# ILD ECAL : simulation

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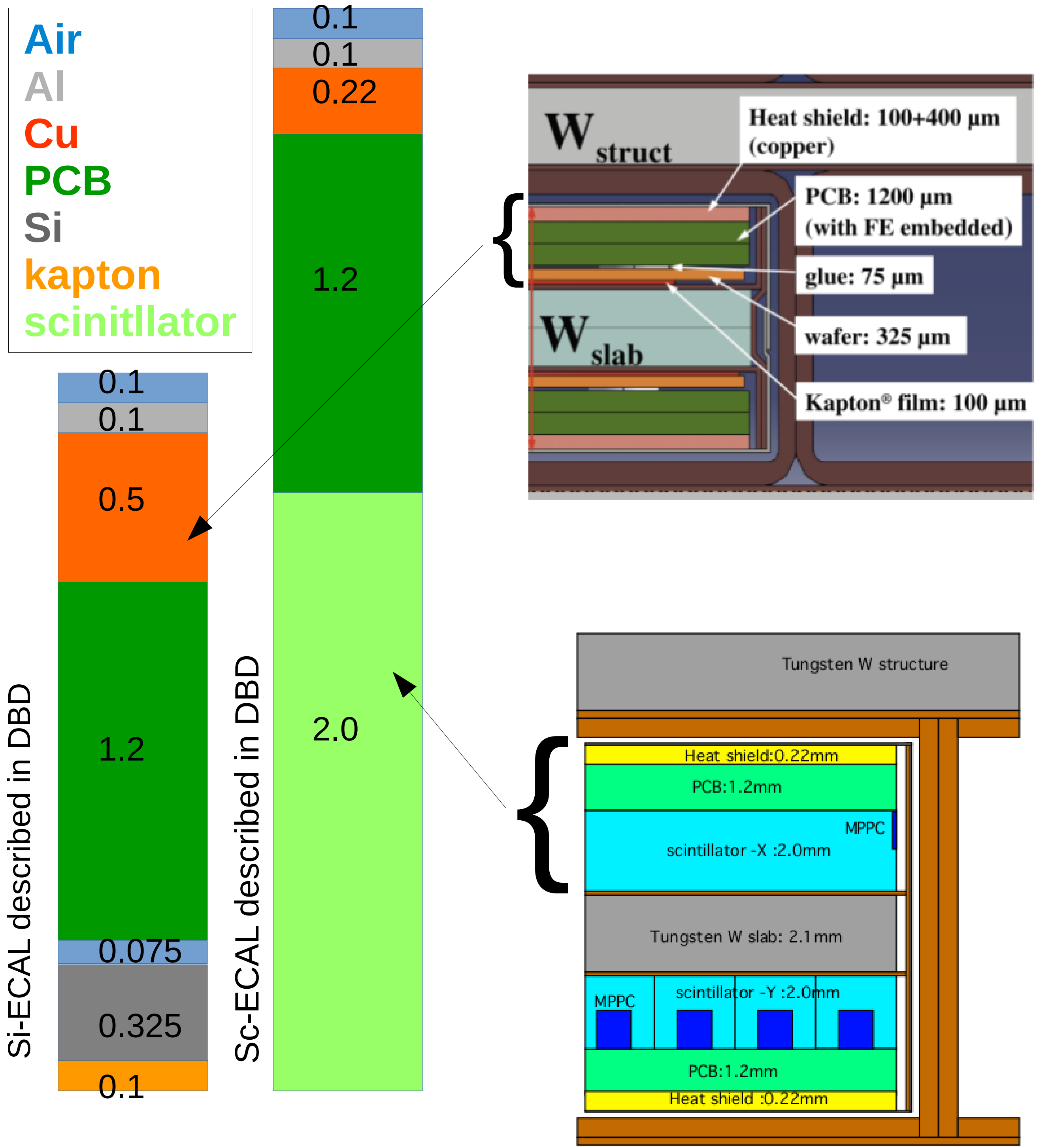
hybrid ECAL simulation

validation

ECAL gap corrections

# DBD design

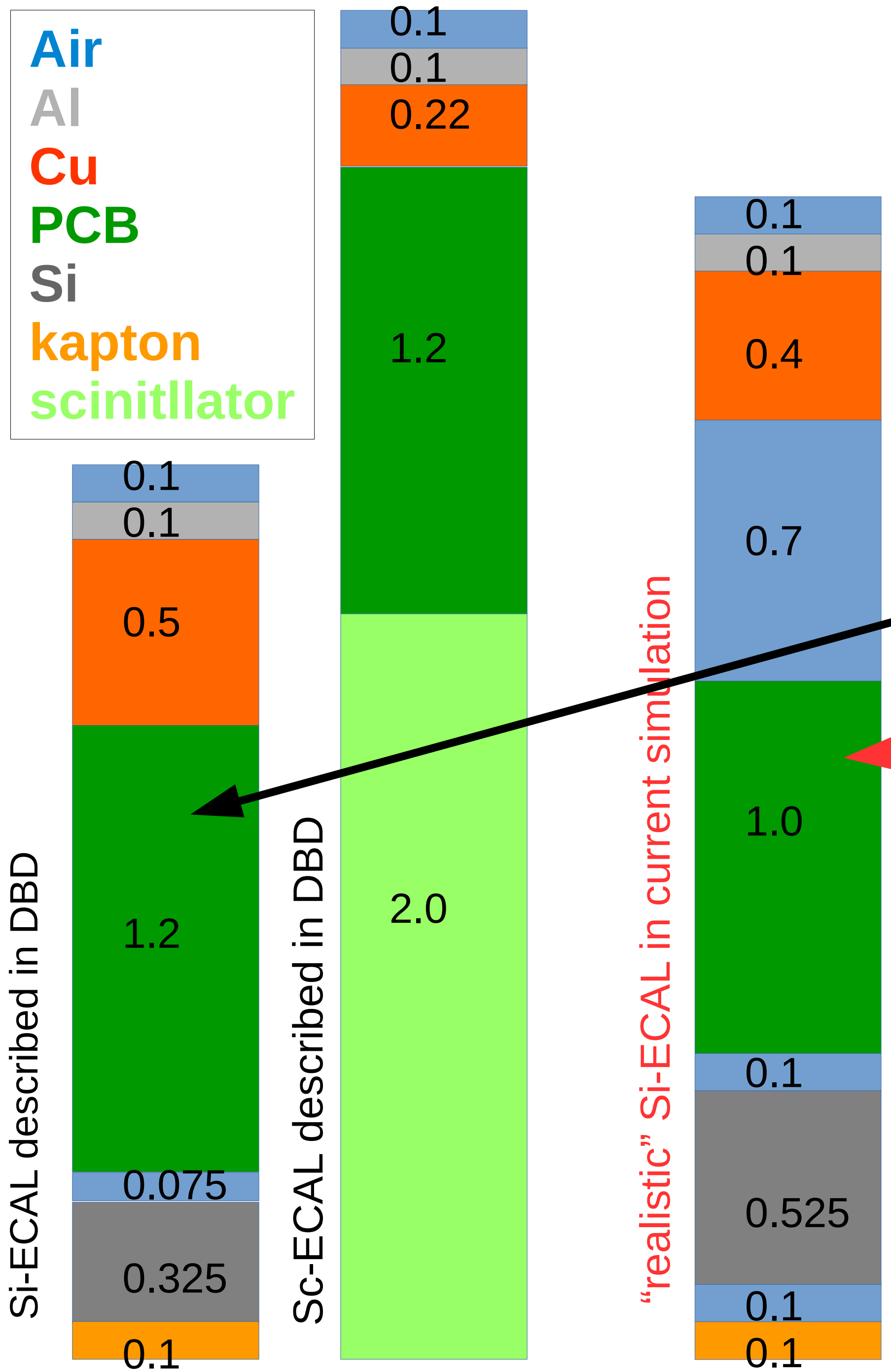
2 technological options




Si-ECAL:
service thickness =
2.075 mm/layer

(“service thickness” =
everything that is
not active and
not structural)

