Update on ECAL photon optimisation

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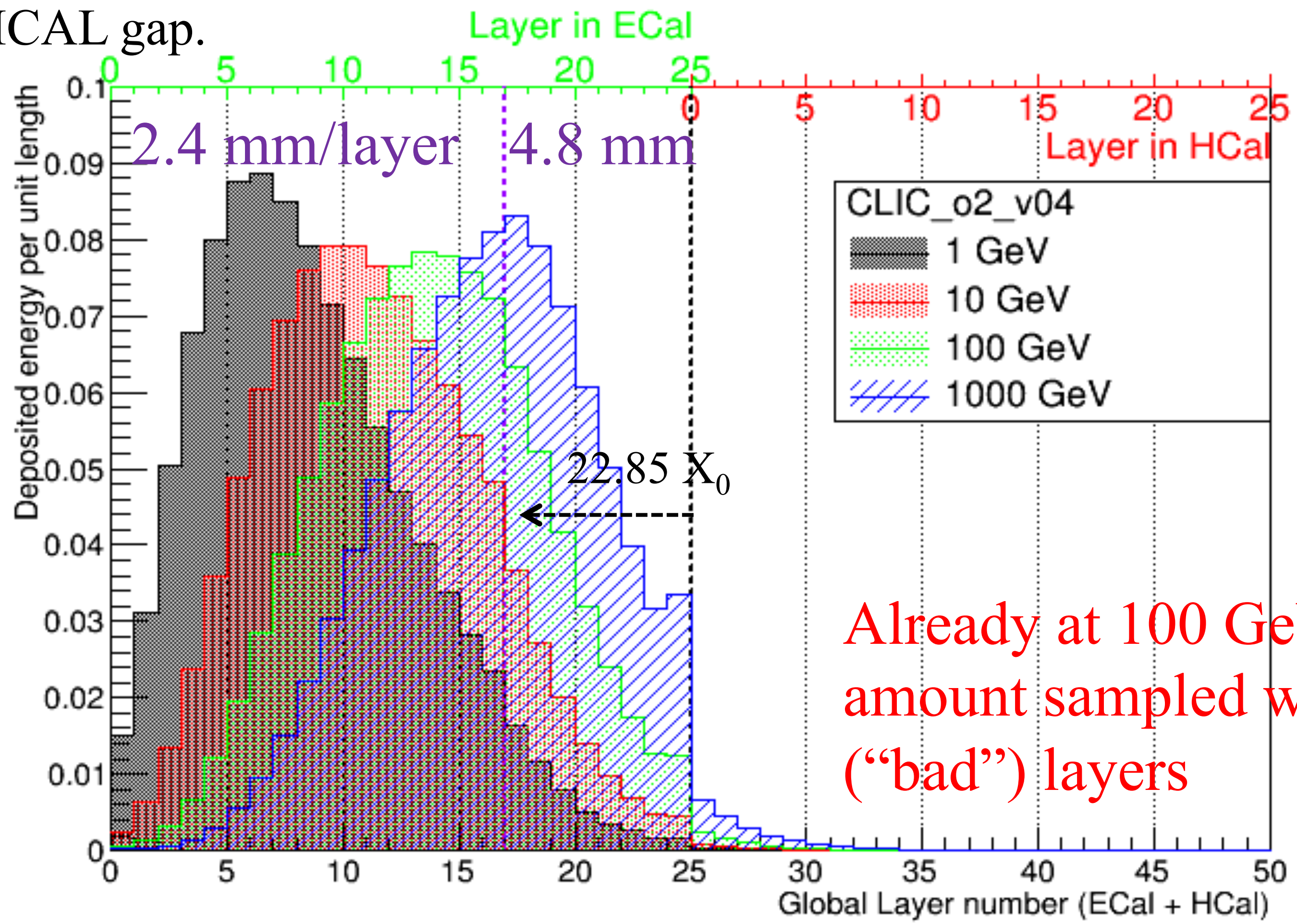
Reminder: Possible Models

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 (current)	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_10 (possible high granularity option)	30	1.5	0.5	1.5	0.41	2	0.06	105	13.89	155	22.58
	10	3	0.5	1.5	0.81	2	0.06	50	8.68		
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		
CLICdet_40 (possible high granularity option)	40	1.9	0.5	1.5	0.51	2	0.06	156	22.85	156	22.85
	0	0	0	0	0.00	0	0.00	0	0.00		
CLICdet_40 x195	40	1.95	0.5	1.5	0.53	2	0.06	158	23.39	158	23.39
	0	0	0	0	0.00	0	0.00	0	0.000		

Energy deposited per unit length CLIC_o2_v04 (CLIC_18_7)

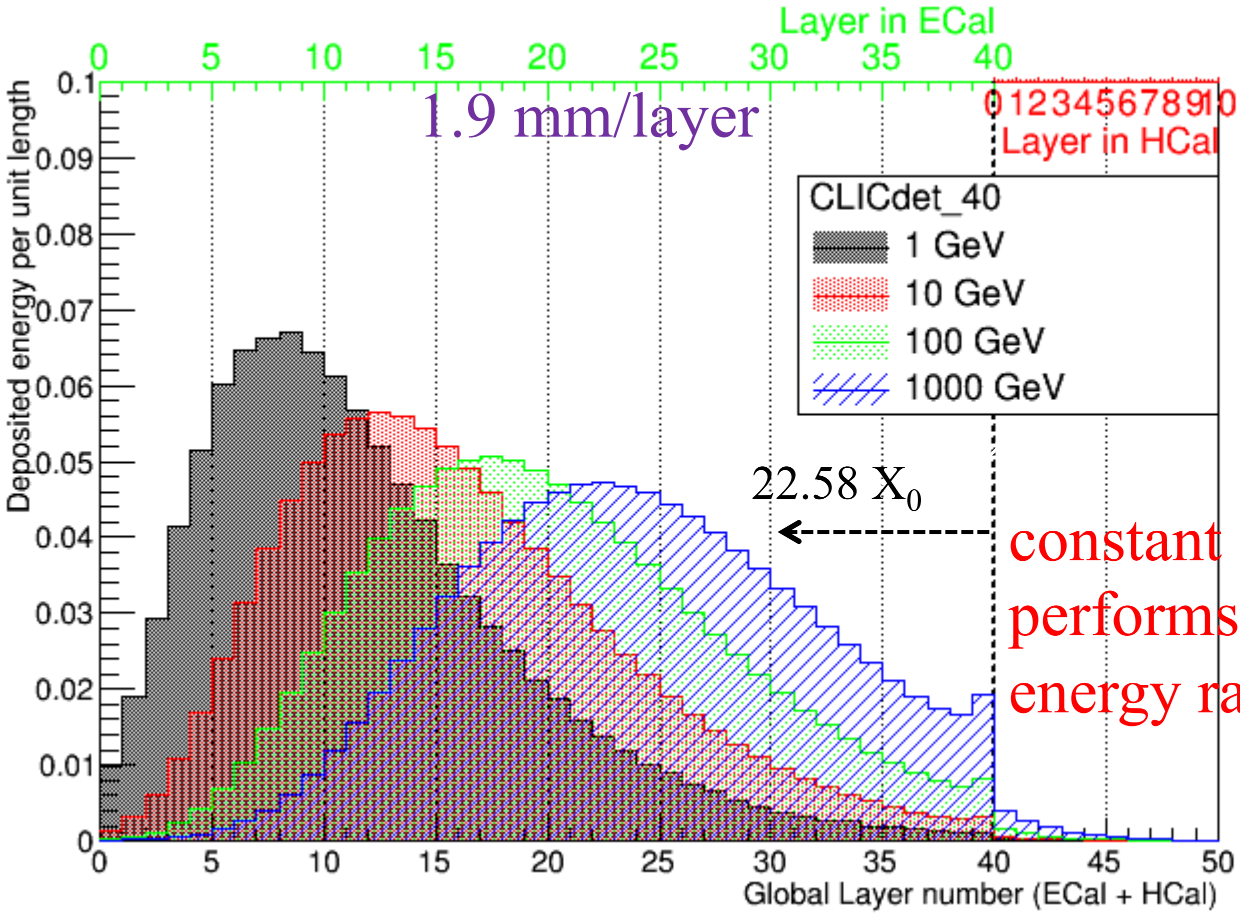
Raw energy deposited in sensitive volume as reported by Geant4, divided by sensitive volume thickness. Normalization to 1 for high energies affected by loss of energy in ECAL-HCAL gap.



