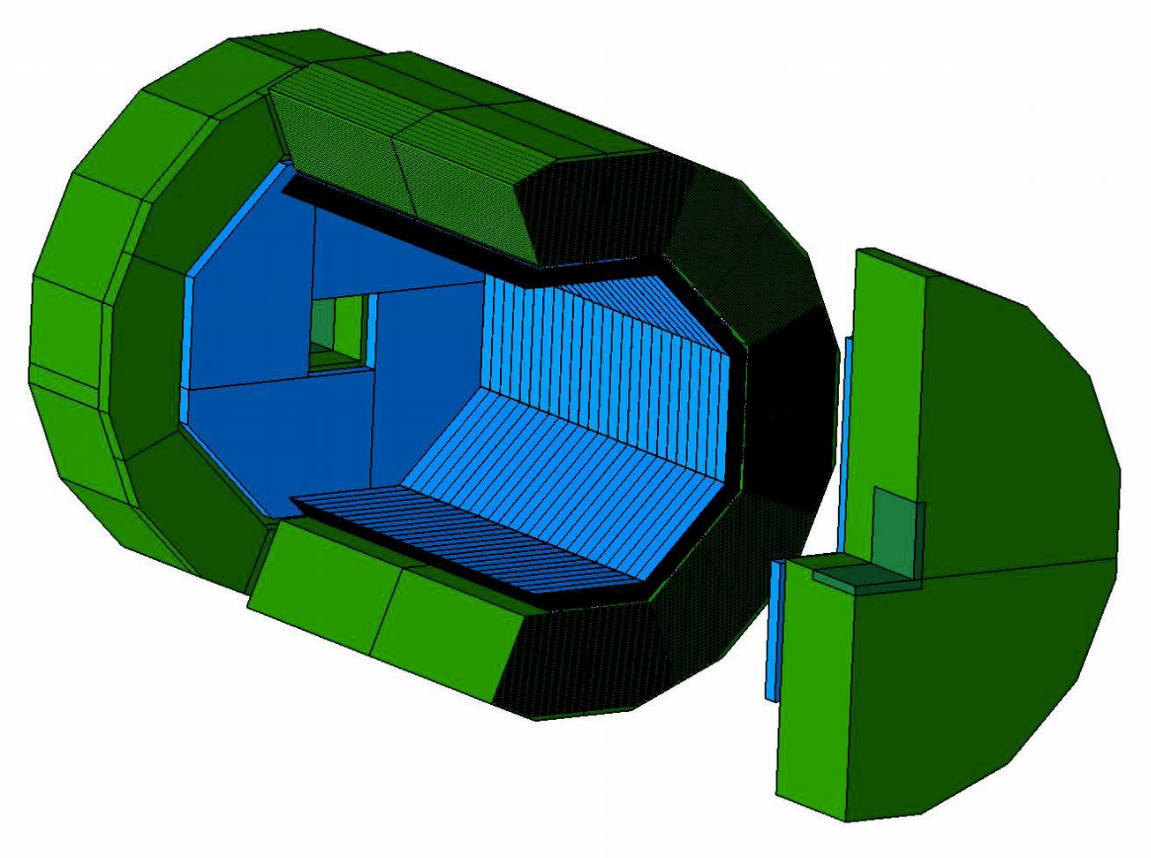
LC calorimetry



Katja Krüger
ILC project meeting,
29 May 2015

HELMHOLTZ ASSOCIATION

CALICE

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

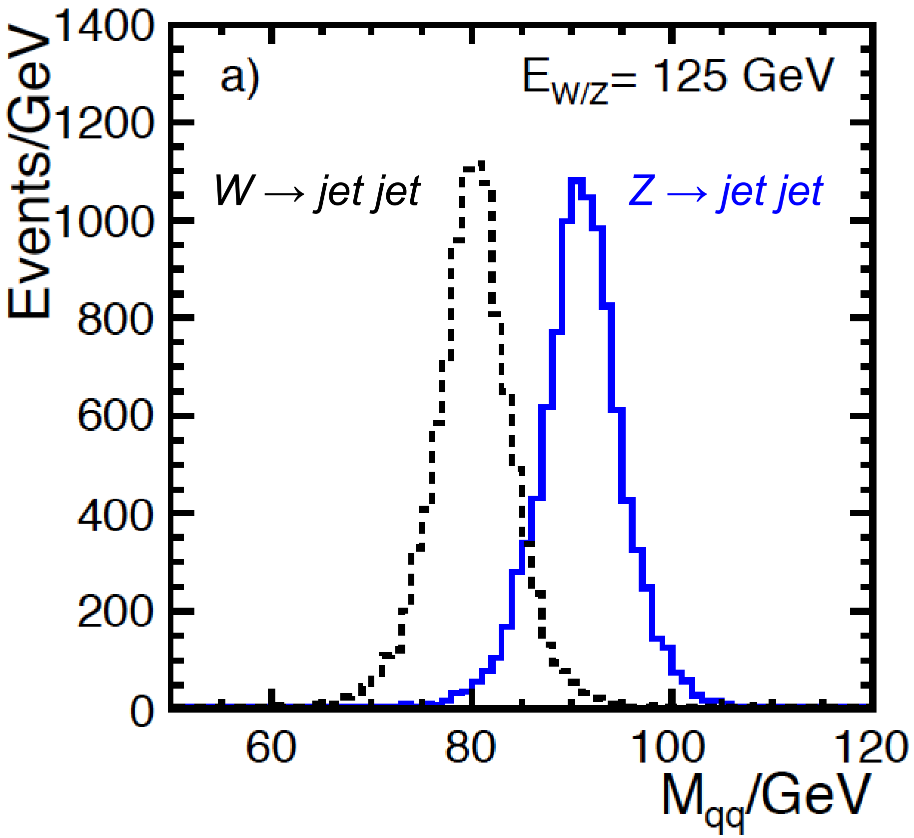
DESY

Overview

- very nice and complete overview on LC calorimetry given by Felix in ILC project meeting on 9 May 2014
- don't want to repeat that now
- will give a brief introduction
- then concentrate on new results, mainly from CALICE and ILD meetings during ALCW2015 at KEK
  - many results are work in progress
  - personal selection

- introduction: jet energy resolution, particle flow and high granularity calorimeters
- calorimeter prototypes
- comparison to simulation
- particle flow algorithms and detector optimisation
- highly granular calorimeters beyond LC

Why highly granular calorimeters?

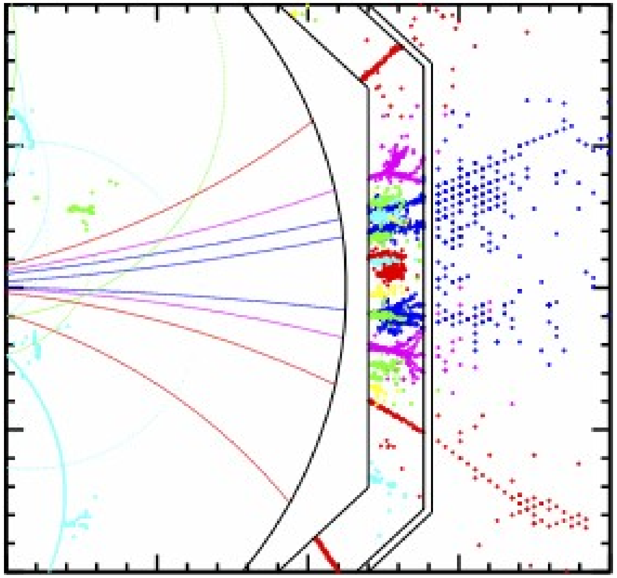


from: M.A. Thomson, Nucl.Instrum.Meth. A611 (2009) 25

- goal: distinguish the decays
  $Z \rightarrow$ *jet jet* and $W \rightarrow$ *jet jet*
  by their reconstructed mass
- Required resolution:
  $\sigma(E_{jet})/E_{jet} \approx$ 3-4%
  for $E_{jet} \approx$ 40 to 500 GeV
- "typical" calorimeter:
  $\sigma(E_{jet})/E_{jet} \approx 60\%/\sqrt{E(\mathrm{GeV})} \oplus 2\%$
  $\Rightarrow \sigma(E_{jet})/E_{jet} \approx 10\%$ at E_{jet} = 50 GeV
- promising solution:
  Particle
  Flow
  Algorithms

Particle Flow Algorithm

- Idea:
  for each individual particle in a jet,
  use the detector part with the best
  energy resolution

