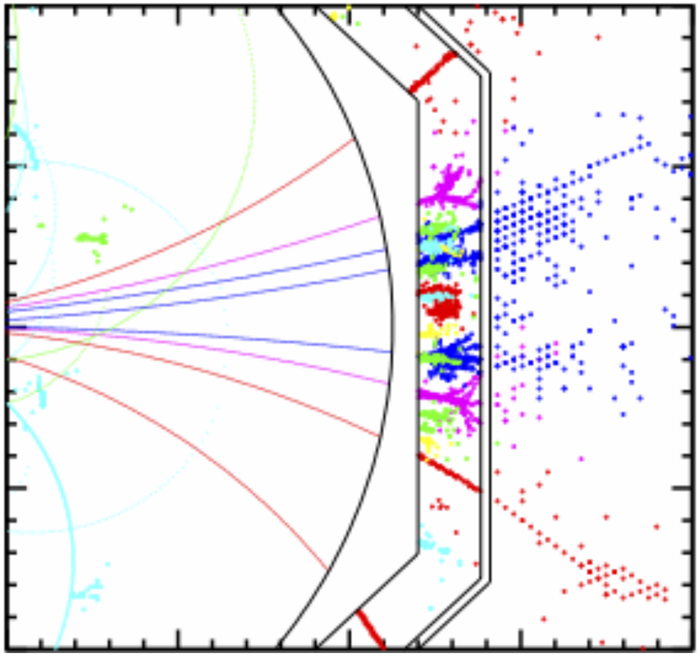
AHCAL Optimisation in ILD



Huong Lan Tran

CALICE AHCAL main meeting

10-11 December 2015

Outlines

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

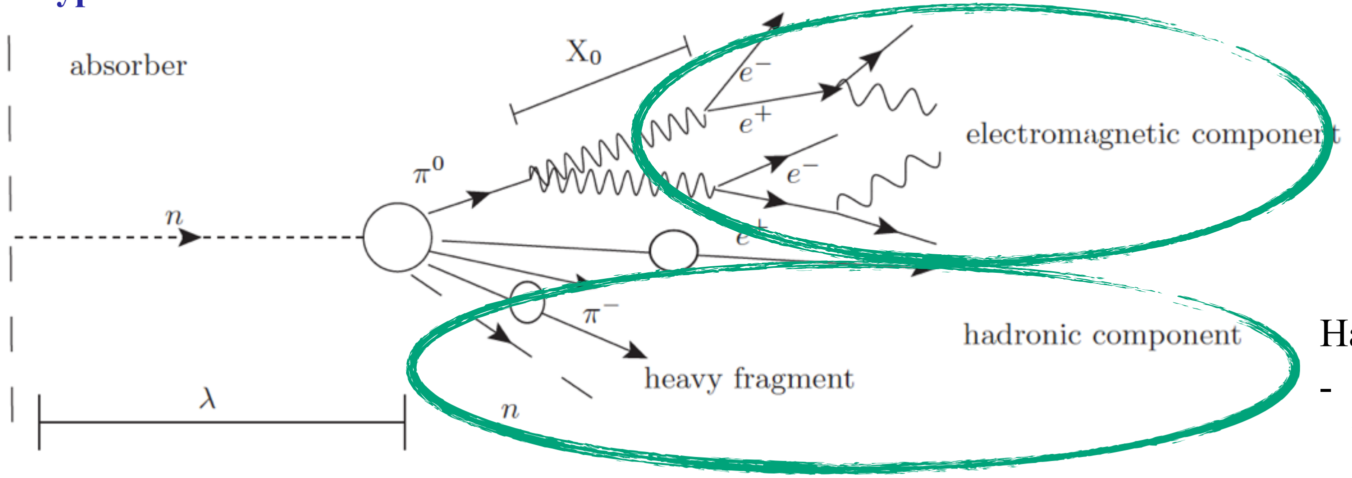
In this talk: Software compensation for AHCAL optimisation

- Motivation
- Updates on fitting procedure
- Towards a common SC technique for different types of HCAL
- Bonus: Implementation in Particle Flow Algorithm

Why Compensation?

- ILD calorimeters are ***non-compensating***

Typical hadronic shower



Detected via energy loss of electrons and photons in active medium

Hadronic components:
- Energy loss of charged hadrons, photons, neutrons…
- *Invisible energy*: nuclear binding energy or target recoil

➪ Smaller calorimeter response for this part

➢ **<u>Consequences:</u>**

- Higher detector response for electromagnetic compared to hadronic showers $\frac{e}{h} > 1$
- Non-linearity for hadronic calorimeter response
- Degradation of energy resolution

Methods to achieve Compensation

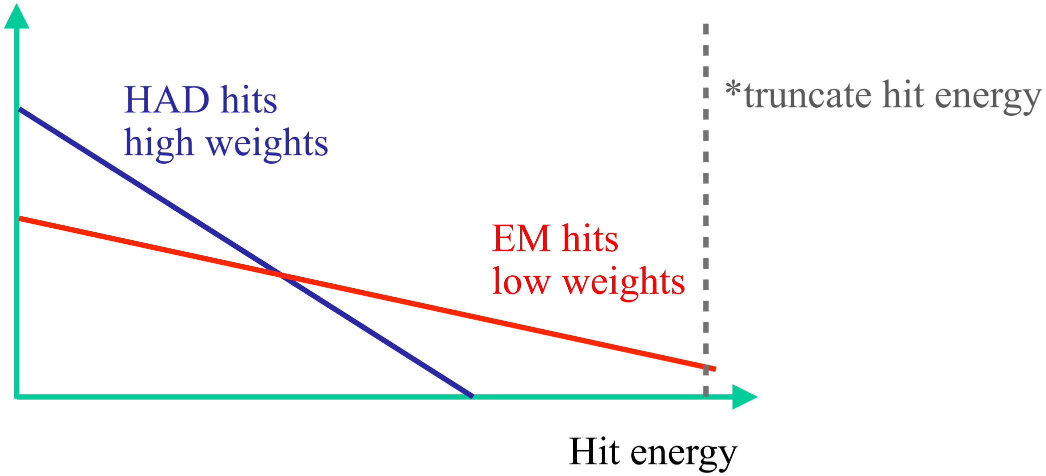
- Reducing electromagnetic response
- Increasing hadronic response

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.

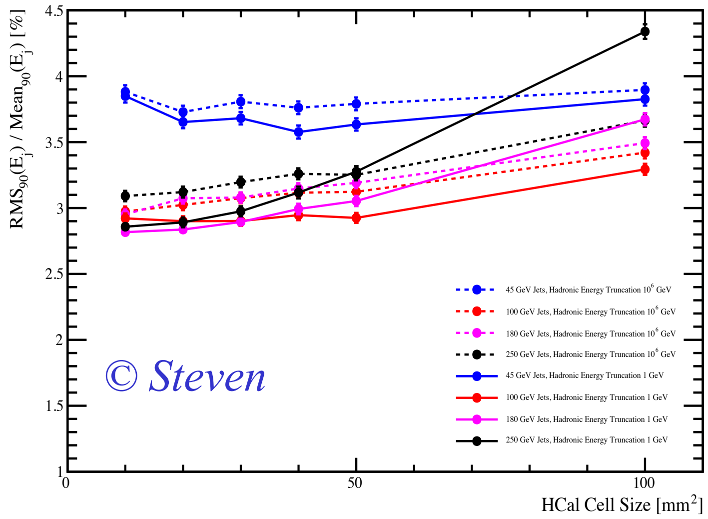
➢ Cut out high energy hits to reduce EM response *

➢ Applying different weights for hits of different energy densities



Software Compensation in AHCAL optimisation

- 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

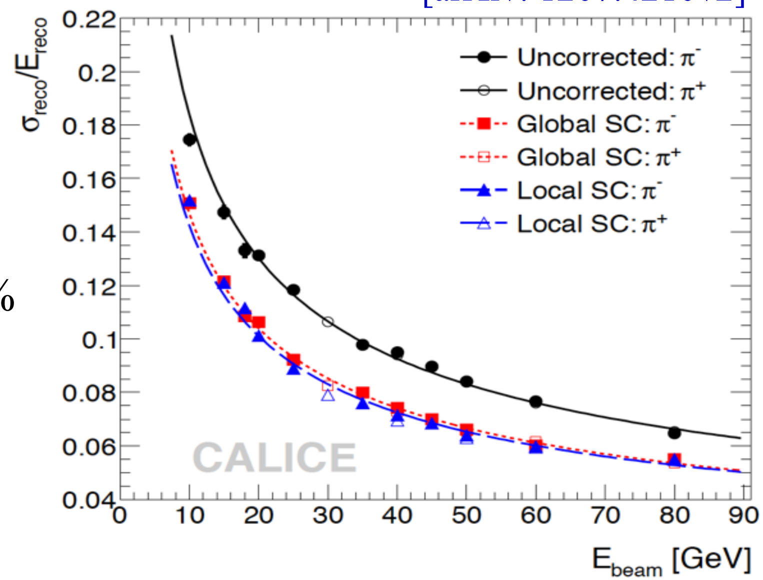


➢ Cell energy truncation mimics software compensation

➢ Software compensation can do better and must be applied properly

[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



Software Compensation in AHCAL optimisation

- ***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*

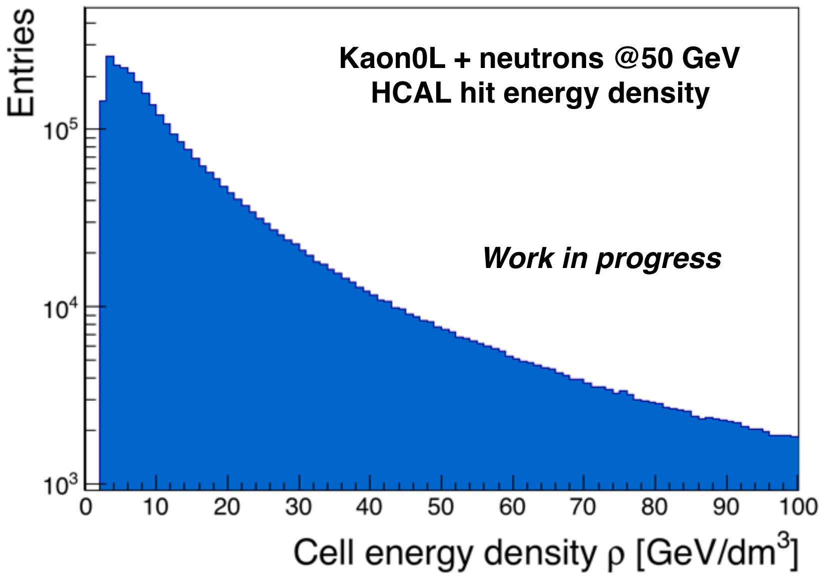
- Energy of cluster then computed in software compensation method as:

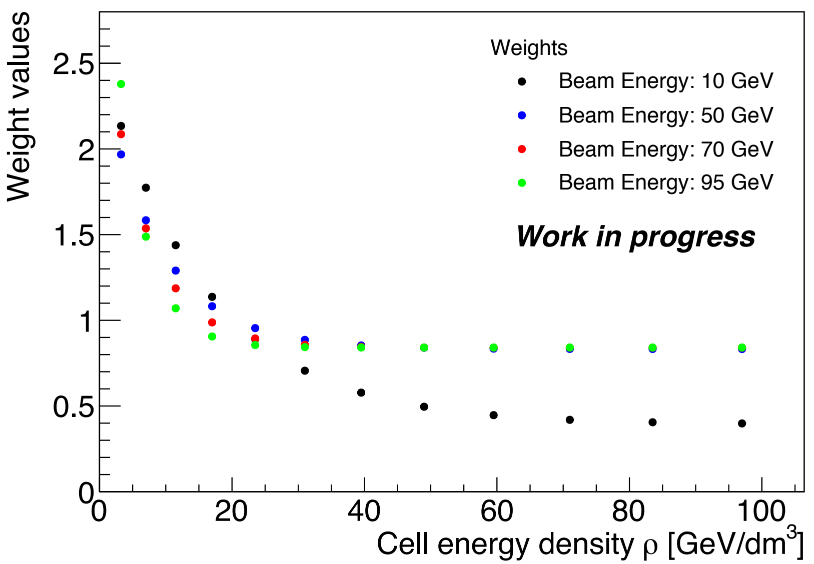
$$E_{SC} = \sum_{hits} E_{ECAL} + \sum_{hits} (E_{HCAL}.\omega(\rho))$$

- Weights determined through minimising a χ^2 function:

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

Hit Energy Density and Weights





Weight determination:

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

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

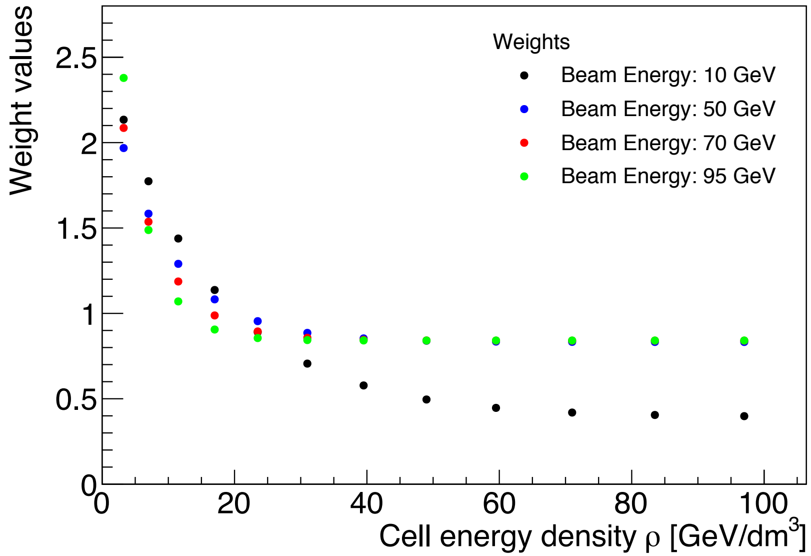
where p_1, p_2, p_3 are energy dependent parameter (defined directly in χ^2)

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

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

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

Weight parameters



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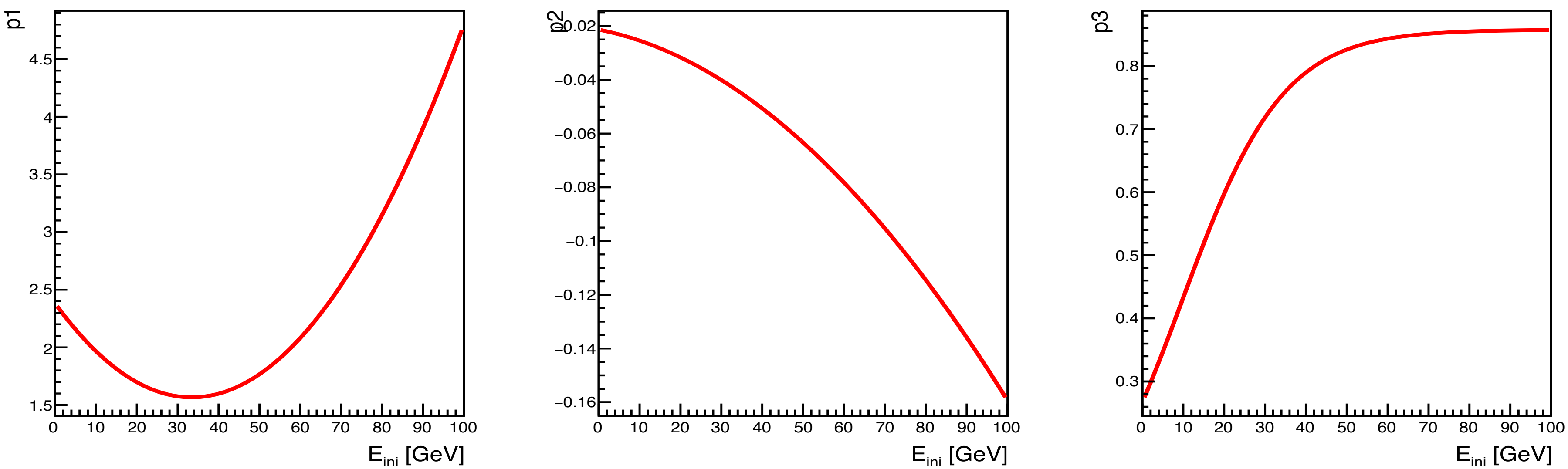
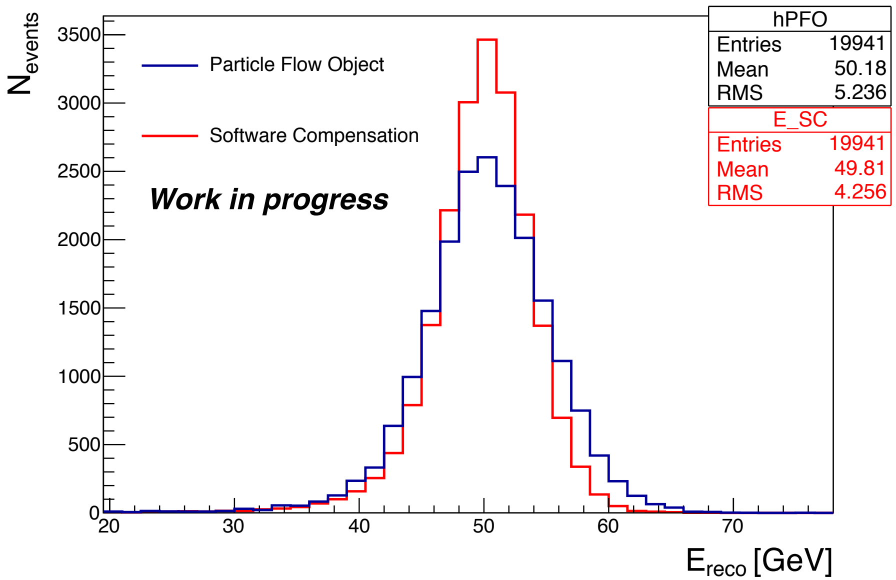


Single Particle Energy Reconstruction

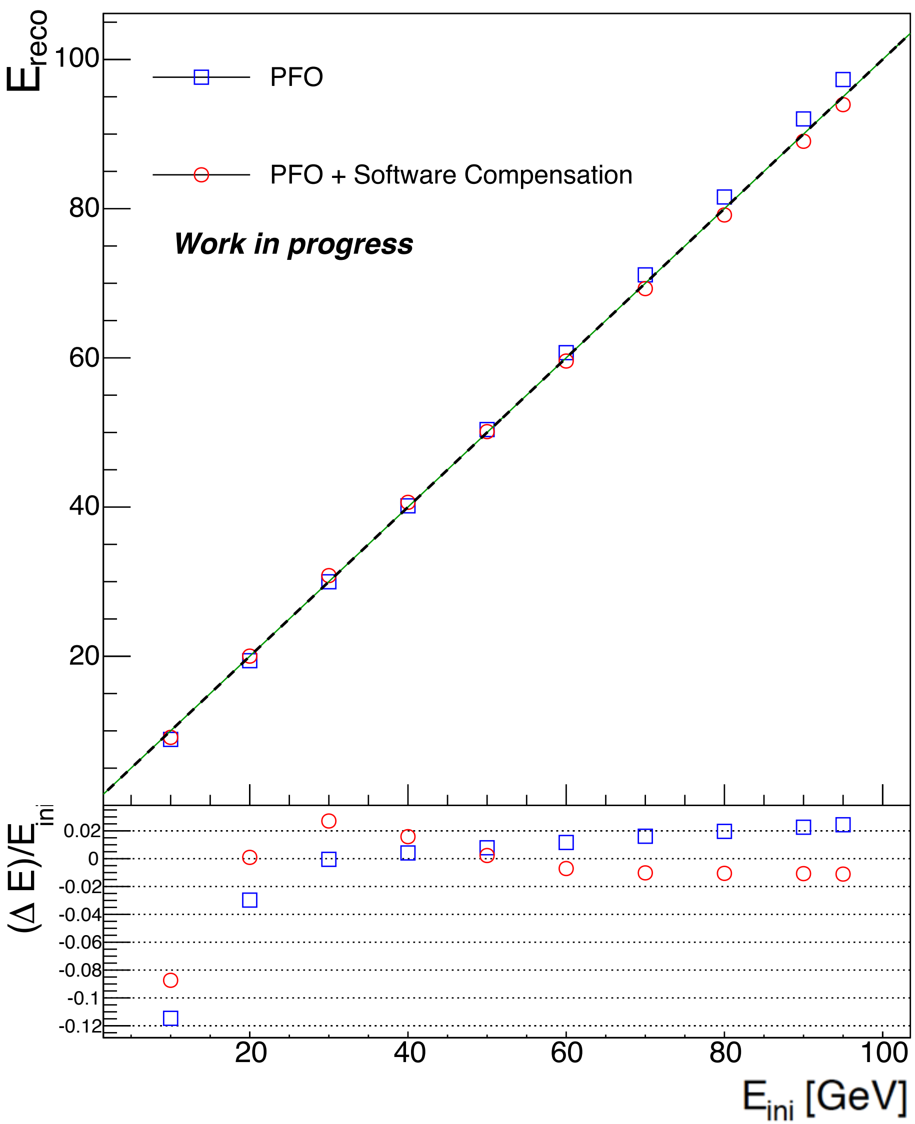
- Correction of neutral hadron PFOs energy
- Initial estimation of cluster's energy used for determination of weights
- Apply to set of Kaon0L and neutron samples from 10 to 95 GeV