Already at 100 GeV sizable amount sampled with the larger ("bad") layers

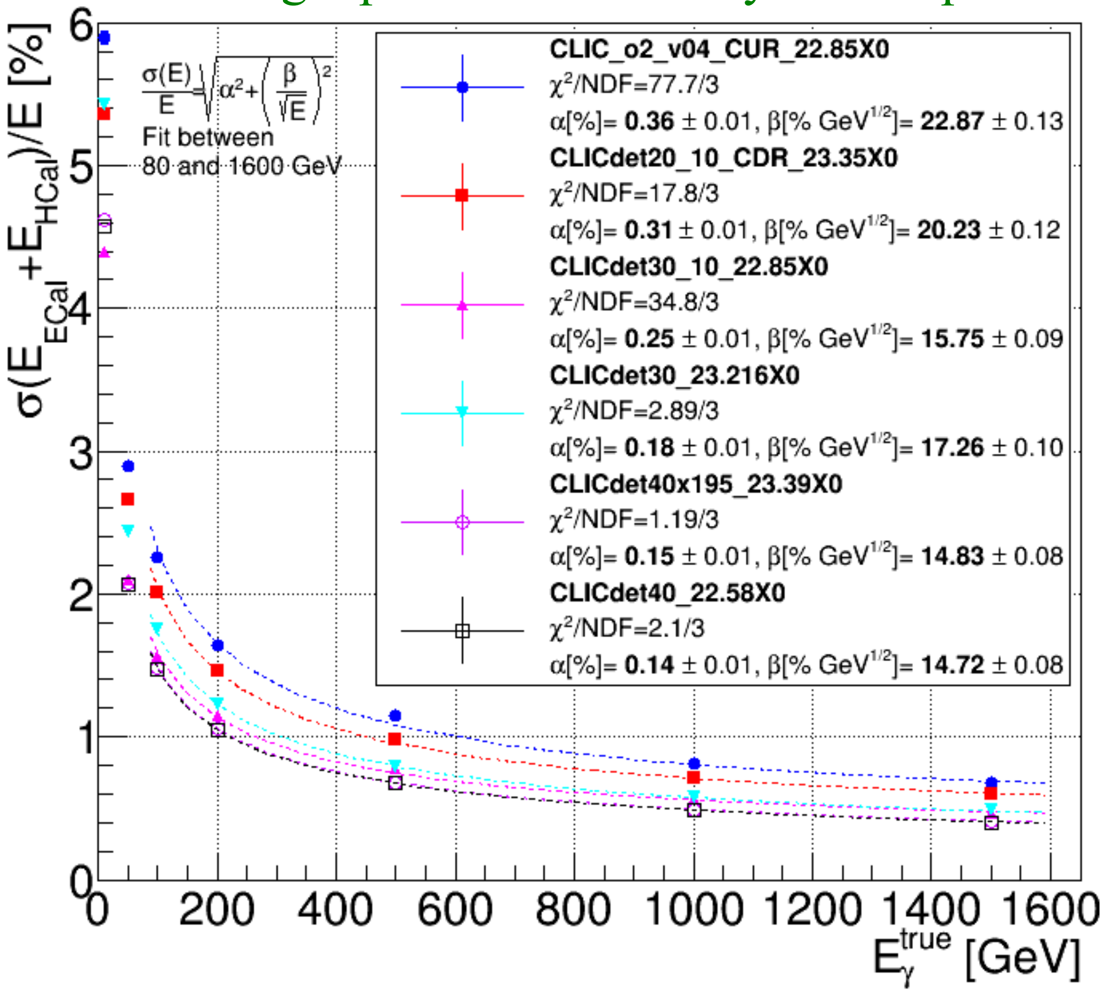
Energy deposited per unit length CLIC_40

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.



Resolution of total ECAL and HCAL Energy

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



- Fits agree more or less, but constant term <1%, fit agrees with the trend of the points.
- 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 (1.9 mm and 1.95 mm comparable)**

New Model CLIC_o3_v5

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>
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Model CLIC_o3_v05: 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 = "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"/>
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</layer>
```

Model CLIC_o3_v05: most central point

Compare old and new model: use point phi=0, theta=90 degrees

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

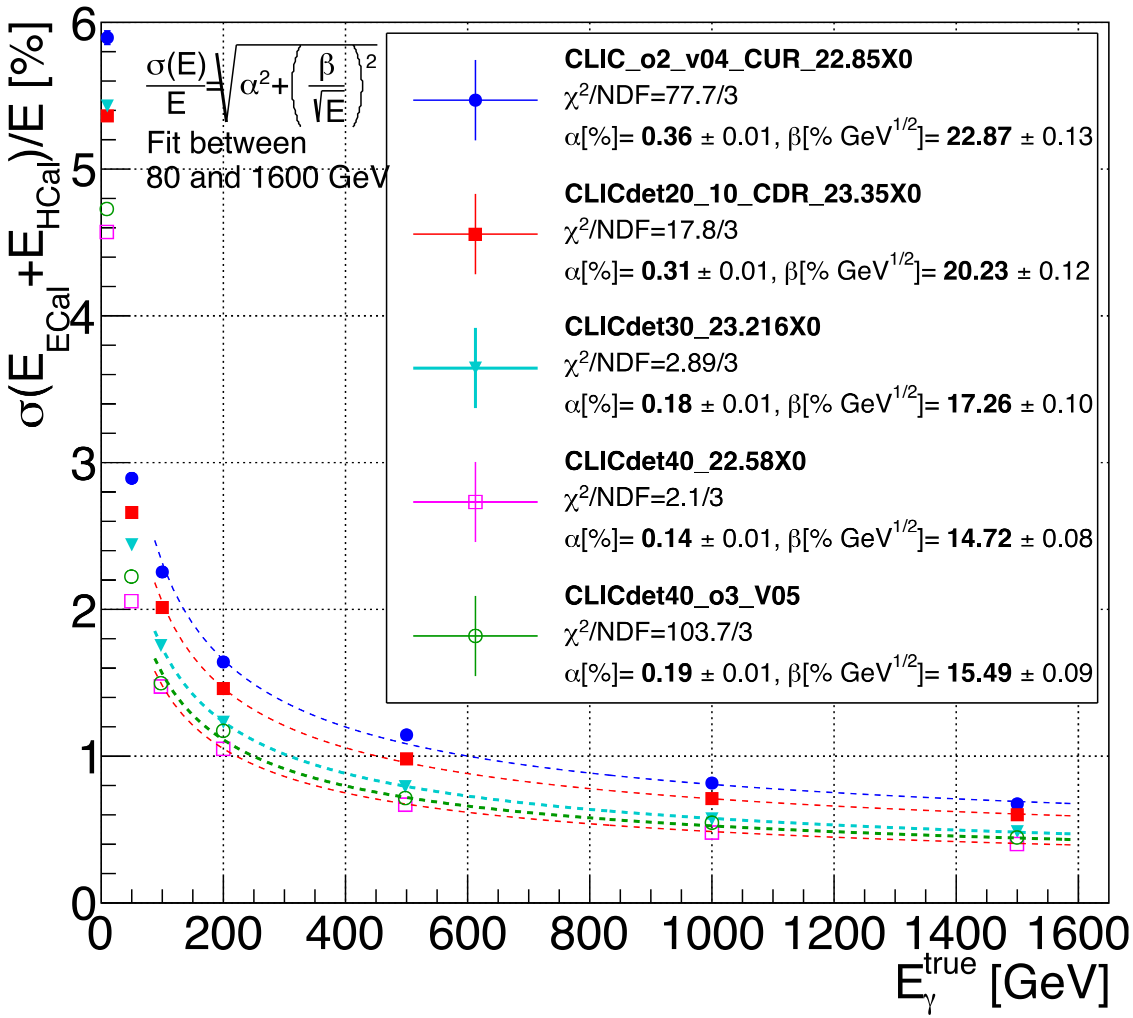
measure of $\sigma(E_{rel})$: RMS and gausian fit (in %)

Old model determined through iterative gaussian fits around mean within 3 sigmas

E (GeV)	10	50	100	200	500	1000	1500
$\sigma(E_{rel})$	4.72±.03	2.11±.02	1.49±.01	1.077±.008	.707±.007	.537±.005	.438±.003
