Robustness of a SiECAL used in Particle Flow Reconstruction

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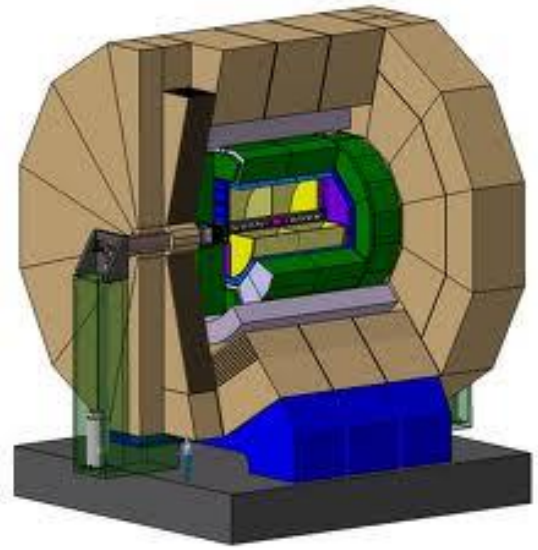
Outline

- Introduction
- ECAL optimization
  - Guard ring width
  - PCB thickness
- Robustness study
  - Dead pixels/chips
  - Noisy pixels
  - Mis-calibration
  - Cross talk

The ILD detector -Particle Flow Algorithm(PFA)-

- ILD is **optimized for PFA** in hadronic jets. PFA does calorimeter tracking and separates each particle cluster, and **identifies** whether the **particle is charged, a neutral hadron, or photon.**

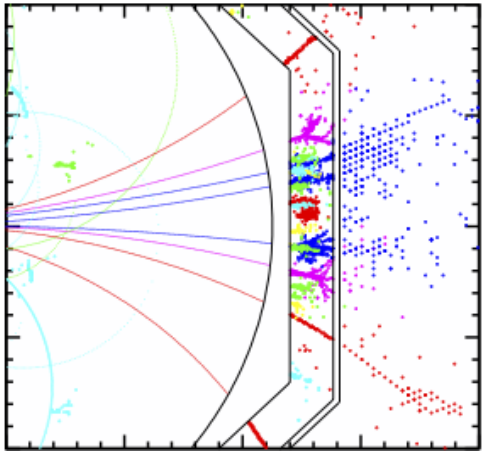


- Particles in jets

  Charged particle(~65 %)→TPC

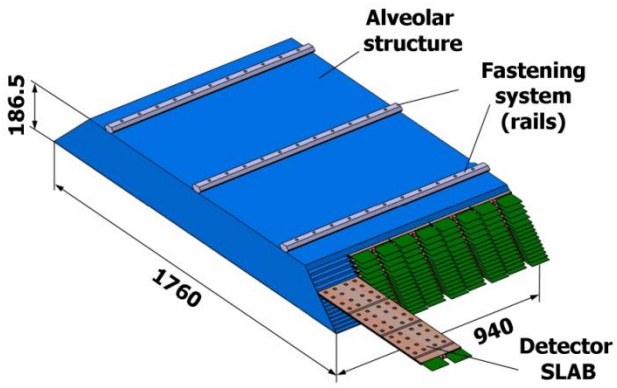
  Photon (~25 %) →ECAL

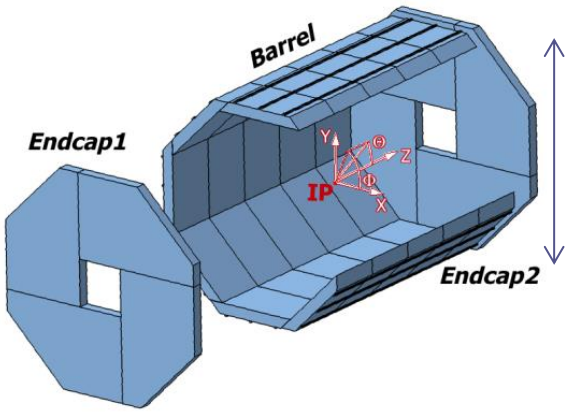
  Neutral hadron (~10 %) →HCAL



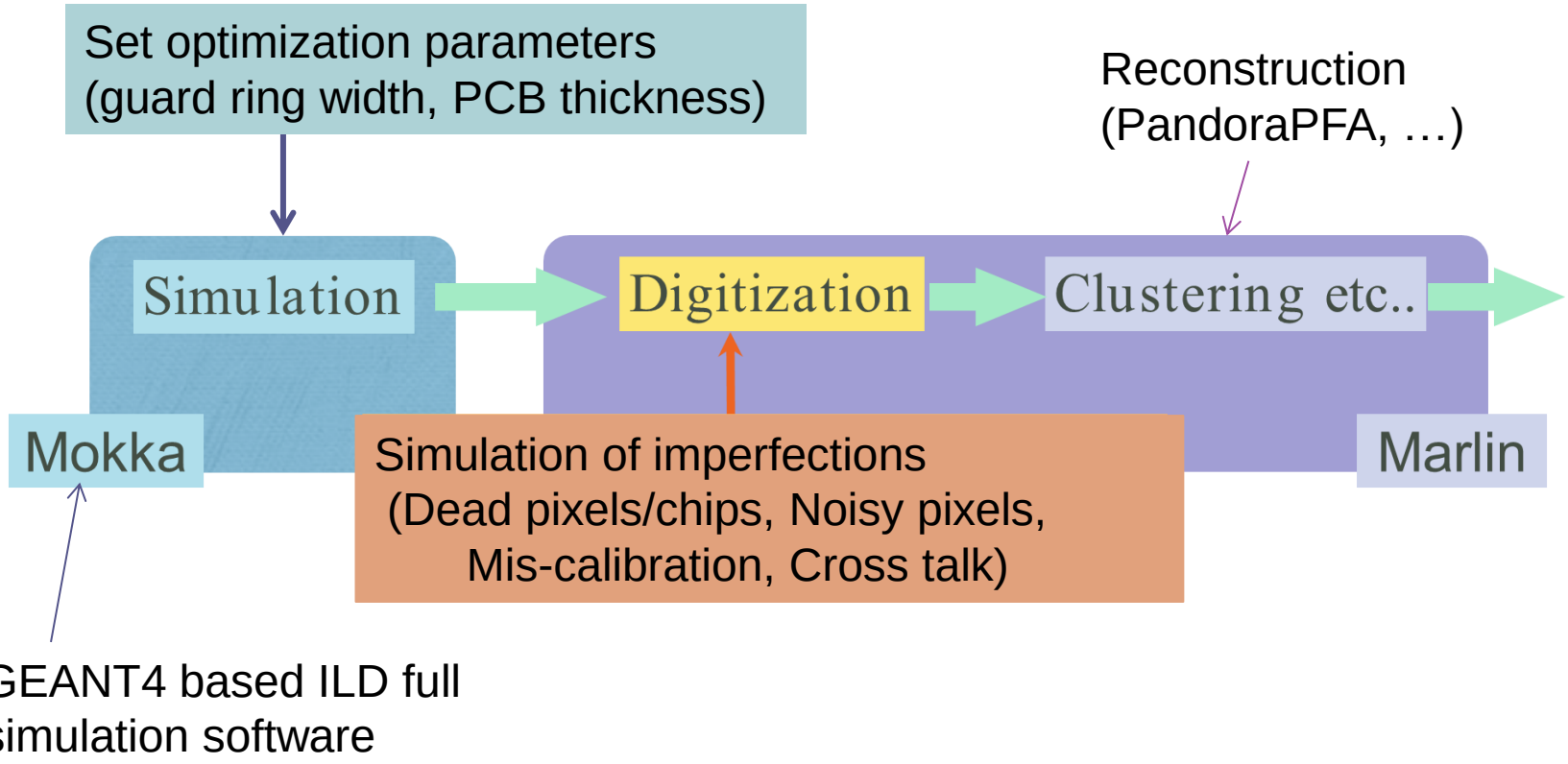
SiW ECAL design

- One of the options for the ILD ECAL
  - Sandwich calorimeter with silicon PIN diodes as detector layer
- Optimized design for PFA
  - Tungsten absorber: compact EM showers
  - 5×5 mm^2 pixel size, O(10^8) channels in total
  - Thin silicon sensor is available.