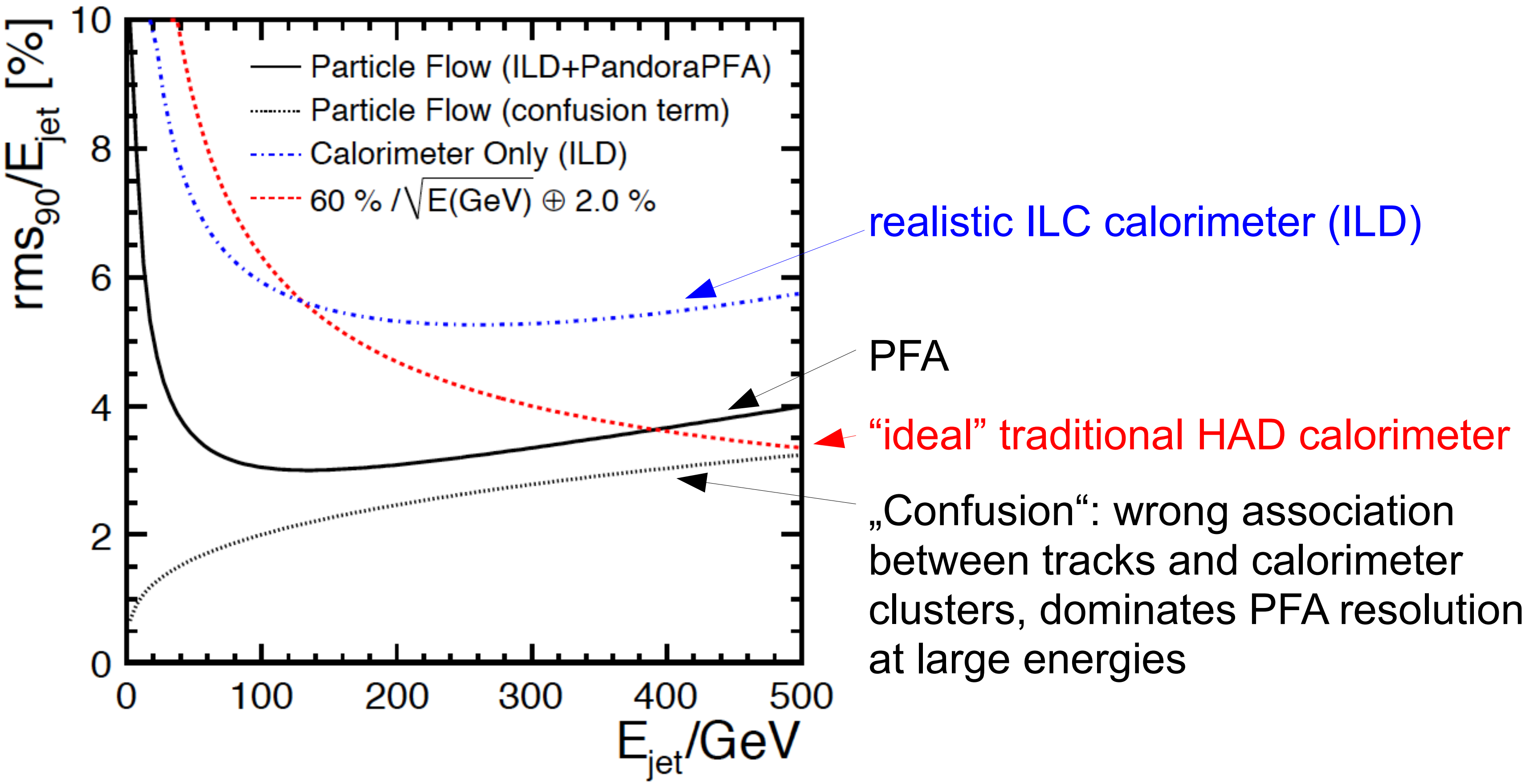


from: M.A. Thomson,
Nucl.Instrum.Meth. A611 (2009) 25

- „typical“ jet:

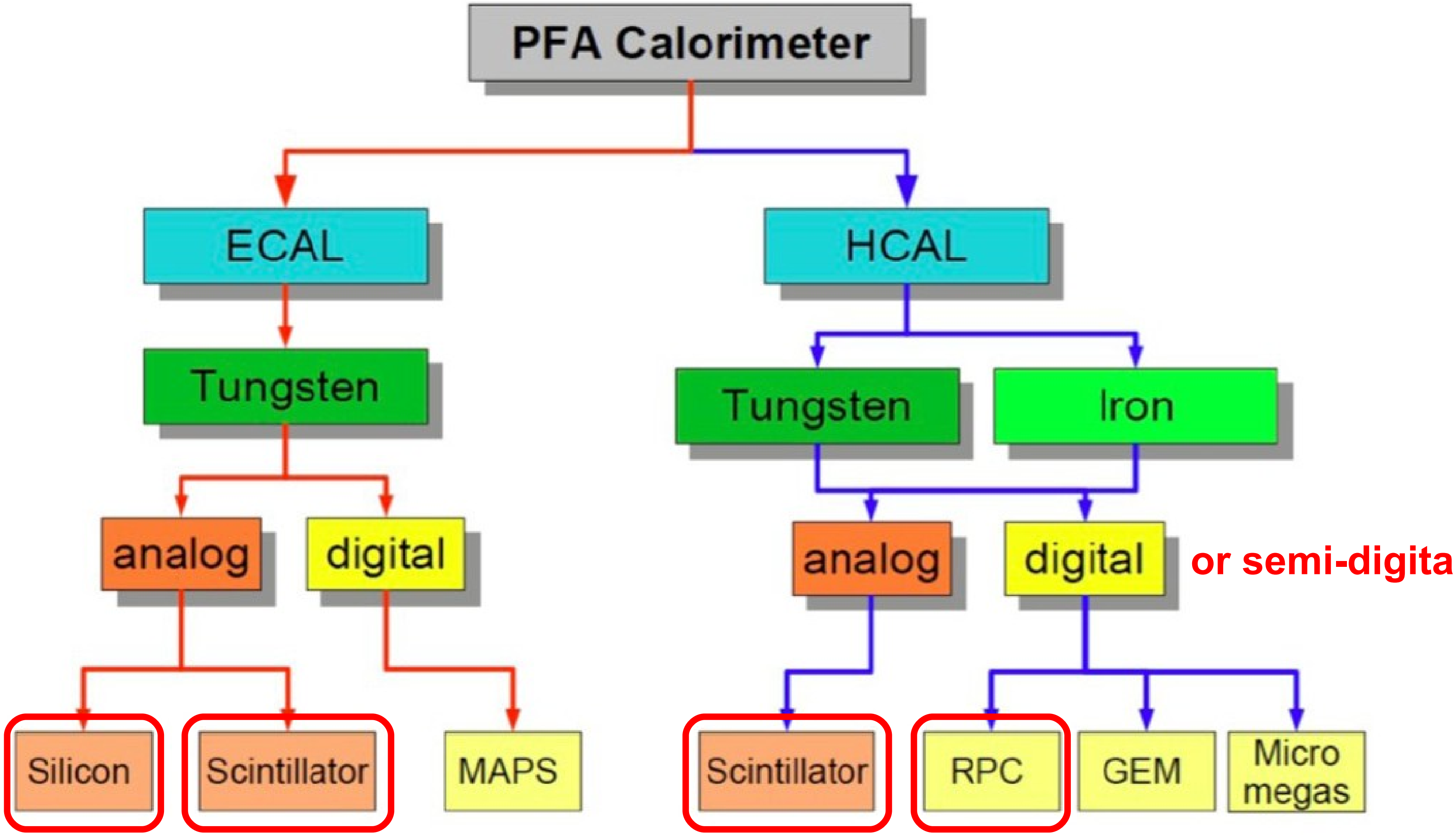
		$(\sigma_{jet})^2$
~ 62% charged particles	tracking	$\approx 0.62\ (\sigma_{tracks})^2$
~ 27% photons	EM calorimeter	$+\ 0.27\ (\sigma_{EMCalo})^2$
~ 10% neutral hadrons	HAD calorimeter	$+\ 0.10\ (\sigma_{HADCalo})^2$
~~ 1% neutrinos~~		$+\ (\sigma_{loss})^2 + (\sigma_{confusion})^2$

Jet Energy Resolution



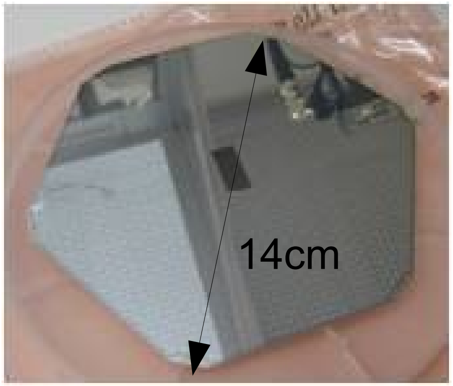
- PFA resolution is clearly better than calorimeter alone
- correct association between tracks and calorimeter clusters is very important ⇒ "imaging" calorimeter with very high granularity

