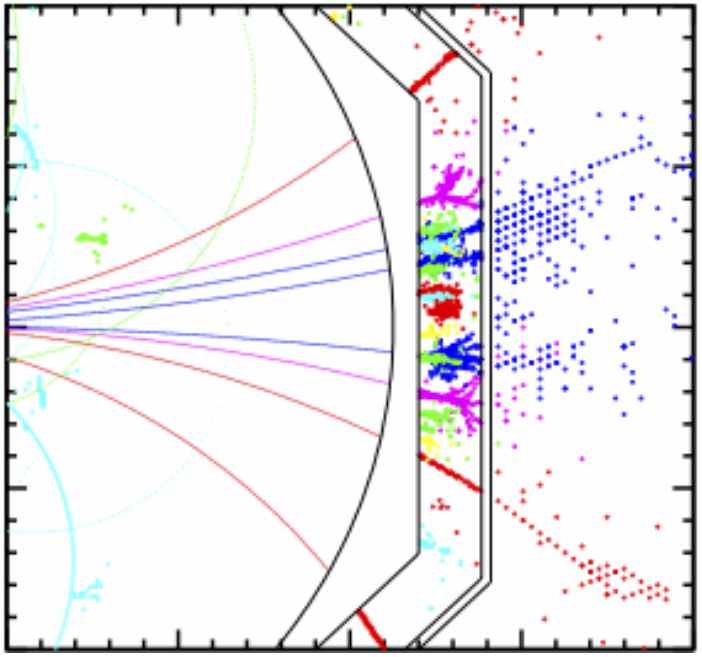
Software Compensation for AHCAL Optimisation



Huong Lan Tran

ILD Analysis/Software Meeting

16 December 2015

HELMHOLTZ ASSOCIATION

CALICE

DESY

Outlines

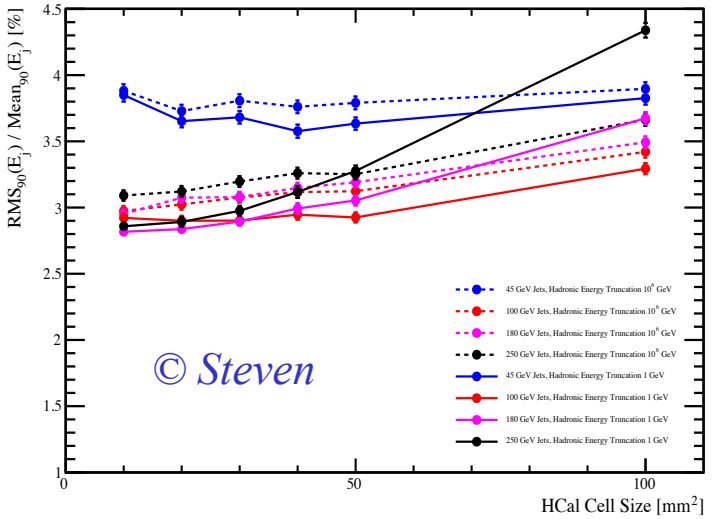
- Efforts for AHCAL optimisation are converging
  - Fruitful collaboration with Munich and Cambridge group concerning software compensation and its implementation
  - Good results achieved

In this talk: Software compensation for AHCAL optimisation

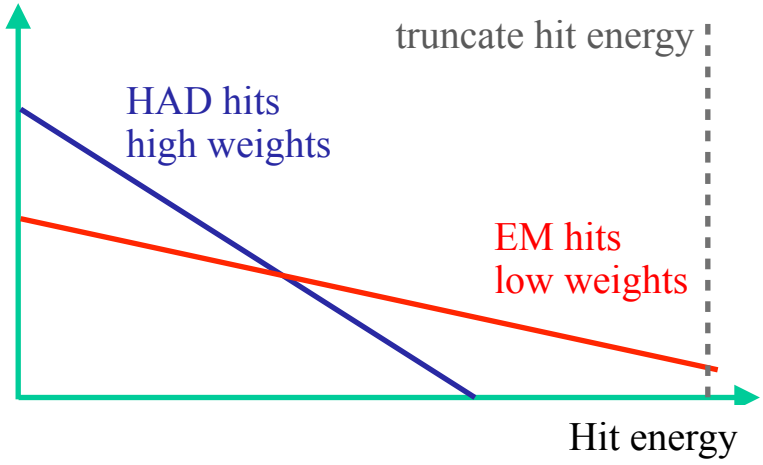
- Brief on software compensation technique & results
- Implementation in Particle Flow Algorithm
- Bonus: Towards cost optimisation

Software compensation in AHCAL optimisation

- Dependence of JER on HCAL cell size apparently reduced compared to results from LoI: for LoI results *HCAL cell energy truncation cut at 1GeV*
  - Improves JER for small cell sizes and at small energies
  - Degrades JER for large cell sizes at higher energies
- HCAL cell energy truncation mimics idea of ***software compensation***: reduce response to electromagnetic sub-showers.



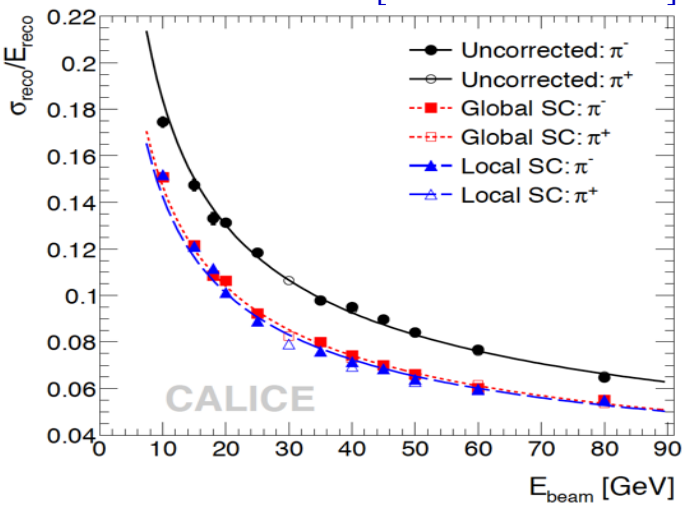
- Ways to recover JER at high energies for large cell sizes:
  - Using ***optimised*** HCAL cell energy truncation (see Steve's talk)
  - ***Software compensation***



Software compensation in AHCAL optimisation

[arXiv: 1207.4210v2]

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



- ***Idea:*** Applying different weights for hits of different energy densities
- ***Weight*** defined as:

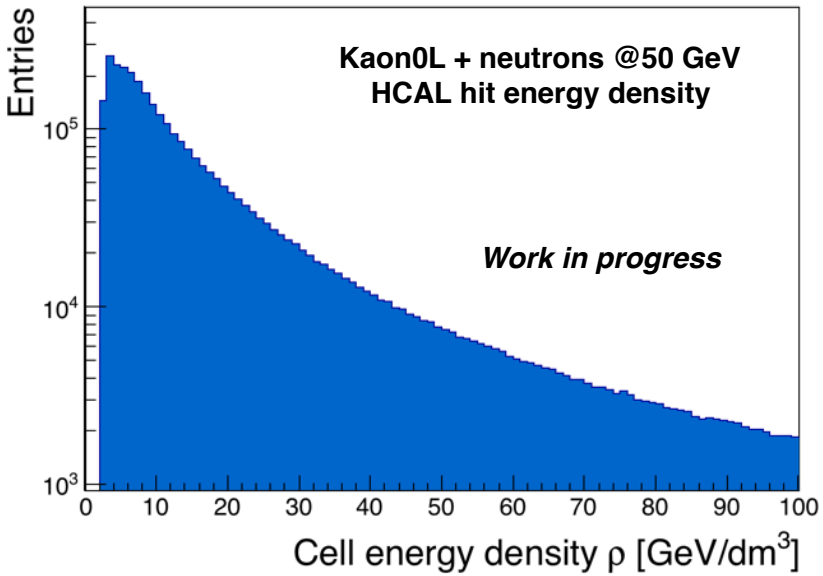
$$\omega(\rho) = p_1.exp(p_2.\rho) + p_3$$

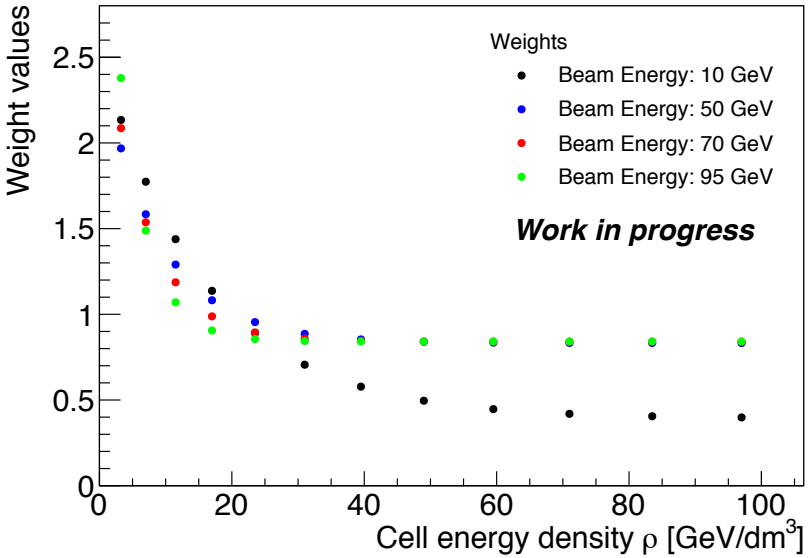
where ρ is hit energy density, p_1, p_2, p_3 are *beam energy dependent parameters*

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

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

Hit energy density and Weights





Samples:

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

Weight determination:

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

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

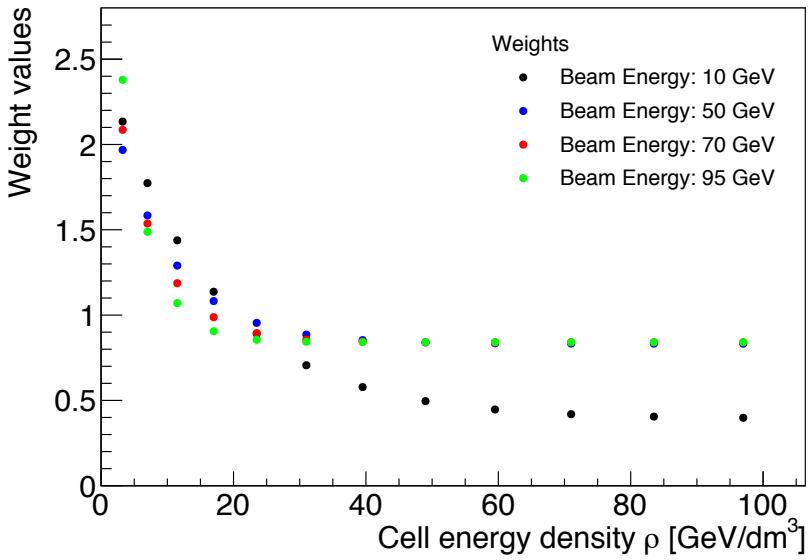
where

$$p_1 = p_{10} + p_{11} \times E_{ini} + p_{12} \times E_{ini}^2$$

$$p_2 = p_{20} + p_{21} \times E_{ini} + p_{22} \times E_{ini}^2$$

$$p_3 = \frac{p_{30}}{p_{31} + e^{p_{32} \times E_{ini}}}$$

Weight parameters



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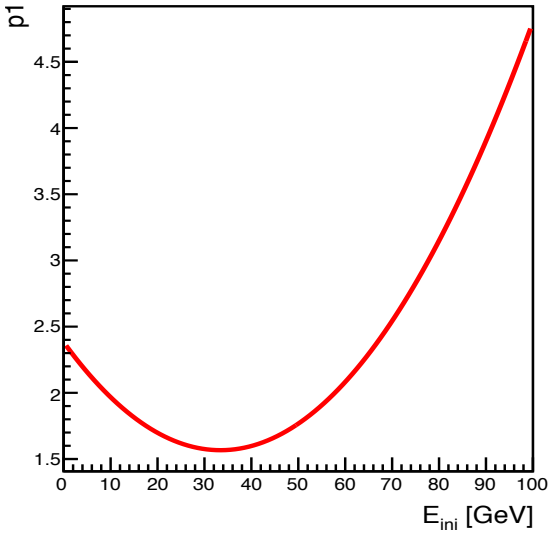
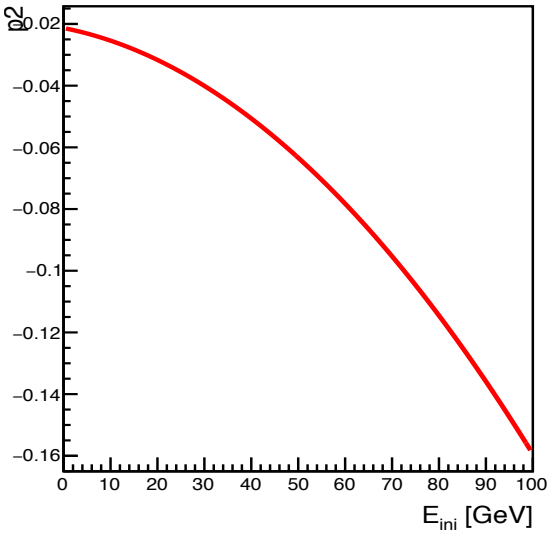
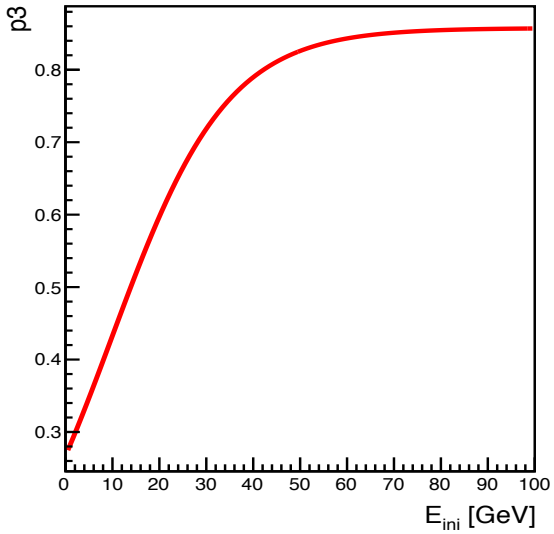
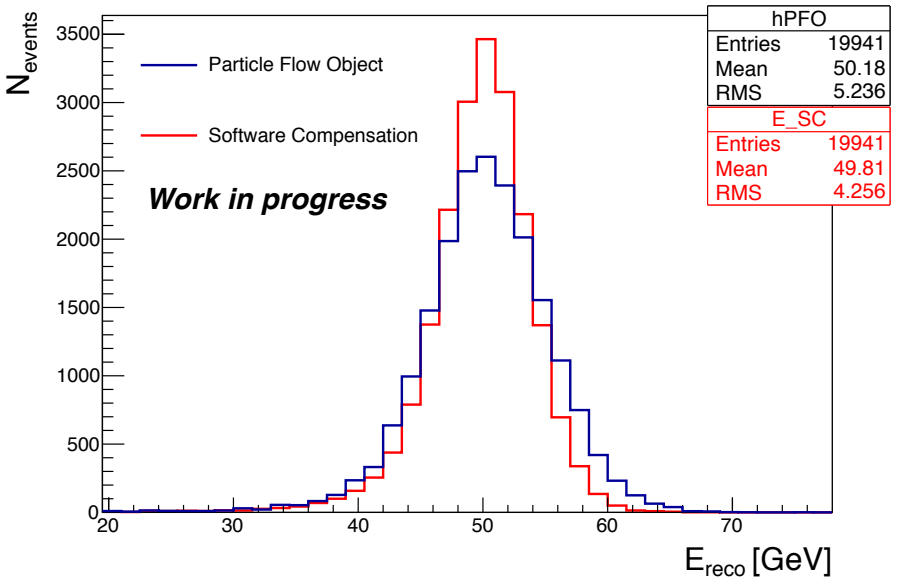






Single particle energy reconstruction

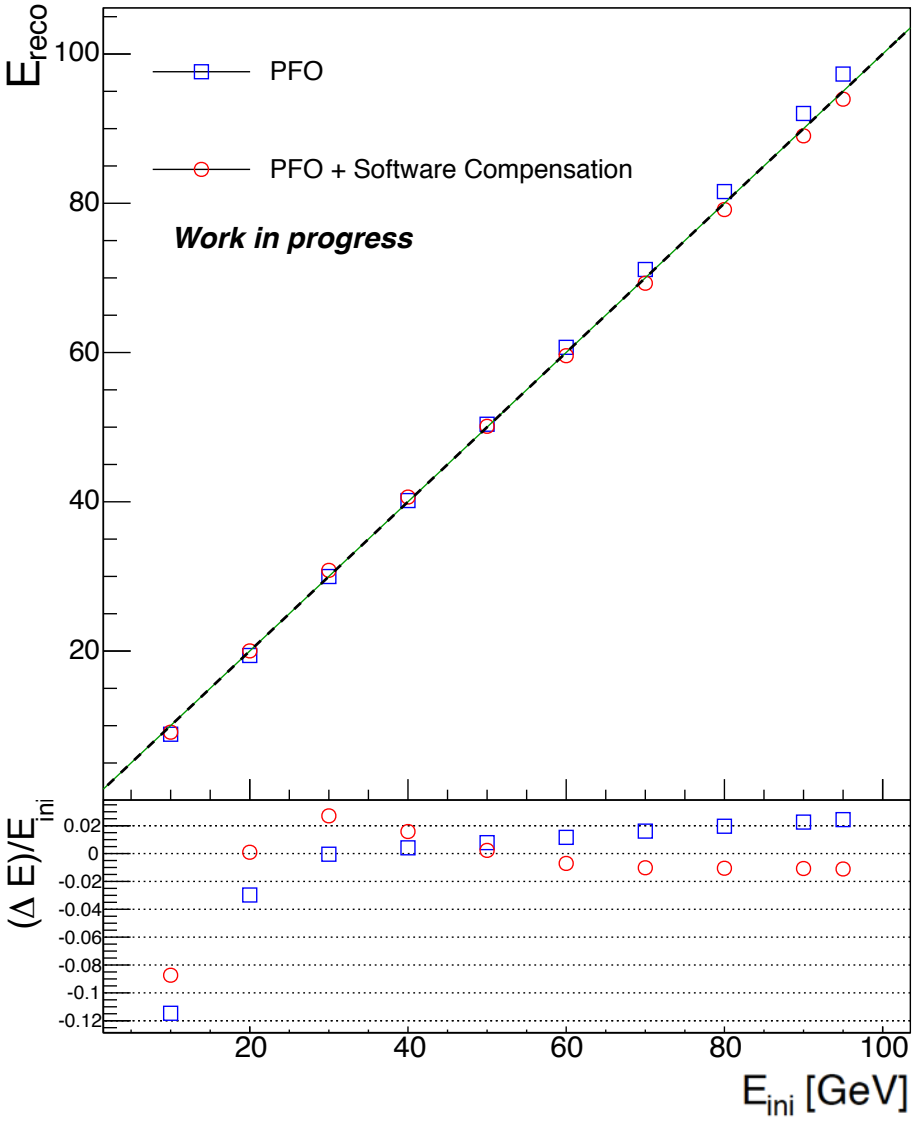
- Correction of neutral hadron PFOs energy
- Initial estimation of cluster's energy used for determination of weights
- Apply to set of Kaon0L and neutron samples from 10 to 95 GeV



