

Performance of High Granularity Si pad ECAL for CEPC



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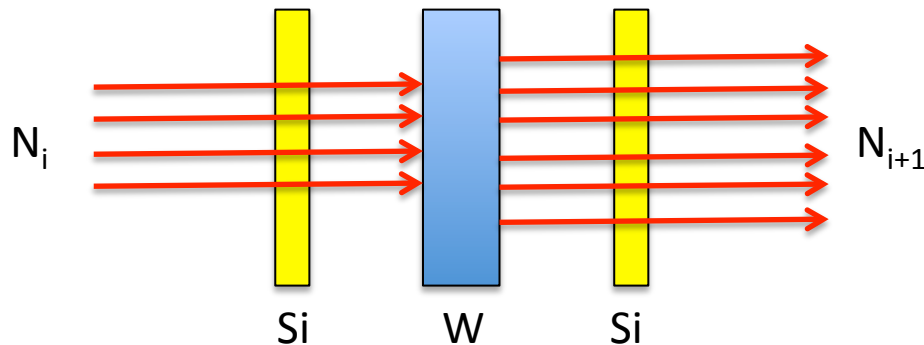
Photo: Lin Chih-Hsun (AS)
Sensors produced in Taiwan in June

Motivation

- Explore the optimum EM initial calibration method for Silicon pad high granularity calorimeters.
- Optimize the design of future calorimeters (CEPC here).
 - Homogeneous ECAL
 - Inhomogeneous ECAL (increasing passive material thickness).
- Understand some basic questions:
 - Origin of a $\sim 1\%$ constant term observed in an example of such calorimeter with increasing passive material thickness.
 - How to correct for upstream material losses (presampling).
 - How to correct for leaking EM energy.

EM initial calibration

- dEdx: estimate the number of MIPs through a passive layer



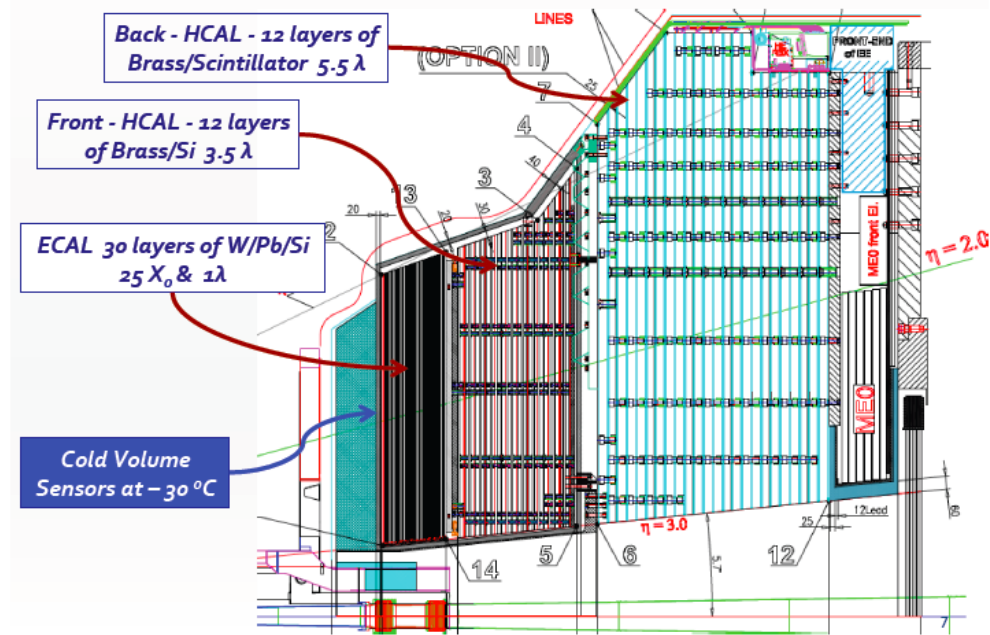
$$E_{\text{rec}} = \sum_1^{30} (N_{\text{mip}} \times w_{\text{mip}} + E_{\text{Si}})$$

- Alternative method (this talk): use the sampling fraction

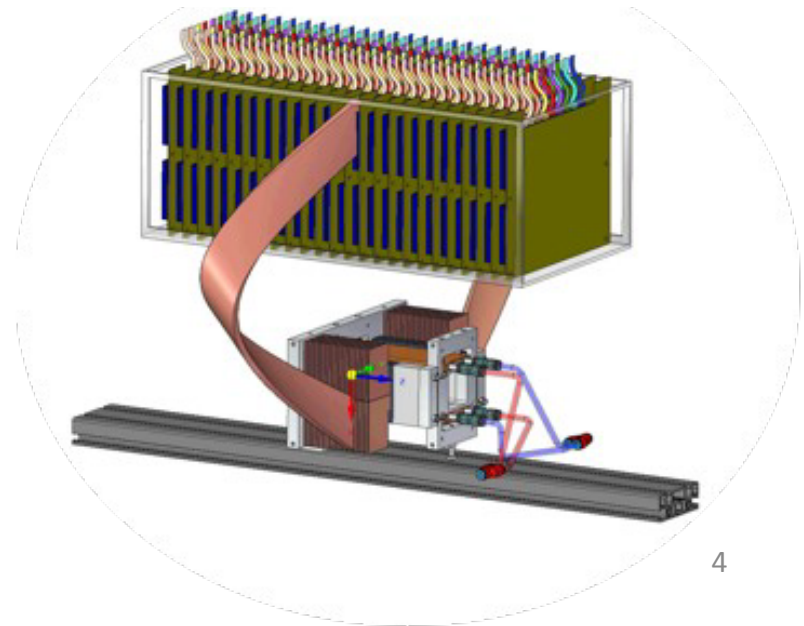
$$SF = \frac{\sum_1^{30} E_{\text{active}}}{\sum_1^{30} (E_{\text{active}} + E_{\text{passive}})}, \quad E_{\text{rec}} = \sum_1^{30} E_{\text{active}} \times \frac{1}{SF}$$

Si HG Sampling ECAL projects

HGCal, CMS
(older 30 Layer ECAL)



Calice, SiD (and CEPC?)



