Status of ECAL optimisation at CLIC

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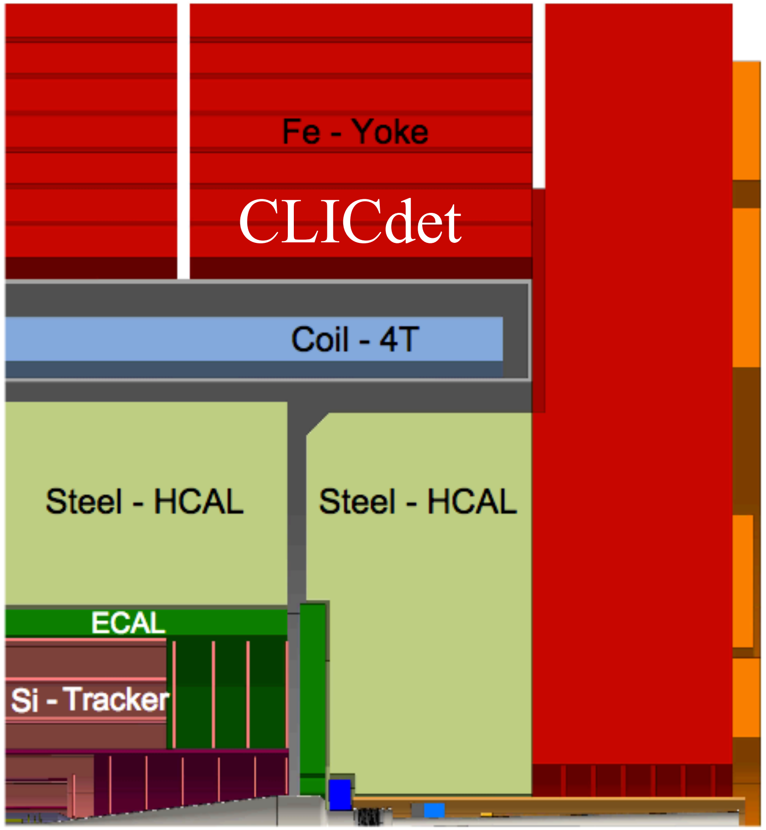
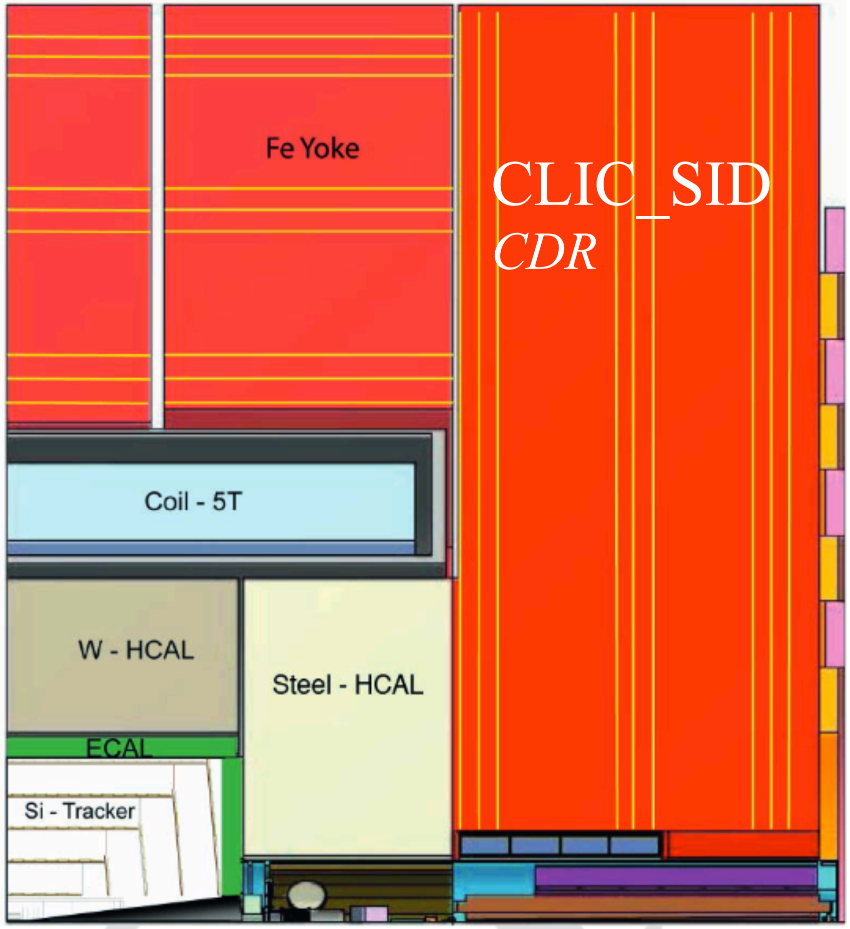
on behalf of the CLICdp collaboration

New CLIC detector model CLICdet

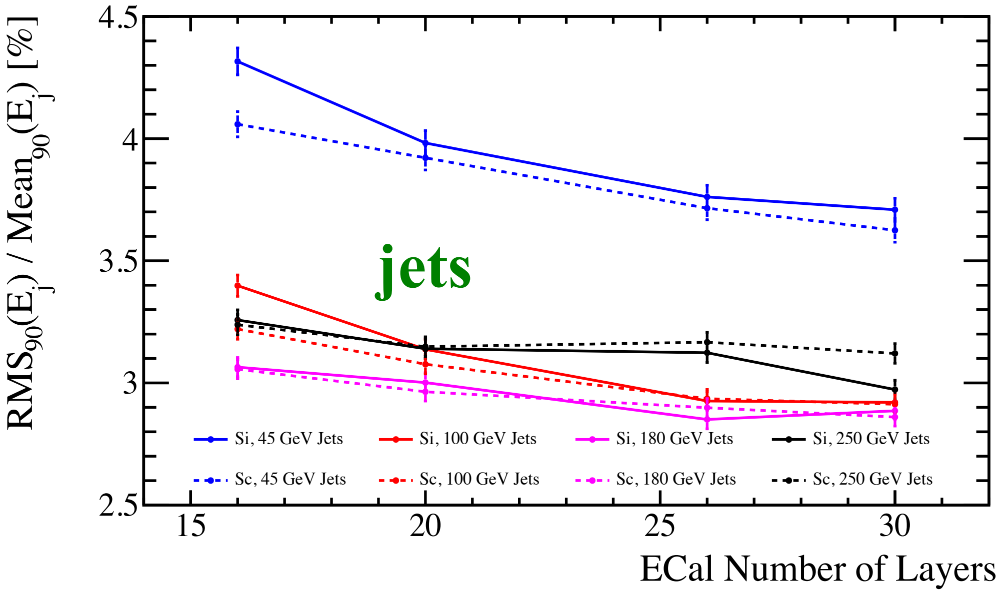


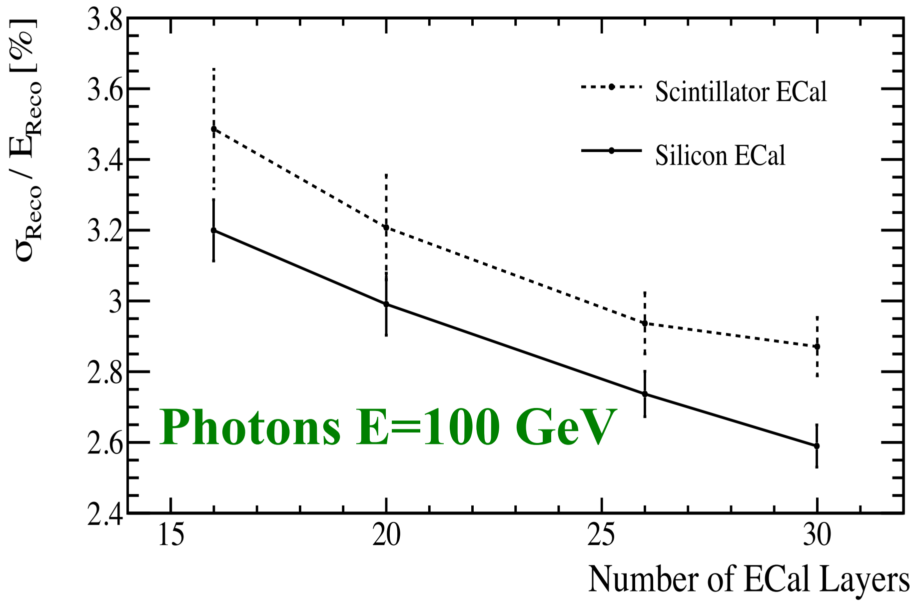


New optimised model **CLICdet** for new benchmark studies:
Single detector, 4 Tesla solenoid field, all steel HCAL, smaller return Yoke, quadrupole magnet outside of detector allowing better forward HCAL coverage