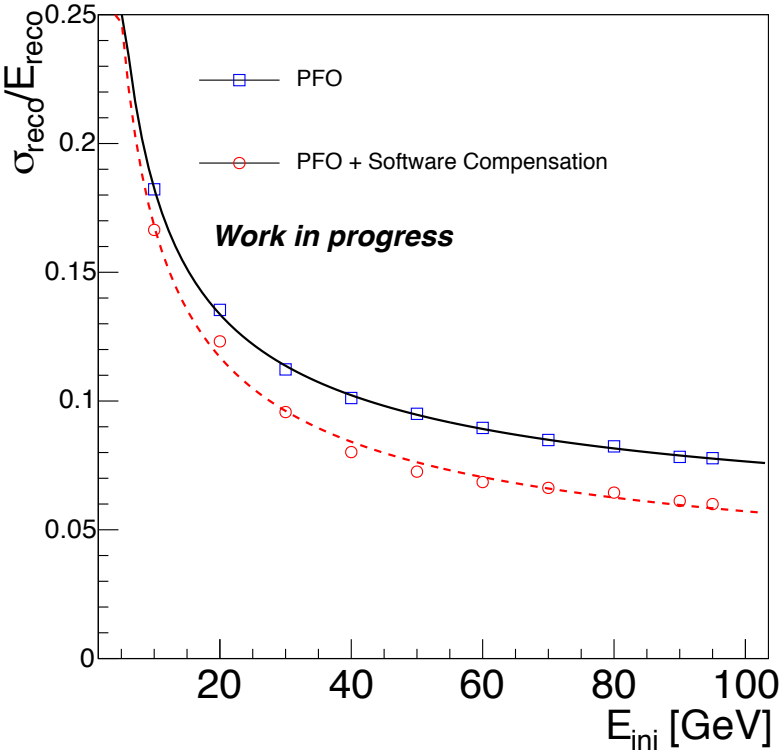
50 GeV Kaon0L

- Improvement of mean reconstructed energy
- RMS significantly reduced

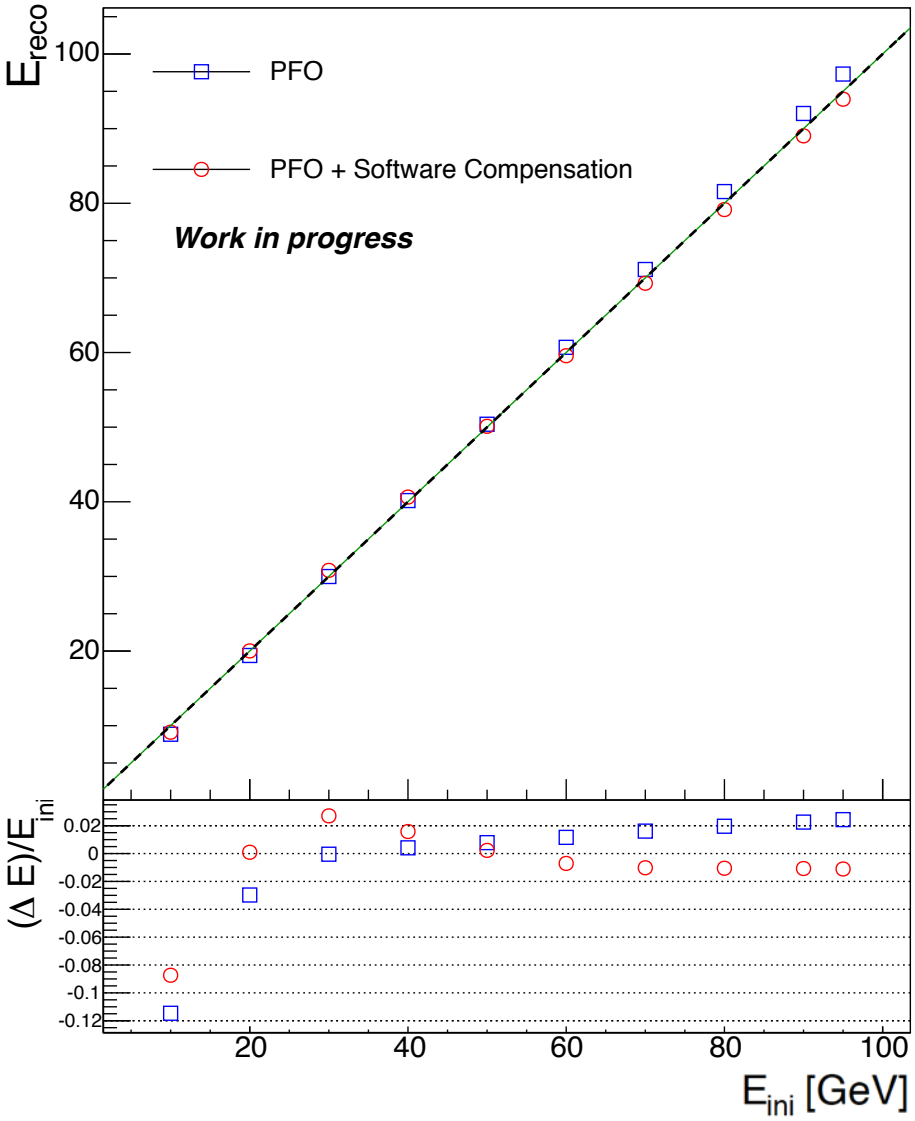
Single particle energy reconstruction



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



Single particle energy reconstruction



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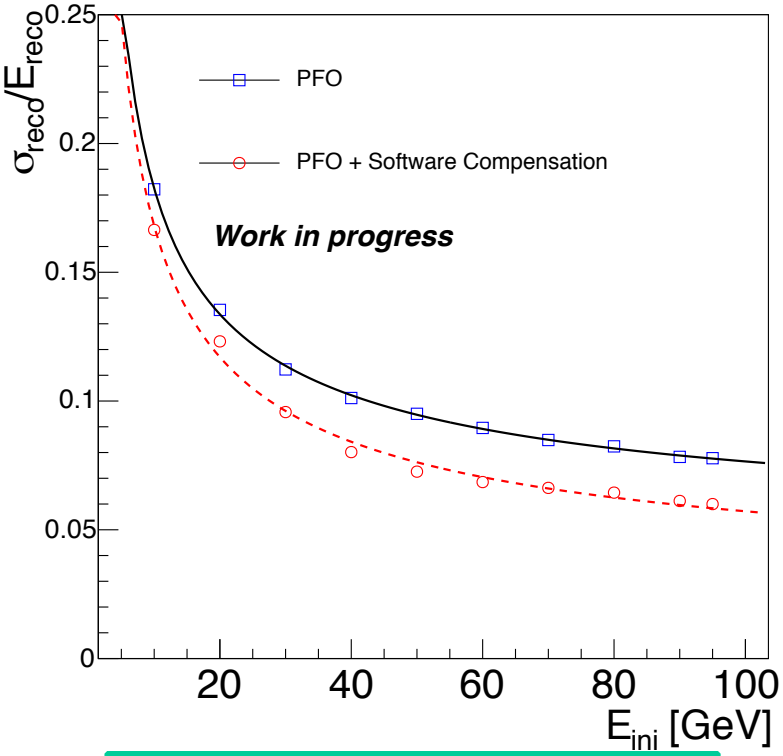
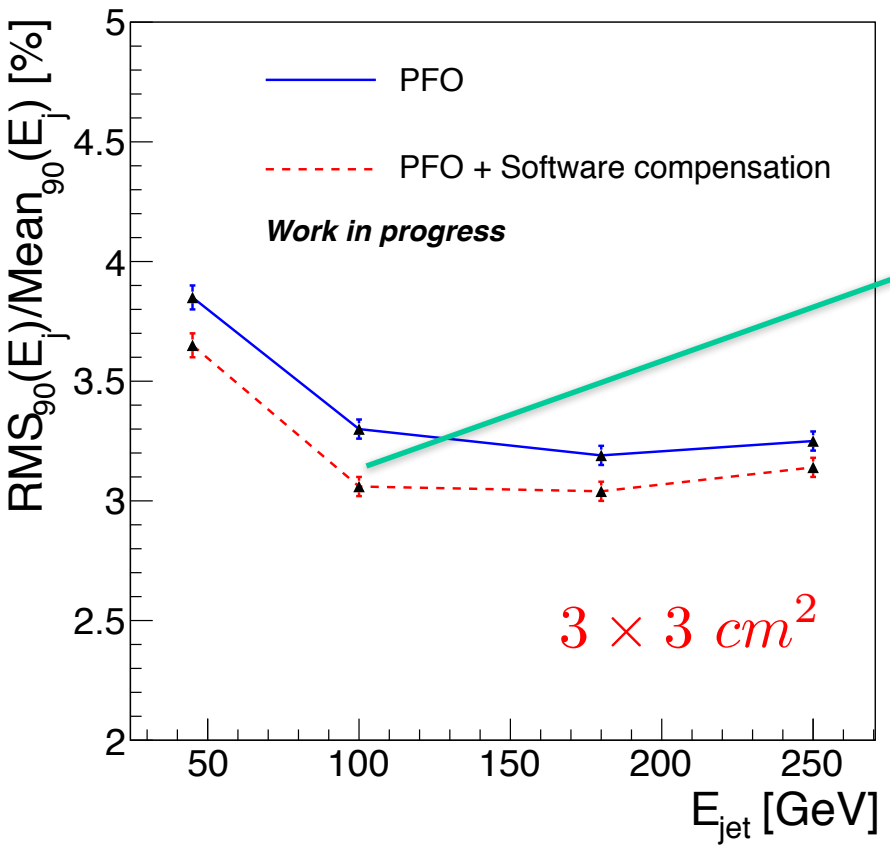
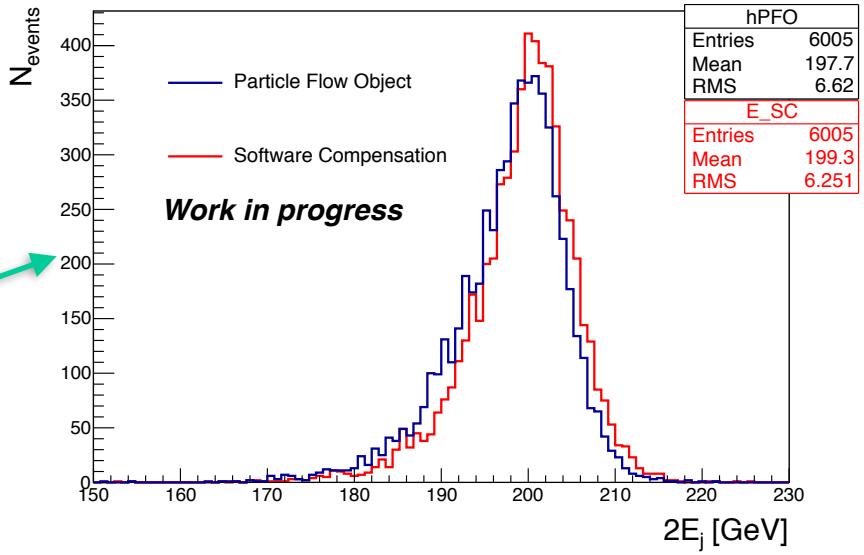


- Testbeam results reproduced
- Overall slightly worse because of missing tail catcher

Jet energy resolution

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



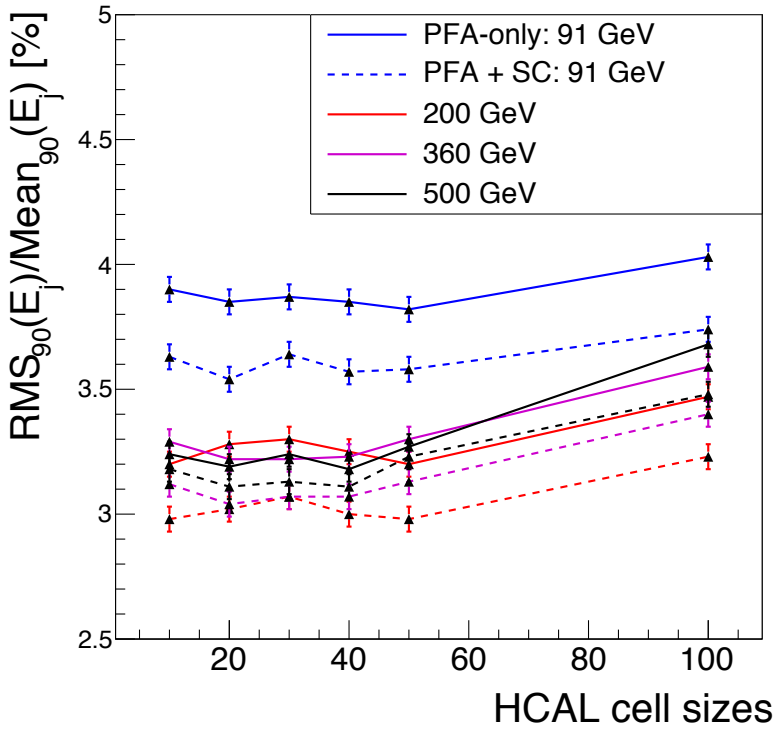


- Reconstructed energy distribution closer to simulated energy and width of distribution smaller
- Improves jet energy resolution in whole range

JER vs cell size

- SC weights depend on hit energy density ➢ Dependence on detector model (cell size, …)

  ➢ one SC weights set per each detector model
- JER improved overall with software compensation
- At high energy slightly worse compared to Steve's numbers using cell energy truncation cut
  - Direct comparison see Steve's talk
  - For higher energy jets (large confusion) this is expected (*see next slide*)

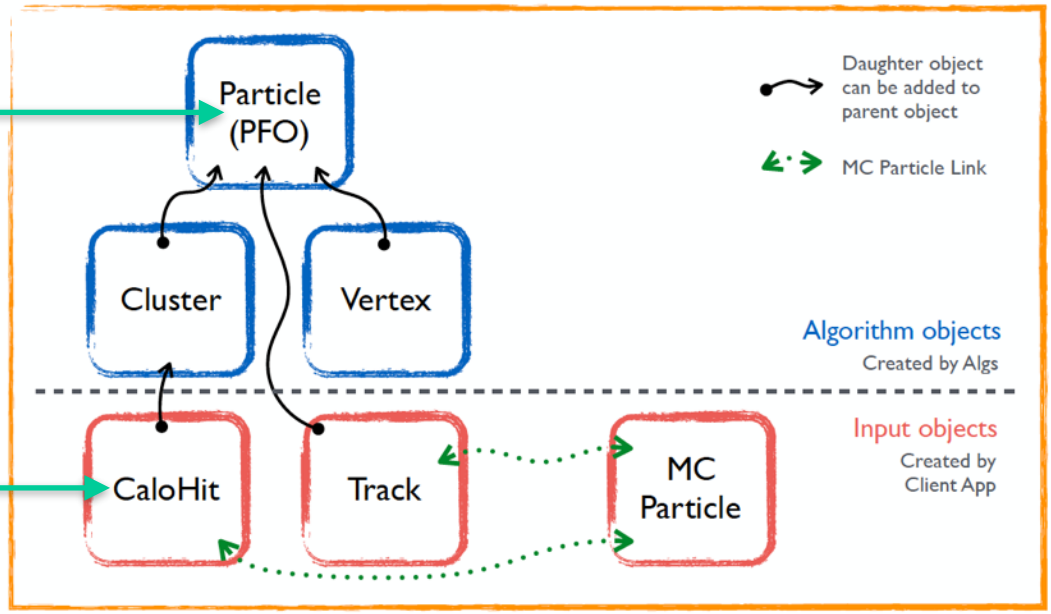


JER vs cell size

- HCAL cell energy truncation and software compensation are applied at different stages

Current software compensation:
Neutral hadron PFO energy correction

HCAL cell energy truncation applied at CaloHit level:
- Already takes effect at *clustering step*
- Software compensation cannot be applied at CaloHit since it needs *first energy estimation*



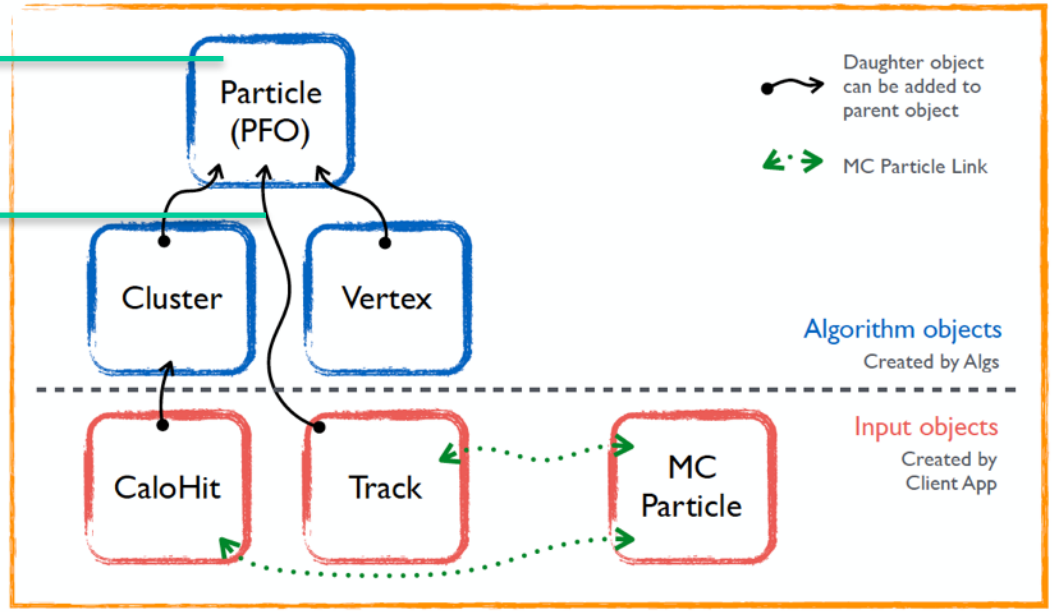
➢ How to implement software compensation into Pandora in the most effective way?

