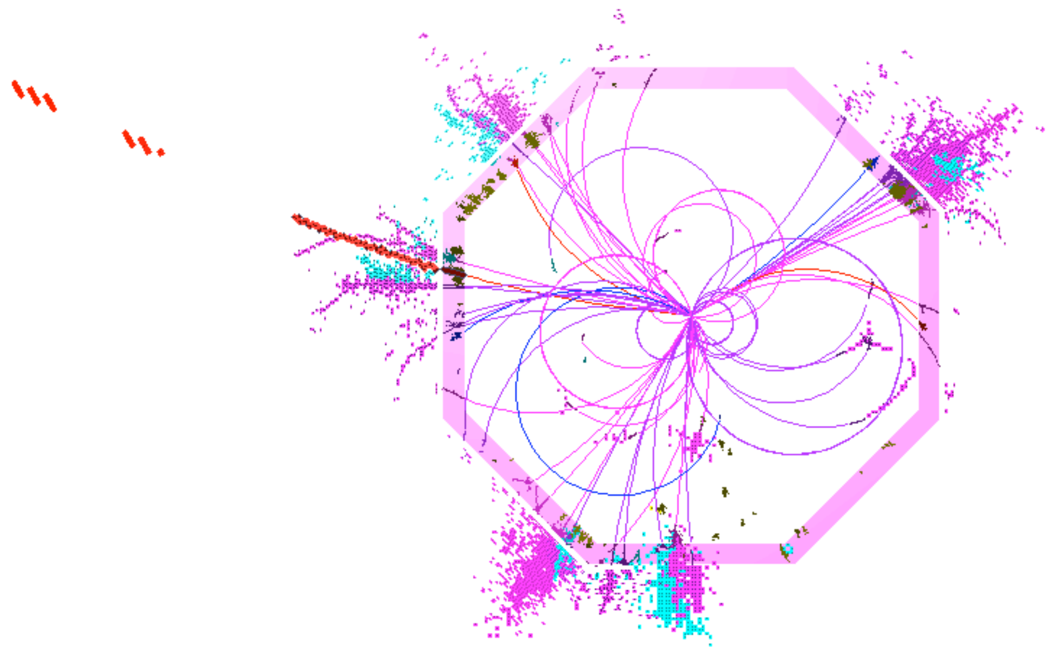
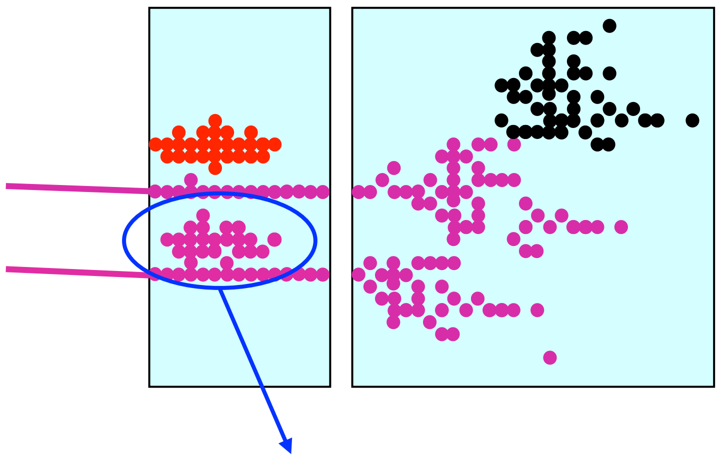


PFA with SiW and ScW ECAL

J.S. Marshall, University of Cambridge
ECFA LC2013, 29th May 2013

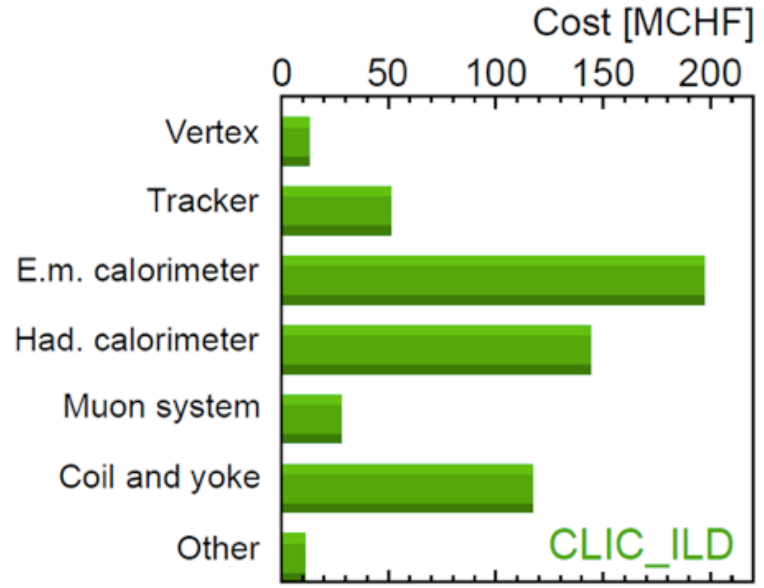
Cost-Effective ECAL Studies

- Role of the ECAL is to measure energies of photons, and the early parts of hadronic showers, and to enable EM shower ID.
- In a particle flow approach, use pattern recognition algorithms to separate the energy deposits from different particles.
- Photons may be close together, or may overlap with charged hadrons, so require fine segmentation to allow separation.



Failure to resolve photon

- Granularity requirements and use of silicon as active material make the ECAL a very expensive component of the detector.
- Recently launched a new working group, to develop a more cost-effective ECAL model for ILC and CLIC.
- Particle flow relies on both hardware and software: aim to develop full understanding of both to make recommendation.



New contributions welcome! Mailing list: lcd-ecal@cern.ch

Indico category: http://indico.cern.ch/categoryDisplay.py?categId=4379

Strategy

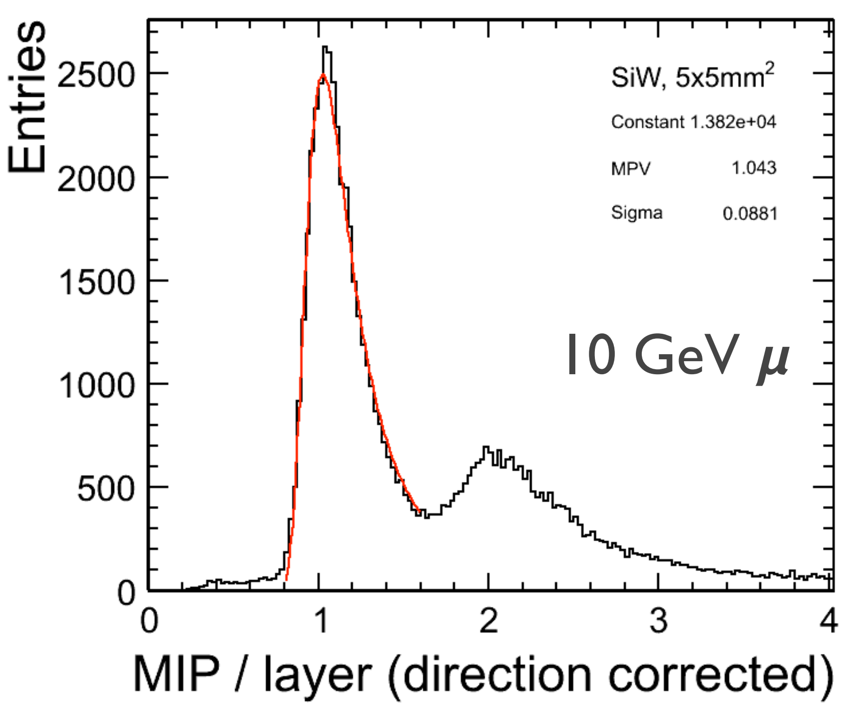
- Starting point for study is the SiW ECAL in ILD_o1_v05:
  - 20 x 2.1mm + 9 x 4.2mm W absorber; interspersed with...
  - 29 x 0.5mm silicon active material, divided into 5.1x5.1mm^2 pixels.
- Cost-effective models may use Si for first few active layers, but then move to scintillator (with SiPM read-out) deeper in calorimeter. Sc cell sizes may then increase with depth.
- Begin by examining PFA performance with full simulation of SiW and ScW ECAL models using **5x5mm^2 square cells**. Then proceed to vary ECAL parameters: cell sizes, nLayers, etc.

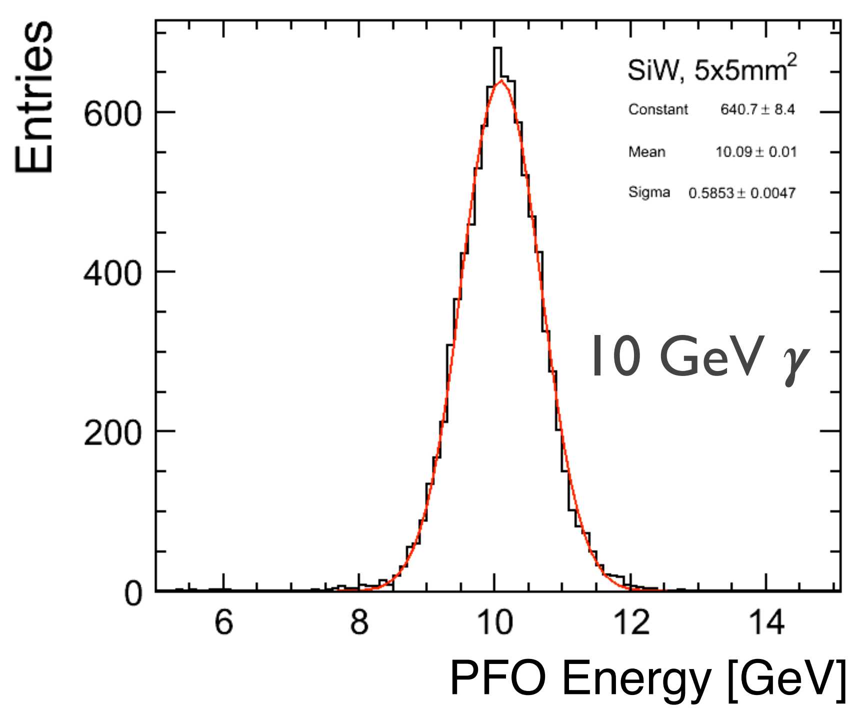
- **Technical details:** Can reproduce most results using SEcal05 driver from Mokka trunk (svn rev 436), with Ilcsoft v01-16-02 (GEANT4 9.5.p02) and QGSP_BERT physics list.
- Approach is to take ILD_o1_v05 and replace ECAL with a newly configured SEcal05 model:
  - Ecal_Sc_Si_mix: 000000000000000 (full SiW), 333333333333333 (full ScW)
  - Ecal_Sc_thickness: Si thickness 0.5mm, investigate 0.5mm and 2.0mm Sc
  - Ecal_cells_size: control square Si pixel sizes and first Sc strip dimension
  - Ecal_Sc_N_strips_across_module: control second Sc strip dimension (module ~180mm)

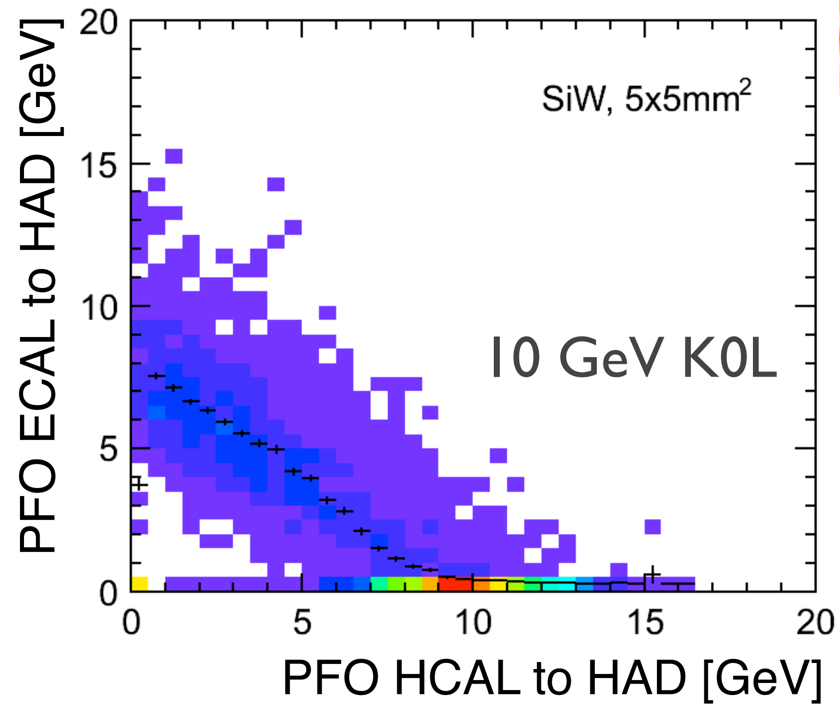
ECAL Calibration

- Determine ECAL calibration constants using 10 GeV γ, μ and K0L samples. Leave HCAL constants unchanged from DBD. For SiW expect entire calibration to remain unchanged.