Sc-ECAL:
service thickness =
1.62 mm/layer

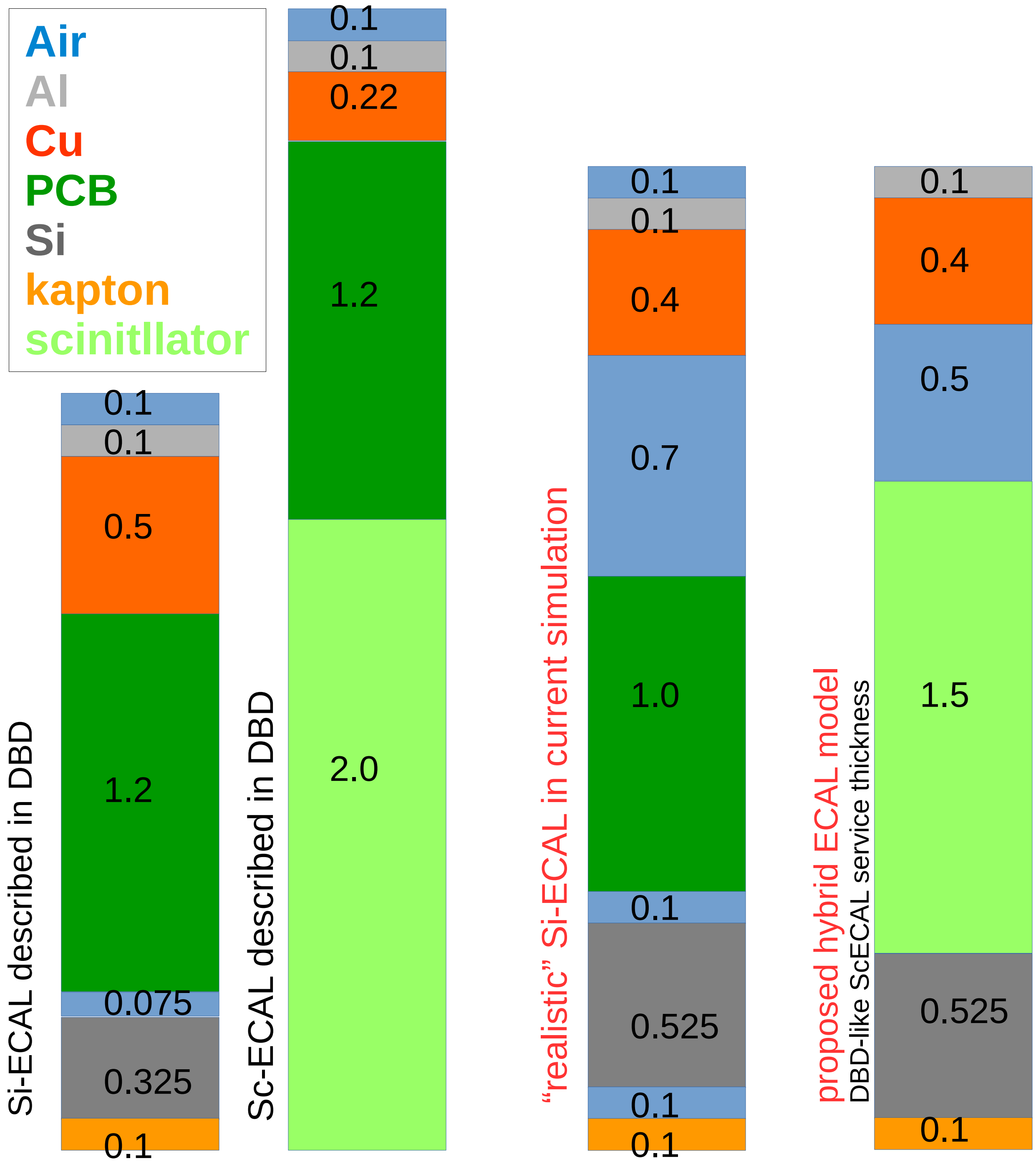



DBD Si-ECAL:
service thickness =
2.075 mm/layer

new realistic design:
increased to
2.6 mm/layer

sufficient space for reasonable hybrid Si-Sc ECAL simulation ?

simultaneously simulate two technologies
→ choose technology at reconstruction time
→ reduced computing
→ direct comparisons




hybrid model should be:
– same thickness as “realistic” si-ECAL
– technologically reasonable for both technologies
→ maintain service thickness

reduce scintillator thickness
2.0 → 1.5 mm

replace PCB and some air
of Si-ECAL by scintillator

replace PCB of ScECAL by
Si + Cu + air

service thickness of
SiECAL → same as realistic
ScECAL → ~same as DBD

material mix not identical
but overall X0 rather similar

implemented in
ILD_[l/s]5_v02 models

# validation of hybrid ECAL simulation

single photons,
- various energies,
  - various detector regions (ranges in theta)
    - equally distributed in azimuthal angle

- exclude photons which convert before ECAL

look at simulated hits only ( → energy deposit in active layer)

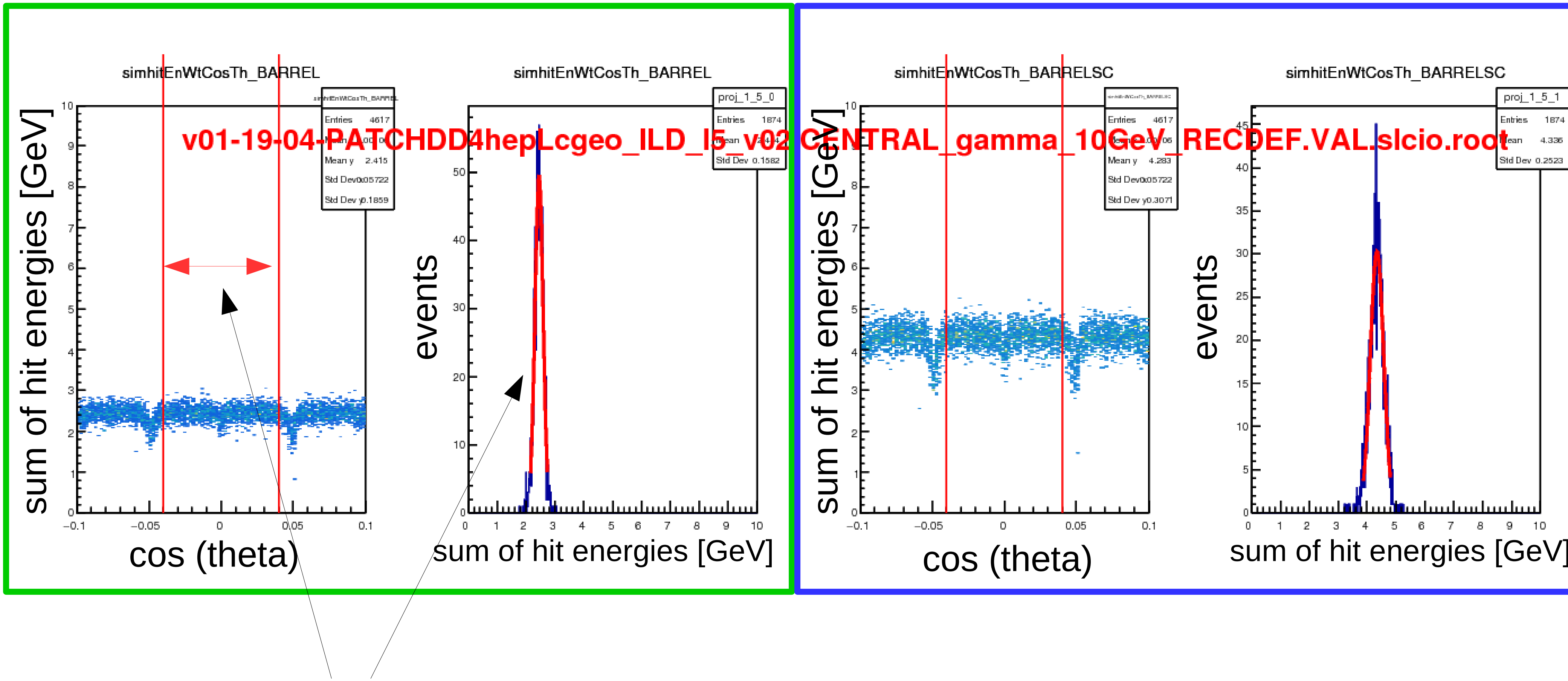
weighting to account for thicker absorber in second stack
- no additional hit digitisation, reconstruction, or clustering

compare:
- **silicon-only model (ILD_l4_v02)**
- **silicon hits in hybrid model (ILD_l5_v02)**
- **scintillator hits in hybrid model (ILD_l5_v02)**

