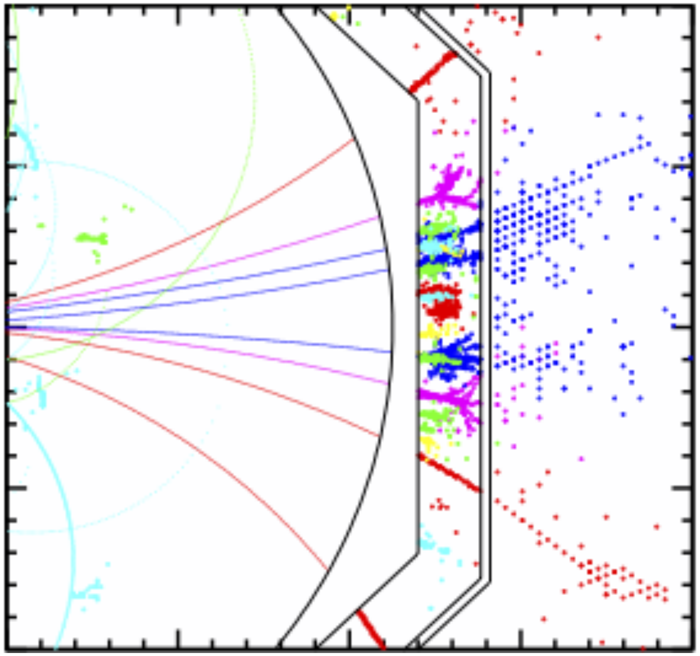
AHCAL optimisation using Pandora



Huong Lan Tran

ILD Collaboration Meeting - November 4, 2015

LCWS2015, Whistler, Canada

HELMHOLTZ ASSOCIATION

CALICE

DESY

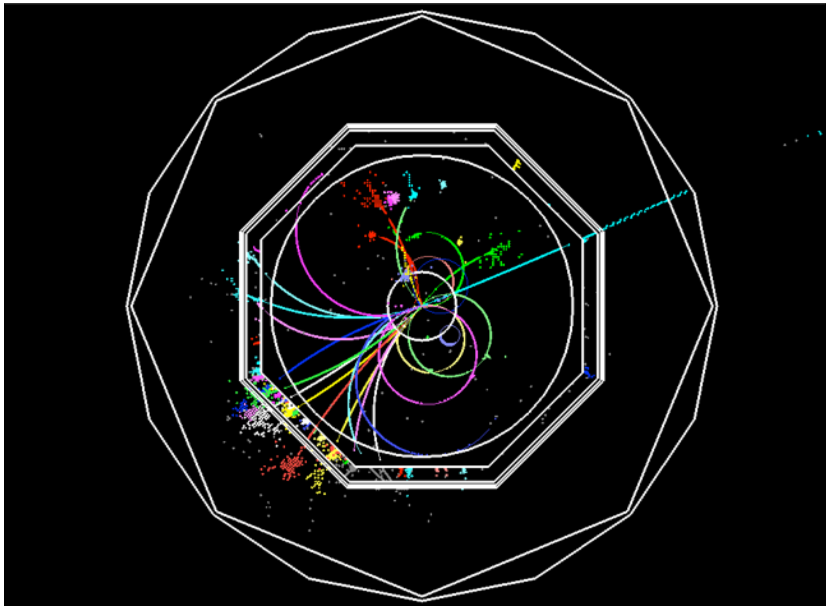
Outlines

- Intensive work on-going to re-optimise HCAL
  - New version of Pandora shows better resolution
    - Impact of energy reconstruction
  - Discussion about overall size of ILD and cost
    - HCAL cell sizes, HCAL thickness,
      different granularities @ different depth
  - Proof of design (absorber structure) in term of mechanics and physics

In this talk:

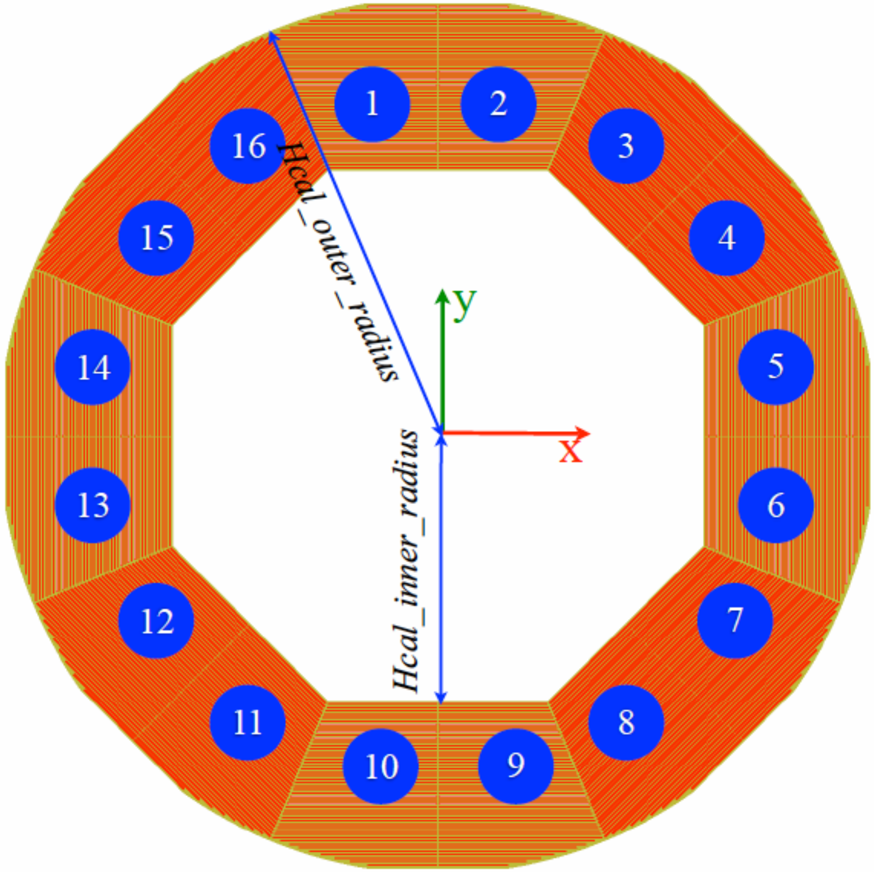
- Effect of boundary regions in support structure
- Implementation of software compensation into Pandora
- Outlook: HCAL granularity revised

Study effect of iron structure on energy reconstruction in (r,phi)



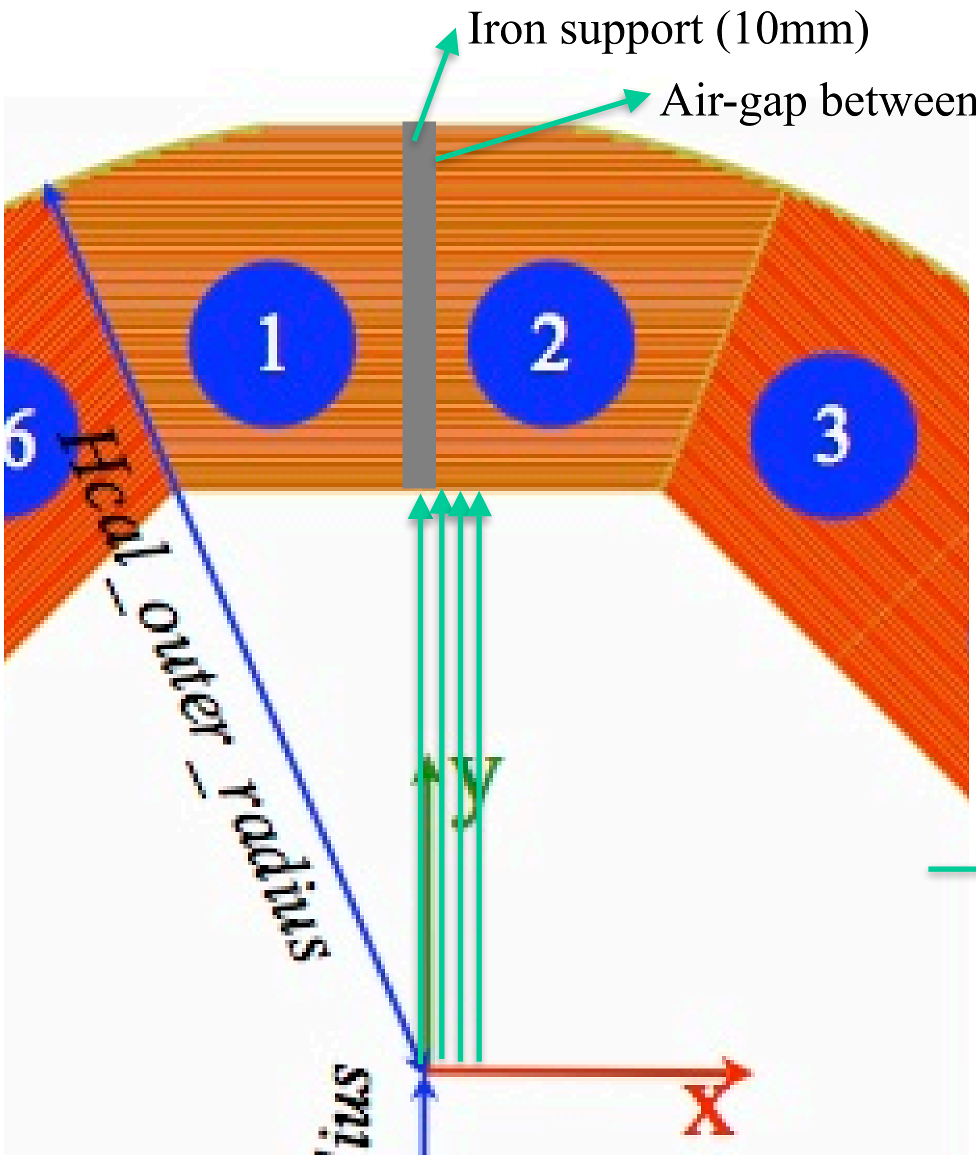
Effect of supporting structure (*r*,phi) plane

ILD-AHCAL view (*r*,phi)

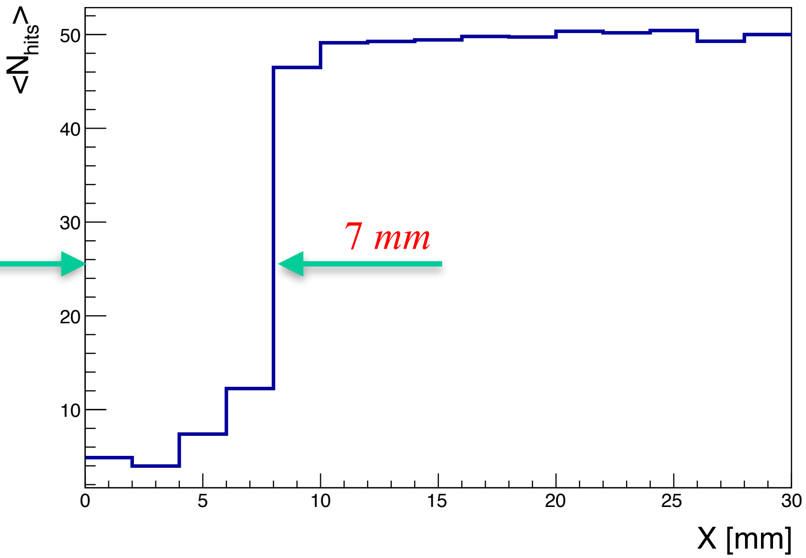


- Highly symmetric structure: 16 sectors of identified shape, but pointing cracks (filled with steel)
- Can be made non-pointing, but less simple construction
- Question: How big is the effect?

