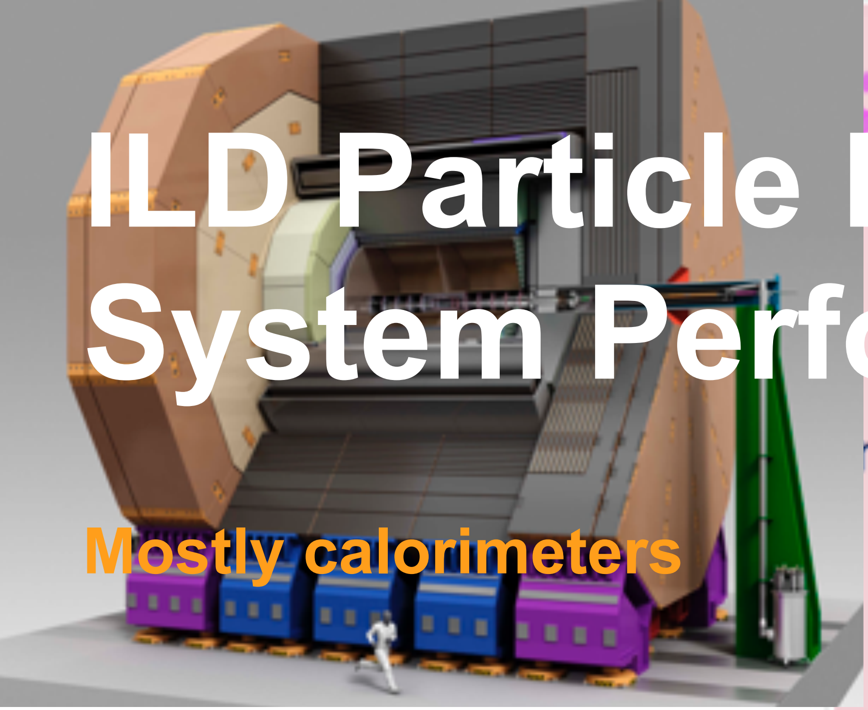


ILD Particle Flow and System Performance

Mostly calorimeters

ILD Meeting

Ichinsoseki, February 20, 2018

Felix Sefkow
DESY

This talk

The next 30 minutes.

Charge:

- **Reminder of design principles and performance drivers**
- **Reminder and review of requirements**
  - **impact of staged ILC**
- **New concepts, ideas, directions**

Since Santander (June 2016):

- **main emphasis on transition to DD4HEP and validation of new simulations**
- **refer to D.Jeans' very comprehensive talk on the status of ILD optimisation**

Today:

- **address the charge**
- **deeper understanding of particle flow performance and software compensations**

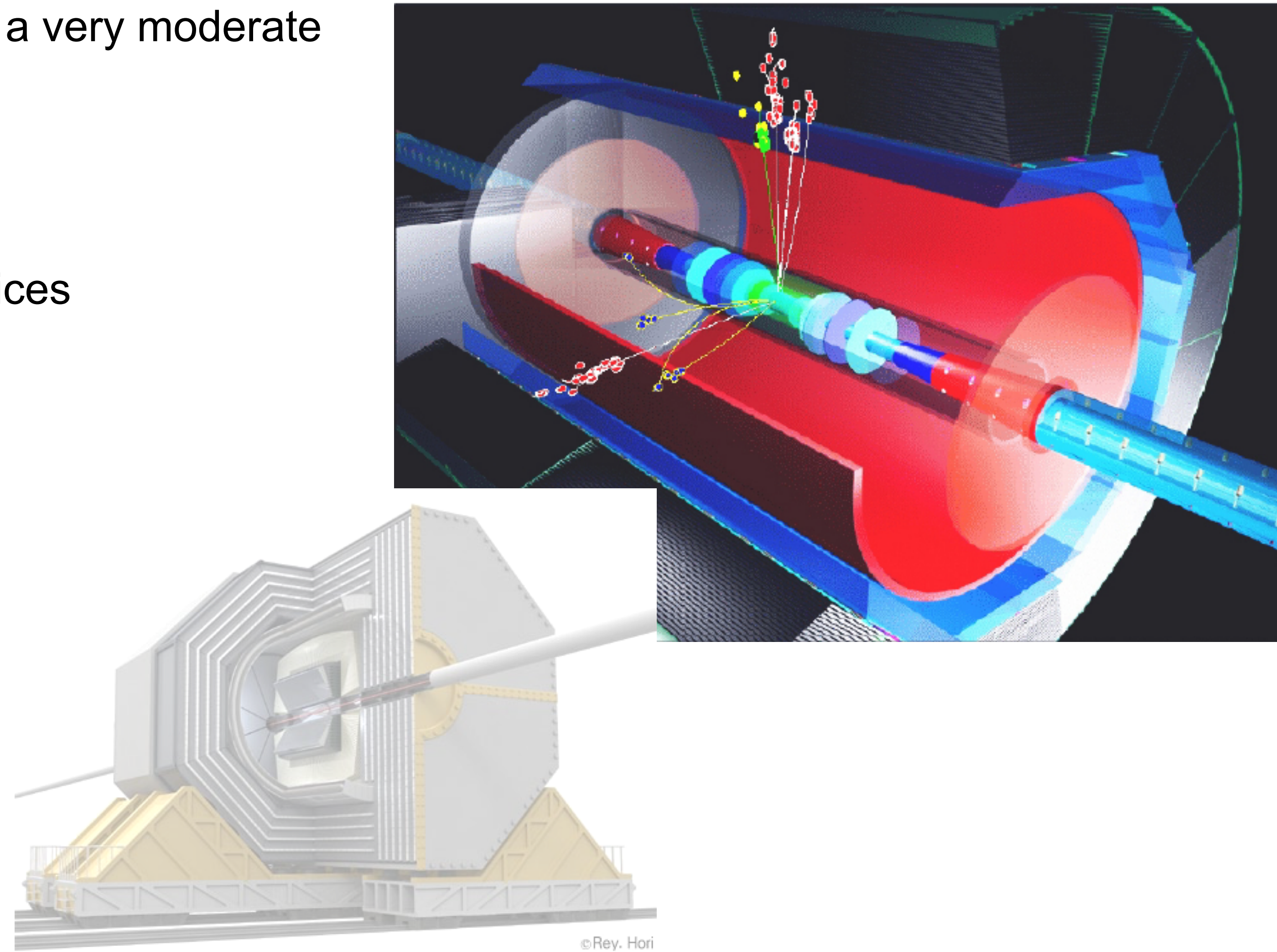
A personal view, not a rapporteur's talk

Reminders and review

ILD design principles

Particle flow since the turn of the century.

- The ILD design has been formulated in 2007 as a very moderate evolution from the TESLA detector (2001)
  - 15 years younger than LHC detectors
  - 15 years older than LHC upgrades
- Should be prepared to justify the very basic choices
- A Particle Flow detector
  - driven by W Z separation and tau ID
  - efficient and ultra-light tracking
  - ECAL and HCAL inside the coil
  - An ultra-compact ECAL
    - low X_0 high λ: tungsten
  - Low-noise active technologies
- Hermetic for missing momentum signatures
- Particle ID



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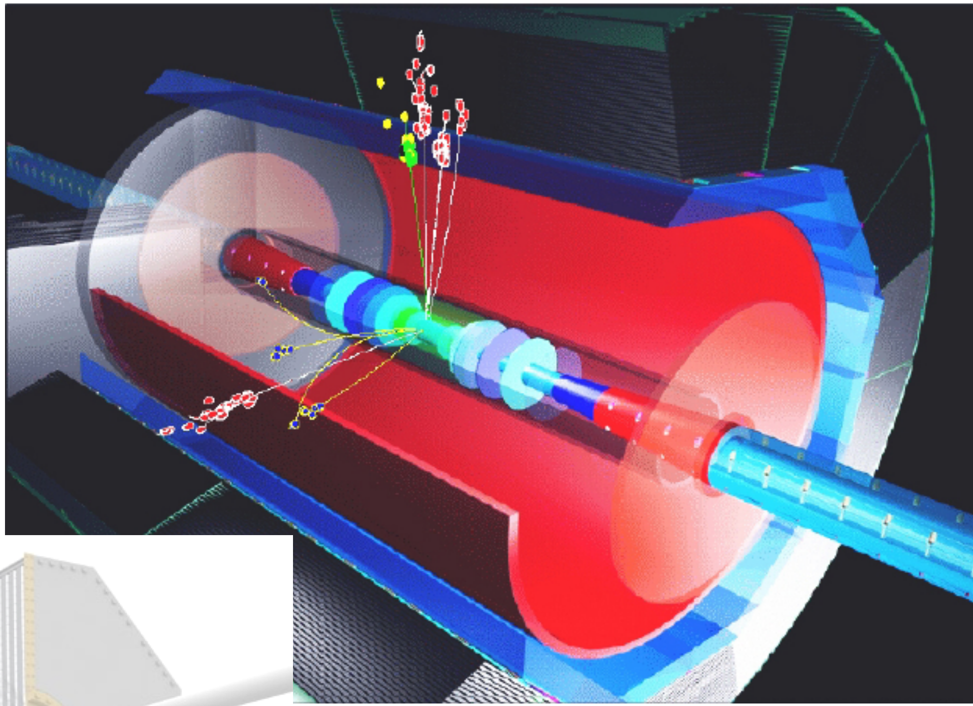
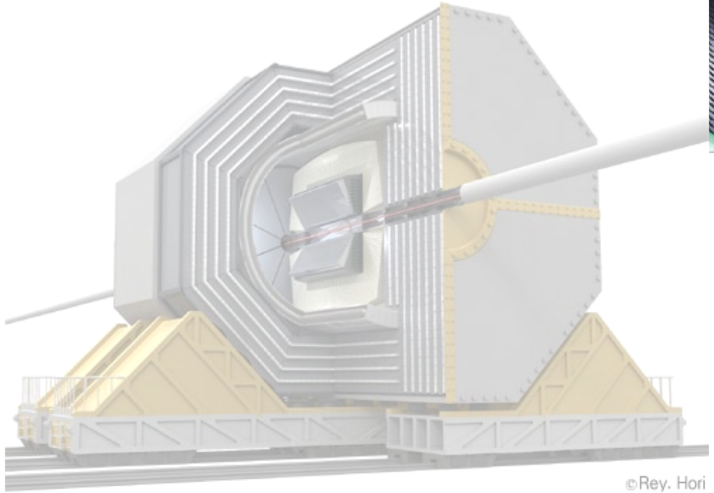




GESCHÄFTSVEREINIGUNG LIMMATQUAI-DÖRFLI

Calorimeter choices

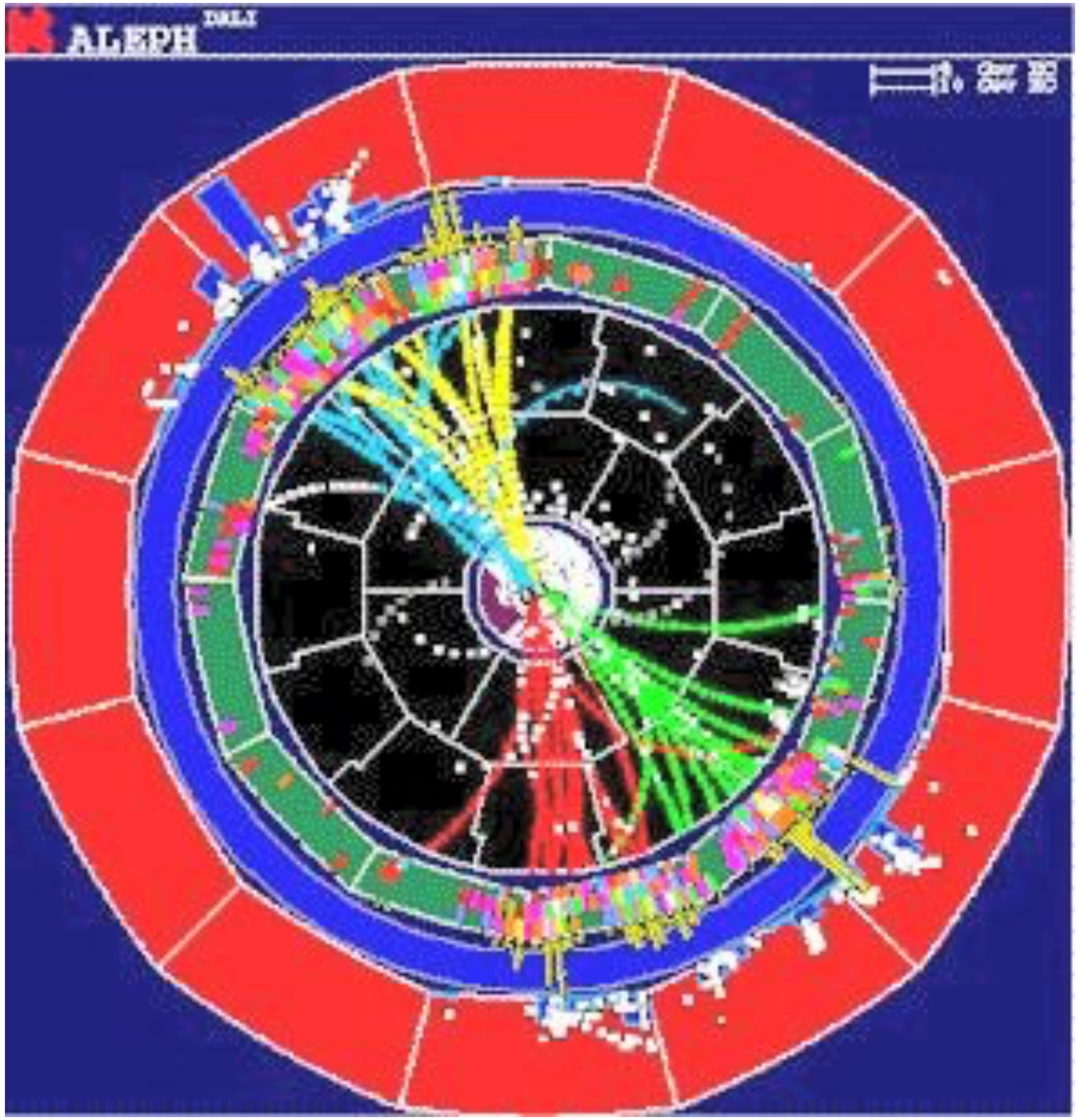
The basics.

- HCAL inside coil:
- lesson learnt from ALEPH

- At FCC-ee B limited to 2T
- Consider a coil in front of the entire calorimeter (DR)
- We should study how sensitive we are to material and distance between ECAL and HCAL

- CMS HGCAL uses Pb in e.m. section
- Performance degradation vs cost?

- And why does ILD have a short barrel large endcap?
    - SID has long barrel and plug



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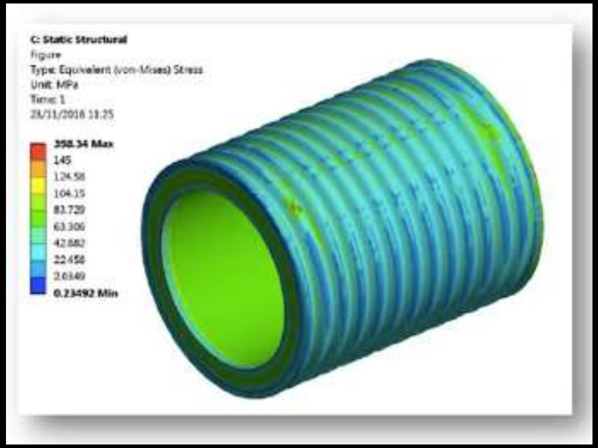
Detector solenoid

INFN Istituto Nazionale di Fisica Nucleare

- 2T field solenoid – Rin = 2 m
  - Can be made very thin ~30 cm total = 0.74 X_0 (0.16 λ) at $\theta = 90^{\circ}$
    - Calorimeter can be located outside coil
  - Small yoke thickness 50-100 cm Fe
    - Scales with B R^2 → cost reduction over large coil

Property	Value
Magnetic field in center [T]	2
Free bore diameter [m]	4
Stored energy [MJ]	170
Cold mass [t]	8
Cold mass inner radius [m]	2.2
Cold mass thickness [m]	0.03
Cold mass length [m]	6



Courtesy of H. ten Kate et al.