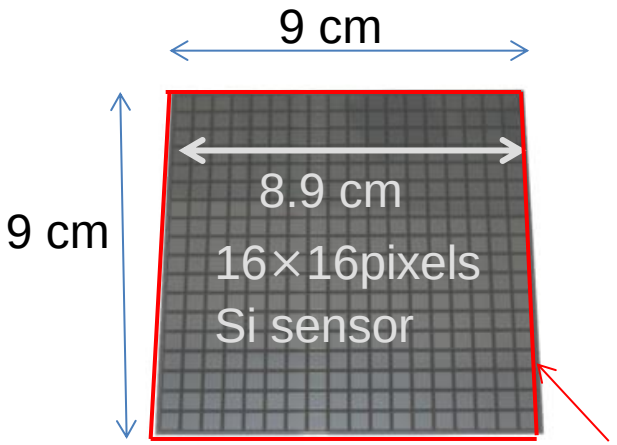


Simulation


Set optimization parameters
(guard ring width, PCB thickness)
Reconstruction
(PandoraPFA, …)
Simulation
Digitization
Clustering etc..
Mokka
Marlin
Simulation of imperfections
(Dead pixels/chips, Noisy pixels,
Mis-calibration, Cross talk)
GEANT4 based ILD full
simulation software

Guard ring in Si sensor

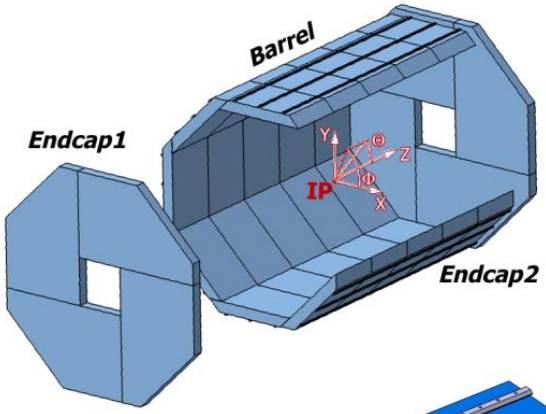
- A sensor is a matrix of PIN diodes.
- Guard ring **prevents surface leakage current.** Thus it **decreases noise** and **keeps the dynamic range**. However it creates **a less efficient area.**

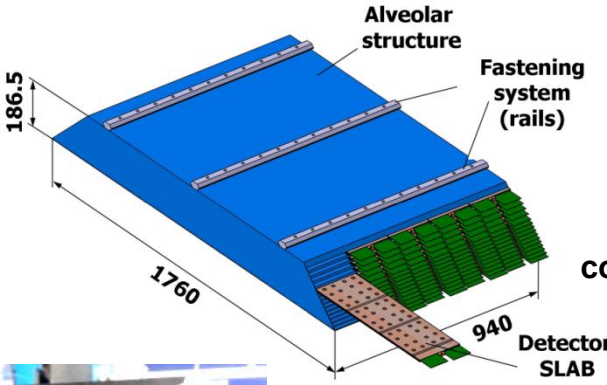


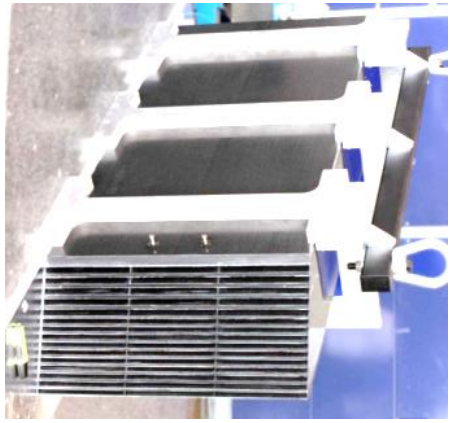
Sensor for ILD.
guard ring-induced
dead area width:
0.5 mm(default value)

Guard ring picture
from Kyushu Univ.

Guard ring effect -SiECAL structure-

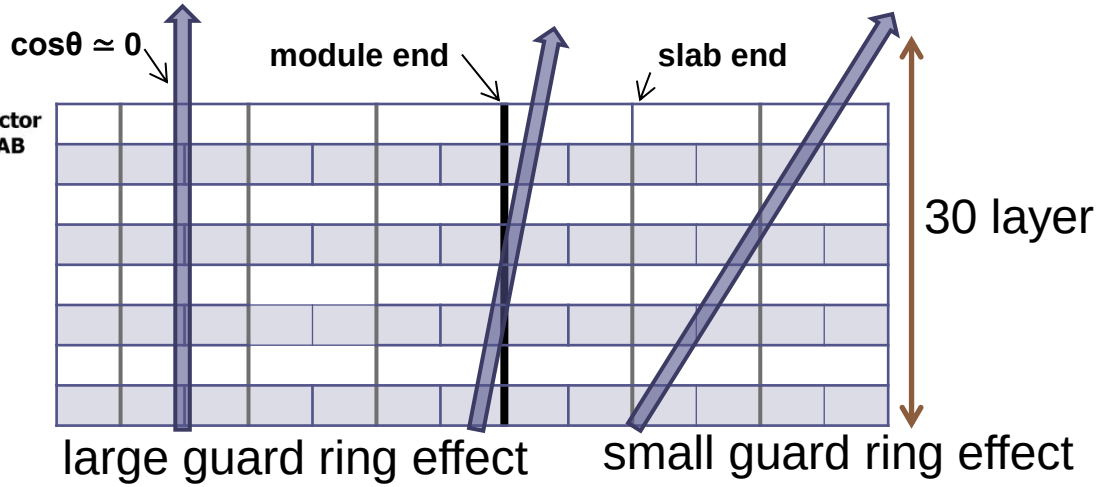






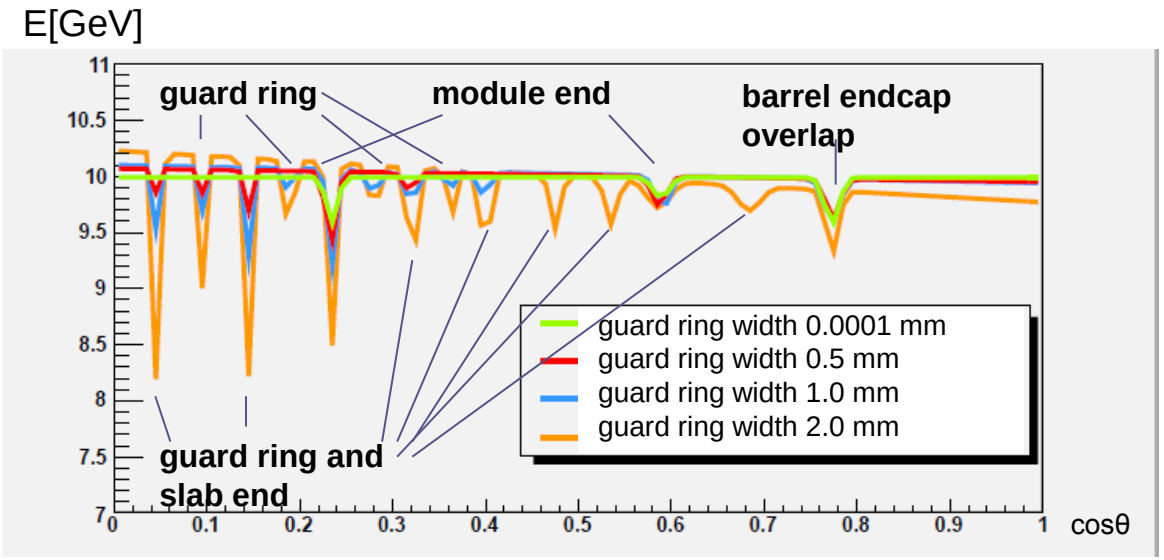
- We will have guard ring effect particularly in vertical direction to the beam pipe.