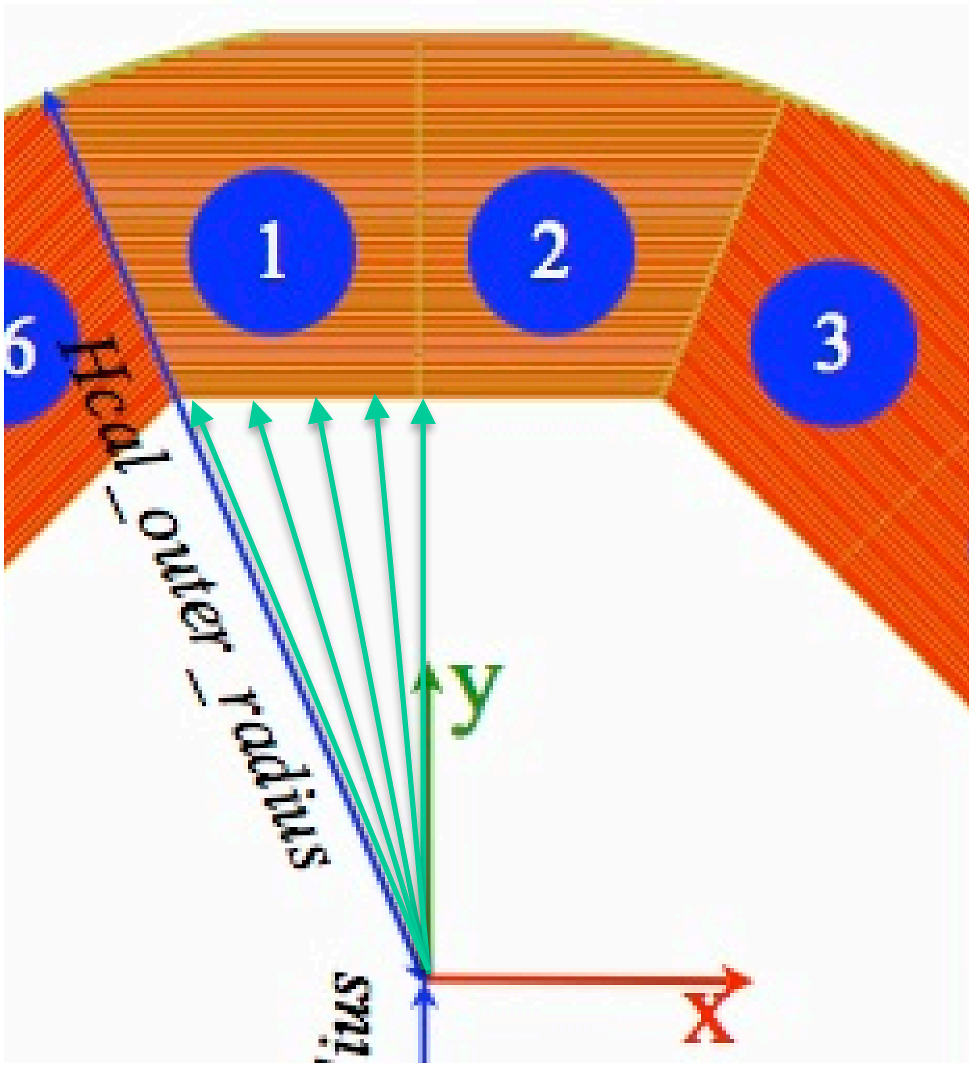
Simulation at supporting structure and neighbouring area



- Shooting muon parallel to iron support in 2mm step to check boundary modelling (0-30mm range)
  - At X>7mm (=10mm/2 + 2mm) muon should leave hits on 48 layers

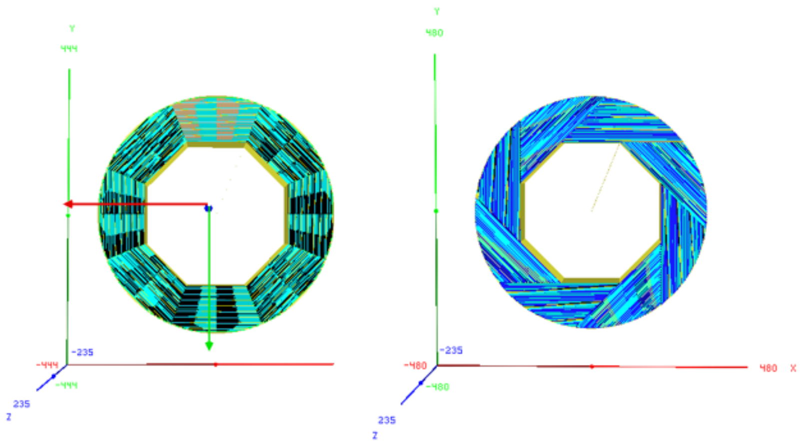


Effect of supporting structure (*r*,phi) plane



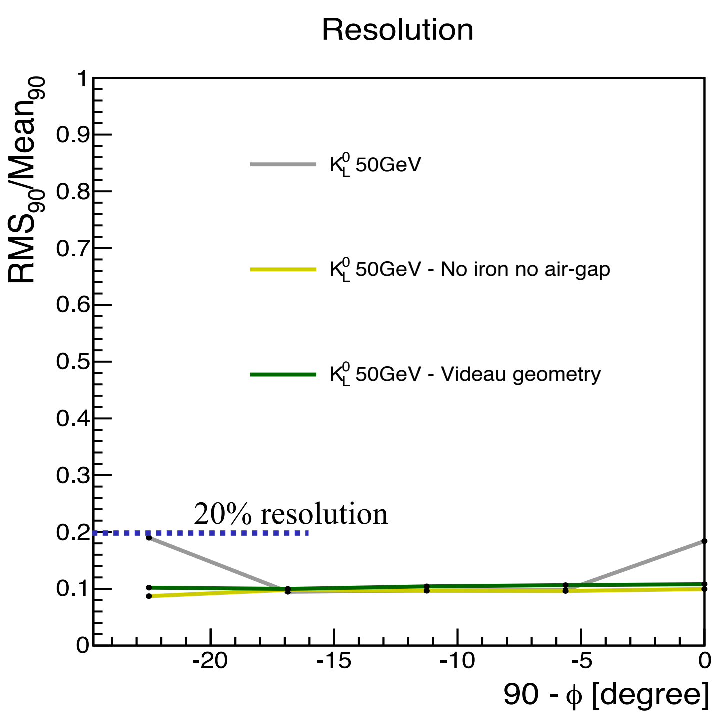
- Shooting Kaon0L in 5 different directions:
  - Avoid iron support at z = 0
  - Direction 1 and 5 correspond to iron support between modules
  - Compare with other geometry designs to estimate the effect

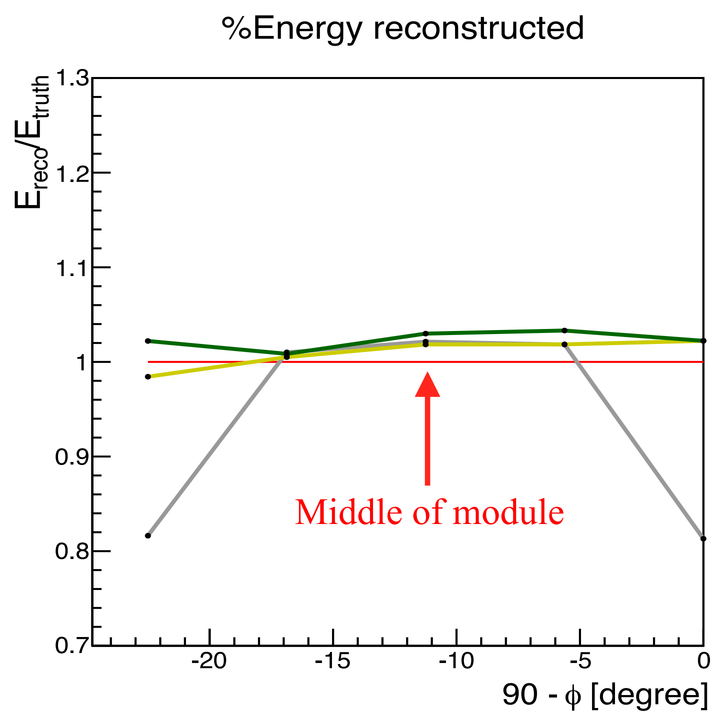
Compare AHCAL and SDHCAL geometries



- Reconstructed energy comparison of 3 geometries:
  - AHCAL geometry
  - Ideal AHCAL geometry w/o iron and air gap in Phi
  - SDHCAL geometry

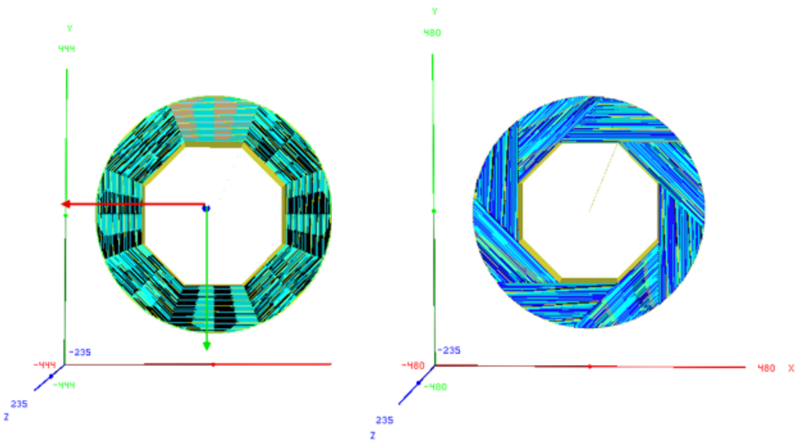
➢ Clear loss of energy response and resolution due to iron crack for AHCAL geometry





But phi steps are large (!)

Compare AHCAL and SDHCAL geometries



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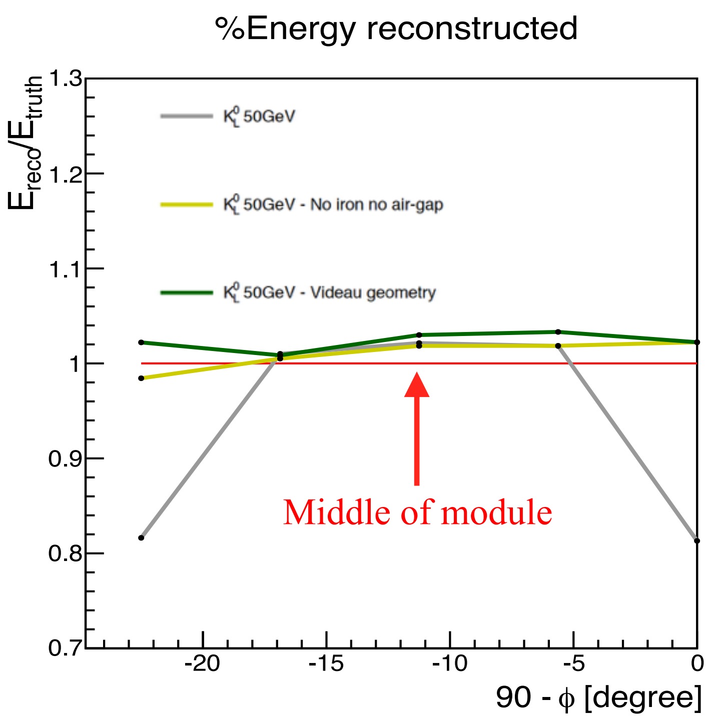
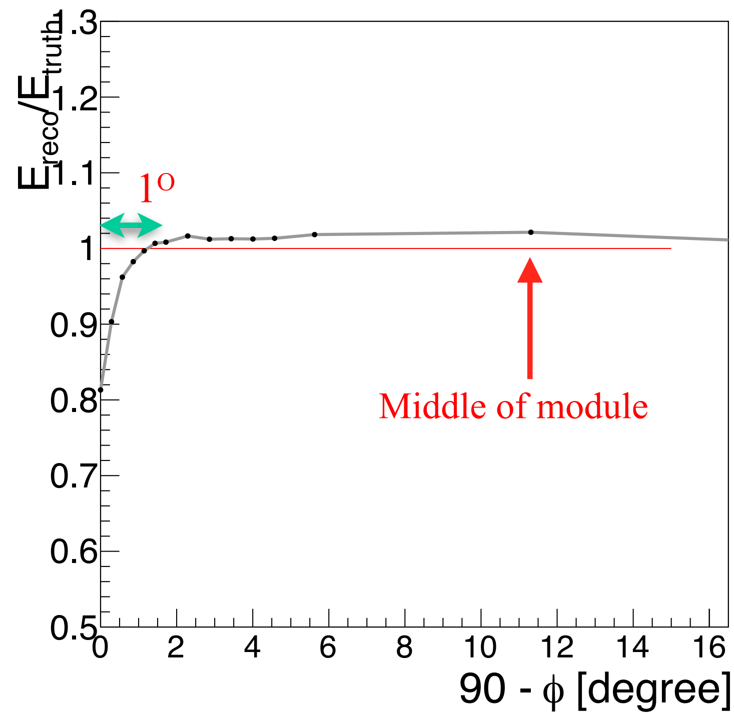
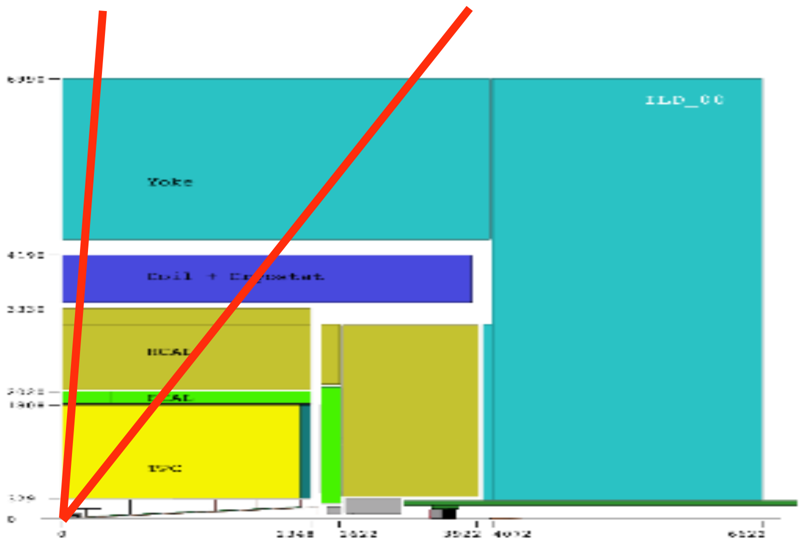