$RMS(E_{rel})$	4.82±.03	2.13±.02	1.52±.01	1.170±.008	.713±.005	.544±.004	.473±.003
o2_v05	4.58±.03	2.07±.02	1.48±.01	1.05±.008	.673±.005	.491±.004	.403±.003
30 layers	5.43±.04	2.44±.02	1.75±.01	1.23±0.009	.790±.006	.572±.004	.485±.004

Resolution of total ECAL and HCAL Energy

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



Additional material leads to a slightly higher resolution than with the original 40 layer assumption, still performs better than 30 layer options (both with constant and non constant sampling) over whole range

Model CLIC_o3_v5: Calibration

Use particle gun samples for calibration, 10000 evts: 50 GeV K^0_L, 10 GeV μ

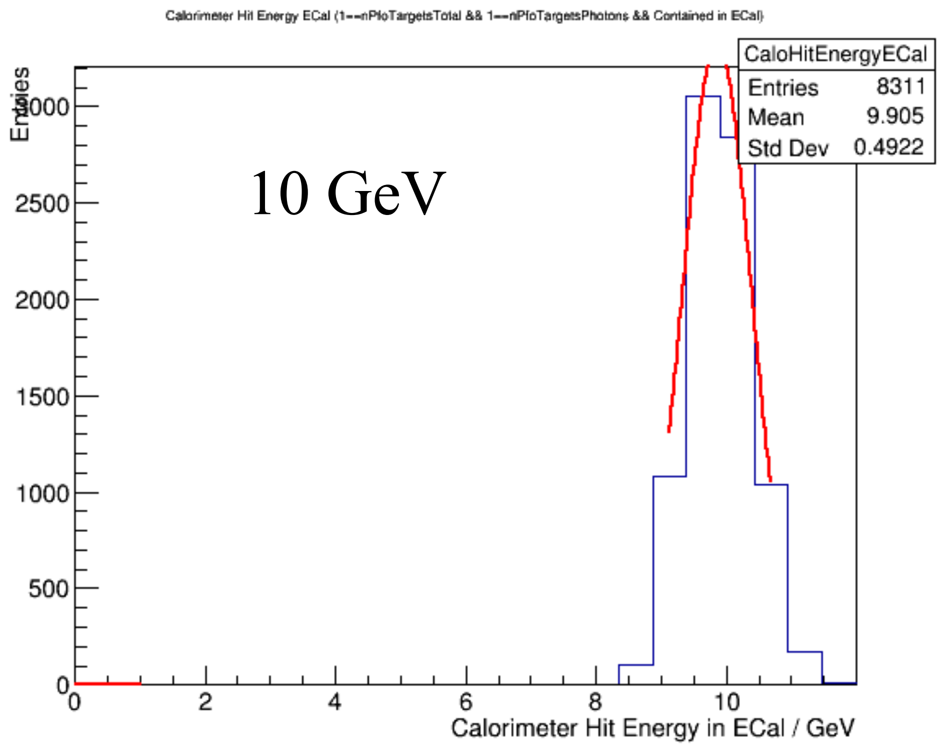
Photons at 10, 50, 100, 200 GeV, test very high E: 500, 1000, 1500 GeV

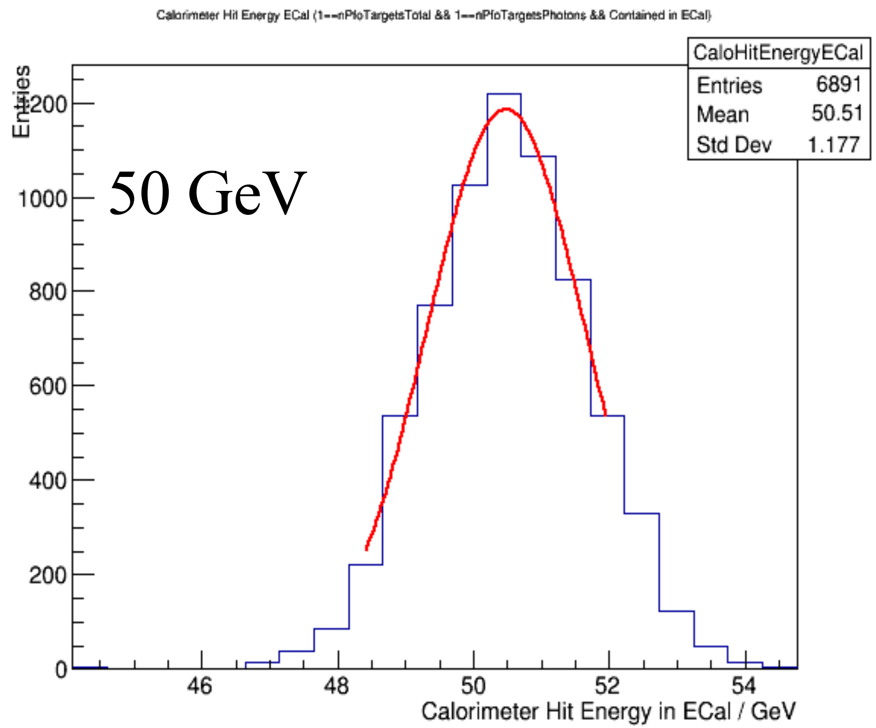
- Produced with uniform distribution in phi and theta
- Two campaigns, one restricted to barrel $|\cos\theta| < 0.7$, second no restriction in θ
- Simulated with DD4hep, use iLCSoft package at

/cvmfs/clicdp.cern.ch/iLCSoft/builds/2016-07-04/x86_64-slc6-gcc48-dbg

Slight modification of ECAL Digitization extraction code

Model CLIC_o3_v5: Calibration Results





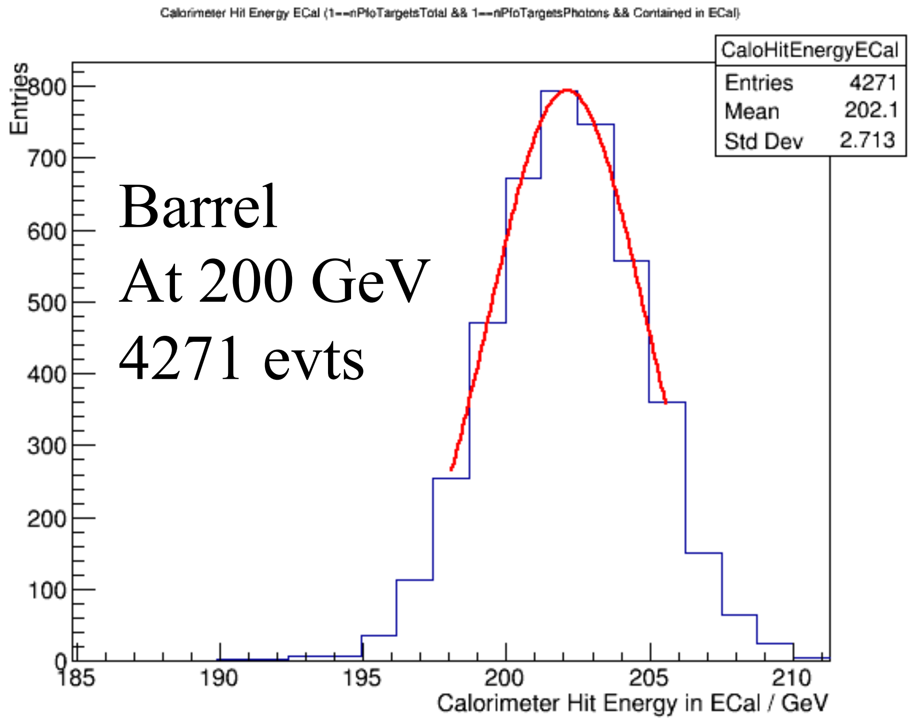
CALIBRECAL="35.776"

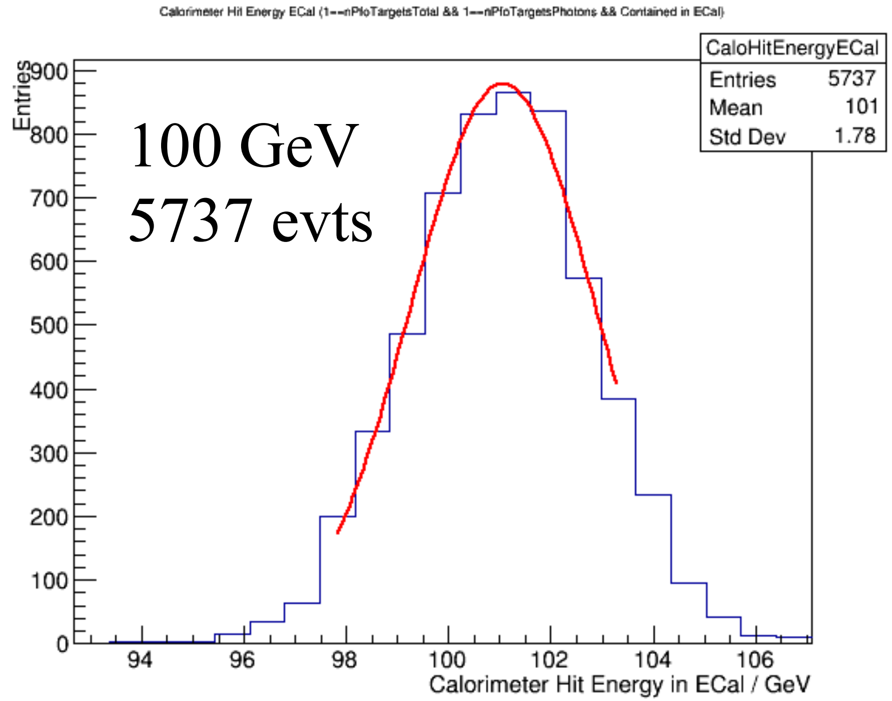
CALIBRECAL="35.652"

