Improving realism of ILD ECAL simulation and digitisation

-Introduction
-Simulation
-Digitisation

Daniel Jeans, U.Tokyo
for the ILD ECAL groups

AWLC @ FNAL, May 2014

東京大学
THE UNIVERSITY OF TOKYO

Introduction

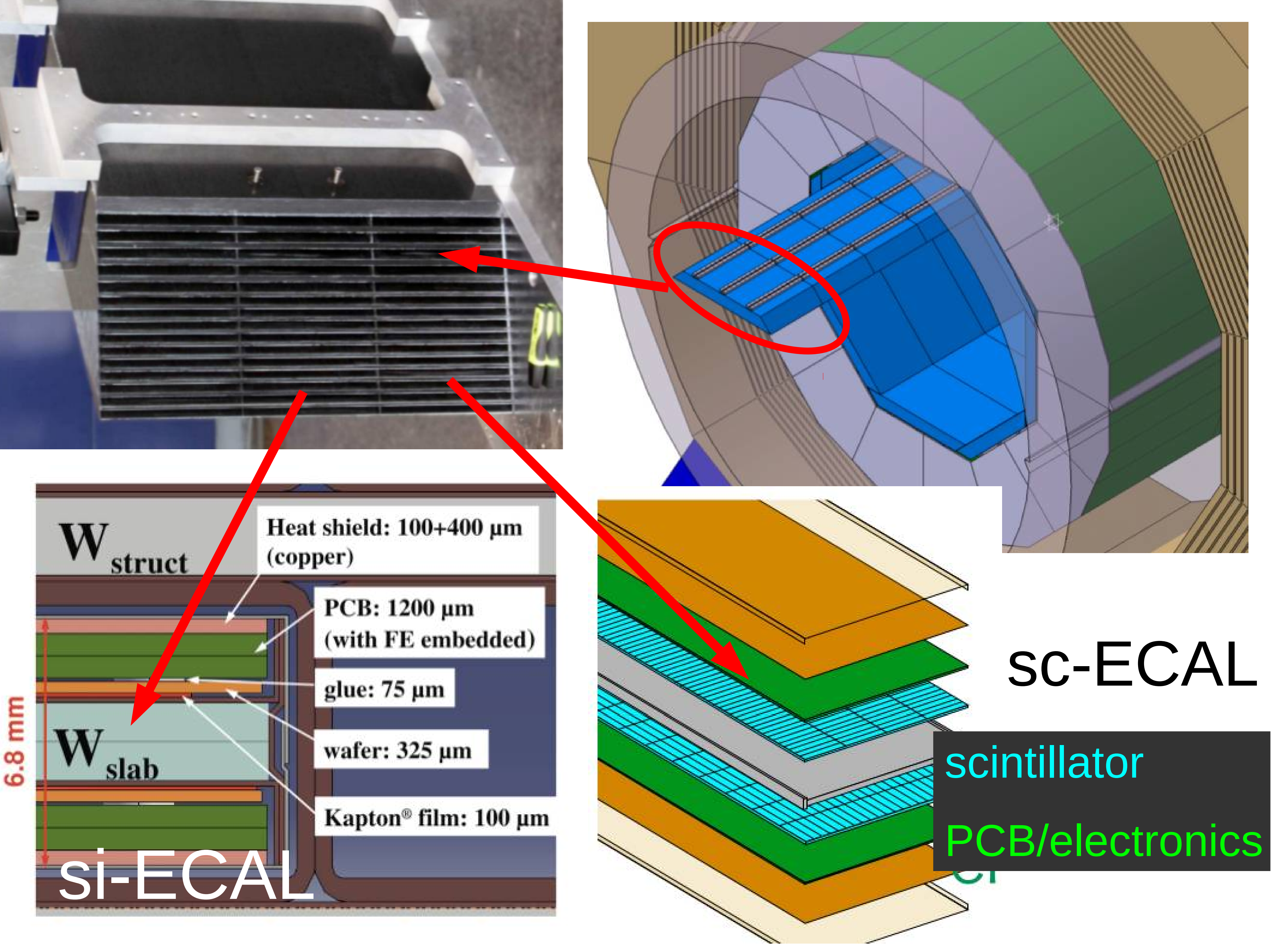
Two options for the ECAL of ILD
- silicon PIN diodes
- scintillator strips + MPPC

~ same mechanical and absorber structure

We (ILD ECAL groups) have been discussing how to ensure that different ECAL options are simulated with a **sufficient** and **similar** level of realism

more confidence in
predictions of performance
comparisons between technologies

This talk is NOT about optimisation of # layers, technologies, radius, cell size, ...
but about ensuring that these studies can be performed using
simulations with a good, and comparable, level of realism



W struct
Heat shield: 100+400 μm (copper)
PCB: 1200 μm (with FE embedded)
glue: 75 μm
W slab
wafer: 325 μm
Kapton® film: 100 μm
6.8 mm
si-ECAL
sc-ECAL
scintillator
PCB/electronics

Modeling of ECAL in ILD is already (DBD) quite realistic

Mechanical structures
Dead zones
Services

Digitisation of ECAL hits is rather simplistic

Energy deposit in scintillator / silicon
Rejection of hits with energy < 0.5 MIP

now is a good time to revisit some key parameters:

reasonable extrapolations from today's CALICE prototypes

Simulation

Both options simulated using Mokka framework
- parameterised geometrical models
  - e.g. cell size, material thicknesses,
    - gaps / tolerances

I will highlight parameters we plan to update
- *these are proposals, not yet set in stone*

