Particle Flow Algorithm with a strip-scintillator ECAL

Fine-tuning problem was fixed here! but artificially :-)

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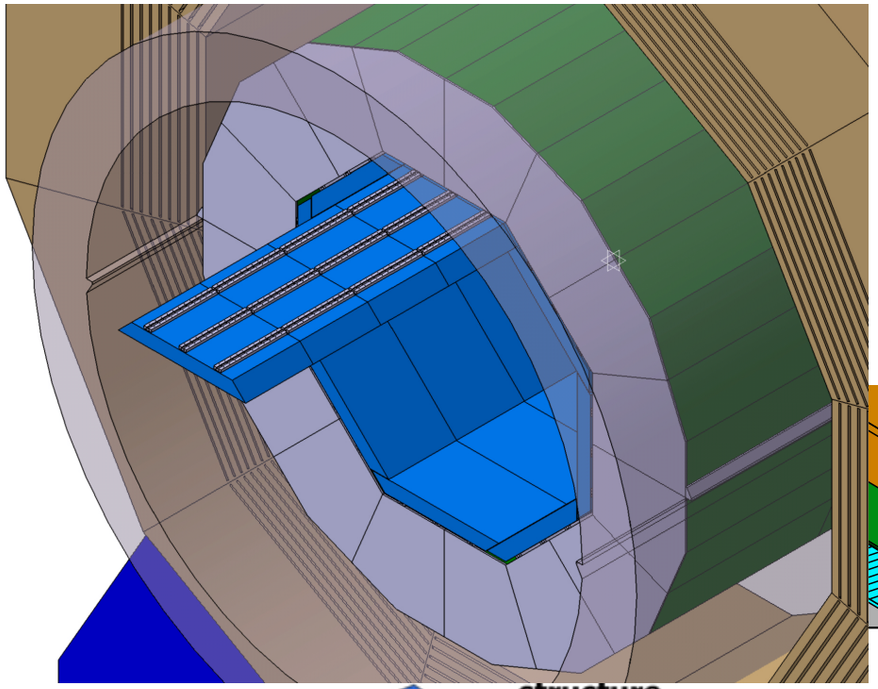
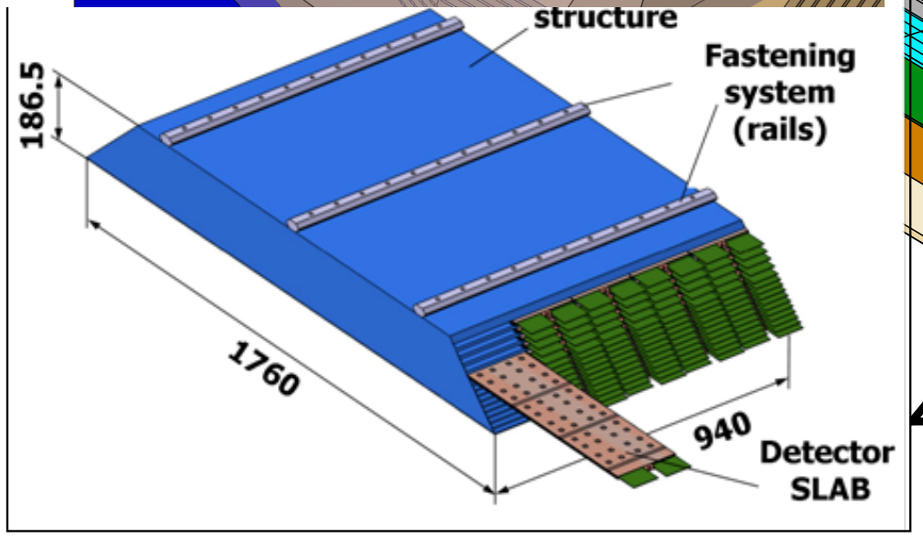
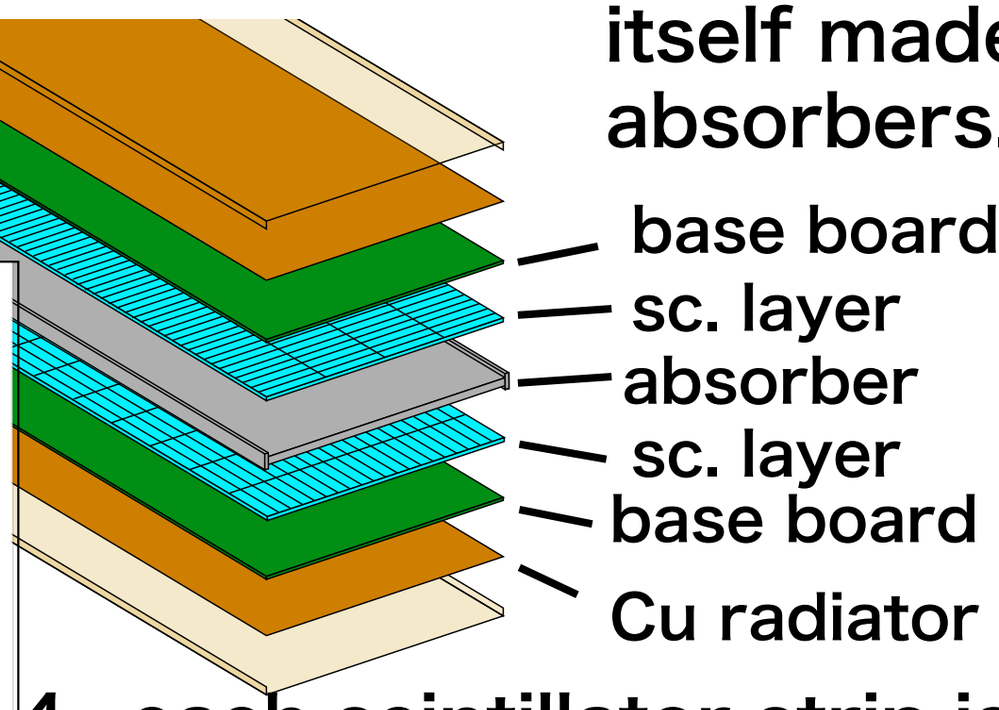
1. Introduction to the strip-scintillator ECAL in ILD,
2. introduction to the strip splitting method,
3. performance on the single particles,
4. performance on two-jet events,
5. and summary.

Introduction to the high granular strip-scintillator ECAL

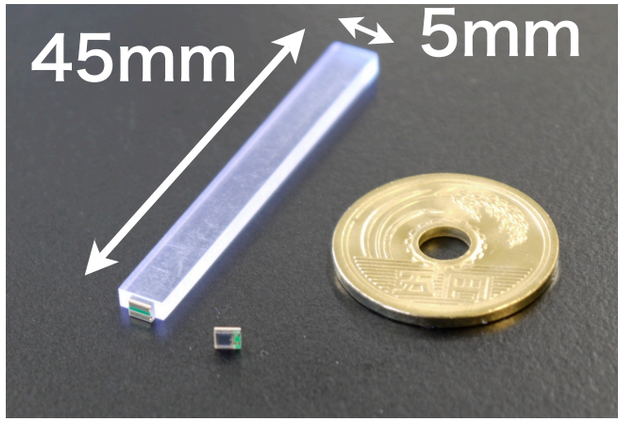
Strip ScECAL in ILD







1. Mechanical design of the barrel and the endcaps is the same as SiECAL.
2. the alveolar structure itself made of W absorbers.
3. strip directions are orthogonal to each others.



4. each scintillator strip is read out with a PPD (MPPC).
5. Physics prototype @ FNAL performed

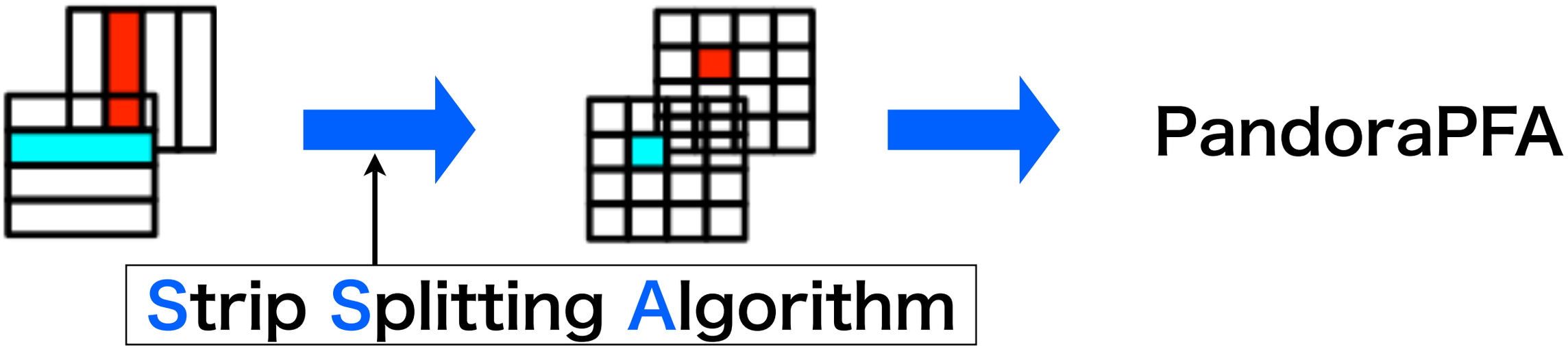
   $\sigma_E/E = (12.9 \pm 0.4/\sqrt{E} \oplus 1.2^{+0.4}_{-1.2})\%$

   for 2 - 32 GeV CALICE preliminary

   (CALICE note 16, 16a, 16b)
6. Required granularity: 5 x 5 mm^2

Introduction to the Strip Splitting Algorithm (how to extract 5 x 5 mm^2 segmentation from 45 x 5 mm^2 strip ECAL)

Strip ECAL reconstruction



Working on Marlin/Mokka framework for ILD (v01-16)

Marlin:

ModularAnalysis and Reconstruction for the LINear collider,

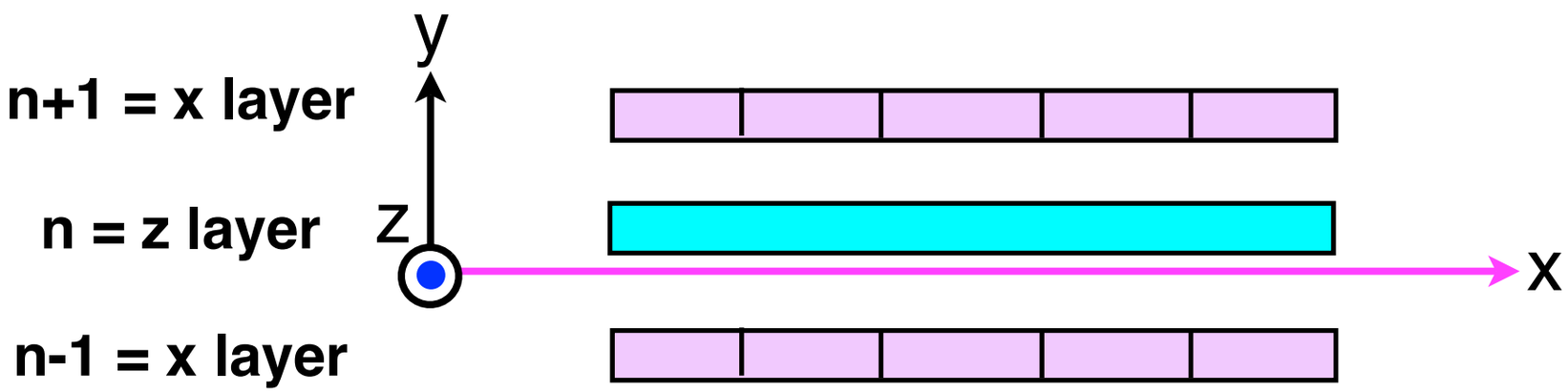
Mokka:

Full simulation using Geant 4 and a realistic description of a detector for the futer linear collider.

Strip Ecal reconstruction with the strip splitting algorithm

1. Assume that n-th is a z-layer (fine segmentation in z direction), while n±1 layers are x-layers (fine segmentation in x direction).
2. a particle shower comes from the bottom in y direction.
3. split each strip in n-th layer into pseudo-square cells

Split method



4. energy deposit in n-th layer is distributed in pseudo cells referring adjacent n±1th layer strips.
5. The position and energy of pseudo square cells are fed into PandoraPFA.

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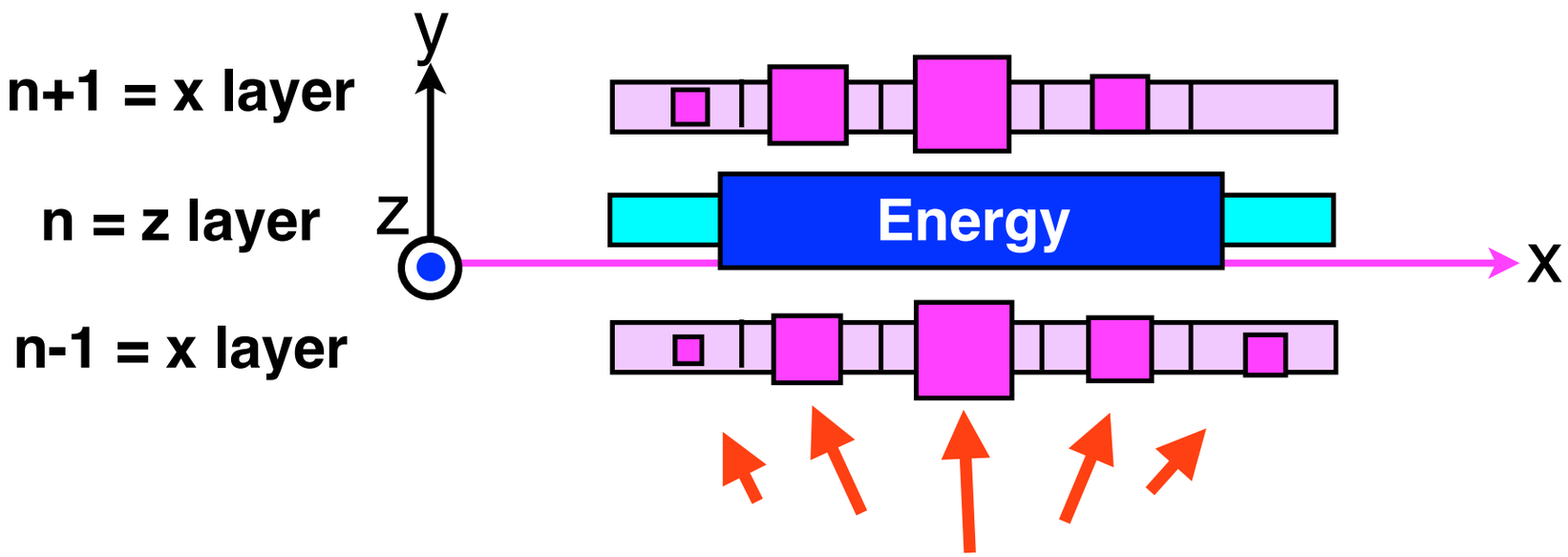

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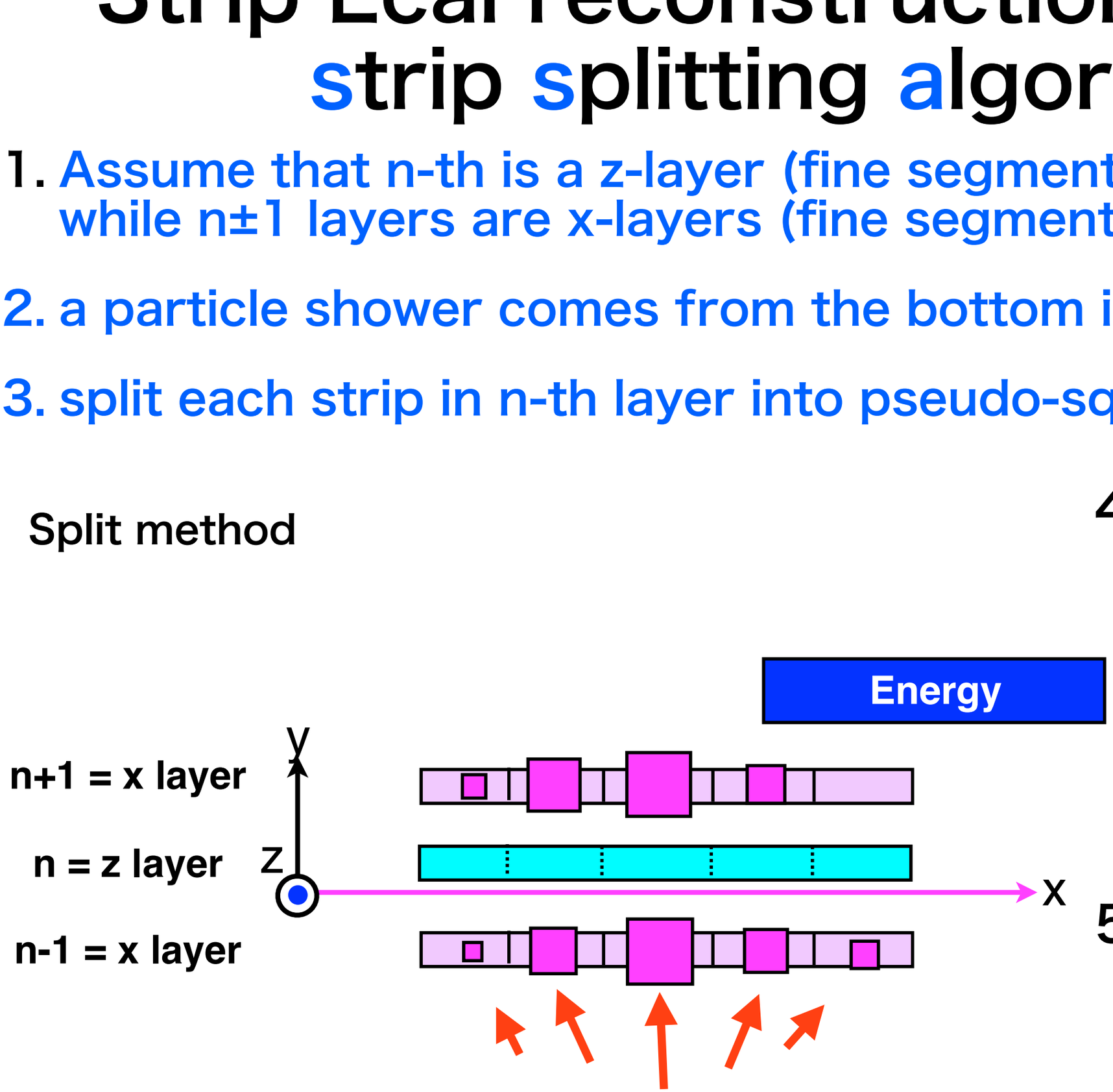

