Simulation Study on SiW ECAL optimization

Guard ring / PCB thickness
Dead pixel

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+ Outline

- Structural optimization of SiW ECAL
  - Width of guard ring of the sensor
  - PCB thickness
  - Effect of dead channels

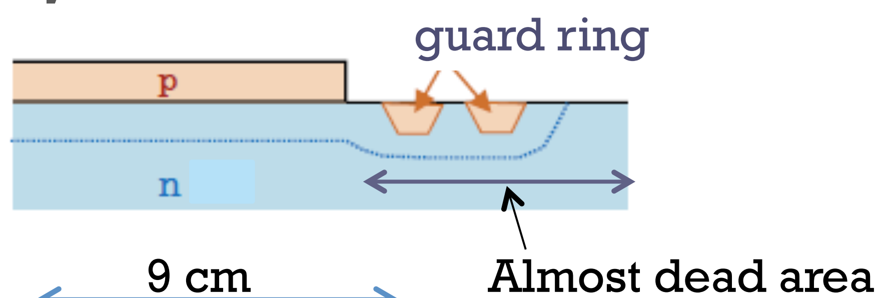
- Simulation with ILD detector Model (DBD version)

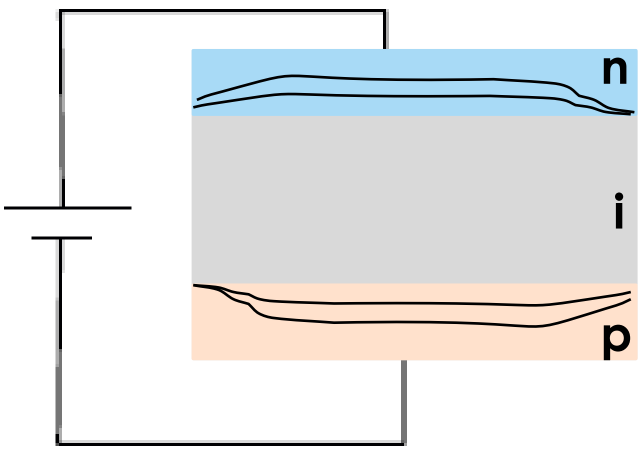
Guard ring width problem

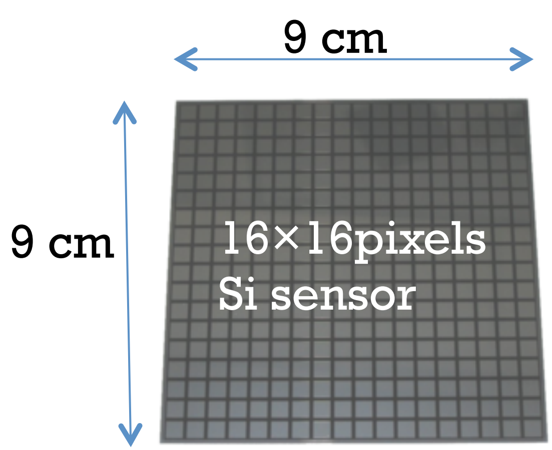
By C. Kozakai

P-doped band embedded around the edge of Si pad

- **Prevent surface leakage current.**
  (⇒ less **dark noise, fine dynamic range**)
- Improve distortion of depletion layer
- Create dead area



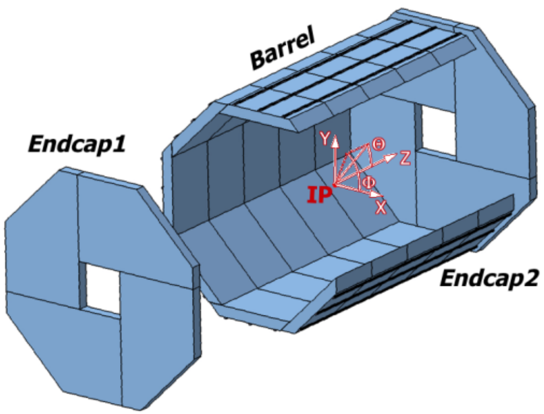




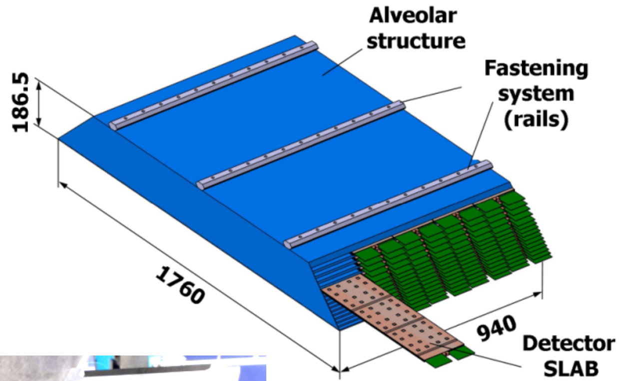
Many designs are being developed by HPK

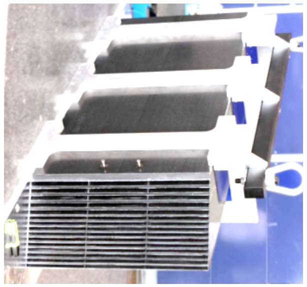
ILCsoft default:
0.5 mm th.

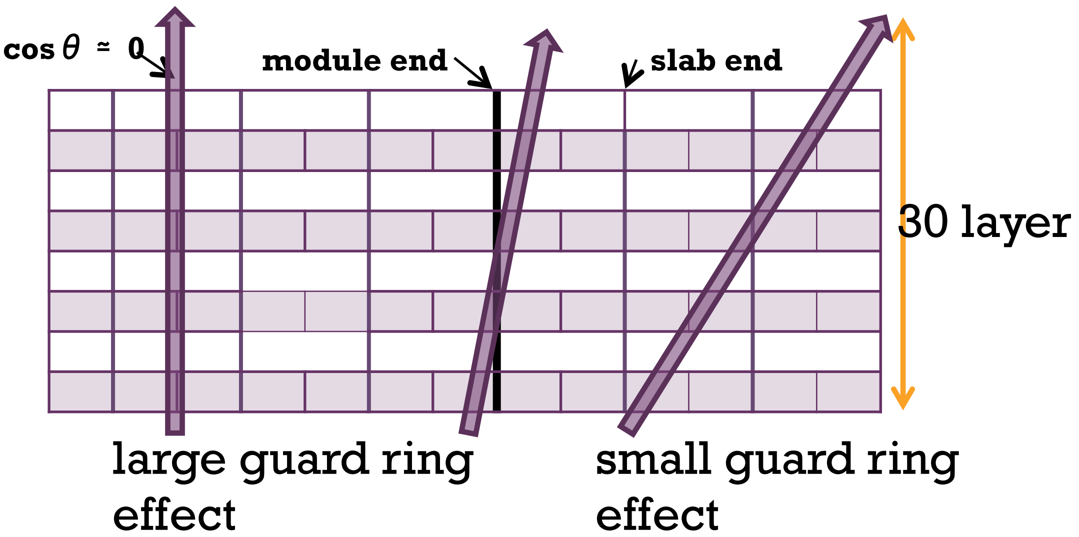
Expected effect by guard rings



- No stagger
- Perpendicular direction (cos θ =0) has most serious effect
- Forward events will be (more or less) uniformly affected