Calibration pretty stable at different energies

Model CLIC_o3_v5: Calibration Barrel

ECAL digitization uses photons contained in ECAL (99% of total deposited Energy)





CALIBRECAL="35.619”

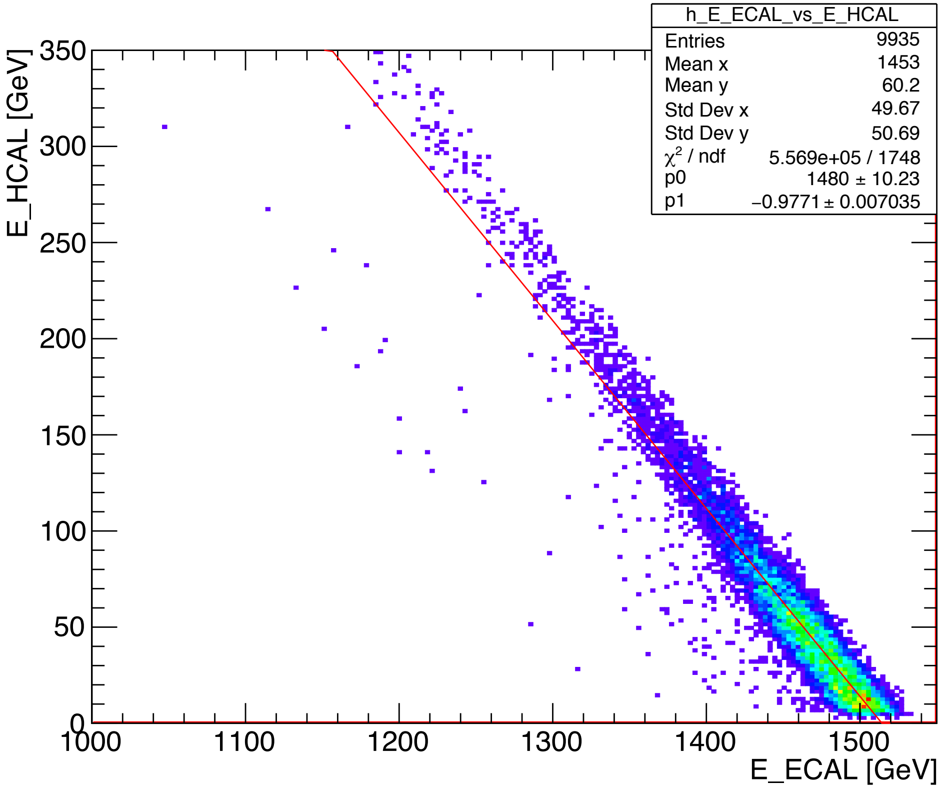
CALIBRECAL="35.617”

As expected requirement of 99 % is more stringent for higher energy samples

Model CLIC_o3_v5: Calibration at high Energy

Expect slight modification of EM scale in HCAL based on previous study (based on one point in phi=0):

Fit a line in 2D plot of ECAL vs HCAL Energy:



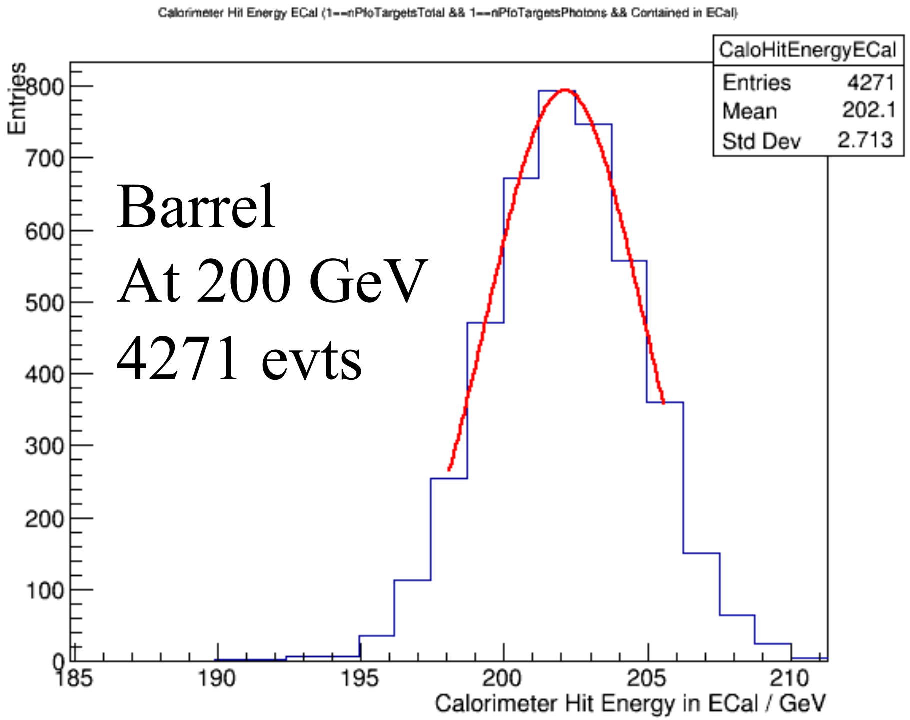
Moderate modification:

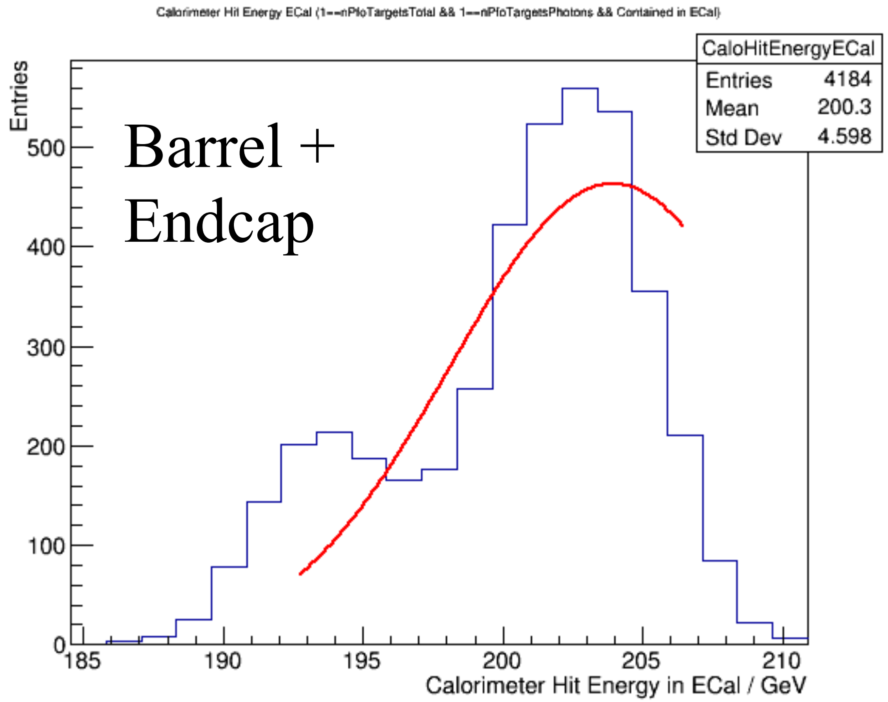
ECAL: 0.99

HCAL: 0.95

Model CLIC_o3_v5: Calibration: whole detector

ECAL digitization uses photons contained in ECAL (99% of total deposited Energy)

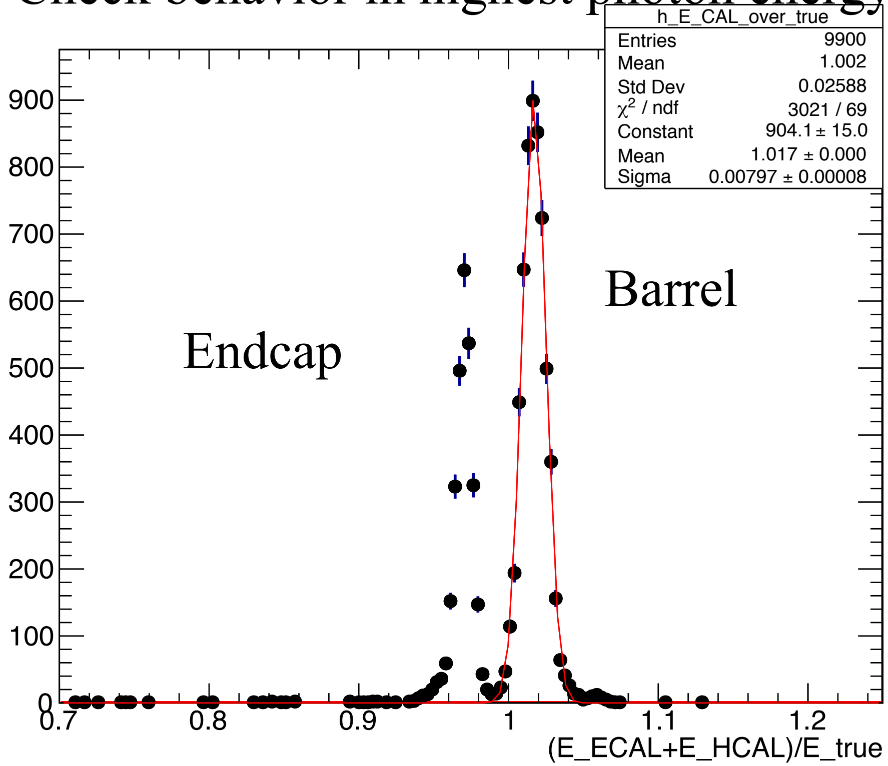


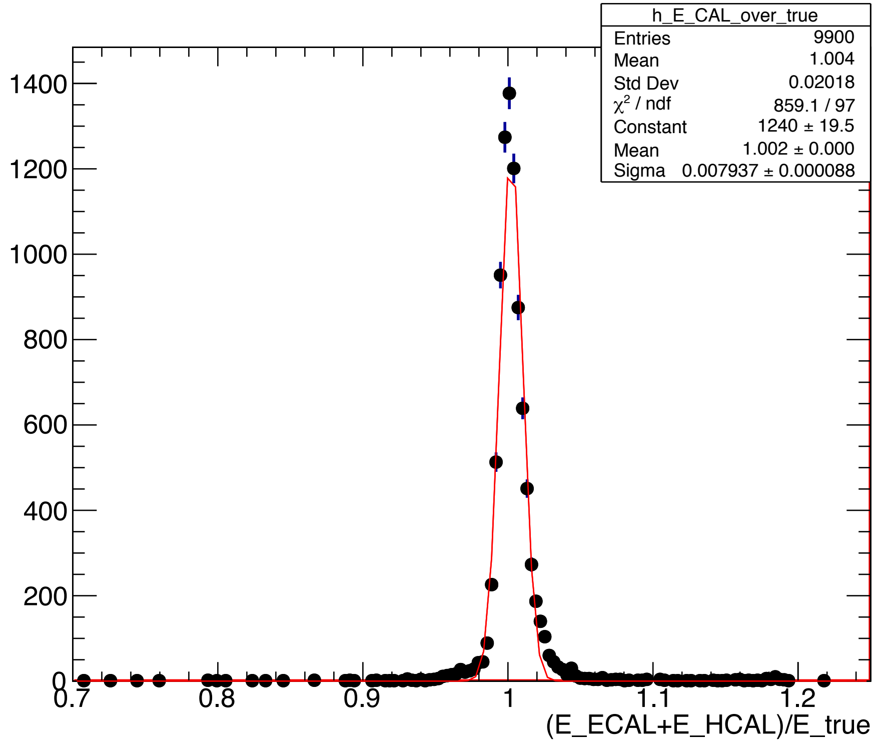


Use values from samples up to 200 GeV, for Barrel and EndCap mix two peaks start to appear, due to different behavior of energy contribution from HCAL

Model CLIC_o3_v5: Calibration: whole detector

Check behavior in highest photon energy bin: E = 1500 GeV





Default calibration constants: clear two peak, higher peak barrel, lower peak endcap

Different HadToEM scale needed for HCAL energy contribution in barrel and endcap: recovers scale behavior