Readout PCB

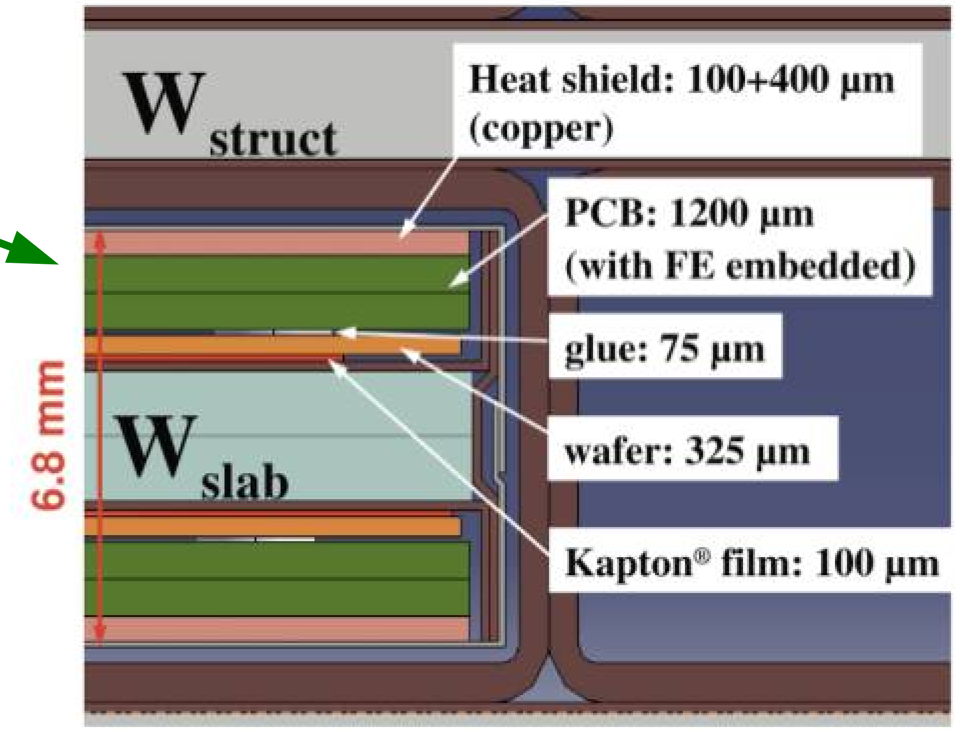
In DBD simulation, 0.8mm thick

We now recognise that this is
technically very challenging

Based on today's "technological" prototypes,
(and depending on:
ECAL technology,
who you talk to)

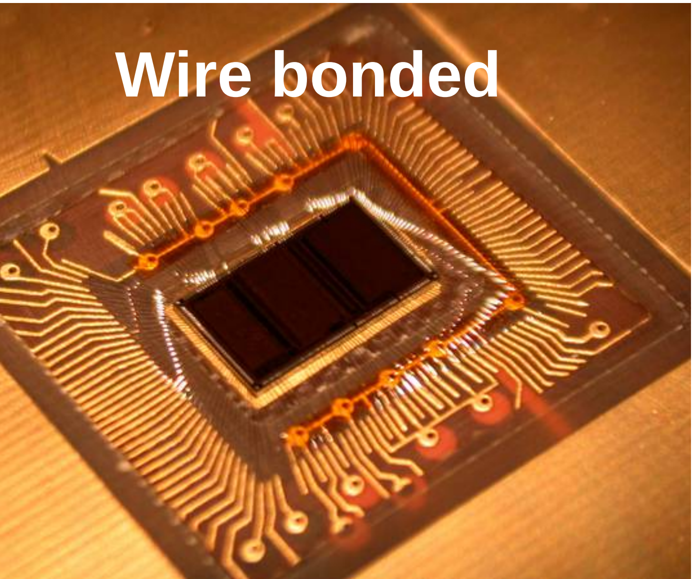
we expect PCB thickness will be in the
range 1.2 ~ 2.8 mm

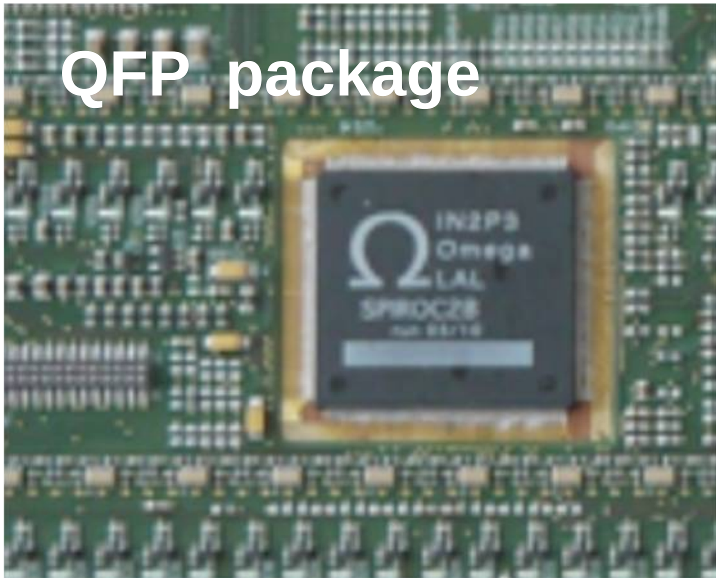
Increasing PCB thickness affects
effective Moliere radius



(outdated engineering model)

(depends on the ASIC packaging and flatness requirement)





Other important parameters:

silicon thickness:
reduce from 500 -> 320 microns
(preferred thickness for Hamamatsu large scale production)

scintillator thickness:
reduce from 2 -> 1 mm
(current ScECAL design)

dead zone at sensor edge (guard ring)
maintain at 0.5 mm

dead zone at surface of scintillator (reflector film)
maintain at ~60 microns

Digitisation

Conversion from

energy deposit in sensor material

to

detector signal

Digitisation

Presently rather simple:

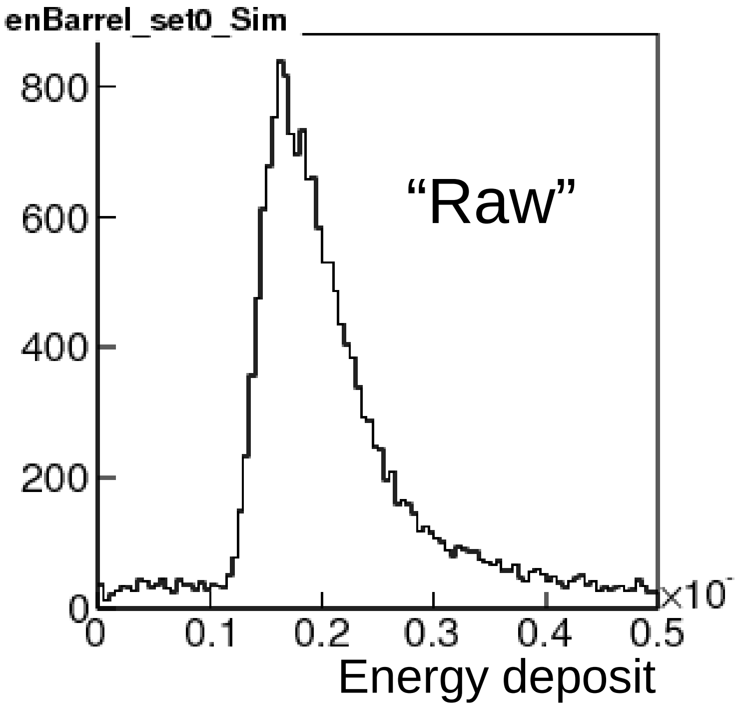
- Detector signal proportional to energy deposited in cell
- 0.5 MIP threshold is applied to each cell's signal