Finer phi steps

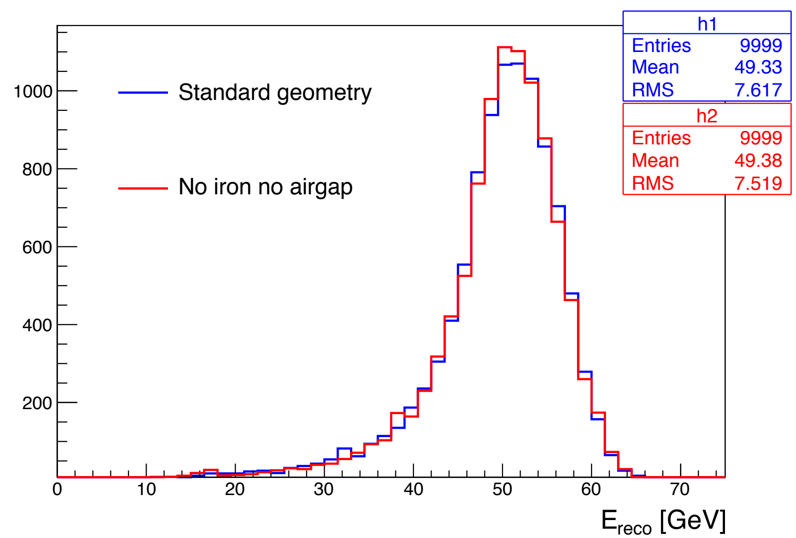


Average effect of supporting structure (*r*,phi) plane



- Cut on Theta to avoid iron support at z = 0 and barrel-endcap gap
- Look at energy distribution ***integrated over all phi***:
  - Standard geometry
  - Standard geometry w/o iron and air gap in Phi

For single particle

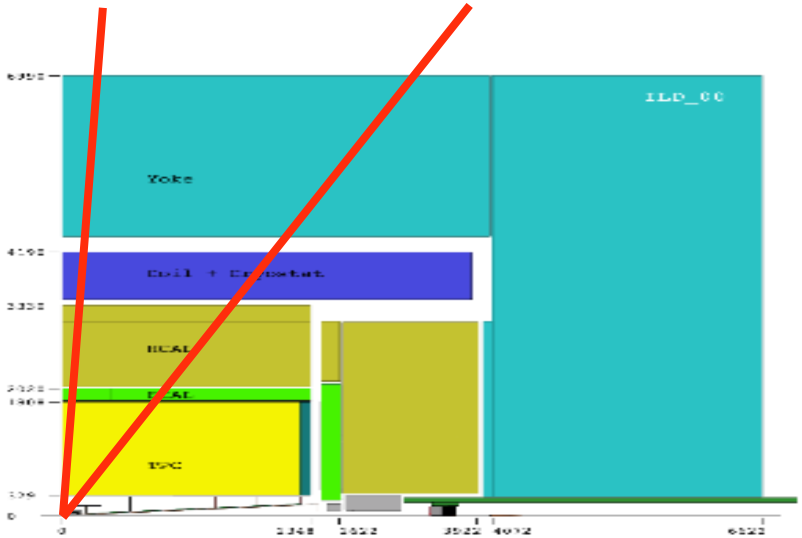


Fit Gaus90

Mean: 50.6938
Sigma: 5.07267
Res(Gaus90) = 10%

Mean: 50.7438
Sigma: 5.15704
Res(Gaus90) = 10.2 %

Average effect of supporting structure (*r*,phi) plane



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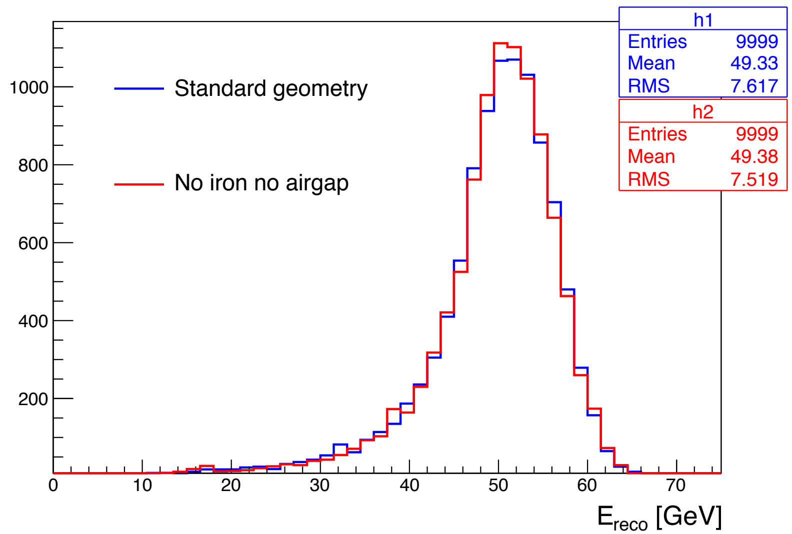
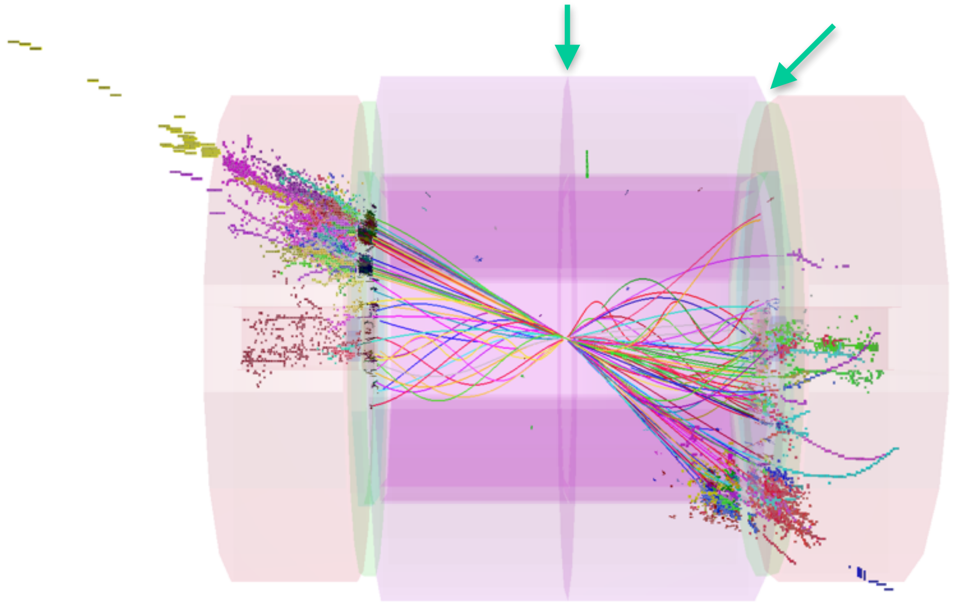


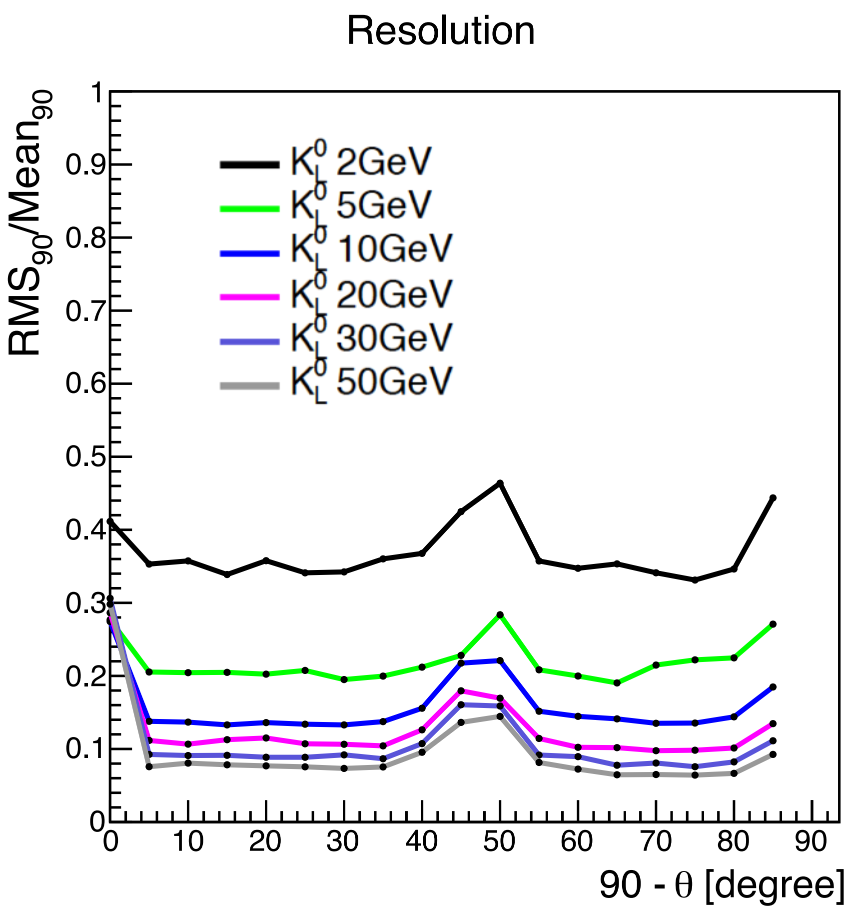
➢ Effect of iron support on energy reconstruction is very small when integrating over all phi

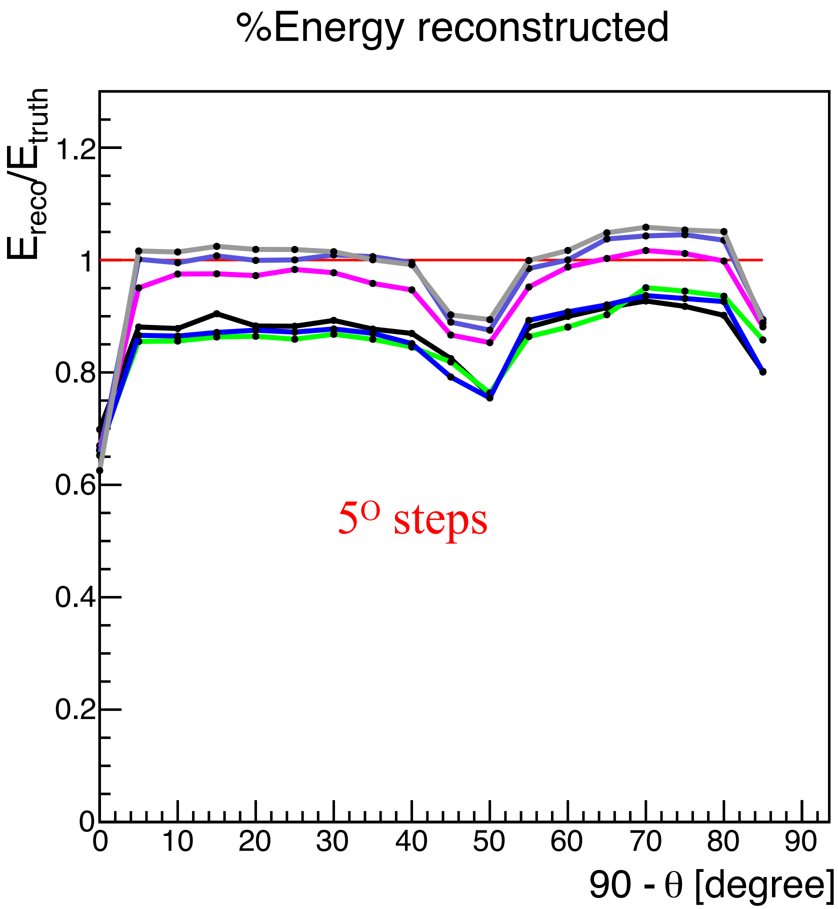
- Can be further mitigated by dead material correction
- Probably not sufficient to motivate a design modification

Study effect of iron structure on energy reconstruction in (r,theta)



