Simulation Study for the Hybrid ECAL

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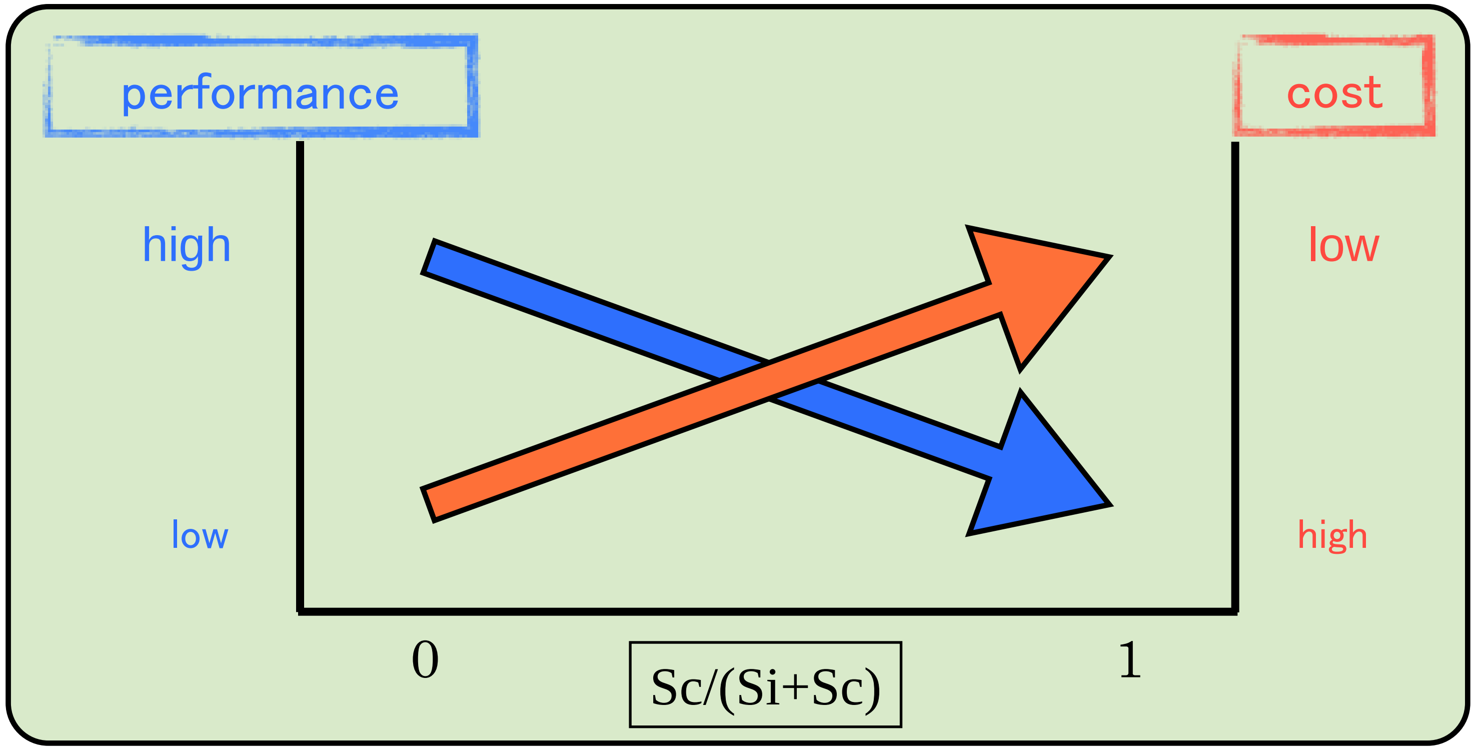
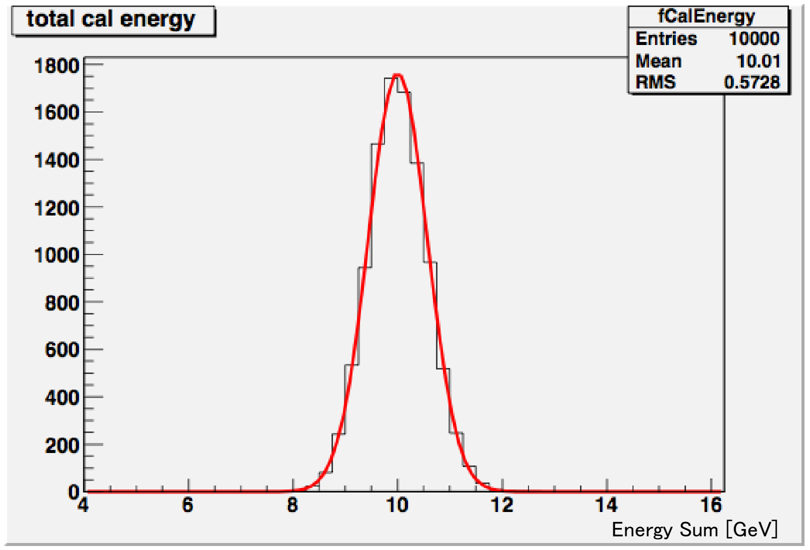
Motivation for the Hybrid ECAL

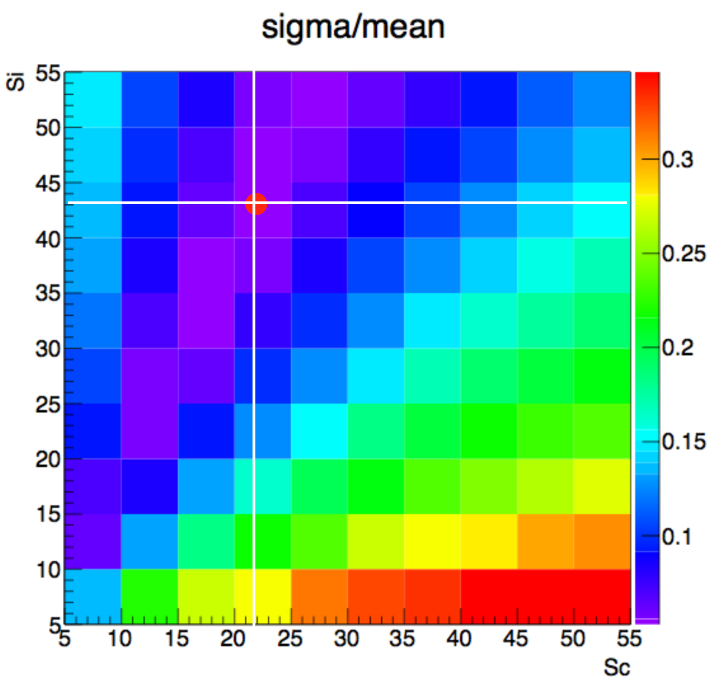
- A highly granular calorimeter is required for a future linear collider experiment in order to optimally utilize Particle Flow Algorithm. An electromagnetic calorimeter (ECAL) with silicon sensors is a promising candidate to realize such fine granularity.
- Another option to make the ECAL at a lower cost, while keeping the performance as much as possible, would be to use a mixture of silicon and scintillator-strip layers (Hybrid ECAL).