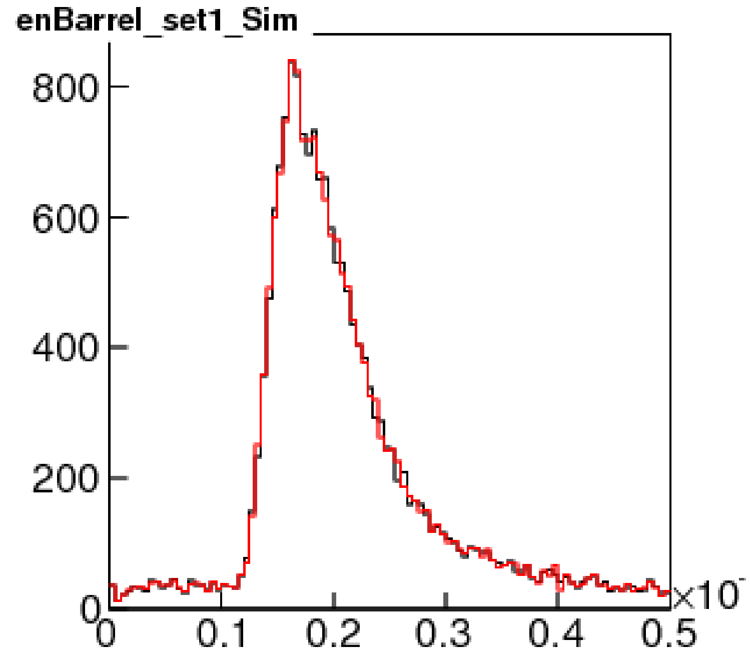
We have been developing framework to apply more realistic digitisation
- parameterised models of:
  - intrinsic detector characteristics
  - (uncorrelated) electronics noise
  - dynamic range of electronics

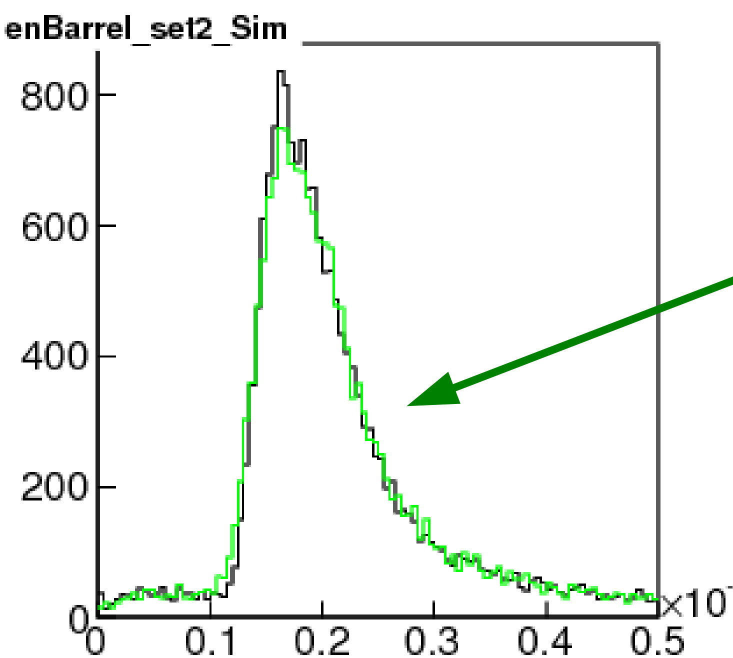
In the next few slides I show the effect of
- taking these factors into account

The parameters I have used are close to my personal “best guess”,
- but are not agreed among us, and should be considered “illustrative”

10 GeV muons: energy of hits in si-ECAL barrel





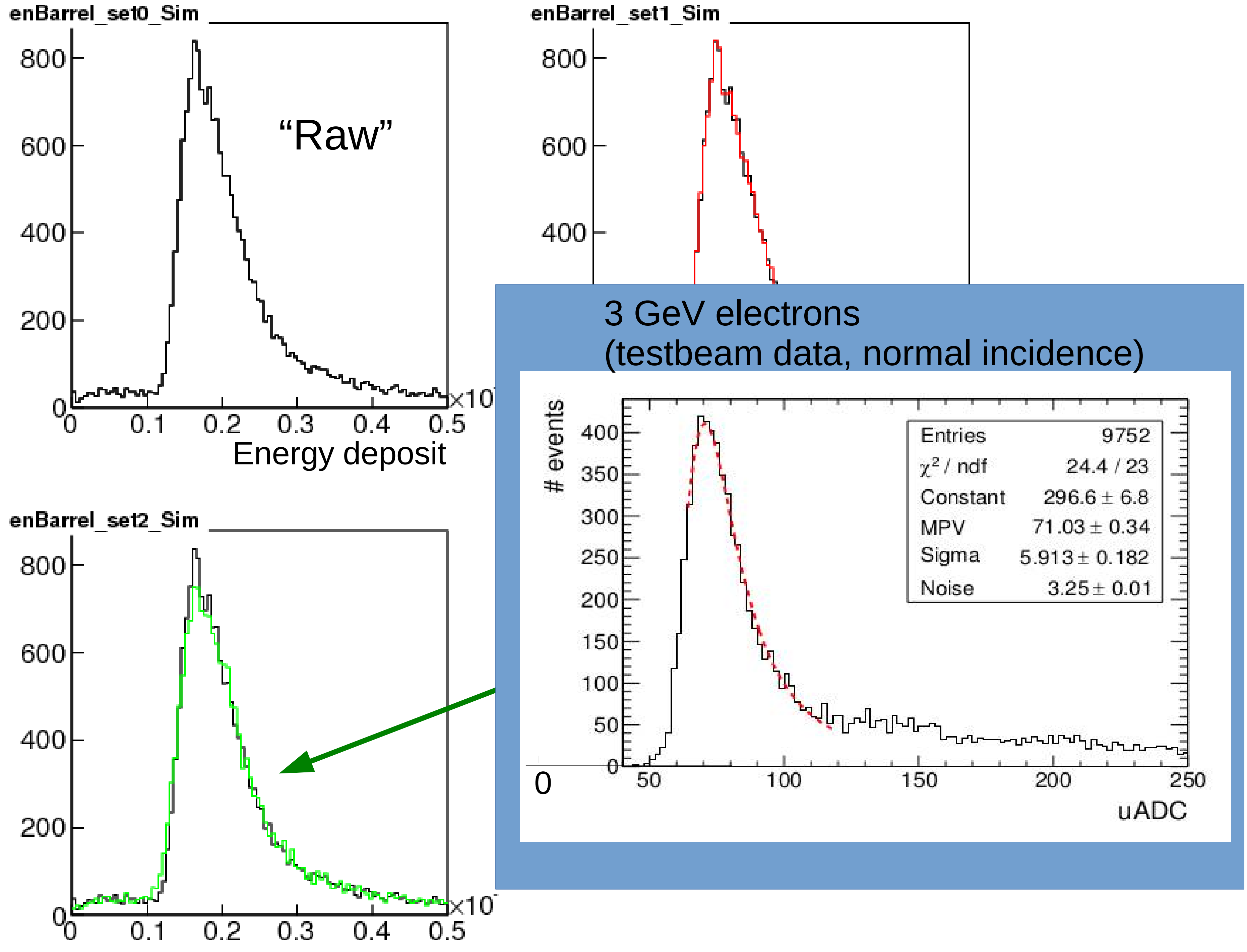


Take account of:

- finite # of e-h pairs in silicon
- electronics noise (1/15)*MIP

Rather small effects

10 GeV muons: energy of hits in si-ECAL barrel

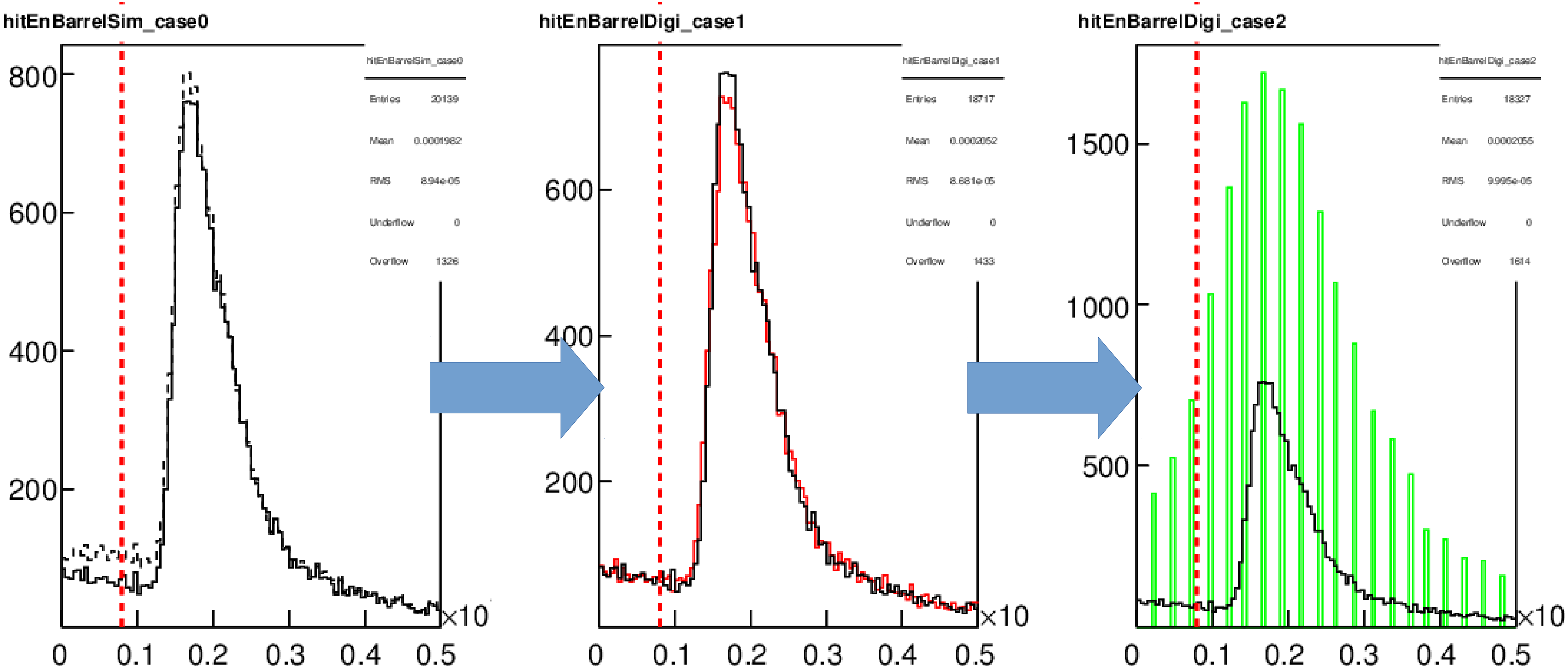


Scintillator + SiPM/MPPC modeling

Somewhat naive model:

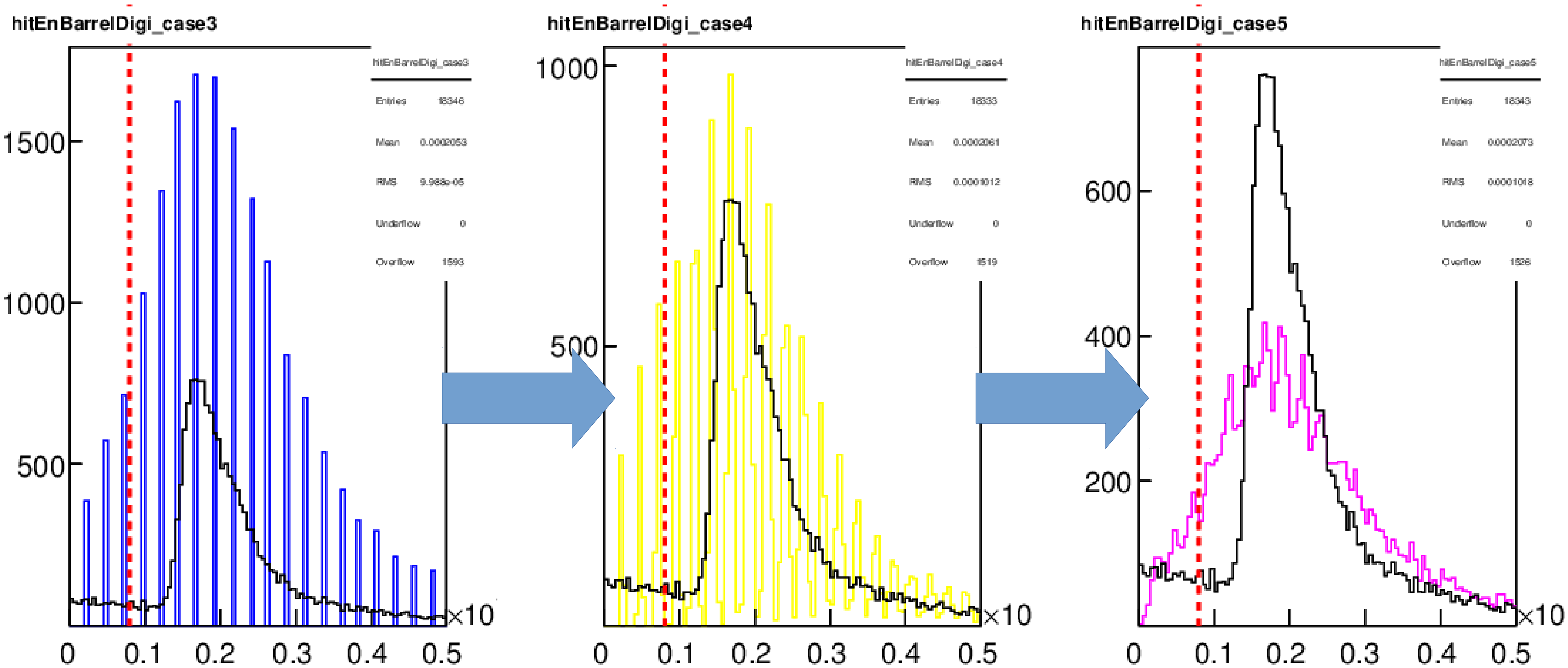
- Non-uniformity of response along scintillator strip
  - Simplified exponential dependence
- Finite number of photo-electrons created in MPPC
  - fluctuations at low signal levels
- Finite number of pixels in MPPC
  - saturation at high signal levels