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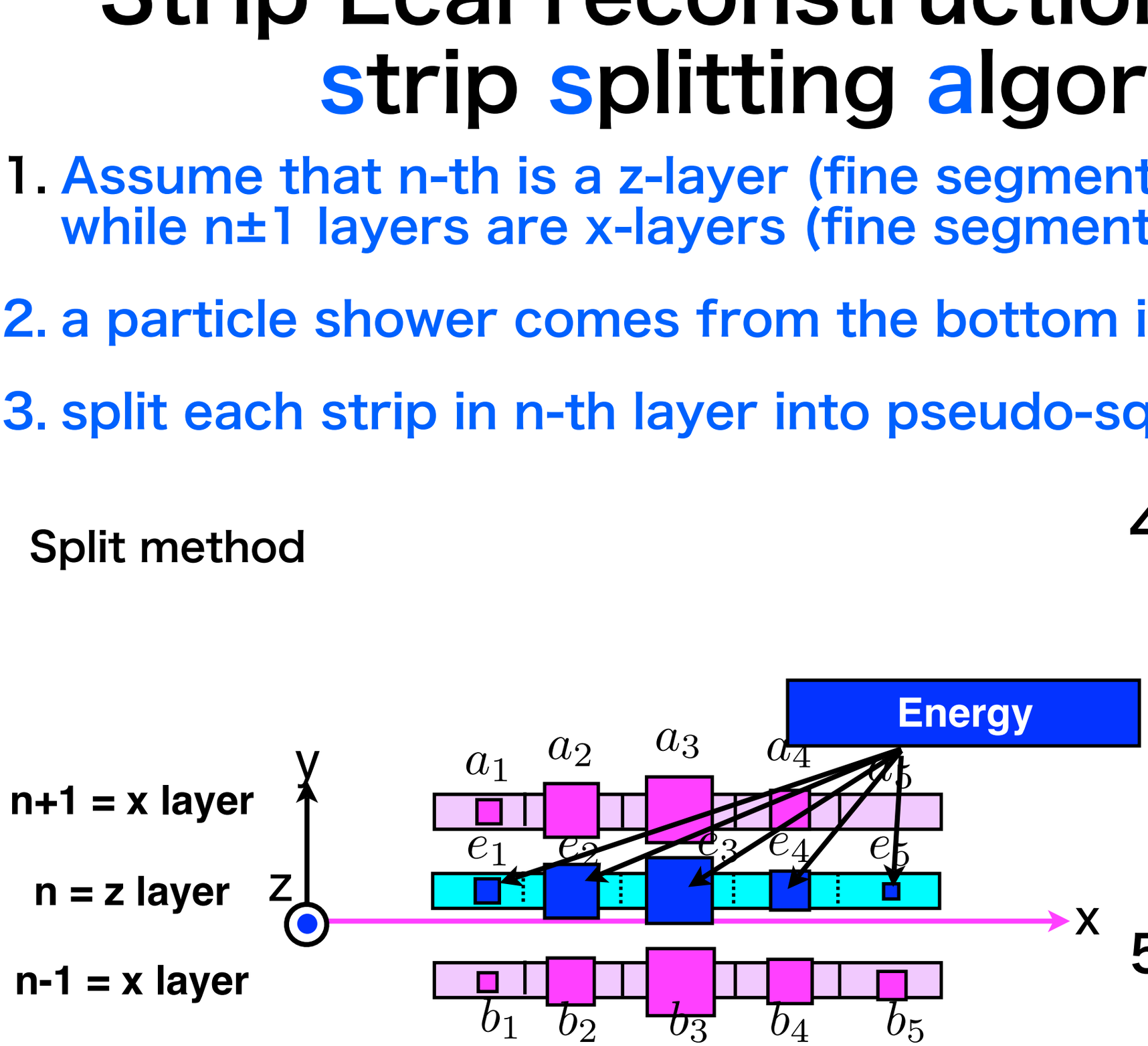

$$e_i = E_{\mathrm{n}} \cdot \frac{a_i + b_i}{\sum a_i + \sum b_i}$$

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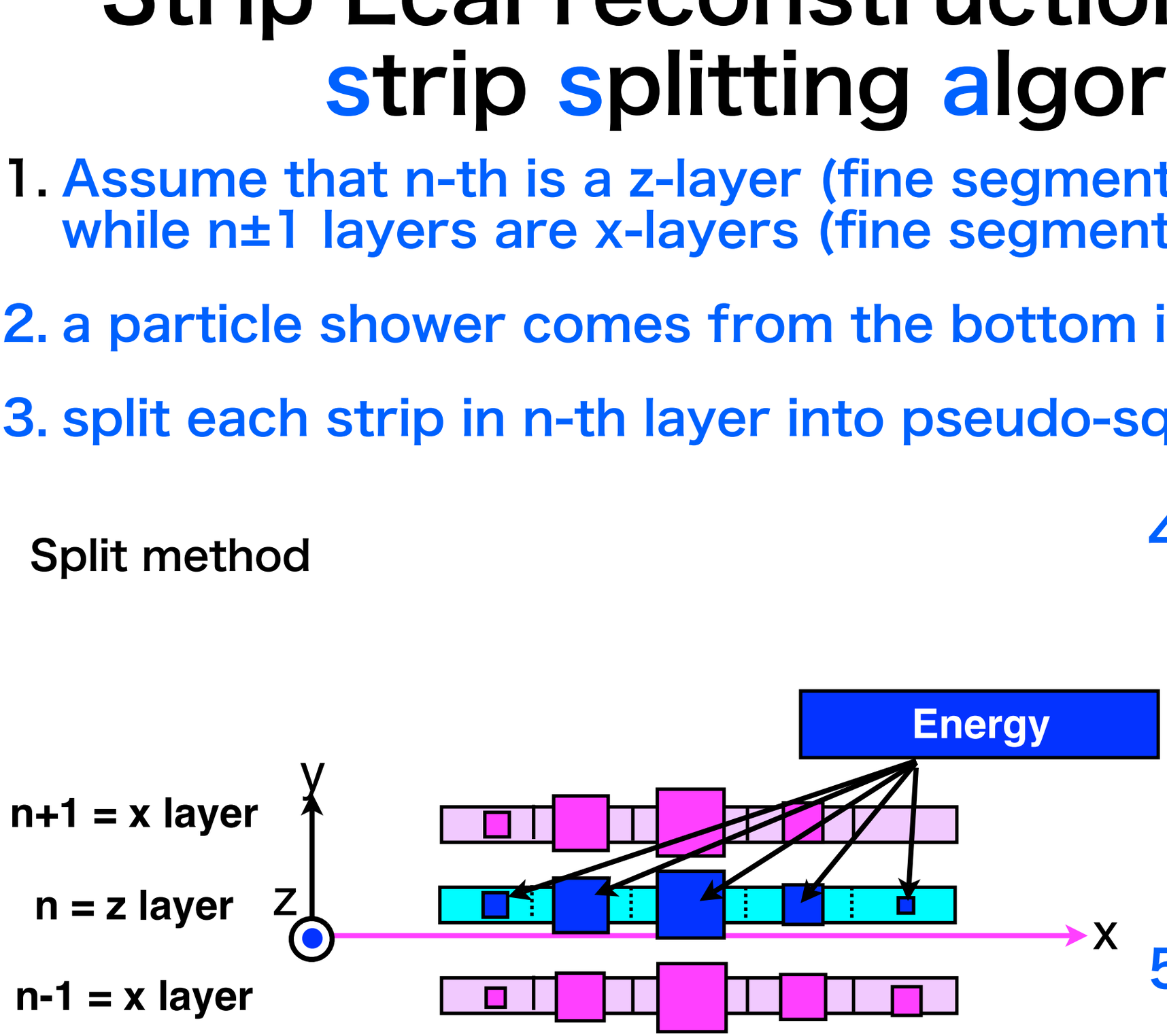

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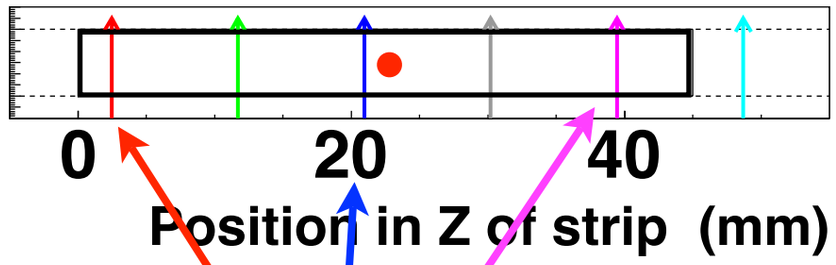
Strip Splitting Algorithm

Response to the single particles

Position
Gravitational center of energy

10 GeV photons are injected on the ScECAL of ILD, changing injection position w.r.t. a scintillator of the first layer.

Side view of a scintillator of the first layer and injection point of photons

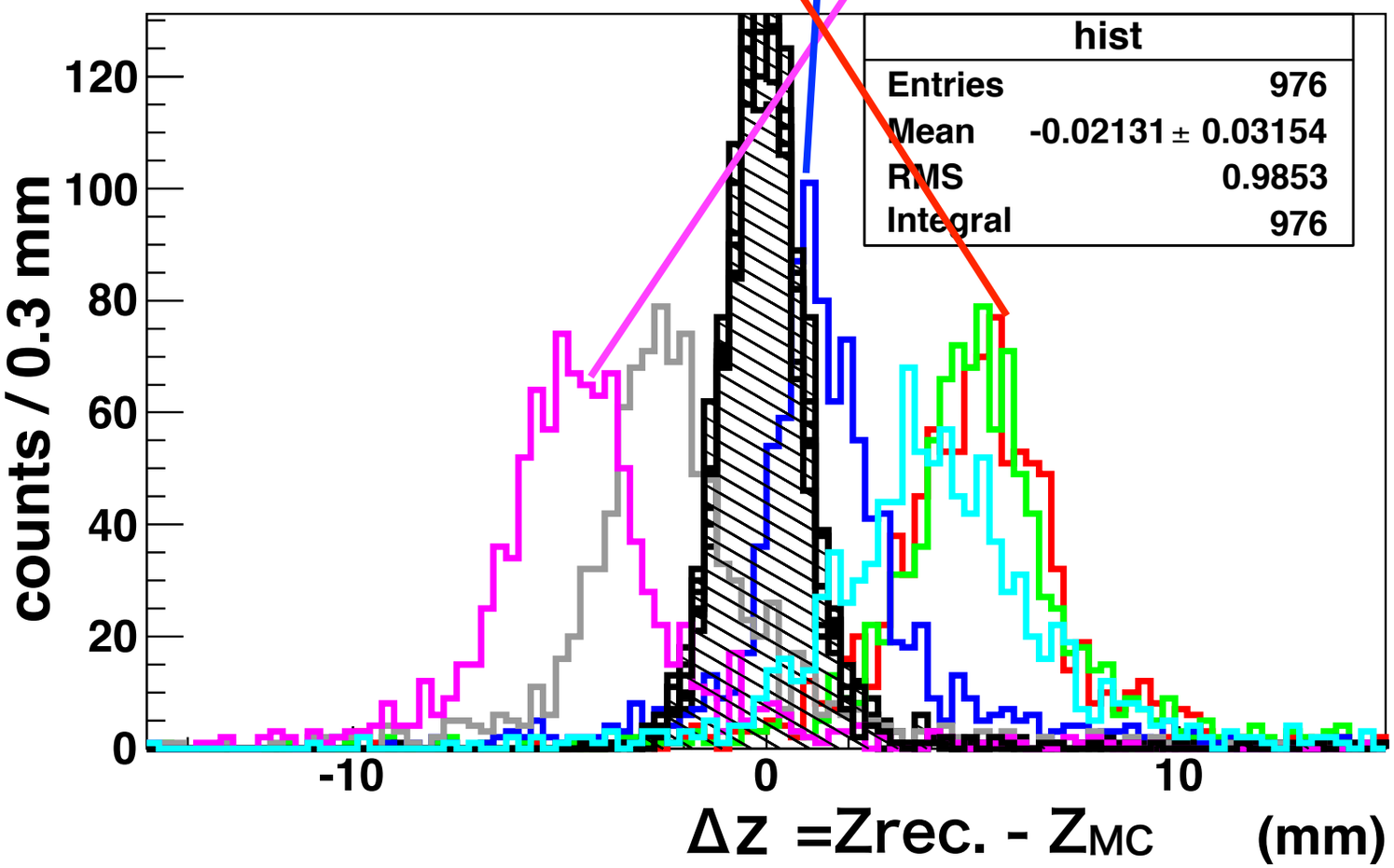


Black hatched: reconstructed PF object with SSA, not depend on injection position. Position resolution is ~1 mm

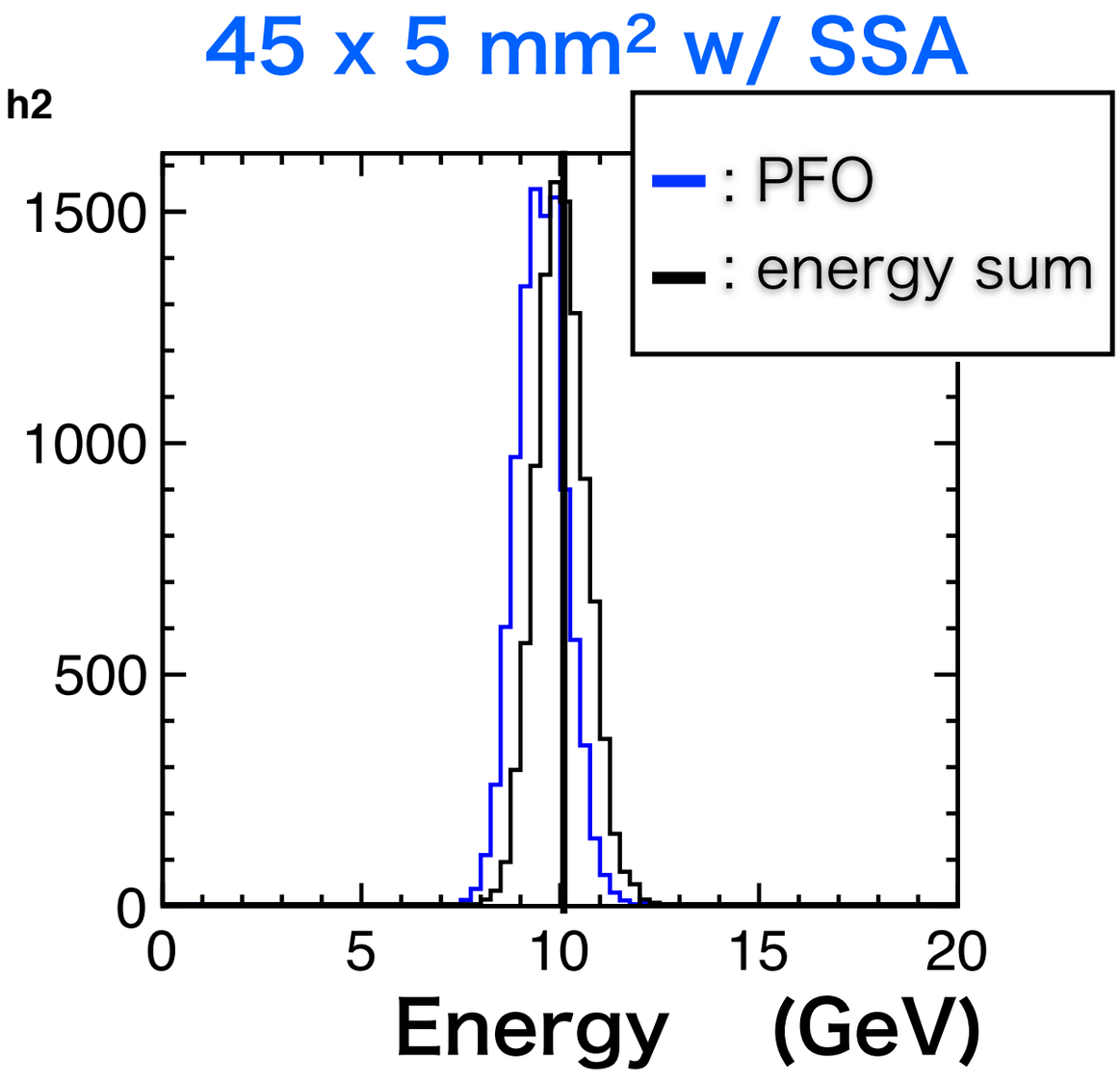
Color lines: without SSA

Systematic shift is removed by the SSA

Distance btw. position of re-constructed PFO and MC true in z.