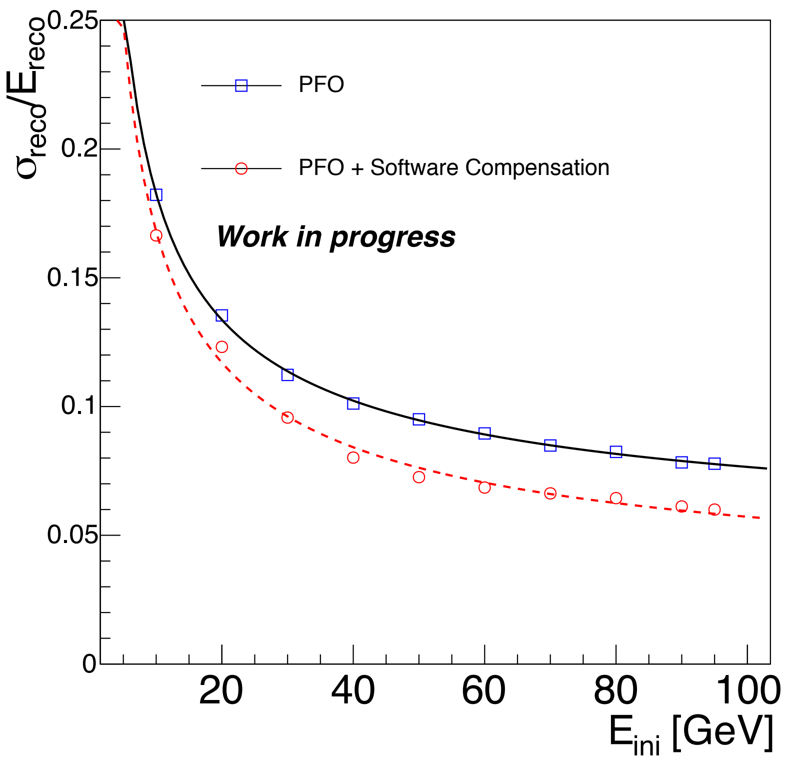
50 GeV Kaon0L

- Improvement of mean reconstructed energy
- RMS significantly reduced

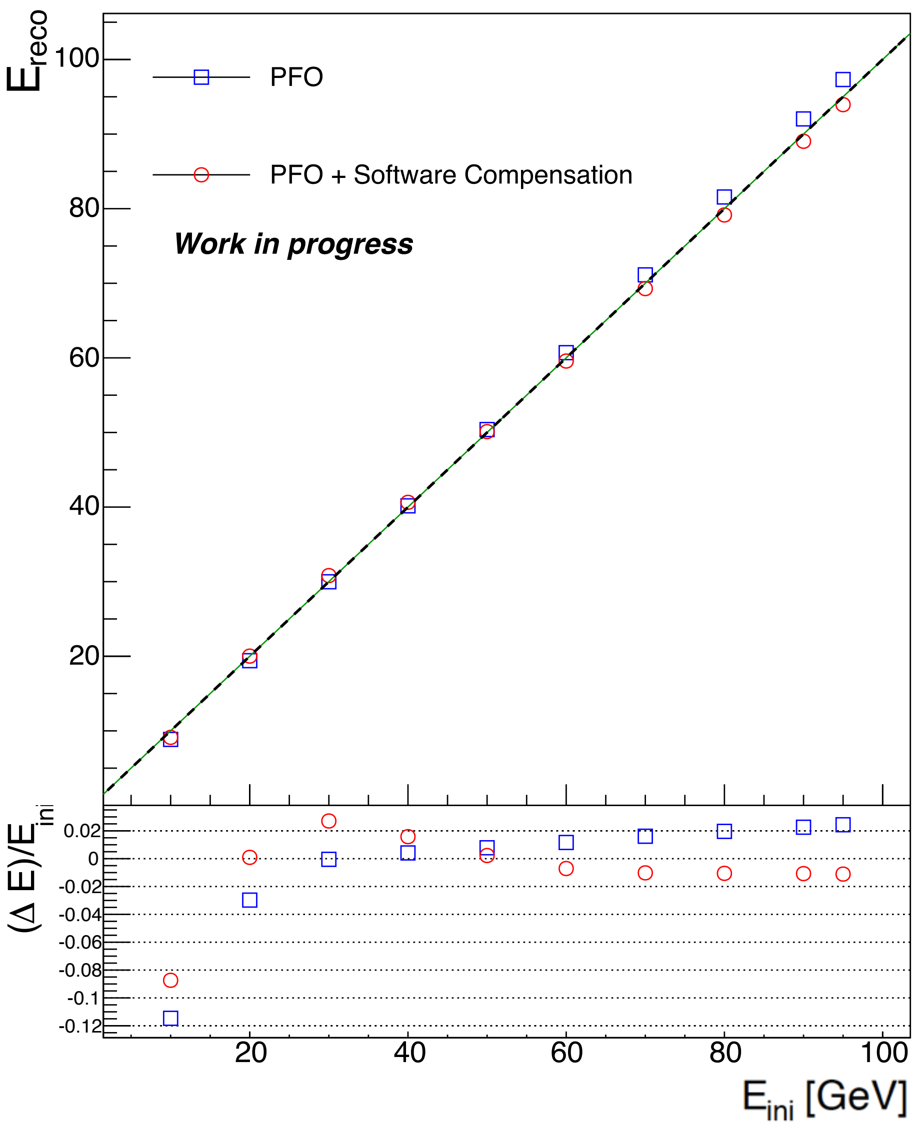
Single Particle Energy Reconstruction



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



Single Particle Energy Reconstruction



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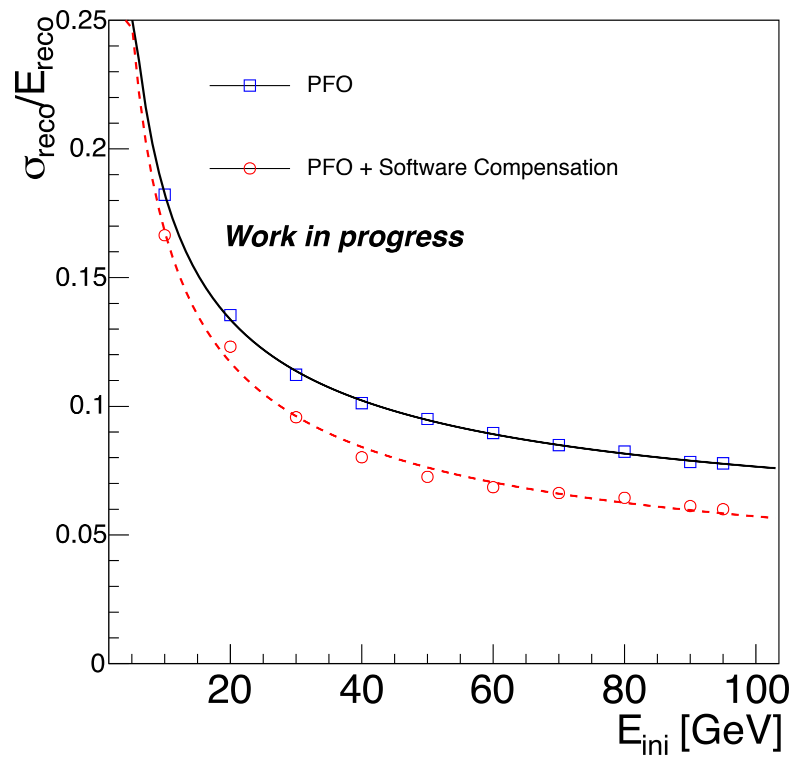
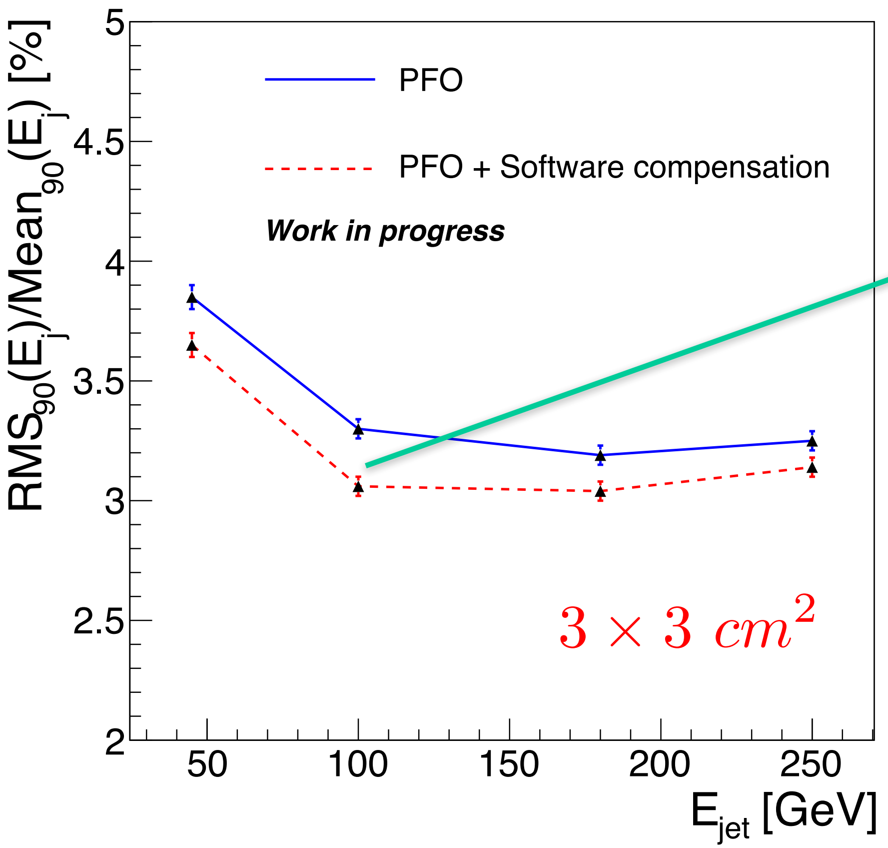
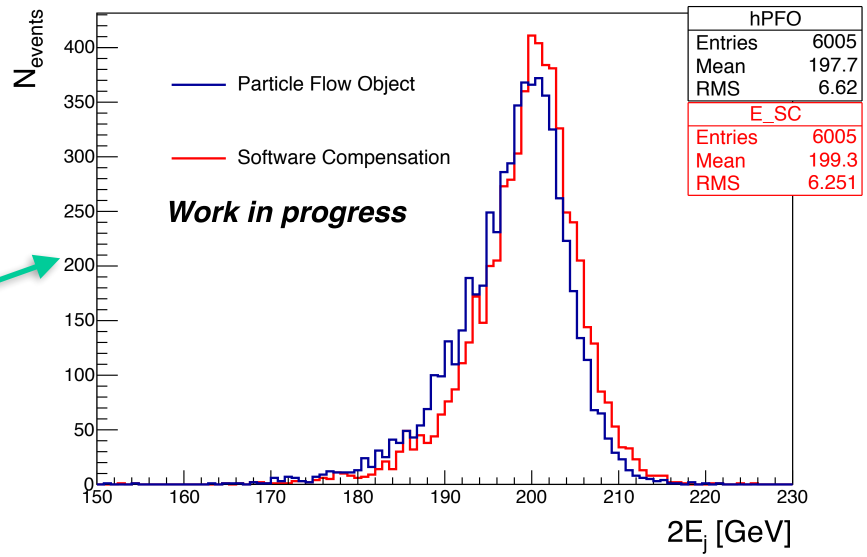