for example: **hybrid model**, 10 GeV photons shooting at central region

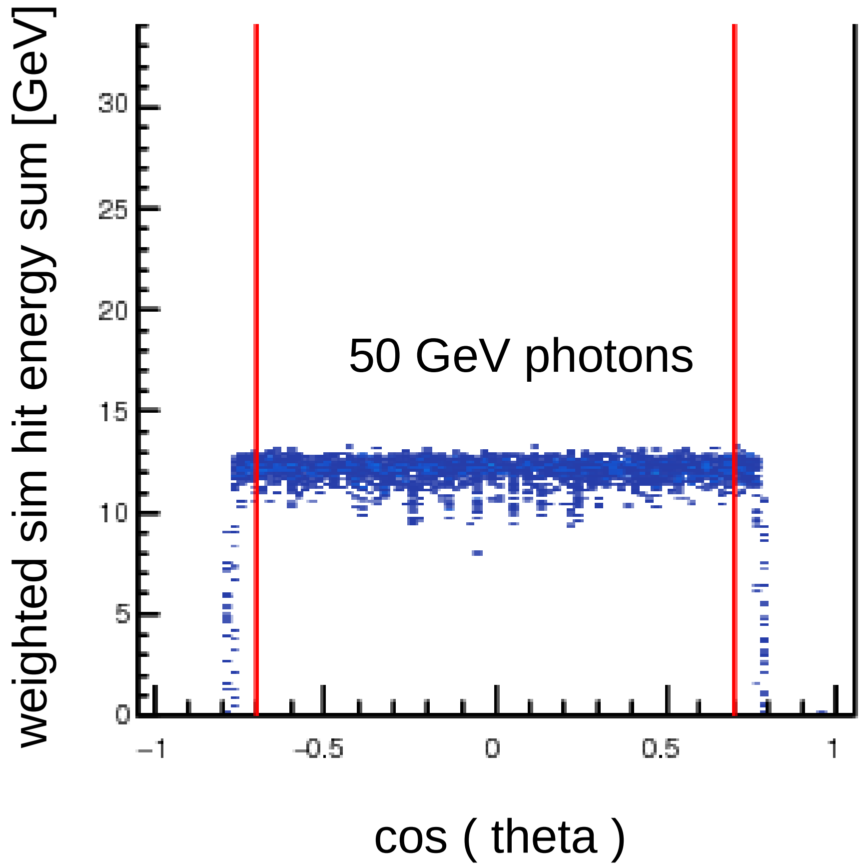
silicon hits

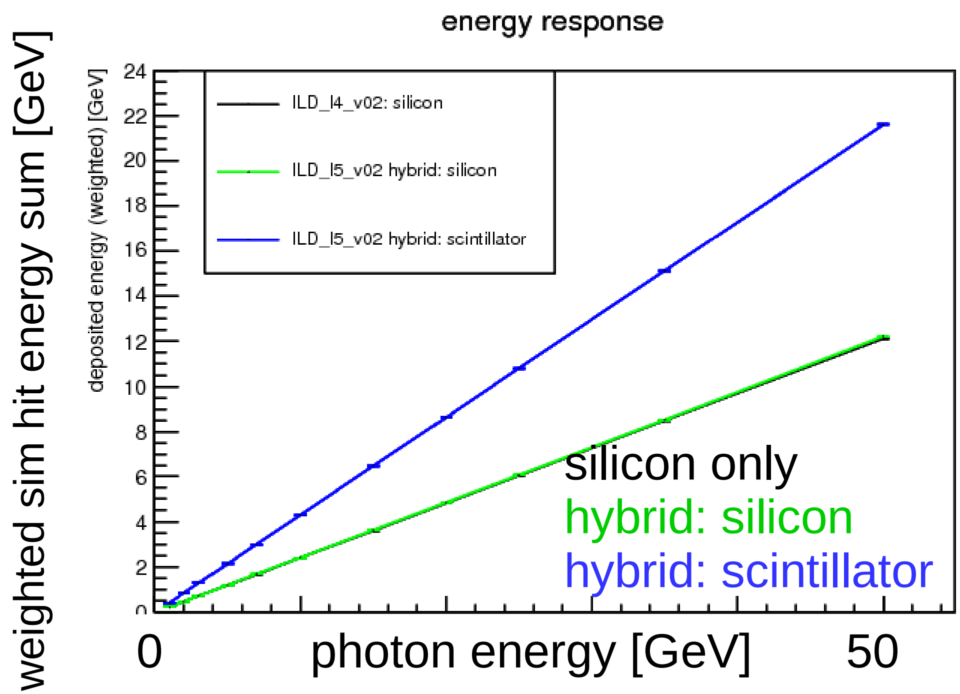
scintillator hits

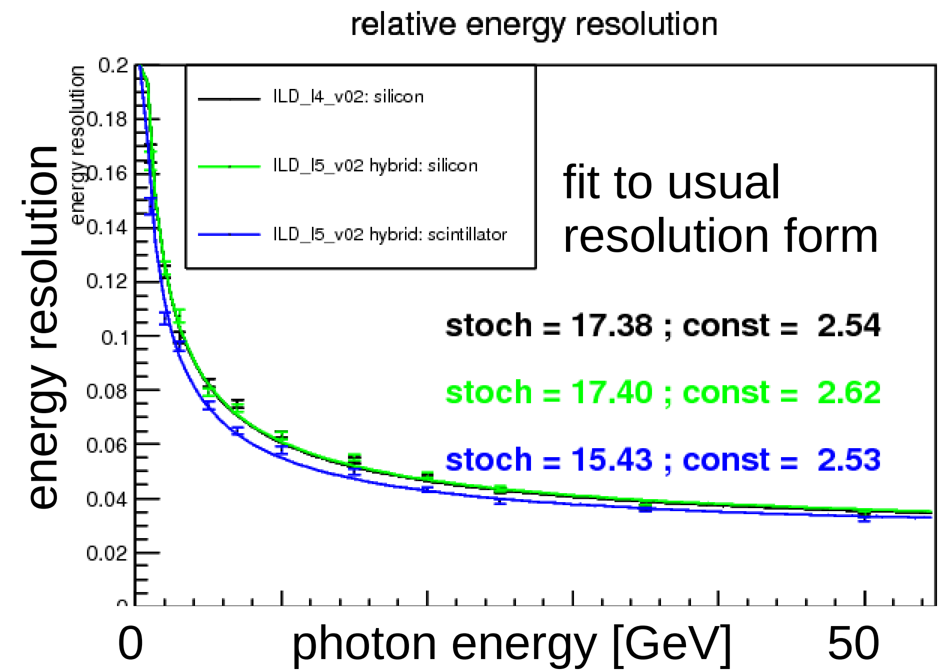



fit energy distribution
away from major gaps :
Gaussian in range ±2 σ

e.g. integrating over photons in barrel region ( | cos (theta) | < 0.7 )




silicon hits not affected by hybrid simulation

scintillator hits look OK

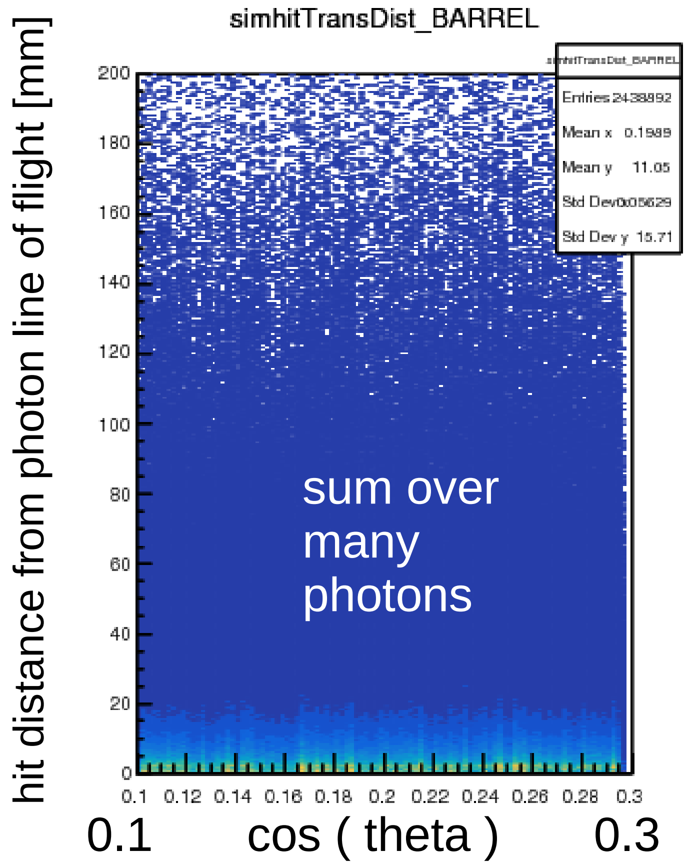
Check that shower shape is reasonable described

