SiW ECAL optimization study

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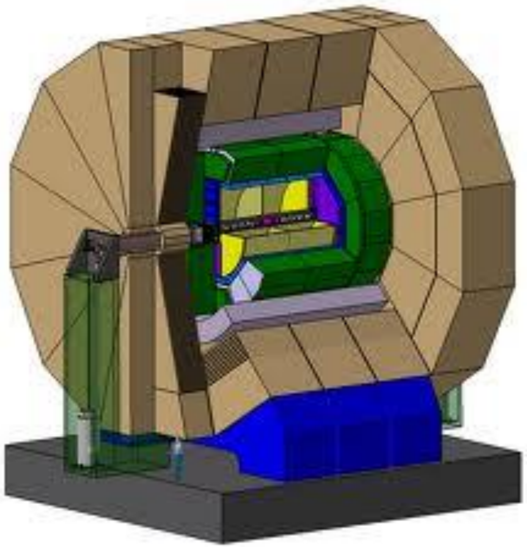
Outline -ILD simulation-

- SiW ECAL Simulation with model ILD detector(DBD version)
  - Dead area from guard ring width
    - Energy correction by direction for photon
  - PCB (Printed Circuit Board) thickness
  - Dead channels effect

ILD detector -Particle Flow Algorithm(PFA)-

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

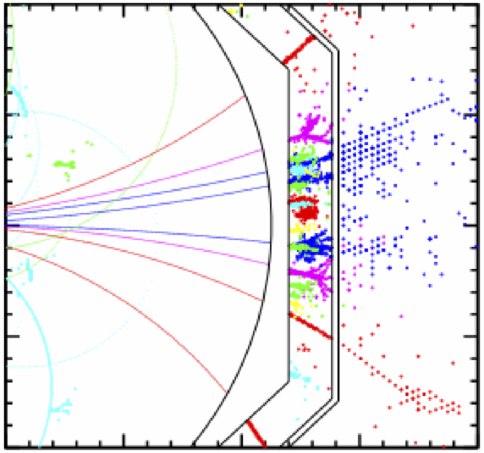


- Particle in jet

  Charged particle (65 %)→TPC

  Photon (25 %) →ECAL

  Neutral hadron (10 %) →HCAL

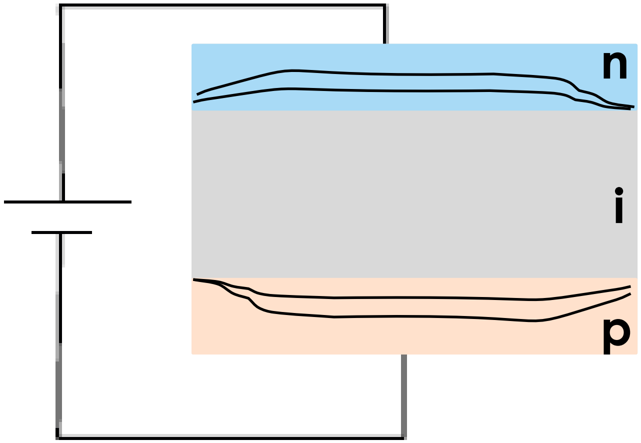


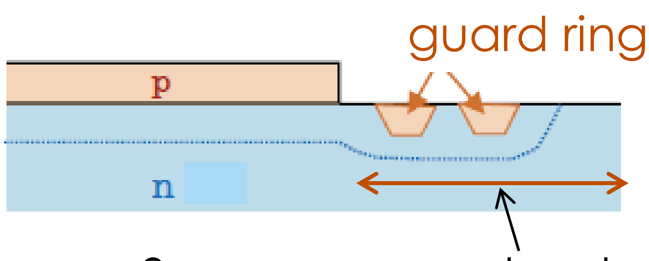
ECAL structure in ILD

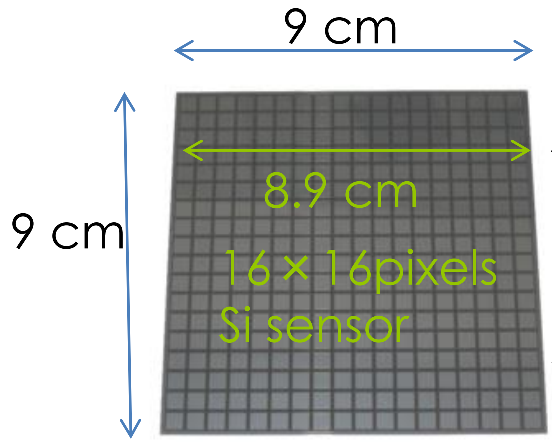
- Sandwich calorimeter with **tungsten absorber** and **Silicon sensor** or **scintillator and MPPC** for detector.
- Tungsten absorber for **short radiation length** X_0 (0.35 cm), **small Molière radius**(0.93 cm) and **large ratio of interaction length to radiation length**(27.4).
- For PFA, **high 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.