Implementation into Pandora

- Software compensation can help at different stages of Particle Flow Algorithm:
  - Particle Flow Object creation: Correction of neutral hadrons energy (**Current status**)
  - Re-clustering: Cluster-Track compatibility

Neutral hadrons PFO registered with software compensated energy

Cluster-Track compatibility: if failed, re-clustering



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Implementation into Pandora

- Software compensation can help at different stages of Particle Flow Algorithm:
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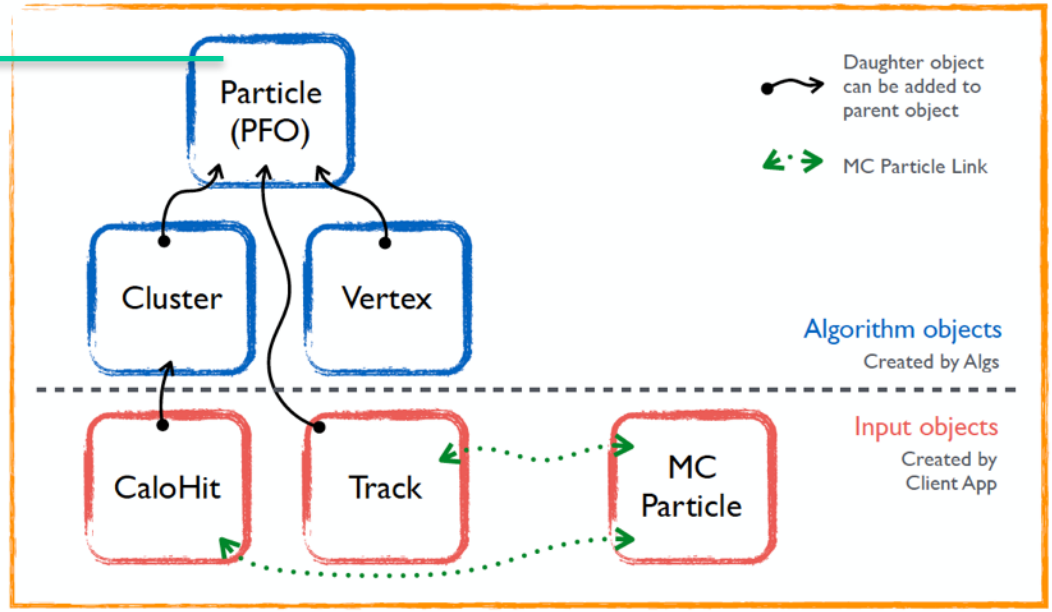
Neutral hadrons PFO registered with software compensated energy ✓



- Flag in MarlinPandora steering to apply software compensation:

```
    <parameter name="ApplySoftwareCompensation" type="bool"> false </parameter>
    <parameter name="SoftwareCompensationParameters" type="FloatVec"> 2.54231 -0.0470912 ...
</processor>
```

Implementation into Pandora

- Software compensation can help at different stages of Particle Flow Algorithm:
  - Particle Flow Object creation: Correction of neutral hadrons energy (**Current status**)
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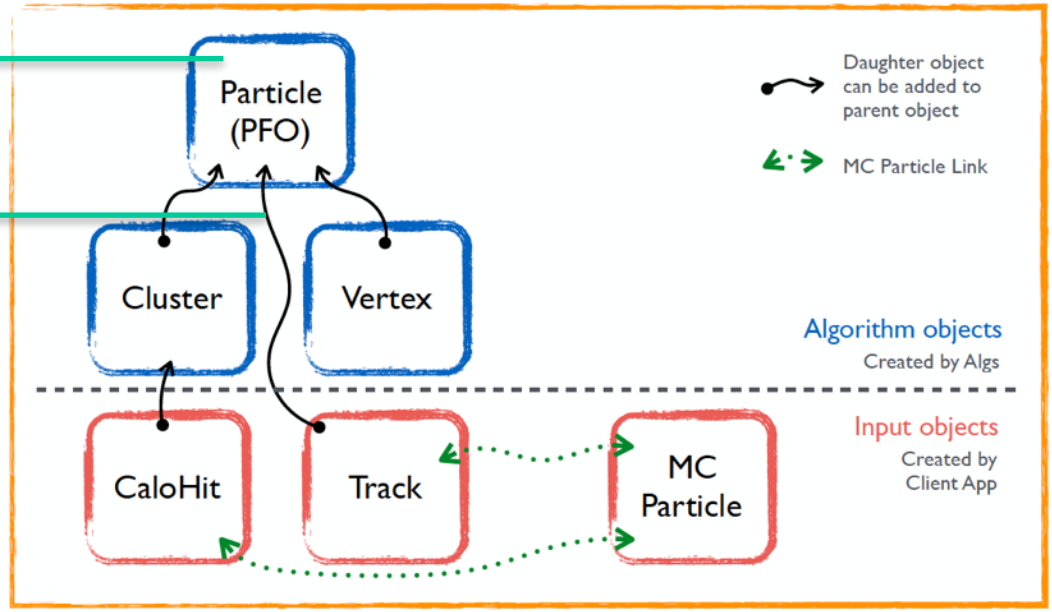
Neutral hadrons PFO registered with software compensated energy ✓

Cluster-Track compatibility: if failed, re-clustering

- Performed through EnergyCorrection plugin: Not yet works as expected



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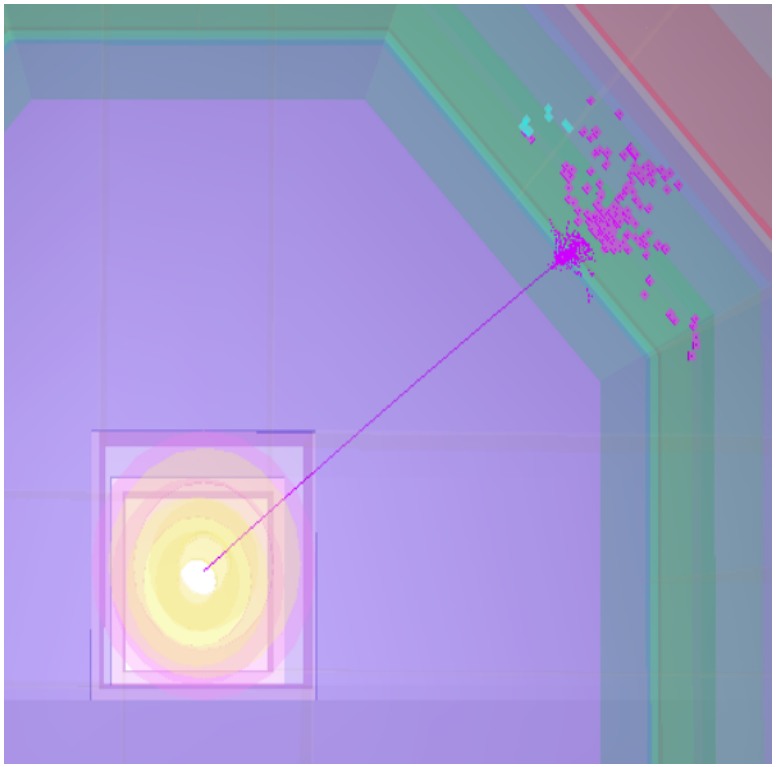
Software compensation in re-clustering

- 50 GeV Pi-
  - Standard PFA: 12.32 ± 0.60 %
  - PFA + Software compensation : 12.48 ± 0.62 %

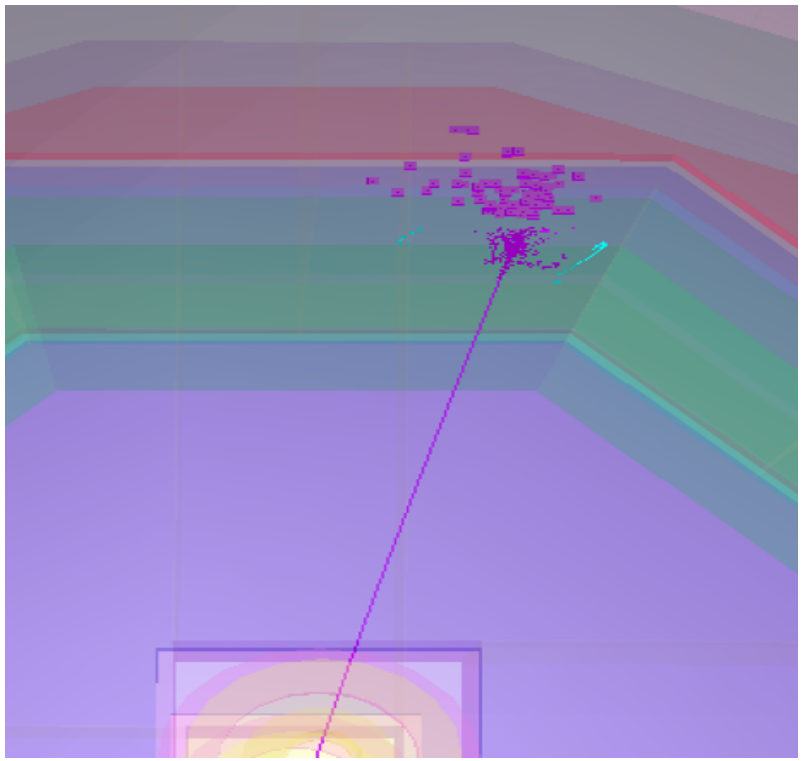
User cluster energy estimation for SC



- **Event 15:**
  - Charged object: EtrackPFO = 50.09
    Ecluster = **48.80**
  - Neutral object: EneutralPFO = **0.46**
    Ecluster = 0.46
- Energy correction with SC:
  - Charged object: EtrackPFO = 50.09
    Ecluster = **48.81**
  - Neutral object: EneutralPFO = **0.71**
    Ecluster = 0.46
- After re-clustering :
  two objects are not merged

Software compensation in re-clustering

- 50 GeV Pi-



User cluster energy estimation for SC

- **Event 44:**
  - Charged object: EtrackPFO = 50.22
    Ecluster = **51.09**
  - Neutral object 1: EneutralPFO = **1.05**
    Ecluster = 1.05
  - Neutral object 2: EneutralPFO = **0.41**
    Ecluster = 0.41

- Energy correction with SC:
  - Charged object: EtrackPFO = 50.22
    Ecluster = **51.30**
  - Neutral object 1: EneutralPFO = **2.00**
    Ecluster = 1.05
  - Neutral object 2: EneutralPFO = **0.78**
    Ecluster = 0.41

- After re-clustering :
  three objects are not merged

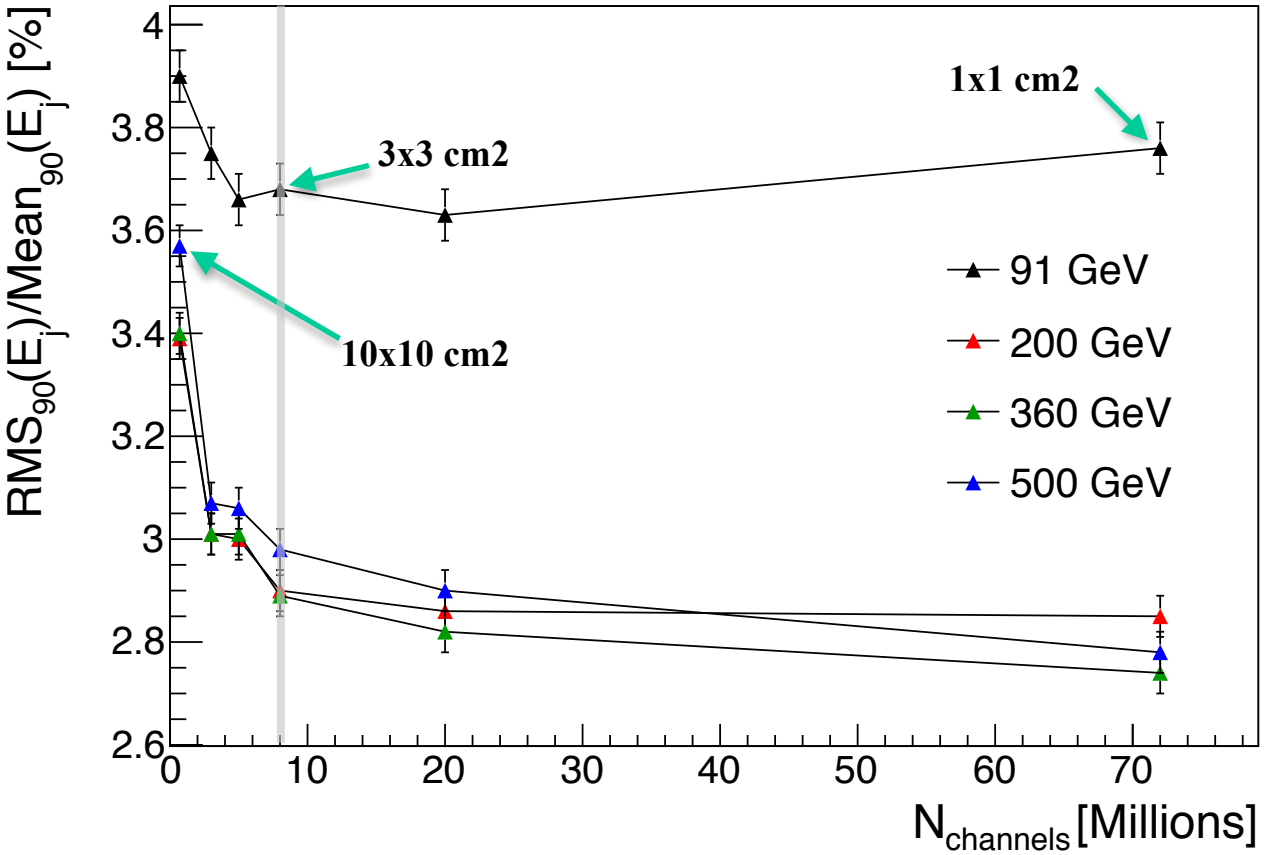
Towards cost optimisation

- Optimisation study has to achieve best balance between:
  - Physics performance
  - Detector cost
  - Reality: sometimes not always as expected/simulated