Effect of supporting structure (*r*,theta) plane

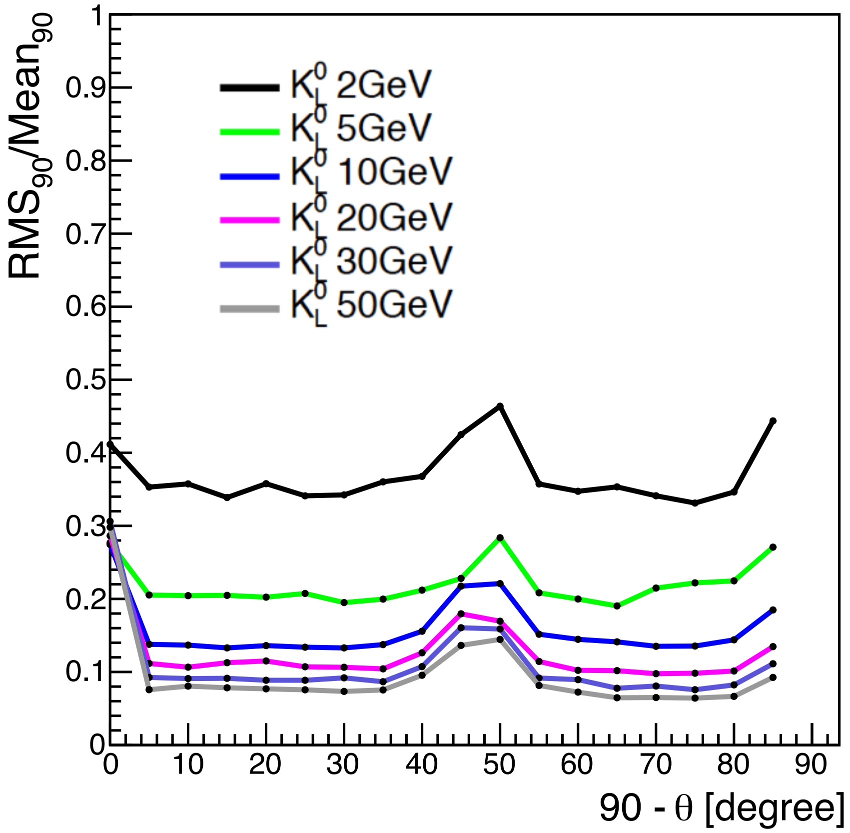




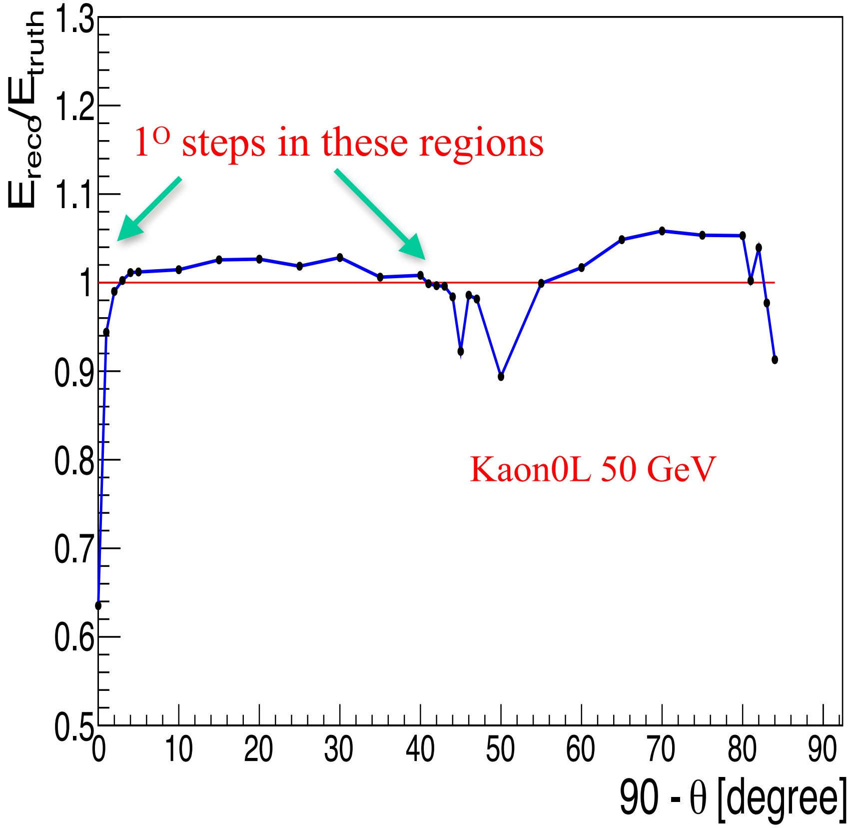
➢ Clear loss of energy response and resolution at central iron plate and in transition region between barrel and endcap

Effect of supporting structure - Theta dependence

Resolution



%Energy reconstructed



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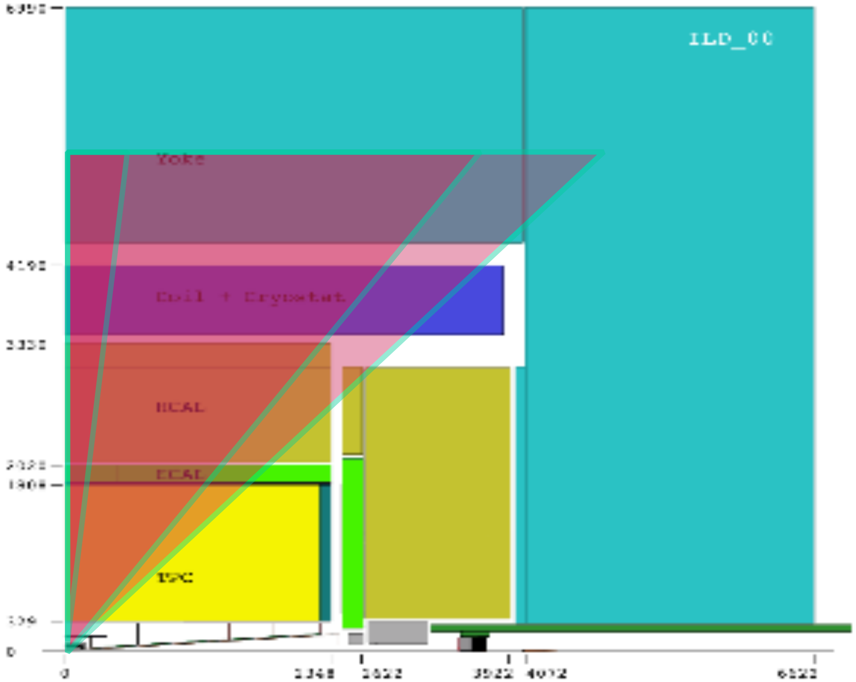
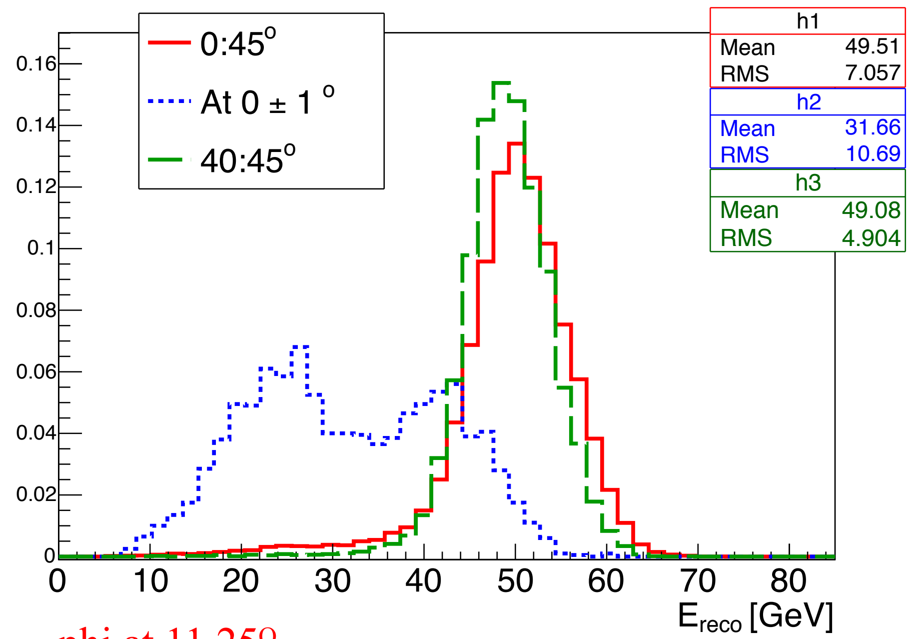
Effect of supporting structure (*r*,theta) plane





phi at 11.25°

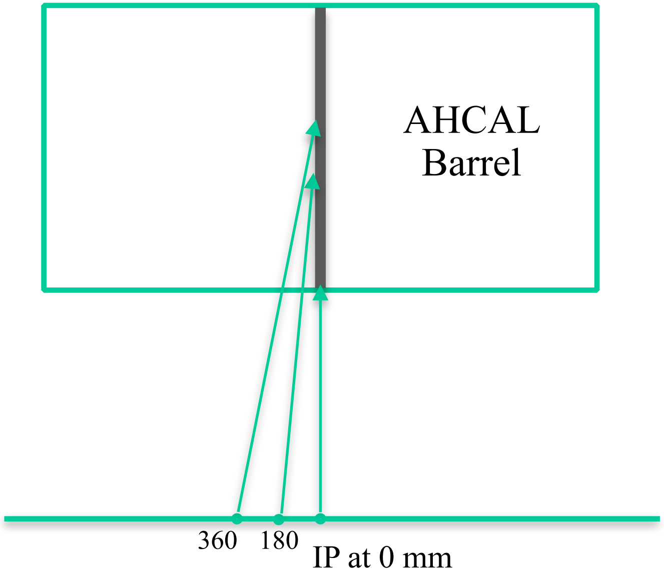
➢Middle stave iron support seems to have stronger effect on energy reconstruction.

Possible improvements:

- Cluster's energy correction as a function of theta
- Or: Asymmetric design: middle stave iron support is not anymore "middle"

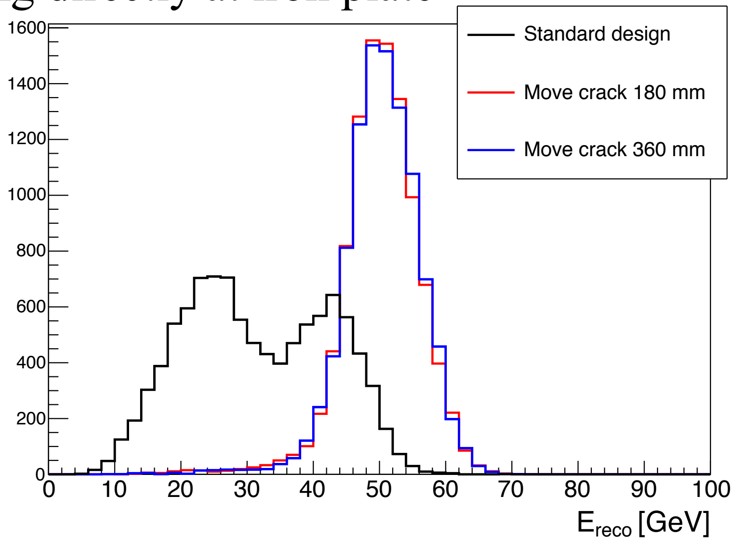
What happens if the middle stave is not anymore "middle"?

- In principle barrel structure could be made asymmetric to avoid pointing crack
- In simulation, easier to move interaction point (IP) instead
- Move IP by 180 and 360 mm (corresponding to half and one HBU in current design of AHCAL)

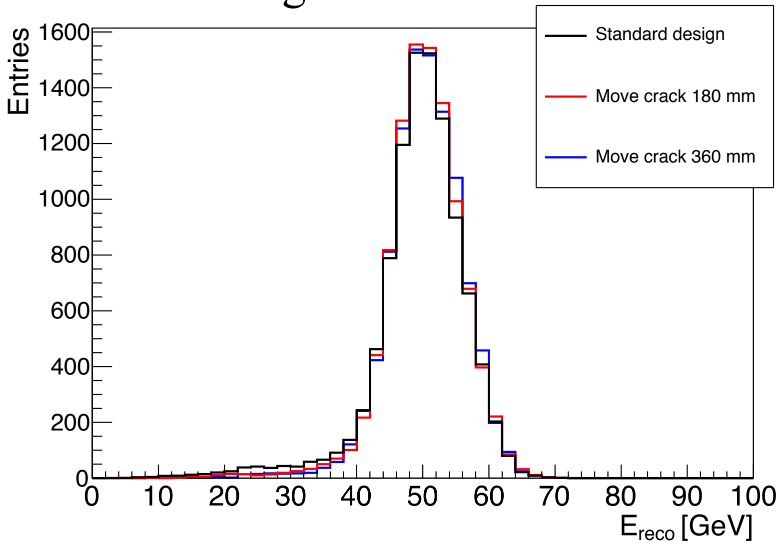


What happens if the middle stave is not anymore "middle"?