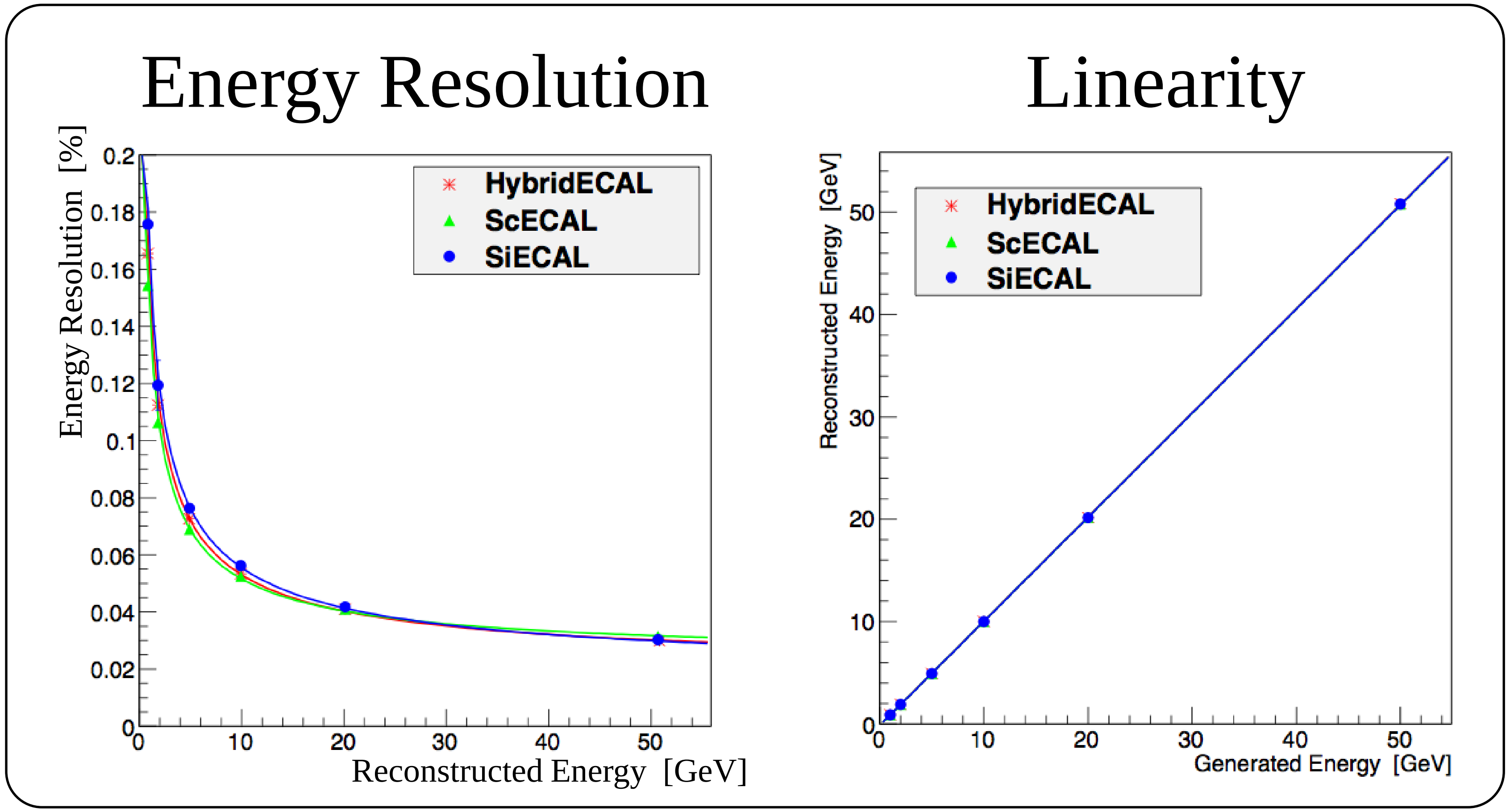


Calibration

- Calibration constants should be determined for Silicon layers and Scintillator layers separately.
- Calibration constants are determined using 10GeV photons.
- Then we evaluated ECAL performance using 1~50GeV photons.



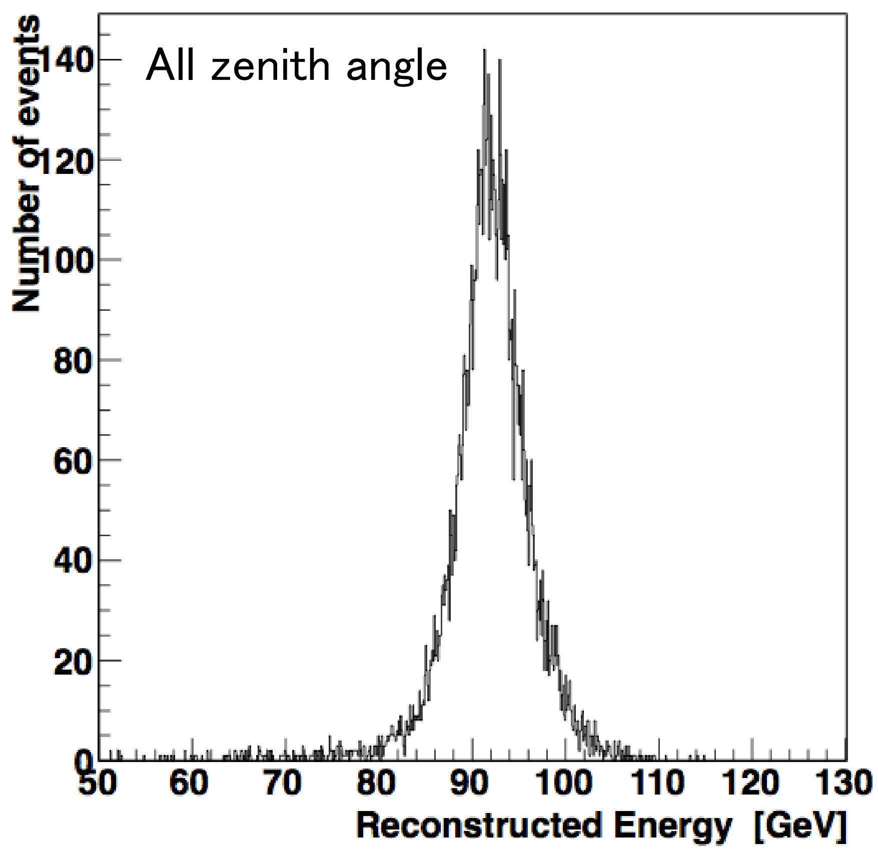


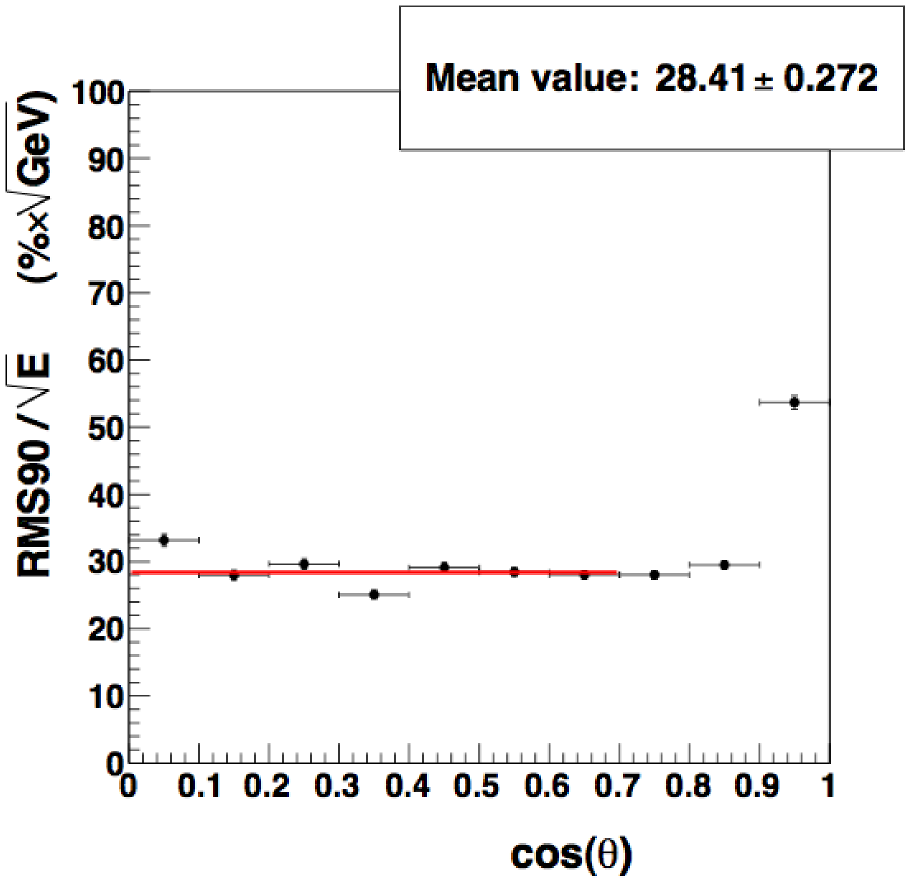


The calibration method works well.