(Projective guard ring zone)



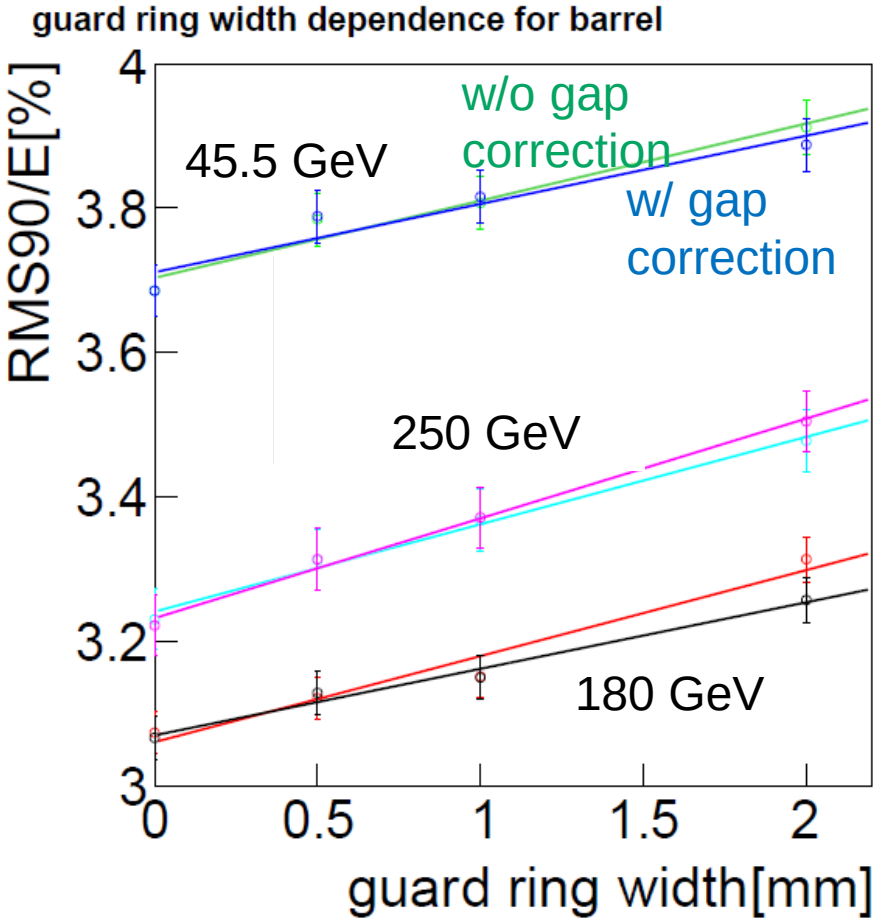
Energy correction function

- These functions were obtained by fitting the cosθ dependence of the reconstructed energy of 10 GeV photons.
- Larger guard ring has larger effect.

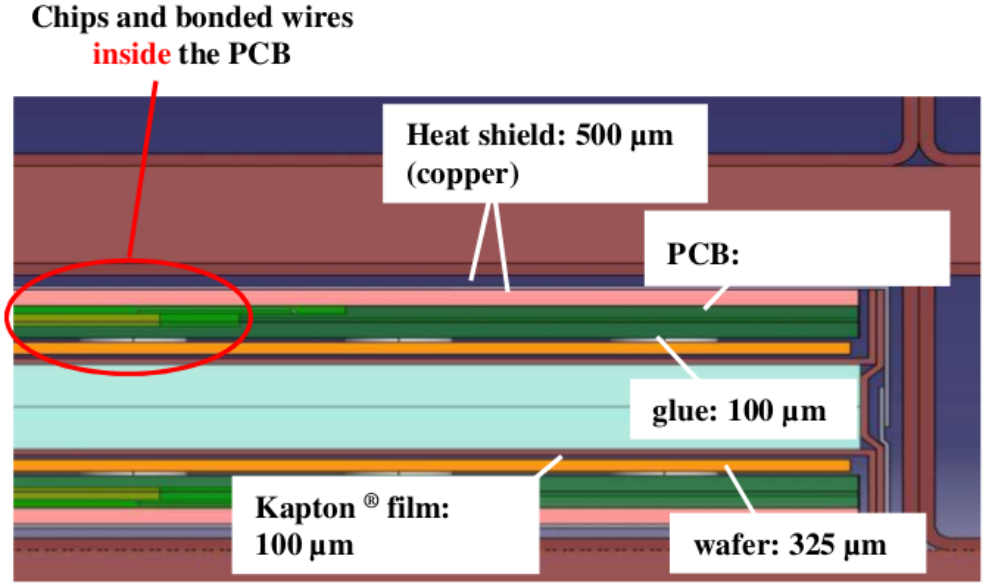


Jet energy resolution (JER) with different guard ring width

- JER increases as guard ring width increase.
- About 6 % difference between 0 mm and 2 mm.
- Direction correction has small effect on RMS90.



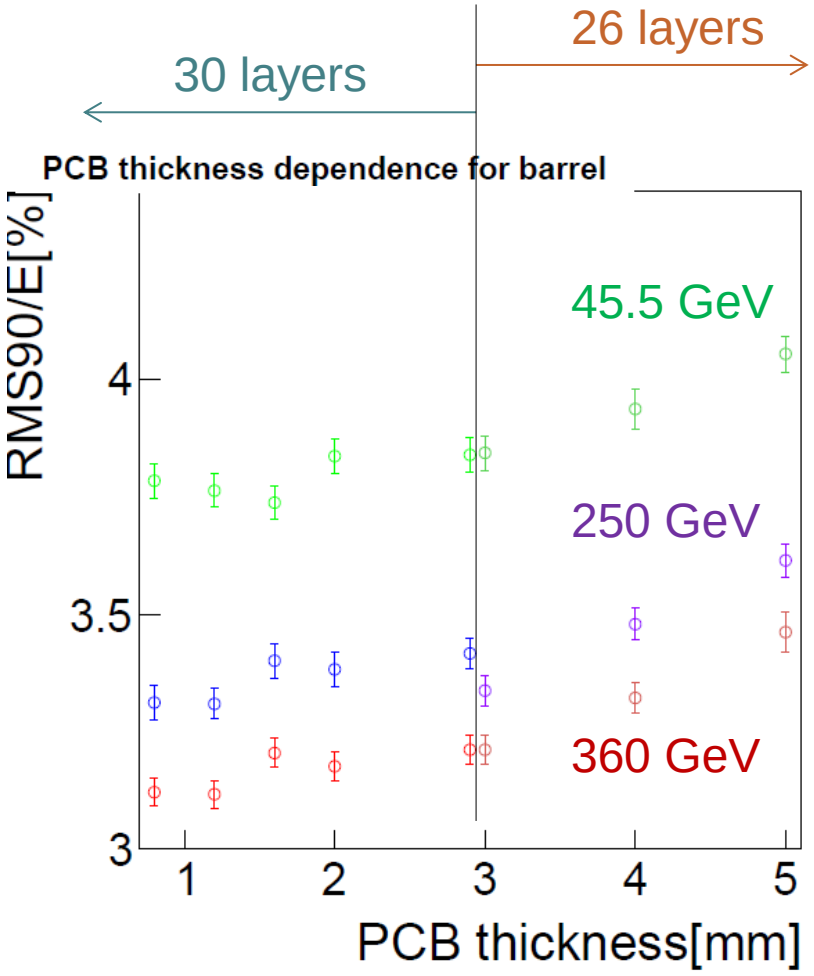
PCB (Printed Circuit Board) thickness effect



- As we have many channels in ECAL, we put PCB in each layer to combine signals (serialize) and reduce number of readout cables.
- **A Thick PCB will increase lateral shower size,** so a thin PCB maybe preferred.
- However, it is technologically difficult to produce a thin and flat PCB.