Calorimeter Technologies for Linear Collider detectors

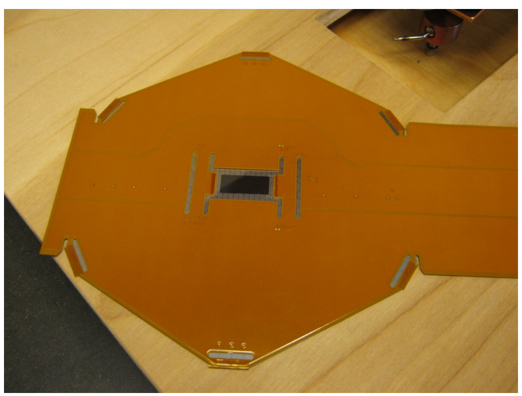


Electromagnetic Calorimeter

Silicon

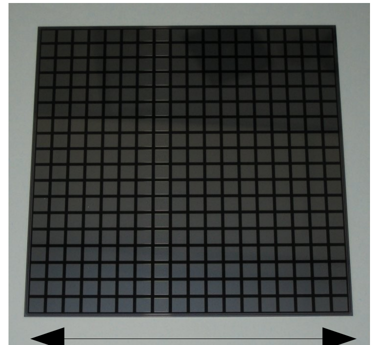


1024 pixel

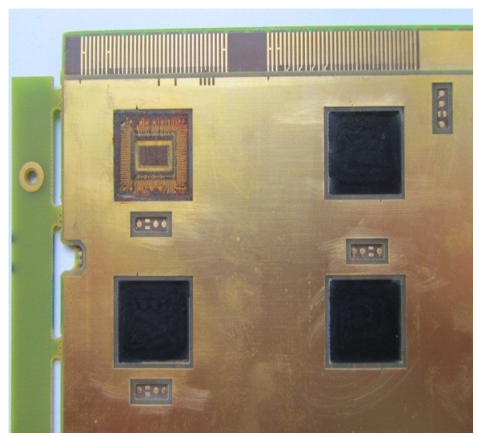


SiD

Silicon

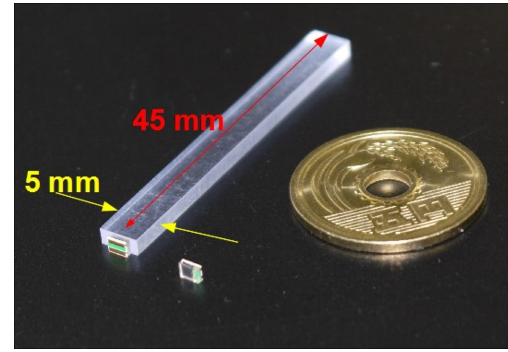


9cm
256 pixel



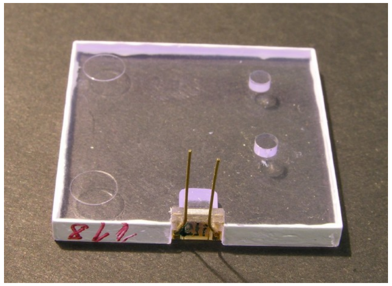
ILD option
SiECAL

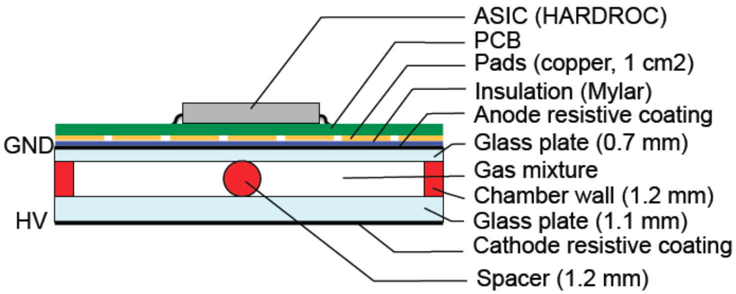
Scintillator



ILD option
SciECAL

Hadronic Calorimeter





- Scintillator tiles read out by SiPMs
- 3*3 cm^2 tiles
- readout: 12 bit (analog)
- **ILD option**
  SiD alternative

AHCAL

- Resistive Plate Chamber: local gas amplification between 2 glass plates with high voltage
- 1*1 cm^2 readout pads
- readout: 1 bit (digital)
- **SiD**

DHCAL

- readout: 2 bit (semi-digital)
- **ILD option**

SDHCAL

Prototypes

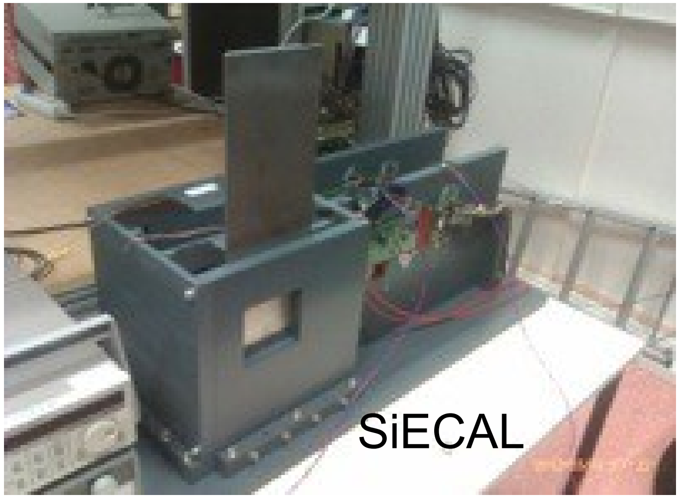
first generation: physics prototypes

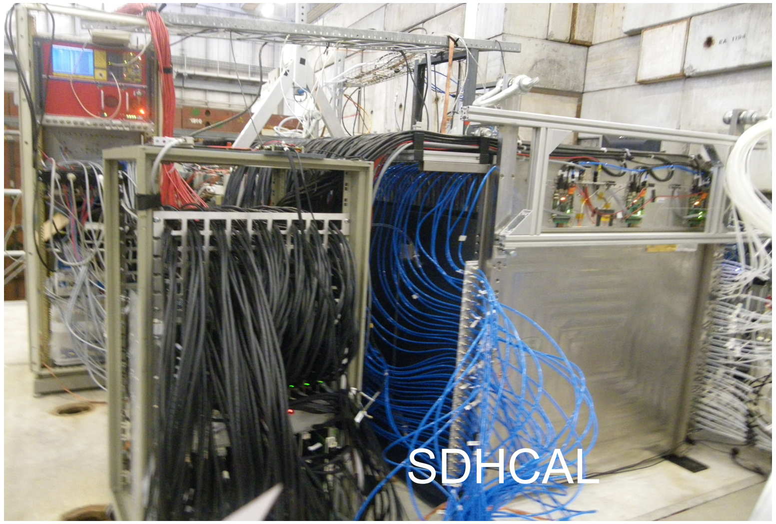
- demonstrate capabilities of the concept
  - linearity of energy reconstruction
  - single particle energy resolution
  - validation of simulation models
  - particle flow: two-particle separation
- validation of simulation models
- large prototypes:
  - SiECAL
  - SciECAL
  - AHCAL
  - DHCAL

Prototypes

second generation: technological (or engineering) prototypes

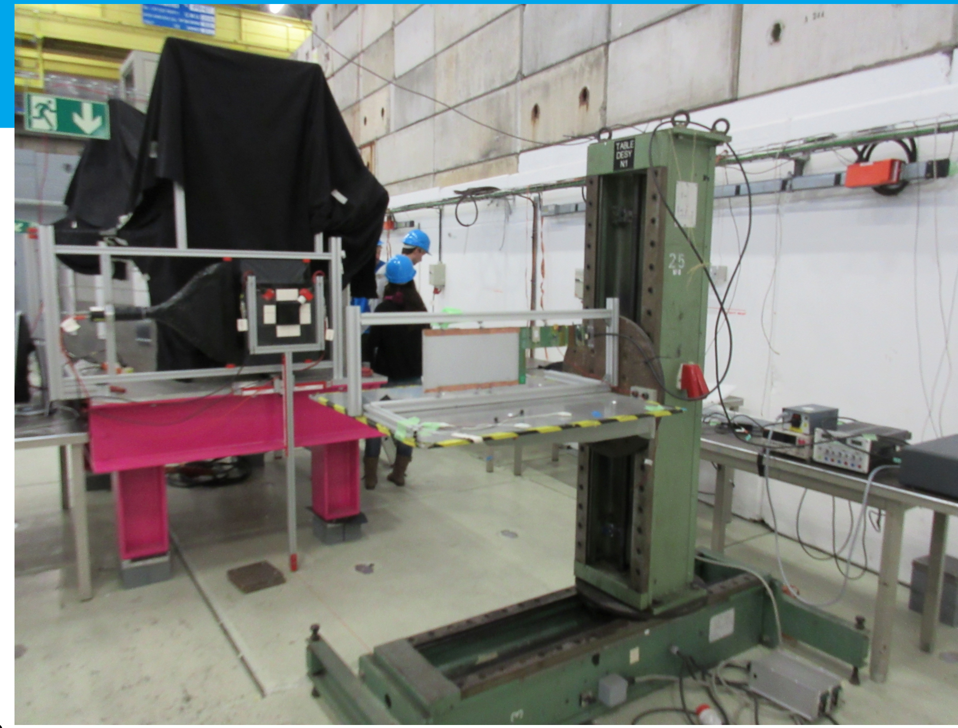
- scalable to full collider detector
- suitable for mass production
- respect power budget (power pulsing)
- prototypes:
  - SiECAL: ~10 small layers, working on long ladders
  - SciECAL: 3 small layers
  - SDHCAL (generation 1.5):
    - 1 m³, testbeam measurements ongoing
    - larger layers to be shown
  - AHCAL: 1 m³ in preparation

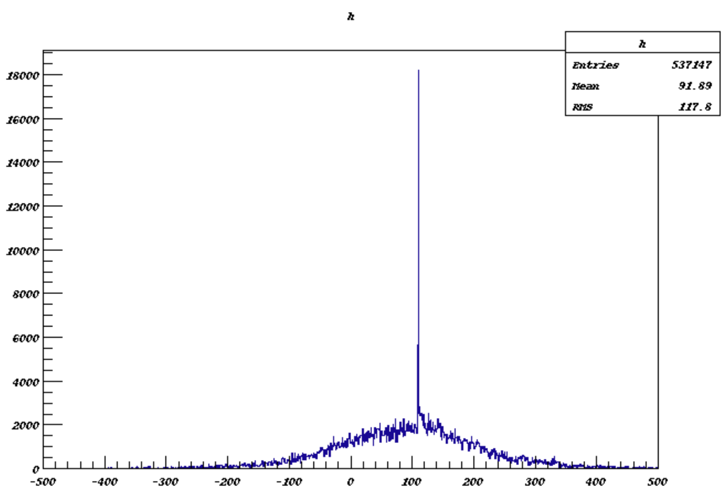




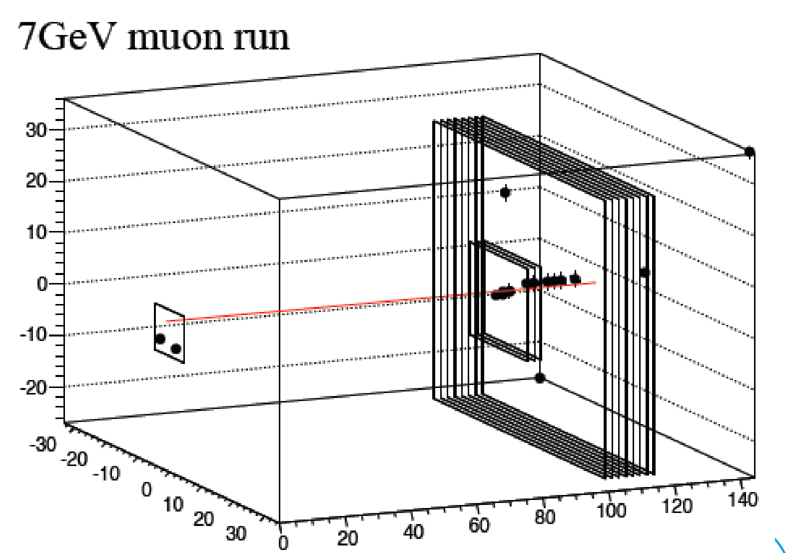
Combined Testbeam

- combined beam test of second generation prototypes at CERN
- proof of principle for common DAQ (but still much to be done)
- active layers:
  - 1 small SiECAL layer
  - 3 small SciECAL layers (inside AHCAL stack)
  - 12 AHCAL layers
- alignment and relative timing of Silicon and Scintillator to be determined





