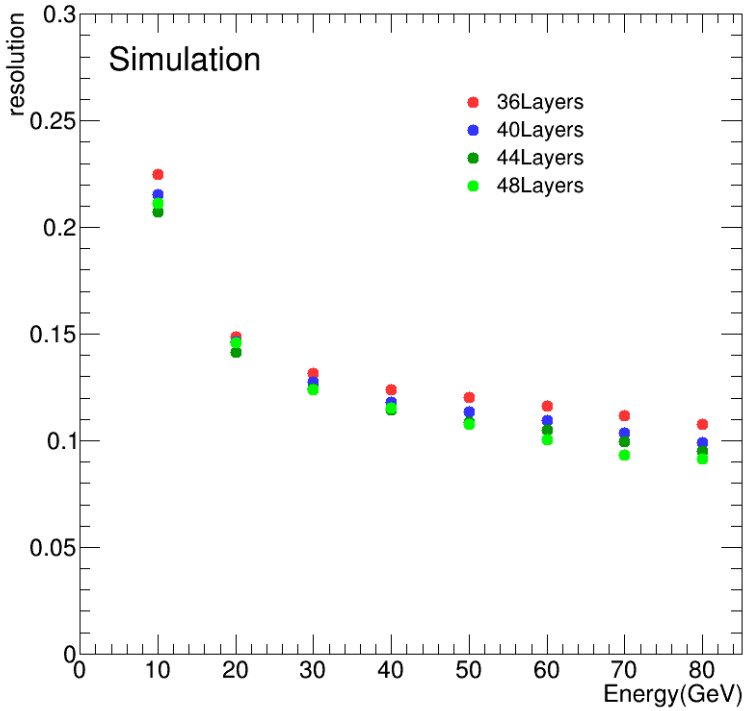
Summary on ECAL Simulation & Optimization

- ~10mm*10mm or smaller cell size is needed for EM shower seperation in tau jets.
- Total Tungsten thickness should be 80-90mm.
- <30 layers is feasible, if thicker sensor can be used to conpensate photon energy resolution loss.

  H. Zhao et al., Particle flow oriented electromagnetic calorimeter optimization for the circular electron positron collider, arXiv:1712.09625.

- Geometry based correction at CEPCv4 has been set up, and will be used to improve H->γγ reconstruction.