Model CLIC_o3_v5: Barrel Resolution

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

measure of $\sigma(E_{rel})$: RMS and gausian fit

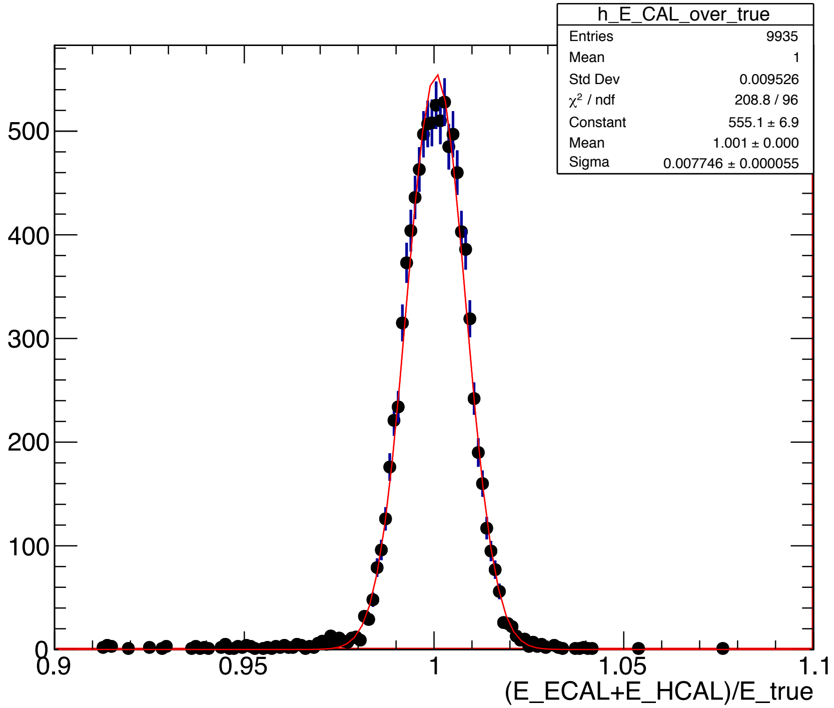
Energy (GeV)	1	5	10	15	30	50
$\sigma(E_{rel})$	15.14±.12	6.942±.051	4.873±.035	3.959±.019	2.829±.020	2.281±.016
$RMS(E_{rel})$	22.94±.16	7.175±.051	4.953±.035	4.000±.030	2.914±.023	2.355±.017
Mean (E_{rel})	0.957	0.996	0.998	0.999	0.999	0.997

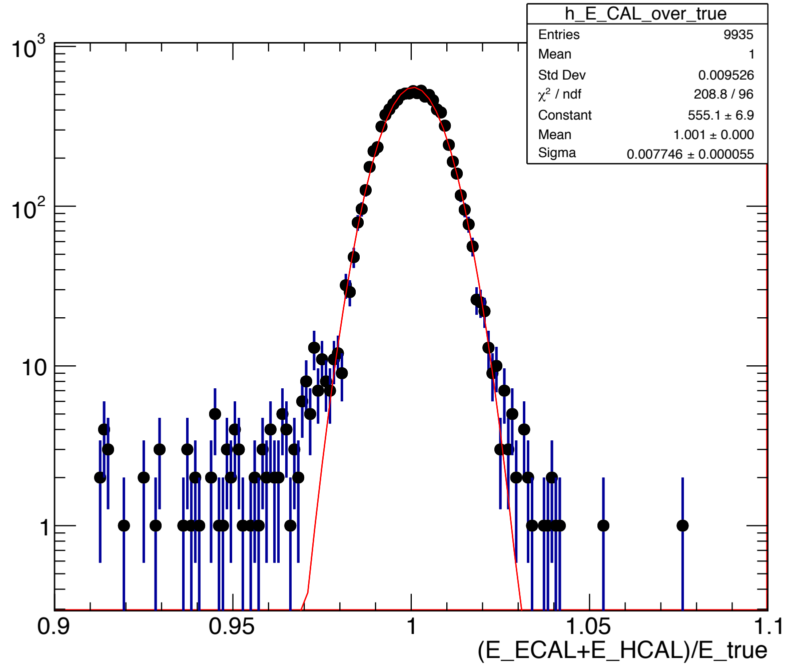
Energy (GeV)	100	200	500	1000	1500
$\sigma(E_{rel})$	1.69±.012	1.27±.009	0.955±.007	0.810±.007	0.775±.006
$RMS(E_{rel})$	1.773±.012	1.366±.010	1.133±.008	1.065±.007	0.953±.007
Mean (E_{rel})	0.997	0.997	0.998	0.999	1.001

Model CLIC_o3_v5: Barrel Resolution

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

measure of σ(E): RMS and gausian fit



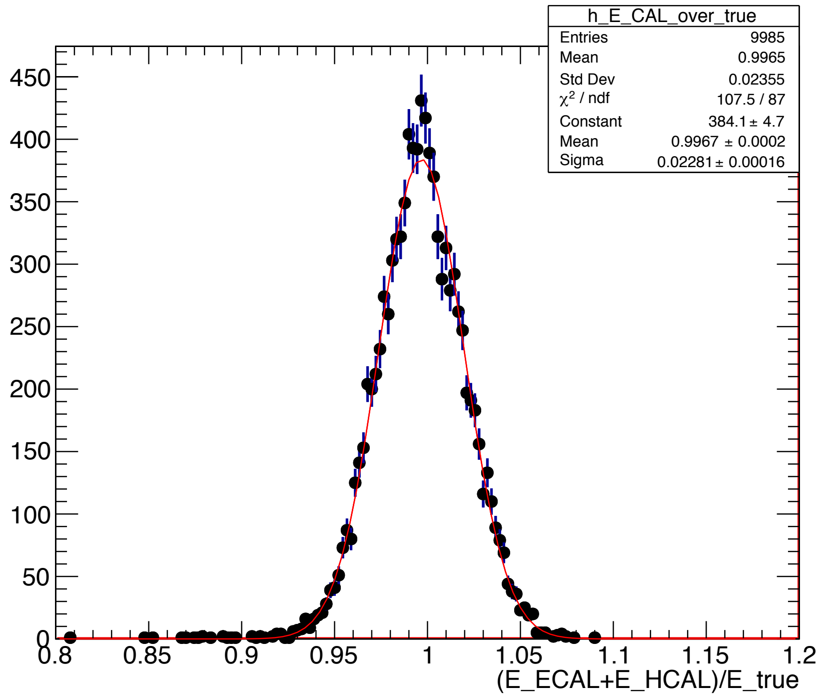


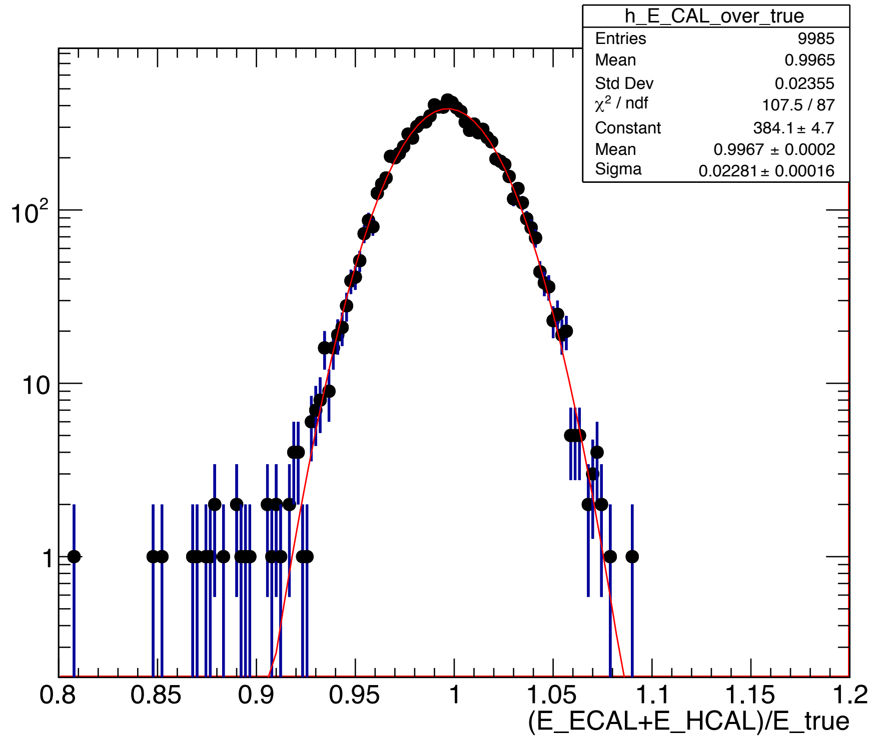
1500 GeV: not large non gaussian tails

Model CLIC_o3_v5: Barrel Resolution

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

measure of σ(E): RMS and gausian fit, now moderate energy 50 GeV, non gaussian tails smaller

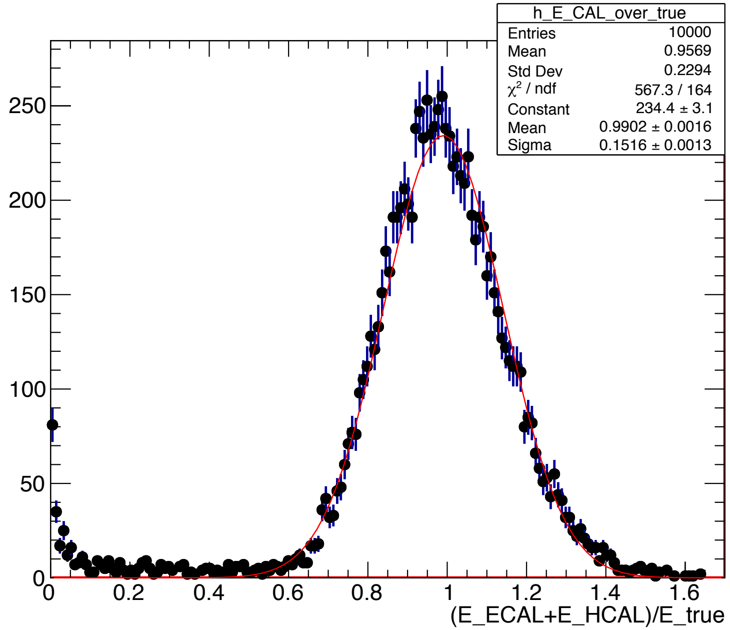


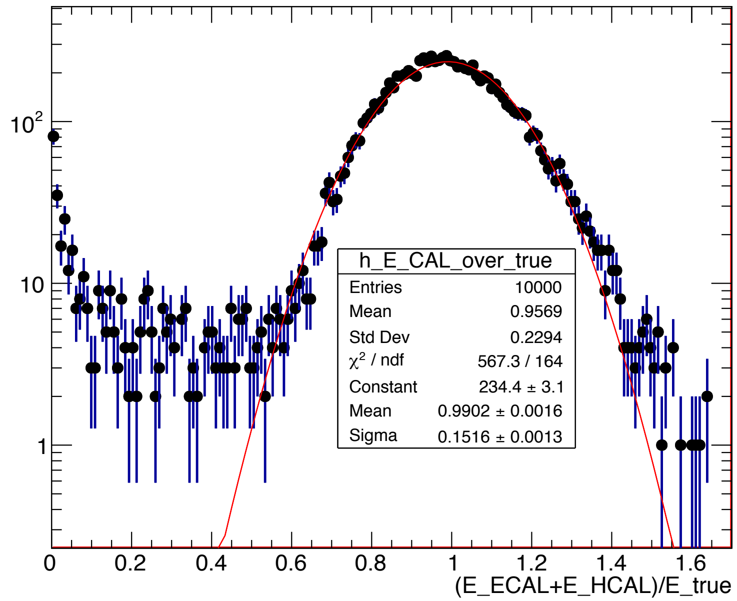


Model CLIC_o3_v5: Barrel Resolution