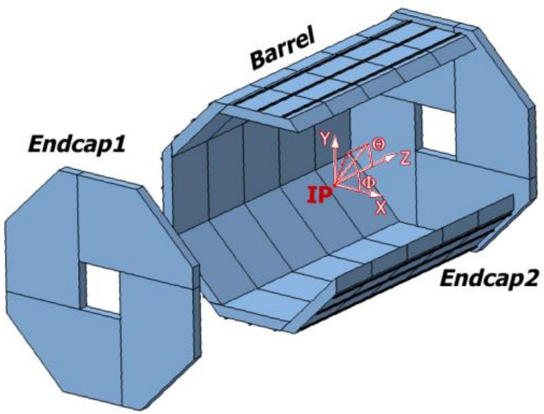


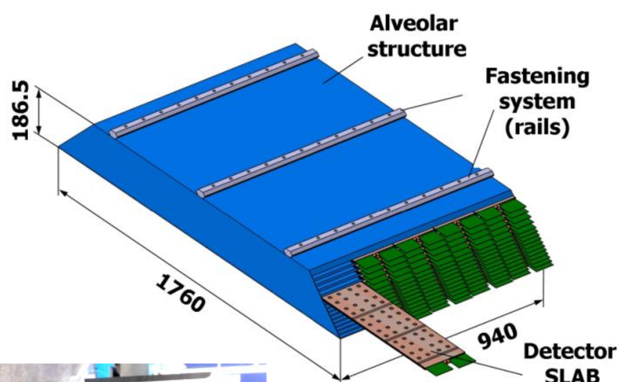


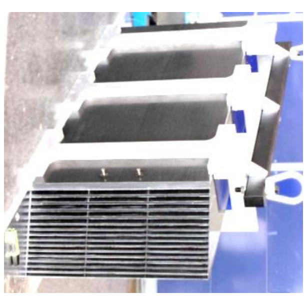


Sensor for ILD. guard ring-induced dead area width: 0.5 mm(default value)

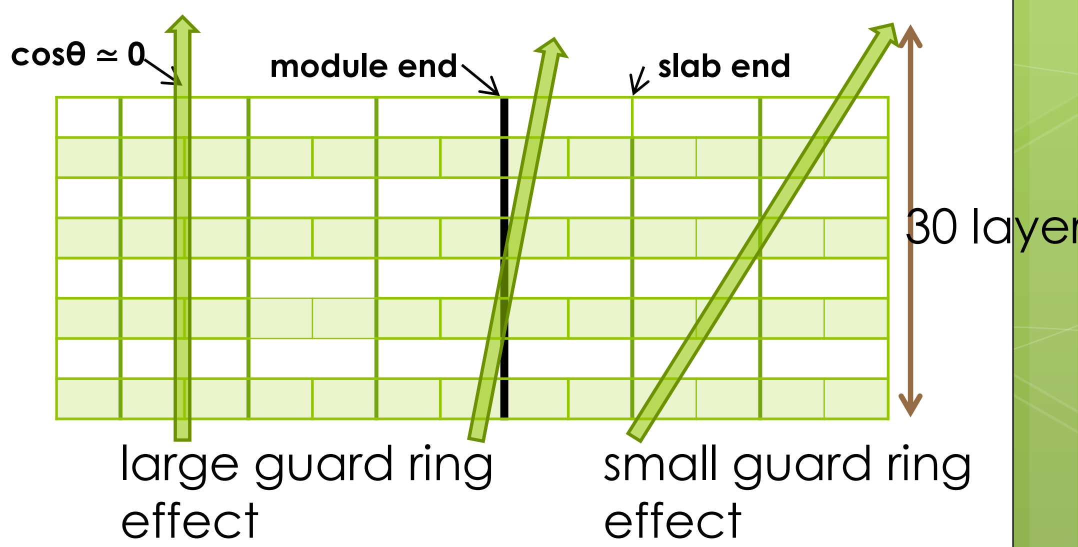
SiECAL structure





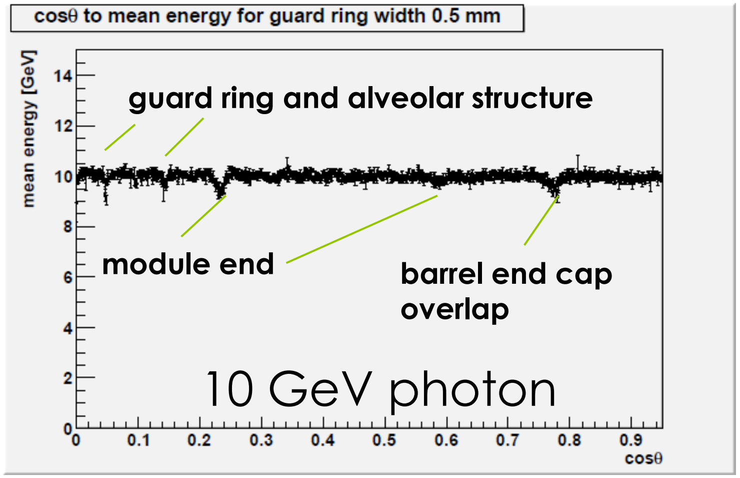


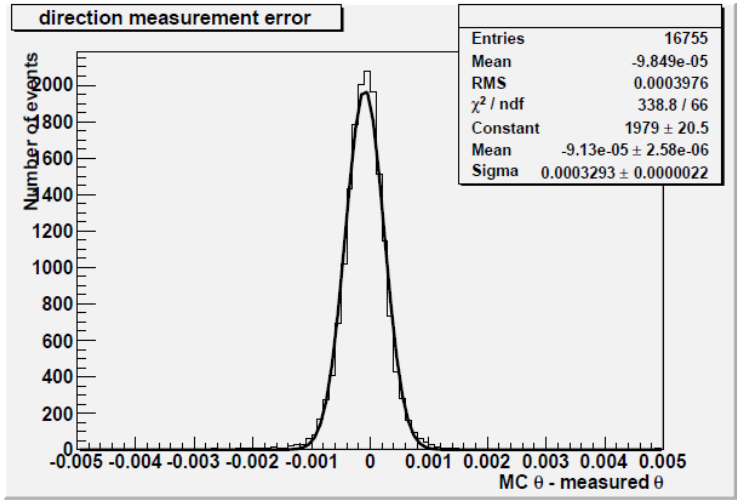
- Study how thin guard ring(=dead area) is required.
- We will have guard ring effect particularly in vertical direction to the beam pipe.