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

Summary & Outlook

- *Software compensation and cell size optimisation:*
  - Software compensation *implemented in Pandora*
  - *Improves* single particle and jet energy resolution
  - Re-clustering step to be done

- Common SC technique for different types of HCAL developed (not mentioned here)
- For a more complete view about software compensation and different approaches:
  - http://www.desy.de/~huonglan/FLCLongTalk_30Nov2015/Lan_FLCLongTalk.pdf
  - http://agenda.linearcollider.org/event/6931/session/4/contribution/22/material/slides/0.pdf

- Final goal: HCAL cell size and sampling optimisation (3D granularity) as a function of depth and for different detector radii

- First week of January in Cambridge

Back-up slides

Towards a common SC technique for different types of HCAL

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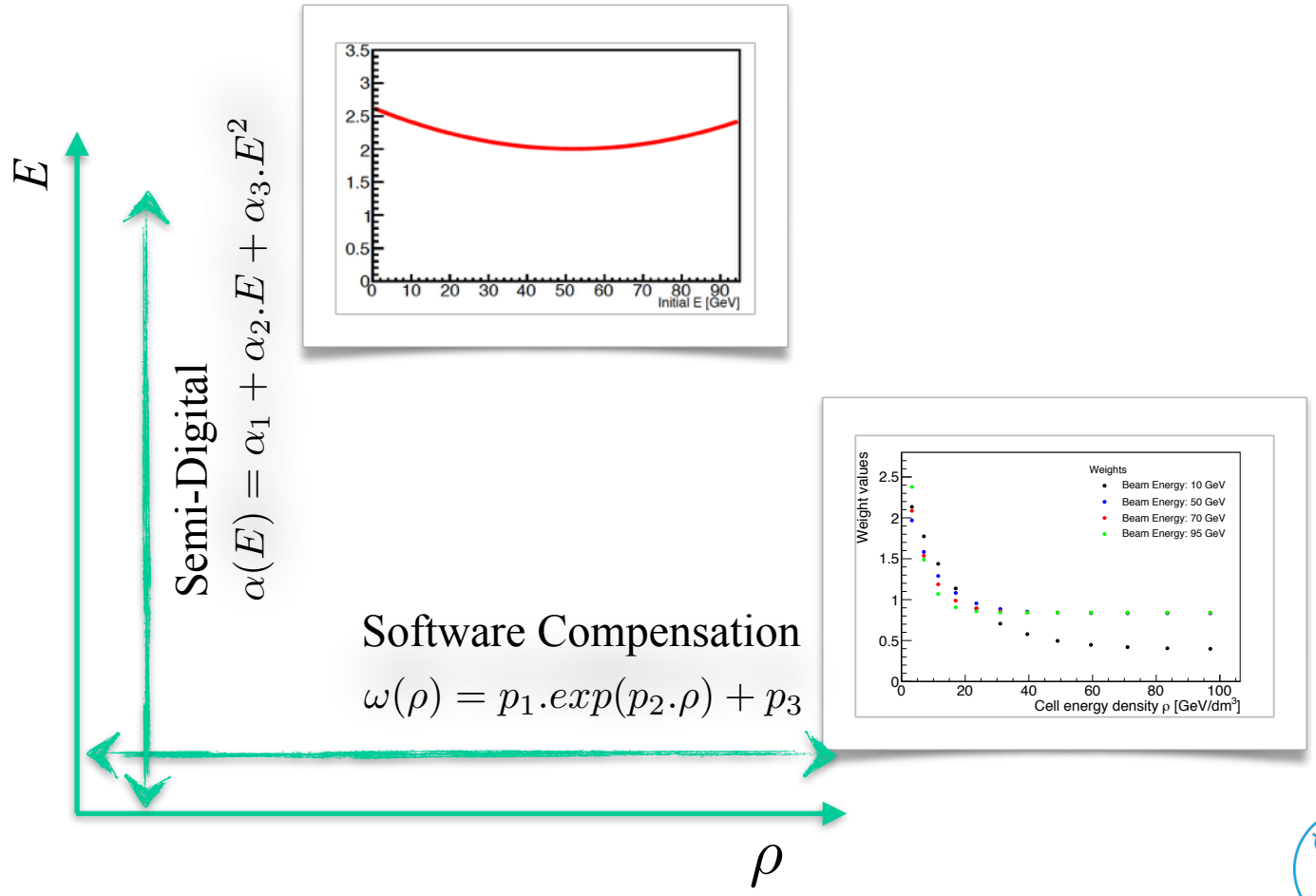
DESY

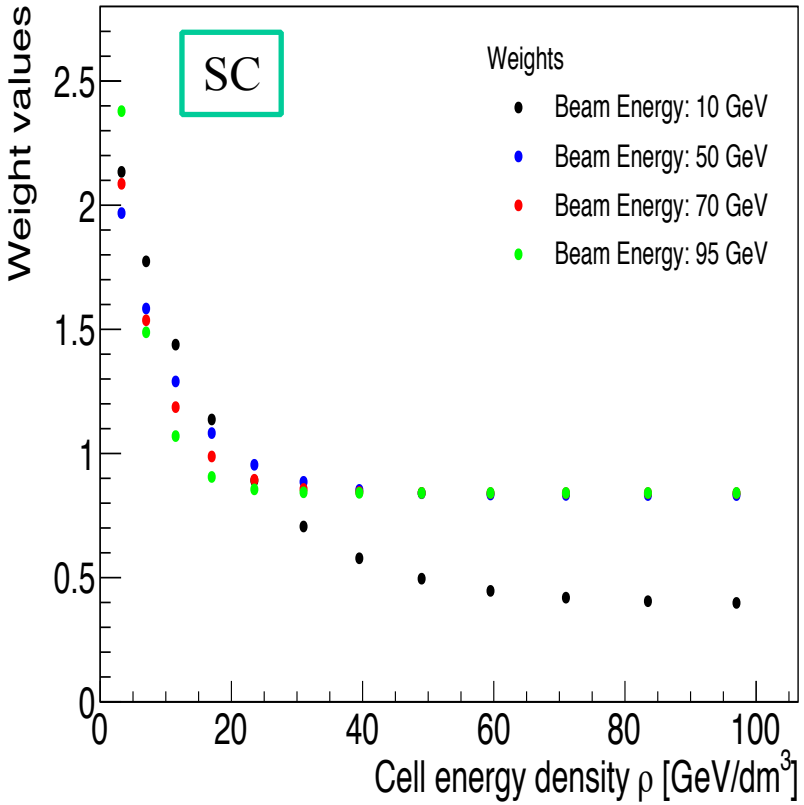
Semi-Digital and Software Compensation

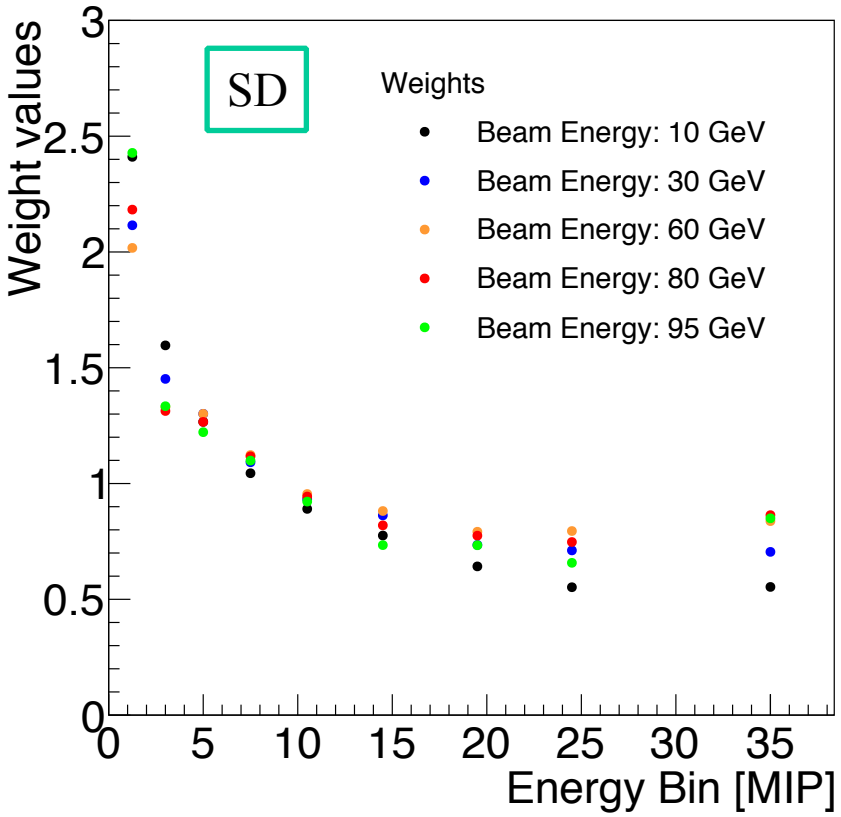
- Software Compensation: weight optimised as a function of ***hit energy density*** ρ
- Semi-Digital: weight optimised as a function of ***particle energy*** E



Software Compensation in S-D style

- New procedure defined:
  - No longer enforce weight to follow exponential behaviour $\omega(\rho) = p_1 \cdot exp(p_2 \cdot \rho) + p_3$
  - Weights determined for each bin of hit energy as a function of beam energy (all-at-one fit)





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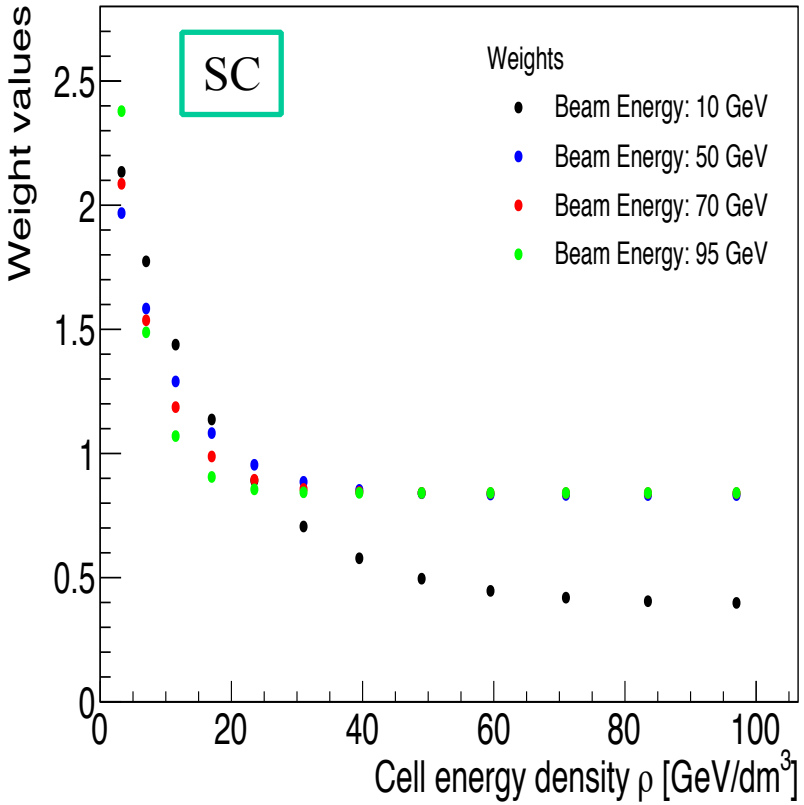

