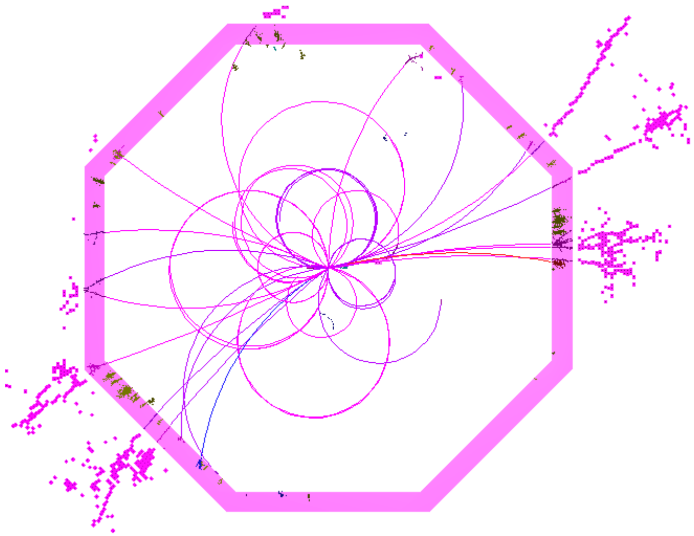

ECAL Simulation Studies – Overview

Wednesday 30th January 2013

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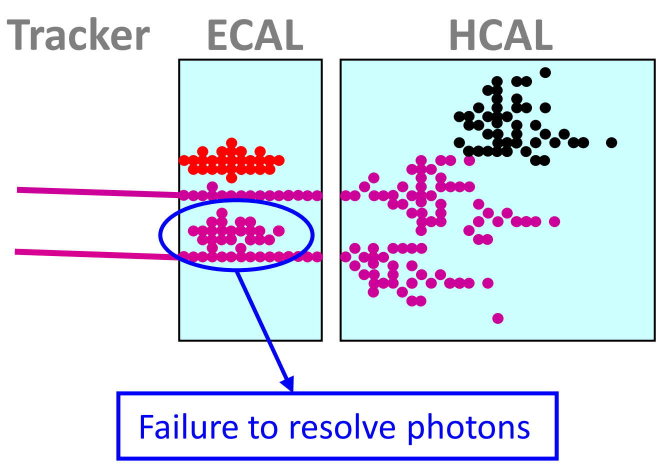
University of Cambridge