1. Set digitisation constant, "CalibrECAL", so sum of all hit energies peaks at 10GeV for γ.
2. Set MIP constant so that direction corrected MIP/layer distribution peaks at 1.0 for μ.
3. Run particle flow reconstruction for γ and K0L, with MIP cuts (0.5 for ECAL, 0.3 for HCAL).
4. Examine distributions of PFO ECALToEM/HAD energy vs HCALToEM/HAD energy and set:
   ECALToEM: weight for ECAL energy deposits identified as part of EM showers
   ECALToHAD: weight for ECAL energy deposits identified as part of hadronic showers

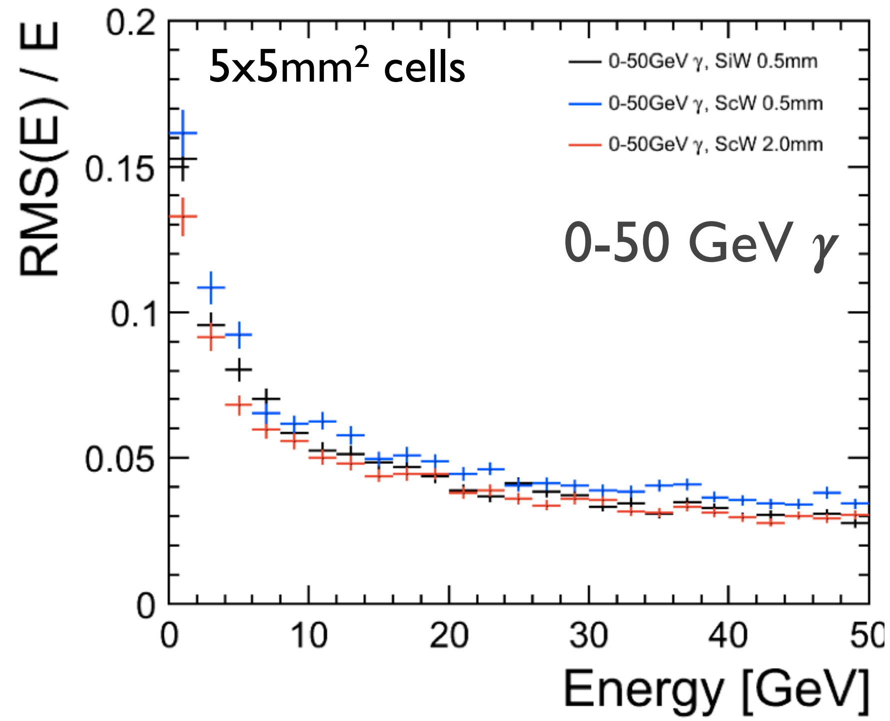


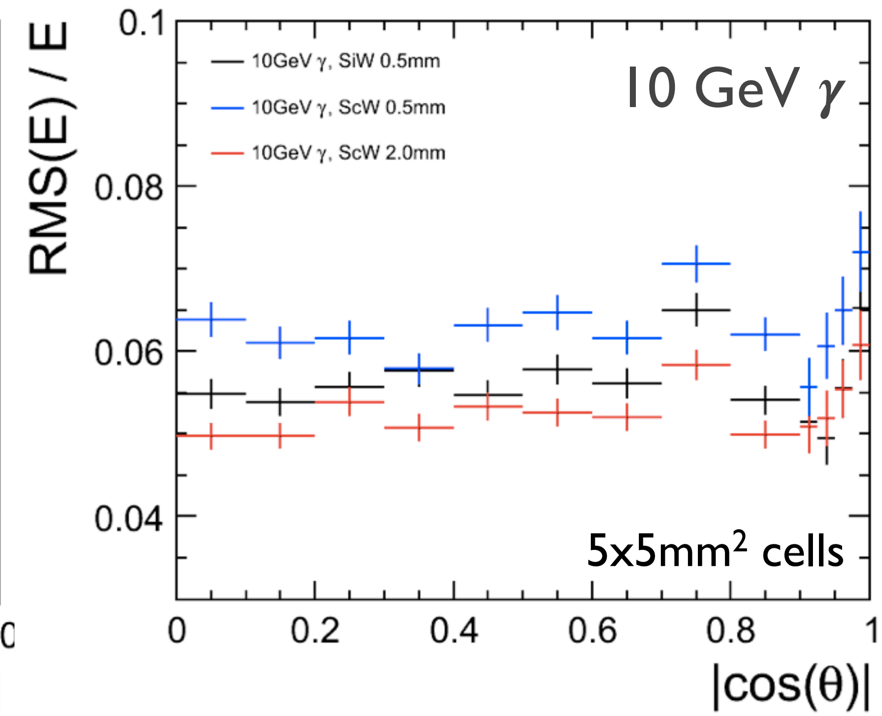


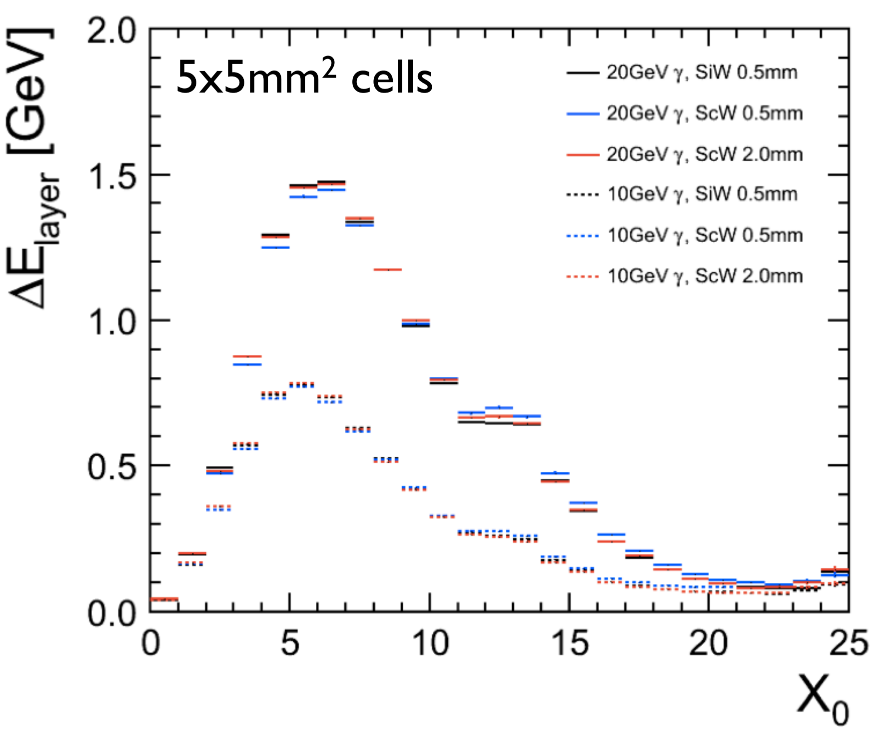


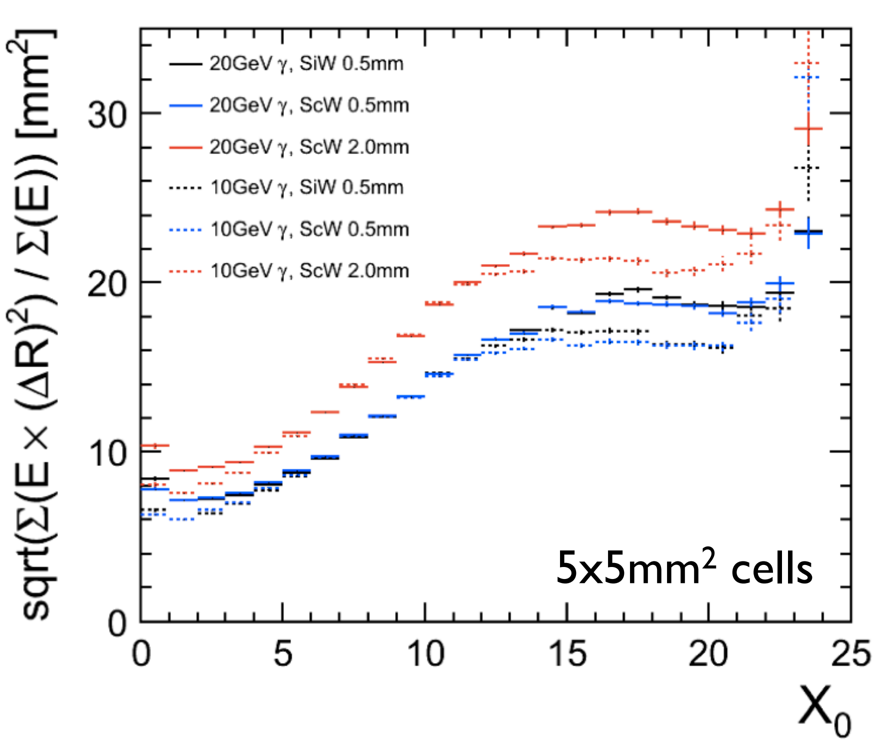
Single Particle Studies

- Compared to SiW ECAL, energy resolution:
  - Improves with 2.0mm Sc
  - Degrades with 0.5mm Sc
- Resolutions flat in barrel region for all models.
- For first studies, use a default Sc thickness of 2.0mm.









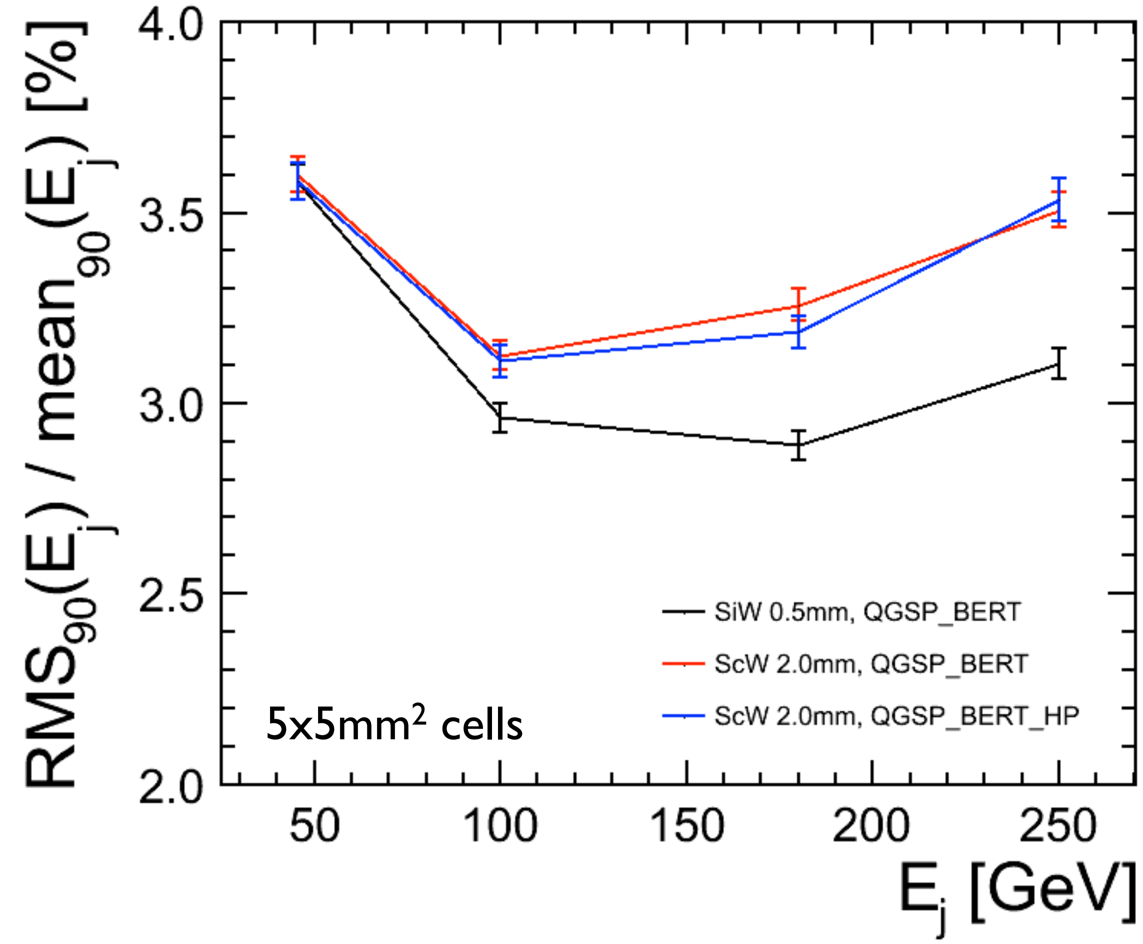
- Examine EM shower profiles:
- Longitudinal profiles same for SiW and ScW ECALs.
- EM showers noticeably wider with 2.0mm Sc thickness.
- 2.0mm Sc could make it more difficult to resolve photons from other nearby particles.

Jet Energy Resolution Studies

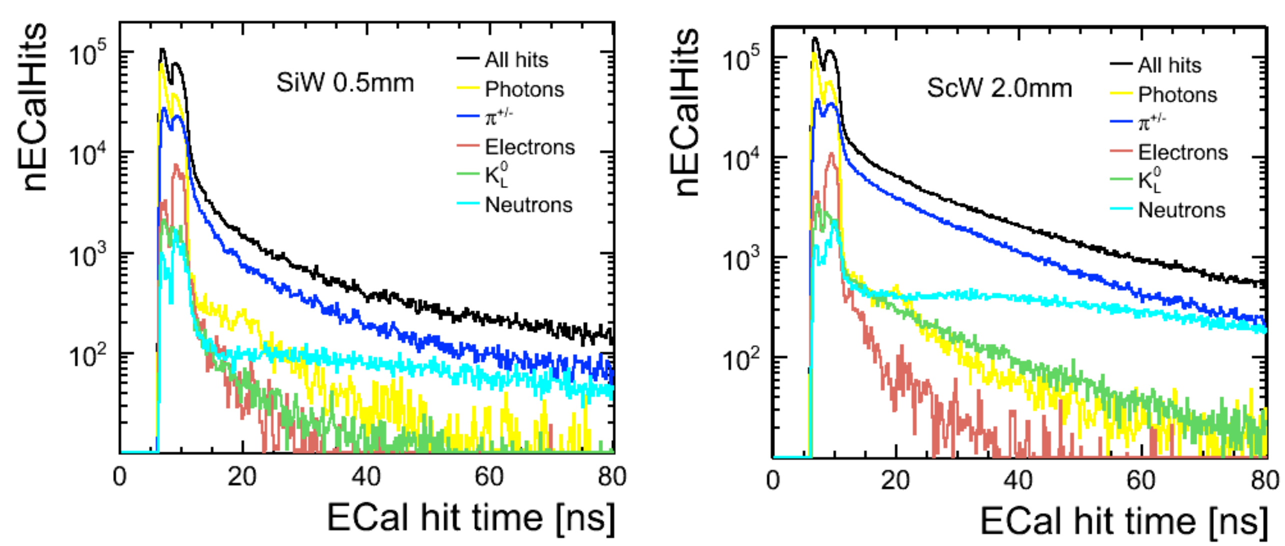
- Assess jet energy resolution using Zs at different E decaying at rest into light quarks.
- Produce two mono-energetic jets. Obtain jet energy resolution from total PFO energy:

$$\frac{\mathrm{RMS}_{90}(E_j)}{\mathrm{mean}_{90}(E_j)} = \frac{\mathrm{RMS}_{90}(E_{jj})}{\mathrm{mean}_{90}(E_{jj})}\sqrt{2}$$