Simulation result

- For 3 mm, # of layer doesn't matter to result.
- no degradation in JER up to 3mm
- Between 3 and 5mm, JER difference is 5-8 %.



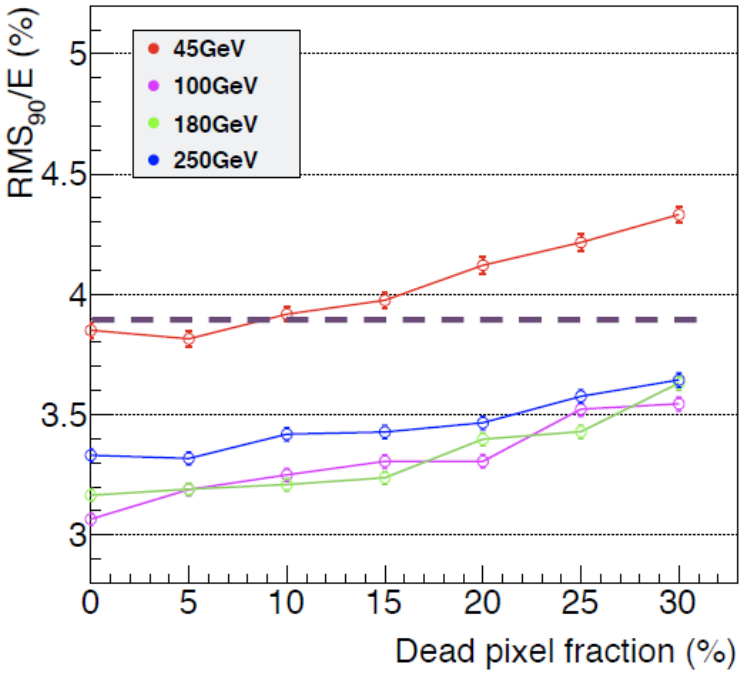
Dead channels effect by S. Chen

- If a few % of dead cells are allowed, this may increase the yield for Si sensor production and reduce cost.
- Some of the readout chip may be damaged during construction or experiment.
  - 1 chip reads out 64 channels

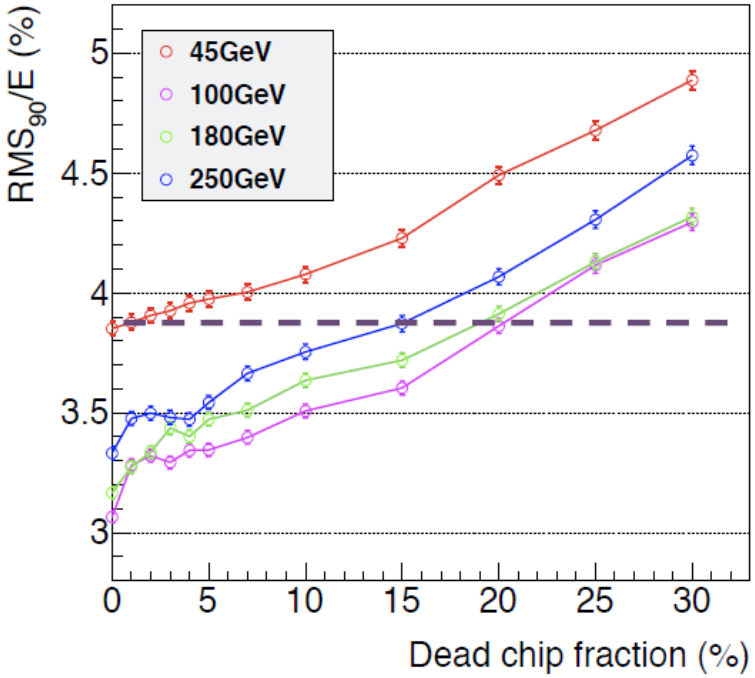
JER dependence on dead pixels / chips fraction

By S. Chen

Dead pixels



Dead chips



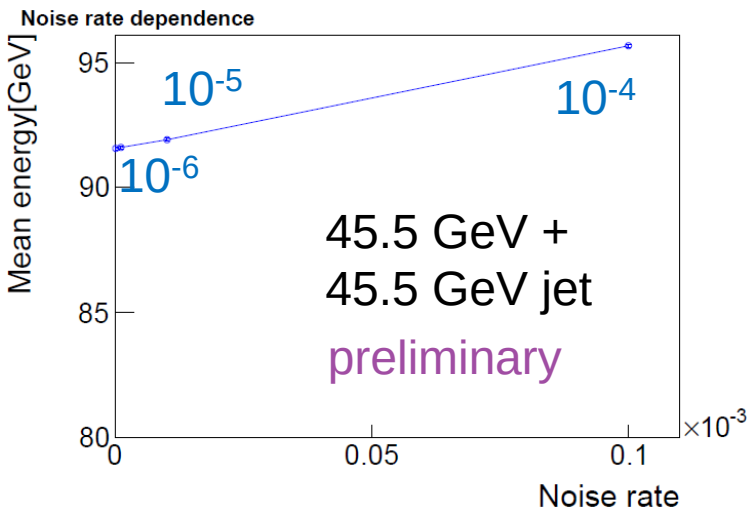
- JER is insensitive to dead pixels ≤ 10%.
- JER is more sensitive to dead readout chips, about 2 times more than for dead pixels.

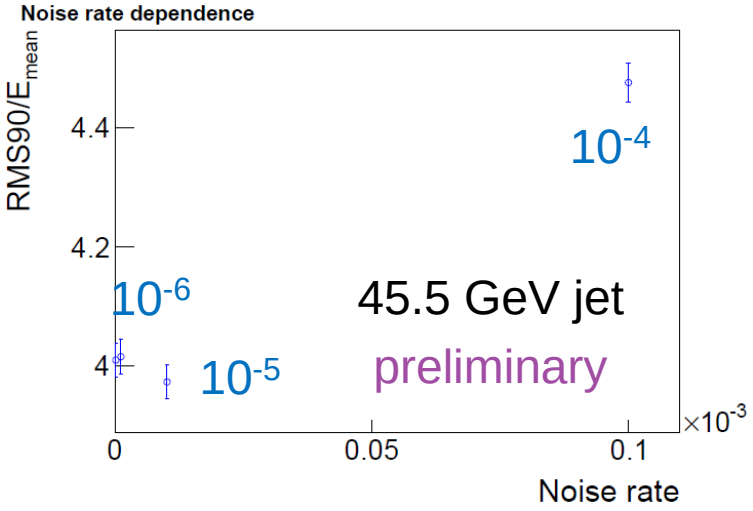
Noisy pixel study

- Typical signal-to-noise in Si-sensor for MIP is ~10.
  - Assume Gaussian noise → 0.5 MIP threshold
    → ~10^{-7} noise rate
- In reality, noise will be worse
  - Investigate 10^{-4}, 10^{-5}, 10^{-6} noise rate
  - Naively assign each noise hit energy of 1.4 MIP
- Investigate effect on particle flow
  - Most noise hits are isolated and not clustered.