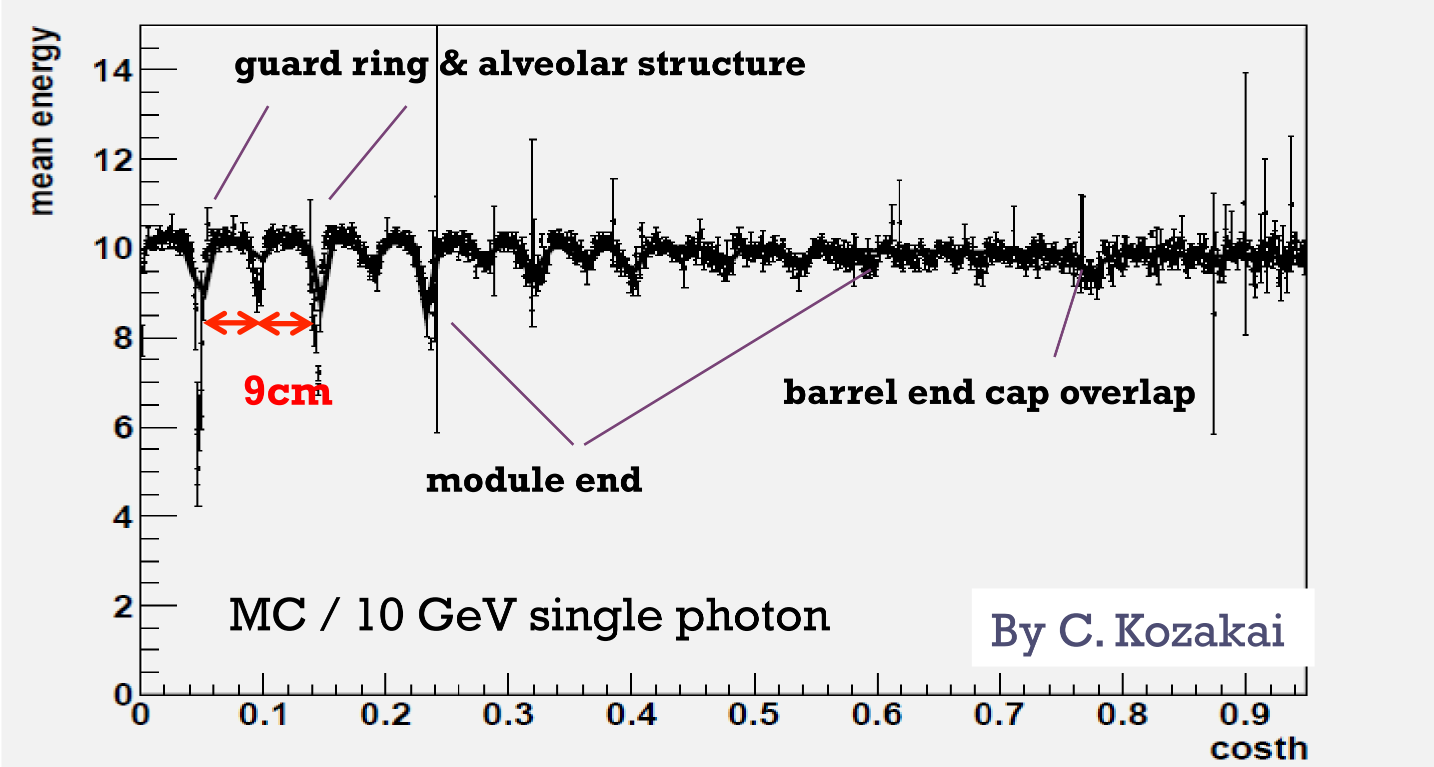


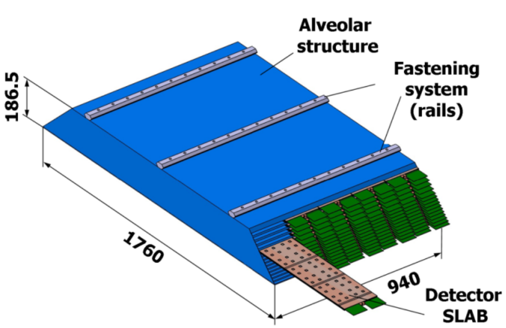


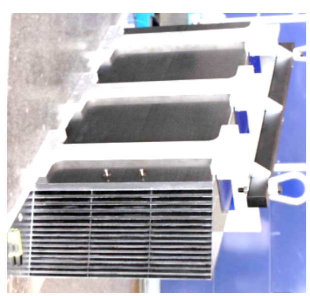


Expected effect by guard rings

Mean energy with MC 10GeV single photon @ 2mm GR th.



