ILD cost-performance optimisation

Trong Hieu TRAN
Laboratoire Leprince-Ringuet, Ecole polytechnique, CNRS/IN2P3

Outline:

- ILD costing
- Re-optimisation of cost-performance
  - SiW ECAL optimisation
  - HCAL optimisation
  - Reduction of entire ILD dimension (radius & length)
  - Effect on jet energy resolution

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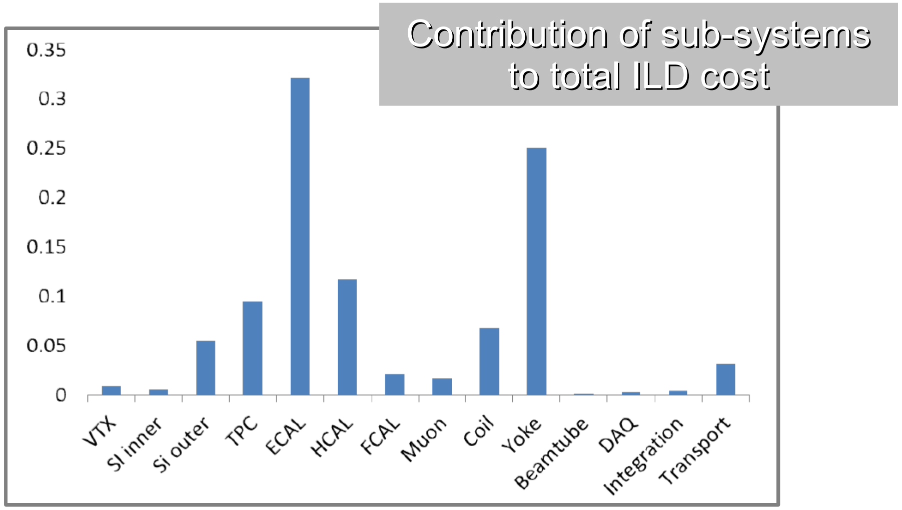
CEA Saclay

Introduction

- **ILD concept**
  - ILD is composed of a vertex detector, tracking system, calorimeters (ECAL, HCAL), forward detectors, coils & return yoke and muon detector
  - ILD is costly, especially SiW-ECAL & Yoke.
  - Studies performed to investigate cost-effectiveness



- **Options**:
  - Choices of calorimeter technologies
  - outer TPC radius
    (→ ECAL, HCAL, Yoke's radii correspondingly)
    together with length (keep ratio constant)
  - ECAL: number of layers PCB thickness, fraction of dead pixels/dead chip, guard ring size
  - HCAL: Hadronic cell size, thickness, geometry (Tesla & Videau)

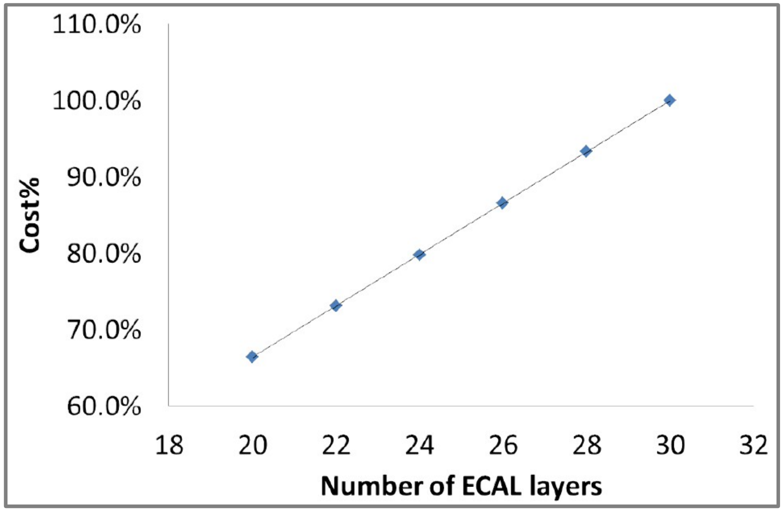
- **Validation of ILD models**
  - Simulation with Mokka (Geant4).
  - Tracking performance (important input for PFA, since 60% of jet energy from charged particles)
  - PFA performance: With recent PandoraPFANew

SiW ECAL optimisation

- Number of layers
- Guard ring size
- PCB thickness
- Fraction of dead pixels/dead chips

SiW ECAL number of layers

- Cost of SiW ECAL : linear dependence on number of layers
- Configurations with different number of layers were considered
- Keep same total absorber (W) thickness, same ratio of inner:outer layer thicknesses at 1:2

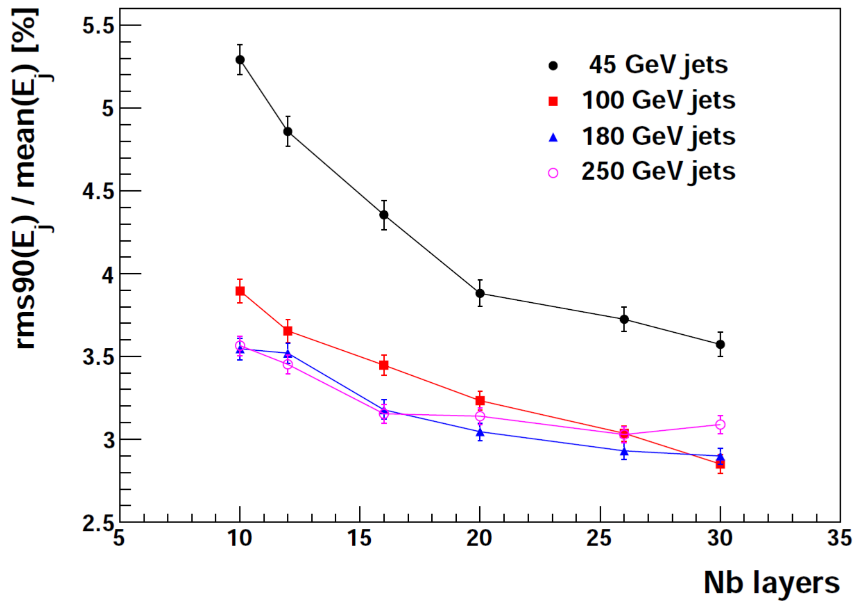


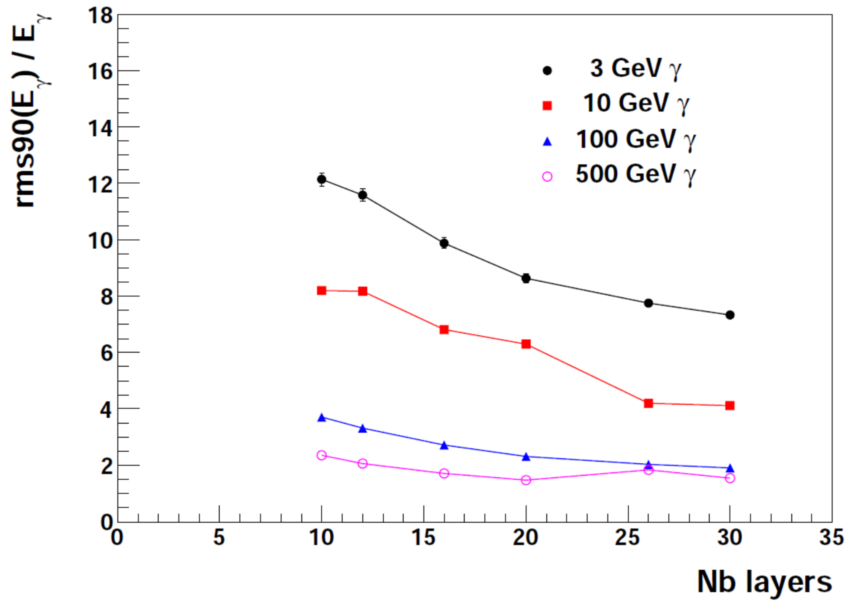
ECAL model	W layers	Layer thickness (mm)
30 layers	20	2.1
	9	4.2
26 layers	17	2.4
	8	4.8
20 layers	13	3.15
	6	6.3
16 layers	10	4.0
	5	8.0
12 layers	7	5.32
	4	10.64
10 layers	6	6.65
	3	13.30

ECAL number of layers

effect on jet and single particle energy resolution

- 30 to 20 layers: slight degradation of JER and single particle energy resolution if choose (for 45 GeV jet: 9%)





- Similar degradation observed for single photon

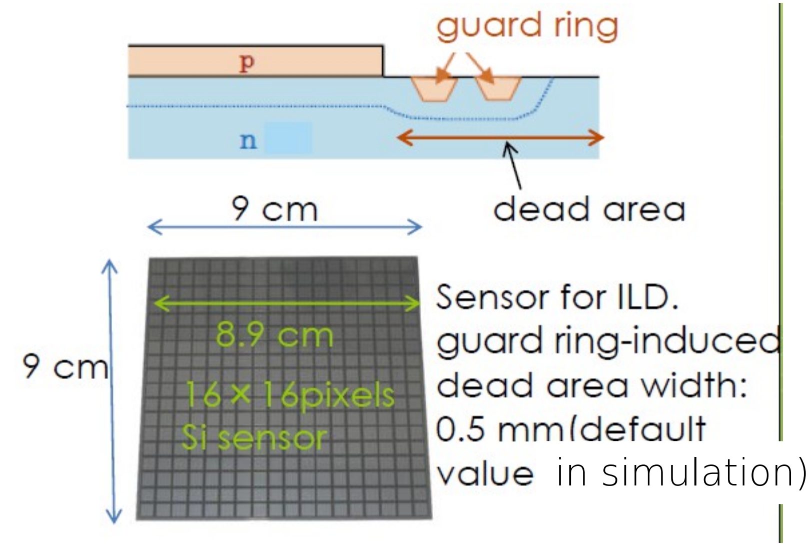
SiW ECAL optimisation

- Number of layers
- Guard ring size
- PCB thickness
- Fraction of dead pixels/dead chips

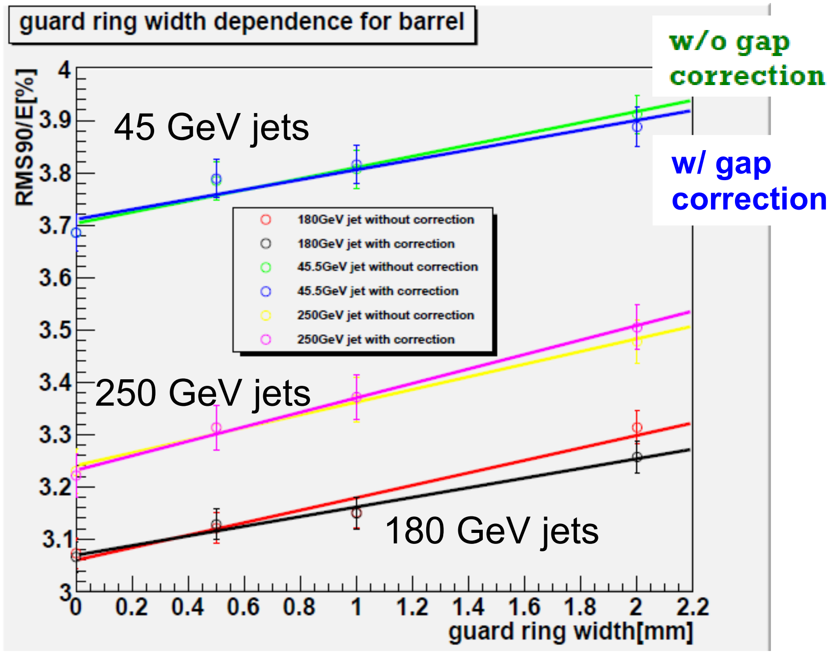
JER with different guard ring widths

S. Chen *et al.*

- Sensor is matrix of PIN diodes
- Guard ring prevents surface leakage current → decreases dark current and improves high voltage stability
- Study how geometrical inefficiency affects JER resolution



- Z → uds events (Z decaying at rest). JER estimated by RMS90 method.
- Linear dependence of JER with 6% difference between 0 mm and 2mm widths
- Angular correction also helps resolution



SiW ECAL optimisation

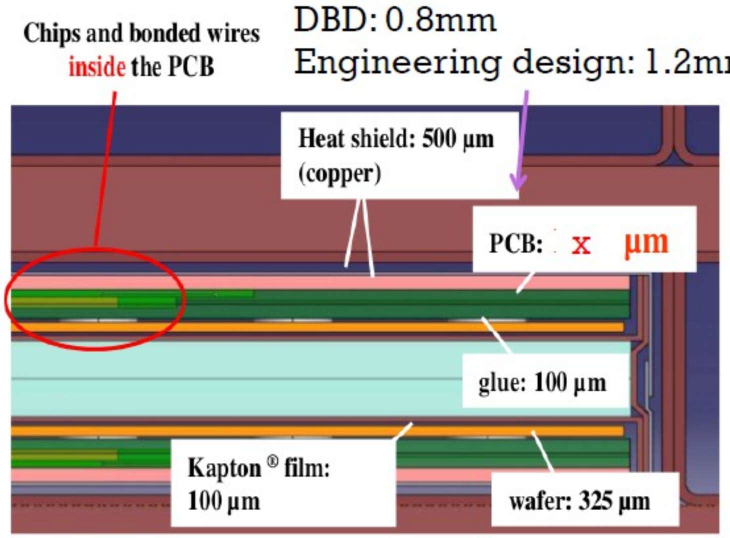
- Number of layers
- Guard ring size
- PCB thickness
- Fraction of dead pixels/dead chips

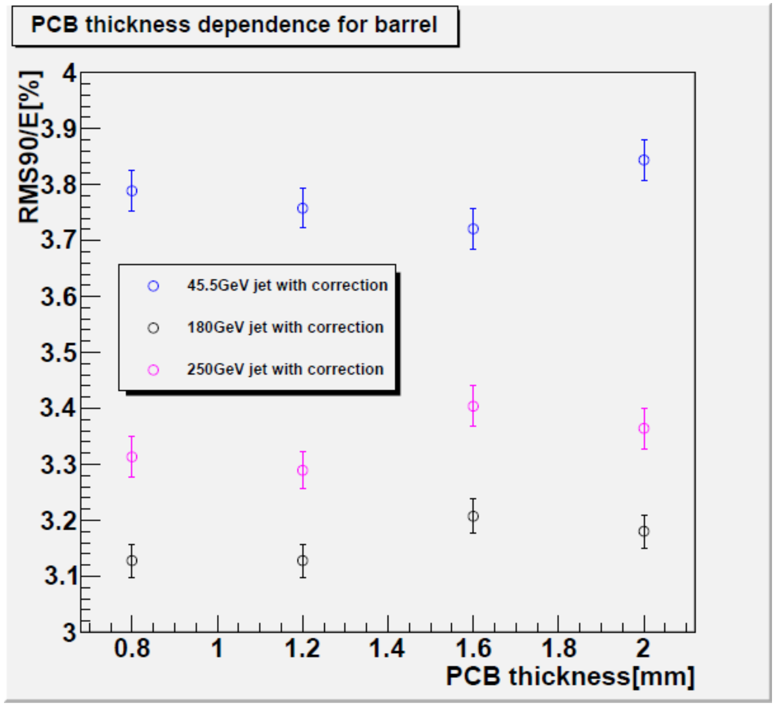
PCB thickness

S. Chen *et al.*

- Increases lateral shower size
- More overlap of particle showers
- Confusion increases → JER is expected to be worse at high E
- Thin PCB is preferable for performance but technologically difficult and expensive