Simulation result

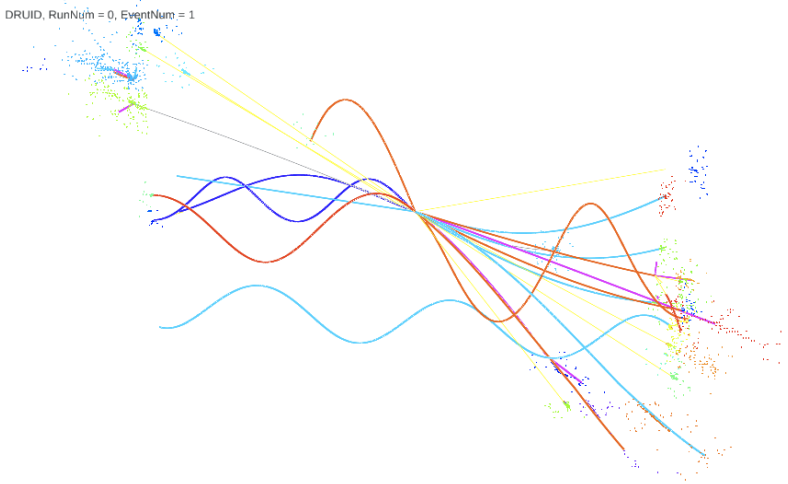
- Mean Shift
  - Linear dependence on noise rate.
  - ~1000 noisy pixels →~5GeV energy increase
- JER
  - Noise rate of O(10^{-5}) does not affect to JER.



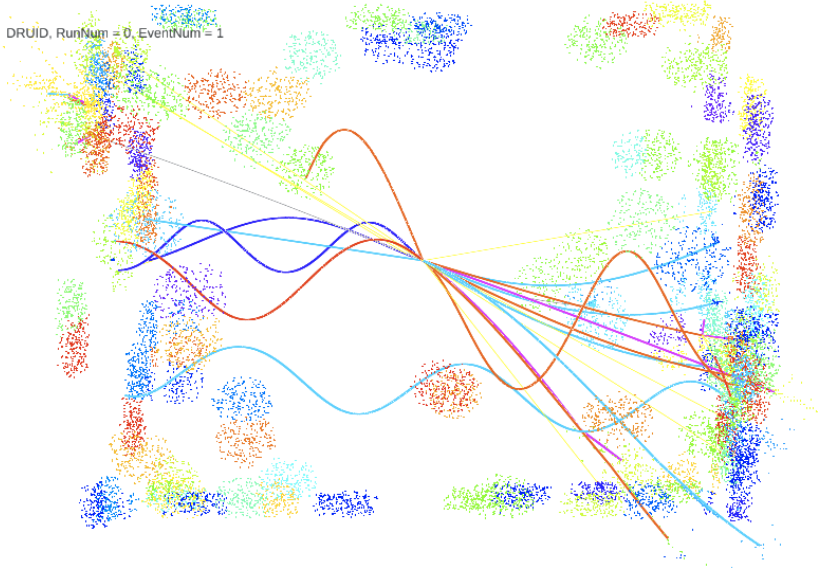


Event display example

- Noise rate of 10^{-5}



Noise rate of 10^{-3}



Many fake clusters of noisy pixels !

Mis-calibration study by S. Chen

- We cannot measure infinitely correct calibration coefficient.
- The calibration factor may change during running period.
  - Radiation damage decrease signal collection efficiency.
  - Temperature effect
  - Electronics problem
- In this simulation, calibration coefficient is multiplied by 1+ Gauss(0, smear)

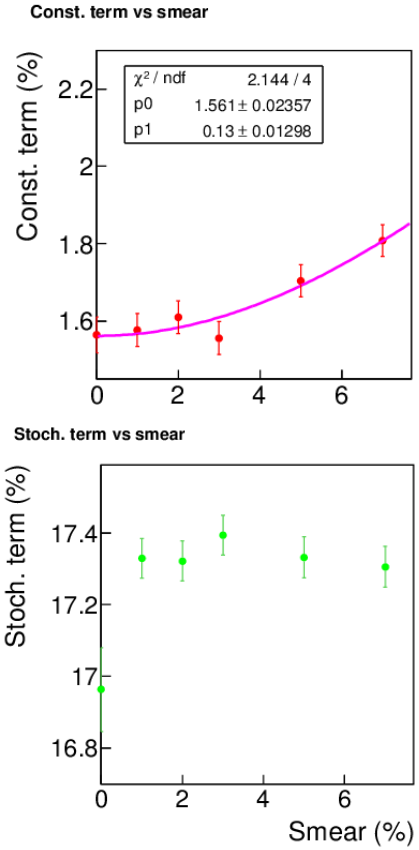
randomly distributes chip by chip

Mis-calibration

By S. Chen

- Only constant term is affected.
- Note: No significant effect on jet measurement

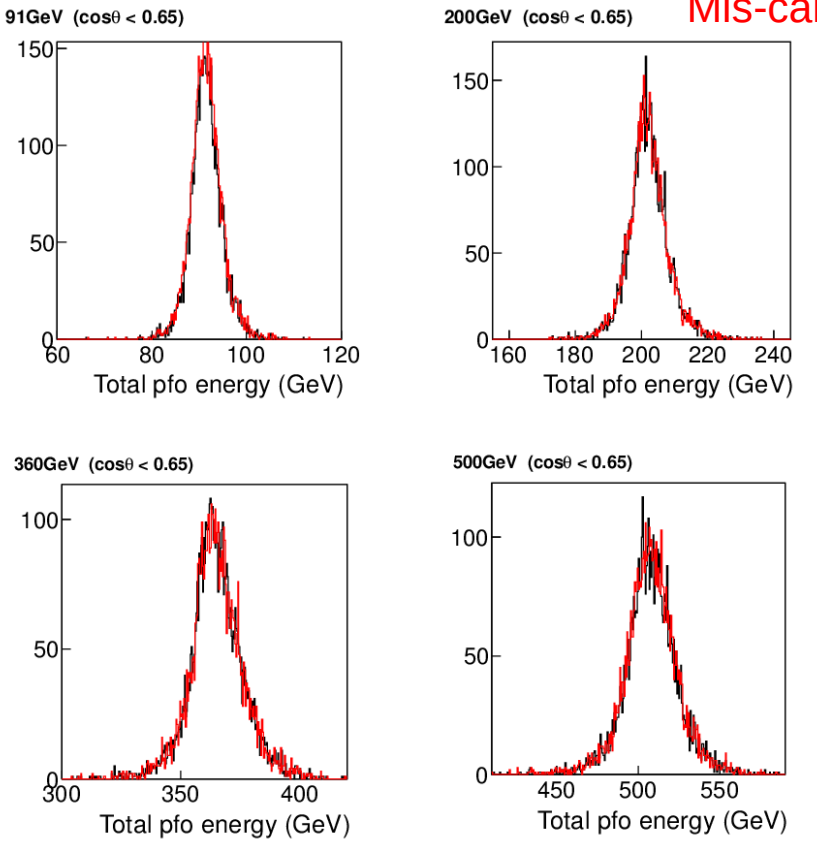
Photon



Jet

correct calibration

Mis-calibration 10%



Cross talk by S. Chen

- Cross talk between channels may occur in the readout chip.
- In this simulation, a certain fraction (few %) of a pixel's energy is added to adjoining pixels.

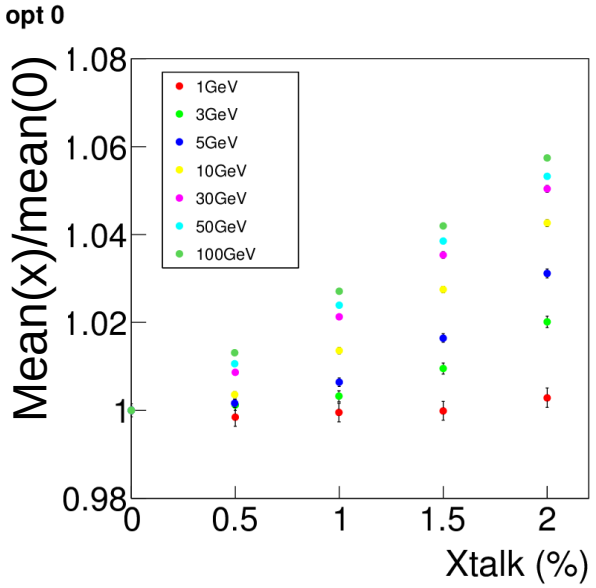
Fake hit by cross talk
Energy = E×const.