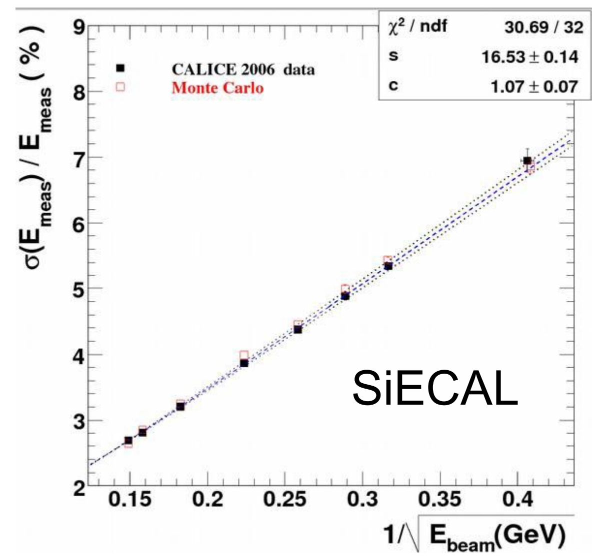
Time difference

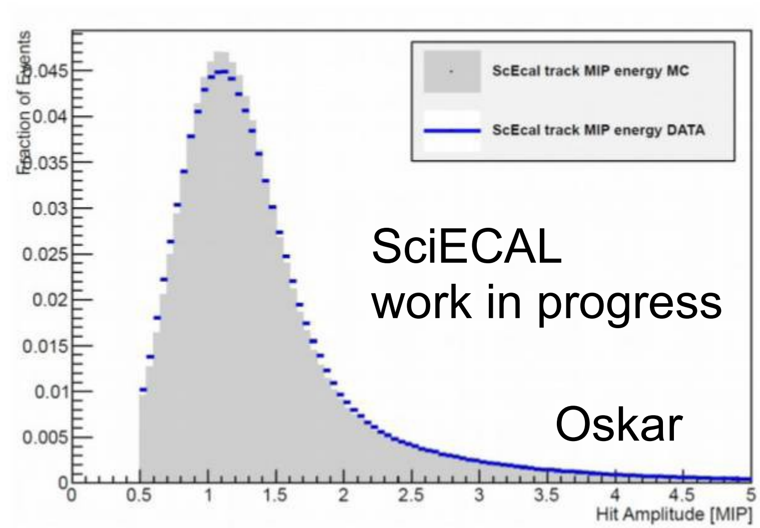


Side view

Comparison with Simulation: ECAL

- SiECAL:
  - energy linearity and resolution well described
  - shower shapes well described
- SciECAL:
  - linearity and resolution well described
  - with new digitisation (SiPM effects), also hit energy spectra and shower shapes look good
- now working on improving the realism in the ILD simulation
  - material thickness
  - fraction of dead area
  - ...

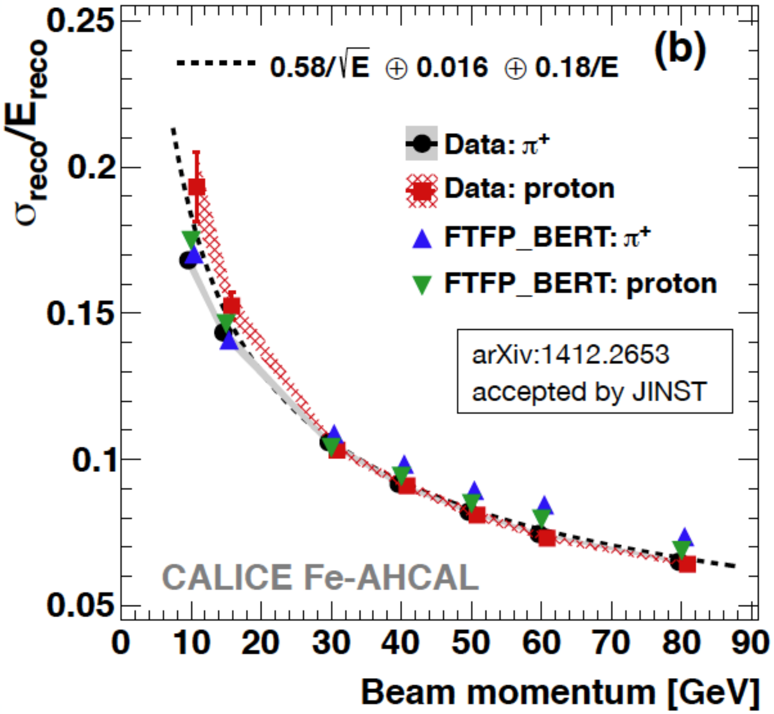


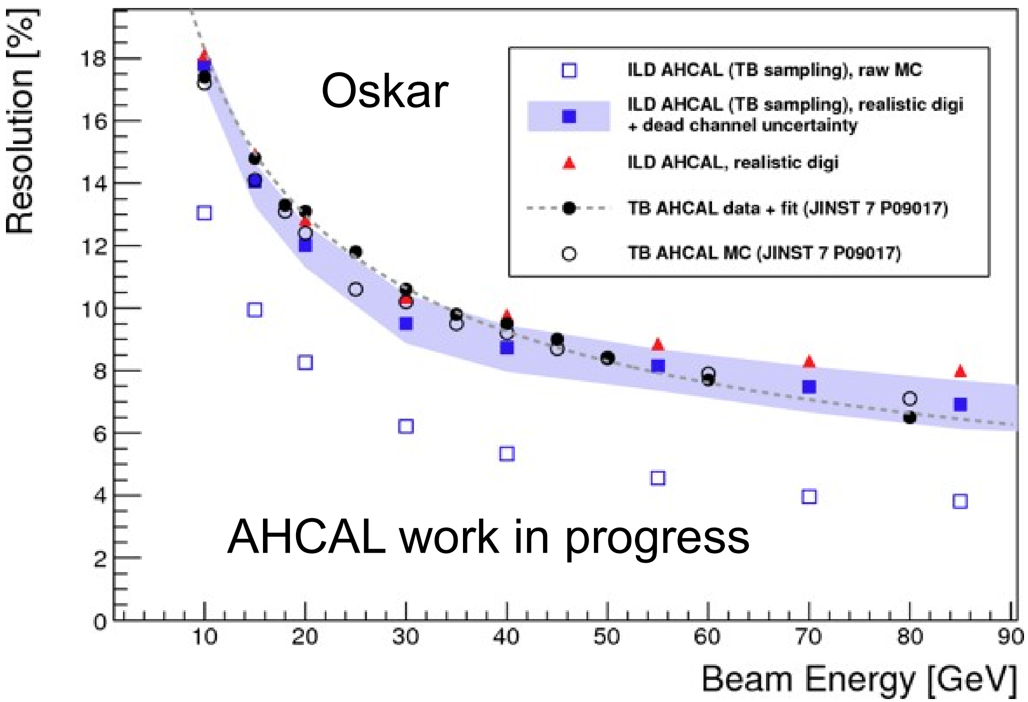


Daniel Jeans
https://agenda.linearcollider.org/event/6557/session/10/contribution/25/material/slides/0.pdf

Comparison to Simulation: AHCAL

- description of linearity, resolution and shower shapes shown in many publications
- studies of hadronic shower models ("physics lists") in GEANT
- recently: show agreement of physics prototype data, prototype simulation and ILD simulation