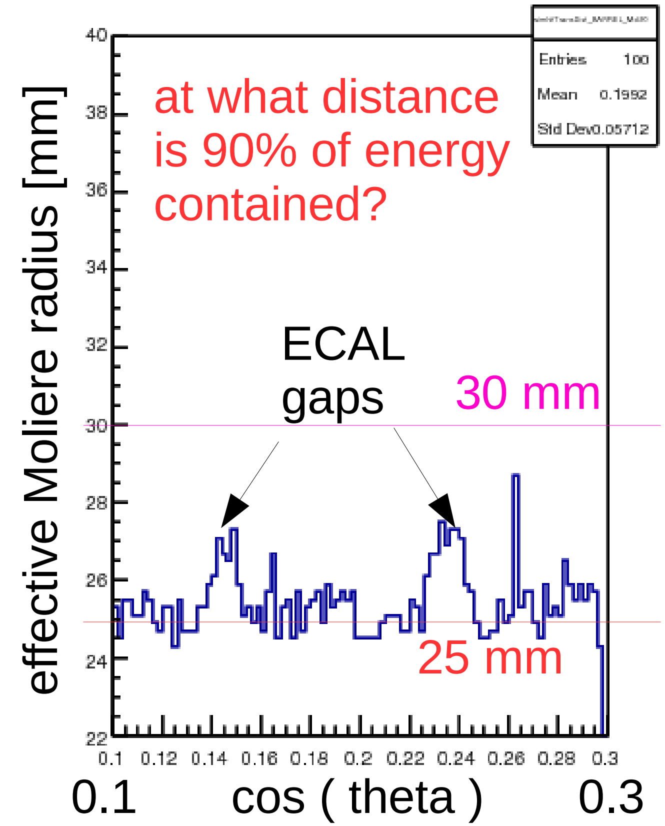
look at distance from hit to photon's line of flight

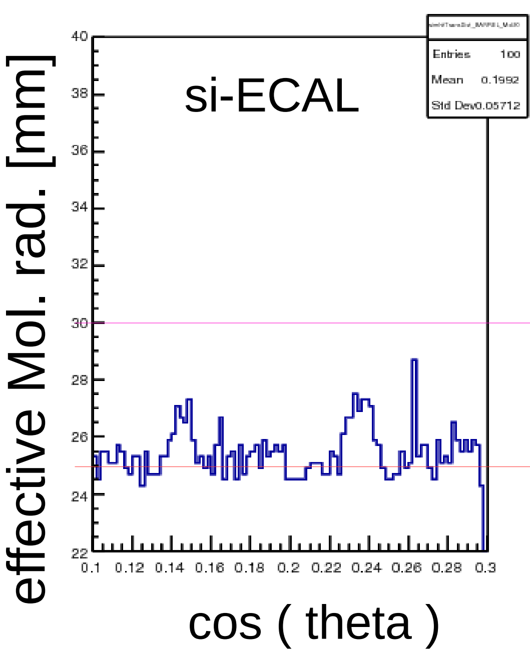
radius of 90% containment:
→ extract Moliere radius

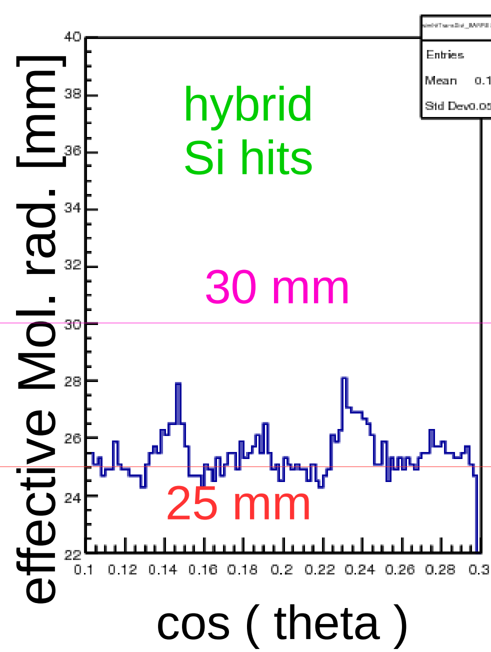
e.g. 0.1 < cos(theta) < 0.3

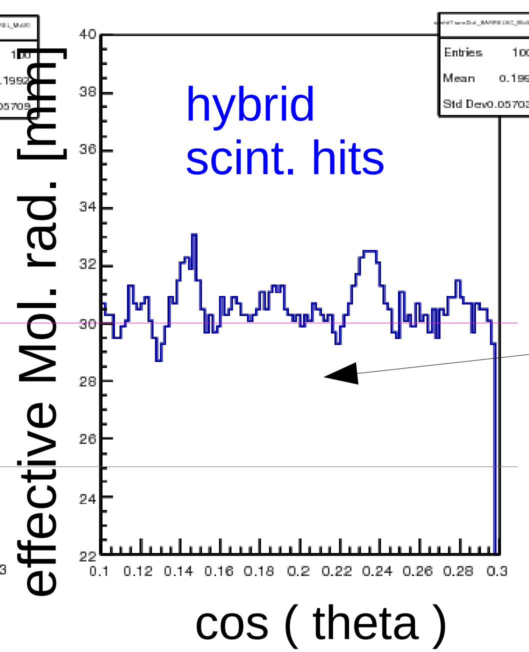
no surprises

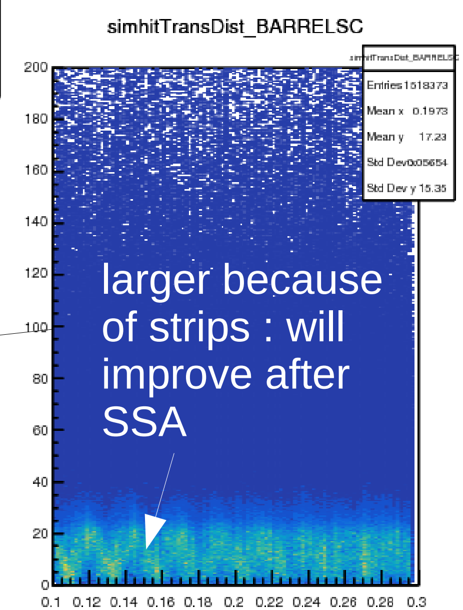


at SimCalorimeterHit level,

i.e. output of simulation, before digitisation and reconstruction

silicon hits in hybrid ECAL model show

no significant differences to si-only ECAL model

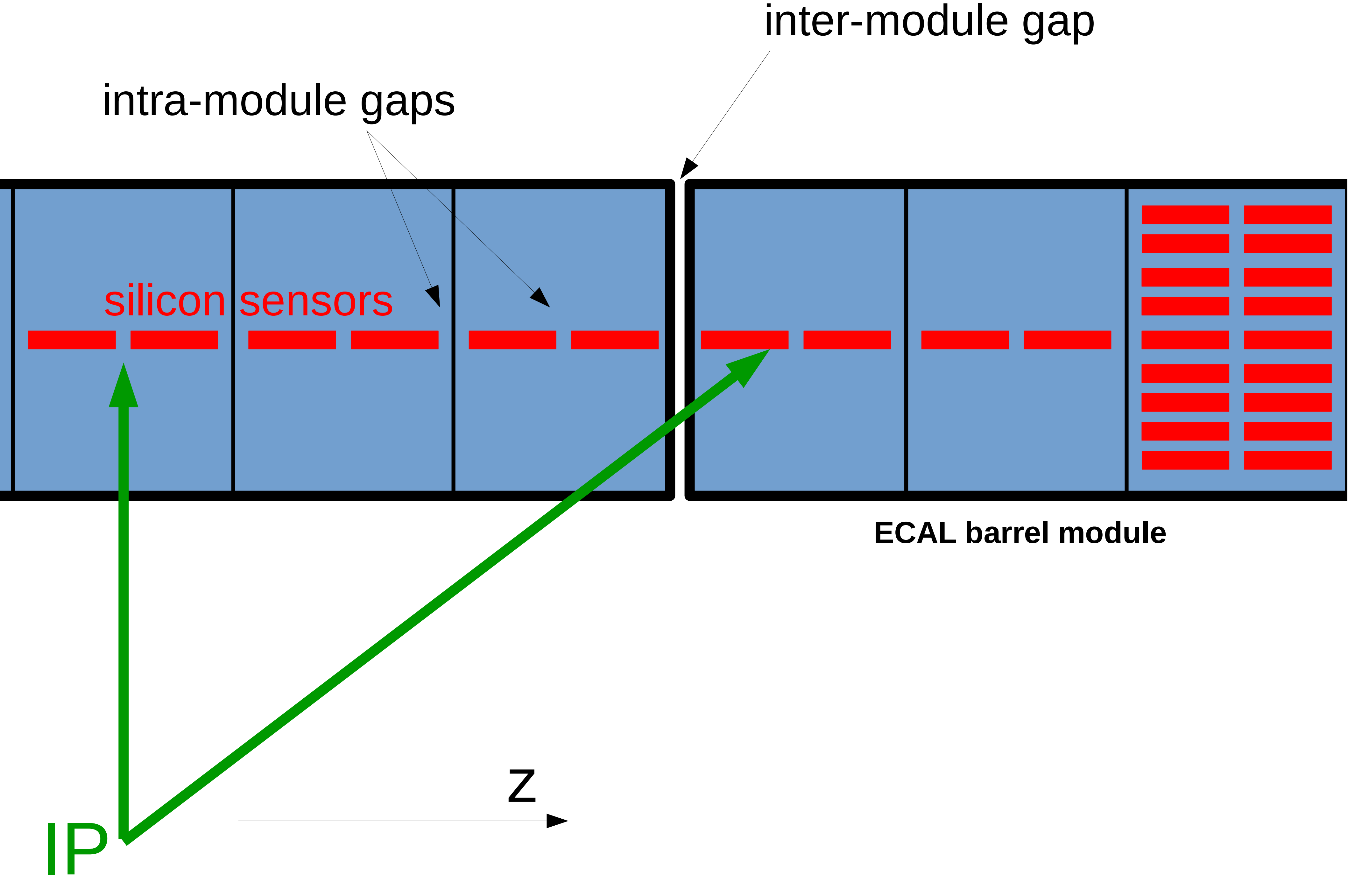
Sc-ECAL hits look reasonable

# what's missing for ScECAL reconstruction:

- decision on realistic parameters for digitisation with
  thinner scintillator
    (e.g. # photo-electrons detected per MIP :
      depends on scintillator thickness)