Shooting directly at iron plate



Integrate over 45 degree



- Moving the crack away from z = 0 improves significantly energy reconstruction when particle shot towards crack
- Over all effect larger than for phi crack but still small
- Can be mitigated with dead material correction
- Discontinuity at z = 0 in TPC too

➢ Need overall ILD approach

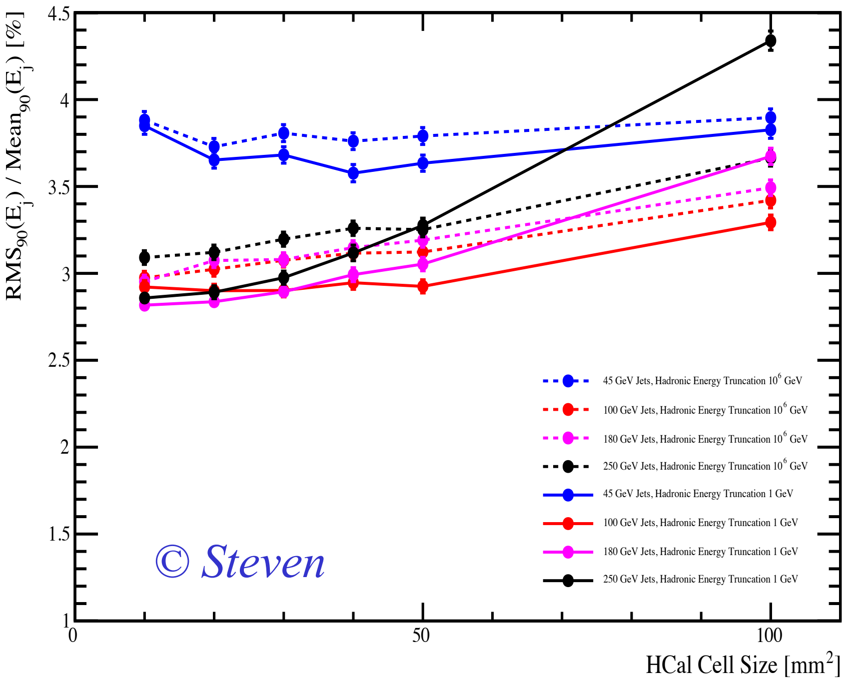
Cell Size Optimisation
& Software Compensation

Motivations for Software Compensation

- Dependence of jet energy resolution on HCAL cell size apparently reduced compared to results from LoI:
  - HCAL cell energy truncation degrades resolution at high energy for higher cell size
  - But: improve energy resolution at smaller cell sizes

➢ Idea of cell energy truncation mimics software compensation

➢ Software compensation can do better and must be applied properly

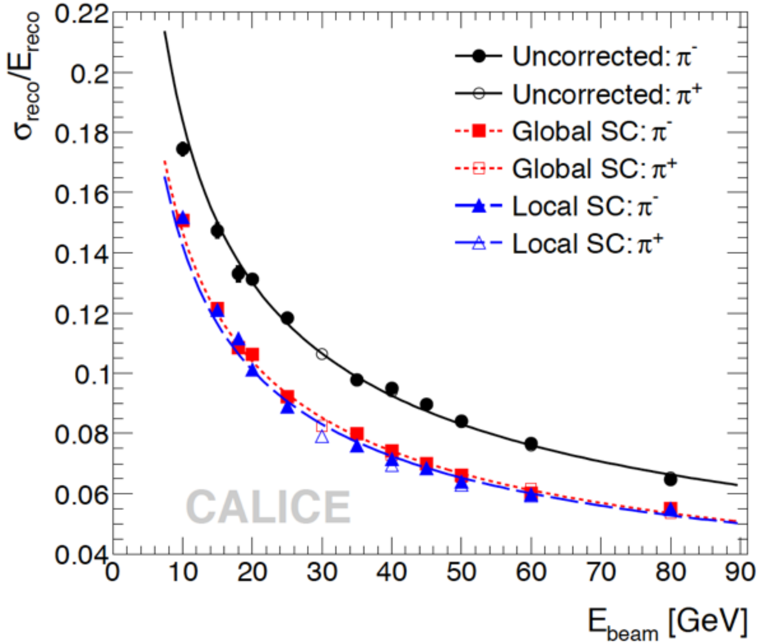


Motivations for Software Compensation

- ILD calorimeters are non-compensating: $\frac{e}{h} > 1$
- Software compensation equalises electromagnetic and hadronic response

- Software compensation applied to testbeam data from physics prototype:
  - Improvement of hadronic energy resolution by 20% for single hadrons from 10 to 80 GeV

[arXiv: 1207.4210v2]



Software Compensation

- ***Implementation:***
  - Electromagnetic showers denser than hadronic showers —> energy of hits inside electromagnetic sub-showers typically are higher compared to hits inside hadronic sub-showers

    —> Applying different weights for hits of different energy densities

- ***Weight*** defined as:

$$\omega(\rho) = p_1.exp(p_2.\rho) + p_3$$

where ρ is hit energy density, p_1, p_2, p_3 are *beam energy dependent parameters*

- Energy of cluster then computed in software compensation method as:

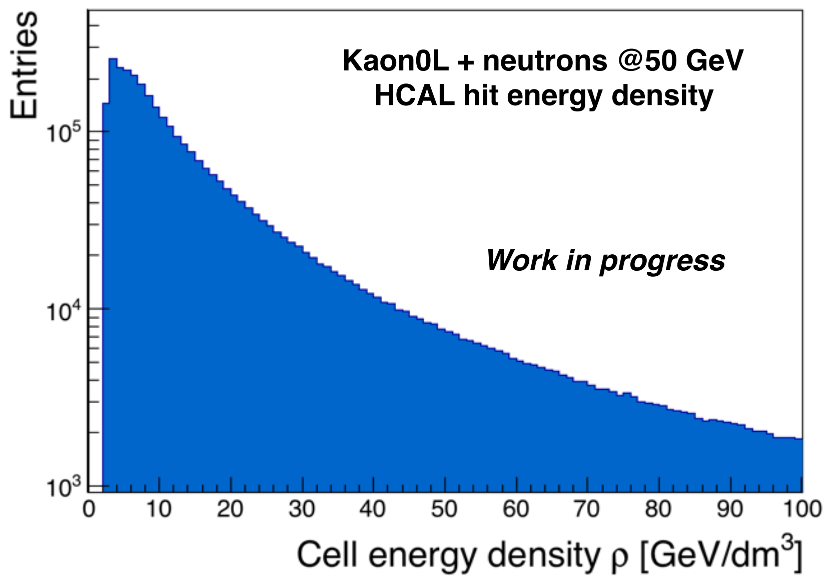
$$E_{SC} = \sum_{hits} E_{ECAL} + \sum_{hits} (E_{HCAL}.\omega(\rho))$$

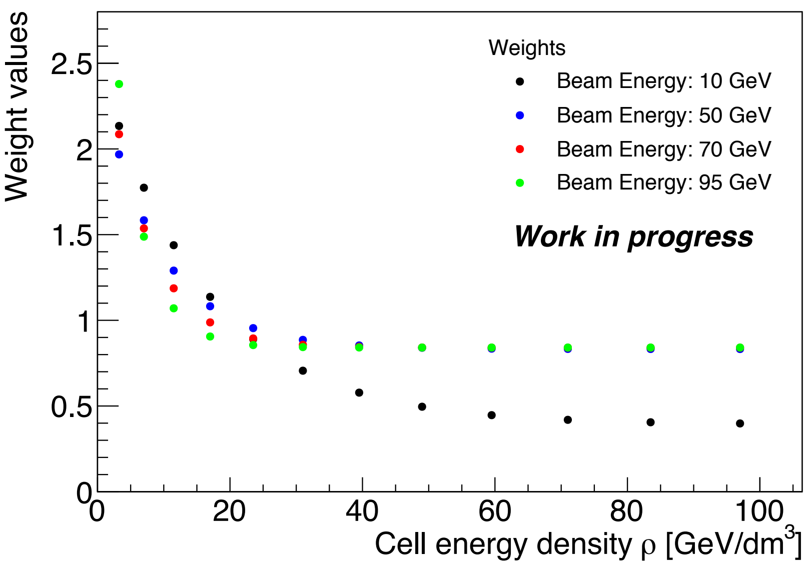
- Weights determined through minimising a χ^2 function:

$$\chi^2 = \sum_{events} (E_{SC} - E_{beam})^2$$

- In following slides: Results on standard ILD detector (with 3x3 *cm2* AHCAL)

Hit Energy Density and Weights





Samples:

- Kaon0L and neutrons from 10 to 95 GeV generated from IP, targeted only to barrel part
- Select only events with 1 cluster
  - Events where hadronic showers started already in EM calorimeter: only HCAL hits are weighted
  - Cluster with no hit in muon chamber

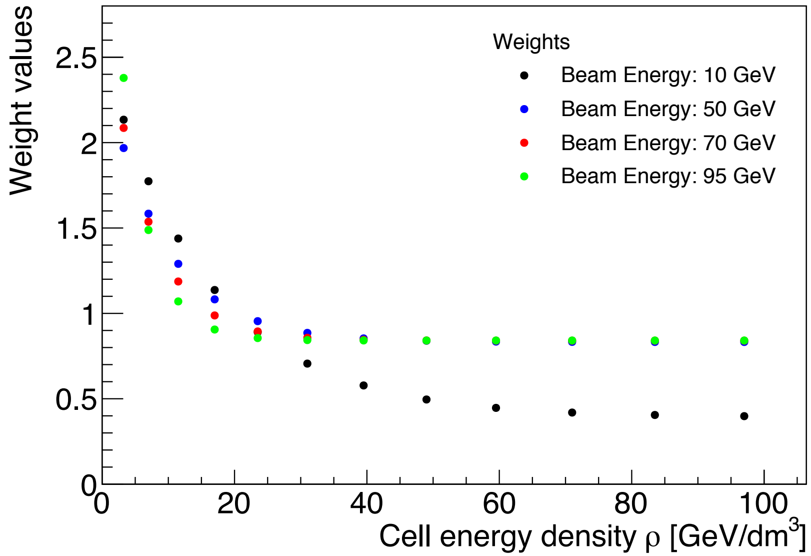
Weight determination:

- Through χ^2 minimisation
- For each beam energy weights are defined with three parameters p_1, p_2, p_3 given by χ^2

$$\boxed{\omega(\rho) = p_1.exp(p_2.\rho) + p_3}$$

- For each of p_1, p_2, p_3 obtain 10 values at 10 energies ➢ fit as function of energy

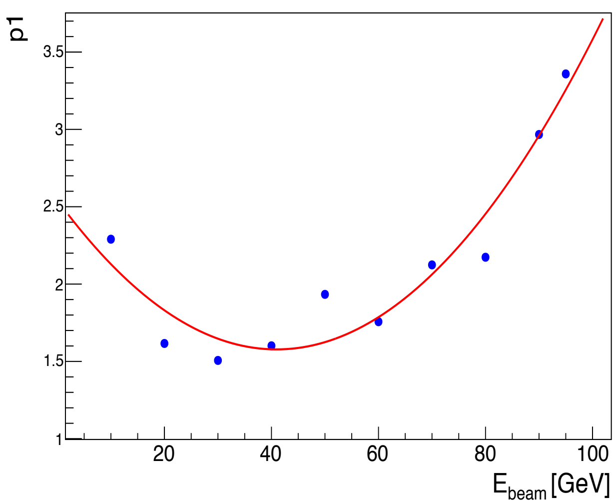
Weight parameters

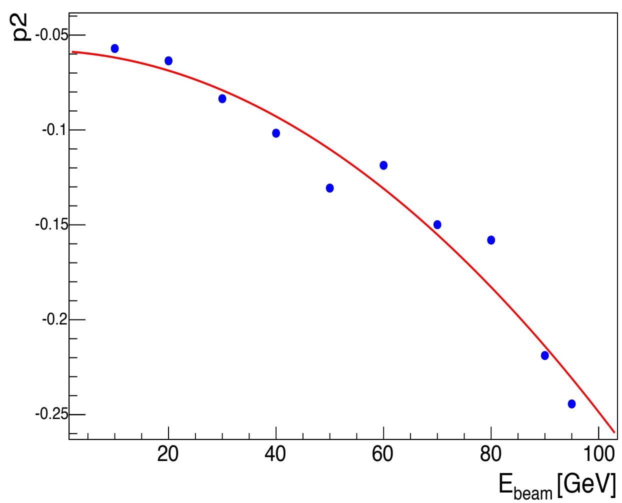


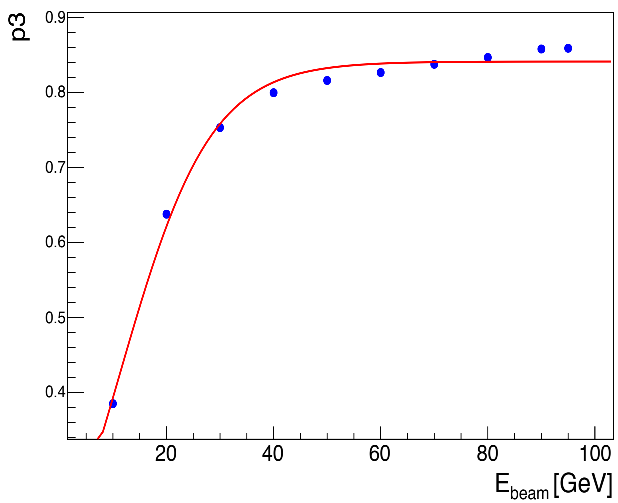
$$\omega(\rho) = p_1.exp(p_2.\rho) + p_3$$