Previous ECAL optimisation

- **Previous** ECAL optimisation studies performed using low (E=10 GeV) and medium energy (E=100 GeV) photons and jets





→ Based on these findings: 25 layers lead to similar performance as 30 layers (CDR geometry)

→ **Now** test performance of different models in addition for high energy (isolated) photons

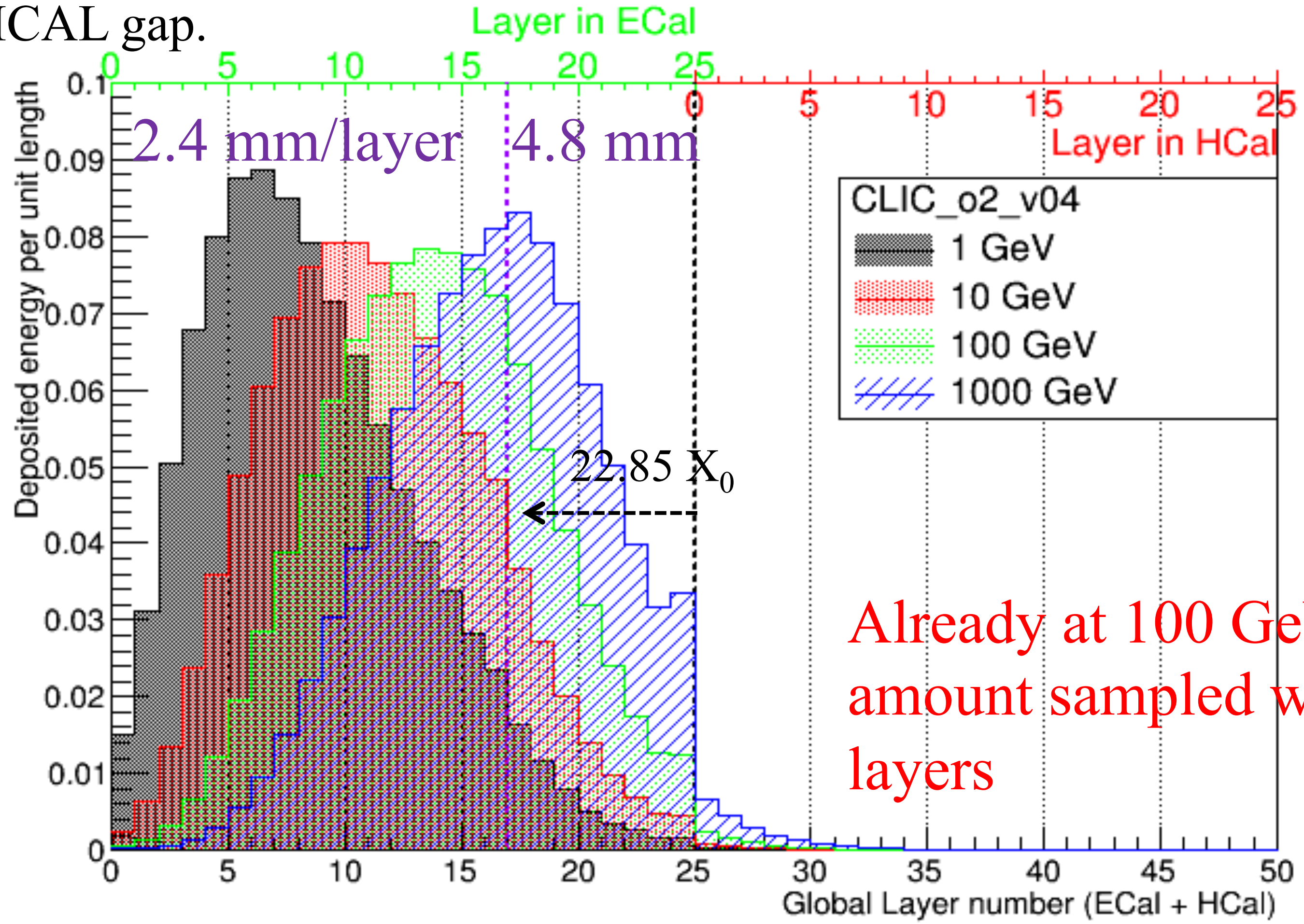
Reminder: possible models

Values calculated from geometry xml file

	# Layers	Absorber Thickness [mm]	Si [mm]	Other (gaps, etc) [mm]	Absorber Thickness [X0]	Si+Other Thickness [mm]	Si+Other Thickness [X0]	Total Thickness [mm]	Total Thickness [X0]	Calorimeter Thickness [mm]	Calorimeter Depth [X0]
CLIC_o2_v04	17	2.4	0.5	1.5	0.65	2	0.06	74.8	12.01	129.2	22.85
	8	4.8	0.5	1.5	1.30	2	0.06	54.4	10.84		
CLICdet_20_10 (original CLIC_ILD)	20	2	0.5	1.5	0.54	2	0.06	80	11.96	140	23.35
	10	4	0.5	1.5	1.08	2	0.06	60	11.39		
CLICdet_30	30	2.65	0.5	1.5	0.72	2	0.06	140	23.22	139.5	23.22
	0	0	0	0	0.00	0	0.00	0	0.00		
CLIC_o3_vo6 CLICdet_40	40	1.9	0.5	**2.65**	0.51	3.15	0.06	20.2	22.85	203	22.85
	0	0	0	0	0.00	0	0.00	0	0.00		

Energy deposited per unit length CLIC_o2_v04 (CLIC_18_7)