10 GeV photon Energy



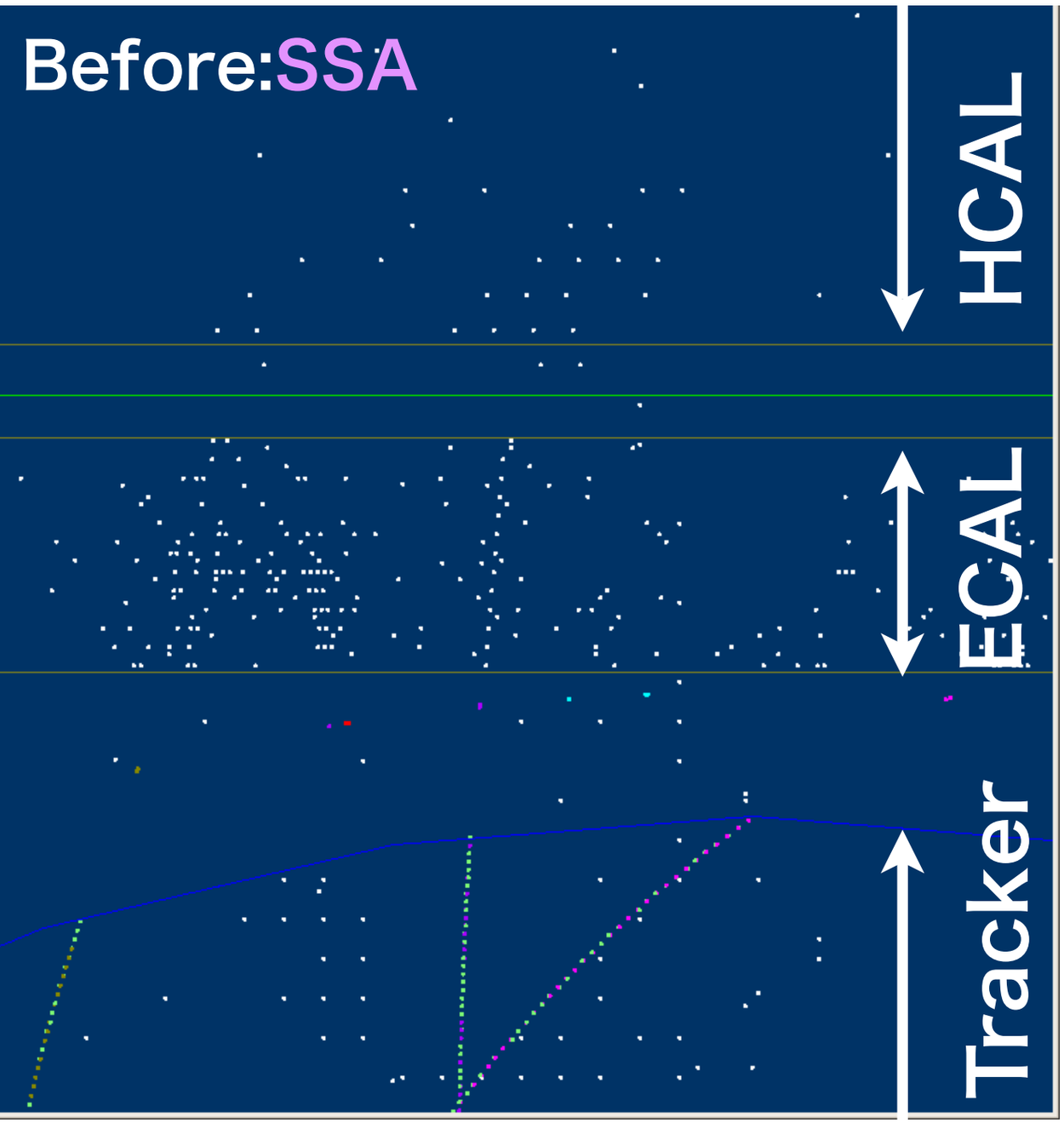
	σE/E
5 x 5 mm²	6.39%
45 x 5 mm² w/o SSA	8.12%
45 x 5 mm² w/ SSA	6.55%

- with common calibration constant
- mean shift comes from setting of the MIP threshold

Response to the jet events

Demonstration in the event display

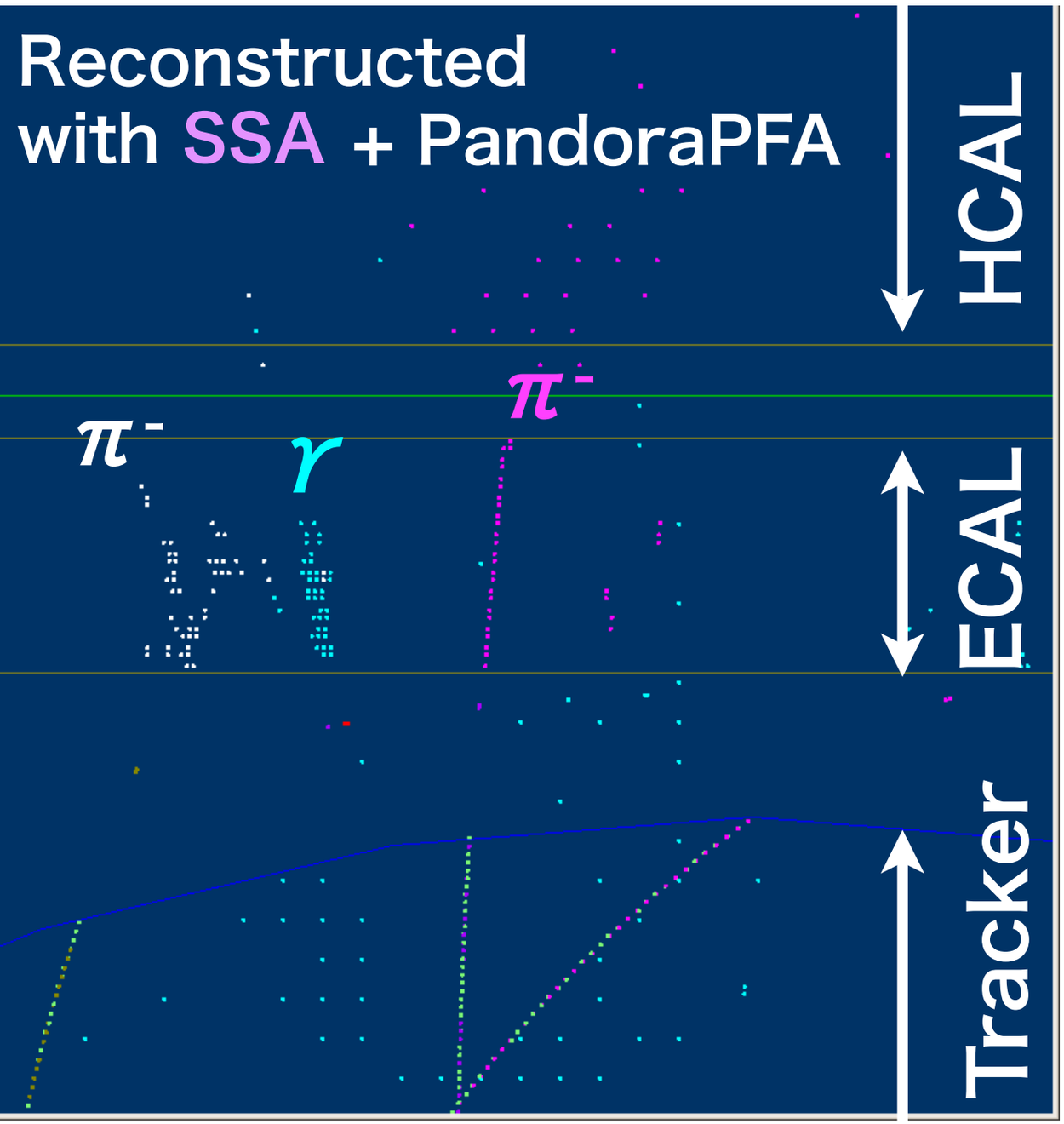
In a 100 GeV jet



Before the SSA, hit positions are messy and zigzag trails are there.

Demonstration in the event display

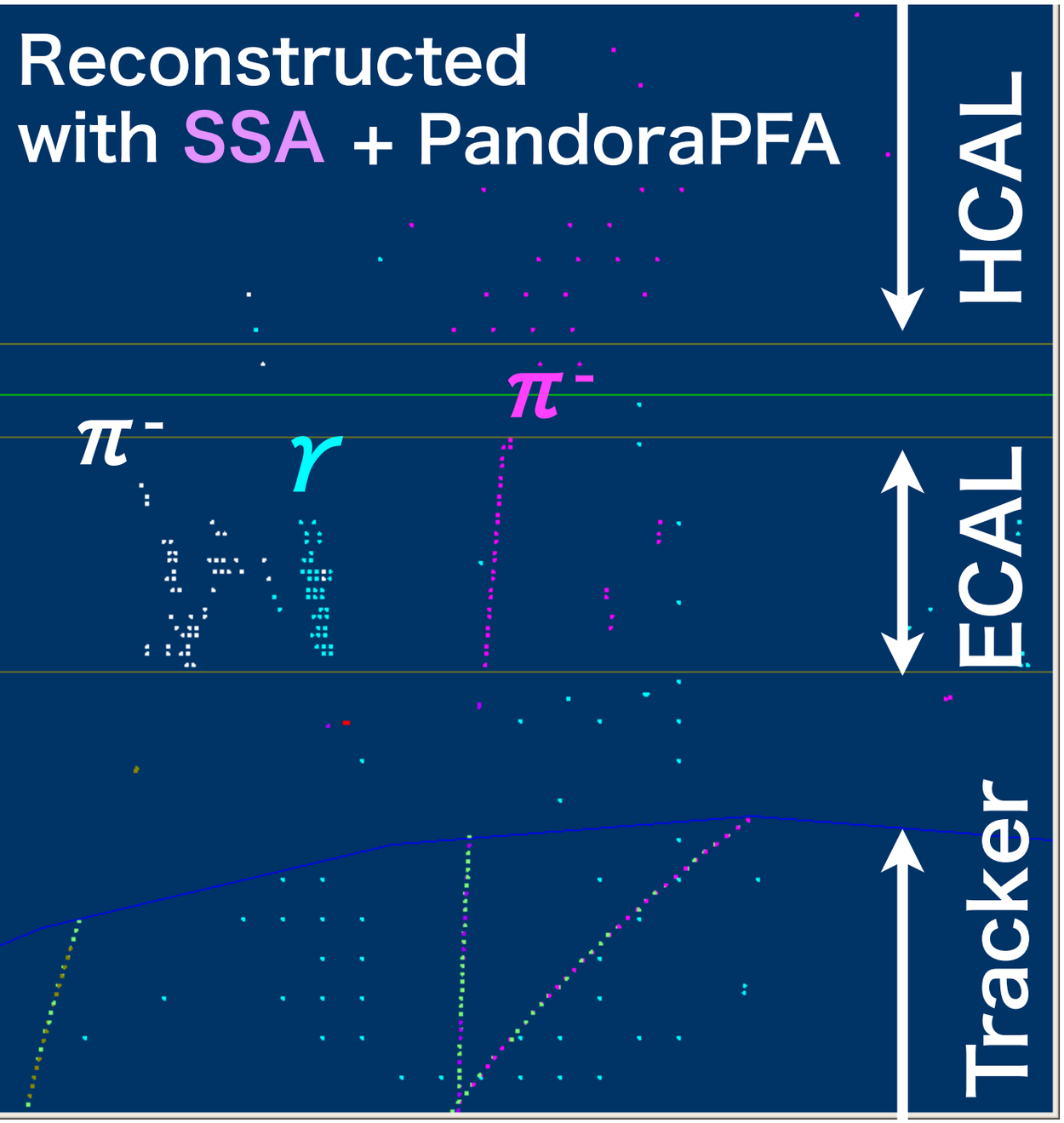
In a 100 GeV jet



After SSA, hadron tracks in ECAL and clusters clearly appeared, but this is an easy case.

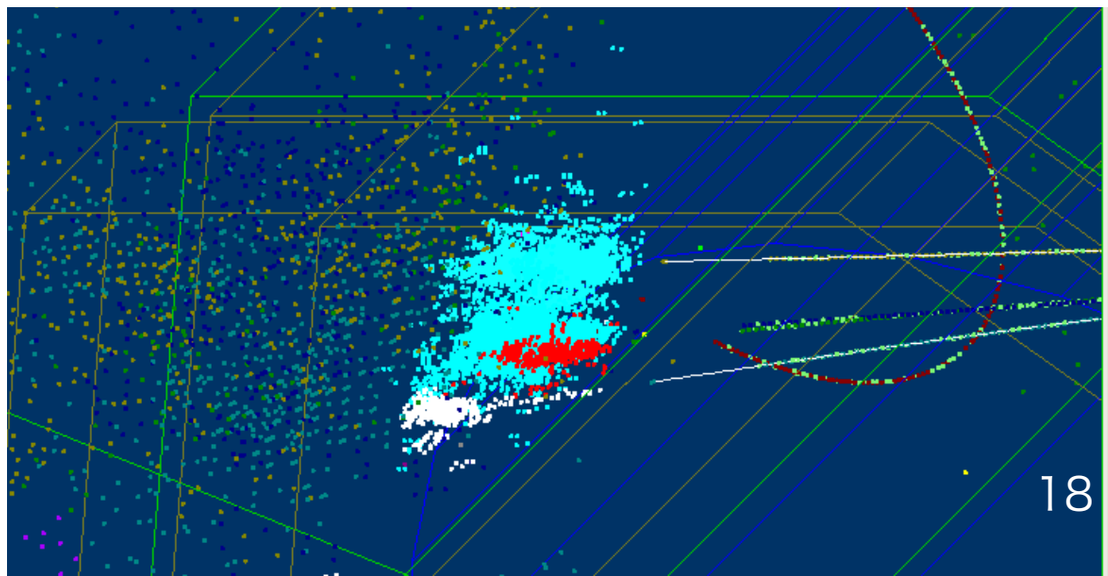
Demonstration in the event display

In a 100 GeV jet

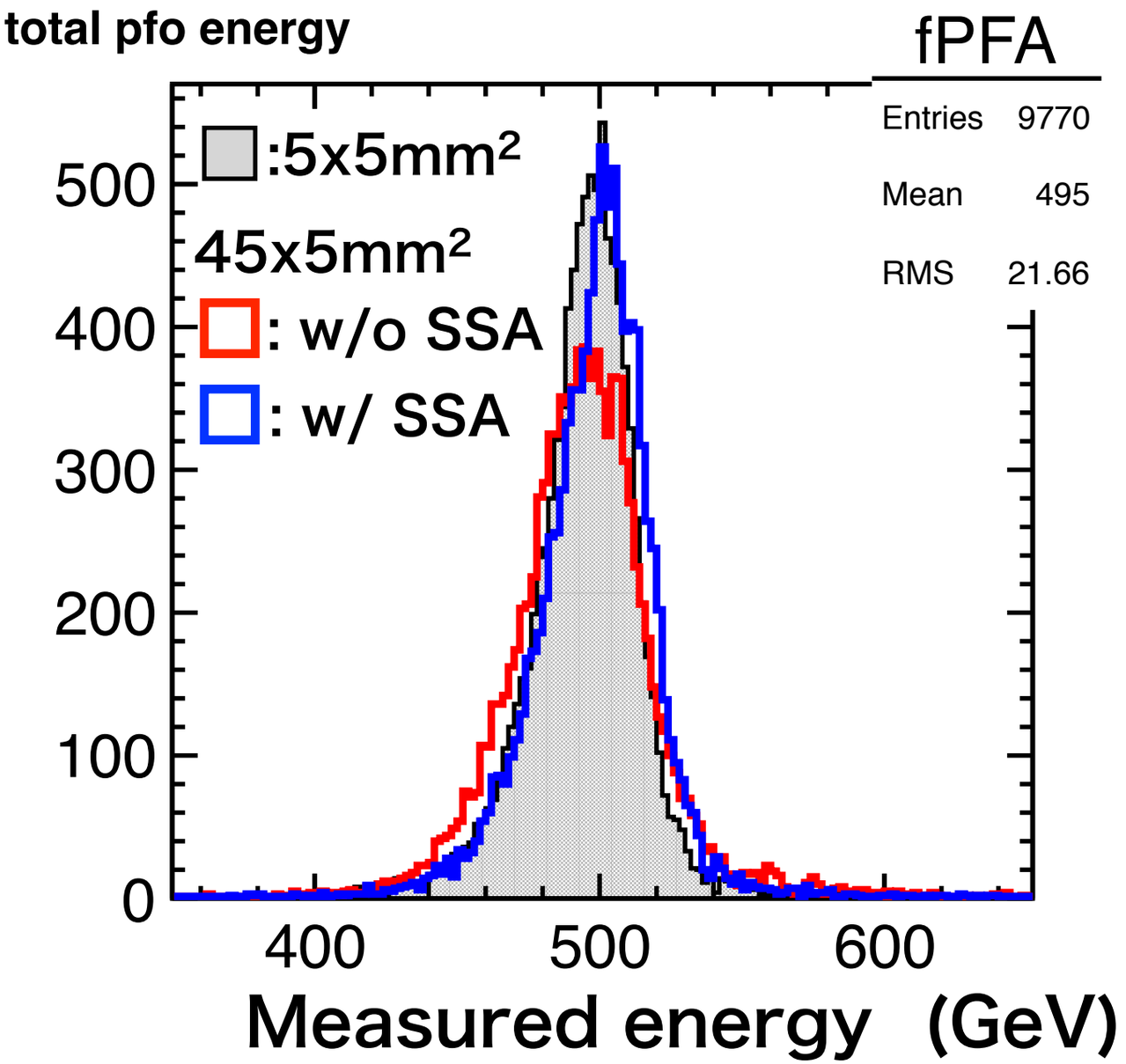


Rather difficult case.

limit of colors makes two clusters in the same color,but they are separated well.