WG11 meeting, Jan 30 5 F. Bedeschi, INFN-Pisa

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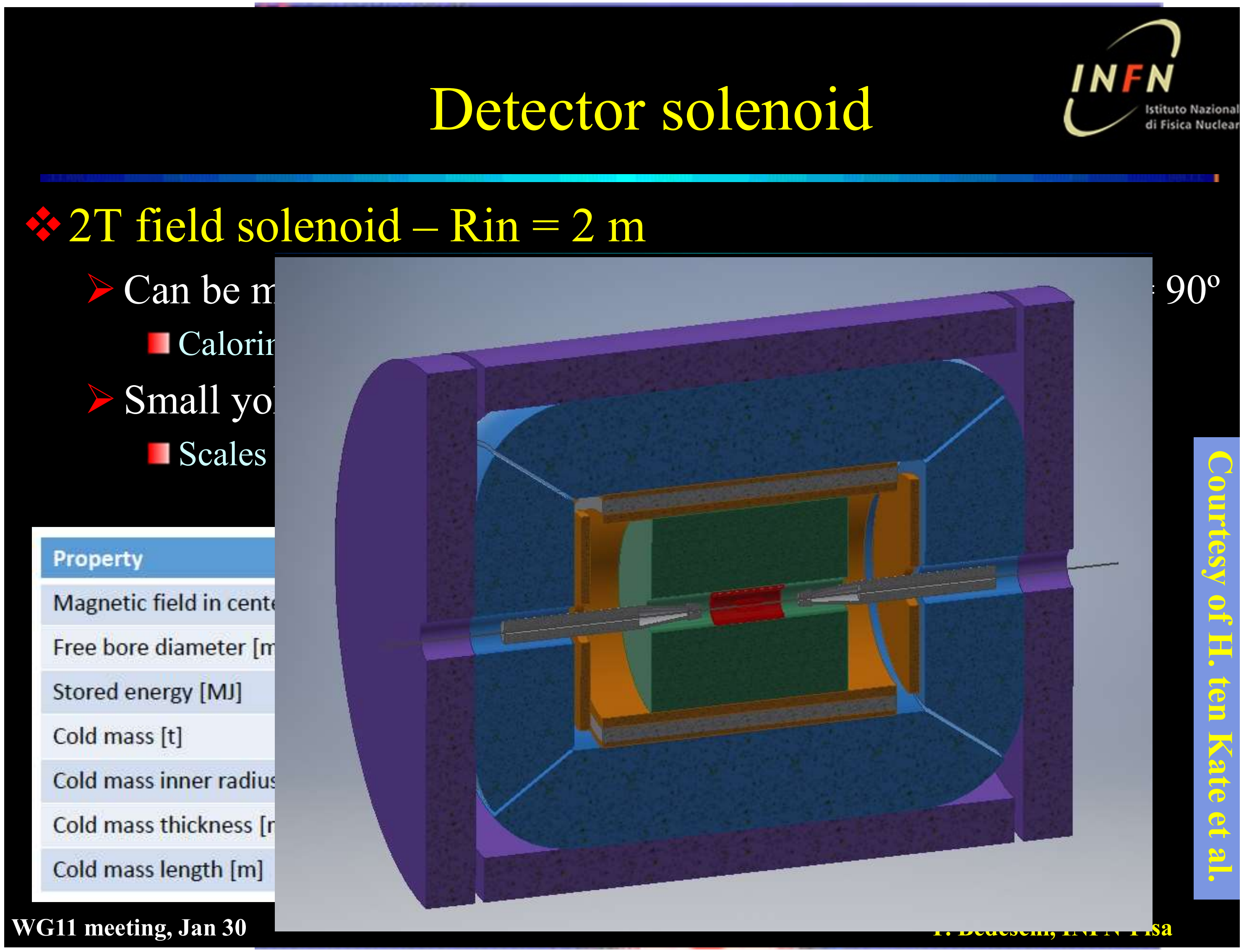
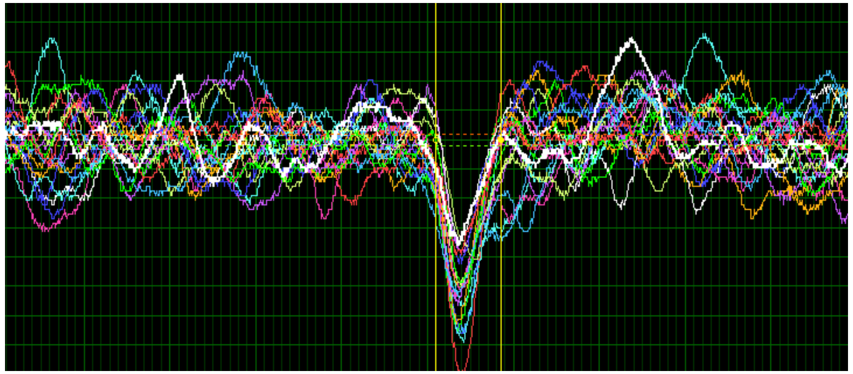
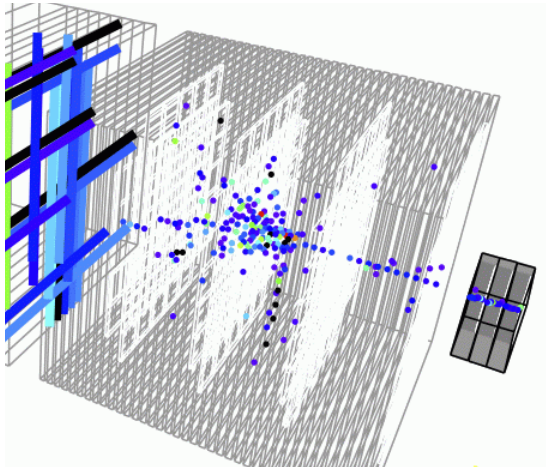


Low noise read-out technologies

It is the imaging.

- Signal over noise considerations drive the granularity - and cost, yes! - of CMS upgrade
  - smaller cells: lower noise and (for scintillator) larger signal
  - heavily debated recently
- Points to consider:
  - MIP calibration
    - with enough statistics MIP signals can be enriched
  - Imaging: event by event
    - MIPs connecting showers to tracks and shower seements with each other
    - muon tracking
  - Bandwidth
    - in ILC case limited by buffer depth in front end ASICs: require 10e-4 - 10e-5
    - with 1st generation SiPMs had few per-mil - and good images
- We should know the S/N requirements for particle flow performance
  - for square cell and for strip geometries

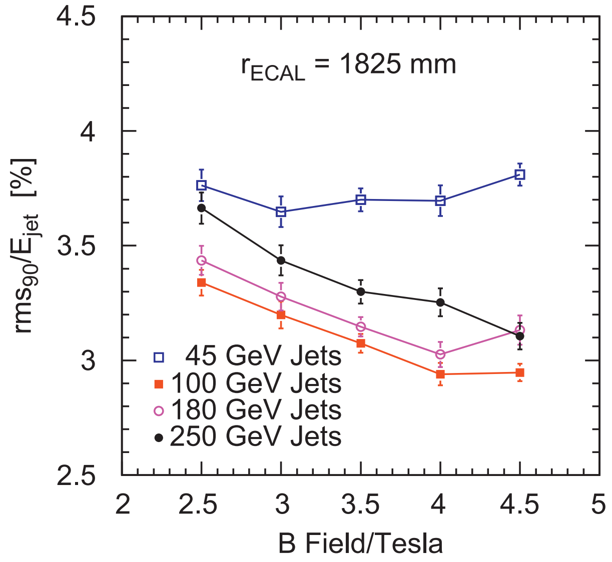


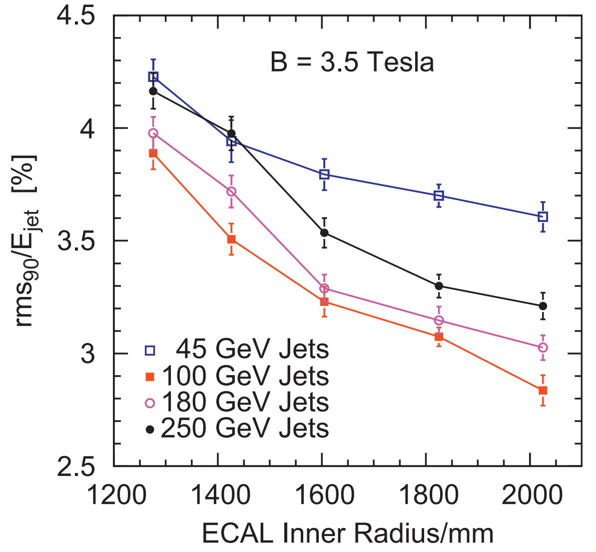


Detector optimisation for particle flow performance

The Thomson papers.

- Basic parameters: B field, ECAL radius, HCAL depth, cell sizes
  - longitudinal sampling studied later
- ILD parameters resulted from the LDC GLD merger and were guided by Pandora-based studies
  - documented in M. Thomaon NIM A611 (2009) 25-40 (250+ citations)
    - extend to CLIC energies, add background: NIM. A700 (2013) 153-162
  - nowhere near a “knee"
  - “Radius is more important than magnetic field.” (*percentages, not Yen*)
  - Flaw in cell size optimisation triggered recent software compensation studies (Eur.Phys.J. C77 (2017) 698)
- ILD - in conscious contrast to SiD - postponed the cost optimisation
  - until when?
- Tracker radius is the most important single cost driver
  - LILD, SILD comparison
- How about the other parameters?





Large vs small: first look at tau reconstruction

Collimated objects.

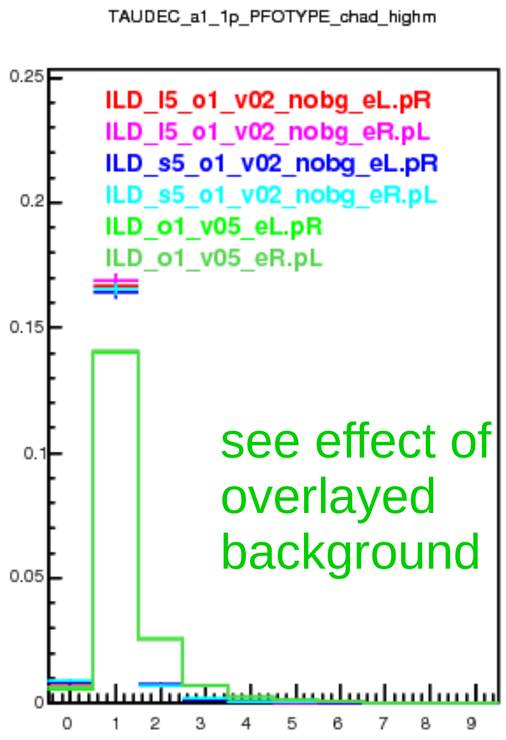
D.Jeans

- We know that dependences of performance measures on detector parameters are shallow.
- We already know from LOI and DBD exercises that ILD and SiD provide similar physics performance
- d Physics / d Performance also shallow (no knees)

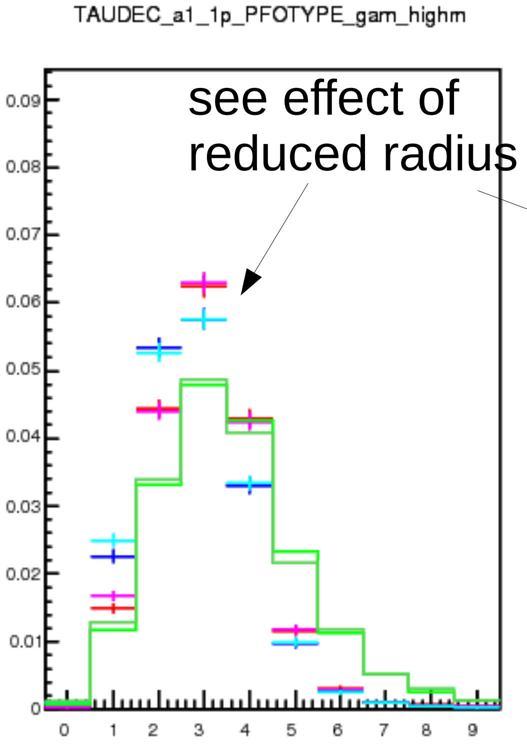
- So, what exactly are the new things we want to learn?

e.g. tau+ → a1+ nu, a1+ → pi+ pi0 pi0
usually 1 charged pion + 4 photons

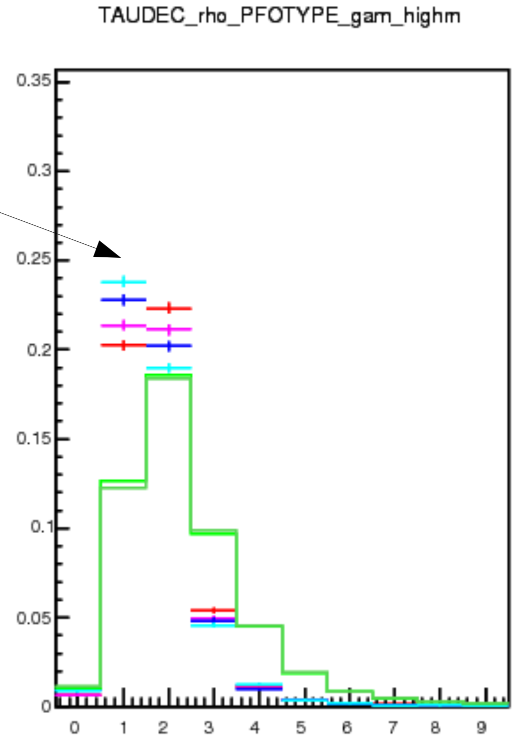
tau+ → rho+ nu
rho+ → pi+ pi0
1 chg pi + 2 photons



chg hadron PFOs / tau



photon PFOs / tau



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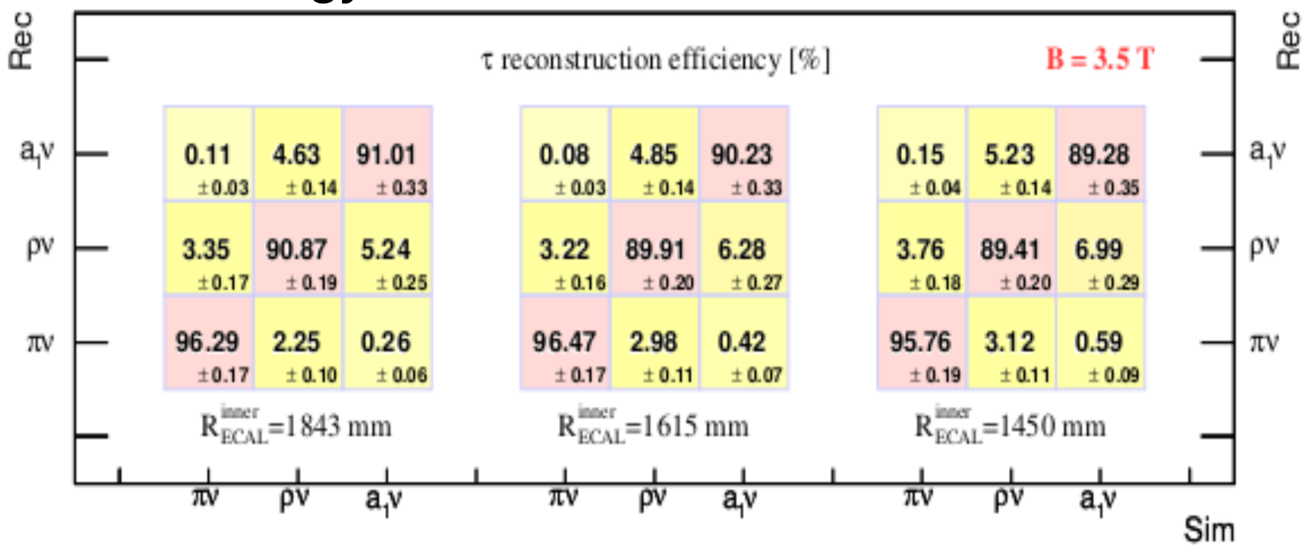
detector radius - tau decay mode reconstruction

tau energy 125 GeV



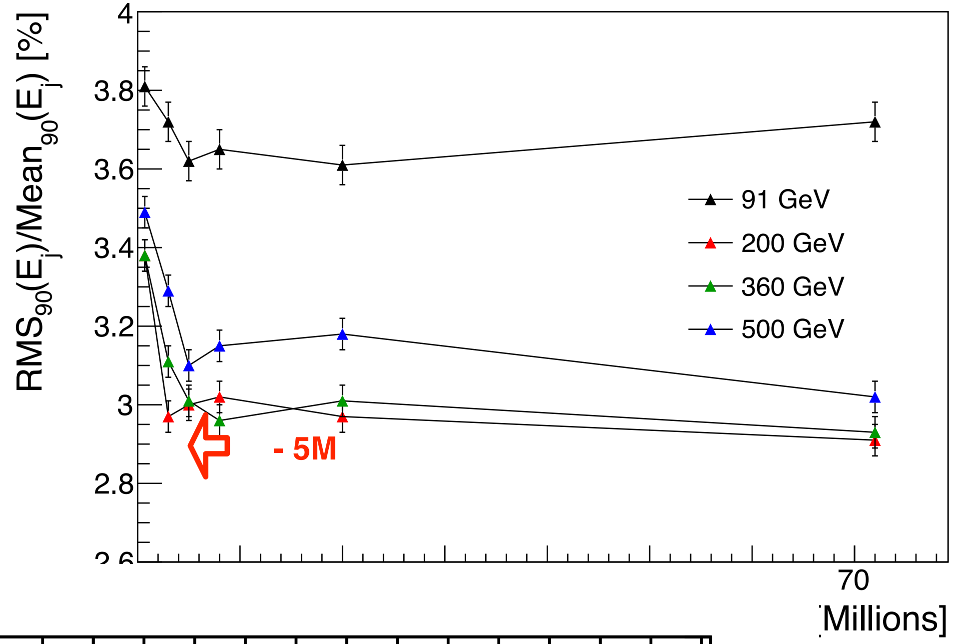
T. H. Tran

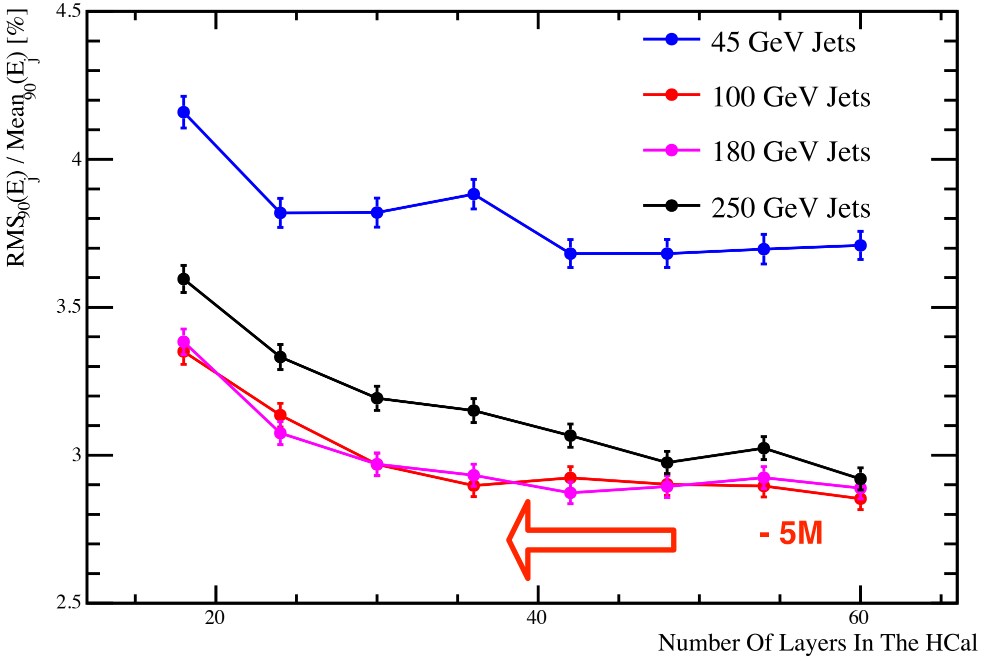
Fig. 2: Tau reconstruction efficiency and purity shown in percent for 1-prong decays estimated for ILD with SiW ECAL of inner radii 1843 mm, 1615 mm and 1450 mm. The corresponding magnetic field is 3.5 T as in the baseline design. Only the statistical uncertainty is shown.