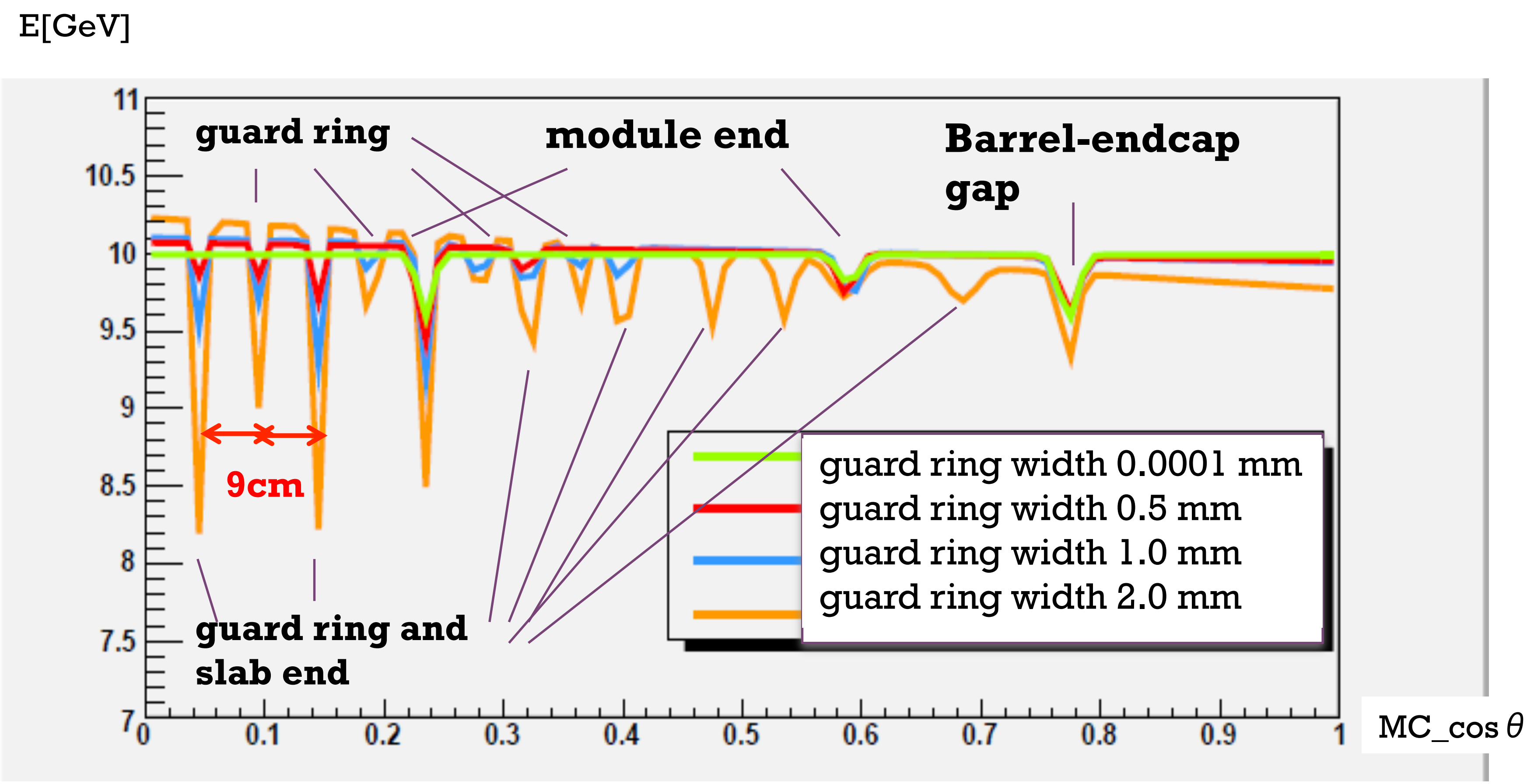




- Gaps due to module ends / supporting structure give the same effect

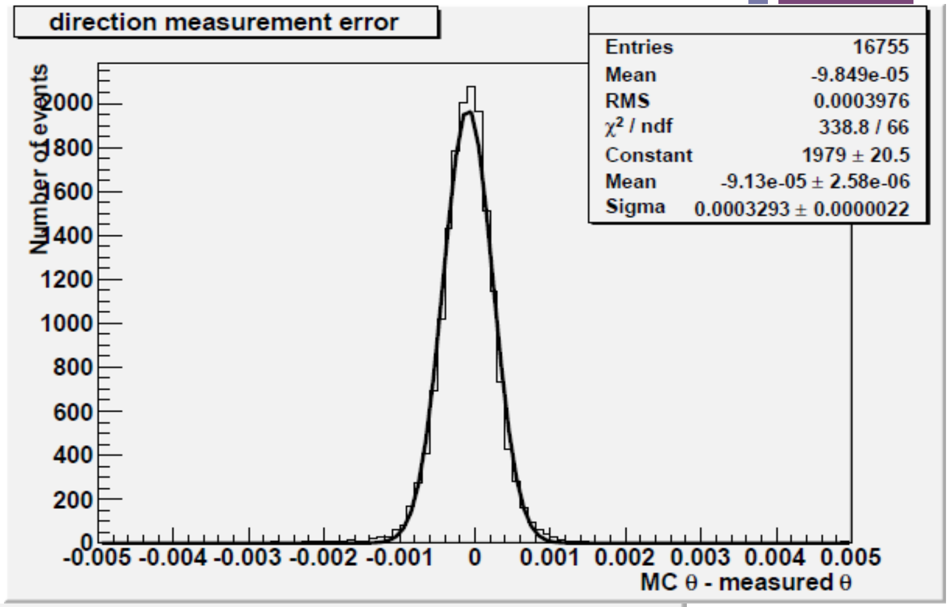
+ Expected effect by guard rings

- Energy drop ~10% @ 1.0mm, ~20% @ 2.0mm
- Linear decrease: More Prob(encounter gaps) in forward evt

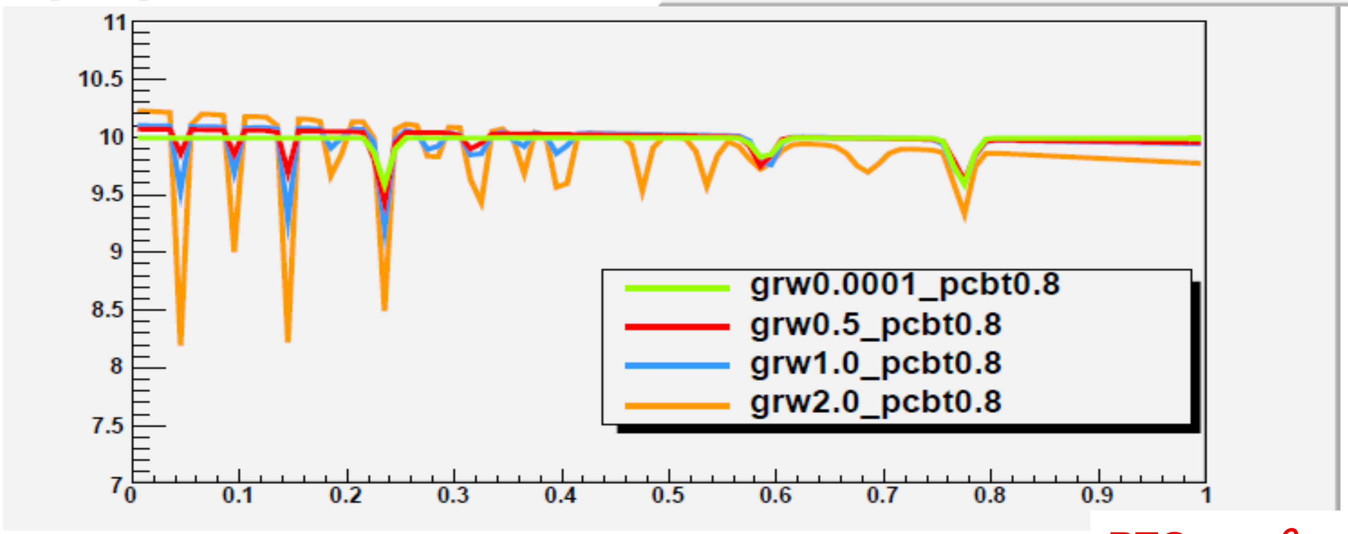


Angular correction

- Particle orientation is reconstructed by Pandora
- Precision of θ _pfo ~ 3.3×10^{-4} rad, **sufficient to use for angular correction θ .**
- **Fit by Linear + Gaussians**



E[GeV]

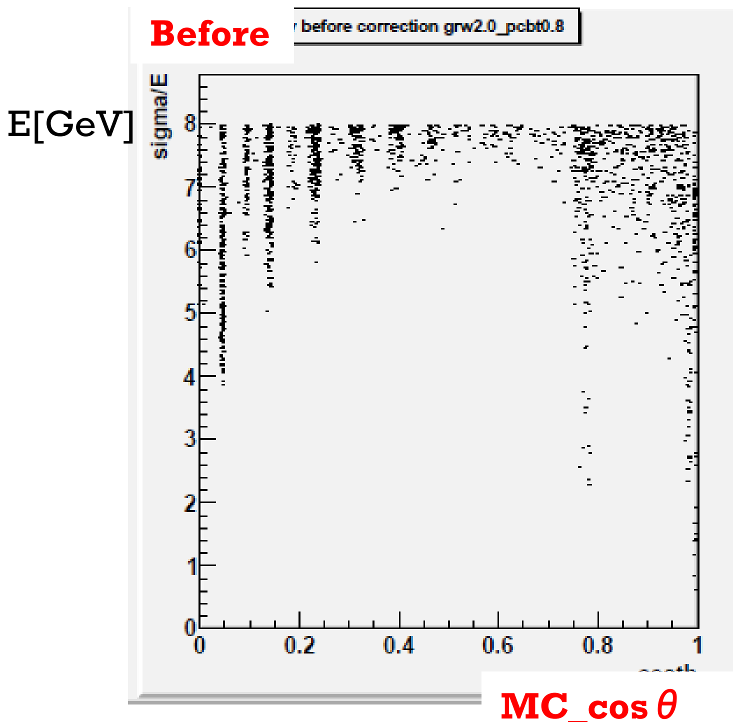


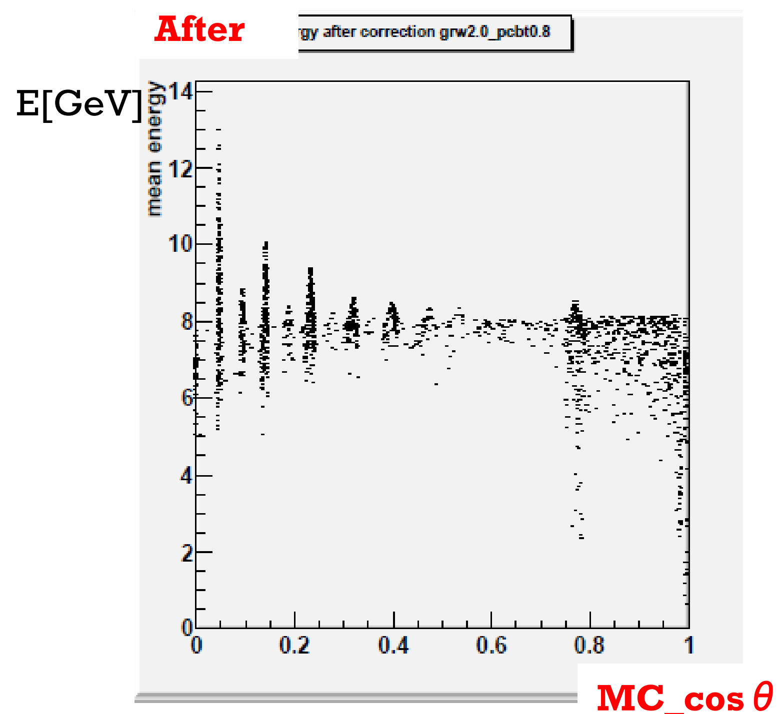
PFO_cos θ

Angular correction

- Most of the gap events are improved to some extent
- Not completely due to bad precision of θ around the gaps

E_ECAL <8GeV with 10GeV single photon @ 2mm GR th.