High Granularity Timing Detector, ATLAS



Example configurations

LAYER	X0	LAYER	X0
Layer 1	0.0919987	Layer 16	0.87511
Layer 2	0.927787	Layer 17	0.798519
Layer 3	0.602529	Layer 18	0.87511
Layer 4	0.575468	Layer 19	0.798519
Layer 5	0.602529	Layer 20	0.87511
Layer 6	0.575468	Layer 21	0.798519
Layer 7	0.602529	Layer 22	1.27463
Layer 8	0.575468	Layer 23	1.20832
Layer 9	0.602529	Layer 24	1.27463
Layer 10	0.575468	Layer 25	1.20832
Layer 11	0.602529	Layer 26	1.27463
Layer 12	0.87511	Layer 27	1.20832
Layer 13	0.798519	Layer 28	1.27463
Layer 14	0.87511	Layer 29	1.20832
Layer 15	0.798519	Layer 30	1.27463

Homogeneous same X_0
0.86 X_0 /layer
Total X_0 25.8

Homogeneous same dEdx
1.162 X_0 /layer
Total X_0 34.86

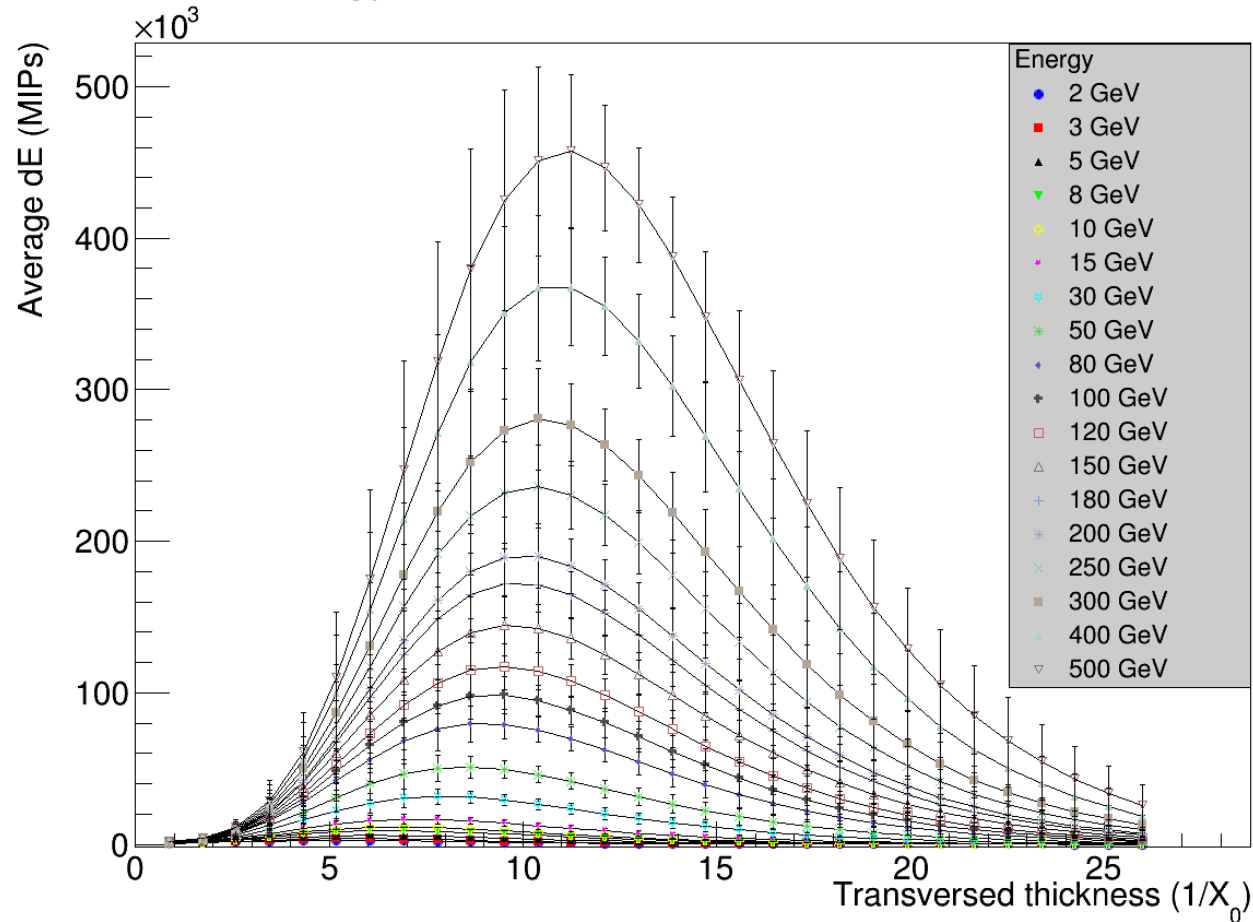
Simulation: stand-alone G4

- The physics list that was used for the simulation was QGSP_BERT that combines the Bertini model at low energies, < 9.9 GeV, with the Low Energy Parametrized model (LEP, based on fits to experimental data) at intermediate energies, 9.5 - 25 GeV, and the Quark-Gluon-String Pre-compound model (theory-driven string parton models) at high energies, > 12 GeV.
 - No digitization used.
 - 30 layers of Silicon, 300microns per layer, 20x20cm² transverse size
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- Next we show the SF method (1,2,3) and the dEdx method (4):
 1. SF: ignore a 1% leakage (E escaping from the back).
 2. SF: add the leakage by hand to isolate calibration effects.
 - 3. SF: add the leakage and correct SF for shower-depth.**
 4. dEdx method: use the dEdx weights (std method)