Determine relative resolution via distribution of $E_{rel} = (E\_ECAL+E\_HCAL)/E\_truth$

measure of σ(E): RMS and gausian fit, very low energy of 1 GeV start to see inefficincies in reconstruction (not the case for to 5 GeV photons)





Model CLIC_o3_v5: Barrel Overview

Summary plot of resolution in ECAL barrel

Model CLIC_o3_v5: EndCap Resolution

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

measure of $\sigma(E_{rel})$: RMS and gausian fit

Events well contained in endcap, exclude transition region, $0.85<|\cos\theta_{ph}|<0.98$

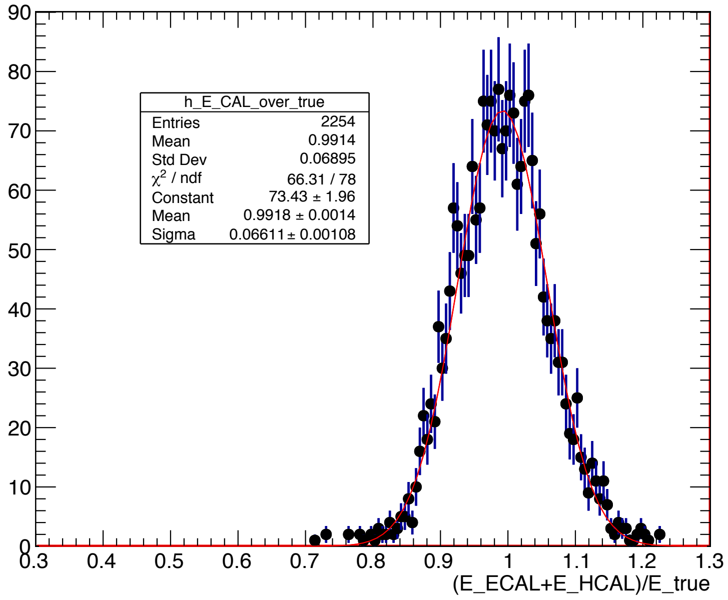
Energy (GeV)	1	5	10	15	30	50
$\sigma(E_{rel})$	14.7±.29	6.61±.10	4.61±.074	3.75±.063	2.679±.044	2.064±.043
RMS(E_{rel})	20.9±.32	6.89±.11	4.81±.072	3.83±.057	2.764±.042	2.16±.034
Mean (E_{rel})	0.966	0.991	0.992	0.994	0.995	0.996

Energy (GeV)	100	200	500	1000	1500
$\sigma(E_{rel})$	1.54±.025	1.10±.016	0.723±.011	0.529±.008	0.454±.008
RMS(E_{rel})	1.58±.023	1.13±.017	0.802±.011	0.560±.008	0.539±.008
Mean (E_{rel})	0.997	0.997	0.998	0.999	1.000

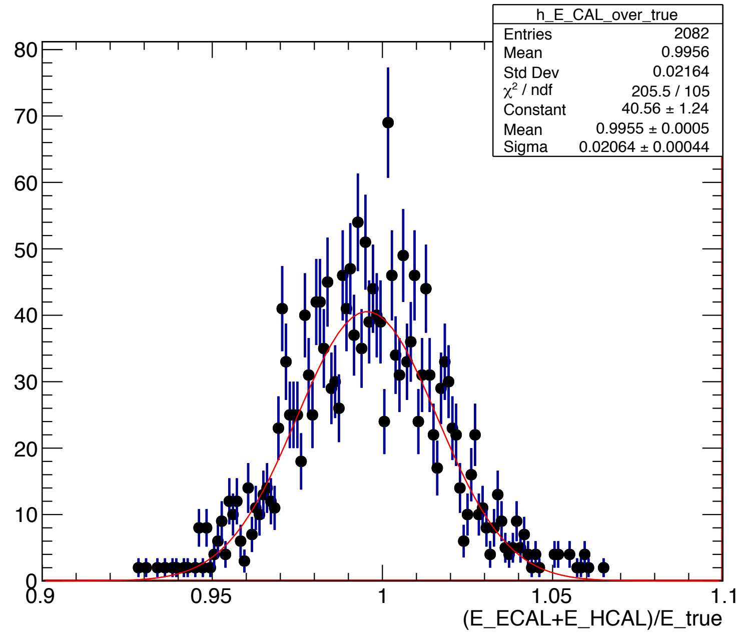
Model CLIC_o3_v5: Endcap Resolution

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

measure of σ(E): RMS and gausian fit, resolution in the endcap a tad better than in Barrel, with larger errors



5 GeV



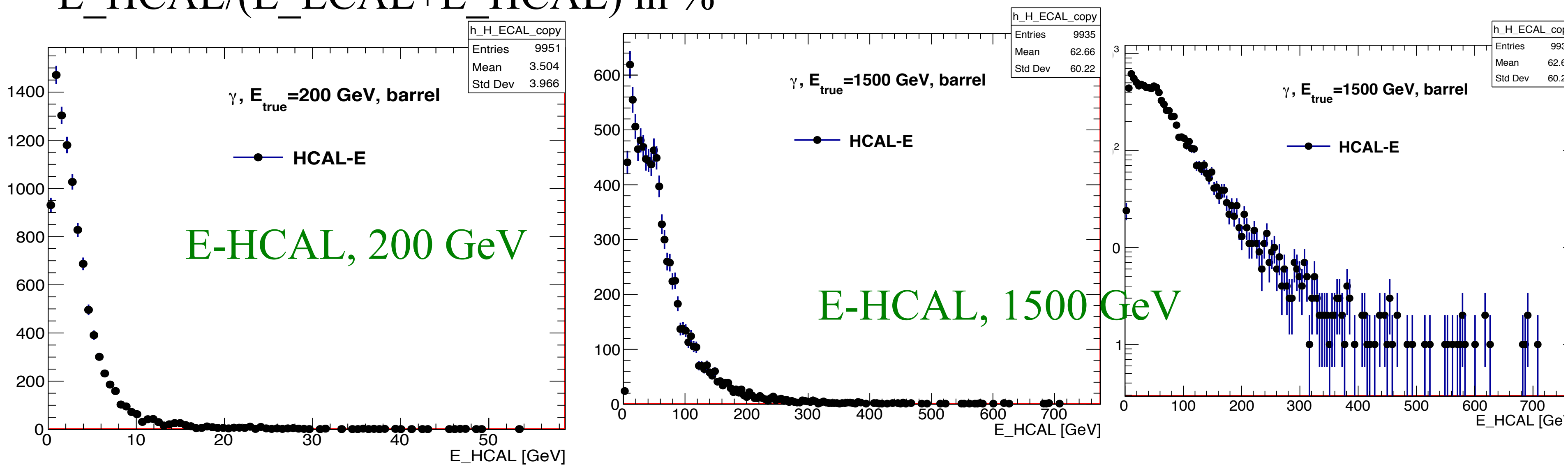
50 GeV