Fitting p_1, p_2, p_3 provides continuous energy dependence

➢ For any particle's energy a weight can be assigned

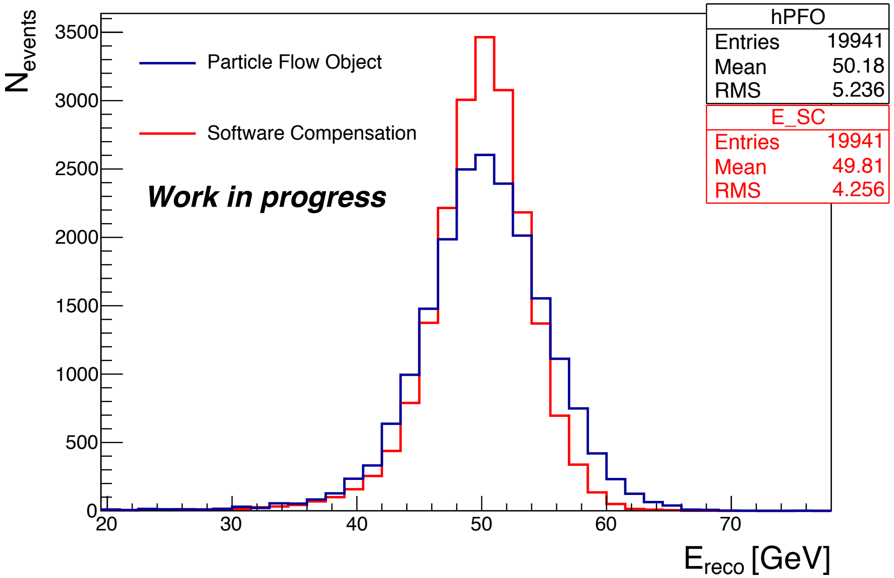






Implementation into Pandora

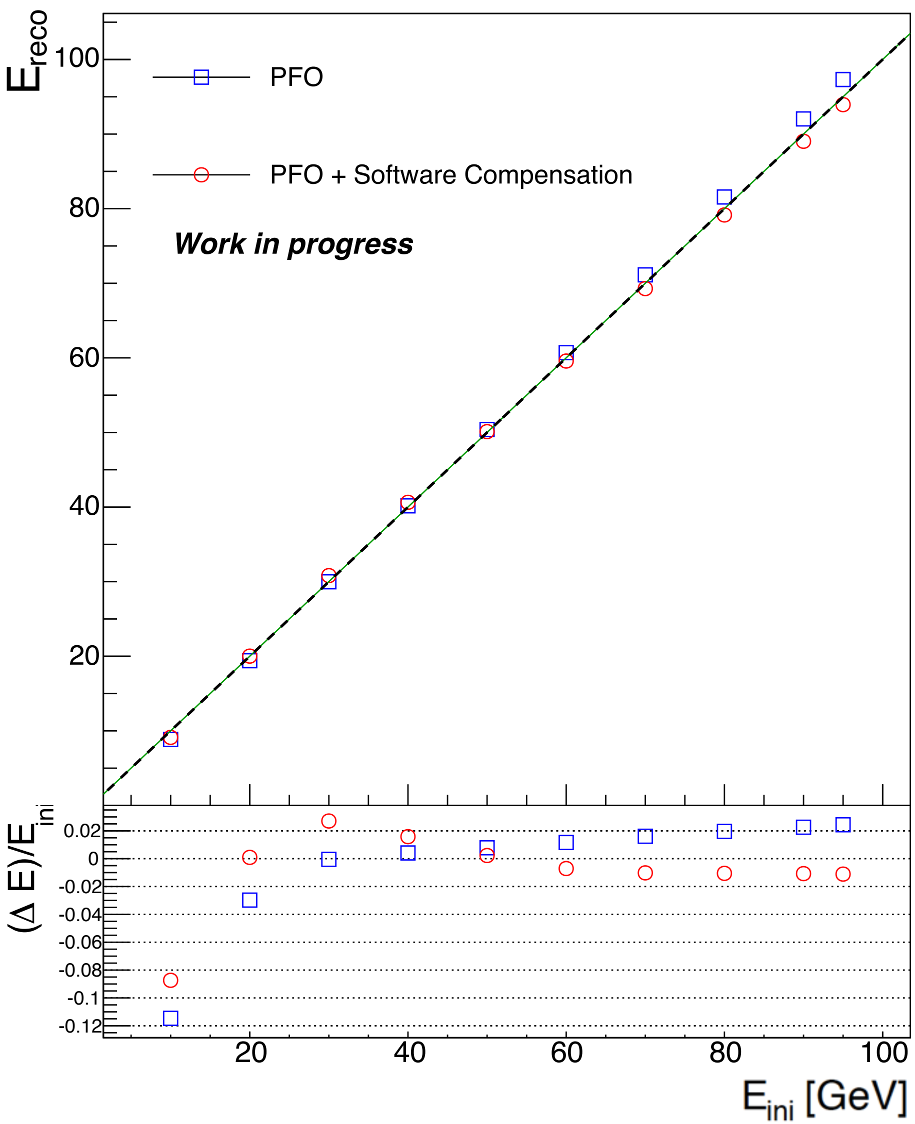
- Beam energy now unknown
- Only initial estimation of cluster's energy used for determination of weights
- Apply to set of Kaon0L and neutron samples from 10 to 95 GeV



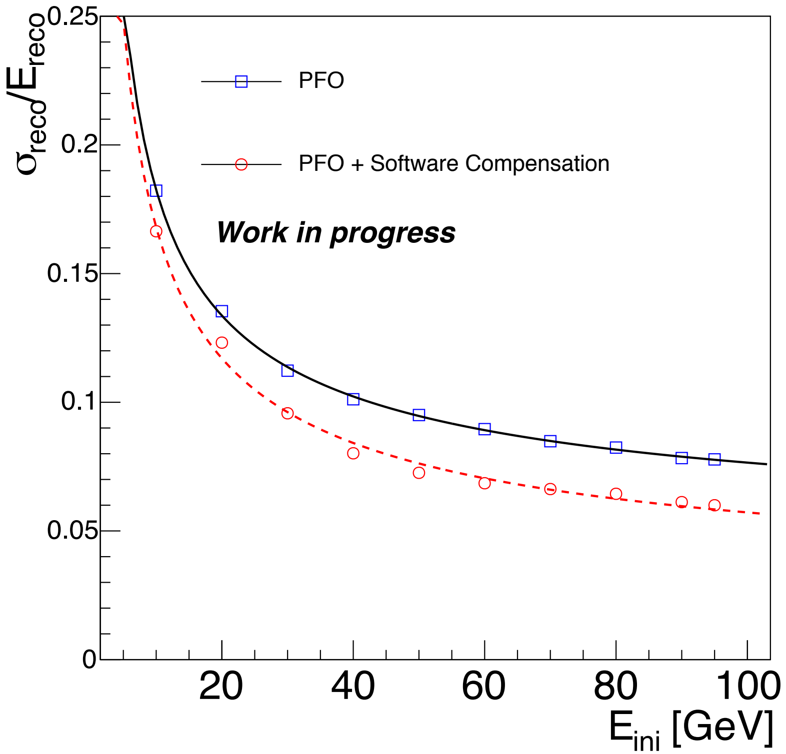
50 GeV Kaon0L

- Improvement of mean reconstructed energy
- RMS significantly reduced

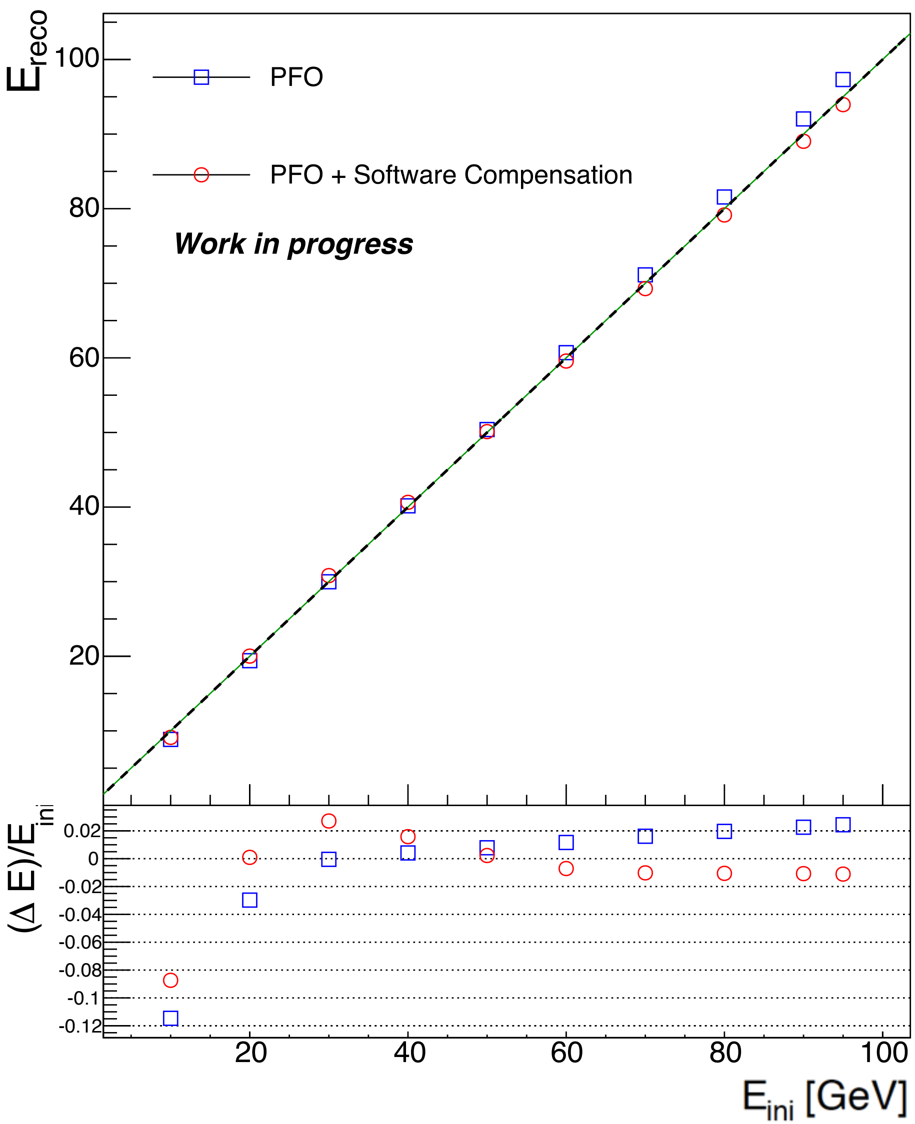
Single Particle Energy Reconstruction



- Improves linearity in whole range
- Improves resolution by ~20% (similar to results obtained for physics prototype)