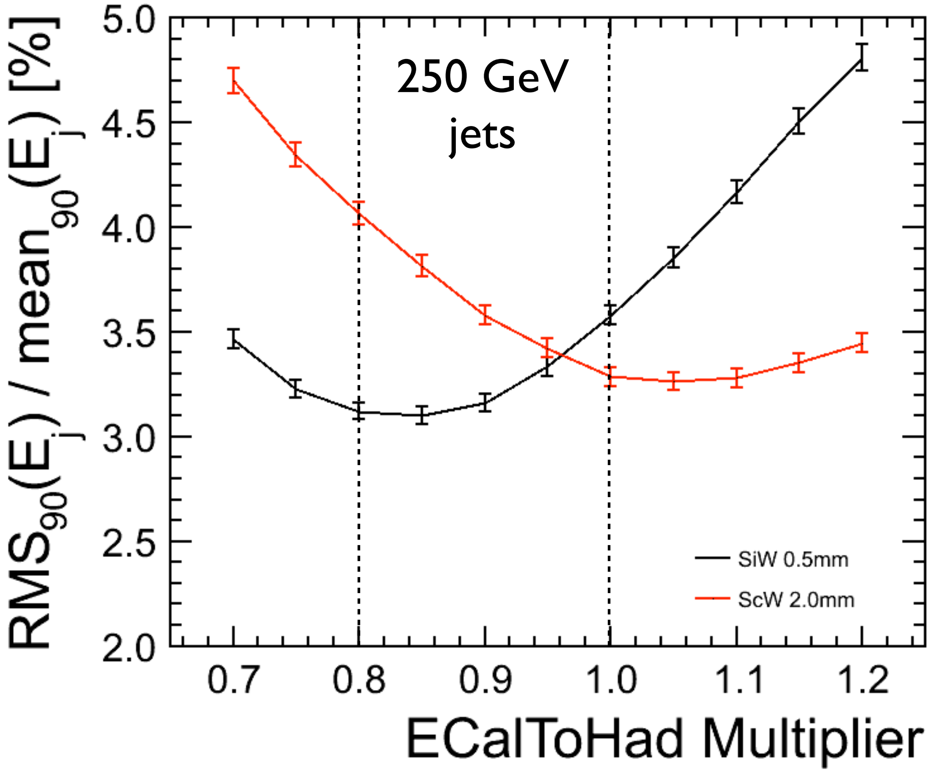
- Initial resolutions for 5x5mm^2 ScW rather poor above 45 GeV (compared to SiW).
- Used QGSP_BERT_HP to check problem wasn't due to (sensitivity to) poorly modelled neutron component.
- Decided to apply ECAL timing window of 20ns in digitisation for more realistic reconstruction.
- During recalibration process, noticed that ECALToHAD constant is very important...

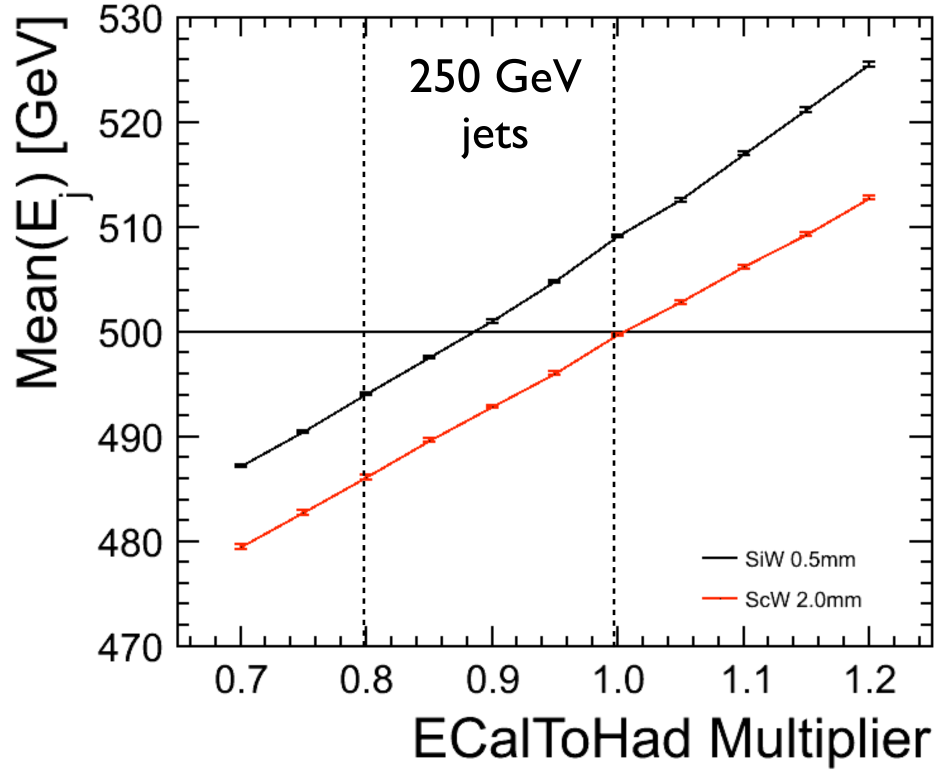


Component SimCalorimeterHits:

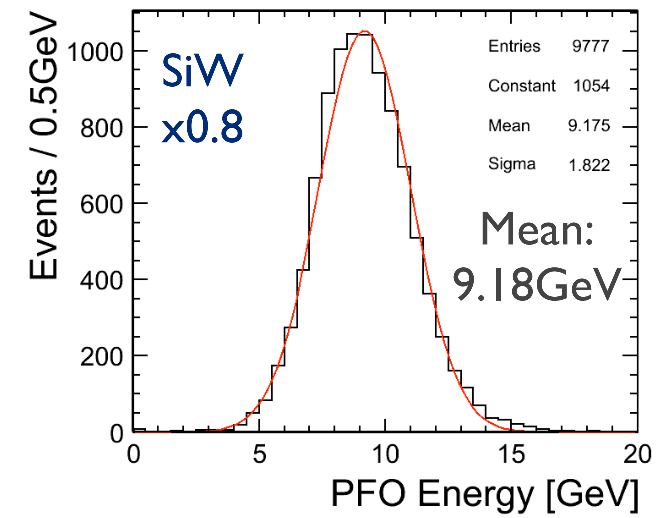


ECALToHAD Parameter Scan

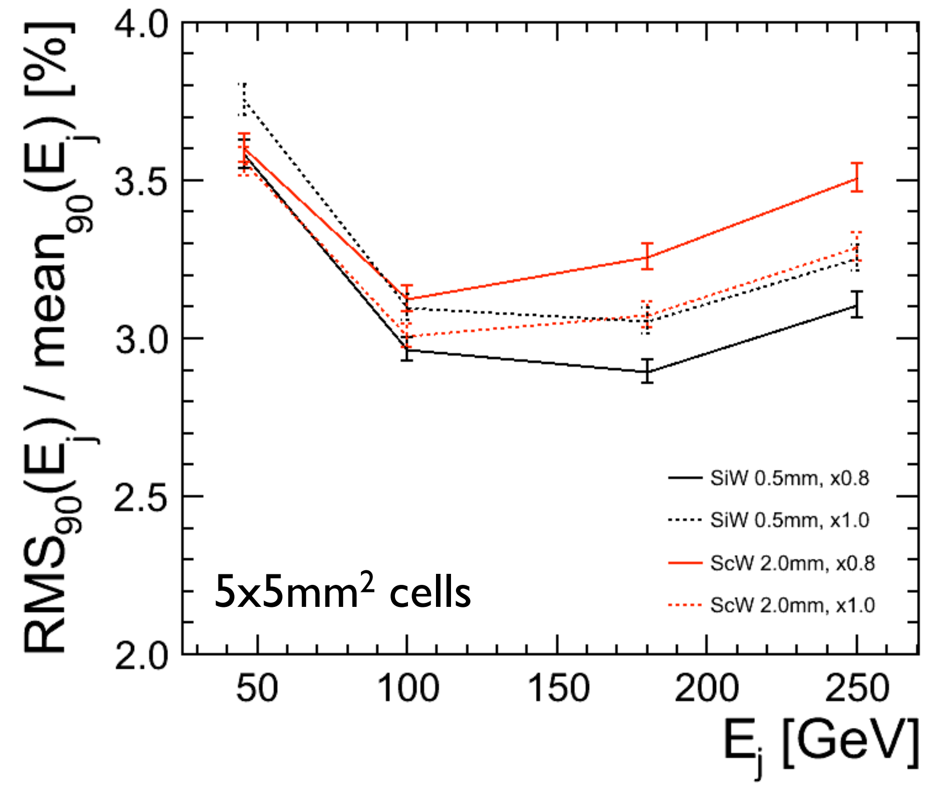




For 10 GeV K0L sample:



- Examine variation of jet energy resolution, for 250 GeV jets, in a sweep through a range of ECALToHAD values.
- Values centered around basic 10 GeV K0L calibration, x1.0. Observe different behaviour for SiW and ScW:
- For SiW, optimal jet energy resolution achieved if ECAL contribution to hadronic showers is deweighted: x0.8
- For ScW, optimal jet energy resolution is achieved with the calibration motivated by 10GeV K0L sample: x1.0

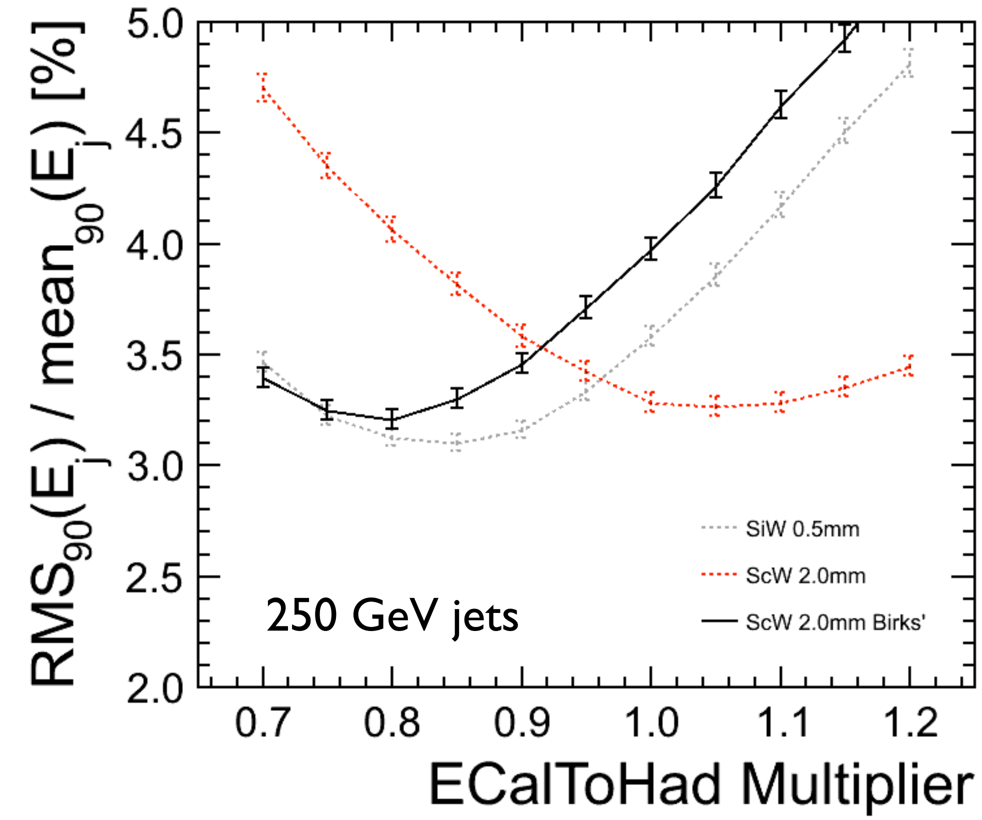


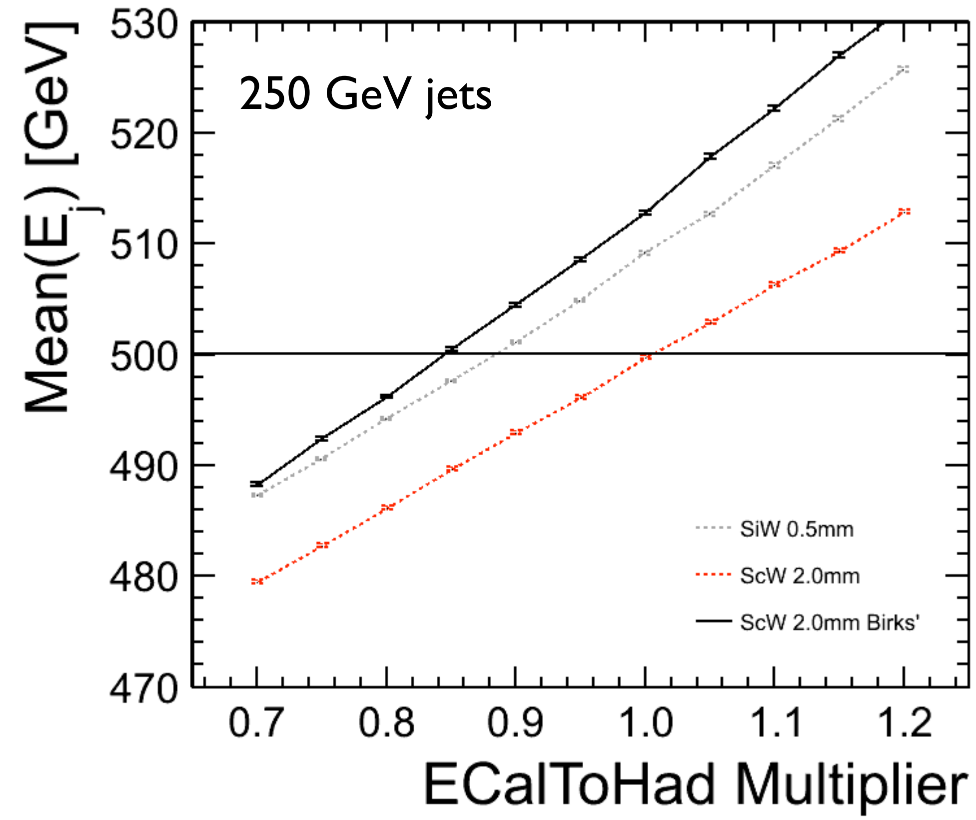
Birks' Law

- Organic scintillator does not respond linearly to ionisation density.
- Dense ionisation columns emit less light than expected on the basis of dE/dx for MIP.
- Birks' Law gives empirical formula for light yield per path length and is included in SEcal05 driver:

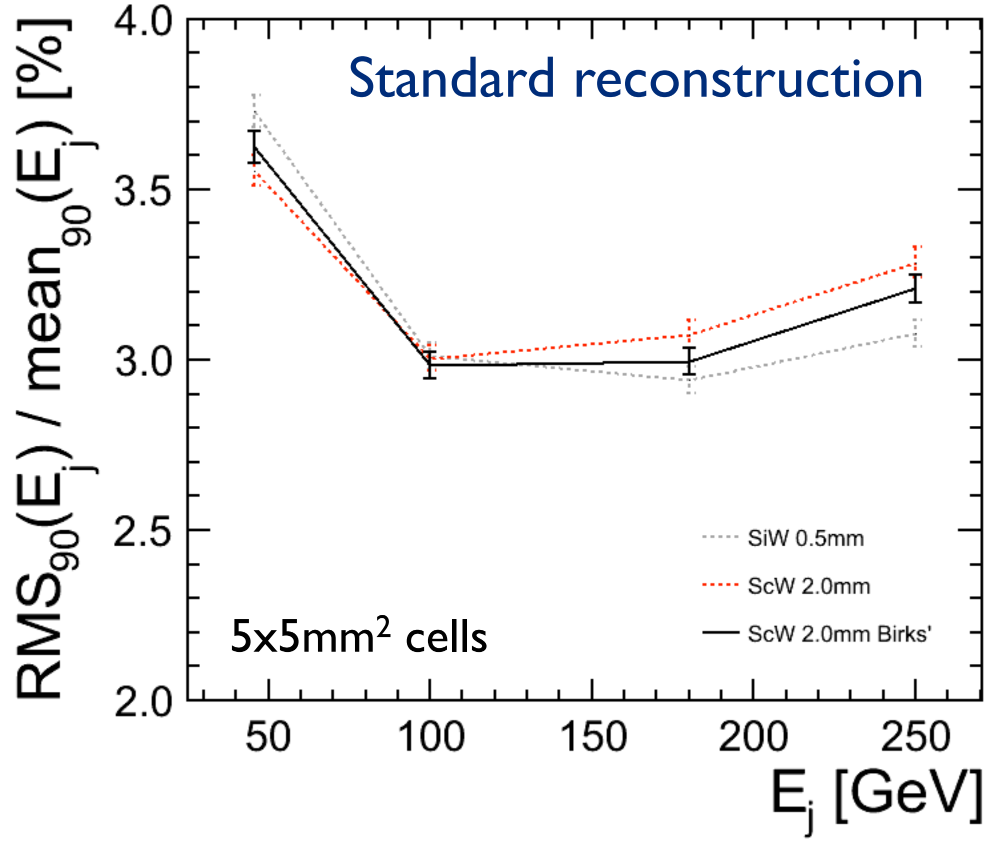
$$\frac{d\mathscr{L}}{dx} = \mathscr{L}_0 \frac{dE/dx}{1 + k_B\, dE/dx}$$

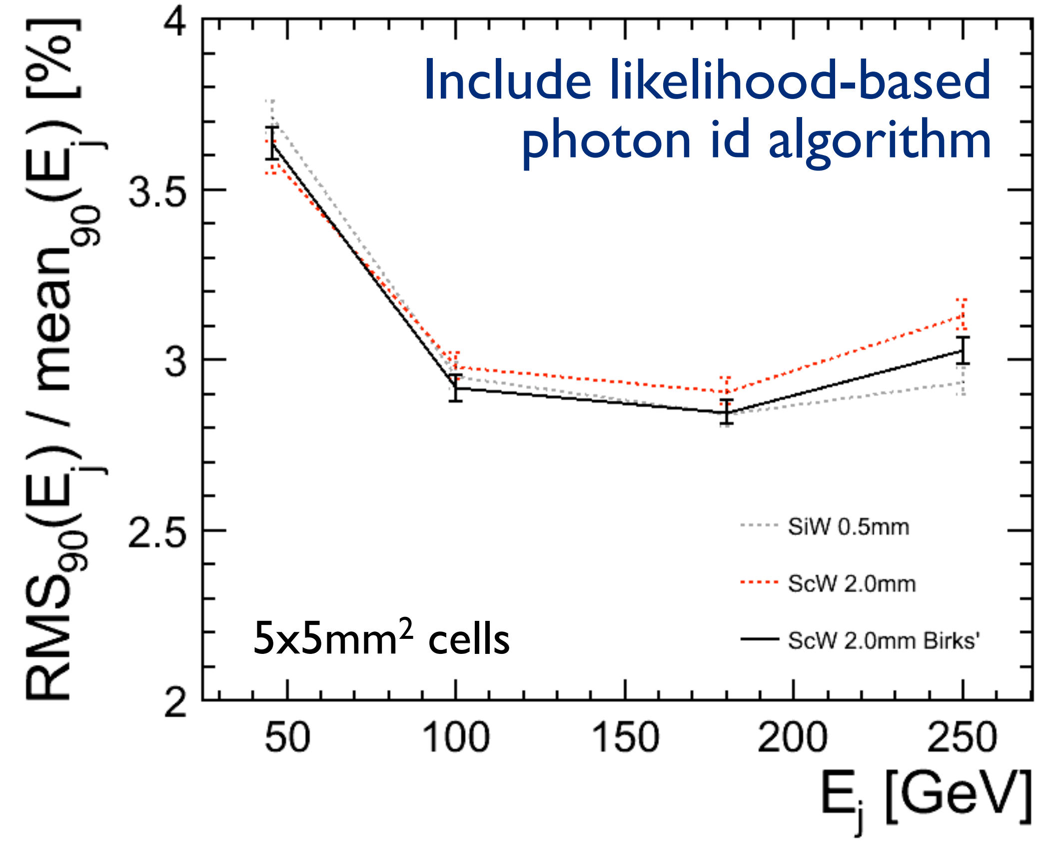
- Birks' Law has a significant impact on ScW ECAL:
  - As expected, CalibrECAL constant must increase.
  - Dramatic change in response of jet energy resolution to variation of ECALToHAD constant.
  - Plots of jet energy resolution vs. ECALToHAD multiplier now very similar for ScW and SiW.
  - Adjusting ScW ECALToHAD value accordingly (x0.8), obtain improved jet energy resolutions.





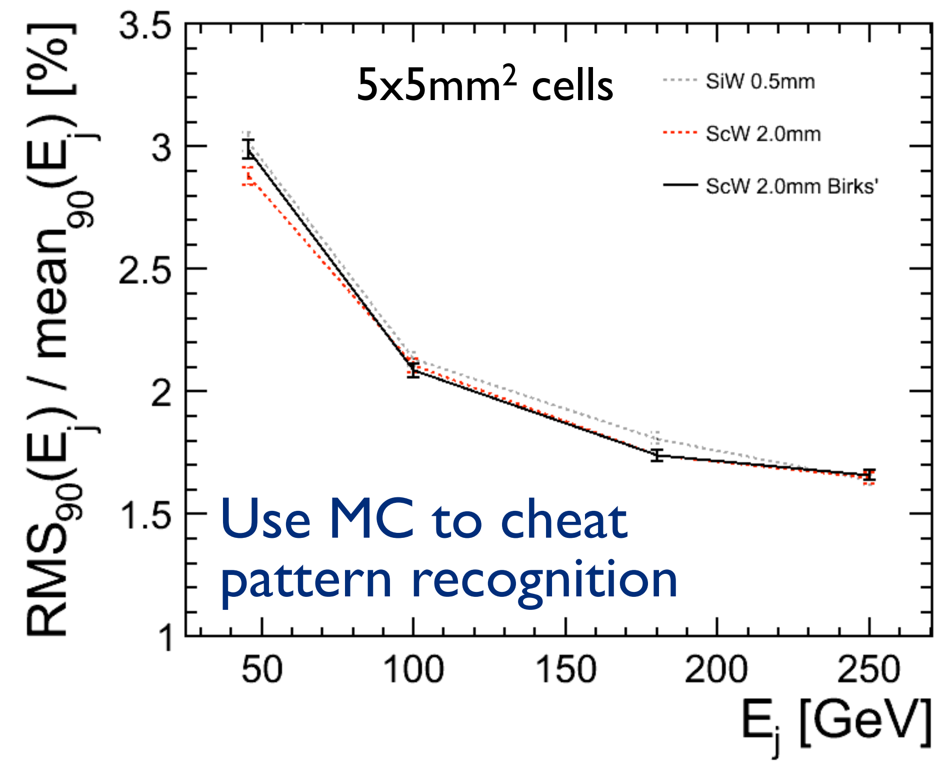
SiW vs. ScW, 5x5mm² Cells





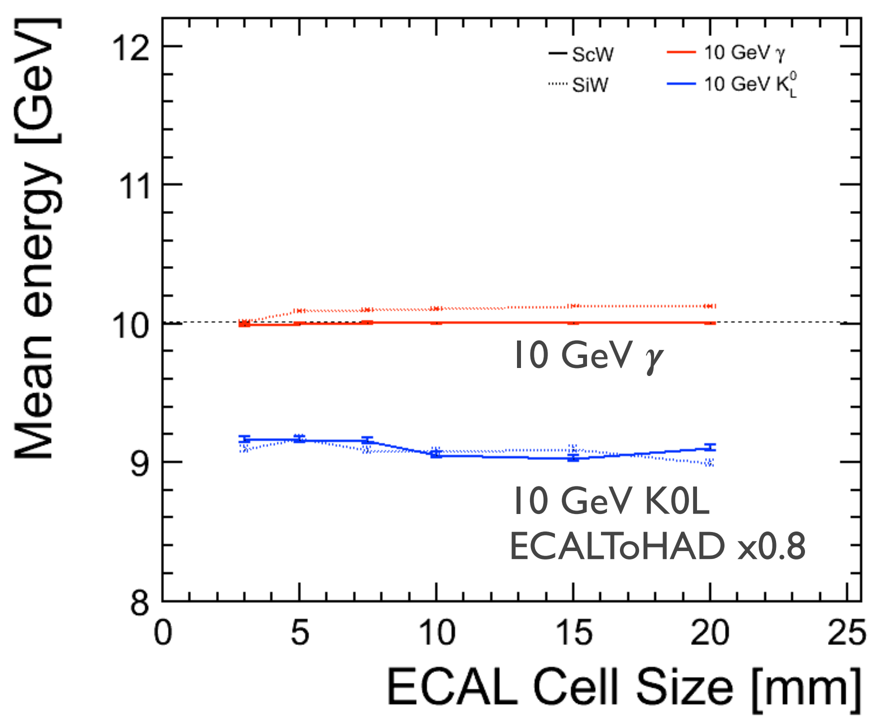
- With tuned ECALToHAD and inclusion of Birks' Law, obtain similar performance for SiW and ScW ECALs.
- Resolutions identical if cheat the pattern recognition.

250 GeV	SiW 0.5mm	ScW 2.0mm	ScW + Birks'
Standard	3.08%	3.28%	3.21%
Photon alg.	2.94%	3.13%	3.02%
Perfect PFA	1.64%	1.64%	1.66%

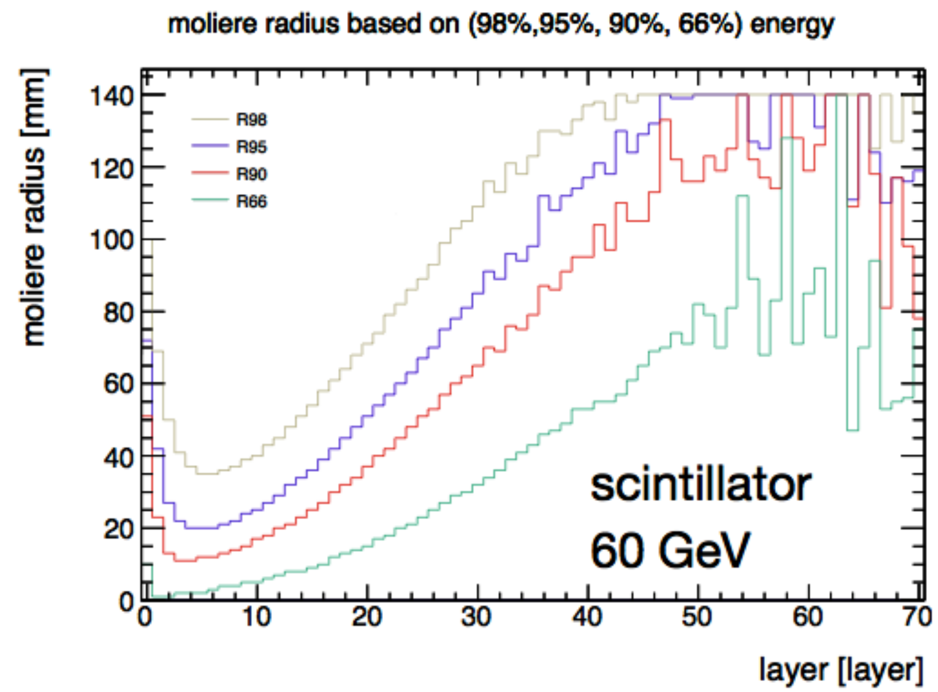


Transverse Granularity Studies

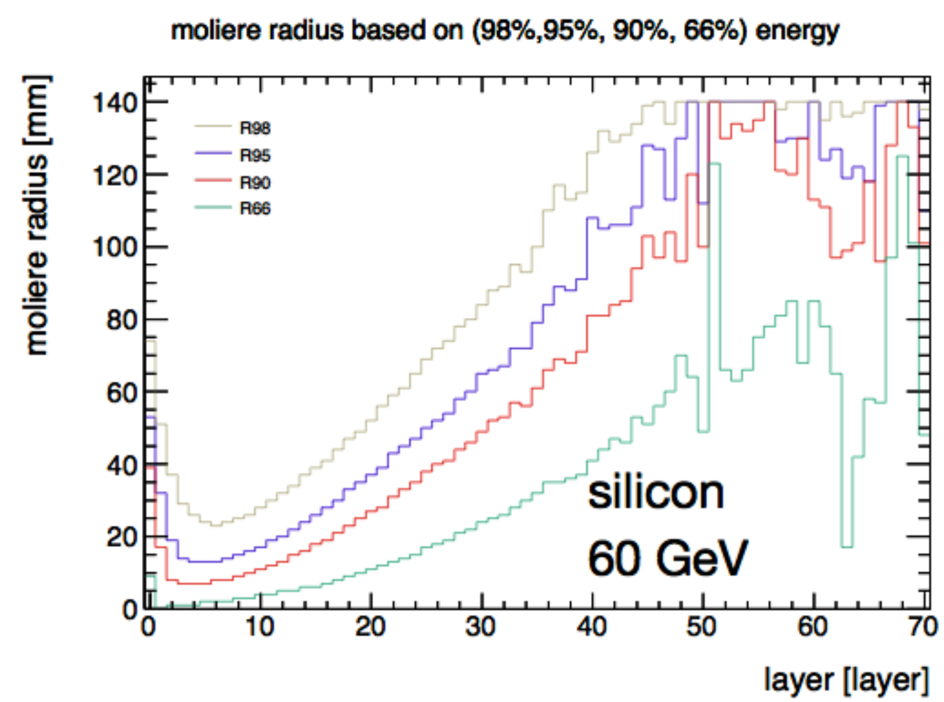
- Study SiW/ScW performance with range of different cell sizes. Keep cells square to reduce algorithm tuning:
  - 3x3 mm^2, 5x5 mm^2, 7.5x7.5 mm^2, 10x10 mm^2, 15x15 mm^2 and 20x20 mm^2
- This range of cell dimensions was motivated by studies of transverse shower size as function of depth.
- Aim to understand how contributions to jet energy resolution vary with cell size, so try gradually swapping Pandora algorithms with MC "cheating" versions.