Frank Simon
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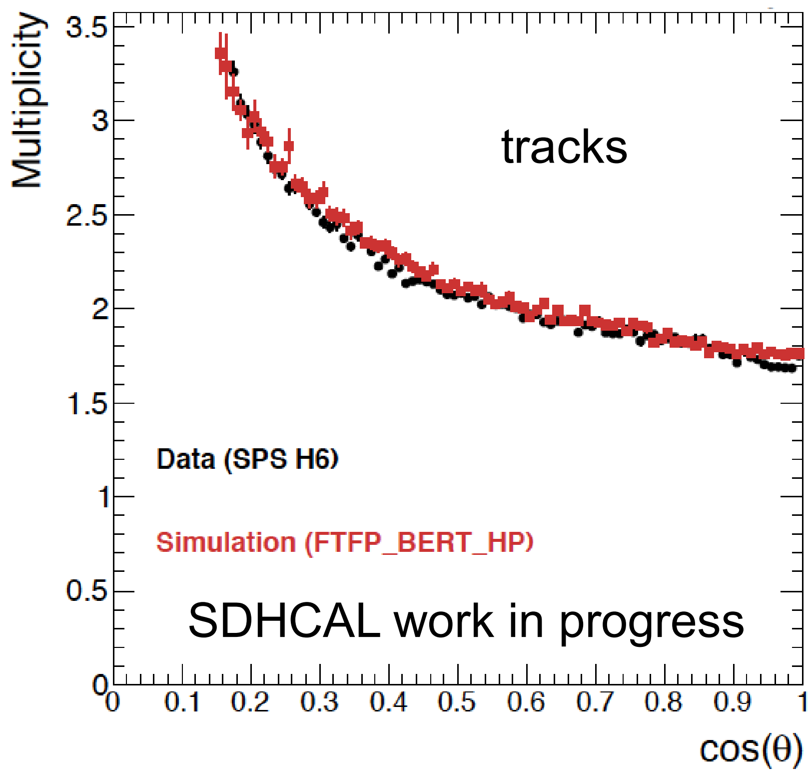
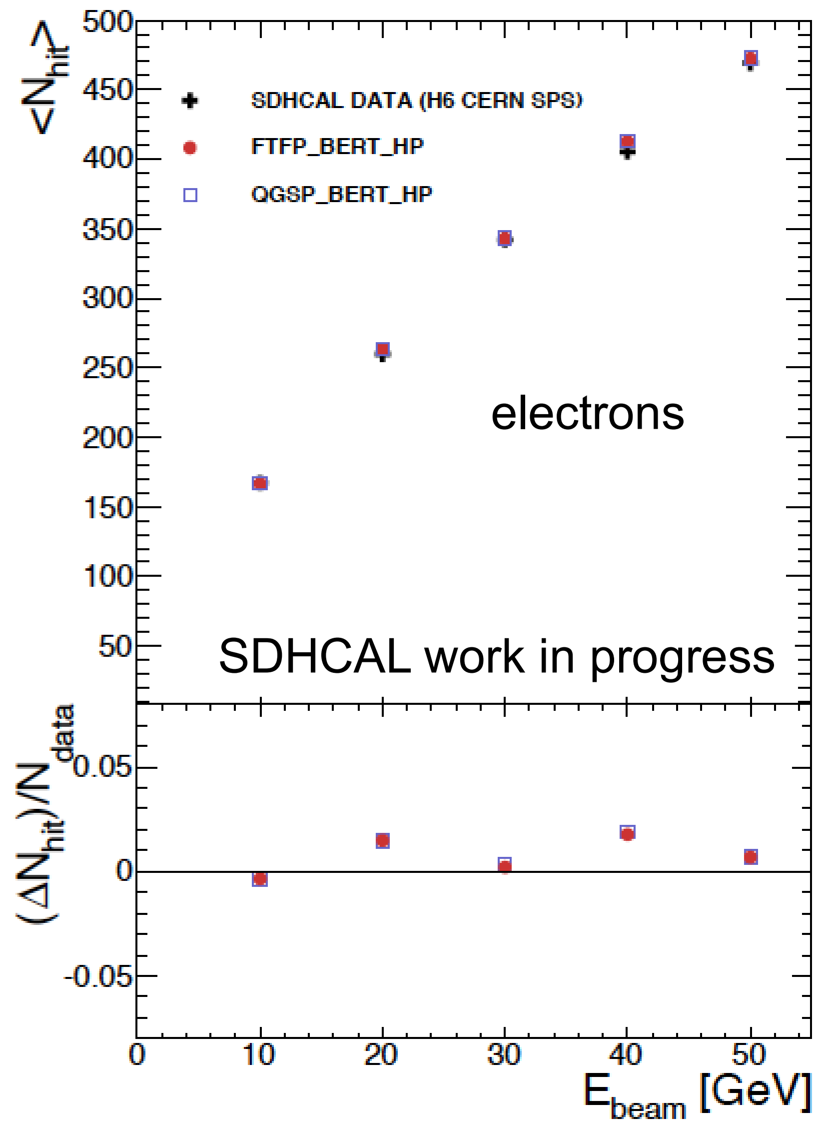
Comparison to Simulation: SDHCAL

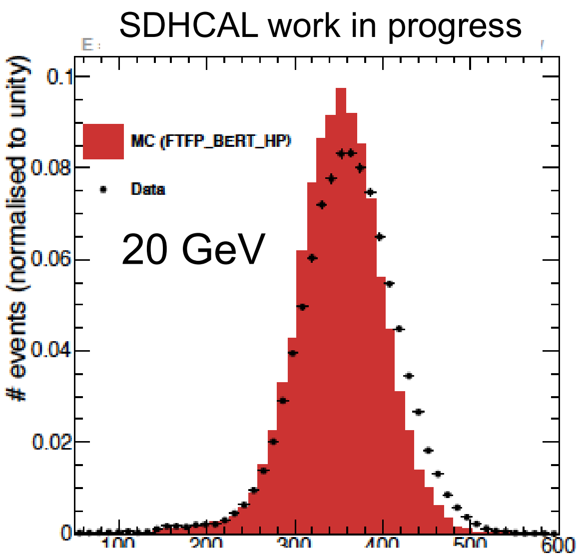


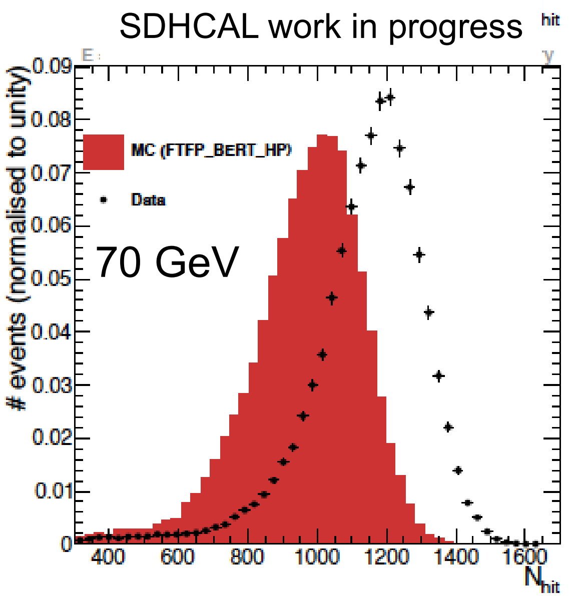


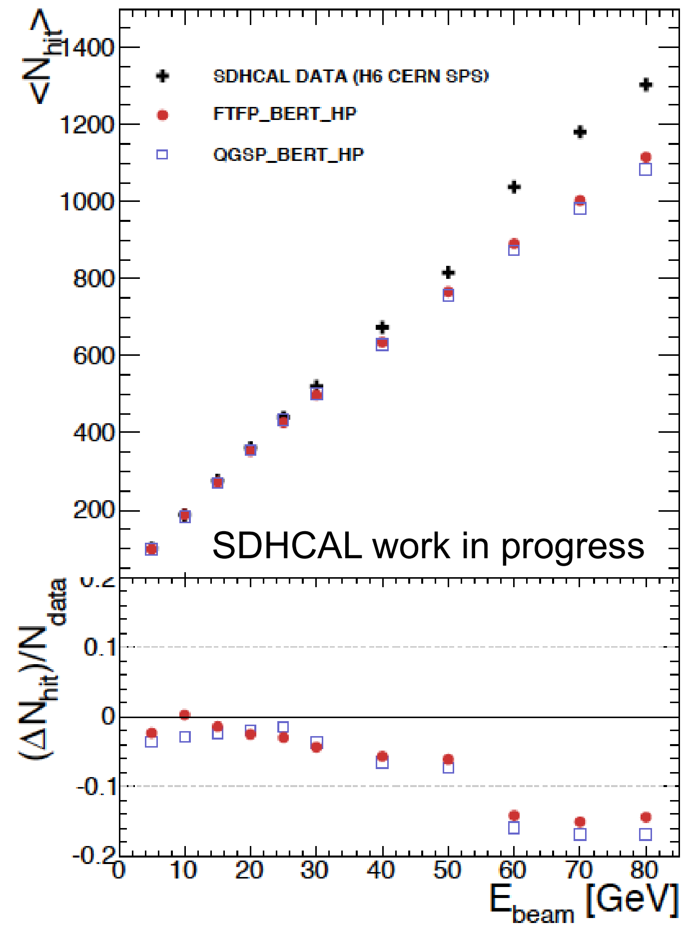
- digitisation (avalanche in gas, charge splitting) important to describe data
- digitisation parameters tuned to muon and electron data

Arnaud Steen, Imad Laktineh
https://agenda.linearcollider.org/event/6557/session/0/contribution/184/material/slides/0.pdf

Comparison to Simulation: SDHCAL

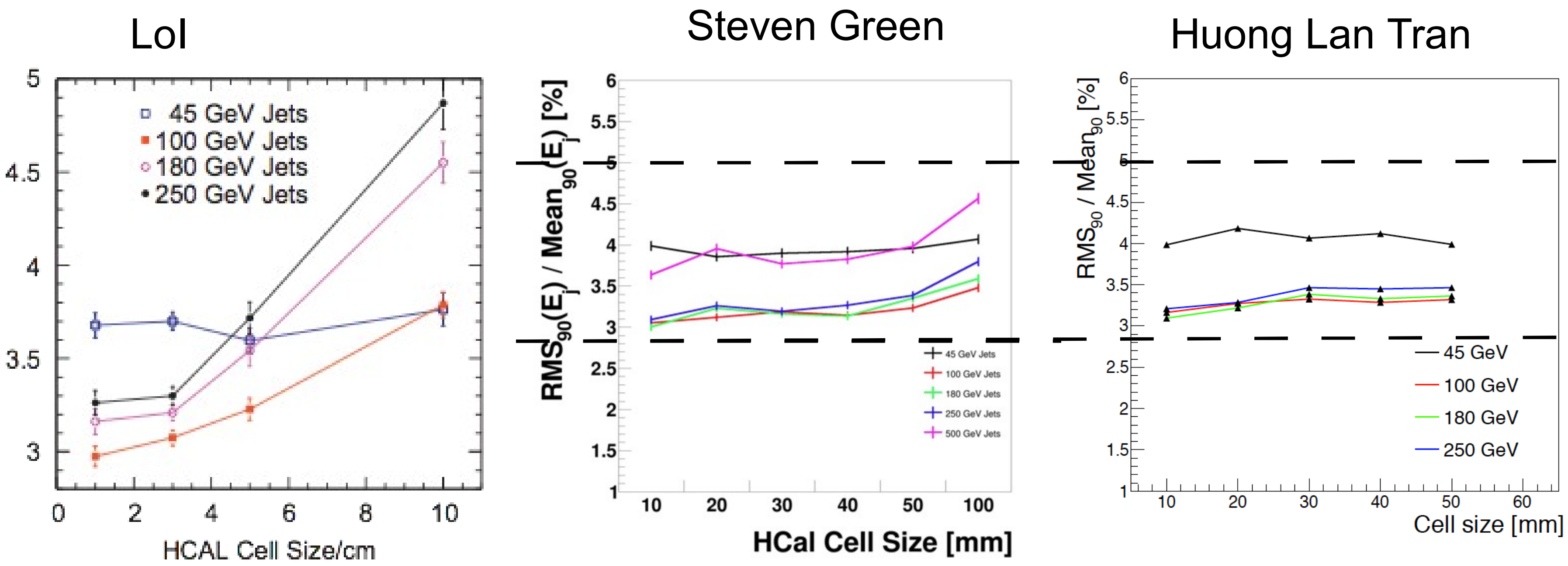






- pion showers described reasonably up to 50 GeV
- for higher energies: digitisation or shower modelling?