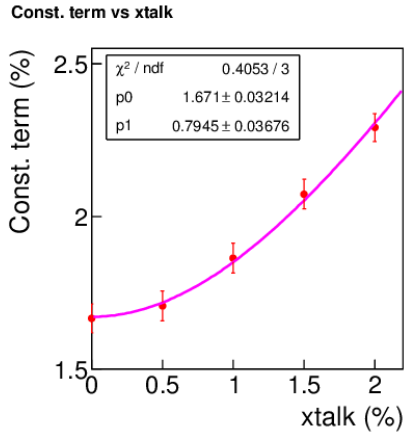
E*x	E*x	E*x
E*x	Hit E	E*x
E*x	E*x	E*x

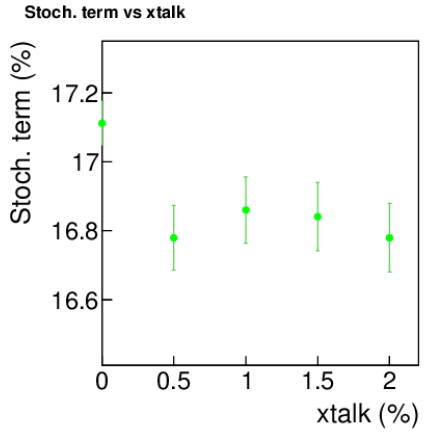
Photon study on cross talk

By S. Chen

- Mean energies get larger as cross talk fraction increase non-linearly.
- Only constant term is affected.







Summary

- We are studying the optimization and robustness of SiW ECAL for ILD.
- Jet energy resolution(JER) increases with guard ring width. The relative increase between 0 and 2 mm is about 6 %.
- With increasing PCB thickness, JER starts to degrade at around 3 mm. Between 3 and 5mm, JER difference is 5-8 %.
- JER is more sensitive to dead readout chips, about 2 times more than for dead pixels.
- Noise rate ≤ $O(10^{-5})$ may be tolerable (for current PFA)
- Mis-calibration and inter-pixel cross talk affects the constant term of the photon energy resolution.

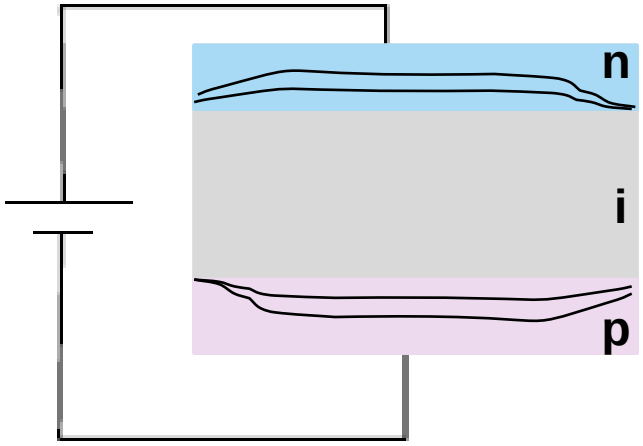
Back up

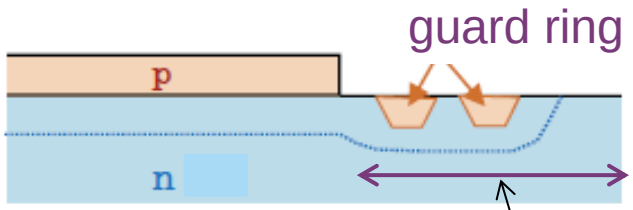
ECAL structure in ILD

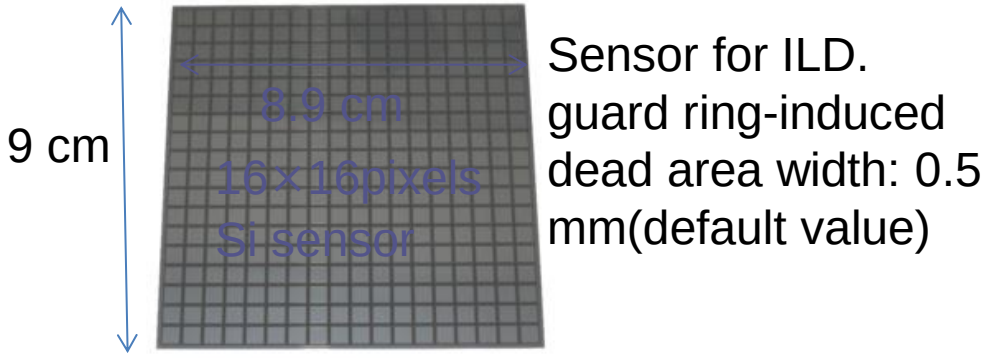
- Sandwich calorimeter with **tungsten absorber** and **Silicon sensor** or **scintillator and MPPC** for detector.
- Tungsten absorber for **short radiation length** X_0 (0.35 cm), **small Molière radius**(0.93 cm) and **large ratio of interaction length to radiation length**(27.4).
  - For PFA, **high granularity is required for good separation of clusters.** The segmentation is **5 mm×5 mm**.
  - ECAL has 30 layers, equivalent to about $24X_0$.

About guard ring in Si sensor

- Sensor is matrix of PIN diodes.
- Guard ring **prevents surface leakage current.** Thus it **decreases noise** and **keeps the dynamic range**. It also extends depletion layer.

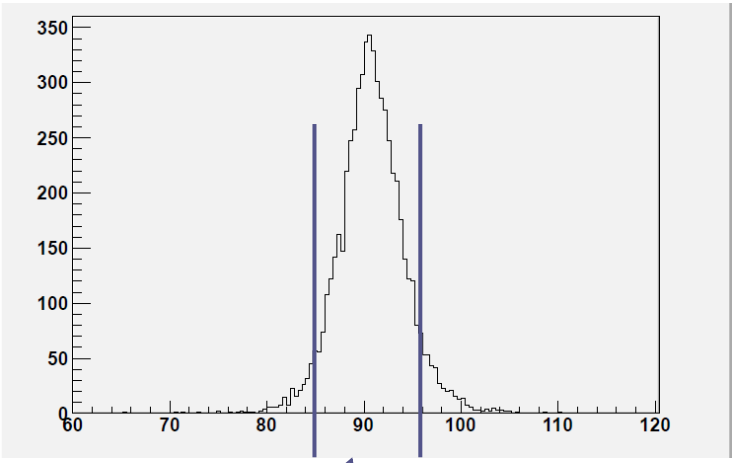






Jet Energy Resolution (JER) evaluation

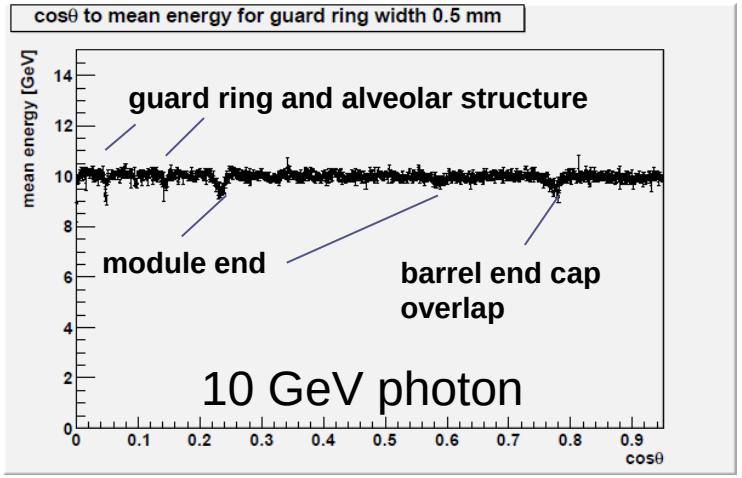
- We use **“Z→uū/ddˉ/ssˉ”** events
  - Z decayed at rest, avoid barrel/endcap overlap region.
- Tails
  - Confusion is significant
  - RMS over-emphasizes the tails
- **RMS90**
  - Defined as the RMS in the smallest range of reconstructed energy which contains **90 % of the events**