Model CLIC_o3_v5: Barrel leakage

Energy (GeV)	1	5	10	15	30	50
Leakage (mean)	0.21	0.343	0.535	0.609	0.8461	1.07
Leakage (median)	0.1		0.2	0.3	0.6	0.7

Energy (GeV)	100	200	500	1000	1500
Leakage (mean)	1.38	1.83	2.36	3.5	4.24
Leakage (median)	1.0	1.3	1.9	2.6	3.3

E_HCAL/(E_ECAL+E_HCAL) in %

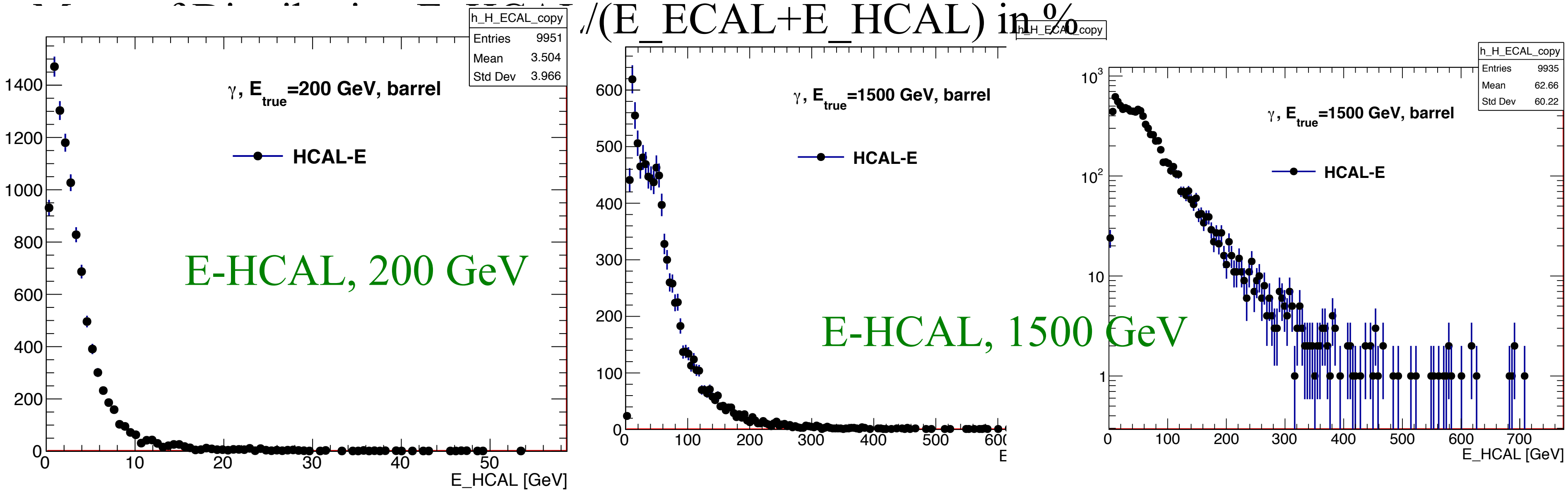


Model CLIC_o3_v5: Barrel leakage

Energy (GeV)	1	5	10	15	30	50
leakage	0.131	0.343	0.490	0.576	0.7731	0.979

Energy (GeV)	100	200	500	1000	1500
leakage	1.30	1.76	2.58	3.4	4.19

/(E_ECAL+E_HCAL) in %



Summary

Study of new model CLIC_o3_v05: no drastic change observed in resolution of photons compared to 40 layer CLIC_o2_v05

ECAL Calibration constants stable across different energies

Resolution values drop to around 1 % at very high energies

- Resolution distributions
- At higher energies non gaussian tails to the lower side

At high energies non negligible contribution from HCAL, different HadToEM scale for endcap and barrel

BACKUP

Model CLIC_o3_v5: Barrel innermost leakage

Energy (GeV)	1	10	50	100	200	500	1000	1500
Leakage (mean)	0.3	0.84	1.71	2.23	3.12	4.47	6.00	7.16
Leakage (median)	0.1	0.5	1.3	1.7	2.4	3.5	4.8	5.8

Fit Values

$$\frac{\sigma(E)}{E} = \sqrt{\alpha^2 + \left(\frac{\beta}{\sqrt{E}}\right)^2}$$

Barrel: chi2/NDF: 229/9