Detector Optimisation



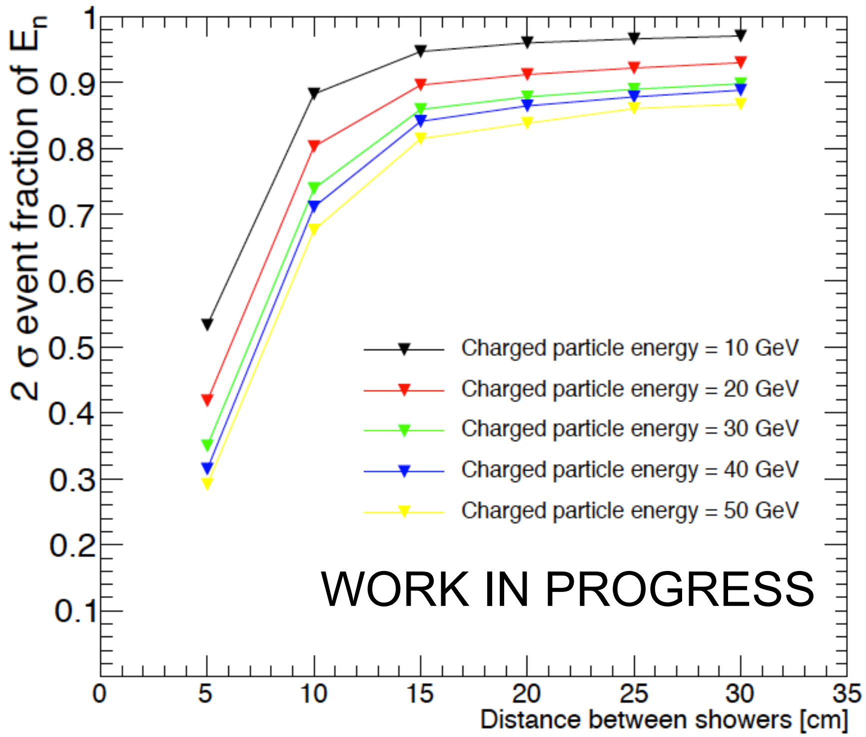
- in LoI studies, jet energy resolution showed strong dependence on HCAL cell size (as expected from confusion term in resolution)
  → AHCAL chose 3*3 cm² tile size
- recent studies show much reduced dependence on HCAL cell size (Steven, Lan)
- many changes: detector model, Pandora version, …
- need to understand the origin, could potentially have huge implications on detector design

Particle Flow Algorithm

(nearly) all analyses including detector optimisation studies are based on PandoraPFAnew

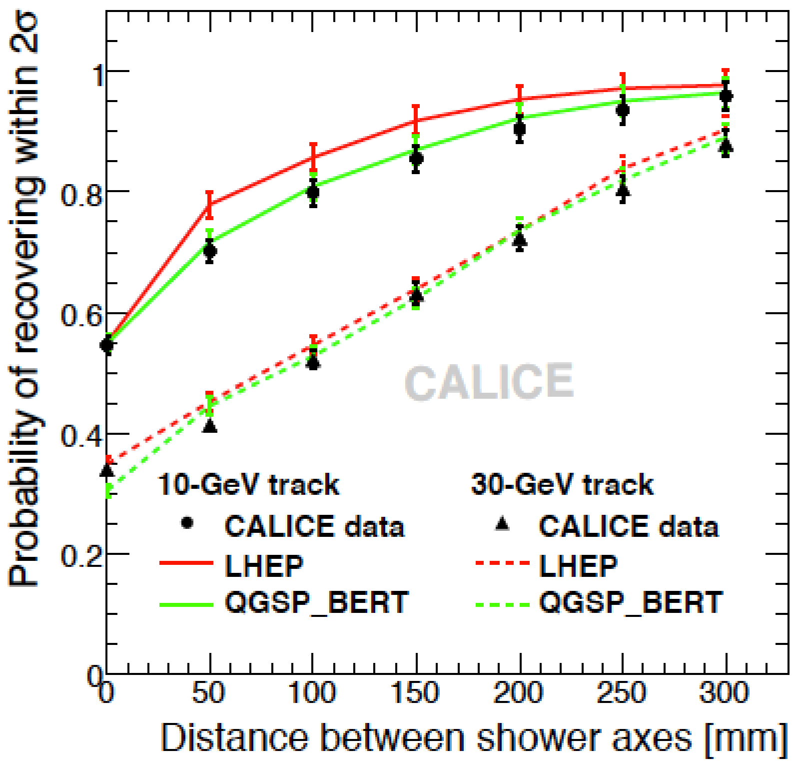
- PandoraPFAnew is very complex software
  - idea: find particle flow objects based on geometry and energy/momentum of clusters and tracks
  - many algorithms, many parameters that can be tuned
  - current version mainly tuned for AHCAL, but parameters largely insensitive to detector design variations
  - constantly evolving and being improved
  - software architecture:
    - PandoraSDK: software framework providing APIs
    - Pandora Client App (MarlinPandora): everything detector-specific
    - Pandora Framework: algorithms
- alternative algorithm: Arbor
  - based on geometry, track segments that connect and form a tree
  - particularly suitable for calorimeters with very fine granularity like SDHCAL
  - **new development: new version of Arbor based on PandoraSDK**
  - **similar division into MarlinArbor and ArborContent**
  - **should make it much easier to compare Pandora and Arbor**

ArborPFA on SDHCAL data



- overlay of 10 GeV neutral hadron cluster with charged particle shower in SDHCAL for various energies
- Arbor can separate clusters well for distances above 10-15 cm

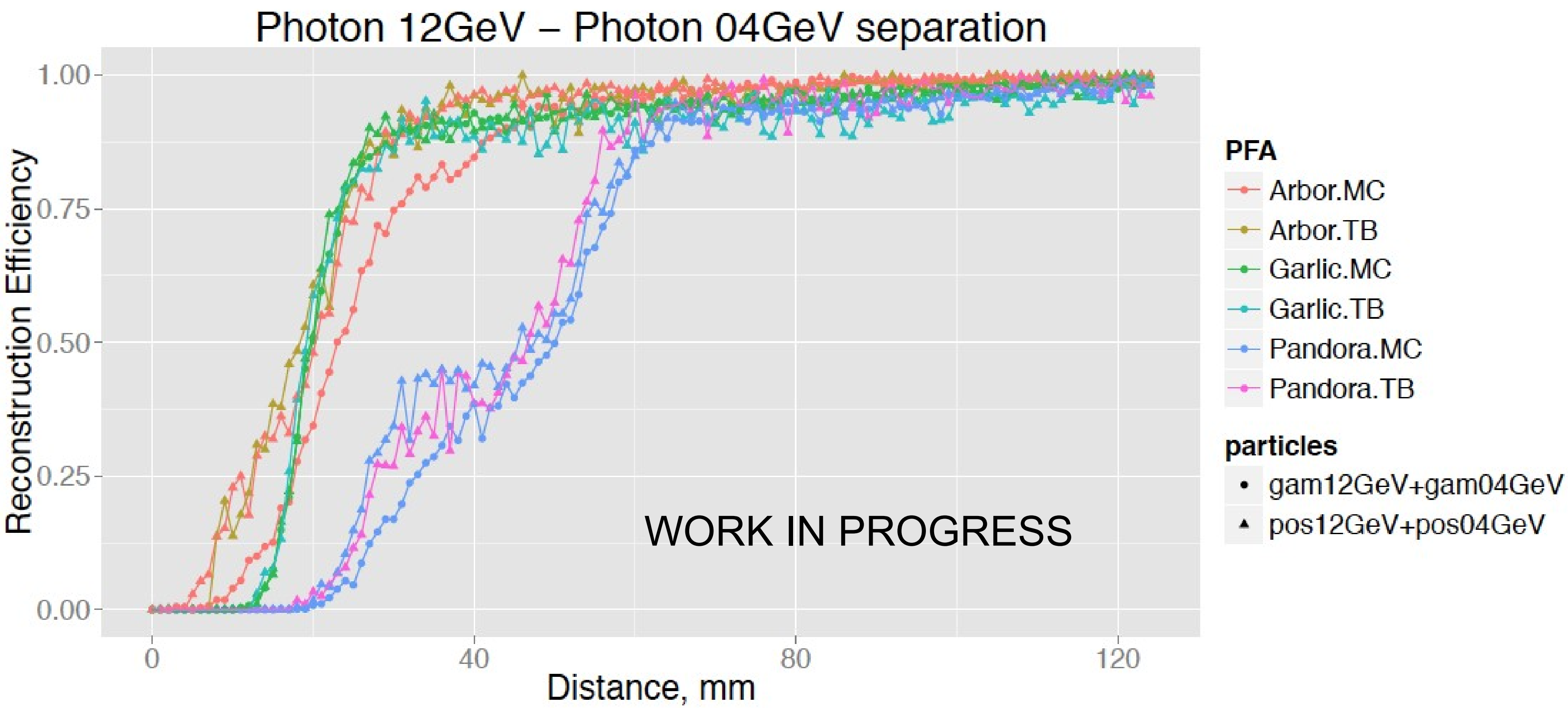
for comparison:
Pandora with AHCAL



Rémi Eté
https://agenda.linearcollider.org/event/6557/session/0/contribution/187/material/slides/0.pdf