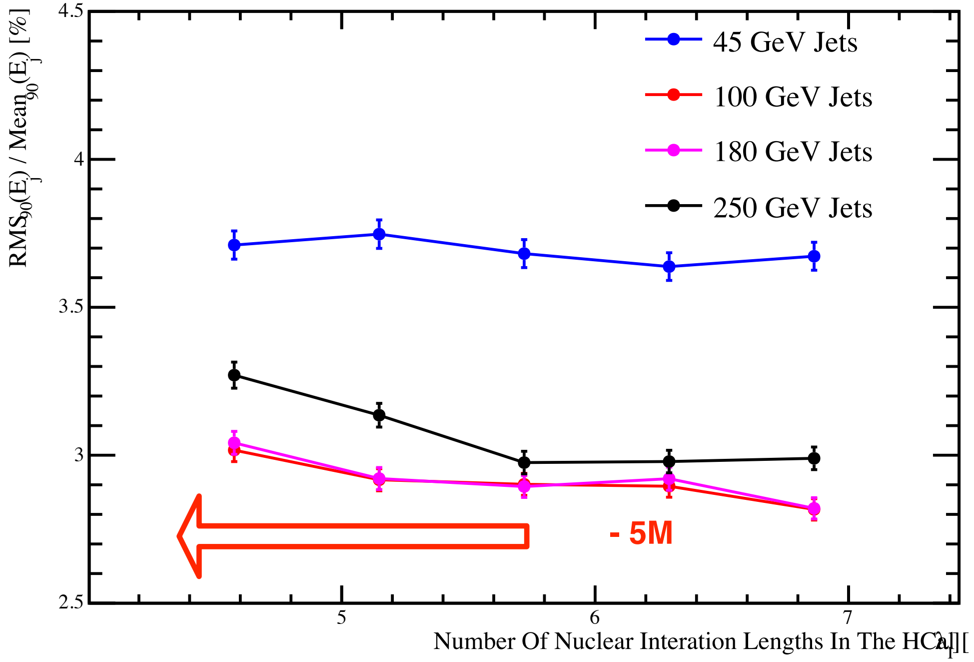
Cost optimisation examples

5 million dollar plots.

- Will be re-done after update of unit costs
- No dramatic changes expected
- Need these for other sub-detectors as well





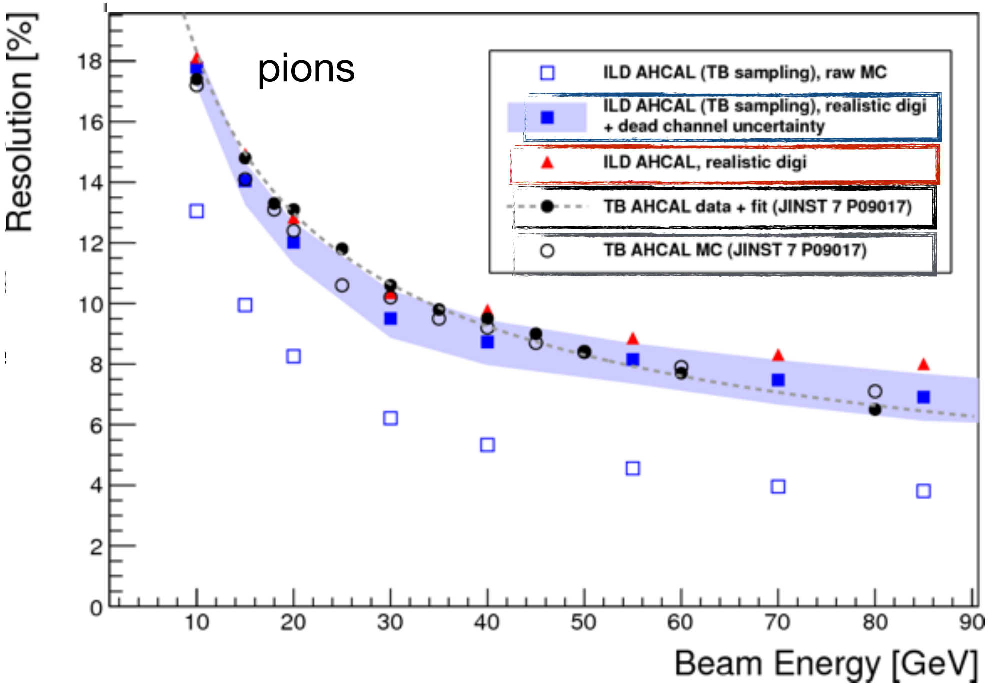


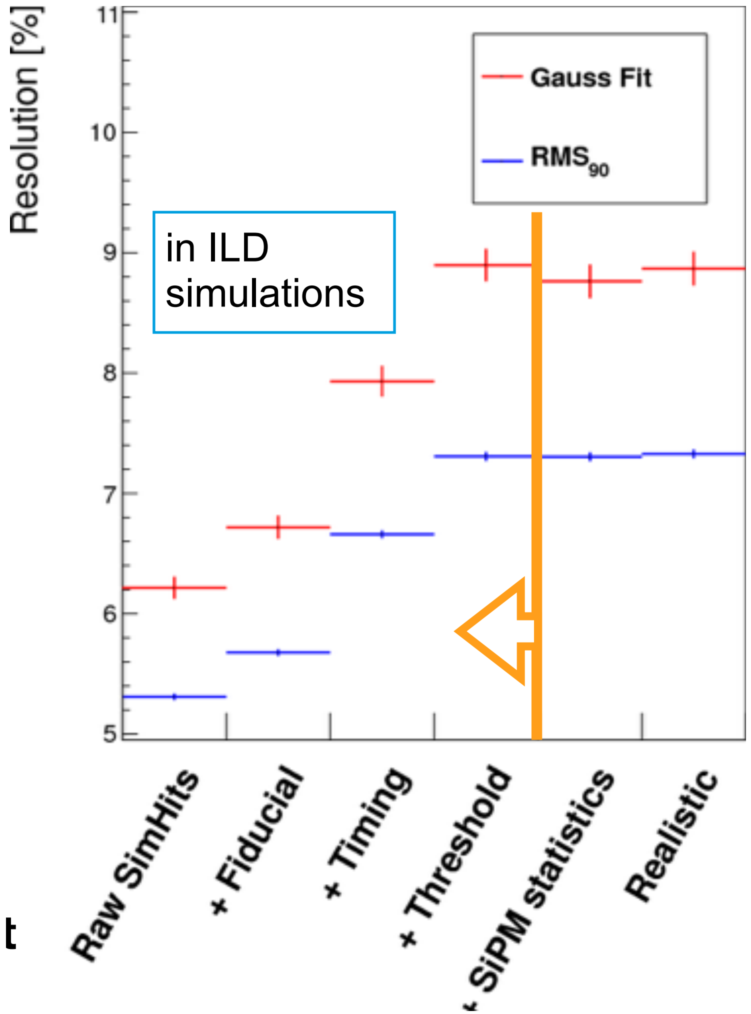
Instrumental effects

Digitisation and test beam validation.

- Reproduce test beam data in simulation, disentangle impact of various effects
- E.g. AHCAL insensitive to detailed SiPM
- Similar studies for the ECALs
  - e.g. robust against random dead channels

Thesis O. Hartbrich 2016



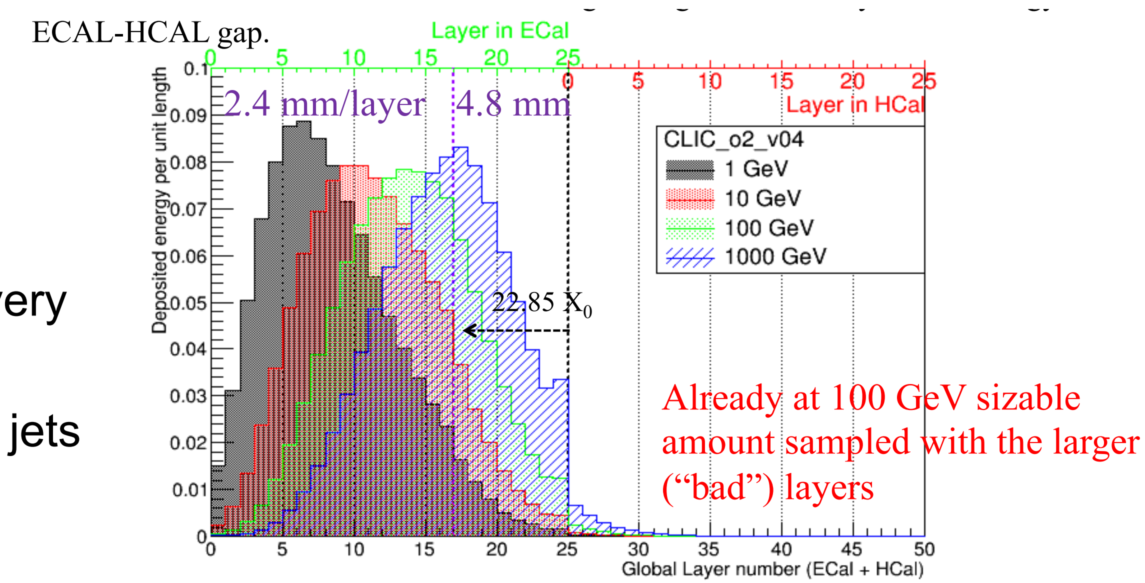


- Establish consistency of test beam with ILD simulations
- Should now be possible for SDHCAL, too

Single particle performance

M. Weber, ECFA-LC Santander 2016

Example photons.



- Requirements less well specified than for jet energies
- **Resolution for photons and electrons**
  - the 750 GeV anomaly is gone, but X→γγ remains discovery channel
  - photon resolution more sensitive to ECAL sampling than jets
- Optimisation of CLICdet resulted in change of ECA design: constant fine sampling
- Leakage from ECAL into HCAL
- Dynamic range for electrons?
- **Particle ID**
- Requirements for muon pion and electron pion separation?
- Studies so far focussed on isolated partuicles
  - should look into jets with semi-leptonic b and c decays
  - cross-calibration of v vertex-based HF tag efficiencies

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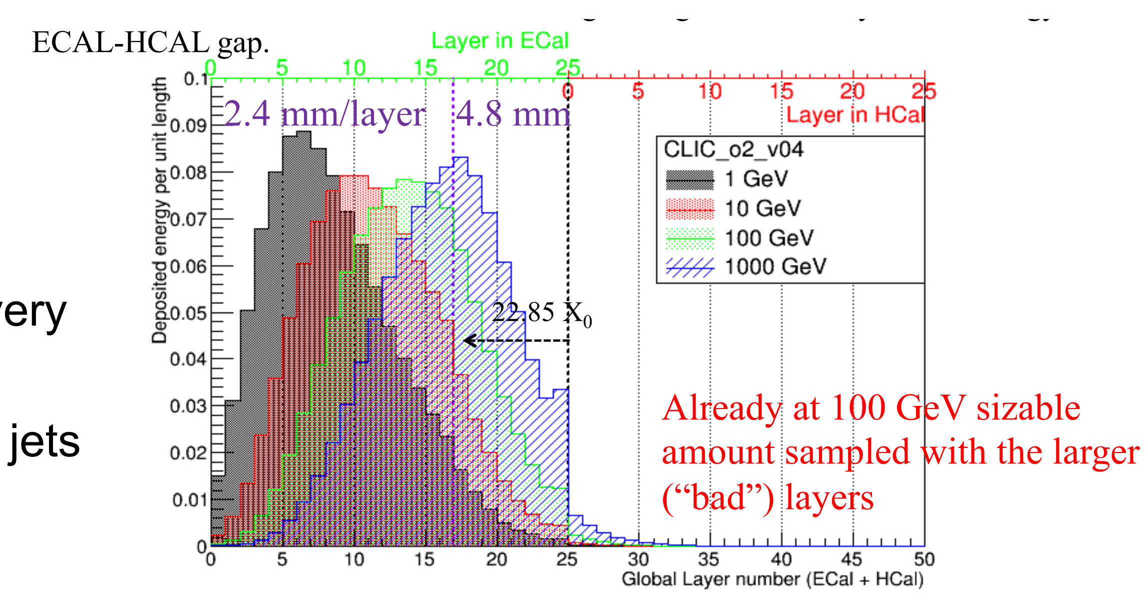
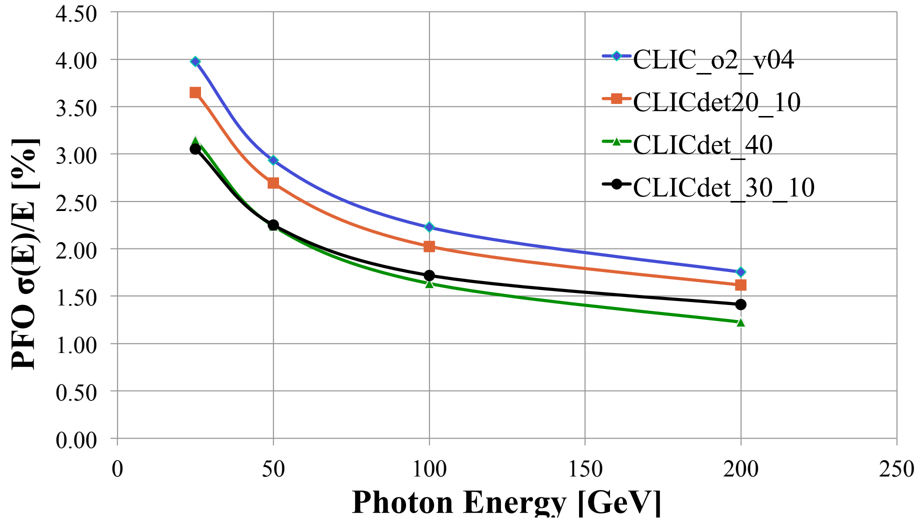


Better performance with larger segmentation

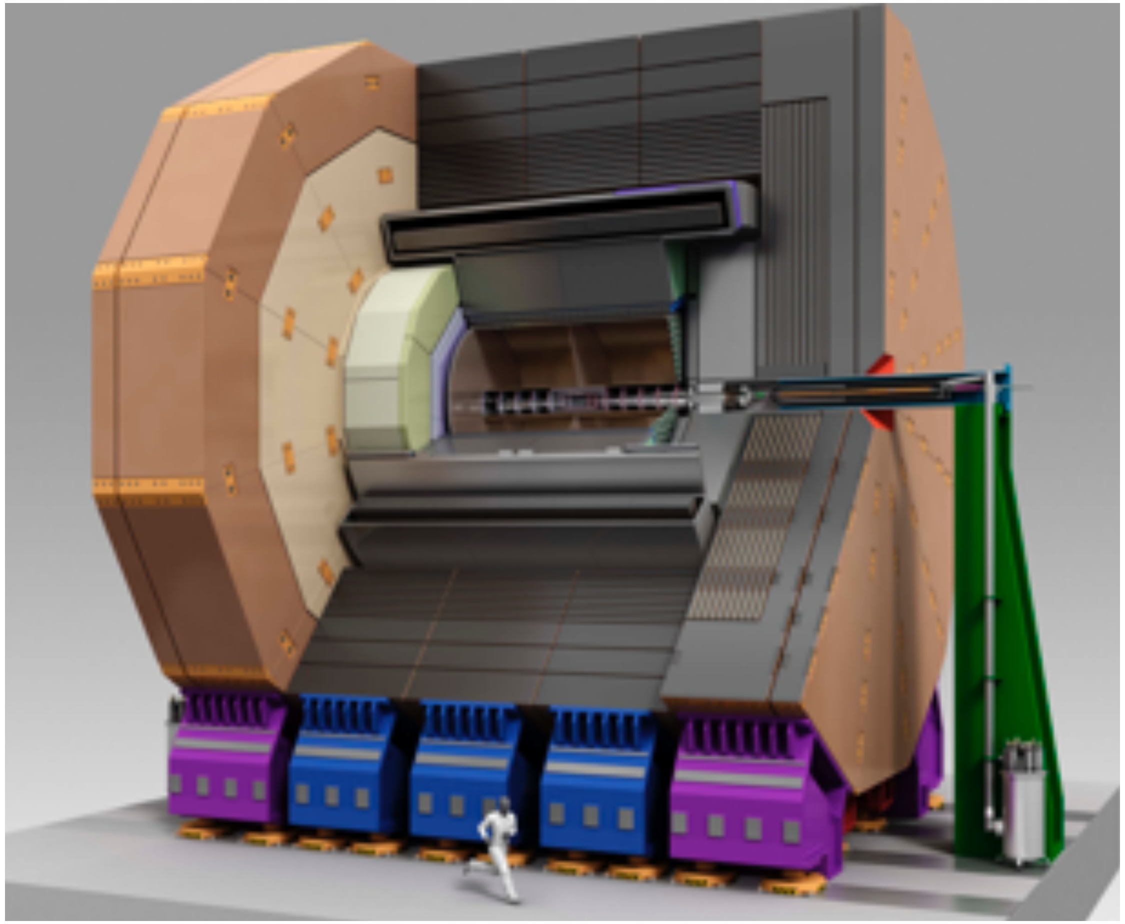


Staged ILC

Detector implications.