Energy correction for photon

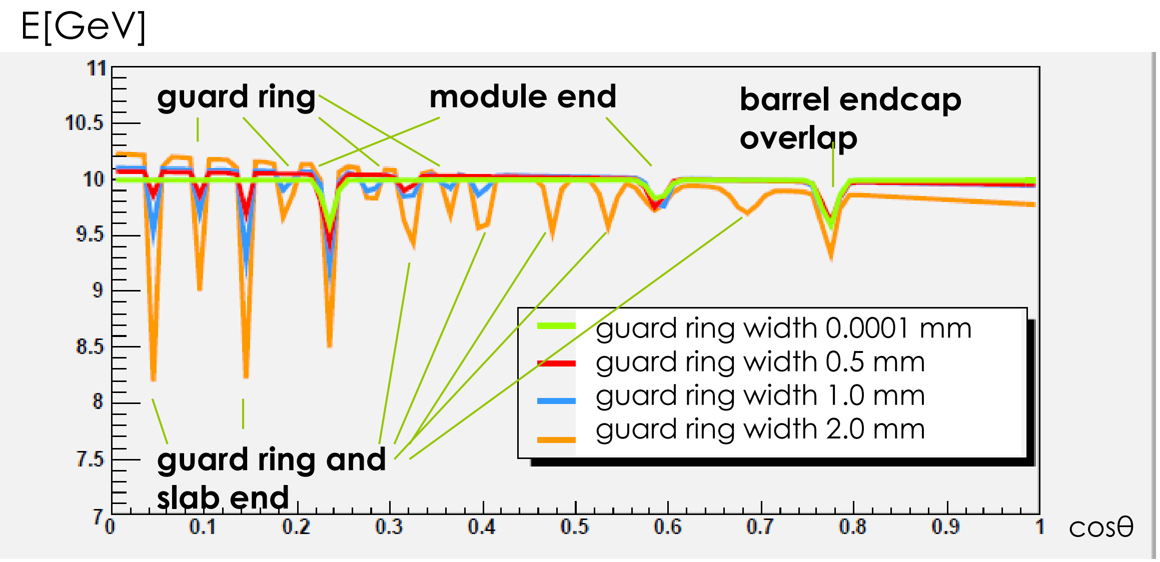
- Energy decreases in central guard ring, alveolar structure, module end and barrel end cap gap.
- **Direction resolution** for θ is **3.3×10^{-4} rad.** It's **sufficient to give a correction by θ.**
- Upper graph can be fitted by linear and Gaussian functions.





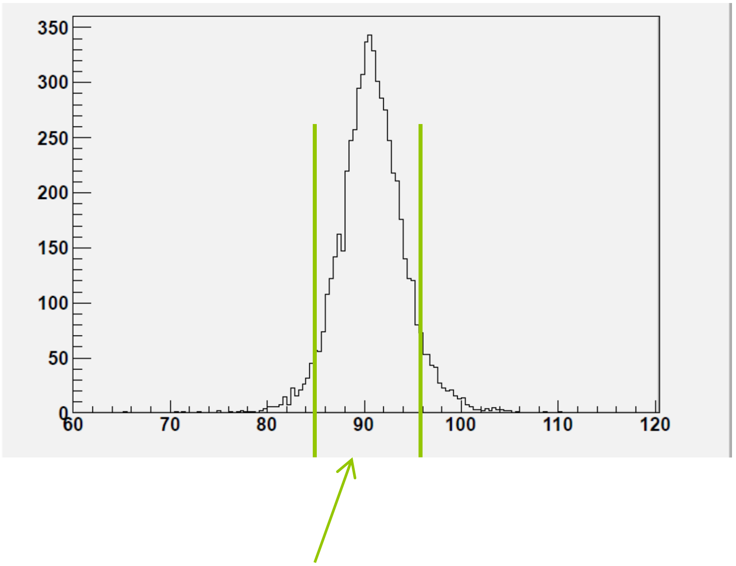
Energy correction function

- These functions are obtained by fitting10 GeV photon energy measurement.
- Larger guard ring has larger effect.



Jet Energy Resolution (JER) evaluation

- We use **"$Z \to u\bar{u}/d\bar{d}/s\bar{s}$"** 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**