Comparison of Pandora, Arbor and Garlic

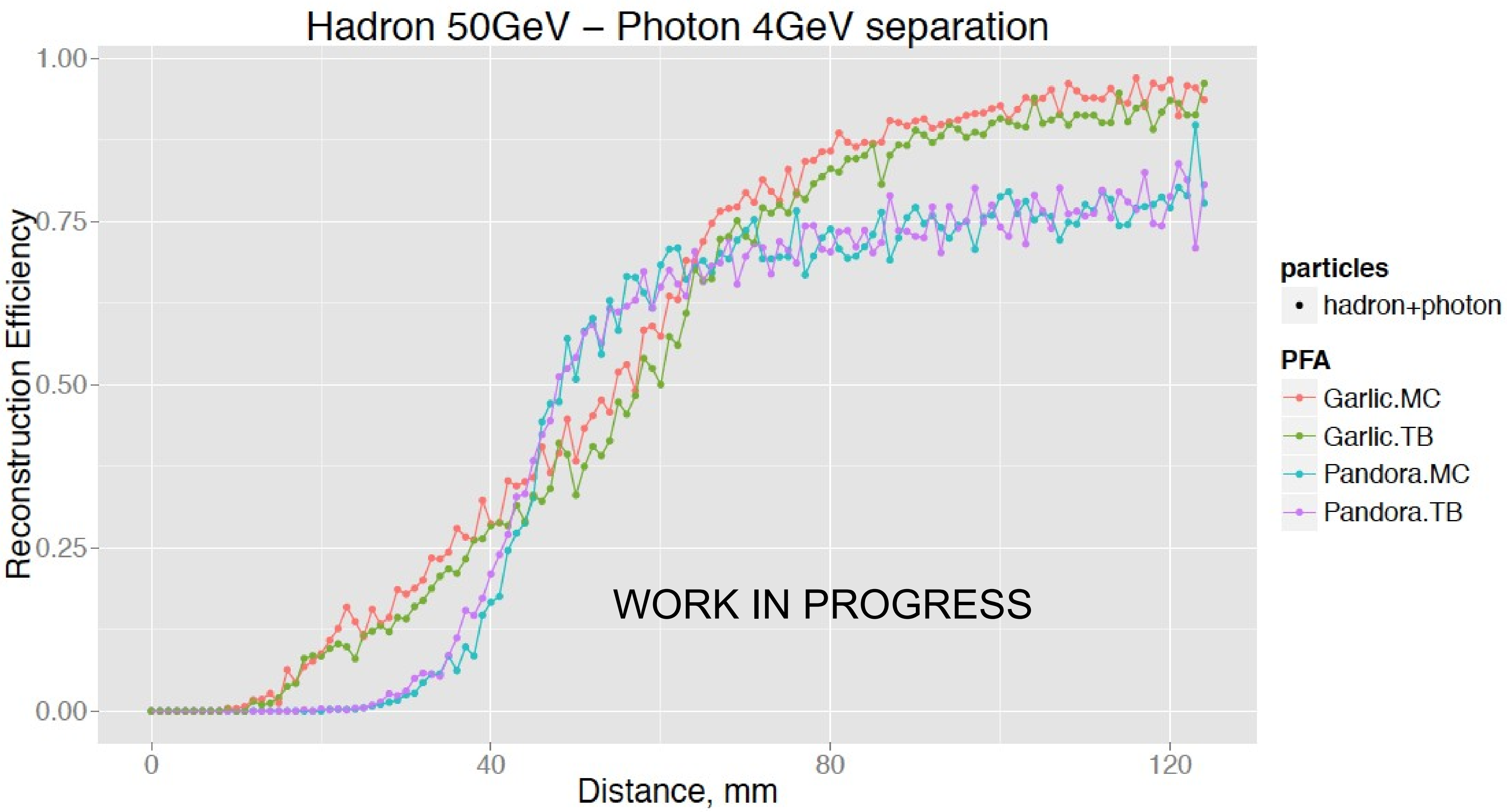
GARLIC: GAmma Reconstruction at a LInear Collider, dedicated algorithm for photon identification in hadronic jets



- SiliconECAL testbeam events (electrons, pions), projected to ILD geometry
- Pandora has a stronger tendency to merge 2 electromagnetic clusters

Kostiantyn Shpak
https://agenda.linearcollider.org/event/6557/session/0/contribution/194/material/slides/0.pdf

Comparison of Pandora, Arbor and Garlic



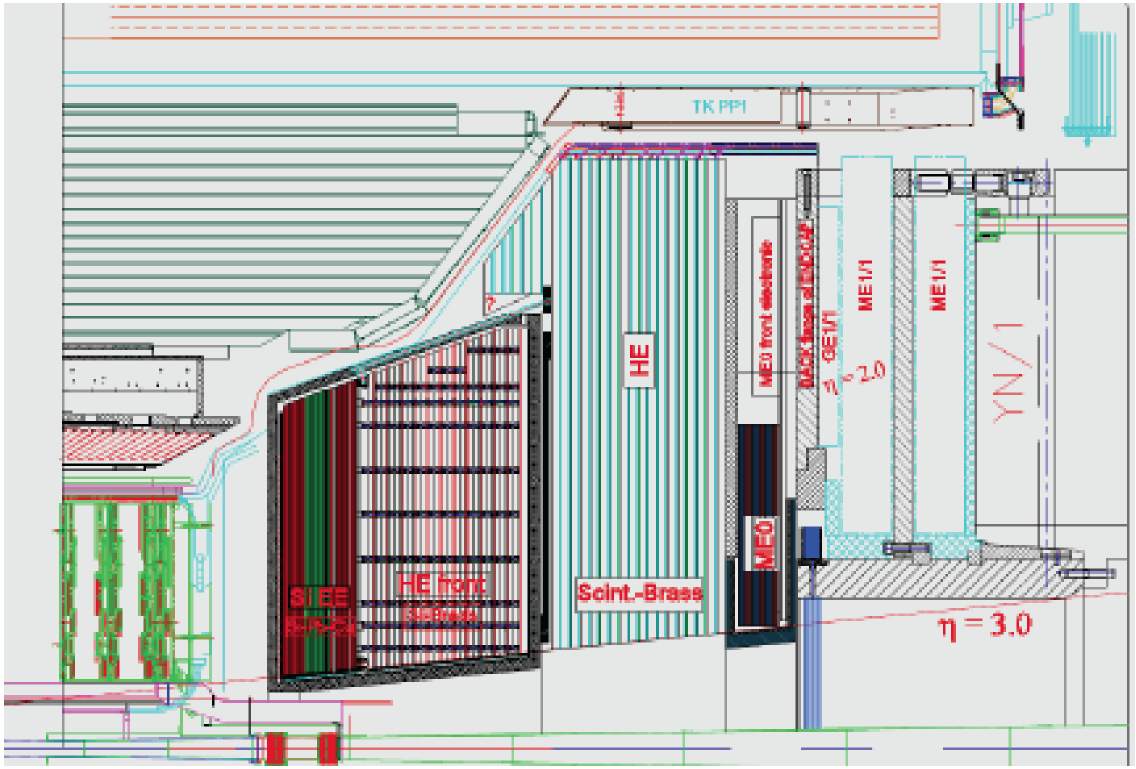
- hadron/photon separation with ECAL information only!
- algorithms seem to have different strengths & weaknesses

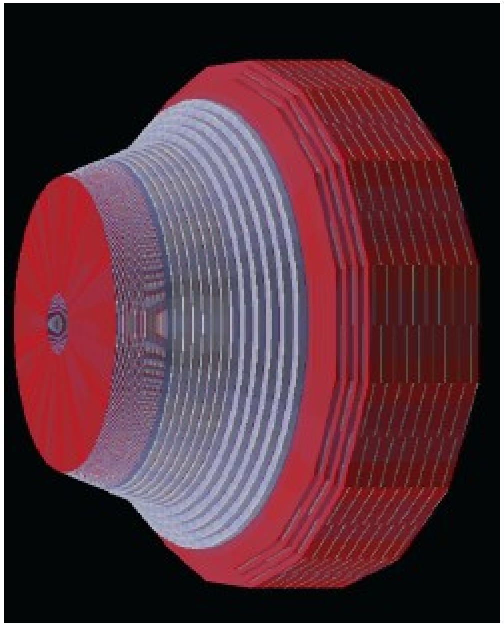
Highly granular calorimeters beyond LC: CMS endcap