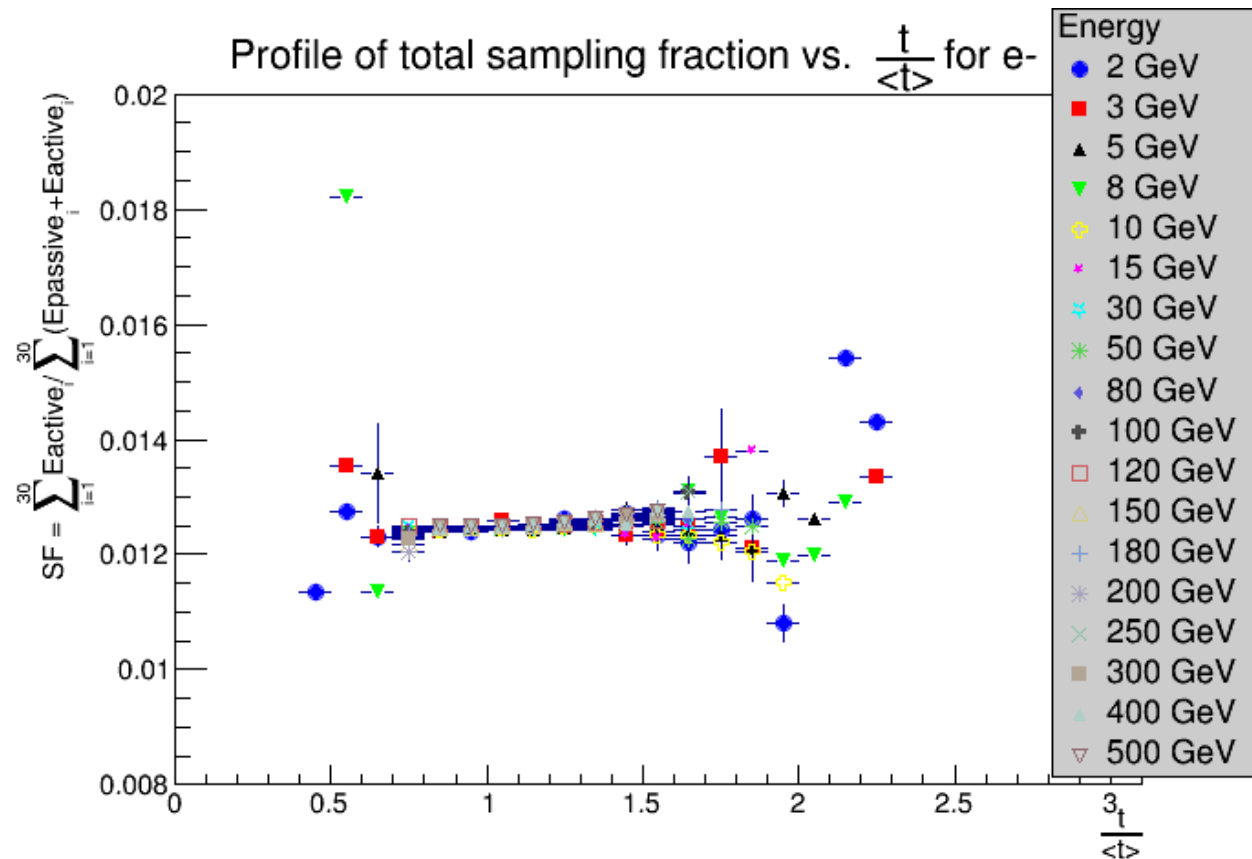
Homogeneous ECAL (30layers, $0.86X_0$ /layer)

Longitudinal Energy deposition

Energy lost vs. transversed thickness for e-



SF vs shower depth

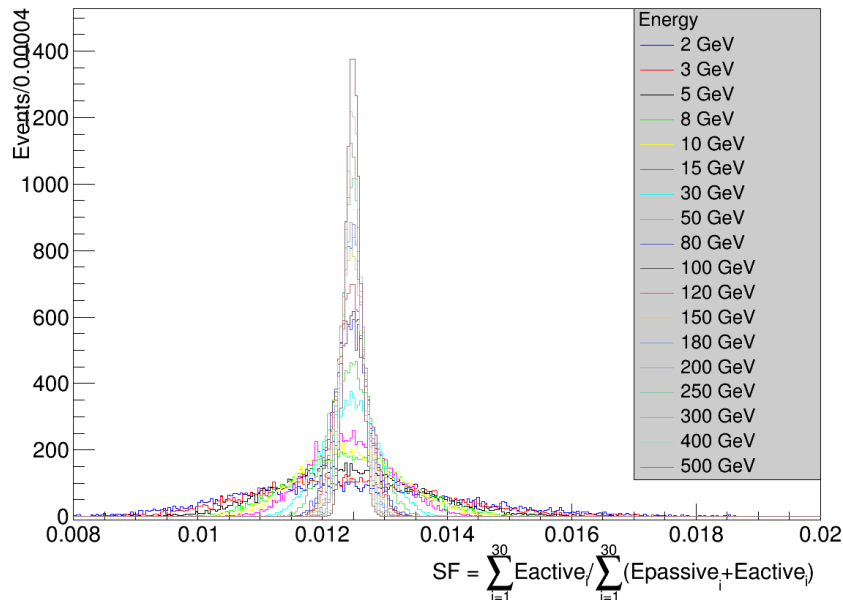


In these longitudinally segmented calorimeters we can measure the shower depth event by event.

The $\langle SF \rangle$ is also pretty much constant as a function of shower depth.