DBD: 0.8mm
Engineering design: 1.2mm





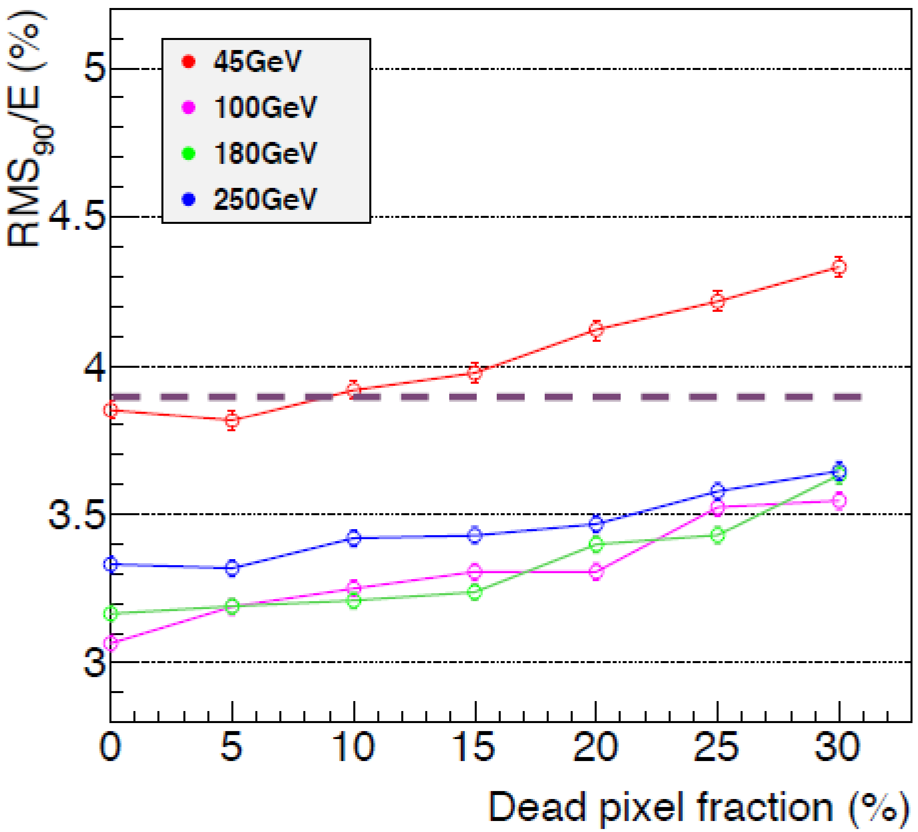
- The rest of modules remains the same as baseline ILD design
- → Whole detector size is bigger than default
- No significant dependence of JER on PCB thickness is observed
- Study to be extended to higher thicknesses of PCB

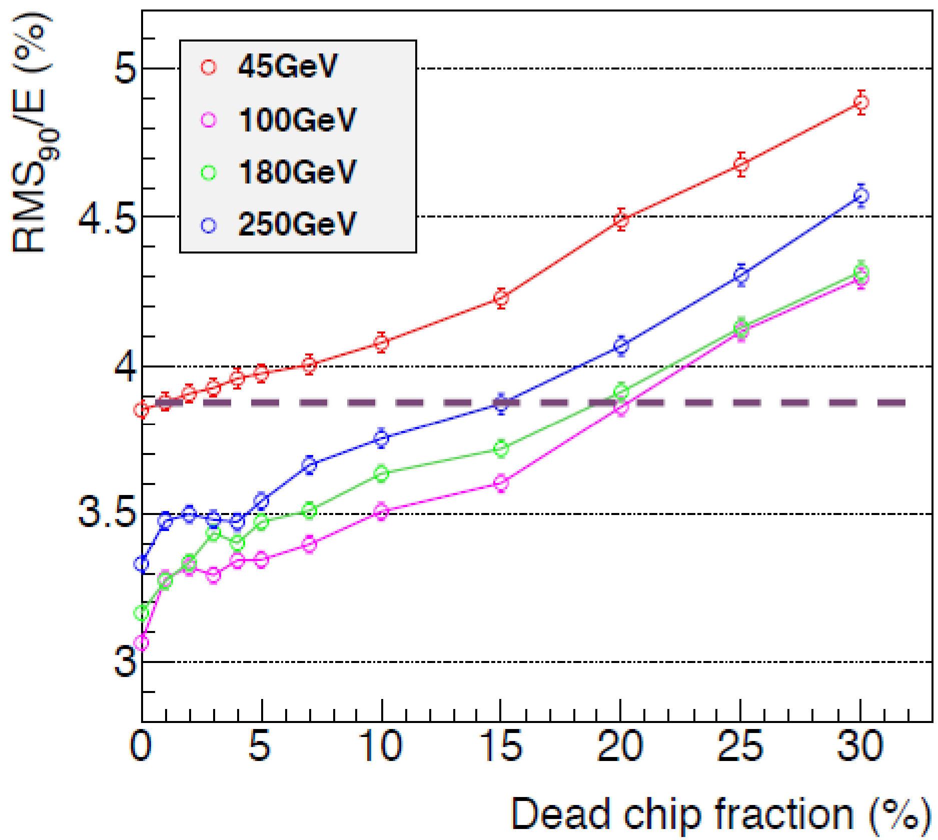
SiW ECAL optimisation

- Number of layers
- Guard ring size
- PCB thickness
- Fraction of dead pixels/dead chips

JER dependence on dead pixels / chips fraction

S. Chen *et al.*





- Almost negligible effect with 10% of dead pixels
- Small effect with 5% of dead chips
- ECAL resolution degrades due to decreasing sampling fraction, but weak effect on JER.
- No serius breakdown. PFA is very robust against dead channels.

HCAL optimisation

- Mechanical structure
- Cell size effect
- Thickness effect

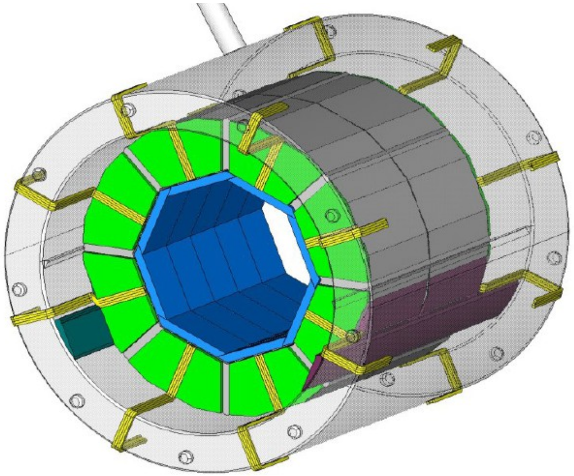
- Two options are proposed for the hadronic calorimeter of ILD: AHCAL and SDHCAL
- Both have 48 active layers interleaved with 2 cm stainless steel layers
  - AHCAL: 3×3 cm^2 scintillator + SiPM with analog readout
  - SDHCAL: $1\times1cm^2$ GRPC with semi-digital readout
- Both give similar Jet energy resolution

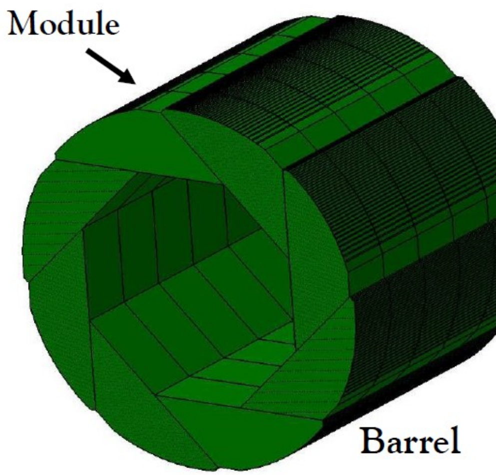
HCAL optimisation

- Mechanical structure
- Cell size effect
- Thickness effect

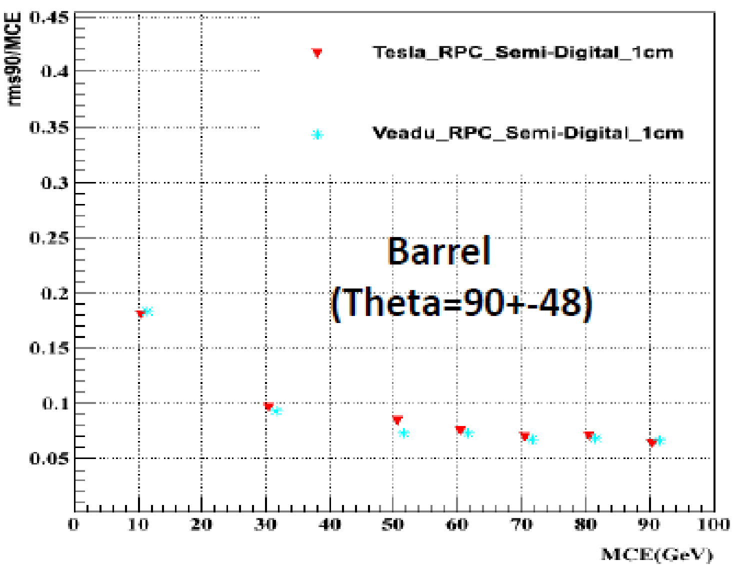
Mechanical structure

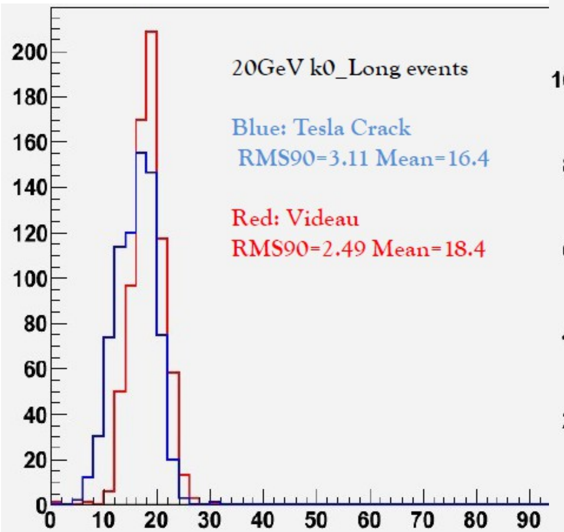
- Two structures are proposed: standard (Tesla) and no-projective (Videau geometry)
- Mechanical robustness of the Videau solution is higher.
- However one needs to assess the difficulty to build both and more importantly what are the impacts on the physics

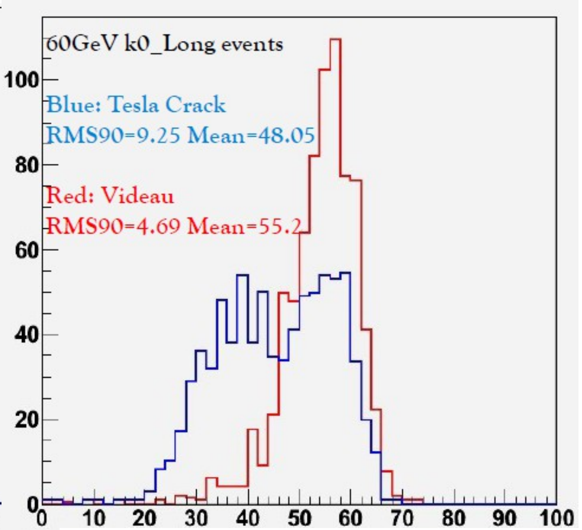




- Two options were considered for SDHCAL (to be done also for AHCAL)

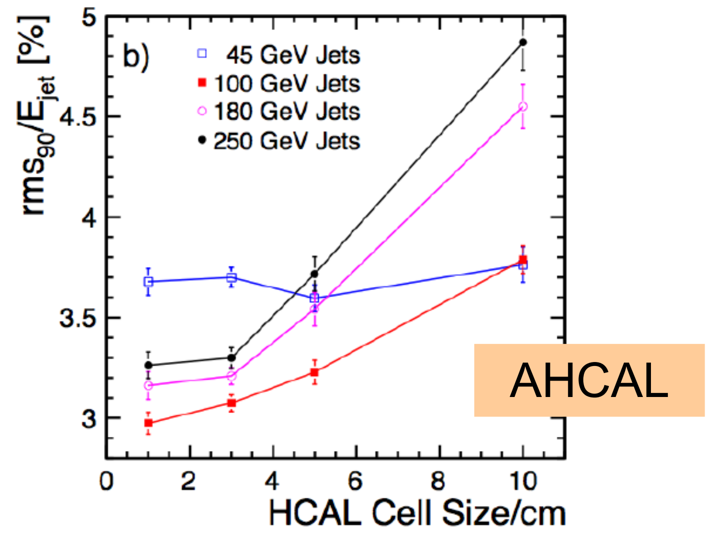




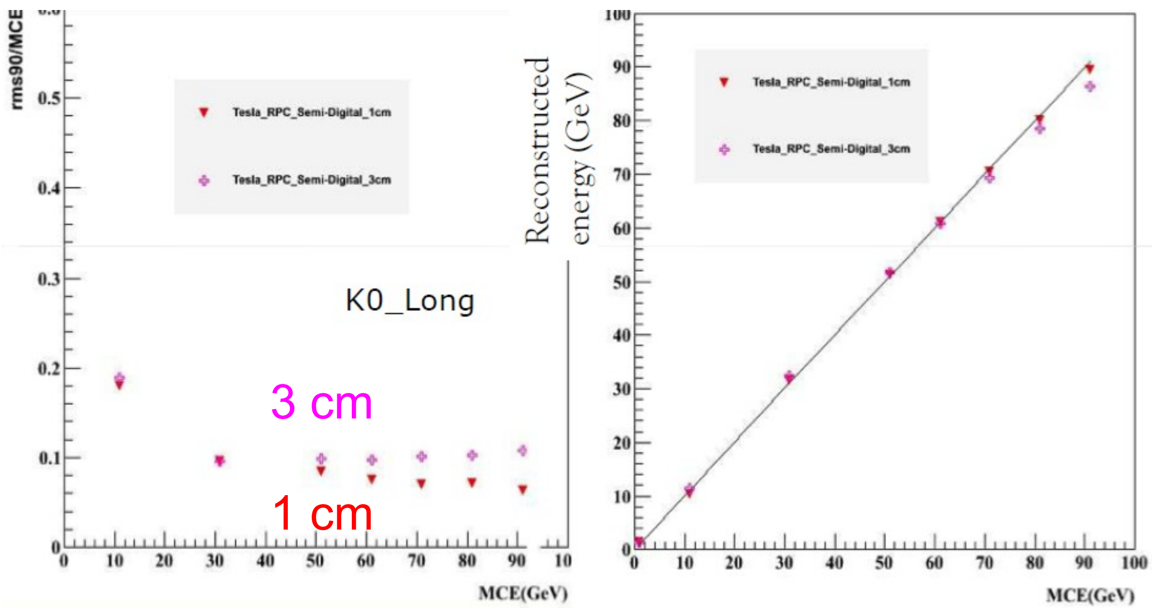


HCAL cell size effect

- The optimisation was performed using the present radius of ILD for both AHCAL and SDHCAL