Hybrid ECAL Evaluation

- We simulated the performances of Hybrid ECAL with iLCSoft **v01-15**.
- We evaluated energy dependence and Sc:Si ratio dependence.
- We generated $e^+e^- \rightarrow q\bar{q}$ ($\sqrt{s}$=91, 200, 360, 500GeV)
- We evaluated barrel region (cos(thrust angle)<0.7) because energy resolution of endcap part is worse than barrel part.





Hybrid ECAL + SSA

ECAL Configurations

We evaluated performance of Hybrid ECAL for 2 cases;

①Keep absorber thickness

- to evaluate difference of performance between Silicon and Scintillator
- thereby module thickness increases as scintillator layers increase

②Keep module thickness

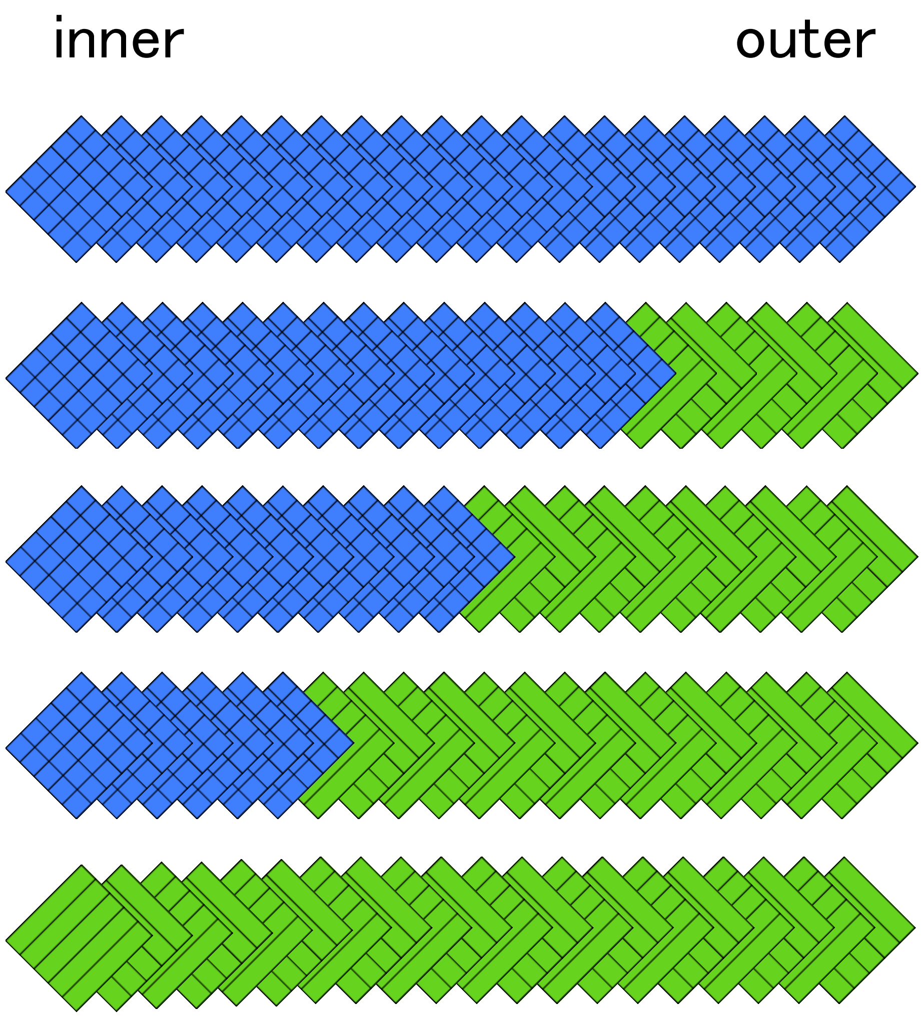
- by changing absorber thickness for outer layers
- to evaluate performance of Hybrid ECAL with practical geometry

Hybrid Configurations

~same absorber thickness~

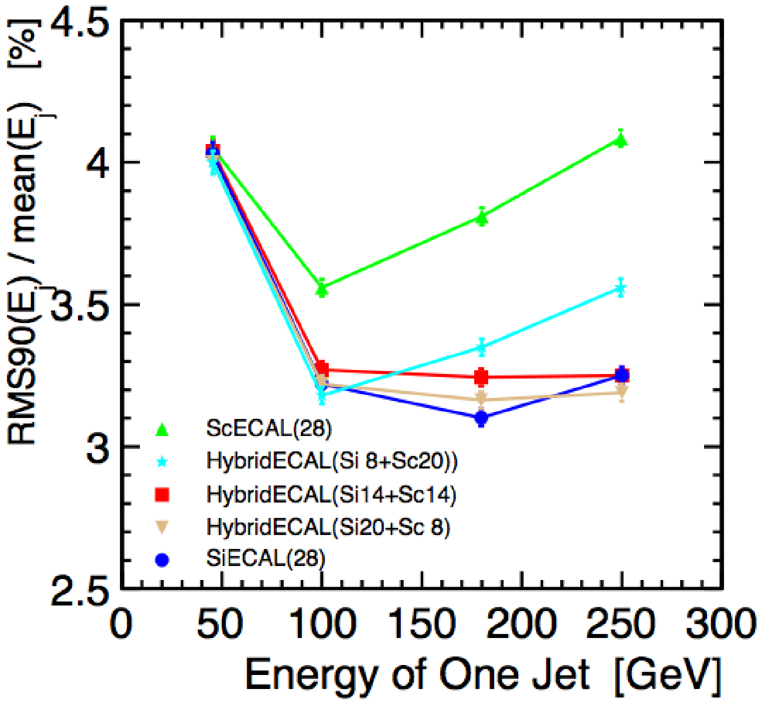
Sc thickness = 2.0mm
Si thickness = 0.5mm

	W thickness (in20,out7)	Module thickness	Radiation Length
SiECAL(28)	2.1/3.5	165.400	$19.14X_0$
Hybrid(Si20Sc8)	2.1/3.5	176.712	$19.73X_0$
Hybrid(Si14Sc14)	2.1/3.5	185.196	$19.14X_0$
Hybrid(Si8Sc20)	2.1/3.5	193.680	$19.98X_0$
ScECAL(28)	2.1/3.5	204.992	$20.27X_0$