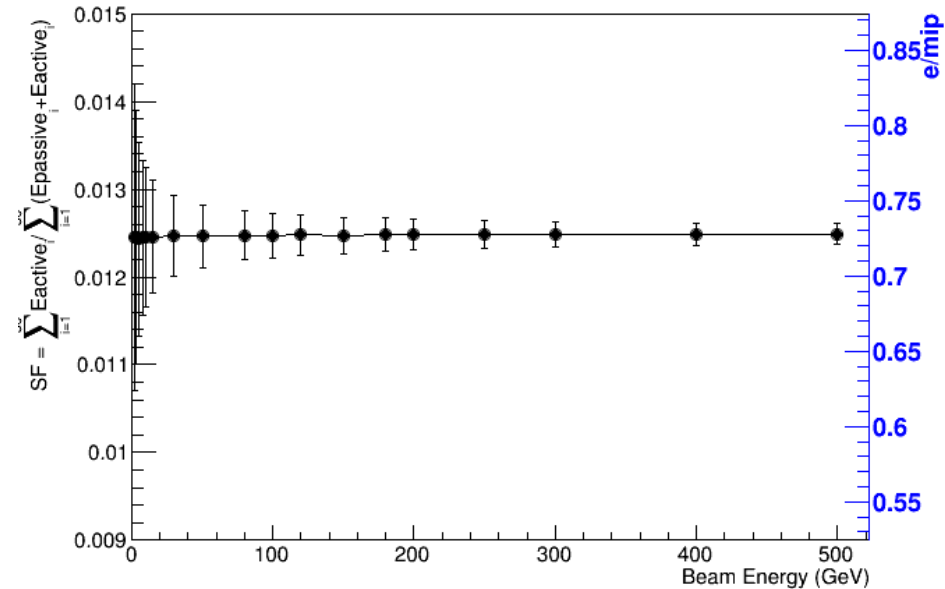
Sampling Fraction

Total sampling fraction for e- beam particle gun



$$SF = \frac{\sum_{i=1}^{30} E_{active,i}}{\sum_{i=1}^{30} (E_{active,i} + E_{passive,i})}$$

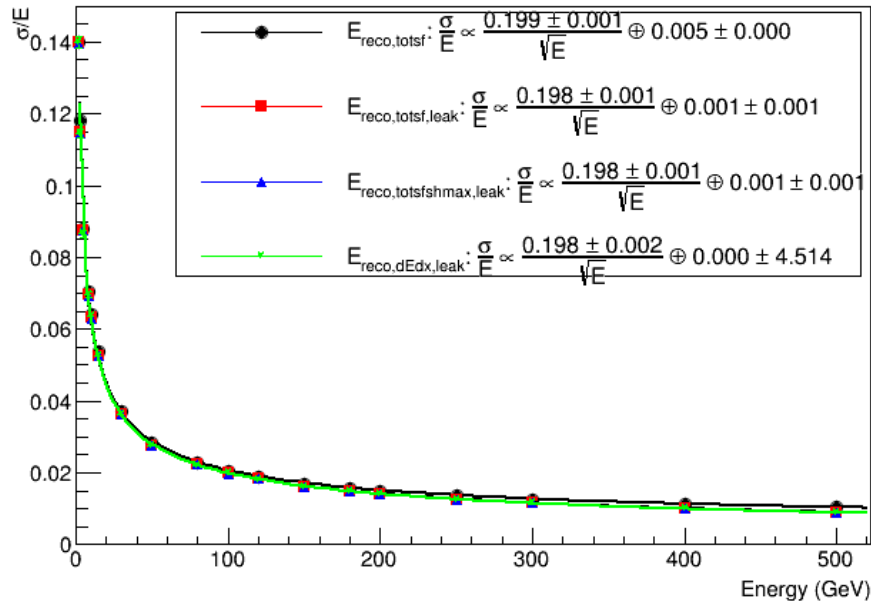
Total sampling fraction for e- for all beam energies



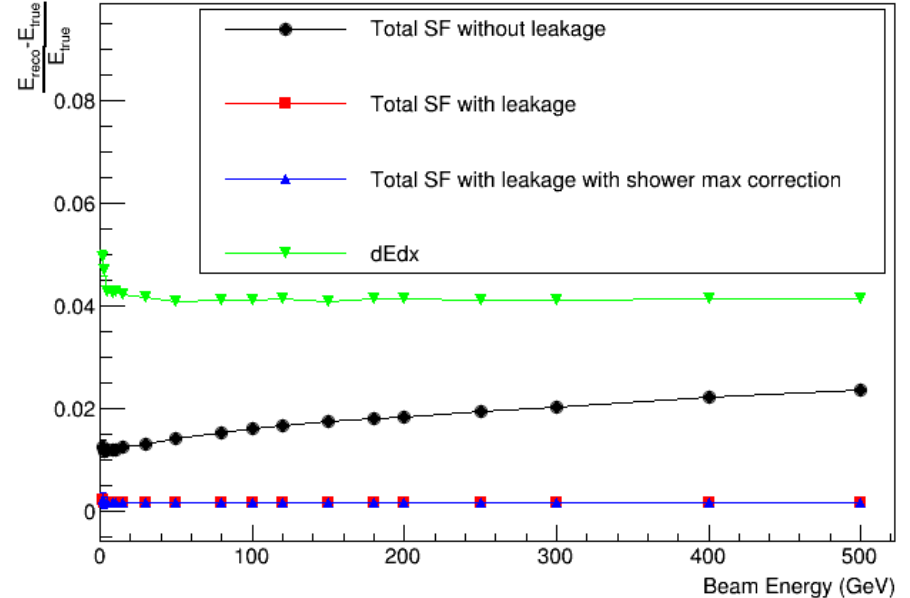
For homogeneous ECAL, the $\langle SF \rangle$ is constant with incident particle energy.