10 GeV muons: energy of hits in sc-ECAL barrel



energy deposit | strip non-uniformity | finite # photo-electrons

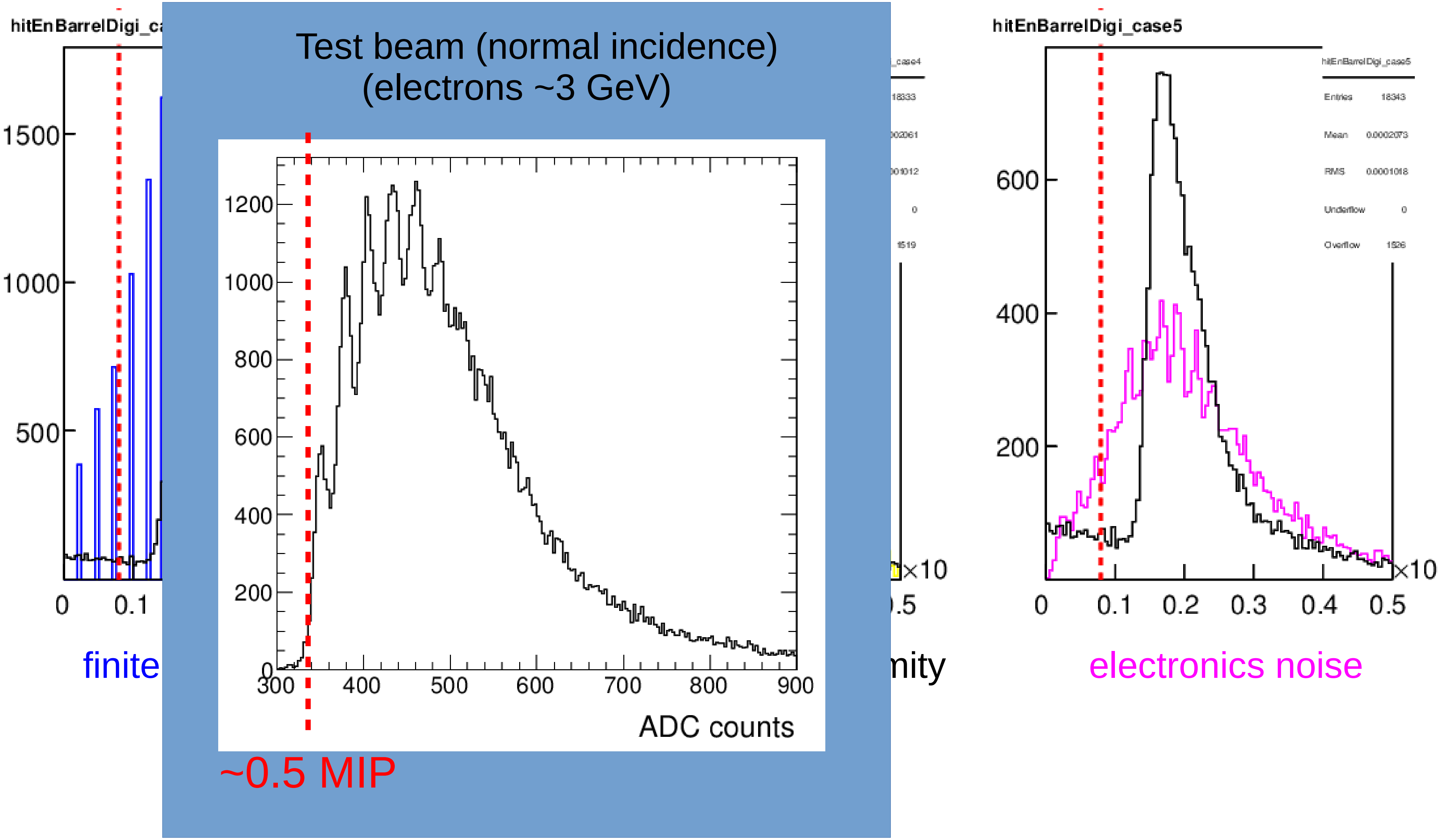
10 GeV muons: hits in sc-ECAL barrel



finite # pixels   pixel-to-pixel nonuniformity   electronics noise

Low energy hits (~ 1 MIP) significantly smeared
some loss of efficiency @ 0.5 MIP threshold

10 GeV muons: hits in sc-ECAL barrel



Summary

Improvements to realism of simulation and digitisation
give simulation models closer to today's prototypes

More realistic digitisation of
- silicon: rather small effects
- scintillator: introduces some effects,
especially for small or large signals.

implemented these parameterised effects in
(still private) version of ILDCaloDigi Marlin processor

Next steps

Reach agreement among ECAL groups on “reasonable” parameters
based on experience of CALICE prototypes
discussions already underway

release digitisation code and recommended parameters backup

- energy deposit in scintillator E

Landau fluctuation (MPV for min. ion. part = E_{mip})
dealt with by Geant4

- conversion to photons

assume (average # photons)/(MIP energy) = n
Fluctuate by **Poisson** statistics

$$n_{gamma} = (E/E_{mip}) * n$$

$$d(n_{gamma})/n_{gamma} = 1/\mathrm{sqrt}(n_{gamma})$$

- creation of p.e.