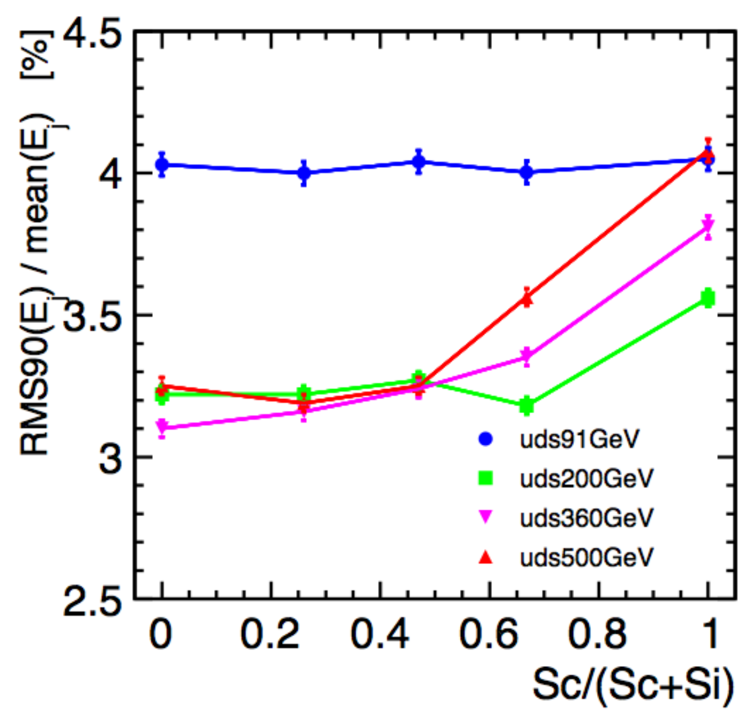
Jet Energy Resolution

Energy Dependence



: ScECAL(28layers)
: Hybrid(Si 8+Sc20)
: Hybrid(Si14+Sc14)
: Hybrid(Si20+Sc 8)
: SiECAL(28layers)

Ratio Dependence



: uds 91GeV
: uds200GeV
: uds360GeV
: uds500GeV

- Hybrid(Si8+Sc20) is same as SiECAL up to 100GeV, then degrade little by little.
- Hybrid(Si14+Sc14) and Hybrid (Si20+Sc8) are same as SiECAL even higher energy.

- Performances are same for uds91GeV.
- At higher energy, performance becomes worse and worse especially from about half and half.

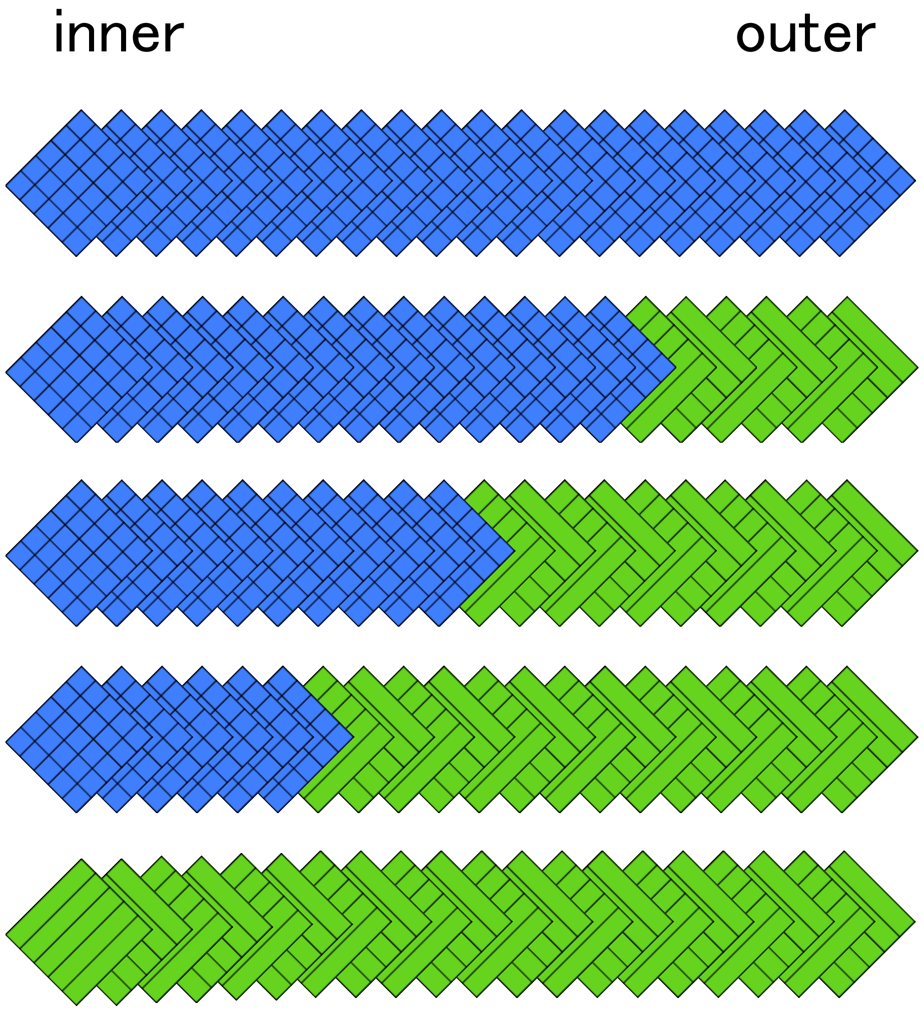
Energy Resolution doesn't degrade up to 50% of Scintillator layers.

Hybrid Configurations

~same module thickness~

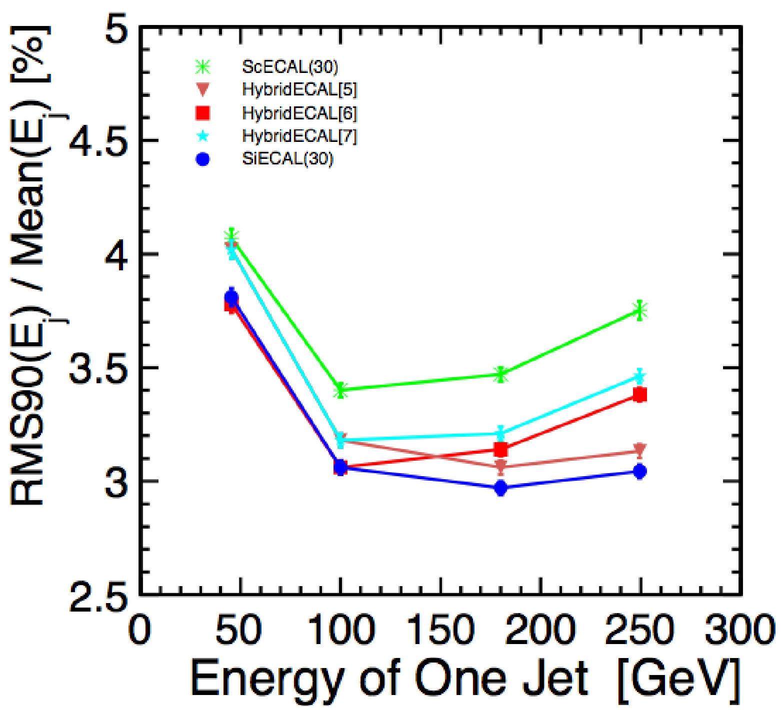
Sc thickness = 1.0mm
Si thickness = 0.5mm

	W thickness (in20,out9)	Module thickness	Radiation Length
SiECAL(30)	2.1/4.2	185.000	22.96X_0
Hybrid(Si22Sc8)	2.1/3.9	185.612	22.33X_0
Hybrid(Si16Sc14)	2.1/3.6	185.396	21.67X_0
Hybrid(Si10Sc20)	2.1/3.3	185.180	21.00X_0
ScECAL(30)	2.1/2.9	185.720	20.14X_0