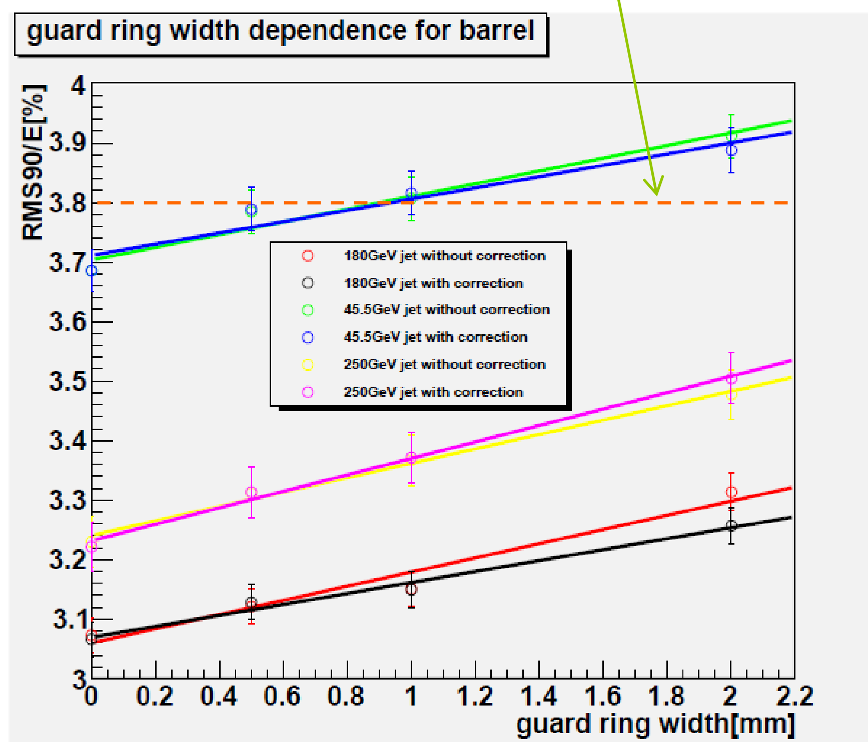


RMS90 is calculated using events in this 90 % area

JER with different guard ring width

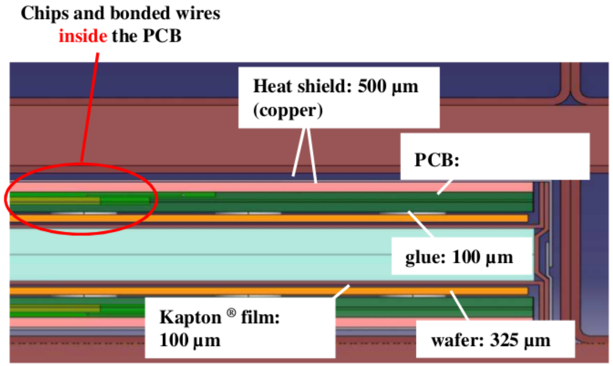
- JER increases as guard ring width increase.
- About 6 % difference between 0 mm and 2 mm.
- Direction correction has small effect on RMS90.

the benchmark resolution for good separation between W and Z boson hadronic decay



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.
- **Thick PCB will increase lateral shower size.** So thin PCB maybe preferred.
- However, too **thin PCB is technologically difficult and expensive.**

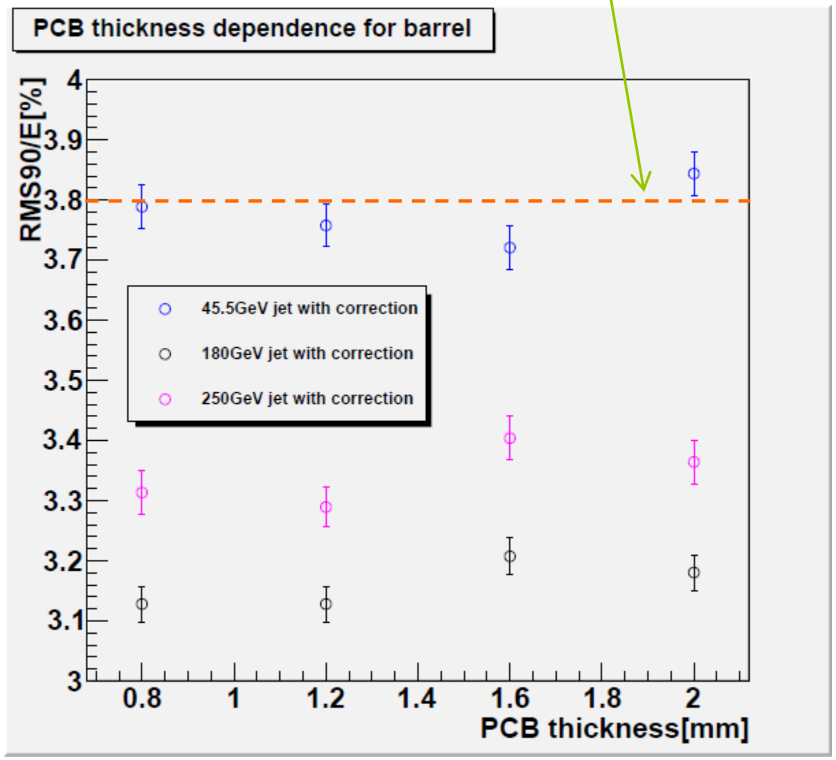


JER dependence on PCB thickness

- 0.4 mm increase →$0.014X_0$ / layer increase.

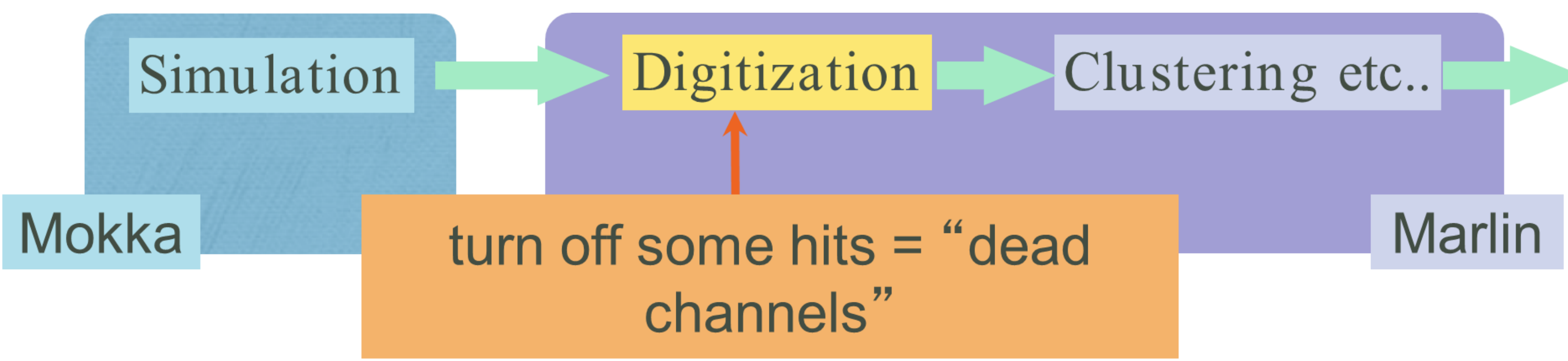
  total ECAL radiation length increase by $0.42X_0$.
- **No significant dependence** is seen.
- With thicker PCB, ECAL, HCAL and coil also become larger.

the benchmark resolution for good separation between W and Z boson hadronic decay