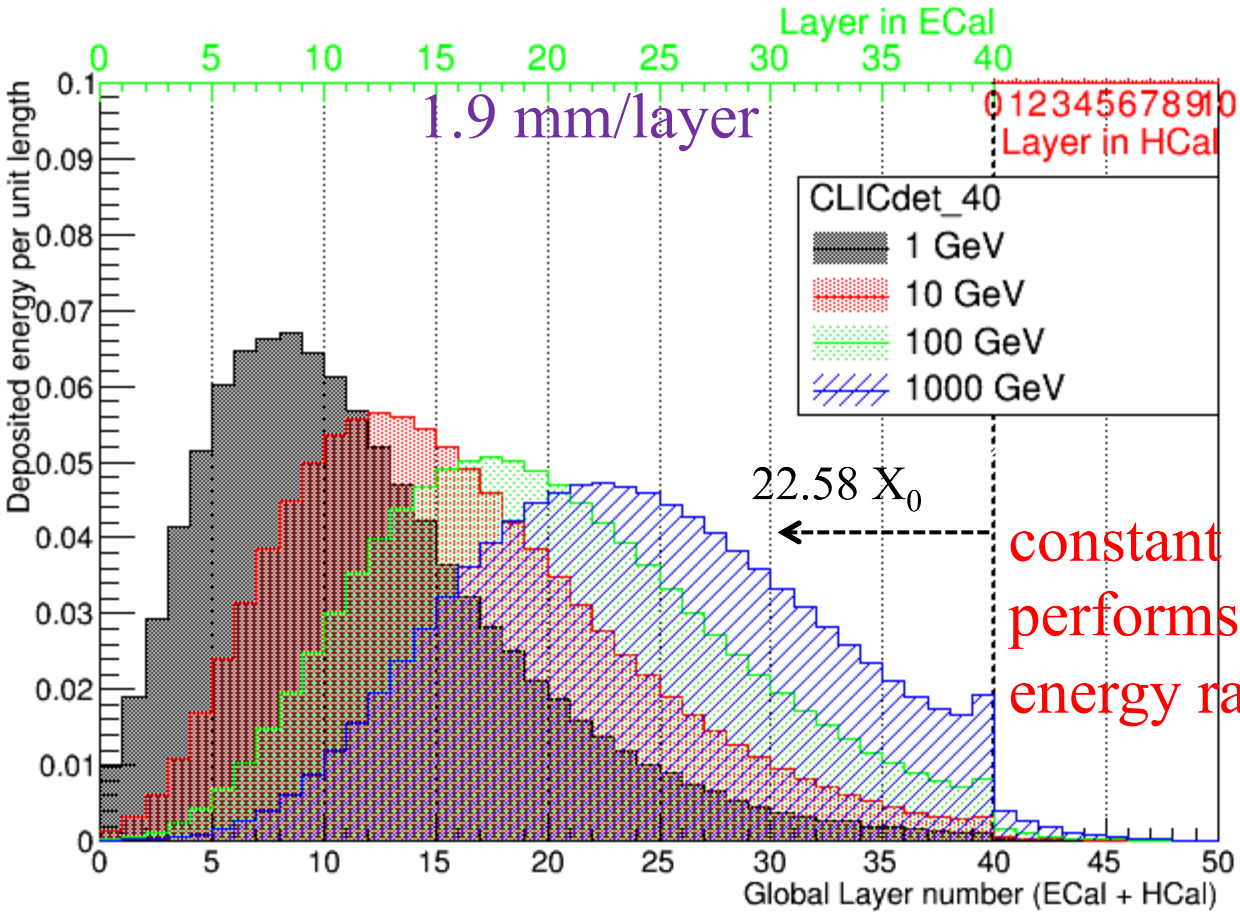
Raw energy deposited in sensitive volume as reported by Geant4, divided by sensitive volume thickness. Normalization to 1 for high energies affected by loss of energy in ECAL-HCAL gap.



Already at 100 GeV sizable amount sampled with the larger layers

Energy deposited per unit length CLIC_40

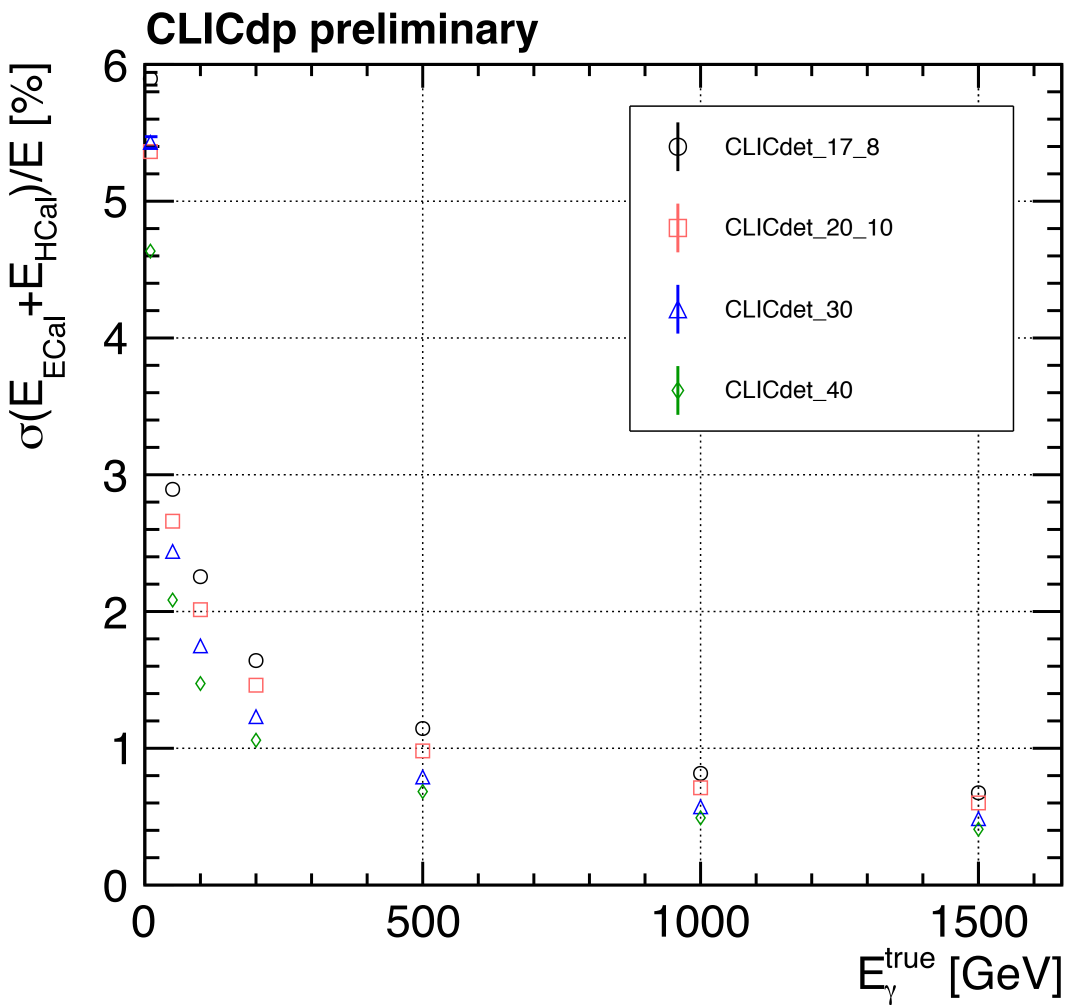
Raw energy deposited in sensitive volume as reported by Geant4, divided by sensitive volume thickness. Normalization to 1 for high energies affected by loss of energy in ECAL-HCAL gap.



constant sampling performs well for vast energy range

Resolution of total energy ECAL+HCAL

Single photons in the very central part of the detector ($\theta \approx 90°$) and $\phi \approx 0°$



- Thicker back layers deteriorate resolution of high energy γ's
- Uniform det30 option better than CDR at high energy, comparable at low energies
- **The uniformly thin option (det40) is best behaving at high energy since it has the thinnest layers at the back**

Model CLIC_o3_v06: calibration

Use particle gun samples for calibration, 45000 evts: 50 GeV K^0_L, 10 GeV μ^-

Photons at 10 GeV produced uniformly distributed in φ and cos ϑ

- verified previously calibration constants for photons largely independent of photon energy
- Simulated with DD4hep 0.18 , use iLCSoft package at