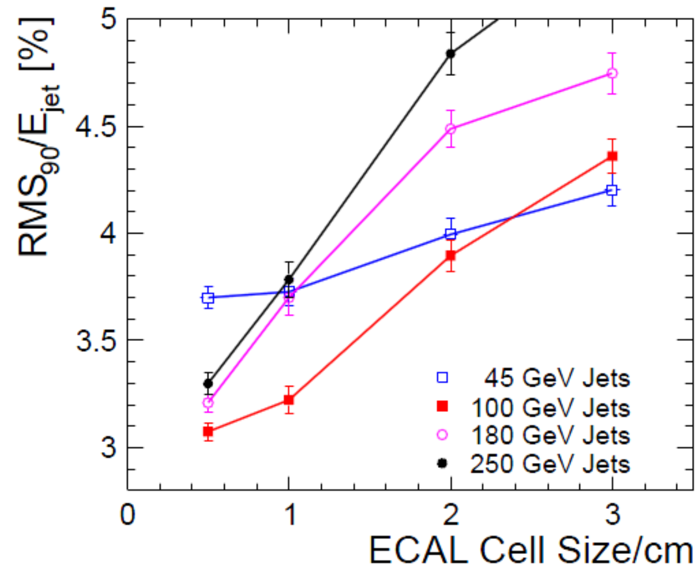
Previous ECAL Studies

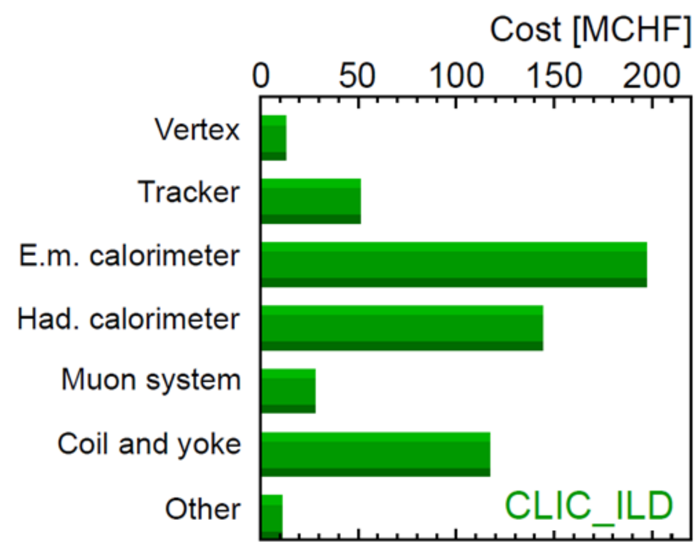
- Role of ECAL is to measure energies of individual photons and early parts of hadronic showers.

- Photons may be close together, or may overlap with charged hadrons. Require fine segmentation to allow separation.

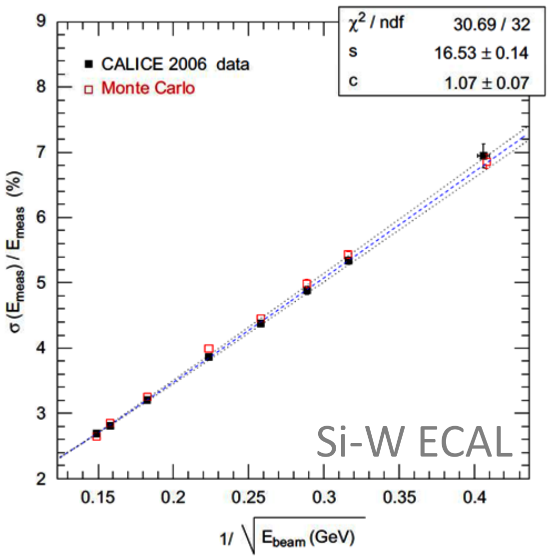


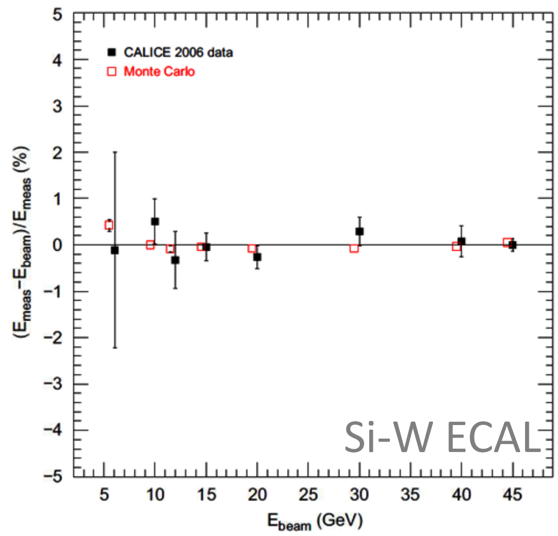
- **ECAL in CLIC_ILD_CDR, sampling calorimeter, 23 X_0, $1\lambda_I$**
    - **20 x 2.1mm + 9 x 4.2mm W, with 29 x 0.5mm Si**
    - **Silicon cells: 5.1 x 5.1mm^2**