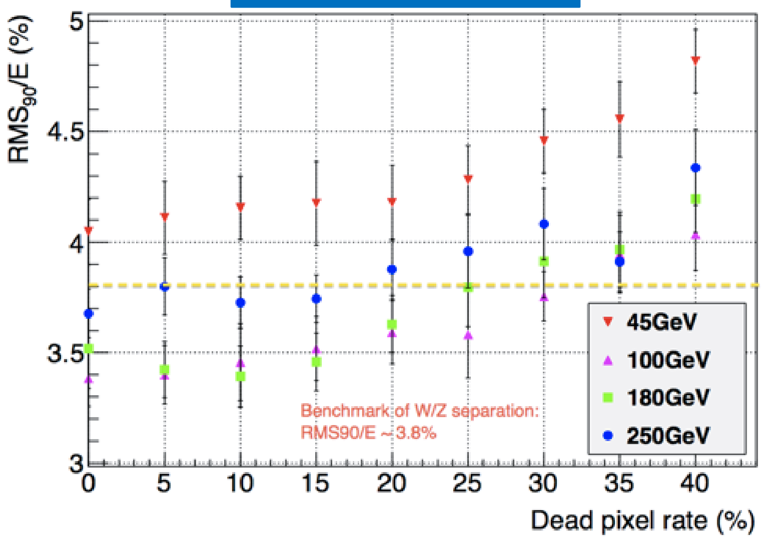
Dead channels effect by S. Chen

- 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.
- How to study dead channel and chip effect:



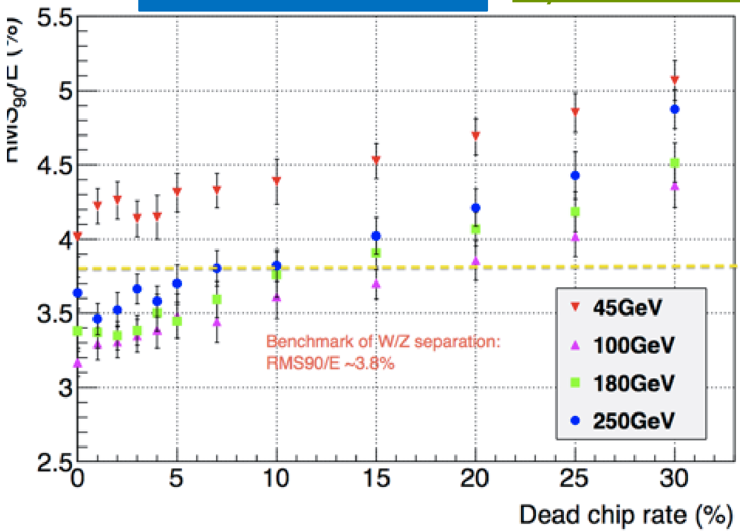
JER dependence on dead pixels / chips fraction

Dead pixels



Dead chips

By S. Chen

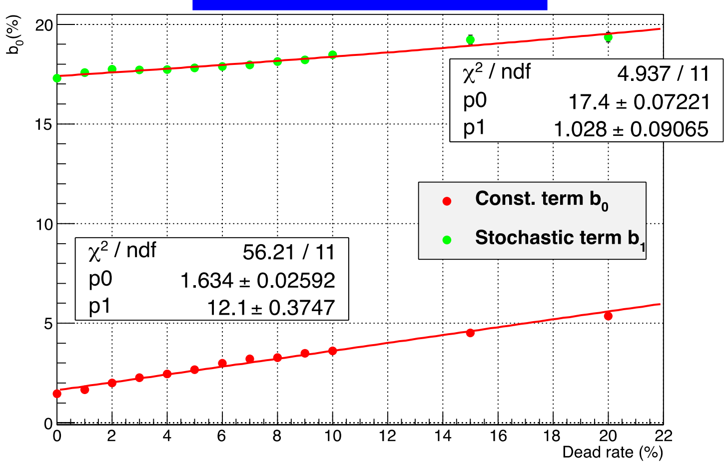


- Small effect under 15 % dead pixels fraction.
  - ECAL resolution is sensitive to dead channels but JER is basically limited by HCAL resolution.
  - Effective granularity is sufficient for PFA.
- As dead chip fraction increases, JER increases linearly.

Modeling of photon energy resolution dependence on dead fraction (ξ)

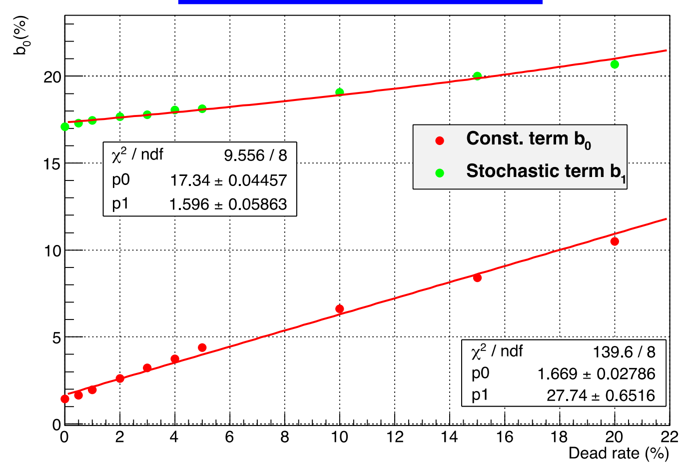
- $\frac{\sigma_E}{E} = b_0(\xi) \bigoplus \frac{b_1(\xi)}{\sqrt{E}}$ = const. ⊕ stochastic
  - Const. term is from non-uniformity (= dead fraction)

Dead Pixel



Dead Chip

By S. Chen



- Most of photons in the jets have low E (≲3 GeV)

→Little contribution by const. term(=dead fraction)