SDHCAL Layer Number

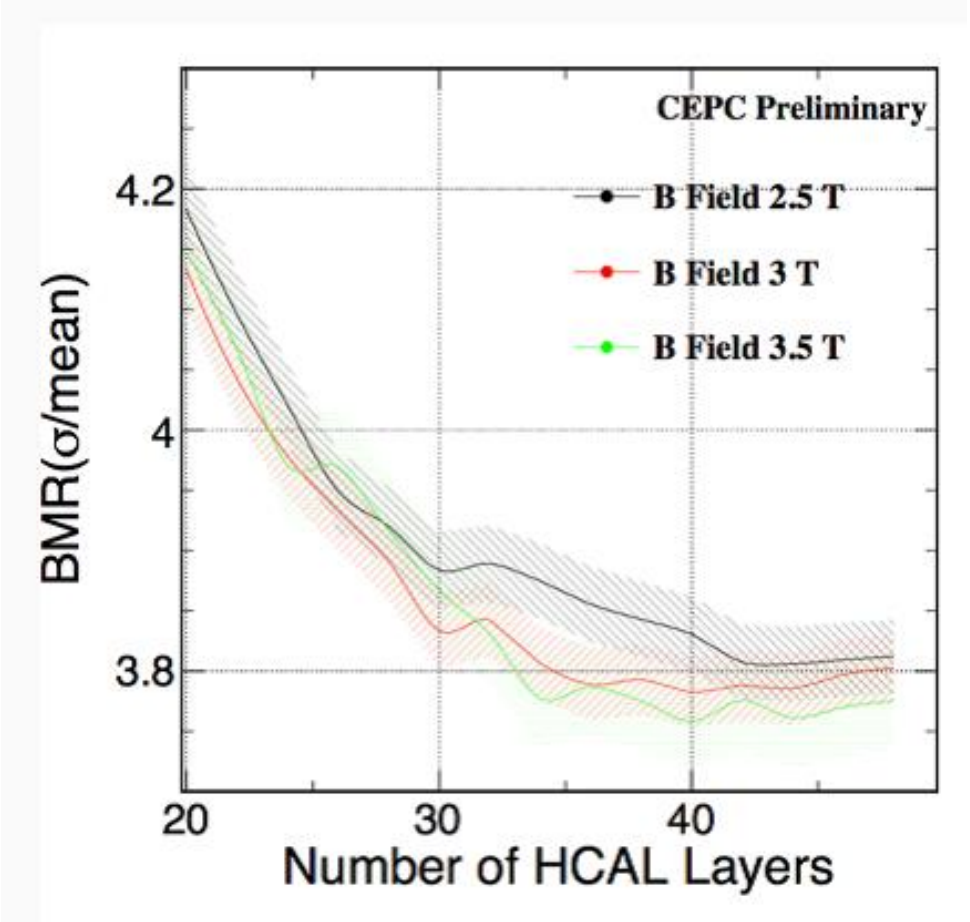


The energy resolution of SDHCAL with different number of layers versus simulated pion energy ranging from 10 GeV to 80 GeV.

SDHCAL with 40-layer yields decent energy resolution, about 15% and 10% with pion energy of 20 GeV and 80 GeV, respectively.

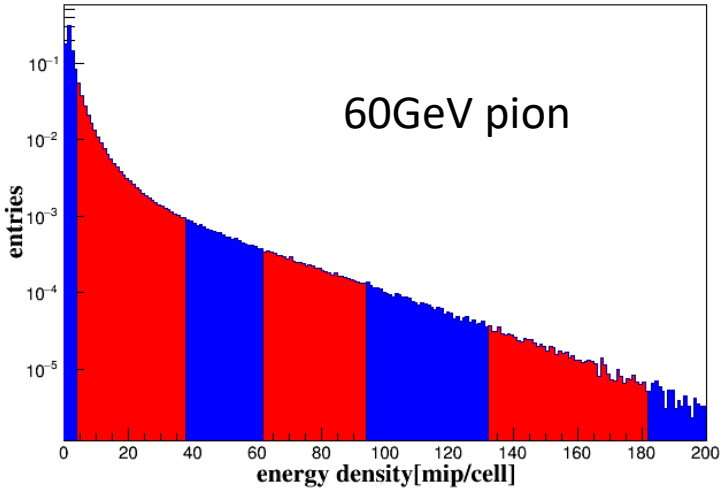
HCAL Thickness & B Field

- HCAL: outer layers unused
- Smaller B Field needed



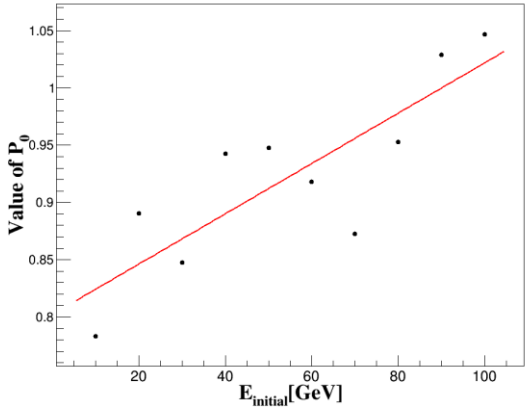
by Dan Yu

Software compensation for Energy reconstruction at AHCAL

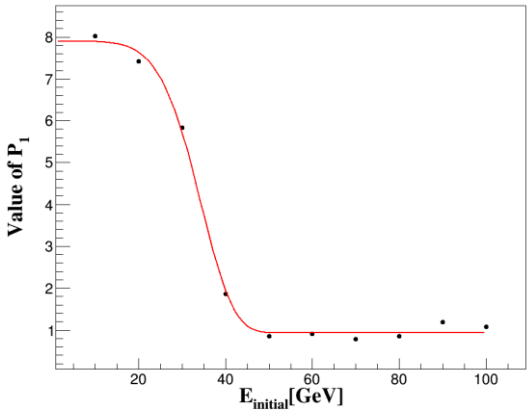


$E_{rec} = \sum_i (E_{HCAL,i} \times w_{i(E)})$XC, $\chi^2 = \sum_i (E_{ini} - E_{rec})^2$