Alpha: 0.6751±0.005 beta: 14.99±0.04

Endcap: chi2/NDF: 11.02/9

Alpha: 0.2561±0.01 beta: 14.77±0.09

Transition region: chi2/NDF: 3.546/7

Alpha: 1.109±0.051 beta: 16.12±0.27

Model CLIC_o3_v5: Endcap leakage

Energy (GeV)	1	5	10	15	30	50
Leakage (mean)	0.785	0.456	0.622	0.732	0.959	1.18
Leakage (median)	0.1	0.1	0.3	0.5	0.7	0.9

Energy (GeV)	100	200	500	1000	1500
Leakage (mean)	1.63	2.06	3.24	4.31	5.23
Leakage (median)	1.2	1.6	2.4	3.3	4.0

Higher leakage in Endcap compared to barrel

Model CLIC_o3_v5: Transition region Resolution

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

measure of $\sigma(E_{rel})$: RMS and gausian fit

Events well contained in endcap, exclude transition region, $0.79<|Cos\theta_{ph}|<0.83$

Energy (GeV)	1	5	10	15	30	50
$\sigma(E_{rel})$	15.4±.57	7.30±.26	5.32±.20	4.44±.18	3.22±.11	2.49±.10
$RMS(E_{rel})$	18.1±.58	7.90±.26	5.33±.18	4.54±.15	3.24±.15	2.78±.10
Mean (E_{rel})	0.988	0.988	0.984	0.989	0.99	0.996

Energy (GeV)	100	200	500	1000	1500
$\sigma(E_{rel})$	1.94±.07	1.62±.07	1.31±.05		
$RMS(E_{rel})$	1.97±.06	1.69±.06	1.47±.05	1.50±.05	1.64±.06
Mean (E_{rel})	0.997	0.989	0.987	0.999	1.000

Values for X_0 calculation

Tungsten 24: 0.37 cm

Silicon: 9.36 cm

G10 (density 1.7 g/cm^3): 19.4 cm

Air: 30420 cm

GroundOrHVMix: 86 % Copper

siPCBMix: 82% Copper