/cvmfs/clicdp.cern.ch/iLCSoft/builds/2016-11-09/x86_64-slc6-gcc48-dbg

- ECAL & HCAL Timing Window 10 ns

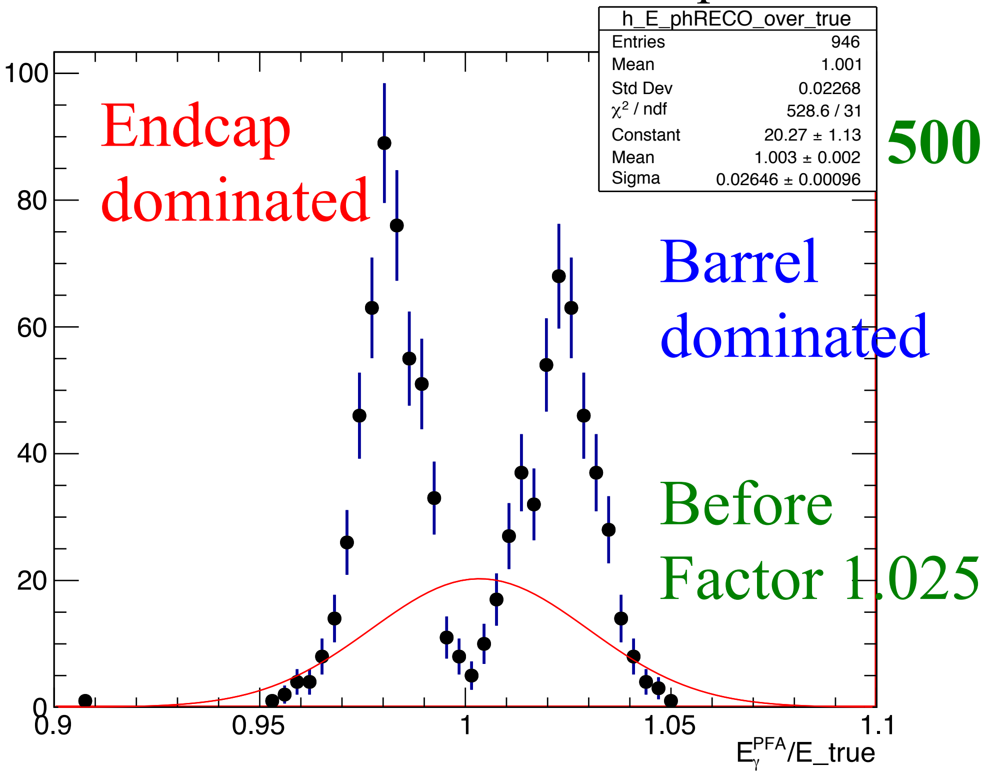
→ Reevaluate photon identification, using hadronically decaying Z's at 500 GeV, produced with pythia 6.4.24

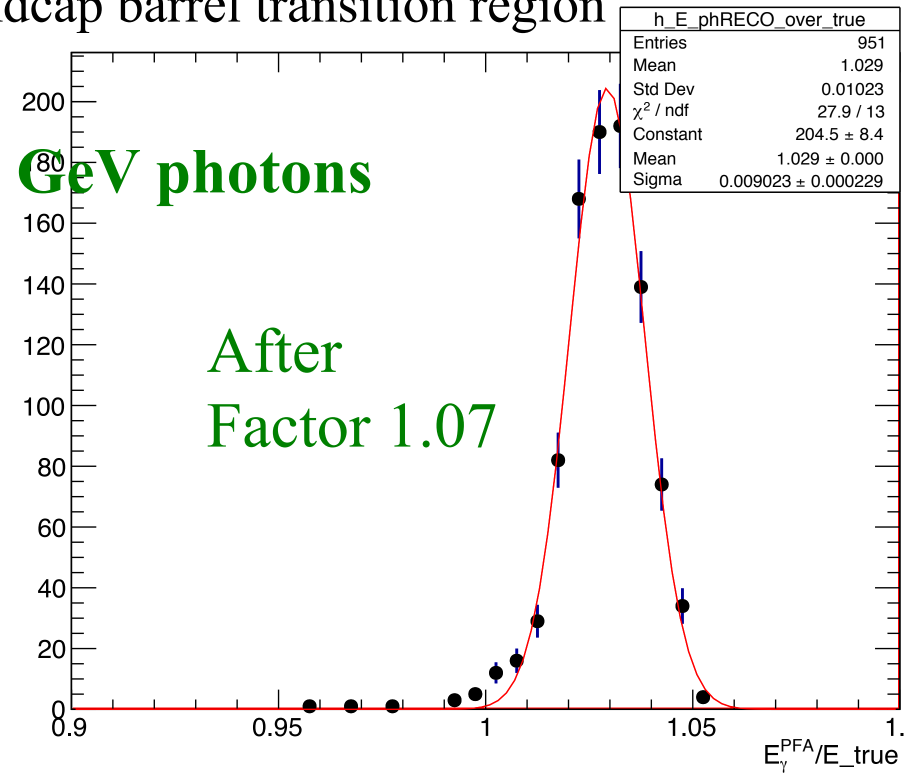
- Reconstructed using DDMarlinPandora 00-03, using PandoraPFA 03-00-00

Effect of new endcap scaling factor

Per default in ILDCaloDigi/DDCaloDigi producer hit calibration constant in the endcap increased by a constant factor of 1.025 →investigate underlying cause for this additional factor and if CLIC model v06 requires a bigger factor