Spectrum of 250 GeV two jets



- $\sigma E/E$

  5 x 5 mm²: 3.44±0.03%,

  45 x 5 mm²:

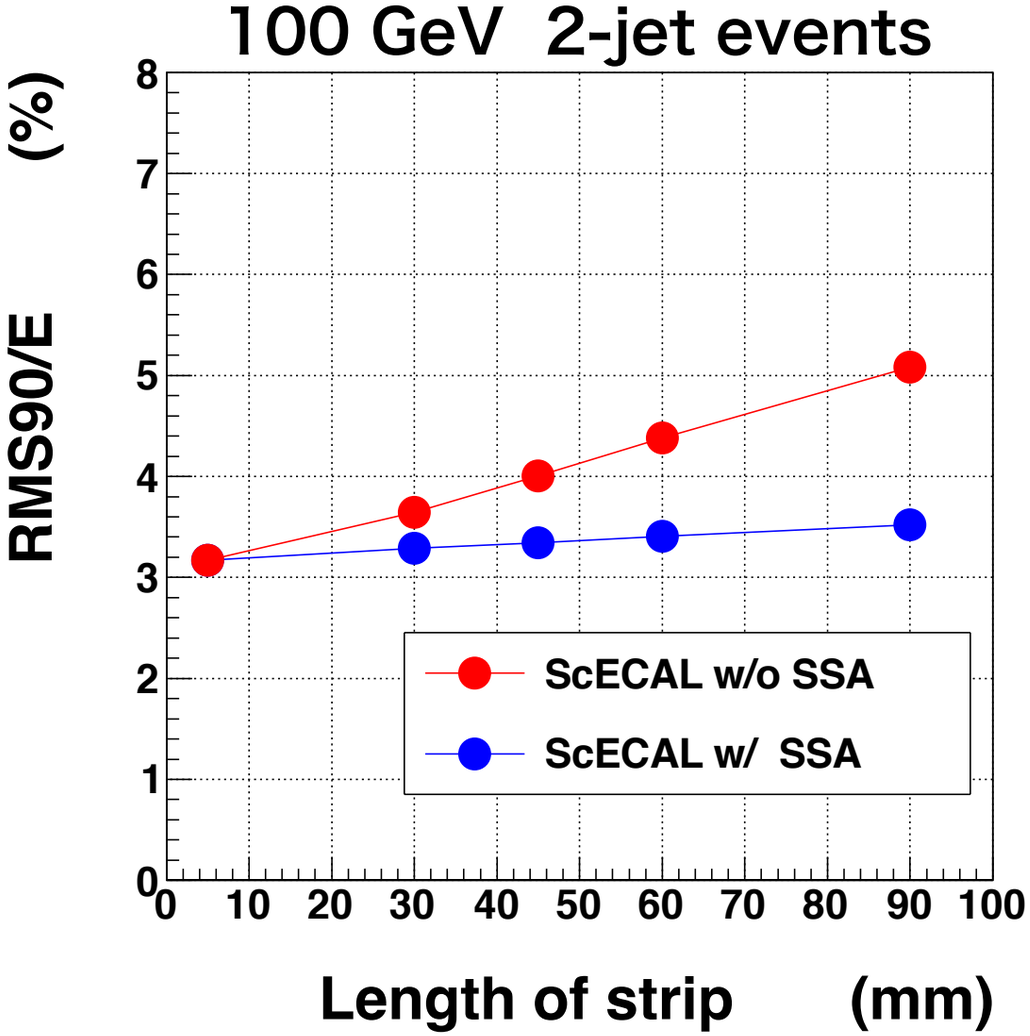
  w/o SSA : 4.80±0.05%,

  w/ SSA : 3.63±0.03%.

- SSA clearly improves the jet energy reconstruction.

Two Jet Energy Resolution

depending on the strip length



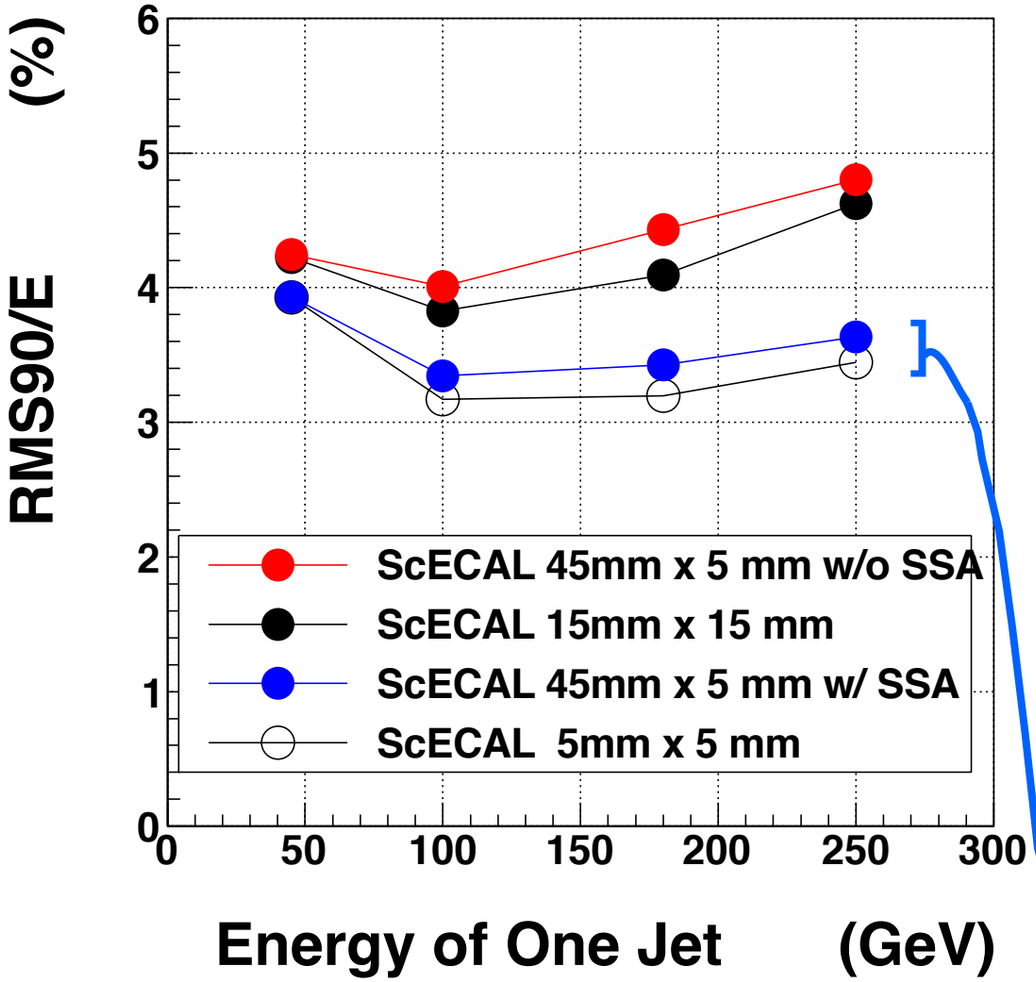
strip width is 5 mm

strip thickness is 0.5 mm, to be suite the default Pandora

- No strong deterioration with increasing the strip length after applying SSA.

Two Jet Energy Resolution

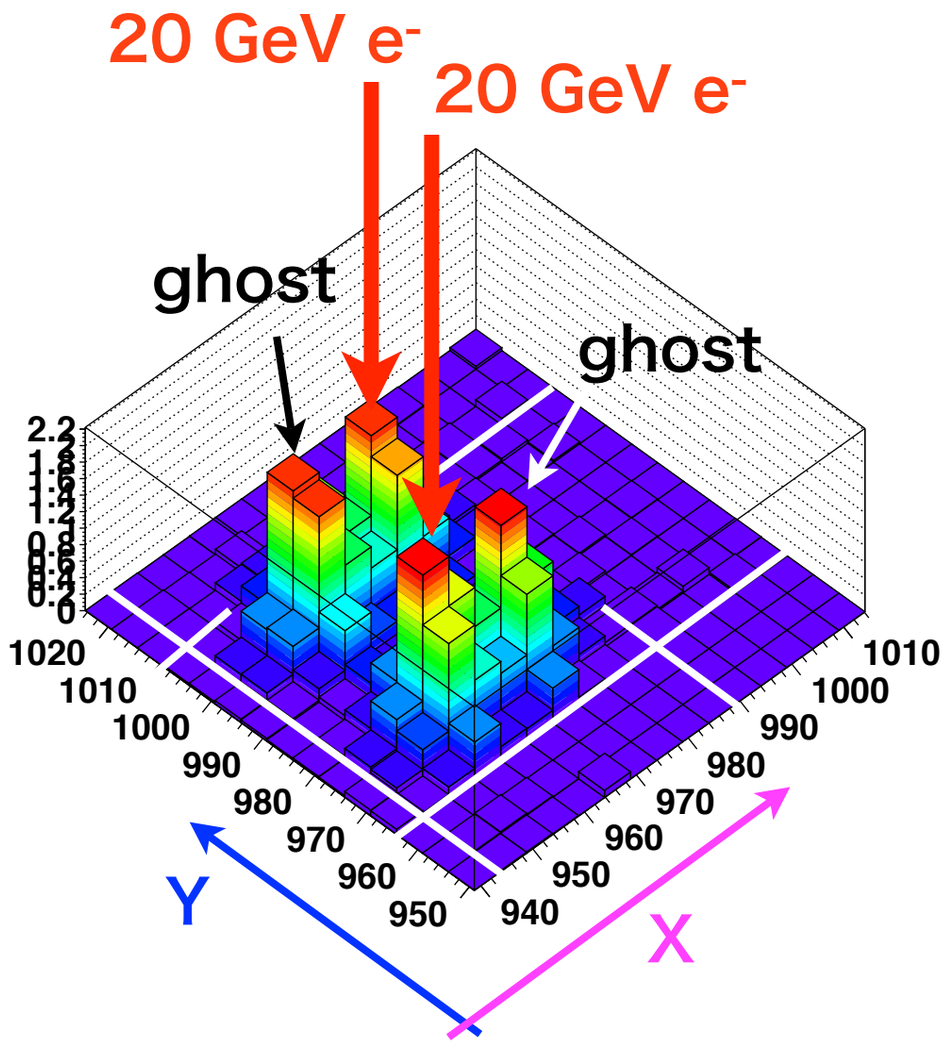
depending on the jet energy



- JER is significantly improved by SSA (● → ●) especially for high energy.
- Comparison of JER between 45 x 5 mm² ECAL with SSA and 15 x 15 mm² ECAL (● → ●) shows also good performance of SSA.
- Performance of 45 x 5 mm² ECAL with SSA is close to that of 5 x 5 mm² ECAL (○ → ●).
- Still a room exists to improve the difference between 5 x 5 mm² and 45 x 5 mm² with SSA.

More improvement

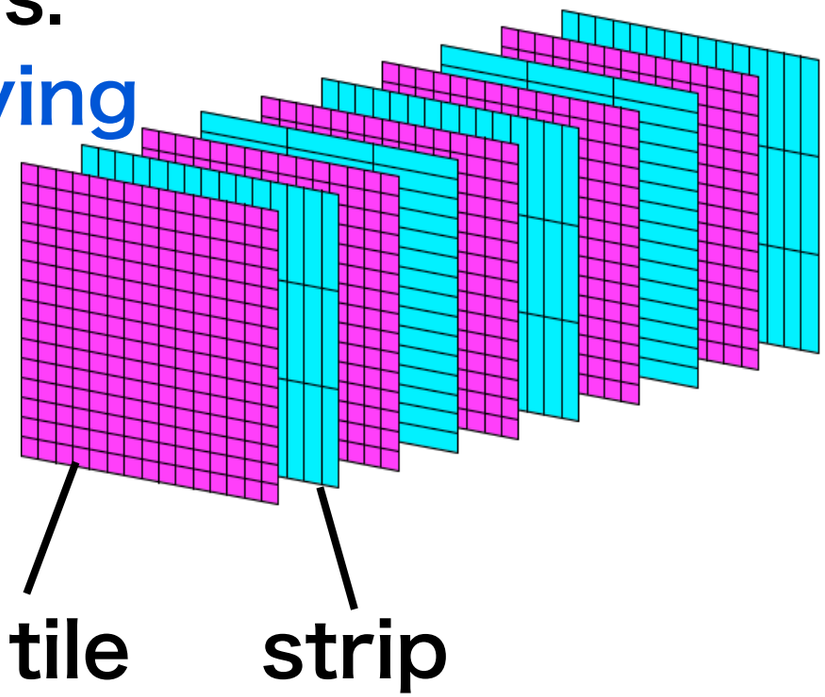
Energy deposit by two close particles.



two close clusters on the orthogonal position in a 45 x 45 mm² area make a set of ghosts

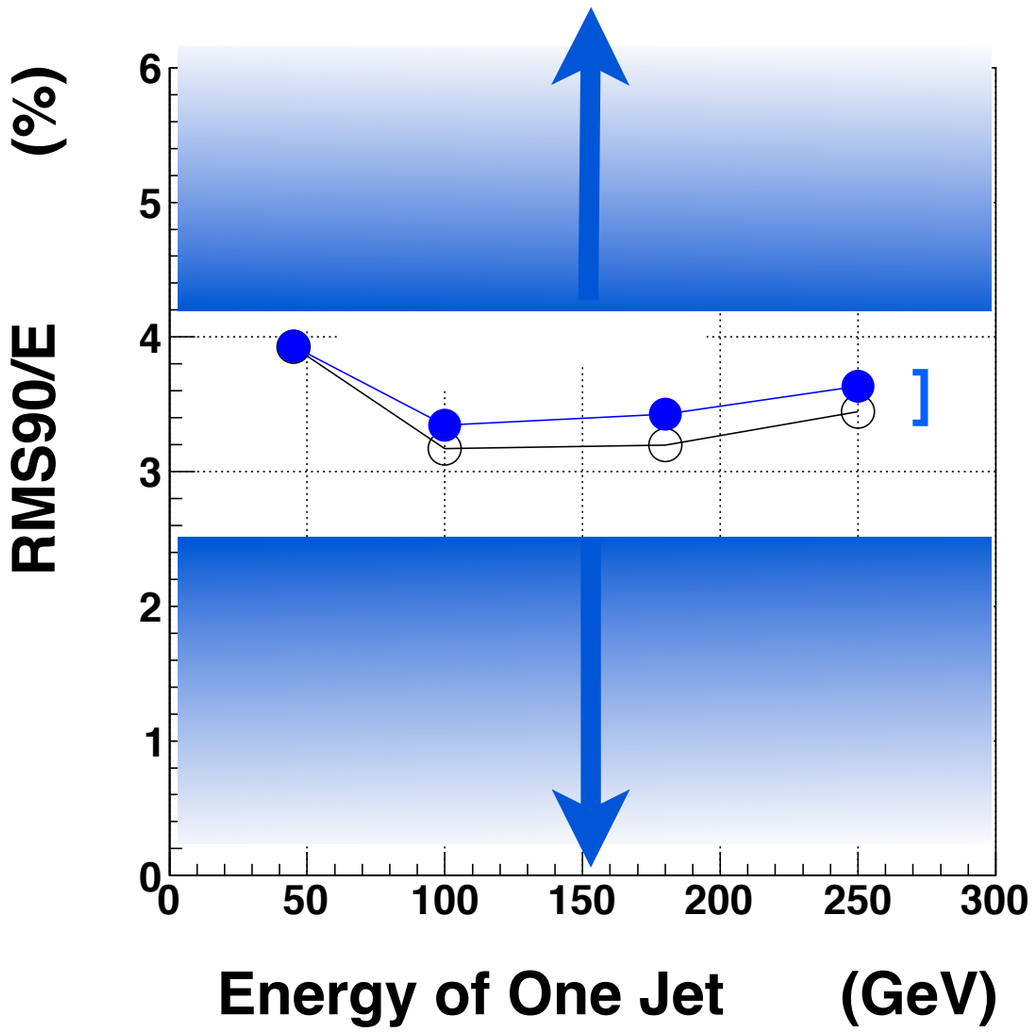
- One of the reason of degrading JER with strip ECAL + SSA comes from the two fold ambiguity (ghost).
- Easiest way to avoid this phenomenon is to put 5 x 5 mm² segmentation layers in between strip layers.

and applying SSA



More improvement

45 x 5 mm² + 5 x 5 mm² alternate



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- The 5 x 5 mm² layers between strip layers improve JER well.
- but 5 x 5 mm² is difficult:
  - ➡ use Si-layers for 5 x 5 mm² → see Hiraku Ueno's talk
  - ➡ use 10 x 10 or 15 x 15 mm² cells with a special algorithm.