- Strip Splitting Algorithm (resolves hit position along strip)
  exists for Mokka-based simulation,
    but not yet adapted for dd4hep-based software

# SiW - ECAL gap filler

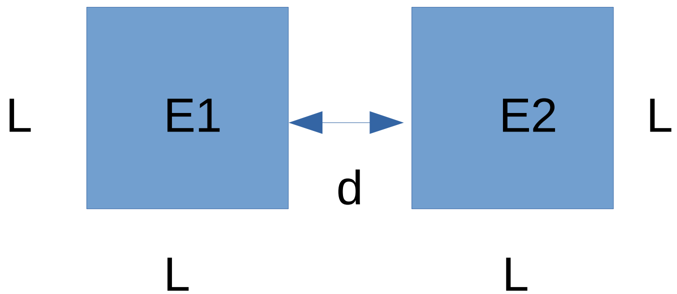


several gaps between sensitive silicon within ECAL's sensitive layers, due to mechanical structures:  size ~mm → ~cm

n.b. gaps are not projective to IP

not negligible compared to narrow high energy core of EM showers

local approach to estimate energy loss in gaps:




two ECAL cells across a gap,
each has size LxL mm,
cell energies E1, E2

use average energy density of neighbours to estimate energy in gap :
$E_{gap} = (d*L) * (E1+E2)/(2*L^2)$

in DBD,

weighted this energy by f = 0.5(1.0) for the inter-(intra-)module gaps:

$E_{hit} = f * E_{gap}$

create a calorimeter hit in the middle of the gap, with this energy in dd4hep-world,

MarlinReco calodigi code was reorganised,

and this method was reimplemented in standalone
BruteForceEcalGapFiller processor

the factor 0.5 for inter-module gap
hits was not included

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ILD validation samples:

reports of too-large reconstructed photon energies
in some theta regions

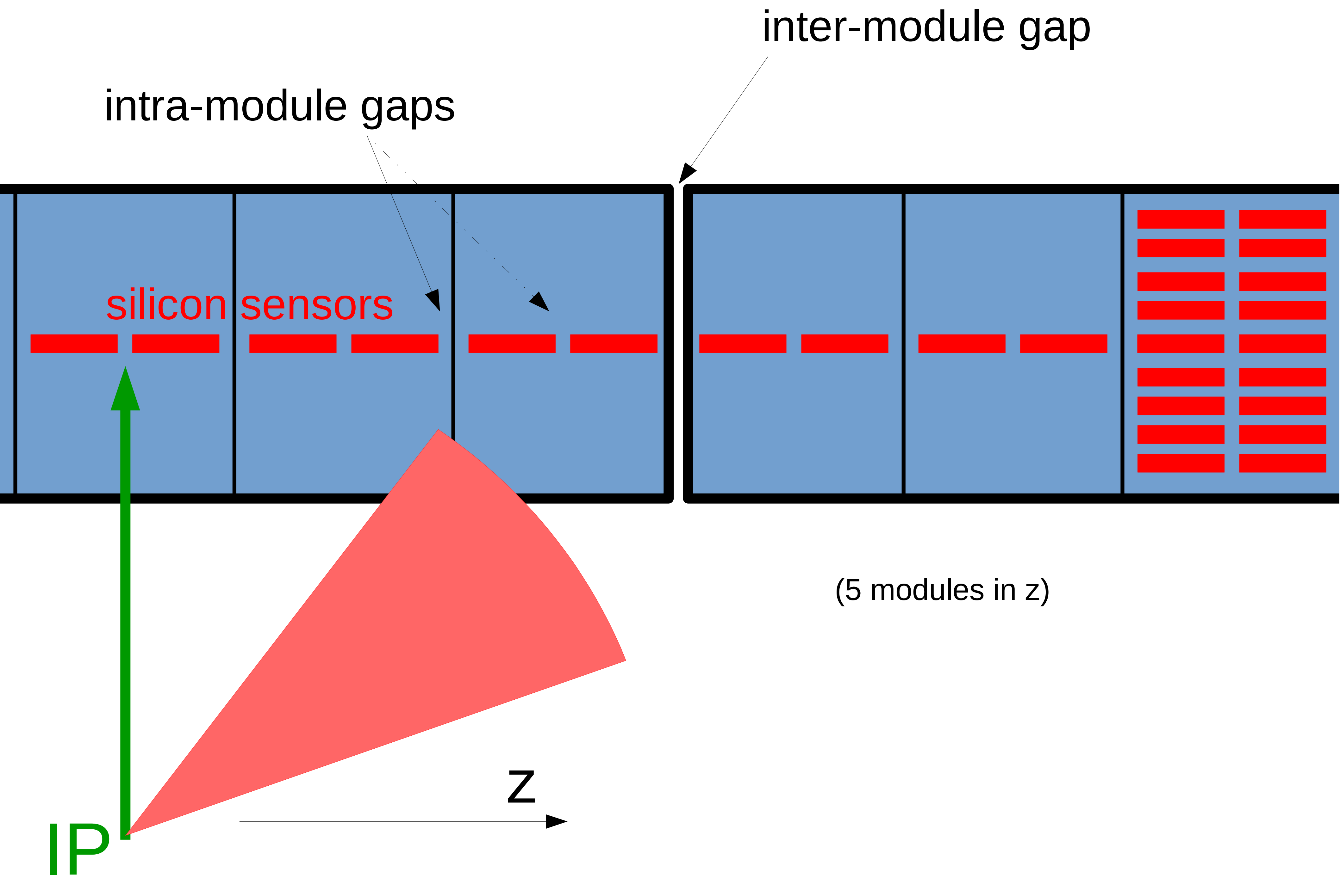
study using single photons 5, 10, 25, 100 GeV

pointing at most important cracks

look at:

- sum of reconstructed ECAL hit energies (after calibration)
- sum of ECAL gap hit energies
- sum of reco and gap hit energies

shoot photons at most gappy region...



