Crystal EM Calorimeter

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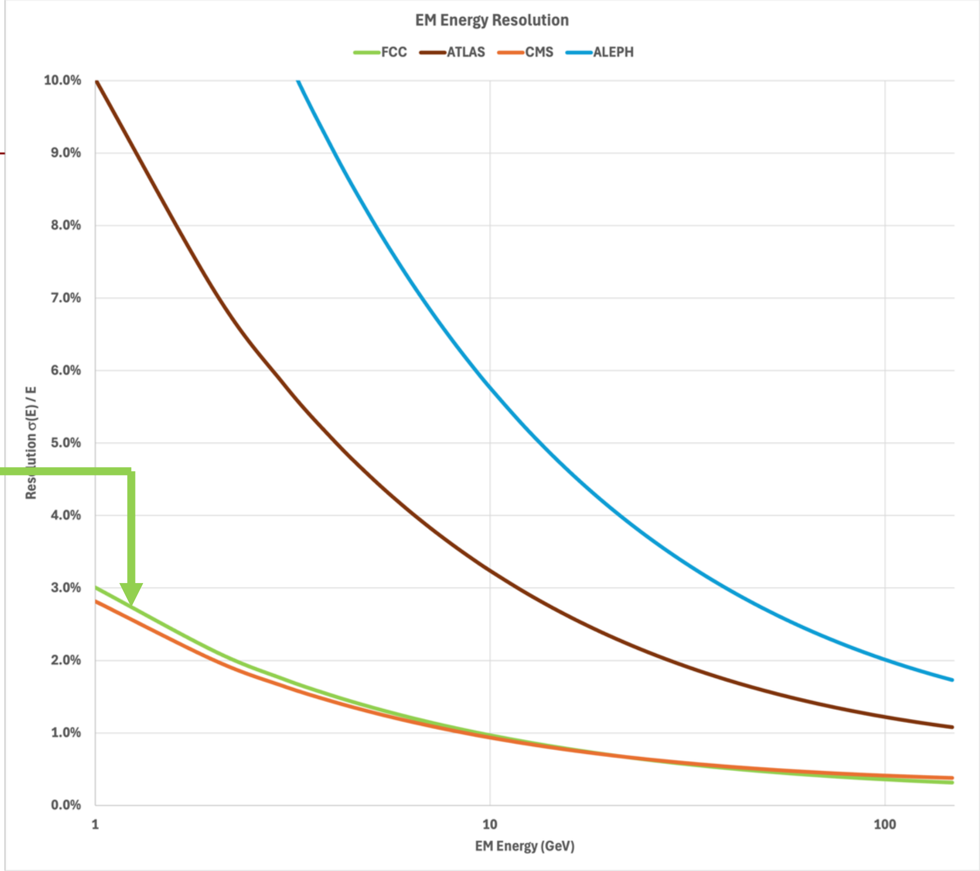
EM Calorimeter

$$\frac{\sigma_E}{E} \approx (a/\sqrt{E}) \oplus b$$

	a (GeV$^{-1/2}$)	*b*	Comments
FCC-*ee*	~3%	~0.2%	Also want γ/π^0 separation
ATLAS	10%	0.7%	Sampling
CMS	2.8%	0.3%	Not sampling
ALEPH	18%	0.9%	Sampling



- Stochastic term "*a*" (target 3%) requires
  - High sampling fraction
  - Minimal dead material in front of EM calorimeter
- Constant term "*b*" requires
  - Excellent calibration
  - Stability