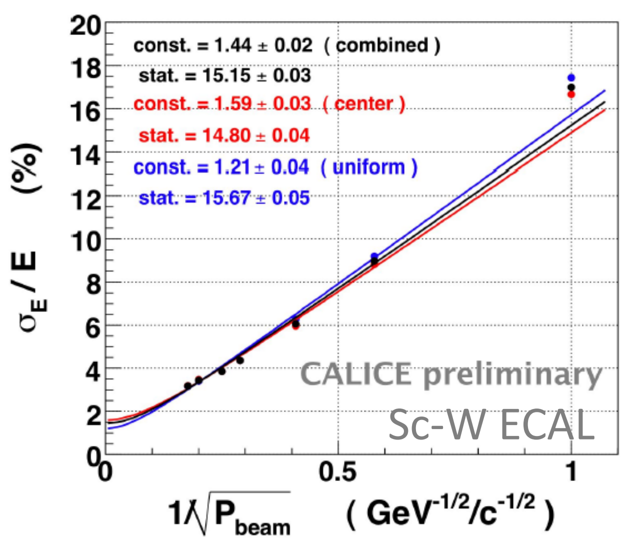
Previous ECAL Studies

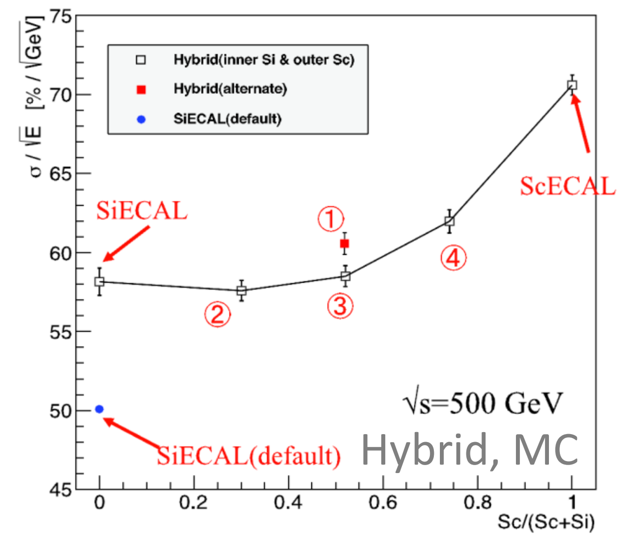




- Prototype Si-W ECAL installed and tested at CERN during 2006.
- 6,480 Si pads, dimensions 1.0x1.0cm^2 and thickness 0.5mm.
- 30 W layers, thickness: 10x1.4mm, 20x2.8mm. 24X_0 at normal incidence.
- Setup simulated with Mokka.

- ScECAL prototype beam-test at FNAL in 2008, e, μ, π beams.
- 30 pairs of Sc (3mm) and W absorber (3.5mm) layers.
- Scintillator strips of alternating alignment: 4.5x1.0cm^2.





New “Cost-Effective ECAL” Studies

- Important aim for new ECAL studies is to ensure that different detector models are examined in a well-defined manner. Want to assess intrinsic physics performance offered by each model.

- Ultimately interested in the optimal jet energy resolution achievable using each detector model, but need to separate software performance issues from underlying “detector ability”:
  - Must isolate effects of calibration changes,
  - May need to re-optimise particle flow algorithms and/or reduce their dependence on geometry,
  - Need to develop standard procedures for measuring ECAL performance.

- Once this has been completed, can start to vary ECAL parameters and observe resulting changes in performance.

- Reasonably large number of parameters to investigate: Si/Sc ratio, Si/Sc cell sizes and thicknesses, absorber thicknesses, number of layers...

- Require studies to motivate (initial) values for these parameters.

Simulation Tools

- **Simulation tools currently available:**
  - **Mokka,**
  - **SLIC**

- Mokka has hybrid ECAL driver available, SECAL04. Angela will discuss status of this driver today. Will most-likely want to use this driver for simulation studies.

- Therefore need to understand this driver and to add any configuration options required for these studies, aiming for full layer-by-layer configuration of ECAL.

- However, it is apparently very quick and easy to generate simple calorimeter stack models using SLIC; may prove useful for shower-shape studies and calibration work.

- Thoughts about digitisation?

Characterisation Tools

- The most important characterisation approach is to obtain the jet energy resolution. Off-shell Z bosons are produced at rest at different centre-of-mass energies.
- These decay into light quarks and typically produce two back-to-back mono-energetic jets. No jet-finding required to assess jet energy resolution, which can be obtained from total event energy.
- Do we need any other characterisation tools? Yes, unless we are sure that the final results are not biased by particle flow reconstruction algorithms optimised for the SiW ECAL design.