- Testbeam results reproduced
- Overall slightly worse because of missing tail catcher

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



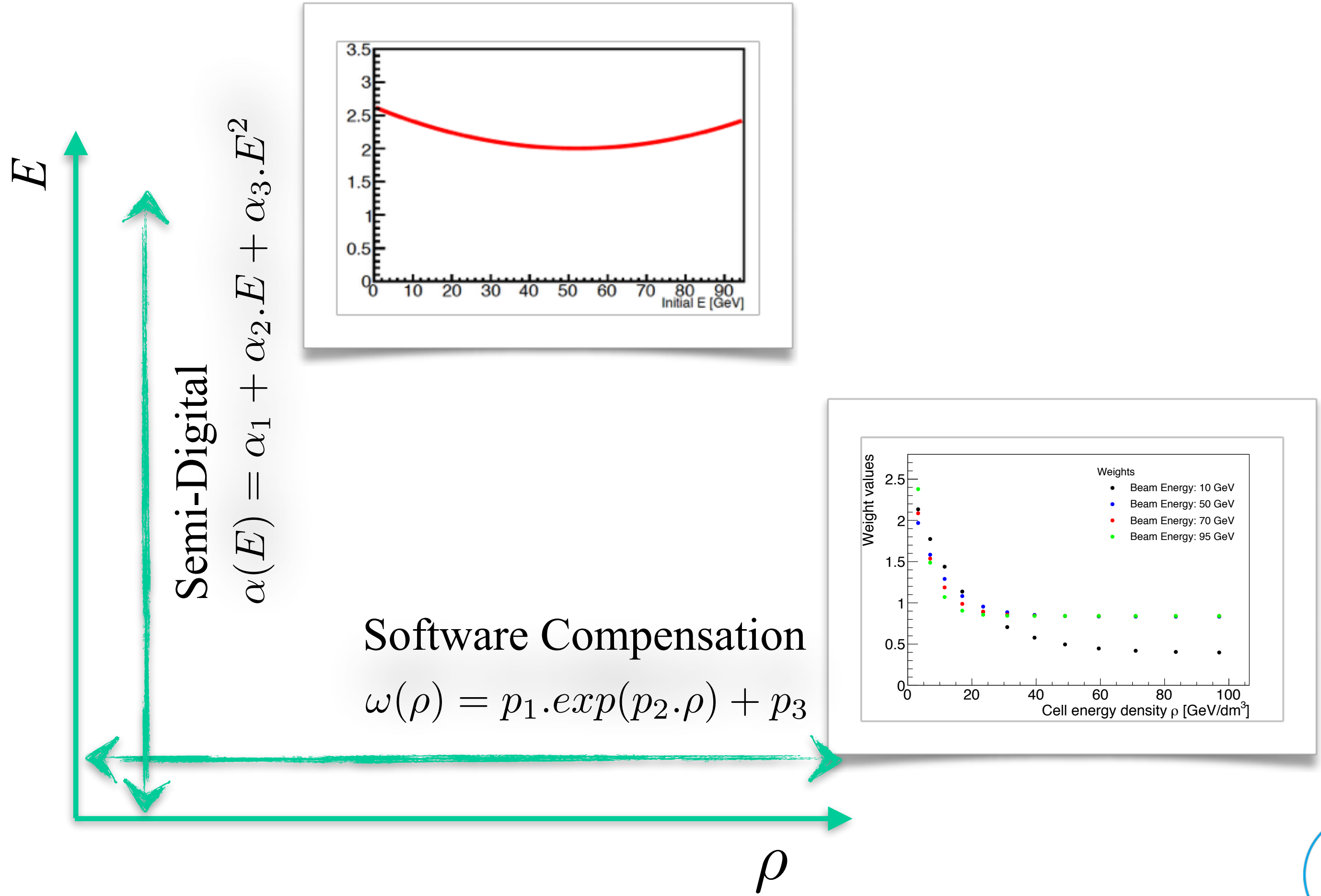


- Reconstructed energy distribution closer to simulated energy and width of distribution smaller
- Improves jet energy resolution in whole range

Towards a common SC technique for different types of HCAL

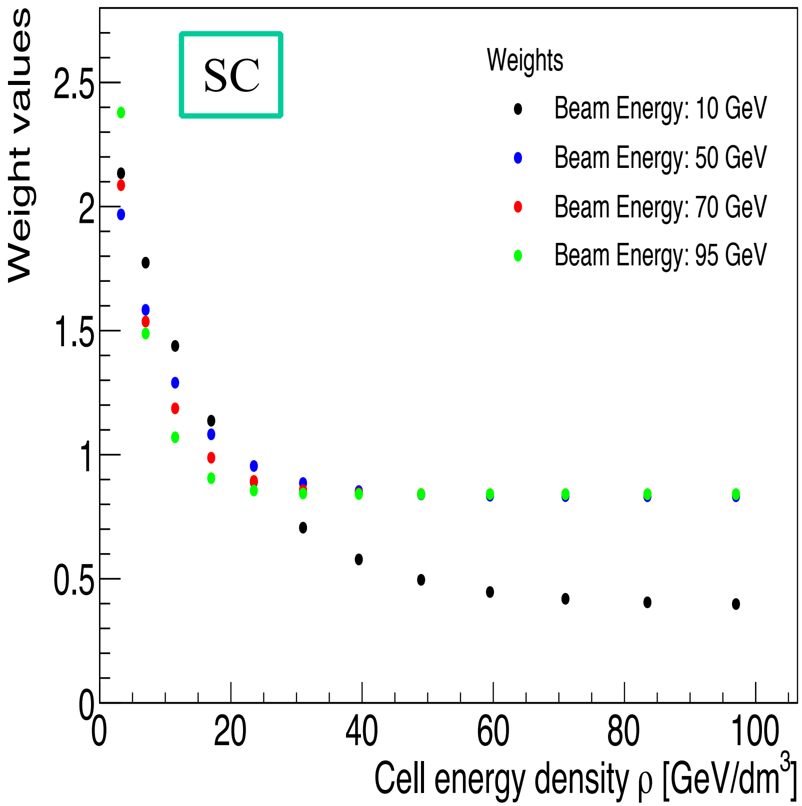
Semi-Digital and Software Compensation

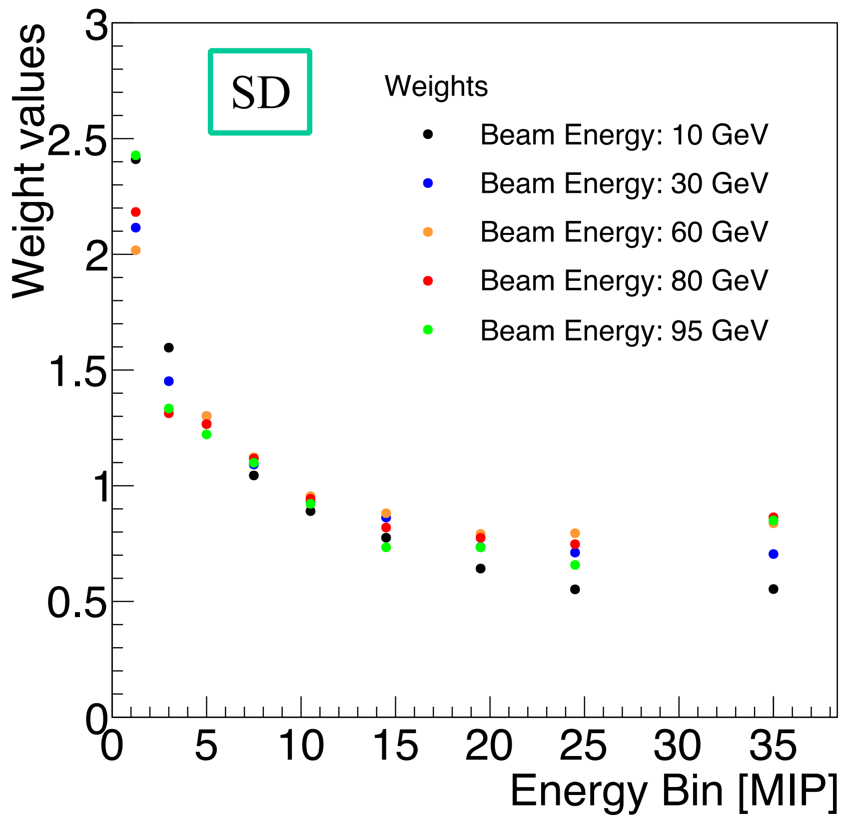
- Software Compensation: weight optimised as a function of ***hit energy density*** ρ
- Semi-Digital: weight optimised as a function of ***particle energy*** E