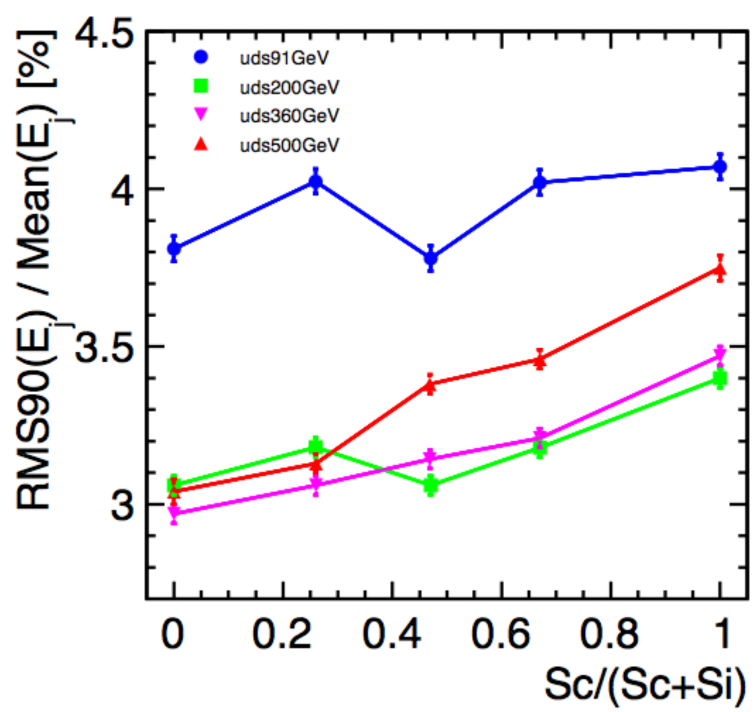
Jet Energy Resolution

Energy Dependence



- ▲ (green): ScECAL(30layers)
- ★ (light blue): Hybrid(Si22+Sc 8)
- ■ (red): Hybrid(Si16+Sc14)
- ▼ (orange): Hybrid(Si10+Sc20)
- ● (blue): SiECAL(30layers)

Ratio Dependence



- ● (blue): uds 91GeV
- ■ (green): uds200GeV
- ▼ (orange): uds360GeV
- ▲ (red): uds500GeV

- Performances of Hybrid seems to depend on Sc:Si ratio.
- Hybrid(Si16+Sc14) is about medium between SiECAL and ScECAL at higher energies.
- Energy resolution becomes worse almost linearly as scintillator ratio increases, but only Hybrid (Si16Sc14) is better than other Hybrids at lower energies.

Hybrid performance becomes worse as scintillator ratio increases.

Summary and Prospects

- We evaluated energy dependence and Sc:Si ratio dependence for 2 types of Hybrid ECALs.
- For the case of same absorber thickness, performance of Hybrid ECAL doesn't degrade so much up to 50% of scintillator layers.
- For the case of same module thickness, performance becomes worse almost linearly as scintillator ratio increase.

- Performance of Hybrid ECAL with 15x15mm scintillator tiles instead of 45x5mm strips
- to study how does SSA improve Jet Energy Resolution.
- Absorber thickness dependence