Reduced bias from software treatment ↑

Single particle studies, measuring intrinsic calorimetric resolution
No processing of events required

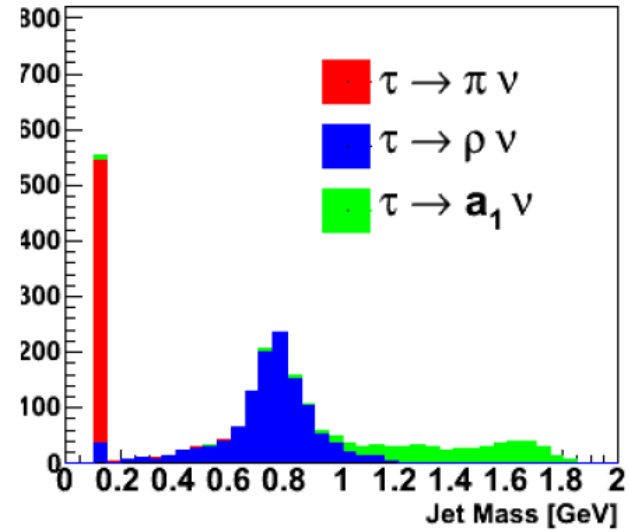
Simple particle reconstruction, involving basic pattern-recognition
E.g. π^0 mass reconstruction, separation of τ decay modes, etc.

Full particle flow reconstruction of jet energies and masses

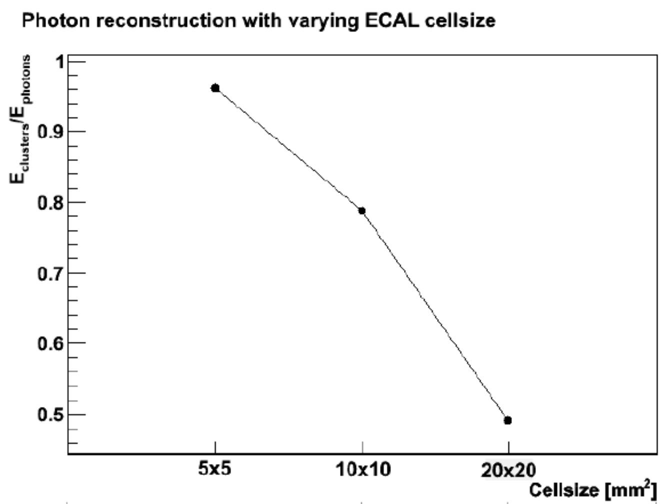
↓ **Better indication of physics performance**

Assessment using basic PFA procedures could include:

- Investigation of mass reconstruction performance for single π^0 and single ρ samples. Investigates intrinsic ability to resolve photon pairs and to separate nearby photon and charged pion.
- Investigation of ability to separate decay modes $\tau\rightarrow\nu\pi$, $\tau\rightarrow\nu\rho$ and $\tau\rightarrow\nu a_1$. For ILD LoI, this was performed using HZ events ($H\rightarrow\tau\tau$), producing invariant mass and selection matrix shown.



If use full PFA, can examine constituents of reconstructed jets: simulated vs. reconstructed photon energy; photon energy merged with hadrons, etc.

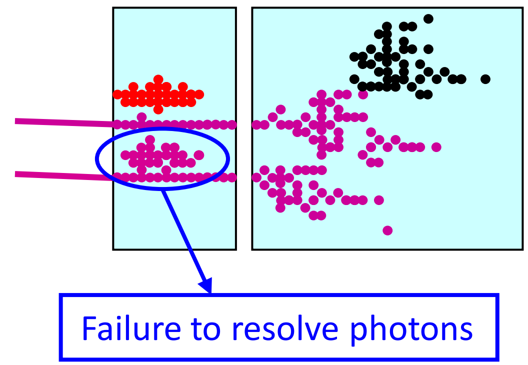


	$5 \times 5\,\mathrm{mm}^2$		
	π_{sim}	ρ_{sim}	$a1_{\mathrm{sim}}$
π_{rec}	98.8	2.8	1.9
ρ_{rec}	1.2	96.5	9.2
$a1_{\mathrm{rec}}$	0	0.7	88.9

Volunteers required!

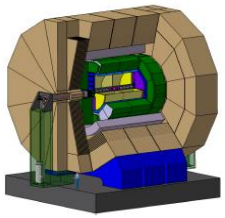
Impact on PFA

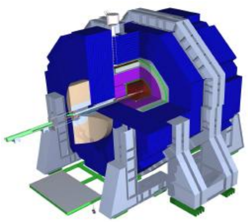
- Pandora framework (detector-independent) provides "complicated" operations for algorithms, which perform the reconstruction.
- Most algorithms work with "hits" (defined positions/volumes), rather then referring to detector; should reduce impact of ECAL changes.
- Hits can be assigned to pseudolayers, which mirror detector structure. Algorithms may work with reference to e.g. layers spanned by clusters.