Summary

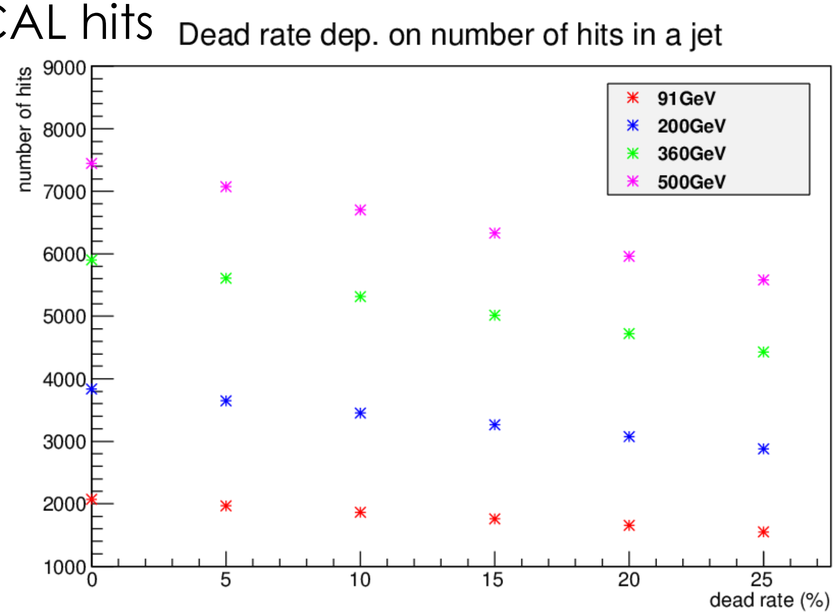
- SiW ECAL for ILD optimization of guard ring width, PCB thickness and dead pixel(chip) was studied.
- Jet energy resolution(JER) increases as guard ring width increase. The difference between 0 mm and 2 mm is about 6 %.
- With different PCB thickness, no significant JER change was seen.
- 15 % of dead channels have very little effect on JER.
- JER increases as dead chip fraction increase.

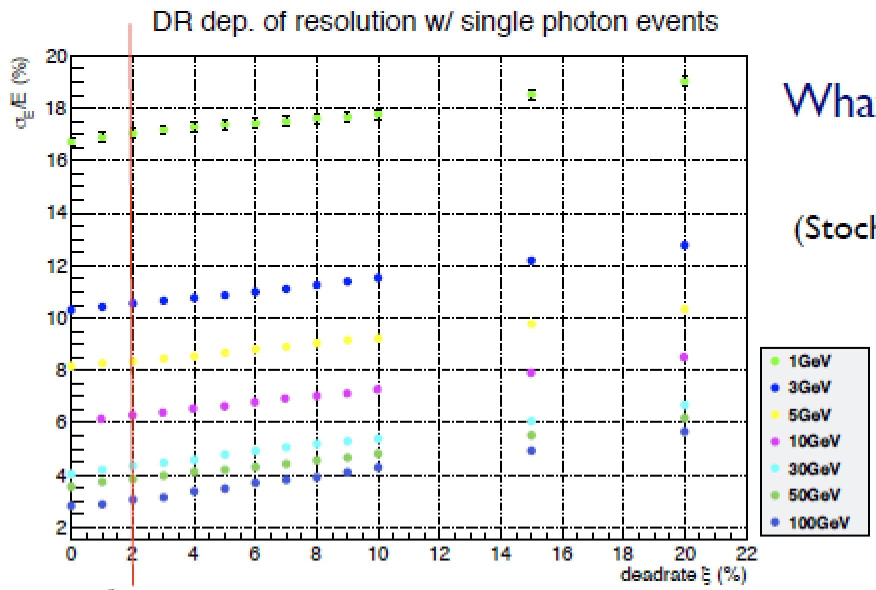
Back up

Dead pixel rate – Number of ECAL hit

- ECAL hits decreases with dead pixel rate

\# of
ECAL hits

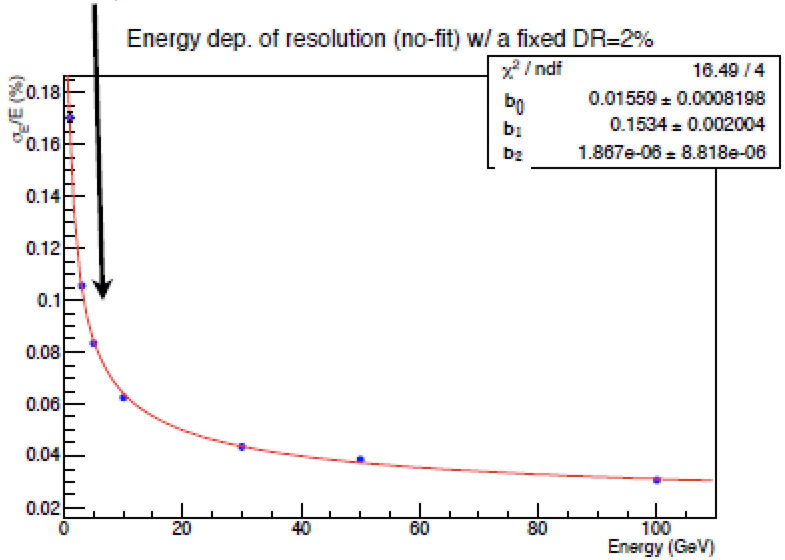




What component of energy resolution grows?