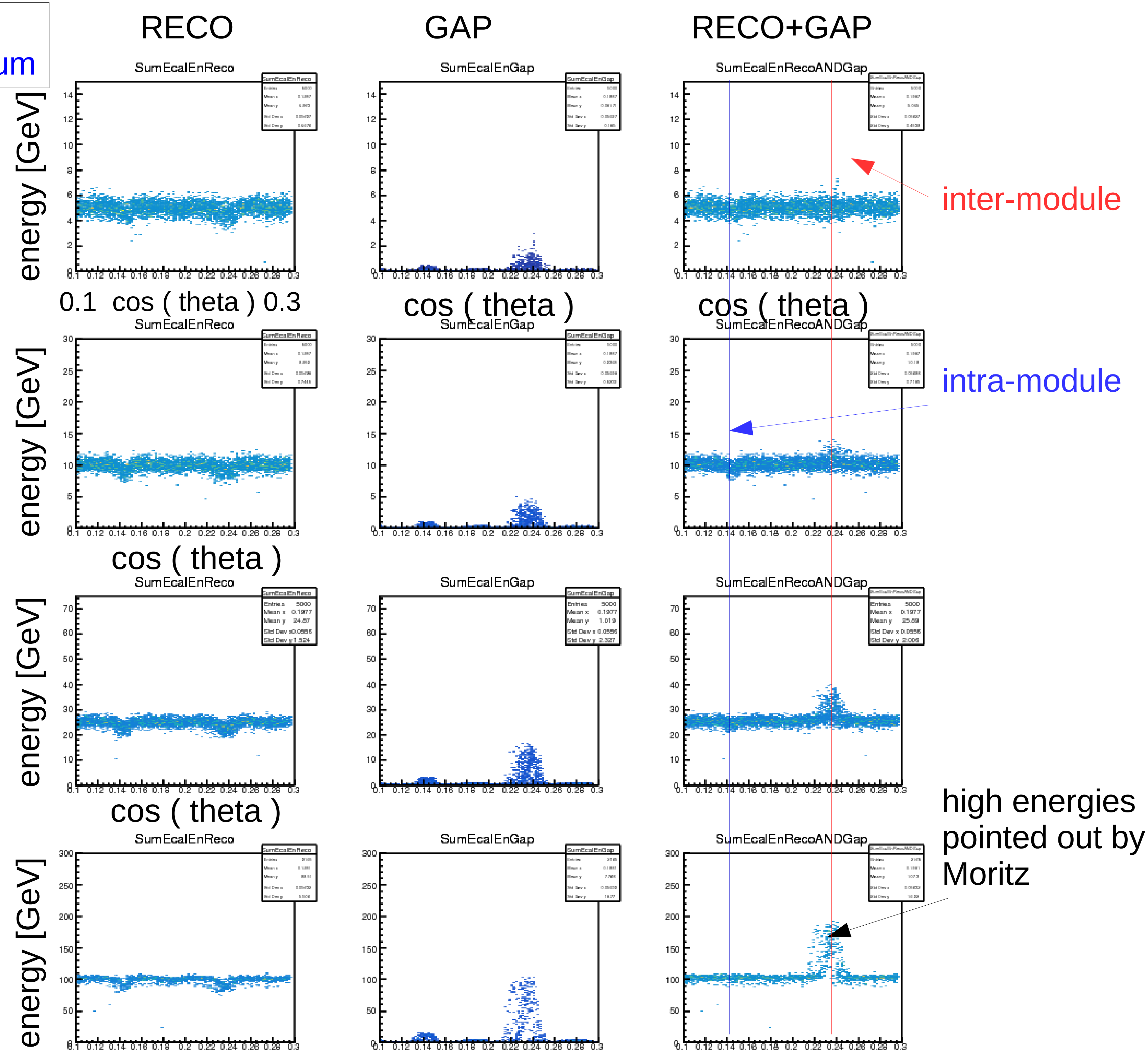
reconstructed and gap hit's energy sum

5 GeV photons

10 GeV

25 GeV

100 GeV




v01-19-04 reconstruction

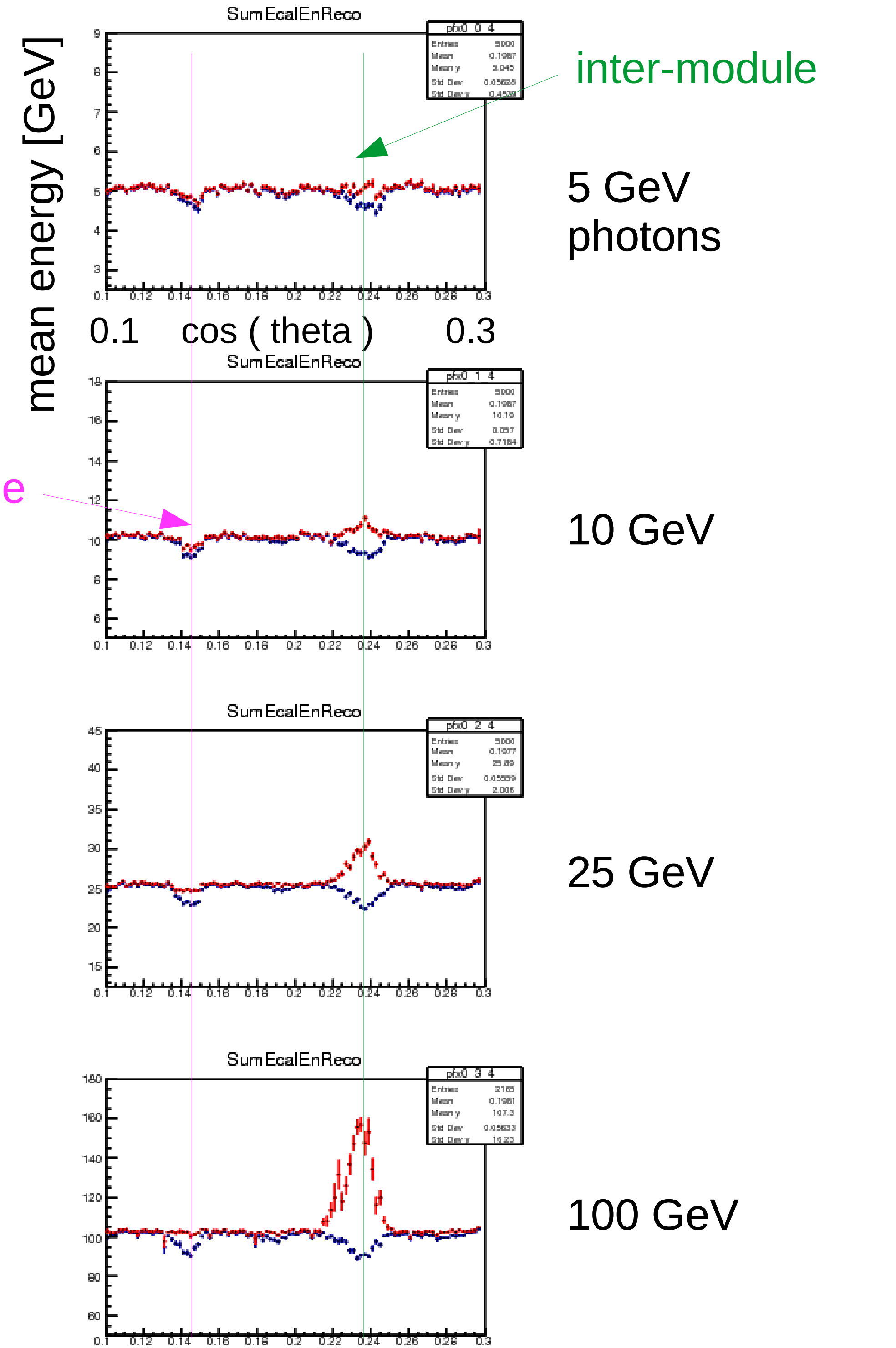
mean RECO energy

mean RECO+GAP energy

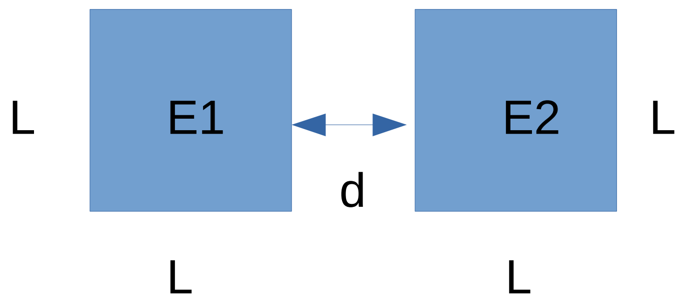
at 5 GeV,
inter-module gap well-corrected
intra-module gap under-corrected

at 100 GeV,
inter-module gap over-corrected
intra-module gap well-corrected

energy-dependent corrections
required



# modified approach to estimate energy loss in gaps:




two ECAL cells across a gap,
each has size LxL mm,
cell energies E1, E2

use average energy density of neighbours to estimate energy in gap :
Egap = (d*L) * (E1+E2)/(2*L^2)

in DBD, energy by weighted by
f = 0.5 (1.0) for the inter-(intra-)module gaps; $E_{hit} = f * E_{gap}$