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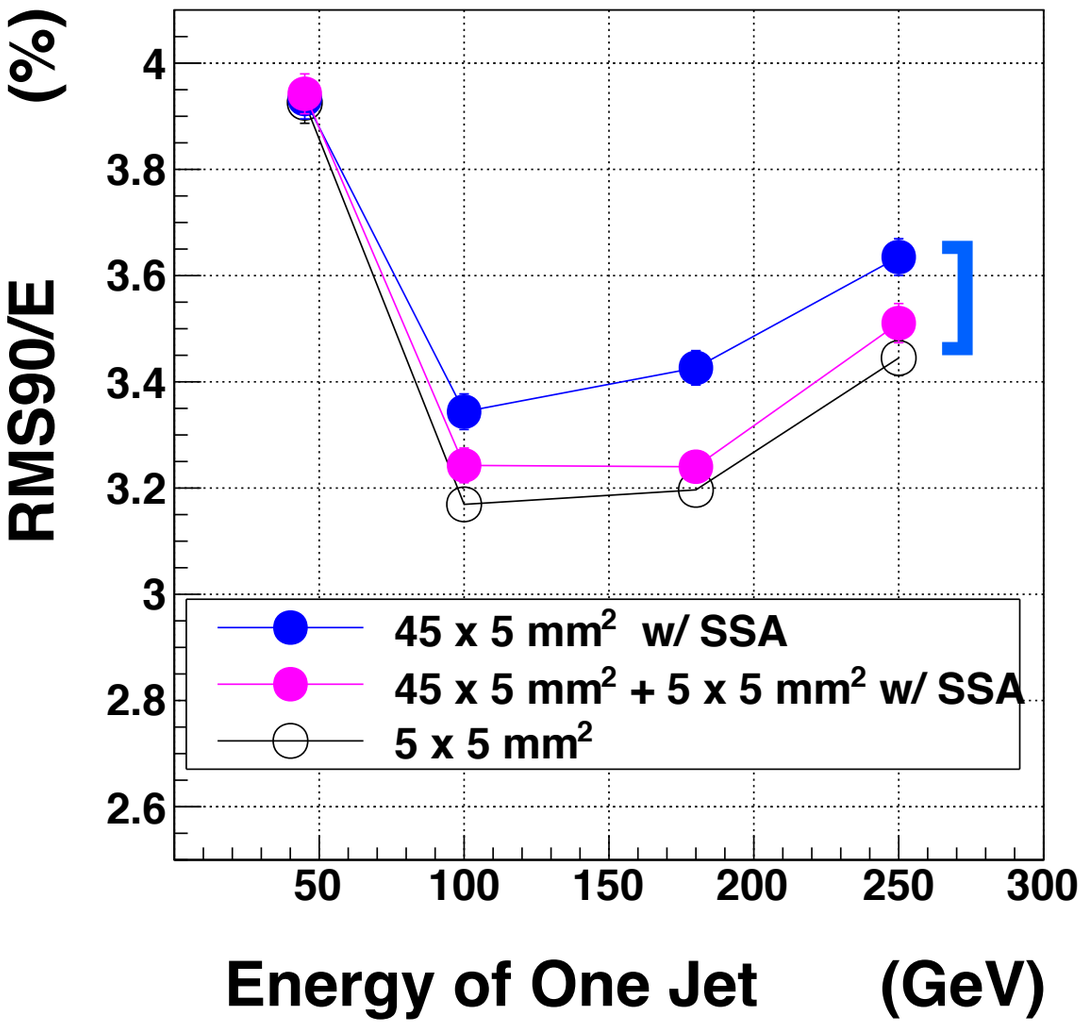

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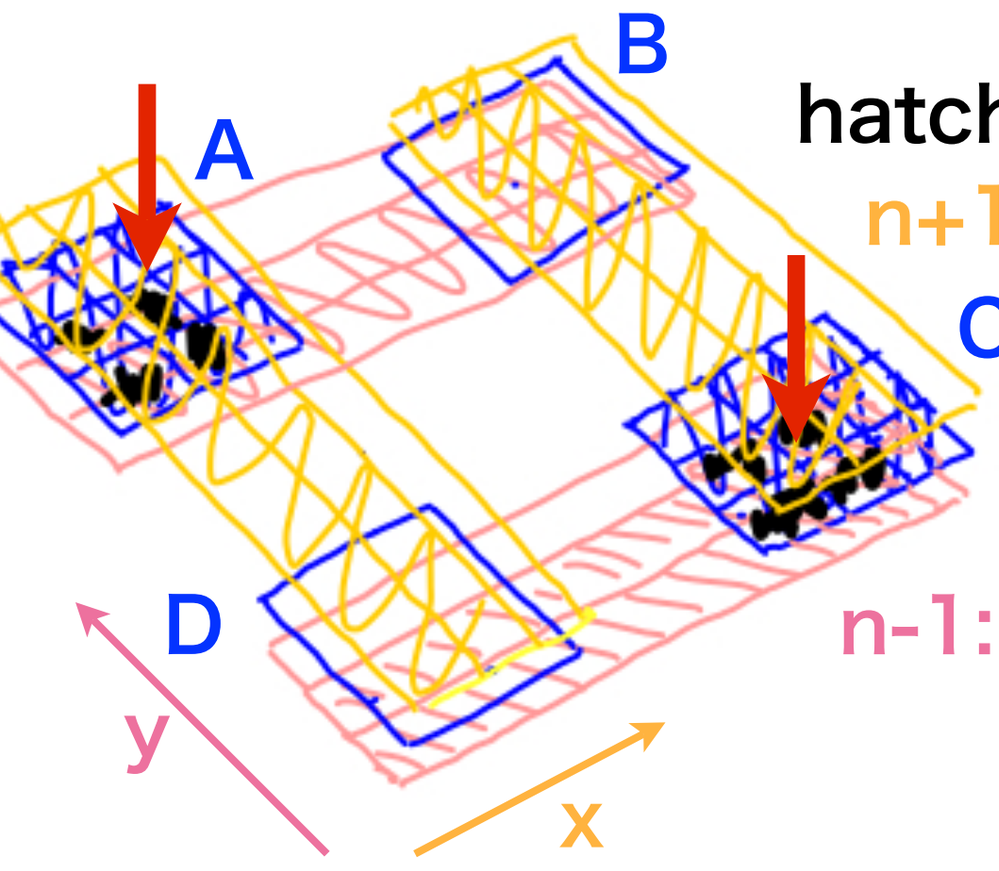
How to prevent ghosts with 15 x 15 mm² tile layers

1. All 15 x 15 mm² tile hits are segmented in virtual 5 x 5 mm² tiles using upper and lower strip information. In cartoon, A and C tiles have hits, then four 5 x 5 mm² virtual tiles (black) are created on each.



hatched cells are hit cells.

n+1: 45 x 5 mm2 strips segmented in x.

n: 15 x 15 mm2 tiles, A, B, C, and D.

n-1: 45 x 5 mm2 strips segmented in y.

2. With 5 x 5 mm² virtual tiles, strip layers are fed into SSA. Imagine that this method uses second order information (next to the nearest layers) for a strip.

Summary

1. We are developing a scintillator strip ECAL for future linear colliders with scintillator strips and PPD (MPPC).
2. Special method, Strip Splitting Algorithm is established in order to extract 5 x 5 mm^2 segmentation from 45 x 5 mm^2 strips.
3. Energy resolution of Sc 45 x 5 mm^2 strip ECAL with SSA is close to that of 5 x 5 mm^2 ScECAL
4. A little degradation is removed by using 5 x 5 mm^2 cell layers between strip layers:
   - realistic ways are;
     1. using Si layers between scintillator strip layers
        1. Hiraku Ueno's talk
     2. using 10 x 10 mm^2 or 15 x 15 mm^2 tile layers with an additional algorithm.

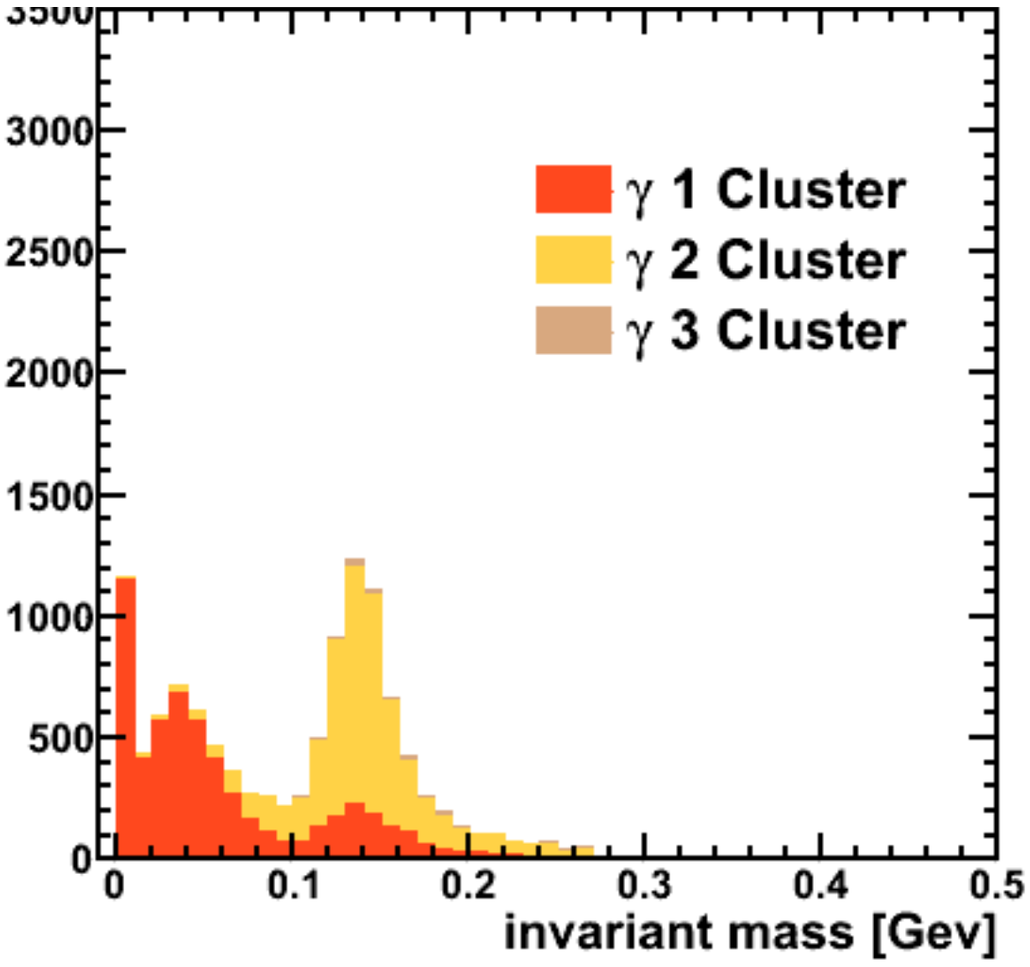
Plan

1. Show the result of the configuration of strip layers + 10 x 10 mm^2 or 15 x 15 mm^2 layers,
2. Show the separation of two particles,
3. Show performance with the multi jets events,
4. Performance for some physics modes,
5. Apply this technique for HCAL.

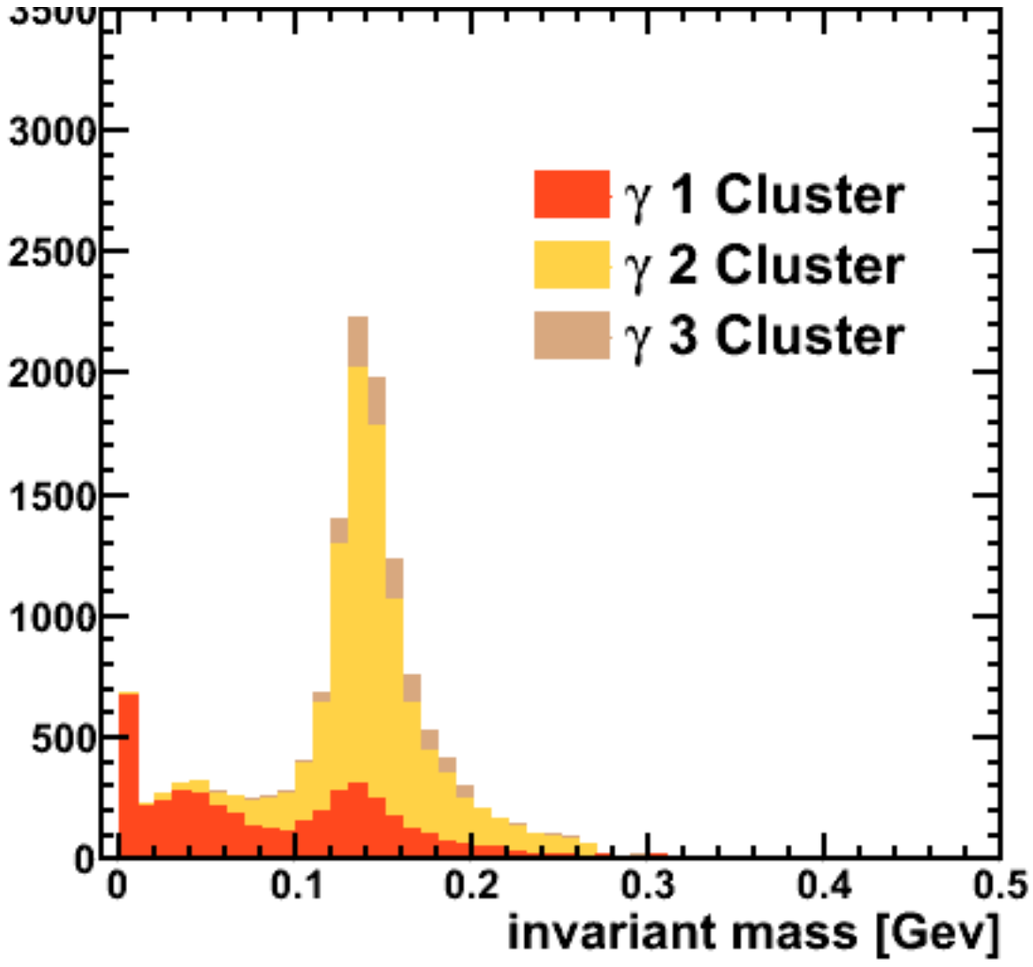
Back up

π^0 reconstruction

45 x 5 mm² w/o SSA



45 x 5 mm² w/ SSA

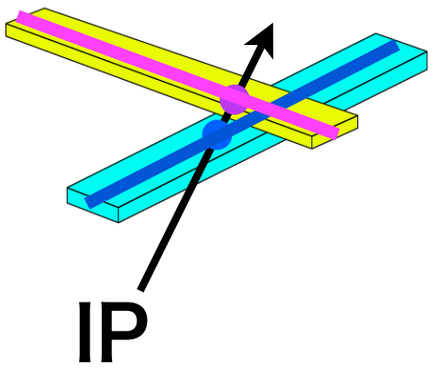


by T. Ogawa

Why we study ScECAL

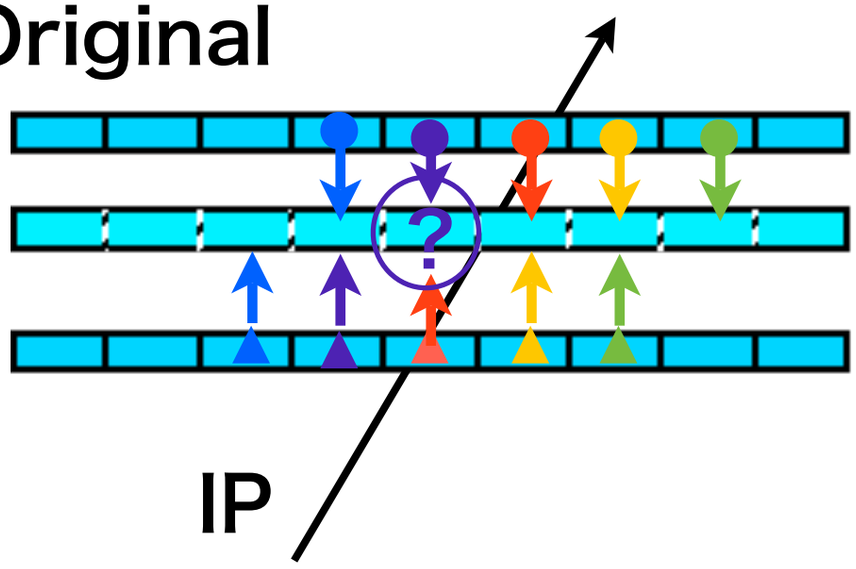
1. Requirements:
    1. 5 mm x 5 mm lateral segmentation
    - robustness for ~ 10^8 channels
    2. Low cost.
2. Drastic development of the PPD (SiPM, MPPC),
    1. high gain, small package,
3. Idea of strip segmentation, the strips in odd layers orthogonal to those in the even layers. $10^8 \rightarrow 10^7$
4. scintillator can make timing measurement with resolution < 1 ns.