Single Particle Energy Reconstruction



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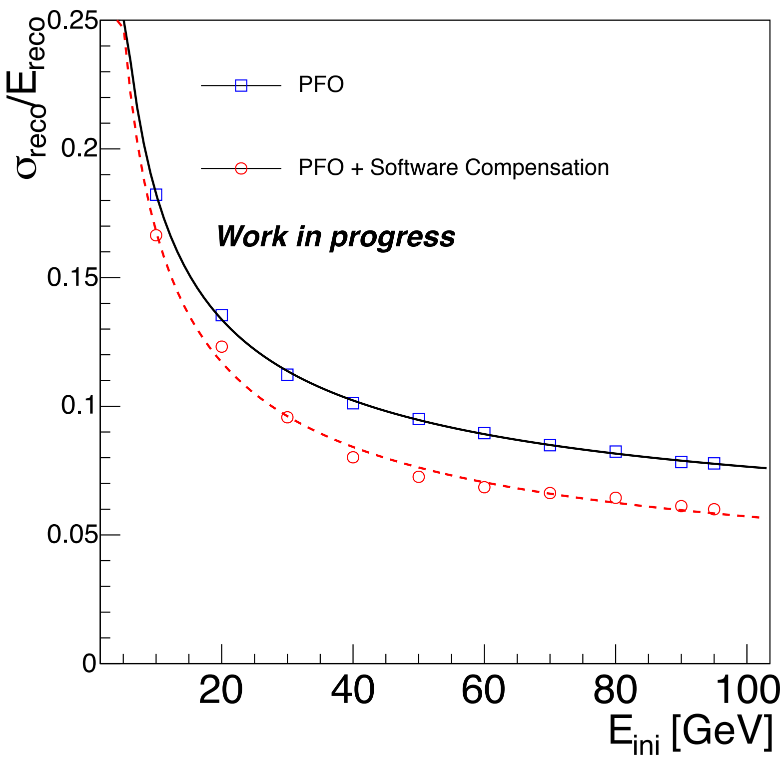
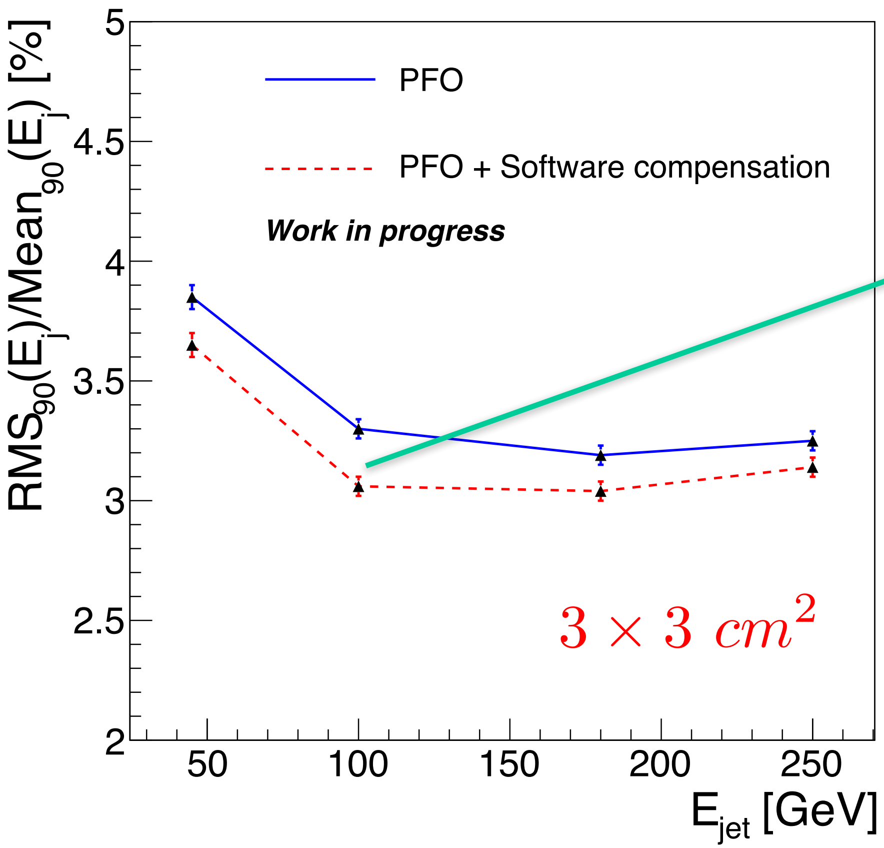
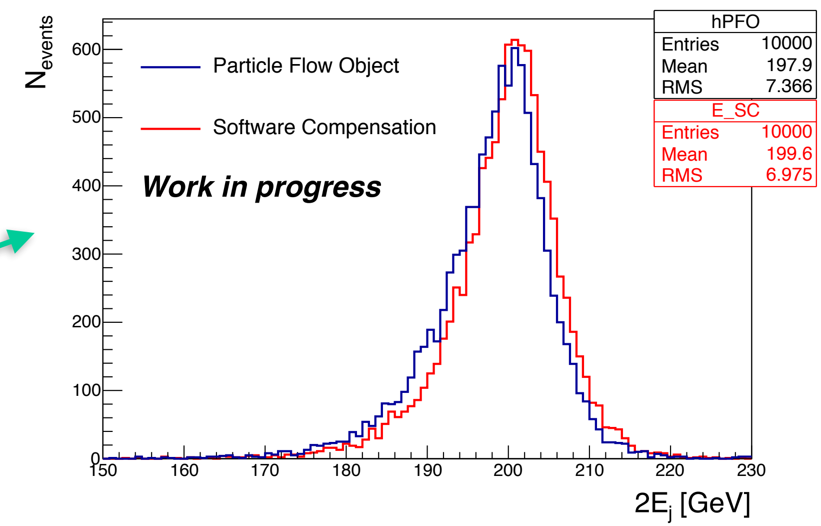


- Testbeam results reproduced
- Overall slightly worse because of missing tail catcher

Jet Energy Resolution

- Software compensation applied for jets
  - Only for neutral hadrons, after clustering step
  - Only hits in HCAL are weighted as explained previously

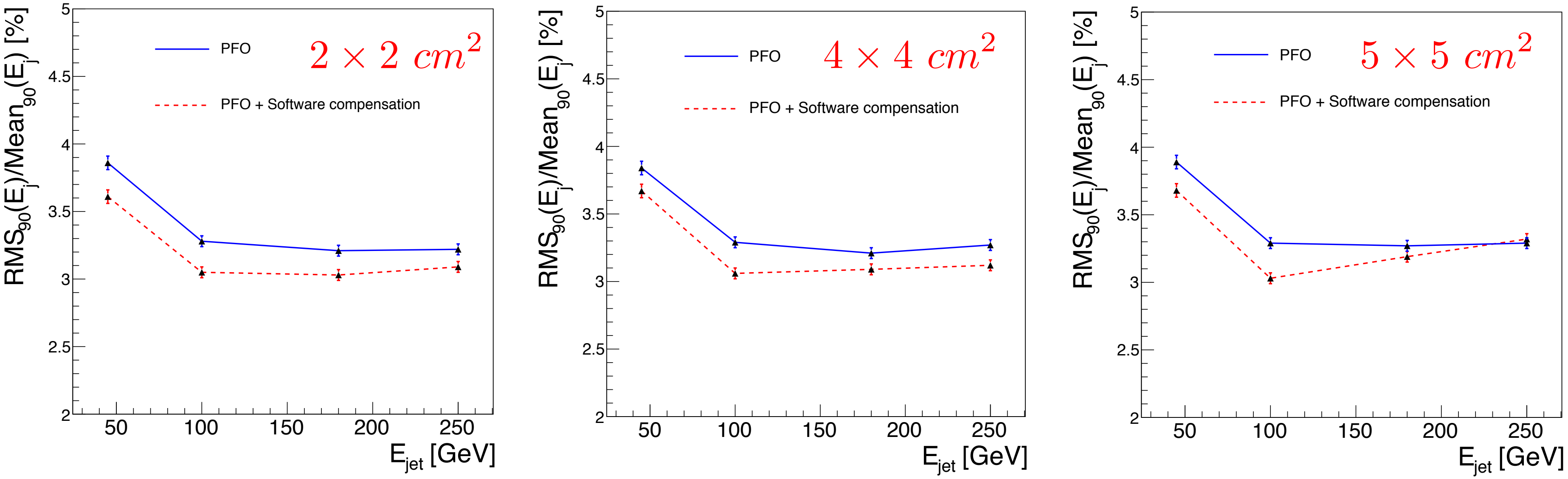




- Reconstructed energy distribution closer to simulated energy and width of distribution smaller
- Improves jet energy resolution in whole range

Jet Energy Resolution for Different Cell Sizes

- For similar cell sizes still expect improvement using weights defined with $3 \times 3\ cm^2$



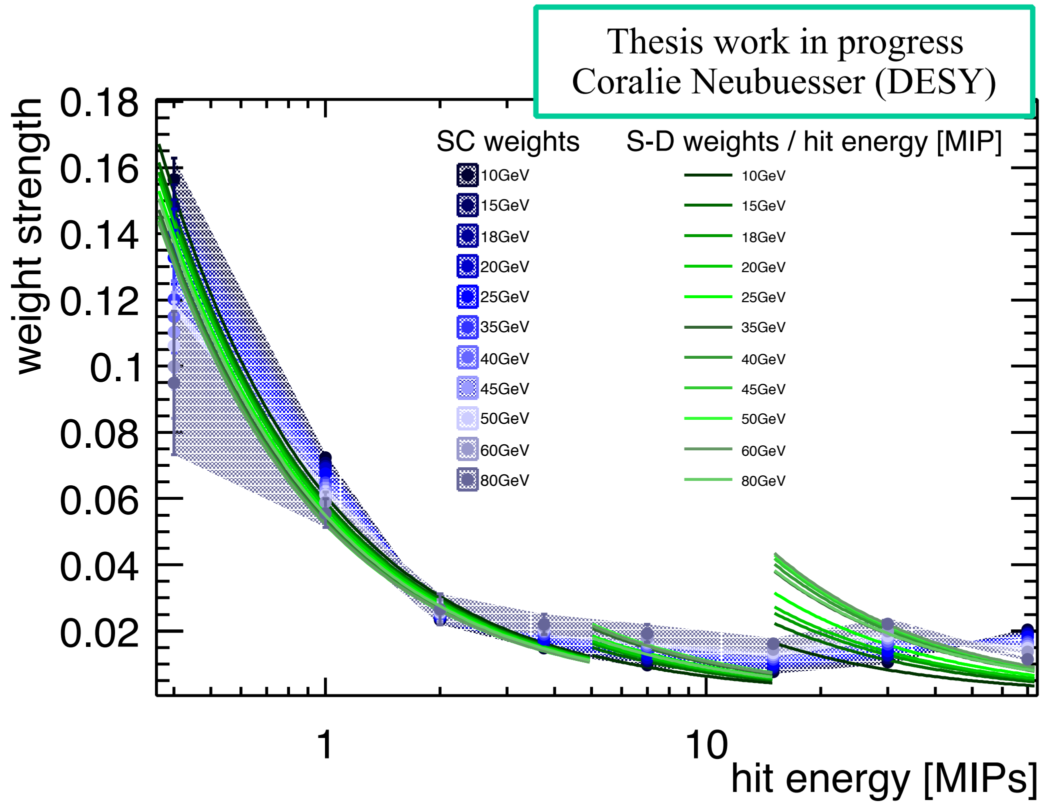
- Proper weights to be done, especially for very small or very large granularities
- SC could also help at re-clustering stage of Pandora (to be tried)

Software Compensation and Semi-digital Reconstruction

- For semi-digital reconstruction is particularly successful at low energies
- In principle hit counting corresponds to weighting hits with 1/E

$$\alpha \times 1 = \alpha * \frac{E_i}{E_i} = \omega * E_i$$

- Both reconstruction methods in same formalism
- Understand differences and learn from each other