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

Slice & fit with each dead rate (ξ)

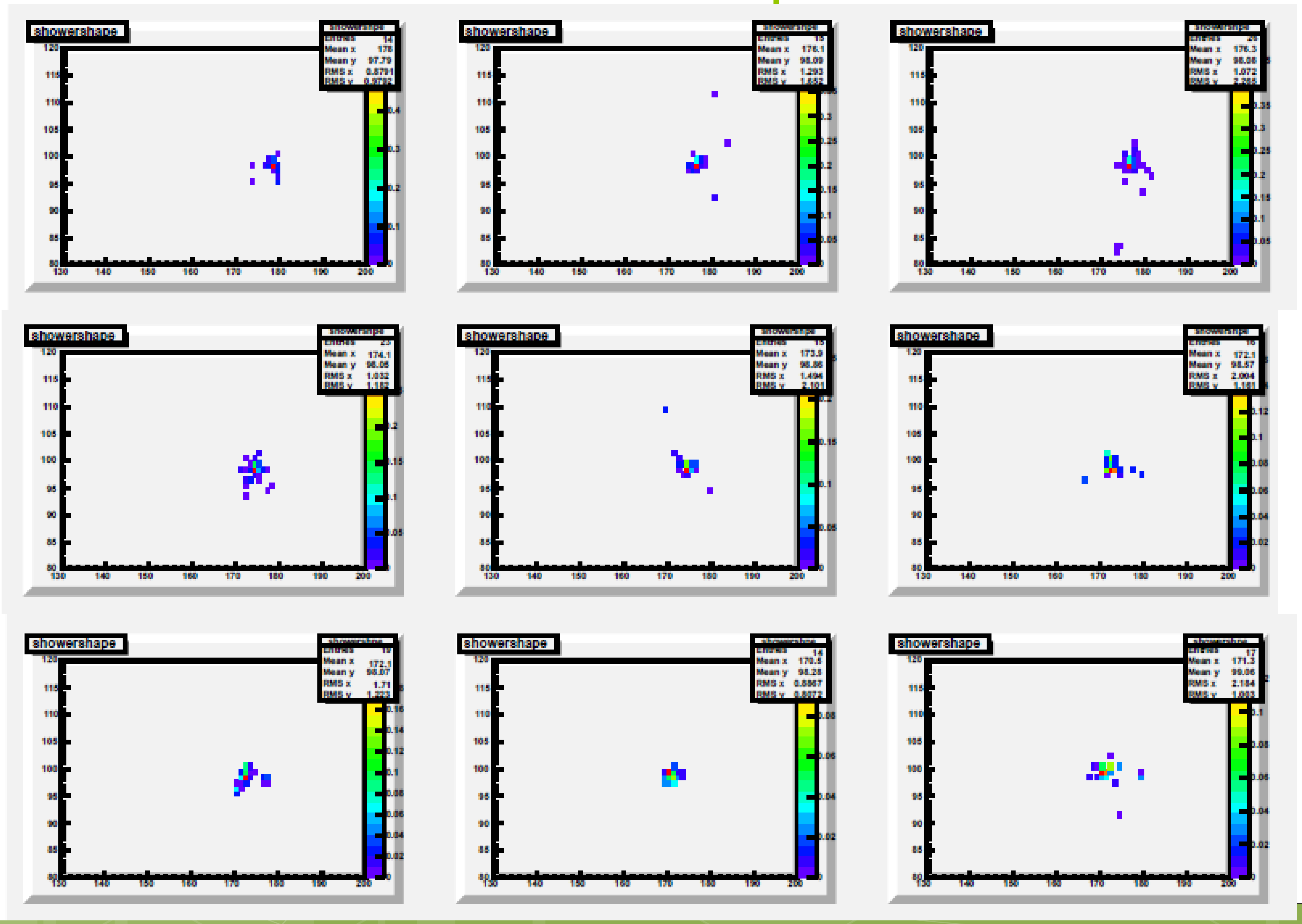


Fitting function:

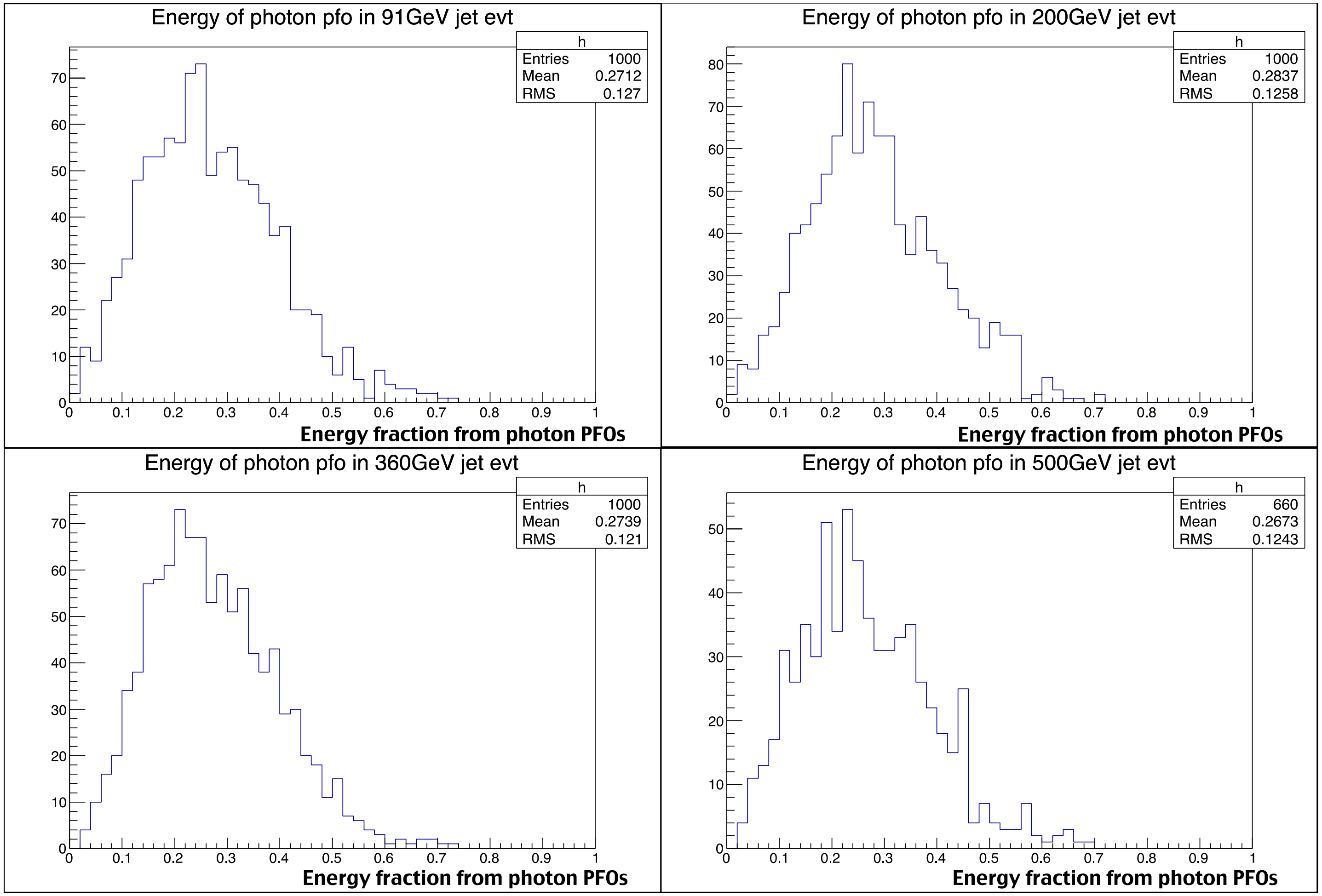
Const. term · **Stochastic term** · **(~0)**