Consider PFA photons in endcap barrel transition region



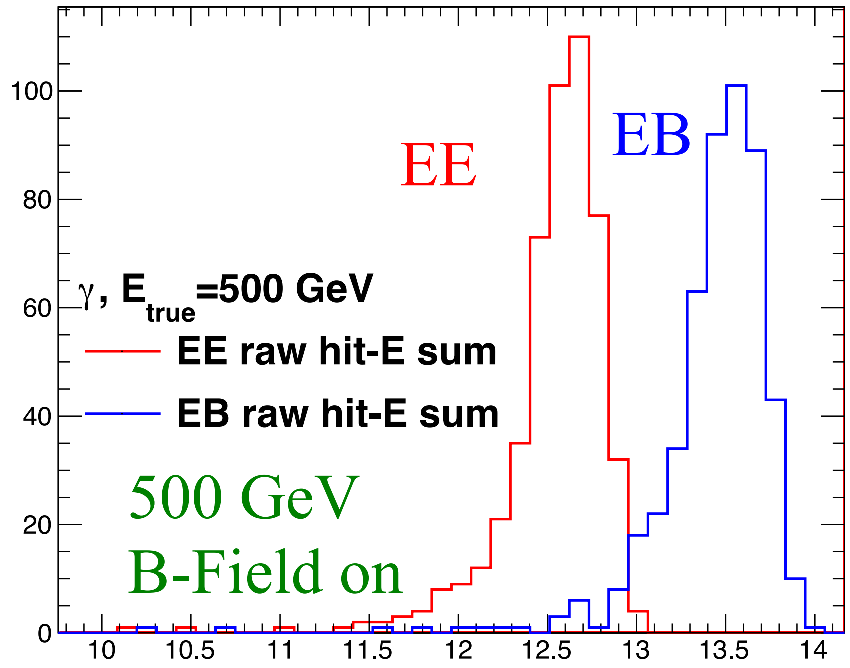


The clear two double peak structure disappears, one peak is observed now

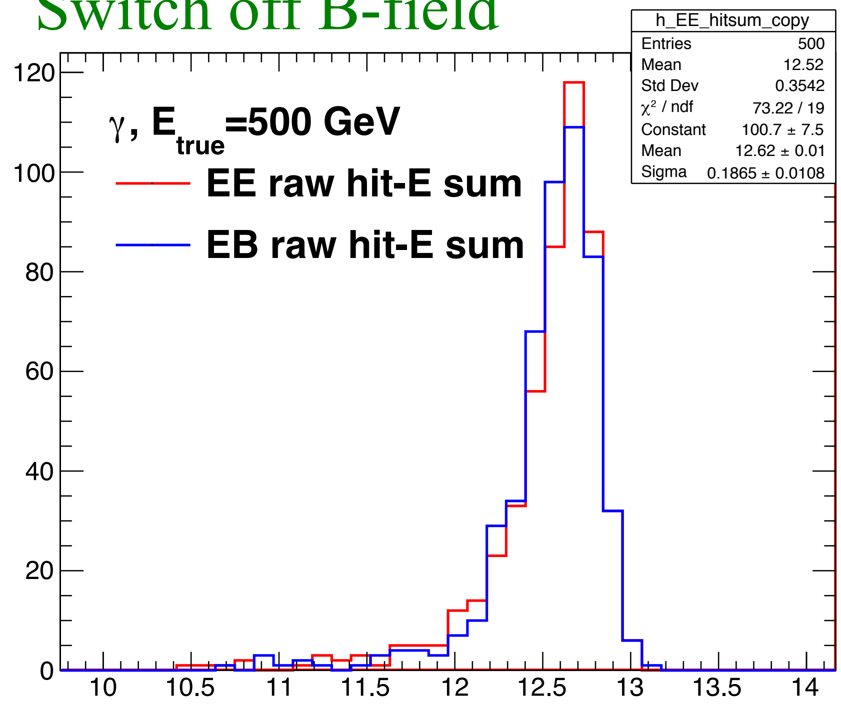
Model CLIC_o3_v06: endcap scaling factor

Underlying cause for this additional factor

- Restrict configuration to similar geometry in endcap and barrel (same incident angle of photons, away from edges in barrel)



Switch off B-field



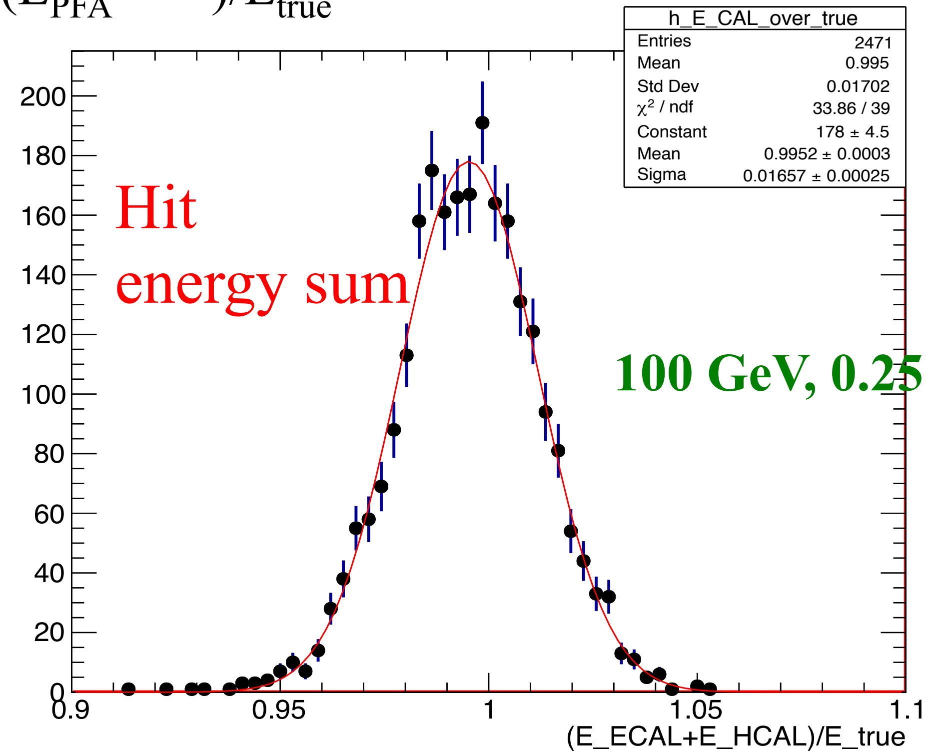
7 % lower raw energy recorded in endcap

Same energy recorded in endcap and barrel (energy shifted to lower values in barrel compared to energy with B-Field)

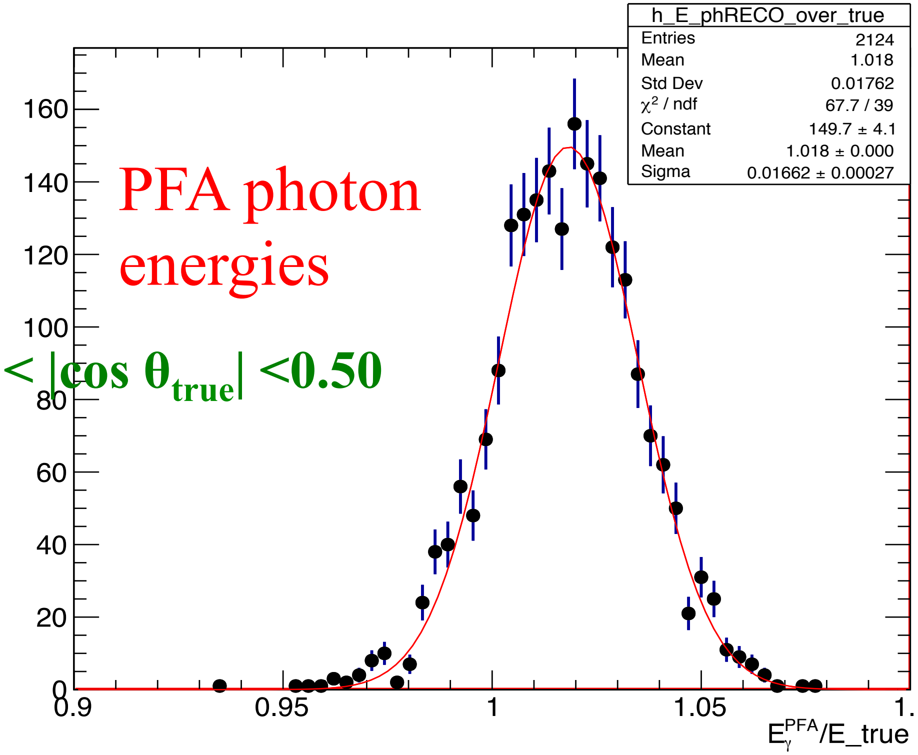
Model: CLIC_o3_v06: energy resolution

Determine relative resolution via distribution of E_{rel} = (E_ECAL+E_HCAL)/E_true

measure of σ(E): gaussian fit, compare well with resolution of PFA-photon energies $\sigma(E_{PFA}^{photon})/E_{true}^{photon}$