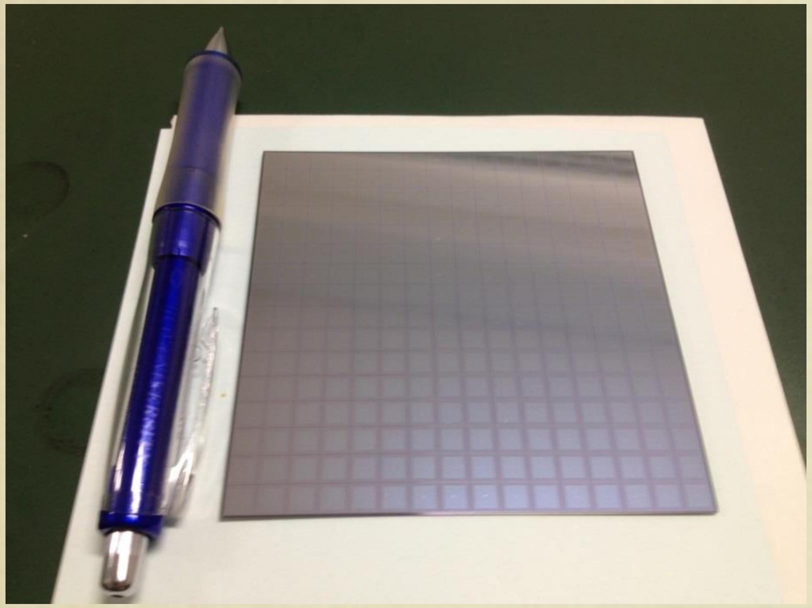
Backup

ILD ECAL

サンプリングカロリメータ

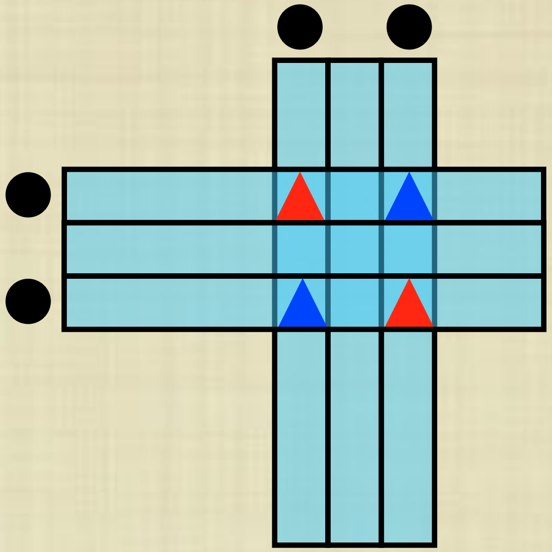
- 吸収層 ... タングステン
- 検出層 ... 2種類の候補

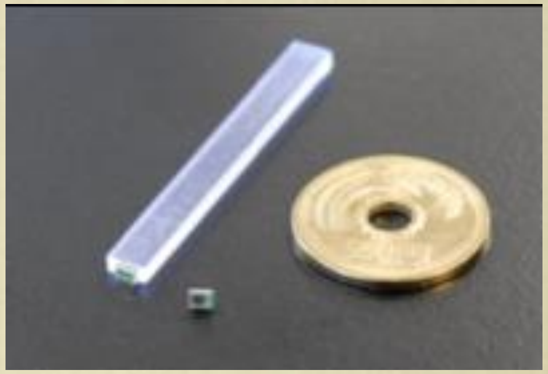
シリコン（Si ECAL）



- Si-pad : 5mm x 5mm cells
- pixel状のためPFAに適している
- コストが高い

シンチレータ+MPPC（Sc ECAL）

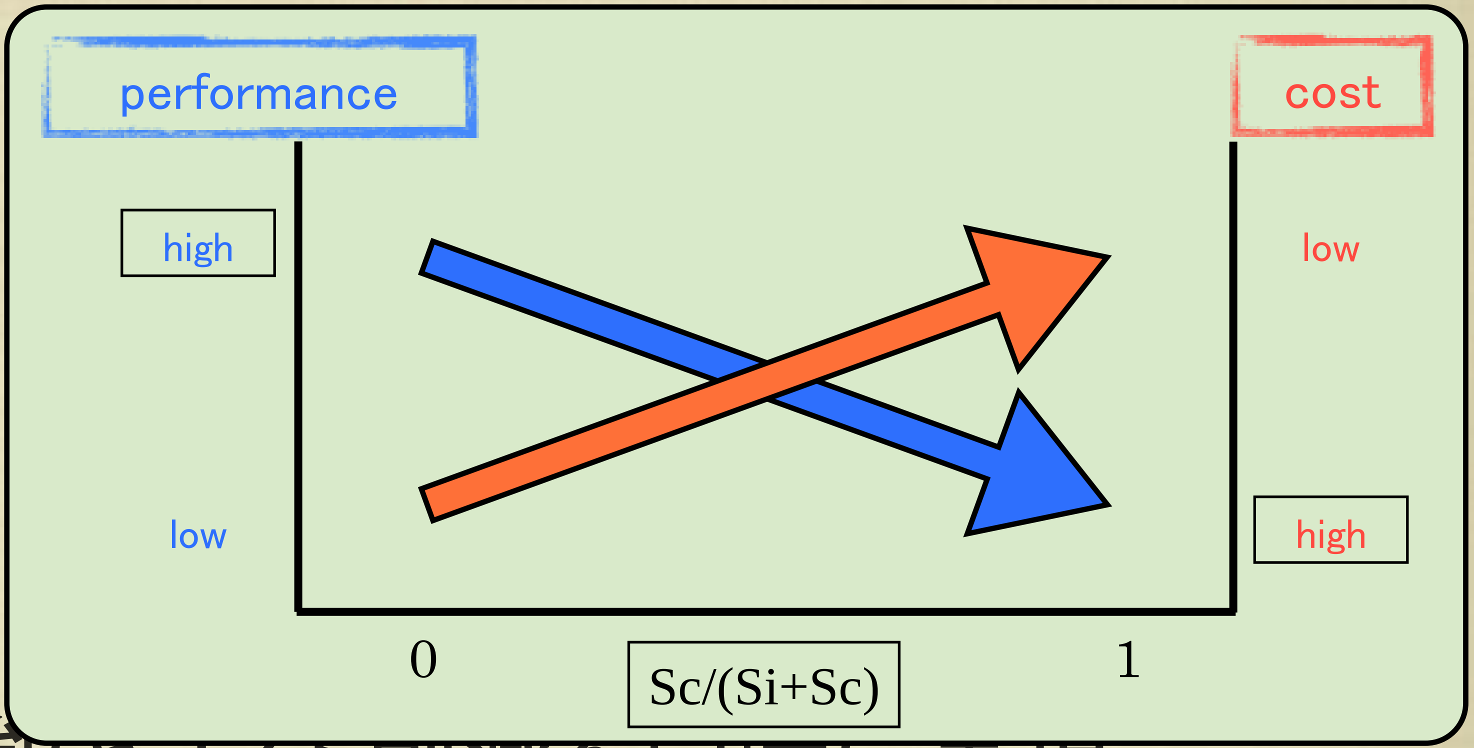




- 45mm x 5mm ストリップを直交配置
  →5mm x 5mmの位置分解能
- 比較的安価である
- ゴーストが生じる
- 解析に専用のソフトウェアが必要

Hybrid ECAL

シンチレータとシリコンを併用(Hybrid ECAL)



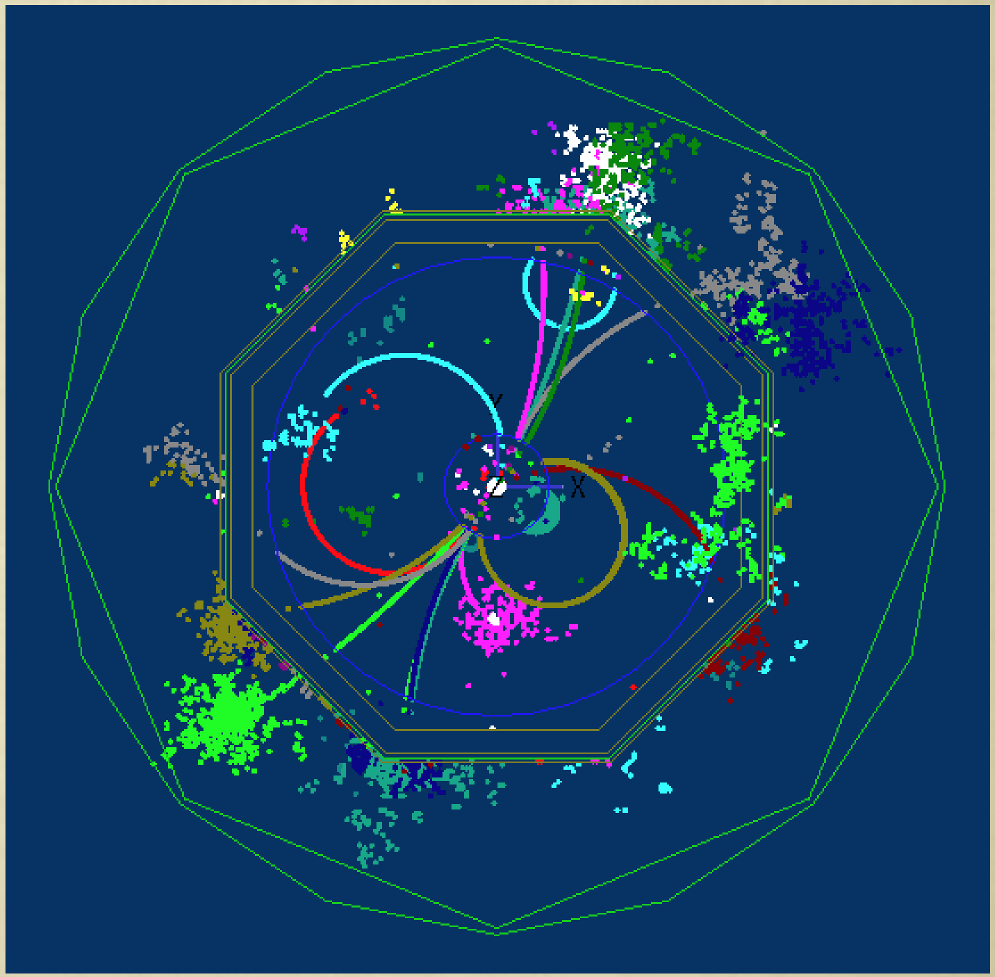
高いエネルギー分解能とコスト削減を同時に実現

**シミュレーションを用いて
ハイブリッド構造を最適化**

Simulation Tools

ILDで標準的に使用 → Mokka, Marlin

- Mokka
  - Geant-4ベースのフルシミュレーションプログラム
  - ILDのgeometryが組み込まれている
  - 設定を簡単に変える事ができる
- Marlin
  - 再構成のフレームワーク
  - Particle Flow Algorithm
  - Strip Splitting Algorithm: シンチレータのストリップ構造を解くアルゴリズム