- CLIC serves as a good reference to how the centre-g-mass energy affects the detector design
- Main impact is on total depth of calorimeter system in terms of hadronic interaction lengths
  - granularity and sampling only mildly affected, but regions with high granularity extend more deeply
  - May drop a few of the outer HCAL active layers
- Outwards: Coil radius and yoke cannot be staged
- Inwards: not seriously…
- However, if worse comes to worst:
  - ILC250: HCAL + Si pre-shower + TPC
  - ILC500: HCAL + full ECAL + Si tracker

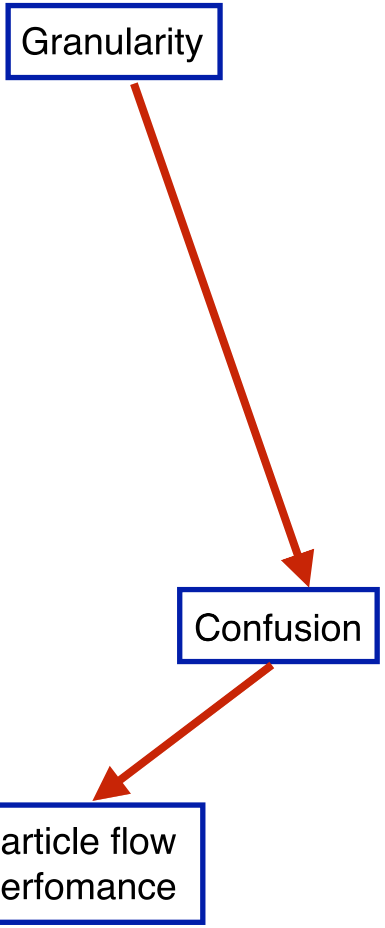
- Emphasise intrinsic extendibility of LC and optimise for 500-1000 GeV

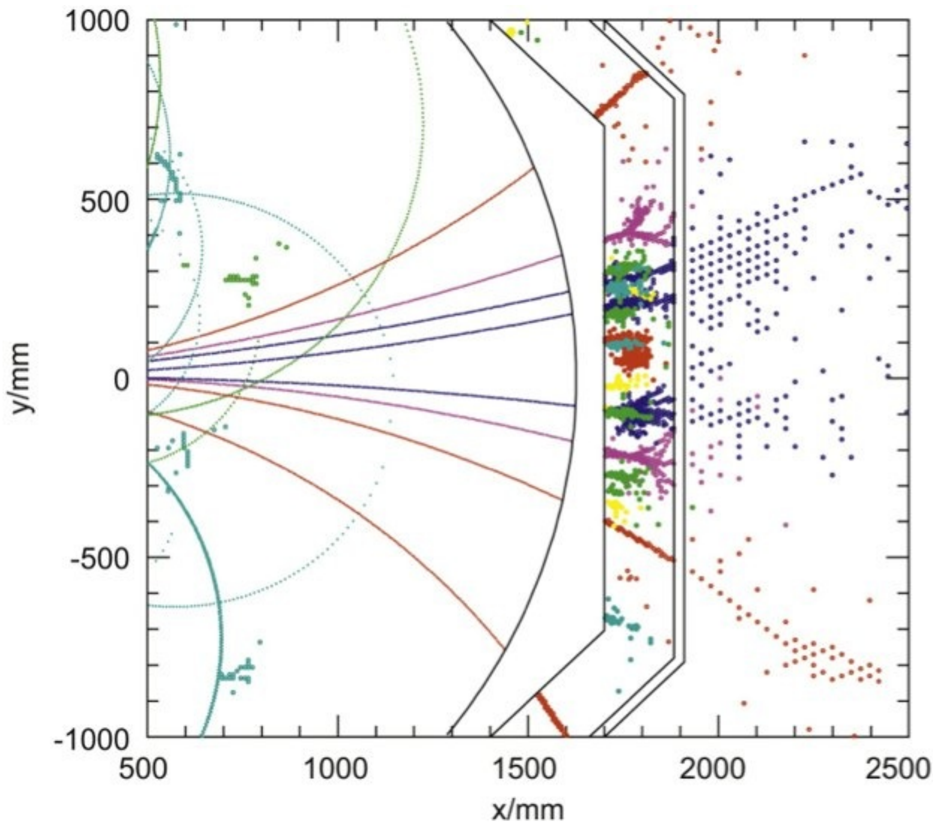


Understanding and optimising particle flow

Energy resolution and granularity

Not: versus.





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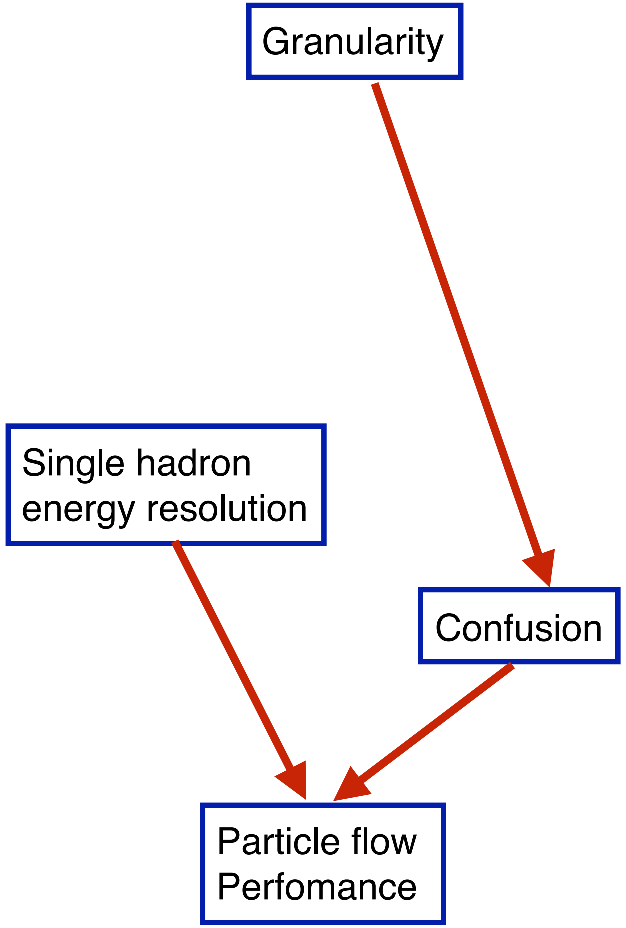

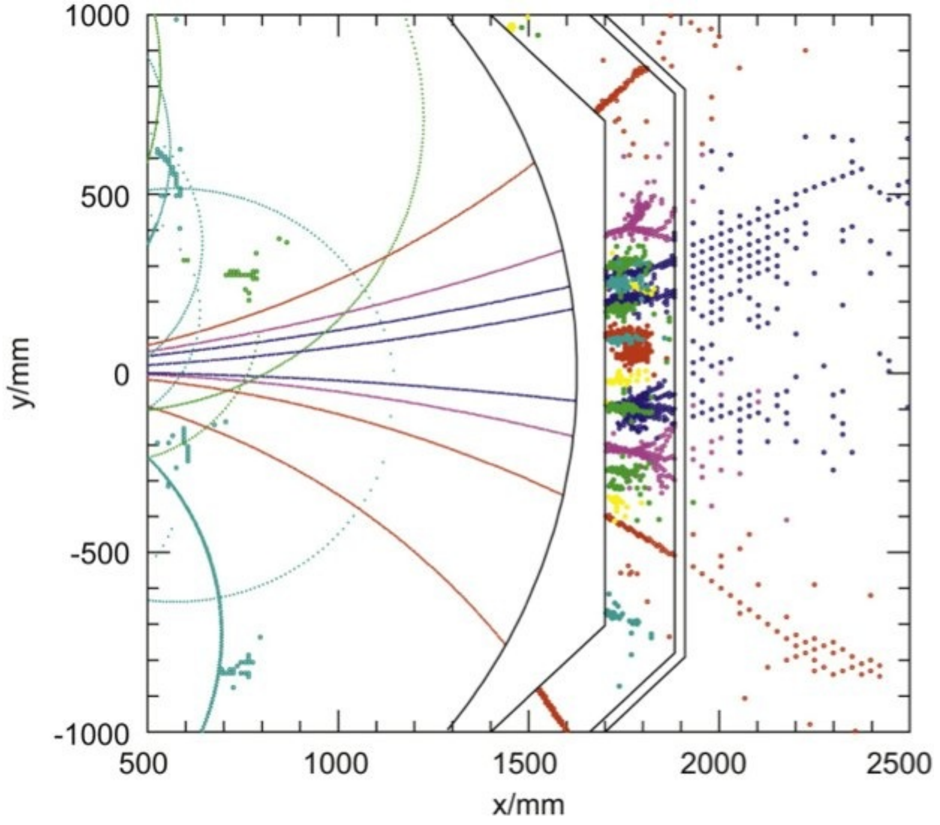

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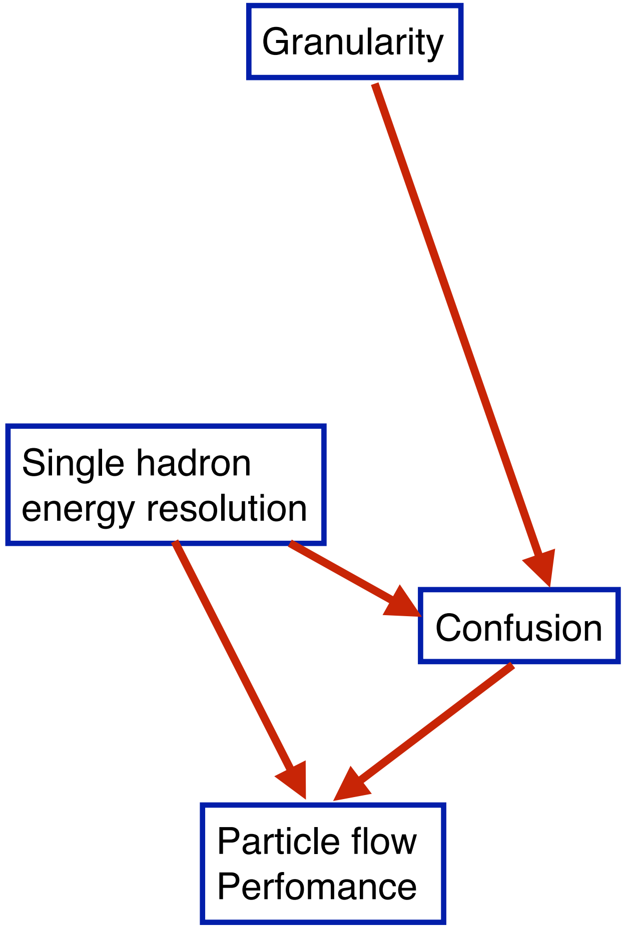

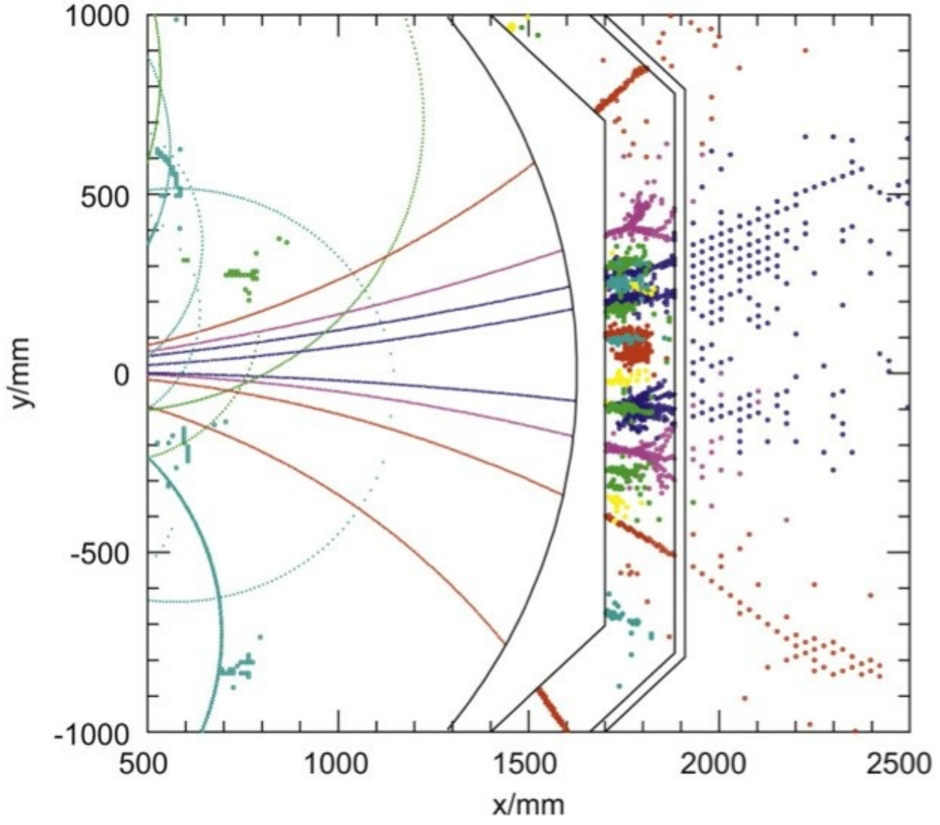

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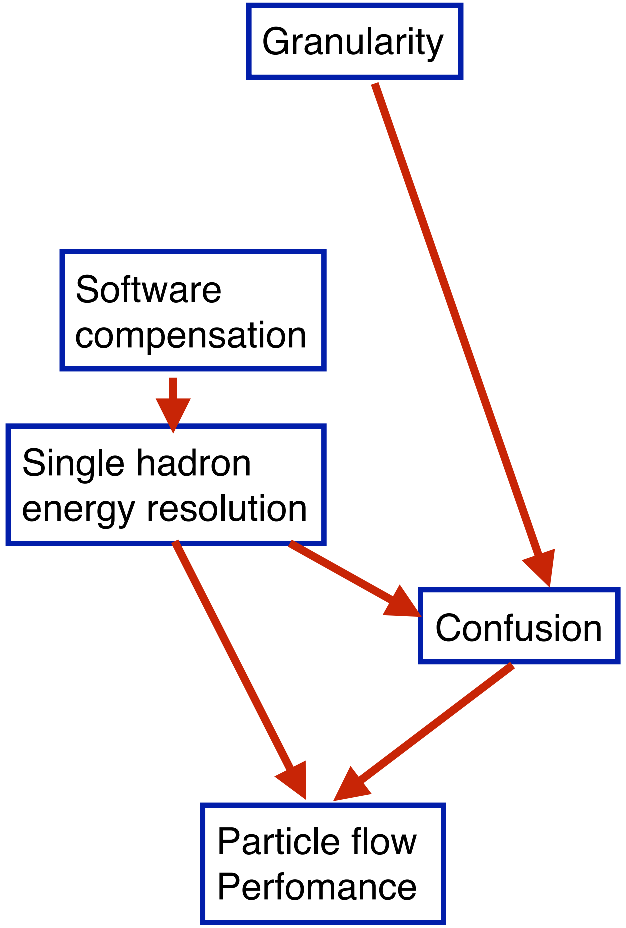

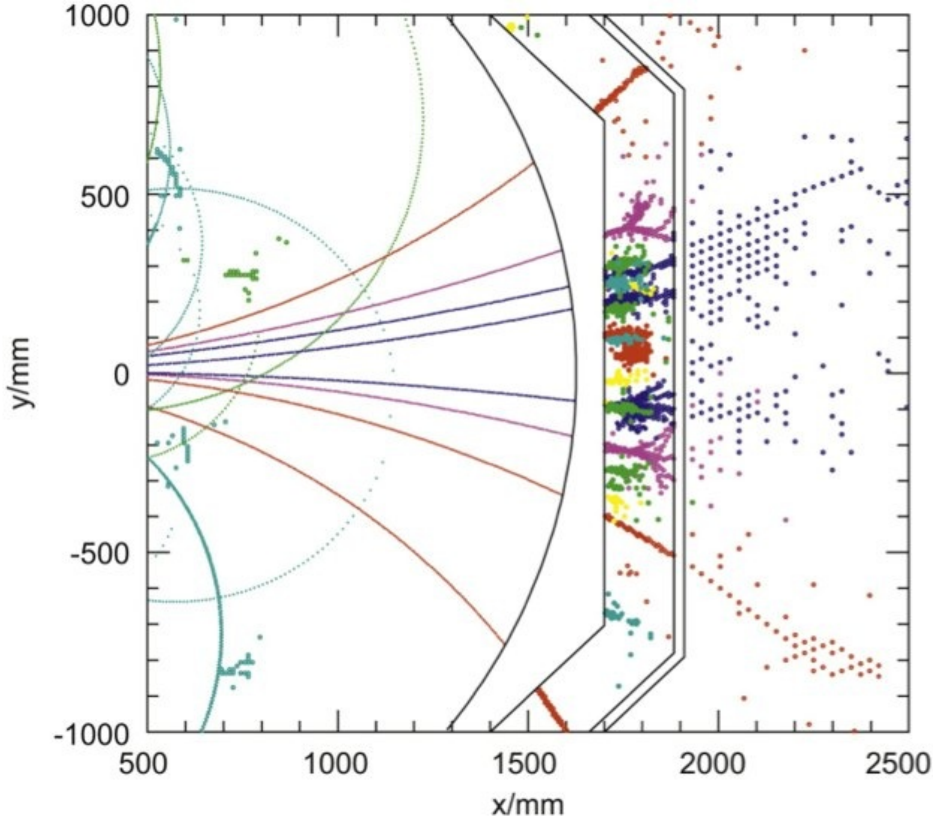

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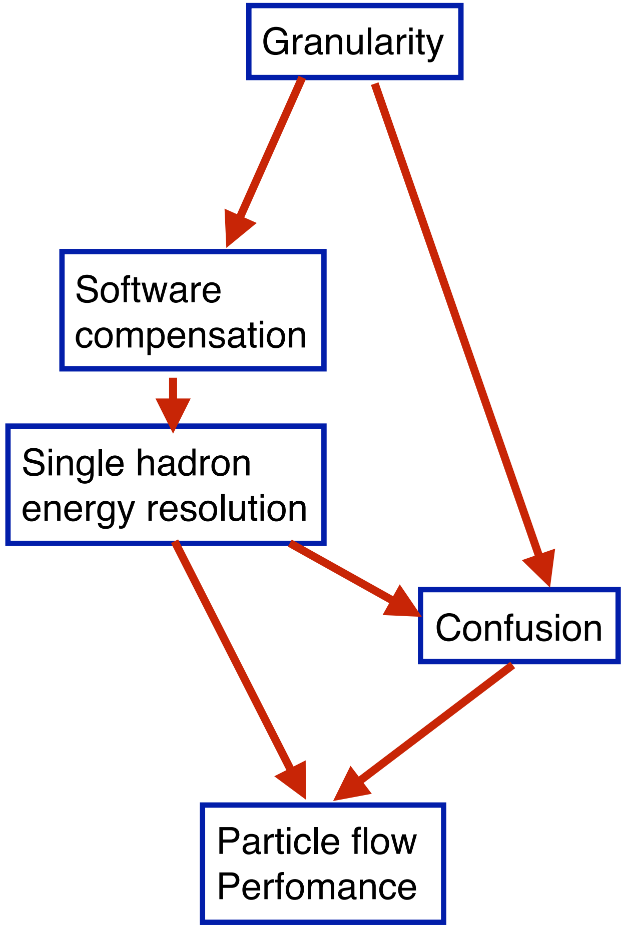