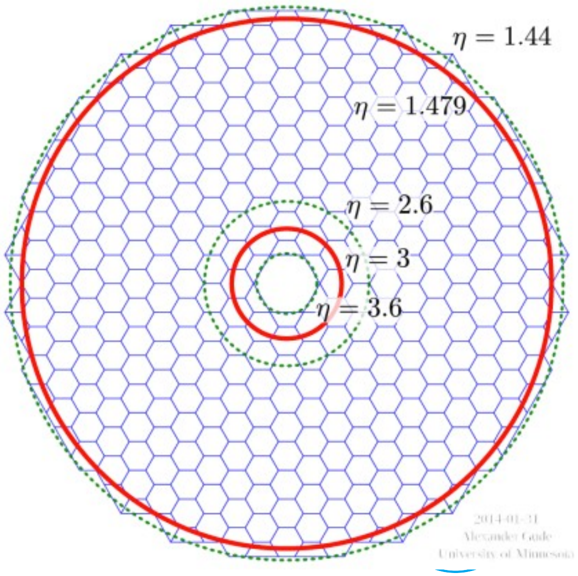
- CMS recently decided to chose High Granularity Calorimeter (HGC) as concept for the upgrade of the calorimeter endcap for HL-LHC (2025)
- **Electromagnetic Calorimeter**
  - 30 layers of lead/copper absorber
  - 25 X0
  - 420 m² silicon pad sensors
  - 3.7 M channels
- **Front Hadronic Calorimeter**
  - 12 layers of brass absorber
  - 4 interaction lengths
  - 250 m² silicon pad sensors
  - 1.4 M channels
- **Backing calorimeter**
  - 10 layers
  - 5 interaction lengths
  - lower radiation level allows use of scintillator or MPGDs

high radiation dose
→ rad. hard silicon
→ keep silicon at -35°C

Highly granular calorimeters beyond LC: CMS endcap



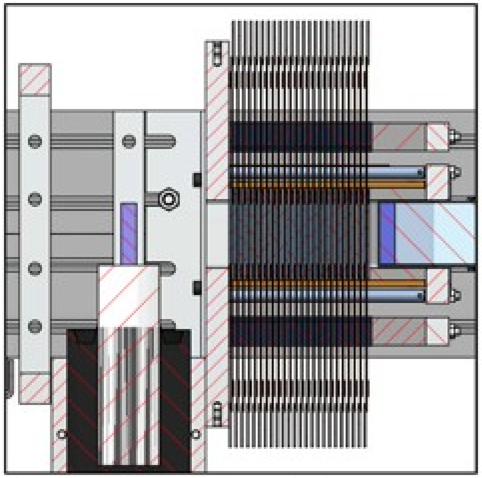


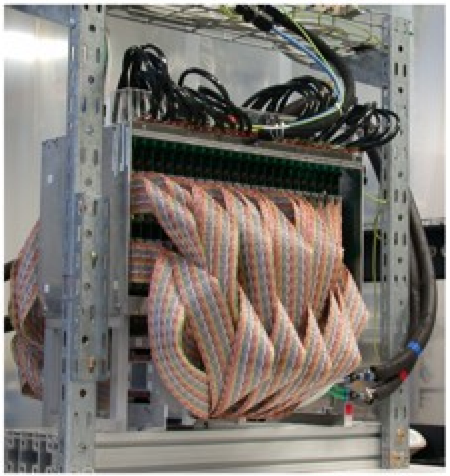


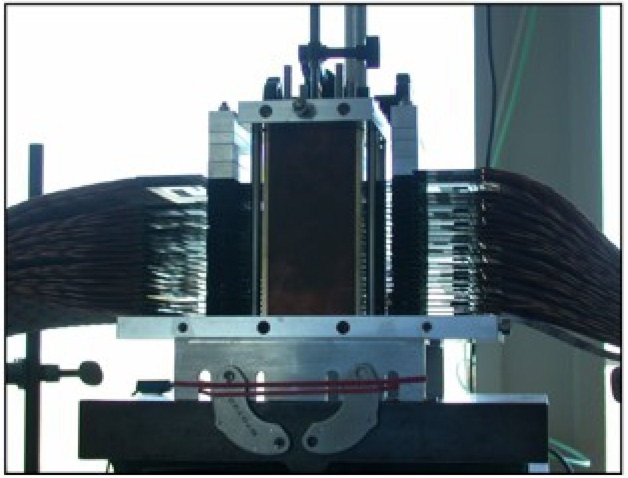
hexagonal sensors

Highly granular calorimeters beyond LC: ALICE FOCAL

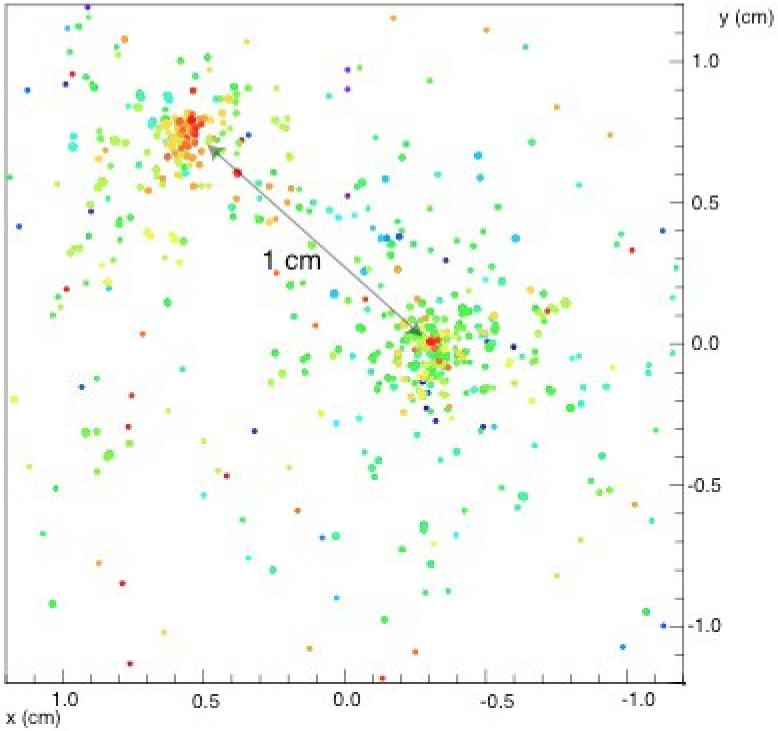
- option for upgrade of ALICE forward region







- digital ECAL (MIMOSA)
- 39 M pixels, 30 µm pitch
- cosmics & beam test data



T. Peitzmann
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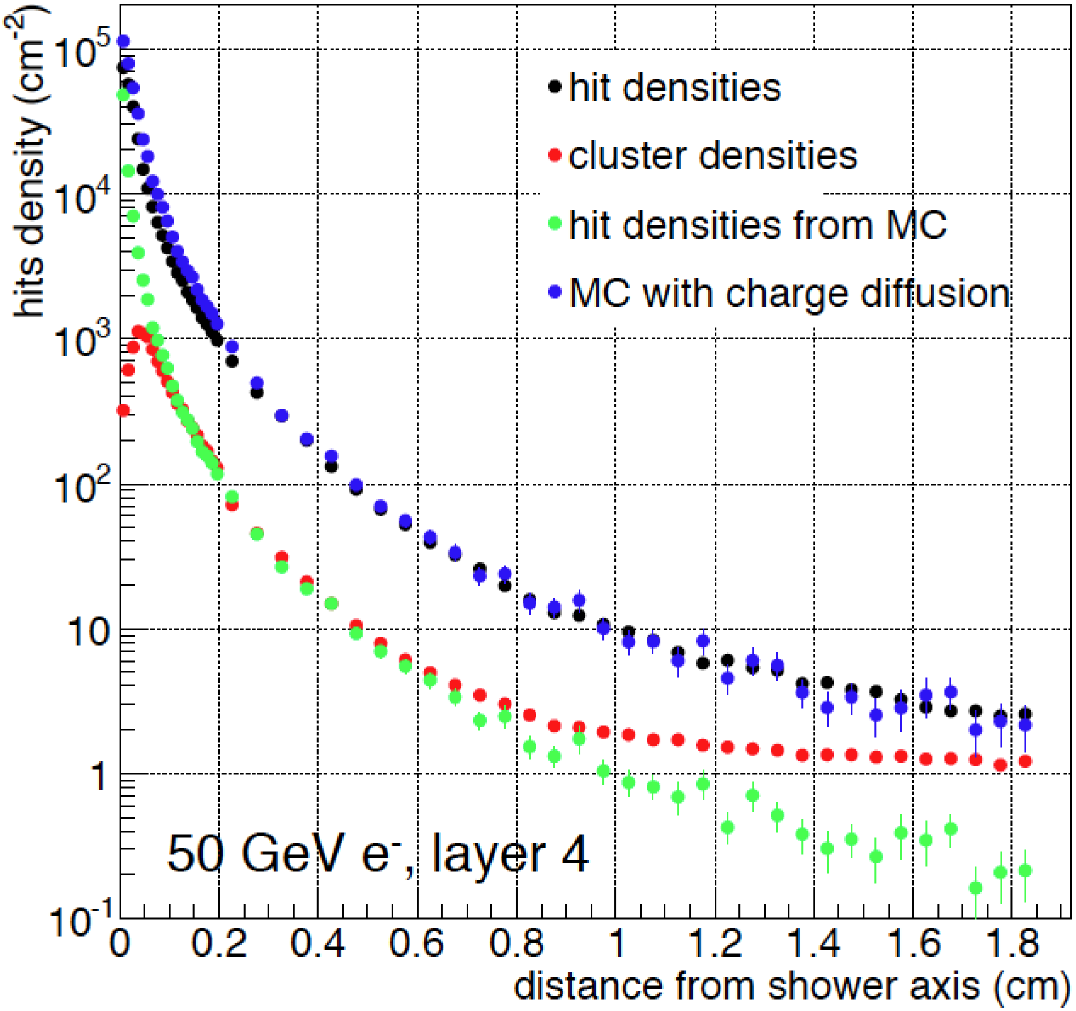
Highly granular calorimeters beyond LC: ALICE FOCAL



- strong variations from sensor to sensor
- comparison to simulation
  - hit densities from pure GEANT simulation (no charge diffusion) not sufficient
  - simple Gaussian diffusion yields good description

Summary

- first generation prototypes: important to establish performance and validate simulation
- second generation prototypes ready to go if funded
- simulation
  - proper digitisation is important to describe data
  - make sure that knowledge is transported from testbeam prototypes to ILD simulation
- optimisation & particle flow algorithms
  - both important to get the optimum detector, interplay might be relevant!
  - hopefully comparison with other PFAs than Pandora easier in the future
- high granularity calorimetry becomes interesting for other experiments, i.e. LHC detector upgrades