Isolate detector and software details, creating self-describing hits, tracks, etc.	Run registered algorithms/tools and perform book-keeping	Access Pandora objects and carry out reconstruction
Pandora Client Apps	**Pandora Framework**	**Pandora Algorithms**
	Algorithm Manager	Clustering
	CaloHit Manager	Track-cluster association
	Cluster Manager, etc.	Fragment Removal, etc.

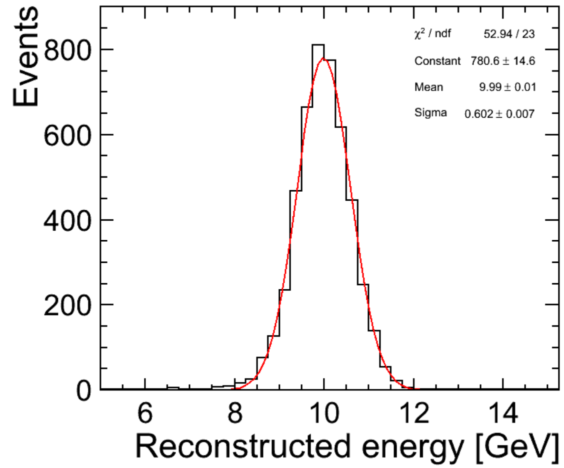
API ⟷ API

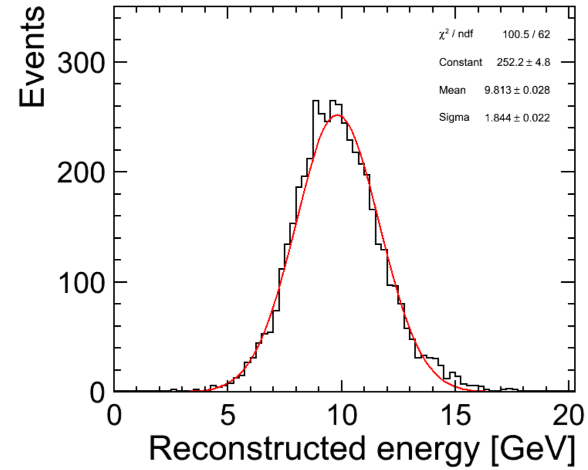

MarlinPandora


SlicPandora

Calibration for PFA

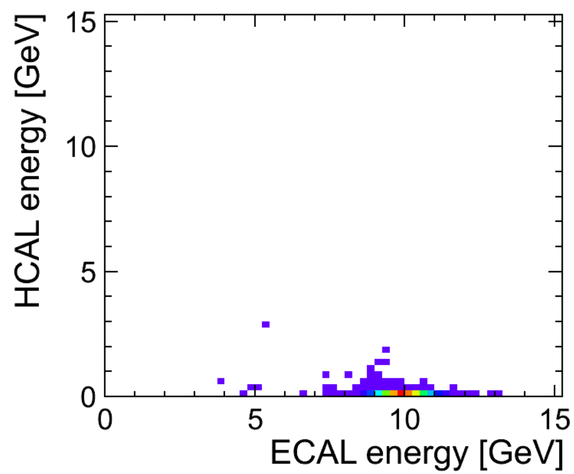
- Following any change to detector or reconstruction software, vital to update PFA calibration.
- Up to now, no formal procedure for performing calibration for ILD Pandora client app (MarlinPandora).
- Simply examined single-particle energy distributions, typically for 10GeV particles, to set constants:
  - **ECAL_To_EM_GeV**
  - **ECAL_To_HAD_GeV**
  - **HCAL_To_EM_GeV**
  - **HCAL_To_HAD_GeV**
  - **MUON_To_GeV**
- In today's session will discuss improved approaches; may require Pandora client app changes.