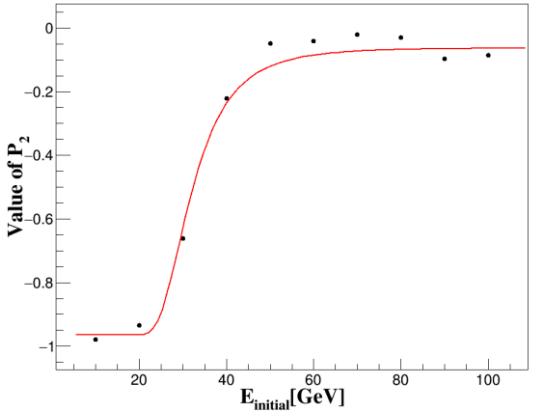
$\omega_j(E) = p_0(E) + p_1(E) e^{(p_2(E) * e_j)}$



$p_0 = a_1 + a_2 \times E$

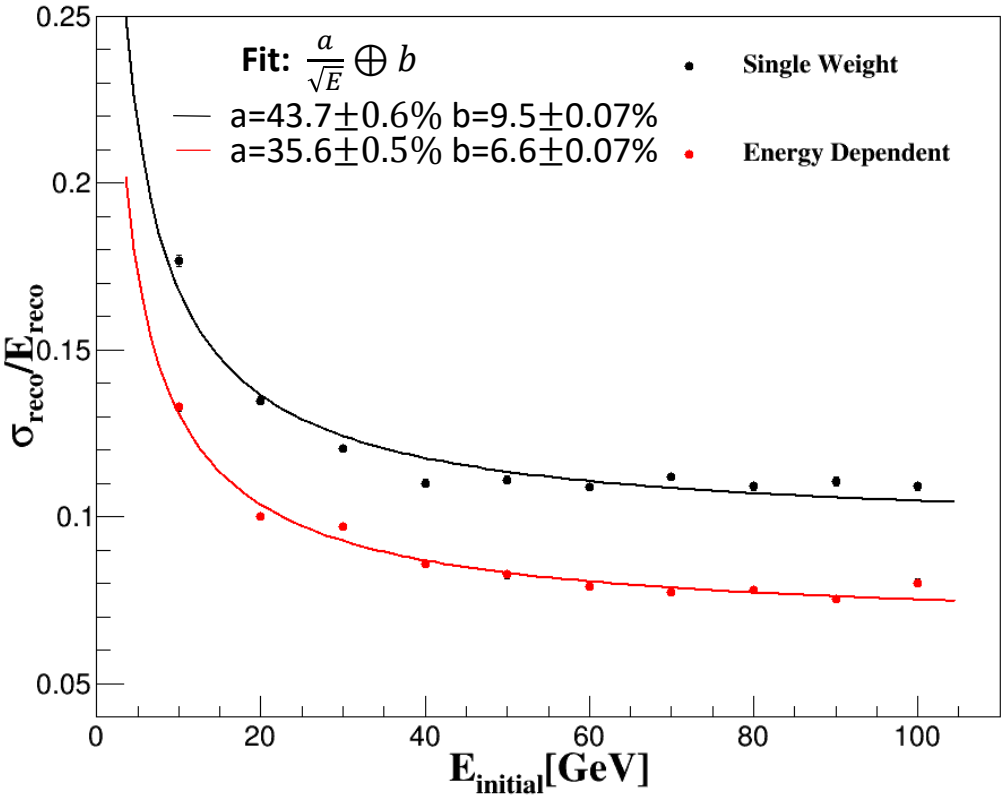


$p_1 = a_0 + a_1 \times e^{a_2 x^{a_3}}$



$p_2 = a_0 + a_1 \times e^{a_2 x^{a_3}}$

Software compensation for Energy reconstruction at AHCAL



Energy resolution improved by 18.5%

From Jiechen Jiang
For more details please check Jiechen's poster

Next: Merge into Full Simulation and make improvements to jet energy resolution and Higgs boson mass resolution

Summary on HCAL Simulation & Optimization

- Total layer number should be ~40.
- Software compensation for Energy reconstruction at AHCAL.