FCC-*ee* Detector Concept - ALLEGRO

Highly granular noble-liquid EM calorimeter as central feature

Web, 2024 Pisa Meeting, EoI

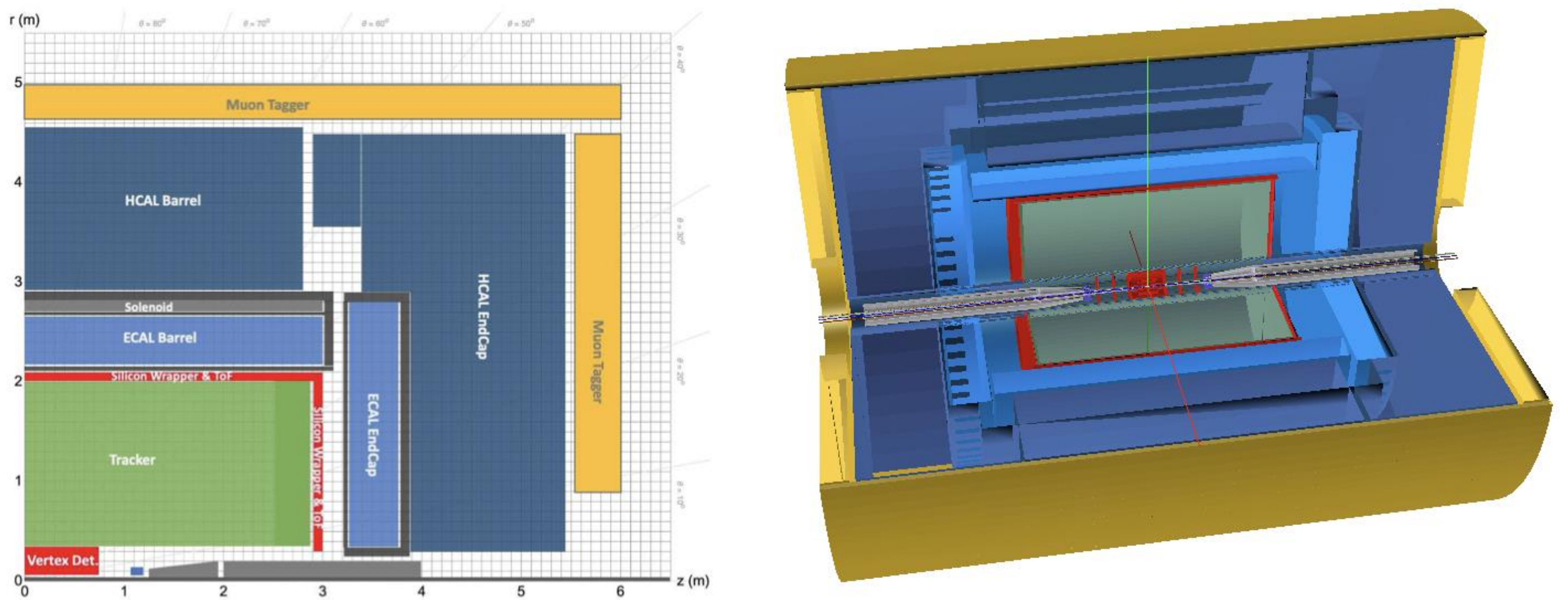


Figure 1. Sketch of a cross-section of a quarter of the ALLEGRO detector concept (left) and 3D view of the implementation into the FCC-SW (right).

Subsystems in radial order:

Vertex - MAPS

Main tracker - drift chamber, straw tube or silicon + Si/LGAD wrapper

PID - RICH (if Si tracker)

ECAL - Pb/W-LAr/LKr

Solenoid - 2 T

HCAL - Fe-scintillator

Muon - MicroMEGA

FCC-*ee* Detector Concept – CLD

Evolution of SiD and CLICdet

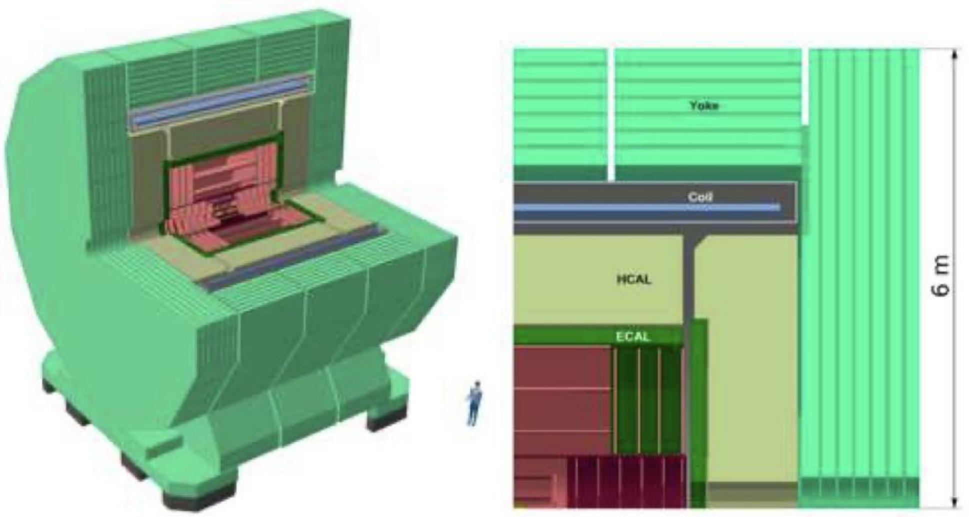


Figure 1: CLD concept (Left: isometric view with one quarter removed; Right: vertical cross section showing the top right quadrant).