Software Compensation in S-D style

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





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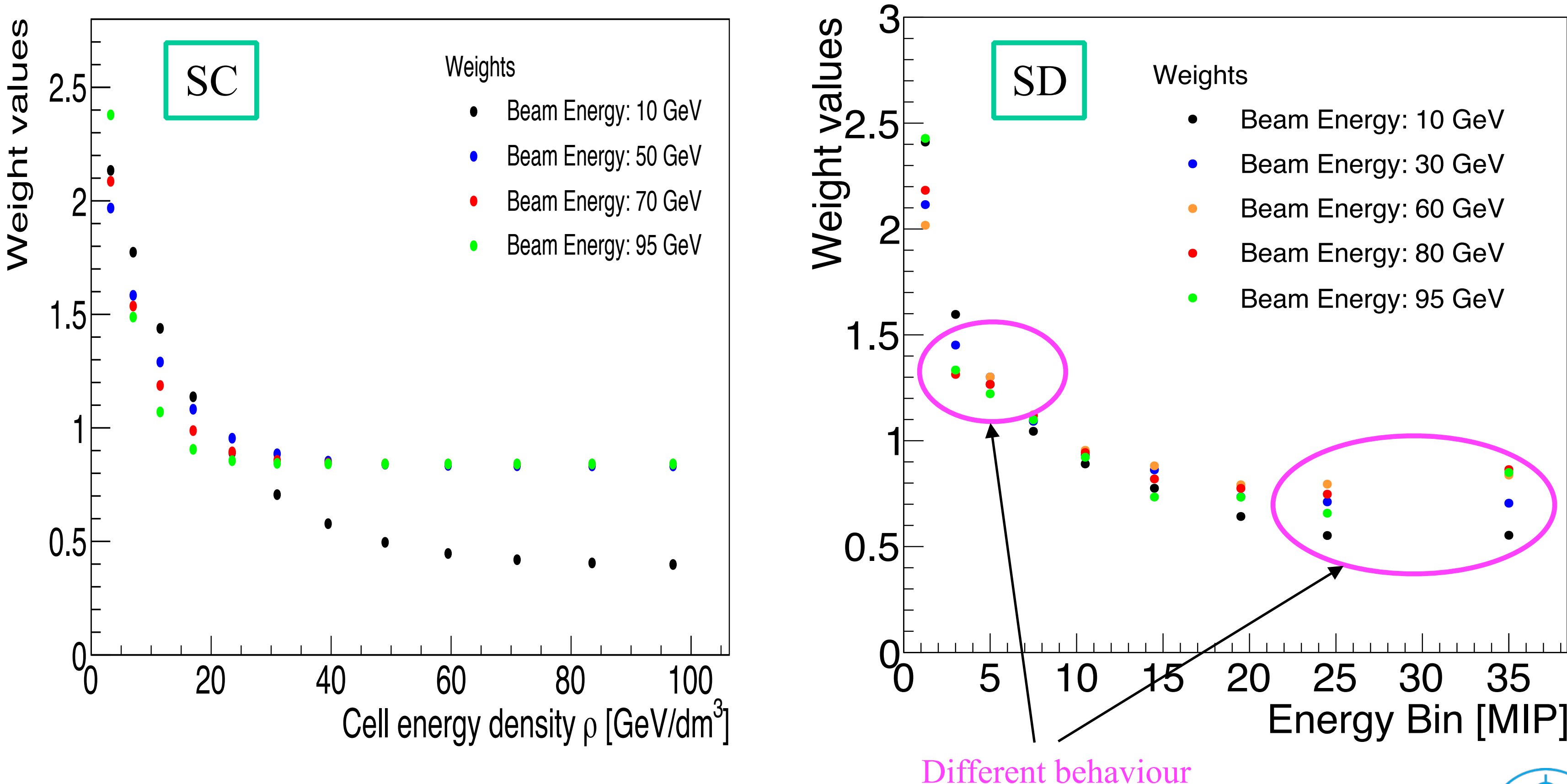

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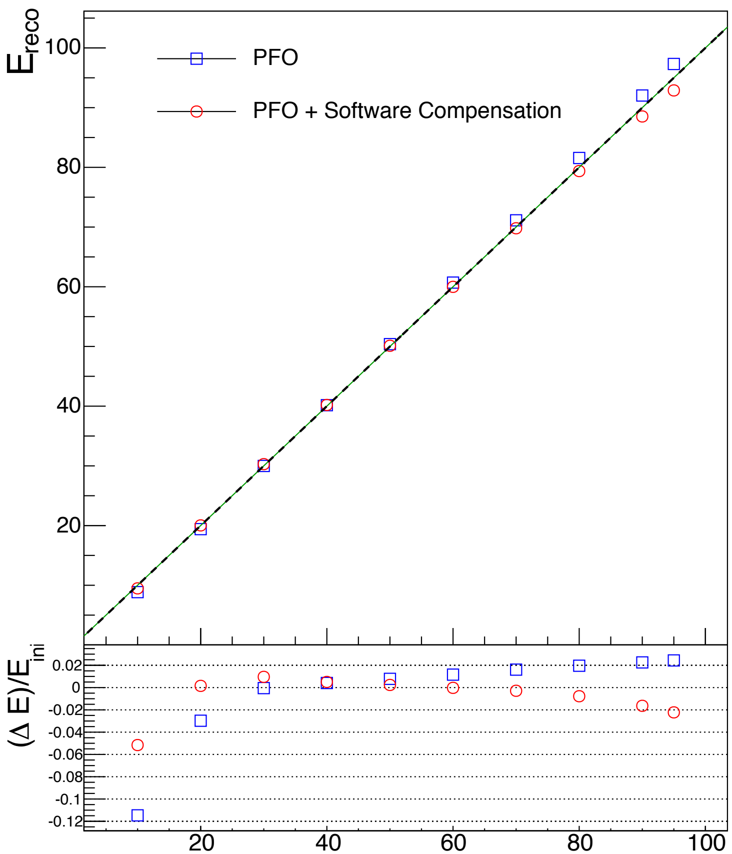
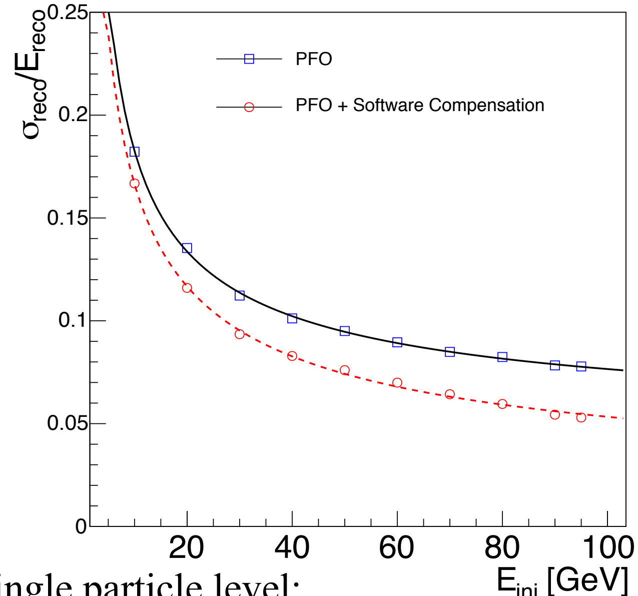
  - Correction for neutral hadrons energy, after clustering and re-clustering step





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

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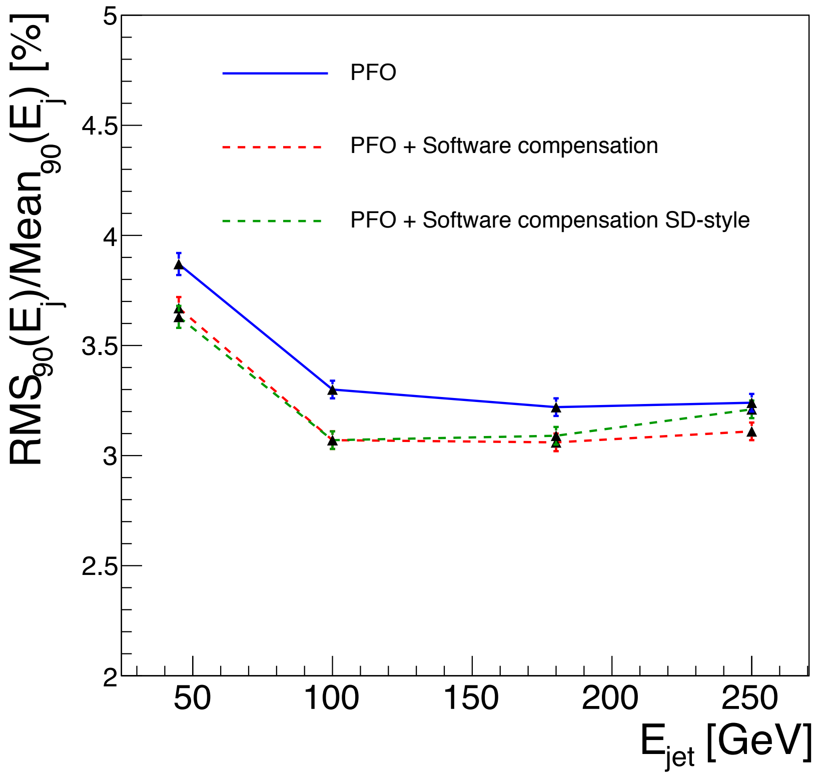
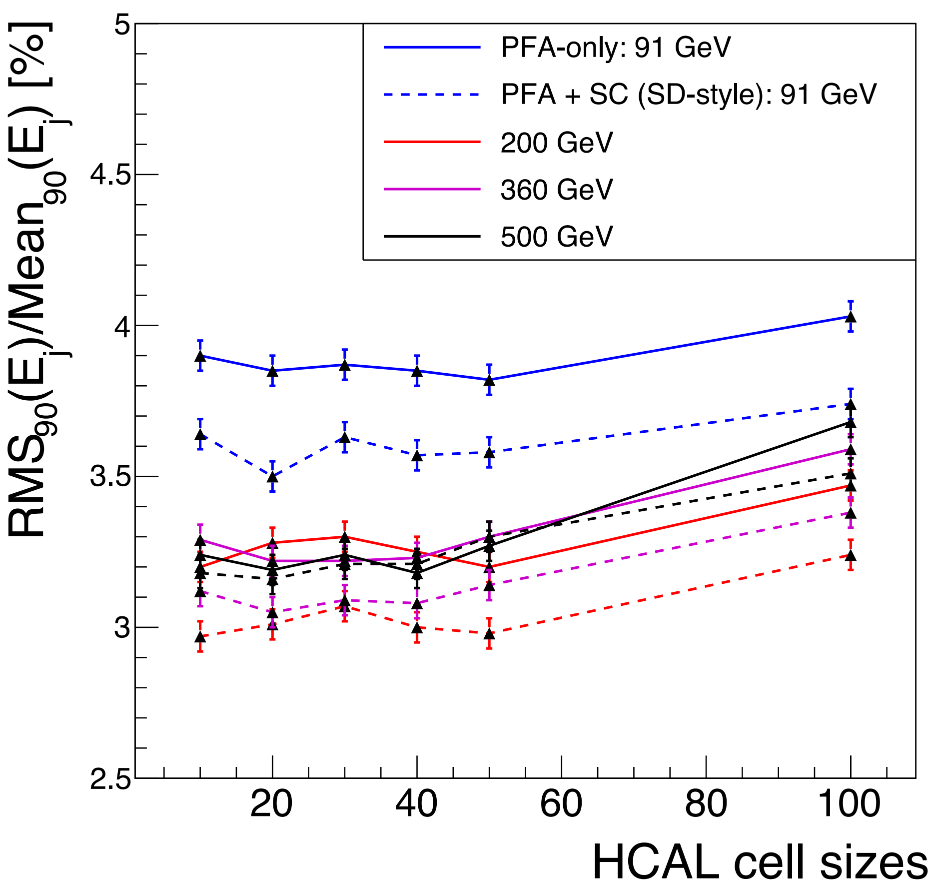