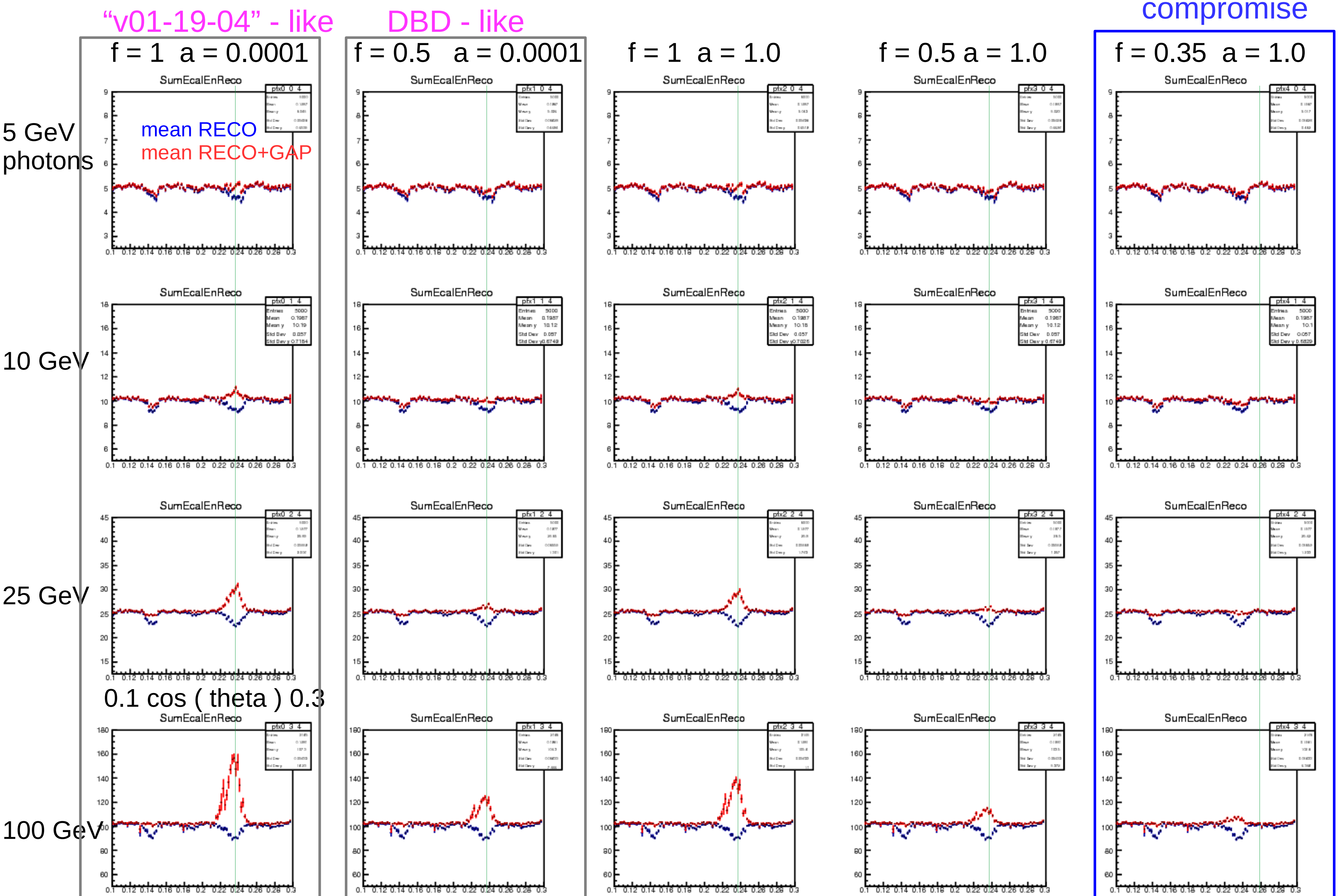
introduce energy-dependence: suppress large-energy gap hits

$E_{hit} = f * (1/a) * \log ( 1 + a*E_{gap} )$ [ for $a*E_{gap} << 1$, $E_{hit} \sim f * E_{gap}$ ]

→ logarithmic suppression of high energy hits
parameter a determines how quickly suppression kicks in
→ overall factor f [as before]

# try different factors for inter-module gaps

Ehit = f * ( 1/a ) * log ( 1 + a*Egap )




neither is perfect: still some energy dependence. Additional cluster-level corrections necessary

# Summary

hybrid ECAL model developed

- allows simultaneous simulation of
  - two technology options

single particle validation checks: OK

development of ECAL gap treatment

- further improvements certainly possible

Backup

# Digitisation

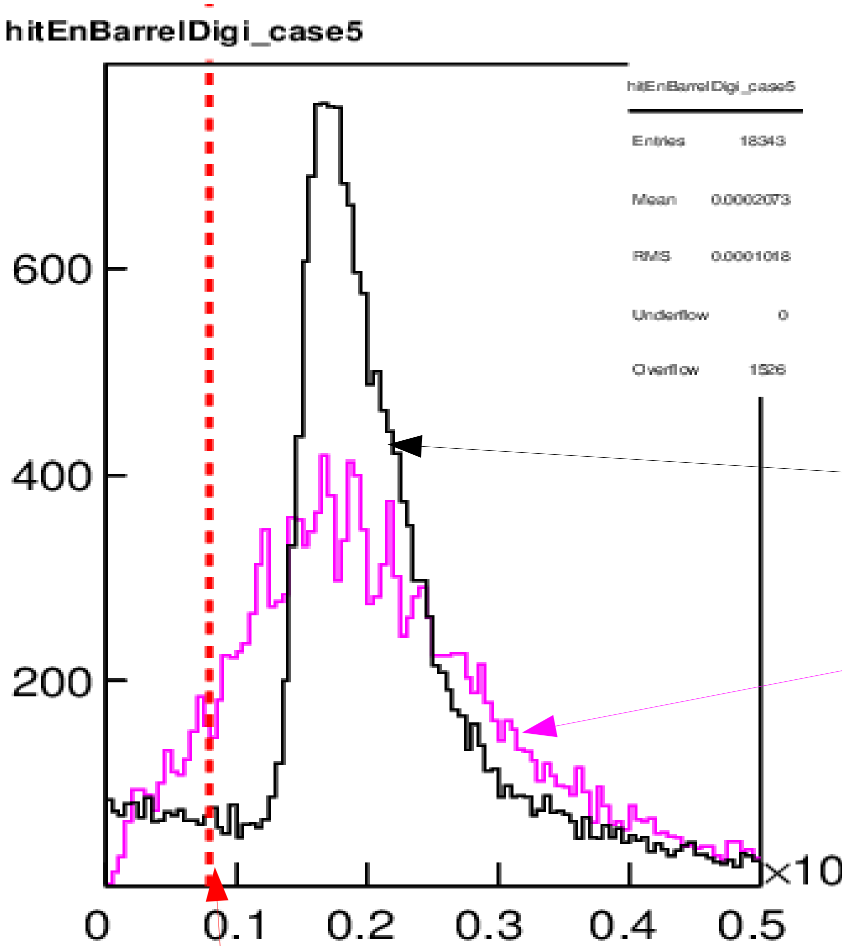
convert from G4 energy deposition in sensitive layer
to something like detector output
→ describe sensor, readout, etc

Since the DBD, several possibilities for more realism have been implemented into the RealisticCaloDigi digitisation processor

- Random gaussian noise
- Saturation of electronics
- Random mis-calibrations (both fully- and un-correlated)
- Random dead channels
- SiPM characteristics: saturation, fluctuations and mis-calibration

These effects are significant for SiPM readout
particularly for small signals (~MIP) [ Poisson fluctuations of #p.e.]
large signals (high energy EM shower core) [saturation]

~ negligible for si-ECAL
fluctuations dominated by Landau fluctuations in energy deposit
→ modelled in G4
fluctuation of # e-h pairs much smaller




Hit Energy [some units]

Typical threshold @ ~0.5 MIP

ILD simulation: ECAL hits for
10 GeV muon

Energy deposited in scintillator

Digitised energy (ILDCaloDigi)
with my educated guesses for
non-uniformity,
MPPC statistics
noise