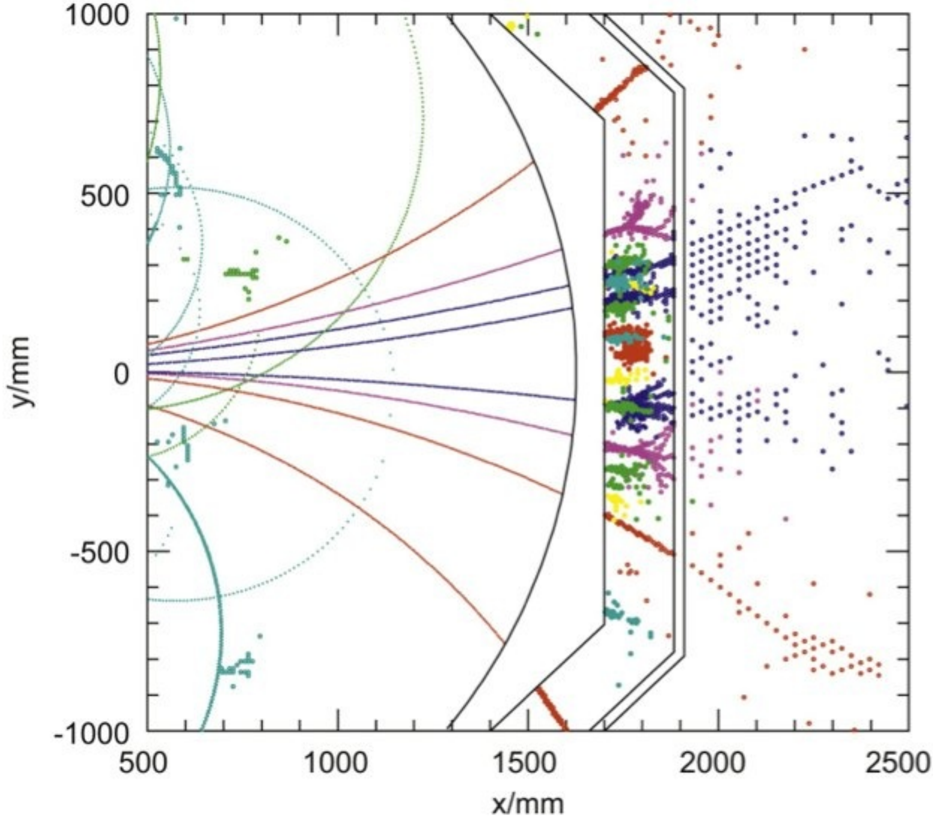

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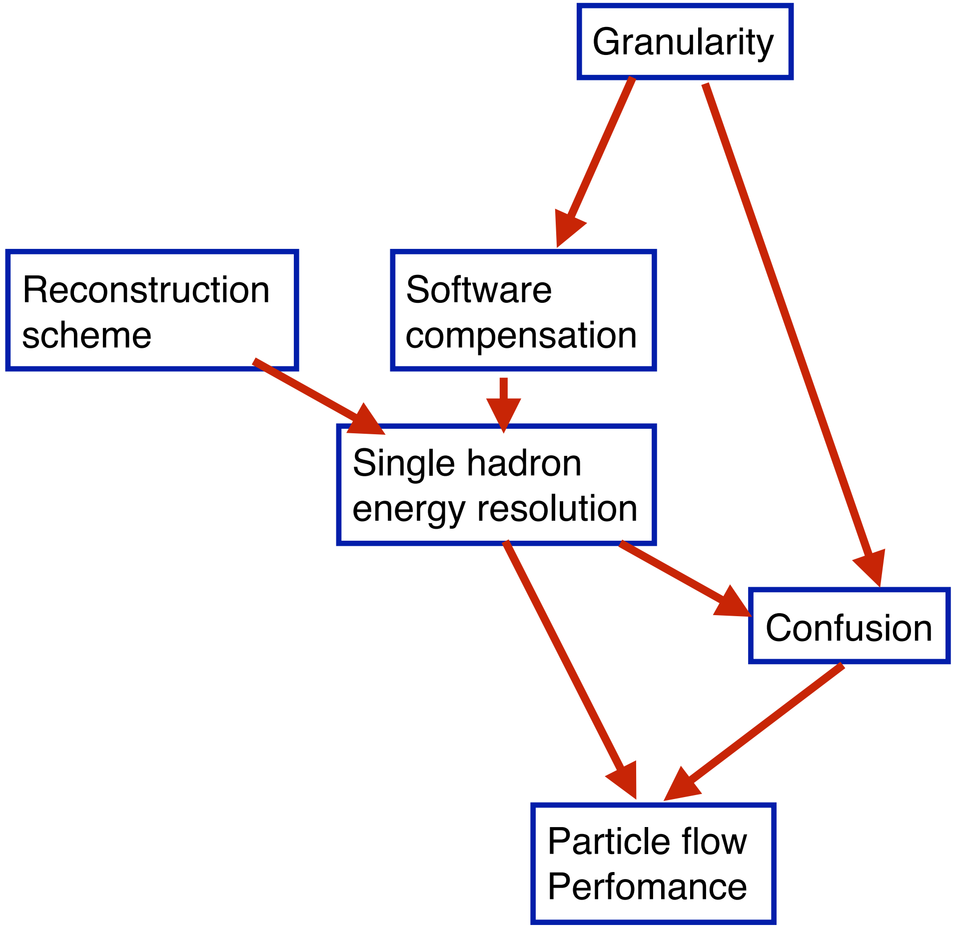

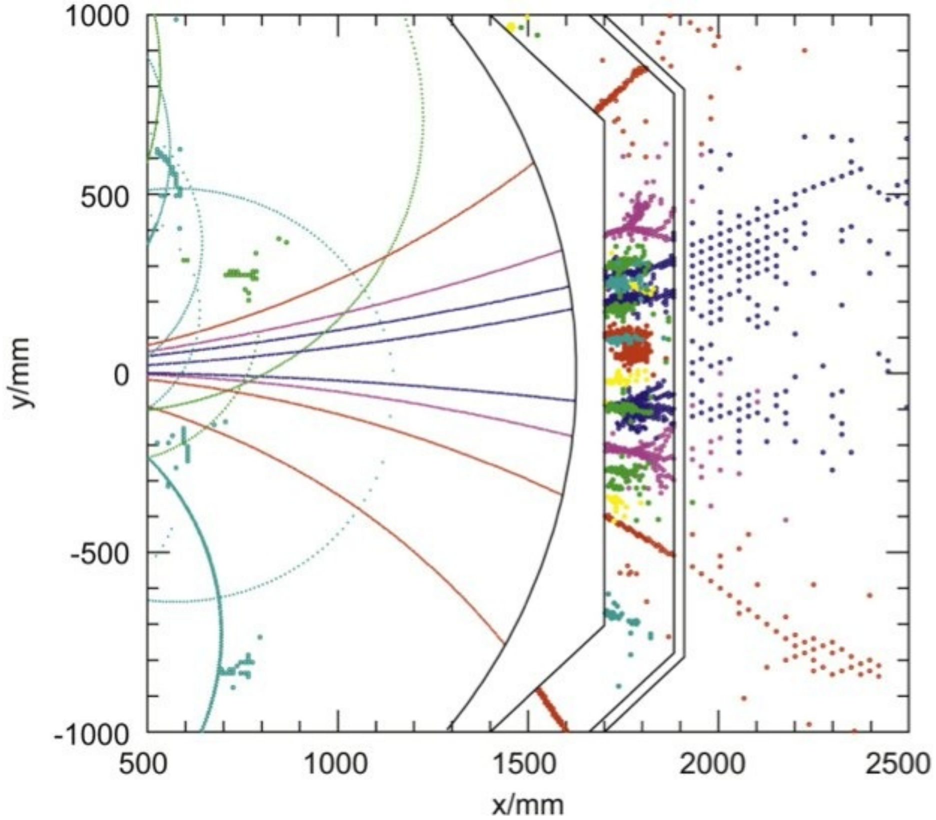

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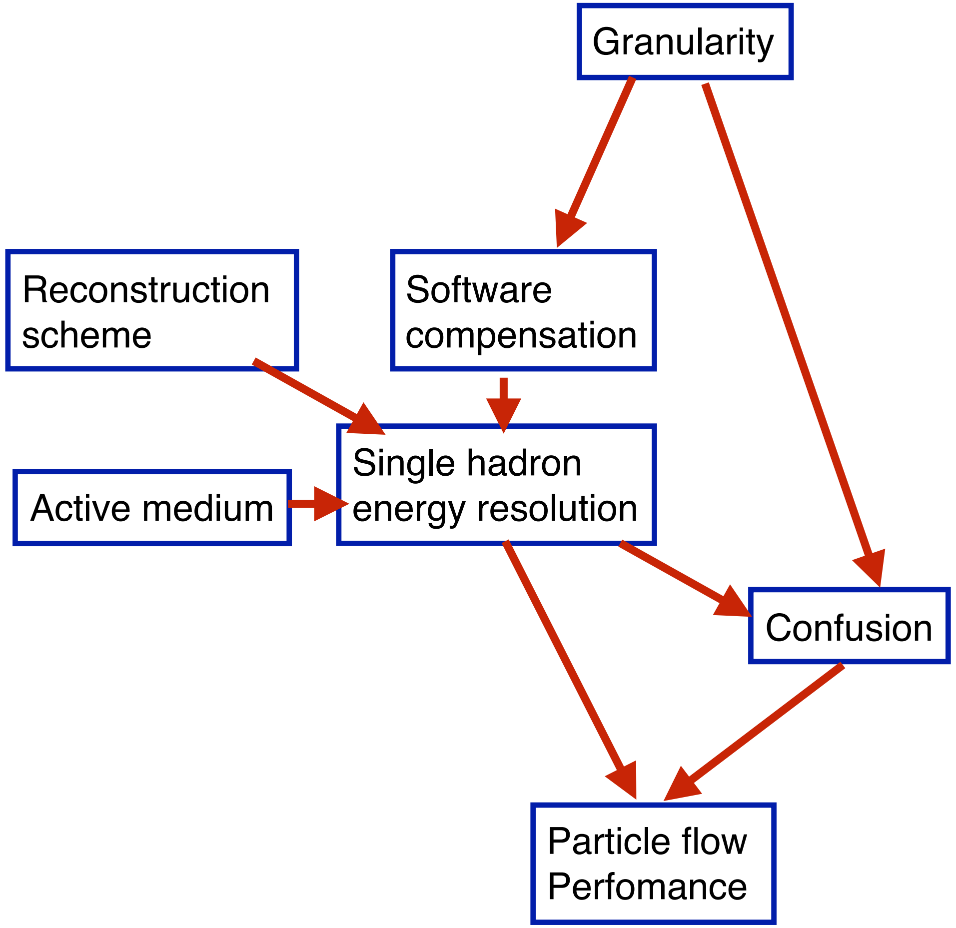
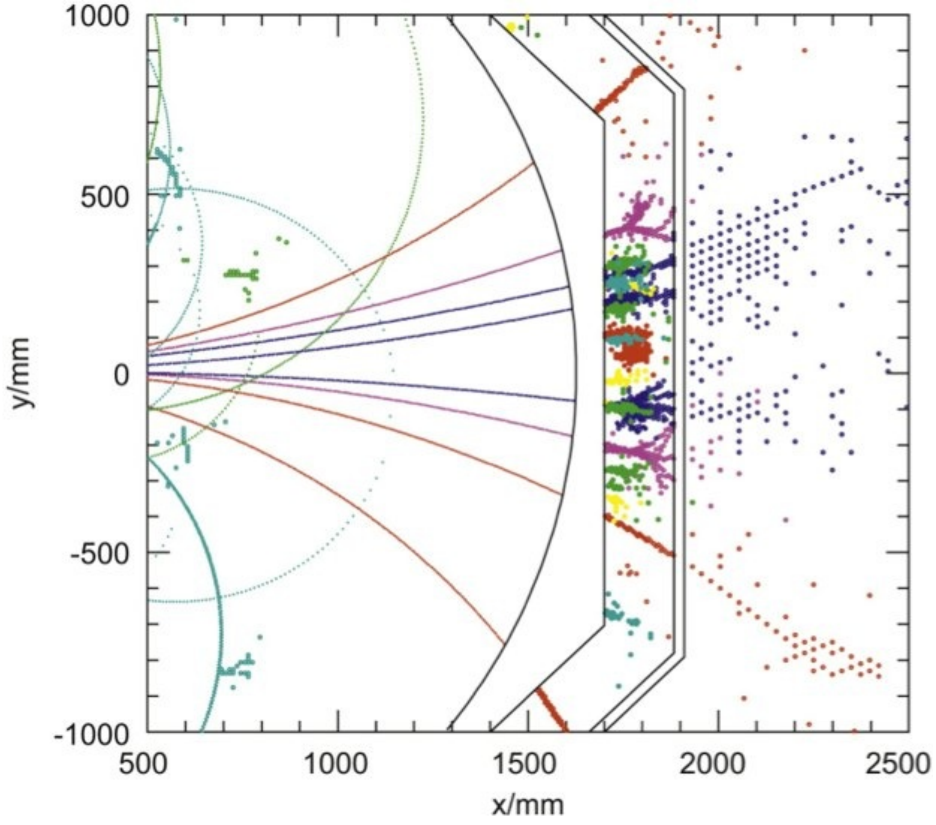


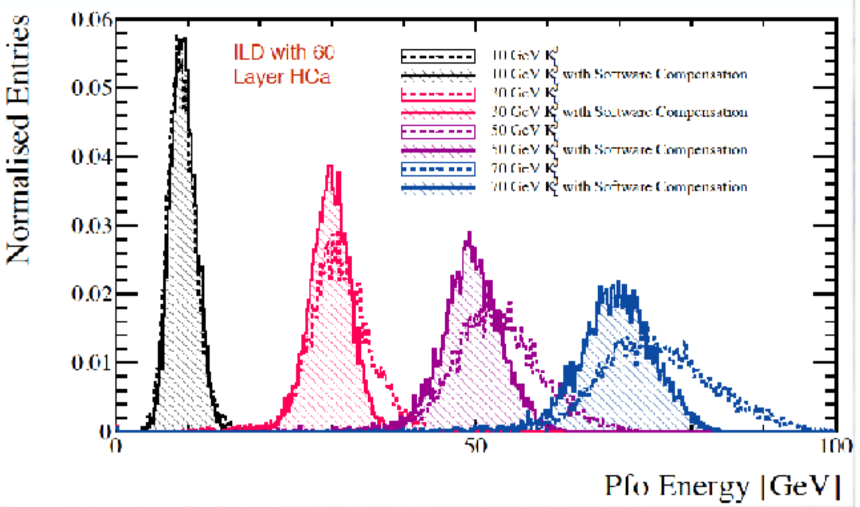


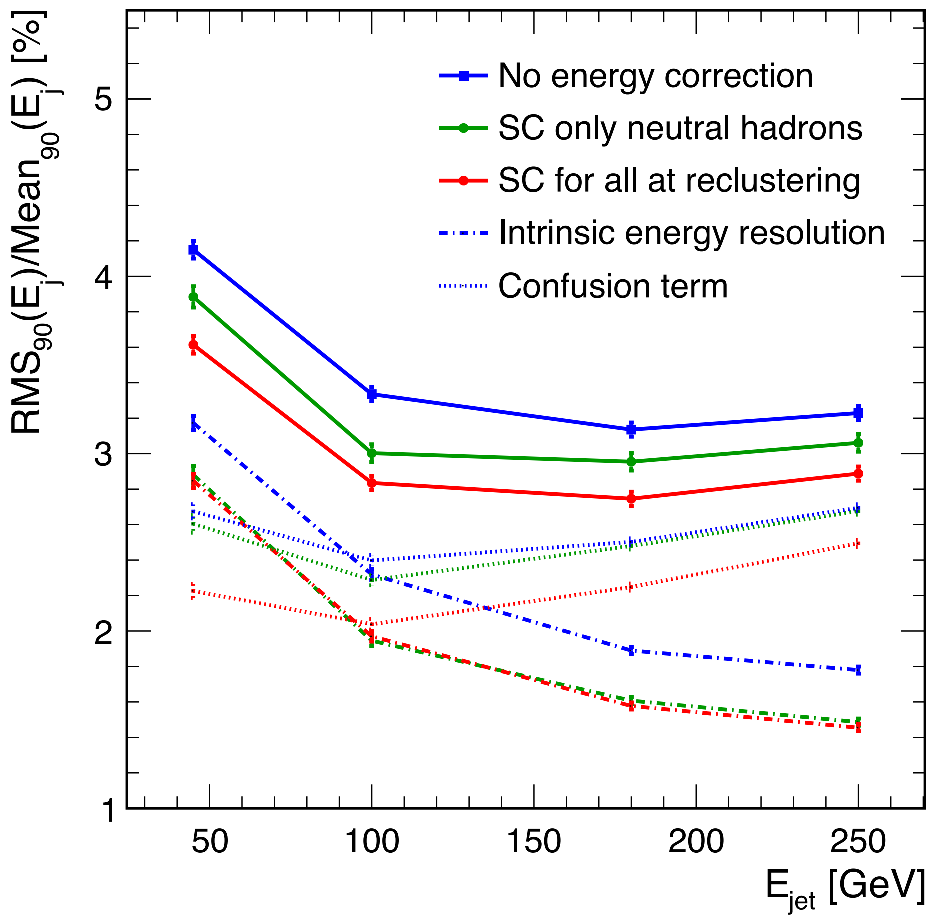
Particle flow and software compensation

Implemented in Pandora.