Assume each photon has a fixed probability p of creating a p.e.
Fluctuate by **binomial** statistics

$$n_{pe} = p * n_{gamma}$$

$$d(n_{pe})/n_{pe} = \mathrm{sqrt}(n_{gamma} * p * (1-p)) \oplus d(n_{gamma})/n_{gamma}$$

- firing of pixels

Fluctuate to take account of possibility of >1 p.e. / pixel
Depends on #pixels in device m ; let $a = n_{pe}/m$

$$n_{firedpixel} = n_{pe} * (1 - \exp(-a))$$

$$d(n_{firedpixel})/n_{firedpixel} = \mathrm{sqrt}(m \exp(-a)(1 - (1+a)e(-a))) \oplus d(n_{pe})/n_{pe}$$

Discussions in progress on whether
simple MPPC model is sufficient
or if measured performance should be used

Such a simple model does not accurately describe
additional effects (cross-talk, after-pulsing, pixel recovery)

Will try to measure of average MPPC response and its fluctuations
If this is not feasible on a short timescale,
may use the simplistic model in the interim

Virtual cells along Sc strip ("Ecal_Sc_number_of_virtual_cells"): 9

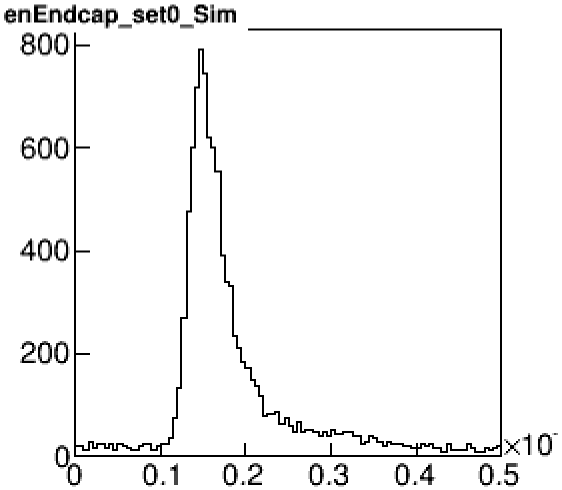
allows implementation of non-uniformity along strip

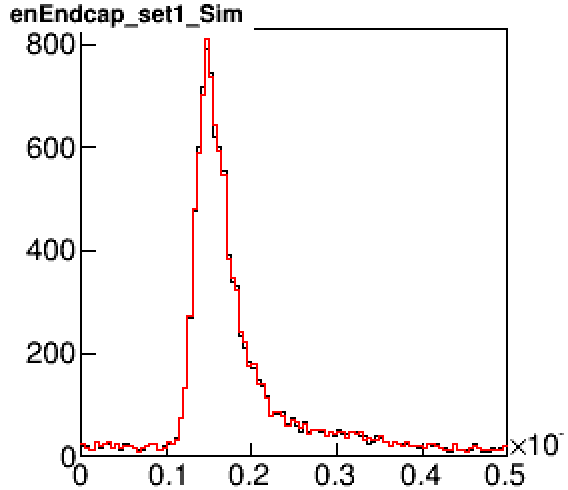
Mokka sums energy deposited in each virtual cell
re-combined in the digitisation stage,
with (optionally) different weights to
approximate exponential response

Parameters I used for plots.

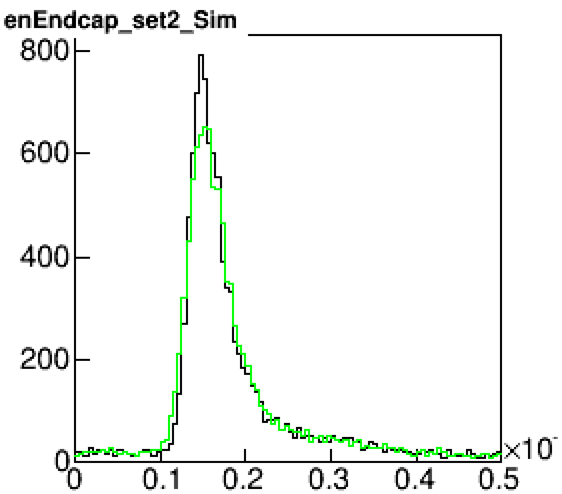
<u>Not “official” or “recommended” parameters</u>

Silicon:	25k e-h pairs / MIP electronics noise = 7% of MIP
Scintillator:	7 p.e. / MIP 10k pixels electronics noise = 5% of MIP absorption length along strip = 200 mm variation in number of pixels = 5% variation in single pixel signal = 5%

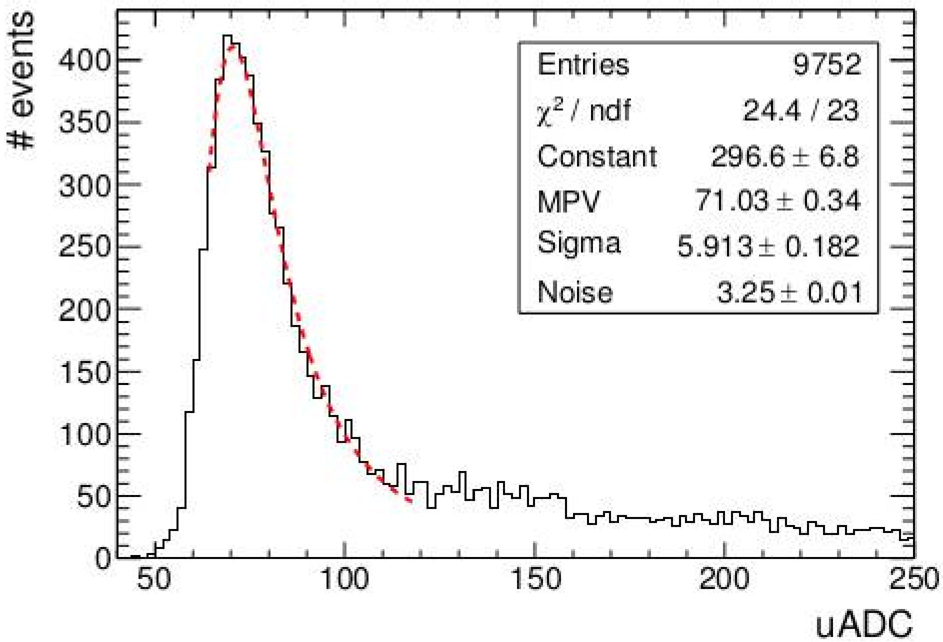




10 gev muon simulation
(corrected for path length in silicon)