Subsystems in radial order:

Vertex - MAPS

Main tracker – silicon

PID – RICH

ECAL – highly granular Si-W

HCAL – highly granular Fe-scintillator

Solenoid: 2 T

Muon - RPC

FCC-*ee* Detector Concept – IDEA

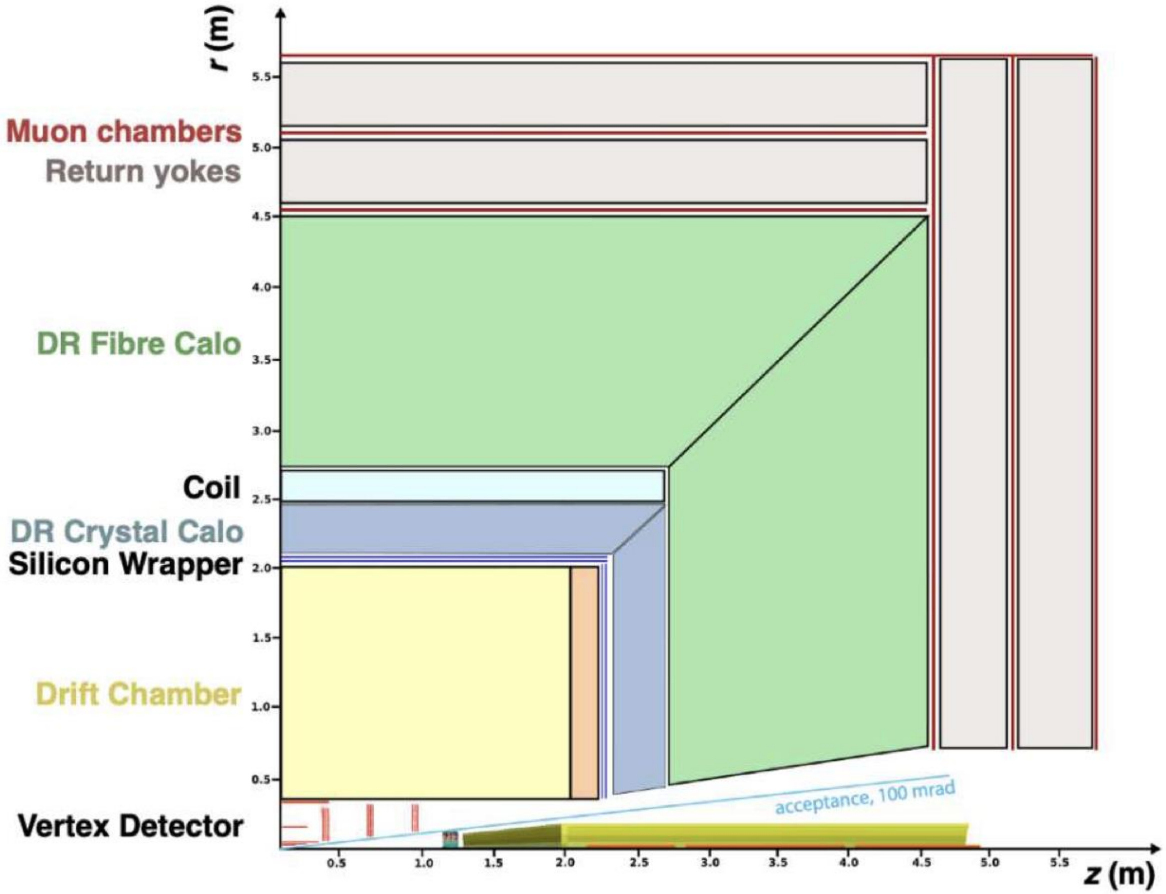


Figure 5 Cross-sectional view of the IDEA detector concept

Subsystems in radial order:

Vertex - MAPS

Main tracker – He-isobutane drift chamber + silicon/LGAD wrapper

PID – TOF + cluster counting (dN/dx)