100 GeV, 0.25 < $|\cos \theta_{true}|$ <0.50

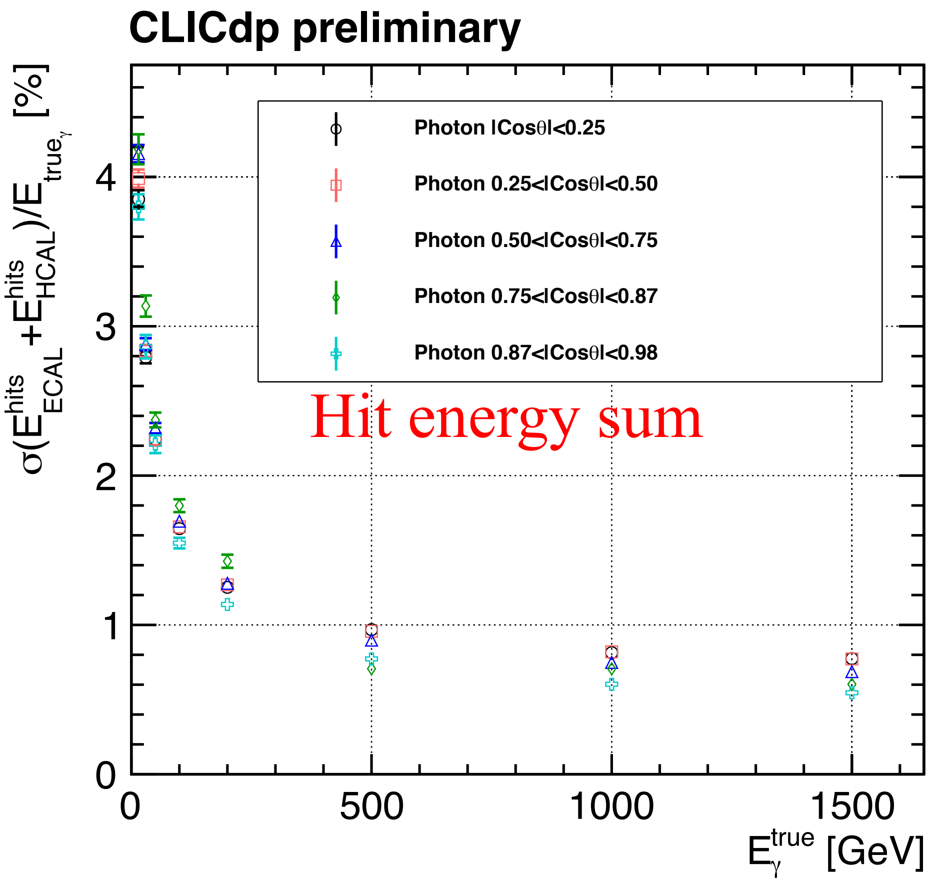


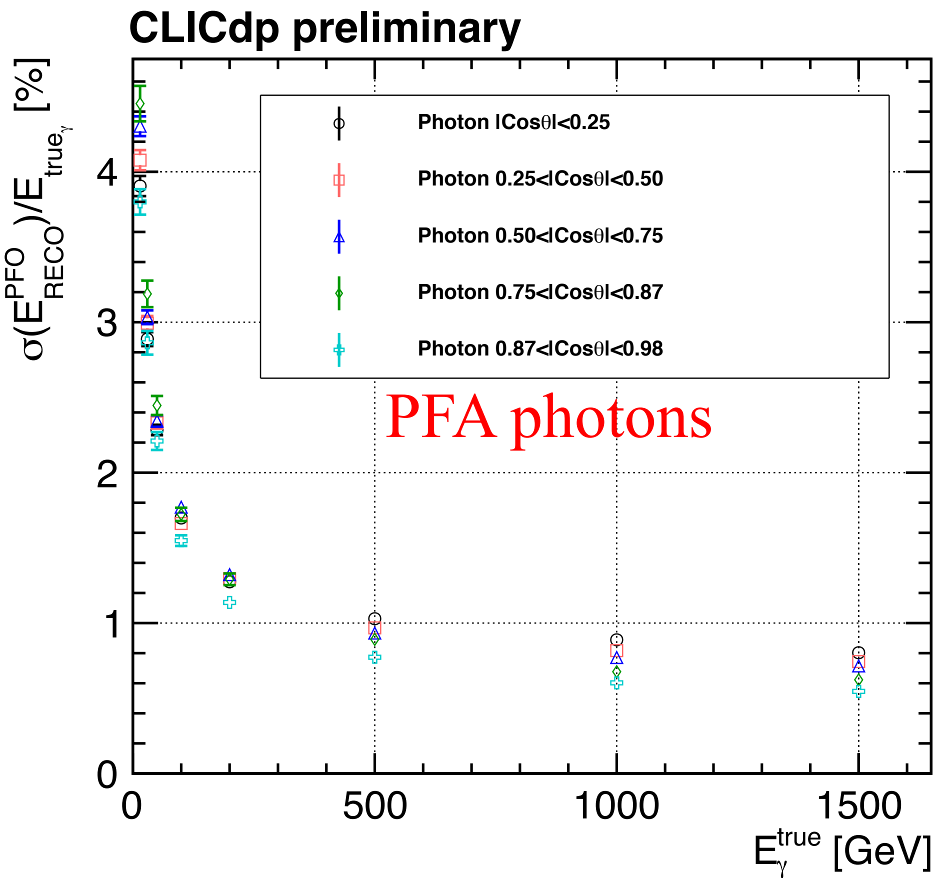
Very similar resolution width for hits and PFA photons, mean shifted to higher values for PFA photons

Model: CLIC_o3_v06: energy resolution

Determine relative resolution via distribution of E_{rel} = (E_ECAL+E_HCAL)/E_true

measure of σ(E): RMS and gaussian fit, compare well with resolution of PFA-photon energies $\sigma(E_{PFA}^{photon})/E_{true}^{photon}$

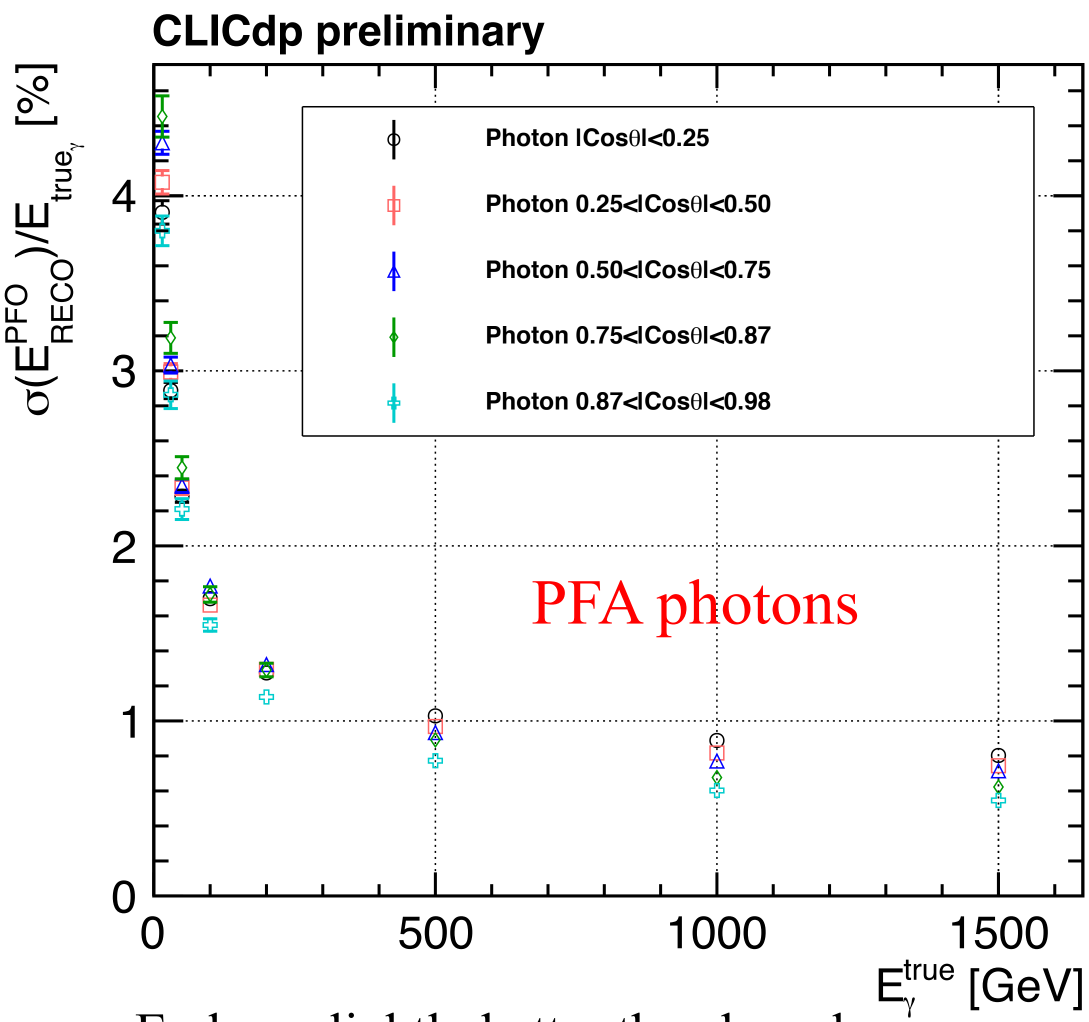




CLIC_o3_v06: energy resolution (PFA photons)