Modified in elegant way by Daniel Jeans

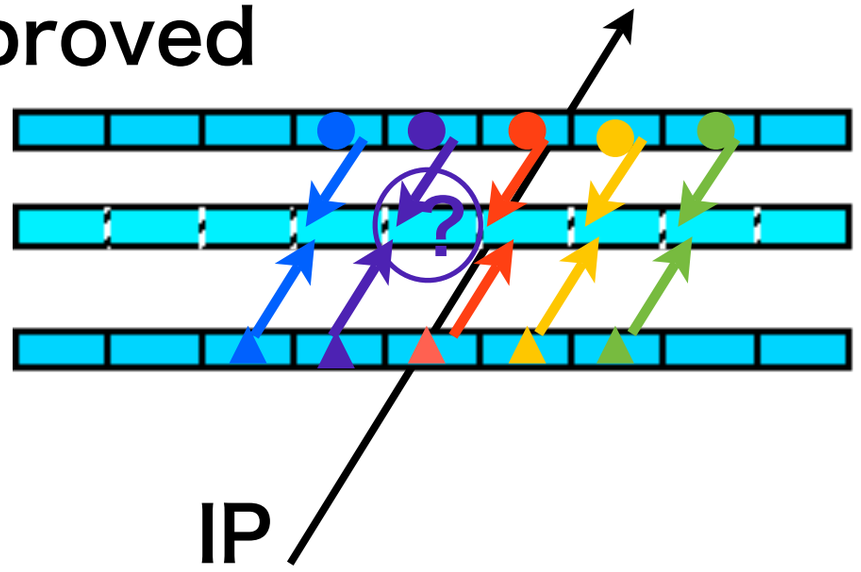


To refer the energy in the nearest neighbor layer, it scans intersection of center lines of respective scintillators toward the IP

Original



Improved

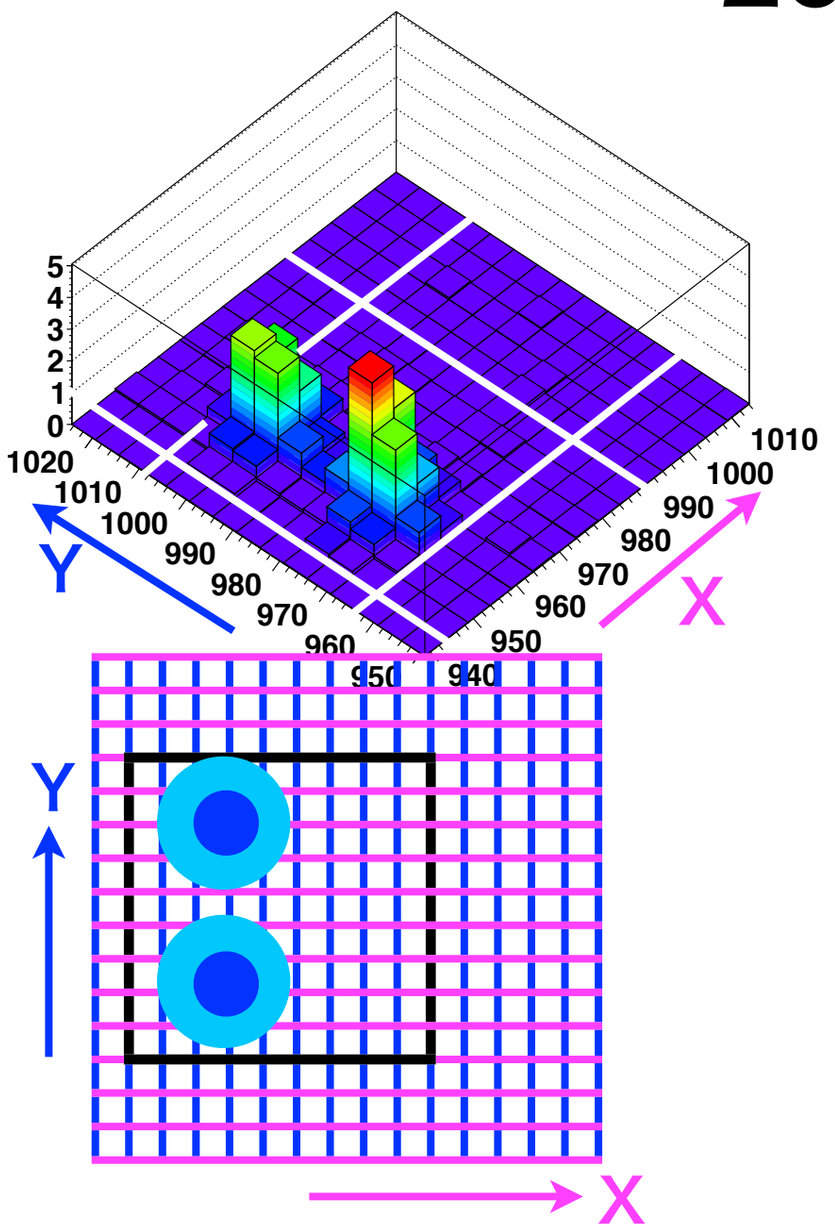


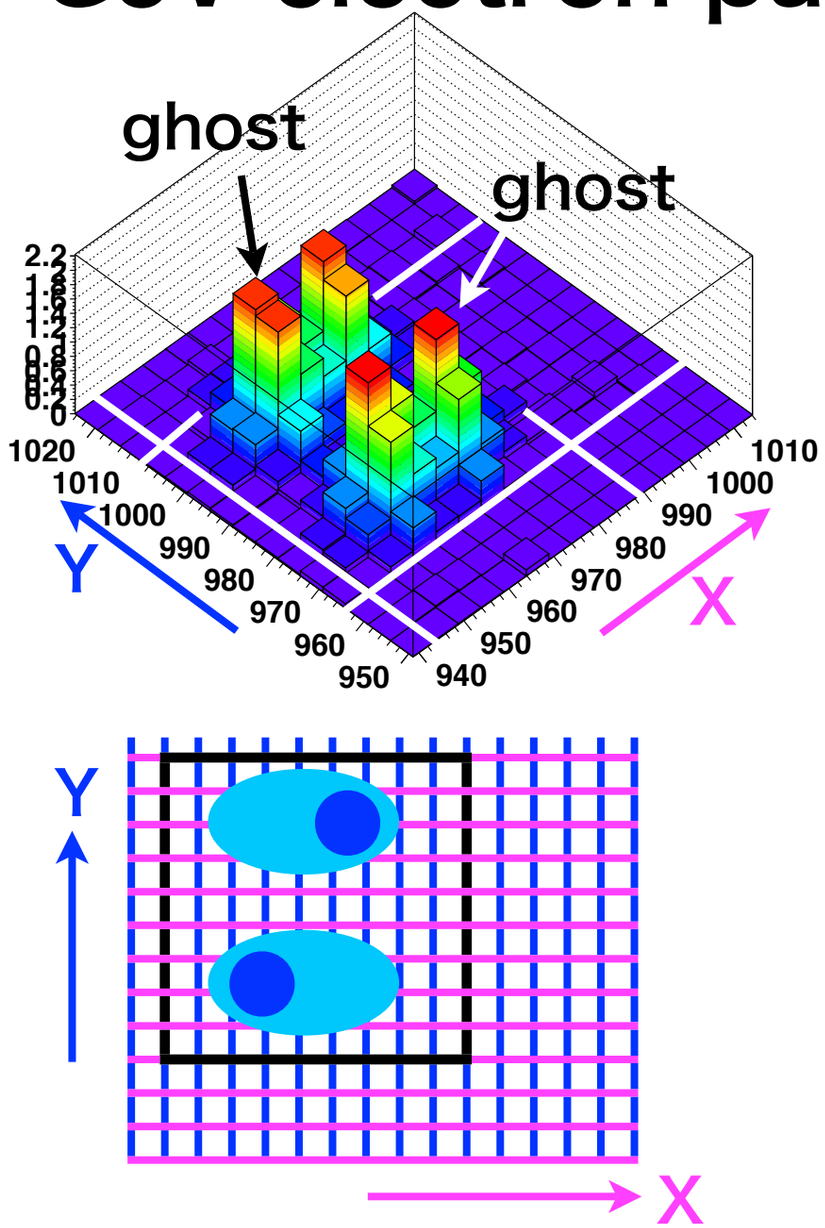
Energy in virtual cell (?) =
Energy on this strip ×
(●+▲) / (▲+▲+▲+▲+▲ + ●+●+●+●+●)

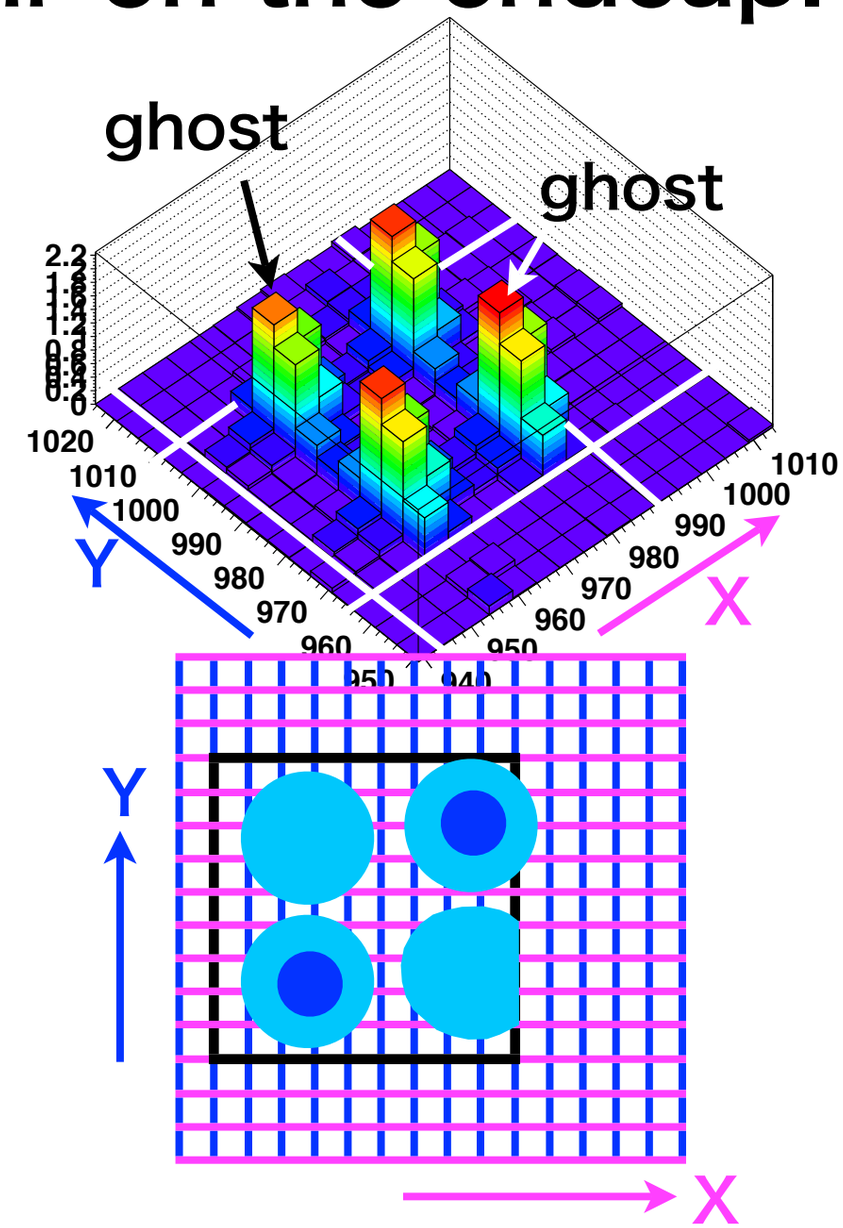
Energy on this strip ×
(●+▲) / (▲+▲+▲+▲+▲ + ●+●+●+●+●)

Separation of two electrons

20 GeV electron pair on the endcap.



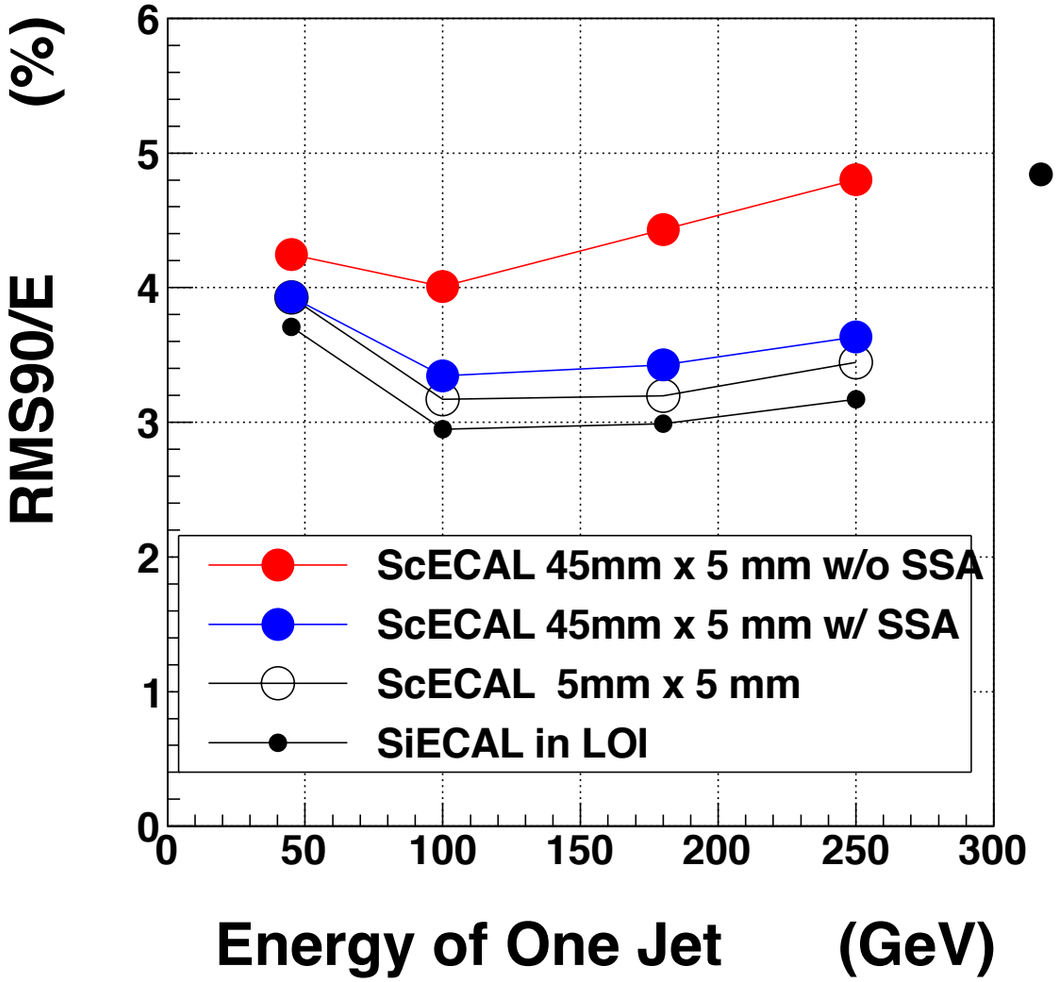




1. Shapes of two clusters simultaneously exist in a 45 mm x 45 mm square area are always strained and typical case makes two ghost clusters.
2. For electrons we can use track info. to resolve this.

two Jet Energy Resolution

depending on the jet energy



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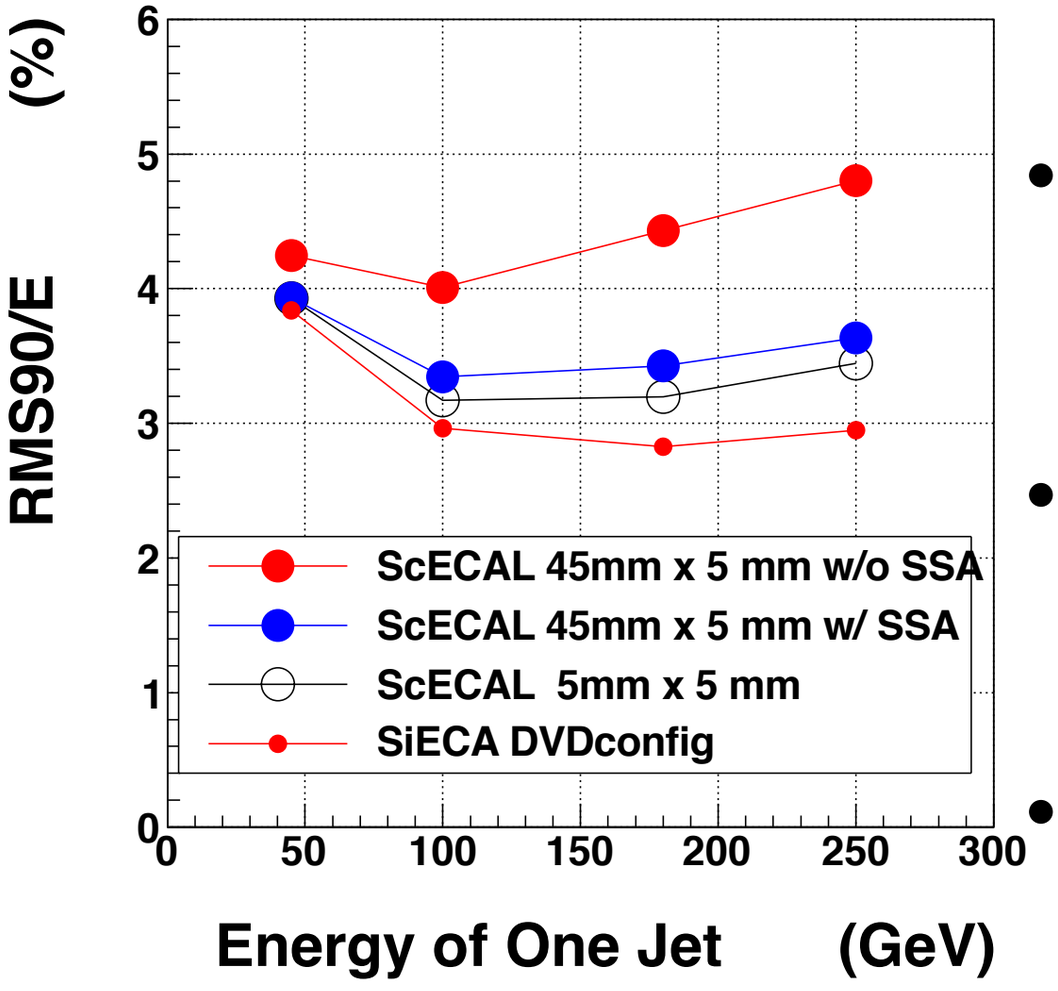