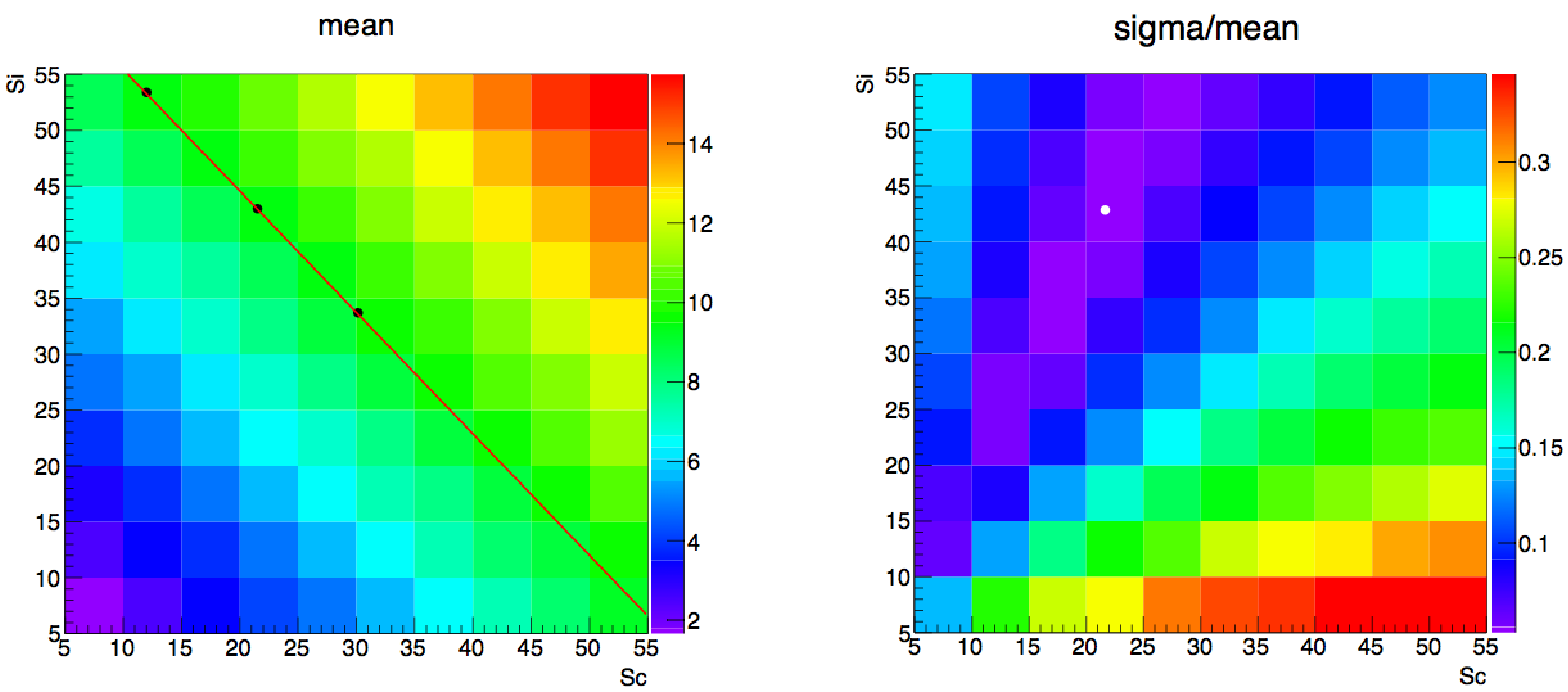


Calibration

Calibration constants for Silicon layers and Scintillator layers should be determined separately.

Calibration constants are determined by using 10GeV photon.

HybridECAL (Thickness - Sc 2.0mm, Si 0.5mm)



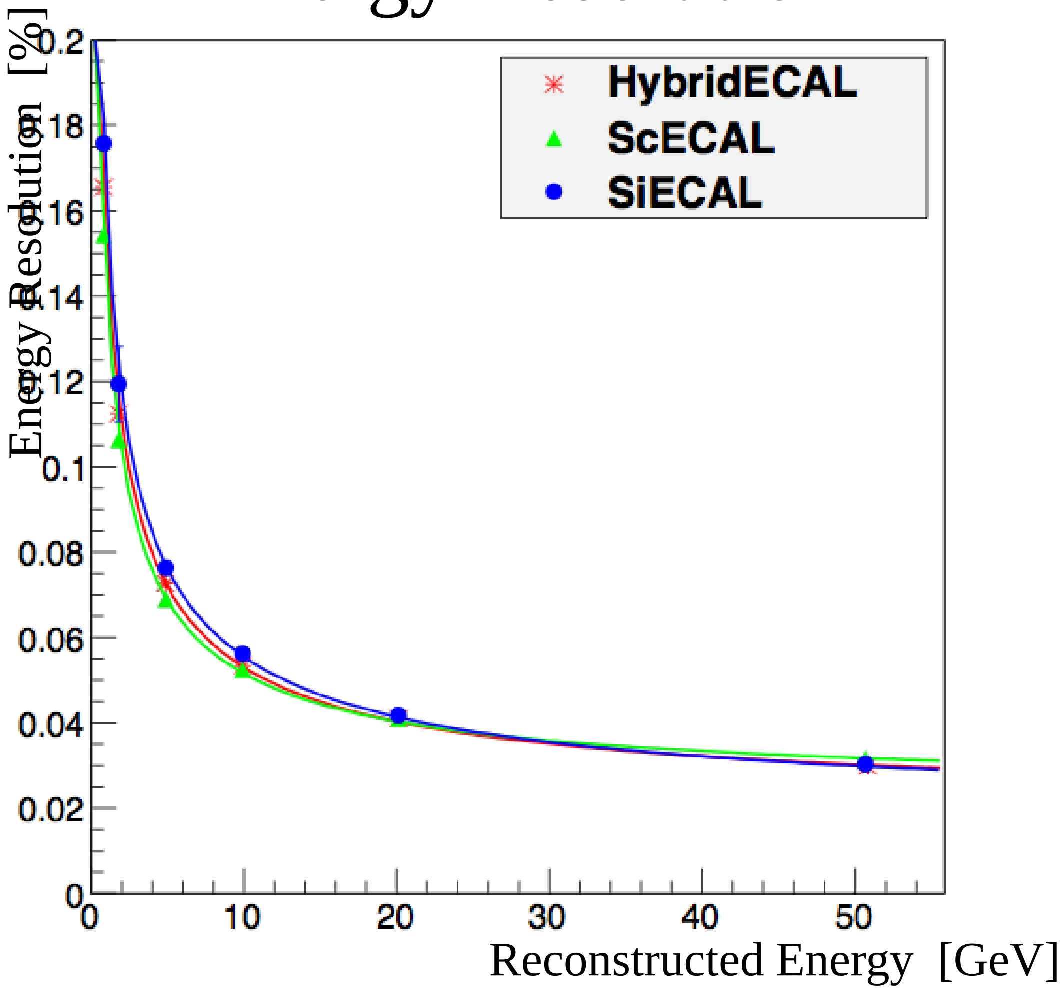
ECAL Performance

In order to check the calibration constants, we have evaluated the energy resolution and linearity of the ECALs by using 1~50GeV photons.

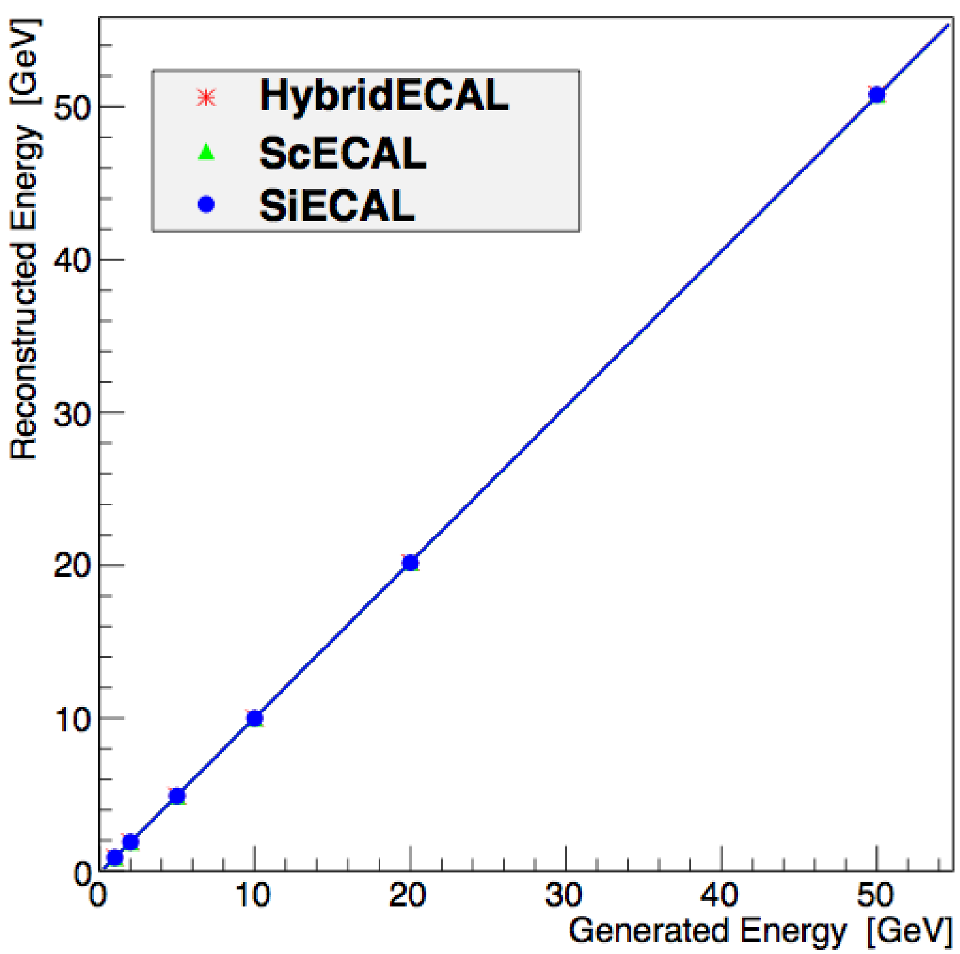
→The calibration method works well.