ECAL – dual-readout crystal

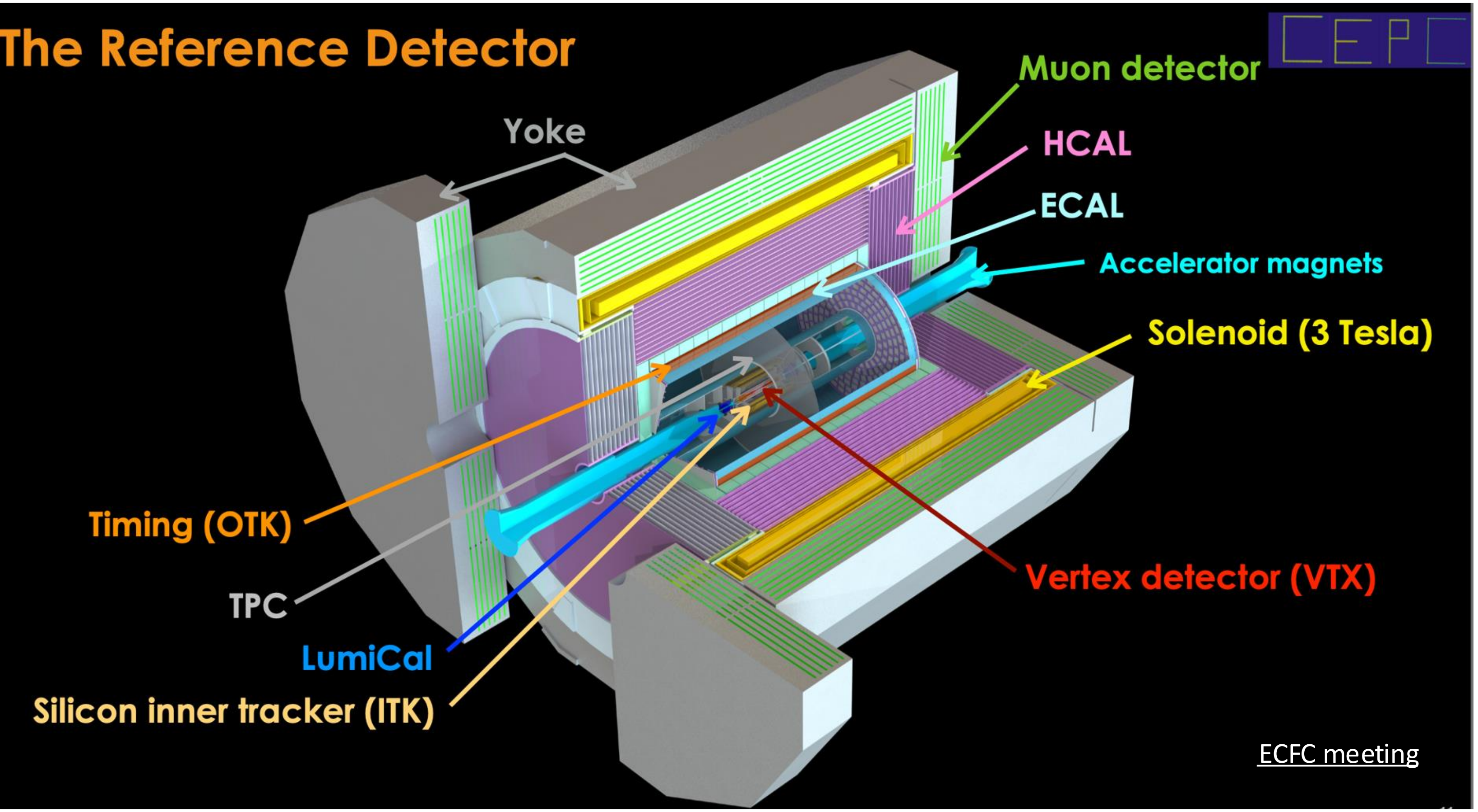
Solenoid – up to 3 T using HTS

HCAL – dual-readout fiber calorimeter

Muon – μ-RWELL

CEPC Reference Detector Concept

Technical Design Report



Subsystems in radial order:

Vertex - MAPS

Main tracker – inner Si pixel + TPC + outer Si/LGAD

PID – TOF + dE/dx

ECAL – 4D transverse crystal

HCAL – Fe-glass scintillator (SiPM)

Solenoid – 3 T

Muon – scintillator (SiPM)