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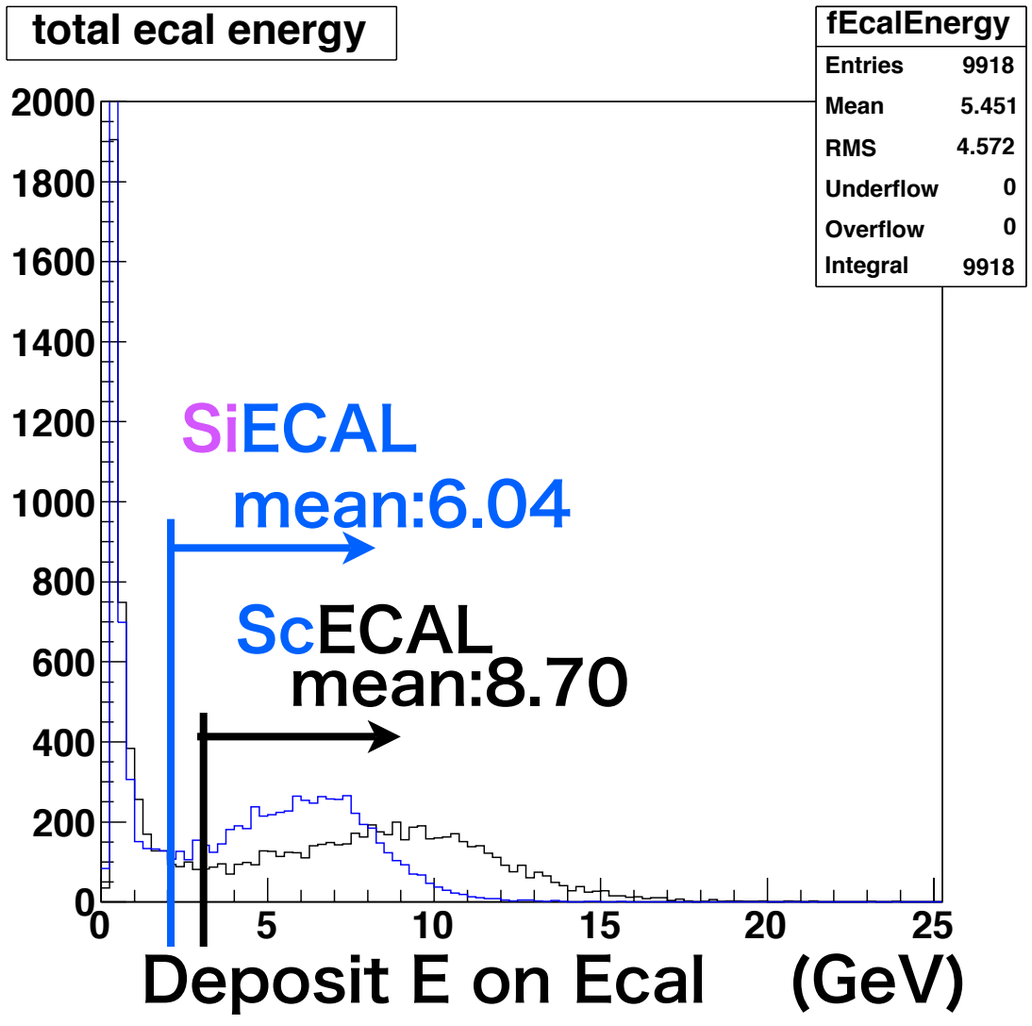
- Comparison between 5 x 5 mm² and 45 x 5 mm² with SSA shows that SSA works well (○ → ●).
- JER by SiECAL with the DBDconfig was improved for high energy Jet (by studying for CLIC?)
- There exist the discrepancy not only between SiECAL and strip ECAL but also between SiECAL and 5 x 5 mm² tile ScECAL (● → ○).➡We need special tune for Scintillator ECAL.

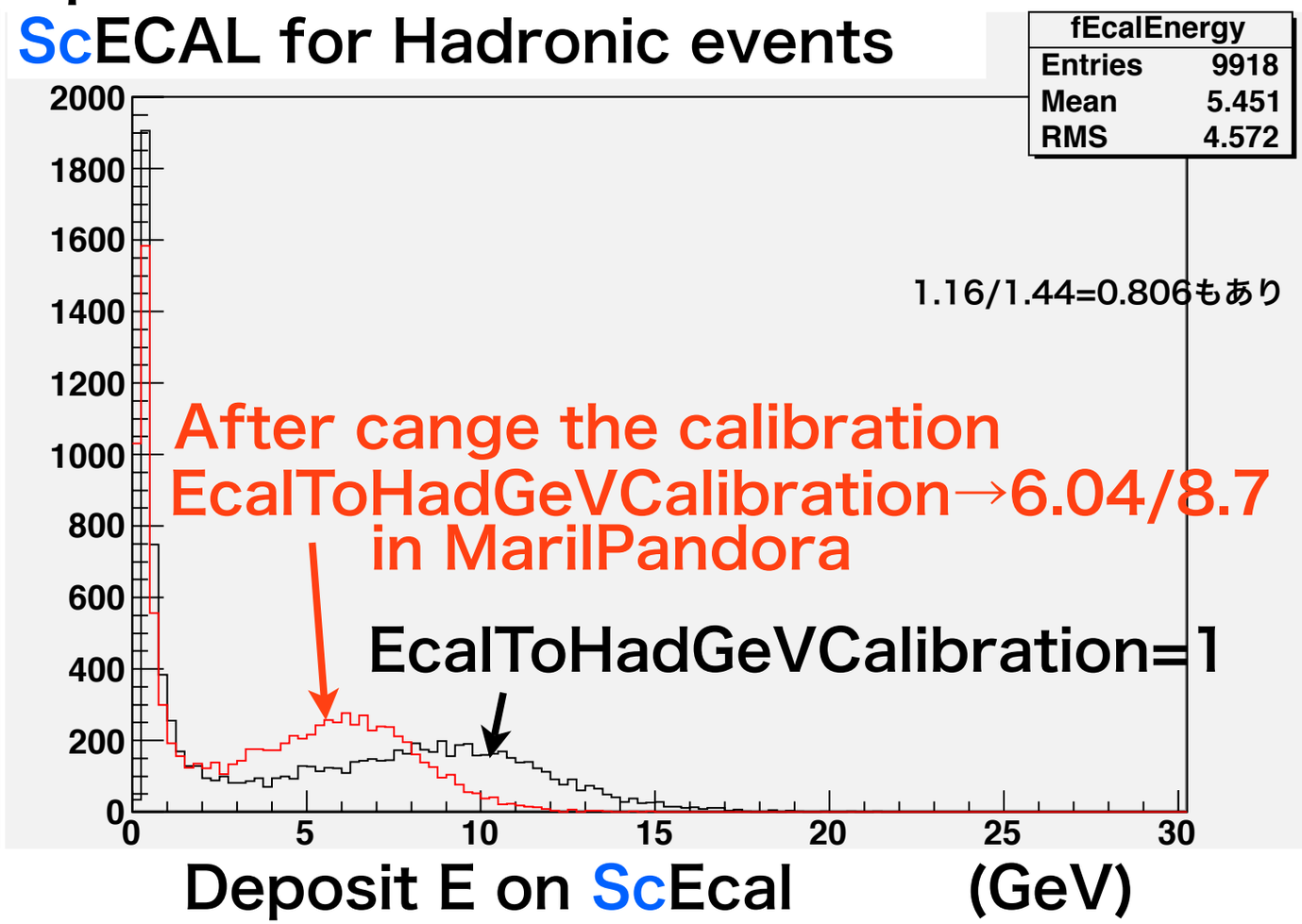
Large difference of energy deposit on ECAL by hadronic events btwn. Si -Sc

➡ Tune a parameter of PandoraPFA

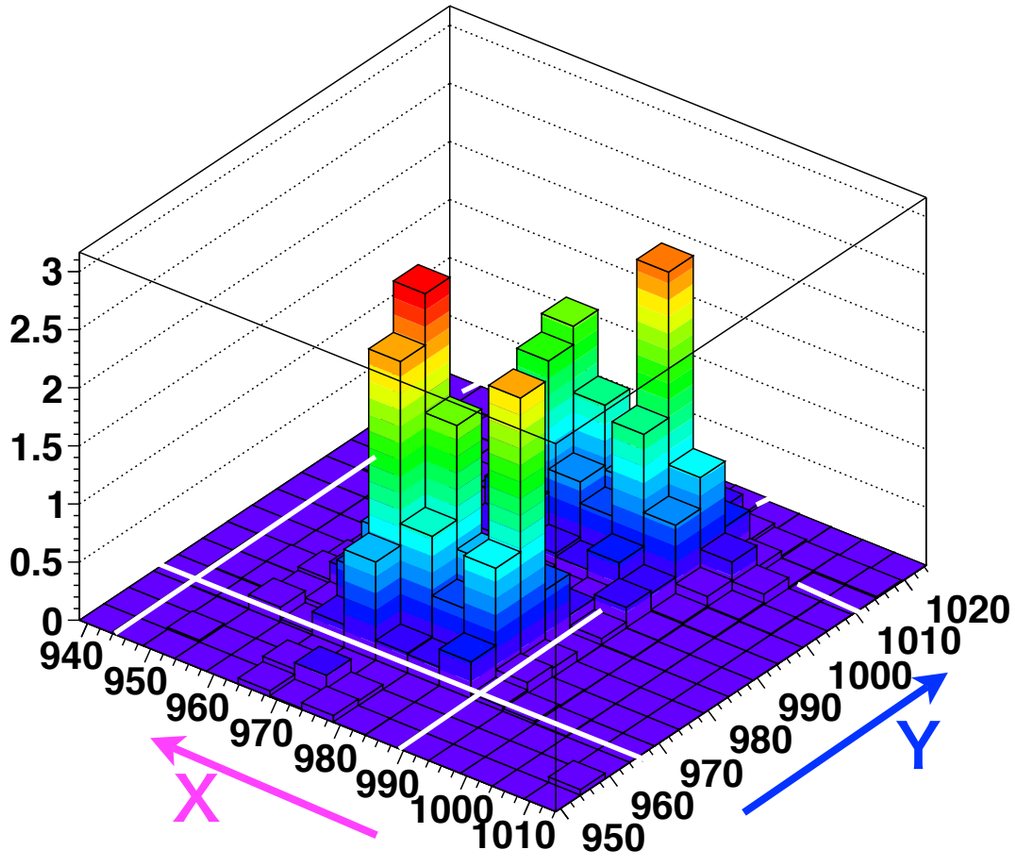
- After tune ECAL with 10 GeV photon
- π^+ 10 GeV (KL maybe O.K.)

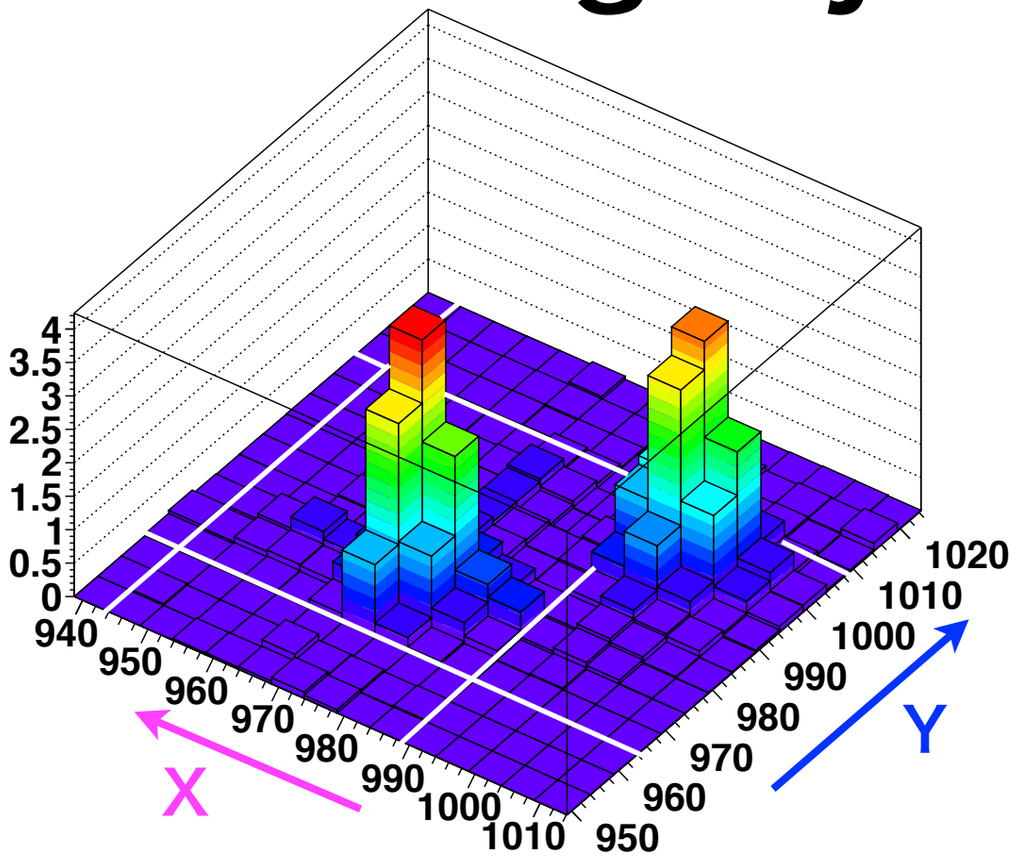


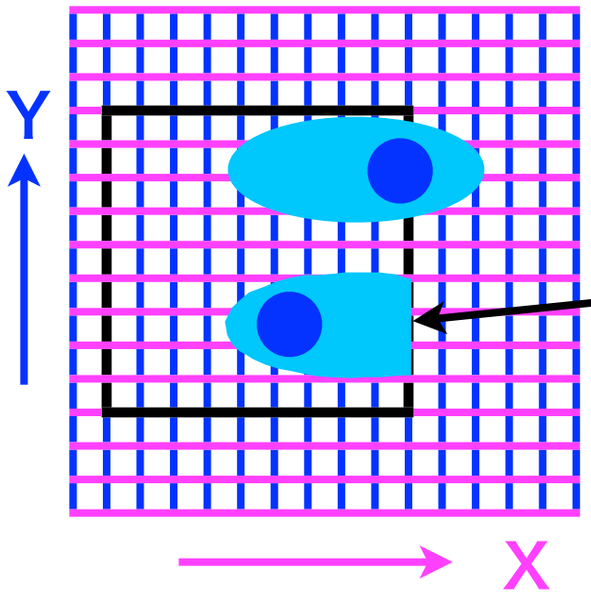
Optimization of Calibration of ScECAL for Hadronic events

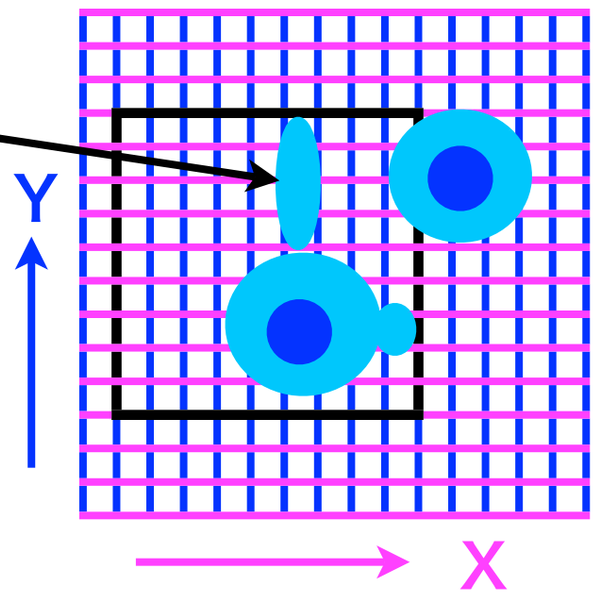


Pattern recognition might help us resolve the two-fold ambiguity







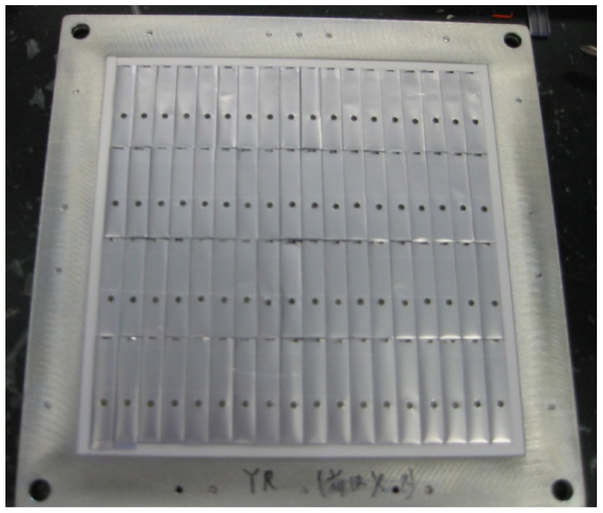


pattern analysis might improve to reduce ghosts.