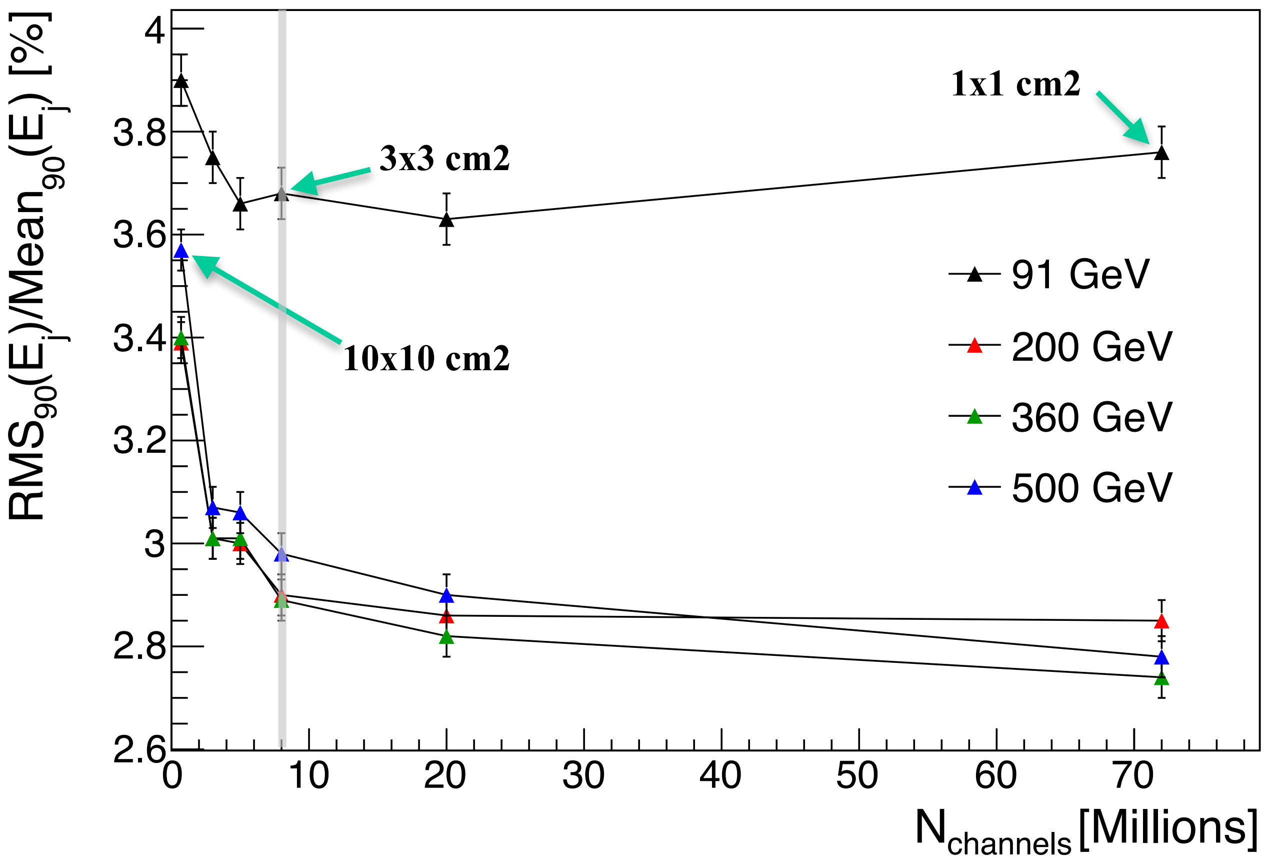


Outlook

Towards cost optimisation

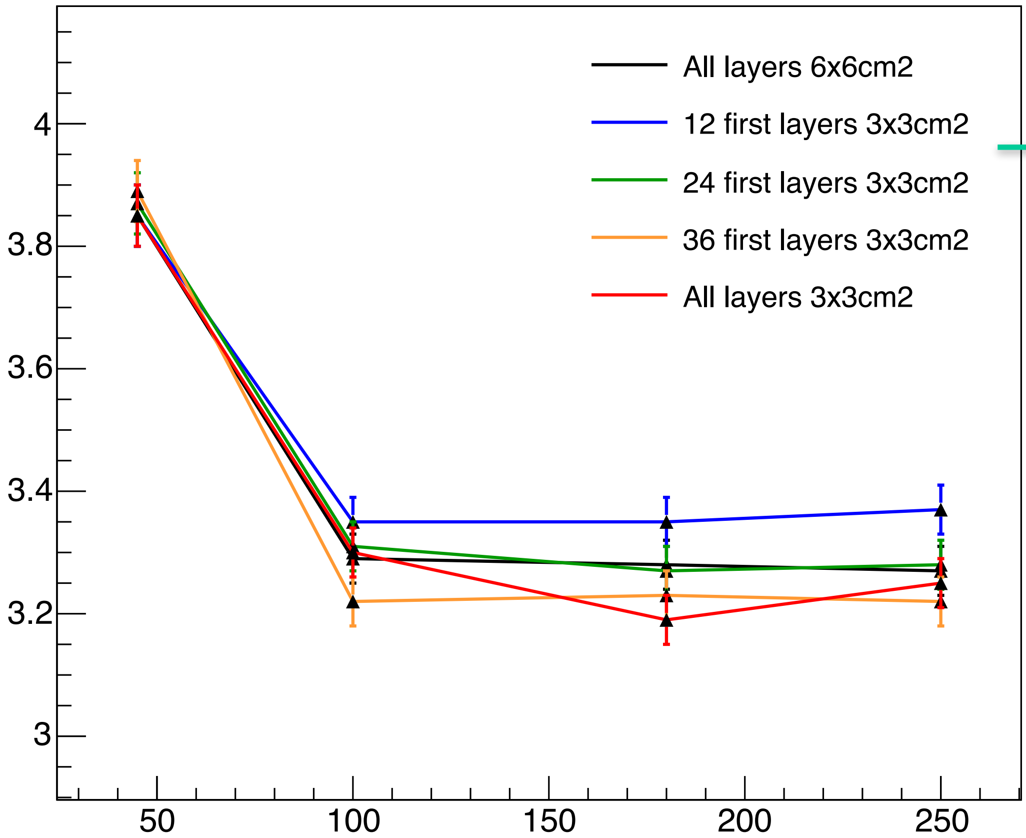
- Look at jet energy resolution as a function of number of channels
- Plot shows that 3x3 *cm2* cell size is still a very reasonable choice with latest Pandora
- Software compensation to be applied

© Steven



Latest results from Steven
To be updated with
software compensation

Different granularities at different depth of HCAL



From top to bottom expect improvement of JER

- Framework implemented
- Effects to be understood

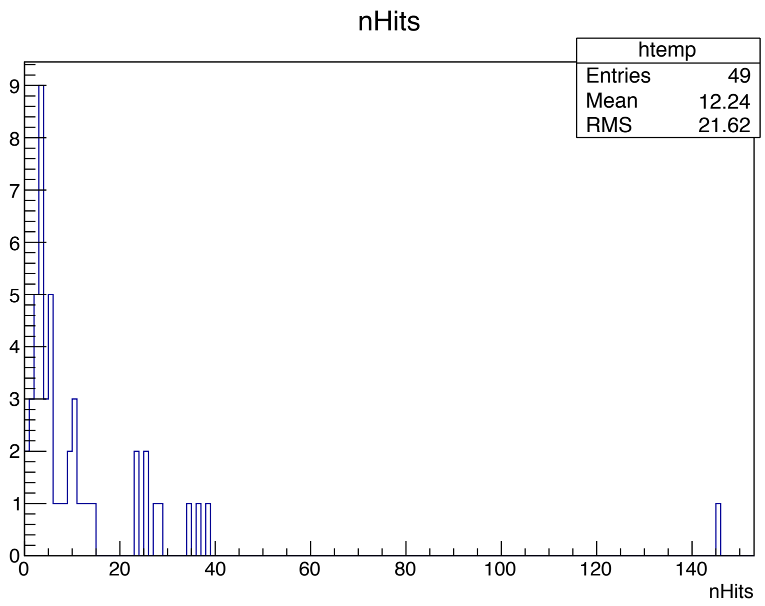
Summary & Outlook

- *Impact of boundary regions in absorber structure*:
  - Effects of crack regions in (*r*,phi) in single particle reconstruction are small
  - Somewhat larger effect of crack at theta = 90 degree
  - ➢ Dead material correction to be developed
- *Software compensation and cell size optimisation:*
  - Software compensation implemented in Pandora
  - Improves single particle and jet energy resolution
- Weight determination for different granularities to be done
- Final goal: HCAL cell size and sampling optimisation (3D granularity) as a function of depth and for different detector radii

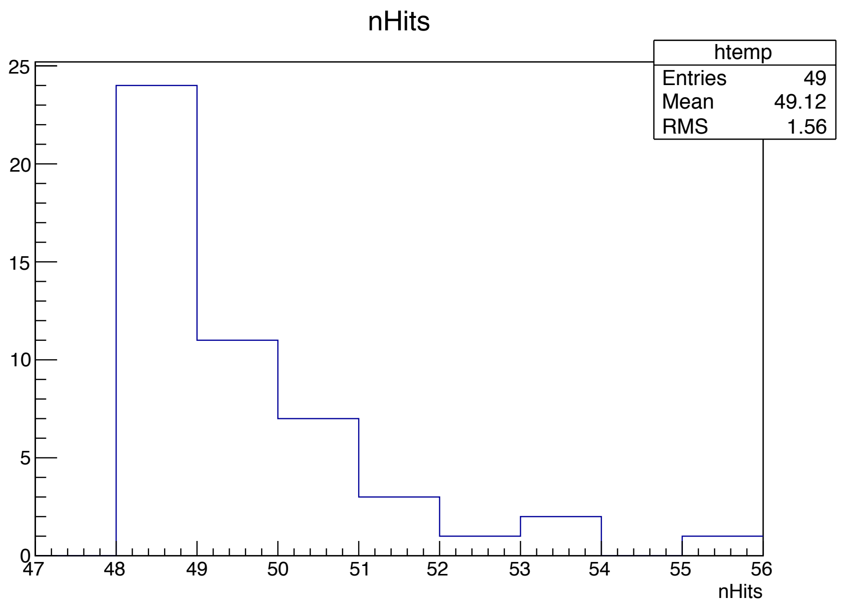
- Many thanks to Frank, Miro, Steve, John for the precious discussions and advices!

Back-up slides

Number of hits

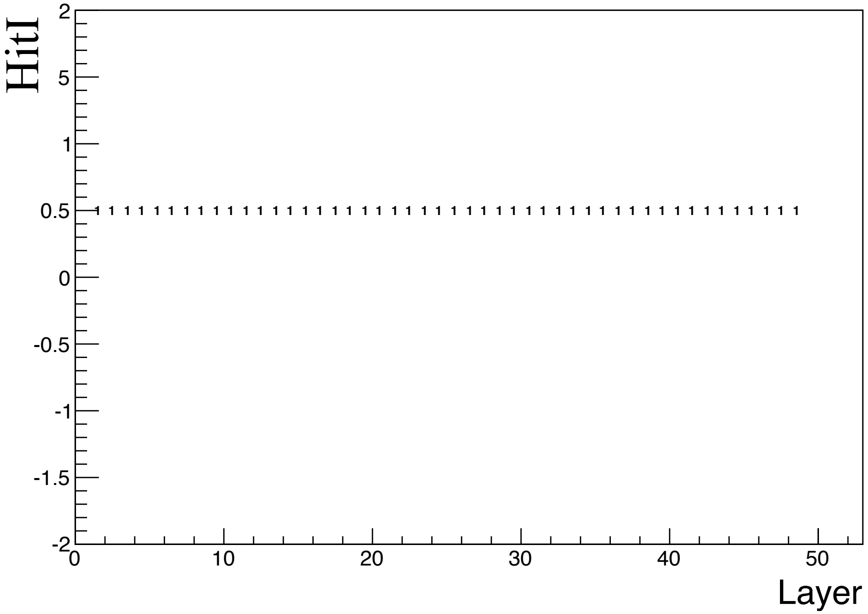


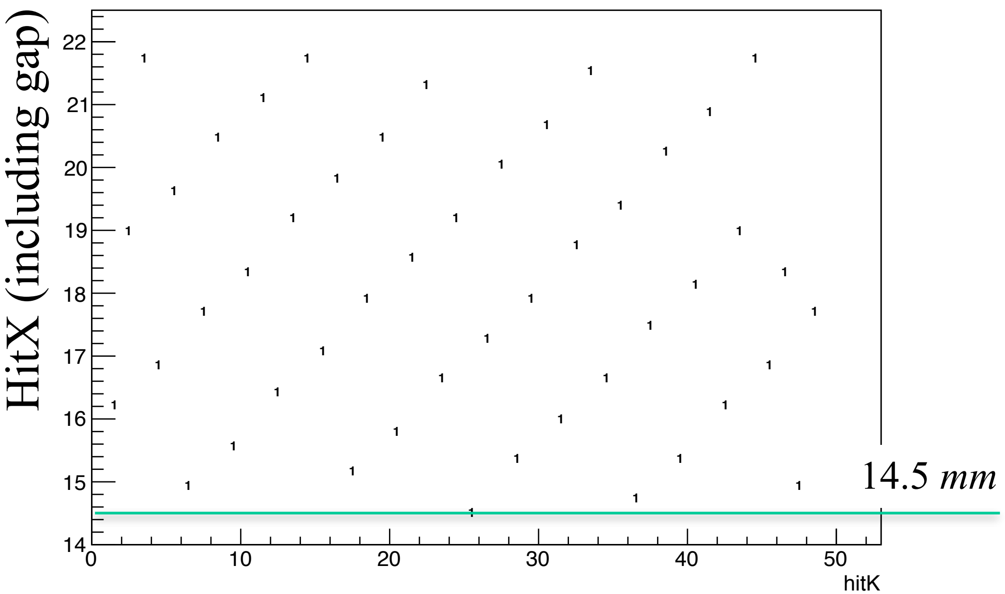
Number of hits when shooting muon at the iron support



Number of hits when shooting muon at 4 *mm* from the iron support

Simulation at supporting structure and neighbouring area





Shooting muon at from position with x = 10 *mm* (4 *mm* from the iron support) gives hits in each layer at I = 0

However X coordinate of hits differ Closest points at 14.5 *mm*, excluding iron+air-gap it is 7.5 *mm* —> cell has size of 15 *mm*.

Outlook - Using my numbers

Towards cost optimisation

- Look at jet energy resolution as a function of number of channels
- Plot shows clear preference for 3x3 *cm2* cell size
- Software compensation to be applied