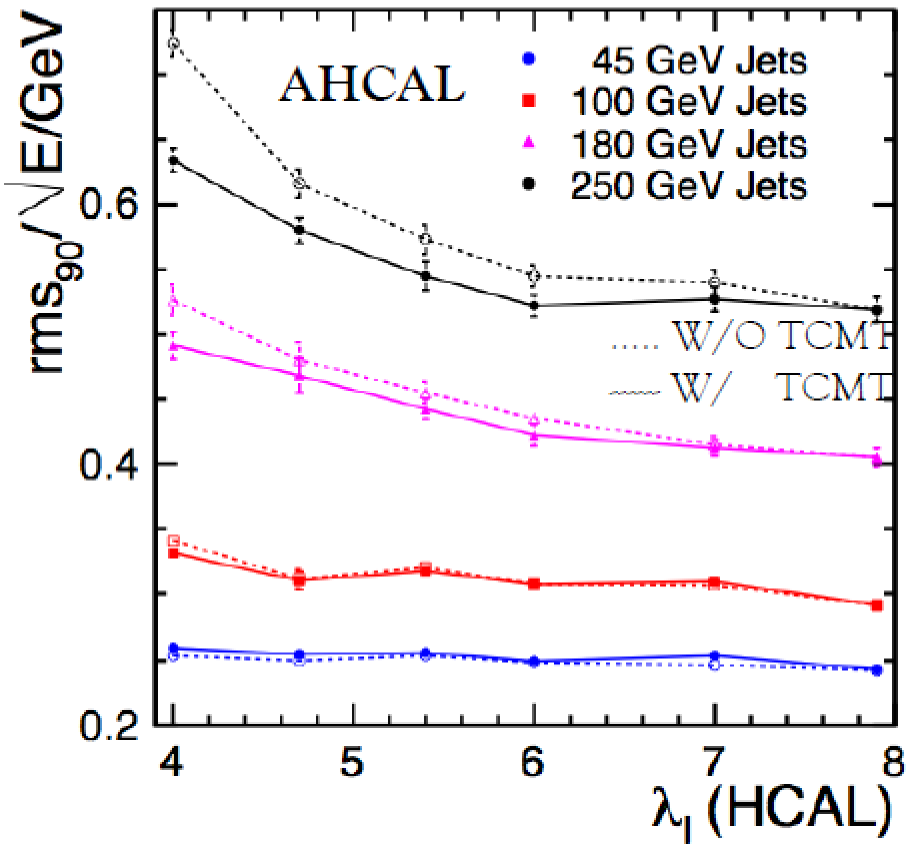
SDHCAL



- Preliminary studies for the SDHCAL concept: cells of few mm present the best granularity but means a tremendous number of electronic channels.
- $1cm^2$ cell seems a good compromise

HCAL thickness

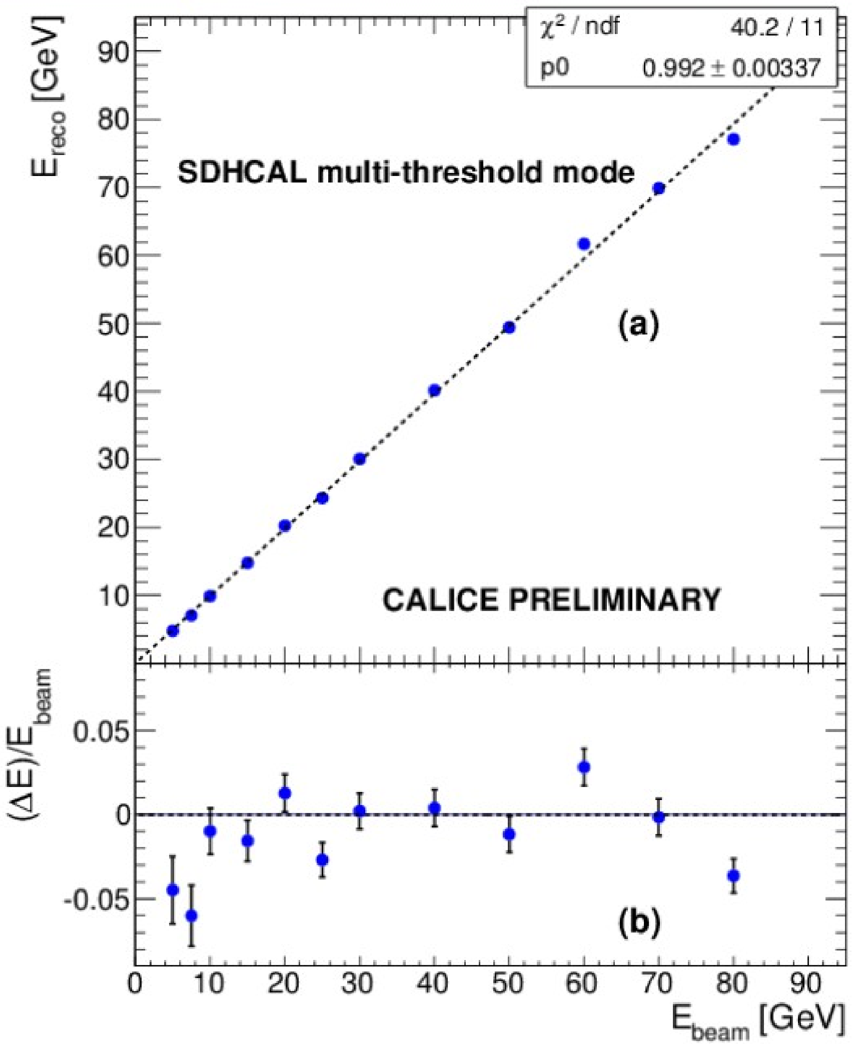
- A priori, thickness of HCAL should not be reduced

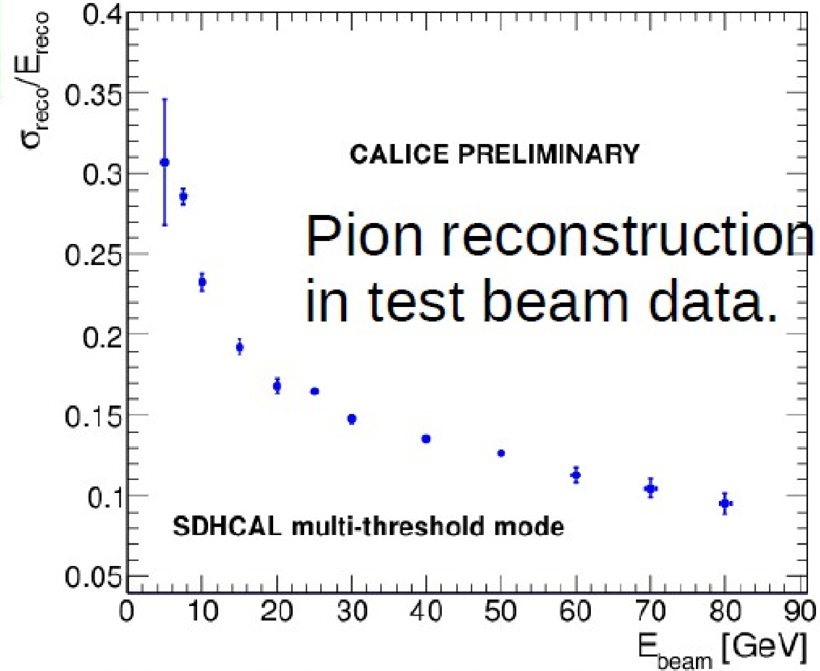


SDHCAL optimisation

- Digitisation
- Energy reconstruction
- Tracking in hadronic shower (not covered)
- Particle flow algorithm (not covered)

SDHCAL optimisation: Energy reconstruction





Pion reconstruction in test beam data.

$$E = \alpha(N_{hit})N_1 + \beta(N_{hit})N_2 + \gamma(N_{hit})N_3$$

$$N_{hit} = N_1 + N_2 + N_3$$

α, β, γ quadratic functions

Better linearity

Plan to modify PandoraPFA to cope with more complex energy reconstruction

Improve resolution : Neural Network with more variables (see algorithms)

Scaling detector size

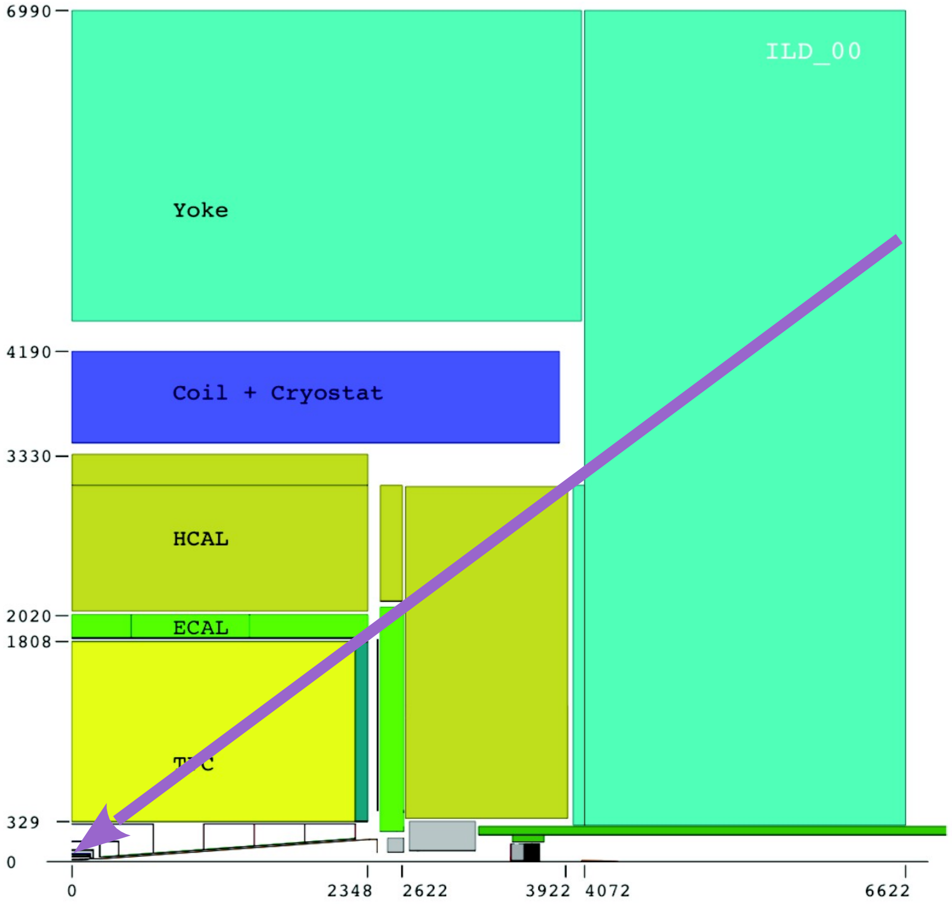
- Reduction of entire ILD radius together with length
- Performance studied via
  - jet energy resolution
  - track resolution
  - $H \rightarrow \mu\mu$

Scaling detector size

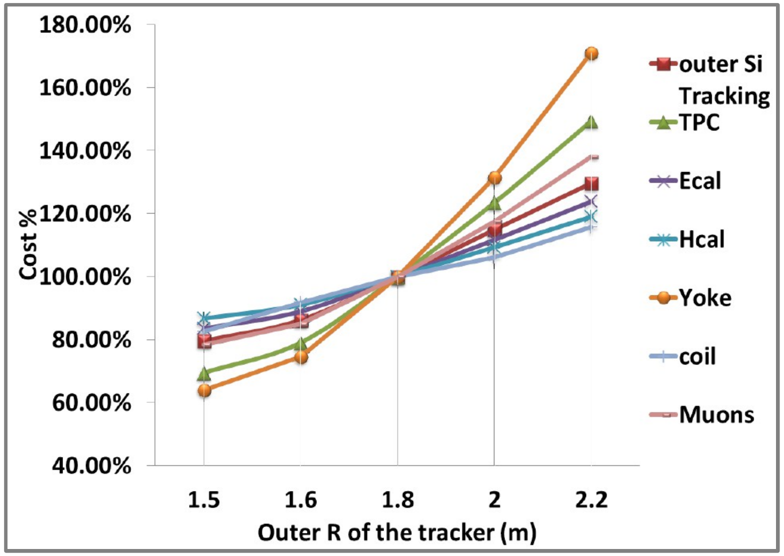
Unit: mm

R_{ECAL}^{inner}	1843	1600	1400	1200
R_{TPC}^{outer}	1808	1565	1365	1165
TPC half_Z	2350	2040	1785	1530

TPC length = $2 \times R_{ECAL}^{inner} \times 2350/1843$

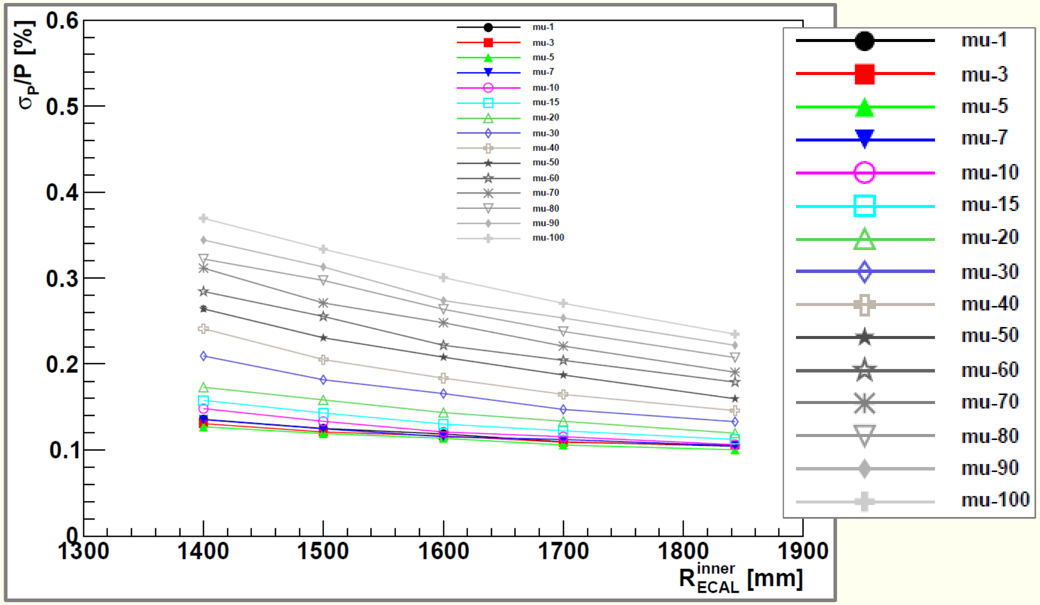


- When mention: R_{ECAL}^{inner} means that the whole ILD detector model is reduced
- For all models, ECAL, HCAL have same thickness as in baseline design
- Same B-field (3.5 Tesla), sensor size (5×5 mm^2 for SiW ECAL and 10×10 mm^2 for sDHCAL)
- SiW ECAL has 30 layers (29 Si layers)