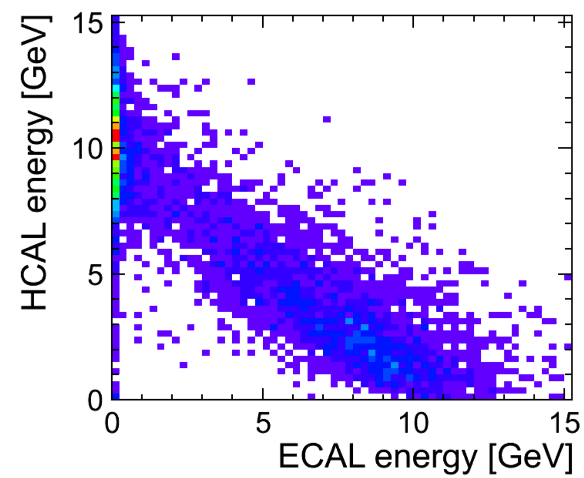




Photons

K0L

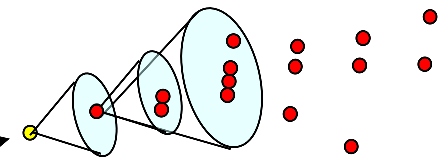


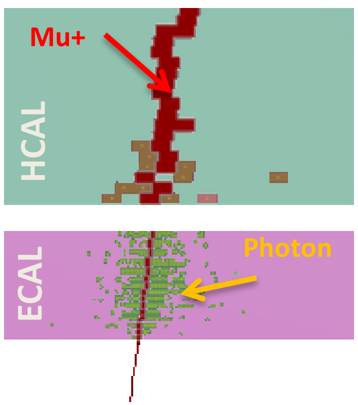


PFA cannot remain a “Black-Box”

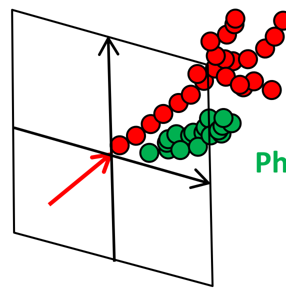
- Hardware determines granularity of the building-blocks available to particle flow reconstruction. Algorithms then simply tell computer how to process these building blocks. A change in granularity or in the energy deposition profiles may harm physics performance.

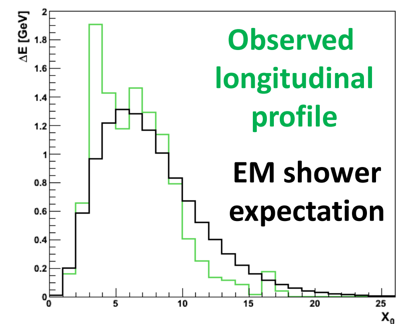
1. Initial clustering: do EM showers now tend to form single clusters; are they split into multiple clusters; are they subsumed into charged particle clusters?





2. Are algorithms still configured correctly to recover EM showers from charged particle clusters?





3. Are algorithms still able to identify the correct neutral ECAL clusters as EM showers?

- Serious effort made to ensure algorithms are reasonably robust against sensible variations in detector. E.g. Algorithms place cuts on number of X_0, rather than absolute distances.
- However, no destruction testing. Need to look for problems whenever we change detector. Expect to be robust against variations in active material tile sizes, provided tiles remain square-faced.