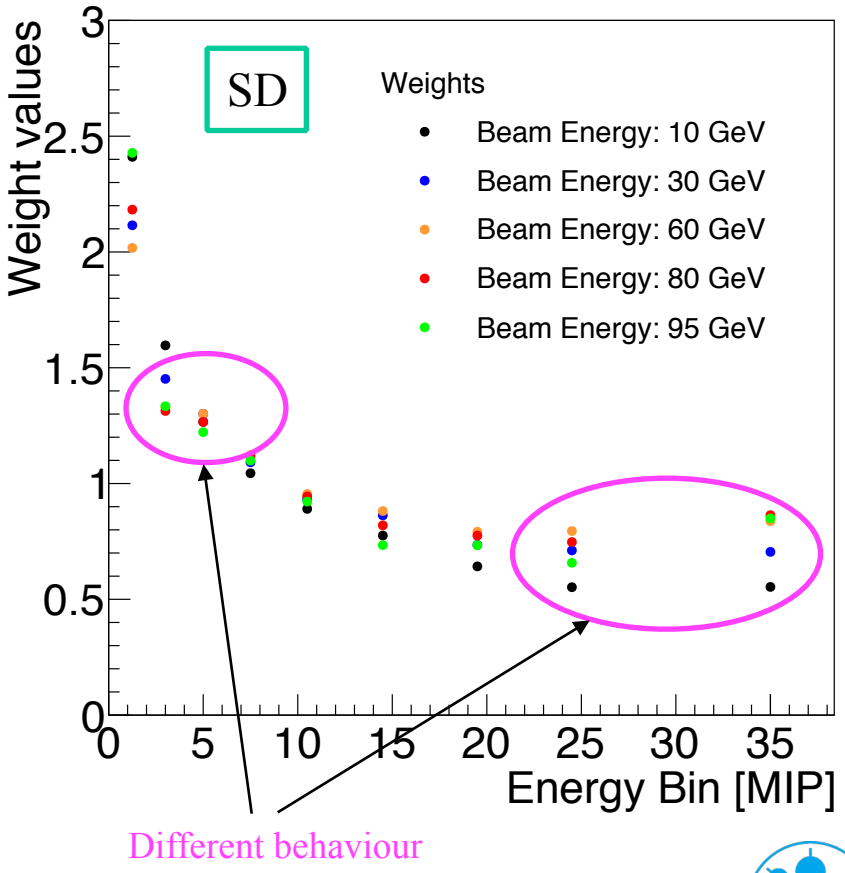

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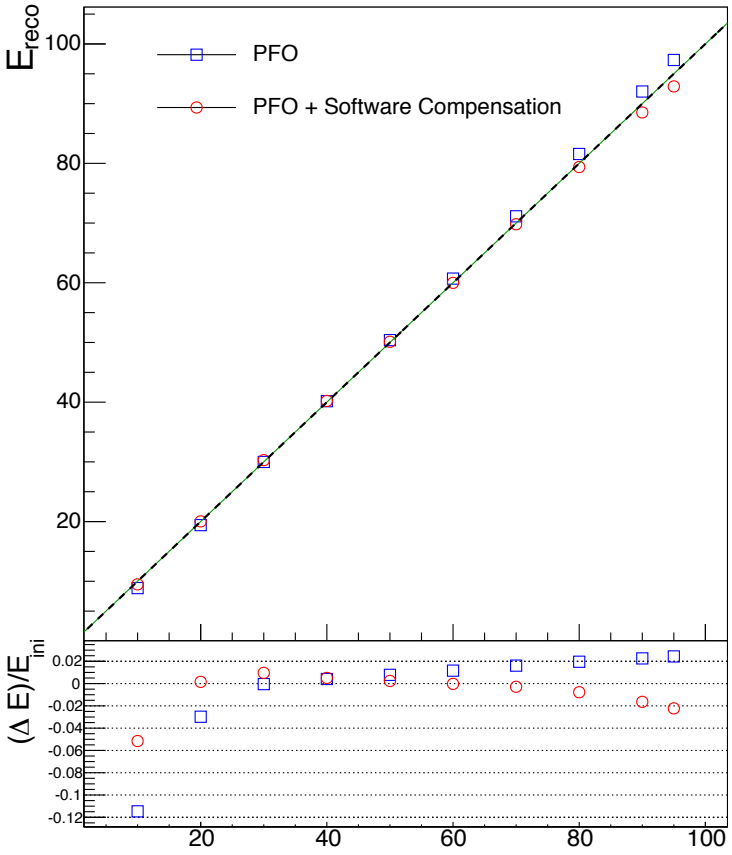

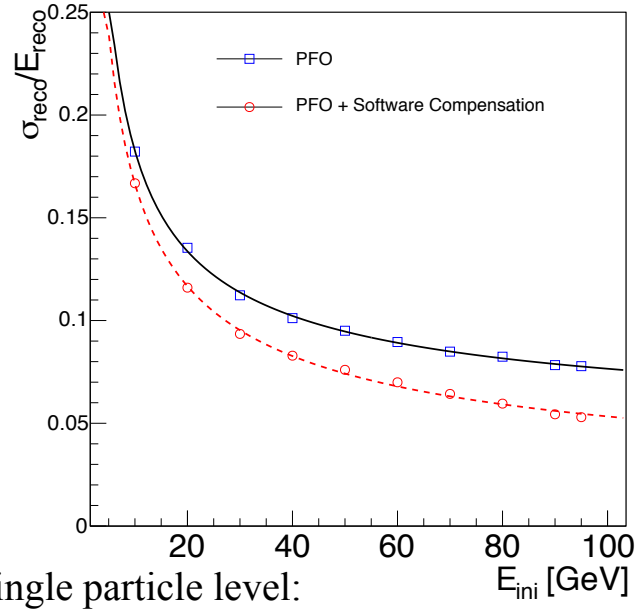

Single particle level:

- Better compared to previous results
- Improves linearity in whole range
- Improves resolution ~ 20%

  For higher energies ~ 30%

Software Compensation in S-D style

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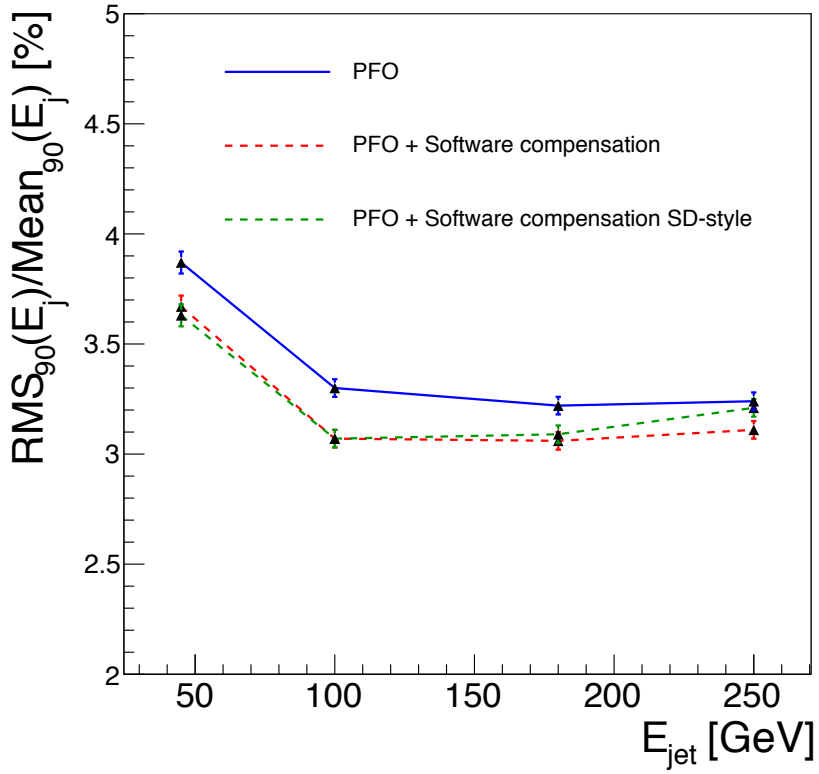


- At jet level gives more or less the same result as previously

Methods to achieve Compensation

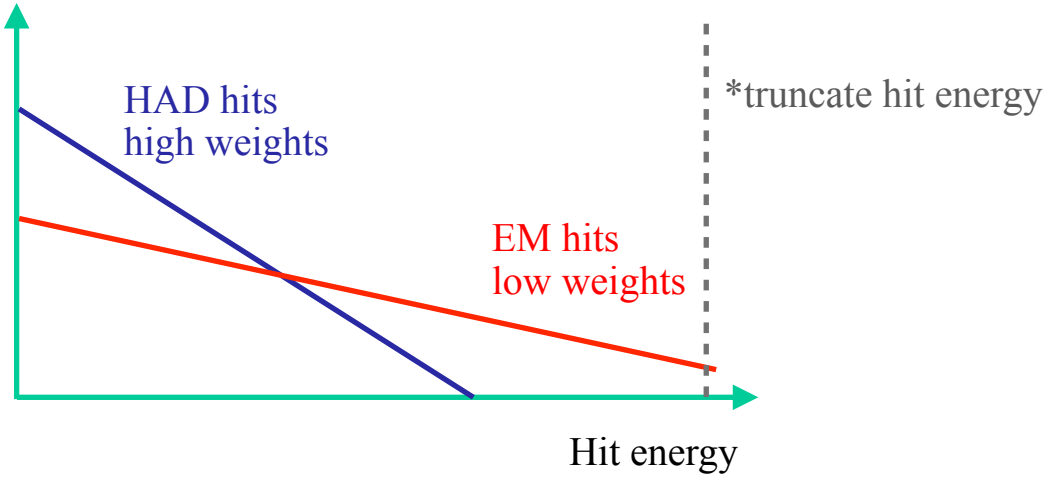
- Reducing electromagnetic response
- Increasing hadronic response

Achievable with detector design

- "Offline" compensation: **Software Compensation**
  - Electromagnetic showers denser than hadronic showers ➢ energy of hits inside electromagnetic sub-showers are typically higher compared to hits inside hadronic sub-showers.

    ➢ Cut out high energy hits to reduce EM response *

    ➢ Applying different weights for hits of different energy densities



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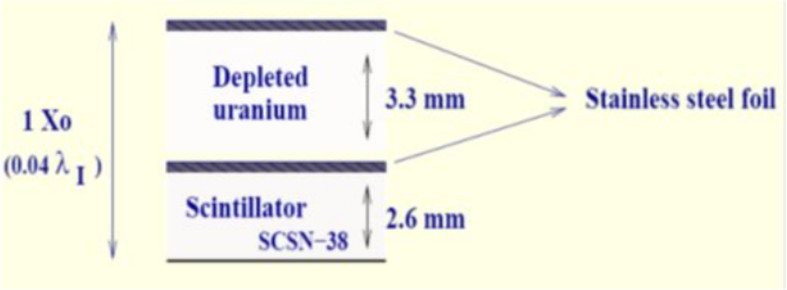
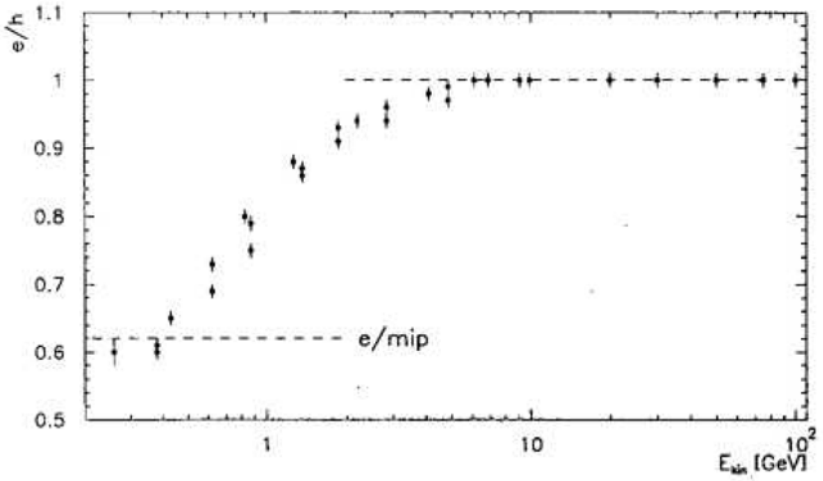


ZEUS Uranium-Scintillator calorimeter

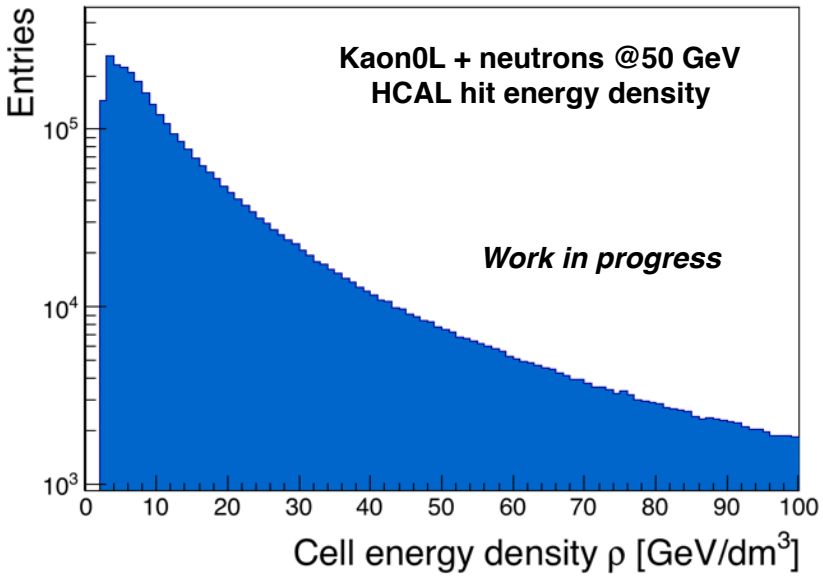
Achievable with detector design

- Increase nuclear fission with absorber material
  - Example: ZEUS detector using ^{238}U
- Manipulating response to (slow) neutrons
- Sampling fractions
- …