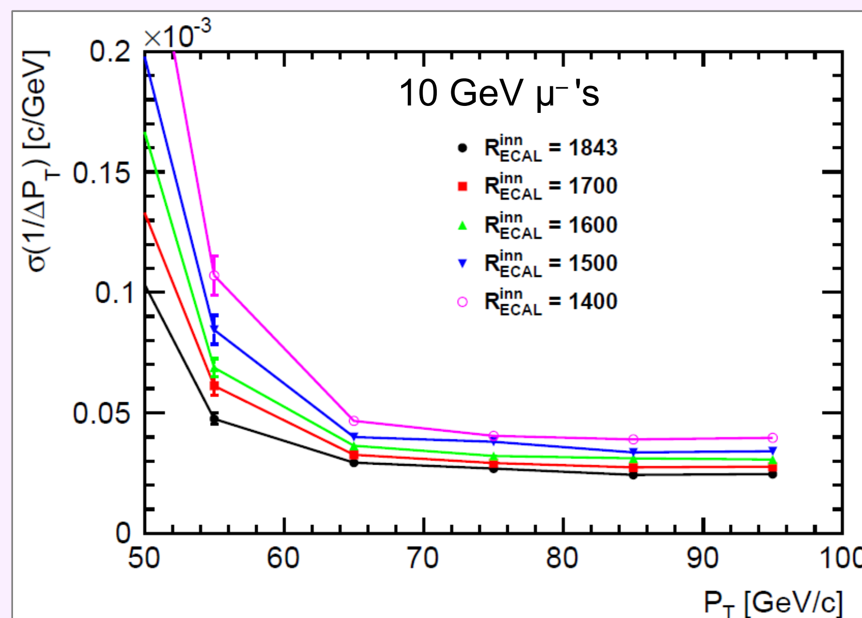
Factor of ILD sub-systems compared to baseline design ($R_{tracker}^{(outer)}$ =1.8 m)

Single particle resolution: muon's

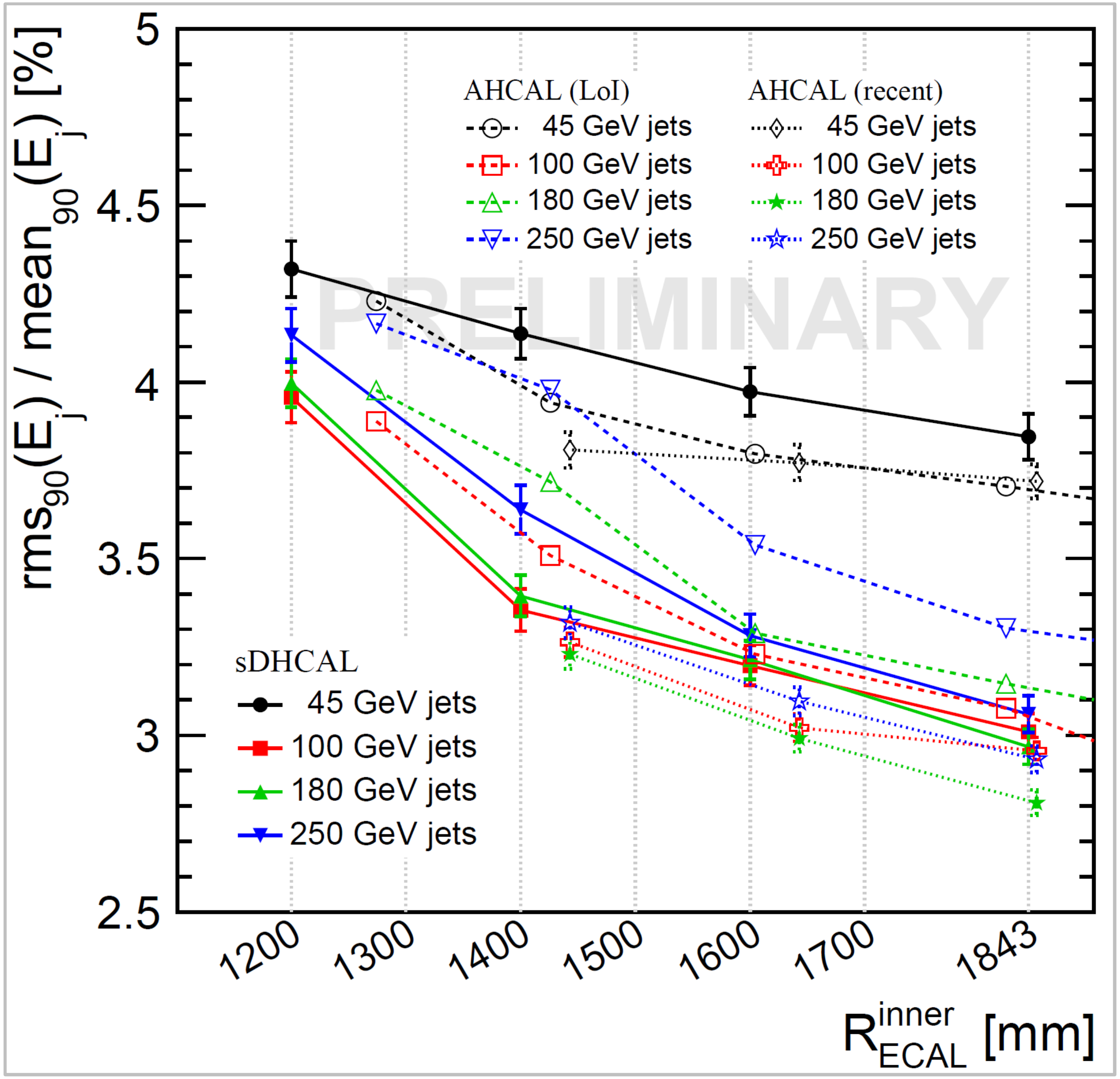


Momentum resolution of muons' at different energies for different radii.
Degradation by, e.g., 40% for muons' at 50 GeV.

Or in terms of resolution of $1/P_T$ of track.
Degradation in $1/P_T$ resolution by ~60% from radius 1843 to 1400 mm.



Jet energy resolution vs Radius



SiW ECAL: 5×5 mm², AHCAL: 3×3 cm², sDHCAL: 1×1 cm²

- JER is determined using Z → uds (Z decaying at rest– qqbar)
- CM energies: 91, 125, 200, 380, 500 GeV → Jet energies: 45, 62, 100, 180, 250 GeV

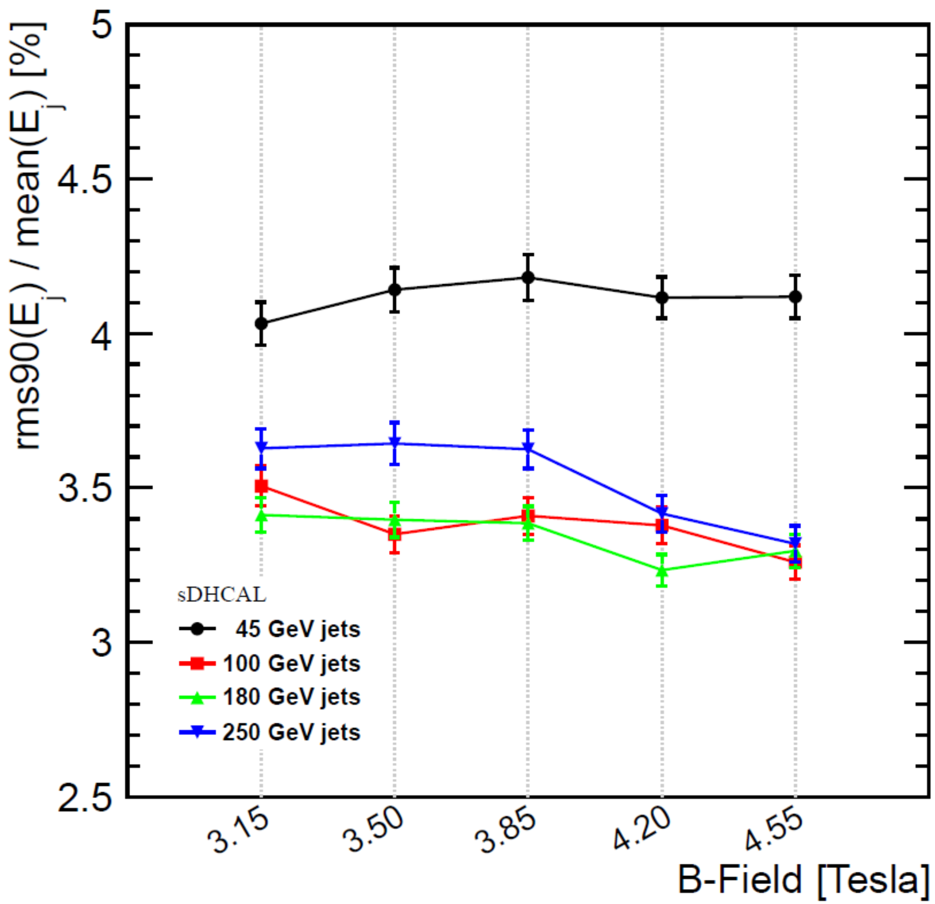
- This study: solid lines, PandoraPFANew v0.09
- Results for AHCAL @ LoI – dashed lines, PandoraPFA
- recent updates for AHCAL – dotted lines, PandoraPFANew v0.12 (cf. J. Marshall's talk.)

- PandoraPFANew is not optimized for 1×1 cm² sDHCAL
- even though, sDHCAL seems to have similar resolution at medium energies as AHCAL

Magnetic field

Change of B-field

- ILD with Ecal inner radius at 1.4 m is chosen for the study
- Change B field (3.5 T) by a factor of 0.9, 1.1, 1.2 and 1.3 → 3.15, 3.85, 4.20 and 4.55 T



R_{ECAL} = 1400 mm, 29 Si layers, 5×5 mm²
sDHCAL 10×10 mm²

- Improvement at high energies – confusion reduced
- For low energy (45 GeV), improvement at low B-field: at higher B-field, loose of low energy tracks

Summary

- Many studies of cost-performance were done for an optimisation of the ILD concept
  - reduction of ECAL number of layers: slight degradation observed
  - different radii, different ECAL&HCAL geometries,
  - cell size, calorimeter thicknesses, ...
- If choose to reduce radius to 1.4m, JER increases:

R_{ECAL} (mm)	E_{jet} (GeV)			
	45	100	180	250
1843	3.85	3.01	2.97	3.06
1400	4.14	3.35	3.39	3.64

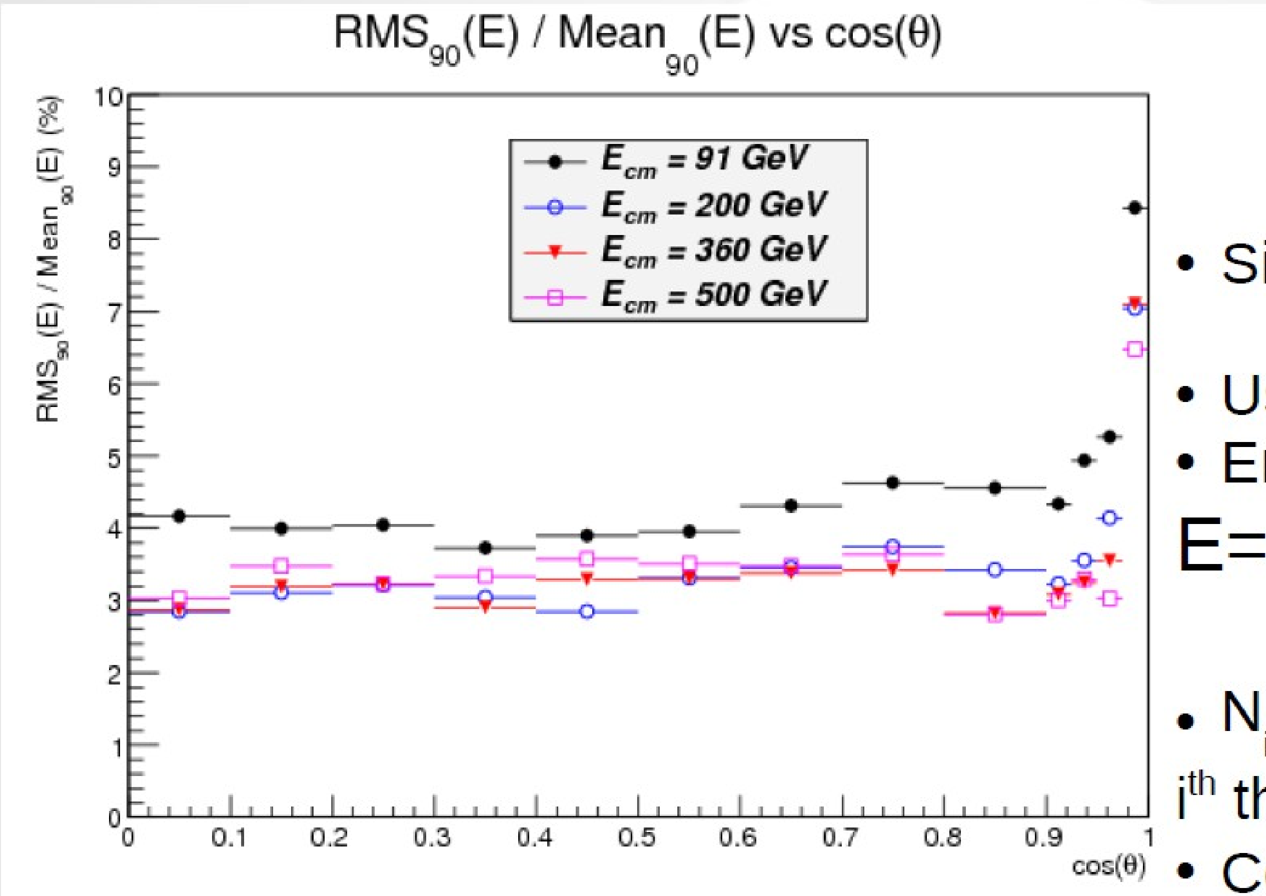
However,
  - we should mention that potential of high granularity is still not fully explored
  - we may allow degradation but we gain in price as a function of R^2 !
-