Crystal EMCal

Focus here on crystal EMCal

- High sampling fraction to keep "a" small
- Need to have high light collection efficiency
- Need high photon sensitivity

SiPM photosensors

- Operations in high B-field
- Compact

IDEA

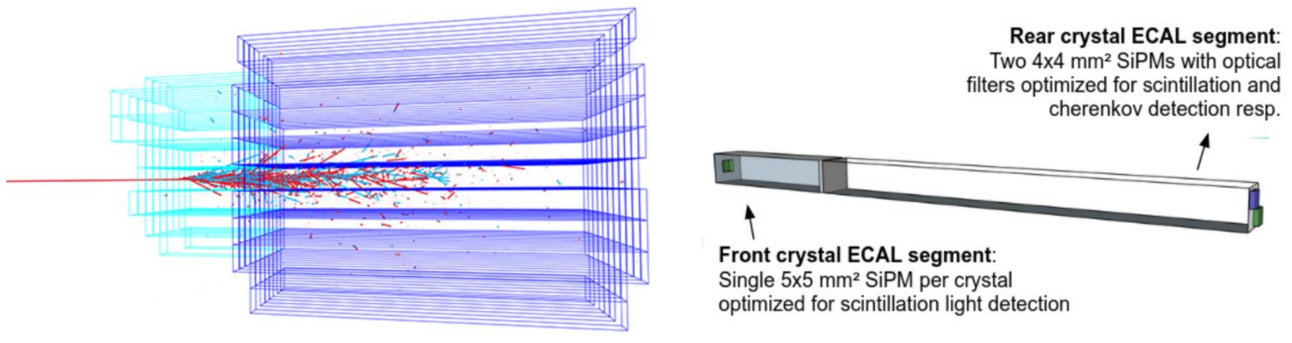


Figure 22: Simulated EM shower display from a 10 GeV electron em shower (left) and schematic drawing of a segmented crystal calorimeter prototype cell and module with SiPM based dual-readout (right).

CEPC

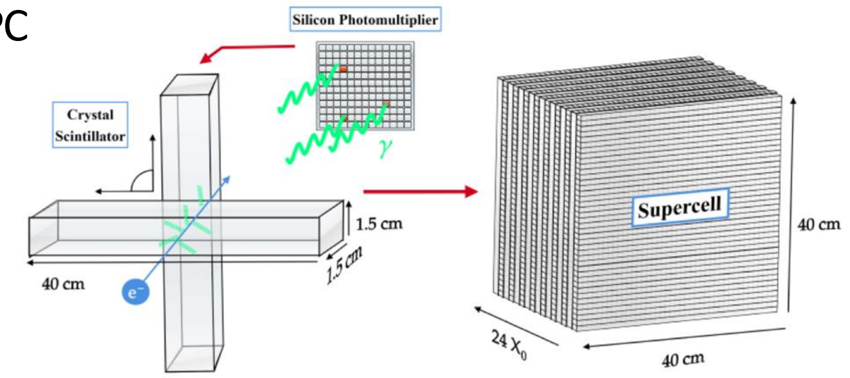


Figure 7.1: The schematics of an ECAL module (i.e. a supercell) with the orthogonal arrangement of long crystal bars to achieve fine segmentation in the longitudinal direction and transverse planes. Each crystal bar is individually wrapped with a reflective foil to ensure a high light collection efficiency and a good response uniformity and avoid any optical crosstalk between crystals. The scintillation light of each crystal is read out by two SiPMs attached at each crystal end.