ZEUS e/h response ratio
=1 within 1% for E > 3GeV

Reminder: Hit Energy Density and Weights

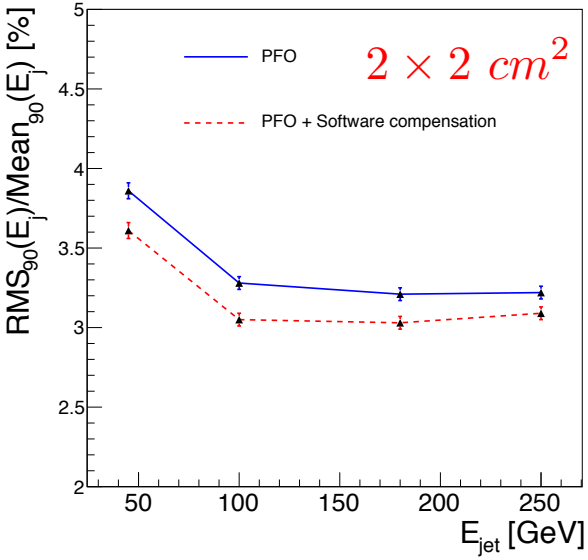


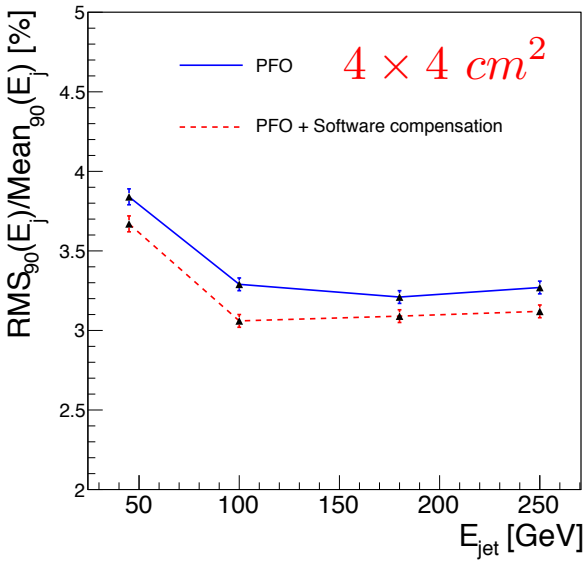
Samples:

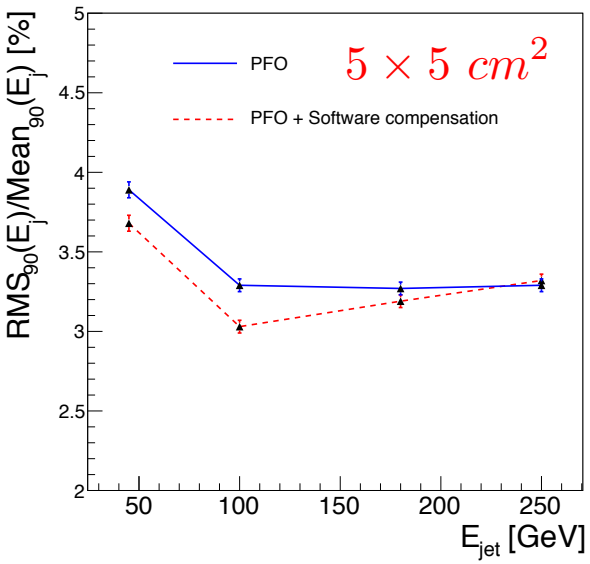
- Kaon0L and neutrons from 10 to 95 GeV generated from IP, targeted only to barrel part
- Select only events with 1 cluster
  - Events where hadronic showers started already in EM calorimeter: only HCAL hits are weighted
  - Cluster with no hit in muon chamber

Jet Energy Resolution for Different Cell Sizes

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





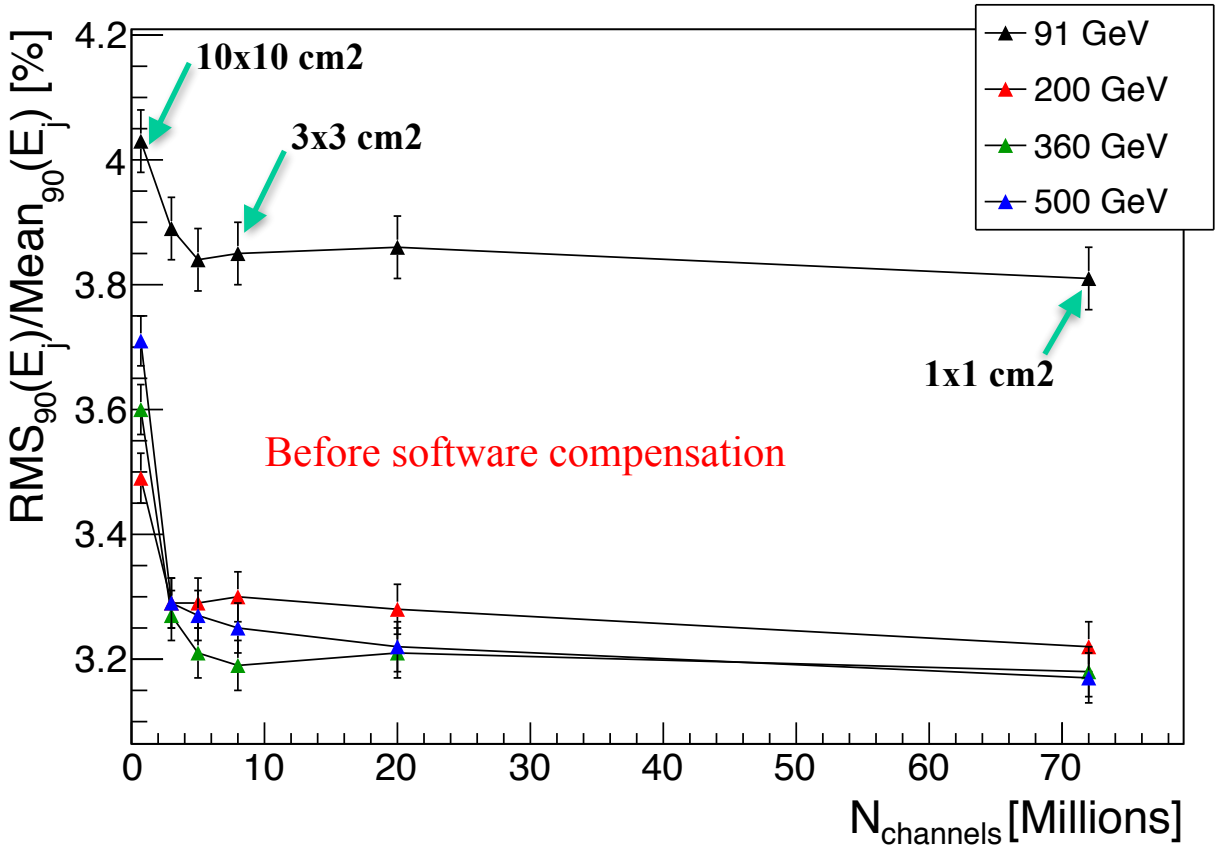


- Proper weights to be done, especially for very small or very large granularities
- SC could also help at re-clustering stage of Pandora
  - At the moment degrades JER, under investigation

Outlook - Using my numbers

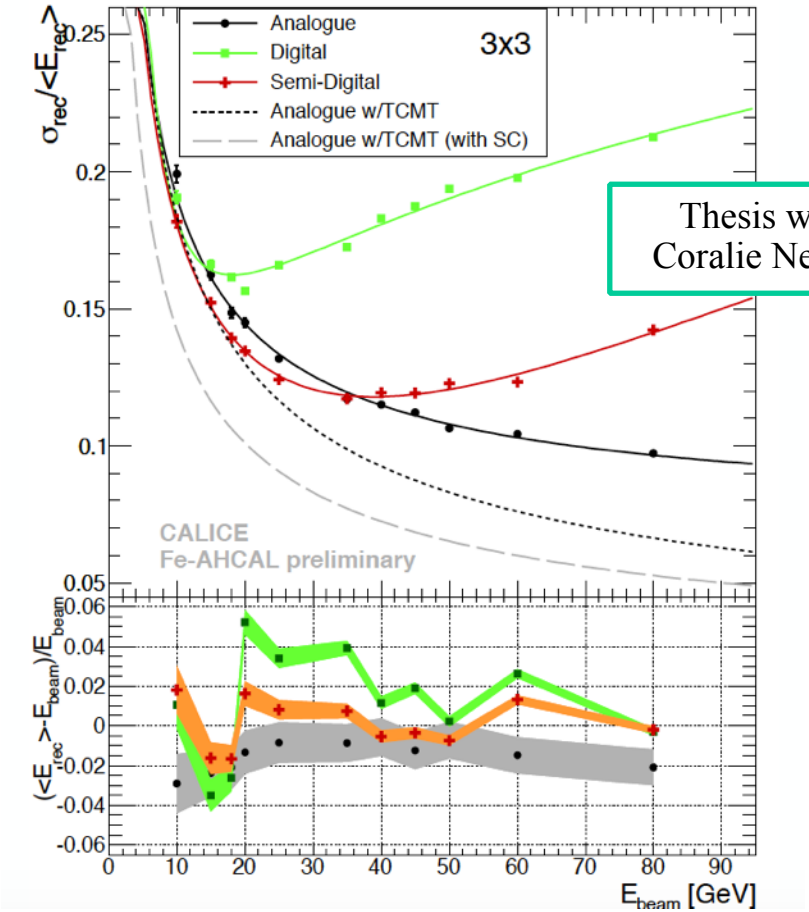
Towards cost optimisation

- 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



Semi-digital Reconstruction

- Semi-digital reconstruction is particularly successful at low energies
  - Counting hits at 3 thresholds N_1, N_2, N_3



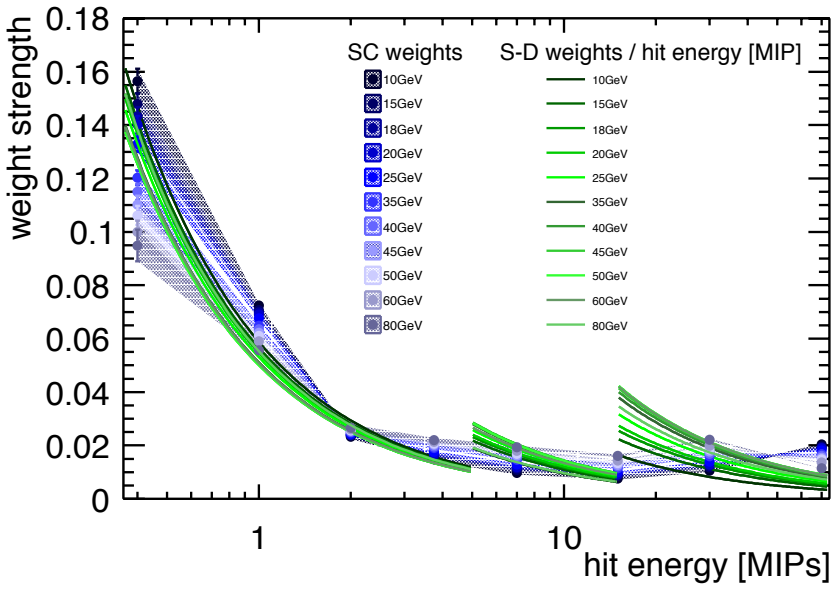
- Reconstructed energy: $E_{SD} = \sum_{bins} \alpha_i . N_i$

or

$$E_{SD} = \sum_{hits} \alpha_j . \frac{E_j}{E_j} = \sum_{hits} \omega_j . E_j \text{ with } \omega_j = \frac{\alpha_j}{E_j}$$

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

Thesis work in progress
Coralie Neubueser (DESY)