Future plan

- Repeat studies to R=1.45m, 25 layers for SiW ECAL

Backup slides

SDHCAL optimisation: software



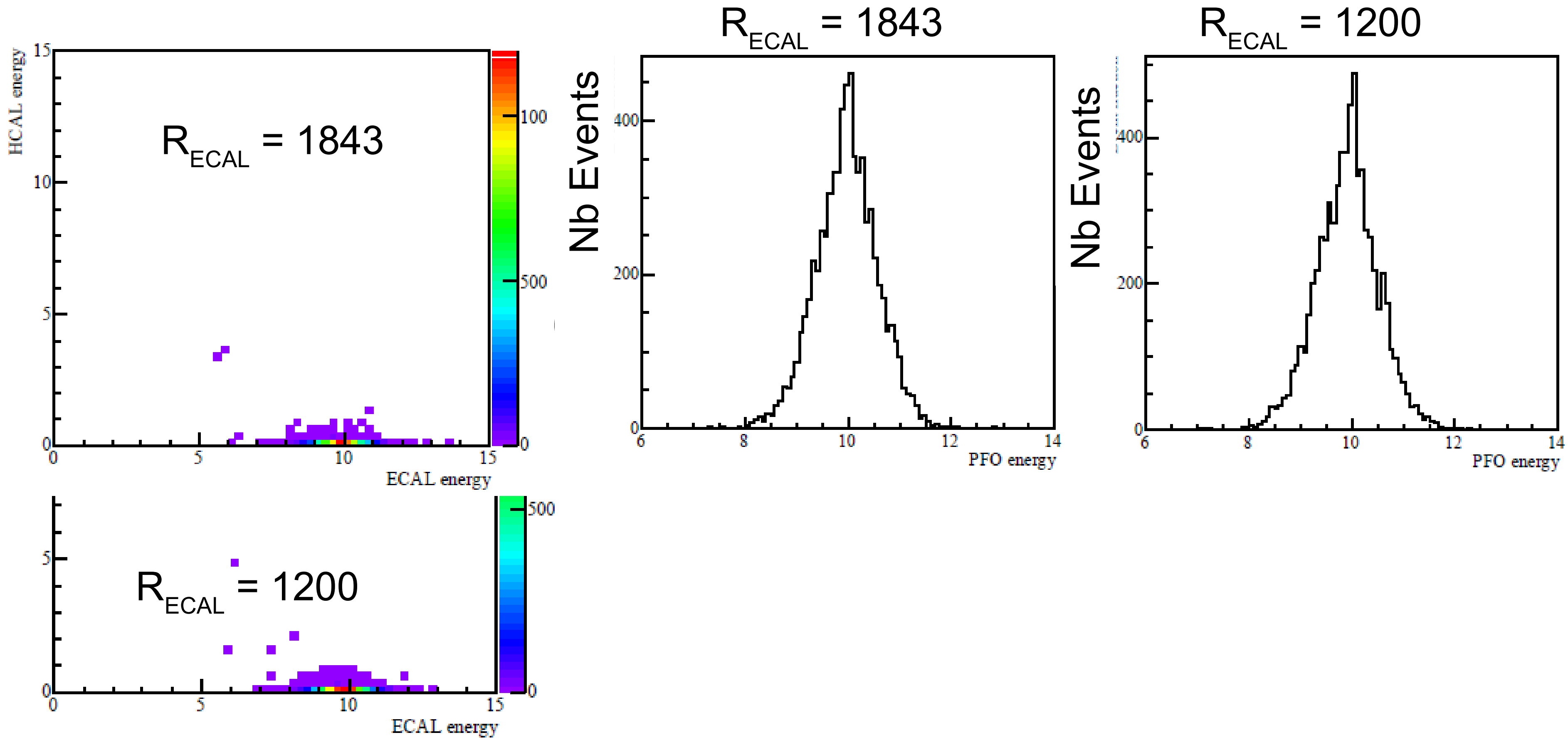
SDHCAL DBD
jet energy resolution

- Simulate GRPC response (digitizer)
- Use PandoraPFA
- Energy is reconstruted as

$$E=\alpha N_1 + \beta N_2 + \gamma N_3$$

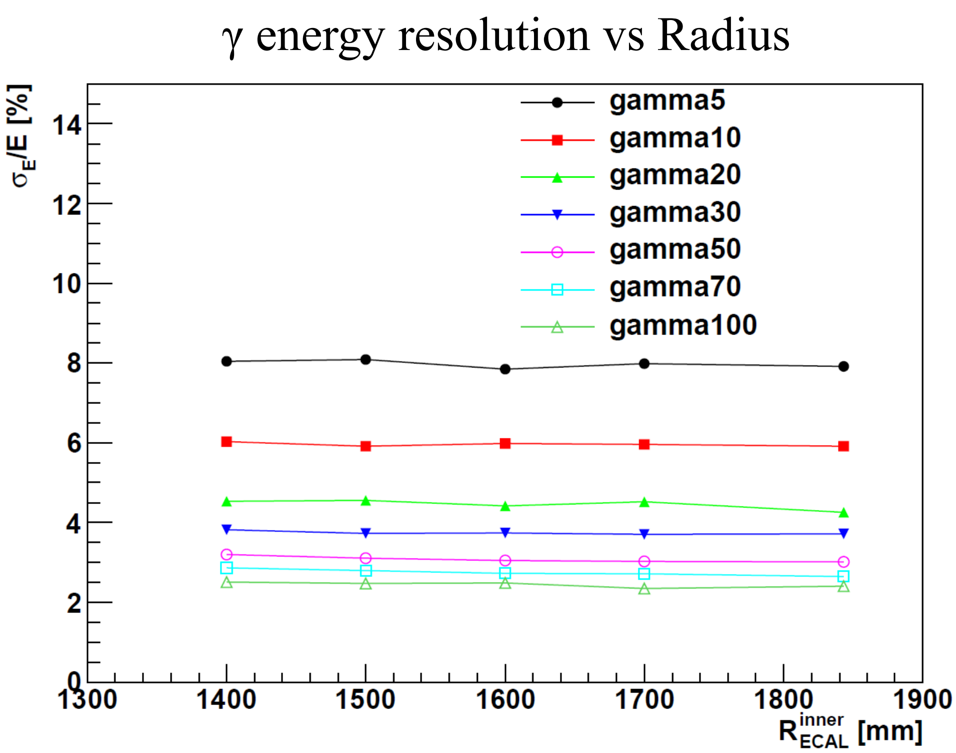
- N_i = number of hits above i^{th} threshold.
- Coeff α,β,γ tuned on pion and muon data

ECAL + HCAL calibration. Step 1.



- Based on single particles
- EM calibration coefficients are adjusted from default value for every radii within 1.5%
- Hadron calibration at calorimeter energy level is fixed
  which was determined for sDHCAL prototype using 3-threshold mode: 0.114, 1.39 and 3.65 pC.

Energy resolution for gamma



Only photons in barrel are taken into account

→ no changes in resolution for single photon events

Hadron calibration: parameter scan. Step 2.

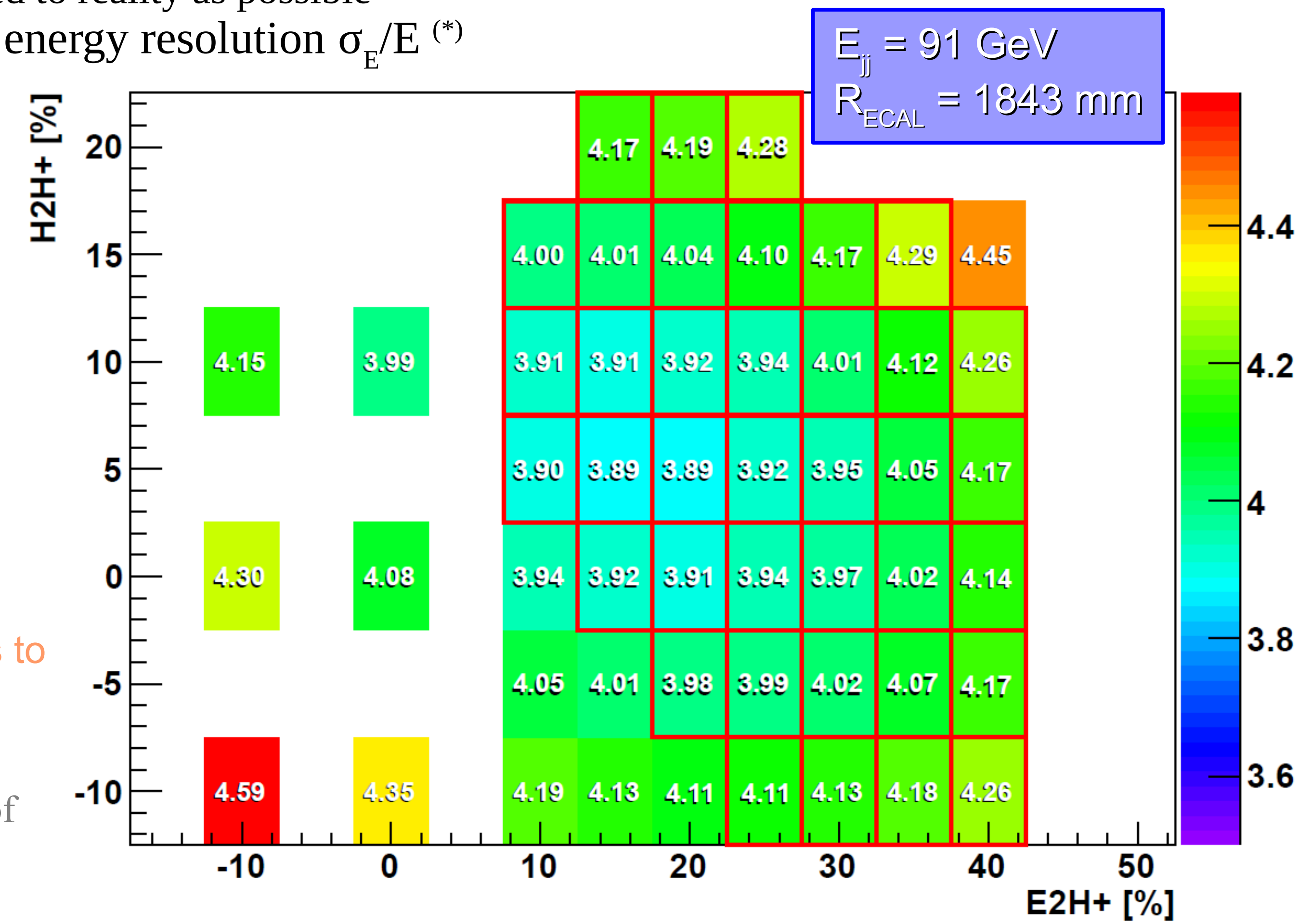
- Two calibration constants within Pandora: weights to energy deposites in ECAL and HCAL which belong to hadronic shower
- Set of parameters are chosen so that:
  - Jet energy resolution is as small as possible (for all energies)
  - mean value as closed to reality as possible
- Scan based on single jet energy resolution σ_E/E (*)

- Once close to minimum, 5% of change in HAD and EM scale does not affect significantly the resolution

red boxes: mean value differs to real value by less than 1%

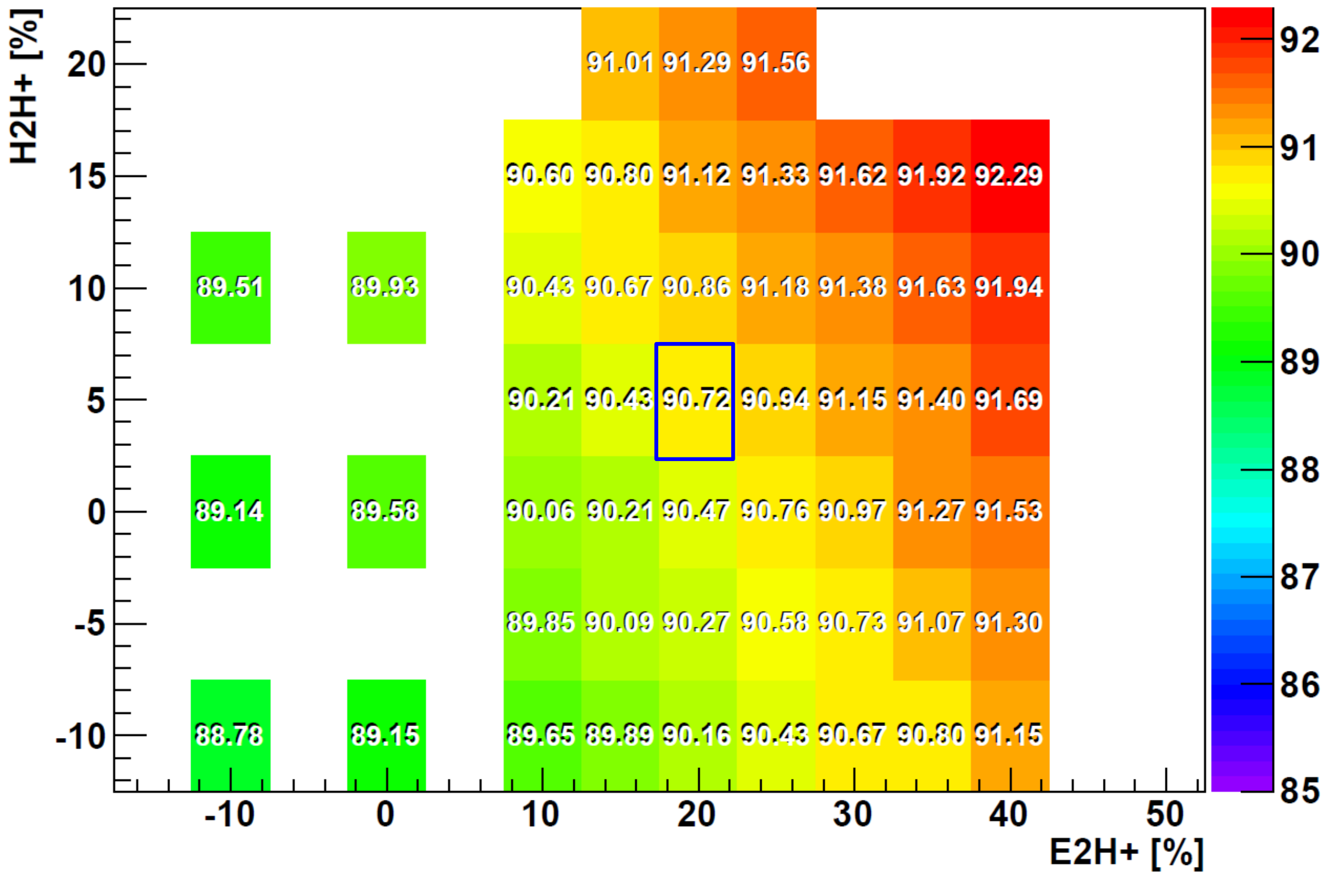
(*) the JER is expressed in terms of RMS90

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



Hadron calibration: parameter scan (cont.)