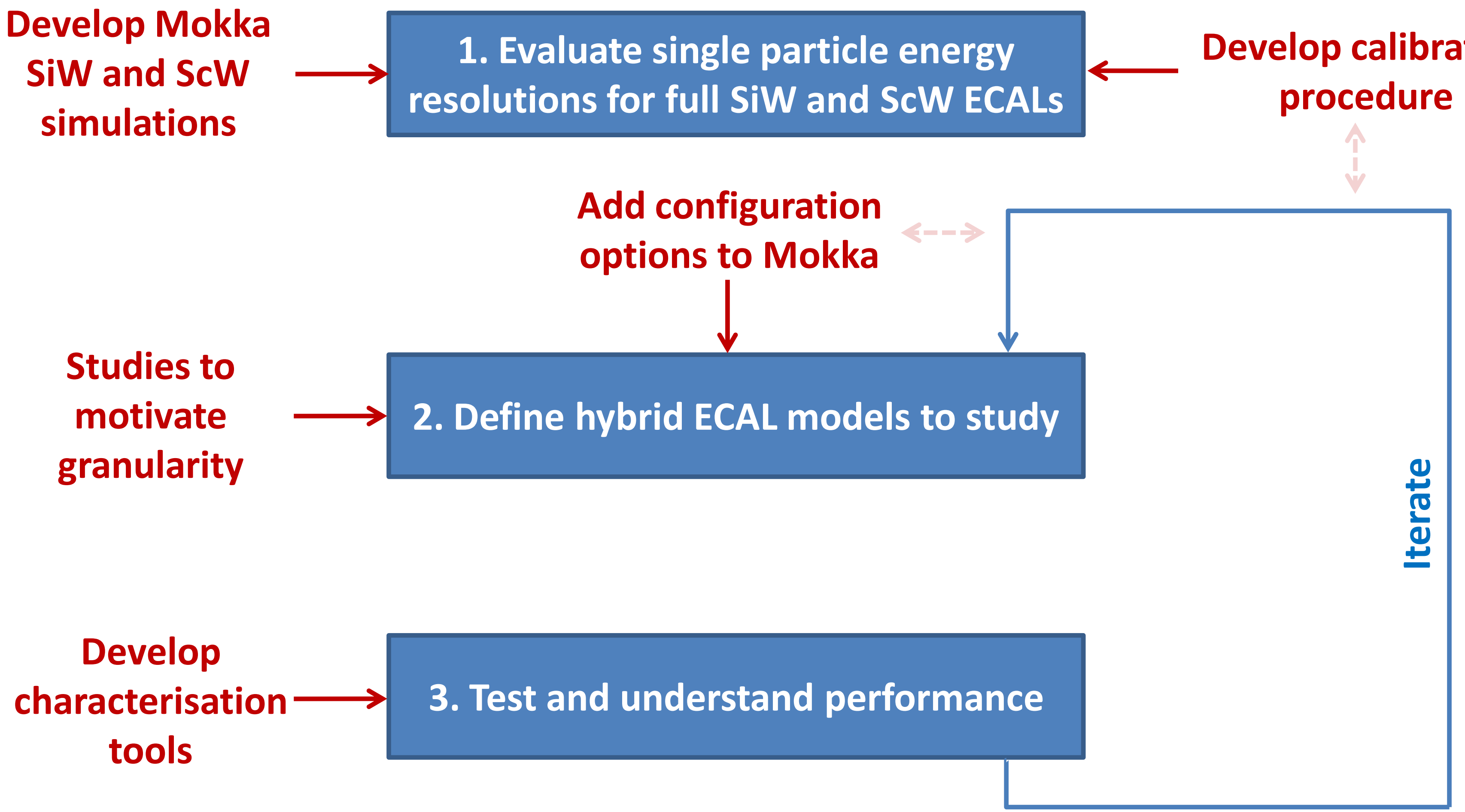
Current Status

- **Current activities:**
  - Review of SECAL04 Mokka driver, with view to adding configuration parameters to allow layer-by-layer specification of Si/Sc active material, cell sizes, absorber and active layer thicknesses.
  - ECAL stack simulations in SLIC, starting with full-Si and full-Sc models. Development of fixed calibration procedure will be a priority using these models.

- **Would like to start in near future:**
  - Study of EM shower widths as a function of depth in the calorimeter. Could work at GEANT4 hit level, or could use fine-grained ECAL stack simulation.
  - First single particle energy resolution studies.
  - First performance characterisation, evaluation of ability to separate tau decay types.

- **Would be "nice to have":**
  - Motivate variation of absorber thicknesses as a function of calorimeter depth. Current 2.1/4.2mm W arrangement motivated by examination of photon energies in physics events.
  - Performance characterisation, via π^0 and ρ mass reconstruction, maybe without using Pandora?