Eur.Phys.J. C77 (2017) 698
DESY and Cambridge

- "Software compensation": cell energy weighting to optimise single hadron resolution
- Improves resulution of identified neutrals
  - dominant contribution to JER for E < 100 GeV
- Improved precision to assist in resolving pattern recognition ambiguities
  - main effect at higher jet energies
- Altogether best performance so far

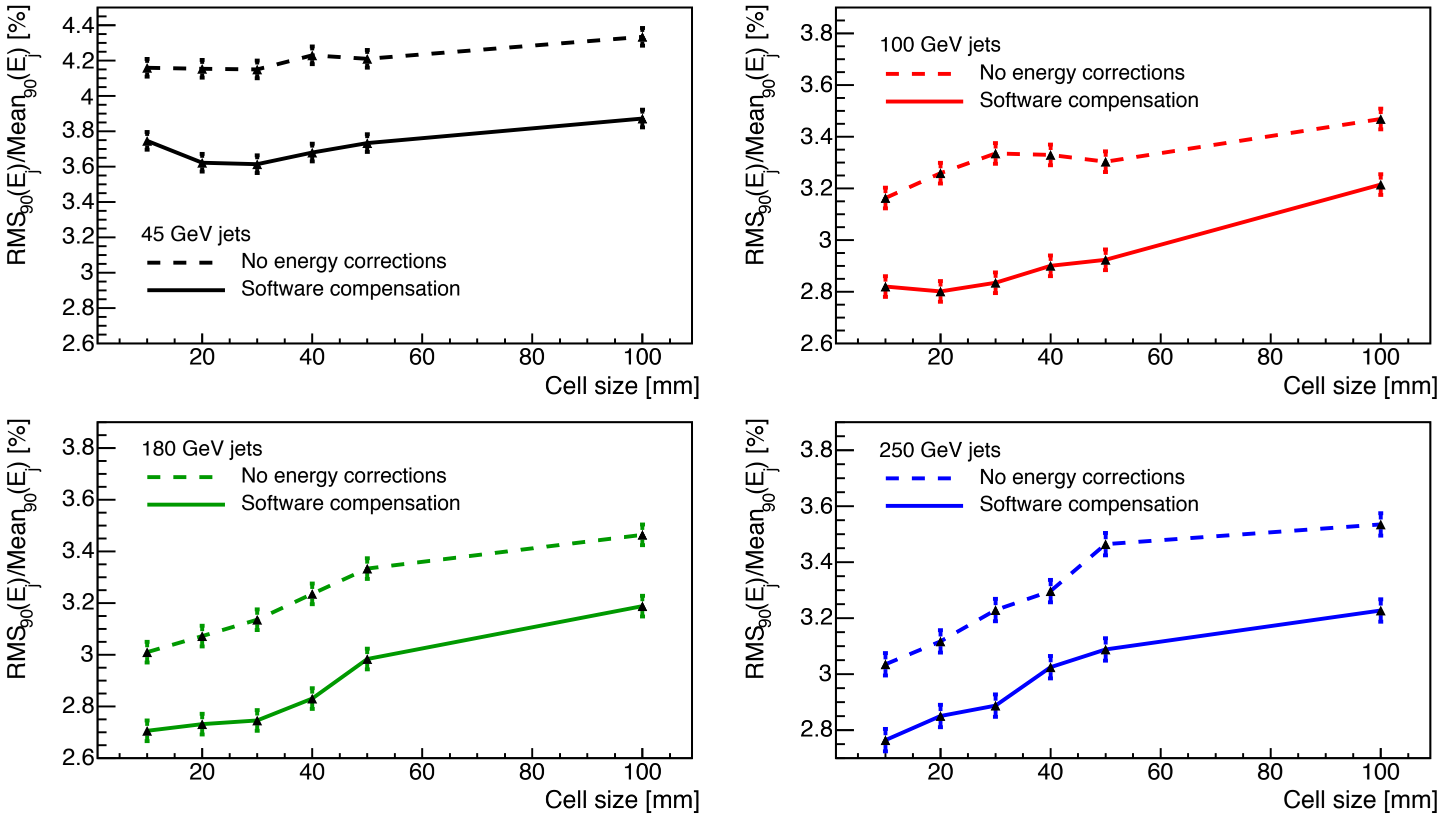




Granularity revisited

Layer-dependent.

- Software compensation does not change the picture
- Initial choices still very reasonable cost - performance choice
- First sections most important (study w/o comp.)



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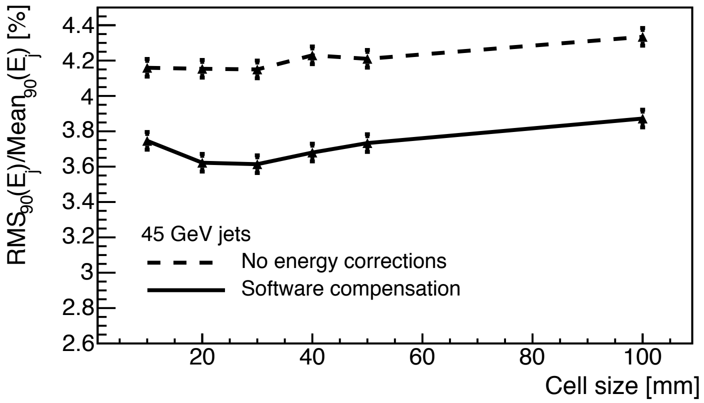

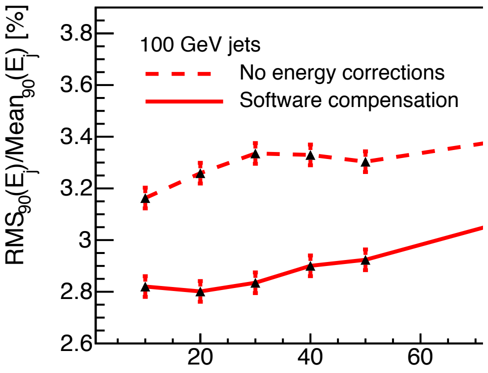

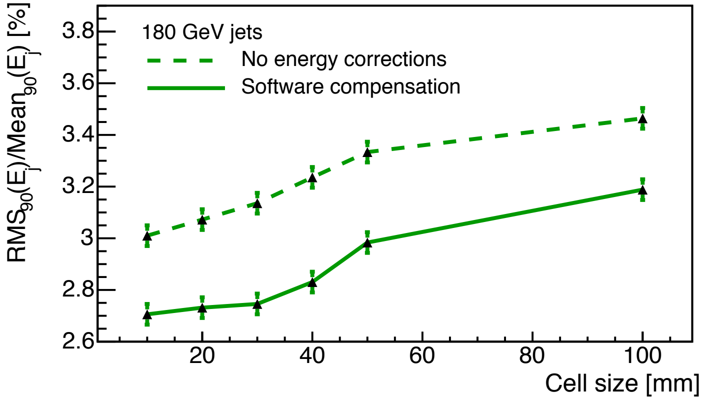

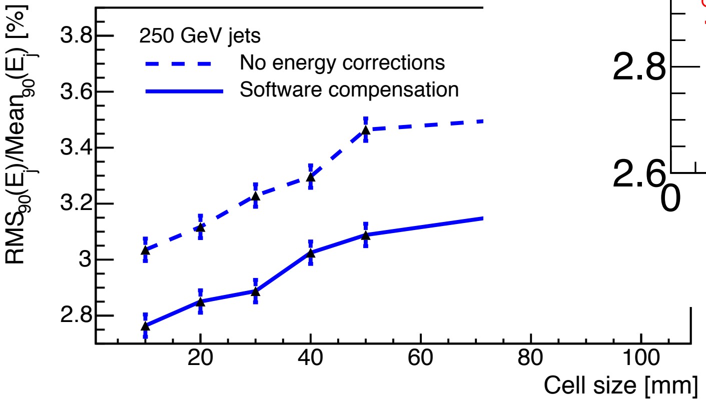

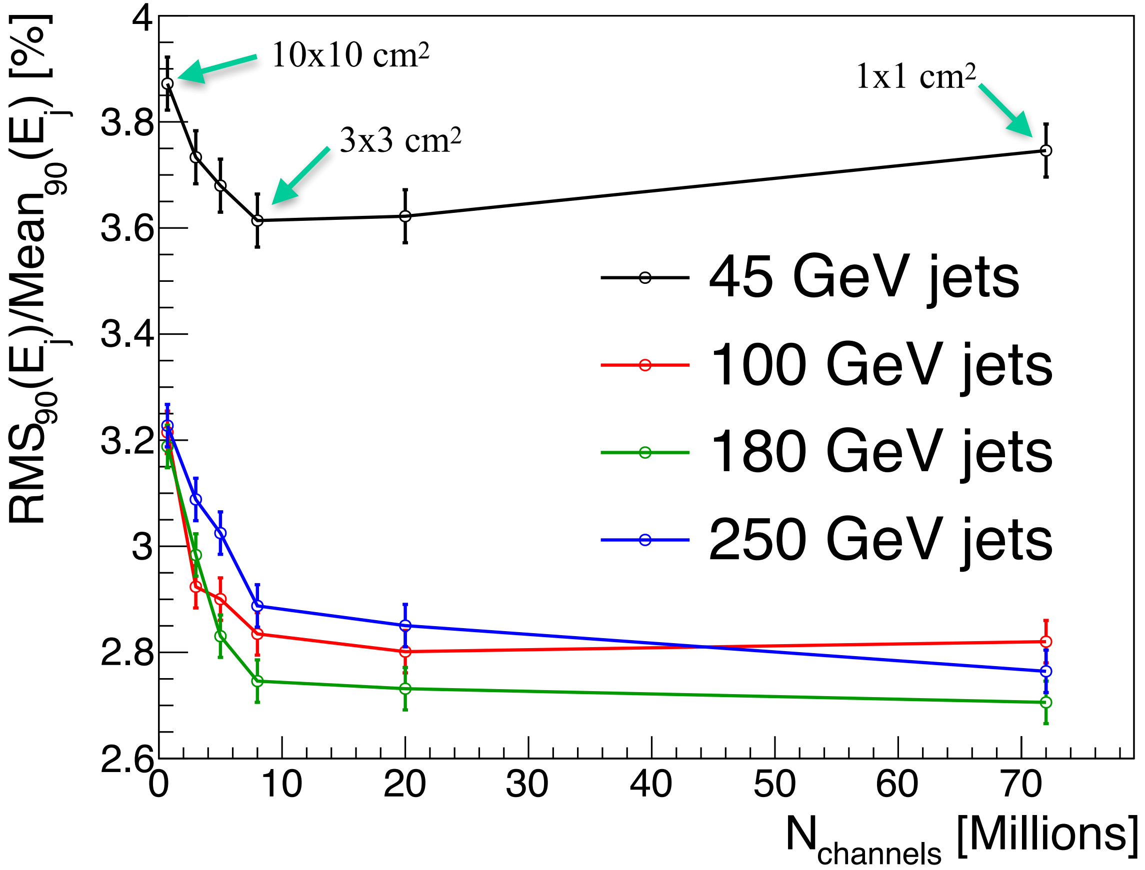

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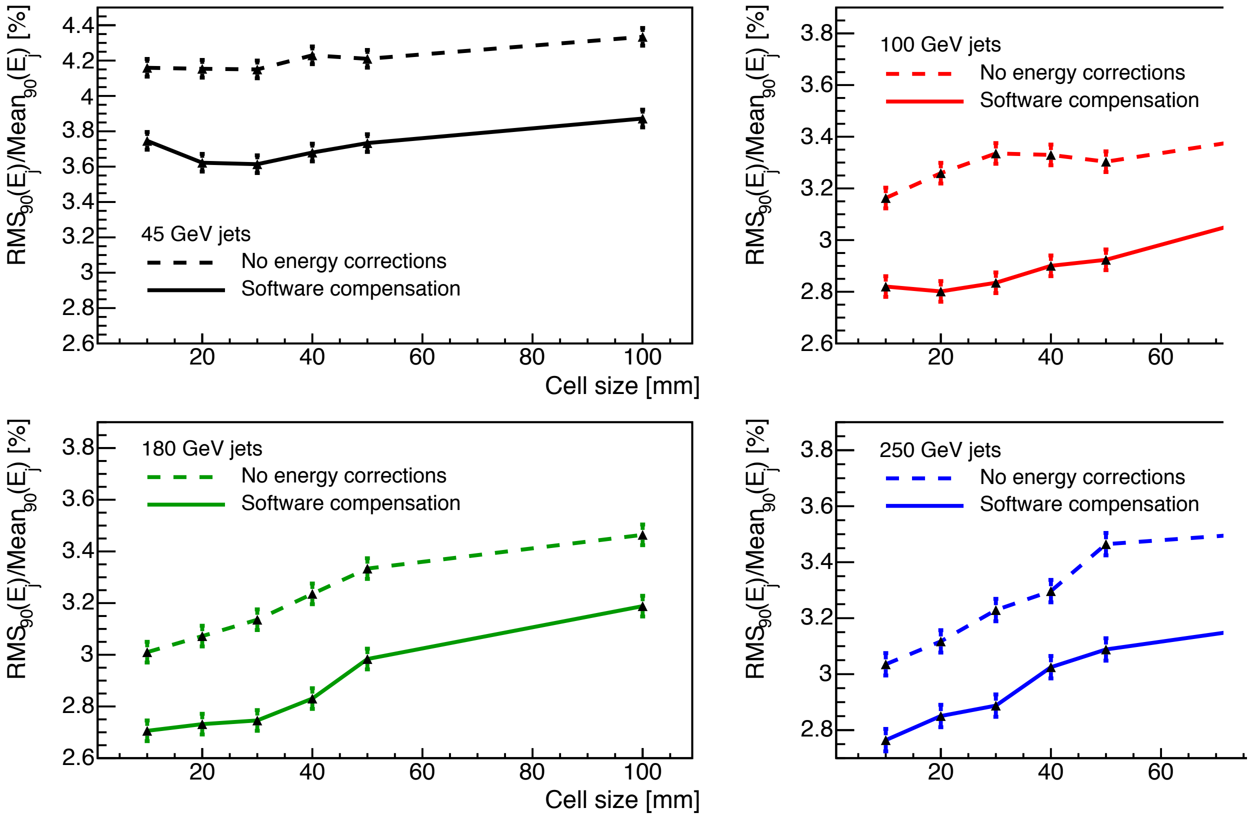