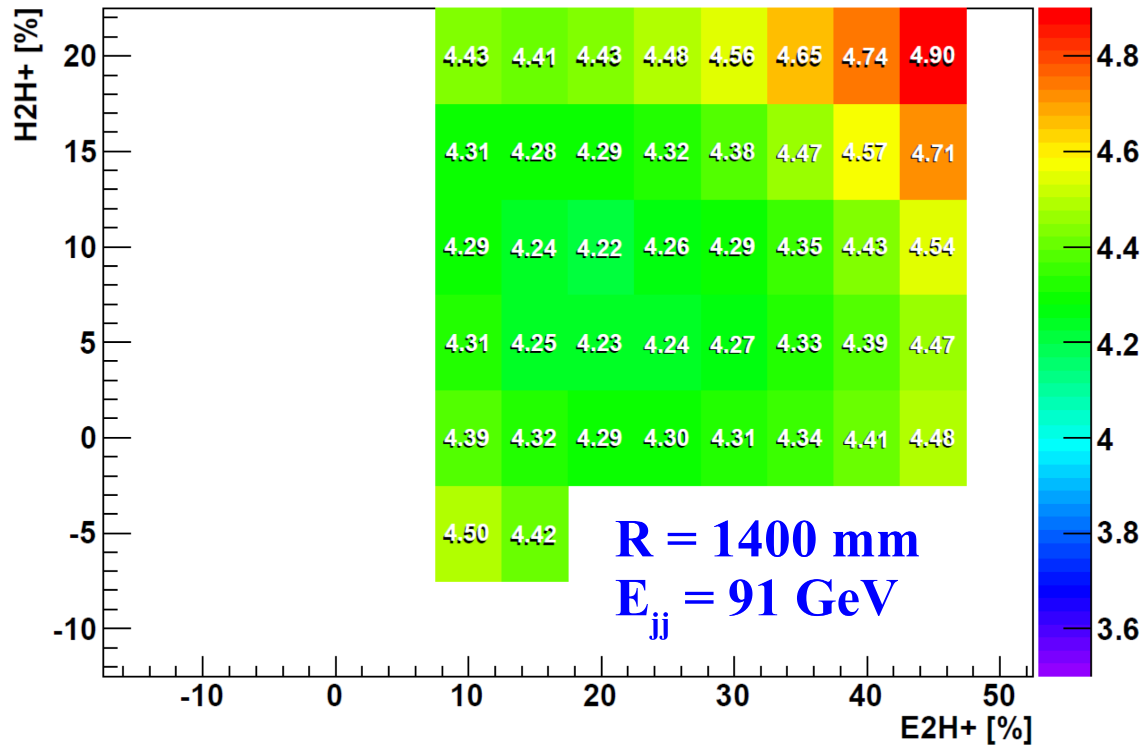
- Scanning should ensure that energy mean value is closed to generated $E_{jet-jet}$

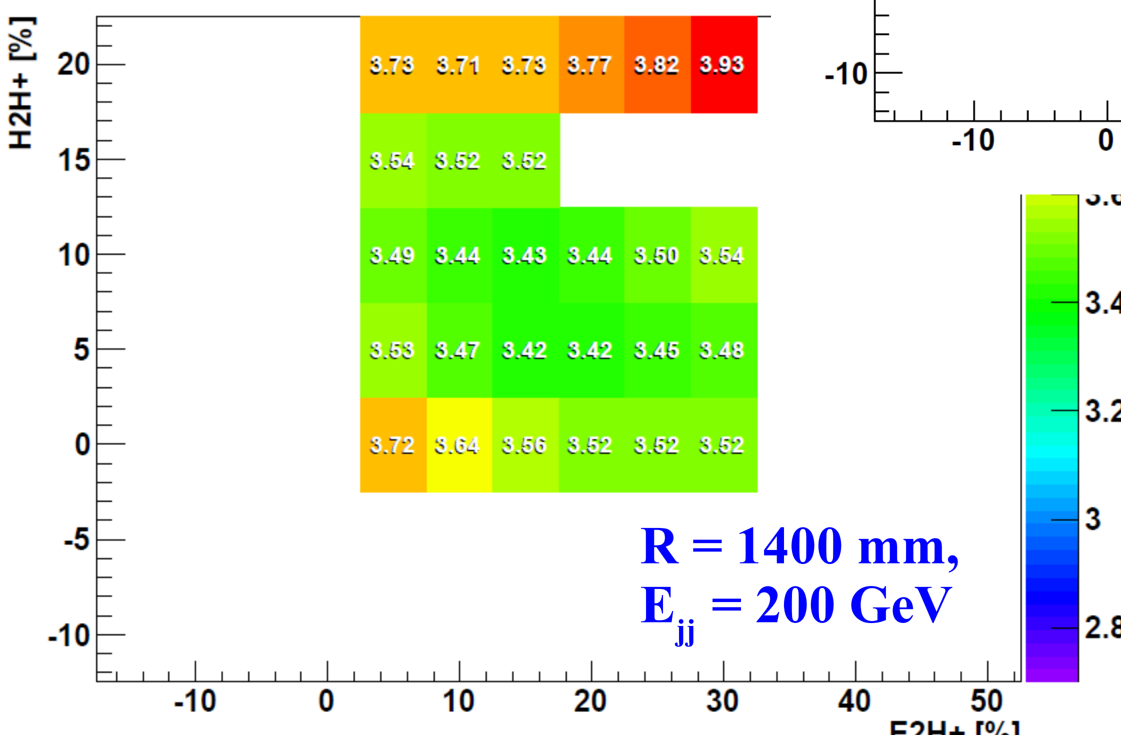


- **Scan results show that:**
  - EM scale should be increased by 20%
  - HAD scale should be increased by 5%

Hadron calibration: parameter scan (cont.)

- Scan repeats for :
  - all radii
  - for energies 91, 200 and part of 500 GeV
- Optimal for JER always at +20% for EM scale and +5% for Had scale

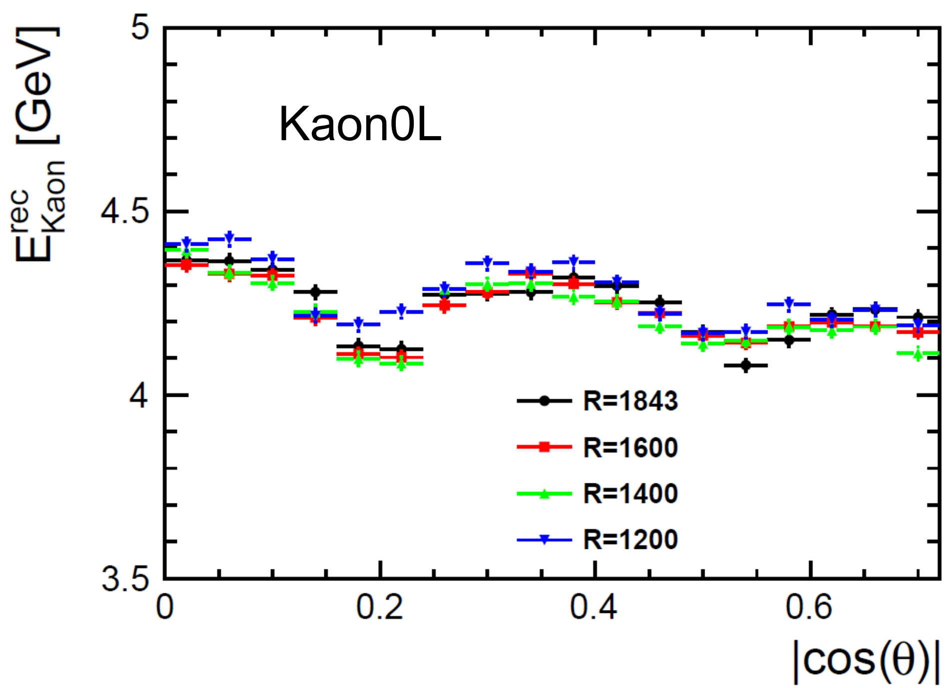


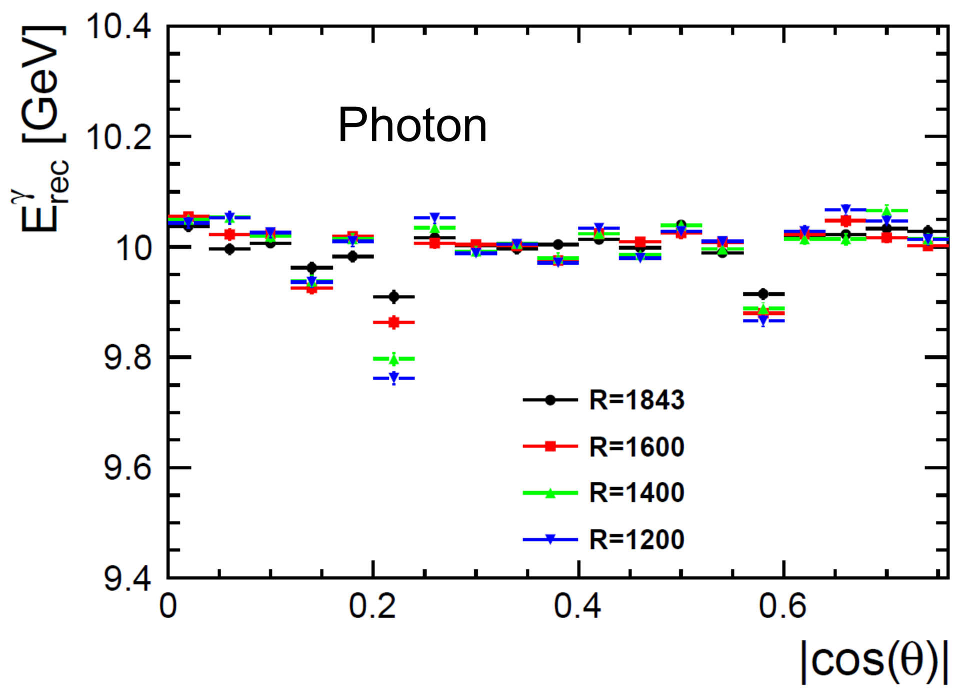


- Variation of JER is <1% if change scale by 5%

Angular energy correction. Step 3.

- Mean value of energy shows a significant dependence on polar angle, especially for lower value of radius: due to gap between modules (ECAL+HCAL), alveolar structures (ECAL), ...

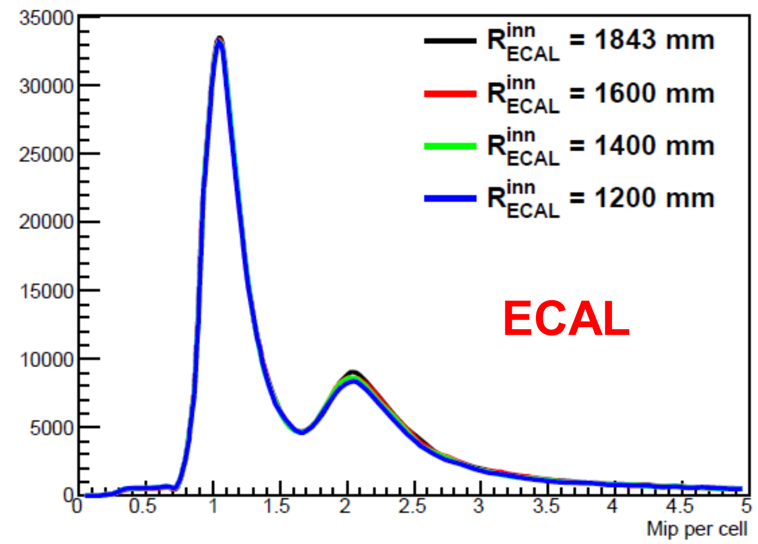


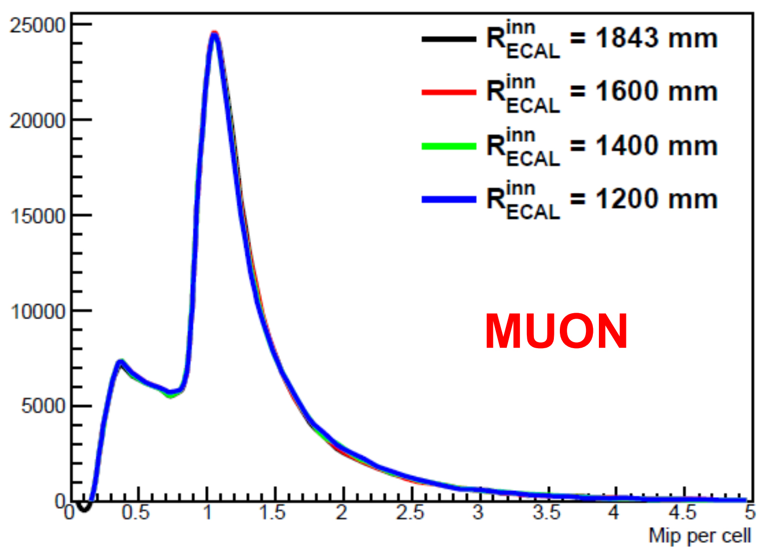


Effect of correction on JER							
E_{jj} (GeV)	R_{ECAL}	before	after	E_{jj} (GeV)	R_{ECAL}	before	after
91	1843	3.89	3.85	500	1843	3.12	3.06
	1400	4.23	4.14		1400	3.71	3.64

Mip calibration: muon's at 10 GeV

- Mip calibration: how energy in calorimeters are translated in to MIP energy
- Controlled by equivalent number of mips per cell for each event

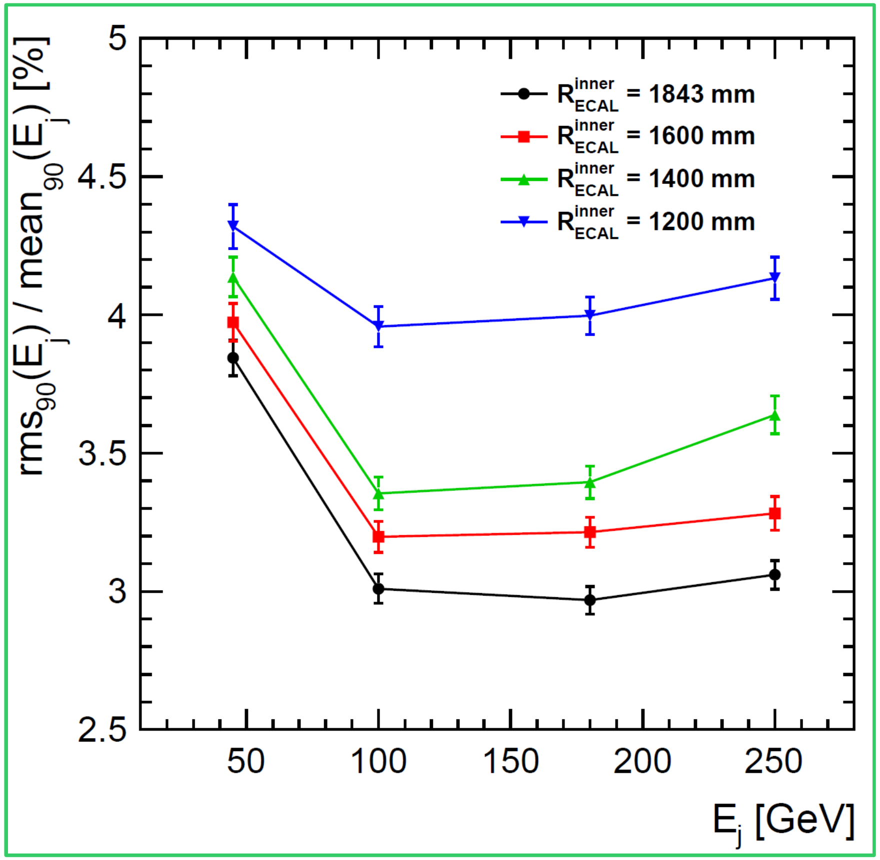




- Double-peak structure for ECAL mip due to two sections with different sampling fractions