- At jet level gives more or less the same result as previously

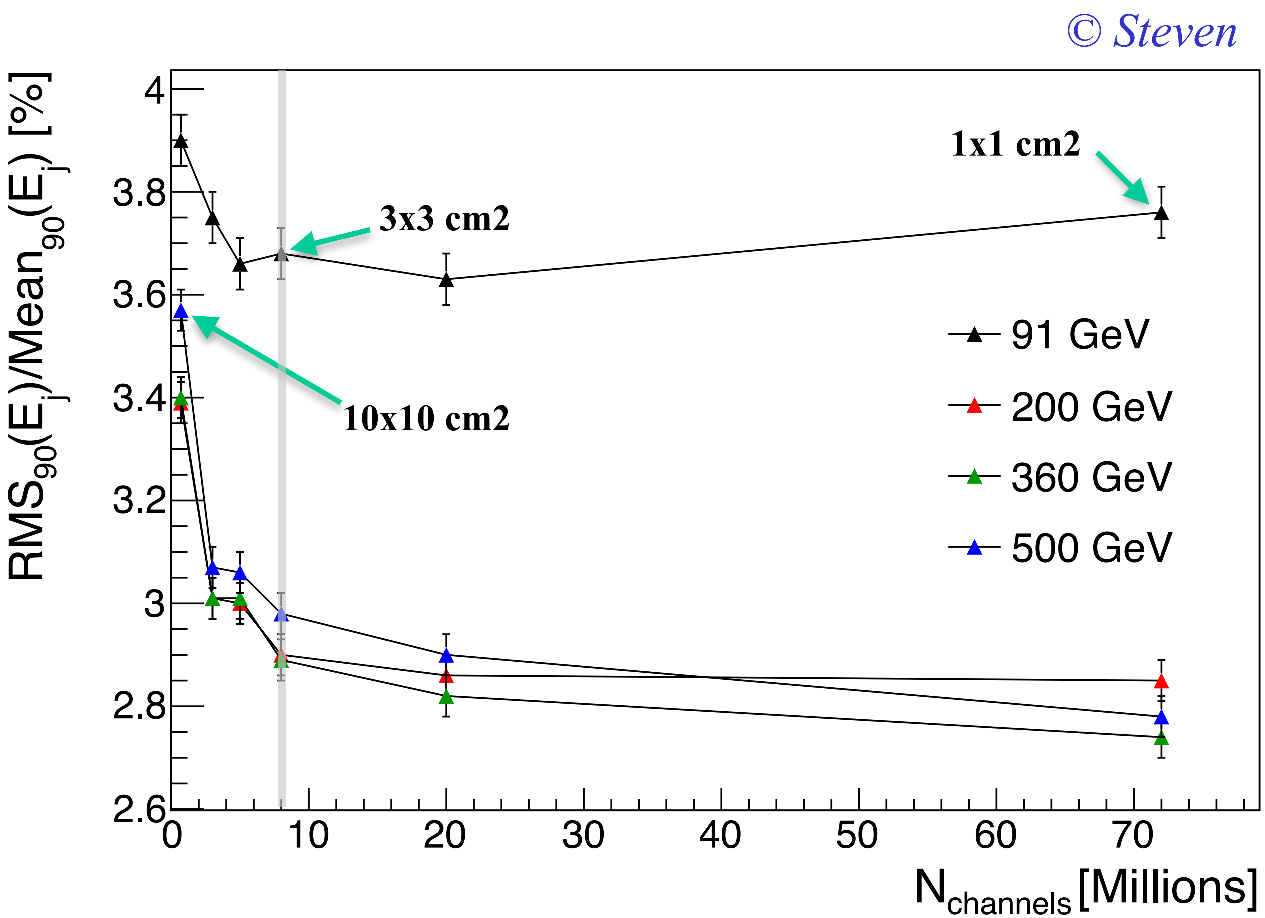
JER vs cell size



- Over all improvement
- At high energy slightly worse compared to Steve's numbers using truncation cut
    - HCAL truncation cut takes effect already at clustering step: for higher energy jets (large confusion) this is expected

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



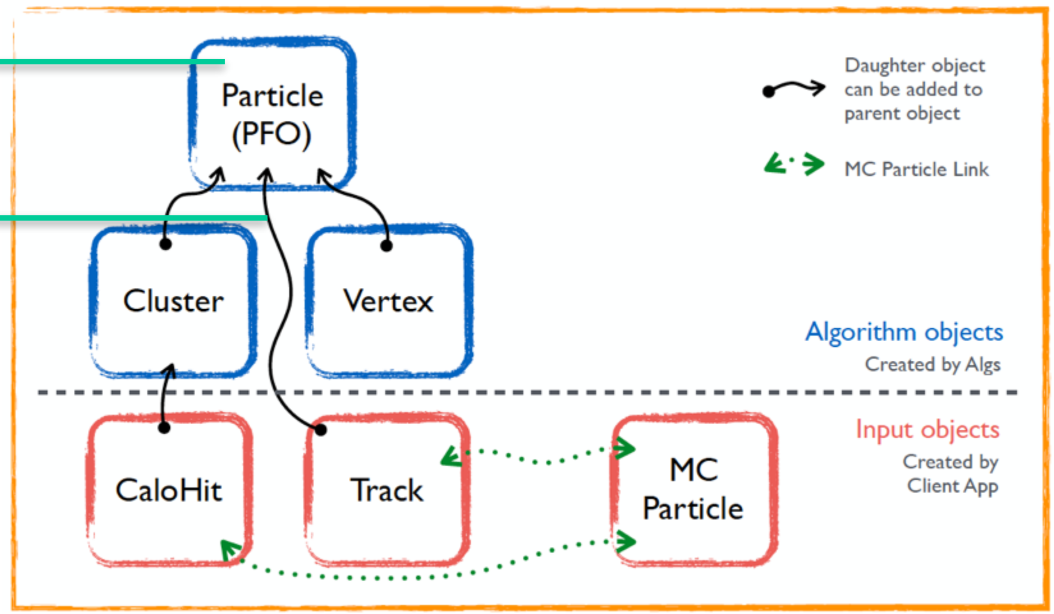
Latest results from Steven
To be updated with
software compensation

Implementation into Pandora

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

Neutral hadrons PFO registered with software compensated energy

Cluster-Track compatibility: if failed, re-clustering



- Flag in MarlinPandora steering to apply software compensation:

NEW

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

Summary & Outlook

- *Software compensation and cell size optimisation:*
  - Software compensation *implemented in Pandora*
    - To be made official
  - *Improves* single particle and jet energy resolution
  - Re-clustering step to be done
- Common SC technique for different types of HCAL developed

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

- One week in Cambridge (whenever my visa makes it way back)

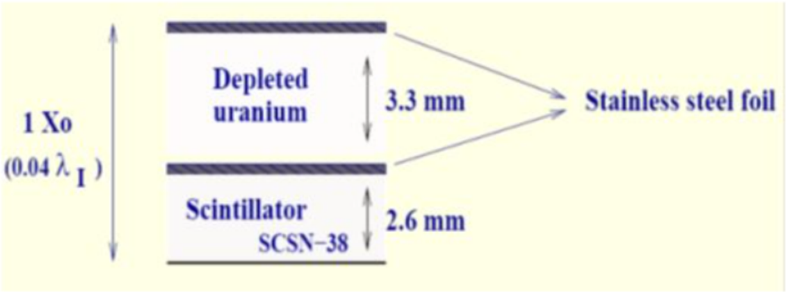
Back-up slides

Methods to achieve Compensation

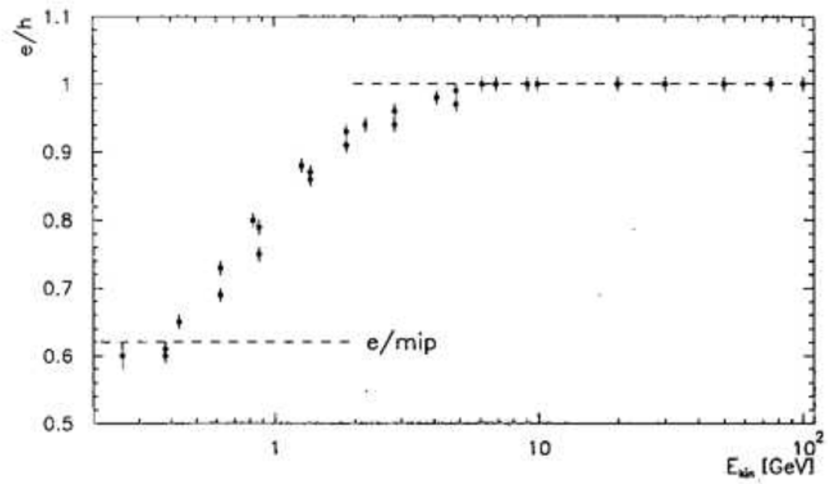
- Reducing electromagnetic response
- Increasing hadronic response