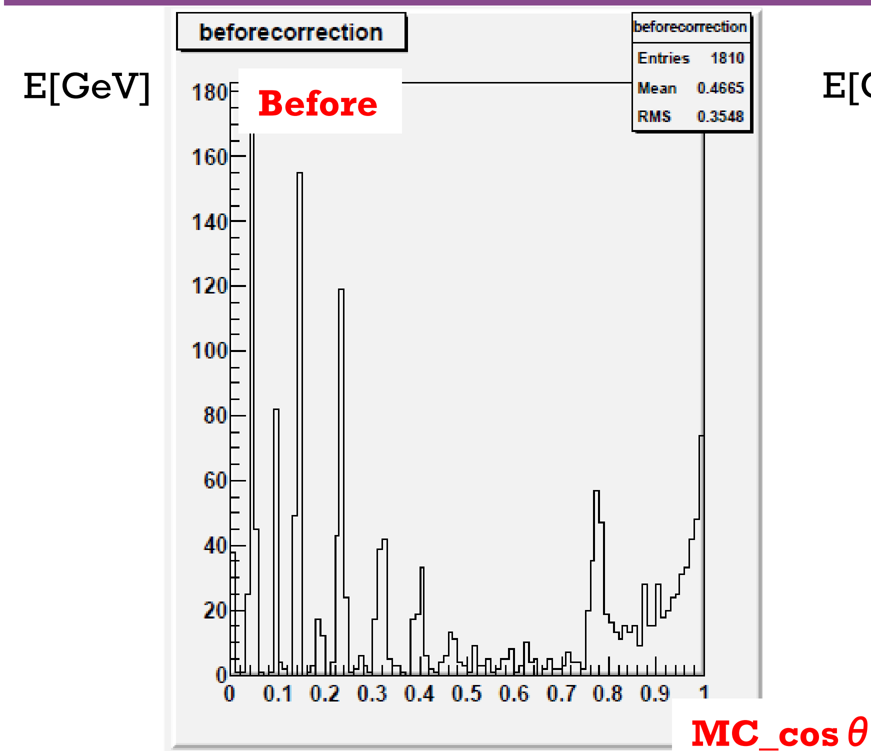


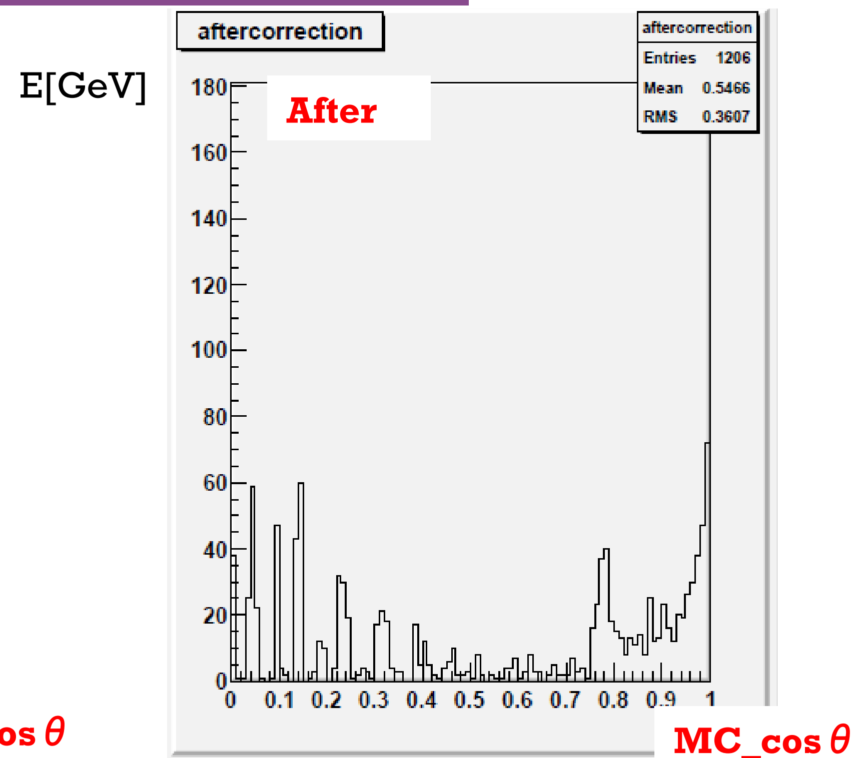


Angular correction

- Precision of θ_pfo ~ 3.3×10^{-4} rad, **sufficient to use for angular correction θ.**
- Some events are over-corrected due to bad precision of θ around the gaps

Number of E_ECAL <8GeV with 10GeV single photon @ 2mm GR th.



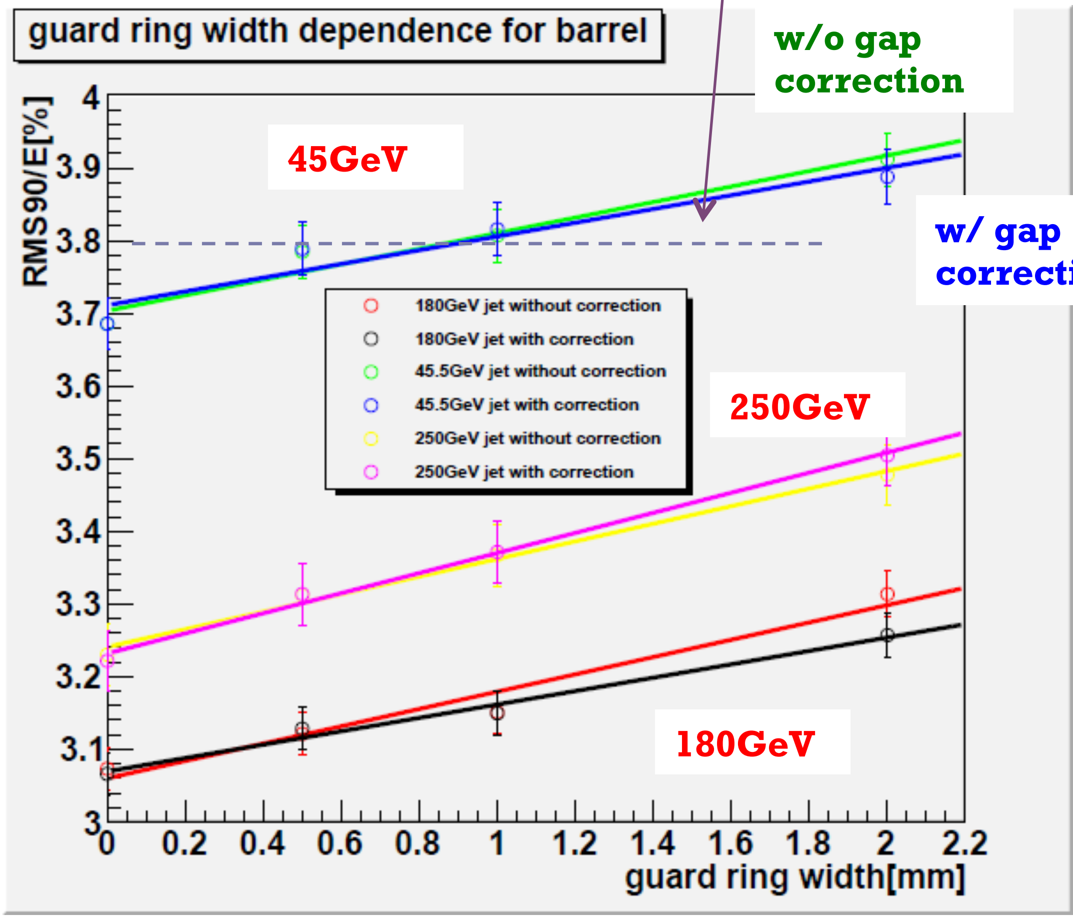


JER VS guard ring width

- Z→uds jets
- Barrel events only ($\cos\theta$ <0.7)