HybridECAL (Thickness - Sc 2.0mm, Si 0.5mm)

Energy Resolution

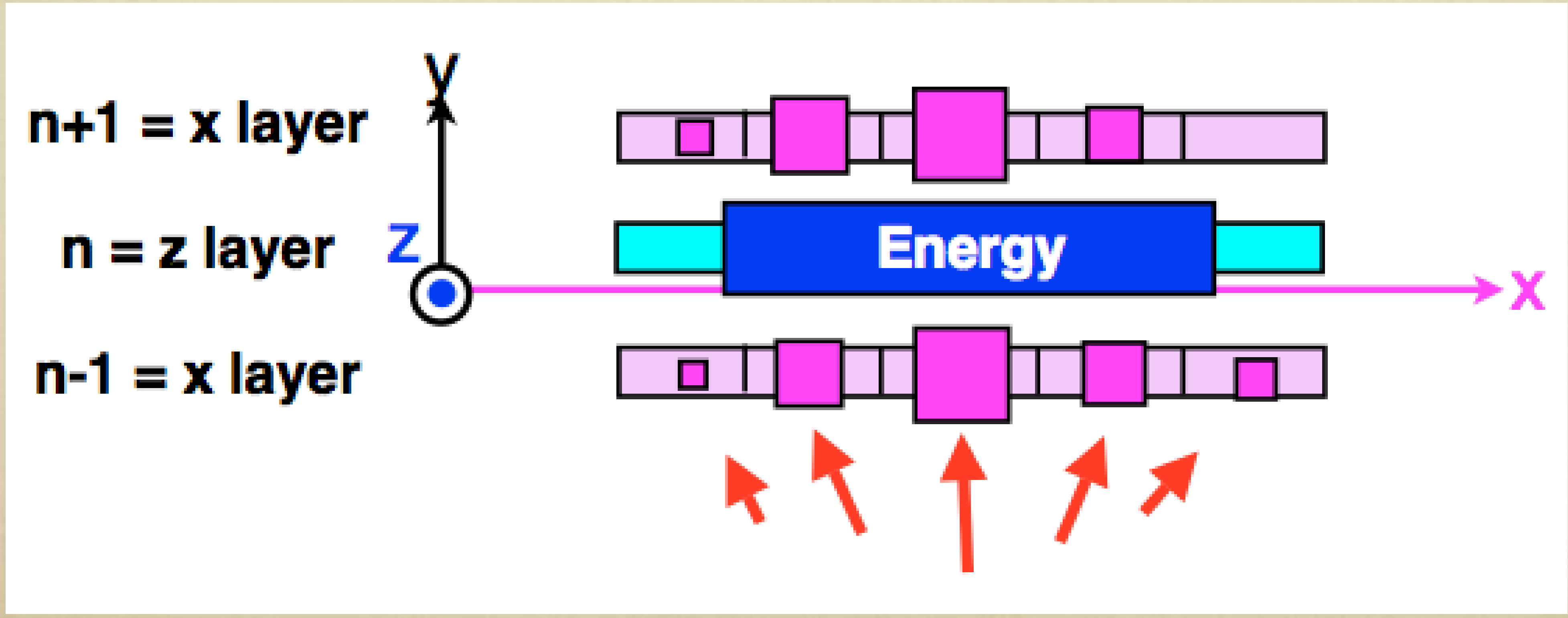


Linearity



Strip Splitting Algorithm

ストリップをヴァーチャルのセルに分け、
前後の層に落としたエネルギーの比を元に
ストリップに落としたエネルギーを振り分ける



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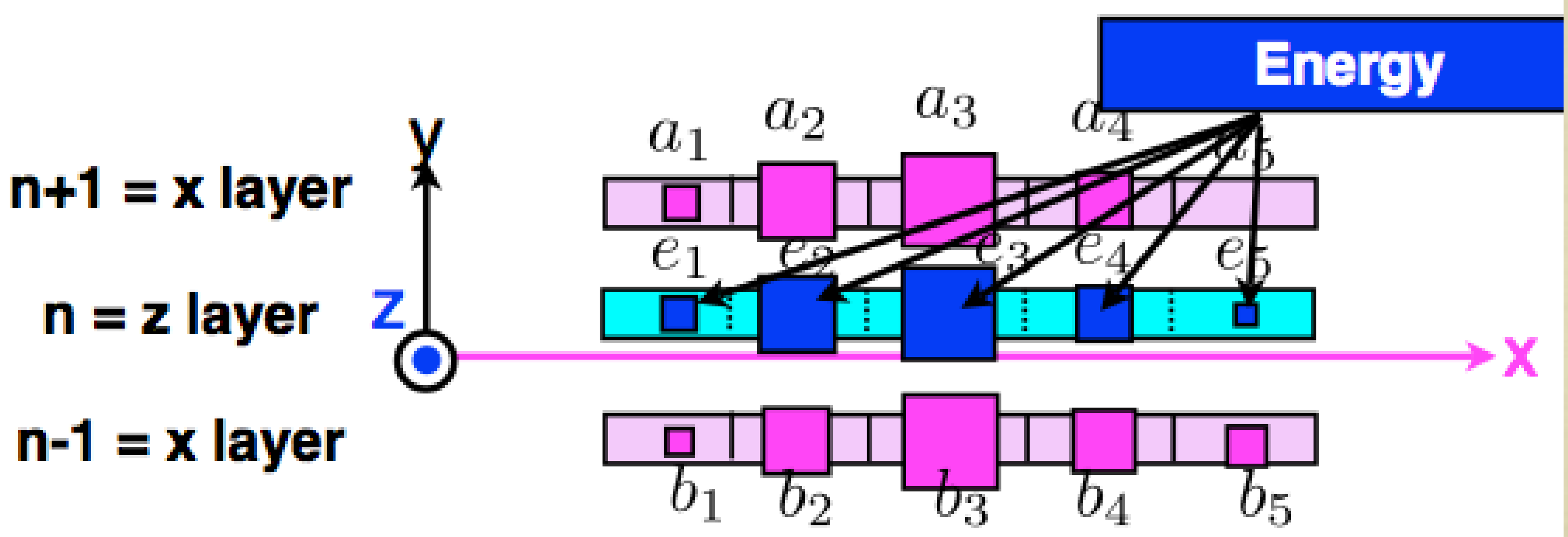

$$e_i = E_{\mathrm{n}} \cdot \frac{a_i + b_i}{\sum a_i + \sum b_i}$$

PFAによるエネルギー分解能の向上

従来の細分化されていないカロリメータ

	fraction	σ/Ex√E[GeV]
ECAL	28%	15%
HCAL	72%	55%

PFAを使用した細分化カロリメータ

	fraction	σ/Ex√E[GeV]
ECAL	30%	15%
HCAL	10%	55%
Track	60%	σ/E x E^2(GeV^2) 3.6 x 10^{-5}