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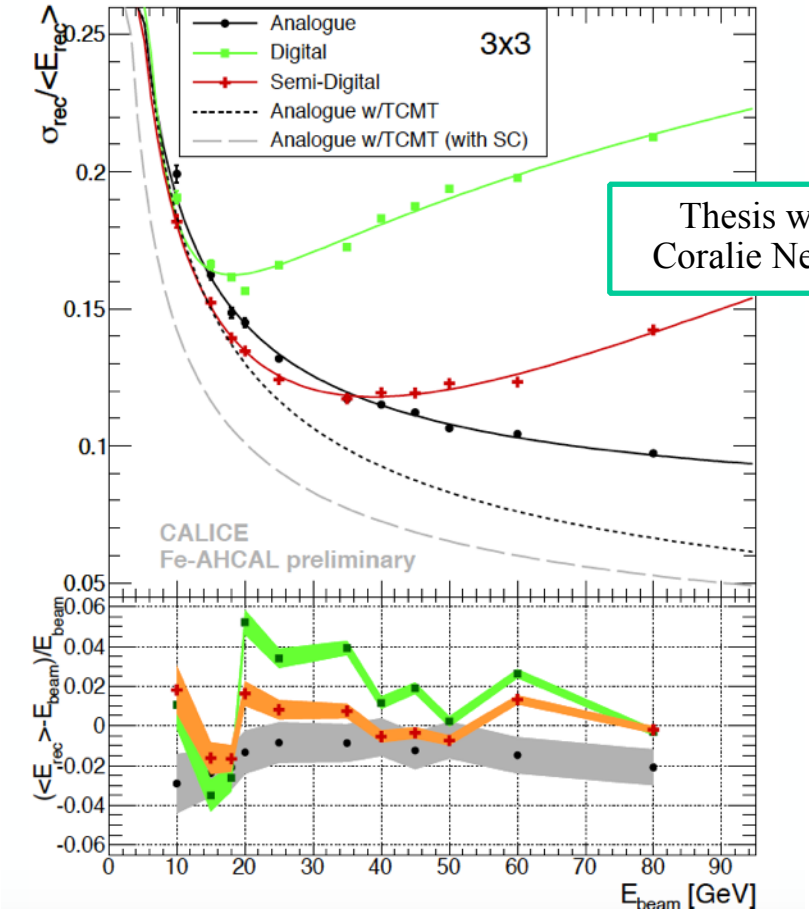

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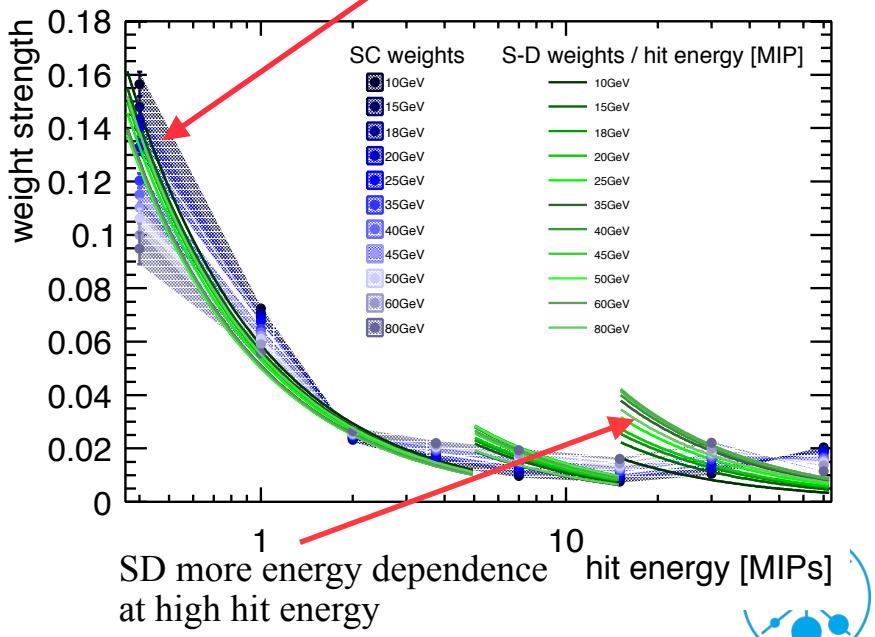
Thesis work in progress
Coralie Neubueser (DESY)

SD less particle energy dependence at small hit energy



SD more energy dependence at high hit energy

Semi-digital Reconstruction

- Semi-digital reconstruction:
  - Counting hits at 3 thresholds N1, N2, N3
  - Ntot = N1 + N2 + N3
  - EnergySD = alpha*N1 + beta*N2 + gamma*N3

where:

alpha = alpha1 + alpha2*N + alpha3*N*N

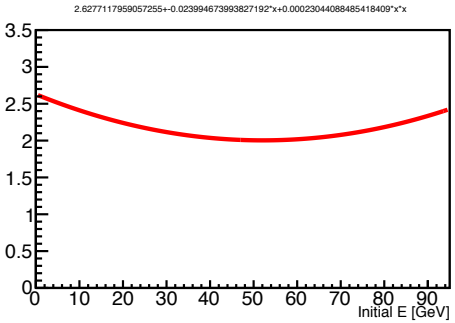
beta = beta1 + beta2*N + beta3*N*N

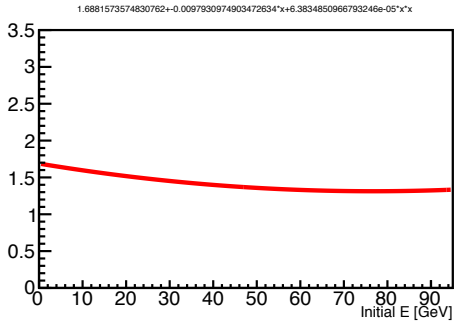
gamma = gamma1 + gamma2*N + gamma3*N*N

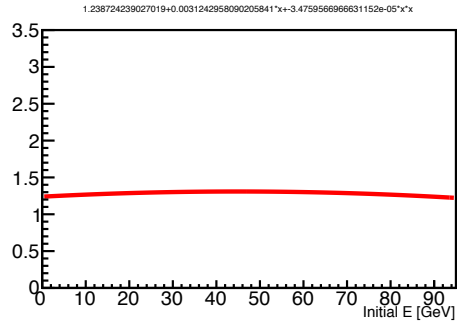
Software compensation mimics Semi-Digital:

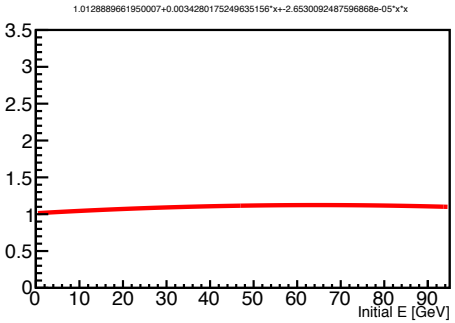
- Define bin
- Energy total = Sum_bin (weight_bin * SumEnergy_bin)
- weight_bin = a + b*E + c*E*E

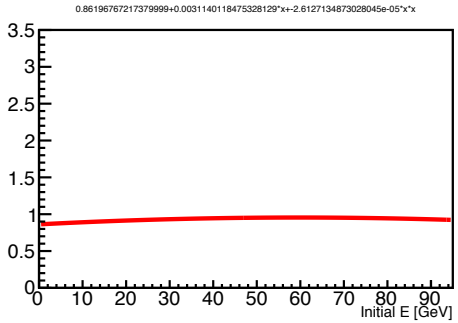
Semi-digital Reconstruction

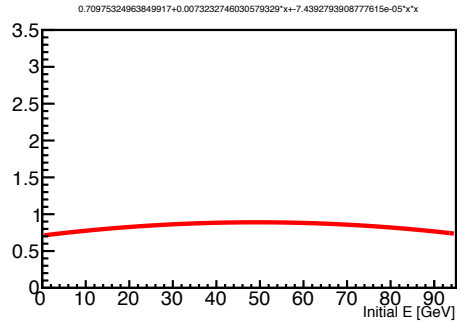


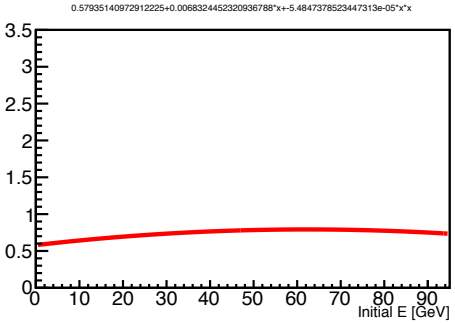


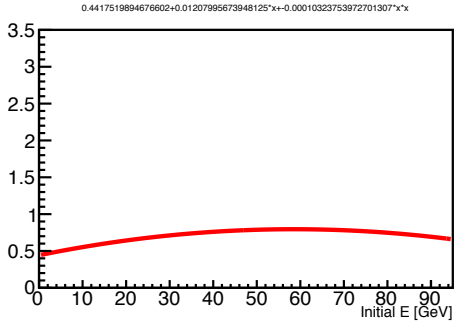


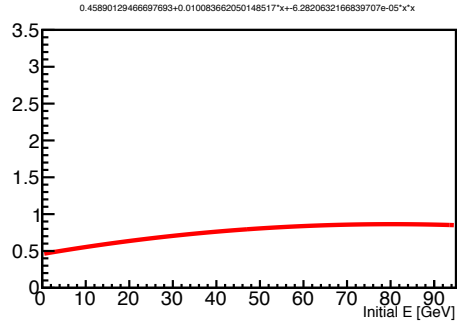




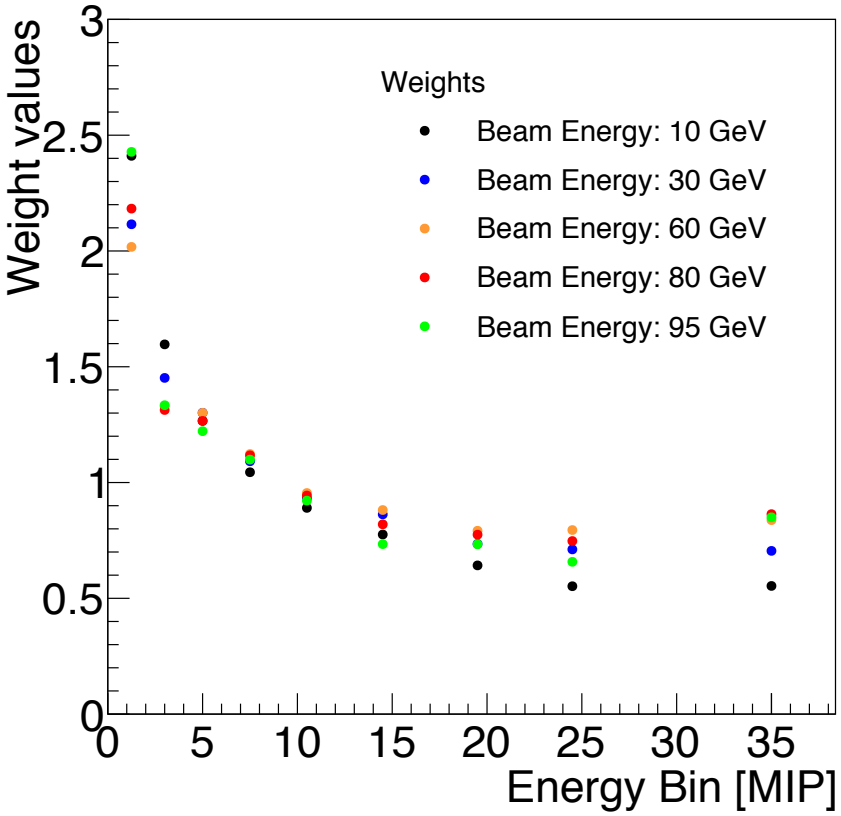


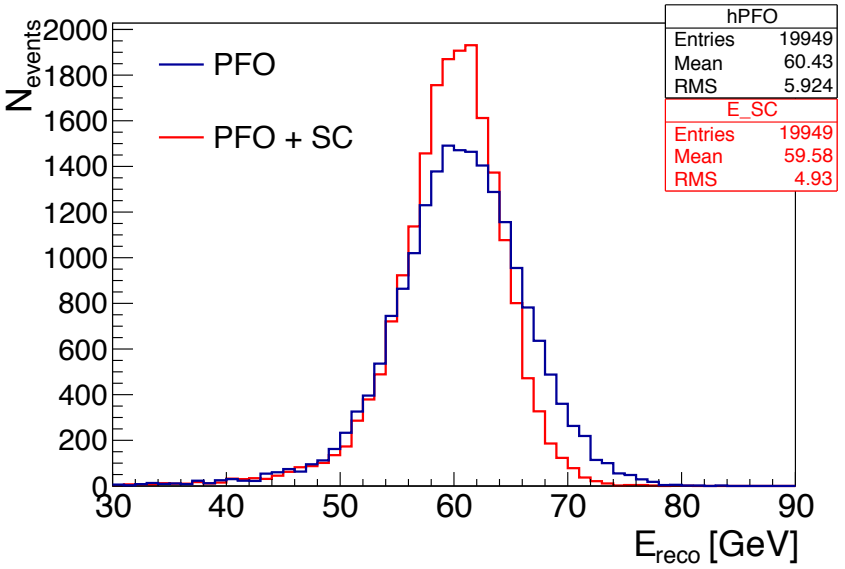






Semi-digital Reconstruction





JER vs cell size