- JER increases as guard ring width increase.
- About ~6 % difference between 0 mm and 2 mm.
- Angular correction also helps resolution

Benchmark of hadronic W/Z decay separation (3.8%)



PCB Thickness

By C. Kozakai

- **Thick PCB will increase lateral shower size.**

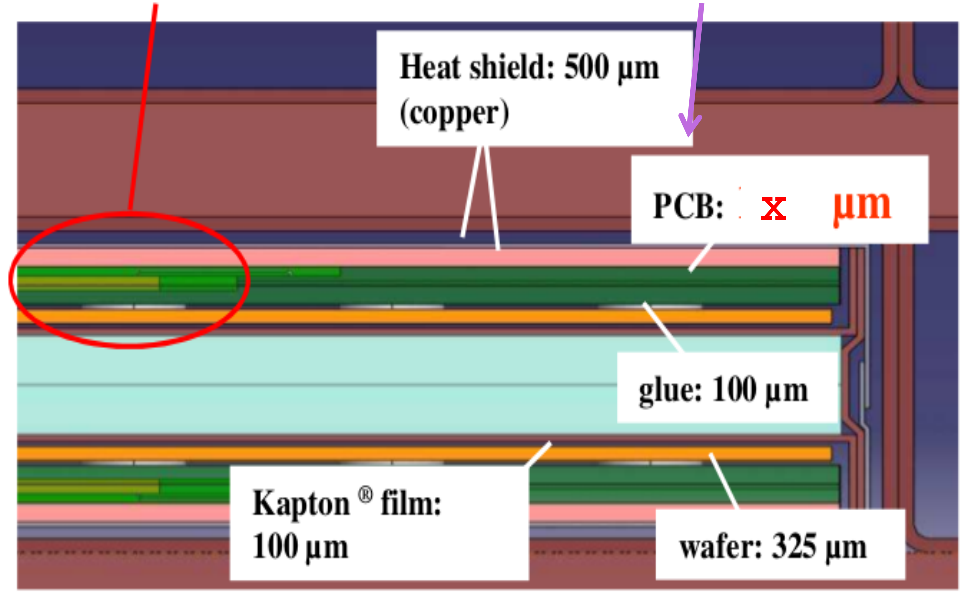
→ Heavier overlap of shower particles

→ Confusion ↑ ↑ JER is expected to be worse (especially in high E)

However, there is still much **industrial difficulty in producing thin, stable PCB.**

The effect to single particle should not very much

DBD: 0.8mm
Engineering design: 1.2mm



+ JER dependence on PCB thickness

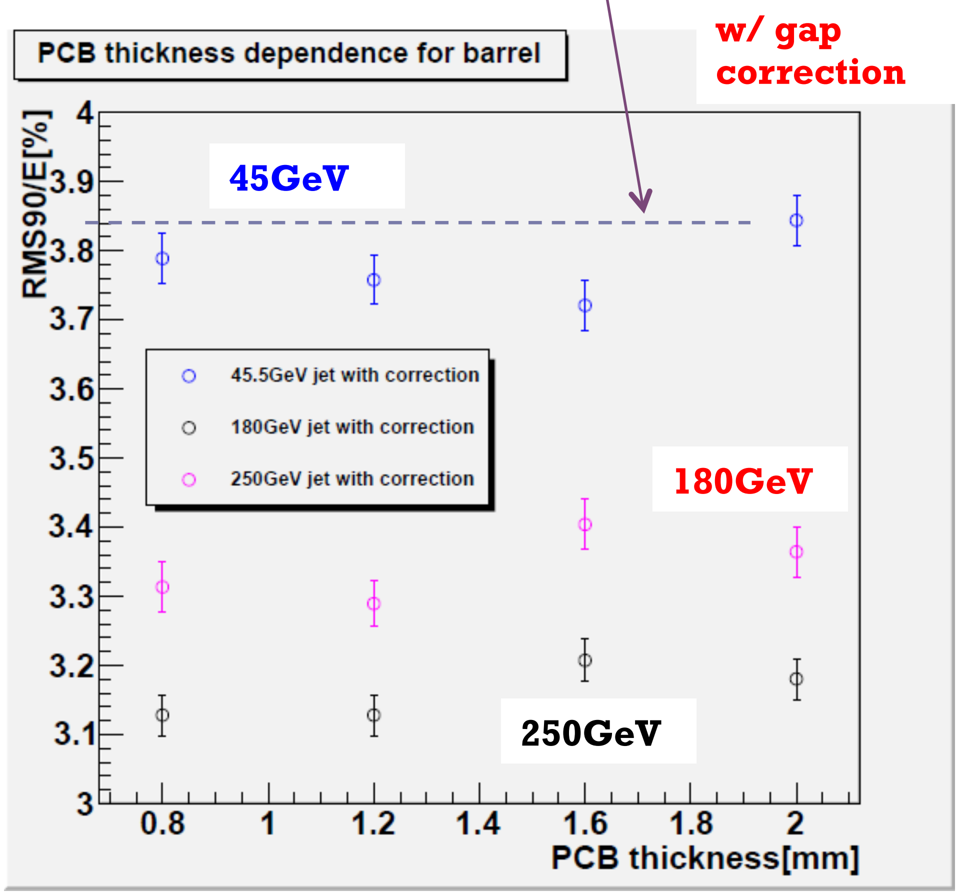
- **No significant dependence** is seen.

(Note)

We kept the size of the other modules in this study.

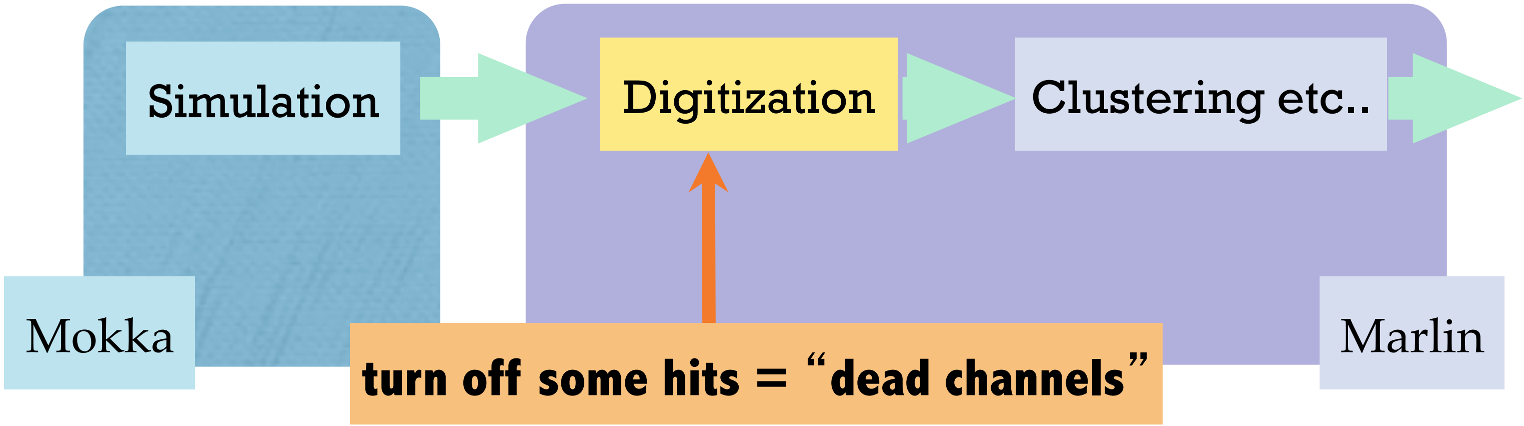
→ Whole detector size is bigger than default