Energy Resolution/Scale/Linearity

Relative energy resolution for e-



Reconstructed energy and true energy for e-

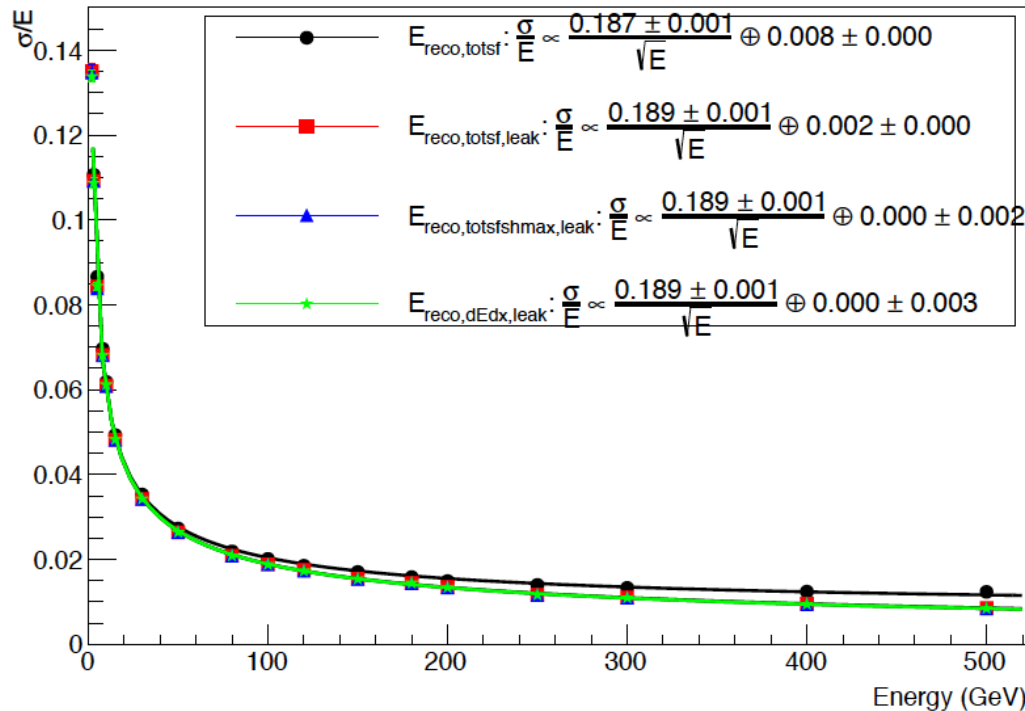


All methods give the same resolution and good linearity. The dEdx method overshoots the energy scale by +4% and is non-linear by 1% below 40GeV.

There is **no constant term** (as expected).

ECAL with 0.8X0 per layer

Relative energy resolution for e-



Resolution Improves at the expense of some leakage from the back, which if not corrected **it appears as a constant term**.

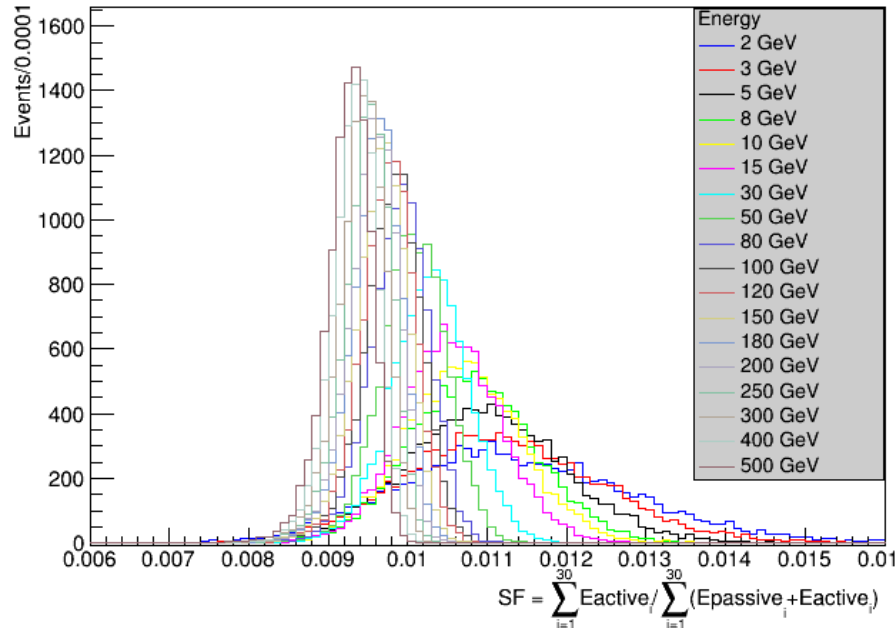
Some conclusions

- The dEdx method gives almost identical performance with the SF method for energies except at lower energies $E < 40\text{GeV}$.
 - The SF does not depend strongly on energy or shower depth.
 - The resolution improves with thinner passive layers at the expense of energy leakage (same number of layers).
 - No constant term (of course there shouldn't be!).
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- One can design a progressively increasing thickness calorimeter, having a higher SF in the earlier parts of the shower, and an improved resolution for the same total X_0 depth.

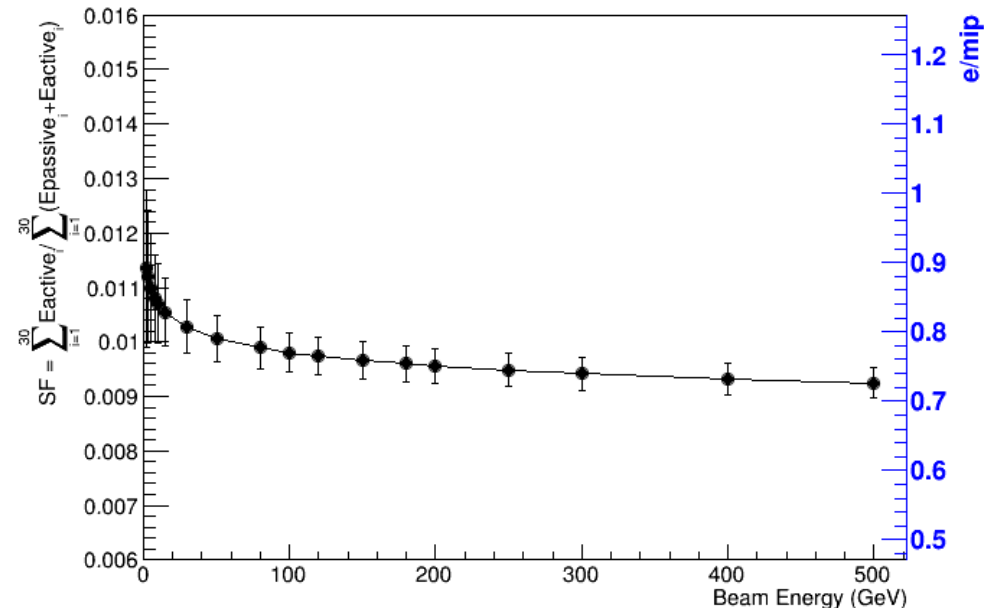
Inhomogeneous ECAL (CMS-style with 30layers)