Achievable with detector design

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

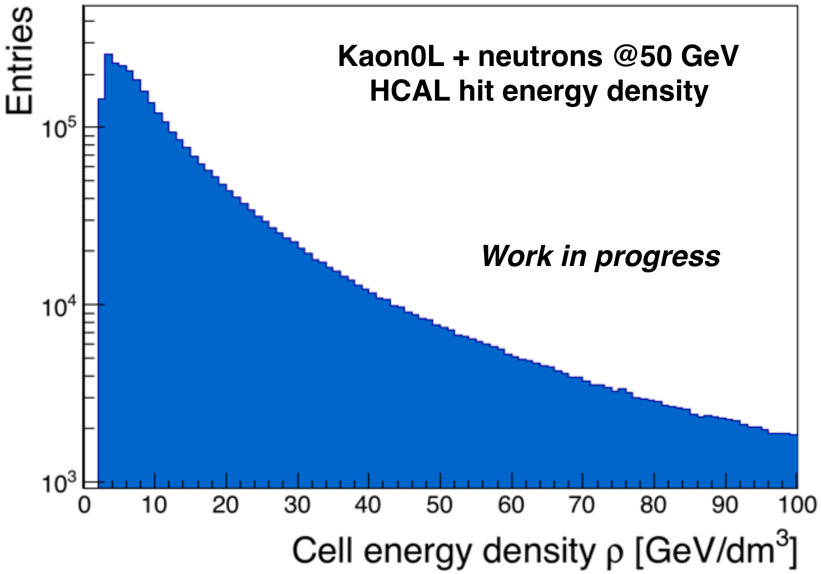


ZEUS Uranium-Scintillator calorimeter



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

Reminder: Hit Energy Density and Weights

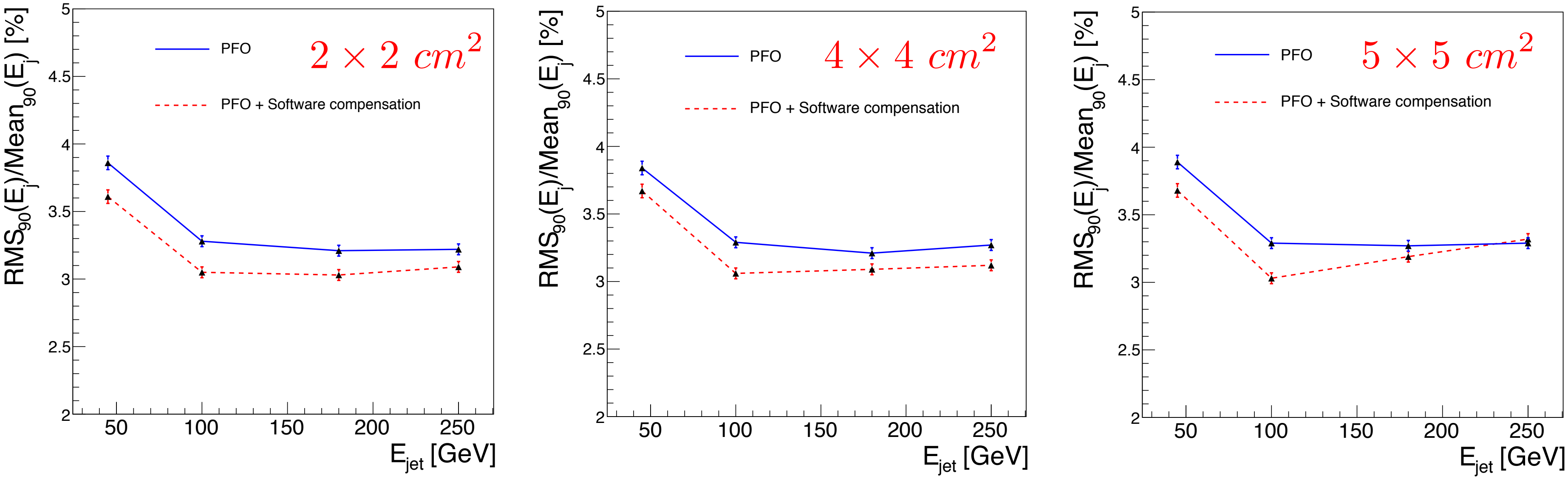


Samples:

- 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 $3 \times 3\ cm^2$

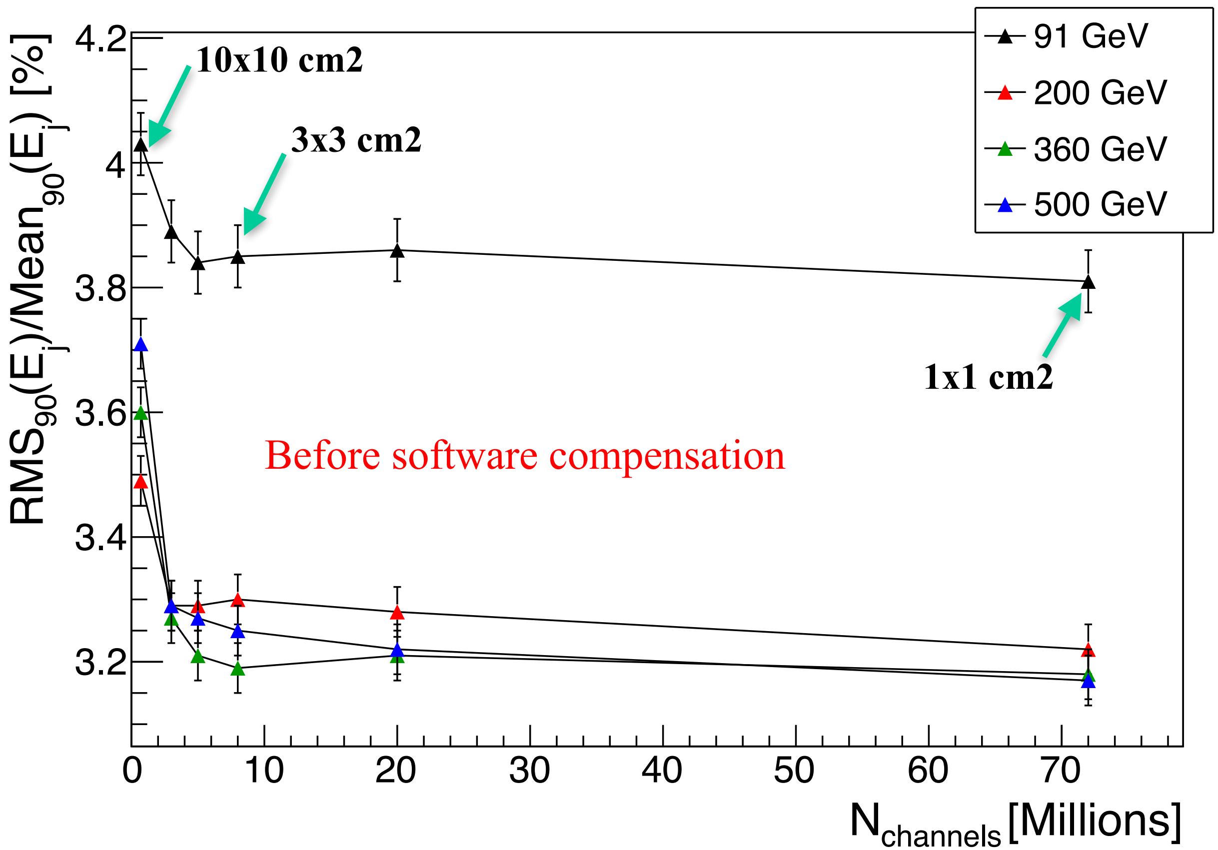


- Proper weights to be done, especially for very small or very large granularities
- SC could also help at re-clustering stage of Pandora
  - At the moment degrades JER, under investigation

Outlook - Using my numbers

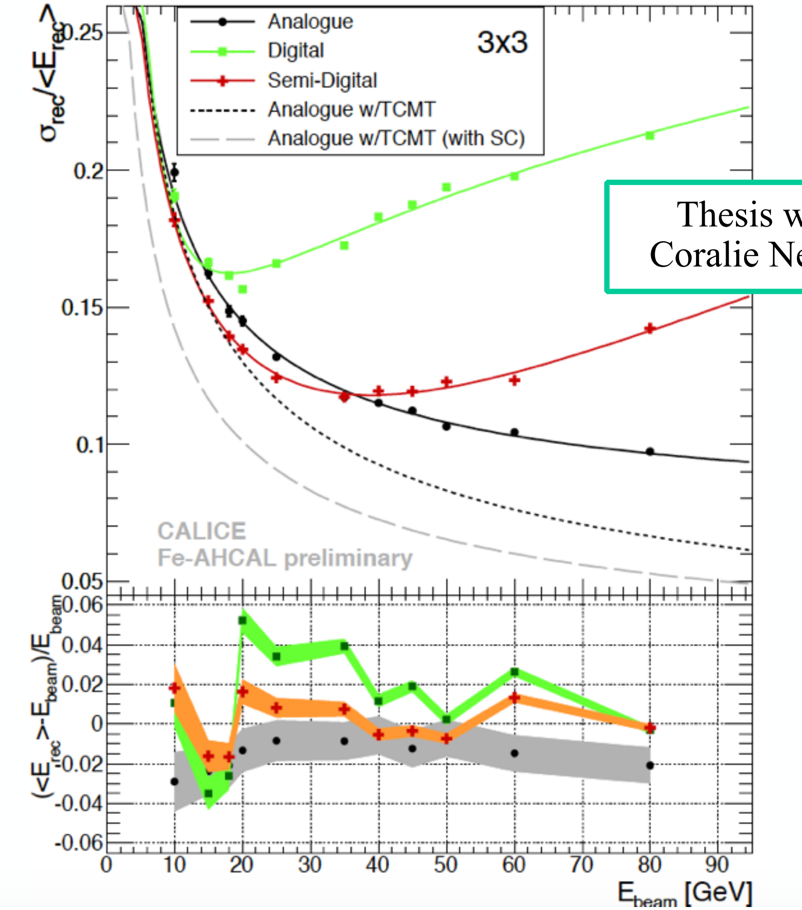
Towards cost optimisation

- 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



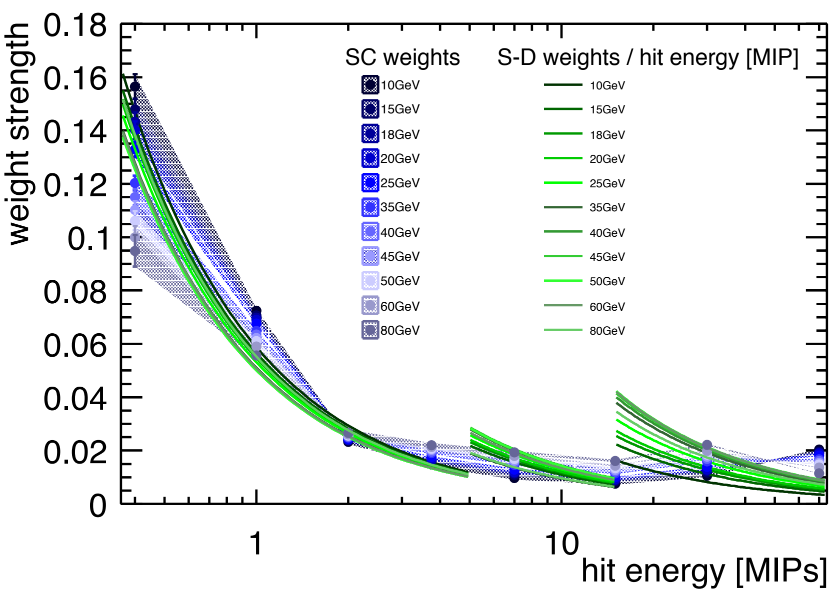
- Reconstructed energy: $E_{SD} = \sum_{bins} \alpha_i . N_i$