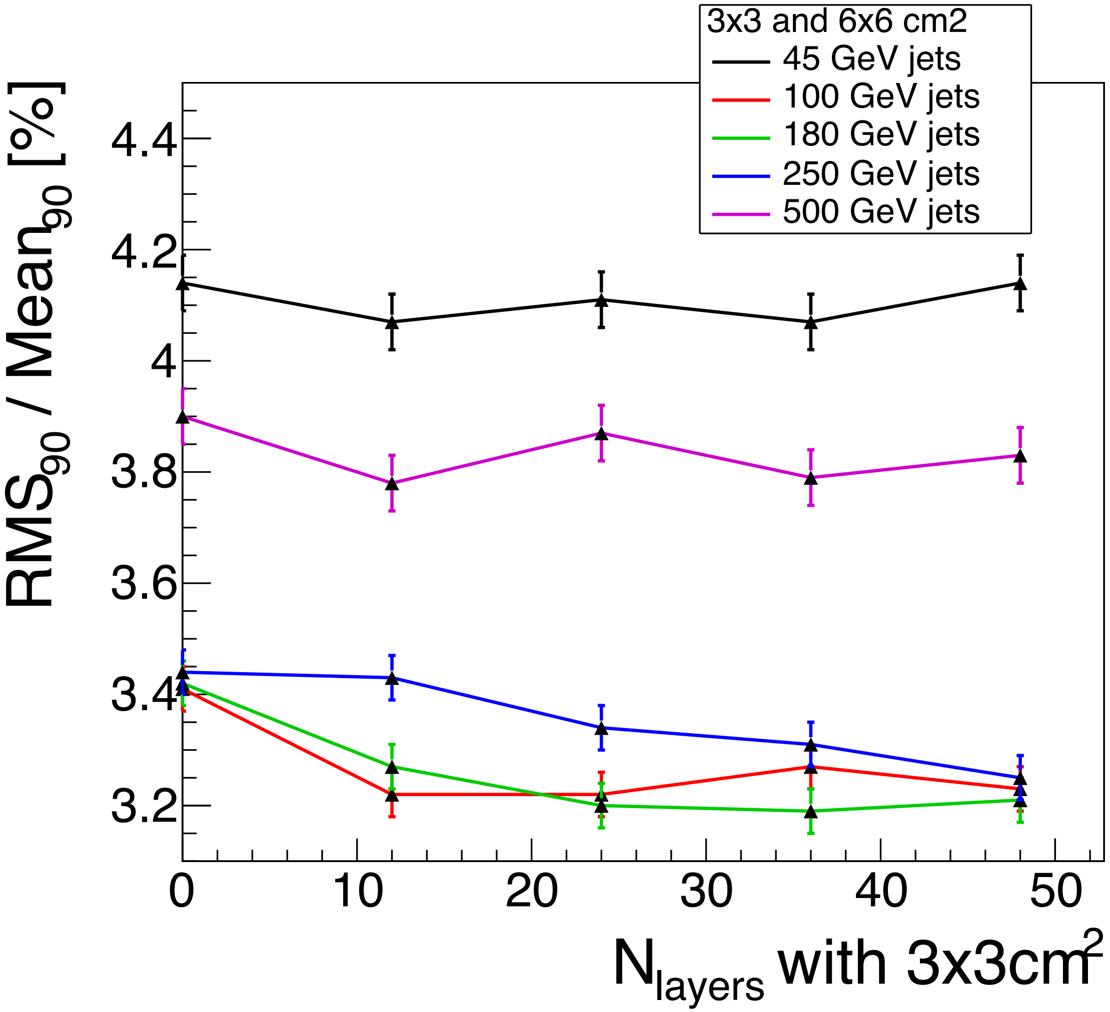

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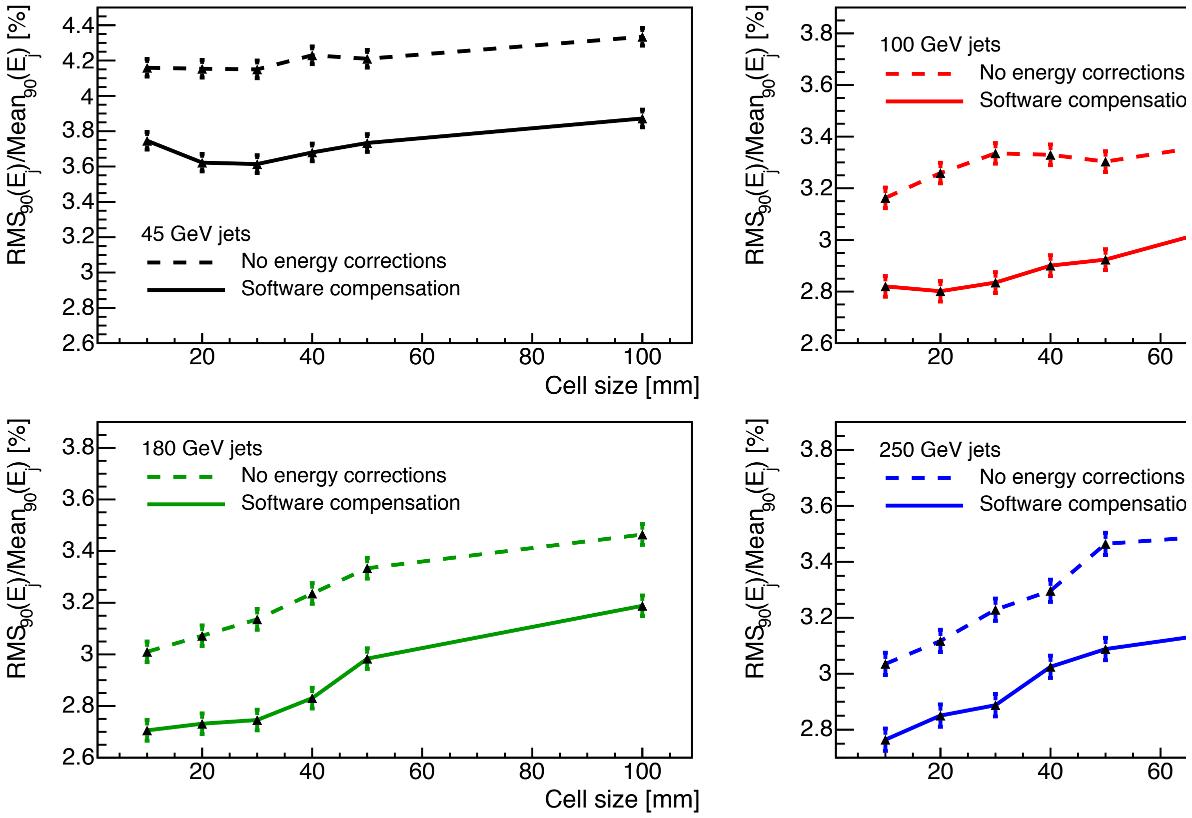
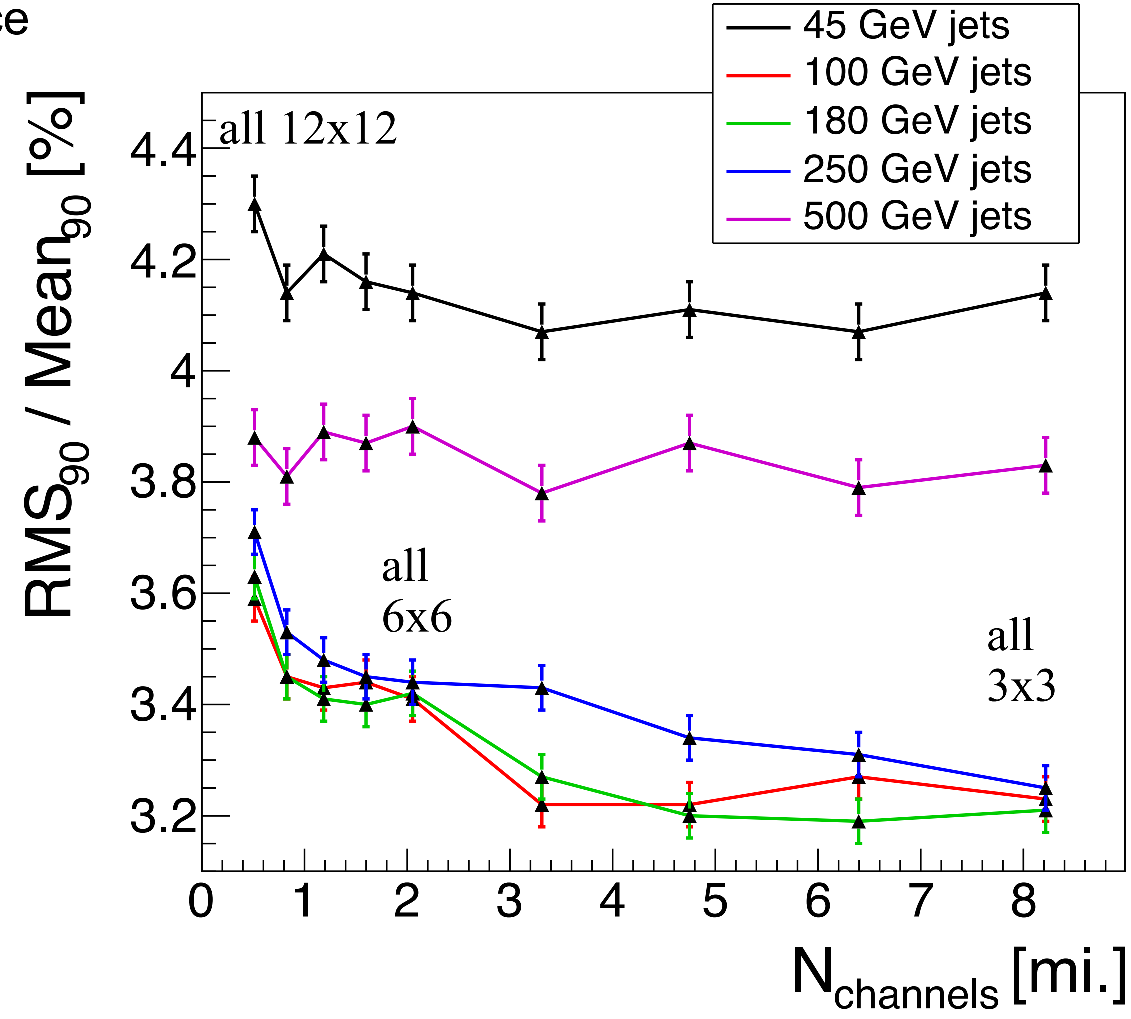
- Initial choices still very reasonable cost - performance choice
- First sections most important (study w/o comp.)





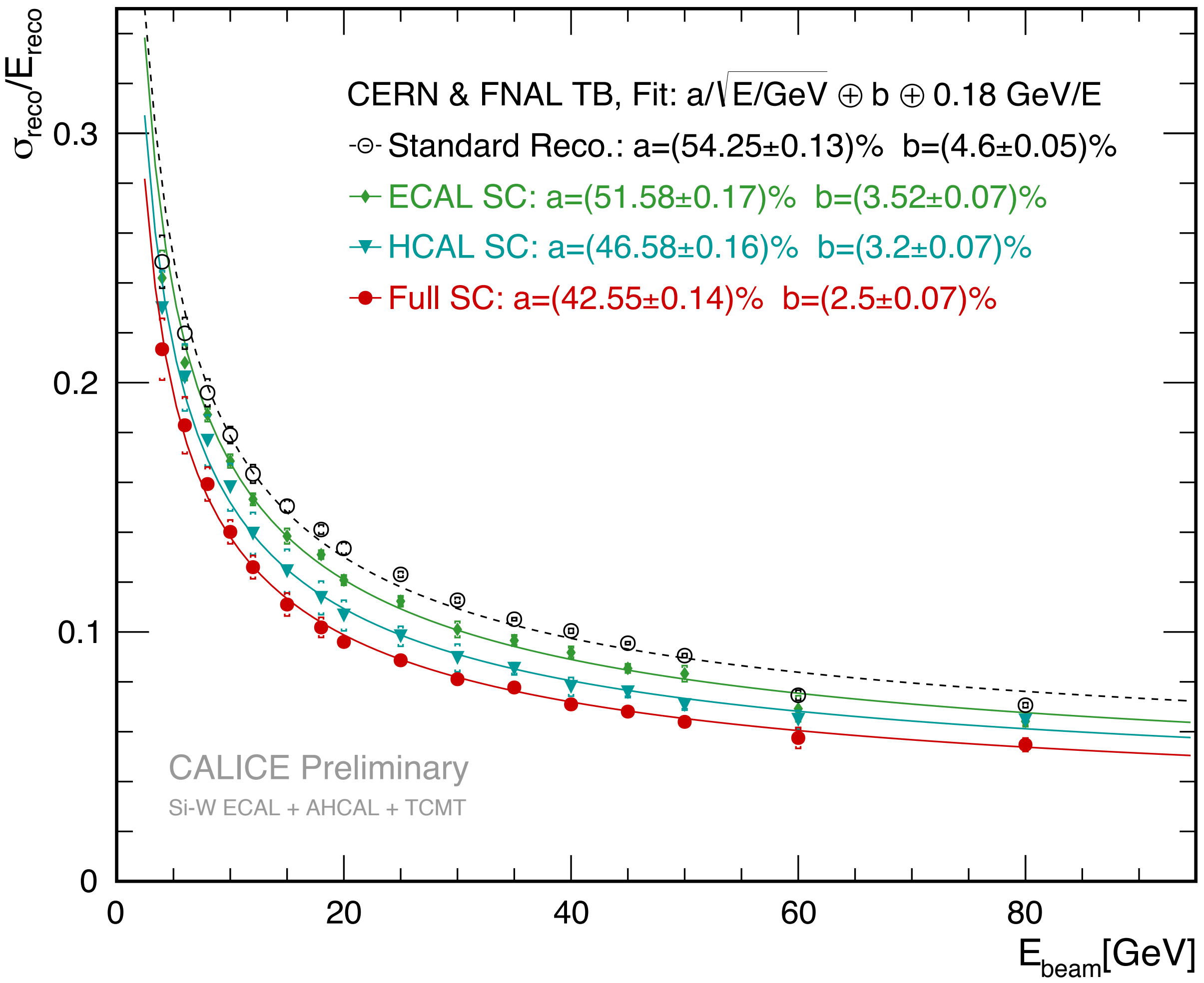
Compensation in ECAL and HCAL

Ultimately want both.

- In the Pandora implementation, so far only HCAL cell energy are weighted
- Inclusion of ECAL a bit more tricky
- Has been solved for combined CALICE test beam data
  - SiW ECAL, SiPM-scint HCAL
  - CERN & FNAL data

- Further improvements expected from adding ECAL
- Largest effect from HCAL

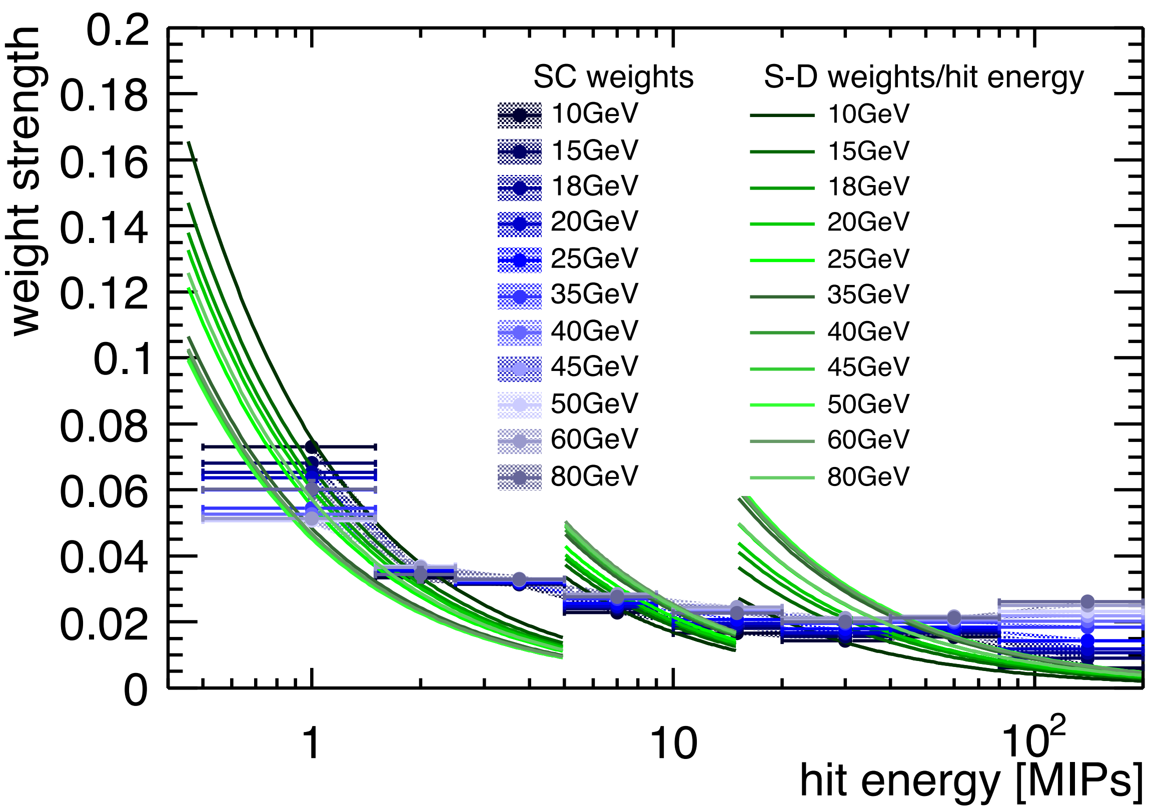
Y.Israeli, F.Simon, CAN-058, 2017



Software compensation and semi-digital reconstruction

A very close relationship.

- In SC the weights depend on hit energy and total shower energy:
  - $E_{SC} = \mathrm{sum}_{hits} (w (E_{hit}, E) \cdot E_{hit})$
  - E is the unweighted estimate
  - w defined in bins of E_{hit}
- This becomes semi-digital reconstruction m 3 steps:
  - reduce number of E_{hit} bins to 3
  - force E_{hit} dependence to be $1/E_{hit}$: counting!
  - express E as function of N_{tot}
- This allows to treat optimised analogue and semi-digital reconstruction in the same formalism
- Has been implemented in Pandora



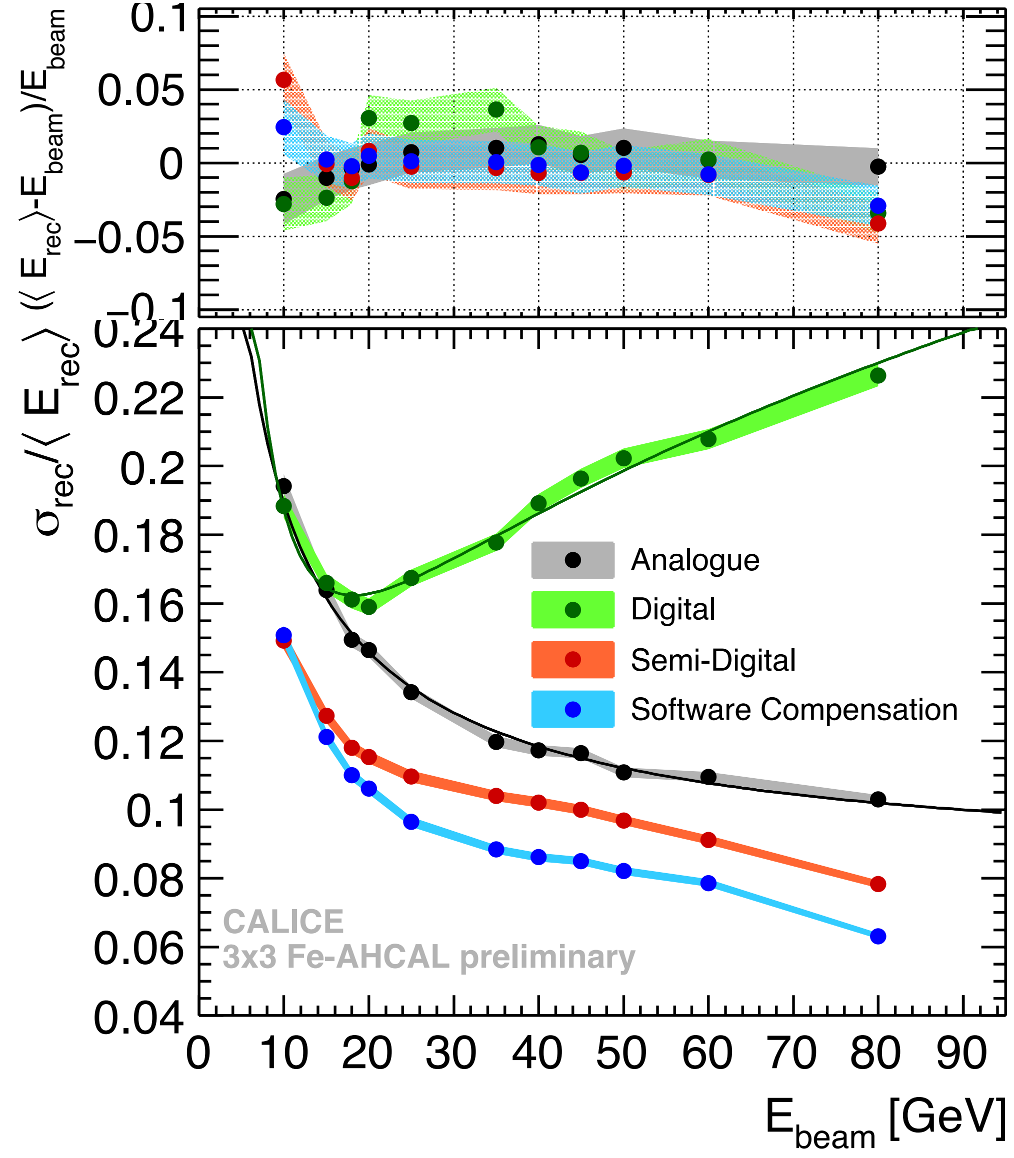
Thesis C.Neubüser 2016

Granularity and reconstruction scheme

CAN-049a, 2016

Close Interplay.

- Try all schemes with AHCAL data
- In simulation, can also reduce cell size, keeping the realism
- $3x3cm^2$: too coarse for semi-digital reconstruction
- $1x1cm^2$: semi-digital (2 bits) is sufficient
- Analogue: $3x3cm^2$ sufficient
- Active medium (sampling fraction) also matters



Granularity and reconstruction scheme

CAN-049a, 2016

Close Interplay.