Sampling Fraction vs energy

Total sampling fraction for e- beam particle gun

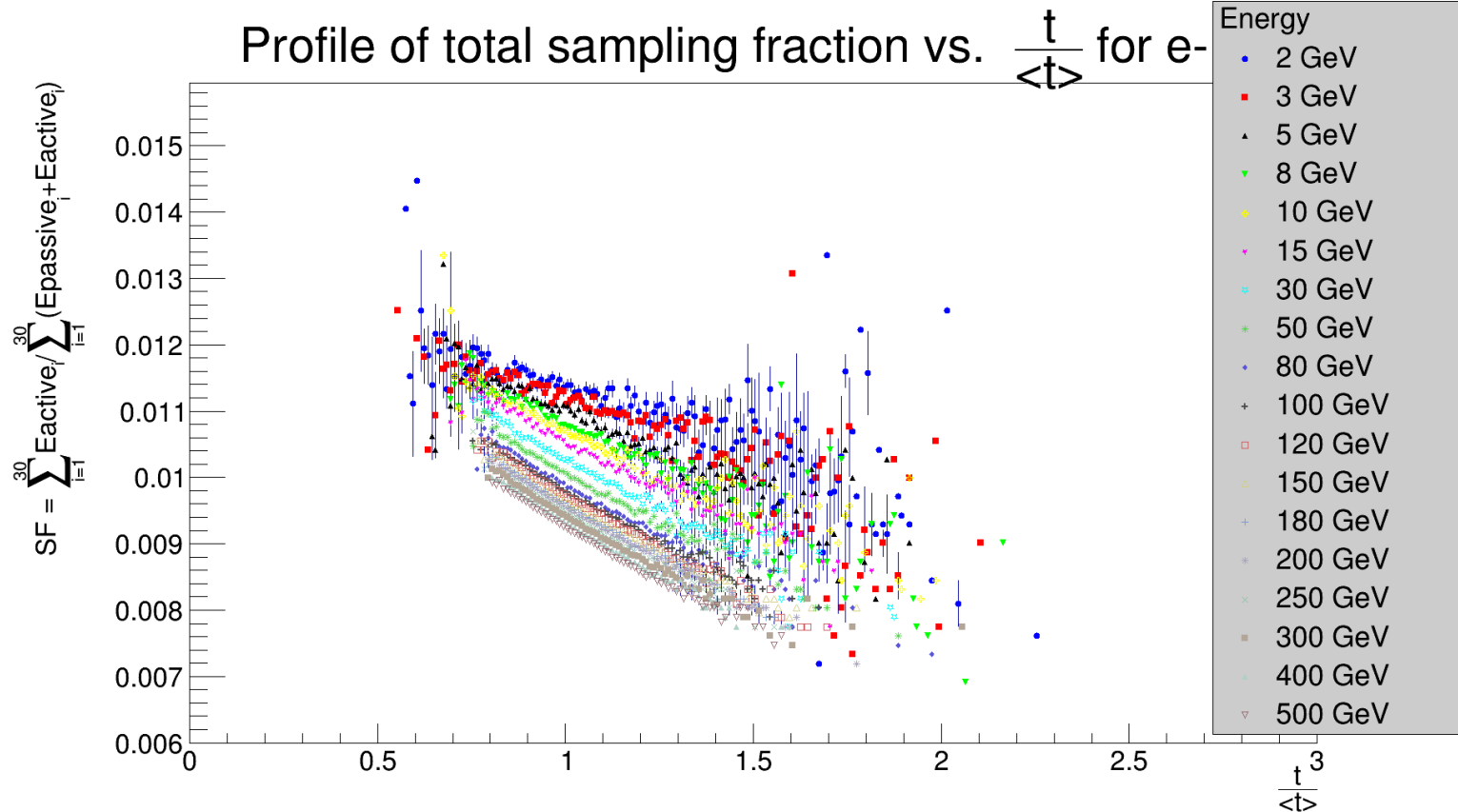


Total sampling fraction for e- for all beam energies



Due to the increasing thickness of the layers, the SF decreases with energy (i.e. more energy is absorbed in the passive Layers because the shower max is deeper in the ECAL).