- **Very small difference in MIP calibration between different radii. (Fluctuation.)**

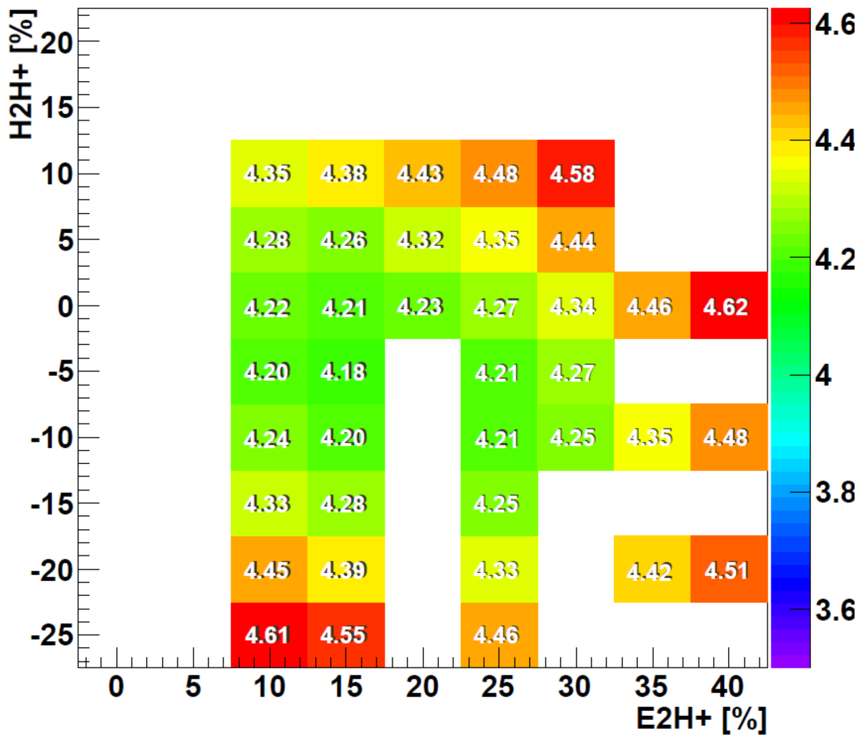
Jet energy resolution vs E_{jet}

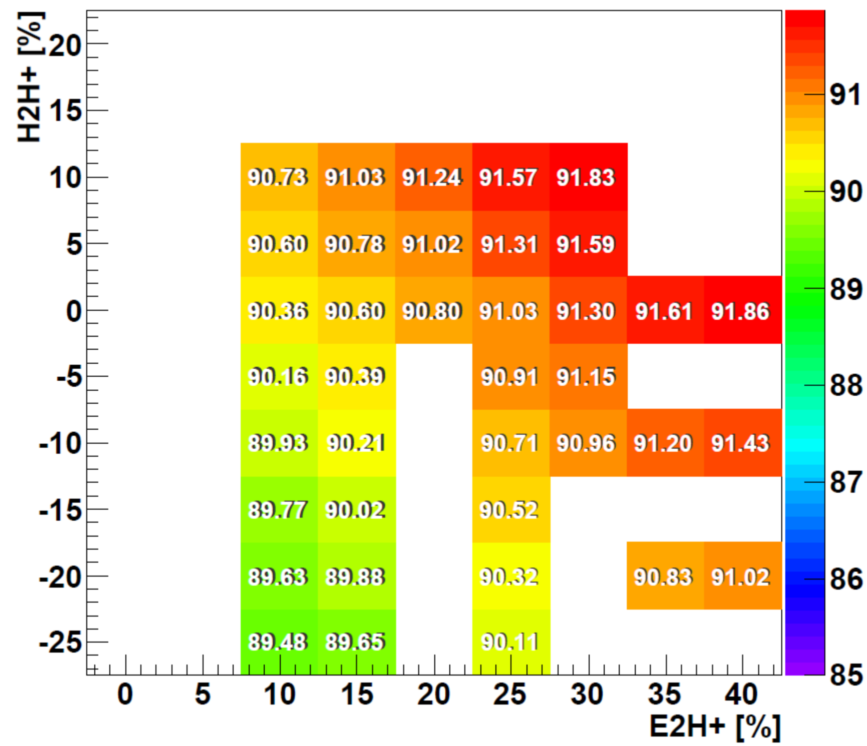


- At low energy, JER is dominated by intrinsic calorimeter resolution – mainly HCAL (1/sqrt(E))
- At higher energy (250GeV) confusion term dominates → JER increases
- R=1200 mm does not seem to be a good option

DHCAL in analog mode

- Take energy as proportional to deposited charge (like AHCAL) in gas
- Recalibration:
  - Conversion factor (charge → energy)
  - Scanning also performed
- However minimum of JER is ~4.18, far from what given with digital mode (hit counting)

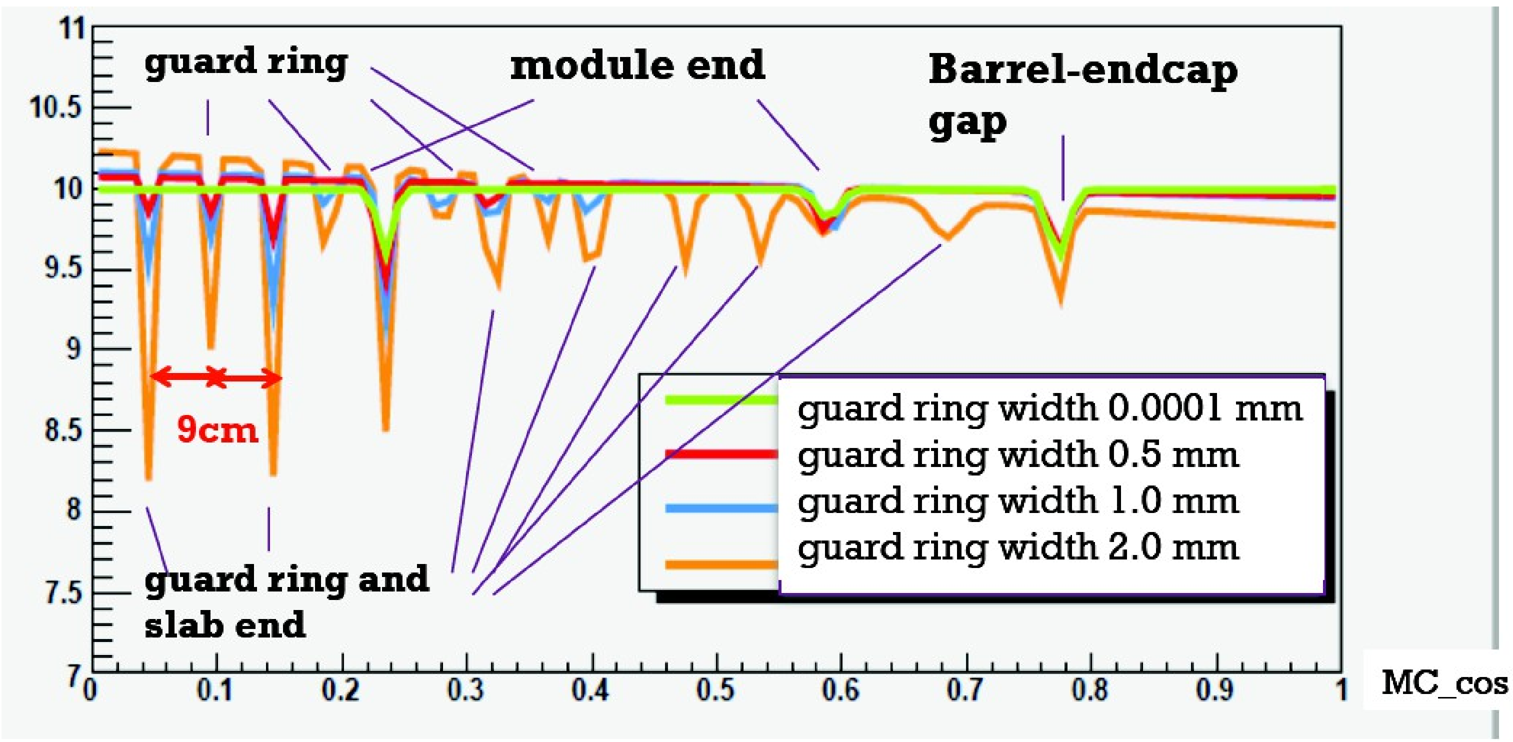




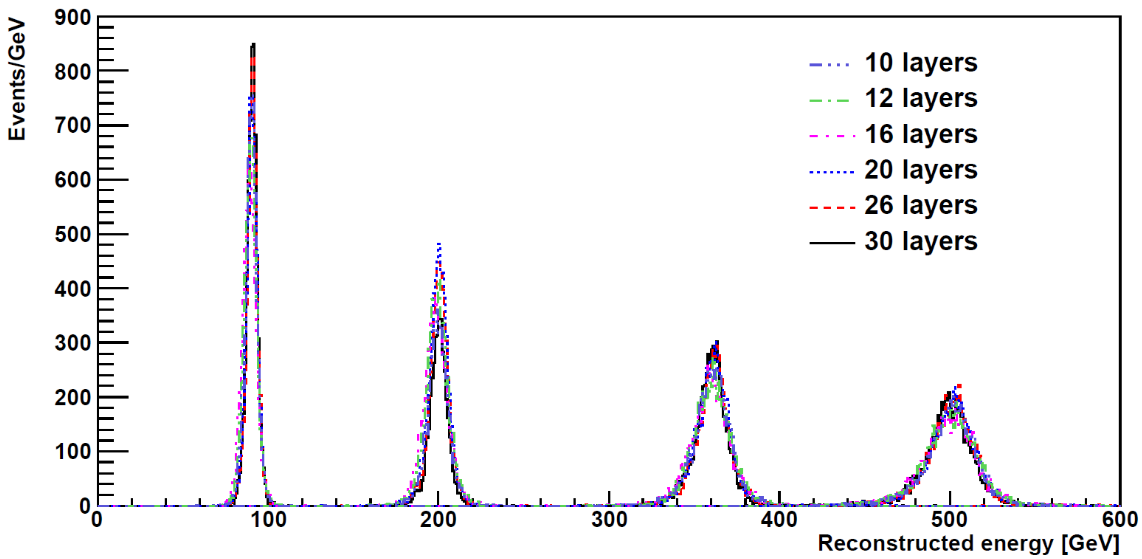
Guard ring in SiW Ecal: energy correction

- Energy decreases in gaps between slab sensors, alveolars, at module ends and barrel/endcap gap.
- Direction resolution for θ of 3.3×10^{-4} rad. Sufficient to give a correction by θ.
- Correction is determined by gaussian+linear fit of simulated response to 10 GeV photon
- Energy drop ~10% @ 1.0mm, ~20% @ 2.0mm