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

Photon shower shape in ECAL

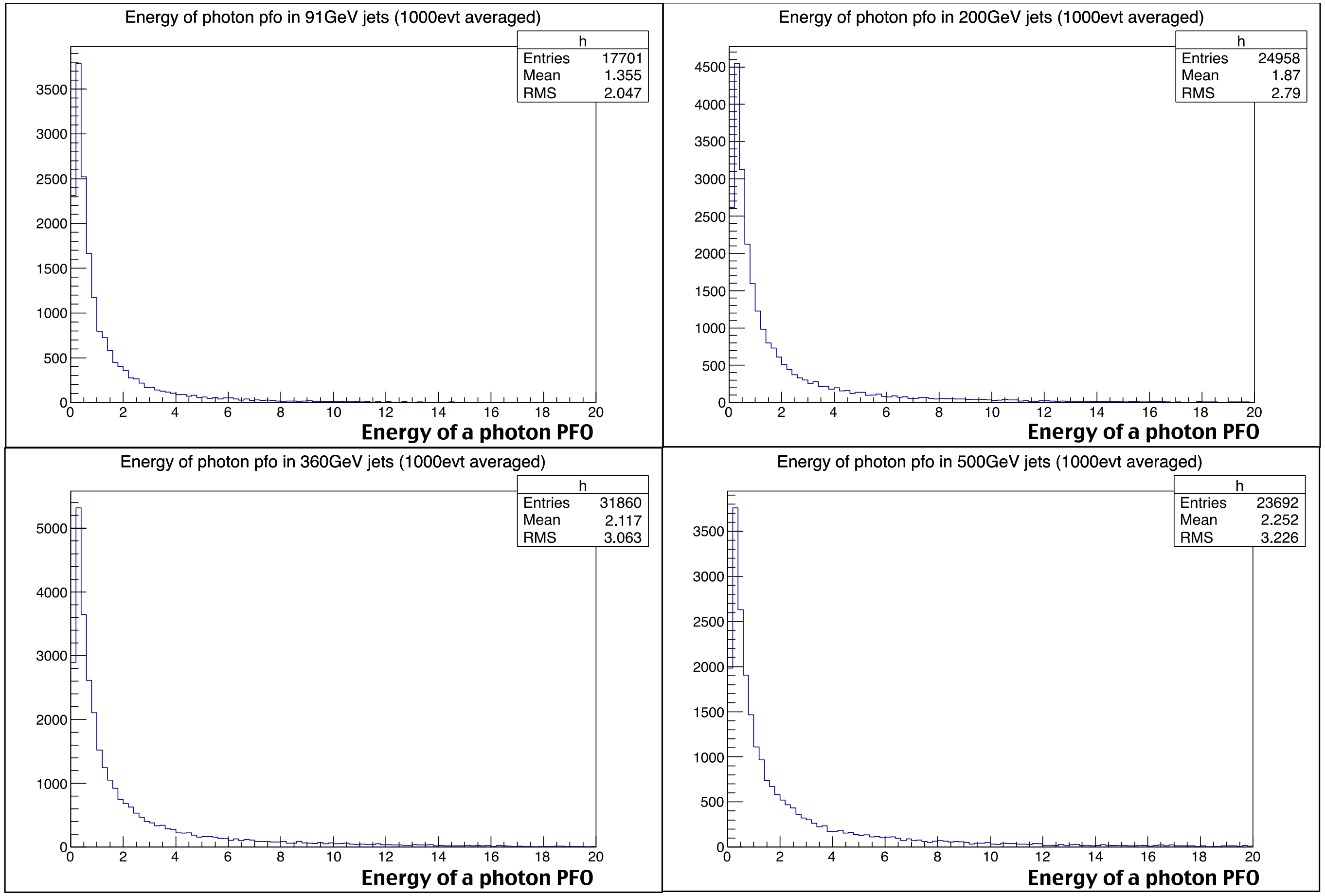


Photon Energy fraction in a jet



- **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

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

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

Assume a typical 45 GeV jet
$N_\gamma = 9$, $N_h=2$,
$E_\gamma=1.4$GeV, $E_h = 3.0$GeV
(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