Benchmark for separation of W/Z hadronic day (3.8%)



Dead channels effect

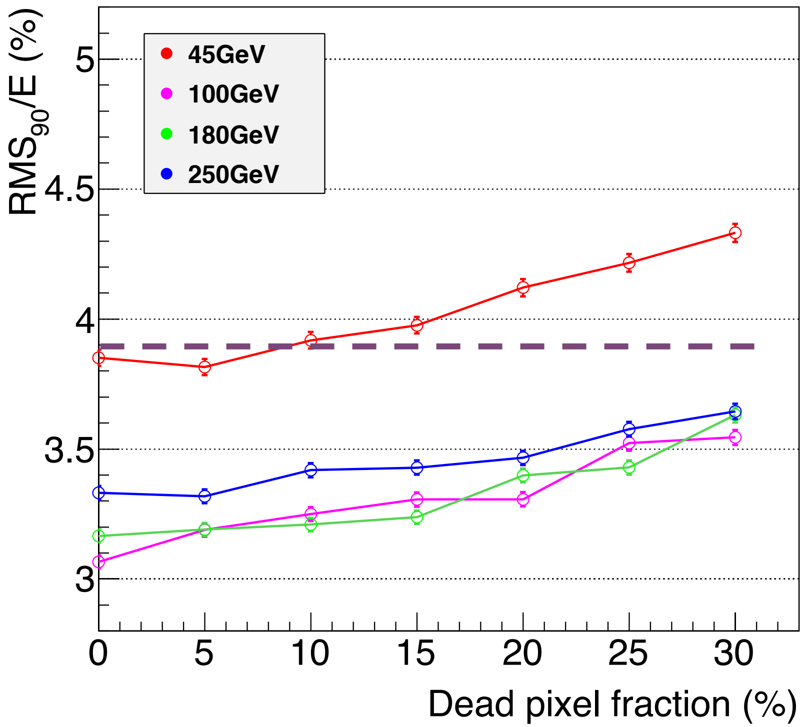
- If a few % dead cell is OK, we can increase yield for Si sensor and reduce cost.
- Some of the readout chip may broken down during construction or experiment.
- Switch hits randomly in digitization :



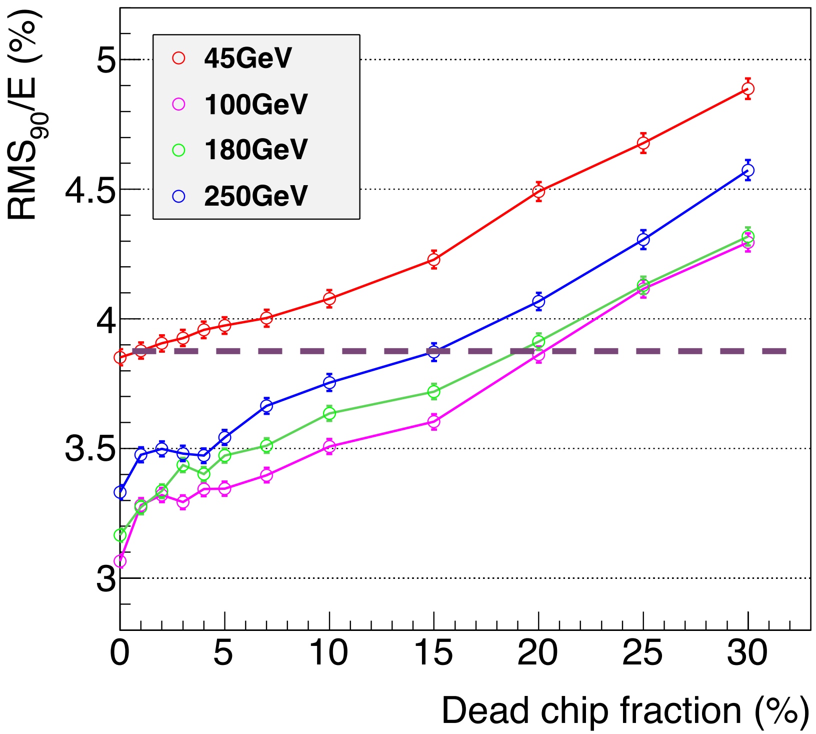
Assume dead channel distributes uniformly in the detector

JER vs dead pixels / chips fraction

Dead pixels



Dead chips



- Small effect with under 10 % of dead pixels, 5% of dead chips
  - ECAL resolution does go bad but not sensitive to JER
  - No serious breakdown. PFA is very robust against dead channels

+ Summary

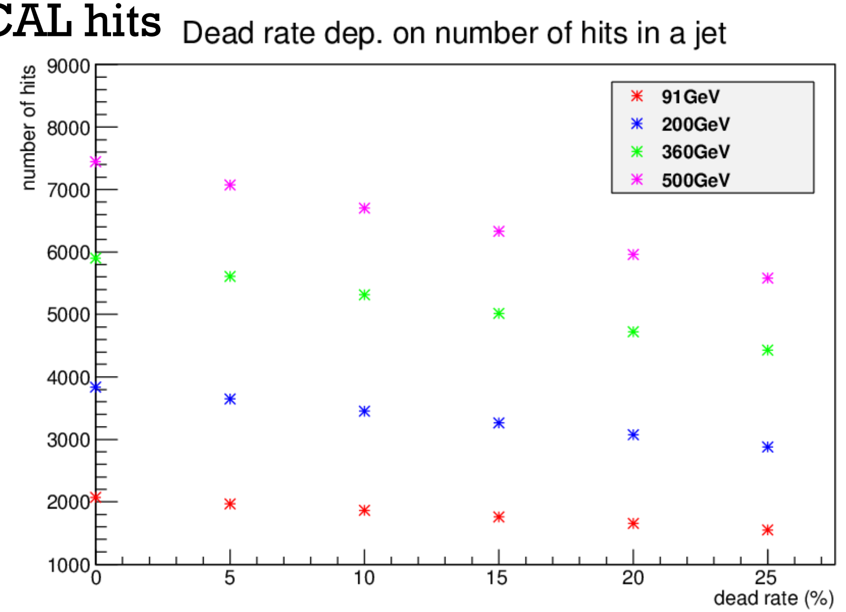
- The effect of guard ring, PCB thickness and dead pixel(chip) was studied.
- Guard ring makes JER worse (~6% @2mm)
- With different PCB thickness, no significant JER change was seen.
- 10 % of dead pixels / 5% of dead chips have very little effect on JER.
- PFA works very robustly