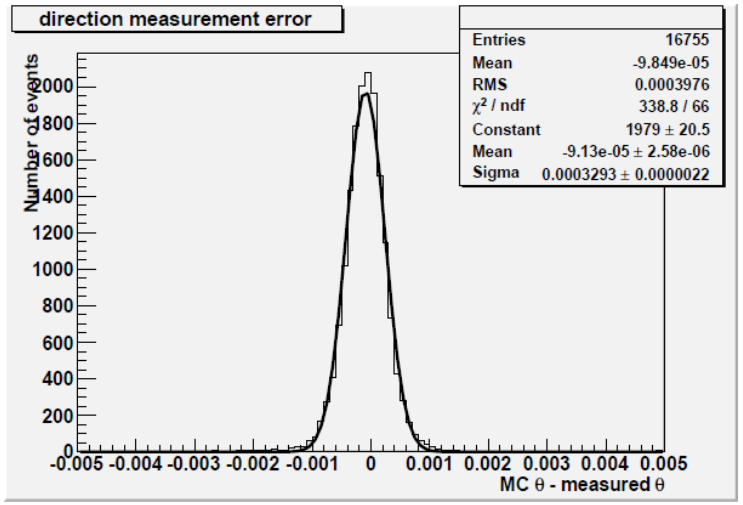


RMS90 is calculated using events in this 90 % area

Energy correction for photon

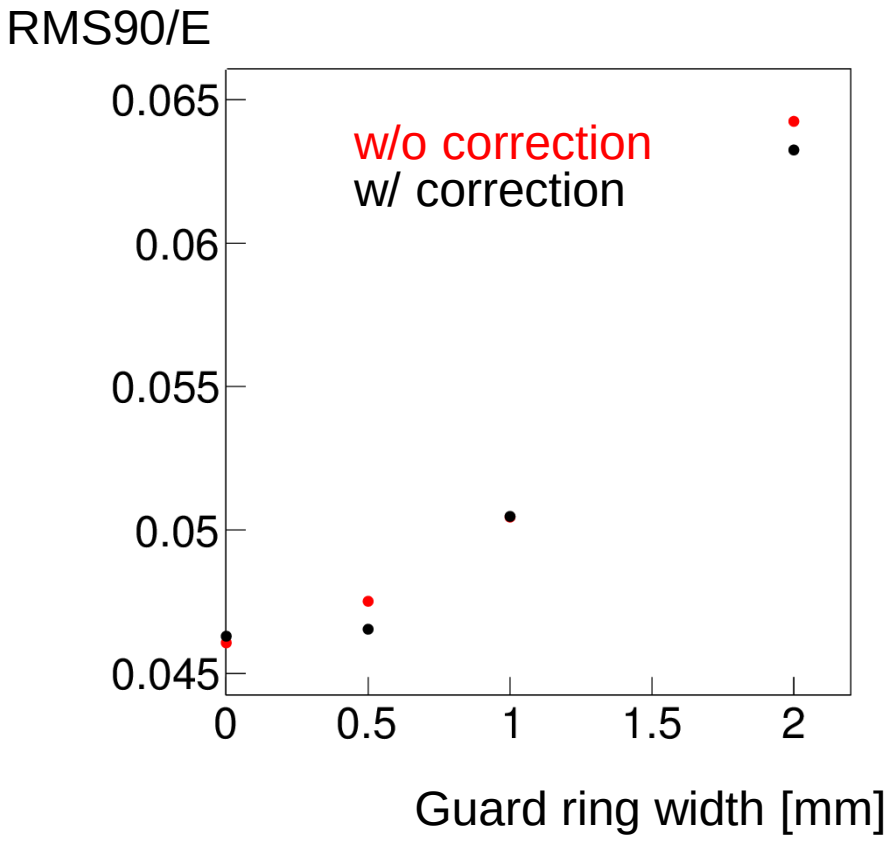
- Energy decreases in central guard ring, alveolar structure, module end and barrel end cap gap.
- **Direction resolution** for θ is **3.3×10^{-4} rad.** It's **sufficient to give a correction by θ.**
- Upper graph can be fitted by linear and Gaussian functions.





10 GeV photon measurement with gap correction

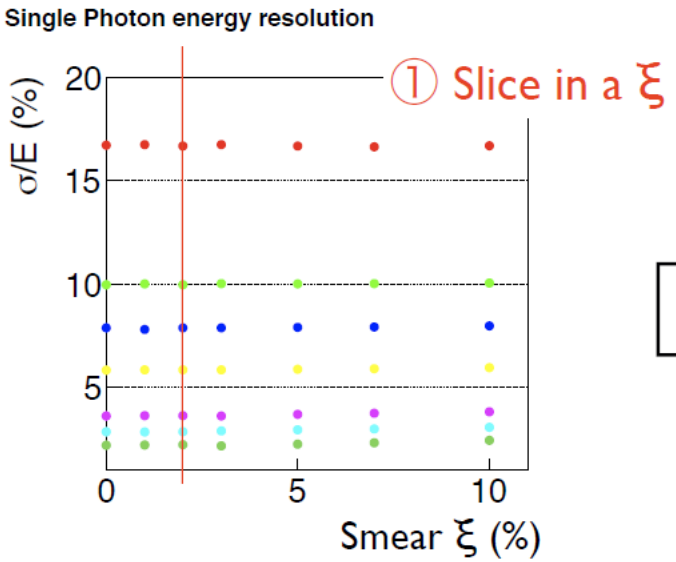
- Small difference with gap correction
  - Largely corrected direction event has much worse resolution than other direction.