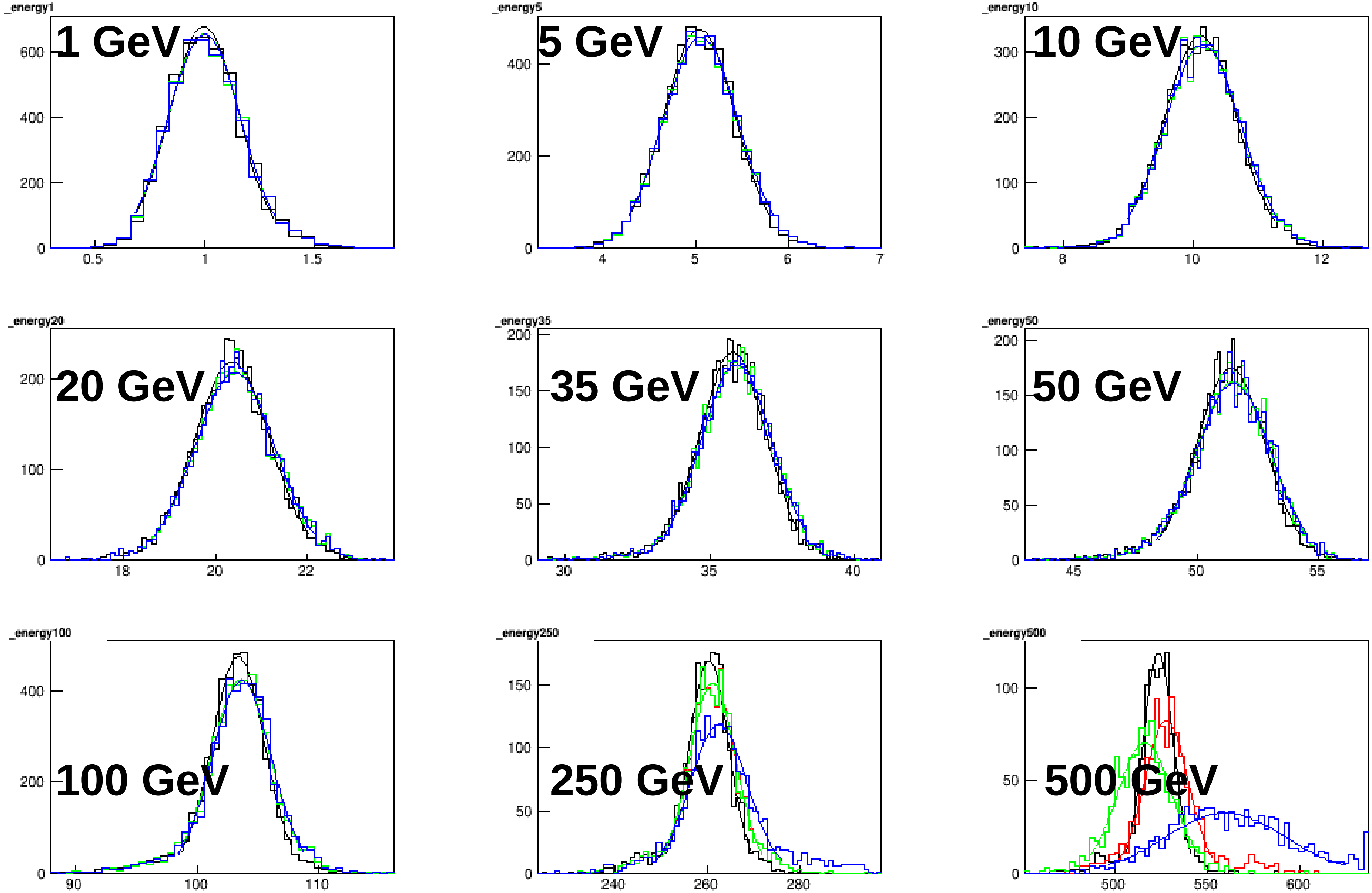
3 GeV electrons (testbeam data),
normal incidence



SiECAL:

ILD simulation vs. Test beam data

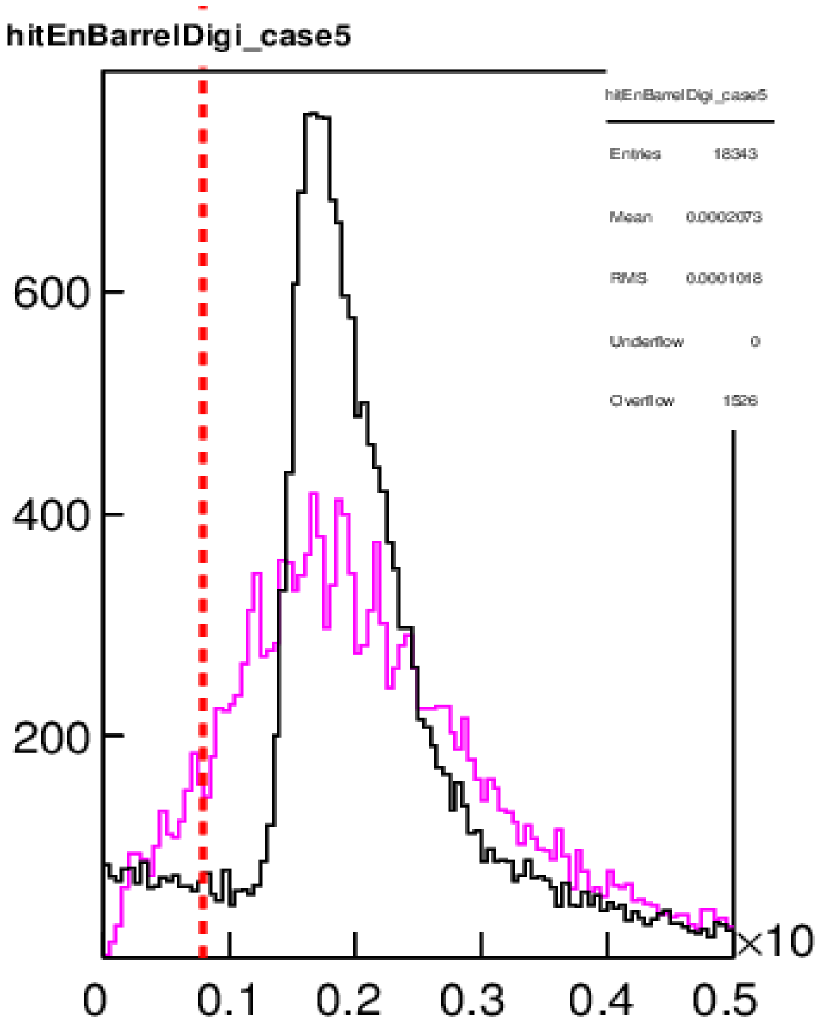
Single (unconverted) photons in ScECAL: sum of PFO energies