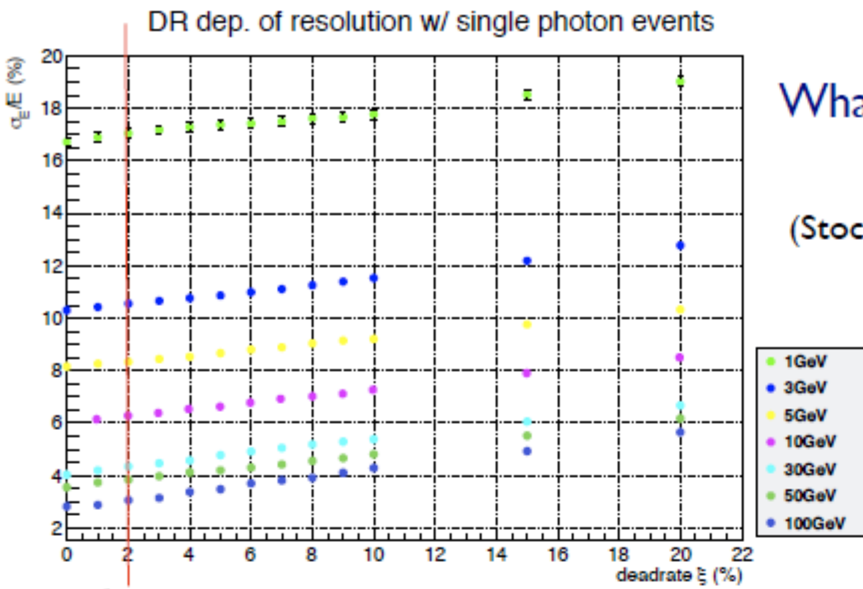
Back up

Dead pixel rate – Number of ECAL hit

- ECAL hits decreases with dead pixel rate

of
ECAL hits



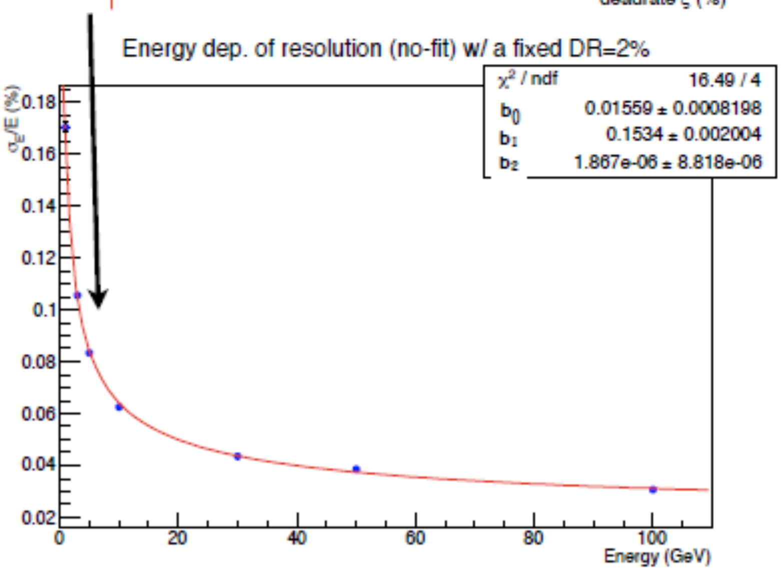


What component of

energy resolution grows?

(Stochastic term, constant term, linear term etc.)

Slice & fit with each dead rate (ξ)



Fitting function:

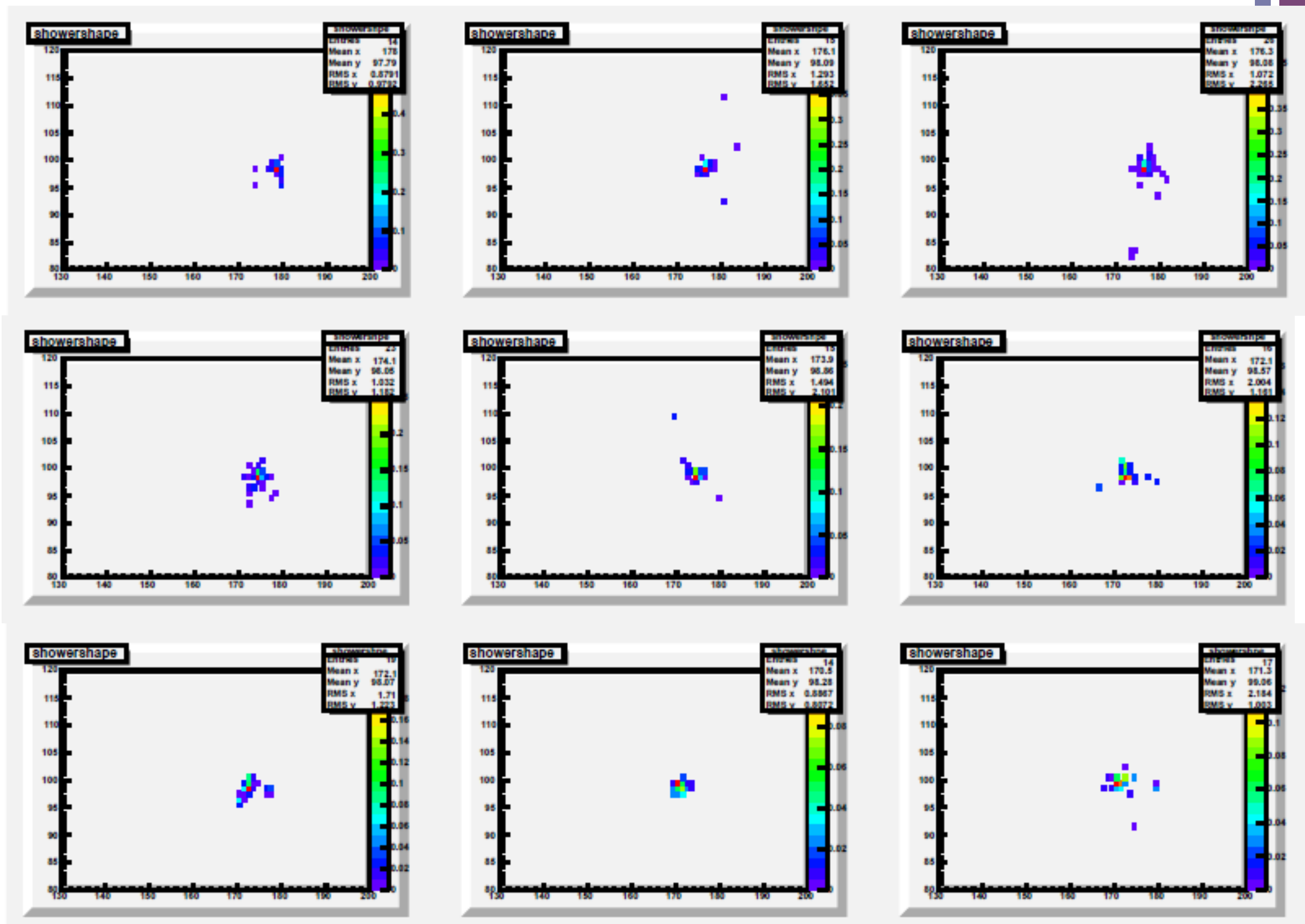
Stochastic term

Const. term

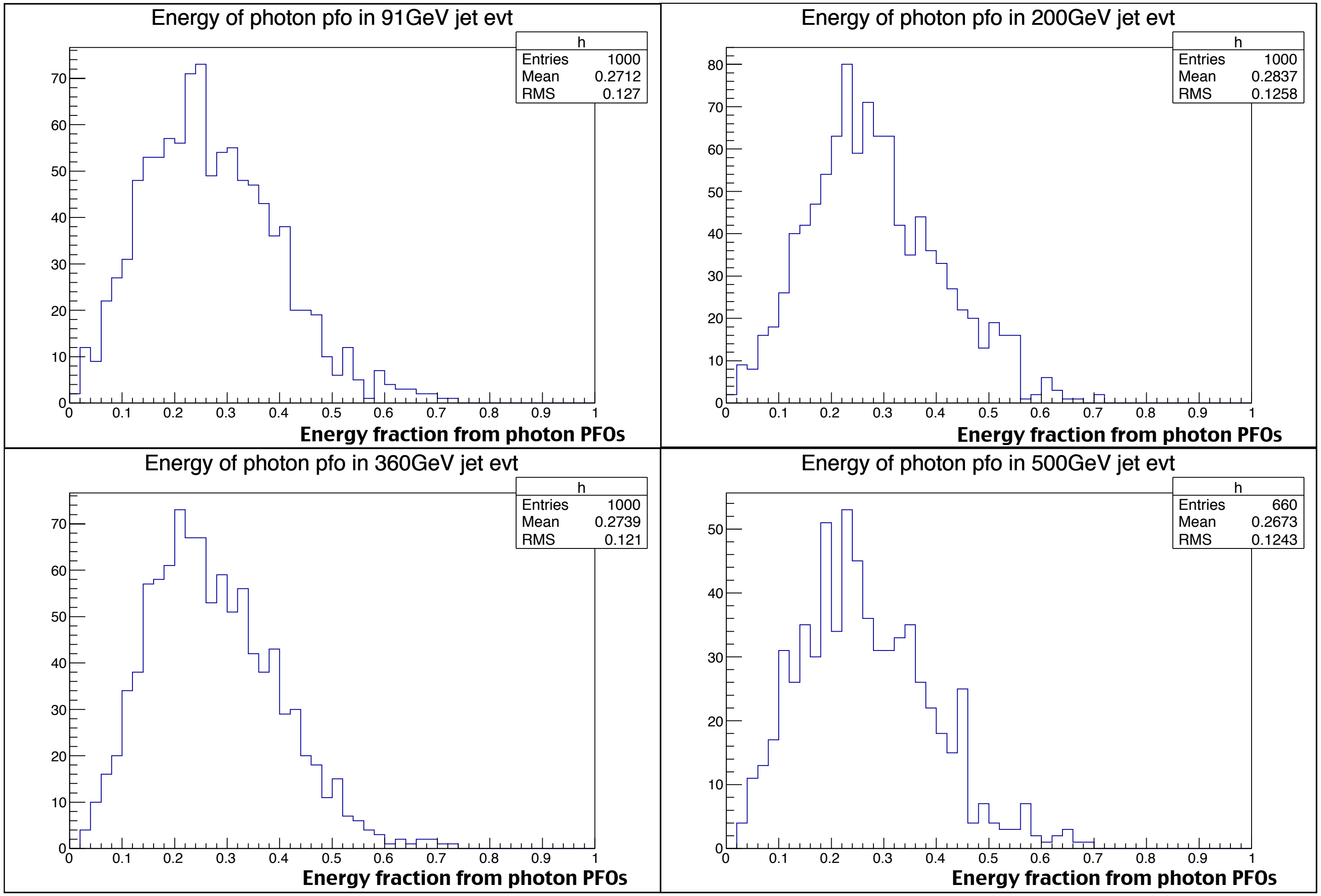
(~0)