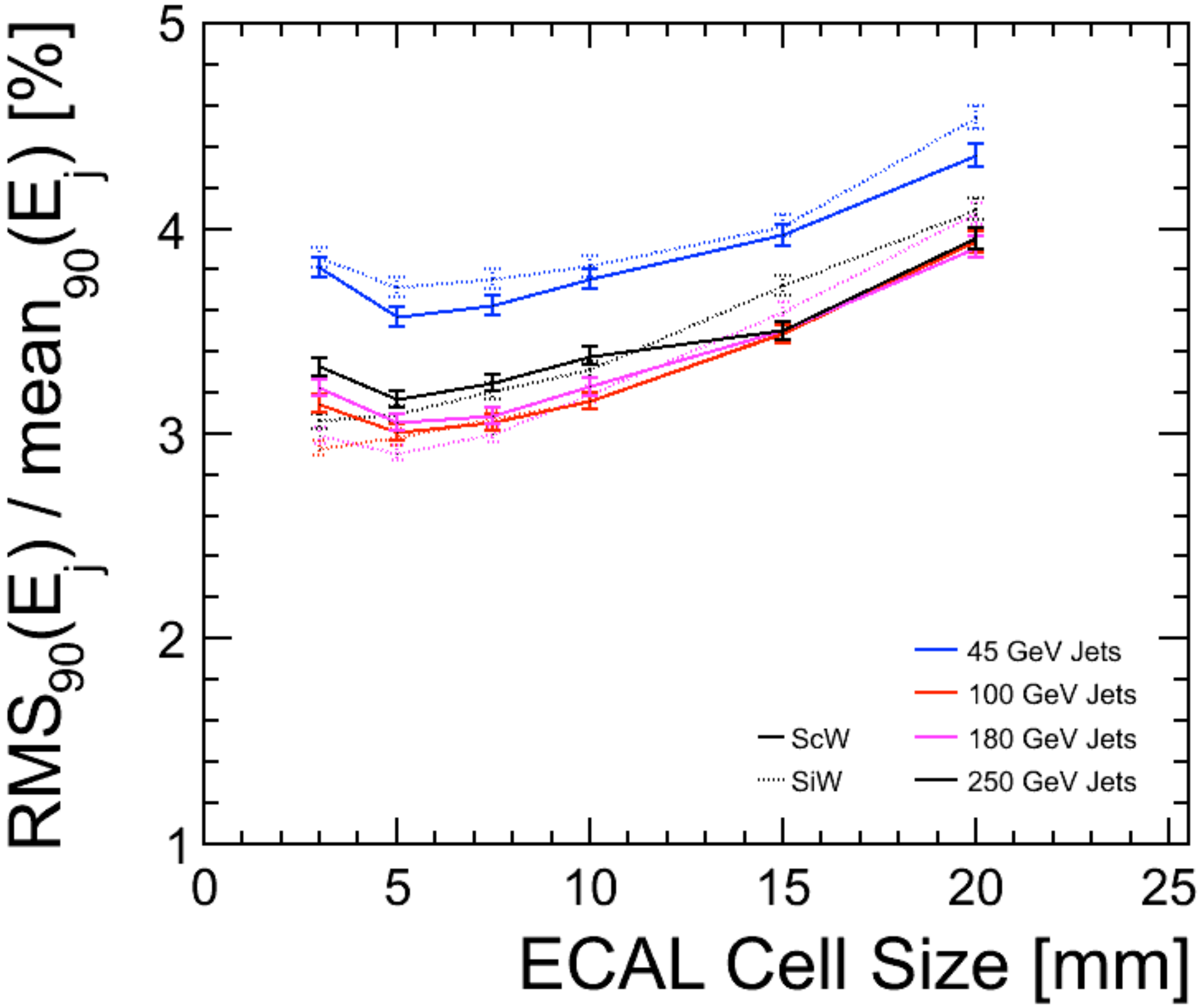


- Check calibration with different cell sizes:
- SiW: same calibration works for all samples.
- ScW: necessary to recalibrate for each scintillator tile size.



D. Schoke, F. Simon
ECAL Meeting 15.04.2013



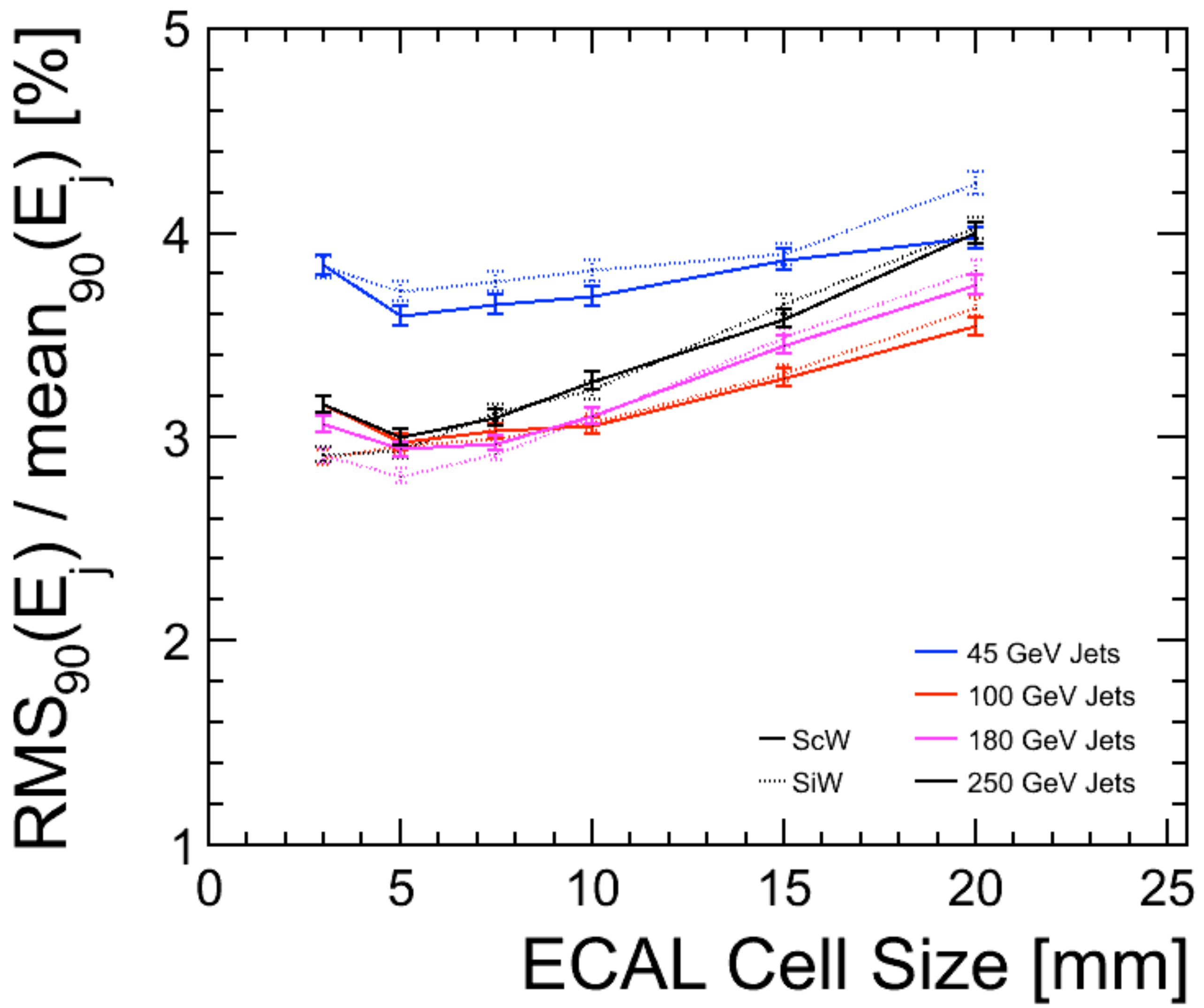


Resolutions for 250 GeV jets:

	3 mm	5 mm	7.5 mm	10 mm	15 mm	20 mm
SiW	3.06%	3.10%	3.21%	3.31%	3.72%	4.09%
ScW	3.33%	3.17%	3.25%	3.38%	3.51%	3.95%

- Begin by examining jet energy resolutions achieved using standard Pandora algs.
- Recall that these algs only optimised for 5x5mm^2 cells; improvements possible.
- However, achieve 3.5% resolution goal, for 100-250GeV jets, up to ~15x15mm^2.
- SiW/ScW performance similar, except at high jet energies with 3x3mm^2 cells.
- Now vary choice of Pandora algs...

Standalone Photon Algorithm

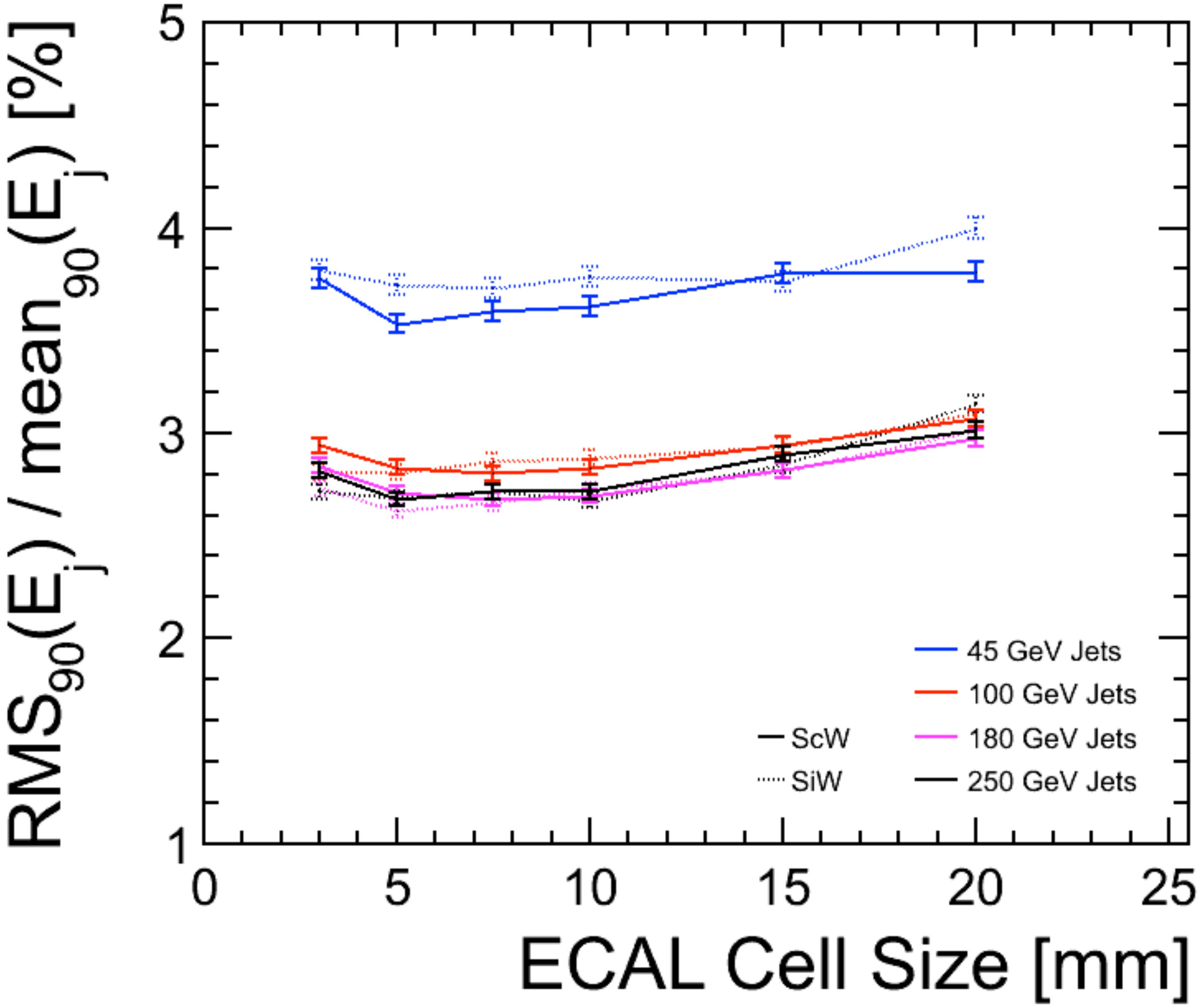


Resolutions for 250 GeV jets:

	3 mm	5 mm	7.5 mm	10 mm	15 mm	20 mm
SiW	2.91%	2.93%	3.12%	3.23%	3.65%	4.03%
ScW	3.16%	3.00%	3.09%	3.27%	3.58%	4.00%

- Concentrate photon reconstruction into single Pandora algorithm, which runs early in reconstruction.
- Examine ECAL hits in transverse plane, looking for peaks and try to separate peak clusters from nearby tracks.
- Use likelihood technique to finalise photon identification. Photon clusters then removed until PFO construction.
- Likelihood PDFs must be recreated for each detector configuration.
- Algorithm consistently improves resolution, but doesn't really reduce sensitivity to granularity changes.