10 GeV photons

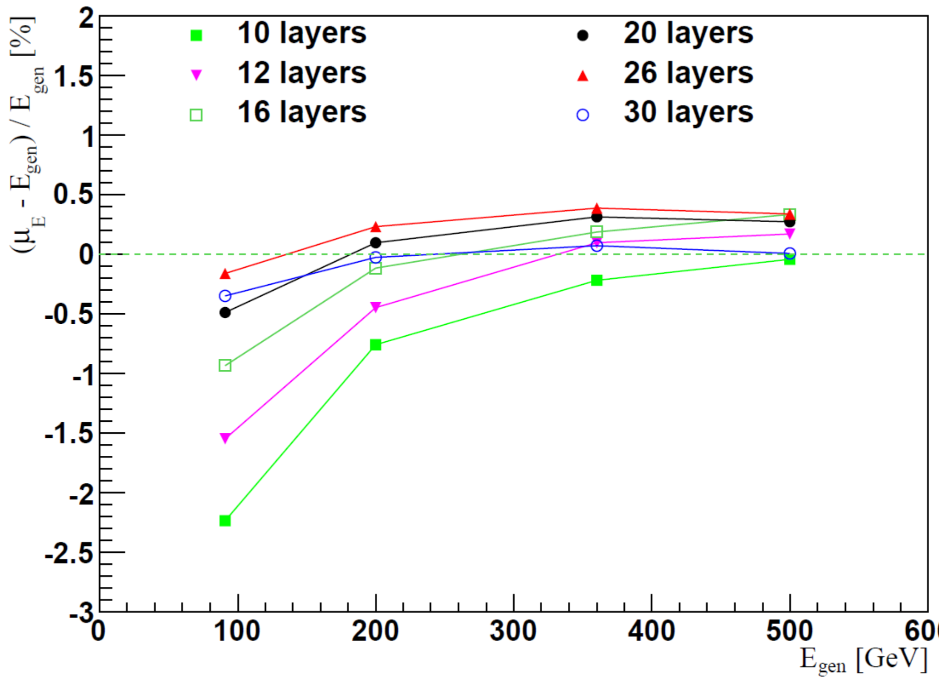


ECAL number of layers: Linearity

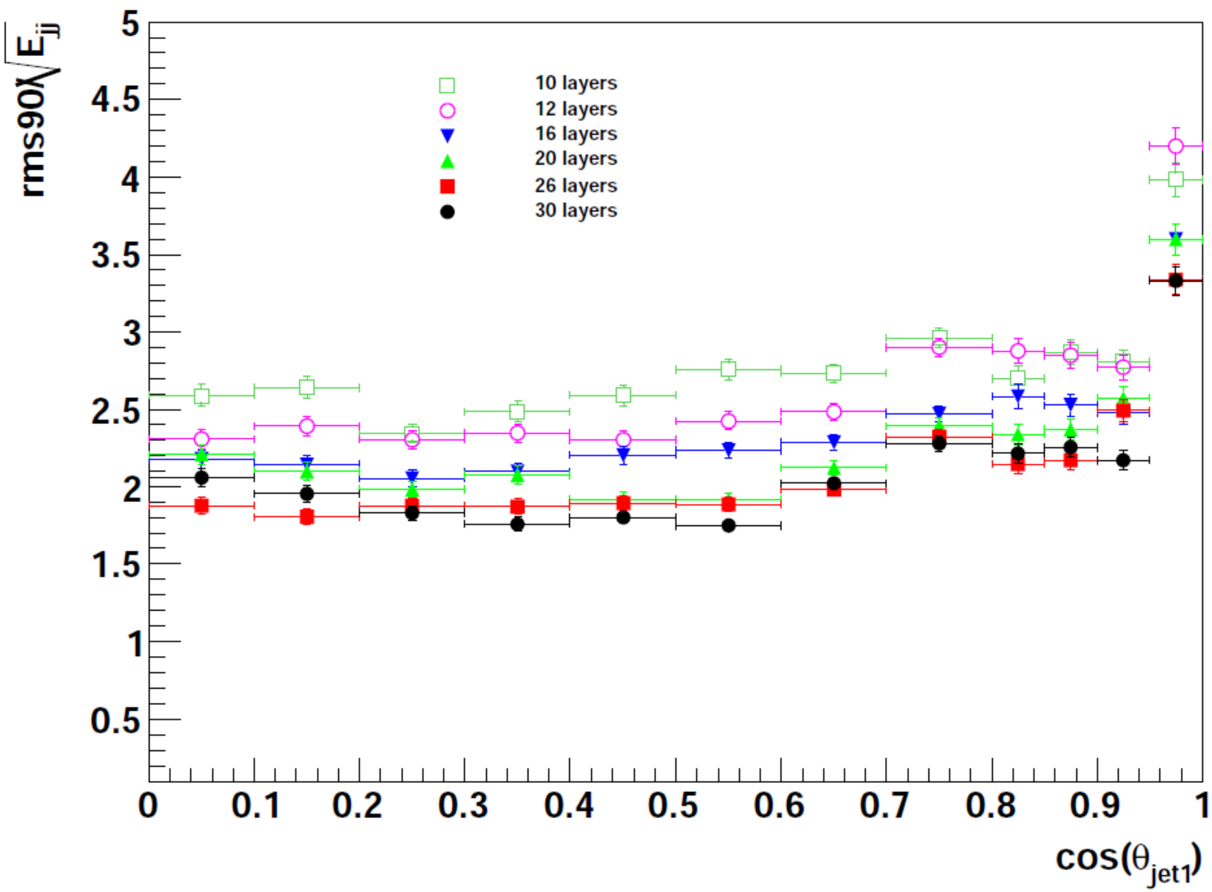


- Reconstructed jet energy for all ECAL models and for events at c.m. energies 91, 200, 360, 500 GeV

- Residual $(E_{rec}-E_{true})/E_{true}$ shown in% as a function of E_{true}
- Linearity within 0.5 % for 30-26-20 layers and significantly degrades for other ECAL models

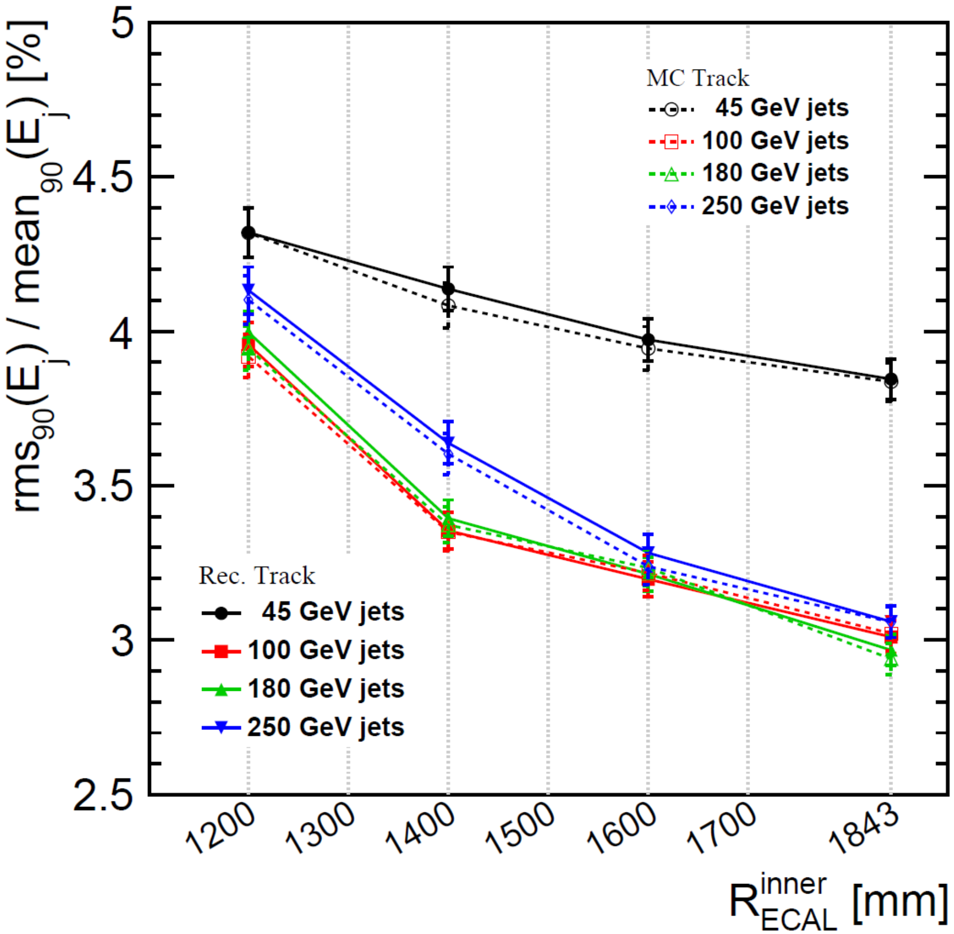


Jet energy resolution vs cos(θ_jet)



- Jet energy resolution presented in function of cos(θ) of first jet
- No significant problem found among full region of cos(θ)
- Example for Z→uds 91 GeV sample

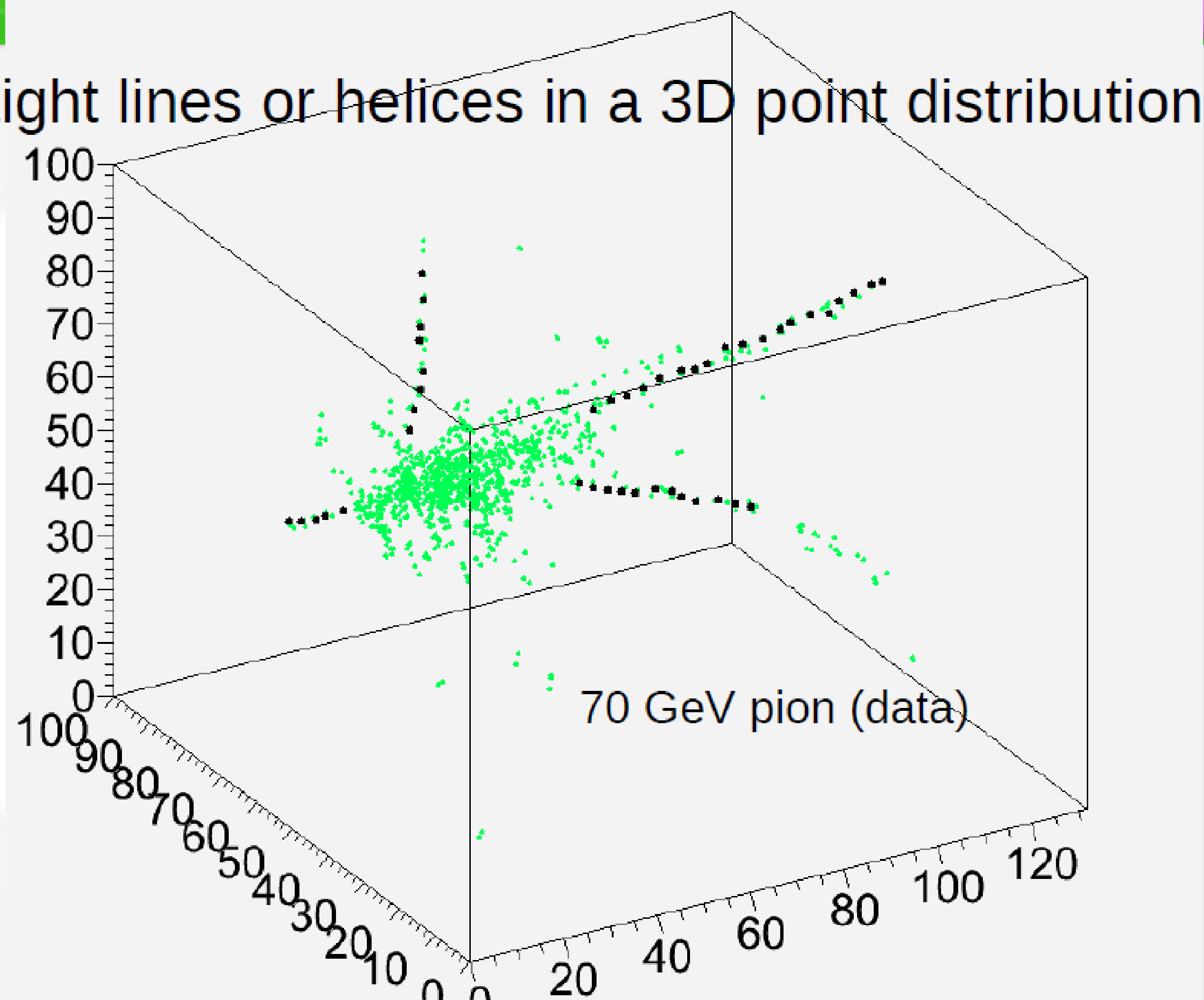
Effect of tracking on JER



- Tracking performance degrades for small radii → effect on PFA performance need to be checked
- Use MC truth tracks as input for PandoraPFA
- Slight difference observed but not dramatic

SDHCAL optimisation: Hough transform

Technique to find straight lines or helices in a 3D point distribution

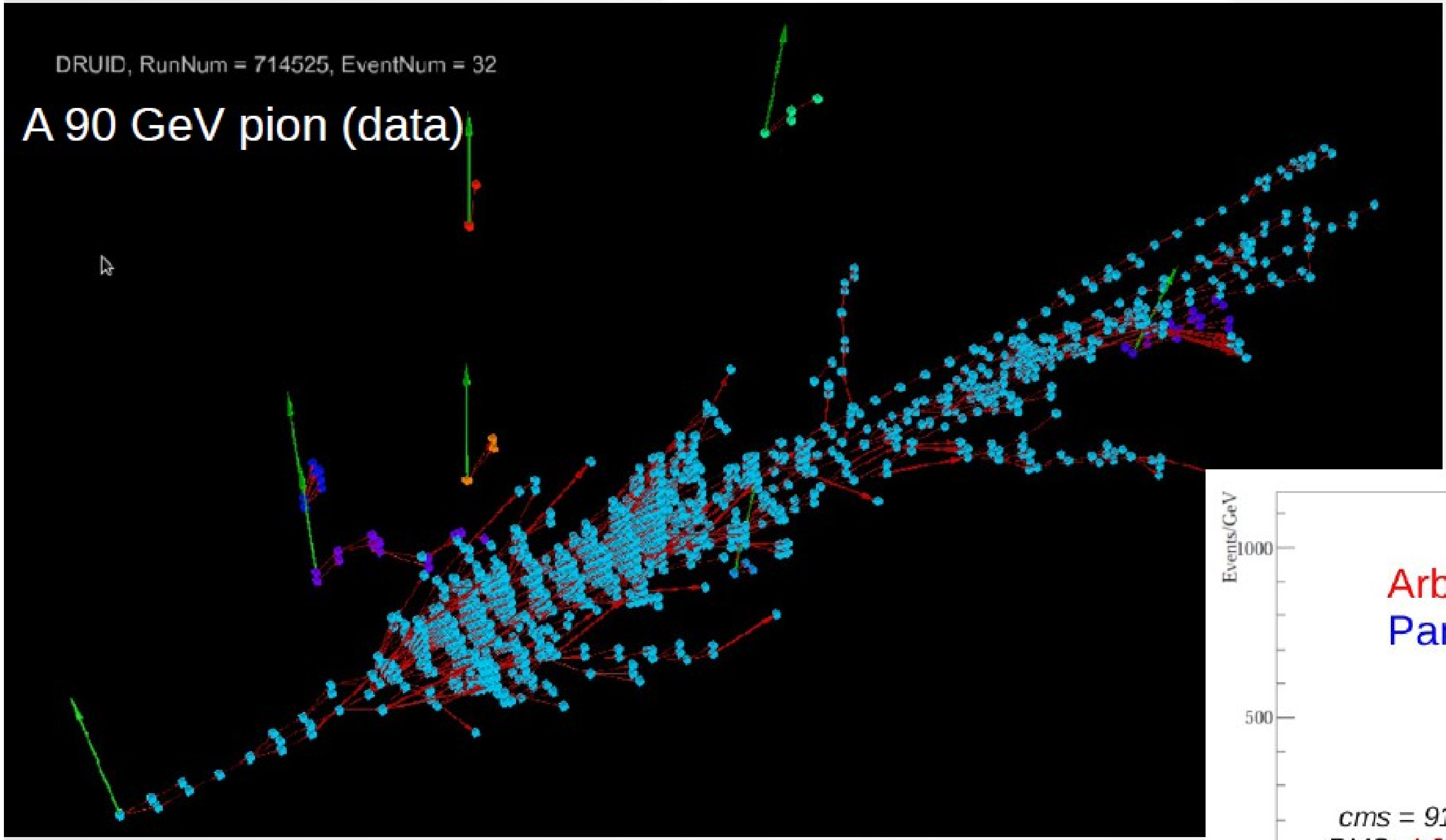


- Reconstructed tracks can be used to measure channels efficiencies
- Hits on tracks can be treated differently for energy reconstruction.

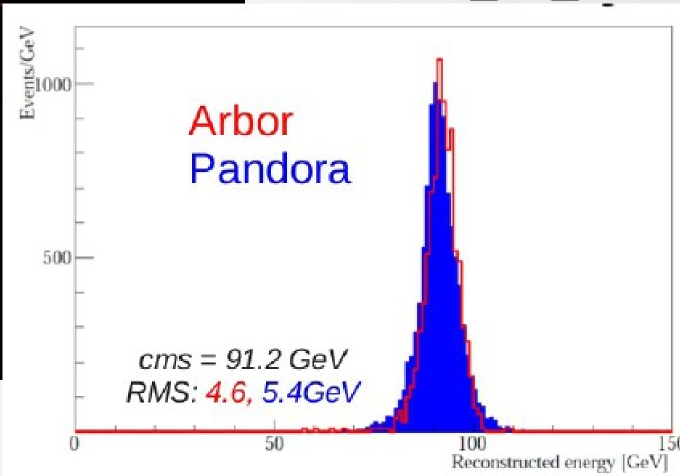
SDHCAL optimisation: Algorithms

Arbor is an optimized Particle Flow algorithm for SDHCAL

A shower looks like a tree : try to reconstruct it as a tree.



Dijet 91GeV
ILD_o2_v05



JER. RMS90.

- RMS of the smallest range of reconstructed energy containing 90% of events

- Single jet energy resolution:

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