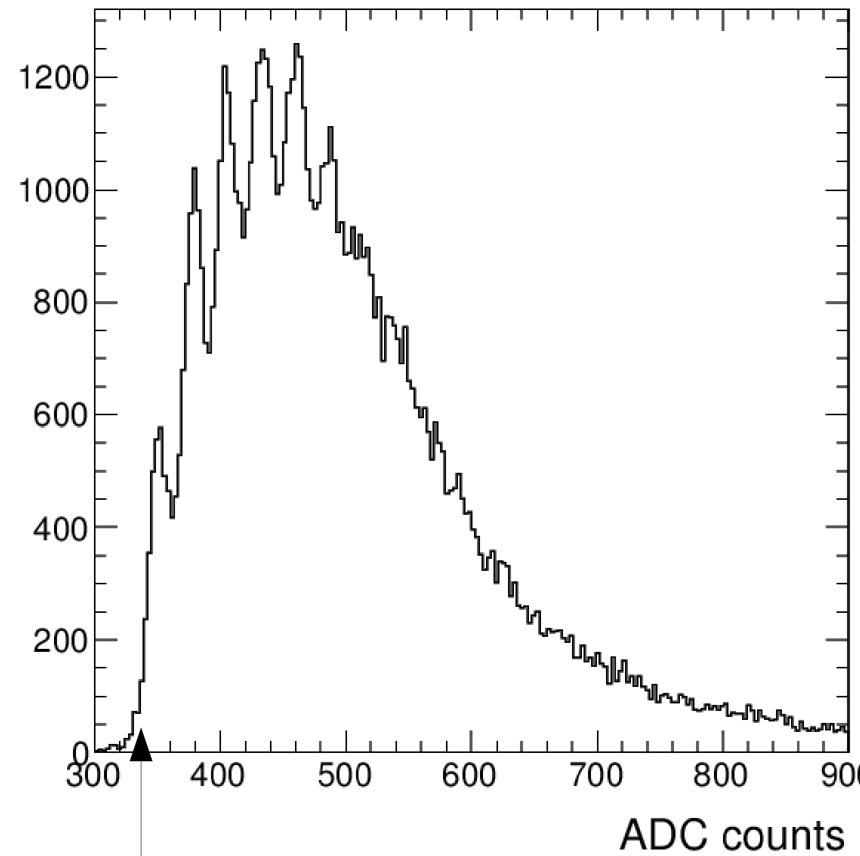
“raw”; realistic: 10k pixel , 10k pixel + electronics dynamic range , 5k pixel

Effects become visible ~ 100 GeV

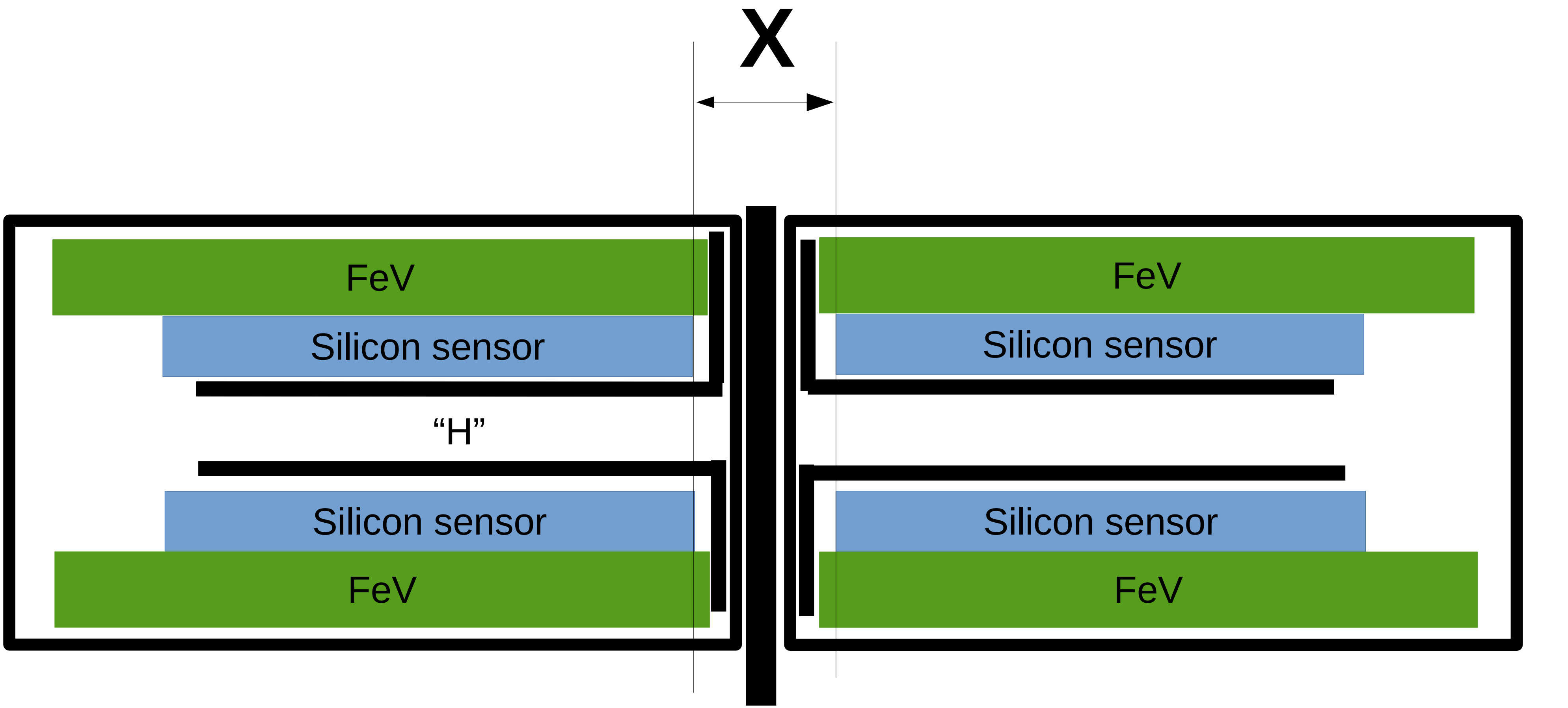
10 gev muon simulation
(barrel)



Test beam (normal incidence)
(electrons ~3 GeV)



~0.5 MIP


X
FeV
Silicon sensor
“H”
Silicon sensor
FeV
FeV
Silicon sensor
Silicon sensor
FeV