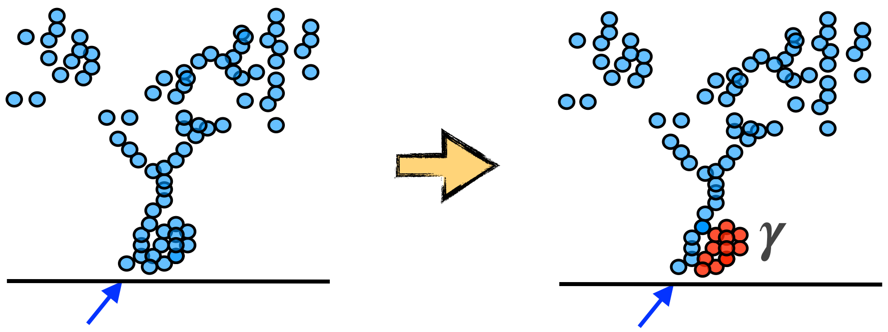
Cheat Photon Clustering



Resolutions for 250 GeV jets:

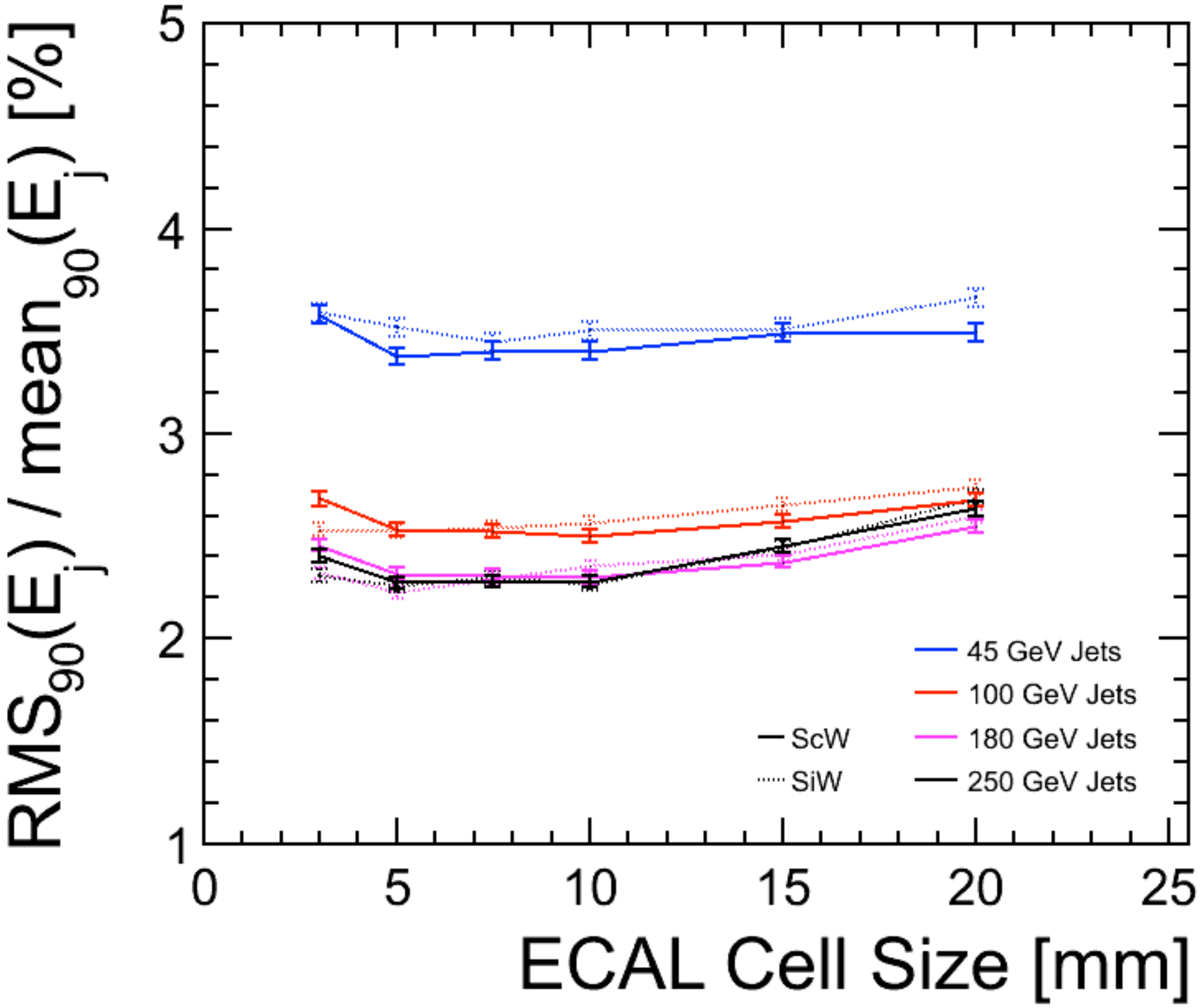
	3 mm	5 mm	7.5 mm	10 mm	15 mm	20 mm
SiW	2.72%	2.69%	2.71%	2.67%	2.84%	3.14%
ScW	2.82%	2.68%	2.71%	2.72%	2.90%	3.02%

- Switch standalone photon reconstruction with an algorithm that uses MC info to cheat the photon clustering:



- True photon energy deposits then removed from Pandora reconstruction and are guaranteed to form photon PFOs.
- Calorimeter energies still used to calculate final photon energies; MC info used only for pattern recognition.
- Additional fake photons may still be formed by standard Pandora algorithms.
- As expected, see dramatically reduced sensitivity to ECAL granularity changes.

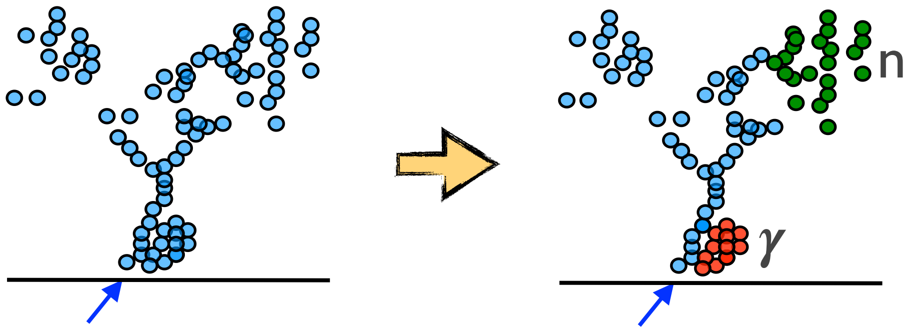
Cheat Photons, Neutral Hadrons



Resolutions for 250 GeV jets:

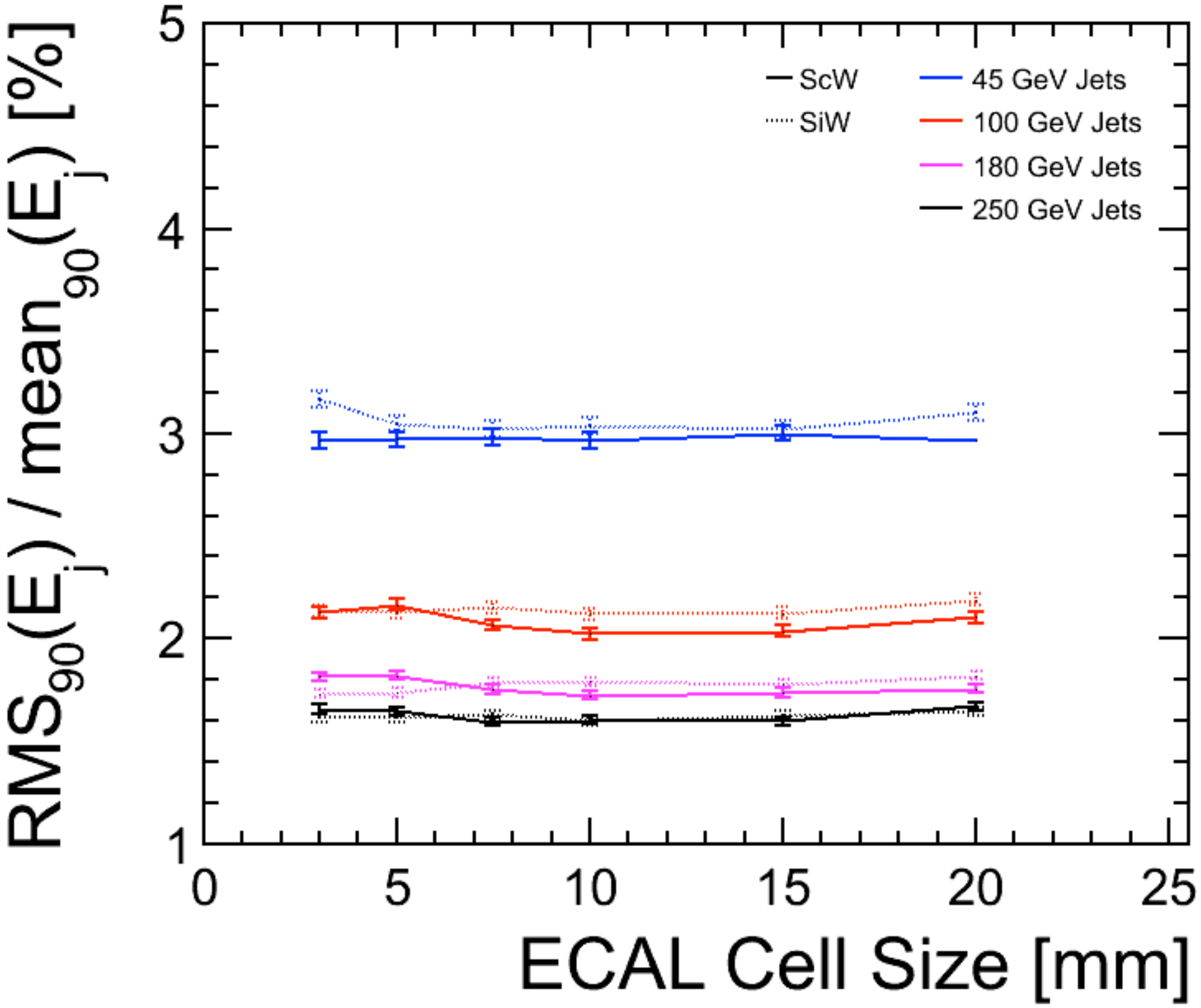
	3 mm	5 mm	7.5 mm	10 mm	15 mm	20 mm
SiW	2.31%	2.26%	2.30%	2.27%	2.45%	2.69%
ScW	2.40%	2.27%	2.28%	2.28%	2.46%	2.63%

- Extend cheated pattern recognition to also include neutrons and K0L:



- Once removed from reconstruction, cheated clusters are only used to collect "isolated hits" and to form PFOs.
- Neutral hadron confusion very important for jet energy reconstruction, but, as expected, its impact is independent of ECAL granularity.

Perfect PFA



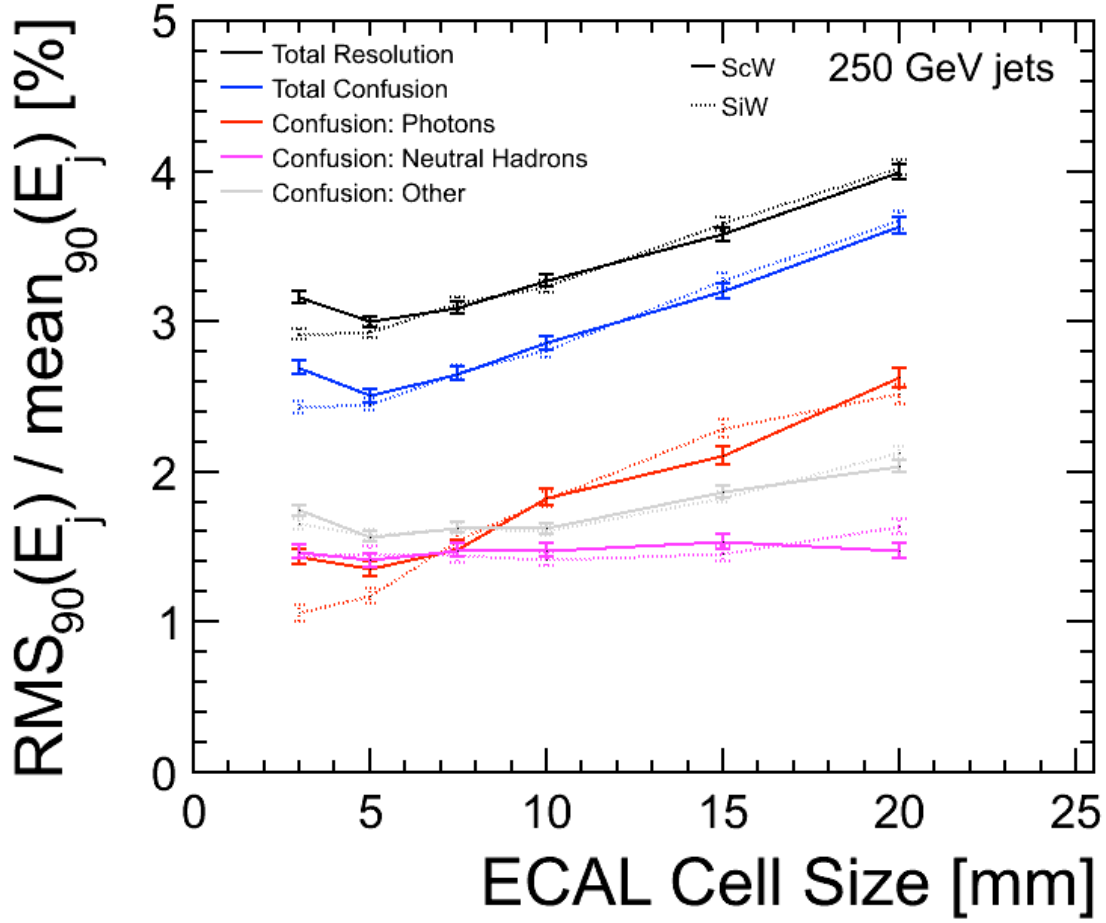
Resolutions for 250 GeV jets:

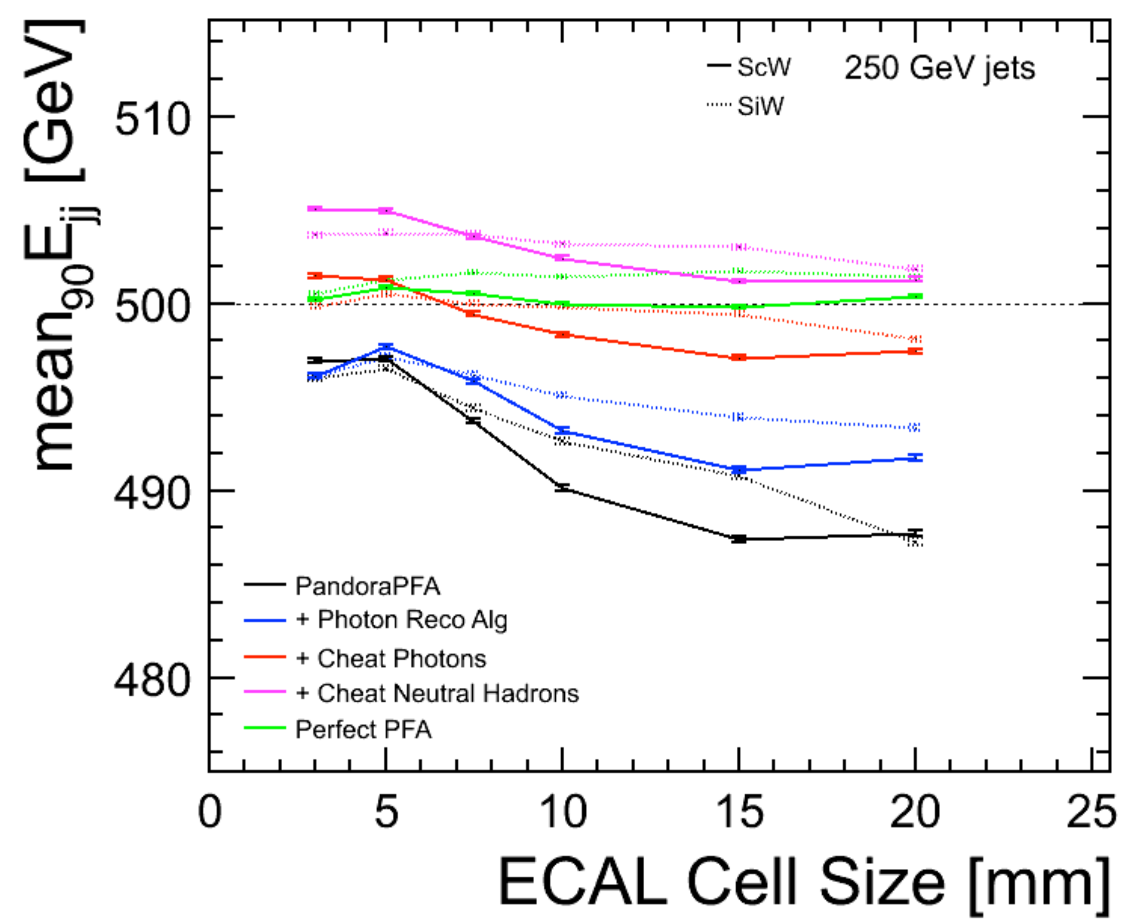
	3 mm	5 mm	7.5 mm	10 mm	15 mm	20 mm
SiW	1.61%	1.61%	1.63%	1.60%	1.62%	1.65%
ScW	1.66%	1.64%	1.59%	1.60%	1.60%	1.67%

- Collect together hits and tracks associated with each MC PFO target (MC particle with vtx radius < 500mm and endpoint radius > 500mm).
- Still use reconstructed hit/track properties to calculate PFO energies, but remove (nearly) all aspects of calorimeter pattern recognition.
- Granularity now only important because associate just one MC particle (that depositing most energy) to each cell.
- Perfect pattern recognition means that resolutions are flat for ECAL cell dimensions in range 3-20mm.
- Important check of robustness of simulation.

Confusion Contributions

- Can examine changes in performance between different algorithm configurations to explicitly determine confusion contributions. Contributions to overall resolution enter in quadrature.

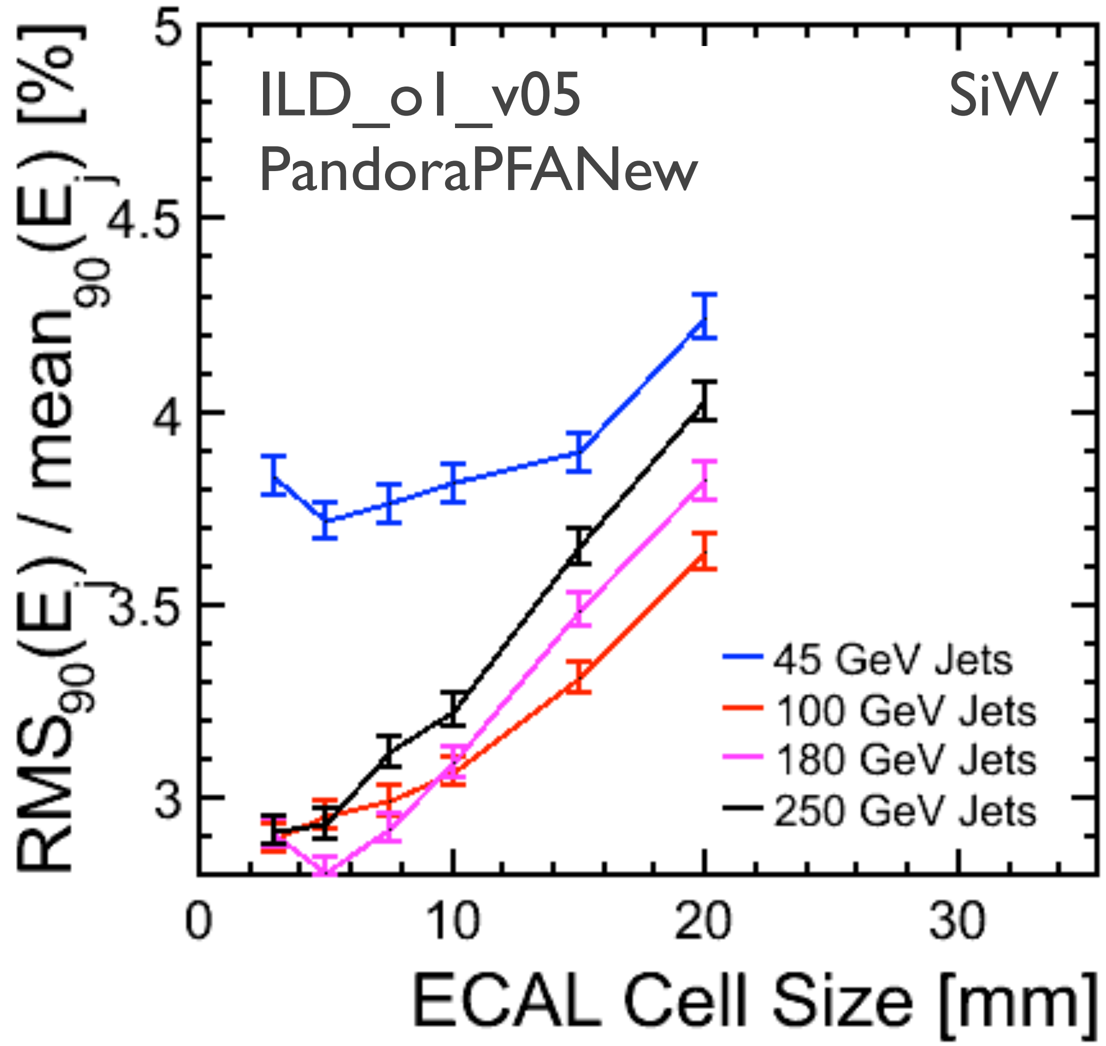


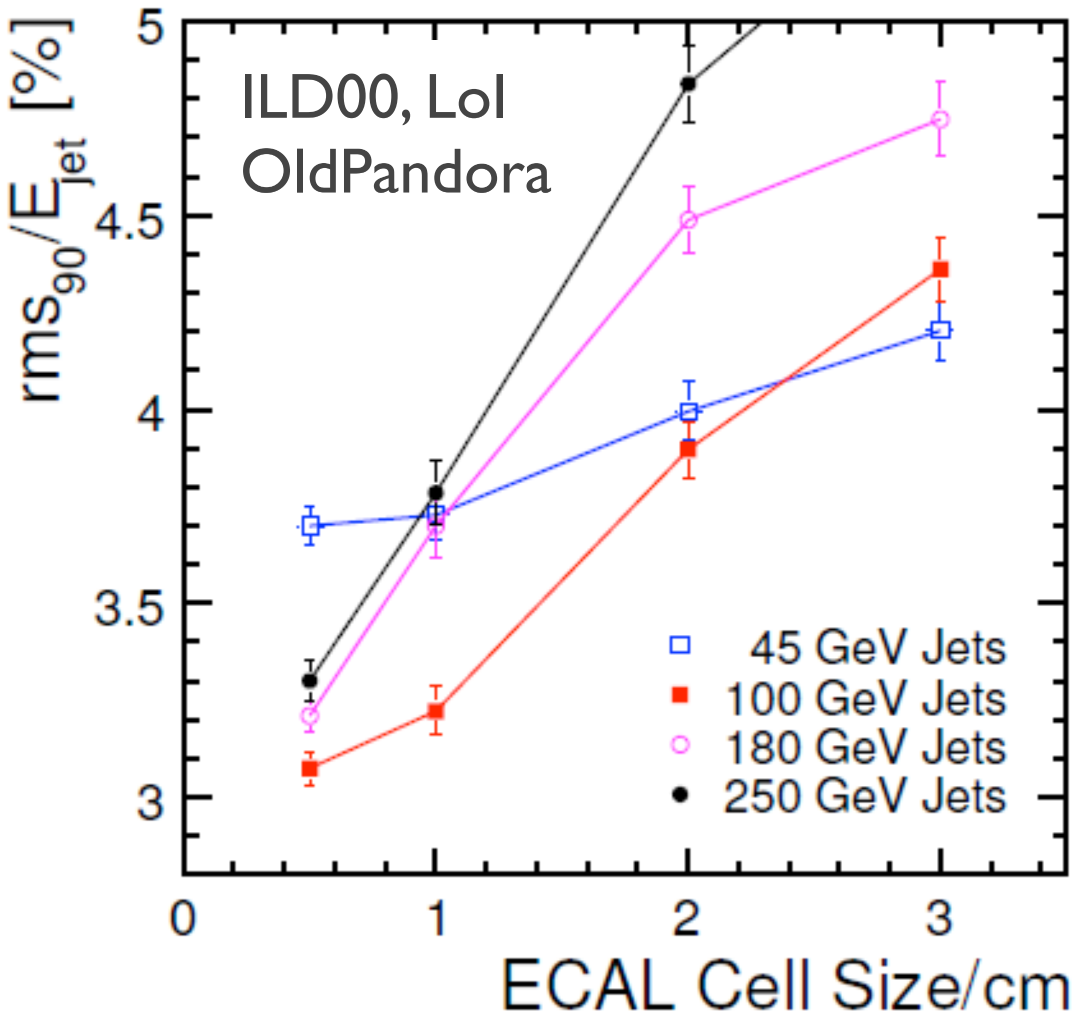


- As could infer from earlier plots, neutral hadron confusion contribution is essentially flat with respect to ECAL cell size, whilst photon confusion increases significantly.
- Total confusion represents difference between best reconstructed resolution and perfect PFA; it comprises neutral hadron confusion, photon confusion and all "other" remaining contributions.
- Loss of photons also clearly evident in plot of mean di-jet energies vs. ECAL cell size.

Comparison with LoI Results

- Finally, compare current results with those obtained for ILD LoI. See same sensitivity to changes in the ECAL granularity, but resolutions have improved markedly for jet energies above 45GeV.
- If aim is to achieve a specific resolution target, could now do so with larger ECAL cells, despite more realistic ILD_o1_v05 model. This is entirely due to pattern-recognition changes.