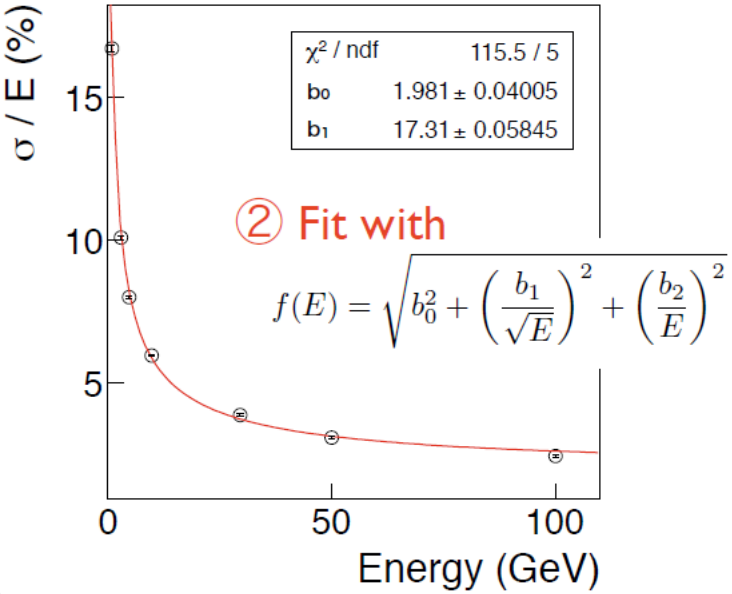


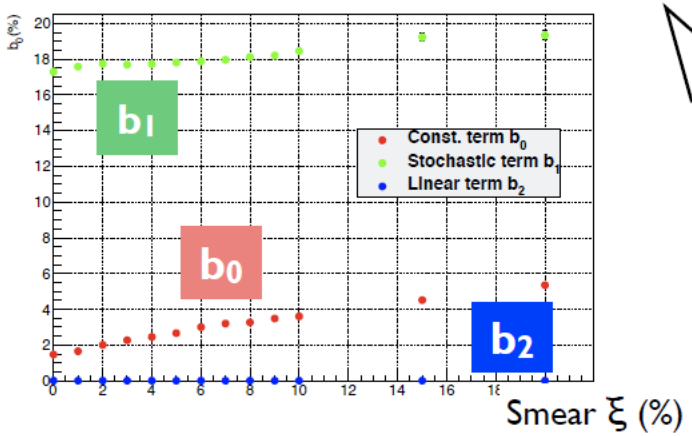
Photon study scheme

By S. Chen

mis-calibration



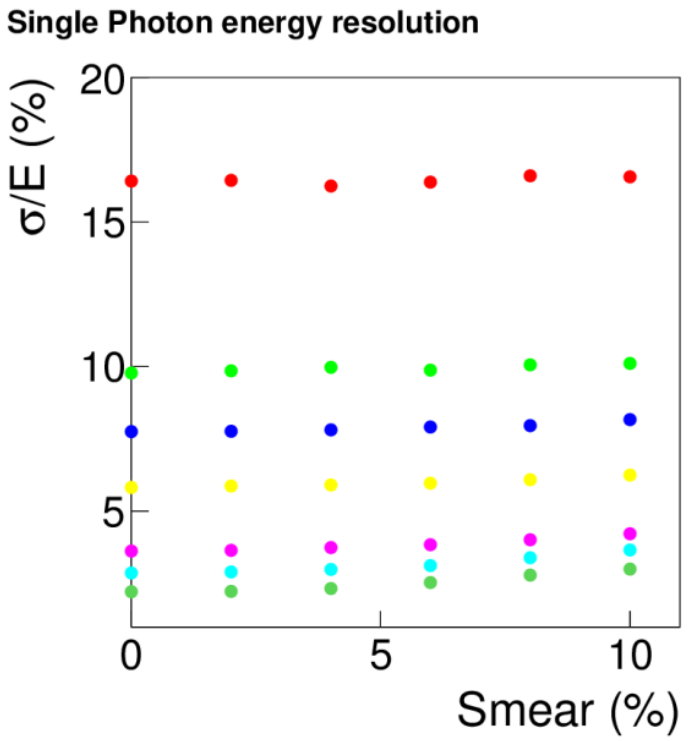




③ Plot b_0, b_1 ,b_2 for every ξ

(b_2 is always ~0 ⇒ Fix b_2 =0)

Mis-calibration of chip



Mis-calibration

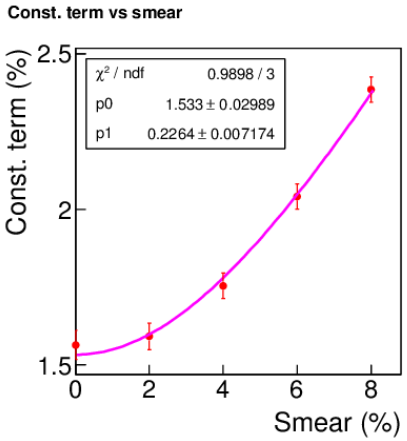
- Perfectly correlated in chip

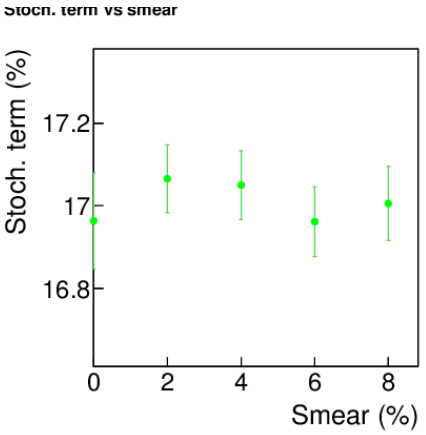
Photon

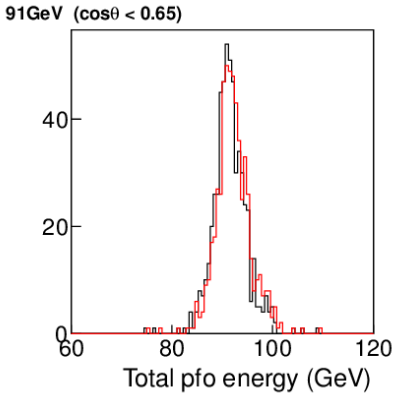
Jet

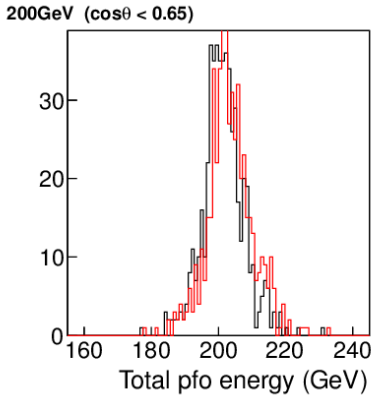
correct calibration

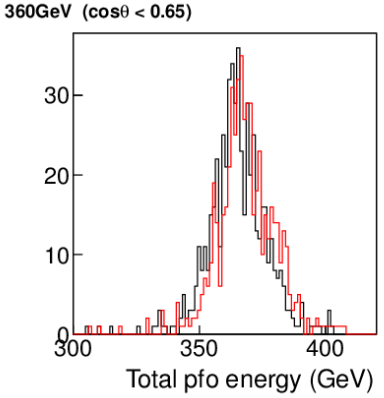
Mis-calibration 10%

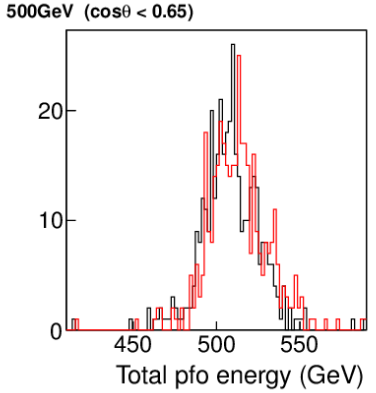




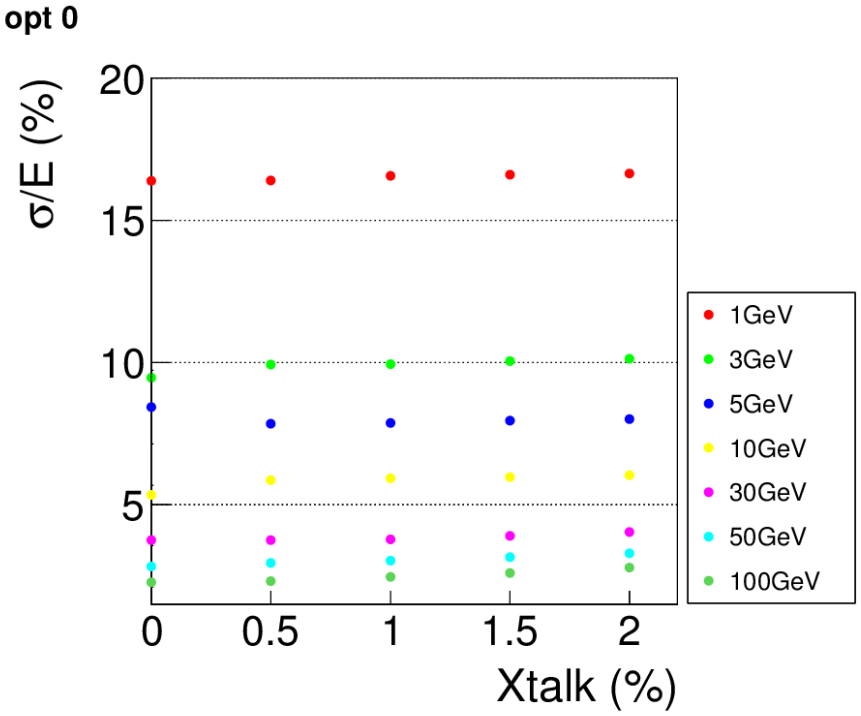








Cross talk


opt 0
σ/E (%)
20
15
10
5
0
0.5
1
1.5
2
Xtalk (%)
1GeV
3GeV
5GeV
10GeV
30GeV
50GeV
100GeV