SF vs depth

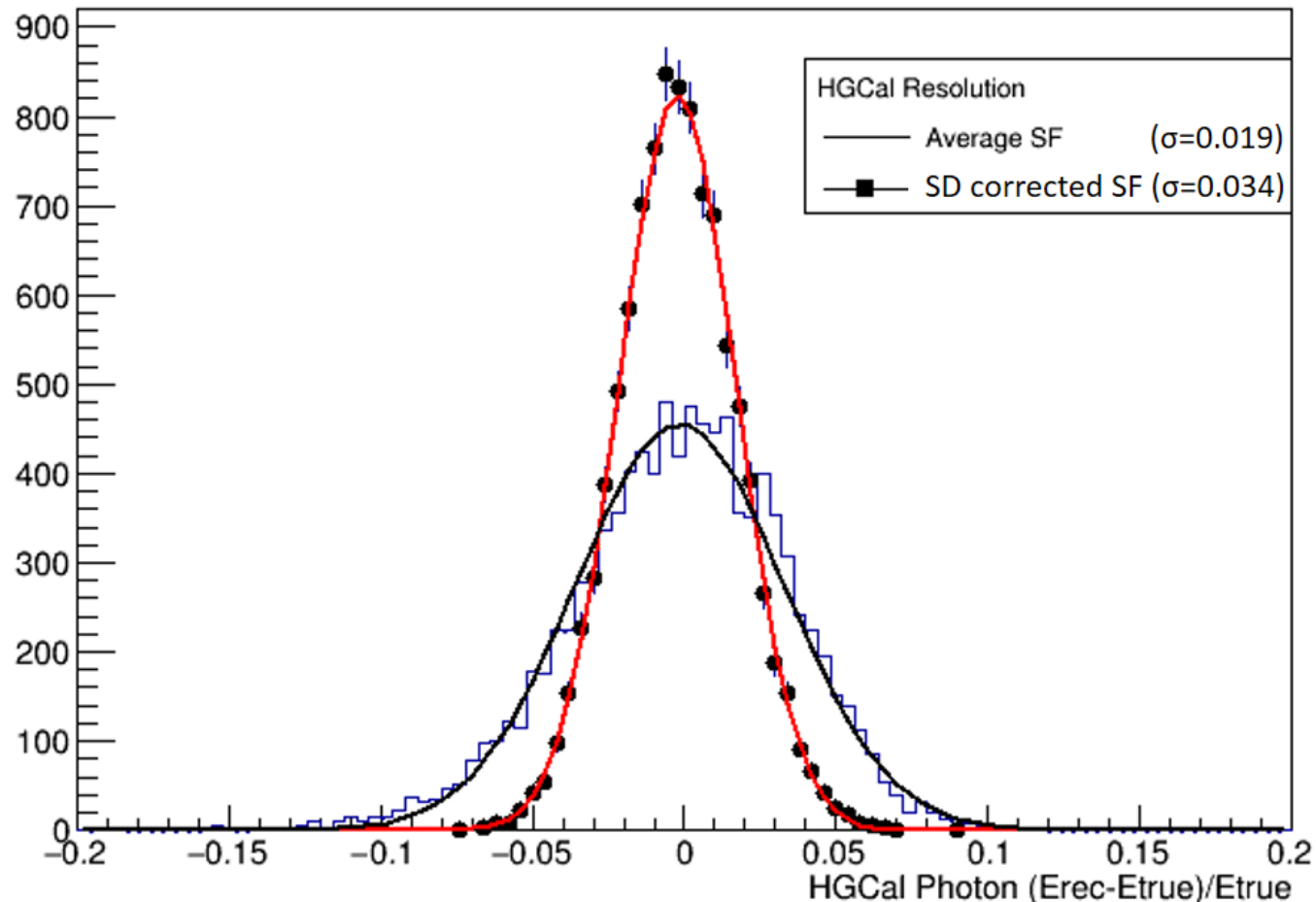


SF reduces linearly with shower depth due to the increasing passive layer thickness.

With the exception of very low beam energy the slope is universal ($t/\langle t \rangle$)

We use a single (universal) slope correction of the SF

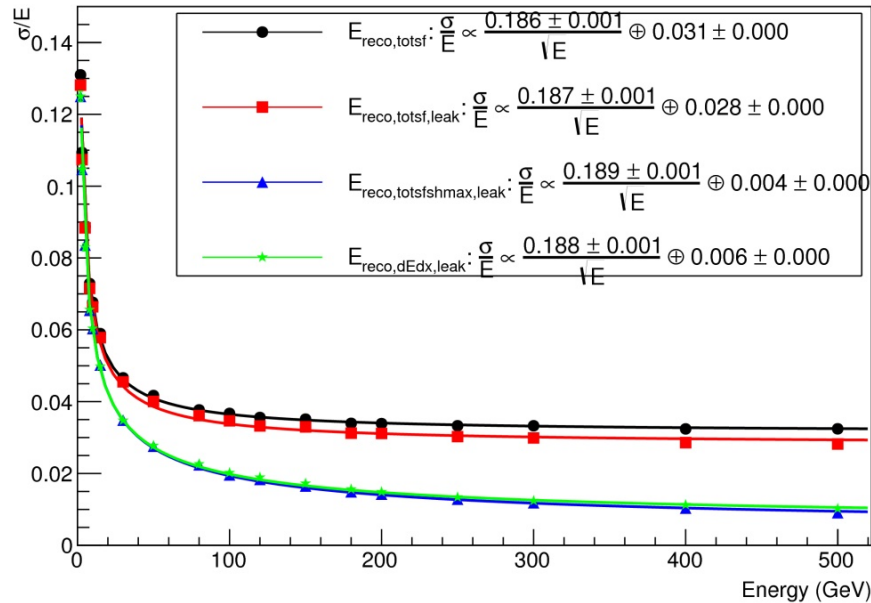
100 GeV: shower depth correction



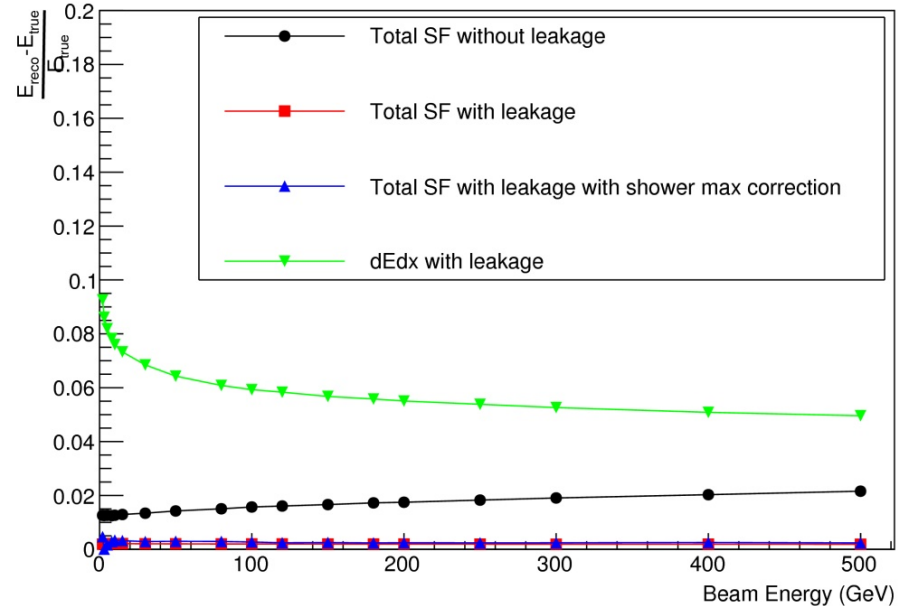
Example of resolution improvement after the SF correction using the shower depth.

Energy Resolution/Scale/Linearity

Relative energy resolution for e-



Reconstructed energy and true energy for e-



The dEdx method has significant non-linearity for energies below 100GeV. It also has an inherent constant term of **0.6%**, not present in the homogen. ECAL.