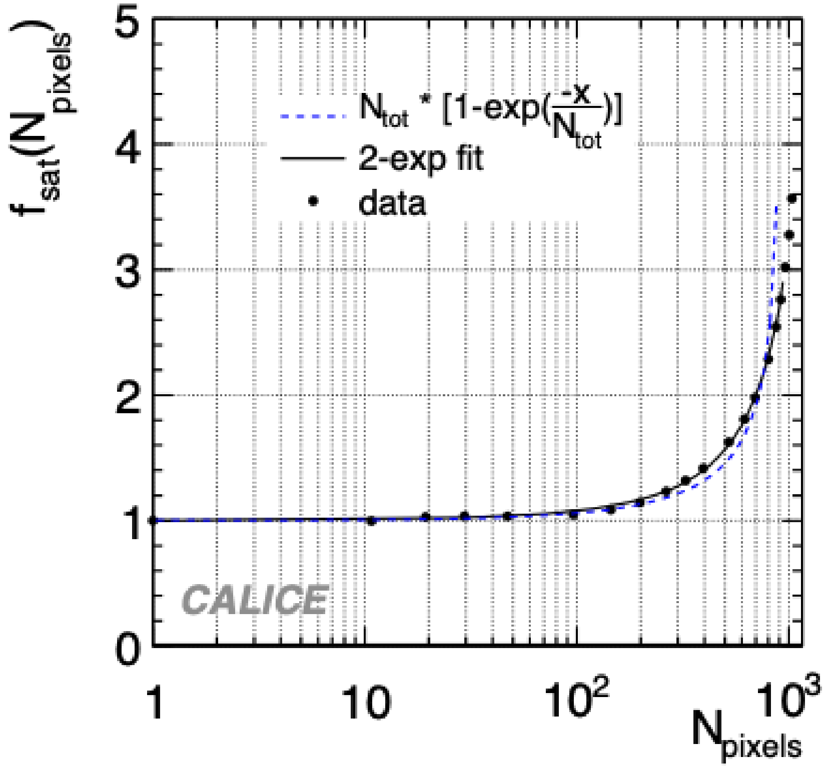
Saturation

Shower properties (in BGO)

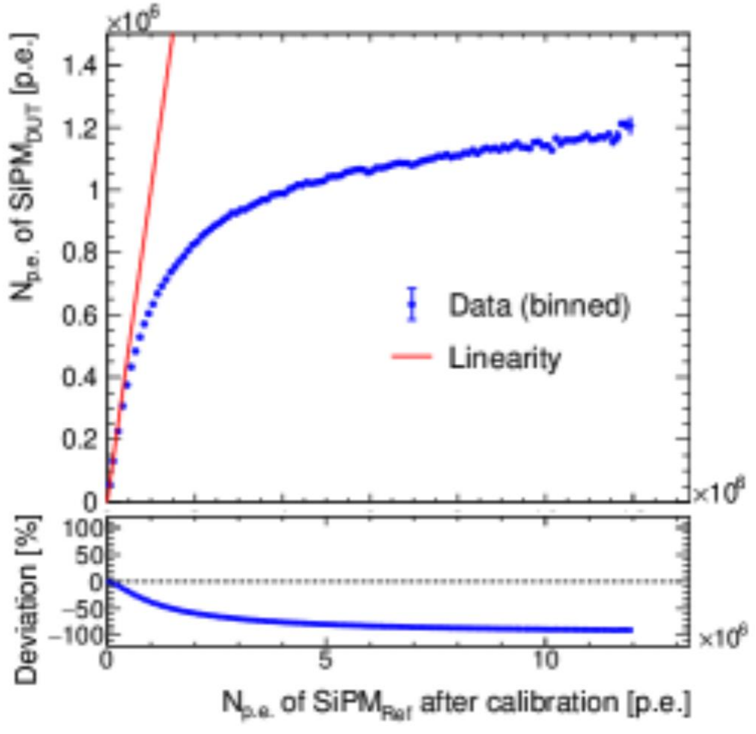
- ~8000 photons / MeV
- Moliere radius R_M ~ 2.2 cm
- Average density ~ 500 / cm^2 MeV => 5 10^6 / cm^2 for 10 GeV
- Density at shower core 50 – 100 x higher => 2.5 – 5 10^6 / mm^2 for 10 GeV

SiPM

- Photon detection efficiency PDE ~ 20% => 0.5 – 1 10^6 / mm^2 expected in shower core for 10 GeV
- Typical SiPM cell density ~ 1000 per mm^2 much smaller
- SiPM is intrinsically digital
  - Response saturates at high occupancy
  - Cell recharge time (10s nsec) longer than shower time



Remedies



Correction based on response curve

- Correct observed #cell (vertical axis) to ”true” #cell (horizontal axis)
- OK for average energy
- Contribution to energy resolution due to event-to-event fluctuation
- Not useful in practice when cell occupancy is large

Filter to reduce incident light intensity

- Operation in (more) linear regime of SiPM
- Turns fully absorbing crystal calorimeter into a sampling calorimeter
- Also question of dynamic range
  - MIP produces ~80,000 photons per cm of path length

Important that performance estimates include these and other real-life effects.