Performance for the single particles

Results from physics prototype @ FNAL

One layer of the prototype

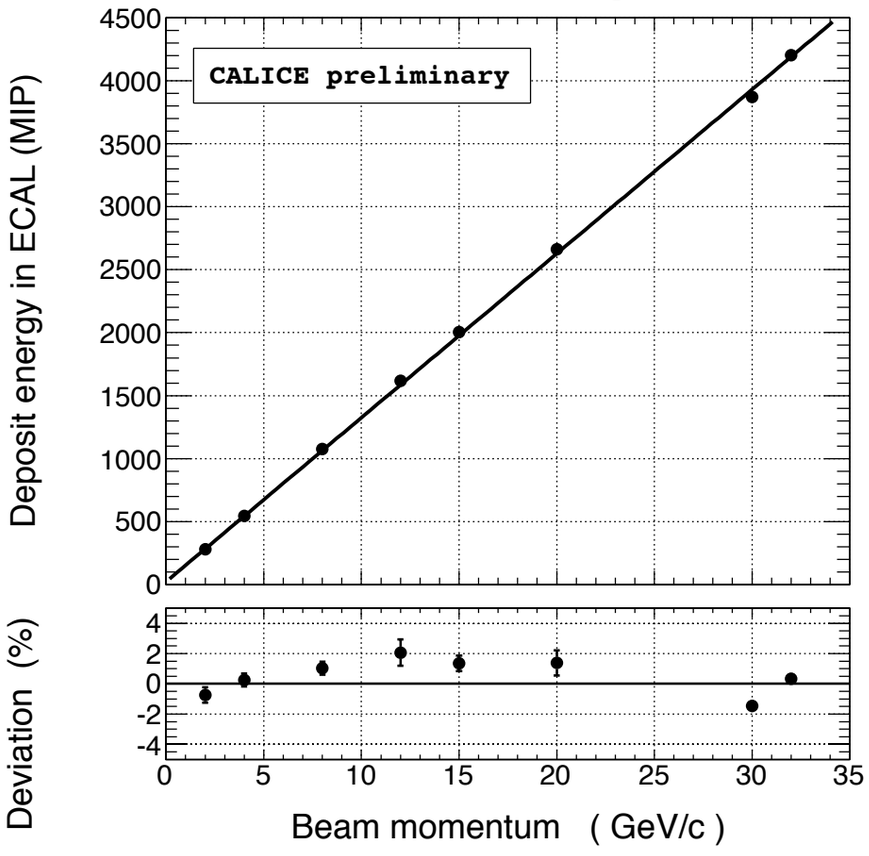


10 x 45 x 3 mm³ using WLS fiber

a. MPPC
b. scintillator strip
c. WLS fiber

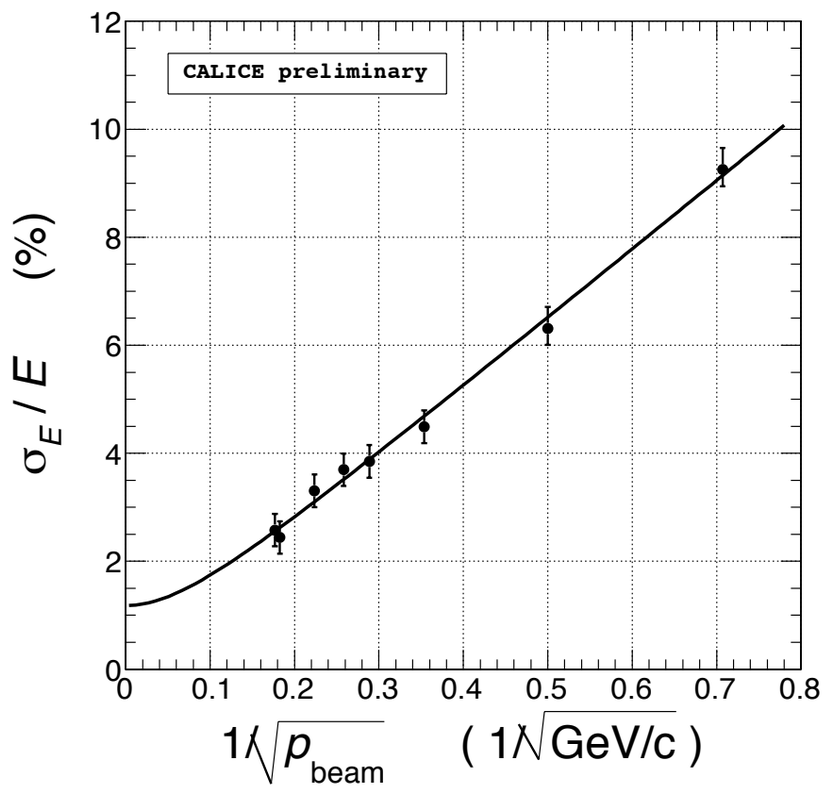
30 layers in the prototype

Linearity



Deviation from the linear fit is less than 2% for 2 - 32 GeV electron beams. MPPC saturation corre. and temperature corre. are implemented

Resolution

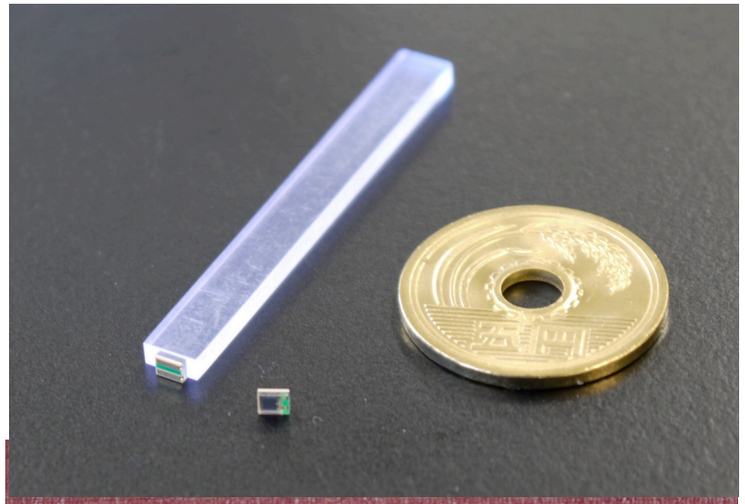


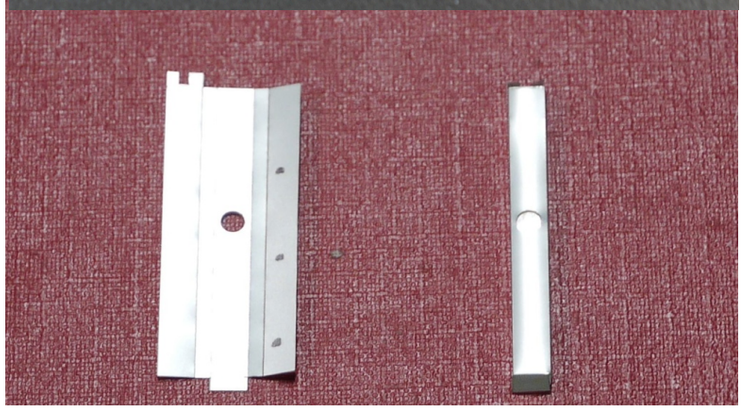
$\sigma_E/E = 1.2 \pm 0.1\,(\text{stat.})\,^{+0.4}_{-1.2}\,(\text{syst.})\,(\%)$

$\oplus\, 12.9 \pm 0.1\,(\text{stat.})\,(\%)/\sqrt{E}$
$\pm\, 0.4\,(\text{syst.})$

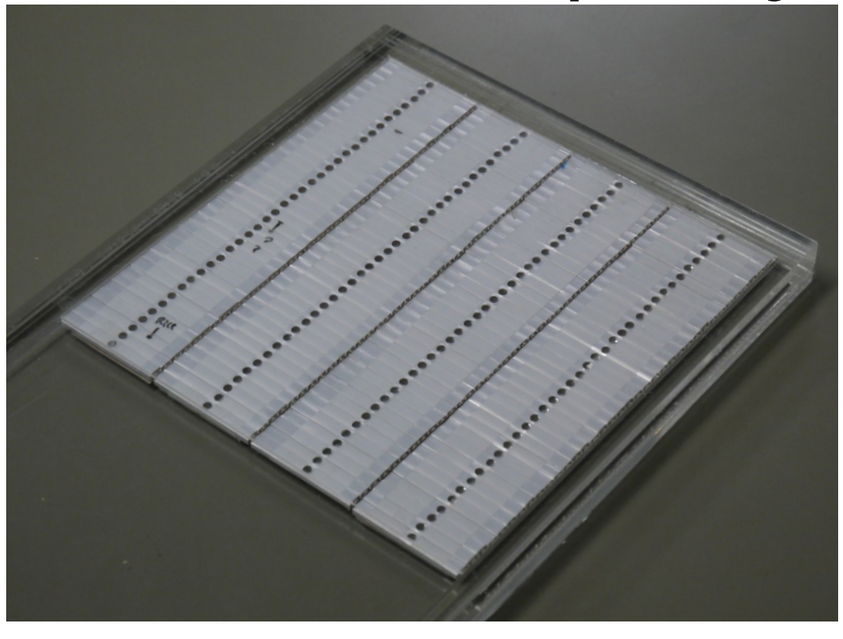
intrinsic beam momentum fluctuation was subtracted

Current design of scintillator and MPPC

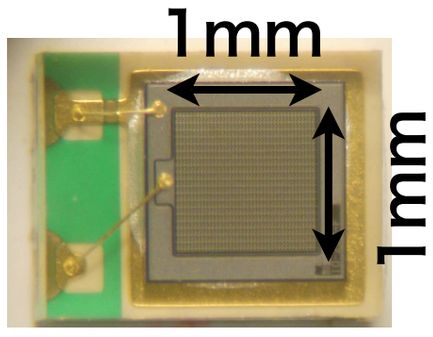


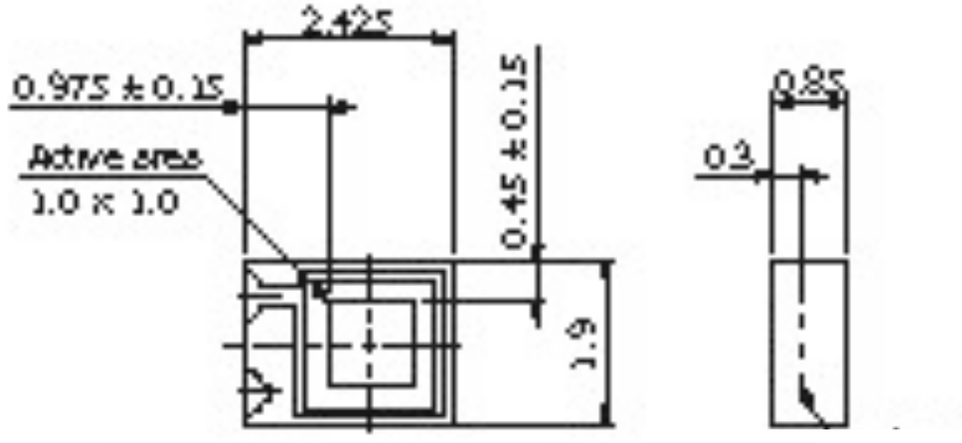


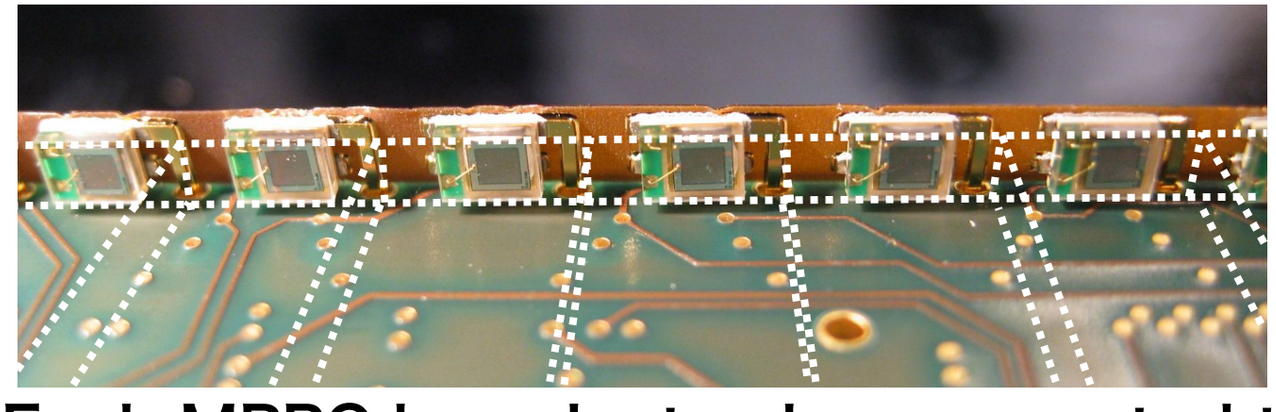
36 x 4 = 144 strip array



1. 45 mm x 5 mm x 2 mm plastic scintillator
2. with surface mounted MPPC
    1. > 1600 pixels in 1 mm x 1mm.
    2. Hamamatsu has developed 10k pixel MPPC recently --> We will test it.
    3. MPPC package: 2.4 x 1.9 x 0.85 mm^3

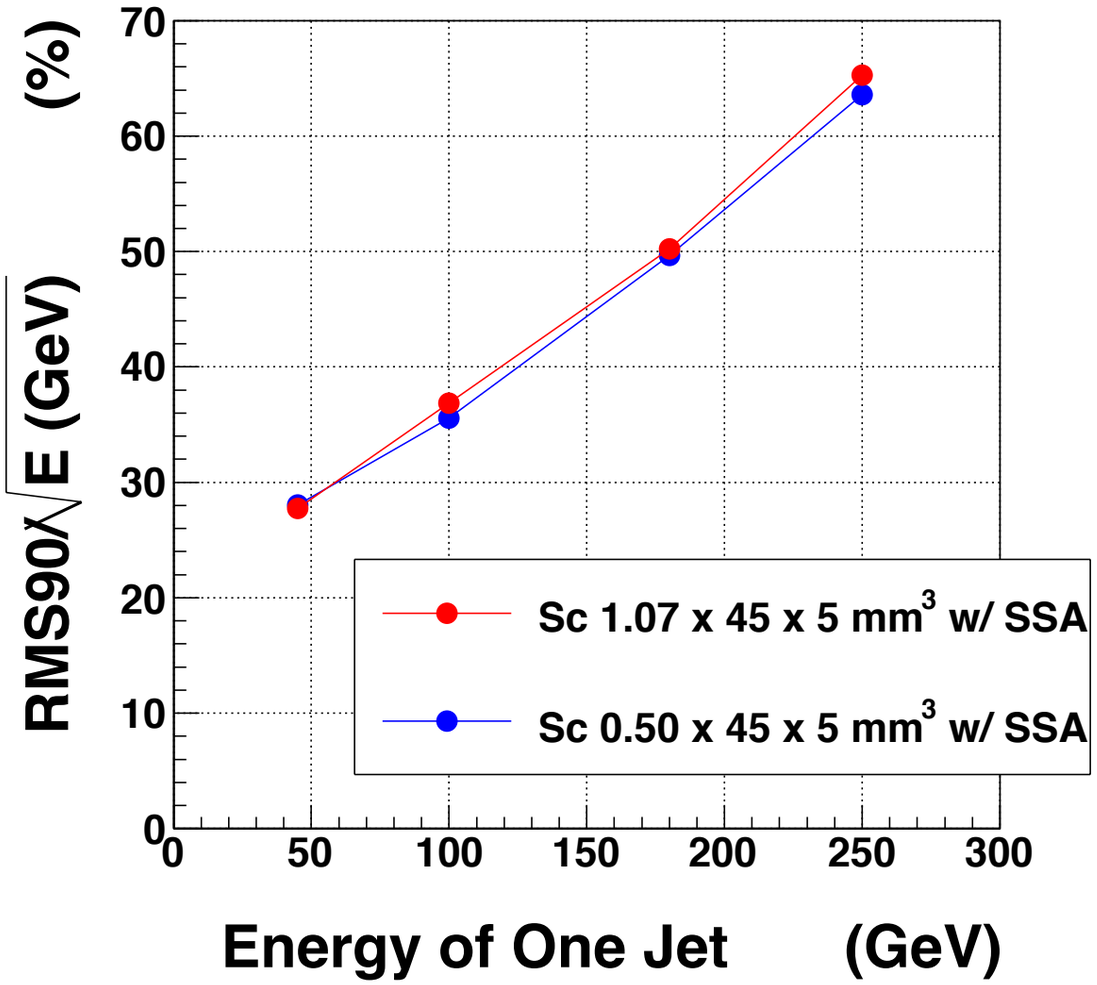






Each MPPC has electrodes connected to the baseboard directly.

1 mm thick scintillator



This study was done by using v0-09-02.

- To make 0.5 mm thick scintillator strip ECAL is difficult with current technology.

Therefore;

- 1 (.07) mm thick scintillator has been tested in Mokka-Marlin.
- JER with 1 mm thick scintillator is comparable with 0.5 mm sc.
- Total module thickness of Ecal becomes only 1.5 cm greater than default Si ECAL of 18.5 cm.