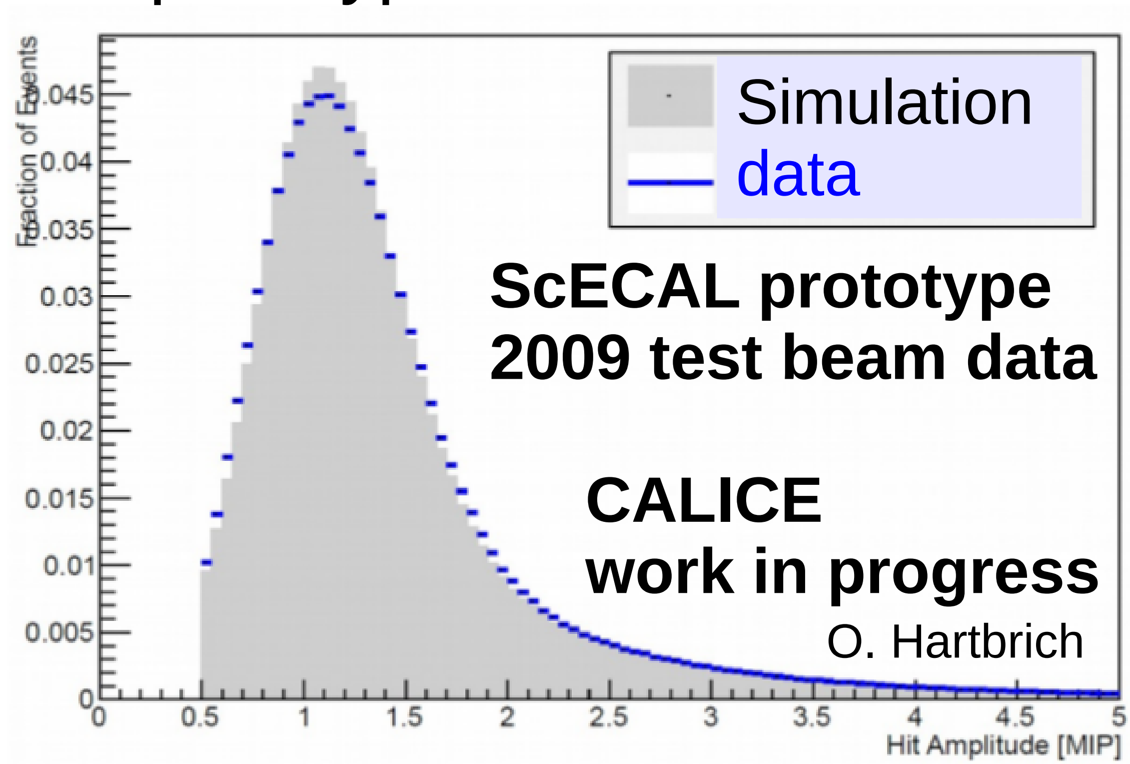
*slightly old plot, but still valid*

# Apply realistic digitisation model to description of ScECAL prototype

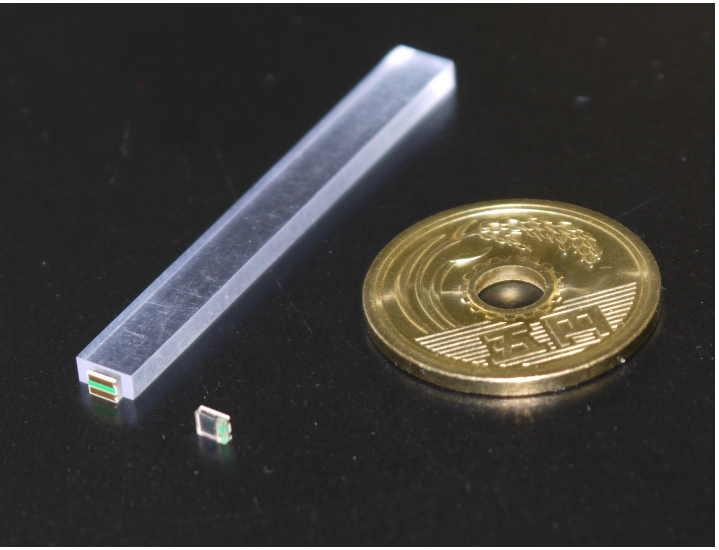
Simulation includes
- MPPC statistics,
- noise,
- perfectly uniform strips

Small data-MC difference may be due to strip non-uniformities

rather minor effect,
even @ MIP level




Energy of selected MIP hits

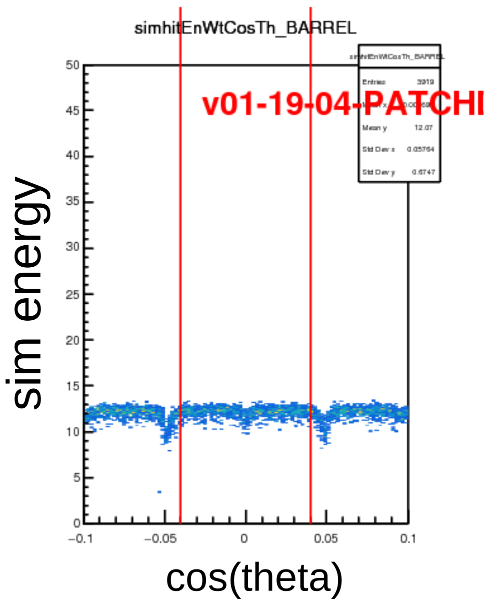


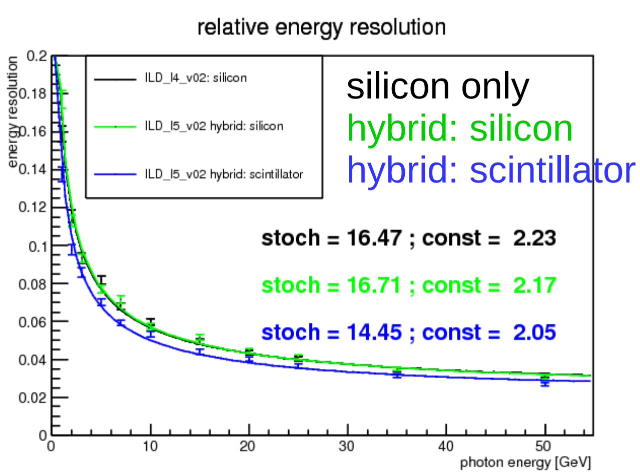
this is for 1600 pixel MPPCs (25 x 25 $\mu m^2$ pixels) used in physics prototype

10,000 pixel MPPCs (10 x 10 $\mu m^2$ pixels) used in technological prototype do not yet give satisfactory results: sensitivity of readout electronics not well matched to smaller pixels

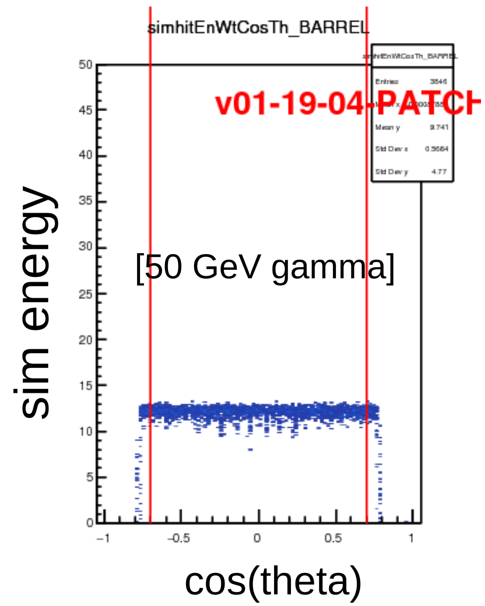
# energy resolution integrating over different cos(theta) ranges
[ reminder: integrated over all azimuthal angle ]

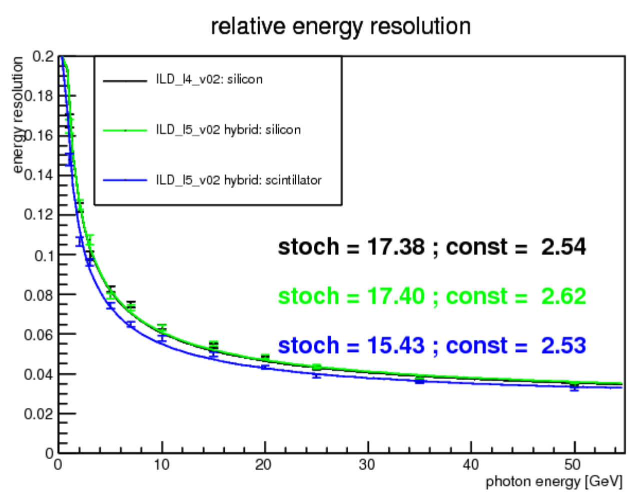
## -0.04 < cos(theta) < +0.04



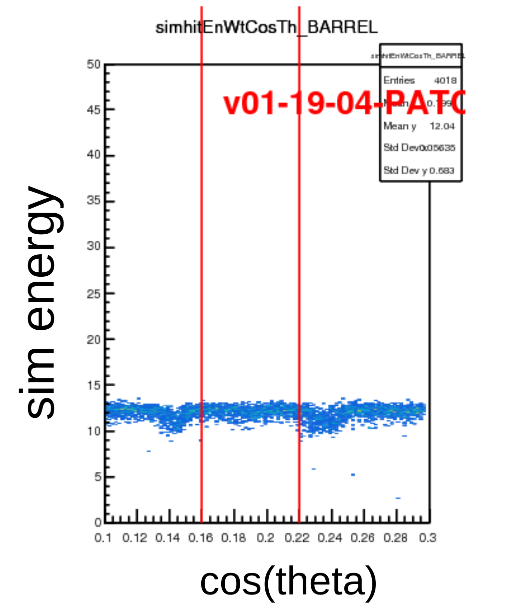



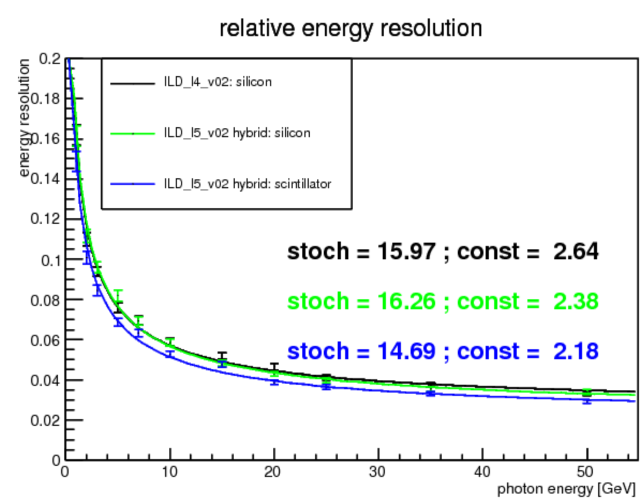

## -0.7 < cos(theta) < +0.7




## 0.16 < cos(theta) < 0.22




no surprises, everything looks consistent