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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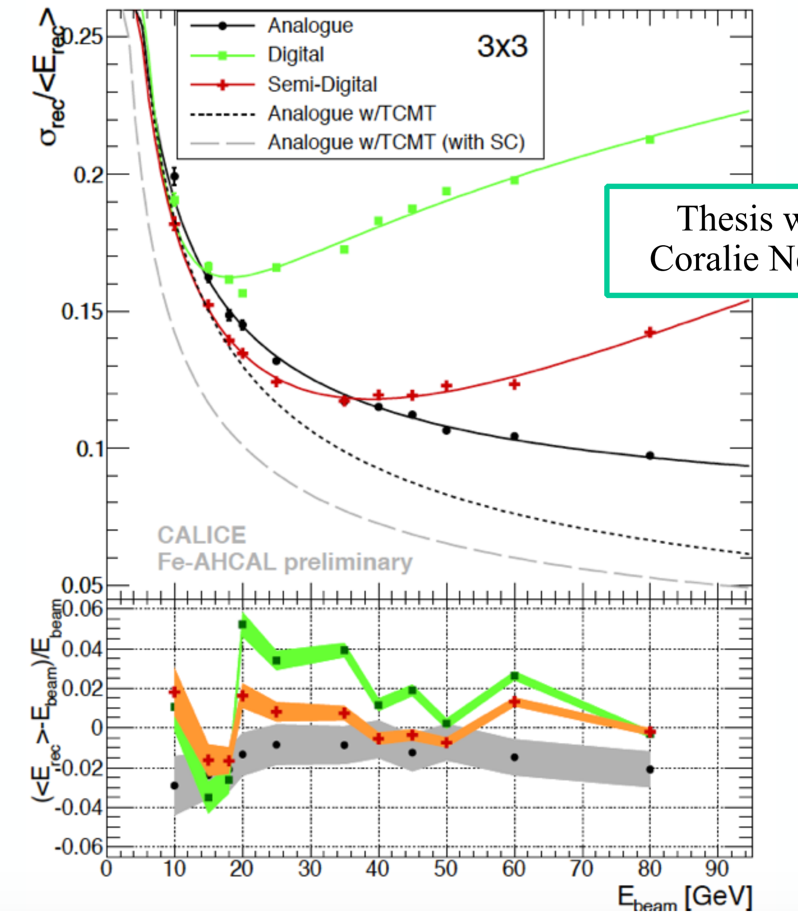

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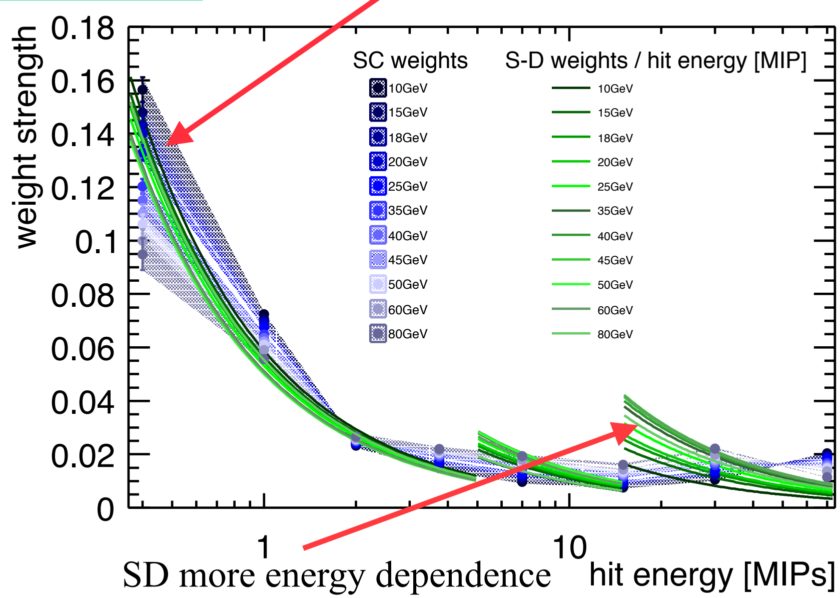
SD less particle energy dependence at small hit energy



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

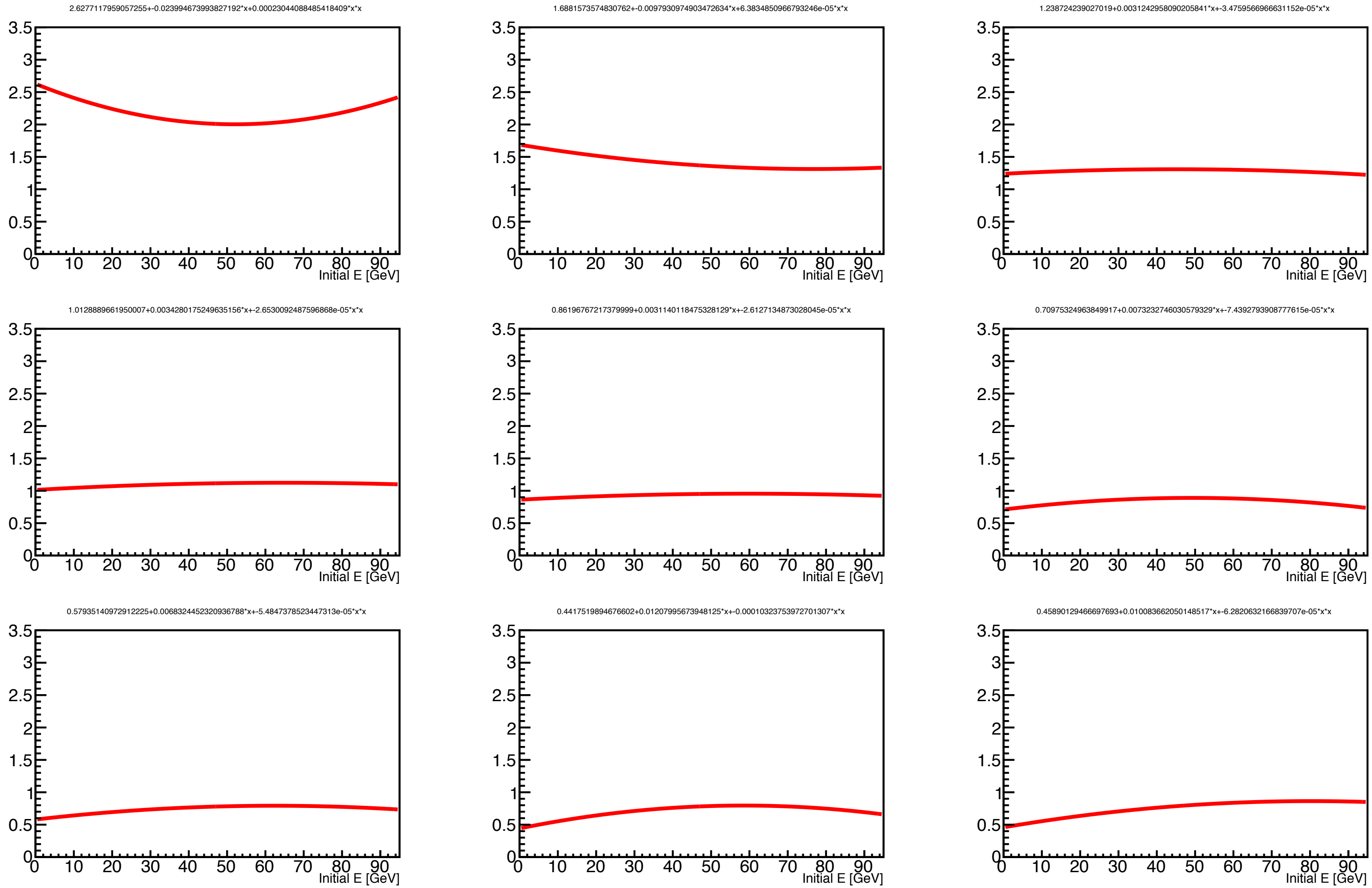
beta = beta1 + beta2*N + beta3*N*N

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



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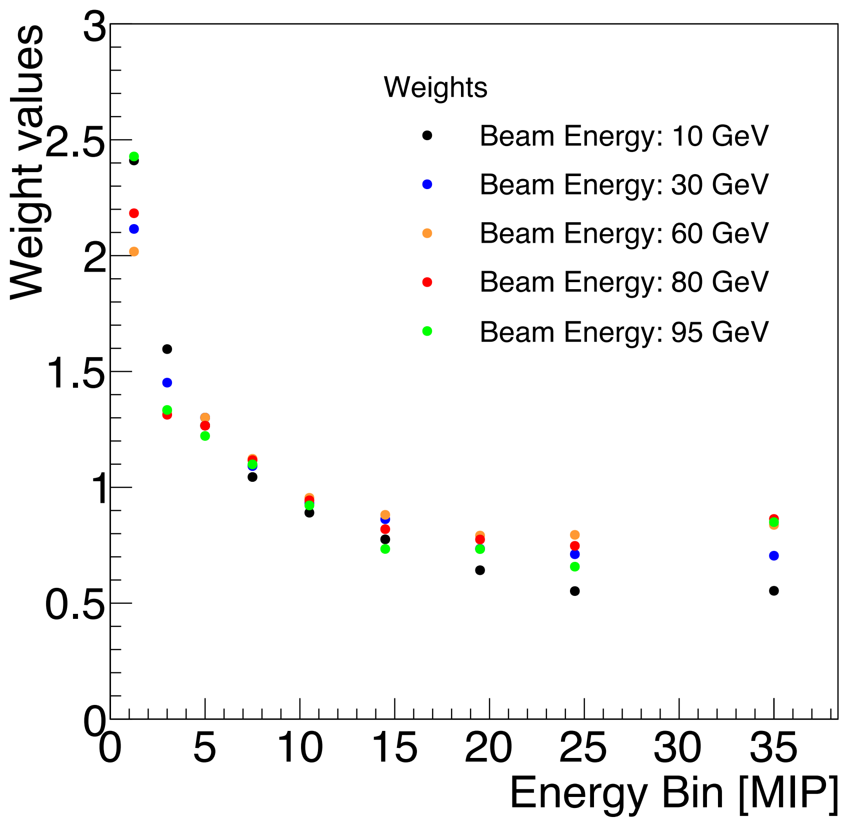

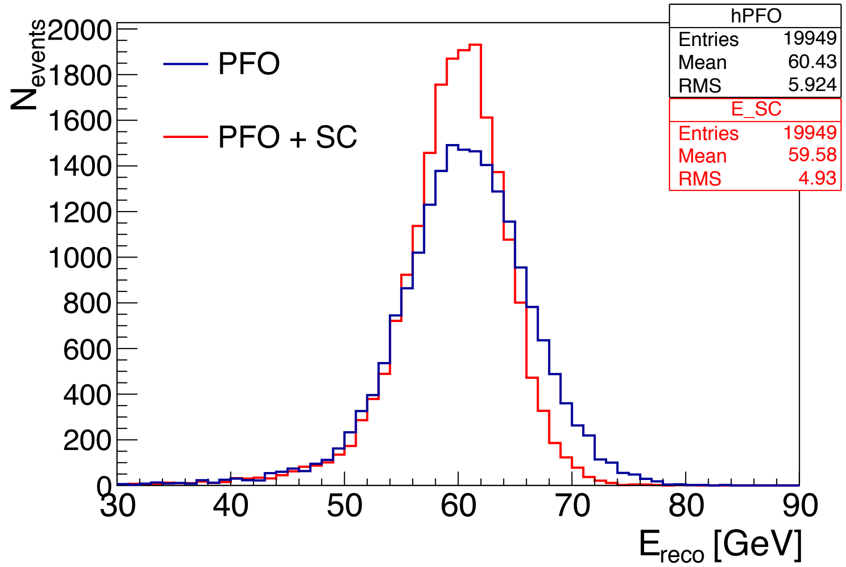

JER vs cell size