- **Long term goal, probably most interested in how quickly (in depth) can move from SiW to ScW...**



Summary

- **Important to ensure that software-related issues do not cloud results from these studies. PFA no longer a "black box", calibration and characterisation tools must be standardised.**

- **Need to ensure measured approach to developing ECAL models: avoid jumping to conclusions due to existing/past work in this area.**

- **Need communication with hardware studies people to ensure two groups don't diverge. Must always keep cost in mind, e.g. will need to assess cost-impact of changes to ECAL outer radius.**

- **Decisions to make, volunteers to find, discussions to have during this week. During next month, need to make transition from initial planning to actually starting studies.**

BACKUP

First ECAL Models

In absence of results from relevant studies, would agree with suggestion of following models (with ongoing simulation development work for any orthogonal ideas):

1. Si-only ECAL, ensure can repeat, or better, expected performance using new tools.

2. Sc-only, in default configuration:
   20 x 2.1mm + 9 x 4.2mm W, with 29 x 2mm scintillator
   Required for determination of calibration constants and good for comparison with full SiW ECAL

3. Hybrid ECAL, start with half-Si-half-scintillator:
   15 x 2.1mm W, with 0.5mm Si + 14 x 3.2mm W, with 2mm scintillator, OR
   15 x 2.5mm W, with 0.5mm Si + 14 x 3.0mm W, with 2mm scintillator

Use new simulation tools and characterisation tools to assess performance obtained with these options. Begin to understand behaviour of particle flow reconstruction and progress from there...

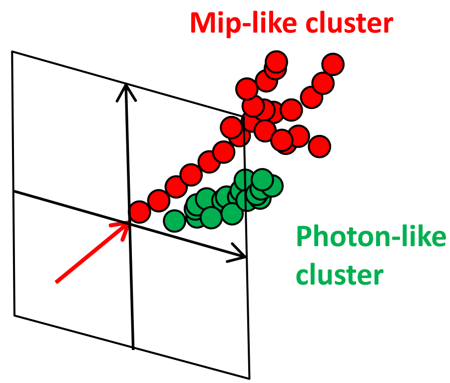
Should naturally lead to variation of number of layers, thicknesses of absorber material and sensitive material, variation of tile sizes, etc.

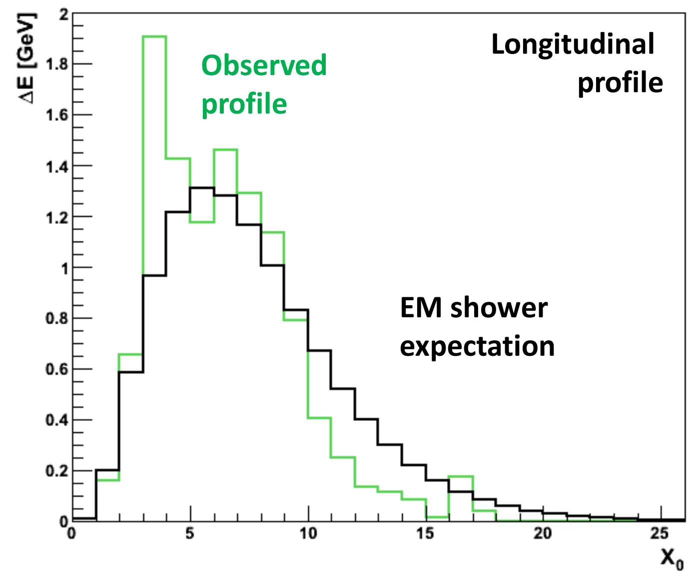
PFA: EM Shower Id

- **One aspect of particle flow reconstruction sensitive to changes in ECAL design is the identification of EM showers.** **Crucial to ensure that single photon/electron samples still identified correctly.**

- Several complementary approaches used. For CLIC CDR, was mainly a single function responsible for controlling use of clusters in algorithms and the final decision to use EM or HAD energy measure.

- Cuts applied to:
  - Cluster mip-fraction
  - Cluster fit direction and RMS
  - Longitudinal energy profile:
    - No. X_0 before shower max
    - No. X_0 before layer_{90}
  - Transverse energy profile:
    - Transverse distance_{90}





- Attempt to make function robust against detector changes by using number of radiation lengths in front of each sampling layer. Should be OK, but will need checking for every detector model.

PFA: Photon Id Algorithm

- New algorithm designed to improve performance AND to concentrate photon reconstruction into a single location.
- Not available for CLIC CDR, but now in use for ILD DBD. Runs very early in the reconstruction, before standard algorithms.
- Examine ECAL hits in transverse plane, looking for peaks and trying to separate peak clusters from nearby tracks.
- Likelihood technique used to finalise photon id; photons then removed from subsequent reconstruction. **Works very well.**
- Recommend we use this; but must retrain if detector changes.