- Try all schemes with AHCAL data
- In simulation, can also reduce cell size, keeping the realism
- 3x3cm^2: too coarse for semi-digital reconstruction
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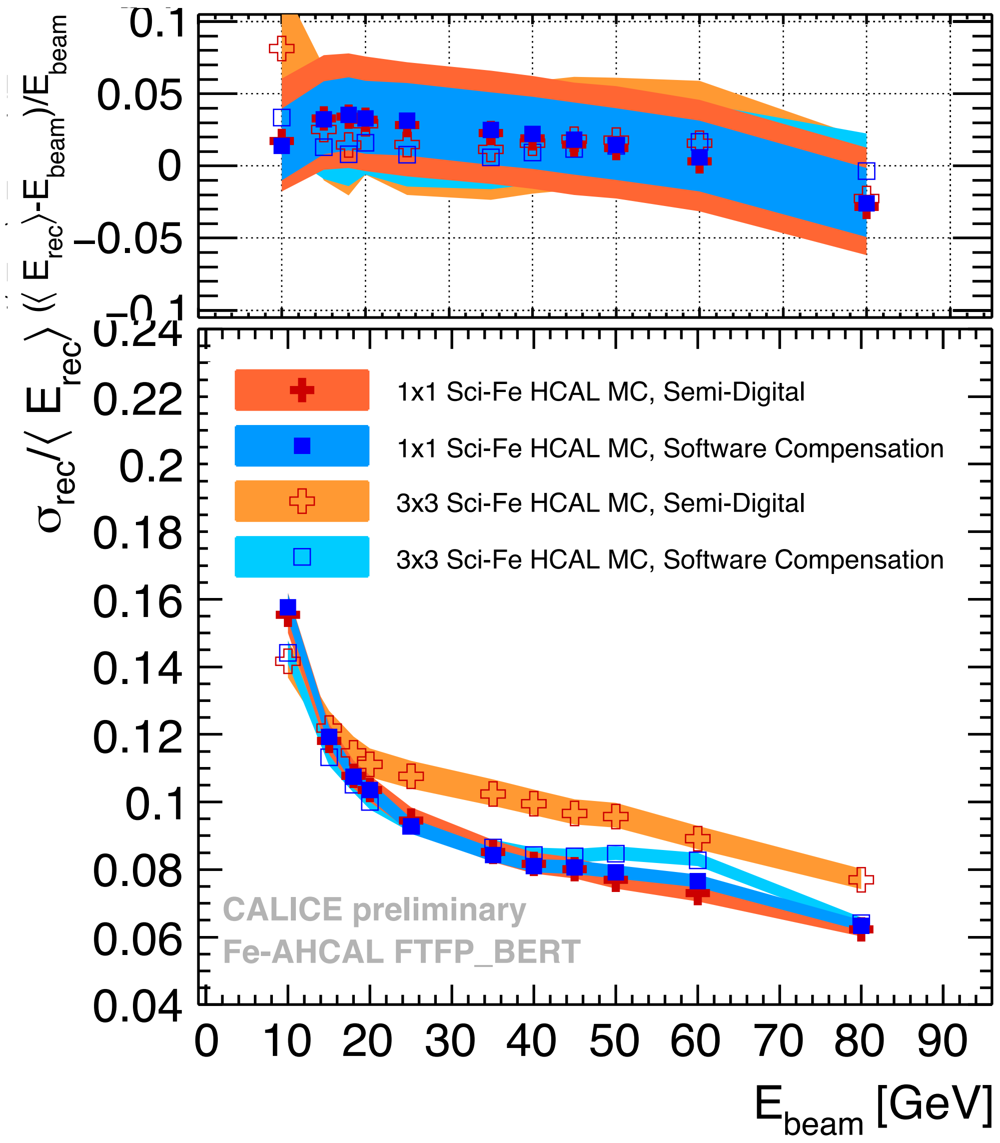
- Analogue: 3x3cm^2 sufficient
- Active medium (sampling fraction) also matters

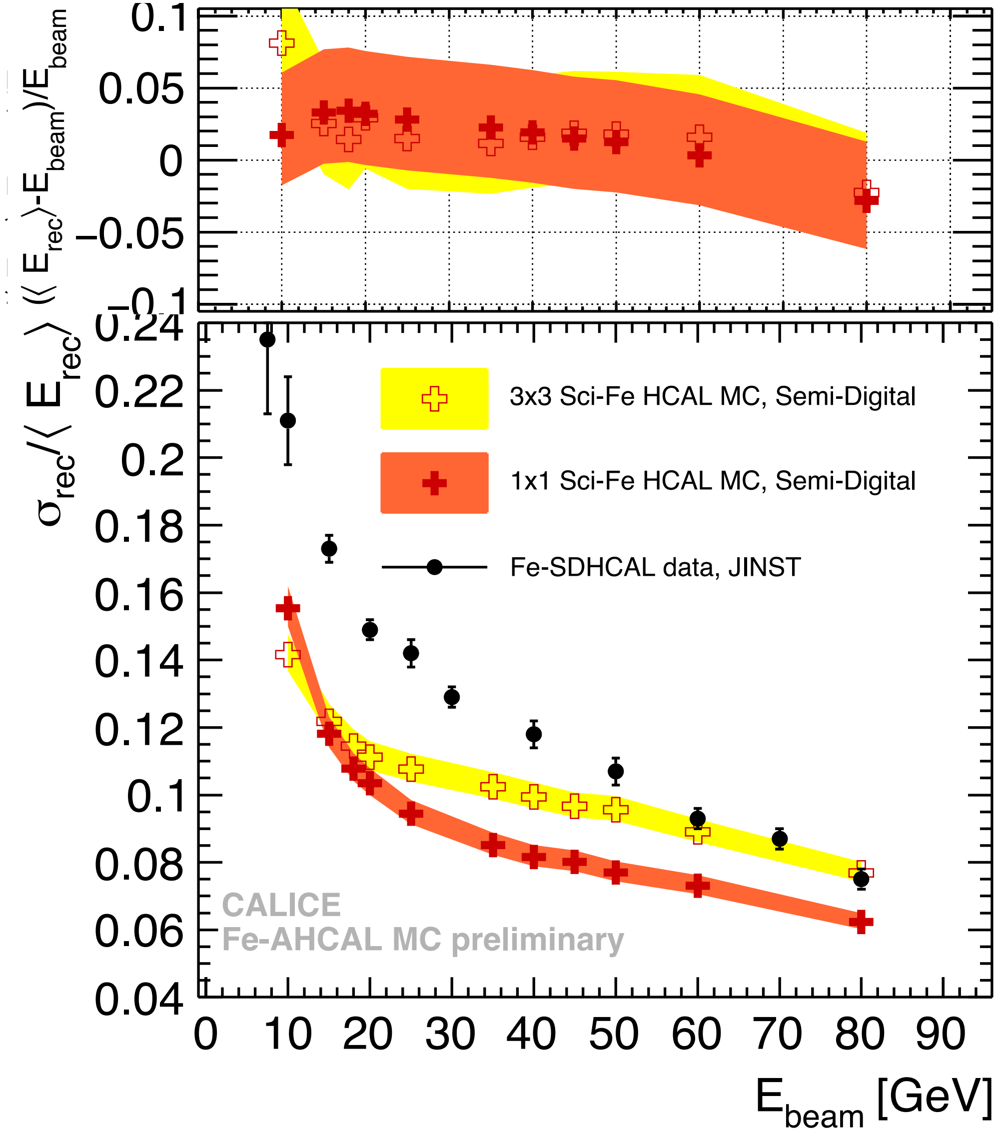


Granularity and reconstruction scheme

CAN-049a, 2016

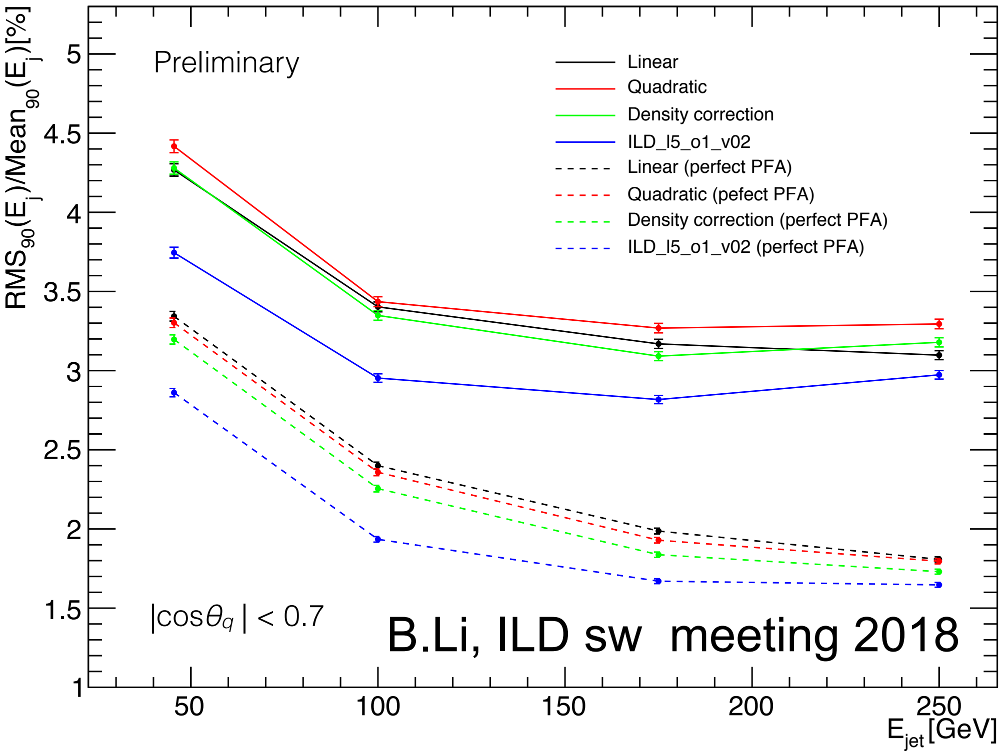
Close Interplay.

- Try all schemes with AHCAL data
- In simulation, can also reduce cell size, keeping the realism
- 3x3cm²: too coarse for semi-digital reconstruction
- 1x1cm²: semi-digital (2 bits) is sufficient
- Analogue: 3x3cm² sufficient
- Active medium (sampling fraction) also matters



Granularity and algorithms

Progress with Pandora and ARBOR.



ARBOR

- SDHCAL reconstruction in Pandora
- ARBOR optimiston on-going
- ARBOR for AHCAL?

New trends and ideas

New ideas and trends: cooling

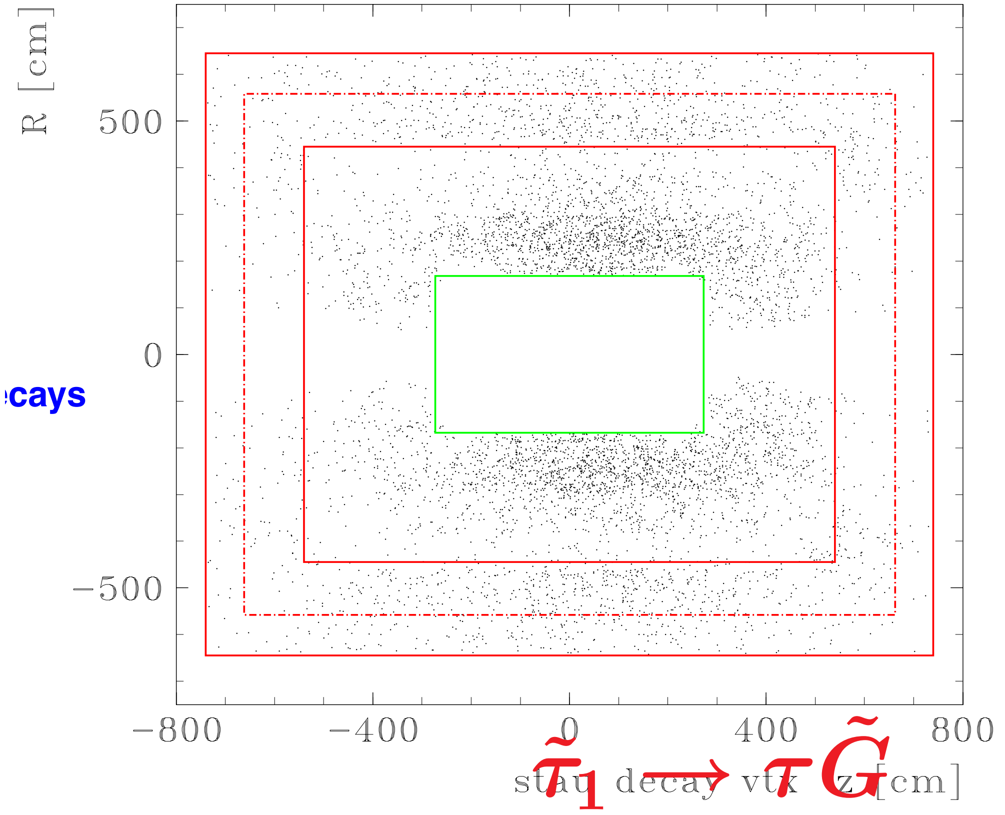
The CO2 revolution

- The total cooling power of CMS HGCAL: 110 kW / endcap
- Conceivable with compact design only with 2-phase CO_2

- The design of the LC detectors capitalises on the low duty cycle of the machine and cycled power in the embedded front-end
- Performance with power pulsing established in test beams with magnetic field

- However date taco is in-active 99% of the time
- Cosmic muon calibration can be replaced with MIP-like track segments in hadronic showers
- Reduced sensitivity to exotic models
- Next-to-LSP may be long-lived, 10^2 -10^8 s, and slow
- Decays in calorimeter volume expected

HU Martyn, ca 2008



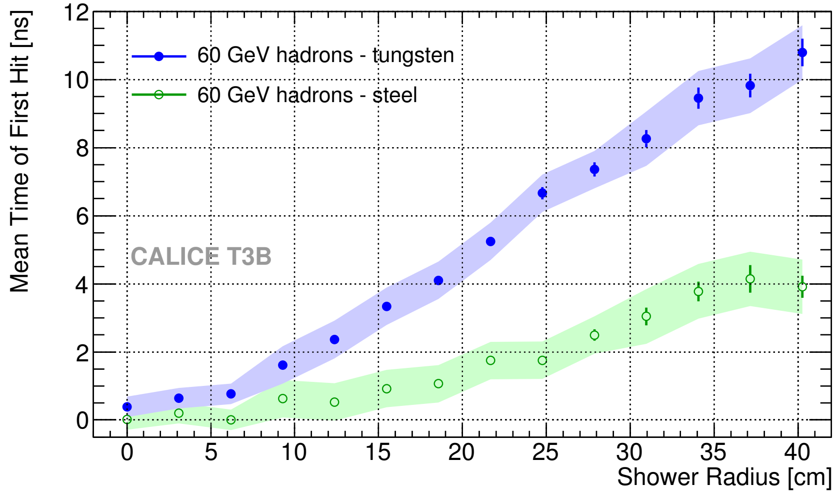
Physics guidance needed

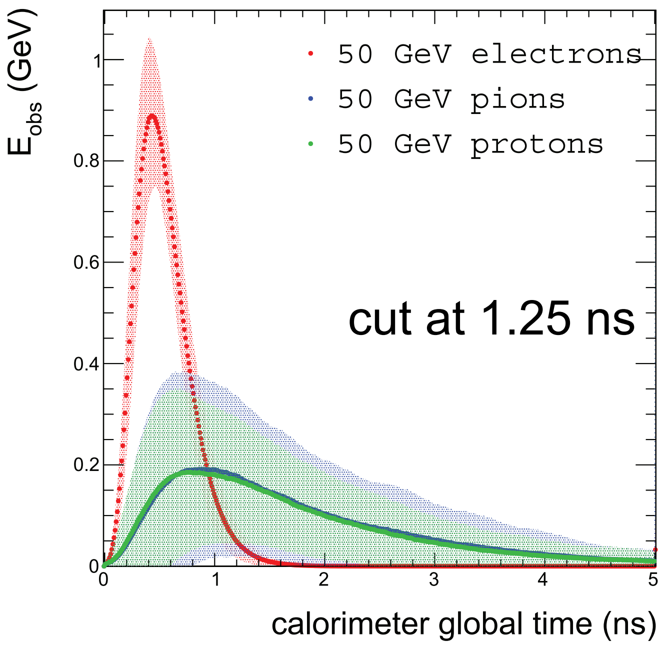
New ideas and trends: timing

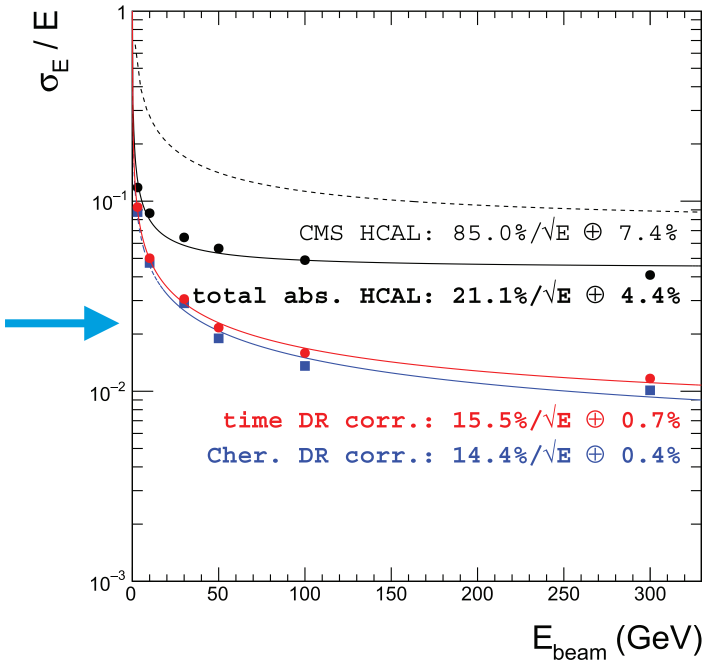
A new dimension.

- Dynamic development, driven by HL-LHC pile-up considerations
  - sensors and electronics
  - few 10ps resolutions come in reach
  - with special sensors even for MIPs
- Present CALICE electronics designed for ns precision
  - originally driven by shower shape considerations
  - GLD: Pb HCAL, CLIC-ILD/SiD: W HCAL
  - In iron only small effects expected, under study

- Further potential:
- Use timing for compensation
  - originally proposed by dual read-out groups
  - ns precision almost sufficient
- Use timing for particle ID with Time-of-Flight
  - MIP timing
  - Roman's idea - see his talk







IEEE Trans.Nucl.Sci. 63 (2016) no.2, 574-579

Summary

And conclusion.

- For 2018
  - cost derivatives: update and extend
  - close test beam validation loop
  - revise single particle performance and requirements

- For the next phase (if ILC goes ahead):
  - ILD design *apparently* converges
  - Should be prepared to question and justify fundamental choices
  - Explore the timing domain

- Think out of the box!