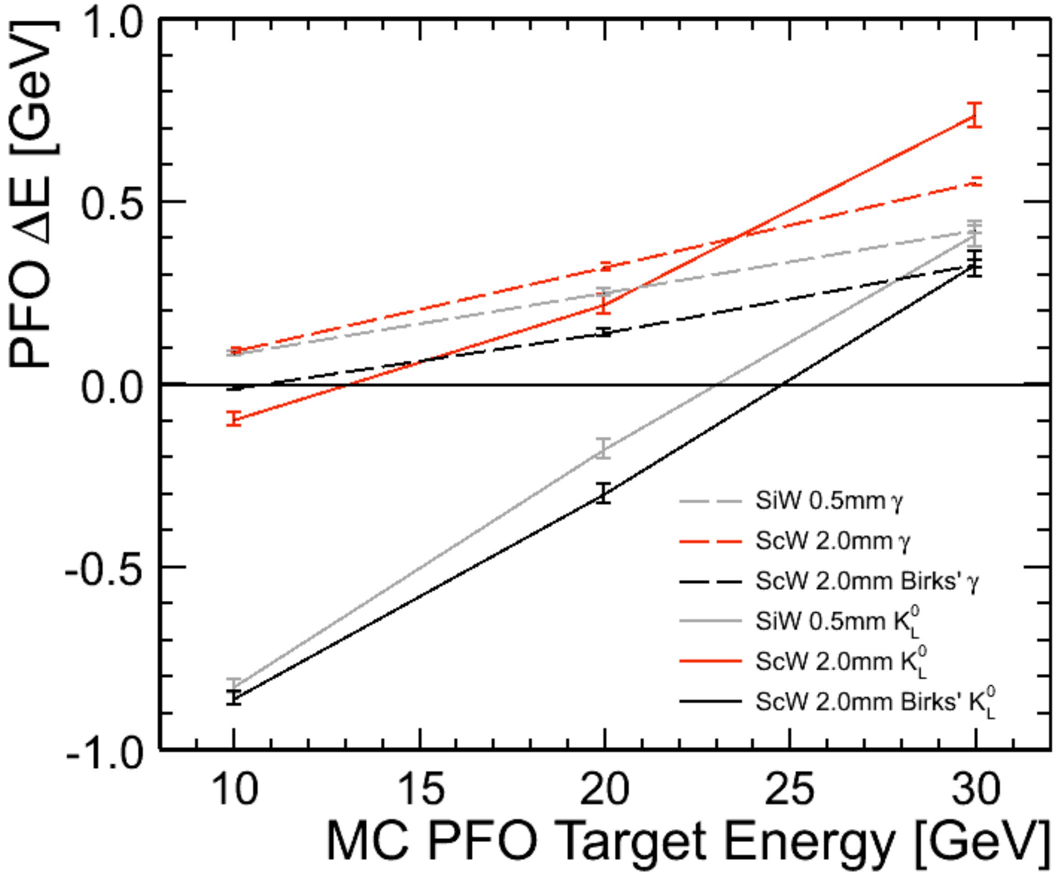
Summary

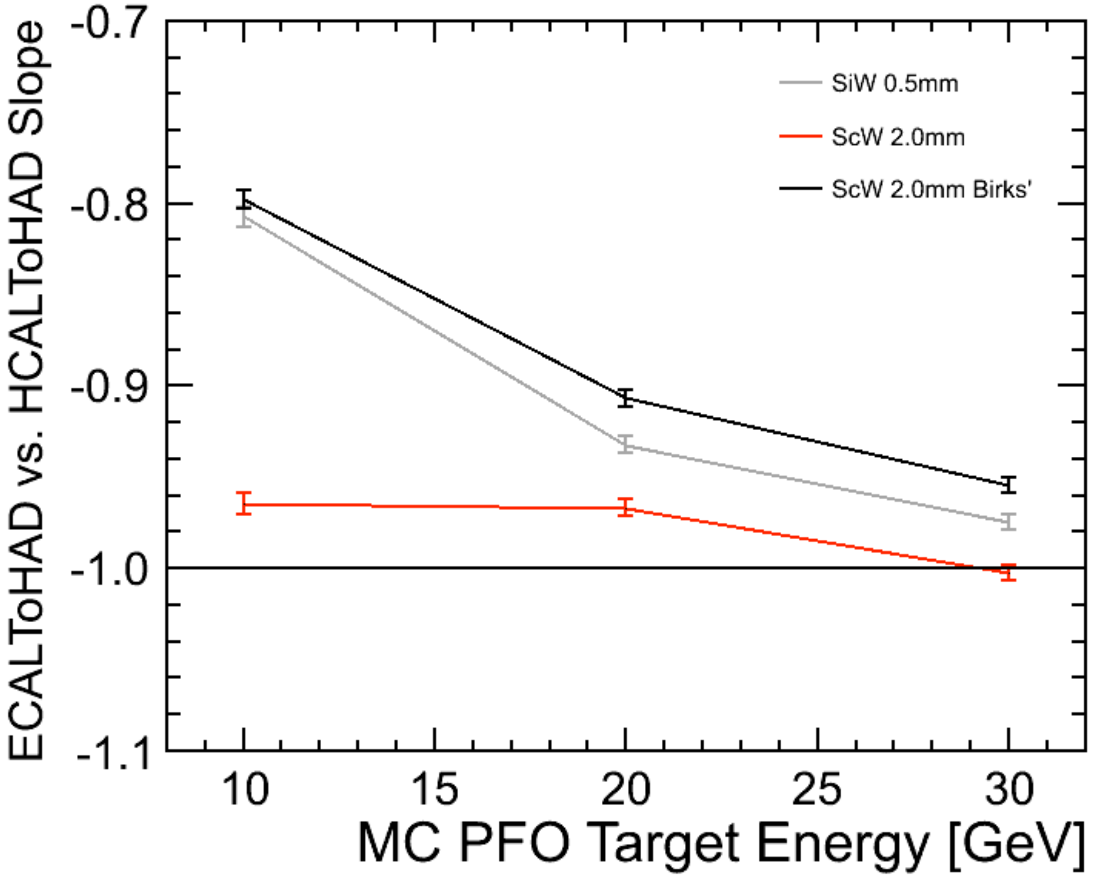
- New cost-effective ECAL studies have begun with a comparison of PFA performance for SiW and ScW models. Replace ECAL in ILD_o1_v05 using SEcal05 Mokka driver.
- With 2.0mm thick scintillator, ScW ECAL energy resolution is slightly better than that for SiW. However, initially saw degradation of jet energy resolutions at high jet energies.
- Adjusted calibration procedure, setting ECALToHAD constant for optimal jet energy resolution and including Birks' Law, to obtain similar performance for ScW and SiW.
- SiW/ScW performance remains similar for square cells in range 5-20mm. Si and Sc provide adequate energy resolution and granularity is the important factor for pattern recognition.
- Jet energy resolution degrades with increasing ECAL cell size, due to reduced ability to separate photons from charged hadrons. Algorithm improvements could help combat this.
- Believe most issues are under control and can now start to study different ECAL options in a controlled manner. Will next investigate effect of increasing cell sizes with depth.

Backup Slides

Higher Energy Calibration Samples

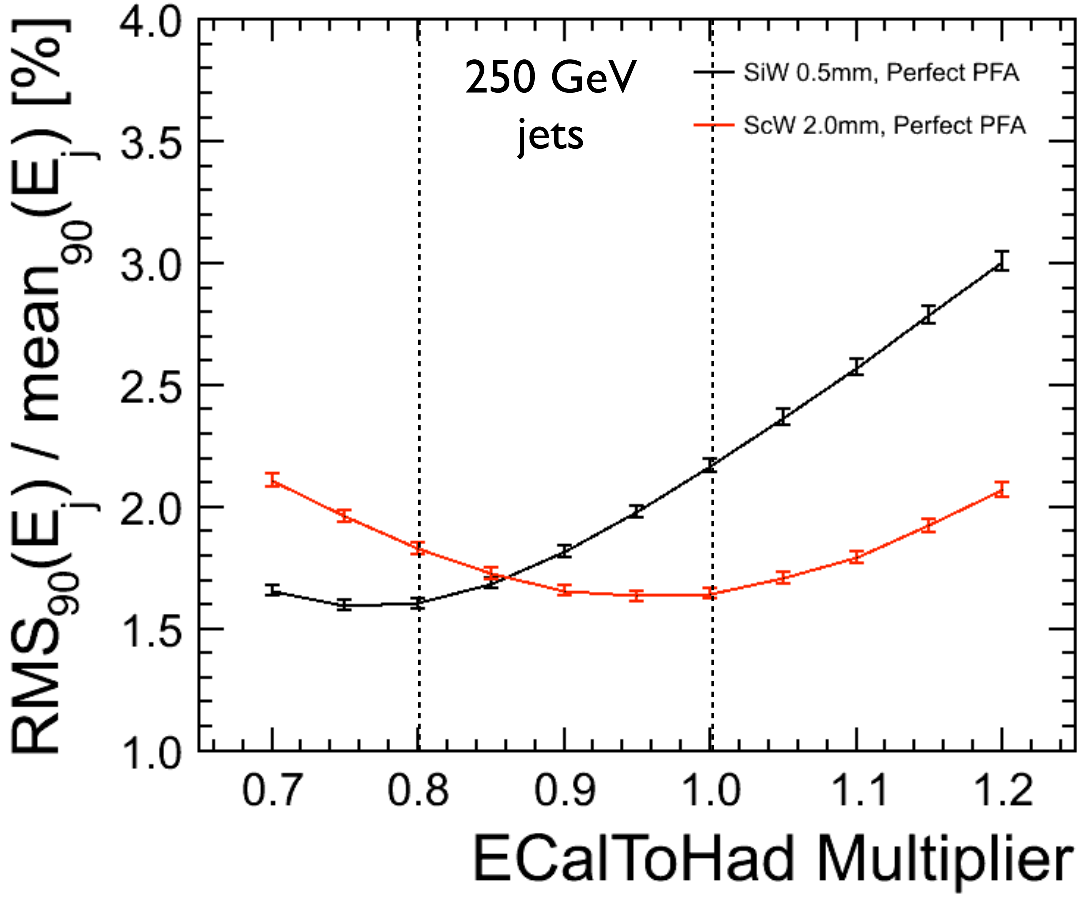
- Further check regarding calibration and basic calorimetry aspects: assess reconstructed energy distributions with new 10, 20 and 30 GeV photon and K0L samples;

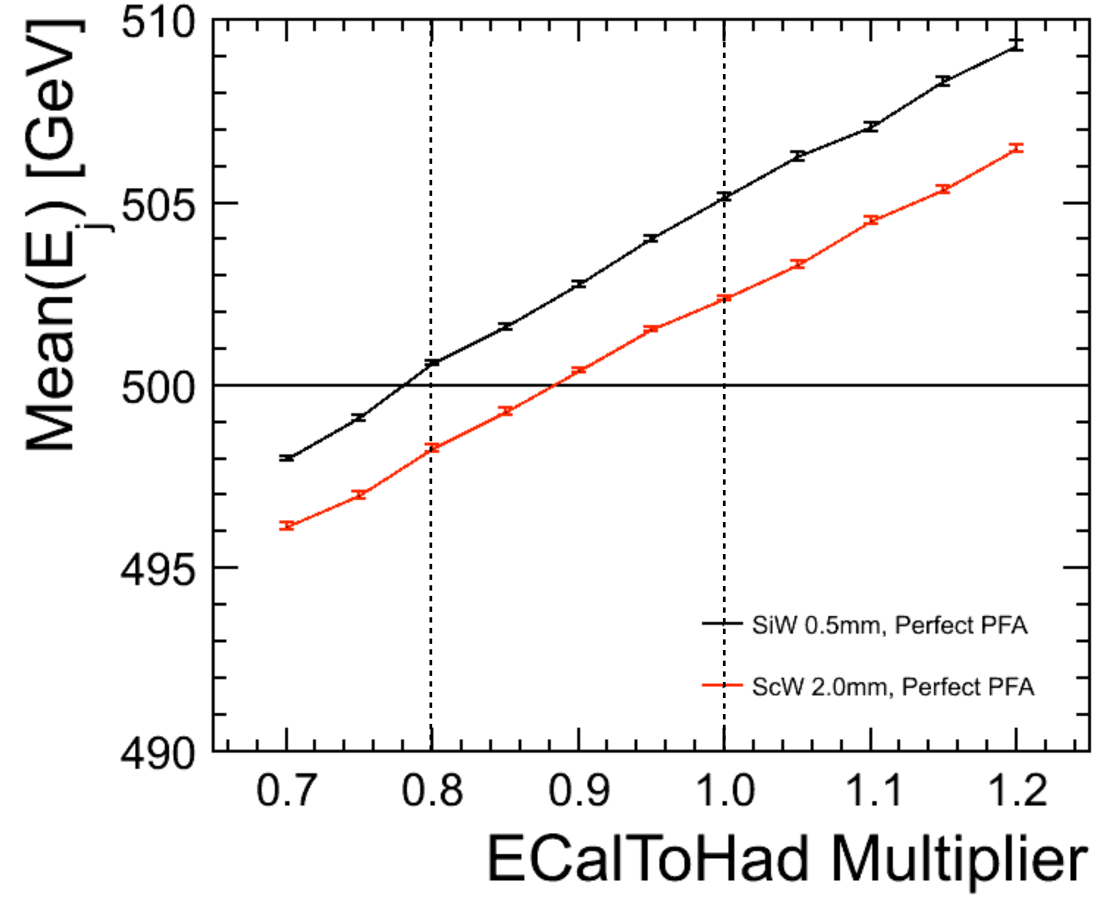




- With Birks' Law for scintillator, ScW and SiW calibration display rather similar behaviour, deweighting lower energy K0L; closer to a single particle calibration for 20 and 30 GeV samples.
- Experiment with energy-dependent calibration (via cluster energy correction function) to correct mean energies: small resolution improvement for 45 GeV jets, no impact at higher energies.

Perfect PFA: ECALToHAD Scan

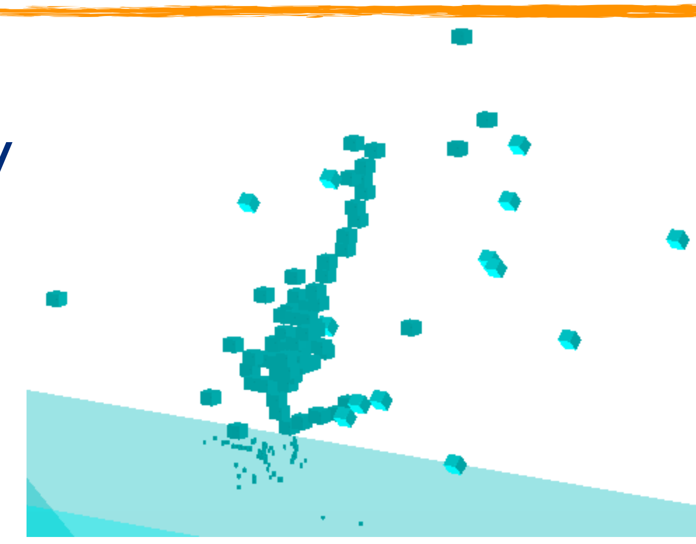




- Repeat earlier scan of jet energy resolution as function of ECALToHAD (no Birks' Law).
- Illustrates threshold issues, as more efficient collection of hits increases reported energies.
- Redefines/lowers "single particle baselines", but new ECALToHAD values still ~optimal.

10 GeV K0L

Standard PFA, lose some isolated hits.



Perfect PFA, able to collect all hits.