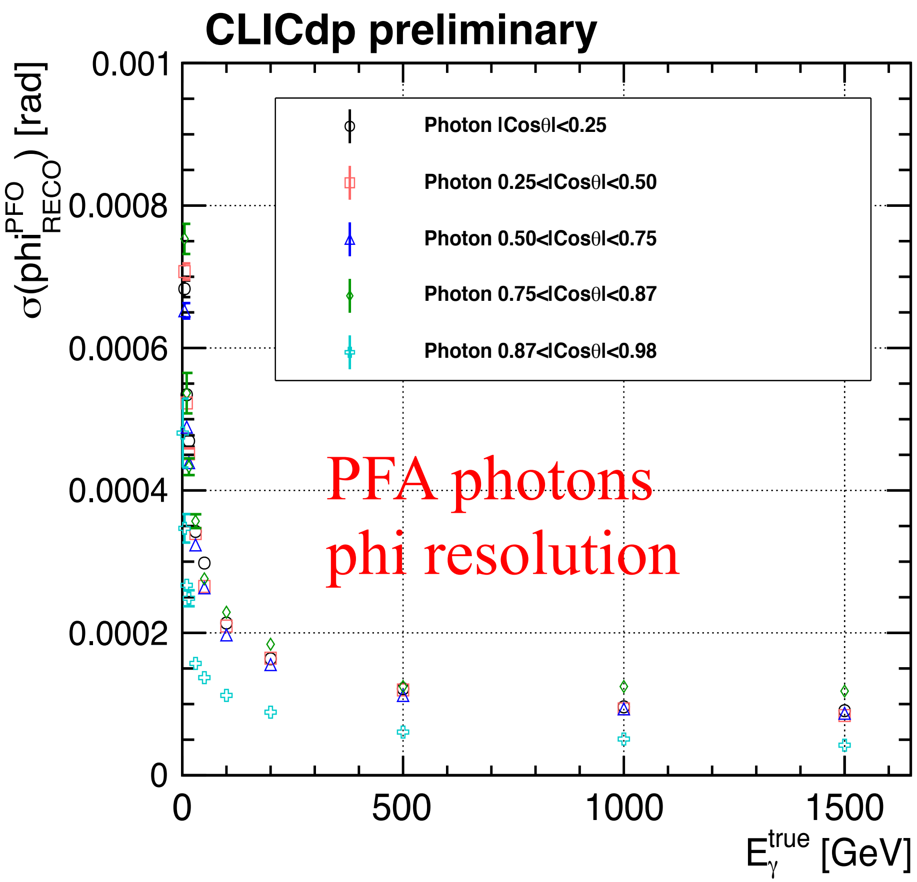
Require exactly one reconstructed photon to avoid any possible bias from PFA reconstruction effects (splitting more prominent at higher energies)

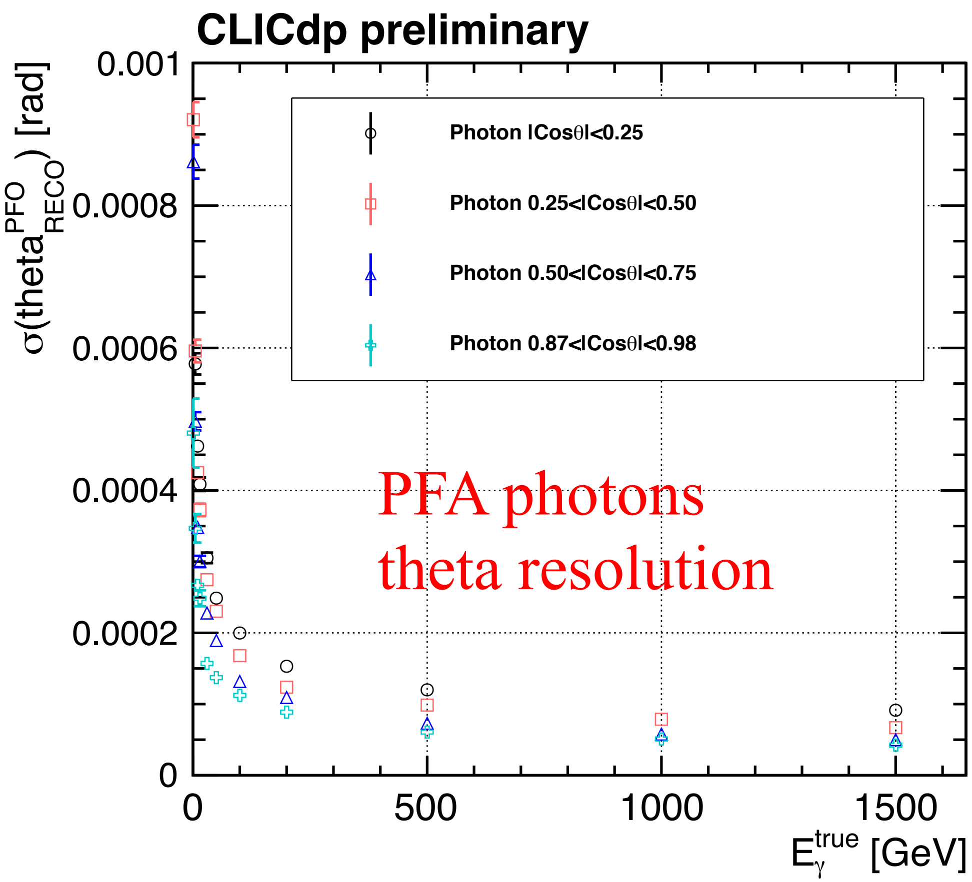
At very high energies non negligible effect of HCAL energy contribution (affects inner most barrel region more than medium and outer barrel)



Endcap slightly better than barrel

CLIC_o3_v06: angular resolution (PFA photons)





Typically below millirad over whole range
1 GeV -1500 GeV photons

Summary

Uniform 40 layer ECAL (model CLIC_o3_v06) shows best performance in photon energy resolution

Impact of magnetic field on energy response reevaluated → endcap calibration correction factor increased from 1.025 to 1.07

Energy and Phi and Theta resolution studied as function of photon energies and cos θ

Next steps:

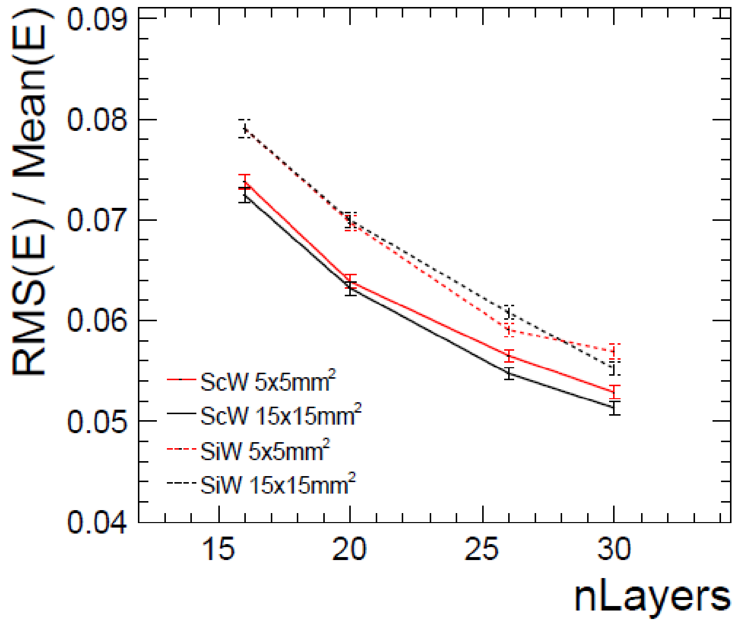
Impact on Jet energy resolution

BACKUP

Settings for previous ECAL optimisation studies

The figures displayed in slide 3 have been produced with the following settings

HCal Timing Cuts : 100 ns
ECal Timing Cuts : 100 ns
HCal Hadronic Cell Truncation: 1 GeV (Optimal for Default HCal)
Software : ilcsoft_v01-17-07, including PandoraPFA v02-00-00
Digitiser : ILDCaloDigi, realistic ECal and HCal digitisation options enabled
Calibration : PandoraAnalysis toolkit v01-00-00



Photons E = 10 GeV

New ECAL model CLIC_o3_v06

Uniform segmentation of ECAL

- 40 layers, absorber 1.9 mm, active material 0.50 mm

Model CLIC_o2_v05: other 1.5 mm: total thickness 15.6 cm

```
c<dimensions numsides="ECalBarrel_symmetry" rmin="ECalBarrel_inner_radius" z="ECalBarrel_half_length*2" />
 <staves vis="ECalStaveVis" />
 <layer repeat="40" vis="ECalLayerVis">
     <slice material = "TungstenDens24" thickness = "1.90*mm" vis="ECalAbsorberVis" radiator="yes"/>
     <slice material = "Air"            thickness = "0.25*mm" vis="InvisibleNoDaughters"/><!-- fiber -->
     <slice material = "GroundOrHVMix"  thickness = "0.10*mm" vis="ECalAbsorberVis"/>
     <slice material = "Silicon"        thickness = "0.50*mm" sensitive="yes" limits="cal_limits" vis="ECalSensitiveVis"/>
     <slice material = "Air"            thickness = "0.10*mm" vis="InvisibleNoDaughters"/><!-- glue -->
     <slice material = "siPCBMix"       thickness = "0.80*mm" vis="ECalAbsorberVis"/>
     <slice material = "Air"            thickness = "0.25*mm" vis="InvisibleNoDaughters"/>
 </layer>
```

Model CLIC_o3_v06: other 2.65 mm: total thickness 20.2 cm

```
<dimensions numsides="ECalBarrel_symmetry" rmin="ECalBarrel_inner_radius" z="ECalBarrel_half_length*2" />
<staves vis="ECalStaveVis" />
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    <slice material = "TungstenDens24" thickness = "1.90*mm" vis="ECalAbsorberVis" radiator="yes"/>
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    <slice material = "GroundOrHVMix"  thickness = "0.10*mm" vis="ECalAbsorberVis"/>
    <slice material = "Silicon"        thickness = "0.50*mm" sensitive="yes" limits="cal_limits" vis="ECalSensitiveVis"/>
    <slice material = "Air"            thickness = "0.10*mm" vis="InvisibleNoDaughters"/>
    <slice material = "siPCBMix"       thickness = "1.30*mm" vis="ECalAbsorberVis"/>
    <slice material = "Air"            thickness = "0.25*mm" vis="InvisibleNoDaughters"/>
    <slice material = "G10"            thickness = "0.75*mm" vis="InvisibleNoDaughters"/>
</layer>
```
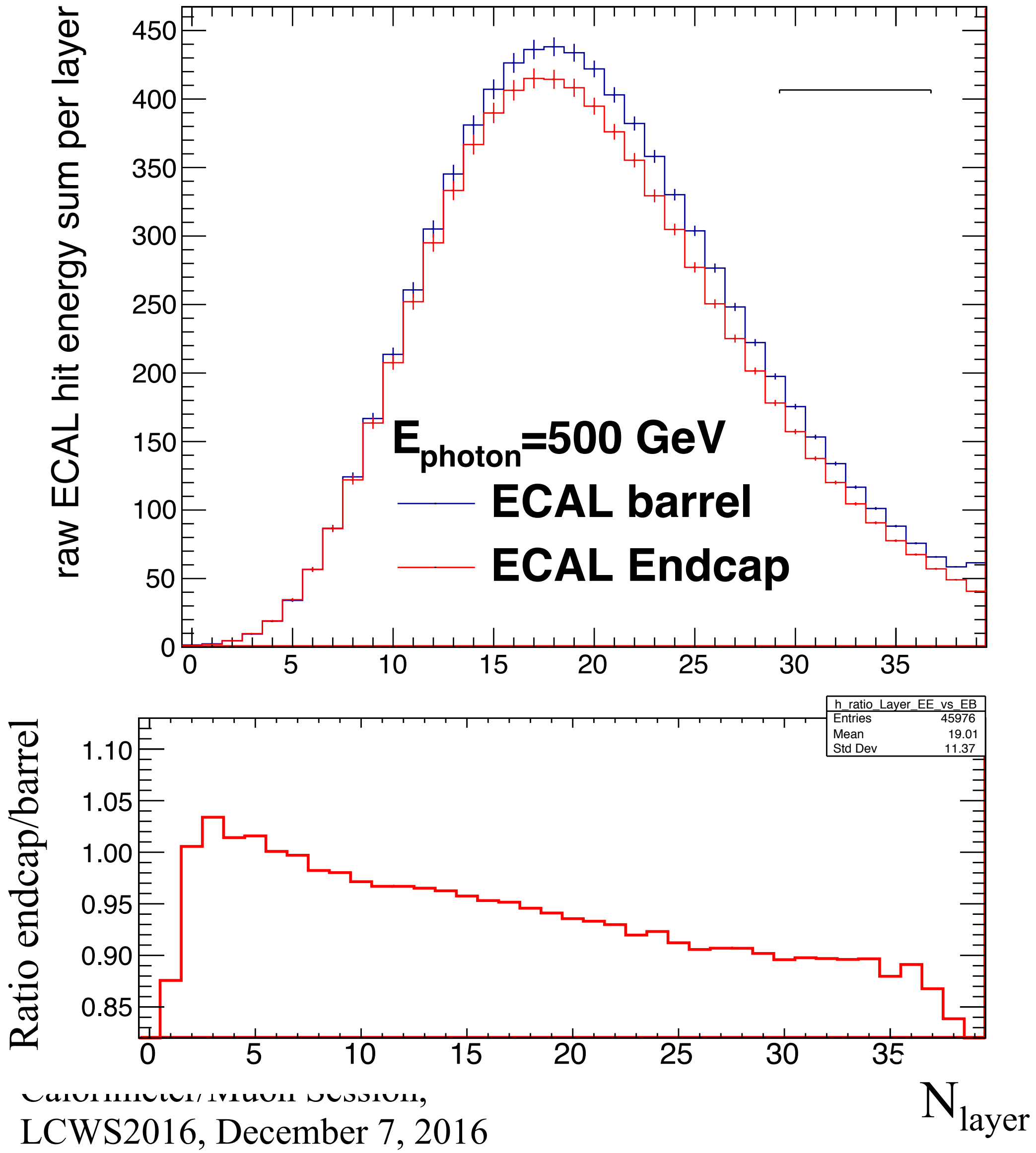

Model CLIC_o3_v06: calibration modification

Check similar angular configuration to exclude possible geometric effects



In endcap:
0.175-0.55 radians away from beam line
In barrel region:
0.175-0.55 radians away from pi/2
Use same number of events in endcap and barrel

Sum of raw hit energy per layer lower for almost every layer