The SF method plus a single universal shower depth correction, has the same stochastic term as the dEdx, but good linearity, scale and lower constant term **0.4%**.

It is possible that additional corrections would remove the residual c.t. (not studied).

Summary

- Inhomogeneous longitudinally segmented Si ECALs require special attention in their initial calibration.
 - Simple dEdx-style calibration leads to significant non-linearity and scale problems.
 - It also leads to a significant constant term in resolution (0.6%)
- Going back to the traditional Sampling Fraction leads to the same resolution performance but provides good linearity and scale.
 - There is still a residual constant factor, probably due to the average nature of the SF correction (not a proven fact yet!)
- Our goal is to test these ideas in upcoming test-beams and establish the best approach.
- **CEPC SiECAL design-studies should take into account such issues.**

Extra Slides



Sampling Fraction Method

- Initially, we find the $\langle SF \rangle$ for bins of the variable $\frac{t}{\langle t \rangle}$, where $t = \frac{\sum_{i=0}^n E_i \left(\sum_{j=0}^i X_0 \right)}{\sum_{i=0}^n E_i}$ and $\langle t \rangle$ the mean value of the t distribution. The i, j indexes refers to layers.
- Then, we fit the graph $\langle SF \rangle = f\left(\frac{t}{\langle t \rangle}\right)$ with a linear function and acquire the slope.
- Finally, the sampling fraction value that is used is
$$slope * \left(\frac{t}{\langle t \rangle} \Big|_i - \frac{t}{\langle t \rangle} \Big|_{bin} \right) + \langle SF \rangle$$
where $\frac{t}{\langle t \rangle} \Big|_i$ is the value of the variable $\frac{t}{\langle t \rangle}$ for the event under consideration, $\frac{t}{\langle t \rangle} \Big|_{bin}$ is the mean value of the same variable in the bin that $\frac{t}{\langle t \rangle} \Big|_i$ belongs, slope is the slope from the fit above and $\langle SF \rangle$ the mean sampling fraction value in the $\frac{t}{\langle t \rangle}$ bin that the event belongs to.
- The above method is performed for a number of energies as well as using a universal fit for all energies.



dEdx method

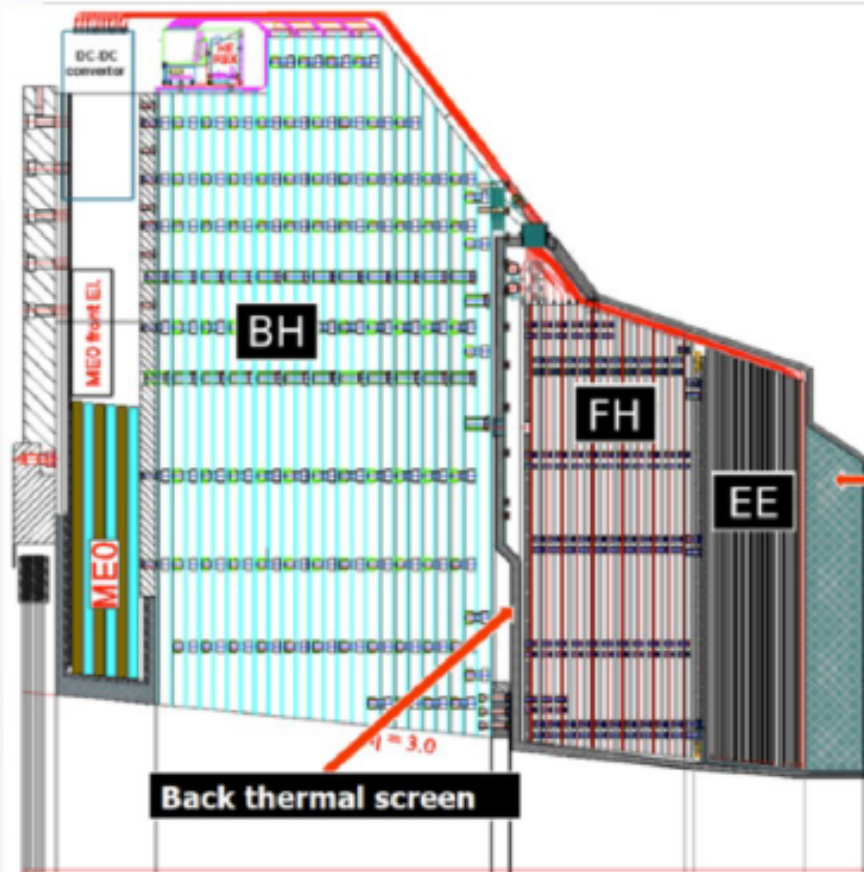
- ❑ The dEdx method is using the measured number of MIPs in a sensitive layer, n_i .
- ❑ Then, estimates the number of MIPs in an absorber layer using his front and back sensitive layer: $\frac{n_{i-1}+n_i}{2}$.
- ❑ Finally, it uses dE/dx to convert the equivalent number of MIPs to energy:

$$\sum_{i=1}^{layers} \left(\frac{n_{i-1} + n_i}{2} \frac{dE}{dx} \Big|_i^{absorber} + \frac{dE}{dx} \Big|_i^{active} \right)$$

Special attention is taken for the first layer.



The CMS HGC Design



Construction:

- Hexagonal Si-sensors built into modules.
- **Modules** with a W/Cu backing plate and PCB readout board.
- Modules mounted on copper cooling plates to make wedge-shaped **cassettes**.
- **Cassettes** inserted into **absorber** structures at integration site (CERN)

Key parameters:

- 593 m² of silicon
- 6M ch, 0.5 or 1 cm² cell-size
- 21,660 modules (8" or 2x6" sensors)
- 92,000 front-end ASICs.
- Power at end of life 120 kW.

System Divided into three separate parts:

EE – Silicon with tungsten absorber – 28 sampling layers – $25 X_0 + \sim 1.3 \lambda$

FH – Silicon with brass absorber – 12 sampling layers – 3.5λ

BH – Scintillator with brass absorber – 11 layers – 5.5λ

EE and FH are maintained at -30°C . BH is at room temperature.