Next

- Reconstruction algorithm for strip readout at Scintillator ECAL (jet level)
- Geometry based Corrections and fine-tuned Calibrations at CEPCv4

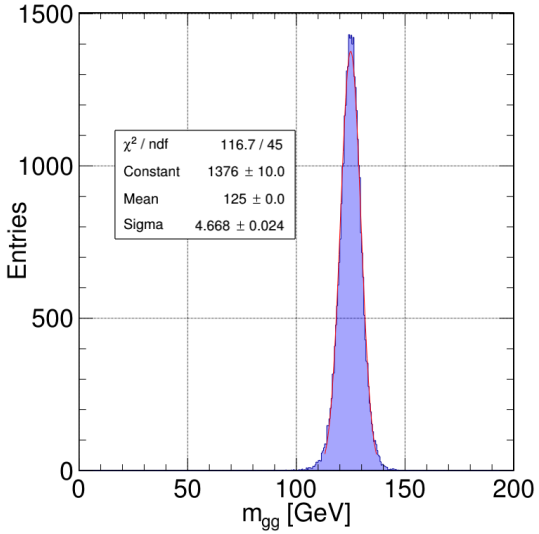
  Yuqiao Shen
  (Changzhou Institute of Technology)
- Scintillator ECAL Digitization Yazhou Niu (USTC)
- Optimization on Energy Resolution for AHCAL Jiechen Jiang (IHEP)
- Geometry Optimization for AHCAL Yukun Shi (USTC)
  Danning Liu (SJTU)

Thanks!

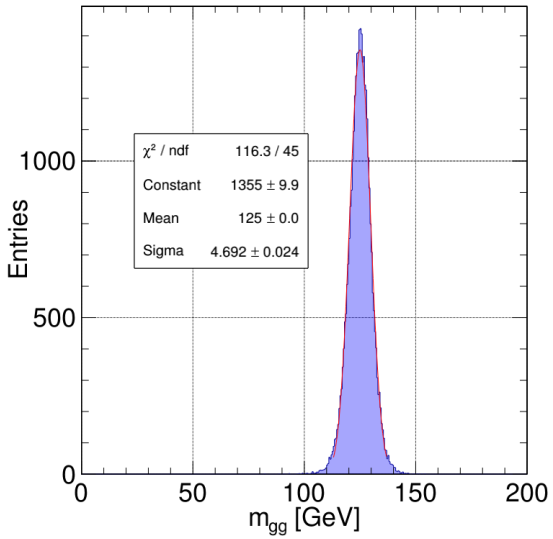
Back up

CEPC Detector Model Results

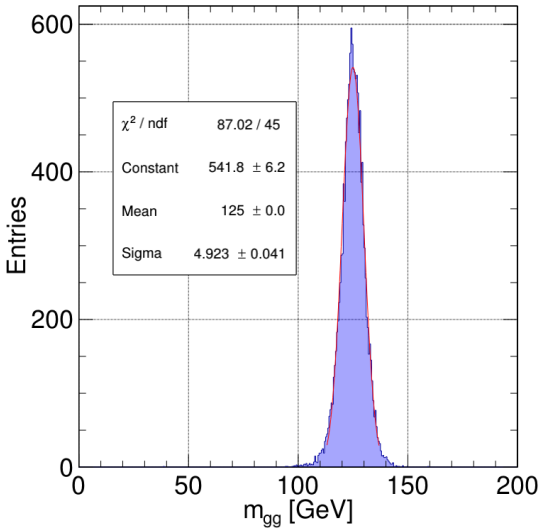
vvHiggs->gluon gluon



5mm*5mm



10mm*10mm



20mm*20mm

Cell Size (mm^2)	5 x 5	10 x 10	20 x 20
Boson Mass Resolution (sigma/mean)	3.74%	3.75%	3.93%