$$\frac{\sigma_E}{E} = b_0(\xi) \oplus \frac{b_1(\xi)}{\sqrt{E}} \oplus \frac{b_2(\xi)}{E}$$

+ Photon shower shape in ECAL

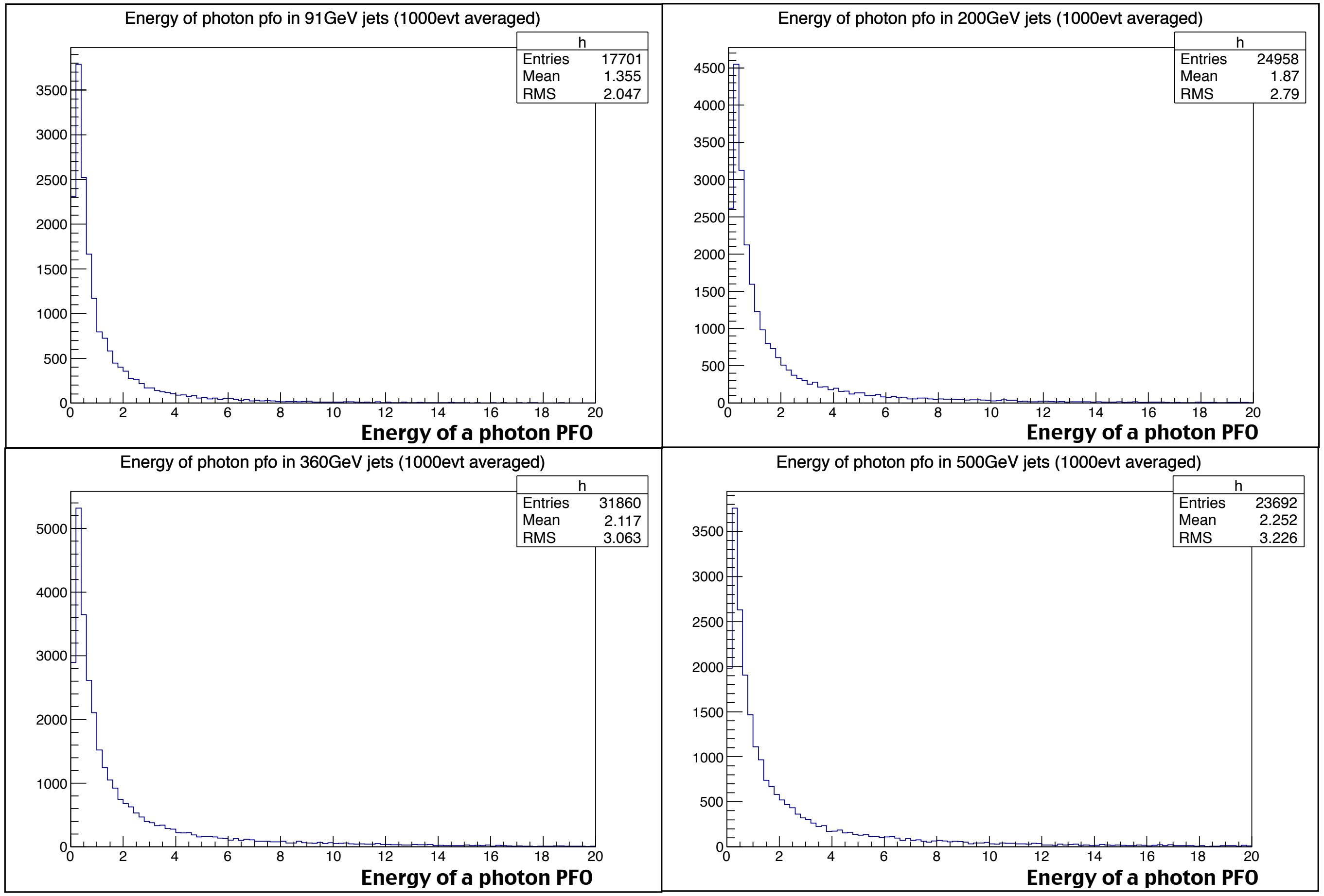


Photon Energy fraction in a jet



- 20%~30% on average (large fluctuation by events)

+ Energy of a photon pfo in a jet



- Mostly under 2~3GeV

  Soft photon PFOs give the dominant contribution to neutral energy in a jet

  The energy resolution is determined mainly by stochastic term

Simple estimation of JER

$$\sigma_j \sim \sqrt{N_c\sigma_c^2 + N_\gamma\sigma_\gamma^2 + N_h\,\sigma_h^2}$$
$$\sim \sqrt{N_\gamma\sigma_\gamma^2 + N_h\,\sigma_h^2}$$

$$\sigma_h \sim 0.55\,\sqrt{E_h(\mathrm{GeV})}$$

Assume a typical 45 GeV jet
N_γ = 9, N_h=2,
E_γ=1.4GeV, E_h = 3.0GeV
(See later slides)

$$\sigma_\gamma = E_\gamma\sqrt{b_0^2(\xi) + \left(\frac{b_1(\xi)}{\sqrt{E_\gamma}}\right)^2}$$

(ξ: dead rate)

(pixel) (←fit with plots in page7→) (chip)

(pixel):
$$b_0(\xi) = 1.6\,(1+12\xi)\,(\%)$$
$$b_1(\xi) = \frac{17.4}{\sqrt{1-\xi}}\,(\%)$$

(chip):
$$b_0(\xi) = 1.6\,(1+28\xi)\,(\%)$$
$$b_1(\xi) = \frac{17.4}{\sqrt{1-1.5\xi}}\,(\%)$$

5% dead	σ_γ/E (%)	σ_j/E_j (%)
pix	15.6	3.50
chip	16.5	3.55

10% dead	σ_γ/E (%)	σ_j/E_j (%)
pix	16.5	3.55
chip	18.7	3.70

20% dead	σ_γ/E (%)	σ_j/E_j (%)
pix	18.6	3.70
chip	24.3	4.13

30% dead	σ_γ/E (%)	σ_j/E_j (%)
pix	21.2	3.89
chip	31.1	4.73

Error bar of JER in simulation (1000 events) ~ 0.2-0.3 % for each point